

NASA VIIRS Ice Surface Temperature Products

Collection 2

User Guide

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1.0 Introduction

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

An objective for VIIRS C2 is to make the NASA VIIRS IST algorithms compatible with the Collection 6.1 (C6.1) MODIS Terra and Aqua IST algorithms to ensure continuity of the MODIS and VIIRS data products and enable development of a multi-sensor CDR. The MODIS C6.1 sea ice product contains both sea ice cover and IST. For VIIRS the sea ice cover and IST are produced as separate products and each product has a user guide.

Details of the data products content, QA, and commentary on evaluation and interpretation of data are given for each product. The reader is referred to the VIIRS IST Algorithm Theoretical Basis Document (ATBD) Tschudi et al., (2016) and to the overview of the NASA VIIRS land and cryosphere products (Justice et al., 2013) for further details.

2.0 NASA VIIRS Ice Surface Temperature (IST) Data Products

The NASA VIIRS ice surface temperature (IST) 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 name begins 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 the S-NPP and JPSS-1 products are the same. When referring to a specific product the unique ESDT name is used. The IST data products are produced in sequence beginning with a Level-2 (L2) swath at a nominal pixel spatial resolution of 750 m with nominal swath coverage of 3200 pixels (across track) by 3248 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]30 product is projected and gridded to make an intermediate Level-2 gridded (L2G) product. The L2G product is on the EASE Grid-2 North and South polar projections and stored as tiles, each tile being 10° x 10°. V[NP|J1]30 data products are gridded into L2G tiles by mapping the V[NP|J1]30 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]30P1 Level-3 (L3) products. The L2G intermediate gridded product V[NP|J1]30E1[D|N] is not archived at the NSIDC DAAC.

The L3 daily IST product V[NP|J1]30P1 is on the EASE Grid-2 projection at 750 m spatial resolution.

The V[NP|J1]30 IST 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 V[NP|J1]30P1[D|N] is in HDF-EOS5 format with CF-1.6 conventions applied.

The series of NASA VIIRS IST products produced in C2 is listed in Table 1. Description of each product, synopsis of the algorithm and commentary on IST calculation, quality assessment, accuracy and errors are presented in the following sections.

Table 1: VIIRS IST products produced in the LSIPS.

| ESDT | LongName | Level | Format |
|----------|---|-------|----------|
| VNP30 | VIIRS/NPP Ice Surface Temperature 6-Min L2 Swath 750m | 2 | HDF5 |
| VNP30P1D | VIIRS/NPP Ice Surface Temperature Daily L3 750m EASE-Grid 2.0 (Polar) Day | 3 | HDF-EOS5 |
| VNP30P1N | VIIRS/NPP Ice Surface Temperature Daily L3 750m EASE-Grid 2.0 (Polar) Night | 3 | HDF-EOS5 |
| VJ130 | VIIRS/JPSS1 Ice Surface Temperature 6-Min L2 Swath 750m | 2 | HDF5 |
| VJ130P1D | VIIRS/JPSS1 Ice Surface Temperature Daily L3 750m EASE-Grid 2.0 (Polar) Day | 3 | HDF-EOS5 |
| VJ130P1N | VIIRS/JPSS1 Ice Surface Temperature Daily L3 750m EASE-Grid 2.0 (Polar) Night | 3 | HDF-EOS5 |

2.1 Addendum

The S-NPP data record begins on 19 January 2012. VNP30 L2 products were available in C1. The L3 VNP30P1[D|N] is new in C2.

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. The names JPSS-1 and NOAA-20 are interchangeable for the operational phase.

3.0 V[NP|J1]30

The V[NP|J1]30 product file format is netCDF/HDF5 and is compliant with the netCDF Climate and Forecast Metadata Conventions Version 1.6 (CF-1.6) for attributes and geolocation of variables. Information on netCDF is available at <https://www.unidata.ucar.edu/software/netcdf/docs/index.html>; information on the Hierarchical Data Format 5 (HDF5) may be found at <https://www.hdfgroup.org/HDF5/>. Many software tools/libraries are capable of working with netCDF or HDF5 data products. A user should contact the NSIDC DAAC user support group with questions about working with these product formats.

The V[NP|J1]30 product contains dimension-scale datasets, a geolocation data group with variables and attributes, an IST data group with variables and attributes, and global attributes. Global attributes provide information on provenance, acquisition time and geographic location. A listing of product contents is given in Appendix A. Variables in V[NP|J1]30 are stored in two data groups. The IST_Data group contains four variables, 1) IST, 2) IST_Basic_QA, 3) IST_map and 4) QA_Flags. The Geolocation_Data group contains the latitude and longitude data.

3.1 Geolocation Data Group

The latitude and longitude data for each pixel in a swath are stored as coordinate variables in the Geolocation_Data data group in V[NP|J1]30. The coordinate variables, attributes and datasets use the netCDF CF-1.6 conventions for geolocation. Software tools/libraries that work with the netCDF4 or HDF5 data formats should be able to work with the V[NP|J1]30 product. Description of the Geolocation_Data group is given in List 1.

List 1. Description of the Geolocation_Data group and attributes in V[NP|J1]30

```
netcdf VNP30.A2019204.1936.002.2021058124633 {
  dimensions:
    number_of_lines = 3248 ;
    number_of_pixels = 3200 ;
  group: Geolocation_Data
  group: Geolocation_Data {
    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 Geolocation_Data
```

3.2 IST Data Group

The V[NP|J1]30 product has the following variables in the IST_Data group; IST, IST_Basic_QA, IST_Map and QA_Flags, each with local attributes. Descriptions of the variables and attributes are given in List 2 and described in the following sections.

List 2. Description of IST_Data group variables and attributes in V[NP|J1]30.

```
group: IST_Data {
  variables:
    ushort IST(number_of_lines, number_of_pixels) ;
      IST:coordinates = "latitude longitude" ;
      IST:long_name = "Ice Surface Temperature" ;
      IST:units = "K" ;
      IST:valid_range = 21000US, 31300US ;
      IST:scale_factor = 0.01f ;
      IST:_FillValue = 65535US ;
      IST:flag_values = 0US, 1US, 11US, 25US, 37US, 39US ;
      IST:flag_meanings = "missing no_decision night land inland_water open_ocean" ;
    ubyte IST_Basic_QA(number_of_lines, number_of_pixels) ;
      IST_Basic_QA:coordinates = "latitude longitude" ;
      IST_Basic_QA:long_name = "Basic QA of Ice Surface Temperature" ;
      IST_Basic_QA:valid_range = 0UB, 6UB ;
      IST_Basic_QA:QA_value_meanings = "0-best, 1-day_good, 2-day_cloud, 3-night_good, 4-
night_cloud, 5-other, 6-poor" ;
      IST_Basic_QA:flag_values = 237UB, 253UB, 254UB ;
      IST_Basic_QA:flag_meanings = "inland_water land bowtie_trim" ;
      IST_Basic_QA:_FillValue = 255UB ;
    ushort IST_map(number_of_lines, number_of_pixels) ;
      IST_map:units = "K" ;
      IST_map:valid_range = 21000US, 31300US ;
      IST_map:flag_values = 0US, 1US, 11US, 25US, 37US, 39US, 50US ;
      IST_map:flag_meanings = "missing no_decision night land inland_water open_ocean cloud" ;
      IST_map:_FillValue = 65535US ;
      IST_map:coordinates = "latitude longitude" ;
      IST_map:long_name = "Ice Surface Temperature with masks" ;
      IST_map:scale_factor = 0.01f ;
    ubyte QA_Flags(number_of_lines, number_of_pixels) ;
      QA_Flags:coordinates = "latitude longitude" ;
      QA_Flags:long_name = "Algorithm QA Flags for IST" ;
      QA_Flags:comment = "Several QA bit flags are set in this version, more may be set in future
version";
      QA_Flags:flag_masks = 1UB, 2UB, 4UB, 8UB, 16UB, 32UB, 64UB, 128UB ;
      QA_Flags:flag_meanings = "L1B_substitutue_cal L1B_out_of_range L1B_saturation
L1B_temp_not_normal spare spare spare spare" ;

  // group attributes:
    :IST_coefficient_source = "Liu, Y.; Key, J.; Tschudi, M.; Dworak, R.; Mahoney, R.; Baldwin, D.
Validation of the Suomi NPP VIIRS Ice Surface Temperature Environmental Data Record. Remote Sens. 2015, 7, 17258-
17271." ;
    :IST_coefficients_LT_240K = -7.335613, 1.030383, 1.264255, -0.438851 ;
    :IST_coefficients_240_260K = -8.606919, 1.03532, 0.641668, 1.83879 ;
```

```

:IST_coefficients_GT_260K = -6.629177, 1.027197, 1.082237, 2.159417 ;
} // group IST_Data
}

