Dataset Documentation/Readme

Title: Sea-Pol Radar Data Version 1.2

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1.0 Data Set Description

This dataset contains the processed Sea-Pol radar moment data. The data have been converted to CfRadial format from the native Sigmet using RadxConvert from the Lidar Radar Open Software Environment (LROSE, DeHart et al. 2024) and additional processing and gridding have been applied. Data are available from 16 August to 23 September 2024 from the deployment aboard the R/V Meteor across the tropical Atlantic as part of the PICCOLO, BOWTIE, and ORCESTRA campaigns. Data were collected with a 10-minute repeat cycle which included both RHI and Surveillance scans as described in section 3.0 below.

2.0 Instrument Description

The CSU Sea-Pol ship- and land-deployable radar measures dual-polarization data over a range out to 245 km. The radar operates at C-band and has a 4.3 m stabilized antenna system. The radar operates in simultaneous transmit and receive mode, as well as horizontal-only mode, with a sensitivity of -7 dBZ at 100 km. A variety of pulse widths and PRFs are supported, within a 0.12% duty cycle limit. For more information on Sea-Pol, please visit https://seapol.colostate.edu/. The following table describes the parameters as set-up for PICCOLO.

Table 1: Sea-Pol radar instrument characteristics for PICCOLO.

Sea-Pol Radar Characteristics	
Transmitter	5.656 GHz
Pulse Width	0.67 μs
Pulse Repetition Frequency	600 or 1200 Hz
Peak Power	250 kW
Radar Noise Figure	<3.5 dB
Dynamic Range	>99 dB
Minimum detectable signal	-7 dB at 100 km
Polarization Switching	HV
Gain	45 dBi
Diameter	4.3 m
Beamwidth	1.0°
First Sidelobe	< -27 dB (typ. -30 dB)
Scan rate ppi (rhi)	17.4°/s (1.5°/s)
Number of range gates	2447 or 1197
Gate spacing	100 m
Number of samples ppi (rhi)	69 (160)
Clutter filter	No clutter filter applied
Nyquist Velocity	7.95 or 15.9 m/s

3.0 Data Collection and Processing

Sea-Pol was deployed on the front of the R/V Meteor ship and had a 10 minute scan repeat cycle. Some volumes had a faster sub-cycle with 2 plan-position indicator (PPI) volumes every 10 minutes, and some had a mix of PPI and range-height indicator (RHI) scans. The RHI data are denoted with *RHI and

the PPIs with *SUR (indicating surveillance) at the end of the file names in the Level 3 data.

4.0 Level 1-3 Data Format

For more information on CfRadial see https://www.eol.ucar.edu/system/files/CfRadialDoc-v2.0-20180430.pdf.
File names in the Level 3 data are in the format:
cfrad.YYYYMMDD_HHMMSS.sss_to_YYYYMMDD_HHMMSS.sss_SEAPOL_{SUR|RHI}.nc

5.0 Data Remarks

5.0 Raw Data "Level 1"

Files are converted from native SIGMET binary format to CfRadial netCDF format. The raw data has no corrections, merely format conversion.

5.1 "Level 2" processing

5.1.1 RhoHV

The RhoHV field provided by the IRIS software removes noise from the variable, which causes a high bias in low-SNR regions. This RhoHV field is preferred for microphysical interpretation, but not for quality control. The raw RhoHV field is stored in the field 'UNKNOWN_ID_82.' RadxConvert handles the type conversion by applying a bias of 128, then subtracting 32768 to convert to a signed integer. To calculate raw RhoHV, we apply a 32640 offset, subtract 1, and then divide by 65533 (original uint16 linear scale: 0 = no data, 1 = 0.0, 65534 = 1.0, 65535 = reserved). The raw RhoHV field is called RHOHV_NNC in this dataset and is used to remove non-meteorological echoes.

5.1.2 Zdr Bias

The Zdr bias was estimated from high SNR data at 45 degree elevation scans with reflectivity values in the range 0-10 dBZ. The data were then binned in 2 dBZ wide bins and the mean value in each bin was calculated. The mean

of the means was then determined to be the Zdr bias. This procedure indicated that there was a very small -0.02 bias which is within the precision of the measurement. Therefore no bias correction was needed for this deployment.

5.1.3 Bad data identification

A bad data filter was applied for RHI and SUR scans separately. RHI data were thresholded on the Signal Quality Index (SQI) of <0.1 and SNR <0. The SUR scans were thresholded using the corrected correlation coefficient (RHOHV) <0.3 and SNR<0. A flag identifying good data (value of 1) and bad data (value of 0) is included as the 'Bad_Data_flag'.

