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# Capturing rapid land surface dynamics with Collection V006 MODIS BRDF/NBAR/Albedo (MCD43) products

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ABSTRACT

MODIS BRDF/NBAR/Albedo products (MCD43) have been widely used for a variety of land surface studies since 2000 (e.g., for climate and biosphere modeling, radiative forcing, phenology, and classification schemes). In the past, limitations in computing and archive capacity had restricted the MCD43 retrievals to only once every eight days. The latest reprocessing of the entire archive of Terra and Aqua MODIS BRDF/NBAR/Albedo products (Collection V006) provide retrievals each day and therefore represent a major improvement for phenological and surface monitoring efforts. Compared to the previous retrieval which occurred every 8-days based on a 16-day retrieval period for Collection V005 MODIS BRDF/NBAR/Albedo, this study demonstrates that the Collection V006 MODIS BRDF/NBAR/Albedo product retrieved every day captures significantly more seasonal vegetation dynamics and rapid land surface changes. The Collection V006 product still utilizes the 16-days of directional reflectances surrounding the day of interest (9th day) to retrieve the model of the surface anisotropy but assigns the highest temporal weight to the day of interest (the center date of the retrieval period). Furthermore, the Collection V006 retrievals utilize the day of interest snow/snow-free status to capture snow albedo (an improvement over the previous Collection V005 strategy which based the retrieval on the predominant snow/snow-free status of the majority of the observations over the 16-day retrieval period). All valid clear sky observations from Terra and Aqua are now used for each retrieval, which improves the inversion quality. This is especially true at high latitudes, where up to nine observations from each sensor can be observed per day. Thus, although the high quality full inversion Collection V006 albedo retrieval values are consistent with the Collection V005 results, the overall number of high quality results retrieved has increased. Furthermore, the accuracy of the poorer quality magnitude inversions (which rely on a back-up algorithm) has improved due to utilization of the latest high quality full inversion retrievals as pixel-specific a priori knowledge. The ability of the latest Collection V006 MODIS BRDF/NBAR/Albedo products to capture land surface dynamics is evaluated by using a globally-distributed record of spatially representative tower measurements. The RMSE of broadband shortwave blue-sky albedo at these sites is $< 0.0318$ and the bias is within $\pm 0.0076$ for all quality results.

## 1. Introduction

Land surface albedo and reflectance anisotropy, recognized as Essential Climate Variables (ECV) by the Global Climate Observing System (GCOS), quantify the radiative interaction between the atmosphere and the land surface (Schaaf et al., 2009). Albedo is one of the crucial parameters used in global land surface climate and biosphere models (Oleson et al., 2003). The MODIS BRDF/NBAR/Albedo products (Schaaf et al., 2002) have been produced since the launch of Terra in 2000 (augmented by Aqua in 2002). The consistent high accuracy of these surface anisotropy (as described by the Bidirectional Reflectance Distribution Function—BRDF), Nadir BRDF-Adjusted Reflectance (NBAR), and albedo values have been validated by comparison with globally distributed ground albedo measurements and with periodic airborne BRDF measurements over a variety of land cover types during both the snow-covered and snow-free periods (Cescatti et al., 2012; Román et al., 2009, 2010; Wang et al., 2012, 2014).

The MODIS BRDF/NBAR/Albedo products have been embraced by a number of global and regional modeling and monitoring communities (Kvalevåg et al., 2010; Lawrence and Chase, 2007). They provide initial conditions for the MODIS land surface temperature and cloud optical properties products (Platnick et al., 2003; Wan, 2014), and have been

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used as a priori and validation data for Advanced Along-Track Scanning Radiometer (AATSR) aerosol retrieval (Sayer et al., 2012), GLOBAlbedo production using European Satellites including MERIS (Muller et al., 2007), Landsat data gapfilling (Roy et al., 2008), Landsat NBAR and albedo (Roy et al., 2016; Shuai et al., 2011), MSG/SEVIRI land surface albedo (Carrer et al., 2010), and the Global LAnd Surface Satellites (GLASS) albedo (Liu et al., 2013) products. MODIS albedo products have been utilized to investigate the impact of land cover change on radiative forcing (Myhre et al., 2005; O'Halloran et al., 2012). While the MODIS albedo measures continue to be used in surface energy budget calculations, the BRDF and nadir view angle corrected reflectance (NBAR), which removes the variability due to angular effects, have been found to improve the accuracy of change detection in intra- and inter-annual temporal dynamics and therefore have been increasingly used to detect natural and human disturbance, to monitor vegetation cover/phenology (Zhang et al., 2003), and to provide measures of the surface variability (Chopping et al., 2011; He et al., 2012).

The BRDF describes the reflectance anisotropy of the surface and can be retrieved from a sufficiently well distributed series of multi-angular satellites observations of a locality. An appropriate BRDF model is fit to these available observations, and the land surface albedo can then be obtained from the integration of the BRDF over the hemispheric view and illumination angles. The MODIS BRDF/NBAR/Albedo products rely on the semi-empirical linear RossThick-LiSparse Reciprocal (RTLSR) BRDF model which utilizes the weighted sum of isotropic, volumetric and geometric parameters (Roujean et al., 1992; Schaaf et al., 2002) to describe the reflectance anisotropy of each pixel. The RTLSR has been utilized to describe the reflectance anisotropy of a large variety of global land covers (Schaaf et al., 2002).

