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TECHNICAL REPORT

DWR Data Monitoring and Processing at NCMRWF

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1 Introduction

Doppler weather radar (DWR) plays an important role in detecting and forecasting severe weather, since it can probe the atmosphere with very high spatial and temporal resolution. India Meteorological Department (IMD) has installed four Doppler weather radars along the east coast of India for monitoring and forecasting the Bay of Bengal cyclones. These DWRs are located at Chennai, Kolkata, Machilipatnam and Visakhapatnam and were installed in the year 2002, 2003, 2004 and 2006 respectively replacing the old generation S-band cyclone detection radars at these stations. These DWRs are manufactured by GEMATRONIK GmbH and the radar observations are processed at the radar site using the RAINBOW application software (proprietary of GEMATRONIK Corporation). In addition to these radars on the east coast, there are plans to install more such radars for use in severe weather forecasting and airport weather warning. Very recently, two DWRs have been installed, one at the Delhi International Airport and another at Hyderabad in the year 2010. These two radars are manufactured by Beijing Metstar and data from these radars are processed using Sigmet IRIS software. Radar reflectivity (Z) and radial wind (V) measurements are two important DWR products which can be used to prepare the initial conditions for NWP models. Reflectivity is the backscattered radiation (originally emitted by the radar) from any object (target) along the radar beam in the direction of the radar scan. When the hydrometeors are present in the atmosphere, radar reflectivity is a measure of the radar signal reflected by the hydrometeors in atmosphere. The radial wind is estimated from the phase delay of the backscattered radiation from the moving targets according to Doppler effect.

1.1 Objective

Since November 2010, the DWR observations of reflectivity (Z), radial velocity (V) and spectrum width (W) are received at NCMRWF via GTS network (from India Meteorological Department) in near real time. It is important to monitor the DWR data received at NCMRWF and also to processes the data for use in the NWP models. With this objective, an operational system is developed and implemented at NCMRWF for 24×7 monitoring of DWR observations received at NCMRWF and also preparation of radar observation for WRF system. This report gives a brief technical summary of the DWR data monitoring and processing at NCMRWF.

1.2 DWR stations

At present the DWR observations from Delhi (28.56 °N, 77.07 °E), Hyderabad (17.44 °N, 78.47 °E), Chennai (13.07 °N, 80.28 °E), Machilipatnam (16.18 °N, 81.15 °E), Kolkata (22.57 °N, 88.35 °E) and Visakhapatnam (17.74 °N, 83.34 °E) are available at NCMRWF in near real time. The radars are operating in the S band (2 - 4 GHz) of radio wave frequency spectrum and provide data on reflectivity (Z) in dBZ, radial wind (V) in m/s and spectrum width (W) in m/s. The radars scan with a beam width of 1^{o}, thus creating 360 beams or *radials* of information per elevation angle (Roy Bhowmik et al., 2011). The scanning strategy followed by IMD consists of two coverage patterns, a long range scan for only reflectivity (Z) at lower elevation angles and short range scan of reflectivity, radial wind and spectrum width for all ten elevations. A sample volume coverage pattern of scan with elevation angle varying from 0.2 to 21 degrees is given in Figure 1. The scans cover more volume in the lower elevation angles than at higher elevations.

