

Overview of NASA Polarimetric Doppler Weather Radar (NPOL) Data Collected in NAMMA

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NPOL Radar Coordinates

Latitude: 14.65654° N
Longitude: 17.09803° E
Altitude: ~80 m MSL
Location: Kawsara, Senegal

Period of Operations

1258 UTC 19 August – 1200 UTC 30 September 2006.

A total of 7299 scans were archived during the campaign with over 29 GB of data collected by NPOL.

Scanning Strategy

NPOL collected 360° PPI data (no sectors or RHIs) and operated nearly continuously during NAMMA. The radar operated on a 15-minute repeat cycle, starting at the top of the UTC hour. During each 15-minute period, a 1-tilt (0.8°) surveillance scan (270 km maximum range) and one 19 tilt volume scan (150 km maximum range) were collected. The multiple tilt volume was chosen according to the existing conditions.

There were 2 options:

NAMMA_FAR_S scanning strategy:

19 angles from 0.7 to 33.0 degrees: 0.7, 1.4, 1.8, 2.3, 3.4, 4.5, 5.7, 6.9, 8.2, 9.6, 11.3, 13.0, 15.0, 17.2, 19.8, 22.5, 26.5, 29.5, 33.0

- This scan was used most often during the field campaign.

NAMMA_NEAR_S scanning strategy:

19 angles from 0.8 to 49.0 degrees: 0.8, 1.5, 3.2, 5.5, 7.9, 10.3, 12.7, 15.1, 17.6, 20.0, 22.6, 25.1, 27.8, 30.5, 33.2, 36.1, 39.1, 44.0, 49.0

- This scan was used occasionally when storms were near NPOL.

Volume scan setup for both scan type

Resolution: 1.4 degrees (azimuth)

Pulse Width: 0.80

Polarization: H + V

Samples: 128
Start Range: 0.00 km/Bin Spacing: 199.9 m
Max Range: 150.0 km
Unambiguous Range/Velocity: 157.8 km/25.4 m/s
High/Low PRF: 950 Hz

Radar Parameters Collected

The following information is the same for both scanning strategies listed above. NPOL collected a variety of conventional and polarimetric fields during NAMMA. The following is a list of parameters and their definitions:

ZT: Total unfiltered reflectivity (dBZ)
DZ: Noise filtered reflectivity (dBZ)
VR: Mean Doppler velocity (m s^{-1})
SW: Spectral width (m s^{-1})
ZDR: Differential reflectivity (dB)
KDP: Specific differential phase (deg/km)
PhiDP: Differential phase (deg)
RhoHV: Correlation between horizontal and vertical polarizations (0 to 1)

Quality Control Procedures

The quality control (QC) algorithm is designed to make two passes through a volume scan, which utilizes more extensive filters in the second pass by examining adjacent range gates around the analysis range gate. Only range gates with valid reflectivity values are analyzed. Running two passes through the volume scan will insure the surrounding data has already been filtered and has some reliability. Figure 1 shows a flow chart of the algorithm.

The first pass of the algorithm consists of three filters. The first filter, Range Dependent Correlation Test, examines the correlation coefficient (ρ_{hv}) of each range gate. Precipitation is found to generally have a ρ_{hv} greater than 0.7 (Ryzhkov et al. 1994) with greater values closer to the radar due to the absence of polarimetric attenuation at close ranges. Therefore, the ρ_{hv} threshold values were decreased with range (from 0.8 to 0.5) to reduce the chance of precipitation being removed due to possible polarimetric attenuation. The freezing level during NAMMA was generally located between 4 and 5 km as was indicated by rawinsonde data at the location of the radar. Ice crystals tend to have lower ρ_{hv} values compared to other hydrometeors (Straka et al. 2000); therefore, this filter was only performed on range gates below 4 km to eliminate the chance of removing valid reflectivity in regions where ice crystals may be present. If a data point passes the Range Dependent Correlation Test without being removed, it is then filtered through the Minimum Reflectivity Test.

