National Aeronautics and Space Administration
Goddard Earth Science Data Information and Services Center (GES DISC)

Data Product User Guide for Spatial Statistical Data Fusion (SSDF) Continental United States (CONUS) Vapor Pressure Deficit (VPD) Level-3 Products

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Revision History

Revision Date	***Changes***	***Author***
2023-02-20	Initial Release	Peter Kalmus
2023-04-18	Added acknowledgment, fixed ISO code link.	Peter Kalmus

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1.0 Introduction

This document provides basic information for using the Version 2 Level-3 Spatial Statistical Data Fusion (SSDF) surface continental United States (CONUS) products, fusing data from the Atmospheric InfraRed Sounder (AIRS) instrument on the EOS-Aqua spacecraft with data from the Cross-track Infrared and Microwave Sounding Suite (CrIMSS) instruments on the Suomi-NPP spacecraft. The CrIMSS instrument suite consists of the Cross-track Infrared Sounder (CrIS) infrared sounder and the Advanced Technology Microwave Sounder (ATMS) microwave sounder.

These products were derived using SSDF data fusion algorithms developed by Amy Braverman, Peter Kalmus, and Hai Nguyen at the Jet Propulsion Laboratory, California Institute of Technology.

The SSDF CONUS Surface products contain near-surface parameters derived from AIRS v7 and CrIMSS CLIMCAPS Level-2 data. The first products, described in a separate User Guide, are near-surface atmospheric temperature products (NSAT, described in Kalmus et al., 2022). Here we describe corresponding vapor pressure deficit (VPD) products. These are all daily products on a ¼ x ¼ degree latitude/longitude grid covering the continental United States (CONUS). These products have been annotated with both file and variable level attributes to fully describe their contents.

In addition to the fused product from two separate satellites, an additional VPD product is produced by applying the SSDF algorithm to just the Aqua AIRS data. This product covers a much longer period, starting in 2002 instead of 2012. In most respects, the VPD product is similar to the NSAT product, e.g. in terms of years of coverage, algorithm used to produce, data quality flags used, etc. In this guide, significant departures between the two products will be indicated. Otherwise, the data fusion paper describing the NSAT products (Kalmus et al. 2022) describes the core methodology used to create the VPD product.

1.1 Input Dataset Descriptions

The SSDF products fuse data for near-surface parameters derived from similar instruments on different satellites using different retrieval algorithms. Specifically, the fused products are the "Aqua/AIRS L2 Support Retrieval (AIRS-only) V7.0" product (AIRS project, 2019) and the "Sounder SIPS: Suomi NPP CrIMSS Level 2 CLIMCAPS Full Spectral Resolution: Atmosphere cloud and surface geophysical state V2" product (Barnet, 2019).

Table 1.1 Data Sources

Dataset	Retrieval	IR vs. IR+MW	Time range	Approx. overpass
AIRS	AIRS v7	IR	2002-2020	1:30pm/1:30am

Dataset	Retrieval	IR vs. IR+MW	Time range	Approx. overpass
CrIMSS	CLIMCAPS v2	IR+MW	2012-2020	1:30pm/1:30am

1.1.1 EOS-Aqua

The EOS-Aqua satellite was launched on May 4, 2002 from Vandenburg Air Force Base in California into an orbit with an altitude of 705 km above the Earth surface, an inclination angle of 98.2 deg and a 13:30 local time ascending node. The Aqua spacecraft is part of the "A-train" (Aqua in the lead and Aura at the tail, the nominal separation between Aqua and Aura is about 15 minutes) or "afternoon constellation" (a loose formation flight which started sometime after the Aura launch July 15, 2004). The objective is to coordinate observations and to provide a coincident set of data on aerosol and cloud properties, radiative fluxes and atmospheric state essential for accurate quantification of aerosol and cloud radiative effects.

1.1.1.1 AIRS Instrument Description

The Atmospheric Infrared Sounder (AIRS) is a grating array spectrometer having 2378 channels sensitive in the range 3.7 to 15.4 microns. The spectral resolution ($\lambda/\Delta\lambda$) is about 1200. A combination of a design philosophy having radiometric accuracy as a foremost goal, cooled and temperature-controlled spectrometer hardware (including most of the optics), and thorough pre-flight calibration have made AIRS a superb instrument that produces very high-quality radiance data.

1.1.1.2 AIRS Retrieval Description

The SSDF VPD product was produced using the Infrared-Only variant of version 7 of the AIRS Level-2 product, AIRS2SUP_007. Fetzer et al. 2020 gives an overview of the AIRS algorithm and products and Thrastarson et al. 2020 describes how to use them.

The AIRS retrieval algorithm generates surface and atmospheric parameters using AIRS radiance observations taken within a 3x3 array of AIRS Fields of View (FOVs) contained within an AMSU footprint, called an AIRS Field of Regard (FOR). Retrievals of most geophysical parameters are performed at AIRS FOR horizontal resolution of about 45 km at nadir. Cloud products are retrieved at AIRS FOV horizontal resolution of 13.5 km at nadir. retrieval process consists of four major components, repeated iteratively:

1. The First Guess. The first guess uses observed AIRS radiances within the AIRS FOR, and a neural network, to generate the initial guess X0 to start the retrieval process.
2. Cloud Clearing. The second algorithm component retrieves clear column radiances in the FOR for all channels, which are updated as part of the overall retrieval process. The cloud-cleared radiance is a derived quantity representing the radiance channel would have observed if the AIRS FOR were cloud-free.

3. The Physical Retrieval. The third retrieval component is a multi-step, physically based procedure, starting with the initial guess X0, that finds geophysical parameters which best match both the observed AMSU radiances and AIRS clear column radiances for those channels used in a given step of the retrieval process. Retrieval steps are done sequentially and determine the following geophysical parameters: surface skin temperature, surface spectral emissivity, surface bidirectional reflectance; atmospheric temperature profile, atmospheric moisture profile, ozone profile, and mid-tropospheric methane and carbon monoxide within an AIRS FOR, as well as the cloud fraction (the product of areal coverage and emissivity) and cloud top pressure in each AIRS FOV. These steps are done sequentially so as to make the retrieval process as linear as possible in each step, and to allow for use of a set of channels in each retrieval step whose radiances are most sensitive to what is being solved for in that step and parameters previously solved for, while also being relatively insensitive to geophysical parameters not yet solved for.

