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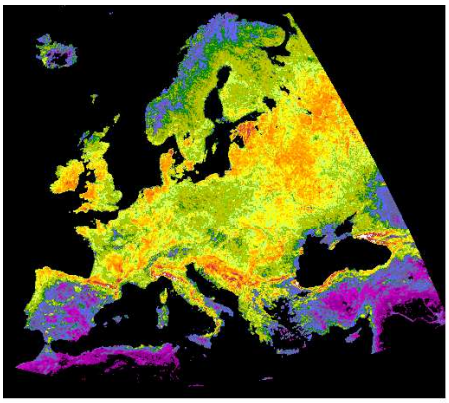
Land surface indicators from Space



Methodology and Preliminary Results

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1 Executive summary

This document overviews the content and the preliminary results of a specific work package entitled "Land Surface Indicators from Space" of the "Land Use and Landscapes" from the Joint Research Center (JRC) and the European Environment Agency (EEA) 2006 work plan described in Kennedy and Stanners (2005).

The first section summarizes the objectives of the activities in the context of the EEA project "Land and Ecosystems Accounts". The main goal is the estimate and the analysis of the Net Primary Productivity (NPP) over terrestrial surfaces from space remote sensing products over various land cover types in Europe. The Knorr and Heimann (1995)'s model is applied to compute the NPP using the current JRC- Fraction of Absorbed Photosynthetically Active Radiation ($FAPAR$) products as input. This simple generic global biosphere model requires also the downward photosynthetic active radiation (PAR) at the surface level. Sections 3, 4 and 5 outline the model, identify the sources of input data stream, and present preliminary results over European countries, respectively. Concluding remarks and perspectives are then given at the end of the document.

2 Introduction

2.1 Objectives

Human Appropriation of Net Primary Productivity (HANPP) has been proposed as a promising global sustainability indicator (Haberl 1997; Haberl et al. 2004). This value is defined as the difference between the potential value, which could be assessed with a model assuming only natural vegetation, and the actual value (derived from current measurements) plus the harvest value (*i.e.* used by human).

$$HANPP = NPP_{potential} - NPP_t \tag{1}$$

where

$$NPP_t = NPP_{act} - NPP_h \tag{2}$$

for which NPP_{act} is the actual NPP and NPP_h the harvest NPP.
It seems that global (or national) statistics are not sufficient for assessing the sustainability of biomass extraction/harvesting. Therefore, there is a need to cross-analyse the aggregated statistics with spatially distributed data on potentials and NPP total and variability (see Weber 2006 for more details).

The state and evolution of terrestrial vegetation is characterized by a large number of physical, biochemical and physiological variables. Few of these are directly observable from space, but they jointly determine the Fraction of Absorbed Photosynthetically Active Radiation ($FAPAR$) which acts as an integrated indicator of the status and health of the plant canopy, that can be retrieved by remote sensing techniques (Gobron et al. 2000). $FAPAR$ plays a critical role in the biosphere path of the global carbon cycle and in the determination of the primary productivity of the land biosphere.

The $FAPAR$ value is defined through the radiation balance between the upward and downward fluxes scattered from and transmitted through the vegetation system. The ability of a vegetation canopy to absorb solar radiation in the visible domain is largely controlled by the amount of chlorophyll available in the leaves and, as a consequence, by the number of green leaves present over a given area. Over terrestrial surfaces, the spatial and temporal analysis of the NPP can be indeed achieved through this biophysical product which can be estimated from space remote sensing data at the global scale.

Seasonal variations of $FAPAR$ depend on land surface types and detecting changes from space gives information on the state and health of vegetated area and thus indicates plant response to prevailing ecosystem conditions, e.g water and heat stress. Over multiple years, comparisons of $FAPAR$ trends indicate ecosystem health including ability to recover from, or bounce-back, from severe ecosystem stress, such as thoses experienced over Europe in the summer of 2003 (Gobron et al. 2005).

In this framework and using sequential and/or contemporaries space sensor in the solar domain, JRC developed a series of algorithms to derive FAPAR (Gobron et al. 2000) and to produce a global dataset at 2.17 km of spatial resolution since September 1997 (Mélin et al. (2002), Gobron et al. (2006)). These products can now be used to approximate the NPP values using a simple global model proposed by Knorr and Heimann (1995). The procedure requires additional ancillary products such as the downward radiation in the PAR region and the so-called global fitting parameters.

2.2 Policy framework

This project aims to contribute to the following international and European environmental policies.

- 6th Environmental Action Programme,
- United Nations Convention to Combat Desertification (UNCCD)
- United Nations Framework Convention On Climate Change (UNFCCC)
- World Summit On Sustainable Development (WSSD)
- Convention On Biological Diversity (CBD)
- Global Monitoring for Environment and Security (GMES)
- NATURA2010
- Pan-European and Mediterranean assessments: Pan-European Ecological Network, incl. report to Belgrade 2007, SEBI2010 and UNEP/MAP cooperation
- Implementation of the UN System of Economic-Environmental Accounts (in cooperation with Eurostat).

2.3 Scope

This document outlines the method and the data which are needed to generate NPP products from the JRC-FAPAR space derived products (see `http://fapar.jrc.ec.europa.eu/`.

2.4 Revision history

This version is the first release of the document.

