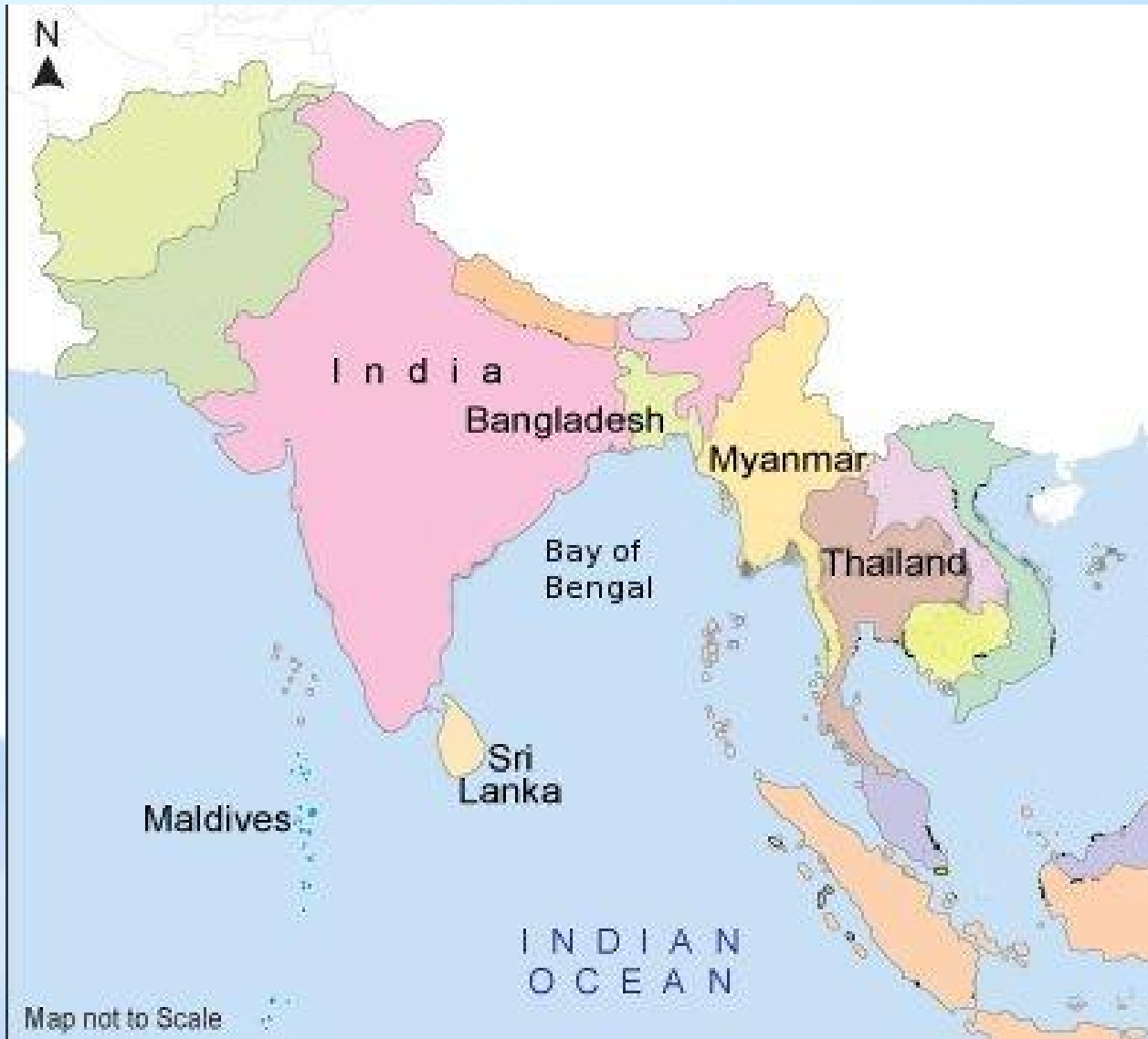




STATUS OF THE DEVELOPMENT OF THE SWFDP FOR THE BAY OF BENGAL (SOUTH ASIA)

S.K. Roy Bhowmik

**भारत मौसम विज्ञान विभाग
INDIA METEOROLOGICAL DEPARTMENT**



Participating Countries

- India (Lead)
- Bangladesh
- Myanmar
- Thailand
- Sri-Lanka
- Maldives



Background

- ❖ SWFDP initiative intended to (a) further explore and enhance the application of outputs of existing NWP systems, available through WMO's GDPFS in the improvement of severe weather forecasting in countries where sophisticated NWP outputs are not currently used, or poorly used, and (b) delivery of warning services through the Public Weather Services Programme (PWSP).
- ❖ SWFDP had been implemented successfully in Southern Africa and other three projects are in progress for the South Pacific Islands, Eastern Africa and for the Southeast Asia.
- ❖ The sixteenth World Meteorological Congress (May 2011) suggested to further expand the SWFDP to other WMO Regions
- ❖ SWFDP regional project for the Bay of Bengal (South Asia) as an excellent opportunity to improve both the application of science and technology that supports forecasting and severe weather warning services, and to enhance the capabilities of NMHSs in more effectively supporting the disaster management and civil protection organizations, as well as socio-economic sectors, in particular agriculture and fisheries, within their countries, and coordinated effectively within a geographical region.



WMO Delegation to IMD Delhi during Nov 7- 8, 2011

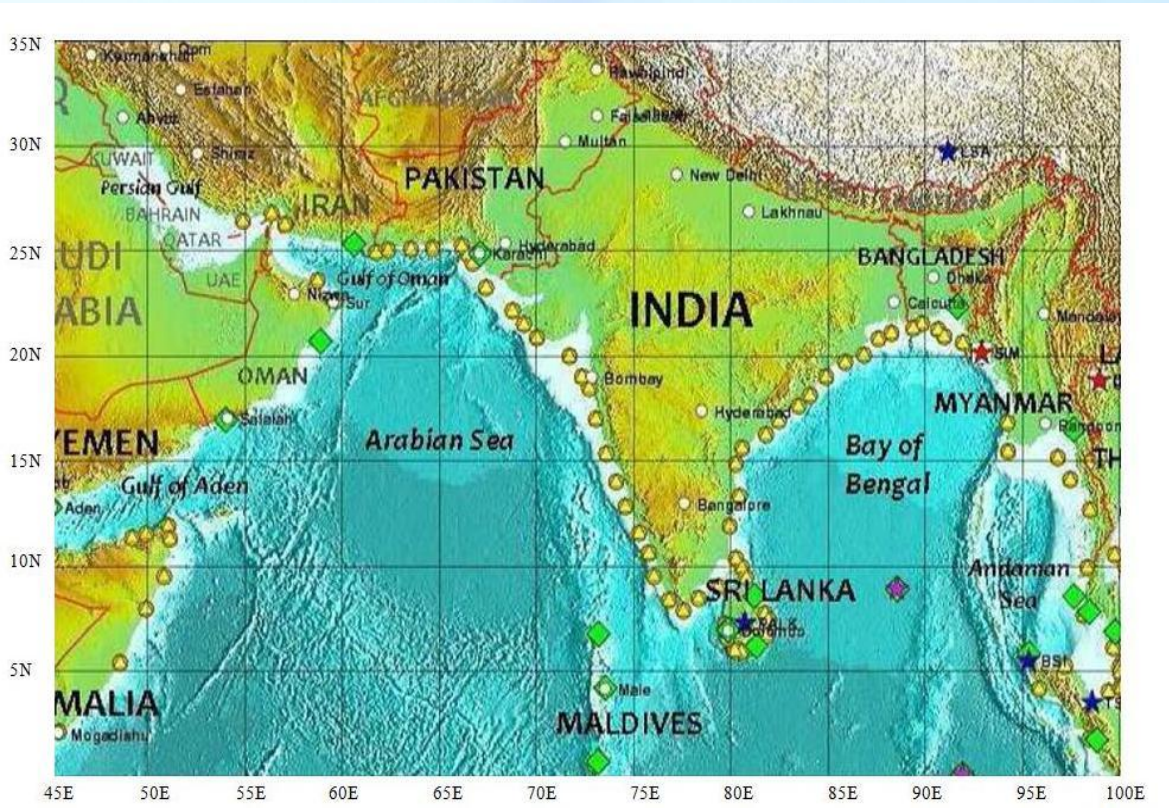


To assess the potential for expanding role of the RSMC New Delhi to carry out the role of lead Regional Centre for Severe Weather Forecast Demonstration Project (SWFDP) for the Bay of Bengal (south Asia).



RSMC New Delhi – Tropical Cyclone

Countries: Bangladesh, Maldives, Myanmar, Pakistan, Sultanate of Oman, Sri Lanka and Thailand



- Round the clock watch on weather situations over the entire north Indian Ocean.
- Issue of Tropical Weather Outlook and Tropical Cyclone Advisories to the Panel countries in general.



Support Divisions of IMD

- ❖ NWFC New Delhi
- ❖ NWP New Delhi
- ❖ Telecom Division New Delhi
- ❖ Satellite Division New Delhi
- ❖ Radar Division New Delhi
- ❖ Regional Cyclone Division
- ❖ Agro-meteorology Division
- ❖ Media Cell

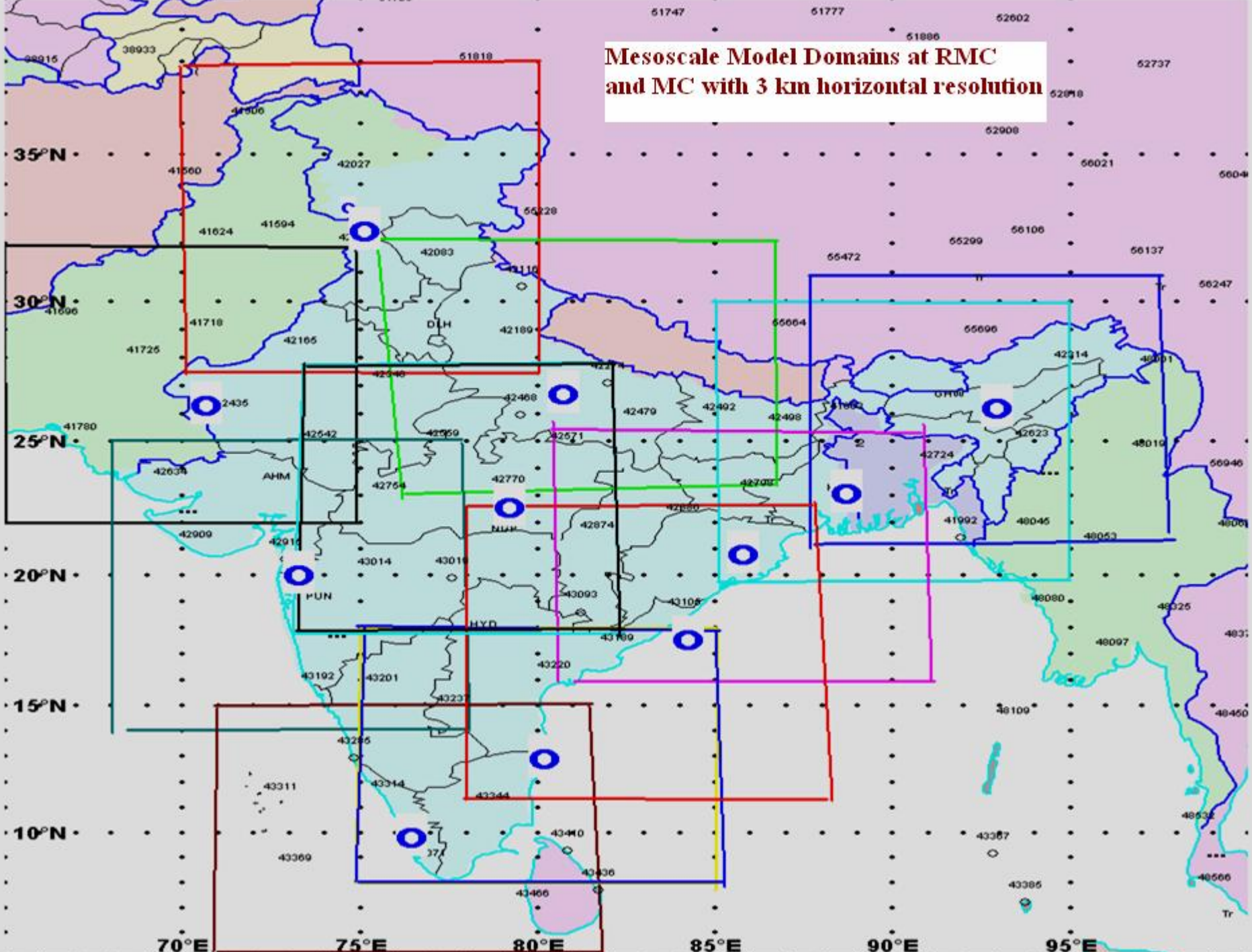


NWP System of IMD

- ❖ **Medium Range Forecast**
 - > *GFS T-574 with GDAS (00 & 12 UTC)*
- ❖ **Short Range Forecast**
 - > *WRF (ARW) VAR at 27 km and 9 km*
 - > *WRF (NMM) at 9 km for TC 4 times a day*
 - > *HWRF*
 - > *MME Cyclone Forecast*
 - > *TIGGE Tropical Cyclone TRACK*
 - > *Polar WRF Antarctica*
 - > *Storm Surge Model*
- ❖ **City Forecast (Very short range & Nowcast)**
 - > *Hourly venue specific forecast- WRF (3 km)*
 - > *ARPS with DWR at 9 km*
 - > *Nowcast System*
- ❖ **MME based District Level Forecast**
- ❖ **Extended Range Forecasts**
- ❖ **LRF for Monsoon**