4. Quality Control. The fourth retrieval component derives error estimates for retrieved geophysical parameters, and uses these error estimates to generate case-dependent quality control (QC) flags for retrieved geophysical parameters. (Susskind 2020)

1.1.2 Suomi-NPP

The S-NPP satellite was launched on October 28, 2011 from Vandenburg Air Force Base in California into an orbit with an altitude of 824 km above the Earth surface, an inclination angle of 98.7 deg and a 13:30 local time ascending node [Reference 3]. SNPP is the first in a series of next generation U.S. weather satellites of the Joint Polar Satellite System (JPSS). CrIMSS (CrIS and ATMS) are two of the five instruments onboard the S-NPP satellite. The other instruments are: Clouds and the Earth's Radiant Energy System (CERES), Ozone Mapping and Profiler Suite (OMPS) and Visible Infrared Imaging Radiometer Suite (VIIRS).

1.1.2.1 CrIS Instrument Description

The Cross-track Infrared Sounder (CrIS) is a Fourier Transform Spectrometer (FTS) which measures interferograms in three Infrared (IR) bands simultaneously. The CrIS interferometer includes a beamsplitter, a stationary and moving mirror, and a laser sampling system. The scene radiance entering the interferometer is split by the beamsplitter into two beams along two separate paths. One beam travels towards the moving mirror; the other to a stationary mirror. The two beams are reflected from the corresponding mirrors and recombine before converging on the detector. The optical path difference (OPD) traveled by the two beams is twice the physical path difference between the two mirrors. As the moving mirror sweeps from one side of the zero path difference (ZPD) to the other, a time-varying interference pattern known as the interferogram is recorded. A convolution of the interferogram with a Finite Impulse Response (FIR) numerical filter is applied in real-time on the spacecraft to reduce the internal data rate to meet telemetry requirements. This results in a complex-valued interferogram of a fixed number of sample points which is included in the downlinked data packets.

The products for S-NPP were produced using version 2 of the CrIS Level-1B product in Normal Spectral Resolution (NSR) and Full Spectral Resolution (FSR).

1.1.2.1.1 S-NPP CrIS Instrument Resolution

For the first part of the SNPP mission, the effective spectral resolution of CrIS data received from the satellite was lower in the short-wave and mid-wave infrared bands than in the longwave infrared band. Level 0 data received during this initial period is referred to as Normal Spectral Resolution (NSR).

On December 4, 2014, the resolution of the short-wave and mid-wave data transmitted from SNPP was increased to match the long-wave resolution. Level 0 data received from this time through November 2, 2015 is referred to as Full Spectral Resolution (FSR). After the transition to FSR, the effective spectral resolution of short-wave data received on the ground was quadrupled, and the effective spectral resolution of mid-wave data was doubled, with the Level 0 data volume increasing accordingly.

On November 2, 2015, SNPP began transmitting long-wave and short-wave interferograms with extra points on the ends. Level 0 data received from this time onward is referred to as Extended Spectral Resolution (XSR). These points had previously been discarded, but were added to the data stream because it was determined that they could be used to improve the quality of the calibration.

1.1.2.2 ATMS Instrument Description

ATMS is a 22-channel cross-track scanning microwave sounder providing temperature soundings. Table 1.4.1 contains a summary of the ATMS instrument parameters.

The ATMS instrument's Scan Drive Mechanism on S-NPP has been experiencing additional wear on the bearings. To extend the life of the instrument, a decision was made to perform scan reversals for the purpose of 're-wetting' the bearings. The scan reversals are now occurring twice per orbit, starting Aug 9, 2016. The end result of this maneuver is a slight loss of data. This loss of data is represented by the use of Fill Values.

1.1.2.3 CrIMSS CLIMCAPS Retrieval Description

The SSDF VPD products utilize L2 products from the Community Long-term Infrared Microwave Coupled Atmospheric Product System (CLIMCAPS).

The CLIMCAPS retrieval approach is based on the AIRS Level-2 science team algorithm design [https://disc.gsfc.nasa.gov/information/documents?title=AIRS%20Documentation], employing many of the same components as the AIRS V7 algorithm, such as cloud clearing, channel sub-setting, sequential optimal estimation and scene-specific information content analysis. Two significant departures are that CLIMCAPS (i) replaces the AIRS V7 first guess, namely the SCCNN neural net statistical retrieval, with MERRA2 as a-priori (GMAO, 2015)

and (ii) ingests and propagates two-dimensional error covariance matrices for a full accounting of algorithm, measurement and atmospheric state uncertainty [https://airs.jpl.nasa.gov/system/presentations/files/381_StatusBarnet.pdf].

Technical details of the Level-2 processing steps and calibrations can be found in Kalmus et al. 2022. See references.

1.2 Data Disclaimer

Version 2 SSDF CONUS Level-3 data are released to the public as is. Every effort has been made to properly represent the data which this document describes.

1.3 Data Caveats and Known Issues in SSDF VPD v02_42_00

1.3.1 Extrapolation

Occasionally, the SSDF algorithm attempts to extrapolate and this can produce inaccurate estimates. When this occurs, it is often in the Florida region, and when only one input instrument is available.

1.3.2 Extreme elevations above 2.5 km MSL

At elevations 2.5 km above mean sea level, SSDF might increase bias relative to the input datasets (Kalmus et al., 2022).

1.3.4 Missing days in the SSDF VPD products

The SSDF product cannot be created on days or nights for which there is no input data. There are 70 missing days for the AIRS-only product in the period spanning 2003-2020:
20031029,20031030,20031031,20031101,20031102,20031103,20031104,20031105,20031106,20031107,20031108,20031109,20031110,20031111,20031112,20031113,20031114,20031115,20031116,20031117,20031118,20040622,20041107,20100109,20100110,20100111,20100112,20100113,20100114,20100115,20100116,20100117,20100118,20100119,20100120,20100121,20100122,20100123,20100124,20100125,20130209,20140322,20140323,20140324,20140325,20140326,20140327,20140328,20160925,20160926,20170607,20170608,20170629,20200816,20200817,20200818,20200819,20200820,20200

821,20200822,20200823,20200824,20200825,20200826,20200827,20200828,20200829,
20200830,20200831,20200901.

The consecutive two-instrument product begins on 2012-11-28, and there are no missing days subsequent to this date and through the end of 2020. However, note that the S-NPP CrIMSS-CLIMCAPS v2 dataset begins on 2012-04-01. The beginning of the two-instrument SSDF product (SNDR13IML3SSDFCVPD) will be updated to correspond to 2012-04-01 in a future version.

1.4 Where to find the Products

The Version 2 SSDF CONUS Level-3 products can be found at and downloaded from the Goddard Distributed Active Archive Center (GDAAC). There you will find additional information and documentation about this product and other products of interest. Search "SSDF CONUS" (with quotes) under Data Collections.

https://disc.gsfc.nasa.gov

Alternatively, enter the ECS Shortnames directly into the Earthdata search string to quickly find SSDF level 3 products. The data at the GDAAC is organized by unique versioned shortnames. A third approach is to search by DOI number below.

