NCAR | EARTH OBSERVING LABORATORY

M2HATS

NSF NCAR/EOL ISS Surface Meteorology, Ceilometer, PurpleAir and Webcam Products Data Report

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In-situ Sensing Facility

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National Center for Atmospheric Research
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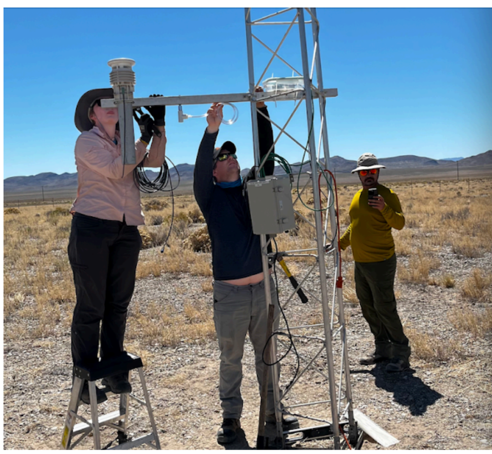


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Web References

M2HATS Homepage: https://www.eol.ucar.edu/field_projects/m2hats
ISS Operations during M2HATS: https://www.eol.ucar.edu/content/iss-operations-m2hats
ISS Homepage: https://www.eol.ucar.edu/observing_facilities/iss
LROSE (Lidar Radar Open Software Environment): http://lrose.net/
Visualizations Plots:
https://archive.eol.ucar.edu/docs/isf/projects/m2hats/iss/realtime/summary/iss1/
Time-height plots from Windcube Lidar: http://datavis.eol.ucar.edu/time-height-plot/M2HATS
Windcube lidar PPI and RHI plots (ISS1 WLS200S) on the EOL Instrument Field Catalog:
https://catalog.eol.ucar.edu/operations/lidar

Dataset Version Control

Version	Date	Author	Change Description
1.0	21 Feb 2023	J. Witte	Initial Release

Dataset Citation

If these data are used for research resulting in publications or presentations, please use the following citation:

> NSF NCAR/EOL ISS Team. 2024. M2HATS ISS Surface Meteorology, Ceilometer, PurpleAir and Webcam Data Products. Version 1.0. UCAR/NCAR - Earth Observing Laboratory. https://doi.org/10.26023/30XE-MB6C-SC14. Accessed 21 Feb 2024.

The ISS Platform Citation

Please acknowledge EOL/ISS and NSF by including the following citations, as appropriate:

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Acknowledgement

Users of EOL data are expected to add the following acknowledgement to all of their publications, reports and conference papers that use those data:

"We would like to acknowledge operational, technical and scientific support provided by NCAR's Earth Observing Laboratory, sponsored by the National Science Foundation."

Overview

M2HATS (Multi-point Monin-Obukhov similarity horizontal array turbulence study) was conducted at Tonopah, Nevada during the summer of 2023. The Integrated Sounding System (ISS) system for M2HATS provided profiling observations of fundamental meteorological variables (P-T-U, winds, etc) within the atmospheric boundary layer. These measurements, combined with energy and mass balance observations from flux towers, will provide benchmarks of the most reliable approaches testing the multi-point Monin-Obukhov similarity hypothesis. As part of the integrated suite of sensors, ISS operated surface meteorology stations at 3m and 10m, three webcams, and two PurpleAir sensors.

Location: Tonopah, Nevada, USA

Project time period: 23 July - 23 September 2023

**Note that a few datasets will include extra data taken before and after the official project period, as sensors were gradually set-up and torn down.

Orderable Datasets

Datasets have been tar.gz for bulk download. In particular, webcam jpegs are available as monthly tar.gz files to break up the large file sizes. The archive has a 32 Gb order limit. Refer to **Table 1** below for sizes and individual file specs.

Data Product	Orderable Dataset (size)	File Format	File Freq.	Data Resol.
Surface Met.	m2hats_iss1_sfcmet_10m-tower_netcdf_v1.tar.gz (6.5 Mb) m2hats_iss2_sfcmet_3m-tower_netcdf_v1.tar.gz (5.1 Mb)	netcdf3	daily	1 min
Ceilometer CL61	m2hats_iss1_ceilometer_cl61_netcdf_v1.tar.gz (4.0 Gb) m2hats_iss1_ceilometer_cl61_jpg_v1.tar.gz (6.4 Gb)	netcdf4	daily	1 min
PurpleAir aerosol	m2hats_iss1_purpleair_10m-tower_v1.tar.gz (2.4 Mb)	csv	daily	2 min
Webcam Imagery*	m2hats_iss1_isfs-4m-tower_microseven_camera_1min_Jul2023.tar.gz (3.9 Gb) m2hats_iss1_isfs-4m-tower_microseven_camera_1min_Aug2023.tar.gz (14 Gb) m2hats_iss1_isfs-4m-tower_microseven_camera_1min_Sep2023.tar.gz (9.0 Gb)	jpeg	1 min	1 min
	m2hats_iss1_10m-tower_microseven_camera_1min_Jul2023tar.gz (4.3 Gb) m2hats_iss1_10m-tower_microseven_camera_1min_Aug2023.tar.gz (14 Gb) m2hats_iss1_10m-tower_microseven_camera_1min_Sep2023tar.gz (9.9 Gb)			
	m2hats_iss2_windcube-lidar_microseven_camera_1min_Jul2023.tar.gz (3.3 Gb) m2hats_iss2_windcube-lidar_microseven_camera_1min_Aug2023.tar.gz (12 Gb) m2hats_iss2_windcube-lidar_microseven_camera_1min_Sep2023tar.gz (8.5 Gb)			

*Webcam imagery is stored in daily folders with the file format Pyymmddhhmmss00.jpg.

Table 1. List of orderable ISS in-situ datasets that have been tar.gz. Information on individual file formats and frequency, and time resolution of the measurements. 'iss1' refers to sensors on the 10 m tower or sharing the same data logger. 'iss2' refers to sensors on the 3 m tower or sharing the same data logger. 'windcube-lidar' refers to sensors attached to the Vaisala/Leosphere WindCube lidar.

Data Capture

The surface sensors at all three sites ran almost uninterrupted for the entire M2HATS campaign and final data capture was close to 100% for all variables in the final netCDF files.

Set-up and Instrumentation

ISS set-up a 3 m and 10 m tower, equipped with meteorological sensors, close to each other and within half a mile southwest of the ISFS towered flux array (see **Schematic 1** for a top down view of the overall set-up). and equipped with meteorological sensors.

Also at the site were 449 MHz and 915 MHz wind profilers, Vaisala and Halo wind lidars, and a Vaisala CL61 ceilometer. Radiosondes were launched daily at 10am and 3pm local time. Refer to **Photo 1** for a top down view of the set-up of the ISS sensor suite relative to other instruments.

Table 2 lists the sensors mounted on each tower and other locations. Data measured at the data loggers on the 3m tower is designated iss1 and the 10 m tower iss3.

Three MicroSeven operated on the 10 m tower, adjacent to the Vaisala/Leosphere Lidar, and on one of the ISFS flux towers (t44). **Photo 3** shows where each webcam was mounted and their respective view. A second PurpleAir was mounted on the ISFS one of the array towers, t44. However, at present these data are not available due to bad timestamps.

(a) 10 m tower (iss1 dataset)

Sensor	Height	Variables
2D Gill Windobserver 65	10 m	U, V, wind speed, wind direction
Lufft WS300	2 m	P, T, RH
Vaisala PTB210 Barometer	2 m	P
Microseven M7B 5MP - SWSAA webcam	2 m	1 min jpg images looks southeast towards the ISFS array of flux towers
PurpleAir PA-II-SD	2 m	Aerosols

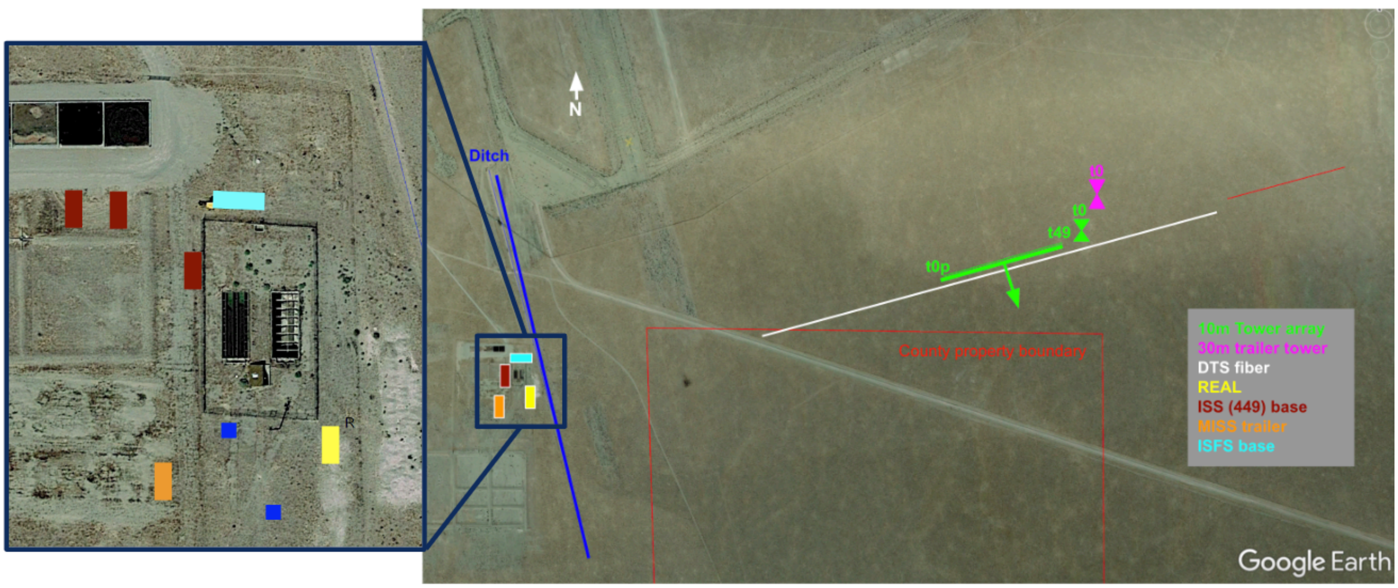
(b) 3m tower (iss2 dataset)

Sensor	Height	Variables
CS125	3 m	Visibility [m]
Lufft WS800-UMB	3 m	P, T, RH, winds, global radiation
Hukseflux NR01-T2	1 m	Downwelling and upwelling shortwave and longwave radiation

(c) Other

Sensor	Site	Notes
Vaisala CL61 ceilometer	Next to UVA Halo Lidar	Refer to Appendix B for a complete list of netCDF metadata contents
MicroSeven M7B 5MP - SWSAA	Windcube Lidar	1 min jpg images viewing northeast towards the ISS suite of sensors
MicroSeven M7B 5MP - SWSAA	ISFS t44 tower	1 min jpg images viewing southwest
PurpleAir	ISFS t44 tower	Data not available due to bad timestamps.

