Role of Indian Meteorological Satellite in Improving the Prediction of Extreme Rainfall

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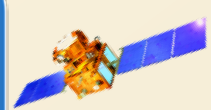
IMS Meeting at Indian Institute of Tropical Meteorology, Pune

Indian EO Programme: Dimensions

Space Infrastructure
- Launch vehicles (PSLV, GSLV)
- Spacecrafts (LEO, GEO and beyond)
- Sensors (optical/microwave)



Ground Segment
- Data Acquisition and Processing
- International Ground stations
- Cal-Val Programme
- TTC Network

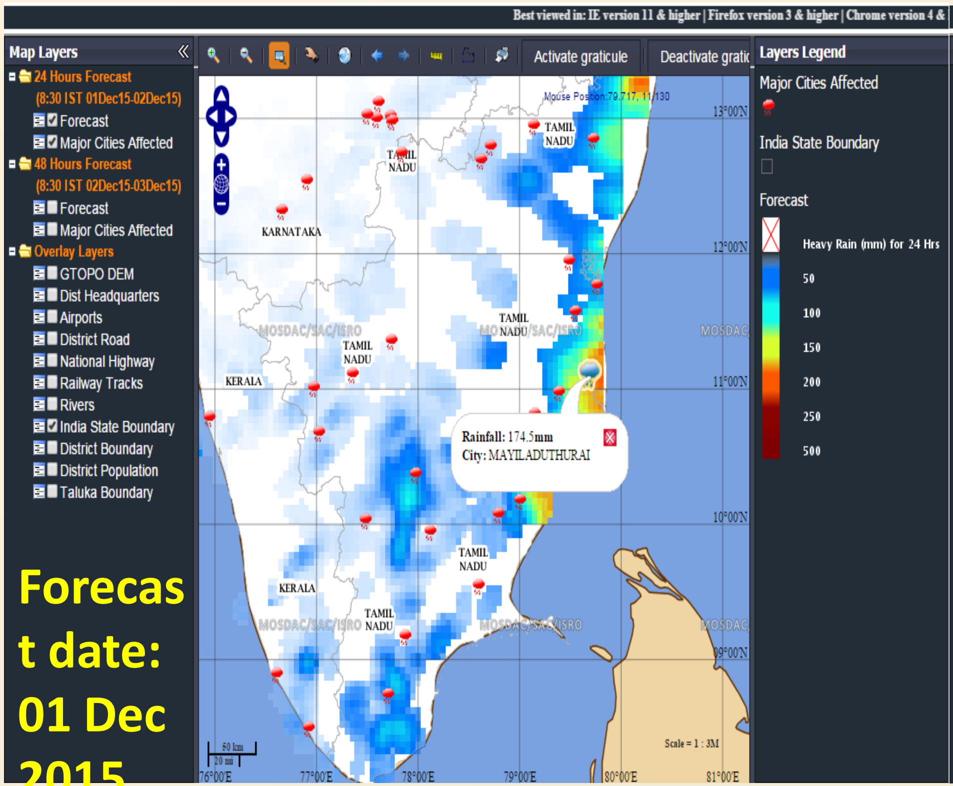
Applications
- Large number of applications towards national development
- Advanced R&D for land-atmosphere-ocean interactions
- Synergy between EO, Satellite Communication & Navigation

Institutionalization
- National Natural Resources Management System (NNRMS)
- Involvement of stake-holders from the planning level
- State Remote Sensing Centres

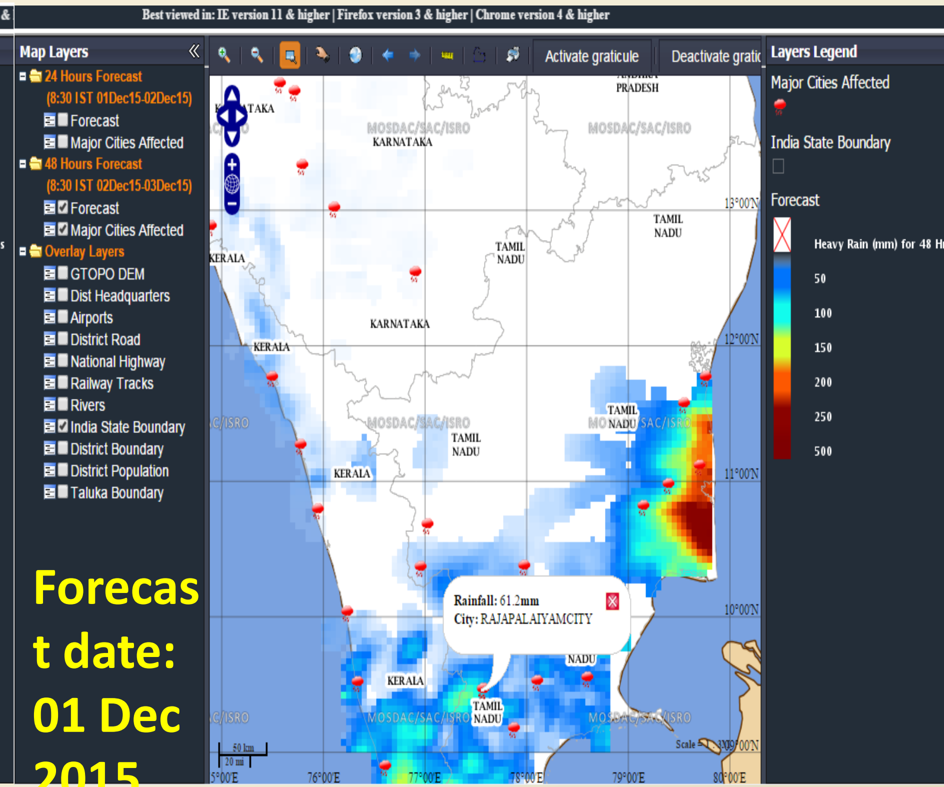
Capacity Building
- Formal education through CSSTE-AP, IIRS, IITs….
- On-the job training

International Cooperation
- Bilateral and multilateral cooperation with various countries and international Organisations (CEOS, GEO, …..)

ISRO is actively involved in weather prediction to support the launch activities, and to validate the impact of observations from EO mission satellites as well as to define the future satellite systems.



24 hour rainfall forecast



48 hour rainfall forecast

Heavy Rainfall = Rainfall exceeding 95th percentile of climatological expectation within 15 days from the day of event. Forecast dissemination through MOSDAC

Evolution of Indian EO Systems: Atmosphere

Meghatropics
(2011)
MADRAS, SCARAB, SAPHIR, GPS OCC.

Kalpana (VHRR) and INSAT-3A
(2001-2005)

VHRR:
- 2.0 km Vis,
- 8 km IR, WV

CCD: (only 3A)
- 1 km MS

INSAT – 2D/ 2E
(1996-2000)

VHRR:
- 2.0 km Vis,
- 8 km IR, WV

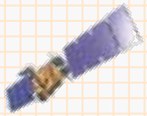
CCD: (only 2E)
- 1 km MS

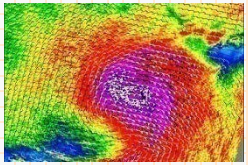
INSAT – 2A/ 2B/ 2C
(1991-95)

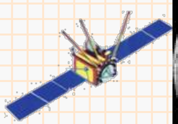
VHRR:
- 2.75 km Vis, 11 km IR

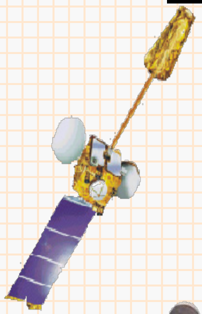
INSAT – 1A/ 1B/ 1C/ 1D
(1982-1990)

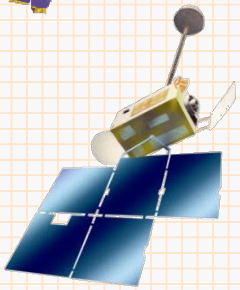
VHRR:
- 2.75 km Vis, 11 km IR



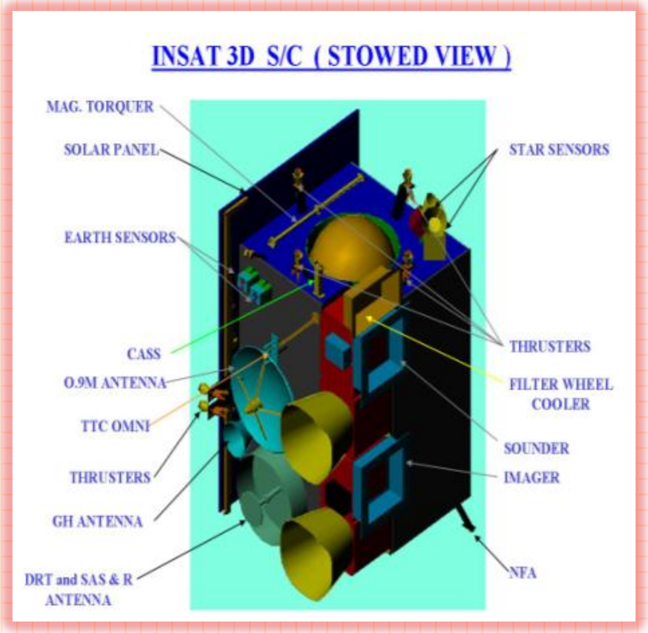








INSAT-3D
(Launched in 2013)
Imager and Sounder

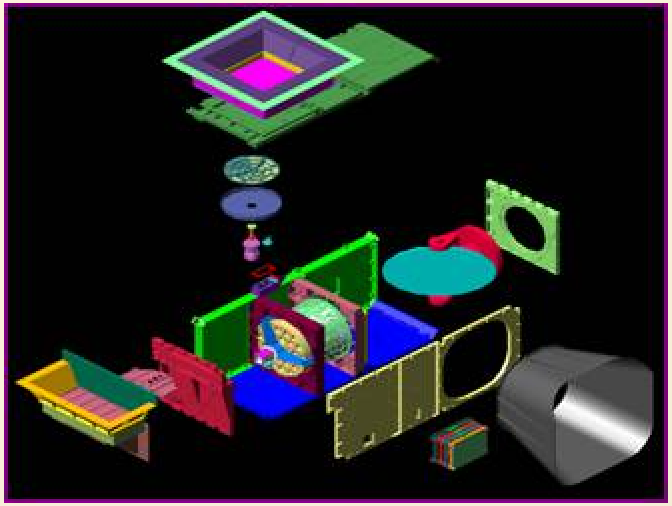


INSAT-3D -R
(Launch in 2016)
Imager and Sounder

INSAT-3D -S
(Launch in 2018)
Imager and Sounder

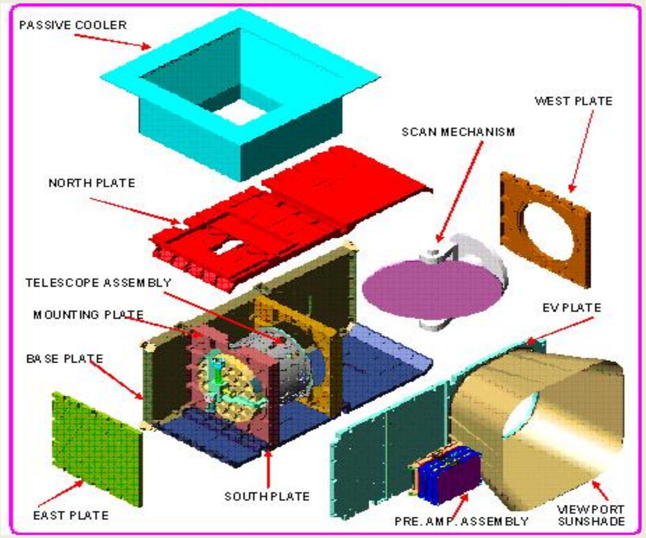
INSAT 3D

Sounder



19 channel Sounder

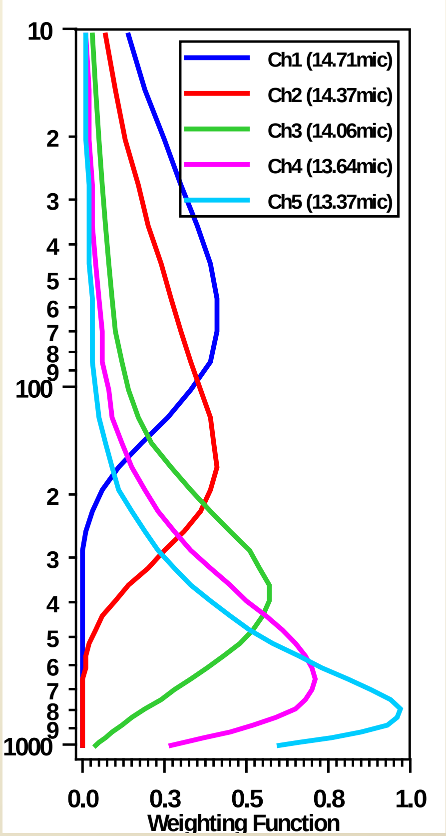
Imager



Advanced 6-channel imager

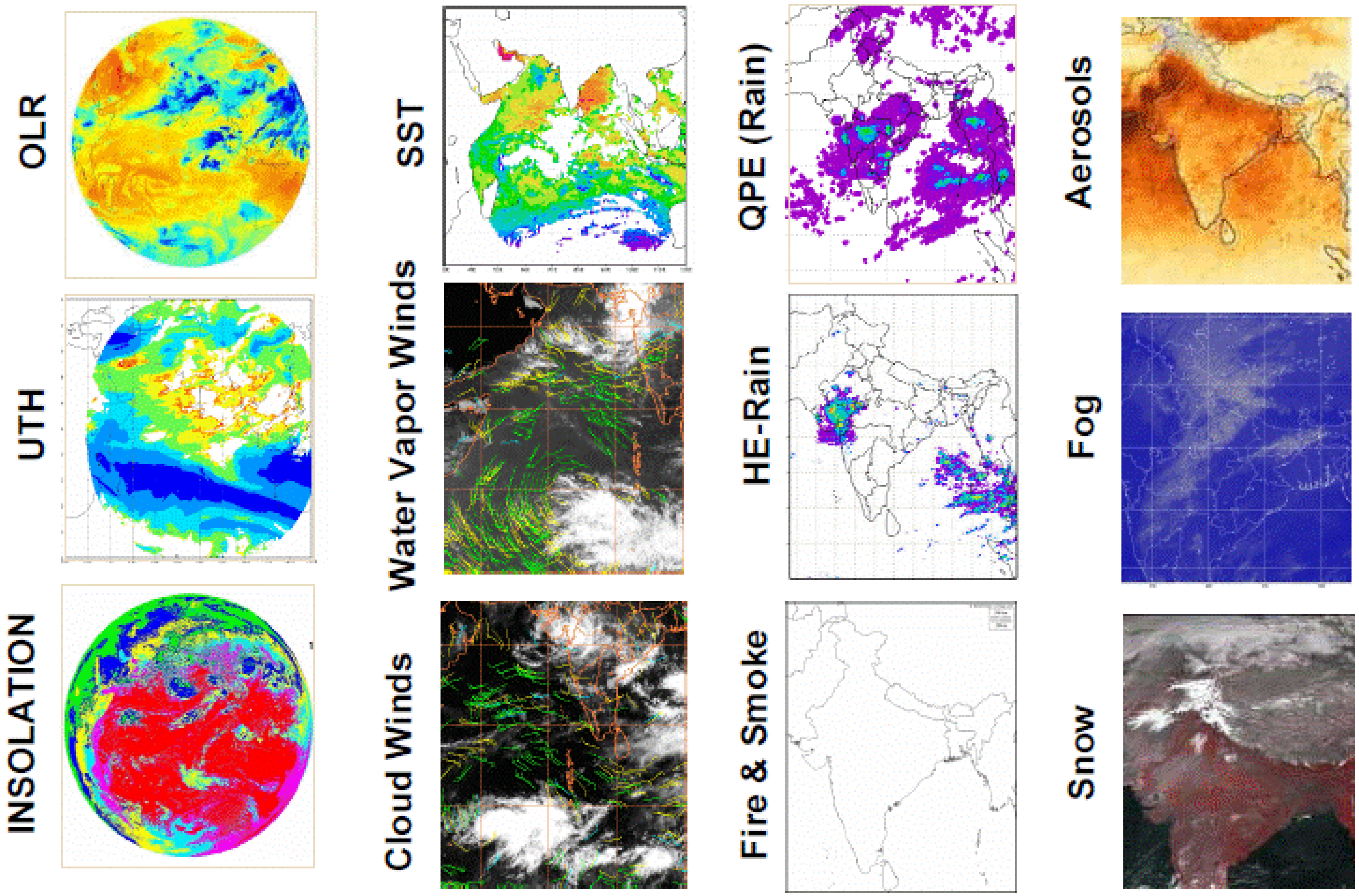
Sensor	Bands (μm)	Spatial Res.
Imager	VIS (0.55-0.75), SWIR (1.55-1.70) MIR (3.8-4.0) WV (6.5-7.1) TIR1 (10.2-11.3), TIR2(11.5-12.5)	1km x 1km 4km x 4km 8km x 8km 4km x 4km
Sounder	19 channels	10km x 10km

Applications: Improved estimation of water vapour content, cloud, wind vector, upper tropospheric humidity, sea surface temperature and surface insolation

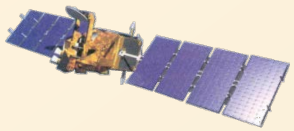


INSAT-3D Weighting function over Indian Region (July)

Geophysical Products from INSAT-3D Imager



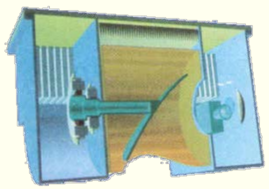
Megha Tropiques



For studying water cycle and energy exchanges to better understand the life cycles of the tropical convective system.

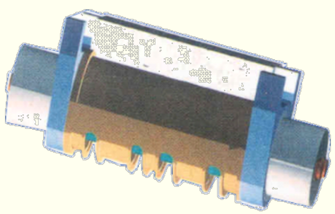
The satellite is contributing to Global Precipitation Mission (GPM)

SAPHIR



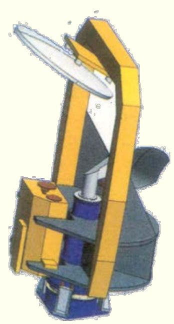
- Water vapour profile
- Six atmospheric layers upto 12 km height
- 10 km Horizontal Resolution

SCARAB



- Outgoing fluxes at TOA
- 40 km Horizontal Resolution

MADRAS

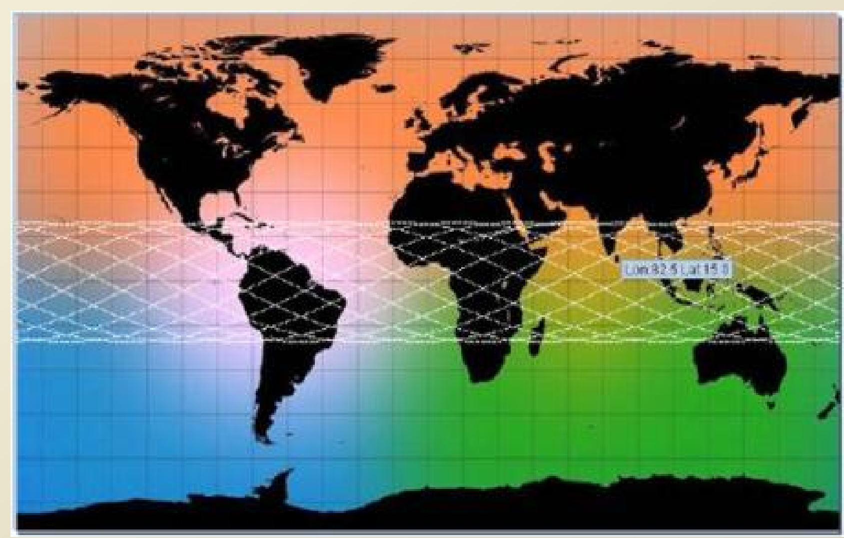


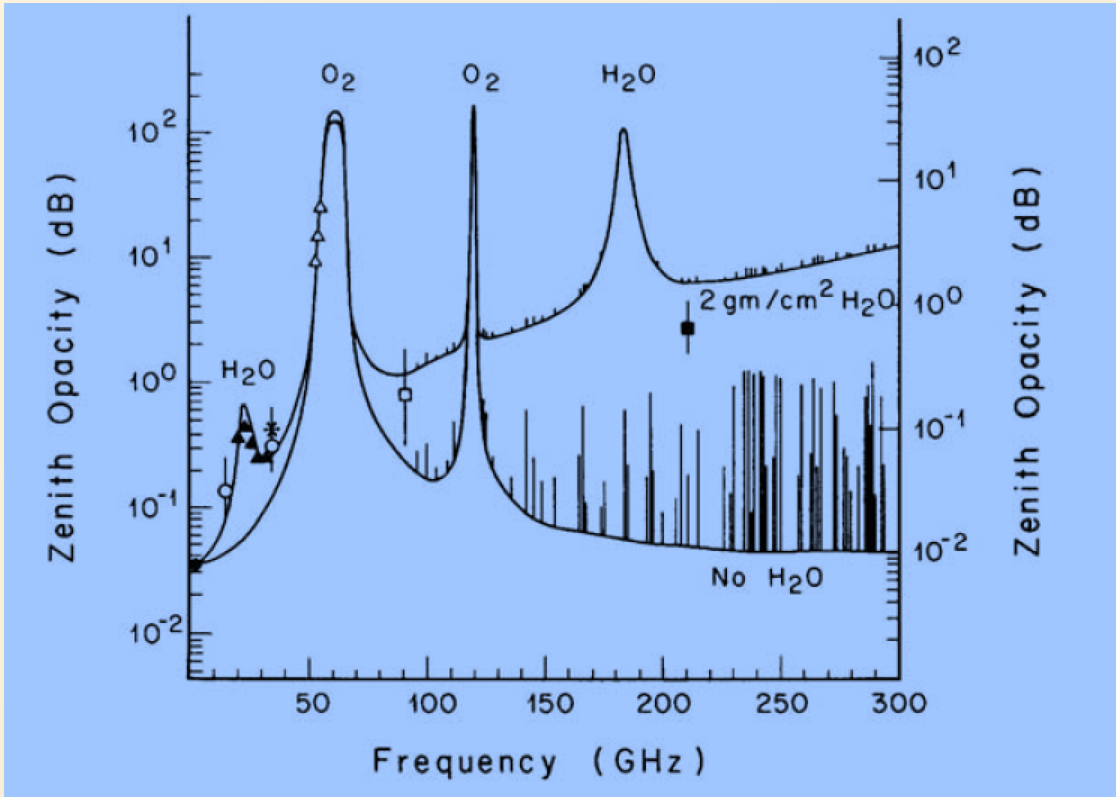
- Precipitation and Cloud properties
- 89 &157 GHz: Ice particles in cloud top
- 18 &37 GHz: Cloud Liquid Water and precipitation; Sea Surface Wind speed
- 24 GHz : Integrated water vapour

APPLICATIONS

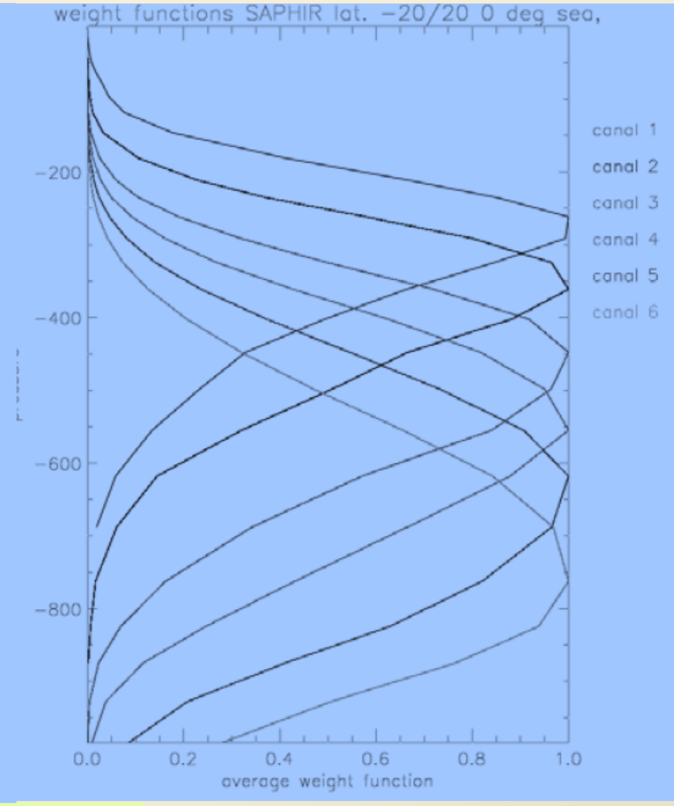
Observations of tropics for

- Water vapour
- Clouds
- Cloud condensed water
- Precipitation
- Evaporation

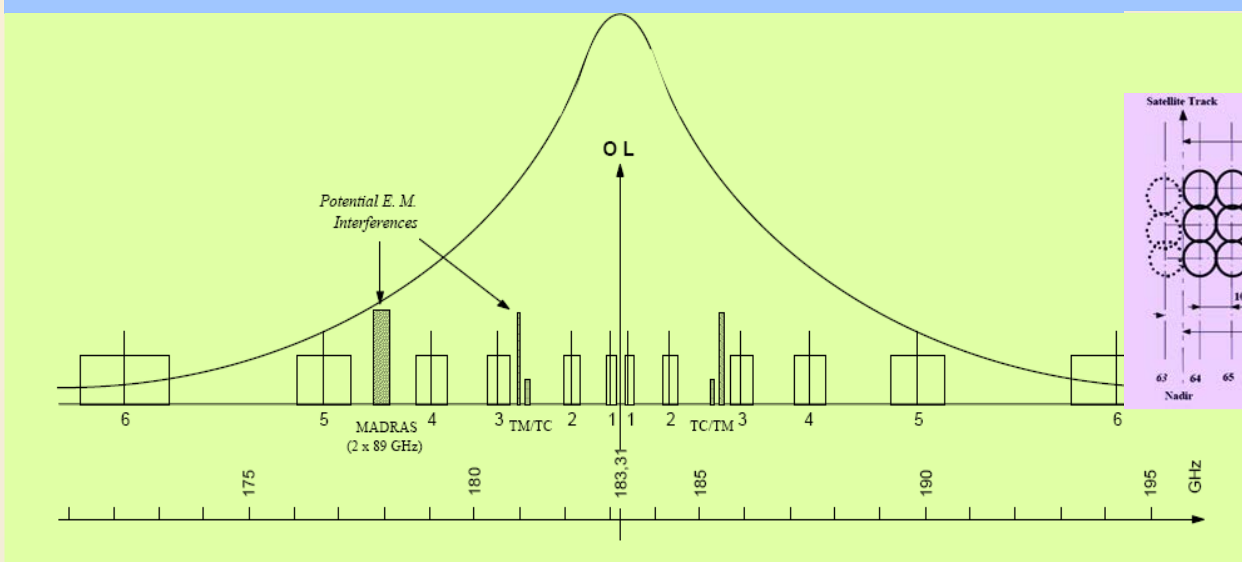




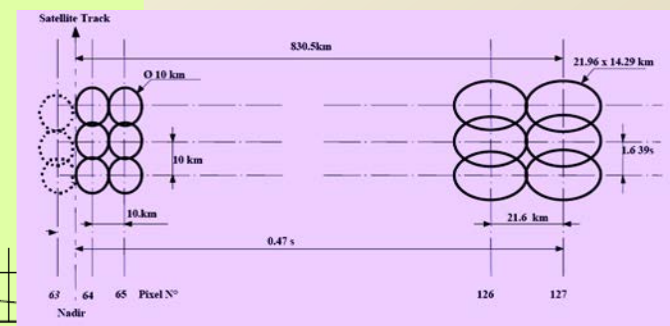
O2
O2
H2O
H2O
2 gm/cm2 H2O
No H2O
Zenith Opacity (dB)
Frequency (GHz)
50
100
150
200
250
300



weight functions SAPHIR lat. -20/20 0 deg sea,
canal 1
canal 2
canal 3
canal 4
canal 5
canal 6
-200
-400
-600
-800
0.0
0.2
0.4
0.6
0.8
1.0
average weight function



O L
Potential E. M. Interferences
MADRAS (2 x 89 GHz)
TM/TC
TC/TM
6
5
4
3
2
1
1
2
3
4
5
6
175
180
183,31
185
190
195
GHz

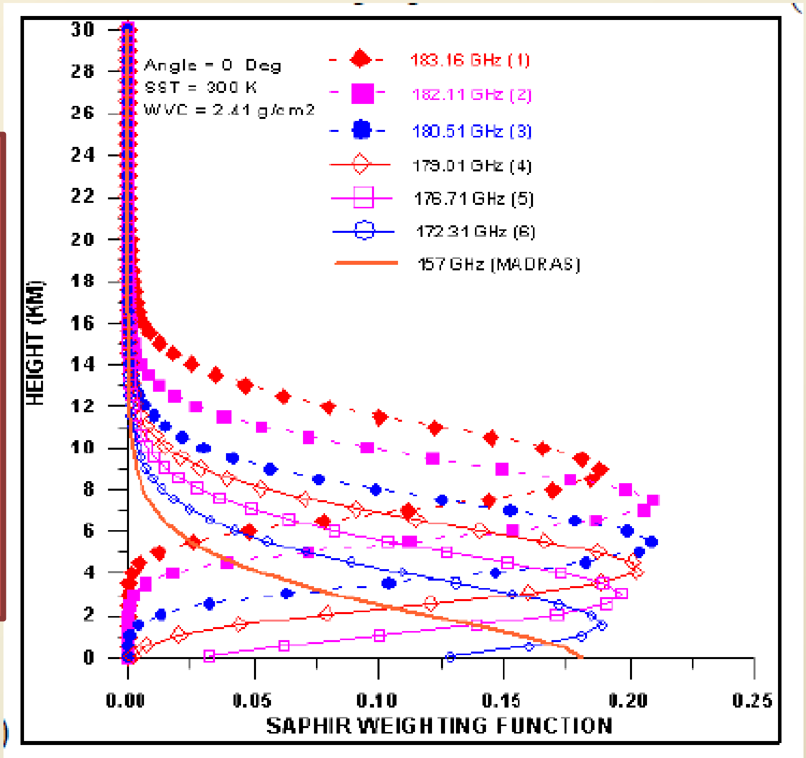


Satellite Track
830.5km
21.96 x 14.29 km
Ø 10 km
10 km
10 km
1.6 39s
21.6 km
0.47 s
63
64
65
Pixel N°
126
127
Nadir

Channel N°.	Central frequencies (GHz)	Bandwidth (MHz)	**radiometric sensitivity (estimated by calculation)**	**polarisation**
S1	183,31 ± 0.20	200	1,82 K	H
S2	183,31 ± 1.10	350	1,01 K	H
S3	183,31 ± 2.70	500	0,93 K	H
S4	183,31 ± 4.00	700	0,88 K	H
S5	183,31 ± 6.60	1200	0,81 K	H
S6	183,31 ±11.00	2000	0,73 K	H

Challenges:

- Varying incidence angle across the scan – (0^0 to 50^0).
- Varying pixel size across scan – 10 km (nadir) – 40 km (pixel# 1 & 182).



GSICS Intercalibration of INSAT-3D Imager and Sounder

INSAT-3D Counts (Imager/Sounder) → **Calibrated Radiances** → **Re-Calibrated Radiance (GSICS)**

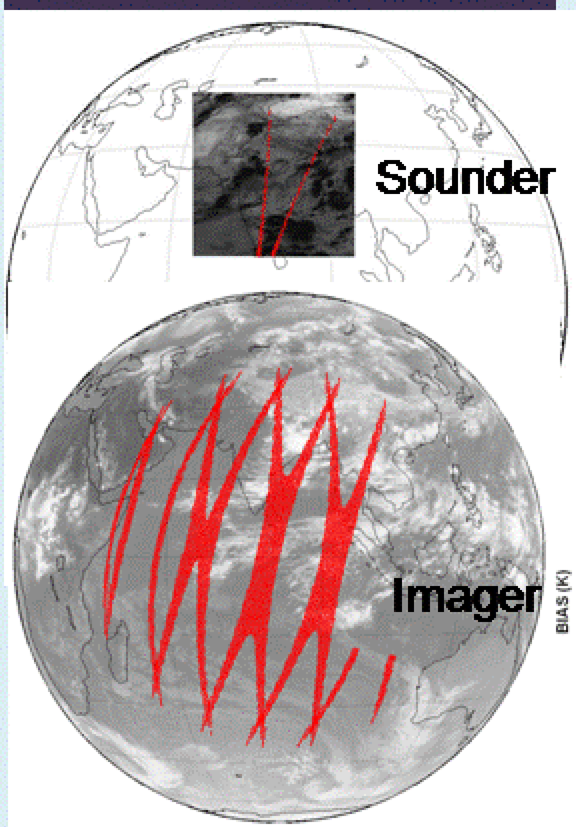
Reference instruments: **Hyperspectral sounder IASI/MetOp** (EUMETCAST at SAC Bopal campu

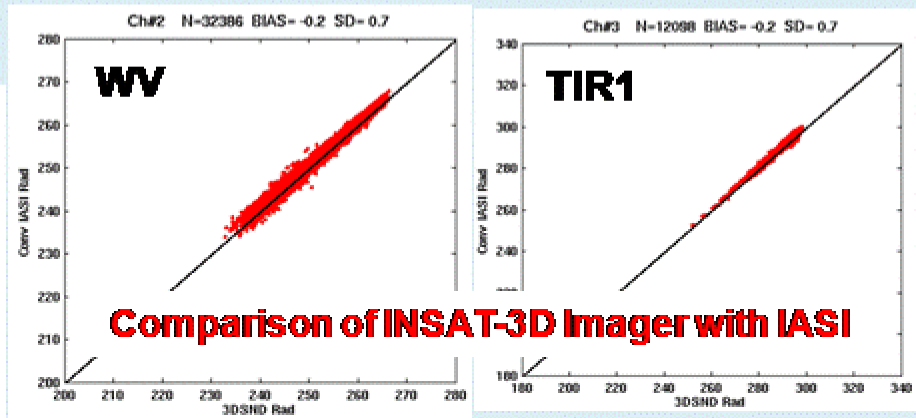
Procedure: Collocation in space, time, observation zenith angle over homogenous scene condition

Convolve hyperspectral radiance over INSAT-3D using SRFs as weight

Validation of the procedure for GOES-13 Imager and Sounder

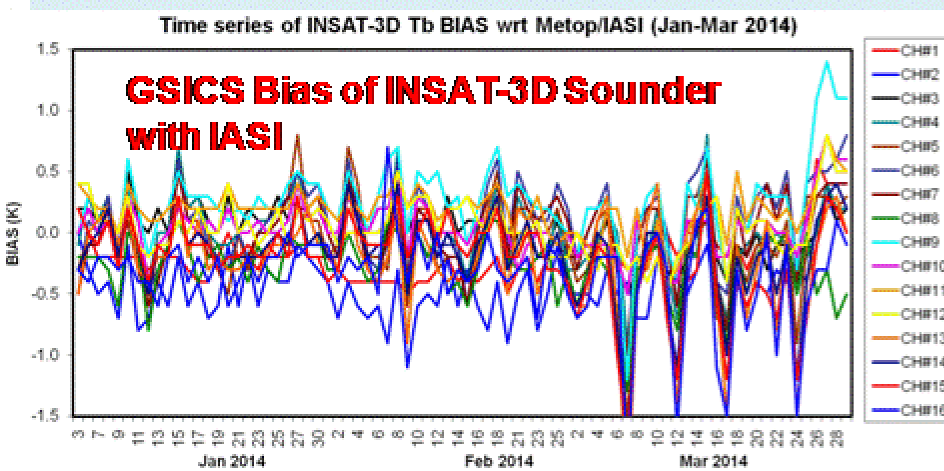
INSAT-3D and IASI Collocation map





Oct-Nov 2013

Ch#	BIAS (K)	SD (K)
MIR	-0.1	0.7
WV	-0.2	0.7
TIR1	-0.2	0.7
TIR2	-0.2	0.7



Night (13-15Z),
Time Collocation: 5 Min,
Spatial homogeneity:
ENV_TB_SD = 1K

Who uses INSAT-3D Products ?

