NASA S-NPP VIIRS Snow Products
Collection 1
User Guide

Version 1.0
Describes
The Swath Level Product

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List of Acronyms

ATBD	Algorithm Theoretical Basis Document
BT	Brightness Temperature
Cx	Collection number
CMG	Climate-Modeling Grid
DOI	Digital Object Identifier
EDR	Environmental Data Record
EOSDIS	Earth Observing System Data Information System
ESDT	Earth Science Data Type
FSC	Fractional Snow Cover
HDF5	Hierarchical Data Format 5
IDPS	Interface Data Processing Segment
L1 / L2 / L3	Level 1, Level 2 or Level 3 data product
LSIPS	Land Science Investigator-led Processing System
MOD10	ESDT of the MODIS L2 snow cover product
MODIS	Moderate-resolution Imaging Spectroradiometer
NDSI	Normalized Difference Snow Index
QA	Quality Assessment
SCA	Snow-Covered Area
SIN	Sinusoidal Projection
S-NPP	Suomi National Polar-orbiting Partnership
SWIR	Short Wave Infrared
SZA	Solar Zenith Angle
TOA	Top-of-Atmosphere
VIIRS	Visible Infrared Imager Radiometer Suite
VNP10*	ESDT name for the VIIRS Level-2 Snow Cover Data Products
VPN10_L2	ESDT name for the VIIRS Level-2 swath-based Snow Cover Data Product
VPN10A1	ESDT name for the VIIRS Level-3 tiled Snow Cover Data Product
VPN10C1	ESDT name for the VIIRS Level-3 global Snow Cover Data Product
VIS	visible

1.0 Overview

The NASA Suomi-National Polar-orbiting Partnership (S-NPP) Visible Infrared Imaging Radiometer Suite (VIIRS) snow cover algorithm and data product are developed synergistically with the Moderate Resolution Imaging Spectroradiometer (MODIS) Collection 6 (C6) snow cover algorithms and data products, leveraging analysis and evaluation from both to make nearly-identical algorithms and data products. The overall objective for VIIRS Collection 1 (C1) is to make the NASA VIIRS snow-cover detection algorithms compatible with the C6 MODIS Terra and Aqua snow-cover algorithms to ensure continuity of the data products and enable development of a climate-data record (CDR) from the three sensors. Differences between the MODIS C6 and the NASA VIIRS algorithms originate from the physical differences between the MODIS and VIIRS instruments, including spatial resolution and band locations. The NASA VIIRS snow cover data products are produced in the NASA Land Science Investigator-led Processing System (LSIPS). The NASA VIIRS snow cover data products are substantially different from the snow cover data products generated in NOAA- Interface Data Processing Segment (IDPS) snow-cover products that were initially developed based on the MODIS Collection 5 (C5) snow cover algorithms.

This User Guide describes each of the three NASA VIIRS C1 snow-cover products in sequence from Level 2 to Level 3: 1) snow-cover swath, 2) daily snow-cover tiled, and 3) daily climate modeling grid (global). This User Guide is a living document developed in increments for each product as they are scheduled to be released, so it is advisable to check that you are using the latest version. This version (1.0) describes the VIIRS swath level (Level-2) snow cover data product which is the first to be produced by the LSIPS and archived at the NSIDC DAAC. The LSIPS has evolved from the LPEATE which had the task of generating and evaluating algorithms and products generated with IDPS algorithms. The LSIPS is now beginning to produce and distribute the NASA VIIRS data products. The VIIRS snow products are referenced by their Earth Science Data Type (ESDT) name, e.g., VNP10_L2. The ESDTs are produced as a series of products in which data and information are propagated to the higher level products. Details of the data products, Quality Assessment (QA) data content, and commentary on evaluation and interpretation of data are given for each product. The reader is referred to the VIIRS Algorithm Theoretical Basis Document (ATBD) [http://npp.gsfc.nasa.gov/documents.html] (Riggs et al., 2016a) and to Justice et al. (2013) for further details.

The data product format of the VIIRS snow cover data products changes with the data product level. The VNP10_L2 product file format is NetCDF4/HDF5 and is compliant with the NetCDF Climate and Forecast (CF) Metadata Conventions Version 1.6. Information on NetCDF4.2 is at www.unidata.ucar.edu/software/netcdf/docs/index.html, Information on Hierachical Data Format 5 (HDF5) may be found at https://www.hdfgroup.org/HDF5/. Either NetCDF4 or HDF5 tools should be able to read these data products. The Level-3 products, VNP10A1 and VNP10C1, will be in HDF5-

EOS file format. The user should contact the NSIDC DAAC user support group with questions about working with these files formats.

The LSIPS ramp-up to full production of NASA VIIRS data products began with producing the LPEATE versions of IDPS algorithms and products for Level-1B and Level-2 products to use as inputs to the NASA algorithms and data products as they were being developed and for initial C1 production. Those LPEATE versions of the L1B products will be replaced by the NASA L1B and L2 products when they become available. The difference between those products is primarily data product format; both contain the same data but are organized in different ways. The current VNP10_L2 uses LPEATE versions of inputs and outputs the VNP10_L2 product. The VNP10_L2 algorithm code will be revised to use NASA L1B inputs but the snow detection algorithm will not be changed and the output product will be the same. Data product inputs are listed as global attributes in VNP10_L2 so a user can determine which L1B inputs were used.

2.0 NASA VIIRS Snow Cover Data Products

The NASA VIIRS land snow-cover data products are listed in Table 1. Snow cover data products are produced in sequence beginning with a swath at a nominal pixel spatial resolution of 375 m with nominal swath coverage of 6400 pixels (across track) by 6464 pixels (along track), consisting of 6 minutes of VIIRS scans. (Note: 5 minutes of VIIRS scans if using LPEATE version of L1B). Products in EOSDIS are labeled as ESDT and have their heritage in the MODIS production system (Wolfe and Ramapriyan, 2010). The ESDT also indicates what spatial and temporal processing has been applied to the data product. Data product levels briefly described are: Level 1B (L1B) is a swath (scene) of VIIRS data in latitude and longitude orientation. A Level 2 (L2) product is a geophysical product that remains in latitude and longitude orientation of L1B. A Level 2 gridded (L2G) product is in a gridded format of the sinusoidal projection for VIIRS land products. At L2G the data products are referred to as tiles, each tile being 10° x 10° area, of the global map projection. L2 data products are gridded into L2G tiles by mapping the L2 pixels into cells of a tile in the map projection grid. The L2G algorithm creates a gridded product necessary for the Level 3 (L3) products. An L3 product is a geophysical product that has been temporally and or spatially manipulated, and is in a gridded map projection format and comes as a tile of the global grid. The VIIRS L3 snow products are in either the sinusoidal projection (VNP10A1) or geographic projection (VNP10C1).

The series of NASA VIIRS snow-cover products to be produced in C1 is listed in Table 1. A description of each product, synopsis of the algorithm and commentary on snow cover detection, quality assessment, accuracy and errors is given in following sections.

Attributes (metadata) describing the time of acquisition of the swath, input products, geographic location of swath, production of the data product, provenance and Digital Object Identifier (DOI) of the product are attached to the root group (the file). Those attributes are listed in Appendix A; they are not described further in this user guide.

Table 1: Summary of land snow-cover products produced at the Land Science Investigator-led Processing System (SIPS).

Products	ESDT	Description
Snow Cover (L2 Daily Swath product)	VNP10_L2	VIIRS/NPP Snow Cover 6-Min Swath 375 m
Snow Cover (L2G Daily Tiled product)	VNP10A1	VIIRS/NPP Snow Cover Map Daily L2G Global 375 m SIN Grid Day
Snow Cover (L3 CMG Product)	VNP10C1	VIIRS/NPP Daily Snow Cover L3 Global 0.05° X 0.05° climate-modeling grid (CMG)

3.0 VNP10_L2

Snow cover is detected using the Normalized Difference Snow Index (NDSI) as in the MODIS C6 snow algorithms (Riggs et al., 2016a and b). The snow cover products contain an NDSI snow cover dataset with masks of clouds, night and oceans applied and the NDSI calculated for all land and inland water pixels, Quality Assurance (QA) datasets and geolocation datasets. The estimate of Fractional Snow Cover (FSC) as was done in MODIS C5 is not made in the MODIS C6 or in the NASA VIIRS C1 algorithms. The NDSI is an index to the presence of snow in a pixel and is a more accurate description of the snow detection as compared to estimating a FSC based on empirical relationships; this change allows a user greater flexibility in interpreting the data. A detailed explanation for providing the NDSI snow cover and abandoning the estimated FSC is given in the NASA VIIRS snow cover ATBD (Riggs et al., 2016a) [http://npp.gsfc.nasa.gov/documents.html].

