Installation Instructions for the Community Satellite Processing Package (CSPP) Microwave integrated Retrieval System (MiRS) Software Version 4.0

University of Wisconsin-Madison, Space Science and Engineering Center (SSEC)

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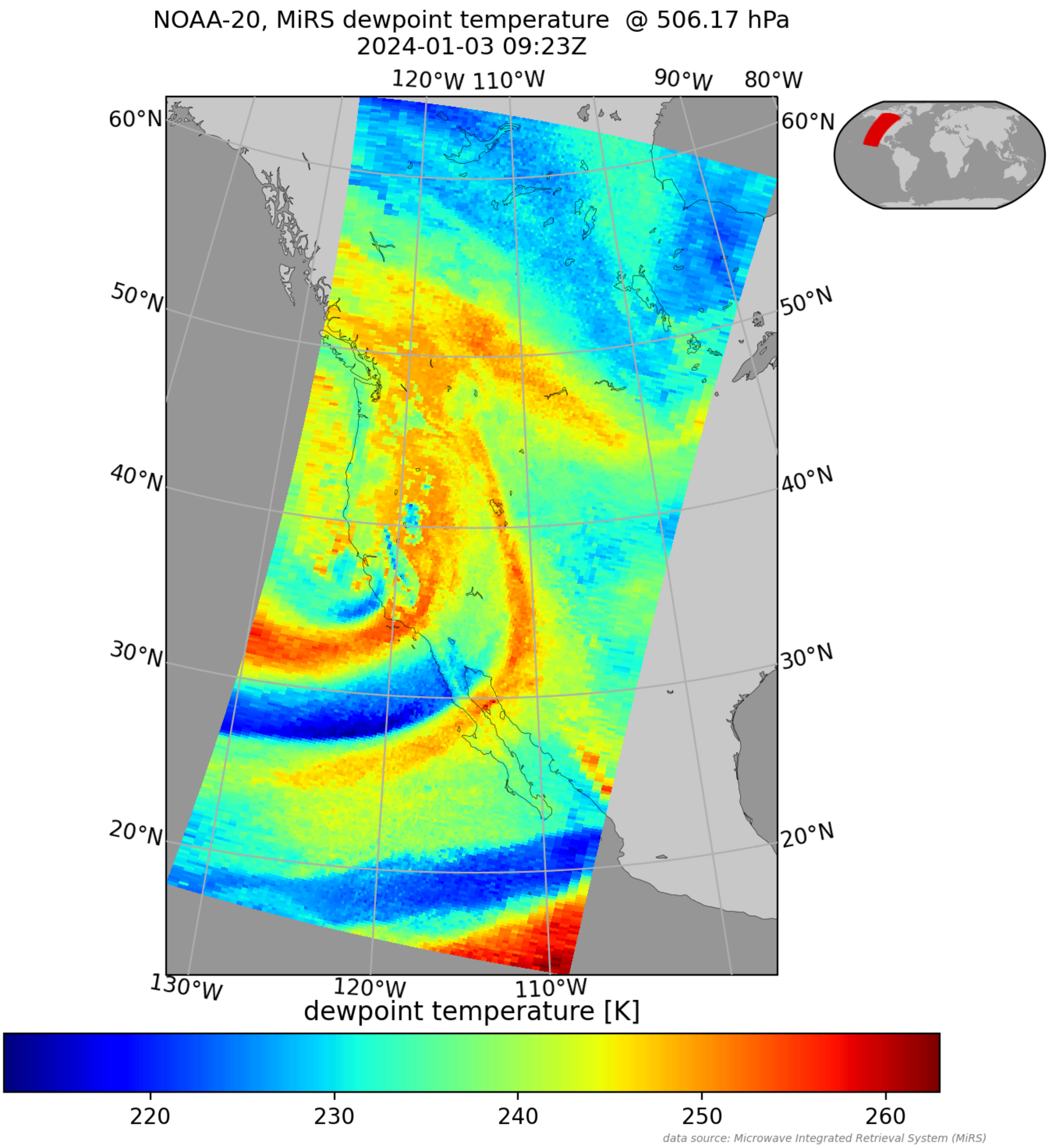

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Section 1: Introduction

1.1 Overview

This document contains instructions for installation and operation of the Community Satellite Processing Package (CSPP) release of the NOAA/NESDIS/STAR Microwave integrated Retrieval System (MiRS) software for retrieving atmospheric profiles and surface properties from direct broadcast NOAA-21, -20, SNPP ATMS Sensor Data Record (SDR), and NOAA-19 and Metop-B, -C AMSU-A/MHS Level 1B data. The MiRS team is led by Quanhua (Mark) Liu and Chris Grassotti at the NOAA NESDIS Center for Satellite Applications and Research (STAR). This CSPP release (CSPP_MIRS) provides MiRS version v11r9 adapted and tested for operation in a real-time Direct Broadcast (DB) environment. The software contains binary executable files and supporting static data files. A separate test data package can be downloaded for verifying a successful installation.

The CSPP_MIRS software is available from the CSPP website:

https://cimss.ssec.wisc.edu/cspp/

Software, test data, and documentation may be downloaded from this web site. Please use the ‘Contact Us’ form on the website to submit any questions or comments about CSPP. Source code for the MiRS package is not included in this release. Source code can be accessed by following the instructions at this NOAA MiRS website:

https://www.star.nesdis.noaa.gov/mirs/download.php

For more information on MiRS, please visit: https://www.star.nesdis.noaa.gov/mirs.

1.2 What’s New in Version 4.0?

- Software is no longer distributed in a container, therefore apptainer is no longer required.
- Software algorithm updated to Version v11r9.
- Added support for NOAA-21 ATMS.
- Removed support for NOAA-18 and Metop-A missions.
- Target Operating System is Rocky Linux 8.8.
- Run script options have changed. Please see **Sections 3.1** and **3.2.**

1.3 System requirements

System requirements for the CSPP_MIRS v4.0 software are as follows:

- Intel or AMD CPU with 64-bit instruction support.
- 16 GB RAM.
- Rocky Linux 8.8 64-bit Linux; the software has also been tested on Rocky Linux 9.3.
- 2 GB of disk space (plus space for your own DB data and CSPP_MIRS products).

Linux terminal commands included in these instructions assume that the bash shell is used.

1.4 Implementation Notes

The directory/file structure of `CSPP_MIRS_4_0` (pruned for the purposes of this document) is shown below:

```
CSPP_MIRS_4_0/
|-- anc                      Static ancillary data.
|-- bin                      CSPP environment and wrapper scripts.
|-- libexec                  Binaries used in creation of products.
cspp_mirs_env.sh             CSPP MiRS environment script.
```

The CSPP_MIRS wrapper script `run_mirs.bash` creates a temporary working directory for each run. At the end of processing, data products are moved out of the temporary working directory and, optionally but by default, the temporary directory is removed.

1.5 Input Data Requirements

CSPP_MIRS produces single Field-of-View (FOV) retrievals from input AMSU-A/MHS Level 1B data and from ATMS SDR calibrated/geolocated data. Metop-B/C and NOAA-19 retrievals are, by default, at the resolution of MHS, and AMSU-A are interpolated to match. NOAA-21/20 and Suomi-NPP retrievals are at the full resolution of ATMS. **Table 1** provides information on the satellites and instruments supported by the CSPP_MIRS software, as well as the required input files and their naming conventions.

Table 1: CSPP_MIRS satellite input data file requirements.

