NASA S-NPP VIIRS Snow Cover Products Collection 2 User Guide

Version 1.0

George A. Riggs
Dorothy K. Hall

April 2021

Table of Contents

1.0 Introduction

The NASA Suomi-National Polar-orbiting Partnership (S-NPP) Visible Infrared Imaging Radiometer Suite (VIIRS) snow cover algorithms are developed synergistically with the Terra and Aqua Moderate Resolution Imaging Spectroradiometer (MODIS) Collection 6.1 (C6.1) snow cover algorithms, leveraging analysis and evaluation from both to make nearly identical algorithms and similar data products. The overall objective for S-NPP VIIRS Collection 2 (C2) is to make the VIIRS snow cover algorithms consistent with the C6.1 MODIS snow cover algorithms to enable development of a climate-data record (CDR) using products from Terra, Aqua and S-NPP. Continuity between Terra, Aqua and S-NPP snow cover products has been demonstrated in Riggs and Hall (2020), Thapa et al. (2019) and Zhang et al. (2020).

The C2 algorithms are revisions of the C1 algorithms. Algorithms are essentially the same for C2 but were revised for changes in input products and product formats. 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.

The VIIRS snow cover data products are in different file formats depending on product processing level. The swath Level-2 (L2) VNP10 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 Level-3 (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, and 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 http:/cfconventions.org, HDF5 https://www.hdfgroup.org/HDF5/) and HDF-EOS5 https://earthdata.nasa.gov/esdis/eso/standards-and-references/hdf-eos5.

The S-NPP VIIRS C2 snow cover products are described in sequence from Level-2 to Level-3 in the following sections. The VIIRS snow products are referenced by their Earth Science Data Type (ESDT) name, e.g., VNP10. The snow cover detection algorithm is applied at L2 using VIIRS reflectance observations, the cloud mask product and geolocation data product to produce VNP10. The VNP10A1 L3 product is produced by projection, gridding, and compositing of VNP10 granules. The cloud-gap-filled product, VNP10A1F, is produced by compositing VNP10A1 tiles. 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., 2016).

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 (EOSDIS) have ESDT names, e.g., VNP10. 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. A Level-2 (L2) product is a geophysical product in latitude and longitude orientation. The VNP10 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° area of the global projection. VNP10 data products are gridded into L2G tiles by mapping the VNP10 pixels into cells of a tile in the map projection grid. The L2G mapping algorithm creates a gridded product used as input to the VNP10A1 Level-3 (L3) products. The VNP10L2G products are not archived at NSIDC. The L3 daily snow product VNP10A1 and cloud-gap-filled (VNP10A1F) are on the sinusoidal projection at 375 m spatial resolution.

The VNP10 snow cover product is in HDF5 format with netCDF Climate and Forecast Metadata Conventions, Version 1.6 (CF-1.6) applied to relevant attributes and variables. The VNP10A1 and VNP10A1F products are in HDF-EOS5 format with CF-1.6 conventions applied.

The series of NASA VIIRS snow cover products produced in C2 is listed in Table 1. 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: 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

3.0 VNP10

The NASA VIIRS snow cover swath product VNP10 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. A full listing of VNP10 contents is given in Appendix A.

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

```
dimensions:
        number_of_lines = 6496 ;
        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 VNP10. 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 VNP10. Description of the GeolocationData group is given in List 2.

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

```
group: GeolocationData {
  variables:
        float latitude(number_of_lines, number_of_pixels) ;
                latitude:long_name = "Latitude data" ;
                latitude:units = "degrees_north" ;
                latitude:standard_name = "latitude" ;
                latitude:_FillValue = -999.f ;
                latitude:valid_range = -90.f, 90.f ;
        float longitude(number_of_lines, number_of_pixels) ;
                longitude:long_name = "Longitude data" ;
                longitude:units = "degrees_east" ;
                longitude:standard_name = "longitude" ;
                longitude:_FillValue = -999.f ;
                longitude:valid_range = -180.f, 180.f ;
  } // group GeolocationData
```

3.2 SnowData Group

Descriptions of the SnowData group 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 VNP10.

```
group: SnowData {
  variables:
        ubyte Algorithm_bit_flags_QA(number_of_lines, number_of_pixels) ;
                Algorithm_bit_flags_QA:coordinates = "latitude longitude" ;
                Algorithm_bit_flags_QA:long_name = "Algorithm bit flags" ;
                Algorithm_bit_flags_QA:flag_masks = 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, 250UB, 251UB, 252UB, 253UB, 254UB ;
                Basic_QA:flag_meanings = "night ocean 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 VNP10 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. An example of the NDSI_Snow_Cover variable with colorized ranges of NDSI_Snow_Cover and flag_values is shown in Figure 1.

