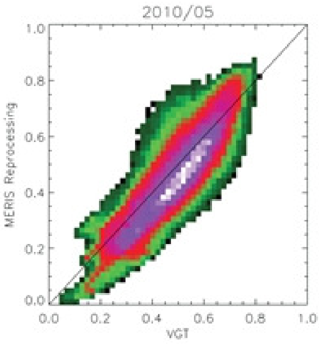

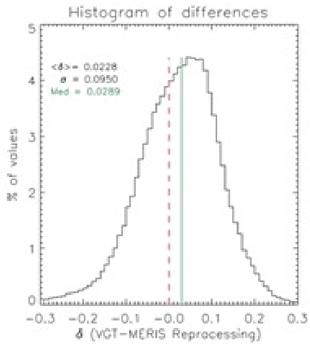

J R C T E C H N I C A L R E P O R T S

Multi-Sensor Intercomparison of JRC-FAPAR products: JRC and VITO implementation

Nadine Gobron and Guido Ceccherini

2012

Report EUR 25668 EN

Joint Research Centre

European Commission
Joint Research Centre
Institute for Environment and Sustainability

Contact information
Nadine Gobron
Address: Joint Research Centre, Via Enrico Fermi 2749, TP 272, 21027 Ispra (VA), Italy
E-mail: nadine.gobron@jrc.ec.europa.eu
Tel.: +39 0332 78 6338
Fax: +39 0332 78 9073

http://ies.jrc.ec.europa.eu/
http://www.jrc.ec.europa.eu/

This publication is a Reference Report by the Joint Research Centre of the European Commission.

JRC76383

EUR 25668 EN

ISBN 978-92-79-27998-0

ISSN 1831-9424

doi:10.2788/7624

Luxembourg: Publications Office of the European Union, 2012

Printed in Luxembourg

1. Summary 6
2. Summary of the JRC-FAPAR algorithm 6
3. Overview of Earth Observation data 7
3.1. MODIS 7
3.2. VEGETATION 9
3.3. MERIS 9
4. Results 9
4.1. MODIS @ 250 m 9
4.2. VEGETATION @1km 11
4.3. VEGETATION-MERIS-MODIS @ 1km 13
5. Conclusions 18
References 19

Contents

1 Maps of FAPAR values and differences over Romania for the 2^{nd} of May 2010. Left panel: JRC calculations using the entire swath. Middle panel: VITO products where the second day has been selected in the 10-days product. Right Panel: Difference between the two products 10
2 Scatterplot and histogram of difference between FAPAR values processed at JRC (x-axis) and VITO (y-axis) using MODIS data at 250 m over Romania. Top and bottom panels correspond to averaged over 1x1 and 3x3 pixels. 10
3 Scatterplot and histogram of difference between FAPAR values processed at JRC (x-axis) and VITO (y-axis) using MODIS data at 250 m over Europe. 12
4 Same as Figure 3 for the same SZA. 12
5 Same as Figure 3 without JRC flag. 12
6 Daily FAPAR maps over Europe from MERIS (ESA), MODIS(JRC) and VGT (VITO)instruments for the 2^{nd} of MAY 2010. 14
7 Same as Fig. 6. but for the 8 of MAY 2010. 14
8 Scatter-plots and histogram of differences between daily values from MODIS TERRA (top panel) and VGT (bottom) versus MERIS instuments. 15
9 Scatter-plots and histogram of differences between daily values from MODIS TERRA and MODIS TERRA instuments. 16
10 Scatter-plots and histogram of differences between 10-days values from MODIS TERRA , MODIS TERRA and MERIS instuments. 17

List of Figures

1 MODIS Input data 8
2 Input parameters over Romania 8
3 Input parameters over Europe 8

List of Tables

1. Summary

Physically-based algorithm for deriving Fraction of Absorbed Photosynthetically Active Radiation (FAPAR) products has been designed and optimized by the Joint Research Centre (JRC) for various Earth Observation (EO) sensors (Gobron et al. 2000).

Among them, VITO implements JRC-FAPAR for 1) Moderate Resolution Imaging Spectroradiometer (MODIS) data at 250 m of spatial resolution and 2) VEGETATION at 1 km. They process data over Europe for delivering them in near-real time to MARS project[1].

The corresponding algorithms are published in Gobron et al. (2006b, Gobron et al. (2006a) and Gobron et al. (2002), respectively.

Note that these above algorithms have been optimized using nominal spectral responses of the first MODIS intrument, *i.e.* **on board the TERRA platform and for VEGETATION 1.**

We propose here to evaluate VITO implementation processing chain using data over Europe by comparing their products to the those computed with original codes at JRC.

The first exercice (see Section 4.1) presents results of direct comparison using daily MODIS data at 250 m over a small region (see Table 2). The second analysis (see Section 4.2) concerns the comparison using VEGETATION data at 1 km over Europe (see Table 2). Section 4.3 presents additional comparisons over Europe between VEGETATION, MODIS and MERIS at 1 km.

2. Summary of the JRC-FAPAR algorithm

Gobron et al. (2000) propose an algorithm which takes the form of a set of several formulae which transform calibrated spectral directional reflectances into a single numerical value. These formulae are designed to extract the green Fraction of Absorbed Photosynthetically Active Radiation (FAPAR) in the plant canopy from the measurements and the rectified channels in the red and near-infrared bands.

The methodology has been optimized to assess the presence on the ground of healthy live green vegetation. The main optimization procedure has been constrained to provide an estimate of FAPAR in the plant canopy, although the outputs are expected to be used in a wide range of applications. The bulk of the information on the presence of vegetation is contained *a priori* in the red and the near-infrared spectral bands.

Addressing the atmospheric problem consists in converting Top Of Atmosphere (TOA) Bidirectional Reflectance Factors (BRFs) into Top Of Canopy (TOC) BRFs. Two classes of atmospheric radiative processes affect the measurements made by space-borne satellites: absorption and scattering. Absorption of radiation by specific gases can be largely avoided by carefully choosing the spectral location of narrow bands.

The effect of scattering cannot be avoided, and both molecular and aerosol scattering are strongly dependent on the wavelength of radiation. Hence, measurements in the blue region of the solar spectrum will provide values much more sensitive to atmospheric scattering than at longer wavelengths. In this approach, the characterization of plant canopies over fully or partially vegetated pixels currently relies on the analysis of data in three spectral bands.

