VIIRS Suomi-NPP Water Vapor Products (WATVP) User Guide

Technical documentation

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Abstract

The purpose of this document is to provide technical information about the VIIRS/Suomi NPP Water Vapor (WATVP) Level-2 and Level-3 Products.

The WATVP algorithm was adapted from the MODIS MOD07 algorithm, with adjustments to accommodate the absence of some sounding spectral bands and to realize the advantage of greatly increased spatial resolution (0.750 km) with good radiometric signal to noise (better than 0.35 K for typical scene temperatures in all spectral bands). We provide total column water vapor properties from merged VIIRS infrared measurements and CrIS plus ATMS water vapor soundings (NUCAPS) to continue the depiction of global moisture at high spatial resolution started with MODIS. While MODIS has two channels within the 6.5 μm H_2O band and four channels within the 15 μm CO_2 band, VIIRS has no infrared (IR) absorption channels. However, the VIIRS IR windows at 8.6, 10.8 and 12 μm give some indication of low level moisture (which constitutes much of the total column amount), which is complemented by the CrIS+ATMS moisture retrievals.

The WATVP Algorithm Theoretical Basis Document (*Borbas et al., 2019*) provides details regarding the methodology and evolution of the WATVP products.

Product version identification

The current version of the products is V001 (SIPS Versions: Level-2: 1.0dev4, Level-3: 1.0dev8)

Introduction

The Suomi NPP VIIRS Water Vapor Products provide total column water vapor (TPW) properties from merged VIIRS infrared measurements and CrIS plus ATMS water vapor soundings to continue the depiction of global moisture at high spatial resolution started with MODIS on the Terra and Aqua platforms.

While the VIIRS is not a sounding instrument, it does have some of the spectral bands useful for integrated total column water vapor. When merged with the CrIS+ATMS sounding data, it becomes possible to generate profiles of temperature and moisture as well as total column estimates of precipitable water vapor from the VIIRS infrared radiance measurements. The VIIRS algorithms were adapted from the MODIS MOD07 algorithm (*Seemann et al., 2003 and 2008*), with adjustments to accommodate the absence of some sounding spectral bands and to realize the advantage of greatly increased spatial resolution (0.750 km) with good radiometric signal to noise (better than 0.35 K for typical scene temperatures in all spectral bands).

While MODIS has two channels within the 6.5-µm H_2O band and four channels within the 15-µm CO_2 band, VIIRS has no infrared (IR) absorption channels. However, the VIIRS IR windows at 8.6, 10.8 and 12 µm give some indication of low level moisture (which constitutes much of the total column amount) and we complement this with CrIS+ATMS column moisture determinations. The NOAA NUCAPS[1] CrIS+ATMS sounding retrievals have been selected because of their spatial coverage and availability. VIIRS/NUCAPS algorithm follows the approach used for MODIS. A clear sky regression relationship has been established between total precipitable water vapor (TPW) and VIIRS IR window brightness temperatures (BTs) and NUCAPS water vapor soundings calculated from a global training radiosonde based profile data set. NUCAPS TPW was added in clear and partly cloudy regions to enhance the TPW depiction and to extend the coverage.

The L2 VIIRS+NUCAPS combined products (called WATVP_L2_VIIRS_SNPP) have been compared with the Microwave Radiometer (MWR), AIRS L2 TPW, and MODIS TPW over the SGP Cart site, and also with the GPS-based TPW over the United States GPS Network. The VIIRS-only TPW products have similar quality as the simulated VIIRS-like MODIS products (generated using only the MODIS spectral band measurements that are found on VIIRS). When the NUCAPS TPW is added to the VIIRS-only retrievals, the bias and standard deviation, and hence the RMS difference, of the VIIRS+NUCAPS products is reduced; the statistical characteristics of the new products become similar to the MODIS MYD07 TPW products.

The VIIRS TPW L3 daily and monthly mean global products (called WATVP_D3_VIIRS_SNPP and WATVP_M3_VIIRS_SNPP) have been evaluated with MOD07 L3, AIRS L3, SSMI and NWP analyses data.

[1] NOAA Unique CrIS/ATMS Processing System

The Level-2 and Level-3 comparisons with Aqua MODIS showed that VIIRS+NUCAPS TPW quality is better than VIIRS or NUCAPS only. To improve the spatial coverage of VIIRS+NUCAPS TPW, values missing in the NUCAPS-only due to failed retrievals are filled by using VIIRS-only values. Values missing in VIIRS-only due to interference by clouds are filled by using NUCAPS values.

The VIIRS+NUCAPS combined TPW algorithm produces near-MODIS quality TPW in the comparison between 2012-2016 with r^2 values greater than 0.95 over land and ocean during both day and night.

The VIIRS Level-2 moisture products

The VIIRS WATVP algorithm is similar to the MODIS MOD07 synthetic regression algorithm (*Seemann et al., 2003, 2008*). This statistical regression retrieval algorithm is performed using observed clear sky radiances (brightness temperatures) over land and ocean for both day and night. In the regression method, the algorithm uses the three VIIRS longwave IR window bands and adds the NUCAPS (CrIS+ATMS) water vapor product to compensate for the absence of VIIRS water vapor channels.

It contains several procedures that include (1) *collocation* between VIIRS and CrIS/ATMS *(2) cloud detection, (3) regression coefficient calculation (this includes forward model calculation), and (4) two TPW retrievals (VIIRS-only and VIIRS+NUCAPS).* The retrieval algorithm has been developed in Fortran using NetCDF4 input/output data format following the guidelines offered by the Atmosphere SIPS and the Atmosphere Measurement Team.

For cloud detection, the MVCM (MODIS VIIRS Cloud Mask) is used. Pixels with Clear Sky Confidence over 0.95 are considered clear for the VIIRS moisture retrievals.

To get the regression coefficients, forward model calculation is performed by the Version 2.1 of the Joint Center for Satellite Data Assimilation (JCSDA) Community Radiative Transfer Model (CRTM, *Han et al., 2005*) using the Optical Depth in Absorber Space (ODPS) transmittance algorithm. In generating the VIIRS water vapor retrieval regression coefficients, global profiles of temperature, moisture, and ozone from the SeeBor profile database (*Borbas et al., 2005*) are used.

The NUCAPS retrievals are smoothed using a radius of 60 VIIRS pixels to reduce blockiness. The VIIRS+NUCAPS TPW is generated in clear skies when NUCAPS has determined a TPW (holes exist when surface emissivity or other issues interfere with a NUCAPS retrieval). The remaining holes in the VIIRS+NUCAPS TPW field are filled with adjusted VIIRS-only or adjusted NUCAPS-only TPWs. The adjustment process for a given 6-minute granule consists of constructing a linear fit of the VIIRS+NUCAPS TPW against the collocated VIIRS-only TPW; another linear fit is determined for the VIIRS+NUCAPS TPW against the collocated NUCAPS-only TPW. The appropriate linear fit is then used to scale the VIIRS-only TPW and the NUCAPS-only TPW to fill holes where possible. The resulting TPW field shows more details than that from VIIRS-only, NUCAPS-only, and MODIS-only. Holes in the NUCAPS-only caused by surface emissivity

issues are filled by using VIIRS-only values. Holes in VIIRS- and MODI-only caused by interference from non-precipitating clouds are filled using smoothed NUCAPS values. The filling procedures are indicated in the product quality flag. More details regarding the methodology and the validation of the Suomi-NPP VIIRS WATVP products can be found in the Suomi-NPP WATVP Algorithm Theoretical Basis Document (*Borbas et al., 2019*).