Satellite	**Instrument**	**Direct Broadcast Processing Software**	**Required input: Example Filenames (Direct Broadcast form)**
NOAA-21	ATMS	CSPP SDR v4.0+ (or IDPS/AWS SDR)	Radiance, antenna temperature, geolocation: SATMS_j02*.h5, TATMS_j02*.h5, GATMO_j02*.h5
NOAA-20	ATMS	CSPP SDR v4.0+ (or IDPS/AWS SDR)	Radiance, antenna temperature, geolocation: SATMS_j01*.h5, TATMS_j01*.h5, GATMO_j01*.h5
Suomi-NPP	ATMS	CSPP SDR v4.0+ (or IDPS/AWS SDR)	Radiance, antenna temperature, geolocation: SATMS_npp*.h5, TATMS_npp*.h5, GATMO_npp*.h5
NOAA-19	AMSUA-A + MHS	AAPP v8+	Level 1B: amsual1b_noaa19*.l1b, mhsl1b_noaa19*.l1b
Metop-B	AMSUA-A + MHS	AAPP v8+	Level 1B: amsual1b_M01*.l1b, mhsl1b_M01*.l1b
Metop-C	AMSUA-A + MHS	AAPP v8+	Level 1B: amsual1c_M03*.l1b, mhsl1c_M03*.l1c

CSPP is the Community Satellite Processing Package and in this instance refers to the SDR generating components of CSPP:

https://cimss.ssec.wisc.edu/cspp/

IDPS is the Interface Data Processing Segment developed by Raytheon Intelligence and Information Systems. JPSS ATMS products created by IDPS are available from the CLASS archive:

https://www.class.noaa.gov/

NOAA Open Data Dissemination Program (NODD) also provides free access to JPSS ATMS data via Amazon Web Services (AWS):

https://registry.opendata.aws/noaa-jpss/

AAPP is the ATOVS (Advanced TIROS Operational Vertical Sounder) and AVHRR (Advanced High Resolution Radiometer) Processing Package distributed by the Met Office:

https://www.nwpsaf.eu/site/software/aapp

Dynamic Ancillary Data

The SnowFall Rate (SFR) product (and associated Prob_SF="Probability of falling snow") is the only product that requires dynamic ancillary data in the form of Global Forecast System (GFS) Numerical Weather Prediction (NWP) model files in GRIB 2 format. There is a flag that can be provided to the main run script (--noSFR) that will prevent the SFR product from being created, and hence not fetch any ancillary data.

SFR is available for all supported missions. The specific GFS files used are 0.5 degree spatial resolution files that comprise 3-hourly forecast times based off of 6-hourly analyses. If needed, they are, by default, automatically downloaded from the CSPP ancillary data server at:

http://jpssdb.ssec.wisc.edu/cspp_v_2_0/ancillary/

The software requires the f000 through f012 three hourly forecast timesteps (5 files) that bound the data time most closely. They have names like:

```
gfs.t00z.pgrb2.0p50.f012.20231128
```

1.6 Output Products

The MiRS retrieval algorithm creates two NetCDF4 output product files, an Imager (IMG) and a Sounder (SND) product, containing the following parameters. For a complete set of output products for both the IMG and SND NetCDF files, please see the **Appendix**.

Official Validated Products for NOAA-21, NOAA-20, Suomi-NPP, NOAA-19, Metop-C and Metop-B

- Temperature profile over open water ocean
- Humidity profile over open water ocean
- Humidity Profile over non-coastal land
- Total Precipitable Water (TPW) over open water ocean
- Total Precipitable Water over non-coastal land
- Land surface temperature
- Surface Emissivity over land and snow
- Surface Type Classification
- Snow Water Equivalent (SWE)
- Sea Ice Concentration (SIC)
- Snow Cover Extent (SCE), based on the SWE
- Vertically-Integrated Non-precipitating Cloud Liquid Water (CLW) over open water ocean
- Vertically-Integrated Ice Water Path (IWP)
- Vertically-Integrated Rain Water Path (RWP)
- Rainfall Rate (RR) over open water ocean and non-coastal, non-snow-covered land surface types
- Snow fall rate and Probability of falling snow
- Effective grain size of snow (over snow-covered land surface)*
- Multi-Year (MY) Type Sea Ice Concentration*
- First-Year (FY) Type Sea Ice Concentration*

*Note that FY and MY Sea Ice Concentration, as well as Snow Grain Size are not officially operational, but preliminary products, which is a higher maturity level than experimental status.

The following products are also produced experimentally for NOAA-19, Metop-B, Metop-C, Suomi-NPP, and NOAA-20. Note that they lack a thorough validation due to the absence of reliable ground truth measurements. These are made available to users for the purpose of evaluating their usefulness.

- Cloud Liquid Water Profile (CLWP) over ocean
- Surface Temperature (skin) extended to snow-covered land surface type
- Surface Temperature (skin) extended to open ocean water

1.7 Disclaimer

Original scripts and automation included as part of this package are distributed under the GNU GENERAL PUBLIC LICENSE agreement version 3. Binary executable files included as part of this software package are copyrighted and licensed by their respective organizations, and distributed consistent with their licensing terms.

The University of Wisconsin-Madison Space Science and Engineering Center (SSEC) makes no warranty of any kind with regard to the CSPP software or any accompanying documentation, including but not limited to the implied warranties of merchantability and fitness for a particular purpose. SSEC does not indemnify any infringement of copyright, patent, or trademark through the use or modification of this software.

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Section 2: Installation and Configuration

2.1 Overview

This software package contains the CSPP_MIRS microwave sensor retrieval system based on the NOAA MiRS version 11.9 software bundled as a stand-alone processing package. The NOAA MiRS Version 11.9 External User's Manual and System Maintenance Manuals are included with this distribution, containing detailed information about the processing system, including input, output, static and semi-static data files.

2.2 Installation of CSPP_MIRS Software

Download the following file from the CSPP website (https://cimss.ssec.wisc.edu/cspp/)

```
CSPP_MIRS_V4.0.tar.gz
```

Install the software as shown below (a new directory named `CSPP_MIRS_4_0` will be created):

```
tar -xf CSPP_MIRS_V4.0.tar.gz
```

Set the `CSPP_MIRS_HOME` environment variable to the name of the directory where CSPP_MIRS is installed, and execute the CSPP MIRS environment script as shown below:

```
export CSPP_MIRS_HOME=$HOME/CSPP_MIRS_4_0          # Edit for your install directory
source $CSPP_MIRS_HOME/cspp_mirs_env.sh
```

If you wish you can edit `cspp_mirs_env.sh` to set your installation directory.

2.3 Installation of CSPP_MIRS Test Data

Test data files are available in a tar file named `CSPP_MIRS_TESTDATA_V4.0.tar.gz`. They unpack into a directory named `CSPP_MIRS_TESTDATA_4_0` on the command:

```
tar -xf CSPP_MIRS_TESTDATA_V4.0.tar.gz
```

Section 3: CSPP_MIRS Software

3.1 CSPP_MIRS Driver Script

The principal driver script is `CSPP_MIRS_4_0/bin/run_mirs.bash`. This bash script checks for the `CSPP_MIRS_HOME` environment variable, and then invokes the Python script `$CSPP_MIRS_HOME/libexec/scripts/cspp_mirs.py`, which contains all the remaining logic to organize MiRS processing. The only required argument is the path and directory name where the input data exists. The directory should contain data from only one mission type, for example NOAA-21 ATMS.

This logic includes creating a temporary directory, pre-processing input files, copying output netCDF4 files to the designated target directory, and purging the temporary directory.

Several command line options are available for `run_mirs.bash` as shown below:

```
run_mirs.bash

usage: run_mirs.bash [-h] [-W work_dir] [-d DYNANC] [-v] [-l] [-q]
                     [-p PROCESSOR] [-f] [--noSFR] [-a] [--noagg]
                     [-x] [-c] [--noclean]
                     input_directory [input_directory ...]
Mandatory Arguments:

  input_directory   Directory containing satellite data from a single satellite.
                       Supported satellite, sensor combinations are:
                       NOAA-21,NOAA-20,SNPP ATMS and NOAA-19,Metop-B,-C AMSU-A/MHS.

                    Direct Broadcast Filename Formats:
                        JPSS ATMS - {GATMO,SATMS,TATMS}_{j02,j01,npp}*.h5
                        NOAA AMSU/MHS - {amsua,mhs}_l1b_noaa19_*.l1b
                         Metop AMSU/MHS - {amsua,mhs}l1b_{M01,M03}_*.l1b

                    NOAA CLASS Global Filename Formats
                        ATMS - {GATMO,SATMS,TATMS}_{j02,j01,npp}*.h5
                        AMSU/MHS NOAA-19 - NSS.AMAX.NP.*.SV, NSS.MHSX.NP.*.SV
                        AMSU/MHS Metop-B - NSS.AMAX.M1.*.SV, NSS.MHSX.M1.*.SV
                        AMSU/MHS Metop-C - NSS.AMAX.M3.*.SV, NSS.MHSX.M3.*.SV


Optional Arguments:

    -h, --help          Show this help message and exit.

    -W work_dir, --work-dir work_dir
                        Directory in which all activity occurs, defaults to
                          current dir.

    -d DYNANC, --dynanc DYNANC
                        Path to root of dynamic ancillary data tree; beneath
                          here data are organized as per SSEC remote ancillary
                          server for CSPP, i.e. %Y_%m_%d_%j where %Y is 4-digit
                          year, %m is 2-digit month, %d is 2-digit day of month
                          and %j is 3-digit day of year. [default: environment
                          var. $CSPP_DYNAMIC_ANCIL_DIR].

    -v, --verbosity      Increases verbosity 1 level ERROR-WARNING-INFO-DEBUG.

    -l, --local          Disable download of remote ancillary data to cache.

    -q, --quarantine     Disable download of remote ancillary data to cache.
                           Same as -l.

    -p PROCESSOR, --processor PROCESSOR
                        Number of processors to use for granule processing.
                          [default: --processors=1, max is 32].

    -f, --SFR          Generate SnowFall Rate (SFR). The only step that
                          requires ancillary (GFS) data to be fetched, so we
                          recommended --noSFR if you do not need this product.
                          [default: --SFR, --noSFR is the contrary option].

    -a, --agg           Aggregated output is produced.
                          [default: --agg; --noagg is the contrary option].

    -x, --xfiles        Use the NOAA filenames for AMSUA/MHS L1B files
                          [default: Direct Broadcast filenames].

    -c, --clean         Deletes temporary working directory under WORK_DIR at
                          process completion [default]. -–noclean is the contrary
                          option.
```

