NCAR | EARTH OBSERVING LABORATORY

SOS
NCAR/EOL ISFS Surface Meteorology and Flux Products Data Report

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Web References

SOS Homepage: https://www.eol.ucar.edu/field_projects/sos
ISFS Homepage: https://www.eol.ucar.edu/observing_facilities/isfs
Calculation of long-wave radiation from Hukseflux NR01 thermopile and case temperature: https://www.eol.ucar.edu/content/calculation-long-wave-radiation

Visualization Resources

- NCharts: http://datavis.eol.ucar.edu/ncharts/projects/SOS
- SOS ISFS Daily Data Statistics and Plots

Related Documentation

ISFS netCDF File Conventions: ISFS netCDF File Conventions
ISFS Guides: https://www.eol.ucar.edu/content/isfs-guides

Citations

If these data are used for research resulting in publications or presentations, please acknowledge EOL and NSF by including the following citations, as appropriate:

The Dataset

NSF NCAR/EOL ISFS Team. 2024. SOS: ISFS Surface Meteorology and Flux Products. Version 1.1. UCAR/NCAR - Earth Observing Laboratory. https://doi.org/10.26023/CYK2-SR3N-880J. Accessed 11 Mar 2024.

The ISFS Platform

NCAR - Earth Observing Laboratory. (1990). NCAR Integrated Surface Flux System (ISFS). UCAR/NCAR - Earth Observing Laboratory. https://doi.org/10.5065/D6ZC80XJ.

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

The ISFS system for SOS provides surface flux observations at multiple levels to better understand how basin-scale wind fields interact with surface turbulence and fluxes. These measurements, combined with energy and mass balance observations and terrestrial lidar scans of the evolving snowfield, will provide benchmarks of the most reliable approaches to measuring snow sublimation in different conditions and improve understanding of sensible and latent heat fluxes in complex terrain. SOS was operated during the winter and spring of 2022-2023.

Data Set Description

Project Period:	01 November 2022 – 31 May 2023
Data set Period:	01 November 2022 – 19 June 2023
Center Location:	Crested Butte, Colorado, USA
Data file frequency:	Daily
Data version:	v1.0
Data access:	public

5-minute data set

Data format:	netCDF3
File name format:	isfs_sos_qc_geo_tiltcor_5min_YYYYmmDD.nc
Time resolution:	5-minute

Geographic coordinates: Yes
Tilt corrected anemometers: Yes

High Rate data set

Data format: netCDF3
File name format: isfs_sos_qc_geo_tiltcor_hr_YYYYmmDD_HH.nc
Time resolution: - Varies from 50 ms to 1 s
- Refer to **Appendix B** for a complete list of variables and sampling rates.
Geographic coordinates: Yes
Tilt corrected anemometers: Yes

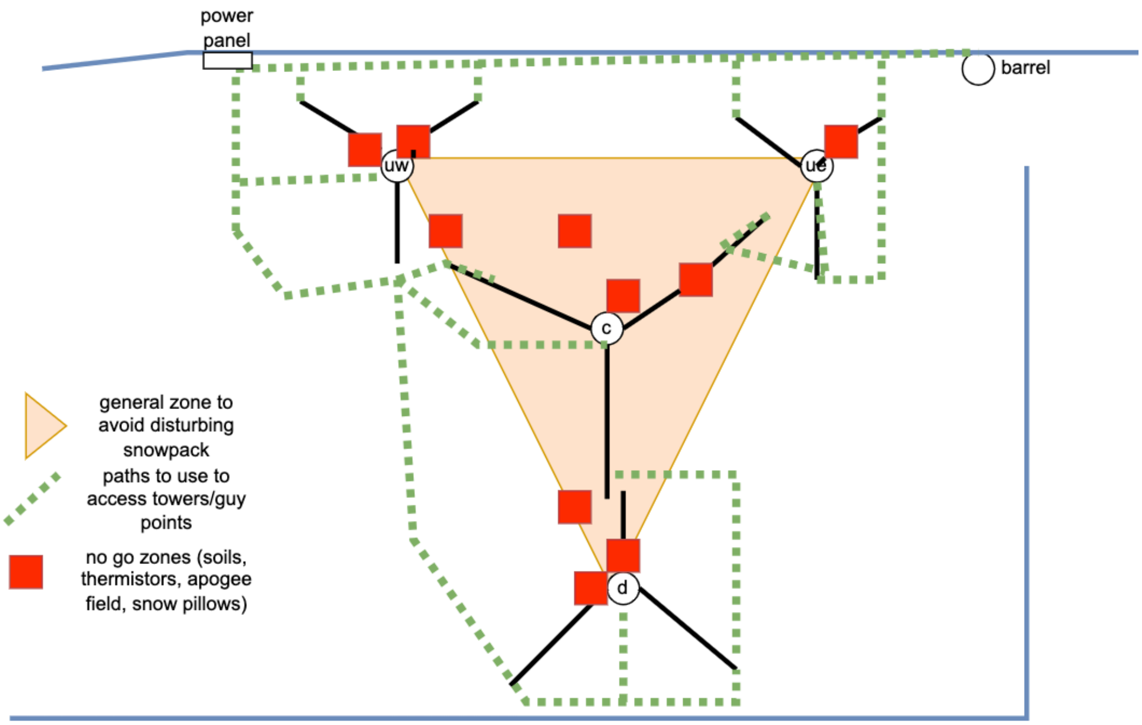
Site Description

Towers:
- 1 x 70 foot (also called 20 meter) tower
- 3 x 35 foot (also called 10 meter) towers

Four flux towers were set-up in a triangular pattern with a center tower. See **Schematic 1** below. The sites have been named uw (upwind west), ue (upwind east), c (center), d (downwind). **Table 1** gives the location of each tower determined by the Leica surveying equipment. Sensors were mounted on a 20m tower at the center site, and 10m towers for the rest.

To protect the snowpack within the zone indicated by the shaded triangle (**Schematic 1**), designated walking paths were determined to access the towers for maintenance and anchor points to measure guy tensions during operations - refer to **Schematic 1** green dashed lines. Red squares mark locations of buried sensors such as soil sensors or sensitive instruments, i.e. thermistors and snow pillows.

Schematic 1. Schematic rendering of site locations in circles. Site d is facing the WNW direction.



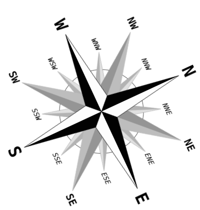


Photo 1. The four flux towers.

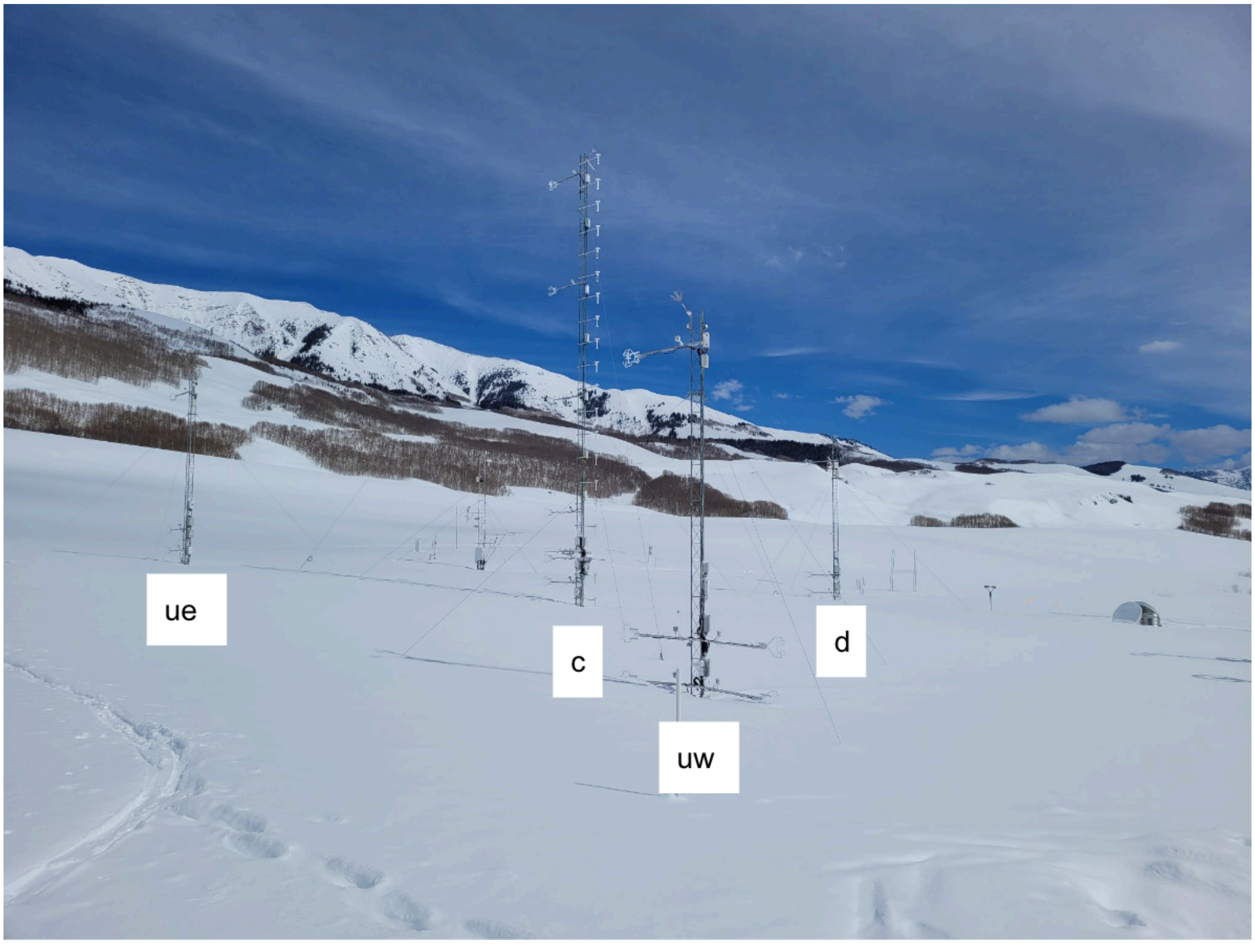


Table 1. Sites and locations. The abbreviated short name is the netCDF sitename definition. Locations were determined by the GPS on the Data loggers and the ground-level altitude was estimated from the Leica surveying equipment.

Long name	Short name	Tower height (m)	Latitude	Longitude	Ground-level Altitude (m)*
center	c	20	38.941799	-106.973062	2860.30
downwind	d	10	38.941661	-106.972925	2859.15
upwind west	uw	10	38.941712	-106.973288	2859.60
upwind east	ue	10	38.941962	-106.973052	2861.13

*Ground-level altitudes are estimates based on theodolite surveys of the 1m sonic heights.

Tower-to-tower differences

Using an English tape measure, we found the following distances between the tower locations:

Distance to the nearest fence line (**Schematic 1**, blue lines) : ue: 32', uw: 33', d: 34'

Tower-to-tower distances: ue-uw, uw-d, d-ue: all 111'

Tower-to-center tower distances: ue-c, uw-c: 62', d-c: 64'

ISFS Flux Tower Instruments

Towers:

- 1 x 70’ (also called 20 meter) tower. Seven sections of Rohn towers were used.
- 3 x 35’ (also called 10 meter) towers. Three and a half Rohn tower sections were used to build the 35’ tower.

Sensors:

- 17 sonic anemometers with H2O/CO2 infrared gas analyzers
- 20 Temperature/Humidity sensors
- 9 nanobarometers
- 2 sets of 4-component radiometers (one high quality, one medium)
- 1 set of soil sensors, including 16 Tsoils from 0.6--32.4cm depth
- Webcam useful to monitor conditions and operations remotely
- PI Sensors implemented into the ISFS Data Systems

The 20m tower at site c was instrumented to measure basic meteorology and eddy covariance fluxes at discrete intervals. Radiation sensors were mounted at 9m at site d and 2m at site uw. Soil heating and moisture sensors were buried near site d.

A webcam was set-up at 4m on site d looking WNW towards c, uw, and ue taking photos every minute. Refer to **Photos 2 and 3** for a visual reference. The soils were set-up at site d. Radiometers were mounted at 2m at site uw and 9m at site d. A wetness sensor was coupled to the radiometer at site uw to filter incidences of moisture on the sensor dome, i.e. dew, rain, or snow. The standard 5-min and high rate ISFS products include measurements from the sensors listed in **Table 2**.

Table 2. ISFS sensors and description. (A) are non-towered sensors that are provided in the 5-minute dataset only, and (B)-(C) are sensor configuration by tower instruments. Data from (B)-(C) are provided in both the 5-minute and high rate datasets.

(A) Non-towered sensors.

Instrument	Manufacturer	Site	Height	Samples /s
Wetness sensor	Decagon (now METER Phytos 31)	uw	2 m	0.2
Integrated Net Radiometer	4-component Hukseflux NR01	uw	2 m	0.2
Pyranometer / Pyrageometer	Kipp & Zonen CM21 & CG4	d	9 m	0.2
Soil temperature profile sensor	NCAR 4-level Tsoil	d	*0.6 cm, 1.9 cm, 3.1 cm, 4.4 cm, 8.1 cm, 9.4 cm, 10.6 cm, 11.9 cm, 18.1 cm, 19.4 cm, 20.6 cm, 21.9 cm, 28.1 cm, 29.4 cm, 30.6 cm, 31.9 cm	0.2
Soil thermal properties	Hukseflux TP01	d	*2.5 cm	0.2
Soil Moisture	Meter EC-5	d	*2.5 cm	0.2
Heat flux plate	REBS HFT	d	*5 cm	0.2

*All soil sensor heights are below the soil surface.

(B) Sensor configuration on tower c.

Instrument	Manufacturer	Heights (m)	Samples /s
3D sonic anemometer	Campbell Scientific CSAT3**	1, 2, 3, 5, 10, 15, 20	20
H2O/CO2 Open-path InfraRed Gas Analyzer (IRGA)	Campbell Scientific (combination of EC100 and EC150)		
Hygro-thermometer (TRH)	Sensirion SHT85	Every 1 m from 1 m to 20 m	1
Nanobarometer	Paroscientific 6000	(0.8, 0.9, 1.0, 1.1 - PI installed), 10, 20	20

**With the optional CSAT3A sonic anemometer head to couple with the IRGA EC150.

(C) Sensor configuration on towers d, ue, and uw.

Instrument	Manufacturer	Heights (m)	Samples/ s
3D sonic anemometer	Campbell Scientific CSAT3**	1, 3, 10	20
H2O/CO2 Open-path InfraRed Gas Analyzer (IRGA)	Campbell Scientific (combination of EC100 and EC150)		
Nanobarometer	Paroscientific 6000	10	20

Photo 2. Photos from the webcam on site d (shadowed) showing the instrument towered set-up relative to each other. The webcam faces WNW.

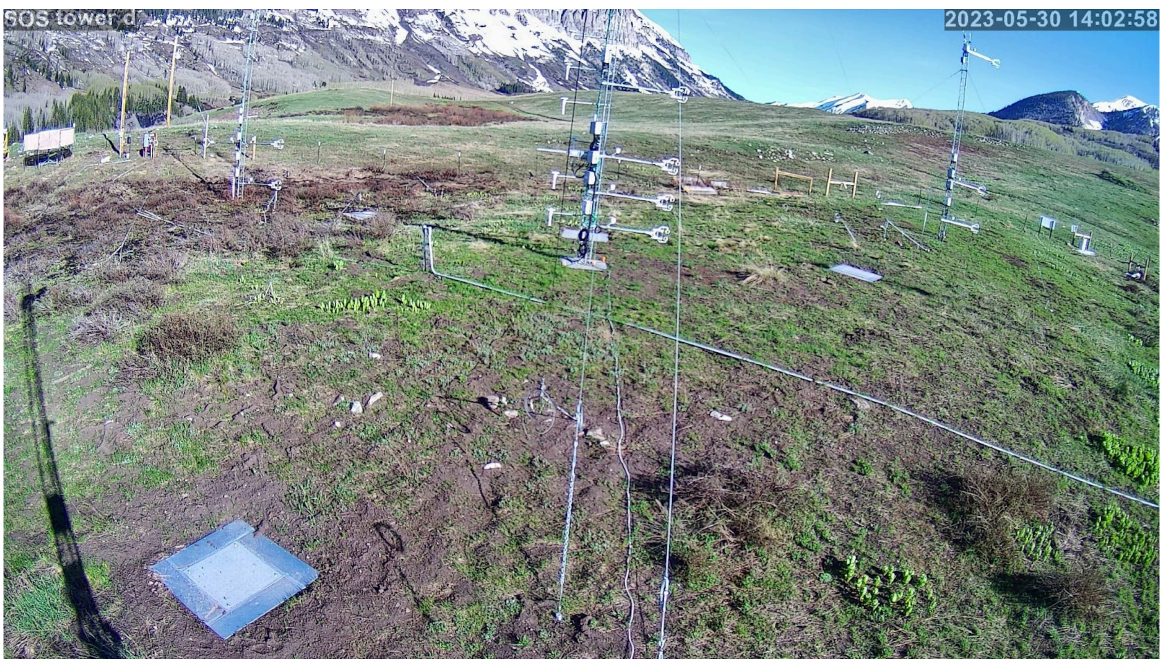
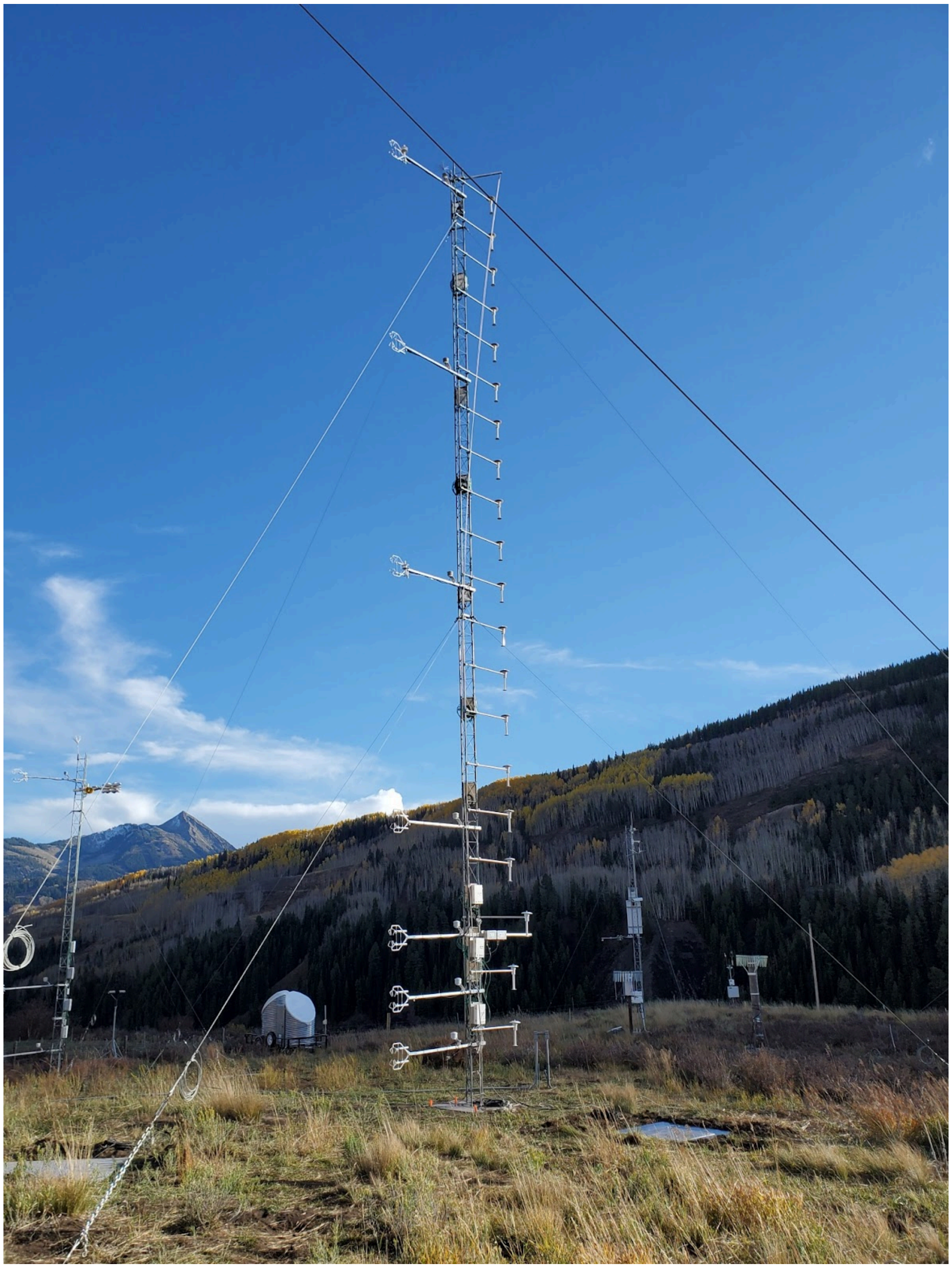


Photo 3. Individual towers. (A) site c, (B) site d, (C) site uw, and (D) site ue.