Mesoscale Model Domains at RMC and MC with 3 km horizontal resolution



Support Organizations

- ❖ NCMRWF Noida
- ❖ INCOIS Hyderabad
- ❖ IITM Pune
- ❖ IIT Delhi
- ❖ MoES MoU: NCEP, UKMO and ECMWF



Technical Planning Workshop on SWFDP-BoB during Jan 23-27, 2012, New Delhi



The final draft report of the workshop is available at the following WMO link:
<http://www.wmo.int/pages/prog/www/CBS-Reports/DPFS-index.html>



Technical Planning Workshop on the SWFDP- Bay of Bengal JAN 23-27, 2012

- ❖ **Participant countries: Bangladesh, India, Maldives, Myanmar, Sri Lanka and Thailand**
- ❖ **Global products centres: JMA, NOAA/NCEP and IMD/NCMRWF)**
- ❖ **WMO Secretariat (DPFS, PWS, AgM and DRA programmes).**
- ❖ **Opening address:**
 - > **Dr L.S. Rathore, Chairman of the Local Organizing Committee**
 - > **Dr Ajit Tyagi, Director General of Meteorology & PR**
 - > **Dr. Peter Chen, Chief of the WMO GDPFS**
 - > **Dr Shailesh Nayak, Secretary, Ministry of Earth Sciences (MoES), Government of India.**



Meeting Out-come

- ❖ The meeting unanimously agreed in principle that the implementation of a SWFDP in Bay of Bengal region would be technically feasible and would bring benefits in terms of enhancement of technical capacity in operational weather forecasting and advancement in service delivery to general public and key application areas such as agriculture and fisheries, in countries of the region, including Bangladesh, India, Maldives, Myanmar, Sri Lanka and Thailand. Specifically, the proposed regional project should focus on the following severe weather events (and associated hazards such as flooding, droughts, etc): heavy rain (50mm, 100mm); strong winds (17 knots, 34 knots); high waves / swells (2.5 m) and storm surge (1 m).



Meeting Outcome

- ❖ It was agreed in the Planning Workshop that IMD New Delhi shall be carrying out the functions of the lead regional forecasting support centre for the project. It shall be responsible for synthesizing all available and relevant products and information and making the best use of these products in order to provide daily severe weather forecasting guidance. IMD New Delhi shall also be responsible for developing and managing the Project Web Portal. The participating countries shall be responsible for the warning services to the key users (general public, agriculture and fisheries). The Global NWP Centres to be involved in the project are: New Delhi (IMD supported by NCMRWF), Exeter (UK Met Office), Washington (NCEP, USA), ECMWF and JMA.



Action Points

- ❖ Establishment of Project Management Team
- ❖ Project Management Team Meeting for drafting of Project Implementation Plan (September/October 2012)
- ❖ Finalizing of Implementation Plan before start of field phase (October 2012)
- ❖ Preparatory Training Workshop (July 2012)
- ❖ End of Field Phase (September 2013)



Recommendations

- ❖ The RSMC New Delhi (India) representative to coordinate the setting up of a small project development team to undertake the drafting of an implementation plan;
- ❖ WMO Secretariat to follow up on developing a provisional programme for the Preparatory Training activities;
- ❖ Prior to field phase implementation: (i) Met Office (UK), JMA, NCEP (USA), IMD (supported by NCMRWF) and ECMWF to adapt model output products to the SWFDP – Bay of Bengal domain window, and possibly RSMC New Delhi to run the Regional NWP model covering the same region;
- ❖ NMCs to prepare a list of forecasting and warning products required;
- ❖ NMCs to provide all warning criteria currently used
- ❖ NMCs to provide information on Internet access capability
- ❖ NMC are encouraged to incorporate non-GTS data in the regional and global models
- ❖ WMO Secretariat to share previous training material



Recommendations

- ❖ To encourage the forecasting, hydrometeorological and agrometeorological NMHS staff to work together to develop forecasting products with regards to the SWDFP;
- ❖ NMCs to develop plans for service delivery based on guidance/templates provided by WMO Secretariat (e.g. users identification, users' requirements, delivery mechanisms);
- ❖ NMCs to develop plans for communication/contact channels and outreach programmes;
- ❖ NMCs to develop plans for the processes of user feedback, analysis and reporting;
- ❖ Feedback mechanism should be develop to allow NMCs to provide feedback to GPCs on their products;
- ❖ Regional project may consider to include Nepal, Bhutan, Afghanistan and Pakistan into the project at some point after the initial demonstration phase;
- ❖ Name of the project could be revised with the addition of more countries;
- ❖ Secretariat to support NMCs efforts by providing training on design of products and services, and in the development of cross-border exchanges of alerts and warnings;
- ❖ Secretariat to prepare a questionnaire table for gather information under (d) – (f)



NWP Future Plan: Short to Medium Range

Medium Range

- ❖ G EPS T 190

Thrust Area: Probabilistic Forecast of high impact weather in short to medium range time scale

Short Range

- ❖ WRF at 9 km 3 km and 1 km
- ❖ Six hourly cycle
- ❖ Rapid updates of Cyclone Model HWRF

Thrust areas: (a) Assimilation of new observations like: DWR, satellite Radiance etc; (b) Land Surface Process with Indian conditions, (c) GIS based rainfall analysis and forecast for river basins, (b) block level forecast for Agro-meteorology



Nowcasting and Meso-scale Modelling

- ❖ GIS and DWR based Nowcast and meso-scale forecast system for major cities/airports of India
- ❖ Air quality forecast for metropolitan cities
- ❖ Fog forecast system
- ❖ Rapid updates of high resolution rainfall analysis and forecasts for the entire country
- ❖ Rapid updates of model run for aviation forecasts

Trust Areas: Assimilation of DWR data and GIS applications



THANKS

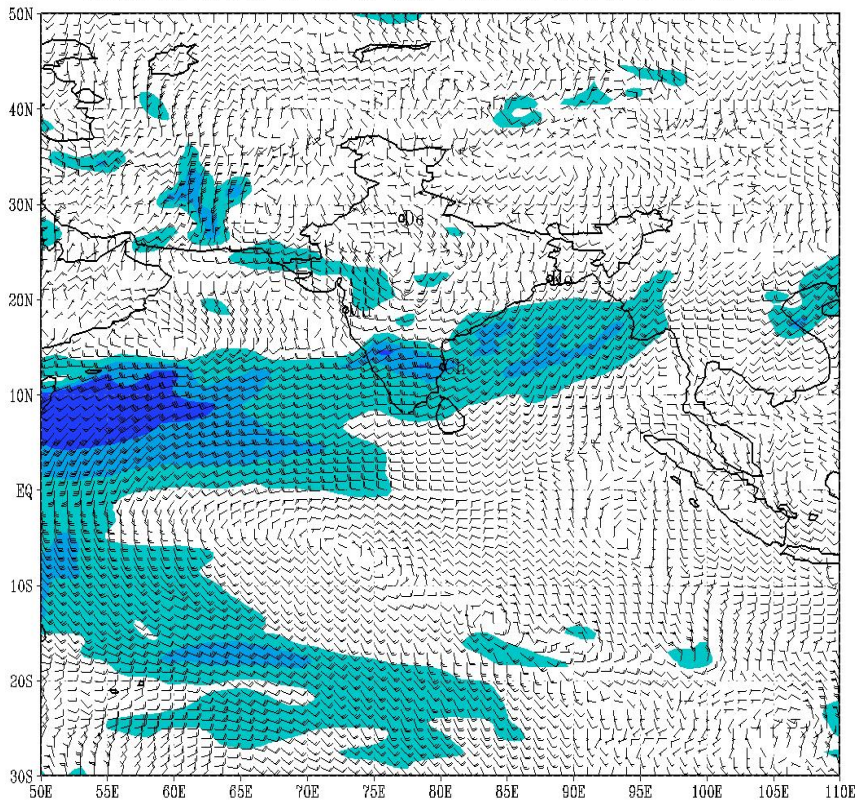


भारत मौसम विज्ञान विभाग
INDIA METEOROLOGICAL DEPARTMENT



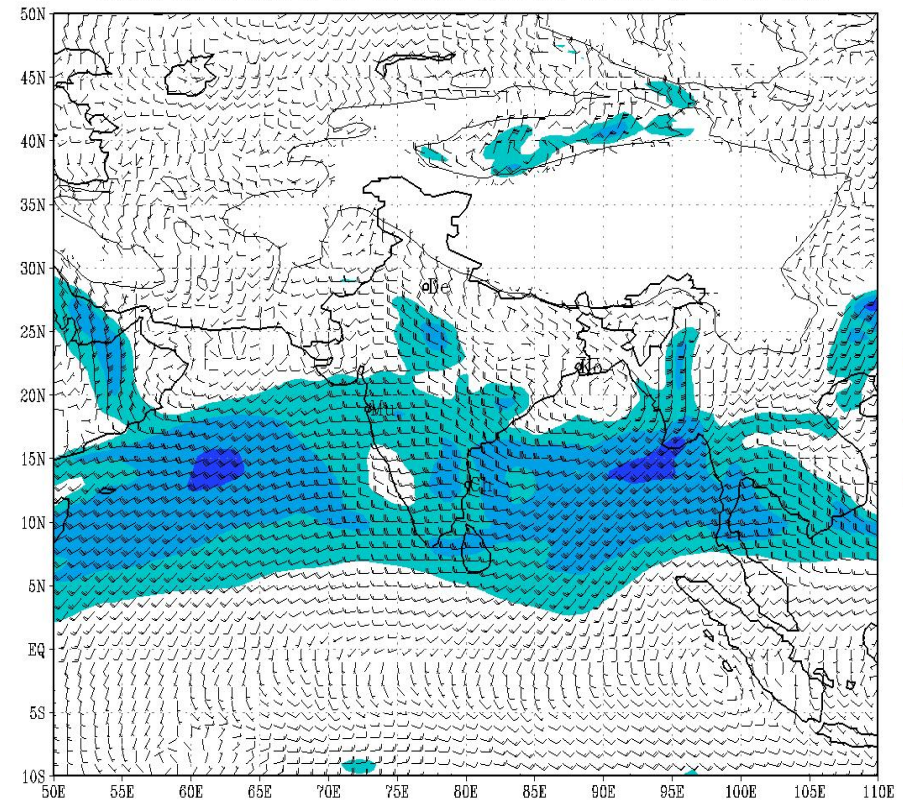
<p>GFS T-382 (35 km)</p>	<p>WRF –ARW 27 km, 9 km</p> <p>Polar WRF 15 km</p> <p>MME TC</p>	<p>WRF –ARW 3 Kms Venue Specific F/C 24 Hours (hourly)</p>	<p>ARPS 9 kms Hourly updates Next 6 hours</p>	<p>Nowcasts</p>	<p>Extended Range Probabilist ic Forecast</p> <p>MME District</p>
<p>Medium Range (1-7 days)</p>	<p>Short Range (1-3 days)</p>	<p>Short Range (36 hours)</p>	<p>Very short range (6-24hrs)</p>	<p>Now casting</p>	<p>Week to month</p>
<p>Products Available</p> <p>Analysis (MSLP & Winds at 925,850, 700,500,300,20 0 100 hPa)</p> <p>F/c for 7 days (MSLP, & Winds at 925.850.700</p>	<p>Products available</p> <p>Analysis (MSLP & Winds at 925,850,700, 500,300,200 hPa)</p> <p>F/c for 3 days (MSLP & Winds at 925,850,700, 500,300,200 hPa and R/f)</p>	<p>Products available</p> <p>Meteograms For Location specific sites in Delhi /major airports</p> <p>Wind spd (10m) Rainfall RH</p>	<p>Products Available</p> <p>Winds Reflectivity Rainfall</p>	<p>Products Available</p> <p>reflectivity</p>	<p>Products Available Rainfall, Temperature</p>

