RADAR INPUTS

TC MONITORING & PREDICTION

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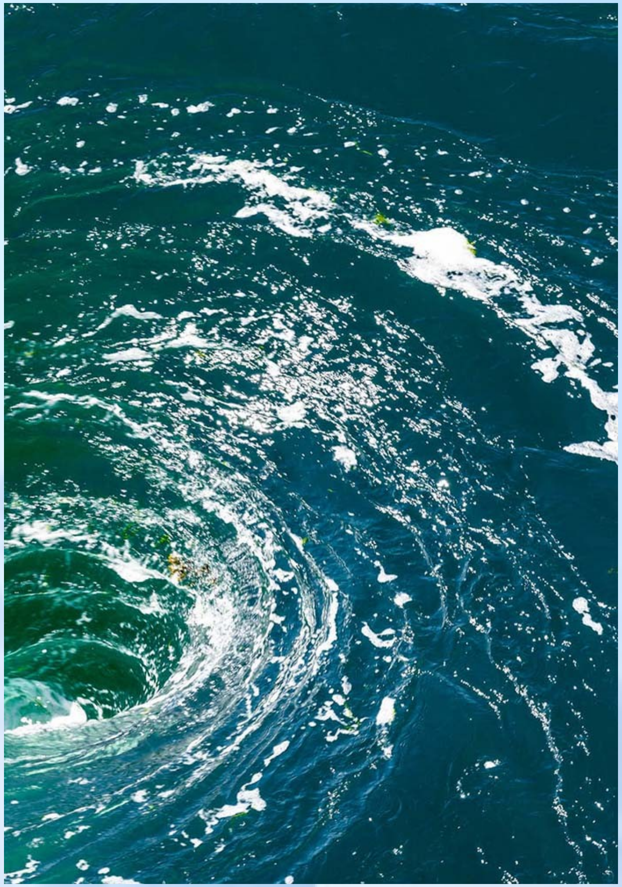
भारत मौसम विज्ञान विभाग
INDIA METEOROLOGICAL DEPARTMENT

Discussion with WMO-ESCAP-II meet

05.04.2022

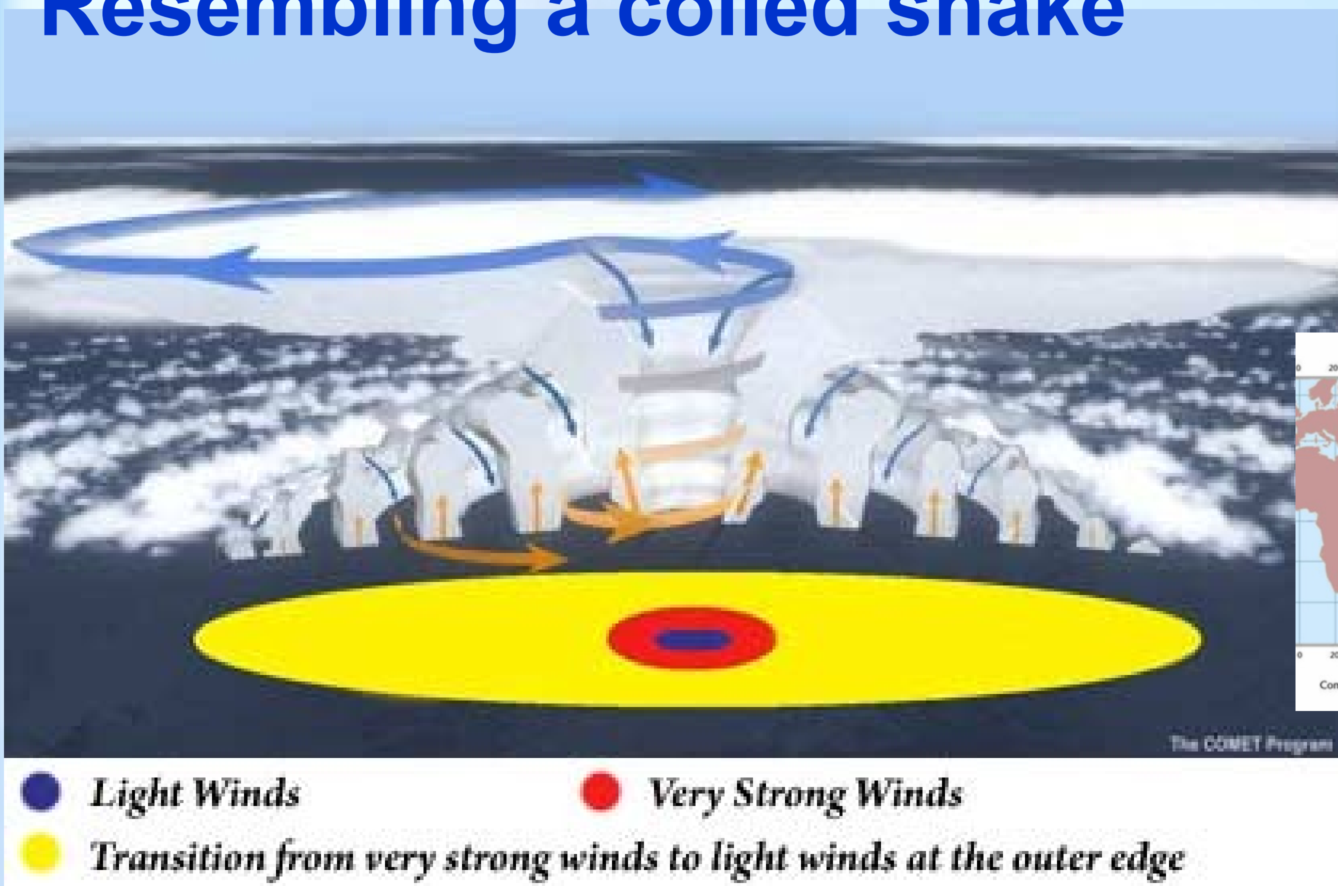
Predictability – Novelty – Vagaries

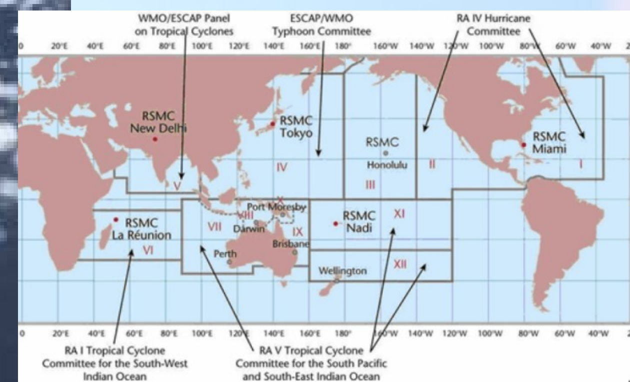


SIMPLIFIED

swirling moist air mass
Resembling a coiled snake

Nomenclature	Wind
Low	< 17kt
Depression	17kt – 27kt
Deep depression	28kt – 33kt
Cyclonic storm	34kt – 47kt
Severe cyclonic storm	48kt – 63kt
Very severe cyclonic storm	64kt – 90kt
Extremely severe cyclonic storm	91kt – 119kt
Super cyclonic storm	120kt and more



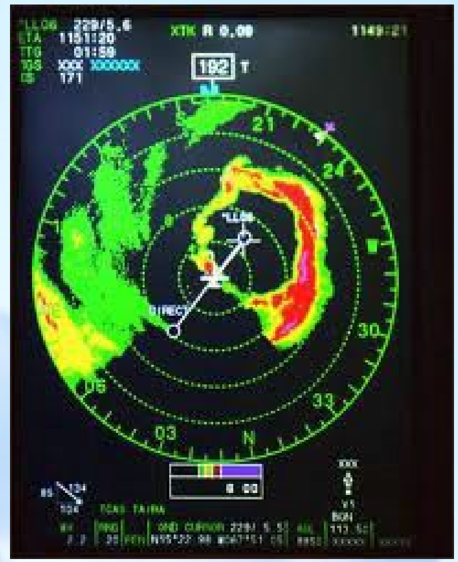


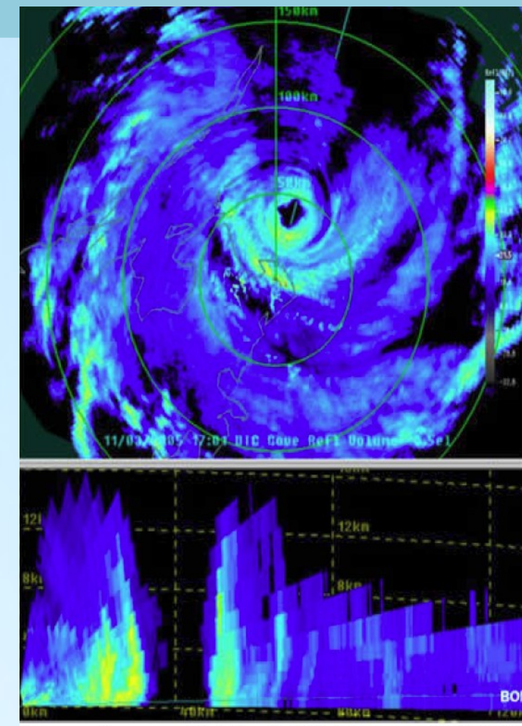
Role Mechanism: CISK

$P = f\,(\zeta+5)\,(S_z+3)^{-1}\,E\,(\partial\theta_e/\partial p + 5)\,(RH-40)/30$ Threshold 73×10^{-8} Cal°Ksec^{-1}Cm^{-3}

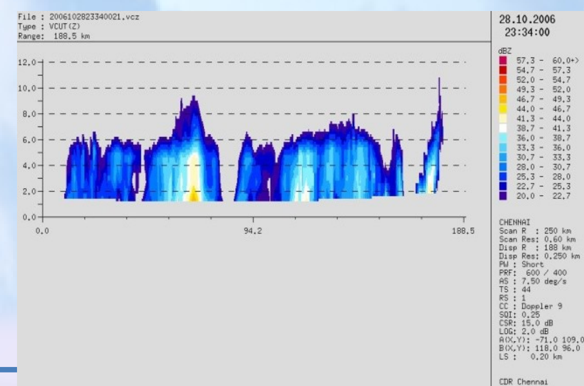
OBSERVED by Radar

- **System pattern/features**
  - Shape
  - Cloud cover and type
  - Spread
  - Orientation
  - Intensity
- **System Parameters**
  - Location
  - Centre
  - Eye (dia. & features)
  - RMR, RMW
- **System Tendency & Movement**
- **Other Relevant Derived info.**
  - Wind Fields
  - RF
  - Turbulence



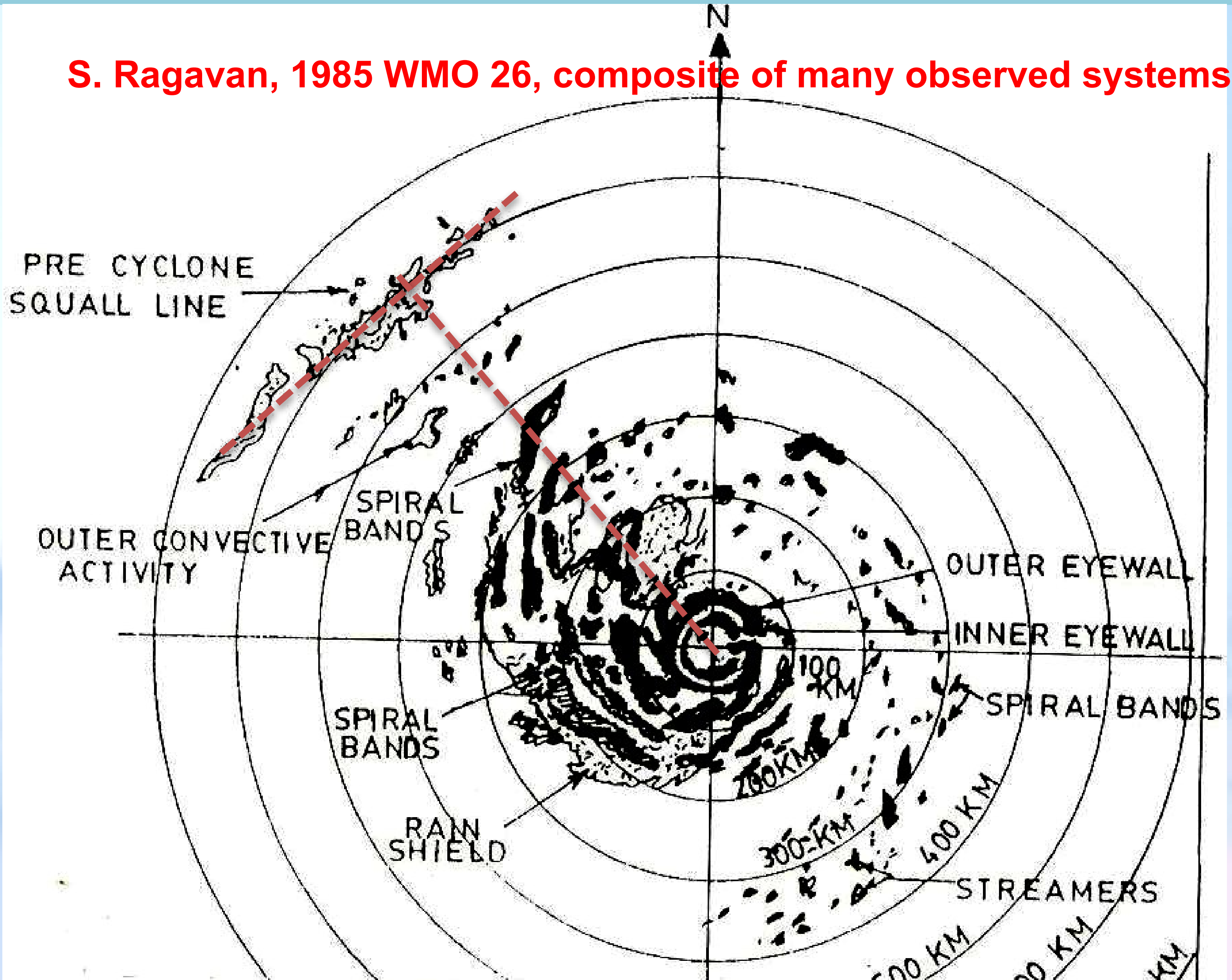


Gove radar 11 March 2005 1700 UTC
courtesy Australian Bureau of Meteorology



Radar observed Cyclone features

S. Ragavan, 1985 WMO 26, composite of many observed systems



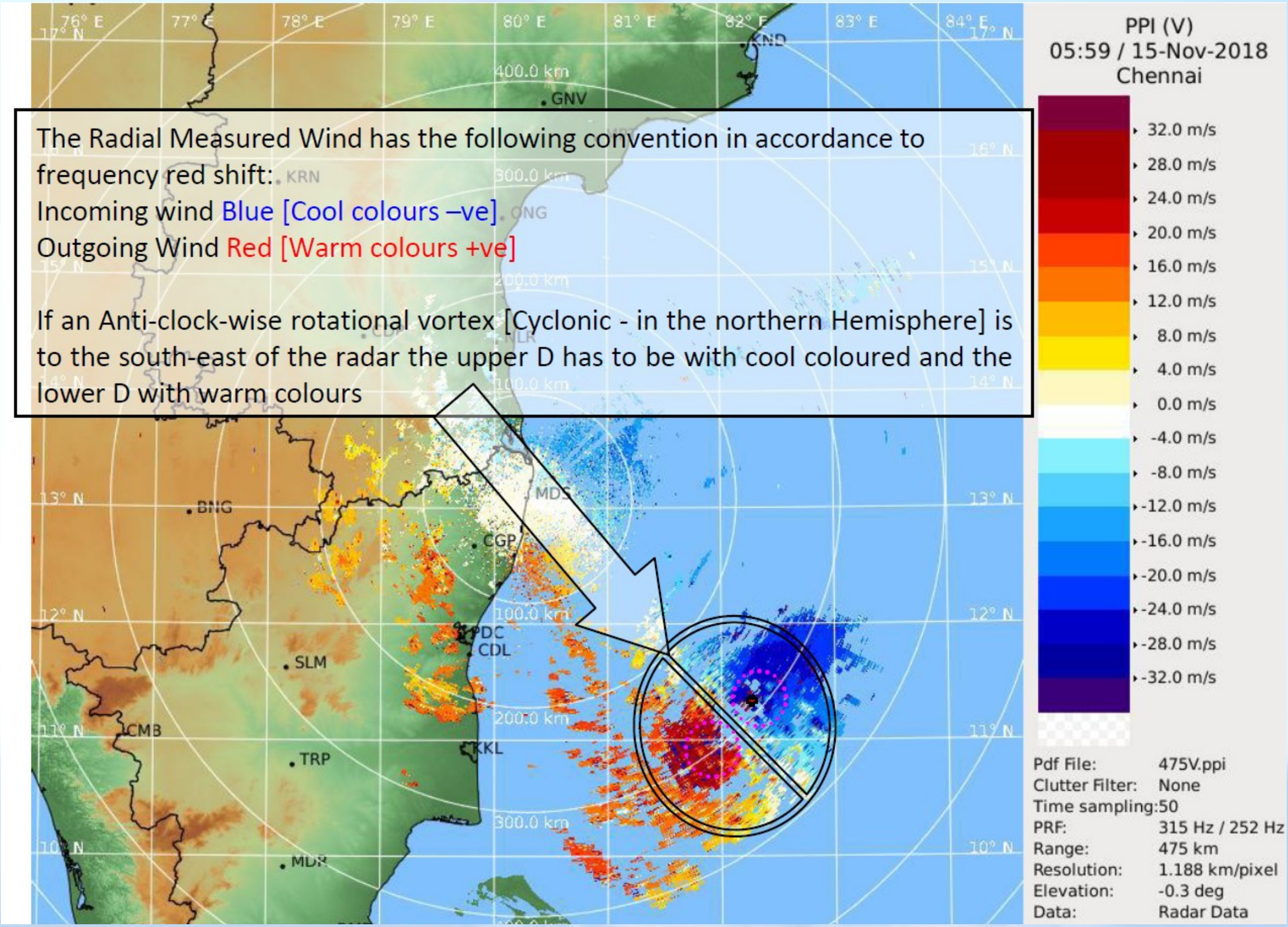
Radar observed Cyclone features

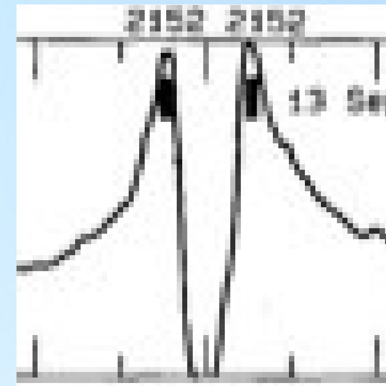
The Radial Measured Wind has the following convention in accordance to frequency red shift:

Incoming wind Blue [Cool colours –ve]

Outgoing Wind Red [Warm colours +ve]

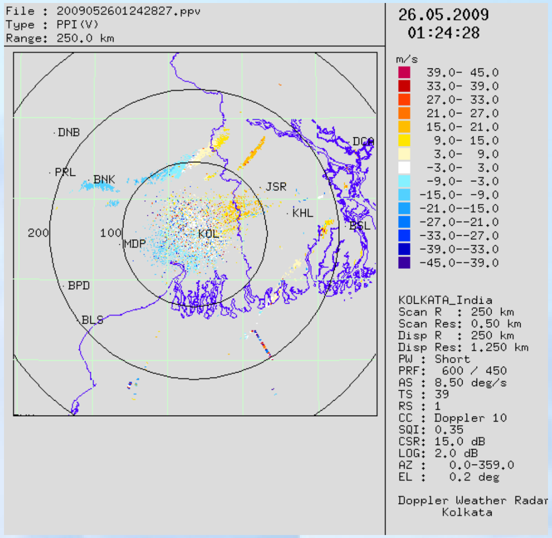
If an Anti-clock-wise rotational vortex [Cyclonic - in the northern Hemisphere] is to the south-east of the radar the upper D has to be with cool coloured and the lower D with warm colours



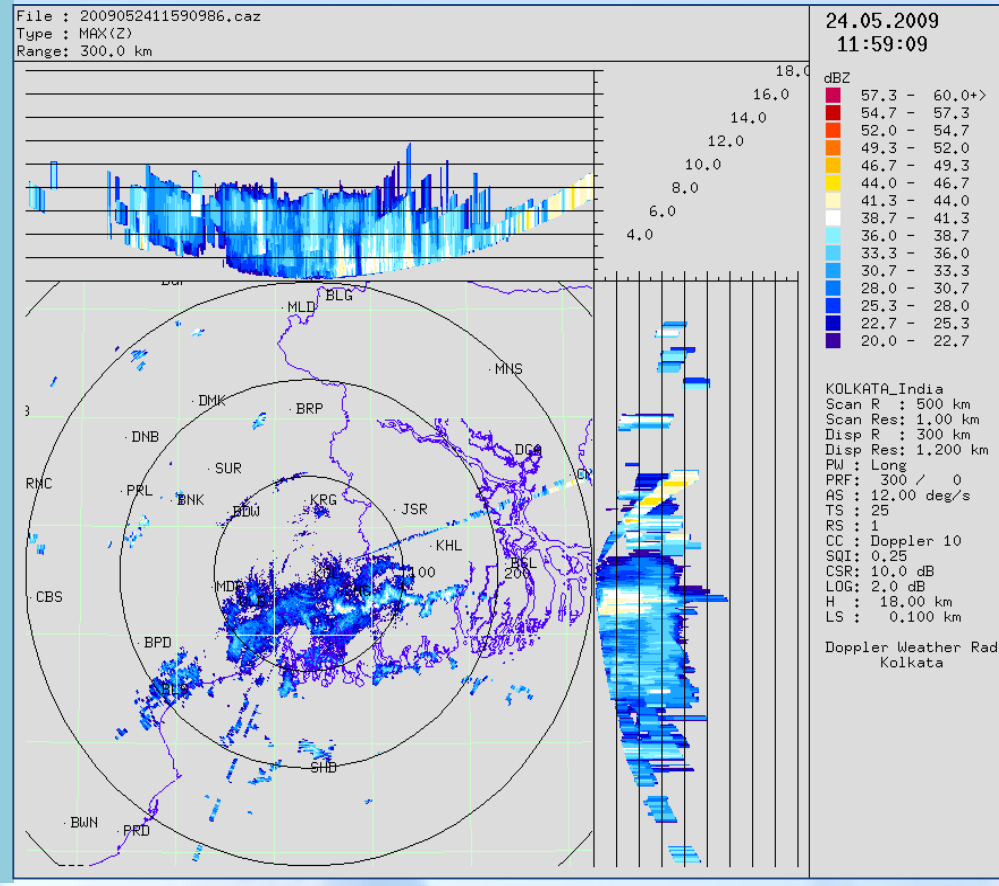


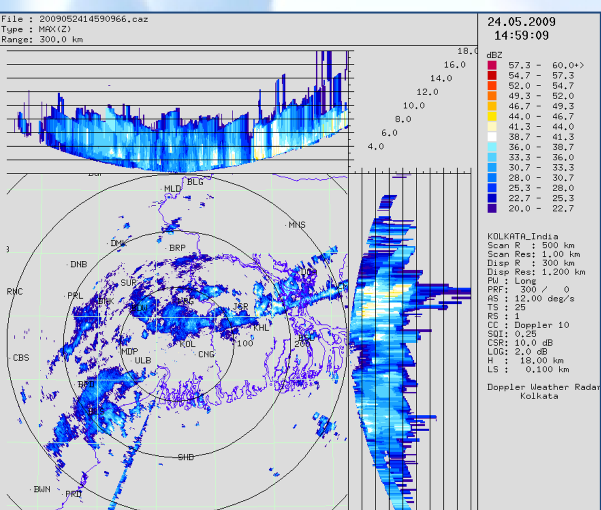
Movement prediction

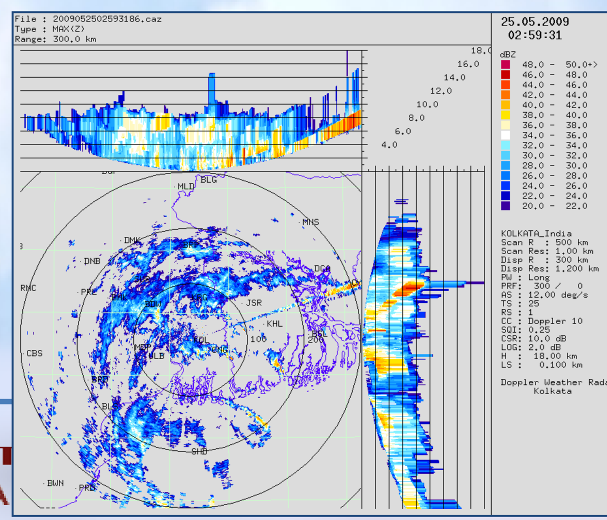
- Squall line indicator
- Squall line movement (Gust front, Bright band)
- Automated track
- Playback & extrapolate

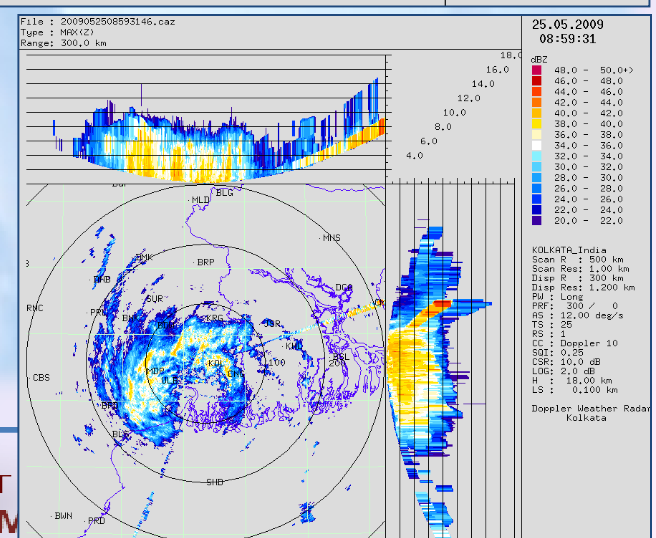


Cyclone movement

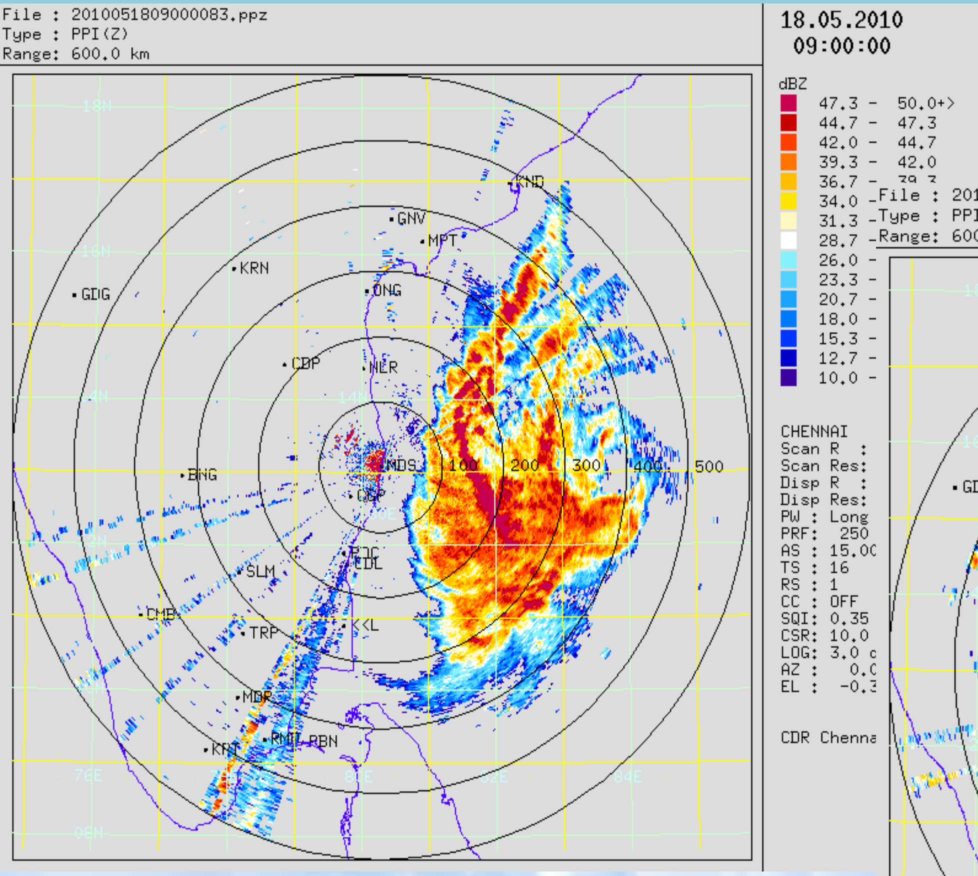


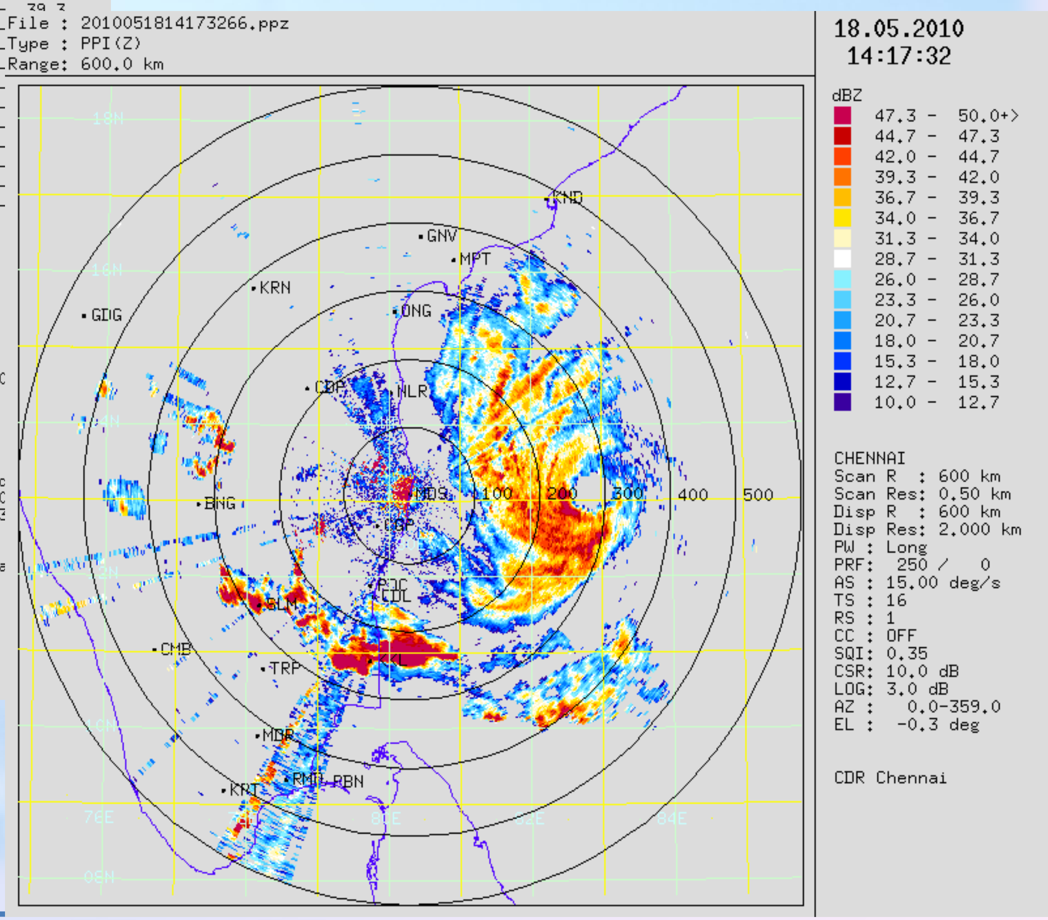






Probable movement





Center identifying

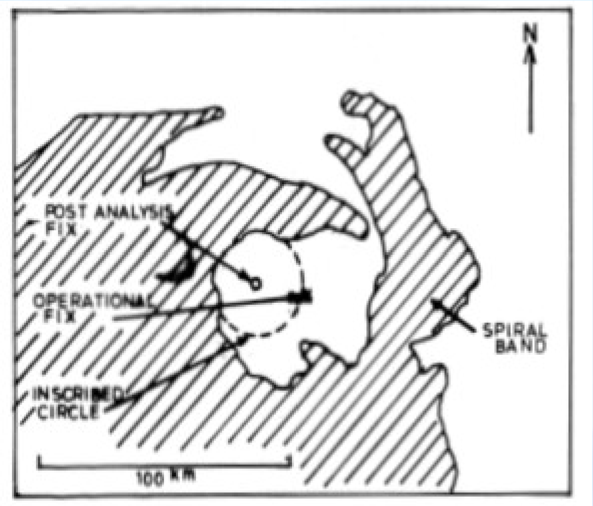
- ❖ **Meighen's method**
- ❖ **Logarithmic spiral**
- ❖ **Velocity doublet**
- ❖ **Zero isotach line**
- ❖ **Animated Sequence**

System intensification – eye reveals

RMV at the eye wall region (RMR)

- Intense TC's shall be even without an eye (Weatherford and Gray 1988).
- cyclone too close - partial eye is observed - sub-refraction (Raghavan etal 1980)
- The farther side is not usually seen - ray attenuation
- Eye of intense TC tends to be circular, Ellipses/polygons/irregular shapes are common (Lewis and Hawkins 1982, Muramatsu 1986).
- The eye shape varies with time and also rotate around center.
- Eye distorted due to radar observational limitations, and rotation may be spurious

Fixing of centre



Meighen's method yields a different center position and a different eye size.
Fixes obtained by his method gives smoother track .

