SENTINEL-3 OCEAN LAND COLOR IMAGER (OLCI): LAND PRODUCTS AND VALIDATION

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ABSTRACT

This paper first summarizes the operational land products of the future Ocean Land Colour Instrument (OLCI) on board Sentinel3, in particular, the Fraction of Absorbed Photosynthetic Active Radiation (FAPAR) and the OLCI Terrestrial Chlorophyll Index (OTCI). Then the validation plan of these products is then presented: it focuses on an independent strategy for making use of ground-based measurements over a large sample of vegetation types together with radiative transfer modelling for assessing theoretical accuracies from both space and in-situ retrieval methods.

INTRODUCTION

Monitoring the state and changes of vegetated surfaces is mandatory for understanding the climate change impacts on our planet. Satellite remote sensing has been used for over a decade to achieve this scientific goal.

Following the operational land products from Envisat's Medium Resolution Imaging Spectrometer (MERIS), the up-coming Ocean Land Color Instrument (OLCI) on board Sentinel-3 will provide continuity to the so-called MERIS Global Vegetation Index (MGVI) and MERIS Terrestrial Chlorophyll Index [1][2][3][4] datasets. The MGVI corresponds to the Fraction of Absorbed Photosynthetically Active Radiation (FAPAR), recognized as an Essential Climate Variable (ECV) by the Steering Committee for Global Climate Observing System [5][6].

Both MGVI and the chlorophyll index (MTCI) have been delivered to scientific community on a daily basis. They have been primarily used to analyse and monitor land surface change and phenology but have also found applications in the scientific studies assessing carbon exchanges [7][8][9][10][11][12].

The systematic validation of these biophysical products during the sensor life is highly desirable in order to evaluate whether the quality of the products continues to be in conformity with the pre-flight specifications as well as the GCOS accuracy criteria imposed by the requirements of the above applications. The definition of the retrieval algorithm performance and actual validation exercises are required to assess the uncertainties required by any assimilation system dealing with global issues.

OPERATIONAL OLCI LAND PRODUCTS RETRIEVAL ALGORITHMS

The ESA/JRC FAPAR algorithm developed by [13] requires Top-Of-Atmosphere (TOA) Bidirectional Reflectance Factors (BRFs) in three spectral bands (blue, red and near-infrared) as well as the geometry of measurements as input. Apart from these data no additional information (i.e. *a priori* knowledge) is required.
Moreover the OLCI FAPAR retrieval algorithm belongs to the family of JRC FAPAR algorithm which are designed to be optimized for a given sensor's spectral characteristics. This is achieved on the basis of an extensive set of synthetic scenarios designed for mimicking typical atmospheric and vegetation canopy conditions using two physically-based radiative transfer models: one in the atmosphere [14] and the second in the vegetation layer [15]. When developing the OLCI FAPAR algorithm the atmosphere model used so far was updated to include polarization [16] and more optical depth values and geometrical view/illumination conditions were added (see Table 1 and 2).

The OLCI FAPAR algorithm consists of two steps. First the BRFs are "rectified", that is any angular effects are removed and then the information from the blue channel is used to decontaminate the red and near-infrared bands from any atmospheric influence. Such an approach does not require any assumptions on the ambient atmospheric properties. The optimized parameters are published in [17].

The Envisat MERIS Terrestrial Chlorophyll Index

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(MTCI) is designed to monitor vegetation condition via an estimation of chlorophyll content using reflectance in the red edge region of the reflectance spectra. Unlike conventional vegetation indices which are based on the normalised difference between reflected solar radiation in red and near-infrared wavebands, MTCI makes use of the shift of the 'red edge' where absorption drops dramatically as the wavelength increases. The use of red shift means that the MTCI product remains responsive even at high chlorophyll content levels where conventional vegetation indices saturate.

Table 1: Geophysical scenarios underlying the simulated radiance fields used in the training datasets for the OLCI-FAPAR retrieval algorithm (additional values in red).

Medium	Variable	Meaning	Range of Values
Atmosphere	AOD	Aerosol opt. thickness	0.05,0.2,0.35,0.5, 0.65 and 0.8
Vegetation	LAI	Leaf Area Index	0, 0.5, 1.,2.,3., 4 and 5
	Hc	Height of canopy	0.5 m and 2 m
	dl	Equivalent diameter of single leaf	0.01 m and 0.05 m
	LAD	Leaf Angle Distribution	Erectophile and Planophile
Soil data base	Rs	Soil Albedo	5 soil spectra, from dark to bright

Table 2: Illumination and observation geometries of the simulated radiance fields used for developing the OLCI FAPAR retrieval algorithm (new values in red).