The Second Simulation of the Satellite Signal in the Solar Spectrum (6S) atmospheric model of Vermote et al. (1997) is used to represent the atmospheric absorption and scattering effects on the measured reflectances.

---

[1] `http://mars.jrc.ec.europa.eu/`

The FAPAR values are computed using the closure of the energy balance inside the plant canopy in the spectral range 400 to 700 nm. The various geophysical scenarios performed to simulate the radiance fields use a sampling of vegetation parameters and angular values which are chosen to cover a wide range of environmental conditions. These simulations constitute the basic information used to optimize the formulae. The sampling selected to generate the Look Up Table (LUT) has been chosen so as to generate a robust global FAPAR algorithm.

The LUT of bidirectional reflectance factors representing the sensor like data is created using the physically-based semi-discrete model of Gobron et al. (1997) to represent the spectral and directional reflectance of horizontally homogeneous plant canopies, as well as to compute the values of FAPAR in each of them. The soil data required to specify the lower boundary condition in this model were taken from Price (1995).

Once this LUT is created, the design of the algorithm consists in defining the mathematical combination of spectral bands which will best account for the variations of the variable of interest (here, FAPAR) on the basis of (simulated) measurements, while minimizing the effect of perturbing factors such as atmospheric or angular effects. All spectral simulations are done using specific spectral response of each band,

The following assumptions have been made in the design of the JRC-FAPAR:

(1) The spectral reflectances used as input to this algorithm have to be corrected for the seasonally variable distance between the Earth and the Sun.

(2) The plane-parallel approximation for radiation transfer has been assumed to be valid in the atmosphere.

(3) Plant canopies are assumed to be horizontally homogeneous within a pixel.

(4) All orographic effects have been ignored.

(5) Adjacency effects have been ignored.

The retrieval of vegetation characteristics in hilly or mountainous regions may or may not be reliable. If the approach turns out to be unreliable in the presence of significant topographical features, additional tests may have to be implemented to screen out these regions on the basis of appropriate Digital Elevation Model (DEM) data. This would imply access to the corresponding elevation data sets, to reliably navigated satellite data, and the presence of an additional orographic flag.

The optimization of the algorithm was performed using a set of simulated TOA reflectance values which are expected to represent the most commonly encountered geophysical conditions. Although a wide range of possibilities were investigated, there is no guarantee that the most common geophysical scenarios have been implemented.

The sun zenith angle should be lower than 60° (due to the limitation of the radiative transfer models.)

The viewing zenith angle should be lower than 40°.

3. Overview of Earth Observation data

3.1. **MODIS.** MODIS swath products contains calibrated and geolocated radiances for 36 discrete bands located in the 0.4 to 14.4 micron region of electromagnetic spectrum.

These data are generated from the MODIS Level 1A scans of raw radiances and converted to Bidirectional Reflectance Factor (BRF) by dividing them by the cosinus of actual illumination angles from MOD03 products (MODIS Characterization Support Team 2006).

The BRF in the blue, red, and near-infrared bands, centered at 469-nanometers, 645-nanometers, and 858-nanometers, respectively, are used for computing the JRC FAPAR values.

The algorithm at 250 m requires three different types of information:

- top of atmosphere reflectance data at 250 m in Band 1 (red channel) and Band 2 (near-infrared channel) (MOD02QKM);
- top of atmosphere reflectance data at 500 m in Band 3 (blue band) (MOD02HKM);
- values of the solar and viewing angles at 1 km (MOD03).

Collection 5 data were download from `ftp://ladsftp.nascom.nasa.gov/allData/5/`

The geolocation fields contained in MOD03 data set are calculated for each 1 km MODIS Instantaneous Field of Views (IFOV) for all daily orbits and include geodetic latitude, longitude, solar zenith and azimuth angles, satellite zenith and azimuth angles.

Table 1. MODIS Input data

Shortname	Platform	MODIS Products	Raster Type	Res (m)	Band
MOD02QKM	Terra	Calibrated Radiances	Swath	250	Red, NIR
MOD02HKM	Terra	Calibrated Radiances	Swath	500	Blue
MOD021KM	Terra	Calibrated radiance	Swath	1000	Red, NIR, Blue
MOD03	Terra	Geolocation Fields	Swath	1000	-

3.1.1. *Remapping Tool.* The MRTSwath code (available on-line at `https://lpdaac.usgs.gov/tools/modis_reprojection_tool_swath`) provides the capability to transform MODIS Level 1b from HDF-EOS swath format to an uniformly gridded image that is geographically referenced.

This tool has been choose to remap necessary data over the two geographical regions described in Table 2 and Table 3.

Table 2. Input parameters over Romania

Latitude Minimum	27.78125° N
Latitude Maximum	29.7688° N
Longitude Minimum	44.5812° E
Longitude Maximum	47.57875° E
Output map projection	Geographic (Lat/Lon)
Re-sampling Method	Nearest neighbor
Spatial Resolution of Reprojected map	250 m

Table 3. Input parameters over Europe

Latitude Minimum	30° N
Latitude Maximum	70° N
Longitude Minimum	20° W
Longitude Maximum	10° E
Output map projection	Geographic (Lat/Lon)
Re-sampling Method	Nearest neighbor
Spatial Resolution of Reprojected map	1 km

3.2. **VEGETATION.** The top of atmosphere reflectance data, *e.g.* free-P VGT2 , have been provided by VITO and correspond to the 1^{st} of May, 2010. We used these inputs data in the JRC processing chain and compared the output results against S10 products. (We selected pixels for which the time corresponds to 1 in the S10 products of the same period).

3.3. **MERIS.**

In addition, we compare the VITO VEGETATION products against MERIS and MODIS generated at ESA and JRC, respectively, over Europe at 1km.

MERIS and MODIS spatial resolution FAPAR map corresponds to 1 km at the equator, *i.e.* 0.001° whereas VEGETATION map delivered by VITO is given at 0.00892857143° .

The VEGETATION data or products have been therefore resampled into the same window of MERIS and JRC-MODIS one for allowing direct comparisons.