Steps of WATVP_L2_VIIRS_SNPP product processing**:**

1. Get input data in the SIPS Internal File Format (IFF): VIIRS L1B and VIIRS Cloud Mask (MVCM)
2. Get NUCAPS TPW as input
3. Get collocation indices between VIIRS L1B and the CrIS/ATMS (NUCAPS) resolution (using collopak)
4. Smooth NUCAPS TPW products
5. Calculate retrievals using VIIRS-only
6. Calculate retrievals using VIIRS+NUCAPS
7. Fill retrieval holes with VIIRS-only or NUCAPS-only retrievals

Parameters included in the 6-minute WATVP_L2_VIIRS_SNPP (VIIRS TPW Level-2 water vapor) 750m resolution products are:

(e.g., WATVP_L2_VIIRS_SNPP.A2014288.2136.001.2018127191505.nc output filename)

- *atmosphere_water_vapor_content_nucaps_bg (collocated NUCAPS retrieval)*
- *atmosphere_water_vapor_content_viirs_nucaps (VIIRS+NUCAPS retrieval)*
- *atmosphere_water_vapor_content_viirs_only (VIIRS-only retrieval)*
- *surface_skin_temperature*
- *quality_flag*
  - *1 = good retrieval-VIIRS and NUCAPS data are available;*
  - *2 = filled with VIIRS-only retrieval;*
  - *3 = filled with NUCAPS-only retrieval;*
  - *4 = No retrievals - no VIIRS nor NUCAPS data are available or non-physical retrievals*
- *model_atmosphere_water_vapor_content (from Climate Forecast System Reanalysis (CFSR))*
- *model_surface_pressure (from CFSR)*
- *geolocation and cloud mask data: land_sea_mask, latitude, longitude, sensor_zenith, solar_zenith, clear_sky_confidence*

The algorithm contains a sanity check by filtering out the 90 mm or higher water vapor products (viirs_only, nucaps_bg and viirs_nucaps), and also has a constraint for the VIIRS-only and NUCAPS-only (nucaps_bg) retrievals to be inside the minimum and maximum values of the granule. Figure 1 and Tables 1 a/b summarize the latest SIPS process flow with the up-to-date version number of the inputs.

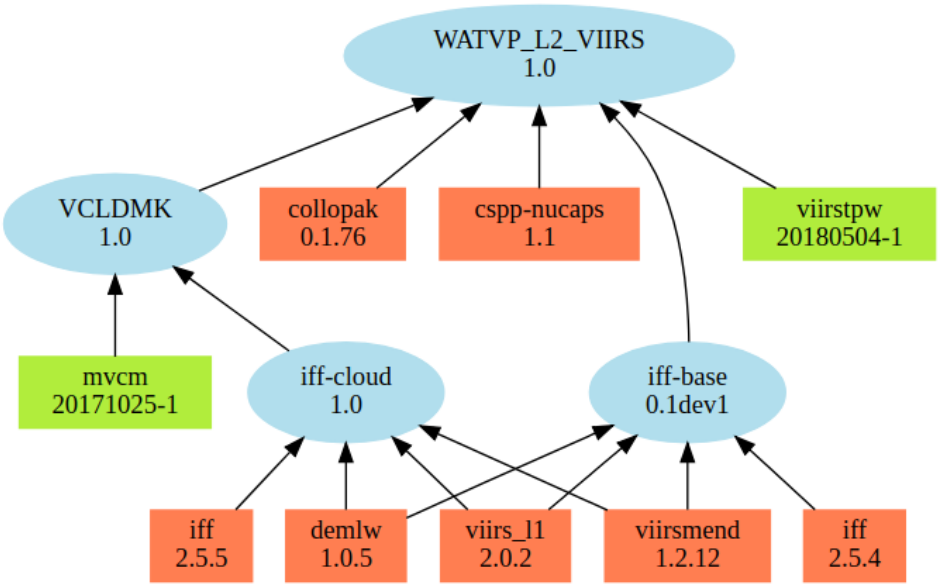

Figure 1: Input data flow of the S-NPP VIIRS TPW processing with an indication of the data version numbers.

Table 1a: Direct inputs required directly by the WATVP_L2_VIIRS_SNPP product.

Name	Package	Type
VIIRS TPW software	viirstpw: 20180504-1	delivery
Collocation data	collopak: 0.1.76	support
IFF: base config	iff-base: 0.1dev1	product
VIIRS Cloud Mask	VCLDMK: 1.0	product
CSPP NUCAPS	cspp-nucaps: 1.1	support

Table 1b: Indirect inputs not directly required by the product but part of the input graph.

Name	Package	Type
Land-water mask generation	demlw: 1.0.5	Support
VIIRS L1B bowtie restoral	viirsmend: 1.2.12	Support
NASA VIIRS Level 1	viirs_l1: 2.0.2	Support
Intermediate File Format	iff: 2.5.5	Support
MODIS/VIIRS Cloud Mask	mvcm: 20171025-1	Delivery
IFF: Cloud Team Config	iff-cloud: 1.0	Product

The Level-3 daily mean and monthly mean products

Level-3 global 0.5° by 0.5° daily and monthly mean data products were developed by using a gridding software (called *Yori*) developed at UW-Madison SSEC (*Veglio et al., 2018*). The development of *Yori* is framed by NASA VIIRS Atmosphere SIPS. *Yori* has been adapted for the Level-2 VIIRS TPW products and has been processed based on the SIPS-processed L2 (1.0dev4) data.

The Level-3 processing workflow using the Yori software is structured in five separate steps:

1. Preparing the YAML file (configuration file for our products)
2. Preparing the transitional/intermediate input NetCDF files (*preyori.py*)
3. Gridding the Level-2 input granule (*rungrid.py*, see Fig 2)
4. Aggregating a day (*yori_aggregate.py*)
5. Aggregating a month (*yori_aggregate.py* , see fig 3).

The data can be filtered by a given mask specified by the users. For the VIIRS WATVP products, only the day/night mask was used based on the solar zenith angle. The pixels having solar zenith angle less than 95 degrees are considered as "day" while solar zenith angle more than 95 degrees are considered as "night."

Parameters included in the WATVP_D/M3_VIIRS_SNPP (VIIRS TPW Level-3 daily (D3) and monthly mean (M3) water vapor products:
(e.g., WATVP_M3_VIIRS_SNPP.A201410.001.2018117134711.nc output filename)

group: night_atmosphere_water_vapor_content_viirs_nucaps (VIIRS+NUCAPS retrieval)
variables: standard_deviation, sum, sum_squares, n_points, mean
group: night_atmosphere_water_vapor_content_ nucaps_bg (NUCAPS retrieval)
variables: standard_deviation, sum, sum_squares, n_points, mean
group: night_atmosphere_water_vapor_content_viirs_only (VIIRS-only retrieval)
variables: standard_deviation, sum, sum_squares, n_points, mean
group: day_atmosphere_water_vapor_content_viirs_nucaps (VIIRS+NUCAPS retrieval)
variables: standard_deviation, sum, sum_squares, n_points, mean
group: day_atmosphere_water_vapor_content_nucaps_bg (NUCAPS retrieval)
variables: standard_deviation, sum, sum_squares, n_points, mean
group: day_atmosphere_water_vapor_content_viirs_only (VIIRS-only retrieval)
variables: standard_deviation, sum, sum_squares, n_points, mean

Figure 4 illustrates the results of step 3 in the process, when the L2 VIIRS TPW granule products (Fig 4 top panels) have been converted into the corresponding 0.5° resolution gridded products (Fig 4 bottom panels). As an example, the L3 daily and monthly aggregated products have been shown in Figure 5 for Oct 15, 2014 and Oct 2014 respectively and compared to the MYD08 products. Please note the better coverage, due to 1) using the all-sky NUCAPS TPW products and 2) filling with modified NUCAPS or VIIRS-only TPW values.

