VIIRS/NPP Snow Cover 6-Min L2 Swath 375m, Version 1

USER GUIDE

How to Cite These Data

As a condition of using these data, you must include a citation:

Román, M. O., G. Riggs, and D. K. Hall. 2017. *VIIRS/NPP Snow Cover 6-Min L2 Swath 375m, Version 1*. [Indicate subset used]. Boulder, Colorado USA. NASA National Snow and Ice Data Center Distributed Active Archive Center. https://doi.org/10.5067/VIIRS/VNP10.001. [Date Accessed].

FOR QUESTIONS ABOUT THESE DATA, CONTACT NSIDC@NSIDC.ORG

FOR CURRENT INFORMATION, VISIT https://nsidc.org/data/VNP10

National Snow and Ice Data Center

TABLE OF CONTENTS

1 DETAILED DATA DESCRIPTION

Snow covered land typically has a very high reflectance in visible bands and very low reflectance in the shortwave infrared. The Normalized Difference Snow Index (NDSI) reveals the magnitude of this difference, with values greater than 0 typically indicating the presence of at least some snow. The algorithm for this data set calculates NDSI using VIIRS image bands I1 (0.64 µm, visible red) and I3 (1.61 µm, shortwave near-infrared) and then applies a series of data screens designed to alleviate likely errors and flag uncertain snow detections.

1.1 Format

Data files are provided in NetCDF-4/HDF5 (.nc) format, following the NetCDF Climate and Forecast (CF) Metadata Conventions (Version 1.6). JPEG browse images are also available.

NetCDF is a set of software libraries and self-describing, machine-independent data formats that are specifically designed to help create, access, and share array-oriented scientific data sets. Note that NetCDF-4 is not a file format. It is a convention for storing data as HDF using the NetCDF data model. For more information, visit the HDF Group's HDF5 Home Page and Unidata's NetCDF Documentation website.

1.2 File Contents

VNP10 files contain six minutes of swath data (a scene), during which the instrument sweeps out 202 (and occasionally 203) cross-track scans along a 12 km viewing path. VIIRS I bands are equipped with 32 detectors and thus VNP10 scenes typically contain 6,464 I-band pixels in the along-track direction. The instrument's ±56.28° Earth-view scan width produces 6,400 I-band pixels in the cross-track direction.

1.3 File Naming Convention

VIIRS file names begin with a product identifier (VNP10) followed by the acquisition date and time. Dates are specified as a 4-digit year and 3-digit day of the year. Acquisition times are specified as HHMM and reflect the start time of the 6-minute scene, beginning with 0000 and ending with 2354. The following section describes the full VIIRS file naming convention:

Example File Name:

```
VNP10.A2012019.0018.001.2017261225202.nc
VNP[PID].A[YYYY][DDD].[HHMM].[VVV].[yyyy][ddd][hhmmss].nc
```

Refer to Table 1 for descriptions of the file name variables listed above.

Table 1. Variables in the VNP10 File Naming Convention

Variable	Description
`VNP`	VIIRS Suomi NPP
`PID`	Product ID
`A`	Acquisition date follows
`YYYY`	Acquisition year
`DDD`	Acquisition day of year
`HHMM`	Acquisition hour and minute in Greenwich Mean Time (GMT)
`VVV`	Version (Collection) number
`yyyy`	Production year
`ddd`	Production day of year
`hhmmss`	Production hour/minute/second in GMT
`.nc`	NetCDF-4/HDF5 formatted data file

NetCDF-4/HDF5 data files contain metadata including global attributes, which store important details about the data, and local attributes such as keys to data fields. In addition, each data file has a corresponding XML (.xml) metadata file. For detailed information about metadata fields and values, consult the NASA S-NPP VIIRS Snow Products Collection 1 User Guide.

1.4 File Size

Data files are typically 200 MB — 300 MB.

