Atmospheric parameters from Indian Satellites for assimilation in NWP model

P K Thapliyal

Atmospheric & Oceanic Sciences Group

Space Applications Centre, ISRO

Ahmedabad – 380015

pkthapliyal@sac.isro.gov.in

Data Requirement for NWP system

❖NWP is an initial value problem: - given an estimate of the present state of the atmosphere (**initial conditions**), the model simulates (forecasts) the atmospheric evolution. The more accurate the estimate of the initial conditions, the better the quality of the forecasts

❖ The initial conditions used to start the **forecast model** are provided by the **analysis**

❖ The **analysis** is generated from **observations** relating to the geophysical parameters **combined with** *a priori* **background information** (usually a short-range forecast from the previous analysis).

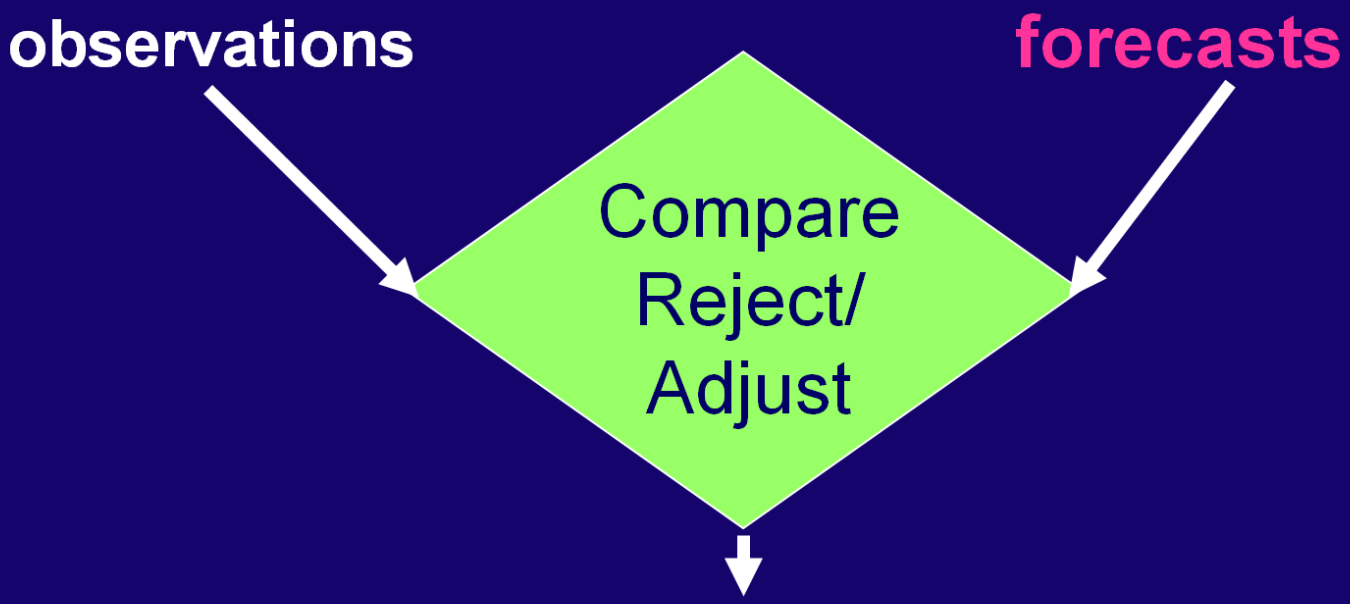
❖Observations:- Conventional, Satellites, Radars

What is data assimilation?