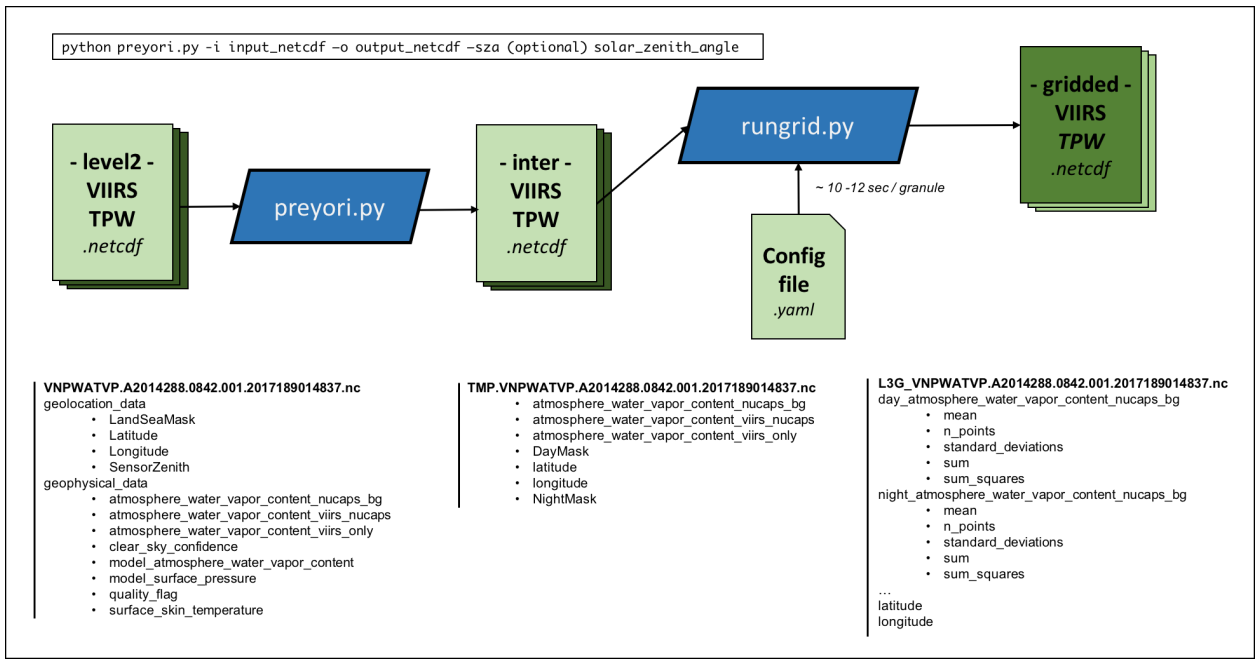

Figure 2: Work flow of VIIRS TPW L3 Processing (steps 1-3) to create L3 gridded granule products.

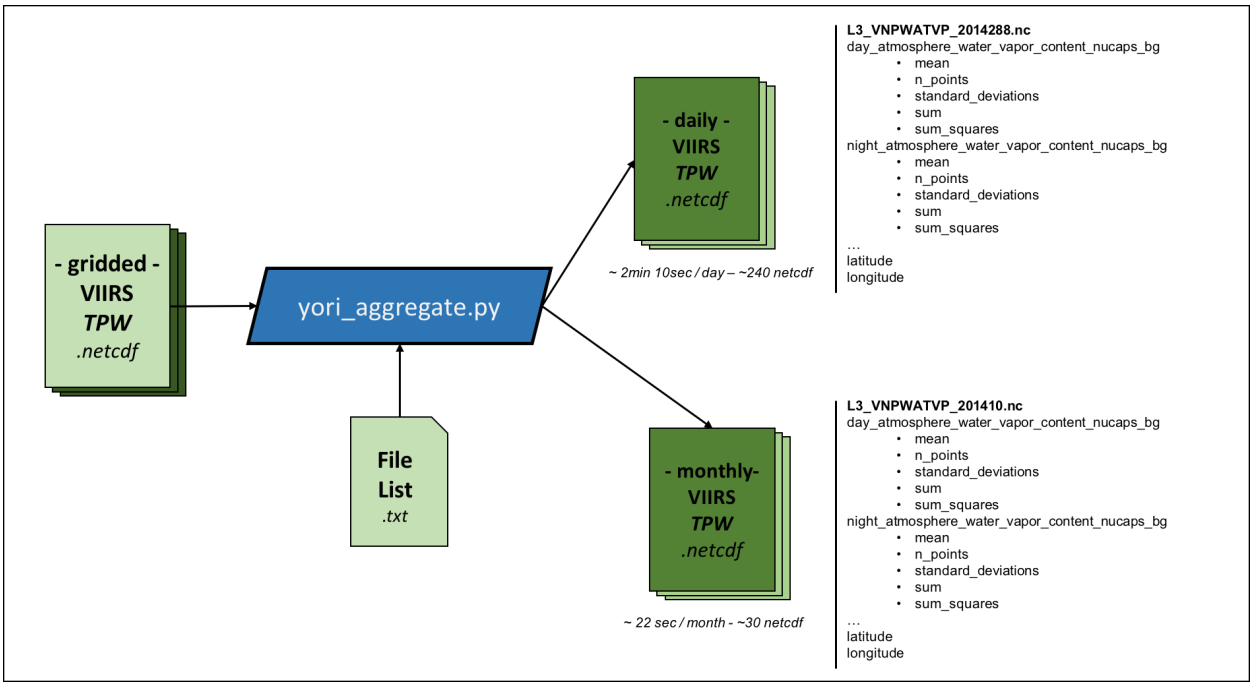

Figure 3: Work flow of VIIRS TPW L3 Processing (steps 4-5) to create L3 gridded daily and monthly mean products.

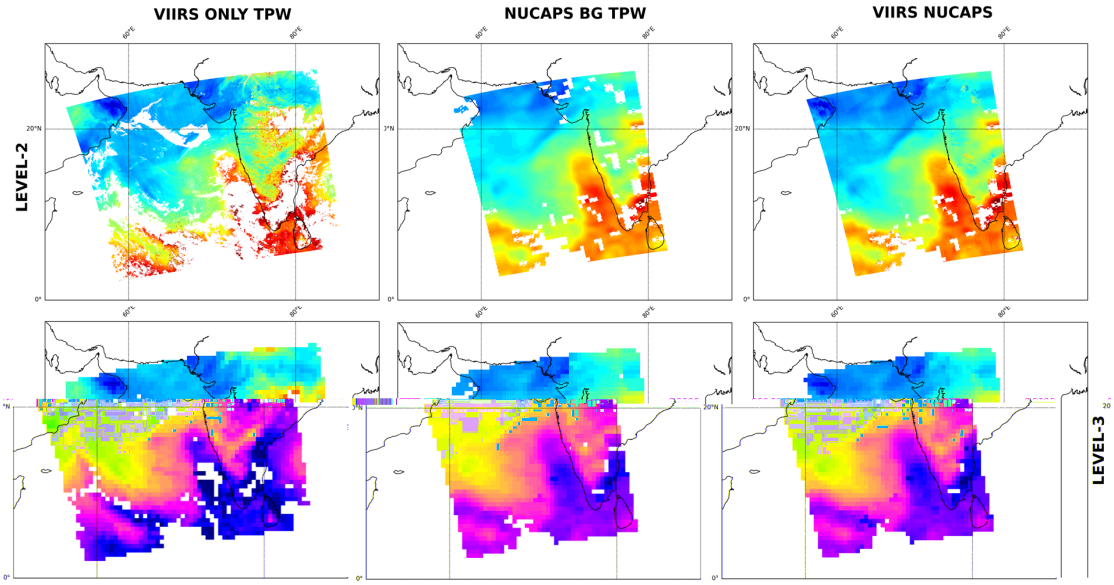

Figure 4: Processing a VIIRS TPW granule (top) to a gridded granule (bottom) on 15 October 2014 at ~08:50 UTC. VIIRS-only (left), NUCAPS background (middle) and VIIRS+NUCAPS (right) TPW fields are shown.

