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

NASA CLIMCAPS Level 3 Data Product User Guide: File Format and Definition

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Version 2.0

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Revision History

Document Version	***Software Version***	***Revision Date***	***Changes***
1	1.03	2019-08-28	Initial Release
2	2.0	2021-04	Addition of JPSS-1 Addition of Aqua Addition of Appendix A: Test Results

1.0 Introduction

This document provides basic information for using Version 2 Level-3 products from the Community Long-term Infrared Microwave Coupled Atmospheric Product System (CLIMCAPS).

The products described in this document are derived from Infrared/Microwave (IR/MW) sounder suites:

1) The Cross-track Infrared and Microwave Sounding Suite (CrIMSS) instruments on the Suomi-National Polar-Orbitting Partnership (S-NPP) and NOAA-20 / Joint Polar Satellite System (JPSS-1) satellites.
2) Atmospheric Infrared Sounder (AIRS) and its Advanced Microwave Sounding Unit A (AMSU-A) on the Aqua satellite.

The CrIMSS instrument suite consists of the Cross-track Infrared Sounder (CrIS) infrared sounder and the Advanced Technology Microwave Sounder (ATMS) microwave sounder.

The Level-3 retrieval products contain a variety of geophysical parameters including temperature profiles, water vapor, ozone, clouds, and surface properties, all gridded 1x1 degree latitude/longitude. There are one-day and monthly products and two different quality control strategies. These products have been annotated with both file and variable level attributes to fully describe their contents.

1.1 Overview of Sounder SIPS

The S-NPP / JPSS Sounder SIPS, is one of six SIPSs formed by NASA to provide climate-quality products by processing of level 0 data through level 1, level 2 and level 3 from the Suomi NPP (previously known as NPP) satellite and the NOAA-20 / JPSS-1 satellite. The Sounder SIPS is specifically responsible for producing atmospheric sounding products from the CrIMSS instrument suite and continuity products from the corresponding AIRS/AMSU-A instrument suite on the EOS-Aqua platform.

The S-NPP Sounder SIPS is a team made up of the Jet Propulsion Laboratory (JPL) and the Goddard Earth Sciences Data and Information Services Center (GES DISC). JPL provides the overall project management, science algorithm software integration, test and validation support. The GES DISC performs level 0 data acquisition and routine data processing operations. The GES DISC / Distributed Active Archive Center and distribution of the data products and associated documentation.

1.2 Mission Description

Hyperspectral IR/MW sounder suites use the complementary sensing abilities of hyperspectral IR sounding instruments and MW sounding to retrieve atmospheric conditions. A series of these instrument suites on platforms in similar 1:30 PM sun-synchronous orbits provide information on the atmospheric state for weather prediction and collectively provide a climate record from 2003. Infrared (IR) and microwave (MW) sounders are designed to be used together as IR/MW sounding suites. The retrieval algorithm combines IR data from AIRS or CrIS with MW data from AMSU-A or ATMS in a single IR+MW retrieval.

An atmospheric sounder measures how the physical properties of a column of air vary with altitude. The measurement as a function of altitude is sometimes called a “profile”, a “sounding”, or a “retrieval”. The term "sounder" refers to measuring how the temperature and salinity are similarly measured in the ocean using sound waves. “Retrieval” refers to using a computer algorithm to extract the profile from the measured data.

The hyperspectral IR instruments measure the upwelling spectrum in the infrared emitted from the Earth's surface and absorbed and emitted from the atmosphere's constituents. Each infrared wavelength, or channel in the IR instrument, is sensitive to different atmospheric constituents corresponding to a range of heights in the atmosphere depending on the degree of absorption of that constituent. Temperature profiles are produced by measuring CO_2 absorption features with varying degrees of absorption; channels with little absorption see closer to the surface, while channels with high absorption see higher in the atmosphere. Water vapor profiles use H_2O absorption features in a similar way. The CLIMCAPS retrieval uses an instrument-specific set of channels to create a profile with altitude, or sounding of the atmosphere. This is called a “retrieval.” MW sounding instruments contribute information on precipitation and surface type, and also help with cloud clearing because they see through non-precipitating clouds.

The Aqua satellite was launched on May 4, 2002 into a polar sun-synchronous orbit. You can see the orbital parameters in Table 1.2.1 below. AIRS and AMSU-A are 2 of 6 instruments onboard the Aqua satellite. The other operating instruments are: Clouds and the Earth's Radiant Energy System (CERES), Moderate Resolution Imaging Spectroradiometer (MODIS) and Advanced Microwave Scanning Radiometer – Earth Observing System (AMSR-E). Details about the Aqua Mission can be found at: https://airs.jpl.nasa.gov/

The S-NPP satellite was launched on October 28, 2011 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. SNPP is the bridge between NASA's Earth Observing System and the Joint Polar Satelite System (JPSS) and is a result of a partnership between NOAA, NASA and the Department of Defense (DoD). SNPP is the first in a series of five next generation U.S. weather satellites of the 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).

The NOAA-20 / JPSS-1 satellite was launched on November 18, 2017 from Vandenburg Air Force Base in California with similar orbital parameters and instruments as S-NPP. It is the second of 5 planned satellites of the JPSS. As is practice with NOAA when a satellite has successfully reached orbit, completed all on-orbit checkouts and is declared 'operational' it is renamed to follow the naming of NOAA satellites. JPSS-1 was renamed to NOAA-20 on May 30, 2018. The satellite will be referred to as JPSS-1 or J1 in this document.

More information about both the S-NPP and JPSS Missions can be found at: https://www.nasa.gov/mission_pages/NPP and https://www.jpss.noaa.gov/, respectively

Table 1.2.1 contains a summary of orbital platform parameters.

Table 1.2.1 Approximate Aqua, S-NPP and JPSS-1 orbital parameters

Platform	Alt (km)	Orbit Incl. (°)	Equator X Time	Period (mins)	Repeat Orbits	Repeat Days	Launch
Aqua	705	98.2	13:30	98.8	233	16	04 May 2002
S-NPP	824	98.7	13:30	101	228	16	28 Oct 2011
NOAA-20 / JPSS-1	824	98.7	13:30	101	228	16	18 Nov 2017

1.3 AIRS Instrument Description

AIRS is a cross-track scanning instrument. A scan mirror rotates around an axis along the line of flight and directs infrared energy from the Earth into the instrument. As the spacecraft moves along, this mirror sweeps the ground creating a scan 'swath' that extends roughly 800 km on either side of the ground track. Between Earth scans, the scan mirror also allows the instrument to view various calibration sources. The scan mirror provides ±49.5° (from nadir) Earth coverage along with views to space and to on-board spectral and radiometric calibration sources every scan cycle. The AIRS scan mirror rotates 360° every 8/3 of a second (2.667 seconds), so that AIRS does three scans for every 8-second AMSU-A scan.

1.4 AMSU-A Instrument Description

AMSU-A, part of the AIRS Project Instrument Suite, is a microwave temperature sounder implemented as two independently operated modules. AMSU-A also measures surface and moisture information. AMSU-A is one of a series of similar instruments. Aerojet (now part of Northrop Grumman) built AMSU-A.

AMSU-A has a total of 15 channels:

- Module 2 (AMSU-A2) has 2 channels (23.8 GHz and 31.4 GHz, numbered 1-2) providing surface and moisture information (total precipitable water and cloud liquid water).
- Module 1 (AMSU-A1) has 12 channels (numbered 3-14) in the 50-58 GHz oxygen absorption band, providing the primary temperature sounding capability.

- Module 1 also has 1 channel at 89 GHz (numbered 15) providing surface and moisture information

Like AIRS, AMSU-A is a cross-track scanner. The three receiving antennas, two for AMSU-A1 and one for AMSU-A2, are parabolic focusing reflectors that rotate to scan.

AMSU-A scans once per 8 seconds, three times more slowly than AIRS. The footprints are approximately three times as large in diameter as those of AIRS (45 km at nadir). This results in three AIRS scans per AMSU-A scan and nine AIRS footprints per AMSU-A footprint.

1.4.1 AMSU-A status as of 2021

- channels 3, 8, 10-13, and 15 are working well
- channels 1, 2, 4, and 5 are no longer usable
- channels 6, 7, 9, and 14 function but have noise issues.

In order to be able to process data after the 2016 failure of AMSU-A2, CLIMCAPS Aqua v2 is also processed in an IR-Only mode. See section 2.8.

1.5 Data Disclaimer

Version 2.0 CLIMCAPS CrIMSS and AIRS/AMSU-A Level-3 data are released to the public as is. Every effort has been made to properly represent the data which this document describes.

All users are encouraged to read the appropriate documentation listed in the references related to these data products to further understand the contents.

Attention should be given to quality flags and fill values before being used for any analysis or higher processing of the product.

1.6 Where to find the Product

The CLIMCAPS Level-3 products can be found at and downloaded from the NASA GES DISC. First time users are asked to register and create an EARTHDATA login account to access the GES DISC collections. There you will find additional information and documentation about this product and other products of interest. The preferred method to locate a data collection is via the unique Digital Object Identifier (DOI) link [see Table 1.6].

Alternatively, users can enter the ShortName from the table below directly into the GES-DISC search string to quickly find CLIMCAPS level 3 products. The data at the GES DISC is organized by unique versioned ShortNames. Also, a general search using the string “CLIMCAPS” under Data Collections will take to you a listing of CLIMCAPS products.

NASA GES-DISC URL: https://disc.gsfc.nasa.gov

Table 1.6 ECS ShortName and DOIs

ECS ShortName	DOI	Title
SNPP		
SNDRSNIML3CDCCPN	10.5067/1RA8NH5L19QB	Sounder SIPS: Suomi NPP CrIMSS Level 3 Comprehensive Quality Control Gridded Daily CLIMCAPS Normal Spectral Resolution V2
SNDRSNIML3CMCCPN	10.5067/CPKN9PVSSL1H	Sounder SIPS: Suomi NPP CrIMSS Level 3 Comprehensive Quality Control Gridded Monthly CLIMCAPS Normal Spectral Resolution V2
SNDRSNIML3SDCCPN	10.5067/HRSFWSRE4IWV	Sounder SIPS: Suomi NPP CrIMSS Level 3 Specific Quality Control Gridded Daily CLIMCAPS Normal Spectral Resolution V2
SNDRSNIML3SMCCPN	10.5067/C0RELPJG8BYW	Sounder SIPS: Suomi NPP CrIMSS Level 3 Specific Quality Control Gridded Monthly CLIMCAPS Normal Spectral Resolution V2
SNDRSNIML3CDCCP	10.5067/L98ZW61HG7TI	Sounder SIPS: Suomi NPP CrIMSS Level 3 Comprehensive Quality Control Gridded Daily CLIMCAPS Full Spectral Resolution V2
SNDRSNIML3CMCCP	10.5067/LPZQT2UE6S0F	Sounder SIPS: Suomi NPP CrIMSS Level 3 Comprehensive Quality Control Gridded Monthly CLIMCAPS Full Spectral Resolution V2
SNDRSNIML3SDCCP	10.5067/MM7Q3G0Y7URR	Sounder SIPS: Suomi NPP CrIMSS Level 3 Specific Quality Control Gridded Daily CLIMCAPS Full Spectral Resolution V2
SNDRSNIML3SMCCP	10.5067/IHHLJSPI5W3O	Sounder SIPS: Suomi NPP CrIMSS Level 3 Specific Quality Control Gridded Monthly CLIMCAPS Full Spectral Resolution V2

JPSS-1		
SNDRJ1IML3CDCCP	10.5067/111ANV0FK5CY	Sounder SIPS: JPSS-1 CrIMSS Level 3 Comprehensive Quality Control Gridded Daily CLIMCAPS V2
SNDRJ1IML3CMCCP	10.5067/8H55OE9ZUJZ0	Sounder SIPS: JPSS-1CrIMSS Level 3 Comprehensive Quality Control Gridded Monthly CLIMCAPS V2
SNDRJ1IML3SDCC	10.5067/1L6PHQX2VYH3	Sounder SIPS: JPSS-1 CrIMSS Level 3 Specific Quality Control Gridded Daily CLIMCAPS V2
SNDRJ1IML3SMCCP	10.5067/0X6PTK8V19M8	Sounder SIPS: JPSS-1 CrIMSS Level 3 Specific Quality Control Gridded Monthly CLIMCAPS V2
Aqua		
SNDRAQIML3CDCCP	10.5067/MAIIRGMT0JPH	Sounder SIPS: AQUA AIRS IR + MW Level 3 CLIMCAPS : Comprehensive Quality Control Gridded Daily V2
SNDRAQIML3SDCCP	10.5067/1J4UCYY49IW4	Sounder SIPS: AQUA AIRS IR + MW Level 3 CLIMCAPS : Specific Quality Control Gridded Daily V2
SNDRAQIL3CDCCP	10.5067/BZBSA32DWAPN	Sounder SIPS: AQUA AIRS IR-only Level 3 CLIMCAPS : Comprehensive Quality Control Gridded Daily V2
SNDRAQIL3SDCCP	10.5067/47IB56XWPHB3	Sounder SIPS: AQUA AIRS IR-only Level 3 CLIMCAPS : Specific Quality Control Gridded Daily V2
SNDRAQIML3CMCCP	10.5067/RXHQI7P4AGIL	Sounder SIPS: AQUA AIRS IR + MW Level 3 CLIMCAPS : Comprehensive Quality Control Gridded Monthly V2
SNDRAQIML3SMCCP	10.5067/I9AJNY3T70UC	Sounder SIPS: AQUA AIRS IR + MW Level 3 CLIMCAPS : Specific Quality Control Gridded Monthly V2
SNDRAQIL3CMCCP	10.5067/ZPZ430KOPMIX	Sounder SIPS: AQUA AIRS IR-only Level 3 CLIMCAPS : Comprehensive Quality Control Gridded Monthly V2
SNDRAQIL3SMCCP	10.5067/9UYH1Z35DOC8	Sounder SIPS: AQUA AIRS IR-only Level 3 CLIMCAPS : Specific Quality Control Gridded Monthly V2

1.7 Contact Information

For information, questions or concerns with any of these CLIMCAPS Level-3 data sets, please send to: sounder.sips@jpl.nasa.gov or submit questions to: https://airs.jpl.nasa.gov/data/support/ask-airs

For information, questions or concerns with dataset completeness or downloading issues, please send to: gsfc-dl-help-disc@mail.nasa.gov

1.8 References

References 1 - 7 below will take you to a NASA GES-DISC landing page. To get to the actual document, please click on the 'Documentation' tab from the landing page. If links do not resolve, copy the URL into a browser. Also, application user documents offer more science content about trace gases and go into a little more detail about additional sensors CLIMCAPS supports.

