Severe Weather Forecasting : Issues and Challenges

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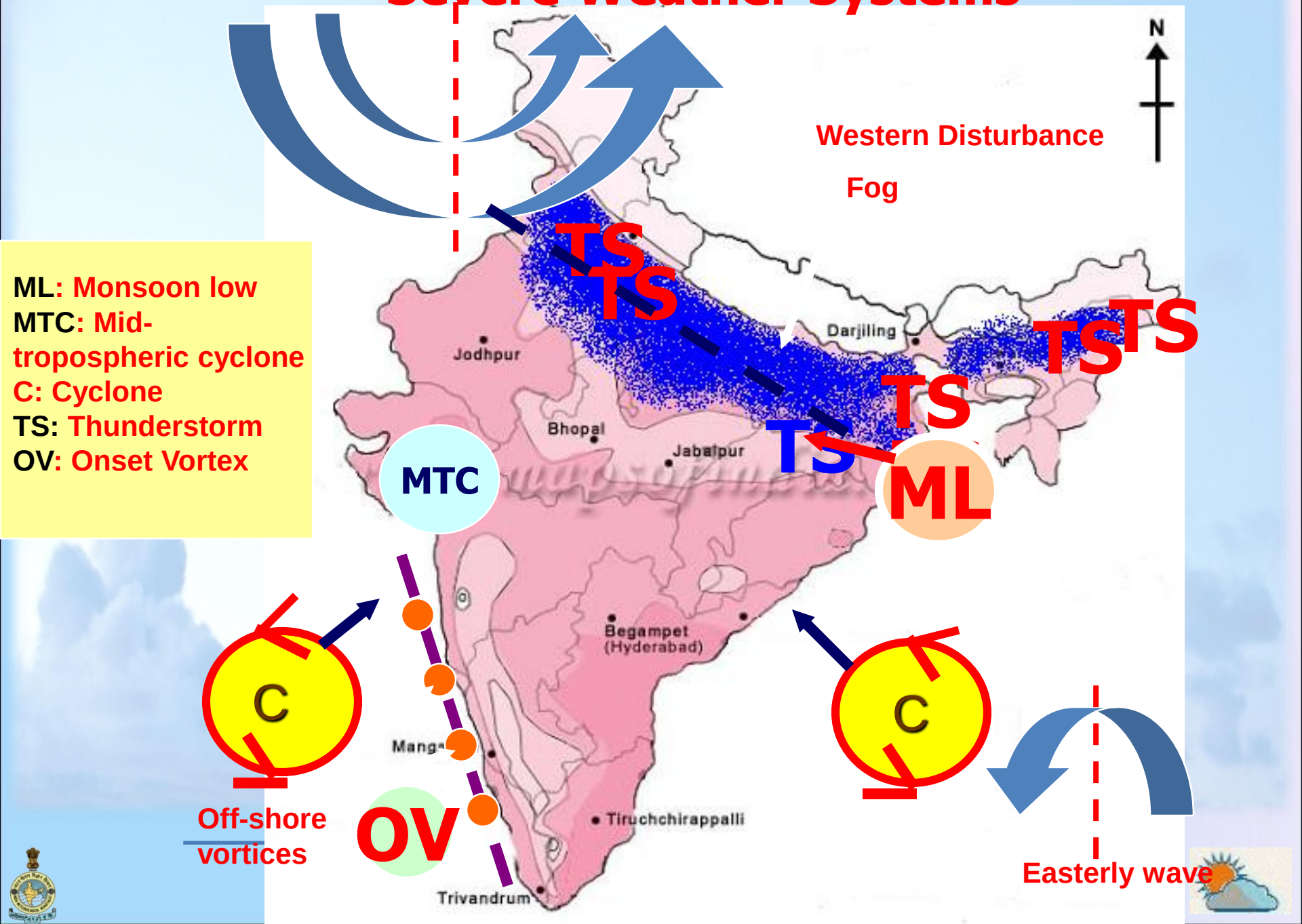
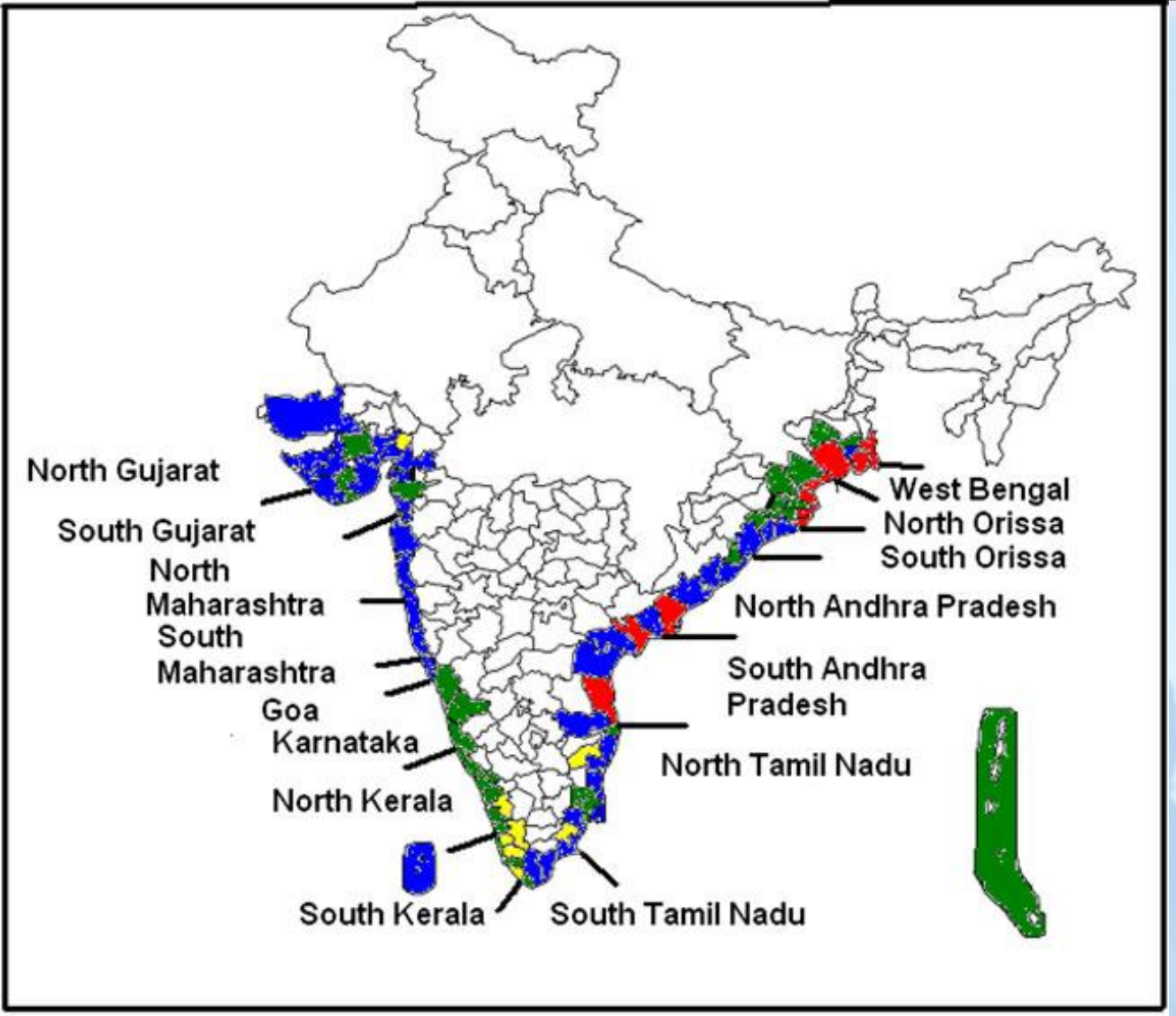
भारत मौसम विज्ञान विभाग
INDIA METEOROLOGICAL DEPARTMENT

Severe Weather Systems



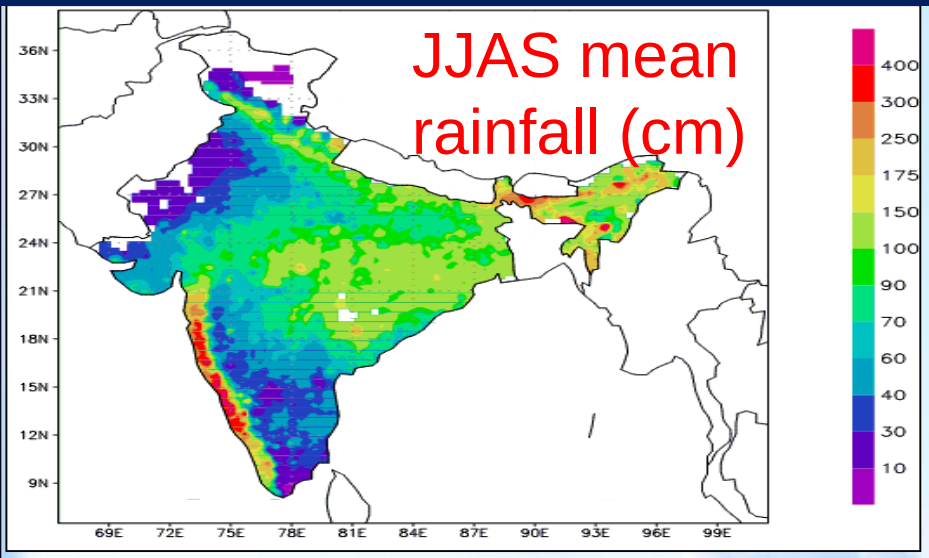
ML: Monsoon low
MTC: Mid-tropospheric cyclone
C: Cyclone
TS: Thunderstorm
OV: Onset Vortex



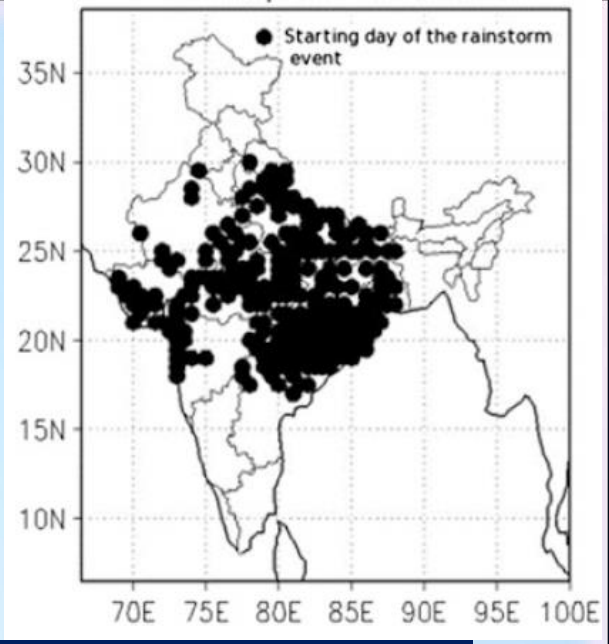
Cyclone hazard prone districts of India based on

- frequency of total cyclones,
- total severe cyclones,
- actual/estimated maximum wind,
- Probable Maximum Storm Surge (PMSS) associated with the cyclones and
- Probable Maximum Precipitation (PMP) for all districts

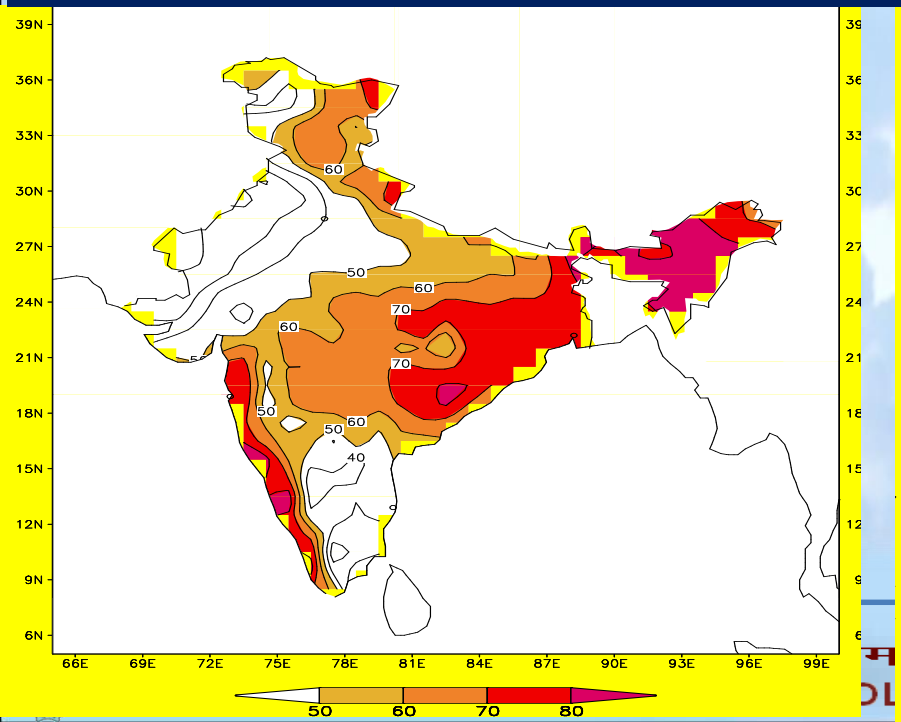
Monsoonal Heavy Rainfall (June to September)



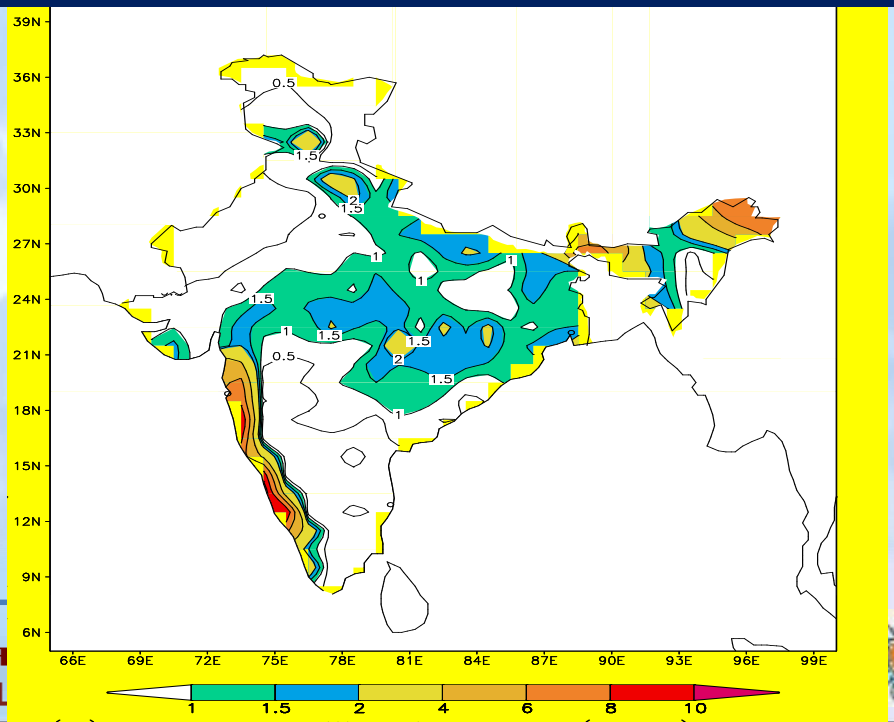
Spatial Variation in Origin of Rainstorms over India during southwest Monsoon Season (1951-2015)

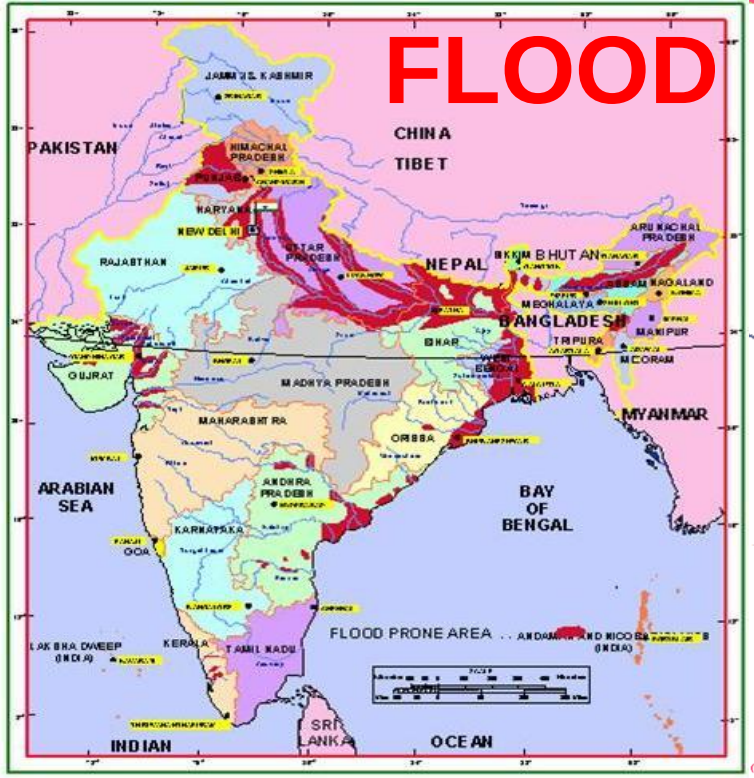


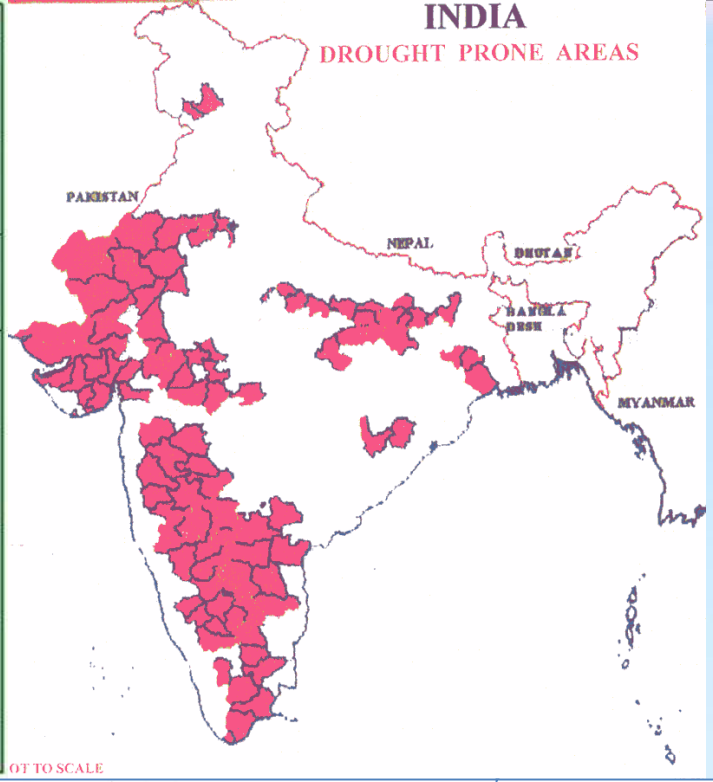
Mean % of Heavy rainfall days



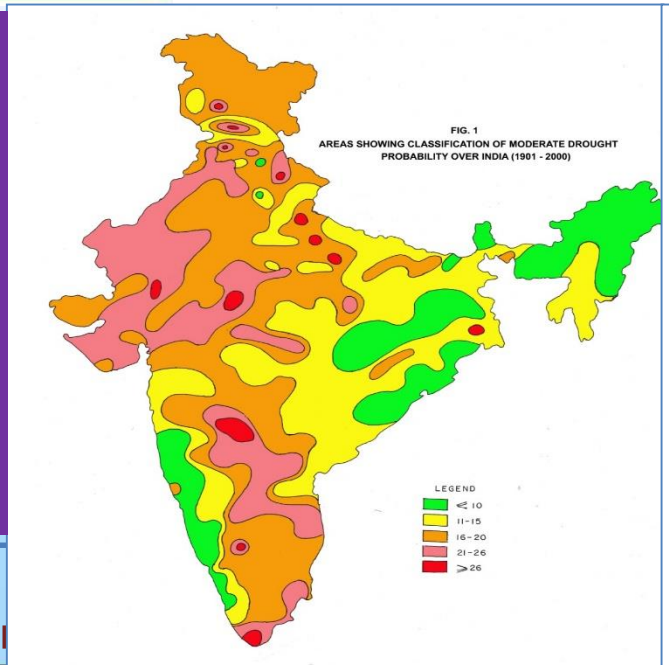
Mean % of Very heavy rainfall days

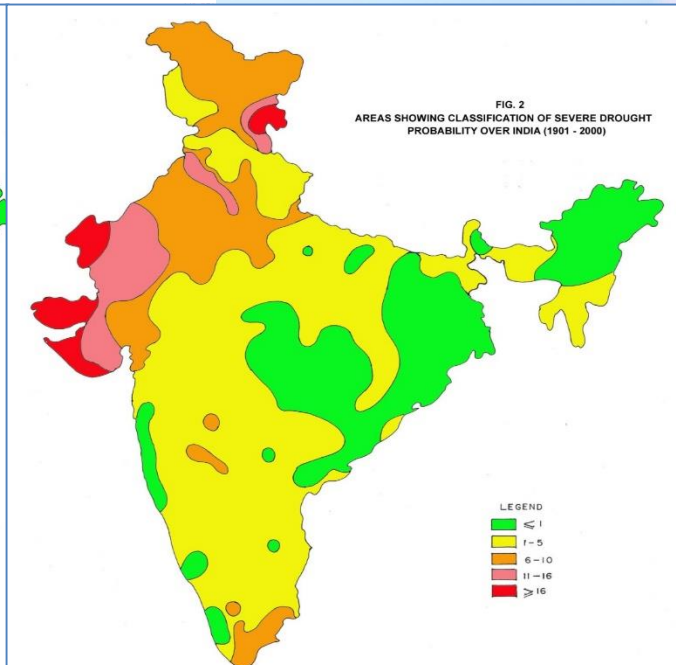




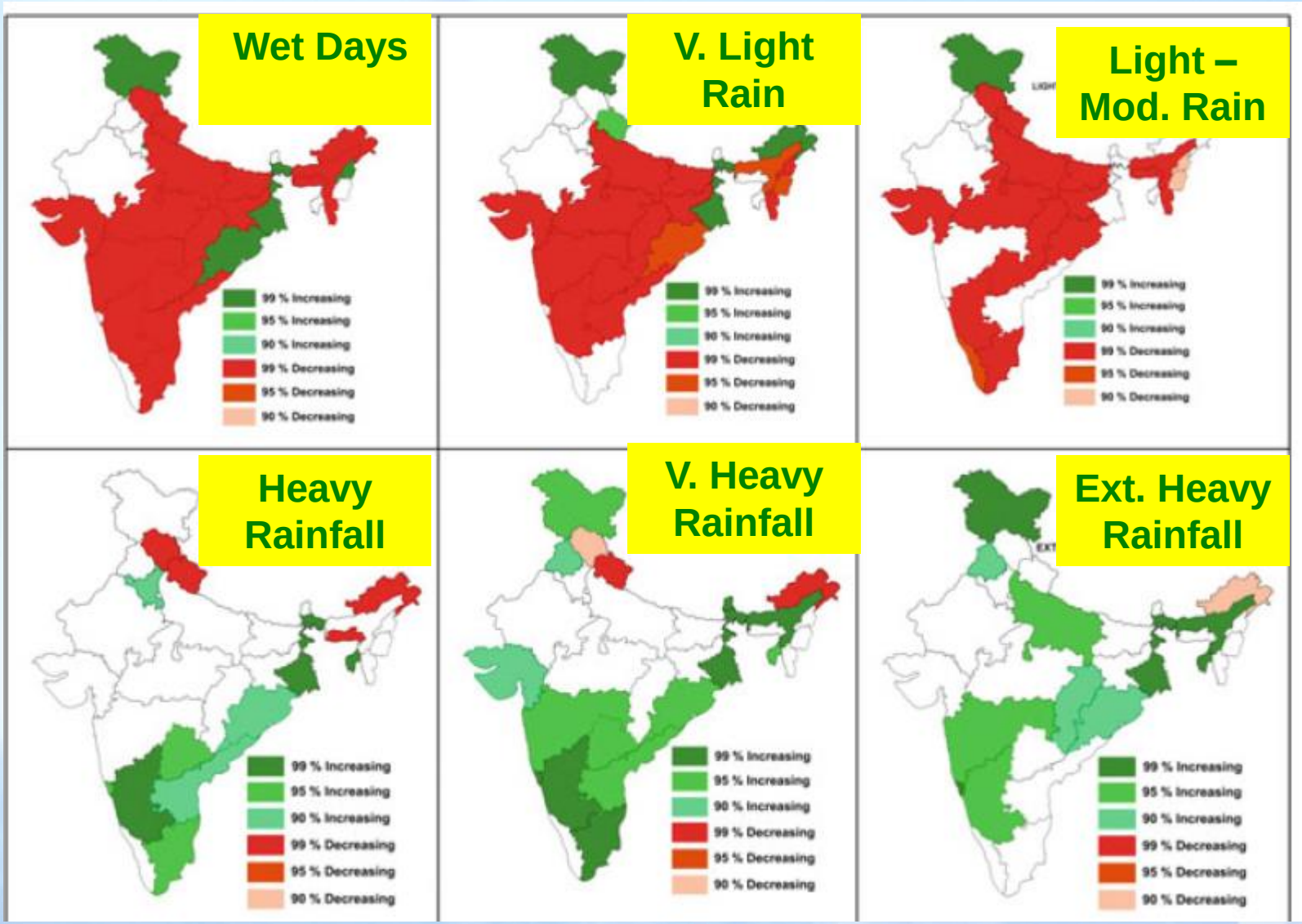


PROBABILITY OF MODERATE AND SEVERE DROUGHT (1901-2000)



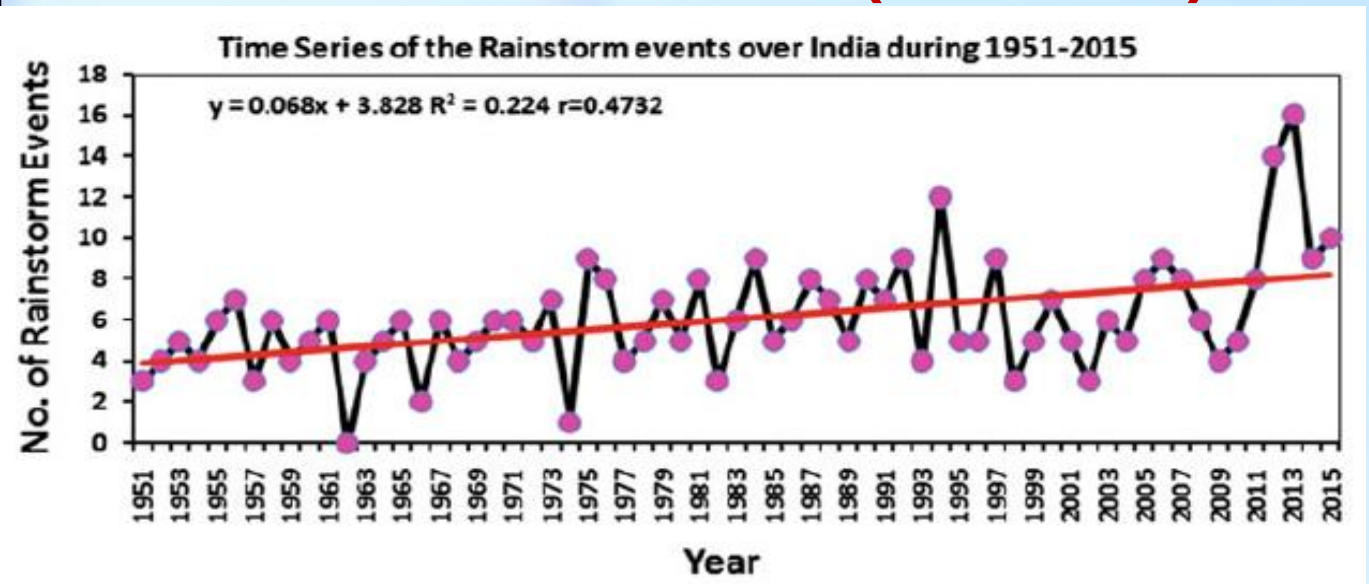


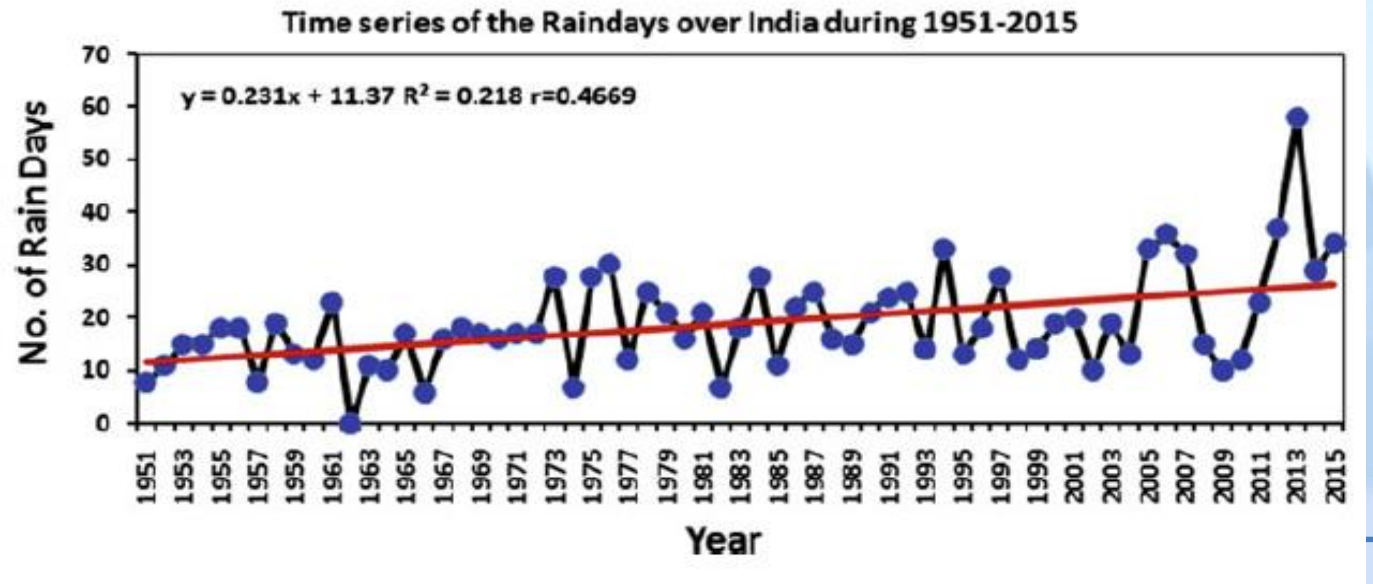
Trends in frequencies of different rainfall events during Monsoon Season



