NASA S-NPP VIIRS Snow Products
Collection 1 (C1)
User Guide

Release 1.0

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List of Acronyms

ATBD	Algorithm Theoretical Basis Document
BT	Brightness Temperature
Cx	Collection number
CDR	Climate Data Record
CMG	Climate-Modeling Grid
EDR	Environmental Data Record
EOSDIS	Earth Observing System Data Information System
ESDT	Earth Science Data Type
FSC	Fractional Snow Cover
HDF5	Hierachical 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 swath-based Snow Cover Data Product
VNP10A1	ESDT name for the VIIRS Level-3 tiled Snow Cover Data Product
VNP10C1	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 is developed synergistically with the Moderate Resolution Imaging Spectroradiometer (MODIS) Collection 6 (C6) snow cover algorithms, leveraging analysis and evaluation from both to make nearly-identical algorithms and similar data products. The overall objective for VIIRS Collection 1 (C1) is to make the NASA VIIRS snow cover mapping algorithms compatible with the C6 MODIS snow cover algorithms for eventual development of a climate-data record (CDR) using products from the two sensors. Differences between the MODIS C6 and the NASA VIIRS algorithms originate from the physical differences between the MODIS and VIIRS sensors, including spatial resolution and band location and width, and the respective cloud masks that are input to the algorithms. The NASA VIIRS snow cover algorithms and data products in C1 have been significantly revised and data content has been increased compared to the original NOAA-Interface Data Processing Segment (IDPS) snow cover products that were developed based on the MODIS Collection 5 (C5) snow cover algorithms.

Snow cover is detected using the Normalized Difference Snow Index (NDSI) snow cover. As in MODIS C6 snow products, both a NDSI snow cover map with masks of clouds, night and oceans are applied and the NDSI calculated for all underlying land pixels in the products. The estimate of Fractional Snow Cover (FSC) that was done in MODIS C5 is not made in the algorithm. The NDSI is related to the presence of snow in a pixel and is a more accurate description of the snow detection as compared to estimating FSC based on empirical relationships and allows a user greater flexibility in interpreting data. A detailed explanation for the change from FSC to NDSI snow cover is given in the NASA VIIRS snow cover ATBD [http://npp.gsfc.nasa.gov/documents.html]. Should a user want to estimate FSC they could develop their own relationship between NDSI and FSC for a given study area.

The VIIRS snow cover data products are in NetCDF4.2 CF-1.6 or Hierarchical Data Format 5 (HDF5) (http://www.unidata.ucar.edu/software/netcdf/docs/index.html and https://www.hdfgroup.org/HDF5/) depending on product level. Level-2 products consists of 6-minute swaths. Those are both changes from the MODIS C6 products which are in HDF-EOS4 and consist of 5- minute swaths. The daily tiled product will be projected to the sinusoidal (SIN) projection, which is the same as for MODIS, but will be at the VIIRS nominal spatial resolution of 375 m.

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). The VIIRS snow products are referenced by their Earth Science Data Type (ESDT) name, e.g., VNP10*, in this guide (the asterisk refers to all of the NASA VNP snow products, not a specific product). The ESDTs are produced as a series of products in which data and information are propagated to the higher level products. Details of the algorithms and 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., 2016) for further details.

Note: The User Guide is developed in increments for each product as they are scheduled to be released so check that you have the latest version of the guide.

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. Products in EOSDIS are labeled with ESDT name, e.g. VNP10*, in which the asterisk refers to all three of the NASA VIIRS snow cover products. The ESDT name is used to identify the snow data products. The ESDT also indicates the spatial and temporal processing that has been applied to the data product. Data product levels briefly described are: Level 1B (L1B) is a swath (scene) of VIIRS data geolocated to latitude and longitude. A Level 2 (L2) product is a geophysical product that remains in the 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 products. A level 3 (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 VNP10 snow cover product is in NetCDF4.2 CF-1.6/HDF5 format, and HDF5 tools have been used to extract and list data contents. NetCDF Climate and Forecast (CF) Metadata Conventions, Version 1.6, 5 December 2011, have been adopted for relevant metadata. In HDF5 metadata are written as attributes, the terms attribute and metadata are synonymous in this guide.

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

Metadata describing the time of acquisition of the swath, geographic location of swath, production of the data product, provenance and 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 guide.

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

Products	ESDT	Description
Snow Cover (L2 Daily Swath product)	VNP10	VIIRS/NPP Snow Cover 6-Min Swath 375 m

Snow Cover (L3 Daily Tiled products)	VNP10A1	VIIRS/NPP Snow Cover Map Daily L3 Global 375 m SIN Grid Day
Snow Cover (L3 CMG Products)	VNP10C1	VIIRS/NPP Daily Snow Cover L3 Global 0.05°x0.05° climate-modeling grid (CMG)

3.0 VNP10

The NASA VIIRS snow cover swath product, VNP10 contains dimensions, a snow data group of datasets and attributes, group attributes, and global attributes for the file. Contents of VNP10 are given in List 1.

List 1. File level description of the contents of the VNP10 product.

```
dimensions:
        number_of_lines = 6464 ;
        number_of_pixels = 6400 ;
global attributes:
group: GeolocationData
group: SnowData
```

3.1 Geolocation Data

The latitude and longitude data for each pixel in a swath are stored as coordinate datasets in the GeolocationData group in the VNP10. The coordinate variables, attributes and datasets use the netCDF CF conventions for georeference. Software tools that work with the netCDF or HDF5 data formats should be able to work with the VNPD10 product. Description of the GeolocationData group is given in List 2.

