VIIRS BRDF, Albedo, and NBAR Product Algorithm Theoretical Basis Document (ATBD)

Science Principal Investigator: Dr. Crystal B. Schaaf

Correspondence e-mail address: Crystal.Schaaf@umb.edu

Prepared by: Yan Liu, Qingsong Sun, Zhuosen Wang, Zhan Li, Miguel O. Román, and Crystal Schaaf

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NASA Goddard Space Flight Center

Greenbelt, Maryland

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ABSTRACT

The Visible Infrared Imaging Radiometer Suite (VIIRS), onboard on the Suomi-National Polar-orbiting Partnership (NPP) satellite, will continue the long-term remote sensing environmental data records (EDR)begun by the MODerate Resolution Imaging Spectroradiometer (MODIS) sensors. To provide a continuous data record in to the future, the VIIRS daily Bidirectional Reflectance Distribution Function (BRDF) parameters, Albedo and Nadir BRDF adjusted Reflectance (NBAR) products are being generated with retrieval strategy similar to that used to

produce the NASA operational MODIS Collection 6 daily BRDF, Albedo and NBAR products (MCD43). This algorithm makes use of multi-date, multi-anglular surface reflectance observations fit to the Ross-Thick/Li-Sparse-Reciprocal semi-empirical kernel-driven bidirectional reflectance model. The VIIRS products are available at a gridded 500m resolution for the I bands, a gridded 1km resolution for the M bands (both on tiled sinusoidal projections) and on 30arc second, and 0.05 degree global climate modeling grids (CMG) (all in Hierarchical Data Format (HDF)). This product is evaluated by comparison with the concurrent MODIS MCD43 products , as well as with *in situ* tower albedo measurements to assess the products' ability to provide follow-on VIIRS BRDF, Albedo and NBAR products for long-term surface energy budget, modeling, phenology, and land cover studies.

1.0 INTRODUCTION

1.1 Science/Applications Rationale for the Product

Land surfaces reflect surface radiation out over all possible view angles as a function of the scattering behavior of the surface cover and structure, and the solar illumination in a manner described as the Bidirectional Reflectance Distribution Function (BRDF) (Nicodemus et al., 1977; Schaepman-Strub et al. 2006). Intrinsic measures of surface albedo can be estimated by hemispherically integrating the appropriate BRDF. Surface albedo, the ratio of upwelling to downwelling radiative flux, is an essential climate variable for modeling the global surface energy budget (Dickinson 1983). Satellite imagers however, normally only obtain directional surface reflectances of land surface locations under a particular solar illumination angle. Therefore, directional surface reflectances must be first used to establish an appropriate BRDF model before the corresponding surface albedo quantities can be estimated. This BRDF model also be subsequently used to correct time series of observations over that location to a common view angle. . The Nadir BRDF-Adjusted Reflectance (NBAR) is a directional reflectance, acquired under a particular solar zenith angle, which has been corrected to a nadir view angle using the BRDF parameters associated with that location. The MODerate resolution Imaging Spectroradiometer (MODIS), onboard the Terra and Aqua satellite platforms, has been providing operational BRDF, Albedo and NBAR products (MCD43) since 2000 (Schaaf et al. 2002, 2011).

In addition to the use of the MODIS albedo products for surface energy modeling (Lawrence and

Chase 2007; Morcrette et al. 2008; Oleson 2003; Zhou 2003), the product has been used to track the effects of ephemeral snowfall and snow melt (Wang et al. 2012). The BRDF products have been used as *a priori* surface anisotropy information for other satellite sensors with limited angular range (such as MERIS, Landsat, and AATSR) to estimate sensor specific albedo estimates and to establish sensor inter-comparisons(Gao et al. 2004; Sayer et al. 2012; Shuai et al. 2011). Since the BRDF is related to the surface structure, it has also been used to help characterize surface structure (Chopping et al. 2011; Hill et al. 2008; Wang et al. 2011). The MODIS NBAR product (with consistent local solar noon illumination, and nadir view geometries) has been used to monitor phenology changes (Shuai et al. 2013; Zhang et al. 2003), estimate biomass (Baccini et al. 2008) and analyze surface vegetation patterns (Hill et al. 2008). The NBAR product also serves as the primary inputs to other MODIS products, such as the MODIS land cover and phenology products (MCD12) (Friedl et al. 2010; Cai et al., 2015; Ganguly et al. 2010; Gray et al., 2014). With the MODIS sensors on both Terra and Aqua sensors aging, continuity products must, in the future, rely on data from the daily weather satellites represented by the Suomi National Polar-orbiting Partnership (NPP)(Justice et al. 2013; Román et al. 2011),which was launched on October 28, 2011, and its successors in the JPSS program. Thus, by implementing a similar processing strategy as to that used with MODIS, the Visible Infrared Imaging Radiometer Suite (VIIRS), sensors onboard Suomi-NPP and JPSS, will be able to provide consistent BRDF, Albedo, and NBAR products into the future. Note that while this algorithm theoretical basis document describes the VIIRS Albedo, BRDF, NBAR products circa 2017, more current information is maintained for the VNP43 Users Guide and the Project Publications at https://www.umb.edu/spectralmass .

1.2 Intended user community

The research and modeling communities which are currently using the MODIS BRDF, Albedo, and NBAR products, need to be able to rely on similar VIIRS products when the MODIS product are no longer available. The communities include, but are not limited to:

- Global and regional modeling communities;
- Vegetation and disturbance monitoring communities;

- Satellite product development communities;
- Direct Broadcast and Near Real Time (NRT) communities;
- Sensor validation communities;

2.0 THE ALGORITHM

2.1 Technical Background and Heritage

The VIIRS BRDF, Albedo, and NBAR products (Lui et al., 2017) have adopted a processing strategy similar to that of the operational MODIS Collection V006 daily product (Wang et al., 2017). The algorithm makes use of a multi-day period of cloud free angular surface reflectances that adequately sample the viewing geometry in order to fit an appropriate kernel-driven, Ross-Thick/Li-Sparse-Reciprocal (RTLSR) semi-empirical BRDF model for that surface location. This BRDF model can then be used to estimate the Albedo, and NBAR products (Lucht et al., 2000). The Ross-Thick kernel is derived from radiative transfer models (Ross, 1981), and the Li-Sparse reciprocal kernel is based on geometric-optical shadow casting theory (Li and Strahler 1992). The combination of these two kernels and an isotropic parameter Roujean et al., 1992) has been shown to describe the surface reflectance anisotropy of the variety of land covers distributed world-wide (Privette et al., 1997; Lucht et al. 2000). This retrieval is attempted each day using 16 days' worth of inputs with the day of interest appropriately weighted. Similar kernel combinations have also been used to obtain BRDF and albedo information from other satellite sensors, including the Polarization and Directionality of Earth Reflectance (POLDER) instrument (Hautecœur and Leroy 1998), the Advanced Very High Resolution Radiometer (AVHRR) (d'Entremont and Schaaf 1999; Sütterlin et al. 2015), the MeteoSat-2 Spinning Enhanced Visible and Infrared Imager (SEVIRI) (Carrer, Roujean, and Meurey 2010), and the Multi-angle Imaging SpectroRadiometer (MISR) (Martonchik et al., 1998; Rahmen et al., 1993). A detailed algorithm description of the VIIRS processing is provided is in the following section.