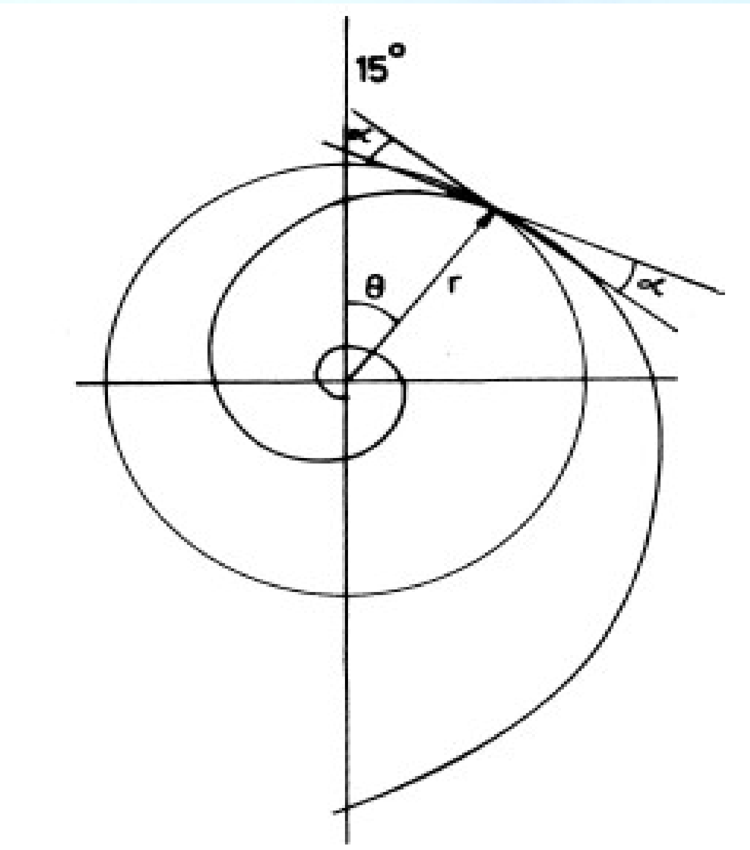
Fixing of centre

Logarithmic spiral of CS reveals the system centre through spiral fit

Each organized spiral may have a different center

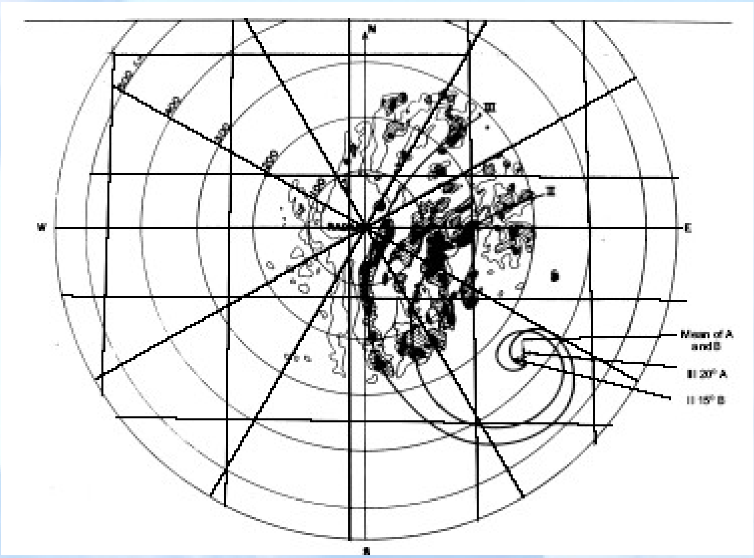
Cross angle is considered to be reflecting the intensity and organization of the system

$$r = Ae^{\theta \tan \alpha}$$

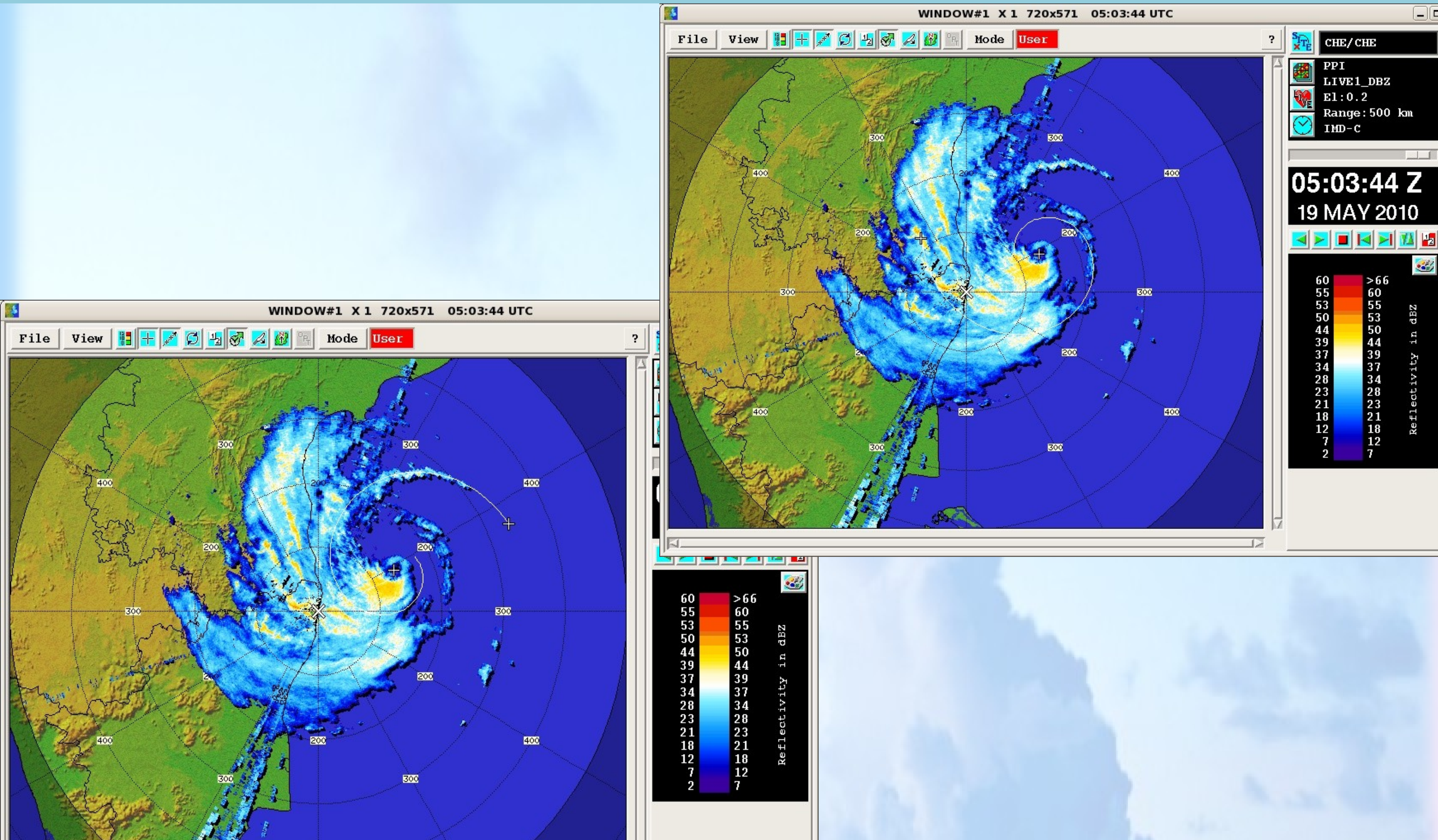


System intensification – eye reveals

During eye formation the inner most SCS has cross angle zero

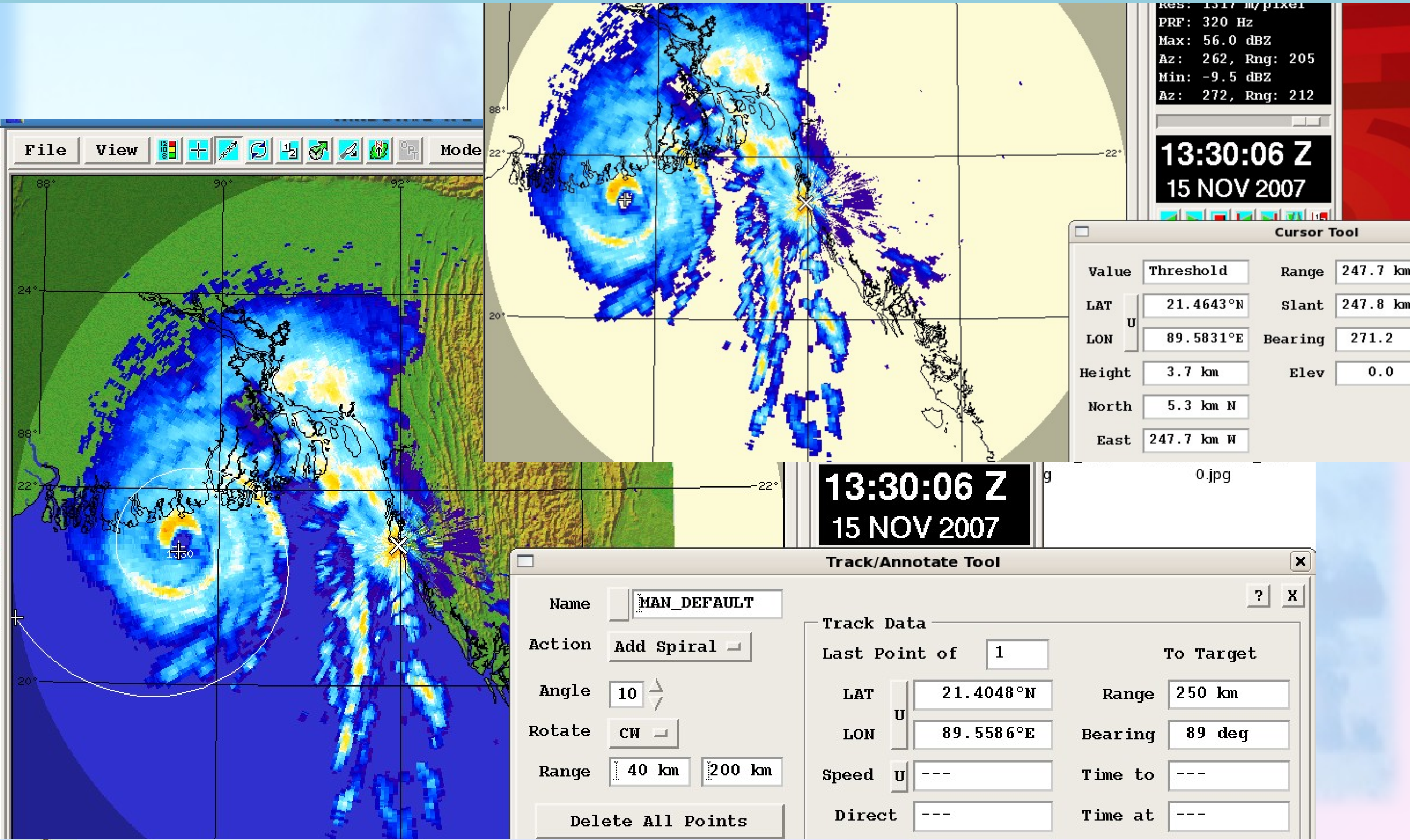


LOG SPIRAL FIX

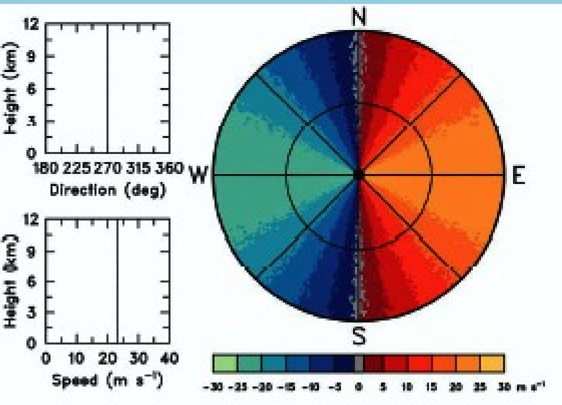


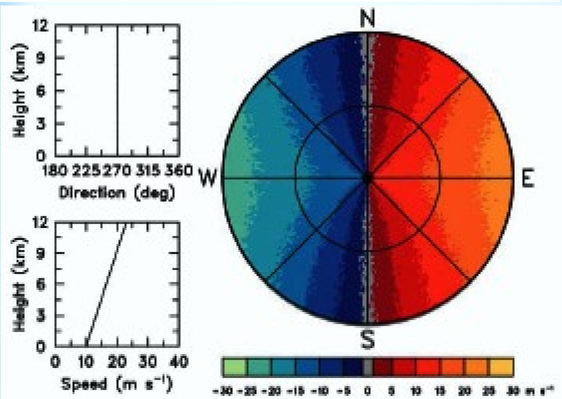
Radar Cyclone center: 13.6325°N 81.4065°E

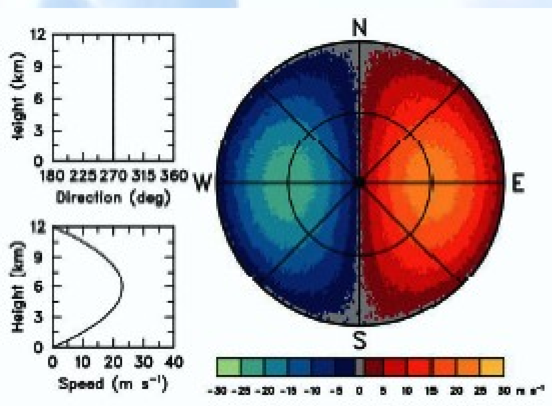
Center Log spiral and Meighen's

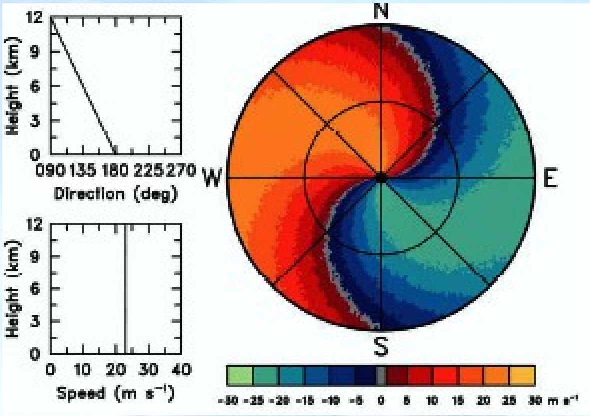


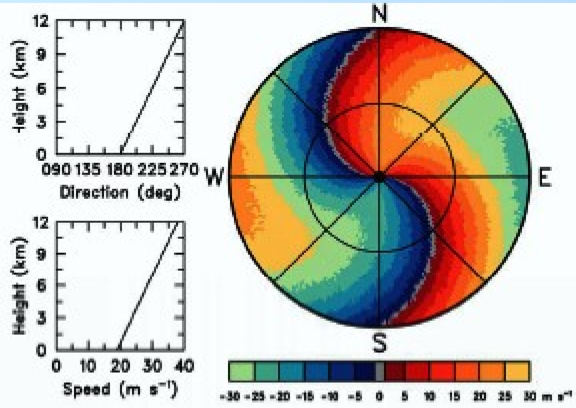
Wind Analysis

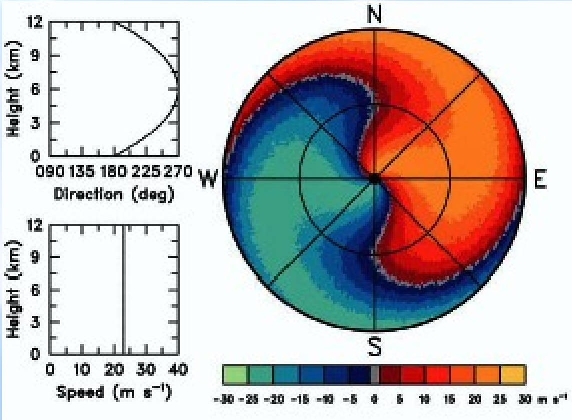


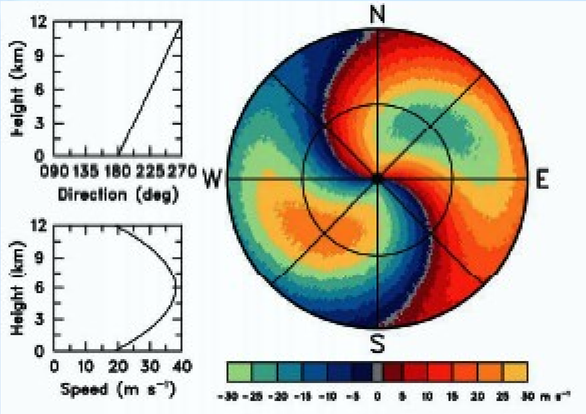




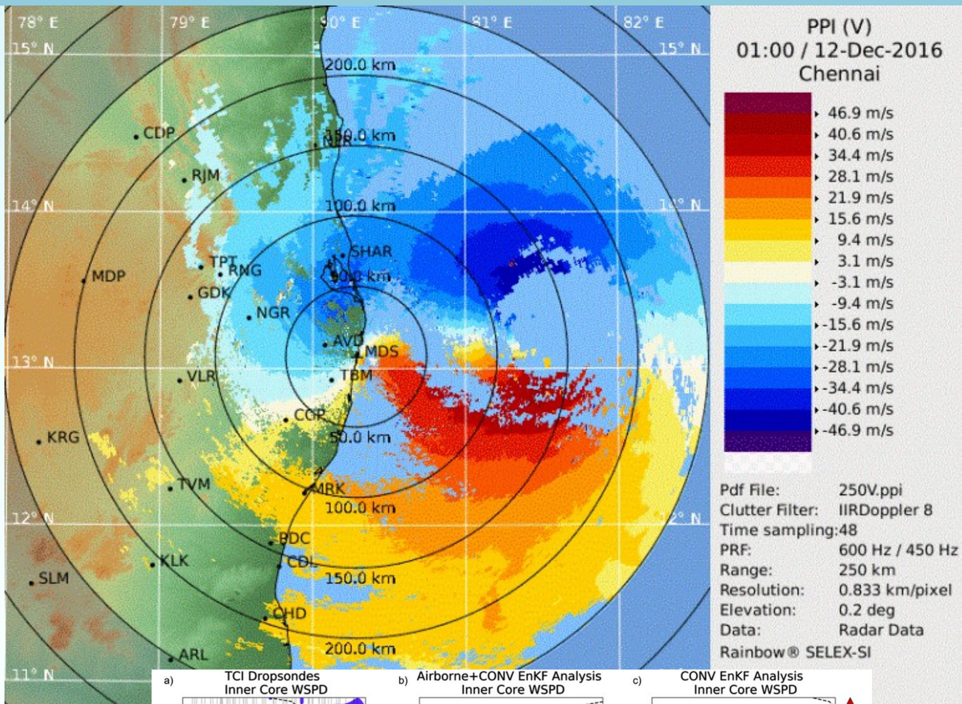


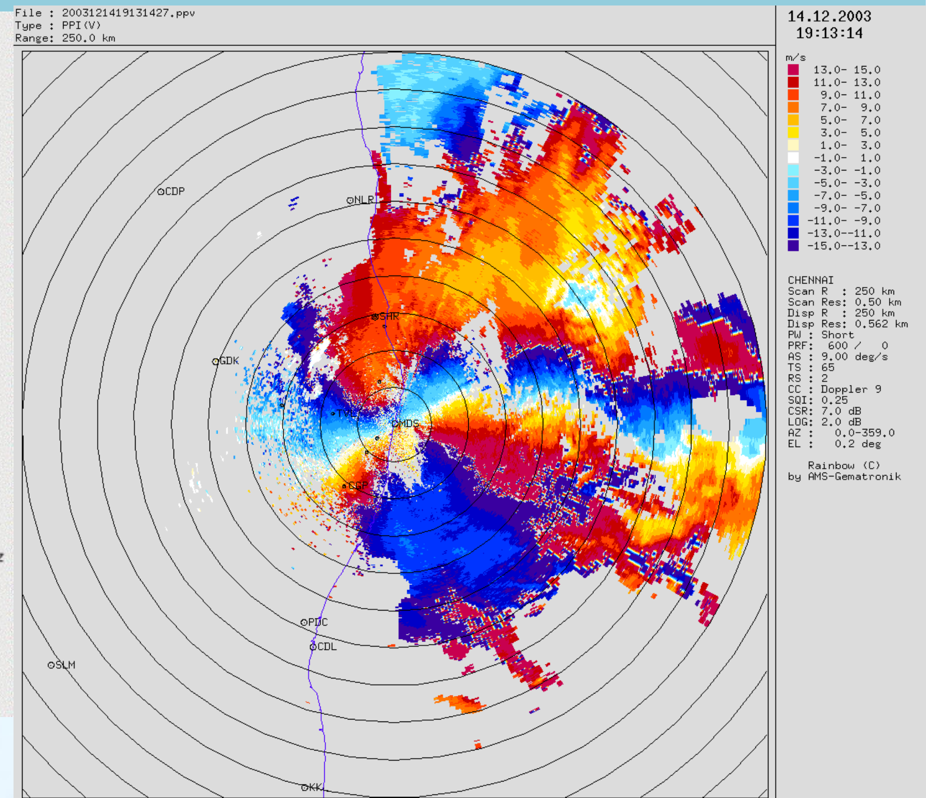


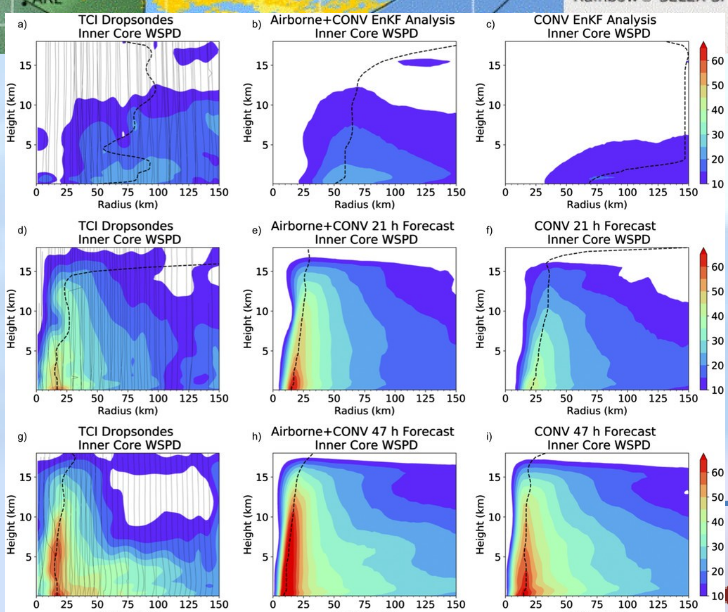


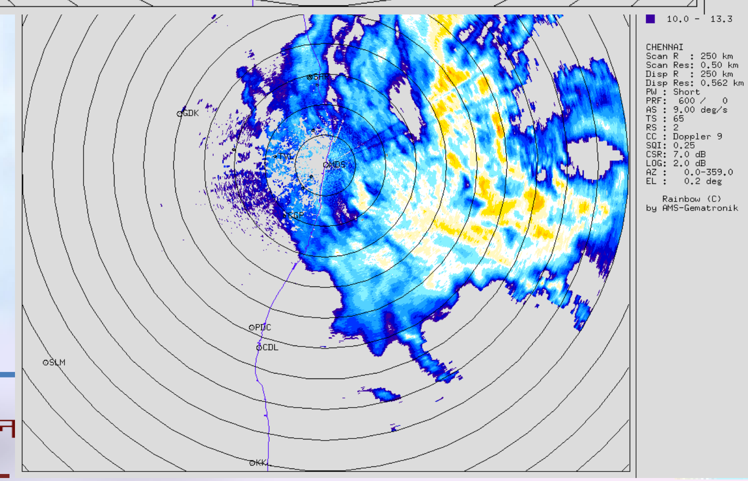


Fixing of centre

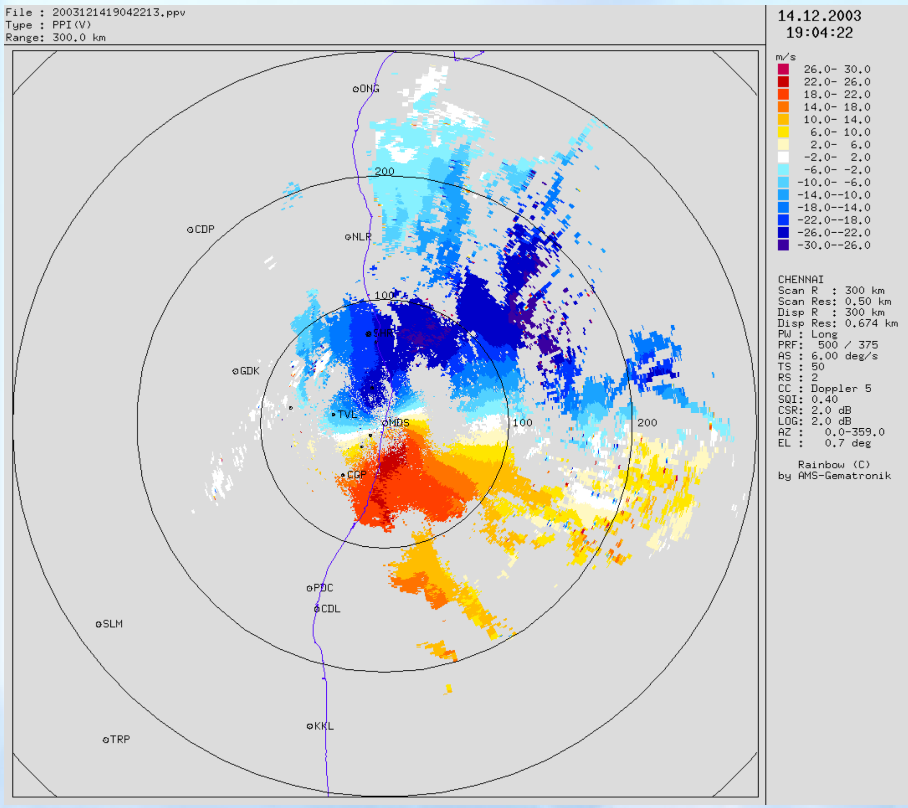






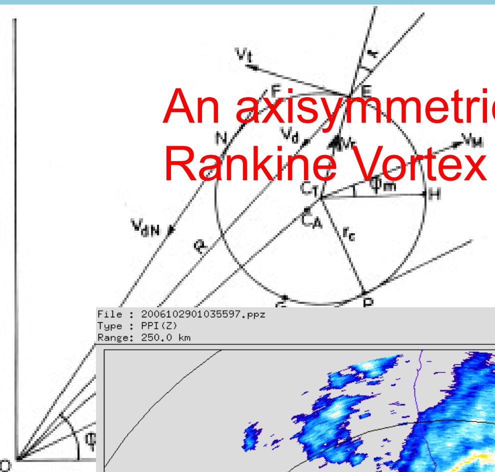


WIND FIELD

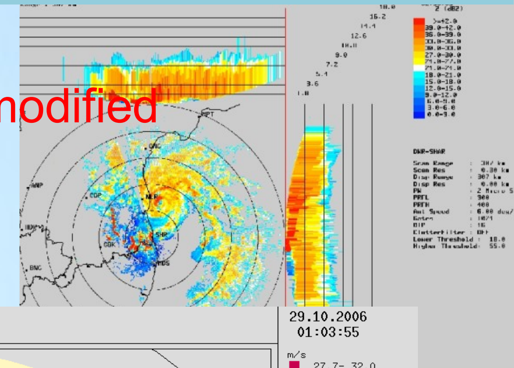


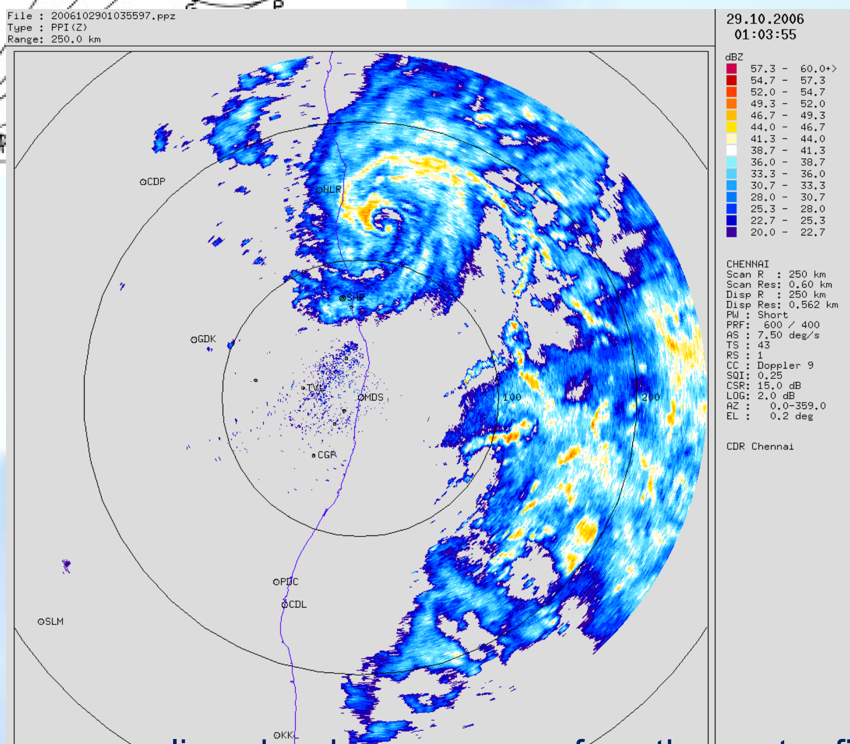
Basin of origin	Name	Date (DD/MM/YYYY)	Time (UTC)	Latitude (lat.)	Longitude (lon.)	CI No [or "T. No"]	Central Pressure (hPa) [or "E.C.P"]	Maximum Sustained Surface Wind (kt)	Pressure Drop (hPa) [or "delta P"]	Grade (text)
BOB		11/12/2003	1200	4.5	90.5	1.5	1004	25	2	D
BOB		12/12/2003	0300	6.0	89.0	1.5	1006	25	2	D
BOB		12/12/2003	1200	7.5	88.0	1.5	1004	25	2	D
BOB		13/12/2003	0300	9.0	87.5	2.0	1004	30	4	DD
BOB		13/12/2003	1200	9.5	87.0	2.5	1002	35	6	CS
BOB		13/12/2003	1500	10.0	87.0	2.5	1002	35	6	CS
BOB		13/12/2003	1800	10.0	87.0	2.5	1002	35	6	CS
BOB		13/12/2003	2100	10.5	86.5	2.5	1000	35	6	CS
BOB		14/12/2003	0000	10.5	86.0	2.5	998	35	6	CS
BOB		14/12/2003	0300	11.0	85.0	3.0	998	45	10	CS
BOB		14/12/2003	0600	11.0	85.0	3.0	996	45	10	CS
BOB		14/12/2003	0900	11.5	84.5	3.0	994	45	10	CS
BOB		14/12/2003	1200	12.0	83.5	3.5	992	55	14	SCS
BOB		14/12/2003	1500	12.5	83.0	3.5	992	55	14	SCS
BOB		14/12/2003	1800	12.8	82.5	3.5	992	55	14	SCS
BOB		14/12/2003	2100	13.4	82.2	3.5	992	55	14	SCS
BOB		15/12/2003	0000	13.8	81.7	3.5	992	55	14	SCS
BOB		15/12/2003	0300	14.0	81.5	3.5	992	55	14	SCS
BOB		15/12/2003	0600	14.3	81.5	3.5	992	55	14	SCS
BOB		15/12/2003	0900	15.0	81.0	3.5	992	55	14	SCS
BOB		15/12/2003	1200	15.5	81.0	3.5	990	55	14	SCS
BOB		15/12/2003	1500	15.8	81.0	3.5	992	55	14	SCS
BOB		15/12/2003	1800	16.0	81.0	3.5	992	55	14	SCS
CROSSED COAST NEAR TO MACHILIPATNAM AROUND MID-NIGHT ON DECEMBER 15										
BOB		15/12/2003	2100	16.5	81.0	/	/	/	/	CS
BOB		16/12/2003	0000	17.0	81.0	/	/	/	/	CS
BOB		16/12/2003	0300	17.0	81.0	/	/	/	/	DD
BOB		16/12/2003	0600	17.5	81.5	/	/	/	/	D
BOB		16/12/2003	1200	17.5	81.5	/	/	/	/	D

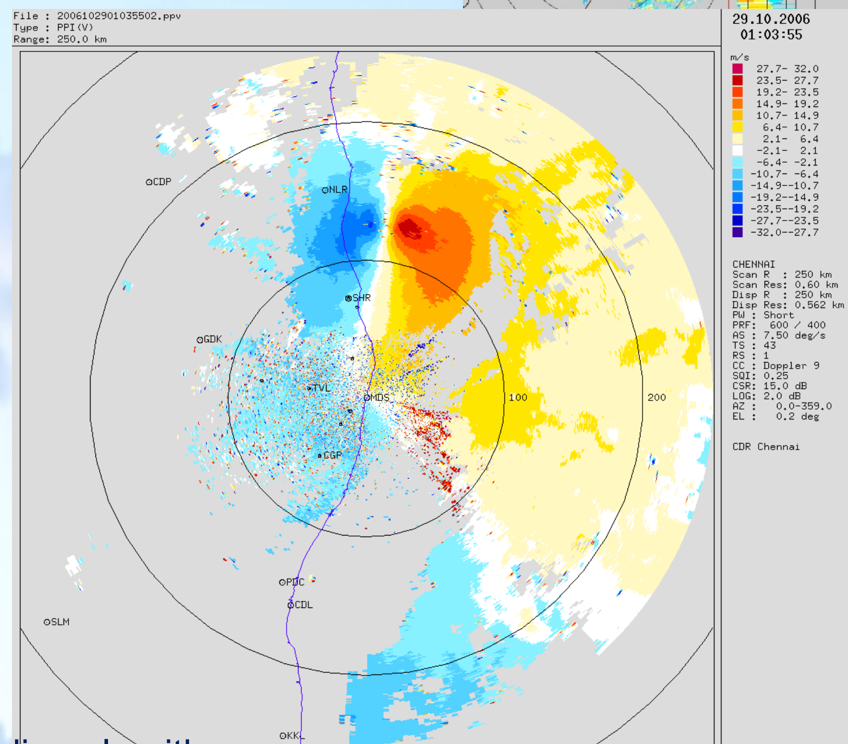
Movement Prediction and center fixing



An axisymmetric vortex can ideally be considered to be a modified Rankine Vortex (Rankine 1901).