3 Model identification

The net primary production NPP, corresponds to the difference between the gross primary photosynthesis of the canopy noted GPP, *i.e.* the uptake of carbon, C, by the plant, and the autotrophic respiration R_a, *i.e.* the 'release' of carbon into the atmosphere:

$$NPP = GPP - R_a \tag{3}$$

GPP represents the actual quantity of C which is used by the canopy during the photosynthetic process and this quantity depends on the $FAPAR$ through:

$$GPP \approx \epsilon \times FAPAR \times PAR \tag{4}$$

where ϵ is the radiation efficiency factor, $FAPAR$ the fraction of the PAR absorbed by the green vegetation, and PAR the incident photosynthetically active radiation.

Following the approximation proposed by Monteith (1972) and Monteith (1977), one can assume that R_a is a constant factor of GPP and Eq. 3 can be rewritten as:

$$\begin{aligned} NPP &= GPP - \alpha \times GPP && (5)\\ &\approx (1. - \alpha)\epsilon \times FAPAR \times PAR && (6)\\ &\approx A \times FAPAR \times PAR && (7) \end{aligned}$$

The ϵ and α parameters should depend on the vegetation itself but Knorr and Heimann (1995) proposed to use a Simple Diagnostic Biosphere Model (SDBM) (see Eq. 7) at the **global scale** by optimizing A as a global fitting parameter. PAR, which is the incident radiation at the surface, corresponds to the actual downward solar radiation in the spectral range of $[0.4\mu m, 0.7\mu m]$. The optimization of A was made for various models (see results in Knorr and Heimann (1995)) against in-situ measurements of C with the atmospheric tracer transport model model, TM2 (Heimann 1995). The exercise has been performed using meteorological and derived remote sensing data in the 80's. In the context of our application, one model (version VII) has been chosen (see Eq. (5)) with an optimized value of $A = 0.61 \pm 1.1\% \, (gCperMJ\,PAR)$ (Knorr, personal communication).

The uncertainties can be estimated, as a first approximation, throught the propagation error equation using the derivate of Eq. 7

$$\Delta_{NPP} = \frac{\partial NPP}{\partial A}\Delta_A + \frac{\partial NPP}{\partial FAPAR}\Delta_{FAPAR} + \frac{\partial PAR}{\partial PAR}\Delta_{PAR} \tag{8}$$

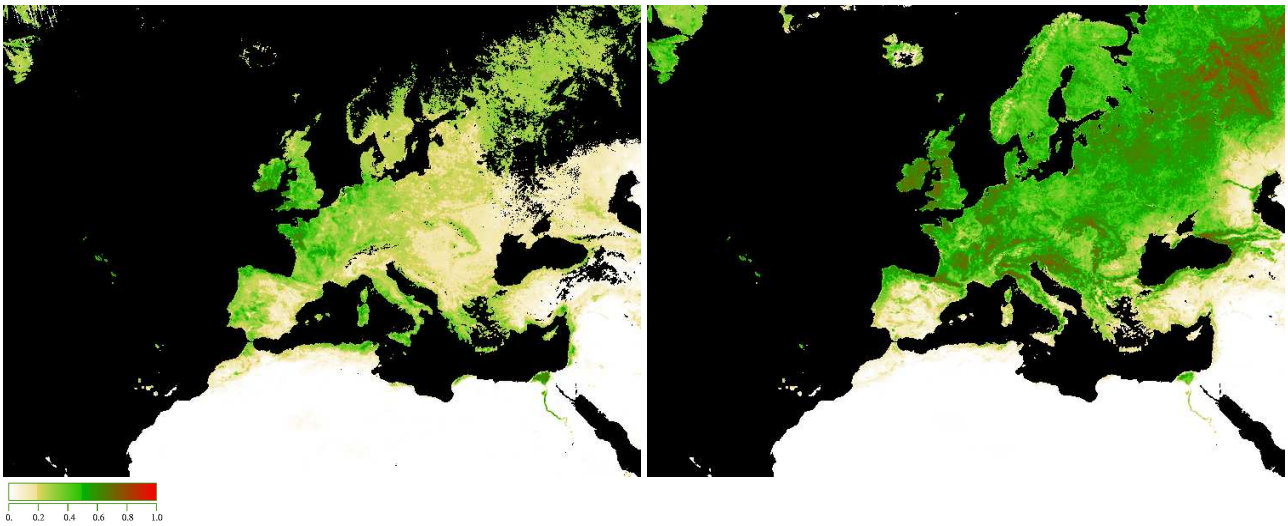


Figure 1: FAPAR map at 10 km of spatial resolution in March (left) and July (right) 2000.

with

- $\Delta_A = 1.1\,\%$,
- $\Delta_{PAR} = 10\,\%$,
- $\Delta_{FAPAR} = Max(10\,\%, STDEV_{FAPAR})$

where $STDEV_{FAPAR}$ corresponds either to the spatial standard deviation, when the $FAPAR$ products have been aggregated, or to the temporal deviation of $FAPAR$ over the composite period when using highest resolution.

4 Ancillary data

4.1 FAPAR

JRC-FAPAR dataset products are quasi-systematically generated over Europe at 2 km and 10 km of spatial resolution in the Lambert Azimuthal Equal Area (LAEA) following the projection's definition published in `http://crs.bkg.bund.de/`.
Examples of European FAPAR maps at 10 km derived from SeaWiFS are shown in Figure 1 for March (left) and July (right) 2000. The color scale goes from white for low values (over semi-arid region) to red color for higher values (when the photosynthetic productivity is maximum over agricultural fields.) of FAPAR.