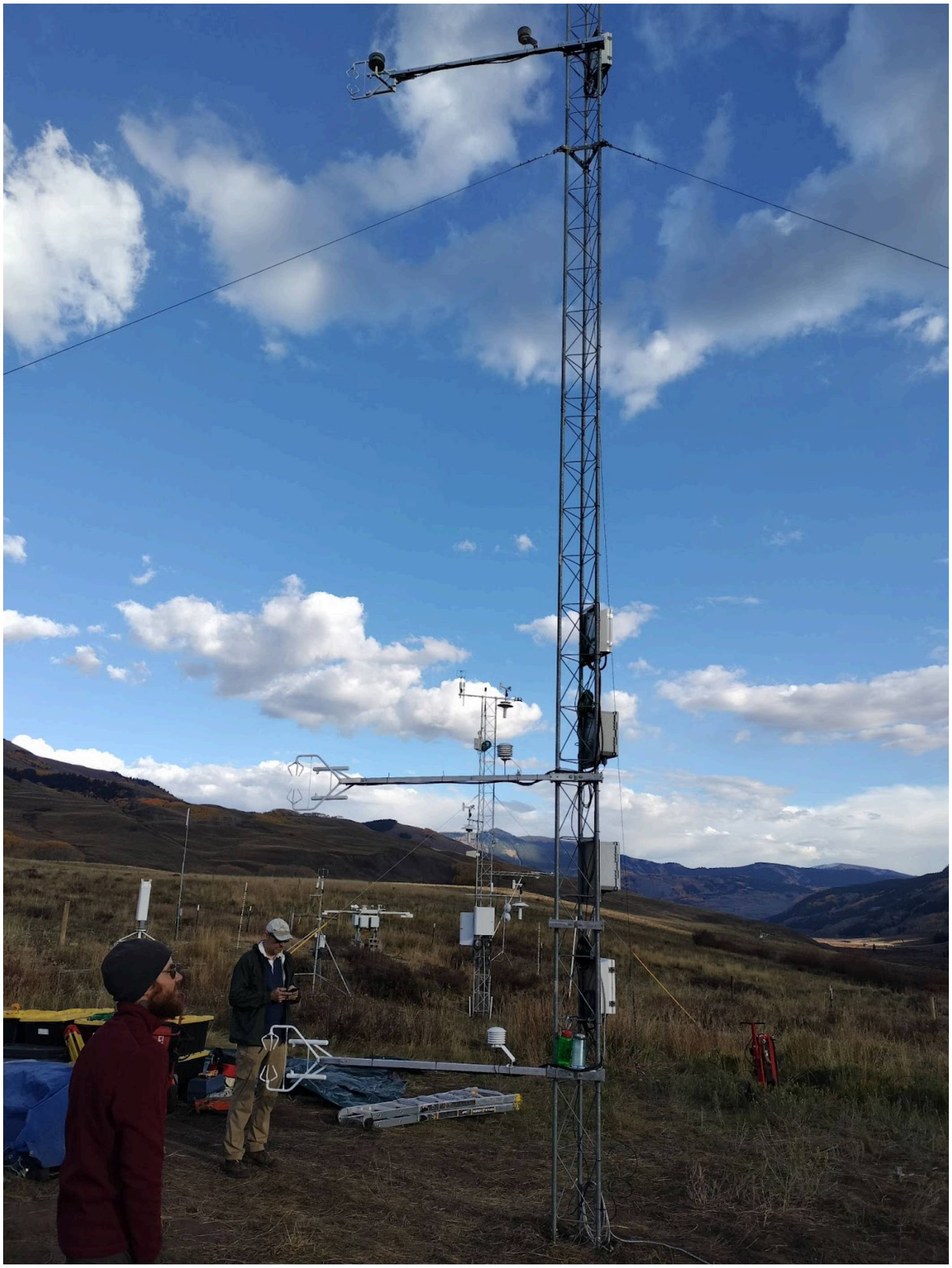
(A) Site c



(B) Site d

(C) Site uw

(D) Site ue



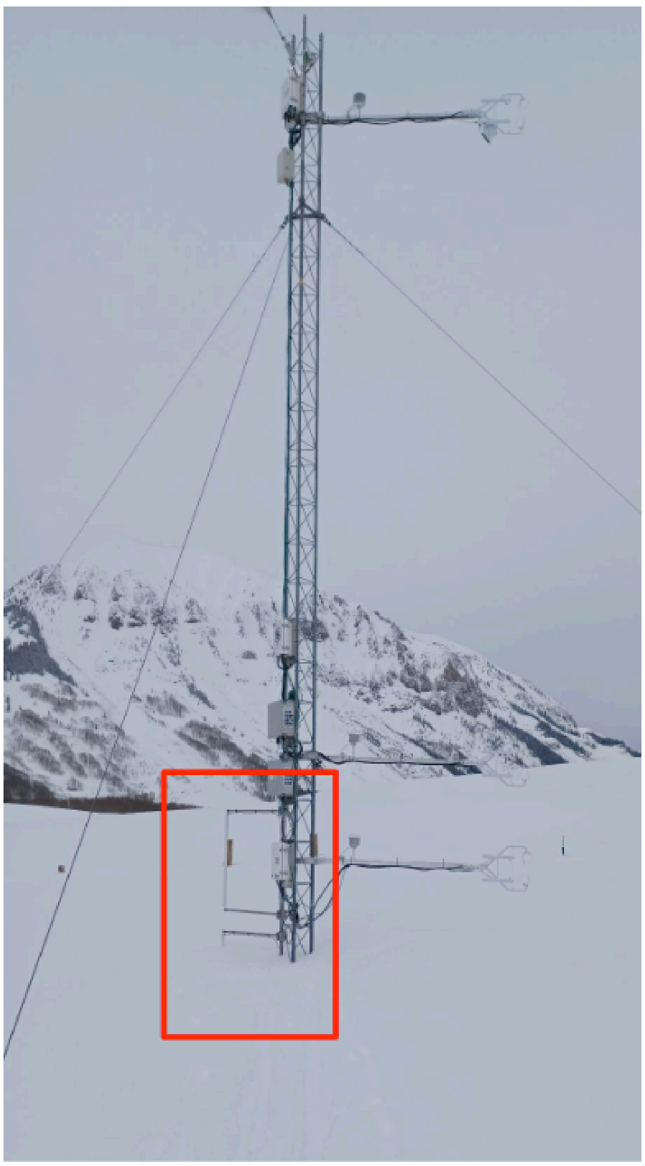
PI-supplied Instruments

ISAW FlowCapt FC4 sensor

Measures solid particle flux intensity and wind speed (**Photo 4A**).

- Set-up at site ue at 1m and 2m.
- FlowCapt sensors are secured inside a PVC pipe and stacked vertically at 1m and 2m and mounted to the Rohn tower to observe what flow hits it along the side of the pipe.

Photo 4A. The vertical PVC pipes (red square) houses the FlowCapt sensor at 1m (half buried in this photo) and 2m .

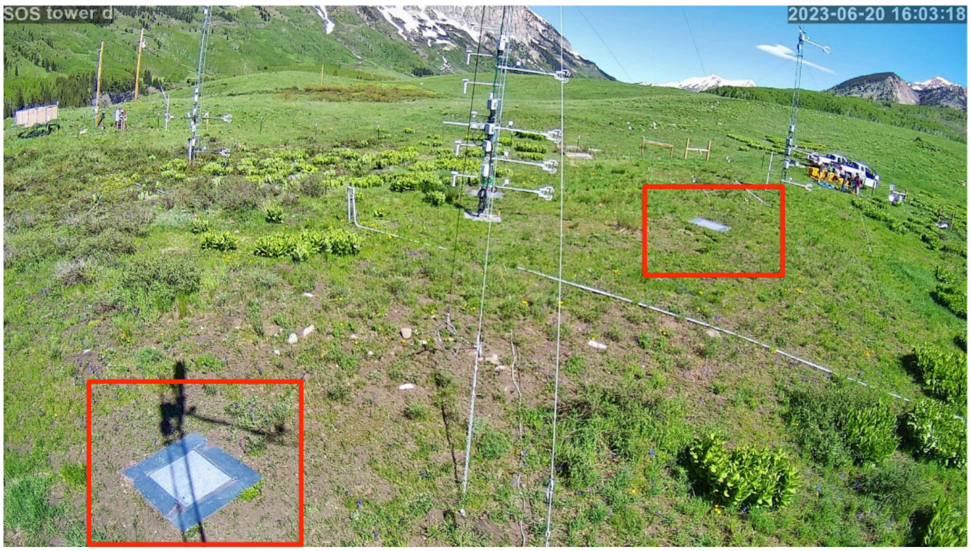


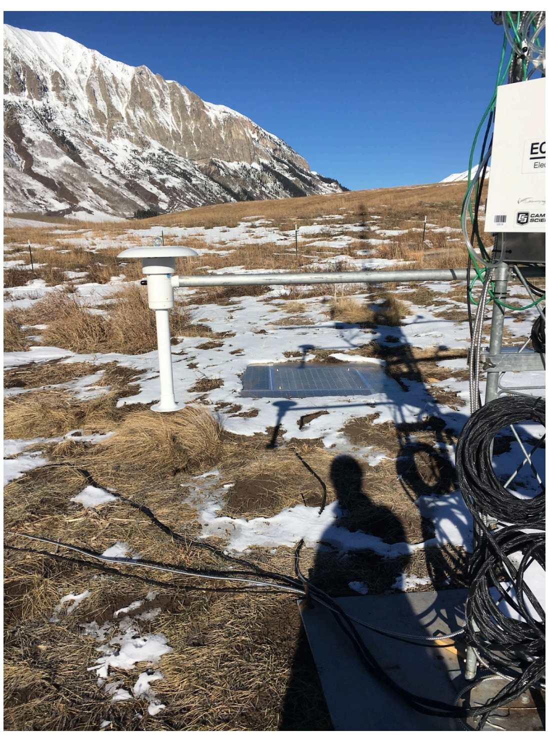
Alpine Hydromet FSP5 sensor

Measures snow water equivalent (**Photo 4B**).

- Four square-shaped snow pillows set-up within the snowpack triangle (refer to **Schematic 1**). All their data was ingested at site c data system module.
- Load.1.p1 refers to the 1st snow pillow sensor and 1st corner of the square sensor, Load.1.p3 refers to the 1st sensor in the 3rd corner, Load.3.p2 refers to the 3rd sensor and 2nd corner of the individual pillow, and so on.

Photo 4B. Two Alpine Hydromet FSP5 sensors are visible as the square plates identified in the red square (top). Another sensor plate is identified (below).





Apogee SIF-III infrared radiometer

Measures thermistor voltages to derive surface temperature (**Photo 4C**).

- Set-up at all four sites

Photo 4C. The apogee mounted at site d.

Wired thermistors

Measures the temperature of the snowpack (**Photo 4D**)

- Set up at sites d and uw
- 11 thermistors were assembled by ISFS staff, and popsicle stick boards were created for each thermistor. Thermistors were mounted at 0.4m, 0.5m, 0.6m, 0.7m, 0.8m, 0.9m, 1.0m, 1.1m, 1.2m, 1.3m, 1.4m, 1.5m at d and uw**.**

Photo 4D. Partially buried thermistors at site d. Photo taken 17 April 2023.

Data Collection and Processing

All sensors were sampled independently with a Linux-based Data System Module or DSM. Data were stored directly onto USB sticks provided for every DSM. At SOS, all DMSs used a shared ubiquiti wireless link to transmit raw data in real time to servers at EOL for local storage and added back-up. Data acquisition and processing were performed by the NIDAS software developed at EOL.

NIDAS (NCAR In-situ Data Acquisition Software) handles the data processing for all ISFS measurement systems. Each sensor is sampled independently. A time tag is assigned to each sample at the moment it is received, based on a system clock synchronized to GPS time. 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 archival and further processing.

NIDAS reads a series of configuration and calibration files that contain pertinent sensor metadata and, more importantly, any input variables that are to be applied to the data either during operations or in post-processing. NIDAS will also apply quality control flags and filters, and thresholds. To generate the 5-minute average and high rate data sets, NIDAS reads the variables from the raw information, applies calibrations and quality control filters, generates 5-minutes averages for those data sets, then writes the variables to netcdf.

- Further introduction to NIDAS and access to the software can be found on its GitHub Wiki.
- NIDAS version used to process data sets is v1.2.3.
- NIDAS version on DSM *c*, with updates for snow pillow prompting: v1.3.253
- NIDAS version on DSMs *d, ue,* and *uw*: v1.3.235

Data File Contents

Data files are provided in netCDF3 format. Research parameters contained in the 5-minute and high rate data are provided below.

ISFS netCDF File Conventions

Refer to the ISFS netCDF File Conventions for a readme guide to understanding how ISFS netCDF data files are constructed and how standard variables are defined.

Also, please note that 5-minute averaging often is insufficient to capture all of the scales of turbulence contributing to the total flux, especially in unstable (daytime) conditions. We recommend averaging longer, which can easily be done from the 5-minute average data, using the procedure described in combining short-term moments.

SOS Variable name convention

ISFS Variable naming convention follows the convention of <variable>_<height>_<site shortname> or <variable>_<site shortname>. For example, spd_2m_c refers to the 3D anemometer wind speed at 2 meters at site c, Tsoil_18_1cm_d refers to soil temperature buried 18.1 cm at site d. **Table 3** lists the relevant research variables.

Table 3. ISFS Instruments and measurements.

Instrument or Type	Variable Name	Unit	Measurement
CSAT 3D sonic anemometer	u	m/s	Wind U component
	v	m/s	Wind V component
	w	m/s	Wind W component
	dir	deg	Wind direction
	spd	m/s	Wind speed
	ldiag	-	diagnostic 0=OK
	tc	C	Virtual air temp from speed of sound
EC150 InfraRed Gas Analyser	h2o	g/m^3	Water vapor density
	co2	g/m^3	CO2 density
	irgadiag	-	diagnostic, 0=ok
	Pirga	mb	IRGA pressure
	Tirga	C	IRGA temperature
Sensirion SHT85	T	C	Air temperature
	RH	%	Relative humidity
	Rfan	rpm	TRH aspiration fan speed
Barometer	P	mb	Air pressure
Radiometers: NR01	Rsw.in, Rsw.out	W/m^2	Incoming, outgoing shortwave
	Rpile.in, Rpile.out	W/m^2	Incoming, outgoing thermopile
	Tcase	C	Case temperature
	Wetness	V	Leaf wetness
Radiometers: Kipp&Zonen CM21	Rsw.in, Rsw.out	W/m^2	Incoming, outgoing shortwave

Radiometers: Kipp&Zonen CG4 Pyrgeometers	Rpile.in, Rpile.out	W/m^2	Incoming, outgoing thermopile
	Tcase	C	Case temperature
Power	Icharge	mA	Charging current
	Iload	mA	Load current
	Vbatt	V	Battery voltage
GPS	GPSnsat	-	Number of GPS satellites tracked
	GPSstat	-	GPS receiver status: 1=OK, 0=warning
	Stratum	-	Status of time service (1 is best)
	Timeoffset	µs	Clock offset: system-reference
	GPSdiff	s	
Soils	Tsoil	C	Soil temperature
	Qsoil	m^3/m^3	Soil moisture
	Gsoil	W/m^2	Soil Heat Flux
	Lambda	W/m/K	Soil thermal conductivity
	Tau63	s	Time to decay to 37% of Vpile (the 63% response time)
	Vpile	V	Thermopile after heating
	Vheat	V	Heater voltage

PI-supplied Variables

Table 4 below lists the quantities measured by each instrument. Note, PI's also supplied additional barometers to measure near the surface.

Table 4. PI Instruments and measurements.

Instrument or Type	Variable Name	Unit	Measurement	Sites
Alpine Hydromet FSP5 - Snow Pillow	Load	kg	Weight of each corner of the square plate of the "pillow". The sum of the four corners is the weight of the plate plus the snow on top of it.	c
	Iexc	mA	Excitation current - diagnostic	
	Status	-	Diagnostic, 0=OK, 1=Bad	
	SWE	mm	Snow Water Equivalent, calculated from the sum of the Loads (minus some tare), divided by the area of the plate. SWE is reported by the pillow, SWE_calc is our attempt to reproduce this calculation.	
	Tint	C	Internal temperature	
ISAW FlowCapt FC4	SF	$g/m^2/s$	Snow Flux	ue
	Spd	m/s	Wind speed	
Thermistor	Tsnow	C	Temperature	d, uw
	Vtherm	V	Thermistor voltage	
Apogee IR**	Vpile Vtherm IDir	V V -	Thermopile voltage Thermistor voltage Apogee serial number	d, c, uw, ue
Barometers	P_a P_b P_c P_d	hPa	0.8m 0.9m 1.0m 1.1m	c

**Refer to Apogee section below on equations in R to derive the surface radiative temperature (in degC).

Dimension Variables

Variable name	Quantity Measured	unit
base_time	seconds since 1970-01-01 00:00:00 00:00	s
time	seconds since 2022-04-01 00:00:00 00:00	s

Higher Moments

We provide a long list of 2nd and 3rd moments among the winds, h2o, and co2. They follow the naming convention:

2nd moment: varname_varname__height_sitename

3rd moment: varname_varname_varname__height_sitename

For example,

```
float u_w__3m_uw(time) ;
        u_w__3m_uw:_FillValue = 1.e+37f ;
        u_w__3m_uw:long_name = "2nd moment" ;
        u_w__3m_uw:short_name = "u\'w\'.3m.uw" ;
        u_w__3m_uw:units = "(m/s)^2" ;
        u_w__3m_uw:counts = "counts_3m_uw" ;

float w_w_tc__10m_d(time) ;
        w_w_tc__10m_d:_FillValue = 1.e+37f ;
        w_w_tc__10m_d:long_name = "3rd moment" ;
        w_w_tc__10m_d:short_name = "w\'w\'tc\'.10m.d" ;
        w_w_tc__10m_d:units = "(m/s)^2 degC" ;
        w_w_tc__10m_d:counts = "counts_d" ;
```

Refer to the ISFS netCDF document which provides further detail on the ISFS instruments and their parameters, the netCDF naming convention, time sampling, and attributes.