2.2 Algorithm Description

All high quality, cloud-free, multi-angle surface reflectance data are utilized over a 16 day period to provide both adequate sampling of the viewing geometry and sufficient observations to fit an appropriate Ross-Thick/Li-Sparse-Reciprocal (RTLSR) semi-empirical BRDF model. The ninth day is the day of interest. The model is described by (Roujean, Leroy, and Deschamps 1992) as:

$$R(\theta,\upsilon,\phi,\lambda)=f_{iso}(\lambda)+f_{vol}(\lambda)K_{vol}(\theta,\upsilon,\phi)+f_{geo}(\lambda)(\lambda)K_{geo}(\theta,\upsilon,\phi) \quad (1)$$

Where θ, υ and ϕ are solar zenith, view zenith and relative azimuth angles. K_{vol} is the volumetric kernel derived from Ross-Thick volume scattering radiative model, and K_{geo} is the geometric kernel derived from Li-Sparse geometric shadow casting theory. f_{iso}, f_{vol} and f_{geo} are spectrally dependent BRDF kernel weights; also known as BRDF model parameters for isotropic, volumetric and geometric kernels respectively. $R(\theta,\upsilon,\phi,\lambda)$ is the inversed reflectance at given geometry (θ,υ,ϕ) of band λ. The detailed product processing architecture is displayed in figure 1.

A 16 day multi-date retrieval period was chosen to accumulate the required observations both because this is the repeat cycle of MODIS and VIIRS, and because a study of the global impact of clouds on the production of MODIS BRDF, Albedo, and NBAR products indicated that this was an appropriate balance between the possibility of cloud free observations and the stability of land surfaces (Roy et al. 2006). With only one Suomi-NPP VIIRS sensor providing data over the same 16 day retrieval period, the VIIRS products tends to achieve somewhat fewer high quality retrievals globally than MODIS products from both Aqua and Terra. However, the quality is still quite hight (Liu et al., 2017) with more VIIRS sensors being launched in the future on the JPSS, the probability of obtaining enough observations for high quality full inversions will increase.

Snow, fractional snow, and snow-free observations are separated. A pre-inversion outlier analysis is also used to filter out undetected cloud or heavy aerosol observation(Schaaf et al. 2002). Then the observations are weighted based on the reflectance quality and the observation coverage of each reflectance. Also, to emphasize the day of interest, the observations are weighted based on their temporal proximity(Wang et al. 2012).

A least-squares error function is used to derive analytical solutions of the kernel weights(Lucht et al. 2000).

$$e^2(\Lambda)=\frac{1}{d}\sum_l \frac{(\rho(\theta_l,\nu_l,\phi_l,\Lambda)-R(\theta_l,\nu_l,\phi_l,\Lambda))^2}{w_l(\Lambda)} \quad (2)$$

Where $\rho(\theta_l,\nu_l,\phi_l,\Lambda_l)$ is observed angular reflectance, $R(\theta_l,\nu_l,\phi_l,\Lambda_l)$ is kernel model calculated angular reflectance, $w_l(\Lambda)$ is the weight of given observation. Analytical solution can generated by making $\frac{\partial e^2}{\partial f_k}=0$.

$$f_k(\Lambda) = \sum_i (\sum_j \frac{\rho(\theta_j,\nu_j,\phi_j,\Lambda)K_i(\theta_j,\nu_j,\phi_j,\Lambda)}{w_j(\Lambda)} * (\sum_l \frac{K_i(\theta_j,\nu_j,\phi_j,\Lambda)K_k(\theta_j,\nu_j,\phi_j,\Lambda)}{w_l(\Lambda)})^{-1}) \qquad (3)$$

If at least seven observations are available, a high quality full inversion is attempted using this analytical solution. However, high quality is not just based on the number of observations. Of more importance is ability of the available angular observations to adequately capture the surface anisotropy of the surface.

Therefore the quality of the retrieval is driven by the Root Mean Squared Error (RMSE) (Eq. 4) and the Weight of Determination (WoD) (Eq. 5) (Lucht and Lewis 2000). These measures are used to determine whether the retrieval is of sufficient high quality or a poorer quality magnitude inversion will be used instead.

$$RMSE = \sqrt{\frac{\sum_{i=1}^{n}((\rho(\theta_i,\nu_i,\phi_i,\Lambda)-R(\theta_i,\nu_i,\phi_i,\Lambda))^2 \times w_i)}{n-3}} \qquad (4)$$

$$WoD_u = \frac{1}{w_u} = [U]^T[M^{-1}][U] \qquad (5)$$

Where U is a vector composed of the terms μ_i, M^{-1} is the inverse matrix providing the analytical solution of inversion equations.

The RMSE describes the deviation of the model fits. The larger the RMSE, the higher the uncertainty in the model fit. The WoD is derived from an uncertainty calculation of the least-squares fitting. It describes the behavior of the RTLSR models under the limited and varying angular sampling conditions available (Lucht and Lewis 2000). Higher WoD means lower confidence in the angular sampling pattern and the ability of the available observations to appropriately characterize the surface anisotropy. The thresholds for these two measures are based on a quality assessment of the MODIS operational BRDF, Albedo, NBAR product (Shuai et al. 2008), of 0.08 for RMSE, 1.65 for WoD-NBAR, and 2.50 for WoD- White-sky albedo (WSA).

Magnitude inversions will be performed when the RMSEs or WoDs are poor or there are insufficient observations (2 to 6) to even attempt a full inversion. The pixel will be labeled as a filled value if the available observation number is less than 2.

The magnitude inversion (also called the backup-algorithm) uses the most recent high quality full retrieval with same phenology phase as an *a priori* BRDF shape, which is then adjusted to match any available observed reflectances.

By minimizing the following equation,

$$e_m{}^2 = \sum_i \{\rho(\theta_i, \nu_i, \phi_i, \Lambda) - qR_m(\theta_i, \nu_i, \phi_i, \Lambda)\}^2$$

$$= \sum_i \{\rho(\theta_i, \nu_i, \phi_i, \Lambda) - q \sum_k f_{mk} K_k(\theta_i, \nu_i, \phi_i)\}^2 \qquad (6)$$

The new observed BRDF can be estimated

$$f_k = qf_{mk} = \frac{\sum_i \rho(\theta_i,\nu_i,\phi_i,\Lambda) R_m(\theta_i,\nu_i,\phi_i,\Lambda)}{\sum_i R_m(\theta_i,\nu_i,\phi_i,\Lambda)^2} f_{mk} \qquad (7)$$

Where f_{mk} is the most recent full retrieval of the BRDF parameters, $R_m(\theta_i, \nu_i, \phi_i, \Lambda)$ is simulated angular reflectance using those BRDF parameters, and q is the adjusting factor.

With the BRDF parameters established, a spectral White-sky Albedo (bihemispherical reflectance), Black-sky Albedo (Directional Hemispherical Reflectance (DHR)) at any desired solar angle, and angular reflectance at any desired solar and view angle can be estimated.