Performance and validation exercises of the FAPAR products have been done and published in Gobron et al. (2006) for Sea-viewing Wide Field-of-view Sensor (SeaWiFS) data-sets and in Gobron et al. (2007) for other optical instruments. The uncertainties values resulting from the input data errors show that the $FAPAR$ can be estimated in average within 10%. The validation against ground-based estimates demonstrates than the values agree within ± 0.1 over various vegetated cover.

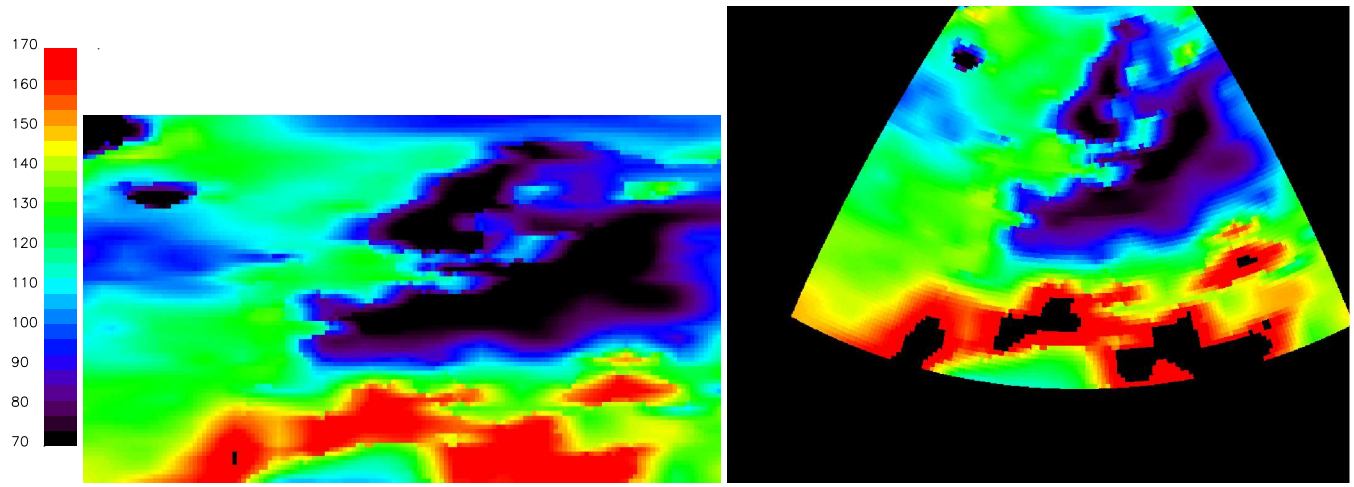


Figure 2: Examples of original Incident radiation I_n (W/m^2) in the 2.5 ° × 2.5 ° grid (left) and its representation at 10 km in LAEA projection (right) for the July 2000.

4.2 Short Radiation in the Photosynthetically Active Radiation (PAR) domain

A review for datasets of downward radiation in the PAR domain at the surface level has been achieved and we concluded that no such dataset is currently available nor systematically produced at the spatial resolution of interest.

Previous methods to estimate the PAR over terrestrial surfaces have been proposed by Whitlock et al. (1995) and Pinker et al. (1995) but only PAR products dating before 1995 have been generated. Recently, various methods have been proposed by Tang et al. (2006) and Liang et al. (2006) using the MODerate Resolution Imaging Spectrometer (MODIS) data to estimate the net surface shortwave radiation and the PAR (preliminary products are currently available but only over northern American continent), respectively.

In this study, PAR is assumed to be half of the total solar radiation, $I_n(Wm^{-2} = Js^{-1}m^{-2})$, which corresponds to the actual radiation reaching the surface. It means that the cloud cover has been taken into account. The European Center for Medium-Range Weather Forecasts (ECMWF) dataset at 2.5° × 2.5° has been selected. The monthly products are directly derived from hourly data available in the reanalysis ECMWF 40 years Re-Analysis (see Uppala et al. (2005)).

Since the available spatial resolution is coarser than the actual $FAPAR$ datasets, we approximate the solar downward radiation with a sub-sampling technique over the higher spatial resolution of interest (see Figure 2 the original map (left) and the new one (right)).

5 Products Description

The NPP values have been computed for the entire year of 2000, 2001 and until June 2002 over Europe at 10 km of spatial resolution and at 1 km (using a nearest neighbour technique from 2.17 km data sets) for only 2000. In addition, we provided the associated uncertainty Δ_{NPP} derived from a propagation error (see Eq. 8). Each monthly products is stored in one HDF file and four GeoTiFF files:

- `SEA01_ORB01_`*YYYYMMDD*`_`*YYYYMMDD*`_L4_NPP_000002_`*GEO*`_`*RES*`_PRO.HDF`
- `SEA01_ORB01_`*YYYYMMDD*`_`*YYYYMMDD*`_L4_NPP_000002_`*GEO*`_`*RES*`_FLT.GEOTIFF`
- `SEA01_ORB01_`*YYYYMMDD*`_`*YYYYMMDD*`_L4_NPP_000002_`*GEO*`_`*RES*`_RGB.GEOTIFF`
- `SEA01_ORB01_`*YYYYMMDD*`_`*YYYYMMDD*`_L4_DPP_000002_`*GEO*`_`*RES*`_FLT.GEOTIFF`
- `SEA01_ORB01_`*YYYYMMDD*`_`*YYYYMMDD*`_L4_DPP_000002_`*GEO*`_`*RES*`_RGB.GEOTIFF`

where

- *YYYY* indicates the year
- *MM* is the month of the year
- *DD* is the day of the month
- *YYYYMMDD* and *YYYYMMDD* are the first and the last dates of the period, respectively.
- *GEO* indicated the geographical window (minimum and maximum latitudes and longitudes values and the projection type).
- *RES* referes to the spatial resolution of the product.
- `FLT` indicate that the value is coded in float.
- `RGB` indicate that the value are coded in byte (from 0 to 255) and a color image is provided.
- `NPP` and `DPP` contain the value and the uncertainty of NPP into the GeoTiff files, respectively.

6 Preliminary Applications

The first application uses the PAR and $FAPAR$ products at 10 km for the year 2000 and 2001. The monthly NPP values over 2000 and 2001 have been produced for the pastures and natural grasslands defined as dominant species inside the 10 km $\times$ 10 km grid cell derived from the Corine Land Cover 2000 (CLC 2000).

The CLC definition of pasture and the natural grassland can be found in the report published at `http://reports.eea.europa.eu/CORO-landcover/en`.

6.1 Annual NPP Values

The annual NPP is computed for both species and reported in Table 1. The pastures contribute by more than 10 % to the European NPP in both years and the natural grasslands by 2.60 %, respectively. Note that the land cover map is derived by taking the dominant species inside the 10 km grid using the original CLC 2000 map.

Table 1: Annual NPP ($kgC/m^2/year$) and contribution (%) to the European[a] value over natural grassland and pasture in 2000 and 2001.

	Natural Grassland	Pasture	European
2000	4.73 (± 1.40) (2.60 %)	5.84 (± 1.47) (10.44 %)	4.69 (± 1.24)
2001	4.70 (± 1.38) (2.60 %)	5.78 (± 1.46) (10.40 %)	4.66 (± 1.23)

a defined in CLC 2000 map.

6.2 Seasonal Profiles

The four panels in Figure 4 display the annual time series of NPP spatially averaged over the natural grassland pixels (top panels) and the pasture ones (bottom panels) during year 2000 (left panels) and 2001 (right panels). The vertical bars correspond to the spatial standard deviation value. One can notice that NPP time profiles differ over those two species. From a year to another year, we have differences as can be expected by inter-annual variations of meteorological conditions.