1.5 Spatial Coverage

Coverage is global. The following sites offer tools that track and predict NPP's orbital path:

- Space Science and Engineering Center (SSEC) NPP Orbit Tracks
- NASA LaRC Satellite Overpass Predictor (includes viewing zenith, solar zenith, and ground track distance to specified lat/lon)

1.5.1 Spatial Resolution

VIIRS I-bands have a spatial resolution of 375 m at nadir.

1.6 Temporal Coverage

Data are available from 19 January 2012 to present. However, because the NDSI depends on visible light, data are not produced for the night phase of each orbital period or for those portions of fall and winter in polar regions when viewing conditions are too dark. If you cannot locate data for a particular date or time, check the VIIRS Data Outages web page.

1.6.1 Temporal Resolution

Each data file contains 6 minutes of the orbital swath.

VIIRS scans the entire globe every one to two days. As such, most locations on Earth are imaged at least once per day and more frequently where swaths overlap, for example near the poles. Suomi NPP's sun-synchronous, near-circular polar orbit is timed to cross the equator from sorth to nouth (ascending node) at approximately 1:30 P.M. local time. The repeat cycle is 16 days (quasi 8-day).

1.7 Parameters

Data files contain NDSI snow cover, raw NDSI, basic QA, and bit flags that store the results of data screens applied by algorithm. Geolocation data consist of 375 m resolution latitude and longitude arrays plus HDF5 dimension scales as defined by the NetCDF Climate and Forecast (CF) Metadata Conventions (Version 1.6). Refer to Table 2 and Table 3 for details about these variables.

Table 2. VNP10 Snow Data Variable Names and Descriptions

Variable Name	Description
`NDSI_Snow_Cover`	NDSI snow cover plus other results, stored as 8-bit unsigned integers. Valid values are: 0 - 100: NDSI snow cover (no snow to completely snow covered) 201: no decision 211: night 237: lake 239: ocean 250: cloud 251: missing data 252: unusable L1B (input) data 253: bowtie trim[1] 254: L1B (input) fill 255: fill

Variable Name	Description
`NDSI`	Raw NDSI calculated by the algorithm before data screens are applied, stored as 16-bit integers. NDSI is calculated as: NDSI = (band I1 – band I3) / (band I1 + band I3) Values are scaled by 10^3 for storage, s.t. $-1000 \le$ NDSI ≤ 1000.
`Algorithm_bit_flags_QA`	Bit flags indicating data screen results and the presence of inland water. All bits are initialized to off (0). A bit is set to on (1) when the following conditions are encountered: bit 0: Inland water bit 1: Low visible screen failed, snow detection reversed to no snow. bit 2: Low NDSI screen failed, snow detection reversed to no snow. bit 3: Combined temperature/height screen failed. On means *either*: • $T_b \ge 281$ K, pixel height < 1300 m. Flag set, snow detection reversed to not snow. *OR*, • $T_b \ge 281$ K, pixel height ≥ 1300 m. Flag set, snow detection NOT reversed. bit 4: Spare bit 5: Shortwave IR (SWIR) reflectance anomalously high. On means *either*: • Snow pixel with SWIR > 0.45. Flag set, snow detection reversed to not snow. *OR*, • Snow pixel with 0.25 < SWIR <= 0.45, flag set, snow detection NOT reversed. bit 6: Spare bit 7: Solar zenith angle > 70° (but < 85°, i.e. night). Uncertain snow detection due to low illumination.
`Basic_QA`	General quality estimate for pixels processed for snow. Possible values are: 0: good 1: poor 2: bad 3: other 211: night 239: ocean 250: cloud 252: no decision 253: bowtie trim 255: fill
`Latitude`	375 m resolution (6464 x 6400) latitude array.
`Longitude`	375 m resolution (6464 x 6400) longitude array.