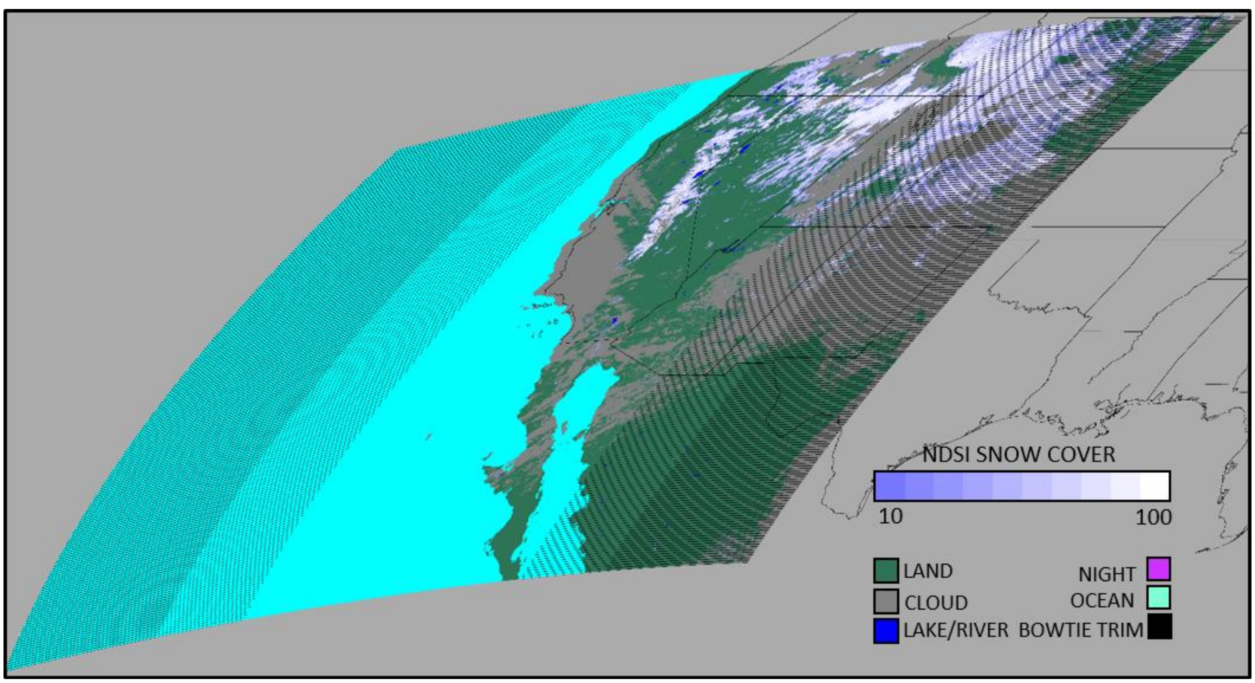

Figure 1. VNP10.A2019013.2048.002.*.nc. NDSI_Snow_Cover. The western United States imaged on 13 January 2019. Image projected to Sinusoidal projection. The lines of bowtie trim appear curved due to the projection.

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 applied in the algorithm. 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. Features e.g., oceans, are set to flag_values. This quality value indicates quality ranging from best quality to poor quality. 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 theoretical range of -1.0 to +1.0. A 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 > 1.0 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 VNP10 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 VCST calibrated radiance and top-of-atmosphere (TOA) reflectance L1B products are used in C2. The C2 L1B products include data on detector calibration and quality that was not in C1. The land water mask (LWM) is input from the VIIRS geolocation product VNP03IMG. The LWM is the MODIS LWM projected to 375 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 VNP35_L2 cloud mask product in C2 is similar to that in C1, only minor revisions were made in product format. The processing flow for a pixel is determined based on the land/water mask. Land and inland water bodies in daylight are processed for snow detection or ice/snow on water detection.

The LWM in the VIIRS geolocation product VNP03IMG 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 a 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. Then data screens are applied to a pixel observation. Data screens applied to a pixel depend on the NDSI value, different series of data screens are 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 overlaid as flag_values and 2) the NDSI observation for all land or inland water pixels without data screens or cloud mask applied.

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

ESDT	Variable	Center wavelength	Nominal spatial resolution
VNP02IMG	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
VNP02MOD	Reflectance_M4	0.555 µm	750 m
VNP03IMG	latitude, longitude, solar_zenith, land_water_mask, height		375m
VNP35 _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, the following series of screens are applied to alleviate 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 to 'on' if an observation failed a screen. Specific bit flags or combinations of bit flags can be extracted for analysis.

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 pixel fails to pass this screen and the results is lake (a flag_values) if passed 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 pixel fails to pass this screen and the results is "no snow", if passed the NDSI value is the result. This screen is tracked in bit 1 (zero based count) 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 "no snow" result 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 on low elevations that appear spectrally similar to snow but are too warm to be snow. It is also used to flag snow detections on high elevations that are warmer than expected. 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), 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 pixel at elevations ≥ 1300 m and with estimated BT ≥ 281 K that snow detection is flagged as unusually warm by setting bit 3 in the Algorithm_bit_flags_QA 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 but also to allow snow detection in situations where snow cover SWIR reflectance is anomalously high. This screen has two threshold settings for different situations. While snow typically has SWIR reflectance less than about 0.20, in some situations, e.g., low sun angle, snow can have a higher reflectance in the SWIR. If a snow pixel has a SWIR reflectance in range of 0.25 < SWIR ≤ 0.45, it is flagged as unusually high for snow and bit 4 of Algorithm_bit_flags_QA variable is set. If a snow pixel has SWIR reflectance > 0.45 it is reversed to "not snow" and bit 4 of Algorithm_bit_flags_QA 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.

3.3.2 Lake Ice Algorithm

The lake ice/snow covered ice detection algorithm is the same as the NDSI snow cover algorithm except for 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 from the water may be erroneously detected as snow/ice covered.

3.3.3 Cloud Masking

Clouds are masked using the LSIPS produced VNP35_L2 cloud mask product. The cloud confidence flag variable from VNP35_L2 is read and applied 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 then 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 bits five and 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 value, 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 solar zenith data 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° ≤ SZA < 85°, the QA is set to other to indicate increased uncertainty in results because of low illumination. Pixels are set to good by data screens described above. For features e.g., ocean and night, flag_values are written.

The Algorithm_bit_flags_QA variable is bit flags of data screen results and for other conditions observed. The data screens provide information on quality of an observation and the result, they 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 to "on" 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 SNPP snow cover is 98% consistent with MODIS snow cover (Thapa et al., 2019). Accuracy of the S-NPP snow cover is similar to MODIS, varying with landscape (Zhang et al., 2020). Conditions that can 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, 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 solar zenith flag (bit 7) in the Algorithms_bit_flags_QA variable 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 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, right image. However, snow commission errors, blue pixels center image, may occur associated with the periphery of cloud shadowed land.

The cloud confidence flags for probably clear and probably cloud conditions are also shown in Fig. 2, right image.