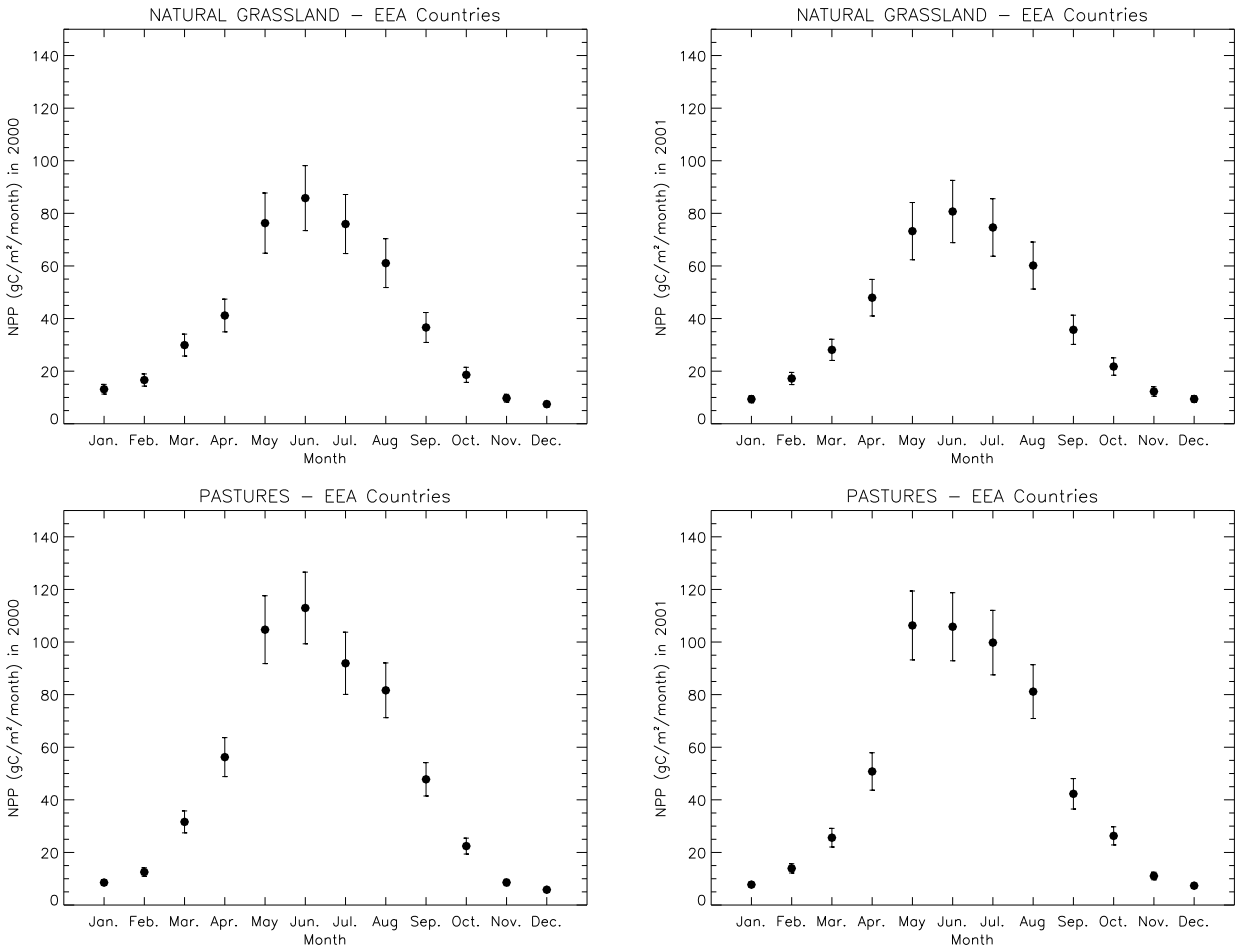


Figure 3: Time series of NPP values averaged over the natural grassland(top panels) and pastures (bottom panels) in Europe for 2000 (right panels) and 2001 (left panels), respectively. The error bars indicate the spatial standard deviation value.

6.3 National Contribution

Figure 5 shows first the national contribution in term of area, when computing statistics by using the dominant species classification in the 10 km LAEA map, with respect to both land cover types. The natural grassland are mainly found in Spain (25%), United Kingdom (17%), Italy (13%) and France (12%) whereas the pasture are mostly located over France (22%), United Kingdom (18%), Germany (18%) and Ireland (10%).

When comparing to the national contribution in term of NPP (see pies Figure 6), we retrieved the four main countries, *i.e.* Spain (22%), United Kingdom (20%), Italy (14%) and France ($13-14\%$) which contribute to more than half of the total NPP for the natural grassland in 2000 and 2001. There is no difference in the national contribution between the two years, except +1% to France from 2000 to 2001. Concerning the pastures, France ($25-26\%$), United Kingdom (19%), Ireland and Germany ($11-12\%$) mostly contribute to the total NPP in both year.

Table 2 summarizes the correlation between the contribution to the NPP for the two species with respect to the area. One notice that, in general, the contribution is not surprisingly proportional to the surfaces. However, one can also see that over the pastures, the contribution of France is 4 % more important in term of NPP: it means that the photosynthetic process may be higher than other. Nevertheless, this type of preliminary study has been done on dominant species with assumptions that the radiation efficiency factor is geographically the same, which may be not the case. The principal benefit from this study is that we used actual measurements of $FAPAR$ which may in fact take into account the spatial and temporal variability of the vegetation photosynthetic activity.

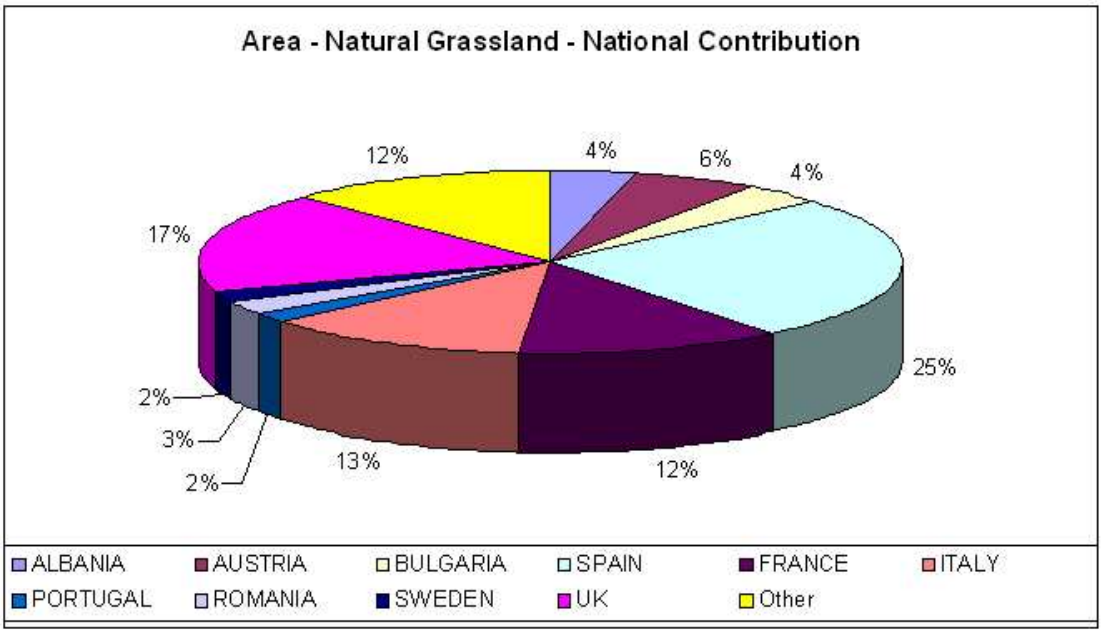
Table 2: National contribution (%) to the Area and NPP of European[a] value over natural grassland and pasture in 2000 (2001).