Table 3. VNP10 Dimension Scale Data Sets

Variable Name	Description
`number_of_lines`	HDF5 scalar data set/NetCDF shared dimension. 32-bit floating point (6464,1)
`number_of_pixels`	HDF5 scalar data set/NetCDF shared dimension, 32-bit floating point (6400,1)

2 SOFTWARE AND TOOLS

VIIRS NetCDF4/HDF5 data files can be accessed using either NetCDF4 or HDF5 tools. In addition, NASA's Worldview application allows users to interactively browse VIIRS satellite imagery within hours of it being acquired.

3 DATA ACQUISITION AND PROCESSING

3.1 Derivation Techniques and Algorithms

3.1.1 Snow Cover

The VIIRS snow mapping algorithm identifies snow cover based on the Normalized Difference Snow Index, or NDSI. Snow typically exhibits a very high reflectance in visible bands and very low reflectance in the shortwave infrared. The NDSI reveals the magnitude of this difference and as such can be used to distinguish snow from most bright surface features and clouds.

The NDSI is derived from VIIRS data by normalizing the difference in reflectance between image bands I1 and I3, which measure visible red light at 0.64 μm and shortwave near-infrared at 1.61 μm, respectively. NDSI is calculated for all land and inland water pixels using the following equation and the raw value is written to the NDSI data array.:

$$NDSI = (I1 - I3) / (I1 + I3)$$

Computed in this manner, the NDSI lies in the theoretical range of $-1.0 \leq NDSI \leq 1.0$. If snow is present and viewable by the satellite, the NDSI > 0. Values of NDSI ≤ 0 indicate no snow.

Given clear skies and good viewing geometry and solar illumination, the NDSI has proven effective at detecting snow cover on the landscape. However, errors of omission or commission can occur under certain conditions: for example, surface features which exhibit snow-like reflectance, some cloud types, and low illumination at high solar zenith angles. During the course of the MODIS mission, the Science Team and user community identified the most common drivers of snow confusion and devised screens that examine the NDSI relationship more closely to help circumvent these potential error sources.

This approach has been adapted for and applied to snow detection with the VIIRS instrument. Once the NDSI is calculated for all land and inland water bodies in daylight, pixels determined to have some snow present are subjected to a series screens designed to detect reflectance relationships that are atypical of snow. Pixels that fail a screen are either: 1) reversed to "no snow" or "other"; or 2) left unchanged but flagged to indicate higher uncertainty. All pixels—snow and no snow—are screened for high solar zenith angle/low illumination.

Each screen has a corresponding bit flag in the `Algorithm_bit_flags_QA` data array that is set to on (1) when a pixel fails, allowing users to extract specific flags for analysis. All data screens are applied to all snow detections. As such, a single pixel can have multiple flags set. In addition, inland water bodies are mapped using bit 0. Note that inland water is also stored in the NDSI snow cover array, along with cloud, ocean, and night, to provide a thematic map of snow cover.

Users who wish to generate snow-covered area (SCA) maps, like those included with the MODIS Version 5 products, can easily do so by applying the commonly accepted threshold value of NDSI ≥ 0.4. SCA maps were discontinued starting with MODIS Version 6 and are likewise not produced for the VIIRS snow products, based on numerous studies which have demonstrated that different thresholds may yield better results for certain conditions. Thus, the choice of an appropriate threshold is left to the user.

Table 4 lists the data products that are input to the VIIRS snow detection algorithm. These data are used to check the quality of radiance measurements, identify land and water pixels, detect snow or ice/snow on water, and compute screen pass/fail thresholds:

Table 4. Input Products to VNP10

Product	Data Set	Wavelength	Spatial Resolution
NPP_VIAES_L1	Reflectance_I1	0.640 µm	375 m
	Reflectance_I2	0.865 µm	
	Reflectance_I3	1.61 µm	
	BrightnessTemperature_I5	11.450 µm	
NPP_VMAES_L1	Reflectance_M4	0.555 µm	750 m
NPP_IMFTS_L1	Solar zenith angle, surface height	—	375 m
VNP35 _L2	Cloud confidence flag, land/water mask	—	750 m

3.1.2 Data Screens

The following sections briefly describe the VIIRS data screens, criteria, and actions taken when a pixel fails.

