NASA VIIRS Snow Cover Products

Collection 2

User Guide

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George A. Riggs
Dorothy K. Hall

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1.0 Introduction

The NASA Suomi-National Polar-orbiting Partnership (S-NPP) Visible Infrared Imaging Radiometer Suite (VIIRS) and Joint Polar Satellite System (JPSS) VIIRS snow cover algorithms and data products are nearly identical. The same algorithms are used to ensure continuity of data products and enable development of a moderate-resolution snow cover climate-data record (CDR). This User Guide describes the NASA VIIRS Collection 2 (C2) Level-2 (L2) and Level-3 (L3) snow cover products produced for the VIIRS instruments on S-NPP and JPSS-1. The JPSS-1 is the first satellite in the series of JPSS satellites. Details of the data products, Quality Assessment (QA) data content, and commentary on evaluation and interpretation of data are given for the products. The Addendum section has information about data products and collections.

The C2 products are produced from revised C1 product algorithms. The daily global Climate Modelling Grid (CMG) product is included in C2; it was not available in C1. For C2 the NASA VIIRS L2 calibrated reflectance products generated from VIIRS Characterization Support Team (VCST) algorithms are the inputs to the L2 algorithms/products. In C1 the VIIRS L2 calibrated reflectance products generated from Land Project Evaluation and Test Element (LPEATE) algorithms were used as input.

An objective for VIIRS C2 is to make the VIIRS snow cover algorithms consistent with the MODIS Collection 6.1 (C6.1) snow cover algorithms to enable development of a CDR using products from Terra, Aqua, S-NPP and JPSS-1. Continuity between Terra, Aqua and S-NPP snow cover products has been demonstrated in Riggs and Hall (2020), Hall et al. (2019), Thapa et al. (2019) and Zhang et al. (2020).

2.0 NASA VIIRS Snow Cover Data Products

The NASA VIIRS snow cover data products (Table 1) are produced in the Land Science Investigator-led Processing System (LSIPS) and archived at the National Snow and Ice Data Center (NSIDC) Distributed Active Archive Center (DAAC). Products in the Earth Observing Data and Information System (EOSDIS) have Earth Science Data Type (ESDT) names. The ESDT names begin with VNP for S-NPP products and with VJ1 for JPSS-1 products. In this guide the combined name beginning of V[NP|J1] is used when referring to both the S-NPP and JPSS-1 products. When referring to a specific product the unique ESDT name is used. Snow cover data products are produced in sequence beginning with a Level-2 (L2) 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 instrument scans. An L2 product is a geophysical product in latitude and longitude orientation. The V[NP|J1]10 snow cover product is projected and gridded to a projection to make an intermediate Level-2 gridded (L2G) product. The L2G product is on the sinusoidal projection and stored as tiles, each tile being 10° x 10°. V[NP|J1]10 data products are gridded into L2G tiles by mapping the V[NP|J1]10 pixels into cells of a tile in the map projection grid. The L2G mapping algorithm creates a gridded product used as input to the V[NP|J1]10A1 Level-3

(L3) products. The V[NP|J1]10L2G products are not archived at NSIDC. The L3 daily snow V[NP|J1]10A1 and cloud-gap-filled V[NP|J1]10A1F products are on the sinusoidal projection at 375 m spatial resolution. The daily global snow cover extent product V[NP|J1]10C1 on a geographic project at ~ 5 km resolution is made by mapping the V[NP|J1]10A1 observations to a CMG grid cell and binning the observations to calculate the extent of snow in a grid cell.

The snow cover data products are in different file formats depending on product processing level. The swath L2 V[NP|J1]10 product is in Hierarchical Data Format 5 (HDF5) and uses netCDF Climate and Forecast (CF-1.6) conventions for global and local attributes and for geolocation of variables. The L3 tiled products are gridded and projected to the sinusoidal projection, which is the same grid and projection used for MODIS products but at the VIIRS nominal spatial resolution of 375 m. The L3 VIIRS CMG product is on the same geographic projection as the MODIS CMG product. The L3 products are in HDF-EOS5 format with the addition of CF-1.6 conventions for global and local attributes and for geolocation of variables. Information on file formats can be found at: netCDF https://www.unidata.ucar.edu/software/netcdf/docs/index.html, CF-1.6 cfconventions.org, HDF5 https://www.hdfgroup.org/HDF5/) and HDF-EOS5 https://earthdata.nasa.gov/esdis/eso/standards-and-references/hdf-eos5.

The series of NASA VIIRS snow cover products produced in C2 is listed in Table 1. The snow cover detection algorithm is applied at L2 using VIIRS reflectance observations, the cloud mask product and geolocation data product to produce V[NP|J1]10. The V[NP|J1]10A1 L3 product is produced by projection, gridding, and compositing of V[NP|J1]10 swaths. The cloud-gap-filled product, V[NP|J1]10A1F, is produced by compositing V[NP|J1]10A1 tiles. The V[NP|J1]10C1 product is made by mapping the V[NP|J1]10A1 observations to a CMG grid cell and binning the observations to calculate the extent of snow in a grid cell. Summaries of the algorithms, data products content, and commentary on evaluation and interpretation of data are given for each product. Full descriptions of the algorithms are presented in the VIIRS Algorithm Theoretical Basis Document (ATBD) (Riggs et al., 2015). Description of each product, synopsis of the algorithm and commentary on snow cover detection, quality assessment (QA), accuracy and errors are presented in following sections.

Table 1: VIIRS Snow cover products produced in the LSIPS.

ESDT	LongName	Level	Format
VNP10	VIIRS/NPP Snow Cover 6-Min L2 Swath 375m	2	HDF5
VNP10A1	VIIRS/NPP L3 Snow Global 375m SIN Grid	3	HDF-EOS5
VNP10A1F	VIIRS/NPP CGF Snow Cover Daily L3 Global 375m SIN Grid	3	HDF-EOS5
VNP10C1	VIIRS/NPP Snow Cover Daily L3 Global 0.05Deg CMG	3	HDF-EOS5
VJ110	VIIRS/JPSS1 Snow Cover 6-Min L2	2	HDF5

	Swath 375m		
VJ110A1	VIIRS/JPSS1 L3 Snow Global 375m SIN Grid	3	HDF-EOS5
VJ110A1F	VIIRS/JPSS1 CGF Snow Cover Daily L3 Global 375m SIN Grid	3	HDF-EOS5
VJ110C1	VIIRS/JPSS1 Snow Cover Daily L3 Global 0.05Deg CMG	3	HDF-EOS5

2.1 Collection and Product Notes

The S-NPP data record begins on 19 January 2012.

The JPSS-1 data record begins on 26 October 2018. JPSS-1 products are first available in C2.

The JPSS-1 satellite was declared operational on 30 May 2018 and renamed NOAA-20. NOAA designates satellites with an operational number when declared operational after their on-orbit checkout period. The JPSS-1 name is used in the guide as that name was originally used by LSIPS for identifying data products. The names JPSS-1 and NOAA-20 are interchangeable.

The V[NP|J1]10 C2 L2 snow cover detection algorithm was revised to read detector QA flags in V[NP|J1]02IM to find noisy detectors and to average over noisy detectors. The VCST has flagged one VIIRS JPSS-1 SWIR detector as noisy.

Processing and reprocessing of C2 S-NPP products in LSIPS commenced on 6 September 2022. The C2 User Guide was updated to include revisions to the algorithms and products that have been made since C1.

Notable revisions/updates to products:

In the VNP10 snow cover algorithm the low reflectance thresholds for snow detection were changed to match thresholds used in the MODIS C 6.1 algorithm.

A data filter was added to the VNP10 algorithm to provide a quality flag that could potentially be useful to mitigate the occurrence of ‘false snow’ detections in the algorithm in certain situations.

The daily global CMG snow cover extent product V[NP|J1]10C1 is produced.

3.0 V[NP|J1]10

The NASA VIIRS snow cover swath product V[NP|J1]10 in HDF5 format contains dimensions, a SnowData group of variables and a GeolocationData group of variables. A file level description is given in List 1 and the data groups, variables and attributes are described in following sections. The ‘number_of_pixels’ in a swath is constant. The ‘number_of_lines’ in a swath is nominally 6464 in a six-minute swath but may have more or fewer for long or short swaths. A full listing of V[NP|J1]10 contents is given in Appendix A.

List 1. File level description of the contents of the V[NP|J1]10 product.

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

Global attributes with information on date and time of acquisition, geographic location, production, summary statistics, provenance and other information are attached to the root group. Global attributes are listed in Appendix A.

3.1 Geolocation Data

Latitude and longitude data for each pixel in a swath are stored as auxiliary coordinate variables in the GeolocationData group in V[NP|J1]10. The coordinate variables, attributes and datasets follow netCDF CF-1.6 conventions for geolocation. Software tools that work with the netCDF or HDF5 data formats should be able to work with V[NP|J1]10. Description of the GeolocationData group is given in List 2.

List 2. Description of the GeolocationData group and attributes in V[NP|J1]10.

```
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 variables and their attributes and group attributes are given in List 3 and in Section 3.2.1. The variables are the same as in C1. Local attributes of the variables are similar to those in C1, but the names and data format now conform to CF-1.6 conventions. Notable change was made to the group attributes, some that are summary statistics were moved to global attributes and several are new. The new attributes provide information on VIIRS detector quality (see Section 3.3).

List 3. Description of SnowData group datasets and attributes in V[NP|j1]10.

```
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 = 1UB, 2UB, 4UB, 8UB, 16UB, 32UB, 64UB, 128UB
;
                Algorithm_bit_flags_QA:flag_meanings = "inland_water_flag low_visible_screen
low_NDSI_screen combined_surface_temperature_and_height_screen_or_flag
high_SWIR_screen_or_flag cloud_mask_probably_cloudy cloud_mask_probably_clear 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:_FillValue = 255UB ;
                Basic_QA:flag_values = 211UB, 239UB, 249UB, 250UB, 251UB, 252UB, 253UB, 254UB
;
                Basic_QA:flag_meanings = "night ocean SWI_screened cloud missing_L1B_data
cal_fail_L1B_data bowtie_trim L1B_fill" ;
                Basic_QA:coordinates = "latitude longitude" ;
                Basic_QA:long_name = "Basic QA value" ;
                Basic_QA:valid_range = 0UB, 3UB ;
                Basic_QA:key = "0=best, 1=good, 2=poor, 3=other" ;
        short NDSI(number_of_lines, number_of_pixels) ;
                NDSI:coordinates = "latitude longitude" ;
                NDSI:long_name = "NDSI for all land and inland water pixels" ;
                NDSI:valid_range = -1000s, 1000s ;
                NDSI:scale_factor = 0.001f ;
                NDSI:flag_values = 21000s, 29000s, 24000s, 25000s, 31000s, 30000s ;
                NDSI:flag_meanings = "night ocean L1B_missing L1B_unusable bowtie_trim L1B_fill" ;
                NDSI:_FillValue = 32767s ;
        ubyte NDSI_Snow_Cover(number_of_lines, number_of_pixels) ;
                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:flag_values = 201UB, 211UB, 237UB, 239UB, 250UB, 251UB,
252UB, 253UB, 254UB ;
                NDSI_Snow_Cover:flag_meanings = "no_decision night lake ocean cloud
missing_L1B_data cal_fail_L1B_data bowtie_trim L1B_fill" ;
                NDSI_Snow_Cover:_FillValue = 255UB ;

  // group attributes:
                :I01_Noisy_Detectors_Count = 0s ;
                :I01_detector_quality_flag_values = 0UB, 0UB, 0UB, 0UB, 0UB, 0UB, 0UB, 0UB, 0UB,
0UB, 0UB, 0UB, 0UB, 0UB, 0UB, 0UB, 0UB, 0UB, 0UB, 0UB, 0UB, 0UB, 0UB, 0UB, 0UB, 0UB, 0UB,
0UB, 0UB, 0UB, 0UB, 0UB ;
                :I02_Noisy_Detectors_Count = 0s ;
```