1. NASA SNPP Cross Track Infrared Sounder (CrIS) Level 1B Product Users' Guide https://www.doi.org/10.5067/9NPOTPIPLMAW

2. NASA SNPP Cross Track Infrared Sounder (CrIS) Level 1B Quality Flags Description Document https://www.doi.org/10.5067/9NPOTPIPLMAW

3. NASA Advanced Technology Microwave Sounder (ATMS) Level 1B Data Product User Guide https://www.doi.org/10.5067/HFDD6A30MA10

4. CLIMCAPS Level-2 ATBD Uncertainty Characterization and Propagation in the Community Long-Term Infrared Microwave Combined Atmospheric Product System (CLIMCAPS) https://www.doi.org/10.5067/9HR0XHCH3IGS

5. NASA CLIMCAPS Level-2 Products User Guide: File Format and Definition https://www.doi.org/10.5067/9HR0XHCH3IGS

6. Test Report of Performance of CLIMCAPS-SNPP and CLIMCAPS-JPSS1 Retrievals https://disc.gsfc.nasa.gov/datasets/SNDRSNIML2CCPRETN_2/summary

7. Version 2 CLIMCAPS-Aqua Retrieval Product Performance Test Report https://www.doi.org/10.5067/JZMYK5SMYM86

8. AIRS on-line Documentation Page: https://disc.gsfc.nasa.gov/information/documents?title=AIRS%20Documentation

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

10. MERRA-2 https://gmao.gsfc.nasa.gov/reanalysis/MERRA-2/

11. NASA Data Processing Levels https://earthdata.nasa.gov/collaborate/open-data-services-and-software/data-information-policy/data-levels

12. AIRS Level-2 Science team Status of CLIMCAPS https://airs.jpl.nasa.gov/system/presentations/files/381_StatusBarnet.pdf

13. Suomi-NPP: https://www.nasa.gov/mission_pages/NPP

14. Joint Polar Satellite System: https://www.jpss.noaa.gov/

2.0 Level-3 Product Overview

Level-2 products are created from the Level-1B observations using CLIMCAPS. The results are then collected into 1-day and 1-month gridded Level-3 files. The product files types described in this document are the following for both quality control " Specific" (QCS) and "Comprehensive" (QCC) :

a. Level-3 CLIMCAPS-Aqua AIRS + AMSU-A
b. Level-3 CLIMCAPS-Aqua AIRS
c. Level-3 CLIMCAPS-SNPP NSR
d. Level-3 CLIMCAPS-SNPP
e. Level-3 CLIMCAPS-JPSS-1

2.1 Product Granulation

The Level-3 products are produced for every day and for every month. Each daily file has a nominal date, but actually contains data extending beyond the boundaries of the nominal date. Data is separated by the "orbit_pass" dimension into observations taken while the spacecraft is moving northwards (ascending) and while it is moving southwards. For 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). The second element is the descending element, with data taken around 1.5 hours or 1:30 AM local time. Data is divided among days such that each orbit_pass element for each day contains data for longitudes [-180, 180], and images from successive days could be stitched together. Data in the same location for the two orbit_passes is offset by 12 hours. Variables orbit_pass, obs_time_tai93, obs_time_tai93_bnds, and obt_time_utc can help with interpretation.

Monthly Level-3 products are summaries of the data from the 28-31 daily Level-3 products in a calendar month.

2.2 Level-2 Algorithm Background

The Sounder SIPS Level-3 data products are a product of processing NASA Level 0 data through Level 1A, Level 1B, Level-2, and Level-3. For a definition of the NASA Data Processing Levels go to:
https://earthdata.nasa.gov/earth-science-data-systems-program/policies/data-information-policy/data-levels

The CLIMCAPS retrieval approach is based on the AIRS Level-2 science team algorithm design [AIRS Documentation], 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 [Reference 8] (doi:10.5067/WWQSXQ8IVFW8)

(ii) ingests and propagates two-dimensional error covariance matrices for a full accounting of algorithm, measurement and atmospheric state uncertainty. [Reference 10]

Technical details of the Level-2 processing steps and calibrations can be found in the Algorithm Theoretical Basis Document (ATBD). [Reference 4.]

2.3 Level-3 Algorithm Summary

The Level-3 daily algorithm selects which observations belong to each grid cell, determines which observations pass quality control, and averages the accepted observations.

Level-2 observations are determined to be ascending or descending according to the "asc_flag" Level-2 variable.

Although CLIMCAPS performs a Field-of-Regard (FOR) based retrieval, with only one retrieved value of most variables per FOR, the data is treated as if this value was separately observed for the central lat/lon of each of the 9 associated Fields-of-View (FOVs).

Level-2 observations are associated with a nominal date according to whether the longitude-adjusted observation time (obs_time_tai93 + 240.0 * fov_lon) is within 12 hours of the appropriate orbit_pass mean time.

Level-2 observations are associated with the 1x1 degree latitude/longitude grid cell in which the {fov_lon, fov_lat} falls.

Quality control can be either "Specific" (QCS) or "Comprehensive" (QCC). QCS products maximize yield of each individual species and level by collecting all cases where the corresponding *_qc value is 0 (best) or 1 (good). QCC products ensure analyses will be consistent across levels and species by including all cases where the whole profile is considered to be quality 0 or 1 for temperature, water vapor, etc.

Level-3 monthly products summarize the 28-31 daily products in a calendar month. The mean value from each day is weighted equally, not according to the number of observations contributing, in order to maximize representativeness.

2.4 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. See section 3.0 Data Content for a listing of key dimensions and attributes.

2.5 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 C.

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

2.6 File Naming Convention

File naming for Sounder SIPS products will be unique and include the following tokens separated by the delimiter '.' Each token that makes up the filename is also in the global attributes of the data file.

<product_name_project>.<product_name_platform>.<product_name_instr>.<gran_id>.<product_name_duration>.<product_type_name_id>.<product_name_variant>.<product_name_version>.<product_name_producer>.<product_name_timestamp>.<extension>

Where:

- product_name_project = SNDR
- product_name_platform = SNPP, J1, AQUA
- product_name_instr = CRIMSS, AIRS, AIRS_IM
- gran_id nominal start time where:
    - yyyy = year
    - mm = month of year (01-12)
    - dd = day of month (01-31)
- product_name_duration = D01 or M01 (1 day or 1 month)
- product_type_name_id =
    - L3_CLIMCAPS_QCC_NSR for CLIMCAPS products derived from CrIS NSR spectral resolution, accumulated with QCC=Comprehensive QC
    - L3_CLIMCAPS_QCS_NSR for CLIMCAPS products derived from CrIS NSR spectral resolution, accumulated with QCS=Specific QC .
    - L3_CLIMCAPS_QCC for CLIMCAPS products derived from AIRS or from CrIS FSR spectral resolution, accumulated with QCC=Comprehensive QC

    - L3_CLIMCAPS_QCS for CLIMCAPS products derived from AIRS or from CrIS FSR spectral resolution, accumulated with QCS=Specific QC .
- product_name_variant = std
- product_name_version (vmm_mm) - eg. v02_39
    - Versioning will be synchronized across Sounder SIPS products
    - Version 2 Level-2 and Level-3 products are derived from version 2 Level-1B products
- product_name_producer- G=Operations, J=SIPS at JPL, T=Test
- product_name_timestamp (yymmddhhmmss) - 150407123456
- Extension (.nc)

Example Filename: Level-3 products for January 2016:

```
SNDR.AQUA.AIRS_IM.20160131.D01.L3_CLIMCAPS_QCS.std.v02_39.G.201030232004.nc
SNDR.AQUA.AIRS.20160101.M01.L3_CLIMCAPS_QCC.std.v02_39.G.201024024822.nc
SNDR.AQUA.AIRS_IM.20160101.M01.L3_CLIMCAPS_QCC.std.v02_39.G.201028081347.nc

SNDR.SNPP.CRIMSS.20160101.M01.L3_CLIMCAPS_QCC_NSR.std.v02.39.G.190409202653.nc
SNDR.SNPP.CRIMSS.20160101.M01.L3_CLIMCAPS_QCC.std.v02.39.G.190409202653.nc
```

2.7 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.

2.8 Data Holdings

Version 2 of CLIMCAPS Level 2 collection will include the following data sets:

a) SNPP NSR data from January 20, 2012 to present
b) SNPP FSR from Nov 2, 2015 to present
c) JPSS-1/NOAA-20 from Feb 17, 2018 to present
d) Aqua AIRS+AMSU-A from August 30, 2002 to Sept 24, 2016
e) Aqua AIRS-only from August 30, 2002 to present

Note that because CLIMCAPS uses MERRA-2 as a background, the forward processing stream will always be about one month behind the present date.

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 C.

Selected fields are highlighted in this section.

3.1 Dimensions

Key dimensions for CLIMCAPS Level-3 products.

Table 3.1 Key Dimensions

Name	Size	Description
lon	360	1-degree longitude grid
lat	180	1-degree latitude grid
orbit_pass	2	orbit pass: {Ascending/Day, Descending/Night}
air_pres	100	Fine atmospheric pressure levels for temperature and most gases starting from the top
air_pres_h2o	66	Fine atmospheric pressure levels for water-vapor variables starting from the top

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 C.

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 MD_CoverageContentTypeCode
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 are the groups:

Group	Purpose
/ (root)	Main group, with temperature and water vapor profiles, along with supporting location and quality information
/nobs	The number of observations for the gridded physical quantities
/dof	Mean degrees of freedom from the retrieval of the physical quantities
/sdev	Standard deviation of the observations gridded. For monthly products this is the standard deviation over the daily values.

3.5 Geolocation

These products use a simple latitude/longitude 1x1 degree grid.

Longitudes run from -180 to 180 degrees East, with grid centers at {-179.5, -178.5, …179.5} as recorded in variable "lon". Associated bounds variable lon_bnds gives the boundaries of each cell: { [-180, -179), [-179, -178], … [179, 180)}.

Latitudes run from -90 to 90 degrees North, with grid centers at {-89.5, -88.5, …89.5} as recorded in variable "lat". Associated bounds variable lat_bnds gives the boundaries of each cell: { [-90, -89), [-89, -88], … [89, 0)}.

3.6 Science Data Variables

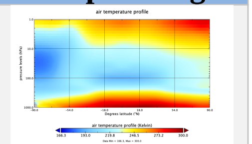
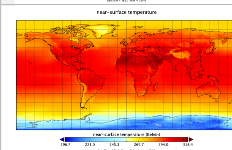
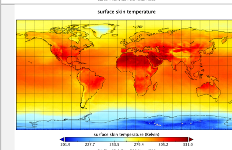
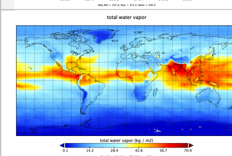
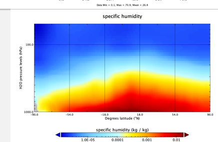
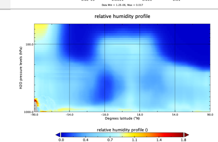
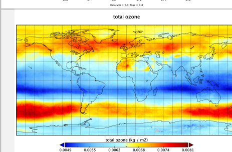
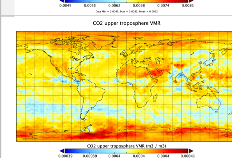
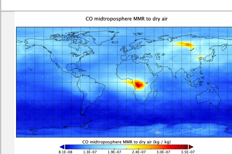
These retrievals provide information on a wide variety of geophysical parameters, including temperature, water vapor, ozone, clouds, and surface parameters.

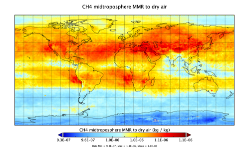
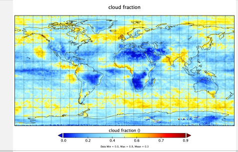
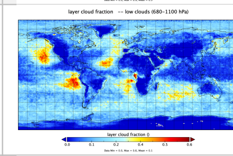
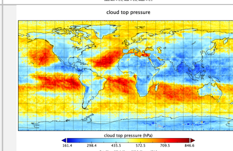
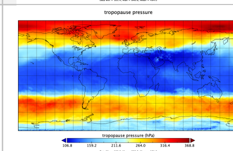
For each retrieved variable there is a corresponding variable in the /nobs group giving the number of observations associated with it. For example nobs/air_temp_nobs gives the number of observations contributing to each element of air_temp. In daily Level-3 products this counts the number of FOVs averaged, so the number of independent retrievals is lower. For monthly Level-3, nobs counts the number of days averaged.

Key science data fields are defined in Table 3.6 below. See the appendixes for a full listing.

The last column of Table 3.6 includes global images from CLIMCAPS SNPP July 2016 QCS Ascending monthly. These images were generated using Panoply.