Weather Prediction

Synoptic Forecasters

VIS/IR/WV Images
Fog
T/Q Profiles
Stability Indices

Aviation Forecasters

VIS/IR/WV Images
Fog
T/Q Profiles
Stability Indices

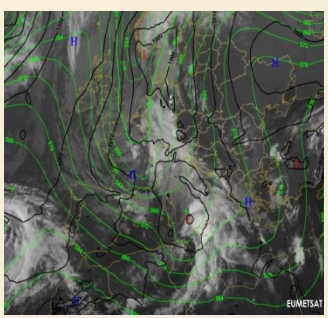
NWP/Data Assimilation

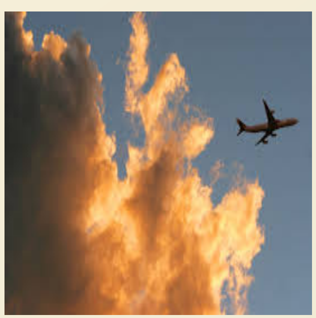
AMVs

Imager Radiances
Sounder Radiances

SST

OLR





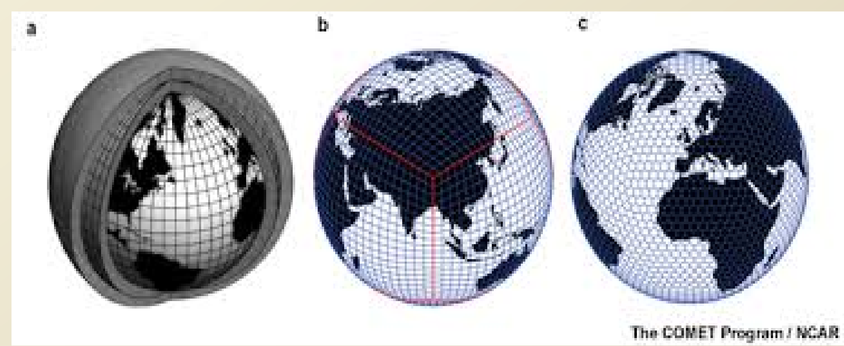
Agriculture/Energy

Agriculture

Insolation
Land Surface Temp
Evapotransp.
Fog
Rainfall

Energy

Insolation
LST
Wind



Who uses INSAT-3D Products ?

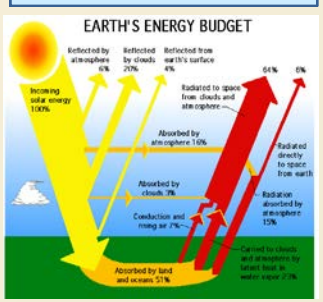
Climate Change Science

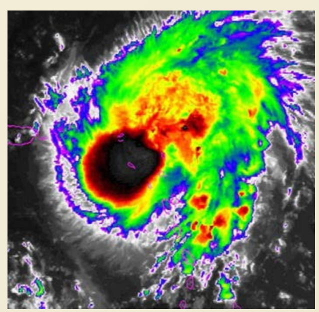
Earth Radiation
- OLR
- SST
- LST

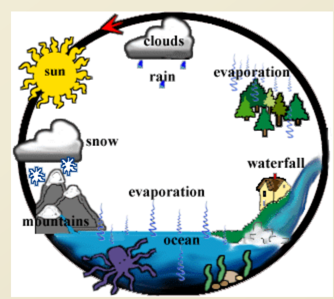
Tropical Cyclones
- Cyclogenesis
- Cyclone Size
- Cyclone Intensity
- Cyclone Rainfall

Hydrological Cycle
- Rainfall
- SST

Himalayan Snow
- Snow Extent



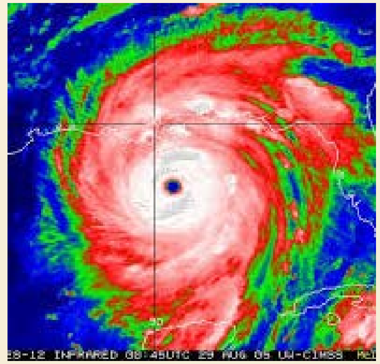




Climate-change studies need long-term continuity of observations !!

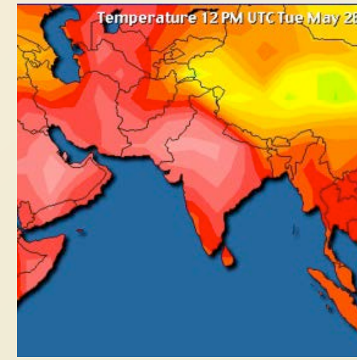
HYDROMETEOROLOGICAL HAZARDS

Floods



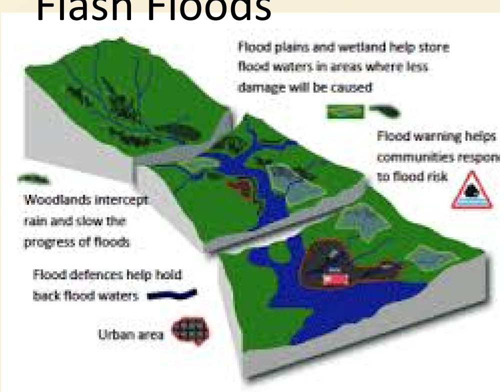
Tropical Cyclones

Droughts



Heat Waves

Flash Floods



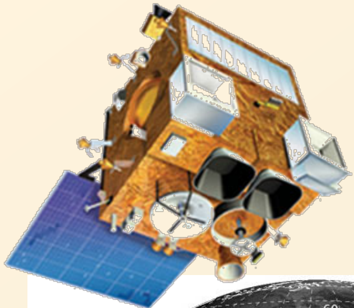
COST OF NATURAL DISASTERS

ECONOMIC LOSS IN ASIA DUE TO NATURAL DISASTERS FROM 1900 TO 2013

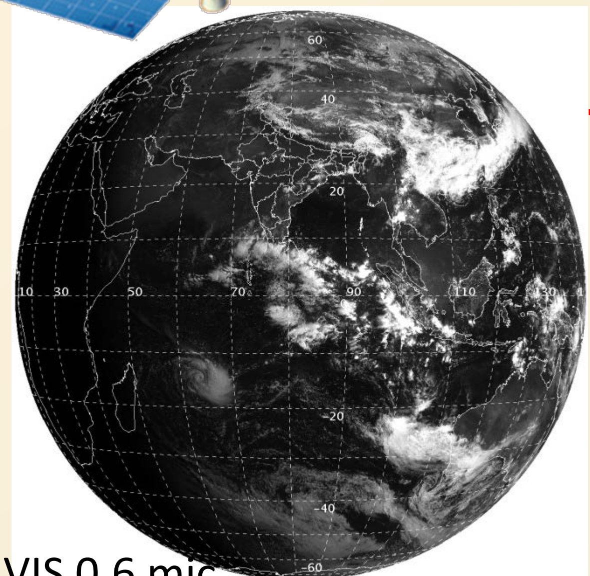
359 Billion	314 Billion	223 Billion	167 Billion	34 Billion	3 Billion
FLOODS	EARTHQUAKE	TSUNAMI	CYCLONE	DROUGHT	Extreme Heat

(FIGURES ARE IN US DOLLARS)

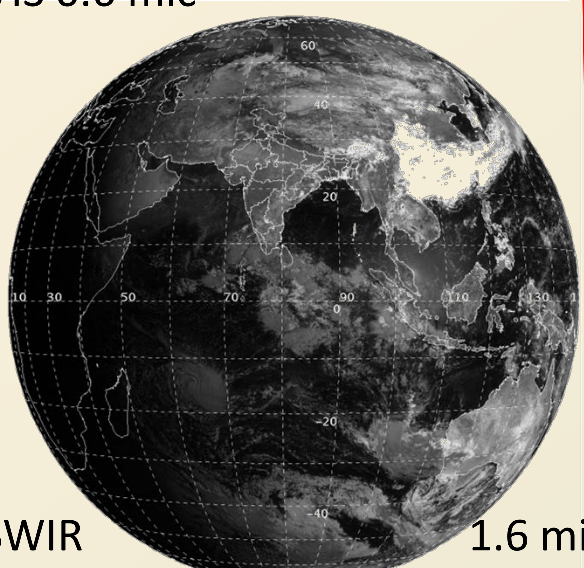
(SOURCE: CENTRE FOR RESEARCH ON THE EPIDEMIOLOGY OF DISASTERS)



INSAT-3D Imager Channels

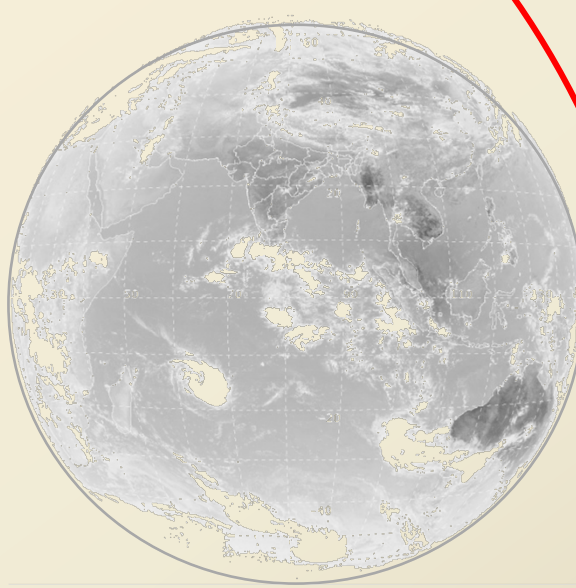


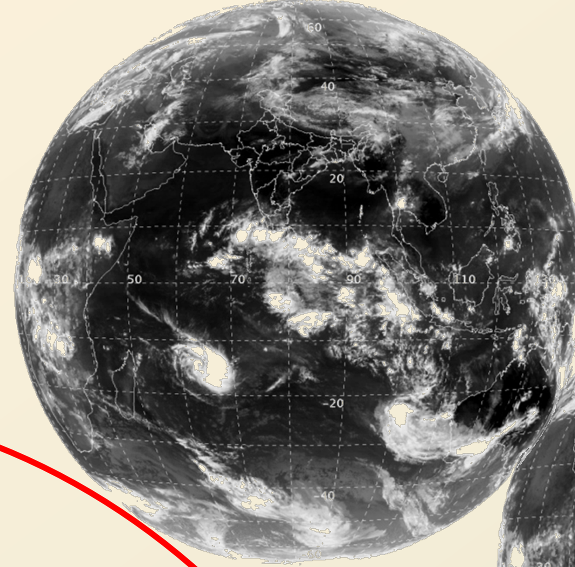
VIS 0.6 mic



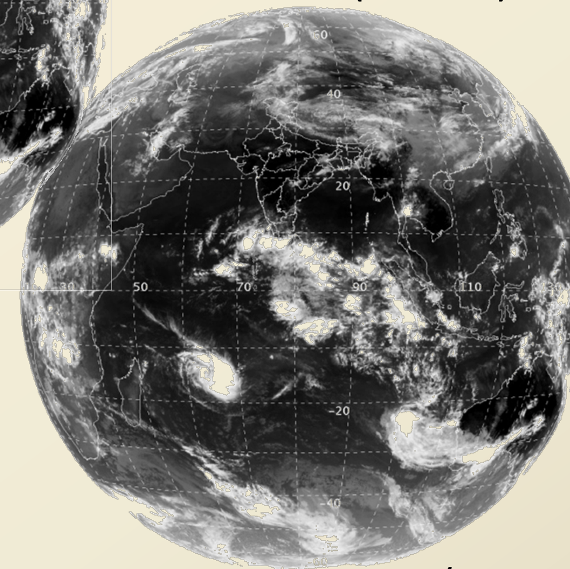
SWIR 1.6 mic

MIR 3.9 Mic

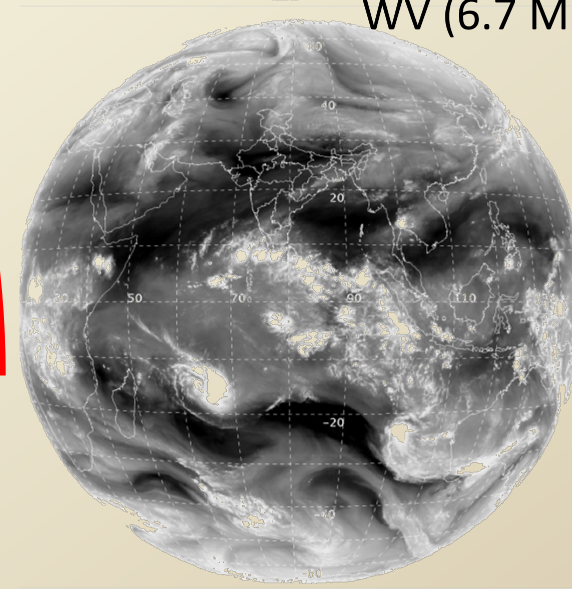




TIR1 (11 Mic)

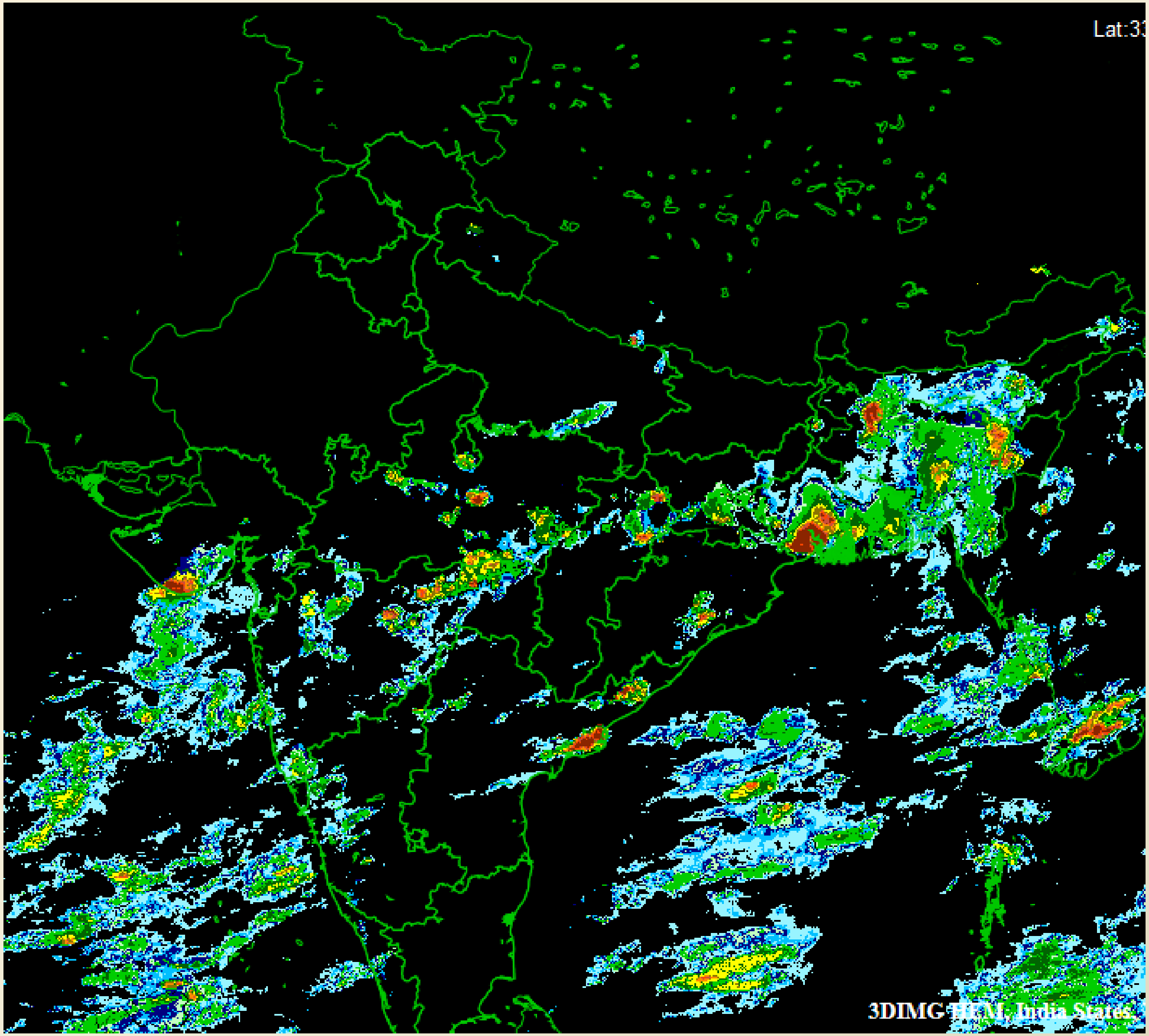


TIR1 (12 Mic)

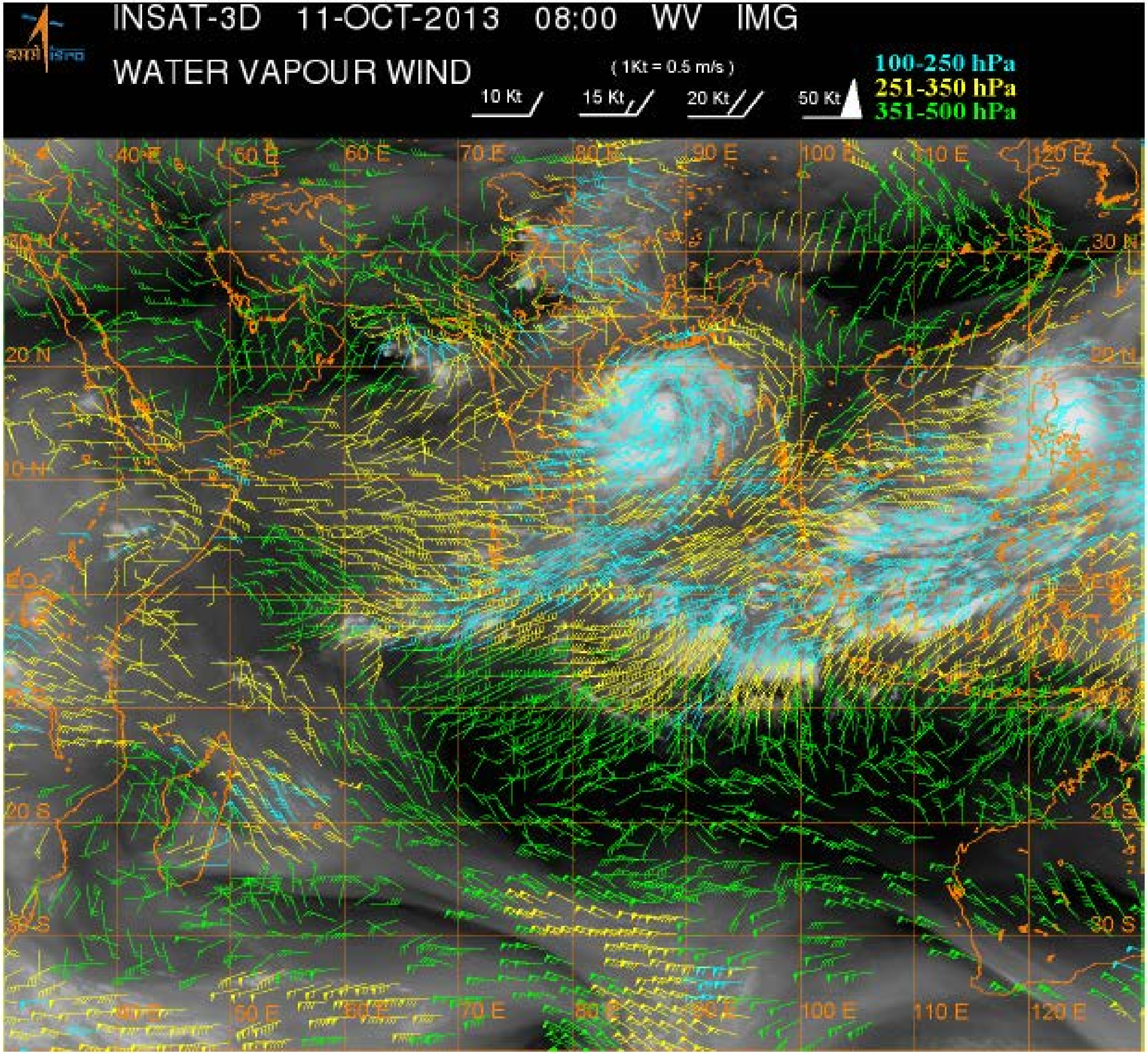


WV (6.7 Mic

High Resolution Rainfall Product using IR and WV Channels



Atmospheric Motion Vector Winds (AMVs)



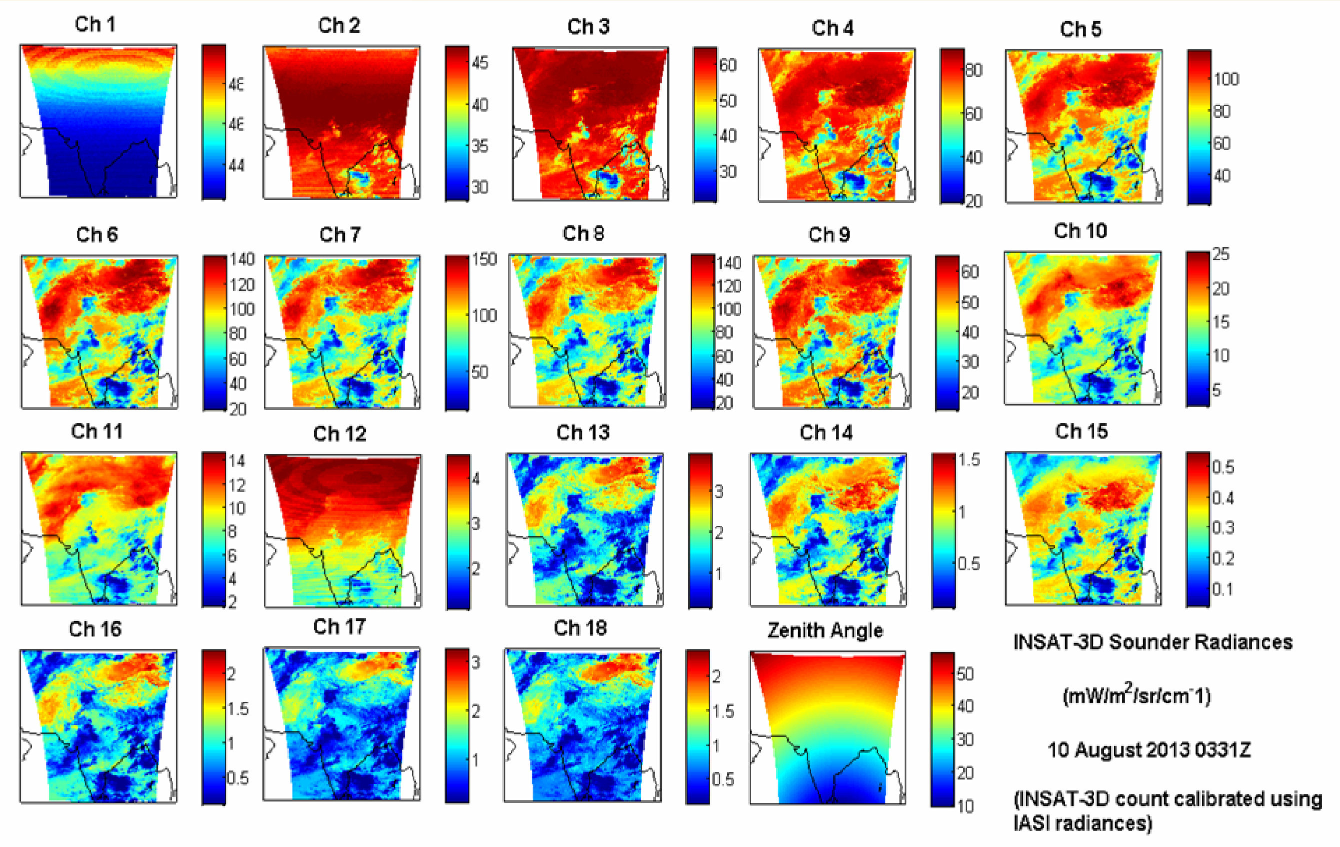
Important Products from INSAT-3D Sounder

Humidity Profiles

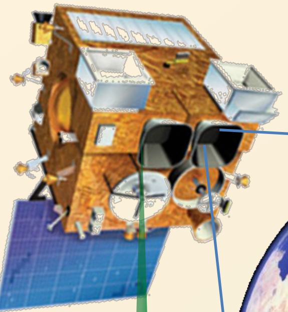
Geopotential Height

Stability Indices

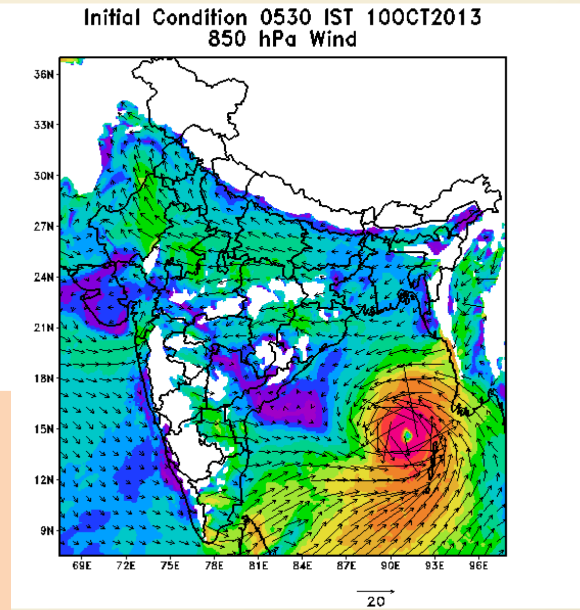
Channel Radiances



Arguably, the most efficient method to use INSAT-3D Data to Assimilate them in NWP models

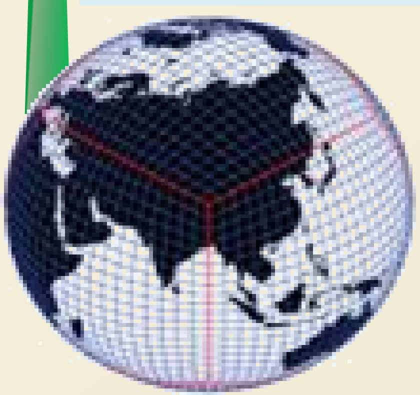


(2)Assimilation process uses few observations to correct the initial conditions of related variables

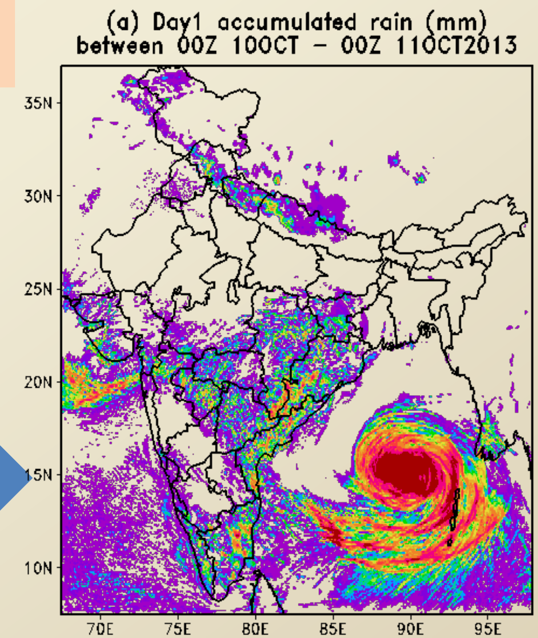


(3) Unfortunately not all the data that comes from INSAT-3D Can be assimilated. Most important of them is the cloudy data

(1) NWP models contain the complete (almost) Processes that govern the weather.

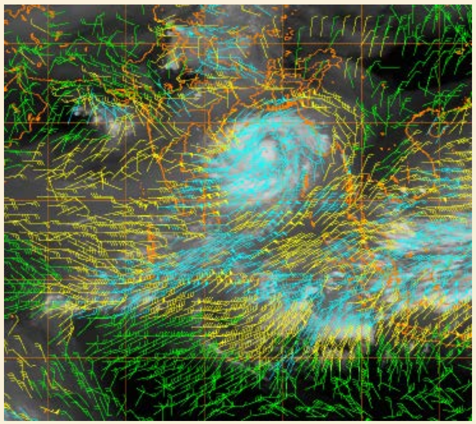


Data Assimilation System

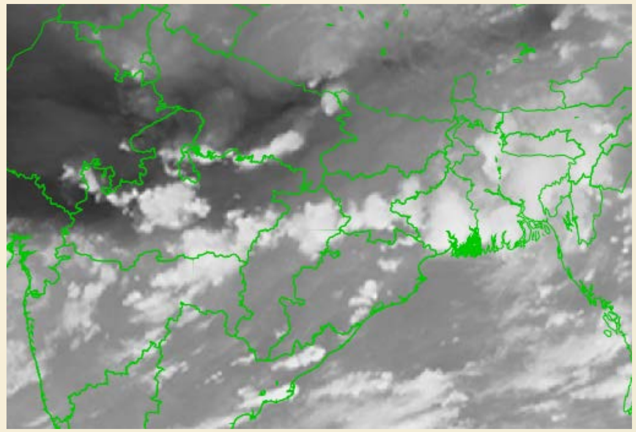


What INSAT-3d Data Gets Assimilated in NWP Models ?

Vis/IR/WV/NIR WInds



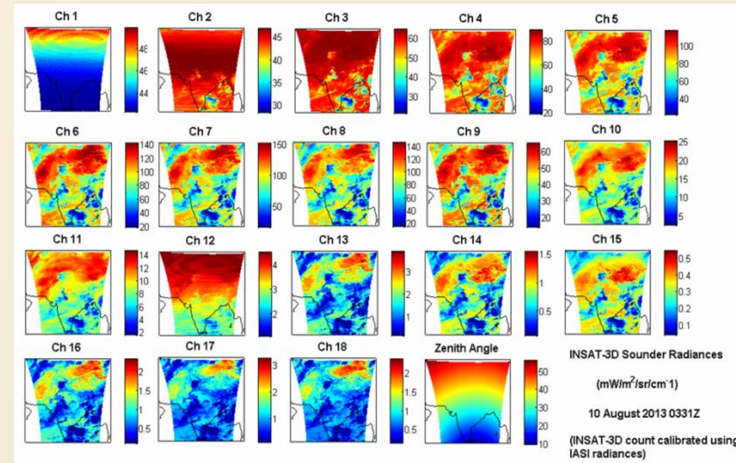
WV Radiances



No Clouds Allowed

INSAT-3D Sounder

Channel Radiances

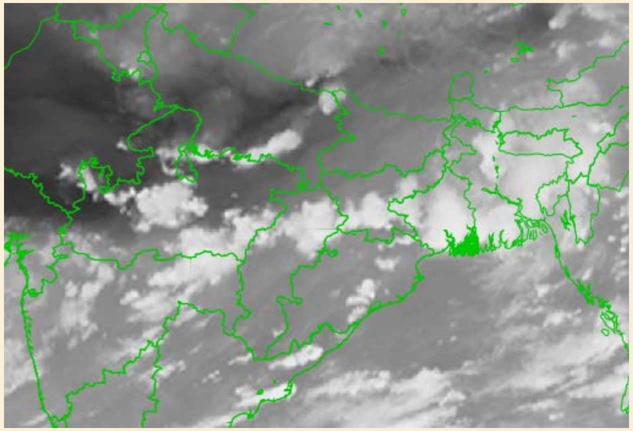


No Clouds Allowed

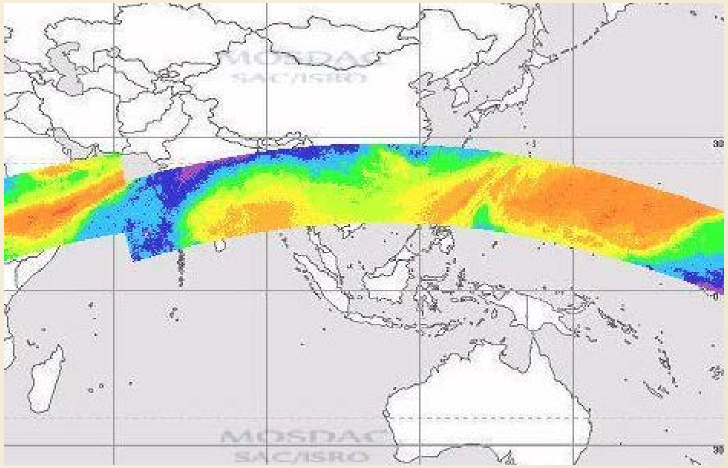
…….. So, we have to find other ways to use information from clouds !

Strategies for Optimum Utilization of Satellite Observations

Visible/Infrared Data



Active/Passive Microwave



For NWP Assimilation

Use Clear-Sky Data (< 30% Area)

Use Cloud-cleared Data (~ 60% Area)

Use Cloudy & rainy data (100% Area)

For diagnostic & nowcasting techniques

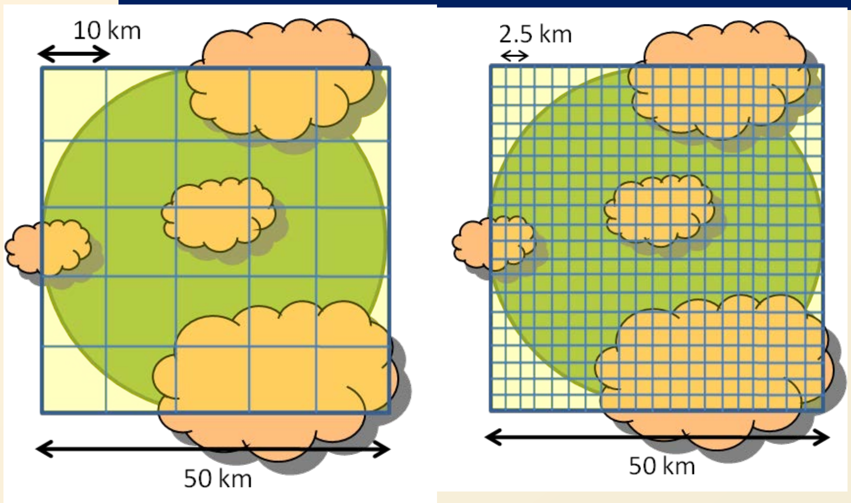
Clouds are not limitations, but the source of information.