```

3.2.1 IST

The IST variable is the ice surface temperature generated by the algorithm. The IST valid_range is 210 – 313 K, which is the same range as the MODIS IST data products MOD29 and MYD29 (Hall et al., 2004; Riggs et al., 2016). The IST is given for day and night pixels and does not have the cloud mask applied. The cloud mask is not applied so that a user has access to IST for all pixels regardless of cloud cover. The cloud mask is applied to the IST_Map, and in the Basic_QA datasets. Providing the data in this way allows a user access to IST for all ocean pixels in a swath and allows them to determine or interpret cloud cover from the QA data or an independent cloud data product. An example of the IST and IST_Map variables with colorized temperature range is shown in Figure 1. Local attributes are attached to the variable. The onboard bowtie trim fill data is retained and appears as horizontal stripes on left and right sides of the IST and IST_map images in Fig.1.

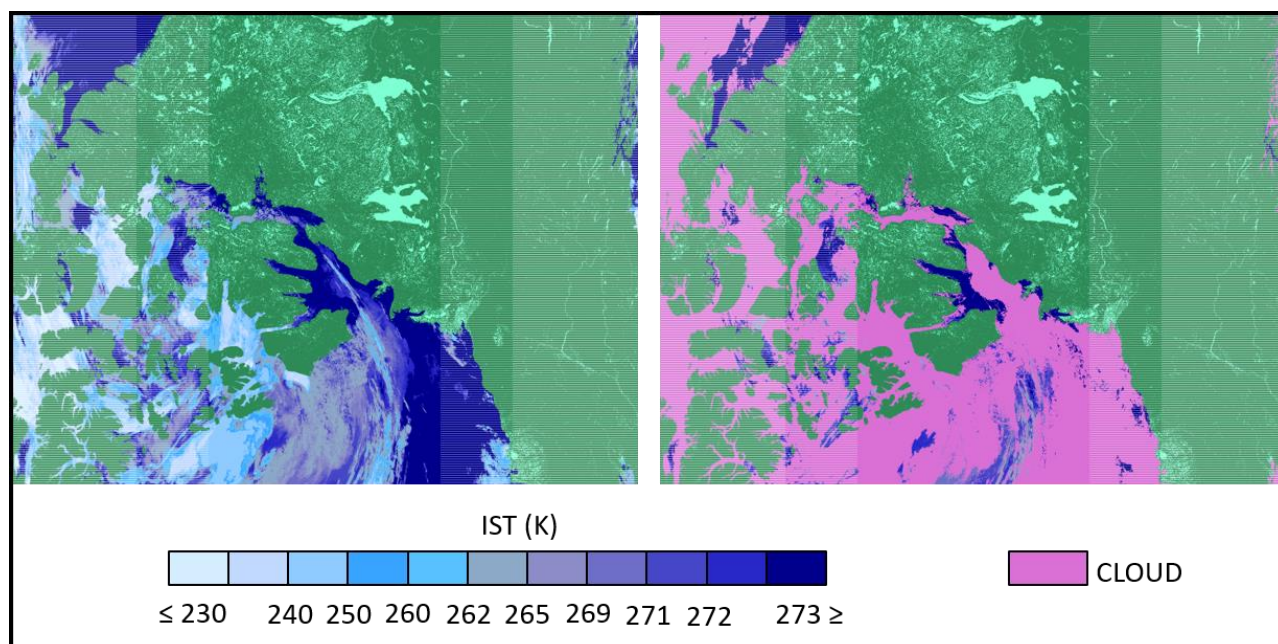


Figure 1. VNP30.A2019204.1936.002.*.nc IST and IST_map variables. The IST without the cloud mask (left) and the IST_map (right) with the cloud mask applied. Images are not projected.

3.2.2 *IST_map*

To give a view of cloud conditions in the scene, the cloud mask is overlaid on the IST data to make the IST_Map, Fig.1 right image.

3.2.3 *QA_Flags*

Several bit flags are set based on certain L1B calibrated data input QA flags. Those flags are described in List 2. See Section 3.3.1 for a description of the bit flags.

3.2.4 *IST_Basic_QA*

A general quality value is given for pixels processed for ice surface temperature. The approach to setting the basic QA value is similar to the approach used for the MODIS IST products (Riggs et al., 2016). However, the basic QA has been revised to include setting values for day and night pixels, and for cloud cover. The basic quality value indicates quality ranging from best to poor, providing a convenient value for initial quality assessment of the data. Local attributes describing the data are included. The IST basic QA data are described in local attribute QA_value_meanings; "0-best, 1-day_good, 2-day cloud, 3-night good, 4-night cloud, 5-other, 6-poor," and flag_values of 237, 253, and 254 with flag_meanings; "inland_water land bowtie_trim."

3.3 *IST Algorithm*

A brief description of the algorithm approach is provided to describe the flow of the algorithm and the basic method used to calculate ice surface temperature. A detailed description of the algorithm can be found in the NASA VIIRS ATBD (Tschudi et al., 2016). Sea ice surface temperature is computed using the split-window technique as described by Tschudi et al. (2016), and is the same technique used for the MODIS C6.1 IST products based on the Key and Haefliger (1992) but with VIIRS specific coefficients. The heritage of the VIIRS IST algorithm is Key and Haefliger (1992) with substantiation of robustness and accuracy by later work (Key et al., 2013, 1994; Yu et al., 1995; Lindsay and Rothrock, 1994; Massom and Comiso, 1994). The basis of the NASA VIIRS IST algorithm is the work of Key et al. (1997), who state that the demonstrated accuracy of the algorithm is sufficient for most climate process studies. The major caveat with the algorithm is that it is applicable only to clear-sky conditions. Inadequate cloud masking may result in significant error in estimating the IST.

The NASA VIIRS L1B products supported by the VCST and generated by the LSIPS are the inputs to the V[NP|J1]30 algorithm. Input products are listed in the global attribute InputPointer. The IST is computed from VIIRS bands M15 (10.763 μm) and M16 (12.013 μm) brightness temperature data using the split-window method of Yu et al. (1995), updated for VIIRS M15 and M16 bands.

Cloud masking is done using the LSIPS version of the cloud mask, V[NP|J1]35_L2, to maintain continuity between MODIS and VIIRS products. The cloud confidence flag is used to mask clouds. The cloud confidence flag has four values: "confident cloudy", "confident clear," "probably clear," and "probably cloudy." If the flag is "confident clear" for an observation, then the observation is interpreted as "clear." If the flag value is

“confident cloudy,” “probably clear” or “probably cloudy” then the observation is interpreted as “cloud obscured.” This interpretation is made to minimize cloud/ice confusion.

The IST is calculated for polar oceans in day and night. Day or night observations are determined by the solar zenith angle (SZA) of an observation. Day observations are those with a solar zenith angle $< 85^\circ$, night observations are at a solar zenith angle $\geq 85^\circ$. Solar zenith data is read from the geolocation product V[NP|J1]03MOD. The same IST equation and coefficients are used for day and night observations. Day and night observations are flagged in the IST_Basic_QA variable.