Table 3.6 Key Science Data Variables

Name	Dimensions	Description	Units	**Sample Image**
air_temp	orbit_pass, air_pres, lat, lon	air temperature profile	Kelvin	
surf_air_temp	orbit_pass, lat, lon	near-surface air temperature (~2 meters above surface)	Kelvin	
surf_temp	orbit_pass, lat, lon	radiative temperature of the surface	Kelvin	
h2o_vap_tot	orbit_pass, lat, lon	total precipitable water vapor	kg / m2	
spec_hum	orbit_pass, air_pres_h2o, lat, lon	mass fraction of water vapor in moist air	kg / kg	
rel_hum	orbit_pass, air_pres_h2o, lat, lon	relative humidity over equilibrium phase	unitless	
o3_tot	orbit_pass, lat, lon	Total column ozone. (Multiply by 4.670e4 to convert to Dobson Units from kg m^-2)	kg m-2	
co2_vmr_uppertrop	orbit_pass, lat, lon	Carbon Monoxide volume mixing ratio to dry air between 20,000-50,000 Pa, near the peak of sensitivity	m3 / m3	
co_mmr_midtrop	orbit_pass, lat, lon	Carbon Monoxide mass mixing ratio to dry air at 50000 Pa, near the peak of sensitivity	kg / kg	

ch4_mmr_midtrop	orbit_pass, lat, lon	Methane mass mixing ratio to dry air at 40000 Pa, near the peak of sensitivity	kg / kg	
cld_frac	orbit_pass, lat, lon	effective cloud fraction	unitless	
lay_cld_frac	orbit_pass, cld_pres_lay, lat, lon	coarse layer effective cloud fraction	unitless	
cld_top_pres	orbit_pass, lat, lon	cloud top pressure	Pa	
tpause_pres	orbit_pass, lat, lon	tropopause pressure, where tropopause is determined according to the WMO definition	Pa	

3.7 Quality Control

Quality Control (QC) for Level-3 is based on the QC information embedded in the Level-2 products. Level-3 values are means of accepted cases from Level-2. There are two QC strategies:

1) Specific QC (QCS) uses the QC values for each specific variable and level to determine which observations to include. This gives the greatest possible yield for any given level, but might give misleading results for lapse rates or other comparisons because different ensembles of observations are used for different levels and variables.
2) Comprehensive QC (QCC) uses only cases where the temperature and water vapor are QC 0 or 1 from the top of the atmosphere down to the surface. This gives a lower yield than QCS for most levels but can safely be used for lapse rates and other comparisons.

CLIMCAPS Level-2 products include Quality Control (QC) scores of {0, 1, 2} for each level of each retrieved geophysical variable. CLIMCAPS decides an entire FOR retrieval is good or bad and sets all levels of all variables collectively to 0 or 2.

Table: 3.7.1 Level-2 *_qc Values

Value	Meaning
0	Highest quality – use without reservation
1	Good quality – suitable for most purposes
2	Do not use. In some cases a physical value is present but is not considered reliable. In other cases only fill values are present.

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

3.9 Key supporting information variables for profiles

These variables provide supporting information to interpret the science variables.

Name	Dimensions	Description	Units
air_pres	air_pres	pressure levels	Pa
air_pres_h2o	air_pres_h2o	H2O vapor pressure levels	Pa
cld_pres_lay	cld_pres_lay	pressure at the middle of each coarse cloud layer	Pa
cld_pres_lay_bnds	cld_pres_lay, bnds_1d	Min and max pressure of each cloud layer	Pa
lat	lat	Grid cell center latitudes (-89.5, -88.5, …89.5)	degrees_north
lat_bnds	lat, bnds_1d	Min and max latitude of each grid cell	degrees_north
lon	lon	Grid cell center longitudes (-179.5, -178.5, …179.5)	degrees_east
lon_bnds	lon, bnds_1d	Min and max longitude of each grid cell	degrees_east

orbit_pass	orbit_pass	nominal local solar time at equatorial overpass (13.5, 1.5)	hours

3.10 Vertical profile representation of gases

CLIMCAPS retrieves all gases as vertical profiles on 100 fixed-pressure layers to satisfy internal requirement for radiative transfer calculations. The 100-layer gas retrievals are preserved in the “mol_lay” subgroup, even though CrIMSS measurements do not have information content for all 100 layers. We do this for two reasons, (i) support radiative transfer calculations with CLIMCAPS retrievals and (ii) allow data users to calculate integrated column densities that are specifically targeted to their applications.

For the products in the root group, water vapor and ozone are reported on the 100 fixed-pressure levels which bound the layers. For water vapor, levels at pressures under 5153 Pa (51.53 hPa) are not reported.

For gases CO and CH_4, where there is less than a single degree of freedom, we report MMR only at a single pressure level near the peak of the retrieval sensitivity: 40000 Pa for CH_4, and 50000 Pa for CO.

Pressure levels below the surface are always filled with fill values.

Level concentrations of gases are estimated from the layer gas amounts. CLIMCAPS, using a direct interpolation, preserves information from MERRA2 along with the information from the retrieval.

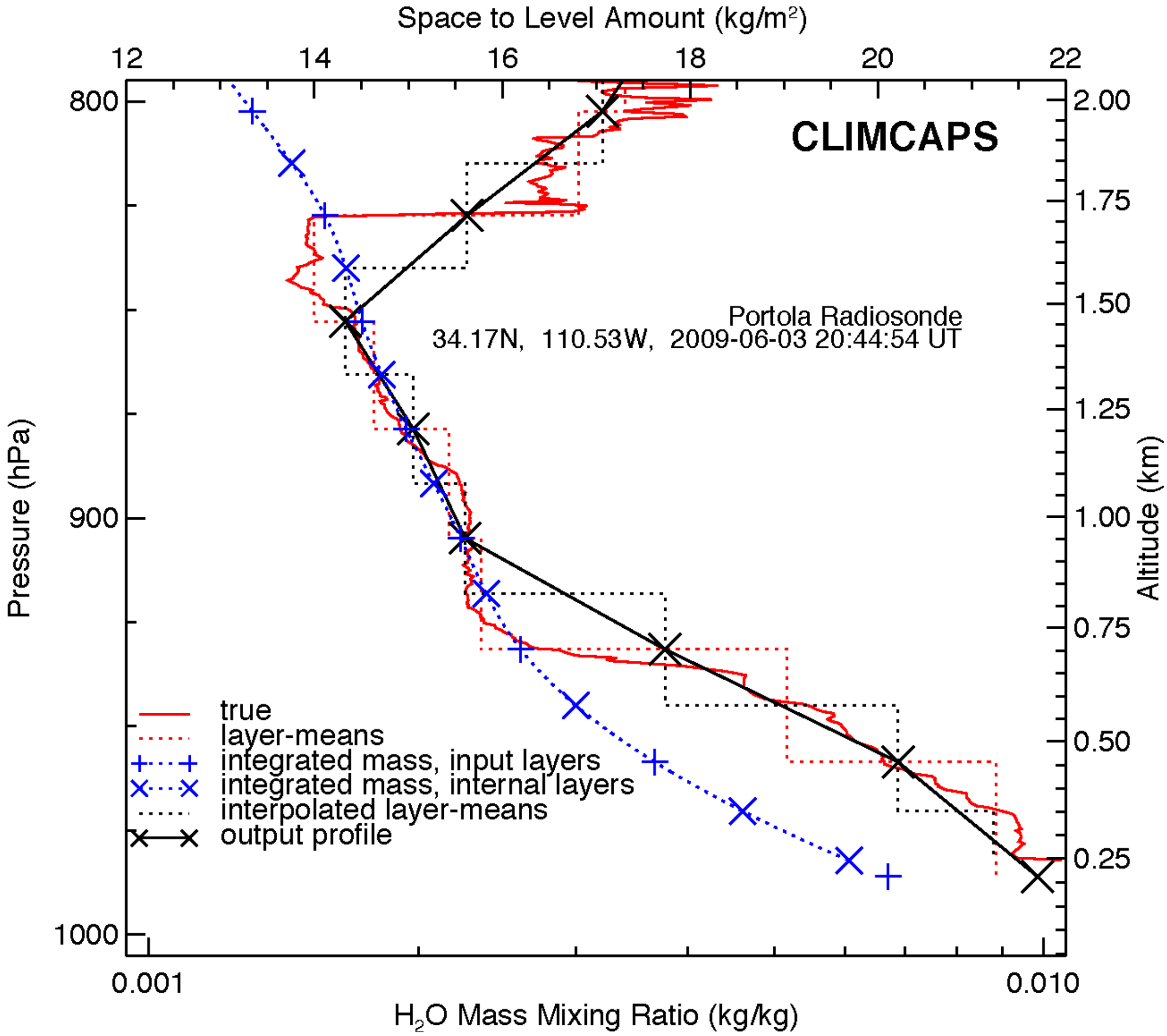


Figure 1. Water vapor level concentration for CLIMCAPS.

For CLIMCAPS, level concentrations of gases are estimated from layer-amounts using the mean-value theorem and assuming that layers with boundaries at

$$P_{\text{bnd}} = \frac{P_i - P_{i-1}}{\ln P_i - \ln P_{i-1}}$$

have mean values which estimate the profile at the levels P_i. Layer-mean mixing ratios are uniquely specified by the layer amounts, the temperature profile and pressure differences through the hydrostatic and hypsometric equations [Wallace and Hobbs, 1977, pgs. 53-54].

Figure 1 illustrates the procedure. A true radiosonde profile of water vapor mixing ratio is converted to layer amounts as would be produced by the CLIMCAPS algorithm. This is shown in the figure as mean mass mixing ratio, which is obtained by dividing the layer water vapor amount by the layer dry air amount. The amounts in each layer are summed from top to bottom to produce a piecewise linear profile of top-to-level integrated amount. The integrated amount is then interpolated to a new set of levels, P_{bnd}, and differenced to produce a new set of layer amount. Similarly, the dry-air top-to-level integrated amounts are interpolated to the new levels, and mean mixing ratios (ratio of gas amount to dry-air amount) are assumed to be the mixing ratio at the levels P_i. Values at the end points are linearly extrapolated from the profile at interior points. The reported profiles have errors from the interpolations and use of the mean value theorem[1]. The algorithm uses linear interpolation in log pressure and top-to-level amount which introduces larger errors when top-to-level amount second derivative is large; these errors are not included in mixing ratio error estimates.

Error estimates for the level mixing ratios are interpolated from the fractional layer-amount errors. Fractional error is assumed to be fully correlated and linearly interpolated in log pressure from the arithmetic mean pressures of each level (uncorrelated error involves linearly interpolating variance).

3.11 Known issues

None.

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 is a nice netCDF data viewer tool for visualizing these files

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.

[1] The mean value theorem says that some point in the interval has the mean value, but not where the point is located.

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

5.0 Data Services

The products are 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.

Appendix A: Test results

A.1 Summary

This report assesses the general quality of the CLIMCAPS-Aqua, CLIMCAPS-SNPP, CLIMCAPS-JPSS1 v02 level 3 (L3) monthly mean tropospheric air temperature (air_temp), specific humidity (spec_hum), and relative humidity (rel_hum) data products. This was done through the inter-comparison of the monthly mean values and their number of observations (nobs) of the three physical variables among the three CLIMCAPS data products. The major findings of this assessment are as follows. (1) All CLIMCAPS-Aqua, CLIMCAPS-SNPP, and CLIMCAPS-JPSS1 V2 L3 monthly mean air-temp, spec_hum and rel_hum data are reasonable and can capture the well-known large-scale weather and climate features. (2) Over the tropics, CLIMCAPS-Aqua is colder/drier than CLIMCAPS-SNPP in the upper troposphere but warmer/moister in the lower troposphere. The opposite is true over the middle and high latitudes. The nobs in CLIMCAPS-Aqua is systematically lower (~10) than in CLIMCAPS-SNPP. These differences may be due to different sensors and/or different microwave channels used in the respective retrievals of the CLIMCAPS-Aqua and CLIMCAPS-SNPP products. (3) The CLIMCAPS-SNPP and CLIMCAPS-JPSS1 V2 L3 monthly mean air_temp, spec_hum and rel_hum data and their nobs are very similar and no significant differences are found.

A.2 CLIMCAPS Test Data

All monthly L3 test data for CLIMCAPS are available on the AIRS machines under different directories. The CLIMCAPS-Aqua monthly L3 test data were produced using the software version v02_39_00. This includes monthly CLIMCAPS-Aqua L3 data for Jan, Apr, Jul, and Oct of 2003 and 2011, Jan 2016, and Jan 2019.

The CLIMCAPS-SNPP monthly L3 test data for Jan, Apr, Jul, and Oct of 2016 were produced using the software version v02_38_00.

The CLIMCAPS-SNPP monthly L3 test data for Jan 2019 were produced using the software version v02_28.G.

The CLIMCAPS-JPSS1 monthly L3 test data for Jul and Oct 2018, Jan and Apr 2019 were produced using the software version v02_38_00.

Where the test data directories contain multiple copies, the latest version were used.

For this release of CLIMCAPS L3 monthly outputs, there are two strategies applied on the quality control of accepted cases while gridding: the specific QC (QCS) and comprehensive QC (QCC). The QCC uses the QC values for each specific variable and vertical level to determine which observations to include, whereas QCC uses only cases where the temperature and water vapor are QC 0 or 1 from the top of the atmosphere down to the surface. Therefore, the QCC gives a lower yield than QCS for most levels, but the QCC guarantees consistent analysis across levels and species, and can be safely used for lapse rates and other comparisons. For this assessment, only QCS products are examined.

A.3 Test methods

We mainly inter-compare the mean values and their numbers of observations (nobs) of the tropospheric air temperature (air_temp), specific humidity (spec_hum), and relative humidity (rel_hum) among the three CLIMCAPS data products (Aqua, SNPP, and JPSS1). For clarity, the L3 mean value is the arithmetic mean of the L3 daily values. The nobs for monthly L3 files are the number of days in that month where we had data in the daily L3. We focus on the tropospheric air_temp, spec_hum, and rel_hum in the eight tropospheric pressure levels from 1000 hPa to 300 hPa, that is, 1013, 931, 852, 706, 596, 496, 407, and 300 hPa, similar to the eight standard tropospheric pressure levels used in AIRS Obs4MIPs data (Tian et al. 2013; Tian et al. 2019; Tian and Hearty 2020). We also use the average of the ascending and descending nodes. For the intercomparison between CLIMCAPS-Aqua and CLIMCAPS-SNPP, we focus on the month of Jan 2016 when both CLIMCAPS-Aqua and CLIMCAPS-SNPP data are available. For the intercomparison between CLIMCAPS-SNPP and CLIMCAPS-JPSS1, we focus on the month of Jan 2019 when both CLIMCAPS-SNPP and CLIMCAPS-JPSS1 data are available.

A.4 Comparison between CLIMCAPS-Aqua and CLIMCAPS-SNPP

Figure A.1 shows CLIMCAPS-Aqua air_temp (K) (left column), CLIMCAPS-SNPP air_temp (K) (middle column), and their differences (right column) for January 2016 at the eight tropospheric pressure levels (different rows). Both CLIMCAPS-Aqua and CLIMCAPS-SNPP air_temp show the well-known vertical structure and spatial pattern of tropospheric air_temp. It decreases with both latitude (warm near the Equator and cold near the poles) and altitude (warm near the surface and cold in the upper troposphere). There are clear differences between CLIMCAPS-Aqua and CLIMCAPS-SNPP air_temp and the differences are within 1 K. It seems that CLIMCAPS-Aqua is colder than CLIMCAPS-SNPP in the upper troposphere but warmer in the lower troposphere over the tropics. The opposite is true over the middle and high latitudes.