List 2. Description of the GeolocationData group and attributes in VNP10.

```
group: GeolocationData {
  variables:
        float latitude(number_of_lines, number_of_pixels) ;
                latitude:long_name = "Latitude data" ;
                latitude:units = "degrees_north" ;
                latitude:standard_name = "latitude" ;
                latitude:_FillValue = -999.f ;
                latitude:valid_range = -90.f, 90.f ;
        float longitude(number_of_lines, number_of_pixels) ;
                longitude:long_name = "Longitude data" ;
                longitude:units = "degrees_east" ;
```

```
longitude:standard_name = "longitude" ;
longitude:_FillValue = -999.f ;
longitude:valid_range = -180.f, 180.f ;
} // group GeolocationData
```

3.2 SnowData Group

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

List 3. Description of SnowData group datasets and attributes in VNP10.

```
group: SnowData {
  variables:
        ubyte Algorithm_bit_flags_QA(number_of_lines, number_of_pixels) ;
                Algorithm_bit_flags_QA:coordinates = "latitude longitude" ;
                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:coordinates = "latitude longitude" ;
                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:coordinates = "latitude longitude" ;
                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:mask_meanings = "201=no decision, 211=night,
237=lake, 239=ocean, 250=cloud, 251=missing data, 252=L1B_unusable, 253=bowtie
trim, 254=L1B fill" ;
                    NDSI_Snow_Cover:_FillValue = 255UB ;
                    NDSI_Snow_Cover:coordinates = "latitude longitude" ;
                    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, 252UB, 253UB, 254UB ;

  // group attributes:
                    :Surface_temperature_screen_threshold = "281.0 K" ;
                    :Surface_height_screen_threshold = "1300 m" ;
                    :Land_in_clear_view = "59.0%" ;
                    :Cloud_cover = "41.0%" ;
                    :Snow_Cover_Extent = "8.8%" ;
  } // group SnowData
}
```

3.2.1 Datasets

The VNP10 product has the following datasets: NDSI_Snow_Cover, Basic_QA, Algorithm_bit_flags_QA and NDSI, each with attributes describing the data,

3.2.1.1 NDSI_Snow_Cover The NDSI_Snow _Cover dataset is the snow cover extent map 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. 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. Onboard VIIRS bowtie trim lines are retained in this swath product. An example of the NDSI_Snow_Cover dataset, with colorized ranges of NDSI is shown in Figure 1.