LOW VISIBLE REFLECTANCE SCREEN (BIT 1)

This screen is applied to prevent errors from occurring when the reflectance is too low for the algorithm to perform well, such as in very low illumination or on surface features with very low reflectance. This screen is also applied to pixels that have no snow cover present (i.e. snow-free pixels) to prevent possible snow omission. If the reflectance from band I1 is ≤ 0.10 or band M4 is ≤ 0.11, the pixel fails and is set to “no decision.” The results of this screen are tracked in bit 1 of `Algorithm_bit_flags_QA`.

LOW NDSI SCREEN (BIT 2)

Pixels detected as having snow cover with 0.0 < NDSI < 0.10 are reversed to no snow and flagged by setting bit 2 in `Algorithm_bit_flags_QA`. This flag can be used to find pixels where low confidence snow cover detections were reversed to not snow.

ESTIMATED SURFACE TEMPERATURE AND SURFACE HEIGHT SCREEN (BIT 3)

This screen serves a dual purpose by linking estimated surface temperature with surface height to: 1) alleviate errors of commission at low elevations that appear spectrally similar to snow but are too warm; and 2) flag snow detections at high elevations that are warmer than expected. Using brightness temperature (Tb) estimated from VIIRS band I5, if snow is detected in a pixel with height < 1300 m and Tb ≥ 281 K, the pixel is reversed to no snow and bit 3 is set in `Algorithm_bit_flags_QA`. This bit is also set for snow detections in pixels with height ≥ 1300 m and Tb ≥ 281 K, to identify them as unusually warm.

HIGH SWIR REFLECTANCE SCREEN (BIT 4)

This screen also serves a dual purpose by: a) preventing non-snow features that appear similar to snow from being detected as snow; b) allowing snow to be detected where snow-cover short-wave infrared reflectance (SWIR) is anomalously high. Snow typically has a SWIR reflectance of less than about 0.20; however, this value can be higher under certain conditions like a low sun angle. The SWIR reflectance screen thus utilizes two thresholds.

Snow pixels with SWIR reflectance > 0.45 are reversed to not snow and bit 4 is set in `Algorithm_bit_flags_QA`. Snow pixels with 0.25 < SWIR reflectance ≤ 0.45 are flagged but not reversed, to indicate an unusually high SWIR for snow cover.

SOLAR ZENITH SCREEN (BIT 7)

When solar zenith angles exceed 70°, the low illumination challenges snow cover detection. As such, this screen is applied to all pixels in the swath and solar zenith angles > 70° are flagged by setting bit 7 in `Algorithm_bit_flags_QA`. Solar zenith angles ≥ 85° are masked as night in the NDSI and `NDSI_Snow_Cover` data arrays.

3.1.3 Lake Ice

Ice/snow covered lake ice are detected by applying the snow algorithm specifically to inland water bodies. Inland water bodies are tracked by setting bit 0 in `Algorithm_bit_flags_QA`. Users can extract or mask inland water in the NDSI snow cover SDS using this flag. The algorithm relies on the basic assumption that a water body is deep and clear and therefore absorbs all of the solar radiation incident upon it. Water bodies with algal blooms, high turbidity, or other relatively high reflectance conditions may be erroneously detected as snow/ice covered.

3.1.4 Cloud Masking

Clouds are masked using the 750 m cloud confidence flag from VNP35_L2, which reports four levels of cloud confidence: confident clear, probably clear, probably cloudy, and confident cloudy. Confident cloudy is masked as cloud in VNP10, while values of confident clear, probably clear, or uncertain clear are interpreted as clear. Cloud mask values at 750 m are applied to the four corresponding VNP10 pixels.

