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Estimating the effective spatial resolution of the operational BRDF, albedo, and nadir reflectance products from MODIS and VIIRS

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ABSTRACT

Satellite derived surface albedo and view-angle corrected surface reflectance products serve as the key inputs for an array of climate, biogeochemical, and hydrologic modeling efforts. This research effort is particularly focused on establishing the effective spatial resolution of the global MODIS and VIIRS Nadir BRDF-Adjusted Reflectance (NBAR) and Albedo products. The standard MODIS Products (MCD43) are created by fitting a kernel-driven, semi-empirical BRDF model to multi-date, multi-angular surface reflectance data to establish the surface reflectance anisotropy of a location. Emphasis on a particular date within the rolling multi-date period has resulted in a daily product reported on a 500 m Sinusoidal grid tiling system. While anecdotal and theoretical experiences have suggested that this product would be representative of a larger surface area than the 500 m grid, this research both quantifies that effect, and verifies that the spatial effective resolution is consistently less than 1 km for MODIS. Results for 500 m VIIRS NBAR product show an improvement of approximately 250 m in spatial effective resolution along the scan direction. In addition to their use in modeling, the MODIS BRDF/Albedo/NBAR products (and into the future with the analogous VIIRS products) are increasingly being relied upon to monitor vegetation phenology, identify land cover and land cover disturbance, track snow fall and melt, and establish surface energy balance variability. Thus, this research provides the quantification both for MODIS and VIIRS necessary for the effective use of these products by the global modeling and monitoring communities.

1. Introduction

The MODIS Bidirectional Reflectance Distribution Function (BRDF), Nadir BRDF-Adjusted Reflectance (NBAR), and Albedo products (MCD43) have now been produced as standard products for a decade and a half by utilizing high quality, directional surface reflectances (Kotchenova, Vermote, Matarrese, & Klemm, 2006, Kotchenova & Vermote, 2007) from both the Terra and Aqua satellites (Lucht & Lewis, 2000; Schaaf et al., 2002; Schaaf, Liu, Gao, & Strahler, 2011; Wanner et al., 1997). A semi-empirical, kernel-driven BRDF model (Ross-thick, Li-sparse Reciprocal) is fit to a multi-date period of these multi-angular observations. The BRDF model retrieved is an intrinsic function of the surface structure governed by the proportion of shadowed and sunlit components produced by a vegetation canopy with distinct vertical and horizontal structure (Li & Strahler, 1992; Lucht & Lewis, 2000; Strahler & Jupp, 1990; Wanner, Li, & Strahler, 1995). The surface anisotropy of the surface cover associated with a location is not merely a simple function of the surface spectral values (such as NDVI for instance, (Gao et al., 2014; Jiao et al., 2014)) but instead is a measure of the intrinsic reflective character produced by the distinct surface structural components at that location (e.g. (Chopping et al., 2011)). In the newest reprocessing of the MODIS record (collection V006) a single date of interest is emphasized to provide a daily product (Wang et al., 2014). The primary standard product of this suite is the BRDF model retrieval (MCD43A1), which is reported on a 500 m Sinusoidal grid tiling system and is accompanied by significant quality information (MCD43A2). The importance of both the goodness of fit of the BRDF model and the weights of determination (provided in the quality information) cannot be underestimated. If the high quality input data are excessively variable (due to factors such as inappropriate atmospheric correction, residual snow or water, or certain field of views that capture significantly different surface covers than the rest of the inputs), or if the input data do not adequately capture the viewing geometry in order to justify a high quality BRDF retrieval, then the product will resort to a backup algorithm, and the retrieval will be flagged as a poor quality result. Once determined, these retrieved BRDF model parameters can be used to produce view-angle corrected reflectances at any desired view zenith angle and illumination angle, as well as produce intrinsic surface albedo quantities at desired illumination geometries. This is the preferred manner of use for the product. However, for ease of use by the global modeling

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community, an NBAR product at local solar noon, a directional-hemispherical reflectance (black sky albedo) at local solar noon, and bihemispherical reflectance (i.e., white sky albedo under isotropic "purely-diffuse" illumination conditions) are also routinely generated as additional standard products (MCD43A4 and MCD43A3). Actual blue sky albedo values can be determined with knowledge of the instantaneous optical depth or with the ratio of direct to diffuse downwelling solar radiation.