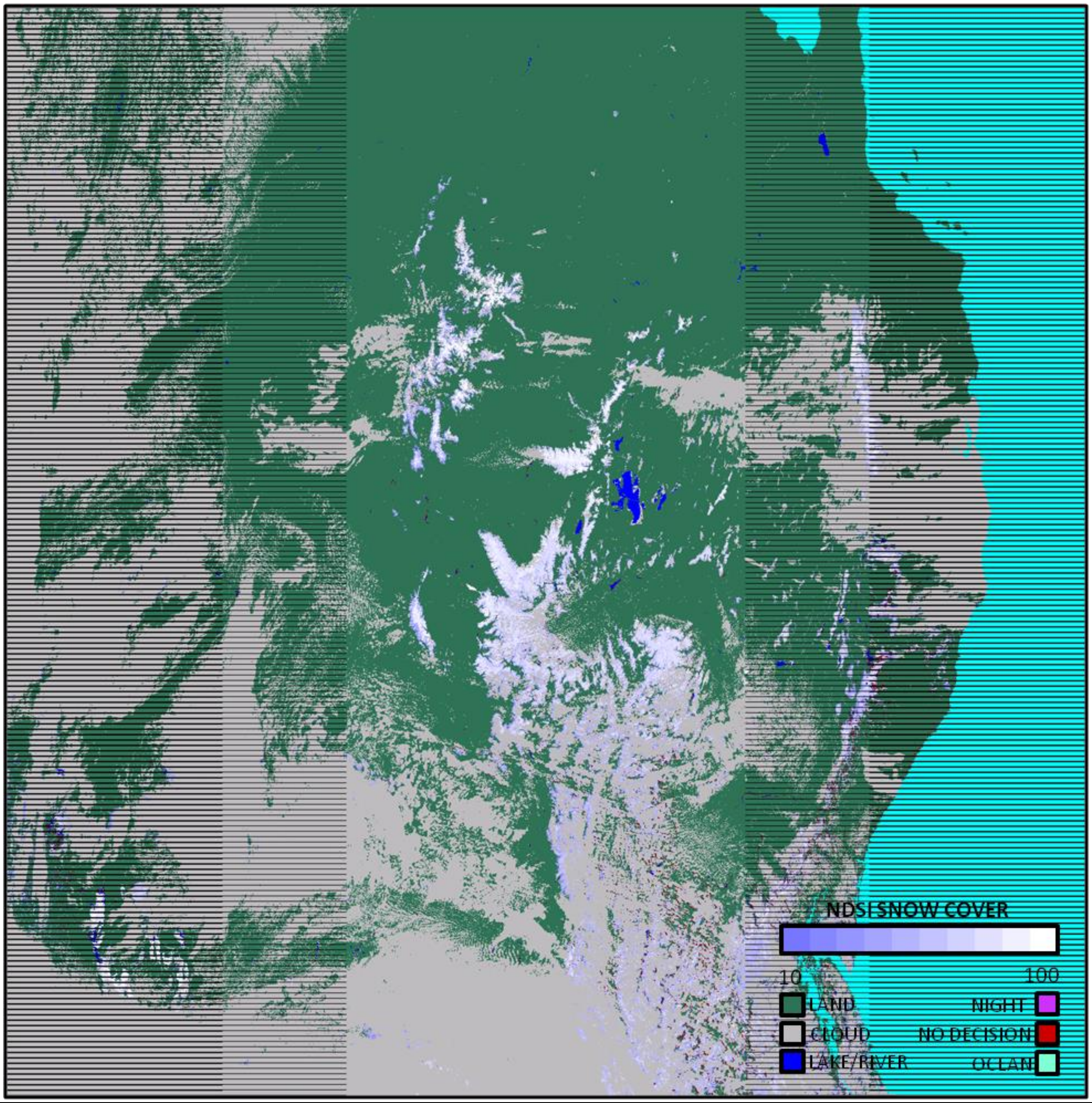

Figure 1. VNP10.A2017105.2012.001.*.nc. NDSI_Snow_Cover map. The western United States is imaged on 15 April 2017. Orientation is with north at bottom of image. Snow covered Rockies in the Colorado region is top center of swath, Uinta Mountain Range and Great Salt Lake are to the north and the Wind River Range, Yellowstone region and Big Horn Range, with cloud cover are to the north of that region.

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 have dual purpose to either reverse a snow detection or to flag uncertain pixel result. Some screens are also applied to all land pixels in clear view. The Algorithm_bit_flags_QA dataset for the swath shown in Fig.1, with selected bit flags displayed is shown in Fig. 2. See Section 3.3.1 for description of bit flags. Local attributes describing each bit flag are included.

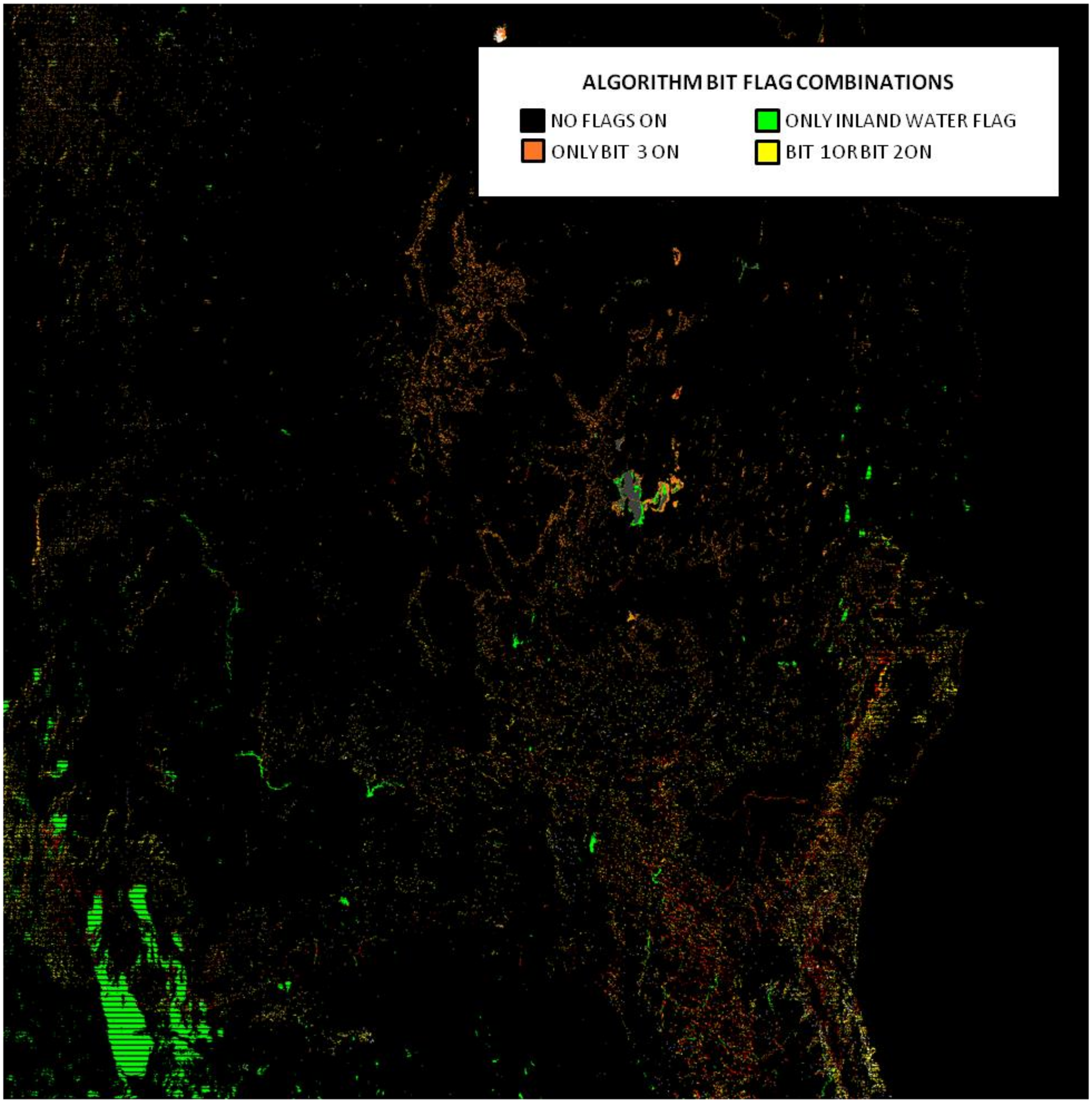

Figure 2. VNP10.A2017105.2012.001.*.nc. Algorithm_bit_flags_QA dataset that corresponds to the NDSI_Snow_Cover map in Fig.1. Only a few bit flags or bit flag combinations are shown to demonstrate how the bit flags can be used in evaluation/analysis of the snow cover map. These bit flags indicate situations where

there is increased uncertainty in snow cover detection along the edges of snow cover, cloud cover and shadowed landscape. At the scale of this image it is difficult to evaluate the results: zooming in on the maps is required for detailed analysis. An example of a detailed analysis is given in Sec. 3.4.

