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DOE/SC-ARM-TR-312

Colorado State University (CSU) X-Band Precipitation Radar Extracted Radar Columns and In Situ Sensors (RadCLss) Value-Added Product Report

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November 2024

ARM

DISCLAIMER

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How to cite this document:

O’Brien, JR, M Grover, RC Jackson, ZS Sherman, SM Collis, A Theisen, BA Raut, M Tuftedal, and D Feldman. 2024. Colorado State University (CSU) X-Band Precipitation Radar Extracted Radar Columns and In Situ Sensors (RadCLss) Value-Added Product Report. U.S. Department of Energy, Atmospheric Radiation Measurement user facility, Richland, Washington. DOE/SC-ARM-TR-312.

Work supported by the U.S. Department of Energy,
Office of Science, Office of Biological and Environmental Research

Executive Summary

In order to validate precipitation, in 2010 the U.S. Department of Energy (DOE) Atmospheric Radiation Measurement (ARM) user facility procured 3- and 5-cm wavelength radars for documenting the macrophysical, microphysical, and dynamical structure of precipitating systems. To maximize the scientific impact, ARM supported the development of an application chain to correct for various phenomena in order to retrieve the "point" values of moments of the radar spectrum and polarimetric measurements.

In estimation from ARM radars, a workflow was created to directly compare radar "point" values with various in situ observations at the surface.

Acknowledgments

This work would not have been possible without the support and patience of the scientific community.

Acronyms and Abbreviations

ACT	Atmospheric Community Toolkit
ARM	Atmospheric Radiation Measurement
CMAC	Corrected Moments in Antenna Coordinates
CSAPR	C-Band Scanning ARM Precipitation Radar
DOE	U.S. Department of Energy
DOI	Digital Object Identifier
KAZR	Ka-band ARM Zenith Radar
MET	surface meteorological instrumentation
MMCR	millimeter wavelength cloud radar
Py-ART	Python-ARM Radar Toolkit
RadCLss	Extracted Radar Columns and In Situ Sensors Value-Added Product
SAIL	Surface Atmosphere Integrated Field Laboratory
TRACER	Tracking Aerosol Convection Interactions Experiment
XSAPR	X-Band Scanning ARM Precipitation Radar

Contents

Figures

Tables

1.0 Introduction

The DOE ARM user facility (Mather and Voyles 2012) has a long history of sensing clouds in the vertical column above instrumented field locations using the millimeter wavelength cloud radar (MMCR, now Ka-Band ARM Zenith Radar [KAZR]). Starting in 2010, ARM embarked on a program to better characterize the domain surrounding these instrumented field locations using scanning radars at millimeter and centimeter wavelengths. To help achieve this goal, a processing workflow called Corrected Moments to Antenna Coordinates (CMAC) was created to process data from the ARM X-Band and C-Band Scanning ARM Precipitation Radars (X/CSAPRs) using the Python-ARM Radar Toolkit (Py-ART; Helmus and Collis 2016). The overarching idea behind CMAC is the identification of the nature of the scattering medium within each gate using the Py-ART GateFilter function. This scattering identification within the gate, or gate-ID, is performed before any corrections are applied so it is indifferent to hydrometeor identification codes and is confined to these classes: rain, melting layer, snow, second trip, terrain blockage, and no significant scatterer (e.g., Dolan and Rutledge 2009, Wen et al. 2015, Al-Sakka et al. 2013, etc.). With gate-ID, modular corrections to the data are then completed to account for specific attenuation, specific differential phase processing, reflectivity corrected for liquid water path attenuation, and beam blockage.

For the Surface Atmosphere Integrated Field Laboratory (SAIL) campaign in Crested Butte, Colorado, additional processing was added to CMAC to provide accurate precipitation estimates for the Upper Colorado River Basin. However, accurate measurements of snowfall within complex terrain from radar are difficult to achieve due to the diversity of hydrometeor characteristics such as crystal habit and distribution of hydrometeor sizes. Therefore, a product was needed to compare radar estimated precipitation with observed precipitation at the surface.

2.0 Data Processing Workflow

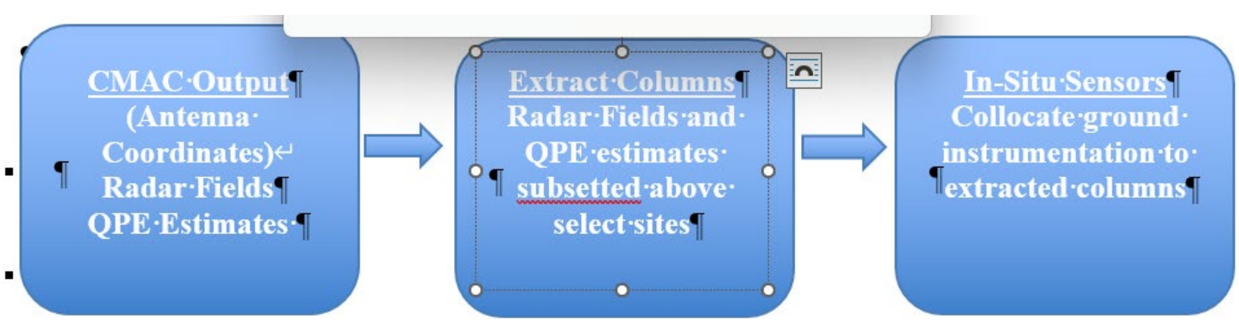

Figure 1. Extracted Radar Columns and In Situ Sensors (RadCLss) workflow, showcasing the subset of radar fields above instrumented sites via Py-ART and collocation with ground instrumentation via the Atmospheric Community Toolkit (ACT).

2.1 Snowfall Retrievals

To estimate snowfall from radar, empirical relationships of the equivalent radar reflectivity factor (Z_e) to liquid-equivalent snowfall rates ($Z_e = aS^b$) are typically applied. The coefficients *a* and *b* are carefully chosen for the environmental conditions of the observations. For SAIL, instead of determining one relationship to relate to each event, an ensemble approach with multiple *a* and *b* coefficients is used. This approach is designed to accurately describe the uncertainty within the precipitation estimates of the region. Taken from Bukovčić et al. (2018), and shown in Table 1, four initial empirical relationships have been chosen to represent the spread within snowfall estimates for the region. Additional relationships are expected to be eventually included upon collaboration with the SAIL community and analysis into more cases throughout the duration of the field experiment.