Black-sky albedo (BSA) is defined as albedo in the absence of a diffuse component and is a function of solar zenith angle. White-sky albedo (WSA) is defined as albedo in the absence of a direct component when the diffuse component is isotropic. Black-sky albedo and white-sky albedo mark the extreme cases of completely direct and completely diffuse illumination(Lucht et al. 2000). With known BRDF parameter, surface reflectances at all view and solar angles in the upper hemisphere can be simulated. Thus, BSA can be calculated by interpolating the reflectances of all view angles at desired solar angle, WSA can be calculated by interpolating reflectances of all view and solar angles. The operational VIIRS product offers WSA, BSA at local solar noon, and NBAR at local solar noon.

Instantaneous actual albedo (Blue-sky albedo) can be estimated by interpolating between WSA and BSA as a function of the fraction of diffuse skylight which is a function of the aerosol optical depth (Lucht et al, 2000; Román et al., 2010). Blue-sky Albedo is not provided as a standard product and must currently be calculated by the user.

The total energy reflected by the Earth's surface in the shortwave domain is characterized by the shortwave (0.3-5.0µm) broadband albedo. The visible (0.3-0.7µm) and near-infrared (NIR) (0.7-5.0µm) broadband albedos are often also of interest due to the marked difference of the reflectance of vegetation in these two spectral regions(Liang, Strahler, and Walthall 1999; Liang 2001). Thus, the spectral BRDF parameters and albedos are further combined via narrow to broadband (NTB) conversion coefficients to provide the broadband anisotropy, and albedo information which are commonly used in climate models (at 0.3-0.7, 0.7-5.0 and 0.3-5.0μm).

To compensate for the different spectral characteristics of snow, two sets of NTB conversion coefficients, snow-free and snow, are used to calculate the broadband albedos (Stroeve et al. 2005). The VIIRS NTB conversion coefficients were generated using the same approaches as used for the MODIS products (Liang et al. 1999, Stroeve et al. 2005).

Table 1 VIIRS NTB conversion coefficient

	Snow-free			Snow		
	Visible	NIR	Shortwave	Visible	NIR	Shortwave
b1	0.1561	-	0.2418	0.0141	-	0.2892
b2	-	-	-0.2010	0.2380	-	-0.4741
b3	0.2295	-	0.2093	0.1654	-	0.6996
b4	0.3328	-	0.1146	0.2997	-	-
b5	0.2815	-	0.1348	0.2839	-	-
b7	-	0.5159	0.2251	-	0.5603	0.2738
b8	-	0.0746	0.1123	-	0.3272	0.1463
b10	-	0.3413	0.0860	-	-0.3222	-0.0309
b11	-	0.0890	0.0803	-	0.1219	-
Intercept	-	-0.0323	-0.0131	-0.0003	0.0045	-

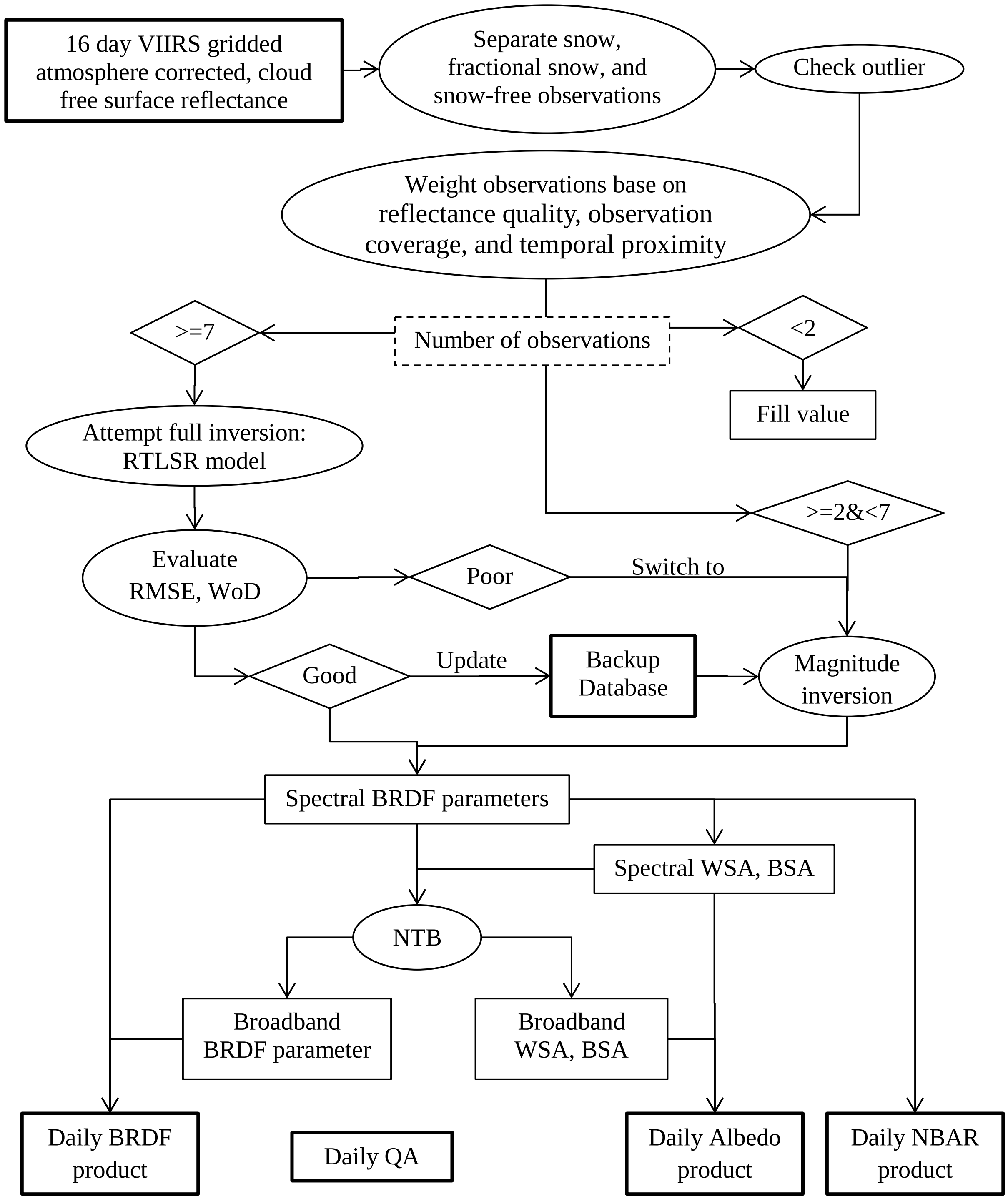

Figure 1 BRDF, albedo, NBAR product Processing architecture

The VIIRS algorithm offers BRDF, Albedo, and NBAR products at gridded 500m (VNP43IA*), at gridded 1km (VNP43MA* and VNP43DNB*) (all on a sinusoidal projection) , as well as 0.05

degree (VNP43C*), and 30arc second (VNP43D*) global climate modeling grid (CMG) products .