MERIS FAPAR products are part of the ESA products and stored in the Level 2 products. We used here the third re-processing products.

VITO provides data of FAPAR in binary files for which the FAPAR values are stored between [0-200]. The period corresponds to the first decade of May 2010 using VITO time-composite algorithm, based on a 'maximum value' type of algorithm.

This time composite algorithm does not follow the one developed at JRC which has been implemented at ESA Grid-On Demand platform.

Therefore, we extracted pixels for which the same corresponding day (provided by VITO) and compared them to daily JRC products.

Note that the JRC and ESA products stored the FAPAR values between [1-255] bits values.

4. Results

4.1. **MODIS @ 250 m.** As MODIS products provided by VITO over Europe are at 250 m it would require downloading and processing of a huge amount of data, we decided to make only direct comparisons over a smaller region, *i.e.* Romania, for the 2^{nd} of May 2010.

Figure 1 shows the maps of FAPAR results from JRC (left), VITO (middle) and the differences (right), respectively.

The scatterplot between FAPAR data processed by the two institutions and histogram of differences are plotted on Figure 2. Top panels correspond to a direct comparison over all valid pixels. Bottom one show results of comparison using averaged values over a grid of 3x3 pixels in case all pixels within the grid are found valid: this reduces any cloud contamination problem.

In the first case of comparison, *e.g.* 1x1, we found that 30% of pixels correspond to the same FAPAR values and the rest may differ by up to ± 0.1. On average the difference is at about -0.0017. When spatial avagering is made for removing cloud contamination pixel but also for reducing geographical discrepencies effects, the difference decreases to -0.0004.

This slight difference may be explained by the use of different processing tools, like during the remapping of the raw MODIS data from original swath into the geographical projection. In the map of differences (righ panel in Fig. 1), one can see that these differences are not changing spatially.

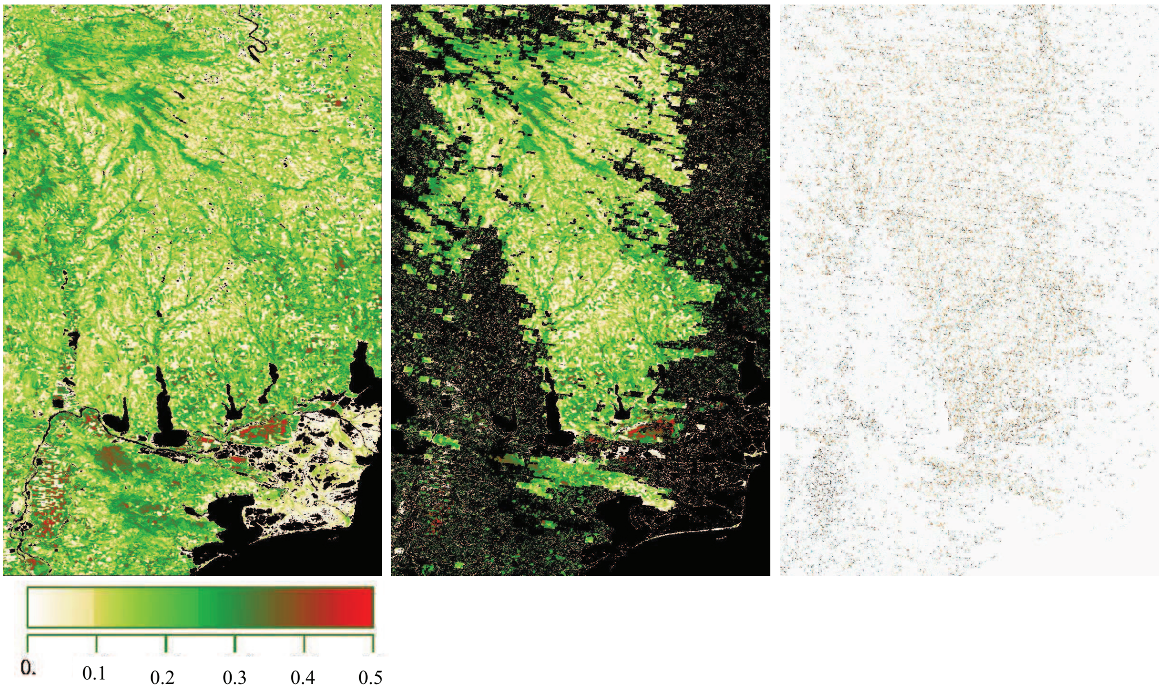

FIGURE 1. Maps of FAPAR values and differences over Romania for the 2^{nd} of May 2010. Left panel: JRC calculations using the entire swath. Middle panel: VITO products where the second day has been selected in the 10-days product. Right Panel: Difference between the two products