The Minimum Reflectivity Test removes any reflectivity values below a minimum threshold, which was set at 0.0 dBZ (before a bias correction was applied) because low reflectivity values tend not to represent precipitation and have little effect on rainfall estimation. It is also known that cirrus clouds have rather low reflectivity values due to the inclusive particle habits and concentrations. Therefore, this filter was restricted to only perform in the lowest two sweeps of the volume scan to try and eliminate the potential removal of cirrus anvil data.

If the reflectivity range gate passes the second filter without removal, it is sent to the Range Dependent Parameter Test which is a filter utilizing the reflectivity, velocity, range, and ρ_{hv} values. Echoes with near zero velocities, low ρ_{hv} values, and rather low reflectivity values are removed from the volume scan. The ρ_{hv} threshold values were decreased every 50 km starting at 0.8 for similar reasons described for the first filter. The reflectivity threshold values were set at 15 dBZ for range gates less than 100 km from the radar. The threshold was then reduced to 10 dBZ for range gates greater than 100 km in range. The velocity threshold started at 2 m/s and decreased by 0.5 m/s every 50 km out to 150 km. A problem with this filter may occur when valid echoes move parallel to the radar giving near zero velocity. The correlation and reflectivity thresholds (before bias correction) were set for this filter to lower the occurrence of falsely removing range gates. If the values meet these criteria, the reflectivity value is removed. Rather coarse thresholds in the last portion of this filter were added to help in the removal of extreme anomalous propagation: reflectivity threshold greater than or equal to 15 dBZ, velocity threshold of 0 ± 0.4 m/s, and ρ_{hv} threshold of less than 0.97.

A reflectivity bias was calculated by comparing NPOL reflectivity data and to TRMM PR reflectivity for coincident overpasses. After comparing the reflectivity data between TRMM PR and NPOL, reflectivity bias was determined to be -2.0 dB. Range gates with values passing the first three filters without being removed are then printed as corrected reflectivity with the reflectivity bias.

A second pass with more extensive filters is then performed on the dataset. The first filter in the second pass examines the vertical extent of the echoes. If reflectivity at any given range gate is only seen in the first sweep with a $\rho_{hv} < 0.8$, the reflectivity value is then removed. This method is a modified portion of the echo top height technique used by Steiner and Smith (2002). If range gates pass this filter, they are sent to the ground clutter test. Ground clutter is generally easy to decipher using ρ_{hv} values. Ryzhkov et al. (1994) have shown ground clutter ρ_{hv} values are between 0.2 and 0.3, so most of the ground clutter should have been removed from the first and third filters in the first pass. However, some ground targets have been noticed to have higher correlation values, so further examination of the data had to be performed. This test was only performed on range gates within 50 km of the radar. A higher ρ_{hv} threshold was placed on the data for range gates within 15 km. A velocity criterion was also tested because ground clutter should have a zero to near-zero velocity parameter. The movement of the antenna will actually transfer some of the motion into the velocity of ground targets. Using the method described in Rinehart (1991), a maximum ground target velocity can be calculated. The distance from NPOL's feed horn to the antenna is approximately 4.4 m. By multiplying the angular velocity of the radar (~ 12 to 13 °/s) and the distance traveled ($2\pi/360^\circ$) with 4.4 m, the maximum velocity any ground target should have is approximately 1 m/s. Storms that happen to propagate parallel to the radar would have near zero velocities, but should remain as precipitation echo due to their higher ρ_{hv} values at close distances from the radar.

The next filter detects and removes backlobes. Backlobes are caused by energy traveling through the mesh-like reflector after leaving the feed horn during transmission. The electromagnetic (EM) waves reflect off hydrometeors behind the reflector and are returned back to the receiver. The returned energy is then recorded as false echoes in the dataset at the opposite azimuth and same

range as the actual precipitation hydrometeors. The backlobe issue seen in previous field campaigns using NPOL seemed to have been mitigated for NAMMA with the engineering adjustments to the antenna. However, the test remained in the algorithm in case there were any remaining backlobe issues with the antenna.