The VNP43MA* products follows the processing steps in Figure 1. For the VNP43IA* products, the NTB process is not utilized since the VIIRS 500m bands only have 3 available narrowbands. The VNP43D* products are derived directly from VNPMA* and VNPDNB* observations , whereas the VNP43C* products are generated by averaging all valid VNP43D* values within a 0.05 degree grid.

2.3 Product Description

VIIRS offers BRDF, Albedo, and NBAR products at gridded 500m, 1km resolutions on a sinusoidal projection , and 0.05 degree and 30arc second global products in geographic lat/lon projection on a climate modeling grid (CMG).

The 500m VIIRS sinusoidal grid tiled products (VNP43IA*) provide information at the three VIIRS Imagery bands, I1, I2, and I3, while 1km VIIRS sinusoidal grid tiled products (VNP43MA*), provide information at the nine Moderate bands, M1- M5, M7-M8, M10-M11, and at 3 broadbands, visible (0.3-0.7µm), near-infrared (NIR) (0.7-5.0µm), and shortwave (0.3-5.0µm). Separately, the 1km VNP43DNB* products are provided for the Day/Night Band (DNB). VNP43IA*,VNP43MA*, and VNP43DNB* all have similar product structures. The VIIRS CMG products, at 0.05 degree (VNP43C*) and at 30arc second (VNP43D*), provide information at the nine Moderate bands and the 3 broadbands, visible (0.3-0.7µm), near-infrared (NIR) (0.7-5.0µm), and shortwave (0.3-5.0µm), and these have different product structures.

The sinusoidal grid products, VNP43IA*,VNP43MA*, and VNP43DNB*, contain 4 sub products as listed in table 2.

Table 2. Summary of L3 Daily sinusoidal Gridded Tiled BRDF, Albedo, and NBAR Products produced at the Land PEATE Earth Science Data Type (ESDT)

Spatial Resolution	ESDT	Description
500m	VNP43IA1	Daily VIIRS/NPP BRDF Parameters and Mandatory Quality. Bands I1- I3
	VNP43IA2	Daily VIIRS/NPP BRDF, Albedo Quality Assessment product. Bands I1- I3
	VNP43IA3	Daily VIIRS/NPP BSA at local solar noon, WSA, and Mandatory Quality. Bands I1- I3
	VNP43IA4	Daily VIIRS/NPP NBAR and Mandatory Quality. Bands I1- I3
1km	VNP43MA1	Daily VIIRS/NPP BRDF Parameters and Mandatory Quality. Bands M1- M5, M7-M8, M10-M11, visible, NIR, and shortwave broadbands.
	VNP43MA2	Daily VIIRS/NPP BRDF, Albedo Quality Assessment product. Bands M1- M5, M7-M8, M10-M11, visible, NIR, and shortwave broadbands.
	VNP43MA3	Daily VIIRS/NPP BSA at local solar noon, WSA and Mandatory Quality. Bands M1- M5, M7-M8, M10-M11, visible, NIR, and shortwave broadbands.
	VNP43MA4	Daily VIIRS/NPP NBAR and Mandatory Quality. Bands M1- M5, M7-M8, and M10-M11.
	VNP43DNB1	Daily VIIRS/NPP BRDF Parameters and Mandatory Quality for Day/Night Band.
	VNP43DNB2	Daily VIIRS/NPP BRDF, Albedo Quality Assessment product for Day/Night Band.
	VNP43DNB3	Daily VIIRS/NPP BSA at local solar noon, WSA and Mandatory Quality for Day/Night Band.
	VNP43DNB4	Daily VIIRS/NPP NBAR and Mandatory Quality for Day/Night Band.

The first set of products, the BRDF Parameters Products (VNP43IA1/VNP43MA1/VNP43DNB1), provides the kernel weights associated with the Ross-Thick Li-Sparse Reciprocal BRDF model, f_{iso}, f_{vol}, f_{geo}. The accompanying mandatory quality flag, simply indicates whether the pixel is a full inversion, magnitude inversion or fill value. This mandatory quality flag is also included in albedo product (VNP43IA3/VNP43MA3/VNPDNB3) and the NBAR product (VNP43IA4/VNP43MA4/VNPDNB4). Thus VNP43IA1 provides the BRDF Parameters for the three VIIRS Imagery spectral bands, VNP43DNB1 provides the BRDF Parameters for the Day/Night Band,and VNP43MA1 provides the BRDF Parameters at the nine VIIRS Moderate spectral bands and the three broadbands (0.3-0.7µm, 0.7-5.0µm, and 0.3-

5.0μm).

These parameters can be used to model the surface anisotropic effects and thus can be used to correct directional reflectances to a common view geometry (this is the procedure that is used to produce NBAR (VNP43IA4/VNP43MA4/VNPDNB4) or to explicitly compute the integrated black-sky (at some specified solar zenith angle) and white-sky albedos (as are done for VNP43IA3/VNP43MA3/VNPDNB3). Alternately, these parameters can also be used with a simple polynomial to easily estimate the black-sky albedo with good accuracy for any desired solar zenith angle (Lucht et al., 2000).

The polynomial is as follows:

$$a_{bs}(\Theta,\lambda) = f_{iso}(\lambda)(g_{0iso} + g_{1iso}\Theta^2 + g_{2iso}\Theta^3) + f_{vol}(\lambda)(g_{0vol} + g_{1vol}\Theta^2 + g_{2vol}\Theta^3) + f_{geo}(\lambda)(g_{0geo} + g_{1geo}\Theta^2 + g_{2geo}\Theta^3) \qquad (8)$$

The appropriate constants for the simple polynomial are:

Table 3. Constants for estimating BSA

Term	Isotropic (iso)	RossThick (vol)	LiSparseR (geo)
g_0	1.0	-0.007574	-1.284909
g_1	0.0	-0.070987	-0.166314
g_2	0.0	0.307588	0.041840

Similarly, the white-sky albedo can be computed by using the equation:

$$a_{ws}(\lambda) = f_{iso}(\lambda)g_{iso} + f_{vol}(\lambda)g_{vol} + f_{geo}(\lambda)g_{geo} \qquad (9)$$

And the constants for the white-sky kernel integrals for the simplified estimate are:

Table 4. Constants for estimating BSA

Term	Isotropic (iso)	RossThick (vol)	LiSparseR (geo)
White-sky integral g	1.0	0.189184	-1.377622

The second set of operational products are the Quality Assessment products (VNP43IA2/VNP43MA2/VNPDNB2), which contain more detailed quality information than the simple Mandatory QA. The Science Data Sets (SDS) associated with each griddled pixel are listed in Table 5.