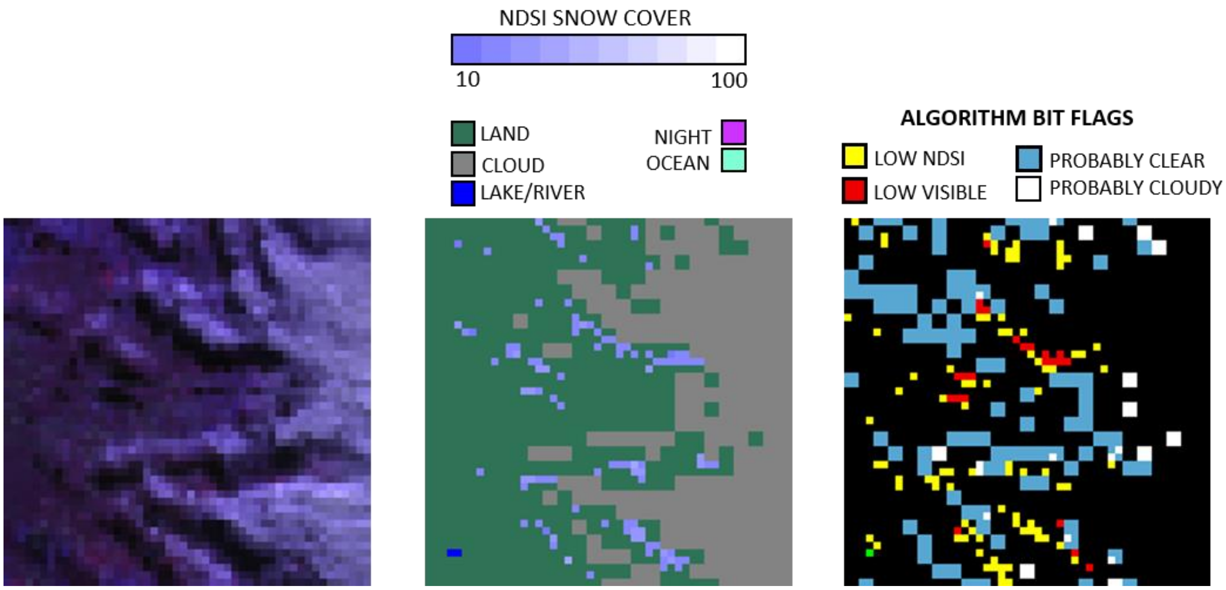

Figure 2. Example of snow commission error associated with cloud periphery and shadowed surfaces. Image is from northern central region of VNP10 shown in Fig. 1. Left image is a false color display of VIIRS bands I2, I1, I3 from the VNP02IMG swath corresponding to VNP10. NDSI_Snow_Cover from VNP10.A2019013.2048.002.*.nc (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 found 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 read.

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 and in the MODIS C6.1 snow cover products. Two sources of cloud/snow confusion are that the cloud mask does not correctly detect cloudy or clear conditions, and where 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 includes four levels of confidence with regard to a pixel being clear or cloudy based on all 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, VNP35_L2 is an input to the VNP10 algorithm. (The cloud mask algorithm and product are described in the Operational Algorithm Document (OAD) https://www.jpss.noaa.gov/sciencedocuments/sciencedocs/2017-06/474-00062_OAD-VIIRS-Cloud-Mask-EDR_J.pdf),

The cloud mask algorithm uses an external snow/ice background product to direct processing along a snow or non-snow path with different cloud spectral and other tests applied in either path. In situations where the snow/ice background flag does not agree with conditions observed in a pixel, then a “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 can cause an underlying snow free surface to 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 Lake ice

The lake ice detection algorithm, applied to inland water bodies mapped in the LWM, is similar to the snow cover detection algorithm. If snow/ice is detected on a lake the NDSI value is written to the pixel in the NDSI_Snow_Cover variables. If the lake is detected as lake, not snow/ice covered the flag_values for lake 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 Algorithm_bit_flags_QA bit 0.

Analysis of VNP10 products and experience with the MODIS snow cover products acquired during 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.

3.4.7 Bright surface features

Surface features such as salt flats, bright sands, or sandy beaches that have VIS and SWIR reflectance characteristics similar to snow may be detected as snow cover based solely on the NDSI value, thus resulting in errors of commission. 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 relevant to a specific research or application.

3.4.9 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 reference products to the sinusoidal projection may be observed in the L3 products as a shifting of features, e.g., lake shoreline location, in cells from day to day.

3.4.10 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 VNP10 is generated for Antarctica, it must be scrutinized for accuracy and quality.

4.0 VNP10A1

The daily, gridded, and projected, snow cover product VNP10A1 product contains the same snow cover variables as in the VNP10 product. The VNP10A1 product is in HDF-EOS5 format with variables and attributes that follow netCDF CF-1.6 conventions and for geolocation which allow for more tools to work with the product. A listing the VNP10A1 product structure and contents is in Appendix B.

4.1 Algorithm Description

There are two processing steps and two intermediate products leading up to the VNP10A1 algorithm. First the VNP10 swath products that cover a tile, 10° x 10°, on the sinusoidal projection are mapped to a tile. The VIIRS bowtie striping present in the VNP10 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 (VNP10L2G) that has multiple observations stored for grid cells. Next a selection algorithm is run with the VNP10L2G, and viewing geometry products, as input and the 'best' observation based on solar zenith angle, distance from nadir and observation coverage in a grid cells 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, which is considered the best sensor view of the surface on a day relevant to snow cover detection is stored in an intermediate VNP10GA 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 VNP10A1 algorithm processes the VNP10GA product to reformat the data, add variables and summary snow cover statistics.

The VNP10A1 includes a pointer variable that points to the granule (VNP10 swath) from which each observation was selected. That pointer can be linked to the beginning and/or ending times of the individual VNP10 input swaths stored as global attributes to determine the date and time of acquisition of each observation.

4.2 Variables

The VNP10A1 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 VNP10 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 3. Local attributes are listed in Appendix B.