The Neighbor Test is the final filter of the QC algorithm. It examines the spatial distribution of bins surrounding the analysis bin. The reflectivity value of the analysis bin is removed if there is only four or less of the surrounding eight range gates containing reflectivity values. This helps remove some of the speckled appearance that occurs from the previous QC filters, as well as from random noise in the receiver. This filter may also smooth some edges around real precipitation; however, the amount removed should be rather insignificant. All values that pass these filters are considered valid precipitation echoes, and are then saved as corrected reflectivity. The uncorrected reflectivity and polarimetric variables are also saved to the output file in order to keep all of the raw dataset accessible.

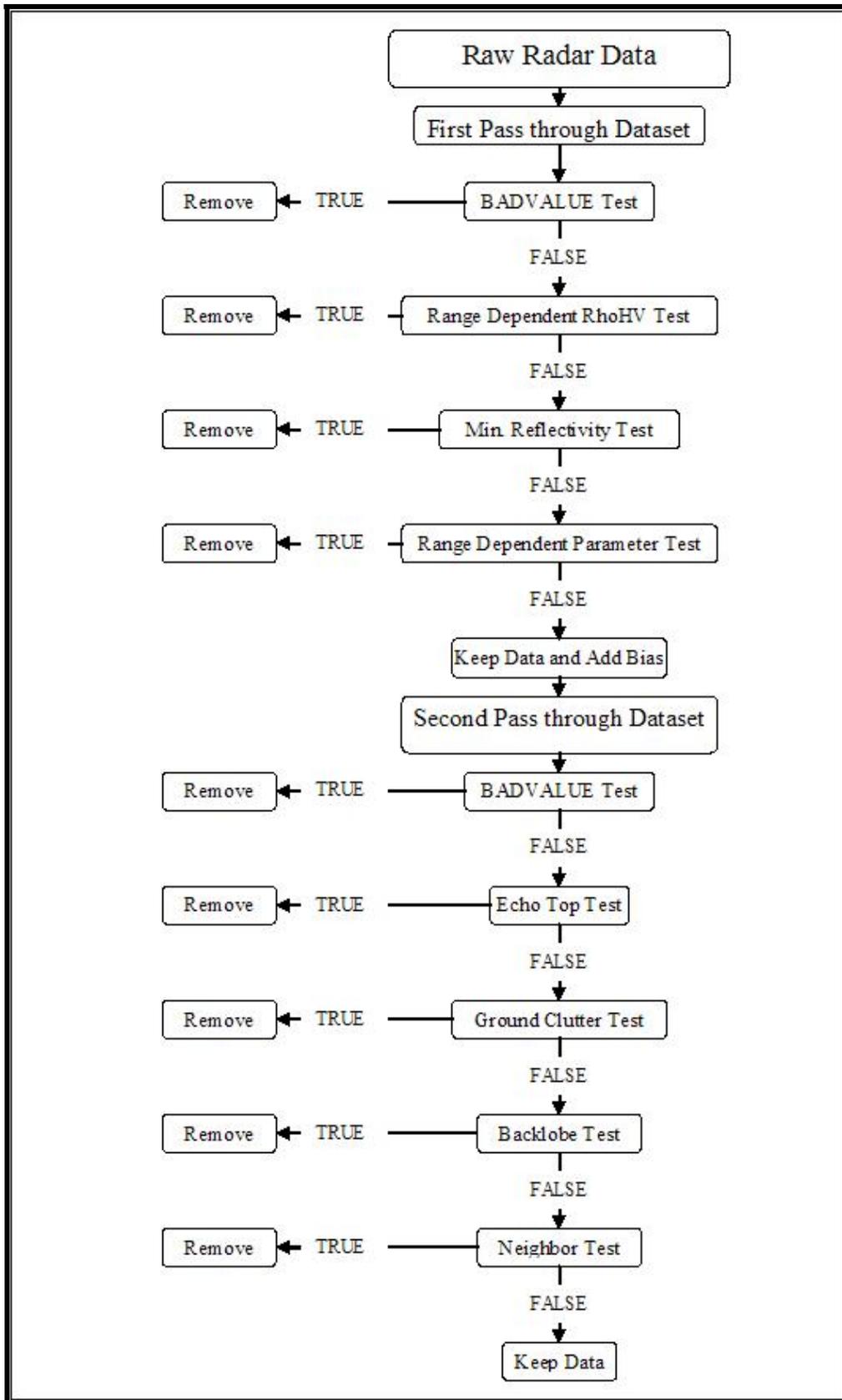


Figure 1: Flow chart of the quality control algorithm.