A note about flux corrections

The calculation of certain fluxes is a bit more involved than just the covariance, due to the spatial separation of some sensors, the sensitivity of the sonic anemometer temperature to humidity, and density effects. For example, when calculating sensible and latent heat fluxes one should apply corrections to the following variables:

Variable name	Quantity Measured	unit	Correction
w_tc__	Covariance of vertical velocity with virtual air temperature from speed of sound	m/s degC	The correction of measured sonic temperature for the effect of moisture (Schotanus et al., 1983, Kaimel and Gaylor, 1991)
w_h2o__	Covariance of vertical velocity with humidity	m/s g/m^3	The “WPL" correction of vertical flux of water vapor density (Webb et al., 1980)
w_co2__	Covariance of vertical velocity with carbon dioxide	m/s g/m^3	The correction for the spatial separation of the EC150 and CSAT3 (Horst and Lenschow, 2009)

A guide of how one can make above corrections can be founds here:
https://www.eol.ucar.edu/content/corrections-sensible-and-latent-heat-flux-measurements

References

Schotanus, P., Nieuwstadt, F. & De Bruin, H. Temperature measurement with a sonic anemometer and its application to heat and moisture fluxes. Boundary-Layer Meteorol 26, 81–93 (1983). https://doi.org/10.1007/BF00164332.

Kaimal, J.C., Gaynor, J.E. Another look at sonic thermometry. Boundary-Layer Meteorol 56, 401–410 (1991). https://doi.org/10.1007/BF00119215.

Webb, E.K., G.I. Pearman, and R. Leuning. Correction of flux measurements for density effects due to heat and water vapor transfer. Quart. J. Roy. Meteorol. Soc., 106, 85-100 (1980). https://doi.org/10.1002/qj.49710644707.

Horst, T.W., Lenschow, D.H. Attenuation of Scalar Fluxes Measured with Spatially-displaced Sensors. Boundary-Layer Meteorol 130, 275–300 (2009). https://doi.org/10.1007/s10546-008-9348-0.

Data Quality by Instrument

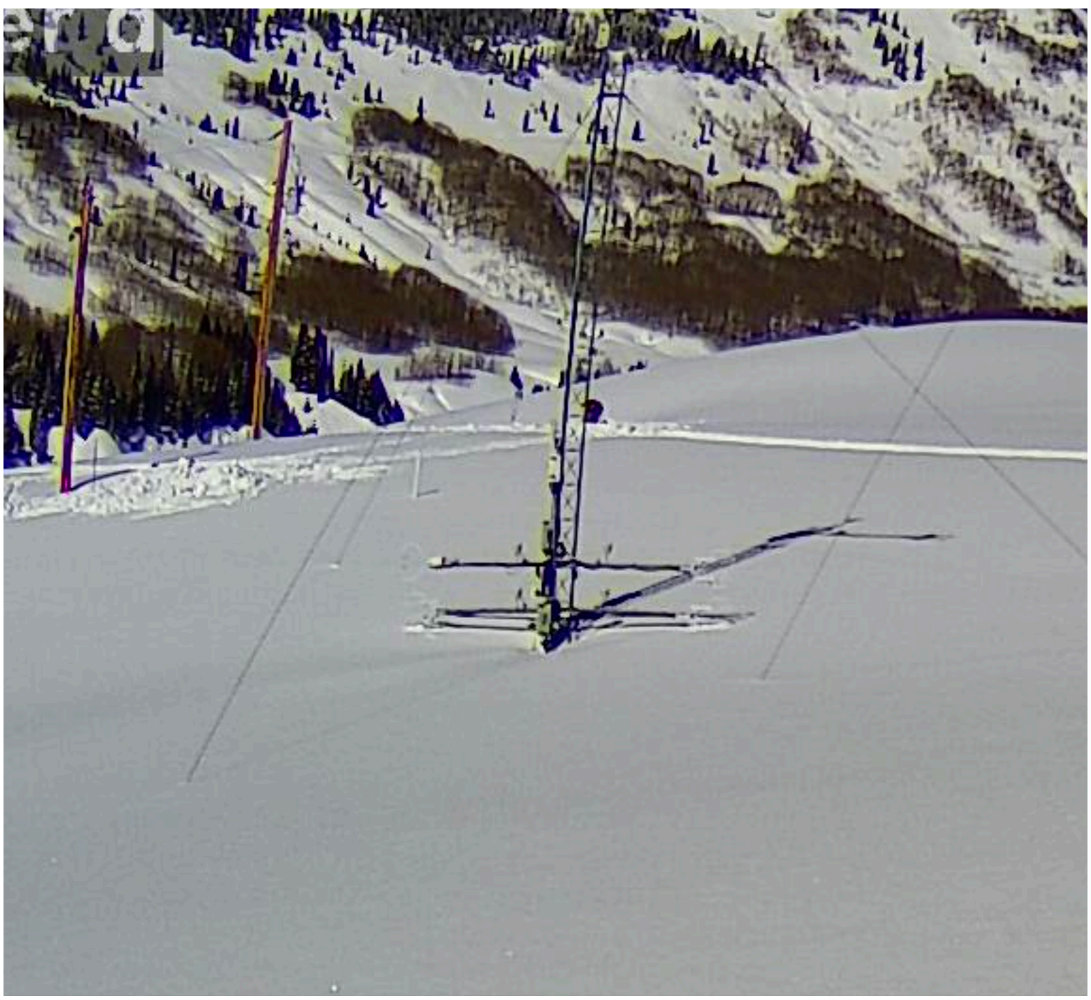
ISFS performed data quality checks on all sensors. Below we provide summaries of the QC workflow for each sensor.

Webcam Images

The webcam images provide invaluable information on snow events and sensors buried under snow. It is recommended to refer to these images to confirm periods where low-level sensors are buried under snow or the occurrence of snow events. Photos have been added to the data set. We used the Microseven M7B5MP 5MP Ultra HD webcam to take jpeg images every 5 minutes. These are available to download along with the data sets.

For example, **Photo 5** shows a picture of the UW tower around April 1st 2023. The lowest level sonics are at 2 meters, the same height as the NR01 radiometers. So the NR01 should be just clear of the snow, but the downward looking radiometers would have a very small field of view.

Photo 5. View ot site uw.



Barometers

The Paroscientific nanobarometers were connected to NCAR-built quad-disk probes, based on the design by Nishiyama and Bedard (1998). All sites had pressure sensors mounted at 10m and the center tower also had a pressure sensor at 20m; and all worked as expected. No problems were found during QC processing for these sensors and none were replaced during operations. Differences in the average pressures are due to the station elevation.

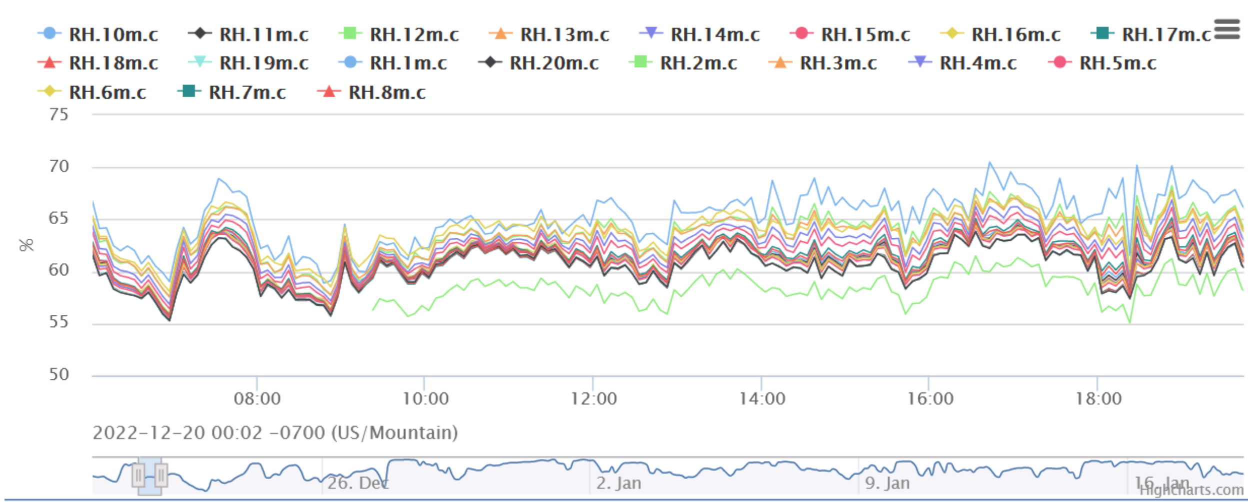
The PI installed four additional pressure sensors on 22 January 2023 11:47:30 MT at heights 0.8m (P_a), 0.9m (P_b), 1.0m (P_c), and 1.1m (P_d) to monitor pressure levels within the snow.

Hygro-thermometer (T, RH)

TRH sensors were mounted at site c at every meter along the tower from 1 to 20 meters. The fan speeds in the sensor housings were collected and used as an indicator that the ventilation fans were functioning as expected. In general, the measurements were fairly stable.

Data Notes:

- TRH at 1m was buried in snow from a snow event on 10 March 2023 and measurements cannot be validated and accuracy is unknown. Thus these measurements have been replaced with fill values from 10 March 2023 23:42:30 through 14 April 2023 10:12:30. If users wish to have this data, contact the data manager for 5 min data or access these data in the high rate dataset.
- 29 Nov 12:07:30 - 21 Dec 2023 - 12m TRH - data were filtered due to a bad fan motor. The TRH sensor was replaced on 21 Dec.
- 19 Jan 2023 - 6m TRH was replaced - bad fan motor
- Replacement of TRH results in a period of conditioning for the RH sensor, where the RH measurement reads approximately 3% RH low for a period of several weeks. This is seen below in plot below when the 12m THR (green trace) was replaced on Dec. 21, and also seen when the 6m sensor was replaced.



Humidity sensors are known to be susceptible to VOCs as well as sustained times at either high or low humidities, so storage can cause some initial offsets that will eventually dissipate as the sensor is conditioned to the new ambient environment.

TRH Calibrations

Calibrations were performed on the TRH sensors in the EOL Calibration Laboratory : https://www.eol.ucar.edu/research-development/calibration-laboratory/calibration-laboratory-resources. Temperature oil baths were used to calibrate the temperature sensors and a Humidity Chamber to calibrate the relative humidity sensors. Three constant temperatures were used to calibrate the RH; 0°C, 20°C, and 40°C. To evaluate the hysteresis effect, the RH chamber was allowed to slowly increase from 10% to 90% RH (we avoid 100% RH to inhibit condensation) then decrease back down to the 10% RH. This process takes three days to complete. Eight RH probes were calibrated at a time. An example of a calibration plot is shown in **Figure 1**.

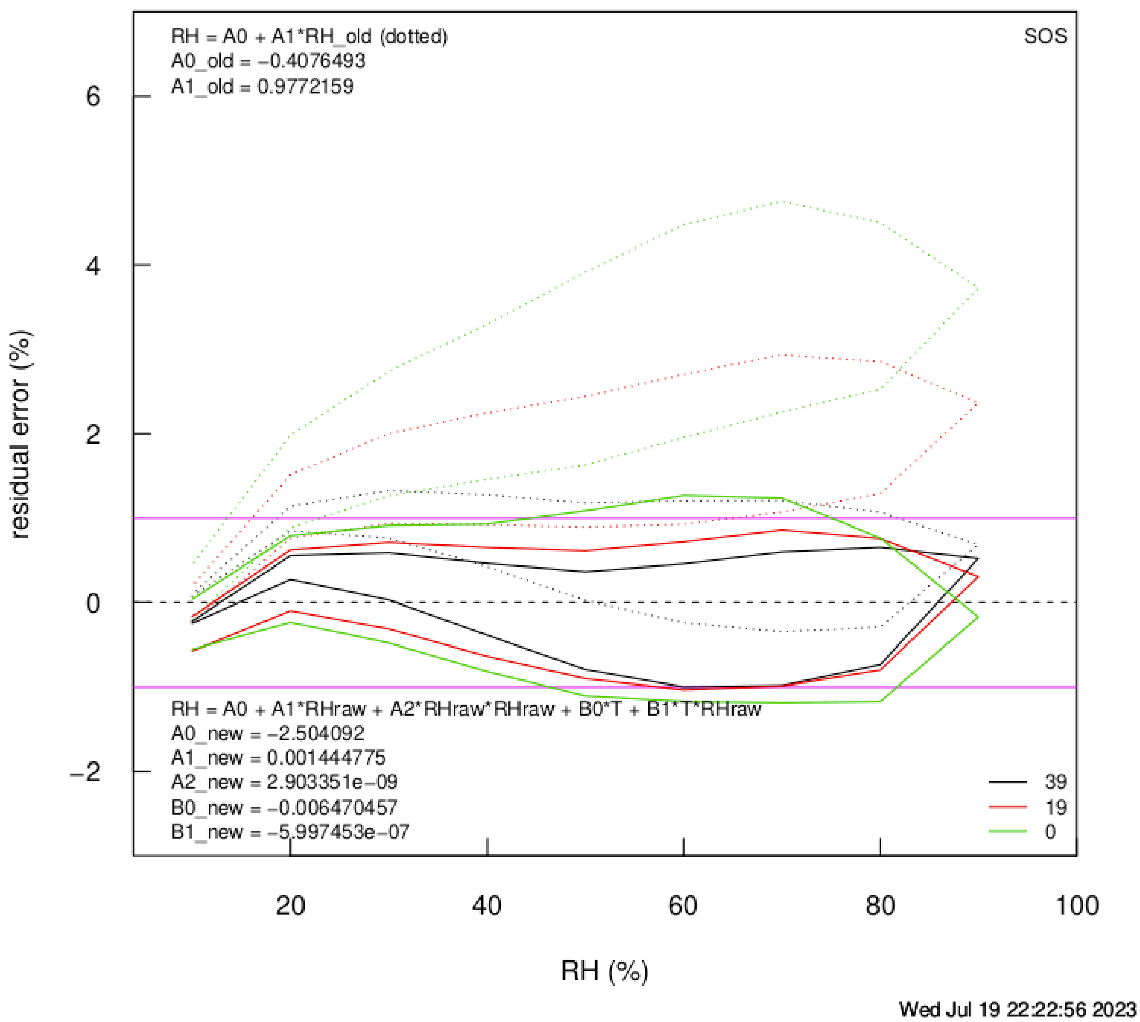


Figure 1. Post-calibration of RH for TRH sensor 111 at constant temperatures (0°C-green, 20°C-red, and 40°C-black). The curved shape is the result of measuring the increase then decrease of the known RH source at each temperature. The difference between the upper and lower bounds of the curve defines the hysteresis effect. Dotted lines are the percent residual error relative to a known source of RH before calibration. The solid lines are the adjustments to the fit to reduce the error to within 2%. The final reported calibration coefficients are the average of the three adjusted curves (solid lines) and are provided on the bottom left of **Figure 1** with additional terms, B0_new and B1_new, that accounts for the temperature dependence.

Pre-calibrations were completed in July and August 2022. All humidity sensors were calibrated to within ± 2% accuracy and all temperature probes were calibrated to within the expected error of ± 0.1°C. Post-calibrations were completed by July and August 2023.

All the temperature probes were within the expected error of ± 0.1°C and no corrections were applied. RH corrections were applied based on the post-calibration coefficients (refer to **Figure 1**).

Radiometers

Radiometer data have been filtered for

- Spikes
- Moisture on the lens due to dew or precipitation as measured by the wetness sensors mounted on the NR01 radiometer.

We used the wetness sensor to filter for moisture on the radiometer lenses. We used a threshold of wetness > 0.26 V. There was only one wetness sensor deployed for this campaign, so we applied it as a filter for both the NR01 and K&Z radiometer data. While this should remove most periods of moisture from dew or precipitation on the radiometers, this is only a first-order correction and may not capture all such events.

Refer to **Figure 8** for final data availability after quality checks for the ISFS-controlled sensors. Calculations of long-wave radiation using the Rpile and Tcase variables as described here: https://www.eol.ucar.edu/content/calculation-long-wave-radiation.

Data notes:

There are periods where the incoming shortwave (Rsw_in) is less than the outgoing shortwave (Rsw_out) for both the K&Z and NR01. This has been observed over short durations during many morning and late afternoon periods in the winter, as well as for longer durations following some snow events. For the short-duration, morning and late afternoon periods, we expect that a combination of low sun angle and terrain shadowing is to blame. The longer duration periods following a snowfall usually means that the incoming shortwave dome is covered by snow. This behavior is expected for the NR01, which does not provide an aspirated fan. However, there are periods when this also occurs with the K&Z despite it having heated airflow. This led to our identifying a problem with the heating for the K&Z, wherein the snow was not being cleared as expected for a portion of the winter. Thus, Rsw_in at 9m height has been filtered out during periods where we expect the K&Z heating to have failed and Rsw_in<Rsw_out. Dates where this occurred are summarized in **Table 5**.

Additionally, it was noted that the NR01 at 2m on site uw would have been very close to the top of the snowpack during some portion of the winter. This would have reduced the field of view for the downward facing sensors and could have produced some shadowing, both of which may impact the quality of some of the Rsw_out and Rpile_out measurements.

Table 5. Periods where data are filtered where incoming shortwave < outgoing shortwave.

Period	Snow event?
2022 Dec 03 10:10 - 2022 Dec 04 00:00 MST	Yes, cleared by next sunrise
2022 Dec 07 07:20 - 2022 Dec 07 12:35 MST	Yes, cleared same day
2022 Dec 24 07:40 - 2022 Dec 24 10:20 MST	Yes, cleared same day
2022 Dec 28 07:40 - 2022 Dec 29 00:00 MST	Yes, cleared by next sunrise
2022 Dec 30 07:40 - 2023 Jan 04 11:20 MST	Big snow event
2023 Jan 06 07:40 - 2023 Jan 07 11:30 MST	Yes, cleared by next day
2023 Jan 10 07:50 - 2023 Jan 11 11:10 MST	Yes, cleared by next day
2023 Jan 15 07:40 - 2023 Jan 15 11:25 MST	Yes, cleared same day
2023 Jan 16 07:40 - 2023 Jan 17 12:50 MST	Yes, cleared by next day

1m CSAT3A sonic and EC150 gas analyser movement

Significant snowpack development due to major snow events in December and early January, as well as snow accumulation due to drifting snow necessitated elevating the 1m sonic and gas analyzer at sites ue, uw, and d. We document its movement by date below. These changes were reflected in the variable naming convention because ISFS variables are defined by height and site. When a new height was established - a new variable name was assigned to the data and the previous variable was set to fill-values.

Jan 10 - May 23, 2023 - site d

- 1m EC150 gas analyzers and CSAT3A sonic anemometers at site d were moved up to 2 m as the snowpack developed on Jan 10.
- The variables for this period became <u,v,w,dir,spd>_2m_d and <h2o,co2>_2m_d and the variables at 1m were set to fill-values.
- Sensors were returned to 1m on 23 May and variables at 2m were set to fill-values.

Jan 10 - May 23, 2023 - site ue

- 1m EC150 gas analyzers and CSAT3A sonic anemometers at site ue were moved up to 2m as the snowpack developed.
- The variables for this period became <u,v,w,dir,spd>_2m_ue and <h2o,co2>_2m_ue and the variables at 1m were set to fill-values.
- Sensors were returned to 1m on 23 May and variables at 2m were set to fill-values.

Jan 06 - March 14, 2023 - site uw

- EC150/CSAT3A was moved up to 2m as the snowpack developed.
- The variables for this period became <u,v,w,dir,spd>_2m_uw and <h2o,co2>_2m_uw and the variables at 1m were set to fill-values.

March 14 - April 17 - site uw

- EC150/CSAT3A at site uw was moved up again from 2m to 2.5m as the snowpack grew.
- The variables for this period because <u,v,w,dir,spd>_2_5m_uw and <h2o,co2>_2_5m_uw and the variables at 2m and 1m were set to fill-values.

April 17 - May 23, 2023 - site uw

- EC150/CSAT3A moved down to 2m as the snowpack shrank.
- The data for this period were returned to <u,v,w,dir,spd>_2m_uw and <h2o,co2>_2m_uw and the variables at 1m and 2.5m were set to fill-values.
- Sensors were returned to 1m on 23 May and variables at 2m and 2.5m were set to fill-values.

Known data gaps in CSAT3A sonics and EC150 gas analysers

Site c

Jan 19 - April 17, 2023

- 1m EC150 gas analyzer and CSAT3A sonic anemometer were disconnected then reconnected on April 17th.