Table 1.3.1 ECS Shortnames and DOIs

Shortname	DOI	Description
SNDR13IML3SSDFCVPD	10.5067/55EOWAJ669WC	SSDF Level-3 CONUS fused Vapor Pressure Deficit V2
SNDRAQIL3SSDFCVPD	10.5067/4RE39DE0GLVE	SSDF Level-3 CONUS AIRS-only Vapor Pressure Deficit V2

1.5 Contact Information

For information, questions or concerns with these Version 2 SSDF CONUS Level-3 datasets, please send your questions to: askairs@jpl.nasa.gov.

A portion of this research was carried out at the Jet Propulsion Laboratory, California Institute of Technology, under a contract with the National Aeronautics and Space Administration (80NM0018D0004).

2.0 Level-3 Product Overview

Level-3 products are created from published Level-2 products for Aqua and S-NPP. The results of these algorithms are fused with the SSDF algorithm to yield 1-day gridded Level-3 files. The product files described in this document are:

1) SSDF Level-3 CONUS VPD (SNDR13IML3SSDFCVPD)
2) SSDF Level-3 CONUS AIRS-only VPD (SNDRAQIL3SSDFCVPD)

The first set covers the period starting when SNPP CLIMCAPS became available on 2012-11-28 and ending 2020-12-31. The second set starts at the beginning of the AIRS record in 2002.

2.1 Product Granulation

The Level-3 two-instrument product is produced for every day from November 28 2012 to December 31 2020. In rare instances, the products in this time range might be produced from only a single instrument (these instances are tagged in the filename; see Section 2.5 below). Each daily file corresponds to a calendar day. Data is separated by the "orbit_pass" dimension into observations taken while the spacecraft is moving northwards (ascending) and while it is moving southwards (descending). For these non-polar regions, ascending data is daytime and descending is nighttime, but at the poles the sun may be over the horizon for neither or both.

The first element in the orbit_pass dimension is the ascending element, with data taken around its nominal 13.5-hour equatorial orbit pass time (1:30 PM local time). UTC time for this data is near T20Z.

The second element is the descending element, with data taken around 1.5 hours or 1:30 AM local time. UTC time for this data is near T08Z, about 12 hours earlier than the ascending data.

Variables orbit_pass, obs_time_tai93, and obt_time_utc can help with interpretation and display of the ascending/descending distinction.

2.2 SSDF Processing and Algorithm Summary

The Level-3 SSDF algorithm, the NSAT product, and its validation is described in detail in Kalmus et al. (2022). The core SSDF algorithm is also described in in Nguyen et al. 2012 and Nguyen et al. 2014. Here, we provide a nontechnical overview. The VPD product is created in exactly the same way as the NSAT product, but using the VPD estimated by the remote

sensing retrievals as the input, and calculating VPD from the ISD ground stations using the Meteo python package "humidity" module (accessed at https://github.com/hendrikwout/meteo/blob/master/meteo/humidity.py) to compute near-surface relative humidity from the near-surface air temperature and dewpoint, i.e.

```
nsrh = humidity.dp2rh(nsat, nsdp)
```

and then calculating

```
vpd = humidity.esat(nsat+273.15)*(1.-nsrh).
```

The SSDF algorithm infers a value for each grid point based on nearby and distant values of the input Level-2 datasets and estimates of the variance of those values, with lower variances given higher weight. Performing the data fusion of two (or more) remote sensing datasets that estimate the same physical state involves four major steps: (1) Filtering input data; (2) Matching the remote sensing datasets to an in situ dataset, taken as a truth estimate; (3) Using these matchups to characterize the input datasets via estimation of their bias and variance relative to the truth estimate; (4) Performing the spatial statistical data fusion. We note that SSDF can also be performed on a single remote sensing input dataset. The SSDF algorithm only ingests the bias-corrected estimates, their latitudes and longitudes, and their estimated variances; the algorithm is agnostic as to which dataset or datasets those estimates, latitudes, longitudes, and variances originated from.

SSDF is a generalization of optimal interpolation that has been used in data assimilation and remote sensing. Optimal interpolation (OI) is also known as objective mapping, Gauss-Markov smoothing, or kriging. In contrast to traditional applications of OI, our input datasets have different footprints, measurement error characteristics and sampling patterns. SSDF accounts for these heterogeneities by using a spatial statistical model that expresses the relationships between the true quantity of interest at a particular location, and all the observations at all locations from all data sources. Once these relationships are quantified, which is accomplished by estimating the parameters of the statistical model using remote sensing observations, we use the model to make estimates of the true profiles. These estimates have associated quantified uncertainties.

Our technical approach is to treat data fusion as an inference problem: we wish to estimate the true but unknown values of an atmospheric profile at a specified point location. By repeating this at a set of locations on a finely spaced grid, we create an estimate of the true field. The observations are provided by *M* different remote sensing datasets each with sparse, possibly incomplete profile measurements defined at their own pressure levels. The remote sensing observations represent footprints rather than point-level measurements, plus an instrument-specific footprint-level measurement error. Even with the instrument-specific measurement errors, the observed variables from the *M* datasets are likely to be correlated because the same atmospheric physics relate them to the common geophysical process of interest. It is this correlation that allows SSDF to produce estimates of the variable of interest from related observations at different locations/times from multiple instruments.

SSDF is based on the methodologies in Nguyen et al. (2012, 2014, 2017). There, the key concept is to construct a spatial dependence function that specifies how any two spatial

locations in our domain are correlated with one another. Once we have that spatial dependence function, it is then possible to construct an optimal estimate of the process of interest at any new location as a function of the data covariance matrix (correlation between observed data points) and the prediction covariance vector (correlation between the observed data points and the new prediction location). Another key set of parameters are the retrieval measurement variance informs the data fusion as to how to weight the various input datasets when combining them. SSDF gives observations with low uncertainties more weight than observations with high uncertainties.

SSDF depends on estimating and taking advantage of the data covariance, which is typically defined as a measure of the joint variability between two variables (e.g., water vapor at two different spatial locations or temperature at the same spatial location but located at two different altitudes). Formally, it can be considered as a measure of the degree of information one might get from any two observations. For instance, if two observations are perfectly correlated, then in effect we only have one piece of information and knowing the value of any one of the observations will allow us to determine the value of the other. On the other hand, if the covariance is zero, then knowing the value of one observation does not in any way inform us about the other.

2.3 File Format and Structure

The files are in Network Common Data Form, version 4 (netCDF4/HDF5) format.