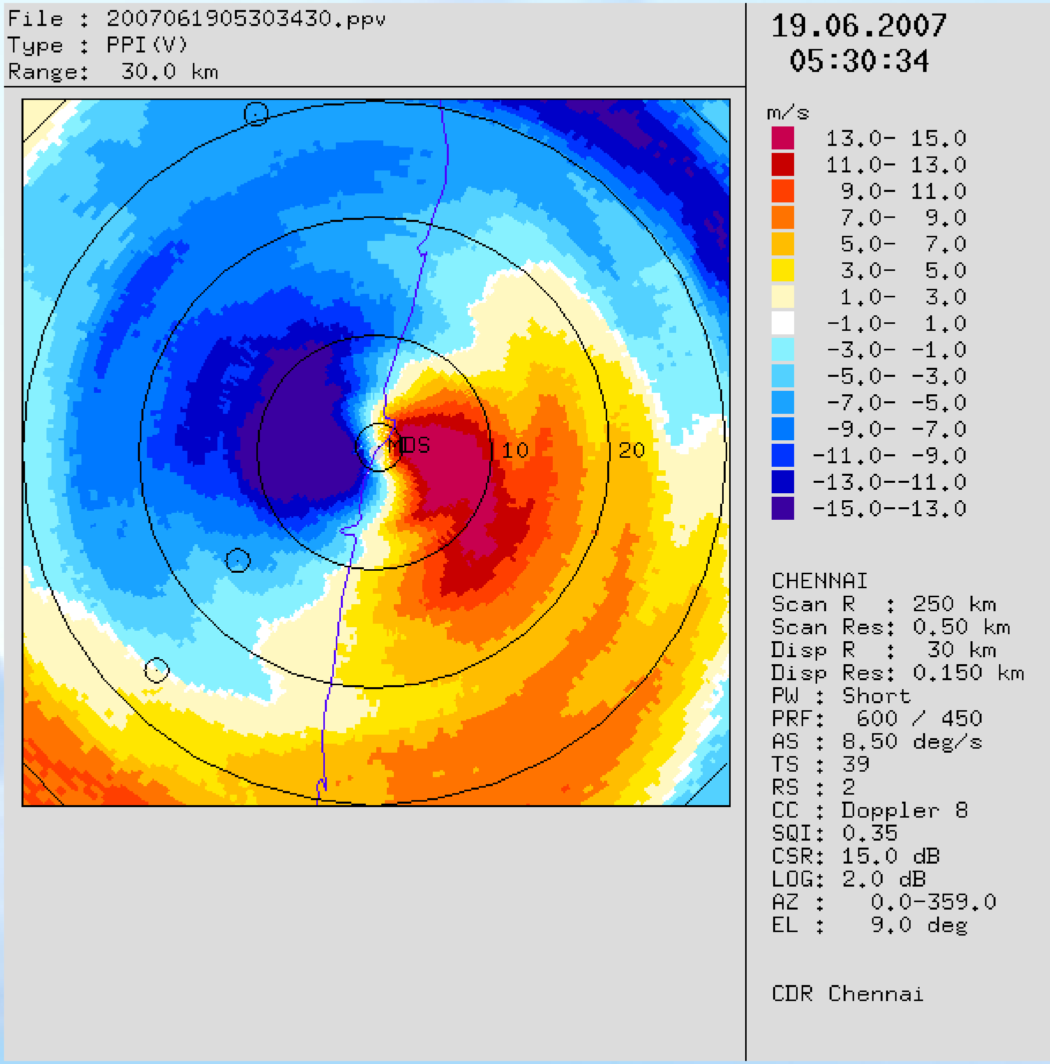


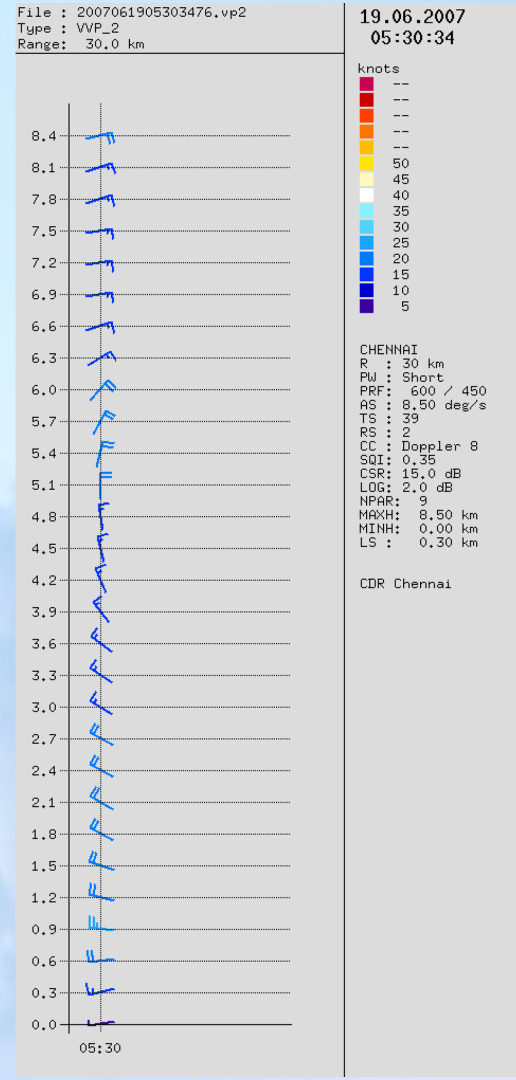


range-aliased echoes may confuse the center-finding algorithm

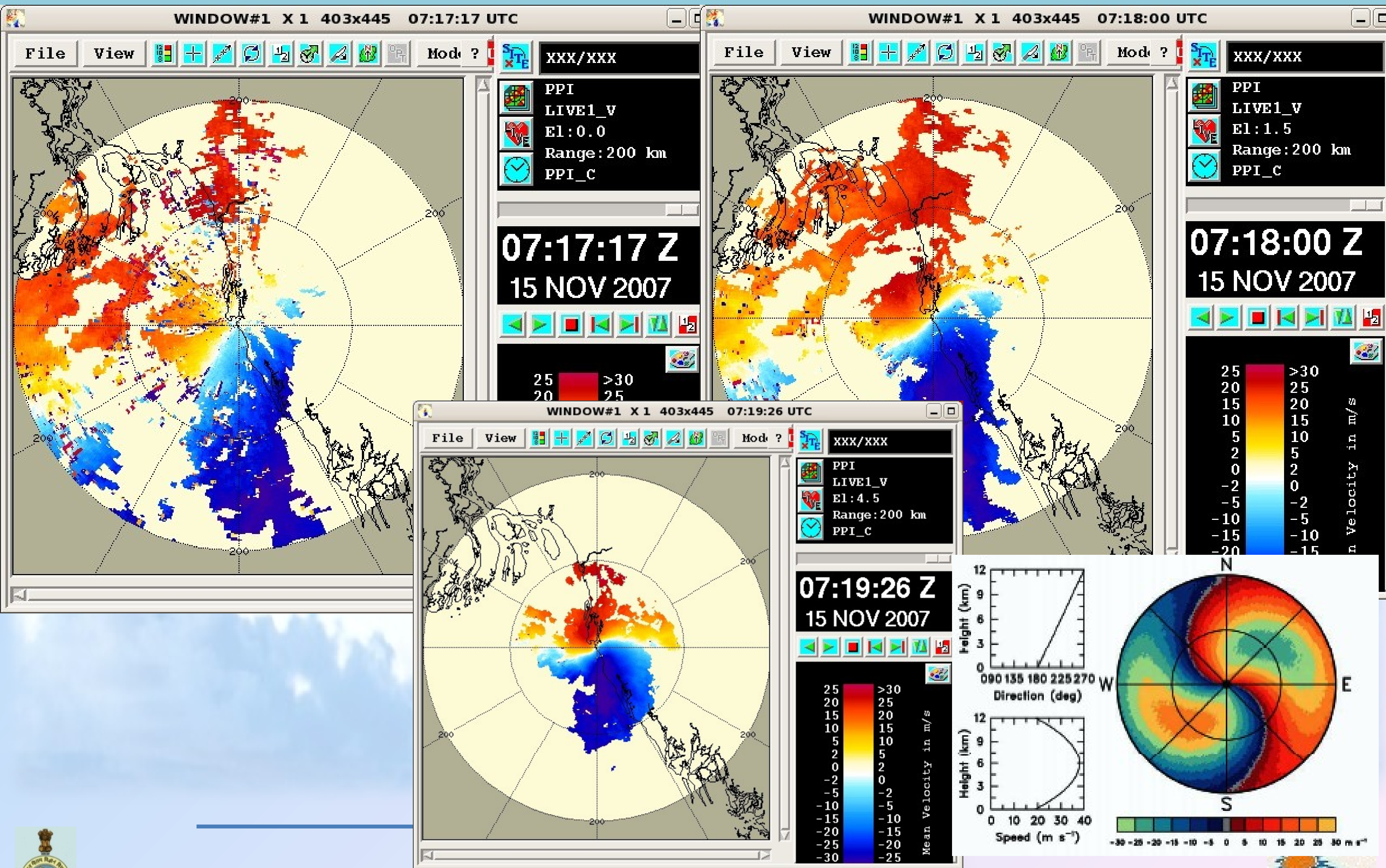
Simulation is for idealised vortex. Generally vortex asymmetric and eye wall incomplete. Localised shear zone confuses while looking for the couplet

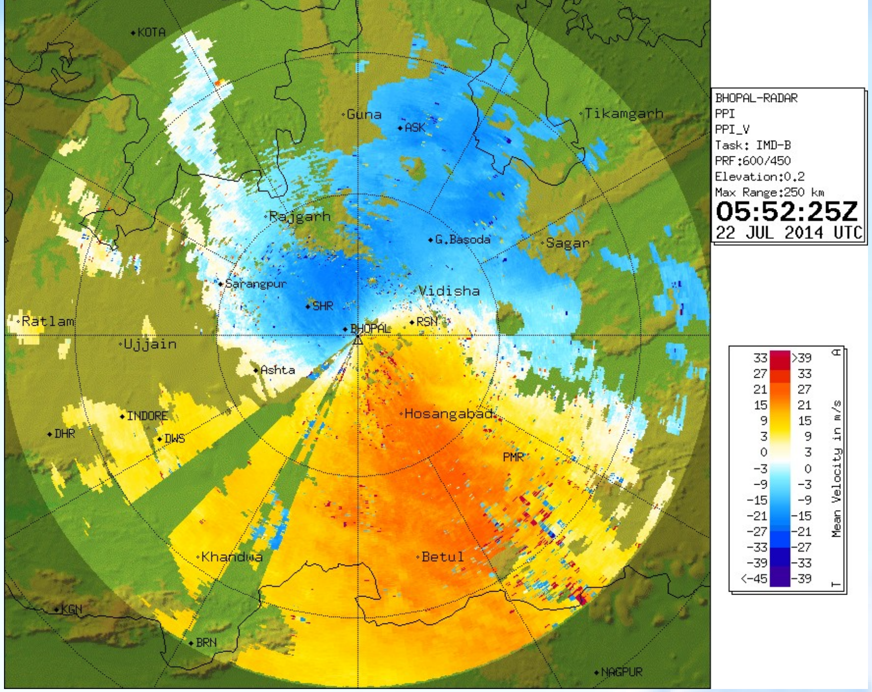
PPI(V) & VVP

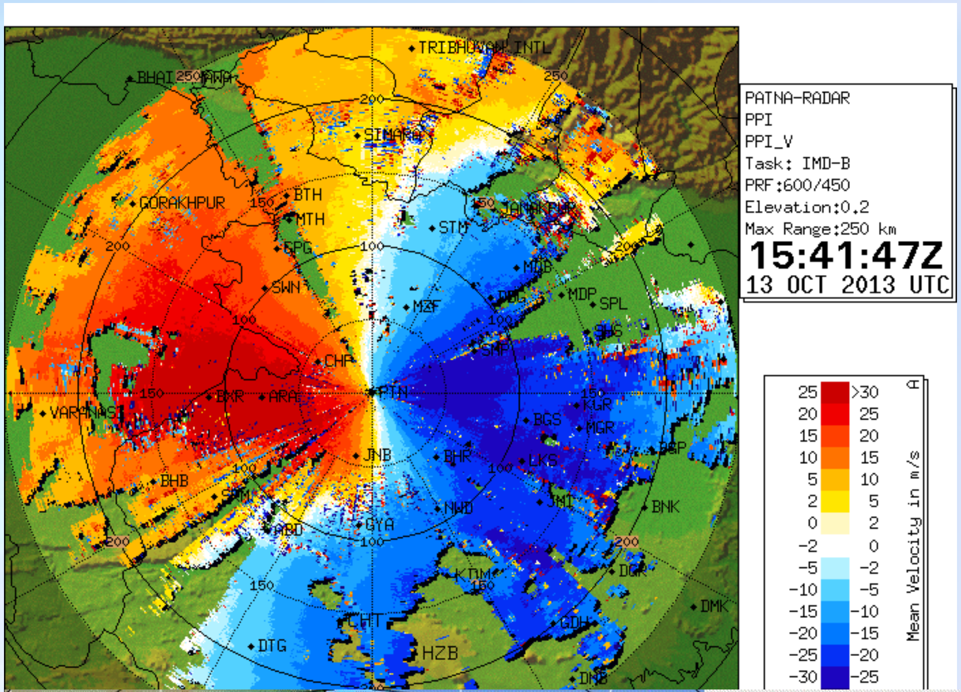

File : 20070619053034 30.ppv
Type : PPI(V)
Range: 30.0 km
19.06.2007
05:30:34
m/s
13.0- 15.0
11.0- 13.0
9.0- 11.0
7.0- 9.0
5.0- 7.0
3.0- 5.0
1.0- 3.0
-1.0- 1.0
-3.0- -1.0
-5.0- -3.0
-7.0- -5.0
-9.0- -7.0
-11.0- -9.0
-13.0--11.0
-15.0--13.0
MDS
10
20
CHENNAI
Scan R : 250 km
Scan Res: 0.50 km
Disp R : 30 km
Disp Res: 0.150 km
PW : Short
PRF: 600 / 450
AS : 8.50 deg/s
TS : 39
RS : 2
CC : Doppler 8
SQI: 0.35
CSR: 15.0 dB
LOG: 2.0 dB
AZ : 0.0-359.0
EL : 9.0 deg
CDR Chennai

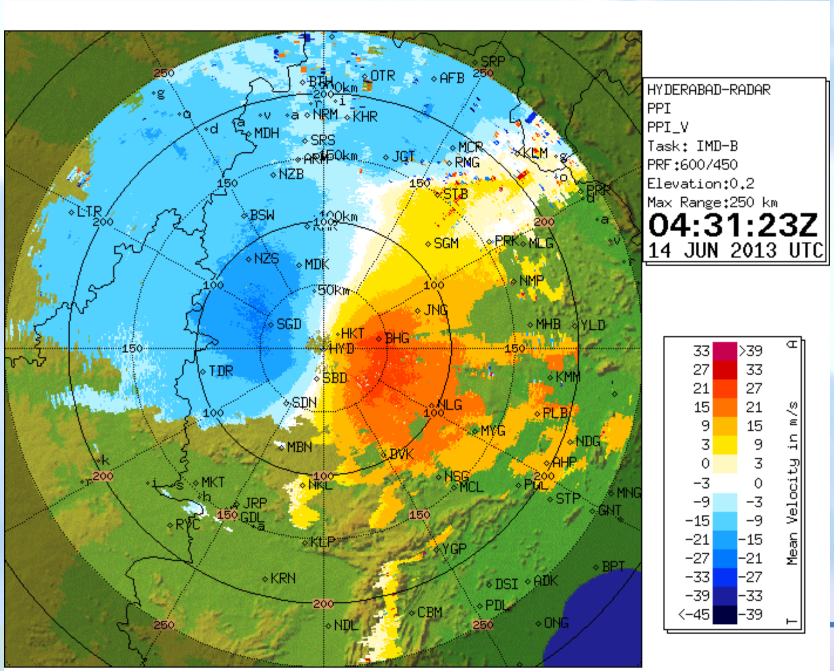

File : 20070619053034 76.vp2
Type : VVP_2
Range: 30.0 km
19.06.2007
05:30:34
knots
--
--
--
--
--
50
45
40
35
30
25
20
15
10
5
8.4
8.1
7.8
7.5
7.2
6.9
6.6
6.3
6.0
5.7
5.4
5.1
4.8
4.5
4.2
3.9
3.6
3.3
3.0
2.7
2.4
2.1
1.8
1.5
1.2
0.9
0.6
0.3
0.0
05:30
CHENNAI
R : 30 km
PW : Short
PRF: 600 / 450
AS : 8.50 deg/s
TS : 39
RS : 2
CC : Doppler 8
SQI: 0.35
CSR: 15.0 dB
LOG: 2.0 dB
NPAR: 9
MAXH: 8.50 km
MINH: 0.00 km
LS : 0.30 km
CDR Chennai

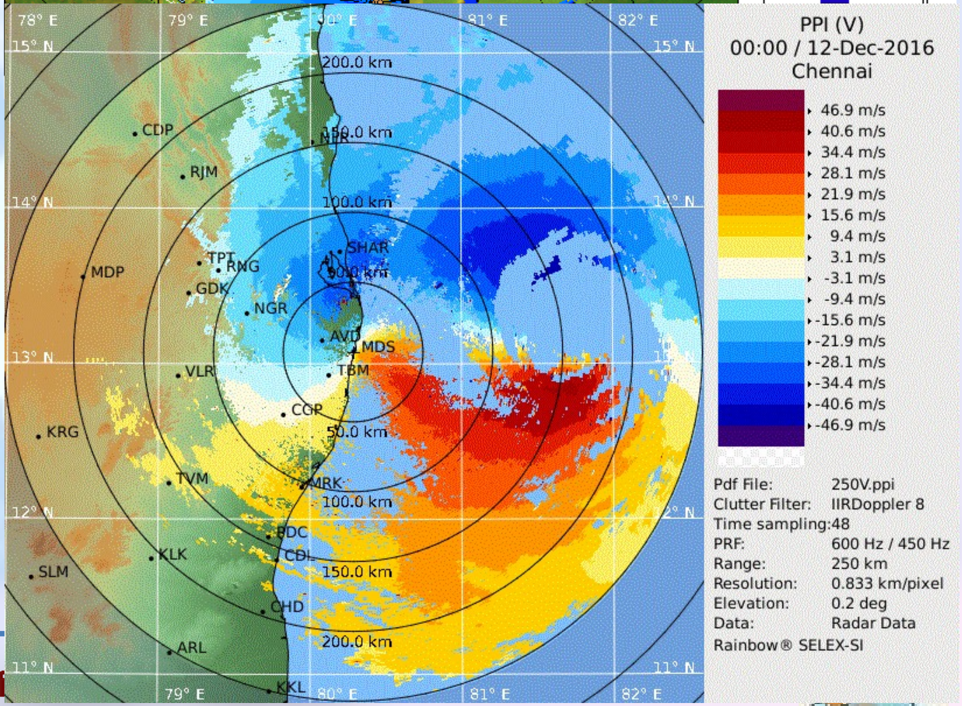
WIND ANALYSIS



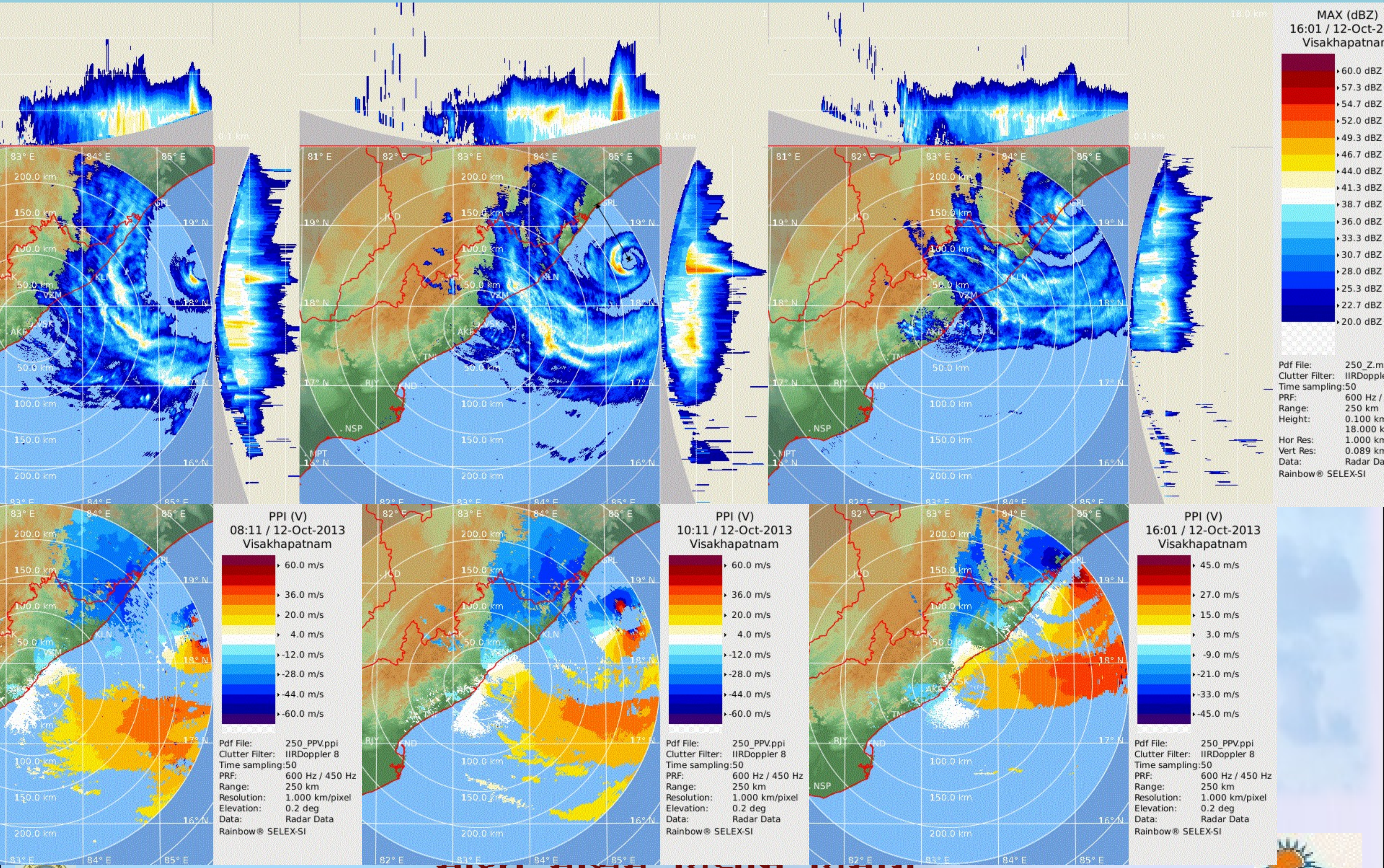

BHOPAL-RADAR
PPI
PPI_V
Task: IMD-B
PRF:600/450
Elevation:0.2
Max Range:250 km
05:52:25Z
22 JUL 2014 UTC
Mean Velocity in m/s

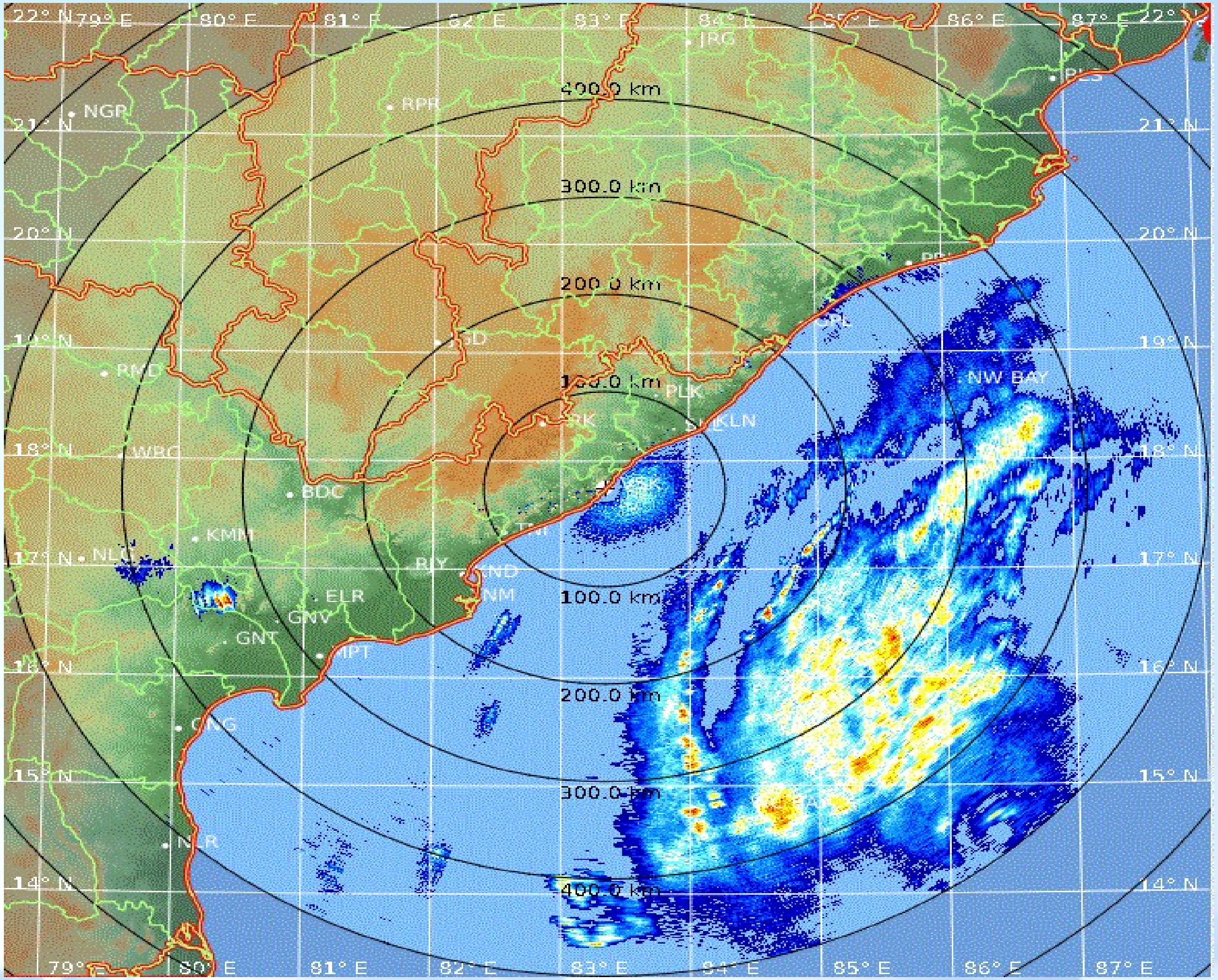

PATNA-RADAR
PPI
PPI_V
Task: IMD-B
PRF:600/450
Elevation:0.2
Max Range:250 km
15:41:47Z
13 OCT 2013 UTC
Mean Velocity in m/s


HYDERABAD-RADAR
PPI
PPI_V
Task: IMD-B
PRF:600/450
Elevation:0.2
Max Range:250 km
04:31:23Z
14 JUN 2013 UTC
Mean Velocity in m/s


PPI (V)
00:00 / 12-Dec-2016
Chennai
Pdf File: 250V.ppi
Clutter Filter: IIRDoppler 8
Time sampling:48
PRF: 600 Hz / 450 Hz
Range: 250 km
Resolution: 0.833 km/pixel
Elevation: 0.2 deg
Data: Radar Data
Rainbow® SELEX-SI

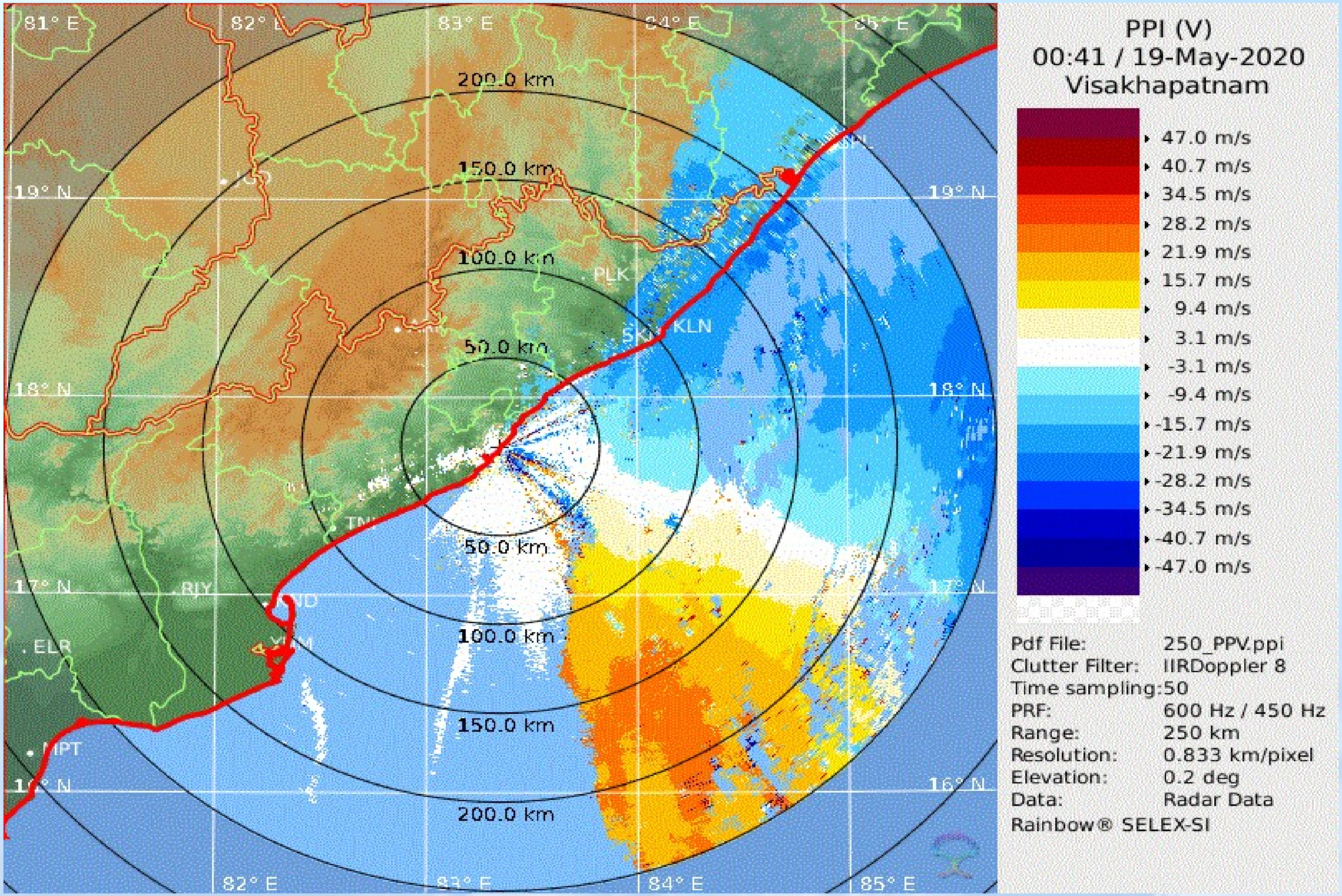
Phailin (Oct 2013)



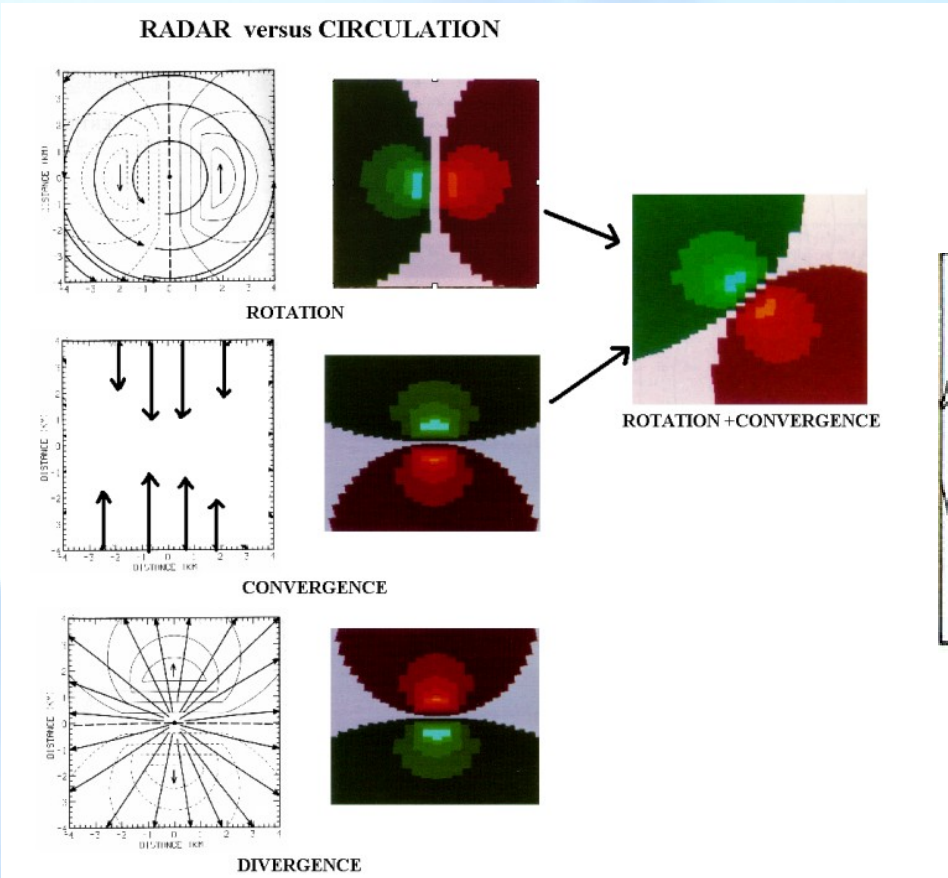


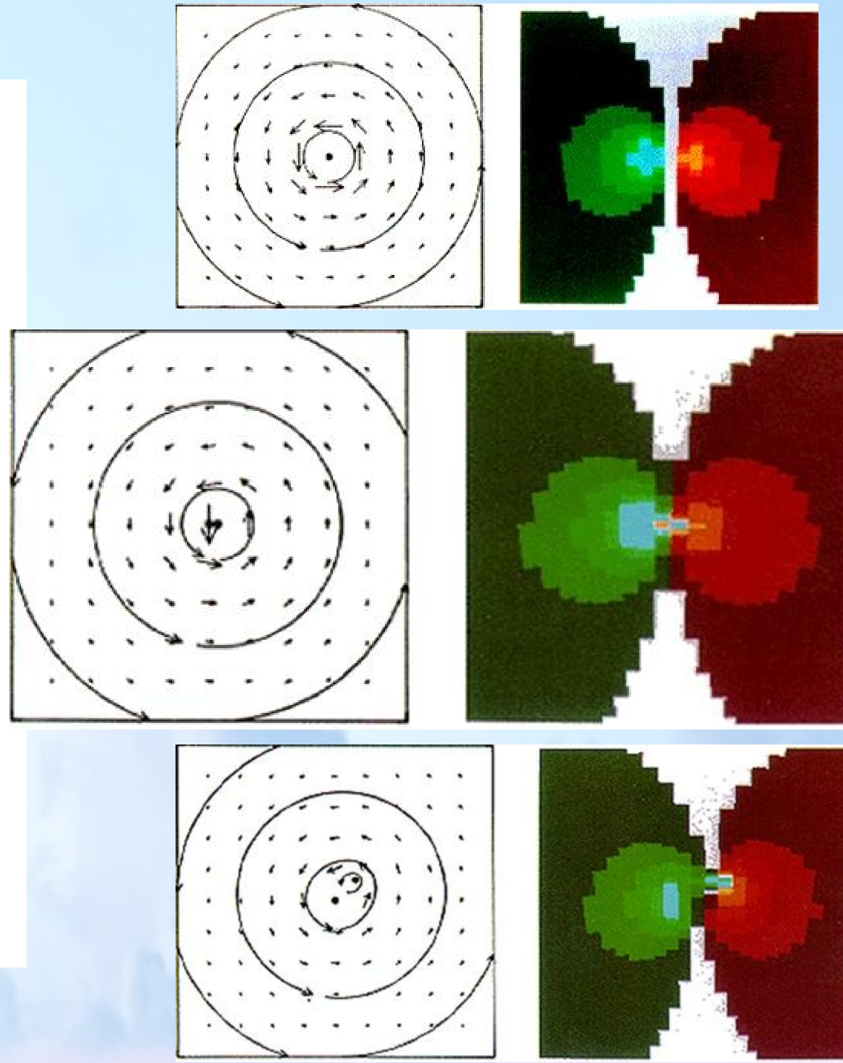
Eye wall height about 13 km , eye seen at around 490km

