PERiLS 2023 Portable In Situ Precipitation Stations (PIPS) Data Documentation

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1.0 Dataset Overview

1.1 Introduction

The Portable In Situ Precipitation Stations (PIPS) are a set of 6 instrumented probes equipped with conventional surface meteorological instrumentation as well as Parsivel 2 laser disdrometers. Their mission in PERiLS was to collect DSD and other surface observations to characterize the surface microphysical and thermodynamic variability in time and space as the QLCS moves over the array. During PERiLS 2023, the PIPS were deployed in IOP's 2-5 in QLCS's and supercells.

1.2 Time period covered by the data and physical location

The nominal period of the 2023 PERiLS field program ran from 8 February-3 May 2023. During this period, observations from up to six PIPS were collected at various locations in the following IOPs (2 PIPS in a single cell indicate the PIPS in question were collocated on that deployment):

- IOP2 (03/03/23)

PIPS ID	Start time (UTC)	End time (UTC)	Lat (deg)	Lon (deg)	Elevation (m ASL)
PIPS1A PIPS2B	03/03/23 08:17	03/03/23 11:50	34.31052	-91.53632	63
PIPS1B PIPS2A	03/03/23 08:41	03/03/23 11:15	34.29825	-91.41585	64
PIPS3A PIPS3B	03/03/23 08:10	03/03/23 11:39	34.35923	-91.53497	61

- IOP3 (03/24/23)

PIPS ID	Start time (UTC)	End time (UTC)	Lat (deg)	Lon (deg)	Elevation (m ASL)
PIPS2A	03/24/23 23:40	03/25/23 02:51	33.39995	-91.31468	41
PIPS3A	03/24/23 23:35	03/25/23 02:42	33.36697	-91.29989	39

- IOP4 (04/01/23)

PIPS ID	Start time (UTC)	End time (UTC)	Lat (deg)	Lon (deg)	Elevation (m ASL)
PIPS1A PIPS2A	04/01/23 07:38	04/01/23 08:24	34.48076	-87.29383	199
PIPS1B PIPS2B	04/01/23 07:10	04/01/23 08:37	34.54313	-87.30602	208
PIPS3A	04/01/23 07:23	04/01/23 08:42	34.46064	-87.29223	196
PIPS3B	04/01/23 07:25	04/01/23 08:26	34.51599	-87.29113	203

- IOP5 (04/05/23)

PIPS ID	Start time (UTC)	End time (UTC)	Lat (deg)	Lon (deg)	Elevation (m ASL)
PIPS1A	04/05/23 16:38	04/05/23 18:20	35.54076	-90.72195/	91
PIPS1B	04/05/23 16:36	04/05/23 18:06	35.62219	-90.72221	82
PIPS2A	04/05/23 16:48	04/05/23 18:31	35.49641	-90.73241	86
PIPS2B	04/05/23 16:30	04/05/23 17:56	35.59624	-90.72235	87
PIPS3A	04/05/23 16:33	04/05/23 18:05	35.55979	-90.72469	80
PIPS3B	04/05/23 16:45	04/05/23 18:17	35.65021	-90.70962	76

2.0 Instrument Description

The Portable In situ Precipitation Stations (PIPS) are instrumented metal-framed probes designed to be quickly deployed in rapidly evolving convective weather scenarios (Figure 1). Table 1 summarizes the instrumentation on each PIPS. Particle Size Distribution (PSD) data are recorded as counts in 32 velocity x 32 diameter bins (non-linearly spaced), along with several derived parameters at 10-s intervals (see further description below), while all other data are recorded at 1-s intervals to an onboard micro-SD card for later downloading and processing. Each PIPS is powered by a 12-volt lead-acid battery with a single charge lasting for 2-3 days of uninterrupted data collection under typical conditions. PIPS 1A,1B,2A, and 2B have identical instrumentation/datalogger setups, while PIPS 3A and 3B have a newer model of the GPS unit as well as an older version of the datalogger (CR1000X instead of the CR6).