Product inputs to the NASA VIIRS IST algorithm are listed in Table 2. The processing flow for a pixel is determined based on the land/water mask (LWM) (see Section 3.4.2) read from the V[NP|J1]03MOD geolocation product. All ocean pixels in day or night are processed. VIIRS radiance observations are checked for nominal quality before IST is calculated. IST is calculated for all ocean pixels. IST is stored in two variables. IST for all ocean pixels is stored in the IST variable (Fig. 1). IST with the cloud mask applied is stored in the IST_map variable (Fig. 1).

Table 2. VIIRS data product inputs to the V[NP|J1]30 algorithm.

| ESDT | Variables | Nominal spatial resolution | Descriptor |
|---------------|--------------------------------|----------------------------|----------------------------|
| V[NP J1]02MOD | M15 | 750 m | Radiance |
| | M15_brightness_temperature_lut | | LUT |
| | M15_quality_flags | | Quality flag |
| | M16 | 750 m | Radiance |
| | M16_brightness_temperature_lut | | LUT |
| | M16_quality_flags | | Quality flag |
| V[NP J1]03MOD | Solar_zenith | 750 m | Solar zenith angle |
| | Sensor_zenith | 750 m | Sensor zenith angle |
| | Land_water_mask | 750 m | Land and water mask |
| | Latitude | 750 m | latitude |
| | Longitude | 750 m | longitude |
| V[NP J1]35_L2 | QF1_VIIRSCMIP | 750 m | confidence flag (bits 2-3) |

3.3.1 Data Screens

The M15 and M16 quality flag (QF) data are checked. If the QF data flag is set to missing, calibration failure, or dead detector, a flag_values is written and basic QA is set to _FillValue.

3.3.2 Cloud Masking

The cloud confidence flag from V[NP|J1]35_L2 is used to mask clouds. The cloud confidence flag gives four levels of confidence, “confident cloudy,” “probably cloudy,” “confident clear,” and “probably clear.” The cloud mask is not applied to the IST variable so that the IST is calculated for all ocean pixels. The cloud mask is applied to the IST_map variable. If the cloud mask flag is set to “confident clear” the observation is considered as “clear.” If the cloud mask flag is to “confident cloud,” “probably cloudy” or “probably clear” it is interpreted as “cloud obscured” and the flag_values is set to “cloud.”

3.3.3 Quality Assessment (QA)

Two QA variables are output: 1) the IST_Basic_QA, which gives a simple value, and 2) the QA_Flags which reports results of data screens as bit flags. The basic QA value is a qualitative estimate of the algorithm result for a pixel. The basic QA value is initialized to the best value and is then set based on the quality of the L1B input data, day or night observation and the cloud mask confidence flag value. The QA_Flags bit flags are set depending on the quality flags of the M15 and M16 radiance data.

3.4 Interpretation of IST Detection Accuracy, Uncertainty and Errors

The IST accuracy is approximately 1K and continues to be assessed via comparisons with the NASA MODIS IST product (Hall et al., 2004) and validated with NASA Operation IceBridge airborne IST measurements (Krabill and Buzay, 2012). Tschudi (2019) validated VNP30 IST accuracy with coincident Operation IceBridge flight IST measurements acquired 14 April 2018 over the Beaufort Sea Figure 2. The mean IST along the flight line (Fig. 2) is 252.21 K from the KT-19 observations, and 253.24 K for the VNP30 product, with standard deviations of 3.94 K and 4.11 K, respectively. There was very good agreement between the KT-19 IST and VNP30 IST along the flight track as shown in Figure 3. The VIIRS IST was found to be within ± 1 K of the airborne IST measurements.

Ice Surface Temperature

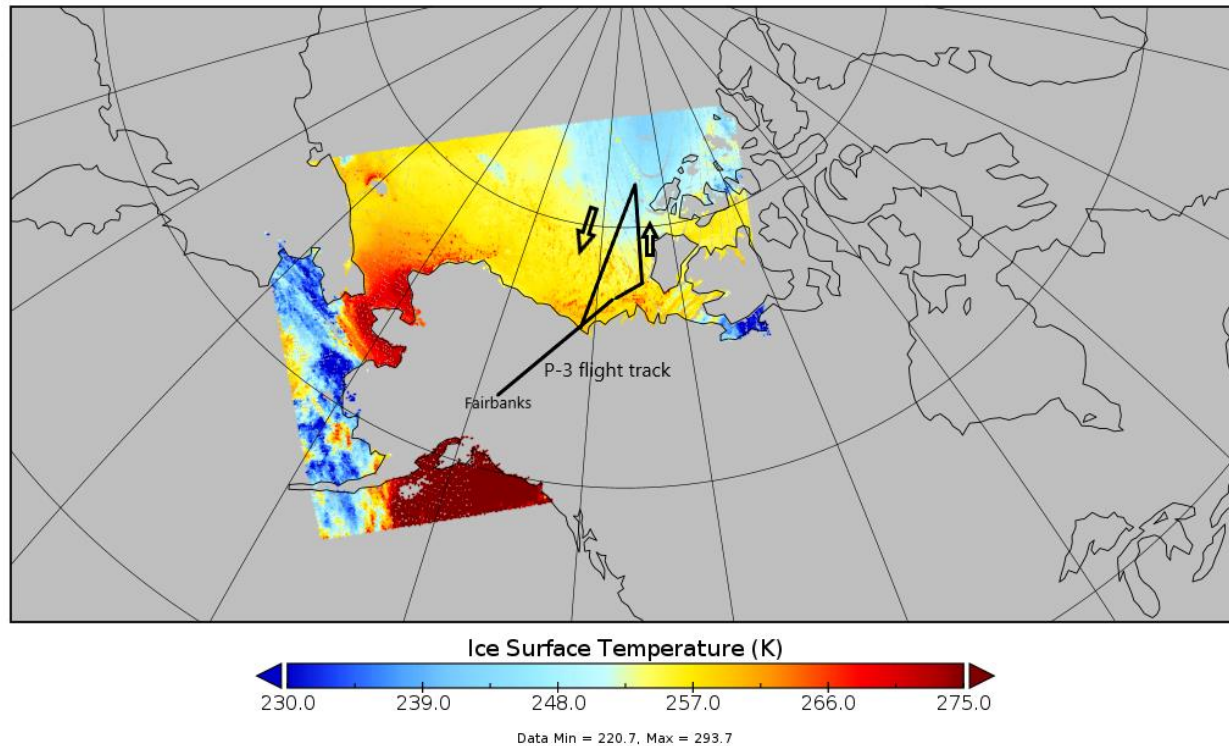


Figure 2. NASA IceBridge flight path on April 14, 2018, overlain onto the NASA VNP30 IST data.

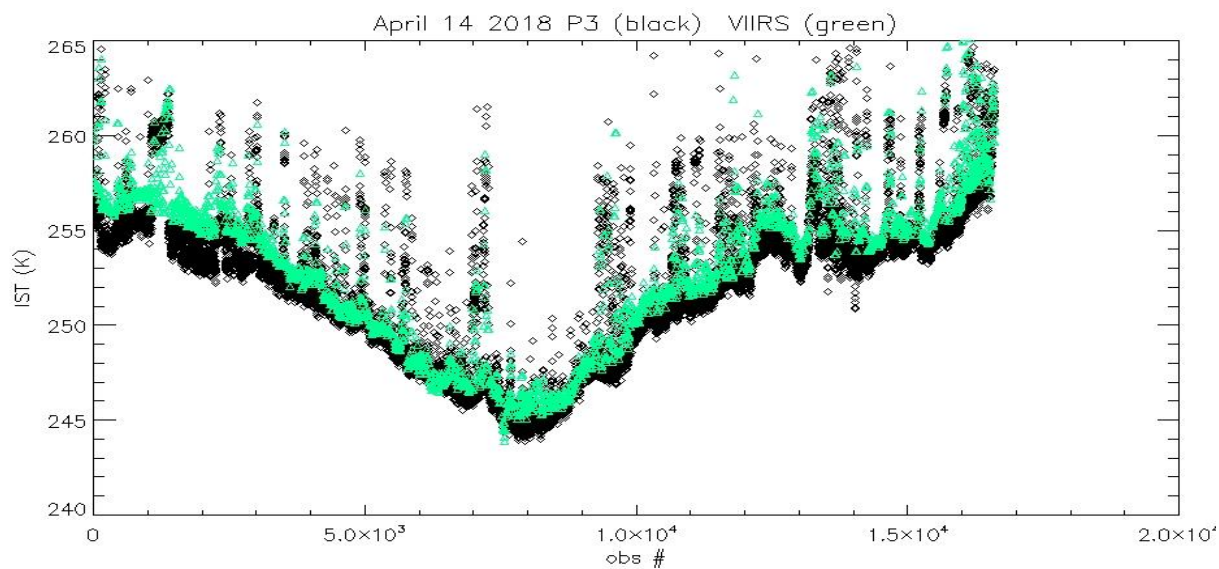


Figure 3. IST from the KT-19 instrument, mounted on the IceBridge P-3 aircraft (in black) flight 14 April 2018. Also plotted is the NASA VNP30 IST (in green) along the same track.