Pulak Guhathukarta et al, 2017, Variability & Trends of Extreme Rainfall & Rainstorms in book entitled Observed Climate varaibility & change over Indian Region Edited by M N Rajeevan & Shailesh Nayak

Time Series of the Rainstorm events and Rain Days over India(1951-2015)





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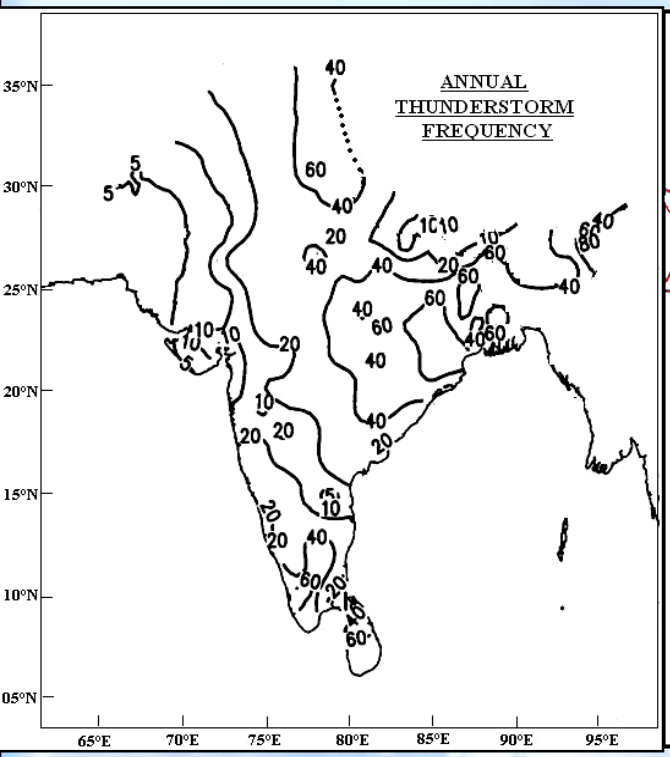
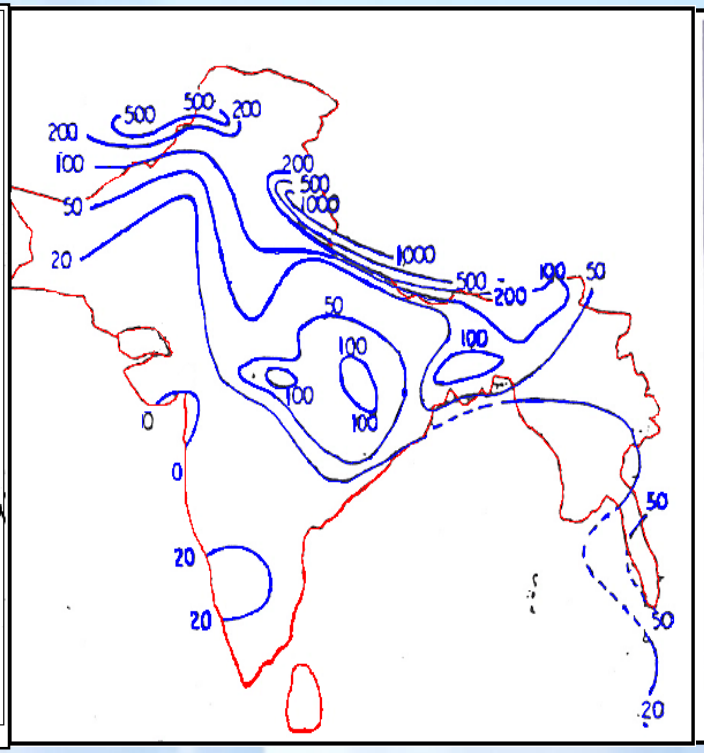
Meso-scale severe weather events

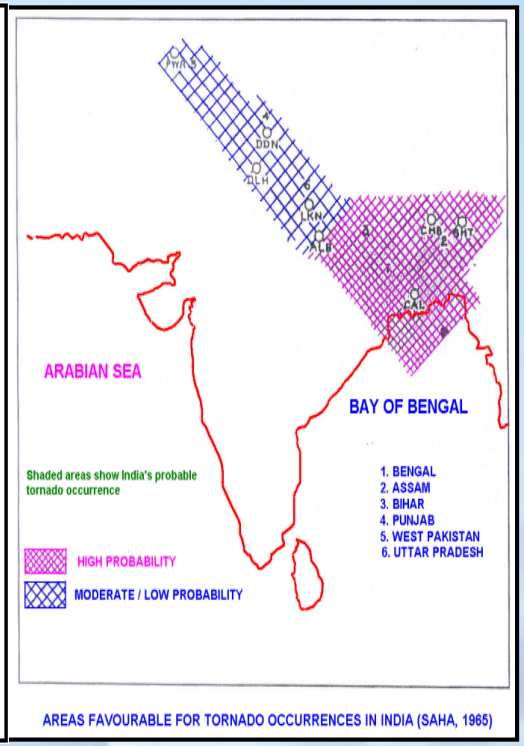
Thunderstorm (Per year)



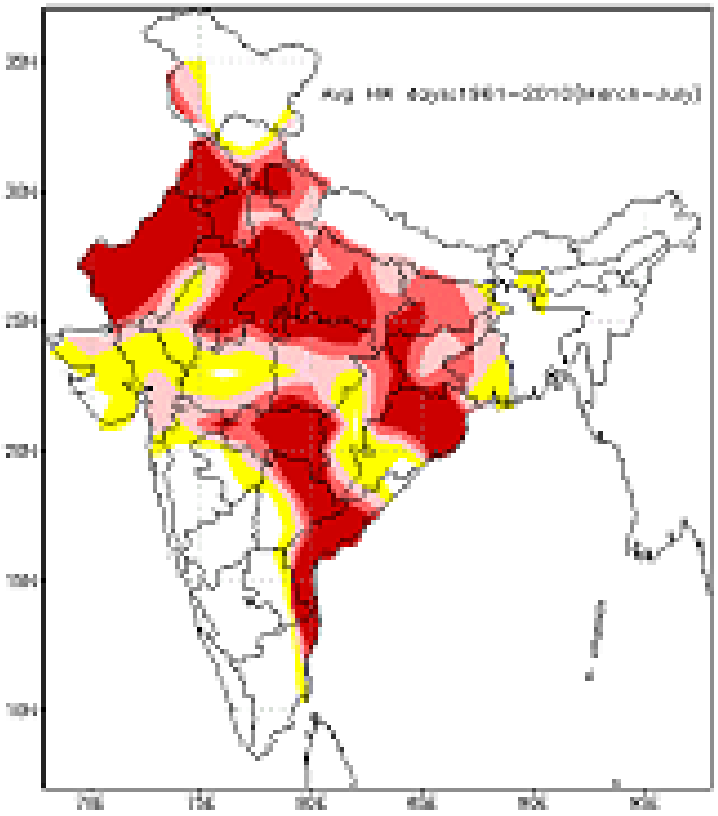
Hailstorm (in 100 years)



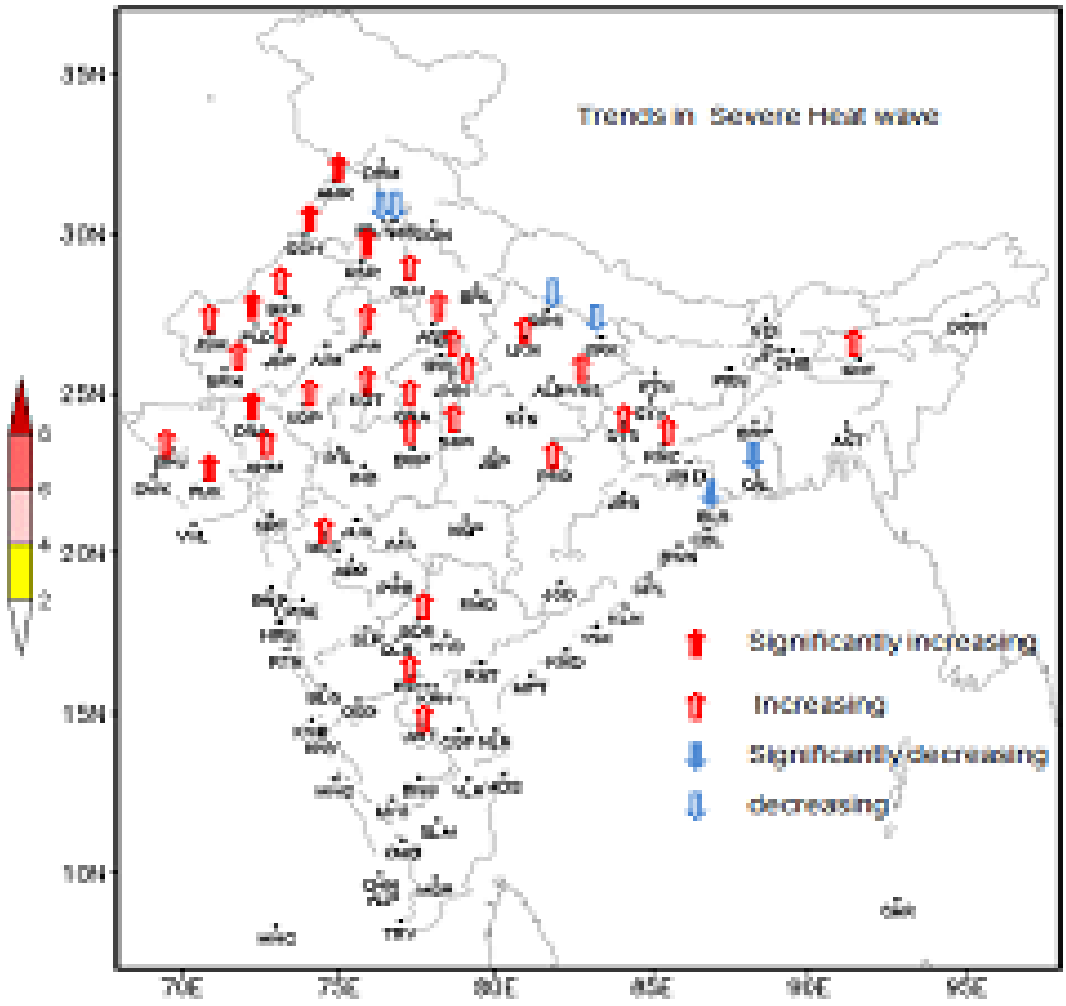
Tornado prone areas



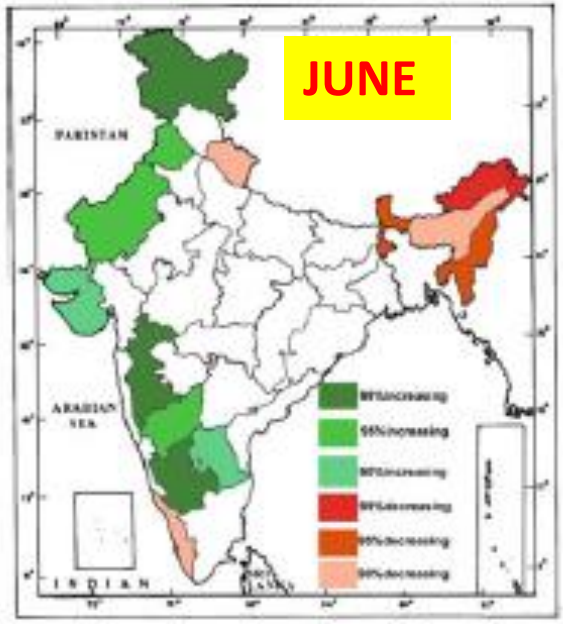
Heat waves over India

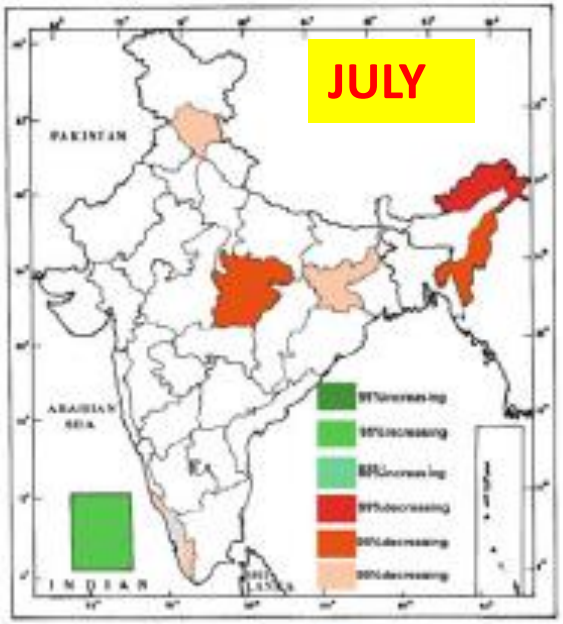


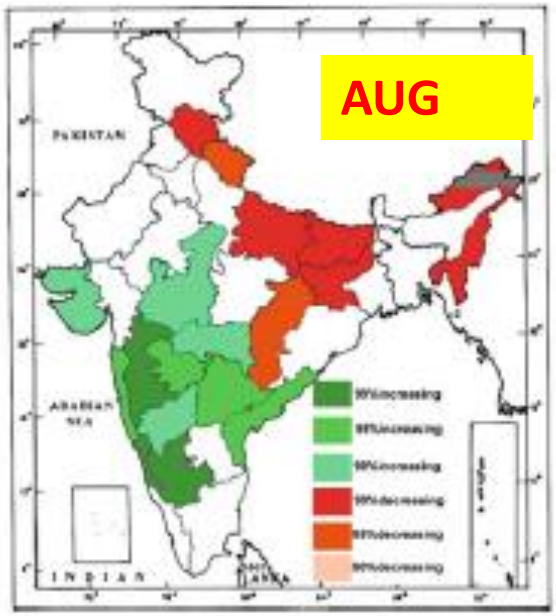
Average Frequency of Heat Wave Days

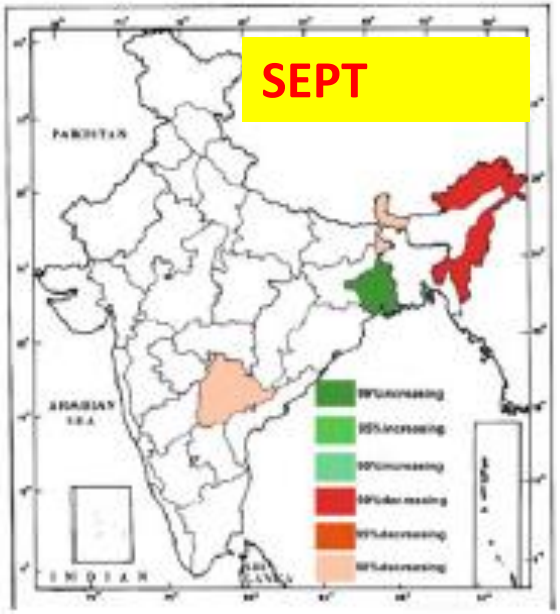


Trends in severe heat waves over India



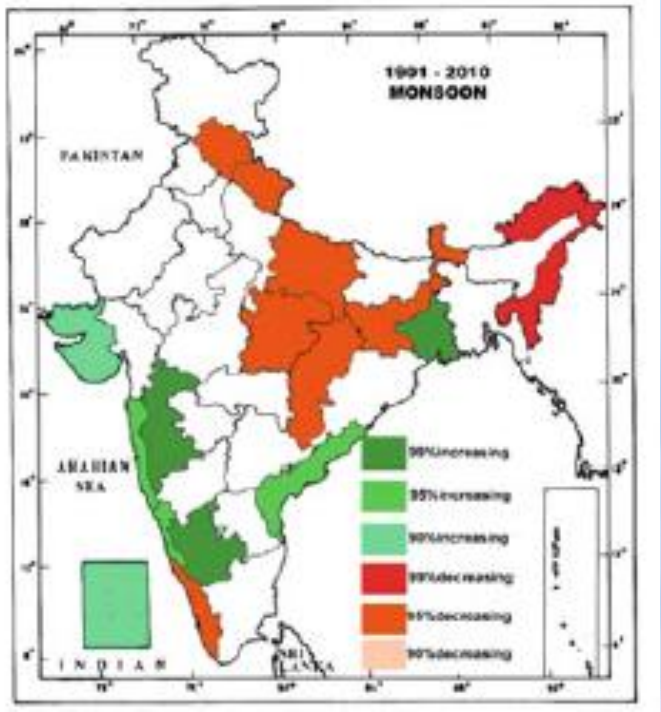






Trends in the monthly rainfall (June, July, August, September and Season for the period 1901–2010.

Trends shown here are qualitative in nature



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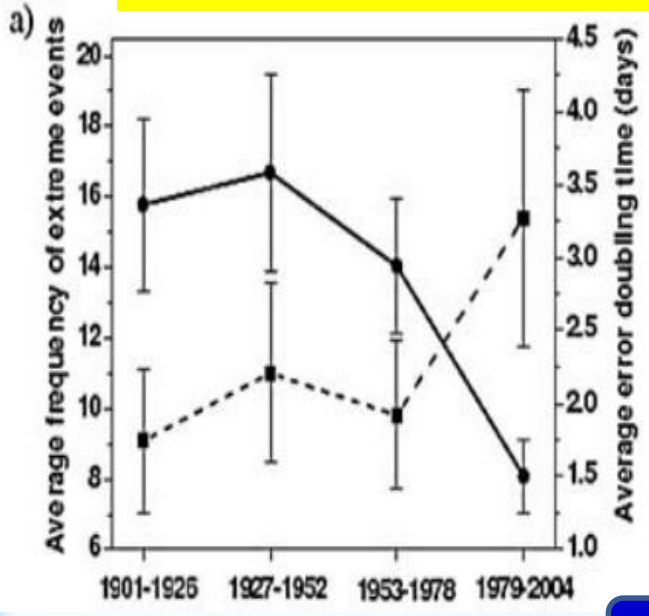
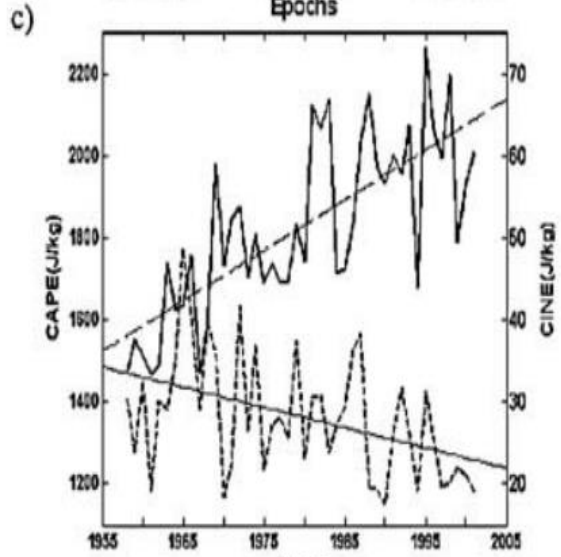
Global Warming on Rainfall Activity



Average error doubling time over central India and frequency of extreme events (rainfall >150 mm/day).



Daily CAPE and CINE during monsoon season

Global Warming

↓

Rise in Temperature

↓

Increase in Evaporation

↓

Increase in Moisture Content of Atmosphere

↓

Increase in Small Scale (Mesoscale) Convective System

↓

Formation of Low Pressure Area → **Increase in Rainstorms over Central & North India**

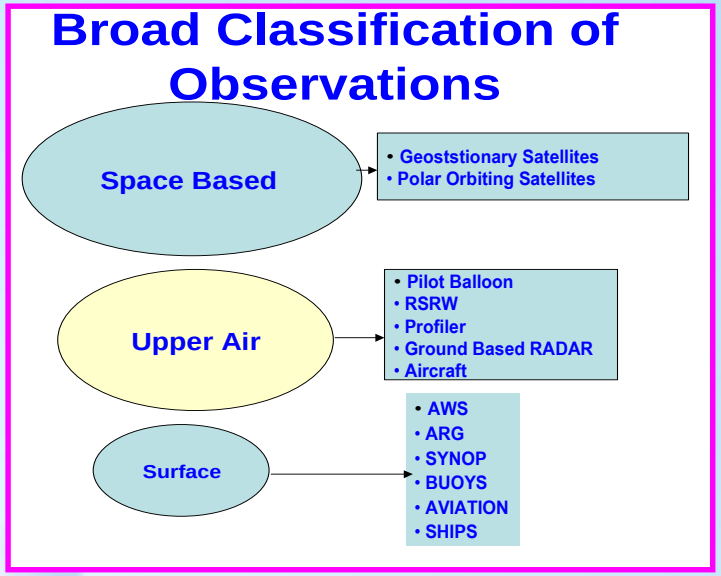
Challenges in Predictability of Mesoscale Events

- Predictability of meso scale system is less
- Due to Global Warming the prediction of Extreme Rainfall Events likely to decrease
- Error doubling time of extreme rainfall event during last 30 years decreased from about 3 days to 1.5 days

Solutions to improve Predictability of Mesoscale Events

- Enhancement of observational network to detect mesoscale systems
- Improve data assimilation of models for these systems
- Use High Resolution Models
- To address uncertainty, provide probablistic forecast
- Warning system & dissemination be made smarter to utilise reduced lead time to reach the last mile
- Capacity building of forecasters, disaster managers media & general public

Early Warning System



Initial conditions (Observations)

Runs of different Models,

Consecutive runs from the same model,

Ensemble runs ("choosing the best member")

Model runs

Forecaster

Decision maker

Action

Numerical forecasts

End forecast

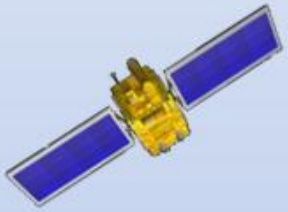
Improved Early warning system with respect to all the above components

How are the observational needs met currently?

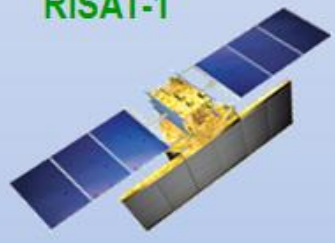
Indian EO Missions – Current & Planned

LAND & WATER

RESOURCESAT-2, 2A

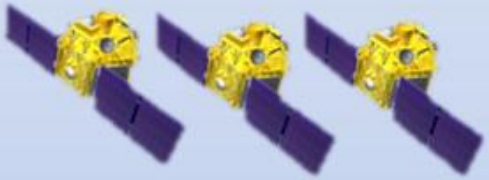


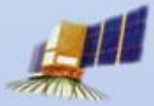
RISAT-1



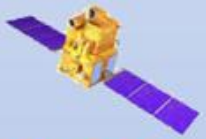
HIGH RESOLUTION

CARTOSAT-2; 2A; 2B; 2S





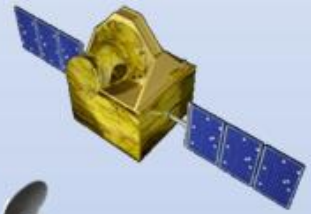
RISAT-2



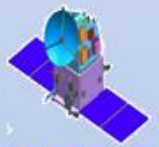
CARTOSAT-1

OCEAN

OCEANSAT-2



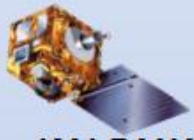
SARAL

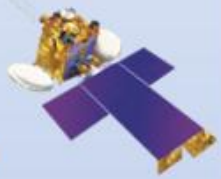


SCATSAT-1

WEATHER; CLIMATE

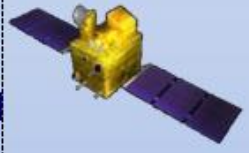
INSAT-3A

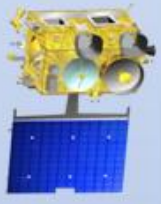




KALPANA

MEGHA-TROPIQUES

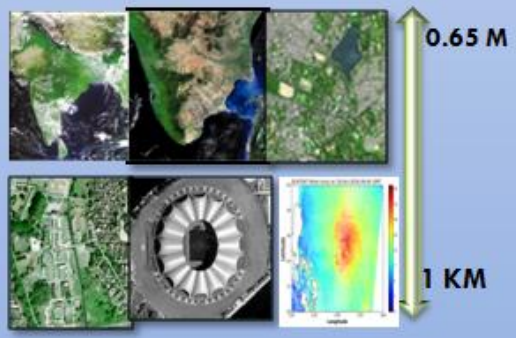




INSAT-3D, 3DR

Cartosat-3, Oceansat-3, Resourcesat-3, RISAT, GISAT in 2017-18 for continuity of services and new capabilities

Imaging Capability

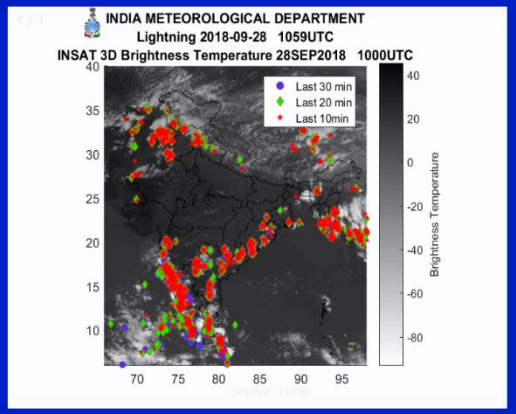


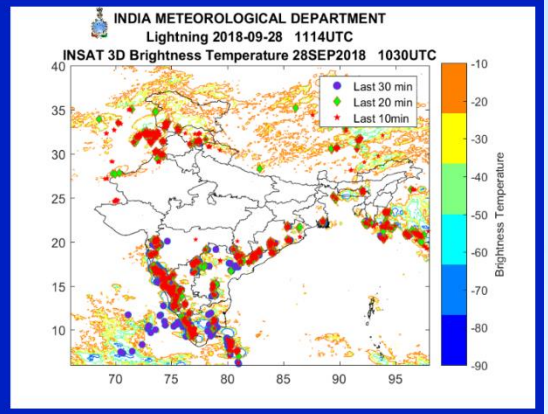
Ground Infrastructure

Comm. devices

INDIA METEOROLOGICAL DEPARTMENT
Ministry of Earth Sciences
LIGHTNING WITH INSAT-3D DATA

SATELLITE BASED OBSERVATIONS

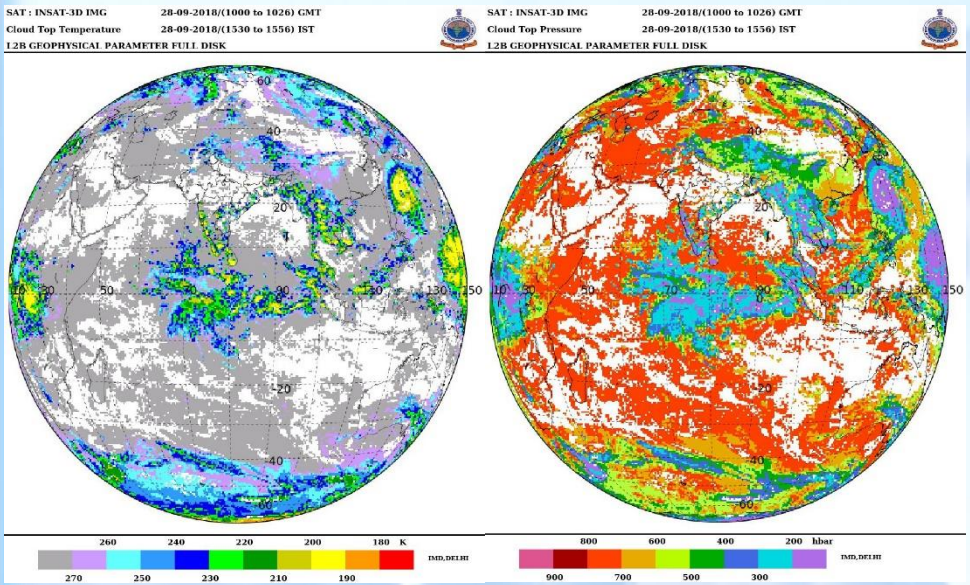




❑**Lightning data** (Updated every 15-minutes) divided into the 3 different time categories 10, 20 and 30 minutes in different colours.

❑However, data frequency is every 2-minutes from IITM and every 15 minutes from IAF.

❑Merged lightening & satellite CTT operational product is a joint collaboration of IMD, IITM & IAF.