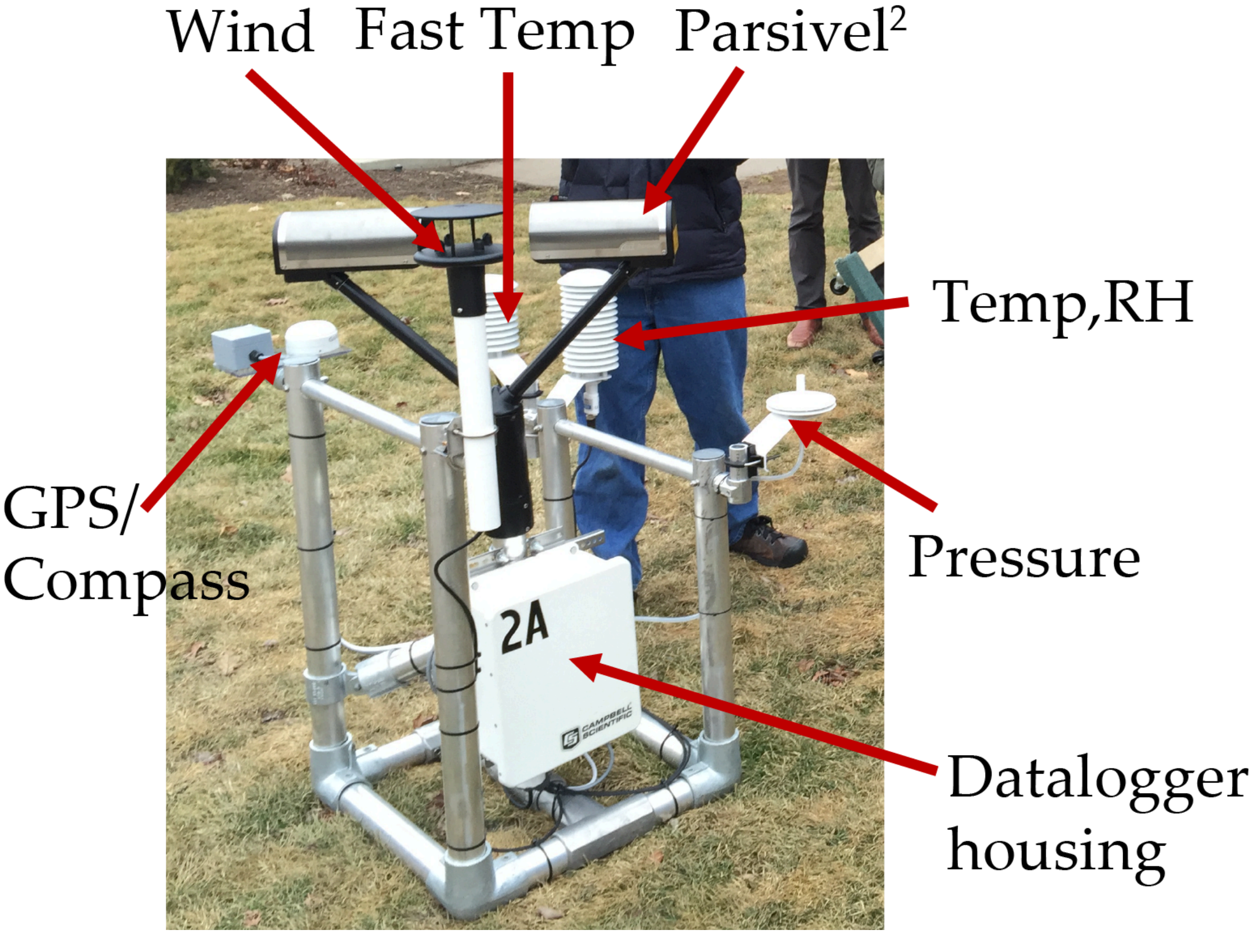

Figure 1. Photograph of a PIPS with instrumentation identified.

The following table summarizes the instrumentation available on each probe.

Table 1: Instrument details

Instrument	**Data interval (s)**	**Measurement height (m AGL)**	**Range/Accuracy**
Campbell Scientific CR6 Datalogger **(PIPS 1A, 1B, 2A, and 2B)**	NA	NA	**Source: https://www.campbellsci.com/cr6**
Campbell Scientific CR1000X Datalogger **(PIPS 3A and 3B)**	NA	NA	**Source: https://www.campbellsci.com/cr1000x**