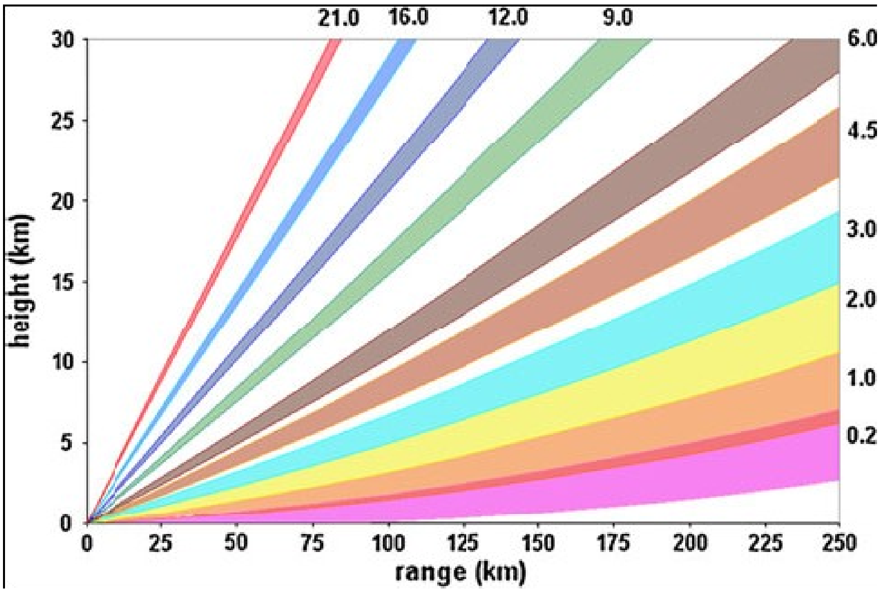

Figure 1 Volume coverage pattern of Indian radar stations (Roy Bhowmik et al, 2011)

The time interval between the start of two consecutive scans is approximately 10 minutes. The highest range of long range scan is 500 km and for short range scan it is 250 km. Detailed discussion on the functioning of IMD radars and the data quality control procedures are given in Roy Bhowmik et al. (2011).

1.3 DWR data file details

The DWR data for each elevation angle is represented as sweep1 to sweep10 in the ascending order of the elevation angle. The data from 10 sweeps is stored in 10 different files. These data files contain data on Z, V and W. Additionally various technical details of the scan are also included in each of the sweep files. Information about different combinations of signal qualifiers like SIG (signal level threshold), SQI (signal quality index), LOG (log receiver signal to noise ratio), CSR (clutter to signal ratio) for each parameter are also given in the file. Header information of a sample netCDF file is given in Appendix1. The missing values in the fields are represented as

"_" in the data file. The magnitude of the field ranges from -127 to 127. For each field a scale factor and an offset value are also given in the header to be applied at the time of processing the data. The start time of the radar sweep (*esStartTime)* and the precise time of each *radial* scan (*radialTime*) are specified as the time (seconds) elapsed from 00UTC of 1-1-1970 (see Appendix 1).

The location of each data point is given in terms of azimuth angle and elevation angle (*radialAzim*, *radialElev*) both expressed in degrees and range in meters. For any further use of the radar observation, the data has to be converted to geographical coordinates. The values of field parameter in the netCDF files are not actual values. These have to be further processed by applying scale factor and adding offset. These values are different for data from different radars. Following section provides description of the steps involved in the processing the DWR data.

2 Data Processing

2.1 Geo-location of the DWR fields.

The location of each data point given by range, azimuth, and elevation (relative to the radar location) is converted to geographical coordinates (latitude, longitude and altitude) using the equations given below (Doviak and Zrnic, 1993, Liang et al, 2006). In the spherical coordinate system azimuth is zero at north and increases clockwise, the elevation angle increases up wards, the range is zero at the radar and increases away from the radar (Liang et al., 2006). The range (S) is computed using information from the distance to first *range bin* (S_1) and distance between two *range bins* (ΔS) which are given in the header of the netCDF file using equation (1).

$$\mathbf{S = (S_1 + \Delta S \times n)} \quad (1)$$

-where (n = 1,2,3,4 …corresponding to bin value)

Altitude is computed based on range (S) and elevation (θ) using equation 2

$$\mathbf{h = (((S)^2 + ((4/3)\times R)^2 + 2\times S\times(4/3)\times R\times\sin(\theta))^{1/2} - ((4/3)\times R) + (h_r/1000))} \quad (2)$$

where

-h is the altitude of observation point above mean sea level in kilometers

- θ is elevation angle in radians,

- h_r is radar height in meter,

-R is radius of earth (6371 km).

The location latitude (λ) and longitude (φ) of the observation point is computed using equations (3) and (4)

$$\lambda = \lambda_r + ((180/\pi)\times\alpha\times\cos(\psi)) \quad (3)$$

$$\varphi = \varphi_r + (180/\pi)\times(\sin^{-1}(\sin(\psi)\times\sin(S_2/R)/\cos(\lambda\times(\pi/180))) \quad (4)$$

where

- λ_r is radar latitude,

- φ_r is radar longitude,

- ψ is azimuth angle in radians,

- $S_2=(4/3)\times R\times\sin^{-1}(S\times\cos(\theta)/(((4/3)\times R)+h_r))$ and

- $\alpha = (S_2/R)$.