Figure A.2 shows CLIMCAPS-Aqua air_temp_nobs (left column), CLIMCAPS-SNPP air_temp_nobs (middle column), and their differences (right column) for January 2016 at the eight tropospheric pressure levels (different rows). Both of them are affected by clouds, topography, and coastlines. However, the number of observations are consistently smaller (~10) in CLIMCAPS-Aqua than in CLIMCAPS-SNPP due to the fact that Aqua has a narrower swath, leaving larger "gores".

Figure A.3 shows CLIMCAPS-Aqua spec_hum (g/kg) (left column), CLIMCAPS-SNPP spec_hum (g/kg) (middle column), and their differences (right column) for January 2016 at the eight tropospheric pressure levels (different rows). Both CLIMCAPS-Aqua and CLIMCAPS-SNPP spec_hum show the well-known vertical structure and spatial pattern of tropospheric spec_hum. It decreases with both latitude (moist near the Equator and dry near the poles) and altitude (moist near the surface and dry in the upper troposphere). The spec_hum data also shows the well-known tropical deep convective features, such as the inter-tropical convergence zone (ITCZ), the South Pacific convergence zone (SPCZ), and the South Atlantic convergence zone (SACZ) and the well-known dry descending regions, such as the equatorial Pacific cold tongue, the subtropical southeastern Pacific and the subtropical northeastern Pacific (Tian and Dong 2020). There are clear differences between CLIMCAPS-Aqua and CLIMCAPS-SNPP spec_hum. Over the tropical deep convective cloudy regions, CLIMCAPS-Aqua seems to be drier than CLIMCAPS-SNPP in the upper troposphere but moister in the lower troposphere.

Figure A.4 shows CLIMCAPS-Aqua spec_hum_nobs (left column), CLIMCAPS-SNPP spec_hum_nobs (middle column), and their differences (right column) for January 2016 at the eight tropospheric pressure levels (different rows). Both of them are affected by clouds, topography, and coastlines and the number of observations are consistently smaller (~10) in CLIMCAPS-Aqua than in CLIMCAPS-SNPP.

Figure A.5 shows CLIMCAPS-Aqua rel_hum (%) (left column), CLIMCAPS-SNPP rel_hum (%) (middle column), and their differences (right column) for January 2016 at the eight tropospheric pressure levels (different rows). Both CLIMCAPS-Aqua and CLIMCAPS-SNPP rel_hum show the well-known vertical structure and spatial pattern of tropospheric rel_hum. The rel_hum data shows the well-known tropical deep convective features, such as the ITCZ, the SPCZ, and the SACZ and the well-known dry descending regions, such as the equatorial Pacific cold tongue, the subtropical southeastern Pacific and the subtropical northeastern Pacific (Tian and Dong 2020). It also shows the well-known moist polar regions and the boundary layer. There are clear differences between CLIMCAPS-Aqua and CLIMCAPS-SNPP rel_hum. Over the tropical deep convective cloudy regions, CLIMCAPS-Aqua seems to be drier than CLIMCAPS-SNPP in the upper troposphere but moister in the lower troposphere.

Figure A.6 shows CLIMCAPS-Aqua rel_hum_nobs (left column), CLIMCAPS-SNPP rel_hum_nobs (middle column), and their differences (right column) for January 2016 at the eight tropospheric pressure levels (different rows). Both of them are affected by clouds, topography, and coastlines and the number of observations are consistently smaller (~10) in CLIMCAPS-Aqua than in CLIMCAPS-SNPP.

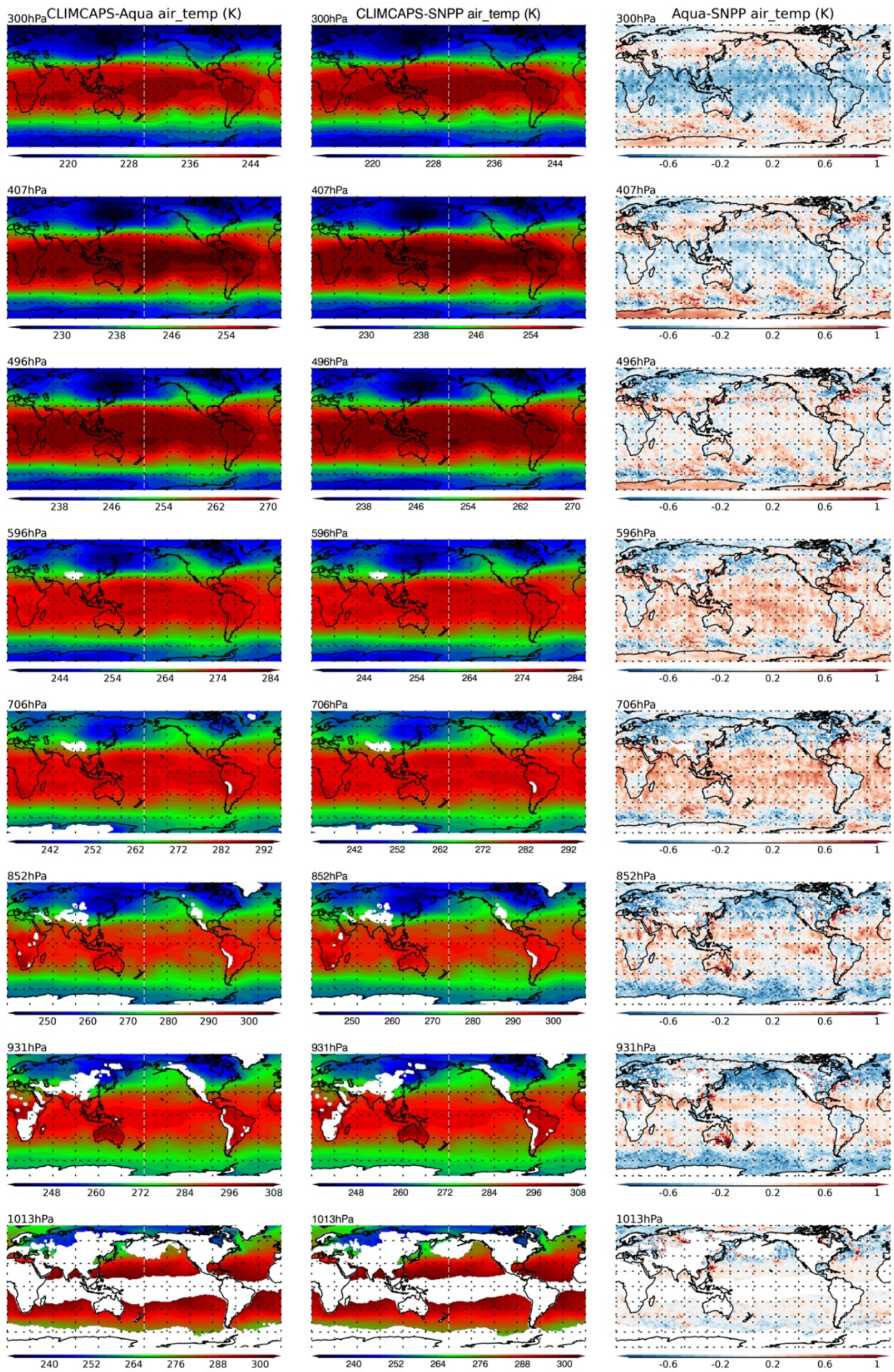


Figure A.1. Tropospheric air_temp (K) for January 2016 at the eight tropospheric pressure levels (different rows) from CLIMCAPS-Aqua (left column), CLIMCAPS-SNPP (middle column), and their differences (right column).

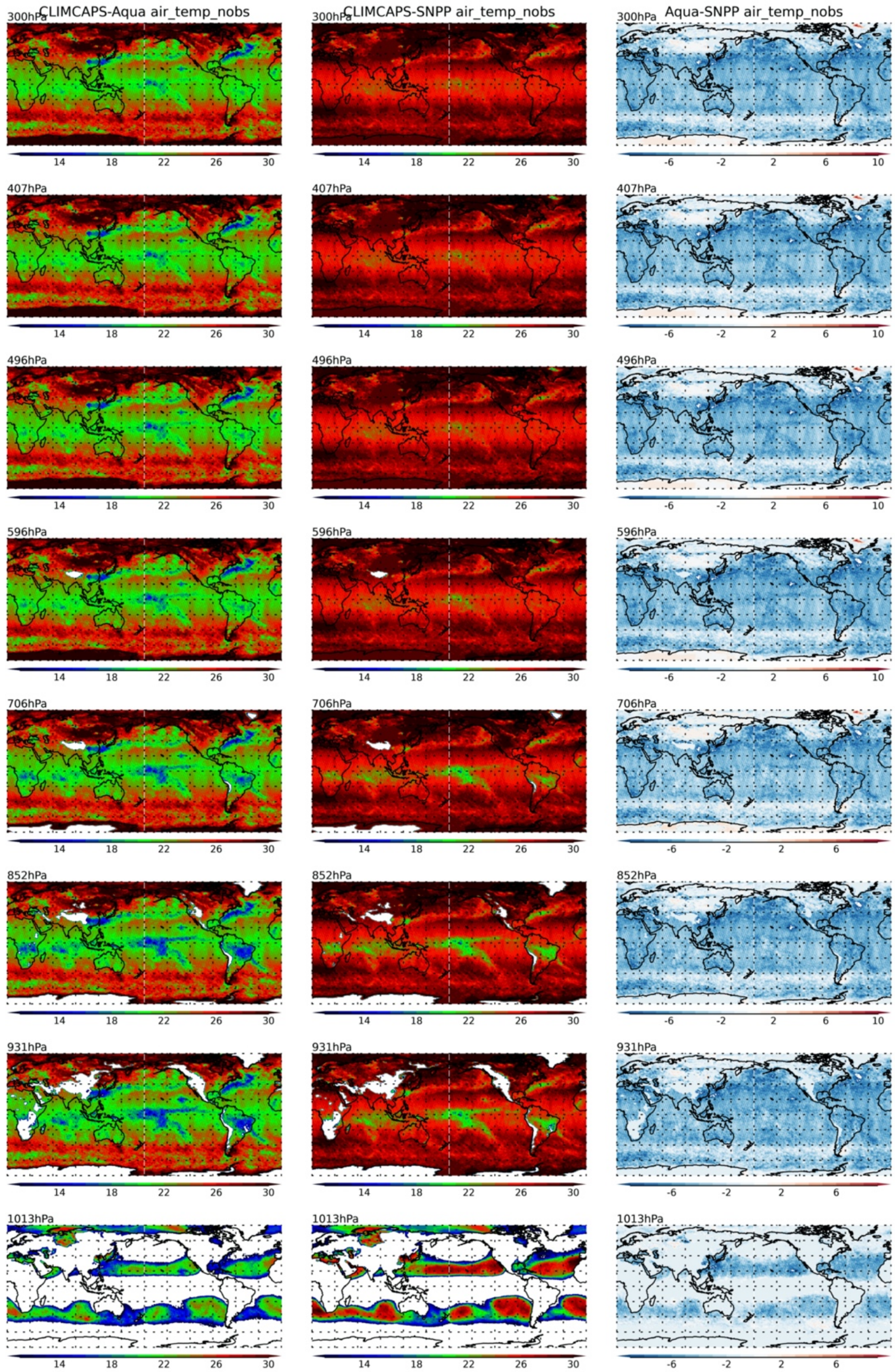


Figure A.2. Tropospheric air_temp_nobs for January 2016 at the eight tropospheric pressure levels (different rows) from CLIMCAPS-Aqua (left column), CLIMCAPS-SNPP (middle column), and their differences (right column).

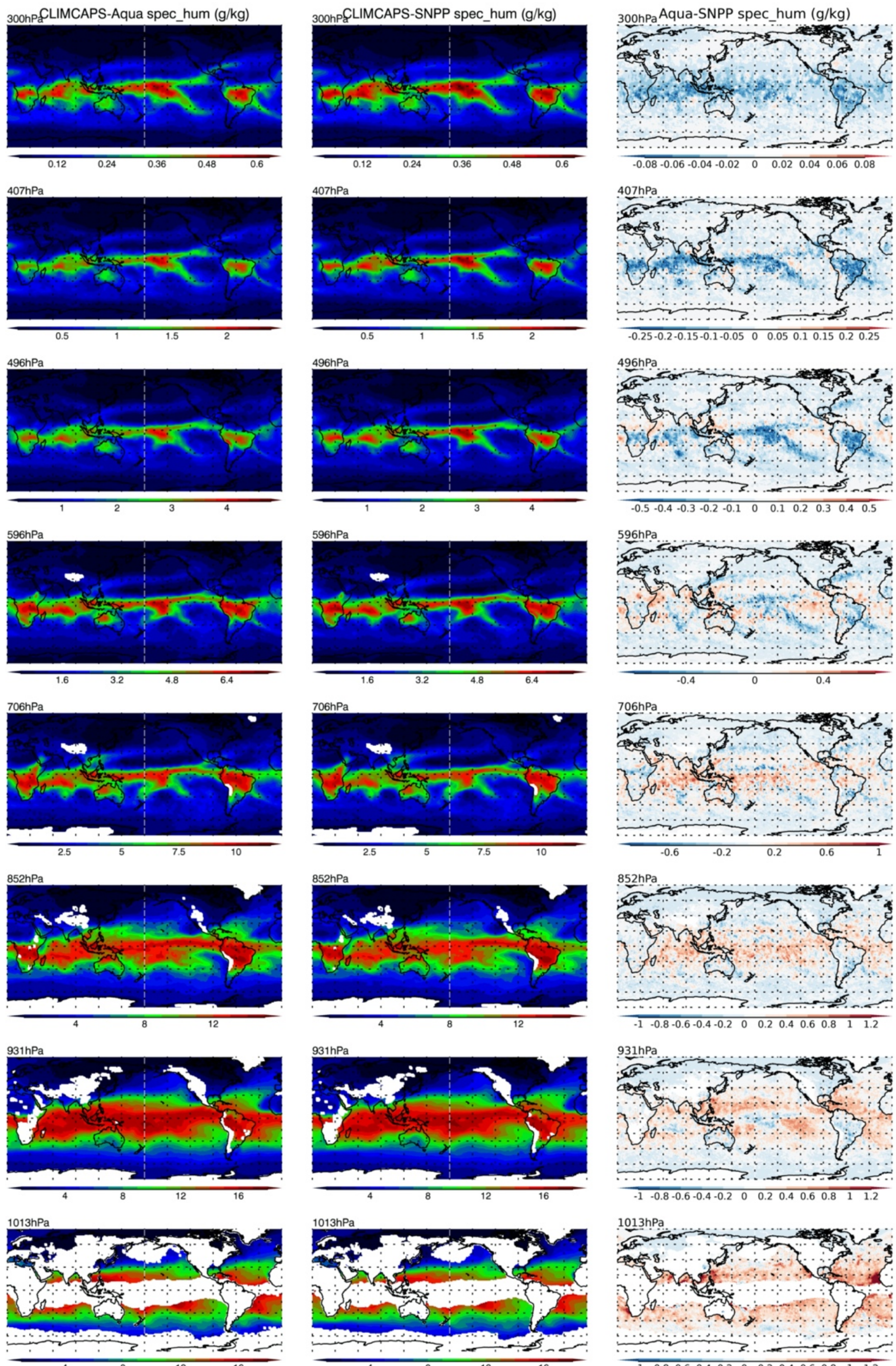


Figure A.3. Tropospheric spec_hum (g/kg) for January 2016 at the eight tropospheric pressure levels (different rows) from CLIMCAPS-Aqua (left column), CLIMCAPS-SNPP (middle column), and their differences (right column).

