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A sub km resolution global database of surface reflectance and emissivity based on 10-years of MODIS data

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ABSTRACT

The MODIS instruments have been flying onboard the Terra and Aqua platforms and have acquired Earth observation data since early 2000 and mid 2002, respectively. After atmospheric correction, the collected data allows the monitoring of the land cover dynamics. Here, we describe a data processing scheme to generate Earth reflectance and emissivity time series at a sub-kilometer spatial resolution and with a period of 8 days. The data processing scheme removes residual cloud and aerosol contamination in the MODIS products, applies directional correction, and fills the gaps resulting from persistent cloud cover. The resulting database, referred to FondsDeSol, offers a significant improvement with respect to the first version proposed in (Gonzalez et al., 2010), and covers a period of ten years against only one year for the first version. The first motivation of the database is to improve the estimation of at sensor radiances for the design of future sensor in the optical domain. Nevertheless, such database opens the way to new research topics like land surface dynamics, land cover changes, and inter-annual variations due to climate perturbations.

1. Introduction

In the optical domain, worldwide spectral surface reflectance climatology is necessary to design any future space borne missions by providing technical characteristics like observable radiances, signal noise ratios, etc. The design of new sensors is achieved from surface reflectances acquired by the targeted sensor using an end-to-end simulator. The latter is able to model first the signal incident to the sensor, second the output signal taking into account its main imaging system characteristics and its related preprocessing, and finally estimates the retrieved signal on ground surface properties after an atmospheric compensation processing. Several end-to-end simulators already exist such as SENSOR (Börner et al., 2001) developed for the preparation of the Airborne Prism Experiment (APEX) (Itten et al., 1997), the simulators to specify the SPECTRA mission (Verhoef and Bach, 2003), Pléiades to sense urban area (Miesch et al., 2004, 2005) or the future Sysiphe (Rousset-Rouviere et al., 2011) hyperspectral airborne mission, the Parameterized Image Chain Analysis & Simulation Software (PICASSO) (Cota et al., 2010), the tool to prepare the Compact Reconnaissance Imaging Spectrometer for Mars (CRISM) (Parente et al., 2010), or the EnMap simulator (Segl et al., 2012). All of these end-to-end simulation tools are implemented in a modular and flexible way so that they can be applied to a large variety of sensors and environmental parameters. Nevertheless, one key point to achieve realistic simulations in a statistical sense is to provide to the simulator representative inputs like ground spectral emissivity and reflectance. The availability of such optical properties is not direct and presents some limitations depending on the measurement conditions: on ground, airborne or space borne.

Ground optical properties usually come from existing database built from laboratory measurements. LOPEX'93 (Leaf Optical Properties EXperiment) (Hosgood et al., 1995) carried out by the European Commission Joint Research Center collected spectral measurements of various elements (leaf, pine needle, stalk) of several vegetation types in the spectral band (0.4–2.5 μm). ASTER (Advanced Spectral Emission and Reflection Radiometer) database (Baldridge et al., 2009) includes a large variety of natural and artificial material spectra (0.4–14 μm) and pure minerals. Even if such data sets are covering a wide range of materials, a first drawback is that these optical properties are measured with a typical sample

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size on the order of a few cm, which is not representative of spaceborne sensor GSD (Ground Sampling Distance). Secondly, such databases do not consider the temporal variability of these properties in a given geographic location. Combining these spectra with a global land cover database offers the possibility to build a global coverage in optical properties but with neither temporal nor climatological representativeness. By making full use of the huge amount of remote sensing data, it is possible to overcome such limitations, with the aim of creating a worldwide climatology of surface optical properties. A first climatology has been proposed by Meygret et al. (1997), in the BDHS (Base de Données Histogramme Spot), but it only delivers the top of atmosphere (TOA) reflectances in the 4 Spot bands. More recently with the advent of new multispectral sensors like VEGETATION (Bartholomé and Belward, 2005), MERIS (Arino et al., 2008), and Bontemps et al., 2010), MODIS (Friedl et al., 2001, 2002, 2010), numerous works have been presented to build surface reflectance databases. For example, GlobCover (Arino et al., 2008; Bicheron et al., 2008) which is based on 1-year MERIS measurements, gives 15-days products with a 300-meter spatial resolution in the Visible band; GlobAlbedo data of the land surface (Lewis et al., 2012, Muller et al., 2011, 2012) are being produced from European satellites data from 1998 to 2011 with a spatial resolution of 1 km, between 0.3 and 3 μm (*http://www.GlobAlbedo.org*); ADAM (A surface reflectance DAtabase for ESA's earth observation Missions) is a global monthly reflectance climatology (ADAM-ESA, 2013) constructed from MODIS measurements on a $0.1^{\circ} \times 0.1^{\circ}$ grid over the 0.3–4 μm spectral range (*http://adam.noveltis.com*). Nevertheless, these databases suffer from one or several limitations: (1) the temporal resolution: they mainly deliver monthly products, except the GlobCover products (15 days); (2) the spectral coverage is restricted to visible and near infrared bands; (3) most of these processed data sets are temporally limited to 1–2 years. It appears thus crucial to simultaneously improve the spatial and temporal resolutions but also the spectral extension of reflectance databases for an optimal specification of future space missions like HYPXIM (Carrere et al., 2014) or MISTIGRI (Lagouarde et al., 2013).