IMD GFS 850 hPa WIND (kt) ANALYSIS (00H)
based on 00 UTC of 14-06-2010 valid for 00 UTC of 14-06-2010



(Background does not depict political boundary)

IMD GFS(T574) 850 hPa WIND (kt) ANALYSIS
based on 00 UTC of 14-06-2011 valid for 00 UTC of 14-06-2011

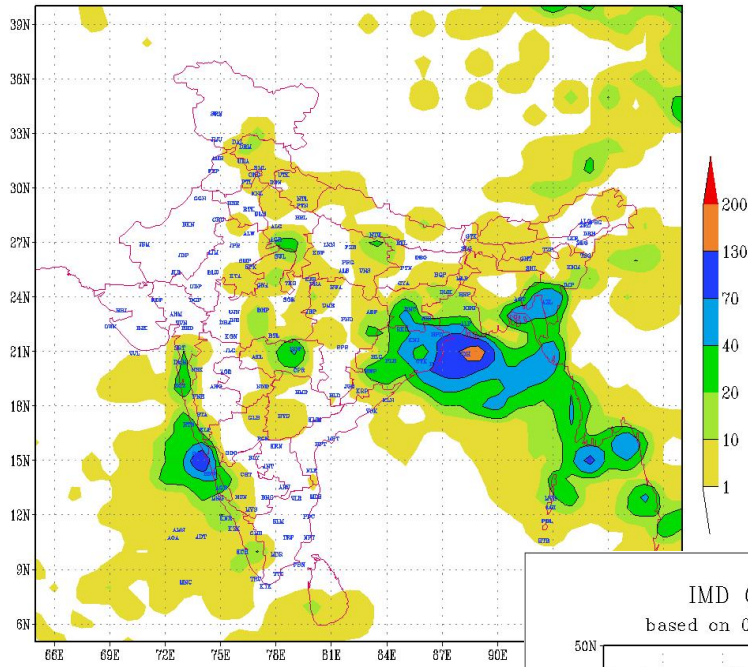


(Background does not depict political boundary)

GFS T382 vs. GFS T574 : Forecast for Depression formed over BOB:16-23 June 2011

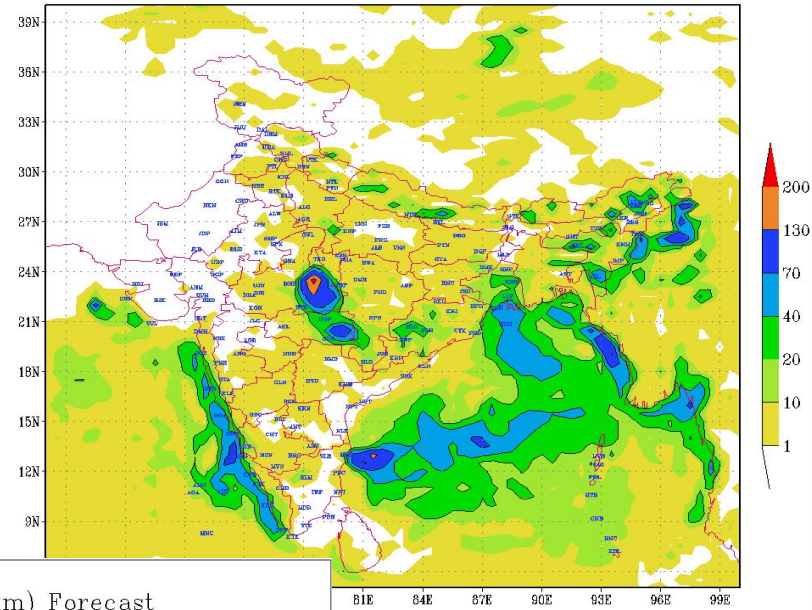


Observed (TRMM + Gauge) Rainfall (mm)
valid for 16-06-2011



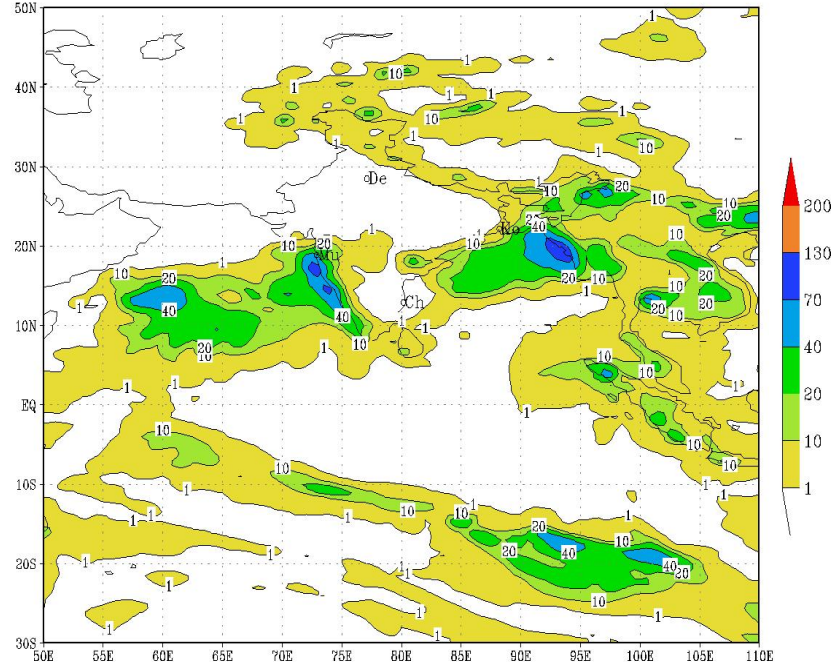
(Background does not depict political boundary)

IMD GFS(T574) 24 hours Rainfall (mm) Forecast
based on 00 UTC of 14-06-2011 valid for 00 UTC of 15-06-2011



(Background does not depict political boundary)

IMD GFS 24 hours Rainfall (mm) Forecast
based on 00 UTC of 14-06-2010 valid for 00 UTC of 15-06-2010



(Background does not depict political boundary)



IMD WDSSII 00 min Reflectivity Forecast for Delhi and neighbourhood based on 20110815 AT 0530 hrs IST

Adopted from NSSL, USA
(based on DELHI Radar Data)

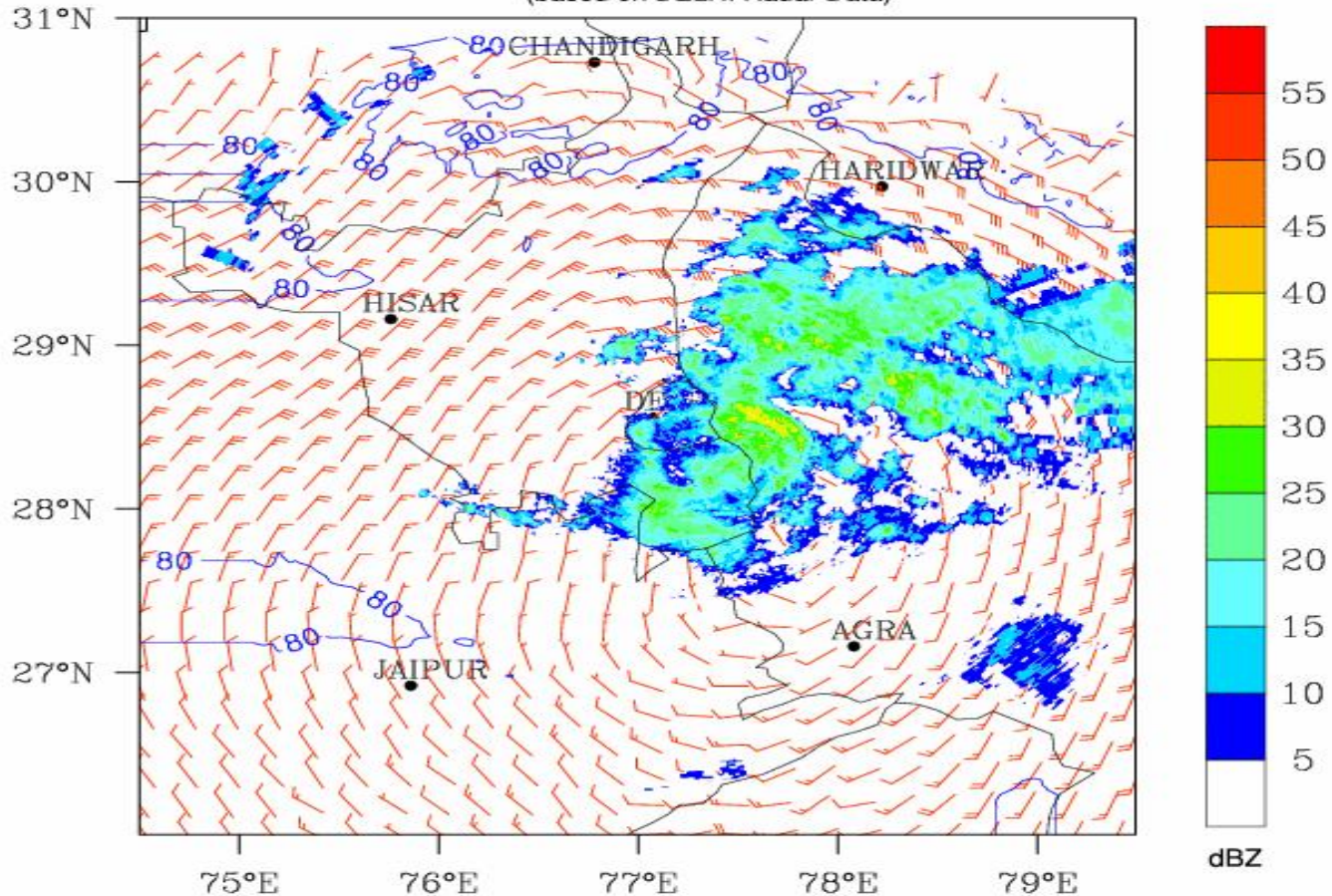
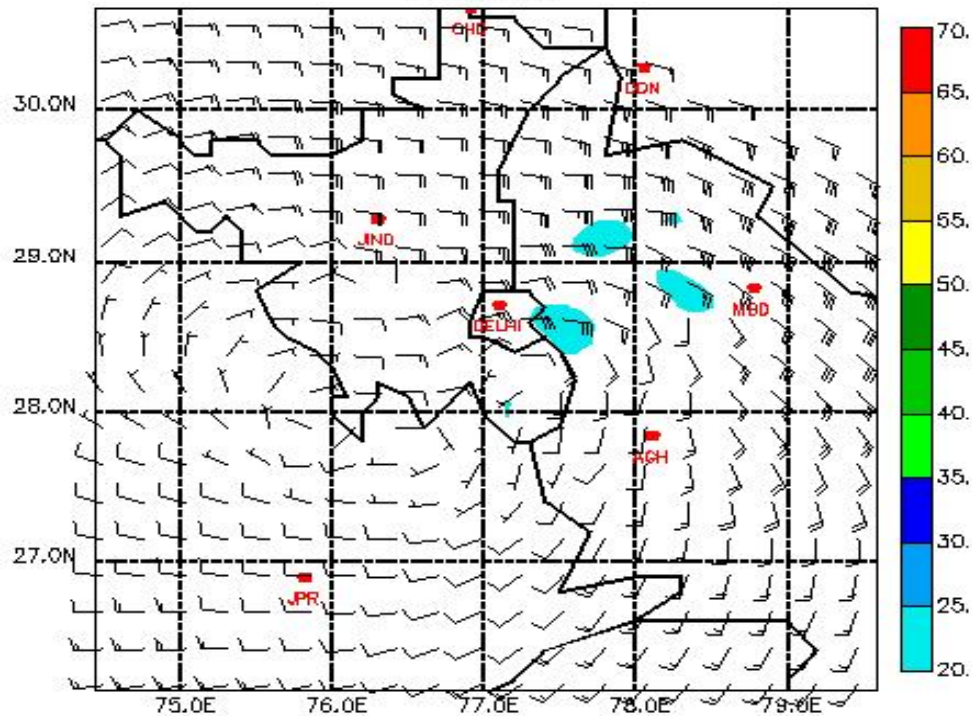