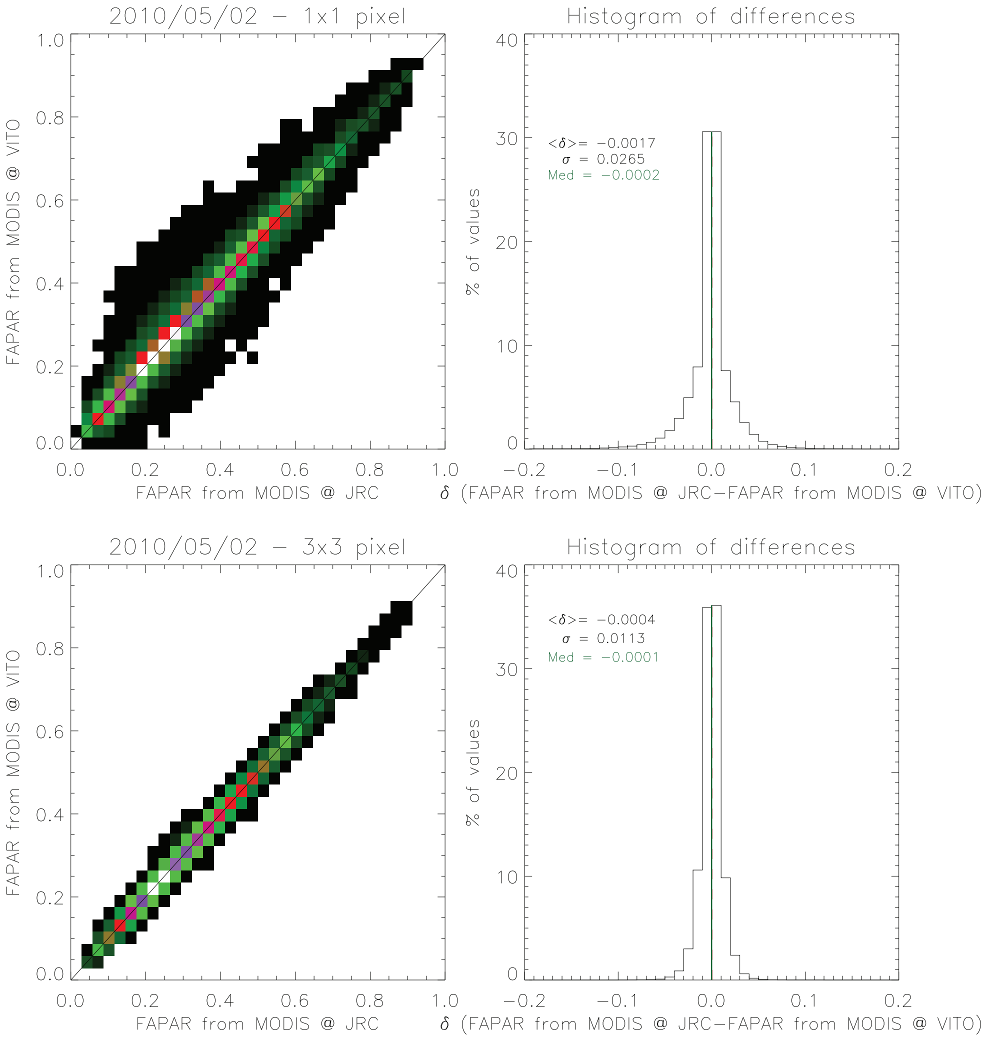

FIGURE 2. Scatterplot and histogram of difference between FAPAR values processed at JRC (x-axis) and VITO (y-axis) using MODIS data at 250 m over Romania. Top and bottom panels correspond to averaged over 1x1 and 3x3 pixels.

4.2. **VEGETATION @1km.** A direct comparison of daily FAPAR values processed by VITO and JRC was done using P-VGT products over Europe.

The differences between the two sets are shown in Figure 3 where both scatterplot and histogram are plotted. One can see that there are 3 clusters of differences.

- Sun Zenith Angle (SZA): Each production center has its own daily tile selection as overlap of tiles occurs during the same day.

  At JRC, the daily selection algorithm consists in selecting the tiles for which the values associated with the SZA is less than 60° and the Viewing Zenith Angle (VZA) less that 45° .

  If the number of daily available observations is larger than 1, JRC algorithm considers as the most representative of day, the value of FAPAR associated with the minimum of VZA. In case the viewing observation angles are equal, the retained value of FAPAR is associated to the minimum SZA.

  By removing the pixels for which the geometry of measurements are not equal, we obtain the results plotted in top panel of Figure 4 which removes several differences. However, whereas the values for which JRC FAPAR is equal to zero, the VITO valid values from [0.,0.5] still remain.

- JRC Flags: JRC FAPAR values are found equal to zero when 'bright surface' is found during pixel identification. However, it looks like pixel selection published in Gobron et al. (2002) has not been implemented by VITO.

  When JRC removes this pixel identification in its own code, we found same results as VITO (see bottom panel in Figure 5).

In conclusion, equations per se, for computing the JRC FAPAR algorithm, are correctly implemented but not the pixel identification as it would be needed.

The selection of daily tile is not done in the same way.

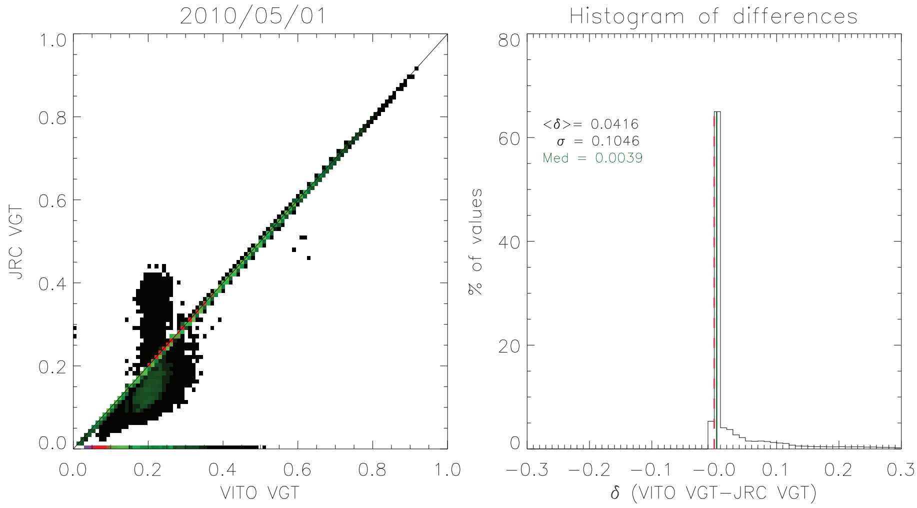

FIGURE 3. Scatterplot and histogram of difference between FAPAR values processed at JRC (x-axis) and VITO (y-axis) using MODIS data at 250 m over Europe.

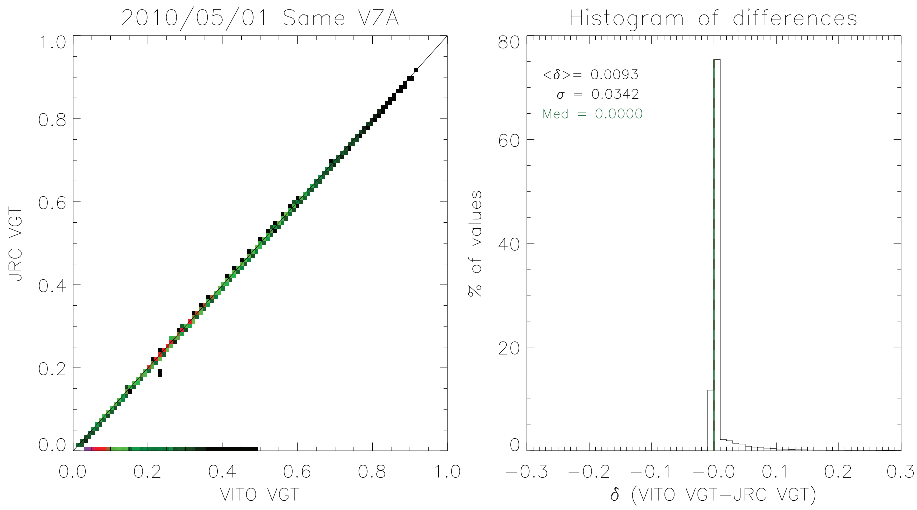

FIGURE 4. Same as Figure 3 for the same SZA.