The product format takes advantage of the netCDF4 data model and makes use of groups, dimensions, variables and attributes to fully describe the science data.

2.4 Metadata

Every effort has been made to ensure that metadata conforms to the Climate and Forecasting (CF), Version 1.6, and Attribute Conventions for Data Discovery (ACDD), Version 1.3, guidelines.

See the full product specifications in Appendix B.

For more information on CF, refer to:
http://cfconventions.org/

For more information on ACDD, refer to:
http://wiki.esipfed.org/index.php?title=Category:Attribute_Conventions_Dataset_Discovery

2.5 File Naming Convention

File names for SSDF CONUS surface products are composed of tokens separated by the delimiter '.'. They have the form:

SNDR.SS1330.IMSS.yyyymmdd.D01.L3_CONUS_SSDF_AQSN.std.vmm_mm_mm.F.ttttttttttt.nc
and
SNDR.AIRS.AQUA.yyyymmdd.D01.L3_CONUS_SSDF.std.vmm_mm_mm.F.ttttttttttt.nc
where:

SNDR.SS1330.IMSS and SNDR.AIRS.AQUA identify the project, platform and instrument for the multi-instrument and AIRS-only products respectively. Because SSDF uses multiple similar sounder suites on multiple platforms in similar orbits, we use "SS1330" (Sun-synchronous 13:30) as the generic platform and "IMSS" (IR-MW Sounder Suite) as the generic instrument suite.

yyyymmdd is the year/month/day of the data.

D01 tags this as a 1-day product.

L3_CONUS_SSDF_VPD is the processing level (L3_CONUS) and product type (SSDF_VPD) for products made only from Aqua data.

L3_CONUS_SSDF_VPD_AQSN is the processing level (L3_CONUS) and product type (SSDF_VPD) and platform combination ("AQ" = Aqua + "SN" = SNPP) for products made with data from Aqua and SNPP.

std is for standard product

vmm.mm.mm is the product version. "v" is the literal character 'v'. It is followed by three pairs of numbers separated by "_"s. These are the major & minor version numbers.

- Version 2 SSDF Level-3 products are v02_42_00.

F is processing facility ID:

"G" for NASA GSFC GES DISC official archival system

"J" for NASA Sounder SIPS JPL operational data system or Sounder SIPS provided

"A" for NASA JPL AIRS processing

ttttttttttt is run tag (00000000000 - 99999999999).

This field is designed to ensure file names are unique, even when the same software is used to reprocess the same data. It is local processing time as yymmddhhmmss. (year, month, day, hour, minute, second).

.nc is the filetype extension for all netCDF products

Example Filename: Daily Fusion Level-3 product for January 1, 2012:

SNDR.SS1330.IMSS.20120101.D01.L3_SSDF_VPD.std.v02_42_00.J.202203041145.nc

2.6 Time Representation

Observation times are provided in both UTC and TAI93 representations as a convenience to users.

Coordinated Universal Time (UTC) is the international standard for representation of time. UTC times are expressed in human-readable form, as a set of values indicating year, month, day, hour and so on. In the data stream received from the satellite, observation times are represented as UTC.

Timestamps in product filenames and attributes are represented as UTC and formatted according to the "ISO 8601:2004" standard. For example, the time January 25, 2016 at 13:00 may be represented as either of the following:

2016-01-25T13:00Z
20160125T1300

The longer form is used in attributes, and the more compact form is used in filenames. The character "Z" indicates "Zulu time", or UTC.

International Atomic Time (TAI) is expressed as number of seconds elapsed on the surface of the Earth since some reference UTC time. The term "TAI93" indicates that the reference time is the beginning of the year 1993, or 1993-01-01T00:00:00Z. This reference time was chosen to be consistent with data products from other instruments, and to allow for precise representation of times spanning the expected mission length.

3.0 Data Content

The Level-3 data products are written in netCDF4 format and therefore makes use of groups, dimensions, variables and attributes (global & variable). Every netCDF4 file contains, at a minimum, one root group which is unnamed.

A full profile of the contents of the files is included in Appendix B.

Selected fields are highlighted in this section.

3.1 Dimensions

Key dimensions.

Table 3.1 Key Dimensions

Name	**Size**	**Description**
orbit_pass	2	orbit pass: {Ascending, Descending}
lon	245	¼ -degree longitude grid
lat	101	¼ -degree latitude grid

3.2 Global Attributes (metadata)

There are two types of attributes: global & variable. In this section we will talk about global attributes. Global attributes, sometimes referred to as 'file-level attributes', provide information about the entire file. This includes observation times, publisher and creator information, and data provenance. Many attributes are required to conform to the CF & ACDD standards while other attributes are written for consistency with legacy products.

A full definition of the global attributes can be found in Appendix B.

Table 3.2.2 Key Global Attributes

Name	Description
date_created	The date on which this version of the data was created
identifier_product_doi	digital signature (DOI)

3.3 Variable Attributes

Each variable has its own associated attributes. Variable attributes are a CF standard and are used to describe the variable in more detail to properly interpret its value.

Table 3.3: Variable Attributes

Attribute	Description
units	units, for variables that represent physical quantities
_FillValue	a single sentinel value indicating the data point contains fill instead of valid data
standard_name	standard name from the CF standard name table, if one exists for the quantity being represented
long_name	a longer name describing the quantity being represented, suitable for a plot title
description	a longer description of the quantity being represented
valid_range	a pair of values indicating the minimum and maximum values to be considered valid
coordinates	a space-separated list of the names of other variables that are coordinates for this variable
coverage_content_type	ACDD/ISO field categorizing types of data: • image • thematicClassification • physicalMeasurement • auxillaryInformation • coordinate • modelResult • qualityInformation • referenceInformation https://wiki.esipfed.org/Concepts_Glossary#Coverage_Content_Type
ancillary_variables	a space-separated list of the names of other variables that contain information about this variable
bounds	defines the extent, for cell variables including obs_time_tai93, lon, lat, and cld_pres_lay
cell_methods	describes statistical methods used to derive data, for cell variables

3.4 Group Structure

One feature which was added to netCDF4 is the ability to structure files with "groups", which are similar to a directory hierarchy. SounderCDF files are designed so that all of the most commonly needed information is contained in "/", the root group. Subgroups contain more specialized information.

These products do not use a group structure. All variables are in the root group.

3.5 Geolocation

These products use a simple latitude/longitude ¼x¼ degree grid covering the area of the continental United States (CONUS).

The values represent point values, not means over a ¼x¼ degree box.

Longitudes run from -125 to -64 degrees East, while Latitudes run from 25 to 50 degrees North.