Variable	Angle	Range of Values
Θ_0	Sun Zenith Angle	20°, 30° and 50°
Θ_v	View Zenith Angle	0°, 25° and 40° (55°)
dφ	Relative Azimuth	0°, 45° , 90°, 135° and 180°

TOWARDS A VALIDATION PLAN FOR OLCI LAND PRODUCTS

Often remotely sensed land products are defined with respect to theoretical rather than ambient illumination conditions that complicate in situ validation efforts. Similarly, the spatial complexity and substantial heights of certain plant environments may prevent a reliable sampling of certain radiation fluxes.

There are currently a wide variety of approaches in use for the estimation of instantaneous FAPAR and chlorophyll content in vegetation canopies. The bias associated with these different estimation schemes can be separated into a sampling error and a transfer bias [20]. The former relates to the impact of both the number and location of the measurements whereas the latter addresses the quality of the theory that relates these measurements to the actual canopy biophysical variables.

Table 3: OLCI land validation sites.

Name	IGBP Land Cover Classification	Latitude (° N)	Longitude (° E)
US-Ne1	Croplands (Maize)	41.1650	-96.4766
US-Ne2	Croplands (Irrigated Maize Soybean rotation)	41.1648	-96.4701
US-Ne3	Croplands (Rainfed Maize-Soybean rotation)	41.1797	-96.4396
DE-Geb	Croplands	51.1001	10.9143
UK-NFo	Natural deciduous forest	50.845053	-1.539841
IT-Tra (2 sites)	Croplands (Vineyards and olive trees)	37.645561	12.852736
IT-Cat	Croplands (Orange)	37.278530	14.883261
SP-Val	Semi-arid Mediterranean	39.570734	1.2882
SP-Ala	Semi-arid Mediterranean	38.451556	1.0645556
IT-Sro	Pinus pinea	43.7278	10.2844
IT-Isp	Mixed Forest (Quercus Robur)	45.8128	8.6345

The relative impact of these two errors may depend on the illumination conditions as well as the structural variability of the plant environment [21]. In principal one should distinguish between environments that behave radiatively like 1) a 1D environment, 2) a series of independent 1D environments (IPA approximation), and 3) fully 3D environments. It is likely that the validation approaches may have to be adapted for these.

Therefore, we propose an independent strategy for making use of ground-based measurements over a large sample of vegetation types distributed around the globe together with radiative transfer modeling for assessing theoretical accuracies from both space and in-situ retrieval algorithms. A step-by-step understanding of validation processes towards the preparation plan for OLCI Land products is expected.

This means that the ground-based measurements for several site and comparisons protocols will be defined in advance. Validated Monte Carlo models in conjunction with highly realistic 3D canopy representations will be used to quantify and separate sources of uncertainties arising with specific ground-based measurement protocols, as well as from the different definitions incorporated in the EO products derived from different satellite sensors [18][20].

IN-SITU VALIDATION SITES

In the validation project, we propose to use a series of sites that are different in terms of land processes; land cover type and structure (see Table 3). The proposed locations sample different types of canopy covers that can be categorized into 3 groups. The first set corresponds to typical long-term measurements network sites such as the FluxNet network [21], which can be also used for EO validation products (see for example [23][24][25]). The second set of sites corresponds to sites which are and have been used for Earth Observation validation products, including MERIS. Finally the last set is associated to the ecosystem network of the Integrated Carbon Observing System [26].

The proposed validation sites are mainly equipped with an eddy covariance tower and meteorological sensors, with which continuous measurements of CO2 fluxes, water vapour and energy fluxes are obtained every hour. The ground-based estimate of the Absorbed Photosynthetically Active Radiation (APAR) is often calculated using incoming PAR (PAR_i), PAR reflected by the canopy (PAR_r), transmitted through the canopy (PAT_t) and reflected by the soil ($PAR_{T*\varepsilon_{rs}}$) following the next equation and as illustrated in Figure 1.

$$\mathrm{FaPAR} = 1 - \frac{\mathrm{PAR}_r}{\mathrm{PAR}_i} - (1 - \varepsilon_{rs})\left(\frac{PAR_t}{PAR_i}\right)$$

The position and number of available above and below canopy sensors will drive the reliability of the in situ FAPAR estimate. Thanks to 3D radiative transfer modelling, it will become possible to estimate the impact of these uncertainties with respect to the ground-based measurements.

