CfRadial - CF NetCDF for Radar and Lidar Data in Polar Coordinates

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See: https://github.com/NCAR/CfRadial/tree/master/docs

CfRadial is a CF-compliant NetCDF convention for RADAR and LIDAR data in polar coordinates.

The conventions for CF (Climate and Forecast) metadata are designed to promote the processing and sharing of files created with the NetCDF API.

The current CF conventions are documented at:
http://cfconventions.org/
http://cfconventions.org/cf-conventions/v1.6.0/cf-conventions.html

HISTORY of CfRadial versions

Date	Version	Remarks
2011/02/01	1.1	First operational version – NetCDF3 Uses a volume-oriented flat structure
2011/06/07	1.2	Minor changes / additions
2013/07/01	1.3	Major changes / additions
2016/05/31	1.4	Adding support for spectra and data quality fields
2017	2.0	Upgrade to use NetCDF4 groups Change to sweep-oriented structure

CfRadial 1 – based on the classic NetCDF 3 design

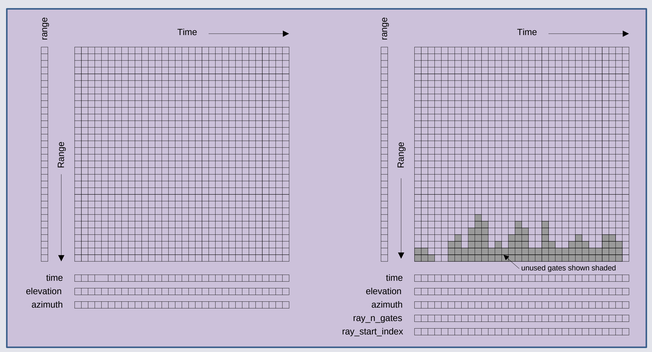
CfRadial versions 1.1 to 1.4 are based on the classic NetCDF 3 model, in which the data structure is inherently **flat**.

All of the metadata variables, and the actual data set arrays, are stored at the same (top) **level**.

This is analogous to storing all of your computer files in a single folder – e.g. your home directory.

Some radar/lidar data contains rays with a constant number of gates. In CfRadial 1, this type of data can be stored in 2-D rectangular arrays where the primary dimension is **time** and the secondary dimension is **range.** *See the figure below left*.

As an alternative, to store the data more efficiently, some data sets have a variable number of gates per ray. This allows us to discard gates beyond the range at which useful data exists for that ray. In this case the field data is stored in a so-called 1-D 'ragged' array, in which the primary dimension is **npoints** – the length of the array. The location of the data for a specific ray is found via the **ray_start_index** and **ray_n_gates** metadata arrays. *This structure is shown in the figure below right*.



2-D rectangular dataset array

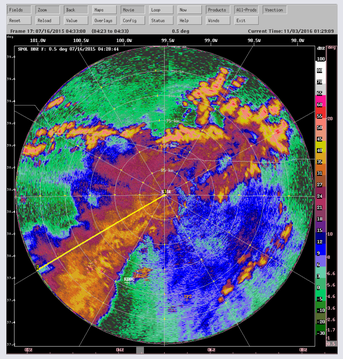
1-D ragged dataset array

In both of these cases, the metadata variables such as time, elevation angle and azimuth angle are stored as 1-D arrays.

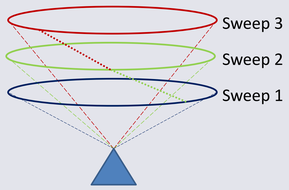
As mentioned earlier, all of these arrays are stored at the top level in the NetCDF file – NetCDF3 has only a single level.

The nature of RADAR/LIDAR data – Polar coordinates

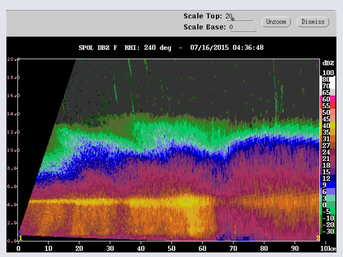
Scanning instruments – such as RADARS and LIDARS – operate natively in polar coordinates.
The intention with CfRadial is to save the data in the native coordinate system without any loss of information.