Calibration Adjustment

Reflectivity Calibration

Based on TRMM PR comparison, the reflectivity for NPOL is estimated to be -2.0 dB low. A +2.0 dB correction factor was added to all NPOL data for the experiment.

Differential Reflectivity Calibration

ZDR bias fluctuated at the beginning because of bad correction offsets, bad noise samples, unexpected power failures, etc. From a detailed echo analysis, the following shows the detailed correction. A few examples of the ZDR vs. reflectivity are presented to highlight a few of the ZDR calibration offsets that were applied.

Correction 1:

19 Aug – 1500 UTC 25 August 2006: +1.8 dB

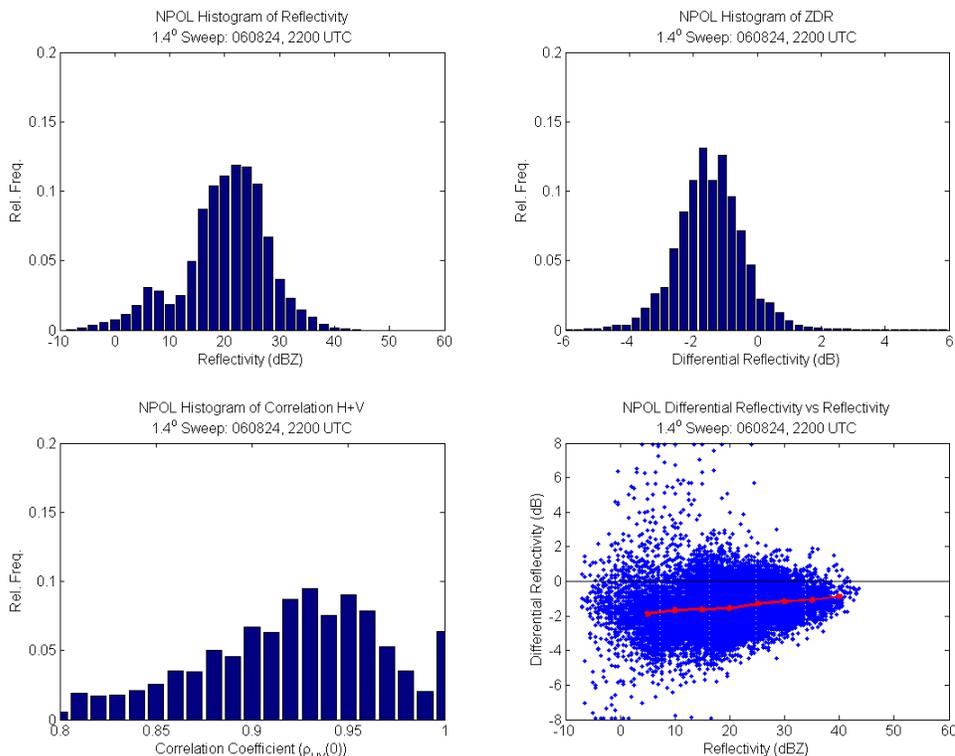


Figure 2: ZDR vs. Reflectivity distribution for the correction 1 time period.

Correction 2:

1500-1545 UTC 25 August 2006: -1.4 dB

Correction 3:

1545 UTC 25 August 2006 – 1200 UTC 26 August 2006: -0.8 dB

Correction 4:
1200 UTC 26 August 2006 – 1645 UTC 28 August 2006: -2.0 dB

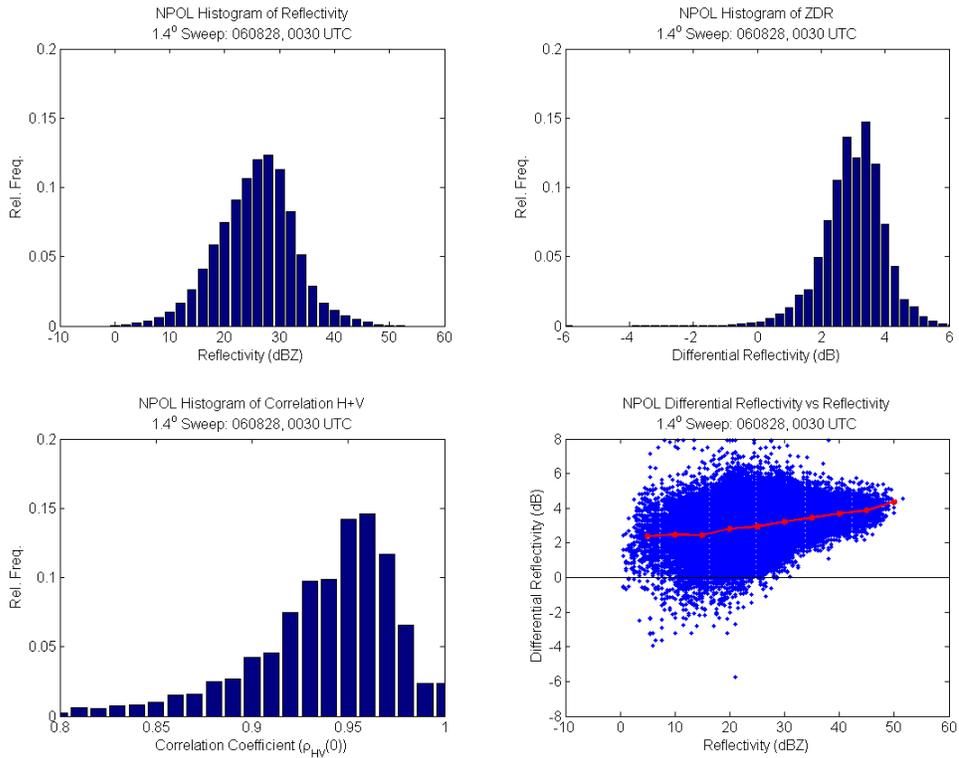


Figure 3: Same as Fig. 2 except the correction 4 time period.

Correction 5:
1645 UTC 28 August 2006 – 30 September 2006: 0.0 dB

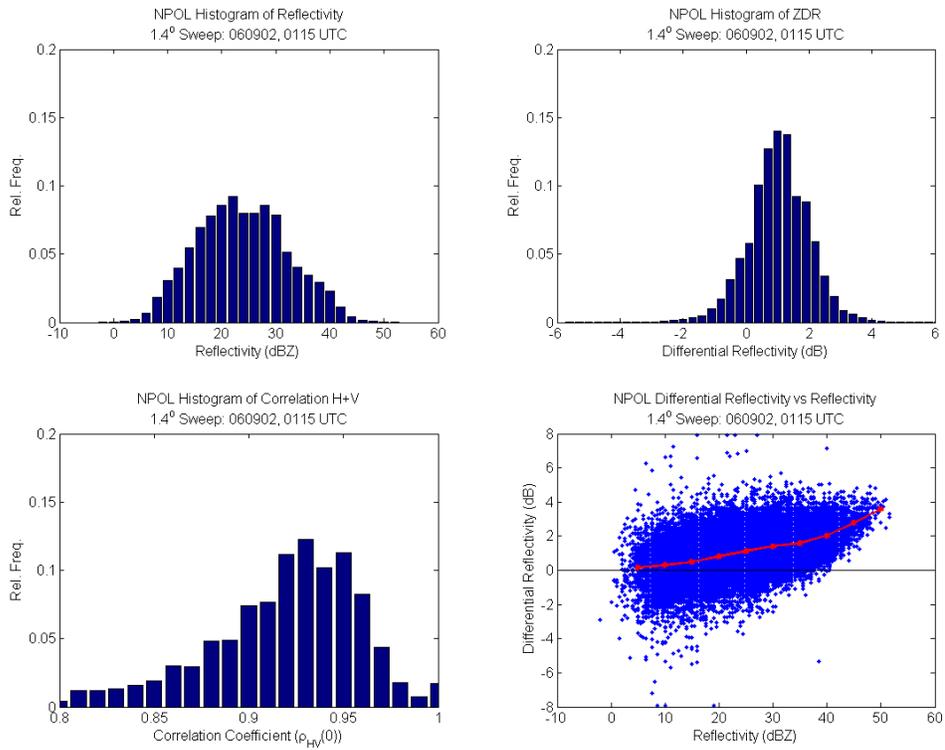


Figure 4: Same as Fig. 2 except for the correction 5 time period.