Abnormal Condition Rules

If radiance data are missing in any of the bands used by the algorithm, the pixel is set to "missing data" and is not processed for snow cover. Unusable radiance data are set to "no decision."

3.1.5 Bow Tie Effect

VIIRS I bands have 32 rectangular detectors in the along-track direction, oriented with the smaller dimension along-scan. To eliminate gaps between adjacent scans, the detector size and scan timing were designed to produce a scan width at nadir that matches the ground-track distance traveled by satellite during one scan period. However, the along-track width of the VIIRS scan at Earth's surface increases from 11.7 km at nadir to 25.8 km at ±56.28°, due primarily to the increasing distance between the sensor and the ground and Earth's curvature. As a result, the scan footprint has the shape of a bow tie (see Figure 1), and adjacent scans begin to visibly overlap at angles greater than approximately 19° and by more than 1 pixel (in M-bands) at angles greater than 32°.

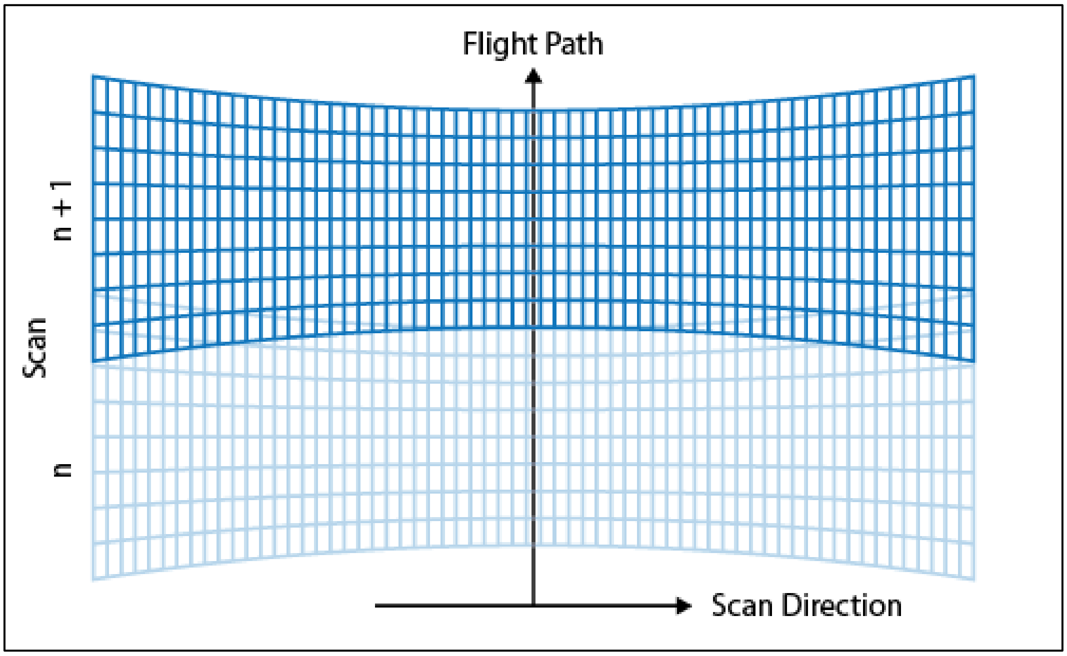

Figure 1. Illustration of the bow tie effect. Increasing scan width away from nadir leads to pixel overlap in adjacent scans.

VIIRS removes overlapping, duplicated pixels in off-nadir portions of scans to save transmission bandwidth, but this practice introduces visual artifacts in raw swath images. Users who wish can remove this "bow tie trim" via interpolation when images are displayed, however the artifacts do not appear in higher-level products in which the scans have been projected and gridded onto Earth's surface.

