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The 2nd INTERNATIONAL WORKSHOP ON CROP AND RANGELAND MONITORING IN EASTERN AFRICA

PROCEEDINGS

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Organized by EU-JRC and UN-FAO

Nairobi, Kenya, 27th to 29th March 2007

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Foreword

The 2nd CRAM Workshop (Crop and RAngeland Monitoring) was held the 27 - 29 March 2007 in Nairobi, Kenya and was jointly organized by the Joint Research Centre of the European Commission, (Institute for the Protection and Security of the Citizen, MARS Unit) and the Food and Agriculture Organization (FAO, Climate Change and Bio-energy Unit).

Its main purpose was to activate the CRAM Network, established following a 1st Workshop "Crop Monitoring and yield forecasting for Food Security" (Nairobi, January 2003) and to facilitate exchange between African experts and projects involved in this field where Earth Observation, crop modelling and ICT have made important progress in the last years.

The recent crisis of soaring Food prices demonstrate the upmost importance of crop monitoring, yield and production forecasts as a source of information for trade and agricultural policies at global, regional or national levels. In food insecure countries, crop and rangeland monitoring requires continuous attention to provide early warning to national institutions and food aid Agencies, with accurate and timely information on where and when shortages or surpluses occur. In the longer term, a better understanding of the cropping systems in relation to soil, land-use and meteorological variability, will also be crucial to support agricultural and rural development policies, and assess the possible strategies in adaptation or mitigation towards Climate Change.

Almost 80 participants from 20 countries met to review the State of the Art in Crop and Rangeland Monitoring with a link to food security, vulnerability assessment and sustainable development. Presentations and discussions covered many domains from ongoing research to operational systems, from information producers to decision makers. The workshop has contributed to sharing experiences, identifying gaps, disseminating best practices and adjusting the products to the evolving Food Security community needs.

An emphasis was put on the Horn of Africa, but contributions by experts from SADC and ECOWAS Regional Economic Communities confirmed a strong interest of scientific exchanges on crop monitoring and Food Security which is a priority concern in the whole Sub-Saharan Africa.

We would like to express our gratitude to all the authors, speakers and participants who contributed to make the workshop a success and specifically to Dr. Derk Rijks, AAA (Agro-meteorological Applications Associates), who animated the CRAM network for more than one year and organized the logistic of this 2nd CRAM Workshop.

Olivier Leo　　Michel Massart　　Felix Rembold

EXECUTIVE SUMMARY

The first objectives of the workshop were to verify the state of the art and the progress made since the first workshop in 2003, and to facilitate the development of a crop and rangeland monitoring system for the whole of Africa with compatible sub-systems having the potential for homogeneous interpretation and utilization.

In the course of the workshop, these objectives were expanded to encompass:

- a more focussed attention to information for livestock-based communities,
- a solidification of the relations between the national services and the EU-JRC activities,
- the inclusion of partners that had, so far, not been included in the network,
- a better focus on a system permitting a more rapid response to warnings of impending critical situations,
- the collection of information and opinions that can facilitate the formulation of the way forward,
- an assessment of the impact of EU-originated information supply on the real-life situation.

The results were :

- An account of the state of the art and the ensuing discussions presented in these proceedings.
- A rekindled interest in using the CRAM-forum and an extending publicity on the benefits of its use to colleagues
- The creation of an awareness and desire for a Pan-African collaboration, including especially the crop and rangeland monitoring activities in West Africa, undertaken by the CILSS AGRHYMET Centre and in Southern Africa , undertaken by the SADC- RRSU Centre.
- A decision to work together to establish a comprehensive catalogue of meta-data. A detailed plan is to be drawn up by JRC and its co-opted collaborators.
- The embryo of an action plan on comparison of rainfall data. JRC, in collaboration with the TAMSAT group and the UCSB group are invited to draw up a detailed work programme. National collaborators are awaiting to contribute to the implementation of these plans.
- The embryo of an action plan on better collection and recuperation of ground data. FAO is requested to draw up a work programme.

- A commitment to collaborate on the updating of CPSZ. FAO is requested to invite the staff of the AFRICOVER project to submit the outlines for its implementation.
- A commitment by all national participants to include components for promotion of sustainability in monitoring and forecasting systems. Guidelines are awaited from JRC and FAO, working in collaboration with the University representatives present at the workshop.
- A request to JRC to make the Forum able to act as a Memory Aid in crop and rangeland monitoring work. This requires the attention of the JRC staff managing the CRAM-forum.
- A list of further items for action to be undertaken by national staff was formulated. These action items deal with the actions that members of the network will undertake in respect of :
  - the relation between users and producers of crop monitoring information,
  - the methods used and the modalities of their transfer to all potential users,
  - the modalities of data collection and dissemination.

The conclusion of a nucleus group present at the workshop is that these activities are eminently possible if the JRC management in charge of the crop and rangeland monitoring activities is prepared to make the necessary manpower available to make a reality of these proposals. A similar attitude by the management in charge of the crop and rangeland monitoring activities at FAO would greatly enhance the chance for success.

OBJECTIVES

The initial objectives of the workshop were to verify the state of the art and the progress made since the first workshop in 2003 and to facilitate the development of a crop and rangeland monitoring system for the whole of Africa with compatible sub-systems having the potential for homogeneous interpretation and utilization.

In the course of the workshop, these objectives were expanded to encompass:

- to a more focussed attention to livestock-based communities
- to the analysis why the first network had not really taken shape as rapidly as expected

- to solidify the relations between the national services and the EU-JRC activities
- to include partners that had, so far, not been included in the network
- to focus on a system permitting a more rapid response to warnings of impending critical situations
- to collect information and opinion that can facilitate the formulation of the way forward.

EXPECTED RESULTS

The expected results were:

A document with the contributions on the current "state-of-the-art" of crop monitoring and yield forecasting in the region.

An account of the scientific and technical discussions and the exchange of experience aimed at improving methods and systems in crop monitoring and yield forecasting that are being developed by international organizations such as JRC and FAO, and others, and their application.

An improved functioning of the network of producers and users of scientific and technical data, products and information, and its gradual expansion to the whole of Africa, that will facilitate the transfer of technology and the exchange of data and information with respect to users' needs.

ORGANIZATION OF THE WORKSHOP

The workshop was organized by the MARS Unit of the Joint Research Centre of the EU, in collaboration with the Kenya Meteorological Department, a specialized administration of the Kenya Government, the GIEWS and SDRN group of the Food and Agricultural Organization (FAO) of the UN, and with Regional and International Agencies based in Nairobi. It took place in the premises of the Jacaranda hotel from 27-29 March 2007. The workshop was opened by Ms Fatuma S. Abdikadir (see Appendix 1), National Coordinator of the Arid Lands Resource Management Project, Office of the President. Further words of welcome were spoken by Dr Rene Gommes, on behalf of FAO and Dr Olivier Leo, on behalf of JRC (Appendix 2). The workshop was closed by Mr John Mwikya, representing the Kenya Meteorological Department (Appendix 2). The agenda is given in Appendix 3.

There were 44 participants from 36 scientific or technical organizations, departments, or agencies. The list of participants is given in Appendix 4.

The written documents prepared by the participants are presented in these proceedings. During the workshop, the substance of many of these documents was given as a PowerPoint presentation.

CONCLUSIONS

1. Users

It was concluded that the immediate target users of CRAM products should be the persons that transmit Crop and RAngeland Monitoring products to decision makers at all levels, including to a certain extend farmers.

It will be necessary, in each institutional context, to formulate modalities to institutionalize the crop and rangeland monitoring structure, so that it becomes part of an established governmental routine.

2. Data

First, an action is necessary to harmonize and complete the presentation of meta-data, associating these with geo-referencing, to make software development easier and permit ready transfer of these data and their associated coding.

A commonly accepted description, and perhaps a standardization of products such as VPI, WRSI, ETA, and others should be made and used in further CRAM work.

CRAM can focus on homogeneous coding, geo-referencing, sharing, collecting and transmitting of data. Raw data should be as "open" as possible, as, in the long run, this may be a means to increase the demand for analyses in different sectors based on these data.

There should be further action on rainfall data, from satellite interpretations and other techniques. It is obvious that in many areas there is a shortage of ground reference information.

It was felt by many that there is an "erosion" of ground data and their collection systems. This is not only the case for data on rainfall, but also for other meteorological parameters, phenological data, crop data and others. CRAM may have a paramount role in reversing this trend. In the maintenance of the data collection system, site selection remains a critical factor.

In respect of data for rainfall monitoring, more advances can be expected once the new satellites are operational.

It was concluded that the NDVI data should be organized in a way that allowed further use by all interested parties, and in a sustainable manner. Archives are available for this type of use. Through AMESD project, support for further users can be organized. The main problem was thought to be not in data sharing, but rather in accelerating training in the use of the data in a context of EWS processes.

A discussion ensued about the Crop Production System Zones (CPSZ) used in actual farming practices. The original version dates from 1994, and contains information for all zones, both on crops and livestock. At present new data are available and make it possible to update the information. This will be a joint IGAD-FAO-JRC project. A suggestion was made that the update should provide aggregation per existing administrative units. Further points concerned the availability of CPSZ data for modeling, the thresholds employed, the inclusion of the varying lengths of the growing periods, farming practices, and of historical information. Some of this work can be done at the country level. In one country this is combined with an additional "livelihood approach".

Finally, access to data, and increased data transmission from dispersed sources, might be improved if more visibility was given to the products, and their benefits, that can be derived from these data. This process might include association with national TV, national or local radio stations and others. It was thought that some countries could accept to upgrade their data collection systems if the benefit obtained from analysis of the data was more evident.

3. Sustainability

The new CRAM would have to involve itself significantly with the sustainability of monitoring and forecast systems, with the actions that should normally arise from the application of the results of the monitoring products, and with the "hotspots", the places of conflicts between continued agriculture and pastoralism and the preservation of the environment, or the (untoward) use or over-exploitation of resources and its spill-over into the political sphere.

Awareness of the need to choose between the short-term maximization of use versus the long-term reduction of risk is not always easy to translate into acceptable practical action.

This will need a far more widespread education about sustainability, especially among the leaders in the political circles. It has been observed that virtually all elder farmers are fully aware of the need to choose, even if they can not always make the choice that they feel is necessary in the long term.

4. Memory

Undoubtedly, there is repetition of work of which the results are already available elsewhere, involving sometimes repetition of errors that had been made by others. It was suggested that the "new" CRAM should formulate references for "best practice". This can help to alleviate the costs associated with development of tools and methods. Results can be made available and updated on the CRAM forum.

Furthermore mentioned was the possibility to keep a copy of the national data bank in a base of an appropriate institution elsewhere, to avoid accidental loss through natural or man-made events.

5. Gaps

It may be appropriate for CRAM to identify situations or realms in which sufficient or all data is lacking, especially when it affects regional issues. There could be a commonly agreed strategy between the African Union, EU-JRC and FAO to tackle this problem. Technical details could be worked out in consultation with technicians in each country or institution concerned.

6. Other points

It was judged desirable that the next CRAM workshop should cover all of Africa south of the Sahara. The timing should be such that the momentum of the present meeting would not be lost, as it has been the case following the 2003 workshop.

Given that the CRAM user community appears to be little "visible" in the EC Headquarters in Brussels, it is proposed to prepare an essay on the use and benefits of the CRAM information. It was also suggested that countries should, at a high level within the Government, endorse the CRAM results and transmit this information to the EC Headquarters. This should be a well-documented and strongly worded message.

SUMMARY OF DISCUSSIONS

After the presentation of each paper, a limited amount of time was available for questions, remarks and discussion. If more time was needed, the discussions were referred to the Round Table Session. For coherence, and to avoid repetition, the various points made by the participants after each presentation are presented together with the remarks made during the Round Table Session under the headings given below.

The purpose of this **Round Table Session** was not only to clarify issues that arose as a result of the presentations made, but also to assess current status, strengths, weaknesses in the present monitoring systems, and to formulate opportunities, and hindrances, for future actions and collaboration for their implementation, and for the exchange of information.

Among the latter are the CPSZ and the future shape and working procedure of the CRAM-forum.

The overall aim was to make practical progress towards the establishment of an Africa-wide system of crop and rangeland monitoring methods.

1. Rangeland monitoring.

Global Positioning System is used to "situate" field observations in Kenya. It was found that good results require a critical mass of GPS users in the monitoring community, forming a network, and thus greatly adding value to the totality of their observations.

FAO was asked to study the feasibility to use GPS entries in their land use inventories.

In West Africa GPS-use is fairly widespread, and its use even by farmers contributing "key-information" is promoted.

In Somalia GPS use was mostly in monitoring locust infestations. Use for crop and rangeland monitoring was envisaged, but not yet operational. Also, and not only in Somalia, it could help greatly in monitoring livestock numbers and migration tracks and in assessing the grazing conditions.

Its use for either observations or for mapping may need separate analysis.

It was concluded that the needs for use of GPS was clear, but that often means and training were not yet available.

NDVI was considered an useful tool for forage assessment, but needed additional inputs to assess forage quality. It can be a tool in defining storage strategies. The interpretation of NDVI information for pastoral systems with mainly grazers or mainly browsers is not necessarily identical.

The question was raised whether NDVI can help not only to assess pasture availability but also to pinpoint available water resources and even watering holes. This remains to be studied.

The additional role of EWS's as a potentially powerful management tool was discussed. To be effectively formulated, the user and the possible rapidity of his capacity to intervene, should be specified. Information given to solicit a response is only valid if it is given at the appropriate time. It was also pointed out that timing and confidence in the information are related. To this end, actual information should always be compared with the "normal", and be considered within the local agricultural context.

Such use was not only for the agricultural community, but also for local governments that had to foresee (infrastructures for) security measures.

Further research should encompass the development and testing of existing and possible new indicators, and their predictive capacity for proactive action.

It was pointed out that action on EWS's for rangeland management did not automatically result in improved livelihood.

In a country like Somalia, 60% of the population is livestock dependent. If possible, early warning systems should also include warnings on strong winds, provoking sand dune movements, and excessive rainfall, provoking erosion, and thus reducing, among others, tree growth.

Among the benefits that can, potentially, be derived from EWS's is the possibility to re-route tracks of migration of livestock to avoid sedentary areas before crops are harvested, thus preventing conflicts. A further benefit is its use to help assess the risk of, and reduce the impact, of bush fires.

It was considered essential to further "institutionalize" the national, regional and international early warning systems for rangeland management, and help build the required capability. In applications the national system would be the best player, the other entities are well-situated to provide cross-border information and help solve difficulties of scale and types of data. National services remain the optimal players to relate to the end user and obtain feedback on the value of the information given.

The point was raised whether maximizing the use of rangeland did also maximize or increase the risk of potential future shortages. This subject has apparently been studied only summarily, but remains a major point to consider if one wishes to obtain long-time sustainable use of rangelands. In certain cases the presence of a sufficient number of unpalatable species may help prevent erosion and thus safeguard the presence of the essential palatable species in the future.

Early warning, and by extension the calculation of the frequency of probable shortages, can be one of the tools that help assess the long-term carrying capacity of rangeland areas.

2. Crop monitoring

It was agreed that, in spite of the heavy reliance on NDVI, crop monitoring was in its origin essentially ground based. This aspect should not be neglected, even the NDVI values were calibrated against ground based observations. A high level of support for these observations should, whenever possible, be maintained. There could be benefit in promoting (private) networks of secondary stations, if their quality was high. Such networks might also furnish crop stage information, and information on the performance of local varieties and crops sown at great inter-plant distances (sparsely-sown crops). Leaf area index figures were useful, but not widely observed.

Ground based observations concern not only vegetation, also rainfall as a primary factor in crop growth for most crops in most of the region. Remotely sensed rainfall estimates are reliable only after calibration against observed rain-gauge values. They do not always concern similar scales, and a conversion in that sense may be required.

NDVI observations can be used with a certain reliability in (semi-) arid zones. In forest zones, this is much less the case. In those zones crop modeling may be a more reliable tool. Similarly, NDVI estimates in cloudy regions are not always a reliable tool, and it was asked whether improvements in this domain could be expected. The question was asked whether NDVI estimates do distinguish between different crops to the extent needed in crop monitoring work.

The question of how to deal with mixed pixels also came up. The answer depends on the details of the specific situation.

The reliability of weather satellite or ground-based data that are being used needs to be assessed in all analysis work. It is being appreciated that WMO and FAO make great efforts to support data quality measures, and such measures should be continued universally.

Crop water balance information is often determinant in semi-arid zones, and not always correctly represented by NDVI values. Crop water balance influences final crop status as from the very earliest stage, sometimes even as from the land and soil preparation stages. Thus these types of ground truths need to be taken into account as well.

The WRSI technique was no longer employed by FAO for regression against yield. It has been replaced by the use of ETA, whose use is based on better practical and theoretical justifications.

Base-line maps of land use were made in the context of the AFRICOVER project, and such maps are still needed and used. Nevertheless, while those maps for rangeland appear still useful, those for crops may or do need up-dating, and the question was raised whether this should be a top-down effort. It was noted that the level of confidence attached to these maps changes with time. There was a consensus that such work should be a one-time activity, repeated in time (sic !), to provide an optimal level of confidence. The criteria would have to be examined and may be re-assessed.

A discussion ensued about area harvested and cultivated and the inclusion or exclusion of zero-yield areas. Should one consider cultivated area or harvested area? Most methods, crop specific, now consider production = f(yield x cultivated area). In most cases, crop area estimates are made using a combination of ground-based and remotely sensed information.

The question was raised whether Early Warnings, issued in the middle of the season, could be retracted. They can and be updated and changed.

A different approach is to include seasonal forecasts in early warning information. It was stressed that the relative reliability and time spans of these two components are as yet very different, and that extreme care should be taken before relying on such methods. In any case, every early warning should specify the possibility and likelihood of extreme conditions that might affect the final reality.

The best or at least effective manner to promote transmission of information to end-users was discussed. The difficulty of providing information to migratory users was raised.

It would be sensible to link early warning information to suggestions for coping strategies.

3. Input data

CRAM needs meta-data in respect of meteorological, phenological, agricultural, crop development, and many other data. It also needs homogeneous coding of such data. In meteorology this coding exists. In phenology and agricultural crop development this has been proposed and is sometimes used. It will require further collaboration, regionally, internationally and interdisciplinary, to expand homogeneous coding to all fields and promote its general acceptance and use. An early attempt in this sense exists in the GMFS project.

A more generalized system of meta-data is certainly ambitious, but also of great potential value for the whole of Africa. Different protocols will have to be harmonized and quality control systems tuned in together. Quality is often determined at the time of observation and initial collection. ICPAC has an experience in these themes, and could collaborate with the other Regional Centers and organizations that administer other types of data to search a common solution for provide data accessibility in many domains to accredited users.

A suggestion has been made to use GPS and mobile telephone systems for rapid, real-time and once-for-all-digital transmission of observations. Data quality could benefit from such a system, but the requirement for data that obviously need correction might be less easy to satisfy. This can concern meteorological and all other types of data. It was proposed that the new CRAM should address this issue in collaboration with other stakeholders, and notably the role of national and regional entities.

It was observed that such a system might not be easily adapted for the collection of indigenous knowledge. This matter will have to be addressed concurrently with the previous one.

It is thought that the implementation of a regionally accepted system might help staff of organizations in different countries to eliminate erroneous estimates near national boundaries, especially on geographically non-homogeneous terrain. The experience in the CILSS countries, that has well defined roles for national and regional institutions, point in this direction.

A potential hesitation among certain institutions that hold data banks to implement such a system could be taken away if it is considered that the added value of an analysis is often many times greater that the value of the raw data. There are often different criteria for the access to daily and processed data.

It must be recognized that for all data there is a cost of observation and initial collection, that somehow needs to be covered. Nevertheless, the knowledge that is intrinsic in data is mostly considered a common good, and should thus be freely available for analysis and provision of information for a common purpose. Data available in one government agency should normally be available for all government agencies, such as those involved in early warning.

A discussion took place about the integration of different data sets including ground truths, the confidence level required for each sub-set, data quality, the inclusion of indigenous knowledge and the flow of field data to national services to regional or international institutes. It was agreed that the reliability of this flow can be increased if there is a systematic return of information on the products that evolve and their benefits for the community. Such a system would also help to strengthen the continuation of the flow of field observations.

Users and entities engaged in analysis should indicate which data are critical and what level of confidence is required. A new type of user is the district office of a national service that can now analyze local data for provision of information that is locally required. But such offices might still need data from elsewhere to situate the current status in a spatially and/or time-wise larger context.

It was suggested that a working paper on this subject should be prepared in the context of a New CRAM.

4. Uses and users

In first instance the monitoring products arising from CRAM activities are used by those persons and instances that transmit the derived information to decision makers in food security matters at all levels, notably for emergency responses. Associated use is made of this information for development purposes.

This definition gave rise to a discussion on "who were the real decision makers".

In second instance, this and associated information is used to show trends, to show specific aspects using relevant "masks", and help establish longer term plans. The information can be a "driver" for change. It can be a tool for the formulation of long-term development measures.

As regards the first type of use, the information is specially adapted to pinpoint "hotspots" in food insecurity, rangeland, and livestock husbandry activities. The earmarking of hotspots can sometimes permit a proactive approach, notably in the form of risk reduction measures.

When "hotspots" occur, the question should be asked whether these are conjectural or structural. The reaction or remedy may or should be significantly different in each of these two cases.

A special case is the one of recurrent emergencies. In this case, the problem becomes institutional in nature. It can be observed that linkages between the short-term view and the long-term one are not necessarily automatic everywhere.

The results of early warning products in respect of rangeland are, in a certain sense, less "visible", in that the deleterious outcome of bad situations may take longer after the event to show itself, but also be much more difficult to remedy. The "hidden face" of the bad situation may in the end prove to be greater, and so may be the impact on the livelihood of the community.

Further work by CRAM can address an elaboration of the list of "indicators of hazards", and a framework of how to use and/or combine these.

A discussion ensued about the combined use of EWS and seasonal forecasts. Farmers have been told that seasonal forecasts exist. However, farmers have not been told that the figures given do often not differ greatly from a chance distribution, that the figures given are probabilities with a rather low level of confidence, and that the timescales used in the forecasts are two orders of magnitude different from the timescales they employ in daily farming operations. Users of and persons transmitting early warning products should not be confused, and be made very much aware, about these highly significant differences in reliability of information. Some decision makers are able to assess the relative value of the one and the other, others may not be aware of the relativity of these values.

It was decided that a process to establish consensus views between decision makers and technicians needs to be engaged in a mutually participatory manner.

The matter of use of local languages was raised. While the initial transmission of information to staff charged with onward distribution to decision makers is usually in French or English, the final distribution is often made in local languages.

The chain of distribution of the products and information is long, with transmitters and users all along the way. The proper steps in this chain should be respected by all involved, to exclude any risk of deformation of the final product issued.

It remains to be established what are the most essential feedbacks to be obtained from users.

5. Other points

A number of other points of interest were raised in the course of the workshop. These often concerned several themes and included:

- involving young persons, who often have had training and can be used as an intermediate agents in transmitting information
- involving all stakeholders in the chain of transmission of information, including extension workers, all along the whole route
- obtaining feedback from users on the value of the final information and their own definition of their needs for information and the form in which they wish to receive it
- training the final users in the practical use of the information furnished
- making an assessment of the need for high and low resolution information for different users
- making an assessment of the compatibility of high resolution information with the field observation collected by users in the field.

At one time, participants were given ten seconds to state the subject that was most on their mind. Some of the subjects mentioned have been discussed in the sessions described above. Others, not yet discussed above, are given as a matter of general interest for those involved in crop and rangeland monitoring :

- Pay attention just as well to climate variability as to climate change.
- Combine more input data to produce a more all-encompassing product.
- How to assess the differences between crops in satellite images?
- Set standards for validation.
- How to include modeled weather forecasts reliably into EW products?
- How to assess comprehensively how CRAM outputs are being used, both upstream and downstream?
- How do CRAM products benefit local communities?

- How can CRAM products usefully be included in humanitarian responses?
- How do we get a maximum of field measurements into the analysis stream in good time?
- Should there be better partnerships for training, to avoid people only thinking with a black-box mentality?
- How to be sure that CRAM products get to the appropriate end-users?
- There is an increase in technicity, but there are still significant differences between methods?
- Are there links missing between the providers of information and the end-users?
- Does the role of field observers need to be strengthened? Can they be both a data provider and a link to end-users?
- How to use better the complementary potential of high- and low-resolution satellite images?
- How to improve interagency collaboration?
- How to involve herdsmen in collection of data and feedback on information provided?
- Can one involve the hydrological community more intensely?
- Can one motivate local staff more by sharing information on the totality of the project activities?
- How can one integrate the capabilities of international and regional institutions with those of national entities to have more consideration for critical issues by politicians, including their support to institutionalize the operations?

And last but not least:

- How can the Early Warning information be harmonized on an Africa-wide basis?
- How can the Early Warning information be used to help people living in the present situation AND ALSO safeguard the fragile environment for equivalent or better use by our children and grandchildren?

SCIENTIFIC CONTRIBUTIONS

ASSESSMENT OF FOOD SECURITY EARLY WARNING SYSTEMS IN SUB-SAHARAN AFRICA

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ABSTRACT

This conytribution is a policy brief note published by FAO's Agriculture and Development Economics Division (ESA) with support from the EC-FAO Food Security Programme. It's the synthesis of key findings and recommendations of a synthetic report prepared by FAO and the African Union and funded by the European Commission under the project "Planning for the future : An assessment of Food Security Early Warning Systems in Sub-Saharan Africa, 2006".

FAO Agricultural and Development Economics Division: http://www.fao.org/es/esa/

EC-FAO Food Security Programme: http://www.foodsecinfoaction.org/

Key words: early warning system.

INTRODUCTION

The crippling famines of the 1970s and 1980s in sub-Saharan Africa (SSA) prompted the development of national and regional early warning systems (EWS) across the continent. Over the past three decades, governments, regional institutions and development partners invested extensively in establishing EWS as a critical element of the emergency response system. Evidence suggests that these systems have been generally been effective in alerting countries and donors to impending food crises. However, there have been cases where inadequate analysis, together with poor communication and ineffective coordination and response mechanisms, have contributed to acute food security emergencies that might have been prevented.

EWS continue to be challenged by several issues, such as the persistent susceptibility of African agriculture to climatic variability and other hazards as well as the vulnerability of millions of chronically impoverished and malnourished households to a diversity of threats, from HIV/AIDS to prolonged violent conflict.

Strengthening EWS was identified in the Cairo Plan of Action of April 2000 as one of the priority areas for cooperation between the African Union (AU) and European Union (EU) to improve food security in Africa. In this context the AU and EU agreed with the Food and Agriculture Organization of the United Nations (FAO) to conduct an assessment of existing EWS on food security in SSA . The assessment reviewed their strengths and weaknesses and provided recommendations on actions for strengthening these systems for improved decision-making at national and regional levels.

The assessment was undertaken in three case study countries in three regions in sub-Saharan Africa (Table 1).

West	Southern	Greater Horn
CILSS	SADC	IGAD
Burkina Faso	Angola	Eritrea
Mauritania	Namibia	Ethiopia
Niger	Zambia	Kenya

FINDINGS

■ EWS in sub-Saharan Africa focus mainly on monitoring agro-climatic shocks and their impact on food production.

One primary use of EWS information is to produce national cereal balance sheets that include an estimate of aggregate food aid requirements. Some EWS are also involved in geographic targeting of food-insecure zones or conducting periodic livelihood or food needs assessments. However, many EWS are confronted by insufficient and low quality data produced by the national systems and the high opportunity cost of obtaining and managing their own data.

■ EWS that perform best are characterized by the government's recognition of their importance in the decision-making process. This includes:

- the political and financial commitment to EWS development;

- a greater willingness to maintain a transparent system and accord analytical autonomy to the EWS;
- effective collaboration between national governments and development partners; and
- innovative partnerships with universities and NGO's and collaboration with technical partners in early warning analysis to help overcome human resource capacity limitations.

■ The way in which information is collected, analysed and disseminated is critical for its use in decision-making and its role in supporting timely national responses to transitory food and nutrition crises.

A more transparent and participatory approach helps stakeholders reach consensus on the food situation and facilitates prompt action for mitigating the impact of food deficits and reducing threats to livelihoods. External technical support that is provided in a longer-term, collaborative and integrated manner has a greater positive impact on system performance than independent projects of limited duration.

■ While each type of institutional setting has advantages and disadvantages, several factors exert a positive influence on an EWS's performance and ability to carry out its mission. These factors include:

- an institutional home conducive to the reciprocal flow of information among the primary decision-making bodies involved in emergency actions and longer term food security analysis and development;
- administrative ease for accessing primary and secondary data from decentralized offices and line ministries;
- managerial independence and analytical autonomy that allow EWS to independently carry out their mission with appropriate political support; and
- the ability to recruit and train a diverse group of food security analysts who can address themulti-sector dimensions of food security.

■ A demand-driven system is critical to EWS effectiveness and long-term sustainability.

Almost all EWS need to clarify their mandate and terms of reference. This should be done in collaboration with their consultative bodies and in the context of available financial resources and human capacity. Too often, decisions on content and methods have been based on assumptions of what is needed rather than on a clear articulation of what users want and will use.

Bringing the demand side to the forefront of system development will require strong commitment and support from governments and technical partners to develop the processes and critical institutional mechanisms for:

- articulating user demand for information and analysis;
- translating demand into a well-defined mandate using appropriate methods; and
- ensuring that the requisite financial and human resources required for long-term sustainability are developed.

Continual reliance on donor funding may present certain risks to many EWS, particularly in terms of long-term sustainability.

Early warning activities can stop or be severely downscaled when external funding is withdrawn. The ability to leverage effective national budgetary support of EWS may require a priori that they meet government decision-making needs using the most cost effective technical methods.

■ Regional economic communities (RECs) have played an important role in supporting national systems. This includes:

- providing methodological support;
- serving as a neutral instrument for validating national crop survey and cereal balance sheet results;
- assuring comparability of analyses across time and space; and perhaps most importantly
- providing a forum for governments, donors and technical partners to discuss and collaborate on early warning issues.

The future role of RECs will depend on the needs of their member states as well as their comparative advantage, capacity and constraints.

IMPLICATIONS

One core recommendation emerging from this assessment is that countries, regional organizations, development partners and the African Union should focus their collaborative efforts on creating and strengthening institutional mechanisms that guide the development of the EWS. This will enable EWS to more effectively meet the decision-making needs of their primary users and to evolve in a dynamic and sustainable manner.

EWS also should become part of an expanded food security information and analysis system that can produce viable, relevant and credible information necessary for responding to short- term emergencies as well as contributing to longer-term development programming.

Achieving these goals will require an improved strategy centred on:

- ownership and commitment to developing a national process;
- strengthened national and regional capacity;
- responsiveness to user needs;
- use of the most cost-effective methods;
- partnerships for improved analysis;
- consensus-building in analysis of the food situation;
- tools to systematically integrate food security indicators into a clear statement about the severity of a crisis and implications for response options;
- linkages to long-term development programming; and
- financial sustainability.

To this end, the FAO is committed to working in partnership with all actors in sub-Saharan Africa.

CROPS AND PASTURES MONITORING ACTIVITIES CONDUCTED AT THE AGRHYMET REGIONAL CENTRE

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ABSTRACT

At the aftermath of the catastrophic droughts that stroke the sahelian region in the early 1970's, the AGRHYMET Regional Centre was created with the mission of training personnel, providing assistance to the national services of nine west African countries with equipment and methodologies to monitor the meteorological, hydrological, crops and pasture conditions during the rainy season. This monitoring is done at both national and regional levels with the objective of issuing alerts, if necessary, to decision makers so that they take measures to prevent massive human and livestock suffering and displacement. In this communication, we present an overview of the institutional set-up and the tools and methodologies developed throughout the years by the AGRHYMET Regional Centre and its partners to achieve this objective. These include monitoring tools for crops and pastures, such as simulation models using both observed ground and remotely sensed data on climate variables and vegetation cover. Activities have also been initiated to provide direct assistance to producers (farmers and herders) so that they optimise their production practices. Many of these activities are conducted in the framework of bilateral and multilateral collaborative programs with national, regional and international institutions.

Key words: crops/pastures monitoring, yield forecasting, drought, early warning, Sahel

RESUME

Suite aux sécheresses catastrophiques que la région sahélienne a connu au début des années 1970, le Centre Régional AGRHYMET a été créé avec pour mission de former le personnel et d'assister les services nationaux des neuf pays membres du CILSS en matière d'équipements et de méthodologies de suivi de la campagne agricole. Ce suivi des conditions météorologiques, hydrologiques, de l'état des cultures et des pâturages s'effectue aussi bien dans les pays qu'au niveau régional dans le but d'émettre des alertes en cas de besoin, afin de permettre aux autorités compétentes de prendre des mesures pour éviter les souffrances et déplacements massifs des personnes et des troupeaux. Dans cette communication, nous présentons le dispositif institutionnel ainsi que les outils et méthodes développés au fil des annees par le Centre AGRHYMET et ses partenaires pour atteindre cet objectif. Parmi ces outils, figurent les modèles de simulation utilisant aussi bien les données de terrain que celles dérivées des images satellitaires sur les variables climatiques et le couvert végétal. Des activités ont également été initiées pour assister directement les producteurs (agriculteurs et éleveurs) afin d'optimiser leurs pratiques de production. Ces activités sont en général conduites dans le cadre de programmes collaboratifs bilatéraux et multilatéraux avec des institutions nationales, régionales et internationales.

Mots clés : suivi des cultures et des pâturages, alerte précoce, prévision des rendements, Sahel, sécheresse.

INTRODUCTION

At the aftermath of the catastrophic droughts of the early 1970's, six West and Central African countries (Burkina Faso, Chad, Mali, Mauritania, Niger, and Sénégal) decided to join their efforts and create the CILSS: Comité Permanent Inter-Etats de Lutte contre la Sécheresse dans le Sahel (Permanent Interstate Committee for Drought Control in the Sahel). The Gambia, in 1974, the Cape Verde Islands, in 1975, and Guinea Bissau, in 1986 also joined CILSS. The current mandate of the CILSS is to undertake actions towards food security and to combat the effects of drought and desertification for a new ecological balance (CILSS, 2000). The AGRHYMET Regional Centre (ARC), one of the specialized institutions of the CILSS, was created in 1974 with the mission of training personnel, providing adequate equipment for the meteorological and hydrological stations networks, and setting up multidisciplinary working groups (MWGs) in member countries to monitor the meteorological, hydrological, crops and pasture conditions during the rainy season.

After thirty years of existence, the ARC continues to support the activities conducted by the MWGs in member countries both financially and technically. Indeed, the main objective of all the new methodological developments undertaken at the Centre is to transfer them to member countries

(Traore et al., 2004). This is done through workshops and long term training sessions attended by the staff of the different technical offices. Those offices are also assisted with equipment to be used for data collection, transmission, storage and analysis. All this is done by the operational units of the AGRHYMET Centre, in collaboration with scientific partners such as ACMAD, CIRAD, FAO, FEWS-NET, IBIMET, IRD, USGS, WMO, etc… Financial support for the activities of AGRHYMET is provided by Danish, French, Italian and US governmental cooperation agencies and other donors. The objective of this paper is to give an overview of the crop and pastures monitoring activities currently conducted by ARC and its national components.

CROP MONITORING ACTIVITIES

Crops and pastures monitoring are part of an integrated early warning system that includes several indicators such as the seasonal rainfall forecasts, dekadal and cumulative rainfall amounts, surface water levels and flows, etc…

Crop monitoring activities begin with the assessment of the start of the season, and continue throughout the season with the analysis of the crop water requirement satisfaction, the available soil moisture, crop pests and diseases, and yields forecasts. All these analyses are done on a 10-daily basis using outputs of a crop water balance simulation model, DHC, which uses either actual rainfall data or rainfall estimates from METEOSAT imagery.

The start of the season

Two models, based on slightly different methods, are used to determine the start of the season. The first method, based on soil water balance simulation, is implemented using the DHC (Diagnostic Hydrique des Cultures) model (Girard et al.1994, Bourneuf et al. 1996). This model uses the daily rainfall data from the regular network of CILSS member countries or rainfall estimates from METEOSAT infrared images, the average dekadal values of potential evapotranspiration (PET), and the soil water holding capacity. The starting date of the rainy season is defined as the day after the 1rst of April when available soil moisture in the soil top layer (15 cm) exceeds 10 mm and the crop water requirements are satisfied at more than 50% during the following 20 days (Figure 1, Figure 2).

The second method, implemented with the ZAR (Zones A Risque) model, determines the start of the season based on a rainfall threshold of 20 mm followed by a dry spell of no more than 20 days in the next 30 days using dekadal METEOSAT derived rainfall estimates (AGRHYMET, 2002). In addition, the ZAR model gives areas of "failed sowings", the potential duration of the season based on a fixed average ending date and other information related to the starting date.

Crop water requirements satisfaction

As with the start of the season, the DHC model is used to monitor the crop water requirement status throughout the season. Once a successful planting date is determined for a given location, the potential crop cycle, the duration of the main four growth stages (initial, development, full vegetation and maturation) and the crop water requirements for every 10-day period are determined by assuming a fixed ending date: the average date after the 1rst of September on which available soil moisture in the one meter layer is irreversibly depleted to less than 10% of the soil water holding capacity (Bourneuf et al. 1996). Crop water requirements are determined using a relationship between latitude and the three characteristics values of the crop coefficients derived from measurements on different sites throughout the Sahel (Fréteaud et al. 1984). The crop water satisfaction index is the ratio of the actual evapotranspiration (AET) to the maximal evapotranspiration (MET) for a given dekad. AET is computed using an algorithm proposed by Eagleman (1971) that relates the water consumption of a crop to its water requirements (MET) and the relative soil moisture content, and MET is the product of the crop coefficient by the potential Penman evapotranspiration (PET). Other assumptions on bare soil evaporation, root growth and soil drainage are made in the computation of AET (Bourneuf et al. 1996; Dingkuhn et al. 2003).

The DHC model gives several outputs related to crop water requirements that can be analyzed and mapped to illustrate the crop water status. These are: the water satisfaction index for the last dekad, the overall water satisfaction index since the start of the season (Figure 3), the water requirements for the remaining of the crop cycle, and the currently available soil moisture (Figure 4).

Crop yield forecasting

The main crop yield forecasting tool used at AGRHYMET and in the member countries is the DHC model (Samba, 1998). As already described, this model calculates the actual crop evapotranspiration (water use) every dekad and evaluates to what extent its water requirements have been satisfied. Following a three year survey in four West African countries (Burkina

Faso, Mali, Niger and Senegal), an empirical relationship was established between millet yields observed on farmers fields and an index derived from the outputs of the DHC model (Girard et al., 1994, Bourneuf et al., 1996; Samba, 1998; Dingkuhn et al., 2003). This relationship is used in the model to predict expected millet yields throughout the Sahel. A first yield estimate is made at the end of August and updated at the end of September. The comparison of the current year with the average gives an indication of a zone being at risk or not. Most recently, a methodology has been developed to feed the DHC model with rainfall data derived from historical records based on PREASO seasonal forecast scenarios. This allows giving yield forecasts already at the end of June, and updating them every 10-day using actually observed rainfall data (Figure 5, Figure 6).

Crop pests and diseases

Several sources of information, including regular reports from member countries, the position of the InterTropical Convergence Zone (ITCZ), the occurrence of rainfall, the emergence and/or presence of vegetation detected on NDVI images, are used to analyse and make forecasts on the possible outbreak of the most important crop pests in the sahelian region (Figure7, Figure 8). These analyses are based on the knowledge of the relationship between the biology of the insects and the environmental factors such as day length, temperature, soil type and moisture content, vegetation status, wind speed and direction, and the position of ITCZ. For example, the grasshopper Oedaleus senegalensis is known to move gradually from south to north at the beginning of the rainy season as the environmental conditions become more and more humid. Towards the end of the season, as the vegetation dries out and the ITCZ moves back southwards, it also takes the same direction and may cause massive damage to maturing crops in the sahelian and sudanian zones (Launois, 1978; Lecoq, 1978).

The desert locust Schistocerca gregaria, on the other hand, remains mostly in desert areas and may reproduce, multiply and migrate to agricultural zones if the environmental conditions become favourable. Several studies have used remote sensing techniques to evaluate the ecological conditions in the desert locust reproduction zones (FAO, 1997). These studies have demonstrated the possibility of monitoring and anticipating the outbreak of grasshoppers using NDVI and METEOSAT rainfall estimates. All these tools are used at AGRHYMET to closely monitor the ecological conditions that may be favourable for the outbreak of these pests, and if necessary, to issue warnings in the regular or special information bulletins.

The status of the natural vegetation

The analysis of the status of natural vegetation is done mostly with remote sensing data. NOAA/AVHRR, MODIS or SPOT-Vegetation derived NDVI are used to monitor the emergence and the advance of the vegetation front throughout the season. Comparisons of the current dekad values with those of the previous one allow to see where conditions were favourable or not for vegetation growth (Figure 9, Figure 10). The results are used by pastoralists and plant protection specialists to evaluate the conditions for the development of livestock or crop pests. AGRHYMET has recently conducted with success a pilot project in the Tahoua region of Niger, where herders were given information on where to locate good pastures every ten days through the RANET system.

Towards the end of the season, the potential productivity of pasture lands throughout the Sahel is evaluated using a model that estimates biomass yield from METEOSAT rainfall estimates and soil data (AGRHYMET, 2002). The outputs of this model, which makes simple assumptions on water infiltration, runoff and nitrogen balance, are potential dry matter yield in kg/ha at the 5 x 5 km scale (Figure 11) and biomass quality based on its nitrogen content. These results are used to evaluate livestock performance in terms of potential meat and milk production.

DETERMINATION OF RISK ZONES

All the indicators mentioned above may be used to declare a zone "at risk". The first signal is given by a delay of more than two dekads in the current year's starting date relative to the average. If that happens in a given location, this usually means that there will be less time for crops to develop and give adequate yield, because of a shortened season. This is based on the observation that the starting date of the rainy season in the Sahel is much more variable than its ending date (Sivakumar, 1988), and that a season starting late does not necessarily mean that it will also end late (Traore et al., 2000). At the AGRHYMET centre, a final assessment of the starting conditions is done at the end of July and all zones with late start are declared to be at risk. Once the season is installed, other indicators are used to determine risk zones, namely, if the crop water satisfaction index falls below 50% for two consecutive dekads. Important outbreaks of pests, floods and below average potential millet yields may also indicate that a particular zone should be considered as at risk. This gives basis for decision makers to focus their attention to those areas by closely monitoring not only rainfall conditions, but also socio-economic activities, and for taking adequate measures to prevent famine.

CHALLENGES AND PERSPECTIVES

In implementing all these activities, the Centre and its partners face several problems, most of which are related to data acquisition in member countries, their timely transmission and the small number of observation points. Since the late 1980s, the Centre has considered the use of satellite imagery to compensate for the lack of sufficient and timely acquisition of ground data. This has given rise to the development of a spatial version of the water balance simulation and yield forecasting model, DHC-CP that uses rainfall estimates from METEOSAT images (Samba, 1998). The ZAR and the BIOMASS models also use METEOSAT rainfall estimates.

Activities are currently underway to upgrade the crop monitoring and yield forecasting model, so that it simulates not only crop water balance, but also crop growth and development using solar radiation and air temperature data. The new model, called SARRA_H (Dingkuhn et al, 2003), was developed by the CIRAD Ecotrop team, in collaboration with CERAAS. It is now being tested for sahelian farming conditions in the framework of AMMA (Niger and Senegal). The new functionalities of the model should allow the yield forecasting to be extended to other crops and agro-climatic situations for which water is not the main limiting factor. This is in accordance with the new mandate of the Centre to extend its activities to all ECOWAS member countries. In this regard, partnerships are sough with scientists from countries like Bénin, Côte d'Ivoire and Guinea Conakry, in addition to those from CILSS member countries (Burkina Faso, Mali and Senegal) to conduct agronomic trials and on-farm surveys for the validation of the SARRA_H crop model.

AGRHYMET has also a METEOSAT Second Generation receiving station, and its operational units are working toward deriving climatic variables to be used as input to the different models.

Collaborative actions are being discussed with IRI and other partners in order to tackle the issues of downscaling seasonal climate forecast products for input in the AGRHYMET crop yield forecasting model.

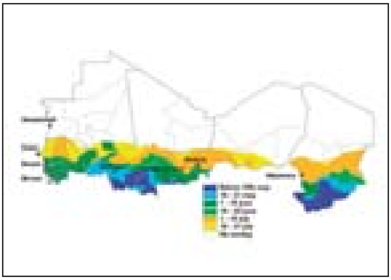

Figure 1: *Onset dates of the 2006 season in CILSS member countries*

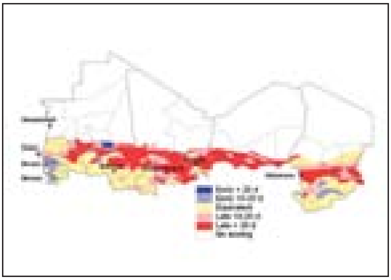

Figure 2: *Onset dates of the 2006 season compared to the average of the 1971-2000 period.*

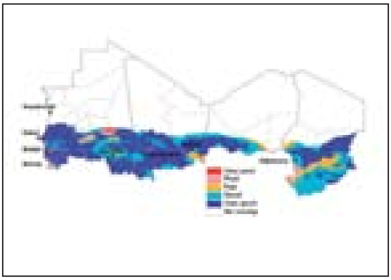

Figure 3: *Crop water satisfaction index as at 31st July 2006 in CILSS member countries*

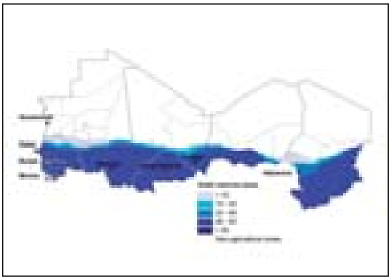

Figure 4: *Soil water reserves as at 31st August 2006 in CILSS member countries*

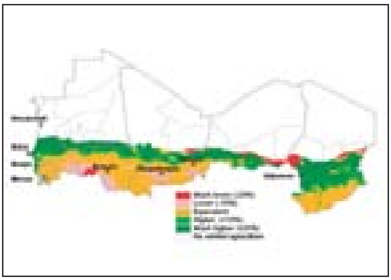

Figure 5: *Expected pearl millet yields as at 30th June 2006 in CILSS member countries*

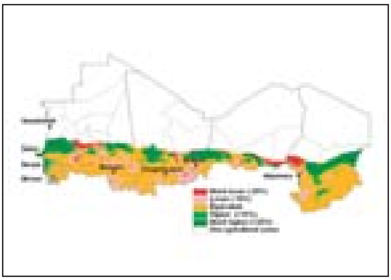

Figure 6: *Expected pearl millet yields as at 31st August 2006 in CILSS member countries*

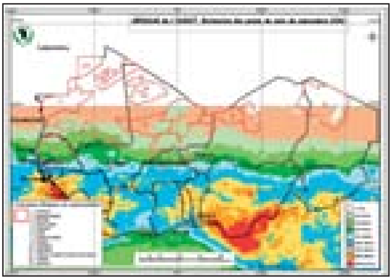

Figure 7: *Monitoring of possible pests outbreak zones using rainfall estimates from METEOSAT imagery*

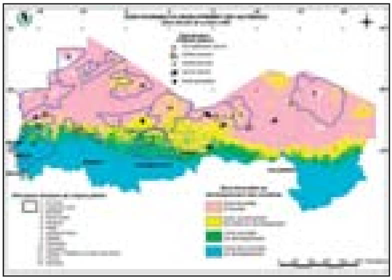

Figure 8: *Monitoring of possible pests outbreak zones using NDVI maps*

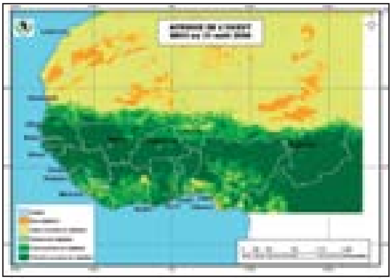

Figure 9: *NDVI map illustrating the status of natural vegetation as at 31st August 2006*

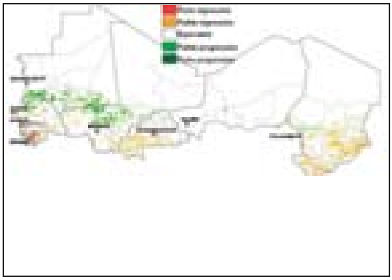

Figure 10: *Comparison of NDVI values for a given dekad with those of the previous year*

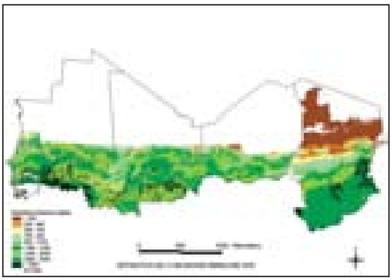

Figure 11: *Estimated herbaceous biomass yield*

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ACRONYMS USED

ACMAD:	African Centre of Meteorological Applications for Development, Niamey, Niger
AGRHYMET:	Regional Centre for applications and training in operational agricultural meteorology and hydrology, Niamey, Niger
AMMA:	African Monsoon Multidisciplinary Analysis, international research project
AVHRR :	Advanced Very High Resolution Radiometer
CERAAS :	Centre d'Etudes et de Recherches sur l'Amélioration et l'Adaptation à la Sécheresse Thiès, Sénégal.
CILSS:	Comité permanent de Lutte contre la Sécheresse au Sahel, Ouagadougou, Burkina Faso
CIRAD:	Centre International de Recherche Agricole pour le Développement, Montpellier, France
DHC:	modèle de Diagnostic Hydrique des Cultures, AGRHYMET
DHC-CP:	modèle de Diagnostic Hydrique des Cultures- Champs Pluviométriques, AGRHYMET
ECOWAS:	Economic Community of West African States
FAO:	Food and Agriculture Organisation of the United Nations, Rome, Italy.
FEWS-NET:	Famine Early Warning System NETwork, Washington DC, USA.
IBIMET:	Institute of BIoMETeorology, Florence, Italy
INSAH:	INstitut du SAHel, Bamako, Mali.
IRD:	Institut de Recherche pour le Développement, France
IRI:	International Research Institute for climate prediction, Palisades, NY, USA
ITCZ:	Inter Tropical Convergence Zone
JAS:	July-August-September
METEOSAT:	european METEOrolological SATellite
MWG:	multidisciplinary working groups
NBA:	the Niger river Basin Authority, Niamey, Niger
NDVI:	Normalised Difference Vegetation Index
NOAA:	National Oceanic and Atmospheric Administration, USA

RANET:	système de communication par RAdio et interNET
SARRA_H:	Système d'Analyses Régionales des Risques Agroclimatiques (_Habillé)
SPOT:	Satellite Pour l'Observation de la Terre, France
USGS:	United States Geological Survey, Sioux Fall, SD, USA
WMO:	World Meteorological Organisation of the United Nations, Geneva, Switzerland
ZAR:	modèle d'identification de Zones A Risques, AGRHYMET

REVISITING THE TARGET CLIENT, INFORMATION NEEDS AND AVAILABLE TECHNOLOGY FOR IMPROVED SERVICE DELIVERY IN AGROMETEOROLOGY

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SUMMARY

In sub-Saharan Africa, 90% percent of agricultural production is rain-fed leaving only 10% to irrigation. At the same time, the continent is susceptible to inter-annual rainfall variability. These facts strengthen the argument that weather and climate are one of the biggest production risk and uncertainty factors impacting on the performance of agricultural systems. Given these facts, Crop and RAngeland Monitoring (CRAM) is critical for understanding annual crop and livestock production and to develop appropriate strategies for food insecurity. This paper discusses the target clientele, looking at the traditional groups that have been receiving information and at the information that is being provided. Also, the paper examines the high potential of the use of the mobile phone technology in data collection. The paper discusses an example of the use of this technology to improve data collection in Africa. The target clientele needs to be re-assessed to increase the use of information generated through monitoring activities. Policies developed as a result of CRAM related activities, should be better documented so that they can be used in other countries for advocacy purposes for funding for crop and rangeland monitoring activities. Eradication of extreme poverty and hunger in the world is among the millennium development goals, and activities of CRAM have great relevance to these. Thus, information obtained through CRAM activities is useful for formulating both short and long term strategies to help avert catastrophes, help reduce human loss, and promote development of appropriate policies.

The density of the observational network is low in many African countries. Available mobile phone technology, developing at an unprecedented rate, can strengthen the collection, on a regular basis, from meteorological staff and volunteer observers in the field, of ground information on food and cash crops, critical in supplementing other data sources. Many businesses are taking advantage of the availability of such a technology to both transfer and receive information.

INTRODUCTION

In sub-Saharan Africa, 90% percent of agricultural production is rain-fed, and only 10% receives irrigation. At the same time, the continent is susceptible to inter-annual rainfall variability. These facts strengthen the argument that weather and climate are one of the biggest production risk and uncertainty factors impacting on the performance of agricultural systems and food security. As a result, Crop and RAngeland Monitoring (CRAM) becomes very critical for understanding crop and livestock production to develop appropriate strategies for food insecurity. Southern Africa faces well-documented challenges in maintaining and improving food security in the face of multiple stresses. Climate stress has compromised the ability of the agricultural sector in the region to sustain production, and may do so even more if there is an increased frequency of extreme precipitation events as a result of possible climate change (IPCC, 2001).

For many years, scientists have been providing specific information to targeted clients using particular communication channels. While these activities have been successful under the circumstances and because the target clients have remained more less the same, it is time to review both the target client and the information needs. The information needed by the target client may well evolve in view of work in the context of the Millennium Development Goals (MDGs) that requires specific information upon which policies can be developed to reduce poverty. While availability of satellite data has greatly enhanced crop and rangeland monitoring, collection of ground truths has lagged behind especially because of the dwindling human and financial resources in the meteorological services.

This paper discusses the target clientele, looking at the traditional groups that have been receiving information, and at the information that is being provided. The paper examines the high potential of the use of the mobile phone technology in data collection and discusses an example of efforts in the use available mobile phone technology to improve data collection in Africa.

THE TARGET CLIENTELE OF FOOD SECURITY INFORMATION

Food security information has a substantial and growing number of clients, in addition to the traditional, large number of government ministries and international agencies. There are many more stakeholders that require food security information to incorporate in their strategies to reduce poverty. These include donors, NGOs, private sector actors, civil society and decentralized local governments. It is critical that all producers of food security information stay abreast of the information needs of clients, who may keep demanding different forms of information. In most cases, the ability to stay abreast of stakeholders' information needs is constrained by the lack of mechanisms to determine, and than act upon informational and analytical requirements of their diverse clients. In the past, systematic surveys to establish user needs have yielded great results but in time, the information may change.

An FAO survey on Early Warning Systems (EWS) in sub-Sahara Africa revealed that none of the national or regional EWS or associated coordination bodies possessed a mechanism through which users could articulate demand for EW information or provide guidance or suggestions that could be systematically discussed and acted upon. Few EWS maintain a technical advisory body to oversee their methodological and analytical work. This void makes it difficult for EWS to fully understand the specific needs for information and subsequently adapt their products accordingly (FAO, 2006). This is a role that CRAM can and has been playing.

FAO also reports that even if information producers claim to know what clients want, they lack institutional procedures to translate requests for new information, analysis and EW products into a modified capability to meet these new demands. The absence of regular communication structures between client and producer can lead to a situation of frustration and unmet expectations for both groups. It may cause an EWS to remain narrowly focused on servicing the immediate information needs of their hosting organization – typically the Ministry of Agriculture or an other agency responsible for disaster or food aid responses (FAO, 2006).

The FAO report continues to explain that establishment of mechanisms to facilitate communication between clients and producers of EW information is important given the growing requests to adopt a multi-sector orientation, addressing access and utilization issues and the diversity of livelihoods. The use of early warning information to identify gaps in and to reformulate a broad range of development policies would logically represent a broadening of its traditional role focused on informing short-term programming decisions (FAO, 2006).

One of the millennium development goals is to eradicate extreme poverty and hunger. The activities of CRAM are relevant to these, if directed to the appropriate clientele. In the short term, information generated through

CRAM has been used to plan humanitarian assistance to serve lives. In the long term, the information can be used to develop policies for sustainable agricultural production for food security.

During the 2003/2004 agricultural season, FAO/WFP through Crop and Food Supply Assessment Missions (CFSAMs) established that there where a number of countries in the SADC region that faced unfavourable crop prospects, as indicated in Table 1. While the CFSAMS are once-only activities that take no more that 2 weeks to conduct per country, the continuous CRAM activities in a country provide a good basis for the outcomes of the CFSAMs. The CFSAMs, using various analytical techniques, were able to establish, see Table 2, that in short term these countries needed international assistance in order to make it through the consumption season.

Countries with unfavourable crop prospects in the SADC Region in 2003/2004 growing season	
Angola	Adverse weather and returnees
Lesotho	Drought
Malawi	Drought
Namibia	Adverse weather
Swaziland	Drought
Zimbabwe	Adverse weather, Economic crisis

Source: FAO GIEWS

Table 1. *Countries with unfavourable crop prospects in the SADC region in 2003/2004*

These processes provide valuable information, but it is not known how much of that information is used for policy development for poverty reduction and hunger in Africa. Some questions remain. In any country, can one describe a policy that has been established as a result of these activities? If policies exist that have been developed as a result of these activities, these would need to be documented so that they can be used in other countries to justify funding for crop and rangeland monitoring activities. If the use of information on CRAM activities has been limited, one may need to revise the list of target clients so that those in strategic institutions are sure to receive the information.

Countries Requiring external Food Assistance in the SADC Region in 2003/2004 Growing Season	
Country	Reason for emergency
Angola	Returnees
Dem Rep of Congo	Civil strife, IDPs and Refugees
Lesotho	Drought
Malawi	Drought in parts
Mozambique	Drought in parts
Swaziland	Drought in parts
Tanzania	Drought in parts, Refugees
Zimbabwe	Adverse weather, Economic crisis

Source: FAO GIEWS

Table 2. *Countries requiring external food assistance in the SADC region in 2003/2004*

INFORMATION NEEDS

The methods used for crop and rangeland monitoring evolved tremendously over the last three decades. This has to a large extent been driven by the availability of new and improved analytical techniques as well as the need to respond to changes in demand for early warning information. FAO reports that demand for early warning information has evolved as users have learned from past experiences and gained a better understanding of the type of information needed to improve responses especially in the short term (FAO, 2006).

While satellite data have been available, ground data collection to obtain ground truths has seriously lagged behind, especially as a result of dwindling human and financial resources in the meteorological services. Nevertheless, ground data collection on a regular basis is an essential component in crop and rangeland monitoring and needs to be strengthened. Biological observations assess crop stage, growth and condition; pests, and diseases incidence and other adverse effects; pasture availability and condition; and livestock condition.

During the 2006/2007 agricultural season, southern Africa has received substantial amounts of rainfall in respect of needs for crop and pasture development. In some instances, these rains have been too much, resulting in water logging and flooding (Figure 1). It is important to note that most of the crop yield models that are being used in Africa do not handle situations of excess water very well in predicting yields.

Figure 1. *Flooding in parts of Zambia*

Some models, even an "established" one, may not perform satisfactorily if it starts well, with crops performing well, followed by situations of water logging and flooding, that can completely upset the performance such a model. For this reason one collects data with the various methods available, and one examines the outcome with regard to ground observations. Ground observation information in situations of water logging and flooding will provide valuable information to make adjustments to crop yield models as well as satellite data interpretation. Ground observations can provide information on the subjects mentioned above and also on planting and replanting times (including delays)

To provide relevant information for early warning purposes, institutional capacity is also very critical. In a survey conducted in southern Africa by the regional Remote Sensing Unit (RRSU) in 2002, the respondents indicated that they did not have sufficient capacity to conduct agrometeorological analyses that would meet the farmers' demands; this meant that the skills and equipment were not adequate (SADC-RRSU, 2002). In many African meteorological services, funding has become a major problem for operational activities and capacity building. Remuneration of staff is often not very competitive, hence the existence of high staff turnover. A lack of institutional capacity has been described by others: the IRI Gap analysis report indicates that at present, there is the lack of effective institutional arrangements to facilitate the generation, analysis and systematic integration of relevant climate information with other pertinent information in a form that planning and operational agencies can use (IRI, 2006).

To improve on information delivery, key relationships with the target clientele need to be established so that clients can articulate their information requirements when these change. For example, a survey conducted by SADC-RRSU in 2002 found that in terms of information supply for agricultural purposes, the producers of climate information did not have access to farmers directly, while agricultural extension officers are interacting with farmers. Unfortunately, there is only a weak link between information producers and the extension services or other agricultural expert intermediaries, preventing the information to be relayed effectively (SADC-RRSU 2002).

AVAILABLE TECHNOLOGICAL ADVANCES

The rate at which technology is developing in Africa is unprecedented. In particular, the use of mobile phones has spread like wild fire in Africa. There are basically more than three service providers in each African country. In 2002, Odame et al. reported that telecommunications connectivity in developing countries is usually available only within the capital and in major secondary cities. Yet the majority of the population lives outside these cities. The report is only 5 years old but at present the scenario is totally different. Many businesses are taking advantage of the availability of this technology to both transfer and receive information. The present workshop may suggest an increase in the use of such data collection systems to supplement satellite and other data sets for crop and rangeland monitoring in Africa.

Phenological observations of crops and pastures, as described above, as well as yield and production forecasts for a year in comparison to the previous year's harvest, have always been critical to supplement the other data sources. The observations are carried out on crops and rangeland conditions in the neighbourhood of a rain gauge or complete meteorological station. With mobile phone technology, data collection can take place basically anywhere where this is available to collect and transmit the data.

In Zambia, mobile phone technology has been used to provide Trade/Market Information Services. The system has worked very effectively and efficiently. This system has been put in place through the collaboration of a mobile phone company Celtel, a company also found in many other African countries, and the farmers union organization. Figure 2 shows the coverage by Celtel in Africa. Codes have been developed for particular crops and locations that are used by those requiring trade/market information for crops and livestock via SMS. This means that each crop has a specific code and provinces or districts also have specific codes. The mobile company has agreed to charge the users at a specific fee.

Figure 2. *Celtel coverage in Africa*

Therefore, if a buyer wants to purchase a particular crop e.g. maize, one would need to obtain a list of individual or organizations selling maize in a particular province or district. To do this, all one does is type in the code for type of crop of interest for example maize i.e. MAIZ and the province or district where one wants to buy the maize e.g. PE for eastern province and send the SMS to 4455. Within a few seconds, one receives the entire list of all those selling the commodity requested. The next stage is to try and get the details of the sellers by selecting one that is offering a price to one's satisfaction by typing the codes of the seller provided and sending it to the same 4455 number as an SMS. Once the contact details have been received, the seller is then contacted and the deal is completed.

The density of the observational network is low in many African countries. Some countries, hampered by lack of trained personnel and limited budgets, have only one or two agrometeorological stations, limiting agrometeorological activities. The availability of data collection by mobile phone through services by volunteer observers can help to complement data collected by national services, even though the cost of an SMS might pose a challenge to the success of this proposal. A solution may have to be found.

To facilitate the data collection using mobile telephone, codes for districts, crop type, crop stage, crop, pasture and livestock condition, phytosanitary aspects, water and grazing availability for livestock, dates of planting and replanting, etc. would have to be developed. For districts, two or letters may be used e.g. Nairobi would be NRB. The same may be done for crops e.g. maize may MZ . For crop stage and condition, the tables below may be used.

Crop Stage

Germination	Vegetative	Flowering	Ripening
1	2	3	4

Crop Condition

Good	Mediocre	Poor	Very poor
1	2	3	4

Furthermore, the WMO has developed codes that might be used. With all the codes in place plus training conducted, an SMS report on maize in Nairobi through an SMS would take the following form:

NRBMZ21

The code above would be interpreted as a report from Nairobi for maize in its vegetative stage and in good condition.

CONCLUSIONS

Looking at policies that have been developed as a result of CRAM related activities, it is important that these are documented so that they can be used in other countries for obtaining funding for crop and rangeland monitoring activities. On the other hand, if information produced by CRAM has been utilized in a limited way, then one may need to revise the target clientele list so that those in strategic institutions are included on the list of that receive the information.

Among the millennium development goals, is the goal to eradicate extreme poverty and hunger in the world. CRAM activities can be part of this process. Information obtained through CRAM activities can be useful for both short term and long term strategies to avert catastrophes and human loss and for development of appropriate policies.

The density of the observational network is low in many African countries. These observations have always been critical in supplementing other data sources. Mobile phone technology, developing rapidly in Africa, can be successfully used to collect field data on crops and pasture from meteorological staff and volunteer observers in the field and thus strengthen the ground data collection to benefit food and cash crop production.

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CROP AREA ESTIMATION USING HIGH AND MEDIUM RESOLUTION SATELLITE IMAGERY IN AREAS WITH COMPLEX TOPOGRAPHY

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ABSTRACT

Reliable estimates of cropped area (CA) in developing countries with chronic food shortages are essential to the design and implementation of appropriate food security programs. Unfortunately, these accurate estimates present a significant challenge. Frequent field surveys are costly and fail to represent the country-level spatial heterogeneity. Satellite interpretation of crop area is an effective alternative. In previous studies, spectral-based classification of satellite imagery produced considerable errors, due in part to sub-pixel mixing. This is particularly the case in developing countries, where small subsistence farms are more prominent than larger mechanized farms. Conversely, bias-corrected texture-based classifications show little deviation from actual crop inventories, when estimates derived from aerial photographs or field measurements are used to remove systematic errors in medium resolution estimates. In this paper, we present a hybrid high-medium resolution technique that combines spatially limited unbiased estimates from 1m-resolution satellite images with spatially extensive Landsat ETM+ estimates and SRTM-based topography.

The technique is used to estimate CA in primary crop production zones of Ethiopia. Ethiopia stands out as the highest food aid recipient in Africa, and accurate assessments of agricultural production continue to plague effective relief efforts. Complex topography and the prevalence of small farms make the study area a particularly challenging geographical region. The study is unique, as CA derived from high spatial resolution (IKONOS) images was used as unbiased truth data. Manual interpretation of points (dots) at 500 meter intervals over 17 one-meter resolution panchromatic IKONOS images stratified over three 30-meter Landsat scenes was used to determine bias CA for 2005. A study area of eight Landsat scenes was manually classified using points at 2 *km intervals to estimate CA over a wide area using the bias estimator derived from the comparison of Landsat to truth. Landsat and IKONOS images were taken during the primary harvest months of 2005 and 2006 respectively. Elevation and slope from the FAO corrected SRTM DEM at 90 m resolution were used to further improve the bias estimator. Land-cover information from the International Livestock Research Institute was used to delineate the landscape into regions of homogenous cropping characteristics.*

The relationships between slope, elevation, Landsat CA percent, and IKONOS CA percent were evaluated using a multivariate linear regression model. Percents were determined from 100-300 point windows. Each indicator, evaluated over dominant land cover types, showed significant ($p<0.001$) and highly correlated relationships with high-resolution CA percents. Results suggest that Landsat estimates generally overestimate the cropped area, but that the extent of this overestimation is dependent on land-cover characteristics and DEM information. From a food security perspective, this could lead to a dangerous over-estimation of crop production. The cross-validated model had an R2 of 0.86 when comparing cropped percentages derived from high-resolution imagery with estimates derived using the Landsat crop percentage and either slope or elevation. This close relationship allows confidence in the wide-area estimates resulting from interpretation of multiple Landsat scenes over much of central Ethiopia. District-level analysis of Landsat based estimates showed good correlation with the Bureau of Agriculture and Rural Development. The study demonstrates a cost-effective method for determining CA in remote areas throughout Africa. Continued work will evaluate the use of segmentation software to automate classification of Landsat scenes for routine CA estimation in the future.

INTRODUCTION

In 2001- 2003, the Food and Agriculture Organization (FAO) estimated that 820 million people were undernourished in developing countries (FAO 2006). Contrary to other regional trends, sub-Saharan Africa has seen a significant increase in undernourishment from 169 million people in 1990-1992 to 206 million people in 2001-2003, representing one-fourth of people suffering chronic hunger worldwide. Ethiopia has achieved a significant reduction in the number of undernourished (17% from 1993-1995 to 2001-2003), which is due primarily to economic growth and significant expansions of per capita food production. Even so, 15 million Ethiopians face chronic or transitory food insecurity, with up to 10% of the population facing food shortages in years of above-average productivity (FAO 2006). As a result, Ethiopia remains the largest food aid recipient worldwide (870,000 tons of food from 1996-2005). Food production is a function of the amount of area being cropped and the yield per cropped unit. Cropped area (CA) is a function of many inputs, such as seed availability, rainfall forecasts and economic incentive. It is therefore imperative for the design and implementation of appropriate food security programs that reliable estimates of cropped area are made.