OTT PARSIVEL^2 Laser Disdrometer	10	1.16	See Table 2
CS HMP155A Temp/RH sensor	1	0.84	**Source: https://www.campbellsci.com/hmp155a** **Temperature sensor**
			Range: -80 to 60 ℃ Accuracy: ∓0.226-0.0028 x T (-80 to 20 ℃) ∓0.055+0.0057 x T (20 to 60 ℃)
			Relative Humidity Sensor
			Range: 0.8 to 100% RH (non-condensing) Accuracy at 15 to 25℃: ±1% RH (0 to 90% RH) ±1.7% RH (90 to 100% RH) Accuracy at -60° to -40°C: ±(1.4 + 0.032 × reading) % RH Accuracy at -40° to -20°C: ±(1.2 + 0.012 × reading) % RH Accuracy at -20° to +40°C: ±(1.0 + 0.008 × reading) % RH Accuracy at 40° to 60°C: ± (1.2 + 0.012 × reading) % RH
CS 109SS-L Fast Temp sensor	1	0.84	**Source: https://www.campbellsci.com/109ss:** Range: -40° to +70°C Accuracy (Worst case): ±0.60 °C (–40 to 70 °C) ±0.49 °C (–20 to 70 °C)
Gill Windsonic1 anemometer	1	1.18	**Source: http://gillinstruments.com/products/anemometer/windsonic.htm** Range: 0 - 60 m s^{-1} Accuracy: ±2º @ 12 m s^{-1}
YoungUSA 61002 pressure port/Vaisala PTB210 barometer	1	0.36	**Source: http://www.vaisala.com/en/products/pressure/Pages/PTB210.aspx** Range: 500 - 1100 hPa Accuracy: ±0.30 hPa
KVH C100 Compass	1	0.84	**Source:http://www.kvh.com/Military-and-Government/Gyros-and-Inertial-Systems-and-Compasses/Compass-Sensors/All-Compass-Sensor-Systems/C100-Compass-Engine.aspx**

			Range: 0 - 359.9º Accuracy: ±0.5°
Garmin 010-00694-00 GPS **(PIPS 1A, 1B, 2A, and 2B)**	1	0.84	**Source: http://static.garmin.com/pumac/GPS_17x_HVS_Tech_Specs.pdf** GPS Standard Positioning Service (SPS) Position: < 15 meters, 95% typical Velocity: 0.1 knot RMS steady state • W AAS/EGNOS/MSAS Position: < 3 meters, 95% typical Velocity: 0.1 knot RMS steady state
Garmin GPS 24xd Antenna/Receiver, NMEA 0183 **(PIPS 3A and 3B)**			**Source: https://www.garmin.com/en-US/p/684247/pn/010-02316-00#specs**

Table 2: OTT Parsivel^2 abbreviated description (Messtechnik 2009)

Optical sensor laser diode	Wavelength	780 nm
	Output power	0.5 mW
	Beam size (W x L)	180 x 30 mm
	Measurement surface	54 cm2, recognition of edge events
Measuring range	Particle size of liquid* precipitation	0.2 ... 5 mm
	Particle size of solid* precipitation	0.2 ... 25 mm
	Particle speed	0.2 ... 20 m/s
Design	32 precipitation size classes	
	32 speed classes	
	Radar reflectivity Z, kinetic energy	
Rain rate	Minimum intensity	0.001 mm/h drizzle rain
	Maximum intensity	1,200 mm/h
	Accuracy	±5 % (liquid) / ±20 % (solid)[1]

[1] Under laboratory conditions and statistically correlated by OTT calibration system with reference particle calibration of 0.5; 1.0; 2.0 and 4.0 mm

*size ranges are given for *internal classification* of liquid vs. solid particles. Sensor will measure liquid drops larger than 5 mm.

3.0 Data Collection and Processing

3.1 Description of Data Collection

Data from the conventional meteorological instruments (i.e. the temperature, relative humidity, wind direction and speed, and pressure), along with compass heading, GPS data, and other diagnostic information, are recorded at 1-s intervals to a micro-SD card on the onboard Campbell Scientific CR6 datalogger. A new data file containing the 1-s data is created every 10 min. A separate series of files (binned every 10 min) records the Parsivel 32x32 velocity/diameter count matrix (flattened into a single dimension), several derived parameters and diagnostic info, in 10-s intervals. These files are then converted from the datalogger format to raw text comma-delimited files. The series of 1-s and 10-s files are then merged into a single CSV file for each PIPS and each deployment. In this merged file, each record contains the 1-s data, with every 10th record additionally containing the Parsivel datastream appended to the end of the 1-s data. Finally, the merged CSV files are parsed by a Python program that converts the data to two netCDF files, one containing the raw 1-s “conventional” data and the other containing the Parsivel 10-s data as well as the conventional data resampled to 10-s intervals.