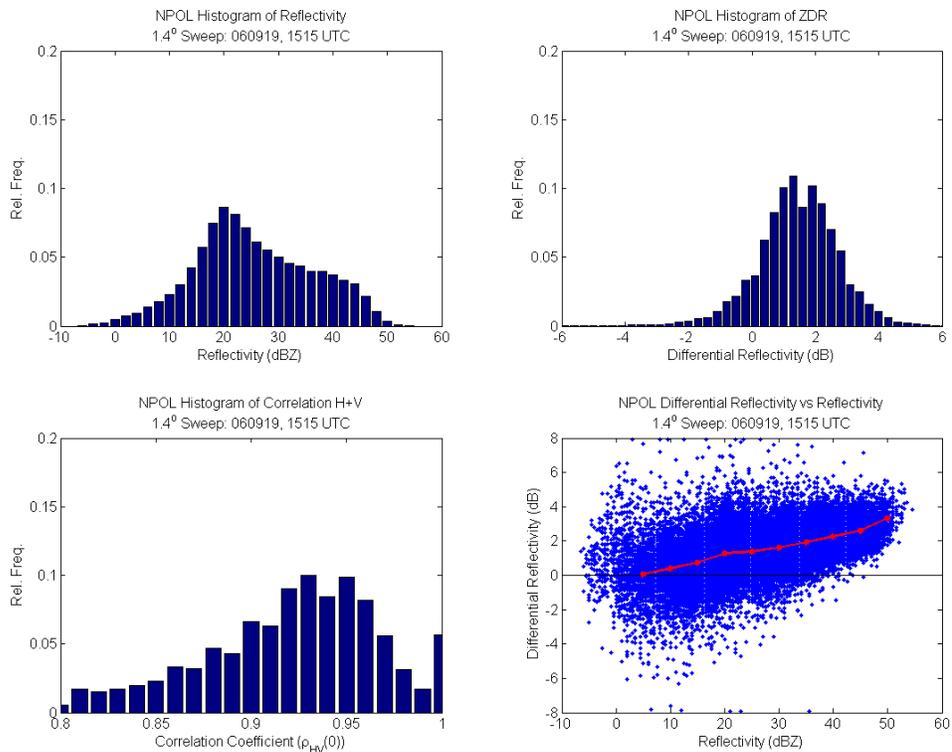


Figure 5: Same as Fig. 2 except for the correction 5 time period.

All other radar fields (Velocity, differential phase, etc.) required no calibration adjustments.

Data Products

For the NAMMA field campaign, four different radar products are available from NPOL:

- A. Quality control (QC) volume data
- B. Quick look gif files of the base reflectivity PPI images
- C. Six-level gridded Cartesian reflectivity maps at a 2 km horizontal resolution
- D. One-level gridded Cartesian rainfall rate map at a 2 km horizontal resolution

QC volume data

Radar data files (Universal Format (UF)) of unfiltered radar reflectivity “ZT”, uncorrected radar reflectivity “DZ”, corrected radar reflectivity “CZ”, radial velocity “VR”, spectral width “SW”, differential reflectivity “DR”, correlation “RH”, differential phase “PH”, and specific differential phase “KD”. The files have been organized by type (volume scan or surveillance), and have been subsetted into directories by day (060831/ : 31 August 2006). The filenames have the following format: NPOL_QC_YYMMDD_HHMM.uf.gz: (Example: NPOL_QC_060831_0900.uf.gz: NPOL QC’ed file for 31 August 2006 at 0900 UTC. The file is in UF format and has been gzipped). The “CZ” field was used to create the gridded reflectivity and rainfall map files described below.