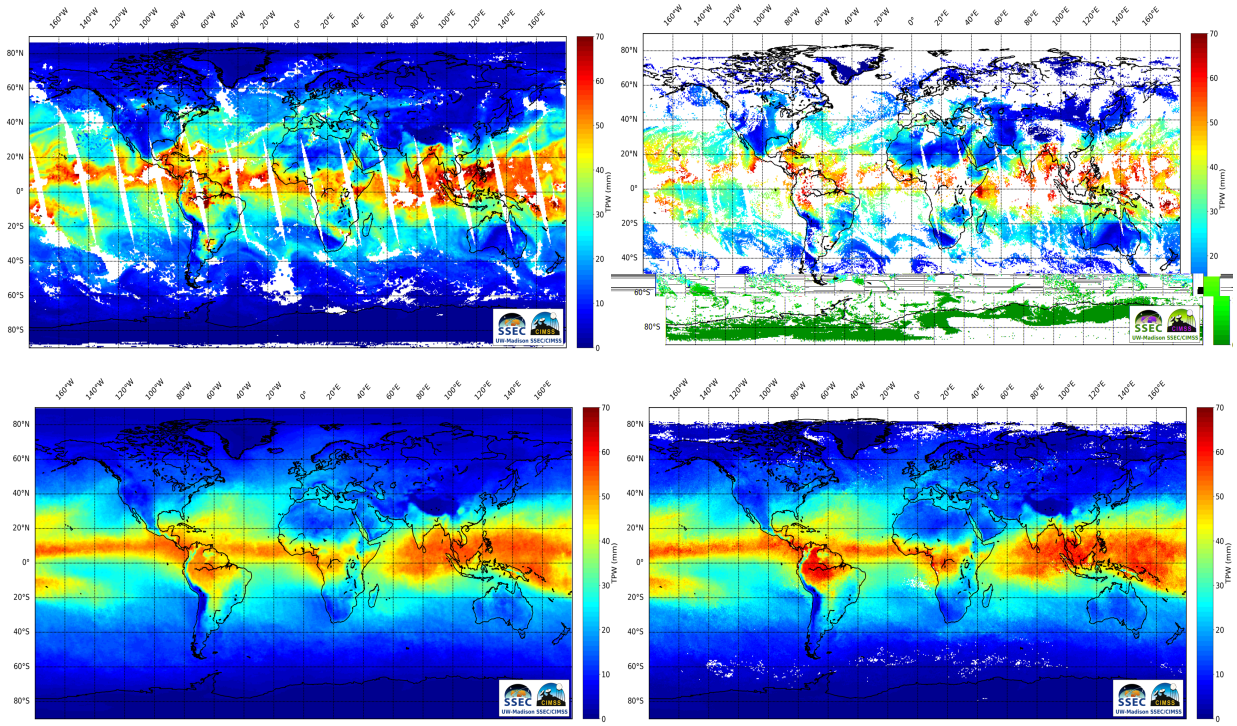

Figure 5: Daytime daily (Oct 15, 2014, top panels) and monthly (Oct 2014, bottom panels) mean 0.5 degree gridded VIIRS/NUCAPS (left) and AQUA/MODIS MYD07 (right) TPW products.

Technical information about the SNPP VIIRS WATVP Level-2 Product File

This section provides technical information about the Suomi-NPP VIIRS Level-2 water vapor product (WATVP_L2_VIIRS_SNPP) file The WATVP Level-2 products are provided in granule NetCDF files with contents (see Table 2) and filename specification as:

Filename: WATVP_L2_VIIRS_SNPP.AYYYYDDD.HHMM.XXX.*.nc, where
YYYY = year DDD= day of the year
HHMM = hour and minute XXX = version number (001) *= SIPS processing time and version
Size: ~140 MB
Format: NetCDF4 (internally compressed)
Dimensions: [number_of_lines, number_of_pixels]
Short Name = WATVP_L2_VIIRS_SNPP"
Product version = 1.0dev5
Identifier product doi = "10.5067/VIIRS/WATVP_L2_VIIRS_SNPP.001"
Identifier product doi authority = https://dx.doi.org

Table 2: The SNPP VIIRS WATVP Level-2 variables

Group: geolocation_data	Type	unit	Description
land_sea_mask	byte	none	Land Sea Mask, 0=ocean, 1=land; copied from VIIRS L1B file
latitude	float16	degrees north	Latitudes of pixel locations; copied from VIIRS L1B file
longitude	float16	degrees east	Longitudes of pixel locations; copied from VIIRS L1B file
sensor_zenith	int16	degrees	Sensor zenith angle at pixel locations; copied from VIIRS L1B file
solar_zenith	int16	degrees	Solar zenith angle at pixel locations; copied from VIIRS L1B file
Group: geophysical_data	Type		Description
atmosphere_water_vapor_content_bg	float16	mm	NUCAPS TPW interpolated to VIIRS pixels
atmosphere_water_vapor_viirs_nucaps	float16	mm	Retrieved VIIRS TPW, NUCAPS used as background
atmosphere_water_vapor_viirs_only	float16	mm	VIIRS-only Retrieved TPW
clear_sky_confidence	float16	%	Clear Sky Confidence derived from the MVCCM file
model_atmosphere_water_vapor_content	float16	mm	TPW from NCEP Climate Forecast System Reanalysis
Model_surface_pressure	float16	hPa	Surface Pressure from NCEP Climate Forecast System Reanalysis (input)
surface_skin_temperature	float16	K	Retrieved skin temperature
quality_flag	int16	none	1 = good retrieval-VIIRS and NUCAPS data are available; 2 = filled with VIIRS-only retrieval; 3 = filled with NUCAPS-only retrieval; 4 = No retrievals - no VIIRS nor NUCAPS data are available or non-physical retrievals

Technical information about the SNPP VIRS WATVP Level-3 Daily and Monthly Mean Product File

This section describes the technical information of the level-3 daily and monthly mean VIIRS/NUCAPS Moisture product file. The WATVP level-3 products are provided in NetCDF files with contents (see Table 3) and filename specification as:

Filename: WATVP_D/M3_VIIRS_SNPP.AYYYYDDD.XXX.*.nc, where

D3=Level-3 daily mean M3=Level-3 monthly mean

YYYY = year DDD = day of the year

XXX = version number (001) *=SIPS processing time and version

Size: ~35 MB

Temporal Resolution: daily or monthly

Spatial Resolution: 0.5 degrees

Format: NetCDF4

Dimensions: [longitude=720, latitude=360]

Short Name = "WATVP_D3_VIIRS_SNPP" or "WATVP_M3_VIRS_SNPP";

Product version = "1.0dev9" ;

Identifier product doi authority = "https://dx.doi.org" ;

Table 3: The SNPP VIIRS WATVP_D/M3 Level-3 variables

Variables:	Type	unit	Description
latitude	double	degrees north	Latitudes of the grid point location
longitude	double	degrees east	Longitude of the grid point location
Group: day_atmosphere_water_vapor_content_nucaps_bg night_atmosphere_water_vapor_content_nucaps_bg day_atmosphere_water_vapor_content_viirs_only night_atmosphere_water_vapor_content_viirs_only day_atmosphere_water_vapor_content_viirs_nucaps night_atmosphere_water_vapor_content_viirs_nucaps	Type		Description: Statistics are separated over daytime and nighttime defined by the solar zenith angle (85°)
standard_deviation	double	mm	Standard Deviation of the values of the L2 pixels fall into the grid cell
sum	double	mm	Sum of the values of the L2 pixels fall into the grid cell
sum_squares	double	mm	Sum of the squared values of the L2 pixels fall into the grid cell
n_points	double	none	Number of the L2 pixels fall into the grid cell
mean	double	mm	Mean of the values of the L2 pixels fall into the grid cell

References

Borbas, E.E., Z. Li, W. P. Menzel, L. Dobor and M. Rada: (2019): VIIRS/Suomi-NPP Water Vapor Products; Algorithm Theoretical Basis Document.