3.2 Description of derived parameters

Both the 1-s and 10-s data are processed to compute several derived parameters. For the 1-s netCDF files, the following derived quantities are computed:

- The environmental (earth-relative) wind direction is derived from the compass heading and measured wind direction as WD = (CH + MWD) % 360, where CH and MWD are the compass heading and measured wind direction, in degrees, respectively. Dewpoint temperature is derived from the slow-response temperature and relative humidity using the Magnus formula:

$$T_d = 243.04 \times \frac{\log\frac{RH}{100} + \frac{17.625\times T}{243.04+T}}{17.625 - \log\frac{RH}{100} - \frac{17.625\times T}{243.04+T}}$$

- Then, relative humidity is rederived following Richardson et al. (1998) using the derived dewpoint and the measured *fast-response* temperature as:

$$RH_{fast} = 100 \times \frac{\exp\frac{17.625\times T_d}{243.04+T_d}}{\exp\frac{17.625\times T_{fast}}{243.04+T_{fast}}}$$

  Both the original RH and the derived RH are included in the output file.

- Potential temperature, water vapor mixing ratio, and (moist) are density are computed from the observed fast-response temperature, the derived RH, and the observed pressure

The 10-s netCDF files also contain several derived quantities. First, the 10-s Parsivel datastream contains several internally derived parameters. Those included in the data files include total particle count, precipitation intensity, total precipitation accumulation, and radar reflectivity.
Several quantities are derived explicitly from the 32x32 drop count matrix and are described below. Of these, three versions of each are provided in the 10-s netCDF files. One set from the raw (pre-QC) 32x32 velocity-diameter count matrix (called *VD_matrix*), a second set using a basic QCed version of *VD_matrix* to remove margin fallers and drops from splashing (called *VD_matrix_qc*) and a third set using a more stringent QC routine that additionally removes all particles not likely to be rain drops (*VD_matrix_roqc, "ro = rain only"*). See Friedrich et al. (2013) for a description of these QC procedures. For comparison with their internally derived counterparts, the total particle count, precipitation intensity, total accumulated precipitation, and radar reflectivity are re-derived for each of the three versions of the counts matrix as well as the following quantities:

1. The total number concentration as a function of (equivalent volume) diameter bin:

   $$N(\overline{D}_{bin}) \;=\; \sum_{V_{bins}} \left[counts(\overline{V}_{bin}, \overline{D}_{bin}) \,/\, (\overline{V}_{bin} \times sample\_interval \times eff\_sensor\_area \;\times\; \Delta D_{bin})\right]$$

   Where $counts(\overline{V}_{bin}, \overline{D}_{bin})$ is the number of drops counted for each velocity-diameter bin, $\overline{V}_{bin}$ and $\overline{D}_{bin}$ are the corresponding mid-point values of the associated bins, $sample\_interval$=10 s is the Parsivel sampling interval, ΔD_{bin} is the (variable) width of each diameter bin, and eff_sensor_area (units of mm^2 for *D* in mm) is given by Jaffrain and Berne (2011) as:

   $$eff\_sensor\_area \;=\; 180 \times (30 - \overline{D}_{bin} / 2)$$

   which accounts for the reduction of the effective sensor area on the margins of the beam as drop size increases.
2. The median volume diameter D_0 computed as the diameter above and below which half of the volume of the distribution lies (the value is linearly interpolated using the diameters of the adjacent bins and therefore doesn't necessarily correspond to a specific midpoint bin diameter.
3. The mass weighted mean diameter $D_{m4,3}$ given by the ratio of the 4th and 3rd moments of the discrete number distribution $N(\overline{D}_{bin})$
4. The spectral width of the mass distribution σ given by

$$\sigma = \frac{\sum_{D_{bins}} \left[(\bar{D}_{bin} - D_{m4,3})^2 \times N(\bar{D}_{bin}) \times D^3 \times \Delta D_{bin} \right]}{\sum_{D_{bins}} \left[N(\bar{D}_{bin}) \times D^3 \times \Delta D_{bin} \right]}$$

Finally, the 1-s “conventional” variables are time-aggregated/resampled to the 10-s Parsivel intervals and included in the 10-s netCDF files. In most cases, for each Parsivel data time stamp, the 1-s data are averaged, over the previous 10 s. For the wind data, this includes the calculation of the 10-s scalar average and vector average wind speed, the vector and “unit” vector average wind direction, and the gust speed (computed as the maximum 3-s running average over the previous 10 s). 10-s average and “unit” average u- and v- wind components are also provided.