Despite the numerous successes of the Large Area Crop Inventory Experiment (LACIE) (Hammond 1975; MacDonald, Hall et al. 1975; MacDonald, Hall et al. 1980) and the Agriculture and Resources Inventory Through Aerospace Remote Sensing (Hixson, Davis et al. 1981a; Hixson, Davis et al. 1981b), food production estimates for many developing African nations still face significant uncertainty. While simple models of crop water scarcity (Senay and Verdin 2001; Verdin and Klaver 2002) tend to track well with yield anomalies in rain-fed semi-arid regions of Africa, the cropped area term of the production equation is still poorly specified. Complex topography and the prevalence of small subsistence farms further amplify CA uncertainty in Ethiopia. Currently, estimates of cropped area in Ethiopia are produced by two governmental agencies, the Central Statistics Authority (CSA) and the Bureau of Agriculture and Rural Development (BoARD). These agencies have significant differences in their cropped area and production estimates. Typically, the BoARD reflects a higher cropped area than the CSA. For all the regions provided in the FAO 2006 Crop and Food Supply Assessment Mission, the BoARD estimate of cropped area is more than 25% greater than the estimate provided by CSA at the national level. The discrepancy in the estimates creates uncertainty in food security for large populations of Ethiopia.

This research seeks to develop a hybrid high-medium resolution technique to determine cropped area for major crop producing zones in Ethiopia during the 2005 planting season that combines spatially limited, unbiased estimates from IKONOS satellite images with spatially extensive and low-cost Landsat ETM+ estimates. The study is unique, as the bias estimator is developed from area-frame samples of high spatial resolution satellite images, instead of aerial photographs or field surveys. Land-cover derived from FAO woody biomass maps and the Shuttle Radar Topography Mission (SRTM)-based elevation and slope were used to refine initial estimates. The method is reproducible and can be updated on an annual basis, using current moderate resolution satellite data from the primary planting season.

BACKGROUND

The area frame sampling approach has been applied in a number of ways in agricultural surveys. The general principle involves a multi-stage sampling approach where the scale of segments, or sampling units, at each stage is different from other stages. A statistical relationship between the high and medium resolution data is than used to estimate the cropped area for the largest unit practical. An example of a number of surveys performed for various countries with different stage sampling units was produced by FAO. In these studies the segments were political districts, crop reporting districts, arbitrary areas on a satellite image, a single farm, or a household. The area frame approach can be structured to take advantage of available resources to maximize the amount of information going into the final statistical estimate.

The study builds on crop area estimation dating back to the distribution of the first Landsat data in the early 1970s. Initial experiments focused on an area frame sampling approach to estimate wheat production for various areas around the globe. While the techniques in manual interpretation have changed– primarily in the shift from analog to digital media – the basic foundation from LACIE efforts are employed in this study. LACIE used a multi-scale approach to crop estimation, by linking district-level crop production figures with interpreted 30 square-mile segments of satellite imagery (Chhikara and Feiveson 1978). While seasonal differences in spectral signature introduced some error, the findings generally supported this approach as a reasonable method for estimating cropped area (Thomas 1978).

Several techniques have been adapted for crop estimation using aerial photographs and satellite images, including: pixel count from supervised/unsupervised classification, Bayesian/fuzzy classification and spectral un-mixing, geo-statistical interpolation, and area frame sampling (Gallego 2004). Pixel count is dependent on classification accuracy, which is limited by the presence of mixed pixels, co-location inaccuracy, and the spatial correlation between training sites and test sites. Furthermore, classification techniques and spectral un-mixing are highly sensitive to the variance among categories and correlation between spectral bands. Location and interpretation error are limitations of area frame sampling as well, however several applications involving unbiased estimators (ground survey or high resolution aerial photos), show little deviation from actual crop inventories (Gallego 1999). In areas where the execution and monitoring of ground surveys is difficult or the area of study is large, the use of remotely sensed image segments has a substantial economic advantage. As a result, several national/regional organizations use area frame sampling to estimate crop area in Europe and the United States, including: the USDA Foreign Agriculture Service, Statistics Canada, European Union Monitoring Agriculture with Remote Sensing Project, and the Italian Agrit Project. Results of a study in Hamadan Province, Iran are promising, as area frame sampling using aerial photos showed an overall accuracy of 99.8% estimation of annual crop inventories (Pradhan 2001).

DATA

The study area for this project (Figure 1) is a highly contentious region, in terms of crop production estimates of central Ethiopia. Seventeen one meter panchromatic IKONOS images stratified over three 30m Landsat 7 ETM + scenes were used to determine bias in Landsat CA. The remaining five Landsat scenes were used to estimate crop area using the bias estimator. Classification was performed using Landsat composites (bands 3 = red, 4 = near infrared, and 5 = mid infrared). IKONOS images were taken during various stages of crop development (May, June, July, and October of 2006), while Landsat images were taken just before and after harvest (October and November of 2005). Seasonal/annual differences and co-location error in Landsat and IKONOS images were assumed to be negligible, because the technique employed in determining crop area significantly reduces the variability in point-to-point classification, and the difference in cropped area between the two years was small.

Slope and elevation were determined from the mosaics of the SRTM 90m digital elevation model (DEM) for Africa. Post-processing of the SRTM DEM was performed by FAO-SDRN (Environmental and Natural Resources Service). Land-cover information was collected from the International Livestock Research Institute multipurpose woody biomass database for Ethiopia, a harmonized compilation of land cover maps and corresponding attribute tables. The product was developed from satellite interpretation, national forest inventories, general forest assessments, and biomass studies for the year 2000. The maps contain unique geometric units linked to attribute tables with information on the percentage and type of primary and secondary land cover.

High-frequency sampling consisted of setting up a regular grid of points at a 500-meter interval across the area covered by the IKONOS imagery. This technique resulted in over 22,000 non-cloud samples that included elevation and slope derived from the SRTM dataset, a land-cover class based on the woody biomass dataset, a crop/no-crop classification based manual interpretation of the IKONOS imagery and a separate crop/no-crop classification based on Landsat.

Comprehensive sampling consisted of a regular grid of points at a 2-kilometer interval covering the eight Landsat scenes used in this exercise. This resulted in over 80,000 samples used in deriving the district cropped area estimates. Each sample was attributed with elevation and slope data, a land-cover class based on the woody biomass dataset, and a crop/no-crop classification based on manual interpretation of the Landsat imagery.

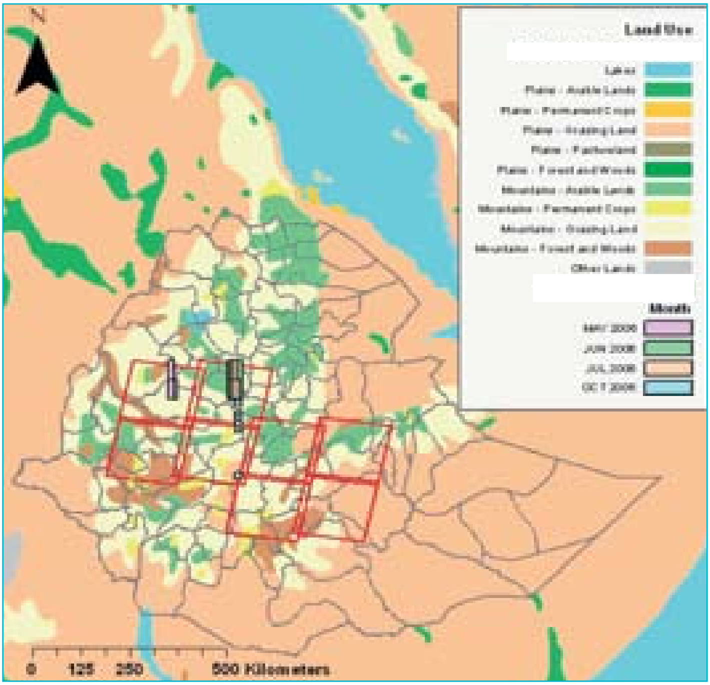

Figure 1: *Eight Landsat ETM+ scenes and 17 IKONOS panchromatic frames over the administrative-district level boundaries and terrain of Ethiopia.*

Manual interpretation of the digital imagery was performed using the LC-Mapper tool developed at EROS Data Center. The manual interpretation used classic heads-up techniques incorporating the color (spectral), shape, texture, shading and pattern information. In the interpretation process the grid of points was overlaid on the digital imagery, appearing as dots on the image. The LCMapper tool allowed for the selection of dots both individually or in clusters, and the selected dots could then be ascribed a crop or non-crop attribute code. The scale of interpretation was dependent on a variety of factors, including the complexity of the landscape, the need for contextual information, and – most importantly – the type of imagery being interpreted. This resulted in two sets of points capturing information at different frequencies over different spatial domains, but with a similar set of attributes that could be used to extend the spatially limited data to a larger area.

METHODS

The approach to estimate cropped area from the available point information uses elevation, slope, land-cover and manual classification of the Landsat data to create a relationship between the groups of points and the crop percentage results of the IKONOS interpretation. The method uses groups of points to create a relationship between the variables and the ground truth for each land-cover type. Five land-cover classes comprised nearly 85% of the high-frequency points, with the other 15% being dispersed among 15 land-cover classes. Because of this, it was decided that the five dominant classes (cultivated: few stocks, cultivated: light stocks, cultivated: moderate stocks, grassland: few stocks, dense shrub-land) would be identified individually with the remaining 15 classes found in the land-cover map combined into an "other" class.

The cluster technique builds on the idea that the imagery is not precisely co-registered, so it is better to interpret groups of points rather than individual dots. Because this project attempts to estimate cropped area at a district-level, rather than a spatially explicit map, the clustering is appropriate.

The first step was to create clusters of data from the same land-cover classification that were near one another using the high-frequency sampling points. The number of points assigned to the cluster depended on the overall size of the class and how many total points were in the class. The number of points in a cluster was between 100 and 300, resulting in 10-24 clusters per land-cover class. The relationship between the different variables and the percent of crop in each cluster was analyzed within each class. It was expected that the between class variation would be explained by the bias estimator describing the average crop percentage of Landsat and IKONOS, while within class variation would be explained by SRTM characteristics.

This methodology is based on the idea that the percentage of points that is interpreted as crop, using Landsat, will provide the most consistent indicator for mean cropped area. It was understood, however, that small-scale farming practices may lead to an overestimation of cropped area based on Landsat. This approach attempts to build a ratio between the Landsat and truth data from the high-frequency dot information, which could un-bias the Landsat results. After rescaling the Landsat-based crop percentage it was then possible to model the residuals using either slope or elevation, depending on the land-cover class. An example of the residuals from this initial re-scaling plotted against slope for the "Cultivated: Few Stocks" class are shown in Figure 2. Both the "grassland: few stocks" and the "other" classes were better described by elevation than moderate resolution imagery. This is likely related to the fact that patterns and structures of the landscape at different elevations may be very similar, but that at low elevations (where it is also hot and dry) there is much less crop than at higher elevations. The similarity in patterns and structure would lead to the over-estimation of crop at these low elevations.

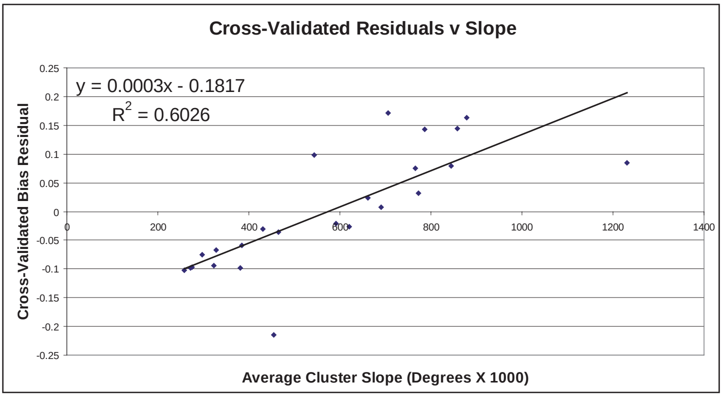

Figure 2. *Scatter-plot of cross-validated residuals with elevation for the class: cultivated: few stocks*

Preparation of the comprehensive dataset involved partitioning points into the different crop-reporting units, and then dividing each reporting unit into the various land-cover classes. From this grouped data, it was possible to calculate the Landsat crop percentage, as well as average slope and elevation for each unique land-cover class in each reporting district, which were converted into an estimated cropped percentage for that land-cover class. The area-weighted average of these estimates resulted in a cropped area percent for each district, which was then multiplied by the area of the district to arrive at the cropped area for the district.

RESULTS AND DISCUSSION

A requirement of the clustering technique is that the class-based estimators are adequate in defining the truth. Results from the clusters of high-intensity data show a very good relationship with cross-validated results for cropped percentage. The R2 of the cross-validated clusters is 0.864 for the 91 clusters, including the "other" class (Figure 3). Additionally, the coefficients in the linear regression are very close to 0.0 and 1.0, such that there is a good 1-to-1 relationship with our estimates and the truth. This high correlation and positive relationship provides confidence in applying these results to the comprehensive data.

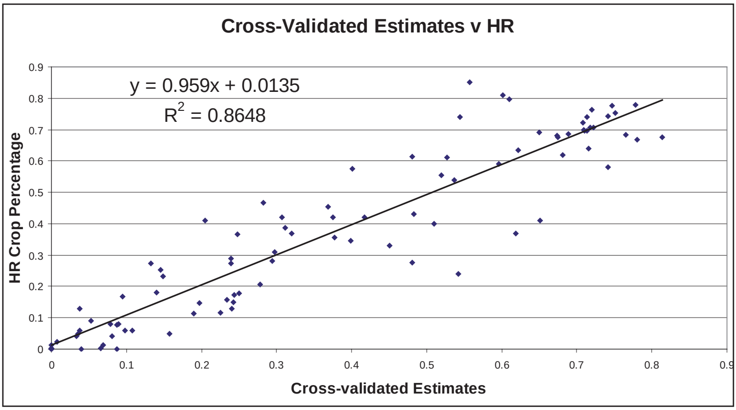

Figure 3. *Scatter-plot of cross-validated estimates with high-resolution crop percentages*

With confidence that the clustering technique can provide reasonable estimates of cropped percentages for an area, we developed district-level cropped area estimates based on the points from the comprehensive sampling. Comparison with published numbers taken from FAO's 2006 CFSAM for Ethiopia (FAO, 2006a) shows the differences between the cropped area estimates. Only crop-growing regions that are covered by the Landsat data are included in this report. Additionally, a few districts that were covered by the Landsat imagery were not included in the CFSAM report.

The results shown in Table 1 present the cropped area estimates for select districts. Variance in the individual district numbers is high, but general trends are captured in all the estimates. The departures in the total cropped area are quite stark and give cause for concern. The CSA areal total is nearly a quarter less than the estimate nearest to it. In this respect the CSA seems to be an outlier from the other two estimates.

	Cluster	CSA	BoARD
Arsi	591	551	733
E. Shewa	412	470	608
E. Wellega	479	309	414
Gurage	211	81	144
N. Shewa	380	350	534
Sidama	209	72	147
W. Harerge	248	200	199
W. Shewa	590	426	639
Yem	12	14	13
Total	3132	2473	3431

Table 1. *Cropped area for nine select districts, reported in thousands of hectares*

The error in the clustering estimates is difficult to define. Error in these estimates may come from sources such as misinterpretation of the Landsat data, errors in defining the coefficients used in the procedure, or the ability of the sampling scheme to adequately capture the landscape. Cross validation using the high-frequency data allowed for the estimates of errors in defining the coefficients, whereas sampling theory could be used to help define the errors related to the grid technique. The interaction of these errors adds to the difficulty in giving a quantitative estimate. Cross validation showed that results of error varied between the land-cover classes, with the cultivated: light stocks and cultivated: moderate stocks showing high error, while there was less error in the cross-validated estimates for the other classes. Integrating this information in the district estimates was beyond the scope of this initial investigation, but should be included in the future.

One aspect of the data that could be expanded to improve the results is the spatial distribution of IKONOS data. In particular, the stratified distribution of high-resolution satellite imagery limited proper representation of the topographic and ecological heterogeneity of the region. This leads to some problems when the elevation for a district is well outside the range captured by the high-resolution imagery and could lead to inaccurate estimates because of extrapolation of the tested relationship. Additionally, while the "other" land-cover class composed only 15% of the high-frequency points, it was nearly 40% of the comprehensive points. Because this group is composed of a number of land-cover types, it is reasonable to expect that the composition of it changes in space, and that the relationship built for our test area may not be spatially invariant. Having additional high-resolution imagery could help in this regard.

CONCLUSION

This study presents a method of using area-frame sampling to estimate cropped area for a region of Ethiopia. The method arrives at results for nine districts where there is complete coverage of the district. When comparing total cropped area for the nine districts to reported figures, the technique presented here is within 10% of the BoARD estimate, yet is more than 25% greater than the CSA. Analysis of the crop percentages for the nine districts is less compelling, but it still shows a stronger correlation with the BoARD than with the CSA values. This study supports the cropped area numbers of the BoARD for the region of Ethiopia being studied.

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CROP MONITORING, FORECASTING AND PRODUCTION ESTIMATION IN KENYA BASED ON THE GEOWRSI CROP MODEL AND ANCILLARY FIELD DATASETS

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ABSTRACT

Kenyan's livelihoods depend largely on rain-fed agricultural activities, which are adversely affected by an erratic onset, poor temporal and spatial distribution and gradually declining seasonal rainfall totals often culminating in failed crop production in marginal areas. It is within these marginal agricultural areas that food insecurity currently manifests itself as a chronic problem that requires close monitoring and forecasting to ascertain crop production prospects for early warning preparedness and response planning.

USGS/FEWS NET recently introduced a beta-version stand-alone Geospatial Water Requirement Satisfaction Index (GeoWRSI) crop model, which allows for localized crop modelling, monitoring and forecasting at the sub-national level, using locally available datasets as model inputs. These may include prevailing weather conditions (rainfall and evapotranspiration), planting dates and lengths of growing periods, crop characteristics and cropping zones. This additional information has proved to be very useful in determining the crop growing conditions within Kenya's diverse Agro-Ecological Zones (AEZ).

Crop production estimates in Kenya can now be objectively determined with adequate lead-time based on spatial integration of the crop model outputs, qualitatively validated baseline maize crop zones (FAO/Africover dataset, 2002) and production statistics at sub-national level (Livelihood Zones data). The estimates compare very well with estimates made by the Ministry of Agriculture (MoA) and those by the Department of Resource Surveying and Remote Sensing (DRSRS) based on the interpreted aerial survey datasets undertaken in the recent past. The preliminary analysis, results and the recommendations for the way forward are also discussed in this paper.

Key words: Food Security, GeoWRSI, Kenya, Mais production estimation

INTRODUCTION

Declining per capita crop production and increasing relief aid to beneficiaries is a major concern in the Greater Horn of Africa (GHA) states. Recent FEWS NET reports (FEWS NET/Executive Overview of Food Security in Sub-Saharan Africa, 2007) indicate that the GHA region (Djibouti, Ethiopia, Kenya, Somalia, Southern Sudan, Tanzania and Uganda) currently accounts for almost 90% of Africa's population requiring food-aid. Recurrent severe droughts of 1984, 1992/3, 2000/2 and 2003/6, land degradation, civil strife, disease, floods and fuel price increases have contributed to declining food production. Livelihoods and coping mechanisms have also been severely affected, leaving large populations living in marginal agricultural and pastoral areas vulnerable to hydro-meteorological shocks. Most GHA countries rely heavily on rain-fed agriculture, which accounts for 30-50% of their national Gross Domestic Production (GDP).

Kenya, one of the more developed agricultural economies in the GHA region, is also experiencing similar problems, as shown in Figures 1a, 1b and 1c, declining rainfall amounts, declining per capita maize production and increasing relief aid beneficiaries, respectively (FEWS NET/Kenya and Ministry of Agriculture, unpublished). These trends have rendered Kenya a net importer of maize and livestock (FEWS NET/Kenya Report, October 2006) from other countries within and beyond the GHA region. This precarious food insecurity situation in Kenya and neighbouring GHA countries underscores the need for increased monitoring of food production indicators and early warning in support of a timely response and contingency planning by both the national Governments and donor community.

Food security is a complex concept. But in simplified terms it can be defined as a function (f) of food availability, access and utilization; all these three terms are interrelated:

Food Security = f (Production, Access, Utilization)

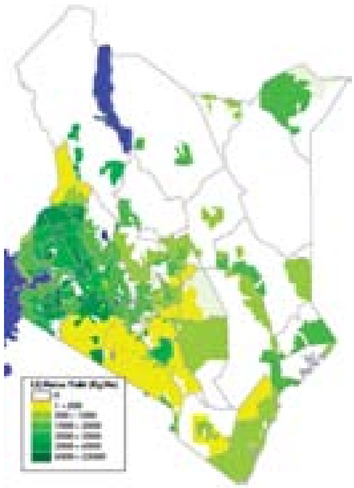
Food availability, or production, is critical to the food security equation, as it largely determines both food access and utilization. Insufficient local food production often impacts negatively on both commodity prices and utilization, or the health, of affected populations.

The paper provides a preliminary study in Kenya on maize crop production estimation at the national and sub-national level, using the USGS/FEWS NET Geo-WRSI crop model, crop zones maps and auxiliary field information data from various sources for the past 10 years (1996-2006). Maize is a staple crop for Kenya and the impact of its failure or insufficient production during a cropping season adversely affects large populations in the country (Reynolds, personal communication).

STUDY OBJECTIVE

The aim of this paper is to report on a study of the possibility of using the Geo-WRSI crop model to reliably estimate maize production in Kenya with adequate lead-time in support food security early warning and response planning. The GeoWRSI relies on both field and satellite based observations. Considering that the satellite observations have a distinct advantage in monitoring trends and changes and not in measuring absolute quantities, it is imperative that the maize production estimates can only be provided in relative terms, i.e as percentage of normal. Further, the Ministry of Agriculture (MoA) agro-statistics used as the ground-truth in this study are also known to have inherent characteristics of being subjective and may only be used to provide estimates in the relative terms; i.e. percentage of normal, or in comparison with the best- and worst-years' production.

Figure 2: *Spatial extent of Maize growing areas in Kenya and average yield at sub-location level (Admin. 6)*



Source: *Livelihood Zone data (MoA/WFP/FEWS & Partners)*

STUDY AREA

Kenya was specifically selected in this study, for three reasons:

- the availability of fairly reliable agricultural and climatological field datasets in the recent 10 years;
- complex agricultural systems ranging from large commercial agricultural farms (more than 100 ha) in high production areas in the west of

Kenya , medium-sized farms (between 50 and 100 ha), small farms (less than 50 ha) to very small shambas (less than 1 ha) with mixed farming practices (in parts of the central highlands and south-eastern Kenya) in both medium to low production areas and

- diverse agro-ecological zones , which is fairly representative agricultural production systems of the GHA region.

Figure 2, depicts the study area, its spatial extent and yield characteristics of Kenya, based on the recently updated MoA/WFP/FEWS NET Livelihood Zones (LZ) dataset. The information of LZ maize production statistics on parts of north-eastern and Northern Rift Valley districts of Kenya, is yet to be harmonized.

Kenya is subject to a bimodal rainfall regime, with the "long-rains" occurring from March to May and the "short-rains" falling from October to December. Moreover, the long-rains extend, for parts of the western sector of the country, into July-September. The long-rains season accounts for almost 80% of the annual total maize production, making it the most important maize-growing season in the country, and thus, the focus of this paper.

Subsequently, it is to be expected that the approach undertaken in this study on the crop production estimation in Kenya, could lend its usefulness to most rain-fed maize, or sorghum, producing areas in sub-Saharan Africa.

DATA AND ANALYSIS

Rain-fed maize crop production is dependant on weather, crop variety, soil characteristics and farm management practices. Of these variables, weather is the most dynamic parameter in Kenya as farm management practices have not changed much in the past 10 years and the usage of commercial fertilizers has increased by less than 20% (Wanzala et al., 2001) and mainly in large commercial farms. High fertilizer application is mainly in export cash crops and less in food crops. This is generally due to escalating fertilizer prices, underlying poverty and low farm-gate maize prices.

Therefore, in this study, the following crop model and datasets are used:

- a robust GeoWRSI crop model outputs to simulate rain-fed maize performance
- the FAO/Africover aggregated rain-fed herbaceous map as the maize baseline map
- DRSRS/Aerial surveys maize maps (2003/5)

- the Livelihood Zone (LZ) baseline on seasonal maize production statistics at sub-location level to characterize maize production in recent past, and
- the Ministry of Agriculture (MoA) inter-seasonal agro-statistics on maize acreage, yield and production (1996-2006).

GeoWRSI crop model

The GeoWRSI crop model (T. Magadzire, unpublished, 2005) is an experimental crop simulation model developed to run at national and sub-national levels. The GeoWRSI is built on the earlier successes of the FAO crop model (1977, 1979 and 1986) and later USGS/FEWS NET raster based crop models (Verdin and Klaver, 2002; Senay and Verdin, 2003).

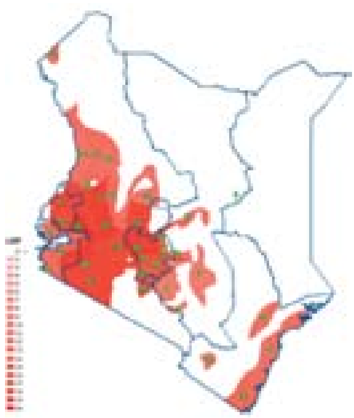
The model is based on crop water requirements and supply during a crop-growing season, which is given as:

WRSI = (AETc /PETc)*100

Where, AETc and PETc, are the actual and potential evapotranspiration (ET) of a crop (c). Guidelines for computing water requirements - FAO Irrigation and Drainage Paper 56 (http://www.fao.org/docrep/X0490E/X0490E00.htm).

The GeoWRSI model used in this study provides the added flexibility in simulating crop performance by utilizing field information on actual planting dates, length of growing period (LGP), crop variety and coefficients and end of season or harvesting periods. This model was run using the updated and validated LGP map for Kenya (Figure 3), following a crop assessment mission funded by Unites States Department of Agriculture (USDA) and supported by USGS/FEWS NET to fine-tune the crop model. (http://www.fas.usda.gov/pecad/highlights/2005/09/croptour_2005/index.htm).

Figure 3: *Updated Length of Growing Period (in Dekads) maps for Kenya*



A Variety of local crops such as maize, sorghum and teff could also be simulated during a crop season.

In recent years, the WRSI simulated crop performance anomalies (yield reduction estimates) have also been used to provide decision support information in Ethiopia (FEWS NET/Ethiopia, 2003; Senay and Verdin, 2003) and in Zimbabwe (Randall et al., 1999). These products have also featured in most reports by FEWS NET and partners that warn of impending poor or good harvest prospects at the national level. Consequently, the inter-seasonal GeoWRSI crop performance spatially averaged anomalies are used in this study to determine their relationships with the corresponding field based MoA yield and production anomalies.

Noting that,

Crop production (CP) = f (Harvested Acreage, Yield) = f (Harvested Acreage, GeoWRSI),

and that yield reduction is a linear function of WRSI (FAO, 1977, 1979, 1986), then

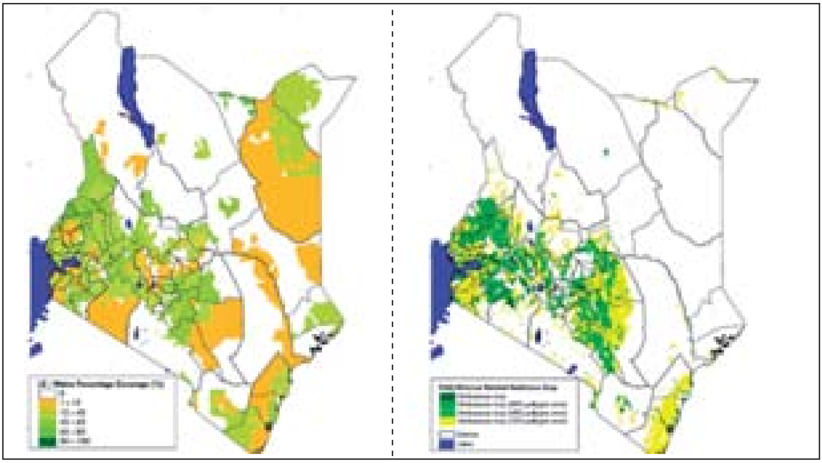
Yield (Y) ~ f(WRSI)

Crop acreage, or area, estimation poses a complex challenge when determining maize harvested acreage in Kenya, due to the varied and mixed farming practises ranging from large commercial enterprises to small mixed plots. Estimation of maize cropped and harvested areas in large commercial farms is fairly easy and feasible using available moderate to high-resolution satellites and supported by field data. However, small scale mixed farming under difficult terrain (shadows) and environment (areas with trees), pose serious and difficult problems of spectrally "un-mixing" pure maize signatures from other crops, shadows and other environmental constraints.

To overcome this problem, this paper proposes first to determine a maize-growing baseline map based on recent information and than to spatially average GeoWRSI crop performance anomalies for areas with a potential for maize harvesting. Secondly, spatially averaging GeoWRSI anomalies for each growing season integrates both the reduction in yield (leaving only maize growing with potential for harvesting) and acreage information. Thirdly, the paper also investigates the shrinking cone of uncertainty associated with GeoWRSI model forecasts as the season advances. This helps identify the dekad when model forecasts can be used to reliably provide crop production estimates.

Figure 4a: *LZ maize crop coverage(%)*

Figure 4b: *FAO/Africover herbaceous coverage(%)*



Therefore, to reliably delineate maize growing areas with currently available datasets and constraints, the recently published Kenya FAO/Africover aggregated rain-fed herbaceous crop map and the yet to be published LZ maize crop dataset, at sub-national level, are used to delineate the maize crop areas, as shown in Figure 4a and 4b respectively. The DRSRS aerial survey data was used in developing the FAO/Africover maps and there is a strong resemblance. These two maps show the geographical extent of maize growing areas within the country. However, they are some spatial disparities that are evident over parts of north-eastern Kenya, which are attributed to an error in the LZ dataset that is presently being harmonized in this specific area.

Determination of the maize growing zones

Recent crop assessment and WRSI validation missions in Kenya and Tanzania (June/July, 2005) by USDA/USGS/FEWSNET, in high to low-maize production areas, recommended the use of FAO/Africover crop map because it fairly well delineates the maize growing areas in Kenya. More than 1800 geo-referenced digital photographs were taken during this mission (http://www.fas.usda.gov/pecad/highlights/2005/09/croptour_2005/index.htm).

Thus, the Africover herbaceous crop dataset is used as a baseline for maize growing areas in determining potential maize growing areas.

Criteria for determination of maize conditions with prospects for harvest

To identify these areas, with their potential for harvest, the following criteria for a successful yield are used on the GeoWRSI anomaly images:

50% ≤ GeoWRSI ≤ 253%

FAO field studies showed that crops with WRSI values less than 50% had crop failures. Field assessments in Kenya showed that areas with a very late start or no start were also likely to have crop failures (GeoWRSI ≥ 253%).

Figure 5: *G_WRSI anomalies for 2006 long-rains using the Africover/ rainfed herbaceous mask and depicting the spatial extent with potential for harvest.*

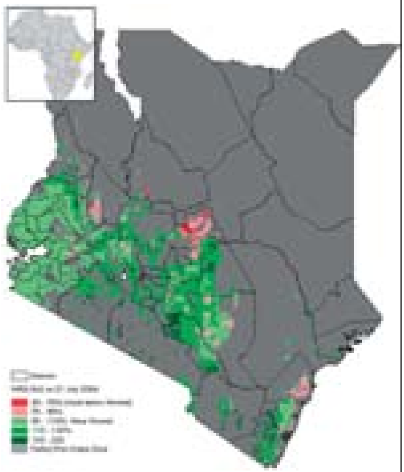


Figure 5, shows the GeoWRSI anomaly image GIS-geo-processed to show only the areas with potential maize for maize harvest based on the above criteria. Annex 1, attached, shows the chronology of GeoWRSI maize crop anomalies from 1996 – 2006 for the long-rains season. The corresponding field based maize crop production (CP) anomalies (MoA), were computed using:

MoA maize CP. anomalies (%) =(CP (MT) * 100) / Potential crop. Prod (MT)

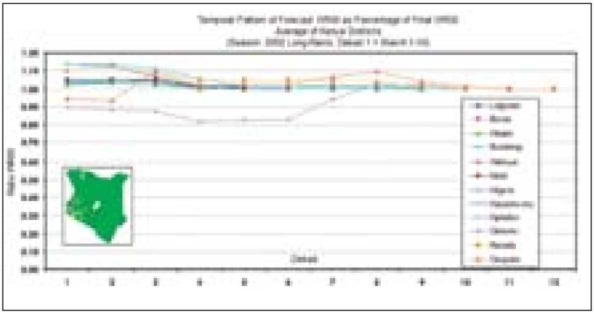
where potential crop production is computed from the maximum harvest realized in the last 10 years (1996 – 2005) which is about 2.71 Million Metric Tons (MMT). The recent past statistics are used in this study because they take into account recent changes in farming management practices. Table 1 provides information on the computed seasonal maize performance from 1996-2006.

Table 1: *Computed seasonal maize production vs. GeoWRSI anomalies with potential for harvest*

Year	1996	1997	1998	1999	2000	2001	2002	2003	2004	2005	2006
MoA Maize Prod. Anomalies (%)	74	65	83	66	59	79	66	81	60	89	?
GeoWRSI Anom (%)	89	92	97	69	43	72	69	78	66	82	90

Determination of the earliest possible period for crop production estimation

To allow for a timely and reliable early warning of potential crop production prospects, the GeoWRSI crop performance anomalies were run throughout the long-rains season to determine the possible period (dekad) when the model forecast's stabilizes. The end of July (21st. dekad) is determined in this study to be the period when the long-rains maize has passed the critical phenological stage (Gabriel Senay, personal communication) and the forecast crop performance simulated by the model is unlikely to change significantly, as shown in Figure 6,



Source: USGS/EDC

Figure 6: *WRSI forecast stability dekad*

unless affected by hydro-meteorological and biological natural disasters such as flooding, pests and fire. In the event of such occurrences, as in the recent recurrent floods, it would be easy and more cost-efficient to determine extent of the localized damage and the extent of food production losses using high-resolution satellite images as was the case for 2006 short-rains floods in Kenya. Additionally, the maize crop phenological cycle was investigated using spatially averaged dekadal NOAA/NDVI images over the defined maize crop baseline map (FAO/Africover herbaceous crop zones) discussed above. The results indicate that the long-term average (20 years) maize vegetation index peak occurs in May, as shown in Figure 7.

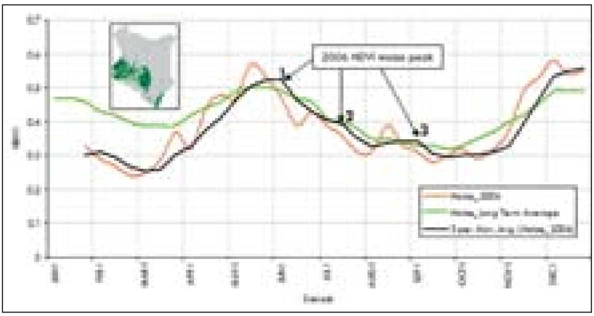
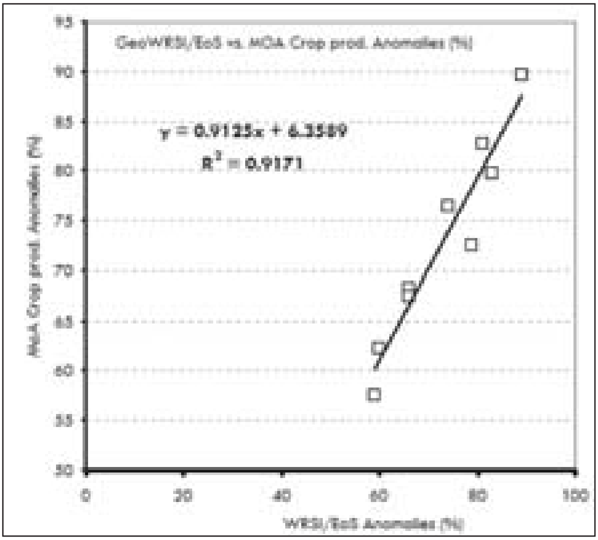


Figure 7: *2006 vs. Long term mean (LTM) Maize crop phenological stages based on NOAA/NDVI analysis over delineated maize zones shown in the inset map*

For the 2006 long-rains, the maximum NDVI peak also occurred in May (point 1), and started maturing/drying towards end of June. However, there were two additional minor NDVI peaks in mid-July (point 2) and September (point 3) and the NDVI stabilized at its lowest values at the end of September, possibly indicating almost complete drying/harvesting in the country. This means that final maize estimates could be undertaken at the end of September of 2006. Preliminary indicative production estimates, can be provided by early July, 2006. A comparison of the two WRSI anomaly images at the end of September (Dekad 28) and July (Dekad 21) depicted minimal changes on the maize crop performance. However, West Pokot, Baringo and Keiyo districts showed decreased WRSI anomaly values. From the MoA agro-statistics, these three districts contribute very little in terms of the long-rains national maize production and had no impact on the overall preliminary crop production estimates.

RESULTS AND DISCUSSIONS

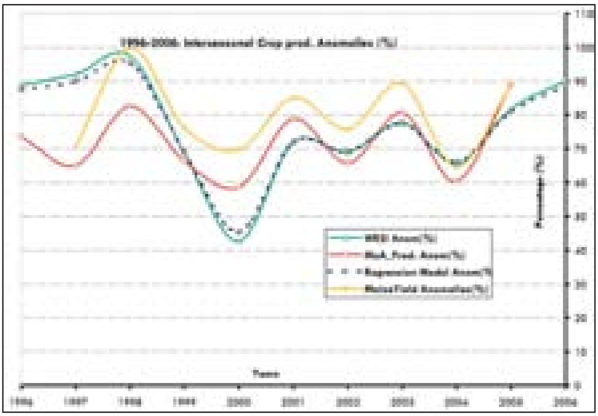
Overall, the GeoWRSI/maize anomalies simulate well the general trend of the national crop production estimated in this study, as shown in Figure 8. However, the 1997 data pair appeared as an outlier and was deliberately eliminated in determining the correlation between the two datasets. The 1997 MoA agrostat data were apparently suspect in some of the districts. These preliminary results indicate that there is strong positive correlation at national level and sub-national level between the corresponding MoA anomalies in terms of acreage, yield and production and GeoWRSI anomalies for areas with potential for harvest. Figure 8 depicts this correlation and a regression equation is provided, which can be used as the first estimate of maize crop production by the end of July every year, i.e. when two-thirds through the growing season. This provides adequate lead-time to support response and contingency planning. From this regression model, the 2006 long-rains maize production is expected to be 89% of its potential production (2.71M MT), which is 2.41 MMT (with a standard error margin of +/- 0.25M MT) i.e. ranging between 2.16 to 2.66 MMT. Official 2006 long-rains MoA maize crop productions were at 2.61 MMT.



Source: USGS/FEWS NET

Figure 8: *Kenya Long-rains GeoWRSI and Maize production anomalies (1996 – 2005)*

To validate its usefulness, the regression equation was run for the period of 1996 – 2006 and the results are shown in Figure 9. These preliminary results indicate the potential usefulness of these GeoWRSI/Maize crop production estimates in Kenya and the neighbouring countries.



Source: USGS/FEWS NET and MOA/Agrostats

Figure 9: *Validation of the Regression model*

CONCLUSION

In this paper, we have demonstrated that GeoWRSI is a tool that can used for reliable and early estimation of maize production estimation in Kenya, with a lead-time of about 3 months, in support of informed response and contingence planning. This tool allows for the simulation of local crops and has flexibility for inputs in respect of length of growing period, onset of rains, and soil information. This information can help improve yield and production estimates. Additionally, it takes advantage of the FAO/Africover datasets, as the maize crop baseline map. This mask has been qualitatively verified through field surveys and by using the latest Kenya Livelihood Zone (LZ) data provided by the Ministry of Agriculture (MoA) in collaboration with World Food Program (WFP) and FEWS NET. Furthermore, the FAO/Africover land cover classification system (LCCS) can be used to update, every 5 years, maize growing areas, to capture changes in the baseline maize zones.

New applications of these technologies may also be envisioned. For example, given climatically analogous years from a seasonal climate forecast forum, it may be possible to develop potential crop production scenarios based on the simulation of possible crop performance and production estimates at the start of season, with of course, relatively less confidence depending the strength of the forecast signals.

Another, potentially more exciting application based on the climate forecasts, is that these simulations could serve as a guide for seed selection and irrigation practices - potentially leading to improved crop performance and yields.

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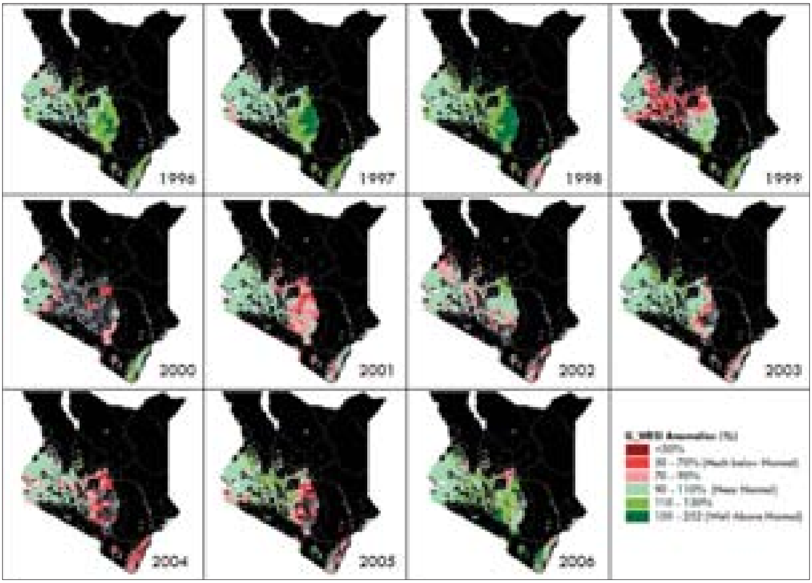
ANNEX 1

Chronology of crop performance in the last 10 years: 1996-2006



Source: USGS/FEWS NET

VGT NDVI IMAGES TO MONITOR THE CROPPING SEASON USING SPOT

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ABSTRACT

In a Conference attended in 1994 at the Agrhymet Institute in Niamey, the author of this paper proposed a way, and presented an application (Griguolo, 1994), to use time series of NDVI images to assess the vegetation performance of individual pixels in a cropping season already terminated, or to monitor their dynamics in a season still ongoing, in order to early detect areas showing possible signs of season's failure.

The method was aimed at Early Warning applications in developing countries, where timely ground-collected data are seldom available and remotely-sensed images offer (in spite of their much discussed reliability) a quick and cheap way to monitor the growth season. Partial results can be up-dated as soon as a new image is available.

Since then, both computing power and the quality of the information available have highly increased. The 32-bit Windows version, capable of directly addressing the full core memory, replaced DOS. CPUs are now incomparably much faster when carrying out heavy tasks like clustering large sets of pixels. Sensors are now available, like the VGT2 mounted on the SPOT5 platform, that produce images of higher resolution (1 km, versus the 7.8 km NOAA-AVHRR GAC images used in the past). Above all, VGT images are more geometrically accurate than the AVHRR ones, and this is very important when the input to the analysis consists of a time series of images of the same region, to be processed together. Besides, they are available for free.

The old proposal has then been reconsidered and is improved to take advantage of the new situation.

The dynamics of the cropping season to be monitored, represented by a suitable time series of NDVI 1km dekadal images, is compared pixel-by-pixel with a reference to an 'expected' evolution.

Processing all the dekads for which images are available (since 1998 for SPOT-VGT), the software computes in a fully automatic way, by pixel and dekad, a new time series of synthetic images that represent a kind of mean ('expected') vegetation cycle in each pixel. This mean cycle is assumed as the reference cycle for comparisons concerning that pixel. Before carrying out this computation the images are pre-processed to fix sudden NDVI decreases caused by mist or partial cloudiness, or to simulate missing values in case of cloudy pixels.

A series of images are then computed that span the time interval to be analysed, corresponding to the cropping season. These images represent the percentage differences, computed pixel-by-pixel, between the current series (the one to be monitored or assessed) and the reference one. They offer ***a multivariate description*** *of the performance of each pixel in the current season with respect to the reference one, and are assumed as the input to a Principal Components Analysis, followed by an unsupervised Clustering. The result is a classified image in which pixels with significantly different performance curves are assigned to different classes. Some graphic tools included in the package enable the analyst to inspect the cycles of individual pixels of interest.*

As an example, an assessment analysis for the Sudan and year 2005 is presented.

The methodology is still provisional for reasons that will be mentioned, but the results appear interesting. It can certainly be of help in letting critical areas emerge, and the package offers some tools to inspect in detail the behaviour of any suspicious or dubious pixel. In the frame of a ***concurrent evidence approach*** *this method can be usefully applied together with others based on water balance, or on comparisons between particular pairs of images carried out using WINDISP.*

INTRODUCTION

Timely ground-collected data are scarcely available in some developing countries. For this reason, Early Warning and Food Security Projects make some use of NDVI images (Santacroce, 1994) that offer - despite their much discussed reliability - a quick and cheap way of monitoring the cropping cycle.

NDVI images were initially used at district level, computing some indicators averaged over all pixels belonging to each district, and using them together with other types of information (demographic, economic, etc.), to prepare a data table to be processed via a multivariate analysis. This was quite unsatisfactory, because the possible high variability of vegetation dynamics in large areas was lost.

On the other hand, the availability of very detailed information (by pixel for NDVI and other remotely-sensed variables) encouraged the development of some new analysis and representation tools, able to deal with single pixels.

It was then decided **to cluster individual pixels** according to a set of suitable descriptive variables, and a computer package was written and distributed to this purpose[1].

Two main streams of interrelated applications are possible, respectively aiming at **zoning** pixels according to some of their features (eco-climatic cycle, rainfall cycle, etc.) or at **monitoring** pixels focusing on the cycle of a variable of interest. While zoning exercises are mature and easy to carry out, applications to monitoring are much more delicate for the following reasons:

1. Monitoring requires the comparison of the current dynamics of the time variable of concern (NDVI, rainfall, etc.) with an "ideal" cycle represented by a series of images assumed as reference. Therefore, the analyst must deal with two series of images.
2. While the reference series is usually complete (in the example reported in Section 3, the series of NDVI VGT images averaged over years 1998-2006 was used as reference), the current one is often affected by missing values. They must be replaced by some reasonable estimations, otherwise the pixel must be excluded.
3. The current series is much more subject to casual errors, which propagate in an unpredictable way through complex processing.
4. Above all, as different pixels have different vegetation cycles, *only the differences of current vs. reference values for the dekads making up the cycle should be considered when computing the Principal Components and the classes of performance*. This is not an easy task from the analytical point of view. The effort in this direction is the main difference (beside the use of Win32 routines) between the version of the package used here and the previous DOS version.

Some work is still necessary to fully cope with this difficulty.

For these reasons, the analytical path and the sample empirical analysis illustrated in the following sections should be seen as a methodological ef-

[1] ADDAPIX (a presentation in Griguolo and Santacroce, 1996; the Manual in Griguolo, 1996) is a DOS package developed with FAO-ARTEMIS support and freely distributed. It is now being replaced by the Win32 version used for the exercise illustrated in this paper. The DOS version is however still available from http://cidoc.iuav.it/~silvio/addapix.html.

fort in progress. The proposed analytical path is a multi-step one, and certainly not simple, but the problem itself is quite complex. Some questions, relevant in order to achieve meaningful operational results, are formulated but not fully solved.

Section 2 shortly reviews the characteristics of the SPOT-VGT images, and the advantages they offer.

Section 3 describes the overall procedure, from the extraction of the Region of Interest (RoI) to the computation of the classes of performance. The results of a sample analysis, carried out for the Sudan and year 2005, are described. The example involves both zoning and monitoring (or season assessment). The zoning stage, aimed both at delimiting the set of pixels to be monitored, and the relevant dekads to be considered, can be performed easily.

The assessment stage that follows is still experimental, but it confirms the possibility to develop a tool capable of clustering pixels according to the similarity of the series of their dekadal performances, and enabling a detailed inspection of the situation pixel by pixel, bringing into focus pixels suspect of failure. The procedure promises to be a useful complement to some other approaches in tackling the complex crop monitoring problem.

Section 4 considers briefly some still pending questions, and possible follow-ups.

SPOT-VGT SATELLITE IMAGES

When a set of multi-temporal images is processed, a high geometric accuracy is absolutely critical. The same pixel, taken from images relative to different dates, must **represent the same ground area**, with a minimum shift. This was not the case for the NOAA-AVHRR images: while the geometry of the low resolution 7.8 km images was more or less acceptable because of their small scale, the 1.1 km images could not hide the geometric insufficiencies.

Under this aspect the new SPOT-VGT images are much better.

The SPOT4 platform, launched in 1998, carried onboard the VEGETATION 1 (VGT1) sensor. A few years later, in 1992, SPOT5 was launched, with the VGT2 sensor onboard, now operational. Images were initially distributed at a cost but nowadays, in the frame of the VEGETATION programme funded by the EC, images can be freely downloaded from the site **http://free.vgt.vito.be.** The available products include the ten-day synthesis (S10) NDVI images, used in the exercise presented here.

The geometric quality of the VGT images is improved through the use of several thousands of Ground Control Points, distributed over the planet's surface. The correction guarantees a maximum error of 300-500 m (less than half pixel) for multi-temporal images, which is totally satisfactory.

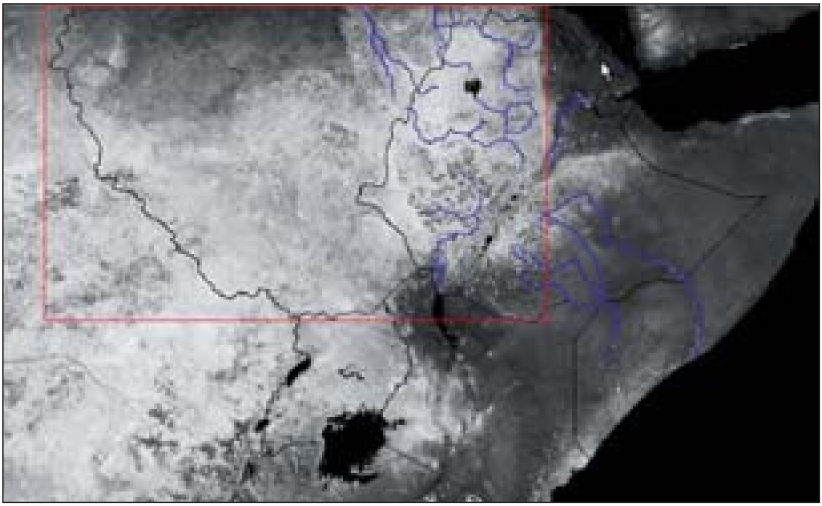

Figure 1 – *Part of the VGT image of Africa, 2nd dekad of September, 2005. The region bordered in red shows the window selected for our exercise, and extracted from the 306 available NDVI dekadal images.*

Products can be downloaded as zipped files, each relative to a continent or part thereof. Each zipped file contains some **unprojected (lon/lat) images** in HDF (Hierarchical Data Format), plus some quick-looks and some metadata text files. The HDF format is not easy to manage, but some free software, like VGT4AFRICA or CROP_VGT2, can be used to extract a rectangular window of interest directly from the zipped files downloaded from the VGT site.

For the exercise described below CROP_VGT was used to extract the window shown in figure 1 from the 306 zipped files that contained the S10 NDVI images ranging from April 1998 to October 2006. CROP_VGT can do the job ***in one go for all the images***, which is quite handy. Besides, it can mask on request, with a code indicated by the user, pixels that are cloudy according to the Status Map[3].

[2] CROP_VGT can be downloaded from the page http://circe.iuav.it/crop_vgt.html.

[3] The Status Map is a synthetic image included in the same zipped file where the NDVI image is stored. It contains some additional information for each pixel: among others, if it is clear, cloudy or dubious.

There was a problem with VGT images when the exercise was carried out, fully solved by the time this paper was reviewed: from February 2003 the VGT2 sensor began to behave different from what was expected. As a consequence, the values of the NDVI images produced since then were underestimated, this underestimation reaching as much as 10% in the worst cases. The affected images are now fully corrected, but more than one year was necessary to complete the task. Owing to this fact, the results obtained when the exercise was performed are not precise, but this does not jeopardize the reliability of the analytical procedure that is presented.

REVIEW OF OVERALL PROCEDURE

The procedure, from the extraction of the window of interest to the final determination of the poor-performing pixels, is quite complex. Its steps are briefly illustrated in different sub-sections.

The objective can be the assessment of the performance in a cropping season already concluded, or the monitoring of a season still ongoing. Our exercise deals with the former case: the assessment of the cropping season in the Sudan for year 2005. Therefore, the analysis is limited to pixels within the Sudanese border, while all external pixels are masked.

Pre-processing the original images

After extracting the window of interest from the 306 S10 images available, the full NDVI series for all pixels are extracted from the images and stored in a file in BIP (Band Interleaved by Pixel) format.

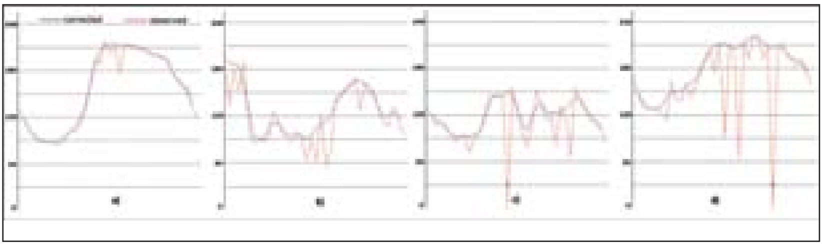

Figure 2 – *Some examples of how the series of a pixel is corrected, and partially simulated if missing values are present. If too many consecutive missing values are found the pixel is eliminated, masking it with a special code.*

These raw series are quite irregular. They must be pre-processed, filling unexpected and unreliably low NDVI values caused by local dampness/mist or partial cloudiness, and simulating reasonable values for cloudy pixels. This is done ***all in one go*** on the series of all pixels, using a particular option of the programme.

Figure 2 shows some examples of how a pixel's series is corrected by interpolating through its maximum values. Red lines represent the irregular series extracted from the original images; the *corrected* series are shown in blue. In the picture the code 0 stands for a missing value. Only some short sequences are shown, excerpted from the actual series of 306-values.

Construction of the series of images to be used as reference

The series of the ***historical average images*** (SHAI) is computed from the series of the 306 dekadal images ('98 through '06) ***after pre-processing*** them. For each pixel, and each dekad of the year, the average of the values taken by the NDVI between 1998 and 2006 is computed and assumed as the normal or expected NDVI value in that pixel and dekad.

The computation of the SHAI is actually done in ***the same run that carries out the pre-processing***. The SHAI is used as the reference normal behaviour in comparisons aiming at estimating the current vegetation performance.

Pixels external to the RoI (the Sudan in our example) are masked. Without modifying any image, this is actually done by marking the pixels to be excluded with a specific code in an ancillary image (the *Work Image*) that stores information on which pixels are valid, which unreconstructed and therefore invalid, which covered with water, or external to the RoI, etc. The Work Image is used to control the flow of the overall process.

The eco-climatic classification

An eco-climatic classification is carried out on the pixels belonging to the RoI, using as input the SHAI series. The goal is to group into the same class pixels having similar annual vegetation cycles.

The inspection of the vegetation dynamics in each class ('*the cycle*') helps the analyst to determine the sequence of dekads in which crop growth is possible or likely for pixels belonging to that class.

The values of NDVI stored in satellite images are obviously related to the photosynthetic activity of the **total vegetation**, both cultivated and natural, in each pixel. For rain-fed areas we will assume that what occurs to natural vegetation occurs also to crops that exist in the concerned pixel.

The eco-climatic classes are determined by submitting all pixels in the RoI, each described by its annual series of historical averages, to a PCA. A suitable number of Principal Components, chosen by the analyst and summarising a sufficient rate of the overall variance, is passed on to a non-hierarchical clustering routine, which constructs the classes and describes them.

As clustering millions of pixels is a heavy computational task, the fact of using only some of the PCs helps a lot. In a PCA performed on the table of pixels' historical average cycles, the first PCs usually have a very high explanatory power: typically, with 36 dekadal values making up a pixel's cycle, three or four PCs often summarise up to 98% of the overall variance. The first PC captures the average vegetation level over the year, while the following ones are related to the *form* of the cycle.

The clustering routine minimizes the global internal variance of the classes of the partition being built; the purpose is to obtain a set of clusters as compact as possible in *the feature space*.

The results (the clusters obtained) are context-dependent. They depend on the characteristics of the particular set of pixels submitted to the procedure, and capture the similarity of their cycles. The classes are built around the most dense regions of the feature space: pixels with very peculiar cycles, but quite rare, will usually not obtain a specific class allocated for them.

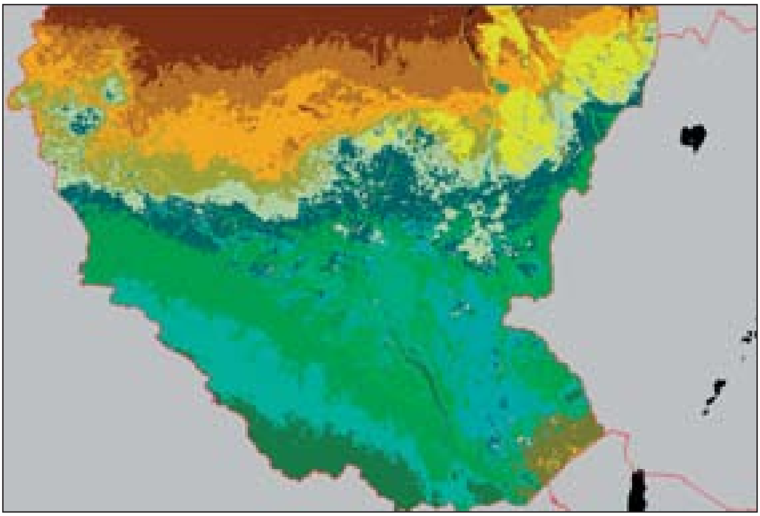

Figure 3 – *The RoI classified in 15 classes. The colours, automatically assigned by the programme to the classes, match those used for the curves of the average profiles of the classes, shown in figure 4.*

Besides, a large RoI will generally consist of too many pixels with qualitatively different behaviours, requiring a high number of classes to account for their differences. Instead, too few classes will result internally inhomogeneous, with confusing features.

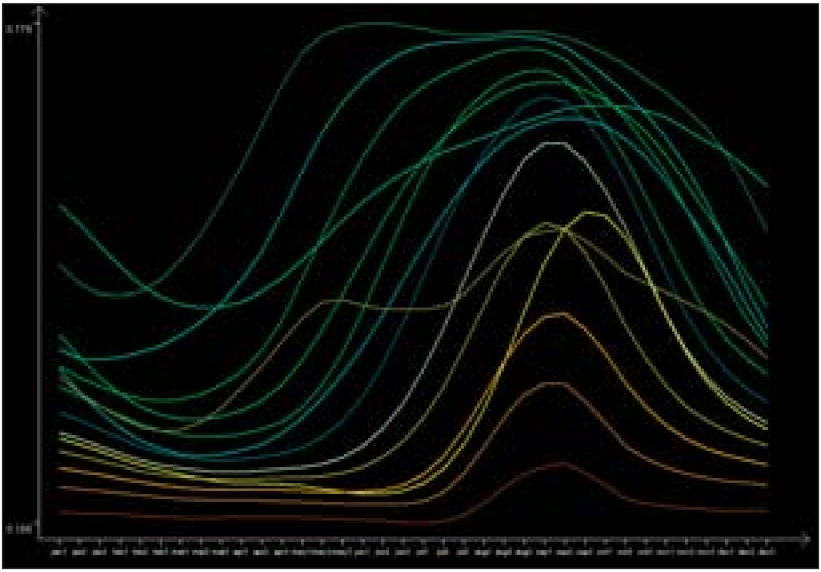

Figure 4 – The average profiles of the 15 classes, automatically displayed by the programme using the same colours as in the classified image of the RoI (figure 3). Pixels belonging to class 15 (whose average profile is represented by the lowest curve in dark brown) are located in the northern part of the RoI. They are very dry, and appear scarcely capable to sustain a significant crop production. They were therefore excluded from the assessment that follows.

Each class' *average vegetation cycle* is assumed to represent, more or less, the behaviour of all the pixels assigned to the class. Therefore, at least approximately, the inspection of a class' average profile can help the analyst to determine the time interval (over a year) during which crop growth appears possible for pixels belonging to that class. It should be noted however that our goal is actually the opposite, namely *to exclude* from the subsequent monitoring analysis the dekads *certainly not related* to cropping activity.

Classes too arid, characterised by a cycle, if any, too low or too short to support cropping activity, are excluded from the analysis that follows, thus further reducing the RoI.

Figure 3 shows the classified image obtained using the first five PCs, sufficient to explain 99.4% of the overall variance. In the PCA the diagonalisation was carried out on *the table of the co-variances*, not that of correlations, as is usually done. This is more reasonable when processing NDVI, because in the construction of the PCs more importance is given to the dekads with higher variance over the RoI.

The non-hierarchical clustering procedure was requested to produce fifteen classes, automatically sorted by the programme according to decreasing values of the first PC in the class' centre (in the *feature space*). Once re-ordered, the classes were automatically assigned colours ranging from dark green (the most highly-vegetated class) to dark brown (the driest one).

As described in this paper our interest is focused on performance assessment, the eco-climatic classification on the SHAI series has been carried out for the following exploratory and instrumental reasons.

- To single out the areas assigned to classes whose average profile betrays a scarce or null agricultural value, and eliminate them from further consideration.
- To delimit a time interval (a range of dekads) encompassing the cropping seasons of ***all the classes*** to be considered. Let us name it "*overall interval of interest*" (OIOI): the analysis of the performance will be limited only to its dekads.
- To determine, by inspecting the average cycle of each single class retained, **the specific subset** of the OIOI that consists of the dekads interested to cropping activity for that class. It can be assumed that dekads included in the OIOI, but external to the interval specific of the class, are uninteresting for the cropped activity: the percentage differences existing between the current and reference values, albeit computed, should have no influence in determining the results of the analysis (table of correlations between dekads, eigenvalues, Principal Components, resulting classes of performance).

The last point is still subject to investigation. It requires a sound method to derive from the average NDVI cycle of each class, and possibly in a fully automatic way, a reasonable estimation of the cropping season, to be applied to all pixels belonging to the class. Besides, it requires also some changes to the mathematical procedure, not at all easy to devise and implement. Some steps in this direction have already been done, and at a first glance the results do not appear too different from those obtained by using the full OIOI for all the classes. However, a sure conclusion is still premature.

After inspecting the average profiles of the classes, it was decided to exclude the class 15 (the driest one) and to limit the comparison between the year 2005 (the *current* series) and the *reference* one (the SHAI series) to the time interval consisting of the 27 dekads ranging from the 2nd dekad of March to the 1st dekad of December (inclusive).

The assessment example: year 2005 vs. historical average

For each pixel ***I,*** and each dekad ***t***, the *current (corrected) value* of the Vegetation Index is compared with its *expected value*. Its *performance* can be expressed by the percentage difference

$$performance\ (i,t) = \frac{current\ (i,t) - expected\ (i,t)}{expected\ (i,t)}$$

Our example deals with the assessment of the performance in year 2005. The historical average NDVI value for pixel ***i*** in dekad ***t*** was assumed as the most likely value to occur, therefore the expected one. The construction of the series of percentage differences is limited to the 27 dekads between March2 and December1, for the reasons explained in section 3.3.

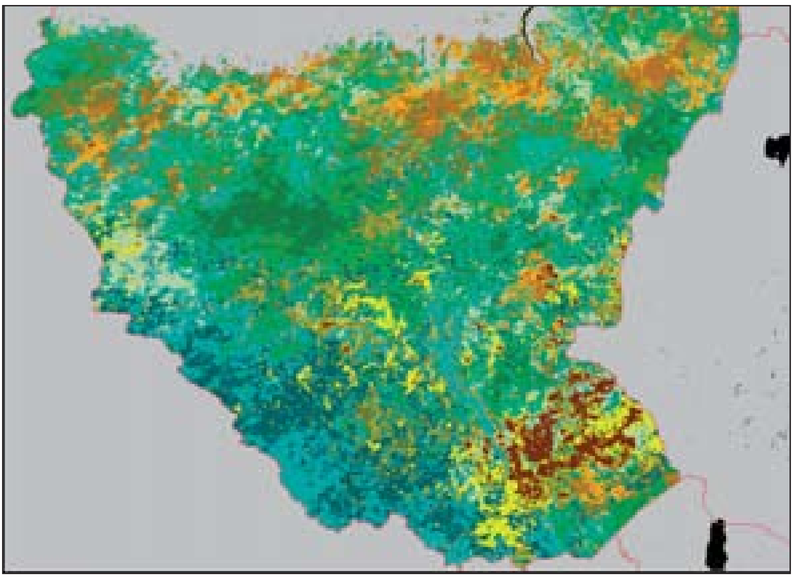

Figure 5 – *The RoI subdivided in 15 classes of performance. The colours, automatically assigned by the programme, match those used for the profiles, displayed in figure 6.*

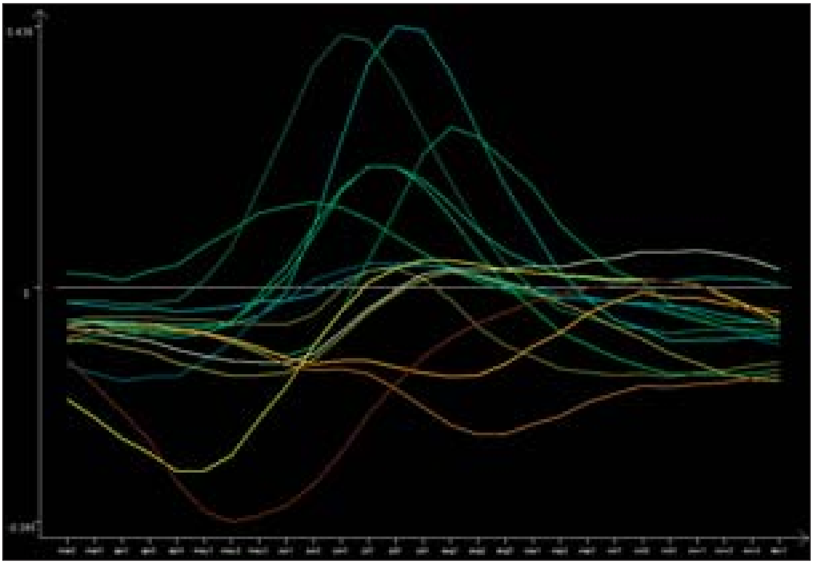

Figure 6 – *The average profiles of the 15 classes of performance, automatically displayed by the programme using the same colours as in the classified image of figure 5. A negative value in a given dekad means that the average NDVI value in 2005, for pixels belonging to the class, is in that dekad lower than expected, and vice versa.*

A multivariate classification can be used to assess the performance. The pixels, each described by its performance series over the dekads assumed as relevant for the cropping season, were submitted to a PCA and then clustered into classes with sufficient internal homogeneity. Alike to what was done for the eco-climatic classification, the classes have been sorted according to decreasing values of the first PC, and displayed using a suitable range of colours, green through brown.

Figure 5 shows the classified image. Poor-performing pixels are displayed in brown shades.

The features of individual pixels (ground areas of 1 square km at the equator) can be inspected. An option of the programme allows the analyst to focus only on some classes of interest, whose spatial location can thus be easily visualised, blanking the rest.

In Figure 7 only the visualisation of class 15 (the most poorly-performing one) is enabled. Clicking on a pixel displays its profiles, allowing a very detailed inspection of its behaviour. The picture shows the individual characteristics of the pixel with geographic co-ordinates (32.454 W, 5.982 N): the curve in yellow (‘*aver*’) is the expected dynamics of the NDVI, while the curve in green (‘*2005*’) gives the actual dynamics in 2005, that appears to be much lower.

The two series have been used to compute the series of dekadal performances for that pixel in 2005, represented by the curve in blue (‘*diff*’). Performances are obviously negative, as current values of NDVI are steadily below the expected ones. The blue curve goes through 0 when the two values are equal. The curve in red gives the average profile of the class of performance to which the pixel of interest is assigned.