Table 2. (a) Table of sensors mounted at the 3 m tower, (b) 10m tower, and (c) other locations.



Schematic 1. Schematic of the overall set-up, in terms of ISS trailer and instrument suite location relative to the ISFS towered flux array.

Photo 1. 3 m tower with the CS125 Visibility sensor and Lufft ws800 mounted at the top. The pressure, temperature, and RH from the Lufft ws800 was used as the surface reference sensor for the radiosondes. The 10 m tower is visible behind and to the left of this tower.

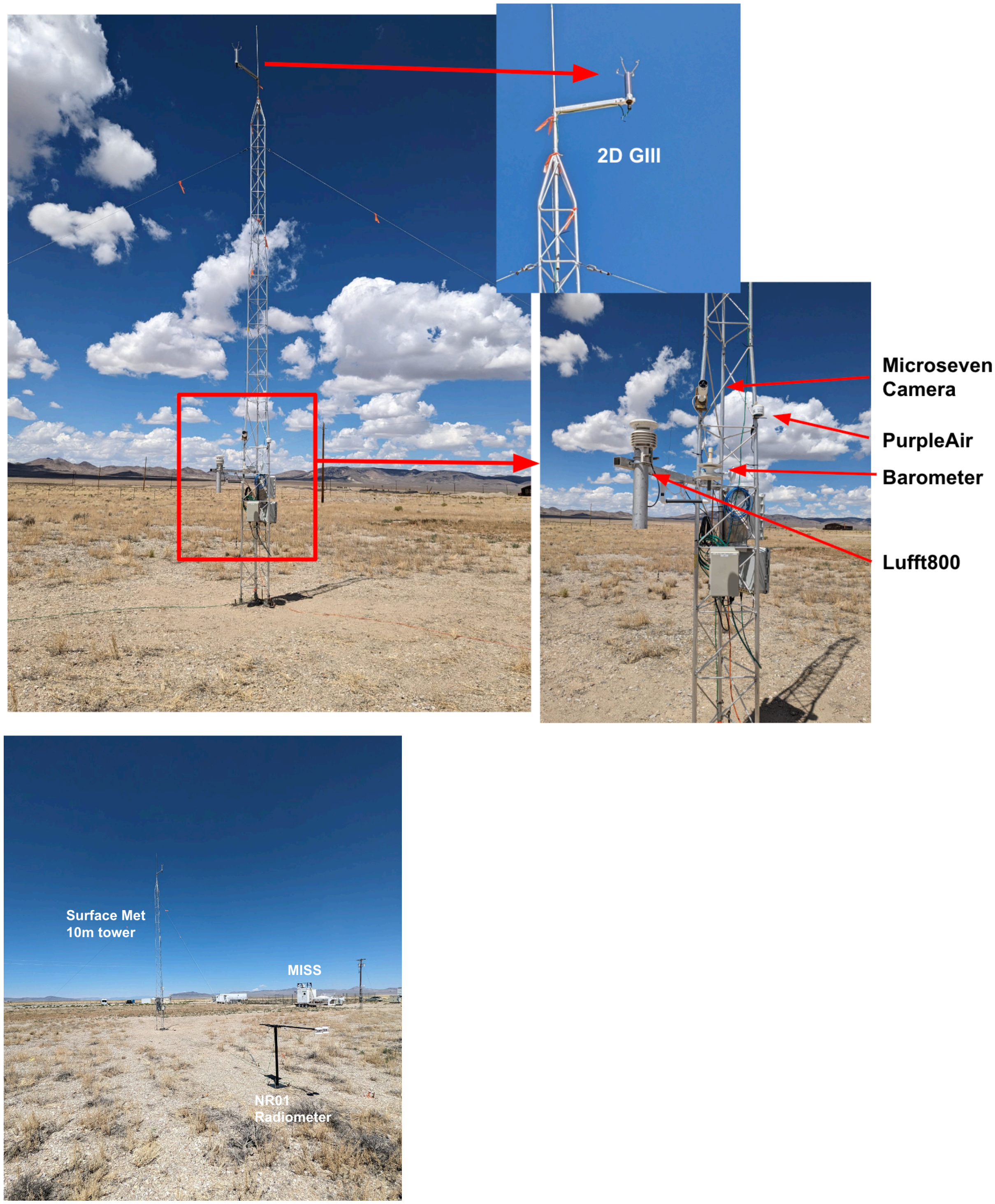
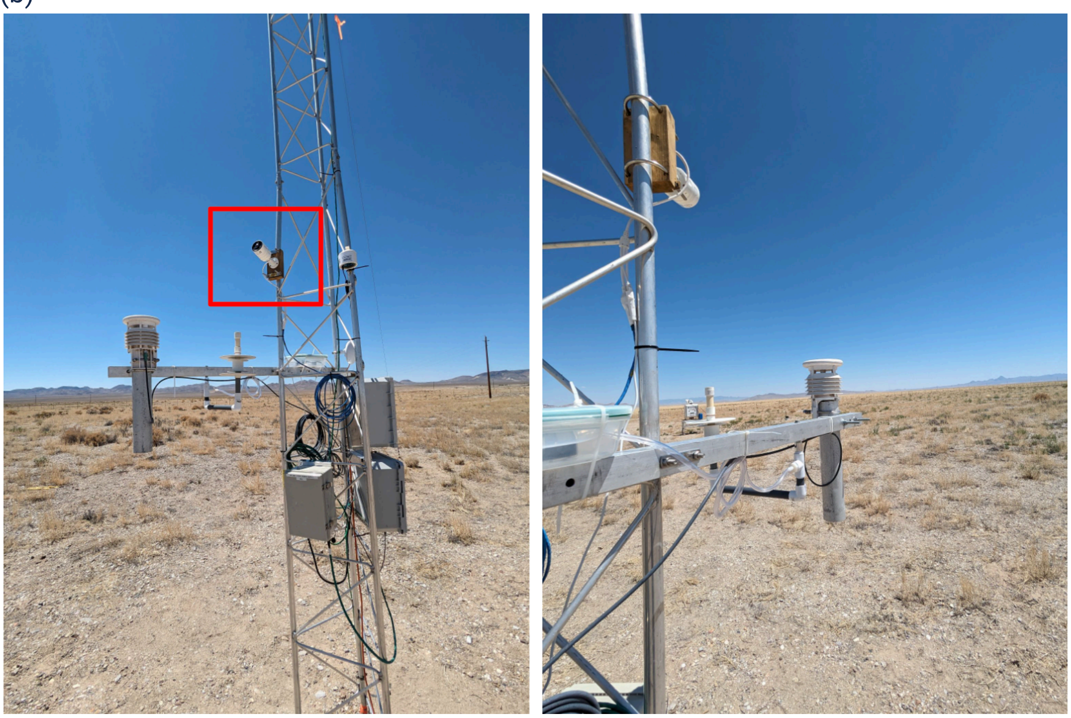


Photo 2. ISS meteorological sensors mounted at that 10 m tower. The Microseven camera was angled southeast with views of the ISFS array of flux towers. A 4-component NR01 radiometer (bottom photo in the foreground) was attached to the tower data logger.

(a)

(b)



(c)

(d)

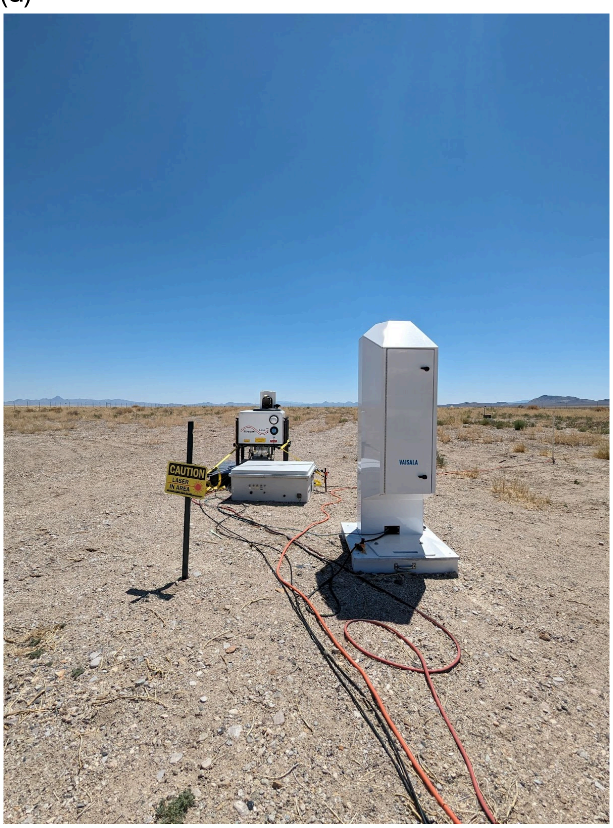


Photo 3. (a) MicroSeven webcam, located adjacent to the Windcube lidar, was connected to the 915 MHz wind profiler trailer and looked northeast at the ISS lidars (right photo). (b) MicroSeven webcam attached to the 10 m ISS tower looked southeast towards the ISFS array (right photo). (c) MicroSeven webcam mounted on ISFS tower, t44, looked southwest (right photo). (d) Vaisala CL61 operated next to the UVA HALO lidar.

Surface Meteorology Data Collection and Processing

All surface meteorology sensors were sampled independently with a Linux-based Data System Module or DSM. Data was stored directly onto USB sticks provided for every DSM. All DSMs were connected by either local network or cell modem, so raw data could also be archived in real-time on a Linux computer at the ISS base trailers. Data was also transmitted from the base trailers to servers at EOL for local storage and added back-up. Data processing was performed by the in-house created data acquisition system called NIDAS. NIDAS (NCAR In-situ Data Acquisition System) is a linux based software that handles the data processing for all ISS surface meteorology measurement systems.

Each sensor is sampled independently in an asynchronous manner. A time tag of microsecond resolution is assigned to each sample at the moment it is received, based on a system clock, which is continually conditioned from a directly connected GPS with a pulse-per-second (PPS) signal - this allows us to compare and combine data from multiple towers. Minimal data interpretation is performed to differentiate individual messages from a sensor, assembling the data exactly as it was received into a sample, with the associated time-tag and an identifier of the sensor and data system. The concatenated stream of samples from all sensors is then passed on for averaging and saved as netCDf daily files.

All surface sensors functioned as expected. No problems were noted during operations. No sensors were replaced during operations.