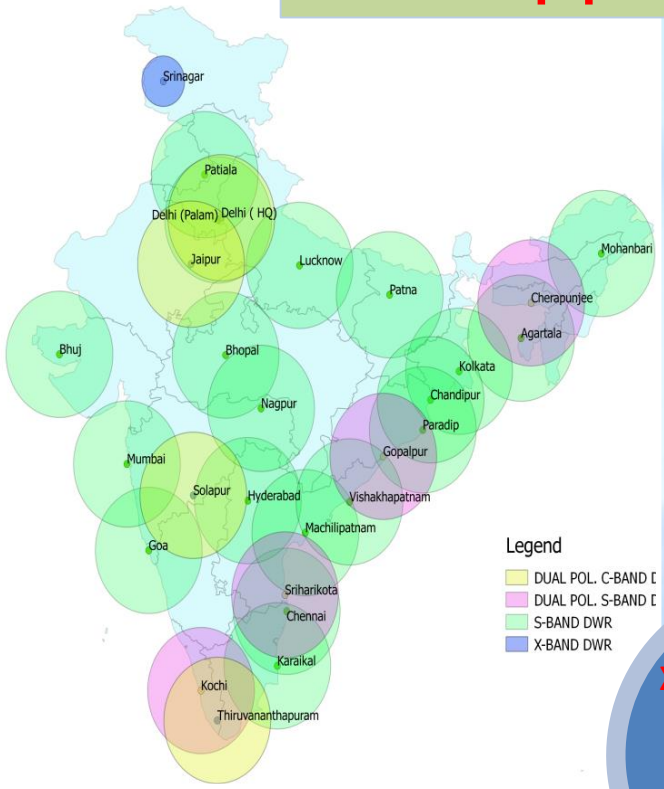


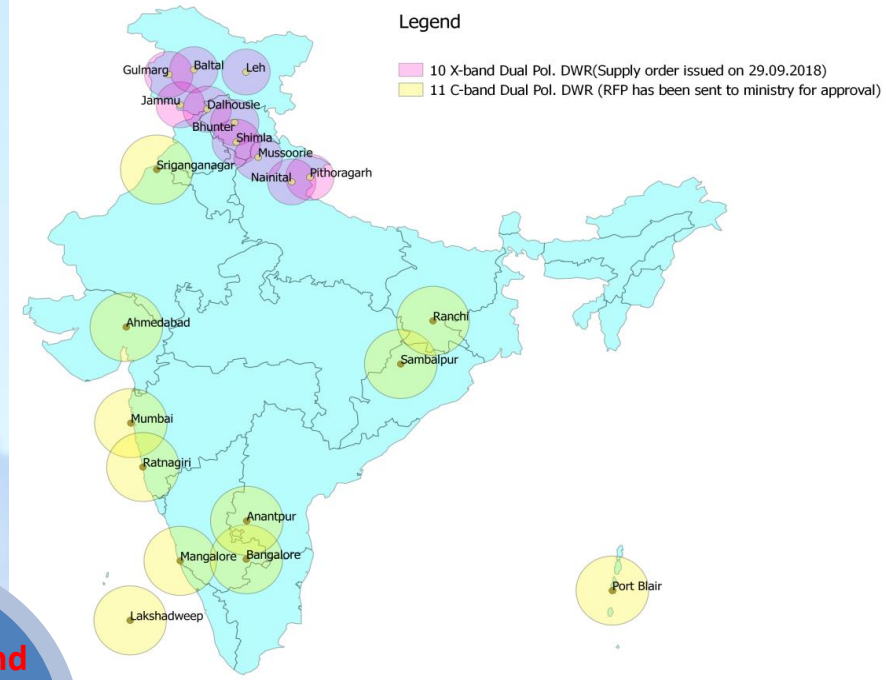
❑Priority work to merge (all 3 types of instrument data) Satellite, RADAR and Lightning data for the weather forecast to be completed by March 2019.

❑Two new products Cloud Top Temperature (CTT) and Cloud Top Pressure (CTP) started. These products are very useful in case of NOWCASTING.

❑Clear Sky Brightness Temperature (CSBT) is also being generated and data is being provided to NCMRWF for assimilation in model.

Doppler Weather Radar Network





2018

Proposed for 2019-20

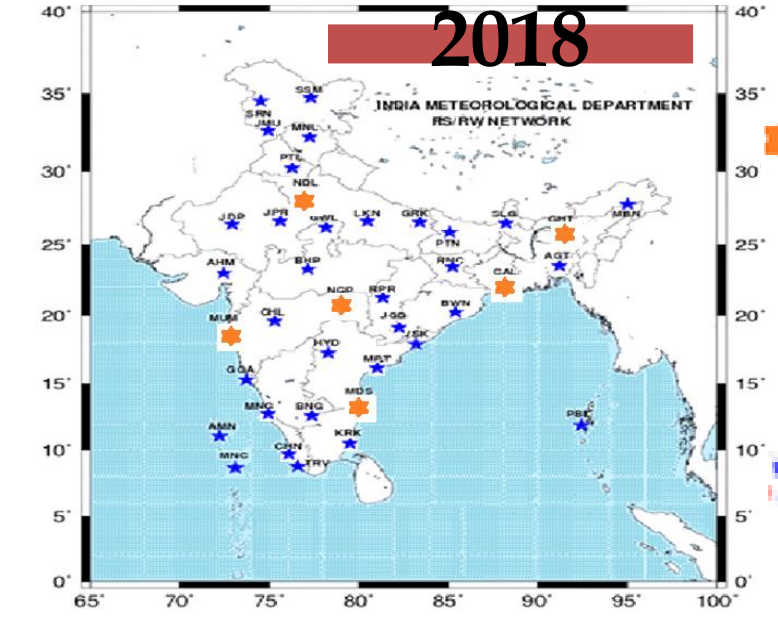
Upper Air Network

43 RS/RW stations upgraded with GPS based radio sounding systems.

Expansion of GUAN standard network from 6 to 12 stations to be completed by March 2019.

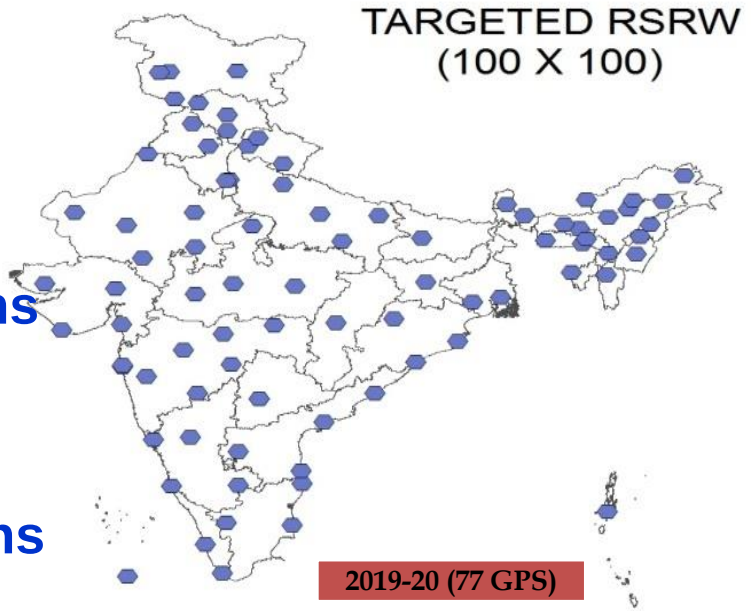
Expansion of RS/RW from 43 stations to 55 to be completed by March 2019.

Continuation of all 43 RS/RW stations with twice a day ascents.



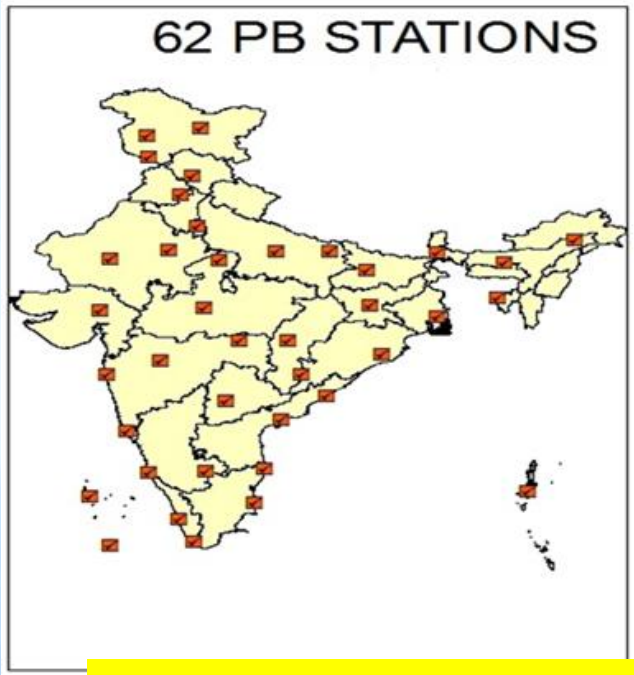
GUAN standard compatible RS/RW stations

Other GPS based stations

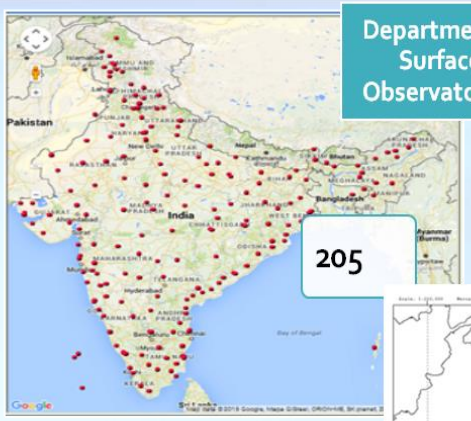


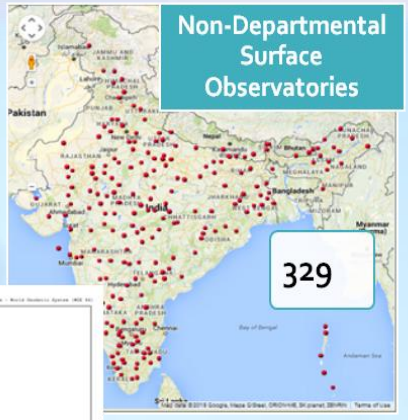
Pilot Balloon Network

- ❖Implementation of indigenous GPS based PB-sonde system done at New Delhi & Mumbai.
- ❖ 18 stations to be operationally up-graded with IMD make pilotsonde by December 2018. Remaining stations would be upgraded by March 2019.
- ❖40 PB stations also to be up-graded by other GPS based PB sonde.

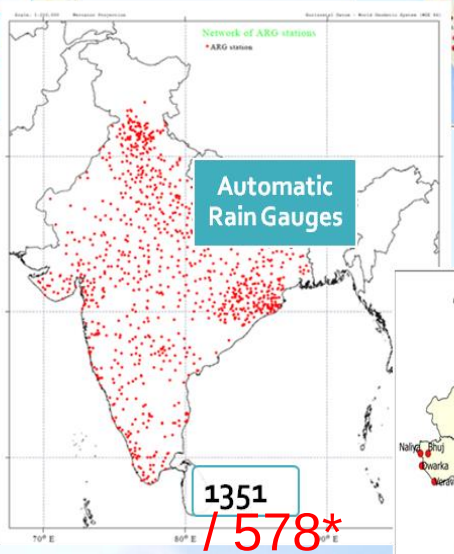


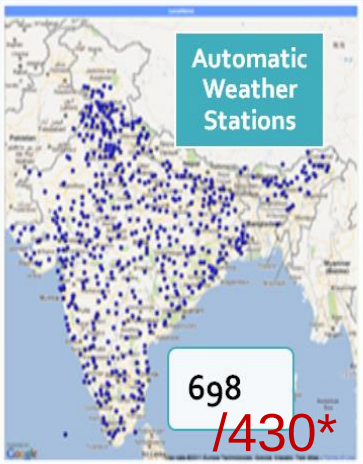
Boost to Make in India and Digital India Initiative by IMD, MoES.



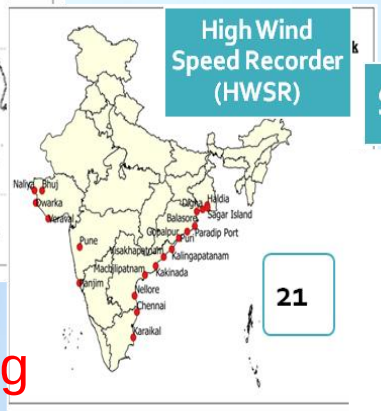


Dual telemetry enabled Data loggers – 300 Nos. procured. 220 Nos. of these data loggers installed at AWS sites. This resulted in improved network availability.



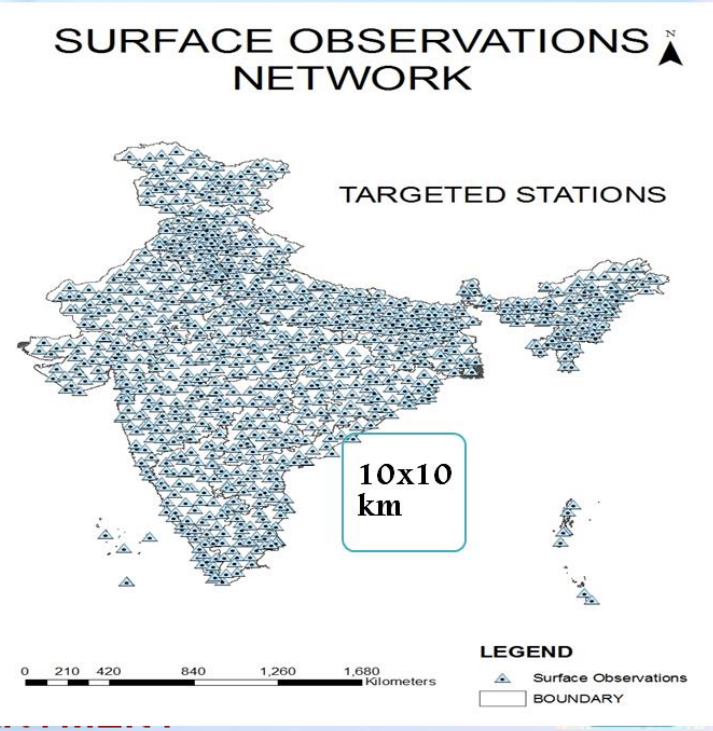


* Stations Working



Digital Station Barometers – 200 Nos. installed at field stations, same to be operationalized by December 2018 after calibration.

Surface Observational Network by 2024



Advances in Modeling and Prediction

Improvement in high power computing.

Current capacity is 10.8 PF

Models in 2018 :

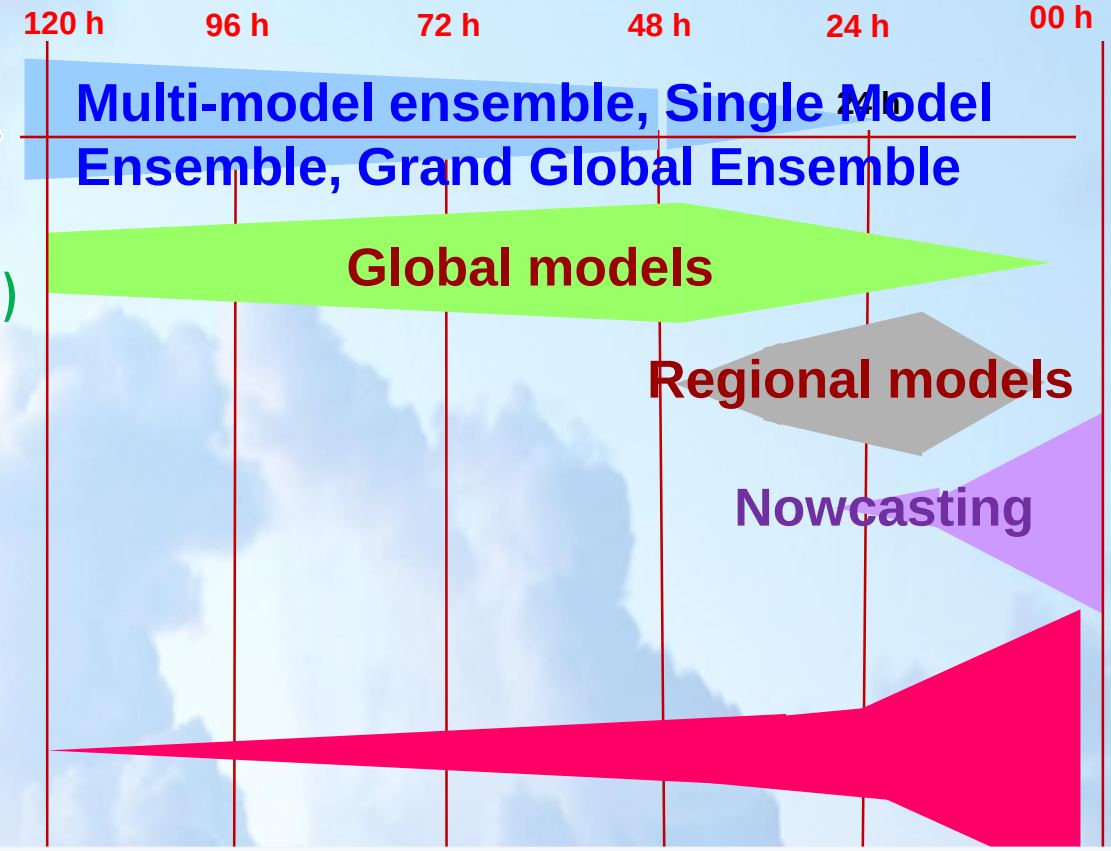
Ensemble Pred. Tools
GEFS(12 km), UMEPS(12 km)

Global Models
GFS(12km), Unified Model(12 km)

Regional Models
WRF(3 km), HWRF(2km)

Nowcasting Tools
(SWIRL, ARPS Model)

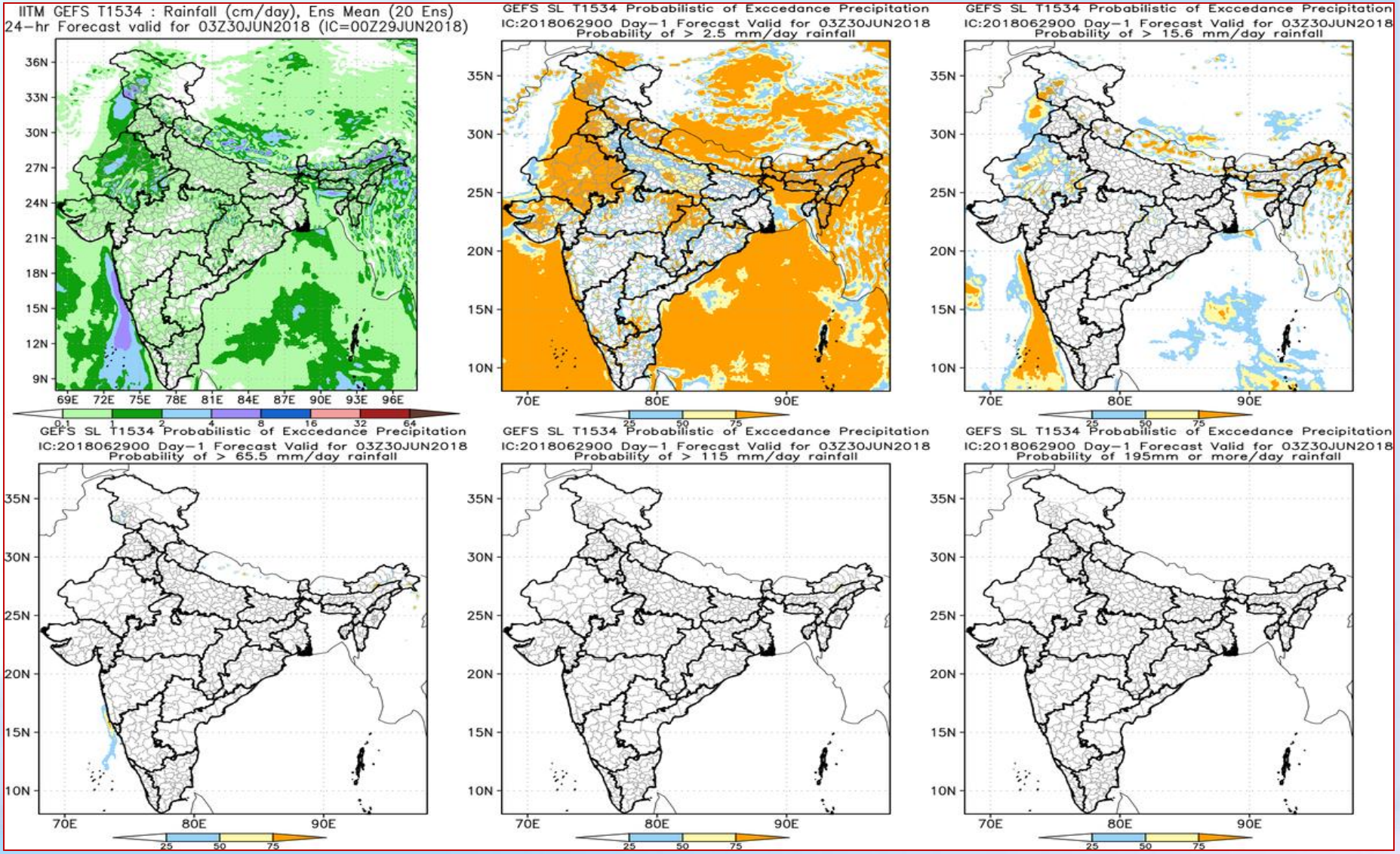
Warnings Activities



By 2019 : 1-3 km Regional multi-model prediction system, ocean-atmosphere coupled severe weather pred. systems, Parametric models and Expert systems – severe weather

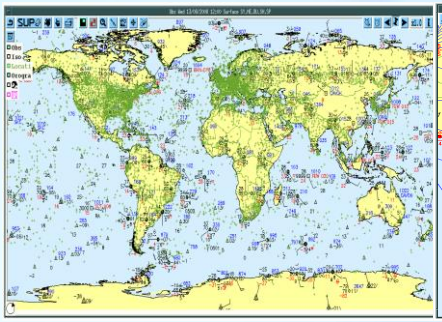
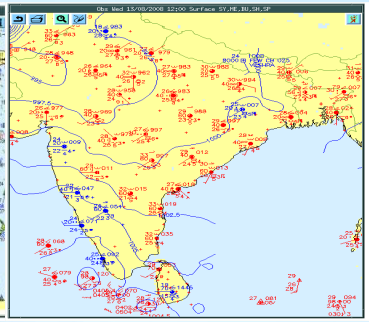
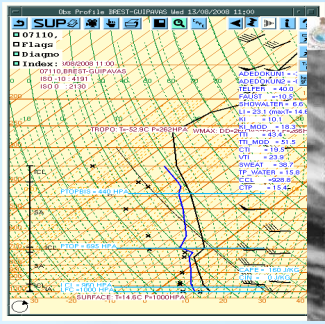
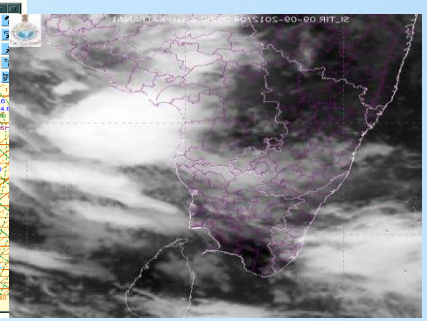
Warning up to 5-7 days, Forecast outlook up to 10-15 days

GEFS Forecast of rainfall probability at different threshold.



Geospatial Application in decision making

Satellite

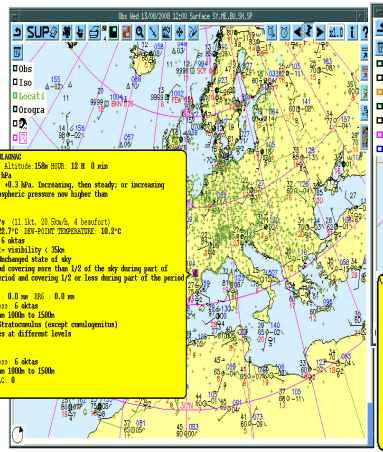
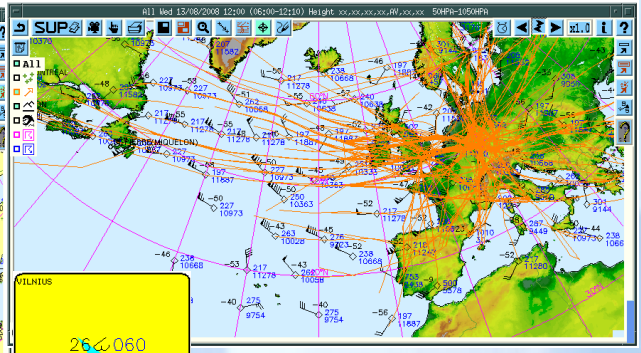
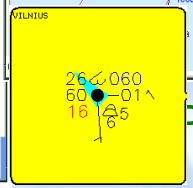





Global plotting

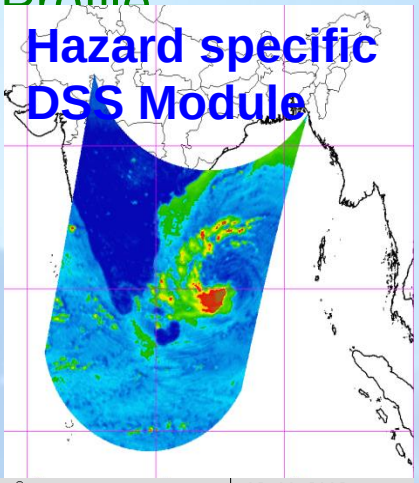
Conditional plotting

Profile

But available at limited places

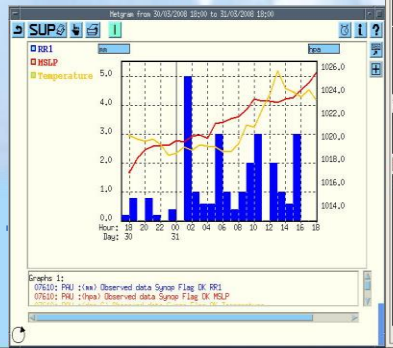
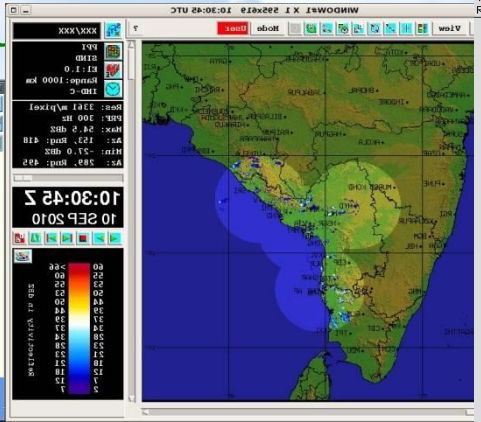
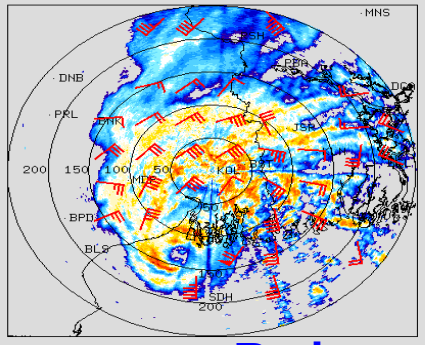
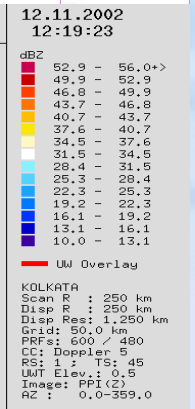




Plane trajectories



Hazard specific DSS Module

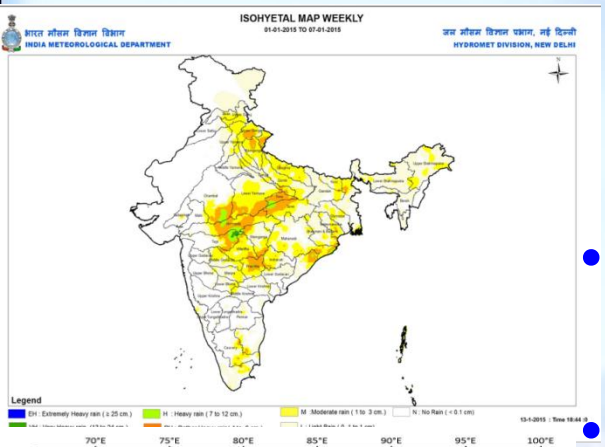
Gau

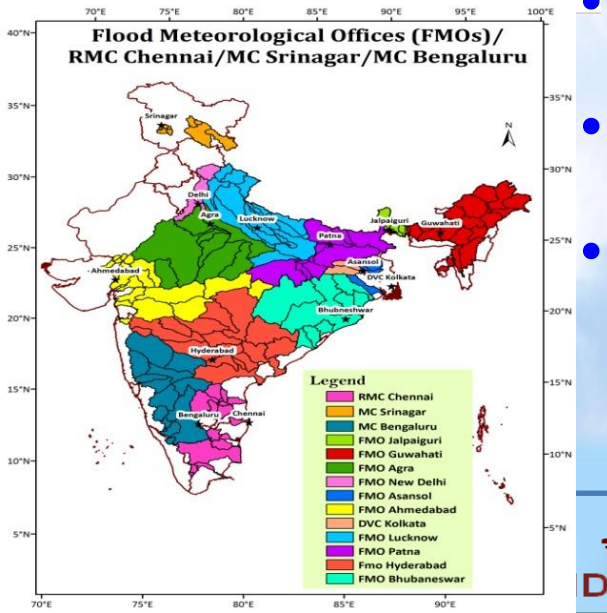
Radar


HYDROLOGICAL SERVICES FOR FLOOD MONITORING AND FORECASTING

- **Preparation of Rainfall Statistics; daily, weekly& monthly. Commended by the President of India.**
- **Provides real-time rainfall information by means of GIS based rainfall products.**



The district-wise and river basin-wise rainfall statistics is helpful to farmers for their agricultural activities and flood forecast/ water management.