```
			:I02_detector_quality_flag_values = 0UB, 0UB, 0UB, 0UB, 0UB, 0UB, 0UB, 0UB, 0UB, 
0UB, 0UB, 0UB, 0UB, 0UB, 0UB, 0UB, 0UB, 0UB, 0UB, 0UB, 0UB, 0UB, 0UB, 0UB, 0UB, 0UB, 0UB, 
0UB, 0UB, 0UB, 0UB, 0UB ;
			:I03_Noisy_Detectors_Count = 0s ;
			:I03_detector_quality_flag_values = 0UB, 0UB, 0UB, 0UB, 0UB, 0UB, 0UB, 0UB, 0UB, 
0UB, 0UB, 0UB, 0UB, 0UB, 0UB, 0UB, 0UB, 0UB, 0UB, 0UB, 0UB, 0UB, 0UB, 0UB, 0UB, 0UB, 0UB, 
0UB, 0UB, 0UB, 0UB, 0UB ;
			:detector_quality_flag_masks = 1UB, 2UB, 4UB, 8UB, 16UB, 32UB, 64UB, 128UB ;
			:detector_quality_flag_meanings = "Noisy Dead" ;
			:Surface_temperature_screen_threshold = "281.0 K" ;
			:Surface_height_screen_threshold = "1300 m" ;
			:Land_in_clear_view = "73.9%" ;
  } // group SnowData
```

3.2.1 Variables

The V[NP|J1]10 product has the following variables: NDSI_Snow_Cover, Basic_QA, Algorithm_bit_flags_QA and NDSI, each with attributes that describe the data.

3.2.1.1 NDSI_Snow_Cover

The NDSI_Snow_Cover variable is the snow cover extent (SCE) detected by the algorithm. SCE 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 a scene, clouds, oceans, and night are included in the NDSI_Snow_Cover as flag_values. Onboard VIIRS bowtie trim lines, missing data and calibration failures in a swath are reported by flag_values. The flag_values value for a “no decision” result in C1 is retained in C2 for compatibility with C1 though the value is not applied in C2. An example of the NDSI_Snow_Cover variable with colorized ranges of NDSI_Snow_Cover and flag_values is shown in Figure 1.

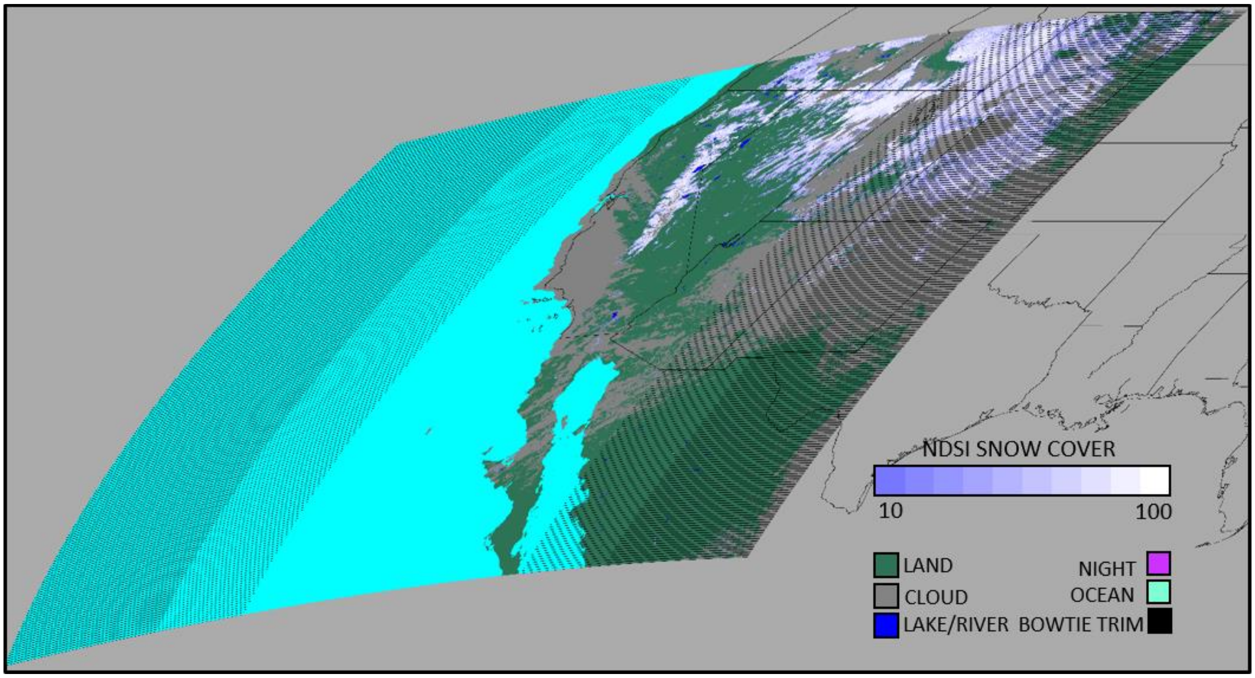

Figure 1. NDSI_Snow_Cover from VNP10.A2019013.2048.002.*.nc. The western United States imaged on 13 January 2019, 2048 UTC. Image projected to the sinusoidal projection. The lines of bowtie trim appear curved due to the projection.

3.2.1.2 Algorithm_bit_flags_QA

Algorithm-specific bit flags are set in this variable for 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, 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. Some of the bit flags have 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 3.3.1 for description of the bit flags. Local attributes describe the bit flags.

3.2.1.3 Basic_QA

A general quality value is assigned for pixels processed in the algorithm. This value indicates quality ranging from best quality to poor quality. Features e.g., oceans, are set to flag_values. Pixels that were detected as snow but flagged by the snow water index (SWI) screen (Section 3.3.1.6) have a specific value in flag_values. Local attributes describe the values.

3.2.1.4 NDSI

The calculated NDSI values for all land and inland water pixels are stored in this variable. The NDSI data is packed (scaled) with an NDSI valid_range of -1.0 to 1.0 (unpacked). The cloud mask is not applied in this variable. Ocean, night, and other masks are applied. Local attributes describe the data.

3.3 Snow Cover Detection Algorithm Synopsis

A brief description of the snow cover detection algorithm is given to provide background to the variables in products. For a detailed description of the algorithm see the VIIRS Snow Cover ATBD (Riggs et al., 2015).

The basis of the NASA VIIRS snow cover detection algorithm 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 based on the normalized difference of snow reflectance in the VIS and SWIR, the greater the VIS-SWIR difference, the higher the NDSI value. The NDSI for VIIRS is:

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

where,
I1 is VIIRS band I1 (0.64 µm),
I3 is VIIRS band I3 (1.61 µm).

If snow is present and viewable by a satellite the NDSI will be in the range of 0.0 to +1.0. The theoretical range of NDSI for all features is -1.0 to 1.0, values ≤ 0.0 are features other than snow. An NDSI value of 0.0 or less indicates no snow. If snow is present the NDSI will be > 0.0. However, there are other surface features or viewing conditions that can have NDSI > 0.0 which can result in erroneous snow detections. Screens to reduce erroneous snow detections or flag uncertain snow detections are applied in the algorithm. NDSI values in the NDSI_Snow_Cover variable are scaled to 0-100 range in the algorithm then written to the variable. The NDSI values are also written to the NDSI variable as packed data.

For C2 the V[NP|J1]10 snow cover detection algorithm inputs the LSIPS produced L1B and L2 products. Input data products are listed in Table 2. In C1 the LPEATE versions of the L1B and L2 products were used as input. The LSIPS products are in a different format, data is stored in different locations and there are differences in sources of data compared to C1 LPEATE products. The cross-calibrated radiance and top-of-atmosphere (TOA) reflectance L1B products are used in C2. Cross-calibration of selected VIS/NIR and SWIR was implemented to mitigate bias observed in TOA reflectance between SNPP and J1 and to constrain them within 1% using MODIS Aqua as the reference (LDOPE 2022). The C2 L1B products include data on detector calibration and quality flags that are not in C1.

The VCST flagged one of the JPSS-1 VIIRS SWIR detectors as noisy. In some situations, depending on solar illumination and land surface condition, the noisy detector sometimes caused snow cover detection errors of omission or commission. The snow cover detection algorithm was revised to read the detector QA flags for both S-NPP and JPSS-1 L1B inputs V[NP|J1]02IMG, bands I1, I2, and I3. If a noisy detector is found the reflectance value of that detector is replaced by the average reflectance of the detectors in the adjoining scan lines. The detector quality flags are attached as attributes to the SnowData data group (List 2 and Appendix A).

The land water mask (LWM) is input from the VIIRS geolocation product V[NP|J1]03IMG. The LWM is the MODIS LWM projected to 375 m resolution. Use of this LWM improved mapping of inland water bodies and provides continuity with MODIS SCE products. In C1 the LWM was input from the cloud mask product.

The LWM from the VIIRS geolocation product V[NP|J1]03IMG is used to direct processing for land and inland water body pixel observations and to exclude oceans. VIIRS TOA reflectance data are checked for missing or uncalibrated values; pixels with those values are set to flag_values. The NDSI is calculated for all land and inland water pixels in daylight, including those that are cloudy. Next the cloud mask is applied; pixels flagged as “certain cloud” in the cloud mask are set to “cloud.” For C2 cloud mask performance is improved though use of 1 km rolling gridded snow inputs and a 1 km vegetation index (VI) file, and algorithm improvements for better delineation of snow at higher latitudes (LDOPE, 2022). Then data screens are applied to a pixel observation. The data screens applied to a pixel depend on the NDSI value. Several different data screens may be applied to a pixel. More than one data screen may be set for a snow detection or a non-snow detection. A bit flag in the Algorithm_bit_flag_QA variable is set for a pixel if that pixel fails a data screen. Multiple screens may be applied so multiple bit flags may be set for a pixel. The cloud mask, oceans, and night are flag_values included in the NDSI_Snow_Cover variable so that a contextual map of SCE can be viewed.

Snow cover is output in two ways: 1) the NDSI based snow cover that reports the NDSI value for snow over the 0 to 100 range with data screens applied to reduce erroneous snow cover detections and with clouds and other features mapped as flag_values, and 2) the NDSI observation, range of -1.0 to 1.0, for all land or inland water pixels without data screens or cloud mask applied.

Table 2. VIIRS data product inputs to the V[NP|J1]10 algorithm.

ESDT	Variable	Center wavelength	Nominal spatial resolution
V[NP|J1]02CCIMG	I01 (reflectance), I01_qualilty_flags	0.640 µm	375 m
	I02 (reflectance), I02_quality_flags	0.865 µm	375 m
	I03 (reflectance), I03_quality_flags	1.61 µm	375 m
	I05, I05_brightness_temperature_lut	11.450 µm	375 m
V[NP|J1]02CCMOD	Reflectance_M4	0.555 µm	750 m
V[NP|J1]03IMG	latitude, longitude, solar_zenith, land_water_mask, height		375m
V[NP|J1]35_L2	QF1_VIIRSCMIP (cloud confidence flag)		750m

3.3.1 Data Screens

If a pixel is determined to have some snow present based on the NDSI value, a series of screens is applied to reduce snow commission errors and flag uncertain snow detections. Screens are used to detect reflectance features 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 checked by screens. Results of screens are stored as bit flags in the Algorithm_bit_flags_QA flags variable. Each screen has a bit flag in the Algorithm_bit_flags_QA variable that is set if an observation failed a screen. Specific bit flags or combinations of bit flags can be extracted for analysis.

Investigation of ‘false snow’ detections associated with mixed pixels at the periphery of some types of cloud formations or along water body edges led to the application of an additional screen to flag possible ‘false snow’ detections. This screen based on the SWI developed by Dixit et al., (2019) is described in Section 3.3.1.6.

3.3.1.1 Low VIS reflectance screen.

The low VIS screen is applied to both land and inland water pixels but with different thresholds. For an inland water pixel, if 0.0 < NDSI ≤ 1.0 and the VIS reflectance in band I1 is ≤ 0.10 or band M4 is ≤ 0.10, then a pixel fails to pass this screen and the result is lake (a flag_values). If an inland water pixel passes the low VIS screen it is considered to be “lake ice” and the NDSI value is the result. For a land pixel, if 0.0 < NDSI ≤ 1.0 and the VIS reflectance in band I1 is ≤ 0.0,7 or band M4 is ≤ 0.07 then a pixel fails to pass this screen and the results is “no snow.” This screen was changed for C2, the visible reflectance thresholds were lowered and result changed from “no decision” in C1 to “no snow” in C2. If a land pixel passes the low VIS screen, the NDSI value is the result. This screen is tracked in bit 1 (least significant bit order) of the Algorithm_bit_flags_QA variable.

3.3.1.2 Low NDSI screen

Pixels detected with snow cover in the 0.0 < NDSI < 0.10 range are reversed to a value of 0, “no snow” and bit 2 of the Algorithm_bit_flags_QA variable is set. This bit flag can be used to locate where a snow cover detection was reversed to “no snow.”

3.3.1.3 Estimated surface temperature and surface height screen.

There is a dual purpose for this estimated surface temperature linked with surface height screen. It is used to alleviate snow commission errors at low elevations that appear spectrally 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. If snow is detected in a pixel at elevations < 1300 m and that pixel has an estimated brightness temperature (BT) ≥ 281 K (VIIRS band I5), then that snow detection decision is reversed to “not snow” and bit 3 is set in the Algorithm_bit_flags_QA variable. If snow is detected for a pixel at elevations ≥ 1300 m and with an estimated BT ≥ 281 K, then that snow detection is flagged as unusually warm by setting bit 3 in the Algorithm_bit_flags_QA variable.

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 and 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 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 the Algorithm_bit_flags_QA variable is set. If a snow pixel has a SWIR reflectance > 0.45 it is reversed to "not snow" and bit 4 of Algorithm_bit_flags_QA variable is set.

3.3.1.5 Solar zenith screen.

Low illumination conditions exist at solar zenith angle (SZA) > 70°, which represents a challenging situation for snow cover detection. A SZA mask of > 70° is created by setting bit 7 of the Algorithm_bit_flags_QA variable. This mask is set across the entire swath. Night is defined as the SZA ≥ 85° and pixels with SZA ≥ 85° are flagged as night.

3.3.1.6 Snow Water Index (SWI) screen.

The purpose of this screen is to set a quality flag for snow cover detection in some situations. Dixit et al. (2019) proposed a snow spectral index called the snow water index (SWI). The SWI achieves significant contrast between snow and other surface features including water bodies. The SWI can eliminate impacts of features like clouds, soil, vegetation, and water on snow mapping. The SWI is given as,

SWI = (green * (NIR-SWIR)) / ((green + NIR) * (NIR+SWIR))

The inclusion of the green and SWIR enables the distinction of cloud from snow. The inclusion of NIR enables discrimination of snow from water. The ratio of (green/green+NIR) reduces the impact of vegetation mixing with snow. An advantage of the SWI is that the ratio of (NIR-SWIR/NIR+SWIR) functions as a water mask. Dixit et al. (2019) report a SWI threshold value for snow of 0.21, snow has SWI values greater than that threshold. The VIIRS SWI is calculated as,

SWI = (M4 * (I2 – I3)) / ((M4 + I2) * (I2+I3))

The SWI is applied as a quality flag screen on the NDSI_Snow_Cover variable. The screen rule is, if the NDSI_Snow_Cover value for a pixel has a value in range of 10-100 and the SWI is ≤ 0.21 the Basic_QA pixel flag_values is set to 249 to indicate a pixel with lower contrast between snow and other features.

3.3.2 Lake Ice Algorithm

The lake ice/snow covered ice detection algorithm is the same as the NDSI snow cover algorithm except it has different thresholds in the low VIS screen. Inland water bodies are tracked by setting bit 0 in the Algorithm_bit_flags_QA variable. An inland water map can be created from this inland water bit flag. This algorithm assumes 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 may be erroneously detected as snow/ice covered.

3.3.3 Cloud Masking

Clouds are masked using the LSIPS produced V[NP|J1]35_L2 cloud mask product. Cloud mask performance was improved though use of a 1 km rolling gridded snow inputs and a 1 km vegetation index (VI) file, and algorithm improvements for better delineation of snow at higher latitudes in C2 (LDOPE, 2022). (The cloud mask algorithm is a NOAA IDPS legacy product, a description of the cloud mask is in https://www.star.nesdis.noaa.gov/jpss/documents/ATBD/ATBD_EPS_Cloud_Mask_v1.2.pdf). The cloud confidence flag variable from V[NP|J1]35_L2 is read and used to flag cloud observations. The cloud confidence flag at 750 m resolution is converted to 375 m resolution by mapping a 750 m pixel value to the four corresponding 375 m pixels. The cloud confidence flag provides four levels of confidence: “confident cloudy,” “probably cloudy,” “probably clear,” and “confident clear.” If the confidence flag is “confident cloudy” the pixel is flagged as cloud. If the cloud mask flag is set “confident clear,” “probably clear,” or “probably cloudy”, it is interpreted as “clear” in the algorithm. The cloud confidence flags of “probably cloudy” and “probably clear” are set as bit flags in the Algorithm_bit_flags_QA variable bit five and bit six respectively. The cloud confidence bit flags can be used to assess quality or investigate cloud/snow confusion.

3.3.4. Quality Assessment (QA)

Two QA variables are output; the Basic_QA which gives a qualitative estimate along with flag_values for certain features or results, and the Algorithm_bit_flags_QA which reports results of data screens, cloud mask confidence flags, and other 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 “best” and is adjusted based on the quality of the L1B input data and the SZA screen. If L1B detector flags indicate poor quality data, then the QA value is “poor.” If the reflectance data is outside the range of 7-100% 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 “other” to indicate increased uncertainty because of low illumination. Pixels are set to “good” by the data screens described above. For features e.g., ocean, or night, flag_values are written. A flag_values value is written for snow cover pixels flagged by the SWI screen.

The Algorithm_bit_flags_QA variable contains bit flags of data screen results and bit flags for other conditions. The data screens provide information on quality of an observation and the result; they also indicate why a snow detection was reversed to “not snow,” or indicate an uncertain snow detection, or challenging viewing conditions. Multiple bit flags may be set for a pixel because multiple data screens can be applied. Bit flags can be used to determine if a snow cover detection was changed to a “not snow” result by a screen or screens, or if a snow pixel has certain screens set that are indicative of an uncertain snow detection. The screens and bit flags have a dual purpose -- some flag pixels where snow detection was changed or flag a snow detection as ‘uncertain.” The bit flags are described in the local attributes flag_masks and flag_meanings.

3.4 Interpretation of Snow Cover Detection Accuracy, Uncertainty and Errors

The 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 https://modis-snow-ice.gsfc.nasa.gov/?c=publications.)

The MODIS and NASA VIIRS snow cover algorithms both use the same NDSI snow-detection algorithm, albeit adjusted for sensor and input data product differences. The S-NPP snow cover is 98% consistent with MODIS snow cover (Thapa et al., 2019). Accuracy of the S-NPP snow cover detection algorithm is similar to the accuracy reported for the MODIS sensors, varying with landscape (Zhang et al., 2020). Conditions that can adversely affect accuracy of snow cover detection or cause errors are briefly discussed in the following sections.

3.4.1 Warm surfaces

Snow commission error can occur on warm non-snow surfaces with positive NDSI values. This error is reduced by screening the estimated surface temperature. 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, > 283 K, for snow and the Algorithm_bit_flags_QA bit 3 is set. Snow cover detection at ≥ 1300 m on a surface that is too warm, > 283 K, for snow flagged as “too warm” by also setting Algorithm_bit_flags_QA bit 3.

The effectiveness of the surface temperature and height screen varies as the surface changes over seasons. It is effective at reversing snow commission errors on 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 in Utah, United States, 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 for various conditions pose challenges to snow detection and may cause snow commission errors. Several data screens are applied, 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 where the low SZA flag (bit 7) in the Algorithms_bit_flags_QA variable is set to on. This indicates a low limit to accurate detection of snow cover on the landscape.

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. The low VIS screen (Section 3.3.1.1) prevents erroneous snow detections where reflectance is very low. The NDSI is calculated for those pixels and stored in the NDSI variable. Pixels that failed this screen can be found by reading Algorithm_bit_flags_QA bit 1 and the corresponding NDSI value in the NDSI variable.

Low reflectance associated landscape shadowed by clouds or terrain, unmapped water bodies or inundated landscape can exhibit reflectance characteristics similar to snow and thus be erroneously detected as snow in the algorithm. Very low visible reflectance is a cause for increased uncertainly in detection of snow cover. Though the data screens applied prevent snow commission errors, some errors can go undetected, notably on cloud shadowed snow free landscape as shown in Figure. 2. A region of scattered clouds over snow free land near the north side of the VNP10 image in Fig. 1 is shown in Fig.2. A few scattered clouds and their shadows on the surface are seen in the left image Fig. 2, and the NDSI_Snow_Cover, center image, with snow commission errors associated with shadowed surfaces. In this situation the cloud mask detects the clouds, and two of the data screens prevent some snow commission errors as shown by the yellow and red colored pixels seen in the right image. However, snow commission errors, blue pixels center image, may occur and are associated with the periphery of cloud shadowed land. The cloud confidence flags for “probably clear” and “probably cloud” conditions are also shown in the right image in Fig. 2.

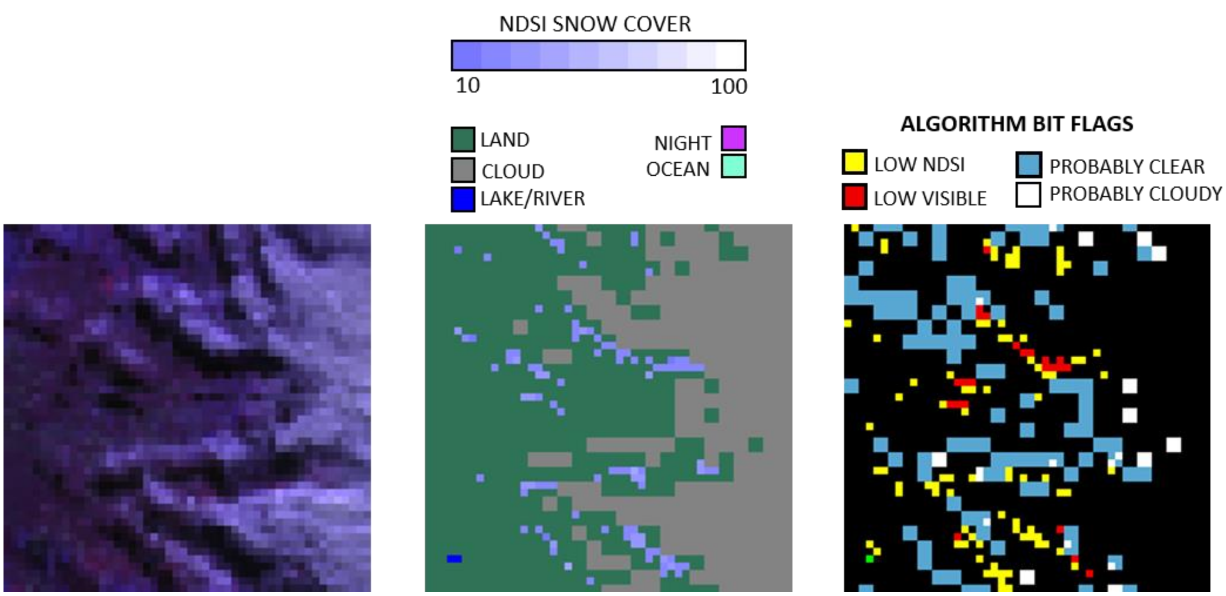

Figure 2. Example of snow commission error associated with cloud periphery and shadowed surfaces. Image is from the northern central region of VNP10 shown in Fig. 1. Left image is a false color display of VIIRS bands I2, I1, I3 (RGB) from the VNP02IMG swath corresponding to VNP10. NDSI_Snow_Cover from VNP10.A2019013.2048.002.*.nc (Fig. 1) is the center image. Selected data screens from the Algorithm_bit_flags_QA that prevent snow commission errors and the cloud mask confidence flags are shown 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. Analysis of many low VIS reflectance situations has revealed that uncertain snow detections or snow commission errors were common when the NDSI was $0.0 \leq \text{NDSI} < 0.1$. Based on that analysis a low NDSI screen is applied. If NDSI is < 0.1 a snow detection is changed to “not snow,” and the low NDSI flag, bit 2, is set in the Algorithm_bit_flags_QA. To locate where this screen was applied, the Algorithm_bit_flags_QA bit 2 flag can be read and the corresponding NDSI value may be found.

3.4.4 High SWIR reflectance