Doppler Velocities

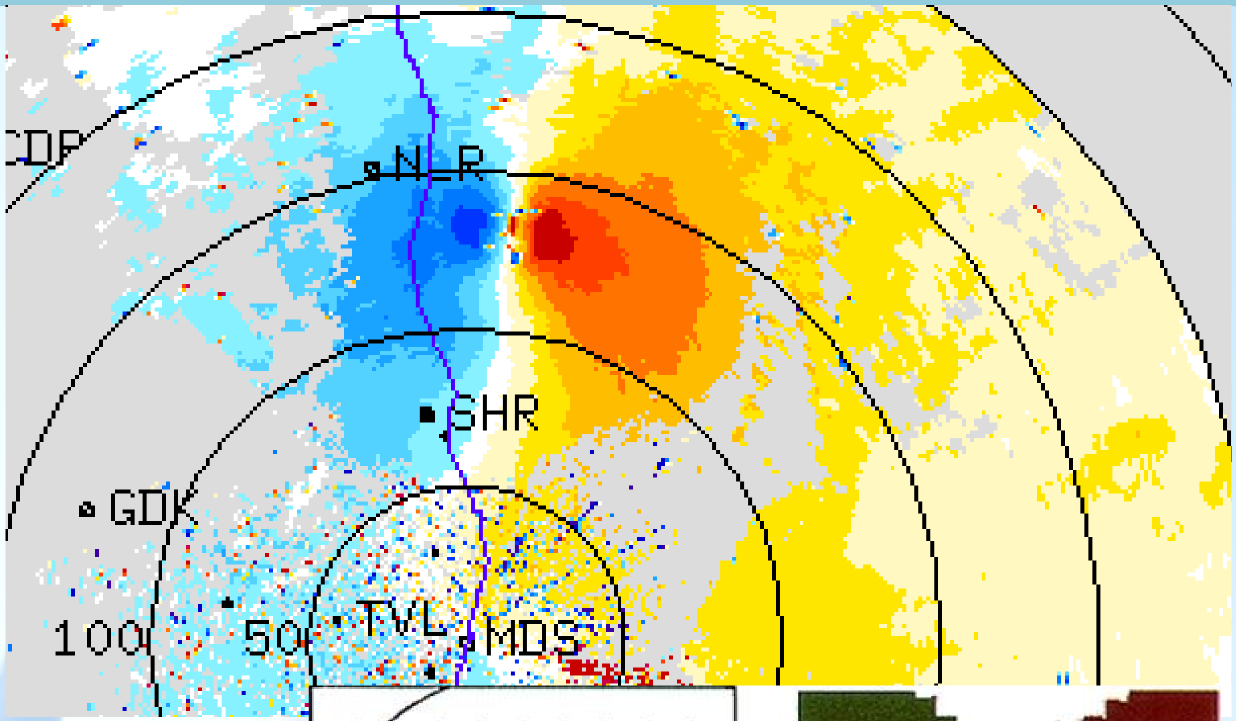


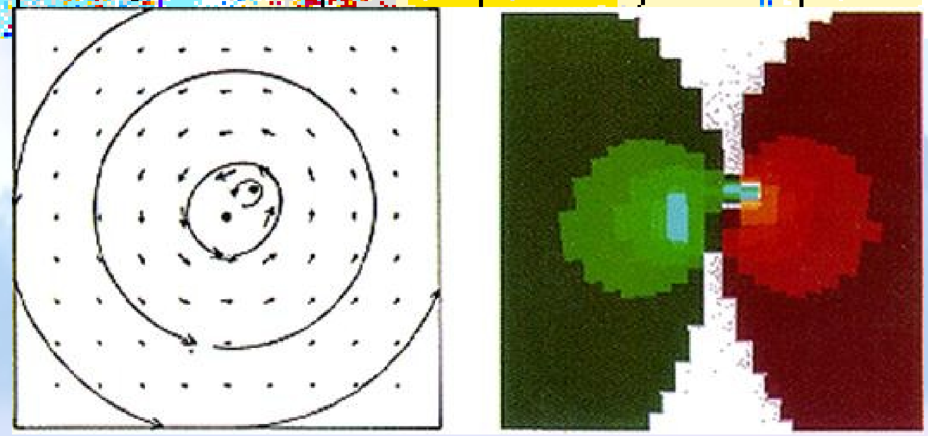
Wind Analysis



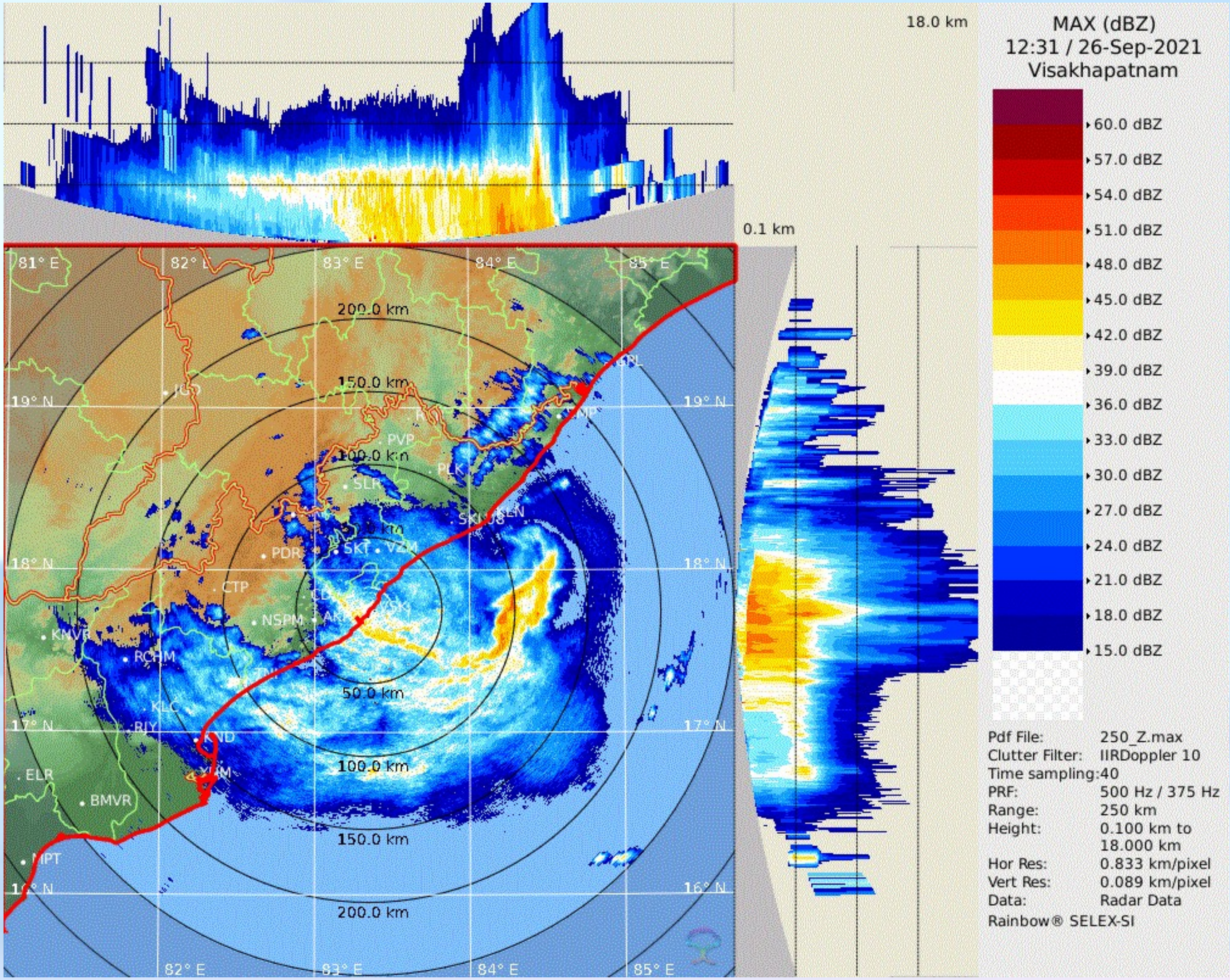


Assymetric Vortex - Movement

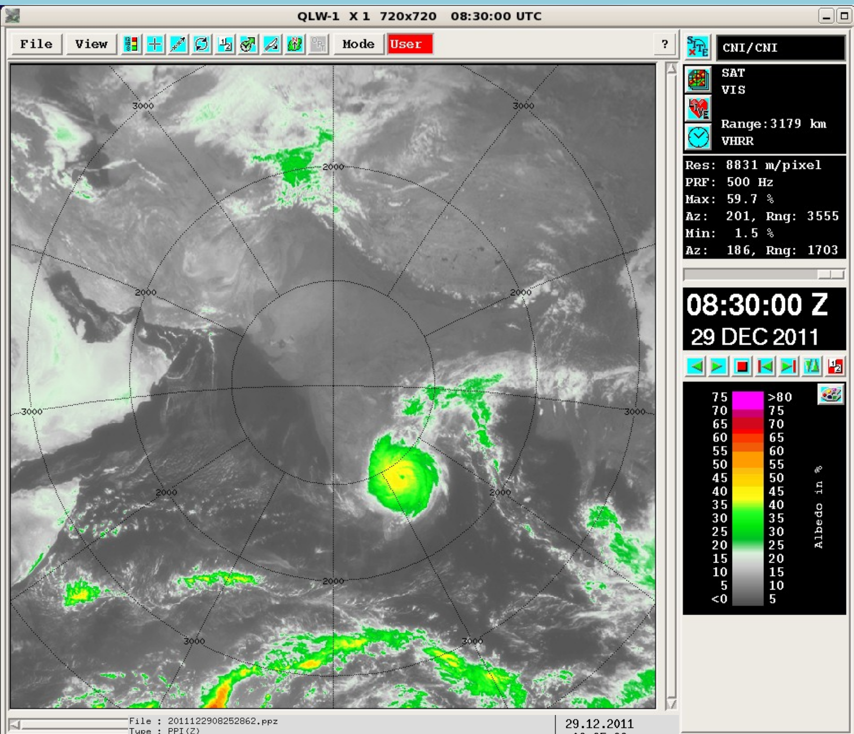


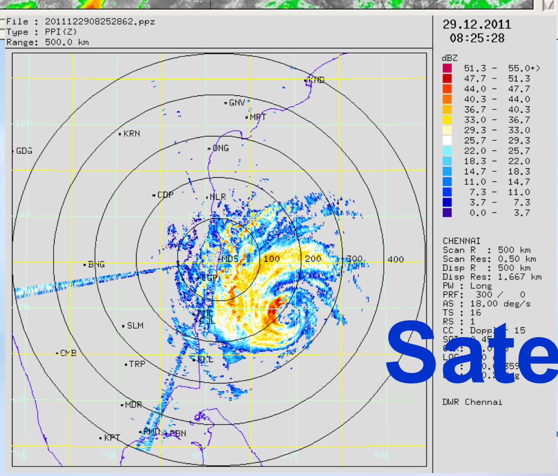


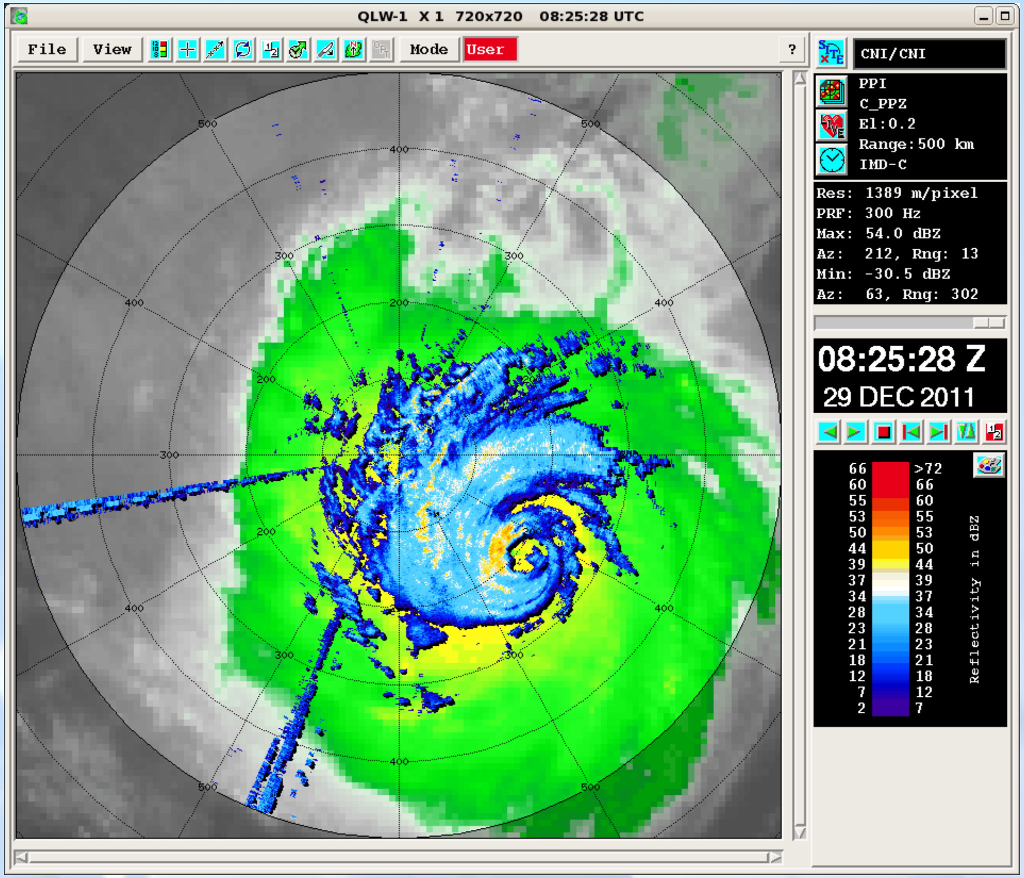
Fixing of centre



CENTRE VARIATIONS



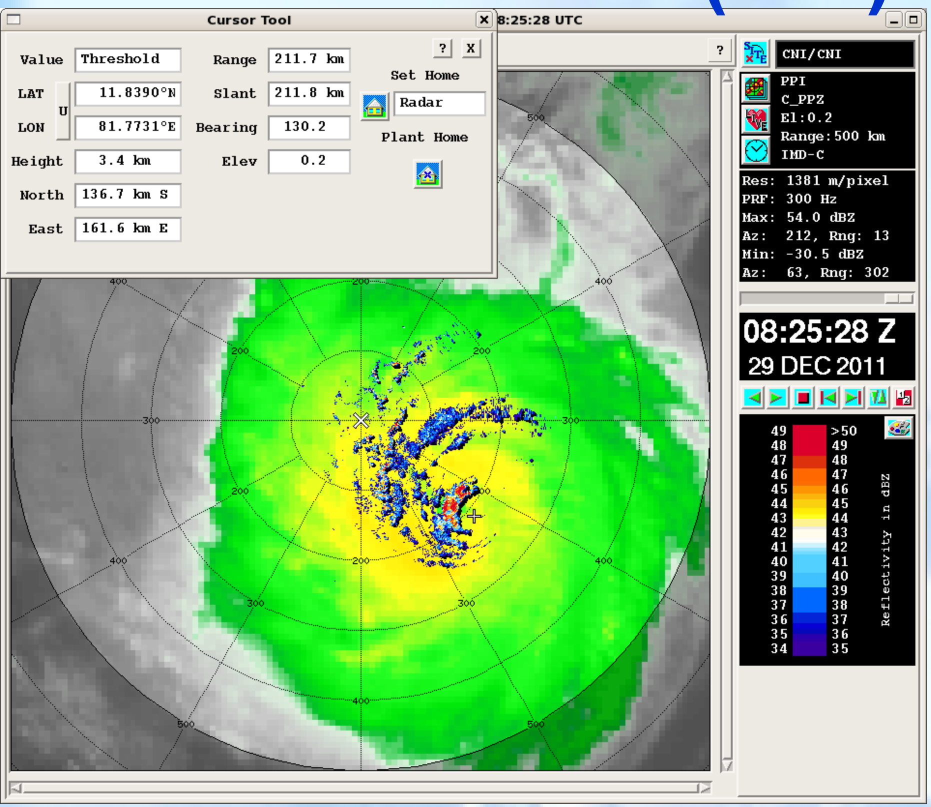


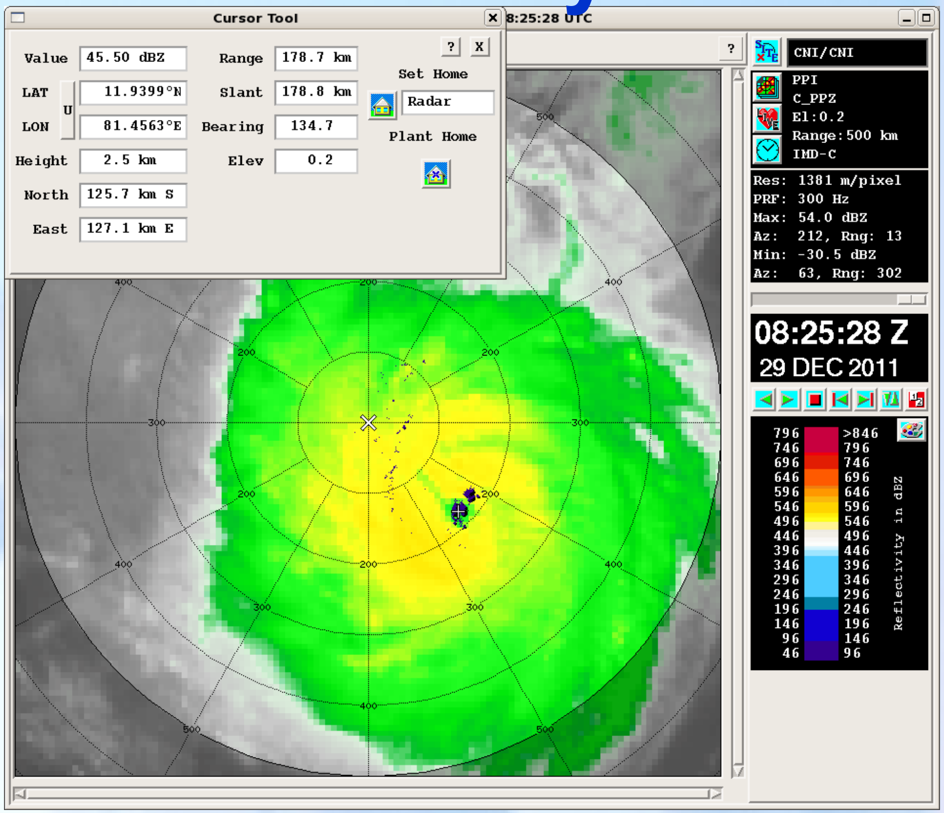


Satellite (VIS) – Radar Overlay

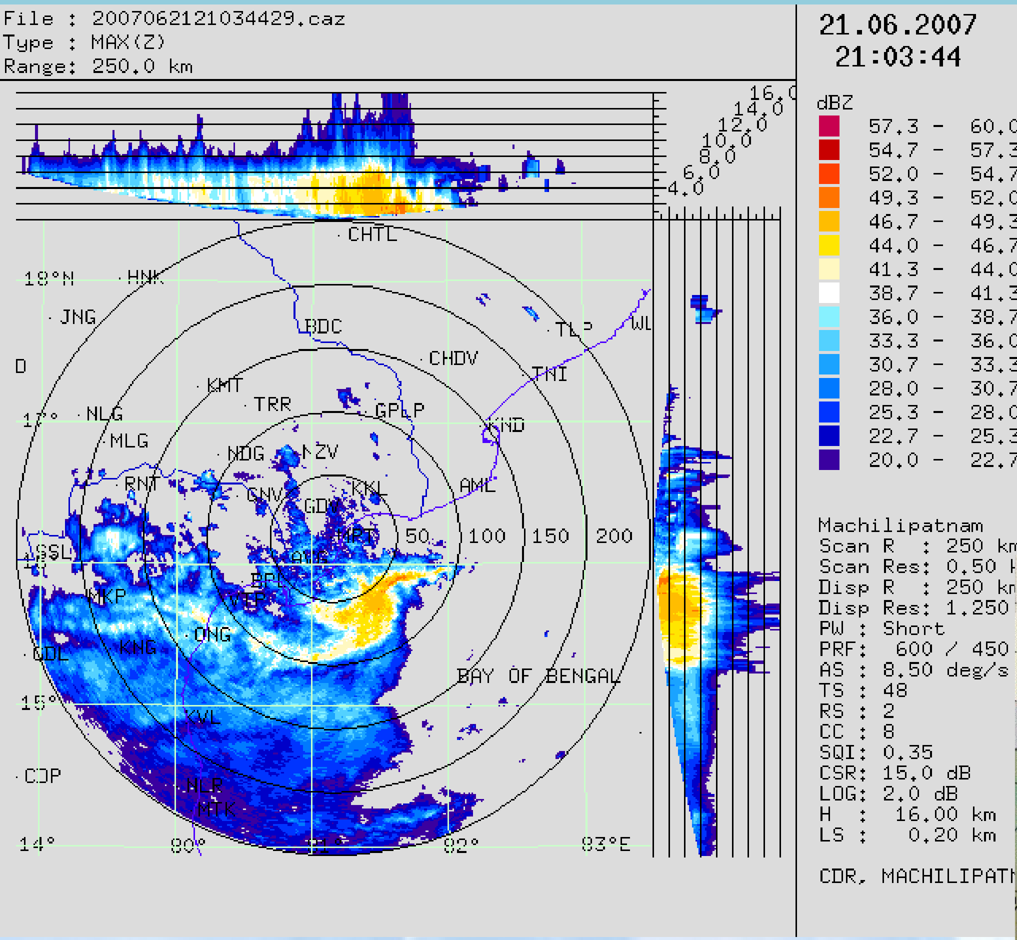
CENTRE VARIATIONS

Satellite (VIS) – Radar Overlay

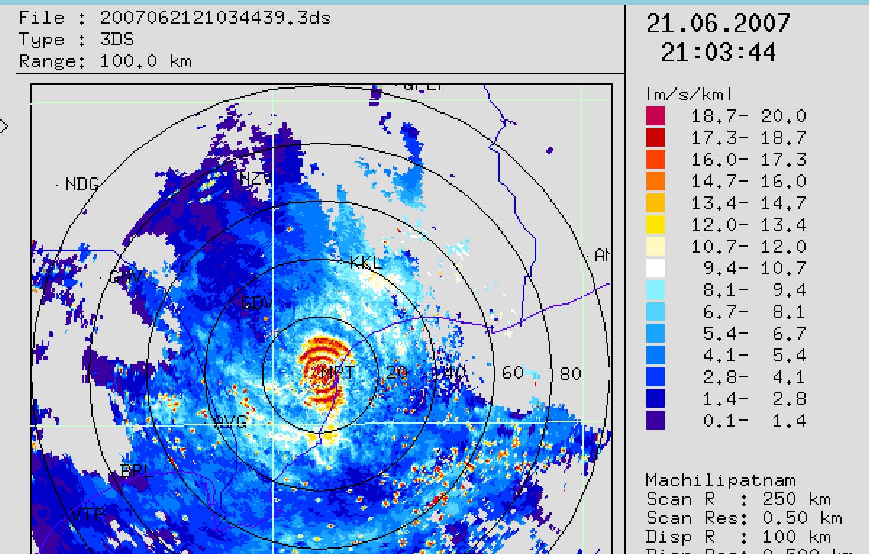




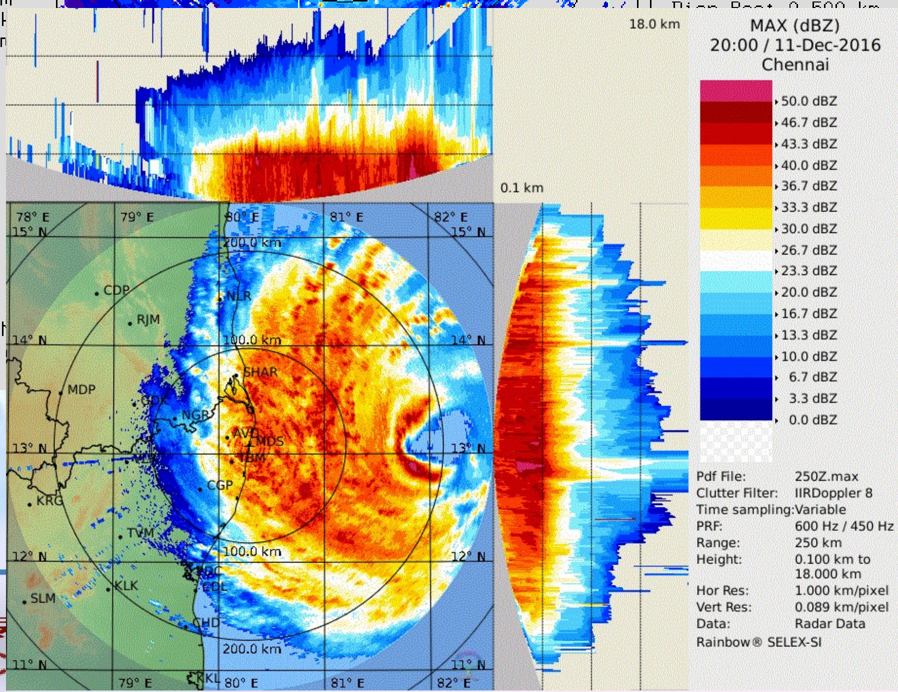
Max-Z & 3DS



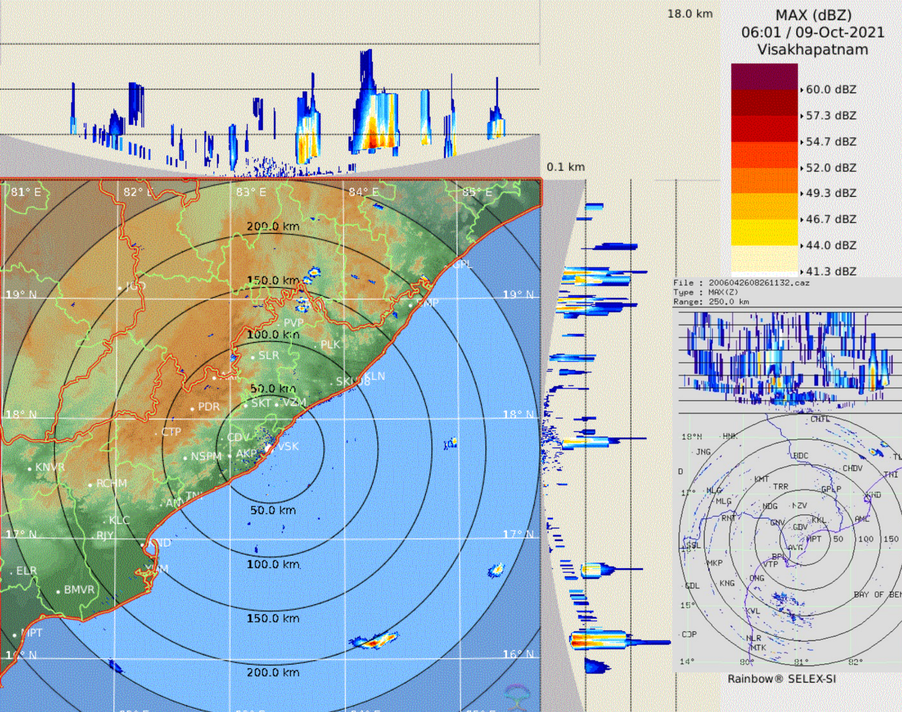
File : 2007062121034429.caz
Type : MAX(Z)
Range: 250.0 km
21.06.2007
21:03:44
dBZ
57.3 - 60.0+>
54.7 - 57.3
52.0 - 54.7
49.3 - 52.0
46.7 - 49.3
44.0 - 46.7
41.3 - 44.0
38.7 - 41.3
36.0 - 38.7
33.3 - 36.0
30.7 - 33.3
28.0 - 30.7
25.3 - 28.0
22.7 - 25.3
20.0 - 22.7
Machilipatnam
Scan R : 250 km
Scan Res: 0.50 k
Disp R : 250 km
Disp Res: 1.250
PW : Short
PRF: 600 / 450
AS : 8.50 deg/s
TS : 48
RS : 2
CC : 8
SQI: 0.35
CSR: 15.0 dB
LOG: 2.0 dB
H : 16.00 km
LS : 0.20 km
CDR, MACHILIPATN
50
100
150
200
BAY OF BENGAL

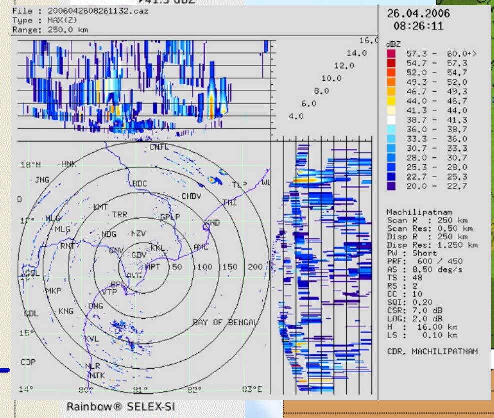


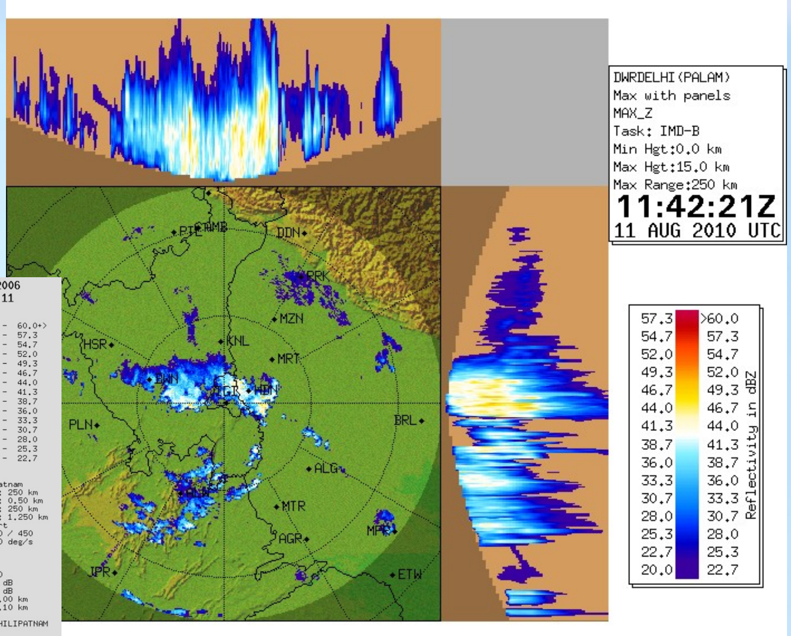
File : 2007062121034439.3ds
Type : 3DS
Range: 100.0 km
21.06.2007
21:03:44
Im/s/kmI
18.7- 20.0
17.3- 18.7
16.0- 17.3
14.7- 16.0
13.4- 14.7
12.0- 13.4
10.7- 12.0
9.4- 10.7
8.1- 9.4
6.7- 8.1
5.4- 6.7
4.1- 5.4
2.8- 4.1
1.4- 2.8
0.1- 1.4
Machilipatnam
Scan R : 250 km
Scan Res: 0.50 km
Disp R : 100 km

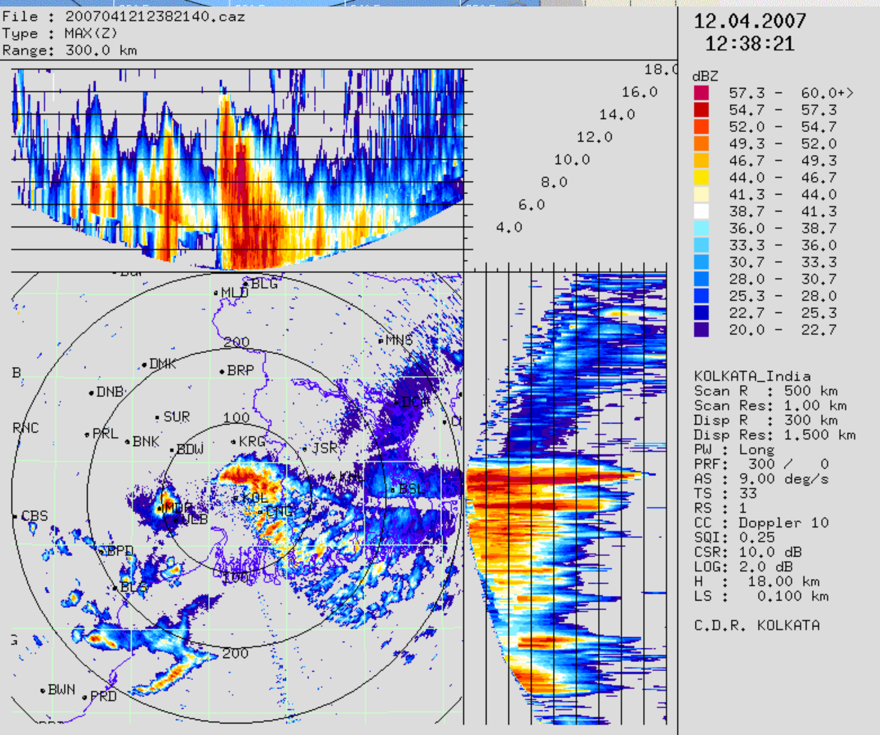


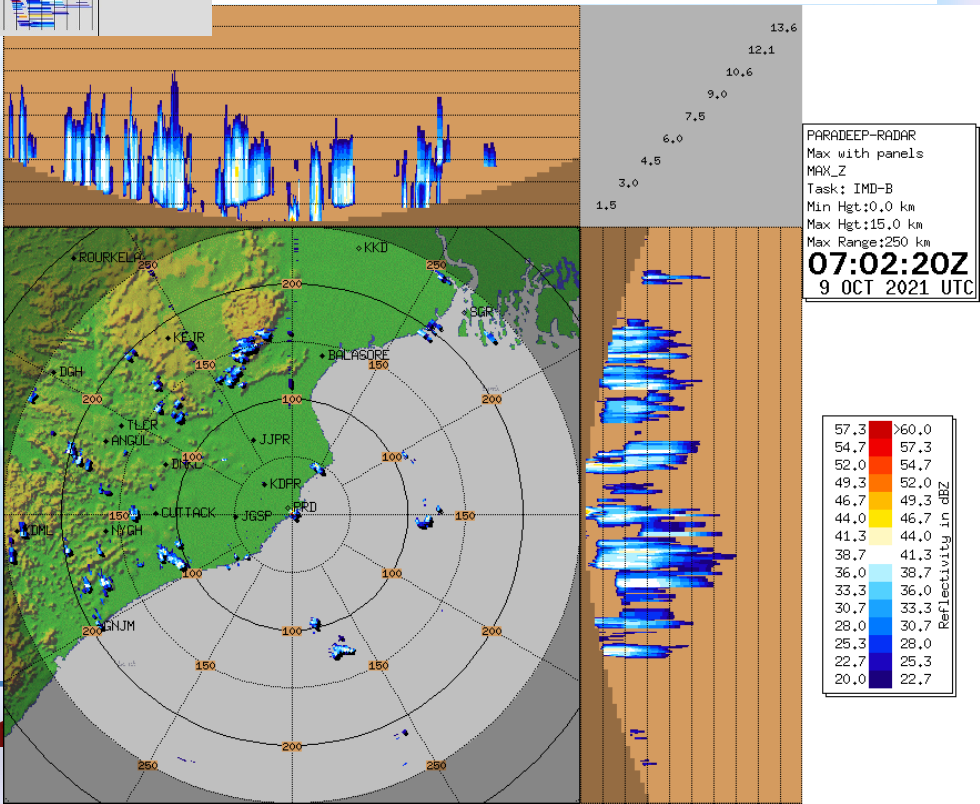
MAX (dBZ)
20:00 / 11-Dec-2016
Chennai
18.0 km
0.1 km
50.0 dBZ
46.7 dBZ
43.3 dBZ
40.0 dBZ
36.7 dBZ
33.3 dBZ
30.0 dBZ
26.7 dBZ
23.3 dBZ
20.0 dBZ
16.7 dBZ
13.3 dBZ
10.0 dBZ
6.7 dBZ
3.3 dBZ
0.0 dBZ
Pdf File: 250Z.max
Clutter Filter: IIRDoppler 8
Time sampling:Variable
PRF: 600 Hz / 450 Hz
Range: 250 km
Height: 0.100 km to 18.000 km
Hor Res: 1.000 km/pixel
Vert Res: 0.089 km/pixel
Data: Radar Data
Rainbow® SELEX-SI


MAX (dBZ)
06:01 / 09-Oct-2021
Visakhapatnam
60.0 dBZ
57.3 dBZ
54.7 dBZ
52.0 dBZ
49.3 dBZ
46.7 dBZ
44.0 dBZ
41.3 dBZ
18.0 km
0.1 km
200.0 km
150.0 km
100.0 km
50.0 km
VSK