Borbas, E., S. W. Seemann, H.-L. Huang, J. Li, and W. P. Menzel, 2005: Global profile training database for satellite regression retrievals with estimates of skin temperature and emissivity. *Proc. of the Int. ATOVS Study Conference-XIV*, Beijing, China, 25-31 May 2005, pp763–770.

Han, Y., P. Delst, Q. Liu, F. Weng, B. Yan, and J. Derber, 2005: User's Guide to the JCSDA Community Radiative Transfer Model (Beta Version), http://www.star.nesdis.noaa.gov/smcd/spb/CRTM/crtm-code/CRTM_UserGuide-beta.pdf.

Seemann, S.W., Li, J., Menzel, W.P., & Gumley, L.E. (2003). Operational retrieval of atmospheric temperature, moisture, and ozone from MODIS infrared radiances. *Journal of Applied Meteorology*, 42, 1072–1091.

Seemann, S.W., Borbas, E.E., Knuteson, R.O., Stephenson, G.R., & Huang, H.L. (2008). Development of a global infrared land surface emissivity database for application to clear sky sounding retrievals from multispectral satellite radiance measurements. *Journal of Applied Meteorology and Climatology*, 47, 108–123.

Veglio P., R. Holz, L. Gumley, G. Quinn, S. Dutcher, and B. Flynn, 2018, Yori: L3 Gridding Tools, Version 1.3.7, https://sips.ssec.wisc.edu/docs/yori.html

WATVP_L2_VIIRS_SNPP data: Borbas, E.E., et al., 2019, VIIRS/SNPP Level-2 Daily Mean Water Vapor Products. NASA MODIS Adaptive Processing System, Goddard Space Flight Center, USA: https://dx.doi.org/10.5067/VIIRS/WATVP_L2_VIIRS_SNPP.001 10.5067/VIIRS/WATVP_L2_VIIRS_SNPP.001

WATVP_D3_VIIRS_SNPP data: Borbas, E.E., et al., 2019, VIIRS/SNPP Level-3 Daily Mean Water Vapor Products. NASA MODIS Adaptive Processing System, Goddard Space Flight Center, USA: https://dx.doi.org/10.5067/VIIRS/WATVP_D3_VIIRS_SNPP.001 10.5067/VIIRS/WATVP_D3_VIIRS_SNPP.001

WATVP_M3_VIIRS_SNPP data: Borbas, E.E., et al., 2019, VIIRS/SNPP Level-3 Monthly Mean Water Vapor Products. NASA MODIS Adaptive Processing System, Goddard Space Flight Center, USA: https://dx.doi.org/10.5067/VIIRS/WATVP_M3_VIIRS_SNPP.001 10.5067/VIIRS/WATVP_M3_VIIRS_SNPP.001

Appendix 1: SNPP VIIRS WATVP L2 Product CDL[2] File

dimensions:

number_of_lines = 3248 ;

number_of_pixels = 3200 ;

// global attributes:

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:summary = "Total column integrated water vapor products derived from VIIRS+NUCPAS; Total column integrated water vapor products derived from VIIRS-only; Surface Skin Temperature " ;

:contributor_name = "Eva Borbas; Zhenglong Li; W. Paul Menzel" ;

:contributor_role = "Principal Investigator; Scientist; Scientist" ;

:keywords_vocabulary = "NASA Global Change Master Directory (GCMD) Science Keywords" ;

:keywords = "EARTH SCIENCE > ATMOSPHERE > Water Vapor > Atmosphere Water Vapor Content " ;

:license = "http://science.nasa.gov/earth-science/earth-science-data/data-information-policy/" ;

:id = "WATVP_L2_VIIRS_SNPP.A2014288.2042.001.2018127191542.nc " ;

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:Conventions = "CF-1.6, ACDD-1.3" ;

:ShortName = "WATVP_L2_VIIRS_SNPP" ;

:product_version = "1.0dev5" ;

:AlgorithmType = "SCI" ;

:identifier_product_doi = "10.5067/VIIRS/WATVP_L2_VIIRS_SNPP.001" ;

:identifier_product_doi_authority = "https://dx.doi.org" ;

:input_files = … too long to list;

:ancillary_files = "cdas1.20141015.t18z.pgrbhanl.grib2" ;

:l1_version = "2.0.2" ;

[2] CDL: Common Data Language (a human-readable notation for NetCDF objects and data)

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        :DataCenterId = "UWI-MAD/SSEC/ASIPS" ;
        :project = "NASA VIIRS Atmosphere SIPS" ;
        :creator_name = "NASA VIIRS Atmosphere SIPS" ;
        :creator_url = "https://sips.ssec.wisc.edu" ;
        :creator_email = "sips.support@ssec.wisc.edu" ;
        :creator_institution = "Space Science & Engineering Center, University of Wisconsin - Madison" ;
        :publisher_name = "LAADS" ;
        :publisher_url = "https://ladsweb.modaps.eosdis.nasa.gov/" ;
        :publisher_email = "modis-ops@lists.nasa.gov" ;
        :publisher_institution = "NASA Level-1 and Atmosphere Archive & Distribution System" ;
        :instrument = "VIIRS" ;
        :GRingPointSequenceNo = 1, 2, 3, 4 ;
        :GRingPointLatitude = 52.46947f, 59.86136f, 39.03573f, 33.94033f ;
        :GRingPointLongitude = -145.1115f, -95.85351f, -96.32218f, -130.1862f ;
        :NorthBoundingCoordinate = 60.06326f ;
        :SouthBoundingCoordinate = 33.94033f ;
        :EastBoundingCoordinate = -95.85351f ;
        :WestBoundingCoordinate = -145.1115f ;
        :startDirection = "Ascending" ;
        :endDirection = "Ascending" ;
        :OrbitNumber = 15372 ;
        :DayNightFlag = "Day" ;
        :xmlmetadata = … too long to list
        :NCO = "\"4.5.5\"" ;