Nov 9 - 17, 2022

- Site c at 5m CO2/H2O gas analyzer and CSAT3A sonic anemometer head died completely. Data was not restored until the next site visit where the EC150 open-path gas analyzer was replaced.

Site d

Mar 30 - April 10, 2023

- Measurements stopped during this period and a site visit by staff noted that sensors were buried in snow.

Site uw

December 22, 2023

- 1m EC150 gas analyzers and CSAT3A sonic anemometers at site uw died due to being buried by blowing snow. Photos below from left to right were taken December 20, 21, 22m 2022 and one can see the gradual burial of the 1m sonic overnight.

Sites d, ue, uw

March 11 - 12, 2023

- Sides d, ue, uw at 1m were affected by a major disruption to the network stream. Data for these sites and dates are not available.

3-D Sonic anemometer - CSAT3

CSAT3 sonic anemometers were used for turbulence measurements on all towers. Refer to the webcam images to determine periods where low mounted sensors (<2 m) were buried under snow. Appendix A contains windrose plots for data spanning the project time period.

Theodolite Geographic Coordinates and Tilt Corrections

As part of the total survey of SOS anemometer instrumentation, the Leica Multistation (MS60 laser theodolite) made scans of the positions and orientation of each sonic anemometer with respect to gravity. The scans were georeferenced using a stand-alone GPS receiver. Refer to wind direction quick reference guide on converting Campbell CSAT3 sonics between instrument and geographic coordinates

The Leica theodolite measures distances relative to itself using a very precise laser and knowledge of its azimuth, with respect to true north, and elevation angle. The distances are measured in x, y coordinates, using the Universal Transverse Mercator (UTM) geodetic projection, and converted to true headings. The GRS 1980 ellipsoid was the reference surface used for the positions.

The flux towers masts/tripods were constructed to face roughly parallel to the local height contours and the anemometer boom to be mounted on this face, i.e. wind from the un-obstructed direction. This was done to minimize distortion of the flow by the mast for winds perpendicular to the ridge lines and also capture up and down valley flows. Although local surrounding obstacles (ridges, trees, shrubs, poles, gates) may interfere with the anemometer.

In order to report winds in geographic coordinates, the orientation of the instrument needs to be known to rotate the wind vectors into geographic coordinates. With a measured azimuth angle taken along the boom mounted sonics, the orientation is known since every anemometer head is rigidly attached to the boom and the sonic heads are attached in a captive manner.

The tilt of a sonic anemometer from true vertical can introduce errors in the measured sensible heat and momentum fluxes. The tilt error in a scalar flux is on the order of 5% per degree of tilt in the vertical plane aligned with the mean wind direction. Consequently, it is often necessary to rotate the coordinates of three-dimensional sonic wind data to correct for this tilt.

We shoot the center of the anemometer sphere at the top and bottom of the CSAT3 transducers, to which we add the sphere's radius to obtain the exact x, y, z position of these spheres. We also shoot the mounting boom near the sonic and near the tower, and add the radius of the boom. From these coordinates, we can calculate the pitch and roll angles (and azimuth) of the sonic array. We input this information into our "calibration files" as lean and lean azimuth, using:

```
deg2rad = pi/180
b3 = tan(-roll*deg2rad)
b2 = tan(pitch*deg2rad)/cos(roll*deg2rad)
lean = round(atan(sqrt(b2^2 + b3^2))/deg2rad, 1)
leanaz = round(atan2(-b3, -b2)/deg2rad, 1)
```

This method replaced the planar fit method that ISFS used in past projects.

Azimuth angles calculated by the Leica laser scanning theodolite for each anemometer are provided in **Table 6.** To rotate the wind vectors, we use the pointing angle of the sonic +V axis (Vazimuth), which is pointing towards the sonic boom minus 90 degrees. Scans were taken several times throughout the project when staff could do a site visit. **Table 6** represents the midpoint of scans taken in February.

Table 6. Azimuth angles and orientation as measured by the Leica for each anemometer. These measurements were taken in February 2023 and represent the middle of the project period. Leica scans aimed between the vertical tower pole and centerline of the boom on which the anemometer is mounted. ‘w offset’ is the mean offset in the measured vertical velocity.

Site	Height (m)	Vazimuth [deg]*	Lean [deg]	Lean Azimuth [deg]	w offset
c	1	128.0	6.7	23.1	-0.024
	2	128.4	6.1	23.0	-0.034
	3	129.4	5.3	23.9	0.008
	5	128.7	3.6	20.2	0.001
	10	129.9	5.6	43.1	-0.019
	15	129.6	4.1	30.4	-0.010
	20	129.8	5.4	29.7	0.000
d	1	132.2	4.6	32.1	-0.021
	3	132.9	5.0	34.4	-0.020
	10	132.7	4.7	41.0	0.015
ue	1	129.6	4.6	34.5	-0.027
	3	130.2	5.2	25.1	-0.001
	10	129.8	5.3	31.1	0.012
uw	1	126.7	5.4	55.3	-0.003

	3	127.5	4.7	53.1	-0.005
	10	126.8	5.6	35.3	-0.024

*Vazimuth's = azimuth - 90 deg.

Sonic Calibrations

Sonic anemometers performed calibration checks in an environmental chamber that operated over a defined stated temperature range (-30°C to +50°C). The anemometers were calibrated with three orientations (on the x, y, z axes) and the u component was examined. Overall, the u component measured deviations between 0.0 cm/s and 0.3 cm/s with a standard deviation of +/- 0.1 cm/s. Calibrations were conducted in July and August 2022. All sonics performed within specification and no adjustments were made. Go to Appendix A to view windrose summary of each 3D sonic.

EC150 Infrared Gas Analyzer (h_2o/co_2)

CSAT3 was coupled with an infrared absorption gas analyzer (EC-150 IRGA) to measure H_2O and CO_2.

The sensors were filtered for

- irgadiag not equal to 0
- Negative spikes in H_2O that are not captured by the internal diagnostics.

Note that measurements will be intermittent during periods of severe snow and blowing snow. Refer to **Table 11** for a list of snow events.

h2o

There is a persistent bias in the h2o at site c at 10m and 15m. **Figure 2** shows this high bias for h2o_10m_c and low bias for h2o_15m_c. Comparison with water vapor derived from the companion TRH measurements (at the same height as the sonics) reveal median offsets of -1.54 g/m3 for h2o_10m_c and +2.786 g/m3 for h2o_15m_c. **Figure 3** shows a summary of the comparisons between the EC150 h2o and TRH H2O. We applied these offset to these variables. The adjusted results can be seen in **Figure 2** (right two variables) named h2o_10m_c_adj and h2o_15m_c_adj.

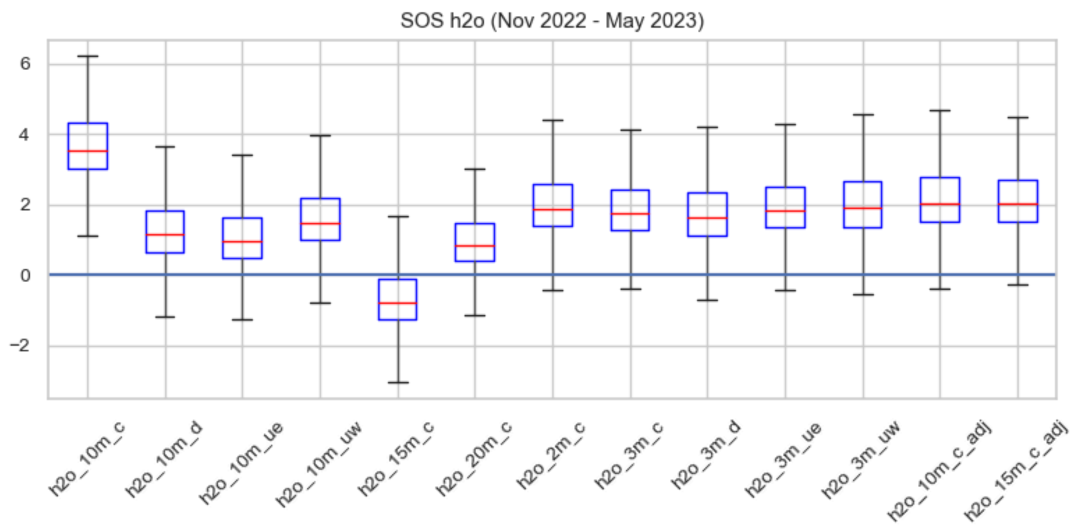


Figure 2. EC150 h2o box-and-whiskers at all sites. Variables h2o_10m_c_adj and h2o_15m_c_adj are adjustments of -1.54 g/m3 and +2.786 g/m3, respectively, applied to the original data.

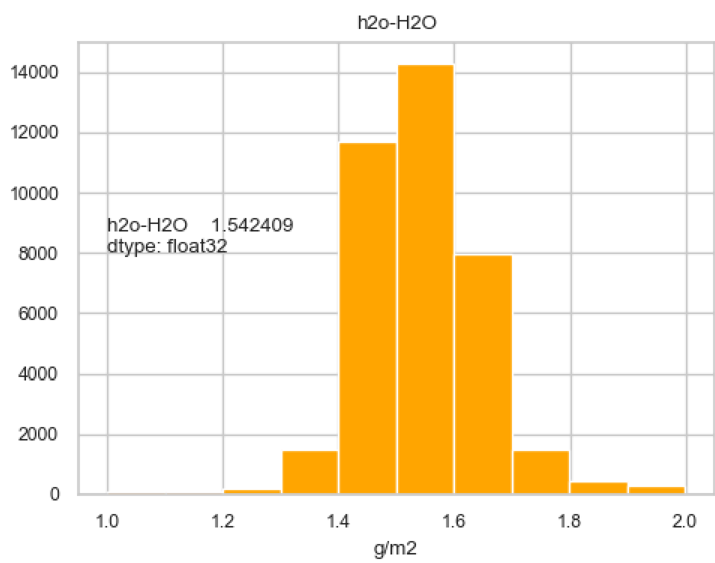


Figure 3. Histogram of the difference between the EC150 h2o and the TRH derived H2O. +1.54 g/m3 represents the median value of the difference.

co2

We cannot discern a clear bias among the co2 measurements (**Figure 4**). No adjustments have been applied to these data.

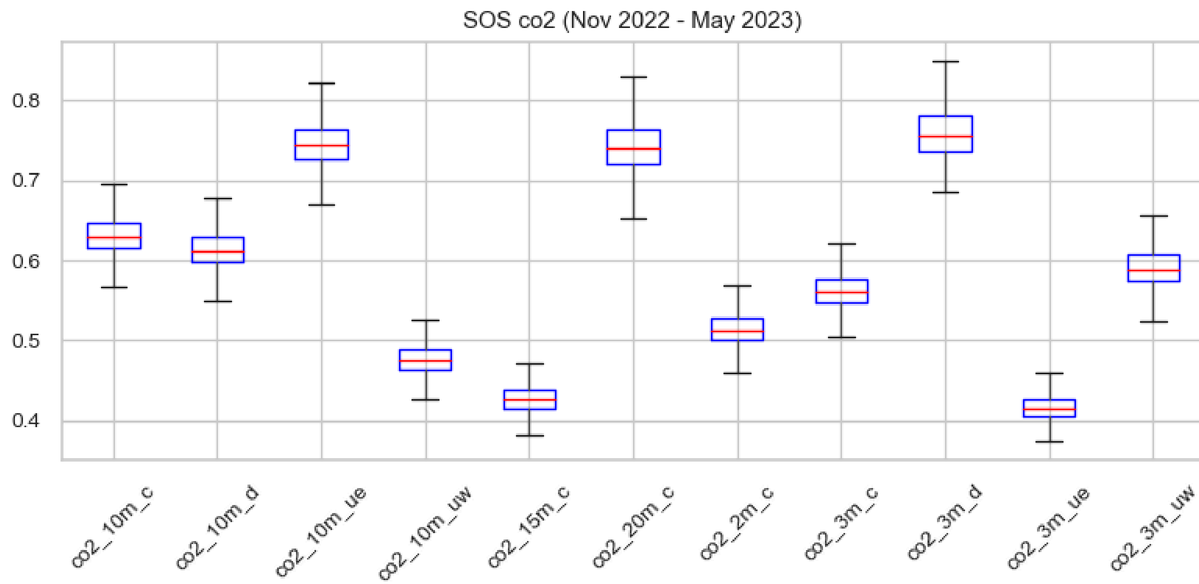


Figure 4. EC150 co2 box-and-whiskers at all sites.

Data notes:

- EC150 variables should be set to the not-a-number fill value for when irgadiag is non-zero. We have noticed this does not happen in all cases. We recommend the user re-apply the irgadiag ≠ 0 filtering criteria when using these data.

Soils

All soil sensors (NCAR 4-level Tsoil, Meter EC-5 Qsoil, REBS HFT Gsoil, and Hukseflux TP01 thermal properties) were buried at 0 – 5 cm layer near the base of towered sites. Refer to documentation on the installation of soil sensors for more details.

Heat flux, Gsoil

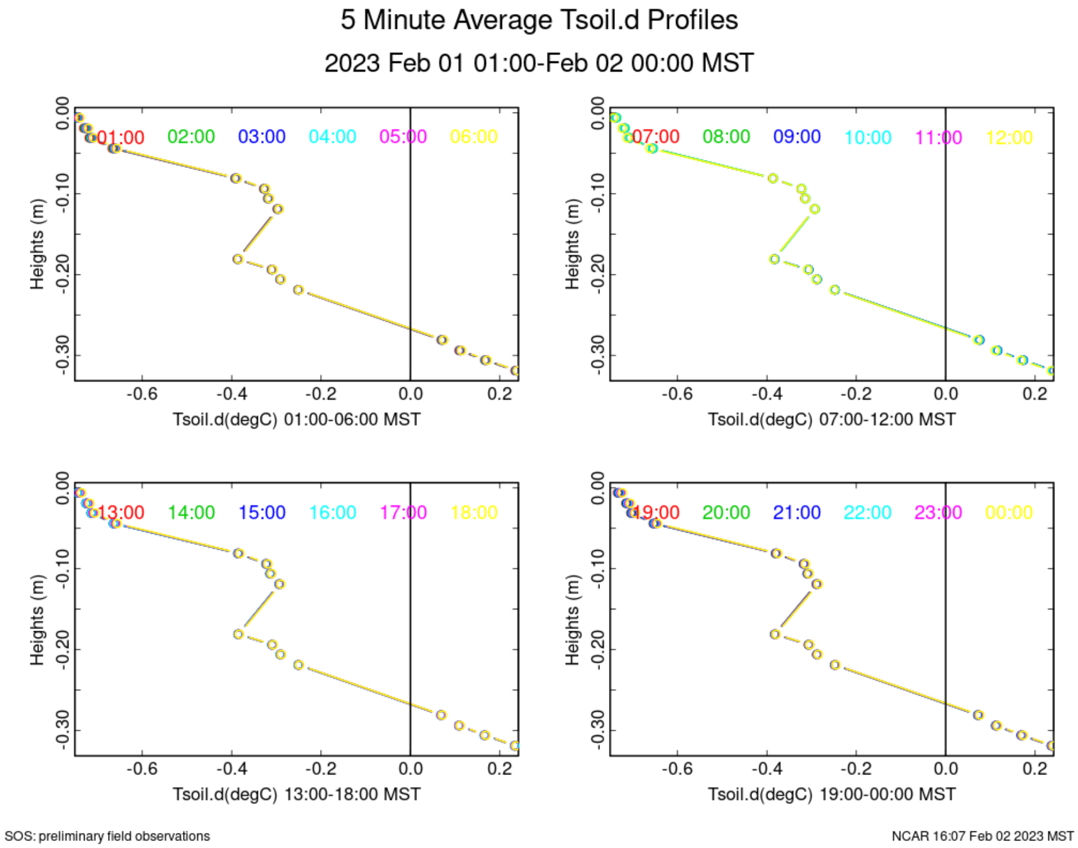
No issues noted during operations. No problems were found during QC processing. Calculations of the heat flux at the surface, corrected for the Phillip correction and heat storage within the 0--5 cm layer of soil using the Tsoil and TP01 data and as described in calculation of soil heat flux at the surface have been added to the 5-minute NetCDF files.

Soil Temperature, Tsoil

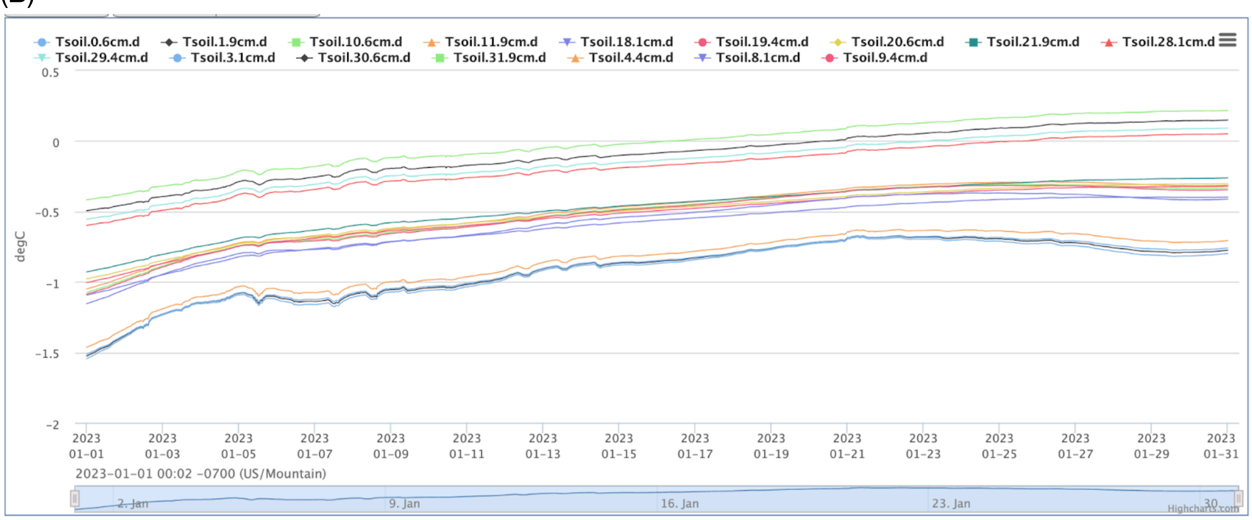
Tsoil sensors were installed at site d only at multiple depths (refer to **Table 2**). Calibrations were performed in the EOL Calibration Laboratory : https://www.eol.ucar.edu/research-development/calibration-laboratory/calibration-laboratory-resources. Temperature oil baths were used to calibrate the Tsoils, similar to the temperature probes of the TRH sensors.

Profiles of preliminary Tsoil reveal a kink in the sensor measurements between 18cm and 22cm (see **Figure 5A**). In particular, we identified a 4 month period where a significant number of Tsoil sensors were reading too cold - starting 2022-12-29 and ending 2023-05-03, for when ground was clearly frozen. Post-calibrations showed offsets in Tsoil relative to the temperature reference that can explain the observed discontinuity. We applied the following post-calibrated offsets to all the Tsoil measurements in **Table 7** that resolved the observed kink in the profiles. **Figure 5B-C** shows the Tsoil time series of the preliminary and corrected values. Notice that overlapping Tsoil values in the preliminary data disappear in the corrected plot. Each Tsoil height shows separate and discrete measurements.