For a complete set of options, type `run_mirs.bash -h`

3.2 Execution Changes From Previous Releases

Changes have been made to the arguments and options available in CSPP MiRS Version 4.0. The significant changes are:

-s: This argument has been removed. It was previously used to supply the input data satellite name. This is now determined from the files provided in the input data directory argument. Only one satellite/instrument file type should exist in the input directory. Mixed satellite/instrument files in the input directory will result in a failure of the CSPP MiRS execution.

-i: This argument has been removed. It was previously used to point to the directory where the input files were located. This has been replaced by the use of the input directory as the sole argument.

-a: This option now affects only the output product. The default is for the output to be aggregated. If --noagg is used, the output MiRS NetCDF files will be unaggregated granules.

-l: This option is common to other CSPP packages if the user wants to execute the software without an internet connection. It is the same as using the **-q** option.

Examples:

run_mirs.bash -p 6 --noagg /atms/sdrs

run_mirs.bash -a -p 4 -W /cspp/work -d /CSPP/EDR/anc/cache /noaa19/input

run_mirs.bash -d /dynamic_anc --noSFR --noclean /metopb/l1b

An example of NOAA (--xfiles) versus Direct Broadcast names for Metop-C is shown below:

NOAA (--xfiles)	Direct Broadcast (default)
NSS.AMAX.M3.D23328.S0128.E0311.B2618485.SV	amsual1b_M03_20231124_0128_26184.l1b
NSS.MHSX.M3.D23328.S0128.E0311.B2618485.SV	mhsl1b_M03_20231124_0128_26184.l1b

Section 4: Verifying the CSPP MIRS Software Installation

4.1 Running the CSPP MIRS Test Cases

To run the MiRS test cases for five supported satellites/instruments, unpack the test data as shown in **Section 2.3** and then execute the commands below.

```
cd CSPP_MIRS_TESTDATA_4_0
mkdir work
./run_mirs_test.bash
```

The script executes `run_mirs.bash` five times for the direct broadcast instruments that are supported. The test script is shown below:

```
#!/bin/bash
# Run the CSPP MiRS test script.
# Creates output products for 5 instruments (CSPP MiRS V4.0 which is
# NOAA MiRS v11r9).
if [ ! -d "$CSPP_MIRS_HOME" ]; then
   echo "ERROR: CSPP_MIRS_HOME must be set. Exiting."
   exit 1
fi

echo
echo -----------------------------------------------------
echo "CSPP MiRS test data product creation initiated."
echo -----------------------------------------------------
echo

echo Running noaa21 ...
echo run_mirs.bash -a -d dynanc -W work/noaa21 -p 6 input/noaa21
run_mirs.bash -a -d dynanc -W work/noaa21 -p 6 input/noaa21
echo -----------------------------------------------------
echo

echo Running noaa20 ...
echo run_mirs.bash -a -d dynanc -W work/noaa20 -p 6 input/noaa20
run_mirs.bash -a -d dynanc -W work/noaa20 -p 6 input/noaa20
echo -----------------------------------------------------
echo

echo Running noaa19 ...
echo run_mirs.bash -d dynanc -W work/noaa19 -p 6 input/noaa19
run_mirs.bash -d dynanc -W work/noaa19 -p 6 input/noaa19
echo -----------------------------------------------------
echo

echo Running metopc ...
echo run_mirs.bash -d dynanc -W work/metopc -p 6 input/metopc
run_mirs.bash -d dynanc -W work/metopc -p 6 input/metopc
echo -----------------------------------------------------
echo

echo Running metopb ...
echo run_mirs.bash -d dynanc -W work/metopb -p 6 input/metopb
run_mirs.bash -d dynanc -W work/metopb -p 6 input/metopb
echo -----------------------------------------------------
echo

echo -----------------------------------------------------
echo "CSPP MiRS test data product creation completed."
echo -----------------------------------------------------

exit 0
```

The test script uses 6 CPUs (`-p 6`) for each satellite/instrument execution. Execution takes place in a work directory (`-W`) which is also where the output files are created. The test script uses the `-a` option for the ATMS instrument inputs, meaning that the output files consist of aggregated granules (one `IMG` and one `SND` file). The test script executes in about 10 minutes on modern hardware.

On completion there will be NetCDF files in the work/satellite directories with names like this:

```
metopb/NPR-MIRS-IMG_v11r9_ma1_s202311291549000_e202311291602000_c202312182247550.nc
metopb/NPR-MIRS-SND_v11r9_ma1_s202311291549000_e202311291602000_c202312182247550.nc
metopc/NPR-MIRS-IMG_v11r9_ma3_s202311291503000_e202311291515000_c202312182246310.nc
metopc/NPR-MIRS-SND_v11r9_ma3_s202311291503000_e202311291515000_c202312182246310.nc
noaa19/NPR-MIRS-IMG_v11r9_n19_s202311291519000_e202311291532000_c202312182244520.nc
noaa19/NPR-MIRS-SND_v11r9_n19_s202311291519000_e202311291532000_c202312182244520.nc
noaa20/NPR-MIRS-IMG_v11r9_n20_s202311292004426_e202311292013143_c202312182241290.nc
noaa20/NPR-MIRS-SND_v11r9_n20_s202311292004426_e202311292013143_c202312182241290.nc
noaa21/NPR-MIRS-IMG_v11r9_n21_s202311291846191_e202311291857307_c202312182240140.nc
noaa21/NPR-MIRS-SND_v11r9_n21_s202311291846191_e202311291857307_c202312182240140.nc
```

The files that include **IMG** in their name are the MiRS Image Product files, and the files including **SND** in their filenames are the MiRS Sounding Product files. Both product file types are in NetCDF4 format. For a full list of products contained in the files, please see the **Appendix**.

To verify your output files against the benchmark output files, execute the following command in the `CSPP_MIRS_TESTDATA_4_0` directory:

```
./mirs_verification_script.bash
```

This script compares the Brightness Temperatures (BT) and Rain Rate (RR) arrays in the MiRS `IMG` output files and the Temperature and Water Vapor profiles (PTemp and PVapor) for all levels in the `SND` MiRS output files for each mission/sensor combination. The Latitude and Longitude arrays are also compared. The number of differences found for each array will be printed. There should be few, if any differences.

Section 5: Creating MiRS Product Images

5.1 Displaying MiRS Imager Products

A subset of MiRS Imager (IMG) products are supported by the CSPP Polar2Grid software package. Polar2Grid provides an easy interface to create high quality reprojected images. It is distributed as part of the CSPP software suite. A complete list of the MiRS IMG file supported arrays are described in the Polar2Grid documentation:

https://www.ssec.wisc.edu/software/polar2grid/readers/mirs.html

A MiRS NOAA20 ATMS band 16 image (88 GHz) created from the test data output benchmark data set is shown below. This and other Polar2Grid images are included in the `CSPP_MIRS_TESTDATA_4_0/output/noaa20` benchmark data directory.