group: geolocation_data {
  variables:
        byte land_sea_mask(number_of_lines, number_of_pixels) ;
                land_sea_mask:long_name = "Land Sea Mask is derived from VIIRS IFF file 0=ocean, 1=land" ;
                land_sea_mask:units = "unitless" ;
                land_sea_mask:missing_data = -1b ;
                land_sea_mask:valid_min = 0b ;
                land_sea_mask:valid_max = 1b ;
        float latitude(number_of_lines, number_of_pixels) ;
                latitude:long_name = "Latitudes of pixel locations" ;
                latitude:units = "degrees_north" ;
                latitude:_FillValue = -999.9f ;
                latitude:valid_min = -90.f ;
                latitude:valid_max = 90.f ;
        float longitude(number_of_lines, number_of_pixels) ;
                longitude:long_name = "Longitudes of pixel locations" ;
                longitude:units = "degrees_east" ;
                longitude:_FillValue = -999.9f ;
                longitude:valid_min = -180.f ;
                longitude:valid_max = 180.f ;
```

short sensor_zenith(number_of_lines, number_of_pixels) ;
sensor_zenith:long_name = "Sensor zenith angle at pixel locations" ;
sensor_zenith:units = "degrees" ;
sensor_zenith:_FillValue = -32768s ;
sensor_zenith:valid_min = 0s ;
sensor_zenith:valid_max = 18000s ;
sensor_zenith:scale_factor = 0.01f ;
sensor_zenith:offset = 0 ;
short solar_zenith(number_of_lines, number_of_pixels) ;
solar_zenith:long_name = "Solar zenith angle at pixel locations" ;
solar_zenith:units = "degrees" ;
solar_zenith:_FillValue = -32768s ;
solar_zenith:valid_min = 0s ;
solar_zenith:valid_max = 18000s ;
solar_zenith:scale_factor = 0.01f ;
solar_zenith:offset = 0 ;
} // group geolocation_data

group: geophysical_data {
variables:
float atmosphere_water_vapor_content_nucaps_bg(number_of_lines, number_of_pixels) ;
atmosphere_water_vapor_content_nucaps_bg:units = "millimeter" ;
atmosphere_water_vapor_content_nucaps_bg:long_name = "Total Precipitable Water integrated from the mixing ratio profile between the surface and 10 hPa pressure level from nucaps as background for retrievals" ;
atmosphere_water_vapor_content_nucaps_bg:_FillValue = -999.f ;
float atmosphere_water_vapor_content_viirs_nucaps(number_of_lines, number_of_pixels) ;
atmosphere_water_vapor_content_viirs_nucaps:units = "millimeter" ;
atmosphere_water_vapor_content_viirs_nucaps:long_name = "Total Precipitable Water integrated from the mixing ratio profile between the surface and 10 hPa pressure level with nucaps as additional predictors" ;
atmosphere_water_vapor_content_viirs_nucaps:_FillValue = -999.f ;
float atmosphere_water_vapor_content_viirs_only(number_of_lines, number_of_pixels) ;
atmosphere_water_vapor_content_viirs_only:units = "millimeter" ;
atmosphere_water_vapor_content_viirs_only:long_name = "Total Precipitable Water integrated from the mixing ratio profile between the surface and 10 hPa pressure level from VIIRS only" ;
atmosphere_water_vapor_content_viirs_only:_FillValue = -999.f ;
float clear_sky_confidence(number_of_lines, number_of_pixels) ;
clear_sky_confidence:units = "%" ;
clear_sky_confidence:long_name = "Clear Sky Confidence derived from the MVCCM file" ;
clear_sky_confidence:_FillValue = -999.f ;
float model_atmosphere_water_vapor_content(number_of_lines, number_of_pixels) ;
model_atmosphere_water_vapor_content:units = "millimeter" ;
model_atmosphere_water_vapor_content:long_name = "Total Precipitable Water derived from NCEP Climate Forecast System Reanalysis" ;
model_atmosphere_water_vapor_content:_FillValue = -999.f ;
float model_surface_pressure(number_of_lines, number_of_pixels) ;
model_surface_pressure:units = "hPa" ;
model_surface_pressure:long_name = "Surface Pressure derived from NCEP Climate Forecast System Reanalysis" ;
model_surface_pressure:_FillValue = -999.f ;

```
  short quality_flag(number_of_lines, number_of_pixels) ;
        quality_flag:long_name = "Quality flag of the VIIRS+NUCAPS TPW Retrievals" ;
        quality_flag:_FillValue = -32768s ;
        quality_flag:comment = "1 = good retrieval-VIIRS and NUCAPS data are available; 2 = filled with VIIRS-only retrieval; 3 =
filled with\n\tNUCAPS-only retrieval; 4 = No retrievals - no VIIRS nor NUCAPS dat are available or non-physical retrievals" ;
  float surface_skin_temperature(number_of_lines, number_of_pixels) ;
        surface_skin_temperature:units = "degK" ;
        surface_skin_temperature:long_name = "Surface Skin Temperature" ;
        surface_skin_temperature:_FillValue = -999.f ;
  } // group geophysical_data
}
```

Appendix 2: SNPP VIIRS WATVP L3 Daily Mean Product CDL File

dimensions:
latitude = 360 ;
longitude = 720 ;
variables:
double longitude(longitude) ;
longitude:_FillValue = 9.96920996838687e+36 ;
longitude:attributes = "" ;
longitude:units = "degrees_east" ;
longitude:long_name = "" ;
double latitude(latitude) ;
latitude:_FillValue = 9.96920996838687e+36 ;
latitude:attributes = "" ;
latitude:units = "degrees_north" ;
latitude:long_name = "" ;

// global attributes:
:_NCProperties = "version=1|netcdflibversion=4.4.1|hdf5libversion=1.8.17" ;
:description = "" ;
:YAML_config = "grid_settings:\n gridsize: .5\n projection: conformal\n lat_in: latitude\n lon_in: longitude\n lat_out: latitude\n lon_out: longitude\n\nvariable_settings:\n - name_in: atmosphere_water_vapor_content_viirs_nucaps\n name_out: day_atmosphere_water_vapor_content_viirs_nucaps\n masks:\n - DayMask\n\n - name_in: atmosphere_water_vapor_content_viirs_only\n name_out: day_atmosphere_water_vapor_content_viirs_only\n masks:\n - DayMask\n\n - name_in: atmosphere_water_vapor_content_nucaps_bg\n name_out: day_atmosphere_water_vapor_content_nucaps_bg\n masks:\n - DayMask\n\n - name_in: atmosphere_water_vapor_content_viirs_nucaps\n name_out: night_atmosphere_water_vapor_content_viirs_nucaps\n masks:\n - NightMask\n\n - name_in: atmosphere_water_vapor_content_viirs_only\n name_out: night_atmosphere_water_vapor_content_viirs_only\n masks:\n - NightMask\n\n - name_in: atmosphere_water_vapor_content_nucaps_bg\n name_out: night_atmosphere_water_vapor_content_nucaps_bg\n masks:\n - NightMask\n" ;
:Yori_Version = "1.2.3" ;
:daily = "True" ;
:attributes = "" ;
:units = "" ;
:long_name = "" ;
:history = "" ;
:source = "VWATVP 1.0dev5, viirstpw_preyori 20180420-1, yori 1.2.3" ;
:date_created = "2018-05-10T16:07:12Z" ;
:product_name = "WATVP_D3_VIIRS_SNPP.A2014288.001.2018130160824.nc" ;
:LocalGranuleID = "WATVP_D3_VIIRS_SNPP.A2014288.001.2018130160824.nc" ;
:Conventions = "CF-1.6, ACDD-1.3" ;
:ShortName = "WATVP_D3_VIIRS_SNPP" ;
:product_version = "1.0dev9" ;
:AlgorithmType = "SCI" ;
:identifier_product_doi = "10.5067/VIIRS/WATVP_D3_VIIRS_SNPP.001" ;
:identifier_product_doi_authority = "http://dx.doi.org" ;
:input_files "WATVP_G3.A2014288.0848.001.2018130152746.nc etc…
:ancillary_files = "" ;
:DataCenterId = "UWI-MAD/SSEC/ASIPS" ;
:project = "NASA VIIRS Atmosphere SIPS" ;
:creator_name = "NASA VIIRS Atmosphere SIPS" ;
:creator_url = "https://sips.ssec.wisc.edu" ;
:creator_email = "sips.support@ssec.wisc.edu" ;
:creator_institution = "Space Science & Engineering Center, University of Wisconsin - Madison" ;
:publisher_name = "LAADS" ;
:publisher_url = "https://ladsweb.modaps.eosdis.nasa.gov/" ;
:publisher_email = "modis-ops@lists.nasa.gov" ;
:publisher_institution = "NASA Level-1 and Atmosphere Archive & Distribution System" ;
:time_coverage_start = "2014-10-15T00:00:00.000000" ;
:time_coverage_end = "2014-10-15T23:59:59.000000" ;
:xmlmetadata = … too long to list;