Unusually high SWIR reflectance may be observed for some snow cover conditions, 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 to flag snow detection with unusually high SWIR. The SWIR screen is bit 4 in Algorithm_bit_flags_QA.

3.4.5 Cloud and snow confusion

Cloud and snow confusion in the VIIRS C2 snow cover products is similar to the cloud and snow confusion observed in C1 however improvements in the LSIPS cloud mask algorithm and higher resolution ancillary inputs have reduced the occurrence of cloud and snow confusion in C2 (see Section 3.3.3). Cloud and snow confusion observed in VIIRS C2 is similar to that observed in the MODIS C6.1 snow cover products. Two sources of cloud/snow confusion are: 1) the cloud mask does not correctly detect cloudy or clear conditions, and 2) subpixel clouds (cloud mask is at 750 m resolution) are not detected.

The cloud mask algorithm has several processing paths based on surface conditions and applies many cloud spectral and other tests to detect cloud. Included in the cloud mask product is the cloud confidence flag that provides four levels of confidence with regard to a pixel being clear or cloudy based on the cloud detection tests applied. The cloud confidence flag from the VIIRS cloud mask product is used in the snow cover detection algorithm. The LSIPS produced VIIRS cloud mask product, V[NP|J1]35_L2 is an input to the V[NP|J1]10 algorithm.

The cloud mask algorithm uses an ancillary snow/ice background product to direct processing along a snow or non-snow path with different cloud spectral and other tests applied in each path. In situations where the snow/ice background flag does not agree with conditions observed in a pixel, then the “wrong” processing path is followed and can result in cloud/snow confusion.

Subpixel 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 may have one or more reflectance features similar to snow. This situation may result 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.

3.4.6 SWI screen quality flag

The snow cover algorithm may detect mixed pixels at edges of inland water bodies, ocean coastline, and periphery of some cloud formations as “snow” when snow is not present in the mix resulting in a false snow detection. The occurrence of false snow detections associated with these situations is highly variable spatially and temporally and is typically observed to be a relatively small number of pixels localized or scattered pixels in a VIIRS scene. The quantitative amount of false snow in any VNP10 product is difficult to estimate. In VNP10 products the occurrence of false snow is typically < 0.1% of the total number of pixels in a VNP10 scene. The count of false snow may increase to around 1% in VNP10 scenes over regions and seasons where many mixed pixels occur at edges of inland water bodies, and at the periphery of some cloud formations. The occurrence of false snow over a region, may vary greatly from day-to-day because of changed cloud conditions and viewing geometry.

From a qualitative perspective false snow is considered a problem because in images or maps created from the products, ‘snow cover’ may be observed in regions and seasons where there should be no snow cover. The qualitative negative impact of false snow detections is perceived as a factor in evaluation of the products that outweighs the very small quantitative percentage of false snow that may occur based on pixel count in a VNP10 scene.

False snow detections in a VNP10 scene are propagated into the daily tiled snow cover VNP10A1 and VNP10A1F products. False snow in the daily snow products affect the quality and accuracy of maps or datasets such as snow cover time series, or snow cover frequency derived from those products. There are spatial and temporal filtering techniques that can be applied to the daily tiled snow cover products or datasets derived from those products to reduce the impact of false snow in the derived datasets. However, if the occurrence of false snow can be reduced in the VNP10 algorithm and product, then the accuracy of the L3 and derived snow cover products would be increased. Reduction of false snow in the L2 snow cover algorithm will be propagated to the L3 products and any data products derived from them.

Two snow algorithms reported in the literature, the Snow Water Index (SWI) (Dixit et al., 2019), and the Universal Snow Ratio Index (USRI) Wang et al. (2021), were evaluated for their ability to accurately detect snow cover and avoid false snow detection compared to the VNP10 snow cover product. The URSI snow detection technique lacked consistency in detecting false snow and in detecting real snow as compared to the NDSI in VNP10. The URSI was inconsistent detecting false snow and in some situations failed to detect extensive areas of real snow cover.

The SWI is described as effective at preventing false snow detections associated with edges of water bodies, and cloud periphery. The SWI developers, Dixit et al. (2019), state that the SWI prevents false snow detection in those situations. A SWI threshold of > 0.21 for snow detection was recommended by Dixit et al. (2019). That SWI threshold was evaluated against the NDSI_Snow_Cover to determine if the SWI could be useful for flagging false snow detections. The objective was to evaluate the SWI as a filter on the NDSI_Snow_Cover to flag false snow cover detection. Comparative evaluation of VNP10 snow cover to SWI snow was done for tens of scenes covering different landscapes with and without snow cover and in different seasons. Snow cover extent detected by the SWI generally agreed with NDSI_Snow_Cover at NDSI values ≥ 40 which is interpreted as snow being the dominant feature in a pixel. In mixed pixels where snow is present, with NDSI in the range of 10-40 the NDSI_Snow_Cover detects snow in those mixed pixels. Situations of mixed pixels in snow-covered forests, lower slopes of forested snow-covered mountains, at periphery of snow-covered regions are detected as snow cover by the NDSI. However, the SWI fails to detect snow cover in those situations compared to NDSI_Snow_Cover. An example of the difference in snow cover detection between VNP10 snow cover and SWI is shown in Figure 3.

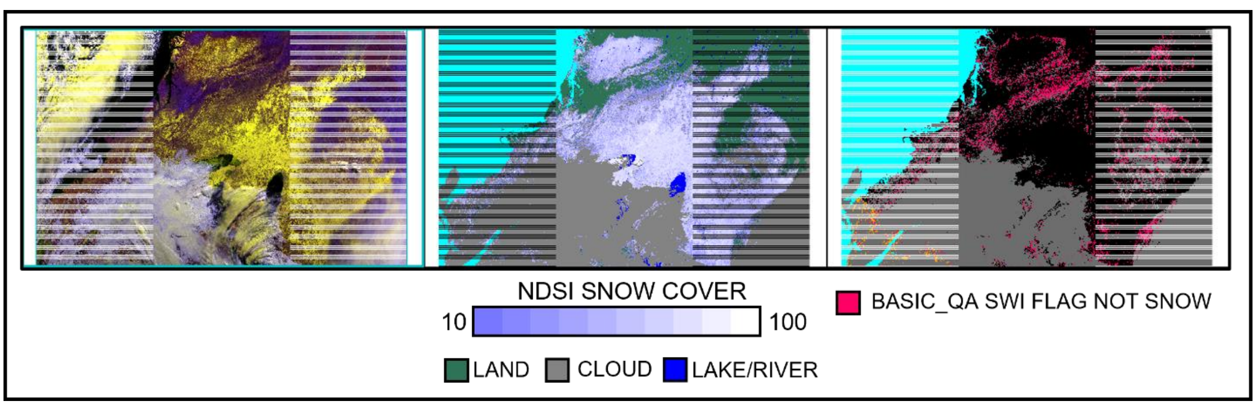

Figure 3. VNP10 NDSI_Snow_Cover and Basic_QA SW1 flag value. VIIRS scene acquired 18 January 2018 1818 UTC, eastern USA imaged, north is at bottom of images, stripes on sides of image are bowtie trim. False color of VIIRS bands I2, I1, I3 (RGB) (left image) shows snow in yellow hues. The VNP10 NDSI_Snow_Cover map is shown in center image. Pixels where the Basic_QA SWI flag does not detect snow but NDSI_Snow_Cover detects are shown in red in the right image.

The VNP10 NDSI_Snow_Cover extent in Figure 3 (center image) agrees very well with visual interpretation of snow-covered regions in the VIIRS imagery (left image). In regions where snow cover is the dominant surface feature, higher NDSI_Snow_Cover values (center image) the SWI also detects snow cover as indicated by the corresponding regions of black (right image). Both the NDSI_Snow_Cover and SWI correctly detect regions of no snow cover. The SWI is set as a quality flag for pixels where NDSI_Snow_Cover is snow and the SWI value is ≤ 0.21 indicating no snow cover detected by the SWI. Pixels where NDSI_Snow_Cover is snow and the SWI indicates not snow are shown in red in Figure 3 (right image). The SWI as a quality flag identifies mixed pixels of snow and other features, primarily vegetation. The SWI quality flag helps to identify the periphery of some snow-covered regions as seen in comparison of NDSI_Snow_Cover and the SWI flag in Figure 3. In mountainous regions the SWI quality flag flags snow cover in forested regions on lower slopes of mountains.

The SWI was found to be far too restrictive to snow cover detection compared to the NDSI_Snow_Cover snow cover to be useful as a screen for false snow detections. However, the SWI applied as a quality flag may be useful for qualitative evaluation of snow cover extent in some situations. Use of the SWI quality flag to identify false snow is only effective in situations where snow is not expected to occur, for example in Florida, USA in the winter, or northeast South America, regions in southern India, or in central Canada in the summer. The SWI quality flag could potentially be combined with temporal and/or spatial filtering of the VNP10 or VNP10A1 or VNP10A1F products to reduce the occurrence of false snow detections in maps or datasets derived from those products.

3.4.7 Inland water body ice

The inland water ice detection algorithm, applied to inland water bodies, lakes and rivers mapped in the LWM, is similar to the snow cover detection algorithm. If snow/ice is detected on inland water the NDSI value is written to the pixel in the NDSI_Snow_Cover variable. If the inland water is detected as snow/ice free, the flag_values for inland water i.e., lake value is written to the pixel. Inland water bodies are mapped to bit 0 of the Algorithm_bit_flags_QA variable. An inland water map can be created from bit 0 of the Algorithm_bit_flags_QA.

Analysis of V[NP|J1]10 products and experience with the MODIS snow cover products acquired during the boreal winter when lakes are frozen indicates that snow/ice covered lakes are detected with 90-100% accuracy. Disappearance of lake ice is observed accurately. 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.

3.4.8 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. Data screens applied in the algorithm reduce the occurrence of snow commission errors in some situations, e.g., a low elevation; too-warm surface may 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 for a specific research or application.

3.4.10 Geolocation accuracy

Geolocation accuracy is ± 50 m in the L2 products which provides consistent high accuracy in mapping of the VIIRS data products. Geolocation error resulting from projecting the L2 latitude and longitude referenced products to the sinusoidal projection may be observed in the L3 products as a shifting of features, e.g., a lake may appear in different grid cells from day to day.

3.4.11 Antarctica

Antarctica is nearly completely ice- and snow-covered year ‘round, with very little annual variation, though some changes are observable on the Antarctic Peninsula. The snow cover detection algorithm is run for Antarctica without any Antarctica-specific processing paths. The resulting snow cover map may show some snow-free areas which is an obvious error. That error is related to the great difficulty in detecting clouds over Antarctica. Similarity in reflectance and lack of thermal contrast between clouds and ice/snow cover, sometimes related to thermal inversions, are major challenges to accurate snow/cloud discrimination over Antarctica. In situations where the cloud mask fails to detect clouds as “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 V[NP|J1]10 is generated for Antarctica, it must be scrutinized by a user for accuracy and quality.

4.0 V[NP|J1]10A1

The daily, gridded, and projected, snow cover product V[NP|J1]10A1 contains the same snow cover variables as found in the V[NP|J1]10 product. The V[NP|J1]10A1 product is in HDF-EOS5 format with variables and attributes that follow netCDF CF-1.6 conventions including geolocation which allow for more tools to work with the product. A listing the V[NP|J1]10A1 product structure and contents is provided in Appendix B.

4.1 Algorithm Description

There are two processing steps and two intermediate products leading up to the V[NP|J1]10A1product. First the V[NP|J1]10 swath products that cover a 10° x 10° area on the sinusoidal projection are mapped to a tile. The VIIRS bowtie striping present in the V[NP|J1]10 is removed in the gridding and reprojection processing. When there is more than one observation in a grid cell the observations are stacked, in no defined order, to produce an intermediate product (V[NP|J1]10L2G) that has multiple observations stored for grid cells. Next a selection algorithm is run with the V[NP|J1]10L2G, and viewing geometry products, as input and the "best" observation based on SZA, distance from nadir and observation coverage in a grid cell is selected. The "best" observation for each product is based only on those criteria so that the observation selected is nearest local solar noon time, nearest the orbit nadir track and with most coverage in a grid cell. This is considered the "best" sensor view of the surface on a day for snow cover detection and is stored in an intermediate V[NP|J1]10GA product. (These intermediate products are not archived at the NSIDC DAAC.) This strategy results in a contiguous mapping of swaths with a weave or checkerboard pattern along stitched-together swath edges within a tile. That weave pattern is sometimes apparent where cloud cover changed between acquisition times of overlapping swaths.

The V[NP|J1]10A1 algorithm processes the V[NP|J1]10GA product to reformat the data, add variables and calculate snow cover descriptive statistics.

The V[NP|J1]10A1 includes a variable that points to the V[NP|J1]10 swath from which each observation was selected. The pointer can be linked to the beginning and/or ending times of the individual V[NP|J1]10 input swaths stored as global attributes to determine the date and time of acquisition of each observation.

4.2 Variables

The V[NP|J1]10A1 product has these variables: NDSI_Snow_Cover, Basic_QA, Algorithm_bit_flags_QA, NDSI, granule_pnt and Projection, all with local attributes. The local attributes follow netCDF CF-1.6 conventions. The variable Projection is for CF-1.6 geolocation of the variables. Brief descriptions of each variable are given in the following sections and a listing of the complete file contents is given in Appendix B.

4.2.1 NDSI_Snow_Cover

The NDSI_Snow_Cover variable is the snow cover extent of the selected "best" observations from the V[NP|J1]10 product(s) for the day. 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 contextual view of snow cover in the tile on a day, clouds, oceans, inland water, and other flag_values are included. An example of the NDSI_Snow_Cover variable with colorized ranges of NDSI_Snow_Cover and colorized flag_values is shown in Figure 4. Local attributes are listed in Appendix B.

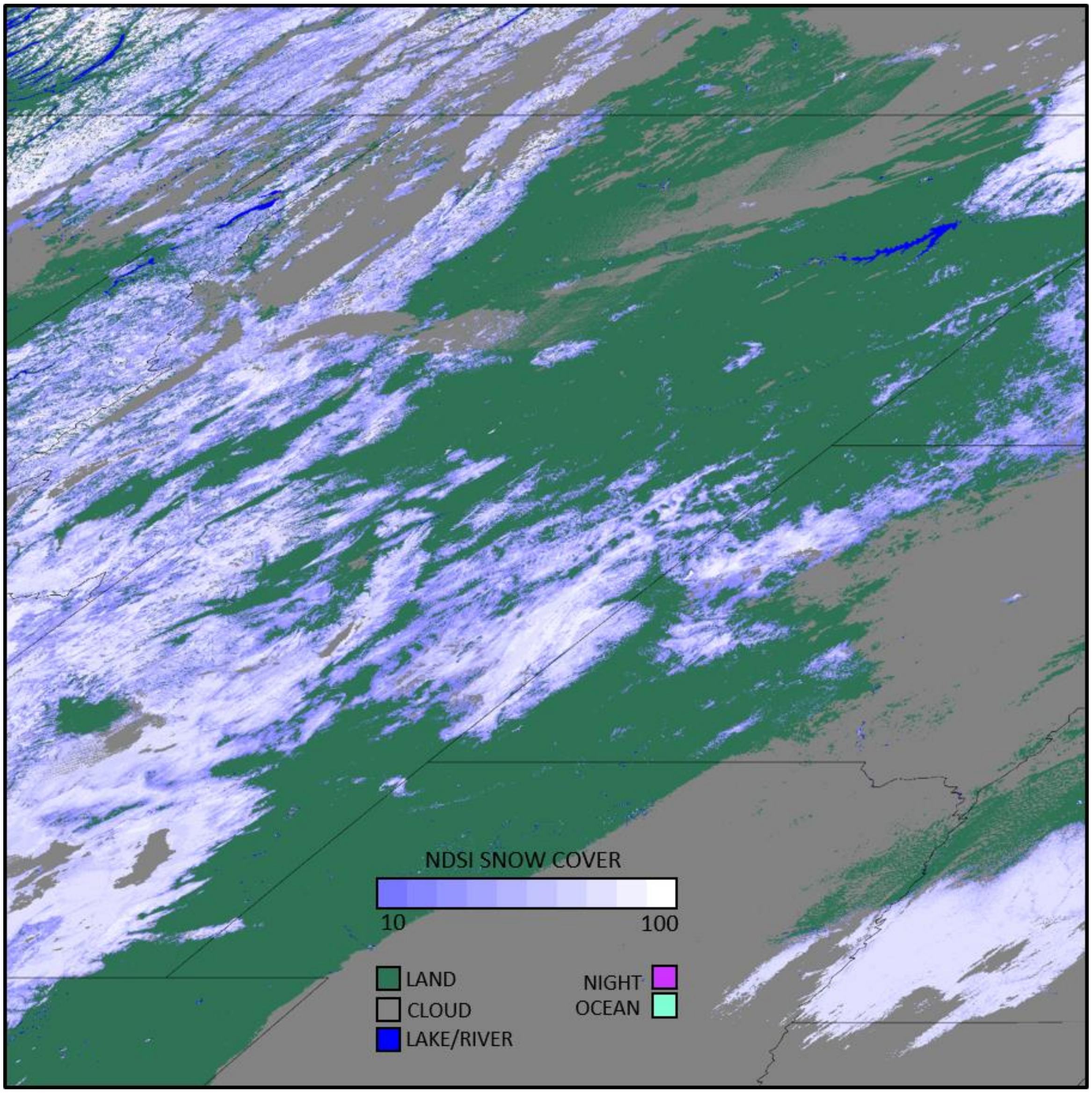

Figure 4. NDSI_Snow_Cover from VNP10A1.A2019013.h10v04.002.*.h5, 13 January 2019. This tile covers parts of the US Great Plains and Rocky Mountains. Tile projected on sinusoidal projection.

4.2.2 Basic_QA

The Basic_QA variable is a general quality value assigned to observations in the V[NP|J1]10product. This basic quality value indicates quality ranging from highest to poor to provide initial quality assessment. Features, e.g., oceans, are set to flag_values. Pixels that were detected as snow but flagged by the SWI screen (Section 3.3.1.6) in VNP10 have a flag_values value of 249. Local attributes are listed in Appendix B.

4.2.3 Algorithm_bit_flags_QA

Algorithm-specific bit flag masks in this variable are the result of data screens that were applied in the V[NP|J1]10 algorithm (Section 3.3.1). These bit flag masks provide QA data specific to an observation. The bit flags can be read to assess quality of an observation. Multiple bit flag masks may be set for an observation. Local attributes are listed in Appendix B.

4.2.4 NDSI

The NDSI variable has the values for all land and inland water pixels without the cloud mask applied. These are the NDSI values calculated in V[NP|J1]10 and correspond to the "best" observation selected. The NDSI is packed data that can be unpacked using the scale_factor local attribute. The NDSI valid range is -1.0 to 1.0, when unpacked and has flag_values for ocean, night, and other conditions. Local attributes are listed in Appendix B.

4.2.5 granule_pnt

The granule_pnt variable data is a pointer, a numeric value that points to the index of values stored in the global attributes GranulePointerArray, GranuleBeginningDateTime and GranuleEndingDateTime. This pointer points to the index of the value in those arrays from which the "best" observation was selected. Non-negative values in the GranluePointerArray correspond by index to the GranuleBeginningDateTime and GranuleEndingDateTime arrays. The time of an observation can be determined using the pointer variable and those data arrays. Local attributes are listed in Appendix B.

4.2.6 Projection

Projection is an empty variable. The Projection variable serves as a container for local attributes that provide information on the projection. These local attributes follow CF-1.6 convention for geolocation and are used by tools to project or re-project from the native sinusoidal projection. Local attributes are listed in Appendix B.

4.3 Interpretation of Snow Cover Detection Accuracy, Uncertainty and Errors

Interpretation of accuracy, uncertainty and errors for snow cover detection is the same for the V[NP|J1]10 product. Refer to Section 3.4 for discussion of accuracy and errors.

Geolocation error caused by uncertainty in gridding and projecting pixels to the sinusoidal projection from the swath latitude and longitude reference system in the L2G projection algorithms may occur. This geolocation uncertainty may be observed in the location of lakes from day to day. In a composite of a tile over the course of several consecutive days the position of a lake shoreline may shift by one or more cells in the horizontal or vertical directions each day resulting in a blurred outline of the lake when composited over time.

5.0 V[NP|J1]10A1F

The daily cloud-gap-filled (CGF) snow cover product, V[NP|J1]10A1F, provides a daily cloud-free map of snow cover extent. The V[NP|J1]10A1F includes the variables CGF_NDSI_Snow_Cover, Cloud_Persistence map Basic_QA and Algorithm_Bit_Flags_QA for observations, and the Daily_NDSI_Snow_Cover and Projection. An example of V[NP|J1]10A1F CGF_NDSI_Snow_Cover is shown in Figure 5.

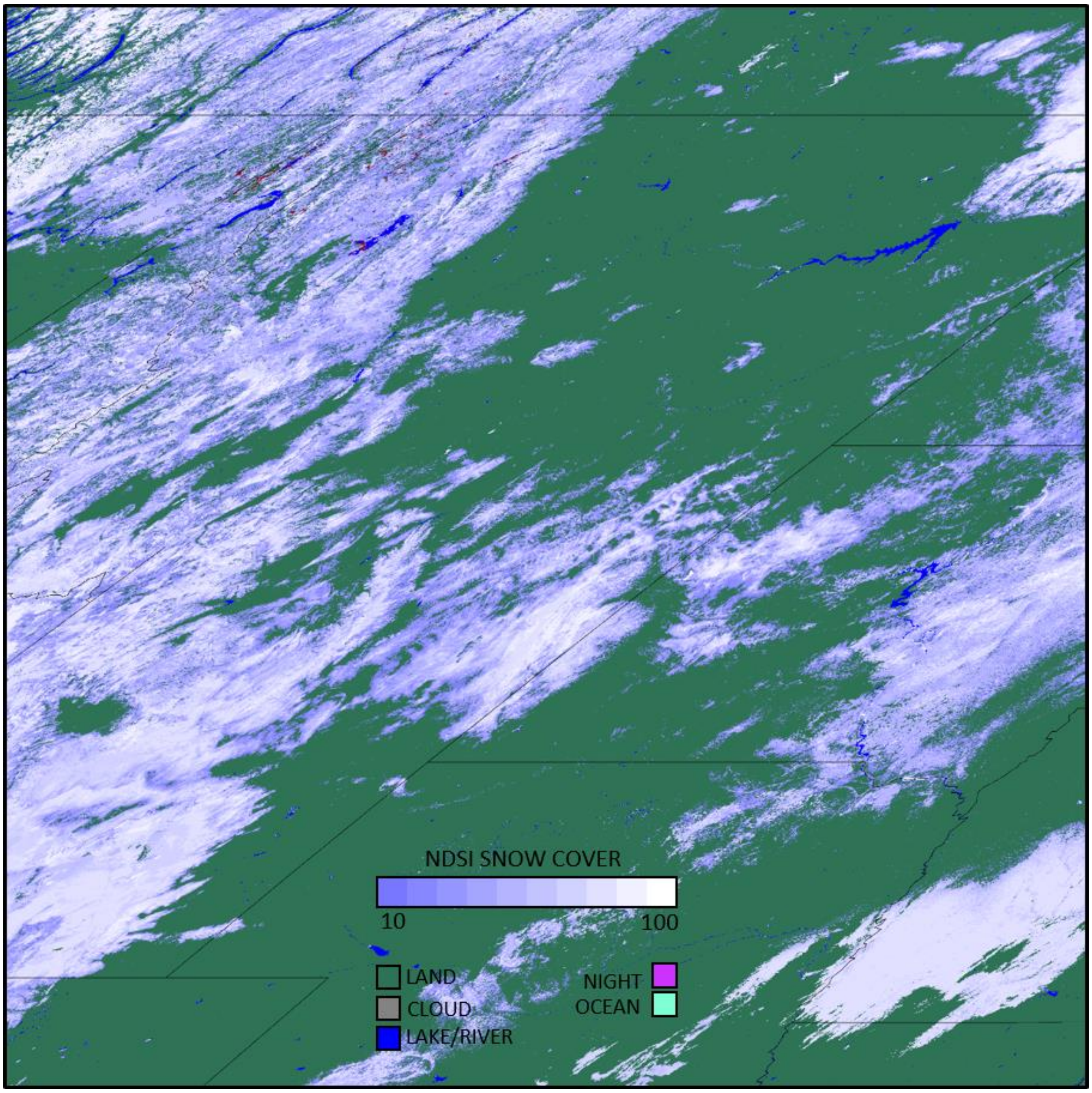

Figure 5. CGF_NDSI_Snow_Cover from VNP10A1F.A2019013.h10v04.002.*.h5, 13 January 2019. This tile covers parts of the US Great Plains and Rocky Mountains. Tile projected on sinusoidal projection. A virtually "cloud free" image of snow cover results from the CGF algorithm. Compare this "cloud free" image to the daily NDSI_Snow_Cover with clouds in Figure 4 to see the difference.

The V[NP|J1]10A1F is in HDF-EOS5 format and includes variables and attributes that follow netCDF CF-1.6 conventions for local and global attributes and for geolocation which allow for more tools to work with the product. A brief description of the algorithm and each variable is given in the following sections. A listing of the complete file contents is given in Appendix C.

5.1 Algorithm Description

The CGF daily snow cover map is generated by using a previous day non-cloud observation when the current day is a cloud observation on a cell-by-cell basis. Inputs to the CGF algorithm are the current day V[NP|J1]10A1 and the previous day V[NP|J1]10A1F. The current day CGF snow cover map is generated by replacing current day cloud observations in V[NP|J1]10A1 with a non-cloud observation from the previous day V[NP|J1]10A1F CGF. Cloud persistence is tracked by incrementing or resetting the count of consecutive days of cloud observed for a cell in the Cloud_Persistence variable. If the current day is a cloud observation, then the count is incremented by one day. If the current day is a non-cloud observation, then the cloud persistence count is reset to 0. The Basic_QA and the Algorithm_Bit_Flags_QA variables in V[NP|J1]10A1F are also set to the current day non-cloud observation corresponding QA data value of V[NP|J1]10A1 or replaced with the previous day V[NP|J1]10A1F values if the current day observation is cloud. The V[NP|J1]10A1F also contains a copy of the current day V[NP|J1]10A1 NDSI_Snow_Cover variable to facilitate comparison with the CGF_NDSI_Snow_Cover variable.

The CGF product is produced as a 12-month sequence corresponding to the United States Geological Survey (USGS) “water year” beginning on 1 October and ending on 30 September of each year for the Northern Hemisphere. For the Southern Hemisphere, the “water year” is 1 July to 30 June. The exception is that for the first year of S-NPP, production will begin on 19 January 2012 which is the start date of data collection. On the first day of the “water year” the V[NP|J1]10A1F is produced as a copy of the V[NP|J1]10A1 variables, with the cloud persistence variable set to one for cells that are cloudy.

In situations where there is fill data in orbit gaps or missing parts of swaths, the fill data is replaced with a non-fill data value from the previous day CGF product, and the cloud persistence count is incremented by one.

There are some days with missing V[NP|J1]10A1 tiles in the S-NPP and NOAA-20 data records. If a missing tile is encountered, the previous day V[NP|J1]10A1F becomes the current day V[NP|J1]10A1F but with the cloud persistence data incremented by one. In this situation, the missing data is treated as a cloud observation and the cloud persistence count of days is incremented by one. The global attribute MissingDaysOfV[NP|J1]10A1 reports the number of missing day(s). There are some gaps in the data record that are longer than a single day.