The geo-located values of radial wind and reflectivity are further processed by

-applying scale factor

-applying the add_offset

Both these factors are specific to each of the DWRs and the factors are obtained from the DWR data header. The processed data of radial wind and reflectivity for the New Delhi DWR is shown in Figure 2. The panels on the left are the graphics obtained from the IMD website and panels on the right are the graphics obtained after processing the DWR data at NCMRWF. The top two panels correspond to the radial wind (V) and the bottom panels show reflectivity (Z) corresponding to 13:52 UTC of 7th February 2011. The reflectivity scales in the right panels are similar to those on the left panels, though not identical. A comparison of these panels clearly shows that the location and magnitude of peak echoes and the variability in patterns of both fields is correctly reproduced after processing the data at NCMRWF.

2.2 DWR data monitoring at NCMRWF

The DWR data monitoring report consist of two parts. First part gives information about number of sweep files available for each station corresponding to 00, 06, 12 and 18 UTC with a time cut off ± 3 hours. Second part gives information about the total number of observations available for each parameter for each of the 10 elevation angles. This is done by counting the number of non-missing values in each file for a particular sweep corresponding to 00, 06, 12 and 18 UTC with a cut off ± 3 hours. The same is done for both radial wind and reflectivity and different sweeps. The number of observations is indexed from 0 to 5 as given in Table1. Separate reports are prepared for reflectivity and radial wind for every 00 06 12 and 18 UTC. A sample report is given in Appendix 2. The total number of observation points varies with prevailing synoptic condition. In general convective conditions result in high echo and more number of observations.