3.2.1.3 Basic QA A general quality value is given for pixels processed for snow cover. 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.

3.2.1.4 NDSI The calculated NDSI values for all land and inland water pixels without the cloud mask is output in this dataset. The NDSI data is scaled (packed data), and the NDSI valid range is -1.0 to 1.0, and has masks, other than the cloud mask applied. Attributes describing the data are included.

3.3 Snow Cover Detection Algorithm Synopsis

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 VIIRS ATBD (Riggs et al., 2015).

The basis of the NASA VIIRS snow-mapping algorithms is the NDSI. Snow typically has very high visible (VIS) reflectance and very low reflectance in the shortwave infrared (SWIR), a characteristic commonly used to detect snow and to distinguish snow from most cloud types. 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:

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. Snow cover is reported over the NDSI > 0.0 range. A binary snow cover area (SCA) map is not output. Users may be familiar with the SCA map that was part of the MODIS C5 snow cover product suite but that SCA is not output in the MODIS C6 or NASA VIIRS C1 snow cover products. Users may want a SCA map. A commonly accepted global NDSI threshold value of 0.4 has been used to make SCA maps, 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 relationships 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 and is no longer static at a threshold of 0.4. In short, a user can make a SCA map using the NDSI snow cover or NDSI datasets in the product by setting an NDSI threshold that is appropriate for a particular study area.

The NDSI is calculated in the algorithm for all land and inland water bodies in daylight, and 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 and basic processing flow is depicted in Figure 3. The processing flow for a pixel is determined based on the land/water mask. Land and inland water bodies in daylight are processed for snow detection or ice/snow on water detection. VIIRS reflectance data is checked for missing or uncalibrated values; pixels with those values are set to a mask value and not processed for snow cover.

Table 2. VIIRS data product inputs to the VNP10 algorithm.

ESDT	Dataset	Center wavelength	Nominal spatial resolution
NPP_VIAES_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_VMAES_L1	Reflectance_M4	0.555 µm	750 m
NPP_IMFTS_L1	Latitude, Longitude, solar zenith angle		375m
VNP35 _L2	Cloud confidence flag, land/water mask		750m

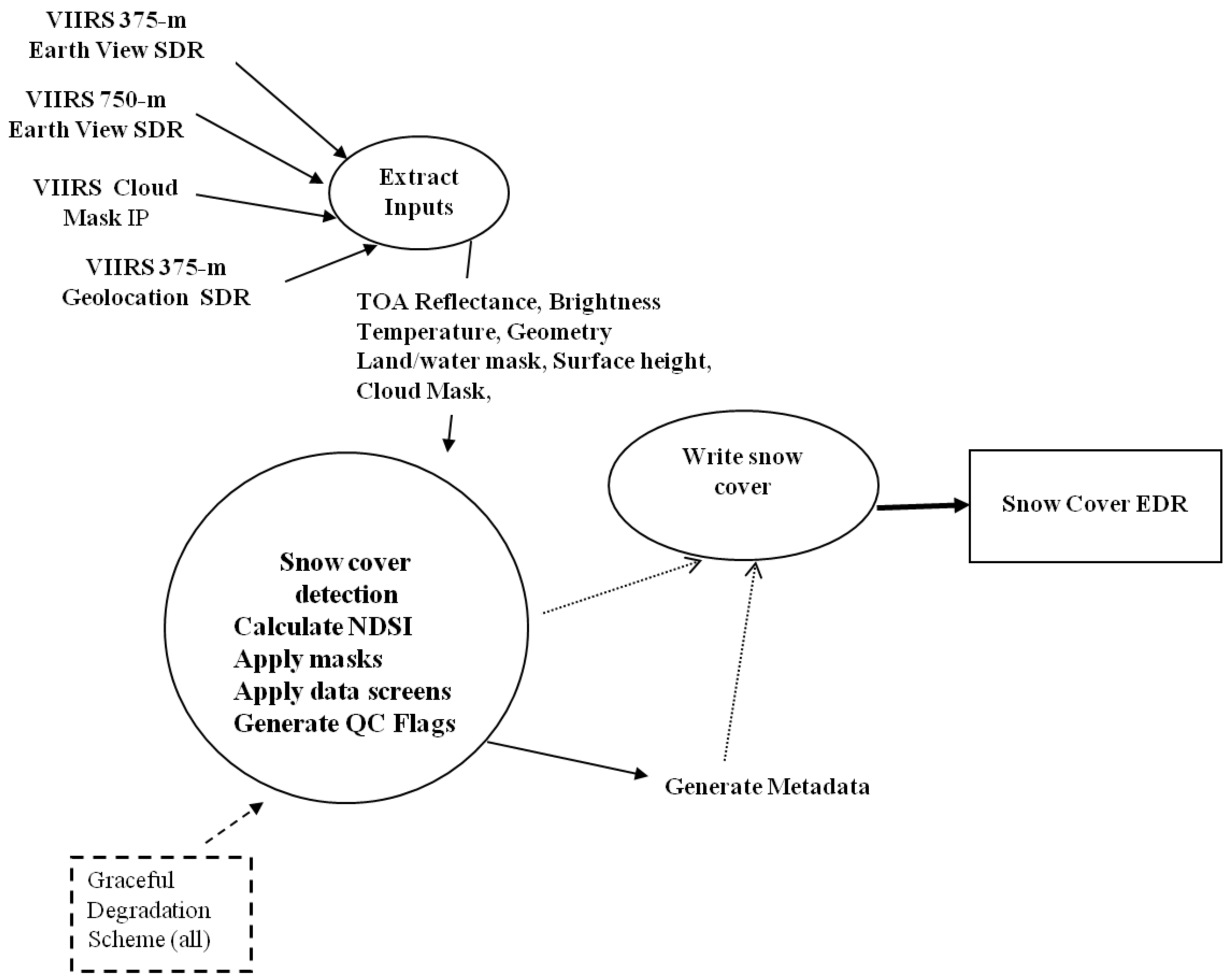

Figure 3. Snow Cover Environmental Data Record (EDR) processing architecture.