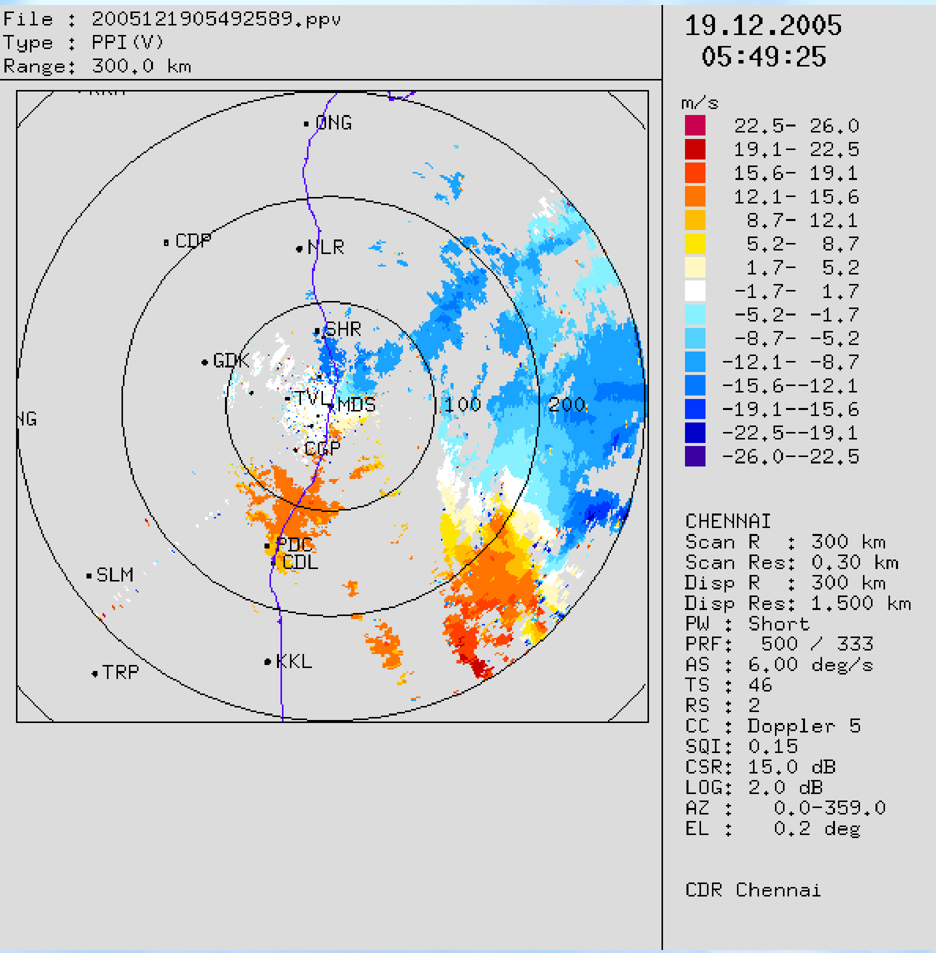

File : 2006042608261132.caz
Type : MAX(Z)
Range: 250.0 km
26.04.2006
08:26:11
Machilipatnam
BAY OF BENGAL
CDR, MACHILIPATNAM
Rainbow® SELEX-SI


DWRDELHI(PALAM)
Max with panels
MAX_Z
Task: IMD-B
Min Hgt:0.0 km
Max Hgt:15.0 km
Max Range:250 km
11:42:21Z
11 AUG 2010 UTC
Reflectivity in dBZ

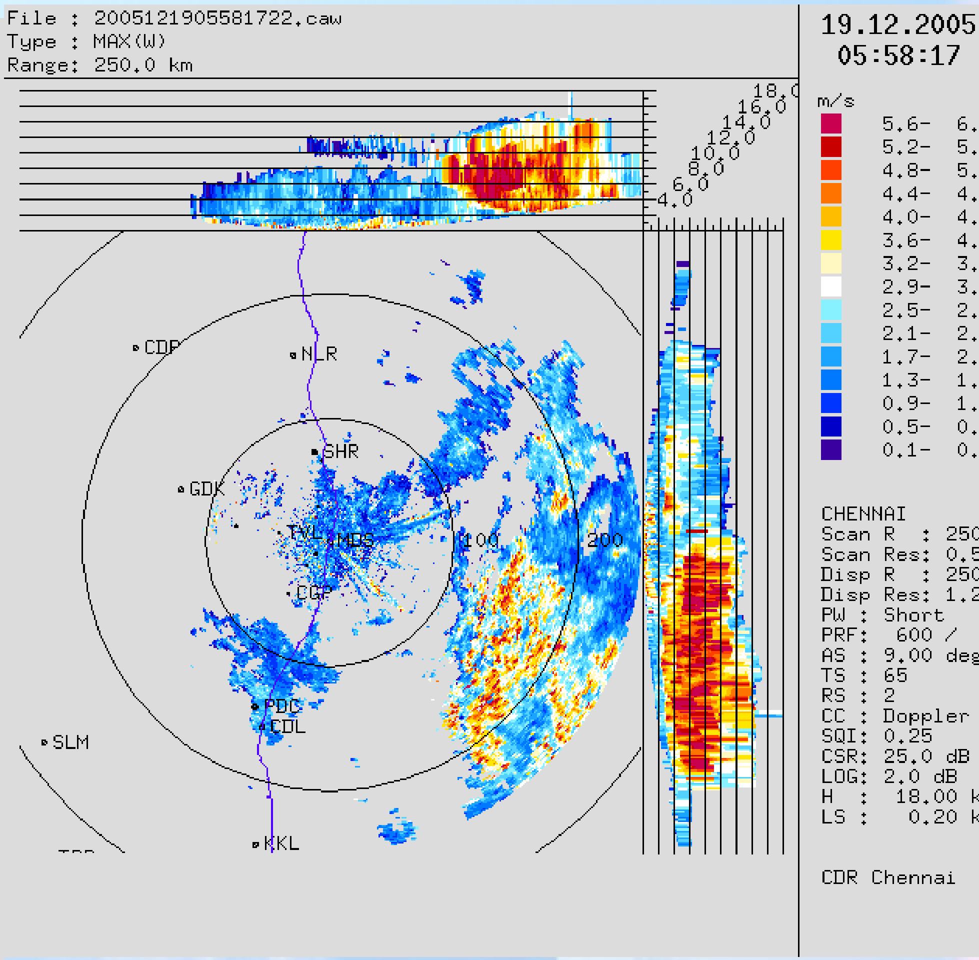

File : 2007041212382140.caz
Type : MAX(Z)
Range: 300.0 km
12.04.2007
12:38:21
dBZ
57.3 - 60.0+>
54.7 - 57.3
52.0 - 54.7
49.3 - 52.0
46.7 - 49.3
44.0 - 46.7
41.3 - 44.0
38.7 - 41.3
36.0 - 38.7
33.3 - 36.0
30.7 - 33.3
28.0 - 30.7
25.3 - 28.0
22.7 - 25.3
20.0 - 22.7
KOLKATA_India
Scan R : 500 km
Scan Res: 1.00 km
Disp R : 300 km
Disp Res: 1.500 km
PW : Long
PRF: 300 / 0
AS : 9.00 deg/s
TS : 33
RS : 1
CC : Doppler 10
SQI: 0.25
CSR: 10.0 dB
LOG: 2.0 dB
H : 18.00 km
LS : 0.100 km
C.D.R. KOLKATA


PARADEEP-RADAR
Max with panels
MAX_Z
Task: IMD-B
Min Hgt:0.0 km
Max Hgt:15.0 km
Max Range:250 km
07:02:20Z
9 OCT 2021 UTC
Reflectivity in dBZ

TENDENCY

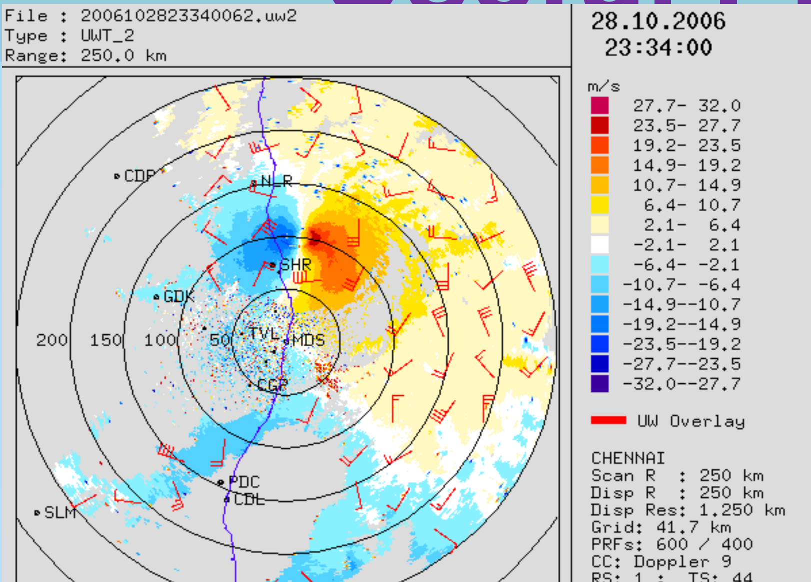


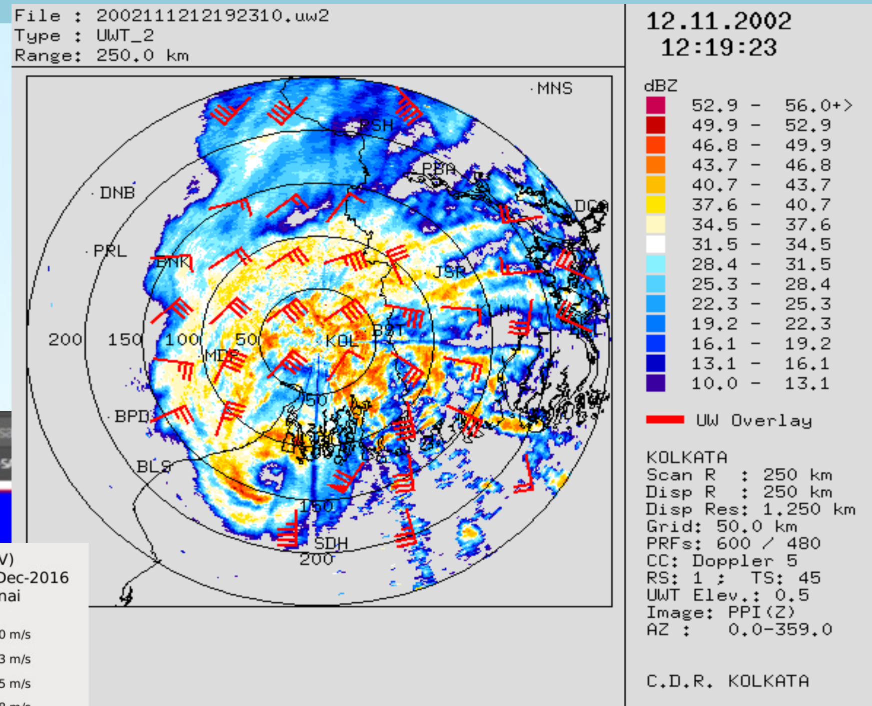
File : 2005121905492589.ppv
Type : PPI(V)
Range: 300.0 km
19.12.2005
05:49:25
m/s
22.5- 26.0
19.1- 22.5
15.6- 19.1
12.1- 15.6
8.7- 12.1
5.2- 8.7
1.7- 5.2
-1.7- 1.7
-5.2- -1.7
-8.7- -5.2
-12.1- -8.7
-15.6--12.1
-19.1--15.6
-22.5--19.1
-26.0--22.5
ONG
CDP
NLR
SHR
GDK
TVL
MDS
CGP
100
200
PDC
CDL
SLM
KKL
TRP
CHENNAI
Scan R : 300 km
Scan Res: 0.30 km
Disp R : 300 km
Disp Res: 1.500 km
PW : Short
PRF: 500 / 333
AS : 6.00 deg/s
TS : 46
RS : 2
CC : Doppler 5
SQI: 0.15
CSR: 15.0 dB
LOG: 2.0 dB
AZ : 0.0-359.0
EL : 0.2 deg
CDR Chennai

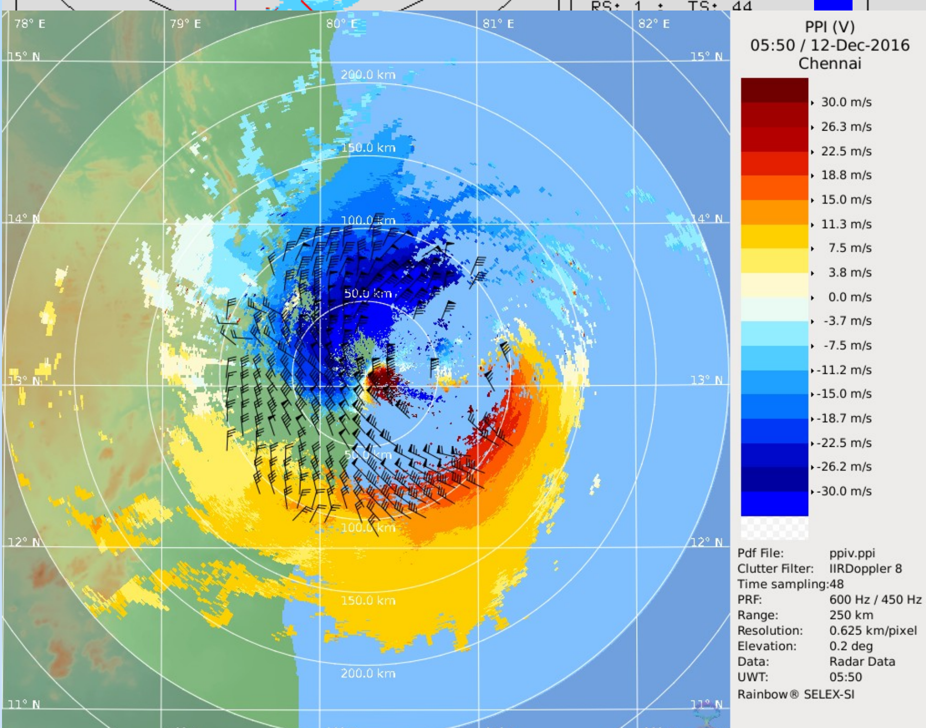


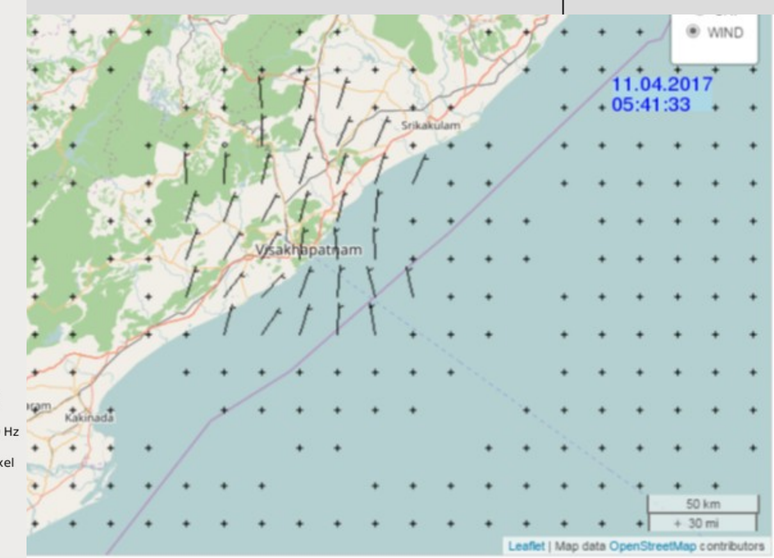
File : 2005121905581722.caw
Type : MAX(W)
Range: 250.0 km
19.12.2005
05:58:17
m/s
4.0
6.0
8.0
10.0
12.0
14.0
16.0
CDP
NLR
SHR
GDK
TVL
MDS
CGP
100
200
PDC
CDL
SLM
KKL
CHENNAI
Short
Doppler
CDR Chennai

Useful Products (UWT)

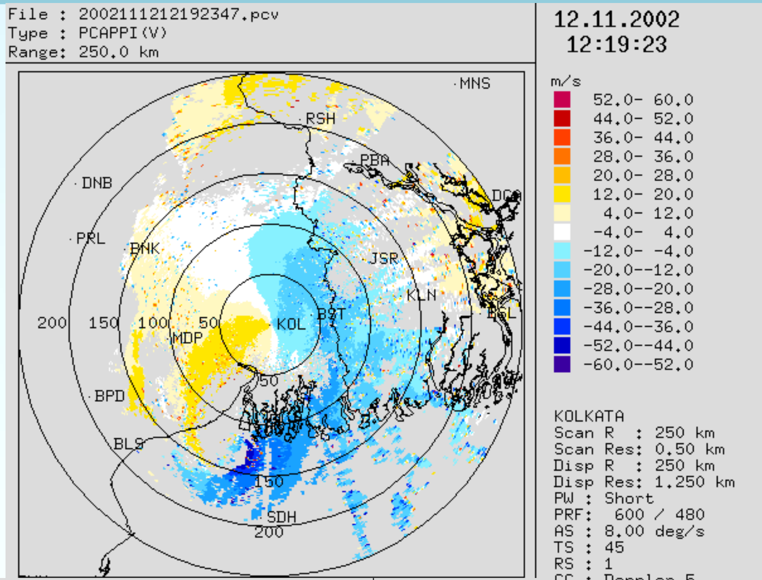


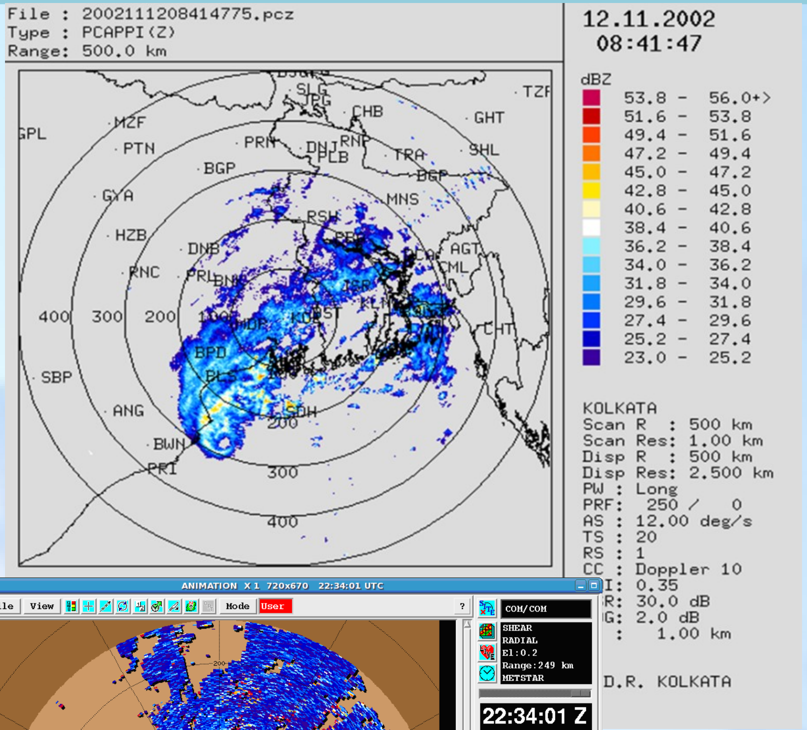


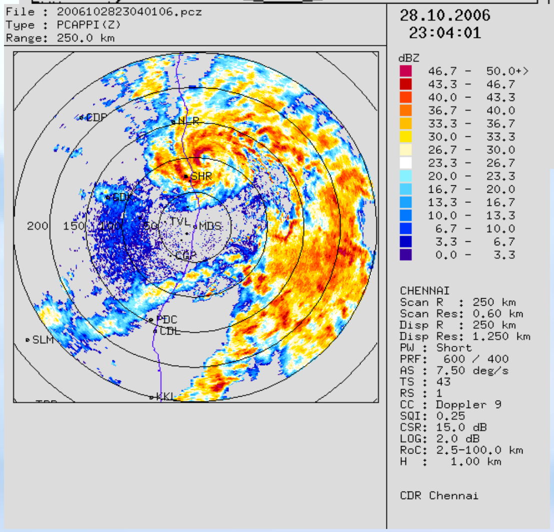


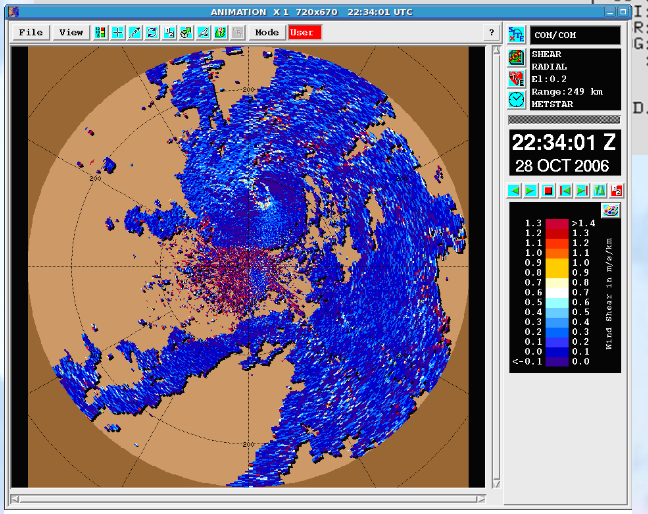


Useful Products (PCAPPI)

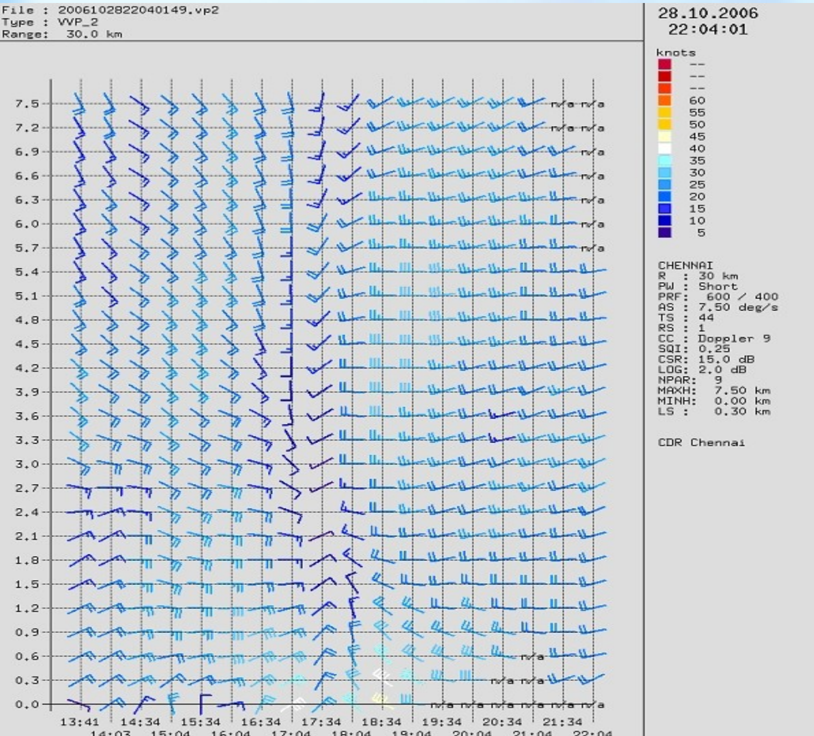


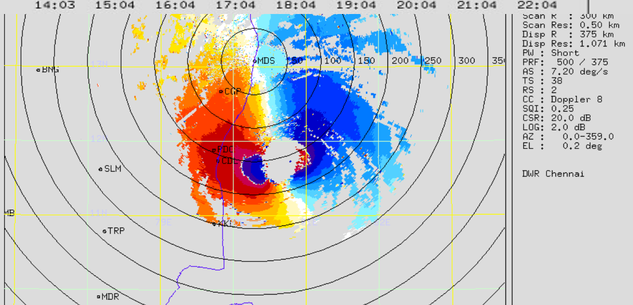


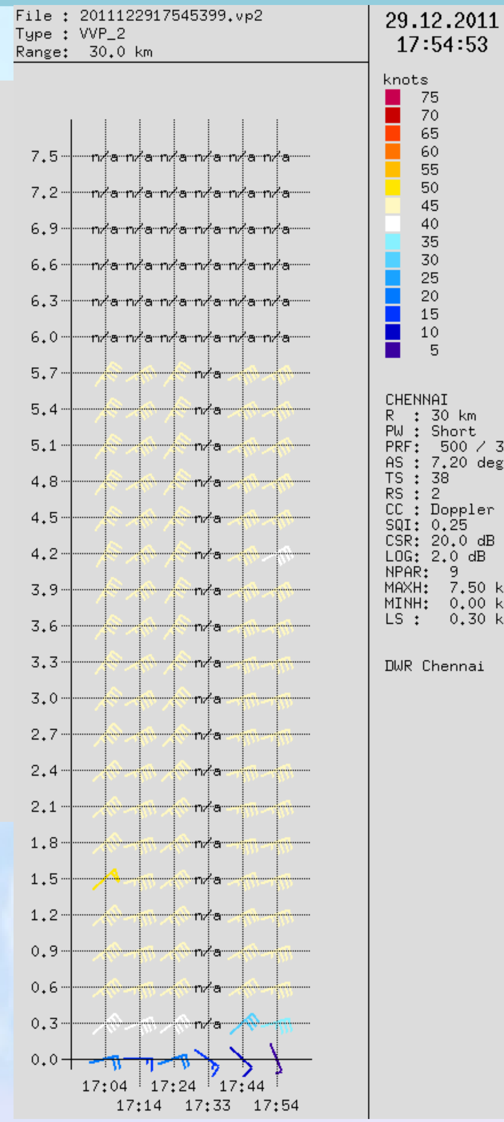


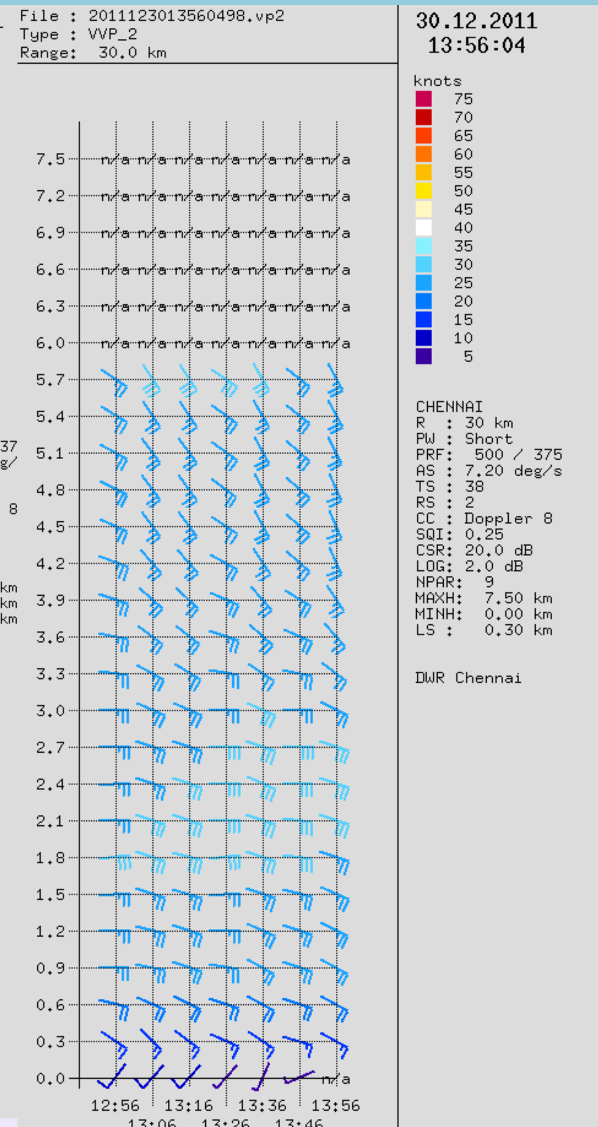


Useful Products (VVP)

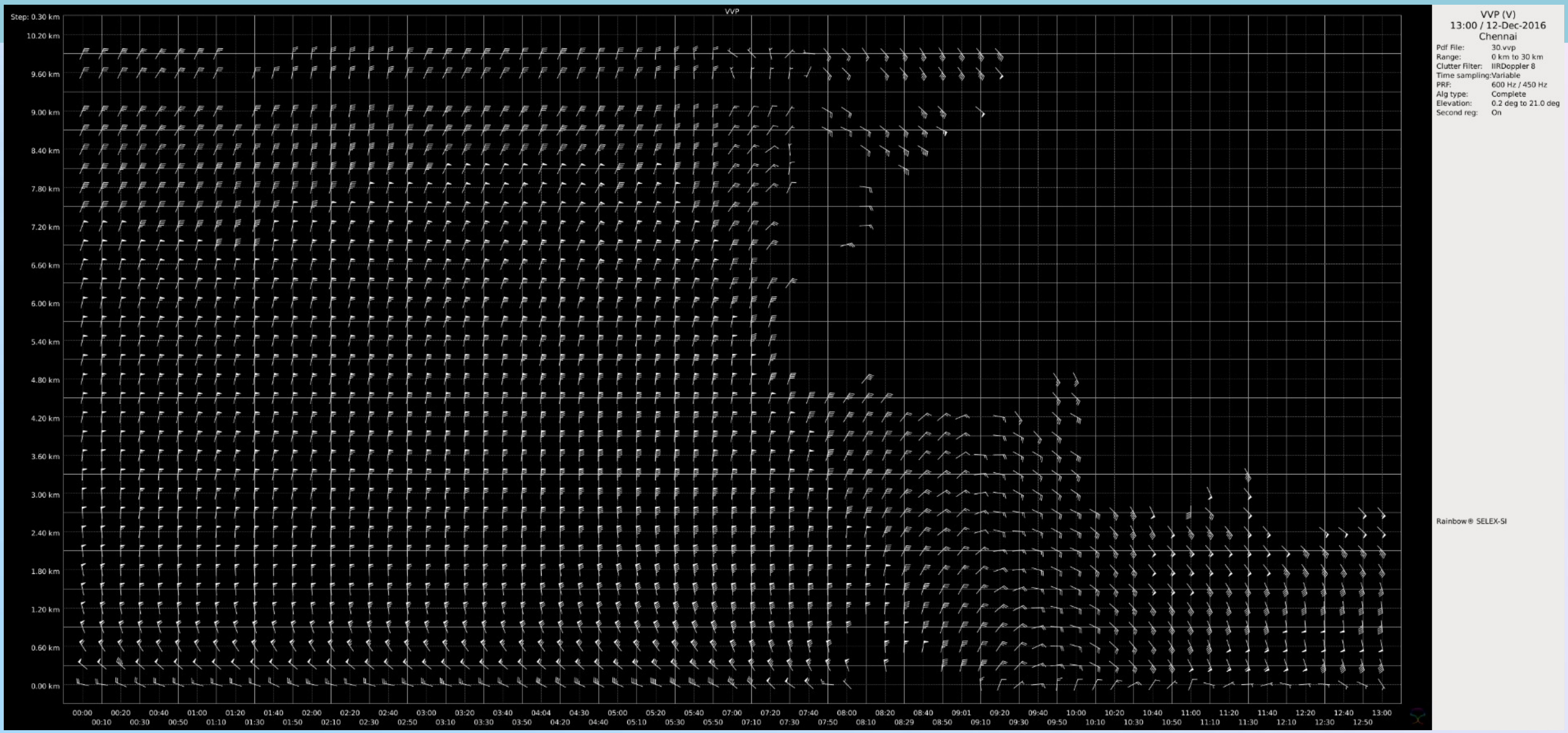


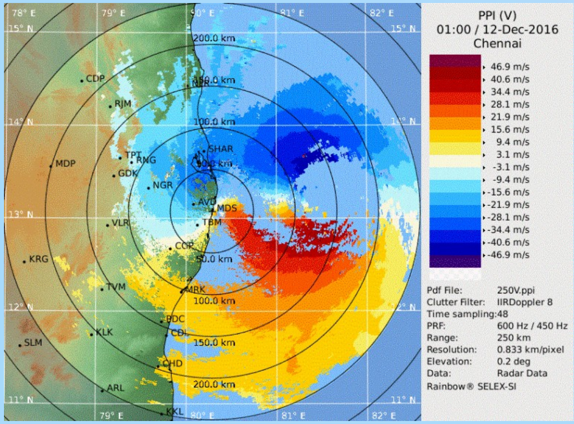


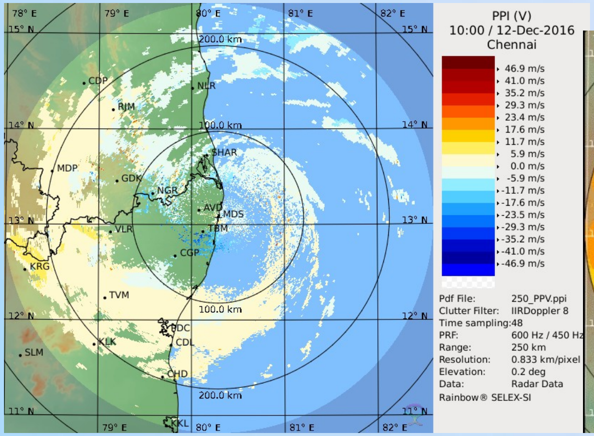


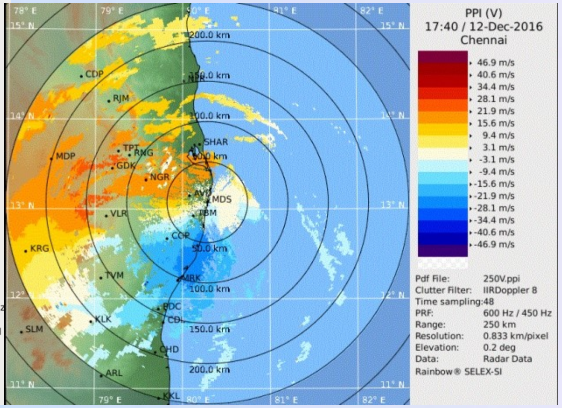


VVP & PPV

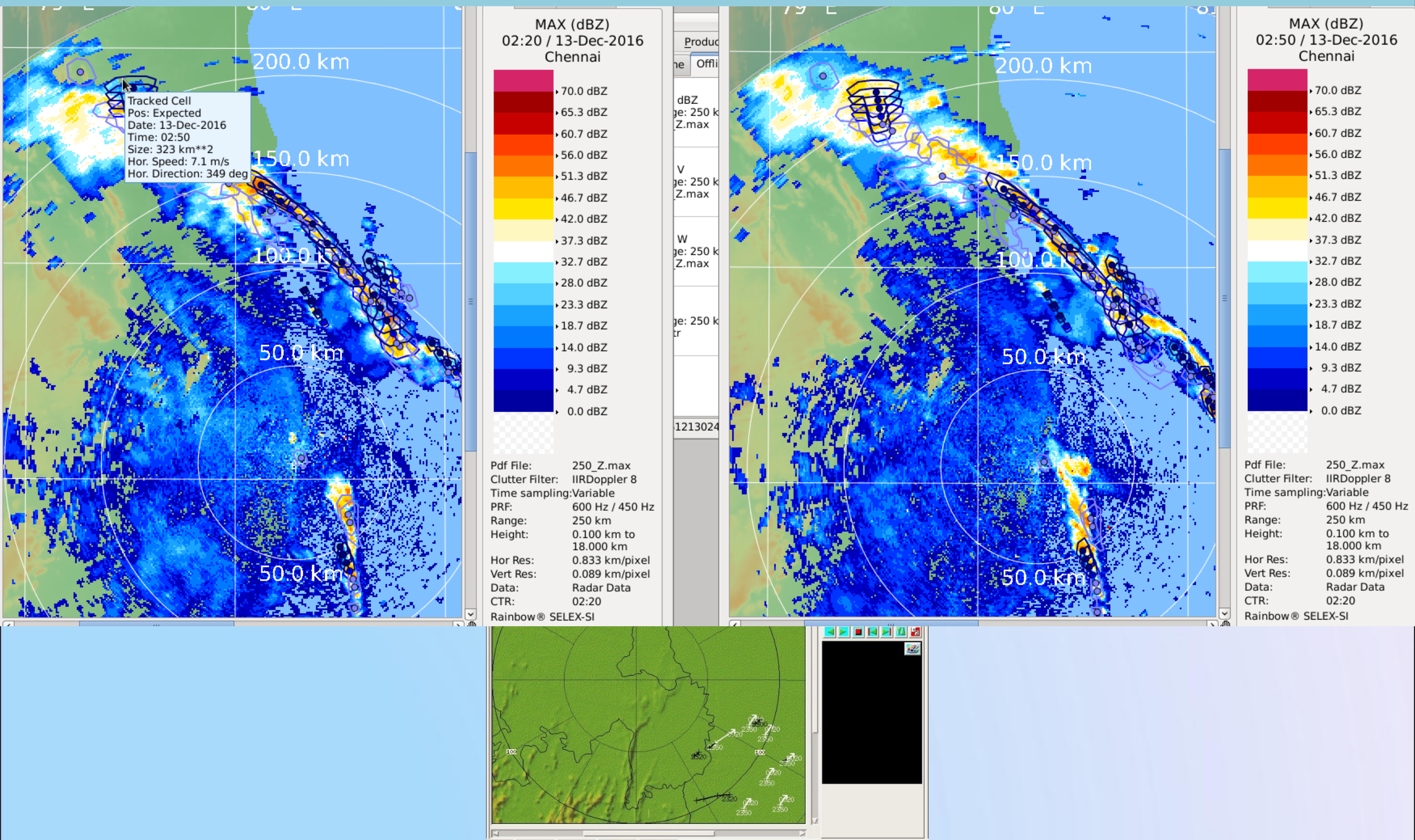

VVP
Step: 0.30 km
VVP (V)
13:00 / 12-Dec-2016
Chennai
Pdf File: 30.vvp
Range: 0 km to 30 km
Clutter Filter: IIRDoppler 8
Time sampling:Variable
PRF: 600 Hz / 450 Hz
Alg type: Complete
Elevation: 0.2 deg to 21.0 deg
Second reg: On
Rainbow® SELEX-SI