Similar considerations and inspections can be carried out for other poor-performing classes, as well as for the well-performing ones. It is immediate to realise that some of the classes are characterised by a profile that indicates a season’s retarded or anticipated start, more than a poor or good performance.

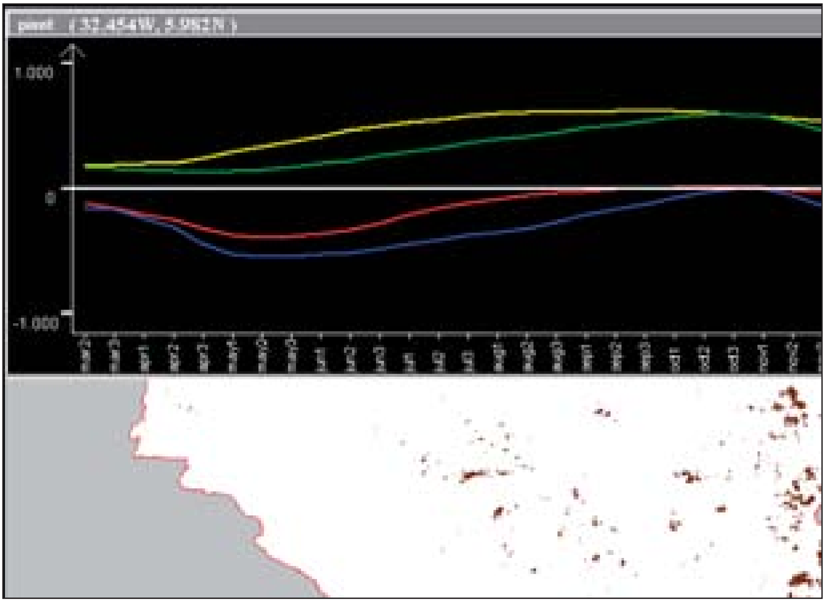

Figure 7 – *The profiles characterising a pixel, displayed by clicking on it (see the text for an explanation). The profiles are updated immediately when the mouse is dragged over the image.*

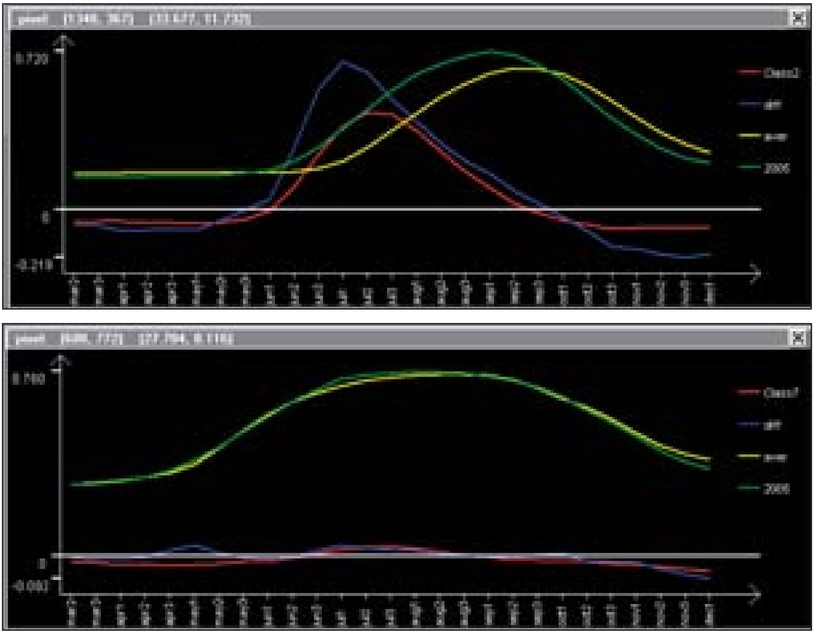

Figure 8 – *Two more examples of pixel profiles.*
Above, a well-performing pixel (class 2): the season, clearly anticipated, evolves regularly and the peak NDVI value (green curve) is higher than expected (yellow curve). Below, a pixel whose evolution matches almost exactly the expected dynamics (class 7).

CONCLUSIONS

Some further effort is necessary to achieve fully satisfactory results from the analytical procedure outlined in this paper.

First of all, the singling out of the dekads significant for crop production: for each eco-climatic class the exclusion of the dekads certainly not significant must be further improved, defining some sound criteria to link the cropping season to the NDVI cycle.

It must be noted that what occurs to a class, in terms of season start, flowering and harvesting dates, is only indicative of what actually occurs to individual pixels belonging to it. The procedure we have followed is synthetic and abstract: it does not focus on individual pixels, but on the average behaviour of all pixels belonging to the same class, which are in general spread all over the RoI, though some spatial grouping can be expected.

Raster maps, derived from a detailed Atlas of Crop Production Zones, like the one compiled for the IGADD Region (van Velthuizen et al., 1995), could be used as ancillary images. When a pixel is processed, the dekads relevant to its cropping season could be read from the auxiliary maps and used in the analysis.

Then, the fact that for each pixel only a range of its dekadal values, depending on the eco-climatic class to which it belongs, are assumed to contribute to the construction of the Principal Components and of the classes of performance, raises some analytical problems that are not yet fully solved.

The attempt to classify the pixels of the RoI in different classes of performance (meant as a multivariate concept, not a synthetic univariate indicator) requires some assumptions that can imply different levels of simplification.

At the highest level of simplification, the same time interval can be assumed as relevant for all pixels not explicitly excluded. This is what was done in the exercise presented: for all pixels the assessment analysis has considered the 27 dekads between March2 and December1. This assumption is supported by the conviction that only within the actual cycle of each eco-climatic class the differences between the current and the expected behaviour become enough relevant to influence the analysis.

At a lower level of simplification, a specific time interval can be assumed as relevant for each class, and ***used for all the pixels*** belonging to it. Though relaxed in comparison with the preceding one, this assumption is still quite strong. We tried to test it: the average cycle of *each eco-climatic class* was directly inspected, determining the two dekads that provided a reasonable delimitation of the growth season. Of course this is quite rough, and certainly not valid for all the pixels belonging to the class, but it must be remarked that the idea is to exclude as many dekads as possible that have certainly nothing to do with the growth season.

A possible alternative is to devise some automatic criteria to determine the start and end dekads, implement these criteria in the programme and apply them to the series of each pixel, thus constructing two auxiliary images sized as the RoI, one storing the start dekad of each pixel, the other the end dekad (or the cycle length...). Actually one single image could be sufficient; it could be loaded by the clustering routine, and the really relevant dekads used for each pixel.

Still better, if more sound and detailed information like that stored in an electronic CPSZ Atlas is available, it can be stored in an auxiliary raster image and used in the assessment procedure for individual pixels or small areas.

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A zipped file (170 MB ca.) including the data of the exercise and the software needed to inspect the classified images can be downloaded from **http://cidoc.iuav.it/~silvio/sudan2005.zip.**

A similar exercise, oriented to monitoring the still ongoing season 2006/07 in Zimbabwe, can be retrieved from **http://cidoc.iuav.it/~silvio/zw0607.zip** (34 MB ca.)

CROP YIELD MODEL DEVELOPMENT IN EASTERN AFRICA. STUDY CASE OF KENYA

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ABSTRACT

Remote sensing (RS) data acquired by satellite have wide scope for agricultural applications owing to their synoptic and repetitive coverage. On the one hand, spectral indices deduced from visible and near-infrared RS data have been extensively used for crop characterization, biomass estimation and crop yield monitoring and forecasting. On the other hand, extensive research has been conducted using agrometerological models to estimate soil moisture to produce indicators of plant-water stress. This paper reports the development of an operational spectro-agrometeorological yield model for maize using a spectral index, the Normalized Difference Vegetation Index (NDVI) derived from SPOT-VEGETATION, meteorological data obtained from the European Centre for Medium-Range Weather Forecast (ECMWF) model and crop-water status indicators estimated by the Crop Specific Water Balance model (CSWB). Official figures produced by the Government of Kenya (GoK) on crop yield, area planted and production were used in the model. The statistical multiple regression linear model has been developed for six large maize-growing provinces in Kenya. The spectro-agrometerological yield model was validated by comparing the predicted province-level yields with those estimated by GoK. The performance of the NDVI and land cover weighted NDVI (CNDVI) on the yield model was tested. Using CNDVI instead of NDVI in the model reduces 26% of the unknown variance. Of the output indicators of the CSWB model, the actual evapotranspiration (ETA) performs best. CNDVI and ETA in the model explain 83% of the maize crop yield variance with a root square mean error (RMSE) of 0.3298 t/ha. Very encouraging results were obtained when the Jack-knife re-sampling technique was applied proving the validity of the forecast capability of the model (r^2= 0.81 and RMSE= 0.359 t/ha). The optimal prediction capability of the independent variables is 20 days and 30 days for the short and long maize crop cycles respectively.

Keywords: Crop monitoring; quantitative yield forecast; early warning; food security; spectro-agrometeorological model; NDVI.

INTRODUCTION

Crop-weather models had long been used for crop monitoring and yield forecasting before the advent of remote sensing products, like the Normalized Difference Vegetation Index (NDVI). More than 50 years have passed since the first paper on mathematical modeling of photosynthesis and productivity in plant communities was published in Japan (Monsi and Saeki, 1953) and these kinds of studies were later continued by research groups formed in Netherlands (de Wit and Goudriaan, 1974). In the USA, McCree (1970) and Curry (1971) published outstanding papers along the same lines.

The introduction of remote sensing and the derived vegetation indices in the early 80's was considered a potential tool to improve simulations by objective observations in real-time. Potdar et al (1999) observed for some cereal crops grown in rain-fed conditions that rainfall distribution parameters in space and time need to be incorporated into crop yield models in addition to vegetation indices deduced from remote sensing data. Such hybrid models show higher correlation and predictive capability than the simple models (Manjunath and Potdar, 2002). The agro-meteorological models introduce information about solar radiation, temperature, air humidity and soil water availability while the spectral component introduces information about crop management, varieties and stresses not taken into consideration by the agro-meteorological models (Rudorff and Batista; 1990). The purpose of this research is to improve the spatial estimation of yield by combining crop-weather models and satellite observations.

MATERIALS AND METHODS

Meteorological data

The rainfall and potential evapotranspiration (PET) data used in this study are products of the European Centre for Medium-Range Weather Forecast (ECMWF model) at Reading in the UK. The data were interpolated from the original 1-degree grid to a final resolution of 0.5 degree (approximately 55 km). Dekadal rainfall and PET were then spatially averaged for each area comprised in the maize crop mask using ArcMap GIS tools (see point 2.6).

Remote-sensing data

The products of SPOT VEGETATION acquired by JRC are 10-day NDVI (Normalized Difference Vegetation Index) synthesis (S10) images, obtained through Maximum Value Compositing (MVC). The images are corrected for radiometry, geometry and atmospheric effects. The 10-day images are delivered to the JRC with a delay of around 2-3 days.

The CSWB model

The FAO CSWB is a very simple but physically sound soil water balance model which is used to assess the impact of weather conditions on crops (Gommes, 1993, Rojas et al., 2005). The water balance of the specific crop is calculated in time increments, usually 10-days.

Planting date estimation model

To start the simulation, the CSWB model requires the current planting date of each crop season. The criterion followed to define the planting dekad (10-days period) was the 1st dekad with at least 20 mm of rainfall followed by two dekads with at least 20 mm of total rain. The same planting date was used to start accumulating NDVI values up to the end of the crop cycle. The crop cycle varies from 90 to 160 days.

Crop statistics

The Kenyan government started collecting disaggregated agricultural statistics by crop season in 1997. However, since the SPOT VEGETATION sensor was launched on board the SPOT 4 satellite later, in 1998, crop data was analyzed between 1998 and 2003. The statistics are collected at district level and aggregated by province.

Maize crop mask

In this study, two levels of maize crop mask were defined. The first level, the 'general' maize crop mask was created using only statistical information; the second one is the result of intersecting the first level of crop mask with the Africover land cover information (Di Gregorio *et al*, 2000).

NDVI

The Normalized Difference Vegetation Index (NDVI) has been the most frequently used vegetation index within agrometeorological analysis. The NDVI values were spatially averaged for each area comprised in the maize crop mask. Three variables were created when aggregating the NDVI values on a temporal scale: cumulated NDVI values starting from planting date up to the end of the length of the crop cycle (NDVIc), maximum NDVI during the crop cycle (NDVIx) and 3 dekad-averages around the maximum NDVI (NDVIa) to smooth the curve when an isolated peak represents the maximum.

CNDVI methodology

The Land cover weighted NDVI method (CNDVI) was used, using Africover database as land cover information (Di Gregorio *et al*, 2000). The CNDVI method is fully documented by Genovese *et al*, 2001. As done with the NDVI, three variables were created aggregating the CNDVI values on a temporal scale: using cumulative CNDVI values starting from planting date up to the end of the crop cycle (CNDVIc), maximum CNDVI during the crop cycle (CNDVIx) and 3 dekad-averages around the maximum CNDVI (CNDVIa) to smooth the curve when an isolated peak represents the maximum.

Crop yield model development and validation

A multiple linear regression analysis was used in the development of the crop yield model testing the following independent variables: WSI, cumulated ETA during the whole maize cycle, ETA cumulated by phenological phase (initial, vegetative, flowering and ripening), cumulated soil water deficit and surplus, NDVIc, NDVIx, NDVIa, CNDVIc, CNDVIx, CNDVIa and total cumulated rainfall during the crop cycle. To increase the number of observations and hence the net degree of freedom, the model was developed considering all the observations from all regions together. The Jackknife re-sampling technique (leaving one data value out each time) was applied to test the forecast capability of the model. To avoid a strong influence of climatic conditions given by a specific year each time it excluded a set of observations belonging to the same year. To assess the prediction capacity of the model, a correlation matrix with the independent variables accumulated during the phenological phase of maize was tested. To study the evolution of the r^2 and RMSE, 4 multiple linear regression models were built at provincial level whereby each model represents a phenological phase of maize (initial, vegetative, flowering and ripening) using the most correlated variables. The Jack-knife technique was applied to each model to validate its forecasting capability.

RESULTS

Trend analysis

The trend in rainfall, area planted, yield and production of maize during the first crop season was studied. The maize yield exhibits a negative trend in Coast, Nyanza and Western provinces; the data was not de-trended due to the fact that this tendency can be explained by the trend in rainfall. Considering the objective of the study, we de-trend when the tendency is explained by variables other than climate, such as technological improvements. Nyanza and Rift Valley have a very positive trend in area planted during the 'Long rains' crop season. Due to the fact that 6-years is a short series to have a conclusive trend analysis, we used the longest series of national aggregated data of Kenya (1985-2003) and analyzed the production, area planted and yield of maize at national level.

The maize production in Kenya has no trend. The average production is above 2.5 million tons with a minimum production of 1.7 million tons which occurred in 1993 followed by a maximum production of 3.0 million tons in 1994. The area planted has a strong positive trend (r^2=0.74) while maize yield has a negative one (r^2=0.37). Kenya has increased the area planted to compensate for decreased productivity and the growing demand for maize. The results of our trend analyses undertaken during the first crop season suggest that the increase in area planted has been concentrated mainly in the Nyanza and Rift Valley provinces, and less extensively in the Coast province. Eastern is the only province that shows a negative trend in area planted during 1998-2003 period.

The trends of annual rainfall (1989-2005), first crop season (1989-2005) and maize yield aggregated at national level (1985-2003), are negative. The trend in annual rainfall shows a small coefficient of determination (r^2= 0.13) when compared with the coefficient of the first crop season (r^2=0.34). The accumulated rainfall from September to January, second crop season (1989-2005) has no trend, signifying that the decrease in maize yields is due to reduced water availability during the main cropping season in Kenya.

NDVI and CNDVI

There is a difference between NDVI and CNDVI that spans from 0.01 to 1.08 when the variables are accumulated for the whole crop cycle. To assess the impact of such differences on the statistics of the model we calculated the reduction in per cent of the unknown variance using 1-r^2. The unknown-variance has been reduced by 26% when CNDVI is used in the model instead of NDVI. We conclude that the CNDVI gives a better spectral signal of maize crop areas than NDVI spatially averaged by the general crop mask.

Spectro-agrometerological model

Figure 1, shows the comparison between the estimated maize yields by the model and the observed ones. The adjusted-r^2 is 0.84. The root mean square error (RMSE) of the model is 0.329 t/ha and the coefficient of variation is 21%. The following equation of the spectro-agrometeorological model was found:

$$\text{Yield} = -1.44 + 0.25 \sum_{i=PD}^{t=EOCC} CNDVI(t) + 0.003 \sum_{i=PD}^{t=EOCC} ETA(t) \quad (1)$$

Adjusted-r^2= 0.83, n = 36, where t is dekad number;

EOCC = End of maize crop cycle;

PD = Planting dekad;

Yield = Maize crop yield expressed in tons by hectare;

CNDVI= Weighted NDVI using Africover land cover by dekad;

ETA= Actual Evapotranspiration in millimetres by dekad

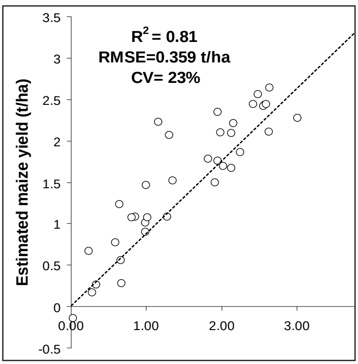

Figure 1. *Comparison between the maize yield estimated by the spectro-agrometerological model and the observed yields for the different provinces.*

Jack-knife re-sampling technique

To validate the forecast capability of the model the Jack-knife re-sampling technique was used. The impact of the difference on climatic conditions of each province was reduced leaving out each time a set of observations belonging to the same year. Figure 2 shows the comparison between the maize yields'estimates done by the model using the Jack-knife re-sampling technique and the observed yields. The r^2 is 0.81, the root mean square error (RMSE) of the model is 0.359 t/ha and the coefficient of variation is 23%. Our results are encouraging when compared with those reported by Lewis *et al* (1998). They used a simple regression model with NDVI from NOAA-AVHRR for estimating maize production in Kenya and they obtained a Jack-knife-r^2 of 0.56.

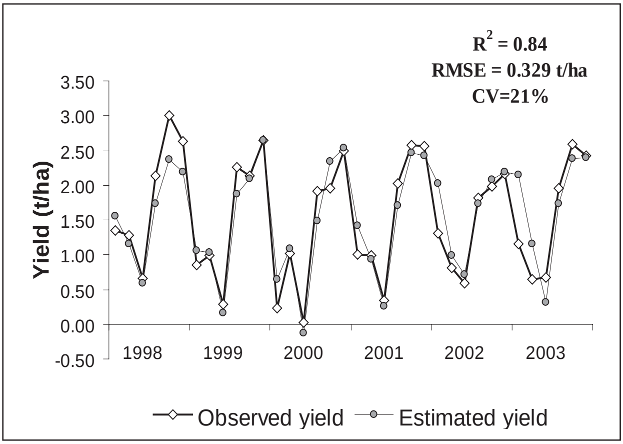

Figure 2. *Comparison between maize yield estimated by the model using the Jack-knife re-sampling technique and the observed yield. The Root mean square error (RMSE) = 0.359 t/ha, coefficient of determination (0.81) and coefficient of variation of 23%.*

Prediction capability of the independent variables

To study the prediction capability of the independent variables the correlation coefficient of CNDVI and ETA with maize yield was calculated. Figure 3 *(a)* shows the evolution of the correlation coefficient accumulated during the whole cycle and accumulated by phenological phases. CNDVI has a very strong correlation during the whole cycle. ETA shows low correlation only during the vegetative phase. The high correlation found in both variables requires further study. During the initial phase CNDVI has higher correlation than ETA, which can be explained by the fact that CNDVI integrates information about the pre-planting condition ("long memory") and is therefore better than simulations by the CSWB model. Also the spectral signal contains information about the characteristics of different soils that is difficult to introduce into the CSWB model. During the vegetative phase, the correlation of both variables by phenological phase decreases, this confirms the well-known low sensibility of yield when some stress happens during this phase. The flowering phase shows a high correlation followed by the ripening phase. It was decided to build a multiple regression model using the CNDVI and ETA accumulated from the initial to ripening phases (that means by phenological phases). The Jack-knife re-sampling technique was used to avoid any strong influence of climatic conditions of a specific year. Figure 3 *(b)* shows the evolution of the adjusted r2 and RMSE after the Jack-knife technique had been applied. Even if the correlation during the initial phase is high in both variables, the adjusted-r2 for this phase is 0.59. The variables at the early stage of the crop explain 59% of the variability of maize yields. Since the adjusted r2 is very high at the beginning of the crop season it should be tested once a longer time series is available to see if r2 remains high. Using the model at this early stage has a lot of uncertainty.

Uncertainty decreases during the flowering period in which the adjusted r^2 increases to 0.74 with a RMSE of 0.42 t/ha. We suggest that using the variables CNDVI and ETA accumulated from planting up to the end of flowering as a preliminary forecast and to refine it when the crop cycle reaches the end. The CNDVI and ETA accumulated for the whole crop cycle explains 81% of the maize yield variance with a RMSE of 0.36 t/ha when the Jack-knife technique is applied.

CONCLUSIONS AND RECOMMENDATIONS

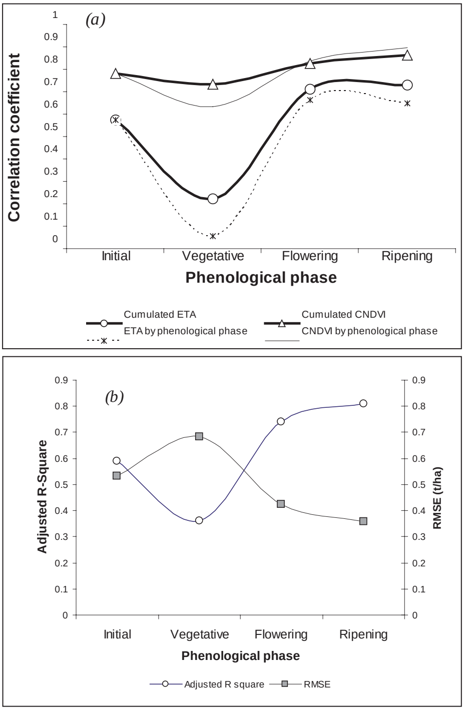

Figure 3 *(a)* Variation of the correlation coefficient (r) with the independent variables cumulated during the whole cycle and cumulated by phenological phases.
(b) Variation of adjusted-r^2 and root mean square error in t/ha of the spectral-agro-meteorological model using the cumulated CNDVI and ETA when applying the Jack-knife re-sampling technique.

It has been shown that it is possible to conduct operational maize yield forecasts using CNDVI derived from SPOT VEGETATION and ETA from the FAO CSWB model. CNDVI showed to improve the spectral signal of the maize crop areas when compared with the simple spatially averaged NDVI using the general crop mask. CNDVI proved to be a simple and valid method for NDVI extraction with low resolution satellite images and highly fragmented high resolution land cover classes. However, significant improvements in extracting pure agricultural time profiles were primarily due to spatial refinements of the crop masks. The model showed a suitable prediction capability of 20 and 30 days before harvest for the short and long maize crop cycles, respectively. Thanks to this prediction capacity it is possible to obtain an early forecast using the CNDVI and ETA accumulated from planting dekad to the end of the flowering phenological phase. A more accurate estimate will be possible when the maize crop cycle reaches the end using the CNDVI and ETA accumulated for the whole length of the maize crop cycle. Even the second forecast using the variables accumulated up to the end of the crop cycle makes it possible to have reliable predictions 3 to 4 months earlier than the official estimates provided by national authorities and based on traditional field sampling surveys. As the time-series of the yield data was limited, some reservations for the model must be made, until a longer series of yield data will become available. The simplicity of the proposed regression yield model should allow an operational implementation in developing countries. Based on these encouraging results, regression models could be developed by MARS-FOOD for other geographical areas in Eastern Africa.

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NATIONAL MODIS NDVI-BASED PRODUCTION ANOMALY ESTIMATES FOR ZIMBABWE

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ABSTRACT

Traditionally, production is estimated as the product of yield and cropped area. Satellite sensors tend to convolve these two sources of 'greenness', and this can make independent assessments of yield and cropped area difficult. In this study we use Moderate Resolution Imaging Spectroradiometer (MODIS) Normalized Difference Vegetation Index (NDVI) time-series to represent crop production anomalies (in percentages). MODIS NDVI data 'cubes' are created and a special temporal filter is used to screen for cloud contamination. Regional NDVI time-series are then composited for crop growing areas, and adjusted in time according to the timing of the onset of rains. A national index is created by taking the cropped area weighted average of the regional series. This spatio-temporal compositing allows for the identification of NDVI-green up during grain filling in crop growing areas. This metric is found to be highly correlated with US Department of Agriculture production figures, and can be used to provide an early proxy for national production.

INTRODUCTION

In food insecure Africa, where two hundred million sub-Saharan Africans were undernourished in 2002, (FA0, 2006), Normalized Difference Vegetation Index images are routinely used to identify areas prone to drought-related reductions in production, as well as poor pasture conditions (Hutchinson 1998, FEWS 2000), malaria (Hay et al. 1998), epizootic diseases such as Rift Valley Fever (RVF) (Linthicum et al. 1999), and damaging pests such as locusts (Hielkema et al. 1986). For Africa, while some applications of NDVI to crop yield and production (Tucker and Sellers, 1986; Rassmussen, 1992, 1996; Bullock, 1992; Groten, 1993; Unganai and Kogen, 1998; Rojas et al., 2004; Rojas 2007) have been made, routine quantitative analysis of NDVI is still fairly uncommon. This differs strongly with satellite precipitation (Adler et al. 1994, Arkin et al. 1994, Huffman et al. 1995, Xie & Arkin 1996, Huffman et al. 1995, 1997, Love et al. 2004), which routinely feed into numerical models of crop yield reduction based on the Water Requirement Satisfaction Index (WRSI, FAO, 1977, 1989, 1986; Reynolds et al., 2000; Verdin & Klaver, 2002; Senay & Verdin, 2003). The WRSI model is a time, crop, and soil type sensitive ratio of actual evapotranspiration compared to the crop water requirement. In this paper we show that a similar metric, the mid-season vegetation sum ($_V$), can provide an early and accurate quantitative proxy for crop production anomalies in chronically food-insecure Zimbabwe.

DATA

Three sets of data are used in this analysis: 500 meter 16-day MODIS NDVI maximum value composites over Zimbabwe (Huete et al., 1994), a regional Landsat-based landcover/landuse classification (Figure 1, CSIR, 2002), and a time-series of national production figures produced by the USDA Production Estimates and Crop Assessment Division (PECAD). The MODIS vegetation index data (MOD13A1) was derived from the Earth Observing System (EOS) Terra surface reflectances which have been corrected for molecular scattering, ozone absorption, and aerosols. The index is produced globally over land at 16-day compositing intervals and provides consistent, spatial and temporal comparisons of vegetation condition. The landcover/landuse database was produced by the Southern African Development Community. The 1 km^2 resolution classification was based on a number of high resolution national landcover datasets that were merged together to produce a regional land use/land cover database. For Zimbabwe, the original dataset is a 1:250,000 map that was produced by the Forestry Commission and German Development co-operation using 1992 Landsat imagery. USDA PECAD figures are routinely produced by best-of-science approaches combining field assessments, crop model evaluation and qualitative analysis of satellite imagery. The production figures used here are national grain production estimates obtained from the PECAD web portal. National/seasonal interpolated rainfall data (1979-2005, Funk et al., 2007) were also used to provide historical context.

METHODOLOGY

The Σv metric

The Σv metric has been developed in analogy to the WRSI water balance metric. The seasonal WRSI is the accumulated ratio of actual evapotranspiration over actual crop water requirement from the onset of rains to the end of the season.

$$WRSI = 100 \frac{\sum_{onset}^{onset+LGP} ET_i}{\sum_{onset}^{onset+LGP} WR_i} \tag{1}$$

The onset of rains is typically estimated from satellite precipitation, and the end of season determined by a crop-specific length of growing period (LGP). The crop water requirement (WR) is a function of potential evapotranspiration, crop stage, and crop coefficients. Actual evapotranspiration (ET) is a function of soil water and root depth, and incorporates water holding capacity, past precipitation and past ET.

In early warning applications WRSI percent anomalies are typically examined to identify areas experiencing crop water stress. Assuming that optimal seasonal water requirements vary little from year-to-year, we can express the WRSI percent anomaly (WRSIA) as a function of actual ET.

$$WRSIA \approx 100 \frac{\sum_{onset}^{onset+LGP} ET_i}{\sum_{onset}^{onset+LGP} \overline{ET}} \tag{2}$$

While the WRSI estimates actual ET via extended moisture balance considerations, it has also been shown than MODIS vegetation indices are a good proxy for actual evapotranspiration (Chong et al., 1993; Nagler et al., 2005a, 2005b). This suggests that the sum of NDVI increases over the mid-season growing period should be a good indicator of crop evapotranspiration.

$$\sum_{onset}^{onset+LGP} ET_i \propto \Sigma_V = \sum_{onset+lag}^{onset+LGP+lag} (NDVI_t - NDVI_{onset}) \tag{3}$$

The Σv calculation incorporates a lag that combines the delays associated with the gradual intensification of the rainy seasons and the delayed response of vegetation to rainfall (Kerr et al. 1989; Richard & Poccard, 1998; Potter et al. 1999; Ji & Peters 2003). NDVIonset is subtracted from Σv to pre-onset influences associated with the previous dry or rainy seasons.

The onset of rains dates used in this study were based on standard WRSI-modeling practices (AGRHYMET, 1996) with the onset defined as the 1st 10-day period in which at least 25 mm of rain fell, followed by two 10-day accumulation periods with a total of at least 20 mm of rain.

Space-time MODIS filtering and pixel-to-nation averaging

While Eq. 3 is physically plausible there are a number of contamination sources that can confound the potential NDVI/ET and crop productivity relationship. Temporally, cloud and moisture contamination can influence the NDVI signal. Furthermore, vegetation signals from before or after the season contain variations not related to grain filling; an onset-of-rains temporal re-alignment accounts for some of these effects. Finally, spatial filtering was used to minimize the influences of non-agricultural vegetation on Σv.

Temporal and Spatial MODIS processing

NDVI data may be affected by a number of phenomena that contaminate the signal, including clouds, atmospheric perturbations, and variable illumination and viewing geometry. Each of these tend to reduce NDVI values. A time series smoothing technique developed by Swets and others (1999) was used to minimize these effects. The technique uses a weighted least squares linear regression approach to "smooth" observations that are of poor quality due to clouds or other atmospheric contamination. A temporal window is used to calculate a regression line. The window is moved one 16-day period at a time, resulting in a family of regression line associated with each point; this family of lines is then averaged at each point and interpolated between points to provide a continuous temporal NDVI signal (Figure 2).

In order to minimize the influence of non-agricultural land cover types on ΣV we applied a mask to the NDVI time-series using a cultivated areas map based on the Southern Africa Development Community's regional land cover database (Figure 1). The classification was produced by the Forestry Commission and German Development Co-operation using 1992 Landsat imagery. The mask was used to calculate NDVI time-series statistics for only those areas classified as cultivated lands.

The end result of the temporal-spatial smoothing procedure was a set of 61 characteristic district level NDVI time-series covering the 2000-2001 season through to 49th Julian day MODIS period (March 5th) of 2007. In

2007, the 65th through 129th Julian day 16-day periods were filled by assuming climatological NDVI changes, estimated from 2000-2006 data.

Temporal re-alignment procedures

NDVI changes outside of the main rain vegetation response period may not relate positively to increase crop productivity. For example, early in the season the clearing of agricultural lands (reduced NDVI) may be positively related to increased production at season's end. Similarly, once the NDVI-responses associated with grain-filling are complete, increasing greenness may represent late season cyclonic activity, which can hamper seed drying and harvesting activity. Late season greenness may also represent continued green-up in non-cultivated regions. Focusing on the mid-season NDVI response helps identify crop-specific vegetation changes. This focus was achieved by estimating Σv over a set of dates indexed by the onset of rains, and specified by the lag and LGP coefficients in equation 3.

National averaging and production anomaly regressions

The space-time filtering and onset specific ΣV calculations produce a 7x61 matrix of Σv values, representing the seven seasons (2000-01 to 2006-07) and 61 districts analyzed. District ΣV percent anomalies were then calculated by dividing by the district mean and scaling by 100. District level weighted averages, based on cultivated area, were then used to develop national level Σv percent anomalies. These values were then regressed against USDA PECAD maize production anomalies for a range of lags and LGP specifications. The 2000-2001 season was screened from the regression process to limit the influence of the large structural changes that occurred within the agricultural system in 2001. This topic is discussed further in section 4.3.

RESULTS

As the first step in our evaluation, we visually examine time series of NDVI growth since the date of onset (Figure 3). These time-series have been derived by taking the cultivated area weighted average of the onset-adjusted district level data. The Σv.calculation subtracts the first NDVI values, so the time-series begin at 0 and increase with vegetation green-up. The vigorous performance of 2005-06 is apparent, and 2004-05 clearly produces less productive vegetation. Mid-season increases in NDVI are generally related to final vegetation status, but several seasons (2001-02 and 2006-07) begin with strong performance, and then decline dramatically later. Note that the converse does not hold. This suggests similarities with the WRSI calculation: moisture deficits can occur early or late, but late moisture surpluses cannot replace early deficits.

Σ_V performance as a function of time

In order to explore the accuracy of the Σ.vmetric, a set of experiments was conducted across a range of lags and LGP periods (Figure 4). Increasing the lags and LGP values tended to increase the coefficients of determination, and these were very high (greater than 0.96) across a broad array lag/LGP combinations. This suggests that the Σ.vmetric is both representative and fairly intolerant to small change in parameter settings. Of the two, lag (the number of 16 day periods since the onset of rains) appears much more important. The weak significance of the LGP setting may be due to the extensive smoothing of the NDVI data (Section 3.2.1). The combination of parameters can be used to identify the last 16 day period used in Σv, and this date is strongly related the to the model R2, up to a maximum of 11 periods (~176 days). Figure 4 suggests that given a typical late October/early November onset of rains, and a maximum date offset of ten 16 day periods, evaluating NDVI response in early April should provide a strong correspondence to crop performance. Thus grain filling in December-January-February relates strongly to February-March-Early April NDVI. Inclusion of NDVI observations after this date can modestly decrease the accuracy modestly. The two month lag between rainfall and vegetation response is broadly in-line with observational studies (Richard & Poccard, 1998; Funk & Brown, 2005), but may be lengthened due to the temporal smoothing applied to the data (Swets et al., 1999). Cloud contamination may also play a role in emphasizing late season vegetation observations, since the accuracy of satellite retrievals will improve as the rainy season subsides, providing a better characterization of true surface conditions.

Given the trade-offs between earlier warning and increasing levels of accuracy, a second set of experiments was conducted. In these experiments, all dates past Julian day 49 were filled using the 2000-2006 average change in NDVI for each district. This filling was accomplished as follows. First, for each 16-day period, the previous seven years of MODIS data were averaged to produce images of average NDVI at each date. The next step subtracted each date image from the following data image, producing estimates of typical NDVI response throughout the course of a season. These images represent the average green-up and brown-down variations expected from a 'typical' season. Missing dates from the end of a season can then be filled by assuming that the temporal response of the vegetation follows the trends of past seasons. For most of the Zimbabwe pixels analyzed, this amounted to a modest decline in greenness (see Figure 3). This filling procedure allowed us to simulate the effect of basing an estimate on the data typically available in mid-March. While a substantial decline in performance did occur, R^2 values of about 0.8 could be obtained. It should be noted that all the coefficients of determination are based on very short time-series, and thus will decay with cross-validation. For an offset of 10 dates and a 4 date LGP setting, take-one-away cross-validation resulted in substantial declines in the mid-March filled estimate (the R^2 went from 0.81 to 0.4), while the unfilled April estimate went from 0.98 to 0.84. This suggests that end-of-season estimates are likely to be more robust.

PECAD production and Σv anomalies mostly represent yield fluctuations

While this study focuses on production anomalies, and a reasonable correspondence is found between PECAD and Σv, it is important to note that we are mainly representing changes in yields. Over the 1999-2007 period PECAD production and yields are highly correlated (R2=0.85), and Σv tracks with both these time-series.

Σ_v performance compared to Maximum and seasonal NDVI

Given that seasonal maximum and seasonal accumulated (or integrated) NDVI is a common metric used in the evaluation of seasonal crop performance, we have included a brief comparison with Σv (Table 1). Again, the R2 with 2000-2006 USDA PECAD production is used as the evaluation metric. The summary statistics were calculated two different ways: i) by estimating the statistics for each district, and averaging the results, and ii) by estimating the statistics using the national-level cultivated area weighted time-series (cf. Figure 3). Values based on both full-season and filled-season data are also reported. The Σv substantially out-performs the other two metrics, though the Maximum NDVI based on the national time-series also shows a strong correspondence to the PECAD figures. Note that the metric Σv and integrated NDVI metrics are linear functions, and give very similar results whether calculated at the district level and averaged nationally, or calculated directly based on the national averages. This linearity makes the

Σv metric scale invariant; a self-consistent analysis can be performed at both national and district scales. Maximum NDVI, on the other hand, is a non-linear function, and provides substantially different results depending on the order of operations used.

Recent declines in Zimbabwe production

Before turning explicitly to an analysis of the 2006-07 season, we must place Zimbabwe production in historical context. Figure 5 shows 1979-80 USDA PECAD production anomalies, together with regression estimates of the same (R2=0.66) based on December-January rainfall totals. The drop between 2000-01 and 2001-02 is precipitous, going from 83% to 28%. While below normal rainfall may have played a role, this drastic decline appears to be mostly due to dramatic changes in agrarian management practices. Rainfall estimates for 2001-02 calibrated against earlier data are much too high (91% as opposed to the PECAD value of 28%). Note that the Σv regression estimate, calibrated over 2001-02 to 2005-06, underestimates 2000-01 production (51% as opposed to 83%). Thus Σv *cannot* capture the systematic changes in agricultural practice. Rather, as equations 1-3 show, Σv is a satellite observed vegetation proxy analogous to the WRSI, and as such requires external calibration.

The 2006-07 filled-season Σv estimate

With these caveats in mind, we turn to the 2006-07 season. Figure 6 shows a scatterplot of recent PECAD and Σv production anomalies, expressed as a ratio of 2005-06 PECAD production. The six estimates cluster into 3 groups: very poor (2001-02, 2004-5), quite poor (2002-03, 2006-07), and poor (2003-04, 2005-06). This year's Σv estimate is about 15% below last season – and may provide an optimistic projection, given that it may not capture a likely 15% reduction in cropped area (Reynolds, 2007). Note also that the Σv production value presented here is based on filled NDVI data for part of February and March. The full time series provides much better results (Figure 4), and additional estimates might be desired later in the season. These estimates may be lower than the current figure, since January-February-March precipitation was quite poor. Figure 7 shows a spatial plot of Σv anomalies, which clearly delineates the north-south dichotomy in crop performance.

SUMMARY

While more research and broader testing is necessary, this initial application of the Σv metric appears promising. One interesting result has been the emphasis on mid-season vegetation response (Figure 4). The long lag between grain-filling precipitation receipts and optimal vegetation responses poses an obstacle to effective early warning. Timely, low-latency NDVI acquisitions will help overcome this hurdle. In the United States, scientists are also working to combine precipitation forecasts (Funk et al., 2006, 2007) with NDVI projections (Funk & Brown, 2005) to provide integrated vegetation observation/forecast systems (Brown et al., 2007). This may also help overcome the early warning liabilities of the lagged rainfall-vegetation responses. Another interesting aspect of the v.a.pproach is linearity: the fact that sub-national productivity measures and onset-of-rains adjusted vegetation time-series can be meaningfully compiled into national level summaries (cf. Figure 3). This transformation of satellite imagery into clear visualizations of probable crop productivity can provide powerful, actionable, information for food security decision makers.

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FIGURES

Figure 1. *Cultivated areas from the SADC landcover/landuse database.*

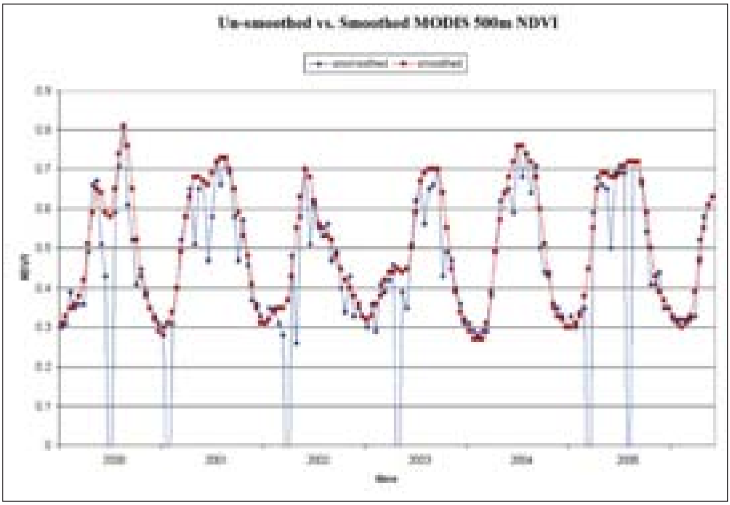

Figure 2. *This time series NDVI plot, for a single 500m pixel, shows un-smoothed data in blue and temporally smoothed NDVI in red. The smoothing algorithm effectively corrects these erroneous NDVI values based on characteristics of the valid NDVI curve.*

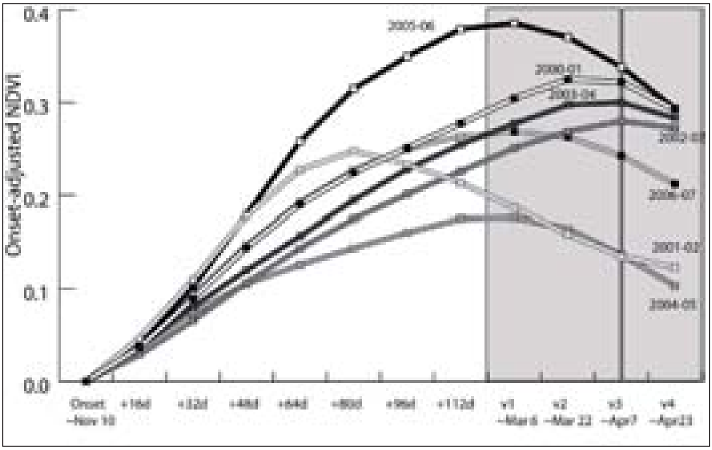

Figure 3. *Composited onset-adjusted NDVI time series from the onset of rains forward.*

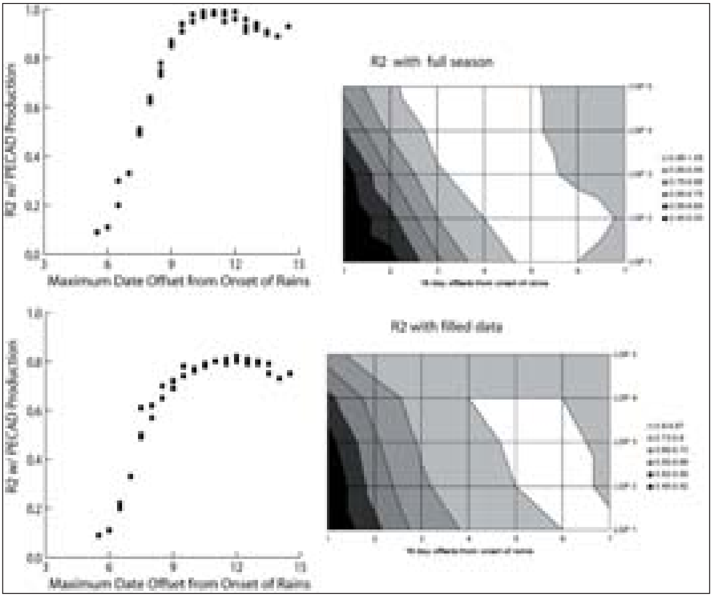

Figure 4. *Full-season and filled-season ∑v R2 values. Based on comparison with 2001-02, 2002-03, 2003-04, 2004-05, and 2005-06 USDA PECAD national maize production figures.*

	Avg Stat Full-season R2	Avg Stat Filled-season R2	Avg NDVI Full-season R2	Avg NDVI Filled-season R2
∑v	0.98	0.80	0.95	0.72
NDVI Max	0.47	0.36	0.76	0.49
Seasonal NDVI Integration	0.49	0.28	0.57	0.26

Table 1. *Comparison of ∑v, NDVI-Maximum, and NDVI integration metrics*

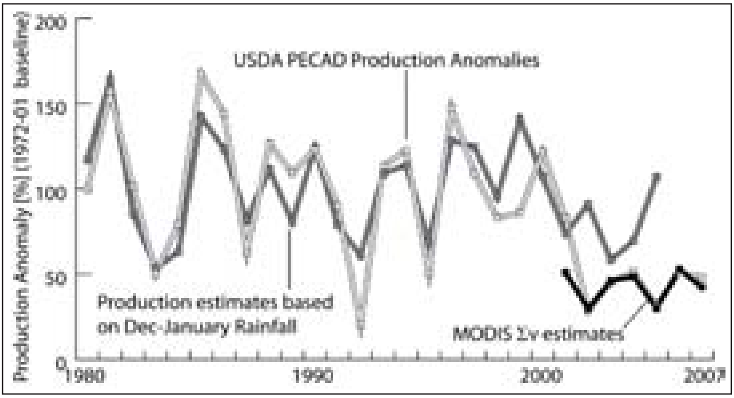

Figure 5. *Three estimates of Zimbabwe national maize production anomalies.*

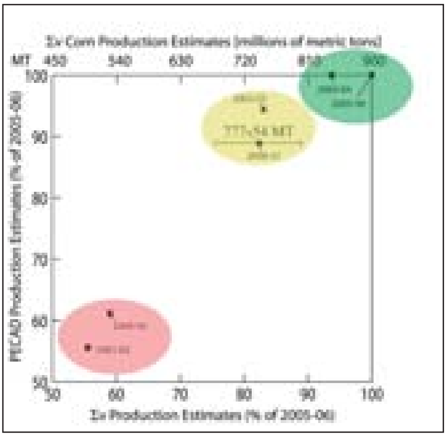

Figure 6. *Scatterplot of six most recent production anomalies,expressed a fraction of 2005-06 production. The 2006-07 estimate is also shown, together with brackets indicating ± 1 standard error (6%).*

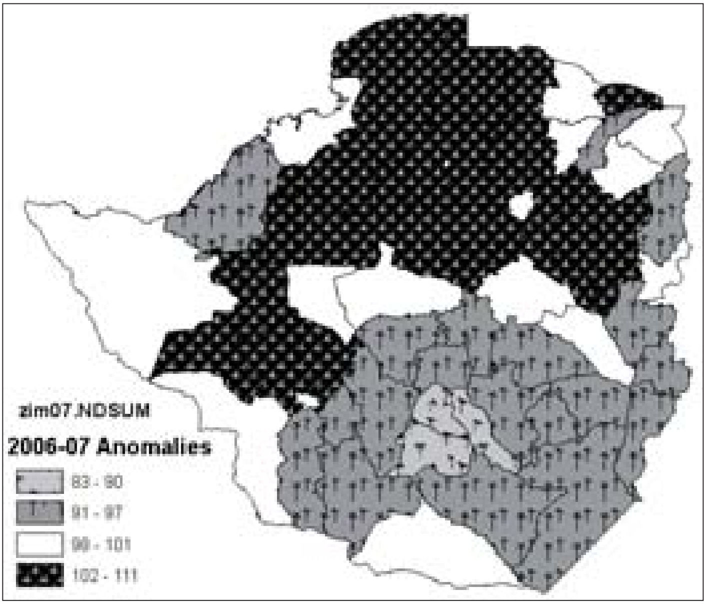

Figure 7. *2006-07 ∑v NDVI anomalies, based on a combination of observed and filled data. Black (grey) areas experienced above (below) normal NDVI growth.*

CROP MONITORING BASED ON REMOTE SENSING AND AGRO-METEOROLOGICAL DATA IN ETHIOPIA and IN EAST AFRICA

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ABSTRACT

Since 2001, MARS-FOOD action has developed a system for crop monitoring and forecasting in food insecure areas. This communication tries to describe one of the monthly bulletin prepared and published by MARS-FOOD action in East Africa. The main example is taken from Ethiopia. Basic data, models and information are presented as well as some important parameters for the crop monitoring.

KEY WORDS : Remote Sensing, Agro-Meteorological model, Food Security

INTRODUCTION

Food Security in the poorer countries of the world is a main concern for European Citizens as reflected by the leading role of the European Union in the international donor community with a yearly contribution of around 500 MEuro. According to the United Nations Food and Agriculture Organization (FAO), 815 million people worldwide are chronically food-insecure.

The MARS-FOOD action of the European Commission Joint Research Centre has developed since 2001, in cooperation with the MARS STAT action and in the framework of the Global Monitoring for Environment and Security (GMES) initiative, a system for regional crop monitoring and forecasting in various parts of the world. During an initial phase (2001 - 2004), four pilot areas were covered: Russia and the New Independent States, the Mediterranean Basin, Eastern Africa and South America (MERCOSUR countries plus Bolivia). Since 2005 the system has been extended to food insecure areas worldwide.

REGION OF INTEREST

In 2006, MARS-FOOD has signed a specific agreement with another European Commission, Directorate General, the DG AIDCO, to strengthen national and regional food security and vulnerability analysis in East Africa. This should lead to the creation of a regional synergy between the sector and country initiatives in order to improve the quality of food security and relief interventions in the Horn of Africa.

The specific objectives of the agreement were (1) to improve the quality and coverage of crop monitoring and forecasting activities, (2) to improve the general knowledge and analysis of food security and vulnerability assessment, (3) to support Governments' capacity in implementing the EC funded Food Security Information System projects and (4) to strengthen MARS-FOOD participation in field missions, such as the Crop and Food Supply Assessment Missions of FAO/WFP.

The first specific objective is covered by the regular publication of crop monitoring bulletins on the countries of the Horn of Africa. These bulletins are produced each month during the main cropping season for Somalia (since 2001), Ethiopia (2005), Sudan (2005), Eritrea (2006) and Kenya (2007). The bulletins are based on meteorological data, satellite remote sensing information and agro-meteorological modelling to analyze crop conditions and to assess crop production.

METEOROLOGICAL AND REMOTE SENSING DATA

Rainfall

Since 2001, MARS-FOOD is acquiring and using the meteorological data of the European Centre of Meteorological Weather Forecast (ECMWF) in its bulletins. Under a specific contract with three European companies (ALTERRA, VITO, Meteo Consult), the data are pre-processed and delivered every day, every ten–days and monthly to JRC. Several parameters, including temperature, precipitation, radiation and wind speed are provided at 1 degree grid resolution and, since 2008, at 0.25 degree grid resolution worldwide. Additional indices are also calculated on the initial data, parameters showing the difference with previous year and with an historical average, on absolute and on relative value. MARS-FOOD can also count on a data archive ERA-40 of more than 30 years (Rojas, 2007).

ECMWF data are forecasted meteorological data based on a general circulation model. They are used for their "operationality", received worldwide, regularly and on real time for the bulletin preparation and publication. Nevertheless, they have shown clear limitations, particularly for rainfall information, in some specific regions. For these reasons, in 2007, MARS-FOOD has decided to invest in alternative rainfall data. Rainfall data based on METEOSAT CCD (Cold Cloud Duration) method are now acquired through the TAMSAT project of the University of Reading. Simultaneously synoptic station data are also acquired following a systematic approach at African level. They will complement the CCD estimations and will be integrated in the rainfall estimation process using a geo-statistical approach. The increase of resolution to 5 Km grid represents also a clear advantage of the MSG data compared to the ECMWF information.

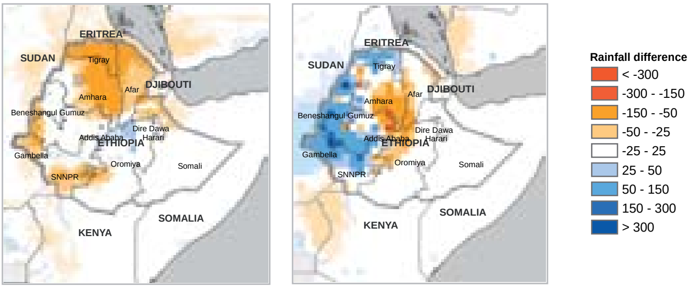

Figure 1. *Comparison between TAMSAT (left) and ECMWF (right) estimates, Rainfall difference with average for the month of August 2008.*

Remote sensing

MARS-FOOD is using SPOT VEGETATION data in its bulletin. The data are received every ten days worldwide at 1 Km resolution grid. Several standard indices are calculated such as the Normalized Difference Vegetation Index (NDVI), the Vegetation Condition Index (VCI), the Dry Matter Productivity (DMP) and the Vegetation Productivity Indicator (VPI). Monthly composites are also produced. The archive of SPOT VEGETATION data is from April 1998. NDVI difference images are computed every ten days, showing the crop condition difference with the current year and the previous year, as well as with an historical average (of the last 10 years).

Considering the small size of agriculture landscape in some regions, MARS-FOOD has also started to acquired in 2007 MODIS 250 m resolution data over East Africa. The data received from NASA are reprocessed by the Vlaams Instituut voor Technologisch Onderzoek (VITO) to generate ten-daily NDVI composites. MODIS data will complement the SPOT VEGETATION information for crop monitoring but will also be used to produce every year a crop map of countries of interest.

THE MODELS

To monitor crop development during the agriculture season two models are currently used by MARS-FOOD, the first one is based on meteorological data, the other one is based on satellite remote sensing observations.

The Agro-Meteorological "Water Requirement Satisfaction Index" (WRSI) model (AgroMetShell, FAO, Hoefsloot, 2005) has been selected for its simplicity in its inputs and for its relevance and reliability in the semi-arid context of East Africa. The water requirement satisfaction index (WRSI) is an indicator of crop performance based on the availability of water to the crop during the growing season. A complete description of the model with input and output can be found in Rojas (2007).

The second approach is based on the observation of the satellite NDVI over the agriculture season. The NDVI is extracted and averaged on the crop areas for each administrative unit. For the extraction, a crop mask is required. Different techniques can be applied, one of the most advanced one being the CNDVI method described in Genovese, 2001. The method is integrated in MARS-FOOD process when the necessary data are available. The Crop specific NDVI extracted every ten days from the SPOT VEGETATION data gives over the season the profile of the crop development and indications on crop performance.

THE BULLETINS

Meteorological information, remote sensing data and model output are presented in the monthly bulletins published. They are usually compared with previous year indices and with historical indices.

The first page of the bulletin presents the general agriculture conditions of the country, displaying the Vegetation Condition Index of the current month with a short text commenting the season and an overall assessment of the evolution of the season with a green to red sign.

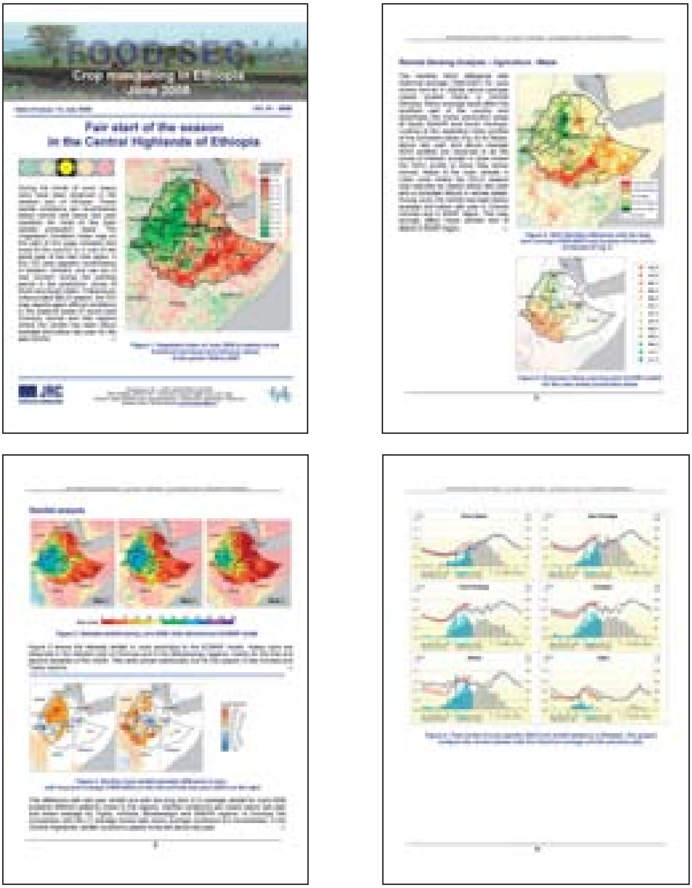

Figure 2. *First pages of the bulletin showing the general crop conditions, the rainfall information and the specific crop pages.*

The second page shows the rainfall conditions of the month, rainfall of each dekad of the month and the monthly rainfall compared to last year, to the average of the last ten years or to an historical average of the last 30 years. Cumulative rainfall graphs from the beginning of the season are also sometimes displayed for specific agro-meteorological regions or watershed.

The following pages of the bulletin display crop specific information. The most important crops for the production of the country are selected. The WRS indices maps (planting date, crop cycle progress or qualitative estimated yield), the NDVI monthly difference maps with last year or with historical average and graphs of specific NDVI profiles are presented. The profiles are displayed for the main administrative units, selected to represent at least 50 % of the national crop production. The graphs show not only the NDVI profile of the current season compared with last year and with an average but also the rainfall profile of the current season compared to the average rainfall. Maps and graphs are commented to evaluate the potential crop yield at the end of the season.

The agriculture season and the crop condition assessments are mainly qualitative, comparing the profiles or the maps of the current season with previous year or with an historical average.

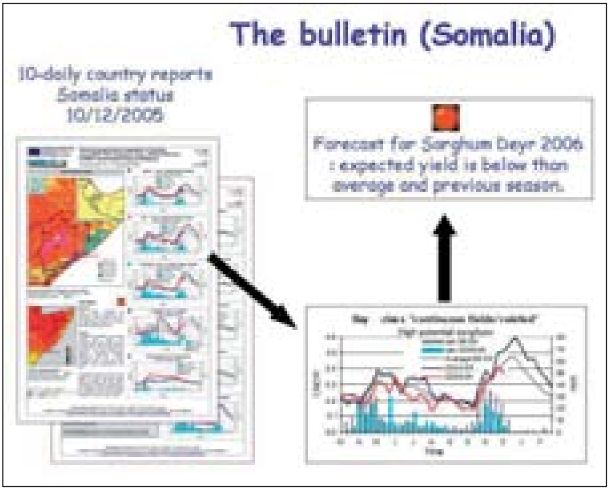

Figure 3. *Crop profiles analysis. Example in Somalia*.

For some countries, a quantitative approach is developed. A three steps approach has been applied in Somalia in 2005. The first step gives a broad estimate of the production or the yield by looking at the historical trend. The two further refinement steps are based on crop profile similarity analysis with previous years and regression computation between national statistics and several crop status indicators. The final production evaluation is then made by an expert, taking into consideration the results of the 3 steps. In 2008, yield estimates of cereals have been produced for Eritrea based on a simple regression analysis between NDVI integrated over the season and the national historical crop statistics. The regression is calculated for each region using the data of the last 10 years. The average coefficient of determination of the regression was around 0.75. In 2007, a more complex model has been developed for Kenya. The Kenyan regression model involves the use of remote sensing NDVI in combination with agro-meteorological parameter (ETA) in the yield estimation (Rojas, 2007).

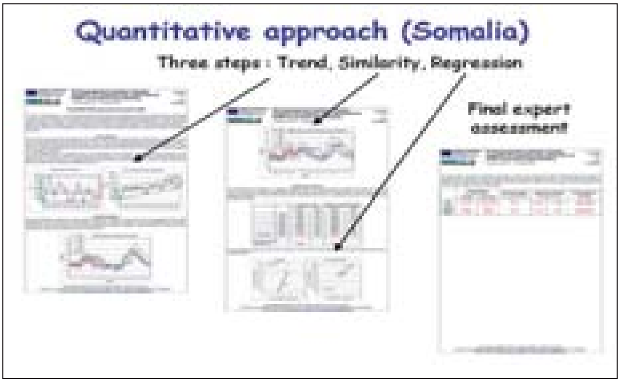

Figure 4. *Quantitative approach in Somalia.*

SOME IMPORTANT PARAMETERS

Agriculture - Crop Mask

To monitor crop development, satellite information, such as NDVI, is specifically extracted on crop areas. In East Africa, the AFRICOVER project produced in the early 2000 land cover maps for several countries. The land cover maps developed using the LCCS classification system (Di Gregorio, 2000) need a class interpretation to derive a crop mask. The resolution of the final maps produced from visual interpretation of LANDSAT data is higher than the SPOT VEGETATION data which allows the calculation of a weighted crop specific NDVI or CNDVI (Genovese, 2001). This approach is applied in Sudan, Eritrea, Kenya and Somalia.

Ethiopia has not been covered by AFRICOVER project (1995). A national land cover map developed by a World Bank and the Ministry of Agriculture and Rural Development project, the "Woody Biomass Project", is available since 2000. The map is also based on LANDSAT interpretation but the resolution does not appear to be fully consistent at national level. To refine the information and to reach a "more" crop specific map, the "cultivation" class of the woody biomass map has been crossed with elevation data which can allow in Ethiopia a certain differentiation of the crops (Reynolds, 2007).

In the absence of any high resolution agriculture map, the Global Land Cover 2000 product has been used as agriculture mask. The map has been produced in 2000 based on the classification of SPOT VEGETATION data at 1 Km resolution. In the same context, other mid resolution products based on MODIS or MERIS data will be available soon, developed under various initiatives like the GMFS program or the ESA-GlobCover project, they may show a clear improvement to GLC 2000.

The advantage of using an agriculture mask for extracting the NDVI is highlighted if a comparison is made with a NDVI extraction without mask (Figure 5). It improves the quality of the information with the focus on agriculture. Nevertheless, the difference between the use of a high resolution (LANDSAT based) and a mid-resolution mask (SPOT VEGETATION or MODIS) is not always straightforward, at least for a qualitative evaluation.

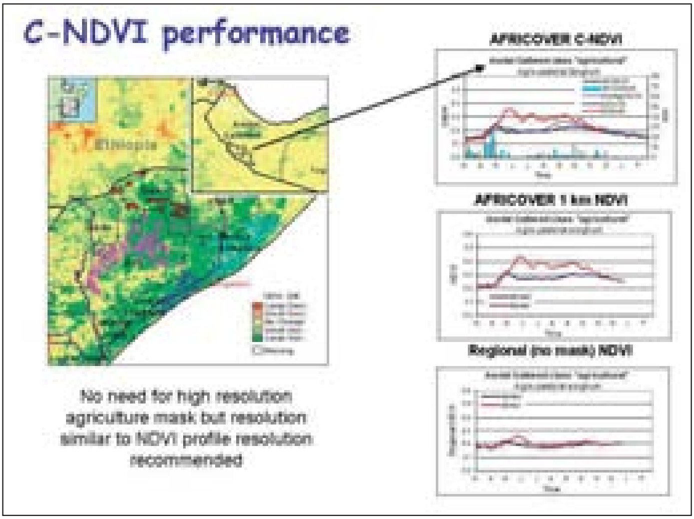

Figure 5. *Difference of NDVI profiles with the use of crop mask.*

Phenology

The importance of rainfall in the WRSI model is clear and is discussed in the paper of O. Rojas. Another element of the WRSI model is the crop phenology. The planting/sowing date is a key element for running the model. Planting date windows (average planting period) are available from FAO databases like the IGAD "Crop Production System Zone" database (Van Velthuizen, 1995) or often from national sources. But the relevant input is the planting date of each year. This information can be observed on the ground. The National Meteorological Agency (NMA) in Ethiopia is reporting crop phenology during the cropping season for around 30 meteorological stations. This information is valuable to calibrate the model but is often not complete or consistent during the season. Another approach is to derive the planting/sowing date from models based on rainfall patterns or NDVI vegetation profiles. MARS-FOOD is currently using a model based on the accumulation of "significative" rainfall during two dekads at the beginning of the rainy season. The parameters of the model derived from rules defined in the Sahel region (AGRHYMET Centre) have been adjusted for East Africa and Ethiopia context. VGT4AFRICA program and JRC provide also a "vegetation start of the season" product based on NDVI profiles analysis. The product is not specifically a "crop planting or sowing" date product but it could be used as a proxy. It thus needs to be calibrated and validated for crops.

National agriculture statistics

The production of quantitative yield estimates needs the calibration of the model with historical crop yield statistics. A specific attention must be paid on the spatial level at which these data are available to be able to consider homogeneous areas, as well as on the length of the time series of the statistics. The quality of the estimation relies of course on the quality of these statistics which is not always easy to assess. In Ethiopia, two sources of agriculture statistics are available, from the Central Statistical Authority (CSA) and from the Ministry of Agriculture. They are produced using two different field survey methods. Since 2006, an EU funded project implemented by FAO is trying to reconcile the two approaches. For their time consistency and easy availability, MARS-FOOD is using today in Ethiopia the CSA data.

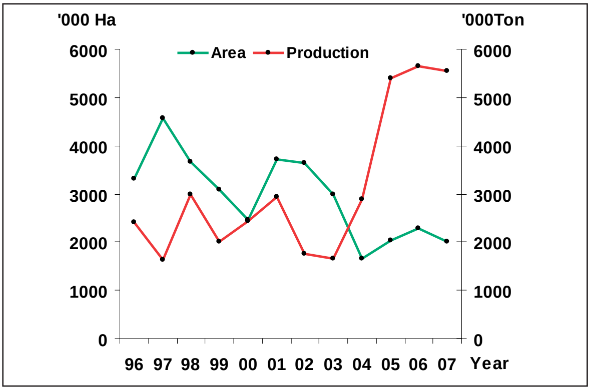

Figure 6. *Statistics difference for area and production of cereals and pulses between the CSA and the Ministry of Agriculture in Ethiopia (source SFSIS, FAO, 2008)*

FIELD ASSESSMENT

At the end of the agriculture season, MARS-FOOD team is involved in national crop assessment surveys where the MARS-FOOD products, bulletins and estimations can be compared to ground observation.

MARS-FOOD team participates, as EU Observers, to Crop and Food Supply Assessment Missions (CFSAM) carried out by FAO and WFP at the request of the Governments at the end of the main agriculture season.

In Ethiopia, since 2006, MARS-FOOD is also joining USDA experts for a Crop Assessment Tour before the harvest (around the end of September) to evaluate crop development. Information is collected by interviewing farmers and observing fields in the main agriculture regions of the country. During the Tour, field photographs are taken regularly and geo-referenced with a Global Positioning System to be further related to satellite images or agro-meteorological outputs.