The NASA VIIRS snow-cover swath product, VNP10_L2, contains dimension scale datasets, a snow data group and attributes for the file, data group and datasets. Contents of VNP10_L2 are given in List 1.

List 1. Datagroups and datasets in a VNP10_L2 product.

```
HDF5 " VNP10_L2.A2016067.2048.001.2016253130607" {
FILE_CONTENTS {
 group     /
 group     /SnowData
 dataset    /SnowData/Algorithm_bit_flags_QA
 dataset    /SnowData/Basic_QA
 dataset    /SnowData/NDSI
 dataset    /SnowData/NDSI_Snow_Cover
dataset    /number_of_lines
dataset    /number_of_pixels
 }
}
```

3.1 Geolocation Data

Geolocation data are the dimension scale datasets (List 2). Latitude and longitude datasets are not written in the product, but are stored in the VNP03IMG geolocation data product corresponding to a VNP10_L2 swath data product.

List 2. VNP10_L2 GeolocationData group datasets (variables) and attributes.

```
netcdf VNP10_L2.A2016067.2048.001.2016253130607 {
dimensions:
        number_of_lines = 6496 ;
        number_of_pixels = 6400 ;
```

3.2 SnowData Group

Descriptions of the SnowData group datasets and attributes are given in List 3 and in Section 3.2.1. SnowData group attributes are descriptive summary statistics compiled during a run of the algorithm that provides information on overall viewing conditions, e.g. cloud cover, extent of snow cover, basic summary of data quality, and threshold settings of some data screens. The purpose of these attributes it to give an overall view of what might be observed in the scene.

List 3. VNP10_L2 description of SnowData group datasets and attributes.

```
group: SnowData {
  variables:
        ubyte Algorithm_bit_flags_QA(number_of_lines, number_of_pixels) ;
                Algorithm_bit_flags_QA:long_name = "Algorithm bit flags" ;
                Algorithm_bit_flags_QA:flag_masks = "1b, 2b, 4b, 8b, 16b, 32b, 64b,
128b" ;
                Algorithm_bit_flags_QA:flag_meanings = "inland_water_flag
low_visible_screen low_NDSI_screen
combined_surface_temperature_and_height_screen/flag spare high_SWIR_screen/flag
spare solar_zenith_flag" ;
                Algorithm_bit_flags_QA:comment = "Bit flags are set for select conditions
detected by data screens in the algorithm, multiple flags may be set for a pixel.Default is
all bits off" ;
```

```
        ubyte Basic_QA(number_of_lines, number_of_pixels) ;
                Basic_QA:long_name = "Basic QA value" ;
                Basic_QA:valid_range = 0UB, 3UB ;
                Basic_QA:mask_values = 211UB, 239UB, 250UB, 252UB, 253UB ;
                Basic_QA:mask_meanings = "211=night 239=ocean 250=cloud
252=no_decision 253=bowtie_trim" ;
                Basic_QA:key = "0=good, 1=poor, 2=bad, 3=other" ;
                Basic_QA:_FillValue = 255UB ;
        short NDSI(number_of_lines, number_of_pixels) ;
                NDSI:long_name = "NDSI for land/inland water pixels" ;
                NDSI:valid_range = -1000s, 1000s ;
                NDSI:scale_factor = 0.001f ;
                NDSI:mask_values = 21100s, 23900s, 25100s, 25200s, 25300s, 25400s ;
                NDSI:mask_meanings = "21100=night, 23900=ocean,
25100=L1B_missing, 25200=L1B_unusable, 25300=bowtie_trim, 25400=L1B_fill" ;
                NDSI:_FillValue = 32767s ;
        ubyte NDSI_Snow_Cover(number_of_lines, number_of_pixels) ;
                NDSI_Snow_Cover:long_name = "Snow cover by NDSI" ;
                NDSI_Snow_Cover:valid_range = 0UB, 100UB ;
                NDSI_Snow_Cover:mask_values = 201UB, 211UB, 237UB, 239UB,
250UB, 251UB, 253UB, 254UB ;
                NDSI_Snow_Cover:mask_meanings = "201=no decision, 211=night,
237=lake, 239=ocean, 250=cloud, 251=missing data, 253=bowtie trim, 254=L1B fill" ;
                NDSI_Snow_Cover:_FillValue = 255UB ;

  // group attributes:
                :Surface_temperature_screen_threshold = "281.0 K" ;
                :Surface_height_screen_threshold = "1300 m" ;
                :Land_in_clear_view = "nan%" ;
                :Cloud_cover = "0.0%" ;
                :Snow_Cover_Extent = "0.0%" ;
                :QA_Best = "0.0%" ;
                :QA_Good = "0.0%" ;
                :QA_Poor = "0.0%" ;
                :QA_Other = "0.0%" ;
  } // group SnowData
}
```

3.2.1 Datasets

The VNP10_L2 product has the following datasets: NDSI_Snow_Cover, Basic_QA, Algorithm_bit_flags_QA and NDSI, each with local attributes describing the data.

3.2.1.1 NDSI_Snow_Cover

The NDSI_Snow_Cover dataset is the snow cover extent generated by the algorithm. Snow cover is represented by NDSI values in the range of 0 – 100, from “no snow cover” to “total snow cover” in a pixel as was done in the MODIS data products (see

Hall et al., 2002 and Riggs et al., 2016b). To give a complete view of conditions in the scene, the cloud mask, ocean mask, and night mask are overlaid on the NDSI snow cover data. The onboard bowtie trim fill data is retained in the dataset. An example of the snow cover dataset, with colorized ranges of NDSI_Snow_Cover is shown in Figure 1. Local attributes are attached to the dataset.

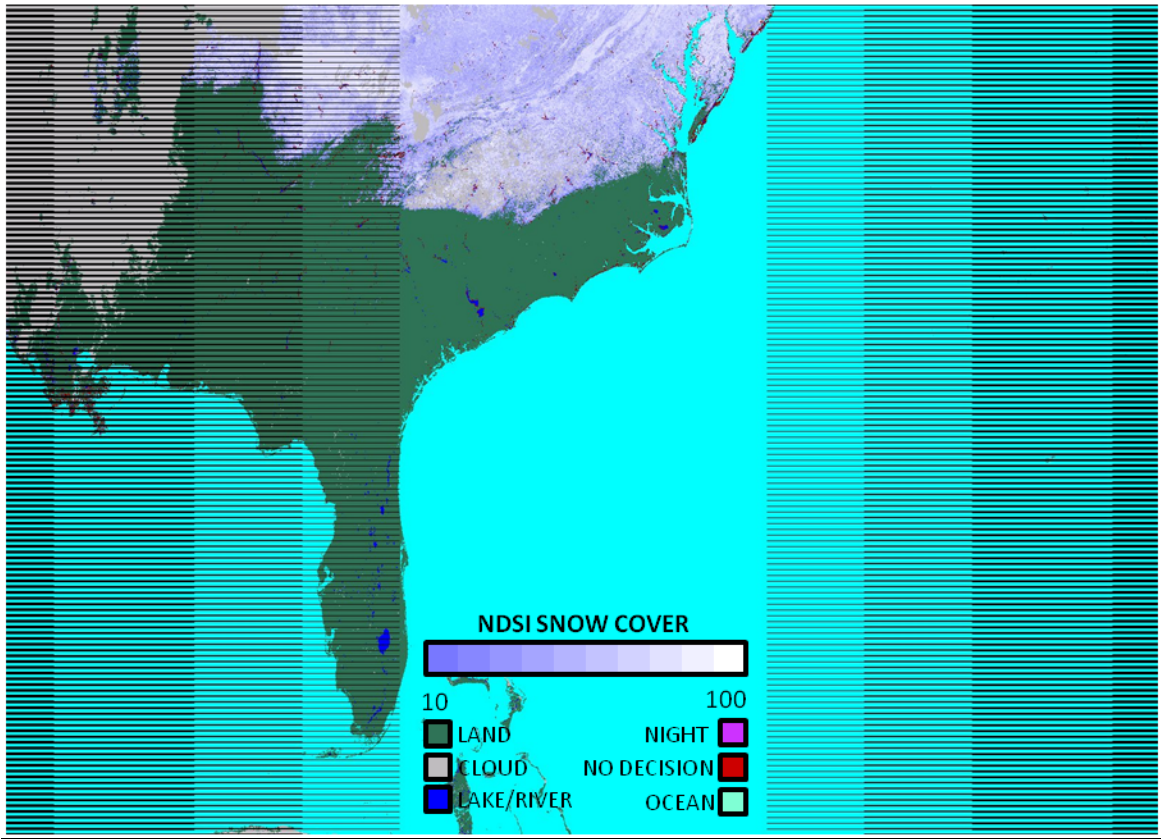

Figure 1. VNP10_L2.A2016024.1810, 1810 UTC, 24 January 2016. NDSI_Snow_Cover map. Snow cover extent, shown in shades of blue to white, across the Mid-Atlantic and Southeastern USA after a winter storm on 22-23 January 2016..