Data Products and Quality by Instrument

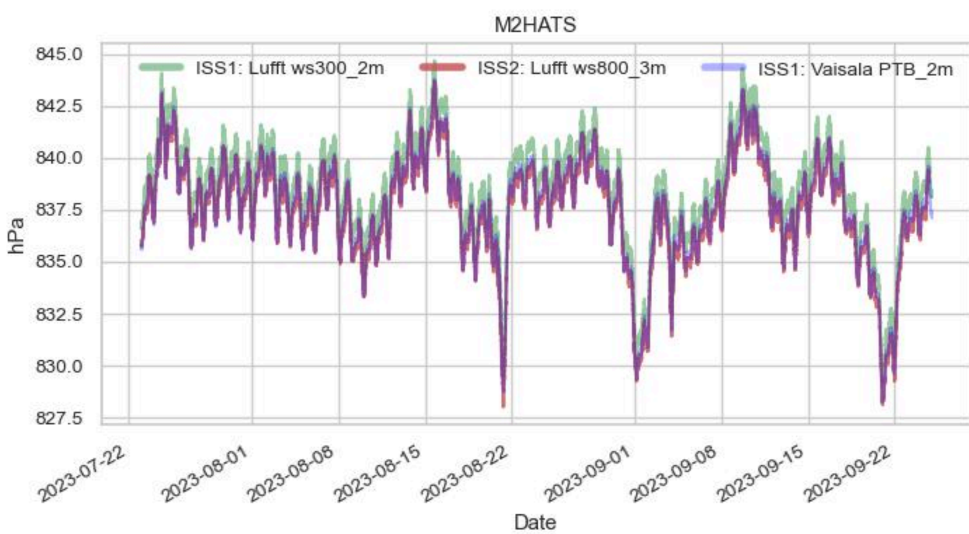
Vaisala PTB210

ISS operated a Vaisala PTB 210 pressure sensor at 2m on the 10 m tower. The variable name in the netcdf data files is P_ptb_2m and are in the iss1 dataset. **Table 3** provides the accuracy and sampling rate. **Figure 1** shows the time series of the Vaisala PTB measurements, as well as pressure measured by the Luffts.

Vaisala PTB210	hPa
Hysteresis	± 0.05
Precision	± 0.05
Calibration uncertainty	± 0.07
Accuracy at +20°C	± 0.15
Temperature dependence	± 0.20
Total accuracy (-40 - +60 °C)	± 0.25

Table 3. Vaisala PTB210 accuracy

(a)



(b)

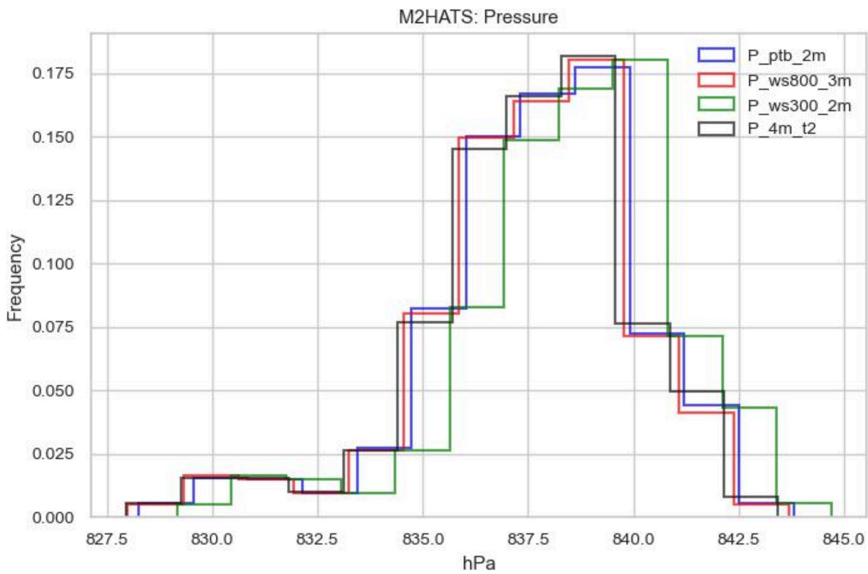


Figure 1. (a) Pressure measured by the Vaisala PTB210 and Luffts. (b) Histograms of ISS pressure sensors, including the ISFS nano barometer (black) on the t2 site which is the closest site to ISS sensor suite.

Lufft WS300 and WS800

PTU and Winds

Pressure was also measured by the Lufft WS800 and WS300. **Table 4** provides a list of research variables and definitions for both Lufft sensors. **Table 5** provides the accuracy and sampling rate of key measurements for both Lufft sensors. Note that the precision and accuracy of the Vaisala PTB210 pressure sensor is higher than the Lufft which reports a 0.1 hPa accuracy. We recommend using the Vaisala pressures for analysis.

The Lufft WS300 measurements were comparable to that of the WS800 (**Figure 2)**. From **Figure 3** the Lufft WS800 wind data compare well with the 10 m 2D Gill instrument.

The Lufft WS800 reports additional wind statistics - min/max, average, vector wind speed. Generation of average, max/min value of wind speed and direction are calculated using a time interval of 10 minutes (refer to **Table 4**). The wind speeds are also calculated vectorially with the same configured time interval as that for the minimum, maximum and average values. **Figure 3** shows an example of a single day of the various Lufft WS800 wind speeds listed in **Table 4**.

Variable name	Quantity Measured	Unit	Instrument	Data Logger
P_ws300_2m	Pressure	mb	Lufft WS300	iss1
T_ws300_2m	Temperature	degC		
RH_ws300_2m	Relative Humidity	%		
Td_ws300_2m	Dewpoint Temperature	degC		
P_ws800_3m	Pressure	mb	Lufft WS800	iss2
T_ws800_3m	Temperature	degC		
Td_ws800_3m	Dewpoint Temperature	degC		
Tchill_ws800_3m	Wind Chill Temperature	degC		
RH_ws800_3m	Relative Humidity	%		
Spd_ws800_3m	Wind Speed	m/s		
Sn_ws800_3m	Min. wind speed**	m/s		
Sx_ws800_3m	Max. wind speed**	m/s		
Sg_ws800_3m	Moving average wind speed**	m/s		
Sv_ws800_3m	Averaged vectorial wind speed**	m/s		
Dir_ws800_3m	Vector wind direction	deg		
Dn_ws800_3m	Min. wind direction**	deg		
Dx_ws800_3m	Max wind direction**	deg		

**The interval for the calculation of minimum, maximum and average values is set at 10 minutes.

Table 4. List of Lufft research variables and definitions.

Lufft WS800/WS300	T, °C	RH, %	Td, degC	P, hPa	Wind Spd, m/s	Wind Dir, °
Measuring Range	-50 - +60	0 - 100	-50 - +60	300 - 1200	0 - 75	0 - 360
Resolution	0.1	0.1	0.1	0.1	0.1	0.1
Accuracy	± 0.2	± 2	± 0.7	± 0.5	±0.3	< 3
Sampling rate	1 min	1 min	1 min	1 min	20 s	20 s

Table 5. Lufft sensor accuracy. Wind speed and direction were measured by the WS800 only.

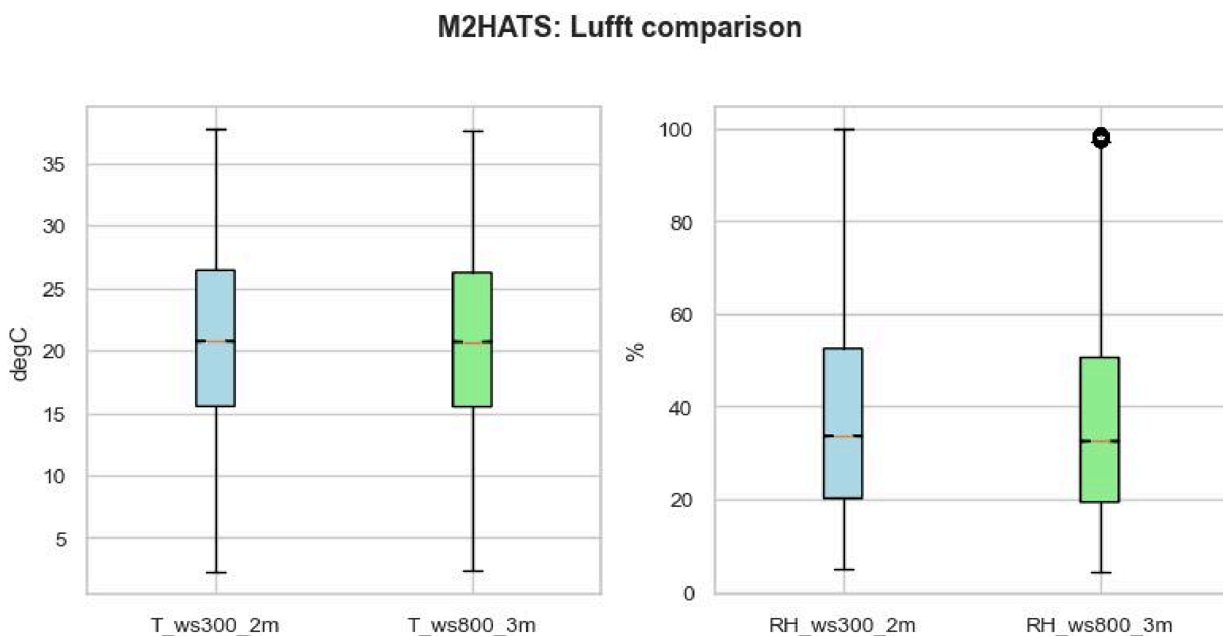


Figure 2. Comparison of the Temperature and RH for the WS300, WS800 Luffts.

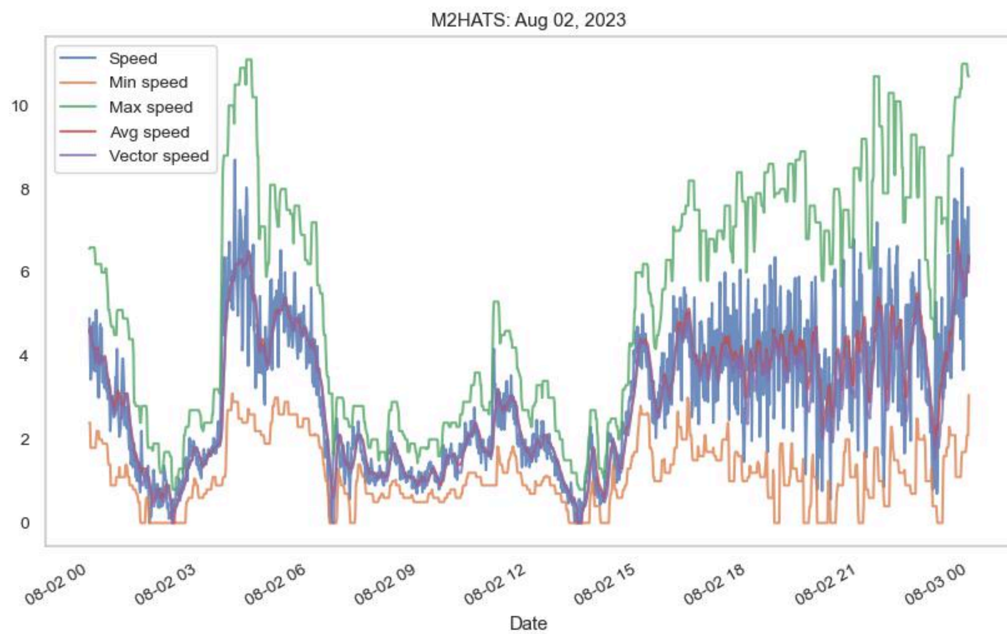


Figure 3. An example of one day of Lufft WS800 wind speed measurements for 02 August 2023.