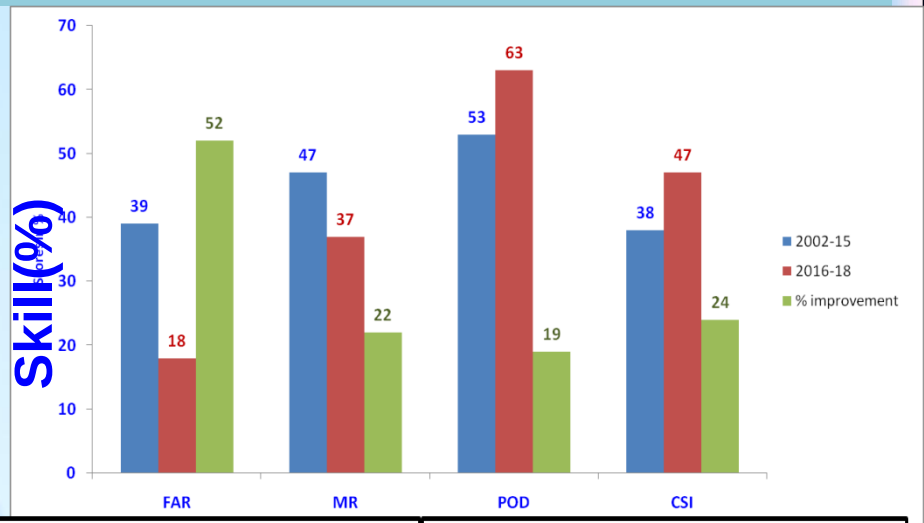


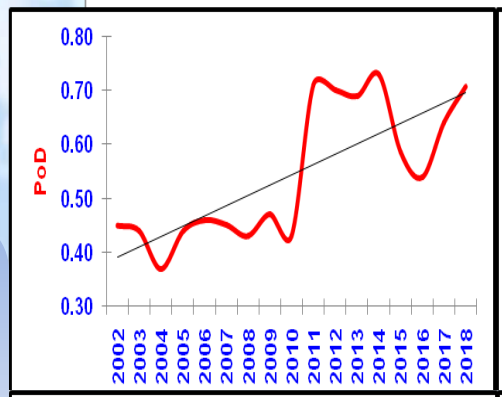
- Quantitative precipitation forecast (QPF) to CWC for flood forecast purposes increased from 125 to 146 river sub-basins.
- QPF increased from 5 day to 7 days from flood season 2015.
- Sub catchment wise QPF from NWP models- GFS for 7days in addition to WRF, MME for 3 days
- QPF for 4 new catchments Jhelum, Pennar, Torsa, Sankosh which involves 12 sub catchments.

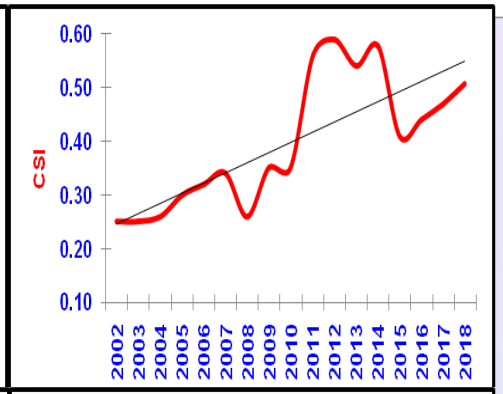
Heavy RainfallWarnings skills

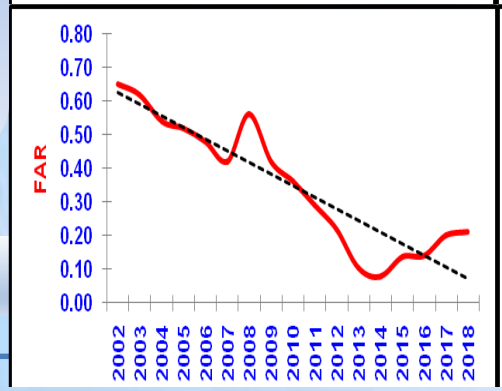
- Noticeable improvement achieved in skill of Heavy Rainfall Forecast

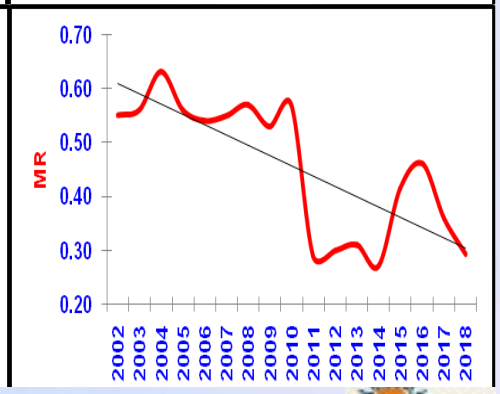
WARNING
WARNING (TAKE ACTION)
ALERT (BE PREPARED)
WATCH (BE UPDATED)
NO WARNING (NO ACTION)







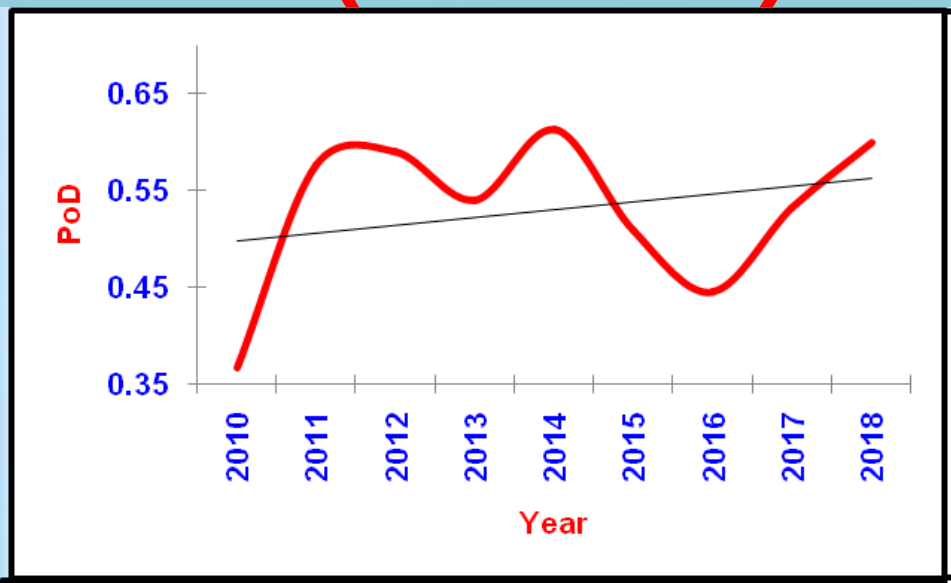


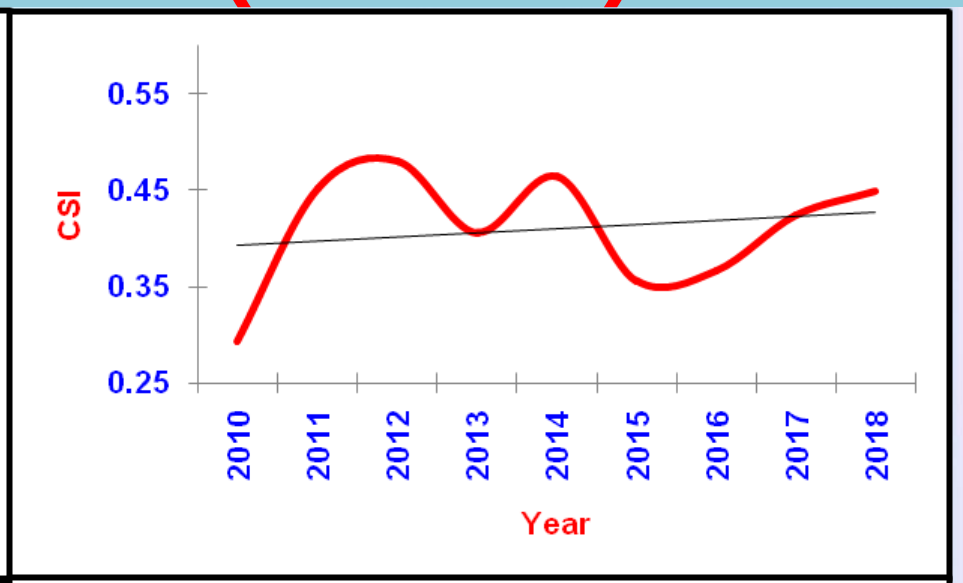


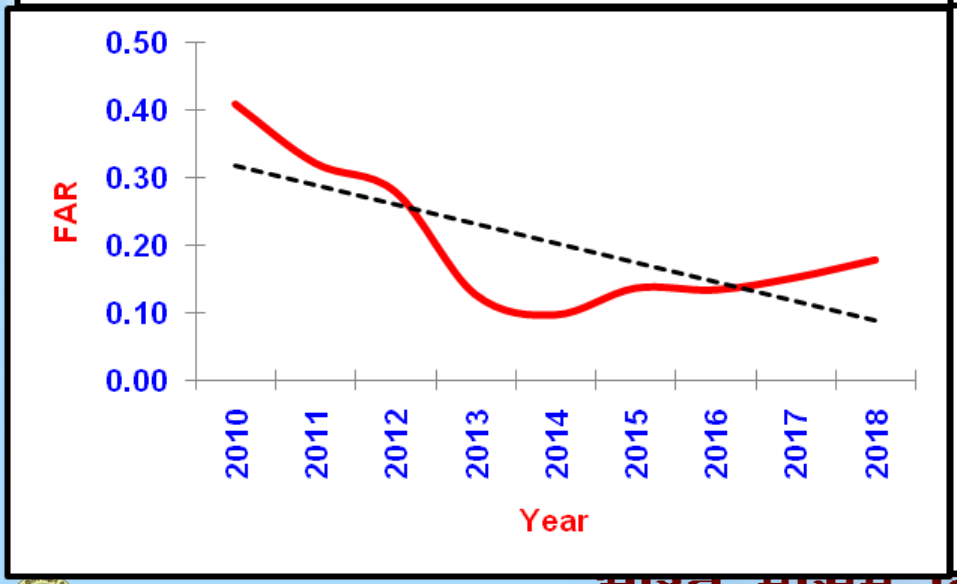
- Lead period of severe weather warning increased from 3 days to five days

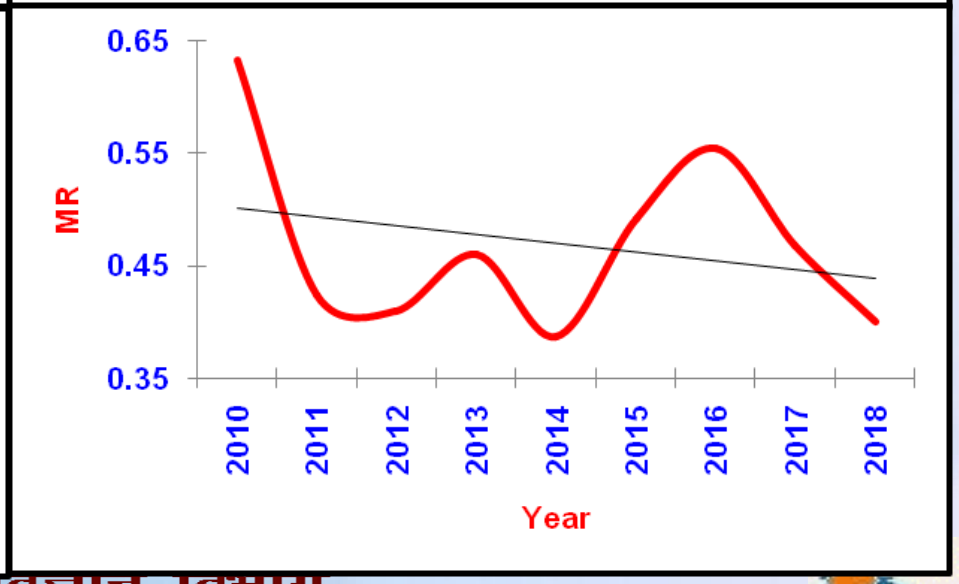
Target for 2020 : Improvement of accuracy and skill by 20% up to 7 days

Southwest Monsoon heavy rainfall (48 hours) scores (2010-18)

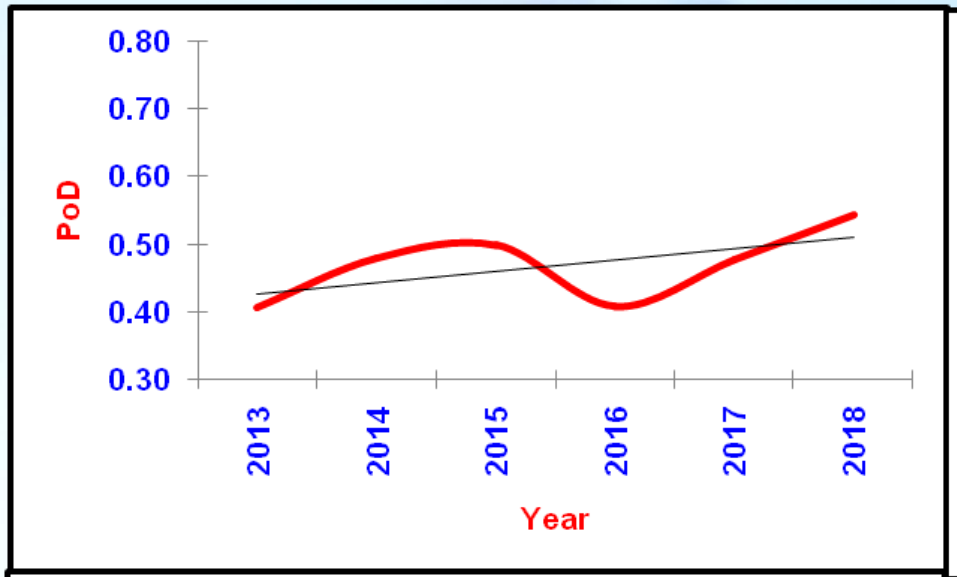


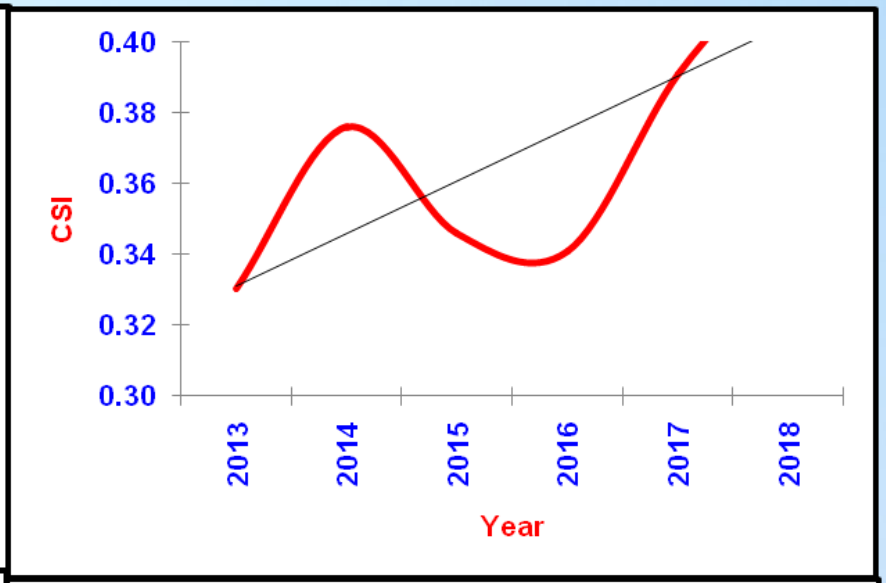


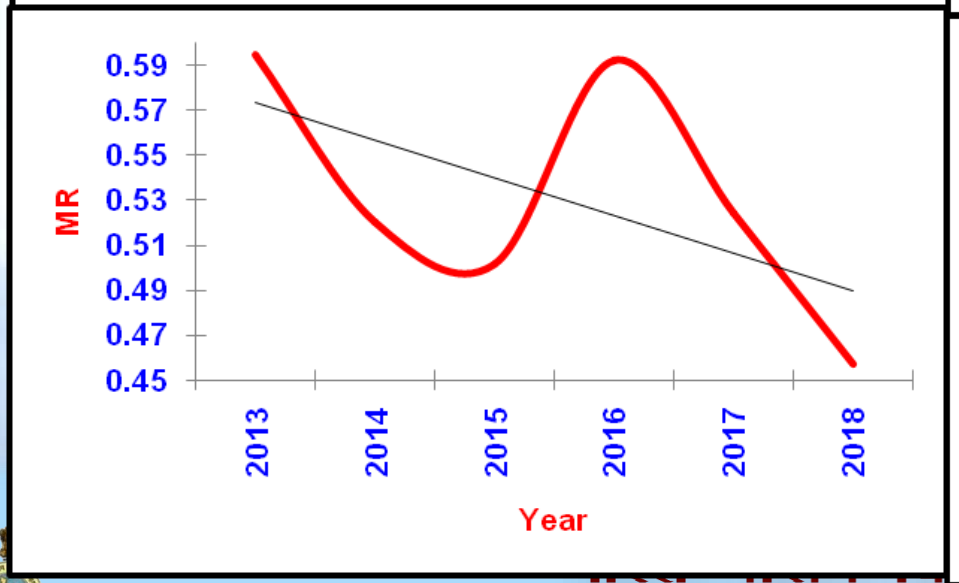


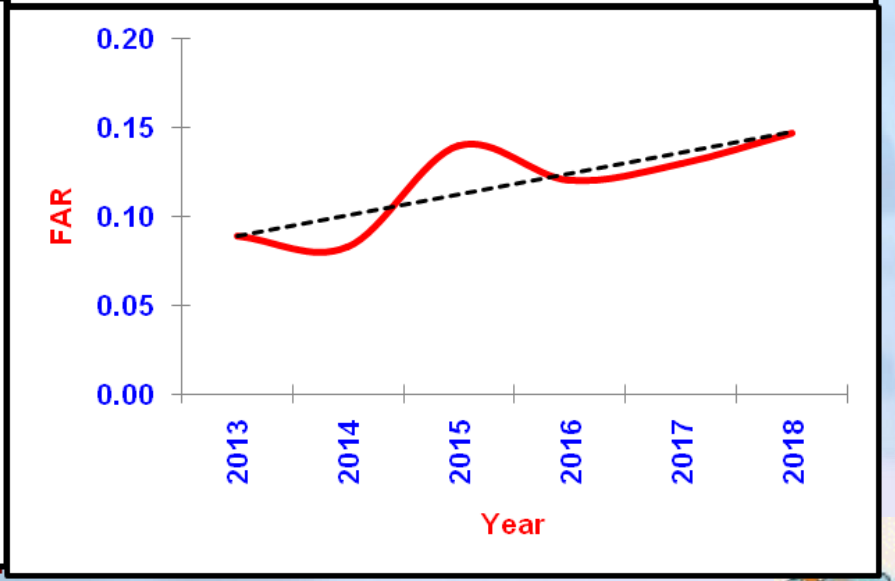


Southwest Monsoon heavy rainfall (72 hours) scores (2013-18)

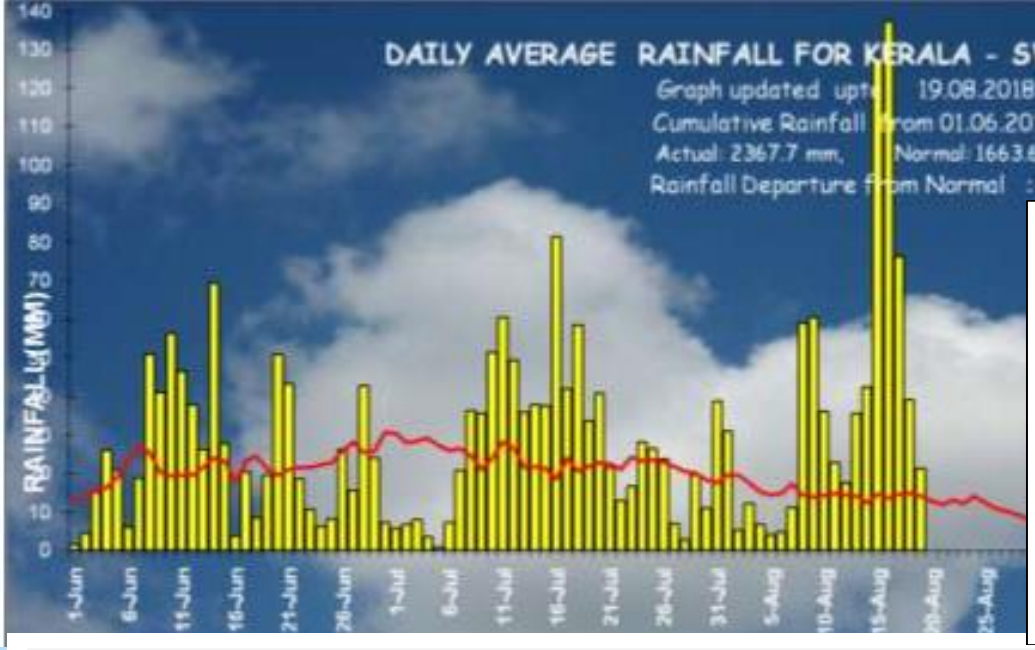


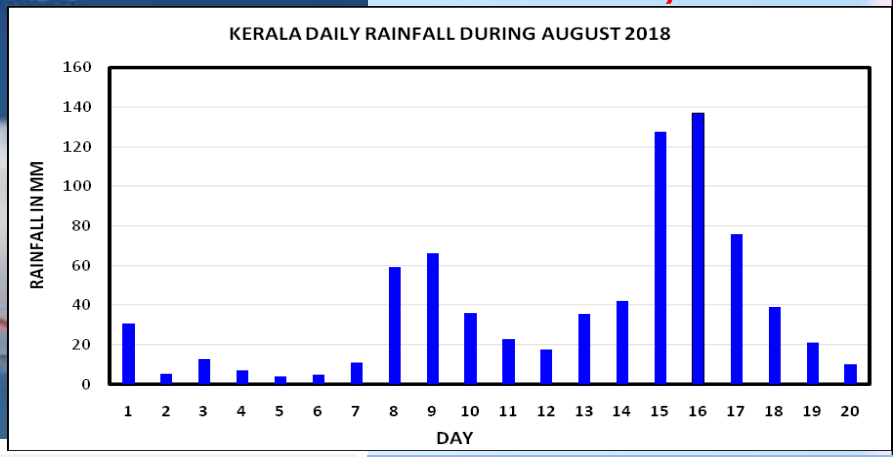


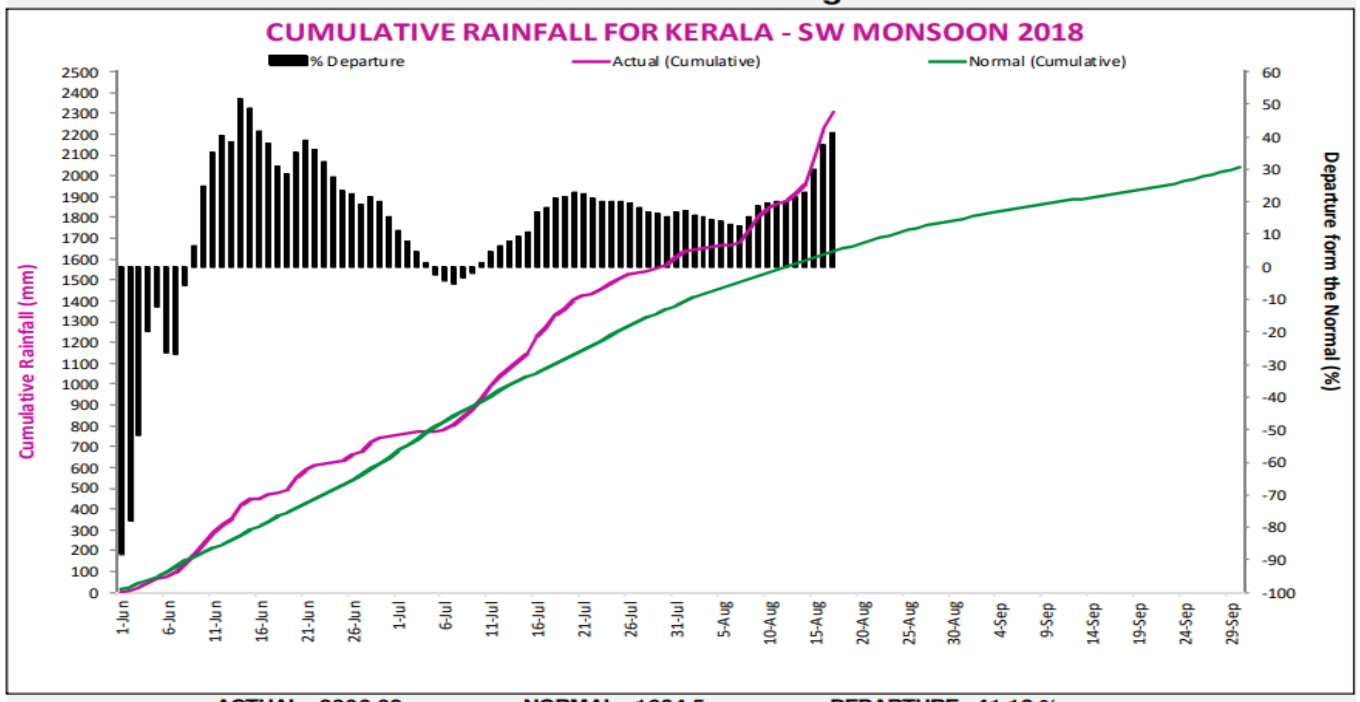




RAINFALL OVER KERALA DURING MONSOON, 2018

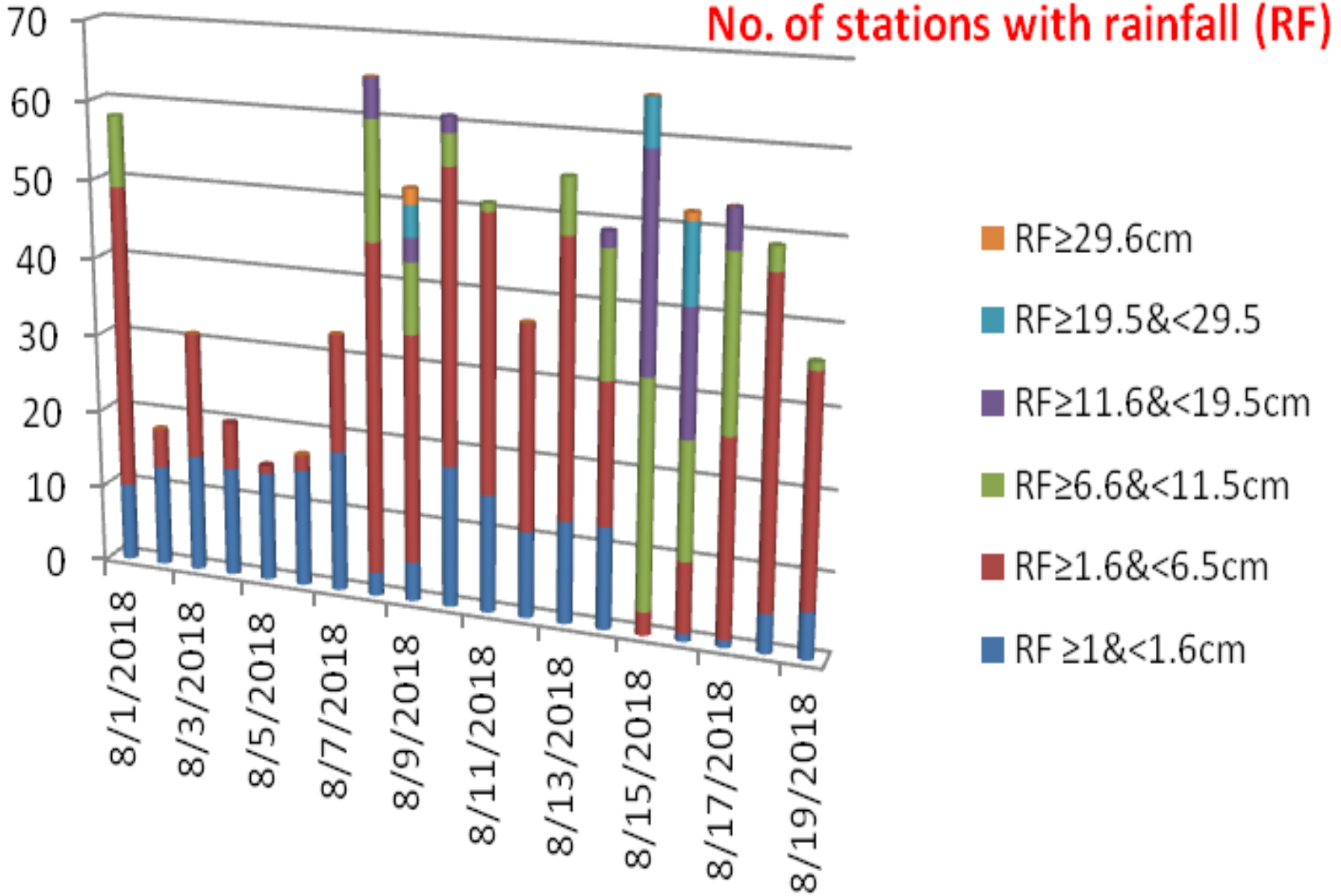






- Rainfall mostly above normal throughout season.
- Two consecutive active spells around 14 & 20 June and another around 20 July.
- Fresh spell of active rainfall 8-10 and 14-17 August

No. of stations with rainfall (RF)



RECORD BREAKING RAINFALL

- During August some stations crossed their previous highest 1- Day, 2 – Day, 3- Day point rainfall.
- Peer made rain gauge station of Idukki district:
- 1-Day rainfall 349.0mm on 16th Aug, 2018.

  Previous highest : 313.7mm on 15/7/1924
- 2-Day rainfall 623.0mm on 15-16 Aug, 2018.

  Previous highest :590.0mm on 22-23/6/2007

- Idduki rain gauge station of Idukki district:
- 1-Day rainfall 295.0mm on 16th Aug, 2018.

  Previous highest : 223.0mm on 5/8/2013
- 2-Day rainfall 530.0mm on 15-16 Aug, 2018.

  Previous highest :353.2mm on 8-9/7/2001
- 3-Day rainfall 710.2mm on 15-17 Aug 2018.