The Polar2Grid Version 3 command used to create the image is:

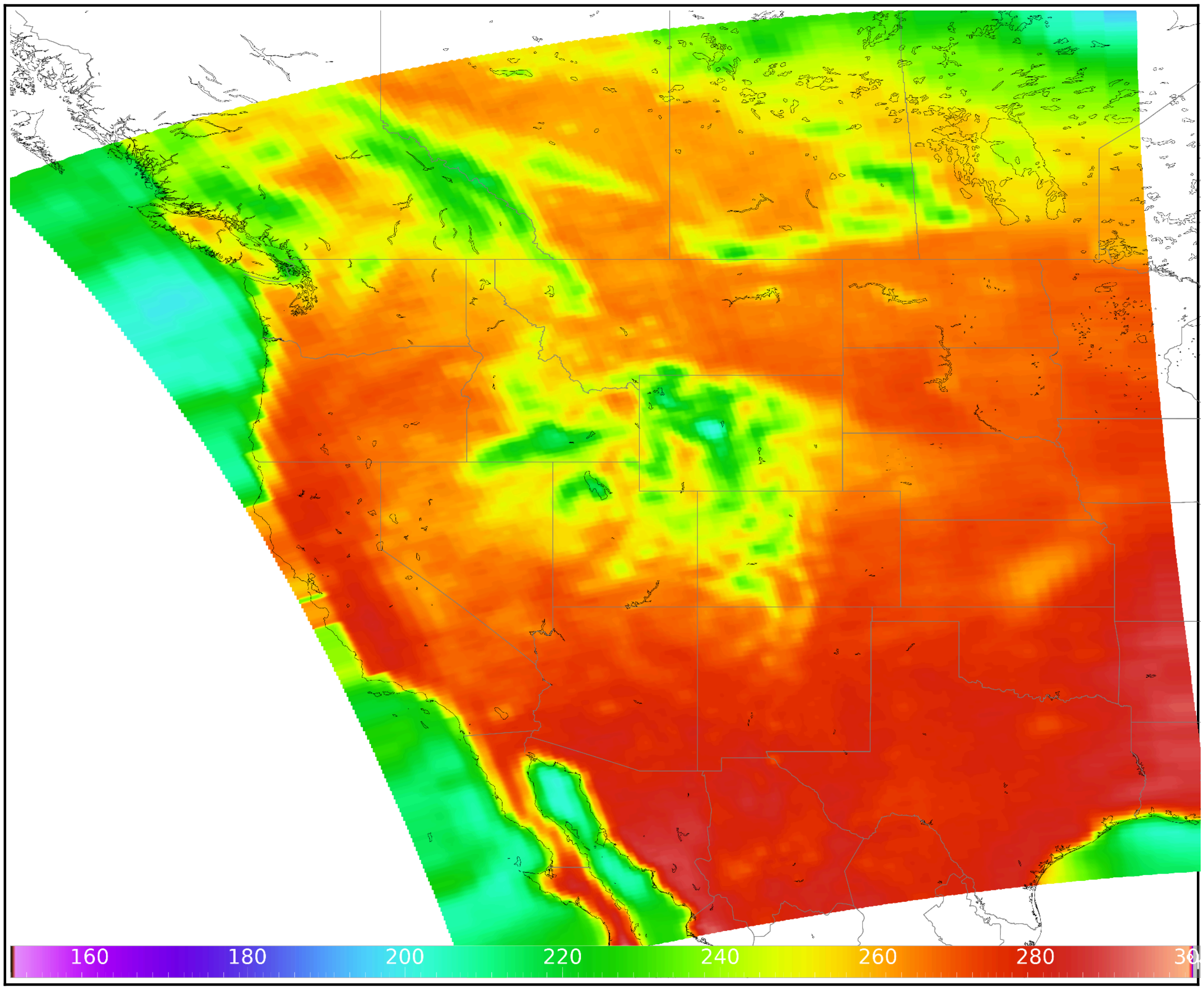
```
$POLAR2GRID_HOME/bin/polar2grid.sh -r mirs -w geotiff -p btemp_88v -f \
NPR-MIRS-IMG_v11r9_n20_s202311292004426_e202311292013143_*.nc
```

This creates the GeoTIFF file `noaa20_atms_btemp_88v_20231129_200442_wgs84_fit.tif`.

Then a colormap, coastlines and a color bar were added using other Polar2Grid commands.

```
$POLAR2GRID_HOME/bin/add_colormap.sh \
$POLAR2GRID_HOME/colormaps/p2g_sst_palette.txt *.tif
```

```
$POLAR2GRID_HOME/bin/add_coastlines.sh   --add-coastlines \
--coastlines-outline "black" --coastlines-width 2 --add-borders \
--borders-level 2 --borders-outline gray --borders-width 4   \
--borders-resolution h --add-colorbar --colorbar-text-color "white" \
--colorbar-units "°K" --colorbar-height 200 --colorbar-text-size=125 \
--colorbar-tick-marks 20 *.tif
```



Polar2Grid 88 GHz image created from the CSPP MiRS benchmark NOAA20 ATMS Imager output product. The direct broadcast overpass was acquired on 29 November 2023.

5.1 Displaying MiRS Sounder Products

MiRS Sounder file (SND) temperature and moisture profiles can be displayed using the CSPP Sounder Quicklook software package.

A subset of MiRS Sounder file (SND) products are supported by the CSPP Sounder Quicklook software package. The software allows users to create Atmospheric Pressure Level images of temperature and moisture as well as Skew-T thermodynamic diagram profiles of temperature and moisture for a given location. A complete list of the supported Sounder file arrays that are supported are described in the CSPP Sounder Quicklook documentation, which can be accessed through the CSPP software download site:

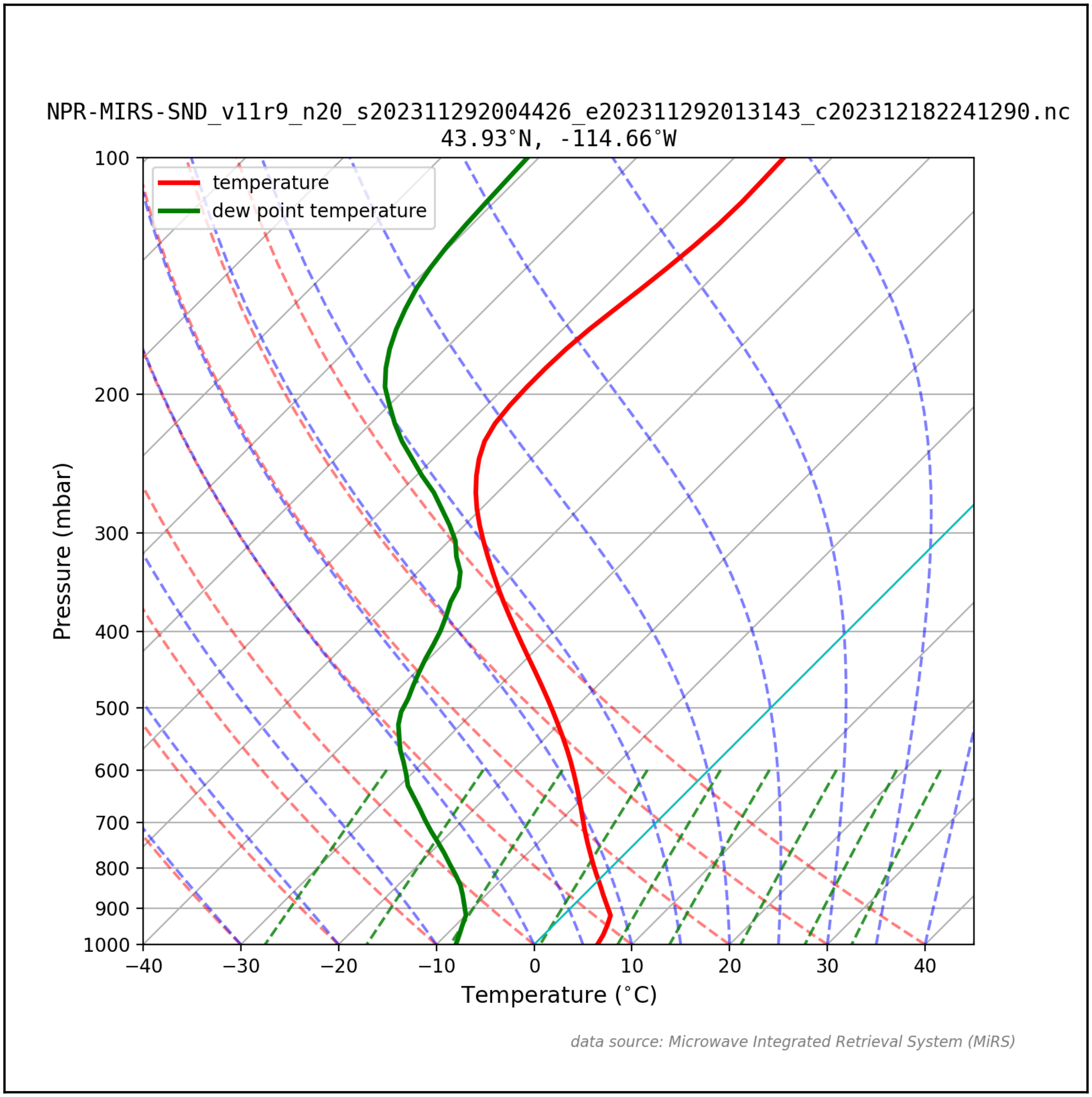
https://cimss.ssec.wisc.edu/cspp/download/

The Sounder Quicklook command used to create a Skew-T Thermodynamic Diagram of MiRS temperature and moisture profiles from the input NOAA20 benchmark dataset is:

```
ql_level2_skewt.sh \
 NPR-MIRS-SND_v11r9_n20_s202311292004426_e202311292013143_c202312182241290.nc \
```

```
MIRS --lat_0 44. --lon_0 -114.7
```

The resulting image, `NPR-MIRS-SND_v11r9_n20_s202311292004426_e202311292013143_c202312182241290.nc.MIRS_SkewT.png` is shown below.