4.0 Data Format

4.1 File Format and Naming Convention

Data are provided in netCDF format. For each deployment, there are two netCDF files that follow the following naming convention:

conventional_raw_IOP$_MMDDYY_PIPS##.nc,
parsivel_combined_IOP$_MMDDYY_PIPS##_10s.nc

where ## is the PIPS identification string (one of 1A, 1B, 2A, 2B, 3A, 3B), $$ is the IOP string (one of 1,2,3), and MMDDYY is the (2-digit) month, day, and year for the given IOP. The “conventional_raw” files contain the measured and derived variables collected at 1-s intervals, while the “parsivel_combined” files contain the 10-s interval Parsivel measured and derived quantities along with the conventional data resampled to the same 10-s intervals (see section #3 above and the table below for a description).

4.2 File Structure

The header information for each “conventional_raw” file is as follows:

Dimensions:	time (variable length)		
Variable Name (all dimensioned by time)	**Format**	**Units**	**Description**
time	int64	Seconds since start of deployment	
voltage	double	V	Voltage of onboard 12V battery
winddirrel	double	degrees	Wind direction relative to probe orientation
windspd	double	m/s	Instantaneous wind speed
winddiag	double	0: Ok 1: Axis 1 failed 2: Axis 2 failed 4: Axis 1 and 2 failed 8: NVM error 9: ROM error	Wind measurement diagnostic flag
fasttemp	double	℃	Fast-response temperature
slowtemp	double	℃	Slow-response temperature
RH	double	%	Relative humidity (measured with slow-response sensor)
pressure	double	hPa	Station pressure
compass_dir	double	degrees	Compass direction relative to true north
GPS_time	string	HHMMSS	GPS time stamp
GPS_status	string	A (valid position) or V (warning)	GPS status

GPS_lat	double	Decimal degrees N (south is negative)	Latitude from GPS
GPS_lon	double	Decimal degrees E (west is negative)	Longitude from GPS
GPS_spd	double	m/s	GPS speed
GPS_dir	double	degrees	GPS direction
GPS_date	string	DDMMYY	GPS date
GPS_magvar	double	degrees	GPS magnetic variation
GPS_alt	double	m	GPS altitude (ASL)
winddirabs	double	degrees	Absolute wind direction (i.e., relative to true north)
dewpoint	double	℃	Dewpoint temperature
RH_derived	double	%	RH derived from fast-response temperature (see section 3.2)
pt	double	°K	Potential temperature
qv	double	kg/kg (unitless)	Water vapor mixing ratio
rho	double	kg/m^3	Moist air density

Global Attribute Name	**Description**
probe_name	Name of probe
parsivel_angle	Angle of long axis of Parsivel disdrometer sampling area relative to N-S axis
deployment_name	Name of IOP and date
location	Tuple of latitude, longitude, and altitude ASL of probe during deployment (taken as an average of raw 1-s GPS readouts)
starting_time	Starting time (UTC) of deployment in YYYYmmDDHHMMSS

	format
ending_time	Ending time (UTC) of deployment in YYYYmmDDHHMMSS format

The header information for each “parsivel_combined” file is as follows:

Dimensions:	time (variable length), fallspeed_bin (32), diameter_bin (32)		
Variable Name (dimensions)	**Format**	**Units**	**Description**
time (time)	int64	Seconds since start of deployment	
precipintensity (time)	double	mm/h	Precipitation rate (from internal firmware algorithm)
precipaccum (time)	double	mm	Accumulated precipitation (from internal firmware algorithm)
parsivel_dBZ (time)	double	dBZ	Radar reflectivity of DSD (from internal firmware algorithm)
sample_interval (time)	double	s	Interval of DSD sampling
signal_amplitude (time)	double	unknown	Amplitude of laser as detected by photodiode array
pcount (time)	int64	number	total number of detected particles of all sizes and fall speeds over interval (from internal firmware algorithm)
sensor_temp (time)	double	℃	Temperature of Parsivel sensor
pvoltage (time)	double	V	Voltage supplied to Parsivel