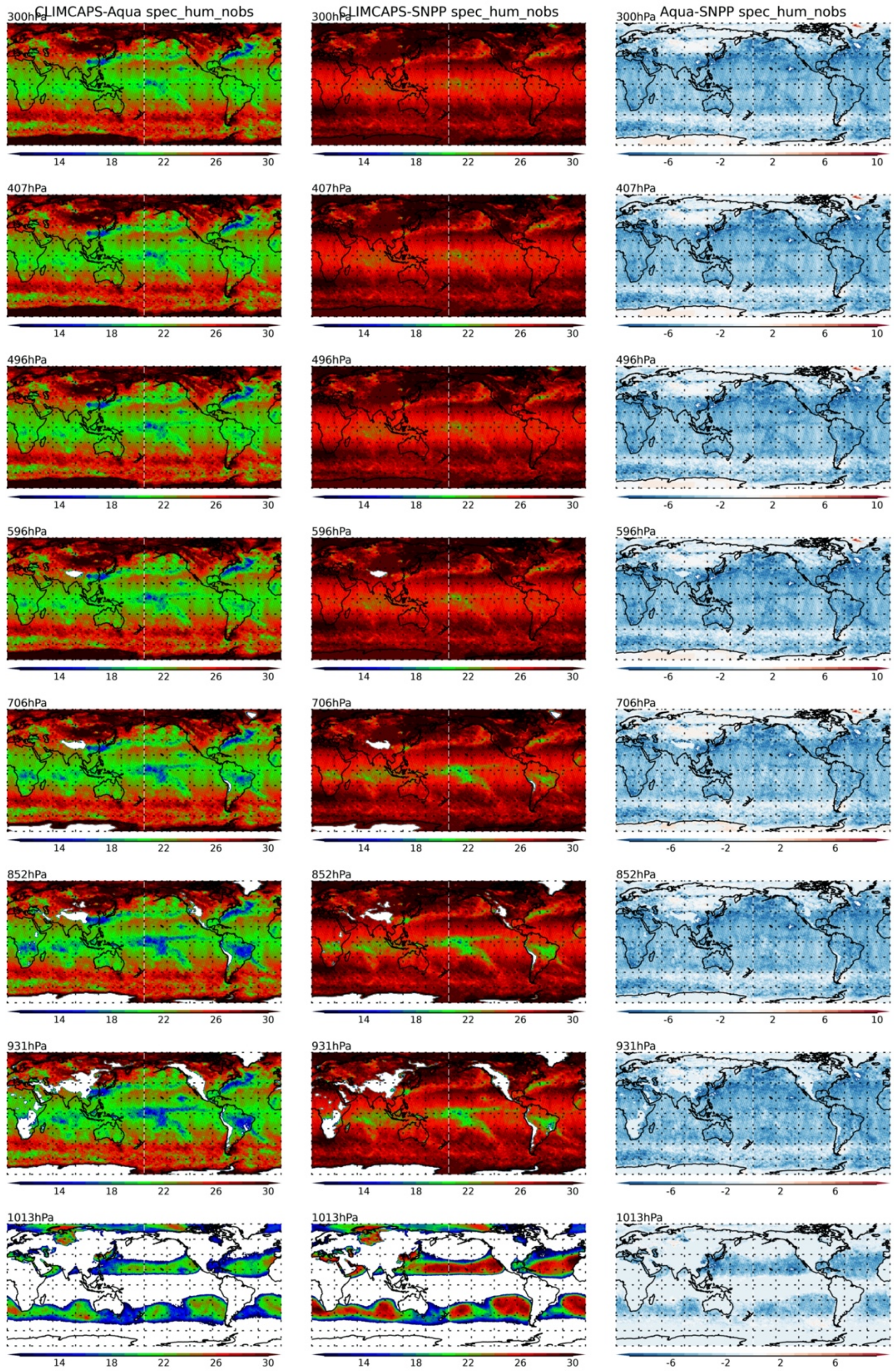


Figure A.4. Tropospheric spec_hum_nobs for January 2016 at the eight tropospheric pressure levels (different rows) from CLIMCAPS-Aqua (left column), CLIMCAPS-SNPP (middle column), and their differences (right column).

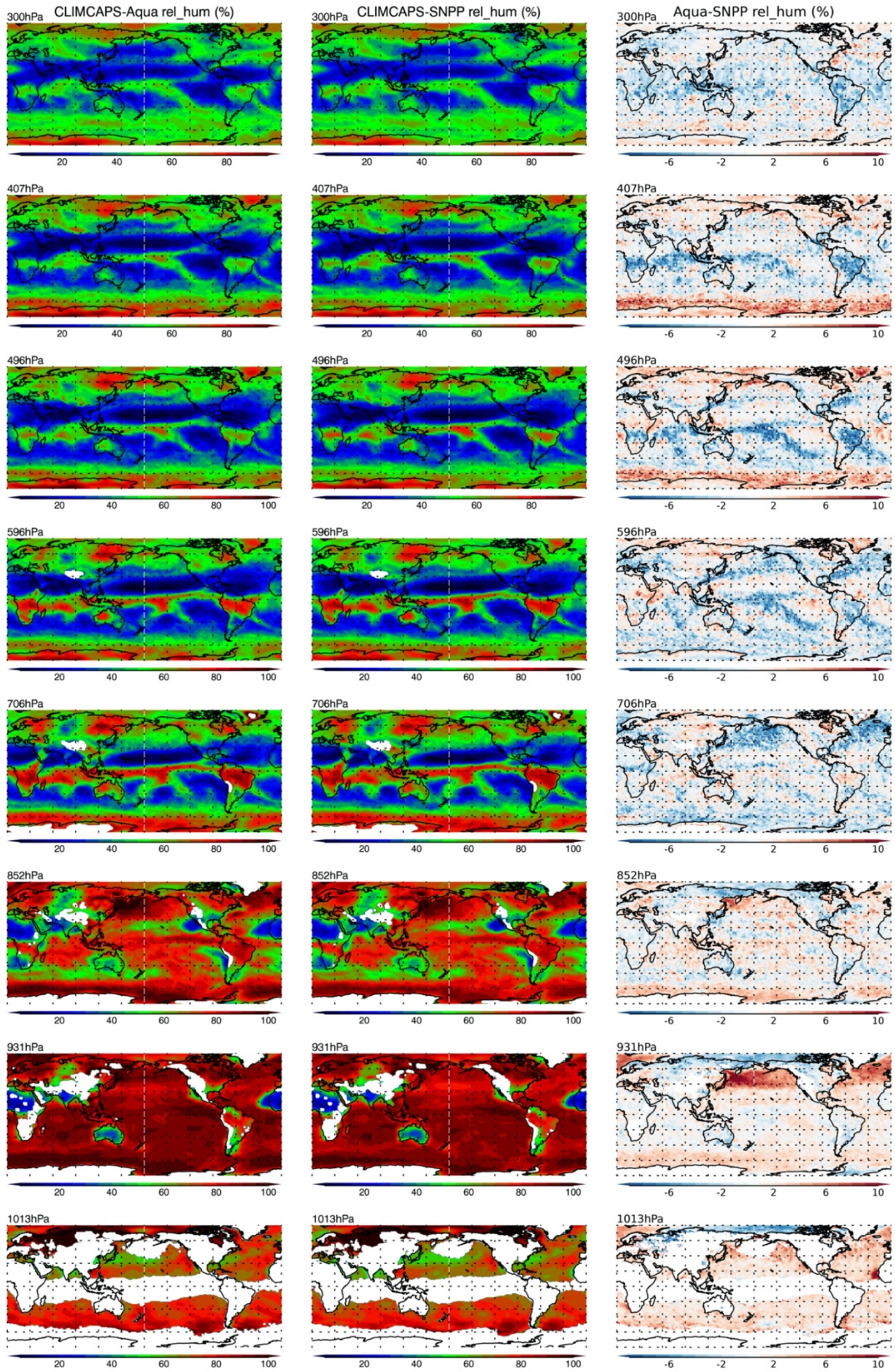


Figure A.5. Tropospheric rel_hum (%) for January 2016 at the eight tropospheric pressure levels (different rows) from CLIMCAPS-Aqua (left column), CLIMCAPS-SNPP (middle column), and their differences (right column).

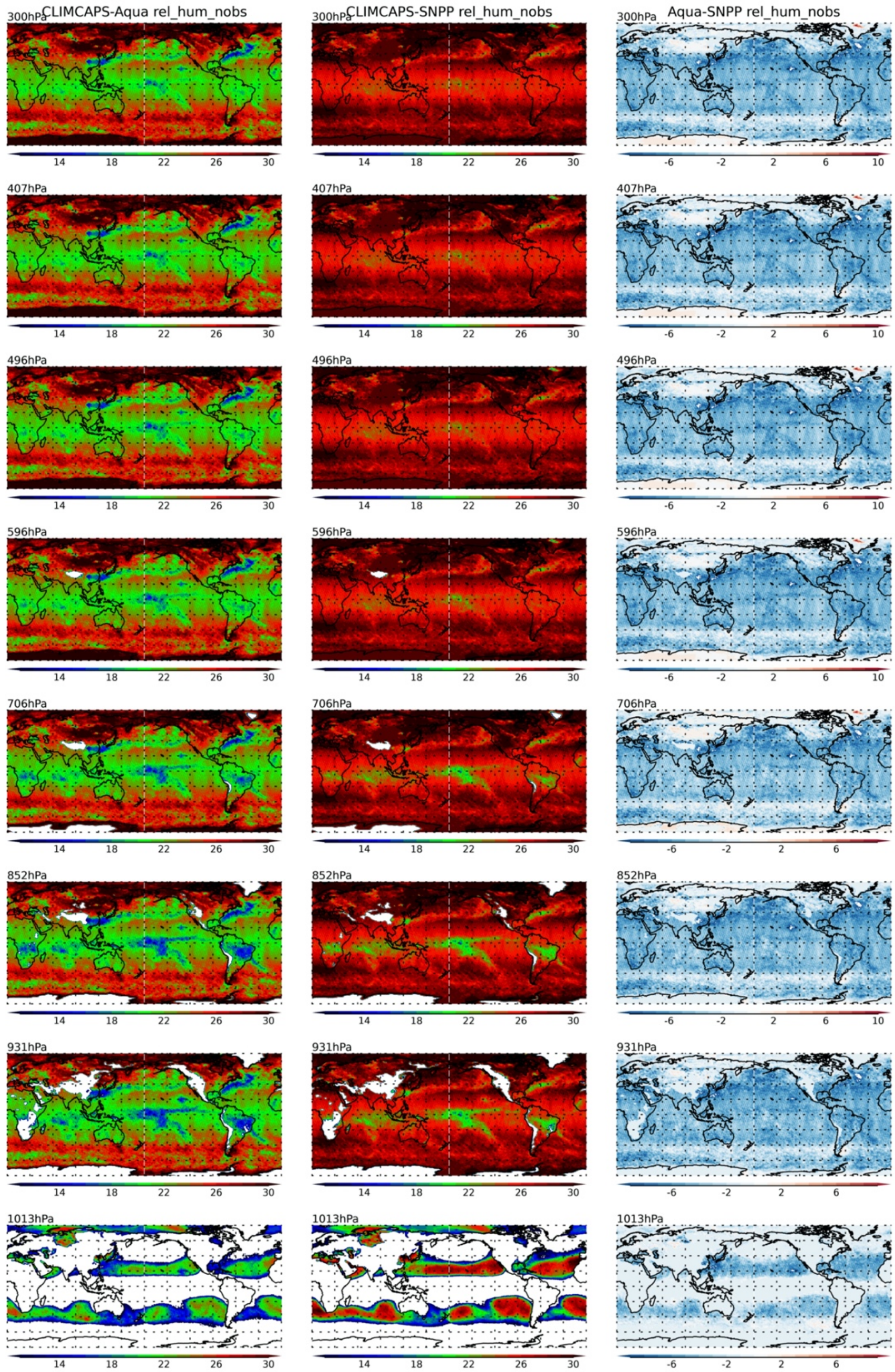


Figure A.6. Tropospheric rel_hum_nobs for January 2016 at the eight tropospheric pressure levels (different rows) from CLIMCAPS-Aqua (left column), CLIMCAPS-SNPP (middle column), and their differences (right column).