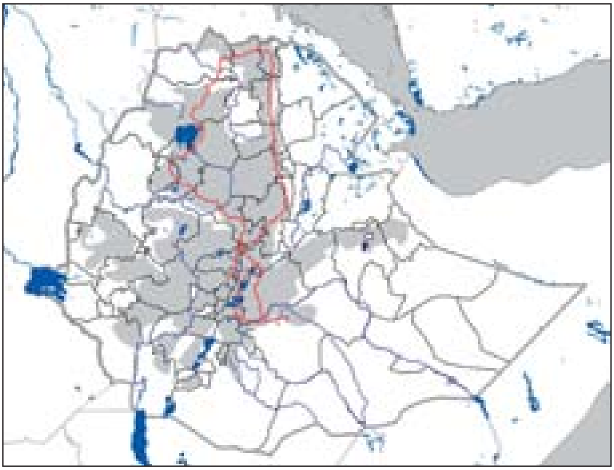

Figure 7. *USDA-JRC Crop Assessment Tour in Ethiopia in 2008 (cropland in grey).*

DATA DISSEMINATION

MARS-FOOD bulletins are disseminated by email using specific distribution lists per country. Each bulletin reaches directly around 100 persons ; European Commission officers, EU Delegations, National institutions of the country concerned, research centres and UN institutions (FAO and WFP). The bulletins are also available on line on the INTERNET site of MARS-FOOD action: http://mars.jrc.ec.europa.eu/mars/About-us/FOODSEC

The MARS-FOOD maps are available on line, on the specific INTERNET site of the MARSOP project. On the site, data temporal profiles for specific regions of interest can be calculated. The maps are available at : http://www.marsop.info/

The MARS-FOOD meteorological data used in the bulletin can be extracted following different format for specific regions of interest on :

http://cidportal.jrc.ec.europa.eu/home/idp/thematic-portals/foodsec-imageserver/

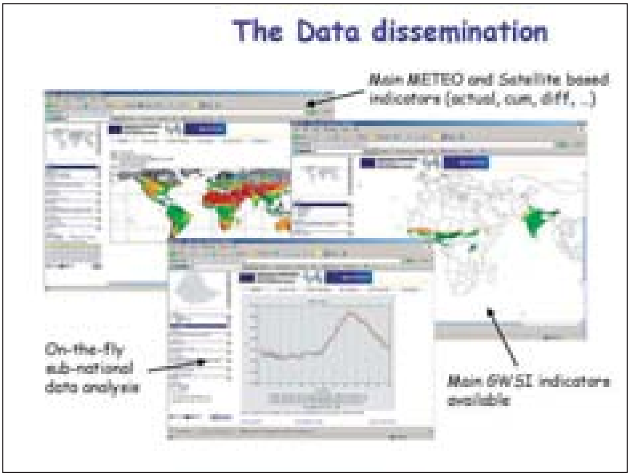

Figure 8. *Examples of MARSOP site products.*

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ESTABLISHMENT OF THE COMMUNITY BASED LIVESTOCK EARLY WARNING SYSTEM

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INTRODUCTION

More than 70 million people or 46% of the total population of the Greater Horn of Africa (GHA) region are perpetually food insecure. Of these, Ethiopia and Eritrea host 41%, Sudan 14%, Kenya 13%, Tanzania 12%, Uganda 9% Somalia 6% and Rwanda 5% (Thrupp with Megateli, 1999). About one third of these vulnerable people are pastoralists that make a living out of the drier parts of the region mainly comprised of rangeland. Only several decades back, pastoralists were the primary users of the rangelands of the GHA. Strategies such as mobility, matching livestock species to the environment and herd splitting ensured their survival as well as the dynamic equilibrium of the ecosystem, such that environmental degradation was insignificant. However, human and livestock populations have tremendously increased over the years. Pastoralists have lost their most valuable grazing resources to other uses and tenure systems such as agriculture, game reserves and private ranches. This has greatly constrained pastoral mobility and eroded the rangelands' ability to support the increasing sedentary pastoral population. The overall trend in these rangelands is depicted by decreasing productivity, increasing degradation and diminishing ability to cope with ecological stress.

Medium- to long-term policy to mitigate the effects of crises that face pastoralist communities must contribute to the overall long-term development of the rangelands. This would improve the livelihoods of the people that are dependent on these poor environments and make them more resilient to the cumulative impact of recurrent droughts and less dependent on perpetuated relief assistance. The currently emerging trend of community based natural resource management acknowledges the important role that ethnic institutions play in participatory development. Key to formulation of effective intervention policy is knowledge of the social networks of pastoralist communities for management and utilisation of common resources. Mobility is the single most important tool used by pastoralists to manage and utilise rangeland. Although some general movement patterns among pastoral groups are documented, spatial and temporal mapping of migration patterns has not been effectively studied (Niamir-Fuller, 2000). The bottom up development approach emphasises the strengthening of traditional institutions and the ability of the local communities to utilise their own expertise and resources to ensure sustainable rangeland and economy. In this approach, focus is on the people as the subjects, determinants, perpetrators and beneficiaries of development. Customary and social institutions and practices are the foundation upon which interventions should be based.

WORKPLAN

Suggested core functions in the implementation of the Livestock Early Warning System

This core function is a Community-based Livestock Early Warning System. In order to prepare for any emergencies and provide for contingency plans, the project will support the setting up of community-based livestock early warning systems (LEWS) in 22 Districts (see Appendix B, project districts). It will also support the building of capacities of pastoral communities to develop, launch and sustain coping strategies during crises. In addition, the project will finance the training and equipping of site monitors, District Officers and drought management committees - institutions involved in managing climate change and drought crises in the Arid and Semi-Arid Lands (ASAL) and the establishment of a database of migration routes, forage reserves, market places, water points, disease hotspots and potential conflict areas in the ASAL. The MoLFD will be supported through training and the provision of necessary equipment to enhance its capacity to monitor, analyse and report on emerging drought conditions and coordinate mitigation efforts. This activity will be carried out in collaboration with KARI and ILRI who already have substantial experience in the field.

Objective: Contingency plans to mitigate effects of crises in pastoral systems.

Resource Mapping Component

The components include: mapping migration routes, forage, water resources, market places and diseases hotspots on migration routes for target communities. They will be used for participatory development of model contingency plans and mechanisms for intervention by various stakeholders particularly pastoralists during drought situations.

The broad objectives of Resource Mapping:

Develop a comprehensive database of mapped resources

(a) Forage reserves

- Forage reserves spatial location
- Forage reserves area
- Temporal change in extent and quality of forage reserves
- Forage reserve carrying capacity (using a standardised conversion rate)
- Forage reserve ownership
- Map forage reserve attributes e.g. salt lick.
- Describe major landform of forage reserve
- Describe major soil type of forage reserve

(b) Households

- Spatial location of households

(c) In/Out Migration routes

- Major migration routes
- Minor migration routes
- Facilities along migration routes

(d) Disease outbreaks

- Identify type of disease and parasites
- Extent of disease and parasites hotspots
- Location of Dips/crush pens
- Map agro vet services in the area (human/ physical)

(e) Insecure/Conflict hotspots

- Category of conflict (Resource Based- RS, Political -P, Ethnic-E, Banditry-B
- Occurrence of conflicts

(f) Livestock Markets

- Category of market: Primary-P, Secondary-S, Tertiary -T
- Network arcs

(g) Administrative centres

- Chief's offices
- Other government offices
- Active groups
- Religious centres

(h) Water Sources (Categorise according to seasonality and ownership)

- Boreholes
- Dug well
- Pond
- Reservoir/dam
- Pan
- Others

(g) Seed database

- Inventory farming systems with seed type used
- Inventory seed supply companies
- Inventory local seed markets

(h) Inventory spatial dimensions of traditional (indigenous knowledge) in crisis mitigation.

- Develop methodologies for identifying potential areas for Crisis Mitigation at local or regional scale
- Analyse the environmental and socio-economic consequences of intervention strategies developed.
- Develop Decision Support (DSS) tools for improved Crisis Mitigation planning and management and equitable sharing of water / forage between adjacent communities.

Specific research questions are as follows:

What is the potential for improving pastoralists' livelihoods through effective Crisis Mitigation?

Can crisis mitigation and environmental conservation go hand in hand through systems technologies?

What are the biophysical and socio-economic conditions for adoption among pastoralists of developed technologies?

How can the institutional capacity be developed and sustained at the community level in order to assure local ownership and adaptability of system technologies?

What institutional mechanisms are required to support these technologies?

What are socio-economic impacts of successful up-scaling of system technologies to pure pastoralists /agro-pastoralists at a local/national/regional scale?

Problem Statement

The biggest challenge for sustainable rural development in pastoralists' areas generally includes:

Increasing natural resource scarcity resulting from increased water demands from the increasing population and high rainfall variability over space and time

Reduce the impacts of climatic shocks and cushion pastoralists against the effect on drought through improving resource utilisation and the introduction of appropriate crisis mitigation innovation.

Food insecurity and increasing poverty levels resulting from climatically induced shocks

Environmental degradation culminating from land use / land cover changes leading to poor human health

To be able to meet the above mentioned challenges, there is need to develop a policy framework to facilitate formulation of effective, site specific, Crisis Mitigation strategies for these regions.

Research Methodology

The methodology to be adopted will be centred on the following aspects;

Consolidation of bio-physical and socio-economic datasets generated into a comprehensive GIS database.

Evaluation of land use and land cover change (LUCC) trends using remote sensing techniques with quantifiable indicators of resource inventory.

Testing and validating of the developed methodologies to enable input from base clients and subsequent customisation and selection of the best methodology for policy advocacy and adoption. Special attention to the indigenous indicators calibrated to become effective early warning determinants will be thoroughly examined and promoted.

Development of a spatial decision support system (SDSS) to be used in Crisis Mitigation

Up scaling of system innovations at national and regional scale.

Spatial Delimitation of survey zones

The target districts will be sampled using the Almanac characterisation Tool (ACT 3.5) software. This will create a cluster of zones with similar climate associated with pastoral ecologies. This will then be stratified into pastoral eco-climates and overlaid with cattle densities and human population/ poverty indices to derive the most vulnerable pastoral communities for pilot surveys in the implementation of the Early warning system with possibility for up scaling to district/regional resolution.

Materials and methods for establishing a Spatial Database

A comprehensive GIS database will be established consisting of spatial and non spatial datasets having both biophysical characteristics (Land use / cover, soils, climate, topography / slope) and socio-economic characteristics (population density, water use / management practices, livelihood systems, farming systems, coping and survival strategies).

Time-series data from both high (SPOT 5) and low (TERRA MODIS) resolution remote sensing imagery for the last 40 years will be acquired and processed using ERDAS Imagine 8.7 to evaluate land use / land cover change. Other datasets that will be incorporated into the database include administration boundaries within the pastoralists regions, drainage networks, water points found in the target areas. Spatial analysis and querying of the database will be carried out in order to identify the most vulnerable communities to be targeted. ARC/INFO/ARC-GIS, both GIS softwares, will be used in establishing the database and also to carryout geo-statistical analysis to identify suitable communities for possible up scaling of the early warning system. Arcview will be used mainly for visualisation and display of the results of these analyses and built up scenarios. Arc Explorer will be used as the free ware for distributing the GIS database with basic query and analytical capacity to be applied within the district early warning offices.

Activities

The project will involve the following activities as stipulated in the activity calendar.

Strategic Planning meetings with site scientists to :

(i) establish the current state with respect to resource mapping in the districts. Undertake a comprehensive reconnaissance mission to acquaint and distribute essential equipment while also training district staff on technologies to be used.

(ii) Strategise on a harmonised data capture methodology

(iii) Harmonise recruitment of field assistants and logistics of training the same.

(iv) Compile a comprehensive data dictionary for use in GPS data capture.

Reconnaissance Surveys to all sites will be made for familiarization, preliminary training of resource surveys and distribution of hardware (GPS, palm tops, download cables and software):

- Image Geometric Correction and Geo-referencing of time series remote sensing imagery.
- Land use / land cover mapping and analysis from Remote sensed data.
- Field surveys and measurements for obtaining image ground truth, establishment of Ground Control Points (GCPs) to compliment remote sensed data
- Development of an interactive GIS Database
- Preliminary spatial data analysis for Crisis Mitigation Strategies
- Designing of a Spatial Crisis Decision support System tool for Crisis Mitigation
- Discussions with all stakeholders at various levels on design of CDSS
- Implementation of CDSS for the Crisis Mitigation Strategy as agreed with stakeholders
- Discussions with all stakeholders at different levels on building up different scenarios
- Building up of a user-friendly graphical user interface within Arcview environment to facilitate the visualization/Dissemination of the CDSS.

Protocol

Guidelines for administration of the questionnaire were as follows.

- A preliminary tour of each survey zone identifying coherent pastoralist community units and suitable community based enumerators.
- Training of enumerators on the questionnaire administration protocol.
- Administration of questionnaire for each identified pastoralist community.
- Data required for preparation of digital maps collected using GPS units. This data includes way points for livestock markets, watering points,

and general location or if possible circumscription of forage reserves, livestock disease hot spots, insecurity / conflict zones and tracks for pastoralist migration and market routes. However, due to insecurity, inaccessibility and other logistical problems, geo-referenced data may not be taken for some map aspects at various locations.

Data Analysis

Indicators of drought to be incorporated into the early warning system will be grouped into four broad categories and summarised by rank order, and frequency of occurrence for each pastoralist zone. Mean, standard deviation, range and coefficient of variation calculated for reported warning times attributed to each category of drought indicators. Strategies used by pastoralist communities from different zones to prepare for and to cope with drought categorised into suitable groups for which frequencies will be determined. A similar treatment is envisaged for strategies invoked in anticipation of and control of epidemics of livestock diseases. The number of communities in which some households sell some of their livestock of different ages to cope with family food demands during drought and the approximate frequency of sales summarised for each zone. The number of communities that migrate in order to cope with drought and the range and average distance trekked to get to the drought refuge worked out for each zone. The distribution of communal grazing reserves, private ranches and game and forest reserves provided for each zone as well as the number of communities that utilise communal and household grazing reserves and protected areas for emergency grazing. The distribution of major water points by category, number, ownership, and seasonal reliability will be determined through GPS mapping for each zone. The number of livestock markets for each zone listed by category and frequency of operation with assessment of available facilities. Available marketing data will be summarised for livestock supply and sales and price differentials between normal times and drought periods. Major livestock diseases and parasites for cattle, small ruminants and camels, will be listed by importance ranking and season of prevalence for each zone.

Short Courses on GIS.

Short courses on GIS skills applications will be conducted by the ILRI Geographic Information System training unit. These courses will impart the requisite skills to stakeholders, district staff and Monitors with specific emphasis on imparting skills that will add value to the sustainability of the Early Warning System.

G.I.S.

Introduction to GIS

Data input and output

Data quality

Data management (Geo- database establishment)

GIS analysis and applications in Early Warning system.

Remote sensing

Introduction to remote sensing

Energy sources and Radiation principles

Remote sensing imagery (Spot, Landsat, NOAA, GOES etc)

Application of Remote sensing in Early Warning System

Global Positioning System (GPS)

Phases of Global Positioning System

GPS Configuration

Geospatial data capture using GPS

Analysis of captured data (track analysis and geo-event edits)

Downloading and uploading from and to the GPS, for resource mapping.

Exporting captured data to GIS environment for Early Warning analysis.

Equipment.

The current budget allocated 1 GPS per district; this may not be feasible given the spatial distance between pastoral populations. It is suggested that the district offices be equipped with a GPS for back up services while the target communities should have at least two units each.

Due to the large amount of polyline data to be generated, etrex vista brand of GPS is recommended together with relevant accessories *viz*. download cables and palm tops for field operations. Each community to be surveyed should have their own Geo-database for the data capture phase. This will be centralised at the district crisis management offices with the same data submitted to the ministry headquarters for analysis and for centralised repository.

Satellite Imagery.

It is envisaged that SPOT 5 image for the target districts will be used to generate NDVI and give potential for up scaling from the survey area to the wider district resolution.

The cost per scene is approximately 300,000/= (12km by 12km for the 2.5 meter Xs scene, see Appendix A for Spot 5 sample image).

It will be necessary to purchase Remote sensing analysis software (Erdas Imagine approximately 10000 US dollars or IDRISI at 2000 US dollars).

GIS software

Due to budgetary constraints, the preferred GIS software's with advanced analytical capabilities (ARC info and Arc GIS) will be too expensive. (Average cost is US dollars 10,000).

Mobility

Data capture will require constant field monitoring and data collation for the central repository. A reliable vehicle to deal with difficult terrain will be necessary to enable the GIS specialist to execute mapping programmes.

World Space Radios

The World Space System is designed to provide an efficient and economic method of delivery of audio and multimedia content via satellite. For field monitors, the Radio will offer a suitable channel for data casting/broadcasting early warning messages to the target communities.

On-going activities

Characterisation of pastoral communities into stratified eco-climatic zones based on vulnerability to climatic shocks. Poverty indices and cattle density will be overlaid to identify pilot sites to be used in the actual survey during the project implementation stage.

Assumptions

The activity schedule will be designed once procurement of the accessories is complete.

Background information of stakeholders, district staff and monitors is necessary to customise the training for optimal early warning application results.

The above concept note will be adjusted to suit prevailing conditions.

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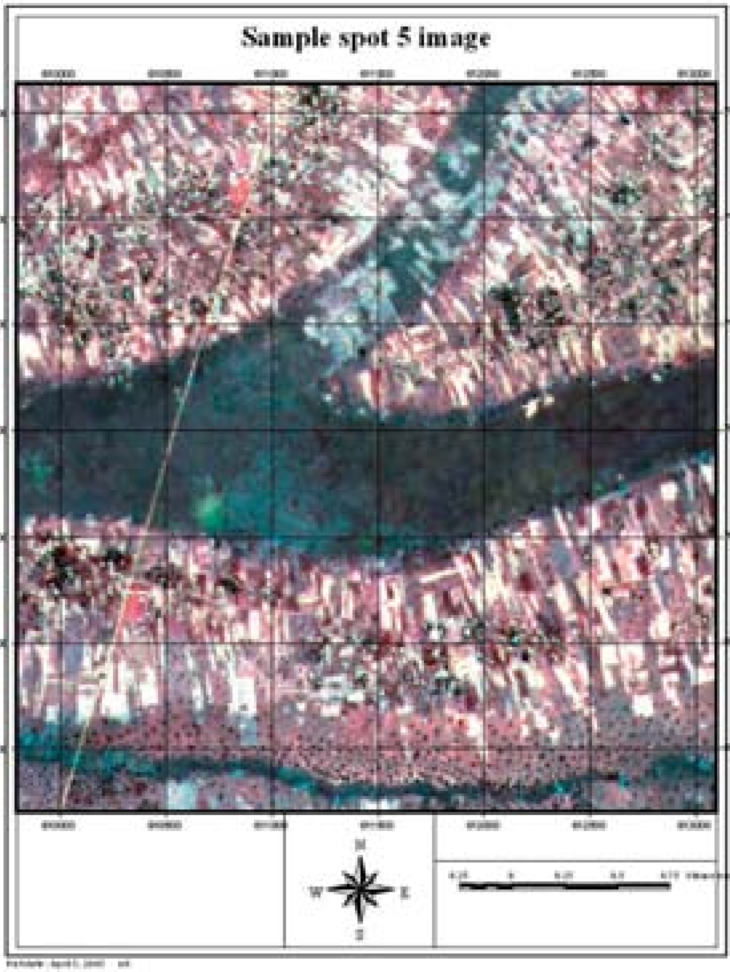
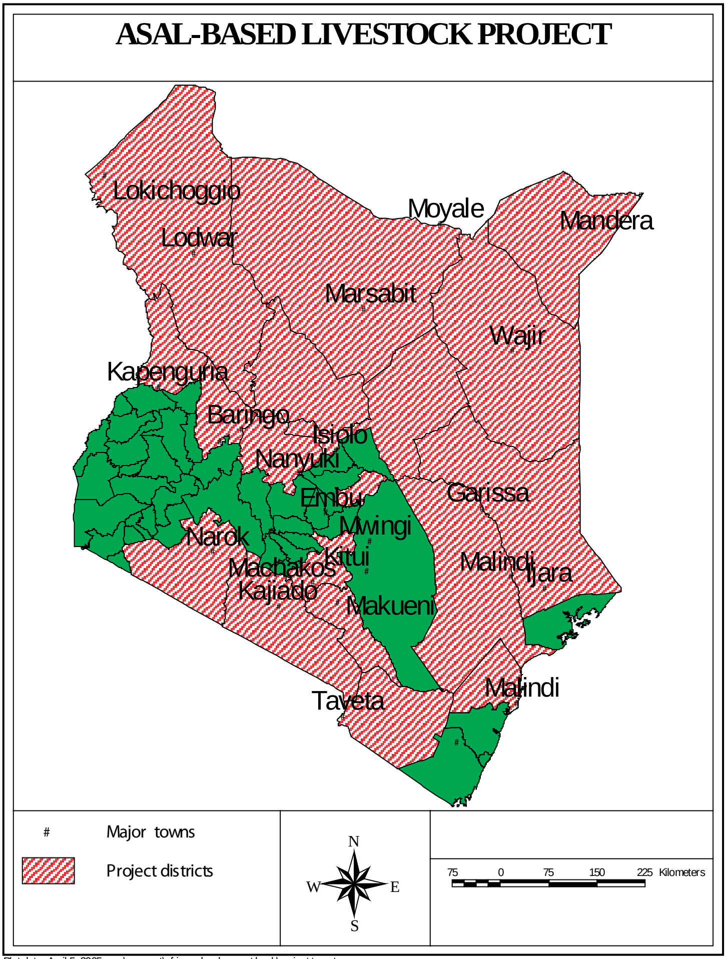
APPENDIX A: SAMPLE SPOT 5 IMAGE



APPENDIX B: PROJECT DISTRICTS



Plot date: April 5, 2005 c:\a-aamet\african development bank\project target areas.apr

GENERATION OF A LAND RESOURCES DATA SET FOR LAND SUITABILITY ASSESSMENT IN A SELECTED AREA IN SOMALIA

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INTRODUCTION

Knowledge of the land and water resources is a key component for planning the development of any region. This knowledge is used in land suitability assessments, which determine the potentiality of the land (land resources supply) for different land use types (land user demand). Land evaluation is the process of predicting land performance over time according to specific types of use (Dent and Young, 1981; FAO, 1983; FAO, 1985; Rossiter, 1996). It is a very important step in land use planning which according to (FAO, 1993) is the systematic assessment of land and water potential and alternatives for land use and economic and social conditions in order to select and adopt the best land use options.

Given the difficult socio-political situation in Somalia, spatial data of land resources for evaluating land suitability in the country is very scarce. The area selected for the present study is one of the most important in terms of agricultural production in the northern part of the country. Land degradation is one of the main problems regarding land resources and yet its extent and severity have not been determined. However, according to different reports (Oduori et al., 2007), the inadequate management of the land contributes to a dramatic negative trend in terms of human induced land degradation. Therefore, there is a need to make an inventory of available land resources and use it to assess the land resources in terms of its suitability for relevant land use types. This study addressed these needs.

STUDY AREA

As described by (Oduori *et al.,* 2007; Monaci *et al.*, 2007; Paron and Vargas, 2007; Vargas and Alim, 2007) the study area is located between 10° 69' - 9°17' N and 43° 01' – 44° 46' E (see Figure 1), covering a total area of 12 939 km2. It is bounded in the north by the Red Sea and Lughaya District, on the east by Hargeisa District and the eastern parts of Hargeisa District, on the south by the Ethiopian border, and on the west by the western part of Borama District.

The climate of the study area is hot dry desert in the coastal plain (Lughaya and northern part of Baki districts) and arid in the surrounding mountainous area. Semi-arid conditions prevail at the higher altitudes of the Al Mountains and south of Gebilley and Borama. Mean annual rainfall ranges between 200 – 300 mm in the coastal area of Lughaye, to 500 – 600 mm in the east of Borama and surroundings, while the rest of the study area has a mean annual rainfall of 300 – 500 mm.

From a geo-morphological point of view [8], the study area may be divided into three landscapes: (1) Piedmonts and the Coastal Plain, (2) Mountainous and Hilland, and (3) Plateau (both dissected and normal). The middle mountain range and the southern plateau are locally known as *Oogo*. There are three main ephemeral river systems that drain from the plateau and traverse the mountain range in the direction of the Red Sea, and from the southern side of the same mountain to the southern highlands respectively. They are locally called *Togga Durdur*, *Togga Biji* and *Togga Waheen*.

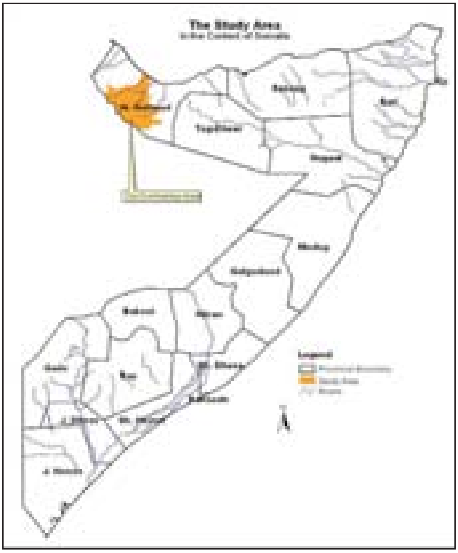

Figure 1: study area

The High Plateau has predominantly deep and heavy textured Vertisols combined with Calcisols. The Mountainous and Hilland area is characterized by rocky and stony Leptosols and shallow Regosols. The Piedmont areas have Leptosols, Regosols and Cambisols. The Coastal Plain is covered by Arenosols and Fluvisols. Fluvisols are also found in all the riverine areas and alluvial plains (Vargas and Alim, 2007).

The land cover of the study area consists mostly of natural vegetation (Monaci *et al.*, 2007). Land cover classes include Open Shrubs, Open Trees and Open to Closed Herbaceous. Closed Trees are not common. Other cover types include Urban and Associated Areas (Settlement/Towns and Airport), Bare Areas (Bare Soils and Sandy areas) and Natural Water bodies.

The main land use in the study area is extensive grazing (pastoralism) [6]. Other minor land uses include rain-fed agriculture, irrigated orchards along alluvial plains, and wood collection.

METHODS

GIS and Remote Sensing techniques and products were used for the baseline data collection. The FAO framework for land evaluation (FAO, 1976) and the ALES software (Rossiter and van Wambeke, 1997) were used for assessing the suitability of the land. The FAO concept is most commonly applied, and although a qualitative approach, it can be complemented and enhanced by more quantitative methods (Triantafilis *et al.*, 2001). Figure 2 shows the methodological framework this study has followed:

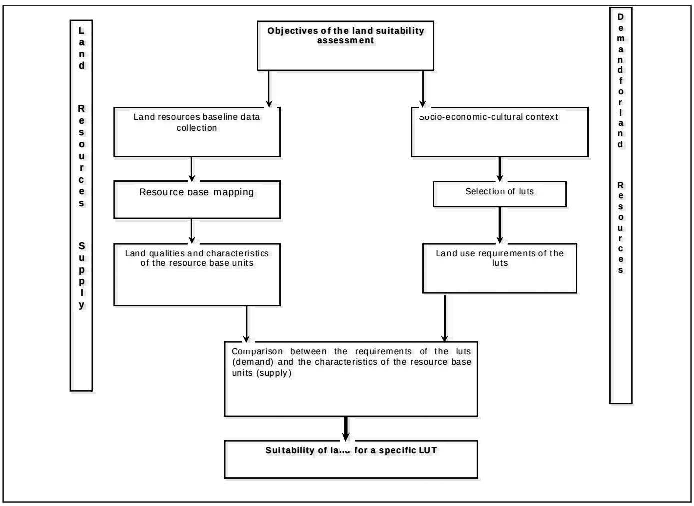

Figure 2: methodological framework

Land resources baseline data collection

Multi-spatial and multi-temporal satellite images were the base for mapping the land resources (landform, land cover/vegetation, soils and land use) in the study area. A combination of visual image interpretation techniques, remote sensing, and GIS tools and field survey were used for producing the different baseline data layers at 1:100 000 scale (Oduori *et al.*, 2007; Monaci *et al.*, 2007; Paron and Vargas, 2007; Vargas and Alim, 2007).

Resource Base Mapping

The methodology of George (George and Petri, 2006) was followed to produce the Resource Base Units (RBU) which is a similar concept to "ecological zone" and is defined as a land area, generally smaller than a region but considerably larger than a farm, with a definable combination of climate, relief, altitude, edaphic conditions and natural vegetation (FAO, 1999). Later, those units are used for determining the potential range of land use options. The resource base units were generated by combining different baseline data layers. The Length of Growing Period (LGP), landform, soils, and land cover/vegetation were overlaid and integrated to try to identify areas with homogeneous characteristics in terms of their land resources.

Selection of LUT

A Land Utilization Type (LUT) is a particular usage of the land, defined by inputs (e.g. labour, capital, technical know-how) and outputs (e.g. crop products) (Venema and Daink, 1992). The level of detail to which a LUT is defined depends on the scale of the evaluation; in our case the scale of evaluation was 1:100 000, therefore the LUT were selected at a broader level (e.g. rain-fed agriculture). The selection criteria were based on the current land use map, from which essential information can be derived, such as prevailing cropping/grazing systems, farm management, soil management and water management. As this study is dealing with physical land suitability, the selecting of LUTs is largely determined by the semi-arid and arid conditions of the study area and the land degradation status. Although each LUT was defined in general terms, specific sub LUT's were also assessed. For example, within the general LUT "Rain-fed agriculture", different crops and varieties were selected, some of tested varieties available from agricultural research stations located in arid and semi-arid regions.

Determination of the Land use requirements

Based on the LUT, a series of requirements or limitations were formulated that have to be fulfilled for the LUT to be used in the area under consideration. To make a comparison between RBUs and LUTs possible, the properties of a RBU have to be described in the same terms as the requirements of the LUTs. The land use requirements for the specific LUT were extracted from available standard values.

Identification of Land qualities and characteristics

Land qualities are physical properties of the Resource Base Units (RBU) that can be directly compared with the Land use requirements (LUR) (Venema, 1998). A land quality is defined by one or more land characteristics, which are attributes of the land and which can be quantified. Land properties and attributes were extracted from the different data layers that define the RBUs. The land qualities and characteristics were then used for its comparison with the land use requirements. A neutral term for both land quality and land use requirement is "factor". For example, factor "n" covers both "nutrient availability" (a land quality) and "nutrient requirements" (a LUR).

Matching demand vs. supply

Land suitability was determined by comparing the physical properties of a Resource Base Unit with the physical requirements of a specific Land Use Type. Decision trees (rules) were built into ALES to allow a process of factor rating which is crucial in the whole assessment process. The characteristics of a RBU unit (what land supplies) were compared with the demand (requirements) of a specific land use type, demanded by or suggested to the land user. Each relevant land quality was then matched with its corresponding land use requirement and a rating given for their relative compatibility. This process is called factor rating. Factors were rated from 1 to 5 in most of the cases. In one extreme a rating of 1 implies a land quality of a RBU is well matched with the corresponding LUR and poses no limitation to the establishment of the LUT. In the other extreme, a land quality may not match at all with its corresponding LUR, and the factor rating of 5 is giving. An example of a decision tree is shown in Table 1.

Table 1: Decision tree for nutrient availability
Land quality: Nutrient availability (n)
LUT: Rs1 (Rainfed sorghum, short GP, 90-100 days, medium input)

Land characteristics						Severity level (1-3)	
pH(H2O)		CEC (25-75cm)		Ca/Mg			
	score		score		score	score add	level
NE	1	L <16	3	VL, VH	3	7	3
6.6-7.5	1		3	L, H	2	6	2
	1		3	M	1	5	1
	1	M 16-24	2	VL, VH	3	6	2
	1		2	L, H	2	5	1
	1		2	M	1	4	1
	1	H >24	1	VL, VH	3	5	1
	1		1	L, H	2	4	1
	1		1	M	1	3	1
AL	2	L	3	VL, VH	3	8	3
7.5-8.5	2		3	L, H	2	7	3
	2		3	M	1	6	2
	2	M	2	VL, VH	3	7	3
	2		2	L, H	2	6	2
	2		2	M	1	5	1
	2	H	1	VL, VH	3	6	2
	2		1	L, H	2	5	1
	2		1	M	1	4	1
VA	3	L	3	VL, VH	3	9	3
>8.5	3		3	L, H	2	8	3
	3		3	M	1	7	3
	3	M	2	VL, VH	3	8	3
	3		2	L, H	2	7	3
	3		2	M	1	6	2
	3	H	1	VL, VH	3	7	3
	3		1	L, H	2	6	2
	3		1	M	1	5	1
Assumptions: - nutrient availability decreases with increasing pH (from neutral to very alkaline) - nutrient availability increases with increasing cation exchange capacity (CEC) - nutrient availability decreases in case of (very) low and (very) high Ca/Mg ratios						3-5 6 7-9	1 2 3

Once the assessment was finalized and the different land suitability classes generated, the results were directly converted into maps. ArcMap 9.2 ESRI (ESRI, 2005) was used for that purpose where the different RBU were assigned their suitability classes for each individual Land Use Type.

Validation of results

Local knowledge was used as a tool for validating the results generated by the physical land suitability assessment. Local experts who have a wealth of knowledge of the physical conditions of the study area to perform specific activities were asked to review the different results in terms of suitability classes for each LUT. If the expert found that some areas were under- or over-estimated in terms of potentiality, the decision trees were modified accordingly.

RESULTS AND DISCUSSIONS

The variability of the land resources in the study area is shown on the Resource Base Units map (Figure 3), which delineates areas which are homogeneous in terms of a number of physical characteristics.

The RBU stratification follows the concept of defining map units within which the resources bases are similar as expressed by George (George and Petri, 2006). In our case we could find a high correlation between the layers length of growing period, relief, soils and vegetation; this is in line with the findings of George.

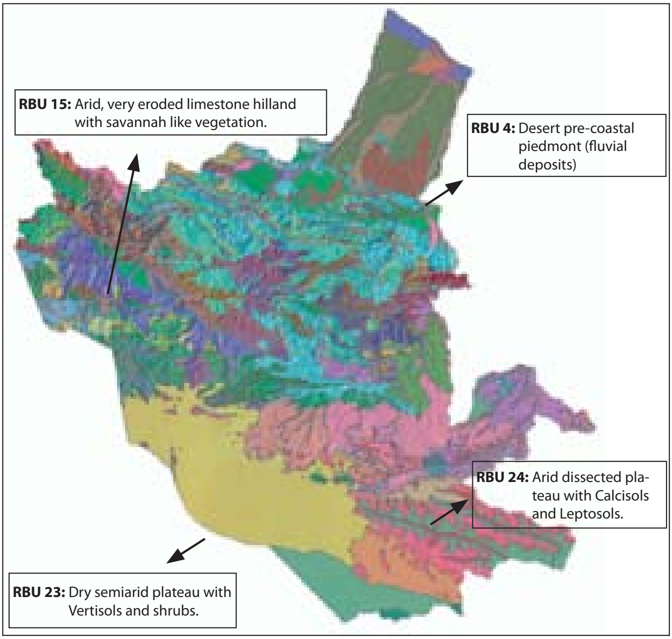

Figure 3: *Resource Base Units Map*

The Somali automated Land Evaluation System (SOMALES, Figure 4) was established to perform land suitability assessments. As Venema (1998) and Rossiter (1996) mentioned, an automated land suitability assessment should be quantitative and include both a physical and socio-economic assessment. In the present study, this has only partly been achieved as only physical parameters have been assessed and some of the data used were of qualitative nature only. However, the system can be modified as soon as more quantitative data in terms of inputs and socio-economic nature becomes available.

Figure 4: *SOMALES*

Three general LUTs and 17 specific Land Use Types were physically assessed. Table 2 shows an inside of the type of land use activities that were assessed in terms of its potentiality in the study area.

Table 2: *Relevant Land Use Types*

General Land Use Types	Specific Land Use Types (Characteristics, purpose, etc)
Rainfed Agriculture	RS1: Rainfed sorghum, short GP (90-100 days), medium input
	RS2: Rainfed "traditional sorghum", total GP (180 days), low input
	Rc: Rainfed cowpea, short GP (80 days), low-medium input
	Rml: Rainfed maize, short GP (80-90 days), medium input
Pastoralism	Pd: Extensive grazing of camels
	Pc: Extensive grazing of cattle
	Pg: Extensive grazing of goats
	Ps: Extensive grazing of sheep
Forestry	Fai: Azadirachta indica (timber, fuel, pesticides, medicines)
	Fan: Acacia nilotica (fodder, timber, fuel, soil conservation)
	Fat: Acacia tortilis (fodder, fuel, soil conservation)
	Fba: Balanites aegyptiaca (fodder, fuel)
	Fce: Casuarina equisetifolia (timber, fuel, soil conservation)
	Fcl: Conocarpus lancifolius (fodder, timber, fuel, soil cons.)
	Fdg: Dobera glabra (fodder, fuel)
	Ffa: Faidherbia albida (fodder)
	Fti: Tamarindus indica (fodder, timber, fuel)

The suitability analysis shows that the Southwest and small portion of the western part of the study area (RBU units 18, 20 and 24) are moderately suitable for rain-fed agriculture (two sorghum varieties, cowpea and maize) under the current conditions. The main physical limitations that restrict these RBU units to be classified as suitable are the erosion hazard, flash-flood hazard, moisture availability and nutrient availability. Currently, these units are famously called as the "sorghum belt" of the Northwest region.

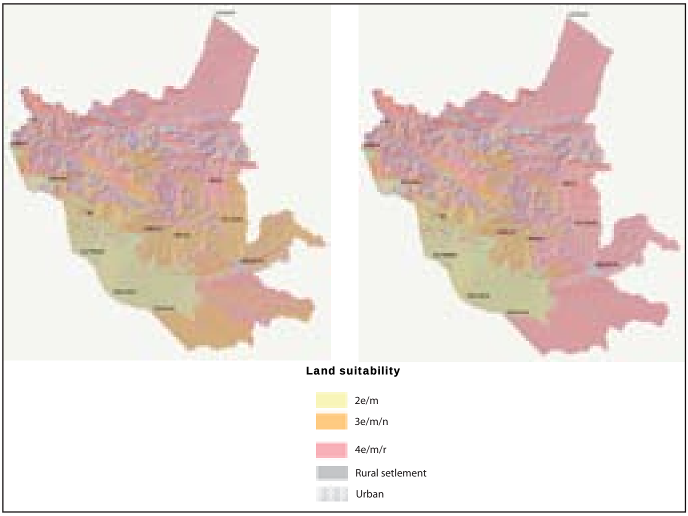

Figure 5: *Suitability for rain-fed agriculture (a) Short sorghum and b) Maize*

The area that is moderately suitable (S2) for rain-fed agriculture covers 14.3% of the total study area in both maps (Figures 5a and 5b) and is mainly located between Hargeisa, Gebiley and Borama. The areas ranked as marginally suitable for rain-fed agriculture (S3) occupy 31.1% (Figure 5a), while 12.9% for maize (figure 5b). Finally 54.1% and 72.3% is unsuitable (N) for rain-fed agriculture mainly because of unfavourable climatic, topographic and soil conditions.

The suitability assessment for Extensive Grazing shows that the potentiality for this activity is quite high. The variability of the land resources makes the suitability of the study area also variable depending on the requirements of the different land use types assessed.

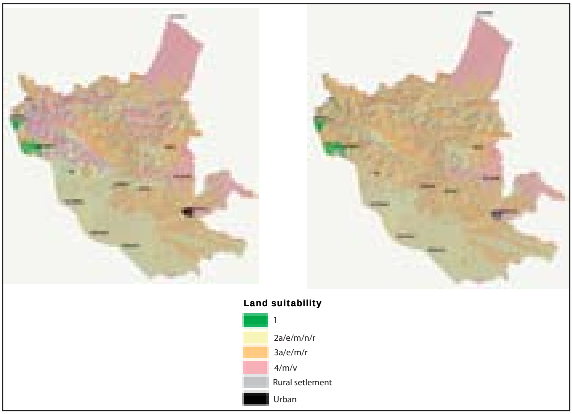

Figure 6: *Suitability for Extensive grazing (a) Camels and b) Goats*

As per Figure 6a, 1% of the study area is highly suitable (S1) for grazing camels, whereas 31.7% is moderately suitable (S2) due to limited accessibility for the animals, erosion hazard, low moisture availability, low nutrient availability and unfavourable rooting conditions for plants. 40.5% of the study area is marginally suitable (S3) for grazing camels mainly due to poor accessibility for the animals in some areas, erosion hazard of the RBU, and unfavourable rooting conditions. 26.3% of the land is unsuitable (N) for extensive grazing of camels.

According to Figure 6b, 1% of the land is highly suitable (S1) for extensive grazing of goats. 26.9% is moderately suitable (S2), mainly due to erosion hazard, low moisture availability, low nutrient availability and unfavourable rooting conditions for plants. In this area, 58.2% is marginally suitable (S3) for extensive grazing of goats; this is due to limiting factors such as erosion hazard, lack of moisture, low soil nutrient availability and rooting restrictions for plants. Finally, 13.4% of the study area is unsuitable (N) for this kind of land use type.

The suitability results for sheep and cattle are quite similar to the ones for camels.

Because of its arid and semi-arid conditions, the area is not very suitable for foresty (Figure 7). Figure 7a shows that 1.1% of the study area is moderately suitable (S2) for *Azadirachta indica* (trees that can be used for timber, fuel, pesticide and medicine). The limitations affecting this land use are inundation hazard, low moisture availability and less than optimal root conditions. Of the study area, 23.3 % is marginally suitable (S3) for growing this species, mainly due to low available soil moisture. Finally, 75.1% of the study area is unsuitable (N) for this tree.

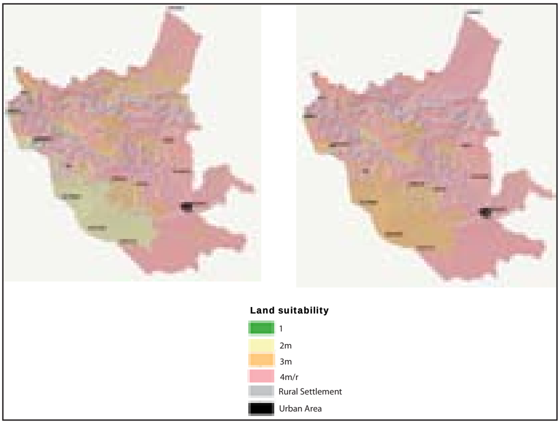

Figure 7: *Suitability for Forestry (a) Azadirachta indica and b) Acacia tortilis*

The suitability assessment (Figure 7b) for the forestry species (used for timber production, fuel and soil conservation) shows that 0.2% of the study area is highly suitable (S1) for *Acacia tortilis.* This tree can be used for timber, fuel and soil conservation. Of the land, 15.2% is moderately suitable (S2) for this species, mainly due to moderate moisture availability. Also, 17.9% is marginally suitable (S3) due to limited moisture availability, and 66.2% of the study area is unsuitable (N) for this tree.

CONCLUSIONS AND RECOMMENDATIONS

Land resources baseline data at a 1:100 000 scale were generated including information on landform, land cover, vegetation, soils, climate and present land use. These baseline data were stored in data layers and integrated in a geographic information system.

The land resources data were used for a semi-quantitative physical land suitability assessment following the FAO framework for land evaluation. Seventeen different land use types were assessed accordingly.

Because of the generalized nature of the baseline data, irrigated orchards, as a land use type, was not assessed. Such land use is only possible in very small pieces of land located along the alluvial plains of the seasonal rivers. Detailed surveys of these areas would be needed to exactly locate suitable sites. Most of the land suitable for irrigated orchards is already in use for that purpose.

Further research is recommended for finding local alternative land use types that could be assessed in the model.

SOMALES could be improved once more quantitative socio-economic data would be available. Also, a new LUT can be included into the whole assessment.

The findings of the present study may be used as the initial stage of a future land use planning exercise aiming at a sustainable natural resources management strategy.

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COMBINATION OF FIELD DATA AND SATELLITE OBSERVATION FOR NEAR REAL TIME MONITORING OF RANGELAND VEGETATION

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ABSTRACT

The monitoring of rangeland conditions is an important factor when considering food security in many African countries. This often involves estimating biomass production. We present methodology for using medium to low resolution satellite imagery to make estimates of biomass in near-to-realtime. To this end, techniques for rapid measurement of the biomass of herbaceous and woody vegetation were developed using a large number of simple plant measurements. A field sampling methodology is presented to make biomass estimates which were compatible with the scale of the satellite imagery spatial resolution and sufficiently close to the time of satellite overpasses to enable correlation with the NDVI from single images. Results show high correlations of biomass with NDVI for individual vegetation cover classes, which appear to be temporally stable. There seem to be different regression equations for the different savanna vegetation types although more field observations are needed to confirm this. The results were exploited to illustrate the potential application of this work for fire management. The combination of rapid field methods and real time image acquisition developed in this work provides a sound basis for biomass monitoring at regional level.

INTRODUCTION

A significant proportion of the African population is dependent on livestock as a source of revenue and food. Most of the African livestock is relying exclusively on rangeland for fodder. Therefore, the monitoring of rangeland is an essential factor in food security assessment. In addition, because of the high spatial and temporal variability of vegetation growth in most parts of Africa, it is essential to monitor rangeland vegetation at regular intervals during the growing season providing real time estimates of vegetation conditions.

One of the key biophysical parameter in the assessment of rangeland vegetation conditions is the determination of biomass production or net primary production. Biomass observations can be collected in the field, but field methods are only suitable to cover a small area and are too costly and time consuming for real time monitoring over large areas. On the other hand, satellite imagery can cover large area on a daily basis using low spatial resolution satellite imagery, but satellite imagery on its own can only provide qualitative estimates of biomass. The provision of quantitative estimates from satellite imagery can only be achieved if the image is calibrated with appropriate field observations. In this work, we present a methodology relying on the combination of medium to low spatial resolution satellite imagery and detailed representative field observations of biomass for deriving near real time maps of biomass estimates.

The methodology was developed in the Etosha National Park in the northern part of Namibia. Etosha covers an area of approximately 23,000km^2. The climate is semi-arid with a rainfall gradient varying from about 450 mm in the East to 300 mm in the West (Le Roux *et al.* 1988). The main feature of the Park is the Etosha pan, a saline desert covering an area of approximately 5,000 km2. Very little or no vegetation grows on the pan which is sometimes recovered by a thin water layer during the rainy season.

The work was carried out in four separate stages: rapid measurements of plant biomass, selection of biomass sites, site sampling strategy and processing of satellite observations. These stages are summarized below, but a more detailed discussion of the methodology is presented by Sannier *et al.* (2002).

RAPID MEASUREMENT OF PLANT BIOMASS

Rapidity is required for costs reasons (more observations can be collected with the same resources. The second reason is that vegetation growth is limited by rainfall and it develops very rapidly following rainfall events, but it is also consumed rapidly by livestock. As our intention was to make the biomass observations coincide with satellite imagery, it was essential to derive field biomass estimates as close to the image acquisition date as possible. To estimate the total green biomass per unit area, it was necessary to calculate contributions from herbaceous and woody components at the scale of the pixels. This was done by a statistical estimator using sample observations.

Herbaceous Biomass

The use of a rising plate or disc pasture meter (DPM) for estimating grass biomass in Australian pastures was first described by Mitchell (1982). It has the advantage of being objective, rapid and easy to operate and was adopted for herbaceous biomass assessment in this work. However, judgement is required when making measurements in stony ground to avoid false readings.

Previous work in Etosha by Kannenberg (1995) produced a calibration curve in using the same calibration procedure as Trollope and Potgieter (1986). The curve includes points from a wide range of locations and the single curve seems to be generally applicable for all Etosha grasses. The linear model for the regression produced a high coefficient of determination (r2) but the scatter of points for biomass below 2000 kg/ha seems to deviate systematically below the regression line with a risk of overestimating biomass below this threshold. An alternative logarithmic model shown in Figure 1, proposed by us for this work, is an improvement and has a higher r2.

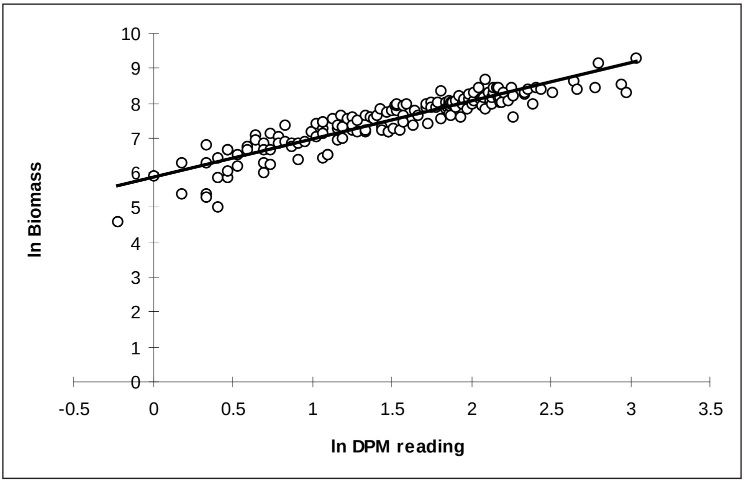


Figure 1. *Estimation of grass biomass with the Disc Pasture Meter*

Woody plant biomass

Green biomass estimation of woody plants is usually by a regression relationship between dry matter weight obtained from direct harvest and some plant parameter, usually specific dimensions (Pieper 1988). The dominant woody species in Etosha, accounting for about 85% of the shrubs and trees in the savanna, is Mopane (*Colophospermum mopane*) which occurs in both forms. Data relating the branch diameter of Mopane to leaf biomass was available from previous work at the Etosha Ecological Institute (EEI, Du Plessis 1995). This was used to create a rapid field technique to estimate the biomass of Mopane trees and shrubs. Table 1 shows the average leaf biomass of Mopane for stems and branches in different size categories. The leaf biomass of a randomly selected sample of 80 Mopane trees and shrubs was estimated in the field by counting the number of primary stems in each of the size categories and using the average leaf weights from the table. The height of the plant and its crown diameter in two perpendicular directions was also recorded. The estimated dry leaf weight was best correlated to the volume of the plant calculated as a cylinder with diameter equal to the average crown size and height equal to the estimated tree height as shown in Figure 2.

Table 1. *Average leaf weight of Mopane stems in full leaf, in different size ranges.*

Stem diameter class (cm)	Average leaf dry weight (g)	SEStandard Error (g)
0 to 0.5	1.6	0.1
0.5 to 1	6.9	0.4
1 to 2	28.3	1.8
2 to 3	84.8	8.2
3 to 4	171.2	11.3
4 to 5	239.7	26.4
5 to 6	387.2	81.3
6 to 7		
7 to 8	785.2	83.6
8 to 10	1240.7	209.6
10 to 12	1595.0	223.9
12 to 14	1714.8	190.3
14 to 16	2683.0	216.6
21 to 28	2883.2	774.0

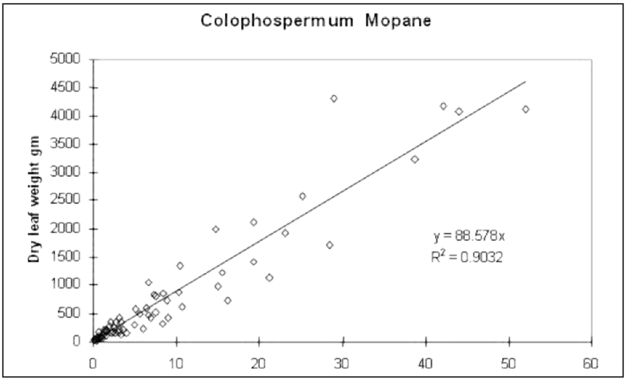


Figure 2. *Calibration of shrub and tree green biomass with crown volume*

The dominant shrub in Etosha steppe areas is Leucosphaera (*Leucosphera bainesii*), accounting for around 80% of steppe shrubs. Unlike Mopane, no previous work on the assessment of plant biomass had been done on Leucosphaera. Seventy-two plants were randomly selected in the field; height and perpendicular crown diameters measured then harvested. Then, the total dry plant weight was determined by standard oven drying. The total dry plant weight was considered more appropriate to use because the plants almost completely disappear during the dry season, therefore any plant material above the ground was considered new material. The best relationship between dry plant biomass and plant dimensions was found with crown area and is shown in Figure 3. Unlike Mopane, plant volume was not better related to biomass because Leucosphaera is a smaller plant which develops itself horizontally rather than vertically.

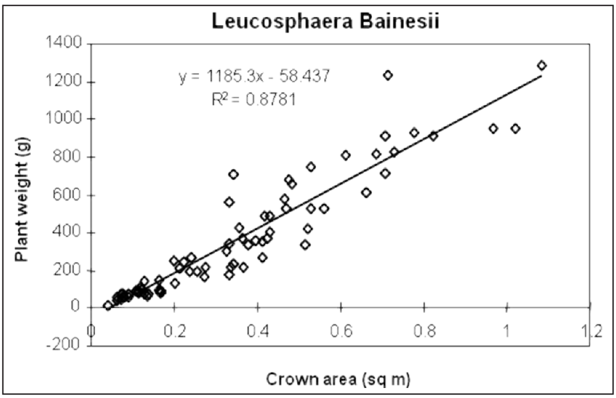


Figure 3. *Calibration of dwarf shrubs with plant crown area*

SELECTION OF BIOMASS SITES

The criteria for selecting calibration sites were that they: be of sufficient size and internally homogeneous, to reduce the effects of errors in co-location of the ground with satellite observations; be accessible and, reflect the range of biomass levels in the Park. Sites were chosen to reflect the variation of main grass, steppe and savanna types in the Park.

The formula derived by Justice and Townshend (1981) gives a guideline for the minimum size, *a*, of a sampling unit in relation to the geometric accuracy: $a = p(1+2l)$ where *p* is the pixel dimensions in distance units and *l* the geometric accuracy in number of pixels. For example, a 1.1km pixel size for NOAA-AVHRR and a geometric accuracy of 0.5 pixel should result in a sampling unit of 2.2km on each side. Generally, it is not feasible to have calibration sites large enough to meet this ideal and in past studies smaller sites have been used. We initially selected candidate homogeneous locations, several square km in size by photo-interpretation of geometrically corrected false colour composites from Landsat TM imagery. By selecting a 1 km^2 site in the middle of a larger homogeneous area, we expected to minimise the effects of geometric correction errors as variation of the biomass in the immediate surrounding area was unlikely to be great and also, surrounding pixels would not be mixed responses including other vegetation types. Field checking with geo-coded enlargements of the TM imagery verified the homogeneity of the selected sites. A total of 11 sites were selected as shown in Figure 4.

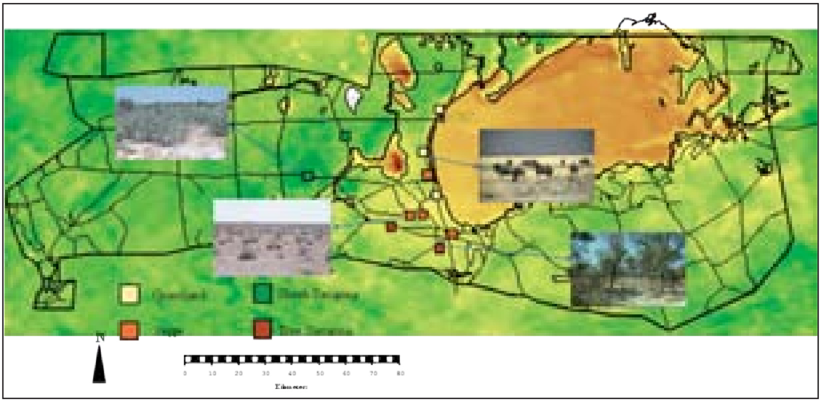


Figure 4. *Selection of survey sites*

SITE SAMPLING STRATEGY

The biomass sampling was carried out along a 1 km transect through the centre of the 1 km square sample site. Because of our previous selection procedure, it is assumed that the site is isotropic and homogeneous so that average biomass along the transect represents the average for the whole of the 1km square area. The sampling scheme for herbaceous vegetation is shown in figure5. DPM measurements were made at ten equally spaced locations along the transect. Navigation was assisted by a Landsat TM enhanced geo-coded image hardcopy and a handheld GPS. Five clustered DPM readings were taken on each side of the transect. This resulted in a total of 100 DPM measurements per site which is the value suggested by Trollope and Potgieter (1986).

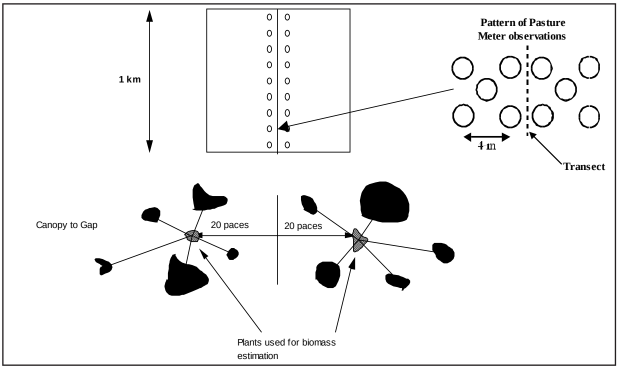


Figure 5. *Sampling strategy for biomass measurements*

The woody plant biomass per unit area is the product of the biomass per plant and the number of plants per unit area. The number of plants per unit area is estimated by dividing proportion of plant cover (canopy area/ unit ground area) by the canopy area per plant. The crown to gap method (Westfall and Panagos 1984, Walker et al. 1988) is a very fast and unbiased method for estimating the percentage canopy cover of woody vegetation (trees, shrubs, dwarf shrubs etc.) over relatively large areas from ground observations or surrogates such as photographs and was selected for this study. Two adjacent plants approximately the same distance from the observer were selected. The ratio , the distance between their crowns (*G*) to the diameter of the crown of one of them (*K*) in Equation 1

$$f = \frac{G}{K} \quad (1)$$

can be: estimated by eye or by a transparency gauge (Westfall and Panagos 1984) or measured on photographs. The average ratio $\bar{f}$, for at least 25 pairs of plants is used in Equation 2, described by Walker et al. (1988) to estimate the percentage covered by the crowns, *C*:

$$C = \frac{100p}{2\sqrt{3}} \left[\frac{1}{(f+1)^2} \right] \quad (2)$$

The sampling of woody vegetation was done on the same 10 locations along the transect as shown in figure 5. A plant was randomly selected on each side of the transect by walking 20 paces perpendicular to the transect using the vehicle as a reference. Then the closest plant was selected to take plant measurements. The reference plant was also used to perform the canopy to gap procedure as shown in figure 3 by choosing five other plants closest to it and evaluating visually the canopy to gap ratio between the reference plant and each of the five other plants measurement.

The whole procedure was repeated on the other side of the transect. In total, for each site, 100 DPM measurements, 100 canopy to gap ratio estimations and 20 plant dimensions were taken.

DETERMINATION OF SITE TOTAL GREEN BIOMASS

The estimation of herbaceous biomass per site is the most simple because DPM measurements are directly related to biomass per unit area. DPM readings were recorded in a spreadsheet. Each cluster of five DPM readings (figure 5) was averaged. This was to create observations comparable with the original calibration procedure. The calibration equation was applied to the averaged value resulting in 20 grass biomass value per site. The overall biomass of the site was calculated by taking the mean of the 20 biomass values. The same method was used in woody vegetation sites without taking into account of the woody cover because grass also often grew under the trees and shrubs and a reading of zero was recorded when the DPM fell on a shrub.

The estimation of woody biomass includes several parameters and the process of averaging was carefully considered because of non-linearity. Each location along and on each side of the transect was treated individually. This was to take into account of all the variations within the site and the non-linearity of the canopy to gap ratio method. A biomass value was calculated for each of the 20 sampled plants associated with 5 measurements of density (canopy to gap ratio). These five estimates of density were averaged to establish the density at each plant location. The density combined with the plant area gives the number of plants per unit area. The number of plants per unit area multiplied by the plant weight gives the biomass corresponding to the plant and density considered. 20 plants and five measurements of density per plant resulted in 100 observations of biomass per site. The estimate of biomass for the whole site was the arithmetic mean of these 100 biomass observations plus the grass biomass.

Weight biomass per plant, *P*, in kilogrammes is determined by the relationship between plant dimensions and biomass defined earlier. The density cover, *C*, is determined according to equation (2). The number of plants per hectare, *N*, is:

$$N = \frac{10000}{A} \cdot C \qquad (3)$$

Finally, the total woody biomass per hectare and plant, *Wi*, is equal to:

$$W = P \cdot N \qquad (4)$$

In the case of Leucosphaera, the calculation of biomass is simplified because the crown area is used in both the calculation of *P* and *N* which are cancelled out. Therefore, for Leucosphaera, woody biomass is only related to *C* and the slope of the calibration between plant biomass and area.

For Mopane, where the relationship with biomass is based on volume, woody biomass is a function of the slope of the calibration, height and *C*. It means that once the relationship between biomass and plant dimensions has been established, it is not required to measure plant area in order to derive estimates of woody biomass. The total woody biomass per site is equal to the average of the 20 estimates derived per plant. The combined grass and woody biomass is obtained by adding the two estimates.

In total 25 observations of biomass were made for the 11 sites selected over two seasons as shown in table 2.

PROCESSING OF SATELLITE IMAGERY

NOAA-AVHRR imagery was used for this work and acquired in real-time from the LARST receiving station installed at the EEI since 1993 (Williams and Rosenberg, 1993). This allowed us to produce NDVI images in near-to-real-time, to select only the best images and to make sure that the images would coincide with the fieldwork. A total of seven images were selected. Data processing consisted of radiometric and geometric correction of the imagery and NDVI calculation.

Radiometric corrections were based on the work published by Kaufman and Holben (1993) and Los (1993) for NOAA9 data and Rao and Chen (1996) for NOAA14, which took sensor degradations into account and was later updated monthly on the NOAA web site.

Geometric correction was based on the selection of control points from the geo-referenced Landsat TM mosaic covering the entire Park. This made it possible to achieve a geometric accuracy of about 0.5 pixel, which is much better than what could have been achieved using satellite orbital parameters.

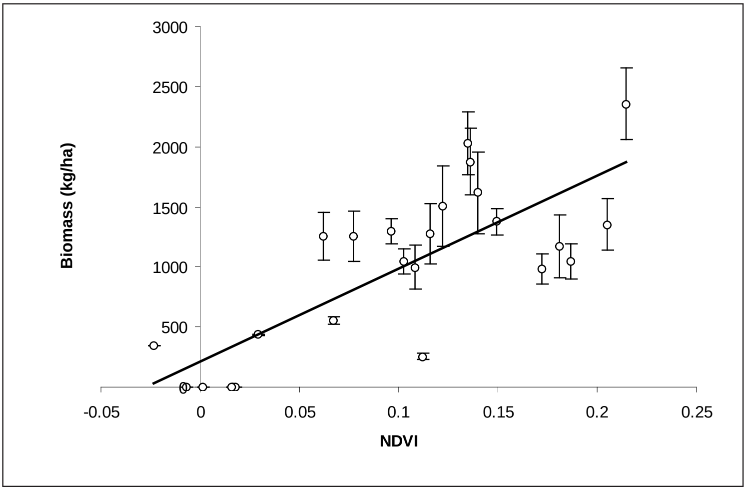
No atmospheric or bidirectional effects correction was performed because it was thought that careful selection of imagery, free of clouds and nearest as possible to nadir would be more efficient in keeping atmospheric effects to a minimum rather than applying an approximate atmospheric correction. Existing methods for removing atmospheric effects often assume constant effects over the entire scene and require ground meteorological data that is not realistic to obtain for near-to-real-time application.

DN values were extracted from the imagery for each waveband and for each site. The data were input into a spreadsheet where radiometric corrections and NDVI calculations were carried out. Corresponding biomass values were input in the spreadsheet as shown in table 2 and regression models were developed as shown in figure 6.

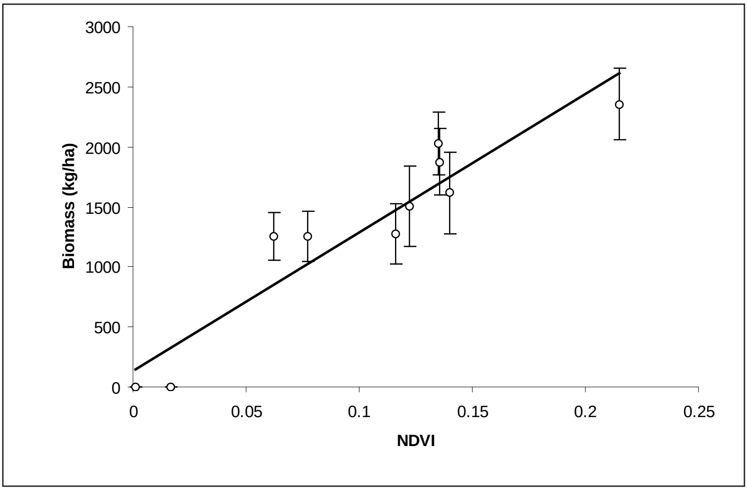
Table 2. *NOAA-AVHRR biomass calibration results*

Site	Vegetation Type	Survey date	Image acquisition	NDVI	Biomass (kg/ha)
S4	Grassland	15/02/95	16/01/95	-0.007	0
S6	Grassland	15/02/95	16/01/95	0.001	0
S7	Grassland	15/02/95	16/01/95	0.016	0
S7	Grassland	01/03/95	02/03/95	0.077	1254
S4	Grassland	01/03/95	02/03/95	0.029	437
S6	Grassland	01/03/95	02/03/95	0.062	1251
S4	Grassland	10/03/95	10/03/95	-0.023	350
S6	Grassland	21/03/95	21/03/95	0.122	1506
S7	Grassland	21/03/95	21/03/95	0.135	2031
S4	Grassland	30/03/95	27/03/95	0.067	553
S6	Grassland	31/03/95	27/03/95	0.140	1615
S7	Grassland	31/03/95	27/03/95	0.136	1874
S4	Grassland	25/03/96	19/03/96	0.112	254
S6	Grassland	21/03/96	19/03/96	0.116	1275
S7	Grassland	25/03/96	19/03/96	0.215	2357
M1	Savanna	20/03/96	18/03/96	0.187	1046
M2	Savanna	27/03/96	06/04/99	0.181	1175
M3	Savanna	28/03/96	06/04/96	0.150	1375
M4	Savanna	03/04/96	06/04/96	0.205	1352
S1	Steppe	15/02/95	16/01/95	0.018	0
S3	Steppe	15/02/95	16/01/95	0.016	0
S1	Steppe	26/03/96	19/03/96	0.172	985
S2	Steppe	19/03/96	19/03/96	0.103	1048
S3	Steppe	01/04/96	19/03/96	0.096	1300
S5	Steppe	02/04/96	19/03/96	0.108	997

The relationship including all observations (figure 6a) is weaker than the relationship including only grassland sites (figure 6b). This seems to suggest that different regression relationships would have to be developed for each vegetation types. However, insufficient data were available to test this hypothesis on the other cover type and more data would need to be collected. Nevertheless the pooled relationship (figure 6b) is still highly significant and was used to produce biomass maps.



(*a*)



(*b*)

Figure 6. *Relationship between NDVI and biomass for (a) all sites, $n=25$, $y=7735x+208$, $r2=0.61(p<0.01)$ and (b) all grassland sites, $n=10$ $r2=0.89$; error bars represent the standard deviation of the field biomass estimate.*

PRODUCTION AND APPLICATIONS OF BIOMASS MAPS

The pooled relationship developed in the previous section (figure 6a) can be used to transform NDVI images acquired at the NOAA HRPT receiving station into biomass maps. There are a number of ways in which these biomass maps can be used. From the point of view of food security, this could include the monitoring of animal movement in relation to fodder availability during a growing season or the monitoring of the animal carrying capacity from year to year and throughout a study area.

However, a more direct application of biomass maps is the correlation between fuel loads and fire risks. Fires occur naturally in the Park and are normally triggered by lightning (Heady 1975). Under favourable conditions, wildfires can spread over large areas and can cause major damage to wildlife and vegetation. However, controlled or prescribed burning is often used to prevent the occurrence of wildfires by reducing fuel loads. Furthermore, controlled fires may benefit livestock and wildlife through positive effects on vegetation regeneration and habitat diversity (Heady 1975, Holechek et al. 1995). Controlled fires have been used in Etosha National Park for the above reasons and the Park was divided in a number of fire blocks as shown in figure 4. Trollope and Potgieter (1986) have shown that in the Kruger National Park, biomass fuel loads needed to reach at least 1500kg/ha to propagate. Therefore, it is possible to use biomass maps reclassified according to a series of thresholds indicating the levels of fire risk. This is illustrated in figure 7, where biomass maps were produced at the end of the rainy season for 1995, 1996 & 1997 using the pooled NDVI / Biomass regression relationship shown in figure 5a. Looking especially at 1995 and 1996, it becomes apparent how such maps could be used to target, for controlled burning, fire blocks corresponding to the high to very high risk classes. 1997 was an exceptional year, with rainfall in excess of 40 to 60% of the median between 1981 and 1996, which explains the extremely high levels of biomass reached throughout the Park. As a result, all the conditions for an extensive fire were met and a wildfire started at the end of the dry season, which burnt nearly 21% of the Park's area outside the pans, crossing several fire breaks. The conditions of 1997 were very unusual, but it is possible that if some controlled burning had taken place in fire blocks where biomass was already relatively high in previous seasons, the wildfire that took place in 1997 would not have spread so extensively.