Lufft WS800 Radiation

Lufft WS800 measurements of radiation quantities are listed in **Table 6**. The global radiation is measured by a pyranometer mounted in the top cover of the sensor. The sampling rate is 10 s with a resolution of less than 1 W/m^2. We recommend using the Hukseflux NR01 radiation data over the Lufft. Accuracy values are unknown.

Variable name	Quantity Measured	unit
Ga_ws800_3m	Global radiation	W/m^2
Gn_ws800_3m	Min. global radiation**	W/m^2
Gx_ws800_3m	Max. global radiation**	W/m^2
Gg_ws800_3m	Avg. global radiation**	W/m^2

**The interval for the calculation of minimum, maximum and average values is set at 10 minutes.

Table 6. List of Lufft research variables and definitions.

2D Gill Windobserver

The 2D Gill mounted at the top of the 10 m tower (refer to **Photo 2**) reports 1-second data that are averaged to 1 minute in the iss1 data files. A table of research variables and wind accuracy are in **Table 7**.

Figure 4 shows windrose plots for the 2D Gill, Lufft WS800 and the nearest ISFS towered Campbell Scientific CSAT3 3D sonic anemometers. Note that the 3D sonic data are recorded as 5 minute averages. Winds compare well overall.

Variable name	Quantity Measured	Unit
Spd_10m	Wind speed	m/s
Dir_10m	Wind direction	deg
Tc_10m	2D sonic temperature	degC
U_10m	Wind U component	m/s
V_10m	Wind U component	m/s

	Wind Speed	Wind Direction
Range	0 - 65 m/s	0 - 359°
Accuracy	±2% @12 m/s	±2° @12 m/s
Resolution	0.01 m/s	1°

Table 7. Gill Windobserver variables in the netCDF data files and the sensor accuracy of the winds.

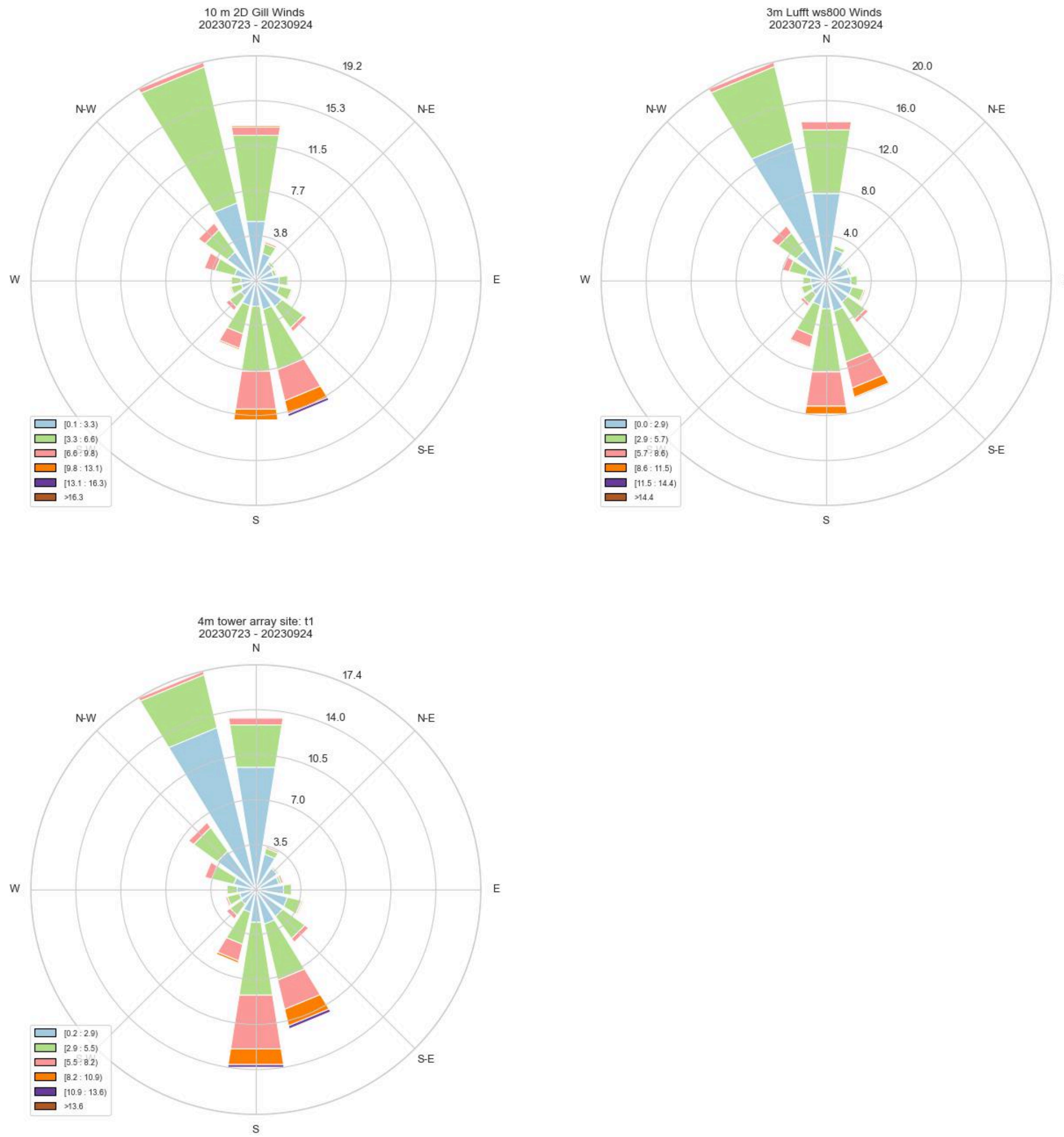


Figure 4. Windrose plots for 2D Gill, Lufft ws800, and the nearest ISFS 3D sonic on tower t1.

Hukseflux NR01 Radiometer

ISS operated a Hukseflux NR01 radiometer (see **Photo 2**) whose data was integrated into the surface meteorology iss1 netCDF files. All sensors functioned as expected. Key variables in the netcdf files are shown in **Table 8**. Calculation of long-wave radiation from the thermopile and case temperatures can be found here: https://www.eol.ucar.edu/content/calculation-long-wave-radiation. There were two NR01 radiometers set-up along the ISFS horizontal array, namely at towers t2 and t49. **Figure 5** shows a histogram summary of the outgoing and incoming radiation measurements compared to the two NR01 sensors set-up along the ISFS horizontal array.

Variable name	Quantity Measured	unit
Rsw_in_1m	Incoming Shortwave	W/m^2
Rsw_out_1m	Outgoing Shortwave	W/m^2
Rpile_in_1m	Incoming Thermopile	W/m^2
Rpile_out_1m	Outgoing Thermopile	W/m^2
Tcase_1m	Case temperature	degC

Table 8. Variables measured by the Hukseflux NR01 radiometer.

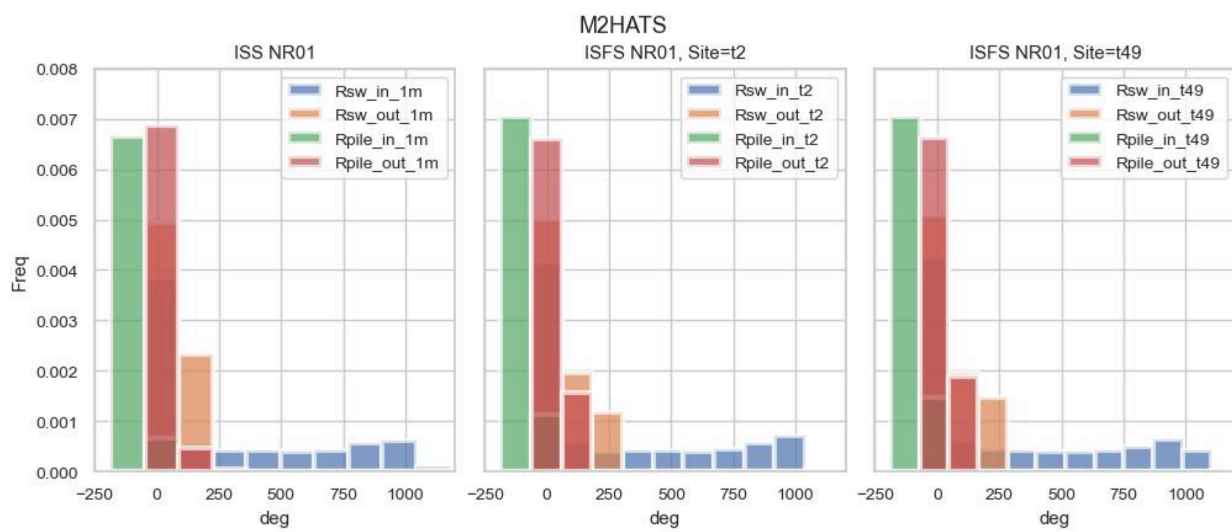


Figure 5. Histograms of Lufft WS800 radiation measurements (left), and two NR01 radiometers along the ISFS towered array: t2 (center) and t49 (right).

Precipitation and visibility data products

The CS125 visibility sensor was mounted at 3m and logged in the iss2 data logger. The sensor functioned as expected. No problems were noted during operations. The Lufft WS800 that operated at all three sites also measured precipitation variables. **Table 9** below shows the netcdf variable names, attributes, and overall accuracy.

Instrument - CS125

Variable name	Quantity Measured	unit	Accuracy
Rainr_3m	Rain rate	mm/h	±15% (against factory calibration standards in the laboratory, for liquid precipitation)
Vis_3m	Visibility	m	±8% (up to 600 m) ±10% (600 to 10,000 m) ±15% (10,000 to 15,000 m) ±20% (above 15,000 m)
Part_3m	Particle count	count/min	

Instrument - Lufft WS800

Variable name	Quantity Measured	unit	Accuracy
rainr_ws800_3m	Rain rate	mm/h	± 2%
raina_ws800_3m	Rain accumulation	mm	
preciptype_ws800_3m	Precipitation type	1	

Table 9.