A.5 Comparison between CLIMCAPS-SNPP and CLIMCAPS-JPSS1

Figure A.7 shows CLIMCAPS-SNPP air_temp (K) (left column), CLIMCAPS-JPSS1 air_temp (K) (middle column), and their differences (right column) for January 2019 at the eight tropospheric pressure levels (different rows). Both CLIMCAPS-SNPP and CLIMCAPS-JPSS1 air_temp show the well-known vertical structure and spatial pattern of tropospheric air_temp. It decreases with both latitude (warm near the Equator and cold near the poles) and altitude (warm near the surface and cold in the upper troposphere). The differences between CLIMCAPS-SNPP and CLIMCAPS-JPSS1 air_temp are very small, less than 0.5 K.

Figure A.8 shows CLIMCAPS-SNPP air_temp_nobs (left column), CLIMCAPS-JPSS1 air_temp_nobs (middle column), and their differences (right column) for January 2019 at the eight tropospheric pressure levels (different rows). Both of them are affected by clouds, topography, and coastlines. The differences between CLIMCAPS-SNPP and CLIMCAPS-JPSS1 are roughly zero-mean, with a wave-like pattern that just reflects the way the orbits of these two spacecraft are out-of-sync.

Figure A.9 shows CLIMCAPS-SNPP spec_hum (g/kg) (left column), CLIMCAPS-JPSS1 spec_hum (g/kg) (middle column), and their differences (right column) for January 2019 at the eight tropospheric pressure levels (different rows). Both CLIMCAPS-SNPP and CLIMCAPS-JPSS1 spec_hum show the well-known vertical structure and spatial pattern of tropospheric spec_hum. It decreases with both latitude (moist near the Equator and dry near the poles) and altitude (moist near the surface and dry in the upper troposphere). The spec_hum data also shows the well-known tropical deep convective features, such as the ITCZ, the SPCZ, and the SACZ and the well-known dry descending regions, such as the equatorial Pacific cold tongue, the subtropical southeastern Pacific and the subtropical northeastern Pacific (Tian and Dong 2020). The differences between CLIMCAPS-SNPP and CLIMCAPS-JPSS1 spec_hum are very small.

Figure A.10 shows CLIMCAPS-SNPP spec_hum_nobs (left column), CLIMCAPS-JPSS1 spec_hum_nobs (middle column), and their differences (right column) for January 2019 at the eight tropospheric pressure levels (different rows). Both of them are affected by clouds, topography, and coastlines. The differences between CLIMCAPS-SNPP and CLIMCAPS-JPSS1 are very small, less than 3.

Figure A.11 shows CLIMCAPS-SNPP rel_hum (%) (left column), CLIMCAPS-JPSS1 rel_hum (%) (middle column), and their differences (right column) for January 2019 at the eight tropospheric pressure levels (different rows). Both CLIMCAPS-SNPP and CLIMCAPS-JPSS1 rel_hum show the well-known vertical structure and spatial pattern of tropospheric rel_hum. The rel_hum data shows the well-known tropical deep convective features, such as the ITCZ, the SPCZ, and the SACZ and the well-known dry descending regions, such as the equatorial Pacific cold tongue, the subtropical southeastern Pacific and the subtropical northeastern Pacific (Tian and Dong 2020). It also shows the well-known moist polar regions and the boundary layer. The differences between CLIMCAPS-SNPP and CLIMCAPS-JPSS1 rel_hum are very small.

Figure A.12 shows CLIMCAPS-SNPP rel_hum_nobs (left column), CLIMCAPS-JPSS1 rel_hum_nobs (middle column), and their differences (right column) for January 2019 at the eight tropospheric pressure levels (different rows). Both of them are affected by clouds, topography, and coastlines. The differences between CLIMCAPS-SNPP and CLIMCAPS-JPSS1 are very small, less than 3.

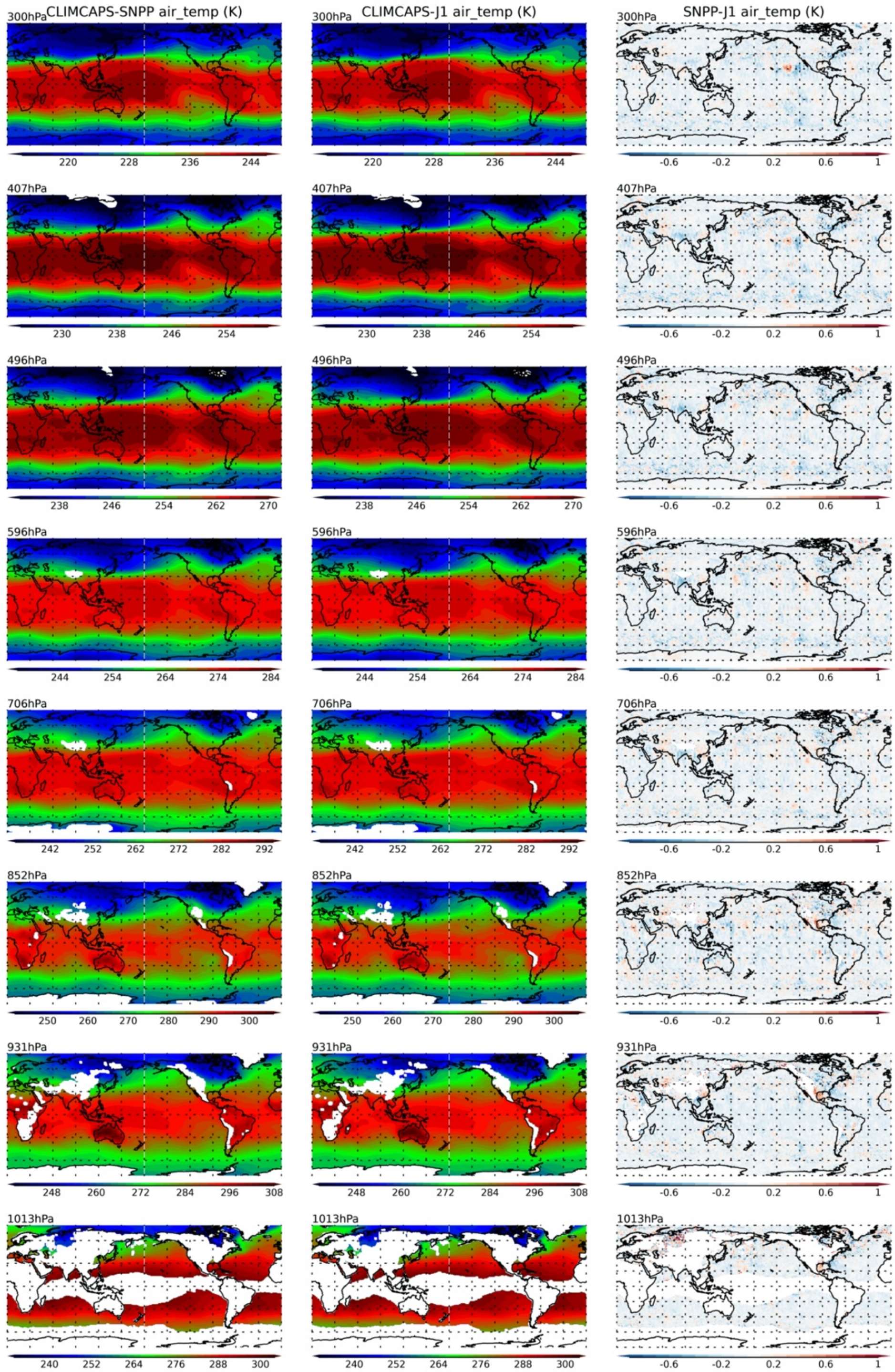


Figure A.7. Tropospheric air_temp (K) for January 2019 at the eight tropospheric pressure levels (different rows) from CLIMCAPS-SNPP (left column), CLIMCAPS-JPSS1 (middle column), and their differences (right column).

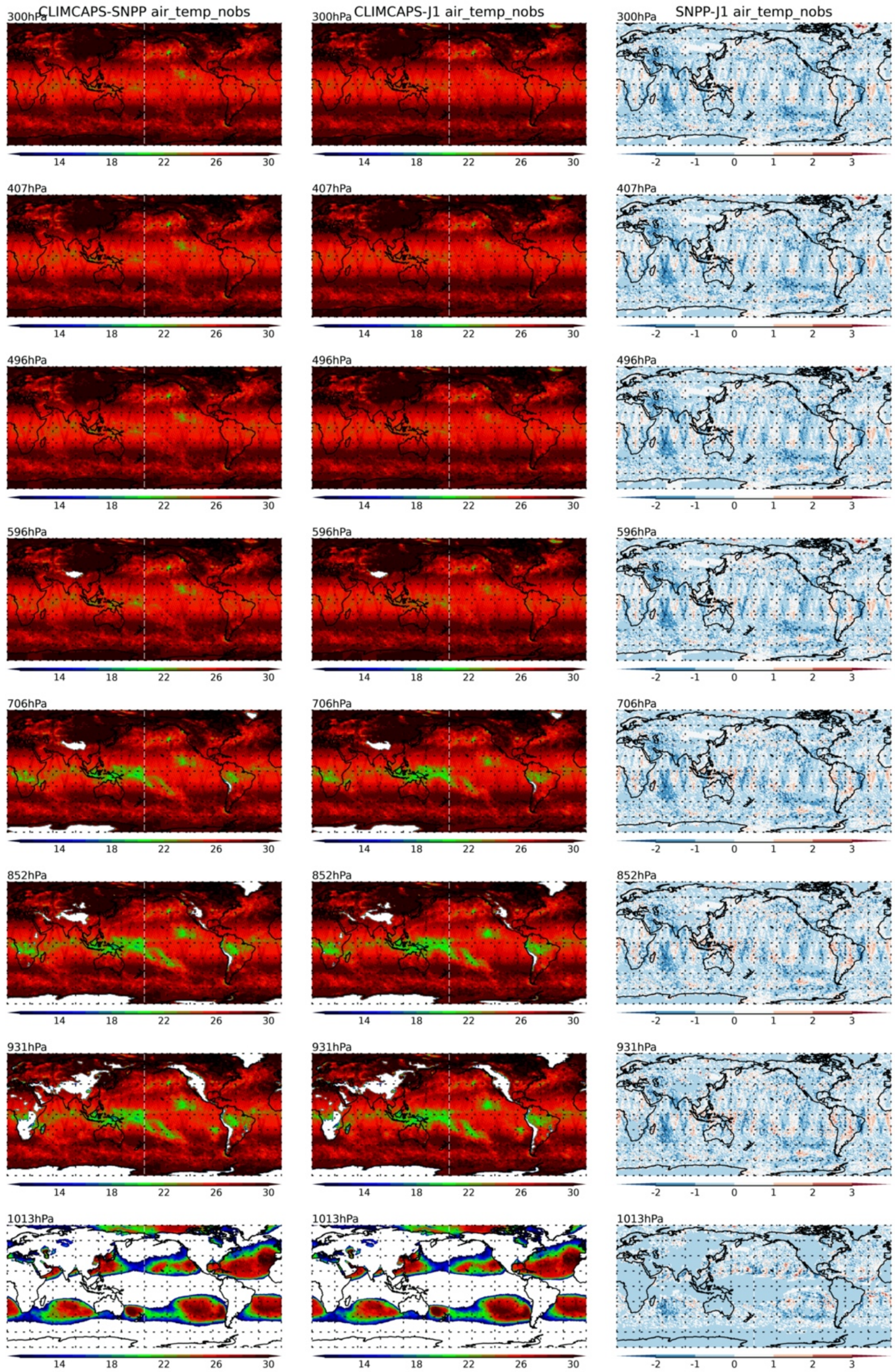


Figure A.8. Tropospheric air_temp_nobs for January 2019 at the eight tropospheric pressure levels (different rows) from CLIMCAPS-SNPP (left column), CLIMCAPS-JPSS1 (middle column), and their differences (right column).

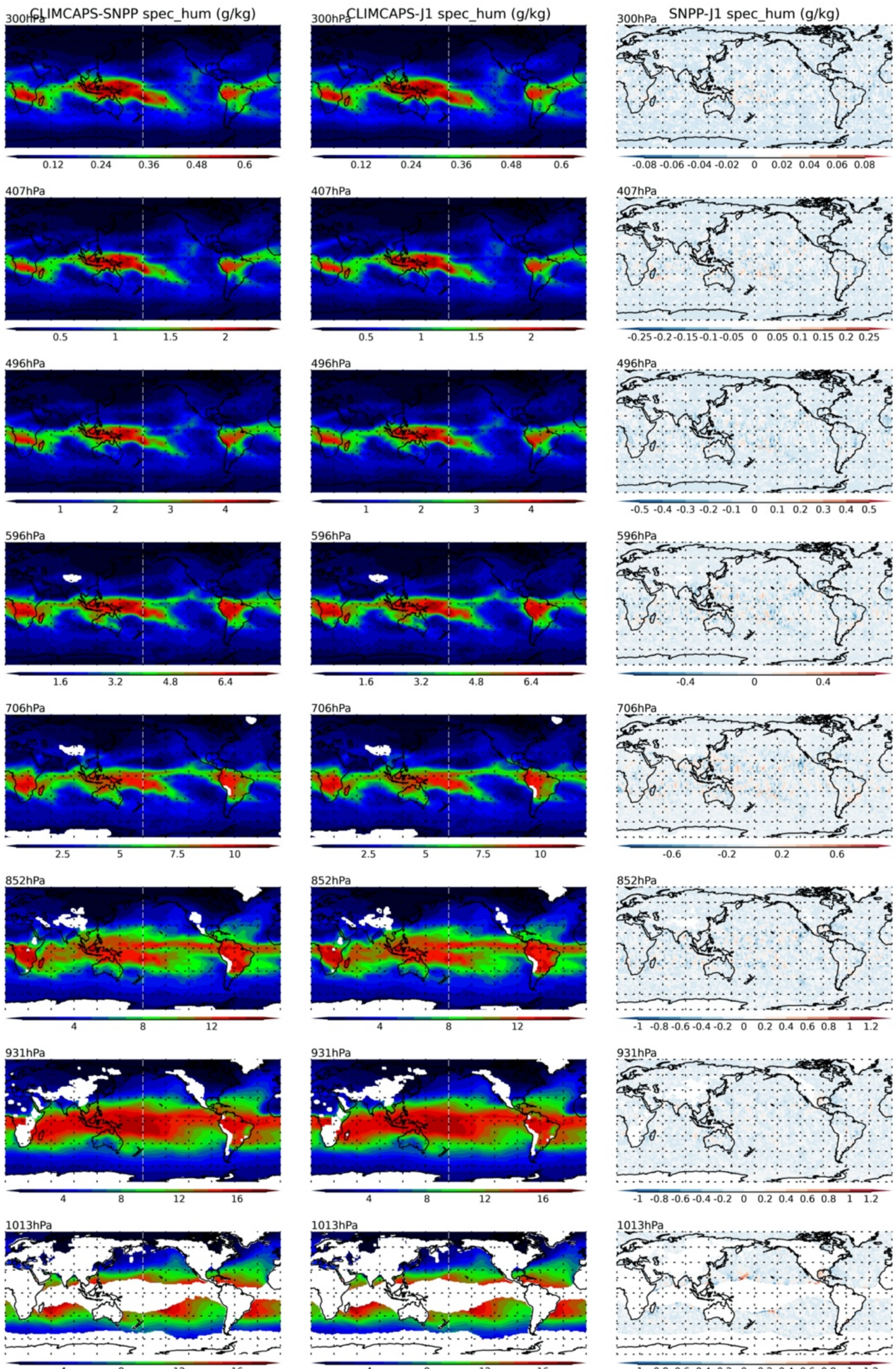


Figure A.9. Tropospheric spec_hum (g/kg) for January 2019 at the eight tropospheric pressure levels (different rows) from CLIMCAPS-SNPP (left column), CLIMCAPS-JPSS1 (middle column), and their differences (right column).