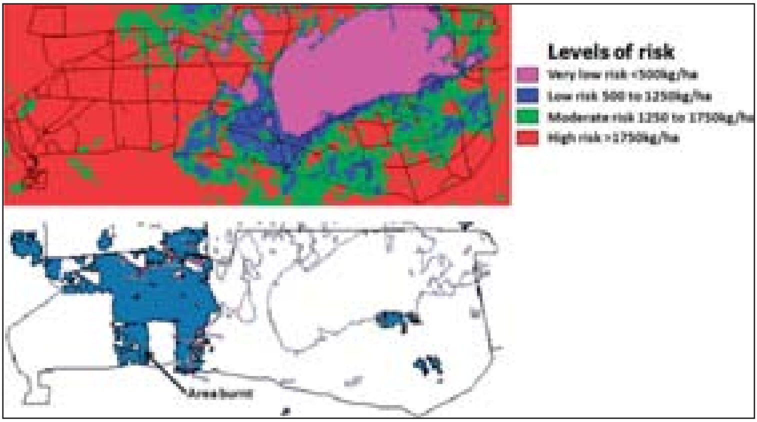


Figure 7. *Example of a biomass map and the extent of the fire that occurred two years after*

CONCLUSION AND FURTHER DEVELOPMENT

Firstly, this study has demonstrated methods for near-to-real-time monitoring of biomass quantity with NOAA-AVHRR. The value and reliability of the DPM has been demonstrated and was shown to be suitable to measure biomass of grassland across large areas. However, its use should really be limited to the grass types for which it has been calibrated. It is possible, in certain circumstances, that several calibration curves might be required depending on the grass types present. The DPM is also not suitable to reliably measure biomass below 1000kg/ha and, other techniques, such as visual estimation, need to be used.

Concerning woody plant biomass, the set of techniques that were derived seem reasonably reliable. The calibration of green plant biomass based on dimensions worked particularly well. The canopy to gap method was also very rapid to implement and seem to be a fairly reliable way to assess canopy cover. Once the calibration of plant biomass with dimensions has been determined, the measurement of woody biomass becomes extremely rapid especially for plant species for which the calibration is based on plant area. In this case, the only parameter required is the canopy cover. For plant species for which the calibration is based on volume, the parameters required are the canopy cover and plant height. This makes the assessment of biomass monitoring sites much faster and it is possible to increase the sample size from 20 to 40 plants within a site allowing a better characterisation of the site's variations.

It would also be desirable to extend the work to other plant species, although the existing calibrations that were developed are valid for about 85% of the Park.

The need to develop a suitable sampling scheme was also identified. The assistance of high resolution imagery for site selection was proved to be very useful and allowed the identification of homogeneous sites for selected cover types at the scale of NOAA. It is also crucial to develop a suitable sampling scheme for the measurement of biomass within the site. The random selection of plants along the transect is particularly important and the measurement of canopy cover needs to be based on the selected plants. This allows the measurement of variations within the site and the assessment of the precision of the estimate.

It was also demonstrated that single AVHRR images, received locally, could be calibrated against biomass allowing near-to-real-time monitoring of biomass quantity. Moreover, the methodology could also be applicable to other sources of imagery such as SPOT VEGETATION or TERRA/AQUA MODIS. Nevertheless, the number of points available for the calibration are still limited and more observations would be needed to confirm that the calibration remains stable through space and time. It already appears that the same calibration could be used for grassland and steppe. This is particularly encouraging because grassland and steppe are present in the same areas and are difficult to differentiate at the scale of NOAA. However, it seems that savanna sites need a different calibration especially when the proportion of woody biomass reaches a certain level. More observations need to be collected to be able to confirm this theory and to determine this threshold.

Biomass maps could potentially be used for several purposes linked to rangeland and wildlife management such as monitoring of animal movement and assessment of carrying capacity. It was shown that biomass maps could be used for the planning of prescribed burning. If local reception of NOAA data is possible, biomass maps can be produced in near-to-real-time and a direct application is to target areas suitable for controlled burning of fire blocks mainly to prevent large scale wildfires. However, more work is required on refining the relationship between biomass and the NDVI for different vegetation communities, but also to investigate whether the effective burning threshold varies according to the vegetation type. This latter point stresses the importance of land cover mapping products as a basis for stratifying the study area.

Finally, although the method was developed over an area of 23,000 km^2, it could potentially be used over a much bigger area such as country wide provided a suitable sampling scheme was implemented across the study area.

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APPLICATION OF GIS AND REMOTE SENSING TO THE MONITORING OF RANGELAND AND WATER BODIES IN NIGER

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INTRODUCTION

For more than two decades, the Sahel has been affected by significant climate variability characterized by gradual deterioration in rainfall conditions (reduction in rainfall amounts, and their uneven distribution in time and space). The variability resulted in droughts, which altered the region's historical climatological records and its very fragile environmental balance. As a result, fluctuations in the botanical composition of the area and in plant production were observed. Furthermore, the prevailing land use and pressure significantly impact on these conditions

Livestock breeders are continuously moving in search of pastures and watering points for their livestock. As a result, exhaustion and even deaths are recorded, which render livestock raising vulnerable in Sahelian areas in general and in Niger in particular.

In this context, the study of the pastoral potential in arid and semi-arid countries is a priority. Therefore, the Permanent Interstate Committee for Drought Control in the Sahel (CILSS) and its AGRHYMET Regional Centre (ARC) have been providing technical and methodological support to technical services of member countries as well as to farmers organizations to help improve mechanisms for monitoring and managing pastoral resources.

Remote sensing increasingly asserts itself as an efficient decision-making tool to acquire information for natural resource monitoring and management. Multi-temporal data give indications on environmental degradation, and the inclusion of this information in resource management systems provides decision makers with planning tools that help them to reduce these degradation phenomena (Bonn, 1992).

Farmers' organizations have increasingly understood the necessity to back their traditional methods with technological innovations to improve their production systems and ease the economic management of natural resources.

This paper presents the responses by the ARC to emerging concerns in pastoralism at a regional and a local level. Such technical support at a local level will be illustrated by two experiments conducted in 2002 and 2006, respectively.

JUSTIFICATIONS FOR THE ARC ACTIVITIES

Equitable access to natural resources by pastoralists and farmers, directing livestock breeders to non-overgrazed areas, consideration of risks of drought to sell livestock in due time and similar measures are top priorities for sedentary and transhumant producers, affected by the vagaries of the climate. Long days' trekking in search of pastures and watering points using classical traditional methods (by foot or on horseback) exhausts the people, especially those sent on ahead, and results in deaths of livestock.

The insistence by livestock breeders to use satellite data has two reasons :

- an *intellectual motivation* characterised first and foremost by the desire
    to adapt to technological advancement and innovations; and
    to strengthen their own capacity to directly manage pastoral resources;
- an e*conomic motivation* mainly consisting of concerns about the absence of a functional observatory for pastoralism on the one hand and the search for landmarks enabling to direct livestock breeders and their livestock to available pastures and watering points on the other hand.

THE RESPONSES OF THE ARC TO PASTORAL CONCERNS AT THE REGIONAL LEVEL

Annual Biomass Estimate

Each year, in late September, which is the period corresponding to maximum phytomass production, ARC carries out biomass estimates based on the following parameters:

- rain fields, obtained from METEOSAT data-based rainfall estimates
- soil characteristics (physical and chemical)
- administrative boundaries of countries
- pastoral entity layers (based on the boundaries of pastoral areas in the countries concerned)

Biomass estimates are made using a plug-in developed by the AP3A Project (Figure 1, Figure 2).

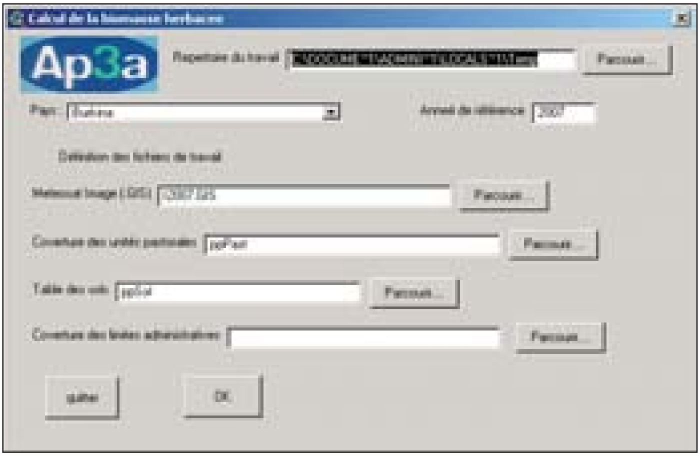


Figure 1. *Opening page of the biomass calculation programme*

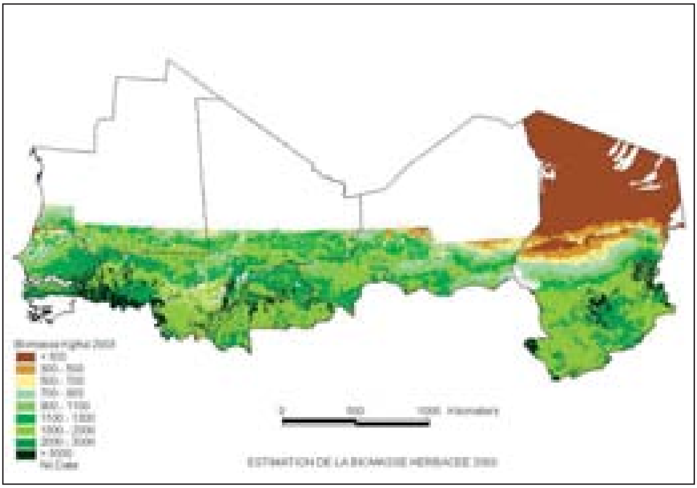


Figure 2. *Estimation of the herbaceous biomass in 2003*

Other Information Provided and Tools Transferred by ARC

In addition to biomass estimates, ARC regularly carries out the following operations:

- provision of computer equipment and software to member countries' technical services;

- dekadal and monthly analyses carried out during the agropastoral season and disseminated in the form of maps and bulletins;
- identification of vulnerable zones by processing climatological data or satellite images;
- information on livestock prices;
- transfer of standardized methodologies;
- training of higher technicians and producers/farmers;
- collaboration between ARC and networks of technical and research partners on pastoral issues.

THE RESPONSES OF THE ARC TO PASTORAL CONCERNS AT THE LOCAL LEVEL

In order to meet the various requests at local level, ARC's response mainly aims at:

- improvement of the living conditions and activities carried out by farmers/producers through transfer of methods and inclusion of decision making tools in the traditional farming/production systems;
- conception of a geographic information system adapted to actual needs of farmers/producers that allows them:
    - to create and manage an observatory for pastoralism
    - to closely monitor ecological dynamics and resources existing in pastoral areas
    - to develop pastoralism in Niger and the Sahel
    - to encourage the training of farmers/producers in technological innovations and to access results of scientific research.

The field tests in 2002 and 2006

The year 2002 was characterized by particularly difficult conditions with regard to livestock raising and gave rise to a well-structured livestock breeders and producers organization with a membership of about 40, 000 persons in the region of Tahoua, Niger (Figure 3). This "Union des Eleveurs Producteurs – Animation pour la Promotion de l'Entraide aux Initiatives Locales en Zones Pastorales" (UEP/APEL-ZP) was determined to use satellite images to identify available pastures and watering points where livestock herders and their herds can be directed.

In 2006, ARC, in collaboration with the Ministry of Animal Resources (MAR) and under the ICRISAT Decision Support Project (abbreviated to DGCD), tested an original method for assessing pastoral potential combining plant matter measurements on the ground with information acquired through satellite imagery. The test was carried out at the Gabi and Zermou sites located in the regions of Maradi and Zinder respectively (Figure 4). The results validated, through fieldwork, and upon inclusion in the GIS, underscores further, the importance of remote sensing in the identification, monitoring and more organized planning of the management of pastoral resources.

The choice of the area of interest can be mainly explained by the three reasons below:

- the test area is a potentially rich geographic zone, attracting nomadic and transhumant livestock breeders from various ethnic groups (tuareg, fulani, hausa, …) and various countries;
- four large *swampy* fossil valleys with plant formations stretch across the area;
- the route taken each year to go to the salt cure ((i.e. to permit the cattle to lick the salty soil of the area) at Ingall in the middle of the area (Figure 3).

A LANDSAT TM mosaic (Figure 5) overlaid with other vectors (villages, tracks, watering points, administrative boundaries) helps to understand the studied environment.

Precise objectives of the field tests

These objectives primarily aim at the following three points:

First, improving farmers' living conditions and activities by providing new decision support tools, using satellite data with a view to help:

- searching for and closely monitoring pasturelands and watering points;
- taking stock of existing pasturelands and watering points;
- assessing wood and grass production over each of these sites, while indicating the expanse of above-ground phytomass cover, grazed or non-grazed dominant species, and land use;
- calculating the carrying capacity of studied sites ;
- correlating fodder availability and NDVI images.

Second, creating a pastoral database;

Third, adopting an approach culminating in a geographic information system, allowing to manage an observatory, ecological dynamics and resources in pastoral areas and to ensure significant development of pastoralism in Niger and the Sahel.

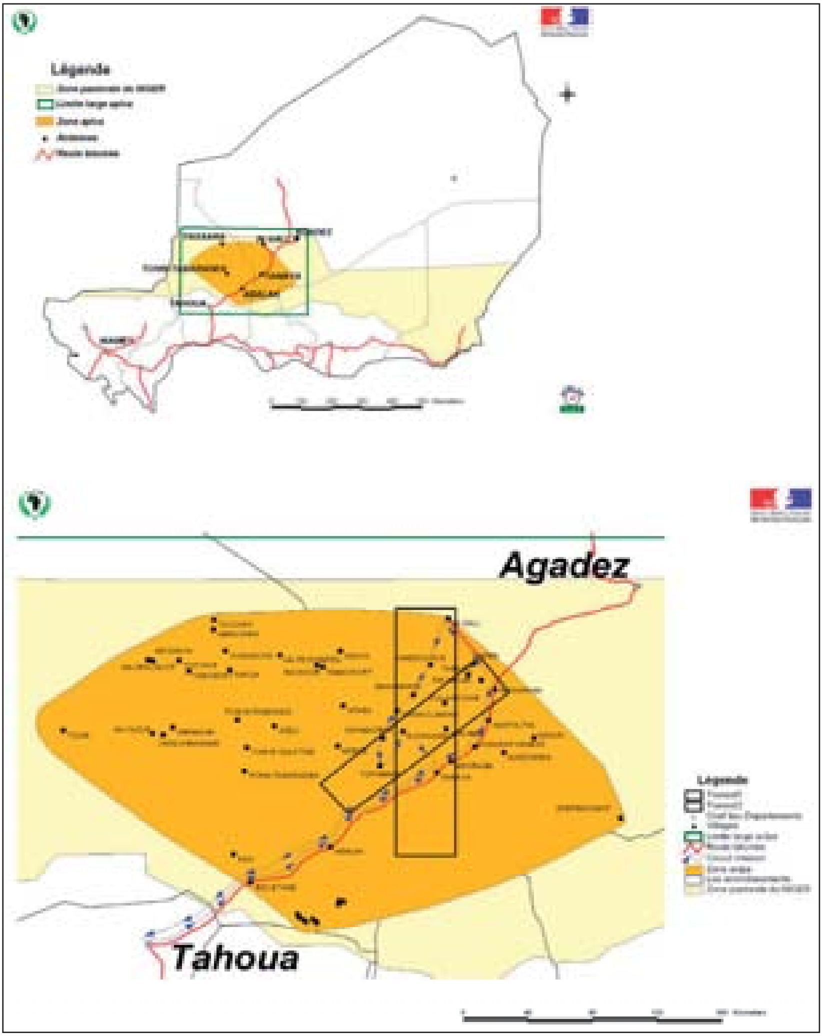


Figure 3. *The study area and itinerary of the observation tour in the field – region of Tahoua.*

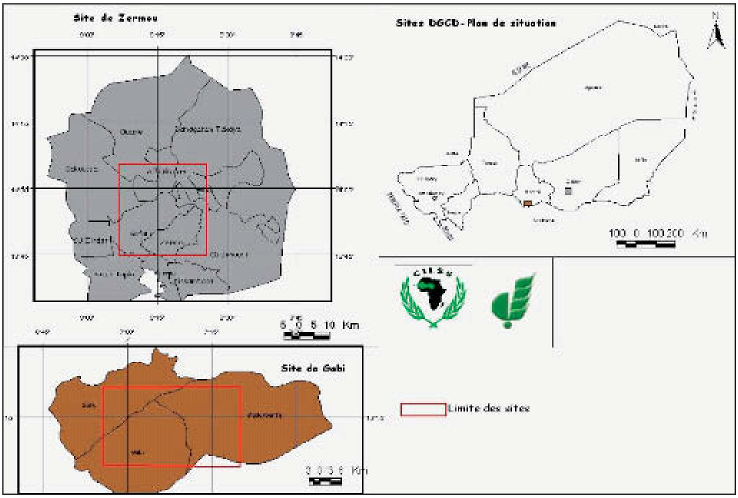


Figure 4. *The study site in Gabi and Zermou*

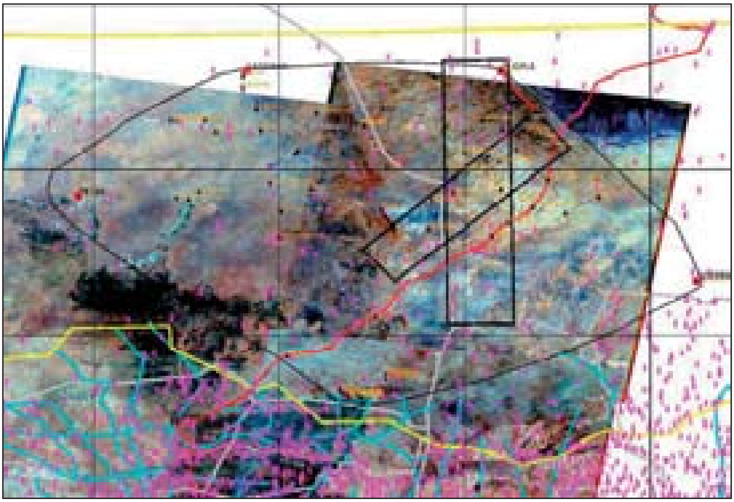


Figure 5. *Use of a Landsat TM mosaic overlaid with vectors facilitates looking for details; 30m resolution*

Methodology

The methodological approach, which was developed with support and backstopping from development partners (ACER, Italian cooperation agency, USGS) at the AGRHYMET Regional Centre, consists of:

- testing the utilization of NOAA AVHRR, SPOT VEGETATION (low resolution, 1-km pixel) and Landsat (Resolution R=1km x 1km) images to design maps and carry out necessary analyses;
- conducting practical training in accessing geographic data and spatial images catering for livestock breeders/producers;
- accessing georeferenced data, (varied topographic and thematic maps), GPS coordinates of existing infrastructures and physical geographical elements;
- designing and accessing VPI, VCI, ICN, NDVI, LULC indicators;
- conducting field surveys (observations, characterization, validation ;
- validating the maps designed;
- reporting to local stakeholders concerned on the research work and results, that was based on a participatory approach.
- experimenting the dissemination of products from ARC to the livestock breeders' units through the RANET system;
- evaluating the project to highlight its achievements.

The aim of the field missions carried out to the selected test sites was:

- to observe landscape units and systems required for the operation of the observatory (natural environment and infrastructures): vegetation, soils, micro-relief, ponds, boreholes, human settlements;
- to record the geographic coordinates of landscape elements using a GPS;
- to validate the maps made by livestock breeders during their training, in the field;
- to include the observations and amendments resulting from the field work or made by the coordinating body of UEP/APEL-ZP;
- to ensure that the system to be developed enables rapid dissemination of the maps made to the project's coordinating body based in Tahoua;
- to ensure continuous remote assistance.

RESULTS

The work addressing the concerns of livestock breeders, and its results, were a tremendous learning experience, from a methodological, technical and scientific standpoint, for the two parties that conducted the field surveys.

The immediate results arising from the field trips are mainly:

1. The design of, and the operational access to, the maps for monitoring pastures based on satellite data. Dekadal NDVI images were processed and than analysed by livestock breeders based on a nomenclature and legend defined by the breeders themselves, in order to characterize as clearly as possible, the phenomena identified in the natural environment. After the field missions, the information collected was re-considered in order to improve the quality of the first maps, as shown in Figure 6, 8, 9, and 10.
2. The creation of a rich geographic database, enhancing knowledge on pasture availability and dynamics. It includes data on the way of life of livestock breeders, livestock prices, main constraints and the priority concerns of the producers.
3. The calculation of the carrying capacity in the different parts of the area

The pasture carrying capacity is a pertinent ecological variable. It consists of the number of livestock units that a given rangeland can continuously sustain, without causing overgrazing, for a given time interval. It is an indicator of the degree and mode of utilization of the rangeland. An example of the calculation is given in Figure 7.

Correlation between production and NDVI

The normalized difference vegetation index (NDVI), which is a derived index adapted to the study of the vegetative cover, expresses the quantity of active chrolophyllous biomass.

The NDVI of each transect is recorded. The relation between the measurements carried on these transects and NDVI values corresponding to locations where measurements were carried out on the ground give the following linear regression lines (Figure 11):

y = 0,0097x + 81,85 with R2= 0,8173 at Gabi

y = 0.0033x + 93.301 with R2 = 0.7468 at Zermou are the normalized difference vegetation index and the quantity of dry matter. The equations enable to obtain the production of non-sampled sites through extrapolation.

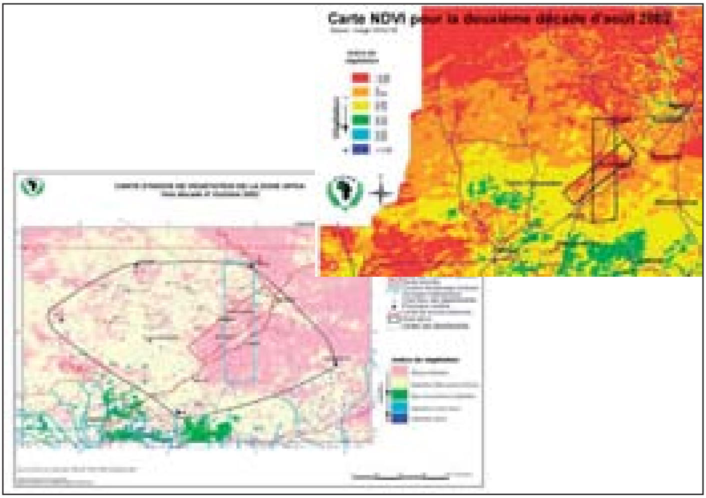


Figure 6. *Improved quality maps, incorporating the field work with the livestock breeders*

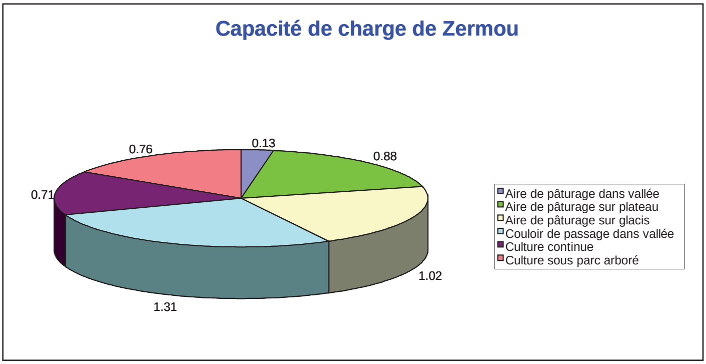


Figure 7. *Description of the carrying capacity of different areas in the region*

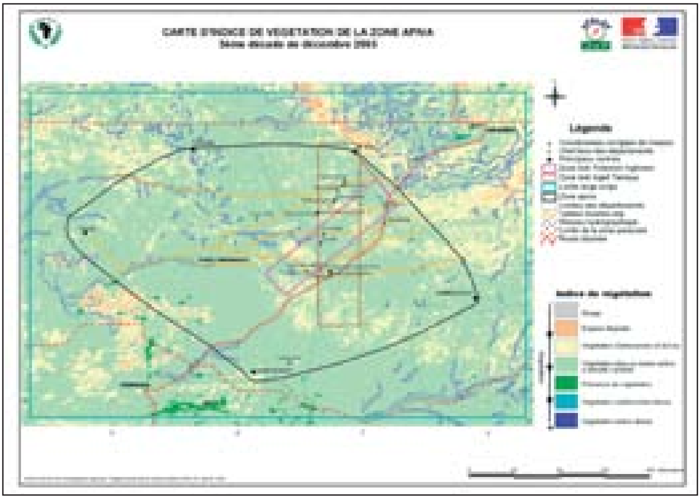


Figure 8. *Maps of the vegetation index in the zone of Apiva*

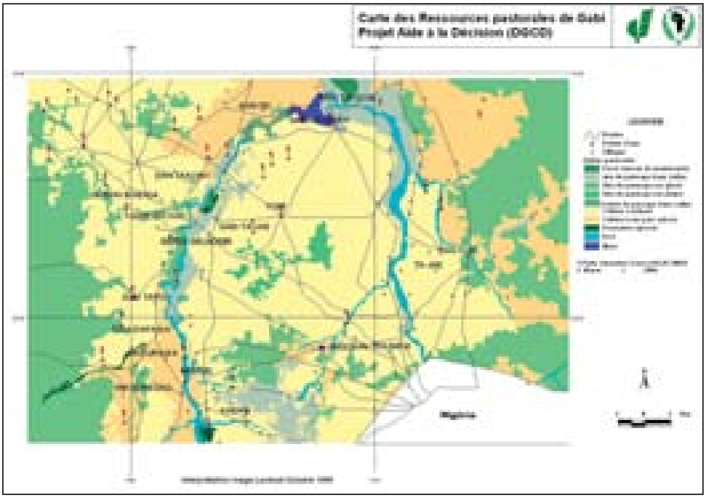


Figure 9. *Maps of pasture resources in Gabi*

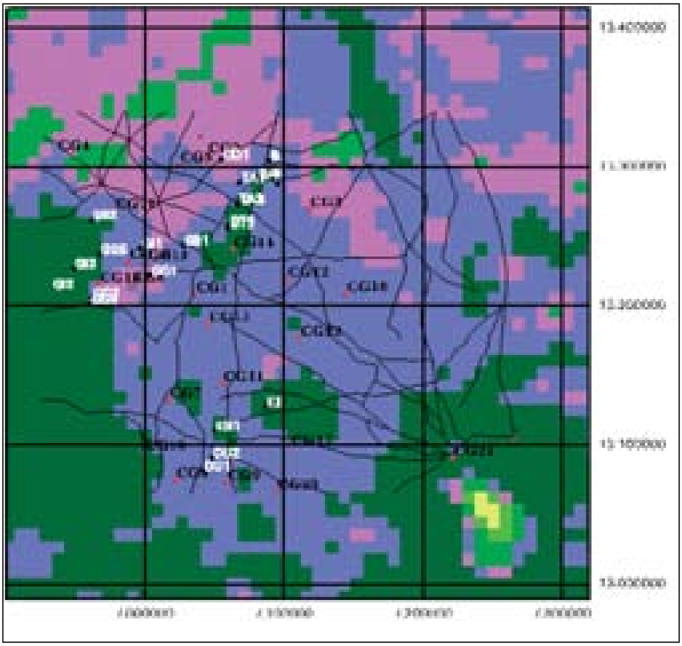
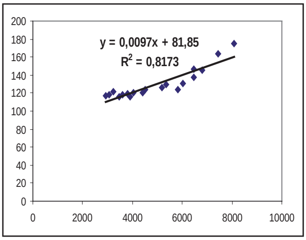


Figure 10. *Maps for pasture monitoring near Maradi*



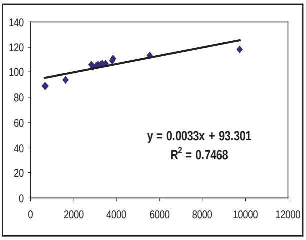


Figure 11: *Regression line between NDVI (y-axis, pixel values) and the quantity of dry matter (x-axis, kgDM/ha) on the sites of Gabi and Zermou, Niger Republic*

IMPROVED DISSEMINATION OF PRODUCTS TO USERS

The dissemination of mapping products to the coordinating body of the producers' organizations was significantly improved through the setting up of a communications system (RANET system, see figure below) with support from the African Centre of Meteorological Applications for Development (ACMAD). The system is made up of

- a server into which are fed products to be disseminated in electronic format;
- a station that sends information from the server to the **AfriStar** satellite, which covers the entire Africa;
- a WORDSPACE radio receiver connected to a terminal to download transmitted data.

After downloading, these products will be analysed by the trained officers of the NGO. The treated information is then rebroadcast to producers on local radio stations in local languages.

Figure 12. *Data transmission system through «RAdio and InterNET for rural communication», RANET*

PROJECT EVALUATION

A mission to evaluate the information system that had been set up for testing, was conducted at the end of the project, and highlighted the following:

Users think that the information provided by ARC is indisputably useful. Livestock breeders underscored:

- the qualities of maps, which are invaluable indicators enabling to locate available pastures and watering points;
- the reduction in distances to cover to reach pastures. The maps made it possible to optimise time and distance, hence to save the energy of livestock breeders and their livestock;
- the desire to renew the experiment while enriching further the maps with point geographic and socio-economic information, to minimize confusions for the benefit of livestock breeders or producers, was clearly expressed!

PROSPECTS AND ACTIVITIES

Short-Term Action Items

To improve predictive and early warning models;

To surmount existing methodological limitations by encouraging collaboration with specialized research institutions with a view to sharing tools, information, methods, and work on common issues;

To strengthen complementary activities in the fields of studies, ground data and capacity building.

Collaboration will be strengthened mainly with:

- the Ministries and technical services in charge of animal resources, agricultural development, water resources and the environment;
- NGOs - Associations - research institutes – sub-regional organizations such as IGAD, SADEC, JRC, FAO, and VITO;
- Farmers' platforms.

Medium-Term Activities

To expand and adapt the experience acquired during this work to other geographic areas;

To design and publish an atlas optimising the use of the database and all the achievements derived from targeted available studies;

To transfer technology and methodology to farmers;

To consider to create a programme for a Master's degree in Natural Resource Management;

To strengthen activities and projects through the ongoing ACER Programme;

To participate in vgt@work (VITO) with applications in adapted thematic domains of interest on the scale of the CILSS region;

To operate a DDS Station (Data Dissemination System);

To institute reception of Envisat data and finished products;

To organize reception of finished products (GMFS, VPI, DMP Dry Matter productivity);

To propose that ARC should act as the Regional node of the SIPSA Project;

To strengthen negotiations underway with USGS, NASA, NOAA for ARC to become a node for data and product distribution;

These future activities involve diversified and close collaboration with various institutions.

CONCLUSIONS

The information system, set up as an experiment in collaboration with agricultural producers, underscores the necessity to introduce producers/livestock breeders to new technologies for development. In spite of the low resolution of the satellite data utilized, the information system put in place made it possible to significantly improve producers' living conditions.

The AGRHYMET Regional Centre has improved its methods for working with local stakeholders, and assessed the limitations of data when the objective of their utilisation changes. This study permitted ARC to calibrating NDVI images for mapping vegetation and improving and harmonizing biomass estimate methods for the direct and immediate benefit of end users. The study led to several major actions:

- the experiment was the subject of a film produced by CILSS;
- the organization of a workshop on the theme « Reflection for the Setting up of an Information System Adapted to Producers' Needs (irriga-

tion practitioners / market gardeners and livestock breeders) of the region of Tillabéri, an agropastoral zone in western Niger, in May 2006;

- a training course for Niger farmers (irrigation practitioners, market gardeners and livestock breeders) organized in December 2006 at ARC.

Last but not least, the Permanent Interstate Committee for Drought Control in the Sahel in general and the AGRHYMET Regional Centre in particular, in collaboration with development partners (French Cooperation), show that on can increasingly provide sustained attention to the interests and involvement of stakeholders in development through the introduction of modern technologies.

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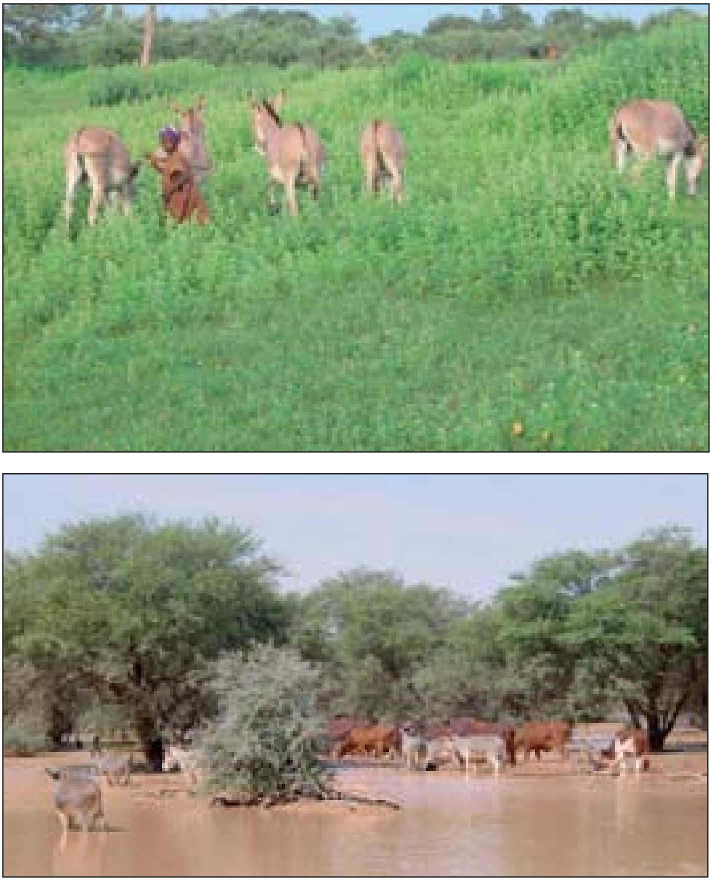

Figure 13. *Niger Field pictures.*

DEVELOPING AN OPERATIONAL RANGELAND WATER REQUIREMENT SATISFACTION INDEX

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ABSTRACT

Developing an operational Water Requirement Satisfaction Index (WRSI) for rangeland monitoring is an important goal of the Famine Early Warning Systems Network (FEWS NET). An operational WRSI has been developed for crop monitoring, but until recently a comparable WRSI for rangeland was not successful because of the extremely poor performance of the Index when based on published crop coefficients (Kc) for rangelands. To improve the WRSI, we developed a simple calibration technique that adjusts the Kc values for rangeland monitoring using long-term rainfall distribution and reference evapotranspiration (ETo) data. The premise for adjusting the Kc values is based on the assumption that a viable rangeland should exhibit above average WRSI (values > 80%) during a normal year. The normal year was represented by the median dekadal rainfall distribution (satellite rainfall estimate from 1996 to 2006). Similarly, a long-term average PET value was input to the geospatial WRSI model of FEWS NET combined with soil water holding capacity data. A dekadal rangeland WRSI has been operational for East and West Africa since 2005. User feedback has been encouraging, especially on the use of the end-of-season WRSI anomaly products that compare the Index's performance to "normal" years. Currently, output from the rangeland WRSI are generated on a dekadal basis and posted for free distribution at the following website: http://earlywarning.usgs.gov/adds/.

INTRODUCTION

Rangeland performance monitoring is important to local and regional decision makers as it relates to forage availability for livestock. The concept of crop water requirement index was first developed by FAO (FAO, 1977;

FAO, 1979, FAO, 1986, FAO, 1998). USGS/FEWS NET implemented FAO's model on a geospatial (grid-cell) environment on a regional scale (Verdin and Klaver, 2002). Senay and Verdin (2003) of USGS/FEWS NET further modified the algorithm by introducing the maximum allowable depletion (MAD) principle and soil stress factor (Ks), borrowed from irrigation engineering practices, and put the model into an operation mode for FEWS NET crop monitoring activities. Initial attempts to apply the existing model for rangeland monitoring revealed the need to modify some of the model parameters. Specifically, published crop coefficients that define the water-use patterns of rangelands appeared to be too high for applications in east and West Africa. The main objective of this paper is to present the method of modification for crop coefficients and present results of an operational rangeland Water Requirement Satisfaction Index from the GeoWRSI model of USGS/FEWS NET.

METHODS

The main difference between the cropland and rangeland WRSI is the difference in the magnitude of the crop coefficients (Kc). WRSI for a given accumulation period since the start of the growing season is calculated using the following equation.

$$WRSI = \frac{ETa}{ETc} * 100$$

Where ETc is the cumulative optimum crop water requirement and ETa is cumulative actual water demand-met by the rainfall and soil moisture for a given accumulation period since the start of the season.

For individual time steps (daily or dekadal), ETa and ETc are calculated as follows:

$ETa = Kc * Ks * ETo$ Ks = varies between 0 and 1

$ETc = Kc * ETo$ Ks = 1.0 (no water limitation)

where Kc is the crop coefficient, Ks is the crop stress factor from a water balance model and ETo is the reference Evapotranspiration calculated using meteorological data from the Global Data Assimilation System (Senay *et al*., 2007). Ks is calculated as a function of soil water as described in Senay and Verdin (2003). The other important inputs to the model include rainfall data from the satellite-based rainfall estimate (RFE) (Xie and Arkin, 1997) and the FAO water holding capacity from digital soils map of the world.

Since the published Kc values for rangelands resulted in very high water demand that was not met by the rainfall distribution in east and west Africa, it was hypothesized that the water demand of grass grown in a modeling unit can be reduced by assuming patches of grass can be grown by taking advantage of redistribution of soil moisture in more favorable places within a modeling unit. This assumption will reduce the total water requirement in a modeling unit while satisfying the requirements of patches of grass within the modeling unit. Thus, the model results, in principle, apply to only patches of grass growing areas within the modeling unit.

In order to estimate the appropriate crop coefficient at the four important phases of the grass growing cycle, a 90-day grass was assumed The seasonal fractions of the four crop developmental stages were 7%, 14%, 54% and 25% for the initial, developmental, mid-season and late-season stages, respectively (FAO, 1998). Furthermore, a model calibration strategy was designed by assuming that a median rainfall distribution (1996-2006) for each pixel will result in a rangeland condition that will yield an average to above average WRSI condition for much of the landscape. Thus, Kc values were successively reduced in small decrements from the published values until a qualitatively satisfying region-wide end-of-season WRSI was obtained.

The qualitatively satisfying (reasonable) WRSI is determined by visual inspection where a high proportion of the region with known pastoral areas receive WRSI values of >= 80 (figure 1b). Crop coefficients of 0.1, 0.2 and 0.1 for the initial (Kc_ini), middle (Kc_mid) and end of season (Kc_end), respectively, provided the most reasonable rangeland WRSI distribution during a median year RFE-based rainfall distribution. The corresponding values from the FAO (1998) handbook are 0.3, 0.75 and 0.75, respectively.

The start of the season for the rangeland WRSI was assumed to be established with the criteria when at least 10 mm of rainfall is received in a given dekad followed by a total of 5 mm in the following two consecutive dekads. The rangeland WRSI model was run using a new set of reduced crop coefficients from 1995 till 2006 for two seasons in east Africa. The rangeland GeoWRSI produces comparable products to the cropland WRSI with key products such as: Current WRSI, Extended (end-of-season) WRSI, WRSI Anomaly with median year and Ratio WRSI with the previous year. Spatial maps and temporal charts were produced for countries in eastern Africa. Results were compared to forage monitoring products produced by the Livestock Early Warning System (LEWS).

RESULTS AND DISCUSSION

Figure 1 shows a comparison between rangeland WRSI generated with the originally published coefficient in FAO (1998) and one modified using "calibrated" Kc values based on a median-rainfall distribution for the long rains in East Africa. The calibrated rangeland WRSI shows an improved performance in much of the region compared to the original. However, it still shows areas where the performance of rangeland WRSI ranges form a high of mediocre to complete failure, particularly in northern Somalia, extreme eastern Ethiopia and the red sea coast of Eritrea. These areas coincide with desert-like regions that are unlikely to produce sufficient pasture to support a sizable livestock on a normal year. Since the absolute WRSI values are prone to modeling assumptions and input data errors, it is recommended to interpret WRSI products to monitor changes from year-to-year using anomalies.

Figure 2 compares the 2005 short-rains rangeland WRSI anomaly products with that produced by the LEWS forage monitoring model. Although the spatial extent of the two products does not quite match, it is possible to see the two products corresponded well in capturing major drought regions in Kenya and Somalia where the LEWS product labeled it as "drought to poor" is labeled as a "no-start" start region in the USGS/FEWS NET model output. Both products also agreed on the "above average" performance on the border region of eastern Ethiopia\northern Somalia.

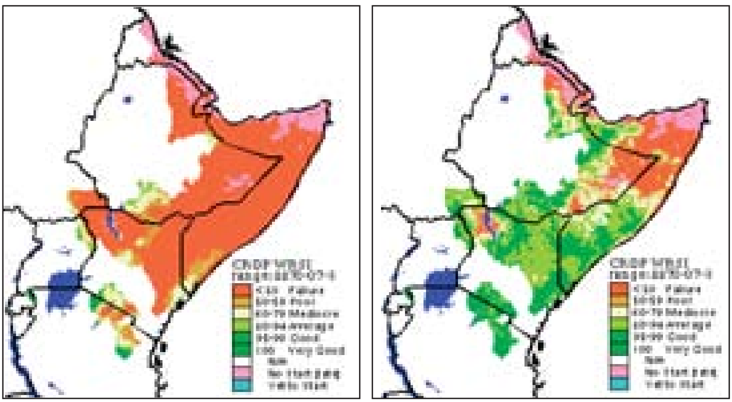

Figure 1: *End-of Season Rangeland WRSI distribution using published (a) and modified ("calibrated") (b) crop coefficients using median rainfall distribution for the long rains (Mar-May) season in East Africa.*

It is important to note that the rangeland WRSI model is supposed to show rangeland WRSI performance in patches of grass–growing areas within a modeling pixel. However, because of the nature of grid-cell based modeling, the rangeland WRSI will tend to show an optimistic WRSI for the entire landscape. For example, Figure 1b shows large areas of Kenya and southern Somalia appear to have average to above average WRSI in a normal year. This should be interpreted as areas that normally favorable to grow grass will perform well in the region on a normal year.

Figures 3 and 4 show time-series of country-average WRSI for three countries for long and short rains, respectively. For all three countries (Ethiopia, Kenya and Somalia) the long rains performed well in the 1990s. There was a major decline in 2000 for Kenya while Ethiopia and Somalia had a major decline in 2001. On the other hand, for short rains (Figure 4) the major decline was observed in 2005, with the most severe decline being observed in Kenya and Somalia. This coincides with a major drought emergency declaration in Kenya. Because of the geographic location of Somalia in relation to Ethiopia and Kenya, when either of the countries experiences drought conditions the country-wide average shows similar conditions for Somalia.

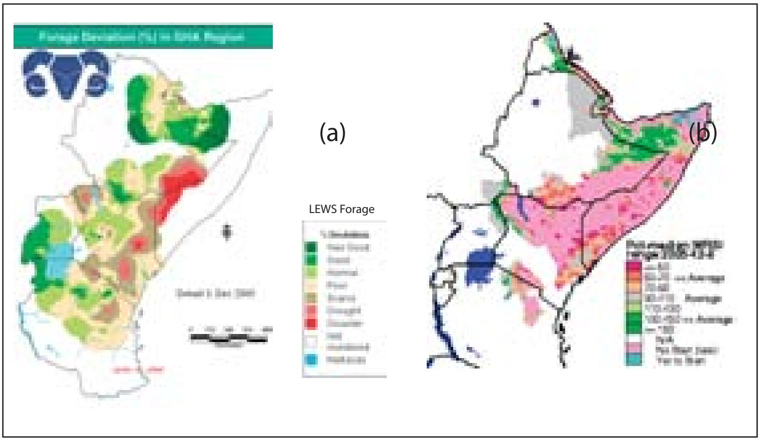

Figure 2: *Comparison between LEWS forage anomaly (a) and rangeland WRSI anomaly (b) products for 2005 short rains (Oct-Dec) season in East Africa.*

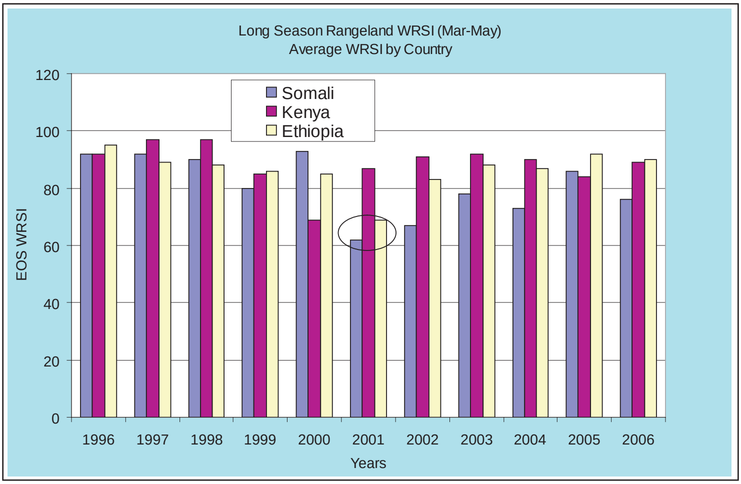

Figure 3: *Country-wide average End of Season (EOS) long-rains (Mar-May) rangeland WRSI from 1996 till 2006 for three east African countries.*

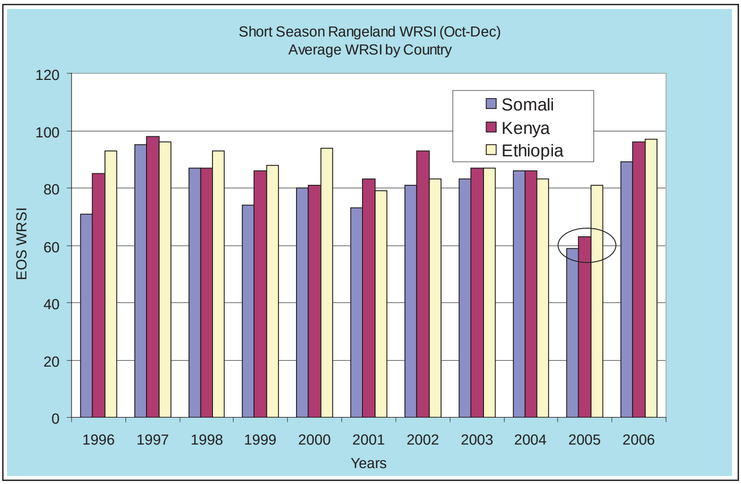

Figure 4: *Country-wide average End of Season (EOS) short-rains (Oct-Dec) rangeland WRSI from 1996 till 2006 for three east African countries.*

Figure 5 shows the year-to-year WRSI traces of long-rains and short-rains WRSI for Kenya. Although the relatively-short times series data precludes a detailed analysis on the relationship between the short and long-rains WRSI, some sort of positive correlation appears to occur where a high/low long-rains WRSI is followed by a generally high/low short-rains WRSI. However, the lowest WRSI for each season occurred in different years, namely 2000 for long rains and 2005 for short rains. In each of the extreme years, the other season showed also a decline, but not as much. More research is required with more years of data to examine the temporal relationship between the two seasons.

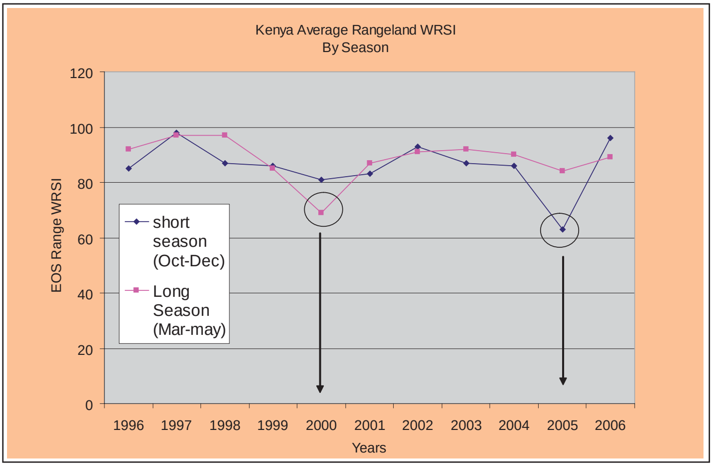

Figure 5: *Temporal comparison between short-rains and long-rains EOS WRSI for Kenya from 1996 till 2006.*

CONCLUSIONS

The main objective of the study was to modify published rangeland crop coefficients so that operational rangeland monitoring can be setup to support FEWS NET activities. The premise of expecting an "average to above-average" rangeland WRSI distribution in a median rainfall year provided the guidance for modifying the crop coefficients. The results from this model compared favorably with an independent forage monitoring output of LEWS. The model also captured major drought events in 2000 and 2005 in Kenya. User feedback has been encouraging, especially on the use of the end-of-season WRSI anomaly products that compare the Index's performance to "normal" years. Currently, USGS/FEWS NET posts rangeland WRSI graphics at the Africa Data Dissemination Service site for two seasons (short and long rains) in east Africa and for the main rainy season (June to September) for the Sahel region of west Africa at http://earlywarning.usgs.gov/adds/. Further research is recommended to evaluate the relationship between the two seasons in east Africa if the performance of one season can be used to forecast the performance of the other.

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MONITORING AND FORECASTING FORAGE SUPPLY IN THE GRAZING LANDS OF EASTERN AFRICA

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ABSTRACT

Pastoral communities in Eastern Africa have faced unprecedented variation in weather, desertification and degradation of forage resources in recent times, leading to large-scale losses of livestock reducing both marketing and management options. With emerging problems associated with increasing population, the changes in key production areas, and the prevalence of episodic droughts and insecurity due to climate change, ecological degradation and expansion of grazing territories, traditional ways of coping of pastoralists have become inappropriate. There is a need for new approaches for early warning to make proactive decisions to before drought sets in. One such possibility is the development of new technologies capable of providing information on emerging forage conditions to assist in improving livestock movement and sales options of pastoralists. The Livestock Early Warning System project of the Global Livestock Collaborative Research Support Program led by Texas A&M University has developed an automated modeling package to assist these mobile dry-rangelands livestock keepers in Eastern Africa to cope with shocks of climate and to make informed decisions about current and future prevailing forage conditions and thereby guide their mobility and decision-making patterns. The approach makes use of modeling techniques, Geographic Information Systems and information communications technology and takes real-time, satellite weather data to drive a biophysical model called PHYGROW to simulate daily forage conditions and near term forecasts of these conditions. Using geo-statistics, these point-based model simulations are linked with Normalized Difference Vegetation Index (NDVI) to create maps of forage supply and its deviation from normal. This information is updated every 10 days with situation reports and maps distributed via WorldSpace radios, email, internet, and newsletters in the region. This technology suite has been developed in collaboration with national government agencies in Ethiopia, Tanzania, Kenya, Uganda, Djibouti, Somaliland and NGOs working in pastoral areas.

KEY WORDS: Early Warning, East Africa, Monitoring, PHYGROW, Co-kriging

INTRODUCTION

Livestock producers in the arid lands of Eastern Africa are facing conditions where traditional drought coping strategies are being undermined by increased population pressure, erratic climatic patterns with higher frequency of drought, limited marketing opportunities, changing land tenure patterns, rising social conflict, limited water supply and greater incidences of disease. One of the primary manifestations of these combined forces is the degradation of the rangeland resources resulting in large scale losses of livestock and famine which makes pastoralists dependent on food aid from donor government and agencies. Traditional coping mechanisms have been eroded by the increased frequency of drought, flooding, conflict, inefficient markets, resource deterioration and encroachment of farming into traditional grazinglands. The increased risks, and the collapse of traditional risk management strategies have necessitated the search for innovative ideas, tools and approaches to overcome this vicious circle. One such approach is the development of new technologies capable of providing information on emerging forage conditions ahead of time to assist in improving livestock movement and sales options of pastoralists.

For the past several years, the Global Livestock CRSP has been leading the implementation of a project to develop a Livestock Early Warning System (LEWS) for the arid land regions in Eastern Africa (Ethiopia, Kenya, Tanzania, Djibouti, Somaliland and Uganda). The LEWS project has assembled a suite of technologies and explored their applications in Eastern Africa including: computer simulation models of plant growth, satellite-based weather data and spatial analysis techniques linked with NDVI (Stuth et.al 2003).

PHYGROW, a Phytomass Growth Simulator biophysical model, which is a hydrological based, spatially explicit multiple-species plant growth/hydrology/animal grazing model is the bedrock of the LEWS toolkit (Figure 1). The toolkit is designed to monitor the impact of emerging weather conditions on forage supply for livestock in the pastoral regions of East Africa. The model uses soil and plant community characteristics, livestock traditional management decision rules and weather data for a particular location to simulate daily forage available for different kinds of livestock and other major herbivores (wildlife). These attributes are organized in a comma delimited parameter file to go into PHYGROW to simulate daily forage.

Forage monitoring is becoming increasingly important in East Africa, as frequent and recurring droughts affect large areas of the region. Determining forage production over large regions requires a large amount of both human and financial resources. These resource limitations have greatly hindered the ability to determine the effects of desertification particularly as it relates to vegetation loss within the context of rangeland monitoring, assessment programs, and livestock early warning systems. The technique of linking the PHYGROW model with satellite-based weather data offers a major breakthrough in establishing a point-based sampling system of large landscapes and linking it to other readily available data to interpolate results to areas not actively monitored using co-kriging. The technique involves the use of a secondary variable (covariate) that is cross-correlated with the primary or sample variable of interest. The secondary variable is the NASA NDVI product for the continent of Africa that provides a spatially rich data across the landscape that has been correlated with plant biomass production (Tucker et al., 1985).

Various geostatiscal methods and GIS techniques are employed to produce surface maps of available forage using the point data generated through the automation process. These techniques allow for the estimation of forage yield for large areas of non-sampled locations. Such techniques offer a cost-effective way for monitoring forage in vast areas in a timely manner. This paper will focus on the integrated technology toolkit developed by LEWS/GLCRSP to monitor current and forecast expected forage situations in pastoralist regions of East Africa.

KEY ELEMENTS OF THE LIVESTOCK EARLY WARNING TOOLKIT

PHYGROW Model

PHYGROW is a hydrological-based plant growth model that simulates daily available forage for livestock capable of simulating multi-species or multi-functional plant groups simultaneously across multiple years on daily time steps (Figure 1). The model requires initial parameterisation of a representative site for monitoring carefully selected to be as representative as possible for corresponding 8 x 8 km satellite weather and NDVI grids. The characterization includes identifications and measurements on the plant species in a typical plant community for the monitoring site, measurement of soil properties and collection of information about the traditional livestock management to constitute the primary inputs for the model. These inputs can also be directly entered into an on-line version of the model to estimate forage condition. The parameter file contains the listing and this parameter file is comprised of four major modules, including soils, plant communities/species attributes, grazer stocking rules/plant preferences and weather representing the initial values for all of the key variables provided by the user either through field sampling of representative sites or sourcing from available literature. These parts interact in a PHYGROW model simulation driven by weather to produce a final output. These inputs are driven by Meteosat Rainfall Estimation (RFE) imagery, an automated (computer-generated) product which uses Meteosat infrared data, rain gauge reports from the global telecommunications system, and microwave satellite observations, within an algorithm to provide RFE in mm at an approximate horizontal resolution of 10 km, for each location to estimate daily forage available for livestock and wildlife. The methods of generating and use of satellite-based rainfall and temperature data have been extensively explored by Xie and Arking (1998), Grimes et al. (1999) and Funk et al. (2003). Similarly, the use of NDVI satellite data has been well established (Tucker et al. 1991).

Long term daily weather data are initially needed to drive the model in order to set up a baseline, or long-term normal, for each site. The weather variables include: minimum and maximum temperatures (C), rainfall (cm), and solar radiation (Langley). Currently, the long-term rainfall data is derived from a combination of the 1961-1997 CHARM rainfall data developed by Funk et al. (2003) and the RFE from the Climate Prediction Center dataset for Africa (1998 to present). Temperature and solar radiation data through 1997 was generated by the WXGEN weather generator.

Once all the inputs are provided, the model is implemented with a long-term weather to stabilize the simulation for each site. During stabilization, a scientist examines both the input and the output parameters for reasonableness in key variables, in the output, on how they track the situation on the ground and for inadvertent errors in the input. Once a parameter file is set up and stabilized, the only module that is updated for each simulation period is the weather that drives the model. Stabilized model parameter files are placed in a web based automation process to run and report daily forage conditions, percentile ranking of forage on offer, and deviations from a long-term average with projections for the next 90 days on a near real-time basis (http://glews.tamu.edu/africa) with minimum human interference. This information forms the basis of a livestock early warning system.

Another integral component of the early warning system is the process of verification of results to help build confidence in the system by the users. Verification of model simulated forage production (Jama et. al, 2003) is conducted and the ensuing analysis and information is shared with key institutions to build "strength of evidence" of emerging forage conditions, thus allowing increased confidence in the products, to allow policy makers and users to act on the information. PHYGROW model outputs of strategically selected sites are ground-truthed by a LEWS team to insure adequate tracking of the forage conditions on the ground. So far, the results indicate that PHYGROW accounted for 96% of the observed variation in herbaceous forage on offer with a standard error of prediction of 161 kg/ha. Mean difference in sampled and predicted forage on offer was 15 kg/ha (Figure 2). This indicates that when parameterised properly, the PHYGROW model performs well for the resolution of analysis required for the LEWS programme in East Africa.

Spatial Analysis and Co-Kriging with NDVI

The point based PHYGROW forage output is further correlated with NDVI data through a geo-statistical technique called co-kriging in order to build forage supply maps of deviation from normal and rate of change of forage (Figure 3). Co-kriging allows the use of biophysical model data collected for a small set of samples in a large landscape to be coupled with a more spatially rich NDV dataset to interpolate forage responses for areas across a region that are sampled. However, for co-kriging to work effectively, a good linear relationship must exist between the model simulated forage values and corresponding NDVI data. Since the correspondence between model output and NDVI in co-kriging is spatially dependent, areas where a lack of correspondence exists can be identified, thus allowing the LEWS teams to determine where new monitoring points need to be located using GPS technology to locate these sites. Presently, the co-kriging is conducted using commercial software (GS+); however, preparations are underway for an automated mapping system based on GSTAT algorithms that will be deployed in the near future.

Projections into the future

Using the relationship generated by PHYGROW and weather data, historically derived forage estimates are coupled with spatially and temporally coherent NDVI data to forecast likely forage production up to 90 days in advance with a level of accuracy that is within normal field sampling error (Kaitho et al. 2003). The forecasting procedure analyses and projects the data using an AutoRegressive Integrated Moving-Average (ARIMA) model. This approach combines past forage and NDVI conditions along with current forage estimates from the PHYGROW model to predict future standing crop (Figure 3).

The ARIMA procedure in SAS (1999) analyses and forecasts equally spaced uni-variate time series data using the autoregressive moving-average (ARIMA) model. The ARIMA model (Box at al., 1994), predicts a value in a response time series as a linear combination of its own past values (autoregressive), past errors, shocks or random disturbances (moving average), and current and past values of other related time series (covariate). In this process, the PHYGROW forage output and NDVI data are first subjected to "white noise" or "pre-whitening" analysis which removes the intra-relationship in the individual series and inherent noise in the data series. This allows for the accurate assessment of the interrelationship between the input and the output series (Kaitho et. al 2003). Each data series is then made stationary by applying the appropriate differencing from its ARIMA model. Seasonal dependency (seasonality) patterns are identified, and given the variability in weather patterns over the region and differences of the onset and end dates of rainfall, an annual circle produced the best correlation. Serial dependency is removed by differencing the series to identify the hidden nature of seasonal dependencies in the series and to make it series stationary, which is necessary for the ARIMA.

Furthermore, the de-noised NDVI and forage data are subjected to a second step of parameter estimation using the function minimization procedure (non-linear estimation), so that the sum of squared residuals are minimized. These parameter estimates are used in a final stage (Forecasting) to calculate new values of the series (beyond those included in the input data set) as well as confidence intervals for those predicted values. The estimation process is performed on transformed data (differenced) before the forecasts were generated. The resulting series are integrated so that the forecasts are expressed in values compatible with the input data.

Automation and Analysis Portal

The lack of trained personnel constitutes one of the major constraints to deploying a complex technology such as LEWS in developing countries. Therefore, LEWS team has strived to devise methods where data is automatically acquired with pre-designed analysis conducted by resident programs that are scheduled to run unattended to generate an output for dissemination to outreach partners in the region. Currently, it is only the mapping technology that requires human intervention to select the best model fit for the co-kriging process. Concerted research efforts are underway towards full automation including the mapping module. The

LEWS automation system is presently located at the Texas A&M University Centre for Natural Resource Information Technology (CNRIT). CNRIT has a large on-going program in information technology and therefore provides a minimal cost locale to insure that the data is acquired, analysed and disseminated in a timely manner to all partner organizations in East Africa.

Reports and Dissemination

Dissemination of the LEWS information suite is critical to the success of the program. After all, the impact of the Livestock Early Warning System will ultimately be determined by the extent to which livestock producers, practitioners, development agencies and policy makers utilize the information generated to aid their decision processes. It is important to note that dissemination of any livestock information into the remote underdeveloped pastoral areas in the Eastern Africa region remains a formidable challenge. Currently, LEWS places all analyses on the Africa Livestock Early Warning System website portal (http://glews.tamu.edu/africa) with 10 day updates. Furthermore, subsets of the analyses are reconfigured for broadcast via WorldSpace satellite radios using African Learning Channel bandwidth and containers from the Arid Lands Information Network (ALIN) and RANET. The maps and minimal narrative goes to ALIN for distribution in their network of 200+ radios across East Africa. The full situation reports are distributed by RANET in their larger container.

The WorldSpace radio technology allows for the deployment of mobile Communication Nodes (MCN) consisting of a computer laptop, solar panel, adapter, portable printer, and a satellite radio receiver. The satellite receiver will pick up the broadcasts, which can be downloaded and viewed via a connection to a computer, preferably a laptop. The downloaded information can be printed out for posting in public locations or incorporated into existing communication pathways. The inclusion of a solar panel allows use of the MCN, giving it more flexibility to be deployed in remote pastoral zones where electricity is not available. Communication nodes are established across East Africa involving a satellite radio linked to an inexpensive laptop or desktop computer via an adapter to transfer reports at scheduled times each day. Many of these communication nodes are located in NGO offices, district offices and communication offices of early warning agencies of the countries.

The LEWS situations reports are made available on the LEWS analysis portal. Condensed versions of the situation reports are also e-mailed to the appropriate country-level information officers in the host countries through an e-mail list serve. LEWS advisories are being delivered by a network of over 800 key decision makers representing a large number of NGOs, regional organizations and early warning units of each of the four country's governments and their district offices throughout the region. A consortium of FEWS NET, USGS, WFP, ICPAC) and LEWS also produces a monthly Greater Horn of Africa Food Security Bulletin with LEWS focusing on forage situation outlook in the pastoral areas within that bulletin.

INSTITUTIONALISATION AND SUSTAINABILITY

A key element in the implementation of a livestock early warning program is developing a vision for sustainability to ensure institutionalisation of these activities and connecting institutional decision makers using the information with the analytical tools. The issue of identification of key decision makers and training of those individuals to correctly interpret the data generated by the system and act upon the information in an expedient manner was one important aspects of LEWS dealt with in the early days of the program. The LEWS program gave a lot emphasis on developing an automated analysis within the Centre for Natural Resource Information Technology (CNRIT) at Texas A&M University. CNRIT offers a commitment and a mechanism to provide a stable home for generating the LEWS analyses even after the current donor support ends. However, the same computing platform can be also be replicated in collaborating institutions with staff training provided in maintaining the equipment, running the models, distributing the data and educating institutional and community users of the products generated from the system if the commitment and local resources are available. Because the PHYGROW system can run on UNIX/LINUX or WINDOWS operating systems, the LEWS automation environment can be implemented in a wide variety of institutional arrangements.

The LEWS project of GLCRSP uses model of the university research environment conducting the research and development of ICT to be applied in developing countries. Access to that ICT is stabilized for relevant host country organizations by maintaining it within the University system until that organization has the staffing, funding and institutional commitment to transfer the technology. This arrangement allows the developing countries and GLCRSP to work on lower cost outreach activities to accelerate the impact of the technology until a critical mass is attained in terms of government or institutional commitment. The key ingredient to making this approach work is the concept of fully automated ICT. The LEWS team made a concerted effort to design software that can monitor and acquire model input data on a prescheduled basis, check that data for quality control and then implement the data applications to compute the current and future forage conditions. This automation technique allows LEWS to deliver the technology long into the future at minimal costs to the host country institutions. Another key ingredient is building strong and stable networks of organizations that report data. The goal is to lower the upfront burden of technology, develop low maintenance, automated systems for advanced organizations to support emerging skills and capabilities in developing countries. This will allow developing countries to focus on high impact outreach initially and then eventually grow into the technology as the institutional and human commitments emerge.

ACKNOWLEDGEMENTS

The Livestock Early Warning System (LEWS) Project is supported by the Global Livestock Collaborative Research Support Program (GL-CRSP) funded in part by the United States Agency for International Development (USAID). The opinions expressed do not necessarily reflect the views of USAID. Partial funding for this program is made by the Association for Strengthening Agricultural Research in East and Central Africa - Crisis Mitigation Office, Kenya Agricultural Research Institute, Ethiopian Agricultural Research Organization, Uganda National Agricultural Research Organization, and the Tanzanian Ministry of Livestock and Water Development.

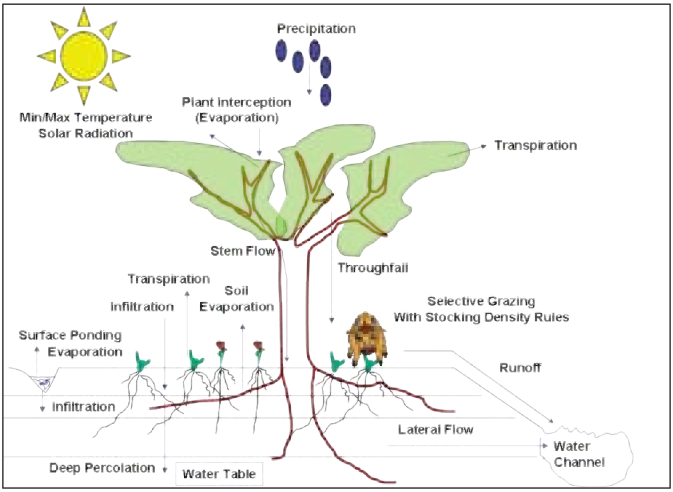

Figure 1. *PHYGROW model: a hydrologic based forage production model that accommodates multiple plants and multiple grazers.*

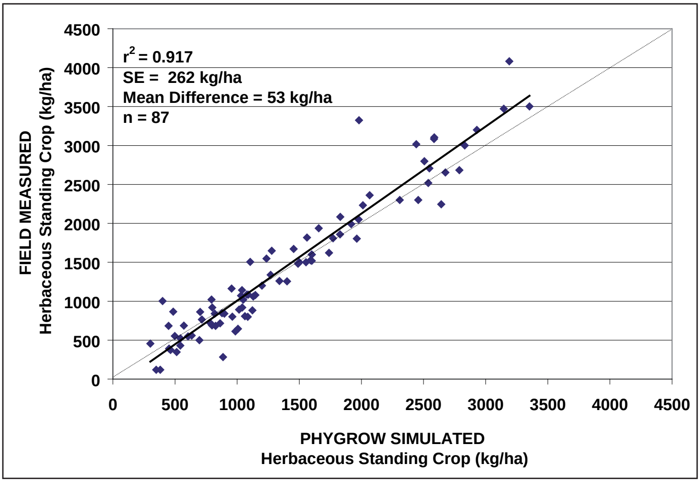

Figure 2. *Relationship between PHYGROW simulated forage production and ground measurements of available forage in selected monitoring sites in Eastern Africa.*

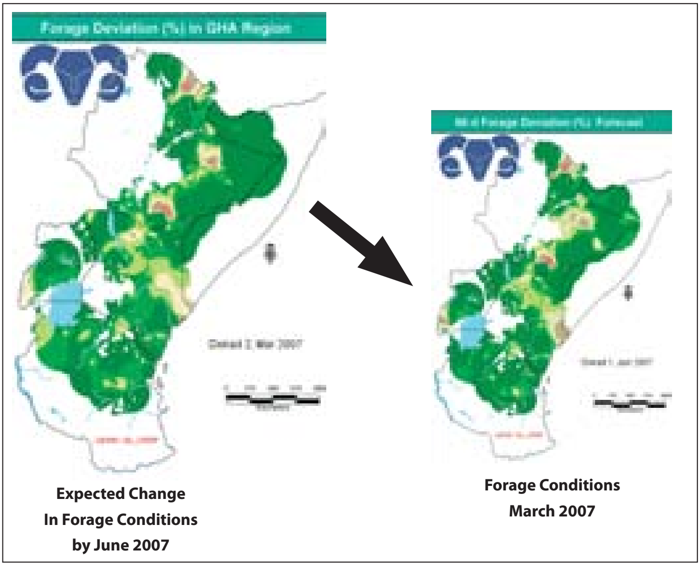

Figure 3: *Forage deviation in March 2007 and expected change in forage conditions by June 2007 for the Greater Horn of Africa region*

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NON-PARAMETRIC CROP YIELD FORECASTING

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ABSTRACT

Operational crop yield forecasting is mostly achieved with empirical statistical regression equations relating regional yield with predictor variables, termed "factors".