windspd (time)	double	m/s	Scalar average wind speed over sample interval
windspdavgvec (time)	double	m/s	Vector average wind speed over sample interval
winddirabs (time)	double	degrees	Vector average wind direction over sample interval (relative to true north)
winddirunitavgvec (time)	double	degrees	Unit vector average wind direction over sample interval (relative to true north)
windgust (time)	double	m/s	Maximum of running 3-s scalar average wind speed over sample interval
uavg (time)	double	m/s	average u-component wind over sample interval
vavg (time)	double	m/s	average v-component wind over sample interval
unit_uavg (time)	double	m/s	average u-component wind over sample interval assuming unit wind vector length for the given direction
unit_vavg (time)	double	m/s	average v-component wind over sample interval assuming unit wind vector length for given direction
compass_dir (time)	double	degrees	average compass

			direction over sample interval
winddiag (time)	double	0: Ok 1: Axis 1 failed 2: Axis 2 failed 4: Axis 1 and 2 failed 8: NVM error 9: ROM error	Wind measurement diagnostic flag (maximum value over sample interval)
fasttemp (time)	double	℃	Average fast-response temperature over sample interval
slowtemp (time)	double	℃	Average slow-response temperature over sample interval
RH (time)	double	%	Average relative humidity (measured with slow-response sensor) over sample interval
RH_derived (time)	double	%	Average RH derived from fast-response temperature (see section 3.2) over sample interval
pressure (time)	double	hPa	Average station pressure over sample interval
GPS_lat (time)	double	Decimal degrees N (south is negative)	Average latitude from GPS over sample interval
GPS_lon (time)	double	Decimal degrees E (west is negative)	Average longitude from GPS over sample interval
GPS_alt (time)	double	m	Average GPS altitude (ASL) over sample interval

voltage (time)	double	V	Average battery voltage over sample interval
dewpoint (time)	double	℃	Average dewpoint temperature over sample interval
rho (time)	double	kg/m^3	Average moist air density over sample interval
fallspeed (fallspeed_bin)	double	m/s	midpoints of Parsivel fall-speed bins
diameter (diameter_bin)	double	mm	midpoints of Parsivel diameter bins
min_diameter (diameter_bin)	double	mm	minimum diameters (left edges) of Parsivel diameter bins
max_diameter (diameter_bin)	double	mm	maximum diameters (right edges) of Parsivel diameter bins
min_fallspeeds (fallspeed_bin)	double	m/s	minimum fallspeeds (left edges) of Parsivel fallspeed bins
max_fallspeeds (fallspeed_bin)	double	m/s	maximum fallspeeds (right edges) of Parsivel fallspeed bins
flagged_times (time)	int64	1 or 0 depending on whether the DSD was flagged for strong wind contamination (Friedrich et al. 2013)	
NOTE: for each of the italicized variable entries below, the files also include versions using the basic QC and the "rain-only" QC (see section 3.2). The variable names are appended by "_qc" and "_roqc", respectively, for these versions.			

VD_matrix (time, fallspeed_bin, diameter_bin)	*double*	*number*	*number of detected particles in each Parsivel velocity-diameter bin over sample interval*
ND (time, diameter_bin)	*double*	*number / m^3 / mm*	*number concentration of particles per diameter bin width detected over sample interval*
rainrate_derived (time)	*double*	*mm/h*	*Precipitation rate derived from VD_matrix*
pcount_derived (time)	*double*	*number*	*total number of detected particles of all sizes and fall speeds over interval summed from VD_matrix*
reflectivity_derived (time)	*double*	*dBZ*	*Radar reflectivity of DSD derived from VD_matrix*
D0 (time)	*double*	*m*	*Median volume diameter derived from VD_matrix*
Dm43 (time)	*double*	*m*	*Mass-weighted mean diameter derived from VD_matrix*
sigma (time)	*double*	*m*	*Spectral width of mass distribution derived from VD_matrix*

Global Attribute Name	**Description**
nominal sample interval	chosen sample interval for DSD (10 seconds for files in this dataset)
probe_name	Name of probe

parsivel_angle	Angle of long axis of Parsivel disdrometer sampling area relative to N-S axis
deployment_name	Name of IOP and date
location	Tuple of latitude, longitude, and altitude ASL of probe during deployment (taken as an average of raw 1-s GPS readouts)
starting_time	Starting time (UTC) of deployment in YYYYmmDDHHMMSS format
ending_time	Ending time (UTC) of deployment in YYYYmmDDHHMMSS format
DSD_interval	Same as “nominal sample interval” for files in this dataset

5.0 Data Remarks

5.1 Instrument and Data Quality Issues

These data should be considered preliminary at this time. Some quality-control procedures have been applied to both the conventional data and Parsivel data, which are described below.