Table 1. Empirical relationships used to calculate estimated snowfall rates from radar.

Source	Z(S)	A Coefficient	B Coefficient	Radar Band
Wolfe and Snider (2012)	$Z = 110S^2$	110	2	S
WSR-88D High Plains	$Z = 130S^2$	130	2	S
Braham (1990) 1	$Z = 67S^{1.28}$	67	1.28	X
Braham (1990) 2	$Z = 114S^{1.39}$	114	1.39	X

2.2 Radar Column Extraction

To compare radar-estimated snowfall rates (calculated with relationships in Table 1) with snowfall accumulation at the surface, the distance and direction from the radar to the desired surface instrumentation must be known. With knowledge of the surface site latitude and longitude, the Py-ART *column_vertical_profile* utility is used to determine the distance from the radar to the location, the direction from the radar to the location, and subset each of the radar elevation scans above a given location.

To determine distance, given the latitude and longitude of a location, the haversine formula (1-3) is used to calculate the 'great-circle distance' (3), or distance along a sphere, from the radar to the location of desired surface instrumentation. To determine the direction from the radar to the surface location, the forward azimuth angle (4), or the angle between two locations on a sphere, is also calculated from the latitude and longitude of the surface site. As shown in Figure 1, with knowledge of the surface site distance and direction from the radar, within each radar elevation scan, the individual rays from three azimuth angles that overlay the site location are determined. Following the methodology from Murphy et al. (2020) and Bukovčić et al. (2020), three individual range gates from these azimuth angles spanning the in situ location are extracted and averaged for each field within the CMAC files. The lowest valid range gate, as defined by CMAC gate-ID, is chosen to collocate with surface instrumentation. As shown in Figure 2, this may not necessarily be the lowest available gate above a location due to beam blockage.

$$a = sin^2\left(\frac{\Delta\varphi}{2}\right) + cos\,cos\,\varphi_1 * cos\,cos\,\varphi_2 * sin^2\left(\frac{\Delta\lambda}{2}\right) \quad (1)$$

$$c = 2 * atan2\left(\sqrt{a}, \sqrt{1-a}\right) \quad (2)$$

$$d = R * c \quad (3)$$

where λ is longitude, ϕ is latitude, and R is the earth's radius

$$\theta = atan2(sin\ sin\ \Delta\lambda\ * cos\ cos\ \varphi_2\ ,cos\ cos\ \varphi_1\ *sin\ sin\ \varphi_2\ -sin\ sin\ \varphi_1\ * cos\ cos\ \varphi_2\ * cos\ cos\ \Delta\lambda \quad (4)$$

where $\varphi_1\lambda_1$ is the radar location and $\varphi_2\lambda_2$ is the site location

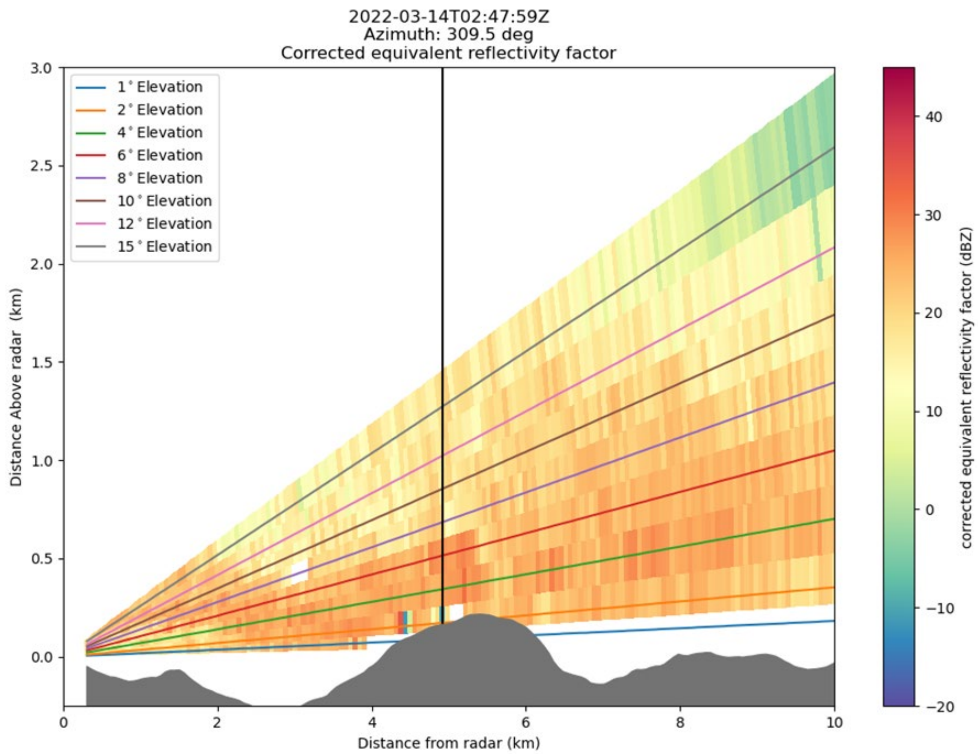

Figure 2. Colorado State University's (CSU) X-Band radar elevation scans above the ARM Mobile Facility site (38.9565°N, 106.986°W) with the extracted column overlayed for a select scan on 14 March 2022.

2.3 In Situ Sensor Collocation

For each of the SAIL sites of interest (shown in Figure 3), radar columns are extracted from each individual CMAC-processed CSU X-Band scan. As shown in Figure 3, only sites that contain valid radar fields determined by CMAC gate-ID can be extracted. Select surface instrumentation, listed in Table 2, are opened and quality controlled with the ACT *read_arm_netcdf* functionality. As the frequency of the in situ surface observations vary between instruments, all in situ sensors are resampled to five minutes and linearly interpolated to match the CSU X-Band extracted column time. These matched extracted columns and in situ sensors are collected for all CSU X-Band scans for a given date and merged to form a daily time series. The final product, shown in Figure 4, allows for the investigation of radar-estimated snowfall retrievals with ground instrumentation.