  Previous highest: 435.7mm on 7-9/7/2001

INDIA METEOROLOGICAL DEPARTMENT

MC THIRUVANANTHAPURAM

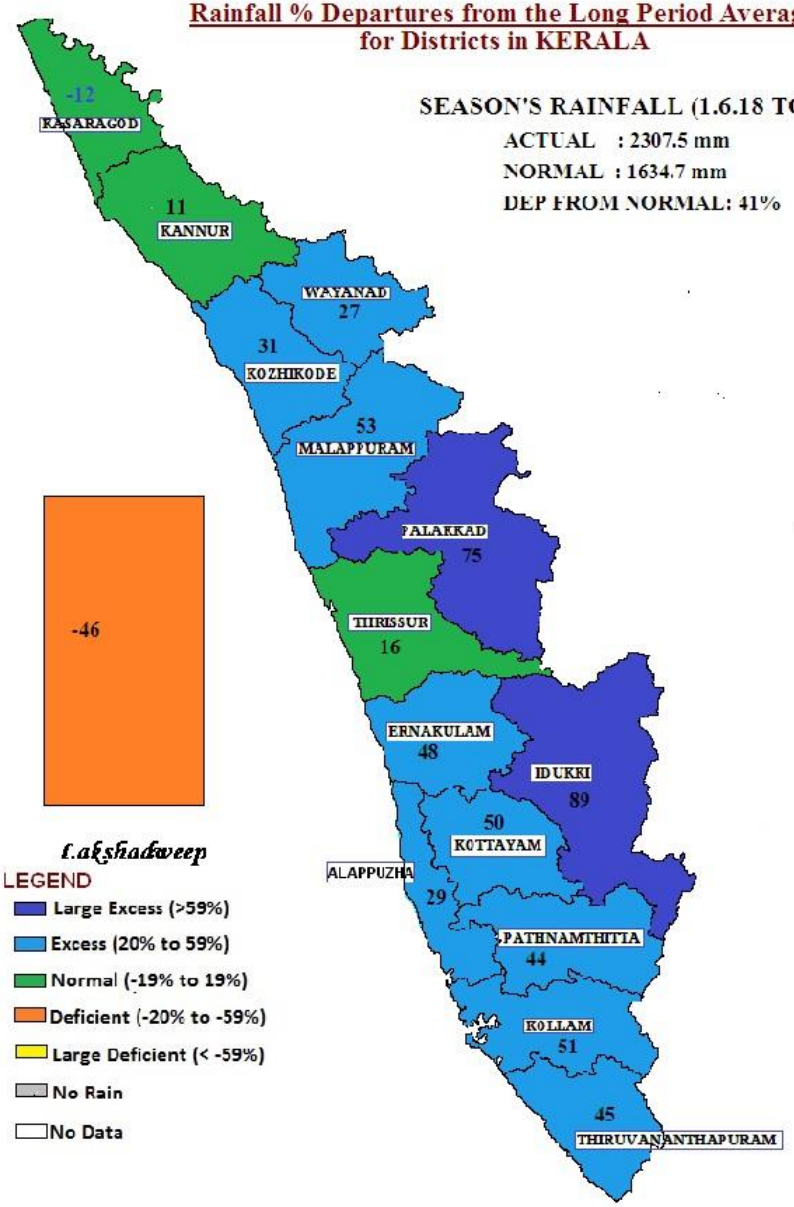
Rainfall % Departures from the Long Period Averages for Districts in KERALA

SEASON'S RAINFALL (1.6.18 TO 17.8.18)

ACTUAL : 2307.5 mm

NORMAL : 1634.7 mm

DEP FROM NORMAL: 41%



INDIA METEOROLOGICAL DEPARTMENT

MC THIRUVANANTHAPURAM

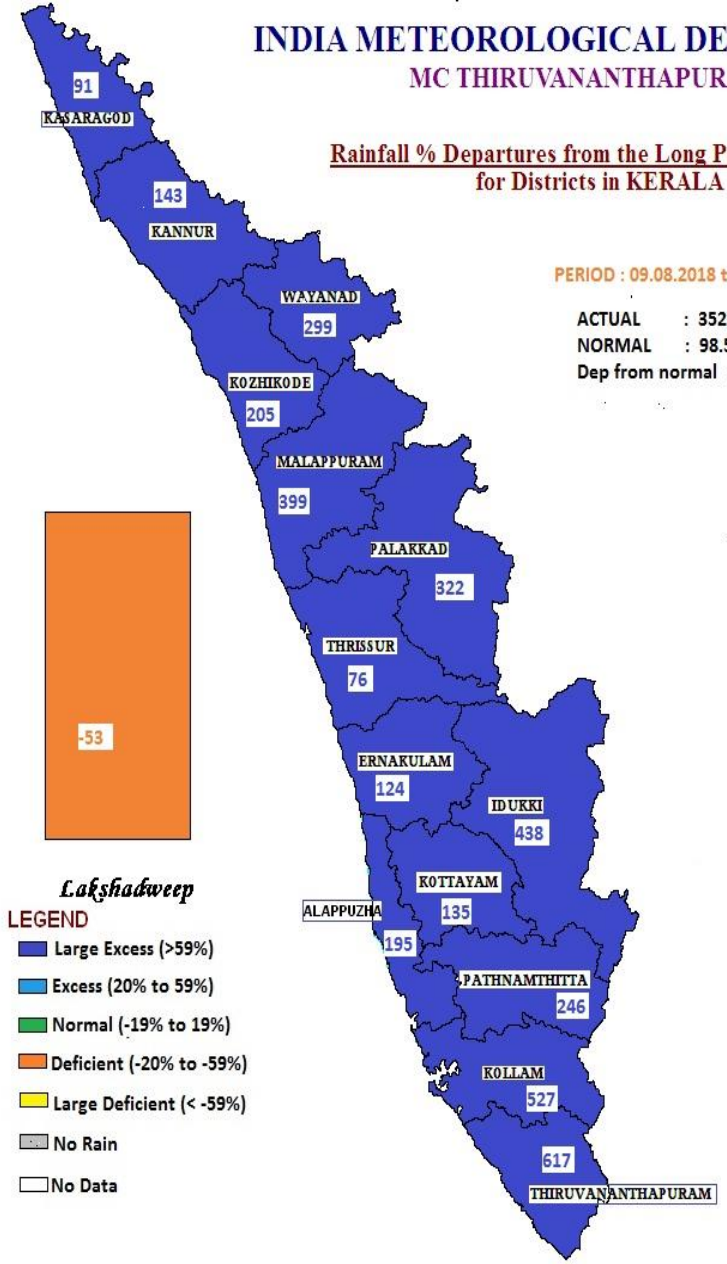
Rainfall % Departures from the Long Period Averages for Districts in KERALA

PERIOD : 09.08.2018 to 15.08.2018

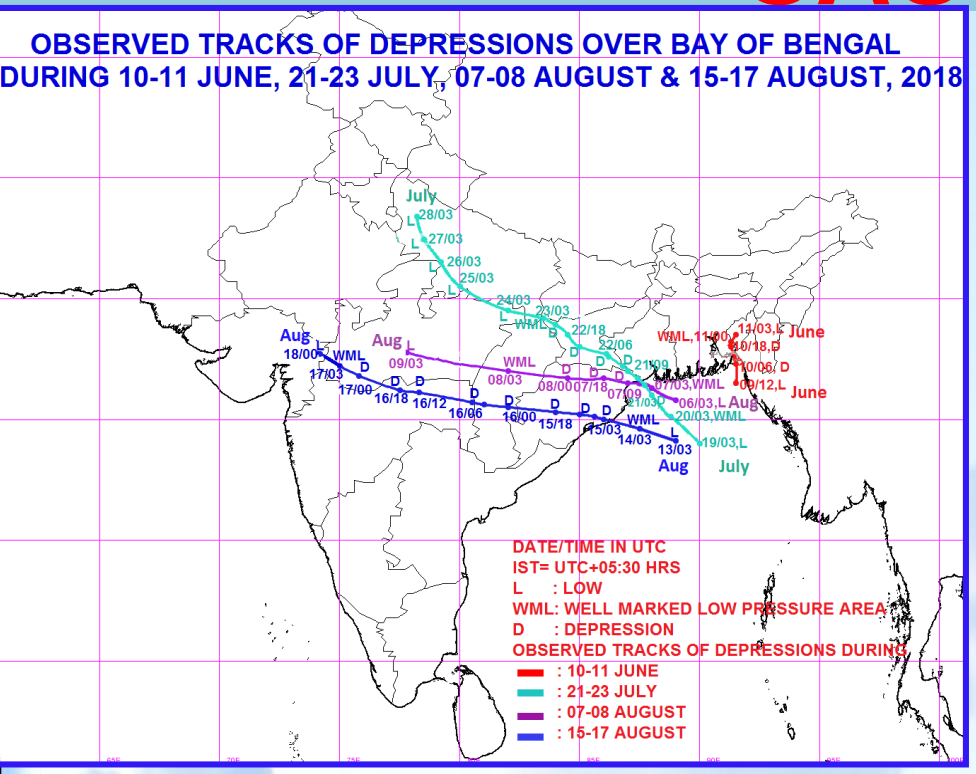
ACTUAL : 352.2 mm

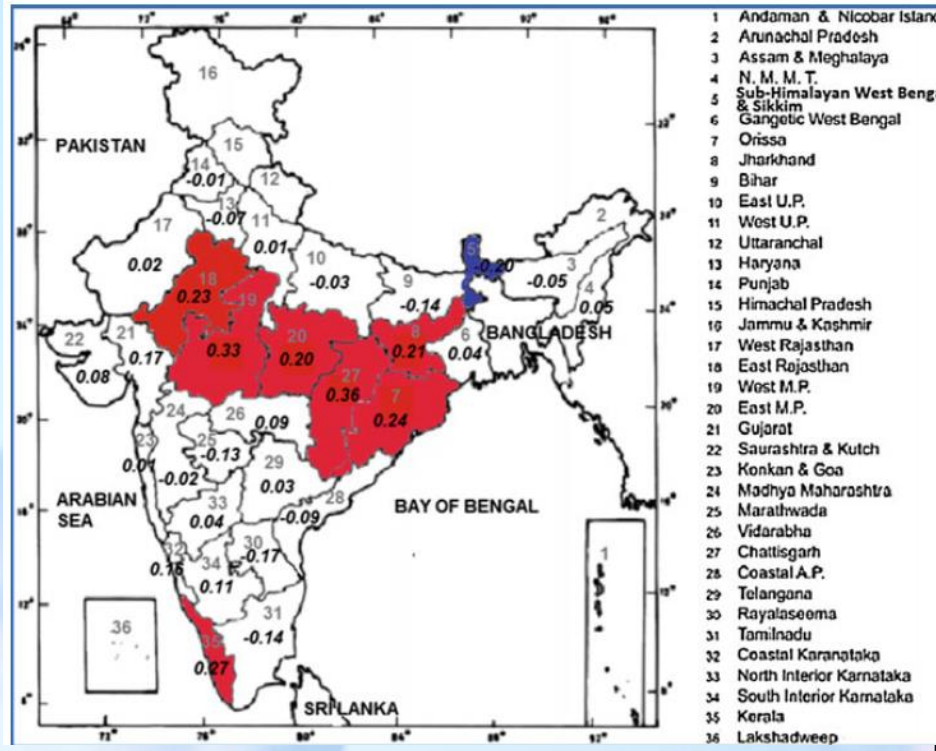
NORMAL : 98.5 mm

Dep from normal : 258%



CAUSES





- **Westnorthwestward movement of two depressions**
- **(6-9 August)**
- **(13-18 August)**

Red: significantly positive CC
Whole Nos are Meteorological subdivision
Real Nos. are CC values upto two decimal places such that CC>0.19 significant at 95% confidence level

M. Mohapatra et al, 2017, In book entitled Observed Climate varaibility & change over Indian Region Edited by M N Rajeevan & Shailesh Nayak

3 Day District-wise Forecast issued by IMD during 12-15 August for Kerala

12 August 2018	Day 1	Day 2	Day 3
Thiruvananthapuram			
Kollam			
Pathanamthitta			
Alappuzha			
Kottayam			
Idukki			
Ernakulam			
Thrissur			
Palakkad			
Malappuram			
Kozhikode			
Waynad			
Kannur			
Kasaragode			

13 August 2018	Day 1	Day 2	Day 3
Thiruvananthapuram			
Kollam			
Pathanamthitta			
Alappuzha			
Kottayam			
Idukki			
Ernakulam			
Thrissur			
Palakkad			
Malappuram			
Kozhikode			
Waynad			
Kannur			
Kasaragode			

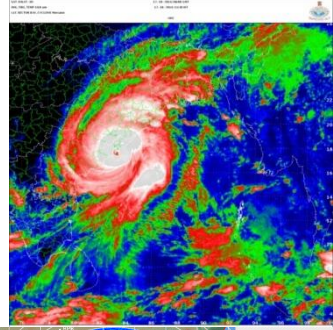
14 August 2018	Day 1	Day 2	Day 3
Thiruvananthapuram			
Kollam			
Pathanamthitta			
Alappuzha			
Kottayam			
Idukki			
Ernakulam			
Thrissur			
Palakkad			
Malappuram			
Kozhikode			
Waynad			
Kannur			
Kasaragode			

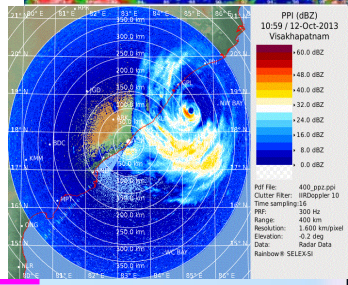
15 August 2018	Day 1	Day 2	Day 3
Thiruvananthapuram			
Kollam			
Pathanamthitta			
Alappuzha			
Kottayam			
Idukki			
Ernakulam			
Thrissur			
Palakkad			
Malappuram			
Kozhikode			
Waynad			
Kannur			
Kasaragode			

Monitoring and Forecast Process of Cyclones

Broad Classification of Observations

- **Space Based**
  - Geoststionary Satellites
  - Polar Orbiting Satellites
- **Upper Air**
  - Pilot Balloon
  - RSRW
  - Profiler
  - Ground Based RADAR
  - Aircraft
- **Surface**
  - AWS
  - ARG
  - SYNOP
  - BUOYS
  - AVIATION
  - SHIPS





Initial conditions (Observations)

Runs of different Models,

Consecutive runs from the same model,

Ensemble runs ("choosing the best member")

Model

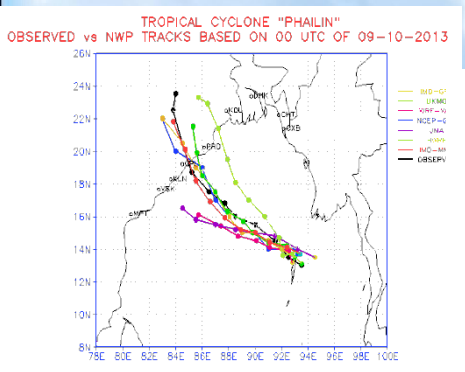
Forecaster

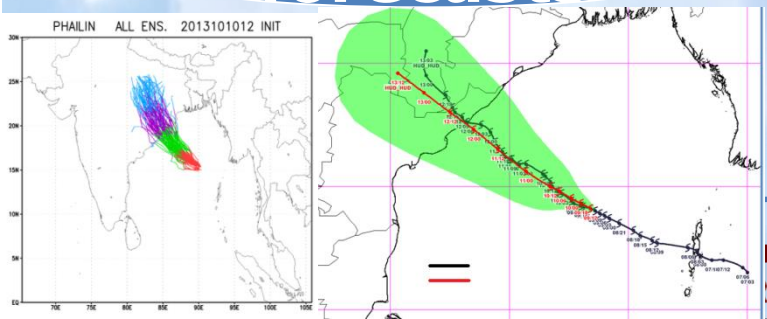
Action

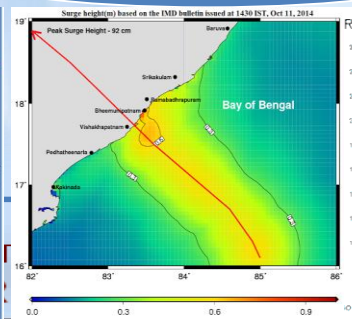
Decision maker

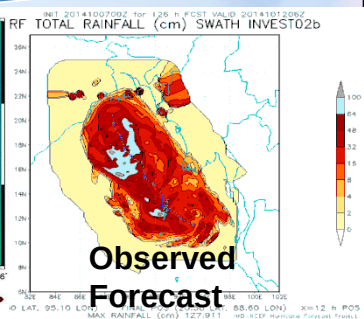
Numerical forecasts

End forecast

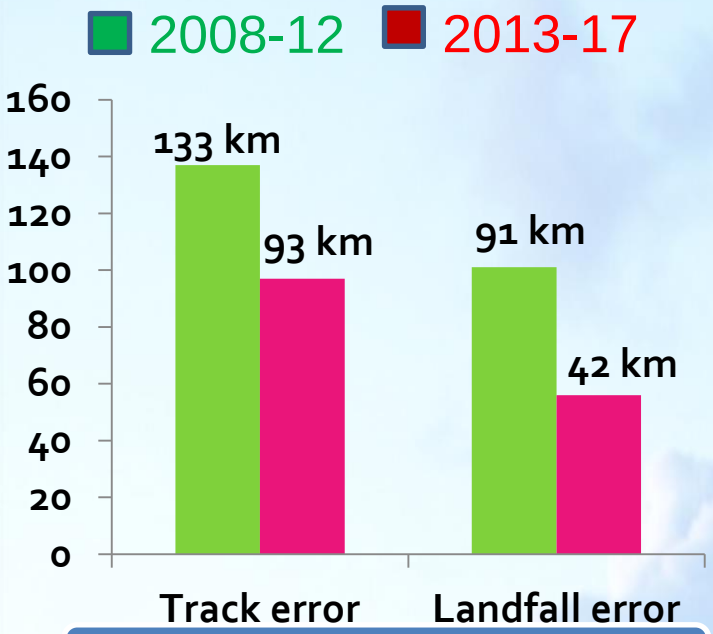




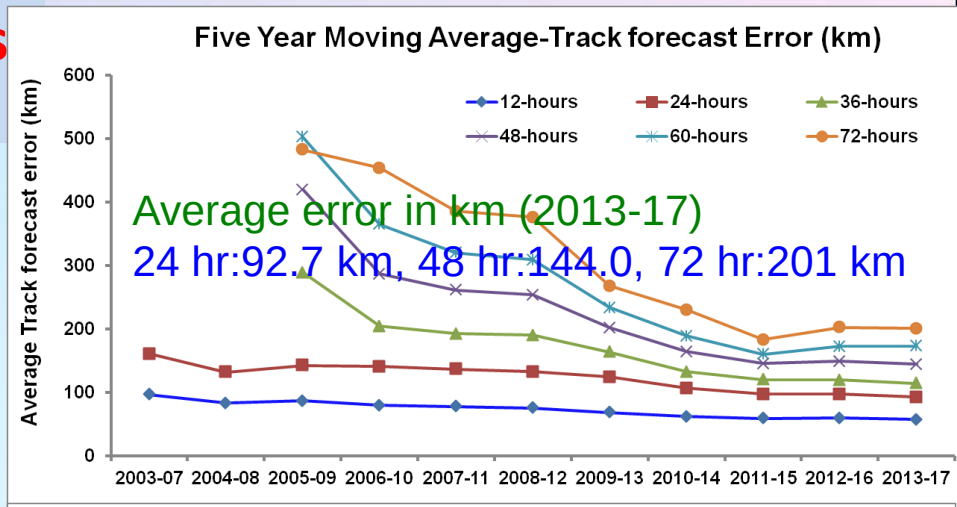


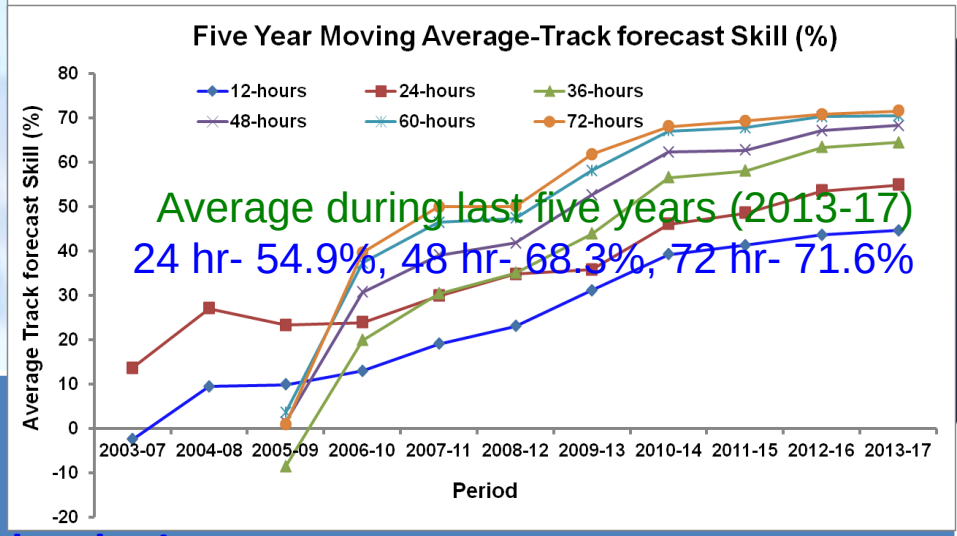


Cyclone Forecast:Accomplishments and Challenges



24 hr forecast errors





Challenges:

Genesis forecast with lead period for systems developing near coast

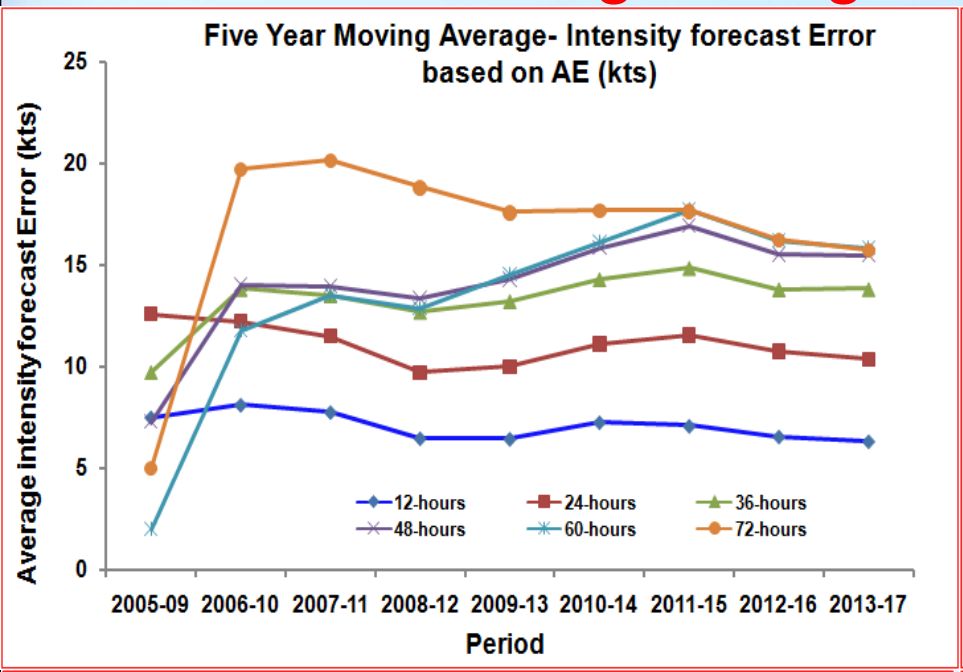
Intensity forecast, specially rapid intensification and weakening

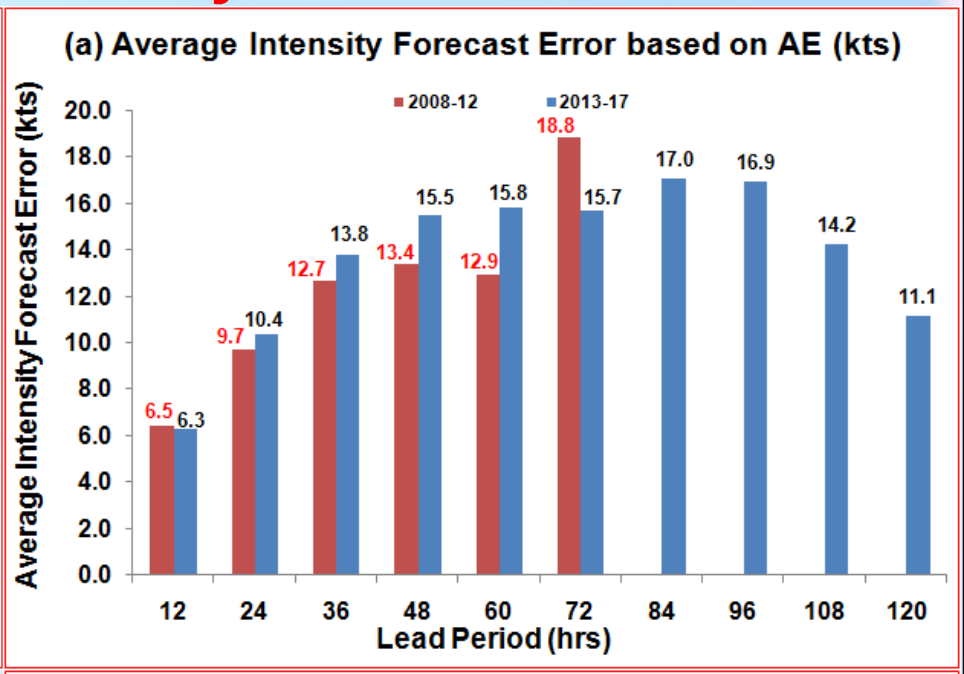
Heavy rainfall warning, Location specific and river catchment wise

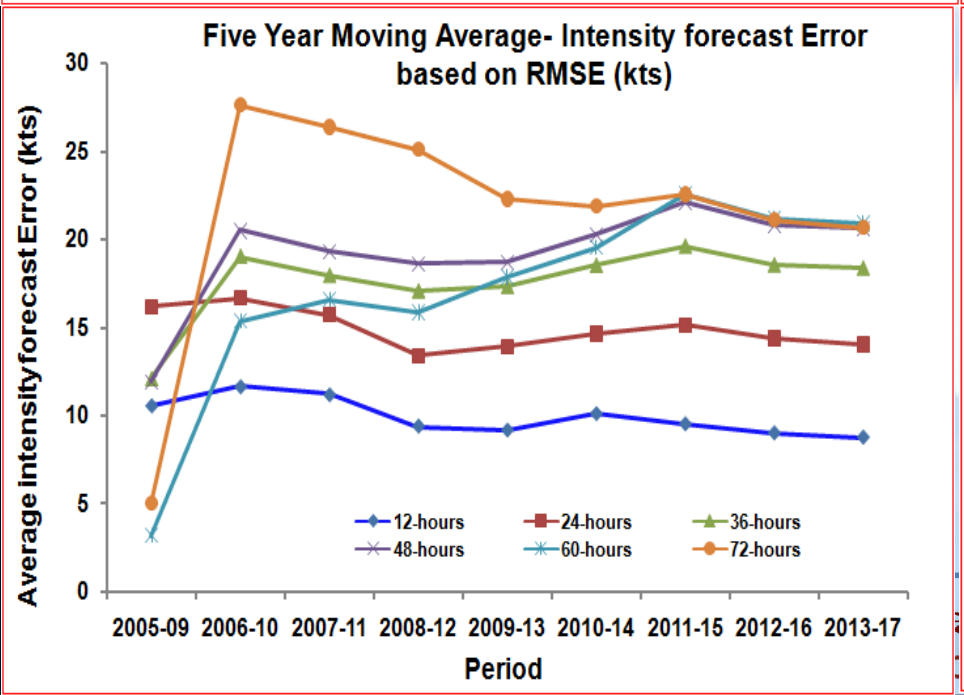
Target for 2024 : Reduction in error & Improvement of skill by 20% up to 7 days

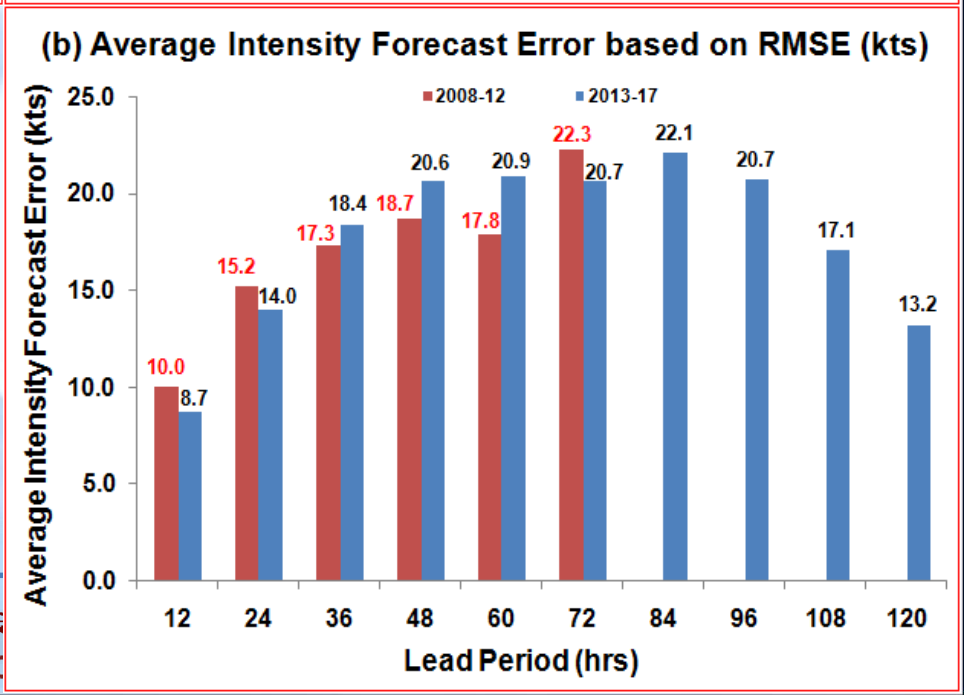
Target for 2024 : Dynamical Impact based Forecast and Warning