Table 5 QA product SDS

QA name	Explanation
Snow_BRDF_Albedo	0 = snow-free albedo retrieved 1 = snow albedo retrieved
BRDF_Albedo_LandWaterType	Indicate if the pixel is covered by water or land
BRDF_Albedo_LocalSolarNoon	Solar Zenith Angle at Local Solar Noon
BRDF_Albedo_ValidObs_Band*	Indicates the day from which the observed reflectances (among the 16 days) were used for each of the bands. This 16 bit QA needs to be unpacked to binary for the 16 days. A 1 value means the observed reflectance from that day was used for the retrieval, while a 0 value means it was not used.
BRDF_Albedo_Band_Quality_Band*	0 = best quality, full inversion (WoDs, RMSE majority good) 1 = good quality, full inversion 2 = Magnitude inversion (numobs >=7) 3 = Magnitude inversion (numobs >=2&<7) 4 = Fill value
BRDF_Albedo_Uncertainty	WOD of WSA albedo

The BRDF_Albedo_Band_Quality_Band* provides more detailed information about each bands' quality. The quality of those full inversion retrievals are further divided into best quality and good quality based on the RMSE and the WOD of WSA. The quality of the magnitude inversions is divided into 2 groups governed by the number of available observations, (equal or more than 7 obs versus number of obs between 2 to 6).

The third set of operational products, the albedo products (VNP43IA3/VNP43MA3/VNPDNB3), provides the BSA at local solar noon, the WSA and the mandatory quality flag. VNP43IA3 provides WSA and BSA at the three VIIRS Imagery spectral bands, while the VNP43MA3 provides WSA and BSA at the nine VIIRS Moderate spectral bands and the three broadbands (0.3-0.7µm, 0.7-5.0µm, and 0.3-5.0µm).

Note that a blue-sky actual albedo at a particular time and atmospheric condition (similar to what is measured at the surface by tower mounted albedometers) can be estimated by interpolating between WSA and BSAas a function of the atmospherica state. Therefore by assuming an isotropic distribution of the diffuse skylight, the actual blue-sky albedo can be interpolated between WSA and BSA as a function of the fraction of diffuse skylight.

$$a_{\Lambda,blue-sky}(\theta_i) = SKYL(\theta_i)a_{\Lambda,white-sky} + (1 - SKYL(\theta_i))a_{\Lambda,black-sky}(\theta_i) \qquad (10)$$

Where $SKYL(\theta_i)$ is the fraction of diffuse skylight.

This assumption is approximate but can capture the major part of the phenomenon. However, for large solar zenith angles and bright surfaces it's more appropriate to use the full anisotropic expression (Román et al. 2010). Note that these products are clear-sky products. Therefore they are NOT appropriate for use with hazy or cloudy skies and large optical depths.

The fourth set of operational products (VNP43IA4/VNP43MA4/VNPDNB4) provides NBAR at local solar noon for the VIIRS spectral bands, and an associated Mandatory Quality for each band. Since the view angle effects have been corrected out of the directional reflectances, the result is a stable and consistent nadir reflectance product.

The ESDT of the VIIRS CMG products, VNP43C* and VNP43D*, are displayed in table 6 and 8 respectively. Once again, the VNP43C products are averages of the VNP43D products, while the

VNP43D products represent direct retrievals. Therefore the quality of the VNP43D products is higher and this product should be relied upon for more detailed asssments.

Table 6. Summary of L3 Daily VNP43C* Products produced at the Land SIPS

Spatial Resolution	ESDT	Description
0.05 Degree	VNP43C1	Daily VIIRS/NPP BRDF Parameters and Quality assessment. Bands M1- M5, M7-M8, M10-M11, DNB, visible, NIR, and shortwave broadbands.
	VNP43C2	Daily VIIRS/NPP Snow-free BRDF Parameters and Quality assessment. Bands M1- M5, M7-M8, M10-M11, DNB, visible, NIR, and shortwave broadbands.
	VNP43C3	Daily VIIRS/NPP BSA at local solar noon, WSA, and Quality assessment. Bands M1- M5, M7-M8, M10-M11, DNB, visible, NIR, and shortwave broadband.
	VNP43C4	Daily VIIRS/NPP NBAR and Quality assessment. Bands M1- M5, M7-M8, M10-M11, and DNB.

VNP43C1 provides the kernel weights associated with the Ross-Thick Li-Sparse Reciprocal BRDF model representing f_{iso}, f_{vol}, f_{geo} at 0.05 degree spatial resolution in global files in a geographic (lat/lon) projection VIIRS Moderate spectral bands, DNB and three broadbands(0.3-0.7µm, 0.7-5.0µm, and 0.3-5.0µm). The Quality Assessment of the averaged values is displayed in table 7. The Quality Assessment of VNP43C* includes the BRDF_Quality, Percent_Inputs, the Percent_Snow, and the BRDF_Albedo_Uncertainty. These quality assessments, along with the Local_Solar_Noon are attached in all VNP43C* products with the exception of the Percent_Snow flag which is not in the VNP43C2 product as it is the snow-free BRDF parameters product.

These model parameters are based on the underlying 30arc second model parameters. Note that along coastlines, this means that the 30arcsecond pixels that lie over shallow water will be averaged into the 0.05 degree CMG pixel, and this averaging applies to all VNP43C* products.

Table 7 Quality Assessment of VNP43C* product

QA name	Explanation
BRDF_Quality	0 = best quality, 100% with full inversions 1 = good quality, 75% or more with best full inversions and 90% with full inversions

	2 = relative good quality, 75% or more with full inversions 3 = mixed, 75% or less full inversions and 25% or less fill values 4 = all magnitude iversions or 50% or less fill values 5 = 50% or more fill values 255 = Fill Value
Percent_Inputs	percent of the processed finer resolution data which contributed to this CMG pixel
Percent_Snow	The percentage of the underlying pixels that were present and were snow covered
BRDF_Albedo_Uncertainty	WOD of WSA albedo

VNP43C2 provides the same information as VNP43C1 but for only the snow-free pixels (rather than both snow covered and snow free). Since this is a snow-free product, "Percent_Snow" is not provided.

VNP43C3 provides both the white-sky albedos and the black-sky albedos (at local solar noon) for the Moderate spectral bands, M1- M5, M7-M8, M10-M11, for the DNB, and for the three broad bands (0.3-0.7µm, 0.7-5.0µm, and 0.3-5.0µm), allat a 0.05 degree spatial resolution in global files in a geographic (lat/lon) projection. The quality assessment as listed in table 7 is also provided. These albedo values calculated from the BRDF parameters in VNP43C1.

VNP43C4 is computed for each of the Moderate bands, M1- M5, M7-M8, M10-M11, and DNB at the local solar noon zenith angle of the day of interest. . The quality assessment as listed in table 7 is also provided. These NBAR values are calculated from the BRDF parameter in VNP43C1.

Table 8 Summary of L3 Daily VNP43D* Products produced at the Land SIPS

Spatial Resolution	ESDT	Description
30 arc second	VNP43D01-39	Daily VIIRS/NPP BRDF Parameters. Bands M1- M5, M7-M8, M10-M11, DNB and visible, NIR, and shortwave broadbands.
	VNP43D40	BRDF/Albedo Quality. 0 = best quality, full inversion (WoDs, RMSE majority good) 1 = good quality, full inversion 2 = Magnitude inversion (numobs >=7) 3 = Magnitude inversion (numobs >=2&<7) 255 = Fill value
	VNP43D41	Local Solar Noon
	VNP43D42-51	Valid observation. Bands M1- M5, M7-M8, M10-M11, and DNB.
	VNP43D52	BRDF/Albedo Snow status
	VNP43D53	BRDF/Albedo Uncertainty
	VNP43D54-66	BRDF/Albedo BSA at local solar noon. Bands M1-M5, M7-M8, M10-M11, DNB and visible, NIR, and shortwave broadband.
	VNP43D67-79	BRDF/Albedo WSA. Bands M1- M5, M7-M8, M10-M11, DNB and visible, NIR, and shortwave broadband.
	VNP43D80-89	BRDF/Albedo NBAR. Bands M1- M5, M7-M8, M10-M11, and DNB.