The VJ130 IST was validated by Tschudi (2021) with NASA IceBridge campaign airborne measurements of IST. A KT-19 nadir-pointing radiometer was mounted on the underside of a P-3 aircraft to measure radiometric surface temperature. On April 6, 2019, the NASA P-3 flew across and off the coast of Greenland as part of the IceBridge spring 2019 Arctic campaign (Figure 4). The acquired KT-19 data are used here to compare with the VIIRS IST (VJ130) product.

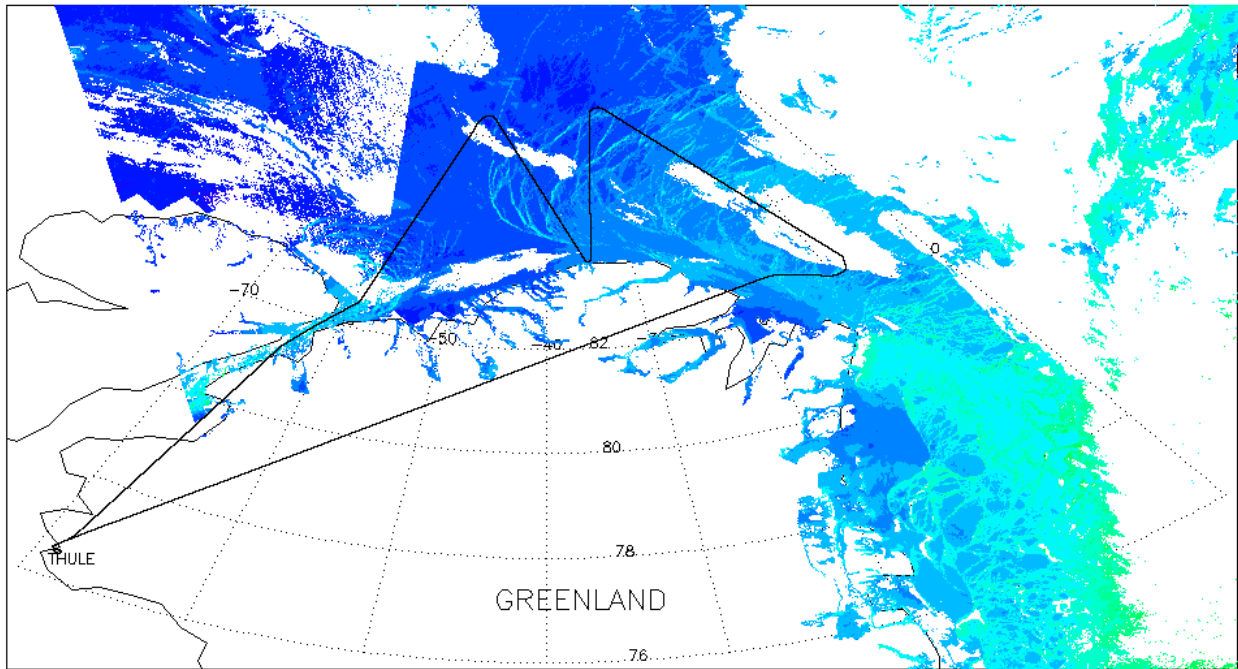


Figure 4. Track of P-3 aircraft (black) on April 6, 2019 during IceBridge campaign. The VIIRS IST (VJ130) is overlaid. VIIRS IST ranged from 240.7K (green) to 253.4K (dark blue).

The surface temperature acquired by the KT-19 over sea ice off the coast of Greenland is compared to the coincident IST from the NASA VJ130 product (Figure 5). It is evident from Figure 5 that the VJ130 IST product compares favorably with the IST acquired by the KT-19 during the IceBridge flight. The mean IST for the VJ130 IST was 246.86K; and for the KT-19 it was 246.06K, for a difference of 0.8K. Standard deviations were 4.79K and 6.15K, respectively.

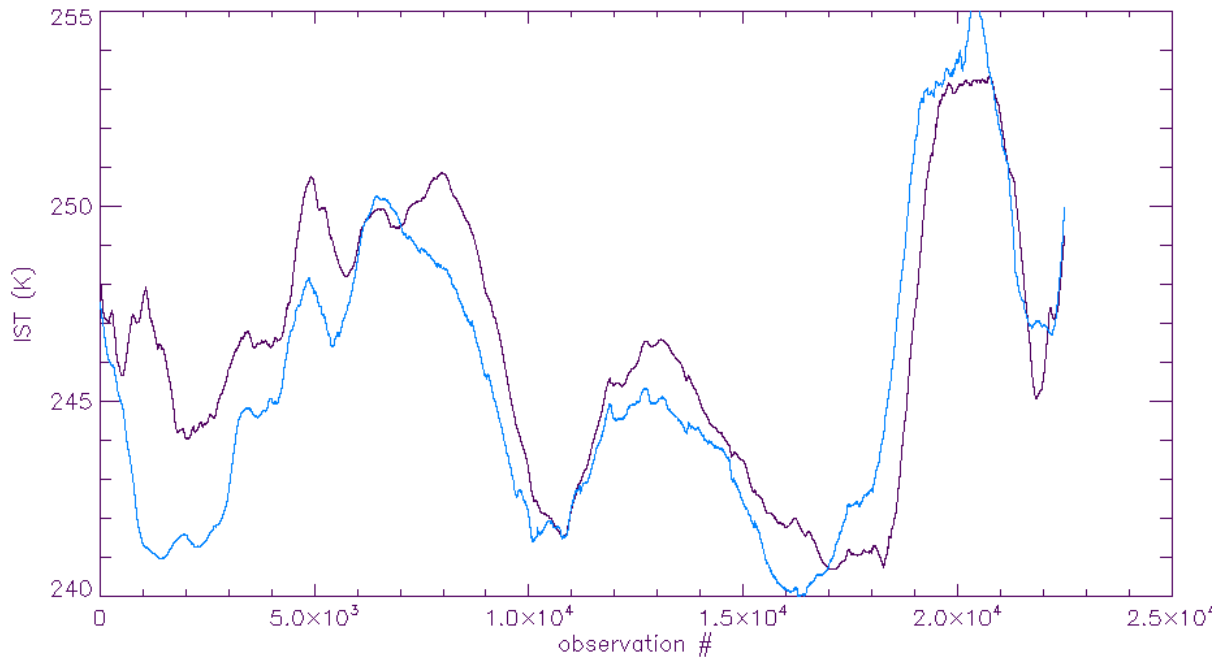


Figure 5. NASA VJ130 IST (purple) and the IceBridge KT-19 measured surface temperature (blue). For this plot, values were smoothed with a running 1000-point filter.

Coefficients obtained from Liu et al. (2015) are used in the NASA VIIRS IST algorithm. The coefficients are based on the VIIRS-specific calculations they performed. Further analysis of NASA VIIRS IST evaluations will be performed to ensure accuracy of the IST data.