Country	Natural Grassland Area	Natural Grassland NPP	Pasture Area	Pasture NPP
France	12	13 (14)	22	25 (26)
Germany	NA	NA	12	19 (19)
Italy	13	13 (14)	NA	NA
Ireland	NA	NA	10	12 (11)
UK	17	20 (20)	18	19 (19)
Spain	25	22 (22)	2	2 (2)

a defined in CLC 2000 map.

7 Concluding remarks and perspectives

This report summarizes the methodology used for assessing the NPP over Europe from biophysical land products derived from space through a simple diagnostic biosphere model. The preliminary results over natural grassland and pastures at 10 km illustrate the potential of this method to track changes in term of NPP in the context of a further land policy application to compute the HANPP.



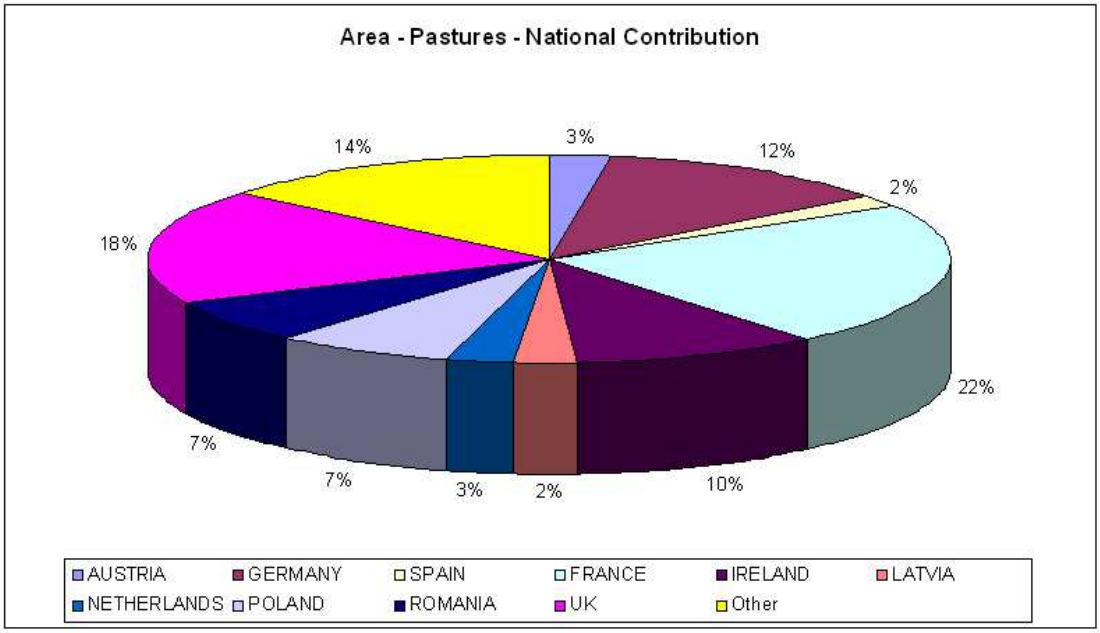
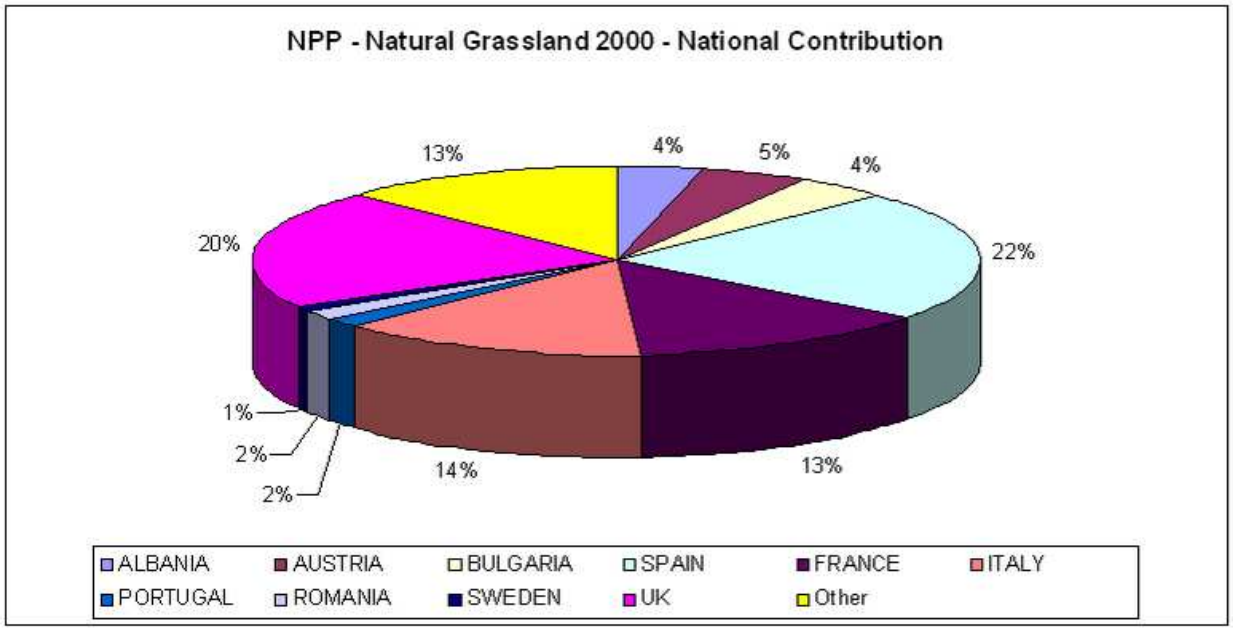


Figure 4: National contribution of the total surface in 2000 for the natural grassland (top pie) and pastures (bottom pie).