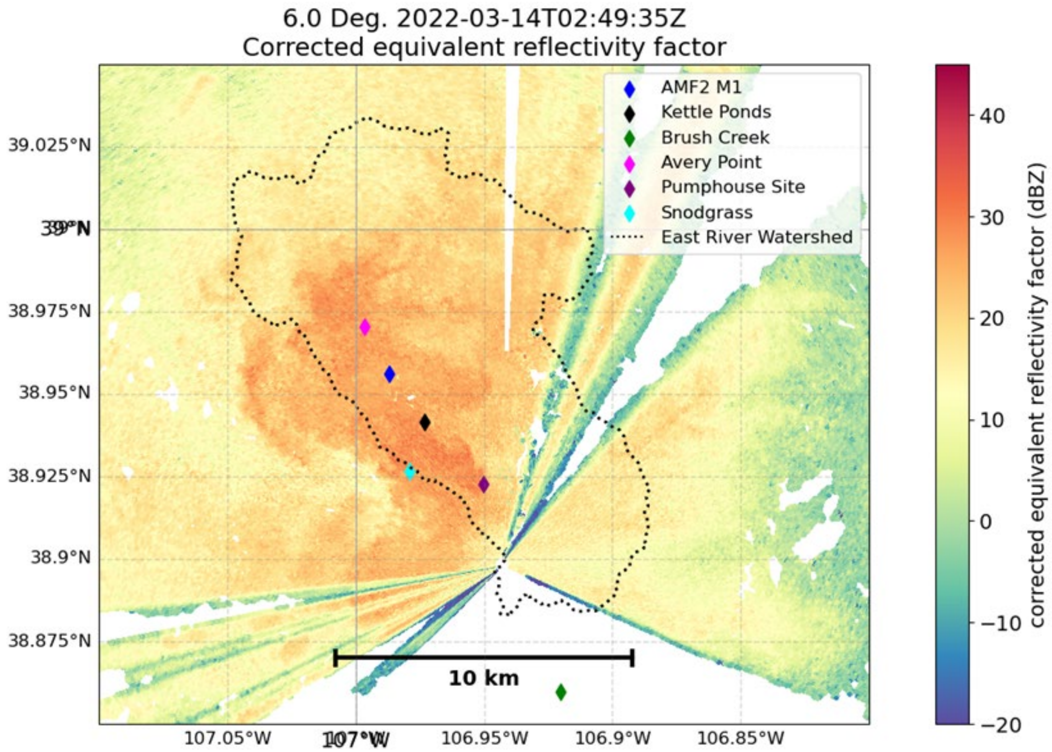

Figure 3. Colorado State University's (CSU) X-Band radar plane phase indicator scan (6-degree elevation) highlighting the in situ observation locations where columns are extracted above.

Table 2. In situ sensors included within the RadCLss Value-Added Product (VAP).

Instrument	ARM Datastream	Key Measurements
Pluvio weighing bucket rain gauge	WBPLUVIO2 (DOI: 10.5439/1338194)	Precipitation accumulation and rates
Surface meteorological instrumentation	MET (DOI: 10.5439/1786358)	Wind speed and direction, air temperature, relative humidity, barometric pressure, rain-rate
Laser disdrometer	LD (DOI: 10.5439/1779709)	Drop size spectra and fall velocity of hydrometeors
Balloon-borne sounding system	SONDEWNPN (DOI: 10.5439/1595321)	Vertical profiles of air temperature and dewpoint, along with wind speed and direction
Radar wind profiler	915WPRECIPMEANLOW (DOI: 10.5439/1972784)	Vertical wind profiles
Ceilometer	CEIL (DOI: 10.5439/1181954)	Cloud base height

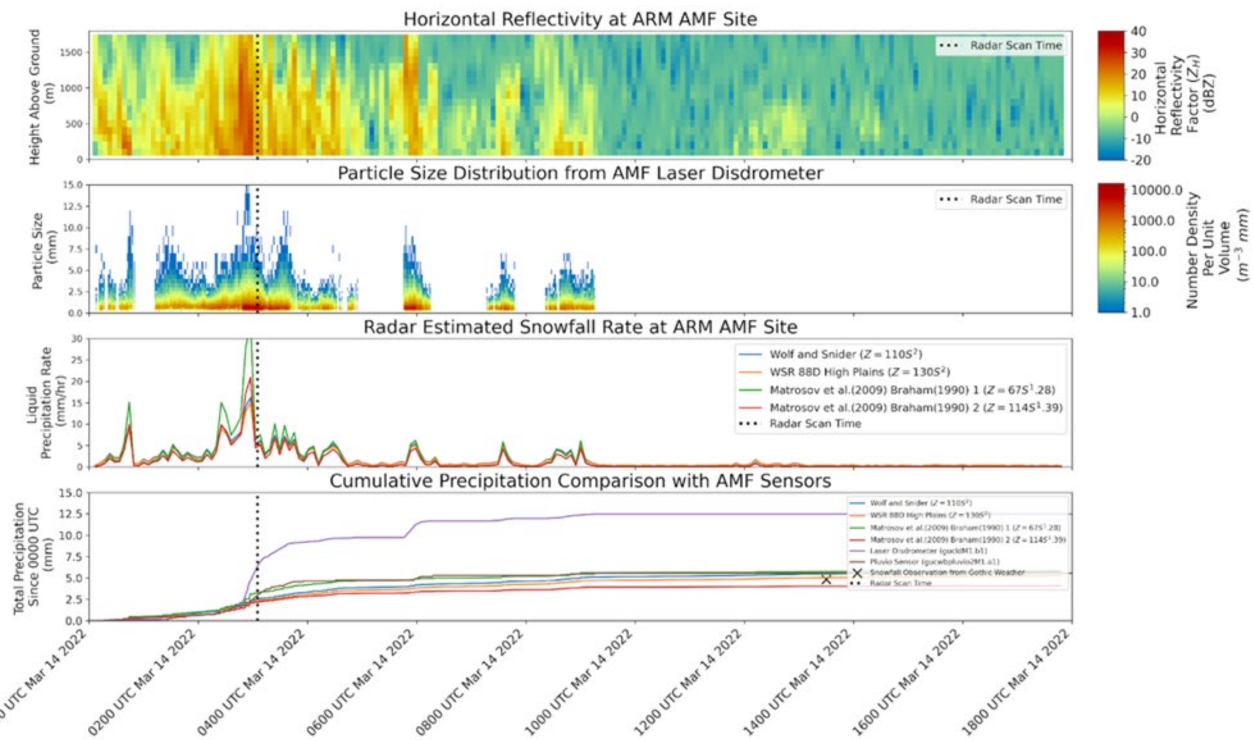

Figure 4. Horizontal reflectivity factor from the Colorado State University's (CSU) X-Band radar on 14 March 2022 extracted above the (AMF) site (38.9565°N, 106.986°W) and collocated with laser disdrometer and Pluvio weighing bucket rain gauge.