3.2.1.2 Algorithm_ bit_flags_QA

Algorithm-specific bit flags are set in this dataset for the data screens that are applied in the algorithm. Multiple bit flags may be set for a pixel. For all pixels that were detected as snow the data screens were applied and the snow detection may have been reversed to “not snow” or flagged as “uncertain snow detection.” Algorithm bit flags are set if a snow detection was reversed or flagged as uncertain by one or more data screens applied in the algorithm. Some of the bit flags serve a dual purpose to either reverse a snow detection or to flag an uncertain pixel result. Some screens are also applied to all land pixels in clear view. See Section 3.3 for a description of bit flags. Local attributes describing the data, i.e. each bit flag, are included.

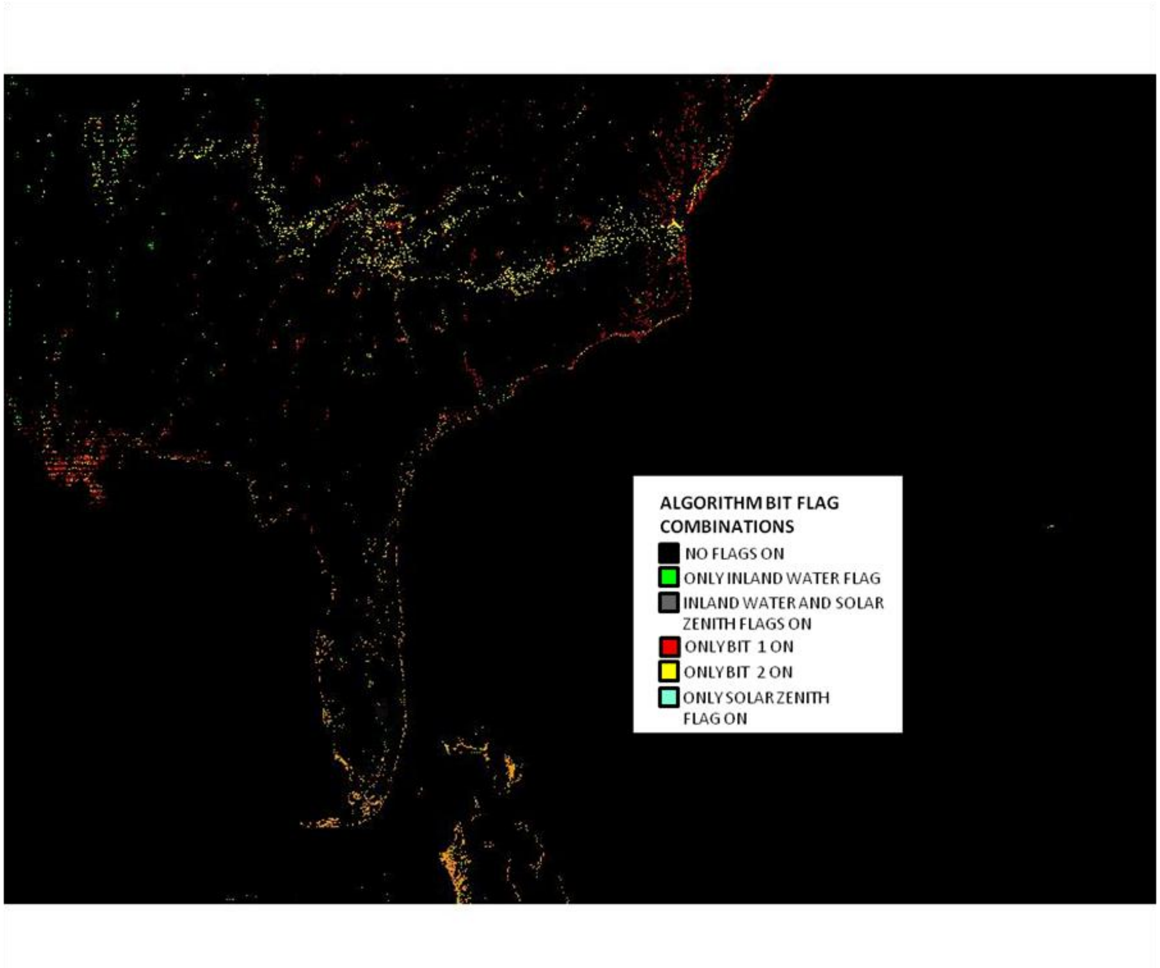

Figure 2. VNP10_L2.A2016024.1810, 1810 UTC, 24 January 2016 Algorithm_bit_flags_QA map. A selection of QA bit flags and combinations of bit flags showing situations where there is an increased uncertainty in snow cover detection.

3.2.1.3 Basic QA

A general quality value is given for pixels processed for snow cover as in the MODIS snow-cover products (Riggs et al., 2016b). Masked features, e.g. oceans, are set to the masked value. This is a basic quality value use to indicate quality ranging from best to poor to provide a user with a convenient value for initial quality assessment of the data. Local attributes describing the data are included.