5.2 Variables

The V[NP|J1]10A1F product has these variables: CGF_NDSI_Snow_Cover, Basic_QA, Algorithm_Bit_Flags_QA, Cloud_Persistence, Daily_NDSI_Snow_Cover and Projection. Local attributes follow netCDF CF-1.6 conventions. The variable Projection is for CF-1.6 geolocation of the variables. A brief description of each variable is given in the following sections. A complete list of file contents is provided in Appendix C.

5.2.1 CGF_NDSI_Snow_Cover

The CGF_NDSI_Snow _Cover variable is the cloud-gap-filled snow cover extent map produced 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 contextual view of snow cover in the tile clouds, oceans, inland water, and other flag_values are included. The list of local attributes is provided in Appendix C.

5.2.2 Basic_QA

The Basic_QA variable is a general quality value assigned to observations in the V[NP|J1]10 algorithm. This quality value indicates quality ranging from highest to poor to provide a value for initial quality assessment. Features, e.g., oceans, are set to flag_values. Pixels that were detected as snow but flagged by the SWI screen (Section 3.3.1.6) in VNP10 have a flag_values value of 249. The observation selected corresponds to the observation selected for the CGF_NDSI_Snow_Cover variable. The list of local attributes is provided in Appendix C.

5.2.3 Algorithm_Bit_flags_QA

Algorithm specific bit flag masks in this variable are the result of data screens that were applied in the V[NP|J1]10 algorithm (Section 3.3.1). Multiple bit flag masks may be set for an observation. The observation selected corresponds to the observation selected for the CGF_NDSI_Snow_Cover variable. The list of local attributes is in Appendix C.

5.2.4 Cloud_Persistence

The number of consecutive days of cloud cover observed for a cell is tracked in this variable. If the current day observation is “not cloud,” the count is set to 0. If the current day observation is cloud, the Cloud_Persistence value from the previous day V[NP|J1]10A1F is incremented by one. The cloud persistence count is also incremented for _FillValue or missing_data. Comparison of the Cloud_Persistence with the CGF snow cover for a tile (Fig. 6) reveals where snow cover observations are current and where they are a few to many days old.

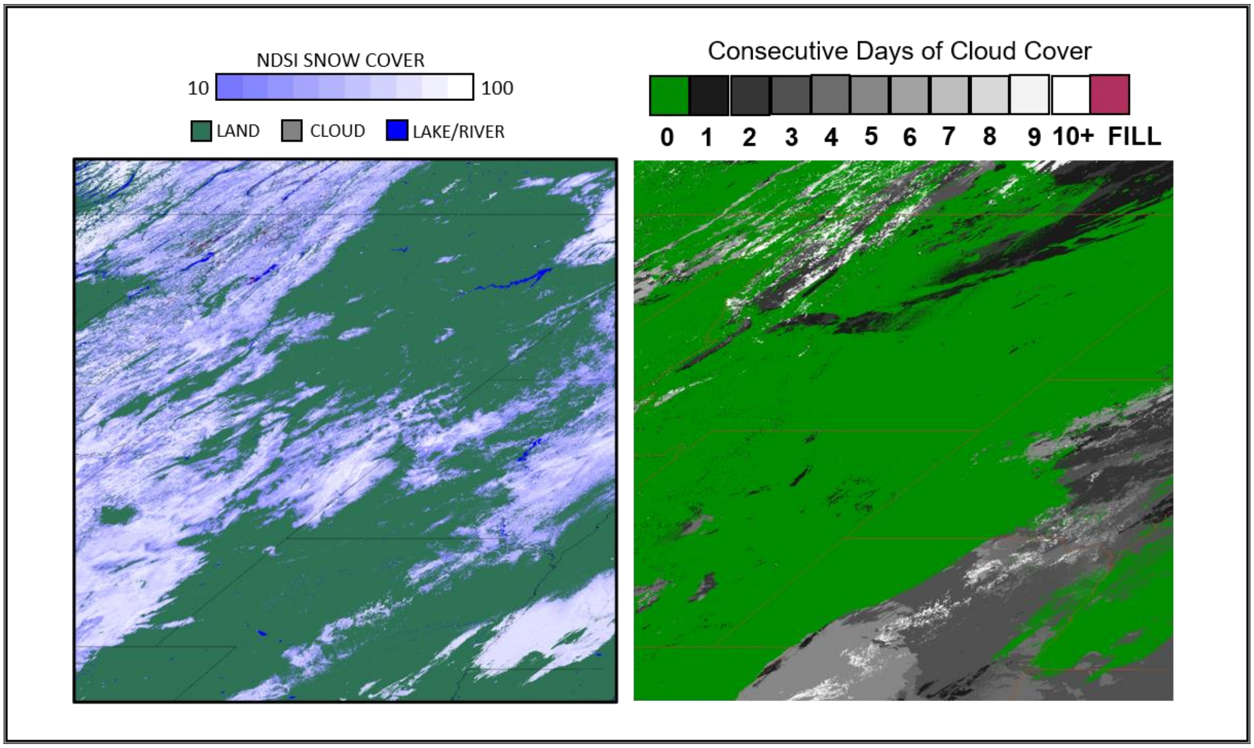

Figure 6. Cloud_Persistence from VNP10A1F.A2019013.h10v04.002.*.h5, 13 January 2019. The cloud persistence (right) shows regions clear skies (green) and where clouds have been observed on preceding days. Comparison with the CGF snow cover (left) (Fig. 5) reveals where snow cover observations are a few to many days old. Tile projected on sinusoidal projection.

5.2.5 Projection

Projection is an empty variable. The Projection variable serves as a container for local attributes that provide information on the projection. These local attributes follow CF-1.6 convention for geolocation and are used by tools to project or re-project from the native sinusoidal projection. List of local attributes is provided in Appendix C.

5.2.6 Daily_NDSI_Snow_Cover

The Daily_NDSI_Snow_Cover variable is a copy of the V[NP|J1]10A1 NDSI_Snow_Cover variable input. It facilitates a convenient comparison with the CGF_NDSI_Snow_Cover variable. 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 contextual view of snow cover in the tile clouds, oceans, inland water, and other flag_values are included with the snow cover data. The list of local attributes is provided in Appendix C.

5.3 Interpretation of Snow Cover Accuracy, Uncertainty and Errors

The CGF snow cover map is an estimate of the snow cover that might exist under current cloud cover. The CGF snow cover map is made by replacing the current day cloud observations in V[NP|J1]10A1 with a non-cloud (clear view) observation from the previous day V[NP|J1]10A1F. The previous day V[NP|J1]10A1F observation may be one or more days old. Persistence of cloud cover is tracked by incrementing the count of days of consecutive cloud cover observed in a cell. The number of days since the last non-cloud observation in a cell is tracked in the Cloud_Persistence variable. For a cloud-free observation the cloud persistence count is reset to 0. If the cloud persistence is 0 for a grid cell that means that a cloud-free observation was made on the current day. A cloud persistence value of 1 or greater means that the current day was cloudy. Cloud persistence is the number of consecutive days of cloud cover observed for a cell, or the number of days since a non-cloud observation was observed. The Cloud_Persistence variable should be used to determine how many days since the last clear view observation was acquired for a grid cell. The Basic_QA and Algorithm_Bit_Flag_QA variables are copied from the V[NP|J1]10A1 for non-cloud observations and from a previous day V[NP|J1]10A1F for cloudy observations. The snow Basic_QA and Algorithm_Bit_Flag_QA were set in the V[NP|J1]10 processing and described in Section 3.4.

On the first day of V[NP|J1]10A1F production, the CGF snow cover map is the same as the V[NP|J1]10A1 snow cover map; on successive days the cloud cover in the CGF declines, eventually to zero, as non-cloud observations replace cloud observations over time. A reasonable estimate of the number of days to reach a nearly cloud free CGF is five to seven days but is dependent on the season and location imaged. V[NP|J1]10A1F production follows the USGS “water year” beginning on 1 October and ending on 30 September, except for the first year of S-NPP which begins 19 January 2012. (For the Southern Hemisphere, the “water year” is 1 July to 30 June.) The initial day of a time series of V[NP|J1]10A1F is identified in the global attribute FirstDayOfSeries. FirstDayOfSeries is set to “Y” for the first day in a time series and to “N” for all other days in the time series. The global attribute TimeSeriesDay is the count of days in the series since the first day.

The accuracy, uncertainty and errors discussed for the V[NP|J1]10, Section 3.4, and V[NP|J1]10A1, Section 4.3, products are also relevant to the V[NP|J1]10A1F product. Comparison of the CGF snow cover with the current day snow and cloud cover is facilitated by a copy of the V[NP|J1]10A1_NDSI_Snow_Cover stored in the V[NP|J1]10A1F product.

There are some single day or multiple days of missing V[NP|J1]10A1 tiles in the SNPP and NOAA-20 data records. The CGF algorithm processes a missing tile as a completely cloudy day. In this case the previous day V[NP|J1]10A1F becomes the current day V[NP|J1]10A1F and the cloud persistence count is incremented by one. The global attribute MissingDaysOfDailyData reports the number of missing days, it is incremented by one for each missing day then reset to 0 when V[NP|J1]10A1 is again available. The S-NPP VIIRS data outages are listed at https://modaps.modaps.eosdis.nasa.gov/services/production/outages_npp.html and the NOAA-20 data outages are listed at https://modaps.modaps.eosdis.nasa.gov/services/production/outages_noaa_20.html. A single day of missing data has minimal impact on the continuity of SCE however, the impact can vary temporally and by region. The effect of multiple consecutive days of missing V[NP|J1]10A1 tiles has not been assessed but would probably be significant, especially during periods when snow cover could be reasonably expected to occur or change in spatial extent.

If orbit gaps or missing swath data occur in the V[NP|J1]10A1 the CGF algorithm processed that fill data in a manner similar to how a cloud observation is processed. A fill data value is replaced with a non-fill data value from yesterday's V[NP|J1]10A1F and the cloud persistence count is incremented by one. If the observation from previous day V[NP|J1]10A1F is fill data, then fill data is written for the cell and the cloud persistence count is incremented by one. The objective of processing fill data in this way is to provide a CGF snow map without fill data disrupting the continuity of the CGF snow cover map over time. However, situations of persistent fill data will be retained as fill data until non-fill data is available.

6.0 V[NP|J1]10C1

V[NP|J1]10C1 is a daily global view of snow cover. All the daily V[NP|J1]10A1 tile products, approximately 320 tiles, are mapped onto the MODIS climate modeling grid (CMG), a geographic projection at 0.05° (~ 5 km) resolution (https://modis-land.gsfc.nasa.gov/MODLAND_grid.html) to make this daily snow cover extent product. SCE is given as the percentage of snow cover, 375 m resolution observations, mapped into a ~ 5 km resolution cell of the CMG. A corresponding map of cloud cover percentage is also generated and stored. The snow and cloud percentage arrays can be combined to get a synoptic view of snow and cloud extents for a day. Examples of the VNP10C1 snow cover and cloud cover maps are shown in Figures 7 and 8.

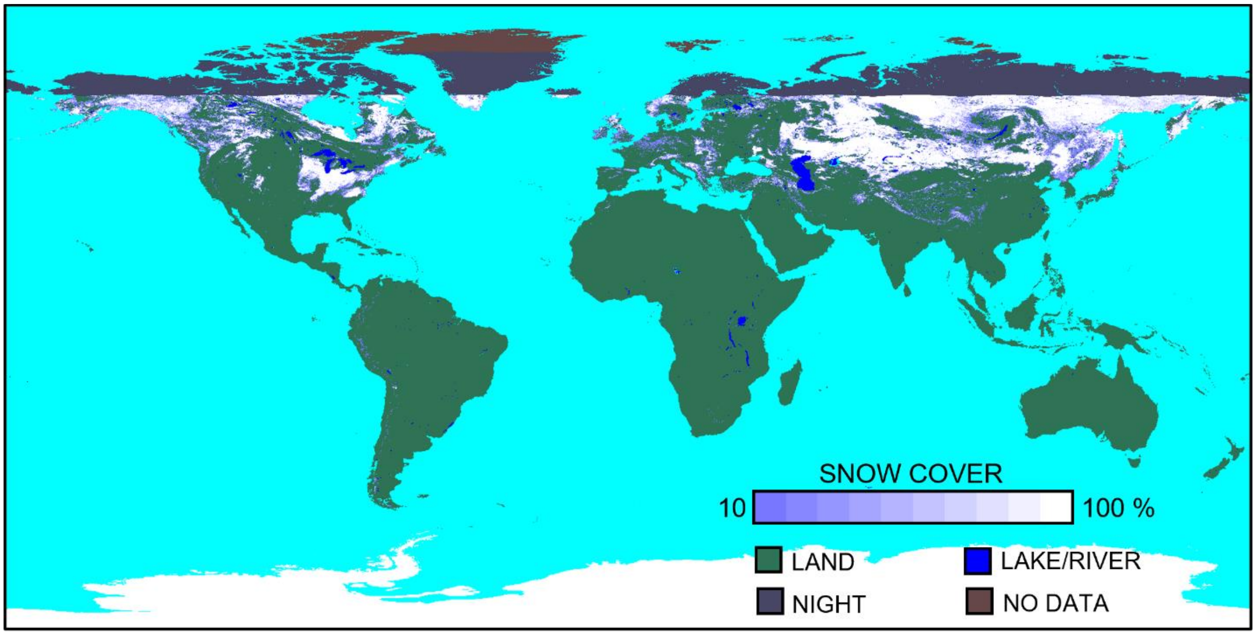

Figure 7. VNP10C1 snow cover 18 January 2018. Snow cover is from VNP10C1.A2018018.002.2022258114419.h5.

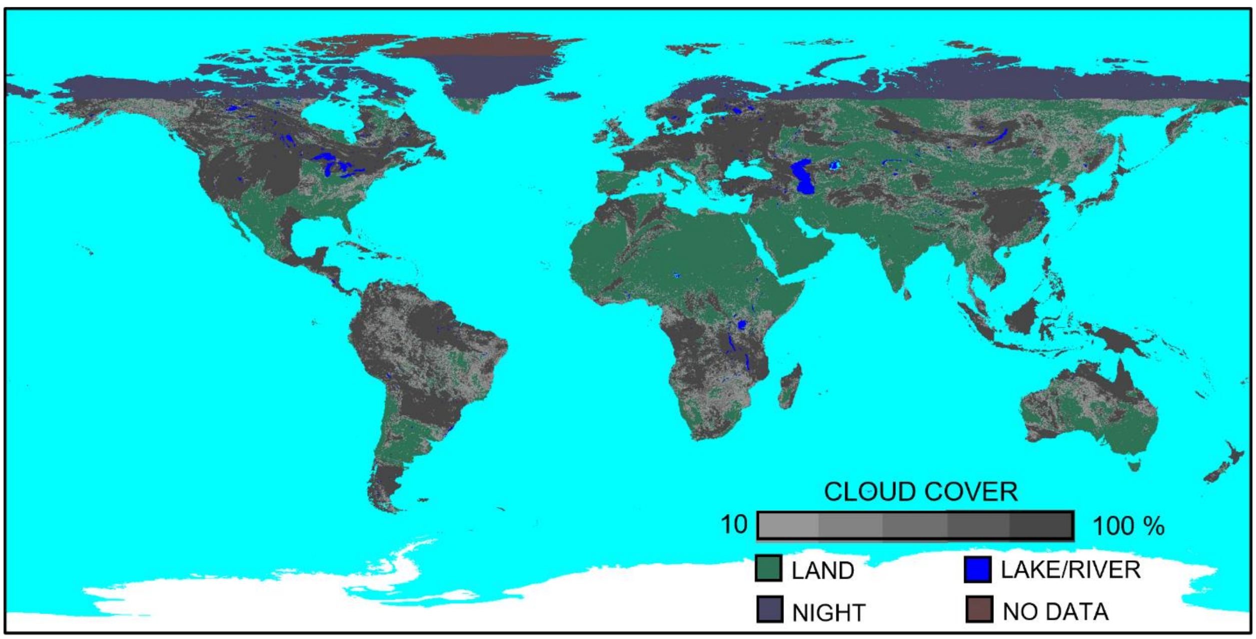

Figure 8. VNP10C1 cloud cover 18 January 2018. Cloud cover is from VNP10C1.A2018018.002.2022258114419.h5.

6.1 Algorithm Description

A binning algorithm is used to determine snow cover extent, cloud cover extent, and associated QA in a CMG grid cell. The input V[NP|J1]10A1 NDSI_Snow_Cover data is translated to a 'snow' or 'not snow' flag that is counted in the binning algorithm to determine the percentage of snow observations in a cell. The NDSI snow cover, from 0-100, is interpreted as a binary snow flag to tally observations of snow mapped in a grid cell. Cloud observations are interpreted and tallied using the same method. Inputs to the algorithm are listed in Table 15. The binning algorithm generates the snow and cloud cover maps based the total number of observations of a feature, e.g., snow, cloud, snow-free land, etc. and total number of land observations mapped into a cell of the CMG. Lake ice coverage is also included in the snow map. Inland water bodies are determined using the water flag bit in the NDSl_Snow_Cover_Algorithm_Flags_QA for counting the number of water body observations in a grid cell. Observations are tallied for lakes; if the water body has more lake ice observations than open water observations it is interpreted as lake ice with a value of 107 in the output. Lakes that are cloud obscured are output as cloud obscured with a value of 250.

A CMG-specific land base mask was made for use with the binning algorithm. The 0.05° land mask was derived from the University of Maryland 1km global land cover data set. That specific dataset has been superseded by other land cover data product at the UMD Global Land Analysis & Discovery group (https://glad.umd.edu/). If a CMG cell contains 12% or greater area of land then it is considered to be land and analyzed; if it is less than 12% it is considered to be ocean. That threshold was selected as a balance that minimized snow errors along coasts yet was sensitive to mapping snow along coasts.

The extent of clear views in a cell is presented as an index of the amount of surface observed in the grid cell. This index is called the clear index (CI) and is intended to provide users with an estimate of percentage of all observations mapped in a grid cell that were clear. The CI is essentially 100 minus the percentage of cloud in a cell, though it is calculated based on observation counts in the algorithm code. The CI values are stored in the Clear_Index variable. A high CI is indicative of clear conditions and a low CI is indicative of a lot of cloud cover and that snow percentage may not be a good estimate because of cloud cover obscuring all or parts of a cell.

The extent of polar darkness is determined based on the latitude of the CMG cell nearest the equator that is full of night observations. Land CMG cells poleward from that latitude are filled as night. Polar darkness is determined this way so that a neat demarcation of night and day is shown in the CMG. Observations of polar land regions in polar darkness that were acquired with VIIRS in night mode are mapped as no data.

Antarctica has been masked as 100% snow covered. That masking was done to improve the visual quality of the data display. This product is not recommended for study of snow cover in Antarctica. During the austral summer some coastal regions, mainly on parts of the Antarctic Peninsula, may be snow free for a brief period of time. Study of those or other areas of Antarctica should use the V[NP|J1]10 product that is of higher resolution and contains more data and information on accuracy and error.

A global mask showing where the occurrence of snow is extremely unlikely, e.g., the Amazon, the Sahara and the Great Sandy Desert, is applied at the end of the algorithm to eliminate probable erroneous snow cover detection. The source of erroneous snow in those regions is the V[NP|J1]10 product where erroneous snow detection occurs and is carried forward through the processing levels to the CMG. At the CMG level the use of this extremely unlikely snow mask eliminates erroneous snow from the masked regions but allows it in regions where snow may be a rare event.

6.2 Variables

The V[NP|J1]10C1 product has these variables: Snow_Cover, Cloud_Cover , Basic_QA, and Clear_Index. Local attributes follow netCDF CF-1.6 conventions. A brief description of each variable is given in the following sections. A complete list of file contents is provided in Appendix D.

6.2.1 Snow_Cover

The percentage of snow cover in a CMG cell is given in the Snow_Cover variable. Snow cover is the percentage of snow observations mapped into a grid cell based on the count of all land observations mapped in the CMG grid cell. No attempt was made to interpret snow cover possibly obscured by cloud. Percentage of snow is reported in the range of 0-100%. The list of local attributes is provided in Appendix D.

6.2.2 Cloud_Cover

The percentage of cloud cover in a CMG cell is given in the Cloud_Cover variable. Cloud cover is the percentage of cloud observations mapped into a grid cell based on the count of all land observations mapped in the CMG grid cell. That is the same count basis as used to calculate percentage of snow. Percentage of cloud is reported in the range of 0-100%. The list of local attributes is provided in Appendix D.

6.2.3 Basic_QA

The Basic_QA value for a grid cell is the most frequent Basic_QA value associated with the V[NP|J1]10A1 observations mapped into a grid cell. The binning algorithm returns the most frequent QA value; if there is a tie in QA values then the highest QA value of the tied values is reported. The Basic_QA flag_values are not used in calculating the basic QA value. The list of local attributes is provided in Appendix D.

6.2.4 Clear_Index

The clear index (CI) is intended to provide users with an estimate of percentage of all observations mapped in a grid cell that were clear. The CI is essentially 100 minus the percentage of cloud in a cell. A high CI is indicative of clear conditions and a low CI is indicative of a lot of cloud cover. A low CI indicates that the snow percentage may not be a good estimate because of the cloud cover obscuring all or parts of a grid cell. The clear index ranges from 0 -100%. The list of local attributes is provided in Appendix D.

6.3 Interpretation of Snow Cover Accuracy, Uncertainty and Errors

The daily V[NP|J1]10C1 provides a synoptic view of snow cover extent. The snow cover and cloud cover data can be combined to make a synoptic view of snow cover with the cloud cover overlaid. Snow cover and cloud cover are produced in separate data arrays so that a user may interpret or combine the data relevant to their research or applications. Understanding the propagation of sources of possible snow and cloud errors in the products from the V[NP|J1]10 to the CMG is useful for interpretation and possibly filtering the data to reduce uncertainty. V[NP|J1]10C1 can contain snow cover errors propagated from the V[NP|J1]10 to the V[NP|J1]10A1 into the V[NP|J1]10C1. (See Section 3.4 for discussion of errors and uncertainty). In the V[NP|J1]10C1 Snow_Cover snow cover appearing in locations and at times when snow is not expected is indicative of false snow detections. False snow originates in the V[NP|J1]10 algorithm from detection errors at periphery of clouds and edges of water bodies.

Because of the great difficulty in discriminating between clouds and snow over Antarctica in the V[NP|J1]10 and V[NP|J1]35_L2 cloud mask algorithms the quality of snow cover may vary therefore Antarctica is masked as 100% snow cover. Though masking improves the visual quality of the image, it excludes scientific study of Antarctica.

To reduce snow errors in regions of the world that climatologically should never have snow, a “snow impossible” mask was created and applied in the algorithm. The purpose of this mask is to improve quality of the product by preventing snow in regions of the world that should not have snow. A drawback of application of the mask is that highly unusual snowfall events in some regions may be masked. The V[NP|J1]10 and V[NP|J1]10A1 products should be used to investigate unusual snowfall events because they do not include a “snow impossible” mask.

7.0 References

Dixit, A.; Goswami, A.; Jain, S. Development and Evaluation of a New “Snow Water Index (SWI)” for Accurate Snow Cover Delineation. Remote Sens. 2019, 11, 2774; https://doi:10.3390/rs11232774

Hall, D.K., G.A. Riggs, N.E. DiGirolamo and M.O. Román, 2019: Evaluation of MODIS and VIIRS cloud-gap-filled snow-cover products for production of an Earth science data record, *Hydrol. Earth Syst. Sci.*, 23:5227-5241, https://doi.org/10.5194/hess-23-5227-2019.LDOPE, 2022, VIIRS Land C2 Changes, https://landweb.modaps.eosdis.nasa.gov/NPP/forPage/VIIRS_Land_Changes_09152022.pdf.

Riggs, G., Hall, D.K. and Román, M.O. 2015 VIIRS Snow Cover Algorithm Theoretical Basis Document (ATBD) https://nsidc.org/sites/nsidc.org/files/technical-references/VIIRS_snow_cover_ATBD_2015.pdf

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Zhang, H., Zhang, F., Che, T. and Wang, S. 2020. Comparative evaluations of VIIRS daily snow cover product with MODIS for snow detection in China based on ground observations. Science of the Total Environment, 724, 138156,
https://doi.org/10.1016/j.scitotenv.2020.138156

8.0 Related Web Sites

Suomi-NPP
https://eospso.nasa.gov/missions/suomi-national-polar-orbiting-partnership

VIIRS
VIIRS Land: https://viirsland.gsfc.nasa.gov/
VIIRS Snow Cover:
https://viirsland.gsfc.nasa.gov/Products/NASA/SnowESDR.html

MODIS and VIIRS Snow and Ice Global Mapping Project https://modis-snow-ice.gsfc.nasa.gov

Imagery and Data Product Viewing
Worldview: https://worldview.earthdata.nasa.gov
LANCE: https://wiki.earthdata.nasa.gov/pages/viewpage.action?pageId=2228234

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/

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

Acronyms

ATBD	Algorithm Theoretical Basis Document
BT	Brightness Temperature
C2	Collection 2 (VIIRS)
C6.1	Collection 6.1 (MODIS)
CDR	Climate Data Record
CF-1.6	Climate and Forecast Metadata Conventions Version 1.6
CGF	Cloud-Gap-Filled
DAAC	Distributed Active Archive Center
EOSDIS	Earth Observing System Data and Information System
ESDT	Earth Science Data Type
HDF5	Hierarchical Data Format 5
HDF-EOS5	Hierarchical Data Format – Earth Observing System Version 5
JPSS	Joint Polar Satellite System
JPSS-1	Joint Polar Satellite System, first satellite in the system
L1 / L2 / L3	Level 1, Level 2 or Level 3 data product
L2G	Level-2 Gridded Data Product
LPEATE	Land Project Evaluation And Test Element
LSIPS	Land Science Investigator-led Processing System
LWM	Land Water Mask
MODIS	Moderate-resolution Imaging Spectroradiometer
NASA	National Aeronautics and Space Administration
netCDF	network Common Data Format
NDSI	Normalized Difference Snow Index
NOAA	National Oceanic and Atmospheric Administration
NOAA-20	National Oceanic and Atmospheric Administration polar orbiting satellite number 20. Formerly known as JPSS-1
NSIDC	National Snow and Ice Data Center
QA	Quality Assessment
SCA	Snow Covered Area
SCE	Snow Cover Extent
SIN	Sinusoidal Projection
S-NPP	Suomi National Polar-orbiting Partnership
SWI	Snow Water Index
SWIR	Short Wave Infrared
SZA	Solar Zenith Angle
TOA	Top-of-Atmosphere
USGS	United States Geological Survey
USRI	Universal Snow Ratio Index
VCST	VIIRS Characterization Support Team
VIIRS	Visible Infrared Imager Radiometer Suite
VJ1	VIIRS JPSS-1 NASA Product
VJ110	ESDT name for the VIIRS JPSS-1Level-2 swath-based Snow Cover Data Product

VJ110A1	ESDT name for the VIIRS JPSS-1 Level-3 tiled Snow Cover Data Product
VJ110A1F	ESDT name for the VIIRS JPSS-1 Level-3 tiled Cloud-gap-filled SnowCover Data Product
VJ110C1	ESDT name for the VIIRS JPSS-1 Level-3 global Snow Cover Data Product
VNP	VIIRS S-NPP NASA Product
VNP10	ESDT name for the VIIRS S-NPP Level-2 swath-based Snow Cover Data Product
VNP10A1	ESDT name for the VIIRS S-NPP Level-3 tiled Snow Cover Data Product
VNP10A1F	ESDT name for the VIIRS S-NPP Level-3 tiled Cloud-gap-filled SnowCover Data Product
VNP10C1	ESDT name for the VIIRS S-NPP Level-3 global Snow Cover Data Product
VIS	Visible

Appendix A

Example of V[NP|J1]10 product contents.

