Title: Wyoming Cloud Radar (WCR) Level-2 Data

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1.0 Data Set Description

- Summary: This dataset includes Wyoming Cloud Radar data collected aboard the NSF/NCAR C-130 aircraft (tail number N130AR) during the CAESAR project. NetCDF files contain the equivalent radar reflectivity factor (Z or dBZ), Doppler velocity (m/s) of hydrometeors corrected for aircraft motion, and other supporting variables.
- Version: 1.0
- Release date: 11 October 2024
- Data Status: Full Release
- Project: Cold Air Outbreak Experiment in the Sub-Arctic Region (CAESAR)
- Project base: Kiruna, Sweden
- Temporal coverage:
  - Begin datetime: 2024-02-09 19:06:25
  - End datetime: 2024-04-03 15:49:01
- Spatial coverage:
  - Maximum (North) Latitude: 82.00
  - Minimum (South) Latitude: 66.00
  - Minimum (West) Longitude: -14.00
  - Maximum (East) Longitude: 24.00
- Data Frequency: 0.05 seconds (L1) or 0.20 seconds (L2)
- Data source: University of Wyoming
- Web address references: http://flights.uwyo.edu/uwka/wcr/
- Data set restrictions: Authorization required for 1 year following data collection

2.0 Instrument Description

The Wyoming Cloud Radar (WCR) is an airborne polarimetric Doppler radar operating at W-band (94.94 GHz). Up to 4 antennas are employable and can be configured to observe targets above and below the aircraft. The WCR provides high-resolution measurements of reflectivity and radial velocity, along with the capability of measuring differential reflectivity and linear depolarization ratio. It is deployable aboard both the University of Wyoming King Air and the NSF/NCAR C-130 research aircraft.

Parameter	CAESAR Value
Frequency / Wavelength	94.940 GHz / 3.16 mm
Pulse Width	250 ns
Pulse Repetition Freq. (PRF)	18.18 KHz (occas. 16.67 KHz)
Nyquist (max) velocity	14.35 m/s (occas. 13.16 m/s)
Maximum Range	6,115 m (occas. 6,360 and 7,560 m)
HP Beamwidth (up, down, down-aft)	0.63, 0.78, 0.78 degrees
Polarization (up, down, down-aft)	H, H, H
Minimum Detectable Signal (3 sigma @ 1km)	-28.2, -34.3, -32.5 dBZ
Estimated accuracy / precision	2.5 / 1.0 dB
Beam Vector Uncertainty	0.05 degrees
Doppler Velocity Uncertainty	0.1 m/s

3.0 Data Collection and Processing

WCR data were collected during all 10 research flights and during test flights 1, 2, 4, & 6.

The radar calibration constant was determined before and after the project by transmitting through the down antenna towards a trihedral corner reflector with known radar cross section. The down and down-aft antennas were calibrated against the down antenna using times when the aircraft flew through cloud.

Antenna beam pointing vectors for the down antennas were determined from test flights with circle maneuvers by minimizing the velocity of the ground (Haimov and Rodi, 2013). The up-antenna beam vector is chosen to produce a smooth velocity profile when merged with the down velocity. The beam vectors are then used with aircraft attitude, velocity, and acceleration data to subtract aircraft motion from the Doppler measurements. The result is hydrometeor radial velocity relative to the earth. The C-130 IRS data is used to correct the up antenna (which is mounted to the C-130 fuselage) while an independent IRS attached to the WCR rack (Applanix) is used to correct the down and down-aft antennas (which are mounted to the C-130 ramp).

The Applanix IRS data was processed using the IN-Fusion PPP Processing method provided in the Applanix POSPac software. This method is appropriate for data post-processing when base receivers are not available (e.g. over the open ocean). A mounting adjustment was applied during processing to align the roll, pitch, and heading of the Applanix to those of the C-130 IRS. The C-130 IRS data was used as provided.

The WCR down antenna was disabled when the aircraft altitude dropped to ~1,500 ft or less to protect radar components.

When flying high-altitude ferry flights to and from the area of interest, the distance to the ground along the beam path occasionally exceeded the WCR maximum range so that the ground is not visible. This mostly occurred in the down-aft antenna. The maximum range was extended (and PRF reduced) in later flights to sample all the way to the ground.

Data acquisition plots, L1 data plots, and L2 data plots have been reviewed for quality assurance.

4.0 Data Format

Processed radar data are saved in NetCDF files. Since 2022, NetCDF-4 is used and variables are organized into structured groups following CfRadial v2.1 guidelines. Prior data files had a single group of variables in a NetCDF file. For detailed information about CfRadial v2.1 see the draft documentation at https://github.com/NCAR/CfRadial/tree/master/docs. If more than one WCR antenna is active it is designated as a sweep group. For WCR, 'sweep' is equivalent to 'antenna'. Within a sweep group, radar products are recorded as separate 2-D variables. Supporting data are organized into appropriate georeference, monitoring, or spectrum groups in that sweep group.