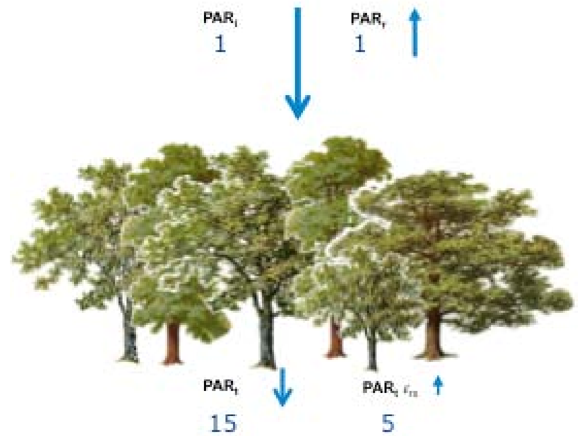

Figure 1: Example of FAPAR estimates at IT-Isp site with number of sensors used for respective PARx measurements..

Both the semi-arid Mediterranean type land cover at the Valencia and the Alacant Anchor Stations (Eastern Spain) (Figure 2) are well-known validation sites which are have been used in the framework of GERB, CERES and SMOS missions since 2001, and which are being prepared for forthcoming missions such as SMAP, EarthCARE and, obviously, SENTINEL-3. Accurate estimation of vegetation stage is achieved through simple measurements over well-chosen areas such as vegetation height, phenological stage (number of leaves in vineyards/plant, etc…). In some fields, digital photographs giving general information on the phenology (in orchards and vineyards), Leaf Area Index (LAI) measurements in vineyards, shrubs areas, allometric parameter sampling in tree areas to relate plant dimensions to vegetation characteristics and vegetation water content sampling that can be used in 3-D reconstruction scene. The Gebesee site, DE-Geb, located at the intersection between the German states of Thuringia and Saxonia-Anhalt with forested regions in the Harz Mountains and intensively used agricultural areas in the south and west as well as a wetland belonging to the Ramsarlist of protected regions. The Nordhausen site encompasses an area of 31 km x 39 km which is being intensively sampled since 2005 for the ENVILAND-1 and -2 projects and continuing until 2011 [27]. Field sampling includes crop type, phenological description, plant height and density, LAI, structural description of plant parts, destructive biomass sampling, description of field heterogeneities and photo documentation. Soil types have already been laboratory analysed, soil moisture will be measured using gravimetric samples and Time Domain Reflectometers.

Figure 2: Photo of SP-Val and SP-Ala sites in two seasons.

UK-NFo sites covers natural deciduous forest is located in a fairly flat terrain and was composed entirely of broadleaf deciduous forest stands with the main tree species being: Oak (Quercus robur) approximately 40%, Beech (Fagus sylvatica) -approximately 45% and Silver birch (Betula pendula)-approximately 5%. The surrounding areas of the site have similar vegetation composition. There has been a series of ground measurement (LAI, chlorophyll, FAPAR) and airborne hyper-spectral data acquisitions that can be used as scaling up ground data and in radiative transfer modelling. Already used in previous validation campaign, the IT-Tra site is characterized by homogeneous canopy development and flat topography. The average field size was about 30 ha. There has been a series of ground measurement (LAI, chlorophyll) and airborne hyper-spectral data acquisitions which can be used as scaling up ground data and in radiative transfer modelling. Additionally IT-cat is characterized by irrigated agriculture (mainly maize, alfalfa and fruit trees) with homogeneous canopy development and greenhouse vegetable production. The extent of the study site is 30 x 30 km with flat topography and the average field size is about 10 hectares. Both ground measurements and high resolution remote sensing data such as RapidEye were available for this site.

CONCLUSION

This contribution summarizes first the SENTINEL-3 OLCI land products which are designed to monitor the state and change of terrestrial vegetation and to provide a homogeneous, harmonized dataset with respect to the ones derived from MERIS. These products correspond to the FAPAR essential climate variable and the Chlorophyll Index. Both the OLCI land products validation approach and ground-based measurements sites have been presented. The overall strategy is to merge both RT model-based and in situ quality assessments in order to achieve a coherent and traceable validation scheme for assessing the accuracies of the foreseen products by understanding the theoretical accuracies from both space and in-situ retrieval algorithms.

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