5.1.4 Azimuth angle correction

A solar calibration to determine the absolute azimuth pointing angle in earth-relative coordinates was performed after radar installation on the R/V Meteor prior to the ship cruise. Due to unknown reasons, the calibration was not correct and additional angle correction was needed. An azimuth correction of 16.3 degrees was determined using the position of solar scans during the cruise and the position of land clutter from islands. This correction was added to all scans.

5.2 Quality Control "Level 3"

5.2.1 Non-meteorological data (NMD) removal (clutter, etc.)

Several thresholds were applied to remove noisy, non-meteorological, or clutter data. A flag identifying good data (value of 1) and bad data (value of 0) is included as the "QC_Flag". From 07 UTC 28 August to the end of the project, polarimetric data was used to identify land and sea clutter. Data was removed using standard deviation of PhiDP>13+dBZ<10, RhoHV <0.7, SNR <0.6, and SQI < 0.35. Data were also removed using a 2D smoothed Gaussian filter applied to the SQI field with smoothed values less than 0.4, which identifies 2nd trip echoes. To remove residual ground clutter, echoes with altitude less than 500 meters, DBZ > 55, abs(VEL)<0.5, and SW<0.02 were removed. After all thresholding was applied, a despeckler removed isolated gates less then 4

gates (400 m) in the radial direction. An additional mask was applied to the data due to ship obstructions from 37 to 43 degrees azimuth for the mast and 105 to 210 degrees for the ship superstructure. Due to the azimuth error, these masks were applied twice – once to the original uncorrected azimuth angles in the field by sector blanking of the transmitter, and again manually in post-processing using the corrected azimuth angles.

From 16 August to 07 UTC 28 August, only single polarimetry was available due to a hardware failure. The processing was similar to the dual-polarization, but without the polarimetric thresholds. An additional threshold of SW > 8 and azimuthal despeckler of 2 gates were applied to remove sea clutter. All data below 500 meters were removed due to residual sea clutter.

5.2.2 Kdp Calculation

Specific differential phase was calculated from the level 3 Phase data using the LROSE RadxKdp package. This uses the Hubbert and Bringi FIR filter. It was set to a filter length of 30, with 12 gates smoothing.

5.2.3 Attenuation Correction

DBZ and ZDR were attenuation corrected using LROSE RadxRate following the procedure and temperature-averaged coefficients detailed in Table 7.1 (page 494) of Bringi and Chandrasekar (2001).

5.3 Radial "Level 3" Products

5.3.1 Particle and Hydrometeor Identification

NCAR Particle Identification was calculated from level 3 DBZ, ZDR, KDP_RADX, RHO_HV and temperature using the LROSE RadxPid package. The NCAR PID is based on Vivekanandan et al. (1999). The temperature was interpolated from the GFS reanalysis to the radar domain. The 17 NCAR PID categories are the following:

1: Cloud
2: Drizzle
3: Light Rain

4: Moderate Rain
5: Heavy Rain
6: Hail
7: Rain and Hail
8: Graupel and Small Hail
9: Graupel and Rain
10: Dry Snow
11: Wet Snow
12: Ice Crystals
13: Irregular Ice Crystals
14: Supercooled Liquid
15: Flying Insects
16: Second trip
17: Ground clutter

Since the NCAR PID is tuned for continental precipitation, we also calculated the CSU Hydrometeor Identification (HID) based on Dolan et al. (2013) which is tuned for tropical C-band measurements. These HID categories are:

1: Drizzle
2: Rain
3: Ice Crystals
4: Aggregates
5: Wet Snow
6: Vertical Ice
7: Low-Density Graupel
8: High-Density Graupel
9: Hail
10: Big Drops

The NCAR PID was used for quality control to remove non-meteorological echoes (classes 15, 16, and 17) and as a data mask to identify valid scan regions. In the single polarization period, the SQI field was used as a data mask. The HID field is recommended for meteorological identification over the PID field, but both variables are included.

5.3.2 Rain rate

Rain rates were calculated using the formulas from Thompson et al. (2018). For the single polarization period, a single Z-R relationship was used. For the dual polarization period, the "blended" algorithm that uses multiple polarimetric estimators was used. The specific method (e.g. Z-R, Z-ZDR, KDP, etc.) used for each range gate is recorded in the RATE_CSU_METHOD variable.

5.3.3 CfRadial Data products

Both the Level 2 and Level 3 moment data were stored in the CfRadial files in native radar space. Table 2 lists the name and a brief description of each variable.