Sounder quicklook Skew-T thermodynamic diagram image from 43.9 N, -114.7 W created from the CSPP MiRS benchmark NOAA20 ATMS Sounder output product. The direct broadcast overpass was acquired on 29 November 2023.

Appendix: Complete MiRS Output Product Descriptions

A.1 MiRS IMG Output Product

The following is header file information from the MiRS NOAA21 ATMS Imager test data set:

NPR-MIRS-IMG_v11r9_n21_s202311291846191_e202311291857307_c202312182240140

```
dimensions:
        Scanline = 252 ;
        Field_of_view = 96 ;
        P_Layer = 100 ;
        Channel = 22 ;
        Qc_dim = 4 ;
variables:
        float Freq(Channel) ;
                Freq:long_name = "Central Frequency" ;
                Freq:units = "GHz" ;
        short Polo(Channel) ;
                Polo:long_name = "Polarizations(Horizonal or Vertical)" ;
                Polo:units = "1" ;
        short ScanTime_year(Scanline) ;
                ScanTime_year:long_name = "Calendar Year 20XX" ;
                ScanTime_year:units = "years" ;
                ScanTime_year:_FillValue = -999s ;
                ScanTime_year:valid_range = 2011, 2050 ;
        short ScanTime_doy(Scanline) ;
                ScanTime_doy:long_name = "julian day 1-366" ;
                ScanTime_doy:units = "days" ;
                ScanTime_doy:_FillValue = -999s ;
                ScanTime_doy:valid_range = 1, 366 ;
        short ScanTime_month(Scanline) ;
                ScanTime_month:long_name = "Calendar month 1-12" ;
                ScanTime_month:units = "months" ;
                ScanTime_month:_FillValue = -999s ;
                ScanTime_month:valid_range = 1, 12 ;
        short ScanTime_dom(Scanline) ;
                ScanTime_dom:long_name = "Calendar day of the month 1-31" ;
                ScanTime_dom:units = "days" ;
                ScanTime_dom:_FillValue = -999s ;
                ScanTime_dom:valid_range = 1, 31 ;
        short ScanTime_hour(Scanline) ;
                ScanTime_hour:long_name = "hour of the day 0-23" ;
                ScanTime_hour:units = "hours" ;
                ScanTime_hour:_FillValue = -999s ;
                ScanTime_hour:valid_range = 0, 23 ;
        short ScanTime_minute(Scanline) ;
                ScanTime_minute:long_name = "minute of the hour 0-59" ;
                ScanTime_minute:units = "minutes" ;
                ScanTime_minute:_FillValue = -999s ;
                ScanTime_minute:valid_range = 0, 59 ;
```

```
short ScanTime_second(Scanline) ;
        ScanTime_second:long_name = "second of the minute 0-59" ;
        ScanTime_second:units = "seconds" ;
        ScanTime_second:_FillValue = -999s ;
        ScanTime_second:valid_range = 0, 59 ;
double ScanTime_UTC(Scanline) ;
        ScanTime_UTC:long_name = "Number of seconds since 00:00:00 UTC" ;
        ScanTime_UTC:units = "seconds" ;
        ScanTime_UTC:_FillValue = -999. ;
        ScanTime_UTC:valid_range = 0., 86400. ;
short Orb_mode(Scanline) ;
        Orb_mode:long_name = "Orbital Mode: 0-ascending,1-descending,2-transitioning" ;
        Orb_mode:units = "1" ;
        Orb_mode:_FillValue = -999s ;
        Orb_mode:valid_range = 0, 2 ;
float Latitude(Scanline, Field_of_view) ;
        Latitude:long_name = "Latitude of the view (-90,90)" ;
        Latitude:units = "degrees" ;
        Latitude:_FillValue = -999.f ;
        Latitude:valid_range = -90.f, 90.f ;
float Longitude(Scanline, Field_of_view) ;
        Longitude:long_name = "Longitude of the view (-180,180)" ;
        Longitude:units = "degrees" ;
        Longitude:_FillValue = -999.f ;
        Longitude:valid_range = -180.f, 180.f ;
short Sfc_type(Scanline, Field_of_view) ;
        Sfc_type:long_name = "Type of Surface:0-ocean,1-sea ice,2-land,3-snow" ;
        Sfc_type:units = "1" ;
        Sfc_type:coordinates = "Longitude Latitude" ;
        Sfc_type:_FillValue = -999s ;
        Sfc_type:valid_range = 0, 3 ;
short Atm_type(Scanline, Field_of_view) ;
        Atm_type:long_name = "Type of Atmosphere:currently missing" ;
        Atm_type:units = "1" ;
        Atm_type:coordinates = "Longitude Latitude" ;
int Qc(Scanline, Field_of_view, Qc_dim) ;
        Qc:long_name = "Quality Flag: 0-good, 1-usable with problem, 2-bad" ;
        Qc:units = "1" ;
float ChiSqr(Scanline, Field_of_view) ;
        ChiSqr:long_name = "Convergence rate: <3-good,>10-bad" ;
        ChiSqr:units = "1" ;
        ChiSqr:coordinates = "Longitude Latitude" ;
        ChiSqr:_FillValue = -999.f ;
        ChiSqr:valid_range = 0.f, 1000.f ;
float LZ_angle(Scanline, Field_of_view) ;
        LZ_angle:long_name = "Local Zenith Angle degree" ;
        LZ_angle:units = "degrees" ;
        LZ_angle:coordinates = "Longitude Latitude" ;
        LZ_angle:_FillValue = -999.f ;
        LZ_angle:valid_range = -70.f, 70.f ;
float RAzi_angle(Scanline, Field_of_view) ;
```

```
                RAzi_angle:long_name = "Relative Azimuth Angle 0-360 degree" ;
                RAzi_angle:units = "degrees" ;
                RAzi_angle:coordinates = "Longitude Latitude" ;
                RAzi_angle:_FillValue = -999.f ;
        float SZ_angle(Scanline, Field_of_view) ;
                SZ_angle:long_name = "Solar Zenith Angle (-90,90) degree" ;
                SZ_angle:units = "degrees" ;
                SZ_angle:coordinates = "Longitude Latitude" ;
                SZ_angle:_FillValue = -999.f ;
        short BT(Scanline, Field_of_view, Channel) ;
                BT:long_name = "Channel Temperature (K)" ;
                BT:units = "Kelvin" ;
                BT:coordinates = "Longitude Latitude Freq" ;
                BT:scale_factor = 0.01 ;
                BT:_FillValue = -999s ;
                BT:valid_range = 0, 50000 ;
        short YM(Scanline, Field_of_view, Channel) ;
                YM:long_name = "Un-Corrected Channel Temperature (K)" ;
                YM:units = "Kelvin" ;
                YM:coordinates = "Longitude Latitude Freq" ;
                YM:scale_factor = 0.01 ;
                YM:_FillValue = -999s ;
                YM:valid_range = 0, 50000 ;
        short ChanSel(Scanline, Field_of_view, Channel) ;
                ChanSel:long_name = "Channels Selection Used in Retrieval" ;
                ChanSel:units = "1" ;
                ChanSel:coordinates = "Longitude Latitude Freq" ;
                ChanSel:_FillValue = -999s ;
                ChanSel:valid_range = 0, 1 ;
        short TPW(Scanline, Field_of_view) ;
                TPW:long_name = "Total Precipitable Water (mm)" ;
                TPW:units = "mm" ;
                TPW:coordinates = "Longitude Latitude" ;