3.6 Science Data Variables

Each product type contains only one key science variable and the corresponding standard error.

Key science data fields are defined below. See Appendix B for a full listing of all variables.

Table 3.6 Key Science Data Variables

Name	Dimensions	Description	Units
surf_h2o_vap_pres_deficit	orbit_pass, lat, lon	Vapor pressure deficit (~2 meters above surface)	Pa
surf_h2o_vap_pres_deficit_stderr	orbit_pass, lat, lon	Vapor pressure deficit one-sigma standard error (~2 meters above surface)	Pa
num_obs_aqua	orbit_pass	Number of L2 retrievals used from Aqua. Less than 1,000 is considered low, use with caution.	1
num_obs_snpp	orbit_pass	Number of L2 retrievals used from Suomi NPP. Less than 1,000 is considered low, use with caution.	1

See Appendix A for some images made from these variables.

3.7 Key supporting information variables for profiles

These variables provide supporting information to interpret the science variables.

Name	Type	Dimensions	Description	Units
lon	float32	lon	Degrees longitude (1/4-degree cell size)	degrees_east
lat	float32	lat	Degrees latitude (1/4-degree cell size)	degrees_north
orbit_pass	float32	orbit_pass	Nominal solar time when the spacecraft passes over the equator. Orbit pass bounds are defined by closest approach of the spacecraft to the poles.	hours

3.8 Missing Data / Fill Values

Fill values are used where there is no valid data, including profiles level with pressures greater than the surface pressure. The fill value is indicated by the attribute '_FillValue'. It is advised to check the data for fill values before it is used. The fill values per variable datatype are listed in the table below.

Table: 3.8.1 Fill Values

Variable Type	Fill Value
unsigned 8-bit integer	255UB
unsigned 16-bit integer	65535US
unsigned 32-bit integer	4294967295U
floating point	9.96921e+36

4.0 Options for Reading the Data

The product files are written in netCDF4/HDF5. Because netCDF4 builds upon the classic netCDF data model using HDF5 as the storage layer, a user of the data product can take full advantage of tools and libraries readily available to access the data.

Every netCDF4 file is considered an HDF5 file, however, not every HDF5 file is necessarily a netCDF4 file. A limited subset of the HDF5 data model and file format features are used in netCDF4 files. Conformance to the earlier mentioned CF & ACDD standards allows for users to take advantage of most netCDF interfaces.

Tools and libraries for reading netCDF4 as well as a netCDF Users' Guide are written and maintained by Unidata and can be found online at:

http://www.unidata.ucar.edu/software/netcdf/

Panoply and Python are good tools for visualizing these files. A useful Python package for reading these files is Xarray. See Appendix A for images generated using Panoply and Python with this product. https://www.giss.nasa.gov/tools/panoply/

There are a number of interfaces available for reading netCDF for different programming languages including: C/C++, Fortran, Matlab, IDL, Python and Perl.

The files can also be accessed with HDF5 tools and libraries available at:
https://www.hdfgroup.org/products/hdf5_tools/

An example to read data in Matlab:

```
lat = ncread(fname,'lat');

lon = ncread(fname,'lon');

surf_h2o_vap_pres_deficit = ncread(fname,'surf_h2o_vap_pres_deficit');

surf_h2o_vap_pres_deficit_stderr = ncread(fname,'surf_h2o_vap_pres_deficit_stderr');
```

5.0 Data Services

The product is available to the user community via the Goddard Distributed Active Archive Center (GDAAC). https://disc.gsfc.nasa.gov/
Data at the GDAAC is organized by unique shortnames and version numbers.

shortname_version	Description
Products described in this document	
SNDR13IML3SSDFCVPD_2	SSDF Level-3 CONUS fused Vapor Pressure Deficit V2
SNDRAQIL3SSDFCVPD_2	SSDF Level-3 CONUS AIRS-only Vapor Pressure Deficit V2
Input datasets at GDAAC	
SNDRSNIML2CCPRETN_2	Normal Spectral Resolution: Atmosphere, cloud and surface geophysical state V2
AIRS2SUP_007	AIRS Science-team Level-2 Infrared-only retrieved product

6.0 References

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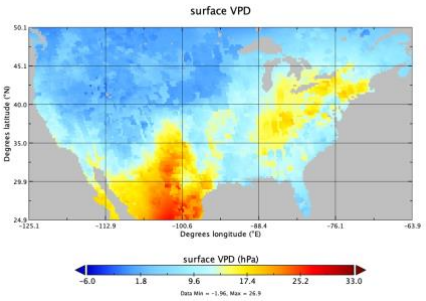
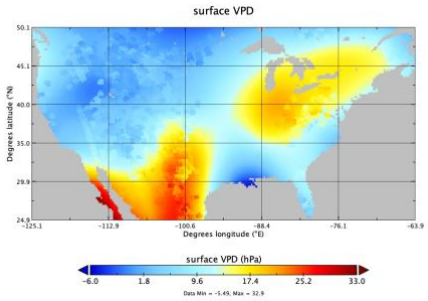
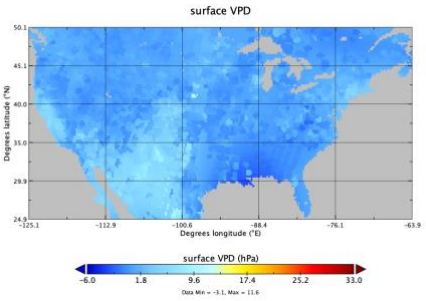
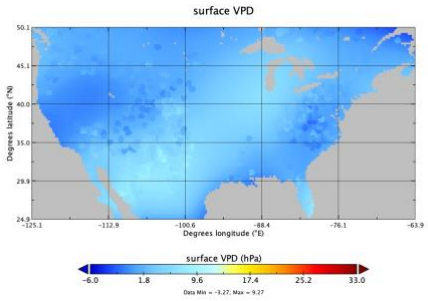
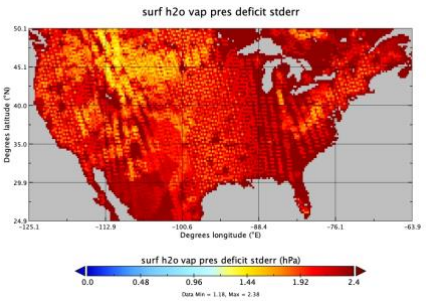
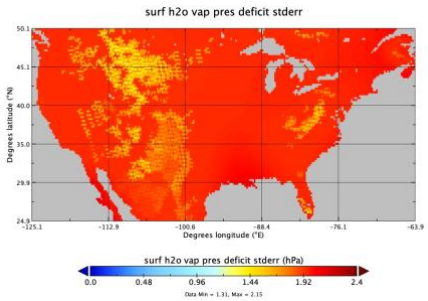
Smith and Barnet, 2019. Uncertainty Characterization and Propagation in the Community Long-Term Infrared Microwave Combined Atmospheric Product System (CLIMCAPS), CLIMCAPS Level-2 ATBD
https://docserver.gesdisc.eosdis.nasa.gov/public/project/SNPP/SNPP_limited_edition/SNPP.CrIMSS.CLIMCAPS_V2.ATBD.pdf