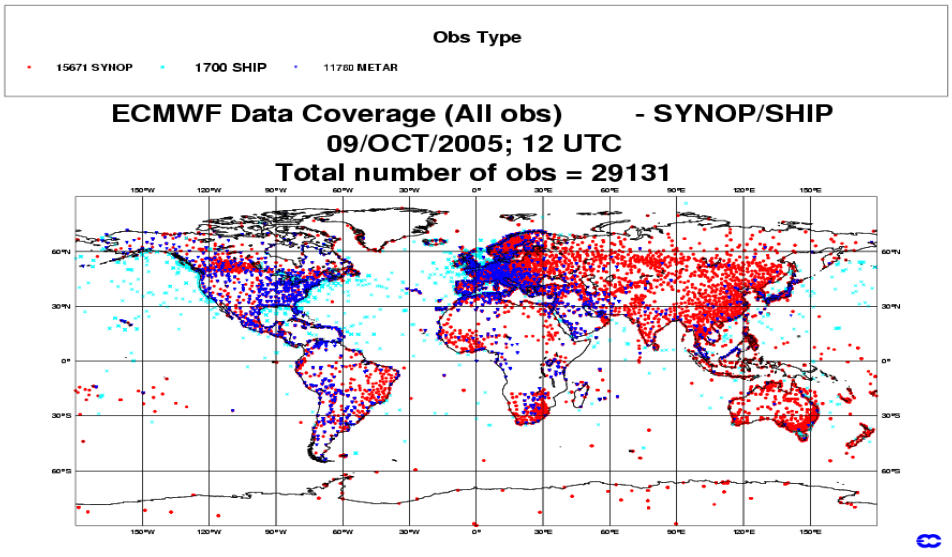
- The process of combining *observations and short-range forecasts to obtain an initial condition for NWP is called* data assimilation

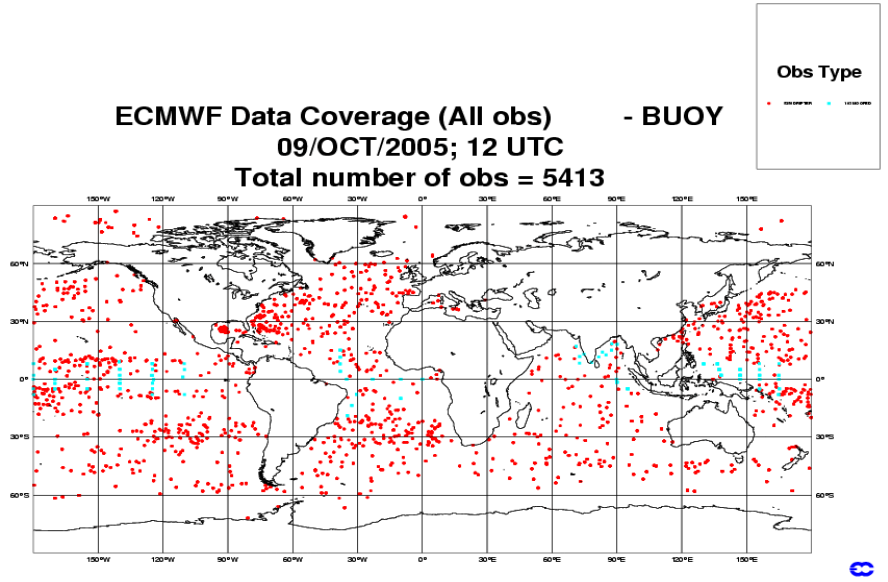
- The purpose of data assimilation is to determine as accurately as possible the state of the atmospheric flow by using all available information.