3.0 Open Science Documentation

To encourage the SAIL and atmospheric science community to collaborate with this product, a repository was created to hold workflow examples. Examples highlighting products derived from the XPRECIPRADAR CMAC corrected observations are also included, as well as, highlights of unique events from the SAIL field experiment. Users are encouraged to review this repository if they are interested in reproducing the outlined methodology or interested in viewing the figures created within this document. Users are also encouraged to submit their own examples of unique SAIL events that may be of interest. The SAIL Open Science Documentation can be found at the following link: https://arm-development.github.io/sail-xprecip-radar.

4.0 Challenges

This VAP is designed to offer users the ability to compare radar estimated precipitation with known standards at the surface. However, this comparison is inherently difficult in complex terrain like the SAIL domain. For the majority of all site locations used within RadCLss, the lowest valid radar gate is hundreds of meters above the surface and this product does not account for environmental factors beneath the CSU X-Band elevation scans (i.e., boundary-layer dynamics). Additionally, remote sensors like the CSU X-Band radar are incapable of determining if scatters within the detected volume are due to precipitation or dynamically swept (e.g., blowing snow). It is expected that radar estimated precipitation will overestimate accumulated precipitation at the surface.

5.0 Future Work

Future work will look into the changes in reflectivity with height and comparison with additional radar products, such as KAZR, to determine the impact of meteorological factors beneath the CSU X-Band elevation scan on estimated surface precipitation.

Additionally, using additional surface instrumentation, such as a ceilometer, and determination of periods of blowing snow will be useful to flag these events for exclusion from radar-derived precipitation estimates.

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Appendix A

Output Data

class: xprecipradarradclss
level: c2
version: 1.4

time = UNLIMITED
height = 138
station = 6
particle_size = 32
raw_fall_velocity = 32

time(time):double
    long_name = Time offset from midnight
    units
    description = Time in Seconds that Cooresponds to the Minimum Height Gate
    calendar = proleptic_gregorian
    standard_name = time
    source = xprecipradarcmacppi.c1

DBZ(time, height, station):double
    long_name = Equaivalent Radar Reflectivity Factor
    units = dBZ
    _FillValue:double = -999999.0
    standard_name = equivalent_reflectivity_factor
    coordinates = elevation azimuth range
    source = xprecipradarcmacppi.c1

VEL(time, height, station):double
    long_name = Radial Doppler Velocity, Positive for Motion Away from Instrument
    units = m/s
    _FillValue:double = -999999.0
    standard_name = radial_velocity_of_scatterers_away_from_instruments
    coordinates = elevation azimuth range
    source = xprecipradarcmacppi.c1

WIDTH(time, height, station):double
long_name = Spectral Width
units = m/s
_FillValue:double = -999999.0
standard_name = doppler_spectrum_width
coordinates = elevation azimuth range
source = xprecipradarcmacppi.c1

ZDR(time, height, station):double
long_name = Differential Reflectivity
units = dB
_FillValue:double = -999999.0
standard_name = log_differential_reflectivity_hv
coordinates = elevation azimuth range
source = xprecipradarcmacppi.c1

PHIDP(time, height, station):double
long_name = Differential Phase
units = degree
_FillValue:double = -999999.0
standard_name = differential_phase_hv
coordinates = elevation azimuth range
source = xprecipradarcmacppi.c1

RHOHV(time, height, station):double
long_name = Cross-Polar Correlation Ratio
units = 1
_FillValue:double = -999999.0
standard_name = cross_correlation_ratio_hv
coordinates = elevation azimuth range
source = xprecipradarcmacppi.c1

NCP(time, height, station):double
long_name = Normalized Coherent Power, also known as SQI
units = 1
_FillValue:double = -999999.0
standard_name = normalized_coherent_power
coordinates = elevation azimuth range
source = xprecipradarcmacppi.c1

DBZhv(time, height, station):double
long_name = Equivalent Reflectivity Factor HV
units = dBZ
_FillValue:double = -999999.0
standard_name = equivalent_reflectivity_factor_hv

    coordinates = elevation azimuth range
    source = xprecipradarcmacppi.c1

cbb_flag(time, height, station):double
    long_name = Cumulative Beam Block Fraction Flag
    units = 1
    _FillValue:double = -999999.0
    coordinates = elevation azimuth range
    source = xprecipradarcmacppi.c1

sounding_temperature(time, height, station):double
    long_name = Interpolated profile
    units = degC
    _FillValue:double = -999999.0
    standard_name = interpolated_profile
    source = xprecipradarcmacppi.c1

signal_to_noise_ratio(time, height, station):double
    long_name = Signal to Noise Ratio
    units = dB
    _FillValue:double = -999999.0
    standard_name = signal_to_noise_ratio
    coordinates = elevation azimuth range
    source = xprecipradarcmacppi.c1

velocity_texture(time, height, station):double
    long_name = Mean dopper velocity
    units = m/s
    _FillValue:double = -999999.0
    standard_name = radial_velocity_of_scatterers_away_from_instrument
    coordinates = elevation azimuth range
    source = xprecipradarcmacppi.c1

gate_id(time, height, station):int
    long_name = Classification of dominant scatterer
    units = 1
    notes = 0:multi_trip,1:rain,2:snow,3:no_scatter,4:melting,5:clutter,6:terrain_blockage
    valid_max:int = 6
    valid_min:int = 0
    flag_values:int = 0, 1, 2, 3, 4, 5, 6
    flag_meanings = multi_trip rain snow no_scatter melting clutter terrain_blockage
    source = xprecipradarcmacppi.c1

simulated_velocity(time, height, station):double
    long_name = Simulated mean doppler velocity
    units = m/s