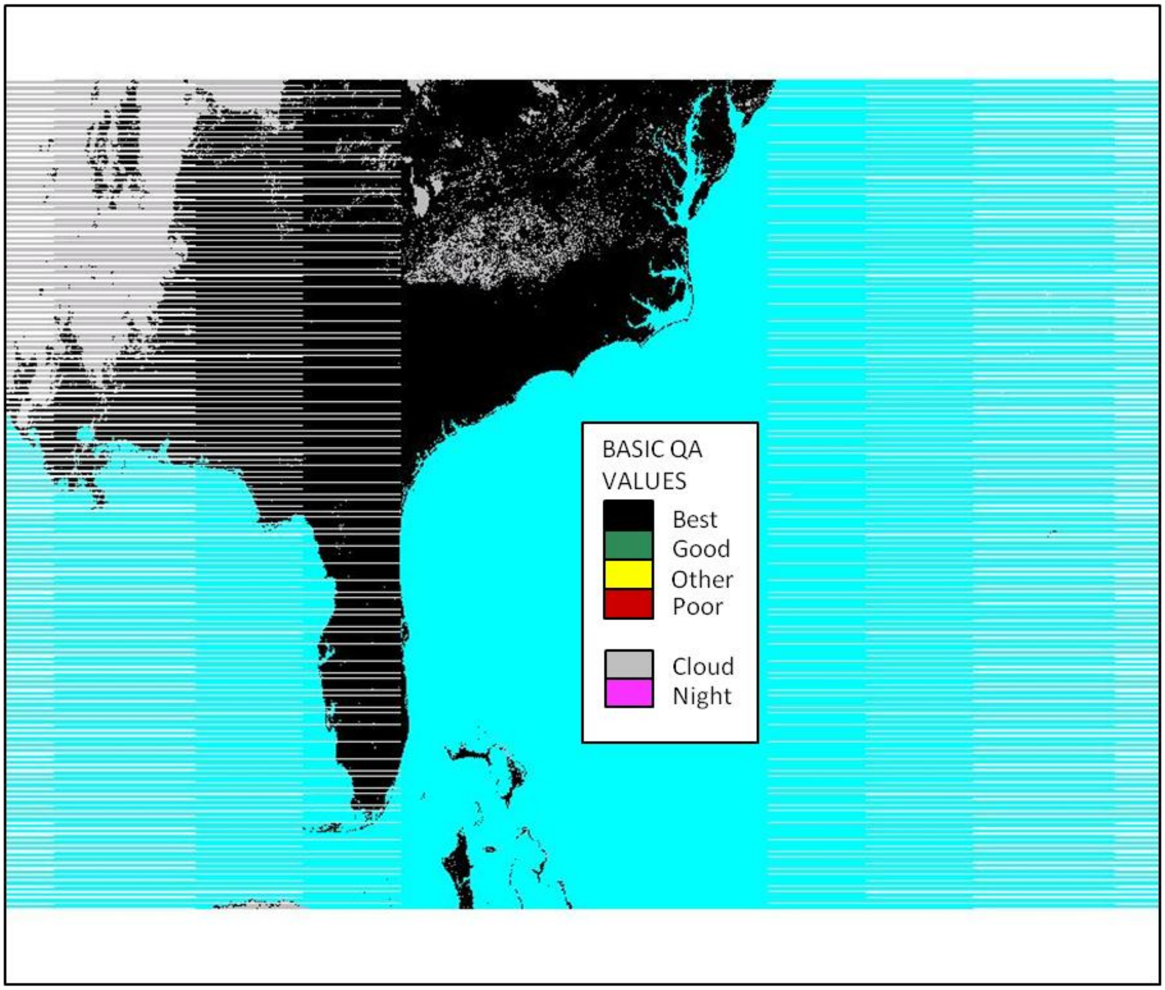

Figure 3. VNP10_L2.A2016024.1810, 1810 UTC, 24 January 2016 Basic_QA map. This is a high quality image based on the parameters used to set the basic QA value so quality is set to “best” for all land.

3.2.1.4 NDSI

The calculated NDSI values for all land and inland water pixels is output in this dataset; the cloud mask is not applied. However, masks other than the cloud mask are applied. The NDSI dataset is packed data so must be scaled when extracted for use. Attributes describing the data are included.

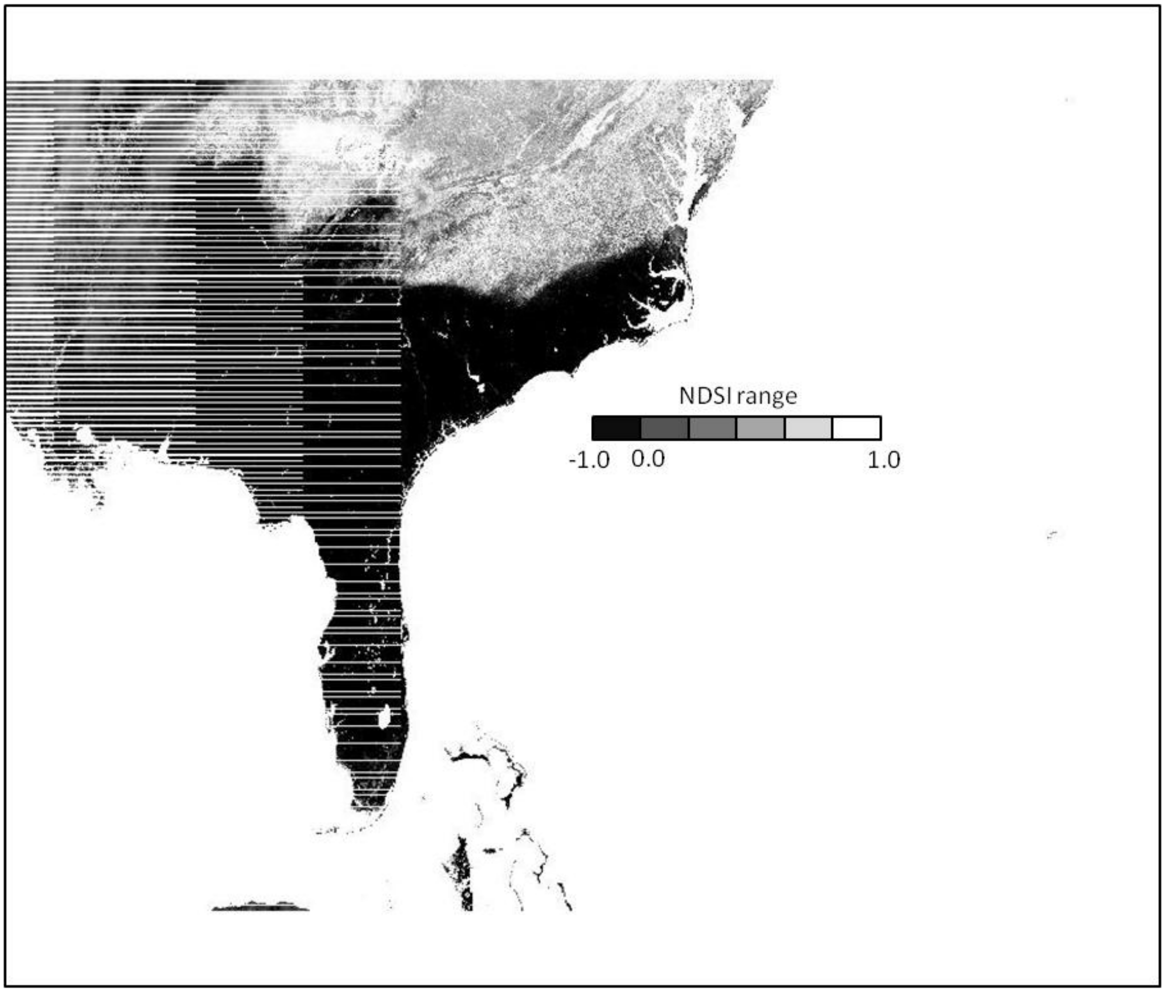

Figure 4. VNP10_L2.A2016024.1810, 1810 UTC, 24 January 2016 NDSI dataset. NDSI values are given in range of -1.0 to 1.0 for all land and inland water pixels. The NDSI dataset is not cloud masked. (The NDSI dataset is packed data.)

3.3 Snow Cover Detection Algorithm

A brief description of the algorithm approach is provided to explain the flow of the algorithm and the basic technique used to detect snow cover. A detailed description of the algorithm can be found in the NASA VIIRS ATBD (Riggs et al., 2016a).

The basis of the NASA VIIRS snow mapping algorithms is the NDSI. (See Dozier and Marks, 1987 and Hall and Riggs, 2011 for a summary of the history of the NDSI.) Snow typically has very high visible (VIS) reflectance and very low reflectance in the shortwave infrared (SWIR); this normalized difference is a characteristic commonly used to detect snow and to distinguish snow and most clouds. The ability to detect snow cover is related to the difference in reflectance of snow cover in the VIS and SWIR in which the greater the VIS-SWIR difference the higher the NDSI. The NDSI for VIIRS is calculated as follows:

NDSI = (I1 – I3) / (I1 + I3),

Where I1 is VIIRS band I1 (0.64 µm), and I3 is VIIRS band I3 (1.61 µm). The NDSI indicates the presence of snow cover on the surface based on the snow characteristics of high VIS reflectance and very low SWIR. If snow is present and viewable by a satellite then the NDSI will be in the theoretical range of -1.0 to +1.0, with a value of 0.0 or less indicating no snow. If snow is present and viewable by the sensor the NDSI will be >0. Users may be familiar with the SCA map that was in the MODIS C5 snow cover products, however that SCA is not output in MODIS C6 or the NASA VIIRS C1 snow cover products. Many users may want a SCA map using the commonly-accepted global NDSI threshold value of 0.4 that has often been used to make SCA maps and they can derive a SCA map easily by thresholding NDSI values. Although many researchers have shown that better SCA maps can be made in specific situations for local or regional snow mapping if, for example, the NDSI is set for that situation with methods of threshold selection based on visual inspection/interpretation, empirical relationship or automated selection. In such cases the NDSI threshold setting may be as low as 0.1 for SCA identification. Thus an NDSI threshold selection is left to the user in MODIS C6 and NASA VIIRS C1. A user can make their own SCA map using the NDSI snow cover or NDSI datasets in the product by setting a NDSI threshold that is appropriate for a specific study area.

The NDSI is calculated for all land and inland water bodies in daylight, then the data screens are applied to snow detections. All the data screens are applied to each snow pixel. Applying all the data screens to a pixel allows for more than one data screen to be set for a snow commission error or uncertain snow detection. A snow pixel that fails any single data screen will be reversed to 'not snow' and since all the data screens are applied, more than a single QA algorithm bit flag may be set. The same data screens are applied to land and inland water pixels. Inland water bodies are mapped with bit 0 of the algorithm bit flags. The cloud mask, ocean mask, and night mask are laid on the NDSI snow cover to make a thematic map of snow cover. The NDSI value is output for all land and inland water pixels.