Wang et al., 2020. Testing Report on S-NPP CrIMSS Level 2 Water Vapor and Temperature Vertical Profiles by the Community Long-term Infrared Microwave Coupled Atmospheric Product System (CLIMCAPS).
https://docserver.gesdisc.eosdis.nasa.gov/public/project/Sounder/CLIMCAPS.V2.Test.Report.SNPP.JPSS1.pdf

Eaton et al. NetCDF Climate and Forecast (CF) Metadata Conventions, Version 1.7,
http://cfconventions.org/Data/cf-conventions/cf-conventions-1.7/cf-conventions.html

Appendix A: Sample images

These Vapor Pressure Deficit images for 2020-11-09 were generated with the **Panoply** visualization tool. See Section 4 for the link for obtaining and installing Panoply.

2020-11-09 SSDF CONUS VPD		
	Fused Aqua and S-NPP	**Aqua-Only**
Day VPD		
Night VPD		
Day VPD standard error		

Appendix B: Detailed file formats

These tables show all of the dimensions, global attributes, and variables in the SDF L3 CONUS VPD products.

A few global attributes differ between the Fused and AIRS-only versions of the SSDF VPD products. These are shown as split cells in the "Values" column of the Global Attributes table below, with the value for the fused product shown on the top and the AIRS-Only product below

For clarity, some variable attributes are omitted, including long_name, standard_name, coverage_content_type, axis, valid_range, coordinates, and _FillValue.

To get a complete listing including all variable attributes, apply "ncdump -h" to any netCDF4 product file.

L3 CONUS SSDF VPD Interface Specification

Interface Specification Version v02.02.29
05-10-2022

Groups

Path	Description
/	Main science data

Global Dimensions

Name	Size	Description
utc_tuple	8	parts of UTC time: year, month, day, hour, minute, second, millisec, microsec
orbit_pass	2	orbit pass: {Ascending/Day, Descending/Night}
lon	245	1/4-degree longitude grid covering CONUS
lat	101	1/4-degree latitude grid covering CONUS

Global Variables

Name	Type	Dimensions	Description	Units
lon	float32	lon	Degrees longitude	degrees_east
lat	float32	lat	Degrees latitude	degrees_north
utc_tuple_lbl	string	utc_tuple	names of the elements of UTC when it is expressed as an array of integers	

Name	Type	Dimensions	Description	Units
			year,month,day,hour,minute,second,millisecond, microsecond	
surf_h2o_vap_pres_deficit	float32	orbit_pass, lat, lon	Near-surface water vapor saturation pressure deficit	Pa
surf_h2o_vap_pres_deficit_stderr	float32	orbit_pass, lat, lon	surf_h2o_vap_pres_deficit one-sigma standard error	Pa
obs_time_utc	uint16	orbit_pass, utc_tuple	Nominal midtime for observations included in grid as an array of integers: year, month, day, hour, minute, second, millisec, microsec	
orbit_pass	float32	orbit_pass	Nominal solar time when the spacecraft passes over the equator. Orbit pass bounds are defined by closest approach of the spacecraft to the poles.	hours
obs_time_tai93	double	orbit_pass	Nominal midtime for observations included in grid	seconds since 1993-01-01 00:00
num_obs_aqua	unint32	orbit_pass	Number of L2 retrievals used from Aqua. Less than 1,000 is considered low, use with caution.	unitless
num_obs_snpp	unint32	orbit_pass	Number of L2 retrievals used from Suomi NPP. Less than 1,000 is considered low, use with caution.	unitless

Global Attributes

Name	Type	Size	Value	Description
keywords	string	1	ATMOSPHERE > ATMOSPHERIC WATER VAPOR > WATER VAPOR INDICATORS > VAPOR PRESSURE	A comma-separated list of key words and/or phrases. Keywords may be common words or phrases, terms from a controlled vocabulary (GCMD is often used), or URIs for terms from a controlled vocabulary (see also "keywords_vocabulary" attribute).
Format	string	1	netCDF	Format of the data, e.g., HDF-EOS5 or netCDF.
Conventions	string	1	CF-1.6, ACDD-1.3	A comma-separated list of the conventions that are followed by the dataset.
history	string	1		Provides an audit trail for modifications to the original data. This attribute is also in the NetCDF Users Guide: 'This is a character array with a line for each invocation of a program that has modified the dataset. Well-behaved generic netCDF applications should append a line containing: date, time of day, user name, program name and command arguments.' To include a more complete description you can append a reference to an ISO Lineage entity; see NOAA EDM ISO Lineage guidance.
source	string	1	AIRS and CrIS instrument telemetry	The method of production of the original data. If it was model-generated, source should name the model and its version. If it is observational, source should characterize it. This attribute is defined in the CF Conventions. Examples: 'temperature from CTD #1234'; 'world model v.0.1'.
			AIRS instrument telemetry	
processing_level	string	1	3	A textual description of the processing (or quality control) level of the data.
product_name_type_id	string	1	L3_CONUS_SSDF_VPD_AQSN	