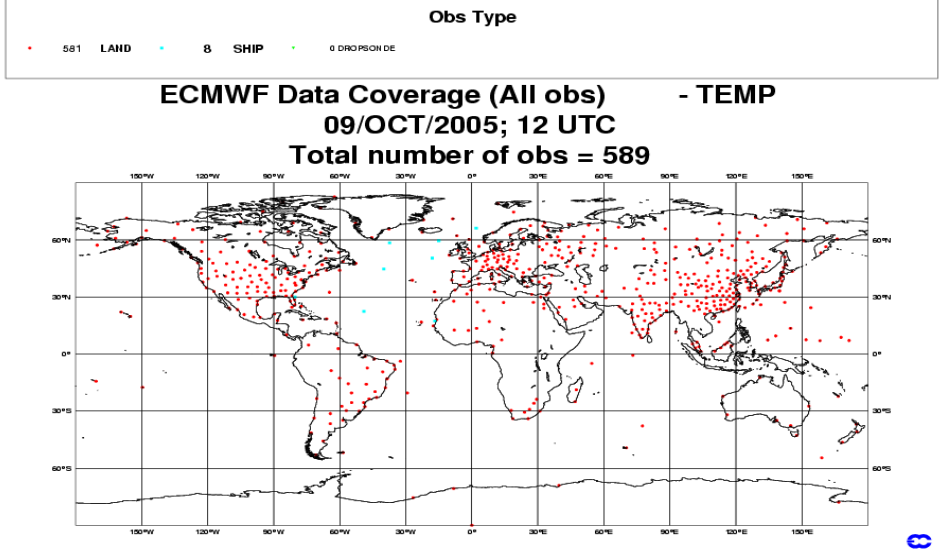
The Data Assimilation Process

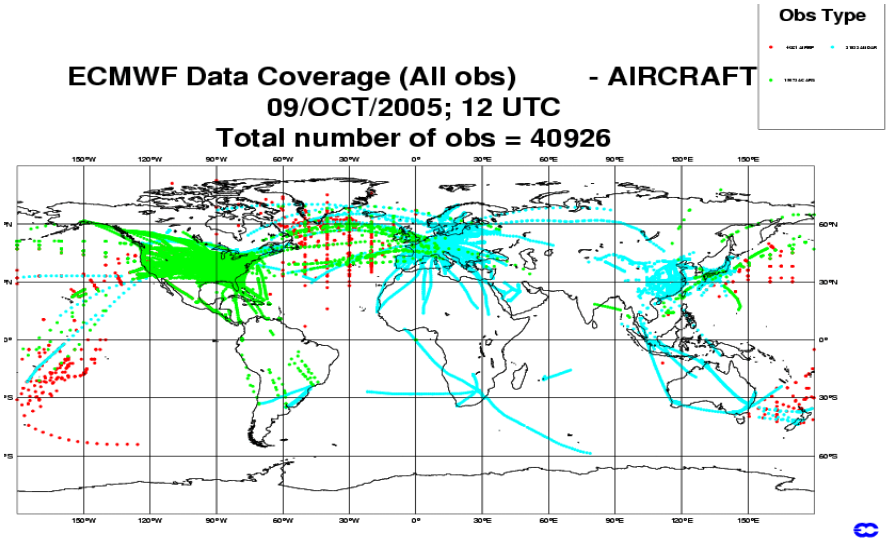


Example of conventional data coverage









Source: ECMWF

Satellite Data

Radiances:

- AMSU-A on NOAA-15/16/17/18(/19), AQUA, Metop
- AMSU-B/MHS on NOAA-16/17/18(/19), Metop
- SSM/I on F-13, AMSR-E on Aqua, TMI on TRMM
- HIRS on NOAA-17(/19), Metop
- AIRS on AQUA, IASI on Metop
- MVIRI on Meteosat-7, SEVIRI on Meteosat-9, GOES-11/12, MTSAT-1R imagers, Kalpana, INSAT-3A

Bending angles:

- COSMIC (6 satellites), GRAS on Metop, (GRACE-A), **Oceansat-II ROSA**

Atmospheric Motion Vectors:

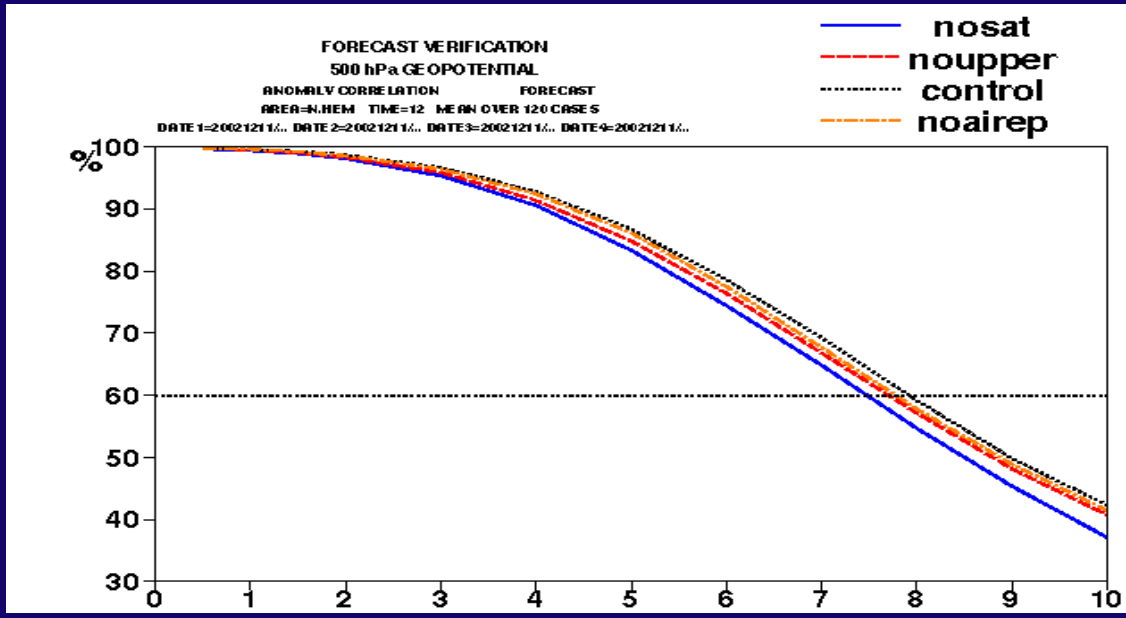
- Meteosat-7/9, GOES-11/12, MTSAT-1R(, FY-2C), MODIS on Terra/Aqua, Kalpana, INSAT-3A