                TPW:scale_factor = 0.1 ;
                TPW:_FillValue = -999s ;
                TPW:valid_range = 0, 2000 ;
        short CLW(Scanline, Field_of_view) ;
                CLW:long_name = "Cloud liquid Water (mm)" ;
                CLW:units = "mm" ;
                CLW:coordinates = "Longitude Latitude" ;
                CLW:scale_factor = 0.01 ;
                CLW:_FillValue = -999s ;
                CLW:valid_range = 0, 10000 ;
        short RWP(Scanline, Field_of_view) ;
                RWP:long_name = "Rain Water Path (mm)" ;
                RWP:units = "mm" ;
                RWP:coordinates = "Longitude Latitude" ;
                RWP:scale_factor = 0.01 ;
                RWP:valid_range = 0, 10000 ;
        short LWP(Scanline, Field_of_view) ;
                LWP:long_name = "Liquid Water Path (mm)" ;
```

```
		LWP:units = "mm" ;
		LWP:coordinates = "Longitude Latitude" ;
		LWP:scale_factor = 0.01 ;
		LWP:_FillValue = -999s ;
		LWP:valid_range = 0, 10000 ;
	short SWP(Scanline, Field_of_view) ;
		SWP:long_name = "Snow Water Path" ;
		SWP:units = "mm" ;
		SWP:coordinates = "Longitude Latitude" ;
		SWP:scale_factor = 0.01 ;
		SWP:_FillValue = -999s ;
		SWP:valid_range = 0, 10000 ;
	short IWP(Scanline, Field_of_view) ;
		IWP:long_name = "Ice Water Path (mm)" ;
		IWP:units = "mm" ;
		IWP:coordinates = "Longitude Latitude" ;
		IWP:scale_factor = 0.01 ;
		IWP:_FillValue = -999s ;
		IWP:valid_range = 0, 10000 ;
	short GWP(Scanline, Field_of_view) ;
		GWP:long_name = "Graupel Water Path (mm)" ;
		GWP:units = "mm" ;
		GWP:coordinates = "Longitude Latitude" ;
		GWP:scale_factor = 0.01 ;
		GWP:_FillValue = -999s ;
		GWP:valid_range = 0, 10000 ;
	short RR(Scanline, Field_of_view) ;
		RR:long_name = "Rain Rate (mm/hr)" ;
		RR:units = "mm/hr" ;
		RR:coordinates = "Longitude Latitude" ;
		RR:scale_factor = 0.1 ;
		RR:_FillValue = -999s ;
		RR:valid_range = 0, 1000 ;
	short Snow(Scanline, Field_of_view) ;
		Snow:long_name = "Snow Cover" ;
		Snow:units = "1" ;
		Snow:coordinates = "Longitude Latitude" ;
		Snow:_FillValue = -999s ;
		Snow:valid_range = 0, 1 ;
	short SWE(Scanline, Field_of_view) ;
		SWE:long_name = "Snow Water Equivalent (cm)" ;
		SWE:units = "cm" ;
		SWE:coordinates = "Longitude Latitude" ;
		SWE:scale_factor = 0.01 ;
		SWE:_FillValue = -999s ;
		SWE:valid_range = 0, 10000 ;
	short SnowGS(Scanline, Field_of_view) ;
		SnowGS:long_name = "Snow Grain Size (mm)" ;
		SnowGS:units = "mm" ;
		SnowGS:coordinates = "Longitude Latitude" ;
		SnowGS:scale_factor = 0.01 ;
```

```
        SnowGS:_FillValue = -999s ;
        SnowGS:valid_range = 0, 2000 ;
short SIce(Scanline, Field_of_view) ;
        SIce:long_name = "Sea Ice Concentration (%)" ;
        SIce:units = "percent" ;
        SIce:coordinates = "Longitude Latitude" ;
        SIce:_FillValue = -999s ;
        SIce:valid_range = 0, 100 ;
short SIce_MY(Scanline, Field_of_view) ;
        SIce_MY:long_name = "Multi-Year Sea Ice Concentration (%)" ;
        SIce_MY:units = "percent" ;
        SIce_MY:coordinates = "Longitude Latitude" ;
        SIce_MY:_FillValue = -999s ;
        SIce_MY:valid_range = 0, 100 ;
short SIce_FY(Scanline, Field_of_view) ;
        SIce_FY:long_name = "First-Year Sea Ice Concentration (%)" ;
        SIce_FY:units = "percent" ;
        SIce_FY:coordinates = "Longitude Latitude" ;
        SIce_FY:_FillValue = -999s ;
        SIce_FY:valid_range = 0, 100 ;
short TSkin(Scanline, Field_of_view) ;
        TSkin:long_name = "Skin Temperature (K)" ;
        TSkin:units = "Kelvin" ;
        TSkin:coordinates = "Longitude Latitude" ;
        TSkin:scale_factor = 0.01 ;
        TSkin:_FillValue = -999s ;
        TSkin:valid_range = 0, 40000 ;
short SurfP(Scanline, Field_of_view) ;
        SurfP:long_name = "Surface Pressure (mb)" ;
        SurfP:units = "millibars" ;
        SurfP:coordinates = "Longitude Latitude" ;
        SurfP:scale_factor = 0.1 ;
        SurfP:_FillValue = -999s ;
        SurfP:valid_range = 0, 12000 ;
short Emis(Scanline, Field_of_view, Channel) ;
        Emis:long_name = "Channel Emissivity" ;
        Emis:units = "1" ;
        Emis:coordinates = "Longitude Latitude Freq" ;
        Emis:scale_factor = 0.0001 ;
        Emis:_FillValue = -999s ;
        Emis:valid_range = 0, 10000 ;
short SFR(Scanline, Field_of_view) ;
        SFR:long_name = "Snow Fall Rate in mm/hr" ;
        SFR:units = "mm/hr" ;
        SFR:coordinates = "Longitude Latitude" ;
        SFR:scale_factor = 0.01 ;
        SFR:_FillValue = -999s ;
        SFR:valid_range = 0, 10000 ;
short CldTop(Scanline, Field_of_view) ;
        CldTop:long_name = "Cloud Top Pressure" ;
        CldTop:units = "millibars" ;
```

```
		CldTop:coordinates = "Longitude Latitude" ;
		CldTop:scale_factor = 0.1 ;
		CldTop:_FillValue = -999s ;
	short CldBase(Scanline, Field_of_view) ;
		CldBase:long_name = "Cloud Base Pressure" ;
		CldBase:units = "millibars" ;
		CldBase:coordinates = "Longitude Latitude" ;
		CldBase:scale_factor = 0.1 ;
		CldBase:_FillValue = -999s ;
	short CldThick(Scanline, Field_of_view) ;
		CldThick:long_name = "Cloud Thickness" ;
		CldThick:units = "millibars" ;
		CldThick:coordinates = "Longitude Latitude" ;
		CldThick:scale_factor = 0.1 ;
		CldThick:_FillValue = -999s ;
	short PrecipType(Scanline, Field_of_view) ;
		PrecipType:long_name = "Precipitation Type (Frozen/Liquid)" ;
		PrecipType:units = "1" ;
		PrecipType:coordinates = "Longitude Latitude" ;
		PrecipType:_FillValue = -999s ;
	short RFlag(Scanline, Field_of_view) ;
		RFlag:long_name = "Rain Flag" ;
		RFlag:units = "1" ;
		RFlag:coordinates = "Longitude Latitude" ;
		RFlag:_FillValue = -999s ;
	short SurfM(Scanline, Field_of_view) ;
		SurfM:long_name = "Surface Moisture" ;
		SurfM:units = "1" ;
		SurfM:coordinates = "Longitude Latitude" ;
		SurfM:scale_factor = 0.1 ;
		SurfM:_FillValue = -999s ;
	short WindSp(Scanline, Field_of_view) ;
		WindSp:long_name = "Wind Speed" ;
		WindSp:units = "m/s" ;
		WindSp:coordinates = "Longitude Latitude" ;
		WindSp:scale_factor = 0.01 ;
		WindSp:_FillValue = -999s ;
	short WindDir(Scanline, Field_of_view) ;
		WindDir:long_name = "Wind Direction" ;
		WindDir:units = "1" ;
		WindDir:coordinates = "Longitude Latitude" ;
		WindDir:scale_factor = 0.01 ;
		WindDir:_FillValue = -999s ;
	short WindU(Scanline, Field_of_view) ;
		WindU:long_name = "U-direction Wind Speed" ;
		WindU:units = "m/s" ;
		WindU:coordinates = "Longitude Latitude" ;
		WindU:scale_factor = 0.01 ;
		WindU:_FillValue = -999s ;
	short WindV(Scanline, Field_of_view) ;
		WindV:long_name = "V-direction Wind Speed" ;
```