Data product inputs to the NASA VIIRS snow detection algorithm are listed in Table 2, currently using the LPEATE version of inputs. The LISPS ESDT names are listed in parentheses and italicized. The basic processing flow is depicted in Figure 5. The processing flow for a pixel is determined based on the land/water mask read from the geolocation data product. Land and inland water bodies in daylight are processed for snow detection or ice/snow on water detection. VIIRS radiance data is checked for nominal quality and converted to top-of-atmosphere (TOA) reflectance.

Table 2. VIIRS data product inputs to the VNP10_L2 algorithm.

ESDT	Dataset	wavelength	Nominal spatial resolution
NPP_VIAE_L1 *(VNP02IMG_L1)*	Reflectance_I1	0.640 µm	375 m
	Reflectance_I2	0.865 µm	375 m
	Reflectance_I3	1.61 µm	375 m
	BrightnessTemperature_I5	11.450 µm	375 m
NPP_VMAE_L1 *(VNP02MOD_L1)*	Reflectance_M4	0.555 µm	750 m
NPP_IMFT_L1 *(VNP03IMG_L1)*	Latitude, Longitude, solar zenith angle		375m
NPP_CMIP_L2 *(VNP35 _L2)*	Cloud confidence flag, land/water mask		750m

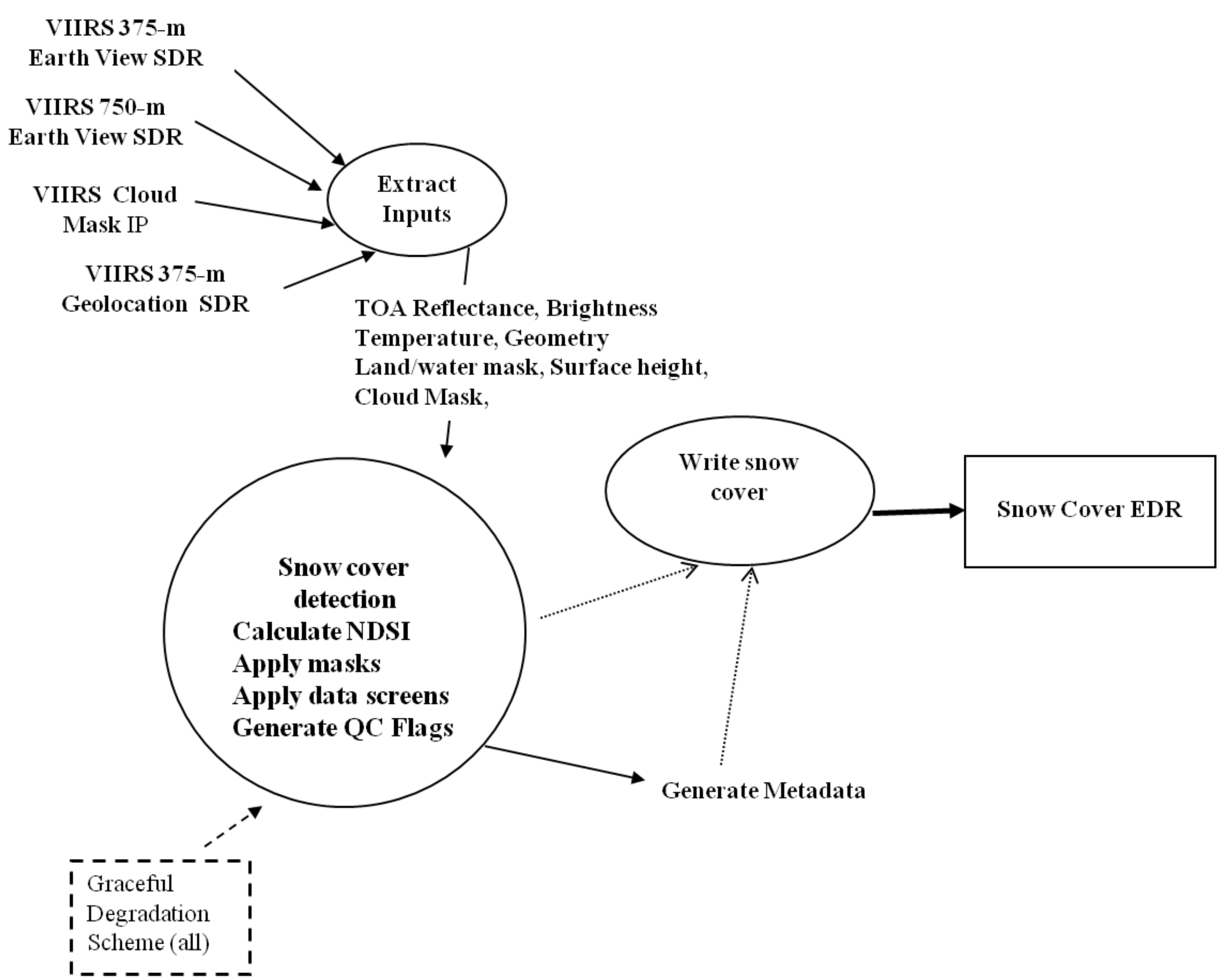

Figure 5. Snow Cover Environmental Data Record (EDR) processing architecture.

3.3.1 Data Screens

If a pixel has been determined to have snow present based on the NDSI, it is subjected to a series of data screens to alleviate snow commission errors and flag uncertain snow detections. Though snow typically has high VIS reflectance and low SWIR reflectance, the amount of reflectance in any band and the difference in reflectance between bands varies with viewing conditions and surface features. Screens are used to detect reflectance relationships atypical of snow and are applied to either reverse a snow detection to a ‘no snow’ or ‘other’ decision, or to flag the snow as ‘possibly not snow.’ Bounding conditions of ‘too low reflectance’ or ‘too high reflectance’ are also set by screens. Each screen has a bit flag in the ‘QA algorithm flags dataset’ that is set to ‘on’ if a screen was failed. Users can extract specific bit flags for analysis. Descriptions of the specific screens follows.

3.3.1.1 Low VIS reflectance screen.
If the VIS reflectance from VIIRS band I1 is ≤ 0.10 or band M4 is ≤ 0.11, then a pixel fails to pass this screen resulting in a “no decision” result. This screen is tracked in bit 1 of the Algorithm_bit_flags_QA.

3.3.1.2 Low NDSI screen.
Pixels detected with snow cover in the 0.0 < NDSI < 0.10 range are reversed to a ‘no snow’ result and bit 2 of the Algorithm_bit_flags_QA is set. That bit flag can be used to find where a snow cover detection was reversed to ‘not snow.’

3.3.1.3 Estimated surface temperature and surface height screen.
There is a dual purpose for this estimated surface temperature screen that is linked with a surface height screen. It is used to alleviate snow commission errors at low elevations that appear spectrally to be similar to snow but are too warm to be snow. It is also used to flag snow detections at high elevations that are warmer than expected for snow. If snow is detected in a pixel at height < 1300 m and that pixel has an estimated brightness temperature (BT) ≥ 281 K (using VIIRS band I5), that snow detection decision is reversed to “not snow” and bit 3 is set in the Algorithm_bit_flags_QA. If snow is detected in a pixel at height ≥ 1300 m and with estimated BT ≥ 281 K, that snow detection is flagged as unusually warm by setting bit 3 in the Algorithm_bit_flags_QA.

3.3.1.4 High SWIR reflectance screen.
The purpose of this screen is to prevent non-snow features that are spectrally similar to snow from being detected as snow but also to allow snow detection in situations where snow cover SWIR reflectance is anomalously high. This screen has two threshold settings for different situations. While snow typically has SWIR reflectance less than about 0.20, in some situations, e.g., low sun angle, snow can have a higher reflectance. If a snow pixel has a SWIR reflectance in range of 0.25 < SWIR ≤ 0.45, it is flagged as ‘unusually high for snow’ and bit 4 of Algorithm_bit_flags_QA is set. If a snow pixel has SWIR reflectance > 0.45 it is reversed to “not snow” and bit 4 of Algorithm_bit_flags_QA is set.

