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Uncertainty estimates for the FAPAR operational products derived from MERIS — Impact of top-of-atmosphere radiance uncertainties and validation with field data

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Abstract

This paper discusses the accuracy of the operational Medium Resolution Imaging Spectrometer (MERIS) Level 2 land product which corresponds to the Fraction of Absorbed Photosynthetically Active Radiation (FAPAR). The FAPAR value is estimated from daily MERIS spectral measurements acquired at the top-of-atmosphere, using a physically based approach. The products are operationally available at the reduced spatial resolution, *i.e.* 1.2 km, and can be computed at the full spatial resolution, *i.e.* at 300 m, from the top-of-atmosphere MERIS data by using the same algorithm. The quality assessment of the MERIS FAPAR products capitalizes on the availability of five years of data acquired globally. The actual validation exercise is performed in two steps including, first, an analysis of the accuracy of the FAPAR algorithm itself with respect to the spectral measurements uncertainties and, second, with a direct comparison of the FAPAR time series against ground-based estimations as well as similar FAPAR products derived from other optical sensor data. The results indicate that the impact of top-of-atmosphere radiance uncertainties on the operational MERIS FAPAR products accuracy is expected to be at about 5–10% and the agreement with the ground-based estimates over different canopy types is achieved within ±0.1.

Keywords: FAPAR; FIPAR; Land surface; MERIS; MODIS; SeaWiFS; Remote sensing; Radiative transfer modeling; Validation

1. Introduction

Understanding the degree of climate change impacts on Earth system requires a better quantification of the uncertainties of the current terrestrial biosphere model outputs, which are mainly used for evaluating the carbon flux variations between land ecosystems and atmosphere. The geophysical products estimated from space remote sensing measurements can be used directly or in data assimilation systems to better quantify this level of uncertainty (Knorr et al., 1995; Pinty et al., 2006a; Raupach et al., 2005; Rayner et al., 2005).

The validation of these biophysical products, mainly derived from optical sensors, is therefore highly desirable in order to evaluate whether the quality of the products is in conformity with the pre-flight specified accuracy that was imposed by the requirements of the anticipated application. The use of space derived products is moreover relevant for environmental applications at global scale only if long term time series of geophysical products are available: this calls for the use and

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interpretation of the spectral measurements collected by multiple space sensors (these instruments may be either flying simultaneously or simply follow each other for recording spectral data over a long time period). 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 (GCOS, 2004; GTOS, 2006; GOOS, 2006). In addition, these analyses are a pre-requisite to merge biophysical products from various sensors, like for the sea surface temperature (Reynolds & Smith, 1994), the ocean color (Maritorena & Siegel, 2005; Mélin & Zibordi, 2007), the surface albedo using geostationary instruments (Govaerts et al., 2004) and the Fraction of Absorbed Photosynthetically Active Radiation (FAPAR) products.

Among the land geophysical products, both the surface albedo and FAPAR have been recognized to be essential variables in the climate system as well as for modeling the carbon cycle. The FAPAR products, directly linked to the photosynthesis process into vegetation canopies, can be either directly used as inputs into diagnostic biosphere models (Prince, 1991; Sellers et al., 1992; Knorr & Heimann, 1995; Running, 1986) or may serve as additional constraints during assimilation into more sophisticated schemes (Knorr et al., 1995, 2005b).

Further to the global climate change issues, this product is also a good indicator for assessing the changes of vegetation canopies state. Time series of these products can be analyzed for various regional land surface phenomena, like drought events or land degradation (Gobron et al., 2005a; Knorr et al., 2005a; Gobron et al., 2005b; Seiler & Csaplovics, 2005), or used for assessing environmental indicators such as the phenology parameters, like the growing season length (Verstraete et al., 2007) and more recently for the retrieval of radiation fluxes quantities for climate modeling (Pinty et al., 2006b). Of course, these applications are relevant only if the associated uncertainties are documented and provided which is hardly the case when empirical methods are used for trend analysis, as discussed in Hall et al. (2006).