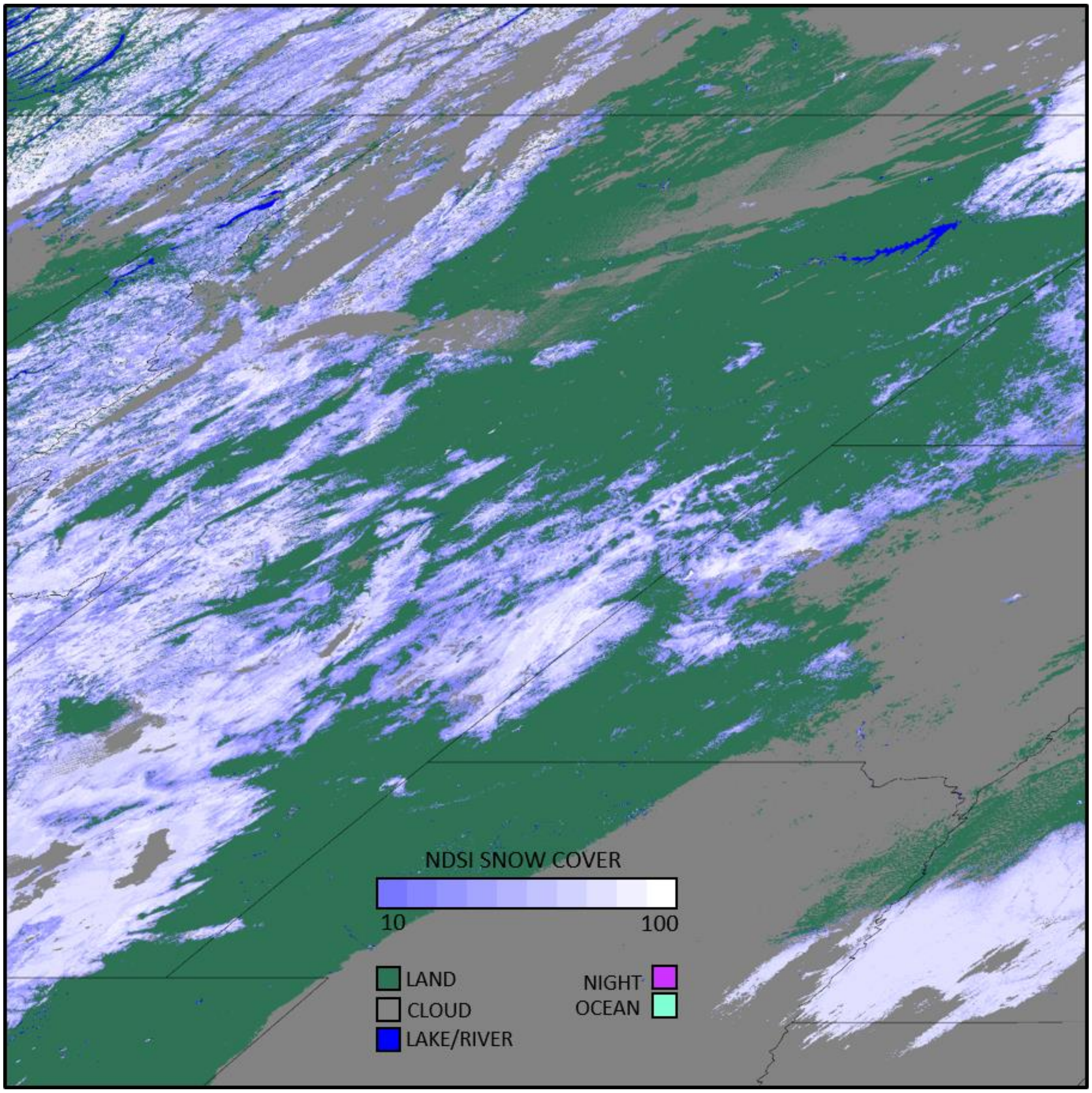

Figure 3. NDSI_Snow_Cover from VNP10A1.A2019013.h10v04.002.*.h5, 13 January 2019. This tile covers parts of the US Great Plains and Rocky Mountains. Tile projected on sinusoidal projection.

4.2.2 Basic_QA

The Basic_QA variable is a general quality value assigned to observations in the VNP10product. 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. 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 VNP10 algorithm (Section 3.3.1). These bit flag masks provide QA data regarding 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 VNP10 and correspond to the ‘best’ observation selected. The NDSI is packed data that can be unpacked using the scale_factor local attribute. 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 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 as for the VNP10 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 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 composited over time.

5.0 VNP10A1F

The daily cloud-gap-filled (CGF) snow cover product, VMP10A1F, provides a daily “cloud-free” map of snow cover extent. The VNP10A1F 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 VNP10A1F CGF_NDSI_Snow_Cover is shown in Figure 4. The VNP10A1F 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 are given in the following sections. A listing of the complete file contents is given in Appendix C.