The VNP43D* values are reprojected from the 1km VNP43MA1 and VNP43DNB1 values. Because of the large size of the products, each Parameter, albedo and NBAR for each of the 9 Moderate bands, DNB and the 3 broadbands are stored in separate VNP43D files as listed in table 7. Therefore VNP43D1 is VIIRS M band 1 f_{iso} parameter, VNP43D2 is Moderate band 1 f_{vol} parameter, VNP43D3 is Moderate band 1 f_{geo} parameter, and so on through to VNP43D39. VNP43D40 is the 30arc second BRDF/Albedo Quality. VNP43D41 is Local Solar Noon. VNP43D42-51 is ValidObs of nine Moderate bands and DNB, this indicates the valid observations from each of the 16 days. VNP43D52-53 are snow status and uncertainty. VNP43D54-66 are the BSAs at local solar noon for the nine Moderate bands, the DNB and the three broadbands, VNP43D67-79 are the WSAs for the nine Moderate bands, the DNB and the three broadbands. Finally VNP43D80-89 provide the 30arcsecond NBARs (at local solar noon) for the 9 Moderate bands and the DNB.

3.0 PRODUCT INPUTS

The input data for this process includes the gridded VIIRS atmosphere corrected surface reflectance product (VNP09GA and VNP39GA) accumulated over 16 days, and the Ancillary BRDF/Albedo database.

The primarly inputs are the gridded VIIRS atmospherically corrected surface reflectance products (VNP09GA and VNP39GA). Besides atmospherically corrected surface reflectance, this products also provide view and solar angle information, quality of the surface reflectances, and the observation coverage-footprint.

The Ancillary BRDF/Albedo database is also used to provide *a priori* BRDF shapes for the back-up magnitude inversions. It maintains the most recent high quality BRDF full retrieval parameters for each of the Imagery bands, the Moderate bands and the DNB.

3.1 Spectral Bands

Both the atmospherically corrected surface reflectance products (VNP09GA and VNP39GA) and the Ancillary BRDF/Albedo database contains three sets of spectral bands: the Imagery bands, the Moderate bands and the DNB.

The VIIRS 1km gridded surface reflectance product has nine bands derived from the Moderate (M) at a nominal 750m resolution, and the 500m gridded surface reflectance product has three bands derived from Imagery (I) at a nominal 375m resolution. The Relative Spectral Response (RSR) of the VIIRS spectral bands are displayed in figure 2.

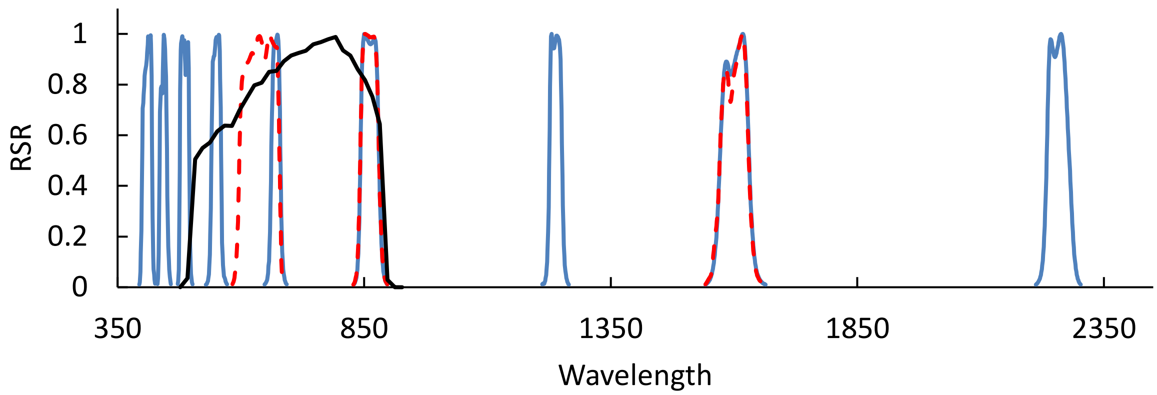

Figure 2 RSR of VIIRS bands, blue lines are RSR of bands at (M) Moderate resolution and red dash lines are RSR of bands at (I) Imagery resolution, and black line is the RSR of DNB.

3.2 Masks, Thresholds and Ancillary Data

The land cover masks are applied before the retrieval occurs since only land areas and coastal areas are attempted for this product. A valid surface reflectance is in the range of 0-1 (0-100%) The ancillary BRDF/Albedo database stores the most recent BRDF full retrieval parameters for each pixel. Each pixel contains three layers representing the different growing phases of Veg.Active, Veg. Inactive, and snow-covered, to adjust the BRDF for changes caused by vegetation growth and senescence.

4.0 PRODUCT ACCURACY /UNCERTAINTY

A number of factors may affect the accuracy of the product. These factors include: the number of cloud clear observations available, the angular sampling pattern, the change in the BRDF during the retrieval period, and any residual cloud or snow not identified. A few of the processing steps can potentially mitigate these impacts, and the quality assessment product provides the estimation of these uncertainties.

The number of the cloud clear observations strongly affect whether full inversion or magnitude inversion will be attempted. However the angular distribution of the available observations is the most important determination of quality.   A few observations located along the principal plane will result in a higher quality retrieval then a large number of observations all clustered together in one part of the viewing hemisphere. The angular sampling pattern is a function of latitude, time of year, and it is also affected by the probability of cloud occurrence during the retrieval period. Note that in reality the BRDF and albedo of a particular land surface may not be constant over a 16 day retrieval period. Variation can be caused by vegetation growth and senescence, or by rapid changes such as crop harvest and fire or rapid short term change such as rainfall (darkening soil) prior to an observation. The observations that have undergone rapid short term change can potentially be captured by the outlier analysis . Changes caused by vegetation growth and senescence can be accommodated in this daily algorithm by weighting the observations based on the temporal proximity to the day of interest. As mentioned certain observations contaminated by residual cloud may not be detected in the surface reflectance product. This residual cloud can lead to poor RMSEs in the model fit and falsely high albedo values . This effect can also potentially be captured and discarded by the outlier analysis if it is an aberrant affect. But in areas with high cloud occurrences, the affect of undetected residual cloud (and for that matter residual snow) can still affect the quality of the result.   .

In addition, topographically complex terrain and coastal areas have relatively low product accuracies due to the topographic and tidal effects. This is particularly true of the 0.05 degree CMG product(VNP43C*), where the averaging of the underlying finer scale retrievals can result in anomalous coarser resolution values.