3.1.6 Error Sources

Although the VIIRS snow cover detection algorithm was designed to detect snow globally in all situations, the accuracy varies depending on land cover and viewing conditions. The highest accuracy typically occurs when skies are cloud-free, illumination is near ideal, and at least several centimeters of snow is present on the landscape. The algorithm is effectively a VIIRS-specific version of the NDSI technique developed for MODIS, which has proven to be a robust indicator of snow around the globe. Since the sensor was first deployed in 2000, numerous investigators have used MODIS snow cover data sets and reported accuracy under cloud-free conditions in the range of 88-93%.

Applying the lessons of MODIS to VIIRS, the conditions that are most likely to confound the algorithm are addressed using the data screens previously discussed in this document. More details about these screens are available in the NASA S-NPP VIIRS Snow Products Collection 1 User Guide.

Confusion between snow and clouds in this data set is similar to MODIS Version 6. Two common sources are: 1) the cloud mask does not correctly flag cloudy or clear conditions; and 2) clouds escape detection due to the coarser resolution of the cloud mask (750 m) compared with the imagery bands (375 m) used for snow cover detection.

The cloud mask algorithm uses many tests to detect cloud. The combination of tests that are applied (the processing path) depends on whether or not the surface is snow covered. Using an external snow/ice background map, the cloud mask algorithm conducts an internal check for snow cover; if that initial determination is incorrect, the algorithm may follow the wrong processing path and output an erroneous cloud determination.

For example, when storms drop swaths of snow across the Great Plains the cloud mask can flag snow on the periphery as "certain cloud." The Science Team has investigated this situation for MODIS and found that the erroneous cloud flag stemmed from a single visible test of the several spectral cloud tests applied in the processing path. By examining the cloud mask algorithm processing path and the results of all spectral tests applied, the cloud mask could be reinterpreted as “clear” in that specific situation to correctly identify snow. However, that reinterpretation has proven only partially effective at resolving cloud/snow confusion in this particular case, and inconsistent results have been found in other situations. As such, this and other tests are still being evaluated.

Due to the spectral similarities of snow and clouds, sub-pixel (750 m) clouds missed by the cloud mask may be erroneously detected as snow. These snow commission errors often occur at the periphery of clouds, especially when scattered, popcorn-like cloud formations overlie vegetated landscapes. Multilayer clouds can also confuse the cloud mask algorithm, in particular layers that consist of different types (both warm and cold) or where cloud shadows fall on other clouds. These situations may lead to cloud cover not being flagged as "certain cloud" and subsequent erroneous snow detections by the snow cover algorithm.

A more detailed discussion and examples are available in the NASA S-NPP VIIRS Snow Products Collection 1 User Guide.

An inland water detection algorithm, using essentially the same approach as snow cover detection, is incorporated with this data set to map snow on ice-covered lakes and rivers and provide a spatially coherent image of the snow-covered landscape. These data are stored in `NDSI_Snow_Cover` array. The location of inland water is recorded in bit 0 of `Algorithm_bit_flags_QA`, so that users can extract the water mask to analyze lake ice or apply it to the snow cover map.

Visual analysis of VNP10 swaths, plus experience with the corresponding MODIS data sets, reveals that snow- and/or ice-covered lakes are detected with an estimated 90% - 100% accuracy during the boreal winter when lakes are frozen. The disappearance of lake ice is also detected with high accuracy.

During the ice-free season, however, changes in the physical characteristics of a lake can greatly affect the algorithm results. Sediment loads, high turbidity, aquatic vegetation, and algae blooms change the reflectance characteristics of the lake in ways that can cause erroneous ice detections on lakes or rivers, especially during the spring or summer. However, these errors have been observed infrequently. The Science Team plans to develop a lake-ice-specific algorithm for future versions.