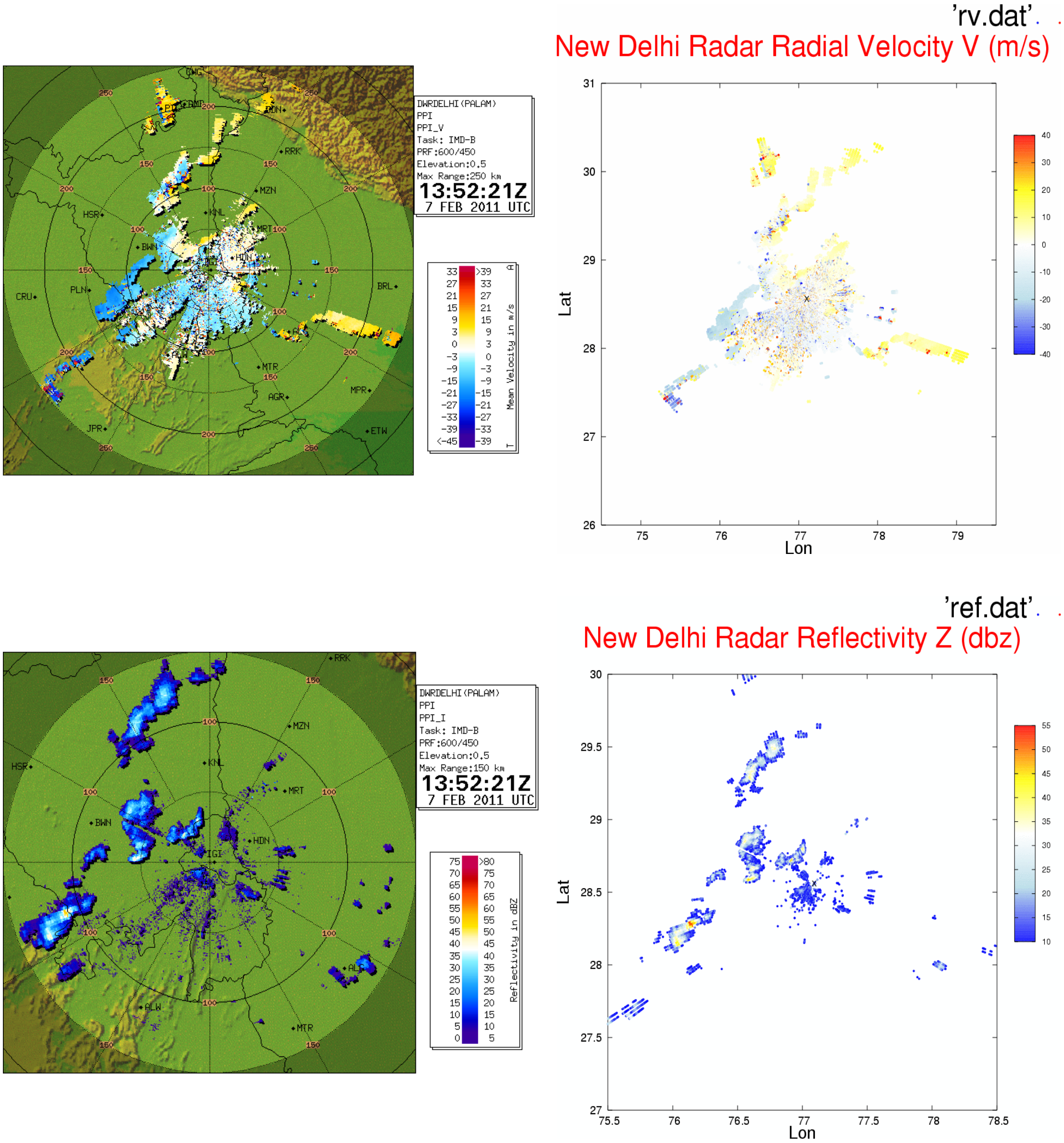

Figure 2. New Delhi DWR observations of radial wind (V) and reflectivity (Z). Panels on the left are graphics obtained from IMD and panels on the right are based on the data processed at NCMRWF

Table 1 DWR monitoring report.

Index	Number of observations
0	0
1	1<10000
2	10000<100000
3	100000<1000000
4	1000000<5000000
5	≥5000000

2.3 Preparation of data for WRV-VAR

In addition to the monitoring of reflectivity and radial wind observations, the data is also packed in the required format for assimilation in WRF model. The DWR data on reflectivity (Z) and radial wind (V) for each sweep corresponding to times 00, 06, 12 and 18 UTC with a cut off ± 30 minutes is prepared for assimilation in WRF model. The negative and low positive values of reflectivity are not included since they represent very low rain rate or snow (*www.vaisala.com*). The reflectivity observation less than 10 dBZ is ignored. The observations coming in the altitude range 0.2 to 18 km is only considered. This is to avoid ground clutter and to limit observations up to tropopause level. Input file for assimilation in WRF model is prepared in ASCII format conforming to the model specifications. A sample file of the data prepared for assimilation is given in Appendix 3.

3. Concluding Remarks

The scope and purpose of this report is to provide a technical description of the operational monitoring and processing of DWR data at NCMRWF. It is important to note that-

- The monitoring of the DWR data is done as per the other conventional data monitored at NCMRWF (i.e., with ± 3 hour time window for each assimilation cycle).

- The DWR data preparation for assimilation takes into account only the data with a ± 30 min., time window and is tailored for the WRF-VAR system.

There are several aspects of data pre-processing prior to assimilation which are to be taken up for future work. These are summarized below.

- The DWR data commonly feature non-meteorological returns. These generally require interactive editing of the DWR data to either recover or filter unwanted echoes.
- Quality control of the data is an important step prior to data assimilation. Too many bad-quality data could ruin the analyses. It requires one to conducted several experiments with and without removal of the unwanted radar data to arrive at a conclusion regarding the data quality. In an operational environment, an objective approach for DWR data quality control is necessary.
- The DWR data are sampled on spherical coordinates (range, azimuth, and elevation) with a resolution that is much higher than that of the operational NWP models. It is important to process the data to a regular grid at a resolution that is compatible with the analysis system. Data thinning and projection on to the model grids reduces redundant data (especially near the radar) and high-frequency features that cannot be resolved by the numerical model.
- Several experiments have to be carried out for various case studies involving deep convection/severe weather to test the assimilation and forecast system before making it in operational use.
- It is also important to pack the DWR data in the standard BUFR format for use in the global forecast system.

References

Doviak R J and D. S. Zrnic 1993: Doppler radar and weather observations, Academic Press, San Diego, California.