    _FillValue:double = -999999.0
    standard_name = radial_velocity_of_scatterers_away_from_instrument
    coordinates = elevation azimuth range
    source = xprecipradarcmacppi.c1

corrected_velocity(time, height, station):double
    long_name = Corrected mean doppler velocity
    units = m/s
    _FillValue:double = -999999.0
    standard_name = corrected_radial_velocity_of_scatterers_away_from_instrument
    valid_max:double = 47.7
    valid_min:double = -47.7
    coordinates = elevation azimuth range
    source = xprecipradarcmacppi.c1

unfolded_differential_phase(time, height, station):double
    long_name = Unfolded differential propagation phase shift
    units = degree
    _FillValue:double = -999999.0
    standard_name = differential_phase_hv
    coordinates = elevation azimuth range
    source = xprecipradarcmacppi.c1

corrected_differential_phase(time, height, station):double
    long_name = Corrected differential propagation phase shift
    units = degree
    _FillValue:double = -999999.0
    standard_name = differential_phase_hv
    valid_max:double = 400.0
    valid_min:double = 0.0
    coordinates = elevation azimuth range
    source = xprecipradarcmacppi.c1

filtered_corrected_differential_phase(time, height, station):double
    long_name = Filtered Corrected Differential Phase
    units = degree
    _FillValue:double = -999999.0
    standard_name = differential_phase_hv
    valid_max:double = 400.0
    valid_min:double = 0.0
    coordinates = elevation azimuth range
    source = xprecipradarcmacppi.c1

corrected_specific_diff_phase(time, height, station):double
    long_name = Specific differential phase (KDP)
    units = degree/km

_FillValue:double = -999999.0
standard_name = specific_differential_phase_hv
coordinates = elevation azimuth range
source = xprecipradarcmacppi.c1

filtered_corrected_specific_diff_phase(time, height, station):double
long_name = Filtered Corrected Specific differential phase (KDP)
units = degree/km
_FillValue:double = -999999.0
standard_name = specific_differential_phase_hv
coordinates = elevation azimuth range
source = xprecipradarcmacppi.c1

corrected_differential_reflectivity(time, height, station):double
long_name = Corrected differential reflectivity
units = dB
_FillValue:double = -999999.0
standard_name = corrected_log_differential_reflectivity_hv
coordinates = elevation azimuth range
source = xprecipradarcmacppi.c1

corrected_reflectivity(time, height, station):double*
long_name = Corrected reflectivity
units = dBZ
_FillValue:double = -999999.0
standard_name = corrected_equivalent_reflectivity_factor
coordinates = elevation azimuth range
source = xprecipradarcmacppi.c1

height_over_iso0(time, height, station):double
long_name = Height of radar beam over freezing level
units = m
_FillValue:double = -999999.0
standard_name = height
source = xprecipradarcmacppi.c1

specific_attenuation(time, height, station):double
long_name = Specific attenuation
units = dB/km
_FillValue:double = -999999.0
standard_name = specific_attenuation
valid_max:double = 1.0
valid_min:double = 0.0
coordinates = elevation azimuth range
source = xprecipradarcmacppi.c1

path_integrated_attenuation(time, height, station):double
long_name = Path Integrated Attenuation
units = dB
_FillValue:double = -999999.0
coordinates = elevation azimuth range
source = xprecipradarcmacppi.c1

specific_differential_attenuation(time, height, station):double
long_name = Specific Differential Attenuation
units = dB/km
_FillValue:double = -999999.0
coordinates = elevation azimuth range
source = xprecipradarcmacppi.c1

path_integrated_differential_attenuation(time, height, station):double
long_name = Path Integrated Differential Attenuation
units = dB
_FillValue:double = -999999.0
coordinates = elevation azimuth range
source = xprecipradarcmacppi.c1

rain_rate_A(time, height, station):double*
long_name = Rainfall Rate from Specific Attenuation
units = mm/hr
_FillValue:double = -999999.0
standard_name = rainfall_rate
valid_max:double = 400.0
valid_min:double = 0.0
coordinates = elevation azimuth range
source = xprecipradarcmacppi.c1
comment = Rain rate calculated from specific_attenuation, R=43.5*specific_attenuation**0.79, note R=0.0 where norm coherent power < 0.4 or rhohv < 0.8

snow_rate_ws2012(time, height, station):double*
long_name = Snowfall rate from Z using Wolf and Snider (2012)
units = mm/h
_FillValue:double = -999999.0
standard_name = snowfall_rate
valid_max:double = 500
valid_min:double = 0
coordinates = elevation azimuth range
source = xprecipradarcmacppi.c1

snow_rate_ws88diw(time, height, station):double*
long_name = Snowfall rate from Z using WSR 88D High Plains
units = mm/h

_FillValue:double = -999999.0
standard_name = snowfall_rate
valid_max:double = 500
valid_min:double = 0
coordinates = elevation azimuth range
source = xprecipradarcmacppi.c1

snow_rate_m2009_1(time, height, station):double*
long_name = Snowfall rate from Z using Matrosov et al.(2009) Braham(1990) 1
units = mm/h
_FillValue:double = -999999.0
standard_name = snowfall_rate
valid_max:double = 500
valid_min:double = 0
coordinates = elevation azimuth range
source = xprecipradarcmacppi.c1

snow_rate_m2009_2(time, height, station):double*
long_name = Snowfall rate from Z using Matrosov et al.(2009) Braham(1990) 2
units = mm/h
_FillValue:double = -999999.0
standard_name = snowfall_rate
valid_max:double = 500
valid_min:double = 0
coordinates = elevation azimuth range
source = xprecipradarcmacppi.c1

intensity_rt(time, station):double
long_name = Heavy precipitation alarm
units = mm/hr
_FillValue:double = -999999.0
valid_min:double = 0.0
valid_max:double = 3000.0
threshold = 6 mm/hr
absolute_accuracy = plus/minus 6
comment_1 = Only measurements that exceed the threshold are recorded. Any measurement below the threshold is reported as 0 mm/hr.
source = gucwbpluvio2M1.a1

accum_rtnrt(time, station):double
long_name = Accumulated amounts of precipitation over the sampling interval exceeding a threshold of 0.05mm or the accumulated amount of fine precipitation observed over the last hour
units = mm
_FillValue:double = -999999.0
valid_min:double = 0.0
valid_max:double = 500.0

threshold = 0.05 mm
absolute_accuracy = plus/minus 0.1
equation = The accum_rtnrt variable is calculated by first measuring the accumulated amount of rain in the last minute. If this measurement exceeds the threshold, it reports this real time value. If the real time measurement does not reach the threshold, it reports the non-real time measurement using the same equation as the accum_nrt variable.
comment = Only measurements that exceed the threshold are recorded. Any measurement below the threshold is reported as 0 mm.
source = gucwbpluvio2M1.a1