Vaisala Ceilometer CL61

CL61 data processing software is developed by Vaisala or third parties. The CL61 reports measurements in NetCDF format using CF-1.8 conventions. Refer to the global metadata attributes below:

```
// global attributes:
            :title = "CL61-D Profiling Ceilometer" ;
            :institution = "" ;
            :source = "" ;
            :conventions = "CF-1.8" ;
            :schema_version = "1.3" ;
            :sw_version = "1.2.7" ;
            :history = "Fri Dec  1 13:54:52 2023: ncrcat;
            :comment = "" ;
            :unit = "m" ;
            :instrument_serial_number = "T3910707" ;
            :file_temporal_span_in_minutes = 5. ;
            :profile_interval_in_seconds = 60 ;
            :NCO = "netCDF Operators version 4.7.5 (Homepage =
http://nco.sf.net, Code = http://github.com/nco/nco)" ;
            :nco_openmp_thread_number = 1 ;
```

The CL61 data does include a depolarization channel which enables some determination of the nature of the particles the scattering occurred from.

Daily files were created from the original 5 min output using the ncrcat netCDF record concatenator tool: https://nco.sourceforge.net/nco.pdf. Otherwise, the ceilometer functioned as expected.

An example of CL61 measurements is shown in **Figure 6** during tropical storm Hilary. The Cloud base can be seen through-out the storm. Backscatter from spherical particles such as water cloud droplets, mist, fog and drizzle is not generally polarized so the depolarization ratio from these particles is close to zero. Rain, dust, smoke, snow, ice pellets, and graupel are non-spherical and thus have an increasingly polarized backscatter (see **Figure 7**).

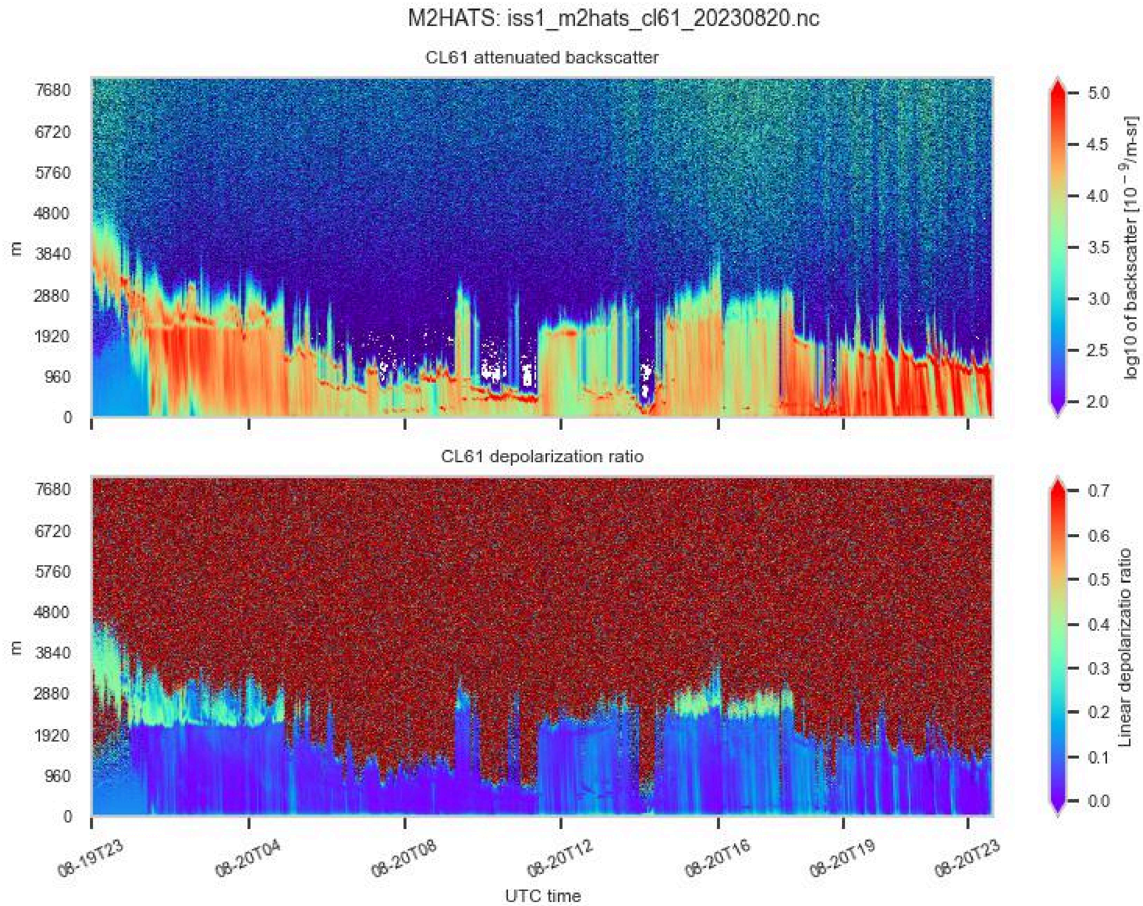


Figure 6. CL61 backscatter and depolarized measurements during tropical storm Hilary.

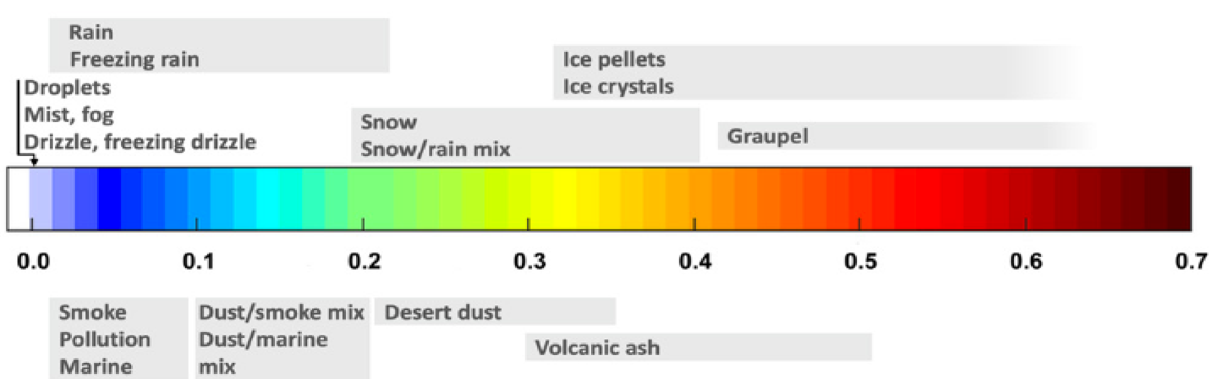


Figure 7. Typical depolarization ratios for a variety of atmospheric scattering conditions. Note that the color scale differs slightly to that in **Figure 6.** (Referenced from the Vaisala CL61 whitepaper).

PurpleAir AQ Sensor

The PurpleAir is a low-cost aerosol sensor based on PMS5003 and PMS1003 laser particulate counters with on-board SD card logger and linked to a PurpleAir's archiving and analysis web service. ISS deployed two PurpleAir PA-II-SD sensors for M2HATS at the 10 m tower and on the t44 ISFS flux tower. Data is available at the 10 m tower only. The PurpleAir at t44 registered incorrect timestamps and is currently not usable. The data reported includes estimates of particle counts for the following sizes: 0.3, 0.5, 1.0, 2.5, 5.0, and 10um. Refer to **Appendix A** for the CSV file header descriptions.

Refer to the PurpleAir website https://www2.purpleair.com/ for instrument overview, specifications and processing. Data is provided as is according to PurpleAir processing.

Ardon-Dryer et. al. 2020 provides a useful discussion of PurpleAir measurements as compared to EPA research quality sensors.

Ardon-Dryer, K., Dryer, Y., Williams, J. N., and Moghimi, N., 2020: Measurements of PM2.5 with PurpleAir under atmospheric conditions, Atmos. Meas. Tech., 13, 5441–5458, doi:10.5194/amt-13-5441-2020.

Tropical Storm Hilary

From 19 - 21 August 2023 the National Weather Service issued a warning alert for Hurricane Hilary that strengthened into a Category 4 hurricane and is tracking west-northwestward in the eastern North Pacific Ocean off the west coast of Mexico early Aug. 18. Hilary weakened into a tropical depression as it tracked generally northward across southern California and Nevada Aug. 21, before dissipating over southeastern Oregon early Aug. 22.

One can see the active rain event in **Figures 8** showing the modular 449 MHz wind profiler measurements for that time period: reds (reflectivity, top panel), blues (vertical velocity, middle panel), and downward wind barbs of high winds aloft starting at 00:00 UT 20 August. **Figure 9** shows the rain rate from several precipitation measuring sensors, including the ISFS OTT Parsivel² disdrometer.

Figure 10 shows accumulated rain from the Lufft WS800, the Campbell CS125, ISFS Ott Parsivel² disdrometer, and a nearby NOAA ASOS station. Note, the ISFS Ott stopped recording around 6 UTC on August 21 and the ASOS station appeared to have problems from 20 UTC (Aug 20) before ending recording several hours later. The close tracking of the Ott and ASOS station for the first 18 hours of the event suggests that the Lufft WS800 and the Campbell CS125 may have been over estimating the accumulated rain, however we have no independent confirmation of that conclusion.