Quick look reflectivity images

Individual image files (gif format) of uncorrected radar reflectivity created by the radar data acquisition and display software (IRIS: Interactive Radar Information System) used with NPOL are available for all the surveillance scans collected during NAMMA. The images provide a “snapshot” of storm activity out to a maximum range of 270 km from NPOL.

Gridded reflectivity files

Radar-reflectivity maps at a 2.0 km horizontal resolution and 2.0, 4.0, 6.0, 8.0, 10, and 12.0 km vertical levels were created and mapped to a 556 x 556 common grid that corresponds to a 10° x 10° latitude-longitude area centered on NPOL during NAMMA. The grid domain is larger than the maximum range of NPOL. However, this same grid has been developed to ingest TRMM PR for that region for longer-term climatological analysis. The Cartesian maps were created using software developed by the PI. The gridded files are stored in netCDF format. The reflectivity values are stored in units of dBZ. There are two flags in the files:

- 88.0: A grid outside the maximum range of NPOL
- 99.0: Inside the maximum range of NPOL, but no echo was detected

Gridded rainfall rate files

The gridded rainfall rate files have a similar format as the reflectivity files. They are mapped to the same common domain. The rainfall rates are mapped to one level at a height of 2 km. The units are in mm h⁻¹. There is one flag: -88.0, which corresponds to a grid outside the maximum range of NPOL. A value of 0.0 mm h⁻¹ indicates no echo was detected by NPOL.

Example Software

A variety of software packages are available to view and edit the data in UF format, including the NASA TRMM Office Radar Software Library (RSL) http://trmmfc.gsfc.nasa.gov/trmm_gv/index.html - follow the "software" link).

Contact the PI if you would like to work with the data in UF format or use sample software written using RSL. The PI can provide example software to read and manipulate the UF files.

An example program (netcdf2ascii.c) to read the netCDF product files has been included with the release. The following provides documentation on how to use the program. The general purpose of this program is to convert the netcdf files created for this project into a readable ASCII format. The general form of the output ascii file has three lines of header. The first holds the month, day, year, hour and minute. The second line holds the number of levels in the file, and the x and y dimensions of each level. The third line holds the height of each level. The rest of the data file is the 556 by 556 mapped grid of each level placed consecutively back to back. Example: A data file with 2 levels will have the first three lines of header information and the data will be printed to a 556 by 1112 array with the first level being the first 556 by 556 set of numbers and the second level will be the second set of 556 by 556 numbers.

Program example:

The command line to run this program looks as follows:

```
"netcdf2ascii -i infile -h height -x XDIM -y YDIM -S RadarID"
```

where "-i infile" indicates the netcdf file being analyzed, "-h height" indicates the height level in which the user wants written to the ascii file. A height value of ZERO (0) will tell the program to convert the all the levels. A value entered that is greater than zero will be analyzed to see if the dataset contains the desired height level. If the level is not in the dataset, the program will give an error message and exits the program. The -x and the -y input require the dimension of the grid: 556. They are command line input options in case the user would like to change the domain size. The "-S RadarID" is a string that identifies the radar name, which in this case would be NPOL. The format of the output file for the extraction of the whole dataset is as follows:

```
"RadarID_yymmdd_hrmn_rr.ascii"
```

or

```
"RadarID_yymmdd_hrmn_dz.ascii"
```

with "rr" and "dz" denoting the type of file being written (rr = rainmap, dz = reflectivity map), yy = year, mm = month, dd = day, hr = hour, and mn = minute of the data. The format of the output file for the extraction of one level of the dataset appears as:

```
"RadarID_yymmdd_hrmn_2kmrr.ascii"
```

or

```
"RadarID_ymmdd_hrmn_2kmdz.ascii"
```

with "2" being the height level printed, "rr" and "dz" denoting the type of file being written (rr = rainmap, dz = reflectivity map), yy = year, mm = month, dd = day, hr = hour, and mn = minute of the data.

A “makefile” has also been provided to accompany the code for compilation. As with any standard makefile, the locations of libraries used within the code must be specified, (if not found in a general location referenced by the compiler) as well as the locations of the header files; specifically the netcdf library, and the header files netcdf.h and hdf2netcdf.h.