Liang T J, Carbone R, Rutledge S A, Ahijevych D and Nesbitt S W, Name 2006: Regional radar composites version2, (*http://radarmet.atmos.colostate.edu/name/composites*).

Roy Bhowmik S K, Soma Sen Roy, Kuldeep Srivastava, B. Mukhopadhay, S. B. Thampi, Y. K. Reddy, Hari Sing, S. Venkateswarlu and Sourav Adhikari 2011: Processing of Indian Doppler weather radar data for mesoscale applications, Meteorol. Atmos Phys, 2011, DOI: 10.1007/s00703-010-0120-x.

HydroClass – Superior hydrometeor classification through fuzzy logic, (*www.vaisala.com*).

Appendix 1

```
netcdf T_HAHA00_C_VECC_20110223003809_RAWsweep2 {
dimensions:
        bin = 750 ;
        radial = 360 ;
        sweep = 2 ;
variables:
        double esStartTime ;
                esStartTime:units = "seconds since 1970-1-1 00:00:00.00" ;
                esStartTime:long_name = "Start time of elevation scan" ;
        short elevationNumber ;
                elevationNumber:units = "count" ;
        float elevationAngle ;
                elevationAngle:units = "degree" ;
                elevationAngle:long_name = "average of last 20 radialElev";
        float radialAzim(radial) ;
                radialAzim:units = "degree" ;
                radialAzim:long_name = "Radial azimuth angle" ;
        float radialElev(radial) ;
                radialElev:units = "degree" ;
                radialElev:long_name = "Radial elevation angle" ;
        double radialTime(radial) ;
                radialTime:units = "seconds since 1970-1-1 00:00:00.00" ;
                radialTime:long_name = "Time of radial" ;
        float siteLat ;
                siteLat:units = "degrees_north" ;
                siteLat:long_name = "Latitude of site" ;
        float siteLon ;
                siteLon:units = "degrees_east" ;
                siteLon:long_name = "Longitude of site" ;
        float siteAlt ;
                siteAlt:units = "meter" ;
                siteAlt:long_name = "Altitude of site above mean sea level" ;
        float firstGateRange ;
                firstGateRange:units = "meter" ;
                firstGateRange:long_name = "Range to 1st gate" ;
        float gateSize ;
                gateSize:units = "meter" ;
                gateSize:long_name = "Gate spacing" ;
        float nyquist ;
                nyquist:units = "meter/second" ;
                nyquist:long_name = "Nyquist velocity" ;
        float unambigRange ;
                unambigRange:units = "kilometer" ;
                unambigRange:long_name = "Unambiguous range" ;
        float calibConst ;
                calibConst:units = "dB" ;
                calibConst:long_name = "System gain calibration constant" ;
        float radarConst ;
                radarConst:units =  ;
                radarConst:long_name = "Radar Constant" ;
        float beamWidthHori ;
                beamWidthHori:units = "degrees" ;
                beamWidthHori:long_name = "Horizontal Beam Width" ;
        float pulseWidth ;
                pulseWidth:units = "usec" ;
                pulseWidth:long_name = "Pulse Width" ;
        float bandWidth ;
                bandWidth:units = "hertz" ;
                bandWidth:long_name = "Band Width" ;
        short filterDop ;
                filterDop:long_name = "Ground clutter filter information" ;
        float elevationList(sweep) ;
                elevationList:units = "degree" ;
                elevationList:long_name = "Elevation list of the task" ;
        float azimuthSpeed ;
                azimuthSpeed:units = "degree/second" ;
```

```
		azimuthSpeed:long_name = "Speed of Azimuth" ;
	float highPRF ;
		highPRF:units = "Hz" ;
		highPRF:long_name = "High PRF" ;
	float lowPRF ;
		lowPRF:units = "Hz" ;
		lowPRF:long_name = "Low PRF" ;
	float dwellTime ;
		dwellTime:units = "millisecond" ;
		dwellTime:long_name = "Dwell time of pulses" ;
	float waveLength ;
		waveLength:units = "cm" ;
		waveLength:long_name = "Radar Wave Length" ;
	float calI0 ;
		calI0:units = "dBm" ;
		calI0:long_name = "Intercept of fit line with Noise Level" ;