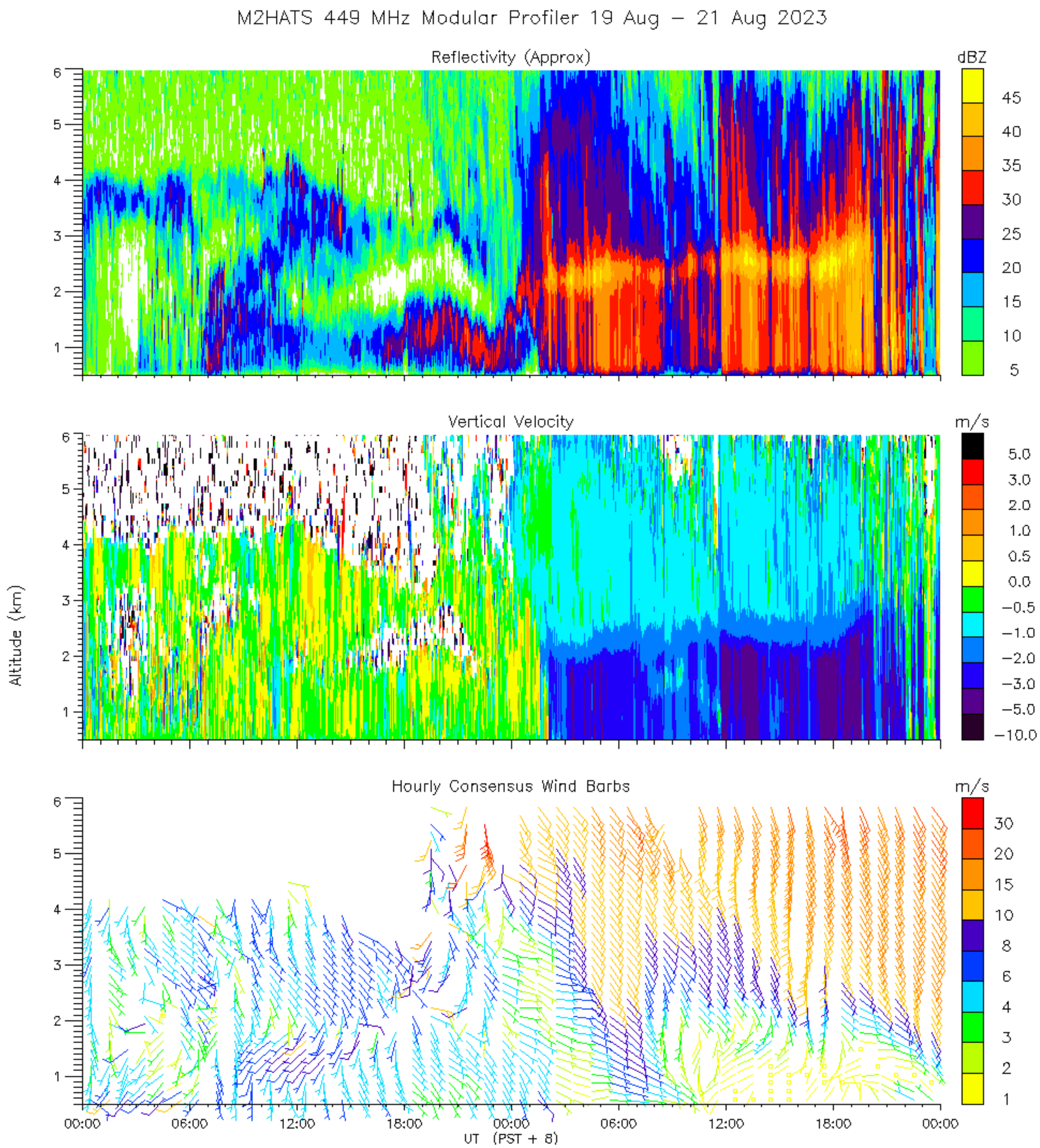


Figure 8. Modular profiler measurements from 19 00:00 UT to 21 August 00:00 UT.

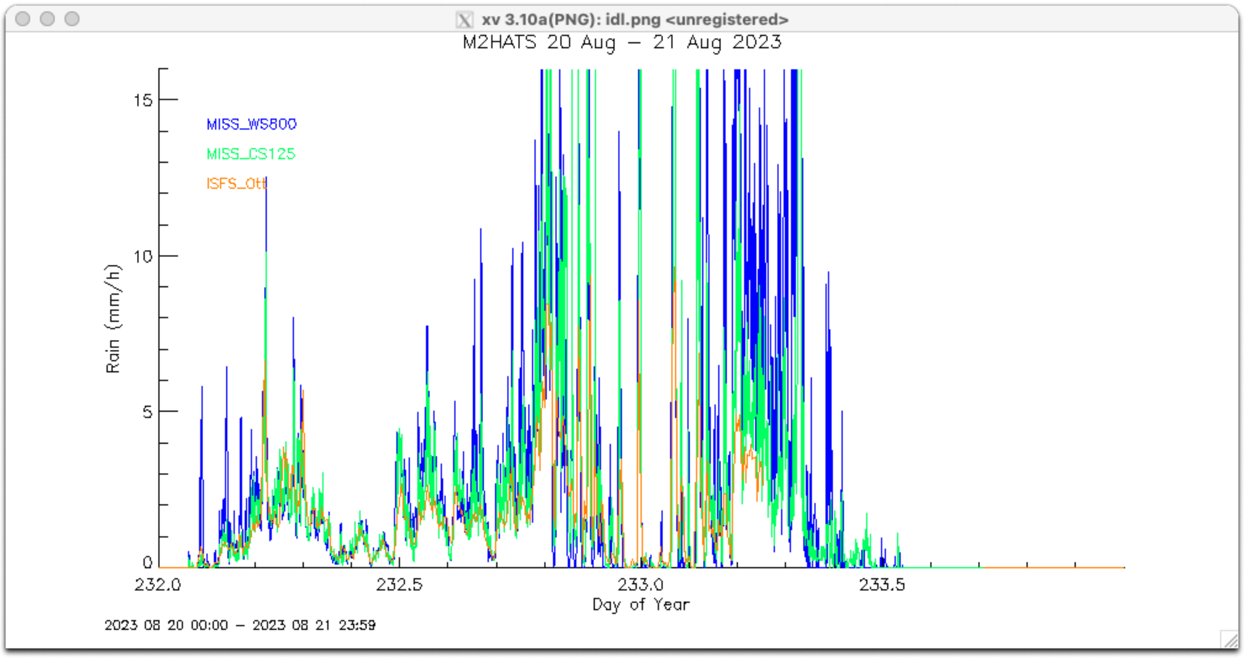


Figure 9. Rain rate (mm/h) measured by the Lufft WS800 (blue), the Campbell CS125 (green) and the ISFS OTT Parsivel² disdrometer (orange). The ISFS disdrometer only recorded until around 6 UTC Aug 21 until the tower batteries ran out.

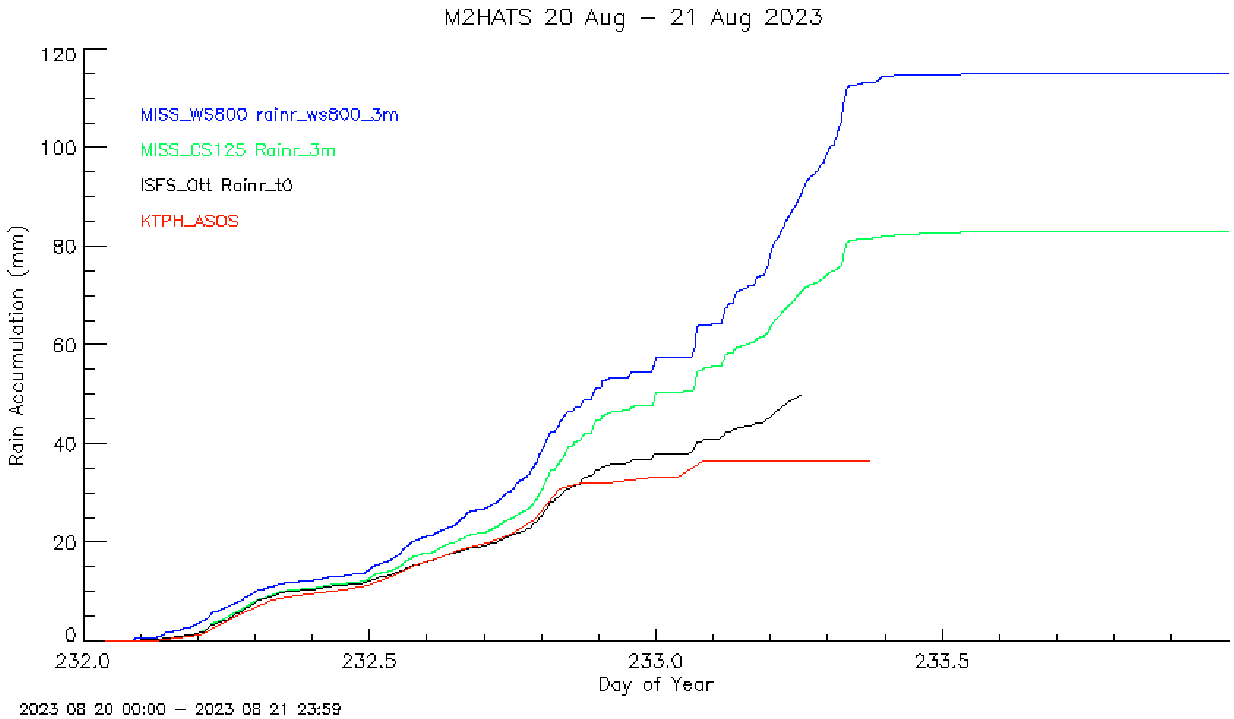


Figure 10. The accumulated rain from the Lufft WS800 (blue), the Campbell CS125 (green), the ISFS Ott Parsivel² disdrometer (black), and the nearby NOAA ASOS station (red). The accumulated totals were (respectively) 115mm, 80mm, 45mm, and 36mm.

Appendix A: PurpleAir SD card CSV File Header Descriptions

URL Reference

The SD Card version of the PA-II (PA-II-SD) has a built in real time clock and OPENLOG serial logger. The SD card contains data in CSV format with the following headers:

`UTCDateTime, mac_address, firmware_ver, hardware, current_temp_f, current_humidity, current_dewpoint_f, pressure, adc, mem, rssi, uptime, pm1_0_atm, pm2_5_atm, pm10_0_atm, pm1_0_cf_1, pm2_5_cf_1, pm10_0_cf_1, p_0_3_um, p_0_5_um, p_1_0_um, p_2_5_um, p_5_0_um, p_10_0_um, pm1_0_atm_b, pm2_5_atm_b, pm10_0_atm_b, pm1_0_cf_1_b, pm2_5_cf_1_b, pm10_0_cf_1_b, p_0_3_um_b, p_0_5_um_b, p_1_0_um_b, p_2_5_um_b, p_5_0_um_b, p_10_0_um_b`

UTCDateTime: The Date and time derived from the Real Time Clock and synced with NTP where possible (in UTC).

Mac_address: The MAC address of the WiFi module on the sensor (used as an ID for the unit).

Firmware_ver: Firmware version of the control board.

Hardware: Hardware the control board has detected.

current_temp_f: Current temperature in F.

Current_humidity: Current Humidity in %.

Current_dewpoint_f: Calculated dew point in F.

Pressure: Current pressure in millibars.

Adc: The voltage reading on the analog input of the control board.

Mem: Free HEAP memory on the control board.

Rssi: WiFi signal strength in dBm

Uptime: Firmware uptime in seconds.