accum_nrt(time, station):double
long_name = Accumulated precipitation over the sampling interval filtered and delayed by 5 minute
units = mm
_FillValue:double = -999999.0
valid_min:double = 0.0
valid_max:double = 500.0
threshold = 0.05 mm
absolute_accuracy = plus/minus 0.1
equation = The accum_nrt variable is calculated by measuring the amount of rain accumulate in a sampling interval at most 1 hour long, with the end of the interval at the given time. The start of the sampling interval occurs within the past hour, but is unknown. The start of the interval is determined once the accumulated sum either exceeds 0.05 or the interval length reaches an hour
comment = Only measurements that exceed the threshold are recorded. Any measurement below the threshold is reported as 0 mm.
source = gucwbpluvio2M1.a1

accum_total_nrt(time, station):double
long_name = Sum of accum_nrt values since the last device start
units = mm
_FillValue:double = -999999.0
valid_min:double = 0.0
valid_max:double = 500.0
threshold = 0.05 mm
absolute_accuracy = plus/minus 0.1
comment = Only measurements that exceed the threshold are recorded. Any measurement below the threshold is reported as 0 mm.
source = gucwbpluvio2M1.a1

bucket_rt(time, station):double
long_name = The currently measured, unfiltered bucket contents since last reset
units = mm
_FillValue:double = -999999.0
valid_min:double = 20.0
valid_max:double = 1800.0
threshold = 0.01 mm
absolute_accuracy = plus/minus 0.1

comment = Only increases that exceed the threshold are recorded. Any increase less than threshold is reported as no increase
source = gucwbpluvio2M1.a1

bucket_nrt(time, station):double
long_name = The currently measured, filtered bucket contents since last reset
units = mm
_FillValue:double = -999999.0
valid_min:double = 20.0
valid_max:double = 1800.0
threshold = 0.01 mm
absolute_accuracy = plus/minus 0.1
comment = Only increases that exceed the threshold are recorded. Any increase less than threshold is reported as no increase
source = gucwbpluvio2M1.a1

intensity_rtnrt(time, station):double
long_name = Rain intensity based upon accum_rtnrt
units = mm/hr
_FillValue:double = -999999.0
valid_min:double = 0.0
valid_max:double = 30000.0
threshold = 0.3 mm/hr
absolute_accuracy = plus/minus 6
equation = Calculated by accum_rtnrt * 60
comment = Only measurements that exceed the threshold are recorded. Any measurement below the threshold is reported as 0 mm/hr.
source = gucwbpluvio2M1.a1

atmos_pressure(time, station):double
long_name = Atmospheric pressure
units = kPa
_FillValue:double = -999999.0
standard_name = surface_air_pressure
source = gucmetM1.b1

temp_mean(time, station):double
long_name = Temperature mean
units = degC
_FillValue:double = -999999.0
standard_name = air_temperature
source = gucmetM1.b1

temp_std(time, station):double
long_name = Temperature standard deviation
units = degC

_FillValue:double = -999999.0
source = gucmetM1.b1

rh_mean(time, station):double
long_name = Relative humidity mean
units = %
_FillValue:double = -999999.0
standard_name = relative_humidity
source = gucmetM1.b1

rh_std(time, station):double
long_name = Relative humidity standard deviation
units = %
_FillValue:double = -999999.0
source = gucmetM1.b1

vapor_pressure_mean(time, station):double
long_name = Vapor pressure mean, calculated
units = kPa
_FillValue:double = -999999.0
standard_name = water_vapor_partial_pressure_in_air
source = gucmetM1.b1

vapor_pressure_std(time, station):double
long_name = Vapor pressure standard deviation
units = kPa
_FillValue:double = -999999.0
source = gucmetM1.b1

wspd_arith_mean(time, station):double
long_name = Wind speed arithmetic mean
units = m/s
_FillValue:double = -999999.0
source = gucmetM1.b1

wspd_vec_mean(time, station):double
long_name = Wind speed vector mean
units = m/s
_FillValue:double = -999999.0
source = gucmetM1.b1

wdir_vec_mean(time, station):double
long_name = Wind direction vector mean
units = degree
_FillValue:double = -999999.0
standard_name = wind_from_direction

source = gucmetM1.b1

wdir_vec_std(time, station):double
long_name = Wind direction vector mean standard deviation
units = degree
_FillValue:double = -999999.0
source = gucmetM1.b1

pwd_mean_vis_1min(time, station):double
long_name = PWD 1 minute mean visibility
units = m
_FillValue:double = -999999.0
standard_name = visibility_in_air
source = gucmetM1.b1

pwd_mean_vis_10min(time, station):double
long_name = PWD 10 minute mean visibility
units = m
_FillValue:double = -999999.0
standard_name = visibility_in_air
source = gucmetM1.b1

pwd_pw_code_inst(time, station):double
long_name = PWD instantaneous present weather code
units = 1
_FillValue:double = -999999.0
source = gucmetM1.b1

pwd_pw_code_15min(time, station):double
long_name = PWD 15 minute present weather code
units = 1
_FillValue:double = -999999.0
source = gucmetM1.b1

pwd_pw_code_1hr(time, station):double
long_name = PWD 1 hour present weather code
units = 1
_FillValue:double = -999999.0
source = gucmetM1.b1

pwd_precip_rate_mean_1min(time, station):double
long_name = PWD 1 minute mean precipitation rate
units = mm/hr
_FillValue:double = -999999.0
standard_name = lwe_precipitation_rate
source = gucmetM1.b1

pwd_cumul_rain(time, station):double
long_name = PWD cumulative liquid precipitation
units = mm
_FillValue:double = -999999.0
source = gucmetM1.b1

pwd_cumul_snow(time, station):double
long_name = PWD cumulative snow
units = mm
_FillValue:double = -999999.0
source = gucmetM1.b1

org_precip_rate_mean(time, station):double
long_name = ORG precipitation rate mean
units = mm/hr
_FillValue:double = -999999.0
standard_name = lwe_precipitation_rate
source = gucmetM1.b1

tbrg_precip_total(time, station):double
long_name = TBRG precipitation total
units = mm
_FillValue:double = -999999.0
source = gucmetM1.b1

tbrg_precip_total_corr(time, station):double
long_name = TBRG precipitation total, corrected
units = mm
_FillValue:double = -999999.0
source = gucmetM1.b1

precip_rate(time, station):double
long_name = Precipitation intensity
units = mm/hr
_FillValue:double = -999999.0
standard_name = lwe_precipitation_rate
source = gucldM1.b1