4.1 Uncertainty Estimate

Extensive quality flags are used to characterize the uncertainties mentioned above. First, the quality flag that indicates whether the pixel is a full inversion or a magnitude inversion, shows the influence of the number of cloud clear observations and the angular sampling pattern. Full inversion indicates that sufficient cloud clear observations with a high WoD (as a measure of the angular sampling) were collected, and the RMSE of the inversion was low. The RMSE is used to estimate the accuracy of the model fit. The valid observations fromwhich day among the 16 days were actually used and WoD values are also provided in the quality assessment product. In addition, since the 0.05 degree CMG product (VNP43C*) is based on the average of the underlying 30arc second product (VNP43D*), the uncertainty of all of the underlying pixels is also provided in VNP43C* product.

The detailed accuracy and uncertainty assessment can be found in the Quality Assessment information Thus users are urged to always check the Quality Assessment information before using the BRDF parameters, Albedo, and NBAR products.

4.2 Validation Approach

The VIIRS Albedo, BRDF, and NBAR products are evaluated with the protocols developed by the Committee on Earth Observation Satellites (CEOS)/Working Group on Calibration & Validation (WGCV)/ Land Product Validation (LPV) radiation subgroup. Evaluations utilize tower albedometer data from spatially representative sites, concurrent MODIS products and occasionally BRDF, Albedo and NBAR values retrieved from multiangular aircraft acquisitions such as from the Cloud Absorption Radiometer (CAR) and the Multi AngLe Imaging Bidirectional Reflectance Distribution Function sUAS (MALIBU).

The source of tower measured albedo include the : Surface Radiation Budget Observing Network (SURFRAD), the Baseline Surface Radiation Network (BSRN), the Long Term Ecological Research Network (LTER), the National Ecological Observatory Network (NEON), the Greenland Climate Network (GC-Net), the Terrestrial Ecosystem Research Network (TERN), and the Ameriflux, Europeflux and other international flux and radiation networks. Only spatially representative towers are utilized to ensure that the VIIRS product can meet the requirements of land surface, climate, and biosphere models (an absolute accuracy of 0.02-0.05 (Bonan et al. 2002; Sellers et al. 1995). The spatial representativeness of each tower is evaluated using higher resolution imagery such as Landsat (Román et al. 2009).

The VIIRS derived daily BRDF, Albedo and NBAR at identical narrowbands and at the broadbands are compared with MODIS derived products to assess whether the VIIRS algorithm can fulfill the data continuity task.

5.0 DATA FORMAT

5.1 Format

The product is delivered in Hierarchical Data Format (HDF). After applying the scale factor, each data value is stored as integer in the Science Data Sets (SDS) with the associated metadata. Detailed descriptions of each SDS of VNP43IA*, VNP43MA*, VNP43DNB* and VNP43C* are listed in tables 9-12. Because of the large size of the product, each VNP43D* only contains one layer (detailed description can be found in table 8).

Table 9 layer content for VNP43IA *

Product	SDS	Description
VNP43IA1	BRDF_Albedo_Parameters_ * I1- I3	3 layers for each band, layer 1: isotropic parameter layer 2: volumetric parameter layer 3: geometric parameter
	BRDF_Albedo_Band_Mandatory _Quality_* I1- I3	1 layer for each band, 0 = full BRDF inversions 1 = magnitude BRDF inversions
VNP43IA2	Snow_BRDF_Albedo	1 layer 0 = snow-free albedo retrieved 1 = snow albedo retrieved
	BRDF_Albedo_LandWaterType	1 layer-Land/Water 0 = Shallow ocean 1 = Land (Nothing else but land) 2 = Ocean and lake shorelines 3 = Shallow inland water 4 = Ephemeral water 5 = Deep inland water 6 = Moderate or continental ocean 7 = Deep ocean
	BRDF_Albedo_LocalSolarNoon	1 layer Solar Zenith Angle at Local Solar Noon in degree
	BRDF_Albedo_ValidObs_Band* I1- I3	1 layer for each band The observed reflectance of which day among the 16 days were used for each bands. Needs to be unpacked to 16 bits binary, 1 means the observed reflectance of that day is used for retrieval, 0 means not used.
	BRDF_Albedo_Band_Quality_B and* I1- I3	1 layer for each band, 0 : best quality, full inversion (WoDs, RMSE good) 1 = good quality, full inversion 2 = Magnitude inversion (numobs >=7) 3 = Magnitude inversion (numobs >=2<7) 4 = Fill value
	BRDF_Albedo_Uncertainty	1 layer

		WOD of WSA albedo
VNP43IA3	Albedo_BSA(WSA)_* I1- I3	1 layers for each band, White sky albedo or black sky albedo at local solar noon
	BRDF_Albedo_Band_Mandatory_Quality_* I1- I3	1 layers for each band, 0 : full BRDF inversions 1 : magnitude BRDF inversions
VNP43IA4	Nadir_Reflectance _* I1- I3	1 layers for each band Nadir BRDF Adjusted Reflectance at local solar noon
	BRDF_Albedo_Band_Mandatory_Quality_* I1- I3	1 layers for each band, 0 : full BRDF inversions 1 : magnitude BRDF inversions

Table 10 layer content for VNP43MA*

Product	SDS	Description
VNP43MA1	BRDF_Albedo_Parameters_ * M1-M5, M7-M8, M10-M11, visible, NIR, and shortwave broadbands	3 layers for each band, layer 1: isotropic parameter layer 2: volumetric parameter layer 3: geometric parameter
	BRDF_Albedo_Band_Mandatory_Quality_* M1-M5, M7-M8, M10-M11, visible, NIR, and shortwave broadbands	1 layer for each band, 0 = full BRDF inversions 1 = magnitude BRDF inversions
VNP43MA2	Snow_BRDF_Albedo	1 layer 0 = snow-free albedo retrieved 1 = snow albedo retrieved
	BRDF_Albedo_LandWaterType	1 layer-Land/Water 0 = Shallow ocean 1 = Land (Nothing else but land) 2 = Ocean and lake shorelines 3 = Shallow inland water 4 = Ephemeral water 5 = Deep inland water 6 = Moderate or continental ocean 7 = Deep ocean
	BRDF_Albedo_LocalSolarNoon	1 layer Solar Zenith Angle at Local Solar Noon in degree
	BRDF_Albedo_ValidObs_Band* M1- M5, M7-M8, M10-M11	1 layer for each band The observed reflectance of which day among the 16 days were used for each bands. Needs to be unpacked to 16 bits binary, 1

		means the observed reflectance of that day is used for retrieval, 0 means not used.
	BRDF_Albedo_Band_Quality_Band* M1- M5, M7-M8, M10-M11	1 layer for each band, 0 : best quality, full inversion (WoDs, RMSE majority good) 1 = good quality, full inversion 2 = Magnitude inversion (numobs >=7) 3 = Magnitude inversion (numobs >=2&<7) 4 = Fill value
	BRDF_Albedo_Uncertainty	1 layer WOD of WSA albedo
VNP43MA3	Albedo_BSA(WSA)_* M1- M5, M7-M8, M10-M11, visible, NIR, and shortwave broadbands	1 layer for each band, White sky albedo or black sky albedo at local solar noon
	BRDF_Albedo_Band_Mandatory_Quality_* M1- M5, M7-M8, M10-M11, visible, NIR, and shortwave broadbands	1 layer for each band, 0 : full BRDF inversions 1 : magnitude BRDF inversions
VNP43MA4	Nadir_Reflectance _* M1- M5, M7-M8, M10-M11	1 layer for each band Nadir BRDF Adjusted Reflectance at local solar noon
	BRDF_Albedo_Band_Mandatory_Quality_* M1- M5, M7-M8, M10-M11	1 layer for each band, 0 : full BRDF inversions 1 : magnitude BRDF inversions