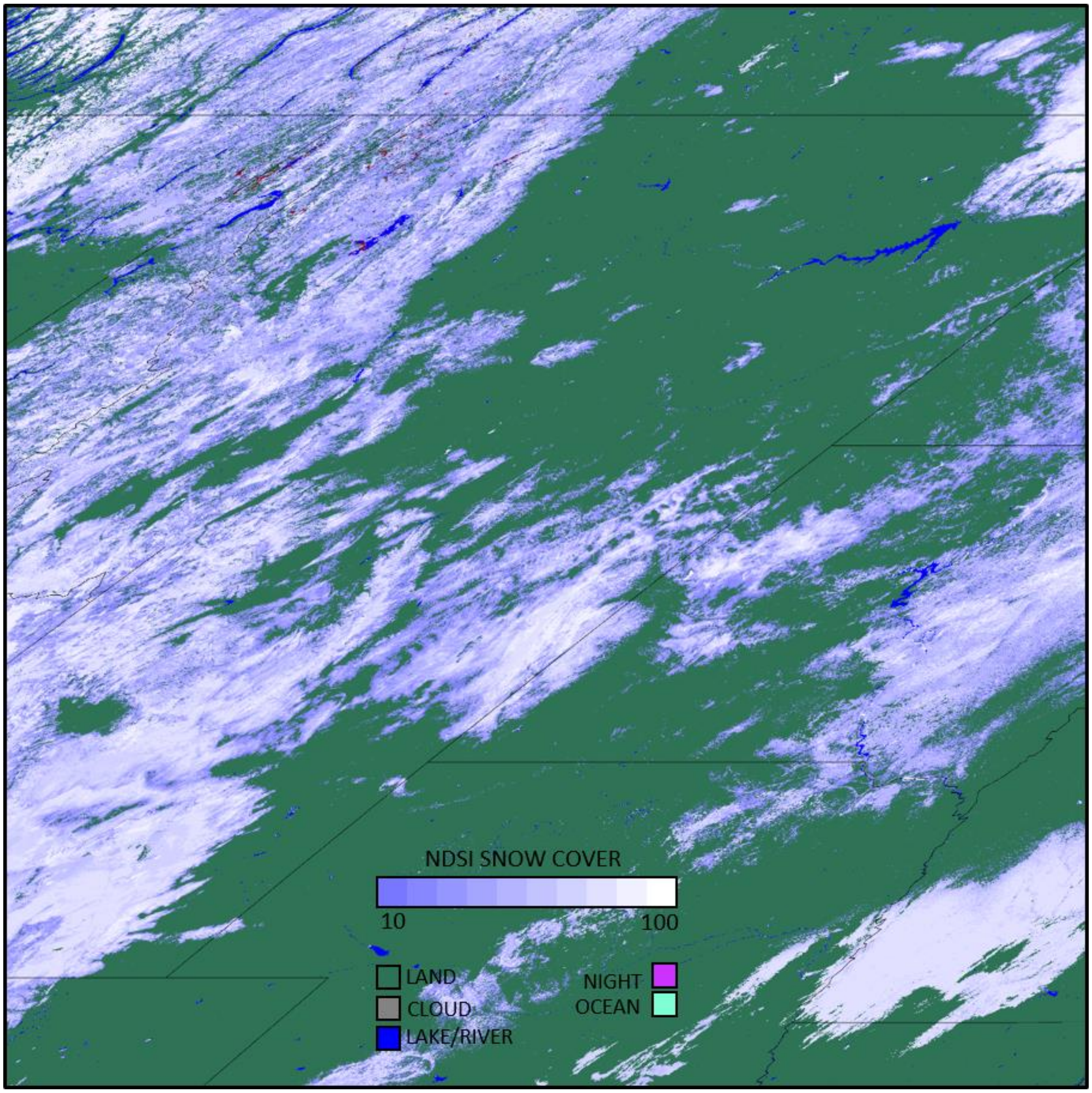

Figure 4. CGF_NDSI_Snow_Cover from VNP10A1F.A2019013.h10v04.002.*.h5, 13 January 2019. This tile covers parts of the US Great Plains and Rocky Mountains. Tile projected on sinusoidal projection. A virtually 'cloud free' image of snow cover results from the CGF algorithm. Compare this image to the daily NDSI_Snow_Cover with clouds in Figure 3.

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. Inputs to the CGF algorithm are the current day VNP10A1 and the previous day VNP10A1F. The current day CGF snow cover map is generated by replacing current day cloud observations in VNP10A1 with a non-cloud observation from the previous day VNP10A1F 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 variabes in VNP10A1F are also set to the current day non-cloud observation corresponding QA data value of VNP10A1 or replaced with the previous day VNP10A1F values if current day observation is cloud. The VNP10A1F also contains a copy of the current day VNP10A1 NDSI_Snow_Cover variable to facilitate comparison with the CGF_NDSI_Snow_Cover variable.

The CGF product will be produced as a 12-month sequence corresponding to the United States Geological Service (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 the start date of data collection. On the first day of the “water year” the VNP10A1F is produced as a copy of the VNP10A1 variables, with the cloud persistence variable 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 missing VNP10A1 tiles in the SNPP data record. If a missing tile is encountered, the previous day VNP10A1F becomes the current day VNP10A1F 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 “MissingDaysOfVNP10A1” 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 VNP10A1F 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. Brief description of each variable is given in the following sections. A complete list file contents is in Appendix C.

5.2.1 CGF_NDSI_Snow_Cover

The CGF_NDSI_Snow _Cover variable is the cloud-gap-filled snow cover extent 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. List of local attributes is in Appendix C.

5.2.2 Basic_QA

The Basic_QA variable is a general quality value assigned to observations in the VNP10 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. The observation selected corresponds to the observation selected for the CGF_NDSI_Snow_Cover variable. List of local attributes is 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 VNP10 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. 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 then the Cloud_Persistence value from the previous day VNP10A1F is incremented by one. The cloud persistence count is also incremented for Fill_value or missing_data.

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 in Appendix C.

5.2.6 Daily_NDSI_Snow_Cover

The Daily_NDSI_Snow_Cover variable is a copy of the VNP10A1 NDSI_Snow_Cover variable input. It facilitates a convenient comparison to 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. List of local attributes is 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 VNP10A1 with a non-cloud (clear view) observation from the previous day VNP10A1F. 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 means that current day was cloudy. A cloud persistence count greater than 1 is the number of consecutive days of cloud cover observed for a cell; it is 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 VNP10A1 for non-cloud observations and from previous day VNP10A1F for cloudy observations. The snow Basic_QA and Algorithm_Bit_Flag_QA were set in the VNP10 processing and described in Section 3.4.