Table 2: Key Variables in the V1.2 CfRadial files.

Variable	**Dimensions**	**Description**
time	Time (s)	Time in seconds since volume start
range	Range (m)	Range from instrument to center of gate
azimuth	Time (deg)	Ray azimuth angle
elevation	Time (deg)	Ray elevation angle
DBZ	Time range	"Level 3" DBZ with NMD removed
DBZ_ATTEN_UNCORRECTED	Time range	"Level 3" Attenuated DBZ
DBZ_L2	Time range	"Level 2" DBZ with bad data removed
DBZ_TOT_L2	Time range	"Level 2" Total DBZ from power returned with bad data removed
DBZ_TOT	Time range	"Level 3" Total DBZ from power returned with NMD removed
VEL	Time range	"Level 3" Doppler velocity with NMD removed
VEL_L2	Time range	"Level 2" Doppler velocity
WIDTH	Time range	"Level 3" Spectrum Width with NMD removed
WIDTH_L2	Time range	"Level 2" Spectrum Width with bad data removed "Level 2"

ZDR_L2	Time range	“Level 2” Bias Corrected Differential Reflectivity
KDP	Time range	“Level 3” Specific differential phase calculated from LROSE /RadX from level 3 data
RHOHV	Time range	“Level 3” Corrected Correlation Coefficient with NMD removed
RHOHV_NNC	Time range	“Level 2” Sigmet Correlation Coefficient not corrected for noise
RHOHV_NNC_L2	Time range	“Level 2” Raw Correlation Coefficient
SQI	Time range	“Level 3” Signal Quality Index with NMD removed
SQI_FOR_MASK	Time range	Raw Signal Quality Index
PHIDP	Time range	“Level 3” Differential phase with NMD removed
PHIDP_L2	Time range	“Level 2” Differential phase with bad data removed “Level 2”
ZDR	Time range	“Level 3” Attenuation corrected, bias Corrected ZDR with NMD removed
ZDR_L2	Time range	“Level 2” Attenuation corrected, bias Corrected ZDR
ZDR_ATTEN_UNCORRECTED	Time range	“Level 3” Attenuated Zdr with bias correction
RHOHV_NNC	Time range	“Level 3” Corrected Correlation Coefficient
RHOHV_NNC_L2	Time range	“Level 2” Raw Correlation Coefficient
SNR	Time range	“Level 3” Signal to noise ratio with NMD removed
SNR_L2	Time range	“Level 2” Signal to noise ratio
RATE_ZH	Time range	“Level 3” Rain rate using Z-R relationship
RATE_CSU_METHOD	Time range	“Level 3” CSU rain ratel method
RATE_CSU_BLENDED	Time range	“Level 3” Rain rate using CSU tropical blended algorithm
HID_CSU	Time range	“Level 3” CSU Hydrometeor identification
PID_FOR_QC	Time range	NCAR Particle Identification
TEMP_FOR_PID	Time range	GFS sounding interpolated to SEAPOL

5.4 “Level 4” products

To facilitate data analysis, Level 4 products are gridded on to 1, 2 or 3D Cartesian grids. Gridding was performed using the Daisho Julia package developed by Michael Bell (https://github.com/mmbell/Daisho.jl). Daisho uses a novel beam weighting instead of the traditional linear interpolation or distance weighting. The constant range and expanding azimuthal beam volume are considered to retain finer detail near the ship and more accurately represent the measured spatial resolution at longer range. The beam weighting retains some finer detail near the ship with coarser detail at longer range. Different weightings are used depending on the desired grid spacing and geometry.

The data has two different missing data flags: -32768 denotes “missing” data where the radar did not scan within the grid space, and -9999 denotes “empty” data where the radar did scan but no data was recorded or was removed by quality control. The “missing” data includes regions such as the blanking sector or areas out of range of the radar. The “empty” data is determined by the MASK variable, which is either SQI for single polarization or PID for dual polarization. The “empty” -9999 data can be considered as non-precipitating clear air, although the user is cautioned that this determination is range-dependent due to the sensitivity of the radar.

Data are indexed at a time resolution of 5 minutes based on the start time of the volume. The exact start and end time of each volume are also recorded for more fine-scale time analysis. Missing data gaps are described in Table 3. Volumes without a 0.5 elevation angle were not included in the rain rate product, but were included in the other 2D and 3D products.

The “qvp_1D” gridding uses the 45 degree elevation angle sweeps near the ship and grids using a vertical 1D column with 100 meter resolution. This gridding preserves the native range resolution of the radar and is representative of a vertical profile near the ship. Due to the 45 degree angle, the higher altitudes are representative of a larger area, approximately corresponding to a circle with radius equivalent to the height. Variables are similar to the Level 3 CfRadial data.