```
netcdf VNP10.A2018017.1836.002.2022258071908 {
dimensions:
        number_of_lines = 6496 ;
        number_of_pixels = 6400 ;

// global attributes:
                :QAPercentCloudCover = "38.8%" ;
                :Snow_Cover_Extent = "30.2%" ;
                :QAPercentBestQuality = "98.3%" ;
                :QAPercentGoodQuality = "0.1%" ;
                :QAPercentPoorQuality = "0.1%" ;
                :QAPercentOtherQuality = "1.6%" ;
                :license = "http://science.nasa.gov/earth-science/earth-science-data/data-information-
policy/" ;
                :processing_level = "Level 2" ;
                :EndTime = "2018-01-17 18:42:00.000" ;
                :LocalGranuleID = "VNP10.A2018017.1836.002.2022258071908.nc" ;
                :GRingPointLongitude = -108.219, -68.0258, -66.7726, -97.3337 ;
                :ProcessingCenter = "LandSIPS" ;
                :Conventions = "CF-1.6" ;
                :publisher_email = "nsidc@nsidc.org" ;
                :RangeEndingDate = "2018-01-17" ;
                :SouthBoundingCoordinate = 24.6632f ;
                :SatelliteInstrument = "NPP_OPS" ;
                :AlgorithmVersion = "NPP_PR10 1.0.13" ;
                :AlgorithmType = "SCI" ;
                :PGE_EndTime = "2018-01-17 18:42:00.000" ;
                :PGENumber = "507" ;
                :creator_email = "modis-ops@lists.nasa.gov" ;
                :PGEVersion = "2.0.5" ;
                :GRingPointSequenceNo = 1, 2, 3, 4 ;
                :RangeEndingTime = "18:42:00.000000" ;
                :ProcessingEnvironment = "Linux minion20050 5.4.0-124-generic #140-Ubuntu SMP Thu
Aug 4 02:23:37 UTC 2022 x86_64 x86_64 x86_64 GNU/Linux" ;
                :naming_authority = "gov.nasa.gsfc.VIIRSland" ;
                :identifier_product_doi_authority = "https://doi.org" ;
                :title = "VIIRS Snow Cover Data" ;
                :PGE_Name = "PGE507" ;
                :ProductionTime = "2022-09-15 07:19:08.000" ;
                :InputPointer =
"VNP35_L2.A2018017.1836.002.2022258071342.hdf,VNP02CCIMG.A2018017.1836.002.202225119043
5.nc,VNP02CCMOD.A2018017.1836.002.2022251190435.nc,VNP03IMG.A2018017.1836.002.20210781
21909.nc" ;
                :publisher_url = "https://nsidc.org" ;
                :project = "VIIRS Land SIPS Snow Cover Project" ;
                :publisher_name = "NSIDC" ;
                :PGE_StartTime = "2018-01-17 18:36:00.000" ;
                :VersionID = "002" ;
                :RangeBeginningDate = "2018-01-17" ;
                :institution = "NASA Goddard Space Flight Center" ;
```