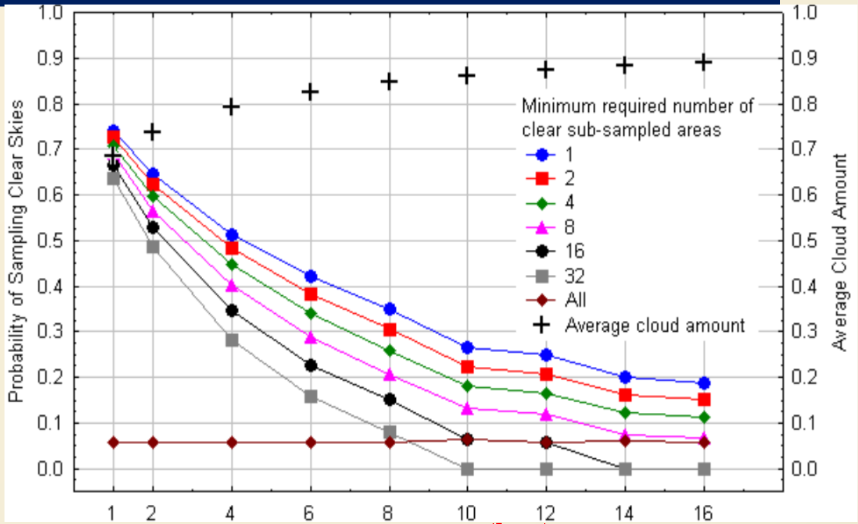
Clouds are not limitations, but the Rainy areas need to be flagged.

Noisy channels to be identified.

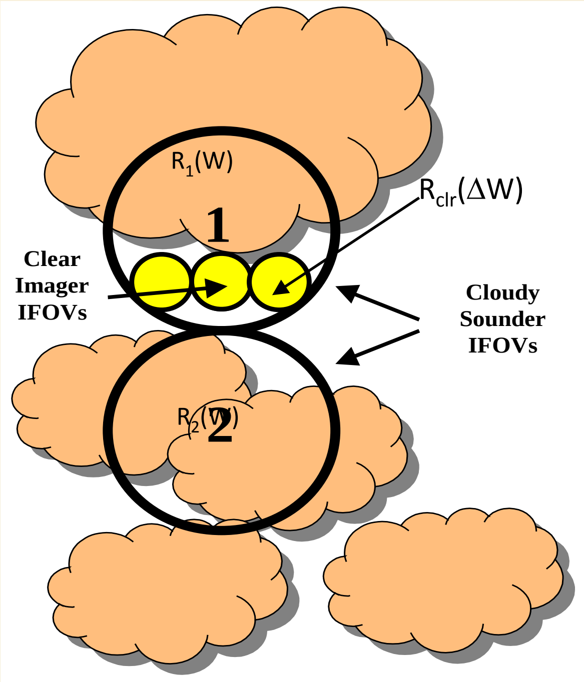
Cloudy Sky Problem ? *Cloud Clearing*

(Assumes Horizontally Uniform Cloud Height and Cloud Microphysics)





FOV size (km)



High Res. IR window channel

Cloud cleared radiance, $R_{clr}(\nu)$

$$R_{clr}(\nu) = \frac{R_1(\nu) - N^*(\nu) R_2(\nu)}{1 - N^*(\nu)}$$

where $N^*(\nu)=\varepsilon(\nu)_1 N_1/\varepsilon_2(\nu) N_2$.

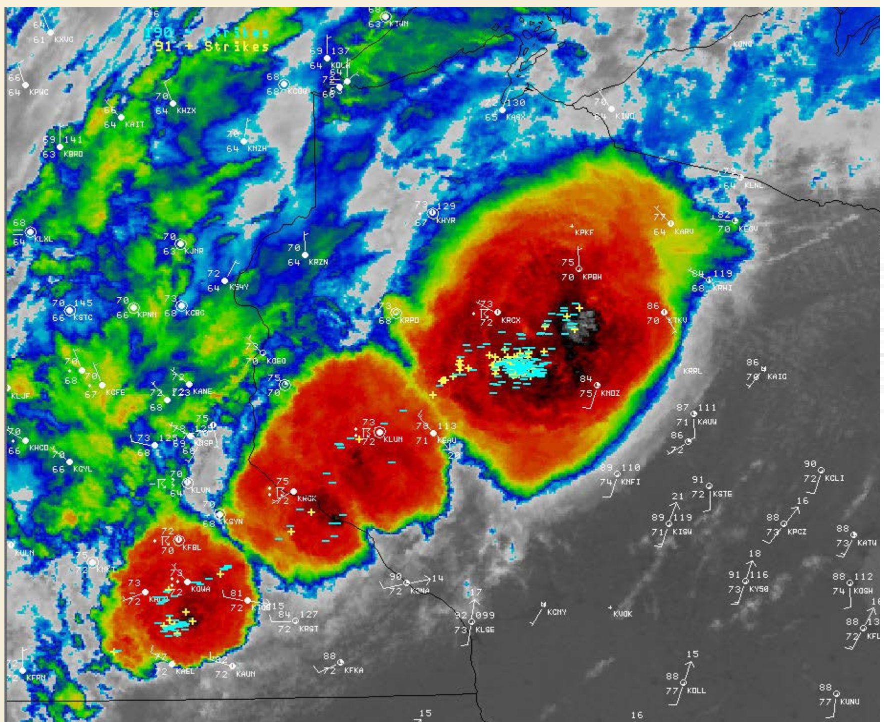
$$N^*(W) = \frac{R_1(W) - \overline{R}_{clr}(\Delta W)}{R_2(W) - \overline{R}_{clr}(\Delta W)}$$

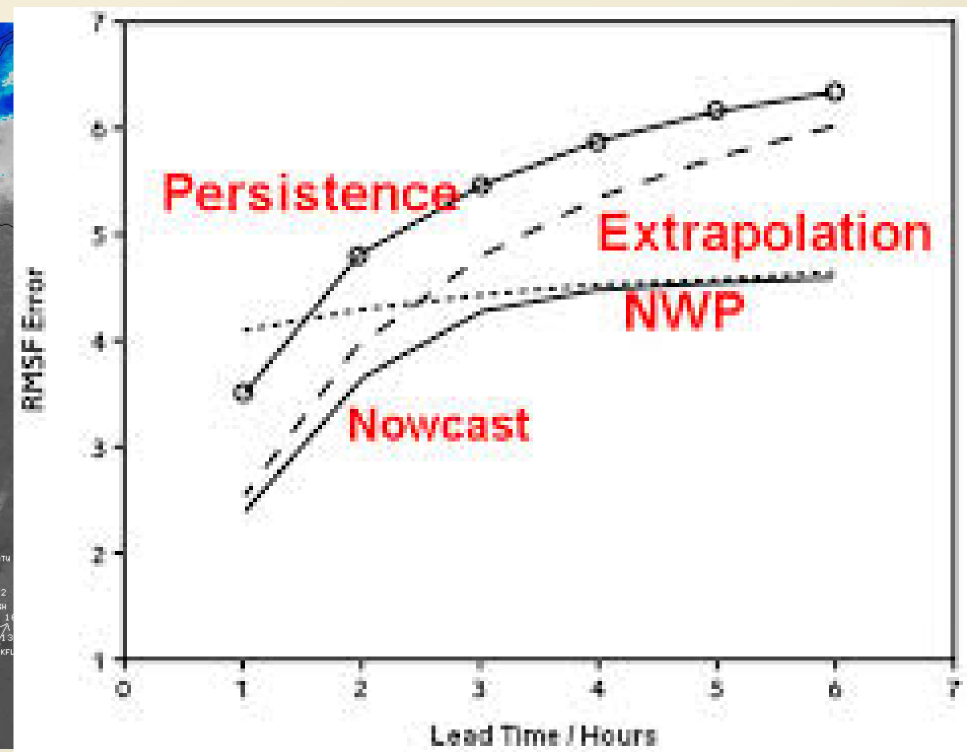
$\underline{R}_{clr}(\nu)$ can be computed from high resolution IR window channel or MW window channel

Coarser Res. MW channel

Satellite Based Nowcasting of Extreme Events

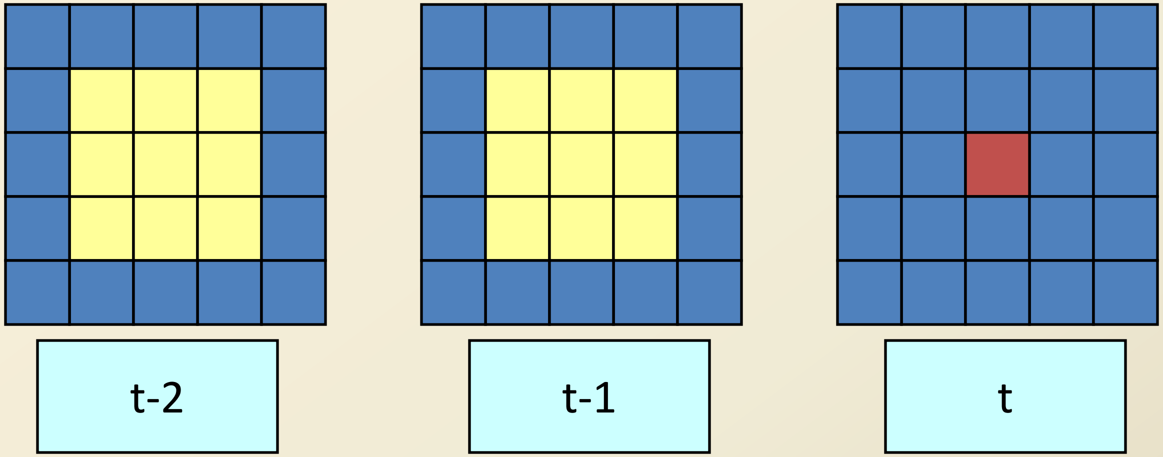
- Nowcasting combines a description of the current state of the atmosphere and a short-term forecast of how the atmosphere will evolve during the next few hours (~ 6 hours)
- Typically shorter than most operational short-range forecasts.
- Nowcasting techniques have better skill than NWP models during first 6-H.





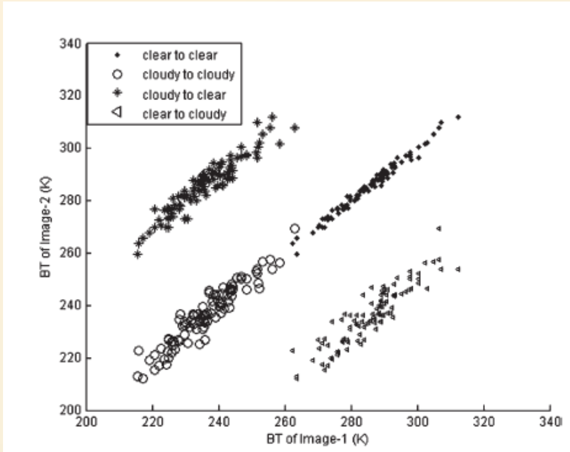
Nowcating using satellite image prediction : Spatio-Temporal Auto Regressive (STAR) Technique

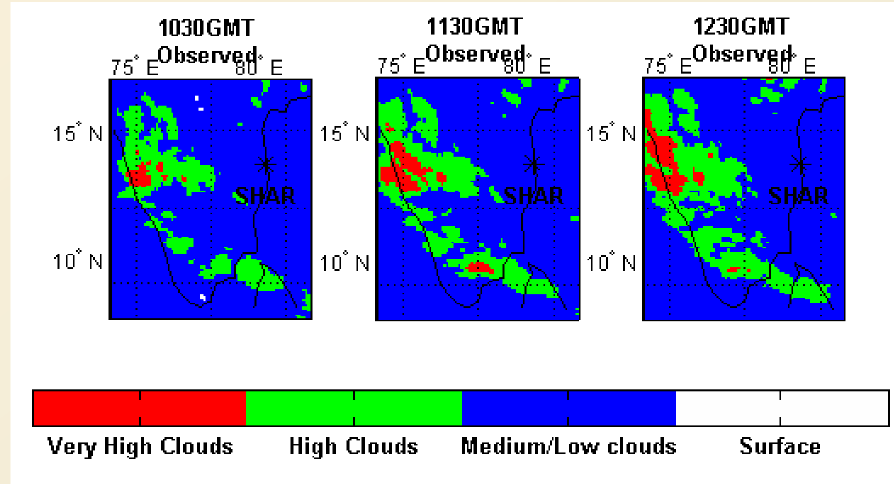
- Based on the principle that any output system is spatially and temporally correlated with its neighbouring region

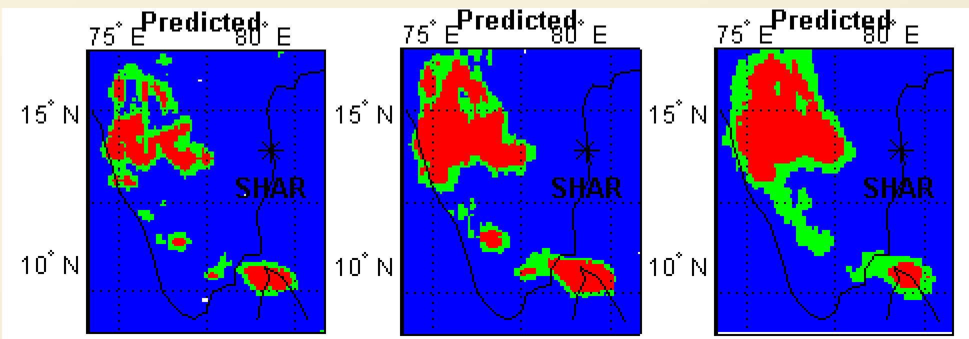


"Extrapolation of Sequence of Geo-stationary Satellite Images for Weather Nowcasting, IEEE GEOSCIENCE AND REMOTE SENSING LETTERS, VOL. 8, NO. 2, 2011

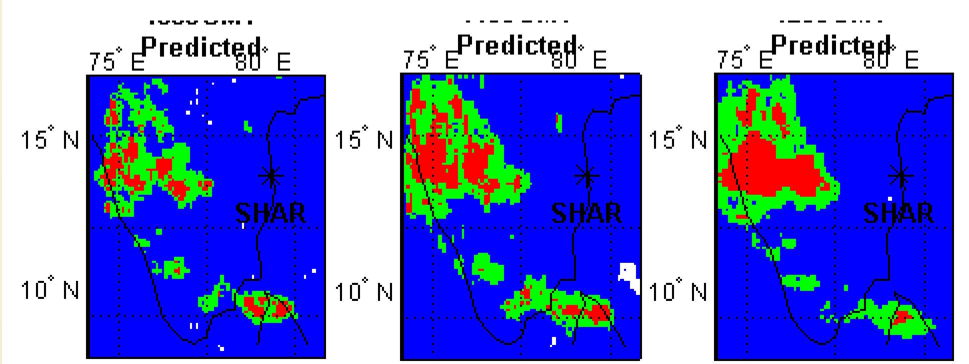
Implementation of Clustering with STAR







Earlier Operational Algorithm

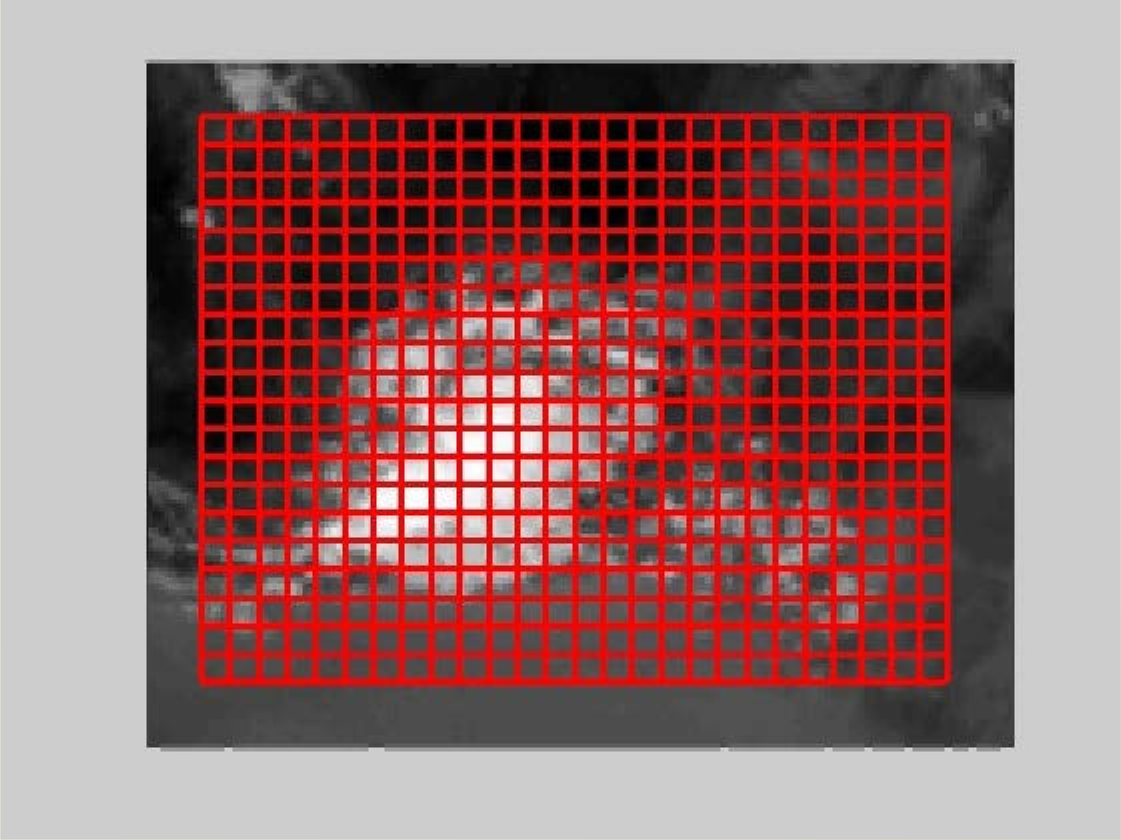


With Fuzzy Clustering

IEEE TRANSACTIONS on GEOSCIENCE AND REMOTE SENSING , ***DOI: 10.1109/TGRS.2013.2280094***

Tracking of clouds :Active contour Models

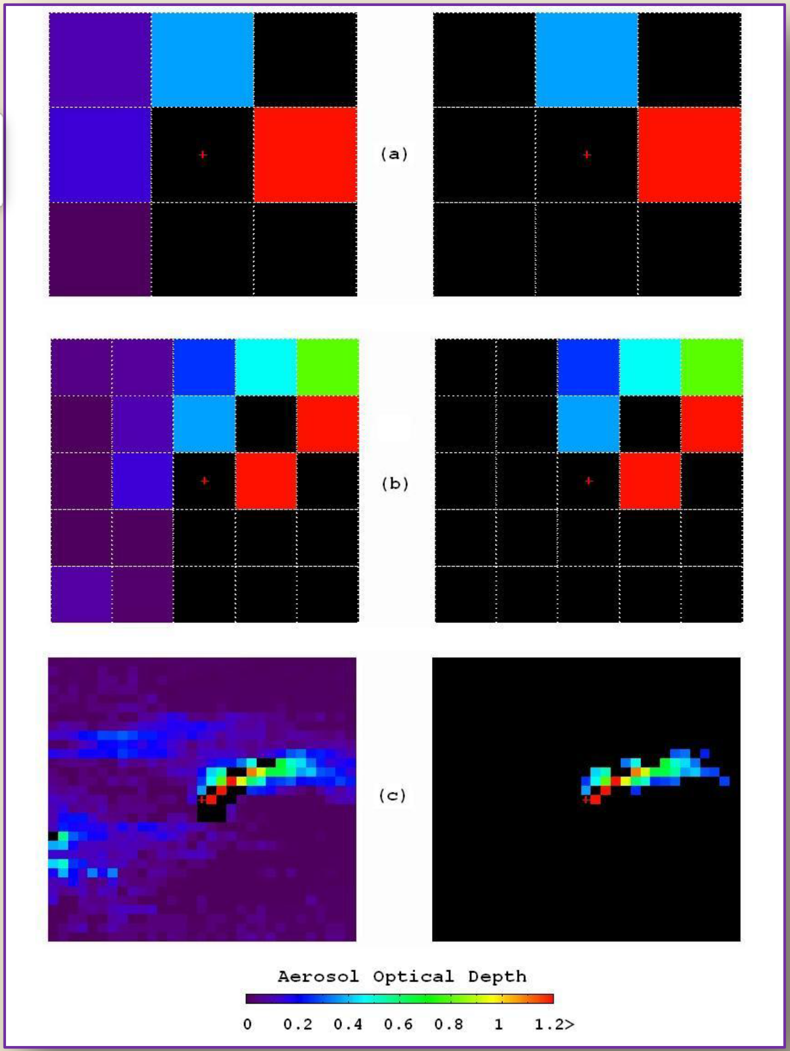
- The intensity distribution of cloud mass is modelled as an active flexible membrane
- The cloud mass is tracked in the consecutive images.
- Based on the tracking, future cloud mass is extrapolated by regression



Tracking and nowcasting of convective systems using Source Apportionment

What is Source Apportionment ?

- **Source Apportionment Technique (SA) is the method to allocate the contributions of different sources to a location of interest.**

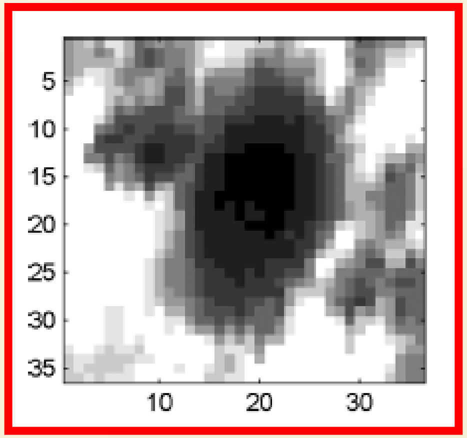


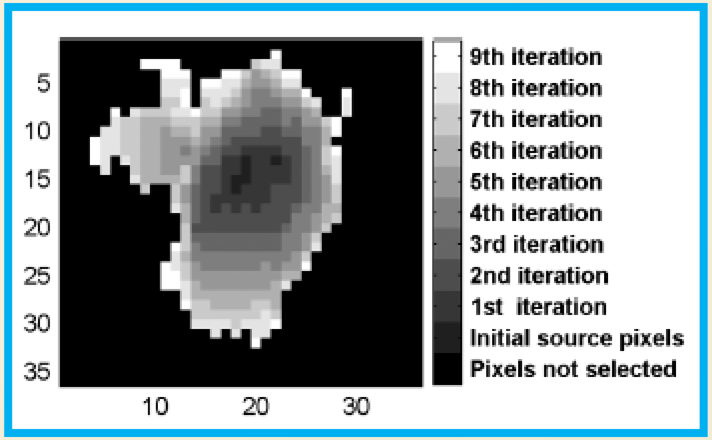
Source Apportionment Technique for Nowcasting of MCS

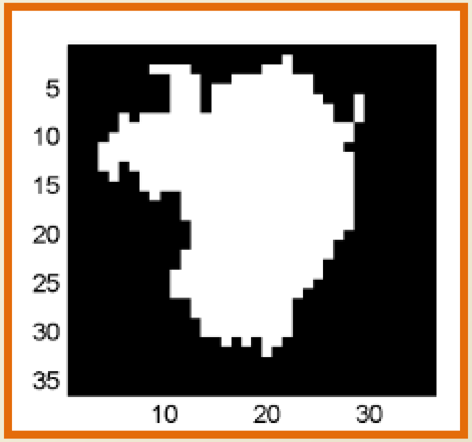
The pixels having minimum brightness temperature (Tbmin) are treated as initial source pixels (P0)

Make 5x5 pixels neighborhood of each P0 and select those pixels as P1 that ratio of Tb(P1)/Tb(P0) less than threshold ratio (R)

$Tb \leq 241$ K and $\Delta Tb < 5$ K







The pixels P1 act as new sources and step 2 is repeated iteratively to select pixels Pi at each i [th] iteration

The iteration is terminated for the conditions

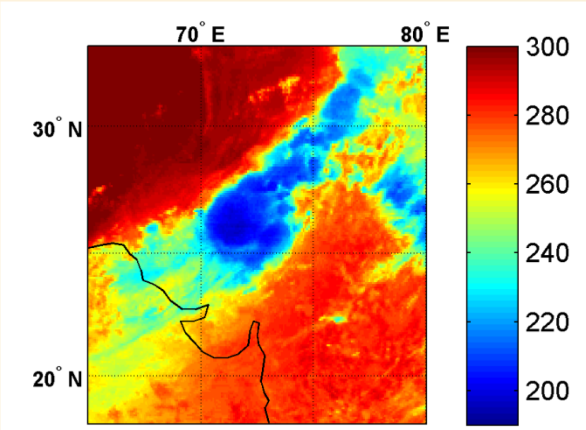
a) No new pixels fulfill the search criteria

b) Tb of selected pixels

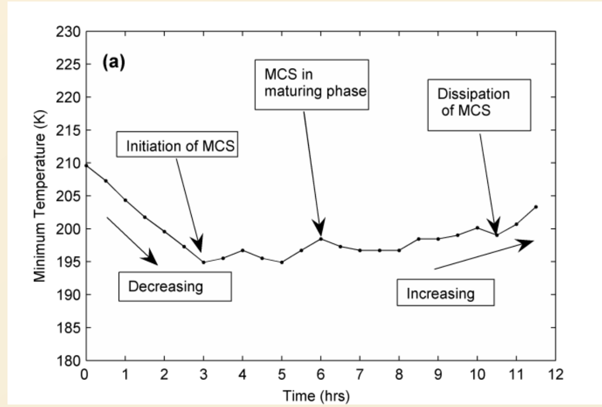
> 241 K

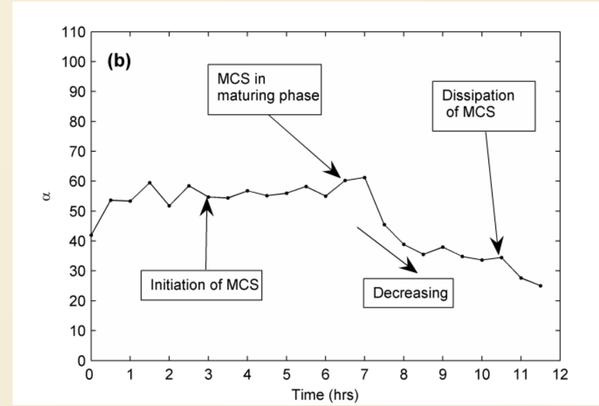
The set of pixels will constitute the extracted cloud system

Tracking and Nowcasting of Mesoscale Convective Systems (MCS) using SA

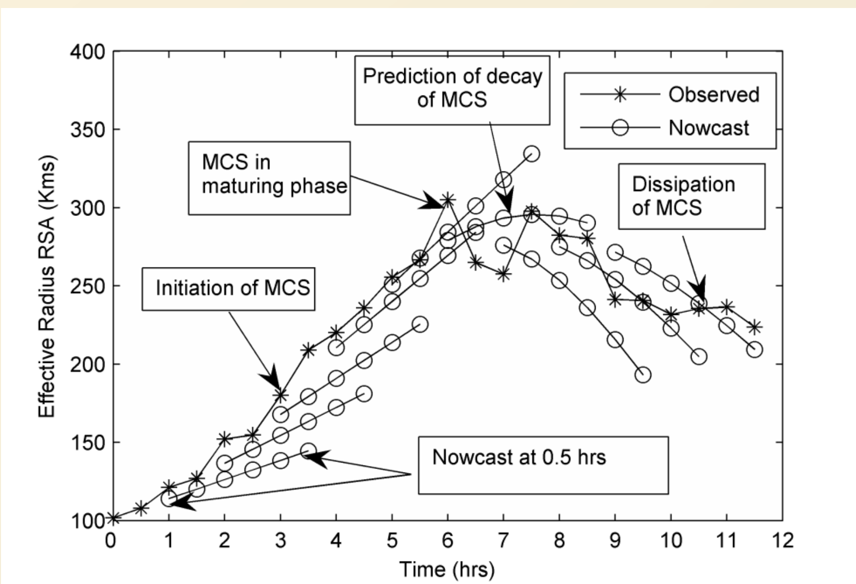


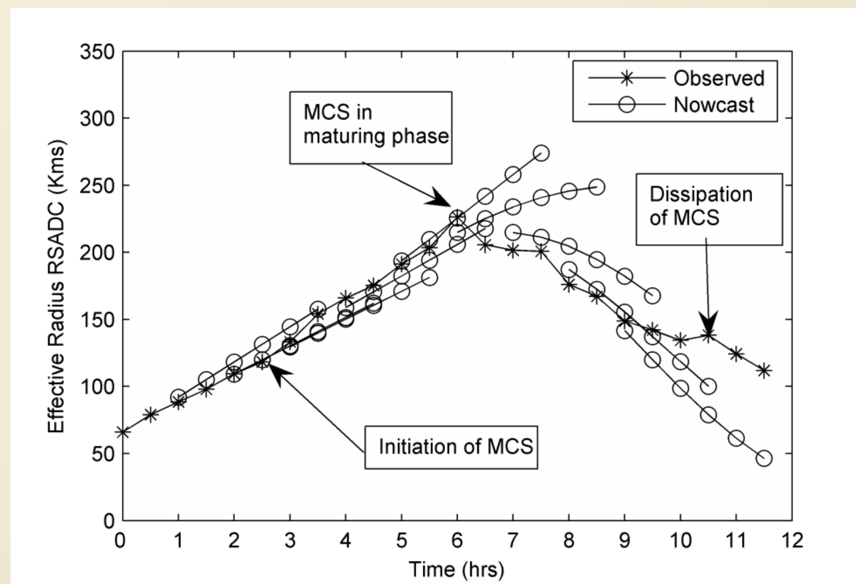
Location of MCS on 13 August 2008 at 1030 GMT using Kalpana TIR BT image





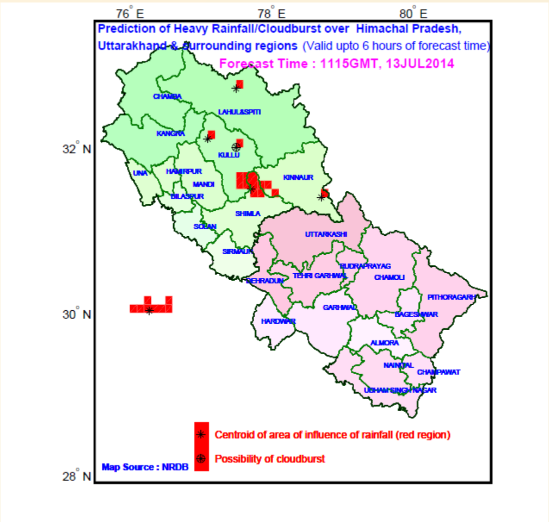
Tracking of (a) Minimum Temperature (b)ratio (%) of deep convective area to the total area of MCS