Name	Type	Size	Value	Description
			L3_CONUS_SSDF_VPD	Product name as it appears in product_name (L1A, L1B, L2, SNO_AIRS_CrIS)
comment	string	1		Miscellaneous information about the data or methods used to produce it. Can be empty.
acknowledgment	string	1	Support for this research was provided by NASA.	A place to acknowledge various types of support for the project that produced this data.
license	string	1	Limited to Sounder SIPS affiliates	Provide the URL to a standard or specific license, enter "Freely Distributed" or "None", or describe any restrictions to data access and distribution in free text.
standard_name_vocabulary	string	1	CF Standard Name Table v28	The name and version of the controlled vocabulary from which variable standard names are taken. (Values for any standard_name attribute must come from the CF Standard Names vocabulary for the data file or product to comply with CF.) Example: 'CF Standard Name Table v27'.
date_created	string	1	Unassigned	The date on which this version of the data was created. (Modification of values implies a new version, hence this would be assigned the date of the most recent values modification.) Metadata changes are not considered when assigning the date_created. The ISO 8601:2004 extended date format is recommended, as described in the Attribute Content Guidance section.
creator_name	string	1	Peter Kalmus	The name of the person (or other creator type specified by the creator_type attribute) principally responsible for creating this data.
creator_email	string	1	peter.m.kalmus@jpl.nasa.gov	The email address of the person (or other creator type specified by the creator_type attribute) principally responsible for creating this data.
creator_url	string	1	Unassigned	The URL of the person (or other creator type specified by the creator_type attribute) principally responsible for creating this data.
institution	string	1	NASA Jet Propulsion Laboratory	Processing facility that produced this file
project	string	1	AIRS	The name of the project(s) principally responsible for originating this data. Multiple projects can be separated by commas, as described under Attribute Content Guidelines. Examples: 'PATMOS-X', 'Extended Continental Shelf Project'.
product_name_project	string	1	SNDR	The name of the project as it appears in the file name. 'SNDR' for all Sounder SIPS products, even AIRS products.
publisher_name	string	1	Goddard Earth Science Data and Information Services Center	The name of the person (or other entity specified by the publisher_type attribute) responsible for publishing the data file or product to users, with its current metadata and format.
publisher_email	string	1	gsfc-help-disc@lists.nasa.gov	The email address of the person (or other entity specified by the publisher_type attribute) responsible for publishing the data file or product to users, with its current metadata and format.
publisher_url	string	1	http://disc.sci.gsfc.nasa.gov/	The URL of the person (or other entity specified by the publisher_type attribute) responsible for publishing the data file or product to users, with its current metadata and format.
geospatial_bounds	string	1	POLYGON ((-125.0 25.0, -64.0 25.0, -64.0 50.0, -125.0 50.0, -125.0 25.0))	Describes the data's 2D or 3D geospatial extent in OGC's Well-Known Text (WKT) Geometry format (reference the OGC Simple Feature Access (SFA) specification). The meaning and order of values for

Name	Type	Size	Value	Description
				each point's coordinates depends on the coordinate reference system (CRS). The ACDD default is 2D geometry in the EPSG:4326 coordinate reference system. The default may be overridden with geospatial_bounds_crs and geospatial_bounds_vertical_crs (see those attributes). EPSG:4326 coordinate values are latitude (decimal degrees_north) and longitude (decimal degrees_east), in that order. Longitude values in the default case are limited to the [-125, -64) range. Example: 'POLYGON ((-111.29 40.26, -111.29 41.26, -110.29 41.26, -110.29 40.26, -111.29 40.26))'.
geospatial_bounds_crs	string	1	EPSG:4326	The coordinate reference system (CRS) of the point coordinates in the geospatial_bounds attribute. This CRS may be 2-dimensional or 3-dimensional, but together with geospatial_bounds_vertical_crs, if that attribute is supplied, must match the dimensionality, order, and meaning of point coordinate values in the geospatial_bounds attribute. If geospatial_bounds_vertical_crs is also present then this attribute must only specify a 2D CRS. EPSG CRSs are strongly recommended. If this attribute is not specified, the CRS is assumed to be EPSG:4326. Examples: 'EPSG:4979' (the 3D WGS84 CRS), 'EPSG:4047'.
geospatial_lat_min	float	1	25.f	Describes a simple lower latitude limit; may be part of a 2- or 3-dimensional bounding region. Geospatial_lat_min specifies the southernmost latitude covered by the dataset.
geospatial_lat_max	float	1	50.f	Describes a simple upper latitude limit; may be part of a 2- or 3-dimensional bounding region. Geospatial_lat_max specifies the northernmost latitude covered by the dataset.
geospatial_lon_min	float	1	-125.f	Describes a simple longitude limit; may be part of a 2- or 3-dimensional bounding region. geospatial_lon_min specifies the westernmost longitude covered by the dataset. See also geospatial_lon_max.
geospatial_lon_max	float	1	-64.f	Describes a simple longitude limit; may be part of a 2- or 3-dimensional bounding region. geospatial_lon_max specifies the easternmost longitude covered by the dataset. Cases where geospatial_lon_min is greater than geospatial_lon_max indicate the bounding box extends from geospatial_lon_max, through the longitude range discontinuity meridian (either the antimeridian for -125:-64 values, or Prime Meridian for 0:360 values), to geospatial_lon_min; for example, geospatial_lon_min=170 and geospatial_lon_max=-175 incorporates 15 degrees of longitude (ranges 170 to -64 and -125 to -175).
time_coverage_start	string	1		Nominal start time. Describes the time of the first data point in the data set. Use the ISO 8601:2004 date format, preferably the extended format as recommended in the Attribute Content Guidance section.
time_of_first_valid_obs	string	1		Describes the time of the first valid data point in the data set. Use the ISO 8601:2004 date extended format.
time_coverage_mid	string	1		Describes the midpoint between the nominal start and end times. Use the ISO 8601:2004 date format, preferably the extended format as recommended in the Attribute Content Guidance section.
time_coverage_end	string	1		Nominal end time. Describes the time of the last data point in the data set. Use ISO 8601:2004 date format,

Name	Type	Size	Value	Description
				preferably the extended format as recommended in the Attribute Content Guidance section.
time_of_last_valid_obs	string	1		Describes the time of the last valid data point in the data set. Use the ISO 8601:2004 date extended format.
time_coverage_duration	string	1	P0000-00-01T00:00:00	Describes the duration of the data set. Use ISO 8601:2004 duration format, preferably the extended format as recommended in the Attribute Content Guidance section.
product_name_duration	string	1	D01	Product duration as it appears in product_name (D01 means full day)
creator_type	string	1	institution	Specifies type of creator with one of the following: 'person', 'group', 'institution', or 'position'. If this attribute is not specified, the creator is assumed to be a person.
creator_institution	string	1	Jet Propulsion Laboratory -- California Institute of Technology	The institution of the creator; should uniquely identify the creator's institution. This attribute's value should be specified even if it matches the value of publisher_institution, or if creator_type is institution.
product_version	string	1	v02.42.00	Version identifier of the data file or product as assigned by the data creator. For example, a new algorithm or methodology could result in a new product_version.
keywords_vocabulary	string	1	GCMD:GCMD Keywords	If you are using a controlled vocabulary for the words/phrases in your "keywords" attribute, this is the unique name or identifier of the vocabulary from which keywords are taken. If more than one keyword vocabulary is used, each may be presented with a prefix and a following comma, so that keywords may optionally be prefixed with the controlled vocabulary key. Example: 'GCMD:GCMD Keywords, CF:NetCDF COARDS Climate and Forecast Standard Names'.
platform	string	1	AQUA > Earth Observing System, SUOMI-NPP > Suomi National Polar-orbiting Partnership	Name of the platform(s) that supported the sensor data used to create this data set or product. Platforms can be of any type, including satellite, ship, station, aircraft or other. Indicate controlled vocabulary used in platform_vocabulary.
			AQUA > Earth Observing System	
platform_vocabulary	string	1	GCMD:GCMD Keywords	Controlled vocabulary for the names used in the "platform" attribute.
product_name_platform	string	1	SS1330	Platform name as it appears in product_name
			AQUA	
instrument	string	1	AIRS > Atmospheric Infrared Sounder, CRIMSS > Cross-track Infrared and Advanced Technology Microwave Sounders, CrIS > Cross-track Infrared Sounder, ATMS > Advanced Technology Microwave Sounder	Name of the contributing instrument(s) or sensor(s) used to create this data set or product. Indicate controlled vocabulary used in instrument_vocabulary.
			AIRS > Atmospheric Infrared Sounder	
instrument_vocabulary	string	1	GCMD:GCMD Keywords	Controlled vocabulary for the names used in the "instrument" attribute.
product_name_instr	string	1	IMSS	Instrument name as it appears in product_name
			AIRS	