3.3.1.5 Solar zenith angle screen.
Low illumination conditions exist at SZAs > 70° which represents a challenging situation for snow cover detection. A SZA mask of > 70° is made by setting bit 7 of the Algorithm_bit_flags_QA. This mask is set across the entire swath. Night is defined as the SZA ≥ 85° and pixels are masked as night.

3.3.2 Lake Ice Algorithm

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

3.3.3 Cloud Masking

The cloud confidence flag from NPP_CMIP_L2 is used to mask clouds. The 750 m cloud mask is applied to the four corresponding 375 m pixels. The cloud confidence flag gives four levels of confidence: confident clear, probably clear, probably cloudy, and certain cloud. If the cloud mask flags “certain cloud” then the pixel is masked as “cloud.” If the cloud mask flag is set “confident clear,” “probably clear” or “uncertain clear” it is interpreted as “clear” in the algorithm.

3.3.4 Quality Assessment (QA)

Two QA datasets are output: 1) the Basic_QA which gives a simple value score, and 2) the Algorithm_bit_flags_QA which reports results of data screens as bit flags. The basic QA value is a qualitative estimate of the algorithm result for a pixel. The basic QA value is initialized to the best value and is adjusted based on the quality of the L1B input data and the solar zenith data screen. If the calculated top-of-atmosphere (TOA) reflectance is outside the range of 5-100% but still usable, the QA value is set to ‘good.’ If the SZA is in the range of 70° ≤ SZA < 85°, the QA is set to ‘okay,’ which means increased uncertainty in results because of low illumination. If input data is unusable the QA value is set to ‘other.’ Conditions for a poor result are not defined. For features that are masked, e.g. ocean and night, the mask values are applied.

The Algorithm_bit_flags_QA dataset contains bit flags of the results of the data screens that are applied in the algorithm. The data screens serve two purposes: 1) they indicate why a snow detection was reversed to “not snow,” and 2) they represent a QA flag for uncertain snow detection or challenging viewing conditions. More than one bit flag may be set because all data screens are applied to a pixel. By examining the bit flags a user can determine if a snow cover result was changed to a “not snow” result by a screen or screens, or if a snow covered pixel has certain screens set to “on” indicative of an uncertain snow detection. The screens and bit flags have a dual purpose-- some flag where snow detection was reversed or flag snow detection as “uncertain.” More than one data screen can be “on” for a snow detection reversal or for uncertain snow detection.

Bits for the data screens are set to “on” if the screen was failed. An example of some of the bit flags and combinations of bit flags is shown in Figure 2. Many combinations of bit flags may be set. A user can investigate any bit flag or combinations of bit flags. The inland water mask is also set as a bit flag (bit 0) to support analysis of inland waters for snow/ice cover.

3.4 Interpretation of Snow Cover Detection Accuracy, Uncertainty and Errors

Snow cover is detectable with high accuracy under cloud-free conditions when illumination conditions are near ideal, and several centimeters or more of snow are present on the landscape. However, the diversity of situations where snow may be found makes it challenging to develop a globally-applicable snow cover detection algorithm because snow cover can be found in many different landscapes, and under all types of viewing conditions that change from day to day and across the landscape.

The NASA VIIRS snow-cover detection algorithm was designed to detect snow globally in all situations, but the accuracy of snow mapping varies with land cover and viewing conditions. The NDSI technique, used in the MODIS snow algorithms, has proven to be a robust indicator of snow around the globe. Numerous investigators have used the MODIS snow products and reported accuracy statistics under cloud-free conditions in the range of 88-93%. (See listing of publications at http://modis-snow-ice.gsfc.nasa.gov/?c=publications and at NSIDC http://nsidc.org/data/modis/research.html). The MODIS and NASA VIIRS snow cover algorithms both use the same basic NDSI snow-detection algorithm, albeit adjusted for sensor and input data product differences.

In MODIS C6 and VIIRS C1 an NDSI-based snow cover map is output in two ways: 1) the NDSI value is reported for snow over the range of NDSI = 0.0 to 1.0 with data screens applied and masks of clouds and other features overlaid, and 2) the snow map is masked for oceans and other features, but without data screens or cloud mask applied. NDSI cutoff values can be applied by the user to create SCA maps for specific regions or conditions to increase the accuracy of snow cover detection. This is an improvement over MODIS C5 in which an FSC product with a static cutoff value was provided to the user.

Prior to MODIS C6 and VIIRS C1, FSC was output in the product. The FSC was calculated using an empirical relationship between NDSI and snow cover extent that was based on the extent of snow cover in Landsat Thematic Mapper (TM) 30 m pixels that corresponded to a MODIS 500 m pixel. Calculation of the FSC was abandoned in development of the MODIS C6 algorithm because it was decided that the user is better served to develop their own determination of FSC that is tuned to their specific study area. More information about the FSC in a specific study area can be extracted from the “raw” NDSI data vs. having a “universal” NDSI cutoff.

Analysis of the accuracy of MOD10 C5 snow cover maps by numerous investigators prompted changes in the snow cover detection algorithm for MODIS C6 and VIIRS C1. The algorithm logic is as follows: snow cover always has an NDSI > 0 but not all features with NDSI > 0 are snow. Snow detection is applied to all land pixels in a swath then snow detections are screened to prevent possible snow commission errors, flag uncertain snow detections and set algorithm flags. Results of the data screens are set as bit flags in the Algorithm_bit_flags_QA. All the data screens are applied so it is possible that more than one flag is set for a pixel. Some situations associated with snow commission errors and possible ways to interpret the algorithm bit flags are discussed below.

3.4.1 Warm surfaces

Positive NDSI values may indicate that snow is present in a pixel on a “warm” surface. These snow commission errors can be reduced by screening based on surface temperature, and therefore a surface temperature screen was applied in the MODIS C5 snow-mapping algorithm to reverse all snow detections that were thought to be too warm to be snow. A decision on any pixel detected as snow cover and having an estimated surface temperature > 283 K was reversed to “no snow.” This temperature screen dramatically reduced the occurrence of erroneous snow cover in warm regions of the world and along warm coastal regions. However, after C5 was released, users of the C5 snow product discovered that the temperature screen also caused significant snow omission errors in spring and summer on snow covered mountain ranges. These errors could be very large especially as the average surface temperature within a pixel increased above 283 K. For example, the effect of the temperature screen on mapping snow cover on the Sierra Nevada from 1 May to 1 August 2010 is shown on the following website: http://modis-snow-ice.gsfc.gov/?c=collection6. Snow omission errors were around 10% at start of that time period then rose to near 90% by August. This is obviously unacceptable and was fixed in MODIS C6 and implemented in NASA VIIRS C1.

In MODIS C6 and NASA VIIRS C1 the surface temperature screen is combined with surface elevation and is used in two ways. This combined screen reverses snow cover detection on low elevation, < 1300 m, surfaces that are too warm for snow and sets the algorithm QA bit flag. Snow cover detection at ≥1300 m on a surface that is too warm for snow is not reversed but that snow cover detection is flagged as “too warm,” by setting the algorithm QA bit flag.

The effectiveness of the surface temperature and height screen varies as the surface changes over seasons. It is effective at reversing snow commission errors of some surface features, and cloud-contaminated pixels over some landscapes when the surface is warm. However when the surface is below the threshold temperature, or cloud contamination lowers the estimated surface temperature, this screen is not effective. A surface feature that is spectrally similar to snow, for example the Bonneville Salt Flats, will have snow detection reversed by this screen when the surface is warm but not reversed when the surface is cold and snow-free in the winter.

3.4.2 Low reflectance

Low solar illumination conditions occurring when the SZA is ≥ 70.0° and near to the day/night terminator are a challenge to snow detection. Low reflectance situations in which reflectance is < ~30% across the visible bands is also a challenge for snow detection. Low reflectance across the VIS and SWIR can result in relatively small differences between the VIS and SWIR bands and can give an NDSI > 0 for some non-snow covered surfaces. Investigation and discussion with some users who encountered errors associated with low reflectance surface conditions resulted in setting a low reflectance limit in the algorithm. If VIS reflectance is too low, a pixel is set to "no decision" and the low VIS data screen bit flag is set. This is considered a low limit to accurate detection of snow cover on the landscape. Low reflectance associated with low illumination, landscape shadowed by clouds or terrain, and unmapped water bodies or inundated landscape can exhibit reflectance characteristics similar to snow and thus be erroneously detected as snow by the algorithm. The NDSI is calculated for those "no decision" results so a user can see the NDSI value by using the low visible Algorithm_bit_flags_QA and NDSI data. Very low visible reflectance is a reason for increased uncertainly in detection of snow cover.