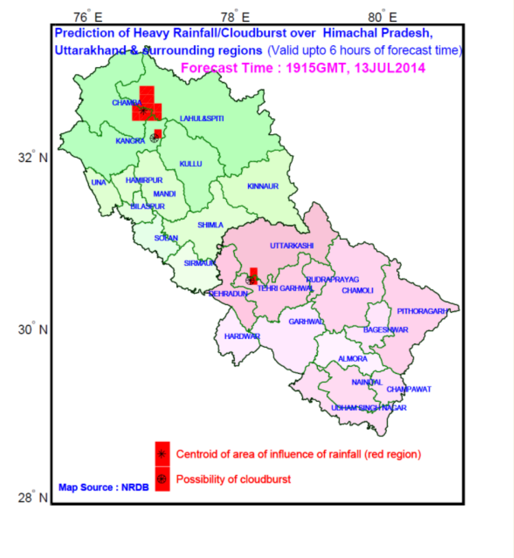


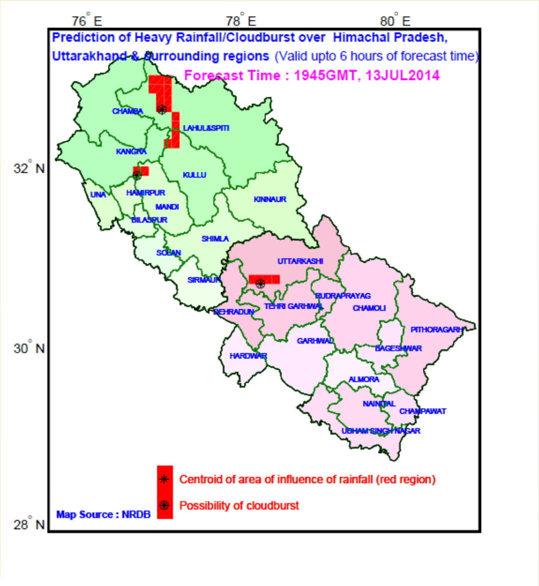


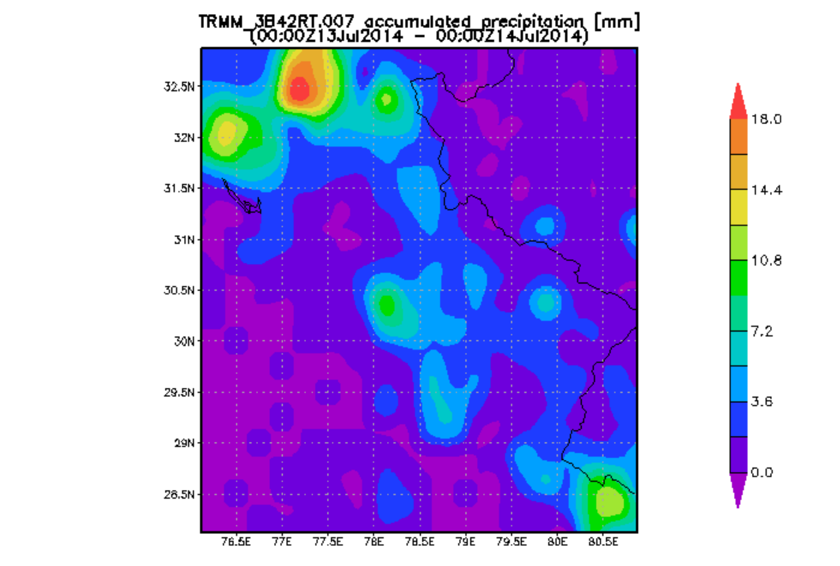
Nowcasting of MCS using size parameters

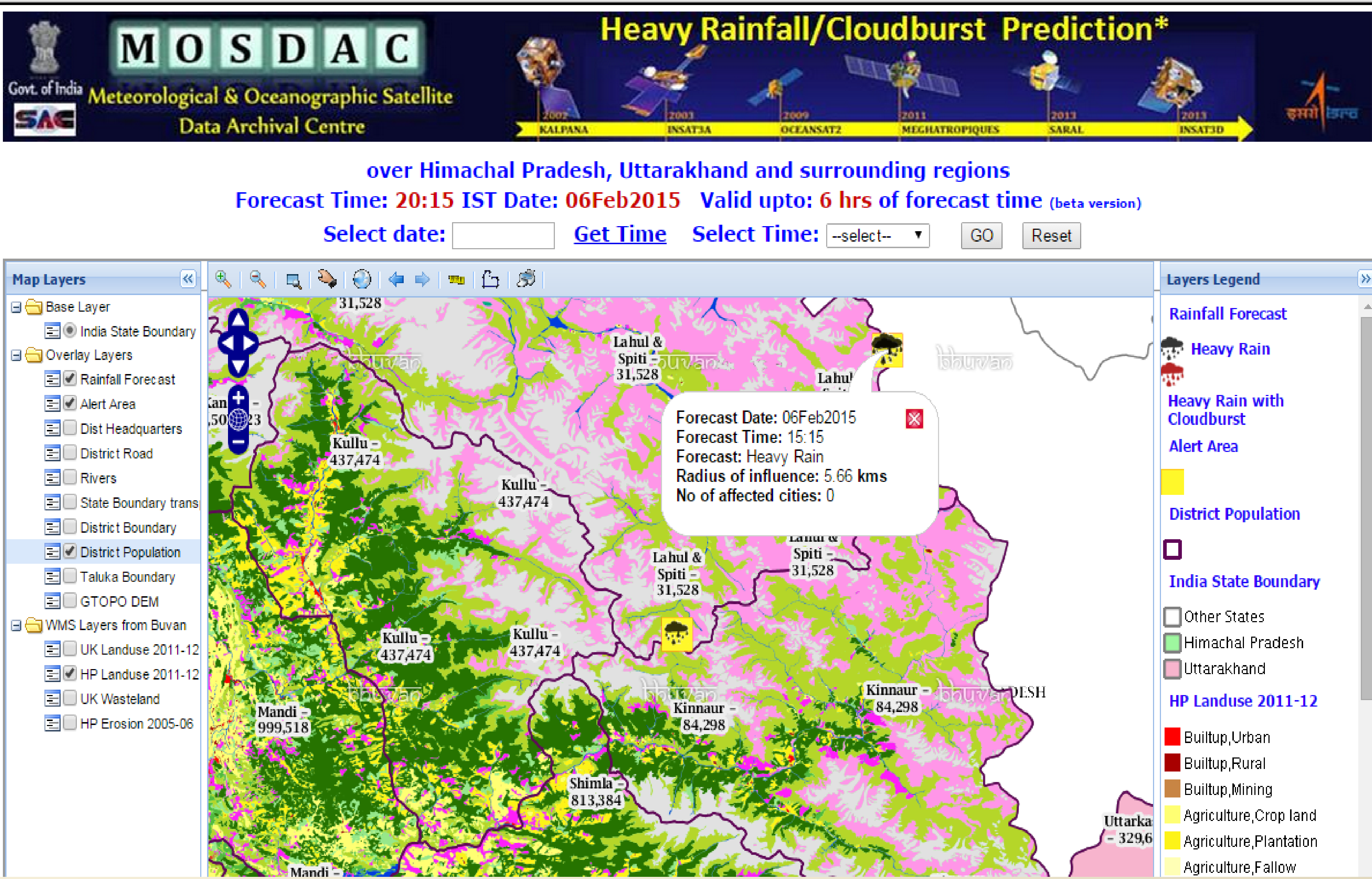
Comparison of real time heavy rainfall nowcasts for 13 July 2014 (Uttarakhand and Himachal Pradesh) with TRMM rainfall



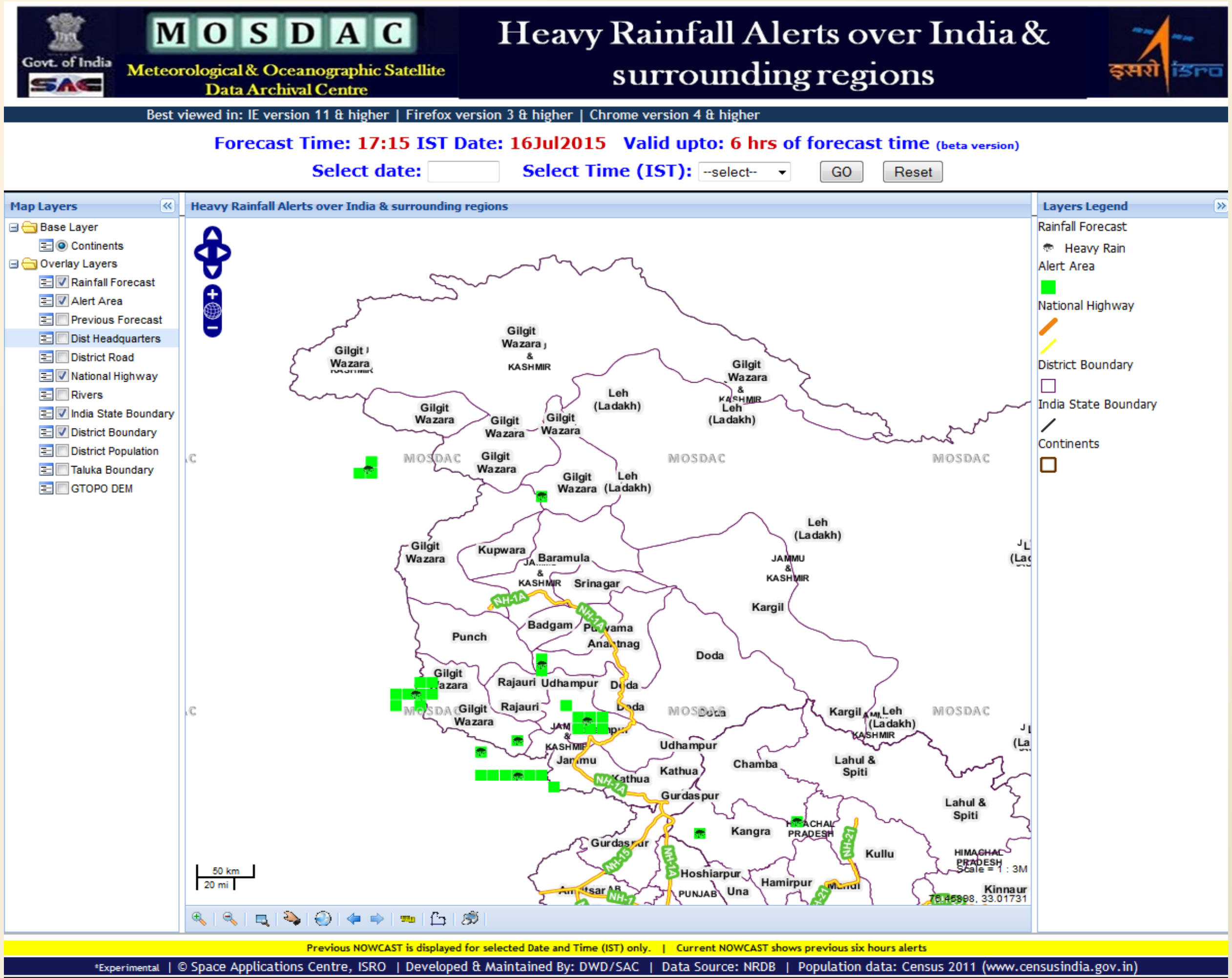







MOSDAC
Govt. of India
SAC
Meteorological & Oceanographic Satellite Data Archival Centre
Heavy Rainfall/Cloudburst Prediction*
2002 KALPANA
2003 INSAT3A
2009 OCEANSAT2
2011 MEGHATROPIQUES
2013 SARAL
2013 INSAT3D
over Himachal Pradesh, Uttarakhand and surrounding regions
Forecast Time: 20:15 IST Date: 06Feb2015 Valid upto: 6 hrs of forecast time (beta version)
Select date:
Get Time
Select Time: --select--
GO
Reset
Map Layers
Base Layer
India State Boundary
Overlay Layers
Rainfall Forecast
Alert Area
Dist Headquarters
District Road
Rivers
State Boundary trans
District Boundary
District Population
Taluka Boundary
GTOPO DEM
WMS Layers from Buvan
UK Landuse 2011-12
HP Landuse 2011-12
UK Wasteland
HP Erosion 2005-06
Lahul & Spiti - 31,528
Kullu - 437,474
Mandi - 999,518
Shimla - 813,384
Kinnaur - 84,298
Forecast Date: 06Feb2015
Forecast Time: 15:15
Forecast: Heavy Rain
Radius of influence: 5.66 kms
No of affected cities: 0
Layers Legend
Rainfall Forecast
Heavy Rain
Heavy Rain with Cloudburst
Alert Area
District Population
India State Boundary
Other States
Himachal Pradesh
Uttarakhand
HP Landuse 2011-12
Builtup,Urban
Builtup,Rural
Builtup,Mining
Agriculture,Crop land
Agriculture,Plantation
Agriculture,Fallow

Kashmir extreme rainfall 16 July 2015



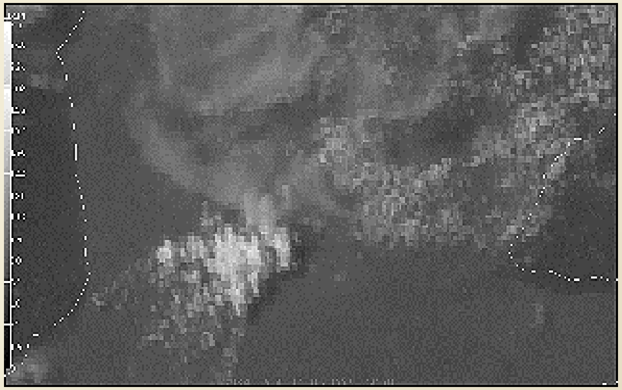
Real Time Alerts using SAC Nowcast Model displayed on MOSDAC web based GIS application (Green pixels are the alert area. The yellow track is the National Highway which was badly affected in the heavy rain events)

Thunderstorm Prediction : NWP Challenges

Overview

- Prediction of initiation, location & intensity of thunderstorm is still a major problem in operational meteorology

- Thunderstorms and flash floods cause more damage to life compared to other meteorological hazards



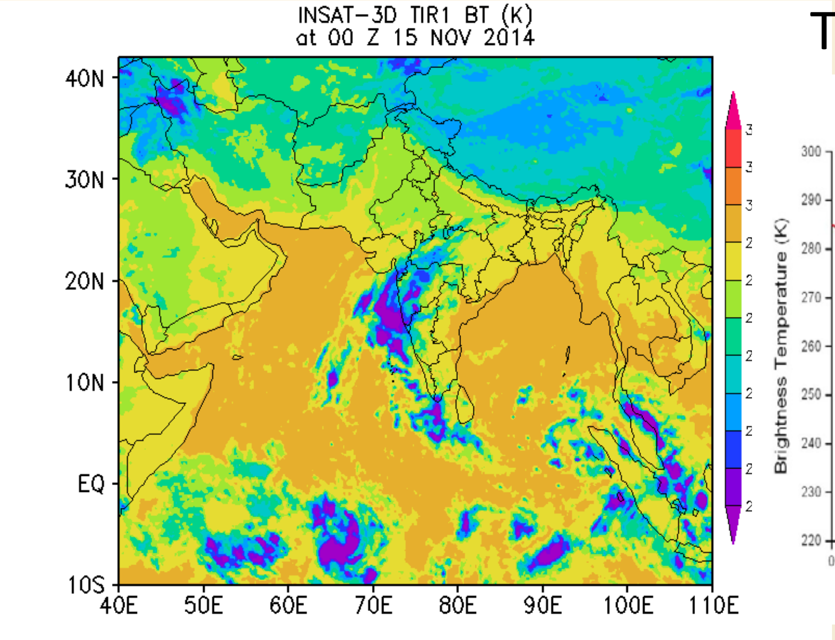
- Thunderstorms are sudden events that give very little time to respond and preparedness

- Predictions of these events is the only way to mitigate the loss of life.

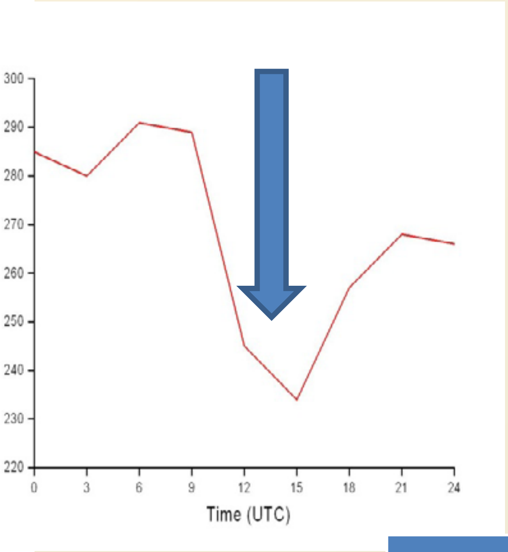
- Improving the prediction accuracy of thunderstorms are therefore much needed

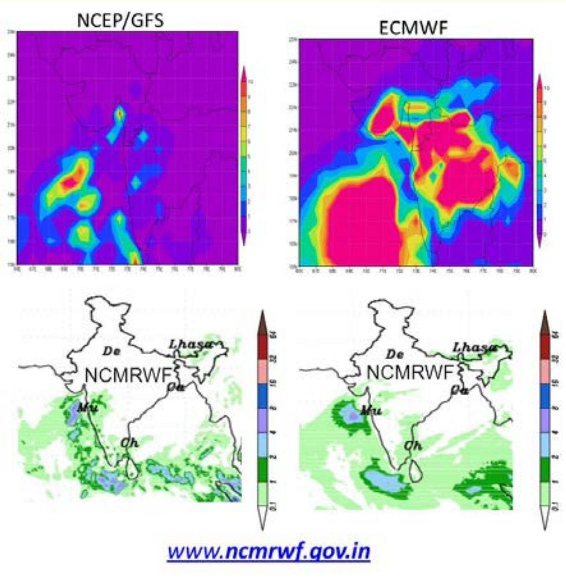
Challenges in Predicting Extreme Weather Event

(Thunderstorm over Ahmedabad, 15 November 2014



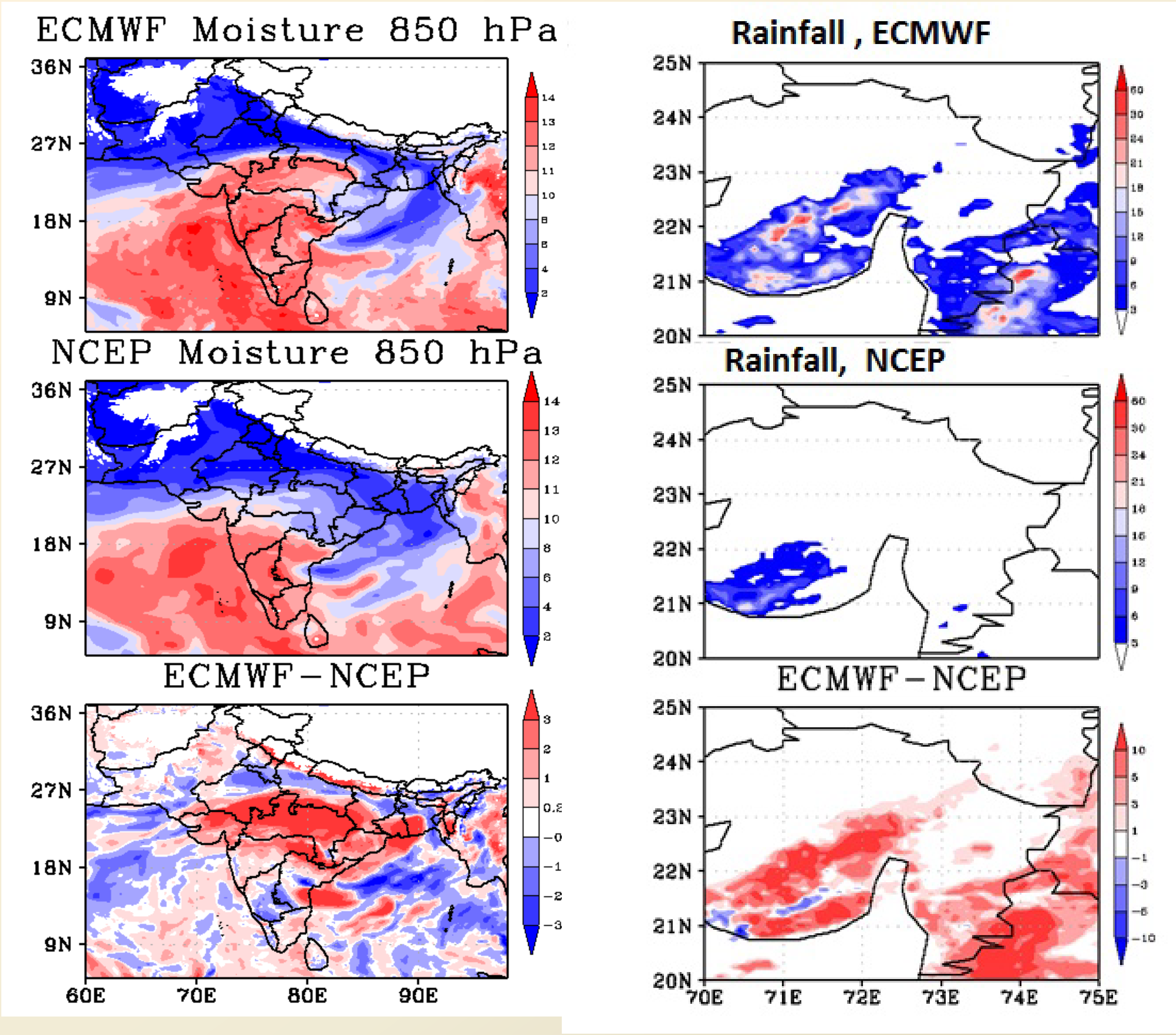
Thunderstorm strikes





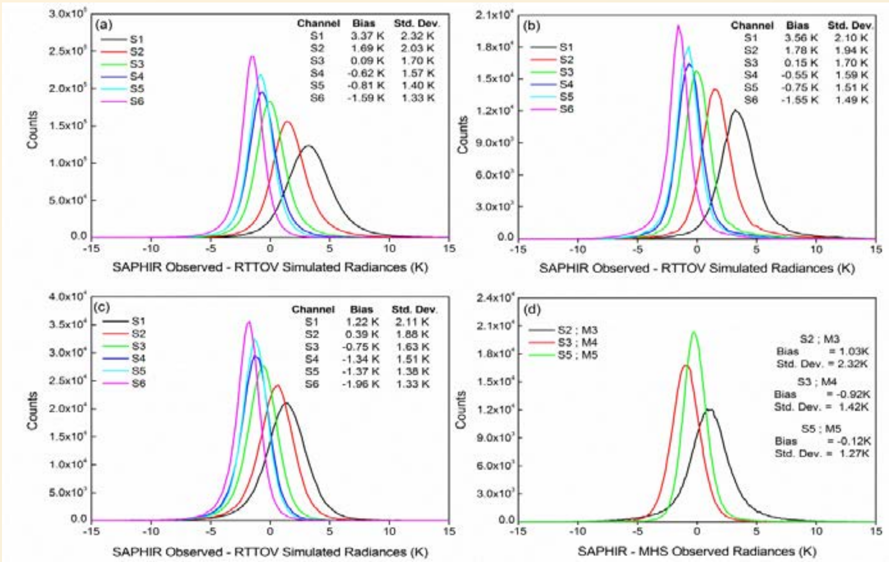
Model	Thunderstorm Predicted ?
ECMWF	No
NCEP GFS	No
NCMRWF GFS	No
NCMRWF UM	No
IMD (WRF)	No

Impact of atmospheric moisture on rainfall associated with thunderstorm

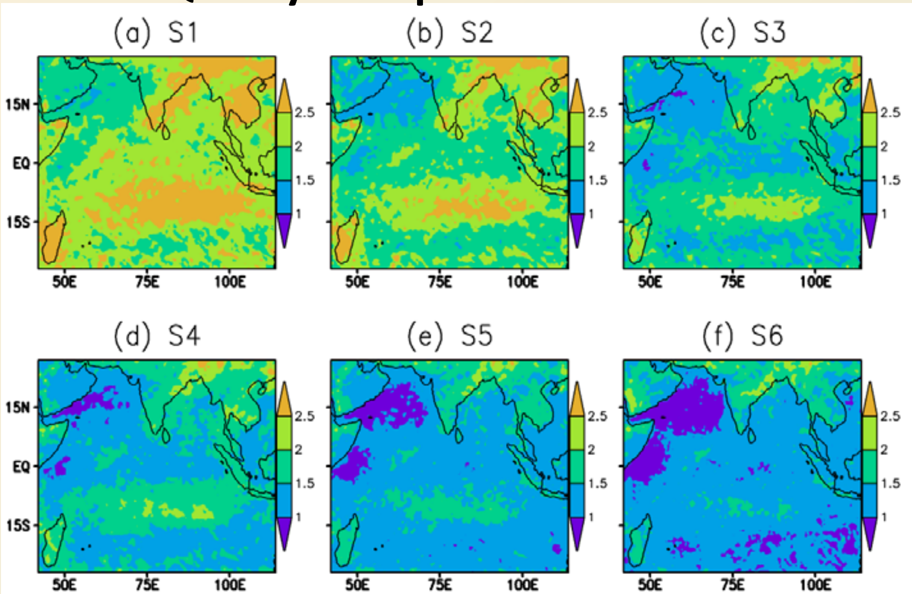


Assimilation of SAPHIR Radiance

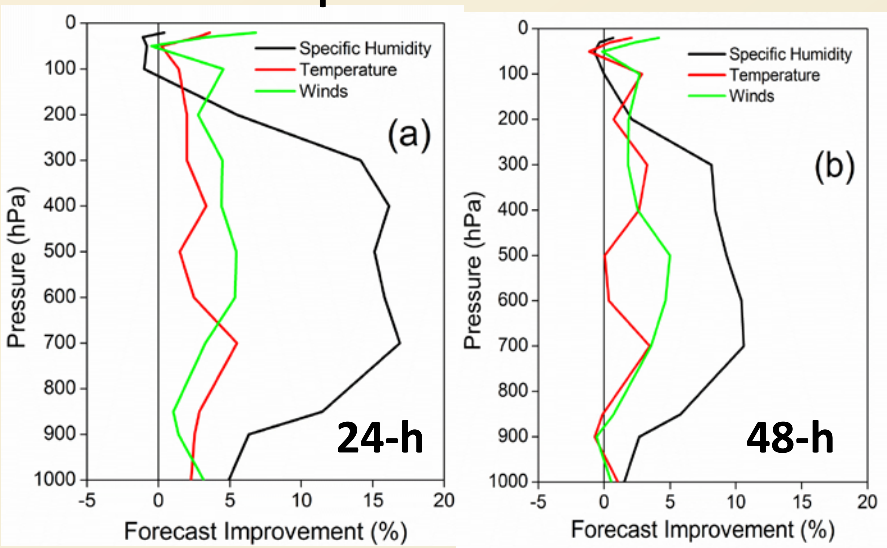
Quality of Saphir Radiance



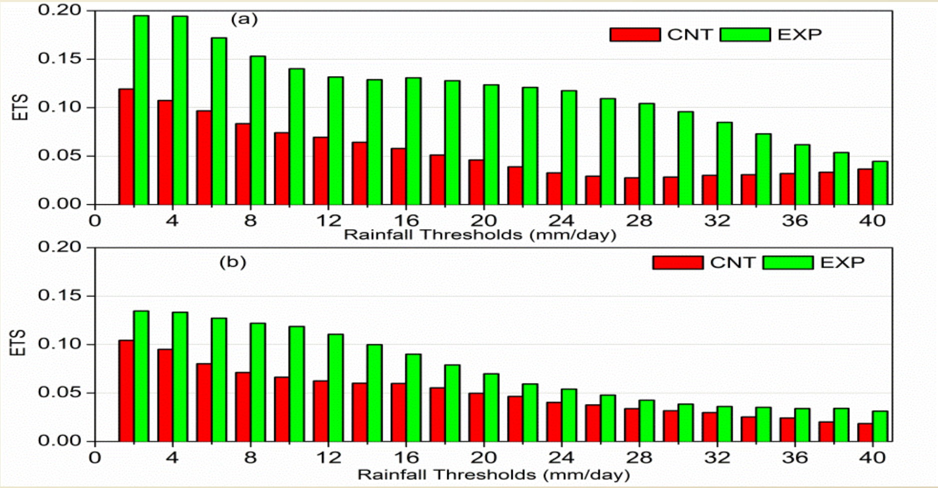
Quality of Saphir Radiance



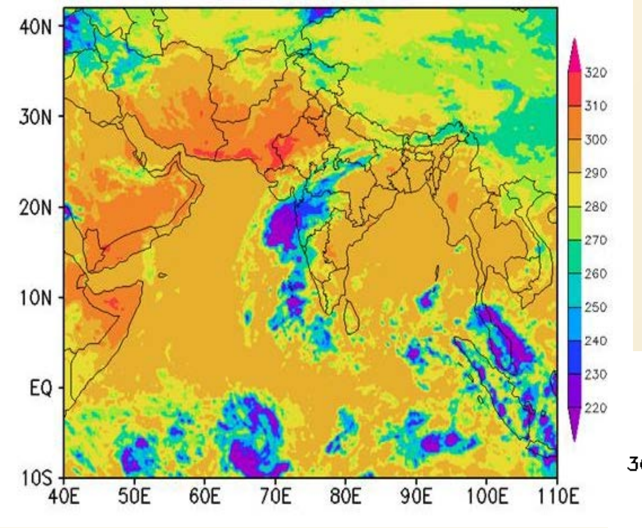
Impact on Forecast



Rainfall prediction skill

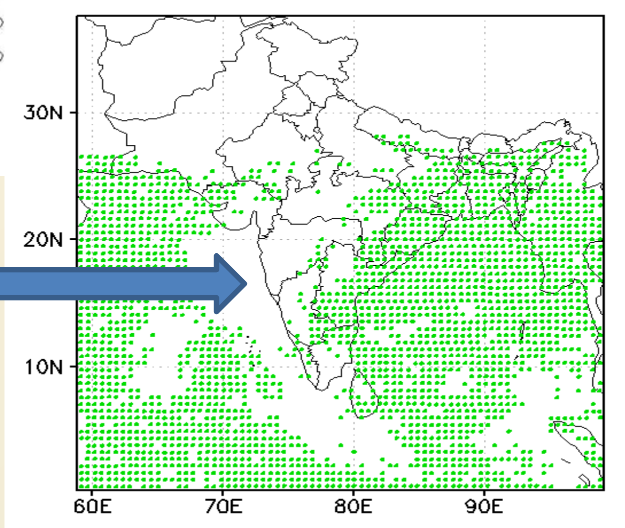


Impact of convective scale moisture information on thunderstorm prediction

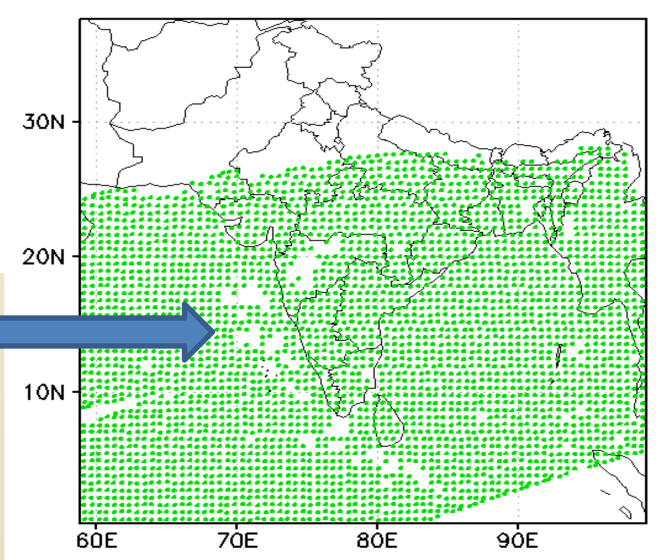


00 UTC, 15th November 2014

Infrared: INSAT-3D Imager



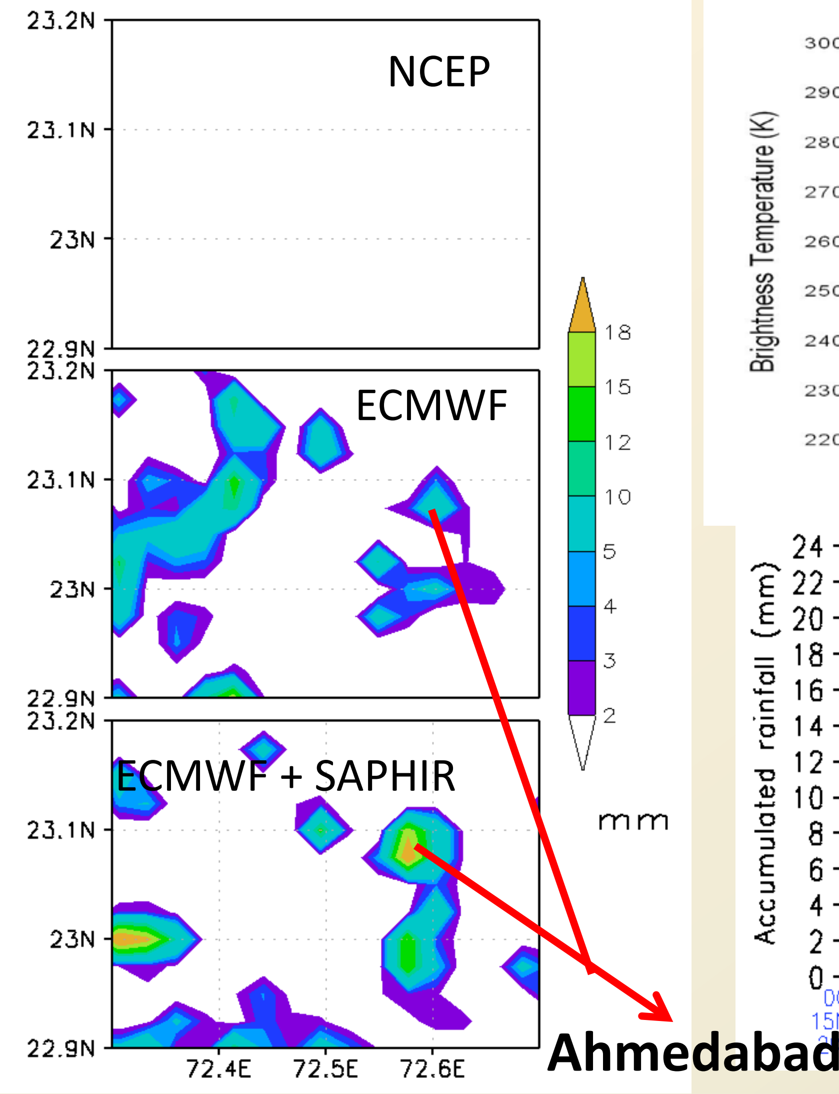
Microwave: SAPHIR

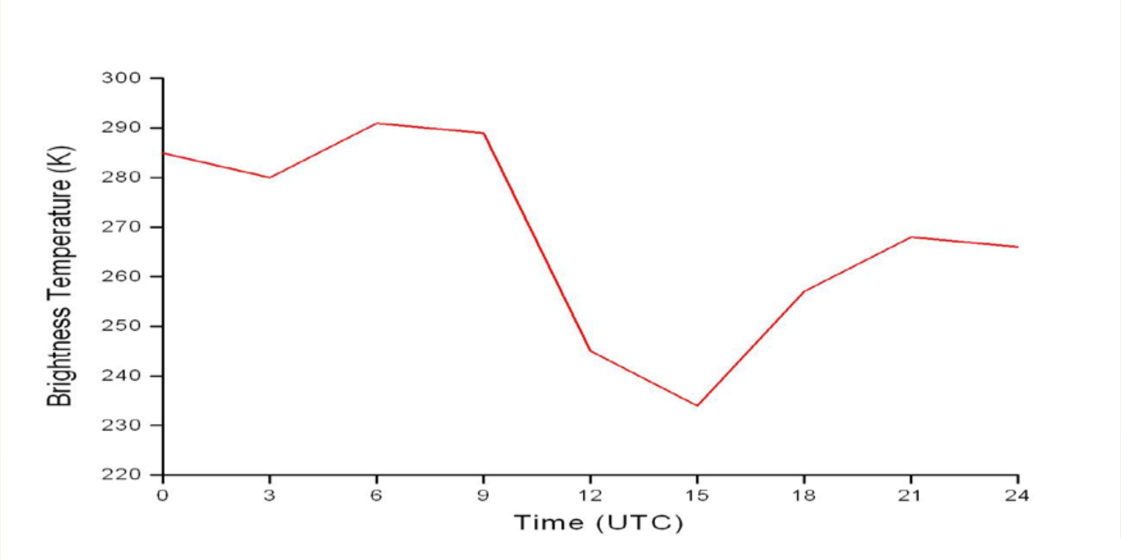


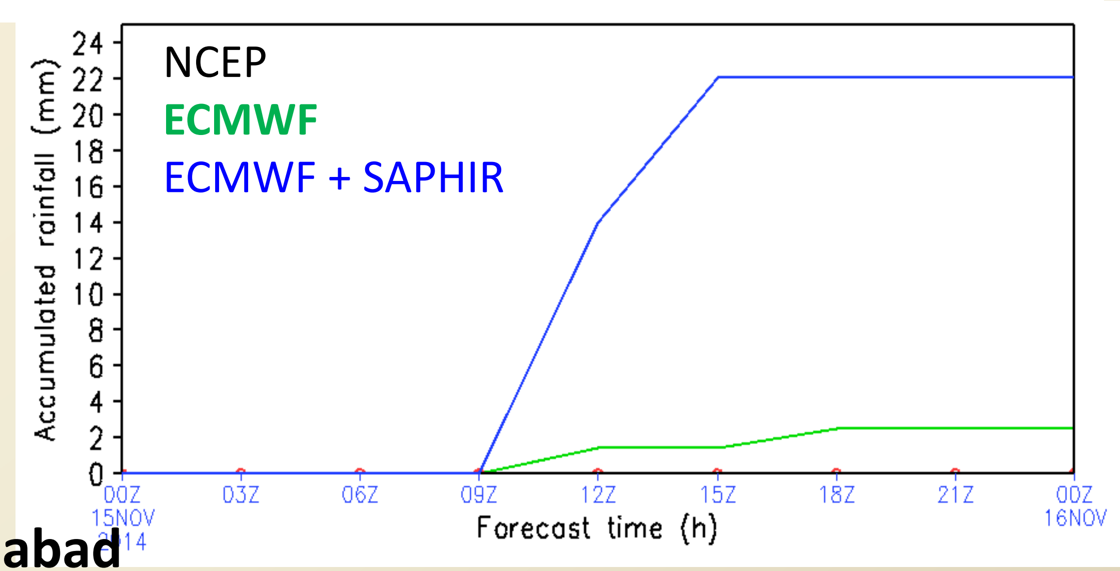
Most of the Infrared observations under cloudy conditions are rejected by data assimilation system's Quality Check process