5.1.1 Conventional Data

Regarding the accuracy of temperature sensors, a small discussion on response time is relevant. While various instruments specify a particular accuracy, it takes a finite amount of time for these sensors to respond to a given change, known as the response time or time constant. This response time is a combination of every factor influencing the measurement being made and thus represents an unknown quantity as it is impossible to completely describe every scenario in which the sensors are being used. This is of particular concern when dealing with rapidly changing environments. Do not equate the accuracies listed above to an absolute accuracy in heterogeneous ambient conditions.

Thus, the HMP155 (Tslow) temperature sensor for example may have a specified accuracy of approximately ± 0.2°C at 20°C, but may take upwards of 30 minutes to reach a final temperature following a large step change in the environment (e.g., Waugh 2012, Fig. 12). The Tslow and RH sensors are located inside a trapped volume enclosed by a microporous membrane that protects the RH probe from being contaminated by pollutants in the air stream (Waugh 2012). Although the membrane is porous to water vapor molecules (thus vapor pressure is equilibrated across the membrane), the temperature response of the volume inside the membrane is slowed and thus the measured Tslow and RH are not representative of the ambient environment outside of the membrane. Instead, a dew point (which is conserved across the membrane) is calculated using the Tslow and measured RH. Then, the dew point and Tfast are used to derive the ambient RH which is reported in the data following Richardson et al. (1998).

In contrast, the 109SS (Tfast) probe responds within a few tens of seconds to the environmental step change. This temperature measurement should be used for all temperature and temperature-related quantities.

As described above, to compute the wind direction relative to true north, the measurements from the digital compass are used to correct the instrument-relative wind directions. However, in the case of PIPS 3A and 3B, the recorded compass direction occasionally contains erroneous readings, which leads to erroneous north-relative wind directions associated with those readings. To correct for this, the compass readings for all PIPS are first filtered to remove all readings that are greater than 1 standard deviation away from the mean of all readings in a given deployment. This effectively removed the aforementioned erroneous readings for 3A and 3B. The mean of all remaining compass readings is then used to recompute the wind directions relative to true north, as well as all derived and resampled wind quantities that depend on this wind direction. **All such corrected versions of the wind variables are present in the netCDF files with the string "_corrected" appended, and it is recommended that these be used for most purposes. The original uncorrected compass and true-north wind directions are still available in the files for completeness.**

For unknown reasons, PIPS 3A and 3B recorded slow-response temperatures ("slowtemp") that displayed a substantial (~0.5 K) cool bias relative to the fast-response temperatures and to the other PIPS. They also demonstrated a great deal of "jitter" from one reading to the next where the temperature would suddenly jump upward by half a degree at times. In contrast, the fast-response temperatures typically agreed very well with each other across all PIPS, and were therefore used in the following procedures to correct the slowtemps. Specifically, to mitigate these issues, the following procedures were performed:

1. For PIPS 3A and 3B only, the erroneous upward jumps were removed by a simple procedure where the data were first detrended and then any large jumps between readings were detected and the associated readings removed from the dataset. This unfortunately results in many missing values.
2. For all PIPS, the mean difference between the slowtemps and the fasttemps were computed for each deployment. this value was then subtracted from the slowtemps in each case in order to remove the systematic bias. This bias was generally small for all PIPS except for 3A and 3B
3. **The corrected slowtemps and all derived/resampled quantities dependent upon them were saved in the netCDF files with the "_corrected" string appended. Additionally, the mean bias subtracted from the slowtemps was stored as an attribute to the "slowtemp_corrected" variable.**

As of the writing of this document, the above procedures were the only quality control procedures applied to the conventional datasets. While overall a high degree of agreement exists in most measurements across the PIPS, there remain some outstanding issues that have yet to be corrected. These include intermittent data dropouts for PIPS 3A and 3B which are either not present or much less frequent for the other probes. These dropouts are most severe for the wind measurements for PIPS 3A and 3B. There also remain some biases in wind direction that are due to slight misalignments in the compass and anemometer headings. Other remaining issues include GPS altitudes for PIPS 3A and 3B that are systematically too high (elevations quoted in the table are correct, but the GPS altitude datastream is not to be relied upon for these probes at the present time), and problems with the derived RH that result in a systematic high bias and in some cases erroneous supersaturations for PIPS 3A and 3B. The latter is partially mitigated by the slowtemp correction procedure noted above, but an overall high bias remains.