Pm1_0_atm: Channel A ATM PM1.0 particulate mass in ug/m3

Pm2_5_atm: Channel A ATM PM2.5 particulate mass in ug/m3

Pm10_0_atm: Channel A ATM PM10.0 particulate mass in ug/m3

Pm1_0_cf_1: Channel A CF=1 PM1.0 particulate mass in ug/m3

Pm2_5_cf_1: Channel A CF=1 PM2.5 particulate mass in ug/m3

Pm10_0_cf_1: Channel A CF=1 PM10.0 particulate mass in ug/m3

P_0_3_um: Channel A 0.3 micrometer particle counts per deciliter of air

P_0_5_um: Channel A 0.5 micrometer particle counts per deciliter of air

P_1_0_um: Channel A 1.0 micrometer particle counts per deciliter of air

P_2_5_um: Channel A 2.5 micrometer particle counts per deciliter of air

P_5_0_um: Channel A 5.0 micrometer particle counts per deciliter of air

P_10_0_um: Channel A 10.0 micrometer particle counts per deciliter of air

Pm1_0_atm_b: Channel B ATM PM1.0 particulate mass in ug/m3.

Pm2_5_atm_b: Channel B ATM PM2.5 particulate mass in ug/m3

Pm10_0_atm_b: Channel B ATM PM10.0 particulate mass in ug/m3

Pm1_0_cf_1_b: Channel B CF=1 PM1.0 particulate mass in ug/m3

Pm2_5_cf_1_b: Channel B CF=1 PM2.5 particulate mass in ug/m3

Pm10_0_cf_1_b: Channel B CF=1 PM10.0 particulate mass in ug/m3

P_0_3_um_b: Channel B 0.3 micrometer particle counts per deciliter of air

P_0_5_um_b: Channel B 0.5 micrometer particle counts per deciliter of air

P_1_0_um_b: Channel B 1.0 micrometer particle counts per deciliter of air

P_2_5_um_b: Channel B 2.5 micrometer particle counts per deciliter of air

P_5_0_um_b: Channel B 5.0 micrometer particle counts per deciliter of air

P_10_0_um_b: Channel B 10.0 micrometer particle counts per deciliter of air

PA-II NOTES:

Each sensor contains two identical laser counters, hence channel A and B. If these two channels do not agree to some extent then there is something wrong with one or both channels.

Plantower PMS sensor notes:

ATM is "atmospheric", meant to be used for outdoor applications

CF=1 is meant to be used for indoor or controlled environment applications

However, PurpleAir uses CF=1 values on the map. This value is lower than the ATM value in higher measured concentrations.