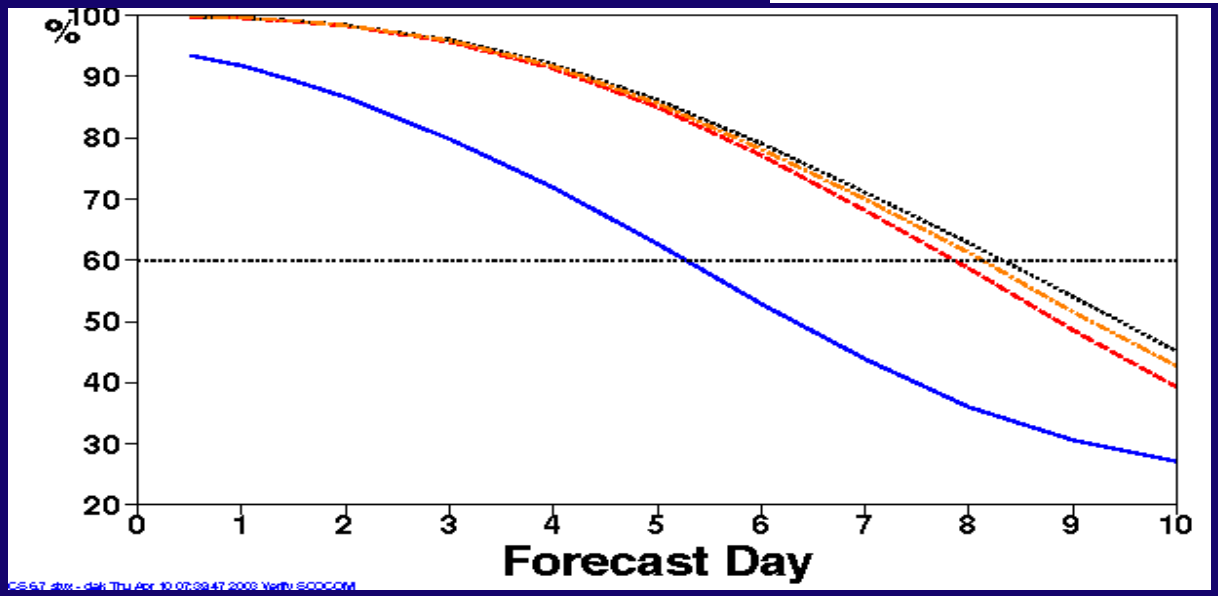
Sea surface parameters (wind speed):

- Seawinds on QuikSCAT, ERS-2, ASCAT on Metop
- **OSCAT on Oceansat-II**

IS SATELLITE DATA IMPORTANT FOR NWP ?

These **O**bserving **S**ystem **E**xperiments (OSEs), aimed at measuring the impact of different types of observation,….





satellite data are the single most important component of the global observing network for NWP

Source - ECMWF

Assimilation Approach

- Retrieved products
  - Temperature
  - Humidity
  - Winds
  - SST
- Direct Radiances

Radiance Assimilation

Y(n) Raw Measurements
(e.g. radiances)

Model Fields
u,v,T,q ----X(FG)

Quality Control

Interpolation

Observation Operator H(x)

Bias Correction

Forward Model

Y(n)
Observed Radiances

H(x)
FG Radiances

Compute Differences

(Y–H(x))

Other Observations

Minimization

Observation and FG Errors (B, R)