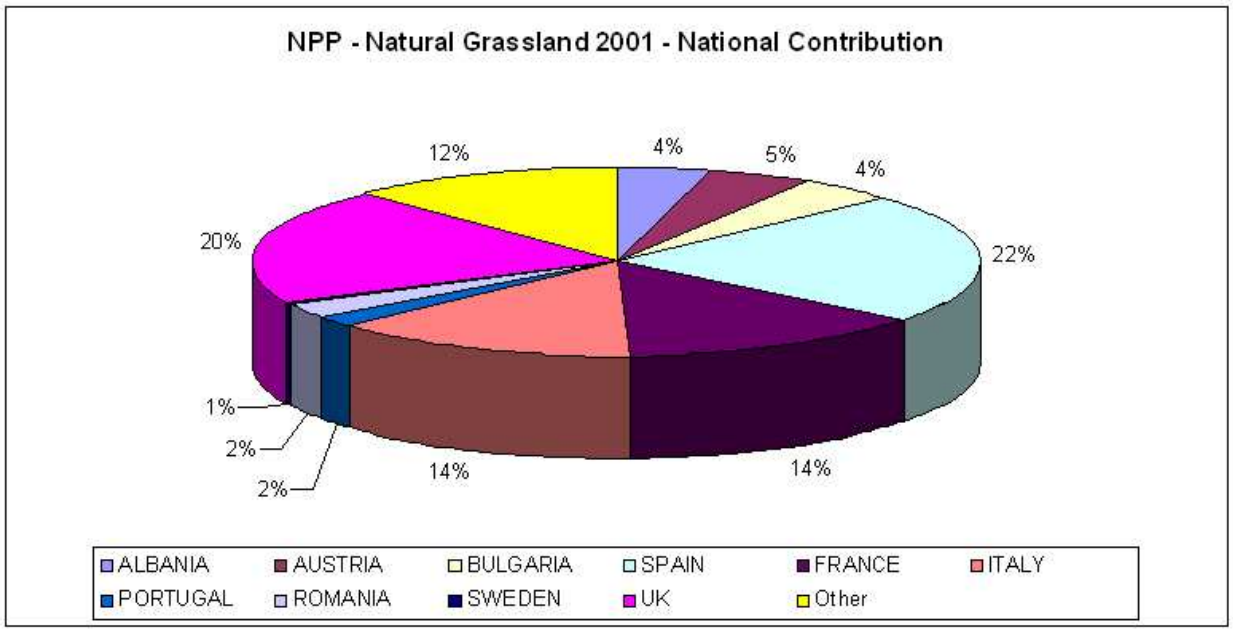
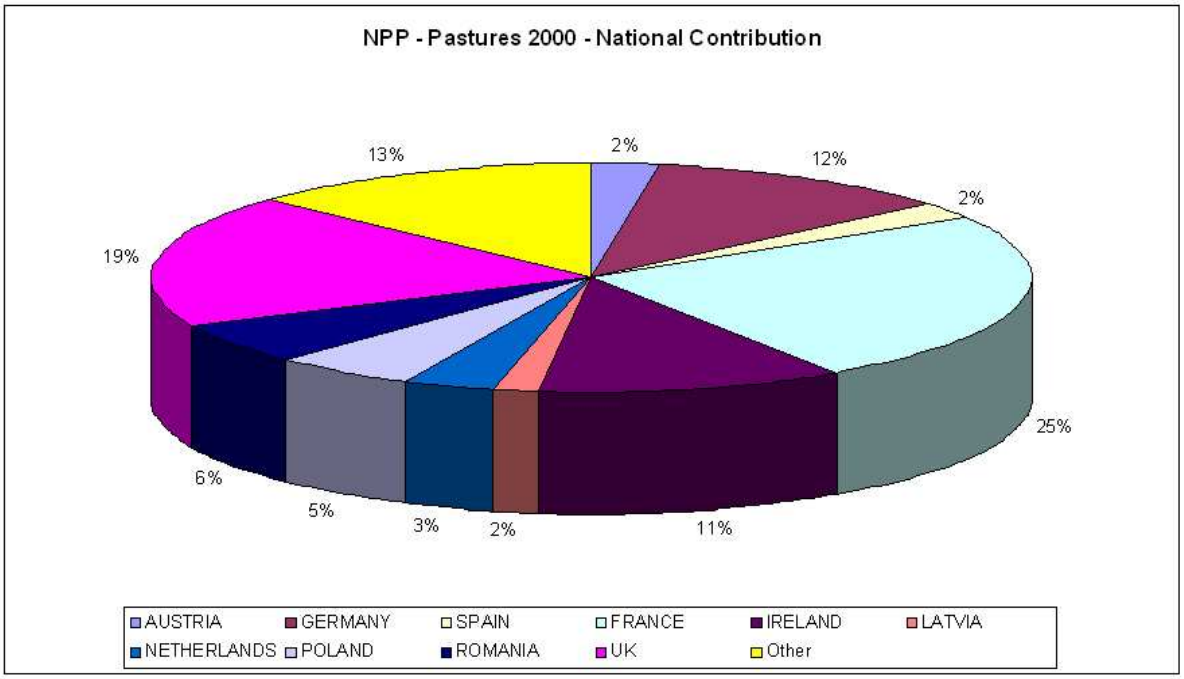


Figure 5: National contribution of the total NPP 2001 for the natural grassland in 2000 (top pie) and 2001 (bottom pie).