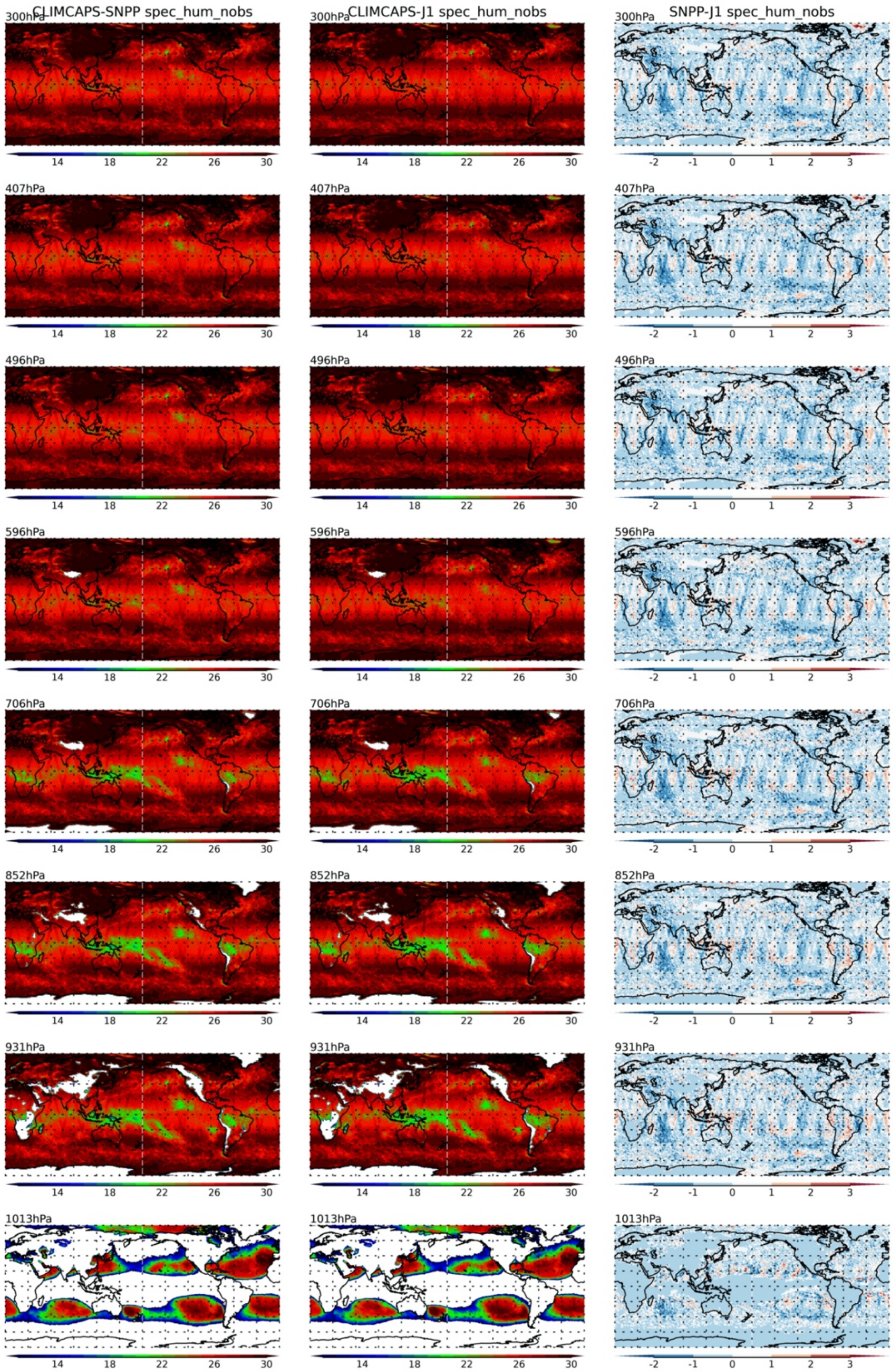


Figure A.10. Tropospheric spec_hum_nobs for January 2019 at the eight tropospheric pressure levels (different rows) from CLIMCAPS-SNPP (left column), CLIMCAPS-JPSS1 (middle column), and their differences (right column).

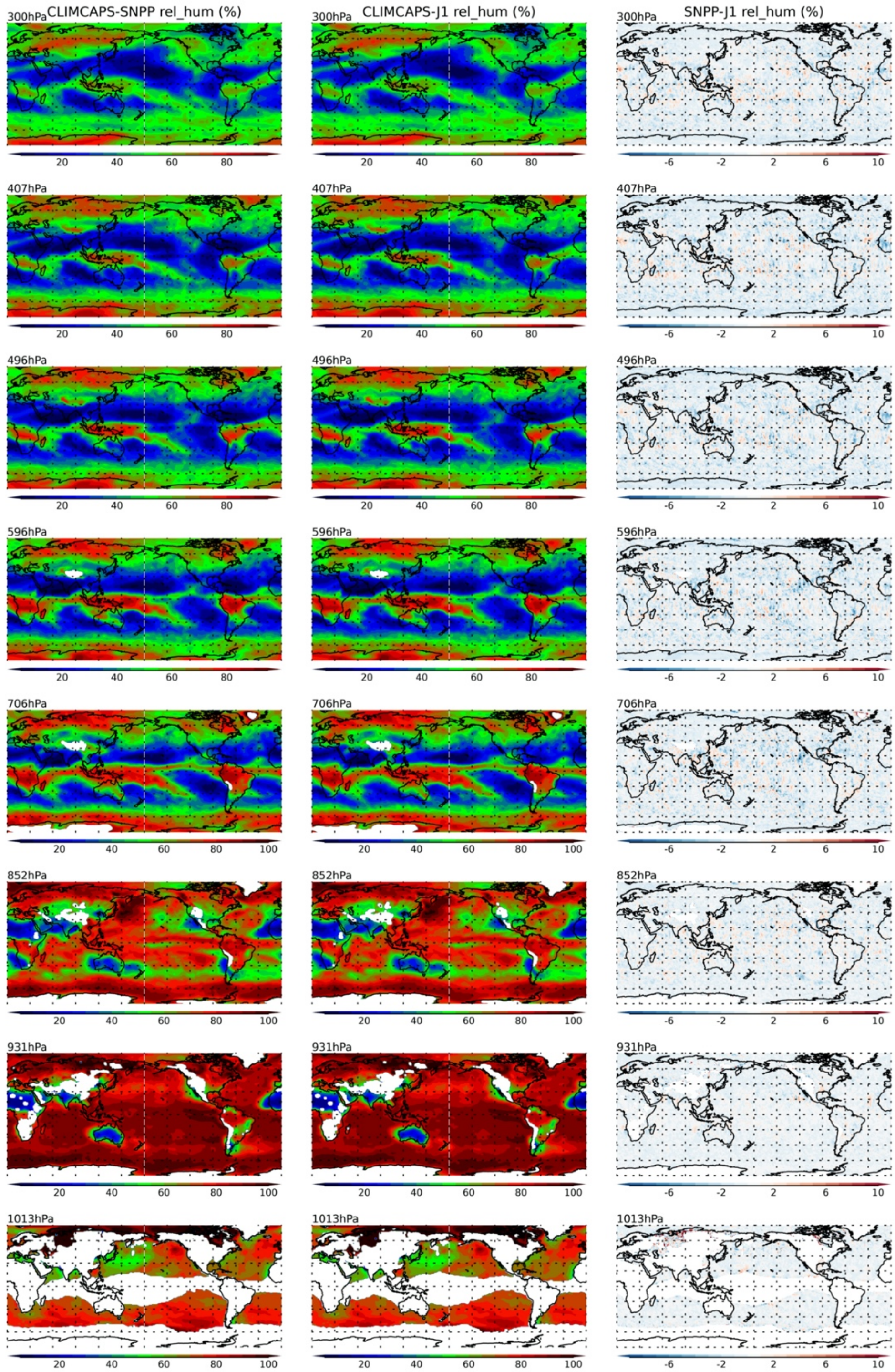


Figure A.11. Tropospheric rel_hum (%) for January 2019 at the eight tropospheric pressure levels (different rows) from CLIMCAPS-SNPP (left column), CLIMCAPS-JPSS1 (middle column), and their differences (right column).

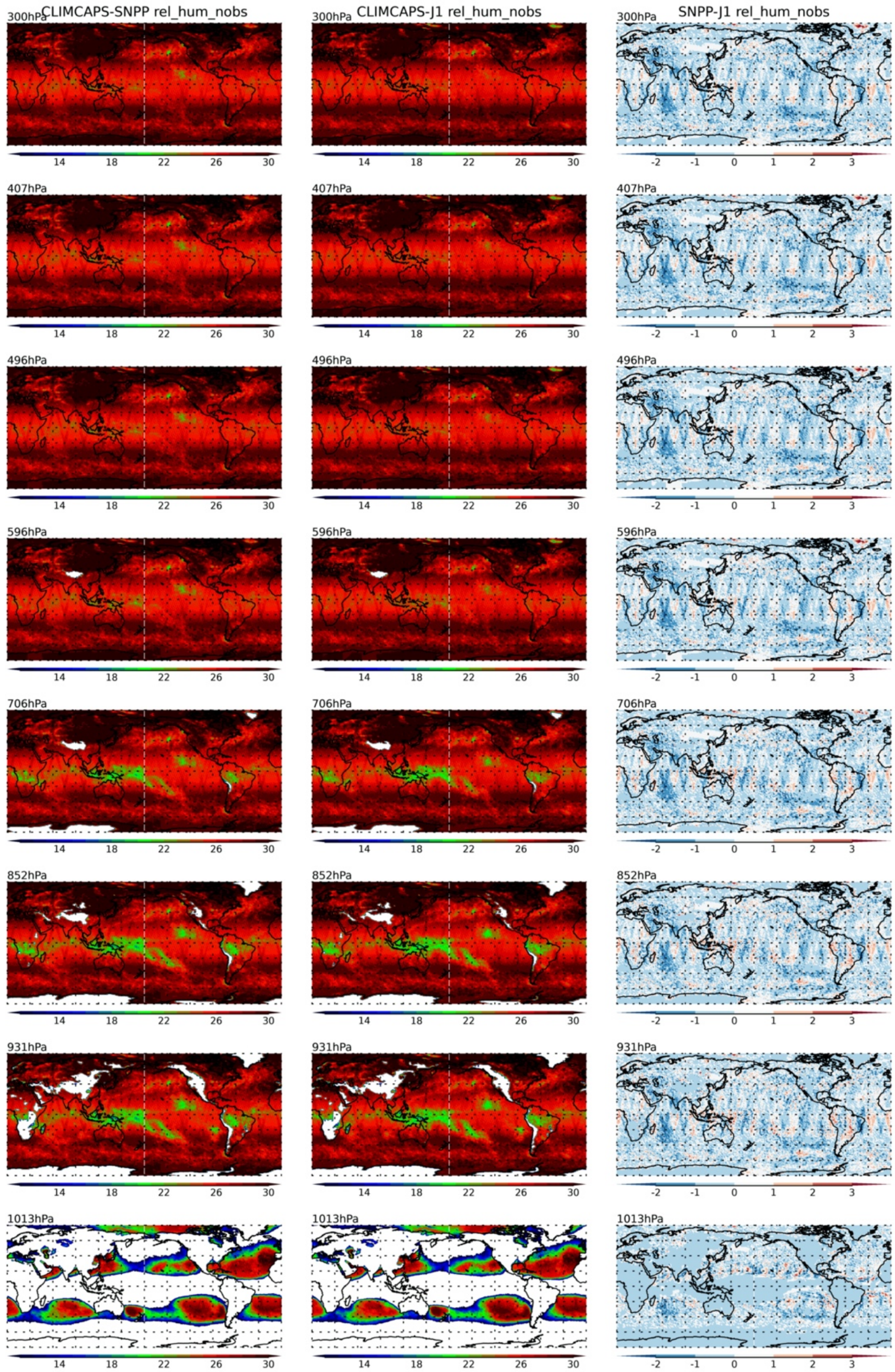


Figure A.12. Tropospheric rel_hum_nobs for January 2019 at the eight tropospheric pressure levels (different rows) from CLIMCAPS-SNPP (left column), CLIMCAPS-JPSS1 (middle column), and their differences (right column).

A.6 References

Tian, B., and T. J. Hearty, 2020: Estimating and removing the sampling biases of the AIRS Obs4MIPs V2 data. *Earth Space Sci.*, **7,** 8, doi:10.1029/2020ea001438.