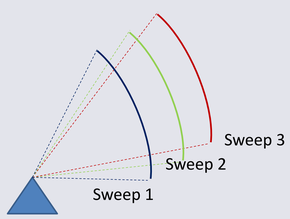


PPI scanning mode – the antenna moves predominantly in azimuth. Sweeps contain rays at a constant elevation angle.

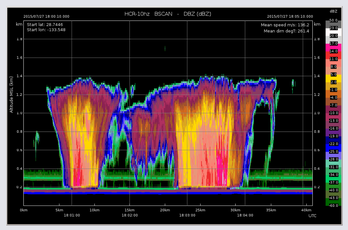


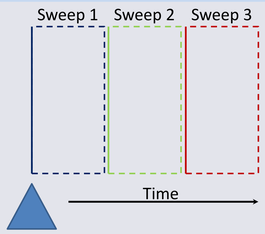
RHI scanning mode – the antenna moves predominantly in elevation. Sweeps contain rays at a constant azimuth angle.





Vertically-pointing mode. Antenna is stationary.
Sweeps contain rays within a given time interval.





RADARs and LIDARs are pulsed instruments, which sample the atmosphere at a series of **range gates**, generally at constant spacing, in the direction at which the antenna or telescope is pointing.

The gates are grouped into **rays**, or beams.

Rays are grouped into **sweeps**, which are logical divisions in the scanning strategy. For example, as a radar scans in PPI mode, a sweep comprises all of the rays at a given elevation angle.

In CfRadial, a **Volume** comprises all of the rays in the file.

References

Axford, D. N., 1968: On the accuracy of wind measurements using an inertial platform in an aircraft, and an example of a measurement of the vertical structure of the atmosphere. J. Appl. Meteor., 7, 645-666.
Dixon M., Lee, W-C., Rilling B., Burghart C., and Van Andel J., 2013: CfRadial Data File Format. Proposed CF-compliant netCDF Format for Moments Data for RADAR and LIDAR in Radial Coordinates. Version 1.3. EOL, NCAR. 66 pp.
Lee, W., P. Dodge, F. D. Marks Jr. and P. Hildebrand, 1994: Mapping of Airborne Doppler Radar Data. Journal of Oceanic and Atmospheric Technology, 11, 572 – 578.
Michelson D.B., Lewandowski R., Szewczykowski M., Beekhuis H., and Haase G., 2014: EUMETNET OPERA weather radar information model for implementation with the HDF5 file format. Version 2.2. EUMETNET OPERA Output O4. 38 pp.

CfRadial 2 – NetCDF4 with groups

NetCDF4, which is based on HDF5, introduced the concept of **groups**.

This allows us to create a **data tree structure**, in which data for different logical components are stored at different conceptual locations, or levels, within the file.

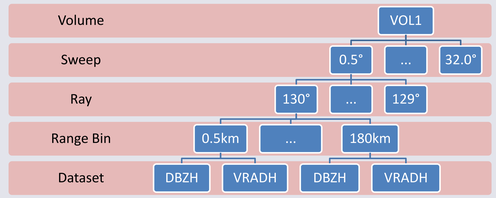
This is analogous to storing data files on your computed in a tree of folders or directories. This leads to a better organization of the data in a logical structure.

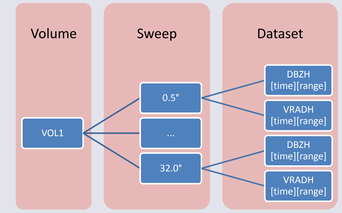
As shown in the center panel (left), it makes sense to separate a radar volume into logical components called **sweeps**.