Five Year Moving Average- Intensity Forecast : An Issue

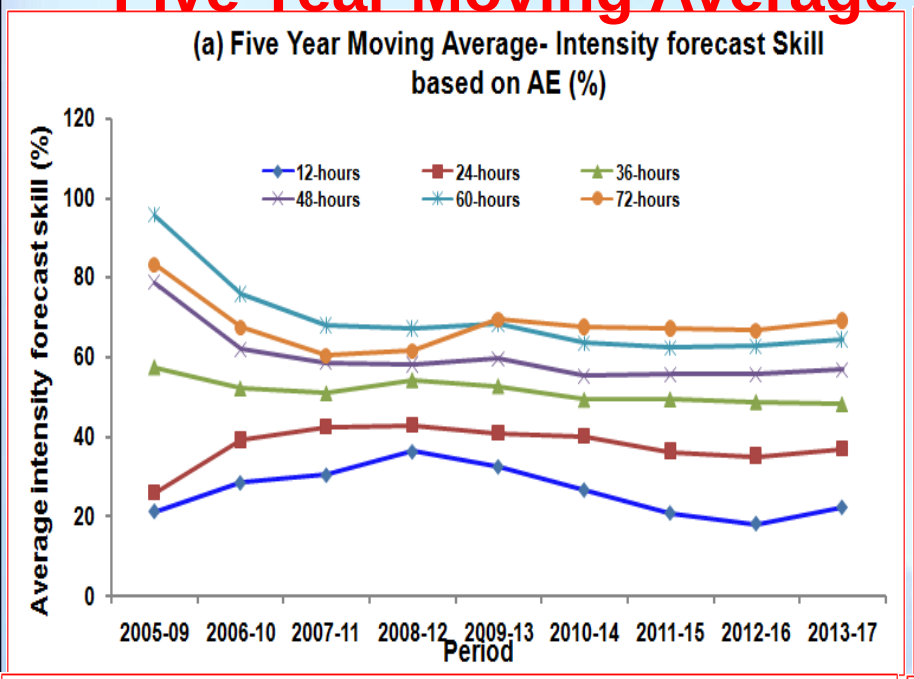


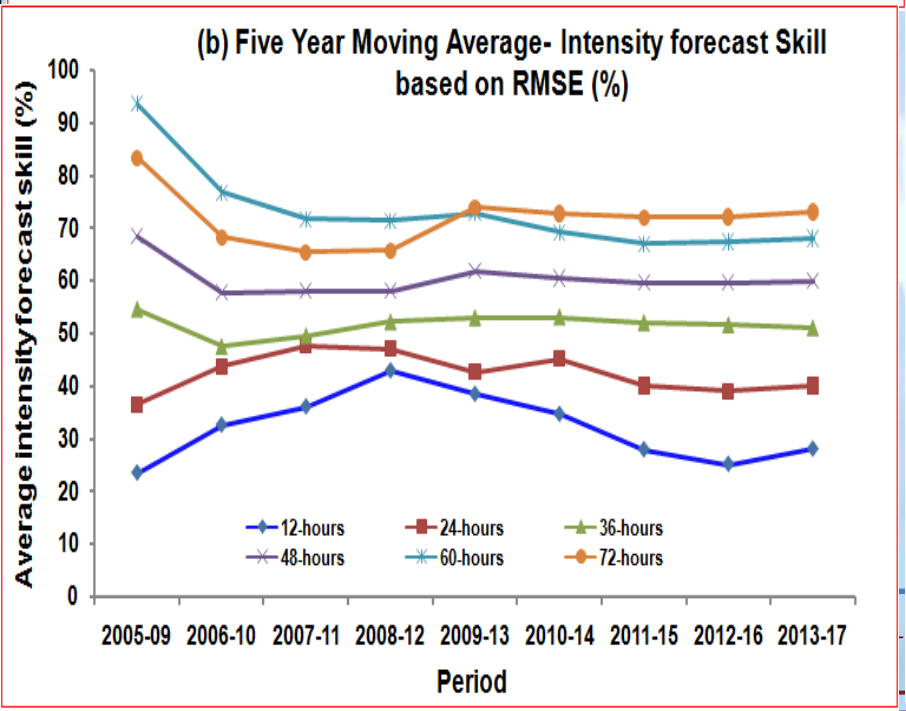


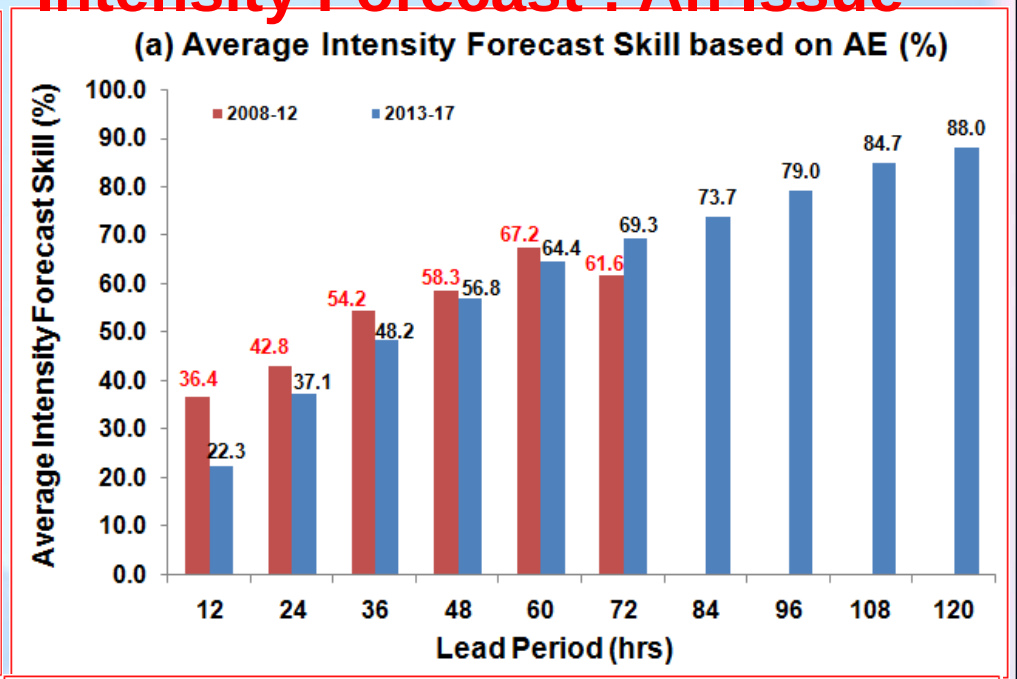


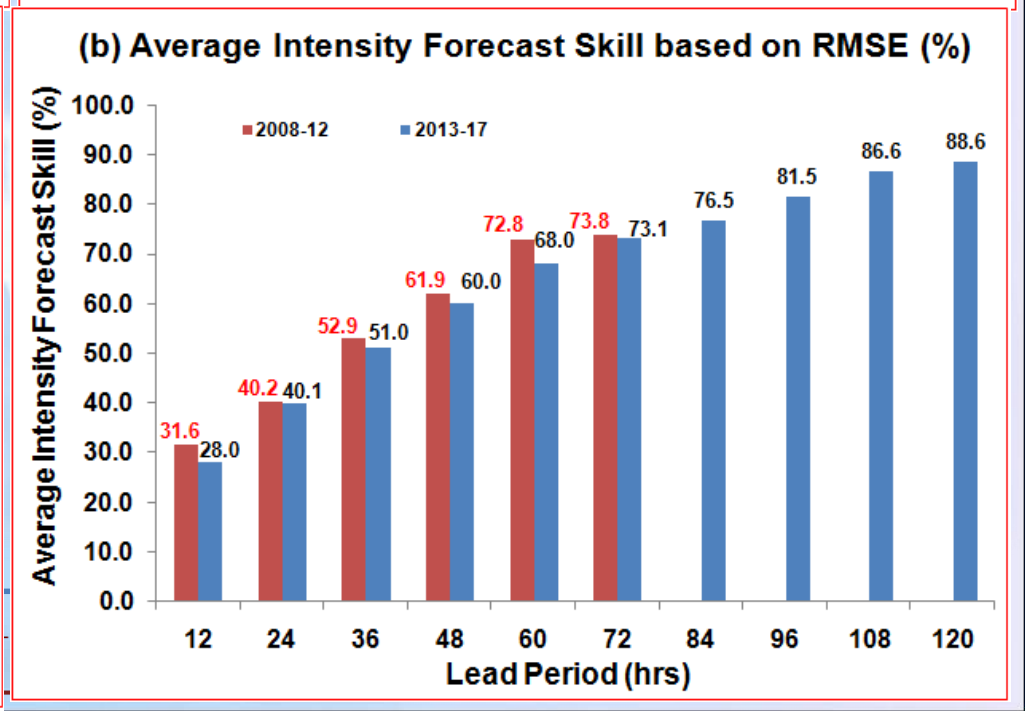


Five Year Moving Average- Intensity Forecast : An Issue



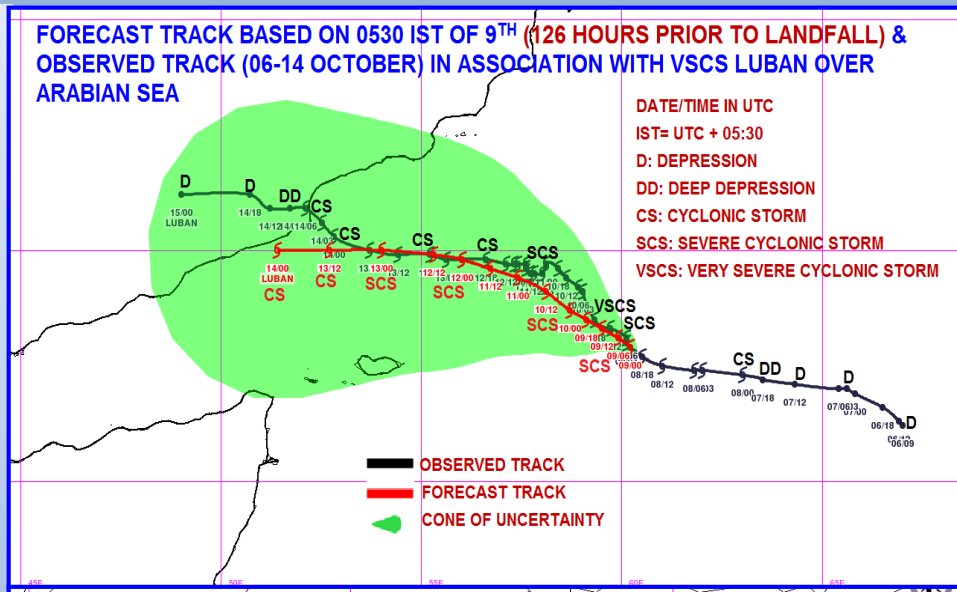


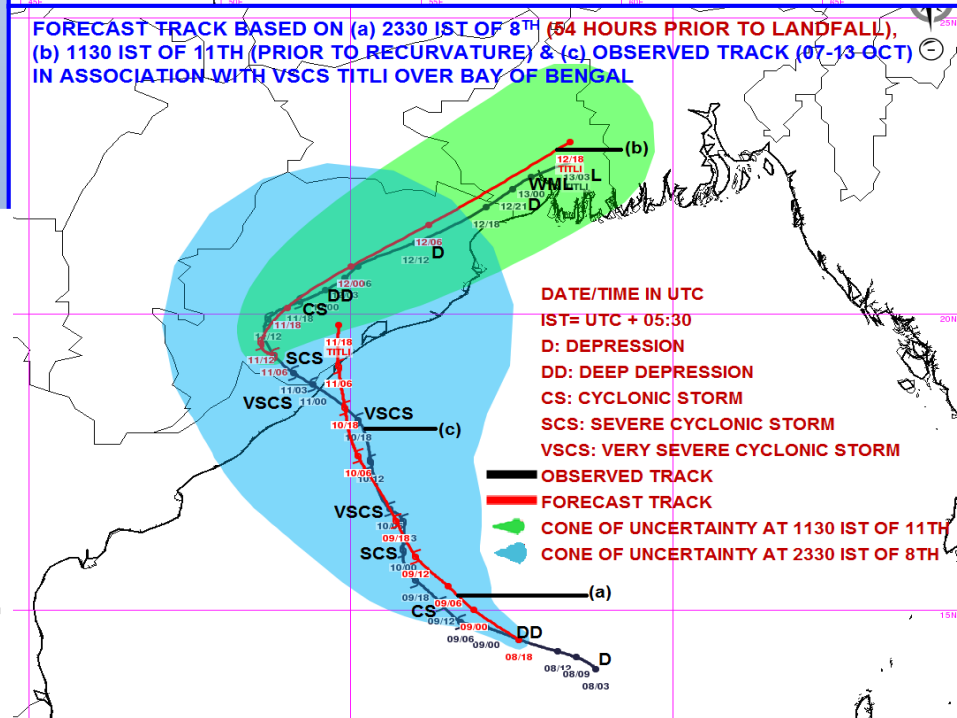


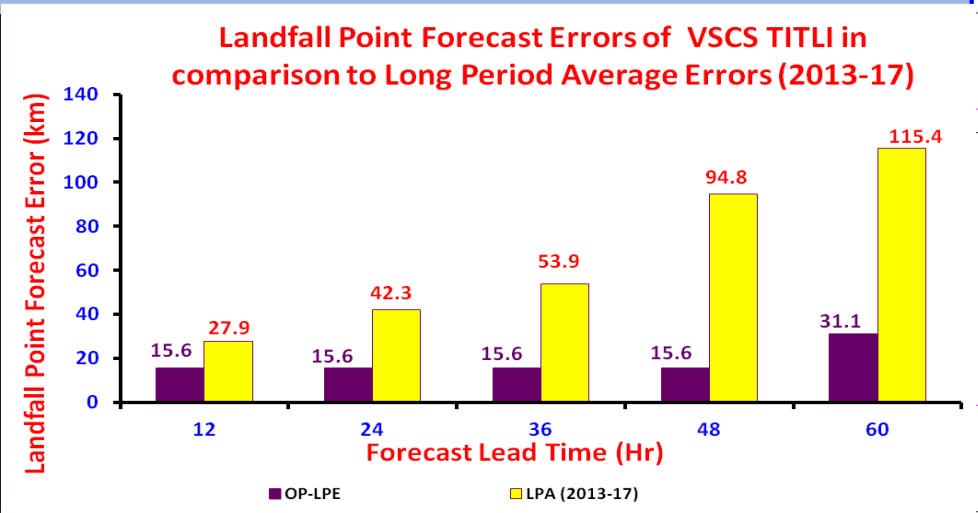


TYPICAL FORECAST AND OBSERVED TRACKS OF VSCS, TITLI AND LUBAN DEMONSTRATING ACCURATE FORECAST

- Both the cyclones had unique track characteristics with northeastward recurvature over the land in case of Titli and multiple recurvature in case of Luban.
- While there was rapid intensification in case of Titli, there was intensification and weakening of Luban over the sea.

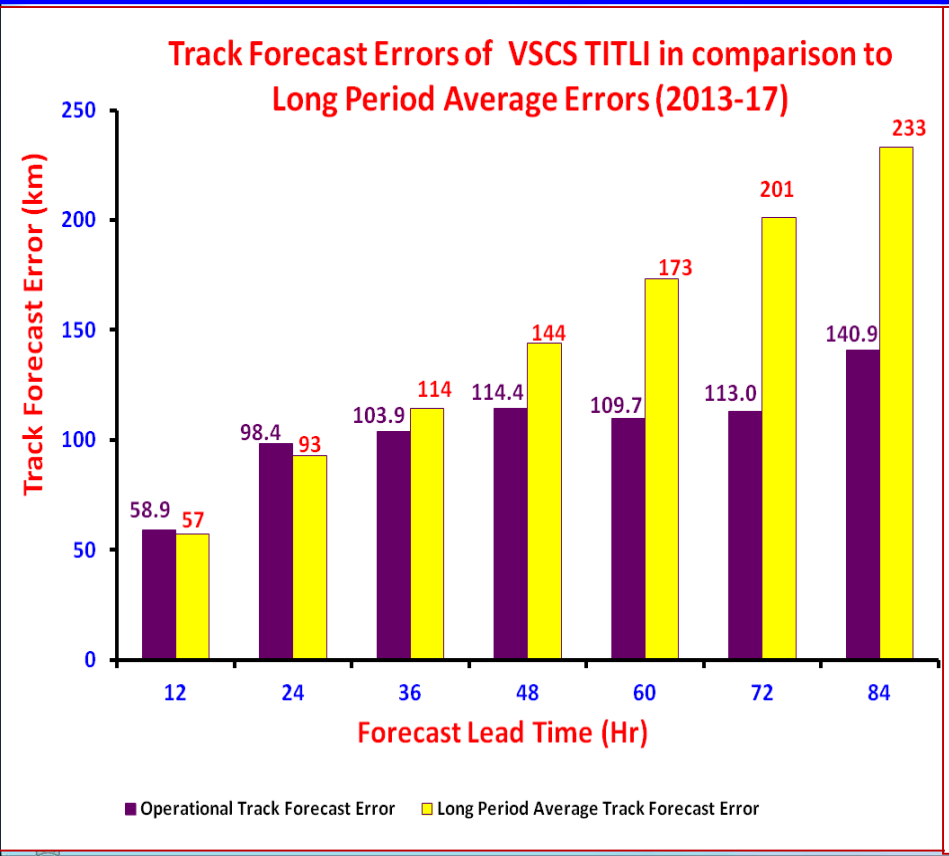


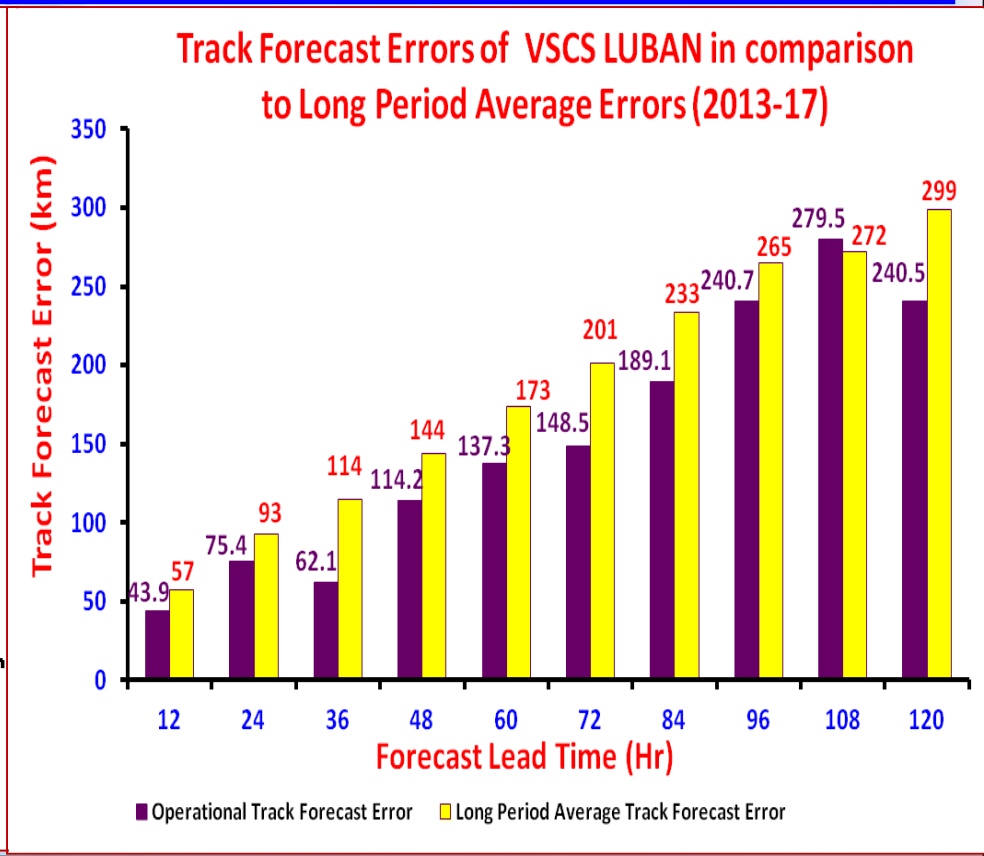




Operational Track Forecast Errors in case of VSCS Titli & Luban compared to Long Period Average of 2013-17

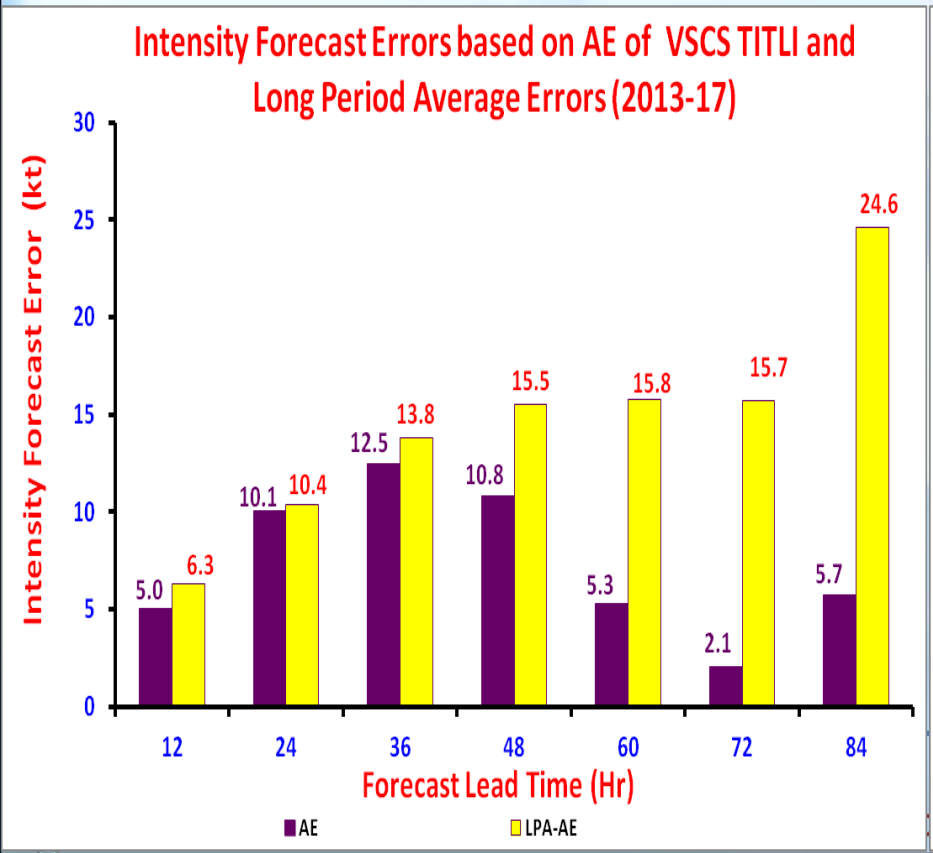
VSCS TITLI	VSCS LUBAN
24 hr-98.4 km (93 km)	24 hr-75.4 km (93 km)
48 hr-114.4 km (144 km)	48 hr-114.2 km (144 km)
72 hr-113 km (201 km)	72 hr-148.5 km (201 km)

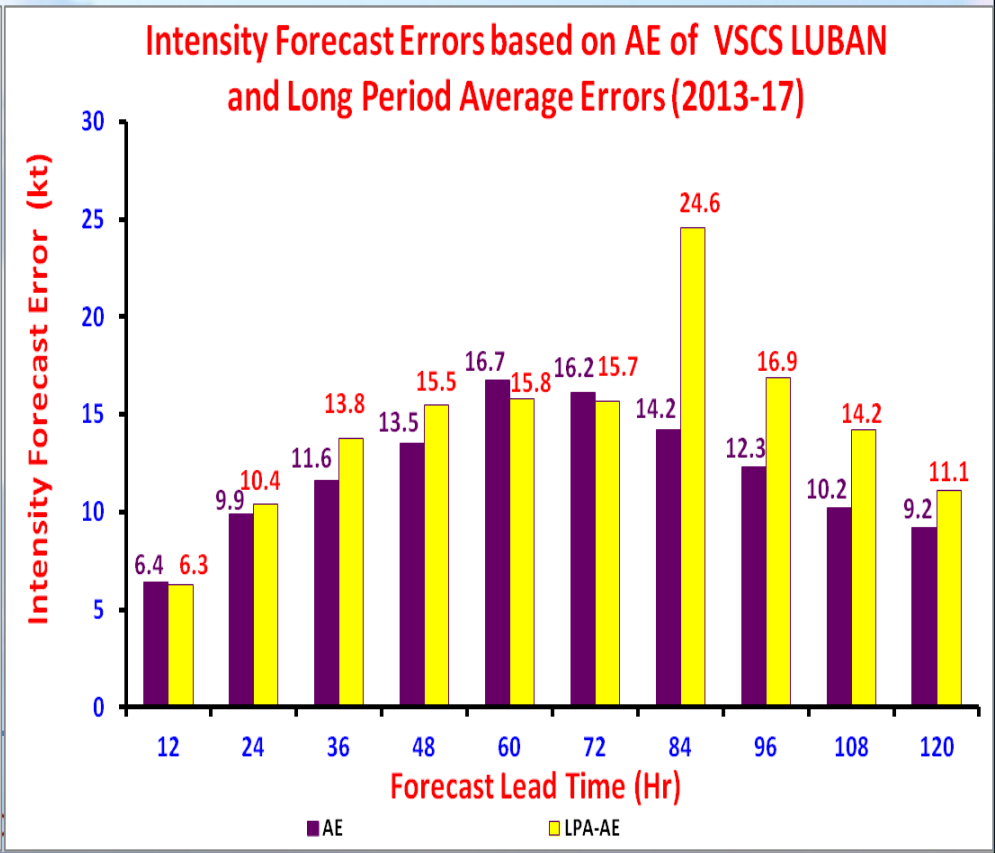




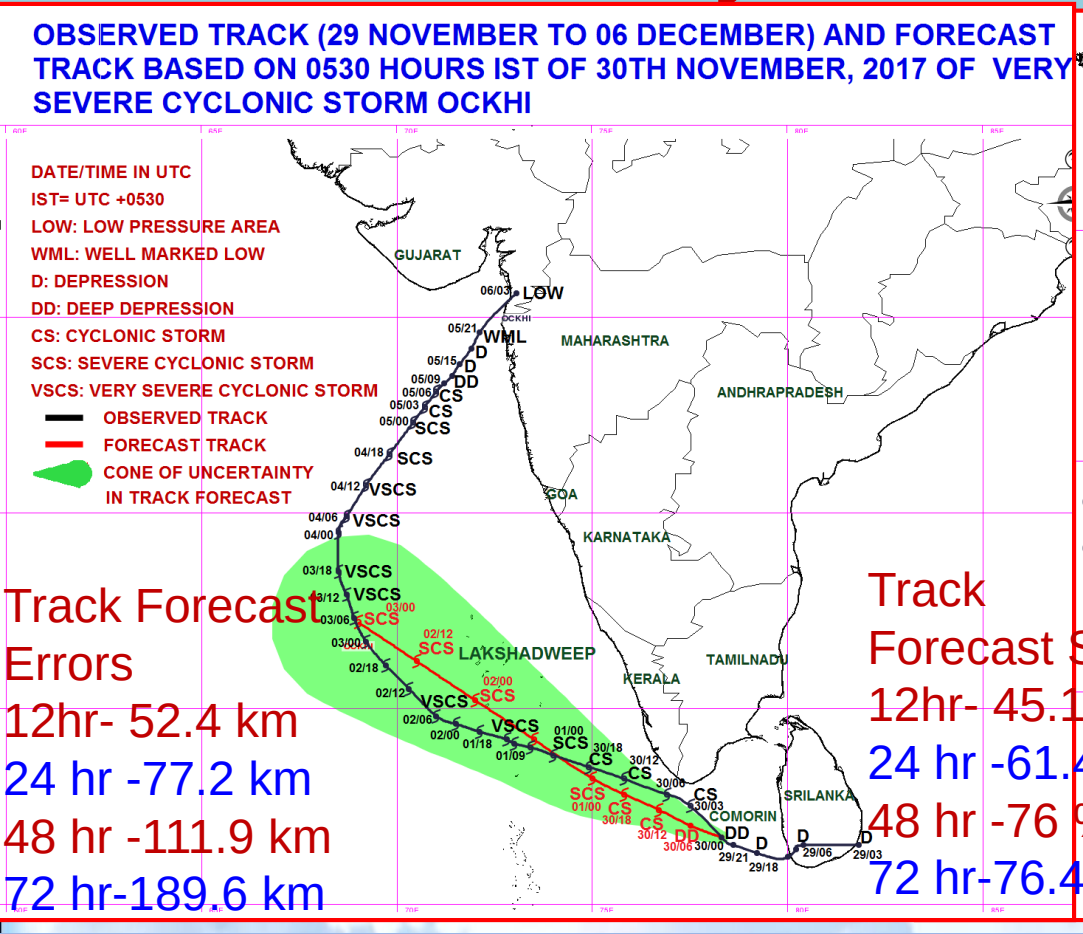
Operational Intensity Forecast Errors in case of VSCS Titli & Luban compared to Long Period Average of 2013-17

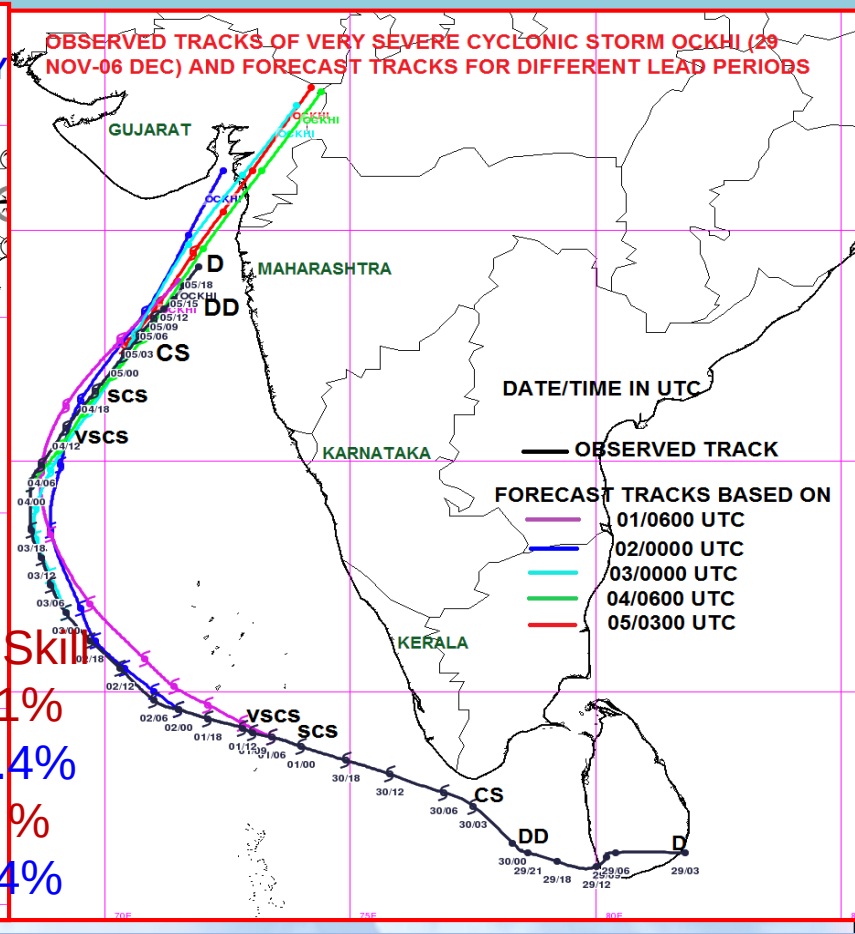
VSCS TITLI	VSCS LUBAN
24 hr-10.1 kt (10.4 kt)	24 hr-9.9 kt (10.4 kt)
48 hr-10.8 kt (15.5 kt)	48 hr-13.5 kt (15.5 kt)
72 hr- 2.1 kt (15.7 kt)	72 hr- 16.2 kt (15.7 kt)