```
group: night_atmosphere_water_vapor_content_viirs_nucaps {
  variables:
        double standard_deviation(longitude, latitude) ;
              standard_deviation:_FillValue = 9.96920996838687e+36 ;
        double sum(longitude, latitude) ;
              sum:_FillValue = 9.96920996838687e+36 ;
        double sum_squares(longitude, latitude) ;
              sum_squares:_FillValue = 9.96920996838687e+36 ;
        double n_points(longitude, latitude) ;
              n_points:_FillValue = 9.96920996838687e+36 ;
        double mean(longitude, latitude) ;
              mean:_FillValue = 9.96920996838687e+36 ;
  } // group night_atmosphere_water_vapor_content_viirs_nucaps

group: night_atmosphere_water_vapor_content_nucaps_bg {
  variables:
        double standard_deviation(longitude, latitude) ;
              standard_deviation:_FillValue = 9.96920996838687e+36 ;
        double sum(longitude, latitude) ;
              sum:_FillValue = 9.96920996838687e+36 ;
        double sum_squares(longitude, latitude) ;
              sum_squares:_FillValue = 9.96920996838687e+36 ;
        double n_points(longitude, latitude) ;
              n_points:_FillValue = 9.96920996838687e+36 ;
        double mean(longitude, latitude) ;
              mean:_FillValue = 9.96920996838687e+36 ;
  } // group night_atmosphere_water_vapor_content_nucaps_bg

group: day_atmosphere_water_vapor_content_viirs_nucaps {
  variables:
        double standard_deviation(longitude, latitude) ;
              standard_deviation:_FillValue = 9.96920996838687e+36 ;
        double sum(longitude, latitude) ;
              sum:_FillValue = 9.96920996838687e+36 ;
        double sum_squares(longitude, latitude) ;
              sum_squares:_FillValue = 9.96920996838687e+36 ;
        double n_points(longitude, latitude) ;
              n_points:_FillValue = 9.96920996838687e+36 ;
        double mean(longitude, latitude) ;
              mean:_FillValue = 9.96920996838687e+36 ;
  } // group day_atmosphere_water_vapor_content_viirs_nucaps

group: day_atmosphere_water_vapor_content_nucaps_bg {
  variables:
        double standard_deviation(longitude, latitude) ;
              standard_deviation:_FillValue = 9.96920996838687e+36 ;
        double sum(longitude, latitude) ;
              sum:_FillValue = 9.96920996838687e+36 ;
        double sum_squares(longitude, latitude) ;
              sum_squares:_FillValue = 9.96920996838687e+36 ;
        double n_points(longitude, latitude) ;
              n_points:_FillValue = 9.96920996838687e+36 ;
        double mean(longitude, latitude) ;
              mean:_FillValue = 9.96920996838687e+36 ;
  } // group day_atmosphere_water_vapor_content_nucaps_bg

group: night_atmosphere_water_vapor_content_viirs_only {
  variables:
        double standard_deviation(longitude, latitude) ;
              standard_deviation:_FillValue = 9.96920996838687e+36 ;
        double sum(longitude, latitude) ;
              sum:_FillValue = 9.96920996838687e+36 ;
        double sum_squares(longitude, latitude) ;
              sum_squares:_FillValue = 9.96920996838687e+36 ;
        double n_points(longitude, latitude) ;
```

```
                n_points:_FillValue = 9.96920996838687e+36 ;
        double mean(longitude, latitude) ;
                mean:_FillValue = 9.96920996838687e+36 ;
  } // group night_atmosphere_water_vapor_content_viirs_only

group: day_atmosphere_water_vapor_content_viirs_only {
  variables:
        double standard_deviation(longitude, latitude) ;
                standard_deviation:_FillValue = 9.96920996838687e+36 ;
        double sum(longitude, latitude) ;
                sum:_FillValue = 9.96920996838687e+36 ;
        double sum_squares(longitude, latitude) ;
                sum_squares:_FillValue = 9.96920996838687e+36 ;
        double n_points(longitude, latitude) ;
                n_points:_FillValue = 9.96920996838687e+36 ;
        double mean(longitude, latitude) ;
                mean:_FillValue = 9.96920996838687e+36 ;
  } // group day_atmosphere_water_vapor_content_viirs_only
}
```

Appendix 3: SNPP VIIRS WATVP L3 Monthly Mean Product CDL File

netcdf **WATVP_M3.A2014213.001.2018215135952** {
dimensions:
latitude = 360 ;
longitude = 720 ;
variables:
double longitude(longitude) ;
longitude:_FillValue = 9.96920996838687e+36 ;
longitude:attributes = "" ;
longitude:units = "degrees_east" ;
longitude:long_name = "" ;
double latitude(latitude) ;
latitude:_FillValue = 9.96920996838687e+36 ;
latitude:attributes = "" ;
latitude:units = "degrees_north" ;
latitude:long_name = "" ;

// global attributes:
:_NCProperties = "version=1|netcdflibversion=4.4.1|hdf5libversion=1.8.17" ;
:description = "" ;
:YAML_config = "grid_settings:\n gridsize: .5\n projection: conformal\n lat_in: latitude\n lon_in: longitude\n lat_out: latitude\n lon_out: longitude\n\nvariable_settings:\n - name_in: atmosphere_water_vapor_content_viirs_nucaps\n name_out: day_atmosphere_water_vapor_content_viirs_nucaps\n masks:\n - DayMask\n\n - name_in: atmosphere_water_vapor_content_viirs_only\n name_out: day_atmosphere_water_vapor_content_viirs_only\n masks:\n - DayMask\n\n - name_in: atmosphere_water_vapor_content_nucaps_bg\n name_out: day_atmosphere_water_vapor_content_nucaps_bg\n masks:\n - DayMask\n\n - name_in: atmosphere_water_vapor_content_viirs_nucaps\n name_out: night_atmosphere_water_vapor_content_viirs_nucaps\n masks:\n - NightMask\n\n - name_in: atmosphere_water_vapor_content_viirs_only\n name_out: night_atmosphere_water_vapor_content_viirs_only\n masks:\n - NightMask\n\n - name_in: atmosphere_water_vapor_content_nucaps_bg\n name_out: night_atmosphere_water_vapor_content_nucaps_bg\n masks:\n - NightMask\n" ;
:Yori_Version = "1.2.3" ;
:daily = "False" ;
:attributes = "" ;
:units = "" ;
:long_name = "" ;
:history = "" ;
:source = "VWATVP 1.0dev5, viirstpw_preyori 20180420-1, yori 1.2.3" ;
:date_created = "2018-08-03T13:58:07Z" ;
:product_name = "WATVP_M3.A201408.001.2018215135952.nc" ;
:LocalGranuleID = "WATVP_M3.A201408.001.2018215135952.nc" ;
:Conventions = "CF-1.6, ACDD-1.3" ;
:ShortName = "WATVP_M3_VIIRS_SNPP" ;
:product_version = "1.0dev9" ;
:AlgorithmType = "SCI" ;
:identifier_product_doi = "10.5067/VIIRS/WATVP_M3_VIIRS_SNPP.001" ;
:identifier_product_doi_authority = "https://dx.doi.org" ;
:input_files = "WATVP_D3_VIIRS_SNPP.A2014232.001.2018212190307.nc,
WATVP_D3_VIIRS_SNPP.A2014231.001.2018212190354.nc,
WATVP_D3_VIIRS_SNPP.A2014228.001.2018212190404.nc,
WATVP_D3_VIIRS_SNPP.A2014227.001.2018212190252.nc,
WATVP_D3_VIIRS_SNPP.A2014244.001.2018212190340.nc,
WATVP_D3_VIIRS_SNPP.A2014229.001.2018212190324.nc,
WATVP_D3_VIIRS_SNPP.A2014224.001.2018212190303.nc,
WATVP_D3_VIIRS_SNPP.A2014223.001.2018212190230.nc,
WATVP_D3_VIIRS_SNPP.A2014226.001.2018212190254.nc,
WATVP_D3_VIIRS_SNPP.A2014225.001.2018212190251.nc,
WATVP_D3_VIIRS_SNPP.A2014242.001.2018212190411.nc,
WATVP_D3_VIIRS_SNPP.A2014237.001.2018212190237.nc,
WATVP_D3_VIIRS_SNPP.A2014238.001.2018212190405.nc,
WATVP_D3_VIIRS_SNPP.A2014239.001.2018212190318.nc,
WATVP_D3_VIIRS_SNPP.A2014240.001.2018212190240.nc,