Regional yield (the "dependent variable") refers to average yield over districts, provinces or, more rarely, whole countries; they are provided by national statistical services. The factors can be any combination of raw environmental variables such as weather variables or indices, satellite indices such as Normalised Difference Vegetation Indices (NDVI), farm inputs (fertiliser use) or outputs from simulation models, for instance water transpired over a given phenological phase, maximum leaf area index (LAI), average soil moisture, etc.

Method	R^2		
	Trend	Method	Total
Average Rainfall	0.1702+	0.4563	0.6265
Water Balance		0.5653	0.7355
Threshold		0.5311	0.7013
Clustering		0.5692	0.7394

The table presents a comparison of the performance of several maize yield forecasting approaches in Zimbabwe. The two parametric methods are (1) a simple regression between average monthly rainfall during the growing season and yield, and (2) regression of yield against Actual Evapo-transpiration (Water Balance). The two non-parametric methods are (3) a categorization of yields according rainfall thresholds during critical months, and (4) the statistical clustering of monthly rainfall into typical profiles, The table shows the fraction of variance accounted for by the different methods.

The approach above is termed "parametric" for two reasons:

1. *it derives or requires a number of parameters, for instance regression coefficients and the parameters characterise crop simulation models and*
2. *it attempts to identify the factors that condition yields and to understand their action.*

The difference between "parametric" and "non-parametric" methods is not clear-cut; it is mostly operational. Parametric forecasting approaches derive a "model" (through a process known as "calibration") based on historical yield and climatic data. The model is subsequently applied to current crops and within season data to issue a forecast of yields. A number of calculations are performed; they are basically the same in the calibration and in the forecasting phases.

Non-parametric crop yield forecasting techniques attempt to establish a typology (qualitative description) of the environmental conditions that occur during the growing season, assuming that similar types of seasons lead to similar yields. Similar years are grouped in classes. During the calibration phase, the types of seasons are defined in such a way as to minimize the variability of yields within classes and maximise between-classes variance. The forecast proper is done by categorizing the current year into one of the classes, and by assigning the class yield to the current forecast. Depending on the actual method, the forecast itself may require little more than comparing some variables with reference values, e.g. a threshold.

The paper offers a rough comparison of simple yet classical parametric approaches with two different non-parametric methods, applied to national maize yields in Zimbabwe. The conclusion suggests that the simple non-parametric approaches are not inferior, in terms of accuracy and ease of use to the more complex parametric models.

The complete version of this paper is in print. It will be published as Gommes, R. 2007. Non-parametric crop yield forecasting, a didactic case study for Zimbabwe. Paper presented at the EU/JRC meeting on Remote Sensing Support to Crop Yield Forecast and Area Estimates, 30 Nov-1 Dec 2006, Stresa, Italy. 5 pp

THE EFFECT OF RAINFALL VARIABILITY ON AGRICULTURAL ACTIVITY AND THE COPING STRATEGIES IN ETHIOPIA

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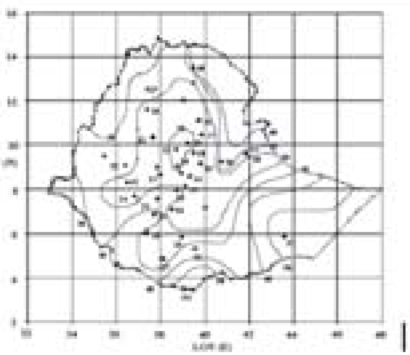
INTRODUCTION

Rainfall in large parts of Ethiopia shows a high level of year-to-year variability. The rainfall variability in the rainy seasons is the most serious problem encountered by Ethiopian farmers. As a result, particularly in drought prone regions of Ethiopia agriculture production is determined by rainfall variability (rain fed agriculture is the dominant practice in Ethiopia). Many research studies have stated that meteorological parameters like rainfall, temperature and wind play an important role in changing agricultural production more than other parameters. Any deviation from the mean climatic condition would affect agricultural activities negatively. Agriculture can show little sensitivity to moderate variations around those means. If the condition persisted a bit longer it could affect the overall physiological activities of the plants and result in crop damage and final yield reduction. With regard to livestock production rainfall seasonality affects forage availability, livestock production and ultimately the livelihoods of those people.



Coefficient of variation of mean annual rainfall over Ethiopia from 1981- 2000 (Almaz Demessie, 2002, MSc. Thesis)

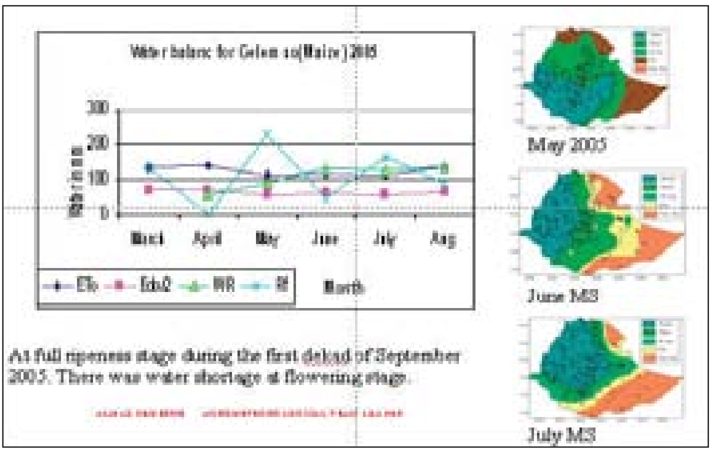
As can be seen from map analysis the variability increases towards the north, northeastern, south and southeastern parts of the country and those areas are not suitable for cultivation. As a result, through diversification and flexibility of farming systems, the farmer tries to adapt both to good and to bad rainfall situations. Besides, the erratic nature of the rainfall could favor the occurrence of pest and disease in these areas. As a result, crop yield is poor in those areas. The CV value of south and southeastern lowlands reaches up to 57%. In northern Ethiopia, the higher variability is 40% around Mekele. The southwestern and central Rift Valley area shows the CV value 37 and 36%, respectively. In case of central highlands, the variability is higher over southeastern Amhara region (Mehal Meda). These areas, particularly with the CV value greater than 30%, are subjected to recurrent drought. Crop damage and livestock losses due to moisture stress are common and frequent phenomena over those areas.

SOME POINTS ABOUT THE RELATIONSHIP OF RAINFALL VARIABILITY AND CROP PRODUCTION

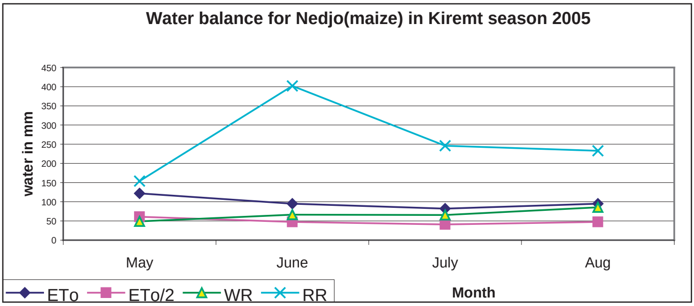
Reliability of rainfall, particularly at critical phases of crop development, has a great importance in terms of yield.

Some examples about the above mentioned point

Example 1.1

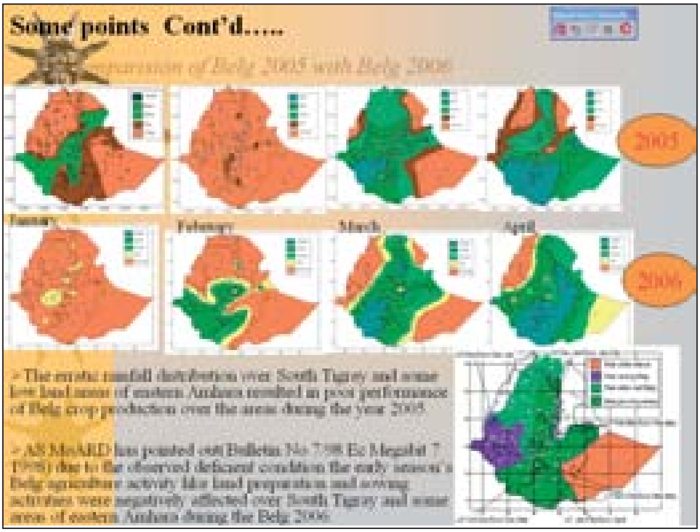


Example 1.2



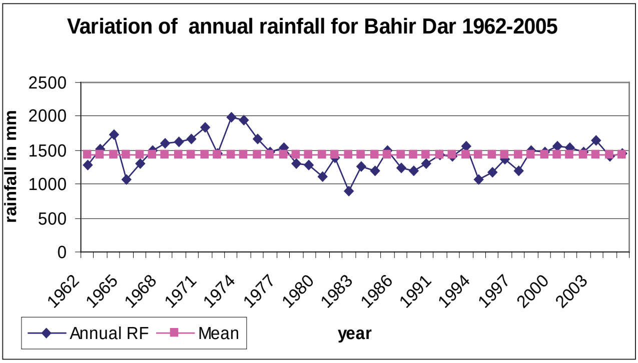
Pursuant to the crop phenological report the crop was at full ripeness stage during the second dekad of September. As indicted in the above analysis (Example 1.2) there was no moisture stress throughout the season. However some other factors like pest infestation, excess moisture, hail damage, untimely rain, etc could affect the performance of final crop yield.

Example 1.3 *Comparison of the moisture performance of Belg 2005 with 2006*

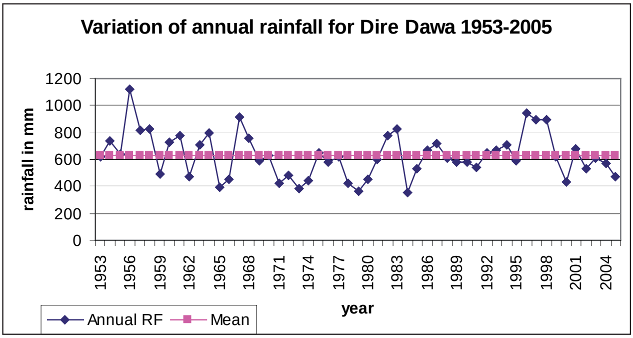


Variation of annual rainfall for some localities

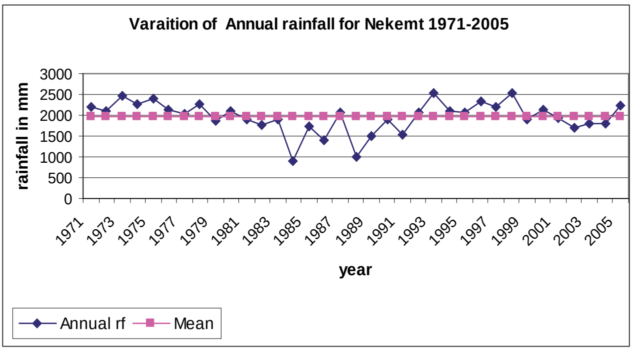
Example 2.1



Example 2.2

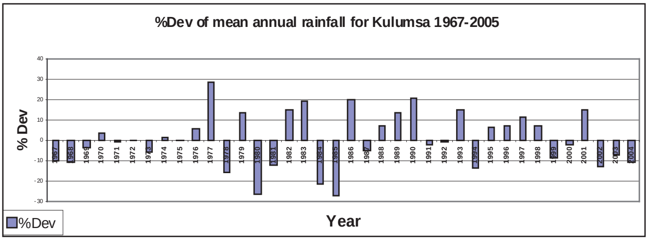


Example 2.3

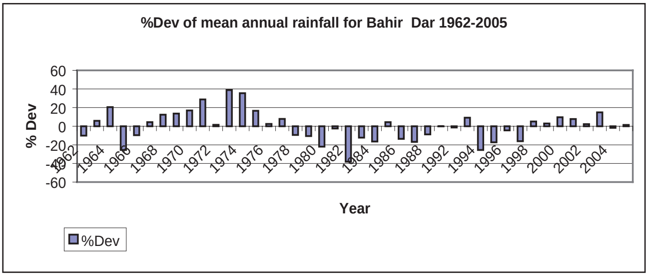


Some examples about annual variation of rainfall for crop producing areas and percent deviation of mean annual yield

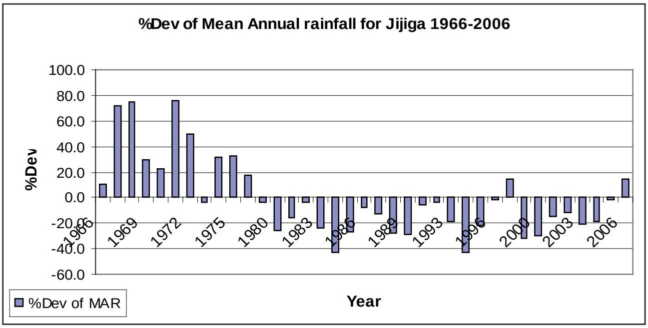
Example 3.1



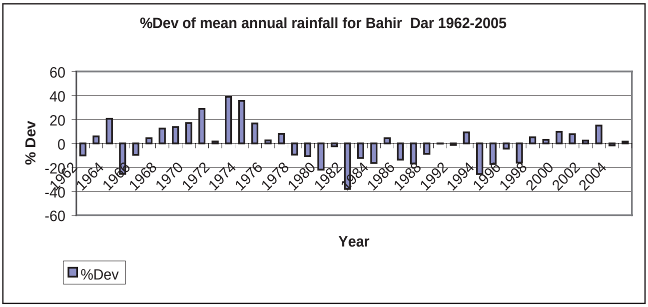
Example 3.2



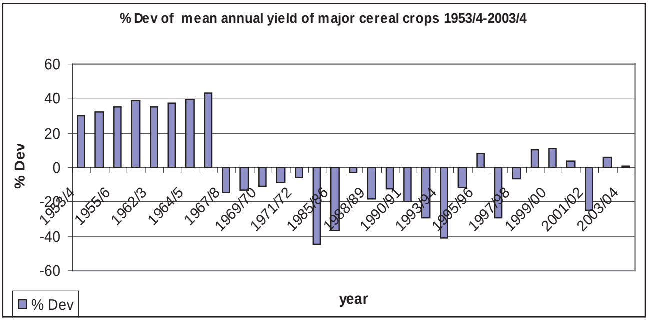
Example 3.3



Example 3.4

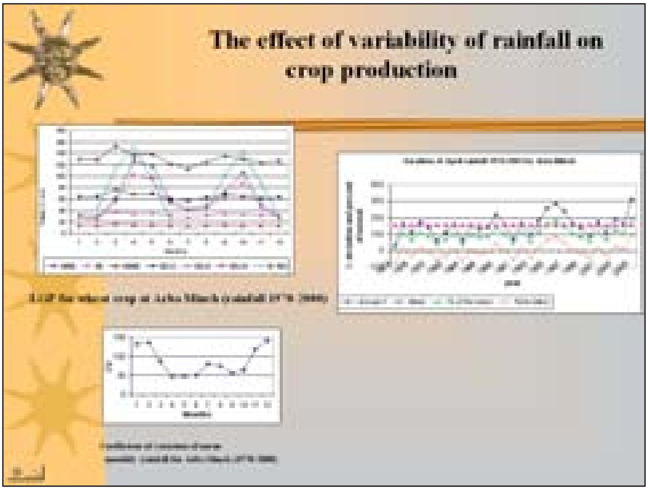


Example 3.5

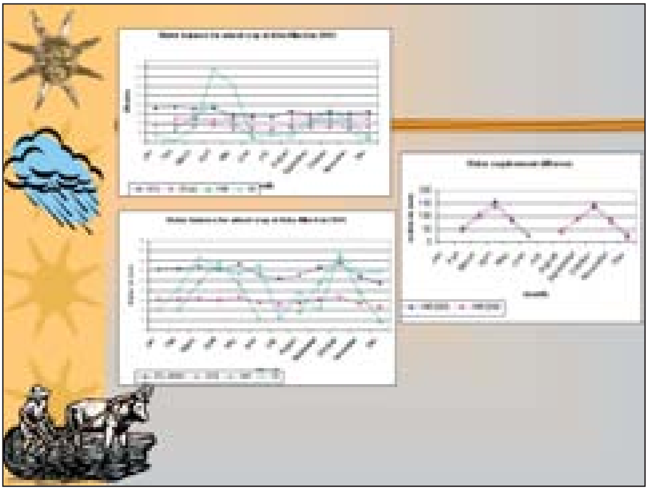


We have to consider other factors like management practices including other adverse conditions different from moisture. Besides the onset distribution and cessation of rainfall have significant impact on yield performance.

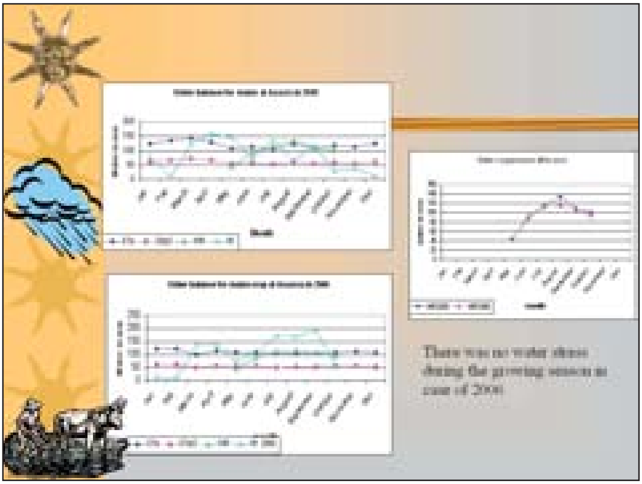
Example 3.6



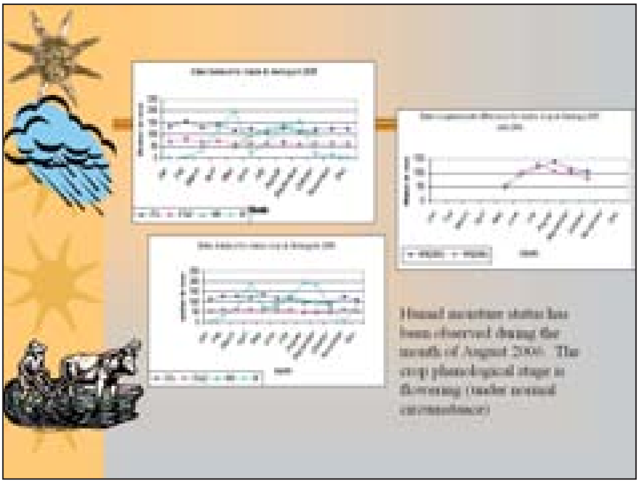
Example 3.7



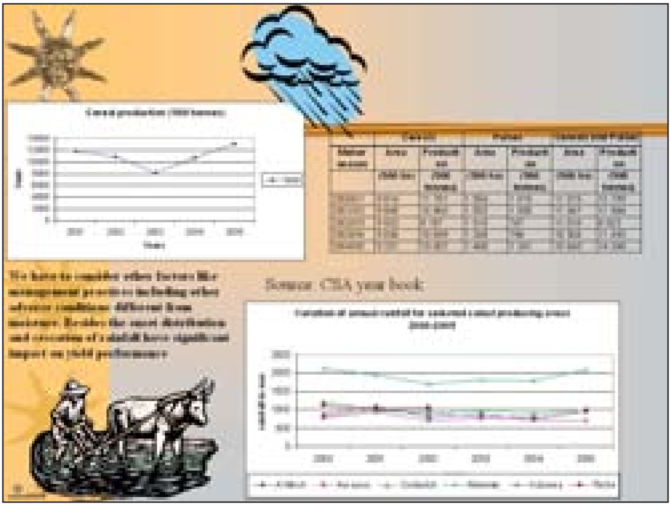
Example 3.8



Example 3.9



Example 3.10



THE SITUATION OF PASTORAL AND AGRO PASTORAL AREAS OF ETHIOPIA

Ethiopia is the home for thousands of pastoral people who herd their livestock in the semi-arid to arid areas of the country. Rainfall seasonality affects forage availability, livestock production and ultimately the livelihoods of those people.

Some ground truth about the rainfall situation of pastoral areas during 2003/4 and 2004/5

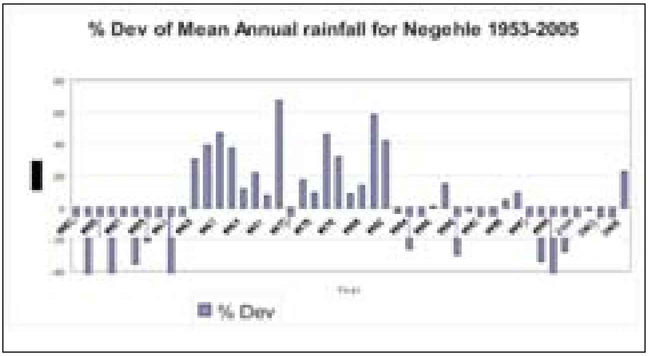
A. Yabello (2004/5)

Because of its erratic nature it was even not sufficient for pasture and drinking water. As a result huge number of livestock movement was observed in searching of water and pasture in neighboring weredas like Hagere Mariam and Burji.

B. Negelle (Liben Wereda) (2004/5)

No rainfall at all during Hageya season, which is normally, contributes 20 – 30% for annual rainfall of the area. As a result farmers are under close mentoring.

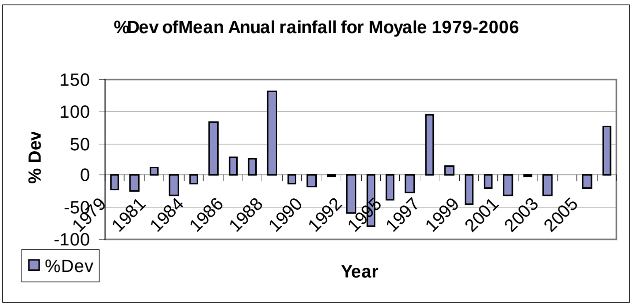
The situation affected animal health in some Kebeles by creating favorable condition for the outbreak of livestock pests.



From the above long years rainfall analysis we can see similar trend for considerable number of years in the form of negative or positive deviation.

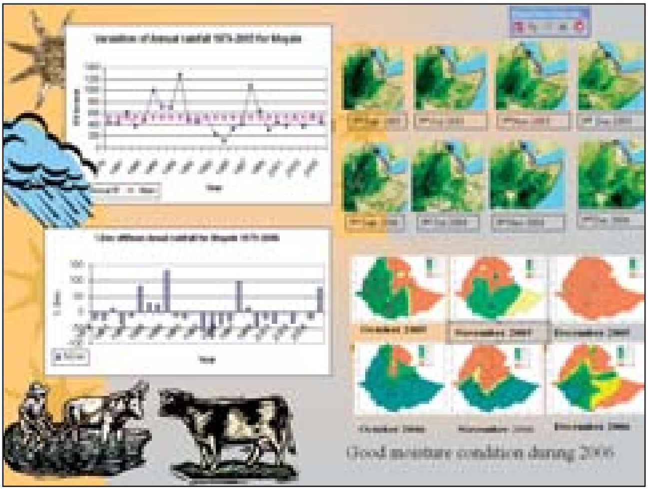
C. Moyale (five Kebeles are agropastoralist out of 15 Kebele) (2004/5)

Late (about one month) on set of Hageya (seasonal rainfall of the area) has been observe in the areas. Besides, the observed rainfall was not sufficient for crop production. As a result there was no Hageya crop in 2004/5. Some agro paternalists tried to use it but they were not successful and used the emerged and dried crop for pasture. However, it had good contribution for pasture and drinking to some extent.



Here we can see the variation of rainfall at Moyale (1979-2006) clearly and the situation of 2005 and 2006(which was good for most pastoral areas)

Example



Source for NDVI picture is USGS the maps (below the NDVI pictures) shows the level of moisture status during the year 2005 and 2006 at the time of a small rainy season of south and southeastern pastoral and agro pastoral areas of the county.

THE COPING STRATEGIES IN ETHIOPIA IN CASE OF CROP PRODUCING AREAS

Small farmers in Ethiopia are especially vulnerable to changes in precipitation. Only a small number of farmers use irrigation. Larger growers, such as the commercial farms are better able to cope with weather extremes, but they are in the minority.

A. Mitigation strategies to minimize the effect of adverse condition in relation to rainfall variability:

- Use of drought resistant crops
- Use of early maturing crops

- Dry seeding
- Intercropping is considered as a copping mechanism in areas where there is high rainfall variability.
- Crop and variety diversification for efficient water use.
- Additional cultural practices like mulching, minimum tillage, etc
- Traditional soil and water conservation methods
- Traditional way of removing excess water from the field at the time of occurrence of heavy fall.
- Traditional pest and disease control methods at the time of the occurrence pest outbreak.
- Different water harvesting techniques like
  - Collect water around the crop area
  - Preparing ponds near the crop fields
  - Roof water harvesting
  - Diverting the river water to the crop fields.

THE COPING STRATEGIES IN CASE OF IN CASE OF PASTORALISTS IN ETHIOPIA

The Ethiopian pastoralists have a diversity of strategies to sustain production. Pastoral strategies for maintaining production include: -

- Sell their livestock at the time of drought.
- Using unusual materials for feed.
- Moving their livestock to a better place in search of pasture and drinking water,
- Raising a diverse range of animal species (Cattle, camels, goats, sheep, etc) at a time for security purpose.
- Keeping species-specific herds to take advantage of the heterogeneous nature of the environment,
- Diversifying economic strategies to include agriculture and wage labor, among others.

The Way Forward

- Cultural practices that can favor the plant need to be further explored and implemented to mitigate the effect of rainfall variability.
- Adopt suitable crop varieties and develop new ones.
- Promote herd diversification
- Promote crop and variety diversification
- Improving resilience of farmers and herders in vulnerable areas to rainfall variability.
- Introduction of drought tolerant crops and develop high yielding, early maturing disease and pest tolerant crops.
- Increased methods of protection against drought and flood hazards, and more effective management of existing water resources.
- Putting in place mechanisms to conserve water, protect watersheds and promote community water harvesting methods.
- Introducing new scientific-based weather/ climate forecast services, which provide accurate and reliable outlooks into the cultural system may help farmers improve yields and cop with risks. Besides, it would be useful for preparedness planning and strengthen early warning system.
- Last but not least the use of weather and climate forecast is related to the vulnerability of targeted users, to enhance adaptive resource management in the affected and vulnerable areas would be a major step forward both in achieving present development aims and in preparing for climate variability and change.

FARMING SYSTEMS AND COPING STRATEGIES CHANGING PATTERNS

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INTRODUCTION

Since the publication of the "Crop Production System Zones of the IGAD Sub-Region" (CPSZ, 1995), many things have changed in the Greater Horn of Africa. In particular the farming systems have undergone significant changes under the pressure of difficult political situations and recurrent droughts.

The CPSZ data base, still representing the core of crop field information, is 10 years old; in the mean-time the availability of data and tools to monitor and manage the food situation in the region has significantly improved.

These facts were taken into account when the objectives of the working group on "Farming systems and coping strategies" were formulated during CRAM in 2003.

The goal of this working group was to try:

- to identify, in so far as possible, *"what is new"* and *"what is changing"* , including the reasons for such changes, in the farming systems in the Horn of Africa, and
- to understand the coping strategies adopted by farmers in order to face food shortages.

In spite of the importance of these goals the working group has found many difficulties in collecting suitable information**.**

While great progress has been made through the use of satellite imagery at a higher spatial resolution and the availability of detailed land-cover maps, offering the possibility of updating and partially re-conceiving the original CPSZ inventory, the specific objective of "understanding why" is still only supported by very spotty and anecdotal information, especially when reference is made to emerging new coping strategies.

JUSTIFICATION OF A STUDY ON COPING STRATEGIES

According to many climate change forecasts, the Horn of Africa will not be dramatically affected by an increasing negative (warmer) trend, as will be other parts of Africa. However, at least according to some of these climate change models, the climate inter-annual variability will, on the contrary, increase, adding additional concerns. The expected consequences of the above variability on crop performance are still under discussion among scientists; opinions are rather discordant and the outcomes rather controversial.

Recently, it has been observed that while the "prediction of future *warming* may be relatively robust, there remain fundamental reasons why one can be much less confident about the magnitude, and even the direction, of regional *rainfall* changes in Africa" (Hulme *et al*, 2005). In spite of these considerations a comparison between rainfall model-simulated anomalies, for 2000-2099, in the three main areas of Africa (the Sahel, East Africa, southeastern Africa) emphasises consistent differences in their trends.

According to Hulme *et al*, 2001, a probability of more frequent annual rainfall anomalies (when using the outcomes of their 10 model simulations) will occur in East Africa. Only 1 out of the 10 simulations provided less frequent anomalies, as shown in the chart and comments, Fig. 1 and its legend, downloaded from Hulme *et al,* 2001. The opposite happens in Southeast Africa, while the Sahel is characterised by a set of rather variable trends according to different simulations.

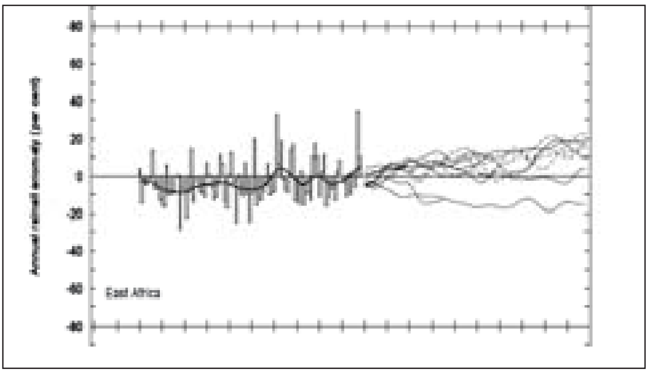

Figure 1. *Observed annual rainfall anomalies for three African regions, 1900-1998, and model-simulated anomalies for 2000-2099.*

Model anomalies are for the 10-model simulations derived from seven DDC-GCM experiments, the four HadCM2 simulations are the dashed curves. All anomalies are expressed with respect to either observed or model-simulated 1961-90 average rainfall. The model curves are extracted directly from the GCM experiments and the results are not scaled to the four scenarios used in this paper. The smooth vcurves result from applying a 20-year Gaussian filter.

From these simulations one may retain that a higher inter-annual variability (i.e. more frequent rainfall anomalies) calls for an open-minded rethinking of cropping systems and their ability to cope with this type of risk. Emphasis should be given to the fact that high inter-annual rainfall variability (rainfall anomalies) can be a more serious concern for farmers than a linear trend towards more or less rainfall.

It is evident that the cropping strategies adopted by farmers (particularly in recurrently deficit areas) are mainly dictated by the need to avoid risks of total crop failure; local cropping systems are the right answers to these concerns. This was demonstrated by many studies, used in the formulation of the CPSZ Atlas, in the course of which significant changes of the cropping patterns during the last two decades of the last century were signalled. Recently observed changes of the cropping systems, although spotty and collected through anecdotal information, confirm the above observations, and call for a more extensive and integrated inventory.

Unfortunately the above changes and the local solutions are not generally observed in current agricultural statistics. For this reason the results of ongoing research on the way in which way farmers have been and are facing these problems become extremely important for any food security issues and policy.

The attempt of the working group has been to gather information about these emerging behaviours. The results, up to now, are rather sporadic and unsatisfactory. The mode of tackling this problem is an important issue for the Nairobi 2007 workshop.

CASE STUDIES

The most relevant contribution the working group gathered and analysed is related to the **increasing importance and role of cassava** (*Manihot esculenta, Crantz*) in East African cropping systems. Cassava has always been the "Cinderella" in East-African agricultural statistics. In many cases its importance has been heavily underestimated, due to underreporting, and in other cases neglected. Its importance in the human diet of a population living in an unreliable environment, both climatic and societal, has seldom been emphasised.

The following two case studies call for more attention. A preliminary conclusion is that the increasing importance, and their recourse to these options, is justified by the farmers for food security reasons that can be different and not necessarily concomitant:

- to increase local food availability particularly when the performance of other crops is rather difficult to be improved;
- to provide food for a "lean period";
- to be a "hidden food" in areas characterised by civil wars, unrests, or in general political instability.

A significant case study has been provided to the working group by an experience, carried out in some villages of the **middle strip of Kilifi district, (**Marson, 2003). In this middle strip of Kilifi district, the villages are located between the coastal area, which has a relative advantage in terms of the tourist and extra-agricultural sectors, and the pastoral inland, which is so arid that agricultural development is almost impossible. The surveyed villages have been the Kitsoeni, Dzunvuni and Tzangalaweni villages, respectively located in Chonyi Division, Ganze Division and Vitengheni Division

Many relatively dry areas of east Africa have been converted, when possible, to maize (corn). Kilifi District, the poorest district of Kenya, is characterized by the associated cropping of maize and of root crops, of which the latter has a role of famine reserve in case of maize shortages.

The following is a quote from the report:

"In the region the rainfall pattern is bimodal and the traditional cropping system relies on two yields, but the unreliability of rainfall makes both yields, and particularly the one in the short rains, low and uncertain. This situation is worsened by the fact that maize is the main crop and it has a high water requirement, needing timely and abundant rains, so that it offers high yield only under optimal weather conditions, while it is prone to complete, or almost complete, failures whenever its growing cycle is subjected to some stress. As local farmers well know, maize is a risky cereal, characterized by high potential gain and losses. Yet, they are fascinated by the high yields expectation and by the easiness of threshing, and their feeding habits were shaped by the food aid practice of providing maize, so that maize is currently at the basis of the local cropping system"… "Indeed, traditional cereals, like millet and sorghum are currently disregarded. These crops have lower, but more stable yields, and are less prone to weather hazards (drought resistant). Furthermore, their nutritional values are at least as high as those of maize. Yet, as they were almost completely abandoned and they are not included in food aid and input provision programmes, their re-introduction is currently difficult".

"Cassava is the second main crop, in terms of cultivated area … . It is mainly harvested in the hungry season, covering an important quota of the energy intake of the local people. During the hungry season it is also sold on the local markets, in the form of fresh root, granting some income to purchase maize. Despite its important role as a famine reserve, or maybe just because of the "second choice idea" related with its role, cassava is not very appreciated in the local diet".

A second case study describes changes in the **Gulu area (Northern Uganda):**

"In Gulu, Northern Uganda one of the biggest obstacles to farmers was theft as the populace lived in IDP camps and went to the fields periodically, as and when they could. More often then not farmers would return to the fields after a gap of few days to find that their crop had been harvested. One coping strategy adopted was to change their crop mix; opting to plant a tuber like Cassava which would be relatively undetected. The lower return on Cassava was the opportunity cost", (Siddharth Krishnaswamy, World Food programme, personal communication).

The introduction of new crops into existing cropping systems has been observed in Ethiopia as a coping mechanism for crop failure. The most frequently observed pattern is related to the introduction of sweet potatoes (*Ipomoea batatas* (L.)) in areas where this crop was previously not included in the crop-mix strategies. According to official statistics a steady increase of sweet potato production has been registered since 1994. Apparently, before 1994, information on this crop was not systematically collected.

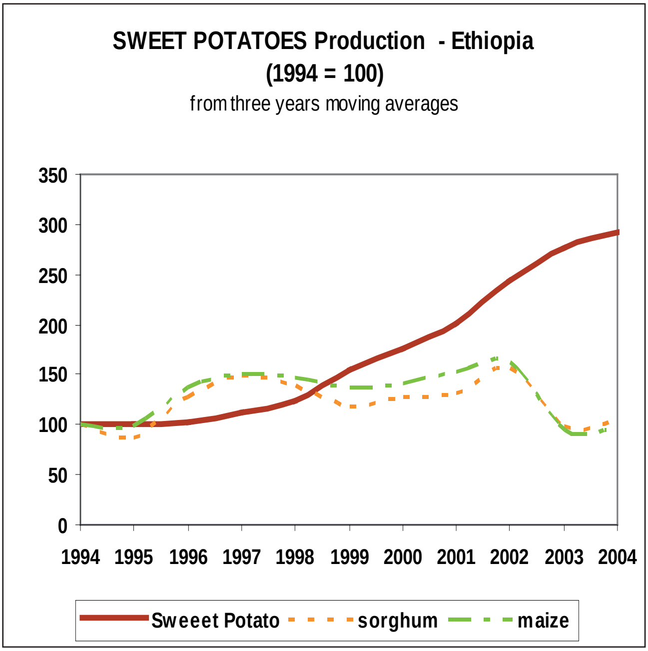

Figure 2. *Government statistics on the increase in production of sweet potatoes, Ethiopia, 1994 - 2004*

Important contributions about this new pattern have been provided by two recent surveys carried out by the Department of Planning (Master Degree on Food Security), University IUAV of Venice (Italy) (Berardo *et al*, 2002; Bau *et al*, 2003).

Villages in Eastern Hararghe (Ethiopia) have been extensively analyzed with particular emphasis on coping strategies, including those related to cropping systems.

The field inspections have shown that in areas where the households can not live just only on their crop production, due to the facts that yields from self-cultivated fields are insufficient to last all year and crop failures are a regular risk due to erratic rainfall, ingenious ways to cope with these problems are practised due to the initiative and capacity of single peasants. A switch towards more drought-resistant crops has been observed.

In the Northern part of Eastern Hararghe, in case of failures with maize and sorghum, many households switched to sweet potatoes, a drought resistant crop. Sweet potatoes are tolerant to a wide range of conditions and respond well to increasing moisture but are considered a drought-tolerant crop because they are deep rooted and capable of developing storage roots under very dry conditions. In addition sweet potatoes grow in a wide range of soils but need good drainage and are sensitive to water-logging and salinity. The most favoured soils are sandy loams overlaying clay subsoil. The growing length period varies from 90 to 120 days, and thus some varieties reach maturity in three months. The growing extension of the cultivation of such crops as a coping mechanism constitutes a good indicator of increasing drought-related difficulties.

Figure 3. *Planting of sweet potatoes.*

Similar coping mechanisms have been observed in the Southern part of the same region, where in many villages, many farmers have chosen to grow sweet potatoes even every time a late begin or an early cessation of seasonal rains affects staple crop production. Although sweet potatoes are botanically a perennial crop, they are usually cultivated as an annual one.

Sweet potatoes grow at temperatures between 15°C and 35°C; lower and higher temperatures have harmful effects on yields. In addition sweet potatoes are sensitive, depending on stage of root development, to changes in soil temperature. For this reason, interestingly, the farmer started to intercrop them, to some extent, with other crops such as sorghum and maize, and in some observed cases with coffee that shadows the soil, even if intercropping may reduce the yield.

Other information, useful for further investigation, is related to the introduction of chickpeas. Berardo *et al*, 2002, observed that, "in some regions, chickpea is considered the last attempt to plant something when a crop failure may occur. It is usually planted at the beginning of *Kremti* and comes to maturity earlier than all the long-cycle (*kremti*) crops. It is important to note that at fieldwork time (halfway through September) chickpeas had been just planted in Hammareti (Sarkema); also in Bali chickpeas cultivation has been detected".

Figure 4. *The chickpea crop is commonly grown on ridges (approximately 30 cm high and 60 cm wide). Generally, these are parallel, leaving one metre between them.*

CONCLUSIONS

The few and anecdotal case studies, as described here, call for more attentive and systematic analysis. A new CPSZ inventory seems urgent, if significant contributions on crop monitoring and food security issues in the Greater Horn of Africa are required.

ACKNOWLEDGEMENT

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SATTELITE-BASED RAINFALL MONITORING FOR AFRICA

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INTRODUCTION

For agricultural, humanitarian and economic reasons, much of Africa is critically sensitive to rainfall amount, yet measurements of rainfall are lacking over large areas of the continent. Rain gauge network densities are typically an order of magnitude below WMO recommendations while operational radar measurements are practically non-existent. (Washington et al., 2006). Seen in this context, satellite-based rainfall monitoring should be of great benefit to Africa. The advantages offered by satellite based sensors are full area coverage, near-real-time data and relatively cheap data acquisition. However, there has been surprisingly little uptake of satellite monitoring as part of routine operational programmes.

In the past this has been due mainly to lack of the necessary technical infrastructure and capacity for the reception and processing of the satellite data. Additionally, there has been a confusing array of methodologies with no clear information as to which approach might be the best for a particular application. Recent improvements in technology and reduction in cost of computer systems have meant that the technical constraints are no longer insurmountable. In particular, the PUMA project has ensured that all African national meteorological services(NMS's) have access to Meteosat Second Generation (MSG) data. In order to determine which methods are the most appropriate for a given application in Africa, it is necessary to have good validation of different methodologies against independent data. Such experiments have been carried out to a limited extent in the Sahel and Ethiopia, however more work is needed to clarify the most useful approaches for specific applications across the African landmass. The aim of this presentation is to describe rainfall monitoring methodologies relevant to Africa and present some recent validation results.

RAINFALL INFORMATION FROM SATELLITES

Electromagnetic radiation at several different wavelengths can be used to provide information about rainfall. Radiation in the visible range (0.4 - 0.9 μm) can be used to infer cloud thickness. Strong reflections of solar radiation in this range indicate thick clouds such as cumulonimbus which can be distinguished from weaker reflections from thinner clouds such as cirrus. Thermal infra-red radiation in the atmospheric window between (10-12 μm) can be used to infer cloud top temperature and thus distinguish cumulonimbus tops from lower, and therefore warmer, stratiform cloud which is less likely to be raining heavily.

Low frequency passive microwave (PMW) radiation (> 8 mm wavelength or < 40 GHz frequency) indicates the presence of rainfall sized droplets within clouds while higher frequency microwave radiation (typically < 4 mm wavelength) experiences strong absorption from ice crystals. The strong low frequency PMW rainfall signal is very good at identifying rainfall against the relatively weak, uniform background of the ocean but less good over land surfaces where the background signal is stronger depending on soil moisture and vegetation.

A summary of the rainfall information from images at different wavelengths is given in Table 1.

a)

Cloud type	TIR	VIS	Rain?
Cumulonimbus	cold	white	YES
Cirrus	cold	grey	NO
Stratiform	warm	grey	uncertain

b)

Surface	PMW > 0.8 mm (<40 GHz)	PMW < 0.8 mm (>40 Ghz)
Ocean	Rain shows warm against cool background	Ice crystals show cool against cool background
Land	Rain shows warm against variable background	Ice crystals show cool against warm background

Table 1. *Summary of information on the presence or absence of rainfall for various wavelength bands (a) thermal infra red (TIR) and visible (VIS) (b) Passive microwave*

Orbits and satellites

Meteorological and environmental satellites are commonly classified on the basis of their orbit. Most are either geostationary or polar orbiting. Geostationary satellites are positioned at a height of about 36,000 km above the equator so that they complete one revolution in exactly 24 hours thus remaining vertically above the same point on the Earth's surface. The geostationary satellites relevant to Africa are the European Meteosat 8 and 9, stationed at approximately 00N, 00E. Because of their fixed location relative to the Earth's surface, geostationary satellites provide a high temporal repetition rate. In the case of Meteosat, this is 4 images per hour for each of the wavelength channels. Polar orbiting satellites, as the name suggests, follow an orbit close to both poles at a height of about 800 km, The orbit is arranged to pass over each spot at the same local times each day. The advantage of the low orbit is that spatial resolution is much better, however it also means that each overpass only covers a small swath of the Earth's surface resulting in a low temporal frequency of two images per day for any location. The polar orbiting satellites useful for African rainfall are the NOAA AMSU (Advanced Microwave Sensing Unit) and the NASA SSM/I (Special Sensor Microwave Imager) sensors.

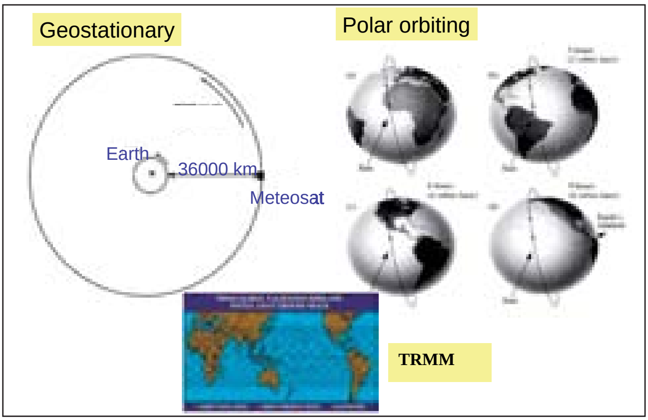

Figure 1. *Geostationary, Polar orbiting and TRMM satellite orbits.*

The Tropical Rainfall Measuring Mission (TRMM) satellite does not fit into either of the above categories. It orbits at a height of about 400 km between 350N and 350S. The complex nature of the TRMM orbit means that the number of overpasses per day for any location varies between 0 and 2.

A summary of orbital configurations is shown in Figure 1.

Sensors

The current Meteosat Second Generation (MSG) satellites carry sensors in 11 separate wavebands covering the infra red, near infra red and visible wavelength ranges. The near infra-red includes wavebands at 6.2 and 7.3 µm which are sensitive to the presence of water vapour. AMSU and SSM/I sensors measure radiation at a range of microwave frequencies, while TRMM covers visible, infra red and microwave wavelengths and is the only satellite to carry . The wavelengths sensed by the various satellites are shown in Table 2.

The spatial and temporal resolution of the satellites are shown in Table 3. Because of the longer wavelength, the spatial resolution of the PMW sensors is much coarser than the TIR and VIS channels on the geostationary satellites in spite of their lower orbit.

Platform	Orbit	Band	Wavelength/µm	Frequency/GHz
Meteosat 8 (MSG)	Geost	VIS	0.6, 0.8	
	Geost	WV	6.2, 7.3	
	Geost	IR	1.6, 3.9, 8.7, 9.7, 10.8, 12.0, 13.4	
AMSU-A	Polar	MW		23.8, 31.4, 89
AMSU-B	Polar	MW		89, 150, 183
SSM/I	Polar	MW		19, 37, 86
TRMM	Low inc	MW		11, 19, 22, 37, 86
	Low inc	radar		13
	Low inc	IR	1.6, 3.8, 10.8, 12.0	
	Low inc	VIS	0.6	

Table 2. *Summary of wavelength bands covered by various satellites*

Satellite	Sensor	Spatial Resn/km	Repetition period
Meteosat 8	Vis, TIR	3	15 min
	Vis High Res	1	15 min
SSM/I (TRMM)	19 GHz	55 (18)	12 h (variable)
	22 GHz	50 (16)	12 h (variable)
	37GHz	33 (10)	12 h (variable)
	85GHz	14 (4)	12 h (variable)
TRMM	14 GHz	1	variable

Table 3. *Summary of spatial and temporal resolution for different satellite sensors*

METHODOLOGIES

Many rainfall estimation methodologies exist. The intention in this presentation is not to provide an exhaustive list of available methodologies but rather to give some examples of algorithms currently available which could be of use for operational purposes in Africa. Four methods are described here. These are the TAMSAT operational dekadal algorithm, the NOAA Climate Prediction Centre RFE and CMORPH methods and the TRMM-based 3B42 algorithm.

TAMSAT

The TAMSAT operational algorithm is based on Meteosat TIR imagery calibrated against local raingauge data. It has been developed for quasi real time estimation of rainfall for agricultural purposes in Africa by the TAMSAT group at the University of Reading, U.K. and is used to generate dekadal (~10 daily) rainfall totals (Thorne et al, 2001). There is an implicit assumption that rainfall is convective and therefore raining clouds can be distinguished from non-raining on the basis of the cloud top temperature. Within a given calibration region, the optimum threshold temperature *Tt* is first identified which best distinguishes raining from non-raining cloud. The cold cloud duration or CCD (defined as the length of time a pixel is colder than *Tt*) is then calculated. Regression of local raingauge amounts against CCD for pixels containing gauges is carried out to determine the optimal parameters for the relationship

$$R=a_0+a_1D \qquad (1)$$

where R is dekadal rainfall amount and D represents CCD for the same period.

Separate calibrations are carried out for each calendar month using historic data to avoid over-reliance on real time gauge data (which may be very scarce and poorly quality controlled). Empirical calibration regions for each month are defined by grouping stations with similar values for $a0$, $a1$ and Tt. As an example of the process, calibration regions for August in northern Africa are shown in Figure 2.

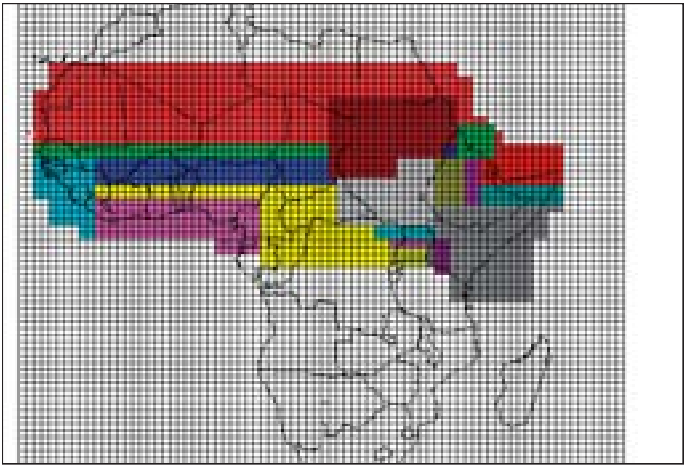

Figure 2. *TAMSAT calibration zones for northern Africa August*

NOAA Climate Prediction Centre CPC-RFE

The NOAA Climate Prediction Centre RFE algorithm uses TIR imagery to calculate the GOES Precipitation Index (GPI) (Arkin and Meissner, 1987). This is similar to the TAMSAT algorithm with fixed parameter values of Tt = 238 K, $a0$ = 0 and $a1$ = 3.0 mm hour-1. The rain rates from the GPI are then merged with rainfall estimates obtained from available PMW imagers using an error weighting process which is based on comparison with available gauge data. The combined rainfall estimates are then merged with real time gauge data available from the GTS such that the satellite field is constrained to agree with the gauge values (Xie and Arkin, 1996).

TRMM 3B42

The TRMM satellite produces several rainfall products. TRMM 3B42 combines rainfall estimate from other PMW sensors with TRMM PMW and PR data and geostationary TIR imagery using an approach described by Huffman et al. (1995). This is done as a four stage process

1. PMW rainfall estimates from TRMM and other sensors are calibrated against TRMM PR and combined
2. TIR imagery is calibrated against the PR rain estimates
3. PMW and TIR estimates are combined
4. Data are rescaled to ensure agreement between monthly totals and gauge data.

NOAA Climate Prediction Centre CMORPH

CMORPH (CPC 'morphing' technique) (Joyce et al., 2004) is a novel approach to combining PMW and TIR imagery. The aim is to make best use of the geostationary TIR high repetition rate and the PMW capability for determining instantaneous rainfall rates. Rainfall rates in a given location are computed for every PMW overpass using any sensor. Individual rainfall events are delineated on the PMW images and the TIR imagery is used to compute cloud system advection vectors between consecutive PMW images. Thus the TIR images are not used to estimate the rainfall but rather to interpolate the location of cloud systems in the time interval between the PMW overpasses. Rainfall amounts are computed with a 30 minute time step and accumulated to give daily, dekadal and monthly totals.

VALIDATION

Validation in Africa

Crucial to the increased usage of satellite-based rainfall monitoring in Africa is a better understanding of the strengths and weaknesses of the various algorithms and hence a better appreciation of which methods are most appropriate for which application. For example, for flood warning one may wish to choose a method which is accurate for high rainfall amounts and can provide estimates in real time at time steps of 1 day or less .On the other hand for agricultural purposes, it is important to represent low and zero rainfall well but the demand for real time data is less urgent. Informed decisions taking these constraints into account can only be made on the basis of good validation experiments.

By validation here is meant comparison of rainfall estimates with an independent set of measurements in order to assess the accuracy and reliability of the estimates. In the context of Africa, the validation data will almost always come from rain gauge data and therefore validation must be carried out within the limitations of these data. Two particular problems arise. One is the sparseness of the gauge network n most of Africa and the second is the spatial mismatch of the satellite estimates (areal averages over at least one satellite pixel covering 10's or 100's of km2) and the raingauge data (observations at a point). Good validation experiments must make best use of available data and make due allowance for the spatial mismatch.

Spatial considerations

One way to deal with the spatial mismatch is to interpolate the raingauge observations to areal estimates at the satellite scale. Numerous experiments (Lebel et al., 1987) have shown that usually the best way to interpolate raingauge data is by the use of kriging or a similar geostatistical technique. This has two advantages: 1) the interpolation is carried out on the basis of the spatial correlation patterns found within the data themselves and not imposed by an arbitrary rule such as inverse distance weighting and 2) the kriging process generates uncertainty estimates which are very useful in assessing the extent of agreement with the satellite estimates.

In order to deal with the sparseness of the gauge data, a useful approach is to ensure that validation is only carried out for those pixels or combinations of pixels where a minimum density of gauges exists.

The remainder of this section describes two examples of good practice in validation of rainfall in Africa.

VALIDATION CASE STUDIES

Sahel 2004

As part of the African Monsoon Multidisciplinary Analysis (AMMA) the Agrhymet Centre, based in Niamey, Niger, has put together a set of monthly rainfall totals for 2004 based on raingauge data for the area in the Sahel shown in Figure 3. The raw raingauge data have been carefully quality controlled and a kriging algorithm applied to give areal averages at scales of

0.50, 1.00 and 2.50. The details of the interpolation process are described by Ali et al., 2004.

Results of an intercomparison of a number of satellite methods using these data as validation are described elsewhere in this volume and also in Jobard et al., (2007). In this presentation, the focus is on the information that can be gleaned about the TAMSAT approach by comparison with the validation data set.

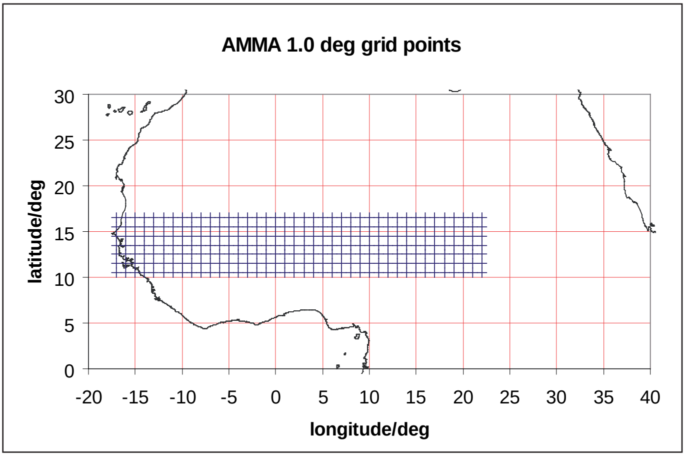

Figure 3. *Area covered by AMMA validation experiment*

Figure 4 shows a scatter plot of satellite estimates against validation data monthly totals for the main Sahelian months of May to September at 2.50 scale. It can be seen that the agreement is good overall with very little bias but there are differences between individual months. For example in May (shown as open circles) TAMSAT consistently overestimates compared to the gauge data. Spatial mapping can also be used to analyse the performance of the algorithm. Figure 5 shows TAMSAT-gauge at 10 scale for Jun and July. Areas of overestimation in the west coast and eastern parts of the validation region show up clearly. Similar results are obtained at 1.00 and 0.50 scales.

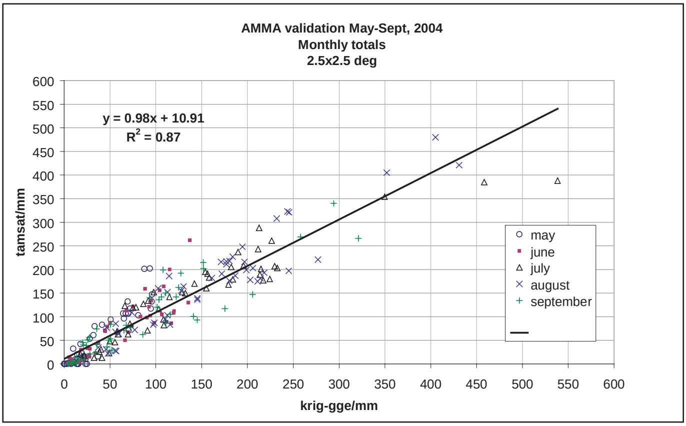

Figure 4. *TAMSAT estimates v. kriged gauge data at 2.50 resolution (monthly totals, 2004)*

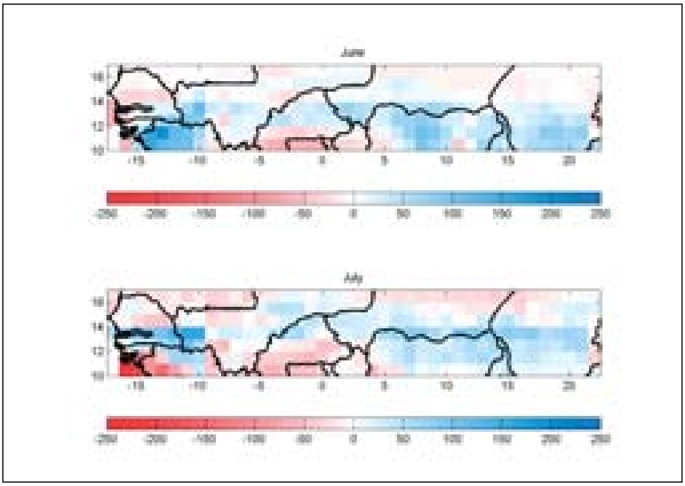

Figure 5. *TAMSAT anomalies for June and July 2004. Maps show (TAMSAT - gauge) in mm*

Ethiopia

A similarly rigorous validation study for Ethiopia has recently been carried out t by Dinku et al. (2007). Satellite algorithms were compared against spatially averaged raingauge data at spatial scales of 1.00 and 2.50. At the finer scale, the methodologies compared were CPC-RFE, TAMSAT, TRMM-3B42 and CMORPH, all described above, as well as the Global Precipitation

Climatology Project one degree daily product (GPCP-1DD). GPCP-1DD uses PMW imagery to delineate rain areas. Meteosat TIR via the Goes precipitation Index (GPI) is used to make an initial estimate of rainfall amount. Daily amounts are rescaled to match local monthly raingauge totals. Figure 6 and Table 4 summarise results of the comparison for years 200-2004. Table 5 summarises results for 2003-2004 separately as CMORPH is only available from 2003 onwards.

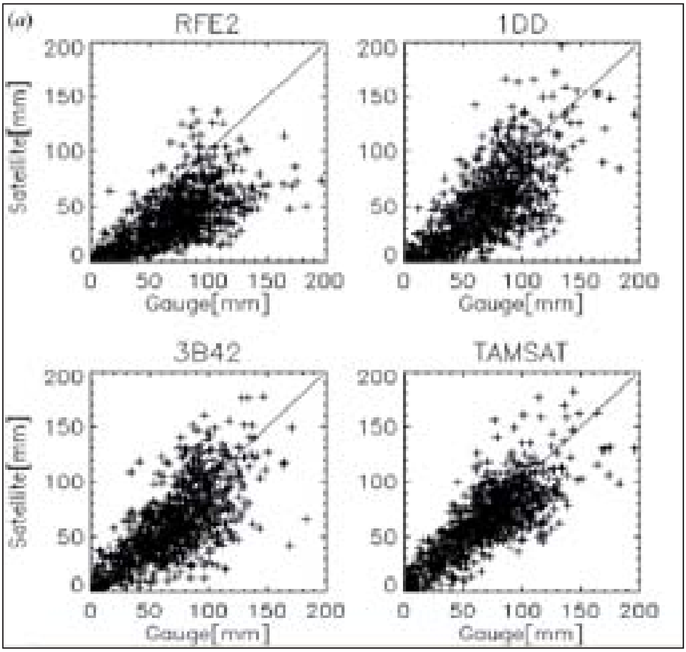

Figure 6. *Validation on of various satellite algorithms against gauge data (2000-2004). After Dinku et al. (2007).*

N=1020	CPC-RFE	GPCP	3B42	TAM
R^2	0.66	0.71	0.72	0.79
Efficiency	-0.45	0.07	0.34	0.59
Bias	0.55	0.72	0.87	0.93
Mean error/mm	-30	-19	-9	-5
RMSE/mm	58	46	39	31

Table 4. *Comparison statistics for various satellite estimation methods (2000-2004). Best performance is shown in bold. After Dinku et al. (2007).*

N=306	CMORPH	GPCP	3B42	TAM
R^2	0.83	0.68	0.68	0.79
Efficiency	0.49	0.04	0.26	0.53
Bias	0.98	0.77	0.94	0.86
Mean Error/mm	-1	-16	-4	-9
RMSE/mm	32	44	39	31

Table 5. *Comparison statistics for various satellite estimation methods (2003-2004). Best performance is shown in bold. After Dinku et al. (2007).*

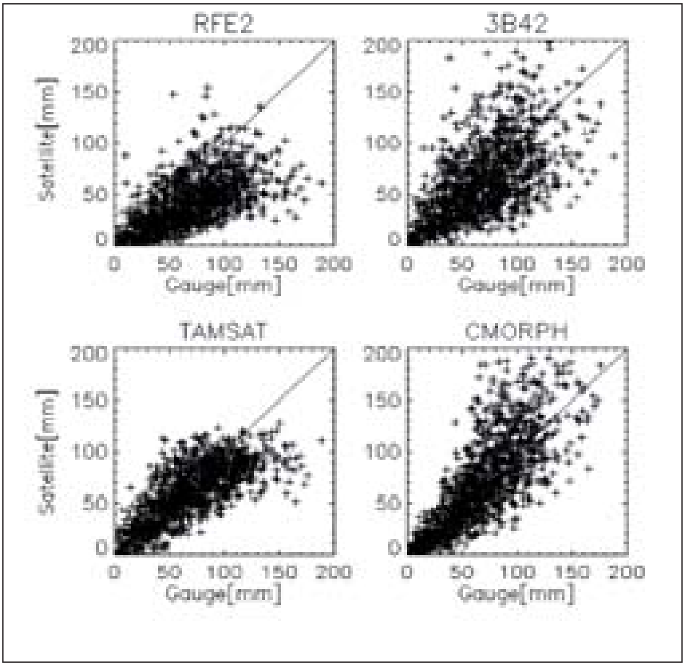

Figure 7. *Validation on of various satellite algorithms against gauge data (2003-2004). After Dinku et al. (2007).*

For the 2000-2004 comparison, the TAMSAT methodology appears best for all parameters with a tighter spread of dekadal amounts around the one-to-one line. All methods do worse for high rainfall amounts and it can be seen that the CPC-RFE algorithm (RFE-2 in the figure) underestimates consistently. For 2003-2004, TAMSAT and CMORPH share the best statistics. Figure 7 confirms that the overall spread for TAMSAT and CMORPH is similar but TAMSAT tends to underestimate high rainfall values. This is a well documented problem with CCD based rainfall algorithms. CMORPH on the other hand tends to overestimate high amounts, although to a lesser extent, thus giving a better bias.

DISCUSSION AND CONCLUSIONS

Africa could benefit greatly from more widespread use of satellite-based rainfall monitoring. The near real-time delivery and good spatial coverage can be immensely useful in agricultural and hydrological applications. Many algorithms exist and the technology is increasingly widely available, however good validation experiments are necessary to understand the advantages and limitations of the various methods and to decide on the most appropriate method for a particular application. A prerequisite of validation is interpolation of the data to the same spatial scale as the satellite estimates. Usually some form of kriging is the best approach.

Well executed validation studies have been carried out in the Sahel, as part of the AMMA project, and in Ethiopia. The AMMA study shows that during the 2004 season, the TAMSAT algorithm performs well at spatial scales of 0.50 and greater but that there was evidence of overestimation in the east and west of the region. There was also consistent overestimation during May. In the Ethiopian study, TAMSAT and CMORPH produced the best overall statistics, although CMORPH data were only available from 2003. TAMSAT showed a tendency to underestimate high rainfall amounts whereas CMORPH tended to overestimate. It is to be hoped that these validation studies can be extended and similar validation experiments can be undertaken elsewhere in Africa to facilitate more widespread use of satellite algorithms.

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AGRICULTURAL APPLICATIONS OF TAMSAT SATELLITE-BASED RAINFALL MONITORING IN AFRICA

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INTRODUCTION

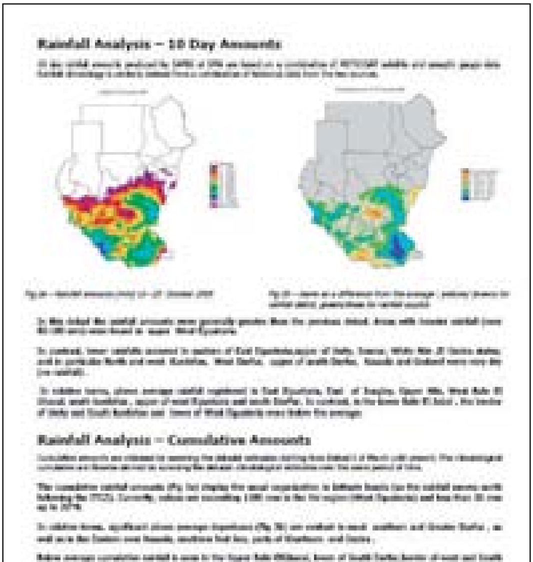
Timely and accurate assessment of crop yield is important for national, regional and international agencies concerned with food security in Africa (Rijks *et al.*, 2003; Verdin *et al.*, 2005). Satellite rainfall estimates (RFE) have the potential to be used as inputs to crop yield prediction models due to the good spatial coverage and high temporal resolution of the satellite information. This is particularly relevant to Africa where the ground-based observational network is often sparse and not always well maintained (Washington *et al.*, 2006). In this presentation we examine a currently operational *qualitative* crop yield information system and look at the results of research into *quantitative* crop yield forecasting which makes use of an ensemble approach to allow the assessment of the uncertainty on the final crop yield estimate.

CURRENT TAMSAT OPERATIONAL APPROACH – SAMIS

The TAMSAT group at the University of Reading, UK, has run an operational system of rainfall monitoring for Africa for a number of years (see http://www.met.reading.ac.uk/tamsat/). The method is based on local calibration of Cold Cloud Duration (CCD) derived from Meteosat thermal infrared (TIR) imagery. Details are given elsewhere in this volume and also in Grimes et al. (1999). From such rainfall estimates, a subjective and qualitative assessment of crop yield can be made, simply by inspecting the cumulative seasonal rainfall at a given stage in the growing season. However, it is also possible to derive secondary products that provide more useful information. These secondary products may include such indicators as spatial maps of sowing rain, dekadal and cumulative anomalies at different stages in the growing season and vegetation indicators such as NDVI derived from NOAA satellite imagery. Such a system (the Satellite AgroMeteorological Information System or SAMIS) has been running operationally in Sudan for several years and has recently been installed in Uganda. An initial set of output products was devised after consultation with user groups in Sudan. These include:

- dekadal rainfall total
- cumulative seasonal total
- dekadal rainfall anomaly
- cumulative rainfall anomaly
- start of sowing season
- difference from previous year
- NDVI
- NDVI anomaly at different stages of the season

The software system is designed around a GIS package that allows the production of output products as simple combinations of the basic rainfall and vegetation indices. This enables a flexible response to changing user demands. The GIS framework also facilitates the production of maps and charts. Figure 1 shows a sample page from the dekadal bulleting produced under SAMIS.


Rainfall Analysis – 10 Day Amounts

Rainfall Analysis – Cumulative Amounts

Figure 1. *Sudan Meteorological Authority SAMIS bulletin*

QUANTITATIVE CROP YIELD FORECASTING

Overview

While a system such as SAMIS is an improvement on raw rainfall data in terms of supplying useful information to the agricultural sector, it does not fully use the quantitative information available from the satellite data. Because of their availability in real time and full spatial coverage, the satellite RFE are well suited for use as input into crop yield forecasting models. To understand whether this approach is useful in the African context, an important consideration is the level of uncertainty on the satellite rainfall estimates and the way in which this uncertainty feeds through to the final crop yield prediction. The approach used is to calculate an ensemble of rainfall fields that reflects the uncertainty in the rainfall values while taking account of their spatial coherence. The members of this ensemble are then used to drive a crop model giving a distribution of possible yields that can be interpreted in terms of error bars or confidence limits.

Case study: groundnut production in the Gambia

As a case study, we have investigated the prediction of groundnut yield in the Gambia using TAMSAT RFE at a daily time step to drive the GLAM crop yield model. GLAM (Generalised Large Area Model) was developed in the Dept of Meteorology at the University of Reading. It is a process-based model with a simple enough structure to allow it to be used with NWP model output or satellite data. A detailed description of GLAM is provided in Challinor *et al* (2004).