The MODIS BRDF/Albedo products have been evaluated to a MODIS Stage 3 over multiple global locations and time periods and the stated accuracy of the high quality 500 m gridded albedos is well less than 5% albedo at the majority of evaluation sites and even the low quality albedo values have been found to be primarily within 10% of the field data (Román et al., 2013, 2009). Cescatti et al. (2012) also found a good agreement between MODIS albedo and in situ measurements with mismatches explained by spatial heterogeneity of the land cover. These MODIS MCD43 products have become standard inputs for the production of land cover and disturbance estimates (Friedl et al., 2010), for efforts to monitor vegetation phenology (capturing both natural cycles and the anthropogenic effects of planting, harvest and grazing) (Shuai et al., 2013; Zhang, Friedl, & Schaaf, 2006; Zhang et al., 2003; Ganguly, Friedl, Tan, Zhang, & Verma, 2010), for studies that track the effects of ephemeral snow fall and snow melt (Wang et al., 2012), for models of the variability in surface albedo and the surface energy budget (Schaaf et al., 2011; Lawrence & Chase, 2007; Morcrette, Barker, Cole, Iacono, & Pincus, 2008; Myhre, Kvalevåg, & Schaaf, 2005; Oleson, 2003; Zhou, 2003) and for a wide range of science-quality satellite products including cloud optical properties (Platnick et al., 2003; King, Platnick, Menzel, Ackerman, & Hubanks, 2013), aerosol information (Hyer, Reid, & Zhang, 2011; Yang, Xue, Guang, & Li, 2012; Levy et al., 2013), and low light imagery (Román & Stokes, 2015).

The MODIS BRDF parameters are also often used to augment other satellite data sets without sufficient angular coverage to produce albedos and view angle corrected directional information on their own (i.e. MERIS (Muller et al., 2012; Gao, Schaaf, Jin, Lucht, & Strahler, 2004), Landsat (Shuai, Masek, Gao, & Schaaf, 2011; Shuai, Masek, Gao, Schaaf, & He, 2014; Roy et al., 2008) and AATSR (Sayer et al., 2012)). Furthermore, when independent BRDFs can be achieved, the long time series of MODIS values are frequently used for inter-satellite comparisons (Carrer, Roujean, & Meurey, 2010; Hill, Averill, Jiao, Schaaf, & Armston, 2008). The at-launch algorithm was originally provided on a 1 km grid (recognizing the effect of view angle growth on pixel size and reflecting the uncertainty over the at-launch geolocation) and at a fixed solar zenith angle (of 45°). However, in subsequent reprocessing, bowing to pressure from the user monitoring and modeling communities (and given the excellent geolocation characteristics of MODIS (Wolfe et al., 2002)), retrievals were increased to a 500 m grid (using a solar zenith angle of local solar noon).