Cloud affected observations are assimilated

Thunderstorm : 15 November 2014, Ahmedabad
Rainfall Forecast





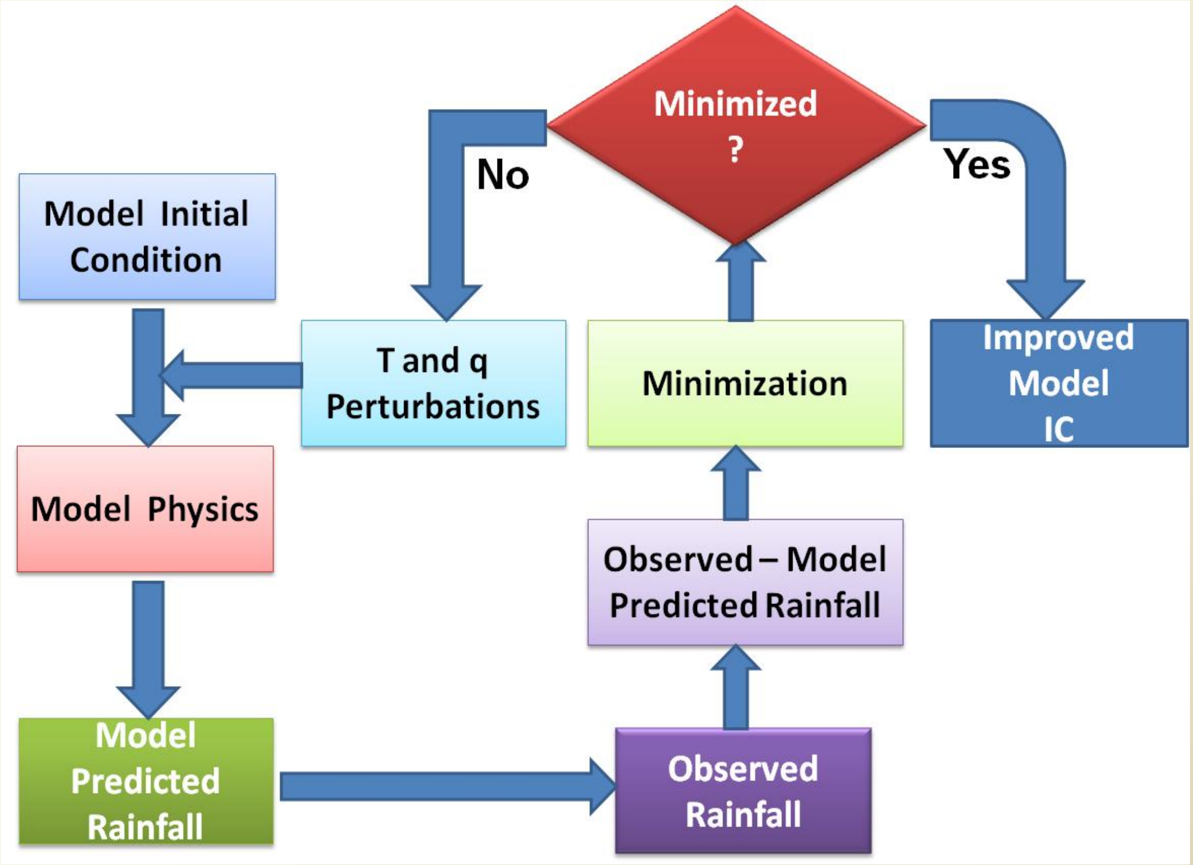


Rainfall Assimilation

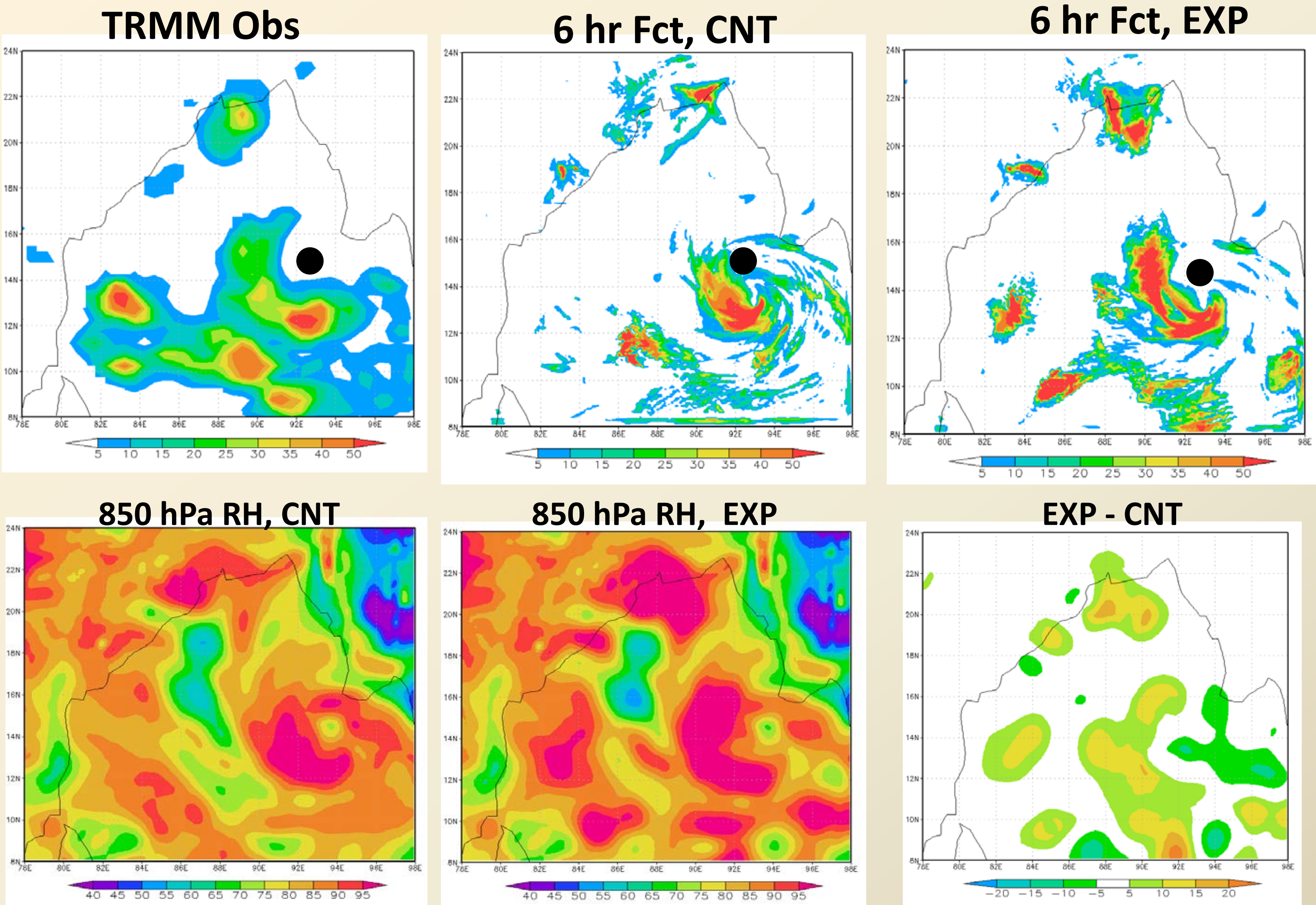
- Rainfall is one of the few parameters that is available over the tropical cyclone.

- Rainfall assimilation is a promising way to improve the initial thermodynamic structure of tropical cyclone

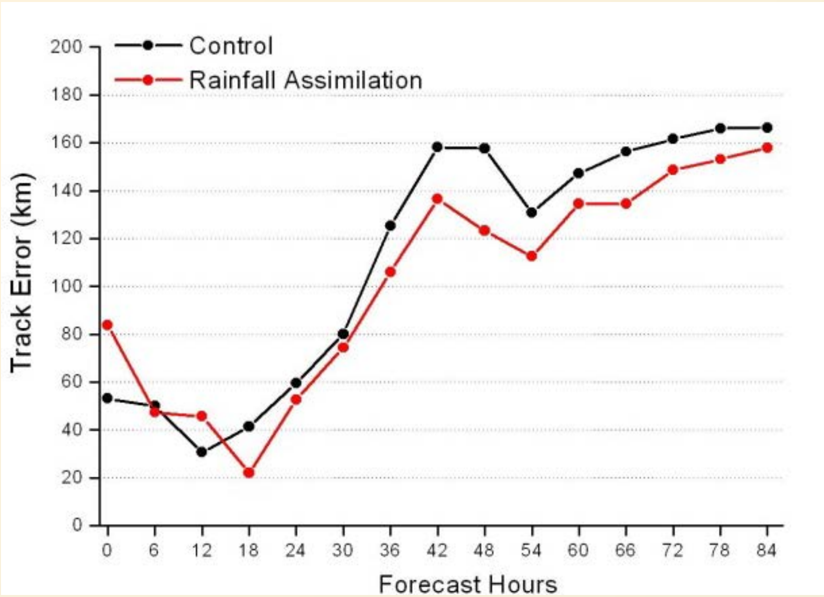
4 Dimensional Variational Assimilation

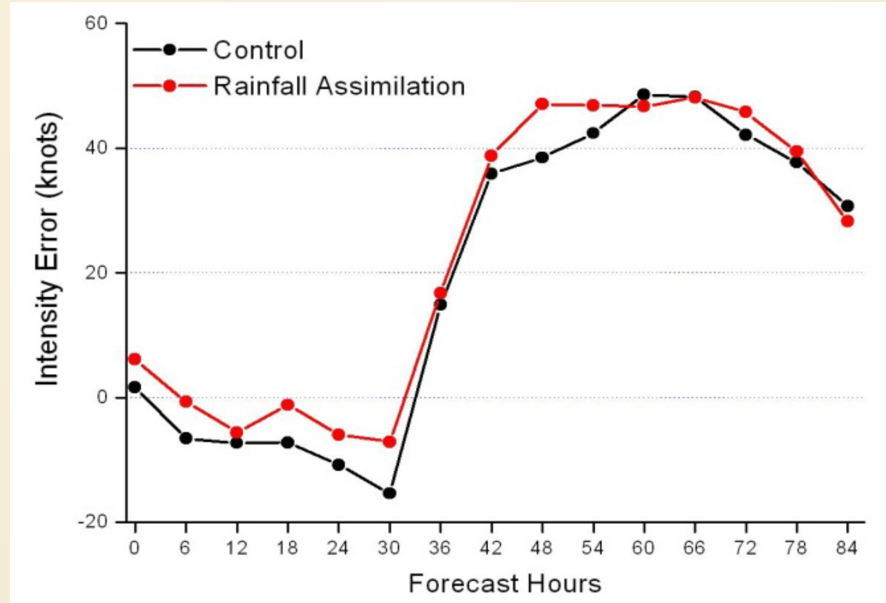


Rainfall Assimilation to define initial TC intensity



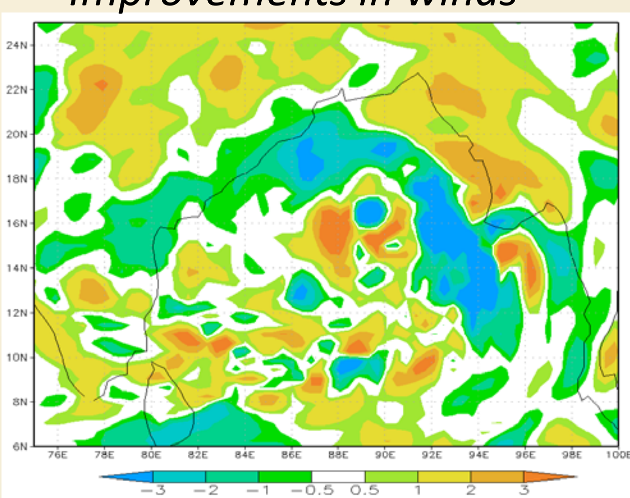
Performance of Rainfall Assimilation



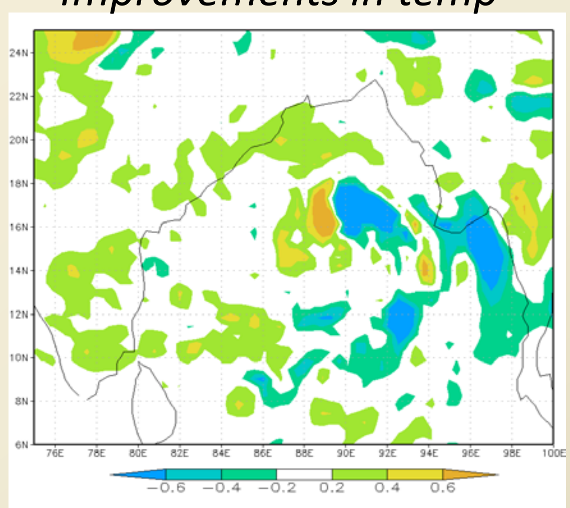


T0+48

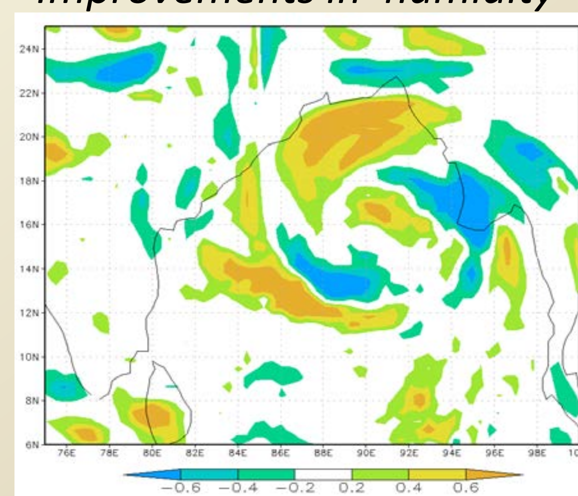
Improvements in winds



Improvements in temp

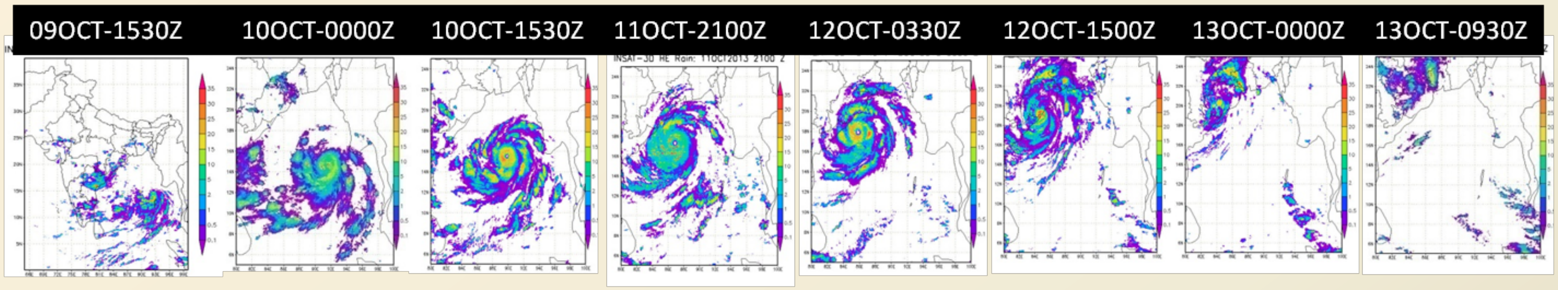


Improvements in humidity



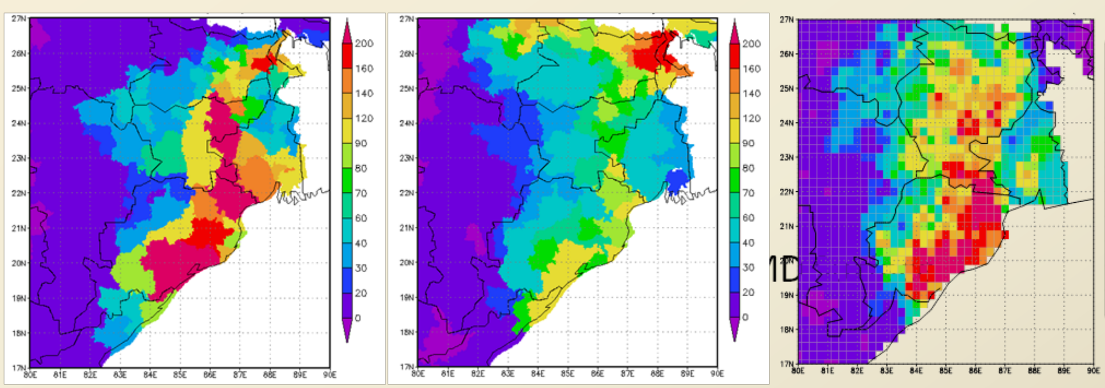
Assimilation of INSAT-3D HE Rainfall in the NWP Model: Impact on Short Range Weather Forecasts

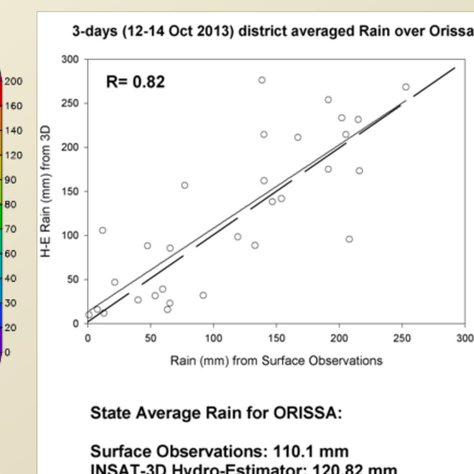
Based on TIR, WV, model-predicted RH, and stability indices. Orography corrections



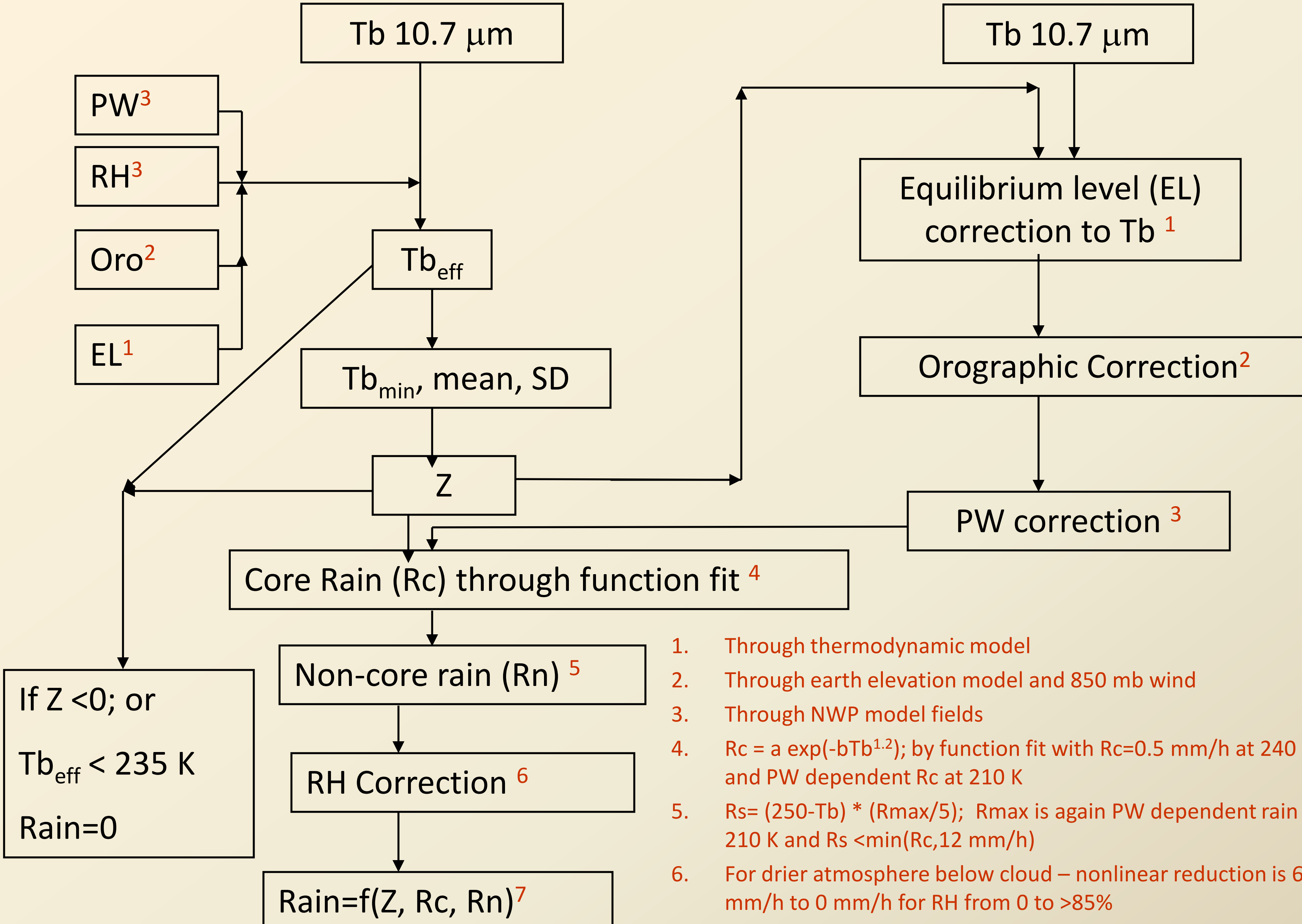
Orissa Cyclone: Average Rain -12-14 Oct 2013

INSAT-3D H-E | TRMM-3B42 | IMD Surface

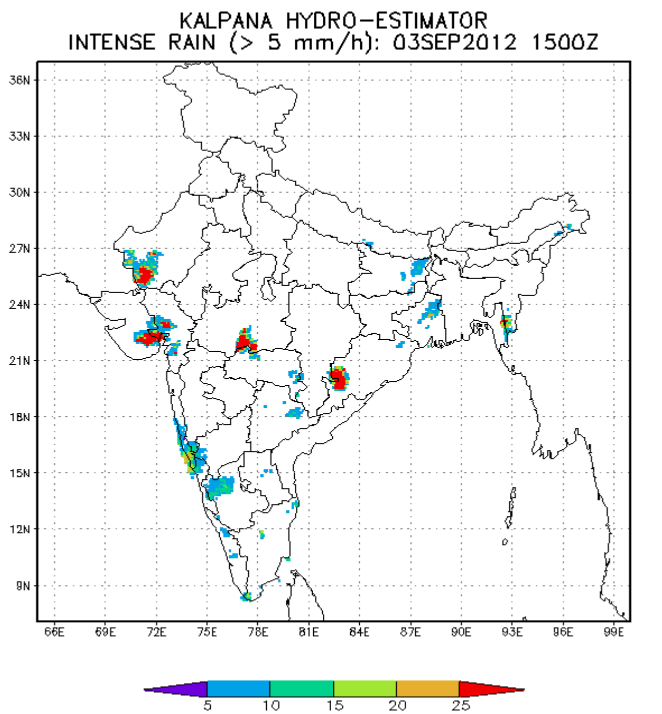




Hydro-Estimator (Simplified block diagram)



1. Through thermodynamic model
2. Through earth elevation model and 850 mb wind
3. Through NWP model fields
4. $Rc = a \exp(-bTb^{1.2})$; by function fit with Rc=0.5 mm/h at 240 K and PW dependent Rc at 210 K
5. Rs= (250-Tb) * (Rmax/5); Rmax is again PW dependent rain at 210 K and Rs <min(Rc,12 mm/h)
6. For drier atmosphere below cloud – nonlinear reduction is 63 mm/h to 0 mm/h for RH from 0 to >85%
7. If Z < 0; RR =0; otherwise $RR1 = [Rc*Z^2 + Rn * (1.5 - Z)^2] / [Z^2 + (1.5 - Z)^2]$



Analysis of the Intense Rain Events

Table 2: DISTRICTS EXPERINCED HIGH RAIN (>5mm) DURING PAST 1 HOUR: 03 SEP 2012 1500 Z

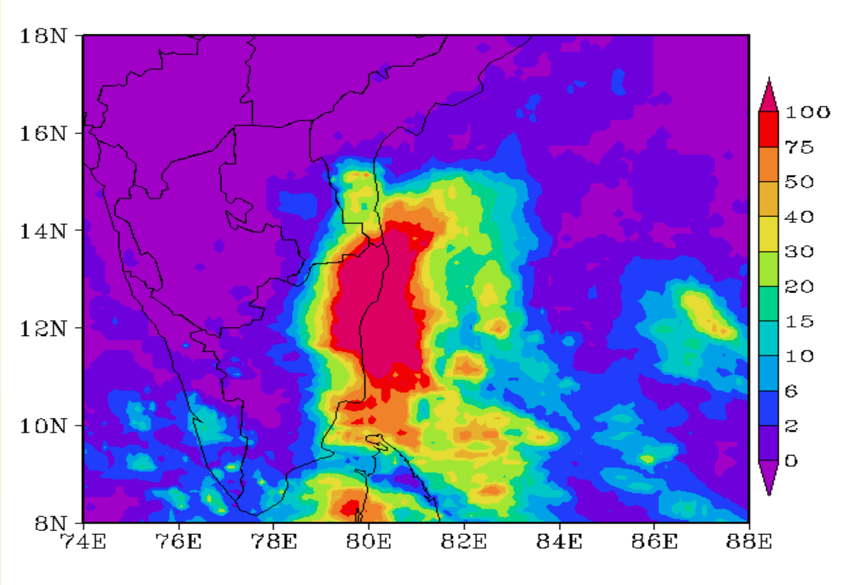
District Name	Met Subdivision	Rain (mm)
KISHANGANJ	BIHAR	5.53
BARMER	WEST-RAJASTHAN	13.28
ARARIA	BIHAR	6.99
PURNIA	BIHAR	7.19
SURENDRANAGAR	SAURASHTRA-&-KUTCH-DADAR-NAGAR-HAVELI-&-DAMAN	16.80
AHMEDABAD	GUJARAT-REGION	35.24
LUNGLEI	NAGALAND-MANIPUR-MIZORAM-TRIPURA	14.95
GANDHINAGAR	GUJARAT-REGION	6.89
KHEDA	GUJARAT-REGION	7.46
RAJKOT	SAURASHTRA-&-KUTCH-DADAR-NAGAR-HAVELI-&-DAMAN	9.34
LAWNGTLAI	NAGALAND-MANIPUR-MIZORAM-TRIPURA	7.06
HARDA	WEST-MADHYA-PRADESH	38.02
EAST-NIMAR	WEST-MADHYA-PRADESH	9.88
BETUL	WEST-MADHYA-PRADESH	12.88
BHAVNAGAR	SAURASHTRA-&-KUTCH-DADAR-NAGAR-HAVELI-&-DAMAN	19.18
BHARUCH	GUJARAT-REGION	5.42
NUAPADA	ORISSA	33.42
BALANGIR	ORISSA	9.09
KALAHANDI	ORISSA	31.35
RATNAGIRI	KONKAN-&-GOA	5.94
KOLHAPUR	MADHYA-MAHARASH	8.09
SINDHUDURG	KONKAN-&-GOA	14.16
NORTH-GOA	KONKAN-&-GOA	17.05
SOUTH-GOA	KONKAN-&-GOA	16.22
CHITRADURGA	SOUTH-INTERIOR-KARNATAKA	5.08
DAVANGERE	SOUTH-INTERIOR-KARNATAKA	9.29
SHIMOGA	SOUTH-INTERIOR-KARNATAKA	7.33
WAYANAD	KERALA	5.17
KANNIYAKUMARI	TAMILNADU-&-PONDICHERRY	10.74

Table 1: Area of the High Rain (Rain >10 mm, and within it the Highest Rain Amount with location

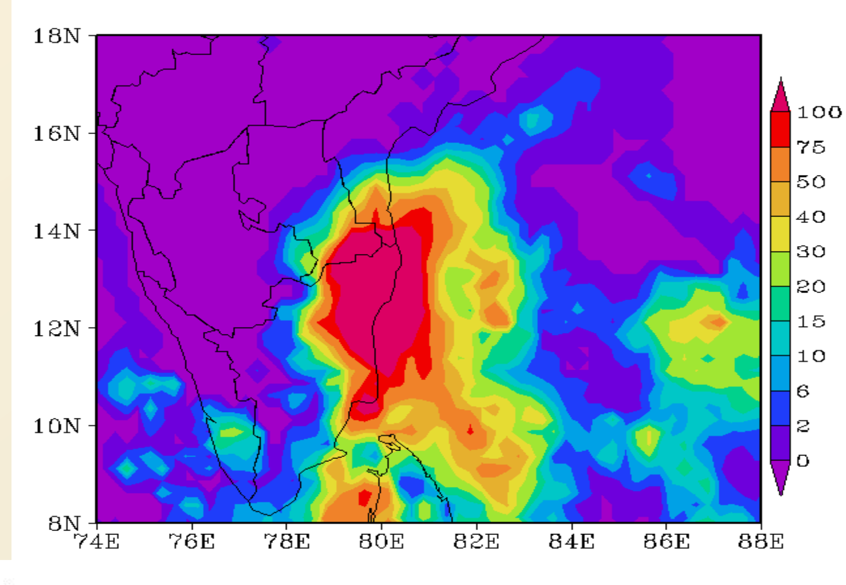
Area(km*2)	Highest Rain	Lat/Long
23168	118.59	22.41/71.86
15808	114.80	19.97/82.91
14528	100.66	21.80/76.95
20480	77.92	25.73/71.56
320	60.34	21.47/73.14
5440	53.11	23.14/92.49
704	26.33	13.34/80.30
448	25.40	28.16/96.29
23424	26.51	15.98/73.59
3008	28.98	23.46/88.16
512	23.08	11.64/78.23
2432	23.32	18.08/80.30
12800	22.32	14.36/76.00
512	21.38	10.41/79.70
3008	19.61	26.04/87.53
2432	18.19	8.29/77.17
1088	18.63	20.05/80.42
1088	16.04	10.56/76.56
448	15.70	25.49/86.54
320	10.21	11.81/75.96

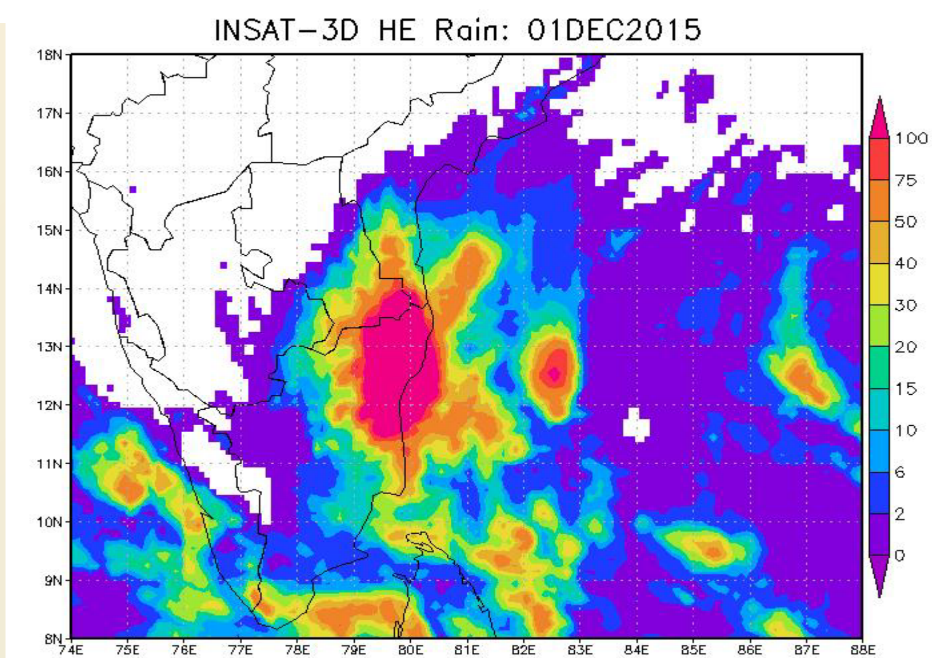
Chennai Rain on 01 December 2015

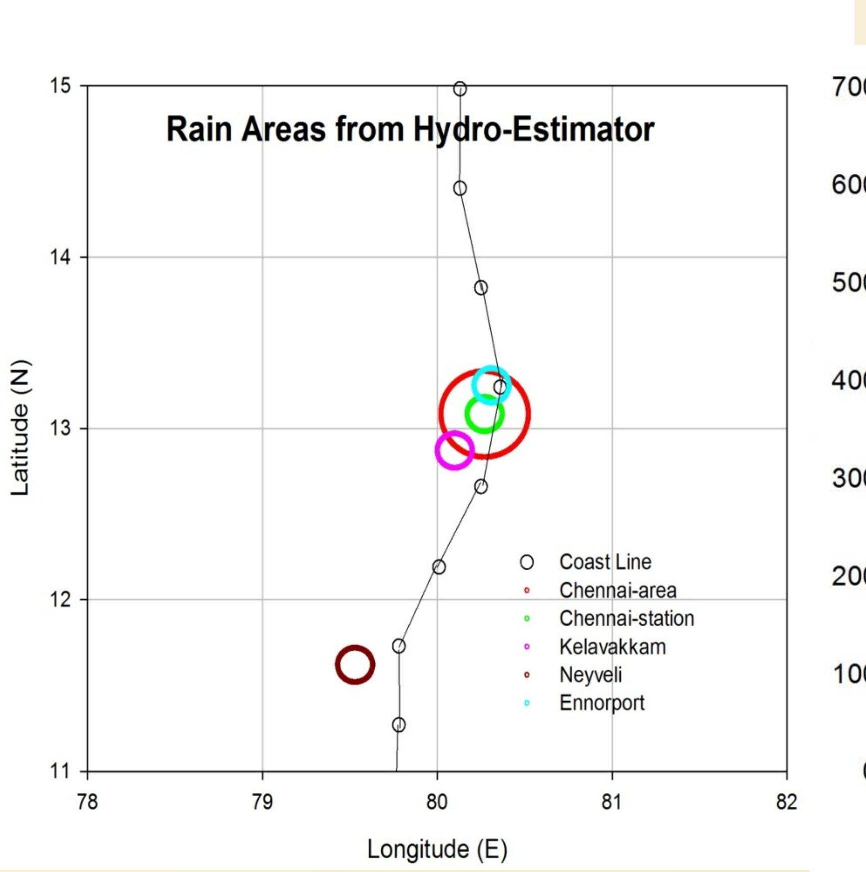
IMERG Rainfall



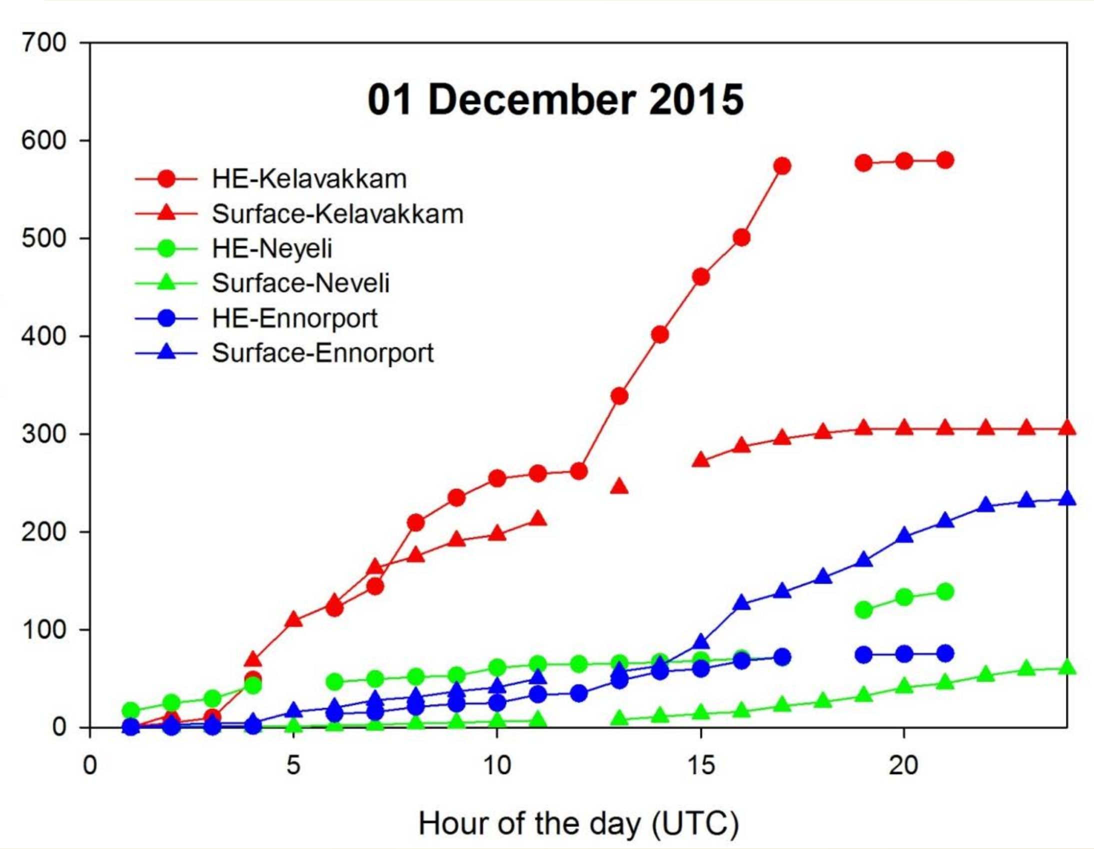
3B42RT Rainfall







Rain Areas from Hydro-Estimator
Latitude (N)
Longitude (E)
Coast Line
Chennai-area
Chennai-station
Kelavakkam
Neyveli
Ennorport