Analysis Xa

Necessary Component of Radiance Assimilation

$$J(x) = (x - x_b)^T \mathbf{B}^{-1} (x - x_b) + (y - \mathrm{H}[x])^T \mathbf{R}^{-1} (y - \mathrm{H}[x])$$

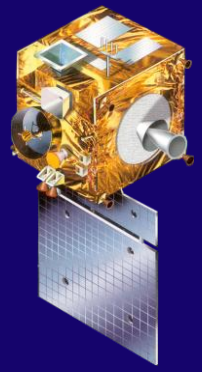
"Observation operator"
H = radiative transfer equation

- The development of Fast Radiative Transfer Model and its adjoint
- Coupling of NWP and Fast RTM
- Monitoring of departures from the observed radiances (OB) and those computed using radiative transfer and a short term forecast from the NWP model, termed the background (FG).
- Bias correction

Indian Missions for Weather & Climate Studies : Current & Future

GEO

Kalpana-1 2002



VHRR

CMV, OLR, UTH,Rain

INSAT-3A (2003)

VHRR, CCD

CMV, OLR, UTH, Rain, Aerosol

INSAT-3D (2012)

6-Ch VHRR
19-Ch Sounder

SST, CMV, OLR, UTH, Rain, T-q Profile, O_3

- INSAT-3D R
- Geo-HR (~2013)
- Follow-up (~2015)

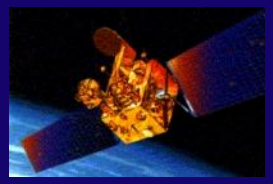
LEO

OCEANSAT–1/2 (1999/2009)

MSMR,
OCM,
Scatterometer
ROSA (GPS)

Vector Winds, Aerosol, T&h Profile

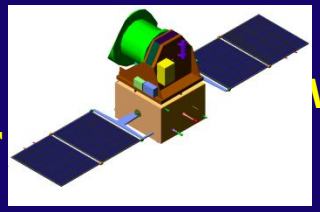
SARAL (2011)



Altimeter

SSH, Waves, Winds

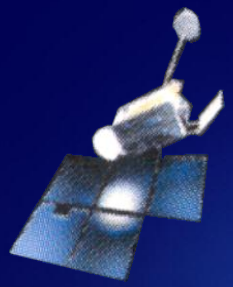
MEGHA-TROPIQUES (2011)



MW Imager,
WV Sounder,
ScaRaB
ROSA

SS Wind, TWV, Rainfall
T, h Profile,
Radiation Budget

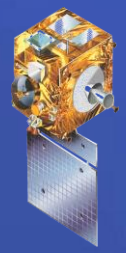
Indian Meteorological Geostationary Satellites



INSAT-1D
VHRR
1990

INSAT-2A/2B
VHRR
1992/93

INSAT-2E
VHRR, CCD
1999



KALPANA-1
VHRR
2002

INSAT-3A
VHRR, CCD
2003

INSAT-3D
Imager/ Sounder
2012

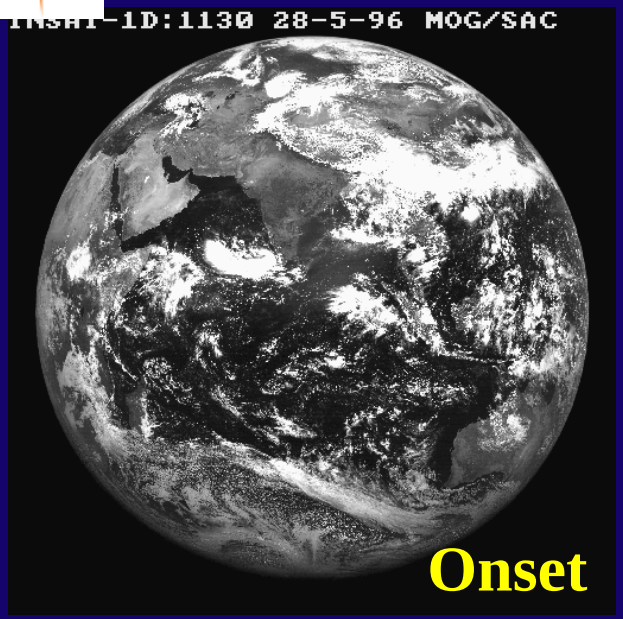
INSAT -1 : Geostationary Satellite Series