Divisional groundnut production data from 1974 to 2002 for the Gambia were obtained from the Department of Planning, the Gambia. The two most important divisions are North Bank Division (NBD) and Central River Division (CRD) shown in Figure 2. Daily weather data during the crop growing seasons (June to November) for agrometeorological and synoptic stations were obtained from the Department of Water Resources of the Gambia. These data include maximum and minimum temperature, relative humidity; sunshine hours, surface wind speed and gauge rainfall.

For all parameters except rainfall, data were spatially interpolated to give daily areal averages for the two important groundnut growing administrative districts - North Bank Division (NBD) and Central River Division (CRD) (see Figure 2). Potential evapotranspiration was derived from the gridded meteorological data using the FAO Penman-Monteith equation. The treatment of raingauge data is described in Section 3.4.

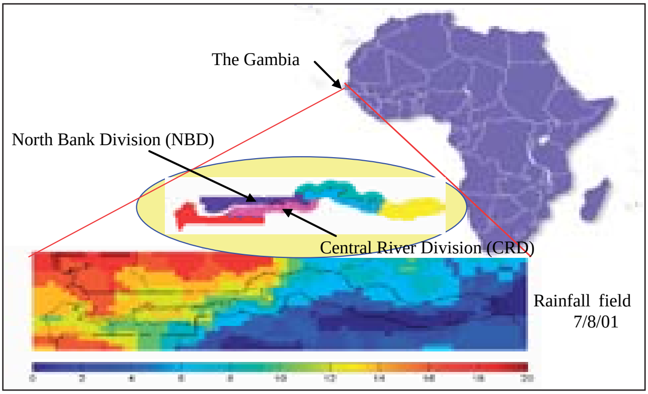


Figure 2. *Map of the Gambia showing the main ground nut growing areas*

Description of ensemble method

The aim here is to generate an ensemble of rainfall estimates for the areal average rainfall over the areas of interest. The range of ensemble members is influenced by:

- the statistical relationship between CCD and raingauge data at a pixel scale taking account of both
- the probability of rain for a given CCD value
- the distribution of rainfall amount, conditional on rain, for a given CCD value
- the spatial correlation pattern of rainfall observed in the gauge data for both rainfall occurrence and rainfall amount.

Having computed an ensemble of rainfall fields, it is then a trivial matter to calculate the areal average daily rainfall over the crop growing districts for each ensemble member. The ensemble of areal averages may then be used as input to the crop yield model to obtain finally a distribution of possible crop yield values from which a confidence interval for the prediction may be derived.

Pre-processing of gauge data

To determine the statistical relationship between gauge and satellite values, it is important that they are compared at the same spatial scale. This was achieved by converting the gauge data to pixel areal averages using kriging. Following the method of Barancourt et al (1992), a two stage operation is performed in which firstly indicator kriging is carried out to determine rainy and non-rainy areas and secondly ordinary block kriging is used to determine the optimal areal rainfall for each satellite pixel. The gauge data processed in this way is hereafter referred to as gauge-pixel data.

Having pre-processed the gauge data, the probability of rainfall and distribution of rainfall amounts for a given CCD may be modelled. The probability of rain *p* is best represented by logistic regression

$$\begin{aligned} &In\left(\frac{p}{1-p}\right) = b0 + b1 \times CCC,\ CCD > 0 \\ &p = p0 \text{ for } CCD = 0 \end{aligned} \qquad (1)$$

where *bo*, *b1*, and *p0* are empirical values to be found by calibration.

For a given CCD, mean rainfall amount and variance conditional on rain (respectively μ+ and σ+) can be modelled by

$$\mu_+ \equiv E\left[z \mid z > 0, CCD\right] = a_0 + a_1 \times CCD \qquad (2)$$

$$\sigma_+^2 \equiv Var\left(z \mid z > 0, CCD\right) - \sigma_k^2 \qquad (3)$$

$$\sigma_+^2 = \left(\kappa_z\, \mu_+^{\theta_z}\right)^2 - \left(\kappa_b\, \mu_+^{\theta_b}\right)^2 \qquad (4)$$

where z is rainfall amount and κ*z*, κ*b*, θ*z*, θ*b* are empirical constants to be found by calibration. The second term in Equation 4 represents the kriging uncertainty in the gauge-pixel values used in calibration. This must be subtracted from the total variance of the RFE v. gauge pixel relationship to give the variance of the satellite rainfall relative to the unknown true rainfall (Grimes et al., 1999).

Representative graphs of probability and rainfall distribution are shown in Figure 3 and Figure 4 respectively.

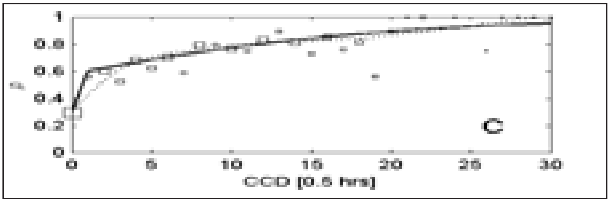


Figure 3. *Probability of rain as a function of CCD*

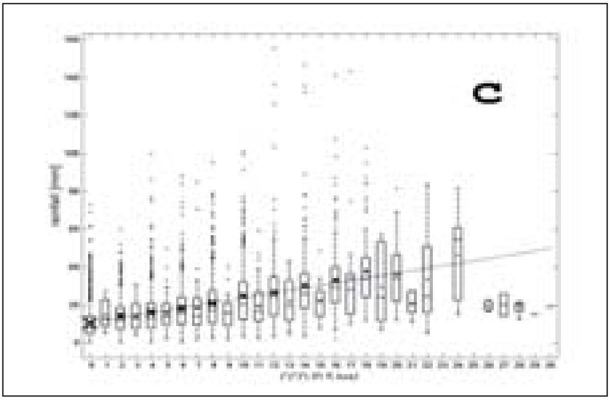


Figure 4. *Boxplot, showing the rainfall amount as a function of CCD. x represents the mean gauge-pixel value for each CCD amount.*

Generation of ensemble members

An ensemble member could be generated by determining for each pixel a binary rainfall indicator using a Bernoulli trial based on Equation (1) and then sampling a rainfall amount for each rainy pixel using Equations (2) and (4). However such a rainfall field would be unrealistic in that the spatial coherence pattern of the true rainfall field would be absent. In order to generate rainfall fields which have the correct pixel statistics as given by Equations 1 to 4 while at the same time preserving the correct spatial correlation patterns for both rainfall occurrence and rainfall amount, the method of Sequential Simulation was used (Goovaerts, 1997). Details of the method are given in Teo and Grimes (2007).

An example of this approach is shown in Figure 5.Here, the left hand column shows the CCD field for one day and the rainfall estimate field (RFE) calculated using Equation 2. Columns two and three show eight individual ensemble members from a total of 500. The mean of the 500 members is shown in Column1 and matches exactly (as it should) the RFE field. It can be seen from Figure 5 that the patterns of rainfall appear realistic in terms of spatial coherence and that although there are considerable differences among the members, there is a general tendency for more rain in the south and west and less in the north and east, consistent with the original CCD field.

The input required for the crop yield model is the daily areal average rainfall for each growing district. This was computed for NBD and CRD divisions for each ensemble member giving an ensemble of possible inputs for each day.

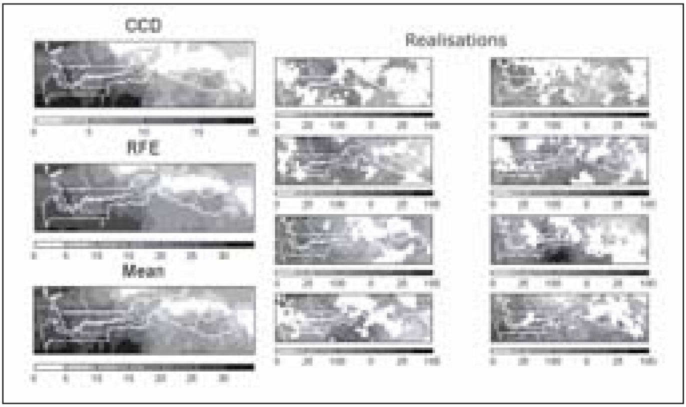


Figure 5. *Left hand column shows CCD map, corresponding RFE calculated using Equation 2, mean of ensemble members. Centre and right hand columns show individual ensemble member rainfall fields*

Validation of ensemble

Validation of the ensemble is non-trivial in that there is not an ensemble of 'true' rainfall fields against which ensemble members could be compared. However, it is possible to make a statistical evaluation by comparing the probability of exceeding specified rainfall thresholds as determined from the ensemble members, and the gauge-pixel data. Results for different thresholds are shown in Figure 6. It is clear that the probabilities of ensemble and gauge data agree well with the exception of slightly elevated probabilities for high rainfall among the ensemble fields. ($z > 20$ mm).

Good agreement was also found in terms of the spatial correlation of the simulated and real rainfall fields. The agreement improved when fields with very small areas designated as rainy were removed from the calculations. This is because the algorithm appears to overestimate the probability of rain for zero CCD in cases where the almost the whole domain is rain free. Figure 7 compares variograms generated from the gauge data and the simulated rainfall ensemble. Again the agreement is very good for all months.

The GLAM model

A schematic of the GLAM model is shown in Figure 8. Required inputs are daily values of rainfall, solar radiation, maximum and minimum temperature and humidity. The model is pre-calibrated with crop-specific parameters that determine timings of phenological stages, length of growing cycle etc. External influences such as management practices, pests and diseases are subsumed into a 'crop-yield factor' which gives the final yield as a fraction of potential yield under idealised external conditions. For a complete description of the GLAM model, see Challinor et al (2004)

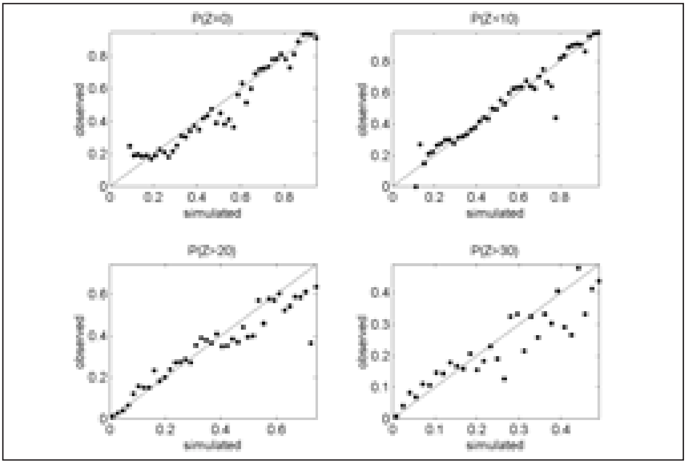


Figure 6. *Comparison of probability of exceedance of various rainfall thresholds for gauge-pixel and ensemble data. The plot is generated by binning pixels according to the RFE probability of threshold exceedance. The bin exceedance probability is plotted on the x-axis; the proportion of gauge-pixel values exceeding the threshold for the binned locations bin is plotted on the y-axis.*

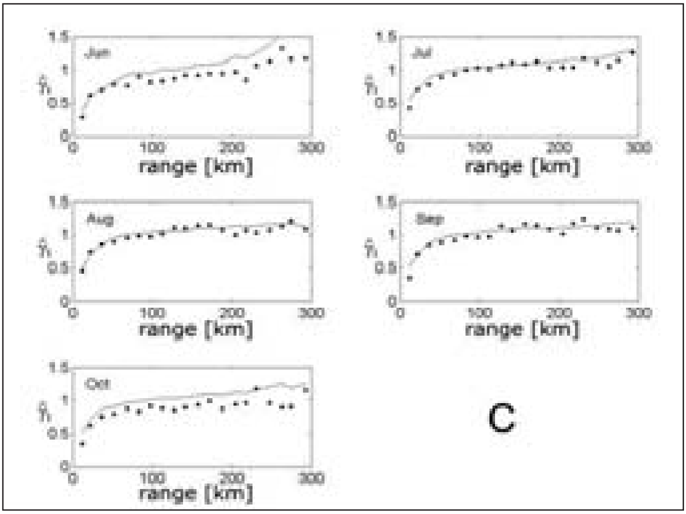


Figure 7. *Comparison of variograms from the ensemble (solid line) and from the gauge data (dotted line) for all months*

RESULTS

Comparison with CSWB

The GLAM model was compared against the FAO CSWB (Crop Specific Water Balance) model using both gauge data and satellite data as input. Results for NBD are shown in Figure 9. For both models, gauge and satellite RFE give similar results with GLAM performing somewhat better than CSWB in matching the inter-annual variability of the observed data. The fact that the TAMSAT satellite RFE estimates perform as well as the gauge data is a good result in that the Gambia has a high density of gauges compared to most African countries. Furthermore, the case study has been performed in hind-cast mode when all gauge data were available. This would not be the case in a real time operational context.

Uncertainty analysis

In order to determine the effect of the uncertainty in satellite rainfall amount on the crop yield output, values of areal mean rainfall were randomly selected from the distributions for each day as described in Section 3.5 and used as input to GLAM to give a final yield estimate.

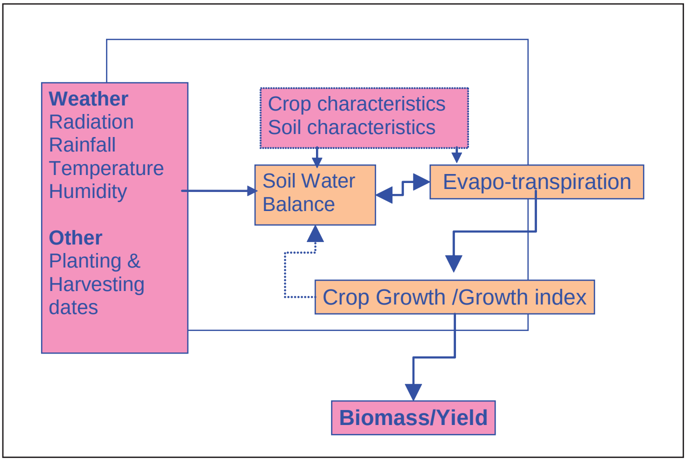


Figure 8. *Schematic of GLAM crop yield model.*

The procedure was repeated 300 times to give a distribution for the final yield for each year. These are plotted as error bars for CRD and NBD as shown in Figure 10.

For comparison, error bars are also plotted for calibration bias (calibration parameters varying by ± 30%) and sowing date uncertainty (± 10 days). Both of these are realistic values in terms of previous observations. It can be seen from Figure 10 that the crop yield uncertainty associated with stochastic uncertainty in the rainfall estimates is actually very small in years of high yield. This is due to the fact that the crop responds primarily to soil moisture rather than rainfall. The integrating effect of soil moisture storage means that provided the rainfall is sufficient, small fluctuations on a day-to-day basis have little impact on final yield. However, in drought years, fluctuations in rainfall for individual days may have a significant impact on the final harvest because of insufficient soil moisture at critical times in crop development.

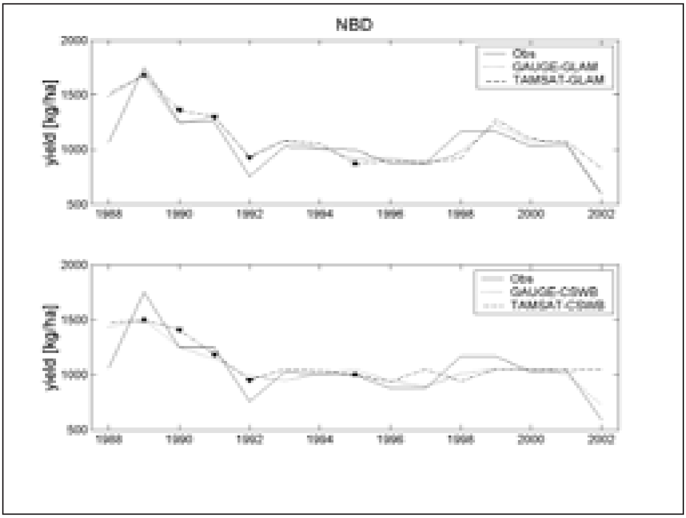


Figure 9. *Comparison of GLAM and CSWB models for the NBD division, using gauge and satellite rainfall as input.*

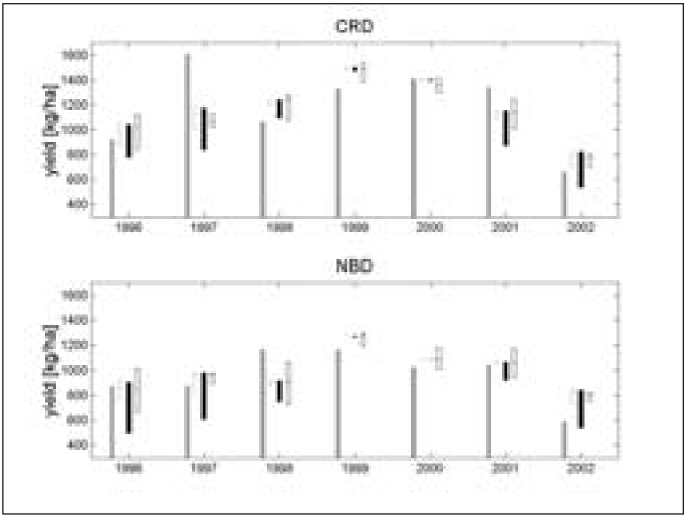


Figure 10. *Uncertainty estimates on crop yield predictions for GLAM using satellite RFE input. Grey open box = uncertainty from rainfall ensemble; black open box = uncertainty on sowing date; black filled box = uncertainty on calibration parameters.*

CONCLUSIONS

Current operational usage of satellite rainfall estimates in African agriculture tends to be limited to qualitative assessment of crop yield depending on rainfall total and comparison with previous years. However, there is great potential to make more quantitative use of the satellite data because of their good area coverage and availability. An example of a system that makes better use of the rainfall data is the SAMIS system currently operational in Sudan and Uganda, although this still only provides qualitative information. For quantitative crop yield predictions, an important issue is the uncertainty associated with the rainfall estimates and how this feeds through to the final yield estimate.

A feasibility study on the use of TAMSAT satellite RFE as input to the GLAM crop yield model has been carried out for groundnut production in the Gambia. In order to investigate the effect of uncertainty on rainfall amount, an ensemble approach based on sequential simulation was used to generate a distribution of final yield amounts.

Results show that the GLAM model outperforms the standard CSWB yield model and that the satellite estimates perform as well as the estimates based on gauge data. As the Gambia has a relatively high density of gauges this is a good result - particularly as these experiments were performed in hind-cast mode and, in practice, the full complement of gauge data would not be available in real time. Results from the ensemble runs show that the crop yield model is relatively insensitive to the uncertainty in the rainfall estimates provided the rainfall is sufficient. This is attributed to the integrating effect of the soil. In drought conditions, however, small changes in daily rainfall may have large effect on the final yield.

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THE APPARENT CURRENT FLUCTUATIONS IN SEASONAL RAINFALL OVER THE PAST FIVE YEARS

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ABSTRACT

Most previous research done on seasonal rainfall dealt with the seasonal total of water available to the crop. Annual or seasonal total precipitation is not a good measure for agricultural production because the distribution of rainfall is a critical factor affecting crop performance. It is devastating for peasants if seedlings perish during dry spells after sowing because of a "pseudo-start" of the growing season.

The current fluctuations in seasonal rainfall are obvious to all in the farming community. This paper examines such fluctuations and the so-called "erratic rains". Four stations were selected on the basis of the length of their records and on their location in marginal areas. Dry spells in the past forty years for Entebbe, Kibanda, Kamenyamigo, and Mbarara were analyzed using INSTAT+ and compared with the current five-year dry spells. Also, the mean start dates of the growing seasons for the main rains in March-April-May (MAM) were compared with those for the current five-year period. The results show normal variations in the dry spells, with a non-significant rise of 30% for Kamenyamigo and 20% for Mbarara. Data for Entebbe showed an upward trend of 65% in the last five years.

Various criteria for the start of the growing season, affecting crop-performance, were used. The resulting "starts" include pseudo-starts, late starts, normal starts, successful starts and failure starts that lead to a no-season situation. This paper presents results of a preliminary analysis of which the objective was to respond to a public outcry about changes in seasonal performance. Further collaborative research is required to give more conclusive results.

INTRODUCTION

The ultimate objective of agricultural science is to improve, directly or indirectly, the economic conditions, and their sustainability, for farmers, and hence food security for all.

To be effective, results of research must be applied to respond to the needs of the community. In an era when climate change is superimposed on climate variability, investigations are needed on uncertainties and fluctuations in the start of the growing season and its impact on agriculture to see if there are changes in the normal variability or a significant shift in the trends. The development of crop monitoring systems in Africa is in line with the above objective.

No crop or animal can gain economic importance in an agricultural system unless it is adapted to the prevailing environment; hence the need to study current changes. Efficient management of the water available to the crop, and understanding the reasons for its fluctuation, is a major factor in agriculture.

The complexity of climate variability, and especially rainfall, both in space and time is a major challenge to meteorologists and demands collaborative sharing of information on research with those in other disciplines. CRAM activities can provide an environment for coordinated studies of climate variability. Spatial and temporal variations in the amount, onset and cessation of the rains, even in places within the same climatic zone, compound the study on the start of the growing season. Dry spells during critical physiological phases cause moisture stress to the crop and can reduce the expected yield. While a dry spell may increase the risk of poor performance of the crop, a pseudo start may cause total loss to the farmer when seedlings fail to develop into plants. Thus the need to study the pattern of these pseudo starts and of prolonged dry spells and their frequency within the growing season and to define "safe" planting dates for the farmers, taking into account that different crops have different crop water requirements (KC) and often changes in available water lead to a reduction in yield.

BACKGROUND OF THE STUDY

In Uganda, Crop and RAngeland Monitoring is exercised through the FEWS-Net activities. The World Food Programme (WFP), the Ministry of Agricultural (MoA) and the Department of Meteorology (DoM) partcipate by providing climate and crop data.

An initial analysis for the present study was done in preparation for the CRAM workshop in 2003; this is now being extended to respond to users' request.

Lake Victoria, the second largest inland water body in the world, and also the lakes Kyoga and Albert have an impact on the rainfall in Uganda. The areas very close to the equator experience a bi-modal type of rainfall

(Fig. 1; Fig. 2); north of 1.5°N, there is a uni-modal type of rainfall. There are some marginal, drought prone, areas, referred to as the cattle corridor that have low annual rainfall ranging between 900 to 500 mm. Rainfall is as high as 2800 mm in the mountains, islands and peripherals of Lake Victoria. Seasonal rainfall amounts are often enough to sustain the crop water requirements (Fig 3). Coffee, cotton, sugar cane, and tobacco are some of the major cash crop grown in the country. Banana, maize, millet and legumes are major food crops. Farmers who normally depend on their indigenous knowledge to determine the start of the rains are frustrated by the seasonal failures that occur. Following this study, farmers that wish to plant early without considering the risk of encountering dry spells of 5, 7, or 10 days (depending on the location) can be advised about the chance of occurrence of such dry spells.

OBJECTIVE OF THE STUDY

The major objective was to respond to requests for information by users, including the MoA and the WFP. Specific points were:

- to identify the current fluctuations in the seasonal rainfall patterns
- to compare current variations with those of the past
- to establish the state of, and the conditions contributing to, the distortions in seasonal rainfall
- to furnish an annual map of the distribution of dry spells similar to the mean annual rainfall map.

METHODOLOGY

Data:

Kibanda, Mbarara, Kamenyamigo, and Entebbe were selected on the basis of the length of their record and their location in the marginal parts or in the wet areas. CLICOM daily and pentad rainfall records covered the period 1963- 2006. As the study is about dry spells, suspicious zeros were taken care of or left out if they preceded a very high value. The digitization exercise under the Hydroclimatic study (2002) had just been concluded taking care of the necessary quality control on the rainfall datasets. A station year was considered missing if it had more than 30% missing data. On average a record length of 30 years was used for each station.

Maize was taken as a base crop and the Kc data for maize were obtained from the FAO CropWat base and cumulative curves were plotted.

Methods:

a. Daily rainfall data were analyzed to obtain the distribution and establish the start of the rains. The frequencies of the daily amounts were established to determine the threshold value of a rain day so that proper criteria of the start of the growing season could be set;

b. CLICOM data was imported into INSTAT+. Because different areas have different rainfall characteristics both in distribution and amounts and different agricultural systems, different criteria were set for each station as can be shown in Table1;

c. The MAM season was analyzed because it is the longest rainy season in many parts of the country. The calendar was set to Julian days and initial rain days established using daily means;

d. Taking daily mean evaporation of each station, criteria of 7, 9, and 10 days of dry spells were set for calculating safe planting dates in the wet and dry areas respectively (Fig. 4);

e. Using INSTAT+ the probable planting dates were calculated in each year by setting criteria of 25 mm of rainfall in 5 days for high annual rainfall stations, such as Entebbe (Fig. 5), and 10 mm totaled over 5 days for the areas of low annual rainfall respectively;

f. The cumulative crop water requirement for Zea Maize, with 110 days of growth, considered as a base crop in Uganda, was calculated;

g. Maximum dry spells and their frequency within the first 90 days after the start of the growing season were calculated using INSTAT+ and assuming that any crop had reached maturity by that time;

h. The mean of the start dates was calculated using both the arithmetic mean and the frequency. The start dates, the dry spells and the length of the growing season were normalized and plotted on a time series graph;

i. Mean starts and early starts were grouped together because they impact positively on crop performance. Late starts and pseudo starts were also grouped together to calculate their frequency in a five-year period.

j. Start dates and the dry spells were normalized and plotted on a time series graph;

k. The trend was calculated using the Least Square method and the significance of the trend was calculated using the Student's t-test

$$T = r\sqrt{\frac{(N-2)}{1-r2}}$$

Where:
N= number of years
r = correlation coefficient

RESULTS

Results as defined below show the nature of various starts, the frequency of the maximum dry spell and the within-season rainfall amounts.

Pseudo Starts: This is when the rain starts earlier than the real effective onset of the rains, giving the farmer a false belief to plant, but when a subsequent prolonged dry spell depletes all the soil moisture so that a farmer looses the early seedlings and his seeds.

Early start: This is when the season starts before the mean start date, meeting the criteria

Late start: The season starts many days after the mean start dates, meeting the criteria much later in the season

Risky planting dates: This designates the time when the rains have started but when the farmer risks the chance of meeting 5, 7, or 10 day dry spells within the season, in other words he does not wait for the rains to be stable

Safe planting: These are the dates, taking into account the risk of dry spells and meeting a set level of probability to avoid these, unwanted, dry spells.

Success Years: This is when the farmer plants early but does not get into the risk of dry spells; these dates normally coincide with those safe planting dates.

Station name	Initial date	Mean start date	No of R/days	Amount totaled over 5day	Minimum threshold of a R/Day	Expected Dry Spells Days
ENTEBBE	40	60	3	30mm	4.0 mm	7 days
MBARARA	30	48	2	10mm	1.0 mm	10 days
KAMENYAMIGO	45	55	2	10mm	1.0 mm	10 days
KIBANDA	40	46	3	15mm	1.0 mm	10 days

Table 1. *Criteria set for the start of the growing season*

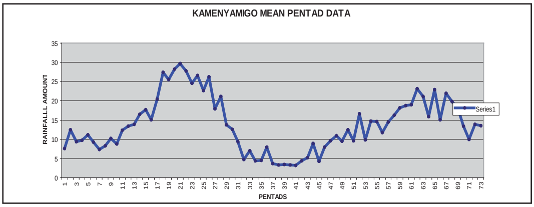

Fig. 1. *Steady rains start around pentad 9 in Kamenyamigo. The season has two peaks.*

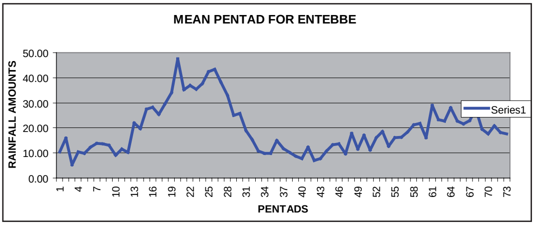

Fig: 2. *Entebbe rain starts towards the 10th pentad. Steady rains without spells start around the 62nd Julian day. The slack around the 8th pentad is due to the first dry spells before the season stabilizes*

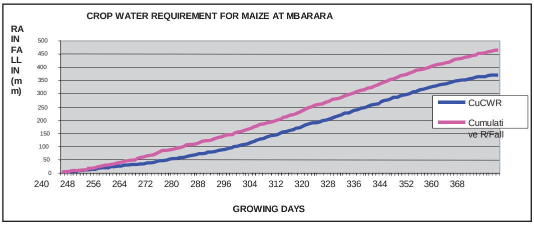

Fig: 3. *The maize crop was considered as a base crop and the rainfall in Mbarara exceeds the water requirement throughout the growing season*

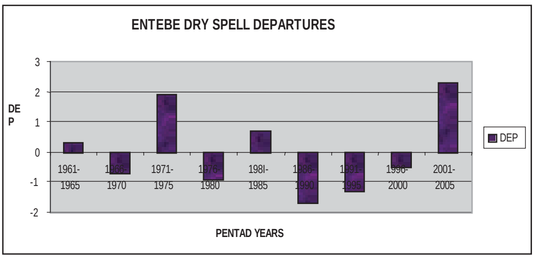

Fig 4. *Entebbe. Difference, in number of days, of the length of within-season dry-spells compared to the five-year mean.*

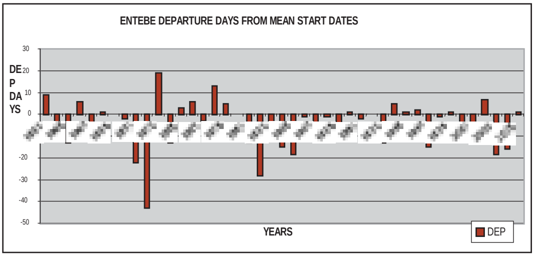

Fig 5. *Entebbe. Departures from the mean dates of start of the season, showing a generdownward trend of 70% within the past 50 years. This indicates more late starts in the recent years.*

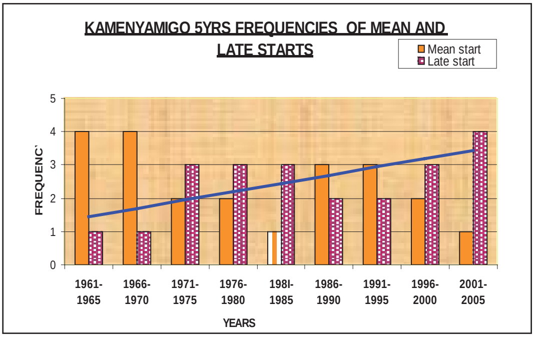

Fig 6a**.** *Frequencies of mean and late starts in every five years. There are normal variations, even though the frequency of late starts in the last five-year period was the highest in the past 30 years*

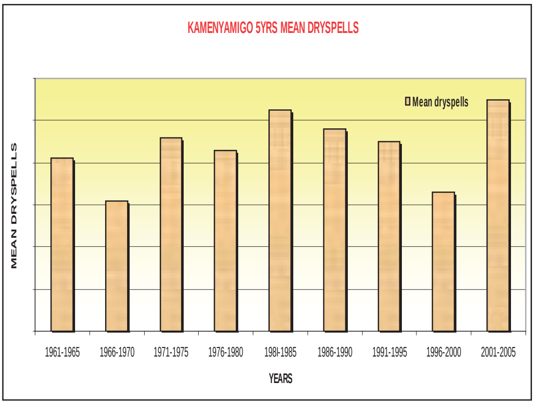

Fig. 6b. *Five-year means of within-season maximum dry-spells. The last five-year period, 2001-2006, has the highest mean of the maximum dry spells*

GRWDT	1999	2000	2001	2002	2003	2004	2005	2006
56	0	0	0	0	0	0	0	22.2
57	0	0	0	0	0	0	0	0
58	0	0	0		1.8	0	0	0
59	0	0	0	7.6	0	0	3.4	0
60	5.9	5.7	0	0	0	0	0.0	13.1
61	0	0		0	3	0	2.0	0
62	7.9	1.5		0	0	0	0.0	0
63	2.4	0		0	0	0	0.0	0
64	3.3	0		0	0	0	26.7	8.3
65	0	2.1		0	0	0	0.0	0
66	0	0		0	0	0	0.0	32.0
67	0	12.5		0	0	0	0.0	0
68	18.8	0		0	0	0	0.0	0
69	13.1	0		0	0	0	15.2	0
70	0	0		36.9	0	0	0.0	0
71	0	0		0	0	12	0.0	0
72	0	0		0	1	0	0.0	0
73	0	0		13.7	20	10.5	0.0	0
74	18.5	54.9		0	0	0	39.3	0
75	11.4	0		0	0	0	2.5	32.4
76	0	3.2		0	0	6.5	0	1.9
77	0	0		2.2	52	0	0	0
78	0	0		7.7	0	0	0	27
79	0	15.4		0	0	0	0.0	0
80	0	0		18.9	8.4	0	0.0	1.3
81	0	0		2.3	0	0	6.3	0
82	0	0		0	0	0	1.4	33.4
83	0	0		0	0	0	0.0	0
84	0.6	0		0.9	0	0	0.0	0
85	5.6	0		14.8	2.5	0	0.0	0
86	17.1	46		0	0	0	0.0	0
87	0	4.8		0	0	0	0.0	0
88	15	0.7		0	0	0	9.7	0
89	25.4	0		18.5	0	0	0.0	0
90	0.8	0		0	42.4	0	2.6	0
91	0	0		0	0	0	0.0	0
92	0	0		30.2	14	0	0.0	9
93	0	2.2		15.8	1	0	0.0	0
94	8.4	9.1		3.4	0	0	0.0	0
95	0	0		0	18	0	0.0	0
96	0.4	2		0	47	1.7	0.0	10
97	0	0		0	45	0	15.1	16.5
98	0	1.4		2.7	5	0	0.0	0.5
99	5.2	0		0	0	10	0.0	0
100	0.5	0.7		0	0	0	17.7	0
101	0	2.3		20.1	8	0	0.6	8.3
102	0	0		9.3	28	1.1	0.0	23
103	0	0		0	10	0	0.0	0
104	0	28.5		0	15	0	1.2	0
105	6.2	0		1.2	0	0	0.0	2.4
106	18.4	0		22.6	13	0	0.0	5.3
107	52.1	0		0.5	64	0	15.1	10.3
108	0	20.1		0	1	0	5.1	0
109	3.1	0		0	39	0	0.0	19.5
110	0	0		0	37	0	2.2	20
111	0	0		0	40	31.5	3.5	5.7
112	0	0		0	12.5	0	0.0	12.1
113	20.2	5		0	0	0	0.0	1.8
114	8.4	1		0	0	13.1	8.1	36.2
115	11	0		0	0	0	0.0	0
116	17.3	4.1		13.5	0	11.9	0.0	0
117	6.3	0		7.2	0	0	0.0	0
118	9.8	11.2		16.9	15	41.5	0.0	22
119	0	0		0	0	0	33.2	30
120	18.5	50		0.8	0	0	9.4	16.4
121	14.2	61		0	0	0	1.1	0
122	2	73		0	0	40.7	0.0	0
123	7.9	9		4.9	16.9	0	0.0	24.5
124	2.6	20		0	0	0	4.8	0.5
125	0	25		0	0	0	2.7	1
126	8.3	2		0	0	0	0.0	0
127	0	5		0	0	0	0.0	0
128	15.1	0		0	0	0	6.9	1.2
129	8	0		0	0	0	1.8	0
130	6.1	0		0	0	0.6	15.6	0
131	12.5	0		0	29.7	2	0.0	1.4
132	8.5	2		0	5.7	0	0.0	0
133	0	8		0	0	0	0.0	0
134	4.3	0		0	0	0	3.9	1.7
135	0	1		11	0	0	0.0	0
136	0	5		0	0	0	0.0	0

KEY: Late start dates and abnormal spells
Normal Dry spells
Favorable condition for the start
Normal raindays within the growing season

Fig. 7. *Kamenyamigo frequency of dry-spells, 1999-2006*

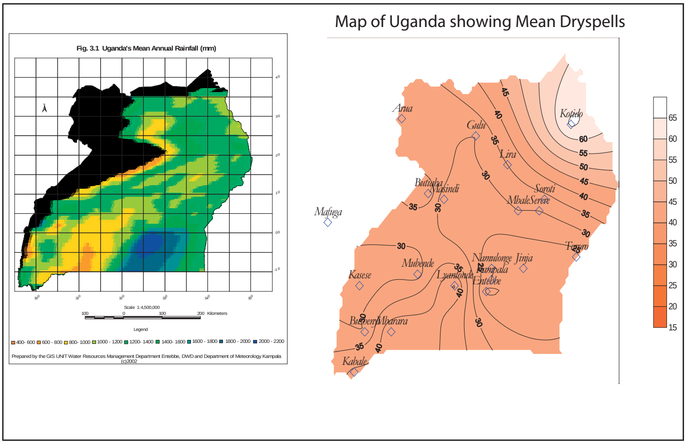

Fig.8. *Annual rainfall map*

	2000	2001	2002	2003	2004	2005	2006
46	0	0	0	0	0	0	0
47	0	0	0	0	0	0	0
48	0	0	0	8.4	0	0	0
49	0	0	10	0	0	0	0.2
50	0	0	0	0	0	0	0
51	0	6	0	0	10.7	0	0
52	0	0.7	0	0	0	0	0
53	0	0	0	0	0	0	0
54	0	0.8	0	0	0	1.1	2.1
55	0	4.4	0	0	0	0.5	0
56	0	0	0	0	0	0	0
57	24	0	2.8	0	0	0	0
58	0	0	58.8	33.3	0	0	0
59	14.2	0	16.7	0	0	0	60.3
60	7.5	0	4.4	0	0	0	20
61	0	0	0	0	0	0	0
62	0	0	24.2	0	0	30.6	0
63	0	0	1.3	0	0	5.7	0
64	0	7.5	8.4	0	0	0	0
65	0	0.7	0	0	0	0	0
66	0.6	0	7.3	0	0	3	0
67	0.4	18.4	24	0	0	0	0
68	0	0.3	0	0	0	0	0
69	0	0	9.6	0	0	0	0
70	0.7	0	8.1	0	0	0	0
71	0.4	0	30	0	0	9.1	0
72	0	2.4	0	0	7.3	4	0.2
73	0.3	0	10.2	3.1	0	0	0
74	5.1	28.2	0	15.3	0	7	9
75	8	2.7	0	3.2	0	0	5.1
76	0	0	29	1.6	0	6.2	0
77	17.2	0	11.1	0.4	0	0	4
78	0	4.2	9	0	0	0	0
79	6	0.6	26.4	0	0	0	0.3
80	0	0	2.6	4.4	0	8.1	0
81	0	0	0	11.7	0	0	0
82	0	0	1.2	33.3	0	0	0
83	0	0	21.4	0	0	0	0
84	0.7	4.4	1.5	0	0	0.2	0
85	2.3	11.5	0	9.5	8.2	6.3	0
86	9.2	0.5	0	11	0	0	6.2
87	1	0	8.4	34.7	0	70	0
88	0	8.3	0	0	0	0	0
89	9.1	9.5	16.5	3.6	0	0	0
90	2.5	0.4	11.4	2.4	6.1	3.7	0
91	0	6.2	15.4	0	30.4	0	4
92							
93	2	0	10	4.1	6.3	0	30.1
94	1	0	10.5	0	0	0	0
95	12.7	5.1	0	0	0	9.1	0
96	12.6	4.3	0	0	7.7	0	0
97	2.2	9	0	0	0	0	5
98	0	0	0	0	0	3.9	0
99	8.4	3.1	0	0	0	0	0
100	4	12.2	0	0	0	0	0
101	21.2	7.8	0.3	0	20.4	0	0
102	1	0	0.7	0	0	0	0
103	14.8	0	1.8	13.3	0	6	0
104	0	0	1.8	0	13.9	9	5.2
105	5.6	4.7	0.4	0	0	0	0

Fig. 9a. *Kibanda within season dry spells*

GRWDT	1999	2002	2003	2004	2005	2006
60	6.7	37.2	0	0.4	2.5	5.3
61	0.4	0.5	0	54.8	15.4	0.6
62	0	13.8	0	0	9.2	0
63	0	7	0	3.2	0	9.6
64	6.2	0	0	0	0	0
65	0	0	0	0	1.6	17.3
66	0.4	36.3	0	0	0	0
67	0	0.7	0	0	0	23.2
68	4	0	0	3.8	6.8	26.5
69	0	5	0	0	0	0.2
70	5.2	0	0	0	0	0
71	0	8.8	3.2	0	0	0.7
72	0.1	0	0	15.5	2.1	2.2
73	0	30.7	2.4	0	4	31.1
74	0	0	24.4	12	21	6.7
75	0.5	6.8	8.3	0	5	0
76	0.3	0	0	0	11.5	0
77	34.6	6	15.6	0	5.8	2.4
78	5.2	0.3	0	0	0	17
79	0.4	7.6	0	2.7	3	3.6
80	1.3	86.9	8.2	1	19.6	0.6
81	0	1.6	2.2	3.2	15.3	5.9
82	0	0	0.4	0	9	0
83	0	19.4	0	0	0	0
84	0	0	0	0	0	4.2
85	0.3	1.5	6.8	2.2	1.8	0
86	2	0	21.7	0	2.5	6.9
87	5.4	0	11.4	0	0.5	0.1
88	0	4.5	0	0	0	0
89	2	18.6	13.3	0	2.7	0
90	11.2	0	0	0	0.6	2.4
91	0	0	0	6.2	0	8.3
92	0	35.2	0.3	0	0	0.6
93	0.9	4.8	3.2	0	0	8
94	5.7	13.9	0	3.2	0	0
95	19.2	2.2	0	3.8	1.1	11.8
96	0	5.4	0	2.1	4.3	0.4
97	0.5	0.1	0	4.8	2.4	43.7
98	58	0	0	0	0.4	0
99	54.7	0	0	0	33.1	0
100	3.7	0	0	0	0.3	16.5
101	1.7	0	22.4	0.5	0.3	39.6
102	6.2	32.8	38.8	13.4	14.4	10.6
103	0	15.8	2.3	1.6	17.8	0
104	7.6	0	4.7	1.9	7.5	22.1
105	43.5	3.8	1	0	0	14
106	15.3	3	0.5	5.6	15.2	6.7
107	3.7	5.8	17.8	1.1	15.5	0
108	0	64	0.3	8.1	10.6	0.1
109	0	2.3	1.6	12.4	1.2	0.5
110	2	19.7	0.4	0	0	13.4
111	0	4.1	4.8	0	0	4.6
112	0	0	8.8	0	0	2
113	19.3	45.3	0	5.8	0	5.8
114	0	38.2	0.8	16	0	6.3
115	0	0	0	11.8	0	0
116	3.1	0	10.1	65.6	0	0
117	6.7	1	51.3	0	0	11.6
118	4.2	0.5	22.2	11.5	2.8	6.3
119	0	3.6	0	8.1	25	6.4
120	5.2	16.9	0	3.2	3.4	23.8
121	13.1	7.1	13.5	0	0	14.9
122	0	3.5	0	78.4	2	43.7
123	7.6	0.2	0.6	0.2	16.4	0.7
124	23.7	5.6	0	0	6	0
125	20	0	0	1.6	0	0
126	0	0.5	0	0	0.5	0

Fig. 9b. *Entebbe within season dry spells*

DISCUSSION

Because different places have different conditions of soils, weather, land cover and environment, criteria set for the start of the rains must take into account all the necessary conditions. In addition to rainfall amounts, evaporation, crop water requirements and crop growth factors must be considered before the start of the season can be calculated.

Results (Fig. 6a; Fig. 6b) are showing normal variation in the start dates and maximum dry-spells of the growing season over the past 44 years. However, as shown in Fig. 4, there is a significant rise of 70% in dry spells in the past five years for Entebbe.

Fig. 7 is an eight-years table showing the inter-seasonal performance for Kamenyamigo. It shows the year 2004 as a typical failure year with a maximum dry-spell of 19 days within the growing season. Furthermore, in all the five years from 2001-2005, there were late starts, later than the mean date of the 45th Julian day, 14th February

Fig. 8a shows the mean annual rainfall in Uganda. The pattern compares well with the map showing the distribution of mean annual maximum dry spell in Uganda (fig. 8b).

Kibanda is located in the same marginal area as Kamenyamigo and Fig. 9a and Fig. 9b. show a similar pattern of rainfall regime with 2004, almost a failure year. The year 2004 has 20 days of within-season dry-spells compared to the expected 12 days. However in comparison with Entebbe, Fig. 9b, located in a wetter area, the seasonal rainfall regime was not as detrimental as those at stations in marginal areas.

CONCLUSIONS

The results show that in the last five years normal variation in the dates of the start of the season occurred and that the pattern of maximum dryspells of the growing season was similar to that of earlier years.

The only major exception was that in the past five years there was a significant rise in the frequency of late starts for Kamenyamigo and in other stations analysed, which is also the trend observed in other regions.

Rainfall in the year 2004 was a failure year in most stations in Uganda.

The challenge is to understand the behavior and characteristics of the start of the rains using the different criteria and to learn which events (such as la-Nina or El-Nino) they preceed or follow so that they can be forecasted.

RECOMMENDATIONS

Rather than furnishing raw data the DoM can collaborate with users to generate immediately useful products. Rigorous and collaborative analysis should be carried out jointly with crop scientists.

CRAM may assume the task to rassemble the experience from different countries and formulate an approach to provide quick responses to users' requests and decision support.

Methods of research and experience in each country should be shared and can be harmonised with CRAM as a focal point.

ABBREVIATIONS

CLICOM	Climate Computing
DoM	Department of Meteorology
INSTAT+	A statistical package for climate analysis
Kc	Crop Coefficient
MAM	March, April, May
SIAC	Statistics in Agricultural Climatology
SON	September, October, November

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THIRD GENERATION RAINFALL CLIMATOLOGIES: SATELLITE RAINFALL AND TOPOGRAPHY PROVIDE A BASIS FOR SMART INTERPOLATION

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ABSTRACT

This short paper discusses a technique for producing 'improved rainfall estimates' (IRE) for Africa. The central objective of IRE is to make reasonable use of the high resolution mean fields, moderate density gauge data, and timely satellite rainfall data typically available at the national/regional level in Africa. In general, traditional rainfall interpolation schemes can be classified into two coarse categories. In the beginning, raw station observations were interpolated by combining the values of surrounding stations. Later, 2nd generation techniques interpolated anomalies from long terms means, thereby reducing the bias and error of the resulting estimates. For air temperature, the systematic relationship between elevation and station observations has been used as a basis for 'smart' interpolation, enhancing estimation accuracies even further. The relationship between precipitation and topography is, alas, substantially more complicated. This paper demonstrates how a combination of temporally-static 0.1 degree satellite-enhanced precipitation mean fields and coarse (2.5 degree) time-varying precipitation fields can be combined to provide a reasonable basis for the 'smart' interpolation of rainfall in areas of complex terrain and limited in situ gauge data. Accuracy assessments are carried out for Ethiopia and Kenya.

INTRODUCTION

In general, there have been two traditional approaches to producing gridded maps of meteorological variables. The first 'naïve' stage used various interpolation schemes to create spatially continuous grids from raw point data. This approach is highly dependent on the spatial distribution of gauge observations, and from the perspective of geo-statistics the non-stationarity of the background mean field violates the optimality constraints of kriging. For temperature fields, it was recognized that background mean fields, often related to elevation via lapse rate relationships, could be estimated and used to provide dramatic enhancements in accuracy. While some success in producing similar advances in precipitation have been achieved, this type of background-augmented 'smart' interpolation of precipitation has proven difficult to achieve in data-sparse Africa. In this paper we discuss how new satellite-based precipitation fields may be blended with traditional 2nd generation rainfall gridding procedures to produce 3rd generation precipitation climatologies that have several desirable characteristics: low bias, high fidelity, near-climatological period of record, and reasonable latency periods.

DATA

Three data sources were combined to produce satellite enhanced mean fields: long term (1996-2005) monthly means derived from the Climate Prediction Centre African Rainfall Climatology (ARC, Love *et al*., 2004), USGS Hydro 1K (Gesch *et al*., 1999) slopes and elevation data re-sampled to the ARC 0.1° grid, and FAO climate normals. We demonstrate the method with two sets of satellite rainfall estimates: the 27 year Global Precipitation Climatology Project data (GPCP, Huffman et al., 1995, 1997, Adler et al., 2003) and the 10 year ARC over Africa. Time-series of station data were obtained by combining data from the Global Historical Climate Network (Peterson and Vose, 1997), FAOCLIM2.0 (FAO, 2001) with data obtained from the Ethiopian Meteorological Service and Famine Early Warning System Network (FEWS NET) archives. Monthly fields were used in all instances.

METHODS

Please note that in the following description we make use of the mathematical convention of using bold characters (i.e. **n**, **w**, **m**, **u**, **p**, **s**) to represent vectors, or sets of values: **n** represents a set of neighbouring rain gauge observations, **w** a set of weights used to combine these observations, **m** a set of long term mean rainfall values, **s** a set of long term satellite rainfall means, and **u** a set of unbiased rainfall estimates. Individual values at some location (indexed by 'i'), are referred to as non-bold characters, so si indicates the long term satellite rainfall average at location i.

General formulation

A first generation rainfall estimate at a given location (ei) is typically produced by defining a set of weights (**w**) for each location and set of neighboring stations (**n**), and then calculating the weighted sum:

$$e_i = \mathbf{n}^T \mathbf{w} \tag{1}$$

where ei denotes the estimate at location i, and **n** and **w** are vectors of neighbouring values. $\mathbf{n}^T \mathbf{w}$ is mathematical shorthand for multiplying each ni by the corresponding wi and taking the sum over all locations. Typically (but not always) **w** sums to 1, and the individual weights are a function of the distance between each neighbour and location i. Second generation approaches includes estimates of a background mean.

$$e_i = (\mathbf{n} - \mathbf{m})^T \mathbf{w} + m_i \tag{2}$$

Where **m** denotes a spatially continuous mean field sampled at a set of neighbouring locations. This type of estimation process takes advantage of information contained in the mean field, and interpolates anomalies from long term averages (**n**-**m**). The long term mean field is then added to the interpolated result (+mi in eq. 2). This is especially useful in (the typical) cases of low gauge density, since in the absence of observations the interpolated field relaxes towards reasonable average values. Third generation approaches modify this relationship, using both time-varying satellite data (**s**) and high-resolution mean fields (**m**) to augment the interpolation process.

$$p_i = \frac{(s_i + \mathrm{e})}{(\bar{s}_i + \mathrm{e})}, \forall i \tag{3}$$

$$u_i = p_i m_i, \forall i \tag{4}$$

$$e_i = (\mathbf{n} - \mathbf{u})^T \mathbf{w} + u_i \tag{5}$$

The first step of this procedure (eq. 3) translates the satellite estimate at each station location s_i into a percentage, p_i, by dividing s_i by the long term mean satellite value at location I, $\bar{s}_i$. A small value ( ) is added to the numerator and denominator to force the percents to 1 as precipitation goes to zero. The $\forall i$ in eq. 3 indicates that this percentage calculation is carried out for each station. This produces a vector of at-station percentages (**p**, ranging from 0 to 1), indicating whether the satellite field is above or below 'normal'. Since satellites exhibit substantial bias, using a good long term rainfall climatology to represent the physical units of 'normality' (i.e. the typical rainfall in mm) can produce unbiased satellite estimates *without* adding any additional station data. This is achieved by multiplying each satellite percentage value p_i by that locations long term mean, m_i (eq. 4). This produces a set of unbiased satellite rainfall estimates (**u**).

Unbiased satellite values can then be used to assist a standard interpolation process (eq. 5). Instead of working with differences from a long term mean (**n-m** in eq. 2), 3rd generation approaches work with differences from a long term mean, modified by satellite observations, (**n-u**). The satellite data, expressed as percentages (**p**) modulates the long term mean field. This produces estimates that benefit from the ability of satellite fields to represent *relative* differences in rainfall rates. 'Typical' rainfall amounts, however, are defined by long term mean fields.

In our implementation we actually use a two-step replacement for equation 5. In the first step the at-station ratio anomalies are interpolated. These gridded ratio fields are then multiplied against the unbiased rainfall fields, producing first guess estimates. In the second step the at-station arithmetic residuals from these estimates are calculated and interpolated. This step allows the addition of rainfall, handling the case in which satellite fields falsely record zero precipitation.

Note that equations 1-5 are quite general, and can incorporate weighting techniques derived from geo-statistics (kriging), mathematical surface fitting (splines and multiquadric formulations) and various inverse distance approaches (e.g. Cressman, Shepard, standard inverse distance weighting). Similarly the specification of the mean field or satellite data set can vary as well. Another possible permutation would be the use of distribution-specific z-score transformations rather than ratio operators. Our view is that while method choice is important, making maximum use of available data is often the quickest way to obtain accurate precipitation estimates. In other words, many alternative data sources and specific algorithms could all produce good results, given the improved rainfall estimation (IRE) schema defined by equations 3-5.

While many choices of interpolation algorithm are available, simplicity is often required in an operational environment. To this end we have developed a simple double-IDW (inverse distance weighting) correction tool. This tool merges stations and rainfall estimate grids in two consecutive passes. In the first pass *ratios* between stations and satellite grids are calculated and interpolated. In the second pass the ratios are multiplied against the UBRF and the arithmetic at-stations *differences* interpolated. This second pass handles instances when the UBRF is 0. The interpolated anomalies are limited by a weighting function based on the distance from the nearest neighbour. This weighting function forces the ratio and arithmetic difference fields to zero and one (respectively) as the distance from a location approaches a user-defined threshold (7° in this case). This simple approach incorporates some of the benefits of kriging, but without substantial user intervention.

The FEWS NET Climatology (FCLIM)

Orographically enhanced mean fields were produced by combining average monthly ARC grids with slope and elevation enhancement factors. The use of satellite rainfall averages as a basis for deriving improved climatologies is, as far as we know, a new innovation. This innovation grows naturally out of the fact that there are strong local regressions between station normals and monthly means ARC ($\overline{a}$). Scatter about these regression lines is in turn typically strongly related to the product of $\overline{a}$ and the local slope ($\overline{a}s$) and/or elevation ($\overline{a}e$). In other words, topography often acts to amplify a broader scale precipitation tendency, represented by $\overline{a}$, and the observed station normals ($\overline{o}$) can be reasonably fit by local regressions of the form $\overline{o} \approx b_o + b_1\overline{a} + b_2\overline{a}s + b_3\overline{a}e$. These models were fit as described in Funk and Michaelsen (2004), except that a series moving spatial windows with a 7° radius (~770 km) were used to develop localized regression models, based on weighted subsets of 6965 FAOCLIM2.0 precipitation normals (FAO, 2001). These moving window regressions produced 12 monthly 0.1° grids of average rainfall. Block kriging was then used to interpolate the 6965 at-station differences (residuals) between the FAO climate normals and regression estimate grids. The regression estimates and kriged anomalies were, combined, yielding 12 monthly FEWS NET climatology fields (FCLIM).

RESULTS

FCLIM annual means.

The at-station accuracy of the FCLIM monthly long term mean fields was evaluated numerically by comparing the regression estimates at each of the 6,965 points to the modeled value for each month. The error statistics were promising, with a coefficient of determination of 0.9, a mean bias error of 0.06 mm month-1, and mean absolute error of 18 mm month-1. Figure 1 shows the mean annual FCLIM precipitation and FAO climate normal locations for sub-Saharan Africa.

Ethiopia IRE Validation

A more detailed cross-validation analysis for Ethiopia examined the at-station accuracies of the full IRE process. This validation calculated at-station statistics based on 11 years (1995-2005) of CPC ARC data and 120 National Meteorological Agency (NMA) station observations. For each month during the two main rainy seasons (Belg and Meher, March-September) a 10% random sample of stations was withheld and the full IRE estimation procedure (UBRF blended with stations) executed. For each of the 77 months (11 years x 7 months) the corresponding 0.1° pixel rainfall estimates were then extracted from the ARC and IRE grids and compared to the excluded stations.

Table 1 summarizes the at-station and pooled (regional) accuracy values. At a monthly/at-station scale the mean absolute error is high (42 mm) when compared to the long term mean average monthly rainfall of 112 mm month-1. The IRE bias is low (~6 mm month-1), however, and averaging in space reduces this value to 18 mm month-1 at the monthly time scale and 8 mm month-1 over a season. At-station monthly, regional monthly, and regional seasonal R2 values are reasonably high (0.62, 0.8 and 0.82 respectively). The relative error values (MAE divided by temporal standard deviation) suggest useful signal to noise ratios; 0.43, 0.34 and 0.36 for the corresponding at-station monthly, regional monthly, and regional seasonal space-time scales. Figure 2 shows time-series of the averages of the excluded stations and the associated IRE pixel estimates. The fidelity is reassuring. Figure 3 shows the monthly bias and R2 values of ARC and IRE estimates. ARC accuracy degrades later in the season, underestimating rainfall amounts and tracking poorly with observations, perhaps due to limitations associated with the cold cloud duration threshold.

Western Kenya IRE Validation

A third detailed validation study was performed for a test site in Western Kenya (34.15°-35.55°E, 1°S-1°N). This site has been used in two previous evaluations: our accuracy assessment for the Collaborative Historical African Rainfall Model (CHARM, Funk *et al.,* 2003a) and a comparison between the CPC and NCAR-NCEP reanalysis fields (Funk and Verdin, 2003). A dense gauge network of 73 daily observations from 1961-1998 was interpolated to an 0.1° grid using inverse distance weighting. These 0.1° daily grids were accumulated to monthly totals and compared to the full IRE process driven by GPCP data.

Though coarse in resolution (2.5°) the GPCP data has the strong advantage of a climatological period of record (1979-2006, 28 years). The GPCP values were translated into ratios of the long term GPCP means and re-sampled using a cubic convolution to an 0.1° grid. These 0.1° ratios were multiplied against the corresponding FCLIM means, producing unbiased rainfall values. These UBRF fields were then merged with 19 stations drawn from the Global Historical Climate Network (Peterson and Vose, 1997).

The downscaled GPCP-based IRE fields recreate the long term mean structure of the region reasonably well, given the 2.5° scale of the GPCP forcing data (Figure 4). While the study site has an area equal to 45% of a GPCP grid cell, the downscaled IRE means correspond fairly well at a 0.1° resolution, with a spatial R2 of these fields of about 0.65 (Table 2). Presumably, even better results could be achieved using higher resolution satellite observations, and more analysis along these lines needs to be carried out. As a reference, we have included regional mean absolute error and mean bias error statistics from our 2003 (Funk & Verdin, 2003) validation study based on RFE1.0 estimates (Herman et al., 1997). These values suggest that IRE based on coarse resolution GPCP data can outperform at least one traditional high-resolution satellite estimate. This is primarily due to a reduction in mean bias error.

Time-series of the monthly regional IRE averages track well with high density gauge estimates (Figure 5). These regional averages show almost no bias, and explain a considerable proportion (87%) of the gauge variance (Table 2). Even at the 0.1° monthly scale the mean absolute error (39 mm) is only 20% of the monthly mean of 175 mm, and about 54% of the monthly temporal standard deviation. This accuracy level (½ a standard deviation) is sufficient to capture extreme hydrologic variations, but not accurate enough to guide agricultural decision making. A GPCP-driven IRE product appears like a good candidate for early warning applications. This, presumably, could be implemented globally over a 29 year period of record. Such a product could likely be a substantial improvement on '2nd generation' climatology products based just on interpolated gauge data. IRE techniques incorporated into a framework combing higher resolution satellite estimates and denser gauge networks may be accurate enough to guide farm decisions, but that remains to be evaluated.

DISCUSSION

The IRE technique combines traditional rainfall interpolation approaches with satellite-based precipitation surfaces. Similar to 'smart interpolation' approaches (Willmott and Matsura, 1995) commonly used to produce gridded fields (New *et al*. 1999, 2000), the IRE procedure is assisted by a long term mean field. In addition to these mean fields, the IRE is also assisted by time-varying satellite rainfall estimates. The recent decline in readily available high quality gauge data makes the use of satellite data critical, especially in many climatically and environmentally important areas of the developing world. Many of the complexities associated with orographic precipitation modeling at monthly and seasonal scales can be absorbed within sophisticated, topographically enhanced mean precipitation grids. These background fields can be used to remove the systematic bias commonly found in satellite precipitation fields, producing unbiased rainfall estimates (UBRF). This procedure can also be used to introduce local variations into coarse precipitation surfaces, such as those produced by the 2.5° Global Precipitation Climatology Project (GPCP, Huffman *et al*., 1995, 1997, Adler *et al*., 2003). The unbiased satellite estimates, in turn, can in turn be combined with station data in a geostatistical framework (an idea originally inspired by Grimes *et al*., 1999) with the final product referred to in this paper as improved rainfall estimates (IRE). Note that 'improved' does not imply that the original satellite estimates are 'bad', but rather that additional information has been added.

The improved rainfall estimation procedure has three distinct steps: i) the creation of satellite-enhanced long term mean fields (FCLIM); ii) the combination of the these fields with time-varying satellite fields to produce unbiased time-varying estimates (UBRF); and the iii) fusion of these time-varying satellite estimates with regional near-real time station data (IRE). The objective is to use all available sources of data to produce accurate, low bias, consistent rainfall fields in a moderately timely manner.

In Africa, effective rainfall estimates (RFE) form the basis of hydrologic early warning. Effectiveness may be defined along several dimensions, with accuracy, low bias, consistency, and timeliness forming a minimal set. Accuracy refers to the capacity of an RFE to recreate the space-time covariance of 'true' rainfall, typically defined by high quality station data. Consistency is a related criterion that establishes reasonably station distribution parameters over a climatological period of record. The explicit meaning of 'timeliness' varies with application. We focus here on a monthly 'hydro-climatic' time-scale, and assume that a timely estimate may be prepared with a one or two week lag. At present, FEWS NET uses multi-satellite RFE2.0 (Xie and Arkin, 1997) and the longer single-satellite African Rainfall Climatology (ARC, Love et al., 2004). Both sets of estimates are constrained by Global Telecommunication System (GTS) observations. These excellent data sets are timely and reasonably accurate, and the 11 year ARC provides a reasonable basis for estimating rainfall means (a first order statistic).

Unfortunately, the GTS network is quite sparse and many additional stations are typically available to National Meteorological Agencies. The RFE2.0 and ARC also tend to exhibit substantial bias at certain seasons and locations (Funk, 2002; Funk & Verdin 2003). This is especially true in complex terrain. After several years spent working with internal gravity waves as a basis for orographic enhancement (Funk et al., 2003; Funk and Michaelsen, 2004), we believe that sophisticated monthly mean fields can be used in near real time to parsimoniously remove substantial bias from satellite RFE, producing unbiased rainfall estimates (UBRF). These UBRF grids may then be augmented by dense non-GTS station observations to produce Improved Rainfall Estimates (IRE).

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TABLES

Table 1. Ethiopian test site evaluation statistics. The March-September and Monthly rows report statistics for the seasonal March-September and individual monthly March-September accumulations, respectively. The first and second columns report mean bias and mean absolute errors based on the average of all stations. The MAE STD-1 column provides a relative metric of uncertainty, with typical errors being about ~33% of the temporal standard deviation. The time R2 is calculated using 11 years of data (1995-2005). The last three columns are similar to the regional metrics, but based on calculations using the individual station values. Seasonal at-station values were not available do to the random sampling associated with the cross-validation.

	Regional Metrics				At-station metrics		
IRE	MBE	MAE	MAE STD^{-1}	Time R^2	MAE	MAE STD^{-1}	Time R^2
Seasonal	6	8	0.36	0.82	---	---	---
Monthly	6	18	0.34	0.80	42	0.43	0.62

Table 2. Kenya test site evaluation statistics. The MAM and Monthly rows report statistics for the seasonal March-May and individual March-April-May accumulations, respectively. The first column reports the R2 of the long term (1979-2005) averages at the 294 (14 rows x 21 columns) 0.1° pixels. The second and third columns report mean bias and mean absolute errors based on the average of all 294 pixels. MAE and MBE are reported in mm month-1. The MAE STD-1 column provides a relative metric of uncertainty, with typical errors being about ~33% of the temporal standard deviation. The time R2 is calculated using 27 years of data (1979-2005). The last three columns are similar to the regional metrics, but based on calculations using the individual 0.1° values.

	Regional Metrics					At-station metrics		
	Spatial R^2	MBE	MAE	MAE STD^{-1}	Time R^2	MAE	MAE STD^{-1}	Time R^2
Seasonal	0.67	0.01	8	0.31	0.87	26	0.52	0.54
Monthly	0.64	0.00	14	0.37	0.75	39	0.54	0.49
Monthly RFE1.0		15	20					

FIGURES

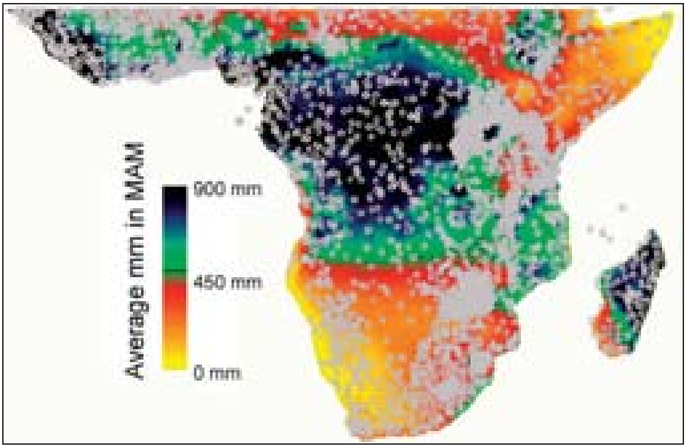

Figure 1. *FCLIM annual means and FA0CLIM 2.0 station locations for sub-Saharan Africa.*

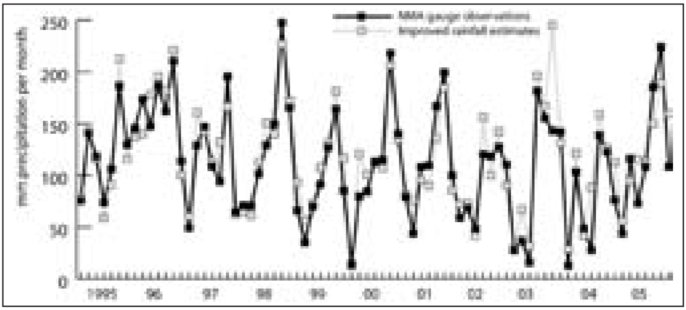

Figure 2. *Ethiopian observed and cross-validated monthly averages. Each observed datum is based on the average of a 10% sample of the NMA gauge network. The corresponding 0.1° IRE pixels were also averaged and plotted. The seven months of the main growing seasons (March-September) are shown.*

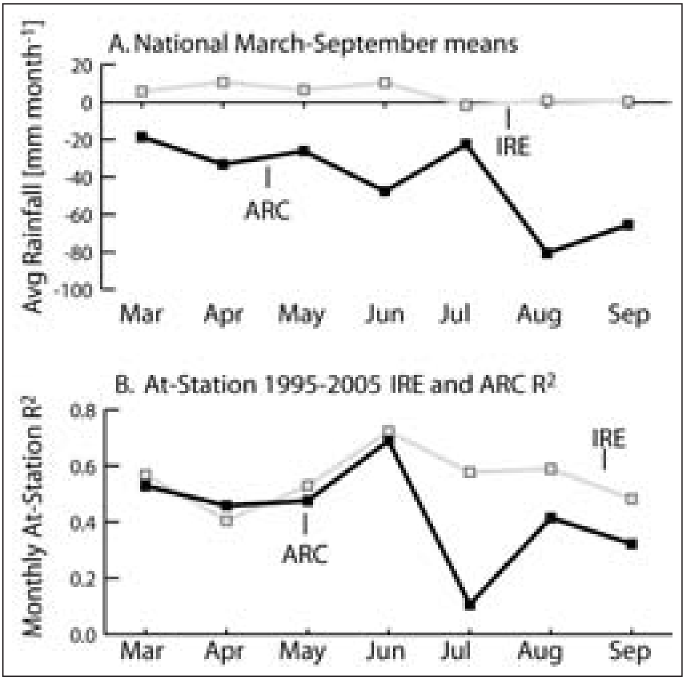

Figure 3. *Monthly rainfall bias and R2 values for the Ethiopian test site.*

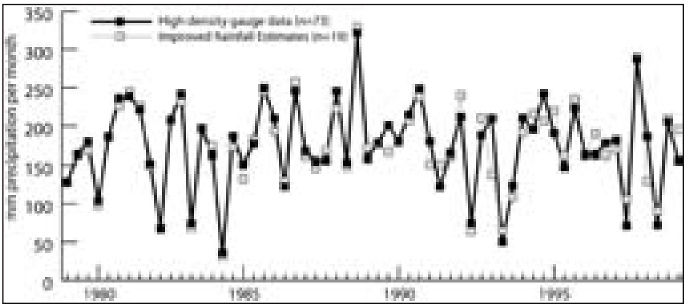

Figure 4. *Regionally averaged 1979-1998 March-April-May rainfall over the western Kenya test site. The first three boxes represents three month from 1979(March, April and May). Each consecutive set of three boxes represents one of the following years.*

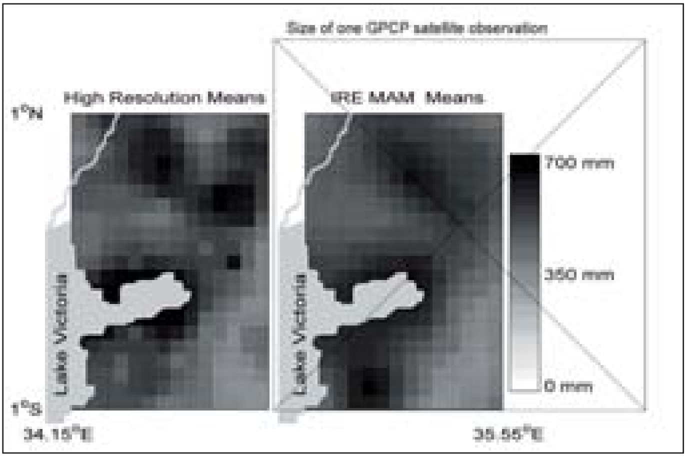

Figure 5. *Monthly March-April-May mean 1979-1998 high density gauge and improved rainfall estimates over the Kenya test site.*

ECMWF AND RFE RAINFALL ESTIMATES COMPARISON FOR AFRICA

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ABSTRACT

Rainfall estimates derived from satellite imagery and global circulation models are frequently used for vegetation monitoring in many areas of Africa, due to the shortage of observed precipitation data and the sparse Meteo-station network. At the same time, this scarce density of rain-gauge stations makes the calibration and validation of the modelled data nearly impossible.