On the first day of VNP10A1F production, the CGF snow cover map is the same as the VNP10A1 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. VNP10A1F production follows USGS “water year” beginning on 1 October and ending on 30 September, except for the first year of SNPP 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 VNP10A1F 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 VNP10, Section 3.4, and VNP10A1, Section 4.3, products are also relevant to the VNP10A1F product. Comparison of the CGF snow cover to the current day snow and cloud cover is facilitated by a copy of the VNP10A1_NDSI_Snow_Cover stored in the VNP10A1F product.

There are some single day or multiple days of missing VNP10A1 tiles in the S-NPP data record. The CGF algorithm processes a missing tile as a completely cloudy day. In this case the previous day VNP10A1F becomes the current day VNP10A1F and the cloud persistence count is incremented by one. The global attribute MissingDaysOfVNP10A1 reports the number of missing days, it is incremented by one for each missing day then reset to 0 when VNP10A1 is again available. SNPP VIIRS data outages are listed at https://modaps.modaps.eosdis.nasa.gov/services/production/outages_npp.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 VNP10A1 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 VNP10A1 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 VNP10A1F and the cloud persistence count is incremented by one. If the observation from previous day VNP10A1F 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 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

7.0 References

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

Riggs, G.A. and Hall, D.K., 2020. Continuity of MODIS and VIIRS snow cover extent data products for development of an Earth Science Data Record, Remote Sensing, 12, 3781, https://doi:10.3390/rs12223781. Accessed 4 February 2021.

Thapa, S., Chhetri, P.K. and Klein, A.G. 2019. Cross-Comparison between MODIS and VIIRS Snow Cover Products for 2016 Hydrological Year, Climate, 7 (57), doi:10.3390/cli7040057.

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.scitotenv2020.138156.

8.0 List of 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 Information System
ESDT	Earth Science Data Type
HDF5	Hierarchical Data Format 5
HDF-EOS5	Hierarchical Data Format – Earth Observing System Version 5
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
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
SWIR	Short Wave Infrared
SZA	Solar Zenith Angle
TOA	Top-of-Atmosphere

USGS	United States Geological Service
VCST	VIIRS Characterization Support Team
VIIRS	Visible Infrared Imager Radiometer Suite
VNP	VIIRS NASA Product
VNP10	ESDT name for the VIIRS Level-2 swath-based Snow Cover Data Product
VNP10A1	ESDT name for the VIIRS Level-3 tiled Snow Cover Data Product
VNP10A1F	ESDT name for the VIIRS Level-3 tiled Cloud-gap-filled SnowCover Data Product
VNP10C1	ESDT name for the VIIRS Level-3 global Snow Cover Data Product
VIS	Visible

9.0 Appendix A VNP10 Contents

Example of VNP10 product contents.

```
netcdf VNP10.A2019013.2048.002.2021058131710 {
dimensions:
	number_of_lines = 6464 ;
	number_of_pixels = 6400 ;

// global attributes:
		:QAPercentCloudCover = "36.6%" ;
		:Snow_Cover_Extent = "18.2%" ;
		:QAPercentBestQuality = "97.7%" ;
		:QAPercentGoodQuality = "0.5%" ;
		:QAPercentPoorQuality = "0.8%" ;
		:QAPercentOtherQuality = "1.0%" ;
		:creator_email = "modis-ops@lists.nasa.gov" ;
		:institution = "NASA Goddard Space Flight Center" ;
		:ProcessingCenter = "LandSIPS" ;
		:ShortName = "VNP10" ;
		:RangeBeginningDate = "2019-01-13" ;
		:creator_name = "VIIRS Land SIPS Processing Group" ;
		:PGE_StartTime = "2019-01-13 20:48:00.000" ;
		:cdm_data_type = "swath" ;
		:GRingPointSequenceNo = 1, 2, 3, 4 ;
		:license = "http://science.nasa.gov/earth-science/earth-science-data/data-information-policy/" ;
		:LocalGranuleID = "VNP10.A2019013.2048.002.2021058131710.nc" ;
		:VersionID = "002" ;
		:DayNightFlag = "Day" ;
		:publisher_name = "LAADS" ;
		:naming_authority = "gov.nasa.gsfc.VIIRSland" ;
		:EndTime = "2019-01-13 20:54:00.000" ;
		:PGEVersion = "2.0.4" ;
		:title = "VIIRS Snow Cover Data" ;
		:PGE_Name = "PGE507" ;
		:WestBoundingCoordinate = -138.286f ;
		:PGE_EndTime = "2019-01-13 20:54:00.000" ;
		:GRingPointLatitude = 39.5396, 45.1073, 24.2871, 19.8582 ;
		:LongName = "VIIRS/NPP Snow Cover 6-Min L2 Swath 375m" ;
		:NorthBoundingCoordinate = 45.1183f ;
		:creator_url = "http://ladsweb.nascom.nasa.gov" ;
		:publisher_email = "modis-ops@lists.nasa.gov" ;
		:InputPointer = 
"VNP35_L2.A2019013.2048.002.2021058131316.hdf,VNP02IMG.A2019013.2048.002.2021050162915.n
c,VNP02MOD.A2019013.2048.002.2021050162915.nc,VNP03IMG.A2019013.2048.002.2021041194155
.nc" ;
		:ProcessingEnvironment = "Linux minion7094 3.10.0-1127.18.2.el7.x86_64 #1 SMP Sun Jul 26
15:27:06 UTC 2020 x86_64 x86_64 x86_64 GNU/Linux" ;
		:stdname_vocabulary = "NetCDF Climate and Forecast (CF) Metadata Convention" ;
		:SouthBoundingCoordinate = 19.8582f ;
		:identifier_product_doi_authority = "https://doi.org" ;
		:ProductionTime = "2021-02-27 13:17:10.000" ;
		:SatelliteInstrument = "NPP_OPS" ;
		:project = "VIIRS Land SIPS Snow Cover Project" ;
```

```
		:StartTime = "2019-01-13 20:48:00.000" ;
		:EastBoundingCoordinate = -99.5287f ;
		:Conventions = "CF-1.6" ;
		:AlgorithmType = "OPS" ;
		:AlgorithmVersion = "NPP_PR10 1.0.13" ;
		:publisher_url = "http://ladsweb.nascom.nasa.gov" ;
		:RangeBeginningTime = "20:48:00.000000" ;
		:processing_level = "Level 2" ;
		:identifier_product_doi = "10.5067/ZZMS6RM8LQS9" ;
		:RangeEndingDate = "2019-01-13" ;
		:RangeEndingTime = "20:54:00.000000" ;
		:GRingPointLongitude = -138.286, -101.378, -99.5287, -128.859 ;
		:keywords_vocabulary = "NASA Global Change Master Directory (GCMD) Science Keywords" ;

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, 250UB, 251UB, 252UB, 253UB, 254UB ;
		Basic_QA:flag_meanings = "night ocean 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 = "63.4%" ;
  } // group SnowData
}
```