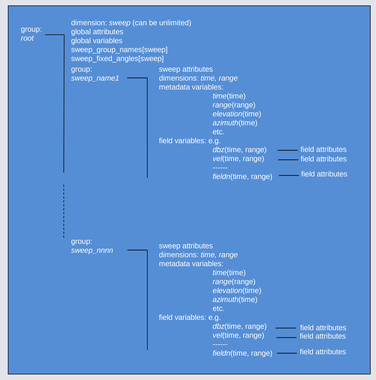
A sweep is defined as a series of rays for which certain characteristics are constant. In a PPI sweep, the elevation angle is held constant. In an RHI sweep, the azimuth angle is constant.

In CfRadial 2, the number of gates is in a sweep is always constant. This allows us to store the data set in a simple rectangular 2-D array, with dimensions time and range.

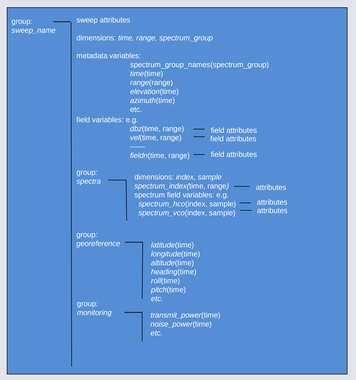
The logical structure of CfRadial2 is shown in the examples below



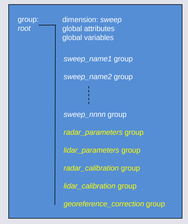




Group structure showing top-level dimensions, attributes, variables and sweep groups



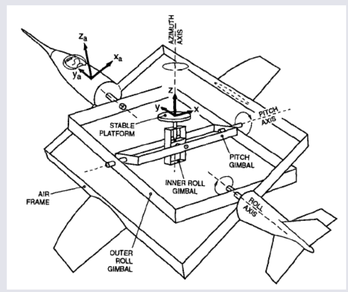
Sweep group structure in more detail, showing support for geo-reference metadata for moving platforms, spectra, and monitoring data



Optional metadata groups (highlighted in yellow) in the root group

Standard name	Short name	Units	Already in CF?
equivalent_reflectivity_factor	DBZ	dBZ	yes
linear_equivalent_reflectivity_factor	Z	Z	no
radial_velocity_of_scatterers_away_from_instrument	VEL	m/s	yes
doppler_spectrum_width	WIDTH	m/s	no
log_differential_reflectivity_hv	ZDR	dB	no
log_linear_depolarization_ratio_hv	LDR	dB	no
log_linear_depolarization_ratio_h	LDRH	dB	no
log_linear_depolarization_ratio_v	LDRV	dB	no
differential_phase_hv	PHIDP	degrees	no
specific_differential_phase_hv	KDP	degrees/km	no
cross_correlation_ratio_hv	RHOHV		no
log_power	DBM	dBm	no
log_power_co_polar_h	DBMHC	dBm	no
log_power_co_polar_v	DBMVC	dBm	no
linear_power	PWR	mW	no
linear_power_co_polar_h	PWRHC	mW	no
linear_power_co_polar_v	PWRVC	mW	no
signal_to_noise_ratio	SNR	dB	no
signal_to_noise_ratio_co_polar_h	SNRHC	dB	no
signal_to_noise_ratio_co_polar_v	SNRVC	dB	no
normalized_coherent_power	NCP		no
radar_estimated_rain_rate	RRR	mm/hr	no
rain_rate	RR	kg/m2/s	yes
radar_echo_classification (should be used for PID, HCA, HID etc)	REC	legend	no

Standard Names:
Only 2 radar fields are currently included in the CF standard name list. This table shows examples of field names that will be requested for addition to the standard name list.



Moving platforms (e.g. aircraft) are supported in CfRadial. Axis definitions and reference frame (reproduced from Lee et al., 1994,originally from Axford, 1968) ©American Meteorological Society. Reprinted with permission.