```
                :EastBoundingCoordinate = -66.7726f ;
                :ShortName = "VNP10" ;
                :WestBoundingCoordinate = -108.219f ;
                :LongName = "VIIRS/NPP Snow Cover 6-Min L2 Swath 375m" ;
                :StartTime = "2018-01-17 18:36:00.000" ;
                :creator_name = "VIIRS Land SIPS Processing Group" ;
                :NorthBoundingCoordinate = 50.2277f ;
                :stdname_vocabulary = "NetCDF Climate and Forecast (CF) Metadata Convention" ;
                :RangeBeginningTime = "18:36:00.000000" ;
                :identifier_product_doi = "10.5067/ZZMS6RM8LQS9" ;
                :DayNightFlag = "Day" ;
                :cdm_data_type = "swath" ;
                :keywords_vocabulary = "NASA Global Change Master Directory (GCMD) Science
Keywords" ;
                :creator_url = "https://ladsweb.modaps.eosdis.nasa.gov" ;
                :SensorShortname = "VIIRS" ;
                :GRingPointLatitude = 44.1262, 50.1767, 29.277, 24.6632 ;

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

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 = 1UB, 2UB, 4UB, 8UB, 16UB, 32UB, 64UB, 128UB
;
                Algorithm_bit_flags_QA:flag_meanings = "inland_water_flag low_visible_screen
low_NDSI_screen combined_surface_temperature_and_height_screen_or_flag
high_SWIR_screen_or_flag cloud_mask_probably_cloudy cloud_mask_probably_clear 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:_FillValue = 255UB ;
                Basic_QA:flag_values = 211UB, 239UB, 249UB, 250UB, 251UB, 252UB, 253UB, 254UB
;
                Basic_QA:flag_meanings = "night ocean SWI_screened cloud missing_L1B_data
cal_fail_L1B_data bowtie_trim L1B_fill" ;
                Basic_QA:coordinates = "latitude longitude" ;
```