Image Superposed with Wind & RH at 850 hPa from WRF-VAR Model
Areas with Reflectivity > 30 dBZ have high probability of rainfall occurrence



NEXT UPDATE AT 08:00 IST
IMD ARPS 850 hPa WIND(kts) & REFLECTIVITY(dBZ) FORECAST
BASED ON 06:30 IST VALID FOR NEXT THREE HOURS

01:00Z Mon 15 Aug 2011 T=90000.0 e (25:00:00)
P=850.00 MB



Composite Ref (dBZ, Shaded) Min=0.00 Max=24.8
U-V (m/s, Barb) Umin=-20.06 Umax=6.92 Vmin=-7.01 Vmax=10.79

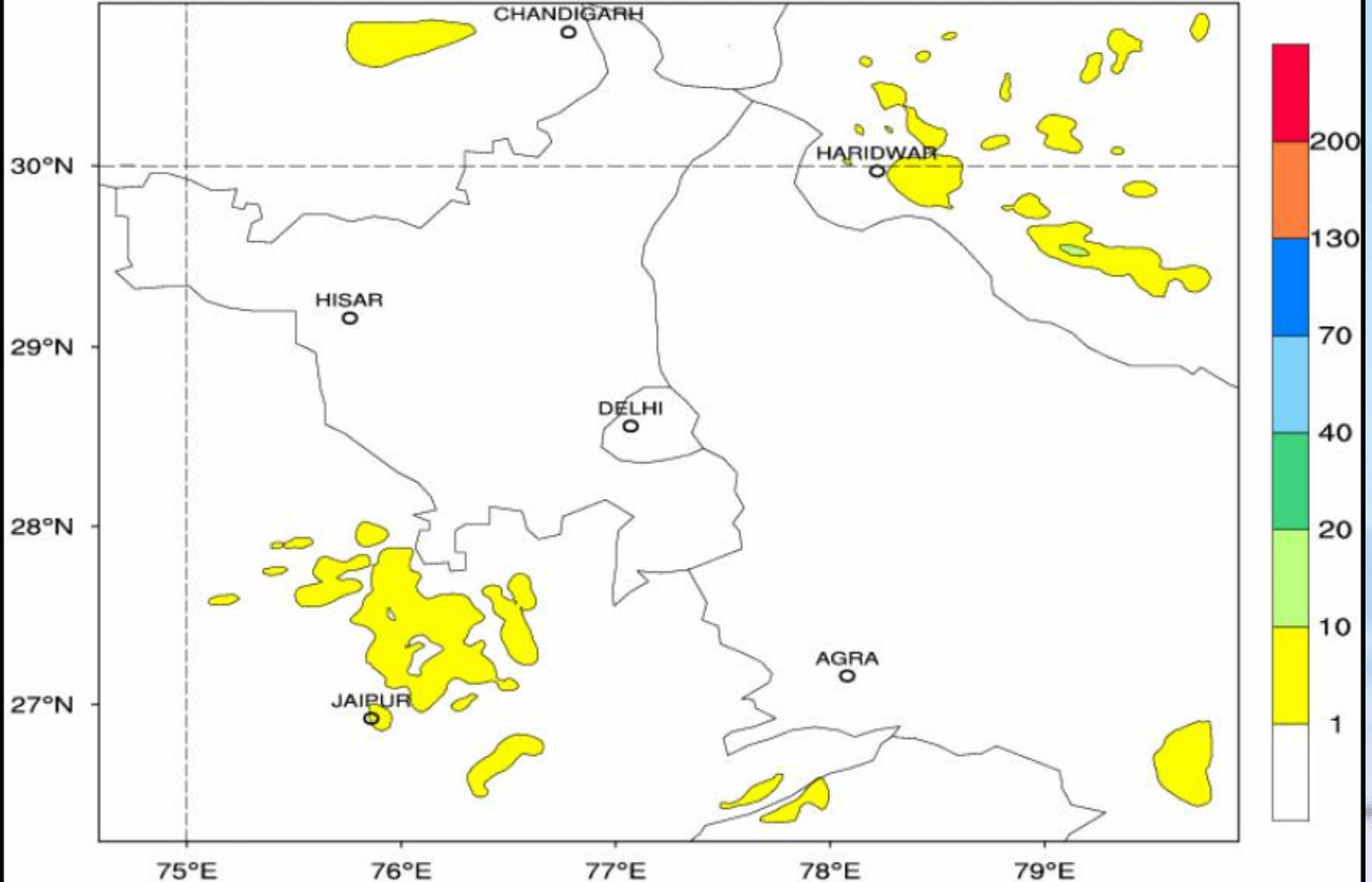
NWP CENTER, IMD, NEW DELHI



WRF hourly Rainfall Forecast: Based on 12 UTC 14-08-2011

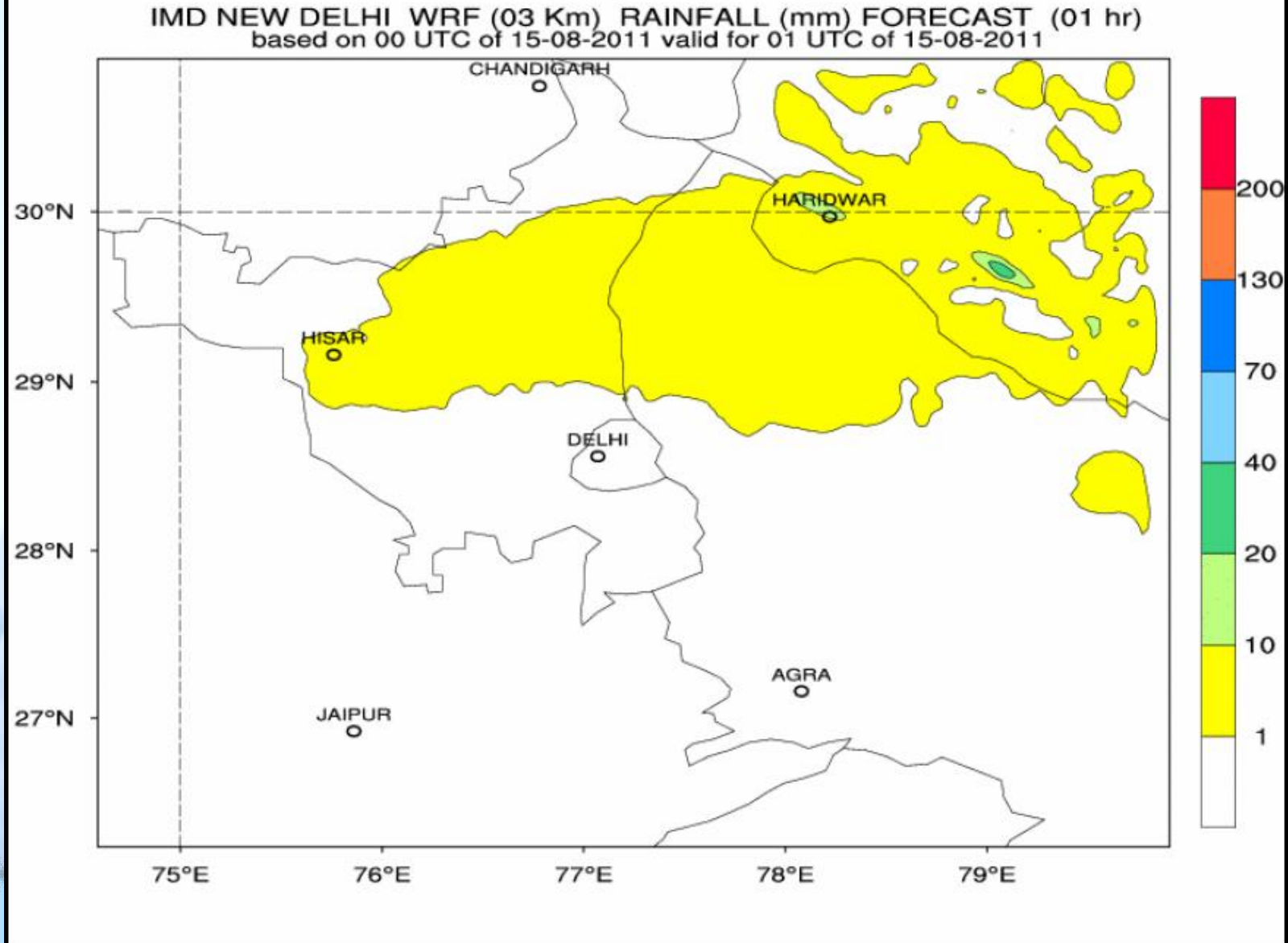
AdGIF UNREGISTERED - www.gif-animator.com

IMD NEW DELHI WRF (03 Km) RAINFALL (mm) FORECAST (01 hr)
based on 12 UTC of 14-08-2011 valid for 13 UTC of 14-08-2011



WRF hourly Rainfall Forecast: Based on 00 UTC 15-08-2011

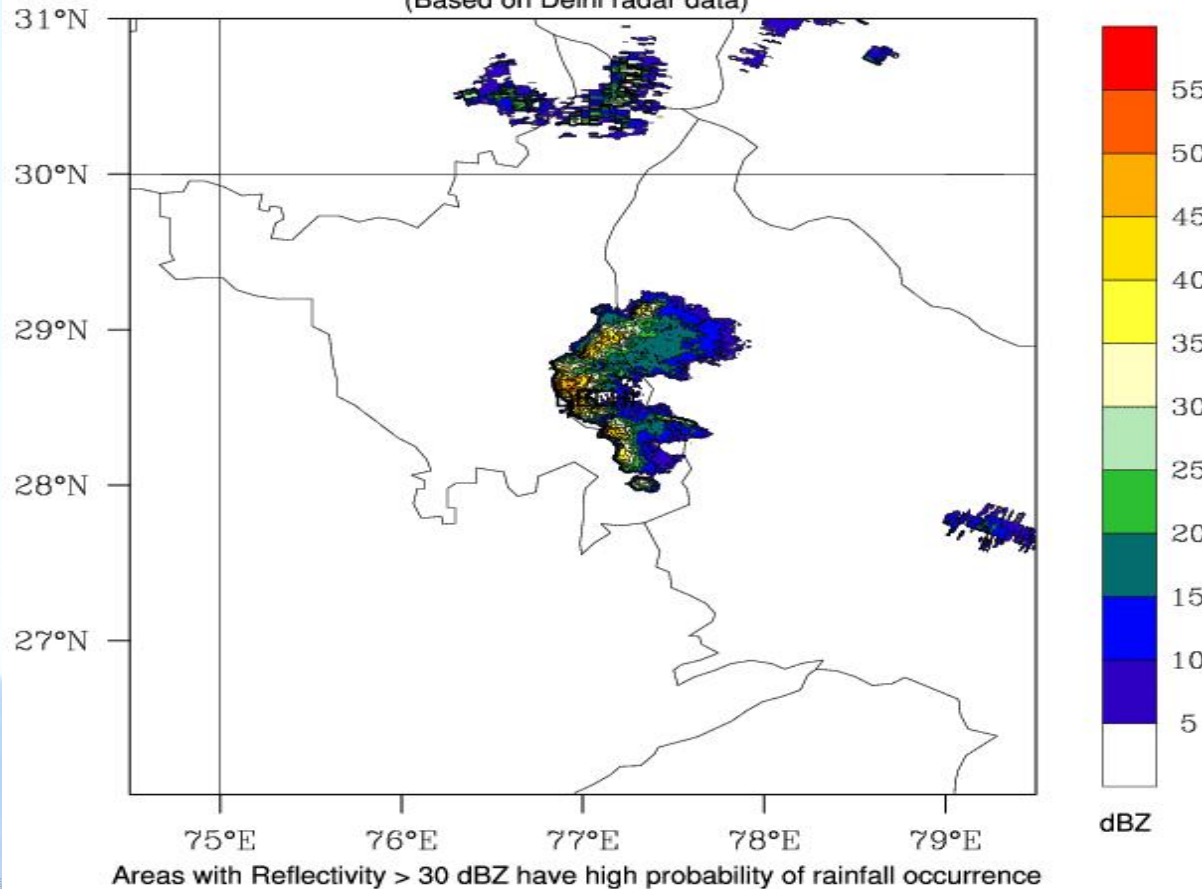
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WDSS-II