[g

10.0 Appendix B VNP10A1 Contents

Example of VNP10A1file contents.

netcdf VNP10A1.A2019013.h10v04.002.2021058163142 {

// global attributes:
:NorthBoundingCoord = 50. ;
:SouthBoundingCoord = 40. ;
:EastBoundingCoord = -91.369808 ;
:WestBoundingCoord = -124.45791 ;
:GeoEstMaxRMSError = 0. ;
:CharacteristicBinAngularSize = 12. ;
:CharacteristicBinSize = 370.650173222222 ;
:GeoAnyAbnormal = "False" ;
:GranuleDayOfYear = "13" ;
:ZoneIdentifier = 0s ;
:NumberofOverlapGranules = 4s ;
:DataColumns = 3000s ;
:DataRows = 3000s ;
:GlobalGridColumns = 108000 ;
:GlobalGridRows = 54000 ;
:GranulePointerArray = -1, 0, 1, 2, 3, -1 ;
:GranuleBeginningDateTime = "2019-01-13 17:30:00.000,2019-01-13 19:06:00.000,2019-01-13 19:12:00.000,2019-01-13 20:48:00.000,2019-01-13 20:54:00.000,2019-01-13 22:36:00.000" ;
:GranuleEndingDateTime = "2019-01-13 17:36:00.000,2019-01-13 19:12:00.000,2019-01-13 19:18:00.000,2019-01-13 20:54:00.000,2019-01-13 21:00:00.000,2019-01-13 22:42:00.000" ;
:Snow_Cover_Extent = "31.7%" ;
:Cloud_Cover_Extent = "30.6%" ;
:Land_Day_Extent = "100.0%" ;
:QAPercentGoodQuality = "53.1%" ;
:QAPercentPoorQuality = "0.6%" ;
:QAPercentOtherQuality = "15.8%" ;
:ProductionDateTime = "2021-02-27T16:31:46.000Z" ;
:PGEName = "PGE543" ;
:SensorShortName = "VIIRS" ;
:LocalVersionID = "1.0.0" ;
:InstrumentShortname = "VIIRS" ;
:RangeBeginningTime = "00:00:00.000" ;
:SatelliteInstrument = "NPP_OPS" ;
:PGEVersion = "2.0.2" ;
:VersionID = "002" ;
:identifier_product_doi = "10.5067/45VDCKJBXWEE" ;
:AlgorithmType = "SCI" ;
:PGE_StartTime = "2019-01-13 00:00:00.000" ;
:RangeBeginningDate = "2019-01-13" ;
:GRingSequence = 1., 2., 3., 4. ;
:GRingLatitude = 39.755674, 49.967704, 50.104591, 39.855422 ;
:RangeEndingDate = "2019-01-13" ;
:GranuleDayNightFlag = "Day" ;

```
		:PGE_Name = "PGE543" ;
		:HorizontalTileNumber = "10" ;
		:RangeEndingTime = "23:59:59.000" ;
		:TileID = "51010004" ;
		:ShortName = "VNP10A1" ;
		:Conventions = "CF-1.6" ;
		:ProductionTime = "2021-02-27 16:31:42.000" ;
		:ProcessingEnvironment = "Linux minion7029 3.10.0-1160.11.1.el7.x86_64 #1 SMP Fri
Dec 18 16:34:56 UTC 2020 x86_64 x86_64 x86_64 GNU/Linux" ;
		:GRingLongitude = -104.52033, -124.88523, -109.00056, -91.190972 ;
		:DayNightFlag = "Day" ;
		:LongName = "VIIRS/NPP L3 Snow Global 375m SIN Grid" ;
		:StartTime = "2019-01-13 00:00:00" ;
		:AlgorithmVersion = "NPP_PR10A1 2.0.0" ;
		:EndTime = "2019-01-13 23:59:59" ;
		:ProcessVersion = "002" ;
		:InputPointer =
"/MODAPSops5/archive/f7029/running/VNP_L5Sm7/16849474/VNP10GA.A2019013.h10v04.002.202105
8163109.hdf" ;
		:PlatformShortName = "SUOMI-NPP" ;
		:PGE_EndTime = "2019-01-13 23:59:59.000000Z" ;
		:VerticalTileNumber = "04" ;
		:identifier_product_doi_authority = "https://doi.org" ;
		:LocalGranuleID = "VNP10A1.A2019013.h10v04.002.2021058163142.h5" ;

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 spare
high_SWIR_screen_or_flag spare solar_zenith_flag" ;
			Algorithm_bit_flags_QA:comment = "A bitfield of flags set for certain conditions detected
by data screens in the algorithm, multiple flags may be set for a pixel." ;
			Algorithm_bit_flags_QA:grid_mapping = "Projection" ;
			Algorithm_bit_flags_QA:_FillValue = 255UB ;
		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, 250UB, 251UB, 252UB, 253UB, 254UB ;
			Basic_QA:flag_meanings = "night ocean cloud no_decision bowtie_trim" ;
			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_data
L1B_unusable 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_5.1.15" ;
  } // group HDFEOS\ INFORMATION
}
```