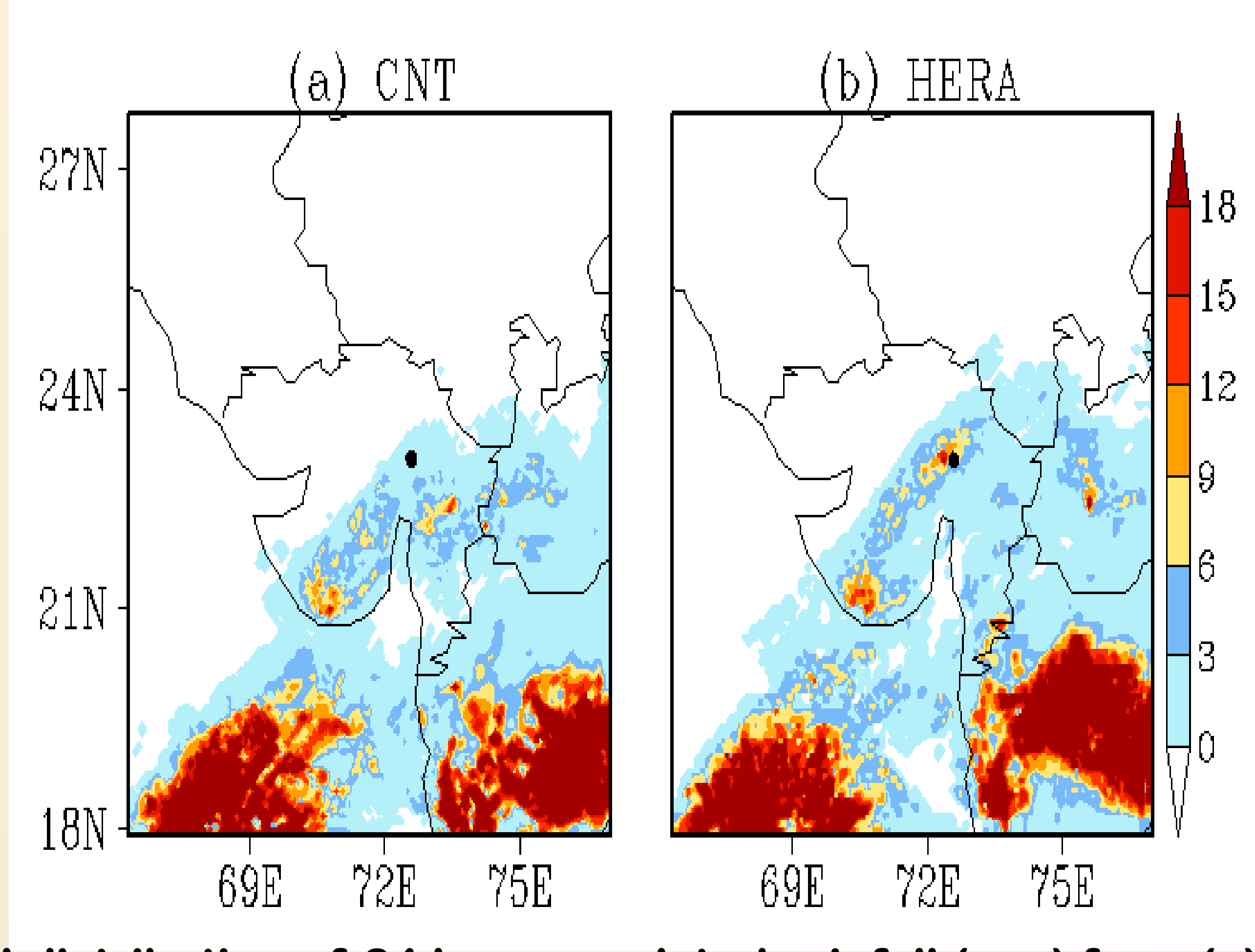


01 December 2015
HE-Kelavakkam
Surface-Kelavakkam
HE-Neyeli
Surface-Neveli
HE-Ennorport
Surface-Ennorport
Hour of the day (UTC)

Assimilation of INSAT-3D Hydro-Estimator Method Retrieved Rainfall on Short Range Weather Prediction

The INSAT-3D retrieved HE rainfall assimilation experiments are able to predict unprecedented rainfall over Ahmedabad region.

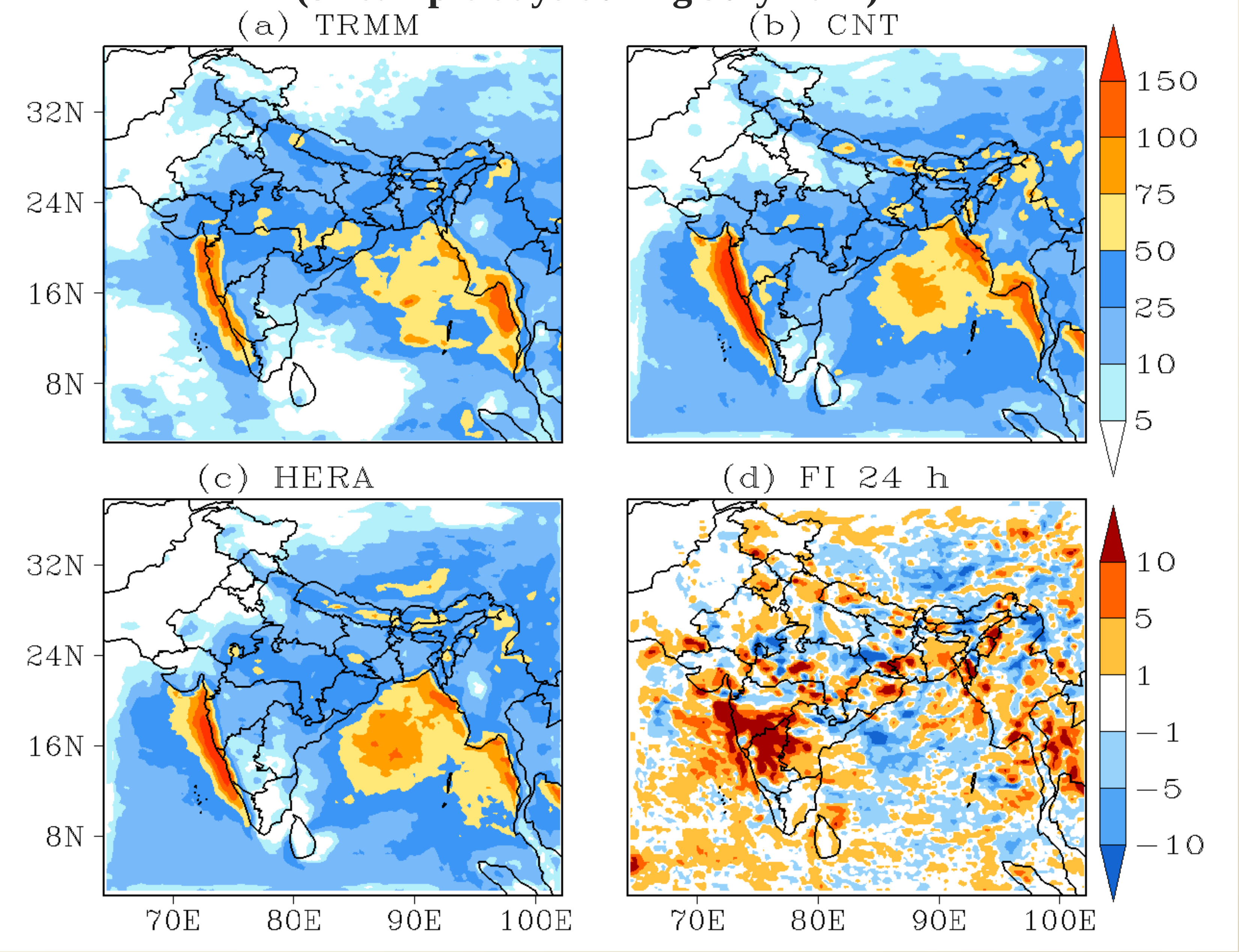
Four dimensional variational data assimilation of INSAT-3D retrieved HE rainfall improved the 24 h rainfall prediction over the Indian landmass (July 2014).



Spatial distribution of 24 h accumulated rainfall (mm) from (a) CNT experiments, and (b) HERA experiments. Black circle represents location of Ahmedabad, India where HERA experiment is able to capture high rainfall.

with Dr. A. K. Varma

Impact of INSAT-3D HE Rainfall Observations on Rainfall Forecasts (31 sample days during July 2014)



Assimilation of INSAT-3D Sounder Radiances in the NWP Model: Impact on Short Range Weather Forecasts

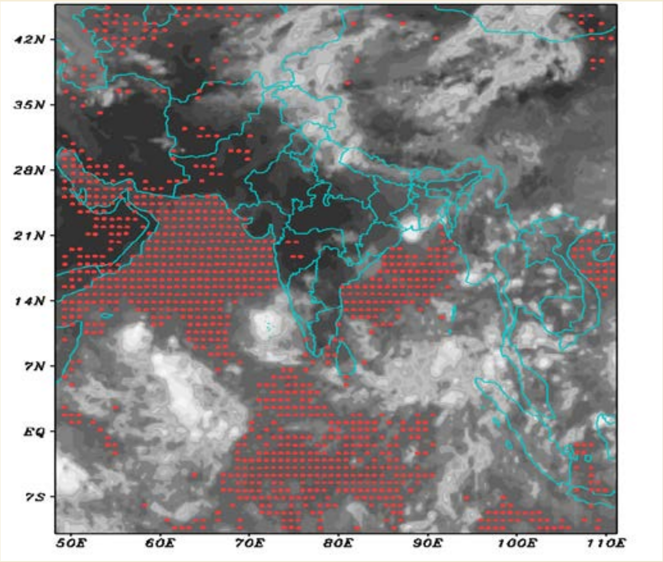
Assimilation of INSAT-3D Radiance

Quality Control

a. No surface sensitive channel is assimilated
b. Cloud Detection (Window Channel thresholds)
c. Observation – Background Check

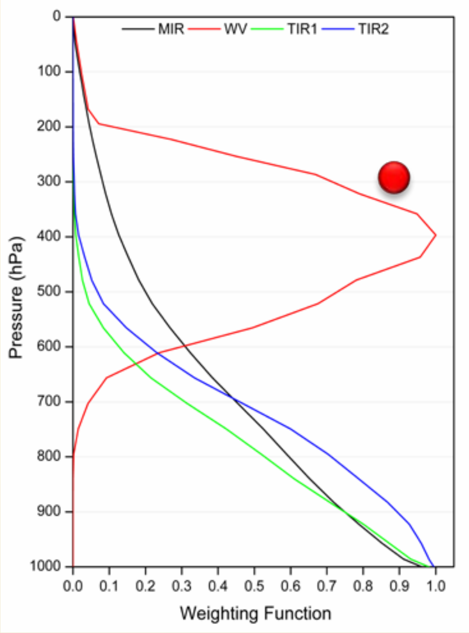
$$|Tb_{obs} - Tb_{fg}| < 3\sigma_{obs}$$

d. Orography check

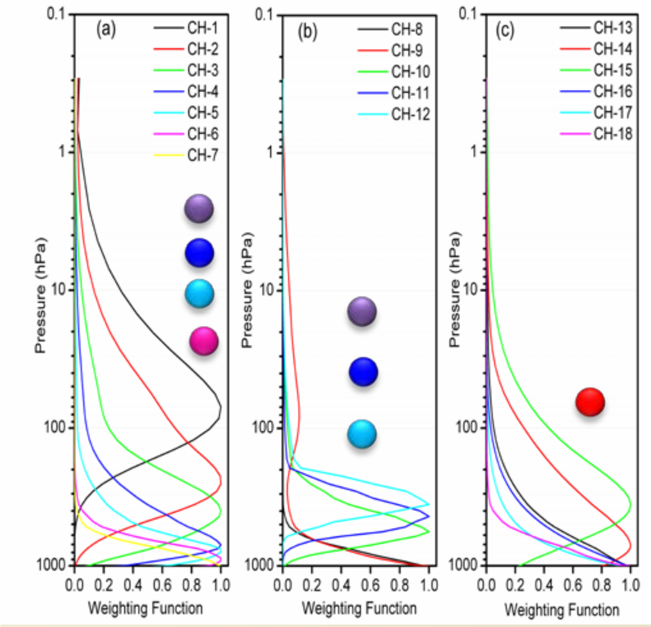


Channel Selection

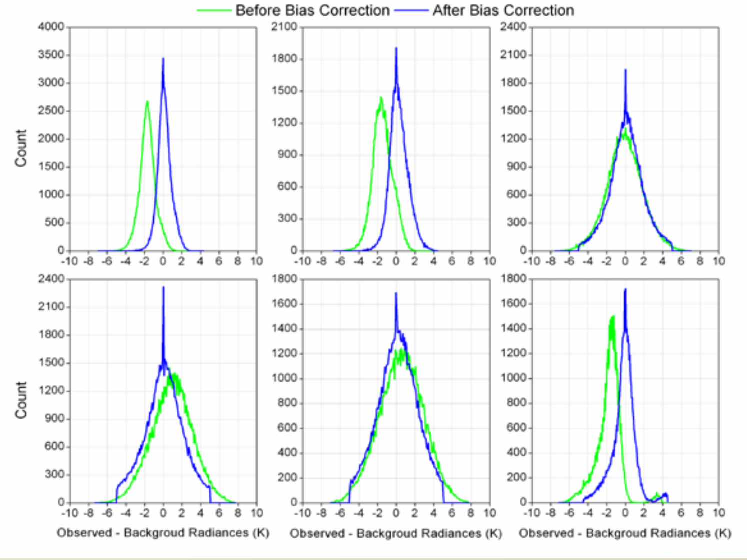
Imager



Sounder



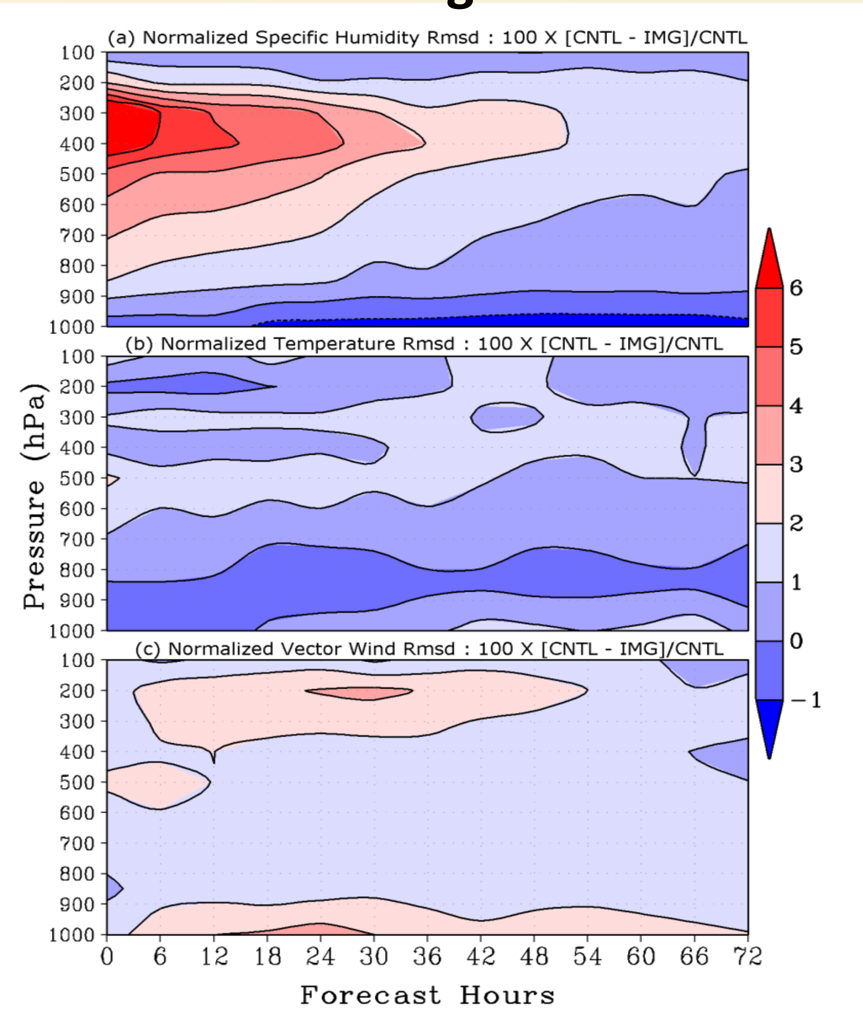
Bias Correction



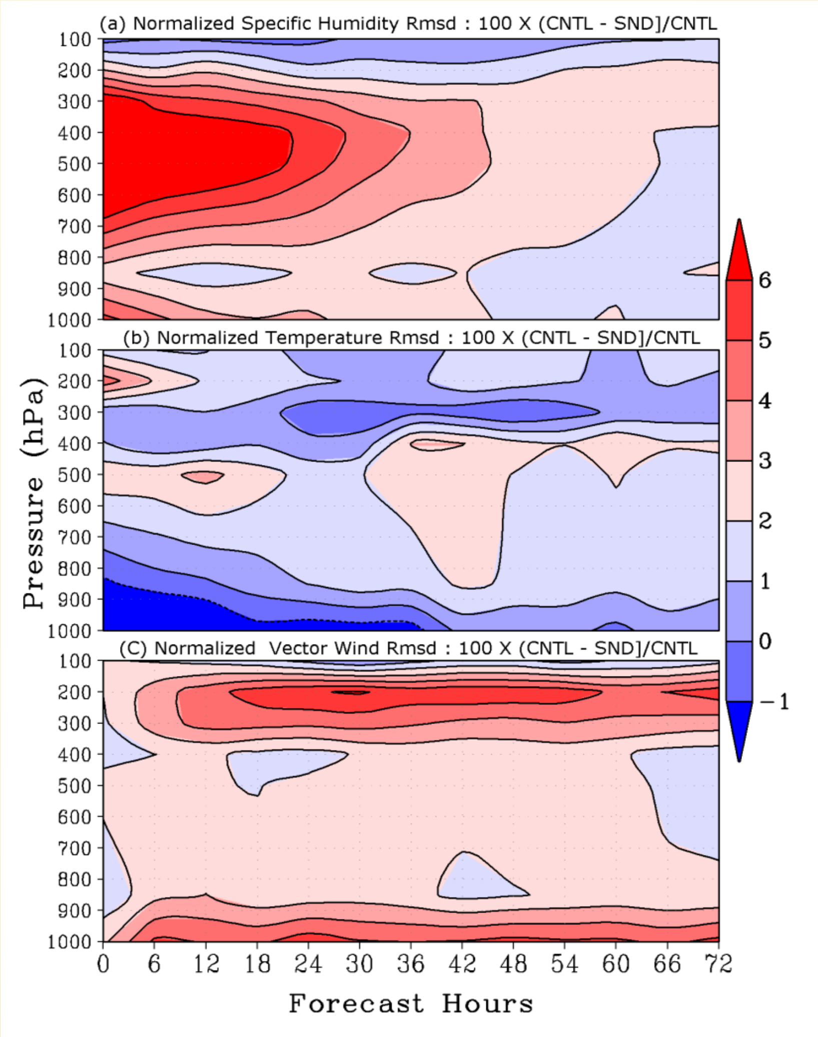
Impact of INSAT-3D Radiances : Forecast Error Reduction (%)

In control, run temperature and moisture are constrained by only conventional observations

Imager

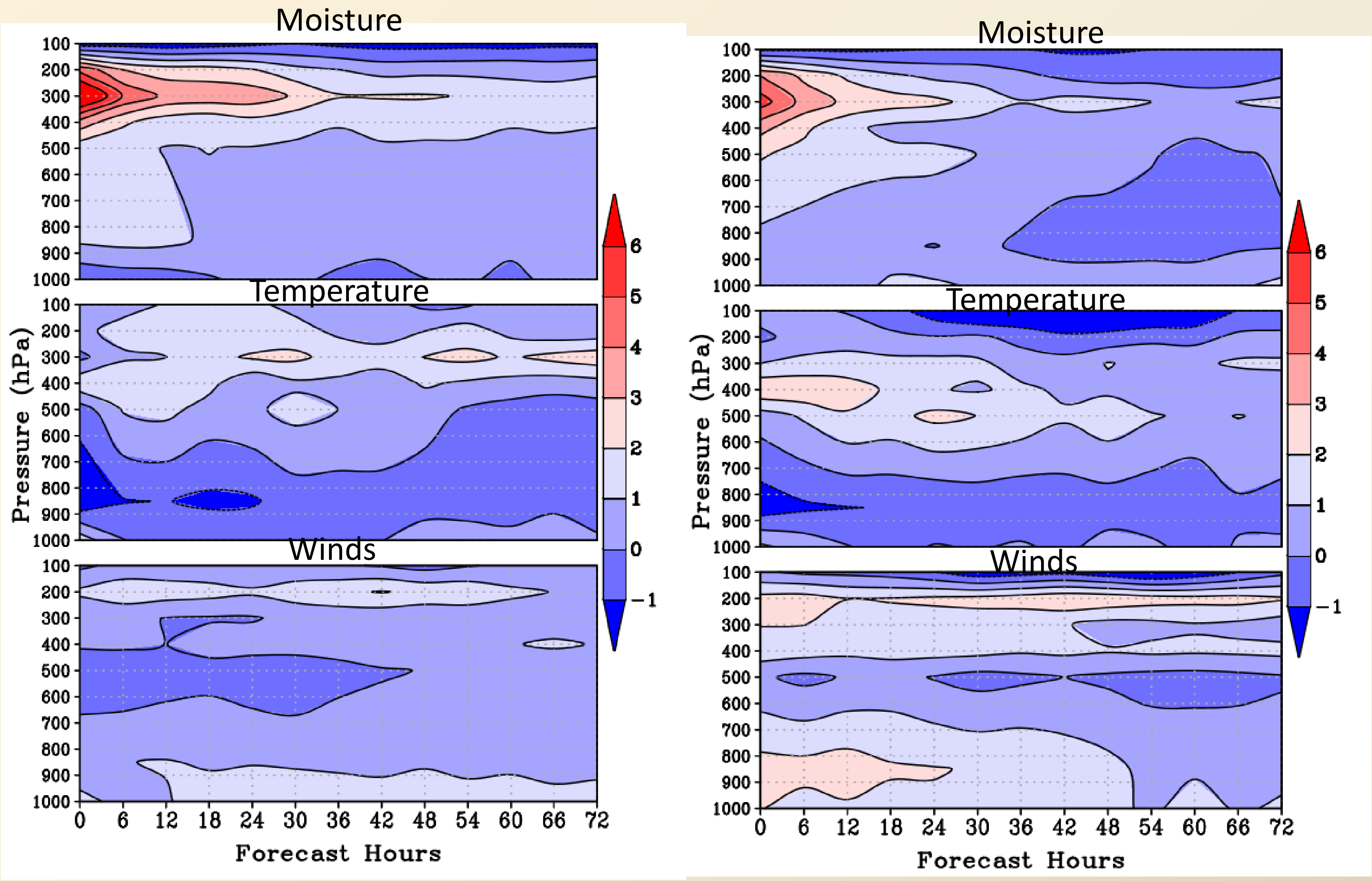


Sounder



Impact of INSAT-3D Radiances : Forecast Error Reduction (%)

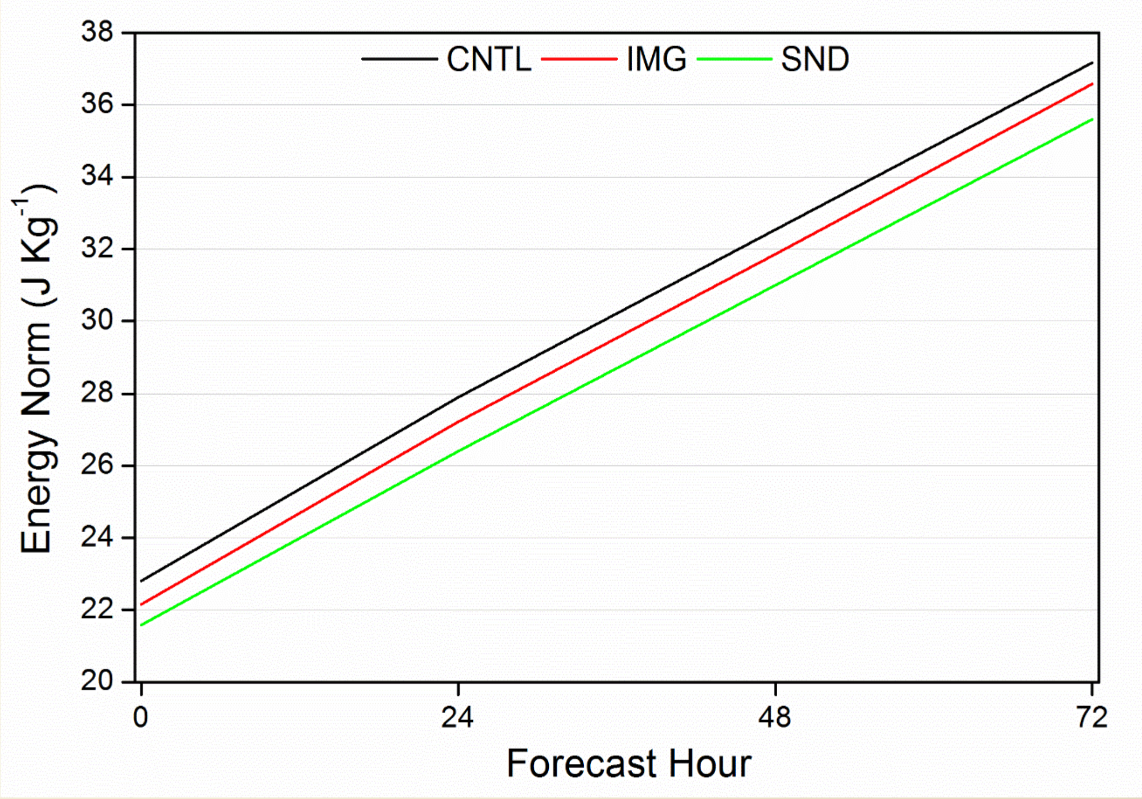
In control run, temperature and moisture are constrained by HIRS and conventional observations



Impact of INSAT-3D Radiances : Moist Total Energy

$$TE = \frac{1}{2D} \iint_D \int_0^1 \left(u'^2 + v'^2 + \frac{c_p}{T_r} T'^2 + RT_r \left(\frac{p'_s}{p_r} \right) + \varepsilon \frac{L^2}{c_p T_r} q'^2 \right) d\sigma dD$$

u′, v′, T′, q′, and p_s′ are the observed minus model predicted zonal wind (ms^{-1}), meridional wind (ms^{-1}), temperature (K), mixing ratio and surface pressure (hPa), respectively



Impact of individual channels

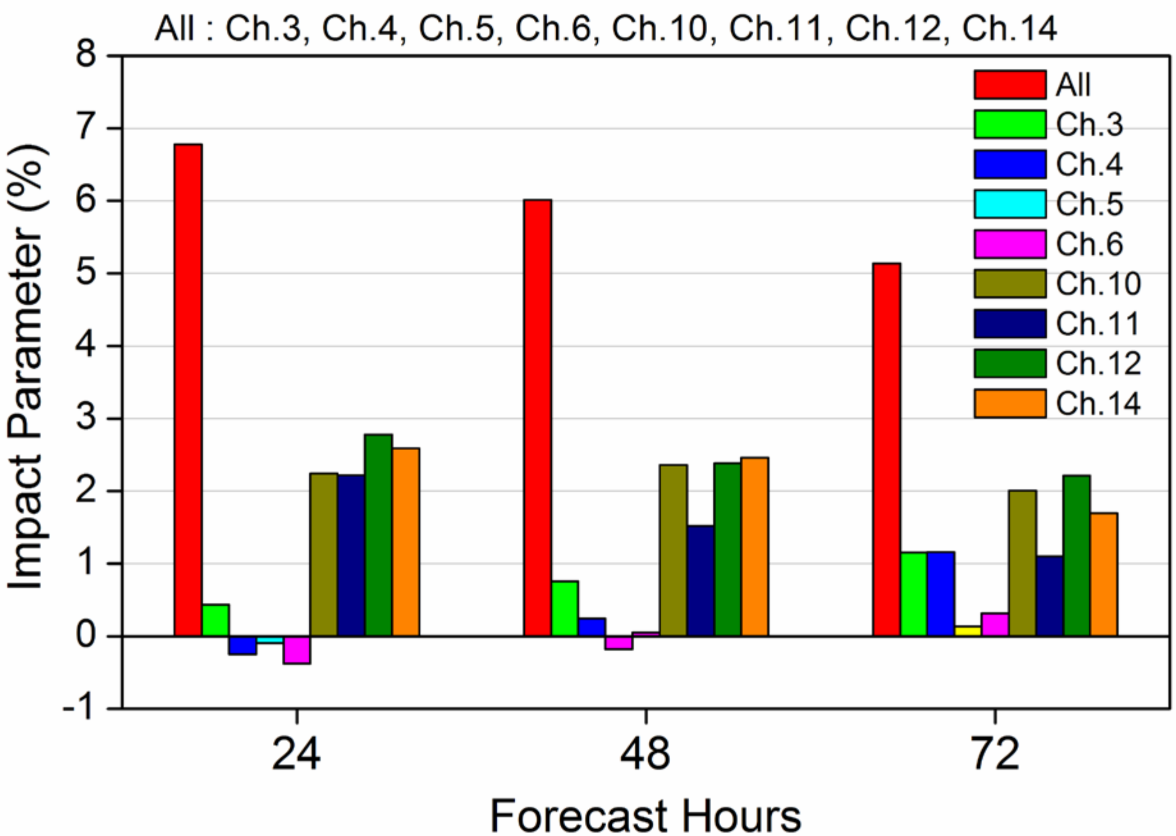
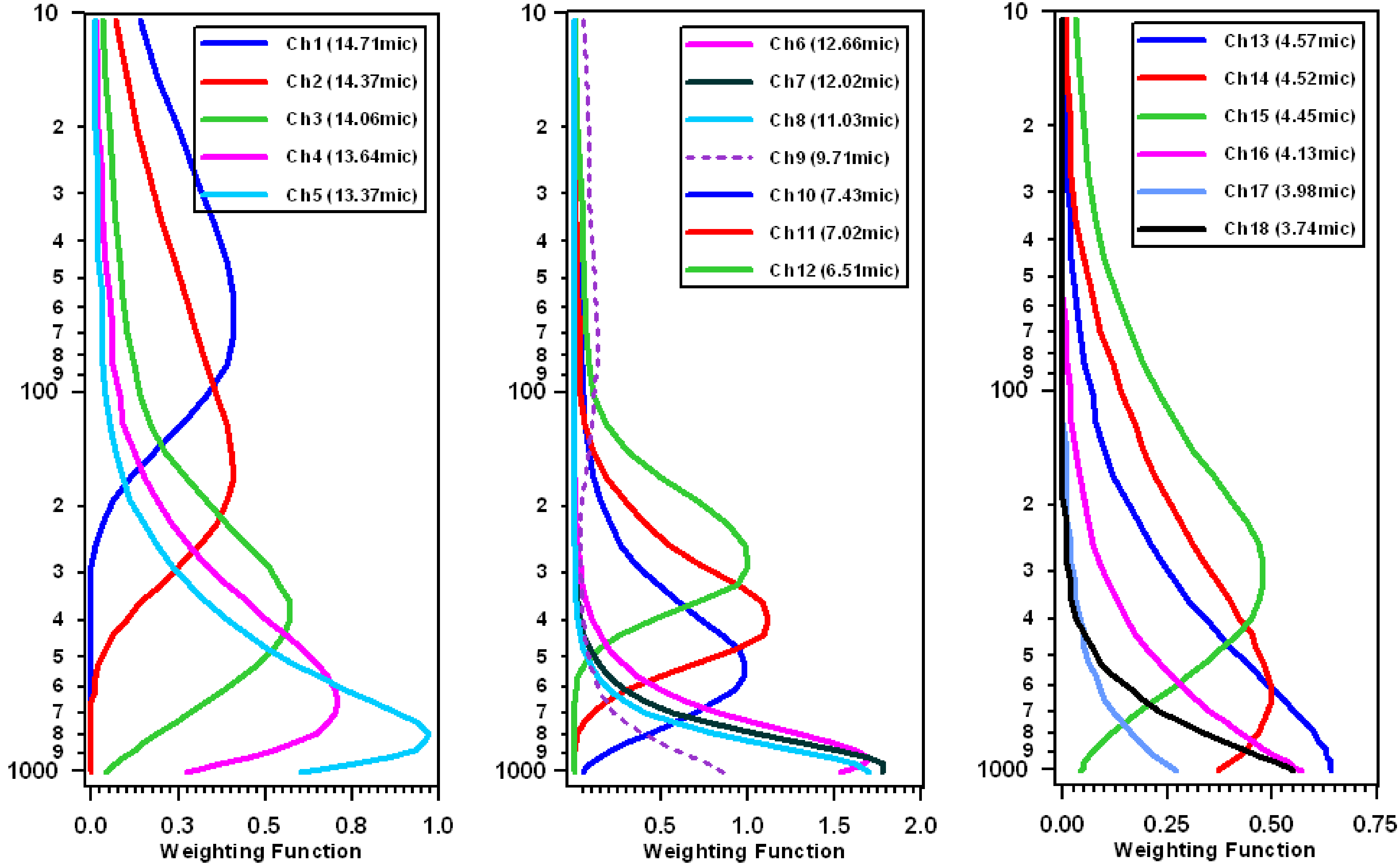