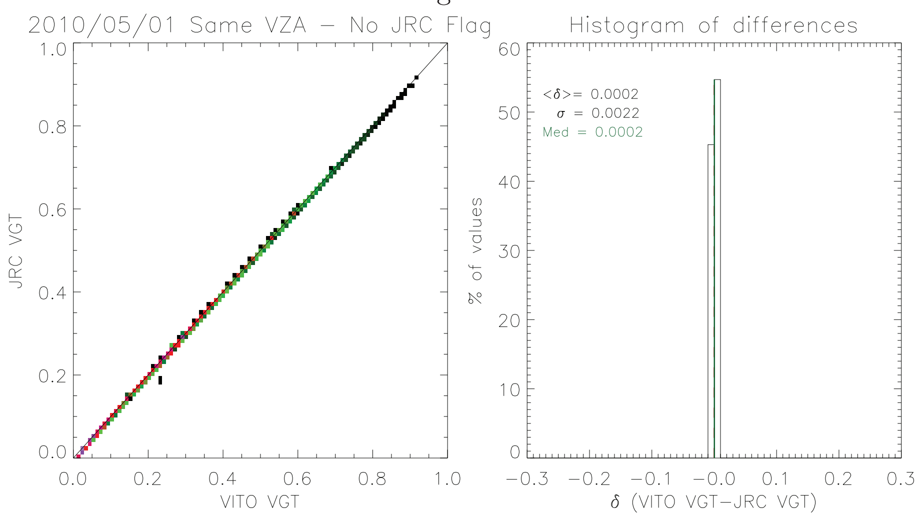

FIGURE 5. Same as Figure 3 without JRC flag.

4.3. **VEGETATION-MERIS-MODIS @ 1km.** We propose here to present various comparisons between JRC FAPAR derived from MODIS and VEGETATION at 1 km against MERIS over Europe.

FAPAR from MODIS, VGT and MERIS have been processed at JRC, VITO and ESA, respectively.

As the JRC algorithm has been optimized to VGT1 (Gobron et al. 2002), we would like to verify if the coefficients optimized for VGT1 can be applied to VGT2 as both calibration and instrumental spectral responses may differ. (It would be better to verify this using two datasets of the same day over the same location from both instruments.)

MERIS Level 2 come from the third (latest) reprocessing held at ESA.

MODIS inputs data come from Collection 5[2]. We did the comparison using the VGT-S10 products and extract for each day common pixels between MERIS and/or MODIS.

Two examples of daily maps are shown on Figures 6 and 7 respectively for the 2^{nd} and 8 of May 2010.

The summary of daily comparisons using 10 days are presented in Figure 8 using the averaged values over a 3x3 pixels for removing cloud contaminations.

When comparing JRC MODIS FAPAR again those of MERIS, we found a lower average differences $< \delta >$ of -0.0212 with a deviation σ of 0.06. These values may be explain by differences of geometry between the two instruments as the JRC FAPAR corresponds to instantaneous value, *i.e.* depends on the actual sun zenith angle.

As MODIS is a scanner each pixel resolution in the original swath vary from 1.0 km at nadir view up to 1.5 km (3.0 km) across(along)-track for a view zenith angle of $\approx 60°$. In this exercice, we therefore retain only pixels for which the view zenith angles is less than 30°.

Additional information of interest is that MODIS TERRA Collection 5 still contain drift sensor problem (see Wang et al. (2012)). When we compare them against MODIS ACQUA, the results from daily TERRA look a little bit lower than with AQUA (see Figure 10).

However when we use the JRC time-composite algorithm over 10 days, we found that the results from the three sensors agree within the prescribed accuracy, *i.e.* ± 0.05.

When comparing VGT FAPAR again those from MERIS, we found a bias of -0.0074 with average differences of 0.02 and σ equal to 0.095. As we discussed in previous section, one part of these differences can be due to the differences of selected day tile but the bias toward higher values of VGT can not be explained by the VITO 'implementation' per se of the algorithm.

Therefore one explanation may be that the P-Products, *i.e.* top of atmosphere reflectance, are either 1) not calibrated or 2) that VGT 2 spectral responses are not exactly the same comparing to the VGT 1 for which the JRC-FAPAR coefficients have been optimized.

[2] `ftp://ladsftp.nascom.nasa.gov/allData/5/`

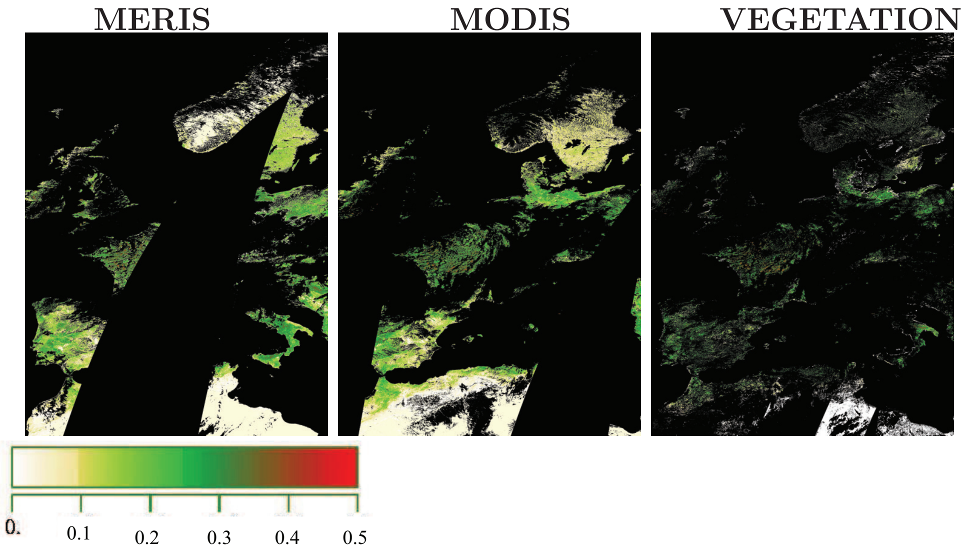

FIGURE 6. Daily FAPAR maps over Europe from MERIS (ESA), MODIS(JRC) and VGT (VITO)instruments for the 2^{nd} of MAY 2010.