PPI (V)
01:00 / 12-Dec-2016
Chennai
46.9 m/s
40.6 m/s
34.4 m/s
28.1 m/s
21.9 m/s
15.6 m/s
9.4 m/s
3.1 m/s
-3.1 m/s
-9.4 m/s
-15.6 m/s
-21.9 m/s
-28.1 m/s
-34.4 m/s
-40.6 m/s
-46.9 m/s
Pdf File: 250V.ppi
Clutter Filter: IIRDoppler 8
Time sampling:48
PRF: 600 Hz / 450 Hz
Range: 250 km
Resolution: 0.833 km/pixel
Elevation: 0.2 deg
Data: Radar Data
Rainbow® SELEX-SI

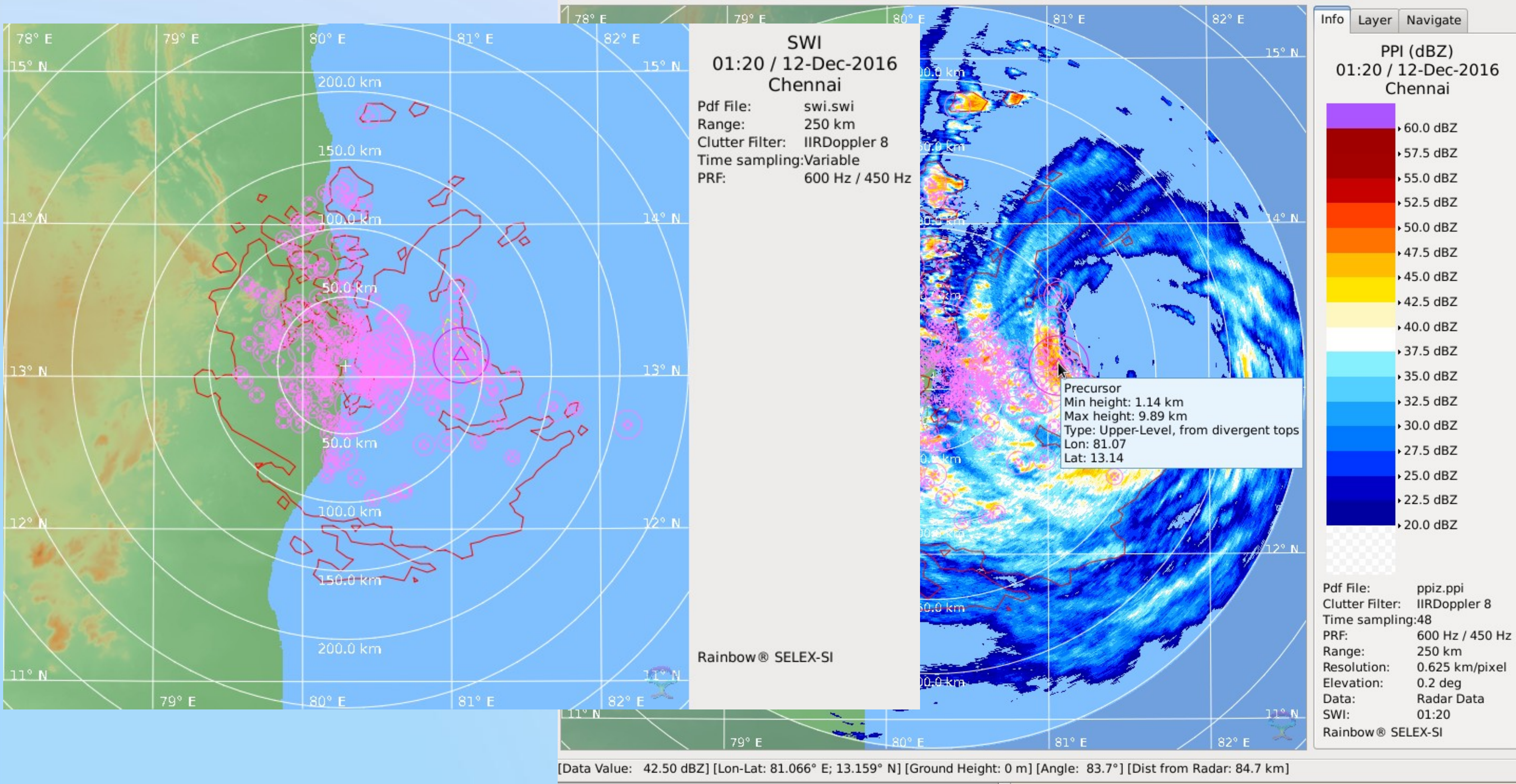

PPI (V)
10:00 / 12-Dec-2016
Chennai
46.9 m/s
41.0 m/s
35.2 m/s
29.3 m/s
23.4 m/s
17.6 m/s
11.7 m/s
5.9 m/s
0.0 m/s
-5.9 m/s
-11.7 m/s
-17.6 m/s
-23.5 m/s
-29.3 m/s
-35.2 m/s
-41.0 m/s
-46.9 m/s
Pdf File: 250_PPV.ppi
Clutter Filter: IIRDoppler 8
Time sampling:48
PRF: 600 Hz / 450 Hz
Range: 250 km
Resolution: 0.833 km/pixel
Elevation: 0.2 deg
Data: Radar Data
Rainbow® SELEX-SI


PPI (V)
17:40 / 12-Dec-2016
Chennai
46.9 m/s
40.6 m/s
34.4 m/s
28.1 m/s
21.9 m/s
15.6 m/s
9.4 m/s
3.1 m/s
-3.1 m/s
-9.4 m/s
-15.6 m/s
-21.9 m/s
-28.1 m/s
-34.4 m/s
-40.6 m/s
-46.9 m/s
Pdf File: 250V.ppi
Clutter Filter: IIRDoppler 8
Time sampling:48
PRF: 600 Hz / 450 Hz
Range: 250 km
Resolution: 0.833 km/pixel
Elevation: 0.2 deg
Data: Radar Data
Rainbow® SELEX-SI

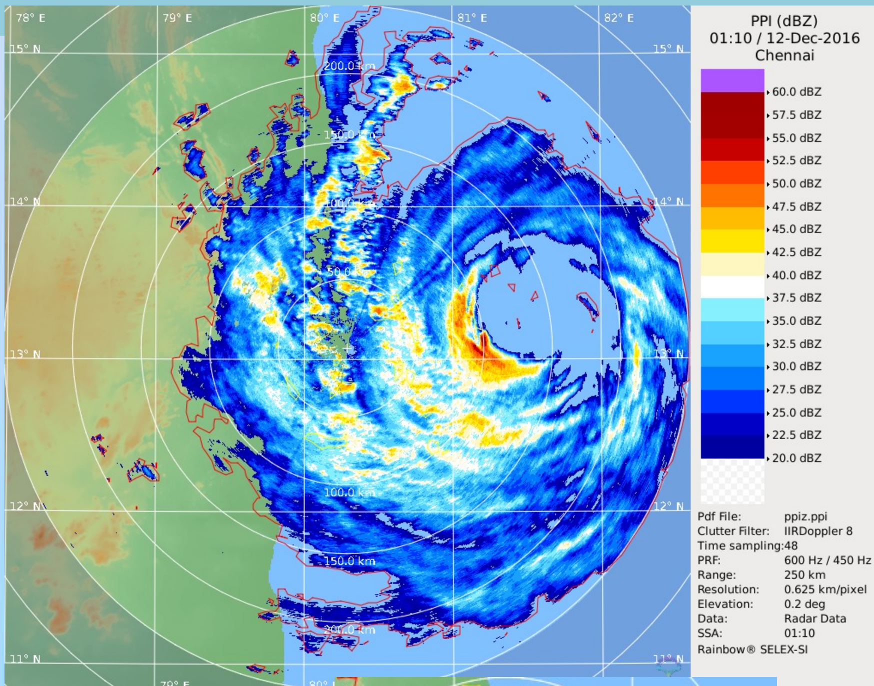
FCST (TRACK)

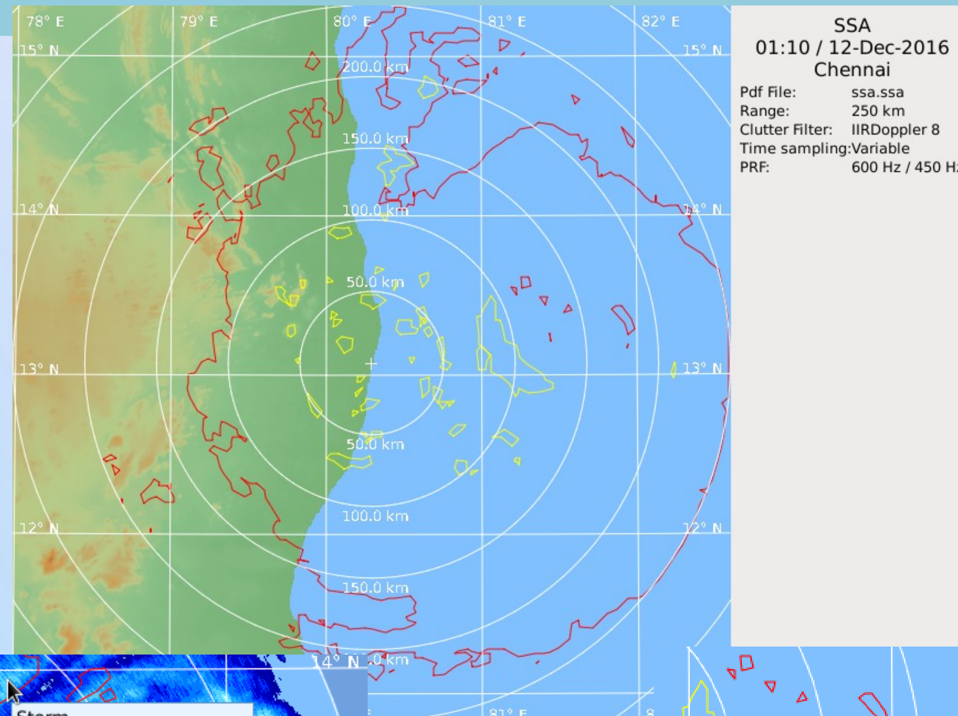

200.0 km
150.0 km
100.0 km
50.0 km
50.0 km
Tracked Cell
Pos: Expected
Date: 13-Dec-2016
Time: 02:50
Size: 323 km**2
Hor. Speed: 7.1 m/s
Hor. Direction: 349 deg
MAX (dBZ)
02:20 / 13-Dec-2016
Chennai
70.0 dBZ
65.3 dBZ
60.7 dBZ
56.0 dBZ
51.3 dBZ
46.7 dBZ
42.0 dBZ
37.3 dBZ
32.7 dBZ
28.0 dBZ
23.3 dBZ
18.7 dBZ
14.0 dBZ
9.3 dBZ
4.7 dBZ
0.0 dBZ
Pdf File: 250_Z.max
Clutter Filter: IIRDoppler 8
Time sampling:Variable
PRF: 600 Hz / 450 Hz
Range: 250 km
Height: 0.100 km to 18.000 km
Hor Res: 0.833 km/pixel
Vert Res: 0.089 km/pixel
Data: Radar Data
CTR: 02:20
Rainbow® SELEX-SI
200.0 km
150.0 km
100.0 km
50.0 km
50.0 km
MAX (dBZ)
02:50 / 13-Dec-2016
Chennai
70.0 dBZ
65.3 dBZ
60.7 dBZ
56.0 dBZ
51.3 dBZ
46.7 dBZ
42.0 dBZ
37.3 dBZ
32.7 dBZ
28.0 dBZ
23.3 dBZ
18.7 dBZ
14.0 dBZ
9.3 dBZ
4.7 dBZ
0.0 dBZ
Pdf File: 250_Z.max
Clutter Filter: IIRDoppler 8
Time sampling:Variable
PRF: 600 Hz / 450 Hz
Range: 250 km
Height: 0.100 km to 18.000 km
Hor Res: 0.833 km/pixel
Vert Res: 0.089 km/pixel
Data: Radar Data
CTR: 02:20
Rainbow® SELEX-SI

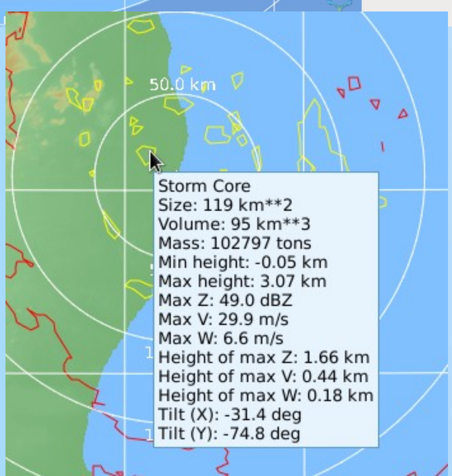
Severe Weather Index

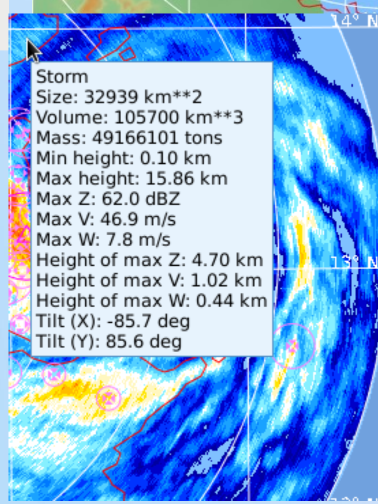


Storm Structure Analysis









Limitations & overcoming

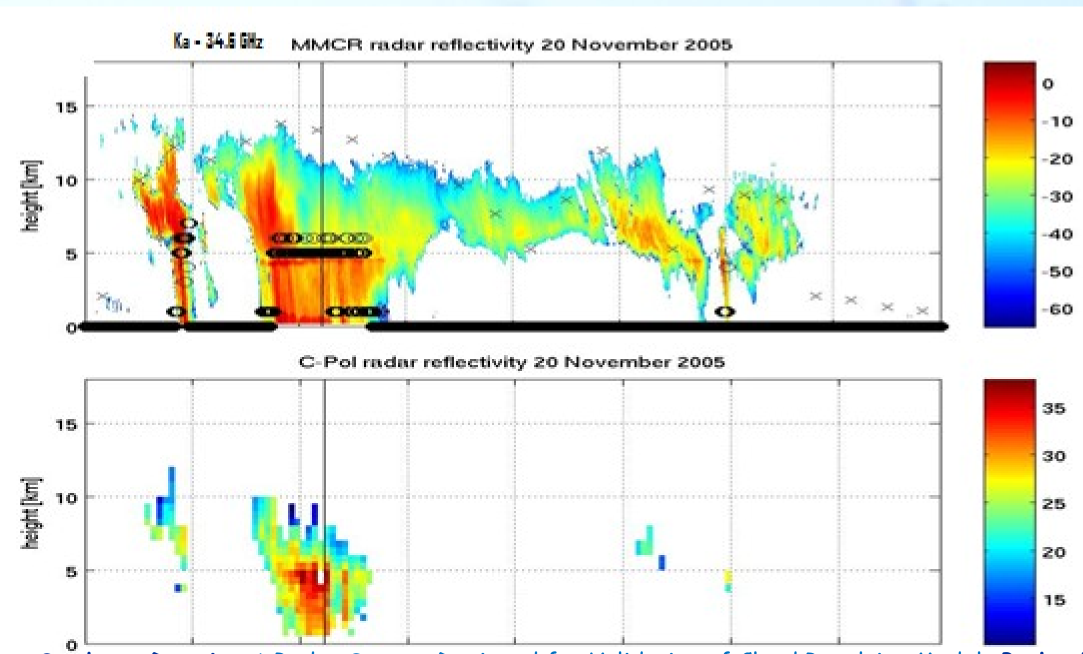
- Type of Radar
- Anomalous propagation
- Signal interference
- Clutter mitigation
- Atmospheric Attenuation
- Earth curvature
- Nyquist Velocity & (Doppler) dilemma
- Beam width resolutions

TYPE OF RADAR Sensitivity Issues

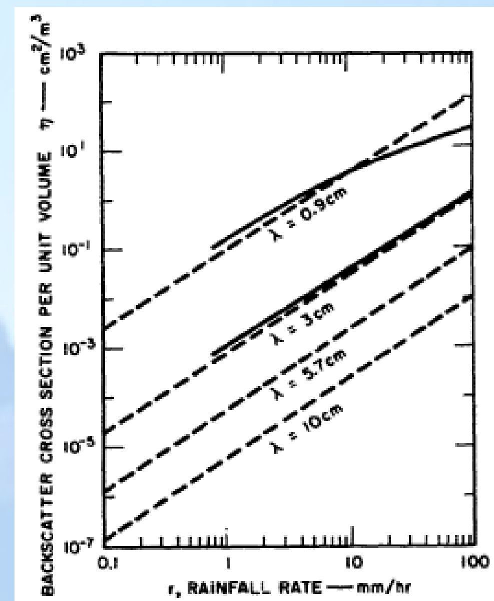
- With increased interaction/ influence of atmosphere at higher frequencies, sensitivity increases provided all other factors are identical (Power transmitted, beam width, scattering mechanism etc.)

Sensitivity of radar bands in decreasing trend:

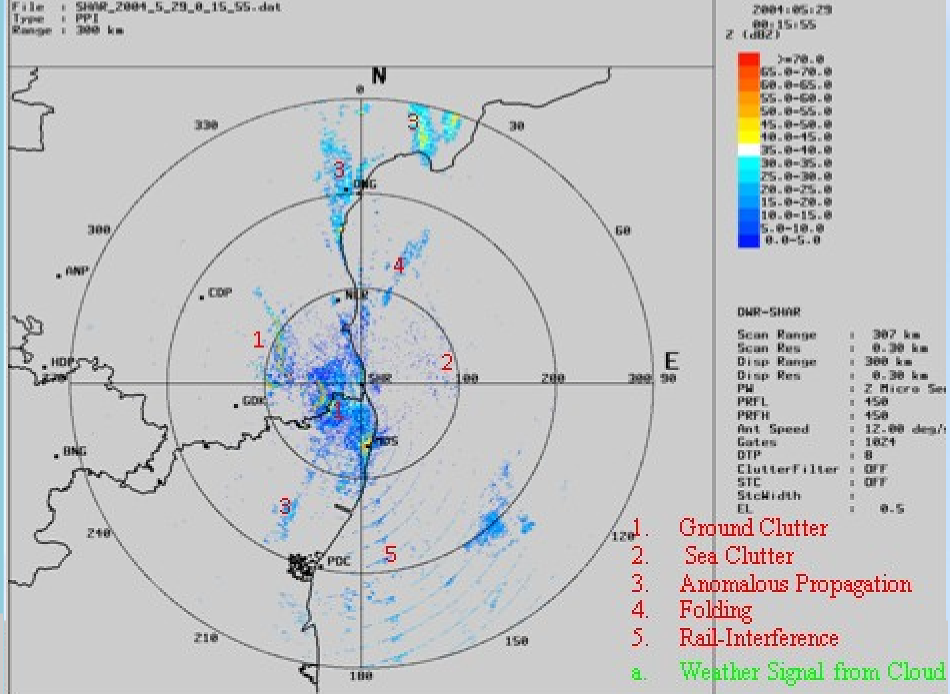
W, V, Ka, K, Ku, X, C, S, L

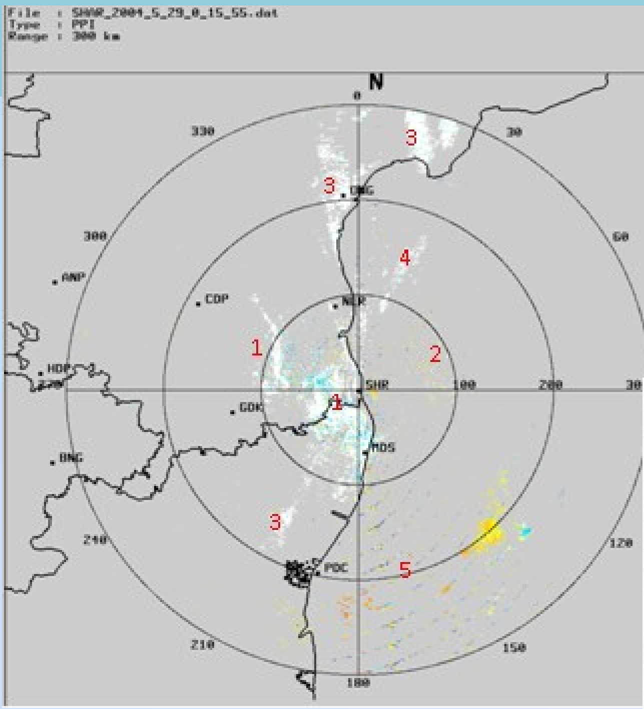


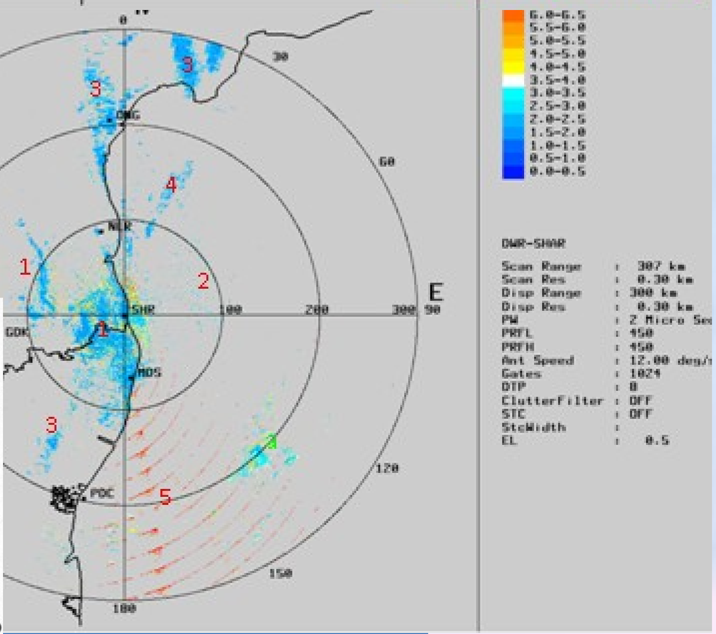
Study at Darwin: A Radar System Designed for Validation of Cloud Resolving Models Pavlos Kollias, Atmospheric Science Division, Brookhaven National Laboratory

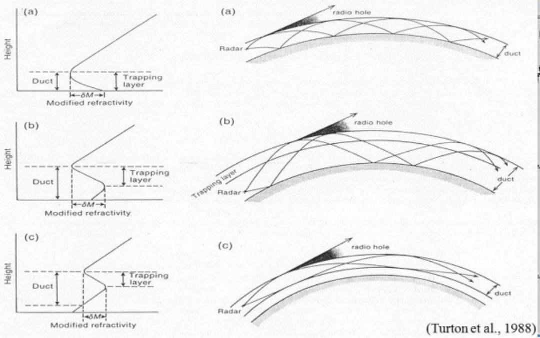


Radar limitations and overcoming - INTERFERENCE & Propagation

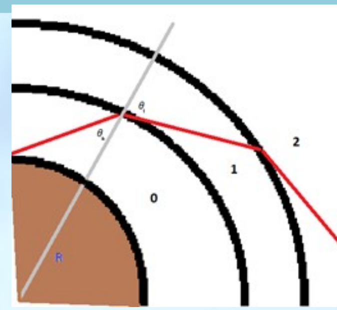




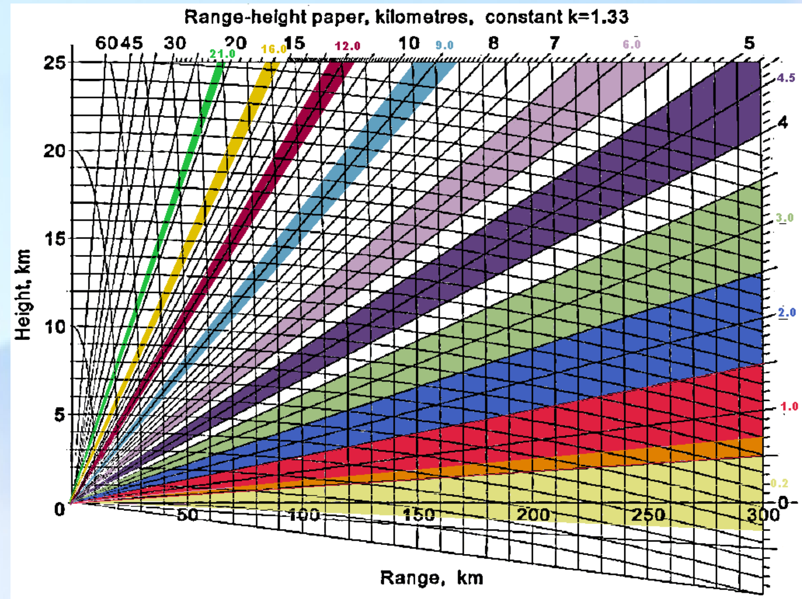




PROPAGATION



$\phi_h^2 - \phi_0^2 = -2h/R_e$ with $R_e = kR$ where $k = \left[1 + \frac{R\,dn}{n_0\,dh}\right]^{-1}$

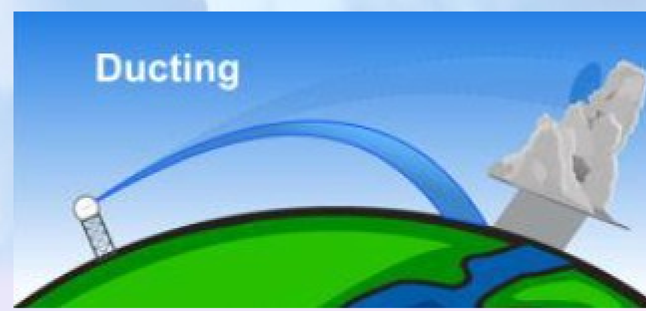


K	RI gradient	Total Ray curvature	Virtual earth	Atmospheric refraction
<1	dN/dh>0	Moves up	More Convex	Sub refraction
1	dN/dh=0	Moves up	Actual	Sub refraction
>1	dN/dh<0	Moves up/down	Convex/flat/concave	Sub/normal/Super
	0>dN/dh>-39	Moves up	Less Convex	Sub refraction
4/3	-39	Moves up	Less Convex	Normal refraction
	-39>dN/dh>-157	Moves down	Less convex	Super refraction
	-157	Moves down	Flat	Super refraction
	<-157	Down	Concave	Super refraction (Ductin

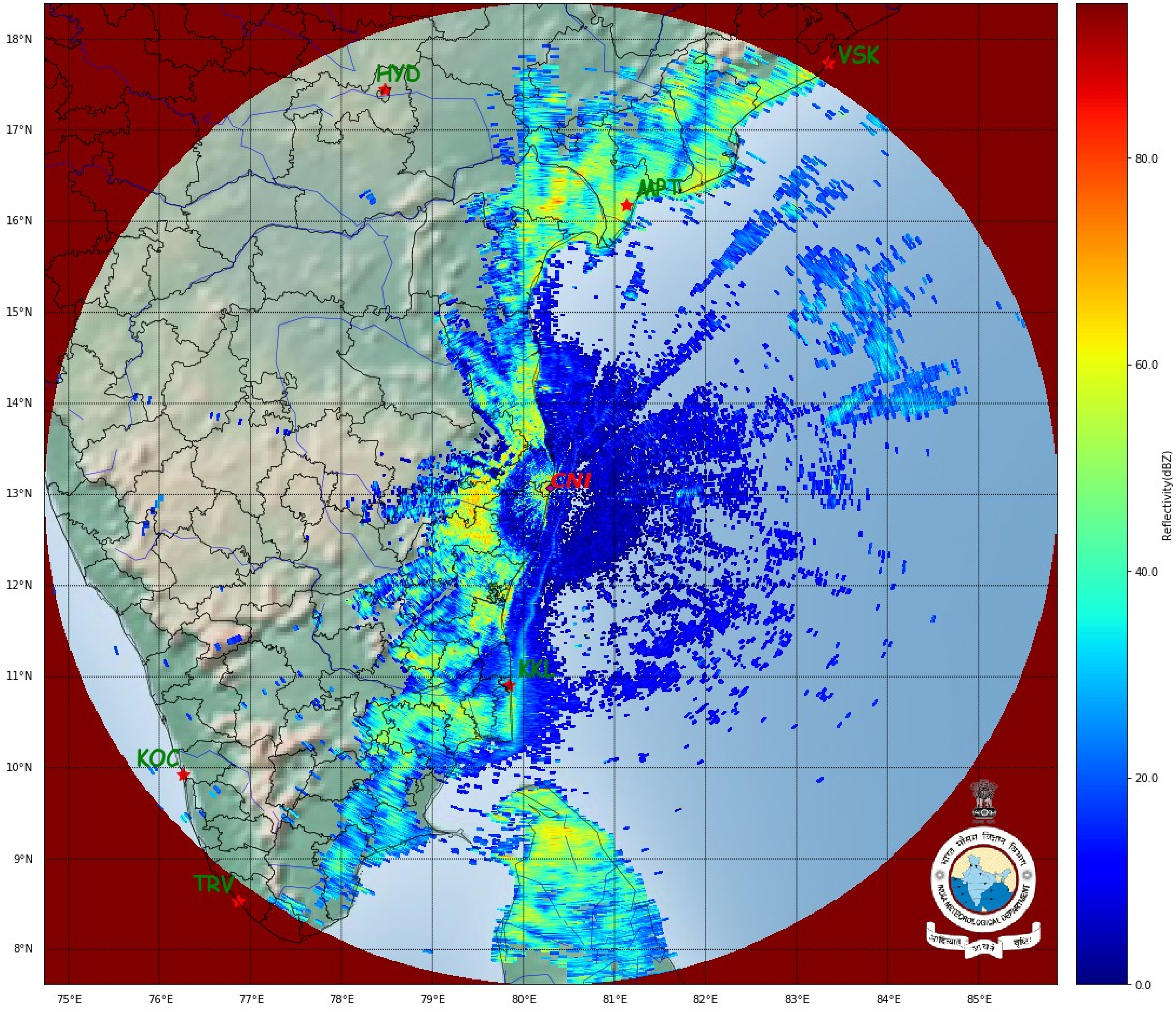
$h = \sqrt{r^2 + R_e^2 + 2\,r\,R_e sin\varphi} - R_e + H_0$

(also $h = r sin\varphi + r^2/2R_e + h_t$)

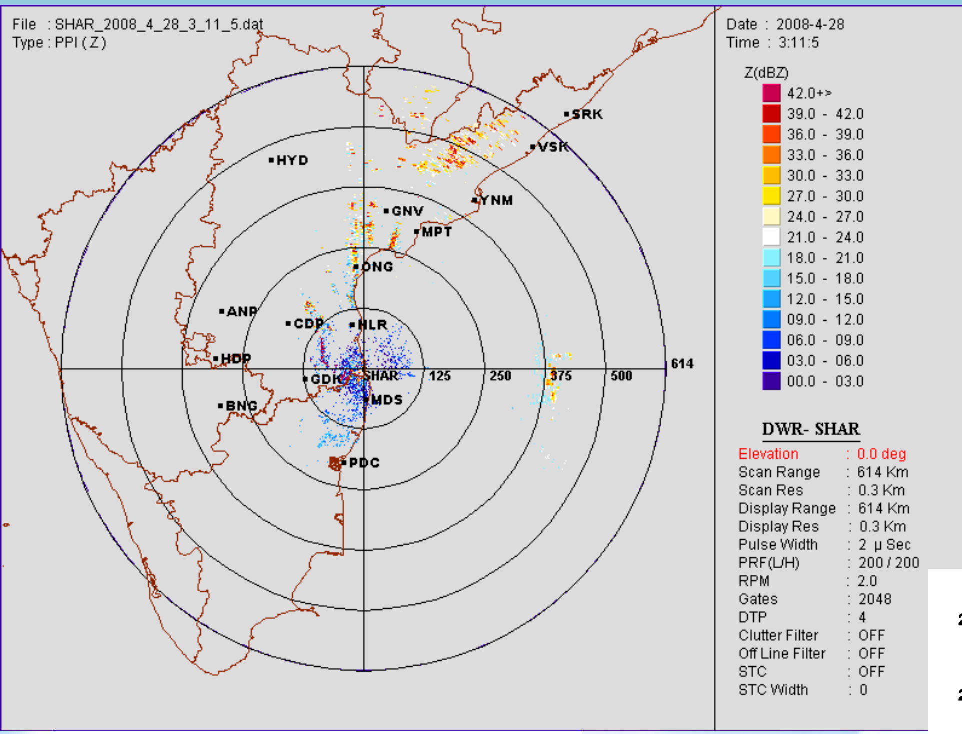
$R_{horizon} = \sqrt{2R_e h_t} + \sqrt{2R_e h_r}$