	float calNoise ;
		calNoise:units = "dBm" ;
		calNoise:long_name = "Calibration Noise" ;
	float groundHeight ;
		groundHeight:units = "meter" ;
		groundHeight:long_name = "Radar Site,Ground Height" ;
	float meltHeight ;
		meltHeight:units = "meter" ;
		meltHeight:long_name = "Melting Layer Height" ;
	int scanType ;
		scanType:units =  ;
		scanType:long_name = "0(Unknown),1(PPI Sector),2(RHI Sector),4(PPI
Full),7(RHI Full)" ;
	float angleResolution ;
		angleResolution:units = "degree" ;
		angleResolution:long_name = "Antenna Angle Resolution" ;
	float logNoise ;
		logNoise:units =  ;
		logNoise:long_name = "LOG Channel Noise" ;
	float linNoise ;
		linNoise:units =  ;
		linNoise:long_name = "Linearized LOG Power Noise" ;
	float inphaseOffset ;
		inphaseOffset:units =  ;
		inphaseOffset:long_name = "Inphase Offset" ;
	float quadratureOffset ;
		quadratureOffset:units =  ;
		quadratureOffset:long_name = "Quadrature Offset" ;
	float logSlope ;
		logSlope:units =  ;
		logSlope:long_name = "LOG conversion Slope" ;
	int logFilter ;
		logFilter:units =  ;
		logFilter:long_name = "Log filter used on first bin" ;
	int filterPntClt ;
		filterPntClt:units =  ;
		filterPntClt:long_name = "Side skip in low 4 bits, 0=feature off" ;
	float filterThreshold ;
		filterThreshold:units = "dB" ;
		filterThreshold:long_name = "Point Clutter Threshold" ;
	int sampleNum ;
		sampleNum:units =  ;
		sampleNum:long_name = "Sample Number" ;
	float SQIThresh ;
		SQIThresh:long_name = "Signal Quality Index Threshold" ;
	float LOGThresh ;
		LOGThresh:units = "dB" ;
		LOGThresh:long_name = "LOG noise threshold " ;
	float SIGThresh ;
		SIGThresh:units = "dB" ;
		SIGThresh:long_name = "Signal power threshold" ;
	float CSRThresh ;
		CSRThresh:units = "dB" ;
```

```
                CSRThresh:long_name = "Clutter Correction threshold " ;
        int DBTThreshFlag ;
                DBTThreshFlag:units =  ;
                DBTThreshFlag:long_name = "UnCorrected Z flags.(Bit 1 for LOG, 2 for
SIG, 3 for SQI, 4 for CSR)" ;
        int DBZThreshFlag ;
                DBZThreshFlag:units =  ;
                DBZThreshFlag:long_name = "Corrected Z flags. see also DBTThreshFlag. "
;
        int VELThreshFlag ;
                VELThreshFlag:units =  ;
                VELThreshFlag:long_name = "Velocity flags. see also DBTThreshFlag. " ;
        int WIDThreshFlag ;
                WIDThreshFlag:units =  ;
                WIDThreshFlag:long_name = "Spectral Width flags. see also
DBTThreshFlag. " ;
        float beamWidthVert ;
                beamWidthVert:units = "degree" ;
                beamWidthVert:long_name = "Vertical Beam Width" ;
        byte Z(radial, bin) ;
                Z:units = "dBZ" ;
                Z:long_name = "Reflectivity" ;
                Z:polarization = "Horizontal" ;
                Z:scale_factor = 0.5f ;
                Z:add_offset = 32.f ;
                Z:valid_range = -127b, 127b ;
                Z:below_threshold = -128b ;
                Z:_FillValue = -128b ;
        byte V(radial, bin) ;
                V:units = "meters/second" ;
                V:long_name = "Velocity" ;
                V:polarization = "Horizontal" ;
                V:scale_factor = 0.164252f ;
                V:add_offset = 0.f ;
                V:valid_range = -127b, 127b ;
                V:below_threshold = -128b ;
                V:_FillValue = -128b ;
        byte W(radial, bin) ;
                W:units = "meters/second" ;
                W:long_name = "Spectrum Width" ;
                W:polarization = "Horizontal" ;
                W:scale_factor = 0.08148438f ;
                W:add_offset = 10.43f ;
                W:valid_range = -127b, 127b ;
                W:below_threshold = -128b ;
                W:_FillValue = -128b ;

// global attributes:
                :Content = "This file contains one scan of remotely sensed data" ;
                :history = "Encoded into netcdf from IRIS data" ;
                :title = "IRIS data" ;
                :Conventions = "FSL netCDF" ;
}
```