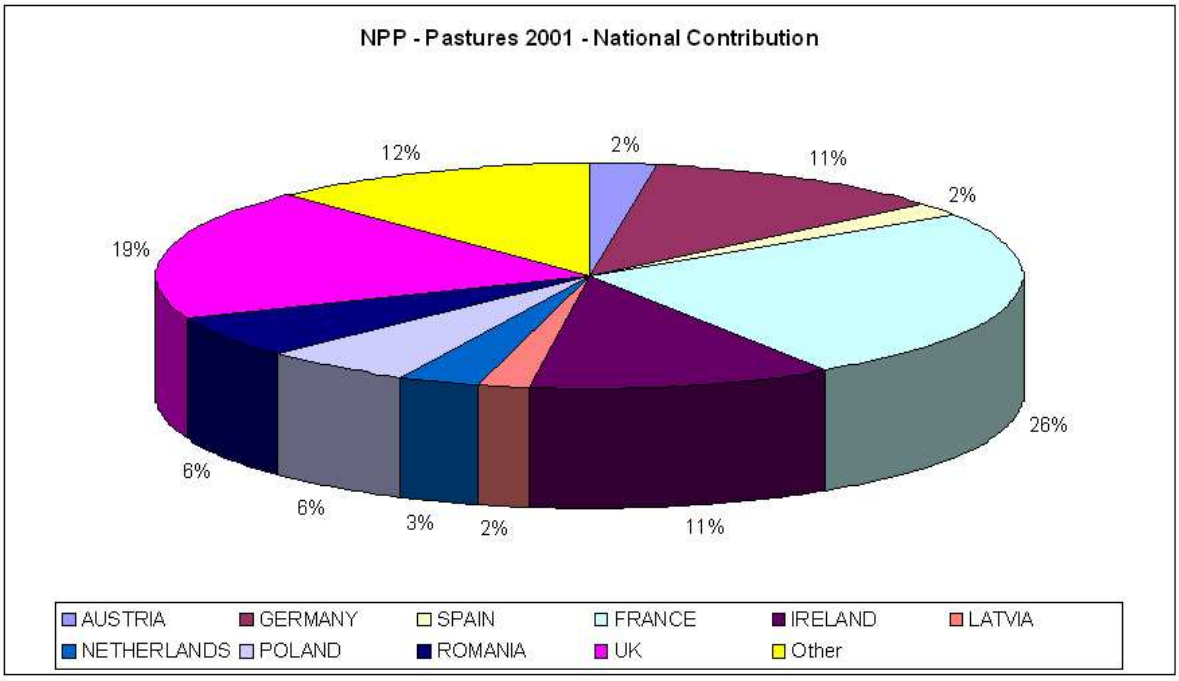


Figure 6: National contribution of the total NPP 2001 for the pastures in 2000 (top pie) and 2001 (bottom pie).

Additional studies are foreseen to verify the actual output values with other source of measurements, like in-situ measurements or state of the art biosphere model simulations (like BETHY (Knorr and Heimann 2001) or ORCHIDEE (Krinner et al. 2005). A refinement of the global fitting parameter, A, using contemporaries value of C measurements and meteorological data, is expected.

The NPP accounting is envisaged to be an additional tool and information that will help EEA to anticipate possible changes on a shorter time than the Corine Land Cover updates. The accounting may be performed on monthly basis and later it will be combined with the meterological datasets (to identify patterns that are correlated with extreme weather events and are not land use changes). As a later stage, the aggregated data will be connected to Land Cover Accounts (LEAC) of the EEA.

The uncertainty associated with this data set is still high and further validations and development of the NPP model probably increase its accuracy.

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Executive Abstract
This document overviews the content and the preliminary results of a specific work package entitled "Land Surface Indicators from Space" of the "Land Use and Landscapes" from the Joint Research Center (JRC) and the European Environment Agency (EEA) 2006 work plan described in Kennedy and Stanners (2005).

The first section summarizes the objectives of the activities in the context of the EEA project "Land and Ecosystems Accounts". The main goal is the estimate and the analysis of the Net Primary Productivity (NPP) over terrestrial surfaces from space remote sensing products over various land cover types in Europe. The Knorr and Heimann (1995)'s model is applied to compute the NPP using the current JRC- Fraction of Absorbed Photosynthetically Active Radiation ($FAPAR$) products as input. This simple generic global biosphere model requires also the downward photosynthetic active radiation (PAR) at the surface level. Sections 3, 4 and 5 outline the model, identify the sources of input data stream, and present preliminary results over European countries, respectively. Concluding remarks and perspectives are then given at the end of the document.

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