3.3.1 Data Screens

If a pixel has been determined to have some snow present based on the NDSI value, it is subjected to the following series of 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 that are 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.

<u>3.3.1.1 Low VIS reflectance screen</u>. 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. If a pixel is failed a “no decision” is the result. This screen is tracked in bit 1 of the Algorithm_bit_flags_QA.

<u>3.3.1.2 Low NDSI screen.</u> Pixels detected with snow cover in the 0.0 < NDSI < 0.10 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".

<u>3.3.1.3 Estimated surface temperature and surface height screen.</u> There is a dual purpose for this estimated surface temperature linked with surface height screen. It is used to alleviate snow commission errors on 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 on high elevations that are warmer than expected for snow. If snow is detected in a pixel at elevations < 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 elevations ≥ 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.

<u>3.3.1.4 High SWIR reflectance screen.</u> 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 thresholds 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 in the SWIR. 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.

<u>3.3.1.5 Solar zenith screen</u>. 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 with SZA ≥ 85° 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_lags_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 VNP35_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 cloudy, probably cloudy, confident clear, and probably clear. If the cloud mask flags "confident cloudy" then the pixel is masked as cloud. If the cloud mask flag is set "confident clear," "probably clear" or "probably cloudy" it is interpreted as clear in the algorithm.

3.3.4. Quality Assessment (QA)

Two QA datasets are output; the Basic_QA which gives a simple value score, and 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 good value and is adjusted based on the quality of the L1B input data and the solar zenith data screen. If the reflectance data is outside the range of 5-100% it is usable, but the QA value is set to 'poor'. If the SZA is in the range of $70° \leq SZA < 85°$, the QA is set to 'poor,' which indicates increased uncertainty in results because of low illumination. If input data is unusable the QA value is set to 'other.' Conditions for a bad 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 data screen results applied in the algorithm. The data screens serve two purposes: 1) they indicate why a snow detection was reversed to "not snow," and 2) represent a QA flag for uncertain snow detection or challenging viewing conditions. More than one bit flag may be set because multiple data screens can be 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 pixels 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. 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

The NASA VIIRS snow cover detection algorithm was designed to detect snow globally in all situations. The NDSI technique for snow detection 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). 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.

Prior to the MODIS C6 snow cover product and this VIIRS C1 product, 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 30 m pixels that corresponded to a MODIS 500 m pixel. Calculation of the FSC was abandoned in the MODIS C6 algorithm because it caused a reduction in information that could possibly be extracted compared to a user having access directly to the NDSI data. Many published studies report on NDSI techniques that can be used to create snow cover area maps for specific regions or conditions that increase accuracy of snow cover detection in that situation as compared to the globally based MODIS snow cover area product. In MODIS C6 and VIIRS C1 snow cover data is output in two ways: 1) an NDSI based snow cover map that reports the NDSI value for snow over the 0.0 to 1.0 range with data screens applied to reduce error in snow cover detections and with masks of clouds and other features overlaid and 2) the NDSI data is output without data screens or cloud mask applied, but is masked for oceans and other features.

Snow cover is detectable with good accuracy when illumination conditions are near ideal, skies are clear, and several centimeters or more of snow are present on the landscape. Snow cover can occur on many different landscapes, including forests, plains and mountains, and under all types of viewing conditions. Viewing conditions change from day to day and across the landscape. The diversity of situations where snow may be found makes it challenging to develop a globally-applicable snow cover detection algorithm.

Analysis of MOD10 C5 snow cover maps, with emphasis on snow cover omission and commission errors observed and reported in the literature 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 in following subsections.

3.4.1 Warm surfaces

Snow commission errors on warm surfaces with positive NDSI values can be reduced by screening based on estimated surface temperature. 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.” That temperature screen was shown to dramatically reduce the occurrence of erroneous snow cover in warm regions of the world and along warm coastal regions. However, it was 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 as the average surface temperature within a pixel increased above 283 K. The effect of the temperature screen on mapping of snow cover on the Sierra Nevada from 1 May to 1 August 2010 is shown at 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% at the end.

In MODIS C6 and NASA VIIRS C1 the surface temperature screen is combined with surface elevation and used in two ways. This combined screen reverses snow cover detection on low elevation < 1300 m surfaces that are too warm for snow and the algorithm QA bit flag is set. 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.

A possible effect of this screen may be observed along the edge of mountain snow where snow cover detection is changed to "no snow". An example of the situation is shown in Fig. 4 on the Uinta Mountain Range, Utah, subimage from Fig. 1, where snow cover detection was changed to "not snow" by only the combined high elevation and surface temperature screen (bit 3 in the Algorithm_bit_flags_QA dataset) shown by the red pixels in the right image. Detecting snow along the edge of the mountain snow cover, i.e. defining exactly where snow cover ends, is a challenge. Visual evaluation of visible and temperature data and NDSI_Snow_Cover find that this screen does have an effect along the edge of snow cover and that it can be interpreted as showing an edge or band of one to few pixels of uncertainty in snow cover. It is possible to change those "no snow" pixels to "snow" pixels by using the unique combination of NDSI_Snow_Cover = 0 and bit3 on (Algorithm_bit_flags_QA = 8) and the corresponding NDSI data value to restore snow to the pixel. This demonstrates that a user has options on how to interpret and utilize the datasets for their research or application.