WindV:units = "m/s" ;
WindV:coordinates = "Longitude Latitude" ;
WindV:scale_factor = 0.01 ;
WindV:_FillValue = -999s ;
short Prob_SF(Scanline, Field_of_view) ;
Prob_SF:long_name = "Probability of falling snow (%)" ;
Prob_SF:units = "percent" ;
Prob_SF:coordinates = "Longitude Latitude" ;
Prob_SF:_FillValue = -999s ;
Prob_SF:valid_range = 0, 100 ;
char quality_information ;
quality_information:long_name = "total number retrievals, percentage optimal retrievals, percentage sub optimal retrievals, percentage bad retrievals" ;
quality_information:units = "1" ;
quality_information:total_number_retrievals = 24192 ;
quality_information:percentage_optimal_retrievals = 0.3209325f ;
quality_information:percentage_sub_optimal_retrievals = 0.6790674f ;
quality_information:percentage_bad_retrievals = 0.f ;

// global attributes:
:missing_value = -999 ;
:notretrievedproduct_value = -888 ;
:noretrieval_value = -99 ;
:cdf_version = 4. ;
:alg_version = 9999 ;
:dap_version = "v11r9" ;
:keywords = "MiRS, ATMS, passive microwave retrieval" ;
:ascend_descend_data_flag = 0 ;
:Conventions = "CF-1.5" ;
:Metadata_Conventions = "CF-1.5, Unidata Dataset Discovery v1.0" ;
:standard_name_vocabulary = "CF Standard Name Table (version 17, 24 March 2011)" ;
:project = "NESDIS Common Cloud Framework" ;
:title = "NPR_MIRS_IMG" ;
:summary = "MIRS imaging products including surface emissivity, TPW, CLW, RWP, IWP, LST." ;
:date_created = "2023-12-18T22:40:15Z" ;
:institution = "DOC/NOAA/NESDIS/OSPO > Office of Satellite and Product Operations, NESDIS, NOAA, U.S. Department of Commerce" ;
:naming_authority = "gov.noaa.nesdis.ospo" ;
:production_site = "CSPP" ;
:production_environment = "DB" ;
:platform = "N21" ;
:instrument = "ATMS" ;
:creator_name = "DOC/NOAA/NESDIS/STAR > MIRS TEAM, Center for Satellite
"NPR-MIRS-IMG_v11r9_n21_s202311291846191_e202311291857307_c202312182240140.nc" ;
:references = "http://www.star.nesdis.noaa.gov/mirs/documentation.php" ;
:history = "Created by MIRS Version 11.9" ;
:processing_level = "NOAA Level 2 data" ;
:source = "SATMS_n21_d20231129_t1846191_e1857307_b05455_c20231129190043822952_cspp_dev.h5" ;
:time_coverage_start = "2023-11-29T18:46:19Z" ;

```
                    :time_coverage_end = "2023-11-29T18:57:30Z" ;
                    :cdm_data_type = "Swath" ;
                    :geospatial_lat_units = "degrees_north" ;
                    :geospatial_lon_units = "degrees_east" ;
                    :geospatial_bounds = "POLYGON(( -96.55  21.16, -72.27  25.32, -75.28  64.14,-120.34
56.78, -96.55  21.16))" ;
                    :geospatial_first_scanline_first_fov_lat = 21.16f ;
                    :geospatial_first_scanline_first_fov_lon = -96.55f ;
                    :geospatial_first_scanline_last_fov_lat = 25.32f ;
                    :geospatial_first_scanline_last_fov_lon = -72.27f ;
                    :geospatial_last_scanline_first_fov_lat = 56.78f ;
                    :geospatial_last_scanline_first_fov_lon = -120.34f ;
                    :geospatial_last_scanline_last_fov_lat = 64.14f ;
                    :geospatial_last_scanline_last_fov_lon = -75.28f ;
                    :total_number_retrievals = 24192 ;
                    :percentage_optimal_retrievals = 0.3209325f ;
                    :percentage_suboptimal_retrievals = 0.6790674f ;
                    :percentage_bad_retrievals = 0.f ;
                    :start_orbit_number = 5455 ;
                    :end_orbit_number = 5455 ;
                    :id =
"leo.ssec.wisc.edu_2023-12-18T22:40:15Z_0000000338670216_SATMS_n21_d20231129_t1846191_e1
857307_b05455_c20231129190043822952_cspp_dev.h5" ;
}
```

A.2 MiRS SND Output Product

The following is header file information from the MiRS NOAA21 ATMS sounder test data set:

NPR-MIRS-SND_v11r9_n21_s202311291846191_e202311291857307_c202312182240140

```
dimensions:
        Scanline = 252 ;
        Field_of_view = 96 ;
        P_Layer = 100 ;
        P_Level = 101 ;
        Channel = 22 ;
        Qc_dim = 4 ;
variables:
        float Freq(Channel) ;
                Freq:long_name = "Central Frequency" ;
                Freq:units = "GHz" ;
        short Polo(Channel) ;
                Polo:long_name = "Polarizations(Horizonal or Vertical)" ;
                Polo:units = "1" ;
        short ScanTime_year(Scanline) ;
                ScanTime_year:long_name = "Calendar Year 20XX" ;
                ScanTime_year:units = "years" ;
                ScanTime_year:_FillValue = -999s ;
                ScanTime_year:valid_range = 2011, 2050 ;
        short ScanTime_doy(Scanline) ;
                ScanTime_doy:long_name = "julian day 1-366" ;
                ScanTime_doy:units = "days" ;
                ScanTime_doy:_FillValue = -999s ;
                ScanTime_doy:valid_range = 1, 366 ;
        short ScanTime_month(Scanline) ;
                ScanTime_month:long_name = "Calendar month 1-12" ;
                ScanTime_month:units = "months" ;
                ScanTime_month:_FillValue = -999s ;
                ScanTime_month:valid_range = 1, 12 ;
        short ScanTime_dom(Scanline) ;
                ScanTime_dom:long_name = "Calendar day of the month 1-31" ;
                ScanTime_dom:units = "days" ;
                ScanTime_dom:_FillValue = -999s ;
                ScanTime_dom:valid_range = 1, 31 ;
        short ScanTime_hour(Scanline) ;
                ScanTime_hour:long_name = "hour of the day 0-23" ;
                ScanTime_hour:units = "hours" ;
                ScanTime_hour:_FillValue = -999s ;
                ScanTime_hour:valid_range = 0, 23 ;
        short ScanTime_minute(Scanline) ;
                ScanTime_minute:long_name = "minute of the hour 0-59" ;
                ScanTime_minute:units = "minutes" ;
                ScanTime_minute:_FillValue = -999s ;
                ScanTime_minute:valid_range = 0, 59 ;
        short ScanTime_second(Scanline) ;
```

```
		ScanTime_second:long_name = "second of the minute 0-59" ;
		ScanTime_second:units = "seconds" ;
		ScanTime_second:_FillValue = -999s ;
		ScanTime_second:valid_range = 0, 59 ;
	double ScanTime_UTC(Scanline) ;
		ScanTime_UTC:long_name = "Number of seconds since 00:00:00 UTC" ;
		ScanTime_UTC:units = "seconds" ;
		ScanTime_UTC:_FillValue = -999. ;
		ScanTime_UTC:valid_range = 0., 86400. ;
	short Orb_mode(Scanline) ;
		Orb_mode:long_name = "Orbital Mode: 0-ascending,1-descending,2-transitioning" ;
		Orb_mode:units = "1" ;
		Orb_mode:_FillValue = -999s ;
		Orb_mode:valid_range = 0, 2 ;
	float Latitude(Scanline, Field_of_view) ;
		Latitude:long_name = "Latitude of the view (-90,90)" ;
		Latitude:units = "degrees" ;
		Latitude:_FillValue = -999.f ;
		Latitude:valid_range = -90.f, 90.f ;
	float Longitude(Scanline, Field_of_view) ;
		Longitude:long_name = "Longitude of the view (-180,180)" ;
		Longitude:units = "degrees" ;
		Longitude:_FillValue = -999.f ;
		Longitude:valid_range = -180.f, 180.f ;
	short Sfc_type(Scanline, Field_of_view) ;
		Sfc_type:long_name = "Type of Surface:0-ocean,1-sea-ice,2-land,3-snow" ;
		Sfc_type:units = "1" ;
		Sfc_type:coordinates = "Longitude Latitude" ;
		Sfc_type:_FillValue = -999s ;
		Sfc_type:valid_range = 0, 3 ;
	short Atm_type(Scanline, Field_of_view) ;
		Atm_type:long_name = "Type of Atmosphere:0-simple scene, 1-retrieved scene" ;
		Atm_type:units = "1" ;
		Atm_type:coordinates = "Longitude Latitude" ;
	int Qc(Scanline, Field_of_view, Qc_dim) ;
		Qc:long_name = "Quality Flag: 0-good,1-usable with problem ,2-bad" ;
		Qc:units = "1" ;
	float ChiSqr(Scanline, Field_of_view) ;
		ChiSqr:long_name = "Convergence rate: <3-good,>10-bad" ;
		ChiSqr:units = "1" ;
		ChiSqr:coordinates = "Longitude Latitude" ;
		ChiSqr:_FillValue = -999.f ;
		ChiSqr:valid_range = 0.f, 1000.f ;
	float LZ_angle(Scanline, Field_of_view) ;
		LZ_angle:units = "degrees" ;
		LZ_angle:_FillValue = -999.f ;
		LZ_angle:valid_range = -70.f, 70.f ;
		LZ_angle:long_name = "Local zenith angle: (-59,59) degree" ;
		LZ_angle:coordinates = "Longitude Latitude" ;
	float RAzi_angle(Scanline, Field_of_view) ;
		RAzi_angle:long_name = "Relative azimuth angle 0-360 degree" ;
```

```
		RAzi_angle:units = "degrees" ;
		RAzi_angle:coordinates = "Longitude Latitude" ;
		RAzi_angle:_FillValue = -999.f ;
	float SZ_angle(Scanline, Field_of_view) ;
		SZ_angle:long_name = "Solar zenith angle (-90,90) degree" ;
		SZ_angle:units = "degrees" ;
		SZ_angle:coordinates = "Longitude Latitude" ;
		SZ_angle:_FillValue = -999.f ;
	float Player(P_Layer) ;
		Player:long_name = "Pressure for each layer in mb" ;
		Player:units = "millibars" ;
		Player:valid_range = 0.011f, 1085.458f ;
	float Plevel(P_Level) ;
		Plevel:long_name = "Pressure for each level in mb" ;
		Plevel:units = "millibars" ;
		Plevel:valid_range = 0.005f, 1100.f ;
	float PTemp(Scanline, Field_of_view, P_Layer) ;
		PTemp:long_name = "Temperature profile in K" ;
		PTemp:units = "Kelvin" ;
		PTemp:coordinates = "Longitude Latitude Player" ;
		PTemp:_FillValue = -999.f ;
		PTemp:valid_range = 0.f, 1000.f ;
	float PVapor(Scanline, Field_of_view, P_Layer) ;
		PVapor:long_name = "Water vapor profile in g/kg" ;
		PVapor:units = "g/kg" ;
		PVapor:coordinates = "Longitude Latitude Player" ;
		PVapor:_FillValue = -999.f ;
		PVapor:valid_range = 0.f, 100.f ;
	float PClw(Scanline, Field_of_view, P_Layer) ;
		PClw:long_name = "Cloud liquid water profile in mm" ;
		PClw:units = "mm" ;
		PClw:coordinates = "Longitude Latitude Player" ;
		PClw:_FillValue = -999.f ;
		PClw:valid_range = 0.f, 1.f ;
	float PRain(Scanline, Field_of_view, P_Layer) ;
		PRain:long_name = "Rain mass profile in mm" ;
		PRain:units = "mm" ;
		PRain:coordinates = "Longitude Latitude Player" ;
		PRain:_FillValue = -999.f ;
		PRain:valid_range = 0.f, 1.f ;
	float PGraupel(Scanline, Field_of_view, P_Layer) ;
		PGraupel:long_name = "Graupel mass profile in mm" ;
		PGraupel:units = "mm" ;
		PGraupel:coordinates = "Longitude Latitude Player" ;
		PGraupel:_FillValue = -999.f ;
		PGraupel:valid_range = 0.f, 1.f ;
	float PSnow(Scanline, Field_of_view, P_Layer) ;
		PSnow:long_name = "Snow mass profile in mm" ;
		PSnow:units = "mm" ;
		PSnow:coordinates = "Longitude Latitude Player" ;
		PSnow:_FillValue = -999.f ;
```

```
                PSnow:valid_range = 0.f, 1.f ;
        float PIce(Scanline, Field_of_view, P_Layer) ;
                PIce:long_name = "Ice mass profile in mm" ;
                PIce:units = "mm" ;
                PIce:coordinates = "Longitude Latitude Player" ;
                PIce:_FillValue = -999.f ;
                PIce:valid_range = 0.f, 1.f ;
        short SurfP(Scanline, Field_of_view) ;
                SurfP:long_name = "Surface pressure in mb" ;
                SurfP:units = "millibars" ;
                SurfP:coordinates = "Longitude Latitude" ;
                SurfP:scale_factor = 0.1 ;
                SurfP:_FillValue = -999s ;
                SurfP:valid_range = 0, 12000 ;
        char quality_information ;
                quality_information:long_name = "total number retrievals, percentage optimal retrievals,
percentage sub optimal retrievals, percentage bad retrievals" ;
                quality_information:units = "1" ;
                quality_information:total_number_retrievals = 24192 ;
                quality_information:percentage_optimal_retrievals = 0.f ;
                quality_information:percentage_sub_optimal_retrievals = 0.f ;
                quality_information:percentage_bad_retrievals = 0.f ;

// global attributes:
                :missing_value = -999 ;
                :notretrievedproduct_value = -888 ;
                :noretrieval_value = -99 ;
                :cdf_version = 4. ;
                :alg_version = 9999 ;
                :dap_version = "v11r9" ;
                :keywords = "MiRS, ATMS, passive microwave retrieval" ;
                :ascend_descend_data_flag = 0 ;
                :Conventions = "CF-1.5" ;
                :Metadata_Conventions = "CF-1.5, Unidata Dataset Discovery v1.0" ;
                :standard_name_vocabulary = "CF Standard Name Table (version 17, 24 March 2011)" ;
                :project = "NESDIS Common Cloud Framework" ;
                :title = "NPR_MIRS_SND" ;
                :summary = "MIRS sounding products including temperature, water vapor, and
hydrometeor profiles." ;
                :date_created = "2023-12-18T22:40:15Z" ;
                :institution = "DOC/NOAA/NESDIS/OSPO > Office of Satellite and Product Operations,
NESDIS, NOAA, U.S. Department of Commerce" ;
                :naming_authority = "gov.noaa.nesdis.ospo" ;
                :production_site = "CSPP" ;
                :production_environment = "DB" ;
                :platform = "N21" ;
                :instrument = "ATMS" ;
                :creator_name = "DOC/NOAA/NESDIS/STAR > MIRS TEAM, Center for Satellite
"NPR-MIRS-SND_v11r9_n21_s202311291846191_e202311291857307_c202312182240140.nc" ;
                :references = "http://www.star.nesdis.noaa.gov/mirs/documentation.php" ;
                :history = "Created by MIRS Version 11.9" ;
```

```
                :processing_level = "NOAA Level 2 data" ;
                :source =
"SATMS_n21_d20231129_t1846191_e1857307_b05455_c20231129190043822952_cspp_dev.h5" ;
                :time_coverage_start = "2023-11-29T18:46:19Z" ;
                :time_coverage_end = "2023-11-29T18:57:30Z" ;
                :cdm_data_type = "Swath" ;
                :geospatial_lat_units = "degrees_north" ;
                :geospatial_lon_units = "degrees_east" ;
                :geospatial_bounds = "POLYGON(( -96.55  21.16, -72.27  25.32, -75.28  64.14,-120.34
56.78, -96.55  21.16))" ;
                :geospatial_first_scanline_first_fov_lat = 21.16f ;
                :geospatial_first_scanline_first_fov_lon = -96.55f ;
                :geospatial_first_scanline_last_fov_lat = 25.32f ;
                :geospatial_first_scanline_last_fov_lon = -72.27f ;
                :geospatial_last_scanline_first_fov_lat = 56.78f ;
                :geospatial_last_scanline_first_fov_lon = -120.34f ;
                :geospatial_last_scanline_last_fov_lat = 64.14f ;
                :geospatial_last_scanline_last_fov_lon = -75.28f ;
                :quality_information_total_number_retrievals = 24192 ;
                :quality_information_percentage_optimal_retrievals = 0.3209325f ;
                :quality_information_percentage_suboptimal_retrievals = 0.6790674f ;
                :quality_information_percentage_bad_retrievals = 0.f ;
                :start_orbit_number = 5455 ;
                :end_orbit_number = 5455 ;
                :id =
"leo.ssec.wisc.edu_2023-12-18T22:40:15Z_0000000338670216_SATMS_n21_d20231129_t1846191_e1
857307_b05455_c20231129190043822952_cspp_dev.h5" ;
}
```