3.4.1 Uncertainty Estimate

Because sea ice can vary in concentration from near zero to 100 percent in a 750 m pixel, the IST can vary within a scene due to mixed-pixel effects. The presence of melt ponds and leads in the summer months will affect the emissivity of the surface and therefore the calculation of ice surface temperature.

The targeted uncertainty of the NASA VIIRS IST product is $\pm 1\text{K}$ over a measurement range of 213-275K. Previous estimation of the Interface Data processing Segment (IDPS) VIIRS IST uncertainty compared to the NASA MODIS IST approach is this uncertainty overall but a greater uncertainty (2-3K) is shown for warmer ISTs ($>250\text{K}$) (Key et al., 2013), with the VIIRS IST being lower than the MODIS IST. Measurement uncertainty is defined as the root-mean-square of the measurement errors.

3.4.2 Land/water mask

The land/water mask (LWM) is extracted from the V[NP|J1]03MOD product and used to mask land and inland water bodies from processing. This is accomplished with the MODIS C6.1 LWM, which was derived from the University of Maryland (UMD) 250 m MODIS Water Mask data product (Carroll et al., 2009). The UMD 250 m Water Mask was converted to a 500 m seven class land/water mask for use in the production of MODIS products in C6.1 to maintain continuity with the land/water mask used in C5. The new land/water mask more accurately provides the location of water bodies (http://landweb.nascom.nasa.gov/QA_WWW/forPage/MODIS_C6_Water_Mask_v3.pdf). The LSIPS adapted the MODIS LWM to create the land/water mask in the VIIRS geolocation product V[NP|J1]03MOD at 750 m resolution.

3.4.3 Geolocation accuracy

Geolocation accuracy for the NASA VIIRS suite of sensors is in range of ± 40 m, providing consistent high accuracy in mapping of the VIIRS data products (Lin et al., 2018). The geolocation uncertainty is negligible in the L2 products; however, geolocation error may be observed from day to day as a shifting of features, e.g., changes in the location of a coast-line in the L3 products.

4.0 V[NP|J1]30P1[D|N]

The daily gridded, tiled IST product contains the mean IST calculated from the V[NP|J1]30 IST observations that were mapped to a grid cell. The V[NP|J1]30 swath products (Sec. 3.0) are mapped and gridded to a tile of the EASE-Grid2 North and South polar projections with approximately $10^\circ \times 10^\circ$ extent and 1360×1360 grid cells at 750 m resolution in LSIPS L2G processing to create the V[NP|J1]30E1[D|N] product. The L2G product contains observations in compact format, and is the input to the V[NP|J1]30P1 algorithm. The V[NP|J1]30E1[D|N] is an intermediate product and is not archived at the NSIDC DAAC.

The V[NP|J1]30P1[D|N] is produced for day and night observations. Day or night observations are based on the VIIRS sensor mode (day or night) set for the visible bands in data acquisition. Sensor mode applies to a scan of data. The sensor mode is switched between day and night at the terminator location in an orbit.

The V[NP|J1]30P1 product is in HDF-EOS5 format and follows CF-1.6 conventions for attributes and geolocation. The product contains variables attached to the grid and a Projection variable with local attributes describing the projection. Global attributes provide information on provenance, production, and summary statistics. A listing of V[NP|J1]30P1 structure and contents is given in Appendix B. The contents of a file are described in Sec. 4.1 and the IST mean algorithm is described in Sec. 4.2.

4.1 Variables

There are five variables with local attributes (Appendix B) in the product: IST_mean, IST_stddev, IST_obs, n_obs, and Projection.

4.1.1 *IST_mean*

The *IST_mean* is the mean IST of the IST observations in the *valid_range* mapped to a grid cell. If there are no IST observations in the *valid_range* then the cell has a *flag_values* or *_FillValue*. The *IST_mean* is packed data so values in the *valid_range* need to be multiplied by the *scale_factor*. An example of the *IST_mean* variable is shown in Figure 6 and the corresponding *IST_stddev* variable is shown in Figure 6.

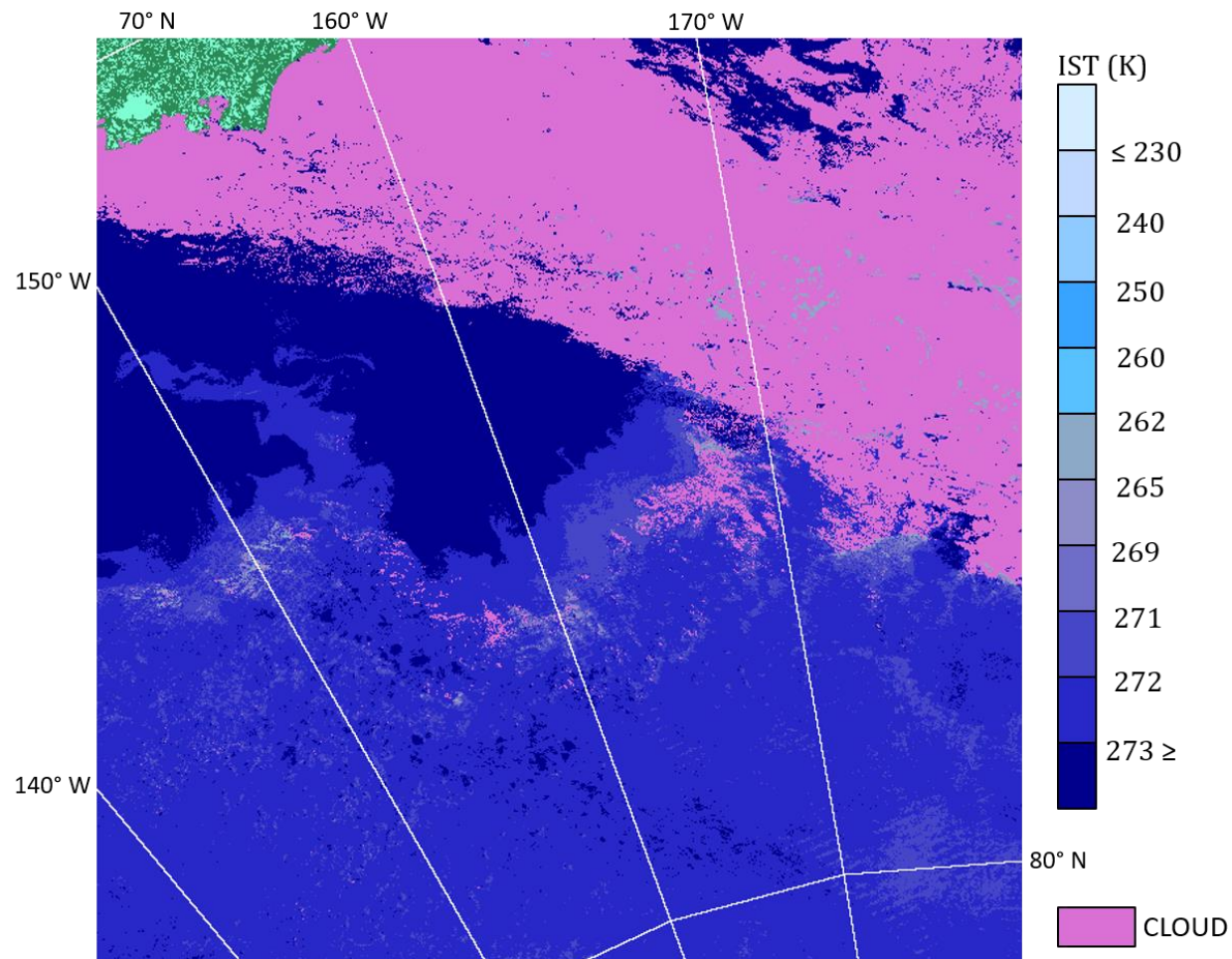


Figure 6. The *IST_mean* data from VNP30P1D.A2019204.h08v07.002.*. Date is 26 July 2019. Tile is projected on the EASEGrid-2 North Pole projection.