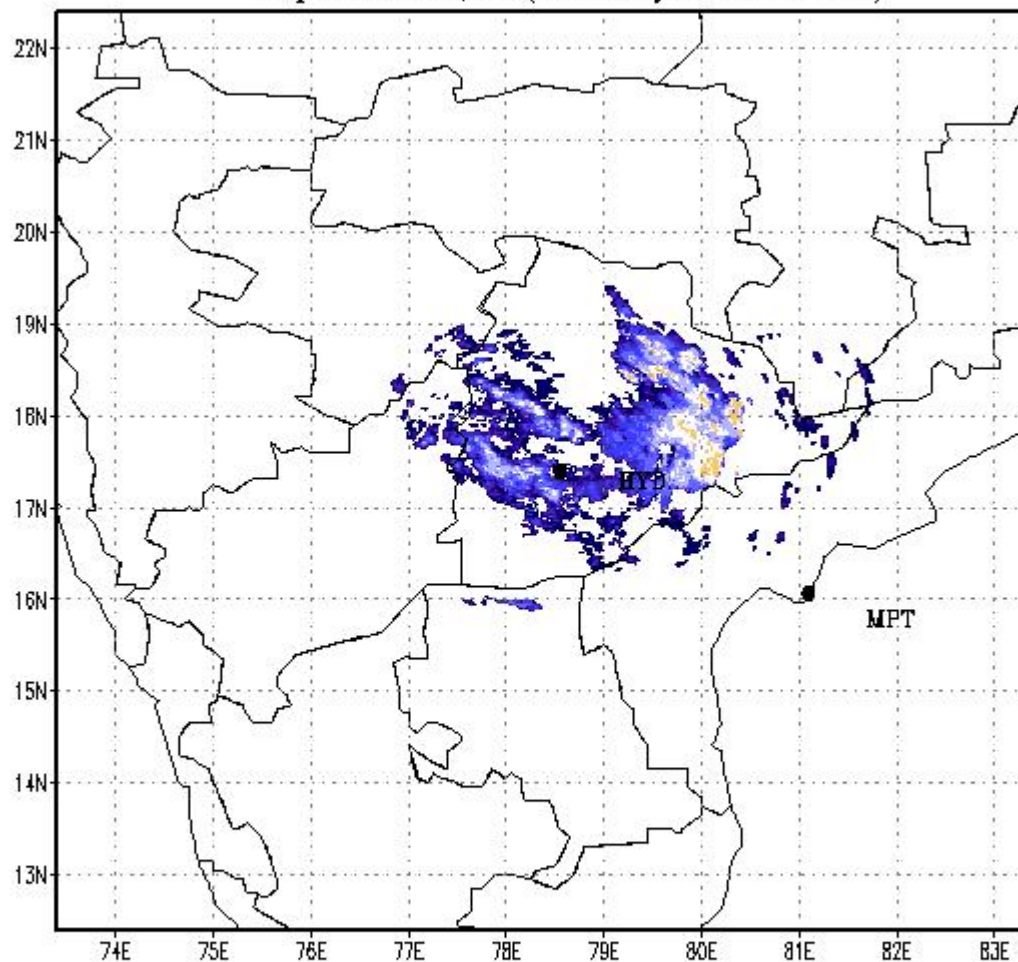
IMD WDSSII 00 min Reflectivity Forecast for Delhi and neighbourhood based on 20101022 at 1618 IST

ADOPTED FROM NSSL, USA
(Based on Delhi radar data)



IMD WDSS-II 00 min Reflectivity Forecast for Hyderabad
and neighbourhood based on data at 20100729 at 1025 hrs IST

Adopted from NSSL, USA (Based on Hyderabad Eadar data)

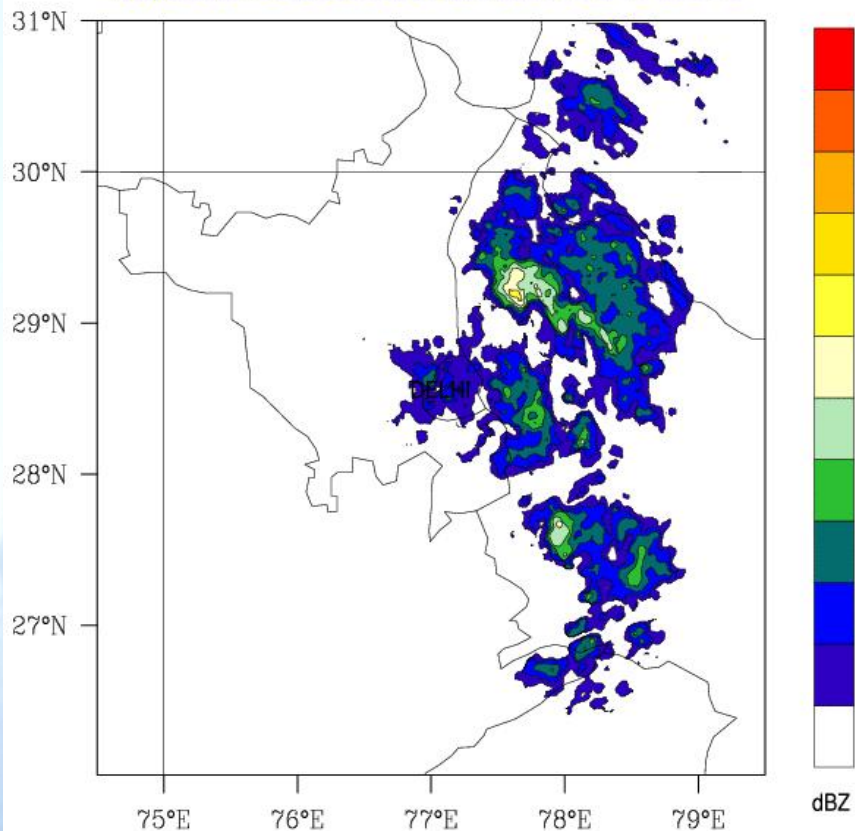


Areas with Reflectivity >30 dBZ have high probability of rainfall occurrence



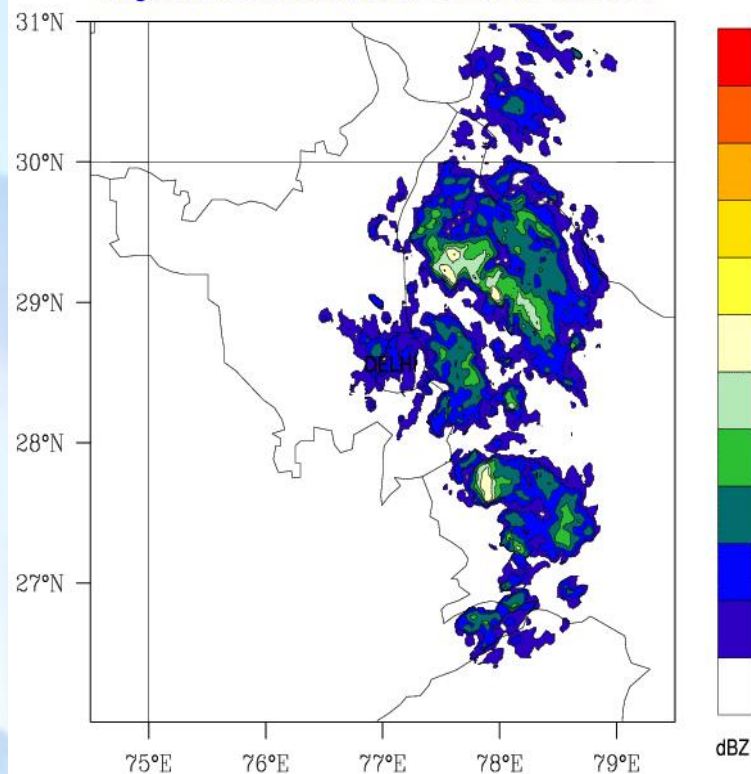
Real-time Nowcast Product of 19 September 2010

IMD WDSII 30 min Reflectivity Forecast for Delhi and neighbourhood based on 20100919 at 1346UTC



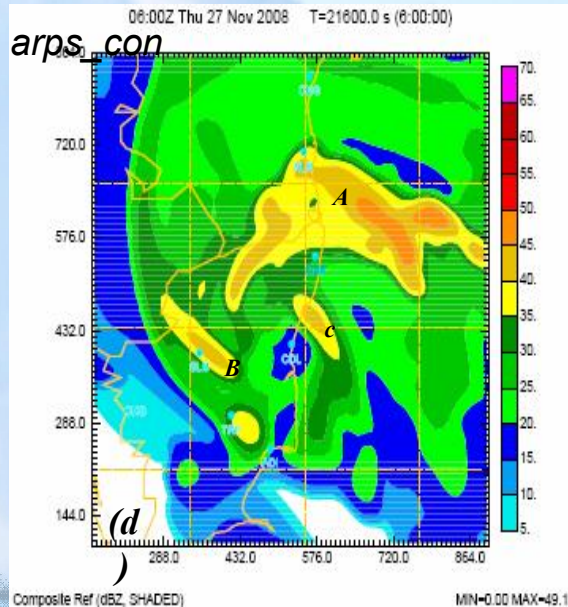
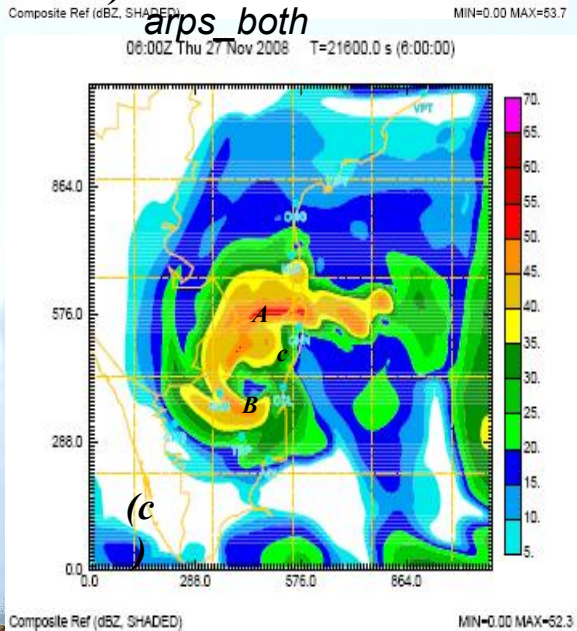
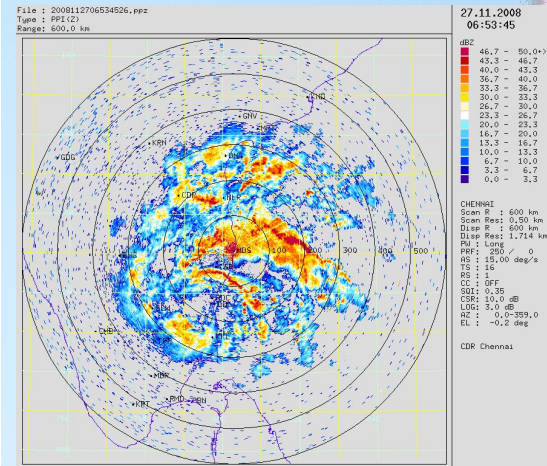
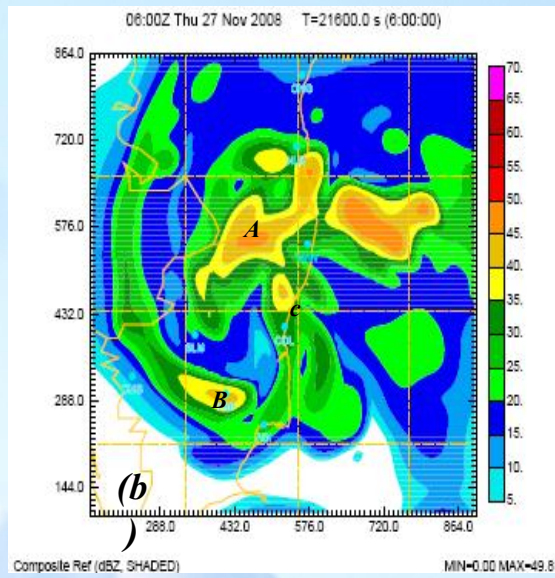
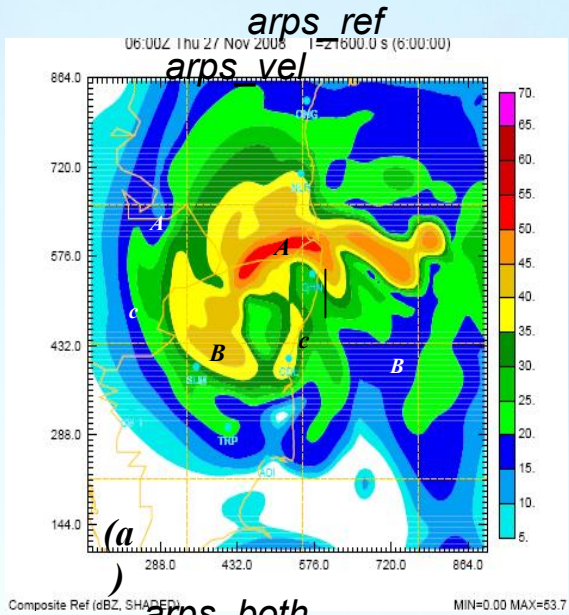
Areas with Reflectivity > 45 dBZ have high probability of rainfall occurrence