The Antarctic continent is nearly completely ice- and snow-covered all year round, with very little seasonal variation (some snow-cover changes can be observed on the Antarctic Peninsula). The snow cover algorithm is applied to Antarctica without any Antarctica-specific processing paths, and as such obviously erroneous areas with no snow cover may be visible. This error stems from the inherent difficulties detecting clouds over the Antarctic continent. The similarity in reflectance and lack of thermal contrast between clouds and ice or snow present major challenges to accurately discriminating between these features. If the cloud mask fails to identify "certain cloud," the snow algorithm assumes a cloud-free view and either identifies the surface as snow free or identifies cloud as snow. In either case the result is wrong. Although this data set includes snow maps for Antarctica, users should scrutinize them carefully for accuracy and quality.

3.2 Instrument Description

The VIIRS instrument is a whiskbroom scanning radiometer with 22 bands (see VIIRS Bands and Bandwidths) covering the spectrum between 0.412 μm and 12.01 μm. Sixteen moderate resolution bands (M-bands), five imaging resolution bands (I-bands), and one panchromatic day-night band (DNB) acquire spatial resolutions at nadir of 750 m, 375 m, and 750 m, respectively. M-bands include 11 Reflective Solar Bands (RSB) and 5 Thermal Emissive Bands (TEBs). I-bands include 3 RSBs and 2 TEBs. More details about the VIIRS instrument are available in the Visible Infrared Imaging Radiometer Suite (VIIRS) Sensor Data Record (SDR) User's Guide and the Joint Polar Satellite System (JPSS) VIIRS Radiometric Calibration Algorithm Theoretical Basis Document (ATBD).

Table 5 lists select technical specifications for the VIIRS instrument:

Table 5. VIIRS Specifications

Variable	Description
Orbit	829 km (nominal) altitude, 1:30 P.M. ascending node, sun-synchronous, near-polar, circular
Scan Rate	1.779 sec/rev, 202.3 deg/sec
Scan Width	±56.28° (Earth view)
Imaging Optics	19.1 cm aperture, 114 cm focal length
Swath Dimensions	3060 km cross-track, 12 km along track at nadir
Samples per Band	M-bands: 6304 samples at 0.312 mrad/sample (3200 aggregated pixels) I-bands: 12608 samples at 0.156 mrad/sample (6400 aggregated pixels) DNB: 4064 pixels at 0.149 to 0.894 mrad/pixel
Weight	275 kg
Power	200 W (single orbit average)
Data Rate	10.5 Mbps (max)
Quantization	12 bit –14 bit A/D converters for lower noise
Launch date	28 October, 2011
Design Life	years (5 year mission)

4 REFERENCES AND RELATED PUBLICATIONS

Dozier, J. and D. Marks. 1987. Snow mapping and classification from Landsat Thematic Mapper data. *Annals of Glaciology* 9:1–7.

Hall, D.K., G.A. Riggs, V.V. Salomonson, N.E. DiGirolamo, and K.J. Bayr. 2002. MODIS snow-cover products. *Remote Sensing of Environment* 83(1–2):181–194. http://dx.doi.org/10.1016/S0034-4257(02)00095-0

Hall, D.K. and G.A. Riggs. 2011. Normalized-Difference Snow Index (NDSI). *Encyclopedia of Snow, Ice and Glaciers*, Springer Netherlands. pp. 779-780.

Justice, C.O., M.O. Román, I. Csiszar, et al. 2013. Land and cryosphere products from Suomi NPP VIIRS: Overview and status. *Journal of Geophysical Research – Atmospheres*118(17):9753-9765.

Riggs, G.A., D.K. Hall, and M.O. Román. 2016. VIIRS snow products algorithm theoretical basis document (ATBD). (See PDF)

Riggs, G.A., D.K. Hall, and M.O. Román. 2016. MODIS snow products user guide for Collection 6 (C6).

4.1 Related Websites

NASA Goddard Space Flight Center | Polar Orbiting Missions | Suomi-NPP

NASA Goddard Space Flight Center | Suomi-NPP VIIRS Land

MODIS Snow/Ice Global Mapping Project

Earthdata | VIIRS is Here

5 DOCUMENT INFORMATION

5.1 Publication Date

June 2017

5.2 Date Last Updated

30 March 2021