In this study we propose a methodology for a quick quality assessment of rainfall estimates, which is based on the well known relationship between rainfall and NDVI. The method allows a rapid detection of major over- and underestimations of different rainfall estimation methods at a continental / regional scale.

KEY WORDS : Rainfall estimates, RFE, ECMWF, NDVI

INTRODUCTION

Previous studies conducted during the end of the 1990's using the NOAA/AVHRR images confirmed the relationship between NDVI and rainfall in different parts of the globe using rainfall from ground stations and different vegetation. Nicholson et al, 1990 showed uncorrelated results in tropical areas with dense vegetation in the Amazon of Brazil (Santos, 1997); in subtropical areas with high correlation between rainfall and NDVI of Kenya and Tanzania in Eastern Africa; and in semi-arid region of Sahel (Mali and Niger). They also found a log-linear relationship between mean annual integrated NDVI and mean annual rainfall in Kenya and Tanzania; for Mali and Niger a linear relationship was found. The linear correlation in Eastern Africa between rainfall and NDVI was 0.82 and the log-linear correlation (between NDVI and the log of rainfall) was 0.89.

The objective of this study is to detect large rainfall divergences between two commonly available rainfall data-sets (ECMWF and RFE) using the known relationship between precipitation and NDVI. We are using this simple relationship to do a rapid assessment of where in Africa the main problem areas are located. Considering as problem areas those areas where rainfall is strongly under- or overestimated by one of the two products (ECMWF or RFE). For those problem areas deeper studies on the rainfall onset, distribution, length and end of the rainy season based on ground measurements should be carried on.

RAINFALL DATA

ECMWF

The European Centre of Meteorological Weather Forecast (ECMWF) at Reading in the UK produces rainfall forecasts based on an general circulation model (www.ecmwf.info). In this study we used data from the ERA-40 dataset, a "global reanalysis" dataset made by modeling again the past predictions with the same numerical model and all available observations (Uppala, S. et al; 2004) for the years from 1999 to 2001. ERA40 is the computerized weather data from September 1957 to August 2002 (i.e. during 45 years), taken from scientific relevant observations worldwide. For the second part of the study period (from 2002 to 2007) we used forecasts from the operational models.

The interest in these data is explained by the fact that the FOOD-SEC action of the Joint Research Centre (JRC) is using them in an operational way for monitoring agricultural and pastoral vegetation on a real time basis for large parts of Africa. The data used for operational monitoring have a 1 ° grid resolution.

RFE

The RFE is a rainfall estimate product of NOAA's Climate Prediction Center currently used by FEWS-NET and several United Nations agencies such as the Food and Agriculture Organization (FAO) and World Food Programme (WFP) for agricultural monitoring in a large number of African countries. There exist two RFE versions (RFE 1.0 and RFE 2.0) produced with different methodologies:

RFE 1.0 uses an interpolation method to combine Meteosat and Global Telecommunication System (GTS) data, and includes warm cloud information for the dekadal estimates; the data is available for the period 1995-2000.

RFE 2.0 uses additional techniques to better estimate precipitation while continuing the use of cold cloud duration (CCD) and station rainfall. Two new satellite rainfall estimation instruments are incorporated into RFE 2.0, namely, the Special Sensor Microwave/Imager (SSM/I) on board Defense Meteorological Satellite Program satellites, and the Advanced Microwave Sounding Unit (AMSU) on board NOAA satellites (Xie, P. and Arkin, P. A. 1997). RFE 2.0 rainfall estimates are available only from 2001.

RFE has a 0.073 ° resolution. In this study we use the rainfall data for the period 1999-2007, which is principally made up of RFE 2.0 estimates.

Both crop monitoring systems (FOOD-SEC and FEWS-NET) have the objective to model the relationship between water availability and biomass production of the main staple crops in Africa for supporting the food aid programs in Africa. The monitoring systems are in fact able to provide early qualitative warnings in case of drought related risks of food insecurity. In some cases it is also possible to use the rainfall and satellite data for producing quantitative yield forecasts.

IIASA Rainfall database

An auxiliary rainfall data set produced by the International Institute of Applied Systems Analyses (IIASA) at 0.5 ° resolution (Leemans, R. and Cramer, W., 1991) was used to build a mask where the areas receiving an annual rainfall below 200 mm where masked-out.

NORMALIZED DIFFERENCE VEGETATION INDEX (NDVI)

In this study we used a product of SPOT VEGETATION, the monthly NDVI synthesis images, obtained by maximum value compositing (MVC) and called also S30 images. These images are corrected for radiometry, geometry, and atmospheric effects. SPOT VEGETATION derived NDVI has 1 km resolution (approximately 0.009 °) and the period used in this study is 1999-2007. The availability of these images (from April 1998) was the main determining factor for choosing the beginning of the analyzed time series, since both ECMWF and RFE data are available for longer periods.

METHODOLOGICAL ANALYSIS

Standardizing the data sets

The 3 data-sets (ECMWF, RFE and NDVI) were transformed into the same resolution of 0.5 ° and reprojected to lat/long where necessary. The mean annual integrated NDVI (that is, the sum of the twelve monthly values) and the mean cumulated annual rainfall (ECMWF and RFE) were calculated. As a first step the mean annual integrated NDVI and rainfall images were visually compared by using an equivalent colour scale to have a preliminary assessment of the information.

Comparison between IIASA, ECMWF and RFE

The 3 rainfall data-sets were compared to detect the areas with major divergence (high over/under estimation of rainfall).

RESULTS AND DISCUSSION

NDVI and rainfall (ECMWF and RFE) comparison

Figure 1 shows the mean annual integrated NDVI and mean annual rainfall (ECMWF and RFE) with an equivalent colour scale. In general there is a good correspondence between the maximum and minimum values of rainfall and the integrated NDVI. Maximum values of both (NDVI and rainfall) are found for instance in the Democratic Republic of the Congo, whereas low values correspond to the semi-arid regions of Africa (i.e. the Sahel).

Overall the ECMWF shows a better estimation of rainfall along the coastlands when compared with RFE. ECMWF shows an underestimation of rainfall when compared with RFE in the Sahel; central part of Kenya, Tanzania, Zambia, Zimbabwe and Angola. ECMWF do overestimate rainfall in the highlands of Ethiopia and Democratic Republic of Congo.

Rainfall data sets comparison (IIASA, ECMWF and RFE)

Figure 2 shows the areas with high over/under estimates of rainfall. Those areas coincide with the areas identified when the NDVI is used as a reference.

CONCLUSIONS

NDVI shown to be a good auxiliary data to detect strong divergence between rainfall estimates having the advantage of the high resolution (1 km resolution) and the continuity of the series time information when compared with the rainfall rain-gauges network in Africa.

The advantage of the ECMWF data along the coastline when compared with the rainfall estimates by RFE is due to the better integration of the influence of the ocean into the model. The weakness of RFE is due to the scarcity of rainfall in some coast areas that produce an increase of the rainfall estimation bias.

FIGURES

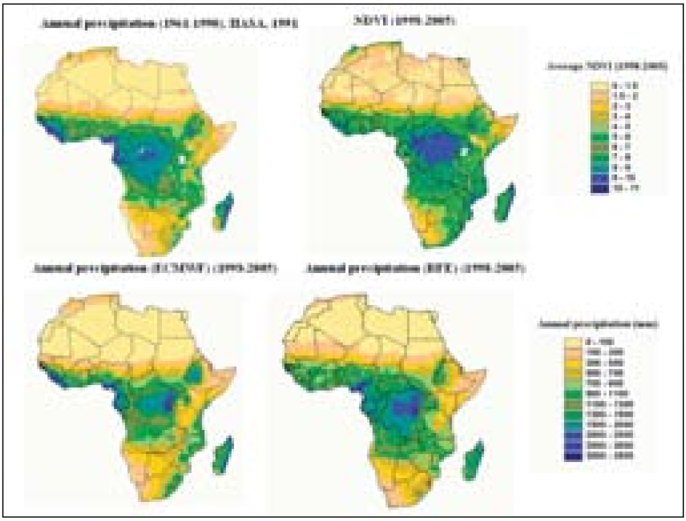

Figure 1. *Comparison between IIASA rainfall, NDVI, ECMWF and RFE rainfall estimates*

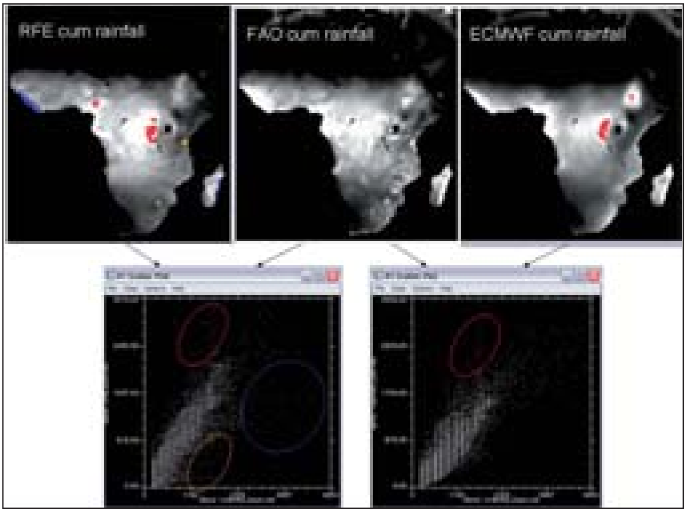

Figure 2. *Rainfall comparison between IIASA-FAO rainfall and rainfall estimates (ECMWF and RFE). On top in colour the areas with high over (in red) and underestimation (blue and* orange). Bottom the scatter plots between IIASA-FAO rainfall and RFE and ECMWF.

MONITORING THE ENVIRONMENT IN AFRICA: VGT4AFRICA AND AMESD PROJECTS

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ABSTRACT

This paper describes two complementary projects. The VGT4Africa project is a R &D project financed by the EC 6th framework Programme for Research and Technological Development whose objective is to bring into operational exploitation prototype EO data processing chains for data coming from the VEGETATION instrument and distribute the derived products to Africa, whereas the AMESD project is a continental-wide project implemented under the aegis of the African Union Commission together with the regional economic groupings of Africa and with the support of the European Development Fund. Its objective is to improve environmental monitoring for the sustainable management of natural resources in Africa, thus making use, i. a. of data provided by the VGT4Africa project.

THE VGT4AFRICA PROJECT

The VGT4Africa project is a "Specific Support Action" project implemented in the framework of the Space/GMES budget line of the 6th Framework Programme for Research and Technological Development implemented by the European Commission.

Projects partners are the TAP department of VITO (Belgium) the project leader, MEDIAS-France, and the MONDE action of the Global Environmental Monitoring Unit of JRC. Solid contacts are established with EUMETSAT and the VEGETATION Programme.

PROJECT POSITIONING AND OBJECTIVES

The VGT4AFRICA project (Borstlap & al 2006, Borstlap 2006) can be seen as a "bridging" activity which takes benefit from a number of opportunities, namely:

The deployment by EUMETSAT of their EUMETCast data broadcasting system (see after for details).

The wish by the partners of the VEGETATION programme (France, Belgium, Sweden, Italy and the European Commission) to expand the use of their 1km resolution products for environmental monitoring purposes, which translated into the decision to provide derived data for free to African users for non commercial applications (Bartholomé & Gontier, 2006).

The installation in 52 African countries of the PUMA receiving stations in each national meteorological service and regional centre (see after for details).

The development of new products derived from VEGETATION data in the framework of various research projects developed either at national or at European level, such as *i.a*. for the European Commission: "improvements for the VEGETATION mission" (FP4), CYCLOPES (FP5), Geoland (FP6), MARS-FOOD, GBA2000, GLC2000 and L3JRC (JRC); for ESA: GMFS; for France: POSTEL; for Belgium: Geosuccess; and "VEGETATION for desert locust monitoring".

The initial preparation steps of the AMESD project (see after), whose broad objective was to take benefit of the installation of the PUMA stations and the extended capacities of the MSG satellite family to develop new environmental monitoring applications not only by and for meteorological services but also other thematic services.

PROJECT ACTIVITIES

The key activity of VGT4Africa project is to provide, in an operational and near real time manner, advanced products from data acquired by the VEGETATION instrument onboard the SPOT satellites (Bartholomé 2006a) to African users via the EUMETCAST system as illustrated in Figure 2.

The list of products is presented in Table 1, which also illustrates the origin of product development and the partner responsible for processing chain development. A full description can be found in the VGT4Africa user manual (Bartholomé 2006b). Final processing chain implementation and operation is ensured by VITO. A full description of each product can be found in the VGT4Africa user manual available in French and English on the vgt4africa web site at www.vgt4africa.org. An example is provided in Figure 3.

In addition to data broadcast via the EUMETcast system the VGT4Africa web site provides a back-up facility to retrieve missed deliveries or ensure data access to users who do not have a EUMECTAST receiving station. Because free access is ensured to African users for non-commercial applications an individual username and password are required. These can be obtained upon request via email at info@vgt4africa.org.

A series of training sessions have been organized by JRC to explain product properties, their theoretical foundation and their potential applications. Because of resource limitation training is being concentrated on regional centres preferably the ones who will be involved in the AMESD project (Table 2). This training effort is not considered to be sufficient and is currently complemented in the framework of the vgt@work project funded under the INCO budget line of FP6. Indeed the experience has shown that short term training sessions should be completed by on-the-job training so as to ensure full integration of new products into already existing environmental assessment procedures and systems.

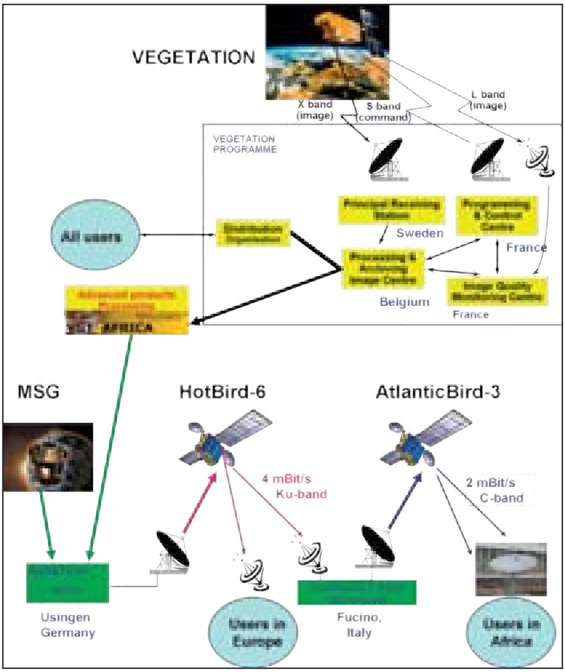

Figure 2: *this picture illustrates the connection established in the framework of the vgt4africa project between the data processing set up of the VEGETATION programme and the EUMETCast data broadcasting system operated by EUMETSAT.*

Table 1: *list of vgt4africa products.*

product name	processing chain development	heritage
S10 NDVI	VITO	standard VEGETATION product
Albedo	MEDIAS-F	geoland, cyclops (MEDIAS & al)
Burnt Area	JRC/GEM-MONDE	gba2000, L3JRC (JRC/GEM & al)
Dry Matter Productivity (DMP)	VITO	Montheith, MARS (JRC)
Fraction of surface covered by vegetation (FCover)	MEDIAS-F	desert locust monitoring (UCL-JRC/GEM) glc2000 (JRC/GEM & al)
Leaf Area Index (LAI)	MEDIAS-F	geoland, cyclopes (MEDIAS & al)
Normalized Difference Water Index (NDWI)	VITO	Gao, 1996
Phenology	JRC/GEM-MONDE	geoland (JRC/GEM)
Small Water Bodies	JRC/GEM-MONDE	JRC
Vegetation Productivity Index (VPI)	VITO	Sannier & al 1996, MARS (JRC)

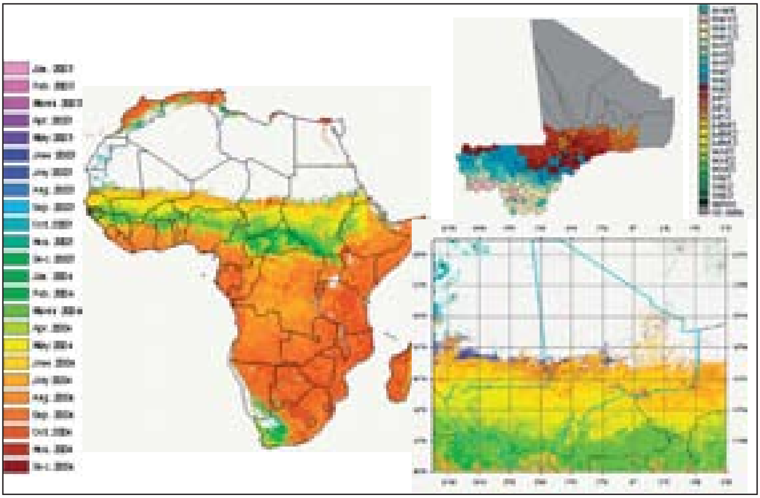

Figure 3: *VGT4africa products (here the date of the start of the growing season) are derived from full resolution VEGETATION data over the whole continent (left). Analysis can therefore be either carried out at full resolution at sub-country level (bottom right) or aggregated over polygons such as administrative units (top right).*

Table 2: *VGT4Africa training sessions*

Place	Hosting institution	Period	Comment
Kinshasa	METTELSAT		Joint training session with PUMA/SERBaK pilot project
Niamey	AGRHYMET		Joint training session, AMESD RIC
Gaborone	Botswana Met Service		Joint training session, AMESD RIC
Maputo	Mozambique Met Service		Joint training session, in parallel to EUMETSAT users forum
Nairobi	ICPAC		Joint training session, AMESD RIC

DATA DISTRIBUTION SUSTAINABILITY

The VGT4Africa project will have been completed by the end of 2007. Project partners are making all efforts to ensure continued data distribution under the GMES aegis until 2012, i. e. the expected end of lifetime of the VEGETATION observing system. Of particular importance in this respect is the guideline laid down in the work plan of the 7th EC Framework Programme in the area of space activities, and in particular in the field of pre-operational validation of GMES services and products. This document states the following: "*The geo-data and information resulting from the projects – in particular as concerns 'core services' – should be made accessible, without charges, and on a non-discriminatory basis to activities of public authorities and downstream service providers when such activities involve developing, implementing and monitoring community policies related to the environment and security through research or operational activities.*" (European Commission 2006a, p. 22). There is therefore good prospect to ensure data distribution continuity as described earlier.

THE AMESD PROJECT

Project definition

AMESD stands for "African Monitoring of the Environment for Sustainable Development". It is a project funded by the European Development Fund (9th EDF), whose general objective is to improve environmental monitoring for the sustainable management of natural resources in Africa by helping African governments in:

Designing, implementing, monitoring and evaluating their regional and continental environmental policies towards sustainable development;

Improving the socio-economical conditions and well-being of African population;

Meeting their obligations towards international environmental treaties;

Participating to the international efforts of global environment surveillance.

To achieve these objectives the project will (i) increase the information management capacity of African regional and national institutions in support of decision-makers and (ii) facilitate access to Africa-wide environmental information derived from Earth Observation technologies.

Institutional background

The AMESD project was conceived and developed in the framework of a quite significant number of policy guidelines and documents at European and international levels: the ACP – EU Partnership Agreement ("Cotonou agreement", EC, 2006b), the EC Development policy (2000), the Euro-African pact to accelerate Africa's development (2005b), the Global Monitoring for Environment and Security (GMES): Action Plan 2004 – 2008 (2004, 2005a), the European Consensus (EC, 2006c), the Plan of Implementation of the World Summit on Sustainable Development (WSSD, 2002), the Dakar's Declaration on AMESD (2002), and the G8- Evian-2003 and Gleneagles- 2005 Summits conclusions.

Technical background: the PUMA project.

The AMESD project does not start from scratch. Indeed it builds on the substantive achievements of a previous EDF-funded project known in Africa as PUMA ("Preparation to the Use of METEOSAT Second Generation in Africa"), which was completed in September 2005. The most prominent results of this PUMA projects have been (i) to set up the technical infrastructure in Africa to receive METEOSAT Second Generation data in each national meteorological service, (ii) to train 275 staff in the operation of the stations and exploitation of the data received, and (iii) to prepare the introduction of new environmental monitoring applications based on new data via 6 trans-national pilot projects.

The PUMA project provided the equipment for all EDF-eligible countries, whereas the other countries were equipped with additional resources provided via the World Meteorological Organization. A total of 52 African countries and 4 regional or continental centres were equipped.

The PUMA receiving station infrastructure is a cornerstone of the deployment of the AMESD project. A typical PUMA station includes 3 PCs for system redundancy, the antenna dish, a DVD card inserted in one of the PCs, and commercial software for data management and weather forecast (see Figure 4). Indeed the whole infrastructure relies on standard Digital Video Broadcast technology available to the broader public (Figure 5). It is therefore reasonably easy to supplement the PUMA network of receiving station with "entry level" cheap receiving stations. Such stations include one PC only, the antenna dish and the DVD card, with shareware or freeware to manage data and generate derived products. See web site addresses below for more details. The PUMA stations allow the reception of the EUMETCast data stream managed by EUMETSAT, which includes the imagery acquired by the METEOSAT Second Generation as well as a number of derived products pre-processed in EUMETSAT's "Satellite Application Facilities" (SAF), such as the Land-SAF hosted by the Portuguese Meteorological Office, which despatches a list of products as described in Table 3. Because the system is based on generic telecommunication infrastructure, it allows the reception of any sort of digital data, including data coming from non METEOSAT satellites, as illustrated by the VGT4Africa project described earlier. EUMETCast is now a component of GEONETCAST, the worldwide network of digital data distribution coordinated by GEO as a GEOSS activity.

Table 3: list of Land SAF products (Viterbo 2006).

Product name	Algorithm development	Status
Land Surface Temperature	I.M.(Portuguese. Met. Office)	operational
Albedo	Meteo-France.	operational
Downwards solar surface flux	Meteo-France	operational
Downwards Thermal Surface Flux	I.M.(Portuguese. Met. Office)	operational
Fraction of Vegetation Cover	U. Valencia	operational
Leaf Area Index (LAI)	U. Valencia	operational
FAPAR	U. Valencia	demo
Evapotranspiration/ Soil Moisture (Europe)	Belgian Met. Office	development
Fire Detection and Monitoring (Active Fires)	I.M.(Portuguese. Met. Office)	development

According to a survey carried out at the occasion of the 7th forum of EUMETSAT users in Africa in Maputo (2006), about 75% of the stations are operational. Identified problems include radio-electrical perturbations (improper station location), hardware and software problems, in some cases due to improper modification of system configuration (Taalas, 2006, Berry, 2006).

Figure 4: *a typical PUMA receiving station. Upper left: the antenna dish for the reception of the C-band signal. Upper-right: the Digital Video Broadcast receiver to be inserted in the PC. Bottom: the set of 3 redundant PUMA station PCs.*

Figure 5: *In Africa the EUMETCast data flow is transmitted via Atlantic bird (picture courtesy EUMETSAT)*

PROJECT IMPLEMENTATION

The project, which is starting in 2007 for a 4-year period, is deployed over all EDF-eligible African countries thanks to a rather complex funding mechanism. Indeed under EDF-9 there was no single financial source which could have covered the whole AMESD budget. Therefore resources were allocated by each Regional Indicative Programme as well as by the "all-ACP" budget according to the following share (Tsiavos, 2006):

all-ACP funds	€ 8 million
CEMAC RIP	€ 2 million
ECOWAS RIP	€ 3 million
ESA/IO RIP	€ 5 million
SADC RIP	€ 3 million
Total	€ 21 million

The project structure was inspired from the PUMA project, probably the first-ever EDF-funded continental-wide project. It is basically a three-tier structure (Figure 6): overall project coordination is ensured at continental scale by the African Union Commission, Department of rural economy, agriculture and natural resources, technical implementation is carried out via regional centres of expertise chosen by each regional economic grouping (CEMAC, ECOWAS, IGAD, IOC, SADC) which in turn interface with the national level via their regional networks. At management level the project will be guided by a programme steering committee. The project will benefit from the technical support and guidance from EUMETSAT and the Joint Research Centre of the European Commission (Bartholomé, 2006c).

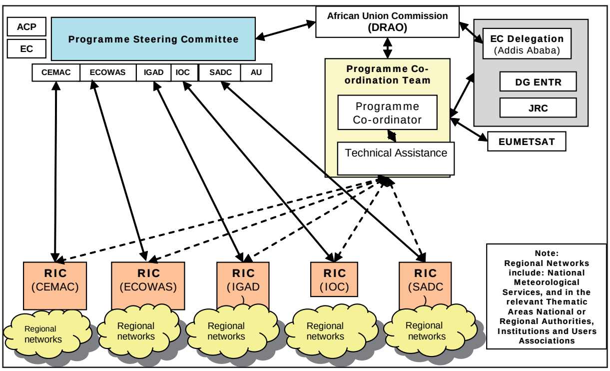

Figure 6: *AMESD project structure (A. Tsiavos, 2006)*

The AMESD project is structured according to 4 main sets of expected results:

1. Improved access to existing sources of basic Earth Observations, field and ancillary data;
2. Operational information services improving decision-making processes in the fields of environmental management and other policies;
3. Policy frameworks strengthened for active and sustainable participation of African governments in global environmental surveillance initiatives;
4. Adequate technical level of AMESD African users ensured

The activities of result 1will include *i.a.* the maintenance and upgrade of the existing PUMA EUMETCast receiving stations, deployment of a limited number of additional low-cost receiving stations, Negotiating sustainability of EO data supply and access

Under result 2 the development of five Regional Thematic Actions is expected as follows:

- **CEMAC:** Management of water resources focusing on environmental aspects of watersheds (Regional Implementation Centre: CICOS, Kinshasa)
- **ECOWAS:** Water management for cropland and rangeland management (Regional Implementation Centre: AGRHYMET, Niamey)
- **IGAD:** Land degradation, mitigation and natural habitat (Regional Implementation Centre: ICPAC, Nairobi)
- **IOC:** Coastal and marine management (Regional Implementation Centre: tbc)
- **SADC:** Agricultural and environmental resource management, [Regional Implementation Centre: Botswana Meteorological Service, Gaborone)

The rationale for choosing a regional specialisation is that it is not realistically feasible to develop all thematic aspects everywhere within the restricted project time frame. Therefore each regional centre will be in charge of developing and testing a thematic area and will exchange its experience and methods with the other regional centres.

Tasks under result 3 will include: the development of regional mechanisms for strengthening environmental M & R for international treaties, strategy development for better incorporation of African needs and interests in future global satellite systems and initiatives such as GMES and GEOSS, the establishment of a “virtual AMESD Forum” and the organisation of two AMESD Fora.

The last area of activities will focus on the training of technical agents in EUMETCast Receiving stations, aiming at self-sufficiency (self-training/tutorial material; EUMETSAT training framework), training on AMESD services (develop capacities for the thematic applications), including North-South and South-South exchanges and fellowships

CONCLUSIONS

This paper illustrates interesting synergies and complementarities developed during the last 5 years between R&D projects mainly carried out in Europe on one side and operational projects carried out in Africa on the other side. The results presented here could be achieved because a number of technologies and methods have reached a good level of maturity and because a common understanding of strategic objectives was shared by a community of scientists, technicians and decision-makers in Europe and in Africa, paving the way for future initiatives as laid down in the Maputo declaration calling for an African component to GMES.

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ANNEX

Web sites dealing with EUMETCAST receiving stations data management and related products:

EUMETSAT: http://www.eumetsat.int

Taylor's MSG data manager software (manages the data received by the DVB receiver): http://www.david-taylor.myby.co.uk/software/msg_dm.htm

Software for the Utilisation of METEOSAT in outlook activities (SUMO): http://www.weathersa.co.za/SUMO/index.jsp

Griguolo's cropvgt and addapix freeware: http://cidoc.iuav.it/~silvio/software.html

Vgt4africa: http://www.vgt4africa.org

Fao's windisp freeware: http://www.fao.org/giews/english/windisp/dl.htm

Land-SAF: http://landsaf.meteo.pt

RELEVANT PROJECTS

VEGETATION programme http://www.spot-vegetation.com

GMES http://www.gmes.info

GEO http://www.earthobservations.org

CYCLOPES http://www.avignon.inra.fr/cyclopes/

GEOLAND http://www.gmes-geoland.info/

MARS-FOOD http://agrifish.jrc.it/marsfood/

Global Burnt Areas 2000

http://www-gem.jrc.it//Disturbance_by_fire/products/burnt_areas/global2000/global2000.htm

Global Land Cover 2000 http://www-gem.jrc.it/glc2000/defaultglc2000.htm

POSTEL http://postel.mediasfrance.org/

GMFS http://www.gmfs.info/

GEOSUCCESS http://www.geosuccess.net

AN OVERVIEW OF THE OPERATIONAL PROCESSING CHAINS AND REMOTE SENSING DATA FOR CROP AND RANGELAND MONITORING IN AFRICA

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ABSTRACT

The Flemish Institute for Technological Research (VITO) operates the processing and archiving center for SPOT-VEGETATION data since 1998. In the past years, and through a variety of projects, VITO has gained significant experience in the processing and archiving of other low and medium sensors such as MERIS, MODIS and NOAA. With a specific focus on Africa, and together with a network of international and European partners, VITO deploys activities with respect to (i) the production of advanced remote sensing based vegetation indicators (e.g. VCI, NDVI, SAVI, fAPAR, DMP) (in collaboration with EC JRC MARS-FOOD); (ii) the distribution of these and other indicators to the PUMA stations in Africa (VGT4Africa project); (iii) capacity building and training (VGT@work project) and (iv) crop monitoring (EC JRC MARS-FOOD and GMFS).

As an example of these different activities, the Global Monitoring for Food Security (GMFS) project is given. It is an ESA financed project and it consists of a partnership with 12 European partners.

Vegetation Indicators are produced based upon the raw input data, either directly from the receiving station or via FTP, and ten-daily and monthly composites are delivered to the end-user for further integration in their crop modeling or early warning activities.

Estimation of the area under cultivation is based on remote sensing and in-situ data. The remote sensing data is a mixture of SAR (ALOS PALSAR, ASAR) and optical (SPOT4/5, Landsat, MERIS, MODIS) data, this is complemented with field data as obtained through a collaborative effort with national and regional partners.

Distribution mechanisms used includes the EUMETCAST system and the ESA DDS system whereby the data is transmitted to low-cost receiving stations in Africa, facilitating the data availability at national and regional level.

INTRODUCTION

Food insecurity is a condition in which a population does not have access to sufficient safe and nutritious food over a given period to meet its dietary needs and allow its people to conduct an active life. Although Food Insecurity persists in many parts of the world, Africa is the continent most affected by famines and hunger. Reasons for food unavailability can be many, including adverse climatic, environmental, political and socio-economic conditions. Famine early warning systems in place in many parts of Africa include the monitoring of one or more of these conditions through a variety of indicators. Remote sensing is particularly of use in the monitoring of the physical environment, climatic conditions and food production among others. For this reason several remote sensing processing chains were developed in the framework of other projects, such as MARSOP, at VITO to be able to supply our African and international end users with the necessary remote sensing data. The distribution of this data is done through different mechanism and different projects. These data dissemination mechanism along with the training and capacity building efforts from different projects like VGT@work and GMFS help to better integrate remote sensing data in the early warning systems.

As an example of this integrated approach of data production, data dissemination and capacity building the Global Monitoring for Food Security (GMFS) partnership is given. It focuses on only one aspect of food security, namely food production. GMFS is a GMES Service Element (GSE) project, part of the ESA contribution to the EU / ESA GMES (Global Monitoring for Environment and Security) Programme. The GMFS service network currently consists of 12 European partners with different fields of expertise. These partners agree in principle to the GMFS "Open Partnership Protocol", and are committed to jointly undertake activities and provide services in support of Food Security Early Warning Systems. In order to facilitate communication with the users in Africa, local staff was hired in order to make sure that GMFS services are addressing the user needs and ensure the successful deployment of GMFS activities. GMFS aims to establish an operational service for crop monitoring in support of Food Security Monitoring to serve policy makers and operational users.

GMFS SERVICES

General

GMFS is part of the ESA GMES Service Element programme (GSE) and is in line with the general principles and guidelines for GSE services. GMFS services are user driven and are subject to continuous re-evaluation and improvement based upon the feedback received from the users. The relationship with the user is governed by a yearly renewable Service Level Agreement (SLA) that specifies the services to be delivered and the corresponding conditions. Evaluation of services in GMFS is done through user interviews and or specific workshops to discuss the achieved results. Subject of those workshops include an in depth evaluation of the products and services and how well this corresponds with the initial requirements. Recommendations for improvements are formulated and further taken up by the partnership to the extent possible. With GMFS, the partnership intends to build up and provide operational and standardized services addressing some food security aspects.

Services

GMFS provides four types of services:

(i) Early Warning Services

(ii) Agricultural mapping services

(iii) Yield assessments

(iv) support to the FAO/WFP Crop and Food Supply Assessment Missions (CFSAM).

These services are closely interlinked and are provided upon request as part of the Service Level Agreements (SLA) concluded between the GMFS partnership and the end user.

Early Warning Services

End users are provided with a set of vegetation indicators derived from different sensors at a decadal or monthly interval. From the acquired MERIS RR images 10-daily fAPAR composites are made covering the entire Africa. The 10-daily / monthly images are typically completed 3-4 days after the last acquisition and are then further distributed to the partner organizations in Africa, cut for the specific region of interest. Users are notified by email, including a quick look, upon new arrival of a product and the products itself are made available through the ESA Data Dissemination System (DDS) or regular FTP. Figure 1 illustrates the quick look attached to the notification email for western Africa for the first decade of February 2007. The same delivery system is used for the SPOT-VGT based vegetation productivity indicator (VPI). But the delay in production is only 2-3 days instead of the 3-4 days with the MERIS products. It is used to assess the overall vegetation condition and is a categorical type of difference vegetation index, referenced against the NDVI percentiles of the historical year. Thanks to this historical comparison it can also be used to detect early or late starts in the agricultural growing season. Figure 2 is a display of the VPI Quick look for western Africa for the second decade of February 2007.

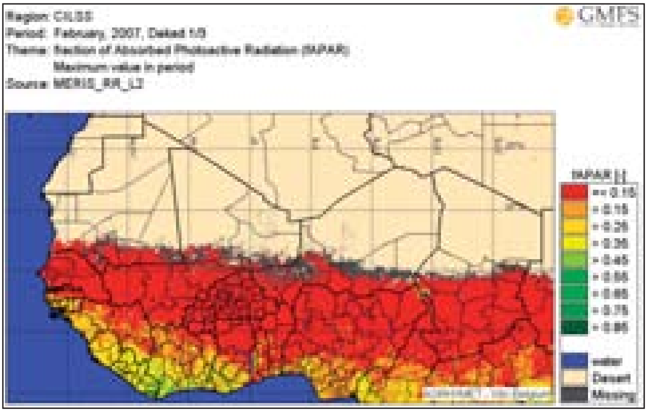

Figure 1: *Quick look of MERIS RR fAPAR image first decade of February 2007*

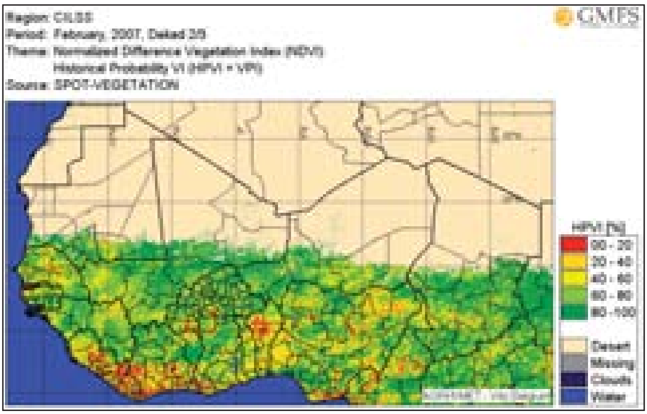

Figure 2: *Quick look of SPOT-VGT VPI image second decade of February 2007*

AGRICULTURAL MAPPING SERVICES

Three main products are provided under the agricultural mapping service:

(i) Crop emergence period;

(ii) Cultivated area for localized areas and

(iii) Crop extent for the entire countries.

The methodology used is strongly based upon the multi-temporal characteristics of the satellite data in response to the changing environment. In essence it is based upon the fact that agricultural land has a specifically different 'growing profile' to that of its surrounding vegetation or land cover types. These changes are picked up, both in the SAR signal as the optical signal throughout the growing season on the basis of which cropped land is identified. In order to derive the cropped area at local and national scale a multi-temporal series of MERIS FR and ASAR covering the entire growing season of the monitored areas are analysed in combination with other satellite data (SPOT-4, Landsat, ASTER, etc) and ground observations.

Clearly, the accuracy and efficiency of the algorithms used is largely based upon the employed management techniques of the agricultural land, the field sizes and degree of fragmentation of the landscape. Subsistence agriculture in Africa is pre-dominant and in some areas agriculture is characterized by small, highly fragmented and scattered fields. In this case ground resolution of the input satellite data is the most limiting factor. Other areas are easier to identify due to the larger field sizes. The use of the product depends upon the final accuracy achieved and ranges from the use as generic crop mask to an input layer for the assessment of total cropped area.

The mapping products are repetitive and cover every growing season. Figure 3 illustrates one of the products for Sudan for the Darfur West area.

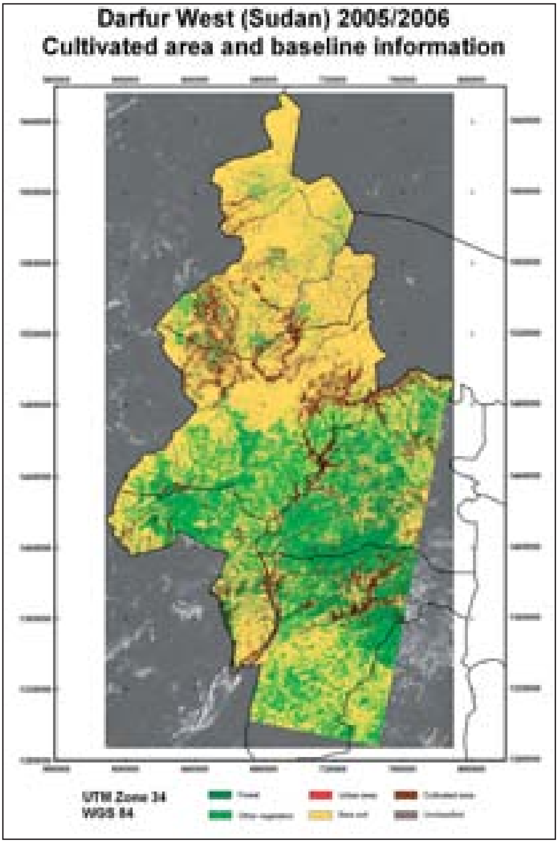

Figure 3: *Cultivated Area in Darfur West, based on a combination of Radar and Optical data*

YIELD ASSESSMENTS

The purpose is to forecast crop yield at the national level as early as possible in the growing season in order to take appropriate action in case of food crisis. Yield forecasts are an important element for estimating final production of major crops in a given country. These are needed to assess the total food availability in a given country. The yield forecast presented here provides the advantage of combining remote sensing data and classical agro meteorological methods. It has the additional advantage that it builds upon the longer term effort of the FAO AgroMetShell (AMS) software, widely used throughout Africa.

The yield forecast is realized at (sub-) national level up to the departmental level (or 2nd administrative boundary level). The yield calculation is based on a yield model obtained from a statistical analysis (stepwise regression) that relates yield to explanatory agro meteorological variables.

The processing is done in two main steps:

- The first step is to generate the explanatory variables for each year and for each department. There are three kinds of explanatory variables:
  - (i) the phenological variables. Those variables are generated by AMS. The required inputs are decadal evapotranspiration and decadal actual rainfall. The decadal actual rainfall is aggregated from daily actual rainfall in AMS (as measured from individual meteorological stations at national level). Some parameters have to be known to make a run with AMS: crop cycle length, soil water holding capacity, percent of effective rainfall, pre-season kcr, starting date of crop growing cycle. Apart from the starting date of growing cycle (which is obtained from a multi-temporal series of satellite imagery, extracted by the low resolution software VAST), all the parameters are considered as constant in all departments.
  - (ii) the remote sensed variables are extracted from NOAA GAC images with the help of Vegetation Analysis in Space and Time (VAST).
  - (iii) the meteorological variables. Combinations of decadal rainfall during the growing cycle period are calculated (e.g.: sum of rainfall from first to third decade following the starting date of the growing cycle, sum of rainfall of the 2 decades before the sowing date, etc.).
- The second step is the statistical study. For each department, the independent variables explained here above are imported in the statistical software. A stepwise regression is led to extract the best-correlated explanatory variables (2 to 4). A leave-one-out cross validation is led to test the ability of the found model to predict yield in the department. Once a good model is found, the yield forecast for the growing season is obtained by replacing the selected explanatory variables by their value for the growing season. This step is repeated for each department. The map is realized with the yields obtained at step 2 and the yield forecast at national level is obtained by aggregating the yields found at departmental level.

It has to be noted that although the same methodology is pursued in the different GMFS regions (West and Southern Africa), the method might be slightly different from one region or country to another, depending upon local requirements, data availability, availability of local meteorological data, etc.

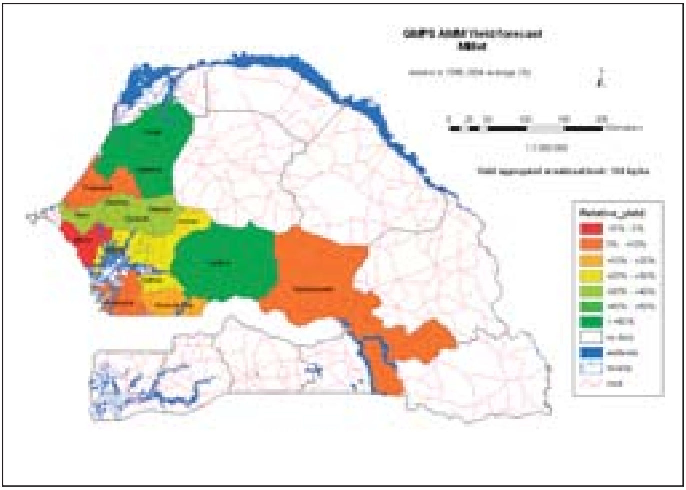

Figure 4: *GMFS Yield Forecast for Millet (Senegal 2005 growing season)*

Support to CFSAM

The service package is generated on an ad hoc basis and contains an analysis of available data and information, either ground-based or space borne. These analyses are presented in document format and possibly maps, e.g. as in Figure 4. These packages are mainly analyses and combinations of the services listed above. The processing algorithm, data requirements etc. are as such described in the relevant sections.

VALIDATION

Given the innovative approach of the employed methods, extensive validation of the products is needed. In essence there are two validation approaches:

Through the collection of ground samples in an area frame approach or through the interpretation of satellite images whenever collection of data on the ground was not feasible (e.g. in war affected zones or due to other political constraints). Extensive surveys have been set up for example in Malawi, on a yearly basis, collecting over 1,000 sample points. The collection of fieldwork points is always done by the staff of the local collaborating institute, that is in most cases the Ministry of Agriculture. Sample points are geo-referenced using GPS and fieldwork forms, that also take into account the surroundings of the sample point, are completed. Pictures are taken to have a visual image of the sample points for later use in the office. The resulting database is checked for quality and further used as main input to the validation exercise.

Based on a statistical analysis of regularly produced official statistics (e.g. comparison (by means of remote sensing data) of the estimated agricultural area in a certain district of a country with the official statistics for that district).

DISSEMINATION

All GMFS service products are disseminated in a similar manner; being it through the GMFS website (http://www.gmfs.info), the GMFS FTP site (ftp.gmfs.info) or the different geo-network nodes:

RCMRD Kenya, (http://196.200.19.218/geonetwork);

SADC-RRSU Botswana (http://www.sadc.int/geonetwork/);

AGRHYMET Niger (http://geonetwork.agrhymet.ne/);

GMFS European Catalog node (http://gmfsgeonetwork.gim.eu).

For the low resolution indicators (or early warning service) two extra dissemination systems were set up. In collaboration with the VGT4Africa project, the VPI is also distributed via the EUMETCAST system. All PUMA stations in Africa are now able to receive this data set.

In order to facilitate availability of fAPAR images to the end users, ESA installed a DDS receiving station in two of the three regional centres (AGRHYMET and RCRMD). The system is now also used to distribute the VPI images.

CONCLUSIONS

The different processing chains, archiving systems and dissemination mechanism give the possibility to provide end users with more remote sensing data. Especially in data- poor and vast regions such as Africa, a combination of multiple satellite data sources can solve part of the input data problem. As an example the GMFS approach, multi-sensor and multi-purpose monitoring techniques, using a combination of Synthetic aperture radar (SAR) and optical data (SPOT-VGT, MERIS and others), for estimating agricultural area, is given. From the feedback received from the end users and the experiences learned it is concluded that GMFS or alike services have the potential of making a valuable contribution to monitoring global food security.

Acknowlegements : We would like to acknowledge GMFS partners, as well as all organizations with whom we closely work together: The GMFS partnership consists of: Flemish Institute for technological Research (VITO); sarmap S.a.; consortio ITA; Fondazione per il Clima e la Sostenibilità (FCS); EFTAS Fernerkundung Technologietransfer GmbH; GIM - Geographic Information Management nv, Université de Liège (ULG); Microsoft - Virtual Earth Netherlands; EARS; ESYS plc; Avia-GIS BVBA; TRASYS NV.

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LIST OF SOME ABBREVIATIONS USED IN THE PROCEEDINGS

ADDS	African Data Dissemination System
ADG	Africover Database Gateway
AFRICNDVI	NDVI methodology using SPOT-VEGETATION instead of NOAA-AVHRR and AFRICOVER instead of CORINE
AICON	ARTEMIS Image converter
AID	Africover Interactive Database
AIMS	Africover Interpretation and Mapping System
AMESD	African Monitoring of the Environment for Sustainable Development
AMIS	Agro-Meteorological Information System
AMS	AgroMet Shell (FAO)
ADDAPIX	From ADDATI and PIXel, a software programme for the analysis of multivariate statistical tabular data, adapted to work on "images" (ref. FAO, SDRN)
AP3A	Alerte Precoce et Prevision des Productions Agricoles
ARTEMIS	Advanced Real-Time Environmental Monitoring Information System
ASAL	Arid and Semi-Arid Lands
ATT	Analytical Tracking Tool
AVHRR	Advance Very High Resolution Radiometer
BERM	Basin Excess Rainfall Map
CCD	Cold Cloud(-top) Duration
CCPI	Crop cycle Progress Index
CFAM	Crop Forecasting and Assessment Mission
CHARM	Collaborative Historical African Rainfall Model
CILSS	Comite Inter-Etats pour la Lutte contre la Sècheresse dans le Sahel
CMYF&EW	Crop Monitoring, Yield Forecasting & Early Warning System
CNDVI	CORINE NDVI (using the CORINE land cover class specifications)

CPC	Climate Prediction Centre
CPSZ	Crop Production System Zones
CRTEAN	Centre Régional de Télédetection, East Africa, Nairobi, see RCMRD
CRTO	Centre Régional de Télédétection de Ougadougou
CTIV	Centre de Traitement des Données de Végetation (VITO)
CSWB	Crop Specific Water Balance
Decade	a ten-year period
Dekad	a ten-day period
Dekadal	with reference to a ten-day period
DBMS	Data Base Management System
DMC	Drought Monitoring Centre
DMCH	Drought Monitoring Centre of Harara
DMCN	Drought Monitoring Centre of Nairobi
DRAO	Delegated Regional Authorizing Officer
DSS	Decision-makers Support System
EAWLS	East African WildLife Society
ECMWF	European Centre for Medium-range Weather Forecasting
EDC	EROS Data Center
EDF	European Development Fund
EOF	Empirical Orthogonal Function
EOS	End Of Season
EROS	Earth Resources Observation System
ESA	European Space Association
ET	Evapo-Transpiration
FACT	FAO AgroClimatic Tool
FEA	Food Economic Assessment
FEWS	Famine Early Warning System
FEWSNET	Famine Early Warning System NETwork

FEZ	Food Economic Zone (FSAU)
FSAU	Food Security Assessment Unit
GCM	Global Circulation Model
GDP	Gross Domestic Product
GEOWEB	A web version of a Geographic Information System
GGE	Rainfall measured in a raingauge, mm
GHA	Greater Horn of Africa
GIS	Geographic Information System
GISD	Global Institute for Sustainable Development
GIEWS	Global Information and Early Warning Service
GLAM	General Large Area Model
GLCRSP	Global Livestock Collaborative Research Support Programme (FAO)
GPS	Global Positioning System
GSDI	Global Specialized Data Infrastucture
GTS	Global Telecommunications System (WMO)
HAPEX	Hydrological and Atmospheric Pilot Experiment
HDI	Human Development Index
HRPT	High Resolution Picture Transmission
IAV	Inter-Annual Variation
IDA	Image Display and Analysis
IDP	Internal Displaced Person (Burundi)
IGAD	Inter-Governmental Authority for Development
IGBP	International Geosphere-Biosphere Programme
INSTAT+	INteractive STATistics, a (climate analysis) software package of the Statistical Services Centre, University of Reading, UK
IR	Infra-Red
IRI	International Research Institute for Climate Prediction
ISV	Intra-Seasonal Variability
ITCZ	Inter-Tropical Convergenge Zone

JRC	Joint Research Centre of the European Union (Ispra, Italy)
KMD	Kenya Meteorological Department
LAC	Limited Area Cover (satellite image)
LAI	Leaf Area Index
LCCS	Land Cover Classification System
LEWS	Livestock Early Warning System
LGP	Length of the Growing Period
LULC	Land Use and Land Cover (used by USGS)
MADAM	Medians, Averages, Deviations, And More, software to process satellite images into statistical images (FAO)
MADE	Multipurpose Africover Database for Environmental Resources
MARS	Monitoring Agriculture with Remote Sensing (a JRC programme)
MCV	Maximum Value Composite
MSG	Meteosat Second Generation
MTAP	Meteorological Transition in Africa Project
NCAR	National Centre for Atmospheric Research, NOAA
NCEP	National Centre for Environmental Prediction
NCM	National Coordination Meeting (Africover)
NDVI	Normalized Difference Vegetation Index
NEWU	National Early Warning Unit
NFPI	National Focal Point Institution
NMHS	National Meteorological and Hydrological Service
NMS	National Meteorological Service
NOAA/CPC	Natonal Oceanographic and Atmospheric Administration / Climate Prediction Centre
NWG	National Working Group

NWP	Numerical Weather Prediction
OARD	Outlook Activities Reference Document
OASD	Outlook Activities Submission Dossier
OCHA	Office for the Coordination of Humanitarian Affairs (UN)
PAIA	Priority Area for Interdepartemental Action
PDUS	Primary Data Users Station
PET	Potential Evapo-Transpiration
PMU	Project Management Unit
PPT	Precipitation
PPT	Power Point (presentation)
PS	Productive Systems
PSC	Project Steering Committee
PUMA	Preparation for the Use of MSG in Africa
PWC	Precipitable Water Content
QBO	Quasi Bi-ennial Oscillation
RCMRD	Regional Centre for Monitoring Resources for Development
RCSSRMS	Regional Centre for Services in Surveying, Mapping and Remote Sensing, now called RCMRD
REFEWS	Regional Famine Early Warning System
RESURS	Russian High Resolution Imagery
REWS	Regional Early Warning System
REWU	Regional Early Warning Unit
RFE	RainFall Estimate
ROI	Region Of Interest
RRSU	Regional Remote Sensing Unit
RSA	Republic of South Africa
SACB	Somalia Aid Co-ordinating Body

SADC	South African Development Corporation
SAMIS	Sudan Agro-Meteorological Information System
SAP-SSA	Système d'Alerte Précoce et de Surveillance de la Sécurité Alimentaire
SARGIA	Early Warning System for Food Information Management (Burundi)
SDRN	Environmental and Natural Resources Service (FAO)
SEDI	Satellite Enhanced Data Interpolation
SERI	Satellite Enhanced Rainfall Interpolation
SFC	Supplementary Feeding Centre
SISP	Système Intégré de Suivi et de Prévision (des rendements); see also AP3A
SMA	Sudan Meteorological authority
SOI	Southern Oscillation Index
SOS	Start Of Season
SST	Sea Surface Temperature
SW	SoftWare; Soil Water
S10	Ten-day Synthesis
TAMSAT	Tropical Application of Meteorology using SATellite data
TCS	Technical Consultation Meeting (of SADC)
TFC	Therapeutic Feeding Centre
TIR	Thermal Infra Red
TM	Thematic Mapper (Landsat)
UCSB	Univ. of California, Santa Barbara
USGS	United States Geological Survey
VAM	Vulnerability Analysis and Mapping
VAT	Value Added Tax
VGT	relative to the VEGETATION satellite or Programme
VGT/NDVI	NDVI data obtained via VGT

VITO	Flemish Institute for Technology
VPI	Vegetation Productivity Indicator
VSRCN	Virtual Satisfaction Rate of Cereal Needs
WFP	World Food Programme
WHC	Water Holding Capacity
WINDISP	from WINdows DISPlay, an FAO/USGS/USFS/FEWS software to analyse remote sensing imagery in a food security context
WR	Water requirement
WRSI	Water Requirement Satisfaction Index
WSI	Water Satisfaction Index
ZAR	Zone-A-Risque, Danger Zone

APPENDIX 1, OPENING REMARKS BY MS FATUMA S. ABDIKADIR, NATIONAL COORDINATOR OF THE ARID LANDS RESOURCE MANAGEMENT PROJECT, OFFICE OF THE PRESIDENT, KENYA.

Madame Abdikadir bid welcome to all participants, from different backgrounds and disciplines involved in food security issues, that had come from 13 countries and more than 30 organizations.

In her opening remarks she mentioned the multidisciplinary nature of work for food security, involving models, satellite based observations and their combination with ground based information. Many of these areas need further development and strengthening.

A major objective is the sharing of this information, not only between scientists involved in their analysis, but especially with the users of all nature. Some potential users do not know that certain types of information they require are indeed available. Thus better dissemination of these products to all potential users is a major task.

A further objective is the coordination and consolidation of early warning information obtained from various systems. Sharing such information between countries and regions in a sustainable manner will add very significant value to the overall effort.

A concern is that different organizations and institutions use different techniques and methodologies for early warning and crop and rangeland monitoring. This can lead to duplication of efforts and difficulties in interpretation of information. She noted that the workshop provided an opportunity to achieve harmonization of methodologies in **all** regions of Africa. Air masses, rivers and soil types do not know national borders, neither does pastoralism or crop production, and therefore neither should the monitoring systems.

Even if credible and timely early warning exists, sometimes the response to impending disasters is late, because of inadequate preparedness and weak linkages between early warning information and response. Therefore it is desirable to better integrate the production of information and response facilities, permitting proactive measures in respect of food security.

This point thus requires better, user-tailored information to avoid a disconnection between science and application on the ground.

A workshop like the present provides an ideal environment for developing solutions to such issues, because it brings together producers and users of crop and rangeland monitoring, early warning and food security information.

The workshop can also contribute to bring the possible solutions, and the associated institutional requirements, to the attention of policy makers, so that policies of Governments and Regional Entities can facilitate their implementation.

In closing her remarks, she hoped that her remarks would help to provoke and nourish the discussions and to develop a way forward in these domains. She thanked the organisers for arranging a timely and important event, because early warning issues come first in risk reduction and disaster management. Reiterating her welcome to the participants, she declared the workshop officially opened.

APPENDIX 2, WORDS OF WELCOME BY DR RENE GOMMES, ON BEHALF OF FAO, AND DR OLIVIER LEO, ON BEHALF OF JRC. WORDS SPOKEN DURING THE CLOSING CEREMONY BY MR JOHN MWIKYA.

A word of welcome on behalf of FAO was spoken by Dr Rene Gommes.

Rene Gommes enumerated the benefits of defining and working for a great variety of stakeholders, nationally and regionally, in the CRAM project, of harmonizing and refining the technical improvements that could be obtained, and the need to take into account, at each step in the process, the respect of the environment.

As the use and contributions of models and remotely sensed data was increasing, the aim behind the activities of CRAM could be to gradually move from food security to human well-being. In this process, it would be necessary to try to take into account the environment of the production systems, that, themselves also, could change.

Thus, new developments should be resource based, and also resource-access based.

As regards the immediate future of the CRAM activities in the whole of Africa, there were a number of points to address:

- At present, participation from Central Africa was absent, in part because food security was a lesser concern. However, future developments should encompass all Africa.
- Greater attention might have to be paid to livestock as a livelihood. This would include statistics and forecasts, and perhaps a greater role for GPS determined information.
- In the political decisions, not only the technical information supplied by a scheme like CRAM should weigh, but also a greater consideration of the situation of the people in the areas concerned.

In all this work, there were roles for international organizations, and FAO was ready to assume these roles.

A further word of welcome, on behalf of JRC, was spoken by Dr Olivier Leo.

Olivier Leo recalled that JRC had been involved for about 30 years in crop and rangeland monitoring. It was time to assess the impact of these activities and the use of its products by policy makers at all levels.

The role of the JRC was twofold, on the one hand, as operator, for the issue of operational forecasts in and around Europe, and on the other hand, as technical advisor, in this case for systems in dryer regions of the world. This meant technical exchanges with partners in Africa and also in South America, and Asia.

The CRAM workshop in 2003 had foreseen a network of technical experts in north-eastern Africa, but this had not really taken shape rapidly. As the situation was now, it would be well to foresee a Pan-African network. This network would need to have many contributors, extensive discussions and an open ear for field workers.

The 2007 workshop has several aims:

- to formulate the state of the art
- to solidify the relations in each country between the national authorities and the EU delegations, and
- to expand discussions to more partners.

It would aim to help in focusing the direction of future work. An example of such an activity is the AMESD project.

The space-part operations of JRC, and the distribution of the by-products of satellite information would be exposed. The applications of such products should be made very visible to the Administrations concerned.

Closing ceremony

Introducing the closure ceremony, Dr Olivier Leo thanked all participants for their presentations and contributions to the discussion, and the staff at the conference center, especially Ms Lillian Omengo, for their exemplary support.

The workshop was closed by Mr John Mwikya, on behalf of the Director of the Kenya meteorological Department. In his closing speech, Mr Mwikya stressed the facilities and environment for collaboration offered by CRAm and CRAM's incentive to staff in all countries to use the most up-to-date methodologies for obtaining scientific information and for exchanging this.

He finally expressed the wisj that participants wouls enjoy the rest of their stay in Kenya, if possibly including a visit to the places that show Kenya's rich natural beauty.

The workshop was closed on 29 March at 18h30.

APPENDIX 3, AGENDA OF THE WORKSHOP

Tuesday 27 March 2007

08h00 Opening and welcome adresses

Ms Fatuma Abdikadir, Arid Lands Resource Management Project, Office of the President, Nairobi, Kenya

Rene Gommes, NRCB, FAO, Rome, Italy

Olivier Leo, AGRIFISH Unit, EU-JRC, Ispra, Italy

08h20 Session 1, Users and uses of Food Security monitoring products

Chairman: Joseph Matere, ILRI

The EU-JRC MARS-FOOD context and perspectives, Olivier Leo, EU-JRC, Ispra, Italy

Review of Early Warning Systems in Africa, Jim Tefft, FAO, Rome, Italy

The agriculture monitoring activities for the CILSS region, Seydou Traore, AGHRYMET Center, Niamey, Niger

The Food Security monitoring system in SADC and RRSU, Blessing Siwela, RRSU, Gaborone, Botswana

Revisiting the target client, information needs and available technology for improved service delivery in agrometeorology, Elijah Mukhale, SADC Regional Center, Gaborone, Botswana

Meta-data initiative to support Food Security analysis in ICPAC, Bwango Apuuli, ICPAC, Nairobi, Kenya

10h40 Session 2, Crop monitoring methods

Chairmen: Rene Gommes, Jim Tefft, FAO

Integrating observation and statistical forecasts over sub-Saharan Africa to support famine early warning, Chris Funk, James Verdin, Greg Husak, Climate Hazard Group – UCSB, Santa Barbara, USA

Crop area estimates using high and medium resolution satellite images in areas with complex topography, Greg Husak, Michael Marshall, Joel Michaelson, Diego Pedreros, Chris Funk, Gideon Galu, Climate Hazards Group – UCSB, Santa Barbara, USA

Crop monitoring, forecasting and production estimation in Kenya, based on crop model and auxiliary field datasets, Gideon Galu, FEWS-NET, Nairobi, Kenya

FSAU crop and rangeland monitoring and analysis, Cindy Holleman, FSAU, Somalia

The use of RS images to monitor the cropping season, Silvio Griguolo, Dept. of Planning, IUVA, Venezia, Italy

Operational maize yield model development and validation based on remote sensing and agro-meteorological data in Kenya, Oscar Rojas, EU-JRC, Ispra, Italy

Modis NDVI-based production anomaly estimates for Zimbabwe during the 2005/06 season, Chris Funk and Mike Budde, Climate Hazard Group, UCSB, Santa Barbara, USA

Use of land cover maps and crop masks for agricultural monitoring in Africa, Felix Rembold, EU-JRC, Ispra, Italy

Crop monitoring activities at the Ministry of Agriculture of Ethiopia, Matthewos Hunde, Ministry of Agriculture, Addis Ababa, Ethiopia

The Crop Statistics System of the Central Statistical Authority, methodology, results and current improvement, Girma Taddesse, Central Statistical Authority, Addis Ababa, Ethiopia

Crop monitoring based on remote sensing and agro-meteorological data in Ethiopia, JRC-MARS-FOOD ten-daily bulletins production, Michel Massart, EU-JRC, Ispra, Italy

Request to each participant for a statement on main issues, President of the session

Wednesday 28 March 2007

08h00 Session 3, Range-land monitoring methods

Chairman: Bwango Apuuli, ICPAC

The establishment of a community based livestock early warning system, Joseph Matere, ILRI, Nairobi, Kenya.

Land resources inventory for land suitability assessment in Somalia: The Dur Dur and Gebiley Case Study, Ronald Vargas, FAO-SWALIM, Somalia

Combination of field data and satellite observation for near real time monitoring of rangeland vegetation, Christophe Sannier, SIRS, Villeneuve D'Ascq, France.

Implementation of VPI products for decision support, Haroun Abdallah, Sudan Meteorology Department, Khartoum, Sudan

Rangeland Monitoring activities at AGHRYMET center, Job Andigue, AGHRYMET Center, Niamey, Niger

Developing an operational rangeland water requirement satisfaction index, Gabriel Senay and James Verdin, USGS, Sioux Falls, USA

PHYGROW, an automated modeling package for livestock keepers, Robert Khaito, LEWS, Texas A&M, USA

11h30 Session 4, Integration of spatially variable information and non-parametric modeling approach

Chaiman: Gideon Galu, FEWS-NET

Keynote presentation: The Integration and exploitation of spatially variable information and on the application of non-parametric modeling approaches, Rene Gommes, FAO, Rome, Italy

12h20 Session 5, Farming systems and coping strategies

Chairman: Gideon Galu, FEWS-NET

The effect of rainfall variability on agricultural activity and on coping strategies in Ethiopia, Almaz Demessie, NME, Addis Ababa, Ethiopia.

Farming systems and coping strategies – changing patterns, Paolo Santacroce, University of Venezia, Venezia, Italy.

14h00 Session 6, Rainfall monitoring methods

Chairman: Olivier Leo, JRC

Satellite based rainfall monitoring for food security in Africa, including information on the African Monsoon Multidisciplinary Analysis, AMMA, David Grimes, TAMSAT-University of Reading, Reading, UK

Qualitative crop yield forecasting based on satellite rainfall estimates, David Grimes, TAMSAT-University of Reading, Reading, UK.

Apparent current fluctuation in seasonal rainfall analyzed over five years, Lubega Fortunata, Uganda Meteorology Department, Kampala, Uganda

A new satellite rainfall estimation method for application in tropical regions in West Africa, Franck Chopin, CNRS - Ecole Polytechnique, Palaiseau, France

Third generation rainfall climatologies; satellite rainfall and topograpgy for smart interpolation, Chris Funk, Climate Hazard Group – UCSB, Santa Barbara, USA

FEWS NET rainfall validation and enhancement activities, Chris Funk, Climate Hazard Group – UCSB, Santa Barbara, USA

Rainfall comparison between ECMWF and RFE model in Africa using NDVI as auxiliary data, Oscar Rojas, EU-JRC, Ispra, Italy

17h00 Session 7, Associated topics and programmes

Chairman: Etienne Bartholome, EU-JRC

VGT4Africa, VGT@Work and AMESD initiatives and products, Etienne Bartholome, EU-JRC, Ispra, Italy.

Remote sensing products from RCMRD, Erick Khamala, RCMRD, Nairobi, Kenya

Support to the Sudan Agromet Monitoring Information System (SAMIS) in the frame of the SIFSIA project, Rogerio Bonifacio, FAO, Khartoum, Sudan

Operational processing and remote sensing data for crop and rangeland monitoring in Africa, Sven Williams, VITO-GMFS-ESA project, Mol, Belgium.

Reviewing the Livelihoods of Agro-Pastoralists and Pastoralists in the GHA, Haile Menghestab, WFP-VAM, Rome, Italy

End of the presentations

Friday 29 March 2007

08h00 Session 8, Round Table discussions

16h00 Session 9, Workshop conclusions

The activities towards an Africa-wide system of compatible crop and rangeland monitoring methods. The way forward.

17h50 Closure

APPENDIX 4, LIST OF PARTICIPANTS AND THEIR ADDRESSES

2nd Workshop on Crop and RAngeland Monitoring
27–29 March 2007
Jacaranda Hotel, Westlands, Nairobi, Kenya.

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ABSTRACT

*The objective of the **2nd International Workshop on Crop and Rangeland Monitoring in Eastern Africa** was to gather the institutions and the experts participating in the Scientific Network to present past and recent activities on crop monitoring, in order to define the state of the art and the progress made since the first workshop held in Nairobi in 2003, and to facilitate the development of a crop and rangeland monitoring system for the whole of Africa. The workshop aimed at discussing possibilities for cooperation involving local groups and experts participating in scientific exchange programmes and joint projects for methodological development and improvement of Pan-African crop monitoring information systems. This publication includes the discussions and the papers presented of the workshop.*