IMD WDSII 60 min Reflectivity Forecast for Delhi and neighbourhood based on 20100919 at 1336UTC



Areas with Reflectivity > 45 dBZ have high probability of rainfall occurrence

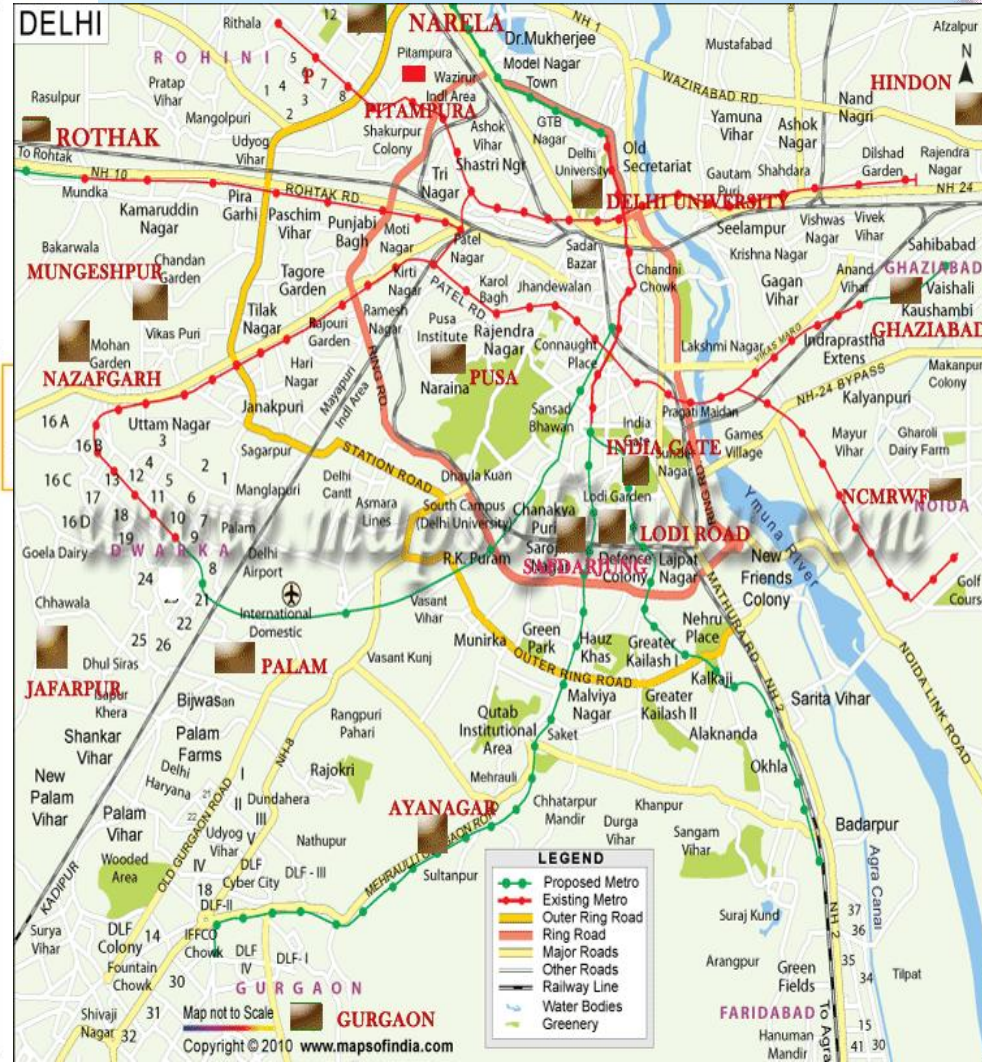
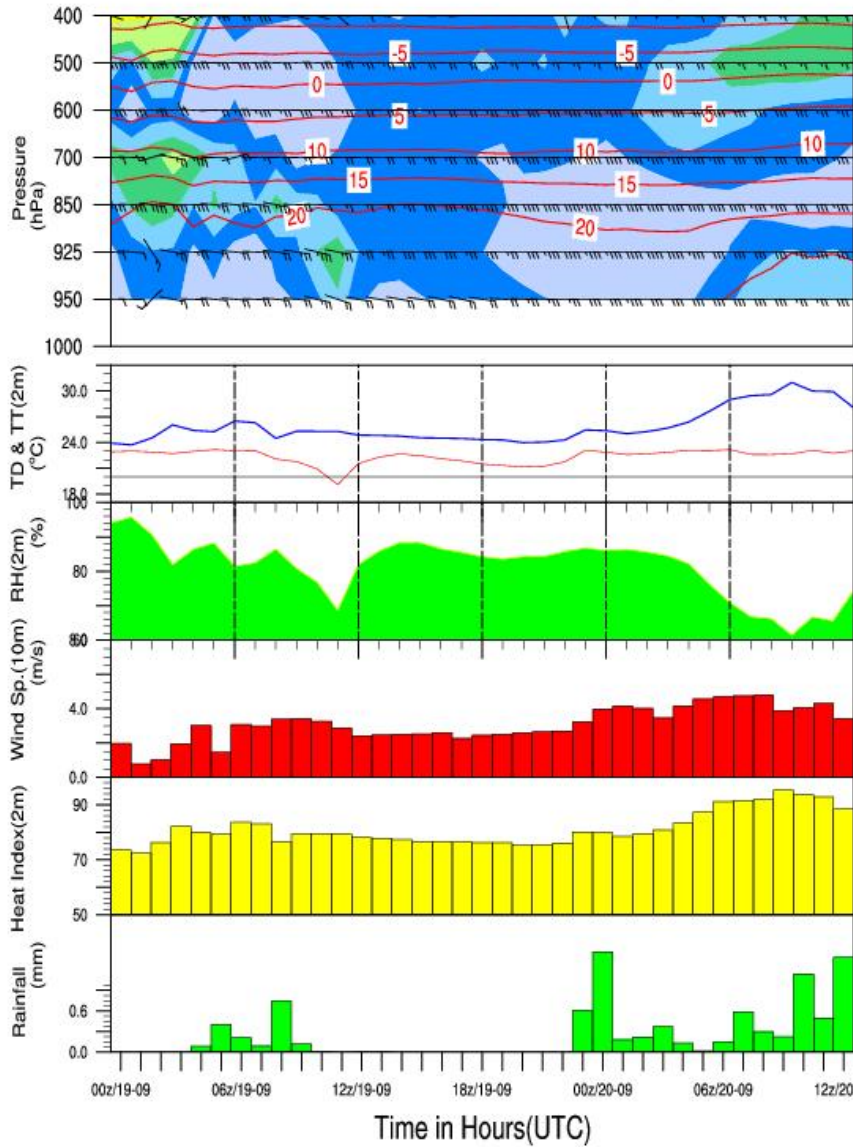