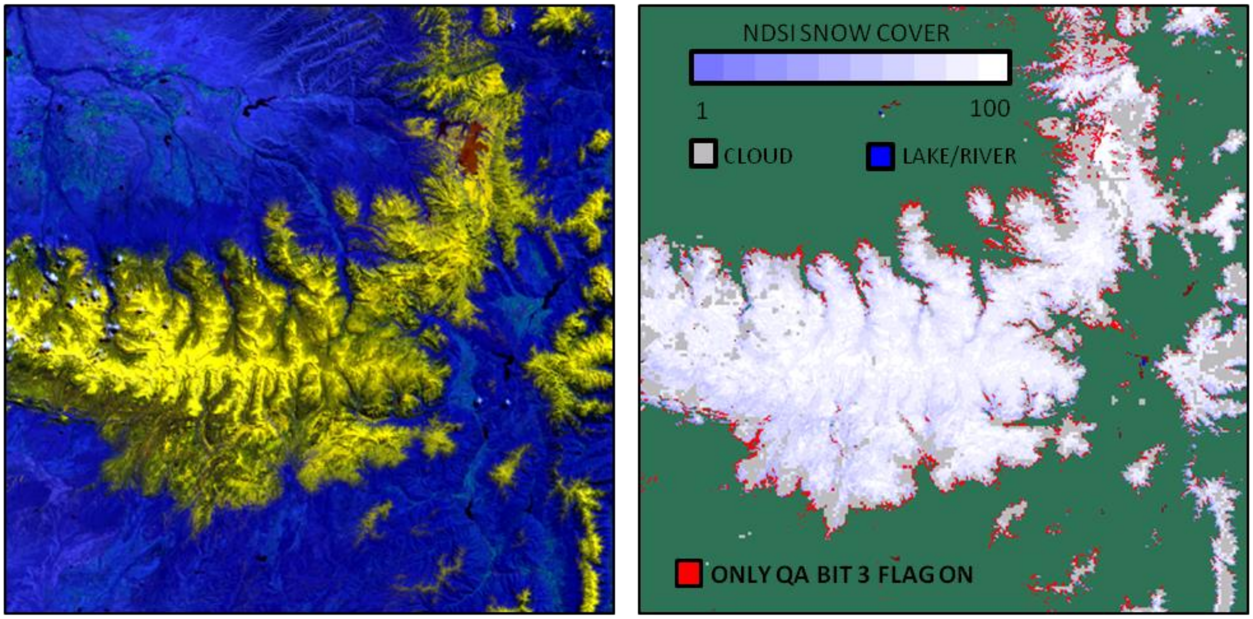

Figure 4. Uinta Mountain Range, Utah, with only the combined high elevation and surface temperature screen showing were snow cover detection was changed to a “no snow” cover result in the NDSI_Snow_Cover map. The left image is a false color of a VIIRS bands I1, I2, I3 subimage from NPP_VIAES_L1.A2017105.2012.001.*.nc. The right image is the corresponding NDSI_Snow_Cover from VNP10.A2017105.2012.001*.nc (Fig. 1) with where only the Algorithm_bit_flags_QA combined high elevation and surface temperature screen (bit3) changed a snow detection to “no snow” shown in red.

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, may have snow detection reversed by this screen when the surface is warm but may not be reversed when the surface is cold and snow-free in the winter.

3.4.2 Low reflectance

Situations of low reflectance from the surface for various reasons pose challenges to snow detection and may cause snow commission errors. Several data screens and bit flags are set for low reflectance conditions.

Low solar illumination conditions occurring when the SZA is > 70.0° and near to the day/night terminator are a challenge to snow detection. That situation is identified by the low solar zenith flag (bit 7) in the Algorithms_bit_flags_QA dataset set to on.

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 bands 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 of the MODIS C5 products 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 in the Algorithm_bit_flags_QA dataset. This is considered a low limit to accurate detection of snow cover on the landscape. 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.

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. Very low visible reflectance is a cause for increased uncertainly in detection of snow cover. Though the data screens applied can prevent snow commission error, some snow commission errors can go undetected, notably on cloud shadowed snowless landscape as shown in Fig. 5. A subimage is shown from a region of scattered clouds over snow free land near the east side of nadir track north of the Big Horn Range in Wyoming from VNP10 (Fig. 1); a few scattered clouds and their shadow on the surface may be seen, left image Fig. 5, and the NDSI_Snow_Cover, center image, with snow commission errors associated with the shadowed surface. In this situation the cloud mask detects the clouds, and several of the data screens prevent snow commission errors as shown by the colored pixels, right image, that are bit flags set to prevent snow commission errors. However snow commission errors, blue pixels center image, occur that are associated with the periphery of cloud and shadowed land.