Cyclone, Ockhi





Track Forecast Errors

12hr- 52.4 km

24 hr -77.2 km

48 hr -111.9 km

72 hr-189.6 km

Track Forecast Skill

12hr- 45.1%

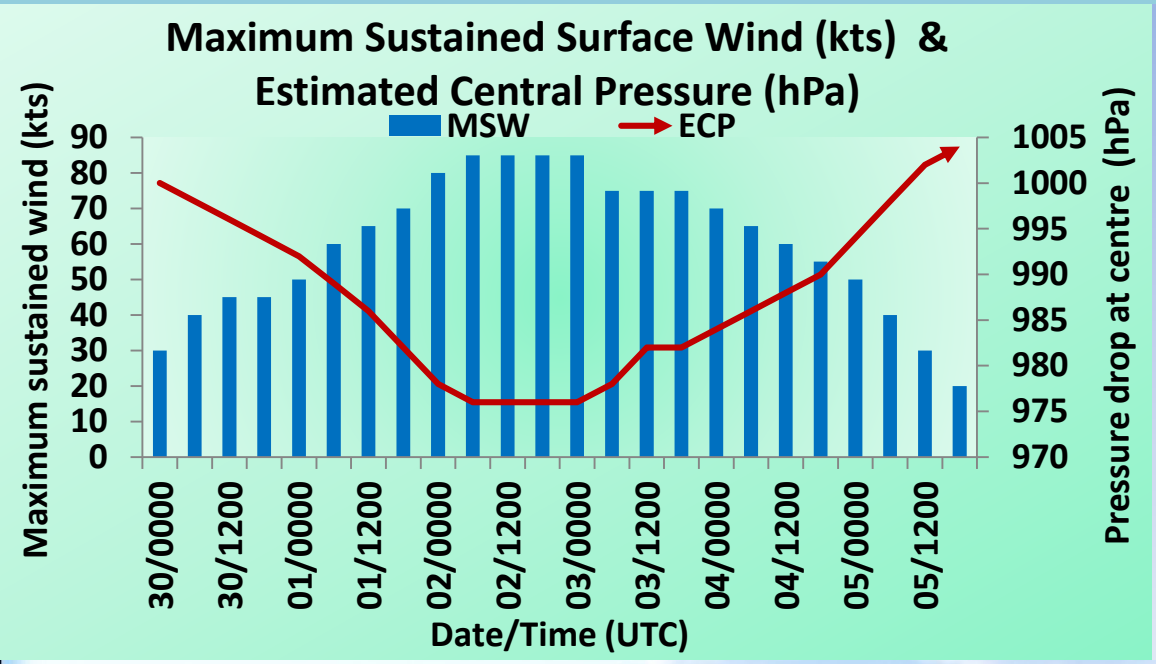
24 hr -61.4%

48 hr -76 %

72 hr-76.4%

- **Northwestward movement towards Lakshadweep was predicted on the first bulletin itself issued at 0830 hrs IST of 29th Nov.**
- **Northeastward recurvature of the track and its movement towards south Gujarat coast was first predicted in the morning of 01st December(five days before it hit south Gujarat coast**

Intensification and Weakening



- Maximum intensity: 85 knots 150-160 kmph in the forenoon of 4th.
- Gradual weakening thereafter
- Intensification of the system was predicted from first bulletin at 1150 IST of 29th.
- Weakening while moving towards Gujarat coast was first predicted on 1 Dec morning

Intensity Forecast Errors

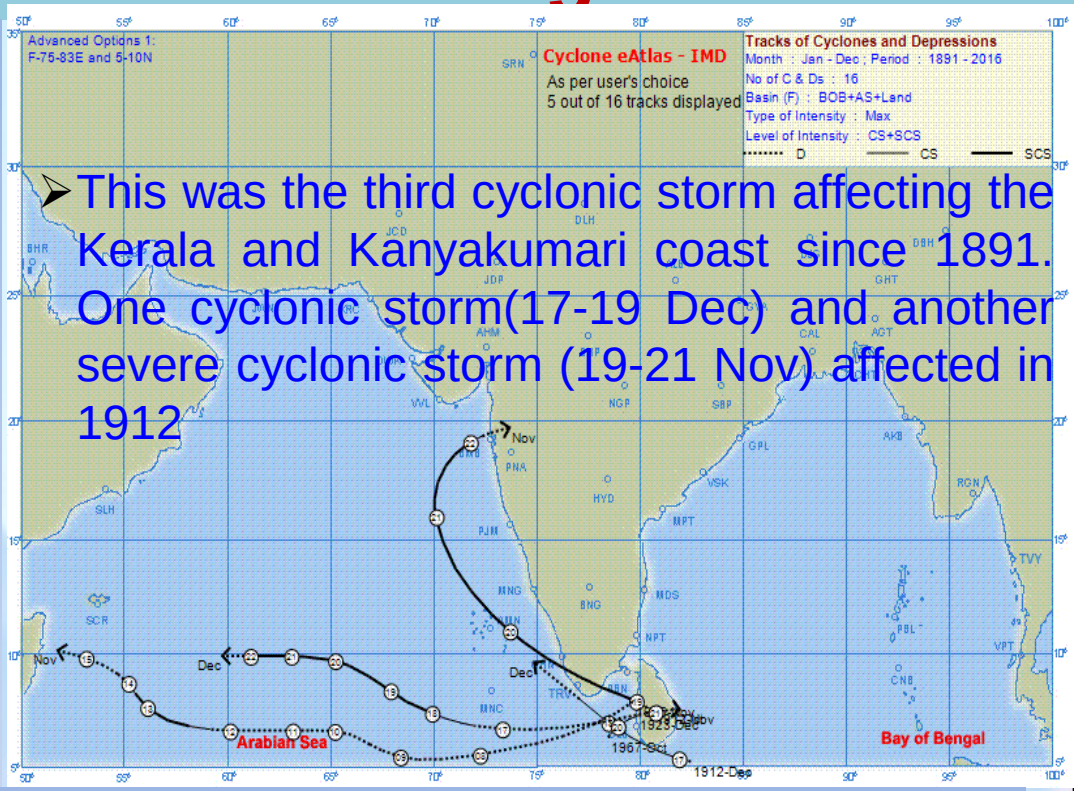
12hr: 5.4 knot against 6.5knot in 2012-16
24 hr: 7.0 knot against 10.7knot in 2012-16
48 hr: 13.5 knot against 15.5knot in 2012-16
72 hr: 16.4 knot against 16.3knot in 2012-16

Intensity Forecast Skill

12hr: 26.6% against 18.2% in 2012-16
24 hr: 48.4% against 35.2% in 2012-16
48 hr: 61.0% against 55.7% in 2012-16
72 hr: 75.7% against 66.8% in 2012-16

Genesis Forecast and actual genesis

- **First information regarding formation of depression during next 48-72 hours (i.e. 29th onwards) was issued at 1200 hours ISTon 28th Nov. in Tropical Weather Outlook**
- **The system developed into a depression in the morning of 29th.**

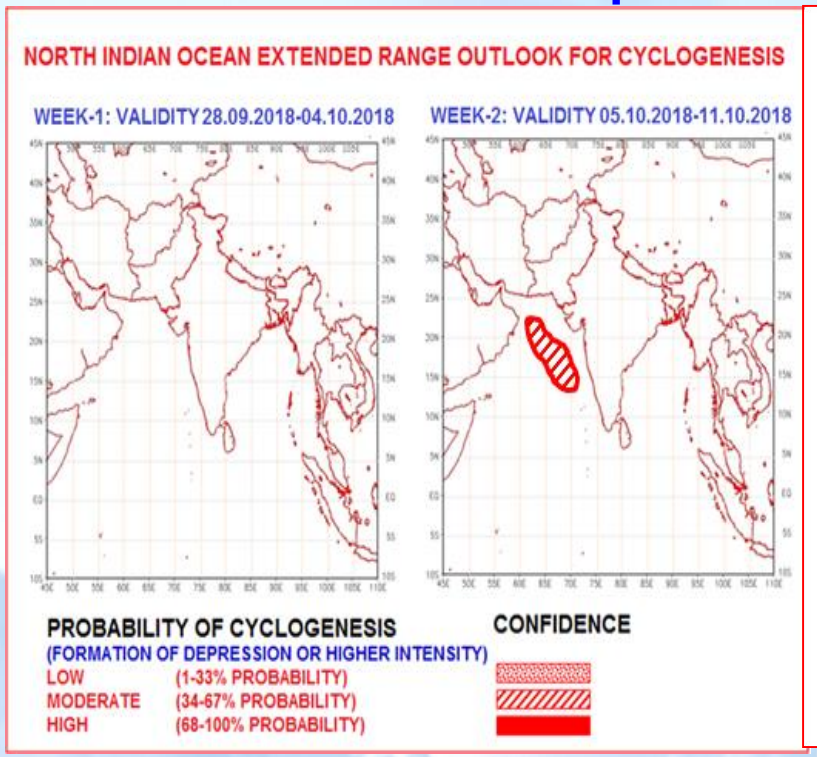


- In the first bulletin based on 1150 IST of 29th Nov, IMD, New Delhi indicated the west-northwestward movement of system and its emergence into Comorin area by 30th.
- It was also mentioned that the system would intensify further.
- The system emerged into Comorin Area during night of 29th and intensified into Deep Depression in the early hrs (0230 IST) of 30th and into Cyclonic Storm in the forenoon (0830 IST) of 30th Nov. 2017.

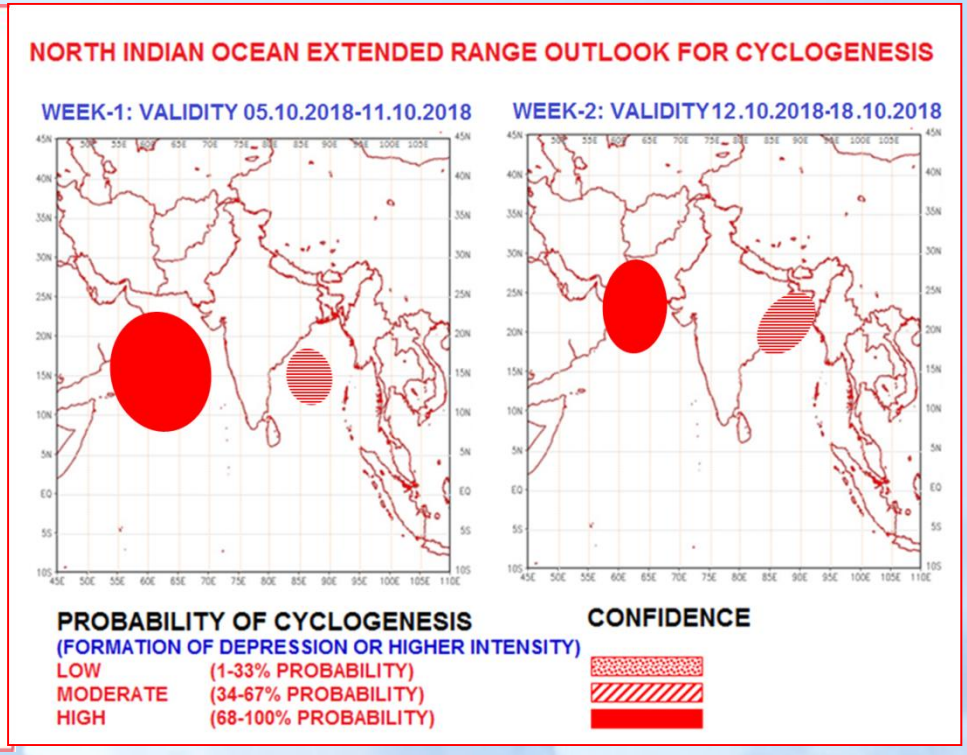
EXTENDED RANGE FORECAST OF CYCLOGENESIS

Introduced since 22 April 2018

Issued on 27-Sep



Issued on 04-Oct



Extended range forecast issued on 27-Sep and 4-Oct. for Cyclogenesis of Titli and Luban

TROPICAL WEATHER OUTLOOK

Cyclogenesis probabilistic forecast extended from 3 days to five days Implemented since 22 April 2018

Example of Outlook issued on 5 Oct. for Titli and Luban

REGIONAL SPECIALISED METEOROLOGICAL CENTRE-TROPICAL CYCLONES, NEW DELHI

TROPICAL WEATHER OUTLOOK

DEMS-RSMC TROPICAL CYCLONES NEW DELHI DATED 05.10.2018

TROPICAL WEATHER OUTLOOK FOR NORTH INDIAN OCEAN (THE BAY OF BENGAL AND ARABIAN SEA) VALID FOR NEXT 120 HOURS ISSUED AT 0600 UTC OF 05.10.2018 BASED ON 0300 UTC OF 05.10.2018.

BAY OF BENGAL:

A LOW PRESSURE AREA (LPA) IS LIKELY TO DEVELOP OVER SOUTH BAY OF BENGAL AROUND 8TH OCTOBER 2018. IT IS LIKELY TO BECOME MORE MARKED AND MOVE TOWARDS ODISHA & ADJOINING NORTH ANDHRA PRADESH COASTS DURING SUBSEQUENT 72 HOURS.

PROBABILITY OF CYCLOGENESIS DURING NEXT 120 HRS:

24 HOURS	24-48 HOURS	48-72 HOURS	72-96 HOURS	96-120 HOURS
NIL	NIL	NIL	NIL	LOW

ARABIAN SEA:

UNDER THE INFLUENCE OF YESTERDAY'S CYCLONIC CIRCULATION OVER SOUTHEAST ARABIAN SEA (AS) AND ADJOINING LAKSHADWEEP & MALDIVES AREA, A LOW PRESSURE AREA (LPA) HAS FORMED OVER SOUTHEAST AS AND NEIGHBOURHOOD AT 0300 UTC OF TODAY, THE 5TH OCTOBER 2018. IT IS VERY LIKELY TO BECOME WELL MARKED LOW PRESSURE AREA OVER THE SAME REGION DURING NEXT 12 HOURS. FURTHER, IT IS VERY LIKELY TO CONCENTRATE INTO A DEPRESSION AND MOVE NORTHWESTWARDS DURING SUBSEQUENT 24 HOURS. IT IS ALSO VERY LIKELY TO INTENSIFY INTO A CYCLONIC STORM SUBSEQUENTLY AND MOVE NORTHWESTWARDS TOWARDS OMAN COAST.

PROBABILITY OF CYCLOGENESIS DURING NEXT 120 HRS:

24 HOURS	24-48 HOURS	48-72 HOURS	72-96 HOURS	96-120 HOURS
NIL	MODERATE	HIGH	HIGH	HIGH

Probability of cyclogenesis (Formation of depression)

Nil: 0%,

Low: 1-25%,

Fair: 26-50%,

Moderate: 51-75%

High:76-100%

Cyclone Warning Centre Thiruvananthapuram

India Meteorological Department has the mandate to monitor and issue warnings regarding tropical cyclones over the north Indian ocean.

Cyclone Warning Centre Thiruvananthapuram operationalised w.e.f 01.10.2018

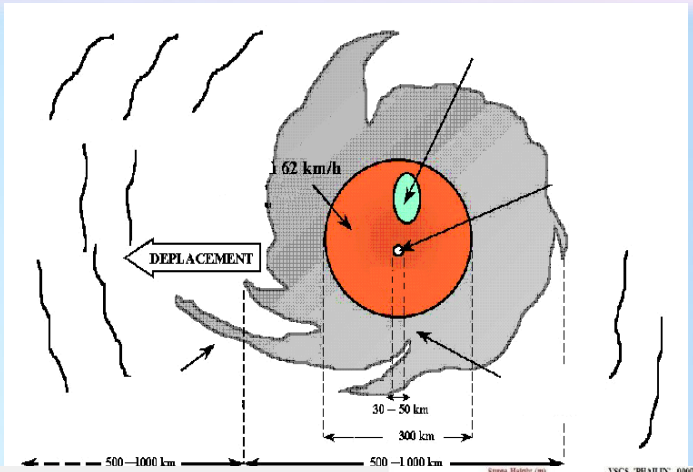
Advances in Warning Dissemination Mechanism

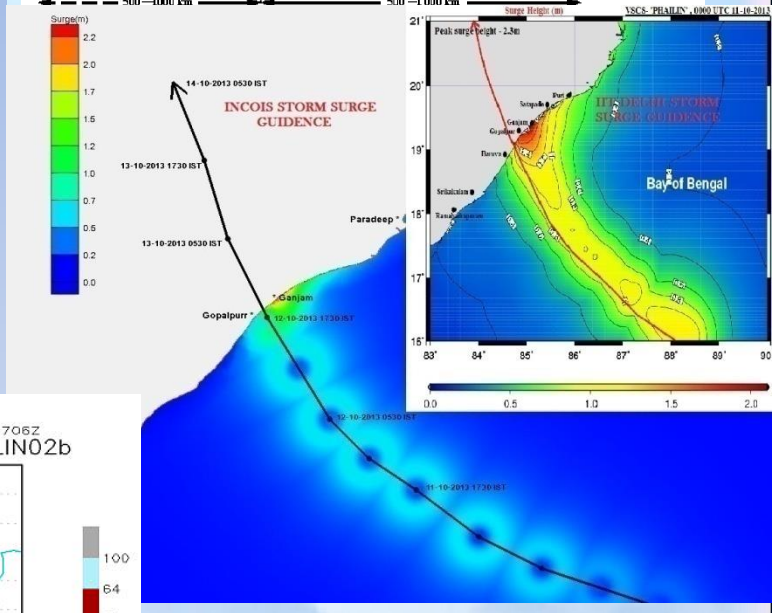
- Telephone, Tele-fax
- Mobile Phones (SMS) through IMD severe weather network, Agromet Network, INCOIS network.
- VHF/HFRT/Police Wireless
- Satellite based cyclone warning dissemination System
- Aeronautical Fixed Terminal Network
- Global telecommunication system (GTS) : (International Telecom centres)
- NAVTEX
- Internet (e-mail), ftp
- Websites, Dedicated website for cyclone (rsmcnewdelhi.imd.gov.in)
- Radio/TV, News Paper network (AM, FM, Comminity Radio, Private TV) : Prasar Bharati and private broadcasters
- GAMES and NAVIK

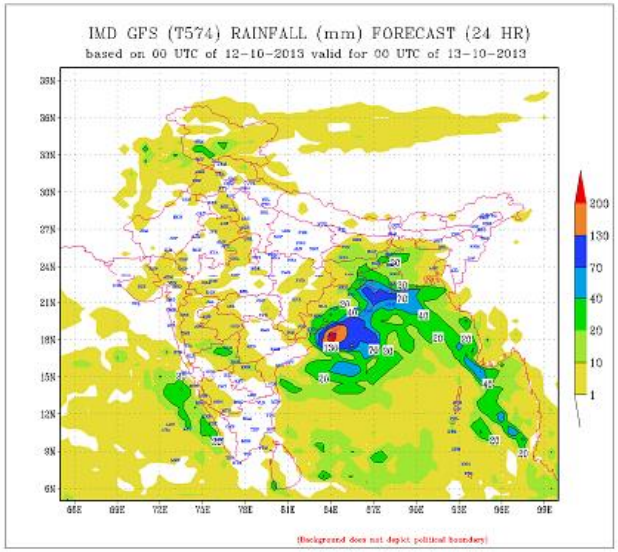
Fishermen warning being provided for entire Bay of Bengal and Arabian Sea valid for next five days

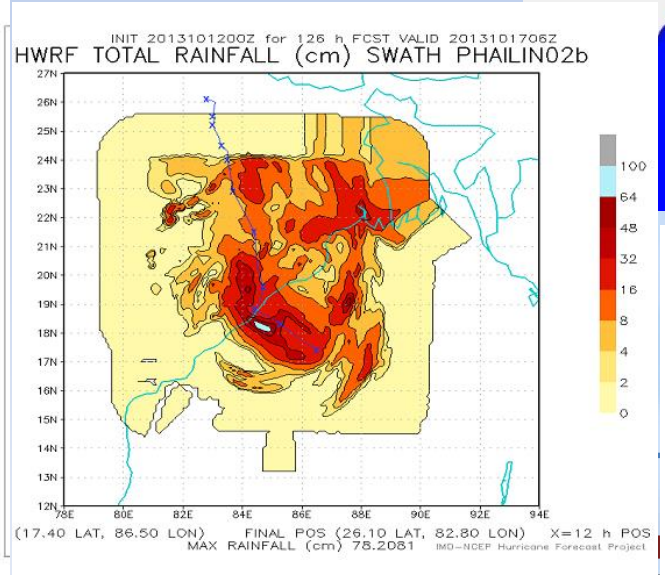
Coastal Flooding due to Cyclonic Disturbances

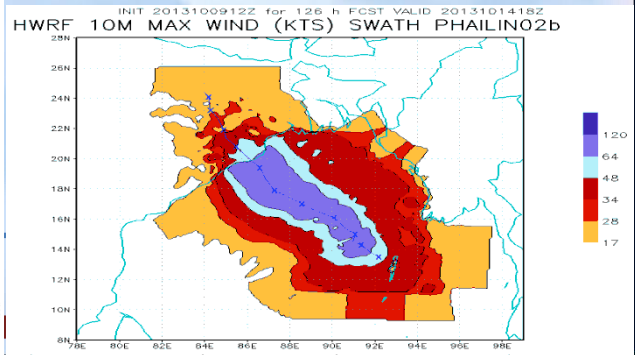
- **Storm Surge prediction -**
  Nomograms, IITD model
  INCIOS Coastal Inundation Model
- **Strong wind**
  Satellite, DWR Method, Climatology
  NWP (global and regional models)
- **Heavy rainfall**
  Synoptic method, Climatological method
  Satellite, Radar and NWP Method



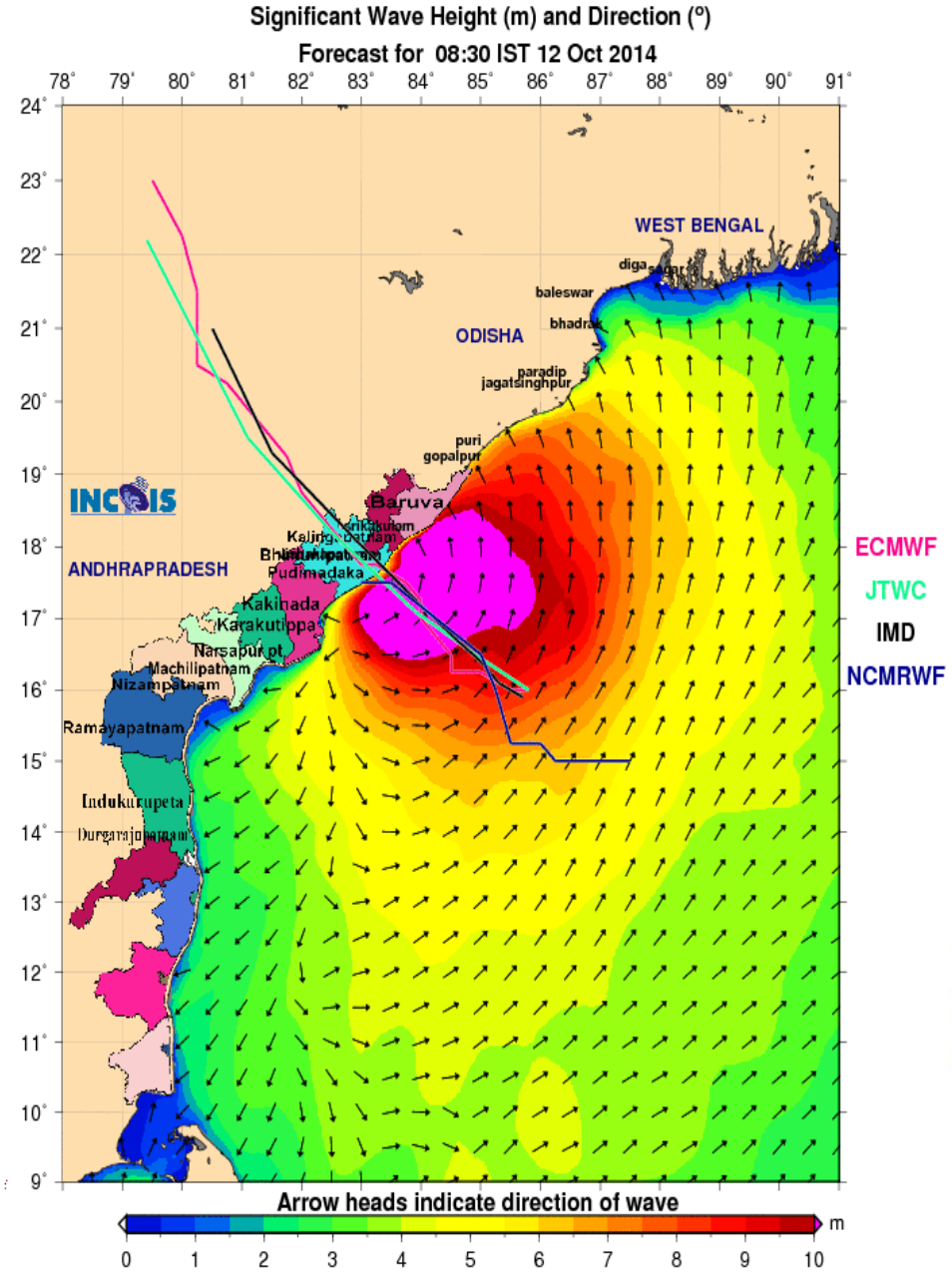


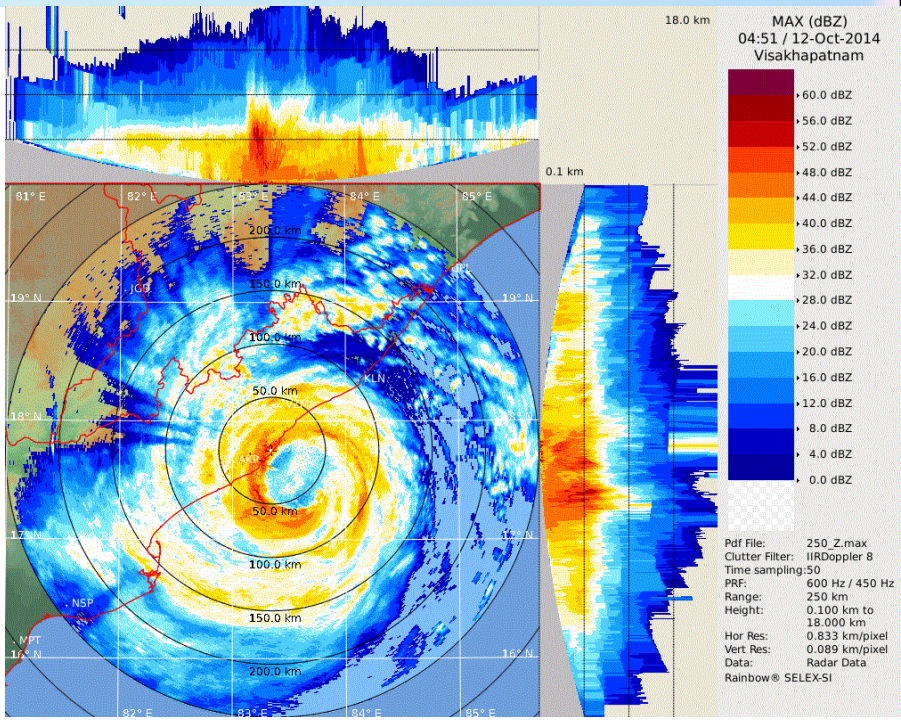


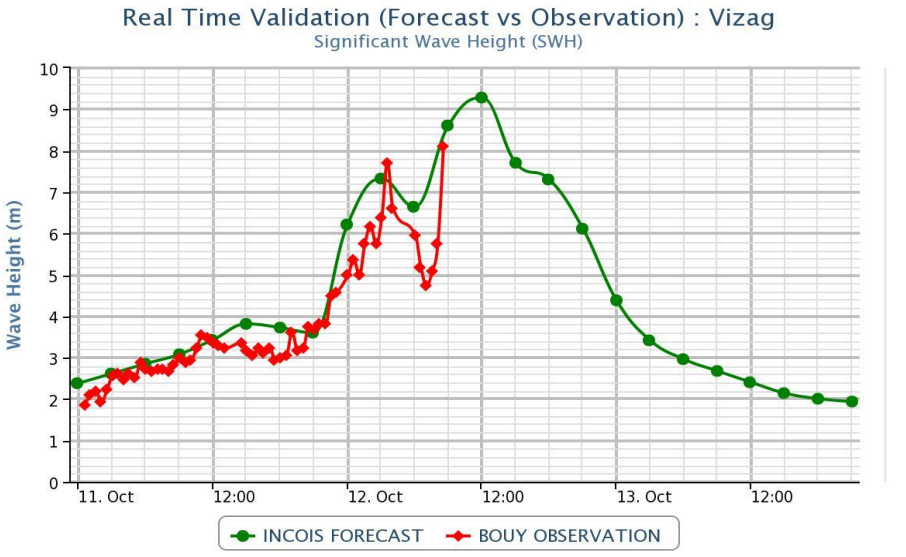




High Wave Warning VSCS Hudhud October 2014







Advances in flash flood guidance and urban flood warning

WORLD METEOROLOGICAL ORGANIZATION

South Asia – Regional Flash Flood Guidance System (SAsiaFFGS)

सत्यमेव जयते
Ministry of Earth Sciences

Global Initiative Project for Flash Floods with MoU between various organisations like UN-WMO, HRC, USAID/ OFDA, NOAA and regional NMHS (IMD).

