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Evaluation of the global MODIS 30 arc-second spatially and temporally complete snow-free land surface albedo and reflectance anisotropy dataset

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ABSTRACT

Land surface albedo is an essential variable for surface energy and climate modeling as it describes the proportion of incident solar radiant flux that is reflected from the Earth's surface. To capture the temporal variability and spatial heterogeneity of the land surface, satellite remote sensing must be used to monitor albedo accurately at a global scale. However, large data gaps caused by cloud or ephemeral snow have slowed the adoption of satellite albedo products by the climate modeling community. To address the needs of this community, we used a number of temporal and spatial gap-filling strategies to improve the spatial and temporal coverage of the global land surface MODIS BRDF, albedo and NBAR products. A rigorous evaluation of the gap-filled values shows good agreement with original high quality data (RMSE = 0.027 for the NIR band albedo, 0.020 for the red band albedo). This global snow-free and cloud-free MODIS BRDF and albedo dataset (established from 2001 to 2015) offers unique opportunities to monitor and assess the impact of the changes on the Earth's land surface.

1. Introduction

Land surface albedo, the proportion of incident radiant flux that is reflected, describes the Earth's radiative energy budget and the exchange of radiative energy between the atmosphere and the land surface. The remaining incident radiant flux is absorbed by the Earth and drives land surface processes, such as photosynthesis, plant growth, evaporation, and snow melt. Thus, albedo is an essential climate variable and is required by climate, biogeochemical, hydrological, and weather forecast models at a variety of spatial and temporal scales (Campagnolo et al., 2016; Charney et al., 1977; Dickinson and Hanson, 1984; Lacaze and Maignan, 2006; Lawrence and Chase, 2007a,b, 2010; Martonchik, 1997; Martonchik et al., 2002; Morcrette et al., 2008; Rahman et al., 1993; Schaaf et al., 2002, 2008; Schaaf et al., 2011; Wang et al., 2004, 2016; Zoogman et al., 2016).

Remote sensing provides the only realistic way to capture land surface albedo at a global scale. As multi-angle data from remote sensing sensors such as AVHRR (Advanced Very High Resolution Radiometer), POLDER (POLarization and Directionality of the Earth's Reflectances), MISR (Multi-angle Imaging SpectroRadiometer), MODIS (Moderate-Resolution Imaging Spectroradiometer), and VIIRS (Visible Infrared Imaging Radiometer Suite) have become available, the retrieval of remotely sensed measures of reflectance anisotropy has been adopted as the most flexible method to accurately derive surface albedo (d'Entremont et al., 1999; Diner et al., 2008; Hautecœur and Leroy, 1998; Hu et al., 2000; Leroy et al., 1997; Lucht et al., 2000; Privette et al., 1997; Schaaf et al., 2008, 2011, 2002; Strugnell et al., 2001; Strugnell and Lucht, 2001; Sütterlin et al., 2015; Wanner et al., 1997).

MODIS provides multi-angle observations of each location on the Earth's surface, nearly every day, in order to sample the Bidirectional Reflectance Distribution Function (BRDF) of that location. High quality, cloud-free, directional surface reflectances from both Terra and Aqua are accumulated during 16-day periods and used to derive gridded (500 m) land surface BRDF model parameters, albedo, and NBAR (Nadir-BRDF Adjusted Reflectance) products (Lucht et al., 2002; Schaaf et al., 2002, 2011). These operational

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MODIS products have been available since the launch of Terra in 2000, and have been validated by various rigorous assessment efforts (Cescatti et al., 2012; Liang et al., 2003; Lucht et al., 2000; Román et al., 2010; Salomon et al., 2006; Wang et al., 2012, 2014). The MODIS BRDF products have been used to establish surface vegetation structure and roughness (Chopping et al., 2011; Hill et al., 2011, 2008, 2012; Jiao et al., 2014; Wang et al., 2011). The MODIS albedo products have been used by various modeling communities (Kala et al., 2014; Lawrence and Chase, 2007a,b, 2010; Morcrette et al., 2008; Myhre et al., 2005; Oleson et al., 2003; Roesch et al., 2004; Roy et al., 2016; Wang et al., 2004; Zhou et al., 2003). The NBAR product, and the vegetation indices derived from NBAR, are the primary inputs to the MODIS land cover and phenology products and are also being used for regional crop and range monitoring applications (Friedl et al., 2010; Glanz et al., 2014; Hill et al., 2016; Zhang et al., 2003, 2012, 2002; Zhou et al., 2016).

However, data gaps caused by cloud or ephemeral snow have somewhat reduced the adoption and application of the operational gridded MODIS anisotropy products (BRDF, albedo, and NBAR). In the Inter-Tropical Convergence Zone (ITCZ) dominated regions, for example, clouds may last for several months which results in long gaps in the anisotropy products. Persistent clouds during the monsoon seasons in India and Southeast Asia also contaminate the anisotropy products and limit their utilization. Modelers often prefer to initialize models with snow-free fields and ephemeral snow seasonally covers large areas of North America and Asia. These regions are particularly critical for modeling efforts in light of climate change.