Clear sky, multi-angle, high quality atmospherically corrected surface reflectance data over a 16 days period from both Terra (MOD09GA) and Aqua (MYD09GA) (Roy et al., 2006) are utilized to obtain sufficient well distributed angularly observations to fit the RTLSR BRDF model for the retrieval of MODIS BRDF/NBAR/Albedo products (MCD43). Each observation is assigned a weight during the retrieval. MCD43 is the MODIS product number assigned to MODIS BRDF/NBAR/Albedo products. The number of high quality observations available, the Root Mean Square Error (RMSE) of the fit and the Weight of Determination (WOD) which indicates whether the observations over the viewing and illumination geometry are sufficiently well distributed to capture the surface anisotropy (Schaaf et al., 2002), are all used to generate a high quality full inversion retrieval. A backup algorithm (or magnitude inversion), using available observations with an a priori BRDF database, is applied if a high quality full inversion BRDF cannot be retrieved due to poor quality input or insufficient sampling of the viewing hemisphere. While this magnitude inversion often provides reliable results, it is always flagged as a poor quality retrieval.

The surface measures of Black-Sky Albedo (BSA) (Directional-Hemispherical Reflectance -DHR) at local solar noon, White-Sky Albedo (WSA) (Bi-Hemispherical Reflectance (BHR) (MCD43A3), and NBAR (MCD43A4) at local solar noon are generated from the BRDF parameters (MCD43A1). These terms are defined in Schaepman-Strub et al. (2006). Spectral NBAR (MCD43A4) values are derived with the geometry of a nadir view zenith angle and local solar noon. Users can also select the solar angles appropriate for their application and derive those quantities from the BRDF parameters themselves. Actual (blue-sky) albedo for a particular instant in time can be obtained by combining the clear sky black and white-sky albedos with an instantaneous measure of solar zenith angle and aerosol optical depth. The effects of multiple scattering and anisotropic diffuse illumination should be considered more carefully for fully snow-covered areas due to the high reflectance of snow and large solar zenith angles of high latitudes, therefore, a full expression blue-sky albedo that solves the multi scattering effect should be used for snow-covered areas (Román et al., 2010). For snow-free surfaces, a simple form of blue-sky albedo can be calculated with an assumption of an isotropic diffuse radiation (Lewis and Barnsley, 1994).

The visible (0.3–0.7 μm), near-infrared (0.7–5.0 μm) and shortwave (0.3–5.0 μm) broadband values of anisotropy and albedo, which are commonly used in surface energy budget models, are generated from spectral values via narrow-to-broadband conversion coefficients for snow-free and snow-covered surfaces (Schaaf et al., 2002). In Collection V006, due to the large number of non-functional or noisy detectors in MODIS Aqua Band 6 (1.628–1.652 μm), separate narrow-to-broadband conversion coefficients without Band 6 are applied for those conditions were Band 6 has failed to be retrieved but all other bands have valid retrievals. Previous research indicates that the accuracy of the MODIS shortwave broadband albedo meets the requirements (< 5%) for both snow-free and snow-covered surfaces (Román et al., 2009, 2010; Wang et al., 2012, 2014).

The Collection V005 MCD43 BRDF/NBAR/Albedo products (Schaaf et al., 2002) were only retrieved every 8 days based on 16 days of observations due to previous limitations in NASA's science production and archiving capacity. However, an albedo product retrieved on a daily basis day is required to improve the energy budget computation in land surface models and to capture surface dynamics (i.e. vegetation phenology and land cover disturbance) with high accuracy. Therefore, the MODIS BRDF/NBAR/Albedo products are retrieved each day in the Collection V006 reprocessing, representing a major milestone in this suite of global land products. This paper demonstrates how the availability of Collection V006 products significantly enhances the detection of land surface dynamic characteristics, especially during rapidly changing situations (Wang et al., 2012, 2014). In particular, this study describes the retrieval strategy employed for the Collection V006 MODIS BRDF/NBAR/Albedo products and evaluates the ability of the new BRDF/NBAR/Albedo product retrieved on a daily basis using a 16-day retrieval window to capture land surface dynamics.

## 2. Methodology

### 2.1. Improvements in input MODIS Collection V006 values

The Collection V006 MODIS Level-1B reprocessing is implemented via numerous calibration Look Up Tables (LUTs) updates (Lyapustin et al., 2014; Toller et al., 2013) which improve the quality and consistency of the downstream Level 2 (L2) and Level 3 (L3) MODIS products for the entire Terra/Aqua mission period. The main Level-1B improvements include solar diffuser (SD) degradation correction, response vs. scan angle (RVS) LUTs updates, and polarization correction. The improvements of MODIS Collection V006 L2G-lite surface reflectance (MO/YD09GA) products include improved aerosol retrieval and correction algorithms; new aerosol retrieval LUTs; and refined internal snow, cloud, and cloud shadow detection algorithms (https://lpdaac.usgs.gov/dataset_discovery/modis/modis_products_table/mod09ga_v006).

The MODIS Collection V006 L2 cloud mask product is improved by including Normalized Difference Vegetation Index (NDVI) to better define cloud detection thresholds and enhance the knowledge of expected surface reflectances (Baum et al., 2012).

Using these improved MODIS surface reflectance and cloud mask products, the Collection V006 implementation of the MODIS BRDF, NBAR and albedo products represents a major improvement for environmental modeling and monitoring. Key upgrades include: (1) retrieved every day using a 16-day retrieval period, (2) expanding the quality and uncertainty values, and (3) implementing an improved backup database for poorer quality retrievals. Furthermore, the Collection V006 reprocessing algorithm utilizes all the valid clear sky observations for the retrieval (whereas earlier versions were limited to only using up to four observations to reduce storage processing volume) (Wolfe et al., 1998). The increased quality and enhanced temporal resolution afforded by the Collection V006 algorithm has the greatest impact at high latitudes, where persistent cloud cover, difficulties in