File naming conventions follow typical CfRadial file format, first indicating a cfradial file (cfrad2), then defining the start and end times that span the data within the file (yyyymmdd_hhmmss_to_ yyyymmdd_hhmmss). Additional identifying information after the end time indicates the data source (WCR), the data level (L0 – L2), the project (e.g. CAESAR24), and the active antennas/ports. Level 2 data files containing profile data with merged up + down antenna products have an “up-down” tag at the end. In a case where the up or down antenna was not active, the tag indicates the active antenna (“up” or “down”).

- Primary dimensions: time, range (L1), altitude (L2)
- Primary variables: reflectivity, velocity
- Data flags/masks: reflectivity_mask (L1), wcrmask (L2)
- See the project .cdl file or a full list of variables and attribute descriptions

<u>L1 Data</u> –
Level-1 processing provides the initial calibrated values of reflectivity and velocity from each antenna. The data remains in their range gates as originally sampled and, therefore, have dimensions of time and range. L1 data may be easier to use for projects that require knowledge of the range from the radar/aircraft, need the highest resolution, or plan on using custom processing. Reflectivity is stored in linear units allowing flexibility for handling weak signals close to the noise level. Positive Doppler velocity values indicate motion away from the radar.

Example File:
"cfrad2.20240402_080743_to_20240402_081740_WCR_L1_CAESAR24.CPP-H1V3V1.nc"

- Data covers the time period between 08:07:43 and 08:17:40 UTC on 02 April 2024
- WCR L1 Data collected during the CAESAR project
- The data were collected with CPP mode using 3 antenna ports (H1, V3, and V1)

L2 Data –

Level-2 processing usually applies some averaging in range and time to lower the minimum detectable signal. The data is transformed from range gates into altitude bins for easy plotting and comparison with other earth-relative datasets. Additionally, the data products are thresholded to remove residual noise (using 3 standard deviations from the mean). If an up and/or down antenna is active, a second file for each period exists that contains the up and down data merged into full profiles extending above and below the aircraft. For files containing data separated by antenna, positive Doppler velocities indicate motion away from the radar. For files with merged up-down profile data, positive Doppler velocities indicate upward motion. Use L2 data to plot easy cross-sections of variables in time vs altitude.

Example File:

" cfrad2.20240402_080743_to_20240402_081740_WCR_L2_CAESAR24.up-down.nc"

- WCR L2 data covering the same time period as the example L1 file
- "up-down" indicates that the file contains a single sweep (sweep_up-down) with products merged into quasi-vertical profiles

5.0 Data Remarks

Instrument issues during RF01 (28 Feb.) caused a period of missing data between 12:09:07 and 15:04:59 UTC (outbound track).

A radar artifact exists in the down-aft antenna reflectivity and velocity due to the strength of the ocean return and transmit leakage through the down antenna. It appears as a horizontal line that is displaced above the ocean or land surface. This "cross-talk" artifact may become negligible where strong hydrometeor targets exist.

There is an unresoved radar artifact in the down-aft antenna similar to the surface cross-talk but displaced from where a surface return leak should occur. No flag exists yet to identify or mask this artifact.

Software compatibility: Any software containing procedures to read NetCDF-4 files (e.g. Python, Matlab, IDL) and software developed for CfRadial v2.

Python Example:

```
# Required libraries --------------------------------------------------------
from netCDF4 import Dataset
import numpy as np

# Open NetCDF file
wcr_root = Dataset("WCR_filePath")

# Choose group e.g. "sweep_up" for up antenna, "sweep_up-down" for L2 merged data
sweep_group =wcr_root.groups["group_choice"]

# Identify the NetCDF variables wanted from each group
velocity = sweep_group.variables['velocity']
```

```
reflectivity =  sweep_group.variables['reflectivity']
time = sweep_group.variables['time']
altitude = sweep_group.variables['altitude'] #Use ‘range’ with L1 data

# Convert to Numpy arrays --------------------------------------------------
time = np.array(time[:])
altitude = np.array(altitude[:])/1000. #change m to km
reflectivity = np.transpose(np.array(reflectivity[:]))
velocity = np.transpose(np.array(velocity[:]))

# Close file
wcr_root.close()
```

6.0 References

Haimov, S., and A. Rodi, 2013: Fixed-Antenna Pointing-Angle Calibration of Airborne Doppler Cloud Radar. *J. Atmos. Oceanic Technol.*, **30**, 2320–2335, https://doi.org/10.1175/JTECH-D-12-00262.1.

7.0 Appendix

Keywords: Radar, Radar Reflectivity, Doppler Velocity, Cloud Properties, Cloud Dynamics, Cloud Microphysics