The purpose of this research is to present and evaluate the high quality global, cloud free, seasonally snow free BRDF, albedo, and NBAR products that have been developed for modeling of the Earth's surface radiation and monitoring of the surface vegetation. This gap-filled dataset utilizes the V005 MODIS 30 arc-second (approximately 1 km at the equator) CMG (climate modeling grid) anisotropy products. Previous coarser resolution (1 arc minute) gap-filling efforts had been made with the MODIS V004 albedo product (Moody et al., 2005, 2008) but never with the underlying BRDF product. An initial albedo gap-filling has also been applied to the coarse resolution 0.05° (or 3 arc-minute, about 6 km at the equator) MODIS V005 CMG albedo product (Zhang, 2009). However, here, gap-filling techniques are applied to the three BRDF model parameters and then these gap-filled BRDF model parameters are then used to calculate the appropriate gap-filled, snow-free, white-sky albedo, black-sky albedo and NBAR global products.

2. Data

The operational MODIS BRDF, Albedo, and NBAR algorithm makes use of a linear combination of an isotropic parameter and two kernels (Roujean et al., 1992): the RossThick kernel which is derived from radiative transfer modeling (Ross, 1981), and the LiSparseReciprocal kernel which is based on surface scattering and geometric optical mutual shadowing (Li and Strahler, 1992). The MOD43D CMG product (V005) provides the three kernel weights (ISO, VOL, and GEO) for the RossThick-LiSparseReciprocal model at a 30 arc-second resolution once every 8 days. Data are available for the seven MODIS land bands (0.47 μm, 0.55 μm, 0.67 μm, 0.86 μm, 1.24 μm, 1.64 μm, 2.1 μm) and three broad bands (the shortwave band (0.3–5.0 μm), a visible band (0.3 μm–0.7 μm) and a near-infrared band (0.7–5.0 μm)). Quality Assessment (QA) information for the products in the MCD43D31 dataset and snow flags in the MCD43D34 dataset are provided for each pixel to indicate inversion quality and snow condition.

The primary gap-filling method applied to the BRDF parameter data is based on temporal fitting. When temporal fitting does not produce reliable results, a secondary spatial fit is attempted using the International Geosphere-Biosphere Programme (IGBP) land cover layer from the 500 m yearly V005 MCD12Q1 product (Friedl et al., 2010). The land cover layer is re-projected to a geographic latitude/longitude projection, aggregated to 30 arc-second, and used sparingly for spatial fitting and spatial smoothing in areas of particularly persistent gaps.

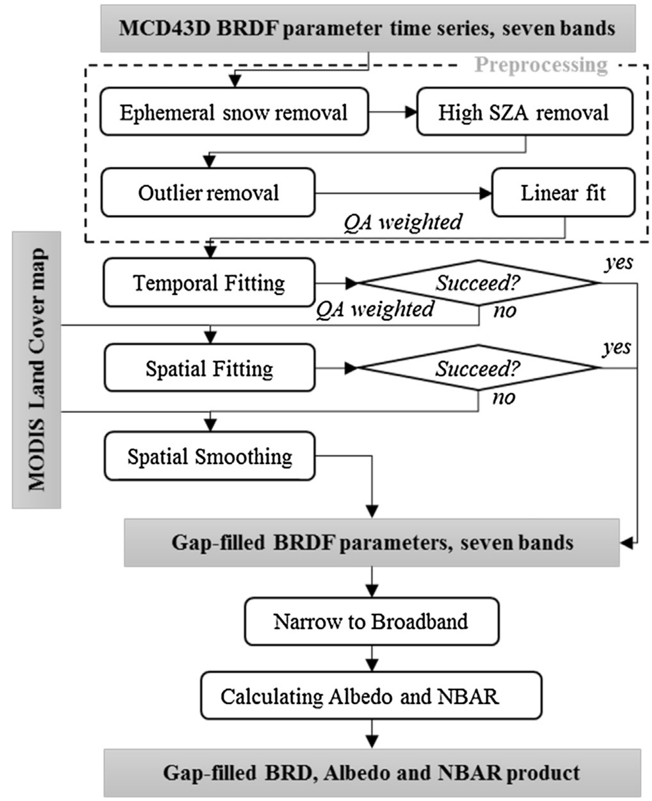

Fig. 1. Flowchart of the gap filling processes.

3. Methods

To create the gap-filled product, we apply temporal fitting techniques, based on vegetation phenology (assisted by spatial fitting techniques), to the global 30arc-second V005 MCD43D CMG BRDF products in order to compensate for missing data and to estimate snow-free situations. We initially apply a temporal fitting method to fill the gaps by creating and fitting each pixel to a one and a half year time series. If the temporal method fails due to limited high quality retrievals, then spatial processes based on land cover mapping are used to fill the gaps with lower quality values. The flowchart is shown in Fig. 1.

3.1. Preprocessing

To generate a snow-free product, pixels with ephemeral snow are removed using the MCD43D34 snow flags (derived from the flags in the original underlying surface relectance data (MO/YD09)). In addition, as the MCD43 products are not recommended for use with solar zenith angles (SZA) beyond 70°, we have removed all of the data for SZA > 70° before initiating the gap filling procedures.

Despite rigorous cloud clearing and atmospheric correction, the original V005 MCD43D products are still contaminated by residual cloud and snow in some regions. This is especially true in the Amazon and in equatorial West Africa, and in high latitude areas. This contamination occurs when the 500 m standard BRDF product