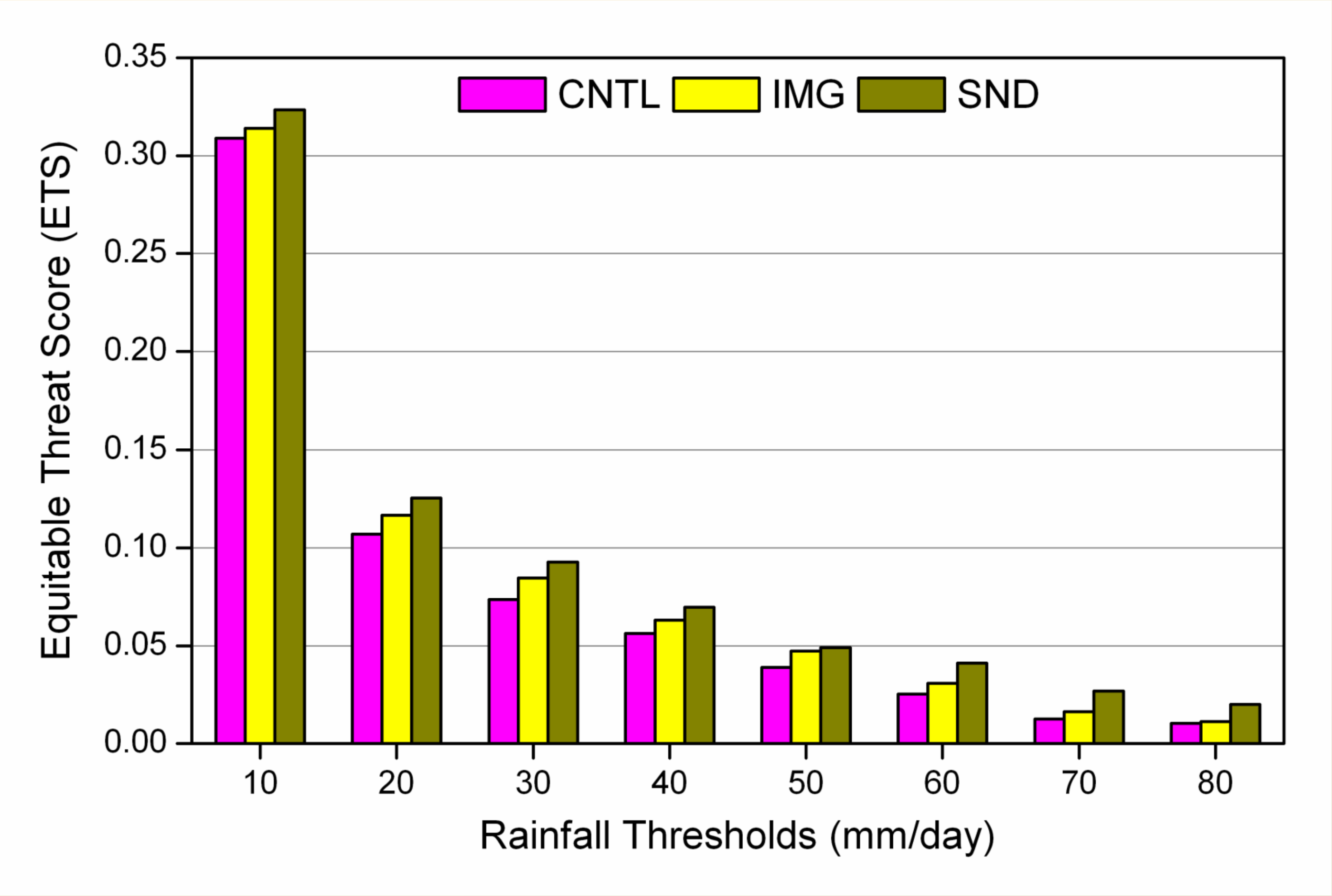
Table-2: INSAT-3D Sounder Channels Characteristics

Channel No.	Centre Wavelength µm (cm^{-1})	Bandwidth µm (cm^{-1})
1	14.71 (680)	0.281 (13)
2	14.37 (696)	0.268 (13)
3	14.06 (711)	0.256 (13)
4	13.96 (733)	0.298 (16)
5	13.37 (749)	0.286 (16)
6	12.66 (790)	0.481 (30)
7	12.02(832)	0.723 (50)
8	11.03 (907)	0.608 (50)
9	9.71 (1030)	0.235 (25)
10	7.43 (1345)	0.304 (55)
11	7.02 (1425)	0.394 (80)
12	6.51 (1535)	0.255 (60)
13	4.57 (2188)	0.048 (23)
14	4.52 (2210)	0.047 (23)
15	4.45 (2245)	0.0456(23)
16	4.13 (2420)	0.0683(40)
17	3.98 (2513)	0.0663 (40)
18	3.74(2671)	0.140 (100)
19	0.695 (14367)	0.05

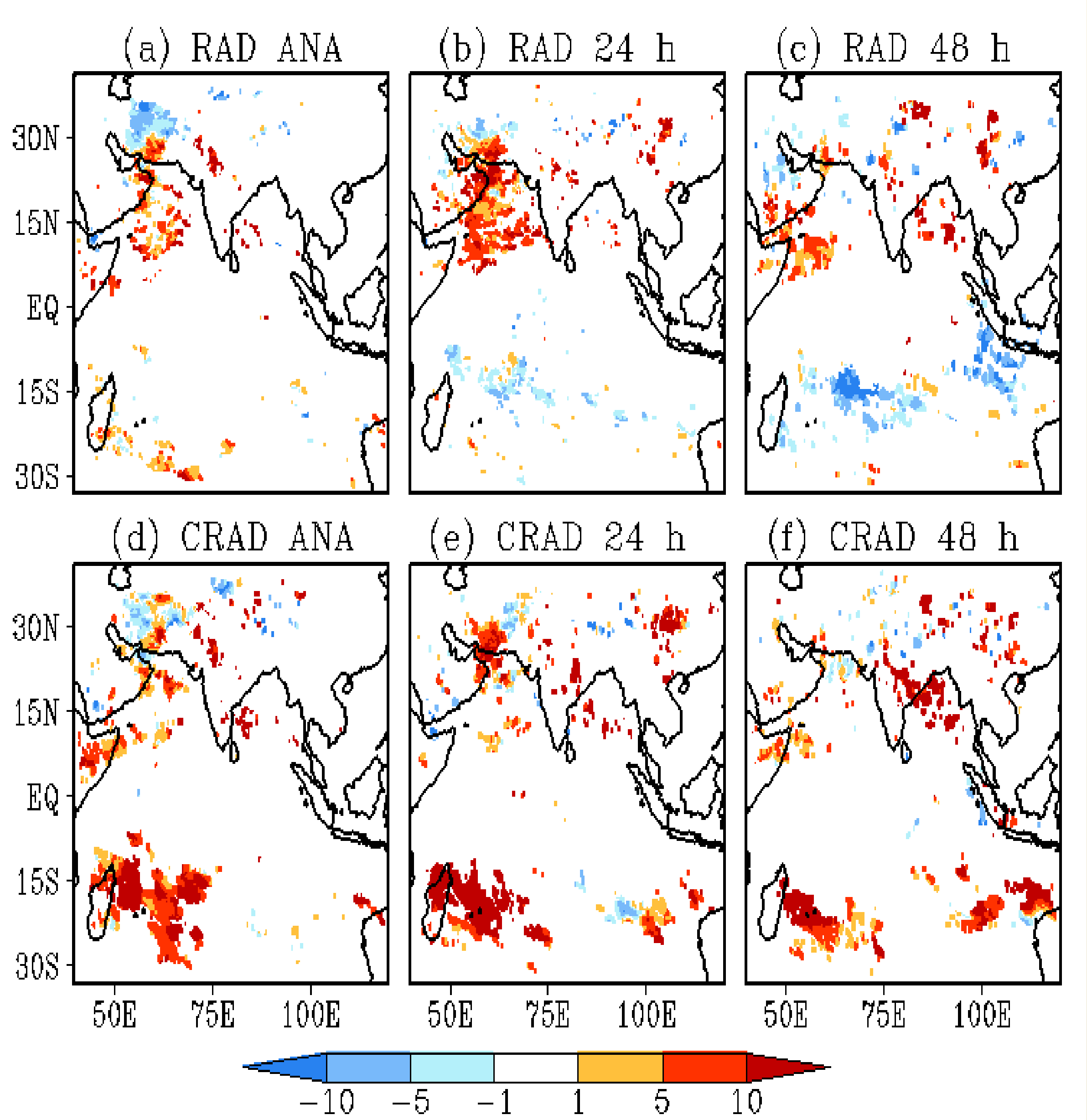
INSAT-3D Weighting Function over Indian Region (July)



Impact of INSAT-3D radiances on rainfall prediction



Significance of Cloud Detection Algorithm of Infrared Sounder on Short Range Weather Forecast (500 hPa Temperature)



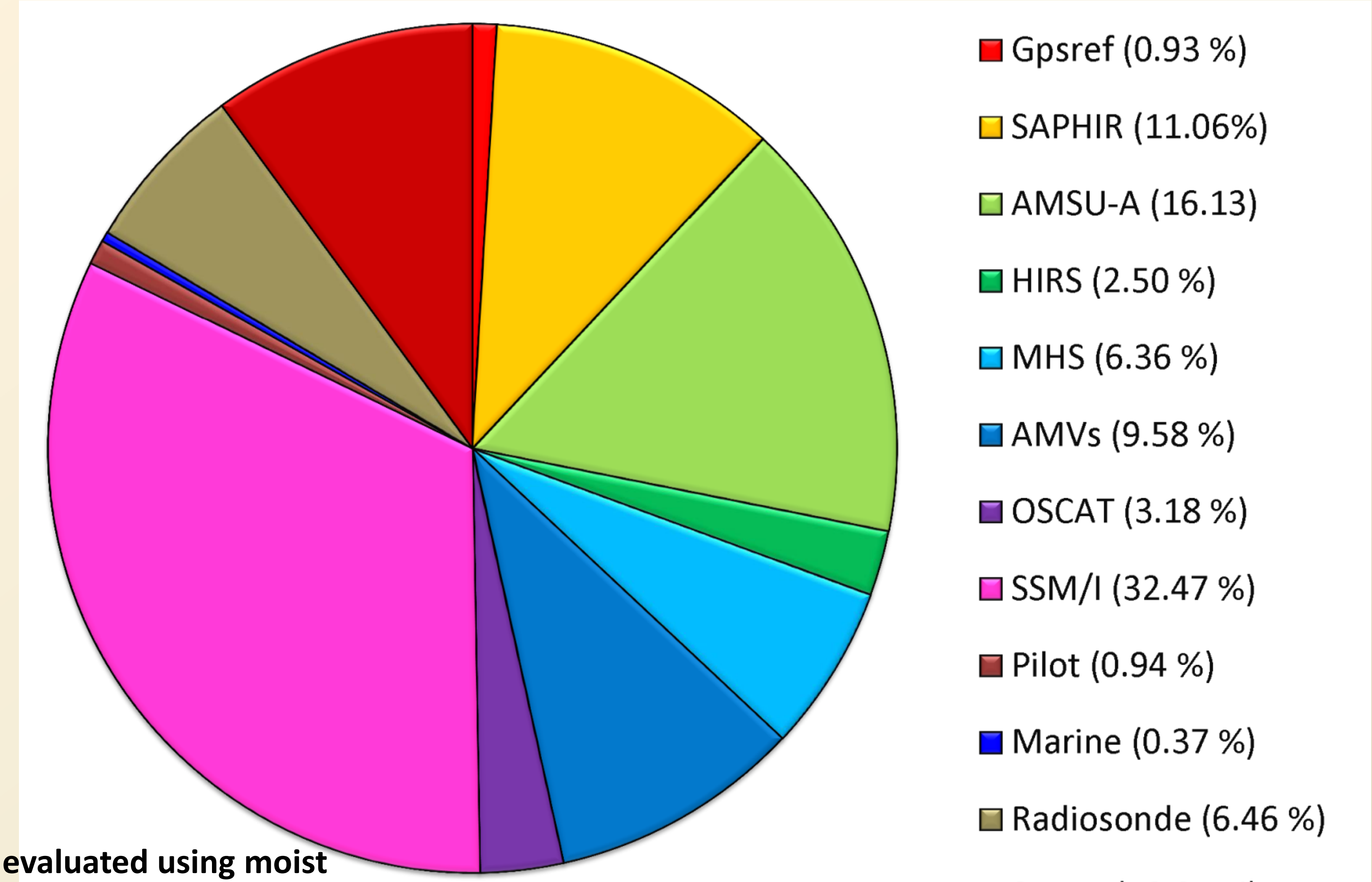
Standard and clear-sky brightness temperature (CSBT) from INSAT-3D Sounder are assimilated in the WRF model at 6-h interval during entire month of the July 2014.

Results showed that the WRF model analyses and subsequent 6-hourly forecasts (for Temperature in Figure) are improved with the assimilation of INSAT-3D CSBT data compared to standard product from INSAT-3D Sounder.

Skill of rainfall prediction for higher rainfall threshold is also increased after INSAT-3D CSBT assimilation as compared to INSAT-3D Sounder L1 radiances and control (without INSAT-3D radiances) experiments.

with Dr. P. K. Thapliyal

Impact of different observing systems on regional monsoon prediction

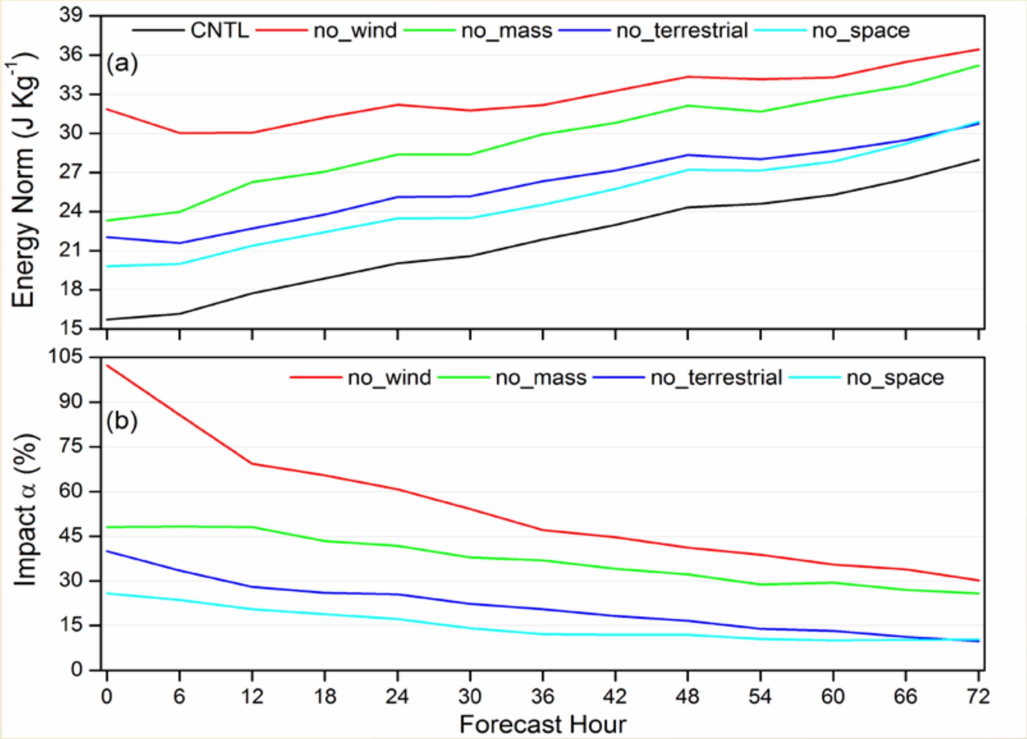


Impact is evaluated using moist total energy norm

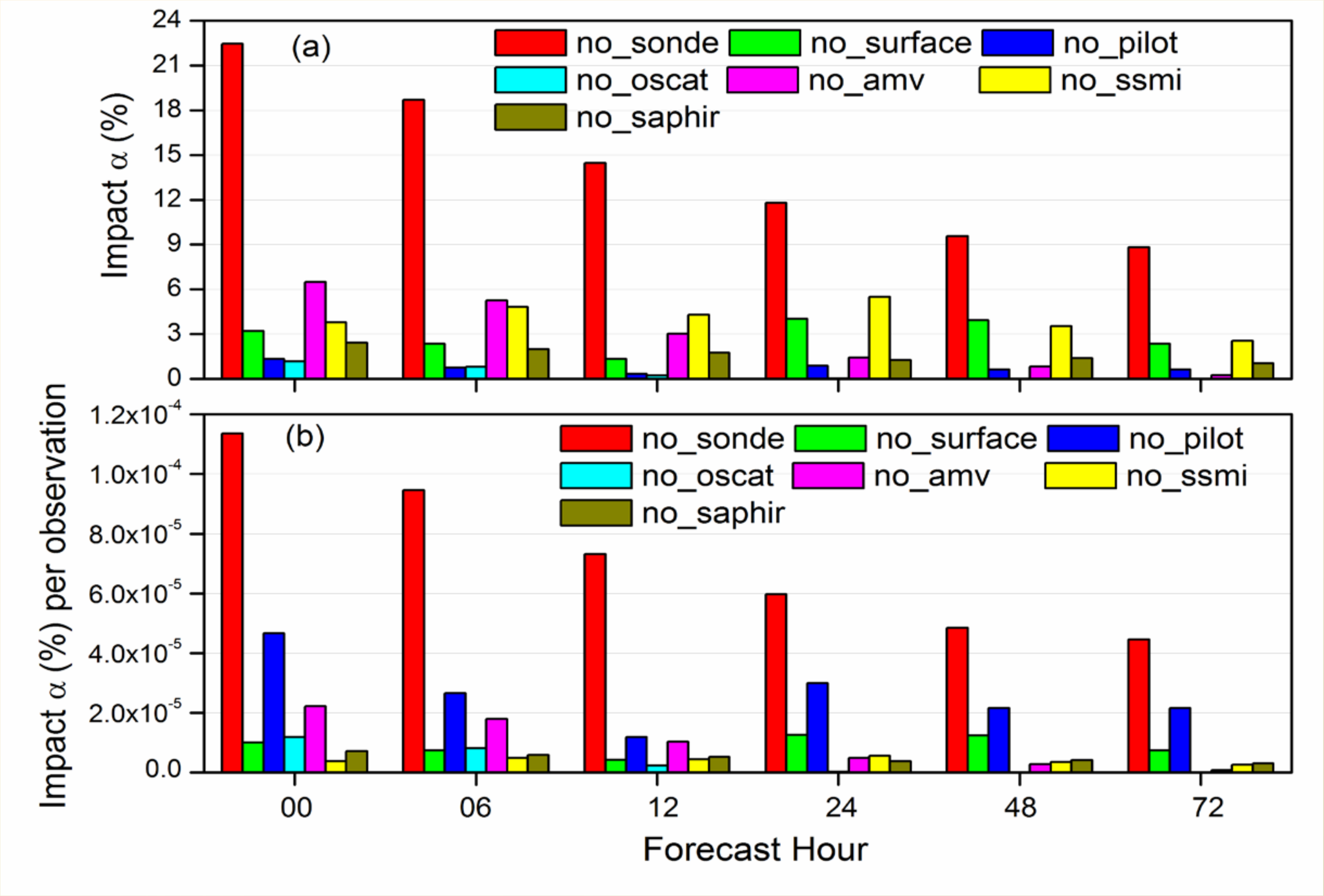
$$TE = \frac{1}{2D} \int_D \int_0^1 \left(u'^2 + v'^2 + \frac{c_p}{T_r} T'^2 + R T_r \left(\frac{p_s'}{p_r} \right)^2 + \epsilon \frac{L^2}{c_p T_r} q'^2 \right) d\sigma dD$$

Impact: Wind versus Mass and Satellite versus Terrestrial based Land

Mass observation : Temperature, moisture and pressure
Wind observations : winds form all observational networks
Land : All in situ observations
Space : All space based observations



Impact of Individual Instruments



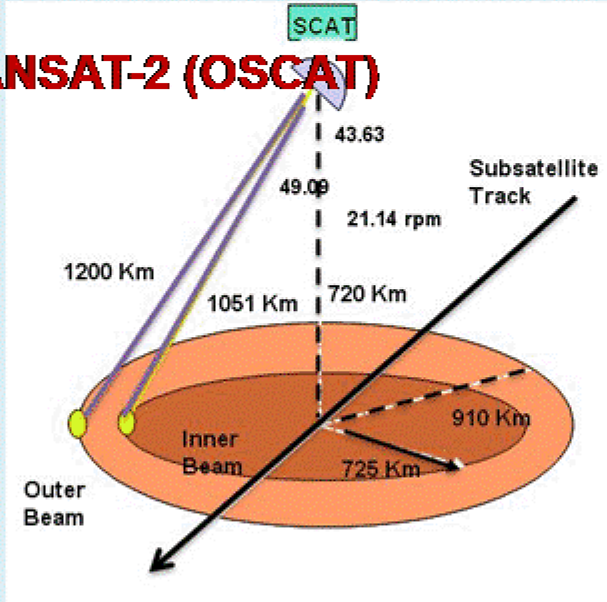
OSE's (Indian Monsoon Region) Conclusions

Terrestrial Based Observations	>	Space Based Observations
Wind observations	>	Mass Observations
Radiosonde	>	All other instruments
Impact of single SAPHIR instrument	>	Three MHS instruments

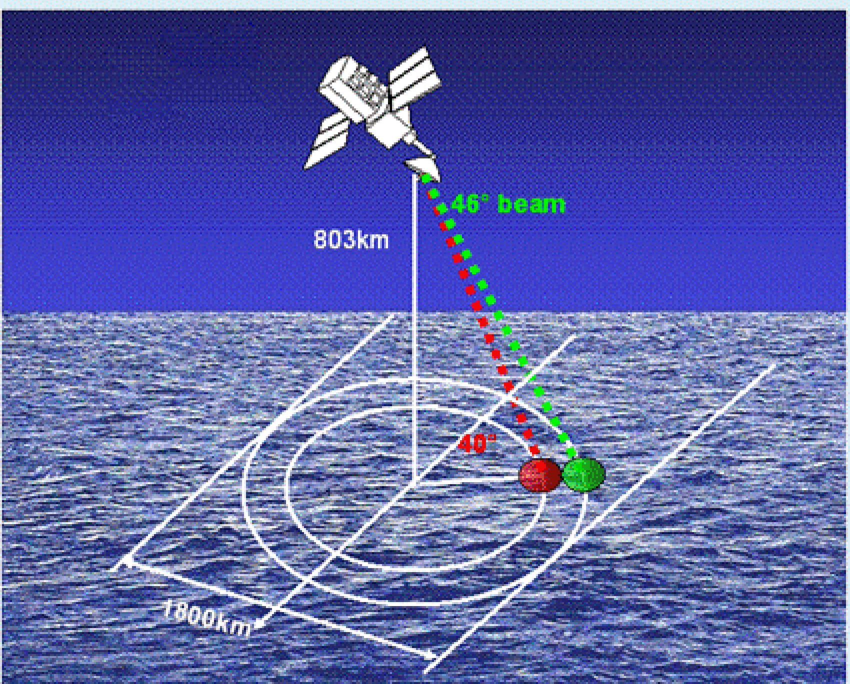
Future ISRO Missions to Help Prediction of Extreme Rain Events

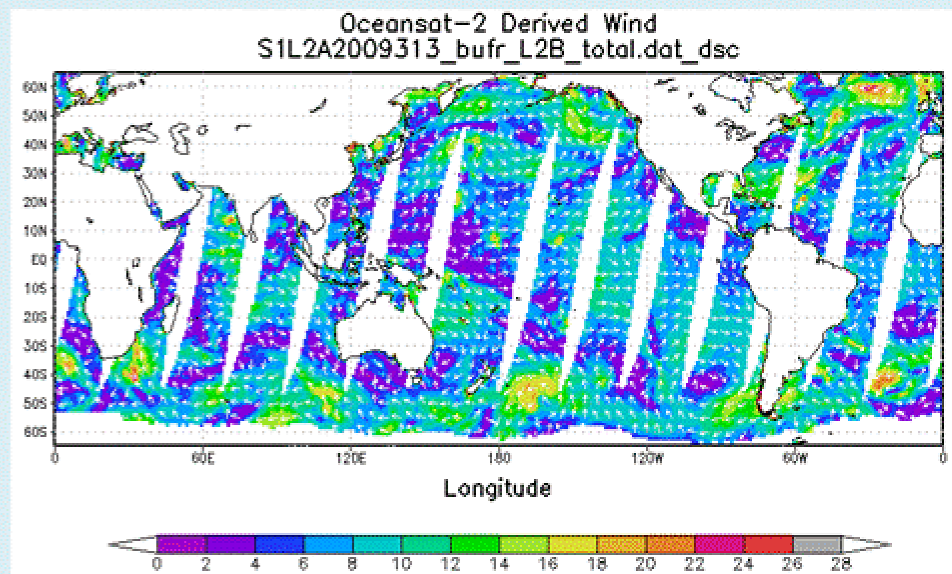
SCATTEROMETER

OCEANSAT-2 (OSCAT)

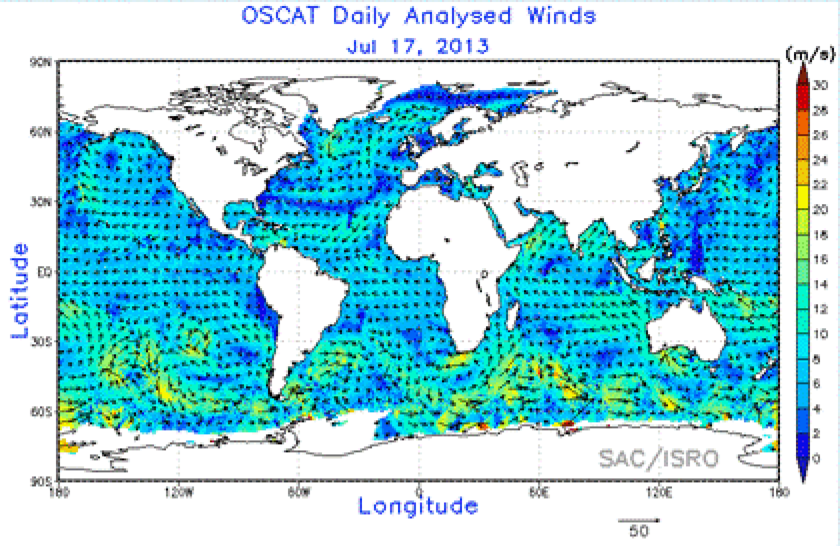


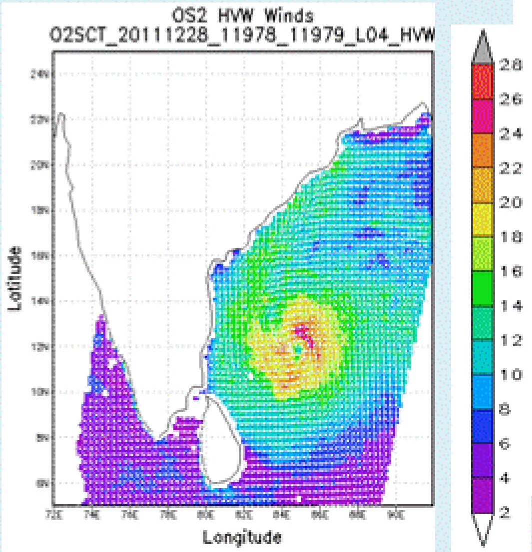
ALTITUDE	720 KM	
FREQUENCY	Ku-BAND (13.73 GHz)	
CONFIG	PENCIL-BEAM	
	INNER	OUTER
INC. ANG. (DEG)	50.16	57.27
POLARIZATION	HH	VV
SWATH (KM)	1450	1820
IFOV (KM)	28 x 38	30 x 45

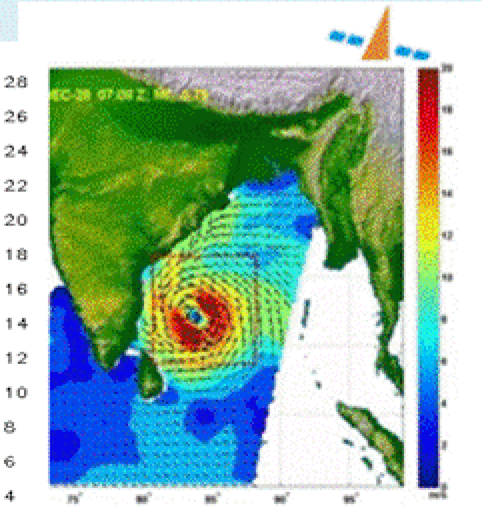


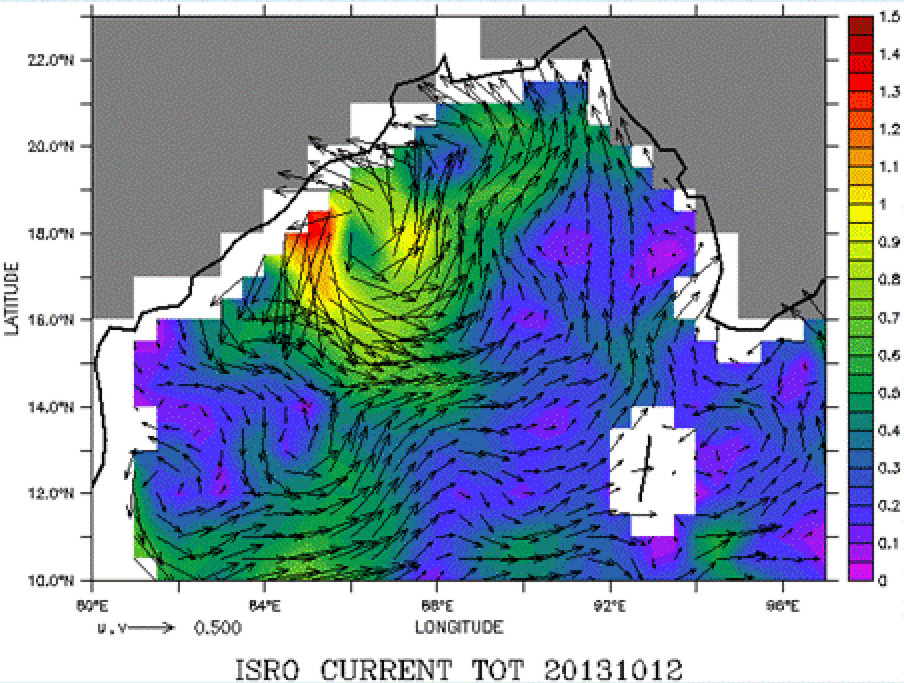


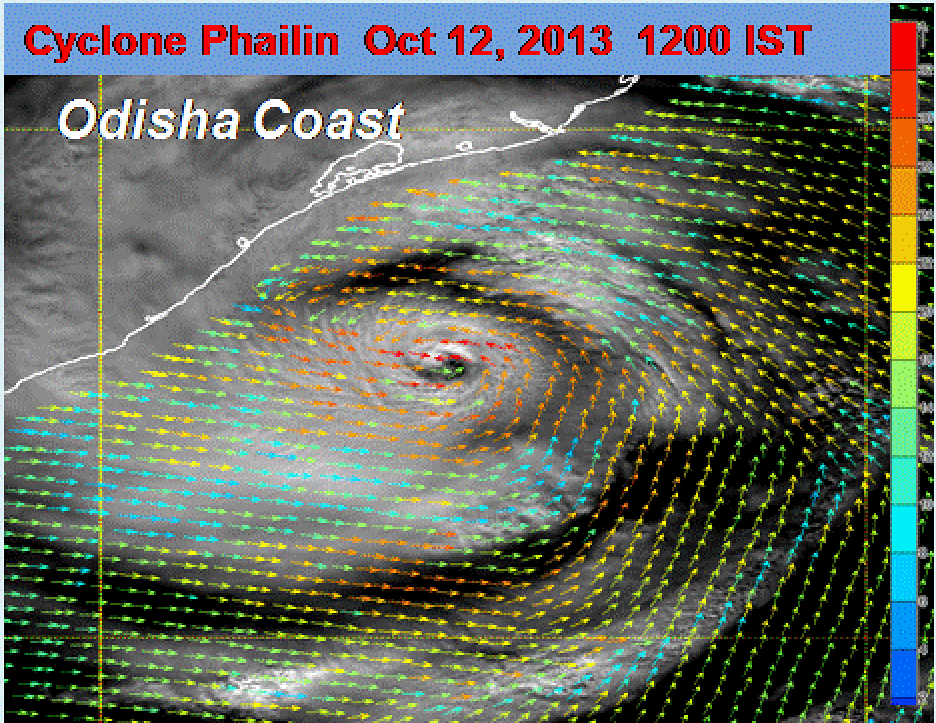
Wind Speed (m/s)