Cyclone Nisha of Nov 2008



TALKATORA STADIUM 00UTC/19-09-2010

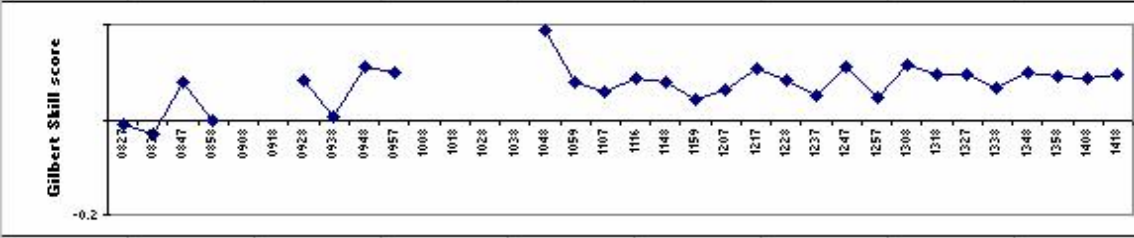
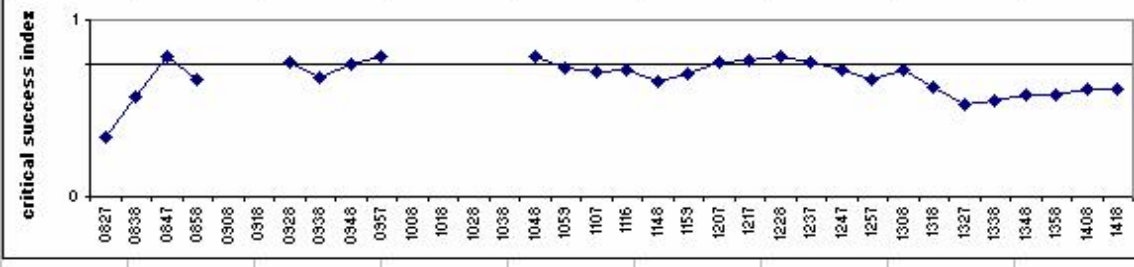
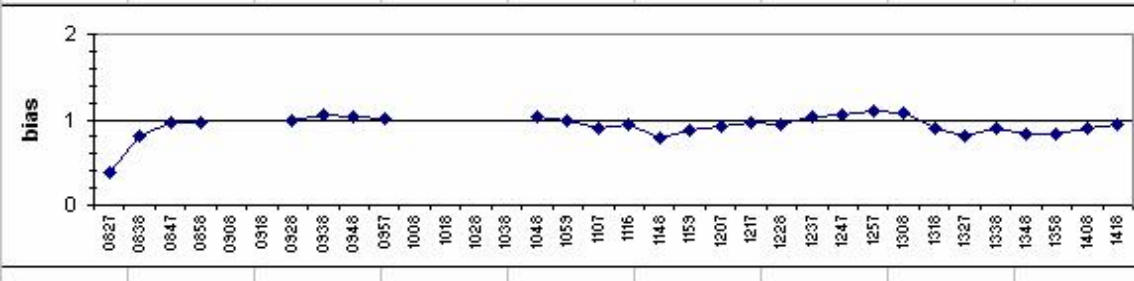
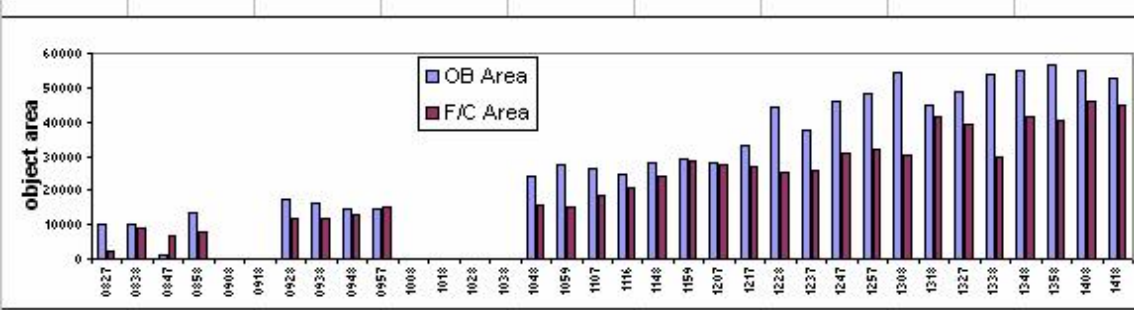
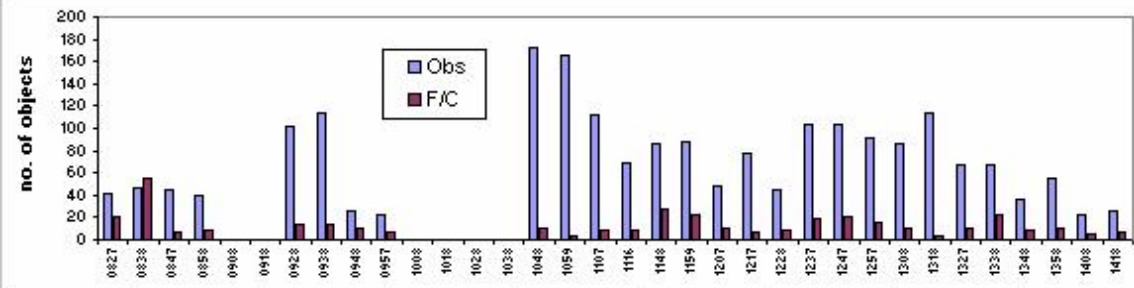


Verification Results

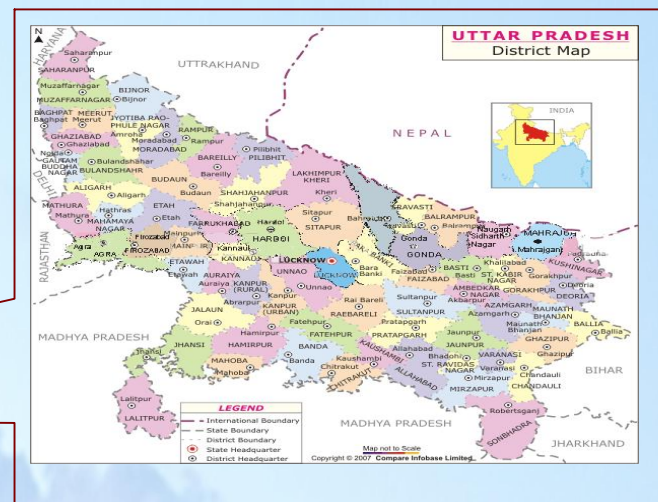
The Threat Score around 0.75 for much of the lifetime of the squall line, but decreases towards the end of the lifetime of the system.

For the initial part of the storm, the Equitable Threat Score is also close to zero indicating very poor skill of forecast during the growth period of the squall line.

During the period when the structure of the squall line does not show much variation, all scores indicate good prediction skills.



IMD Multi-model Ensemble (MME) based District level Forecasts for Integrated Agro Advisory Service of India



Parameters:

- Rainfall
- Max and Min temperature
- Total cloud cover
- Surface Relative humidity
- Surface Wind



Step-2

Generation of Multi-model Forecasts

IMD GFS

JMA

ECMWF

NCEP

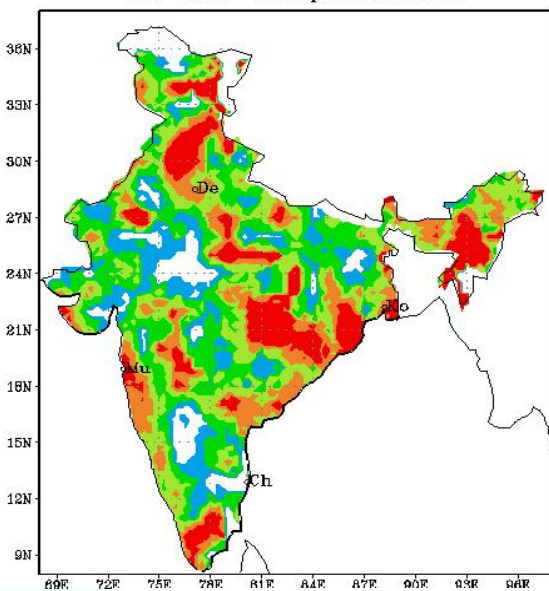
UKMO

$$\text{Forecast (F)} = \sum W_i F_i$$

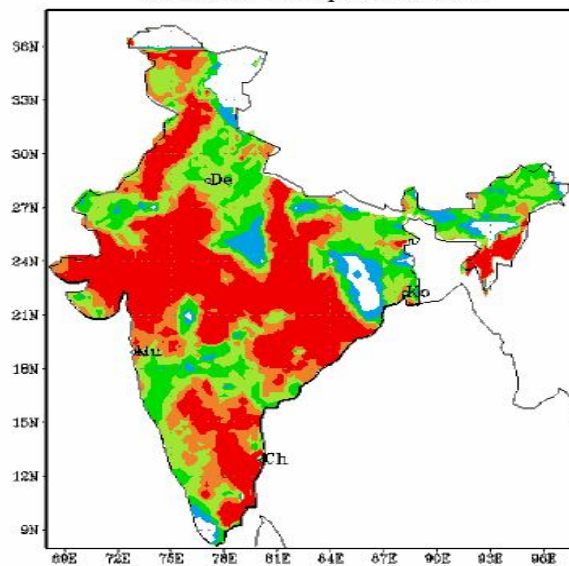
$$W_{i,j,k} = \frac{C_{i,j,k}}{\sum_{k=1}^5 C_{i,j,k}}, \quad i = 1, 2, \dots, 161; \quad j = 1, 2, \dots, 161$$



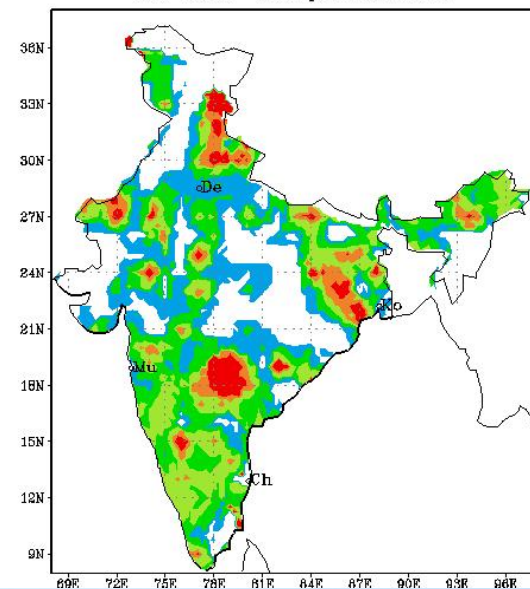
ECMWF WEIGHT DAY-5 FCST
for 1June -30September 2008



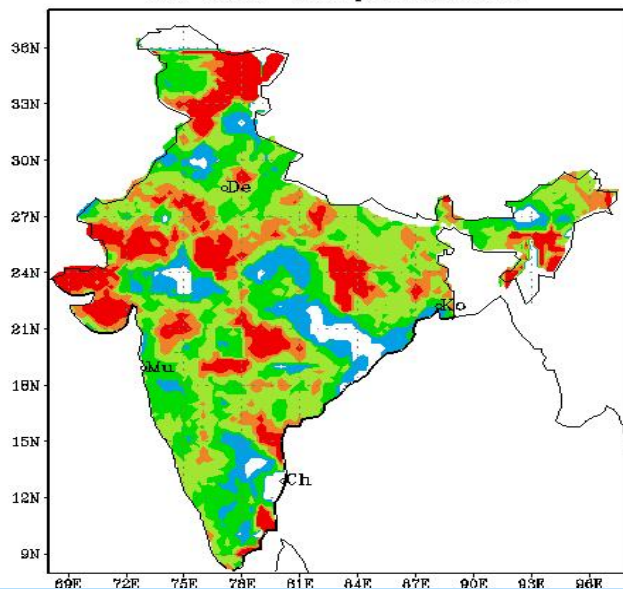
UKMO WEIGHT DAY-5 FCST
for 1June -30September 2008



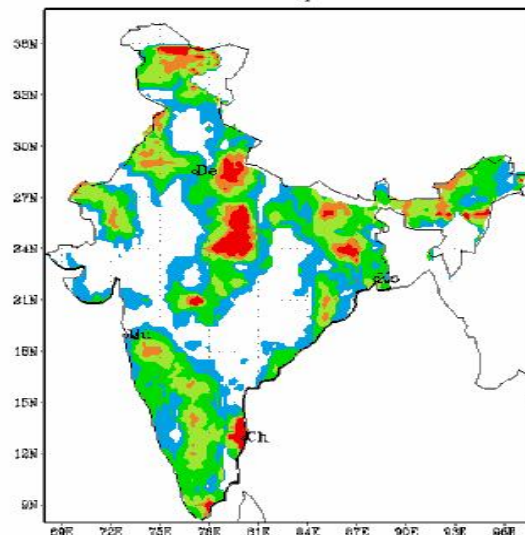
GFS WEIGHT DAY-5 FCST
for 1June -30September 2008