weather_code(time, station):double
long_name = SYNOP WaWa Table 4680
units = 1
_FillValue:double = -999999.0
source = gucldM1.b1

number_detected_particles(time, station):double

    long_name = Number of particles detected
    units = count
    _FillValue:double = -999999.0
    source = gucldM1.b1

mor_visibility(time, station):double
    long_name = Meteorological optical range visibility
    units = m
    _FillValue:double = -999999.0
    standard_name = visibility_in_air
    source = gucldM1.b1

snow_depth_intensity(time, station):double
    long_name = New snow height
    units = mm/hr
    _FillValue:double = -999999.0
    comment = This value is valid on a short period of one hour and its purpose is to provide new snow height on railways or roads for the purposes of safety. It is not equivalent to the WMO definition of snow intensity nor does if follow from WMO observation guide lines.
    source = gucldM1.b1

class_size_width(time, station, particle_size):double
    long_name = Class size width
    units = mm
    _FillValue:double = -999999.0
    source = gucldM1.b1

fall_velocity_calculated(time, station, raw_fall_velocity):double
    long_name = Fall velocity calculated after Lhermite
    units = m/s
    _FillValue:double = -999999.0
    source = gucldM1.b1

raw_spectrum(time, station, particle_size, raw_fall_velocity):double
    long_name = Raw drop size distribution
    units = count
    _FillValue:double = -999999.0
    source = gucldM1.b1

liquid_water_content(time, station):double
    long_name = Liquid water content
    units = mm^3/m^3
    _FillValue:double = -999999.0
    source = gucldM1.b1

equivalent_radar_reflectivity(time, station):double

long_name = Radar reflectivity calculated by the ingest
units = dBZ
_FillValue:double = -999999.0
source = gucldM1.b1

intercept_parameter(time, station):double
long_name = Intercept parameter, assuming an ideal Marshall-Palmer type distribution
units = 1/(m^3 mm)
_FillValue:double = -999999.0
source = gucldM1.b1

slope_parameter(time, station):double
long_name = Slope parameter, assuming an ideal Marshall-Palmer type distribution
units = 1/mm
_FillValue:double = -999999.0
source = gucldM1.b1

median_volume_diameter(time, station):double
long_name = Median volume diameter, assuming an ideal Marshall-Palmer type distribution
units = mm
_FillValue:double = -999999.0
source = gucldM1.b1

liquid_water_distribution_mean(time, station):double
long_name = Liquid water distribution mean, assuming an ideal Marshall-Palmer type distribution
units = mm
_FillValue:double = -999999.0
source = gucldM1.b1

number_density_drops(time, station, particle_size):double
long_name = Number density of drops of the diameter corresponding to a particular drop size class per unit volume
units = 1/(m^3 mm)
_FillValue:double = -999999.0
source = gucldM1.b1

diameter_min(time, station):double
long_name = Diameter of smallest drop observed
units = mm
_FillValue:double = -999999.0
source = gucldM1.b1

diameter_max(time, station):double
long_name = Diameter of largest drop observed
units = mm
_FillValue:double = -999999.0

source = gucldM1.b1

beam_tilt_angle(time, station):double
long_name = Beam tilt angle from the vertical
units = degree
_FillValue:double = -999999.0
source = guc915rwpprecipmeanlowM1.a1

beam_azimuth_angle(time, station):double
long_name = Beam azimuth angle from true north
units = degree
_FillValue:double = -999999.0
source = guc915rwpprecipmeanlowM1.a1

vertical_wind_speed(time, height, station):double
long_name = Vertical wind speed
units = m/s
positive = down
_FillValue:double = -999999.0
source = guc915rwpprecipmeanlowM1.a1

vertical_wind_speed_std(time, height, station):double
long_name = Vertical wind speed standard deviation
units = m/s
positive = down
_FillValue:double = -999999.0
source = guc915rwpprecipmeanlowM1.a1

sonde_pres(time, height, station):double
long_name = Pressure
units = hPa
_FillValue:double = -999999.0
valid_min:double = 0.0
valid_max:double = 1100.0
valid_delta:double = 10.0
resolution:double = 0.1
standard_name = air_pressure
source = gucsondewnpnM1.b1

sonde_tdry(time, height, station):double
long_name = Dry Bulb Temperature
units = degC
_FillValue:double = -999999.0
valid_min:double = -90.0
valid_max:double = 50.0
valid_delta:double = 10.0

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    resolution:double = 0.1
    standard_name = air_temperature
    source = gucsondewnpnM1.b1

sonde_dp(time, height, station):double
    long_name = Dewpoint Temperature
    units = degC
    _FillValue:double = -999999.0
    valid_min:double = -110.0
    valid_max:double = 50.0
    resolution:double = 0.1
    standard_name = dew_point_temperature
    source = gucsondewnpnM1.b1

sonde_wspd(time, height, station):double
    long_name = Wind Speed
    units = m/s
    _FillValue:double = -999999.0
    valid_min:double = 0.0
    valid_max:double = 100.0
    resolution:double = 0.1
    standard_name = wind_speed
    source = gucsondewnpnM1.b1

sonde_wdeg(time, height, station):double
    long_name = Wind Direction
    units = degree
    _FillValue:double = -999999.0
    valid_min:double = 0.0
    valid_max:double = 360.0
    resolution:double = 1.0
    standard_name = wind_from_direction
    source = gucsondewnpnM1.b1

sonde_rh(time, height, station):double
    long_name = Relative Humidity
    units = %
    _FillValue:double = -999999.0
    valid_min:double = 0.0
    valid_max:double = 100.0
    resolution:double = 1.0
    standard_name = relative_humidity
    source = gucsondewnpnM1.b1