The causes of the above issues are currently unknown but those that are most severe or confined entirely to PIPS 3A and 3B are possibly related to the use of CR1000X instead of CR6 dataloggers in these probes. In any case, several mass tests with various combinations of the PIPS collocated in a single location were made before and after the PERiLS data collection period and efforts are ongoing to leverage these collocated data to correct any systematic biases in sensor readings.Several mass tests with various combinations of the PIPS collocated in a single location were made before and after the PERiLS data collection period and efforts are ongoing to leverage these collocated data to correct any systematic biases in sensor readings. An updated quality-controlled dataset with additional biases quantified and corrected (as appropriate) will be made available in the near future.

5.1.2 Parsivel data

The Parsivel data contains copies of the velocity-diameter count matrix (and all quantities that are derived from it) for the raw counts, the basic QC procedure to remove margin fallers and splashing drops, and the “rain-only” QC procedure to remove all particles that are likely not rain drops. Additionally, all times with DSDs that show signs of suffering from strong wind contamination are zero-ed out (within all versions of the V-D matrices derived quantities). To avoid confusion with actual zero-count DSDs, a separate “flagged_times” variable is provided to indicate these times*. See Friedrich et al. (2013) for more details on the QC procedures.

There are some specific Parsivel data quality issues that have been identified for this dataset:

1. PIPS 1A and 1B suffered from an unknown issue that manifested in overall reduced sensitivity to lower rain rates to the point that the DSDs in many periods of lighter rain were not recorded by these instruments. Discussions with the manufacturer and many tests were ultimately unable to determine a cause. Because of this issue and overall noisier data in the smaller drop bins, it is recommended that the DSDs from these two

PIPS be used with caution. Ongoing efforts are focused on determining the degree of degradation through comparison with the DSDs from the other PIPS.

2. For IOP #5, both PIPS 1B and 2B experienced unrecoverable data corruption for the entirety of the Parsivel datastream, and thus these data are not available for these probes for this IOP.

These data should be considered preliminary at this time. No quality-controlled procedures have as yet been applied to the conventional data, while the Parsivel data contains copies of the velocity-diameter count matrix (and all quantities that are derived from it) for the raw counts, the basic QC procedure to remove margin fallers and splashing drops, and the “rain-only” QC procedure to remove all particles that are likely not rain drops. Additionally, all times with DSDs that show signs of suffering from strong wind contamination are zero-ed out (within all versions of the V-D matrices derived quantities). To avoid confusion with actual zero-count DSDs, a separate “flagged_times” variable is provided to indicate these times*. See Friedrich et al. (2013) for more details on the QC procedures. However, analyses of instrument intercomparisons are ongoing and *overall* indicate a high degree of agreement between the six PIPS for both conventional and Parsivel data.

6.0 References

Friedrich, K., E. A. Kalina, F. J. Masters, and C. R. Lopez, 2013: Drop-size distributions in thunderstorms measured by optical disdrometers during VORTEX2. Mon. Wea. Rev., 141, 1182–1203.

Jaffrain, J., and A. Berne, 2011: Experimental Quantification of the Sampling Uncertainty Associated with Measurements from PARSIVEL Disdrometers. Journal of Hydrometeorology, 12, 352–370, https://doi.org/10.1175/2010JHM1244.1.

Messtechnik, O.T.T., 2009. Operating instructions: present weather sensor—Parsivel

Richardson, S.J., S.E. Fredrickson, F.V. Brock and J.A. Brotzge, 1998: Combination Temperature and Relative Humidity Probes: Avoiding Large Air Temperature Errors and Associated Relative Humidity Errors. *Preprints*, 10th Symposium on Meteorological Observations and Instrumentation, Phoenix, AZ. Amer. Meteor. Soc. January 11-16.

Waugh, S., 2012: The "U-Tube": An improved aspirated temperature system for mobile meteorological observations, especially in severe weather. M.S. Thesis, University of Oklahoma, Norman, OK, 76 pp., [URI: http://hdl.handle.net/11244/24679]