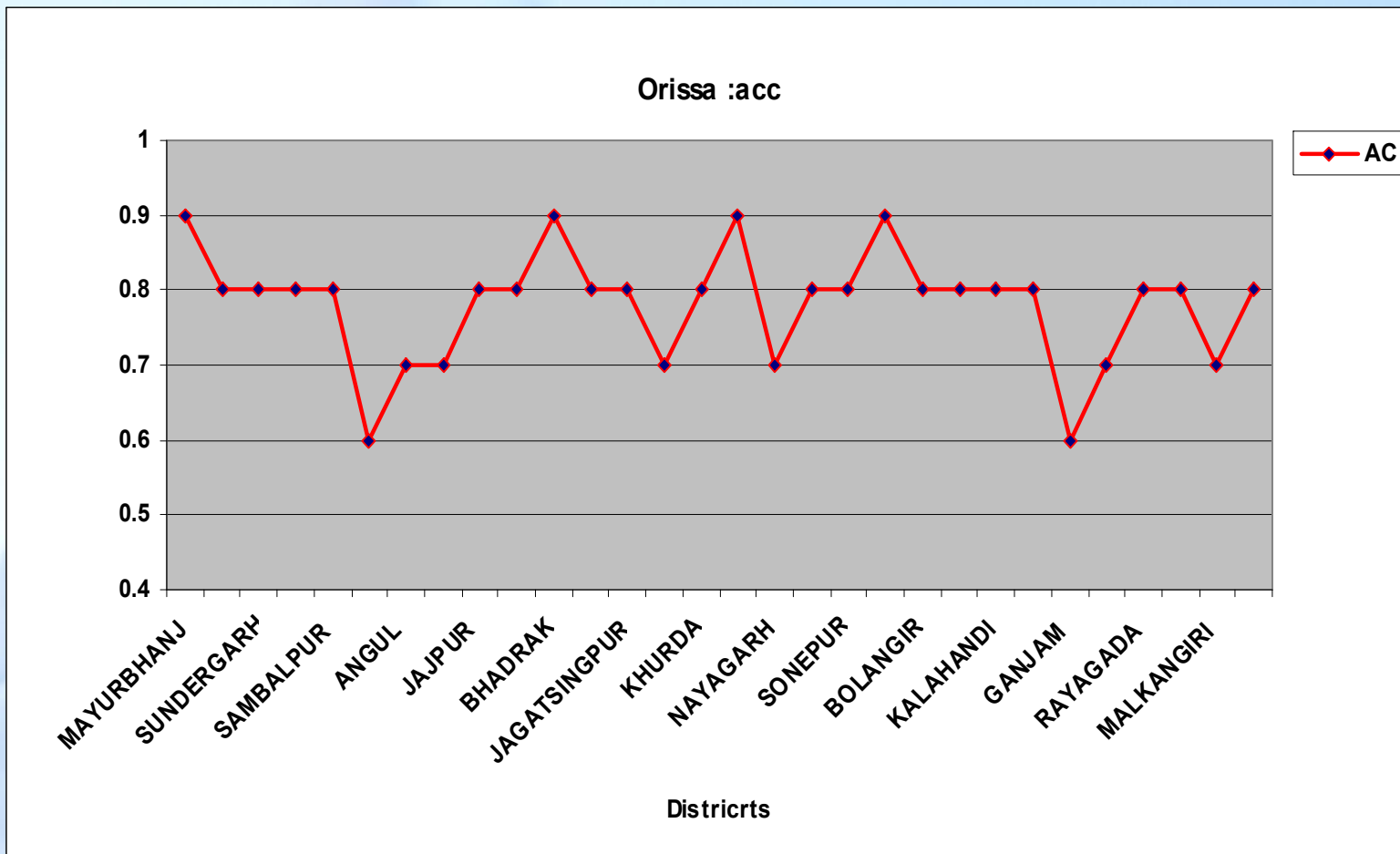


JMA WEIGHT DAY-5 FCST
for 1June -30September 2008



T254 WEIGHT DAY-5 FCST
for 1June -30September 2008





Prediction of Tropical Cyclone

- **CYCLOGENESIS**
- **TRACK PREDICTION**
- **INTENSITY PREDICTION**



The GPP is defined as:

$$GPP = \frac{\xi_{850} \times M \times I}{S} \quad \text{if } \xi_{850} > 0, M > 0 \text{ and } I > 0$$
$$= 0 \quad \text{if } \xi_{850} \leq 0, M \leq 0 \text{ and } I \leq 0$$

Where , ξ_{850} = Low level relative vorticity (at 850 hPa) in $10^{-5} s^{-1}$
 S = Vertical wind shear between 200 and 850 hPa (ms^{-1})

$$M = \frac{[RH - 40]}{30} = \text{Middle troposphere relative humidity}$$

Where RH is the mean relative humidity between 700 and 500 hPa
 $I = (T_{850} - T_{500})$ °C = Middle-tropospheric instability (Temperature difference between 850 hPa and 500 hPa)



TRACK PREDICTION BY NWP MODELS AND MME

- ***WRF***
- ***QLM***
- ***JMA***
- ***ECMWF***
- ***IMD GFS***

MME



MME Cyclone Track Prediction

12-hourly forecast latitude (LAT^f) and longitude (LON^f) positions at time t is defined as:

$$LAT_t^f = a_0 + a_1 ECMWF_t^{lat} + a_2 GFS_t^{lat} + a_3 JMA_t^{lat} + a_4 WRF_t^{lat} + a_5 QLM_t^{lat}$$

$$LON_t^f = a'_0 + a'_1 ECMWF_t^{lon} + a'_2 GFS_t^{lon} + a'_3 JMA_t^{lon} + a'_4 WRF_t^{lon} + a'_5 QLM_t^{lon}$$

for $t =$ forecast hour 12, 24, 36, 48, 60 and 72



Statistical Tropical Cyclone Intensity Prediction (SCIP) Model

Intensity change (dv_t) during the time interval t is defined as:

$$dv_t = a_0 + a_1 IC12 + a_2 SMS + a_3 VWS + a_4 D200 + a_5 V850 + a_6 ISL + a_7 SST + a_8 ISI$$

The predictors: for $t =$ forecast hour 12, 24, 36, 48, 60 and 72

(a) Persistence:

- (i) Initial storm intensity (ISI)
- (ii) Previous 12 hours change in the intensity (IC12)

(b) Thermodynamical factors :

- (i) Storm motion speed (SMS)
- (ii) Sea surface temperature (SST)

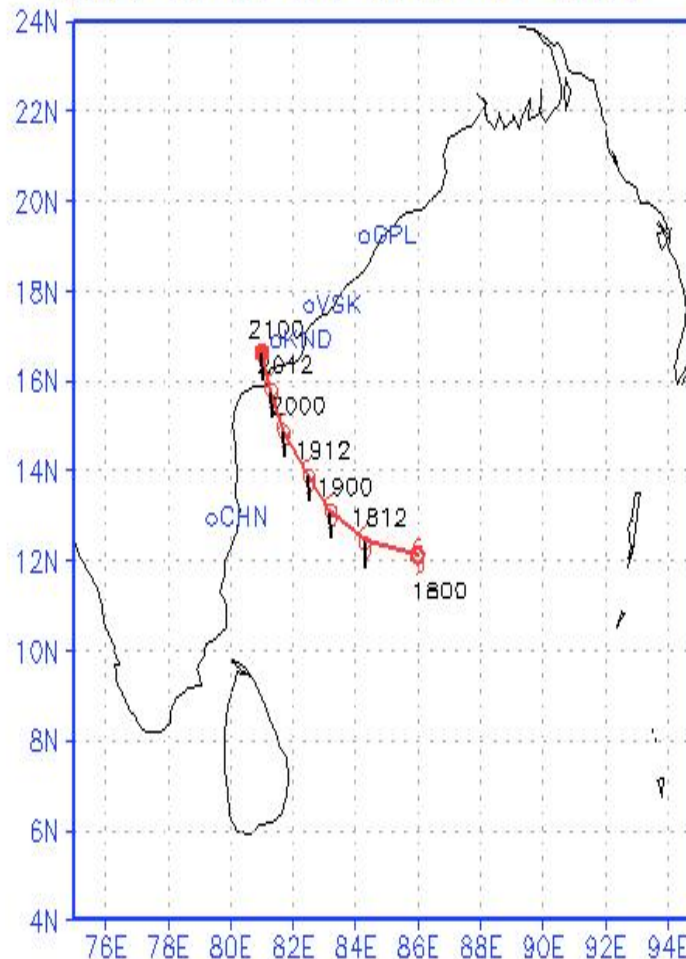
(c) Dynamical factors :

- (i) Initial storm latitude position (ISL)
- (ii) Vertical wind shear (850-200) hPa averaged along storm track (VWS)
- (iii) Vorticity at 850 hPa (V850)
- (iv) Divergence at 200 hPa (D200)



TRACK PREDICTION BY IMD MULTIMODEL ENSEMBLE(MME) based on 00 UTC of 18-05-2010

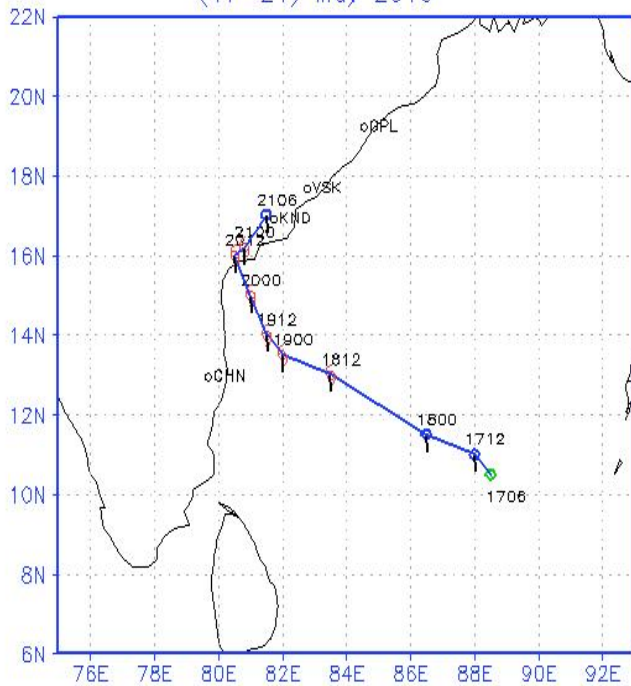
TRACK PREDICTION BY IMD MME based on 00 UTC of 18-05-2010		
FORECAST HOUR	LAT	LON
2010051800	12.1	86.0
2010051812	12.4	84.3
2010051900	13.1	83.2
2010051912	13.9	82.5
2010052000	14.9	81.7
2010052012	15.8	81.3
2010052100	16.6	81.0



INTENSITY PREDICTION BY IMD SCIP MODEL based on 00 UTC of 18-05-2010	
FORECAST HOUR	INTENSITY
2010051800	35 kts
2010051812	39 kts
2010051900	43 kts
2010051912	37 kts
2010052000	38 kts
2010052012	51 kts

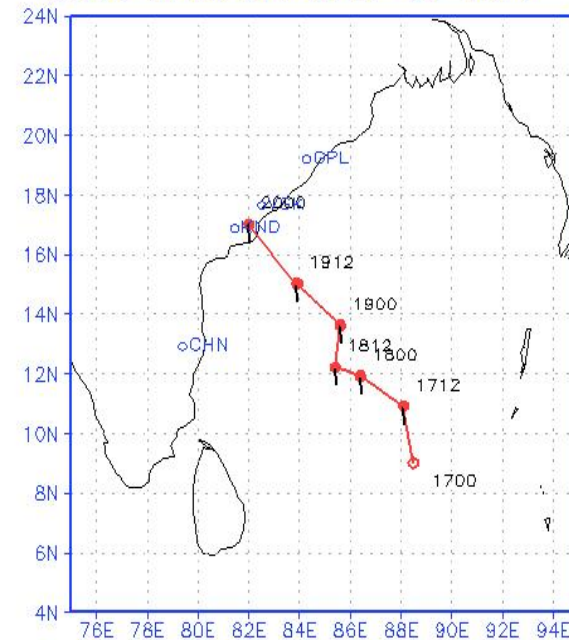


Observed Track of TC LAILA over Bay of Bengal
(17-21) May 2010



TRACK PREDICTION BY IMD MULTIMODEL ENSEMBLE(MME)
based on 00 UTC of 17-05-2010

TRACK PREDICTION BY IMD MME based on 00 UTC of 17-05-2010		
FORECAST HOUR	LAT	LN
2010051700	09.0	83.5
2010051712	10.9	88.1
2010051800	11.9	86.4
2010051812	12.2	85.4
2010051900	13.6	85.6
2010051912	15.0	83.9
2010052000	17.0	82.0



Mean Track forecast errors of NWP Models for Cyclones during 2010

MODEL	12hr	24hr	36hr	48hr	60hr	72hr
ECMWF	54	71	102	170	202	246
NCEP-GFS	158	178	177	236	253	334
JMA	195	96	176	203	232	268
IMD-MM5	118	141	241	350	363	356
IMD-QLM	103	144	167	181	256	311
IMD-MME	72	104	140	205	190	244
IMD-T382	94	124	164	212	246	290
IMD-WRF-VAR	155	137	236	253	234	265
IMD-WRF-NMM	92	109	129	193	216	281



AVERAGE TRACK FORECAST ERRORS (IN KM) FOR THE YEAR 2011

MODELS	Lead time →					
	12 hr	24 hr	36 hr	48 hr	60 hr	72 hr
ECMWF	103	77	75	86	116	118
GFS (NCEP)	86	112	95	143	213	181
JMA	117	118	235	155	211	231
QLM (IMD)	85	156	219	383	542	748
MME (IMD)	68	75	100	119	129	157
GFS (IMD)	126	165	197	217	261	306
WRF(IMD)	152	195	238	277	283	354