Table 11 layer content for VNP43DNB*

Product	SDS	Description
VNP43DNB1	BRDF_Albedo_Parameters_ * DNB	3 layers layer 1: isotropic parameter layer 2: volumetric parameter layer 3: geometric parameter
	BRDF_Albedo_Band_Mandatory_Quality_* DNB	1 layer 0 = full BRDF inversions 1 = magnitude BRDF inversions
VNP43DNB2	Snow_BRDF_Albedo	1 layer 0 = snow-free albedo retrieved 1 = snow albedo retrieved
	BRDF_Albedo_LandWaterType	1 layer-Land/Water 0 = Shallow ocean 1 = Land (Nothing else but land)

		2 = Ocean and lake shorelines 3 = Shallow inland water 4 = Ephemeral water 5 = Deep inland water 6 = Moderate or continental ocean 7 = Deep ocean
	BRDF_Albedo_LocalSolarNoon	1 layer Solar Zenith Angle at Local Solar Noon in degree
	BRDF_Albedo_ValidObs_Band* DNB	1 layer The observed reflectance of which day among the 16 days were used for each bands. Needs to be unpacked to 16 bits binary, 1 means the observed reflectance of that day is used for retrieval, 0 means not used.
	BRDF_Albedo_Band_Quality_Band* DNB	1 layer 0 : best quality, full inversion (WoDs, RMSE majority good) 1 = good quality, full inversion 2 = Magnitude inversion (numobs >=7) 3 = Magnitude inversion (numobs >=2&<7) 4 = Fill value
	BRDF_Albedo_Uncertainty	1 layer WOD of WSA albedo
VNP43DNB3	Albedo_BSA(WSA)_* DNB	1 layer White sky albedo or black sky albedo at local solar noon
	BRDF_Albedo_Band_Mandatory_Quality_* DNB	1 layer 0 : full BRDF inversions 1 : magnitude BRDF inversions
VNP43DNB4	Nadir_Reflectance _* DNB	1 layer Nadir BRDF Adjusted Reflectance at local solar noon
	BRDF_Albedo_Band_Mandatory_Quality_* DNB	1 layer 0 : full BRDF inversions 1 : magnitude BRDF inversions

Table 12 layer content for VNP43 C*

Product	SDS	Description
VNP43C1&2	BRDF_Albedo_Parameter1_ * M1- M5, M7-M8, M10-M11, DNB,	1 layer for each band, isotropic parameter

	visible, NIR, and shortwave broadbands	
	BRDF_Albedo_Parameter2_ * M1- M5, M7-M8, M10-M11, DNB, visible, NIR, and shortwave broadbands	1 layer for each band, volumetric parameter
	BRDF_Albedo_Parameter3_ * M1- M5, M7-M8, M10-M11, DNB, visible, NIR, and shortwave broadbands	1 layer for each band, geometric parameter
	BRDF_Quality	1 layer 0 = best quality, 100% with full inversions 1 = good quality, 75% or more with best full inversions and 90% with full inversions 2 = relative good quality, 75% or more with full inversions 3 = mixed, 75% or less full inversions and 25% or less fill 4 = all magnitude iversions or 50% or less fill values 5 = 50% or more fill values 255 = Fill Value
	Local_Solar_Noon	1 layer Solar Zenith Angle at Local Solar Noon in degree
	Percent_Inputs	1 layer 0-100 percent of the processed finer resolution data contributed to this CMG pixel
	Percent_Snow	1 layer 0-100, not in VNP43C2
	BRDF_Albedo_Uncertainty	1 layer for each band, WOD of WSA albedo
VNP43C3	Albedo_BSA(WSA)_* M1- M5, M7-M8, M10-M11, DNB,visible, NIR, and shortwave broadbands	1 layer for each band, White sky albedo
	BRDF_Quality	Same as above
	Local_Solar_Noon	Same as above
	Percent_Inputs	Same as above
	Percent_Snow	Same as above
	BRDF_Albedo_Uncertainty	WOD of WSA albedo
VNP43C4	Nadir_Reflectance_Band M1- M5, M7-M8, M10-M11, and DNB	
	BRDF_Quality	Same as above
	Local_Solar_Noon	Same as above
	Percent_Inputs	Same as above
	Percent_Snow	Same as above

	BRDF_Albedo_Uncertainty	WOD of WSA albedo

5.2 QA Attributes

For the sinusoidal grid products: VNP43IA2/MA2 and VNP43DNB2 are the quality assessment products (detailed descriptions can be found in table 5). In addition, “BRDF_Albedo_Band_Mandatory_Quality_*” is attached in each of VNP43IA1, VNP43MA1, VNP43DNB1, VNP43IA3, VNP43MA3, VNP43DNBA3, VNP43IA4, VNP43MA4, and VNP43DNB4 for users’ convenience (detailed descriptions can be found in table 9 and 10). Each VNP43C* product also offers a “BRDF_Quality” (as in table 11), which provides detailed QA information. The quality assessments of VNP43D* are provided in VNP43D40 and VNP43D53 (as described in table 8).

In addition to the actual SDS data, each SDS is associated with a number of standard Local Attributes stored in metadata. The datafield attributes associated with each SDS is listed in Table 12-14. To generate the real value, scale factor and offset need to be applied to the product.

Table 13 Datafield Attributes for the BRDF_Albedo_Parameters* Products

Name:	Type:	Value:
long_name	HDF-STRING	"BRDF_Albedo_Parameters*"
valid_range	HDF-int16	0, 32766
_FillValue	HDF-int16	32767
add_offset	HDF-float64	0.0
scale_factor	HDF-float64	0.001

Table 14 Datafield Attributes for the Albedo_BSA(WSA) *

Name:	Type:	Value:
long_name	HDF-STRING	" Albedo_BSA(WSA) *"
valid_range	HDF-int16	0, 32766

_FillValue	HDF-int16	32767
add_offset	HDF-float64	0.0
scale_factor	HDF-float64	0.001

Table 15 Datafield Attributes for the NBAR*

Name:	Type:	Value:
long_name	HDF-STRING	"Nadir_Reflectance*"
valid_range	HDF-int16	0, 32766
_FillValue	HDF-int16	32767
add_offset	HDF-float64	0.0
scale_factor	HDF-float64	1.0E-4

6.0 PRODUCT PUBLICATIONS

Yan Liu, Zhuosen Wang, Qingsong Sun, Angela Erb, Crystal Schaaf, (2017) "Evaluation of VIIRS BRDF, Albedo and NBAR and assessment of their ability to provide continuity with the long term with the MODIS record", *Remote Sensing of Environment*, accepted.

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