4.1.2 *IST_stddev*

The *IST_stddev* is the standard deviation of the IST observations used to compute the mean IST. If there is only a single IST observation the standard deviation is zero. The *IST_stddev* is packed data so values in the *valid_range* need to be multiplied by the *scale_factor*. An example of the *IST_stddev* variable is shown in Figure 7 and the corresponding *IST_mean* variable is shown in Fig. 6.

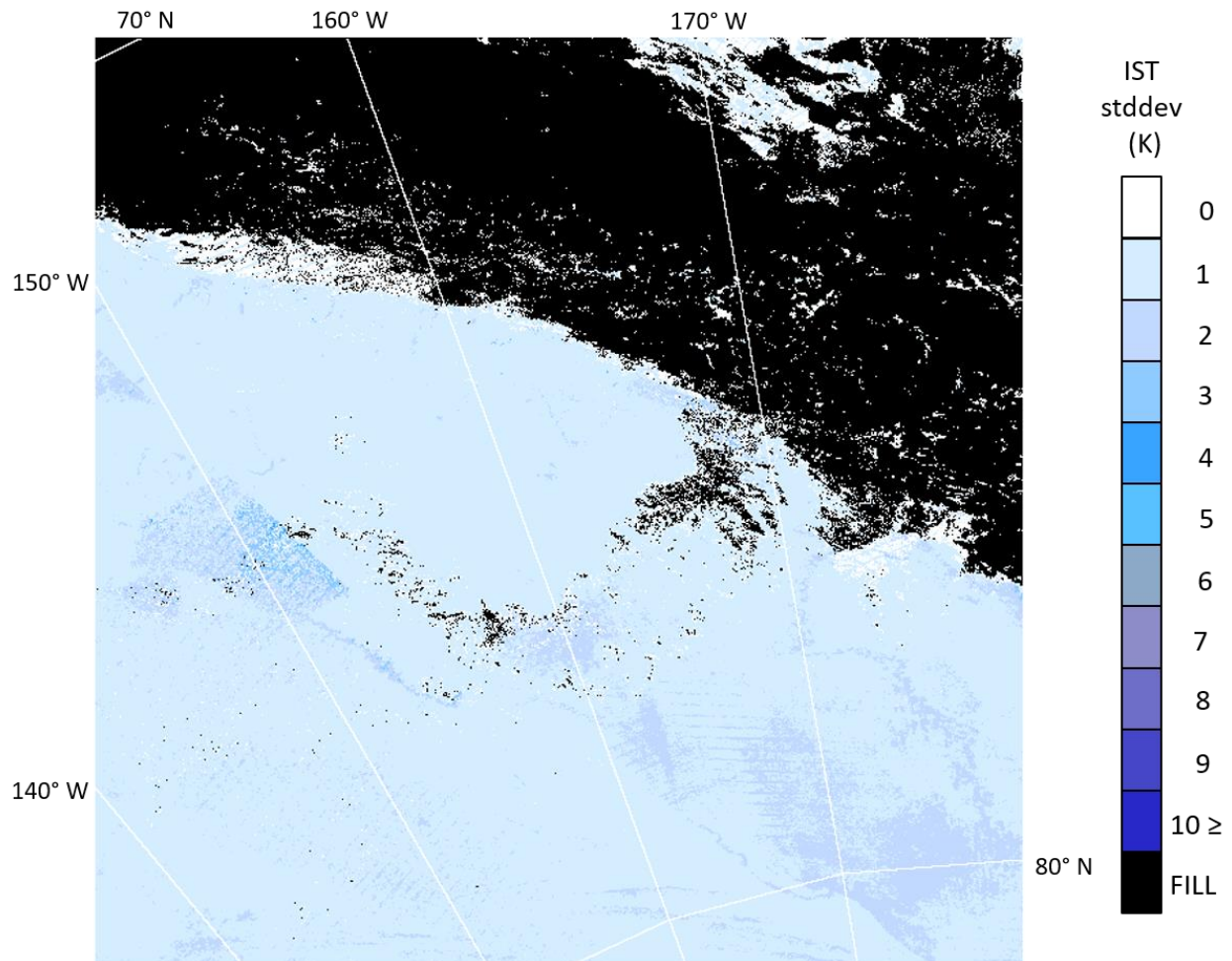


Figure 7. The IST_stddev data from VNP30P1D.A2019204.h08v07.002.*. Fill corresponds to cloud or other flag_values in the IST_stddev data. Date is 26 July 2019. Tile is projected on the EASEGrid-2 North Pole projection.

4.1.3 *IST_obs*

The count of IST observations in the valid_range is recorded for a grid cell. The mean and standard deviation are calculated using this number of IST observations.

4.1.4 *n_obs*

The count of all observations, which include IST in valid_range and flag_values, that are in the grid cell.

4.1.5 *Projection*

The Projection variable is empty. The projection parameters are attached to the Projection as local attributes by CF-1.6 conventions for geolocation.

4.2 IST Mean Algorithm

The algorithm reads and un-compacts the L2G V[NP|J1]30E1[D|N] product to create a stack of observations for each grid cell. The stack of observations is then parsed for IST observations in the valid_range. The mean and standard deviation are calculated for the IST observations in the valid_range. The mean, standard deviation and the count of IST observations are written to grid cells of the V[NP|J1]30P1[D|N] output. If there is only a single IST observation it is output as the mean and standard deviation is 0. The data is packed in the V[NP|J1]30P1[D|N].

Input grid cells that are _FillValue are output as _FillValue. Input grid cells that have 0 observations are output as _FillValue. If a grid cell has all observations as a single flag_values, e.g., land or cloud, the output is that flag_values. If there is a mix of flag_values and no IST in the valid_range in a grid cell, the output is the first flag_values in the stack of observations.

4.3 Interpretation of IST Accuracy, Uncertainty and Errors

Factors that affect the accuracy and uncertainty of the V[NP|J1]30 IST calculation are propagated through to analysis of the mean IST. No screening of IST observations is done, all the L2 V[NP|J1]30 IST observations in the valid_range are used to calculate the mean and standard deviation. The IST_obs and n_obs variables provide information on how many of the IST observations in the stack of all input observations are in the valid_range. The most common reason for these two variables to be different for a grid cell is that there were cloud observations in one or more of the different swaths mapped to a grid cell. Other flag_values such as land could also be a reason for the difference. Geolocation error along a coastline can result in a mix of LWM categories in a grid cell. The difference between IST_obs and n_obs can be interpreted as an estimate of variability of observations in a grid cell.

Discriminating between clouds and sea ice cover is very challenging in both day and night conditions, particularly at night. Accuracy of cloud detection over sea ice is difficult to evaluate. The LSIPS cloud mask product V[NP|J1]35_L2 is applied in the L2 IST algorithm producing V[NP|J1]30. Clouds are masked using the V[NP|J1]35_L2 cloud confidence flag, only “certain clear” observations are considered “clear,” all other values are interpreted as “cloud obscured” (c.f. Section 3.3.2). If there is sea ice/cloud confusion (error) in the L2 IST observation, that confusion is propagated into the mean IST calculation.

Geolocation error associated with mapping of swath observations from the swath to the grid projection is typically less than a grid cell. Geolocation may be observable as changes in location of land and ocean cells or IST observations along coast lines from day to day.