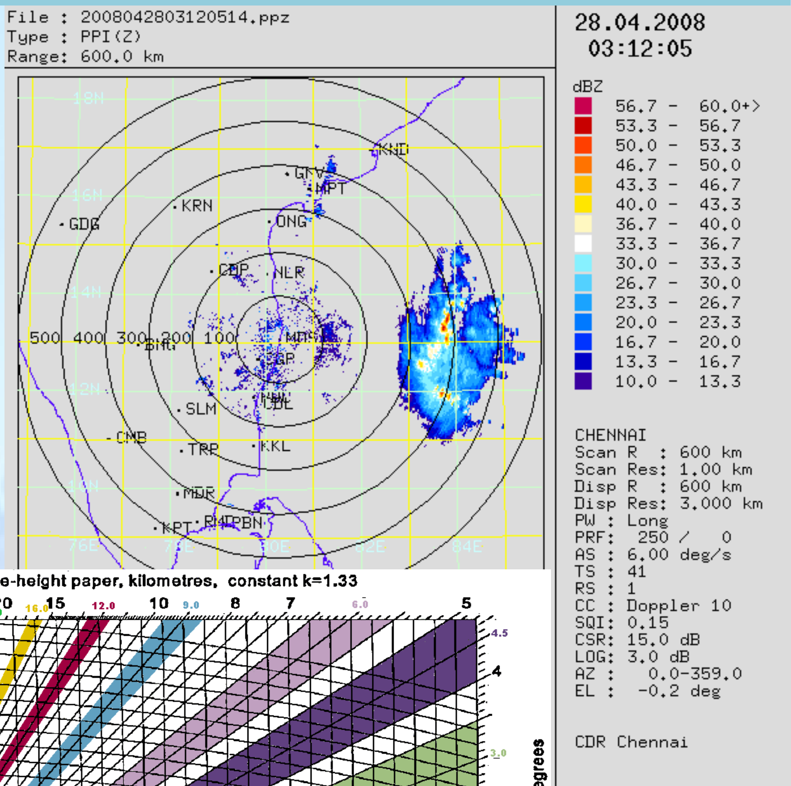


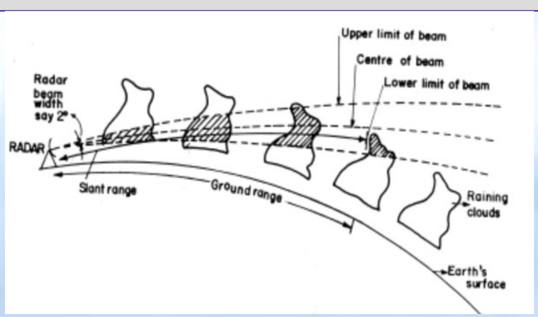
test1.tif

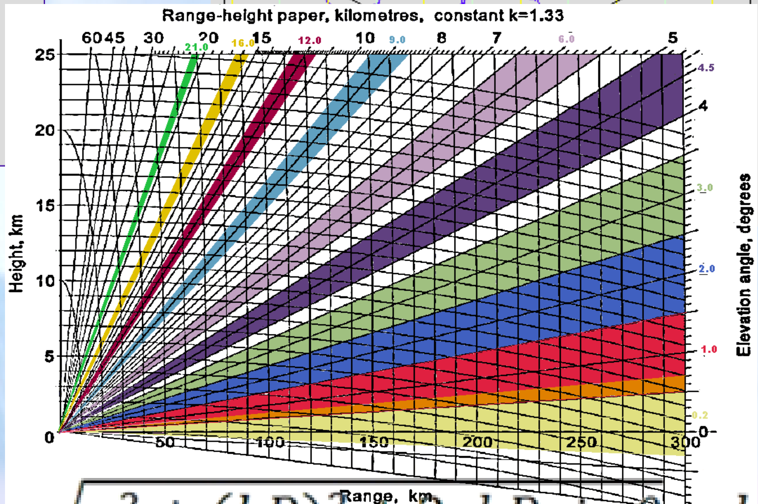

HYD
VSK
MPT
CNI
KKL
KOC
TRV
18°N
17°N
16°N
15°N
14°N
13°N
12°N
11°N
10°N
9°N
8°N
75°E
76°E
77°E
78°E
79°E
80°E
81°E
82°E
83°E
84°E
85°E
Reflectivity(dBZ)
80.0
60.0
40.0
20.0
0.0

Radar Limitations and Overcoming Curvature

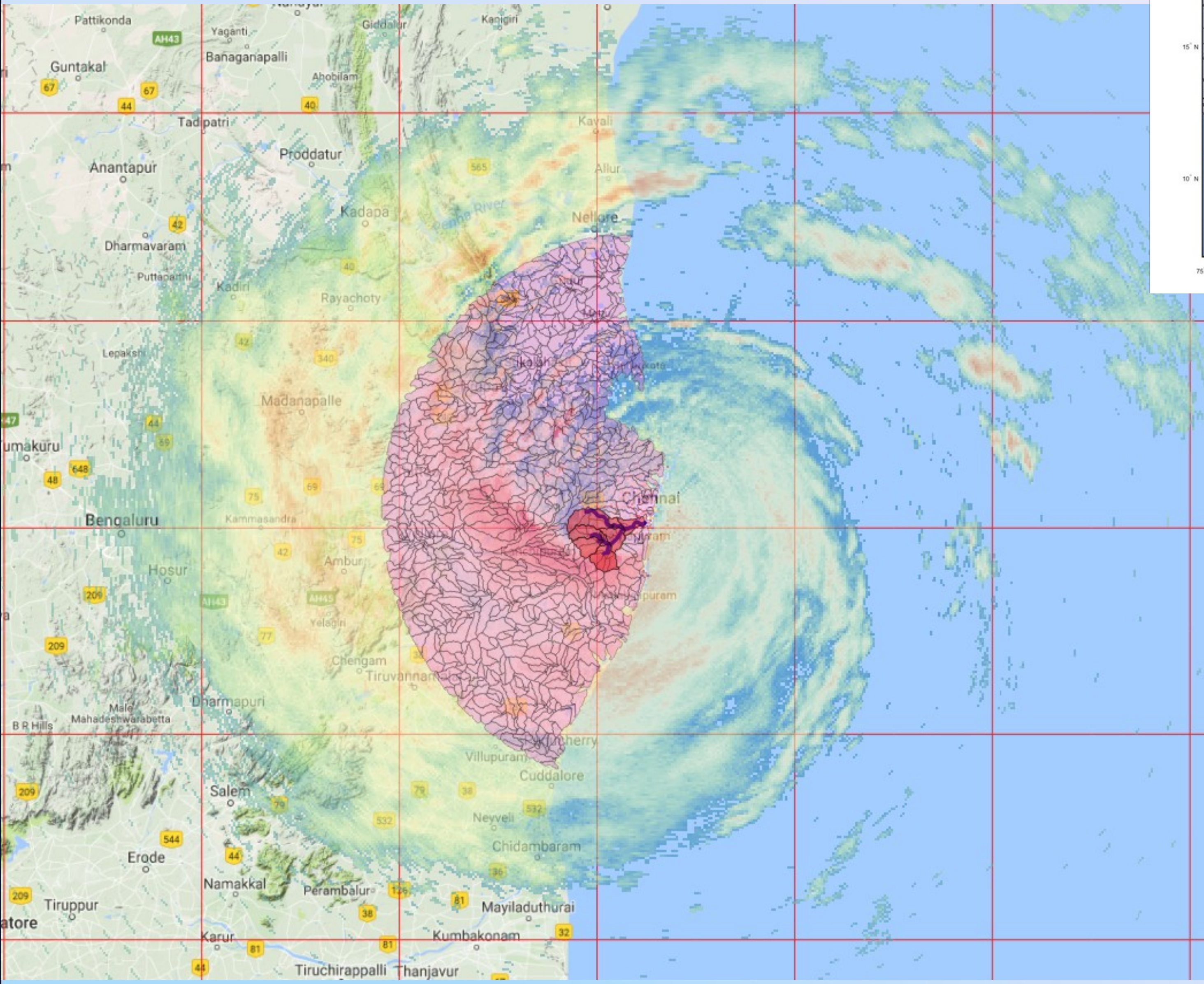


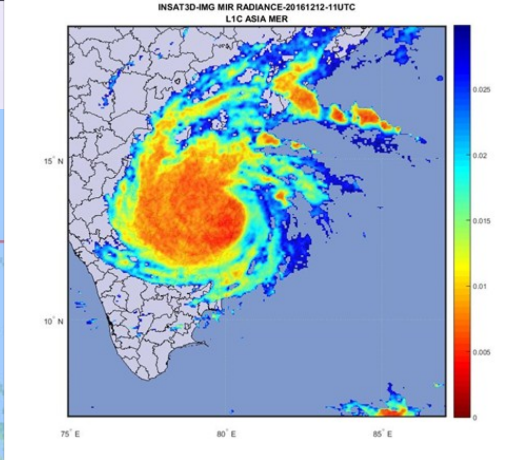


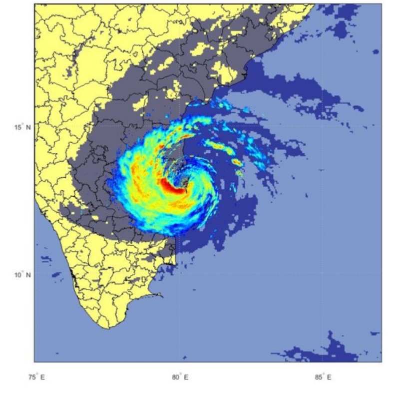


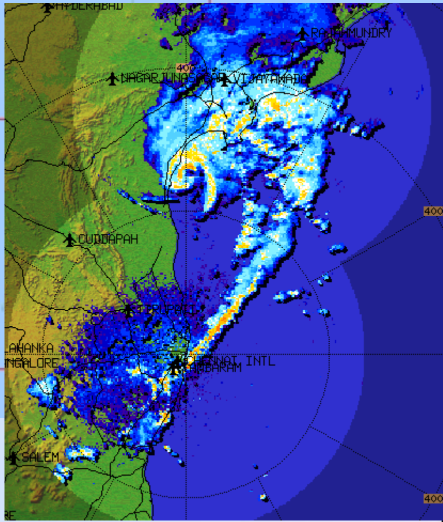


$$h = \sqrt{r^2 + (kR)^2 + 2rkR\sin\theta} - kR + H_0$$

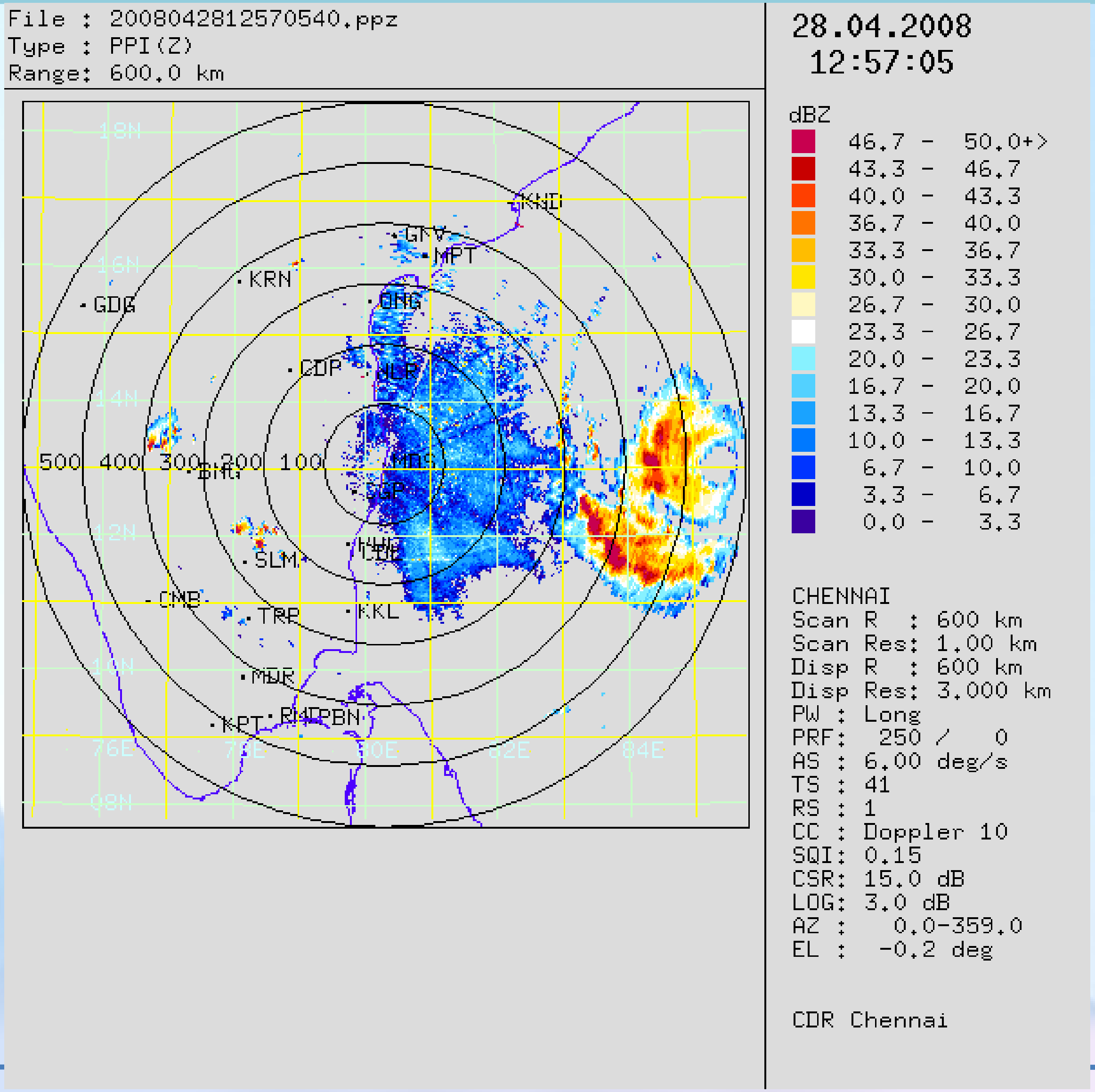

Pattikonda
Yaganti
Giddalur
Kanigiri
Guntakal
Banaganapalli
Ahobilam
Tadipatri
Kavali
Anantapur
Proddatur
Allur
Kadapa
Nellore
Dharmavaram
Puttaparthi
Kadiri
Rayachoty
Lepakshi
Madanapalle
Bengaluru
Kammasandra
Chennai
Hosur
Ambur
Yelagiri
Chengam
Tiruvannamalai
Dharmapuri
Mahadeshwarabetta
B R Hills
Villupuram
Cuddalore
Salem
Neyveli
Chidambaram
Erode
Namakkal
Perambalur
Tiruppur
Mayiladuthurai
Kumbakonam
Karur
Tiruchirappalli
Thanjavur


INSAT3D-IMG MIR RADIANCE-20161212-11UTC
L1C ASIA MER
15° N
10° N
75° E
80° E
85° E

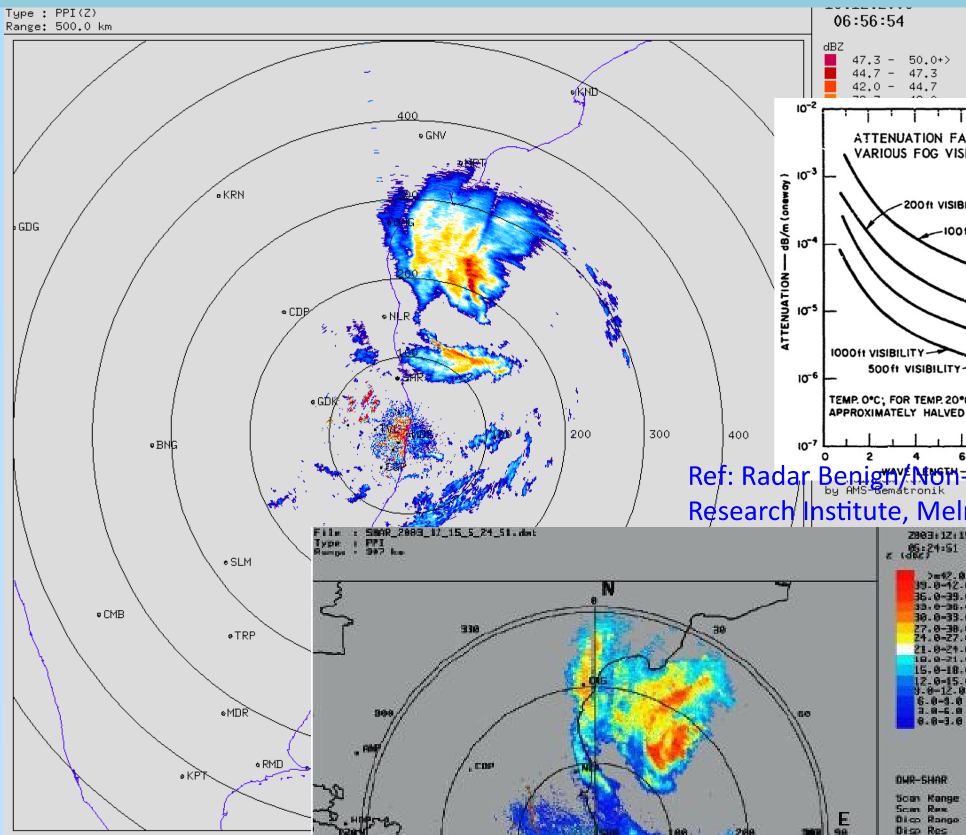

15° N
10° N
75° E
80° E
85° E

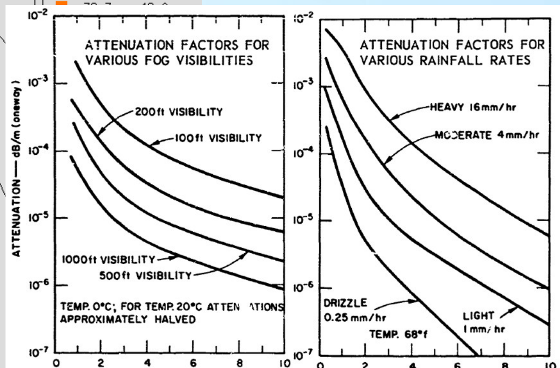

CUDDAPAH
SALEM

Curvature Effects center



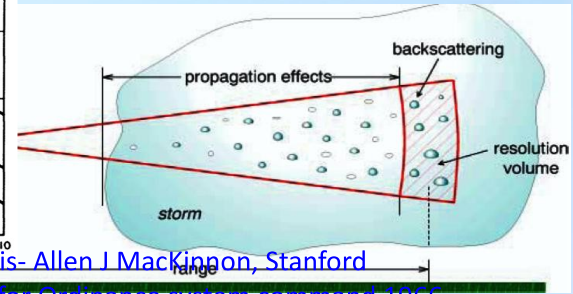
Radar Limitations and Overcoming Attenuation



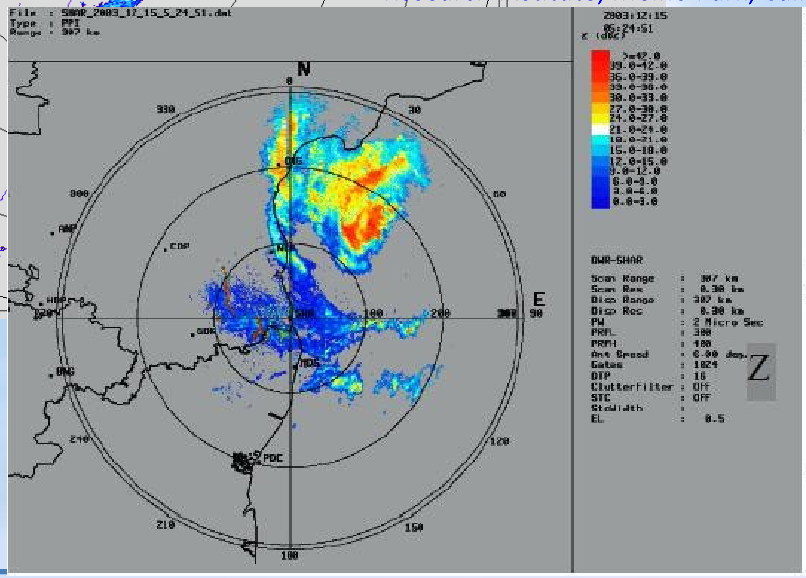


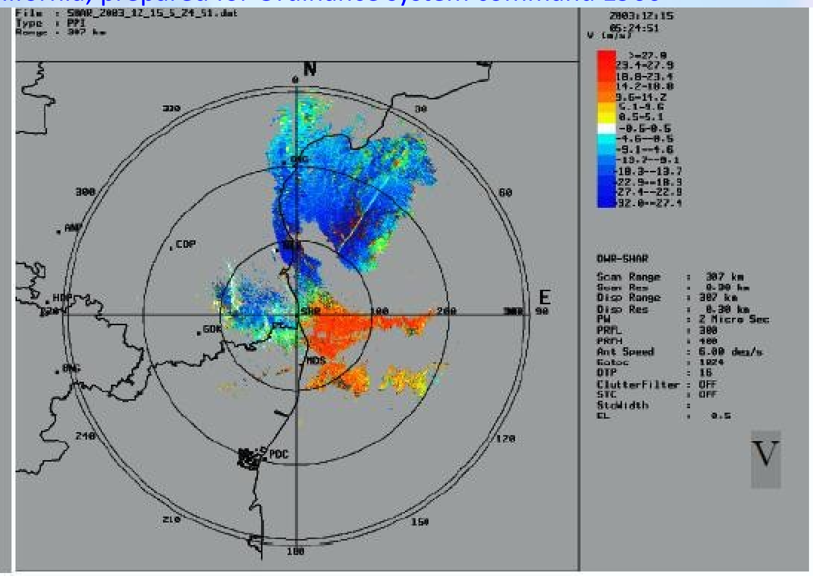
Attenuation Example
R(one-way) = 5 km, rainfall rate = 4 mm/hr

f (GHz)	Band	a (dB) (two-way)
3	S	0.016
5	C	0.073
10	X	0.61
16	Ku	1.9
30	Ka	7.4
100	W	31

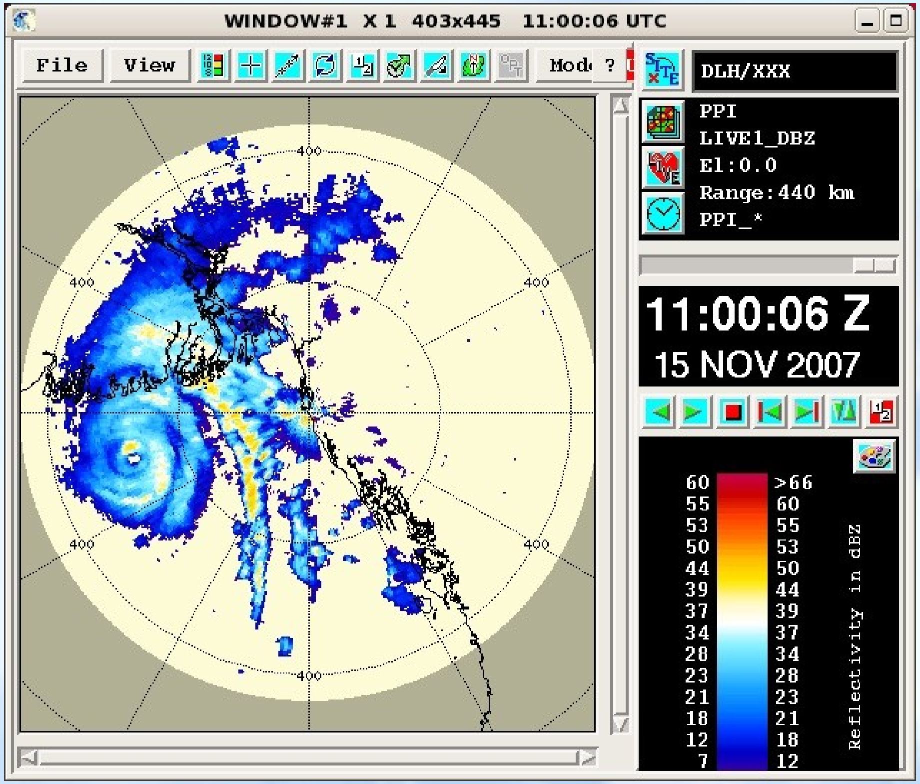


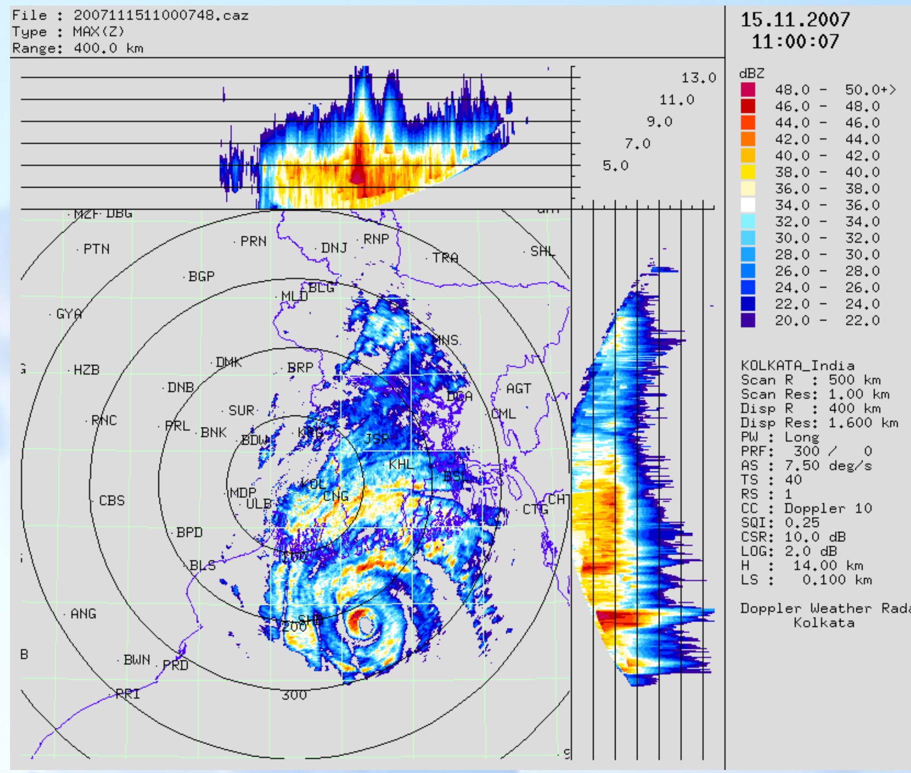
Ref: Radar Benign/Non-Benign Environmental analysis- Allen J MacKinnon, Stanford Research Institute, Melno Park, California; prepared for Ordinance system command 1966





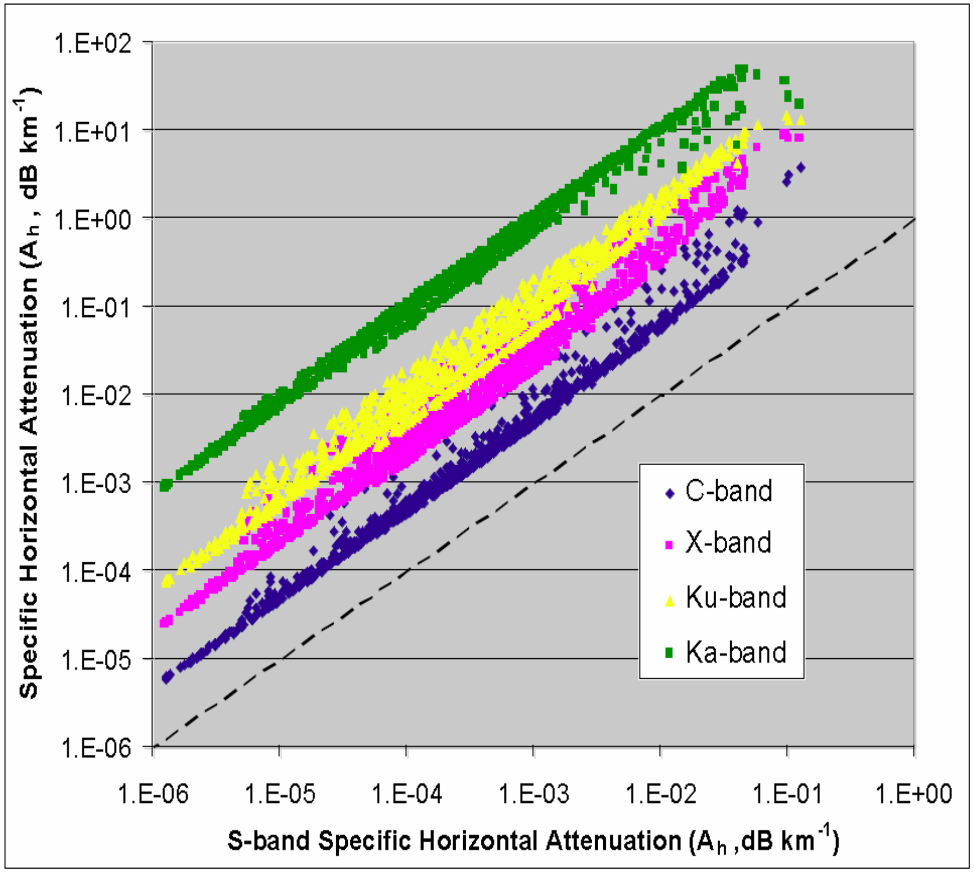
Attenuation Artifacts

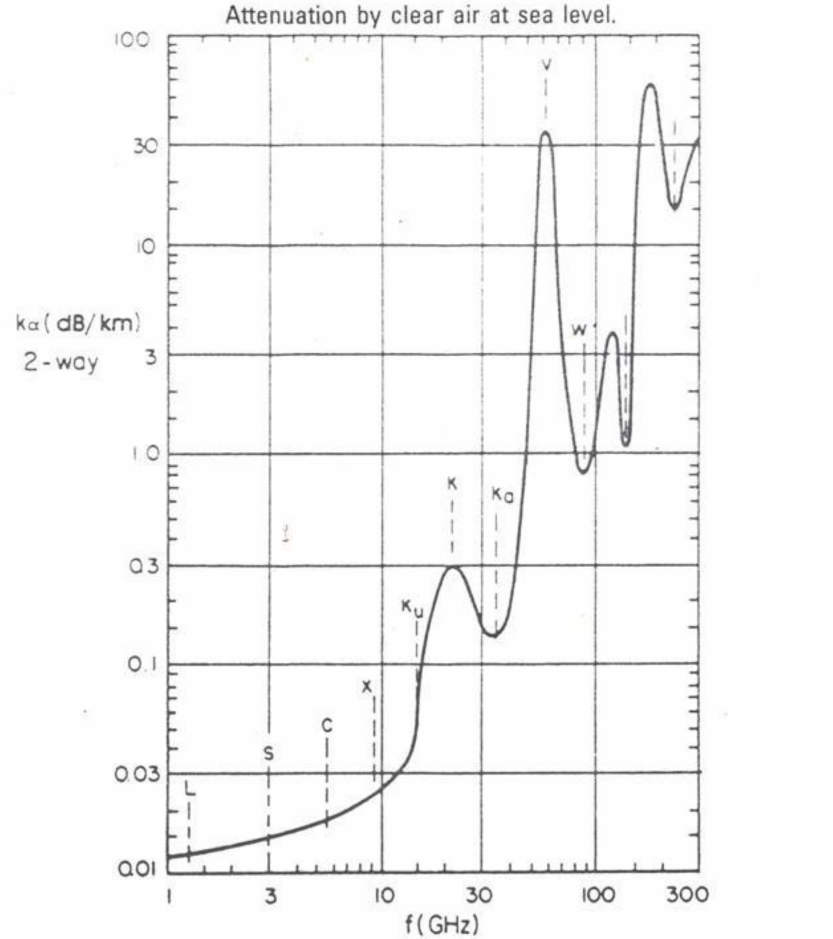




Rayleigh scatter Radars Attenuation in clear air

10x difference in attenuation between Ku-Ka (favorable DWR- if beams matched)

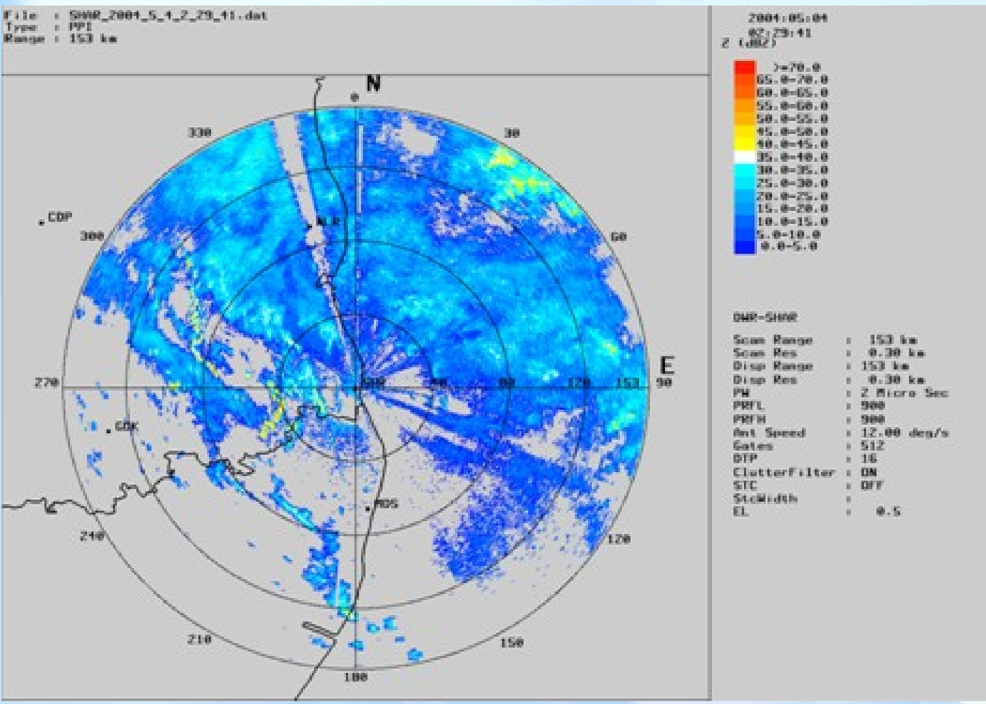


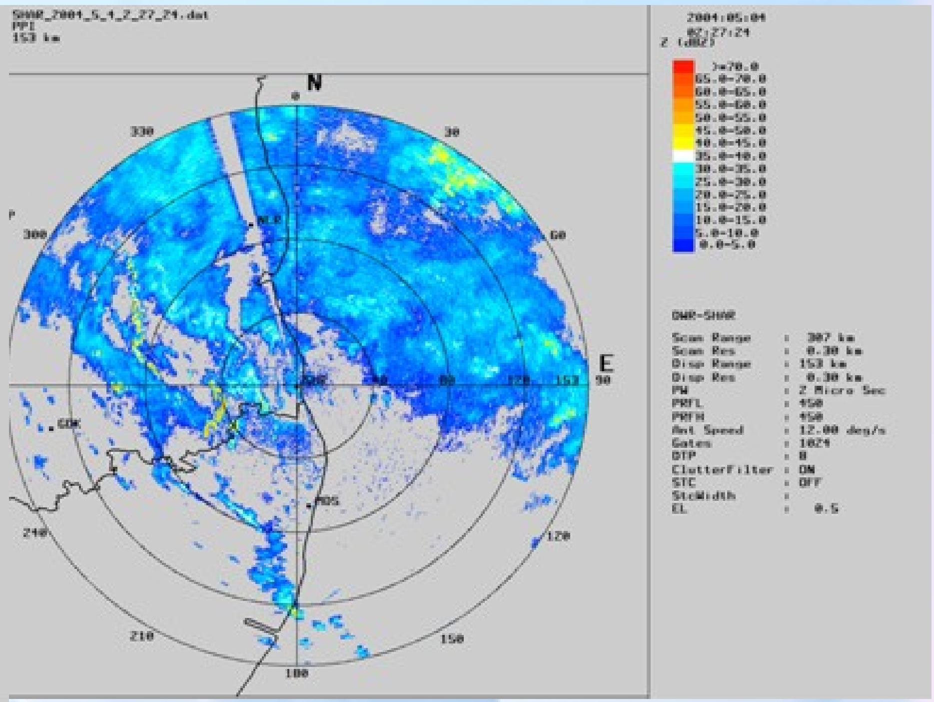


Radar limitation overcoming FOLDING (RANGE)

$$R_u = \frac{c}{2 * \mathrm{PRF}}$$

Range folded | **actual**

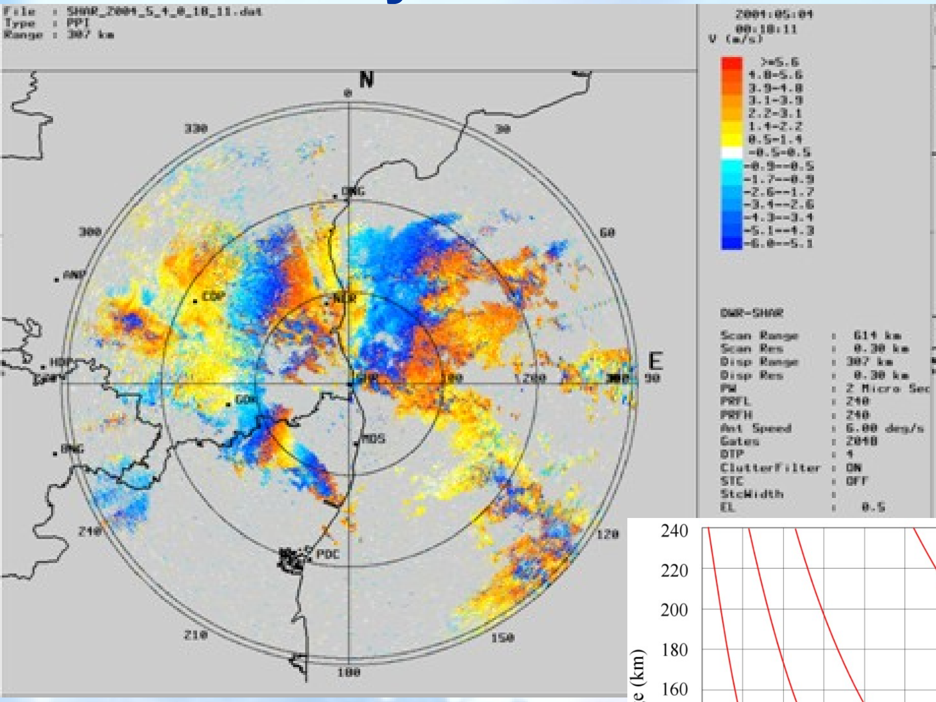




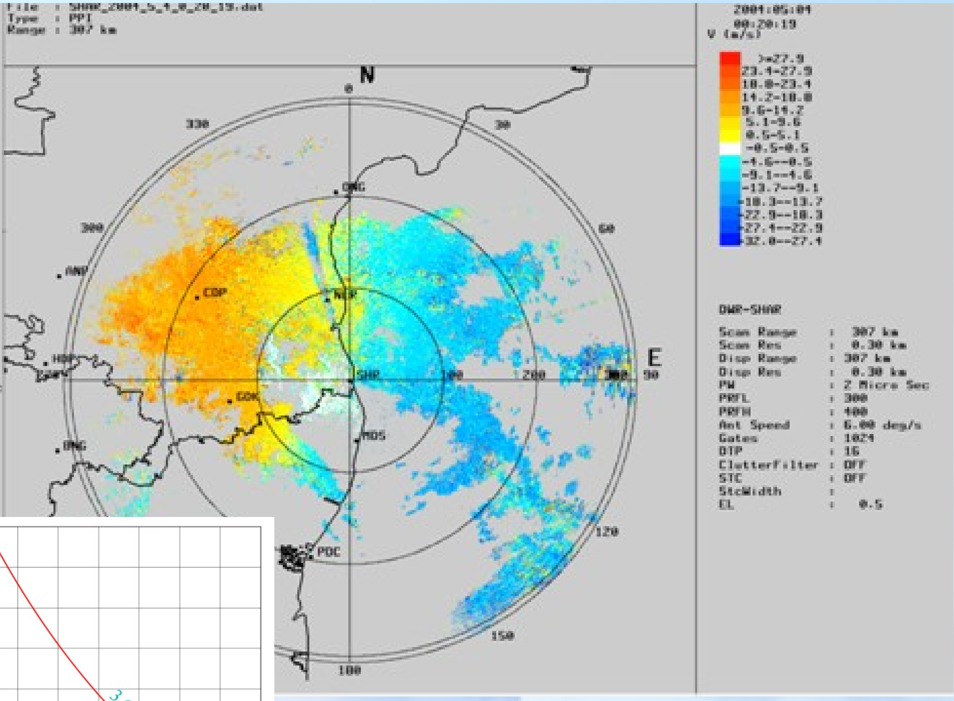
Radar limitation overcoming FOLDING (VELOCITY)