(A)


5 Minute Average Tsoil.d Profiles
2023 Feb 01 01:00-Feb 02 00:00 MST
01:00 02:00 03:00 04:00 05:00 06:00
07:00 08:00 09:00 10:00 11:00 12:00
13:00 14:00 15:00 16:00 17:00 18:00
19:00 20:00 21:00 22:00 23:00 00:00
Heights (m)
0.00 -0.10 -0.20 -0.30
-0.6 -0.4 -0.2 0.0 0.2
Tsoil.d(degC) 01:00-06:00 MST
Tsoil.d(degC) 07:00-12:00 MST
Tsoil.d(degC) 13:00-18:00 MST
Tsoil.d(degC) 19:00-00:00 MST
SOS: preliminary field observations
NCAR 16:07 Feb 02 2023 MST

(B)


Tsoil.0.6cm.d Tsoil.1.9cm.d Tsoil.10.6cm.d Tsoil.11.9cm.d Tsoil.18.1cm.d Tsoil.19.4cm.d Tsoil.20.6cm.d Tsoil.21.9cm.d Tsoil.28.1cm.d
Tsoil.29.4cm.d Tsoil.3.1cm.d Tsoil.30.6cm.d Tsoil.31.9cm.d Tsoil.4.4cm.d Tsoil.8.1cm.d Tsoil.9.4cm.d
degC
0.5 0 -0.5 -1 -1.5 -2
2023 01-01 2023 01-03 2023 01-05 2023 01-07 2023 01-09 2023 01-11 2023 01-13 2023 01-15 2023 01-17 2023 01-19 2023 01-21 2023 01-23 2023 01-25 2023 01-27 2023 01-29 2023 01-31
2023-01-01 00:02 -0700 (US/Mountain)
2. Jan 9. Jan 16. Jan 23. Jan 30.
Highcharts.com

(C)

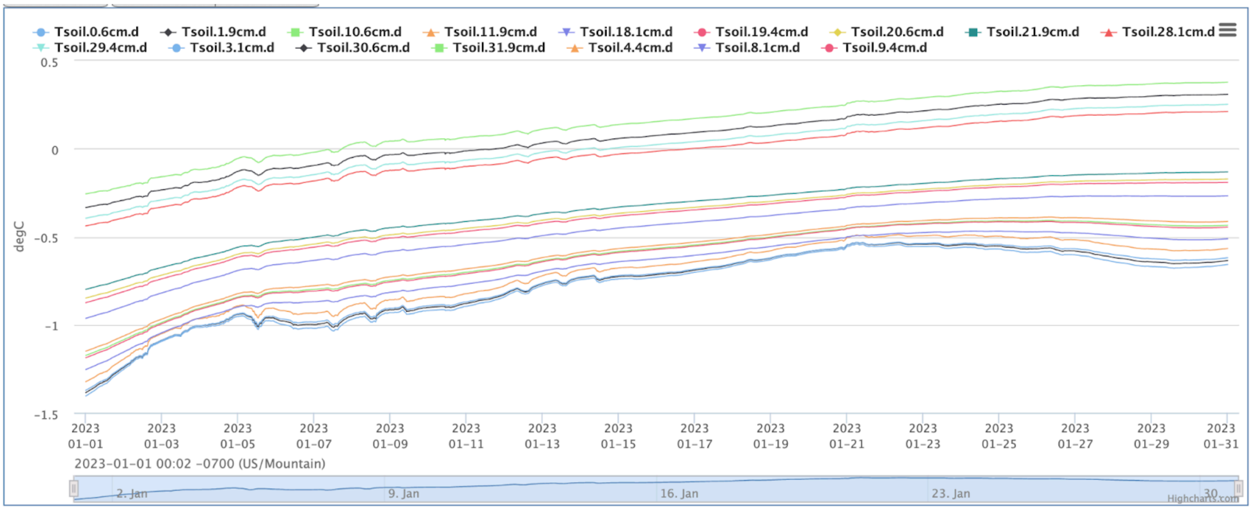


Figure 5. (A) Preliminary profiles of Tsoil plotted as hourly averages. Note the discontinuity between 18 cm and 22 cm. (B) Time series of incorrectly Tsoil. (C) Time series of corrected Tsoil based on **Table 7**.

Table 7. Tsoil calibrated offsets

Tsoil Serial #	Tsoil heights	Offset correction [degC]
TS047	0.6cm, 1.9cm, 3.1cm, 4.4cm	+0.14
TS036	8.1cm, 9.4cm, 10.6cm, 11.9cm	-0.10
TS042	18.1cm, 19.4cm, 20.6cm, 21.9cm	+0.13
TS044	28.1cm, 29.4cm, 30.6cm, 31.9cm	+0.16

Data notes:

- Bad Tsoil probe at 30.6cm since 02 May 2023 21:52:30 MT. These data have been replaced with fill values.
- Bad Tsoil probe at 28.1cm since 03 May 2023 21:30 MT through May 19 18:00. These data have been replaced with fill values.

Soil Moisture, Qsoil

The soil moisture sensor (Qsoil) was installed at a depth of 2.5 cm. We used the manufacturer's calibration values for potting soil.

Three soil samples were taken during the course of the field project. These samples were used to measure soil moisture content by the gravimetric method: a fresh soil core sample is weighed, oven dried until there is no further mass loss, and then reweighed. The moisture content is expressed as mass of water per mass of dry soil. **Figure 6** are the comparisons between Qsoil and the gravimetric results. Other than Qsoil values underestimating the gravimetric results by at least 20%, there is no clear relationship. Two soil samples were taken in October 2022 prior to the start of the project and the last sample was taken after the spring thaw in June 2023 where staff commented on lots of vegetative matter, i.e. roots. Since no correlation can be found (see **Figure 6**), no corrections were applied to Qsoil.

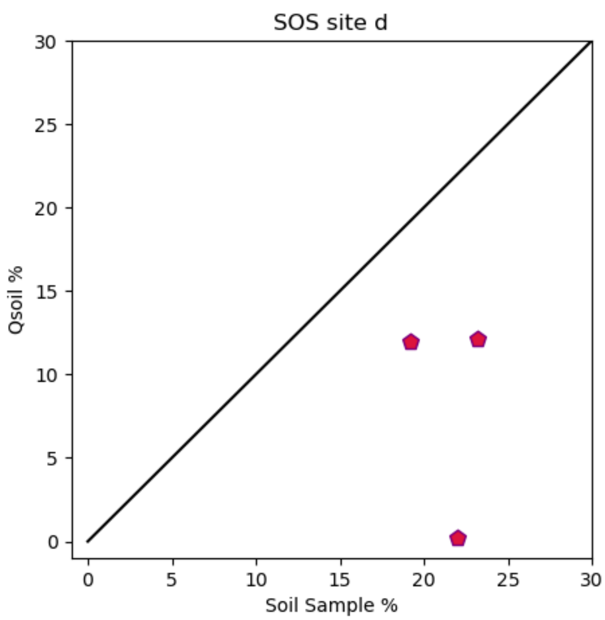


Figure 6. Comparison of Qsoil to the gravimetric soil moisture for each site.

When the soil was frozen:

The standard Qsoil probe used by ISFS, the METER EC-5, measures the dielectric constant at an RF frequency absorbed by liquid water. Once water in the soil freezes, it becomes invisible to this probe. In the case of SOS, the soil froze on 14 November 2022 and was unfrozen by 28 April 2023. Thus, Qsoil is essentially zero for much of SOS.

The gravimetric samples also produce values for the bulk density of the soil at each site. These values are shown in **Table 8**.

Table 8. Bulk density, in g/cm^3, of the soil at each site.

Site	Sample 1	Sample 2	Sample 3
d	1.361	0.634	0.20

Soil thermal properties (TP01)

The Hukseflux TP01 sends a heat pulse into the soil every 3 hours and measures the resulting change in temperature. From these measurements of heating (Vheat), thermopile response (Vpile), and the temperature delay time constant (Tau63), and the thermal conductivity (Lambda) can be calculated. No issues were noted during operations. We have included these derived values in the 5-min NetCDF files.

During the data outage on March 10, there were spikes on March 11 11:00:00 MST until 14:22:00 MST that were removed.

Refer to the manual for sensor description and methods for deriving various thermal properties: https://www.hukseflux.com/uploads/product-documents/TP01_manual_v2028.pdf

PI-instruments

We performed limited data QC on the PI-sensors by filtering outlier data points. Please contact the PI's for additional information and data-use guidance.

ISAW FlowCapt FC4

All negative values from the various for Spd_min, Spd_max, Spd_min, SF_avg, SF_max, SF_min, SF_std variables were replaced with fill values.

Alpine Hydromet FSP5 - Snow Pillow

Alpine Hydromet FSP5 sensors which measure the weight of the snow (Load variables) were experiencing data stoppages. The firmware on all the pillows was upgraded during a site visit 21 December 2022 but that did not alleviate the data outages. On 13 January 2023, a script was installed that monitors the snow pillow data. If any pillow does not report Load data for 20 minutes, the script cycles the power relay. We also lowered the data rate from 0.002 (500s) to 0.001 (1000s) on 04 January 2023 to improve the pillow uptime. This translates to samples taken every 15 min and 20 min.

Various Load* variable datasets contained invalid zero values that were set to fill values. This was especially early in operations in November

We have observed large diurnal swings in Snow Water Equivalent (SWE) (**Figure 7**). Manufacturers report this response is "typical" for early/late season patchy snow, especially with the strong diurnal cycle swings.

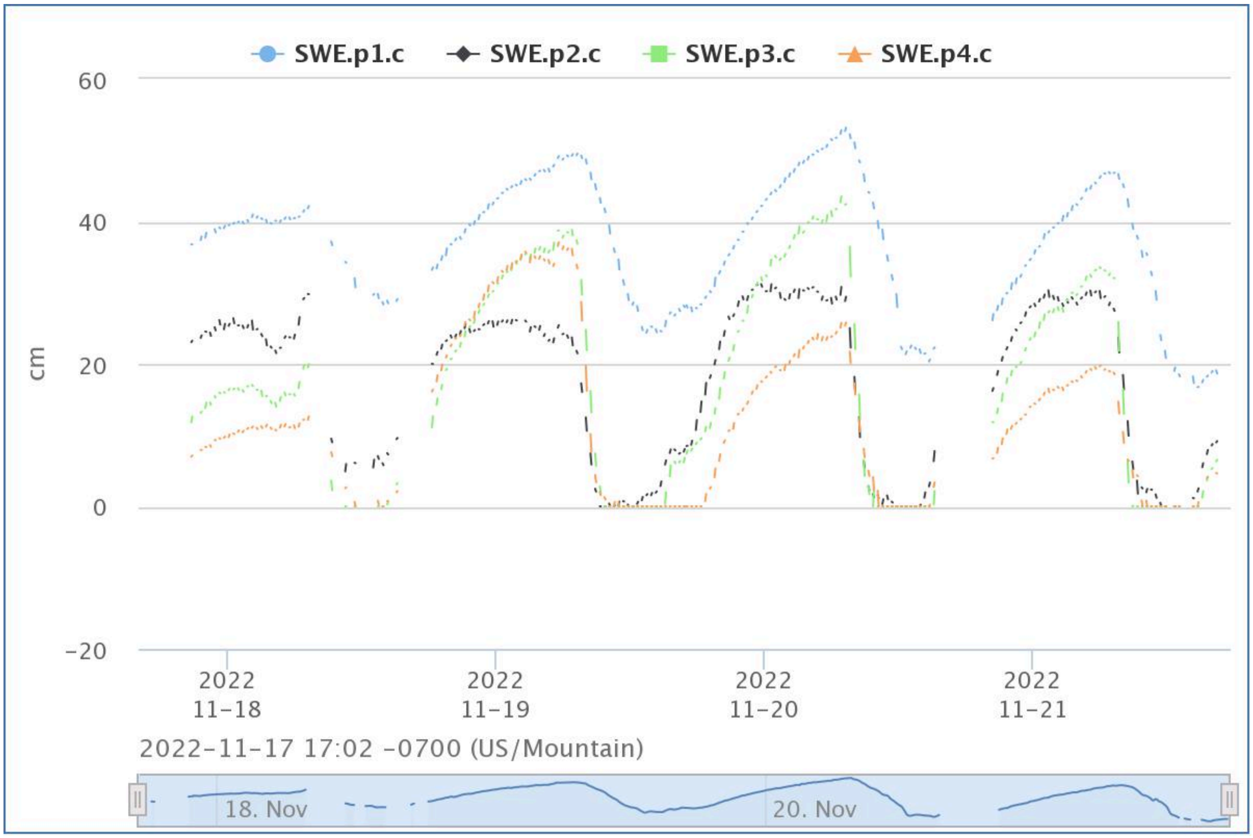


Figure 7. Snow Water Equivalent (SWE).

Thermistors

Table 9. Time periods for which thermistor data either reported nan's or bad samples often when the thermistors were buried in the snow. Post-processing filters the bad samples.

Start Time	End Time	Instrument	Reason NaN
2023 Mar 11 11:07:30 MST	2023 Jun 20 00:00:00 MDT	Tsnow.0.4m.uw	Buried in snow starting 2022-12-22, then started reporting very high positive values, never recovers
2023 Mar 11 11:07:30 MST	2023 Jun 20 00:00:00 MDT	Tsnow.0.5m.uw	Buried in snow starting 2022-12-22, then started reporting very high positive values, never recovers
2023 Apr 15 03:17:30 MDT	2023 Jun 20 00:00:00 MDT	Tsnow.0.7m.uw	Buried in snow starting 2022-12-27, then started reporting very high positive values, never recovers

2023 Mar 31 09:47:30 MDT	2023 Jun 20 00:00:00 MDT	Tsnow.1.0m.uw	Buried in snow starting 2023-02-24, then started reporting very high positive values, never recovers
2023 Apr 10 19:47:30 MDT	2023 Jun 20 00:00:00 MDT	Tsnow.1.2m.uw	Buried in snow starting 2023-02-24, then started reporting very high positive values, never recovers
2023 Apr 30 14:52:30 MDT	2023 Jun 20 00:00:00 MDT	Tsnow.1.3m.uw	Buried in snow starting 2023-02-24, then started reporting very high positive values, never recovers
2023 Apr 18 14:42:30 MDT	2023 May 17 10:57:30 MDT	Tsnow.1.4m.uw	Buried in snow starting 2023-03-11, then started reporting very high positive values, but does recover about a month later
2023 Apr 7 04:52:30 MDT	2023 May 14 06:52:30 MDT	Tsnow.0.4m.d	Buried in snow starting 2022-12-31, then was missing many values, but does recover about a month later
2023 May 26 02:17:30 MDT	2023 Jun 20 00:00:00 MDT	Tsnow.0.4m.d	Unfortunately, Tsnow start reporting high values again and never recovers
2023 Apr 25 23:32:30 MDT	2023 May 13 06:32:30 MDT	Tsnow.0.5m.d	Buried in snow starting 2022-12-31, then was missing many values, but does recover about a month later
2023 May 18 16:12:30 MDT	2023 May 21 17:27:30 MDT	Tsnow.0.5m.d	This instrument does have a few days of very high values, but does recover again

Derivation of Apogee Surface Temperature

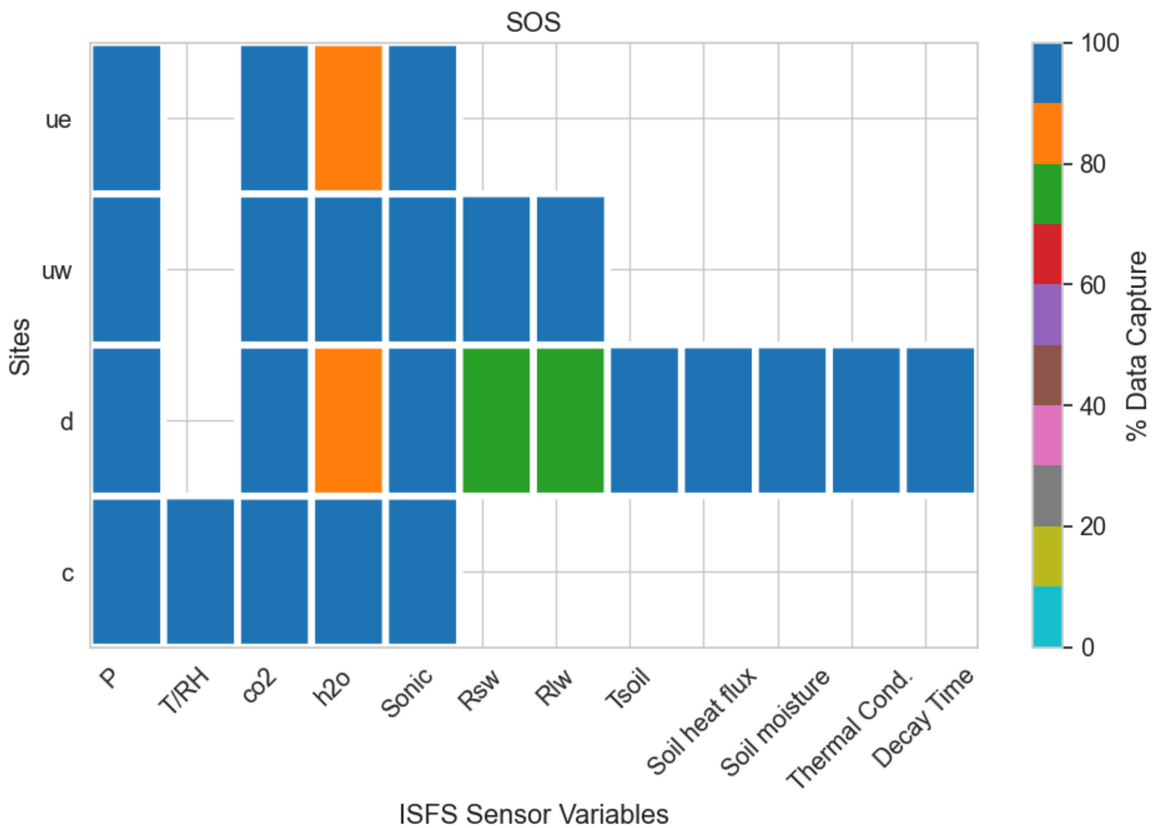
These radiometers are intended to measure surface temperature. The manufacturer provided the equations below to compute temperature from the measure voltages along with calibration coefficients for each probe. Below is R code that applies these equations, along with removing data when either the cable or our front-end A/D converter was bad. There still are some residual spikes and very high readings June 1-3 from 2 sensors that we have left in the data set. Note this script works with 5min data only.

```
# hard-coded sensor-specific calibrations
   Vref = 2.5
   IDir = dat("IDir")
   sns = c(136, 137, 138, 139)
   names(sns) = c("ue","d","uw","c") # Popsicle sticks moved, so do not count on IDs, but sensors
stayed
   im = match(suffixes(IDir,leadch=""),names(sns))
# Apparently, we wanted the "CRBasic" coefficients
   mC0 = 1e5*c(57508.575,56653.007,58756.588,58605.7861)[im]
   mC1 = 1e5*c(289.12189,280.03380,287.12487,285.00285)[im]
   mC2 = 1e5*c(2.16807,2.11478,2.11822,2.08932)[im]
   bC0 = 1e5*c(-168.3687,-319.9362,-214.5312,-329.6453)[im]
   bC1 = 1e5*c(-0.22672,-1.23812,-0.59308,-1.24657)[im]
   bC2 = 1e5*c(0.08927,0.08612,0.10936,0.09234)[im]
# read data and some crude QC
   Vtherm = dat("Vtherm")
   Vtherm[abs(Vtherm)>5] = NA
   Vpile = dat("Vpile")
   Vpile[abs(Vpile)>0.003] = NA
# ...remove periods when the cable on d was bad
   imd = match(".d",suffixes(dat("IDir")))
   ib = utime(c("2022 oct 23 00:00","2022 nov 17 15:00")); Vpile[ib,imd] = NA
# ...remove periods when the popsicle on uw was bad
   imuw = match(".uw",suffixes(dat("IDir")))
   ib = utime(c("2022 oct 23 00:00","2022 nov 14 00:00")); Vpile[ib,imuw] = NA
   ib = utime(c("2022 dec 8 10:00","2022 dec 14 00:00")); Vpile[ib,imuw] = NA
   ib = utime(c("2023 jan 1 00:00","2023 jan 23 10:30")); Vpile[ib,imuw] = NA
# calculation of detector temperature from Steinhart-Hart
   Rt = 24900.0/((Vref/Vtherm) - 1)
   Ac = 1.129241e-3
   Bc = 2.341077e-4
   Cc = 8.775468e-8
   TDk = 1/(Ac + Bc*log(Rt) + Cc*(log(Rt)^3))
   TDc = TDk - 273.15
# finally, calculation of "target" temperature including thermopile measurement
# the manual says that TD in the calculation of m and b are in degC.
   m = mC2*TDc^2 + mC1*TDc + mC0
```

```
b = bC2*TDc^2 + bC1*TDc + bC0
TTc = (TDk^4 + m*Vpile*1000 + b)^0.25 - 273.15 # here, Vpile is in mV
```

Data Capture

Figure 8 shows the overall percent of 5-minute ISFS sensor data remaining per variable, at all heights, after all quality checks and filters have been applied. The lower rates of data availability in the NR01 radiometer data (Rsw, Rlw) are due primarily to filtering of the wetness on the sensor's lens.