```
                Basic_QA:long_name = "Basic QA value" ;
                Basic_QA:valid_range = 0UB, 3UB ;
                Basic_QA:key = "0=best, 1=good, 2=poor, 3=other" ;
        short NDSI(number_of_lines, number_of_pixels) ;
                NDSI:coordinates = "latitude longitude" ;
                NDSI:long_name = "NDSI for all land and inland water pixels" ;
                NDSI:valid_range = -1000s, 1000s ;
                NDSI:scale_factor = 0.001f ;
                NDSI:flag_values = 21000s, 29000s, 24000s, 25000s, 31000s, 30000s ;
                NDSI:flag_meanings = "night ocean L1B_missing L1B_unusable bowtie_trim L1B_fill" ;
                NDSI:_FillValue = 32767s ;
        ubyte NDSI_Snow_Cover(number_of_lines, number_of_pixels) ;
                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:flag_values = 201UB, 211UB, 237UB, 239UB, 250UB, 251UB,
252UB, 253UB, 254UB ;
                NDSI_Snow_Cover:flag_meanings = "no_decision night lake ocean cloud
missing_L1B_data cal_fail_L1B_data bowtie_trim L1B_fill" ;
                NDSI_Snow_Cover:_FillValue = 255UB ;

  // group attributes:
                :I01_Noisy_Detectors_Count = 0s ;
                :I01_detector_quality_flag_values = 0UB, 0UB, 0UB, 0UB, 0UB, 0UB, 0UB, 0UB, 0UB,
0UB, 0UB, 0UB, 0UB, 0UB, 0UB, 0UB, 0UB, 0UB, 0UB, 0UB, 0UB, 0UB, 0UB, 0UB, 0UB, 0UB, 0UB,
0UB, 0UB, 0UB, 0UB, 0UB ;
                :I02_Noisy_Detectors_Count = 0s ;
                :I02_detector_quality_flag_values = 0UB, 0UB, 0UB, 0UB, 0UB, 0UB, 0UB, 0UB, 0UB,
0UB, 0UB, 0UB, 0UB, 0UB, 0UB, 0UB, 0UB, 0UB, 0UB, 0UB, 0UB, 0UB, 0UB, 0UB, 0UB, 0UB, 0UB,
0UB, 0UB, 0UB, 0UB, 0UB ;
                :I03_Noisy_Detectors_Count = 0s ;
                :I03_detector_quality_flag_values = 0UB, 0UB, 0UB, 0UB, 0UB, 0UB, 0UB, 0UB, 0UB,
0UB, 0UB, 0UB, 0UB, 0UB, 0UB, 0UB, 0UB, 0UB, 0UB, 0UB, 0UB, 0UB, 0UB, 0UB, 0UB, 0UB, 0UB,
0UB, 0UB, 0UB, 0UB, 0UB ;
                :detector_quality_flag_masks = 1UB, 2UB, 4UB, 8UB, 16UB, 32UB, 64UB, 128UB ;
                :detector_quality_flag_meanings = "Noisy Dead" ;
                :Surface_temperature_screen_threshold = "281.0 K" ;
                :Surface_height_screen_threshold = "1300 m" ;
                :Land_in_clear_view = "61.2%" ;
  } // group SnowData
}
```

Appendix B

Example of V[NP|J1]10A1 product contents.

```
netcdf VNP10A1.A2018017.h05v10.002.2022258074724 {

// global attributes:
		:identifier_product_doi = "10.5067/45VDCKJBXWEE" ;
		:RangeEndingDate = "2018-01-17" ;
		:VerticalTileNumber = "10" ;
		:InstrumentShortname = "VIIRS" ;
		:GlobalGridColumns = 108000 ;
		:DataResolution = "375m" ;
		:creator_url = "https://ladsweb.modaps.eosdis.nasa.gov" ;
		:EndTime = "2018-01-17 23:59:59" ;
		:TileID = "51005010" ;
		:GeoAnyAbnormal = "False" ;
		:NorthBoundingCoord = -10. ;
		:SatelliteInstrument = "NPP_OPS" ;
		:Cloud_Cover_Extent = "0.0%" ;
		:QAPercentOtherQuality = "0.0%" ;
		:creator_name = "VIIRS Land SIPS Processing Group" ;
		:GranuleDayNightFlag = "Day" ;
		:publisher_name = "NSIDC" ;
		:Land_Day_Extent = "0.0%" ;
		:LongName = "VIIRS/NPP L3 Snow Global 375m SIN Grid" ;
		:ZoneIdentifier = 0s ;
		:GeoEstMaxRMSError = 0. ;
		:ProcessVersion = "002" ;
		:naming_authority = "gov.nasa.gsfc.VIIRSland" ;
		:InputPointer = 
"/MODAPSops7/archive/f20063/running/VNP_L5Sglu/28055057/VNP10GA.A2018017.h05v10.002.20222
58074712.hdf" ;
		:PGEName = "PGE543" ;
		:PGEVersion = "2.0.3" ;
		:DataRows = 3000s ;
		:creator_email = "modis-ops@lists.nasa.gov" ;
		:VersionID = "002" ;
		:SouthBoundingCoord = -20. ;
		:GlobalGridRows = 54000 ;
		:DataColumns = 3000s ;
		:RangeEndingTime = "23:59:59.000" ;
		:GRingSequence = 1., 2., 3., 4. ;
		:identifier_product_doi_authority = "https://doi.org" ;
		:LocalVersionID = "1.0.0" ;
		:NumberofOverlapGranules = 3s ;
		:GranuleEndingDateTime = "2018-01-17 21:48:00.000,2018-01-17 21:54:00.000,2018-
01-17 23:30:00.000,2018-01-17 23:36:00.000" ;
		:ProcessingCenter = "LandSIPS" ;
		:Conventions = "CF-1.6" ;
		:Snow_Cover_Extent = "0.0%" ;
		:QAPercentPoorQuality = "0.0%" ;
		:ProcessingEnvironment = "Linux minion20063 5.4.0-124-generic #140-Ubuntu SMP Thu
Aug 4 02:23:37 UTC 2022 x86_64 x86_64 x86_64 GNU/Linux" ;
```

```
                :HorizontalTileNumber = "05" ;
                :PGE_Name = "PGE543" ;
                :EastBoundingCoord = -121.84442 ;
                :PGE_EndTime = "2018-01-17 23:59:59.000000Z" ;
                :GRingLongitude = -138.34311, -132.0174, -121.40044, -127.20726 ;
                :ShortName = "VNP10A1" ;
                :StartTime = "2018-01-17 00:00:00" ;
                :DayNightFlag = "Day" ;
                :RangeBeginningTime = "00:00:00.000" ;
                :publisher_url = "https://nsidc.org" ;
                :GRingLatitude = -20., -9.9375685, -9.9743545, -20.035295 ;
                :PGENumber = "543" ;
                :RangeBeginningDate = "2018-01-17" ;
                :CharacteristicBinSize = 370.650173222222 ;
                :GranulePointerArray = 0, 1, 2, -1, -1, -1, -1, -1, -1, -1, -1, -1, -1, -1, -1, -1, -1, -1, -1, -1, -1,
-1, -1, -1, -1, -1, -1, -1, -1, -1, -1, -1, -1, -1, -1, -1, -1, -1, -1, -1, -1, -1, -1, -1, -1, -1, -1, -1, -1, -1, -1, -1, -1, -
1, -1, -1, -1, -1, -1, -1, -1, -1, -1, -1, -1, -1, -1, -1, -1, -1, -1, -1, -1, -1, -1, -1, -1, -1, -1, -1, -1, -1, -1, -1, -1, -
1, -1, -1, -1, -1, -1, -1, -1, -1, -1, -1, -1, -1, -1, -1 ;
                :PlatformShortName = "SUOMI-NPP" ;
                :GranuleDayOfYear = "17" ;
                :PGE_StartTime = "2018-01-17 00:00:00.000" ;
                :GranuleBeginningDateTime = "2018-01-17 21:42:00.000,2018-01-17
21:48:00.000,2018-01-17 23:24:00.000,2018-01-17 23:30:00.000" ;
                :ProductionDateTime = "2022-09-15T07:47:24.000Z" ;
                :SensorShortName = "VIIRS" ;
                :CharacteristicBinAngularSize = 12. ;
                :AlgorithmVersion = "NPP_PR10A1 2.0.0" ;
                :publisher_email = "nsidc@nsidc.org" ;
                :LocalGranuleID = "VNP10A1.A2018017.h05v10.002.2022258074724.h5" ;
                :AlgorithmType = "SCI" ;
                :WestBoundingCoord = -138.34311 ;
                :ProductionTime = "2022-09-15 07:47:24.000" ;
                :QAPercentGoodQuality = "100.0%" ;

group: HDFEOS {

  group: ADDITIONAL {

    group: FILE_ATTRIBUTES {
      } // group FILE_ATTRIBUTES
    } // group ADDITIONAL

  group: GRIDS {

    group: VIIRS_Grid_IMG_2D {
      dimensions:
        XDim = 3000 ;
        YDim = 3000 ;
      variables:
        double XDim(XDim) ;
                XDim:standard_name = "projection_x_coordinate" ;
                XDim:long_name = "x coordinate of projection" ;
                XDim:units = "m" ;
        double YDim(YDim) ;
```

```
                YDim:standard_name = "projection_y_coordinate" ;
                YDim:long_name = "y coordinate of projection" ;
                YDim:units = "m" ;

    group: Data\ Fields {
      dimensions:
        phony_dim_2 = 1 ;
      variables:
        ubyte Algorithm_bit_flags_QA(YDim, XDim) ;
                Algorithm_bit_flags_QA:long_name = "Algorithm bit flags QA" ;
                Algorithm_bit_flags_QA:valid_range = 0UB, 255UB ;
                Algorithm_bit_flags_QA:flag_masks = 1UB, 2UB, 4UB, 8UB, 16UB, 32UB, 64UB, 128UB
;
                Algorithm_bit_flags_QA:flag_meanings = "inland_water_flag low_visible_screen
low_NDSI_screen combined_surface_temperature_and_height_screen_or_flag
high_SWIR_screen_or_flag cloud_mask_probably_cloudy cloud_mask_probably_clear 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" ;
                Algorithm_bit_flags_QA:grid_mapping = "Projection" ;
        ubyte Basic_QA(YDim, XDim) ;
                Basic_QA:long_name = "Basic QA value" ;
                Basic_QA:valid_range = 0UB, 3UB ;
                Basic_QA:_FillValue = 255UB ;
                Basic_QA:key = "0=best, 1=good, 2=poor, 3=other" ;
                Basic_QA:flag_values = 211UB, 239UB, 249UB, 250UB, 251UB, 252UB, 253UB, 254UB
;
                Basic_QA:flag_meanings = "night ocean SWI_screened cloud missing_L1B_data
cal_fail_L1B_data bowtie_trim L1B_fill" ;
                Basic_QA:grid_mapping = "Projection" ;
        short NDSI(YDim, XDim) ;
                NDSI:long_name = "NDSI for all land and inland water pixels" ;
                NDSI:valid_range = -1000s, 1000s ;
                NDSI:_FillValue = 32767s ;
                NDSI:scale_factor = 0.001f ;
                NDSI:flag_values = 21000s, 29000s, 24000s, 25000s, 31000s, 30000s ;
                NDSI:flag_meanings = "night ocean L1B_missing L1B_unusable bowtie_trim L1B_fill" ;
                NDSI:grid_mapping = "Projection" ;
        ubyte NDSI_Snow_Cover(YDim, XDim) ;
                NDSI_Snow_Cover:long_name = "Snow cover by NDSI" ;
                NDSI_Snow_Cover:valid_range = 0UB, 100UB ;
                NDSI_Snow_Cover:flag_values = 201UB, 211UB, 237UB, 239UB, 250UB, 251UB,
252UB, 253UB, 254UB ;
                NDSI_Snow_Cover:flag_meanings = "no_decision night lake ocean cloud
missing_L1B_data cal_fail_L1B_data bowtie_trim L1B_fill" ;
                NDSI_Snow_Cover:key = "0-100=NDSI snow, 201=no decision, 211=night, 237=inland
water, 239=ocean, 250=cloud, 251=missing data, 252=L1B unusable, 253=bowtie trim, 254=L1B fill,
255=fill" ;
                NDSI_Snow_Cover:grid_mapping = "Projection" ;
                NDSI_Snow_Cover:_FillValue = 255UB ;
        int Projection(phony_dim_2) ;
                Projection:grid_mapping_name = "sinusoidal" ;
                Projection:longitude_of_central_meridian = 0. ;
                Projection:false_easting = 0. ;
```

```
                Projection:false_northing = 0. ;
                Projection:earth_radius = 6371007.181 ;
        ubyte granule_pnt(YDim, XDim) ;
                granule_pnt:long_name = "Granule pointer" ;
                granule_pnt:valid_range = 0UB, 254UB ;
                granule_pnt:_FillValue = 255UB ;
                granule_pnt:grid_mapping = "Projection" ;
      } // group Data\ Fields
     } // group VIIRS_Grid_IMG_2D
    } // group GRIDS
  } // group HDFEOS

group: HDFEOS\ INFORMATION {
  variables:
        string StructMetadata.0 ;