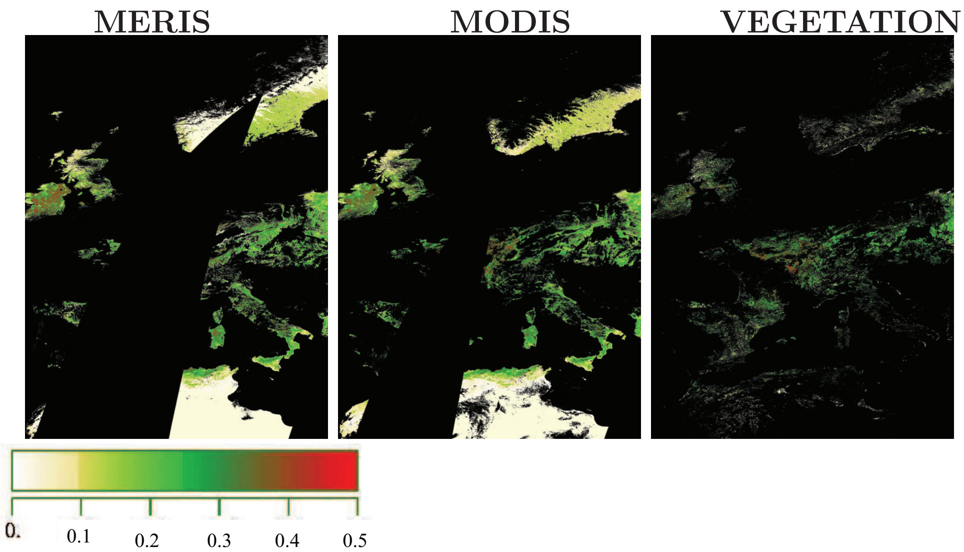

FIGURE 7. Same as Fig. 6. but for the 8 of MAY 2010.

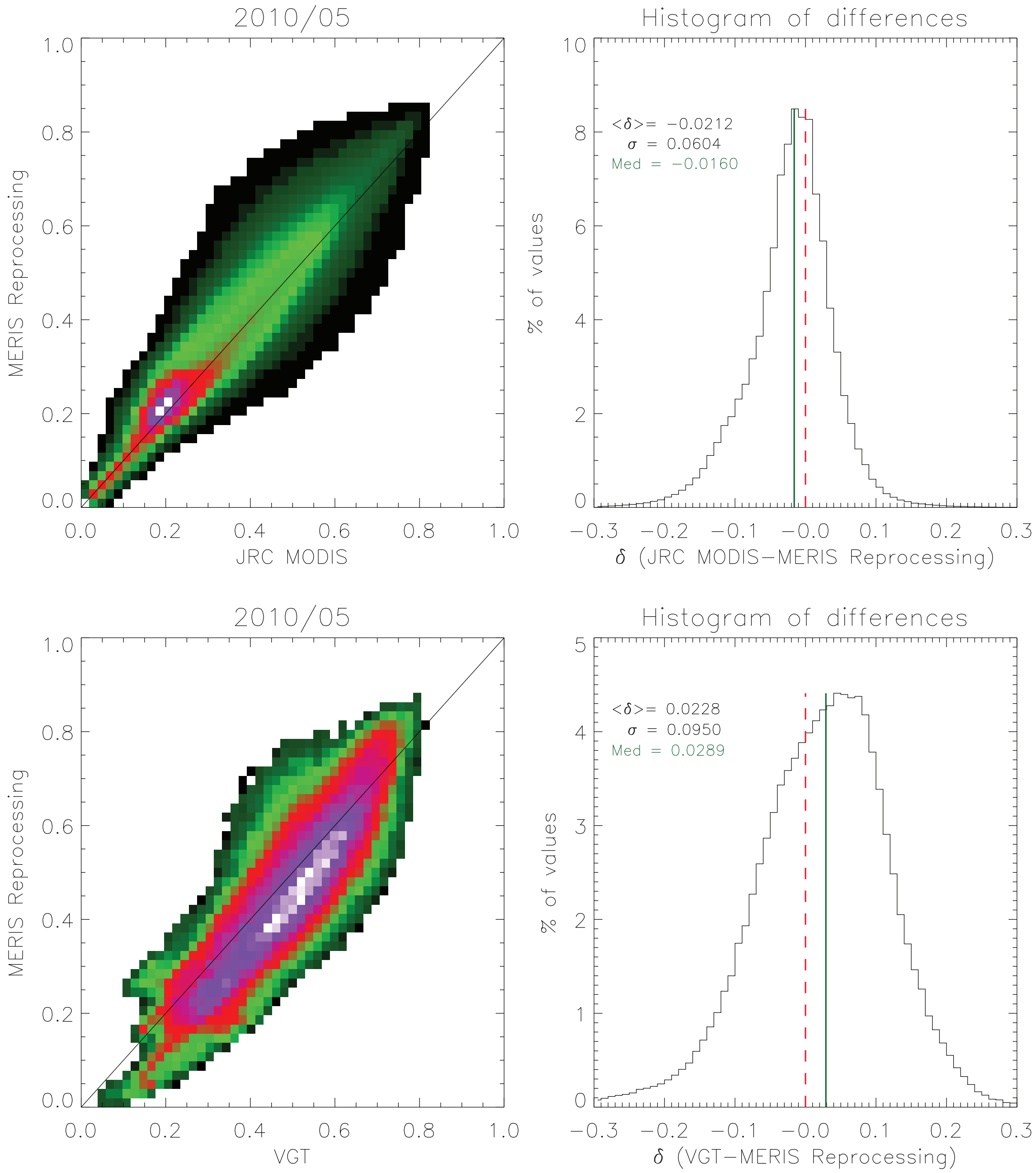

FIGURE 8. Scatter-plots and histogram of differences between daily values from MODIS TERRA (top panel) and VGT (bottom) versus MERIS instuments.