	P	T	co2	h2o	u	Rsw_in	Rpile_in	Tsoil	Gsoil	Qsoil	Lambda	Tau63
c	99.563492	99.806097	93.136724	92.854137	98.085017	NaN	NaN	NaN	NaN	NaN	NaN	NaN
d	99.479918	NaN	92.559524	89.714105	99.313071	71.817881	74.729437	99.776034	99.776034	99.776034	99.718915	99.718915
uw	98.475830	NaN	92.234848	90.462662	97.988817	98.662217	98.662217	NaN	NaN	NaN	NaN	NaN
ue	99.526515	NaN	92.630171	89.953102	98.590067	NaN	NaN	NaN	NaN	NaN	NaN	NaN

Figure 8. Percent of data available during SOS. Most major ISFS sensor data sets are included. Blank areas (or NaN's) denote no sensors were operating.

	FlowCapt	Thermister	Apogee
c	NaN	NaN	99.699375
d	NaN	99.776034	99.776034
uw	NaN	98.662217	98.662217
ue	99.439334	NaN	99.657287

Table 10. Percent of data available during SOS for PI sensors. Snow pillow datasets are not included because the sample rates vary and are inconsistent in the 5min dataset.

Small Data Gaps

Small data gaps occur from time to time in a given sensors' data stream. These may be due to

- Loss of GPS signal when rebooting due to loss of power due to maintenance, i.e. servicing sensors.
- Sensor thresholds on the data.
- Status or error messages from the sensor
-

Snowfall Events

Snowfall events were determined by analyzing instruments like Relative Humidity, Snow Pillows, Radiation, Webcams, and Wetness. The increase in weight in the snow pillows and high RH provided the best determinations for snowfall events during SOS. The wetness sensor wasn't able to capture the smaller snowfall events as well, and the radiation variables helped describe the potential overcast and snowy days during operations. That said, it's important to keep in mind that these snowfall events are still not very well defined since a variety of research describes the difficulty in measuring snowfall autonomously.

Table 11. Observed snowfall events.

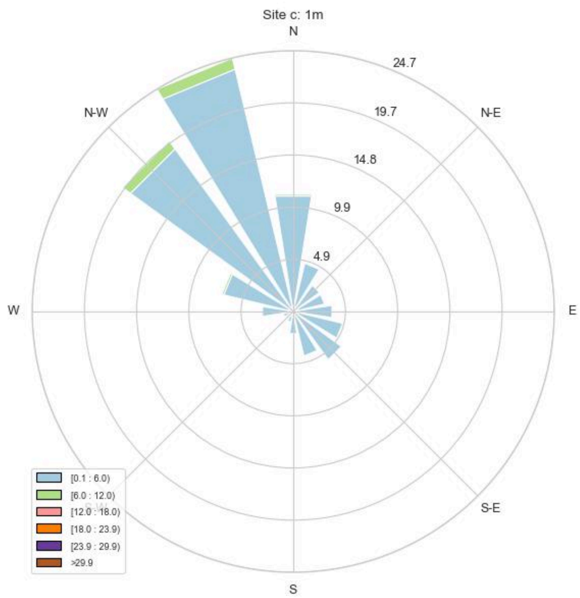
Start Time	End Time	Comment
2022 Oct 23 04:00:00 MDT	2022 Oct 23 07:00:00 MDT	Overnight first snow, but before operations
2022 Oct 25 19:00:00 MDT	2022 Oct 26 12:00:00 MDT	Long snow event... can't see accumulation via pillows
2022 Oct 26 21:00:00 MDT	2022 Oct 27 05:00:00 MDT	First blog with snow pictures
2022 Nov 03 04:00:00 MDT	2022 Nov 04 12:00:00 MDT	
2022 Nov 05 02:00:00 MDT	2022 Nov 05 17:00:00 MDT	
2022 Nov 09 16:30:00 MST	2022 Nov 10 09:30:00 MST	smaller snow event... just about an inch
2022 Nov 18 05:00:00 MST	2022 Nov 18 08:00:00 MST	Another small event

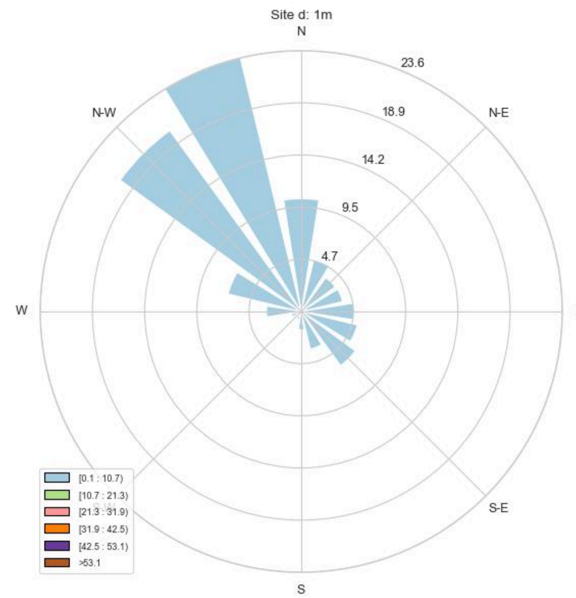
2022 Nov 27 00:00:00 MST	2022 Nov 27 05:00:00 MST	small dusting
2022 Nov 28 18:00:00 MST	2022 Nov 29 14:00:00 MST	Significant snow..... ground snow covered until May
2022 Dec 02 03:00:00 MST	2022 Dec 02 16:00:00 MST	
2022 Dec 03 17:00:00 MST	2022 Dec 04 17:00:00 MST	Largely determined with wetness spikes and high RH
2022 Dec 05 00:00:00 MST	2022 Dec 05 10:00:00 MST	
2022 Dec 06 00:00:00 MST	2022 Dec 07 14:00:00 MST	Long snow event
2022 Dec 08 00:00:00 MST	2022 Dec 08 10:00:00 MST	Determined by increase in pillow data
2022 Dec 20 18:00:00 MST	2022 Dec 22 07:00:00 MST	severe snow storm with high winds and lost of blowing snow
2022 Dec 27 18:00:00 MST	2023 Jan 02 03:00:00 MST	Very long snowfall, also Jacquie's comment, likely some blowing snow in between
2023 Jan 02 10:00:00 MST	2023 Jan 04 06:00:00 MST	
2023 Jan 06 03:00:00 MST	2023 Jan 07 08:00:00 MST	January 6th snowfall
2023 Jan 09 22:00:00 MST	2023 Jan 12 00:00:00 MST	Sonics move from 1m to 2m after this snowfall
2023 Jan 14 20:00:00 MST	2023 Jan 15 14:00:00 MST	
2023 Jan 16 00:00:00 MST	2023 Jan 18 10:00:00 MST	Lots of blowing snow, very minor snowfalls for the next few days based on higher RH and wetness
2023 Jan 27 14:00:00 MST	2023 Jan 28 06:00:00 MST	Snowing in the field
2023 Jan 29 00:00:00 MST	2023 Jan 31 17:00:00 MST	Heavy Snowfall conditions
2023 Feb 06 00:00:00 MST	2023 Feb 06 14:00:00 MST	
2023 Feb 13 12:00:00 MST	2023 Feb 15 07:00:00 MST	Comments on how snow had complete on 2/15
2023 Feb 20 10:00:00 MST	2023 Feb 24 15:00:00 MST	
2023 Feb 28 00:00:00 MST	2023 Mar 02 06:00:00 MST	
2023 Mar 10 06:00:00 MST	2023 Mar 11 11:00:00 MST	snow at lowest level is buried now..... maybe largest snowfall of the ops
2023 Mar 12 00:00:00 MST	2023 Mar 16 00:00:00 MDT	lots SWE accumulation across this 5 day period... 12 inches of new snow reported
2023 Mar 20 12:00:00 MDT	2023 Mar 27 12:00:00 MDT	More instruments are getting buried. Further comments.
2023 Mar 30 15:00:00 MDT	2023 Apr 01 07:00:00 MDT	
2023 Apr 3 20:00:00 MDT	2023 Apr 4 08:00:00 MDT	

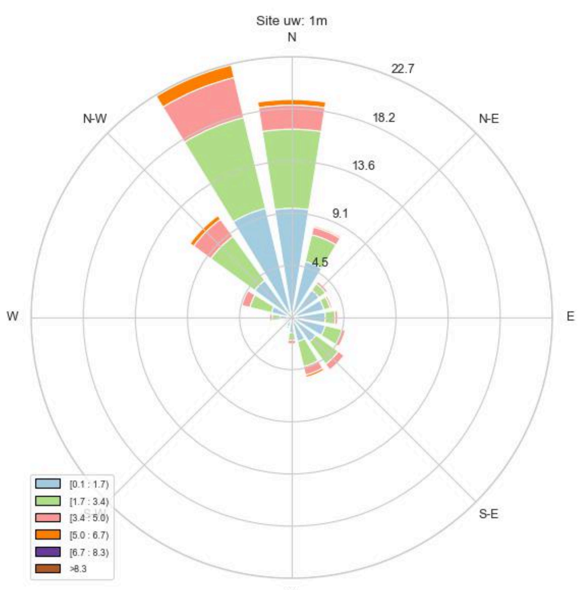
2023 Apr 14 10:00:00 MDT	2023 Apr 15 14:00:00 MDT	
2023 Apr 20 20:00:00 MDT	2023 Apr 23 10:00:00 MDT	
2023 Apr 24 22:00:00 MDT	2023 Apr 26 00:00:00 MDT	
2023 Apr 27 22:00:00 MDT	2023 Apr 28 08:00:00 MDT	
2023 May 10 22:00:00 MDT	2023 May 12 08:00:00 MDT	

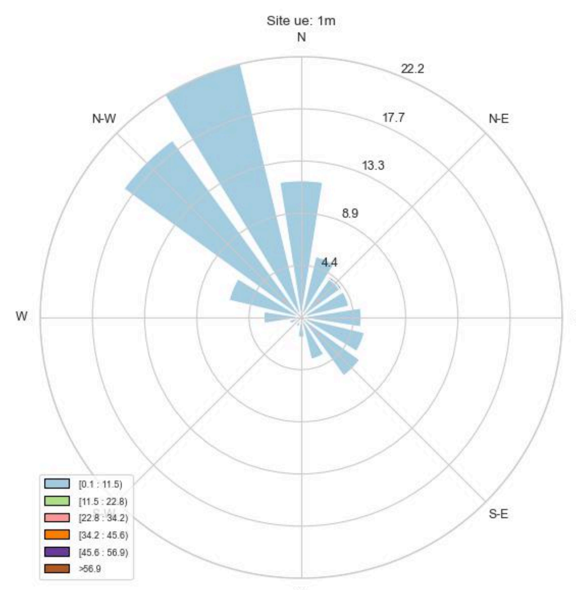
Appendix A: Sonic Windrose Summary Plots for 1 Nov 2022 - 19 June 2023

1m

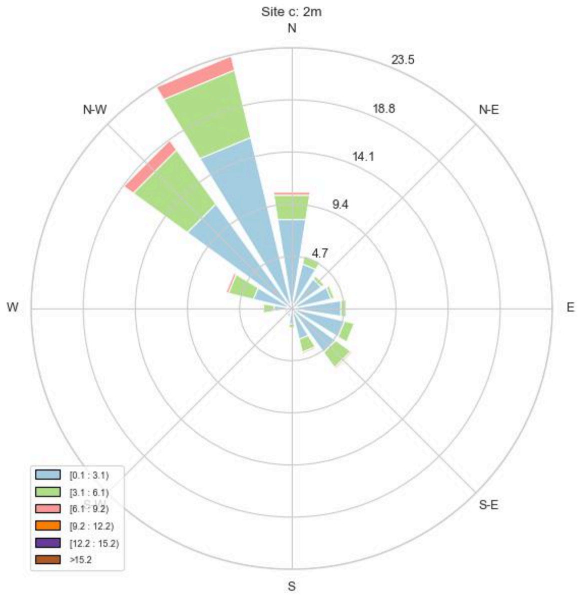




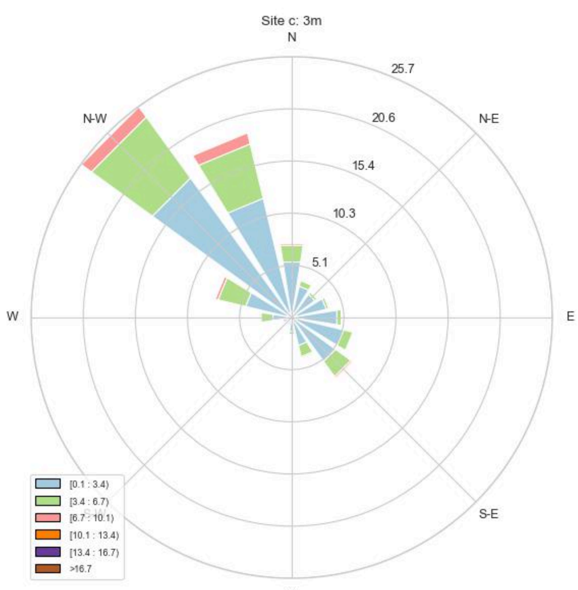


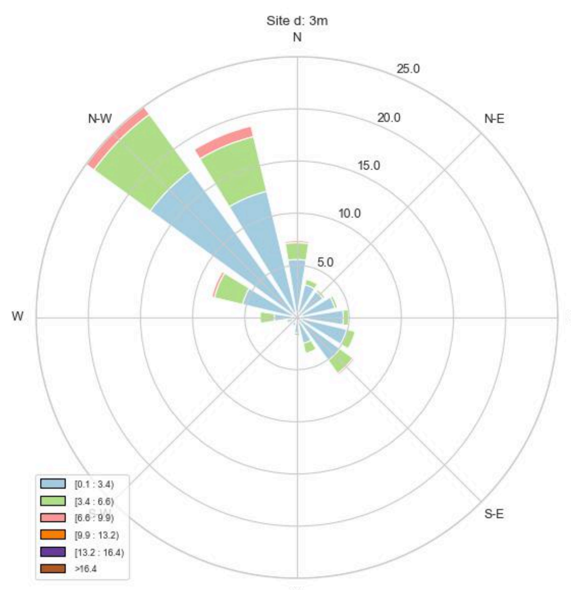


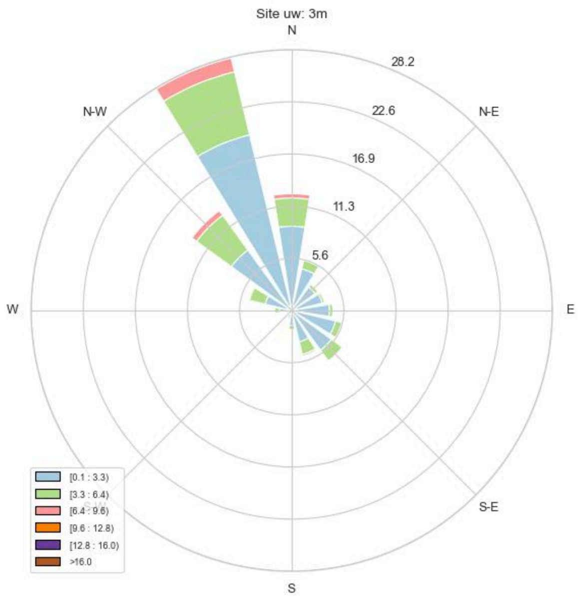
2m

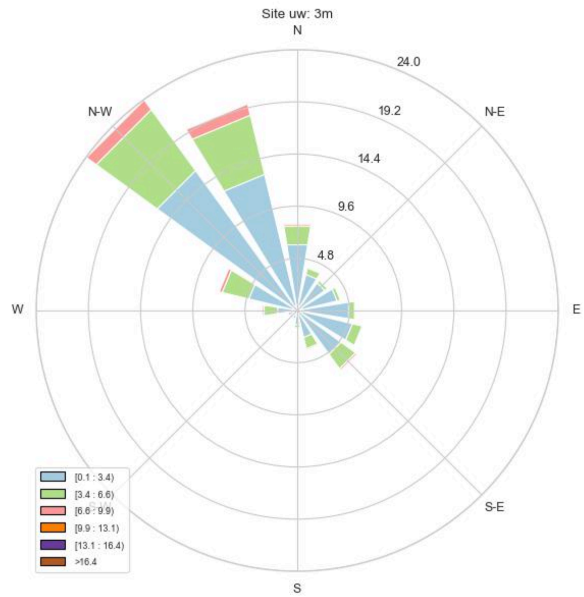

Site c: 2m
N
N-E
E
S-E
S
W
N-W
4.7
9.4
14.1
18.8
23.5
[0.1 : 3.1)
[3.1 : 6.1)
[6.1 : 9.2)
[9.2 : 12.2)
[12.2 : 15.2)
>15.2

3m

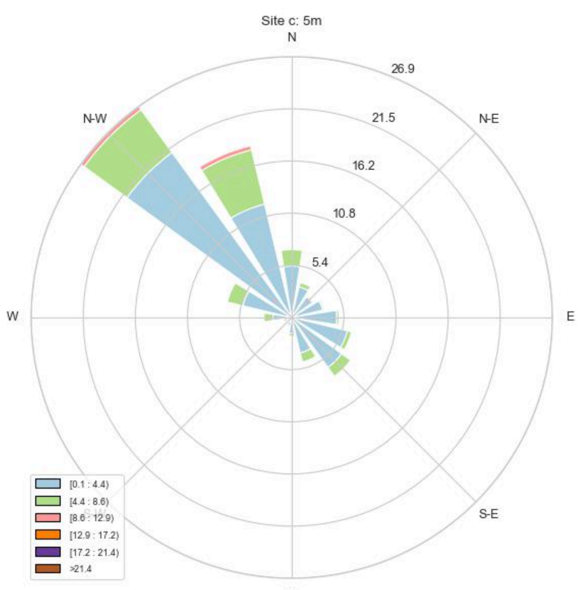

Site c: 3m
N
N-E
E
S-E
S
W
N-W
5.1
10.3
15.4
20.6
25.7
[0.1 : 3.4)
[3.4 : 6.7)
[6.7 : 10.1)
[10.1 : 13.4)
[13.4 : 16.7)
>16.7


Site d: 3m
N
N-E
E
S-E
S
W
N-W
5.0
10.0
15.0
20.0
25.0
[0.1 : 3.4)
[3.4 : 6.6)
[6.6 : 9.9)
[9.9 : 13.2)
[13.2 : 16.4)
>16.4

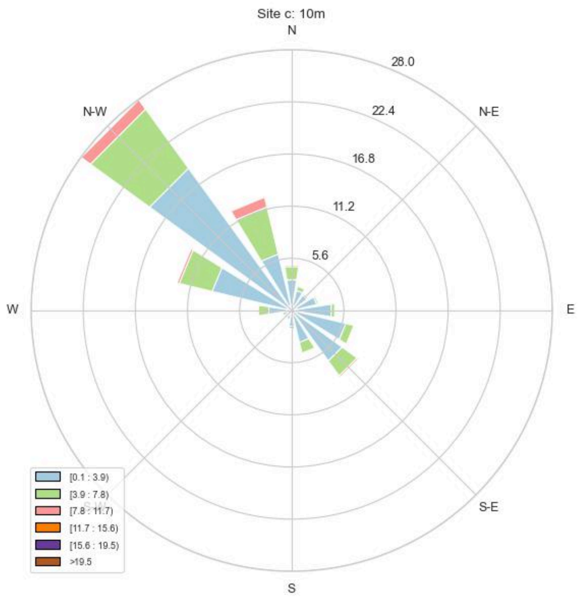

Site uw: 3m
N
N-W
N-E
W
E
S-E
S
28.2
22.6
16.9
11.3
5.6
[0.1 : 3.3)
[3.3 : 6.4)
[6.4 : 9.6)
[9.6 : 12.8)
[12.8 : 16.0)
>16.0