5.0 Related Web Sites

Suomi-NPP

https://www.nasa.gov/mission_pages/NPP/main/index.html (4/22/21)

Suomi-NPP VIIRS Land

<https://viirsland.gsfc.nasa.gov/index.html> (4/22/21)

VIIRS

MODIS and VIIRS Snow/Ice Global Mapping Project: <https://modis-snow-ice.gsfc.nasa.gov> (4/22/21)

Imagery and Data Product Viewing

Worldview: <https://worldview.earthdata.nasa.gov> (4/22/21)

LDOPE Global Browse: <https://landweb.modaps.eosdis.nasa.gov/cgi-bin/browse/browseMODIS.cgi> (4/22/21)

NSIDC Data Ordering & User Services

National Snow and Ice Data Center: <https://nsidc.org/data/viirs> (4/22/21)

HDF5

The HDF Group: <https://www.hdfgroup.org/solutions/hdf5/> (4/22/21)

NetCDF

<https://www.unidata.ucar.edu/software/netcdf/docs/index.html> (4/22/21)

6.0 References

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Acronyms

| | |
|----------|--|
| ATBD | Algorithm Theoretical Basis Document |
| C1 | Collection 1 |
| C2 | Collection 2 |
| C6.1 | Collection 6.1 |
| CDR | Climate Data Record |
| CF-1.6 | netCDF Climate and Forecast Metadata Conventions Version 1.6 |
| DAAC | Distributed Active Archive Center |
| DOI | Digital Object Identifier |
| EDR | Environmental Data Record |
| EOSDIS | Earth Observing Data and Information System |
| ESDT | Earth Science Data Type |
| HDF5 | Hierarchical Data Format 5 |
| HDF-EOS5 | Hierarchical Data Format – Earth Observing System Version 5 |
| IDPS | Interface Data Processing Segment |
| IST | Ice Surface Temperature |
| JPSS | Joint Polar Satellite System |
| JPSS-1 | Joint Polar Satellite System, first satellite in the system |
| L1B | Level-1B, Level-2 data product |
| L2 | Level-2 data product |
| L3 | Level-3 data product |
| LSIPS | Land Science Investigator-led Processing System |
| MODIS | Moderate-resolution Imaging Spectroradiometer |
| NASA | National Aeronautics and Space Administration |
| netCDF | Network Common Data Form |
| 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 |
| S-NPP | Suomi National Polar-orbiting Partnership |
| SZA | Solar zenith angle |
| VCST | VIIRS Characterization Support Team |
| VIIRS | Visible Infrared Imager Radiometer Suite |
| VNP30 | ESDT name for the S-NPP VIIRS Level-2 swath-based IST Data Product |
| VJ130 | ESDT name for the JPSS-1 VIIRS Level-2 swath-based IST Data Product |
| VNP30P1D | ESDT name for the S-NPP VIIRS Level-3 daily tiled IST Day Data Product |
| VJ130P1D | ESDT name for the JPSS-1 VIIRS Level-3 daily tiled IST Day Data Product |
| VNP30P1N | ESDT name for the S-NPP VIIRS Level-3 daily tiled IST Night Data Product |
| VJ130P1N | ESDT name for the JPSS-1 VIIRS Level-3 daily tiled IST Night Data Product |

Appendix A

Example of V[NP|J1]30 product structure and content.

```
netcdf VNP30.A2019204.1936.002.2021058124633 {
dimensions:
    number_of_lines = 3248 ;
    number_of_pixels = 3200 ;

// global attributes:
    :RangeBeginningDate = "2019-07-23" ;
    :ProcessingCenter = "MODAPS-NASA" ;
    :VersionID = "002" ;
    :ProductionTime = "2021-02-27 12:46:33.000" ;
    :NorthBoundingCoordinate = 81.6003f ;
    :GRingPointLatitude = 65.9083, 80.1963, 60.2598, 52.7568 ;
    :identifier_product_doi_authority = "https://doi.org" ;
    :PGE_StartTime = "2019-07-23 19:36:00.000" ;
    :PGE_EndTime = "2019-07-23 19:42:00.000" ;
    :DayNightFlag = "Day" ;
    :processing_level = "Level 2" ;
    :AlgorithmType = "OPS" ;
    :publisher_name = "LAADS" ;
    :ProcessingEnvironment = "Linux minion7016 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" ;
    :creator_email = "modis-ops@lists.nasa.gov" ;
    :RangeEndingDate = "2019-07-23" ;
    :cdm_data_type = "swath" ;
    :StartTime = "2019-07-23 19:36:00.000" ;
    :publisher_url = "http://ladsweb.nascom.nasa.gov" ;
    :RangeEndingTime = "19:42:00.000000" ;
    :institution = "NASA Goddard Space Flight Center" ;
    :WestBoundingCoordinate = -163.799f ;
    :creator_url = "http://ladsweb.nascom.nasa.gov" ;
    :project = "VIIRS Land SIPS Ice Surface Temperature Project" ;
    :AlgorithmVersion = "NPP_PR30 1.0.3" ;
    :publisher_email = "modis-ops@lists.nasa.gov" ;
    :identifier_product_doi = "10.5067/SC6UQYYRF79V" ;
    :ShortName = "VNP30" ;
    :title = "VIIRS Ice Surface Temperature" ;
    :naming_authority = "gov.nasa.gsfc.VIIRSLand" ;
    :SouthBoundingCoordinate = 52.7568f ;
    :EndTime = "2019-07-23 19:42:00.000" ;
    :LocalGranuleID = "VNP30.A2019204.1936.002.2021058124633.nc" ;
    :EastBoundingCoordinate = -61.2939f ;
    :creator_name = "VIIRS Land SIPS Processing Group" ;
    :PGEVersion = "2.0.1" ;
    :GRingPointSequenceNo = 1, 2, 3, 4 ;
    :RangeBeginningTime = "19:36:00.000000" ;
    :LongName = "VIIRS/NPP Ice Surface Temperature 6-Min L2 Swath 750m" ;
    :PlatformShortName = "SUOMI-NPP" ;
    :Conventions = "CF-1.6" ;
    :PGE_Name = "PGE505" ;
    :stdname_vocabulary = "NetCDF Climate and Forecast (CF) Metadata Convention" ;
```

```

:keywords_vocabulary = "NASA Global Change Master Directory (GCMD) Science
Keywords" ;
:SatelliteInstrument = "NPP_OPS" ;
:GRingPointLongitude = -163.799, -61.2939, -79.9308, -129.685 ;
:license = "http://science.nasa.gov/earth-science/earth-science-data/data-information-
policy/" ;
:InputPointer =
"VNP35_L2.A2019204.1936.002.2021058124148.hdf,VNP02MOD.A2019204.1936.002.2021050152125.n
c,VNP03MOD.A2019204.1936.002.2021042014133.nc" ;

group: Geolocation_Data {
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 Geolocation_Data

group: IST_Data {
variables:
ushort IST(number_of_lines, number_of_pixels) ;
IST:coordinates = "latitude longitude" ;
IST:long_name = "Ice Surface Temperature" ;
IST:units = "K" ;
IST:valid_range = 21000US, 31300US ;
IST:scale_factor = 0.01f ;
IST:_FillValue = 65535US ;
IST:flag_values = 0US, 1US, 11US, 25US, 37US, 39US ;
IST:flag_meanings = "missing no_decision night land inland_water open_ocean" ;
ubyte IST_Basic_QA(number_of_lines, number_of_pixels) ;
IST_Basic_QA:coordinates = "latitude longitude" ;
IST_Basic_QA:long_name = "Basic QA of Ice Surface Temperature" ;
IST_Basic_QA:valid_range = 0UB, 6UB ;
IST_Basic_QA:QA_value_meanings = "0-best, 1-day_good, 2-day_cloud, 3-night_good, 4-
night_cloud, 5-other, 6-poor" ;
IST_Basic_QA:flag_values = 237UB, 253UB, 254UB ;
IST_Basic_QA:flag_meanings = "inland_water land bowtie_trim" ;
IST_Basic_QA:_FillValue = 255UB ;
ushort IST_map(number_of_lines, number_of_pixels) ;
IST_map:units = "K" ;
IST_map:valid_range = 21000US, 31300US ;
IST_map:flag_values = 0US, 1US, 11US, 25US, 37US, 39US, 50US ;
IST_map:flag_meanings = "missing no_decision night land inland_water open_ocean
cloud" ;
IST_map:_FillValue = 65535US ;
IST_map:coordinates = "latitude longitude" ;