To go beyond existing databases, one can fully exploit the two MODIS sensors onboard Terra and Aqua platforms, which since 1999 (Terra) and 2002 (Aqua) continuously acquire images of the Earth at a resolution between 250 m and 1 km, depending on the spectral bands covering visible, solar infrared and thermal infrared spectral regions. In this work, we focus on the monitoring of land surfaces dynamics by building a database over 10 years (2003–2012) with high a temporal sampling resolution. The difficulties encountered in the processing of MODIS data have various origins: (1) the MODIS products are not free from artifacts, such as unscreened atmospheric influence or other unwanted effects; (2) the input reflectance time-series cannot be directly exploited and interpreted because of their large time variability that results from the anisotropic properties of land surface reflectances. This paper presents a robust and reliable processing of MODIS data set leading to a reflectance database called FondsDeSol (FDS) that, in a very-near future, will be disseminated through an easy-to-use web interface (http://newtec.univ-lille1.fr/fondsdesol/index_ch.html). FDS is built with a frequency of 8 days, re-projected on a "plate-carrée" grid (±85°/±180°) and contains the spectral reflectance (respectively emissivity) of all MODIS wavelengths at a resolution of 500 m (resp. 1 km). Original data is cleaned from all pixel artifacts. Moreover, ground reflectances are corrected from bi-directionality effects and normalized to a fixed sun and viewing geometry. Therefore, the database can be used either to retrieve directional surface reflectances and albedos or to compute spherical albedos.

Section 2 describes the data processing algorithm, which identifies corrupted measurements, normalizes the directional effects of valid observation, and gap-fills the reflectance time series. Section 3 provides a comparison of the resulting database to the standard MODIS product, to an earlier version of FondsDeSol (Gonzalez et al., 2010), and to the reflectance MCD43C4 product (LP DAAC, 2006). The temporal resolution of FondsDeSol is highlighted by examples of specific events that have been identified and analyzed. Finally, conclusions are given in Section 4.

2. Algorithm description

2.1. Input data

The main input data of the processing chain is the NASA MOD09A1 product (LP DAAC, 2000a), which is available from the two MODIS instruments on board the TERRA and AQUA satellites. The product provides the surface reflectance, after atmospheric correction, in 7 spectral bands ranging from 459 nm to 2155 nm on a sinusoidal projection grid at a 500 m GSD. The best observation over the 8 days period is kept, based on criteria on cloud and aerosol contaminations. The MOD09A1 product also includes the day and the observation geometry of the selected measurement. In addition, we also use two other NASA products over the same time period: the MOD11A2 product (LP DAAC, 2000b), which provides an estimate of the land surface temperature and emissivity derived from MODIS data over global land surfaces under clear-sky conditions; and the MOD10A2 product which quantifies the snow/ice land cover.

The directional signature correction, described below, requires the knowledge of the surface type, which is known at the pixel level through the global land cover classification provided by the MOD12Q1 product (LP DAAC, 2000c). This set of cover types (IGBP) includes eleven categories of natural vegetation covers; three classes of developed and mosaic lands, and three classes of non-vegetated lands. One improvement of FondsDeSol with respect to the 2006 version, is the discrimination of snowy pixels using the snow cover product MOD10A2 (Hall et al., 2006), that includes the maximum snow cover extent and a snow occurrence observation over an 8-day period that can be compared to the MOD09 internal snow flag.

2.2. Algorithm principle

Although the MOD09 processing aims at the identification of cloud or snow contamination and corrects for aerosol scattering, the analysis of reflectance images and time series clearly indicates the presence of remaining contamination. In addition, the measured reflectances have not been corrected from directional effects, which impact the time series. Finally, persistent cloud cover sometimes prevents any observation during the 8-day synthesis period, which leaves gaps in the time series. The data processing, described below, aims at mitigating these defaults. Altogether, the designed algorithm provides reasonable reflectance values, which in practice corresponds to either the true reflectance, or to a realistic value whenever the contaminated pixels dominate.

A 4-steps algorithm is proposed with the objective to keep the general dynamic of the original measurements, to reject the contaminated measurements, and to rebuild the incomplete time series as close as possible to reality. These 4 steps are:

1. Apply a bidirectional reflectance distribution function (BRDF) correction to normalize reflectances.