Appendix 2

RADAR (DWR) DATA MONITORING AT NCMRWF
(21 UTC 20110305 to 03 UTC 20110306)

No. of #### Station
Scans
----
458 NEWDELHI
432 HYDERABAD
0 CHENNAI
0 VIZAG
432 MACHILIPATNAM
352 KOLKATA

Following is the summary of the Radar observations. Summary is in the form 'Index' of total number of observations from each radar scan at 10 elevation angles (10 rows). This summary corresponds to all radar observations available at NCMRWF with a cut off of -03 and +03 hours. (Index-Described in the end.)

NewDelhi 06 03 2011 data availability (Z)
1
2
1
1
1
1
1
1
1
1
Hyderabad 06 03 2011 data availability (Z)
2
2
2
2
2
1
1
1
1
1
Chennai 06 03 2011 data availability (Z)
0
0
0
0
0
0
0
0
0
0
Machilipatanam 06 03 2011 data availability (Z)
2
2
1

1
1
1
1
1
1
1
vizag 06 03 2011 data availability (Z)
0
0
0
0
0
0
0
0
0
0
kolkata 06 03 2011 data availability (Z)
0
0
0
0
0
0
0
0
0
0
Description
Data availability[sweep,time (00 UTC)]
sweep correspond to sweep number
0=0 1=<10000 2=<100000 3=<1000000 4=<5000000 5=≥5000000

Appendix 3

```
TOTAL RADAR =  01

RADAR    IMD        77.072    28.560     235.0  2011-03-06_00:20:23    35   100

FM-128 IMD     2011-03-06_00:20:23        28.593         77.087     235.0        1
          376.0 -888888.000 -88       1.000        12.000   0        1.000
FM-128 IMD     2011-03-06_00:20:23        28.593         77.088     235.0        1
          376.0 -888888.000 -88       1.000        11.500   0        1.000
FM-128 IMD     2011-03-06_00:20:23        28.593         77.089     235.0        1
          376.0 -888888.000 -88       1.000        22.500   0        1.000
FM-128 IMD     2011-03-06_00:20:23        28.625         77.108     235.0        1
          519.0 -888888.000 -88       1.000        11.500   0        1.000
FM-128 IMD     2011-03-06_00:20:23        28.625         77.108     235.0        1
          519.0 -888888.000 -88       1.000        11.000   0        1.000
FM-128 IMD     2011-03-06_00:20:23        28.633         77.112     235.0        1
          555.0 -888888.000 -88       1.000        10.500   0        1.000
FM-128 IMD     2011-03-06_00:20:23        28.595         77.104     235.0        1
          411.0 -888888.000 -88       1.000        14.500   0        1.000
FM-128 IMD     2011-03-06_00:20:23        28.602         77.110     235.0        1
          447.0 -888888.000 -88       1.000        16.500   0        1.000
FM-128 IMD     2011-03-06_00:20:23        28.602         77.110     235.0        1
          447.0 -888888.000 -88       1.000        11.500   0        1.000
FM-128 IMD     2011-03-06_00:20:23        28.595         77.105     235.0        1
          411.0 -888888.000 -88       1.000        10.500   0        1.000
FM-128 IMD     2011-03-06_00:20:23        28.601         77.111     235.0        1
          447.0 -888888.000 -88       1.000        13.500   0        1.000
FM-128 IMD     2011-03-06_00:20:23        28.612         77.129     235.0        1
          519.0 -888888.000 -88       1.000        14.000   0        1.000
FM-128 IMD     2011-03-06_00:20:23        28.624         77.144     235.0        1
          591.0 -888888.000 -88       1.000        11.000   0        1.000
FM-128 IMD     2011-03-06_00:20:23        28.616         77.138     235.0        1
          555.0 -888888.000 -88       1.000        11.500   0        1.000
```