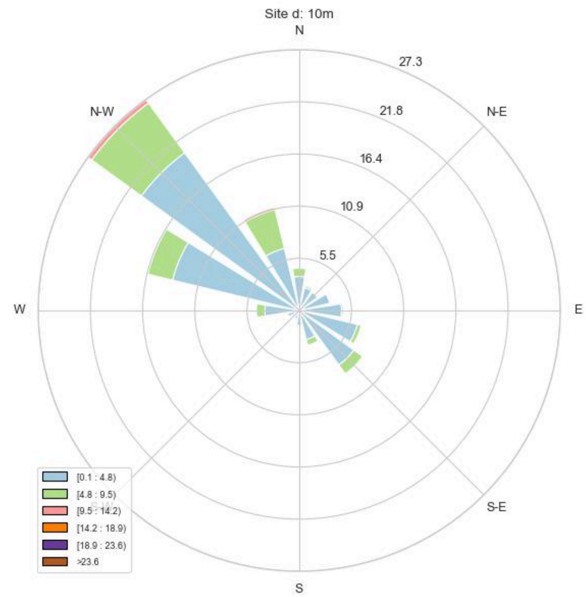

Site uw: 3m
N
N-W
N-E
W
E
S-E
S
24.0
19.2
14.4
9.6
4.8
[0.1 : 3.4)
[3.4 : 6.6)
[6.6 : 9.9)
[9.9 : 13.1)
[13.1 : 16.4)
>16.4

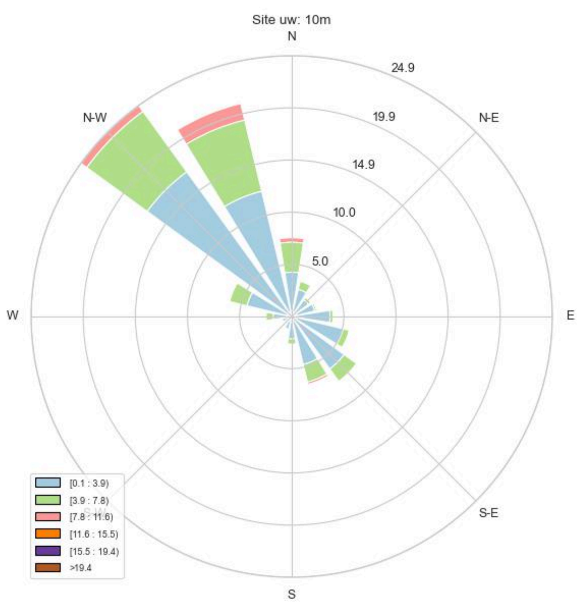
5m

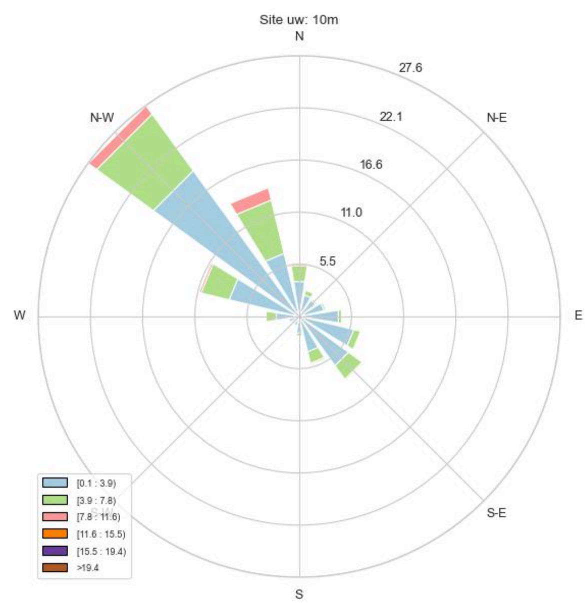

Site c: 5m
N
N-W
N-E
W
E
S-E
S
26.9
21.5
16.2
10.8
5.4
[0.1 : 4.4)
[4.4 : 8.6)
[8.6 : 12.9)
[12.9 : 17.2)
[17.2 : 21.4)
>21.4

10m

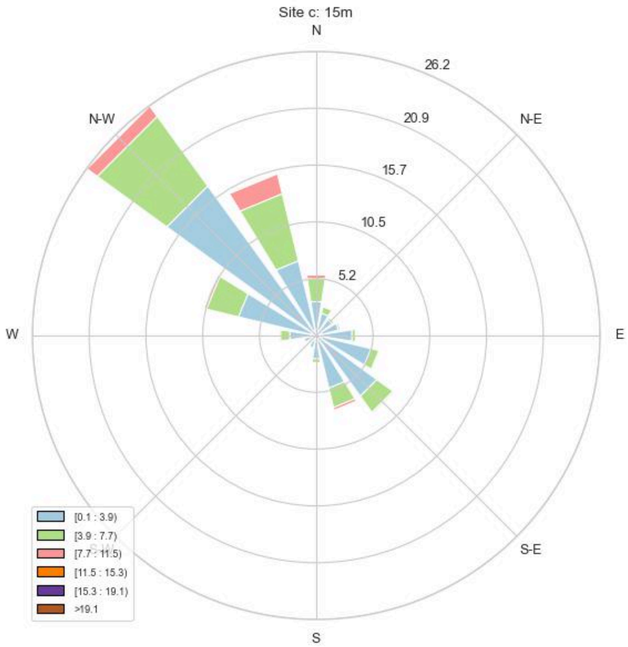

Site c: 10m
N
N-E
E
S-E
S
W
N-W
28.0
22.4
16.8
11.2
5.6
[0.1 : 3.9)
[3.9 : 7.8)
[7.8 : 11.7)
[11.7 : 15.6)
[15.6 : 19.5)
>19.5


Site d: 10m
N
N-E
E
S-E
S
W
N-W
27.3
21.8
16.4
10.9
5.5
[0.1 : 4.8)
[4.8 : 9.5)
[9.5 : 14.2)
[14.2 : 18.9)
[18.9 : 23.6)
>23.6

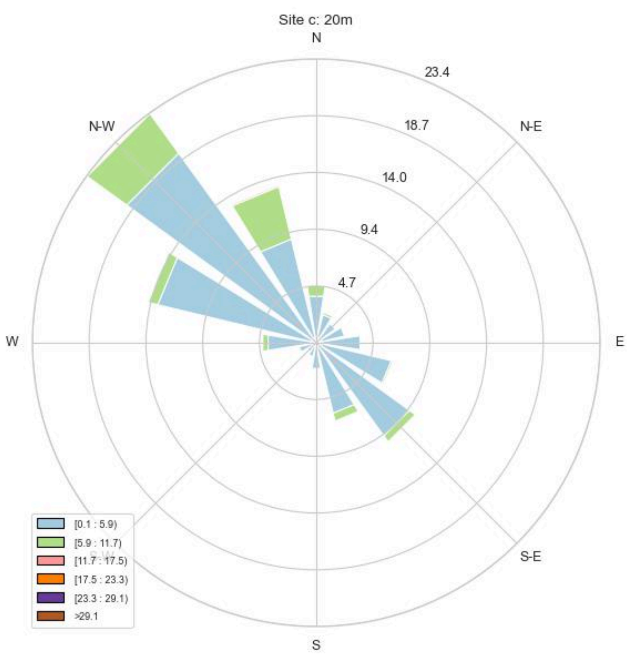

Site uw: 10m
N
N-E
E
S-E
S
W
N-W
24.9
19.9
14.9
10.0
5.0
[0.1 : 3.9)
[3.9 : 7.8)
[7.8 : 11.6)
[11.6 : 15.5)
[15.5 : 19.4)
>19.4


Site uw: 10m
N
N-E
E
S-E
S
W
N-W
27.6
22.1
16.6
11.0
5.5
[0.1 : 3.9)
[3.9 : 7.8)
[7.8 : 11.6)
[11.6 : 15.5)
[15.5 : 19.4)
>19.4

15m


Site c: 15m
N
N-E
E
S-E
S
W
N-W
26.2
20.9
15.7
10.5
5.2
[0.1 : 3.9)
[3.9 : 7.7)
[7.7 : 11.5)
[11.5 : 15.3)
[15.3 : 19.1)
>19.1

20m


Site c: 20m
N
N-E
E
S-E
S
W
N-W
23.4
18.7
14.0
9.4
4.7
[0.1 : 5.9)
[5.9 : 11.7)
[11.7 : 17.5)
[17.5 : 23.3)
[23.3 : 29.1)
>29.1

Appendix B: High rate variables

Variable Name	Samples/s	Sensor	Short Description
u.1m.d	20	CSAT3_IRGA_BIN	'Wind U component, CSAT3'
v.1m.d	20	CSAT3_IRGA_BIN	'Wind V component, CSAT3'
w.1m.d	20	CSAT3_IRGA_BIN	'Wind W component, CSAT3'
tc.1m.d	20	CSAT3_IRGA_BIN	'Virtual air temperature from speed of sound, CSAT3'
diagbits.1m.d	20	CSAT3_IRGA_BIN	'CSAT3 diagnostic sum, 1=low sig,2=high sig,4=no lock,8=path diff,16=skipped samp'
co2.1m.d	20	CSAT3_IRGA_BIN	'CO2 density from CSI IRGA'
h2o.1m.d	20	CSAT3_IRGA_BIN	'Water vapor density from CSI IRGA'
irgadiag.1m.d	20	CSAT3_IRGA_BIN	'CSI IRGA diagnostic'
Tirga.1m.d	20	CSAT3_IRGA_BIN	'CSI IRGA temperature'
Pirga.1m.d	20	CSAT3_IRGA_BIN	'CSI IRGA pressure'
ldiag.1m.d	20	CSAT3_IRGA_BIN	'CSAT3 logical diagnostic, 0=OK, 1=(diagbits!=0)'
u.3m.d	20	CSAT3_IRGA_BIN	'Wind U component, CSAT3'
v.3m.d	20	CSAT3_IRGA_BIN	'Wind V component, CSAT3'
w.3m.d	20	CSAT3_IRGA_BIN	'Wind W component, CSAT3'
tc.3m.d	20	CSAT3_IRGA_BIN	'Virtual air temperature from speed of sound, CSAT3'
diagbits.3m.d	20	CSAT3_IRGA_BIN	'CSAT3 diagnostic sum, 1=low sig,2=high sig,4=no lock,8=path diff,16=skipped samp'
co2.3m.d	20	CSAT3_IRGA_BIN	'CO2 density from CSI IRGA'
h2o.3m.d	20	CSAT3_IRGA_BIN	'Water vapor density from CSI IRGA'
irgadiag.3m.d	20	CSAT3_IRGA_BIN	'CSI IRGA diagnostic'
Tirga.3m.d	20	CSAT3_IRGA_BIN	'CSI IRGA temperature'
Pirga.3m.d	20	CSAT3_IRGA_BIN	'CSI IRGA pressure'
ldiag.3m.d	20	CSAT3_IRGA_BIN	'CSAT3 logical diagnostic, 0=OK, 1=(diagbits!=0)'
u.10m.d	20	CSAT3_IRGA_BIN	'Wind U component, CSAT3'
v.10m.d	20	CSAT3_IRGA_BIN	'Wind V component, CSAT3'

w.10m.d	20	CSAT3_IRGA_BIN	'Wind W component, CSAT3'
tc.10m.d	20	CSAT3_IRGA_BIN	'Virtual air temperature from speed of sound, CSAT3'
diagbits.10m.d	20	CSAT3_IRGA_BIN	'CSAT3 diagnostic sum, 1=low sig,2=high sig,4=no lock,8=path diff,16=skipped samp'
co2.10m.d	20	CSAT3_IRGA_BIN	'CO2 density from CSI IRGA'
h2o.10m.d	20	CSAT3_IRGA_BIN	'Water vapor density from CSI IRGA'
irgadiag.10m.d	20	CSAT3_IRGA_BIN	'CSI IRGA diagnostic'
Tirga.10m.d	20	CSAT3_IRGA_BIN	'CSI IRGA temperature'
Pirga.10m.d	20	CSAT3_IRGA_BIN	'CSI IRGA pressure'
ldiag.10m.d	20	CSAT3_IRGA_BIN	'CSAT3 logical diagnostic, 0=OK, 1=(diagbits!=0)'
P.10m.d	20	Nano	'Barometric Pressure, Paroscientific 6000'
u.1m.ue	20	CSAT3_IRGA_BIN	'Wind U component, CSAT3'
v.1m.ue	20	CSAT3_IRGA_BIN	'Wind V component, CSAT3'
w.1m.ue	20	CSAT3_IRGA_BIN	'Wind W component, CSAT3'
tc.1m.ue	20	CSAT3_IRGA_BIN	'Virtual air temperature from speed of sound, CSAT3'
diagbits.1m.ue	20	CSAT3_IRGA_BIN	'CSAT3 diagnostic sum, 1=low sig,2=high sig,4=no lock,8=path diff,16=skipped samp'
co2.1m.ue	20	CSAT3_IRGA_BIN	'CO2 density from CSI IRGA'
h2o.1m.ue	20	CSAT3_IRGA_BIN	'Water vapor density from CSI IRGA'
irgadiag.1m.ue	20	CSAT3_IRGA_BIN	'CSI IRGA diagnostic'
Tirga.1m.ue	20	CSAT3_IRGA_BIN	'CSI IRGA temperature'
Pirga.1m.ue	20	CSAT3_IRGA_BIN	'CSI IRGA pressure'
ldiag.1m.ue	20	CSAT3_IRGA_BIN	'CSAT3 logical diagnostic, 0=OK, 1=(diagbits!=0)'
u.3m.ue	20	CSAT3_IRGA_BIN	'Wind U component, CSAT3'
v.3m.ue	20	CSAT3_IRGA_BIN	'Wind V component, CSAT3'
w.3m.ue	20	CSAT3_IRGA_BIN	'Wind W component, CSAT3'
tc.3m.ue	20	CSAT3_IRGA_BIN	'Virtual air temperature from speed of sound, CSAT3'

diagbits.3m.ue	20	CSAT3_IRGA_BIN	'CSAT3 diagnostic sum, 1=low sig,2=high sig,4=no lock,8=path diff,16=skipped samp'
co2.3m.ue	20	CSAT3_IRGA_BIN	'CO2 density from CSI IRGA'
h2o.3m.ue	20	CSAT3_IRGA_BIN	'Water vapor density from CSI IRGA'
irgadiag.3m.ue	20	CSAT3_IRGA_BIN	'CSI IRGA diagnostic'
Tirga.3m.ue	20	CSAT3_IRGA_BIN	'CSI IRGA temperature'
Pirga.3m.ue	20	CSAT3_IRGA_BIN	'CSI IRGA pressure'
ldiag.3m.ue	20	CSAT3_IRGA_BIN	'CSAT3 logical diagnostic, 0=OK, 1=(diagbits!=0)'
u.10m.ue	20	CSAT3_IRGA_BIN	'Wind U component, CSAT3'
v.10m.ue	20	CSAT3_IRGA_BIN	'Wind V component, CSAT3'
w.10m.ue	20	CSAT3_IRGA_BIN	'Wind W component, CSAT3'
tc.10m.ue	20	CSAT3_IRGA_BIN	'Virtual air temperature from speed of sound, CSAT3'
diagbits.10m.ue	20	CSAT3_IRGA_BIN	'CSAT3 diagnostic sum, 1=low sig,2=high sig,4=no lock,8=path diff,16=skipped samp'
co2.10m.ue	20	CSAT3_IRGA_BIN	'CO2 density from CSI IRGA'
h2o.10m.ue	20	CSAT3_IRGA_BIN	'Water vapor density from CSI IRGA'
irgadiag.10m.ue	20	CSAT3_IRGA_BIN	'CSI IRGA diagnostic'
Tirga.10m.ue	20	CSAT3_IRGA_BIN	'CSI IRGA temperature'
Pirga.10m.ue	20	CSAT3_IRGA_BIN	'CSI IRGA pressure'
ldiag.10m.ue	20	CSAT3_IRGA_BIN	'CSAT3 logical diagnostic, 0=OK, 1=(diagbits!=0)'
P.10m.ue	20	Nano	'Barometric Pressure, Paroscientific 6000'
u.1m.uw	20	CSAT3_IRGA_BIN	'Wind U component, CSAT3'
v.1m.uw	20	CSAT3_IRGA_BIN	'Wind V component, CSAT3'
w.1m.uw	20	CSAT3_IRGA_BIN	'Wind W component, CSAT3'
tc.1m.uw	20	CSAT3_IRGA_BIN	'Virtual air temperature from speed of sound, CSAT3'
diagbits.1m.uw	20	CSAT3_IRGA_BIN	'CSAT3 diagnostic sum, 1=low sig,2=high sig,4=no lock,8=path diff,16=skipped samp'
co2.1m.uw	20	CSAT3_IRGA_BIN	'CO2 density from CSI IRGA'
h2o.1m.uw	20	CSAT3_IRGA_BIN	'Water vapor density from CSI IRGA'

irgadiag.1m.uw	20	CSAT3_IRGA_BIN	'CSI IRGA diagnostic'
Tirga.1m.uw	20	CSAT3_IRGA_BIN	'CSI IRGA temperature'
Pirga.1m.uw	20	CSAT3_IRGA_BIN	'CSI IRGA pressure'
ldiag.1m.uw	20	CSAT3_IRGA_BIN	'CSAT3 logical diagnostic, 0=OK, 1=(diagbits!=0)'
u.3m.uw	20	CSAT3_IRGA_BIN	'Wind U component, CSAT3'
v.3m.uw	20	CSAT3_IRGA_BIN	'Wind V component, CSAT3'
w.3m.uw	20	CSAT3_IRGA_BIN	'Wind W component, CSAT3'
tc.3m.uw	20	CSAT3_IRGA_BIN	'Virtual air temperature from speed of sound, CSAT3'
diagbits.3m.uw	20	CSAT3_IRGA_BIN	'CSAT3 diagnostic sum, 1=low sig,2=high sig,4=no lock,8=path diff,16=skipped samp'
co2.3m.uw	20	CSAT3_IRGA_BIN	'CO2 density from CSI IRGA'
h2o.3m.uw	20	CSAT3_IRGA_BIN	'Water vapor density from CSI IRGA'
irgadiag.3m.uw	20	CSAT3_IRGA_BIN	'CSI IRGA diagnostic'
Tirga.3m.uw	20	CSAT3_IRGA_BIN	'CSI IRGA temperature'
Pirga.3m.uw	20	CSAT3_IRGA_BIN	'CSI IRGA pressure'
ldiag.3m.uw	20	CSAT3_IRGA_BIN	'CSAT3 logical diagnostic, 0=OK, 1=(diagbits!=0)'
u.10m.uw	20	CSAT3_IRGA_BIN	'Wind U component, CSAT3'
v.10m.uw	20	CSAT3_IRGA_BIN	'Wind V component, CSAT3'
w.10m.uw	20	CSAT3_IRGA_BIN	'Wind W component, CSAT3'
tc.10m.uw	20	CSAT3_IRGA_BIN	'Virtual air temperature from speed of sound, CSAT3'
diagbits.10m.uw	20	CSAT3_IRGA_BIN	'CSAT3 diagnostic sum, 1=low sig,2=high sig,4=no lock,8=path diff,16=skipped samp'
co2.10m.uw	20	CSAT3_IRGA_BIN	'CO2 density from CSI IRGA'
h2o.10m.uw	20	CSAT3_IRGA_BIN	'Water vapor density from CSI IRGA'
irgadiag.10m.uw	20	CSAT3_IRGA_BIN	'CSI IRGA diagnostic'
Tirga.10m.uw	20	CSAT3_IRGA_BIN	'CSI IRGA temperature'
Pirga.10m.uw	20	CSAT3_IRGA_BIN	'CSI IRGA pressure'
ldiag.10m.uw	20	CSAT3_IRGA_BIN	'CSAT3 logical diagnostic, 0=OK, 1=(diagbits!=0)'