Within the framework of delivering long time series of FAPAR products, Gobron et al. (2000, 2007) proposed a generic scheme from sensor specific algorithms that are devoted to the generation of equivalent, and thus comparable, FAPAR products derived from various optical sensors. This Joint Research Centre (JRC) FAPAR algorithm has been developed for the Medium Resolution Imaging Spectrometer (MERIS), Sea-viewing Wide Field-of-view Sensor (SeaWiFS) and MODerate Resolution Imaging Spectroradiometer (MODIS) (Gobron et al., 1999, 2001, 2006a, respectively) by using the measurements in the blue, red, and near-infrared spectral domains.

This manuscript focuses on the assessment of uncertainties of the operational MERIS FAPAR products, also called MERIS Global Vegetation Index (MGVI), available since the launch of the European Space Agency (ESA)'s Envisat platform in March 2002 at the reduced resolution, *i.e.* at 1.2 km spatial resolution. The data used are provided through the MERIS Catalogue and Inventory (MERCI) system for validation purposes (http://merci-srv.eo.esa.int/merci/welcome.do).

The first section presents an estimation of theoretical uncertainties with respect to the spectral measurements precision that can be expected at the top-of-atmosphere (TOA) level in the three spectral domains. This propagation error analysis uses the derivative of the algorithm formulae with simulated Bidirectional Reflectance Factors (BRFs) TOA MERIS-like data as inputs with associated spectral band errors. This contribution thus complements previous efforts to document uncertainty estimates associated with the JRC FAPAR algorithm (Gobron et al., 2006b).

Since the FAPAR is a normalized radiant flux in the visible region of the solar spectrum, *i.e.* over the Photosynthetically Active Radiation (PAR) domain of (0.4–0.7 μm), the task of acquiring field measurements for validation exercises presents a range of challenges that vary in difficulty from one site to the other. Some of these difficulties for generating accurate ground-based estimations of FAPAR, particularly for the purpose of validating remote sensing products, are addressed in Gobron et al. (2006b) and are summarized at the beginning of the third section. This yields the categorization of ground-based FAPAR data sets according to their most probable radiative transfer (RT) regimes. The evaluation of the comparison results is indeed associated with the contextual difficulties specific to each site together with the corresponding in-situ data sets. The comparison results between remote sensing products from the MERIS instrument, but also from other sensors, and ground-based estimations of FAPAR are finally presented and analyzed.

2. Overview of the FAPAR algorithm and MERIS Level 2 products

The JRC generic FAPAR algorithm can be tailored to any sensor acquiring at least three narrow spectral bands in the blue, red and near-infrared regions of the solar spectrum. This algorithm capitalizes on the physics of remote sensing measurements and its development copes with the many operational constraints associated with the systematic processing and analysis of a large amount of data. Basically, the useful information on the presence and state of vegetation is derived from the red and the near-infrared spectral band measurements. The information contained in the blue spectral band, which is very sensitive to aerosol load, is ingested in order to account for atmospheric effects on these measurements. In the particular case of the MERIS sensor which was primarily designed for marine applications, the approach consists in analyzing the relationships between measurements in the blue spectral bands and those available in the red and near-infrared regions (e.g. Govaerts et al., 1999; Gobron et al., 1999). Such relationships can indeed be simulated for a variety of environmental conditions with RT models of the coupled vegetation-atmosphere system. The former are then exploited with polynomial expressions optimized in such a way that TOA BRF measurements in the blue are related to those taken at other spectral bands, located at longer wavelengths *e.g.*, in the red and near-infrared regions. This approach (called rectification) aims at decontaminating the BRFs from atmospheric effects without performing an explicit retrieval of the ambient atmospheric properties. The polynomial expressions are also built to simultaneously account for the dominant bidirectional effects. The latter are themselves approximated from an extensive set of one-