```

```
    IST_map:long_name = "Ice Surface Temperature with masks" ;
    IST_map:scale_factor = 0.01f ;
  ubyte QA_Flags(number_of_lines, number_of_pixels) ;
    QA_Flags:coordinates = "latitude longitude" ;
    QA_Flags:long_name = "Algorithm QA Flags for IST" ;
    QA_Flags:comment = "Several QA bit flags are set in this version, more may be set in
future version" ;
    QA_Flags:flag_masks = 1UB, 2UB, 4UB, 8UB, 16UB, 32UB, 64UB, 128UB ;
    QA_Flags:flag_meanings = "L1B_substitutue_cal L1B_out_of_range L1B_saturation
L1B_temp_not_normal spare spare spare spare" ;

  // group attributes:
    :IST_coefficient_source = "Liu, Y.; Key, J.; Tschudi, M.; Dworak, R.; Mahoney, R.; Baldwin,
D. Validation of the Suomi NPP VIIRS Ice Surface Temperature Environmental Data Record. Remote
Sens. 2015, 7, 17258-17271." ;
    :IST_coefficients_LT_240K = -7.335613, 1.030383, 1.264255, -0.438851 ;
    :IST_coefficients_240_260K = -8.606919, 1.03532, 0.641668, 1.83879 ;
    :IST_coefficients_GT_260K = -6.629177, 1.027197, 1.082237, 2.159417 ;
  } // group IST_Data
}
```

Appendix B

Example of V[NP|J1]30P1[D|N] product structure and content.

```
netcdf VNP30P1N.A2016066.h08v08.002.2020136143328 {
// global attributes:
    :NorthBoundingCoord = 90. ;
    :SouthBoundingCoord = 77.310512 ;
    :EastBoundingCoord = -90. ;
    :WestBoundingCoord = -180. ;
    :GranuleBeginningDateTime = "2016-03-05 00:24:00.000,2016-03-05 02:06:00.000,2016-03-05
03:42:00.000,2016-03-05 03:48:00.000,2016-03-05 05:24:00.000,2016-03-05 05:30:00.000,2016-03-05
07:06:00.000,2016-03-05 07:12:00.000,2016-03-05 08:48:00.000,2016-03-05 08:54:00.000,2016-03-05
10:30:00.000,2016-03-05 10:36:00.000,2016-03-05 12:12:00.000,2016-03-05 12:18:00.000,2016-03-05
13:54:00.000,2016-03-05 15:36:00.000,2016-03-05 17:18:00.000,2016-03-05 19:00:00.000,2016-03-05
20:42:00.000" ;
    :GranuleEndingDateTime = "2016-03-05 00:30:00.000,2016-03-05 02:12:00.000,2016-03-05
03:48:00.000,2016-03-05 03:54:00.000,2016-03-05 05:30:00.000,2016-03-05 05:36:00.000,2016-03-05
07:12:00.000,2016-03-05 07:18:00.000,2016-03-05 08:54:00.000,2016-03-05 09:00:00.000,2016-03-05
10:36:00.000,2016-03-05 10:42:00.000,2016-03-05 12:18:00.000,2016-03-05 12:24:00.000,2016-03-05
14:00:00.000,2016-03-05 15:42:00.000,2016-03-05 17:24:00.000,2016-03-05 19:06:00.000,2016-03-05
20:48:00.000" ;
    :SensorShortName = "VIIRS" ;
    :Ocean_Extent = "95.2%" ;
    :Cloud_Extent = "35.5%" ;
    :IST_Extent = "64.5%" ;
    :_FillValue_Extent = "4.5%" ;
    :PlatformShortName = "SUOMI-NPP" ;
    :VersionID = "002" ;
    :RangeBeginningDate = "2016-03-06" ;
    :ProcessingEnvironment = "Linux nppdev-c7 3.10.0-1062.12.1.el7.x86_64 #1 SMP Tue Feb 4
23:02:59 UTC 2020 x86_64 x86_64 x86_64 GNU/Linux" ;
    :ProcessVersion = "002" ;
    :ProcessingCenter = "LandSIPS" ;
    :LocalGranuleID = "VNP30P1N.A2016066.h08v08.002.2020136143328.h5" ;
    :RangeEndingDate = "2016-03-06" ;
    :InputPointer = "VNP30PGN.A2016065.h08v08.002.2020091101029.hdf" ;
    :EndTime = "2016-03-06 23:59:59" ;
    :RangeBeginningTime = "00:00:00.000" ;
    :DayNightFlag = "Night" ;
    :identifier_product_doi = "10.5067/QH1FCBXVZH57" ;
    :HorizontalTileNumber = "08" ;
    :VerticalTileNumber = "08" ;
    :ShortName = "VNP30P1N" ;
    :TileID = "71008008" ;
    :identifier_product_doi_authority = "https://doi.org" ;
    :PGE_EndTime = "2020-05-15 23:59:59.000" ;
    :SatelliteInstrument = "NPP_OPS" ;
    :DataResolution = "750m" ;
    :LongName = "VIIRS/NPP Ice Surface Temperature Daily L3 750m EASE-Grid 2.0 (Polar) Night"
;
    :PGENumber = "545" ;
    :PGE_StartTime = "2020-05-15 00:00:00.000" ;
    :PGE_Name = "PGE545" ;
```

```

:AlgorithmVersion = "NPP_PR30P1 1.0.0" ;
:AlgorithmType = "SCI" ;
:RangeEndingTime = "23:59:59.000" ;
:StartTime = "2016-03-06 00:00:00" ;
:ProductionTime = "2020-05-15 14:33:28.000" ;
:InstrumentShortname = "VIIRS" ;
:PGEVersion = "2.0.0" ;

group: HDFEOS {

group: ADDITIONAL {

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

group: GRIDS {

group: VIIRS_Grid_L2g_2d {
dimensions:
XDim = 1360 ;
YDim = 1360 ;
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:
ushort IST_mean(YDim, XDim) ;
IST_mean:long_name = "mean of IST observations" ;
IST_mean:units = "K" ;
IST_mean:valid_range = 21000US, 31300US ;
IST_mean:flag_values = 0US, 100US, 1100US, 2500US, 3700US, 3900US, 5000US ;
IST_mean:flag_meanings = "missing no_decision night land inland_water open_ocean
cloud" ;
IST_mean:scale_factor = 0.01f ;
IST_mean:_FillValue = 65535US ;
IST_mean:grid_mapping = "Projection" ;
byte IST_obs(YDim, XDim) ;
IST_obs:long_name = "count of IST observations in the valid_range" ;
IST_obs:valid_range = 0b, 127b ;
IST_obs:_FillValue = -1b ;
IST_obs:grid_mapping = "Projection" ;
ushort IST_stddev(YDim, XDim) ;
IST_stddev:long_name = "standard deviation of IST" ;
IST_stddev:units = "K" ;

```

```
    IST_stddev:valid_range = 0US, 65534US ;
    IST_stddev:scale_factor = 0.01f ;
    IST_stddev:_FillValue = 65535US ;
    IST_stddev:grid_mapping = "Projection" ;
int Projection(phony_dim_2) ;
    Projection:grid_mapping_name = "lambert_azimuthal_equal_area" ;
    Projection:longitude_of_projection_origin = 0. ;
    Projection:latitude_of_projection_origin = 90. ;
    Projection:false_easting = 0. ;
    Projection:false_northing = 0. ;
byte n_obs(YDim, XDim) ;
    n_obs:long_name = "count of all observations" ;
    n_obs:valid_range = 0b, 127b ;
    n_obs:_FillValue = -1b ;
    n_obs:grid_mapping = "Projection" ;
} // group Data\ Fields
} // group VIIRS_Grid_L2g_2d
} // group GRIDS
} // group HDFEOS

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

  // group attributes:
    :HDFEOSVersion = "HDFEOS_5.1.15" ;
} // group HDFEOS\ INFORMATION
}
```