sonde_u_wind(time, height, station):double
    long_name = Eastward Wind Component
```

units = m/s
_FillValue:double = -999999.0
valid_min:double = -75.0
valid_max:double = 75.0
valid_delta:double = 5.0
resolution:double = 0.1
calculation = (-1.0 * sin(wind direction) * wind speed)
standard_name = eastward_wind
source = gucsondewnpnM1.b1

sonde_v_wind(time, height, station):double
long_name = Northward Wind Component
units = m/s
_FillValue:double = -999999.0
valid_min:double = -75.0
valid_max:double = 75.0
valid_delta:double = 5.0
resolution:double = 0.1
calculation = (-1.0 * cos(wind direction) * wind speed)
standard_name = northward_wind
source = gucsondewnpnM1.b1

sonde_wstat(time, height, station):double
long_name = Wind Status
units = 1
_FillValue:double = -999999.0
source = gucsondewnpnM1.b1

sonde_asc(time, height, station):double
long_name = Ascent Rate
units = m/s
_FillValue:double = -999999.0
valid_min:double = -10.0
valid_max:double = 20.0
valid_delta:double = 5.0
resolution:double = 0.1
source = gucsondewnpnM1.b1

first_cbh(time, station):double
long_name = Lowest cloud base height detected
units = m
_FillValue:double = -999999.0
valid_min:double = 0.00
valid_max:double = 7700.0
source = gucceilM1.b1

vertical_visibility(time, station):double
long_name = vertical visibility
units = m
_FillValue:double = -999999.0
valid_min:double = 0.00
valid_max:double = 7700.0
source = gucceilM1.b1

second_cbh(time, station):double
long_name = Second lowest cloud base height detected
units = m
_FillValue:double = -999999.0
valid_min:double = 0.00
valid_max:double = 7700.0
source = gucceilM1.b1

third_cbh(time, station):double
long_name = Third cloud base height detected
units = m
_FillValue:double = -999999.0
valid_min:double = 0.00
valid_max:double = 7700.0
source = gucceilM1.b1

backscatter(time, height, station):double
long_name = backscatter
units = log(1/(sr*km*10000))
_FillValue:double = -999999.0
valid_min:double = 0.00
valid_max:double = 7700.0
source = gucceilM1.b1

height(height):double
long_name = Height above ground level
units = m
standard_name = height
comment = Height Gates above the SAIL/SPLASH instrumentation sites that are extracted from the xprecipradar volume scans
source = xprecipradarcmacppi.c1

station(station):char
long_name = SAIL/SPLASH ground instrumentation station identifiers
units = 1

particle_size(particle_size):float
long_name = Particle class size average

units = mm

raw_fall_velocity(raw_fall_velocity):float
long_name = Fall velocity classes observed by Parsivel2
units = m/s

lat(station):double
long_name = North latitude
units = degree_N
_FillValue:double = -999999.0
valid_min:double = -90
valid_max:double = 90
standard_name = latitude
comment = Latitude of SAIL In-Situ Ground Station

lon(station):double
long_name = East longitude
units = degree_E
_FillValue:double = -999999.0
valid_min:double = -180
valid_max:double = 180
standard_name = longitude
comment = Longitude of SAIL In-Situ Ground Station

alt(station):double
long_name = Altitude above mean sea level
units = m
_FillValue:double = -999999.0
standard_name = altitude
source = gucsondewnpnM1.b1

command_line
Conventions = ARM-1.3 CF/Radial instrument_parameters
process_version
dod_version
input_datastreams
site_id
platform_id
facility_id
data_level
location_description
datastream
references = See XPRECIPRADAR Instrument Handbook
doi = 10.5439/1884520
institution = U.S. Department of Energy Atmospheric Radiation Measurement (ARM) Climate Research Facility

comment = This is highly experimental and initial data. There are many known and unknown issues. Please do not use before contacting the Translator responsible scollis@anl.gov
attributions = This data is collected by the ARM Climate Research facility. Radar system is operated by the radar engineering team radar@arm.gov and the data is processed by the precipitation radar products team. LP code courtesy of Scott Giangrande BNL.
known_issues = False phidp jumps in insect regions. Still uses old Giangrande code. Issues with some snow below melting layer.
source = Colorado State University's X-Band Precipitation Radar Plan Position Indicator data processed with Corrected Moments in Antenna Coordinates 2.0 (xprecipradarcmacppi.c1) (DOI: 10.5439/1883164)
field_names = DBZ, VEL, WIDTH, ZDR, PHIDP, RHOHV, NCP, DBZhv, cbb_flag, sounding_temperature, signal_to_noise_ratio, velocity_texture, gate_id, simulated_velocity, corrected_velocity, unfolded_differential_phase, corrected_differential_phase, filtered_corrected_differential_phase, corrected_specific_diff_phase, filtered_corrected_specific_diff_phase, corrected_differential_reflectivity, corrected_reflectivity, height_over_iso0, specific_attenuation, path_integrated_attenuation, specific_differential_attenuation, path_integrated_differential_attenuation, rain_rate_A, snow_rate_ws2012, snow_rate_ws88diw, snow_rate_m2009_1, snow_rate_m2009_2, latitude, longitude, intensity_rt, accum_rtnrt, accum_nrt, accum_total_nrt, bucket_rt, bucket_nrt, pluvio_status, maintenance_flag, reset_flag, intensity_rtnrt, atmos_pressure, temp_mean, temp_std, rh_mean, rh_std, vapor_pressure_mean, vapor_pressure_std, wspd_arith_mean, wspd_vec_mean, wdir_vec_mean, wdir_vec_std, pwd_err_code, pwd_mean_vis_1min, pwd_mean_vis_10min, pwd_pw_code_inst, pwd_pw_code_15min, pwd_pw_code_1hr, pwd_precip_rate_mean_1min, pwd_cumul_rain, pwd_cumul_snow, org_precip_rate_mean, tbrg_precip_total, tbrg_precip_total_corr, precip_rate, weather_code, number_detected_particles, mor_visibility, snow_depth_intensity, class_size_width, fall_velocity_calculated, raw_spectrum, liquid_water_content, equivalent_radar_reflectivity, intercept_parameter, slope_parameter, median_volume_diameter, liquid_water_distribution_mean, number_density_drops, diameter_min, diameter_max, beam_number, beam_tilt_angle, beam_azimuth_angle, doppler_velocity, spectral_width, spectral_shape_score, signal_power, signal_to_other_ratio, significance, noise_power, dc_power, multi_peak_steering_velocity, multi_peak_average_significance, multi_peak_cumulative_significance, multi_peak_strongest_percentage, multi_peak_partial_bonus_begin, multi_peak_partial_bonus_end, multi_peak_full_bonus_begin, multi_peak_full_bonus_end, cluster_average_significance, cluster_cumulative_significance, cluster_consistency_rank, rwp_quality_flags, number_coherent_integration, number_incoherent_integration, number_FFT_points, interpulse_period, clock_phase_position, clock_phase_good_count, pres, tdry, dp, wspd, deg, rh, u_wind, v_wind, wstat, asc, alt, height, time, site, particle_size, raw_fall_velocity
history

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