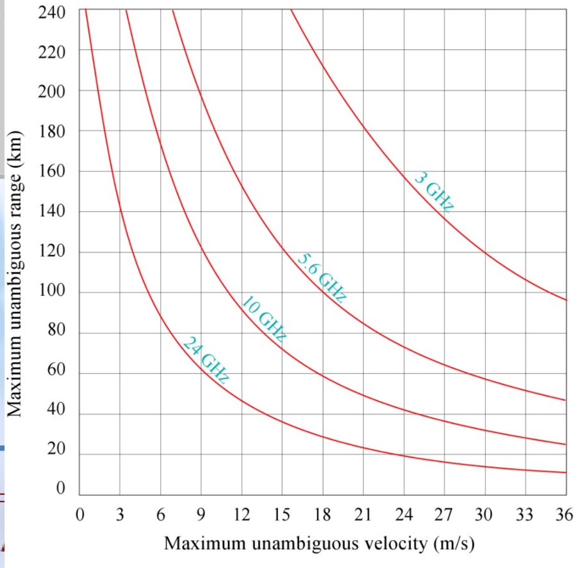
$$V_N = \frac{\lambda}{4}\,\mathrm{PRF}$$

Velocity folded

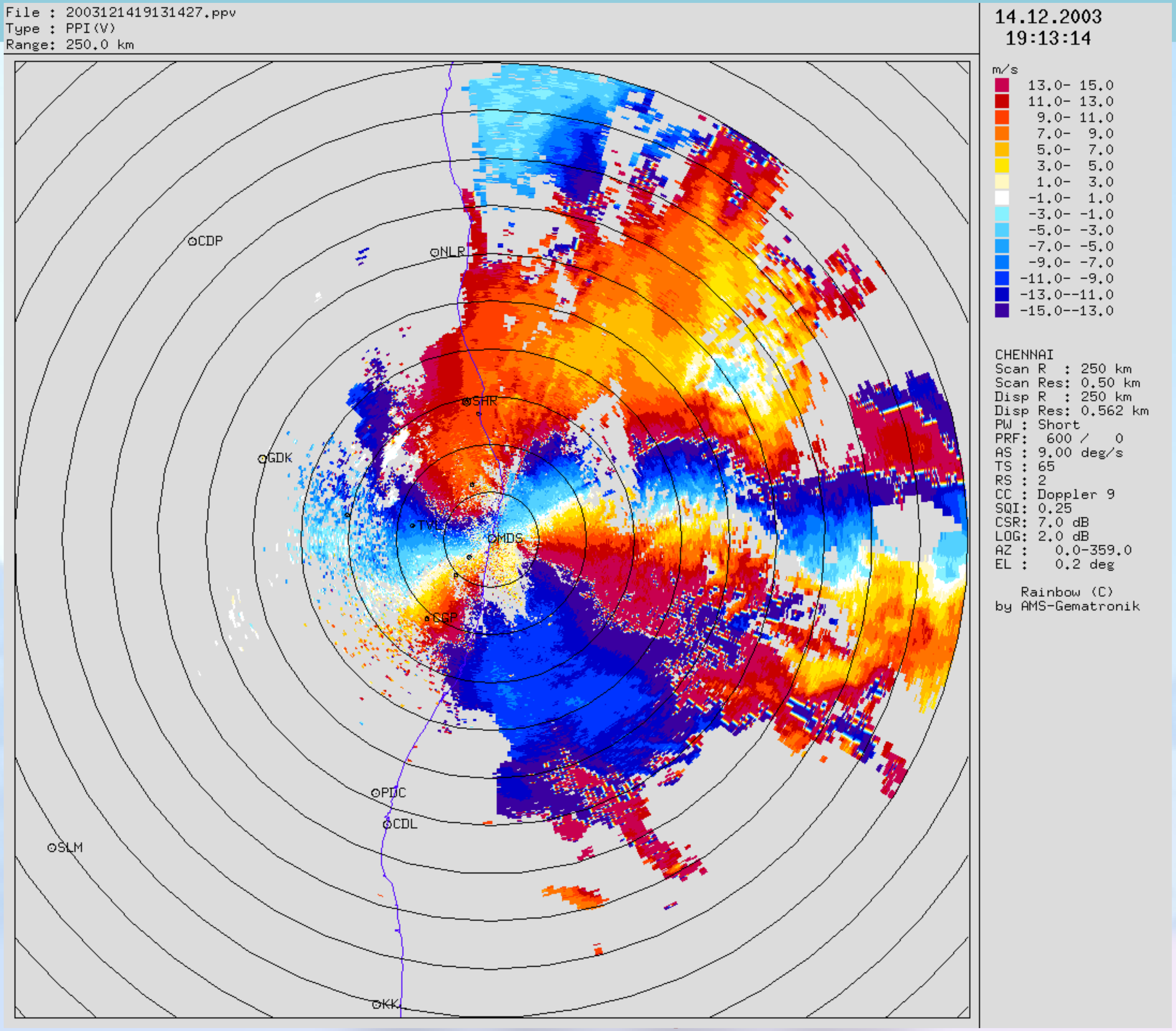


actual





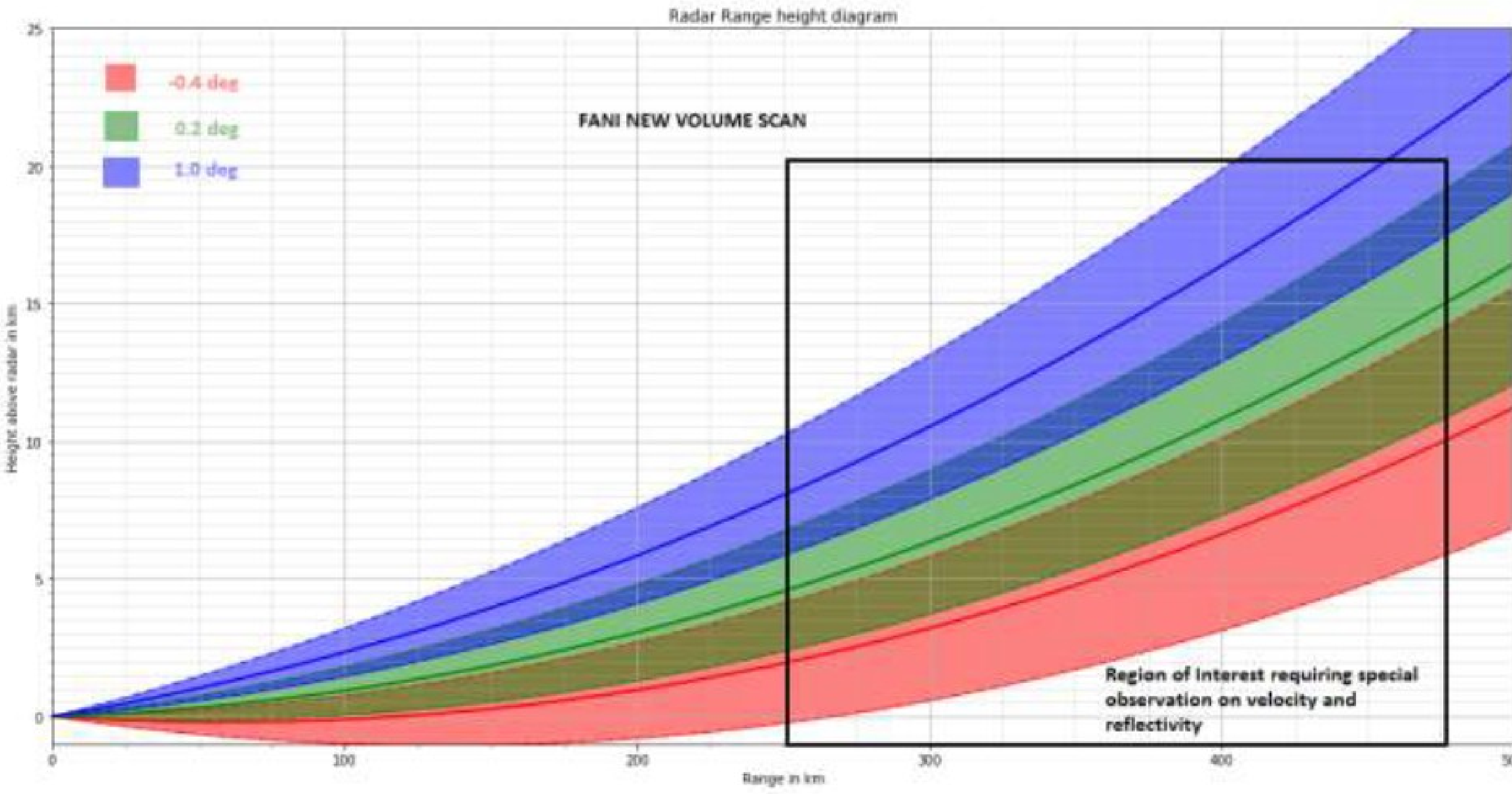
FOLDING

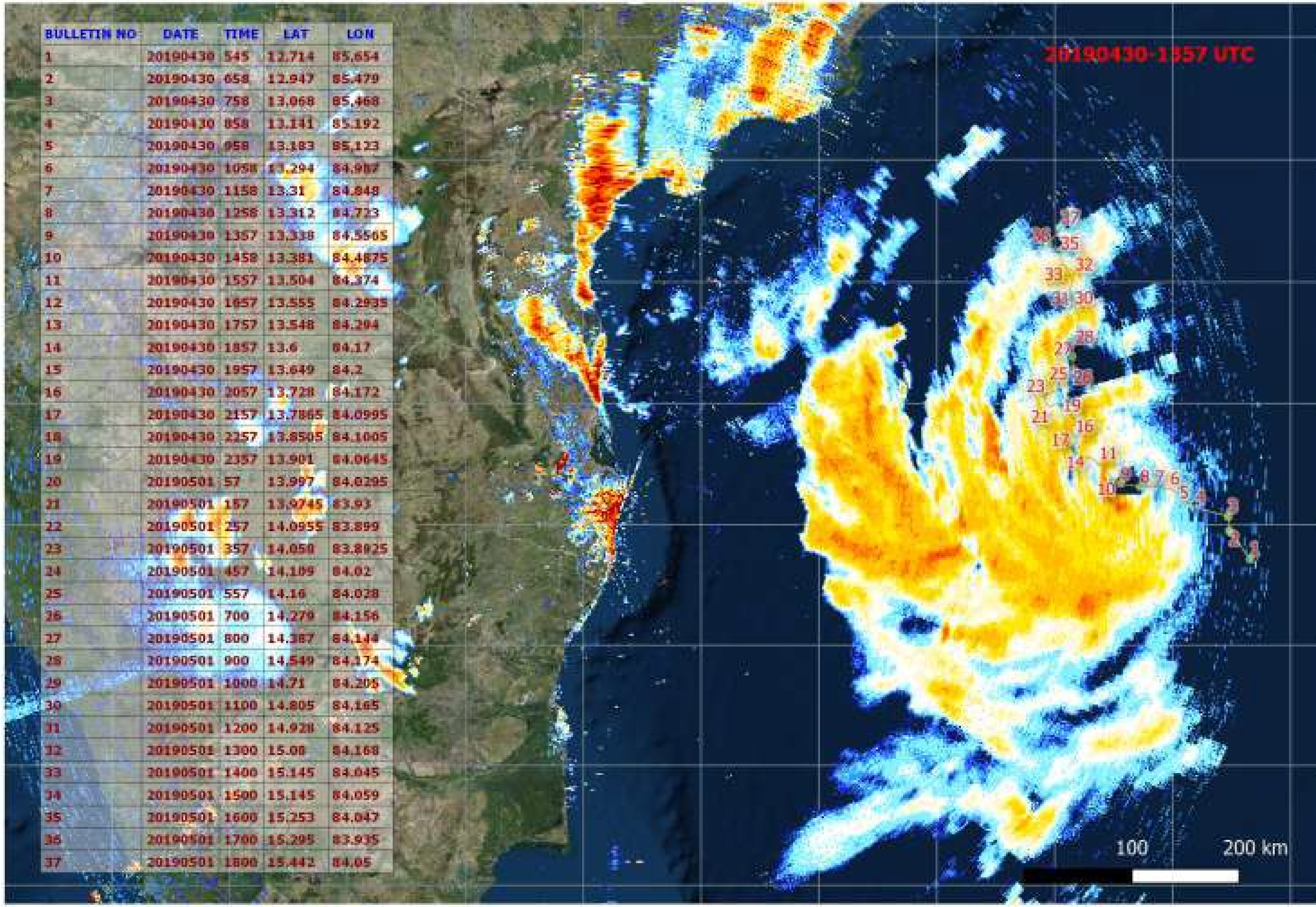


File : 2003121419131427.ppv
Type : PPI(V)
Range: 250.0 km
14.12.2003
19:13:14
m/s
13.0- 15.0
11.0- 13.0
9.0- 11.0
7.0- 9.0
5.0- 7.0
3.0- 5.0
1.0- 3.0
-1.0- 1.0
-3.0- -1.0
-5.0- -3.0
-7.0- -5.0
-9.0- -7.0
-11.0- -9.0
-13.0--11.0
-15.0--13.0
CHENNAI
Scan R : 250 km
Scan Res: 0.50 km
Disp R : 250 km
Disp Res: 0.562 km
PW : Short
PRF: 600 / 0
AS : 9.00 deg/s
TS : 65
RS : 2
CC : Doppler 9
SQI: 0.25
CSR: 7.0 dB
LOG: 2.0 dB
AZ : 0.0-359.0
EL : 0.2 deg
Rainbow (C)
by AMS-Gematronik
CDP
NLR
SHR
GDK
TVL
MDS
CGP
PDC
CDL
SLM
KK

(i) DWR Chennai operational wavelength is 10.4348cm; The requirement is to get range as well as velocity till around 475km. To attain this unambiguous range of 475 the PRFh is 315Hz. Using Maximum unfolding through Dual PRF (ie 4:5) the **PRF combination PRFh:PRFl :: 315:252** has been arrived.

This would give an unambiguous velocity of 32.87m/s. As this ratio of PRF has lot of jitters, IIR clutter filtering has been kept off as would lead to losing of good valid signature, further signal qualifiers of SQI reduced to 0.1, LOG 1.5. Further the scan angles have been chosen to be -0.4, 0.2 & 1 degree that the volume resolves upto 15km height. Beam height diagram placed

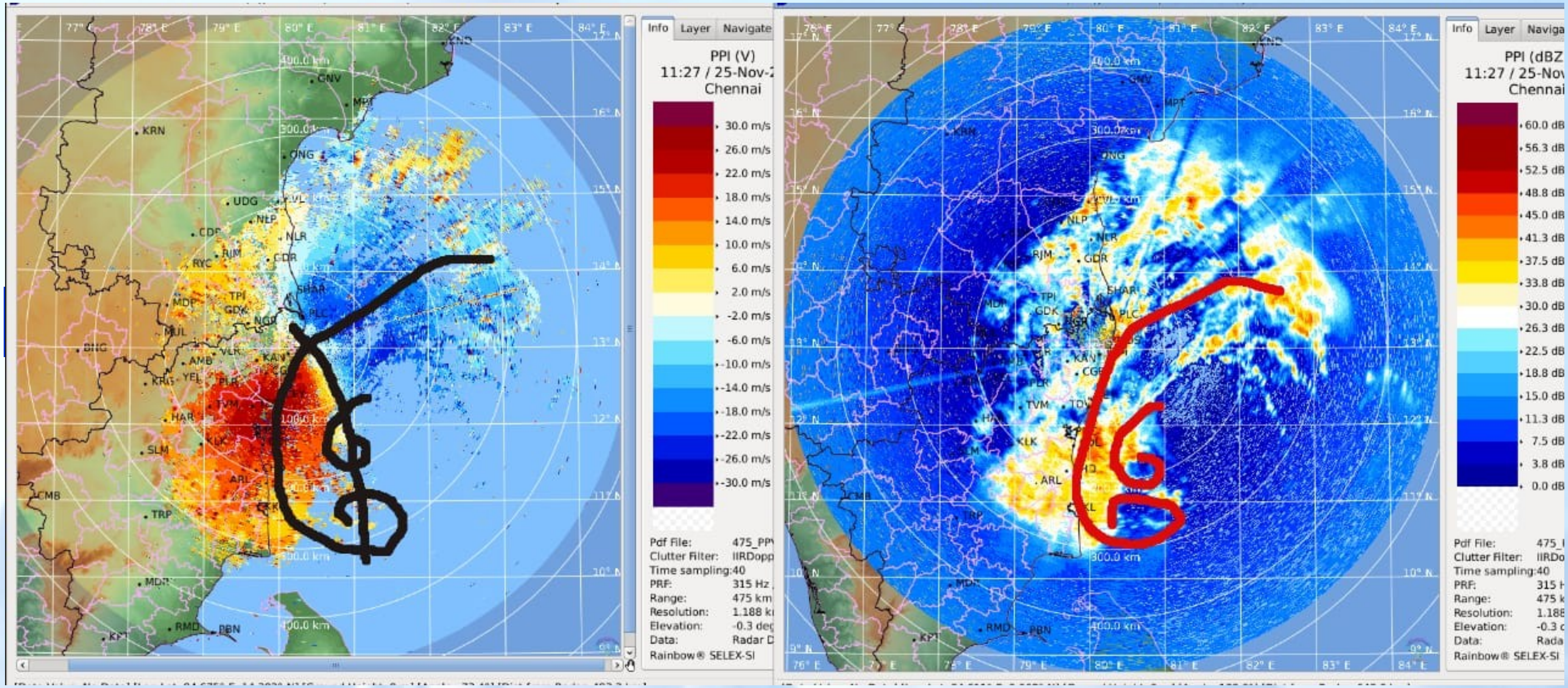




BULLETIN NO	DATE	TIME	LAT	LON
1	20190430	545	12.714	85.654
2	20190430	658	12.947	85.479
3	20190430	758	13.068	85.468
4	20190430	858	13.141	85.192
5	20190430	958	13.183	85.123
6	20190430	1058	13.294	84.987
7	20190430	1158	13.31	84.848
8	20190430	1258	13.312	84.723
9	20190430	1357	13.338	84.5565
10	20190430	1458	13.381	84.4875
11	20190430	1557	13.504	84.374
12	20190430	1657	13.555	84.2935
13	20190430	1757	13.548	84.294
14	20190430	1857	13.6	84.17
15	20190430	1957	13.649	84.2
16	20190430	2057	13.728	84.172
17	20190430	2157	13.7865	84.0995
18	20190430	2257	13.8505	84.1005
19	20190430	2357	13.901	84.0645
20	20190501	57	13.997	84.0295
21	20190501	157	13.9745	83.93
22	20190501	257	14.0955	83.899
23	20190501	357	14.050	83.8925
24	20190501	457	14.109	84.02
25	20190501	557	14.16	84.028
26	20190501	700	14.279	84.156
27	20190501	800	14.387	84.144
28	20190501	900	14.549	84.174
29	20190501	1000	14.71	84.205
30	20190501	1100	14.805	84.165
31	20190501	1200	14.928	84.125
32	20190501	1300	15.08	84.168
33	20190501	1400	15.145	84.045
34	20190501	1500	15.145	84.059
35	20190501	1600	15.253	84.047
36	20190501	1700	15.295	83.935
37	20190501	1800	15.442	84.05

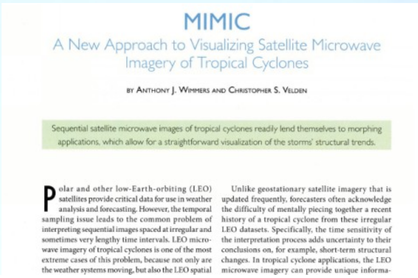
NIVAR – Abnormal Features

Multiple Eye….[Earlier reported Mukherjee etal June 1976]



Cyclone Morphology

MIMIC: Morphed Integrated



MIMIC

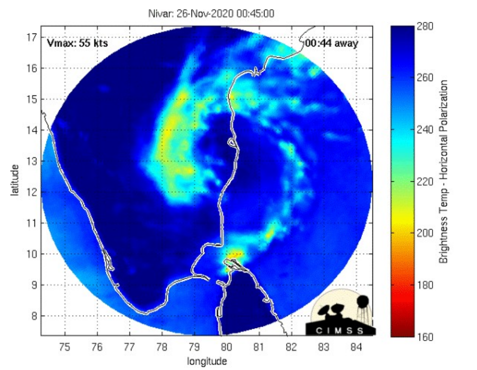
A New Approach to Visualizing Satellite Microwave Imagery of Tropical Cyclones

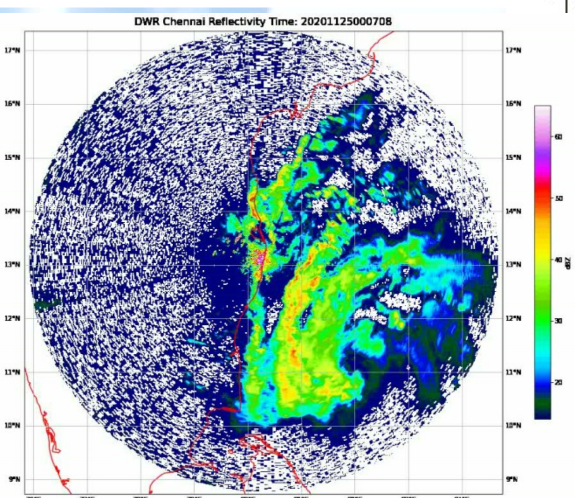
BY ANTHONY J. WIMMERS AND CHRISTOPHER S. VELDEN

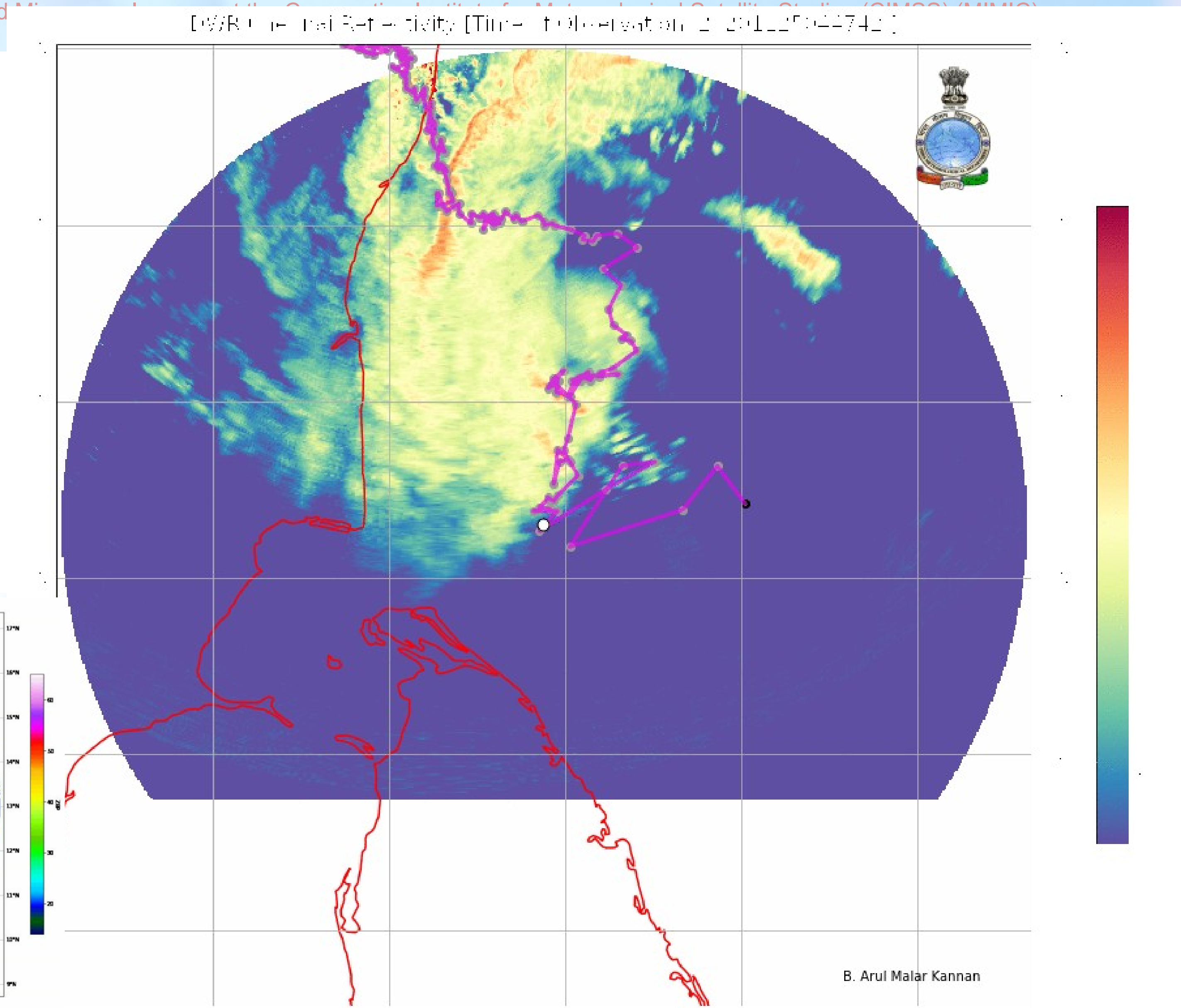
Sequential satellite microwave images of tropical cyclones readily lend themselves to morphing applications, which allow for a straightforward visualization of the storms' structural trends.

Polar and other low-Earth-orbiting (LEO) satellites provide critical data for use in weather analysis and forecasting. However, the temporal sampling issue leads to the common problem of interpreting sequential images spaced at irregular and sometimes very lengthy time intervals. LEO microwave imagery of tropical cyclones is one of the most extreme cases of this problem, because not only are the weather systems moving, but also the LEO spatial

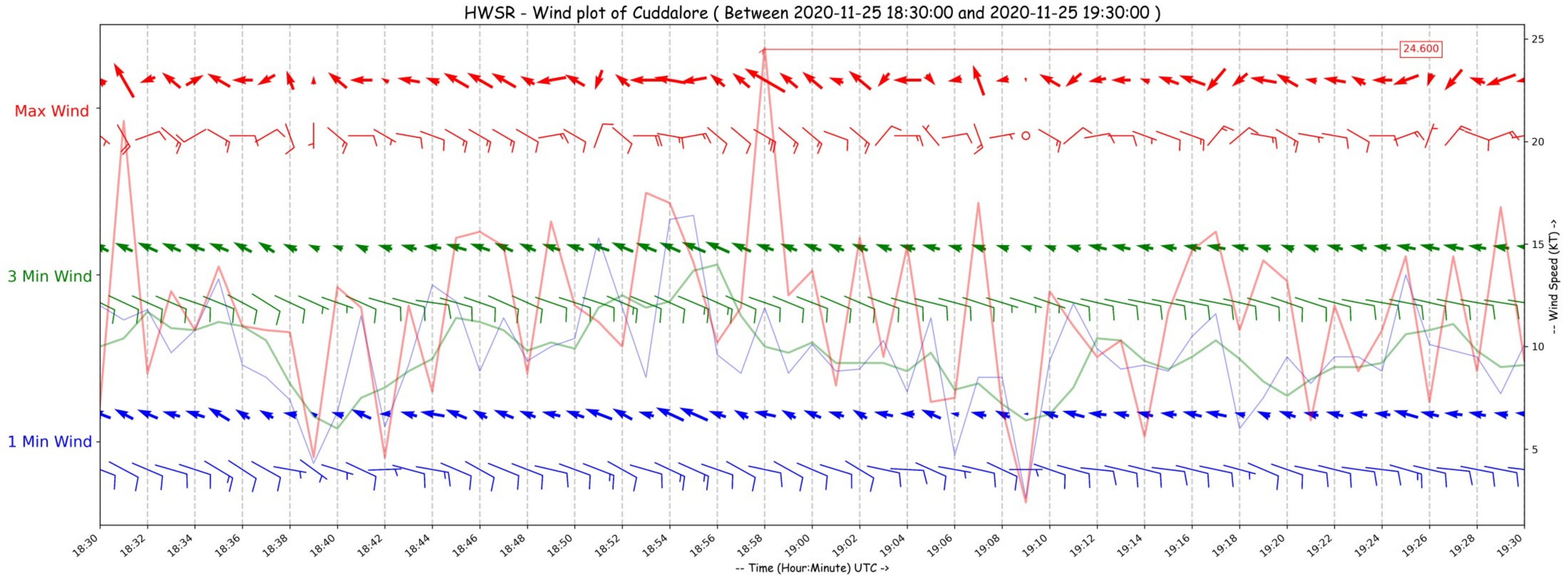
Unlike geostationary satellite imagery that is updated frequently, forecasters often acknowledge the difficulty of mentally piecing together a recent history of a tropical cyclone from these irregular LEO datasets. Specifically, the time sensitivity of the interpretation process adds uncertainty to their conclusions on, for example, short-term structural changes. In tropical cyclone applications, the LEO microwave imagery can provide unique informa-

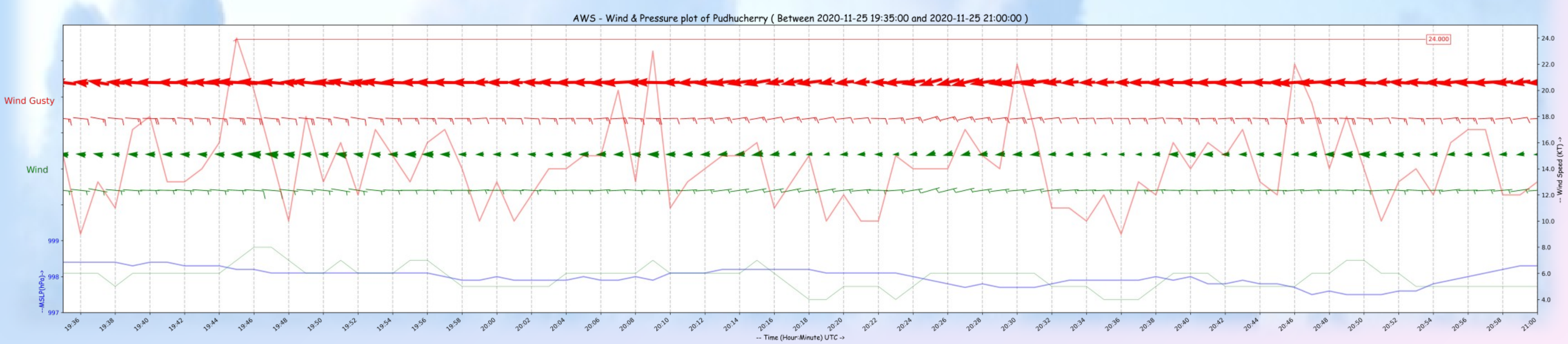






NIVAR





भारत मौसम विज्ञान विभाग
INDIA METEOROLOGICAL DEPARTMENT

Credits to:

1. India Meteorological Department (IMD), MoES, Government of India
2. BMI (COX bazar data of SIDR)
3. COMET training module
4. NOAA, NASA
5. Web resources

Of course, my beloved family too… that silently toils at the background in keeping my spirits alive

Books for a better understanding of weather radars & its applications :

6. Radar Meteorology by S. Raghavan, Kluwer Academic Publishers, Netherlands
7. Radar for Meteorologists by Ronald E. Rinehart, Rinehart Publications, USA
8. Polarimetric Doppler weather radar - Bringi & Chandrasekar, Cam. UP, USA
9. Doppler Radar and Weather Observations-Doviak and Zrnic , Academic Pr,