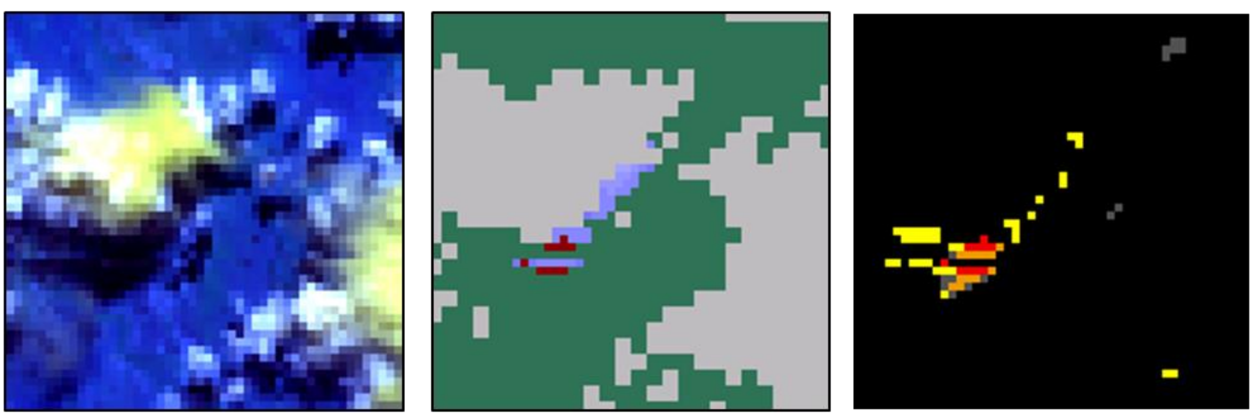

Figure 5. Example of snow commission associated with cloud periphery and shadowed surfaces. The left image (50 x 50 pixels) is a false color of VIIRS bands I1, I2, I3 subimage from NPP_VIAES_L1.A2017105.2012.001.*.nc. The center image is the corresponding NDSI_Snow_Cover from VNP10.A2017105.2012.001*.nc (Fig. 1). Algorithm_bit_flags_QA set on to prevent snow commission error are shown as colored pixels in the right image.

3.4.3 Low NDSI

Low VIS reflectance situations, snow covered or snow free surfaces, where the difference between VIS and SWIR is very small can have very low positive NDSI values. Those 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 $0.0 \leq NDSI < 0.1$. 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 were 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, from some types of clouds not masked as confident cloudy or from non-snow surface features. 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 find where uncertain snow cover detections occurred or where snow detection was reversed to "not snow."

3.4.5 Cloud and snow confusion

Cloud and snow confusion in the VIIRS C1 snow cover is similar to the snow and cloud confusion seen in the MODIS C6 snow cover product. Both cloud masks are cloud conservative which tend to favor cloud detection over cloud clearing. Two common sources of cloud/snow confusion are that the cloud mask does not correctly flag cloudy or clear conditions and where subpixel clouds (cloud mask is at 750 m resolution) escape detection.

The cloud mask algorithm uses many tests to detect cloud and the combination of tests applied to a pixel, the processing path, depends on whether or not the surface is snow covered. (Details of the cloud mask algorithm and product can be found in the cloud mask Operational Algorithm Document (OAD) [https://jointmission.gsfc.nasa.gov/documents.html, Document # 474-0062 VIIRS Cloud Mask (VCM) Intermediate Product (IP) Software – OAD Revision I]. 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 confident cloudy. An example of that can be seen in Fig. 4 where there are clouds along the periphery of the mountain snow cover but no visible evidence of clouds in the corresponding visible color image. This situation can be seen associated with swaths of snow cover from storms crossing the Great Plains where snow on the periphery of the snow covered region is flagged as "confident cloudy" by the cloud mask. We have investigated this cloud/snow confusion situation 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. We found that by examining the cloud mask algorithm processing path and results of all cloud spectral tests applied that the cloud mask could be reinterpreted as clear in that specific situation and the snow could then be correctly detected. That reinterpretation test was partially effective at resolving this specific cloud/snow confusion situation however in global application of that test, inconsistencies in results were found, so further investigation is required.

Subpixel size clouds that escape detection as "confident cloudy" by the cloud mask algorithm may be detected as snow in the snow algorithm because the cloud reflectance can cause an underlying snow free surface to have one or more reflectance features similar to snow. This situation frequently results in snow commission errors associated with the periphery of clouds, especially with cloud formations of scattered, popcorn-like cloud formations over vegetated landscapes. Multilayer cloud formations where there are different types of clouds, warm and cold, and where cloud shadows fall on clouds may have some regions of the cloud cover not detected as confident cloudy which may then be detected as snow in the snow cover algorithm. In those types of cloud cover conditions the subpixel contaminated clouds and self-shadowed clouds are spectrally indistinct from snow in the algorithm. Use of the cloud mask algorithm processing path flags and individual cloud spectral tests flags possibly in combination with other screens for snow reflectance holds promise for resolving some snow/cloud confusion situations and is being investigated. Cloud conditions are typically transient. Such transient cloud/snow commission errors can possibly be filtered temporally or spatially or by a combination of filters developed by users.

3.4.6 Lake ice

A lake ice detection algorithm is included in the 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 bodies mask is the land/water mask in the geolocation product VNP03GEO 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 for use in analysis or to apply as a static water mask.

Visual analysis of VNP10 swaths and experience with the MOD10_L2 products acquired during boreal winter when lakes are frozen finds that snow/ice covered lakes are detected with 90-100% accuracy. Disappearance of lake ice also appears to be detected with a 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. 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 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, e.g., a low elevation; too-warm surface can be blocked by the combined surface temperature and height screen, but may not be effective in other situations. These types of surface features are static so a user could mask or flag these surfaces relevant to a specific research or application.

3.4.8 Land/water mask

In this C1 processing of VNP10 the land/water mask is read from the VNP35 product. That land /water mask (flag) is determined using the Quarterly Surface Type/Land Water Mask specifically for the cloud mask algorithm. That land/water mask was used because it was available in the production stream of input products. That land/water mask is not the same as the MODIS land/water mask used in MOD10_L2 C6 so it is possible that differences in locations of coastlines and water bodies may be observed when comparing VNP10 to MOD10_L2.