Multi-institutional initiative for urban flood warning

PSA/MoES initiative for Chennai

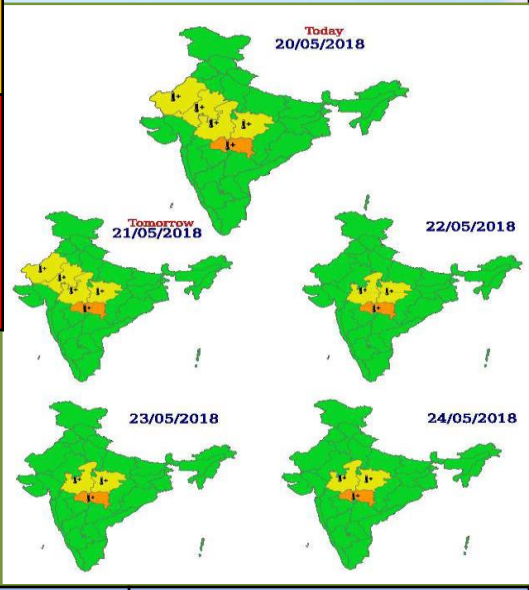
All India Fog warning scores in last three winters

All India	FAR			MR			CSI			POD		
	D1	D2	D3	D1	D2	D3	D1	D2	D3	D1	D2	D3
2017-18	0.15	0.17	0.13	0.16	0.24	0.36	0.64	0.57	0.51	0.84	0.76	0.64
2016-17	0.12	0.12	0.06	0.39	0.52	0.72	0.47	0.36	0.24	0.61	0.48	0.28
2015-16	0.18	0.17	0.05	0.50	0.57	0.87	0.33	0.3	0.11	0.50	0.43	0.13

- ✓Our 72 hours warning accuracy in winter 2017-18 is higher than 24 hours warning accuracy of winter 2016-17 .
- ✓ In General, large scale dense fog was predicted 3 to 5 days in advance.
- ✓Attempt also made to provide the timing of intense fog spell.
- ✓Provided information to various users includes Indian Railway and Medical Association

Heat Wave

Green (No action)	Normal Day	Maximum temperatures are near normal
Yellow Alert (Be updated)	Heat Alert	Heat wave conditions at isolated pockets persists on 2 days
Orange Alert (Be prepared)	Severe Heat Alert for the day	(i) Severe heat wave conditions persists for 2 days (ii) Through not severe, but heat wave persists for 4 days or more
Red Alert (Take Action)	Extreme Heat Alert for the day	(i) Severe heat wave persists for more than 2 days. (ii) Total number of heat/severe heat wave days exceeding 6 days.



- The warning for the heat wave isgiven 3 to 5 days in advance.
- There is significant improvement in the scores in this year as compare to the previous years.

All India	FAR			MR			CSI			POD		
	D1	D2	D3	D1	D2	D3	D1	D2	D3	D1	D2	D3
2017	.07	.06	.02	.33	.51	.77	.40	.32	.19	.67	.49	.23
2018	.03	.04	.02	.09	.28	.52	.54	.40	.32	.91	.72	.48

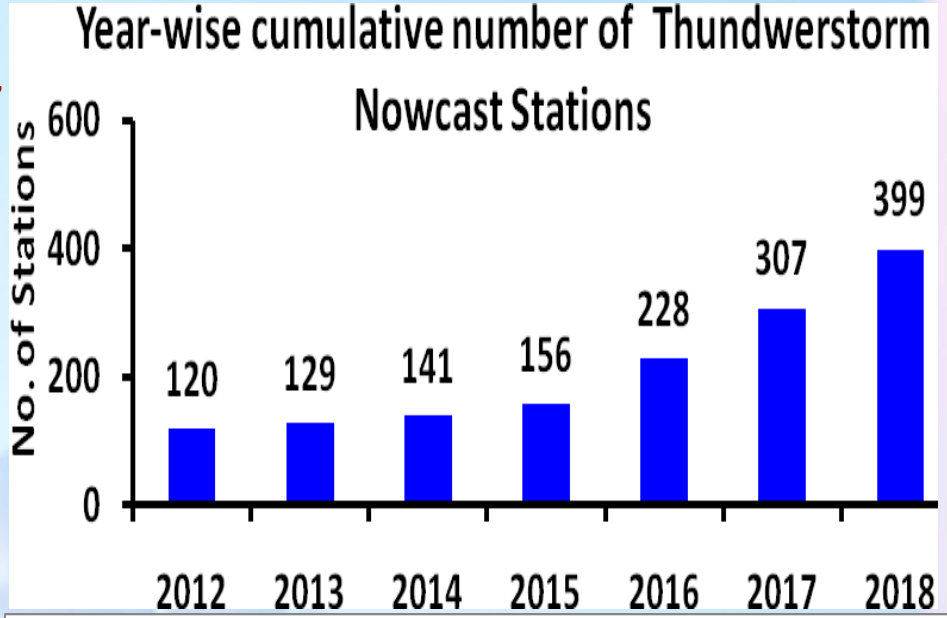
Cold Wave warning verification (Dec. 2016-Feb., 2017

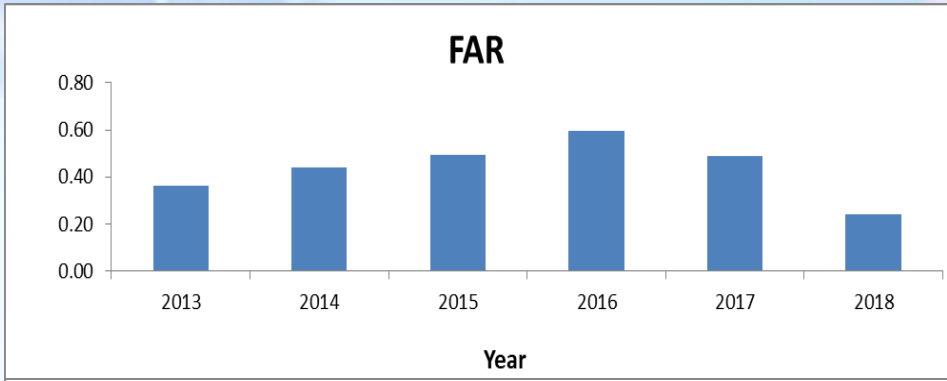
Cold wave/ visibility & frost

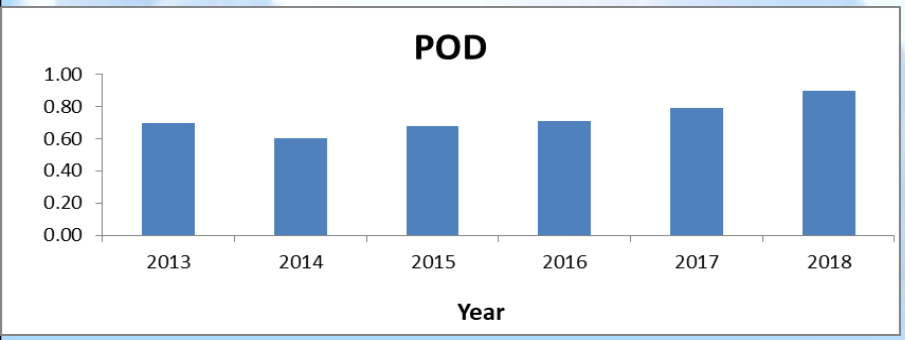
	FAR	MR	CSI	POD
D1	0.04	0.06	0.63	0.94
D2	0.03	0.39	0.44	0.61
D3	0.01	0.71	0.27	0.29

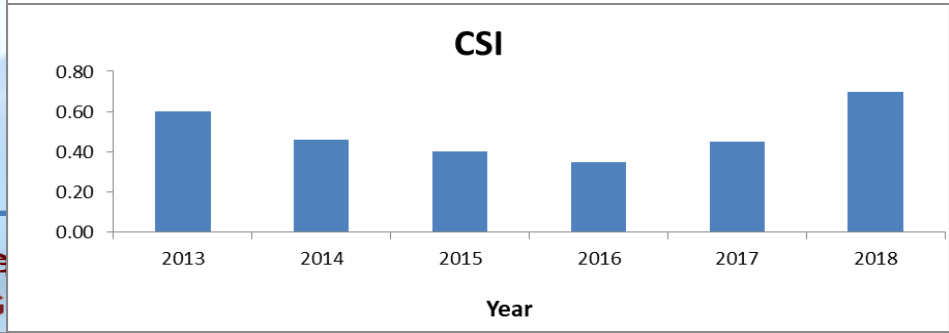
Advances in Thunderstorm Warning

- 399 stations covered by May 2018
- Nowcasting for district level since 2017
- Nowcast Page is updated by Meteorological Centres
- Nowcast bulletins by SMS issued for severe weather for district level and transmitted through SMS and e-mail
- Enhanced DWR network by 2019 with IMD and IAF network covering entire country
- Target: location specific nowcast for 660 stations by 2019



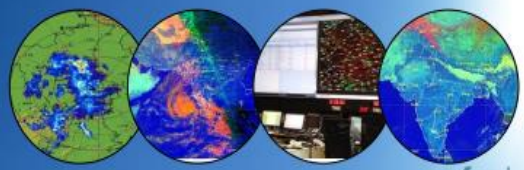






WEATHER INFORMATION PORTAL
FOR
INDIAN POWER SYSTEM

Reference Document



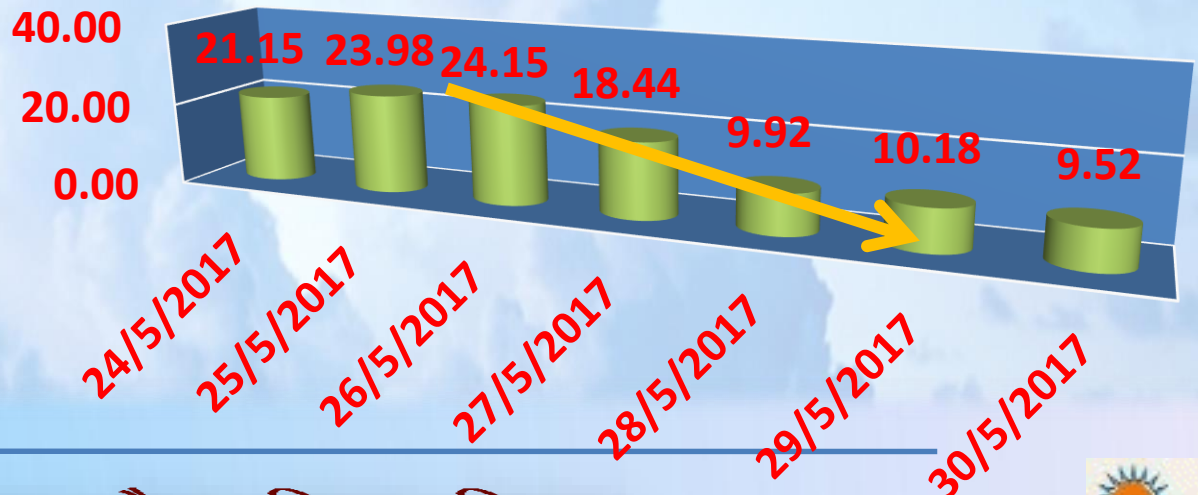
Power System Operation Corporation Ltd.
(A Government of India Enterprise)

- **Weather Portal For Power Sector**
  http://amssdelhi.gov.in/NRLDC/index.html

Benefit achieved by Uttar Pradesh

- Meteogram, wind and rain forecast for 27/28/29-05-2017 helped in better load assessment of UP control area by U.P. State Load Despatch Centre.
- As anticipated, UP demand went down from 19000 MW to 17000 MW due to change in weather conditions.
- Accordingly, STOA & purchase from Power Exchange of the order of 2000 MW was reduced. i.e Backing down of approximately 13 MU of costly thermal generation .

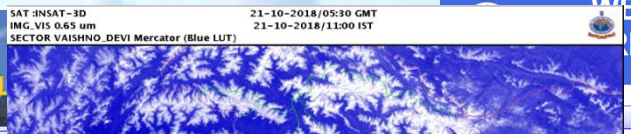
Total Power Exchange & Bilateral

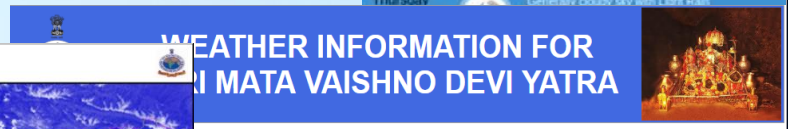


भारत मौसम विज्ञान विभाग
INDIA METEOROLOGICAL DEPARTMENT

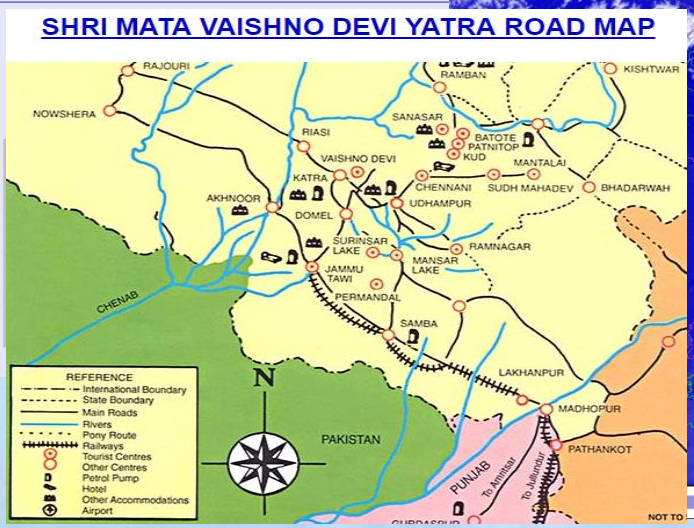
Tourism Forecast Services

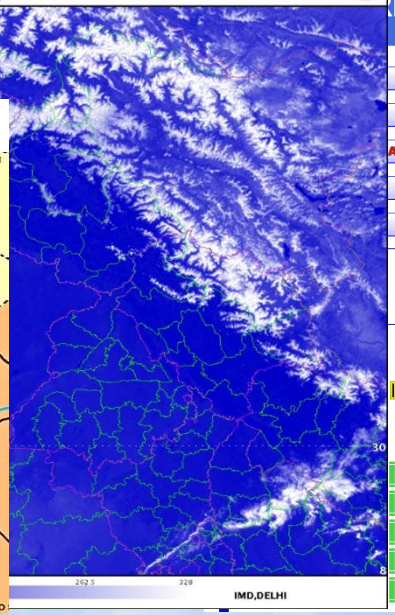
- 438 Tourists Sites from 25 States/UTs in coordination with State Authorities & stake holders for developing tourism forecast identified.





ROUTE MAP LIPULEKH PASS
CURRENT WEATHER OBSERVATIONS
PAST 24 HOURS OBSERVATIONS
SEVEN DAYS FORECAST
YATRA ROUTE WEATHER FORECAST/WARNING/ADVISORY
NOWCAST AND WARNING
SATELLITE IMAAGE
ROUTE MAP NATHULA PASS
MANSAROVAR YATRA FORECAST GANGTOK, SIKKIM

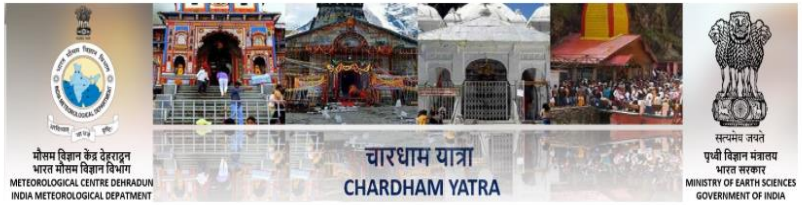




SHRI MATA VAISHNO DEVI YATRA ROAD MAP
YATRA ROUTE WEATHER ADVISORY
ALUE ADDED NOWCAST FOR MATA VAISHNO DEVI YATRA
CURRENT OBSERVATIONS
NWP PRODUCTS FOR SHRI MATA VAISHNO DEVI
LOW LEVEL WIND AND TEMPERATURE CHARTS FOR HELICOPTER OPERATION
THREE DAYS FORECAST
JAMMU DIVISION
SATELLITE IMAGES
INSAT - 3D
VISIBLE
INFRA-RED 1
SHORT WAVE INFRA-RED
INFRA-RED 1 - BRIGHTNESS TEMPERATURE
ANIMATION OF HALF HOURLY IMAGES

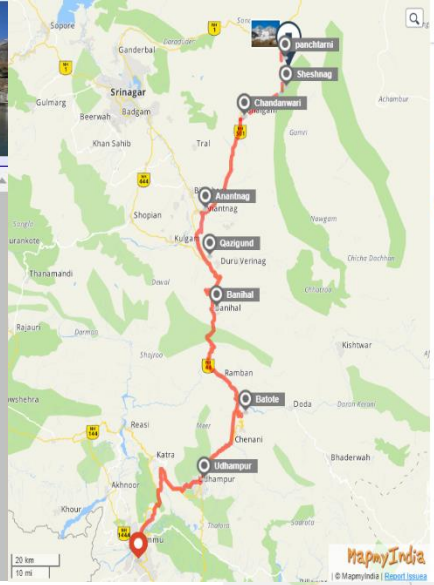
SPECIAL FORECAST FOR CHARDHAM AND HEMKUND SAHIB

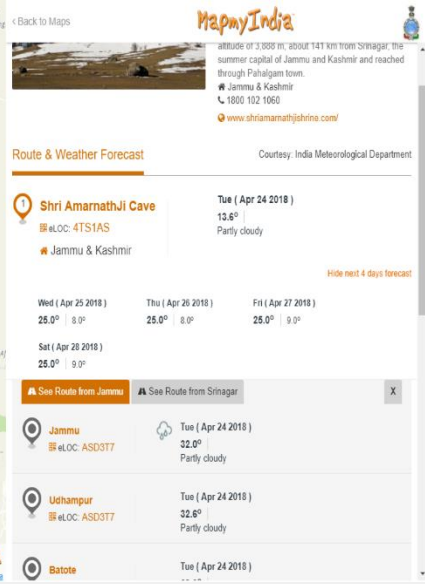
- 7 DAYS FORECAST - GANGOTRI
- 7 DAYS FORECAST - YAMUNOTRI
- 7 DAYS FORECAST - KEDARNATH
- 7 DAYS FORECAST - BADRINATH
- 7 DAYS FORECAST - HEMKUND SAHIB
- SECTORWISE WEATHER FORECAST/WARNING/ADVISORY
- ENROUTE CITY WEATHER FORECAST/WARNING NEW
- LOW LEVEL WIND AND TEMPERATURE CHARTS FOR HELICOPTER OPERATION
- ROUTE MAP
- SATELLITE IMAGES

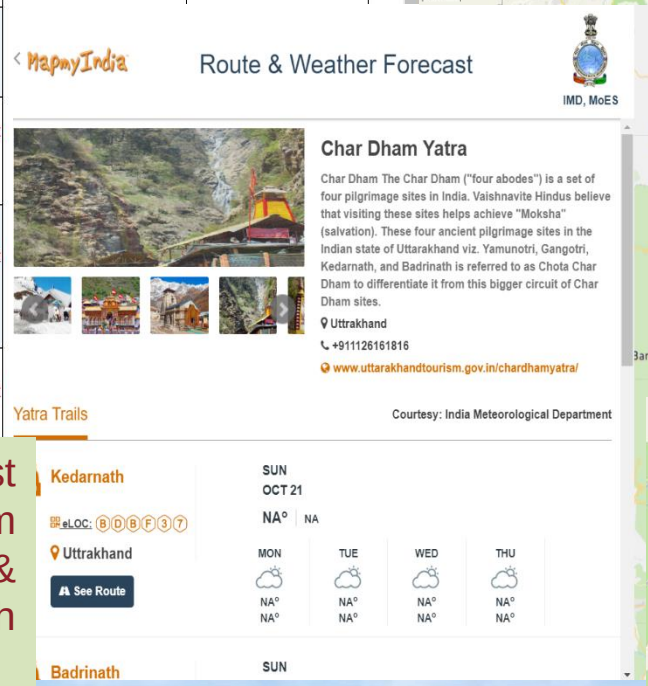


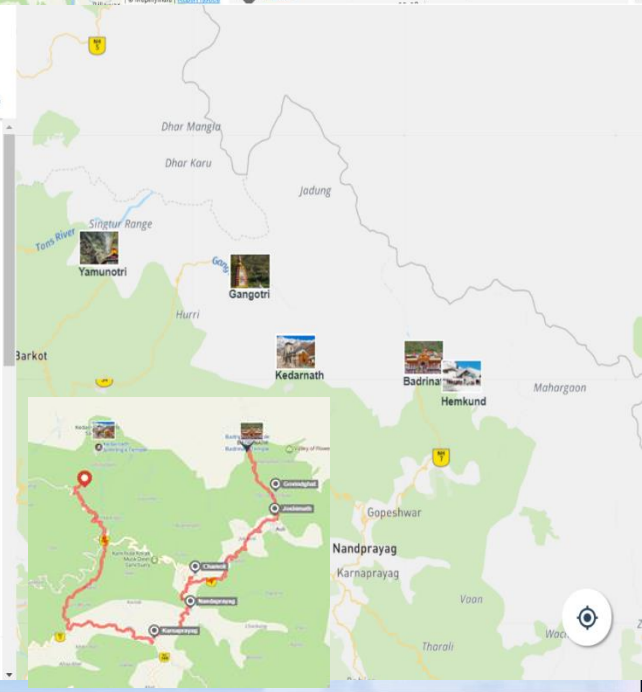
Date: 2018-10-21 Time of Issue: 09:30 hrs IST Print Table

SECTOR		NOWCAST	FORECAST	WARNING
Sector I	Haridwar to Rishikesh	No significant weather		
Sector II	Rishikesh to Rudraprayag (Rishikesh, Devprayag, Srinagar, Rudraprayag)*	No significant weather		
Sector III	Rudraprayag To Joshimath (Rudraprayag,Karnaprayag, Nandprayag, Chamoli, Joshimath)*	Thunder cloud development likely to occur in some areas		
Sector IV	Joshimath To Badrinath/Hemkund Sahib (Joshimath, Govindghat,Pandukeshwar, Badrinath, Hemkund Sahib)*	Thunder cloud development likely to occur in some areas		
Sector V	Rudraprayag To Kedarnath (Rudraprayag, Agastyamuni, Guptakashi,	Thunder cloud development likely to occur in some areas		





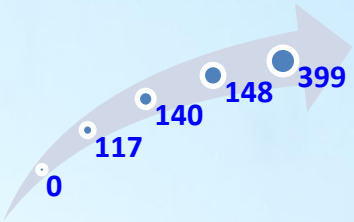


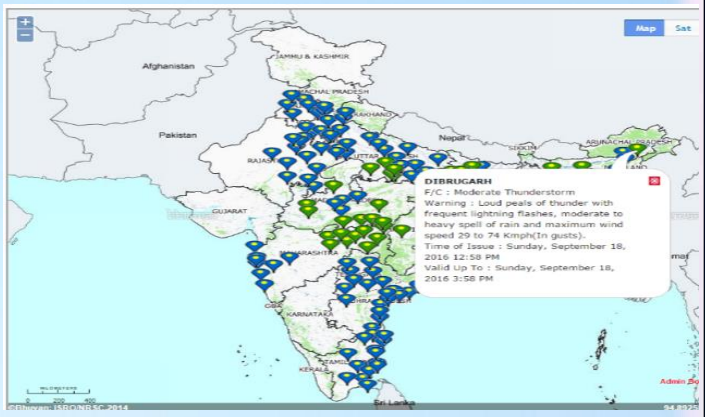


In house developed API for tourist Information on Shri Char Dham Yatra, Shri Amarnath Ji Yatra & other yatras in collaboration with MapmyIndia for hosting services.

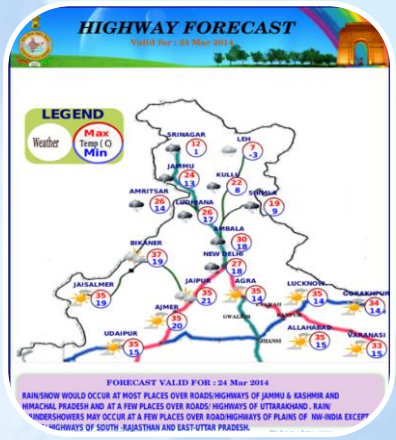
City specific forecasts

Introduced Thunderstorm /Now cast for cities covered under DWRs for 399 cities.





Introduction of Highway Forecast



Increase in city forecast from around 30 in 2006 to 324 in 2018.

Northwest

Southeast

Target for 2024 : 600 cities and improvement in accuracy and skill by 20%

LESSONS LEARNT FOR IMPROVING EWS :

Accuracy and improvement in Service is achieved by :

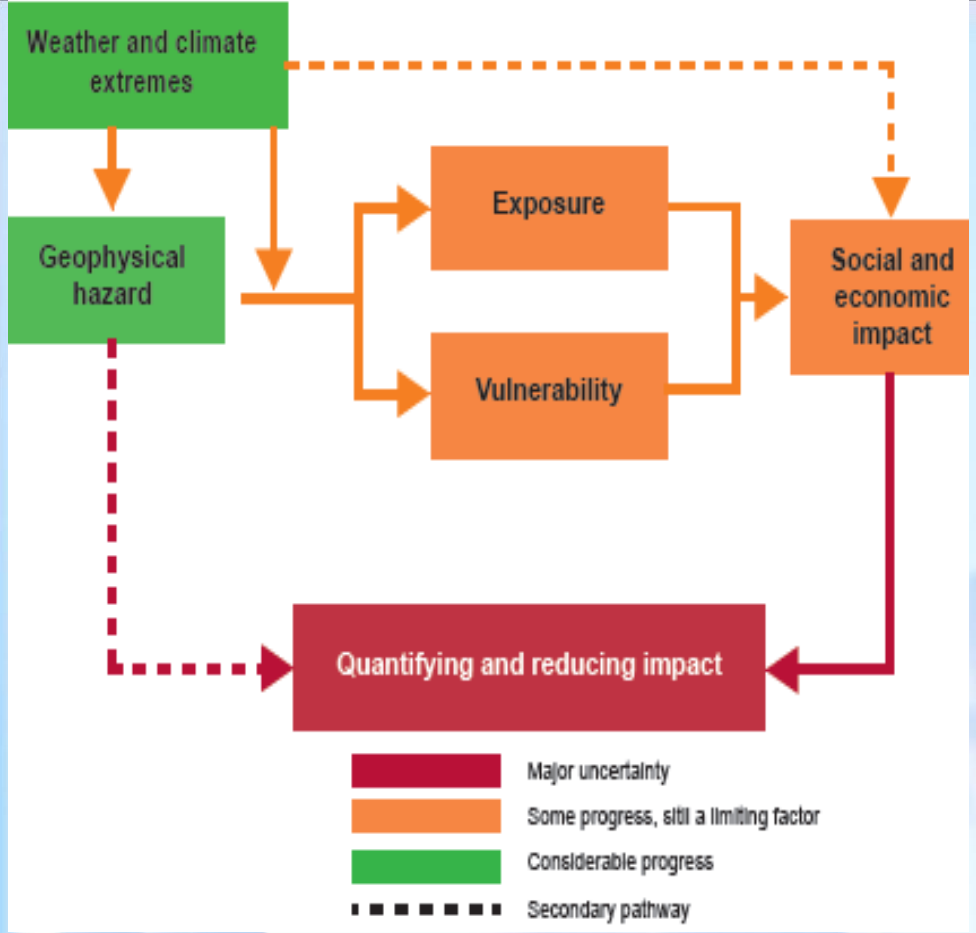
- **Science and Technological Upgradation**
- **Improvement in observational network (Ocean, land and atmosphere) and quality of data**
- **Remotely sensed observations using Satellite and Radar**
- **Fast communication and data Exchange system**
- **Superior computational capabilities, super computer facilities**
- **Improved Numerical modelling capabilities**
- **Skilled Human Resource Capabilities**
- **Improved tools and techniques of forecasting including DSS**
- **Excellent support and Inter- ministerial collaborations from centre and state**
- **Confidence building measures for disaster management agencies and general public**
- **International collaborations**
- **Research and Development**

Challenges

- ❖ Scale up Observing Systems(Surface, Upper Air, Radar and Satellite)
- ❖ Improve Data assimilation & NWP Models
- ❖ Forecasts
  - Block level forecast, location specific & Agro-met Advisories
  - Further improvement in Nowcast, short/medium/Extended Range Forecast, Climate Scale forecast
  - Improve sub-basin scale precipitation forecasts for surface hydrology for river basins and urban hydrology for major cities.
  - improve in predicting severe weather episodes, viz., prolonged heat and cold wave spells, thunder-storms spells etc., and improved forecast accuracy of these episodes in particular for flash flood events over the urban and complex topography.
- ❖ Improved information dissemination system
- ❖ Improvement in Sectoral applications:

Impact based Forecasting

Translating hazard information into impact scenarios



Impact/Risk

Vulnerability

Value at Risk

Exposure

Statistical - census and survey data

Hazard

GIS/Geospatial– Infrastructure, settlements, land use..

Cartographic, Geological, Hydro-meteorological ..
Geospatial Data – Vector and Raster

The most important thing for the success of Impact based Multi-Hazard Forecasting and Risk based Warning System

Building Partnerships and Collaboration

- **Main key and also challenge : To work in partnership with other government agencies and stakeholders (emergency response, mapping agencies, transport, public, etc..)**
- **Data sharing among different agencies and departments vital (demographic, GIS and mapping, economic etc..)**
- **However there is scope for improvement within MoES and also in collaboration with other agencies (Academic, R&D, Industry and others)**
- **Process initiated for collaborative effort in urban flood warning, flash flood guidance**

Thank you