As the MODIS instruments age, continuity in these important surface reflectance anisotropy products will be provided by the Suomi-NPP VIIRS sensor (launched in 2011) (Justice et al., 2013). Operating in similar (although not exact) bands, the VIIRS surface reflectances are provided at 375 m and 750 m spatial resolutions (rather than the 250 m and 500 m resolutions of MODIS). NASA has committed to the production of MODIS heritage BRDF/Albedo/NBAR from Suomi-NPP VIIRS. This current research effort aims to provide the scientific community with important accuracy assessments of the effective spatial resolution of these products as we move into an era of transition from MODIS to VIIRS. As is well understood, the view zenith angle (VZA) determines the size of the footprint of swath observations, although smaller growth is obtained for VIIRS moderate imagery through pixel averaging (Wolfe et al., 2013). Recently, the relation between VZA and the effective resolution of the MODIS gridded daily directional reflectance products (MO/YD09) was quantified for a wide range of VZA values (Campagnolo & Montano, 2014). Products that combine observations from many different views, such as the MODIS BRDF derived products, (which utilize all available high quality multi-angular data acquired over a 16-day period), are more complicated, as their spatial resolution is hard to derive simply from the observation geometry of each of their components. The result has been a dearth of knowledge on the ability of MODIS and VIIRS data to capture the underlining features and processes taking place at their native spatial resolution for the purposes of BRDF estimation. Nonetheless, it is possible to estimate the effective spatial resolution of these products using standard techniques over suitable targets on the ground. Thus this research investigates the effective spatial resolution of the MODIS and VIIRS BRDF, albedo, and NBAR products and quantifies that effective resolution for utilization in future modeling and monitoring efforts.

2. MODIS and VIIRS spatial response and gridding

Level 1 and level 2 (non-gridded) MODIS and VIIRS swath observations are the integrated signals received by each detector during a sampling interval. The length of the interval and the scan angle determine the observation cell size, measured by the horizontal sampling interval (HSI). At nadir, the HSI is by design 250 m for MODIS bands 1 and 2, and 131 m (along scan) and 375 m (along track) for VIIRS I bands. The sensors' spatial response is characterized by their directional line spread functions (LSFs) which have been measured before launch (Barnes, Pagano, & Salomonson, 1998, Wolfe et al., 2013). In the along track direction the LSF is essentially square but in the along scan direction the dynamic LSF it is approximately triangular. The support (i.e. the area on the ground that contributes to the nominal cell signal) is therefore about twice as large as the HSI in the along scan direction with only 75% of the signal being collected from the nominal observation cell itself. While MODIS exhibits a large distortion at the end of scan (Wolfe, Roy, & Vermote, 1998), VIIRS uses a sample aggregation scheme which mitigates the contribution from neighboring cells as illustrated in Fig. 1. Even if there is no aggregation for scan angles larger than 44.68 degrees, VIIRS spatial response is more balanced than MODIS' since its instantaneous field of view is by design smaller along scan than along track.

The rectangles with a dark border indicate the horizontal sample intervals (HSIs) for the detectors while the gray rectangles in the background represent the support of each nominal observation cell; VIIRS' supports are more balanced than MODIS'. The figure also illustrates on-board aggregation scheme for VIIRS; the dashed lines indicate the scan angle values that separate aggregation zones. Distances are in meters and scan angles are in degrees.

In this paper we analyze the MODIS and VIIRS gridded BRDF, NBAR and Albedo products, where the original observations are resampled to a fixed grid. All publicly available gridded MODIS land products are

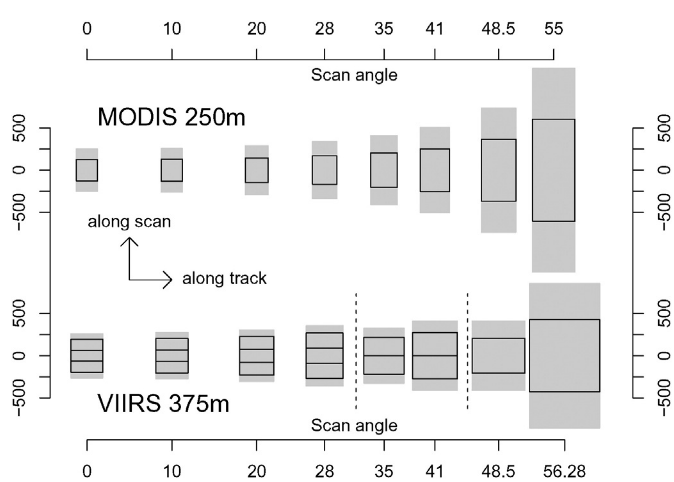

Fig. 1. MODIS and VIIRS support for their respective range of scan angles.