When the NASA VIIRS geolocation data product that contains the MODIS C6 land/water mask becomes available, along with the NASA L1B products, the VNP10 algorithm will be revised to use those inputs.

3.4.9 Geolocation accuracy

Geolocation accuracy is good which provides consistent high accuracy in mapping of the VIIRS data products [https://viirsland.gsfc.nasa.gov/Products/Geolocation.html. The small errors in geolocation are negligible in the swath level products however, geolocation error may be observed in the daily gridded products as a shifting of features, e.g. lake location, in cells from day to day. A comment on geolocation accuracy in gridded products will be provided later when those products are added to future versions 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 changes are observable on the Antarctic Peninsula. The NASA VIIRS C1 snow cover detection 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 and thermal inversions are major challenges to accurate snow/cloud discrimination. In situations where the cloud mask fails to identify “confident cloudy,” 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 VNP10 is generated for Antarctica, it 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: https://viirsland.gsfc.nasa.gov/
VIIRS Cryosphere: https://viirsland.gsfc.nasa.gov/Products/NASA/CryoESDR.html

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/earth-observation-data/near-real-time/download-nrt-data/viirs-nrt

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

LAADS DAAC
https://ladsweb.modaps.eosdis.nasa.gov

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

NetCDF
http://www.unidata.ucar.edu/software/netcdf/docs/index.html

3.6 References

Riggs, G., Hall, D.K. and Román, M.O. 2015 VIIRS Snow Cover Algorithm Theoretical Basis Document (ATBD) https://modis-snow-ice.gsfc.nasa.gov//uploads/VIIRS_snow_cover_ATBD_2015.pdf

Appendix A
Example of VNP10 global attributes.

```
// global attributes:
		:QAPercentCloudCover = "41.0%" ;
		:Snow_Cover_Extent = "8.8%" ;
		:QAPercentBestQuality = "99.9%" ;
		:QAPercentGoodQuality = "0.1%" ;
		:QAPercentPoorQuality = "0.0%" ;
		:QAPercentOtherQuality = "0.0%" ;
		:RangeEndingTime = "20:18:00.000000" ;
		:RangeBeginningTime = "20:12:00.000000" ;
		:AlgorithmType = "OPS" ;
		:processing_level = "Level 2" ;
		:creator_email = "modis-ops@lists.nasa.gov" ;
		:AlgorithmVersion = "NPP_PR10 1.0.3" ;
		:PGEVersion = "1.0.6" ;
		:ProductionTime = "2017-04-16 05:25:46.000" ;
		:keywords_vocabulary = "NASA Global Change Master Directory (GCMD)
Science Keywords" ;
		:title = "VIIRS Snow Cover Data" ;
		:naming_authority = "gov.nasa.gsfc.VIIRSland" ;
		:publisher_name = "LAADS" ;
		:creator_url = "http://ladsweb.nascom.nasa.gov" ;
		:RangeBeginningDate = "2017-04-15" ;
		:WestBoundingCoord = -135.0753f ;
		:Conventions = "CF-1.6" ;
		:ProcessingEnvironment = "Linux minion7239 3.10.0-514.10.2.el7.x86_64
#1 SMP Fri Mar 3 00:04:05 UTC 2017 x86_64 x86_64 x86_64 GNU/Linux" ;
		:VersionID = "001" ;
		:StartTime = "2017-04-15 20:12:00.000" ;
		:SatelliteInstrument = "NPP_OPS" ;
		:stdname_vocabulary = "NetCDF Climate and Forecast (CF) Metadata
Convention" ;
		:publisher_url = "http://ladsweb.nascom.nasa.gov" ;
		:cdm_data_type = "swath" ;
		:institution = "NASA Goddard Space Flight Center" ;
		:GRingPointLongitude = -90.9374, -122.728, -135.075, -91.5693 ;
		:LongName = "VIIRS/NPP Snow Cover 6-Min L2 Swath 375m" ;
		:identifier_product_doi_authority = "http://dx.doi.org" ;
		:ProcessingCenter = "MODAPS-NASA" ;
		:PGE_EndTime = "2017-04-15 20:18:00.000" ;
		:publisher_email = "modis-ops@lists.nasa.gov" ;
		:RangeEndingDate = "2017-04-15" ;
		:SouthBoundingCoord = 28.67912f ;
		:LocalGranuleID = "VNP10.A2017105.2012.001.2017106052546.nc" ;
```

```
                :PGE_StartTime = "2017-04-15 20:12:00.000" ;
                :identifier_product_doi = "10.5067/VIIRS/VNP10.001" ;
                :NorthBoundingCoord = 54.35787f ;
                :GRingPointLatitude = 33.4794, 28.6791, 47.6999, 54.2566 ;
                :DayNightFlag = "Day" ;
                :license = "http://science.nasa.gov/earth-science/earth-science-data/data-
information-policy/" ;
                :EndTime = "2017-04-15 20:18:00.000" ;
                :PGE_Name = "PGE507" ;
                :EastBoundingCoord = -90.93742f ;
                :project = "VIIRS Land SIPS Snow Cover Project" ;
                :ShortName = "VNP10" ;
                :creator_name = "VIIRS Land SIPS Processing Group" ;
                :InputPointer =
"VNP35_L2.A2017105.2012.001.2017106052320.hdf,NPP_VIAES_L1.A2017105.2012.
001.2017106050141.hdf,NPP_VMAES_L1.A2017105.2012.001.2017106050141.hdf,N
PP_IMFTS_L1.A2017105.2012.001.2017106043639.hdf" ;
```