Tian, B., and X. Dong, 2020: The double-ITCZ bias in CMIP3, CMIP5, and CMIP6 models based on annual mean precipitation. *Geophys. Res. Lett.*, **47,** 11, doi:10.1029/2020gl087232.

Tian, B., E. J. Fetzer, and E. M. Manning, 2019: The Atmospheric Infrared Sounder Obs4MIPs version 2 data set. *Earth Space Sci.*, **6,** 324-333, doi:10.1029/2018ea000508.

Tian, B., E. J. Fetzer, B. H. Kahn, J. Teixeira, E. Manning, and T. Hearty, 2013: Evaluating CMIP5 models using AIRS tropospheric air temperature and specific humidity climatology. *J. Geophys. Res.*, **118,** 114-134, doi:10.1029/2012jd018607.

Appendix B: L3 Interface Specification

The tables in this appendix show the interface specification for all of the dimensions, global attributes, and variables in the CLIMCAPS L3 product types. Even though the tables are for a CLIMCAPS-SNPP Level 3 Daily product, the attributes and variables are found in all three satellites. Where differences occur are in the values.

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 Interface Specification

Interface Specification Version 02.02.04

Global Groups

Path	Description
	Science means
/nobs	Counts of observations
/sdev	Standard deviations
/dof	Degrees of freedom

Global Dimensions

Name	Size	Description
utc_tuple	8	parts of UTC time
air_pres	100	Fine atmospheric pressure levels starting from the top
air_pres_h2o	66	Fine atmospheric pressure levels starting from the top
surf_wnum_ir	4	IR surface emissivity reporting wavenumbers
orbit_pass	2	orbit pass: {Ascending/Day, Descending/Night}
lon	360	1-degree longitude grid
lat	180	1-degree latitude grid
cld_pres_lay	3	3 coarse cloud layers: {high, mid, low}
bnds_1d	2	Boundaries for 1-d fields like lon: min, max

Global Attributes

Name	Type	Size	Value	Description
keywords	string	1	ATMOSPHERE > ATMOSPHERIC TEMPERATURE > UPPER AIR TEMPERATURE\, ATMOSPHERE > ATMOSPHERIC WATER VAPOR > WATER VAPOR	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).
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	CrIS and ATMS 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'.
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_CLIMCAPS_QCx_NSR	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.

Name	Type	Size	Value	Description
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	Unassigned	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	Unassigned	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	Unassigned	Processing facility that produced this file
project	string	1	Sounder SIPS	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	Unassigned	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	Unassigned	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	Unassigned	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

Name	Type	Size	Value	Description
				current metadata and format.
geospatial_bounds	string	1	POLYGON ((-180.0 -90.0\, 180.0 -90.0\, 180.0 90.0\, -180.0 90.0\, -180.0 -90.0))	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 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 [-180, 180) 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		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		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		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		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

Name	Type	Size	Value	Description
				geospatial_lon_max indicate the bounding box extends from geospatial_lon_max, through the longitude range discontinuity meridian (either the antimeridian for -180:180 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 180 and -180 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, 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	v01.00.00	Version identifier of the data file or product as assigned by the data creator.

Name	Type	Size	Value	Description
				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	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.
platform_vocabulary	string	1	GCMD:GCMD Keywords	Controlled vocabulary for the names used in the "platform" attribute.
product_name_platform	string	1	SNPP	Platform name as it appears in product_name
instrument	string	1	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.
instrument_vocabulary	string	1	GCMD:GCMD Keywords	Controlled vocabulary for the names used in the "instrument" attribute.
product_name_instr	string	1	CRIMSS	Instrument name as it appears in product_name
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)

Name	Type	Size	Value	Description
product_name_producer	string	1	T	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	Unassigned	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	Unassigned	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	Unassigned	digital signature
identifier_product_doi_authority	string	1	Unassigned	digital signature source
algorithm_version	string	1		The version of the algorithm in whatever format is selected by the

Name	Type	Size	Value	Description
				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.
production_host	string	1		Identifying information about the host computer for this run. (Output of linux "uname -a" command.)
format_version	string	1	v02.02.04	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	Level-3 CLIMCAPS SNPP CrIMSS	a succinct description of what is in the dataset. (= ECS long name)
summary	string	1	The Level-3 CLIMCAPS daily product includes atmospheric state retrieval products from the CLIMCAPS algorithm for one day. These include	A paragraph describing the dataset, analogous to an abstract for a paper.

Name	Type	Size	Value	Description
			temperature and water vapor profiles as well as cloud and surface products and minor gases.	
shortname	string	1	SNDRSNIML3DxCCP	ECS Short Name
metadata_link	string	1	Unassigned	A URL that gives the location of more complete metadata. A persistent URL is recommended for this attribute.
references	string	1		ATDB and design documents describing processing algorithms. Can be empty.

Global Variables

Name	Type	Dimensions	Description	Units	Ancillary Variables
air_pres	float32	air_pres	pressure levels	Pa	
air_pres_h2o	float32	air_pres_h2o	H2O vapor pressure levels	Pa	
air_temp	float32	orbit_pass, air_pres, lat, lon	air temperature profile on 100 levels	Kelvin	err, qc
surf_air_temp	float32	orbit_pass, lat, lon	near-surface air temperature (~2 meters above surface)	Kelvin	err, qc
surf_temp	float32	orbit_pass, lat, lon	radiative temperature of the surface	Kelvin	err, qc
h2o_vap_tot	float32	orbit_pass, lat, lon	total precipitable water vapor	kg / m2	err, qc
spec_hum	float32	orbit_pass, air_pres_h2o, lat, lon	mass fraction of water vapor in moist air	kg / kg	err, qc
rel_hum	float32	orbit_pass, air_pres_h2o, lat, lon	relative humidity over equilibrium phase	unitless	err, qc

Name	Type	Dimensions	Description	Units	Ancillary Variables
gp_hgt	float32	orbit_pass, air_pres, lat, lon	Geopotential is the sum of the specific gravitational potential energy relative to the geoid and the specific centripetal potential energy. Geopotential height is the geopotential divided by the standard acceleration due to gravity.	m	err, qc
o3_tot	float32	orbit_pass, lat, lon	Total column ozone. (Multiply by 4.670e5 to convert to Dobson Units from kg m^-2)	kg / m2	err, qc
ch4_mmr_midtrop	float32	orbit_pass, lat, lon	Methane mass mixing ratio to dry air at 40000 Pa, near the peak of sensitivity	kg / kg	err, qc
co_mmr_midtrop	float32	orbit_pass, lat, lon	Carbon Monoxide mass mixing ratio to dry air at 50000 Pa, near the peak of sensitivity	kg / kg	err, qc
co2_vmr_uppertrop	float32	orbit_pass, lat, lon	Carbon Monoxide volume mixing ratio to dry air between 20,000-50,000 Pa, near the peak of sensitivity	m3 / m3	
surf_ir_emis	float32	orbit_pass, surf_wnum_ir, lat, lon	infrared surface emissivity	unitless	err, qc
cld_frac	float32	orbit_pass, lat, lon	effective cloud fraction	unitless	err, qc
lay_cld_frac	float32	orbit_pass, cld_pres_lay, lat, lon	coarse layer effective cloud fraction	unitless	
cld_top_pres	float32	orbit_pass, lat, lon	cloud top pressure	Pa	err, qc
tpause_pres	float32	orbit_pass, lat, lon	tropopause pressure, where tropopause is determined according to the WMO definition	Pa	qc
surf_alt	float32	orbit_pass, lat, lon	mean surface altitude wrt earth model for observations	m	
prior_surf_pres	float32	orbit_pass, lat, lon	surface pressure from forecast for observations	Pa	
obs_time_tai93	double	orbit_pass	Nominal midtime for observations included in grid	seconds since 1993-01-01 00:00	bnds
obs_time_utc	uint16	orbit_pass,	Nominal midtime for observations included in grid as an array of integers:		

Name	Type	Dimensions	Description	Units	Ancillary Variables
		utc_tuple	year, month, day, hour, minute, second, millisec, microsec		
lon	float32	lon	Degrees longitude	degrees_east	bnds
lat	float32	lat	Degrees latitude	degrees_north	bnds
cld_pres_lay	float32	cld_pres_lay	coarse cloud pressure layers	Pa	bnds
cld_pres_lay_lbl	string	cld_pres_lay	Altitude labels for cloud pressure layers		
surf_wnum_ir	float32	surf_wnum_ir	Infrared surface emissivity frequencies	cm-1	
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	
utc_tuple_lbl	string	utc_tuple	names of the elements of UTC when it is expressed as an array of integers year,month,day,hour,minute,second,millisecond,microsecond		

dof Variables

Name	Type	Dimensions	Description	Units	Ancillary Variables
air_temp_dof	float32	orbit_pass, lat, lon	The trace of the averaging kernel matrix as a measure of the number of pieces of information about the air temperature profile provided by the physical retrieval step.	unitless	
surf_temp_dof	float32	orbit_pass, lat, lon	The trace of the averaging kernel matrix as a measure of the number of pieces of information about the surface provided by the physical retrieval step.	unitless	
h2o_vap_dof	float32	orbit_pass, lat, lon	The trace of the averaging kernel matrix as a measure of the number of pieces of information about the water vapor profile provided by the physical retrieval step.	unitless	
o3_dof	float32	orbit_pass, lat, lon	The trace of the averaging kernel matrix as a measure of the number of pieces of information about the ozone profile provided by the physical retrieval step.	unitless	
ch4_dof	float32	orbit_pass, lat, lon	The trace of the averaging kernel matrix as a measure of the number of pieces of information about the methane profile provided by the physical retrieval step.	unitless	

Name	Type	Dimensions	Description	Units	Ancillary Variables
co_dof	float32	orbit_pass, lat, lon	The trace of the averaging kernel matrix as a measure of the number of pieces of information about the carbon monoxide profile provided by the physical retrieval step.	unitless	
co2_dof	float32	orbit_pass, lat, lon	The trace of the averaging kernel matrix as a measure of the number of pieces of information about the carbon dioxide profile provided by the physical retrieval step.	unitless	

nobs Variables

Name	Type	Dimensions	Description	Units	Ancillary Variables
air_temp_nobs	float32	orbit_pass, air_pres, lat, lon	air_temp number of observations	unitless	
surf_air_temp_nobs	float32	orbit_pass, lat, lon	surf_air_temp number of observations	unitless	
surf_temp_nobs	float32	orbit_pass, lat, lon	surf_temp number of observations	unitless	
h2o_vap_tot_nobs	float32	orbit_pass, lat, lon	h2o_vap_tot number of observations	unitless	
spec_hum_nobs	float32	orbit_pass, air_pres_h2o, lat, lon	spec_hum number of observations	unitless	
rel_hum_nobs	float32	orbit_pass, air_pres_h2o, lat, lon	rel_hum number of observations	unitless	
gp_hgt_nobs	float32	orbit_pass, air_pres, lat, lon	gp_hgt number of observations	unitless	
o3_tot_nobs	float32	orbit_pass, lat, lon	o3_tot number of observations	unitless	
ch4_mmr_midtrop_nobs	float3	orbit_pass, lat, lon	ch4_mmr_midtrop number of observations	unitless	

Name	Type	Dimensions	Description	Units	Ancillary Variables
	2				
co_mmr_midtrop_nobs	float32	orbit_pass, lat, lon	co_mmr_midtrop number of observations	unitless	
co2_vmr_uppertrop_nobs	float32	orbit_pass, lat, lon	co2_vmr_uppertrop number of observations	unitless	
surf_ir_emis_nobs	float32	orbit_pass, surf_wnum_ir, lat, lon	surf_ir_emis number of observations	unitless	
cld_frac_nobs	float32	orbit_pass, lat, lon	cld_frac number of observations	unitless	
cld_top_pres_nobs	float32	orbit_pass, lat, lon	cld_top_pres number of observations	unitless	
tpause_pres_nobs	float32	orbit_pass, lat, lon	tpause_pres number of observations	unitless	
surf_alt_nobs	float32	orbit_pass, lat, lon	surf_alt number of observations	unitless	
prior_surf_pres_nobs	float32	orbit_pass, lat, lon	prior_surf_pres number of observations	unitless	
nobs_max	float32	orbit_pass, lat, lon	Maximum number of observations including those for which no value was retrieved. Can be used with *_nobs to calculate yield.	unitless	

sdev Variables

Name	Type	Dimensions	Description	Units	Ancillary Variables
air_temp_sdev	float32	orbit_pass, air_pres, lat, lon	air_temp standard deviation	Kelvin	

surf_air_temp_sdev	float32	orbit_pass, lat, lon	surf_air_temp standard deviation	Kelvin	
surf_temp_sdev	float32	orbit_pass, lat, lon	surf_temp standard deviation	Kelvin	
h2o_vap_tot_sdev	float32	orbit_pass, lat, lon	h2o_vap_tot standard deviation	kg / m2	
spec_hum_sdev	float32	orbit_pass, air_pres_h2o, lat, lon	spec_hum standard deviation	kg / kg	
rel_hum_sdev	float32	orbit_pass, air_pres_h2o, lat, lon	rel_hum standard deviation	unitless	
gp_hgt_sdev	float32	orbit_pass, air_pres, lat, lon	gp_hgt standard deviation	m	
o3_tot_sdev	float32	orbit_pass, lat, lon	o3_tot standard deviation	kg / m2	
ch4_mmr_midtrop_sdev	float32	orbit_pass, lat, lon	ch4_mmr_midtrop standard deviation	kg / kg	
co_mmr_midtrop_sdev	float32	orbit_pass, lat, lon	co_mmr_midtrop standard deviation	kg / kg	
co2_vmr_uppertrop_sdev	float32	orbit_pass, lat, lon	co2_vmr_uppertrop standard deviation	m3 / m3	
surf_ir_emis_sdev	float32	orbit_pass, surf_wnum_ir, lat, lon	surf_ir_emis standard deviation	unitless	
cld_top_pres_sdev	float32	orbit_pass, lat, lon	cld_top_pres standard deviation	Pa	
tpause_pres_sdev	float32	orbit_pass, lat, lon	tpause_pres standard deviation	Pa	
surf_alt_sdev	float32	orbit_pass, lat, lon	surf_alt standard deviation	unitless	
prior_surf_pres_sdev	float32	orbit_pass, lat, lon	prior_surf_pres standard deviation	Pa	