The “rainrate_2D” grids each PPI elevation angle independently with 1 km grid spacing in 2D out to 240 km. The 0.5 degree elevation angle is then used to construct a rain map as the lowest available rain rate estimate. If data is missing from the 0.5 angle, then successively higher angles are considered until an altitude of 1 km. At longer ranges, the 0.5 angle exceeds 1 km altitude but is still the lowest available rain rate and is retained. This product only contains the best available rain rate (Z-R or blended), the reflectivity, the hydrometeor identification, and the elevation angle used for the estimate. This product is recommended for the best available, lowest altitude rain rate.

The ”composite_2D” product grids all available elevation angles with a 1 km grid in 2D using the maximum reflectivity in the vertical column. The other variables are associated with that maximum reflectivity. This product is recommended for comparison with model output composite reflectivity.

The “rhi_2D” product grids all of the RHI scans with a 250 m grid spacing in the radial and vertical direction. Each RHI angle is gridded independently in 2D. The 250 m grid and weighting parameters were selected as an optimal combination for the oversampled, slower scan rate out to 120 km range.

The “volume_3D’ product grids all available elevation angles with a 1 km grid in 3D. This grid represents the best estimate of the 3D volumetric structure of the radar variables. The 1 km grid and weighting parameters were selected as an optimal combination for the volume out to 120 km range. The Cartesian gridding uses a transverse Mercator map projection. This product is recommended for general volumetric calculations, including constant altitude calculations.

The “latlon_3D” product grids all available elevation angles with a 0.02 degree grid spacing in the horizontal and 1 km grid spacing in the vertical. This resolution corresponds to an approximately 2 km horizontal grid, but uses degrees as the grid spacing to more directly compare with satellite or model products. Since the gridding is coarser than the volume product, it is recommended for comparison against satellite or model grids with similar resolution of 2 km.

Table 3. Data gaps greater than 10 minutes

Gap (min)	Start time	End time	Notes
25	8/16/24 10:45	8/16/24 11:10	Down for testing of dual-pol failure
380	8/16/24 15:00	8/16/24 21:20	LNA testing and diagnosis
75	8/18/24 10:05	8/18/24 11:20	Stop for work on radome
20	8/18/24 14:40	8/18/24 15:00	Radar maintenance
40	8/20/24 13:40	8/20/24 14:20	Testing RHI strategy for EarthCare overpass
15	8/20/24 20:00	8/20/24 20:15	2006 radar stopped due to elevation limit, restarted
25	8/23/24 9:55	8/23/24 10:20	Radar inspection
115	8/24/24 13:00	8/24/24 14:55	Radar off for LNA arrival testing
800	8/28/24 06:55	8/28/24 20:15	LNA repair
-	8/29/24 12:20	8/29/24 13:35	12:30, 13:05, and 13:25 missing 0.5
15	8/30/24 03:20	8/30/24 03:35	EarthCare overpass, long RHI scan
20	8/30/24 14:20	8/30/24 14:40	Dish froze and radiate went to red, an RCP reset was done
30	9/4/24 2:20	9/4/24 2:50	Radar froze, RCP reset done (0245 note)
50	9/4/24 13:55	9/4/24 14:45	Radar down for maintenance
15	9/6/24 13:00	9/6/24 13:15	HALO overpass, long RHI scan
20	9/6/24 14:40	9/6/24 15:00	The radar stopped , servo power turned off, then restarted
20	9/6/24 15:00	9/6/24 15:20	Restart scanning after servo restart
15	9/7/24 8:40	9/7/24 8:55	Scanning out of sync
-	9/9/24 1:20	9/9/24 1:55	1:20, 1:35, and 1:55 missing 0.5
530	9/12/24 6:10	9/12/24 15:00	Power loss
-	9/13/24 7:15	9/13/24 07:55	7:15, 7:35, and 7:55 missing 0.5
-	9/15/24 5:00	9/15/24 7:00	5:00, 5:25, 5:45, 6:05, 6:25, 6:40, 7:00
15	9/16/24 13:30	9/16/24 13:45	HALO Overpass, long RHI scan
810	9/18/24 6:00	9/18/24 19:30	Transmitter issue
-	09/20 17:30	09/20 17:30	17:30 missing 0.5
15	9/21/24 18:00	9/21/24 18:15	RCP shutdown, restart
50	9/22/ß24 19:50	9/22/24 20:30	Group picture, radar down but no weather

6.0 References

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