OSCAT Daily Analysed Winds
Jul 17, 2013
(m/s)
Latitude
Longitude
SAC/ISRO
50

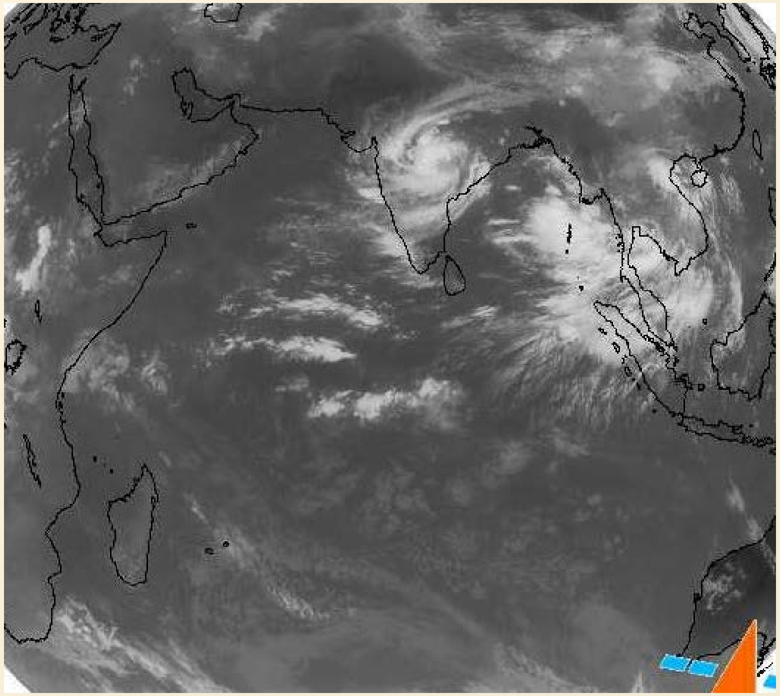

OS2 HVW Winds
O2SCT_20111228_11978_11979_L04_HVW
Latitude
Longitude

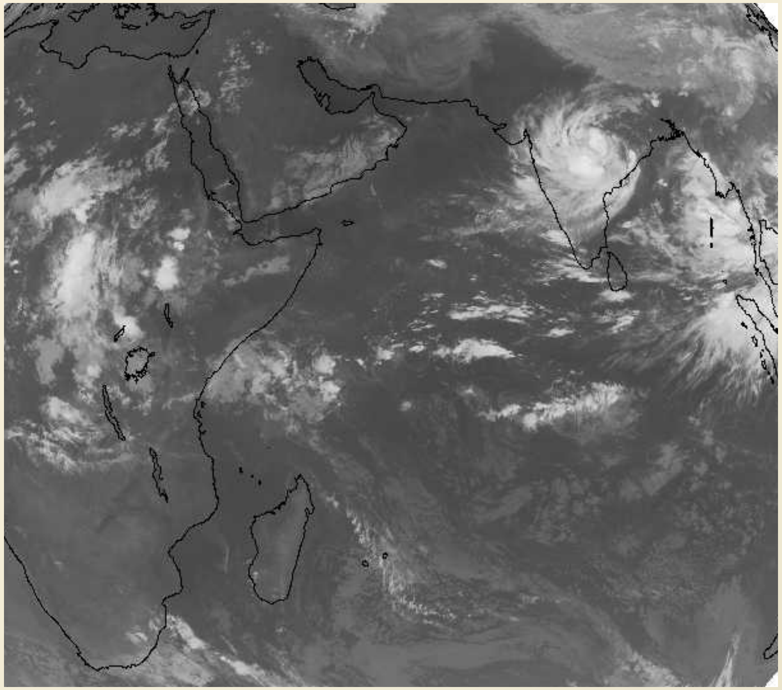



LATITUDE
LONGITUDE
u,v 0.500
ISRO CURRENT TOT 20131012


Cyclone Phailin Oct 12, 2013 1200 IST
Odisha Coast

INSAT-3D-R and INSAT-3D-S (2016 & 2017/18)





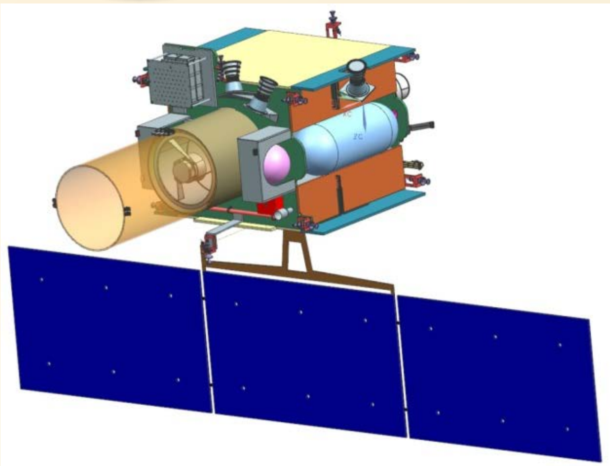
Besides serving an important purpose of operational redundancy, the a pair of Geo satellites Can provide valuable information if operated in staggered mode. Some of the advantages are

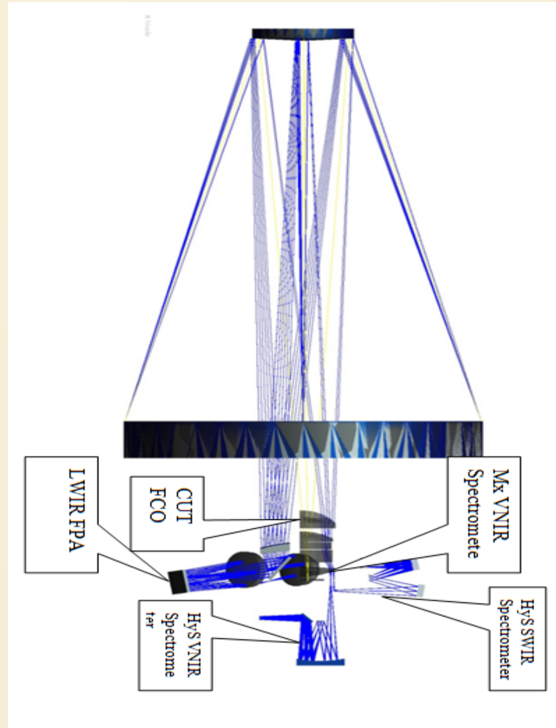
(1) Improved accuracy (~ 10-20% improvement) in derived AMVs
(2) Higher sampling of sounder observations will be beneficial to synoptic prediction in rapidly developing weather situation.
(3) Staggering will make it possible to track vertical cloud growth, providing vertical velocity at cloud top levels. This information could be useful for assimilation.

HIGH RESOLUTION IMAGING SATELLITE FROM GEO ORBIT

HIGH RESOLUTION IMAGING SATELLITE FROM GEO ORBIT

GISAT PAYLOAD CONFIGURATION





Optics size:

Primary mirror :700mm, Secondary mirror: 196mm

Detectors:

MX-VNIR	MX-LWIR	HyS VNIR & SWIR
6 channels	6 channels	>60channels for VNIR, > 150 channels for SWIR
6 lines ×12K Sensor	340×256 Area array	512×256 for VNIR 1000 × 256 Area array for SWIR

HIGH RESOLUTION IMAGING SATELLITE FROM GEO ORBIT

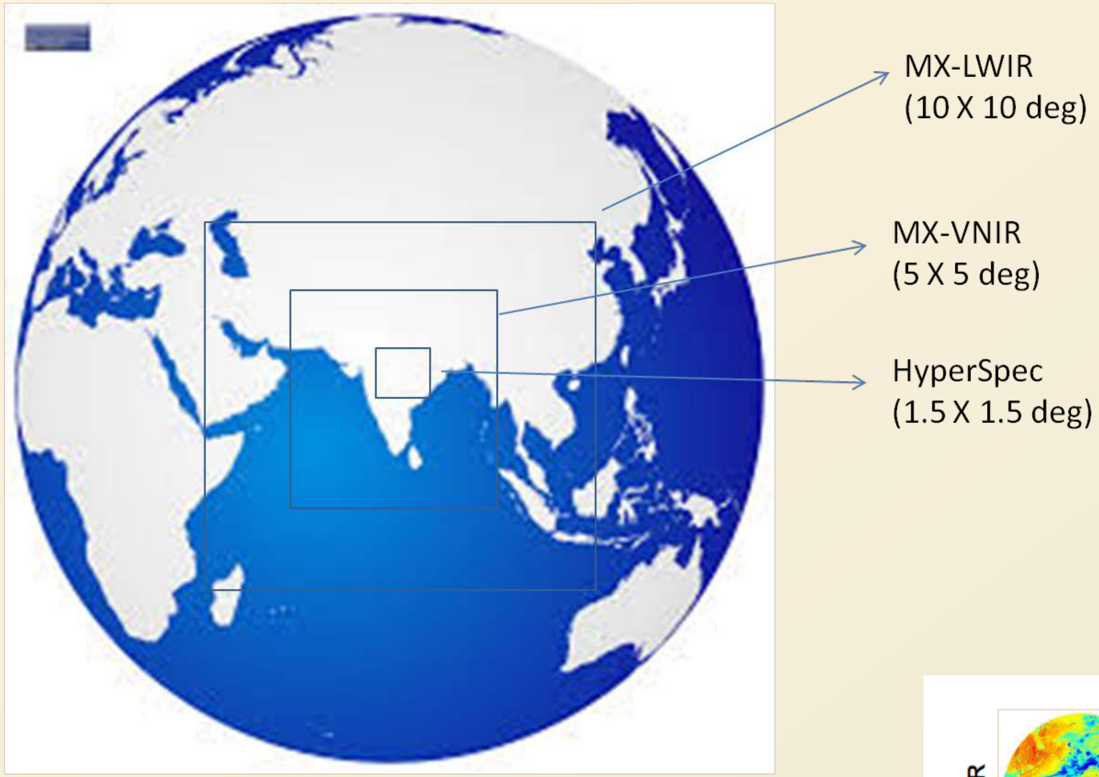
HIGH RESOLUTION IMAGING SATELLITE FROM GEO ORBIT

GISAT PAYLOAD CAPABILITIES

Bands	Resolution @ nadir	Number of bands	Bands
Multi-spectral visible & near-infrared (MX-VNIR)	50m (GSD)	6	B1: 0.45-0.52 µm B2: 0.52-0.59 µm B3: 0.62-0.68 µm B4:0.71-0.74 µm B5: 0.77-0.86 µm B6: 0.845-0.875µm
Hyper-spectral visible & near-infrared (HyS-VNIR) Hyper-Spectral shortwave-infrared (HyS-SWIR)	320 m 192 m	≥ 60 bands ≥150 bands	In range of 0.4 µm to 0.87 µm In range of 1.0 µm to 2.5 µm
Multi-Spectral long wave-infrared (MX-LWIR)	1500m	6	7.1 - 7.6 µm 8.3 - 8.7 µm 9.4 - 9.8 µm 10.3 -11.3 µm 11.5 -12.5 µm 13.0 -13.5 µm

Imaging method: East-west :scan, N-S: Step

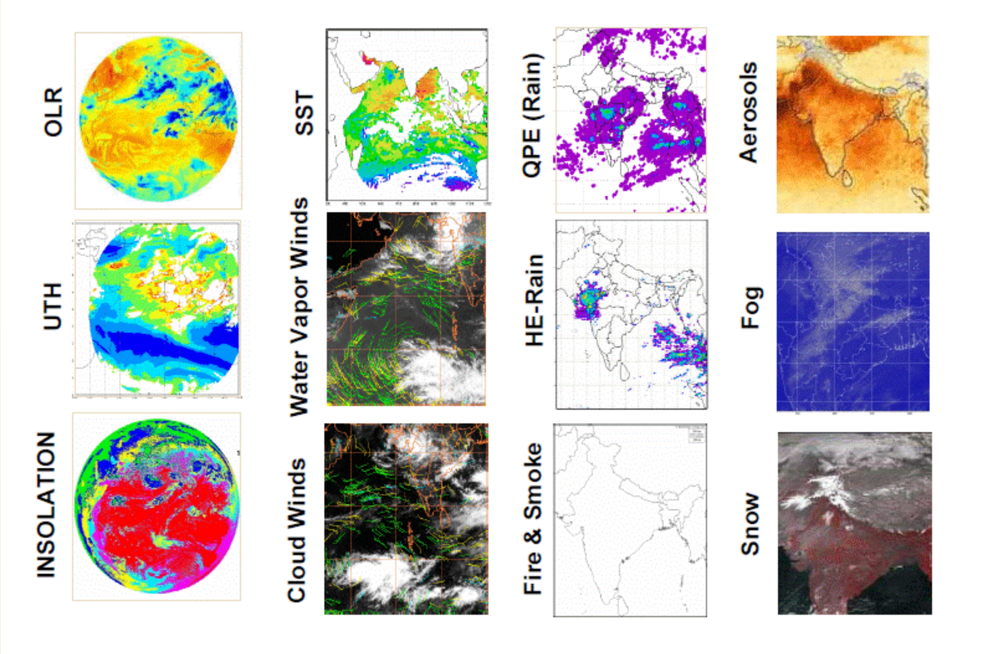
GISAT Coverage



Meteorological Applications of GISAT

1. High resolution winds
2. High resolution SST
3. Nowcasting
4. TC Applications
5. Air quality monitoring
6. High res. water vapor/Ozone
7. Thunderstorm prediction

Sampling interval for LWIR = 30 minutes (A)
08 minute (B)
1 minute (C)



HIGH RESOLUTION IMAGING SATELLITE FROM GEO ORBIT

HIGH RESOLUTION IMAGING SATELLITE FROM GEO ORBIT

Advanced GISAT

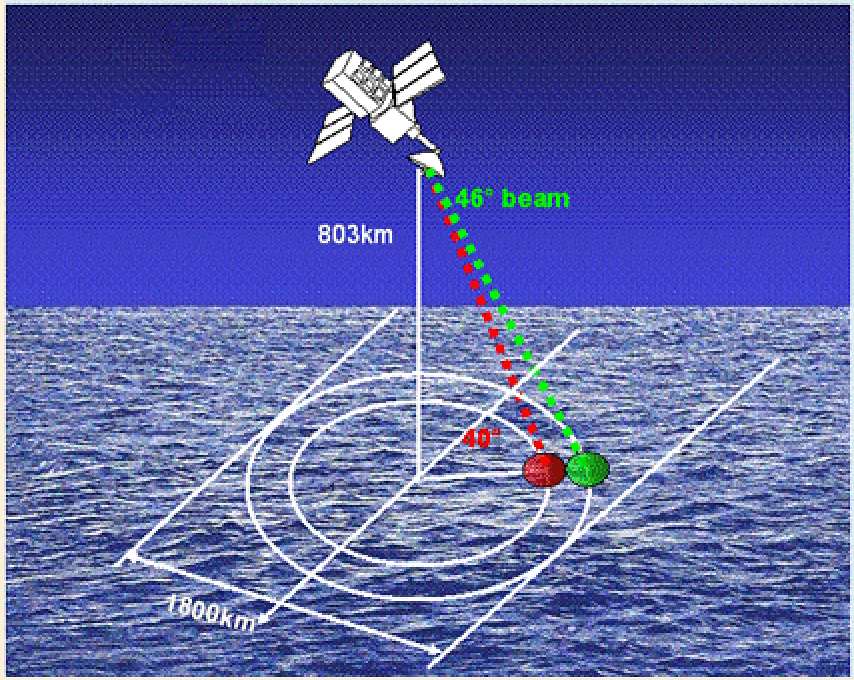
Objectives:

- The mission objective is to design & develop a geo-orbit multispectral advanced satellite to obtain imagery with a very high spatial resolution.
- Performance to be at least three times better resolution than the presently configured GISAT.

Bands	GISAT	AGISAT
VNIR-MX bands	50m	15m
VNIR & SWIR Hyper-Spectral bands	500m	100m
LWIR-MX bands	1500m	500m

- Geographical focus will be primarily entire Indian region and wider region for meteorological applications.
- GSLV MARK-III compatible.

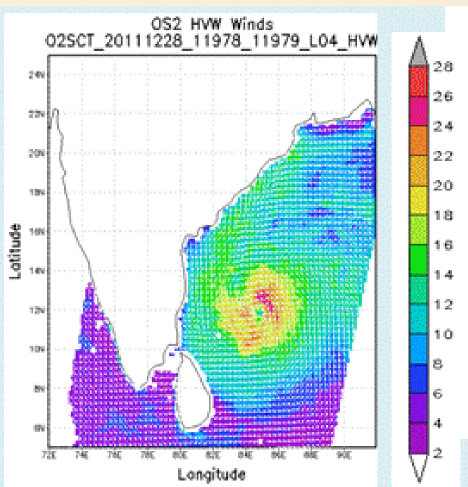
ISRO's Planned Scatterometer missions

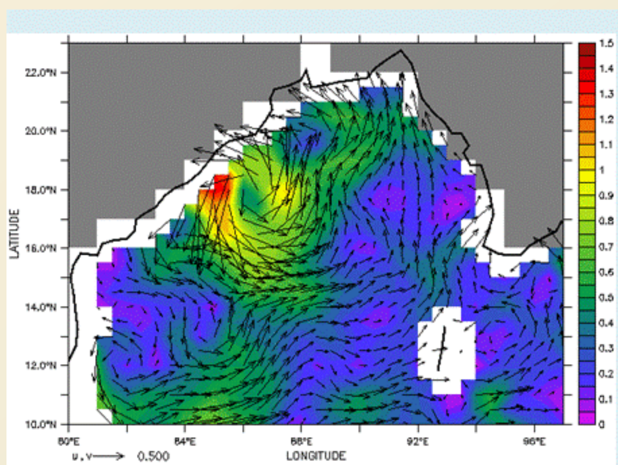


Scatsat : 25 km → 6.2 km
(2016)

Oceansat-3 : 25 km → 6.2 km
(2018)

ALTITUDE	720 KM	
FREQUENCY	Ku-BAND (13.73 GHz)	
CONFIG	PENCIL-BEAM	
	INNER	OUTER
INC. ANG. (DEG)	50.16	57.27
POLARIZATION	HH	VV
SWATH (KM)	1450	1820



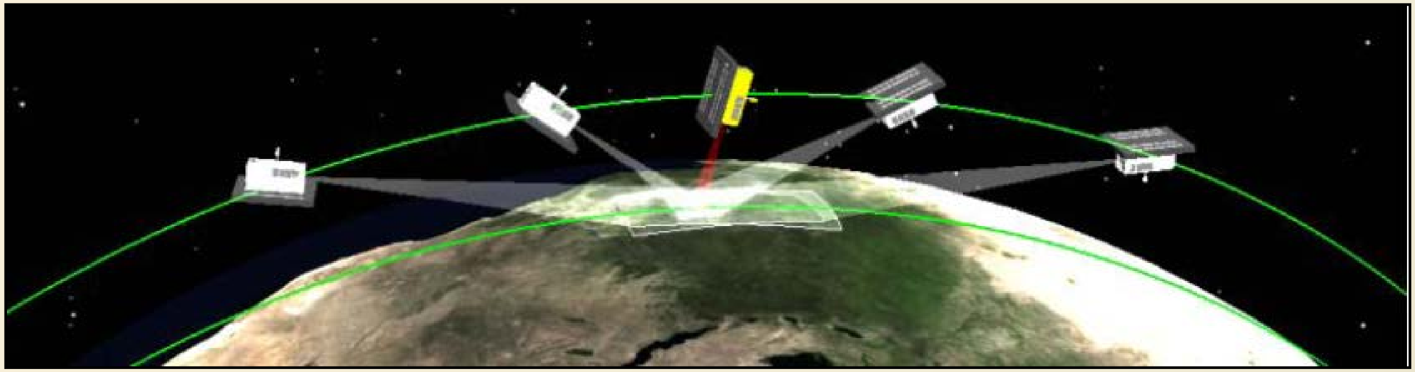


Major Benefits : (a) Tropical cyclone prediction (b) coastal currents
(c) High res. Assimilation

Non-Meteorological Missions with Possible Met Applications

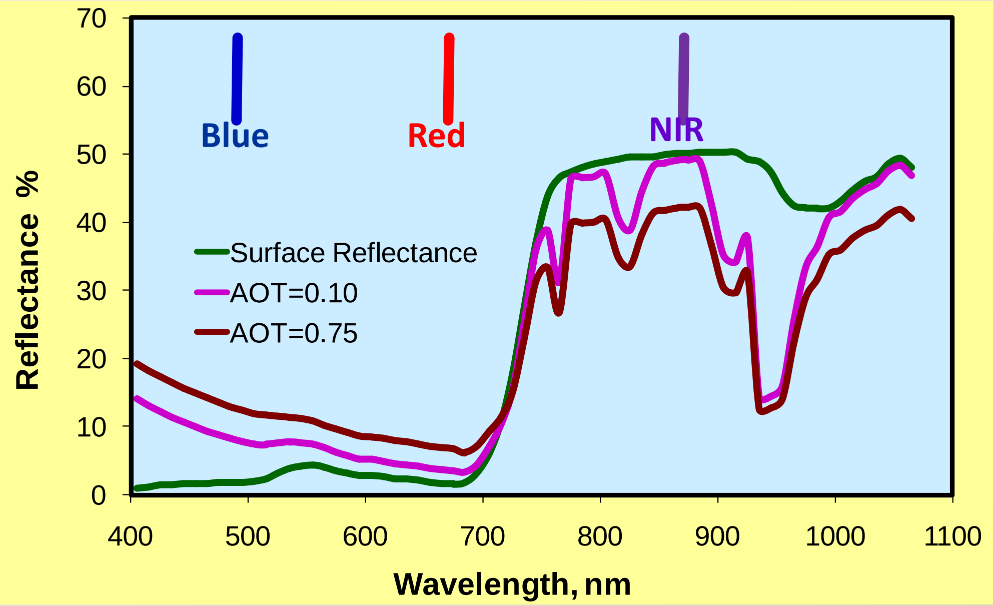
NEMO-AM mission

ISRO has planned a mission NEMO-AM (Nanosatellite for Earth Monitoring and Observation-Aerosol Monitoring) with the goal of retrieving Aerosols properties using polarized reflectance measurements from the polar orbiting satellite



Major specifications & spectral band positions of the sensor onboard NEMO-AM

- 3 spectral bands (Blue-Red-NIR, BW:20nm)
- Spatial resolution: 30m (@500 km altitude)
- View angles ±53^0 by satellite maneuver & Dual polarization (0^0 & 90^0)
- Swath: ~73 km X 26 km
- Radiometric resolution: 12 bits

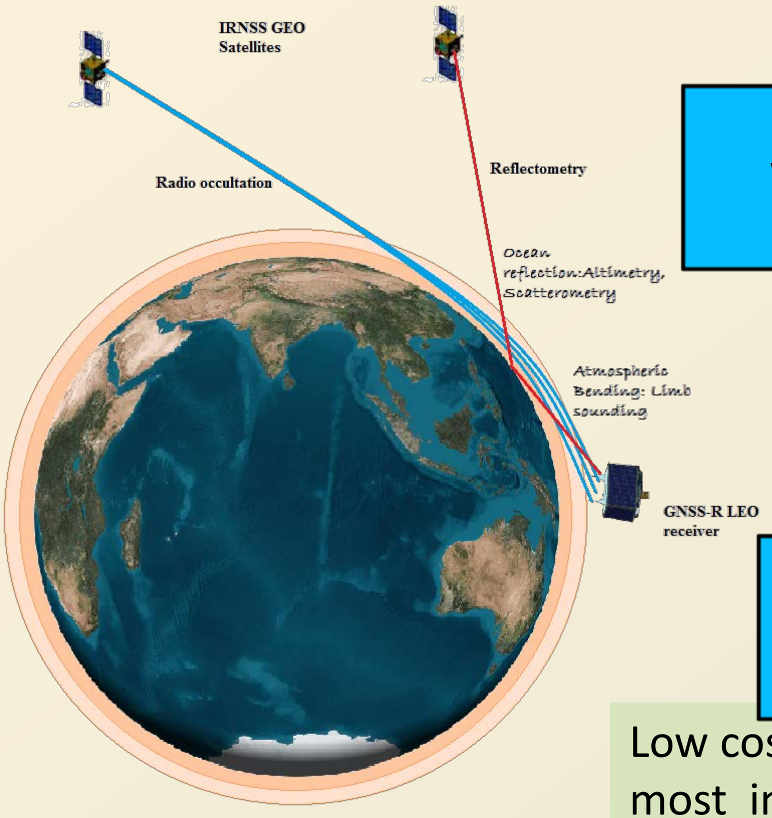


GNSS Reflectometry

GNSS-Remotesensing Receiver : Brief overview

WHAT IS IN THE BOX?

A passive receiver working as Scatterometer , Altimeter and Atmospheric Sounder(RO), operating with reflected and direct received CW GNSS signals .



WHAT CAN IT DO?

Can predict ocean wave heights (detect Tsunami!), surface winds, salinity and moisture content on land and collect information on ice covering, age .

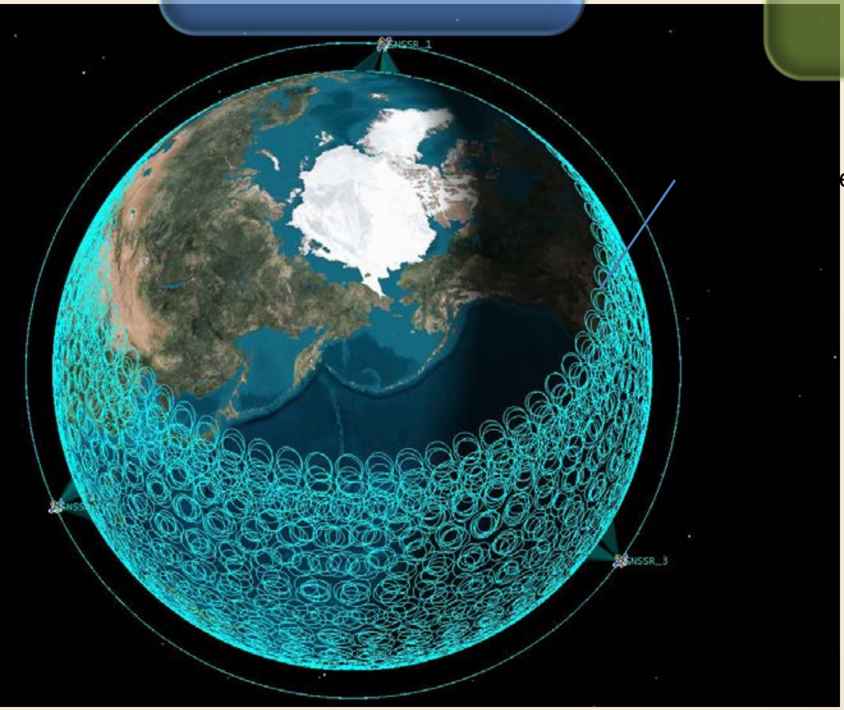
WHAT IS SO SPECIAL WITH IT?

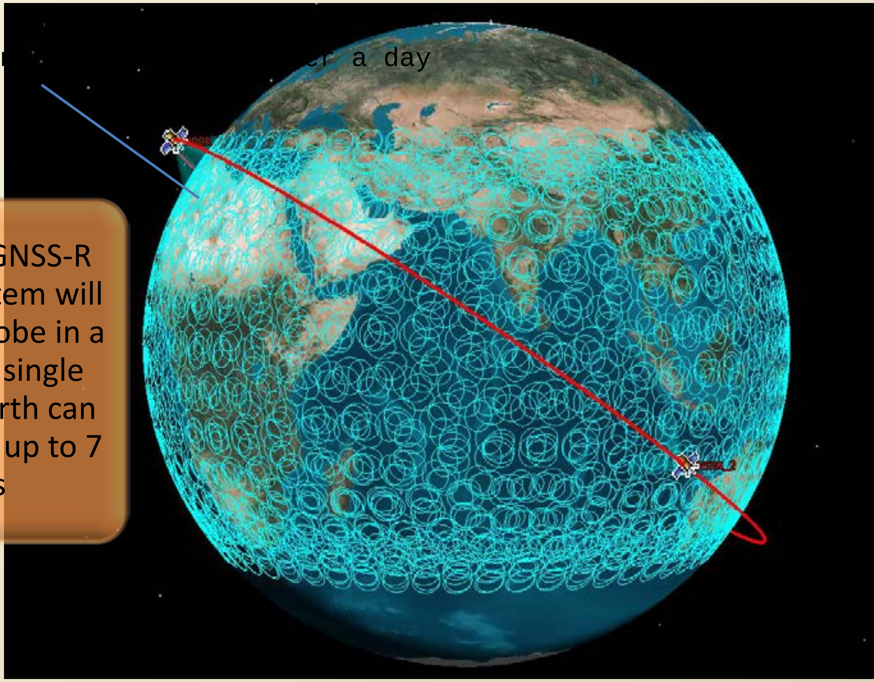
Low cost, high accommodative nature in any satellite and most importantly, high temporal resolution and which makes data available for weather prediction and monitoring reliably dense .

Project plan

Three receiver satellites with 3 different looking beam per satellite, placed in a single Leo orbit(of 30˚ inclination) with different true anomaly.

Specular reflections from GPS,IRNSS, GLONASS, COMPASS signals will be received simultaneously





The three GNSS-R satellite system will cover the globe in a day with a single point on earth can be revisited up to 7 times

Potential applications

- Cyclone eye winds monitoring (Scatterometry)
  - L band has greater penetrability through thick clouds around Cyclone eye
  - Having a high temporal resolution can provide more data for accurate forecast and monitoring.
- Tsunami detection in real time (Altimetry)
  - Code altimetry
  - Phase altimetry
- Ionospheric TEC measurement/ limb sounding (Radio Occultation)

THANKS

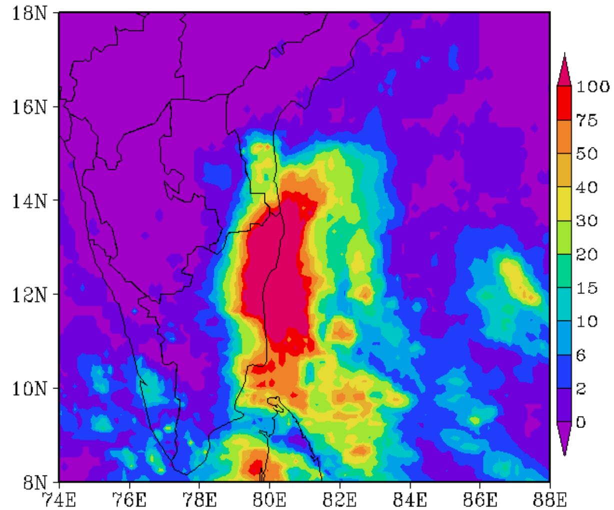
Spatial Distribution of Merged Rainfall Product and WRF model predicted Rainfall from 00Z 01 to 02 December 2015

WRF: Run at 5 km spatial resolution with the use of Indian and International satellites and conventional observations for 72 hours prediction.

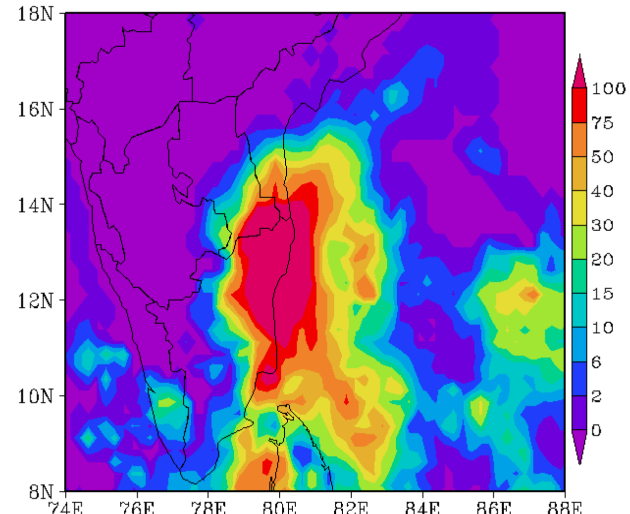
IMERG: Merged Rainfall product from GMI at 0.1 deg spatial and 30 min. temporal resolution

TRMM 3B42 RT: Real time rainfall from TRMM at 0.25 deg spatial and 3 hours temporal resolution

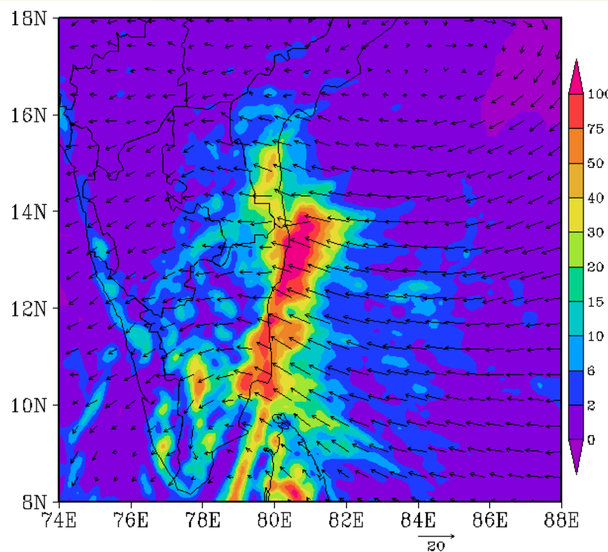
(a) IMERG Rainfall



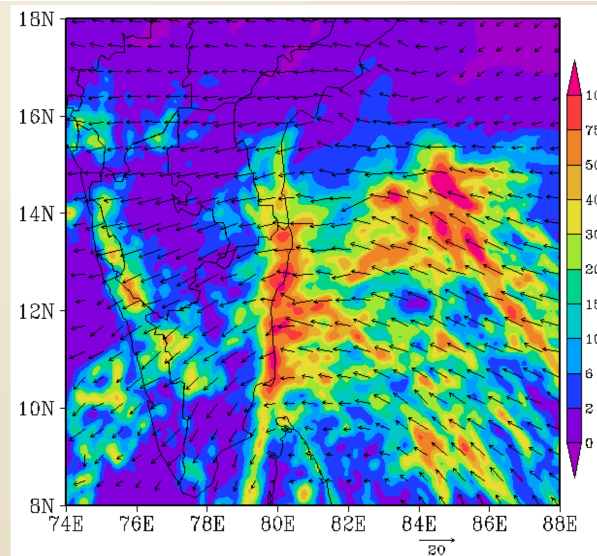
(b) TRMM 3B42RT Rainfall



(c) WRF 24 h Rainfall Forecast



(d) WRF 48 h Rainfall Forecast



Comparison of WRF predicted Rainfall with Ground Observations