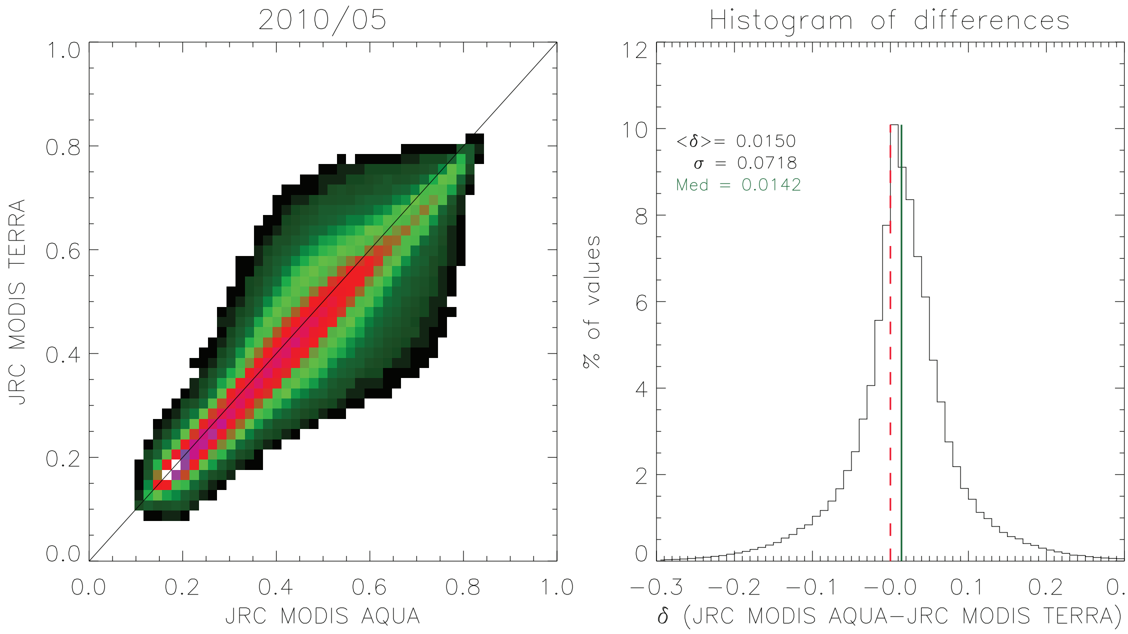

FIGURE 9. Scatter-plots and histogram of differences between daily values from MODIS TERRA and MODIS TERRA instuments.

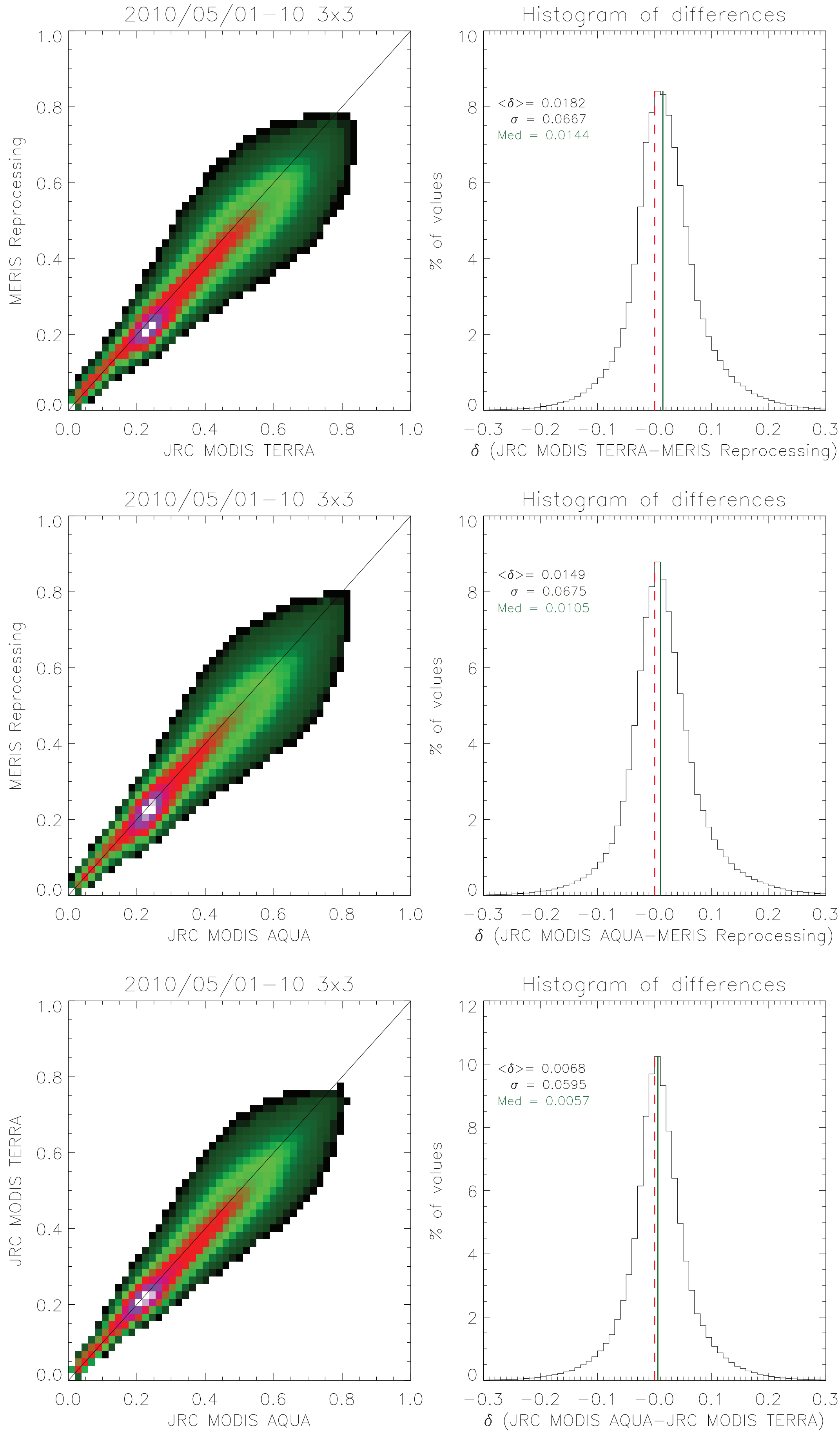

FIGURE 10. Scatter-plots and histogram of differences between 10-days values from MODIS TERRA , MODIS TERRA and MERIS instuments.