11.0 Appendix C VNP10A1F Contents

Example of VNP10A1F file contents.

netcdf VNP10A1F.A2019013.h10v04.002.2021058170207 {

```
// global attributes:
		:GranuleDayNightFlag = "Day" ;
		:GranuleDayOfYear = "13" ;
		:GeoAnyAbnormal = "False" ;
		:DataColumns = 3000s ;
		:DataRows = 3000s ;
		:ZoneIdentifier = 0s ;
		:GlobalGridRows = 54000 ;
		:GlobalGridColumns = 108000 ;
		:CharacteristicBinSize = 370.650173222222 ;
		:CharacteristicBinAngularSize = 12. ;
		:GeoEstMaxRMSError = 0. ;
		:Conventions = "CF-1.6" ;
		:Snow_Cover_Extent = "42.7%" ;
		:Cloud_Cover_Extent = "0.0%" ;
		:Land_Day_Extent = "100.0%" ;
		:QAPercentGoodQuality = "76.1%" ;
		:QAPercentPoorQuality = "1.4%" ;
		:QAPercentOtherQuality = "22.5%" ;
		:ProductionDateTime = "2021-02-27T17:02:10.000Z" ;
		:PGEName = "PGE656" ;
		:SensorShortName = "VIIRS" ;
		:LocalVersionID = "2.0.0" ;
		:FirstDayOfSeries = "N" ;
		:MissingDaysOfDailyData = 0s ;
		:TimeSeriesDay = 105s ;
		:GRingLatitude = 39.755674, 49.967704, 50.104591, 39.855422 ;
		:GRingLongitude = -104.52033, -124.88523, -109.00056, -91.190972 ;
		:SouthBoundingCoord = 40.f ;
		:NorthBoundingCoord = 50.f ;
		:EastBoundingCoord = -91.3698f ;
		:WestBoundingCoord = -124.4579f ;
		:PGE_Name = "PGE656" ;
		:PGEVersion = "2.0.2" ;
		:PGE_EndTime = "2019-01-13 23:59:59.000000Z" ;
		:ShortName = "VNP10A1F" ;
		:identifier_product_doi_authority = "https://doi.org" ;
		:VerticalTileNumber = "04" ;
		:InputPointer =
"/MODAPSops5/archive/f7029/running/VNP_L5SFm7/16851839/VNP10A1.A2019013.h10v04.002.20210
58163142.h5,/MODAPSops5/archive/f7029/running/VNP_L5SFm7/16851839/VNP10A1F.A2019012.h10v
04.002.2021058103856.h5" ;
		:InstrumentShortname = "VIIRS" ;
		:StartTime = "2019-01-13 00:00:00" ;
		:RangeBeginningTime = "00:00:00.000" ;
		:TileID = "51010004" ;
		:EndTime = "2019-01-13 23:59:59" ;
		:VersionID = "002" ;
```

```
                    :ProcessingEnvironment = "Linux minion7029 3.10.0-1160.11.1.el7.x86_64 #1 SMP Fri
Dec 18 16:34:56 UTC 2020 x86_64 x86_64 x86_64 GNU/Linux" ;
                    :PGE_StartTime = "2019-01-13 00:00:00.000" ;
                    :AlgorithmVersion = "NPP_PR10A1F 1.0.1" ;
                    :PlatformShortName = "SUOMI-NPP" ;
                    :SatelliteInstrument = "NPP_OPS" ;
                    :LongName = "VIIRS/NPP CGF Snow Cover Daily L3 Global 375m SIN Grid" ;
                    :RangeBeginningDate = "2019-01-13" ;
                    :ProcessVersion = "002" ;
                    :HorizontalTileNumber = "10" ;
                    :LocalGranuleID = "VNP10A1F.A2019013.h10v04.002.2021058170207.h5" ;
                    :AlgorithmType = "SCI" ;
                    :RangeEndingDate = "2019-01-13" ;
                    :RangeEndingTime = "23:59:59.000" ;
                    :ProductionTime = "2021-02-27 17:02:07.000" ;
                    :identifier_product_doi = "10.5067/PN50Y51IVNLE" ;

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 = "A bitfield of flags set for certain conditions detected
by data screens in the algorithm, multiple flags may be set for a pixel." ;
                    Algorithm_Bit_Flags_QA:flag_meanings = "inland_water_flag low_visible_screen
low_NDSI_screen combined_surface_temperature_and_height_screen_or_flag spare
high_SWIR_screen_or_flag spare 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=good, 1=poor, 2=bad, 3=other" ;
                Basic_QA:flag_values = 211UB, 239UB, 250UB, 252UB, 253UB ;
                Basic_QA:flag_meanings = "night ocean cloud no_decision bowtie_trim" ;
                Basic_QA:grid_mapping = "Projection" ;
        ubyte CGF_NDSI_Snow_Cover(YDim, XDim) ;
                CGF_NDSI_Snow_Cover:flag_values = 201UB, 211UB, 237UB, 239UB, 250UB, 251UB,
252UB, 253UB, 254UB ;
                CGF_NDSI_Snow_Cover:_FillValue = 255UB ;
                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_meanings = "no_decision night lake ocean cloud
missing_data L1B_unusable 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: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:comment = "This is the NDSI_Snow_Cover from the current
day L3 input product" ;
                Daily_NDSI_Snow_Cover:valid_range = 0UB, 100UB ;
                Daily_NDSI_Snow_Cover:flag_values = 201UB, 211UB, 237UB, 239UB, 250UB, 251UB,
252UB, 253UB, 254UB ;
                Daily_NDSI_Snow_Cover:flag_meanings = "no_decision night lake ocean cloud
missing_data L1B_unusable bowtie_trim L1B_fill" ;
                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:_FillValue = 255UB ;
                Daily_NDSI_Snow_Cover:grid_mapping = "Projection" ;
        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_5.1.15" ;
  } // group HDFEOS\ INFORMATION
}
```