P.10m.uw	20	Nano	'Barometric Pressure, Paroscientific 6000'
u.3bh.3m.uw	20	CSAT3BH	'Wind U component, CSAT3BH'
v.3bh.3m.uw	20	CSAT3BH	'Wind V component, CSAT3BH'
w.3bh.3m.uw	20	CSAT3BH	'Wind W component, CSAT3BH'
tc.3bh.3m.uw	20	CSAT3BH	'Virtual air temperature from speed of sound, CSAT3BH'
diag.3bh.3m.uw	20	CSAT3BH	'CSAT3BH diagnostic sum'
ldiag.3bh.3m.uw	20	CSAT3BH	'CSAT3BH logical diagnostic, 0=OK, 1=(diagbits!=0)'
Status.1.p1.c	1	PILLOWS	'Status cell 1'
Status.2.p1.c	1	PILLOWS	'Status cell 2'
Status.3.p1.c	1	PILLOWS	'Status cell 3'
Status.4.p1.c	1	PILLOWS	'Status cell 4'
Status.Text.p1.c	1	PILLOWS	'Status Text'
Status.Tint.p1.c	1	PILLOWS	'Status Tint'
Status.1.p2.c	1	PILLOWS	'Status cell 1'
Status.2.p2.c	1	PILLOWS	'Status cell 2'
Status.3.p2.c	1	PILLOWS	'Status cell 3'
Status.4.p2.c	1	PILLOWS	'Status cell 4'
Status.Text.p2.c	1	PILLOWS	'Status Text'
Status.Tint.p2.c	1	PILLOWS	'Status Tint'
Status.1.p3.c	1	PILLOWS	'Status cell 1'
Status.2.p3.c	1	PILLOWS	'Status cell 2'
Status.3.p3.c	1	PILLOWS	'Status cell 3'
Status.4.p3.c	1	PILLOWS	'Status cell 4'
Status.Text.p3.c	1	PILLOWS	'Status Text'
Status.Tint.p3.c	1	PILLOWS	'Status Tint'
Status.1.p4.c	1	PILLOWS	'Status cell 1'
Status.2.p4.c	1	PILLOWS	'Status cell 2'
Status.3.p4.c	1	PILLOWS	'Status cell 3'

Status.4.p4.c	1	PILLOWS	'Status cell 4'
Status.Text.p4.c	1	PILLOWS	'Status Text'
Status.Tint.p4.c	1	PILLOWS	'Status Tint'
u.1m.c	20	CSAT3_IRGA_BIN	'Wind U component, CSAT3'
v.1m.c	20	CSAT3_IRGA_BIN	'Wind V component, CSAT3'
w.1m.c	20	CSAT3_IRGA_BIN	'Wind W component, CSAT3'
tc.1m.c	20	CSAT3_IRGA_BIN	'Virtual air temperature from speed of sound, CSAT3'
diagbits.1m.c	20	CSAT3_IRGA_BIN	'CSAT3 diagnostic sum, 1=low sig,2=high sig,4=no lock,8=path diff,16=skipped samp'
co2.1m.c	20	CSAT3_IRGA_BIN	'CO2 density from CSI IRGA'
h2o.1m.c	20	CSAT3_IRGA_BIN	'Water vapor density from CSI IRGA'
irgadiag.1m.c	20	CSAT3_IRGA_BIN	'CSI IRGA diagnostic'
Tirga.1m.c	20	CSAT3_IRGA_BIN	'CSI IRGA temperature'
Pirga.1m.c	20	CSAT3_IRGA_BIN	'CSI IRGA pressure'
ldiag.1m.c	20	CSAT3_IRGA_BIN	'CSAT3 logical diagnostic, 0=OK, 1=(diagbits!=0)'
T.1m.c	1	NCAR_SHT	'Air Temperature, NCAR hygrothermometer'
RH.1m.c	1	NCAR_SHT	'Relative Humidity, NCAR hygrothermometer'
u.2m.c	20	CSAT3_IRGA_BIN	'Wind U component, CSAT3'
v.2m.c	20	CSAT3_IRGA_BIN	'Wind V component, CSAT3'
w.2m.c	20	CSAT3_IRGA_BIN	'Wind W component, CSAT3'
tc.2m.c	20	CSAT3_IRGA_BIN	'Virtual air temperature from speed of sound, CSAT3'
diagbits.2m.c	20	CSAT3_IRGA_BIN	'CSAT3 diagnostic sum, 1=low sig,2=high sig,4=no lock,8=path diff,16=skipped samp'
co2.2m.c	20	CSAT3_IRGA_BIN	'CO2 density from CSI IRGA'
h2o.2m.c	20	CSAT3_IRGA_BIN	'Water vapor density from CSI IRGA'
irgadiag.2m.c	20	CSAT3_IRGA_BIN	'CSI IRGA diagnostic'
Tirga.2m.c	20	CSAT3_IRGA_BIN	'CSI IRGA temperature'
Pirga.2m.c	20	CSAT3_IRGA_BIN	'CSI IRGA pressure'

ldiag.2m.c	20	CSAT3_IRGA_BIN	'CSAT3 logical diagnostic, 0=OK, 1=(diagbits!=0)'
T.2m.c	1	NCAR_SHT	'Air Temperature, NCAR hygrothermometer'
RH.2m.c	1	NCAR_SHT	'Relative Humidity, NCAR hygrothermometer'
u.3m.c	20	CSAT3_IRGA_BIN	'Wind U component, CSAT3'
v.3m.c	20	CSAT3_IRGA_BIN	'Wind V component, CSAT3'
w.3m.c	20	CSAT3_IRGA_BIN	'Wind W component, CSAT3'
tc.3m.c	20	CSAT3_IRGA_BIN	'Virtual air temperature from speed of sound, CSAT3'
diagbits.3m.c	20	CSAT3_IRGA_BIN	'CSAT3 diagnostic sum, 1=low sig,2=high sig,4=no lock,8=path diff,16=skipped samp'
co2.3m.c	20	CSAT3_IRGA_BIN	'CO2 density from CSI IRGA'
h2o.3m.c	20	CSAT3_IRGA_BIN	'Water vapor density from CSI IRGA'
irgadiag.3m.c	20	CSAT3_IRGA_BIN	'CSI IRGA diagnostic'
Tirga.3m.c	20	CSAT3_IRGA_BIN	'CSI IRGA temperature'
Pirga.3m.c	20	CSAT3_IRGA_BIN	'CSI IRGA pressure'
ldiag.3m.c	20	CSAT3_IRGA_BIN	'CSAT3 logical diagnostic, 0=OK, 1=(diagbits!=0)'
T.3m.c	1	NCAR_SHT	'Air Temperature, NCAR hygrothermometer'
RH.3m.c	1	NCAR_SHT	'Relative Humidity, NCAR hygrothermometer'
T.4m.c	1	NCAR_SHT	'Air Temperature, NCAR hygrothermometer'
RH.4m.c	1	NCAR_SHT	'Relative Humidity, NCAR hygrothermometer'
u.5m.c	20	CSAT3_IRGA_BIN	'Wind U component, CSAT3'
v.5m.c	20	CSAT3_IRGA_BIN	'Wind V component, CSAT3'
w.5m.c	20	CSAT3_IRGA_BIN	'Wind W component, CSAT3'
tc.5m.c	20	CSAT3_IRGA_BIN	'Virtual air temperature from speed of sound, CSAT3'
diagbits.5m.c	20	CSAT3_IRGA_BIN	'CSAT3 diagnostic sum, 1=low sig,2=high sig,4=no lock,8=path diff,16=skipped samp'
co2.5m.c	20	CSAT3_IRGA_BIN	'CO2 density from CSI IRGA'
h2o.5m.c	20	CSAT3_IRGA_BIN	'Water vapor density from CSI IRGA'
irgadiag.5m.c	20	CSAT3_IRGA_BIN	'CSI IRGA diagnostic'

Tirga.5m.c	20	CSAT3_IRGA_BIN	'CSI IRGA temperature'
Pirga.5m.c	20	CSAT3_IRGA_BIN	'CSI IRGA pressure'
ldiag.5m.c	20	CSAT3_IRGA_BIN	'CSAT3 logical diagnostic, 0=OK, 1=(diagbits!=0)'
T.5m.c	1	NCAR_SHT	'Air Temperature, NCAR hygrothermometer'
RH.5m.c	1	NCAR_SHT	'Relative Humidity, NCAR hygrothermometer'
T.6m.c	1	NCAR_SHT	'Air Temperature, NCAR hygrothermometer'
RH.6m.c	1	NCAR_SHT	'Relative Humidity, NCAR hygrothermometer'
T.7m.c	1	NCAR_SHT	'Air Temperature, NCAR hygrothermometer'
RH.7m.c	1	NCAR_SHT	'Relative Humidity, NCAR hygrothermometer'
T.8m.c	1	NCAR_SHT	'Air Temperature, NCAR hygrothermometer'
RH.8m.c	1	NCAR_SHT	'Relative Humidity, NCAR hygrothermometer'
T.9m.c	1	NCAR_SHT	'Air Temperature, NCAR hygrothermometer'
RH.9m.c	1	NCAR_SHT	'Relative Humidity, NCAR hygrothermometer'
u.10m.c	20	CSAT3_IRGA_BIN	'Wind U component, CSAT3'
v.10m.c	20	CSAT3_IRGA_BIN	'Wind V component, CSAT3'
w.10m.c	20	CSAT3_IRGA_BIN	'Wind W component, CSAT3'
tc.10m.c	20	CSAT3_IRGA_BIN	'Virtual air temperature from speed of sound, CSAT3'
diagbits.10m.c	20	CSAT3_IRGA_BIN	'CSAT3 diagnostic sum, 1=low sig,2=high sig,4=no lock,8=path diff,16=skipped samp'
co2.10m.c	20	CSAT3_IRGA_BIN	'CO2 density from CSI IRGA'
h2o.10m.c	20	CSAT3_IRGA_BIN	'Water vapor density from CSI IRGA'
irgadiag.10m.c	20	CSAT3_IRGA_BIN	'CSI IRGA diagnostic'
Tirga.10m.c	20	CSAT3_IRGA_BIN	'CSI IRGA temperature'
Pirga.10m.c	20	CSAT3_IRGA_BIN	'CSI IRGA pressure'
ldiag.10m.c	20	CSAT3_IRGA_BIN	'CSAT3 logical diagnostic, 0=OK, 1=(diagbits!=0)'
P.10m.c	20	Nano	'Barometric Pressure, Paroscientific 6000'
T.10m.c	1	NCAR_SHT	'Air Temperature, NCAR hygrothermometer'
RH.10m.c	1	NCAR_SHT	'Relative Humidity, NCAR hygrothermometer'

T.11m.c	1	NCAR_SHT	'Air Temperature, NCAR hygrothermometer'
RH.11m.c	1	NCAR_SHT	'Relative Humidity, NCAR hygrothermometer'
T.12m.c	1	NCAR_SHT	'Air Temperature, NCAR hygrothermometer'
RH.12m.c	1	NCAR_SHT	'Relative Humidity, NCAR hygrothermometer'
T.13m.c	1	NCAR_SHT	'Air Temperature, NCAR hygrothermometer'
RH.13m.c	1	NCAR_SHT	'Relative Humidity, NCAR hygrothermometer'
T.14m.c	1	NCAR_SHT	'Air Temperature, NCAR hygrothermometer'
RH.14m.c	1	NCAR_SHT	'Relative Humidity, NCAR hygrothermometer'
u.15m.c	20	None	'Wind U component, CSAT3'
v.15m.c	20	None	'Wind V component, CSAT3'
w.15m.c	20	None	'Wind W component, CSAT3'
tc.15m.c	20	None	'Virtual air temperature from speed of sound, CSAT3'
diagbits.15m.c	20	None	'CSAT3 diagnostic sum, 1=low sig,2=high sig,4=no lock,8=path diff,16=skipped samp'
co2.15m.c	20	None	'CO2 density from CSI IRGA'
h2o.15m.c	20	None	'Water vapor density from CSI IRGA'
irgadiag.15m.c	20	None	'CSI IRGA diagnostic'
Tirga.15m.c	20	None	'CSI IRGA temperature'
Pirga.15m.c	20	None	'CSI IRGA pressure'
ldiag.15m.c	20	None	'CSAT3 logical diagnostic, 0=OK, 1=(diagbits!=0)'
T.15m.c	1	NCAR_SHT	'Air Temperature, NCAR hygrothermometer'
RH.15m.c	1	NCAR_SHT	'Relative Humidity, NCAR hygrothermometer'
T.16m.c	1	NCAR_SHT	'Air Temperature, NCAR hygrothermometer'
RH.16m.c	1	NCAR_SHT	'Relative Humidity, NCAR hygrothermometer'
T.17m.c	1	NCAR_SHT	'Air Temperature, NCAR hygrothermometer'
RH.17m.c	1	NCAR_SHT	'Relative Humidity, NCAR hygrothermometer'
T.18m.c	1	NCAR_SHT	'Air Temperature, NCAR hygrothermometer'
RH.18m.c	1	NCAR_SHT	'Relative Humidity, NCAR hygrothermometer'

T.19m.c	1	NCAR_SHT	'Air Temperature, NCAR hygrothermometer'
RH.19m.c	1	NCAR_SHT	'Relative Humidity, NCAR hygrothermometer'
u.20m.c	20	CSAT3_IRGA_BIN	'Wind U component, CSAT3'
v.20m.c	20	CSAT3_IRGA_BIN	'Wind V component, CSAT3'
w.20m.c	20	CSAT3_IRGA_BIN	'Wind W component, CSAT3'
tc.20m.c	20	CSAT3_IRGA_BIN	'Virtual air temperature from speed of sound, CSAT3'
diagbits.20m.c	20	CSAT3_IRGA_BIN	'CSAT3 diagnostic sum, 1=low sig,2=high sig,4=no lock,8=path diff,16=skipped samp'
co2.20m.c	20	CSAT3_IRGA_BIN	'CO2 density from CSI IRGA'
h2o.20m.c	20	CSAT3_IRGA_BIN	'Water vapor density from CSI IRGA'
irgadiag.20m.c	20	CSAT3_IRGA_BIN	'CSI IRGA diagnostic'
Tirga.20m.c	20	CSAT3_IRGA_BIN	'CSI IRGA temperature'
Pirga.20m.c	20	CSAT3_IRGA_BIN	'CSI IRGA pressure'
ldiag.20m.c	20	CSAT3_IRGA_BIN	'CSAT3 logical diagnostic, 0=OK, 1=(diagbits!=0)'
T.20m.c	1	NCAR_SHT	'Air Temperature, NCAR hygrothermometer'
RH.20m.c	1	NCAR_SHT	'Relative Humidity, NCAR hygrothermometer'
P.20m.c	20	Nano	'Barometric Pressure, Paroscientific 6000'
Vpile_On.d	1	V28MT	'Pile voltage when on'
Vpile_Off.d	1	V28MT	'Pile voltage when off'
Rsw.in.d	1	V28MT	'Incoming Short Wave, Hukseflux NR01'
Rsw.out.d	1	V28MT	'Outgoing Short Wave, Hukesflux NR01'
Rpile.in.d	1	V28MT	'Incoming Thermopile, Hukseflux NR01'
Rpile.out.d	1	V28MT	'Outgoing Thermopile, Hukesflux NR01'
Tcase.d	1	V28MT	'Case temperature, Hukesflux NR01'
Rsw.in.9m.d	1	4comp	'Incoming Short Wave'
Rsw.out.9m.d	1	4comp	'Outgoing Short Wave'
Rpile.in.9m.d	1	4comp	'Pyrgeometer thermopile, incoming'
Tcase.in.9m.d	1	4comp	'Pyrgeometer case temperature, incoming'

Rpile.out.9m.d	1	4comp	'Pyrgeometer thermopile, outgoing'
Tcase.out.9m.d	1	4comp	'Pyrgeometer case temperature, outgoing'
Rsw.in.uw	1	SNOWS	'Incoming Short Wave, Hukseflux NR01'
Rsw.out.uw	1	SNOWS	'Outgoing Short Wave, Hukesflux NR01'
Rpile.in.uw	1	SNOWS	'Incoming Thermopile, Hukseflux NR01'
Rpile.out.uw	1	SNOWS	'Outgoing Thermopile, Hukesflux NR01'
Tcase.uw	1	SNOWS	'Case temperature, Hukesflux NR01'
P_a.c	20	Nano	'Barometric Pressure, Paroscientific 6000'
P_b.c	20	Nano	'Barometric Pressure, Paroscientific 6000'
P_c.c	20	Nano	'Barometric Pressure, Paroscientific 6000'
P_d.c	20	Nano	'Barometric Pressure, Paroscientific 6000'
Vpile.ue	1	APOGEE_IR	'Thermopile voltage'
Vpile.uw	1	APOGEE_IR	'Thermopile voltage'
Vpile.c	1	APOGEE_IR	'Thermopile voltage'
Vpile.d	1	APOGEE_IR	'Thermopile voltage'
Vtherm.d	1	APOGEE_IR	'Thermistor voltage'
Vtherm.ue	1	APOGEE_IR	'Thermistor voltage'
Vtherm.uw	1	APOGEE_IR	'Thermistor voltage'
Vtherm.c	1	APOGEE_IR	'Thermistor voltage'
Tsnow.0.4m.d	1	SNOWS	'Snow Temperature 0.4m'
Tsnow.0.5m.d	1	SNOWS	'Snow Temperature 0.5m'
Tsnow.0.6m.d	1	SNOWS	'Snow Temperature 0.6m'
Tsnow.0.7m.d	1	SNOWS	'Snow Temperature 0.7m'
Tsnow.0.8m.d	1	SNOWS	'Snow Temperature 0.8m'
Tsnow.0.9m.d	1	SNOWS	'Snow Temperature 0.9m'
Tsnow.1.0m.d	1	SNOWS	'Snow Temperature 1.0m'
Tsnow.1.1m.d	1	SNOWS	'Snow Temperature 1.1m'
Tsnow.1.2m.d	1	SNOWS	'Snow Temperature 1.2m'
Tsnow.1.3m.d	1	SNOWS	'Snow Temperature 1.3m'

Tsnow.1.4m.d	1	SNOWS	'Snow Temperature 1.4m'
Tsnow.1.5m.d	1	SNOWS	'Snow Temperature 1.5m'
Tsnow.0.4m.uw	1	SNOWS	'Snow Temperature 0.4m'
Tsnow.0.5m.uw	1	SNOWS	'Snow Temperature 0.5m'
Tsnow.0.6m.uw	1	SNOWS	'Snow Temperature 0.6m'
Tsnow.0.7m.uw	1	SNOWS	'Snow Temperature 0.7m'
Tsnow.0.8m.uw	1	SNOWS	'Snow Temperature 0.8m'
Tsnow.0.9m.uw	1	SNOWS	'Snow Temperature 0.9m'
Tsnow.1.0m.uw	1	SNOWS	'Snow Temperature 1.0m'
Tsnow.1.1m.uw	1	SNOWS	'Snow Temperature 1.1m'
Tsnow.1.2m.uw	1	SNOWS	'Snow Temperature 1.2m'
Tsnow.1.3m.uw	1	SNOWS	'Snow Temperature 1.3m'
Tsnow.1.4m.uw	1	SNOWS	'Snow Temperature 1.4m'
Tsnow.1.5m.uw	1	SNOWS	'Snow Temperature 1.5m'