3.4.3 Low NDSI

There are situations where the difference between VIS and SWIR is very small that can result in very low positive NDSI values, both on snow covered or snow free surfaces. Such low positive NDSI results can occur where visible reflectance is low or high and where the associated SWIR is low or high but slightly lower than the VIS so that the NDSI is a very low positive value. In our analysis of many such situations we found that very uncertain snow detections or snow commission errors were common when the NDSI was 0.0 < NDSI < 0.1. Based on that analysis a "low NDSI screen" is applied. If NDSI is < 0.1 a snow detection is reversed to "not snow," and the low NDSI bit 2 flag is set in the Algorithm_bit_flags_QA. To determine if these situations are found in a swath, a user can use bit 2 flag to find them and the corresponding NDSI value where snow detections were reversed.

3.4.4 High SWIR reflectance

Unusually high SWIR reflectance may be observed for some snow cover situations. Occasionally this occurs on non-snow surface features, but it can also occur when a cloud is not masked as “certain cloud.” A SWIR screen is applied at two thresholds to either reverse a possible snow commission error or flag snow detection with unusually high SWIR. A user can check this bit flag to determine where uncertain snow cover detections occurred or where snow detection was reversed to “not snow.”

3.4.5 Cloud and snow confusion

Cloud/snow confusion in the VIIRS C1 snow cover is similar to the cloud/snow confusion seen in the MODIS C6 snow cover product. Two common sources of cloud/snow confusion are: 1) the cloud mask does not correctly flag cloudy or clear conditions, and 2) subpixel clouds (cloud mask is at 750 m resolution) escape detection.

The cloud mask algorithm uses many tests to detect cloud. Details of the cloud mask algorithm and product can be found in the cloud mask ATBD and user guide which should become available soon. The combination of tests applied to a pixel, the processing path, depends on whether or not the surface is snow covered. An external snow/ice background map and an internal check for snow cover is made in the cloud mask algorithm; if that initial determination for snow is incorrect then the wrong processing path is followed and a possible erroneous cloud determination is made, e.g. flagging snow as ‘certain cloud.’

An example, flagging snow as ‘certain cloud’ can be associated with swaths of snow cover dropped by storms crossing the Great Plains where snow on the periphery of the snow covered region is flagged as “certain cloud” by the cloud mask. We have investigated this situation in MODIS data and found that the snow was detected as cloud by only a single visible cloud test of the several cloud spectral tests applied in the processing path. By examining the cloud mask algorithm processing path and results of all cloud spectral tests applied, the cloud mask could be reinterpreted as “clear” in that specific situation and the snow could then be correctly detected. That reinterpretation test has been partially effective at resolving this specific cloud/snow confusion situation, however inconsistent results have been found in other situations so the test continues as a research activity.

Subpixel size clouds that escape detection as ‘certain cloud’ by the cloud mask algorithm may be erroneously detected as snow because the cloud spectral properties can cause an underlying snow-free surface to be similar to snow. This situation frequently results in snow commission errors at the periphery of clouds, especially when cloud formations of scattered, popcorn-like clouds are present over vegetated landscapes. Multilayer cloud formations where there are different types of clouds, both warm and cold, and where cloud shadows fall on clouds, may have some regions of the cloud cover that are not detected as ‘certain cloud’ which may then be detected as snow in the snow cover algorithm. These situations can result in snow commission errors as shown in an example taken from MODIS in Figure 6.

Subpixel clouds and cloud-shadowed clouds may be spectrally similar to snow and thus may be detected as snow in the algorithm. The ‘combined surface temperature and elevation screen’ is effective at alleviating snow commission error in many regions, with the effectiveness varying with season, land cover and surface temperature. Use of the cloud mask algorithm processing path flags and individual cloud spectral test flags holds promise for resolving some snow/cloud confusion situations especially if used in combination with other screens for snow reflectance. This is continuing to be investigated. Additionally, users may want to develop filters for their particular study areas taking into consideration the fact that cloud conditions are typically transient, and thus cloud/snow commission errors can possibly be filtered temporally or spatially or by a combination of filters.

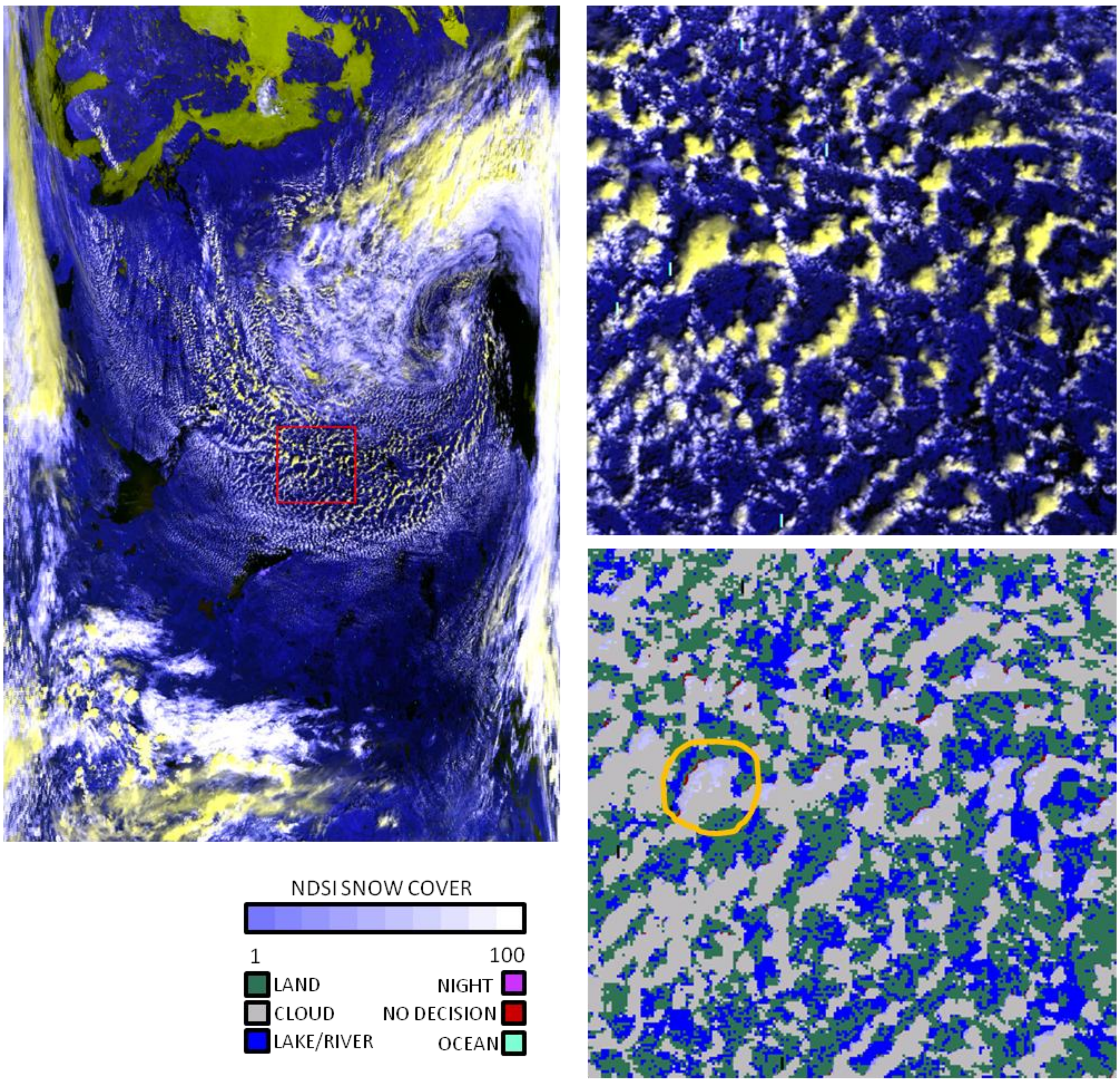

Figure 6. Cloud/snow confusion example. MODIS swath of 13 July 2003 (2003194) 1835 UTC imaging central Canada, left image RGB of bands 1, 4, and 6, Hudson Bay

top right of swath, Great Slave Lake, left center. Cloud type and formation over vegetation in which snow commission errors can occur are shown in image subsets marked by red square in left image, shown in right images, top RGB of bands 1,4 and 6 and NDSI_Snow_Cover, bottom right image. The orange circle highlights a cloud formation where snow commission errors occur on cloud-shadowed cloud and cloud periphery.