5. Conclusions

- The JRC-FAPAR algorithm developed for MODIS Terra data at 250 m looks correctly implemented in the VITO processing chain. However, there are low differences with those computed at JRC. They could be explained by the following reasons:
  - differences in the remapping tools.
  - MODIS input files from different sources.
- The implementation of JRC FAPAR algorithm for VGT is correctly implemented but **not the pixel identification as it should be done**. **There are also differences for the selection of each daily tile.**

We did compare FAPAR values deriving by three sensors and found that daily pixels may be still contaminated by clouds/cloud shadow effects.

Various pre-processing options, such as selection of daily tile and remapping tools may imply larger differences in the final products. The pixel resolution should be closest to the nominal one and therefore it is better to retain only MODIS pixels for which sun angle is lower then 30°.

The results show that differences between MERIS and MODIS are lower than between MERIS and VGT. It could be due to the differences between spectral responses of VGT 1 and VGT 2 or any calibration problems.

To check the coefficients, it would appropriate to compare FAPAR results derived from VGT 1 and VGT 2 on the same day over the same region.

Note that MODIS TERRA Collection 5 still contains drift sensor problem as published in Wang et al. (2012). Daily comparisons done with MODIS ACQUA gave similar results in average.

References

Gobron, N., O. Aussedat, and B. Pinty (2006a). MODerate resolution Imaging Spectroradiometer (MODIS) - JRC-FAPAR at 250m Algorithm Theoretical Basis Document. EUR Report 22279 EN, European Commission - DG Joint Research Centre, Institute for Environment and Sustainability.

Gobron, N., O. Aussedat, and B. Pinty (2006b). MODerate Resolution Imaging Spectroradiometer (MODIS), JRC-FAPAR Algorithm Theoretical Basis Document. EUR Report No. 22164 EN, Institute for Environment and Sustainability.

Gobron, N., B. Pinty, M. M. Verstraete, and Y. Govaerts (1997). A semi-discrete model for the scattering of light by vegetation. *Journal of Geophysical Research 102*, 9431–9446.

Gobron, N., B. Pinty, M. M. Verstraete, and M. Taberner (2002). VEGETATION - An optimized FAPAR algorithm - Theoretical Basis Document. EUR Report No. 20146 EN, Institute for Environment and Sustainability.

Gobron, N., B. Pinty, M. M. Verstraete, and J.-L. Widlowski (2000). Advanced spectral algorithm and new vegetation indices optimized for up coming sensors: Development, accuracy and applications. *IEEE Transactions on Geoscience and Remote Sensing 38*, 2489–2505.

MODIS Characterization Support Team (2006). MODIS Level 1B Product User's Guide For Level 1B Version 5.0.6 (Terra) and Version 5.0.7 (Aqua). MCST Document ; PUB-01-U-0202- REV B, MCST Document.

Price, J. C. (1995). Examples of high resolution visible to near-infrared reflectance spectra and a standardized collection for remote sensing studies. *International Journal of Remote Sensing 16*, 993–1000.

Vermote, E., D. Tanré, J. L. Deuzé, M. Herman, and J. J. Morcrette (1997). Second simulation of the satellite signal in the solar spectrum: An overview. *IEEE Trans. Geoscience Remote Sensing 35-3*, 675–686.

Wang, D., D. Morton, J. Masek, A. Wu, J. Nagol, X. Xiong, R. Levy, E. Vermote, and R. Wolfe (2012). Impact of sensor degradation on the modis ndvi time series. *Remote Sensing of Environment 119*, 55–61.

European Commission
EUR 25668 – Joint Research Centre – Institute for Environment and Sustainability

Title: Multi-Sensors Intercomparisons of JRC FAPAR products:Impacts from VITO implementation

Authors: Nadine Gobron, Guido Ceccherini

Luxembourg: Publications Office of the European Union

2012 – 21 pp. – 21.0 x 29.7 cm

EUR – Scientific and Technical Research series – ISSN 1831-9424

ISBN 978-92-79-27998-0

doi:10.2788/7624

Abstract
Physical-based algorithm for deriving Fraction of Absorbed Photosynthetically Active Radiation (FAPAR) products has been designed and optimized by the Joint Research Centre (JRC) for various Earth Observation (EO) sensors (Gobron et al. 2000). Among them, VITO implements JRC-FAPAR for 1) Moderate Resolution Imaging Spectroradiometer (MODIS) data at 250 m of spatial resolution and 2) VEGETATION at 1 km. They process data over Europe for delivering them in near-real time to MARS project.
The corresponding algorithms are published in Gobron et al. (2006b, Gobron et al. (2006a) and Gobron et al. (2002), respectively.
We propose here to evaluate VITO implementation processing chain using data over Europe by comparing their products to those computed with original codes at JRC.

LB-NA-25668-EN-N

As the Commission's in-house science service, the Joint Research Centre's mission is to provide EU policies with independent, evidence-based scientific and technical support throughout the whole policy cycle.

Working in close cooperation with policy Directorates-General, the JRC addresses key societal challenges while stimulating innovation through developing new standards, methods and tools, and sharing and transferring its know-how to the Member States and international community.

Key policy areas include: environment and climate change; energy and transport; agriculture and food security; health and consumer protection; information society and digital agenda; safety and security including nuclear; all supported through a cross-cutting and multi-disciplinary approach.

Publications Office

ISBN 978-92-79-27998-0

9 789279 279980