Appendix B: CL61 NetCDF metadata contents

ncrcat software was used to create daily files from the 5 min original files. Below is the metadata contents of a single file.

```
netcdf iss1_m2hats_cl61_20230914 {
dimensions:
	time = UNLIMITED ; // (1440 currently)
	layer = 5 ;
	range = 3276 ;
variables:
	int cloud_base_heights(time, layer) ;
		cloud_base_heights:_FillValue = -99 ;
		cloud_base_heights:units = "m" ;
		cloud_base_heights:long_name = "heights (range) of the detected
cloud bases" ;
		cloud_base_heights:coordinates = "time layer longitude latitude" ;
	int vertical_visibility(time) ;
		vertical_visibility:_FillValue = -99 ;
		vertical_visibility:units = "m" ;
		vertical_visibility:long_name = "visibility in the direction of
the instrument beam"
;
		vertical_visibility:coordinates = "time longitude latitude" ;
	float p_pol(time, range) ;
		p_pol:_FillValue = -999.f ;
		p_pol:units = "1/(m*sr)" ;
		p_pol:long_name = "parallel-polarized component of the
backscattered light" ;
		p_pol:coordinates = "time range longitude latitude" ;
		p_pol:averaging_time_in_seconds = 60 ;
```

```
        float x_pol(time, range) ;
                x_pol:_FillValue = -999.f ;
                x_pol:units = "1/(m*sr)" ;
                x_pol:long_name = "cross-polarized component of the backscattered
light" ;
                x_pol:coordinates = "time range longitude latitude" ;
                x_pol:averaging_time_in_seconds = 60 ;
        float beta_att(time, range) ;
                beta_att:_FillValue = -999.f ;
                beta_att:units = "1/(m*sr)" ;
                beta_att:long_name = "attenuated volume backscatter coefficient" ;
                beta_att:coordinates = "time range longitude latitude" ;
                beta_att:averaging_time_in_seconds = 60 ;
        float linear_depol_ratio(time, range) ;
                linear_depol_ratio:_FillValue = -999.f ;
                linear_depol_ratio:long_name = "linear depolarisation ratio of the
backscatter volume
" ;
                linear_depol_ratio:coordinates = "time range longitude latitude" ;
                linear_depol_ratio:averaging_time_in_seconds = 60 ;
        double time(time) ;
                time:_FillValue = -999. ;
                time:units = "seconds since 1970-01-01 00:00:00.000" ;
                time:long_name = "Time" ;
                time:axis = "T" ;
                time:standard_name = "time" ;
                time:cf_role = "profile_id" ;
                time:comment = "represents the end of the averaging period" ;
        double range(range) ;
                range:_FillValue = -999. ;
                range:units = "m" ;
                range:long_name = "measurement distance from the instrument in the
direction of the t
ransmitted laser beam" ;
                range:axis = "Z" ;
                range:positive = "up" ;
        int layer(layer) ;
                layer:_FillValue = -999 ;
                layer:units = "layer" ;
                layer:long_name = "number of the observed cloud layer (1,2,...,5)"
;
        double longitude ;
                longitude:_FillValue = -999. ;
                longitude:units = "degrees_east" ;
                longitude:long_name = "longitude" ;
                longitude:standard_name = "longitude" ;
        double latitude ;
                latitude:_FillValue = -999. ;
                latitude:units = "degrees_north" ;
                latitude:long_name = "latitude" ;
                latitude:standard_name = "latitude" ;
        int elevation ;
```

```
            elevation:_FillValue = -999 ;
            elevation:units = "m" ;
            elevation:long_name = "elevation" ;
            elevation:standard_name = "ground_level_altitude" ;
            elevation:comment = "measurement site height above or below a
fixed reference point,
most commonly a reference geoid" ;
      double azimuth_angle ;
            azimuth_angle:_FillValue = -999. ;
            azimuth_angle:units = "degrees" ;
            azimuth_angle:long_name = "measurement azimuth angle" ;
            azimuth_angle:standard_name = "sensor_azimuth_angle" ;
            azimuth_angle:comment = "reference direction: north" ;
      double beta_att_sum(time) ;
            beta_att_sum:_FillValue = -999. ;
            beta_att_sum:units = "1/(10^4*sr)" ;
            beta_att_sum:long_name = "scaled integral of the attenuated volume
backscatter coeffi
cient" ;
      double beta_att_noise_level(time) ;
            beta_att_noise_level:_FillValue = -999. ;
            beta_att_noise_level:long_name = "a unitless number describing the
noise level of the
 attenuated volume backscatter coefficient" ;
      short tilt_correction(time) ;
            tilt_correction:_FillValue = -999s ;
            tilt_correction:long_name = "tilt correction" ;
            tilt_correction:comment = "on/off (1/0)" ;
      float tilt_angle(time) ;
            tilt_angle:_FillValue = -999.f ;
            tilt_angle:units = "degrees" ;
            tilt_angle:standard_name = "zenith_angle" ;
            tilt_angle:long_name = "instrument tilt angle from the vertical" ;
      short height_offset(time) ;
            height_offset:_FillValue = -999s ;
            height_offset:long_name = "instrument height offset to reference
level" ;
            height_offset:comment = "positive, if the instrument is placed
e.g. on the roof of a
building. Negative, if the instrument is placed below the ground level
altitude e.g. in a pit. This v
alue will be added to the cloud base height results." ;
            height_offset:units = "m" ;
      short airplane_filter_max_range ;
            airplane_filter_max_range:_FillValue = -999s ;
            airplane_filter_max_range:units = "m" ;
            airplane_filter_max_range:long_name = "airplane filter max range"
;
            airplane_filter_max_range:comment = "user configured value, zero
for not in use, othe
rwise the configured range" ;
      short sky_condition_total_cloud_cover(time) ;
```

```
		sky_condition_total_cloud_cover:_FillValue = -99s ;
		sky_condition_total_cloud_cover:units = "oktas" ;
		sky_condition_total_cloud_cover:long_name = "total amount of cloud
cover" ;
		sky_condition_total_cloud_cover:comment = "aggregated across
layers" ;
		sky_condition_total_cloud_cover:coordinates = "time longitude
latitude" ;
	short sky_condition_cloud_layer_covers(time, layer) ;
		sky_condition_cloud_layer_covers:_FillValue = -99s ;
		sky_condition_cloud_layer_covers:units = "oktas" ;
		sky_condition_cloud_layer_covers:long_name = "amount of cloud
cover in different clou
d layers" ;
		sky_condition_cloud_layer_covers:comment = "for up to 5 layers" ;
		sky_condition_cloud_layer_covers:coordinates = "time layer
longitude latitude" ;
	int sky_condition_cloud_layer_heights(time, layer) ;
		sky_condition_cloud_layer_heights:_FillValue = -99 ;
		sky_condition_cloud_layer_heights:units = "m" ;
		sky_condition_cloud_layer_heights:long_name = "height of different
cloud layers" ;
		sky_condition_cloud_layer_heights:comment = "for up to 5 layers" ;
		sky_condition_cloud_layer_heights:coordinates = "time layer
longitude latitude" ;
	int cloud_penetration_depth(time, layer) ;
		cloud_penetration_depth:_FillValue = -99 ;
		cloud_penetration_depth:units = "m" ;
		cloud_penetration_depth:long_name = "cloud penetration depth in
the direction of the
instrument beam" ;
		cloud_penetration_depth:coordinates = "time layer longitude
latitude" ;
	int cloud_thickness(time, layer) ;
		cloud_thickness:_FillValue = -99 ;
		cloud_thickness:units = "m" ;
		cloud_thickness:long_name = "cloud thickness in the direction of
the instrument beam"
 ;
		cloud_thickness:coordinates = "time layer longitude latitude" ;
	short precipitation_detection(time) ;
		precipitation_detection:_FillValue = -999s ;
		precipitation_detection:long_name = "detection of ground reaching
precipitation" ;
		precipitation_detection:comment = "detected/not-detected (1/0)" ;
		precipitation_detection:coordinates = "time longitude latitude" ;
	short fog_detection(time) ;
		fog_detection:_FillValue = -999s ;
		fog_detection:long_name = "detection of fog" ;
		fog_detection:comment = "detected/not-detected (1/0)" ;
		fog_detection:coordinates = "time longitude latitude" ;
	short receiver_gain(time) ;
```

```
            receiver_gain:_FillValue = -999s ;
            receiver_gain:long_name = "receiver gain status" ;
            receiver_gain:comment = "high-gain/low-gain (1/0)" ;
      float range_resolution ;
            range_resolution:_FillValue = -999.f ;
            range_resolution:units = "m" ;
            range_resolution:long_name = "range resolution" ;
            range_resolution:comment = "distance between consecutive profile
elements" ;
      double cloud_calibration_factor ;
            cloud_calibration_factor:_FillValue = -999. ;
            cloud_calibration_factor:long_name = "factory cloud calibration
value" ;
            cloud_calibration_factor:comment = "instrument specific beta_att
calibration value me
asured at the factory" ;
      double cloud_calibration_factor_user ;
            cloud_calibration_factor_user:_FillValue = -999. ;
            cloud_calibration_factor_user:long_name = "user set cloud
calibration value" ;
            cloud_calibration_factor_user:comment = "instrument specific
beta_att calibration val
ue set by the user, same as the factory value by default" ;
      float overlap_function(range) ;
            overlap_function:_FillValue = -999.f ;
            overlap_function:long_name = "instrument specific overlap
function" ;
            overlap_function:comment = "shares the vertical resolution of
profiles" ;

// global attributes:
            :title = "CL61-D Profiling Ceilometer" ;
            :institution = "" ;
            :source = "" ;
            :conventions = "CF-1.8" ;
            :schema_version = "1.3" ;
            :sw_version = "1.2.7" ;
            :history = "Fri Dec  1 13:54:52 2023: ncrcat;
            :comment = "" ;
            :unit = "m" ;
            :instrument_serial_number = "T3910707" ;
            :overlap_function_provided = 1s ;
            :overlap_is_corrected = 1s ;
            :file_temporal_span_in_minutes = 5. ;
            :profile_interval_in_seconds = 60 ;
            :NCO = "netCDF Operators version 4.7.5 (Homepage =
http://nco.sf.net, Code = http://g
ithub.com/nco/nco)" ;
            :nco_openmp_thread_number = 1 ;

group: monitoring {
  variables:
```

```
        double time(time) ;
                time:_FillValue = -999. ;
                time:units = "seconds since 1970-01-01 00:00:00.000" ;
                time:long_name = "Time" ;
                time:axis = "T" ;
                time:standard_name = "time" ;
        float window_condition(time) ;
                window_condition:_FillValue = -999.f ;
                window_condition:units = "percent" ;
                window_condition:long_name = "window condition" ;
                window_condition:comment = "100 for a clean, 0 for a totally dirty
window" ;
        float laser_power_percent(time) ;
                laser_power_percent:_FillValue = -999.f ;
                laser_power_percent:units = "percent" ;
                laser_power_percent:long_name = "laser power percent" ;
        float background_radiance(time) ;
                background_radiance:_FillValue = -999.f ;
                background_radiance:long_name = "background radiance" ;
                background_radiance:range = "[0 1747]" ;
        float internal_temperature(time) ;
                internal_temperature:_FillValue = -999.f ;
                internal_temperature:units = "celsius" ;
                internal_temperature:long_name = "internal temperature" ;
        float internal_humidity(time) ;
                internal_humidity:_FillValue = -999.f ;
                internal_humidity:units = "RH" ;
                internal_humidity:long_name = "internal humidity" ;
                internal_humidity:comment = "percent (% RH)" ;
        float internal_pressure(time) ;
                internal_pressure:_FillValue = -999.f ;
                internal_pressure:units = "hPa" ;
                internal_pressure:long_name = "internal pressure" ;
        float laser_temperature(time) ;
                laser_temperature:_FillValue = -999.f ;
                laser_temperature:units = "celsius" ;
                laser_temperature:long_name = "laser temperature" ;
        float window_blower(time) ;
                window_blower:_FillValue = -999.f ;
                window_blower:long_name = "window blower" ;
                window_blower:comment = "on/off (1/0)" ;
        float internal_heater(time) ;
                internal_heater:_FillValue = -999.f ;
                internal_heater:long_name = "internal heater" ;
                internal_heater:comment = "on/off (1/0)" ;
        float window_blower_heater(time) ;
                window_blower_heater:_FillValue = -999.f ;
                window_blower_heater:long_name = "window blower heater" ;
                window_blower_heater:comment = "on/off (1/0)" ;
        float transmitter_enclosure_temperature(time) ;
                transmitter_enclosure_temperature:_FillValue = -999.f ;
                transmitter_enclosure_temperature:units = "celsius" ;
```

```
            transmitter_enclosure_temperature:long_name = "transmitter
enclosure temperature" ;
  } // group monitoring

group: status {
  variables:
      double time(time) ;
            time:_FillValue = -999. ;
            time:units = "seconds since 1970-01-01 00:00:00.000" ;
            time:long_name = "Time" ;
            time:axis = "T" ;
            time:standard_name = "time" ;
      short Device_controller_temperature(time) ;
            Device_controller_temperature:_FillValue = -999s ;
            Device_controller_temperature:long_name =
"Device_controller_temperature" ;
      short Device_controller_electronics(time) ;
            Device_controller_electronics:_FillValue = -999s ;
            Device_controller_electronics:long_name =
"Device_controller_electronics" ;
      short Device_controller_overall(time) ;
            Device_controller_overall:_FillValue = -999s ;
            Device_controller_overall:long_name = "Device_controller_overall"
;
      short Optics_unit_accelerometer(time) ;
            Optics_unit_accelerometer:_FillValue = -999s ;
            Optics_unit_accelerometer:long_name = "Optics_unit_accelerometer"
;
      short Optics_unit_electronics(time) ;
            Optics_unit_electronics:_FillValue = -999s ;
            Optics_unit_electronics:long_name = "Optics_unit_electronics" ;
      short Optics_unit_overall(time) ;
            Optics_unit_overall:_FillValue = -999s ;
            Optics_unit_overall:long_name = "Optics_unit_overall" ;
      short Optics_unit_memory(time) ;
            Optics_unit_memory:_FillValue = -999s ;
            Optics_unit_memory:long_name = "Optics_unit_memory" ;
      short Optics_unit_tilt_angle(time) ;
            Optics_unit_tilt_angle:_FillValue = -999s ;
            Optics_unit_tilt_angle:long_name = "Optics_unit_tilt_angle" ;
      short Receiver_electronics(time) ;
            Receiver_electronics:_FillValue = -999s ;
            Receiver_electronics:long_name = "Receiver_electronics" ;
      short Receiver_overall(time) ;
            Receiver_overall:_FillValue = -999s ;
            Receiver_overall:long_name = "Receiver_overall" ;
      short Receiver_memory(time) ;
            Receiver_memory:_FillValue = -999s ;
            Receiver_memory:long_name = "Receiver_memory" ;
      short Receiver_voltage(time) ;
            Receiver_voltage:_FillValue = -999s ;
            Receiver_voltage:long_name = "Receiver_voltage" ;
```

```
        short Receiver_solar_saturation(time) ;
              Receiver_solar_saturation:_FillValue = -999s ;
              Receiver_solar_saturation:long_name = "Receiver_solar_saturation"
;
        short Window_blocking(time) ;
              Window_blocking:_FillValue = -999s ;
              Window_blocking:long_name = "Window_blocking" ;
        short Window_condition(time) ;
              Window_condition:_FillValue = -999s ;
              Window_condition:long_name = "Window_condition" ;
        short Window_blower_fan(time) ;
              Window_blower_fan:_FillValue = -999s ;
              Window_blower_fan:long_name = "Window_blower_fan" ;
        short Window_blower_heater(time) ;
              Window_blower_heater:_FillValue = -999s ;
              Window_blower_heater:long_name = "Window_blower_heater" ;
        short Servo_drive_electronics(time) ;
              Servo_drive_electronics:_FillValue = -999s ;
              Servo_drive_electronics:long_name = "Servo_drive_electronics" ;
        short Servo_drive_overall(time) ;
              Servo_drive_overall:_FillValue = -999s ;
              Servo_drive_overall:long_name = "Servo_drive_overall" ;
        short Servo_drive_memory(time) ;
              Servo_drive_memory:_FillValue = -999s ;
              Servo_drive_memory:long_name = "Servo_drive_memory" ;
        short Servo_drive_control(time) ;
              Servo_drive_control:_FillValue = -999s ;
              Servo_drive_control:long_name = "Servo_drive_control" ;
        short Servo_drive_ready(time) ;
              Servo_drive_ready:_FillValue = -999s ;
              Servo_drive_ready:long_name = "Servo_drive_ready" ;
        short Transmitter_electronics(time) ;
              Transmitter_electronics:_FillValue = -999s ;
              Transmitter_electronics:long_name = "Transmitter_electronics" ;
        short Transmitter_light_source(time) ;
              Transmitter_light_source:_FillValue = -999s ;
              Transmitter_light_source:long_name = "Transmitter_light_source" ;
        short Transmitter_light_source_power(time) ;
              Transmitter_light_source_power:_FillValue = -999s ;
              Transmitter_light_source_power:long_name =
"Transmitter_light_source_power" ;
        short Transmitter_overall(time) ;
              Transmitter_overall:_FillValue = -999s ;
              Transmitter_overall:long_name = "Transmitter_overall" ;
        short Transmitter_light_source_safety(time) ;
              Transmitter_light_source_safety:_FillValue = -999s ;
              Transmitter_light_source_safety:long_name =
"Transmitter_light_source_safety" ;
        short Transmitter_memory(time) ;
              Transmitter_memory:_FillValue = -999s ;
              Transmitter_memory:long_name = "Transmitter_memory" ;
        short Maintenance_overall(time) ;
```

```
            Maintenance_overall:_FillValue = -999s ;
            Maintenance_overall:long_name = "Maintenance_overall" ;
      short Device_overall(time) ;
            Device_overall:_FillValue = -999s ;
            Device_overall:long_name = "Device_overall" ;
      short Recently_started(time) ;
            Recently_started:_FillValue = -999s ;
            Recently_started:long_name = "Recently_started" ;
      short Measurement_status(time) ;
            Measurement_status:_FillValue = -999s ;
            Measurement_status:long_name = "Measurement_status" ;
      short Datacom_overall(time) ;
            Datacom_overall:_FillValue = -999s ;
            Datacom_overall:long_name = "Datacom_overall" ;
      short Measurement_data_destination_not_set(time) ;
            Measurement_data_destination_not_set:_FillValue = -999s ;
            Measurement_data_destination_not_set:long_name =
"Measurement_data_destination_not_se
t" ;
      short Inside_heater(time) ;
            Inside_heater:_FillValue = -999s ;
            Inside_heater:long_name = "Inside_heater" ;
      short Receiver_sensitivity(time) ;
            Receiver_sensitivity:_FillValue = -999s ;
            Receiver_sensitivity:long_name = "Receiver_sensitivity" ;
      short Data_generation_status(time) ;
            Data_generation_status:_FillValue = -999s ;
            Data_generation_status:long_name = "Data_generation_status" ;
  } // group status
}
```