  // group attributes:
                :HDFEOSVersion = "HDFEOS_5.1.16" ;
  } // group HDFEOS\ INFORMATION
}
```

Appendix C

Example of V[NP|J1]10A1F product contents.

netcdf VNP10A1F.A2018017.h05v10.002.2022258074906 {

// global attributes:
:identifier_product_doi = "10.5067/PN50Y51IVNLE" ;
:RangeEndingDate = "2018-01-17" ;
:VerticalTileNumber = "10" ;
:InstrumentShortname = "VIIRS" ;
:TimeSeriesDay = 24s ;
:GlobalGridColumns = 108000 ;
:DataResolution = "375m" ;
:creator_url = "https://ladsweb.modaps.eosdis.nasa.gov" ;
:EndTime = "2018-01-17 23:59:59" ;
:TileID = "51005010" ;
:GeoAnyAbnormal = "False" ;
:NorthBoundingCoord = -10.f ;
:SatelliteInstrument = "NPP_OPS" ;
:Cloud_Cover_Extent = "0.0%" ;
:QAPercentOtherQuality = "0.0%" ;
:creator_name = "VIIRS Land SIPS Processing Group" ;
:GranuleDayNightFlag = "Day" ;
:publisher_name = "NSIDC" ;
:Land_Day_Extent = "0.0%" ;
:LongName = "VIIRS/NPP CGF Snow Cover Daily L3 Global 375m SIN Grid" ;
:ZoneIdentifier = 0s ;
:GeoEstMaxRMSError = 0. ;
:ProcessVersion = "002" ;
:naming_authority = "gov.nasa.gsfc.VIIRSland" ;
:InputPointer =
"/MODAPSops7/archive/f20060/running/VNP_L5SFglu/28055723/VNP10A1.A2018017.h05v10.002.2022258074724.h5,/MODAPSops7/archive/f20060/running/VNP_L5SFglu/28055723/VNP10A1F.A2018016.h05v10.002.2022258061540.h5" ;
:MissingDaysOfDailyData = 0s ;
:PGEName = "PGE656" ;
:PGEVersion = "2.0.3" ;
:DataRows = 3000s ;
:creator_email = "modis-ops@lists.nasa.gov" ;
:VersionID = "002" ;
:SouthBoundingCoord = -20.f ;
:GlobalGridRows = 54000 ;
:DataColumns = 3000s ;
:RangeEndingTime = "23:59:59.000" ;
:identifier_product_doi_authority = "https://doi.org" ;
:LocalVersionID = "2.0.0" ;
:ProcessingCenter = "LandSIPS" ;
:Conventions = "CF-1.6" ;
:Snow_Cover_Extent = "0.0%" ;
:FirstDayOfSeries = "N" ;
:QAPercentPoorQuality = "0.0%" ;
:ProcessingEnvironment = "Linux minion20060 5.4.0-124-generic #140-Ubuntu SMP Thu Aug 4 02:23:37 UTC 2022 x86_64 x86_64 x86_64 GNU/Linux" ;

```
                :HorizontalTileNumber = "05" ;
                :PGE_Name = "PGE656" ;
                :EastBoundingCoord = -121.8444f ;
                :PGE_EndTime = "2018-01-17 23:59:59.000000Z" ;
                :GRingLongitude = -138.34311, -132.0174, -121.40044, -127.20726 ;
                :ShortName = "VNP10A1F" ;
                :StartTime = "2018-01-17 00:00:00" ;
                :RangeBeginningTime = "00:00:00.000" ;
                :publisher_url = "https://nsidc.org" ;
                :GRingLatitude = -20., -9.9375685, -9.9743545, -20.035295 ;
                :PGENumber = "656" ;
                :RangeBeginningDate = "2018-01-17" ;
                :CharacteristicBinSize = 370.650173222222 ;
                :PlatformShortName = "SUOMI-NPP" ;
                :GranuleDayOfYear = "17" ;
                :PGE_StartTime = "2018-01-17 00:00:00.000" ;
                :ProductionDateTime = "2022-09-15T07:49:07.000Z" ;
                :SensorShortName = "VIIRS" ;
                :CharacteristicBinAngularSize = 12. ;
                :AlgorithmVersion = "NPP_PR10A1F 1.0.1" ;
                :publisher_email = "nsidc@nsidc.org" ;
                :LocalGranuleID = "VNP10A1F.A2018017.h05v10.002.2022258074906.h5" ;
                :AlgorithmType = "SCI" ;
                :WestBoundingCoord = -138.3431f ;
                :ProductionTime = "2022-09-15 07:49:06.000" ;
                :QAPercentGoodQuality = "100.0%" ;

group: HDFEOS {

  group: ADDITIONAL {

    group: FILE_ATTRIBUTES {
      } // group FILE_ATTRIBUTES
    } // group ADDITIONAL

  group: GRIDS {

    group: VIIRS_Grid_IMG_2D {
      dimensions:
          XDim = 3000 ;
          YDim = 3000 ;
      variables:
          double XDim(XDim) ;
                XDim:standard_name = "projection_x_coordinate" ;
                XDim:long_name = "x coordinate of projection" ;
                XDim:units = "m" ;
          double YDim(YDim) ;
                YDim:standard_name = "projection_y_coordinate" ;
                YDim:long_name = "y coordinate of projection" ;
                YDim:units = "m" ;

      group: Data\ Fields {
        dimensions:
          phony_dim_2 = 1 ;
```

```
    variables:
        ubyte Algorithm_Bit_Flags_QA(YDim, XDim) ;
                Algorithm_Bit_Flags_QA:long_name = "Algorithm bit flags QAsnow cover" ;
                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" ;
                Algorithm_Bit_Flags_QA:flag_meanings = "inland_water_flag low_visible_screen
low_NDSI_screen combined_surface_temperature_and_height_screen_or_flag
high_SWIR_screen_or_flag cloud_mask_probably_cloudy cloud_mask_probably_clear solar_zenith_flag"
;
                Algorithm_Bit_Flags_QA:flag_masks = 1UB, 2UB, 4UB, 8UB, 16UB, 32UB, 64UB,
128UB ;
                Algorithm_Bit_Flags_QA:grid_mapping = "Projection" ;
        ubyte Basic_QA(YDim, XDim) ;
                Basic_QA:long_name = "Basic QA valueed NDSI snow cover" ;
                Basic_QA:valid_range = 0UB, 3UB ;
                Basic_QA:_FillValue = 255UB ;
                Basic_QA:key = "0=best, 1=good, 2=poor, 3=other" ;
                Basic_QA:flag_values = 211UB, 239UB, 249UB, 250UB, 251UB, 252UB, 253UB, 254UB
;
                Basic_QA:flag_meanings = "night ocean SWI_screened cloud missing_L1B_data
cal_fail_L1B_data bowtie_trim L1B_fill" ;
                Basic_QA:grid_mapping = "Projection" ;
        ubyte CGF_NDSI_Snow_Cover(YDim, XDim) ;
                CGF_NDSI_Snow_Cover:long_name = "Cloud Gap Filled NDSI snow cover" ;
                CGF_NDSI_Snow_Cover:valid_range = 0UB, 100UB ;
                CGF_NDSI_Snow_Cover:flag_values = 201UB, 211UB, 237UB, 239UB, 250UB, 251UB,
252UB, 253UB, 254UB ;
                CGF_NDSI_Snow_Cover:flag_meanings = "no_decision night lake ocean cloud
missing_L1B_data cal_fail_L1B_data bowtie_trim L1B_fill" ;
                CGF_NDSI_Snow_Cover:key = "0-100=NDSI snow, 201=no decision, 211=night,
237=inland water, 239=ocean, 250=cloud, 251=missing data, 252=L1B unusable, 253=bowtie trim,
254=L1B fill, 255=fill" ;
                CGF_NDSI_Snow_Cover:_FillValue = 255UB ;
                CGF_NDSI_Snow_Cover:grid_mapping = "Projection" ;
        ubyte Cloud_Persistence(YDim, XDim) ;
                Cloud_Persistence:long_name = "consecutive days of cloud cover" ;
                Cloud_Persistence:valid_range = 0UB, 254UB ;
                Cloud_Persistence:_FillValue = 255UB ;
                Cloud_Persistence:comment = "count of consecutive days of cloud cover" ;
                Cloud_Persistence:grid_mapping = "Projection" ;
        ubyte Daily_NDSI_Snow_Cover(YDim, XDim) ;
                Daily_NDSI_Snow_Cover:long_name = "Current day NDSI snow cover" ;
                Daily_NDSI_Snow_Cover:_FillValue = 255UB ;
                Daily_NDSI_Snow_Cover:flag_meanings = "no_decision night lake ocean cloud
missing_L1B_data cal_fail_L1B_data bowtie_trim L1B_fill" ;
                Daily_NDSI_Snow_Cover:flag_values = 201UB, 211UB, 237UB, 239UB, 250UB, 251UB,
252UB, 253UB, 254UB ;
                Daily_NDSI_Snow_Cover:key = "0-100=NDSI snow, 201=no decision, 211=night,
237=inland water, 239=ocean, 250=cloud, 251=missing data, 252=L1B unusable, 253=bowtie trim,
254=L1B fill, 255=fill" ;
                Daily_NDSI_Snow_Cover:comment = "This is the NDSI_Snow_Cover from the current
day L3 input product" ;
                Daily_NDSI_Snow_Cover:grid_mapping = "Projection" ;
                Daily_NDSI_Snow_Cover:valid_range = 0UB, 100UB ;
```

```
            int Projection(phony_dim_2) ;
                        Projection:grid_mapping_name = "sinusoidal" ;
                        Projection:longitude_of_central_meridian = 0. ;
                        Projection:false_easting = 0. ;
                        Projection:false_northing = 0. ;
                        Projection:earth_radius = 6371007.181 ;
        } // group Data\ Fields
      } // group VIIRS_Grid_IMG_2D
    } // group GRIDS
  } // group HDFEOS

group: HDFEOS\ INFORMATION {
  variables:
            string StructMetadata.0 ;

  // group attributes:
                        :HDFEOSVersion = "HDFEOS_5.1.16" ;
  } // group HDFEOS\ INFORMATION
}
```

Appendix D

Example of V[NP|J1]10C1 product contents.

```
netcdf VNP10C1.A2018003.002.2022256050344 {

// global attributes:
                        :NumberofInputGranules = "323" ;
                        :InputPointer = "VNP10A1.A2018003.h00v08.002.2022256012456.h5, .. truncated list of
inputs ... VNP10A1.A2018003.h35v10.002.2022256025426.h5" ;
                        :Conventions = "CF-1.6" ;
                        :identifier_product_doi = "10.5067/PHOQ2G589HCC" ;
                        :RangeEndingDate = "2018-01-03" ;
                        :DataResolution = "5.6km" ;
                        :creator_url = "https://ladsweb.modaps.eosdis.nasa.gov" ;
                        :SensorShortname = "VIIRS" ;
                        :EndTime = "2018-01-03 23:59:59" ;
                        :NorthBoundingCoord = 90. ;
                        :SatelliteInstrument = "NPP_OPS" ;
                        :creator_name = "VIIRS Land SIPS Processing Group" ;
                        :publisher_name = "NSIDC" ;
                        :LongName = "VIIRS/NPP Snow Cover Daily L3 Global 0.05Deg CMG" ;
                        :ProcessVersion = "002" ;
                        :naming_authority = "gov.nasa.gsfc.VIIRSland" ;
                        :PGEVersion = "2.0.1" ;
                        :creator_email = "modis-ops@lists.nasa.gov" ;
                        :VersionID = "002" ;
                        :SouthBoundingCoord = -90. ;
                        :RangeEndingTime = "23:59:59.000" ;
                        :identifier_product_doi_authority = "https://doi.org" ;
                        :ProcessingCenter = "LandSIPS" ;
```

```
                :ProcessingEnvironment = "Linux minion20203 5.4.0-124-generic #140-Ubuntu SMP Thu
Aug 4 02:23:37 UTC 2022 x86_64 x86_64 x86_64 GNU/Linux" ;
                :PGE_Name = "PGE546" ;
                :EastBoundingCoord = 180. ;
                :PGE_EndTime = "2018-01-03 23:59:59.000000Z" ;
                :ShortName = "VNP10C1" ;
                :StartTime = "2018-01-03 00:00:00" ;
                :DayNightFlag = "Day" ;
                :RangeBeginningTime = "00:00:00.000" ;
                :publisher_url = "https://nsidc.org" ;
                :PGENumber = "546" ;
                :RangeBeginningDate = "2018-01-03" ;
                :PlatformShortName = "SUOMI-NPP" ;
                :PGE_StartTime = "2018-01-03 00:00:00.000" ;
                :AlgorithmVersion = "NPP_PR10C1 2.1.0" ;
                :publisher_email = "nsidc@nsidc.org" ;
                :LocalGranuleID = "VNP10C1.A2018003.002.2022256050344.h5" ;
                :AlgorithmType = "SCI" ;
                :WestBoundingCoord = -180. ;
                :ProductionTime = "2022-09-13 05:03:44.000" ;

group: HDFEOS {

  group: ADDITIONAL {

    group: FILE_ATTRIBUTES {
      } // group FILE_ATTRIBUTES
    } // group ADDITIONAL

  group: GRIDS {

    group: VIIRS_Daily_SnowCover_CMG {
      dimensions:
            XDim = 7200 ;
            YDim = 3600 ;
      variables:
            double XDim(XDim) ;
                XDim:standard_name = "projection_x_coordinate" ;
                XDim:long_name = "x coordinate of projection" ;
                XDim:units = "degrees_east" ;
            double YDim(YDim) ;
                YDim:standard_name = "projection_y_coordinate" ;
                YDim:long_name = "y coordinate of projection" ;
                YDim:units = "degrees_north" ;

      group: Data\ Fields {
        dimensions:
            phony_dim_2 = 3600 ;
            phony_dim_3 = 7200 ;
        variables:
            ubyte Basic_QA(YDim, XDim) ;
                Basic_QA:coordinates = "latitude longitude" ;
                Basic_QA:long_name = "Basic QA mode" ;
                Basic_QA:valid_range = 0UB, 3UB ;
```

```
                Basic_QA:flag_values = 201UB, 211UB, 237UB, 239UB, 243UB, 250UB, 251UB, 252UB,
253UB, 254UB ;
                Basic_QA:flag_meanings = "no_decision night lake ocean Antarctica cloud
missing_L1B_data cal_fail_L1B_data bowtie_trim L1B_fill" ;
                Basic_QA:key_to_QA_values = "0=good, 1=poor, 2=bad, 3=other" ;
                Basic_QA:_FillValue = 255UB ;
        ubyte Clear_Index(YDim, XDim) ;
                Clear_Index:coordinates = "latitude longitude" ;
                Clear_Index:long_name = "Clear index for snow map" ;
                Clear_Index:valid_range = 0UB, 100UB ;
                Clear_Index:flag_values = 201UB, 211UB, 237UB, 239UB, 243UB, 250UB, 251UB,
252UB, 253UB, 254UB ;
                Clear_Index:flag_meanings = "no_decision night lake ocean Antarctica cloud
missing_L1B_data cal_fail_L1B_data bowtie_trim L1B_fill" ;
        ubyte Cloud_Cover(YDim, XDim) ;
                Cloud_Cover:coordinates = "latitude longitude" ;
                Cloud_Cover:long_name = "Cloud cover extent" ;
                Cloud_Cover:valid_range = 0UB, 100UB ;
                Cloud_Cover:flag_values = 201UB, 211UB, 237UB, 239UB, 243UB, 250UB, 251UB,
252UB, 253UB, 254UB ;
                Cloud_Cover:flag_meanings = "no_decision night lake ocean Antarctica cloud
missing_L1B_data cal_fail_L1B_data bowtie_trim L1B_fill" ;
                Cloud_Cover:_FillValue = 255UB ;
        ubyte Snow_Cover(YDim, XDim) ;
                Snow_Cover:long_name = "Snow cover extent" ;
                Snow_Cover:valid_range = 0UB, 100UB ;
                Snow_Cover:flag_values = 201UB, 211UB, 237UB, 239UB, 243UB, 250UB, 251UB,
252UB, 253UB, 254UB ;
                Snow_Cover:flag_meanings = "no_decision night lake ocean Antarctica cloud
missing_L1B_data cal_fail_L1B_data bowtie_trim L1B_fill" ;
                Snow_Cover:_FillValue = 255UB ;
                Snow_Cover:Antarctica_snow_note = "Antarctica deliberately mapped as 100% snow
cover" ;
                Snow_Cover:coordinates = "latitude longitude" ;
        double latitude(phony_dim_2) ;
                latitude:long_name = "latitude" ;
                latitude:units = "degrees_north" ;
                latitude:_CoordinateAxisType = "Lat" ;
        double longitude(phony_dim_3) ;
                longitude:long_name = "longitude" ;
                longitude:units = "degrees_east" ;
                longitude:_CoordinateAxisType = "Lon" ;
      } // group Data\ Fields
     } // group VIIRS_Daily_SnowCover_CMG
    } // group GRIDS
  } // group HDFEOS

group: HDFEOS\ INFORMATION {
  variables:
        string StructMetadata.0 ;

  // group attributes:
                :HDFEOSVersion = "HDFEOS_5.1.16" ;
  } // group HDFEOS\ INFORMATION
```