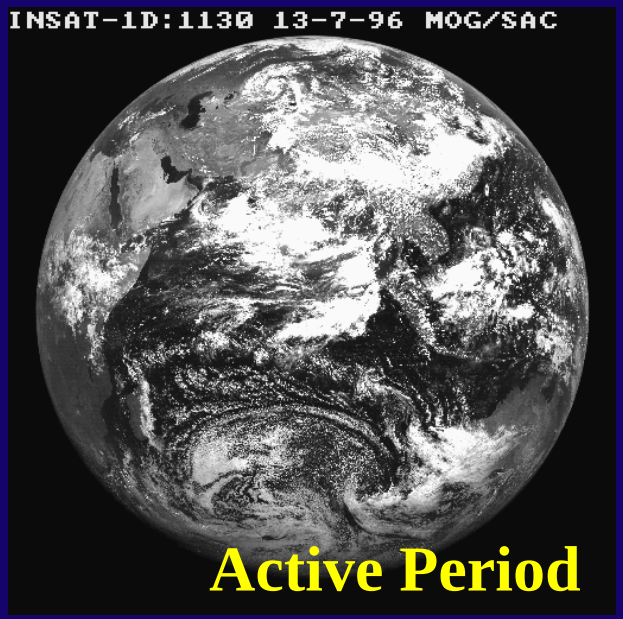
Satellite	Launch Date	Met. Payload with Wavelength Bands	Major Applications
INSAT-1A	10 April 1982	Very High Resolution Radiometer (VHRR) Visible 0.55-0.75μm IR 10.5 - 12.5μm	▪ Monitoring cyclones & monsoon ▪ CMV Winds ▪ OLR ▪ Rainfall Estimation
INSAT-1B	8 August 1983	-do-	-do-
INSAT-1C	22 July 1988	-do-	-do-
INSAT-1D	12 June 1990	-do-	-do-

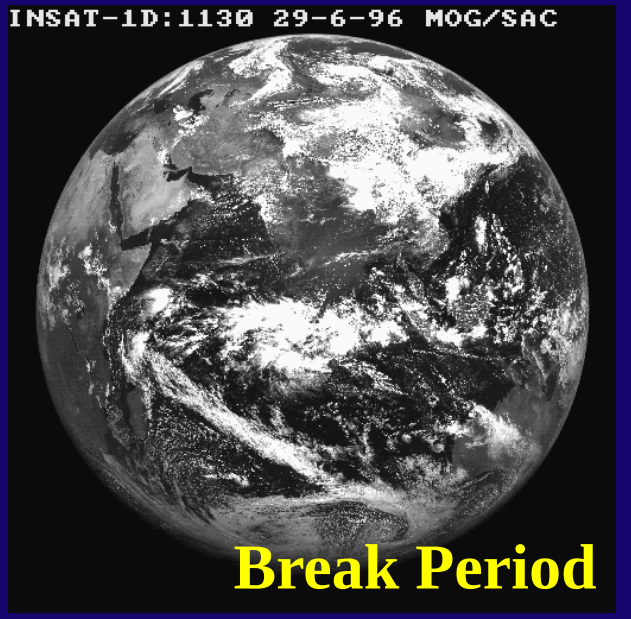
INSAT-1D VHRR

Detector	Spectral Band (μm)	Spatial Resolution (Km)
Visible (Vis)	0.55 – 0.75	2.75
Infrared (IR)	10.0 – 12.0	11