Name	Type	Size	Value	Description
product_name	string	1		Canonical fully qualified product name (official file name)
product_name_variant	string	1	std	Processing variant identifier as it appears in product_name. 'std' (shorthand for 'standard') is to be the default and should be what is seen in all public products.
product_name_version	string	1	vxx_xx_xx	Version number as it appears in product_name (v01_00_00)
product_name_producer	string	1	J	Production facility as it appears in product_name (single character) 'T' is the default, for unofficial local test products
product_name_timestamp	string	1	yymmddhhmmss	Processing timestamp as it appears in product_name (yymmddhhmmss)
product_name_extension	string	1	nc	File extension as it appears in product_name (typically nc)
gran_id	string	1	yyyymmdd	Unique granule identifier yyyymmdd of granule start day, including year, month, and day of granule start time
featureType	string	1	point	structure of data in file
data_structure	string	1	grid	a character string indicating the internal organization of the data with currently allowed values of 'grid', 'station', 'trajectory', or 'swath'. The 'structure' here generally describes the horizontal structure and in all cases data may also be functions, for example, of a vertical coordinate and/or time. (If using CMOR pass this in a call to cmor_set_cur_dataset_attribute.)
cdm_data_type	string	1	Grid	The data type, as derived from Unidata's Common Data Model Scientific Data types and understood by THREDDS. (This is a THREDDS "dataType", and is different from the CF NetCDF attribute 'featureType', which indicates a Discrete Sampling Geometry file in CF.)
id	string	1	10.5067/55EOWAJ669WC 10.5067/4RE39DE0GLVE	An identifier for the data set, provided by and unique within its naming authority. The combination of the "naming authority" and the "id" should be globally unique, but the id can be globally unique by itself also. IDs can be URLs, URNs, DOIs, meaningful text strings, a local key, or any other unique string of characters. The id should not include white space characters.
naming_authority	string	1	http://dx.doi.org/	The organization that provides the initial id (see above) for the dataset. The naming authority should be uniquely specified by this attribute. We recommend using reverse-DNS naming for the naming authority; URIs are also acceptable. Example: 'edu.ucar.unidata'.
identifier_product_doi	string	1	10.5067/55EOWAJ669WC 10.5067/4RE39DE0GLVE	digital signature
identifier_product_doi_authority	string	1	http://dx.doi.org/	digital signature source
algorithm_version	string	1		The version of the algorithm in whatever format is selected by the developers. After the main algorithm name and version, versions from multiple sub-algorithms may be concatenated with semicolon separators. (ex: 'CCAST 4.2; BB emis from MIT 2016-04-01') Must be updated with every delivery that changes numerical results.

Name	Type	Size	Value	Description
production_host	string	1		Identifying information about the host computer for this run. (Output of linux "uname -a" command.)
format_version	string	1	v02.02.29	Format version.
input_file_names	string	1		Semicolon-separated list of names or unique identifiers of files that were used to make this product. There will always be one space after each semicolon. There is no final semicolon.
input_file_types	string	1		Semicolon-separated list of tags giving the role of each input file in input_file_names. There will always be one space after each semicolon. There is no final semicolon.
input_file_dates	string	1		Semicolon-separated list of creation dates for each input file in input_file_names. There will always be one space after each semicolon. There is no final semicolon.
AutomaticQualityFlag	string	1	Missing	"Passed": the granule contains a non-degraded calibrated brightness temperature, radiance, or retrieved value for at least one value in a geolocated FOV; "Suspect": the granule does not qualify as "Passed" but contains a (possibly degraded) calibrated or retrieved value (possibly without associated geolocation); "Failed": the granule contains no calibrated or retrieved values.
qa_no_data	string	1	TRUE	A simple indicator of whether this is an "empty" granule with no data from the instrument. "TRUE" or "FALSE".
title	string	1	Spatial Statistical Data Fusion (SSDF) Level 3: CONUS Near-Surface Water Vapor Pressure Deficit (VPD) from SNPP CrIMSS and Aqua AIRS Spatial Statistical Data Fusion (SSDF) Level 3: CONUS Near-Surface Water Vapor Pressure Deficit (VPD) from Aqua AIRS	a succinct description of what is in the dataset. (= ECS long name)
summary	string	1	The SSDF Level-3 Fused Near-Surface Water Vapor Pressure Deficit daily product includes VPD generated by fusing retrieved values from AIRS and SNPP CrIMSS. The SSDF Level-3 AIRS-Only Near-Surface Water Vapor Pressure Deficit daily product includes VPD generated by applying the SSDF algorithm including bias-correction to AIRS IR-only L2 retrievals.	A paragraph describing the dataset, analogous to an abstract for a paper.
shortname	string	1	SNDR13IML3SSDFCVPD SNDRAQIL3SSDFCVPD	ECS Short Name
metadata_link	string	1	http://disc.sci.gsfc.nasa.gov/	A URL that gives the location of more complete metadata. A persistent URL is recommended for this attribute.
references	string	1	Nguyen, Hai, Noel Cressie, and Amy Braverman. (2012). Spatial Statistical Data Fusion for Remote Sensing Applications. JASA. Journal of the	ATDB and design documents describing processing algorithms. Can be empty.

Name	Type	Size	Value	Description
			American Statistical Association. 107. 10.1080/01621459.2012.694717.	
contributor_name	string	1	Peter Kalmus; Hai Nguyen	The names of any individuals or institutions that contributed to the creation of this data.
contributor_role	string	1	Product Developer; Algorithm Developer	The roles of any individuals or institutions that contributed to the creation of this data.