```
WATVP_D3_VIIRS_SNPP.A2014233.001.2018212190253.nc,
WATVP_D3_VIIRS_SNPP.A2014234.001.2018212190246.nc,
WATVP_D3_VIIRS_SNPP.A2014235.001.2018212190227.nc,
WATVP_D3_VIIRS_SNPP.A2014236.001.2018212190336.nc,
WATVP_D3_VIIRS_SNPP.A2014241.001.2018212190352.nc,
WATVP_D3_VIIRS_SNPP.A2014230.001.2018212190256.nc,
WATVP_D3_VIIRS_SNPP.A2014243.001.2018212190307.nc,
WATVP_D3_VIIRS_SNPP.A2014222.001.2018212190316.nc,
WATVP_D3_VIIRS_SNPP.A2014221.001.2018212190312.nc,
WATVP_D3_VIIRS_SNPP.A2014218.001.2018212190418.nc,
WATVP_D3_VIIRS_SNPP.A2014217.001.2018212190313.nc,
WATVP_D3_VIIRS_SNPP.A2014220.001.2018212190239.nc,
WATVP_D3_VIIRS_SNPP.A2014219.001.2018212190430.nc,
WATVP_D3_VIIRS_SNPP.A2014214.001.2018212190301.nc,
WATVP_D3_VIIRS_SNPP.A2014213.001.2018212190319.nc,
WATVP_D3_VIIRS_SNPP.A2014216.001.2018212190325.nc,
WATVP_D3_VIIRS_SNPP.A2014215.001.2018212190324.nc" ;
                :ancillary_files = "" ;
                :DataCenterId = "UWI-MAD/SSEC/ASIPS" ;
                :project = "NASA VIIRS Atmosphere SIPS" ;
                :creator_name = "NASA VIIRS Atmosphere SIPS" ;
                :creator_url = "https://sips.ssec.wisc.edu" ;
                :creator_email = "sips.support@ssec.wisc.edu" ;
                :creator_institution = "Space Science & Engineering Center, University of Wisconsin - Madison" ;
                :publisher_name = "LAADS" ;
                :publisher_url = "https://ladsweb.modaps.eosdis.nasa.gov/" ;
                :publisher_email = "modis-ops@lists.nasa.gov" ;
                :publisher_institution = "NASA Level-1 and Atmosphere Archive & Distribution System" ;
                :time_coverage_start = "2014-08-01T00:00:00.000000" ;
                :time_coverage_end = "2014-08-31T23:59:59.000000" ;
                :xmlmetadata= … too long to list

group: night_atmosphere_water_vapor_content_viirs_nucaps {
  variables:
        double standard_deviation(longitude, latitude) ;
                standard_deviation:_FillValue = 9.96920996838687e+36 ;
        double sum(longitude, latitude) ;
                sum:_FillValue = 9.96920996838687e+36 ;
        double sum_squares(longitude, latitude) ;
                sum_squares:_FillValue = 9.96920996838687e+36 ;
        double n_points(longitude, latitude) ;
                n_points:_FillValue = 9.96920996838687e+36 ;
        double mean(longitude, latitude) ;
                mean:_FillValue = 9.96920996838687e+36 ;
  } // group night_atmosphere_water_vapor_content_viirs_nucaps

group: night_atmosphere_water_vapor_content_nucaps_bg {
  variables:
        double standard_deviation(longitude, latitude) ;
                standard_deviation:_FillValue = 9.96920996838687e+36 ;
        double sum(longitude, latitude) ;
                sum:_FillValue = 9.96920996838687e+36 ;
        double sum_squares(longitude, latitude) ;
                sum_squares:_FillValue = 9.96920996838687e+36 ;
        double n_points(longitude, latitude) ;
                n_points:_FillValue = 9.96920996838687e+36 ;
        double mean(longitude, latitude) ;
                mean:_FillValue = 9.96920996838687e+36 ;
  } // group night_atmosphere_water_vapor_content_nucaps_bg

group: day_atmosphere_water_vapor_content_viirs_nucaps {
  variables:
        double standard_deviation(longitude, latitude) ;
                standard_deviation:_FillValue = 9.96920996838687e+36 ;
        double sum(longitude, latitude) ;
```

```
                sum:_FillValue = 9.96920996838687e+36 ;
        double sum_squares(longitude, latitude) ;
                sum_squares:_FillValue = 9.96920996838687e+36 ;
        double n_points(longitude, latitude) ;
                n_points:_FillValue = 9.96920996838687e+36 ;
        double mean(longitude, latitude) ;
                mean:_FillValue = 9.96920996838687e+36 ;
  } // group day_atmosphere_water_vapor_content_viirs_nucaps

group: day_atmosphere_water_vapor_content_nucaps_bg {
  variables:
        double standard_deviation(longitude, latitude) ;
                standard_deviation:_FillValue = 9.96920996838687e+36 ;
        double sum(longitude, latitude) ;
                sum:_FillValue = 9.96920996838687e+36 ;
        double sum_squares(longitude, latitude) ;
                sum_squares:_FillValue = 9.96920996838687e+36 ;
        double n_points(longitude, latitude) ;
                n_points:_FillValue = 9.96920996838687e+36 ;
        double mean(longitude, latitude) ;
                mean:_FillValue = 9.96920996838687e+36 ;
  } // group day_atmosphere_water_vapor_content_nucaps_bg

group: night_atmosphere_water_vapor_content_viirs_only {
  variables:
        double standard_deviation(longitude, latitude) ;
                standard_deviation:_FillValue = 9.96920996838687e+36 ;
        double sum(longitude, latitude) ;
                sum:_FillValue = 9.96920996838687e+36 ;
        double sum_squares(longitude, latitude) ;
                sum_squares:_FillValue = 9.96920996838687e+36 ;
        double n_points(longitude, latitude) ;
                n_points:_FillValue = 9.96920996838687e+36 ;
        double mean(longitude, latitude) ;
                mean:_FillValue = 9.96920996838687e+36 ;
  } // group night_atmosphere_water_vapor_content_viirs_only

group: day_atmosphere_water_vapor_content_viirs_only {
  variables:
        double standard_deviation(longitude, latitude) ;
                standard_deviation:_FillValue = 9.96920996838687e+36 ;
        double sum(longitude, latitude) ;
                sum:_FillValue = 9.96920996838687e+36 ;
        double sum_squares(longitude, latitude) ;
                sum_squares:_FillValue = 9.96920996838687e+36 ;
        double n_points(longitude, latitude) ;
                n_points:_FillValue = 9.96920996838687e+36 ;
        double mean(longitude, latitude) ;
                mean:_FillValue = 9.96920996838687e+36 ;
  } // group day_atmosphere_water_vapor_content_viirs_only
}
```