3.4.6 Lake ice

An 'inland water detection algorithm' is included in NASA VIIRS C1 to map ice or snow and ice covered lakes and rivers. The lake ice detection algorithm is similar to the snow cover detection algorithm with lake ice cover included in the NDSI_Snow_Cover dataset. The lake ice algorithm is the same as the NDSI snow detection algorithm. Inland water bodies are mapped in bit 0 of the Algorithm_bit_flags_QA dataset for use in analysis of lake ice. The source of the 'inland water mask' is the land/water mask in the geolocation product VNP03IMG_L1 which is the MODIS land/water mask.

Lake ice is included in the NDSI_Snow_Cover dataset so that a spatially coherent image of a snow covered landscape can be seen. A user can extract the inland water mask from bit 0 of the Algorithm_bit_flags_QA dataset either for their analysis or to apply the water mask to the dataset.

Visual analysis of VNP10_L2 swaths and experience with the MOD10_L2 products acquired during the boreal winter when lakes are frozen reveals that snow/ice covered lakes are detected with ~90-100% accuracy. The disappearance of lake ice is also detected with high accuracy. During the ice-free season, changes in physical characteristics of a lake can greatly affect the accuracy of the algorithm. Sediment loads, high turbidity, aquatic vegetation and algae blooms change the reflectance characteristics and may cause erroneous lake or river ice detection in the spring or summer, however such errors have been observed infrequently. A lake-ice-specific algorithm should be developed in a future version of the algorithm.

3.4.7 Bright surface features

Surface features such as salt flats, bright sands, or sandy beaches that have VIS and SWIR reflectance characteristics similar to snow may be detected by the algorithm as snow cover based solely on the NDSI value, thus resulting in errors of commission. The data screens applied in the algorithm can reduce the occurrence of snow commission errors in some situations such as when a low elevation, too-warm surface is (correctly) blocked by the surface temperature and height screen. But these and other data screens are not effective in some other situations. However, surface features that are static, such as salt flats, etc., are are amenable to being masked or flagged by a user.

3.4.8 Land/water mask

The land/water mask in the NASA VIIRS geolocation product is the MODIS C6 land/water mask which was derived from the UMD 250m MODIS Water Mask data product (UMD Global Land Cover Facility http://glcf.umd.edu/data/) (Carroll et al., 2009). The UMD 250 m Water Mask was converted to a 500 m seven class land/water mask for use in the production of MODIS products in C6 to maintain continuity with the land/water mask used in C5. The new land/water mask more accurately provides the location of water bodies [http://landweb.nascom.nasa.gov/QA_WWW/forPage/MODIS_C6_Water_Mask_v3.pdf . Thus LSIPS adapted the MODIS land/water mask to create the VIIRS land/water mask in the geolocation product.

3.4.9 Geolocation accuracy

Geolocation accuracy in NASA VIIRS is very high, providing consistent high accuracy in mapping of the VIIRS data products. The very small errors in geolocation are negligible in the L2 products, however, geolocation error may be observed in the daily gridded products as a shifting of features, e.g., changes in the location of a lake in cells from day to day. That possible cell shifting of features in daily gridded products will be addressed in later version of this user guide).

3.4.10 Antarctica

The Antarctic continent is nearly completely ice and snow covered year 'round, with very little annual variation, though some snow-cover changes are observable on the Antarctic Peninsula. The NASA VIIRS C1 snow cover algorithm is run for Antarctica without any Antarctica-specific processing paths. The resulting snow-cover map may show areas of no snow cover which is an obvious error. That error is related primarily to the great difficulty in detecting clouds over the Antarctic continent. The similarity in reflectance and lack of thermal contrast between clouds and ice/snow cover are major challenges to accurate snow/cloud discrimination. In situations where the cloud mask fails to identify "certain cloud," the snow algorithm assumes a cloud-free view and either identifies the surface as "not snow covered" or identifies the cloud as snow. In either case the result is wrong. Though the VPN10* snow products are generated for Antarctica, they must be carefully scrutinized for accuracy and quality.

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3.5 Related Web Sites

Suomi-NPP
http://npp.gsfc.nasa.gov/suomi.html

VIIRS
VIIRS Land: http://viirsland.gsfc.nasa.gov/
MODIS Snow/Ice Global Mapping Project:

http://modis-snow-ice.gsfc.nasa.gov

Imagery and Data Product Viewing
Worldview: https://worldview.earthdata.nasa.gov
LANCE: https://wiki.earthdata.nasa.gov/display/GIBS/2015/12/10/VIIRS+is+Here
https://earthdata.nasa.gov

NSIDC Data Ordering & User Services
National Snow and Ice Data Center: http://nsidc.org/data/viirs

HDF5
The HDF Group: https://www.hdfgroup.org/HDF5/

NetCDF4
www.unidata.ucar.edu/software/netcdf/docs/index.html

3.6 References

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

Wolfe, R.E. and H.K. Ramapriyan (2010), Scaling the pipe: NASA EOS Terra data systems at 10, *Proceedings of the Geoscience and Remote Sensing Symposium (IGARSS), 2010*, Honolulu, HI, 25 – 30 July, 2010, 1300 – 1303.

Appendix A

Listing of global attributes in VNP10_L2

```
// global attributes:
        :PGE_StartTime = "2016-03-07 20:48:00.000" ;
        :ProductionTime = "2016-09-09 13:06:07.000" ;
        :ProcessingEnvironment = "Linux minion5581 2.6.18-410.el5 #1 SMP Wed May 11
06:00:14 EDT 2016 x86_64 x86_64 x86_64 GNU/Linux" ;
        :publisher_url = "http://ladsweb.nascom.nasa.gov" ;
        :processing_level = "Level 2" ;
        :PGE_EndTime = "2016-03-07 20:54:00.000" ;
        :naming_authority = "gov.nasa.gsfc.VIIRSland" ;
        :creator_url = "http://ladsweb.nascom.nasa.gov" ;
        :cdm_data_type = "swath" ;
        :InputPointer =
"VNP35_L2.A2016067.2048.001.2016139201152.hdf,NPP_VIAES_L1.A2016067.2048.001.2016097134
203.hdf,NPP_VMAES_L1.A2016067.2048.001.2016097134203.hdf,NPP_IMFTS_L1.A2016067.2048.001
.2016095195212.hdf" ;
        :PGEVersion = "1.0.3" ;
        :creator_name = "VIIRS Land SIPS Processing Group" ;
        :PGE_Name = "PGE507" ;
        :RangeEndingDate = "2016-03-07" ;
        :publisher_email = "modis-ops.nasa.gov" ;
        :LocalGranuleID = "VNP10_L2.A2016067.2048.001.2016253130607.nc" ;
        :title = "VIIRS Snow Cover Data" ;
        :project = "VIIRS Land SIPS Snow Cover Project" ;
        :LongName = "VIIRS/NPP Level 2 6-Min Snow Cover - 375m" ;
        :RangeBeginningDate = "2016-03-07" ;
        :AlgorithmType = "OPS" ;
        :LSIPS_AlgorithmVersion = "NPP_PR10 1.0.3" ;
        :Product_authority = "http://dx.doi.org" ;
        :creator_email = "modis-ops.nasa.gov" ;
        :Conventions = "CF-1.6" ;
        :ProcessVersion = "001" ;
        :SatelliteInstrument = "NPP_OPS" ;
        :ProcessingCenter = "MODAPS-NASA" ;
        :ShortName = "VNP10_L2" ;
        :RangeEndingTime = "20:54:00.000000" ;
        :license = "http://science.nasa.gov/earth-science/earth-science-data/data-information-
policy/" ;
        :publisher_name = "LAADS" ;
        :stdname_vocabulary = "NetCDF Climate and Forecast (CF) Metadata Convention" ;
        :Product_doi = "10.5067/VIIRS/VNP10_L2.v001" ;
        :RangeBeginningTime = "20:48:00.000000" ;
        :keywords_vocabulary = "NASA Global Change Master Directory (GCMD) Science
Keywords" ;
        :institution = "NASA Goddard Space Flight Center" ;
```