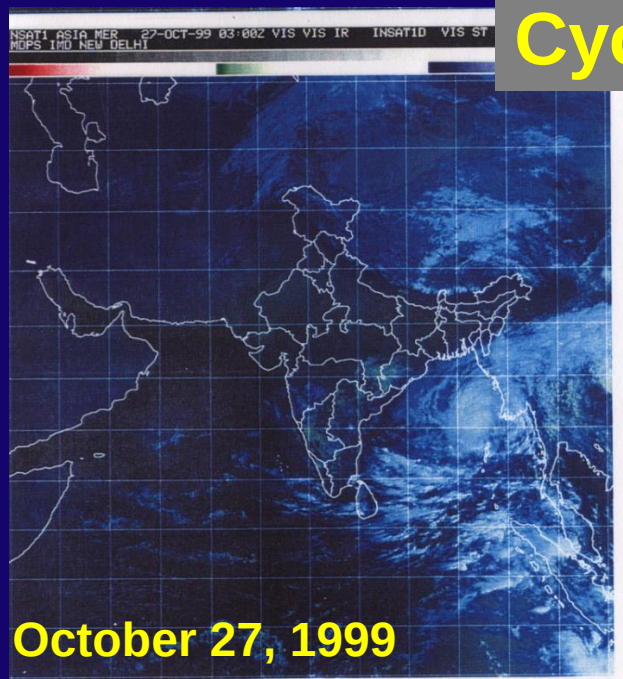
Monsoon Applications

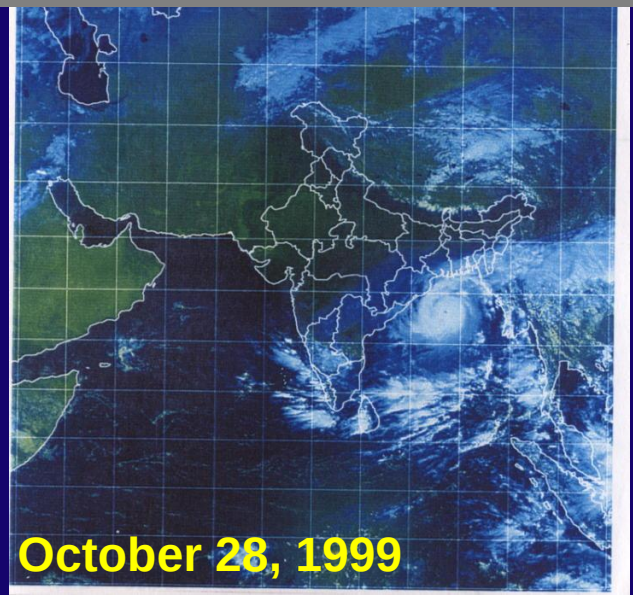


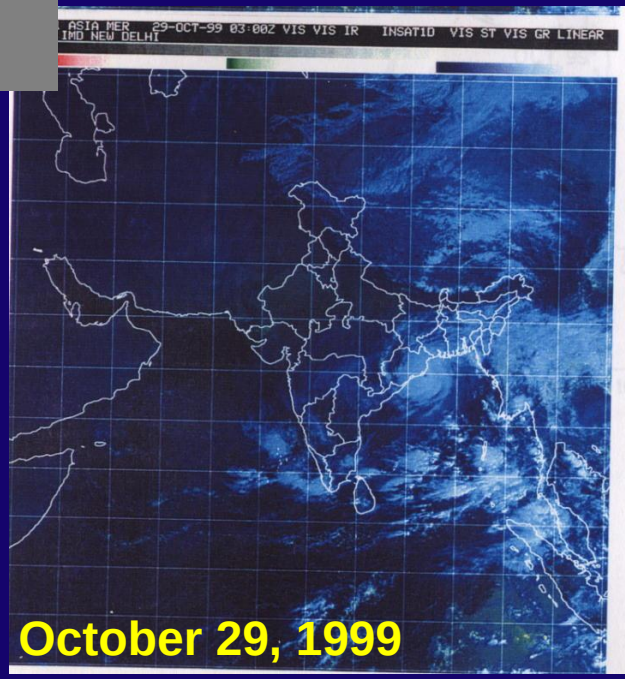




Cyclone Applications







INSAT -2 : Geostationary Satellite Series

Satellite	Launch Date	Met. Payload with Wavelength Bands	Major Applications
INSAT-2A	10 July 1992	Very High Resolution Radiometer (VHRR) Bands 0.55-0.75 μm & 10.5 - 12.5μm	▪ Monitoring cyclones & monsoon ▪ CMV Winds ▪ OLR ▪ Rainfall Estimation ▪ Mesoscale features ▪ Flood/intense precipitation advisory ▪ Snow detection
INSAT-2B	23 July 1993	Very High Resolution Radiometer (VHRR) Bands : 0.55-0.75 μm &10.5 - 12.5 μm	
INSAT-2E	April 1999	**VHRR** : As above + WV Bands : 5-7.1 μm **CCD** : Bands : 0.63 - 0.79 μm 0.77 - 0.86 μm 1.55-1.70 μm	

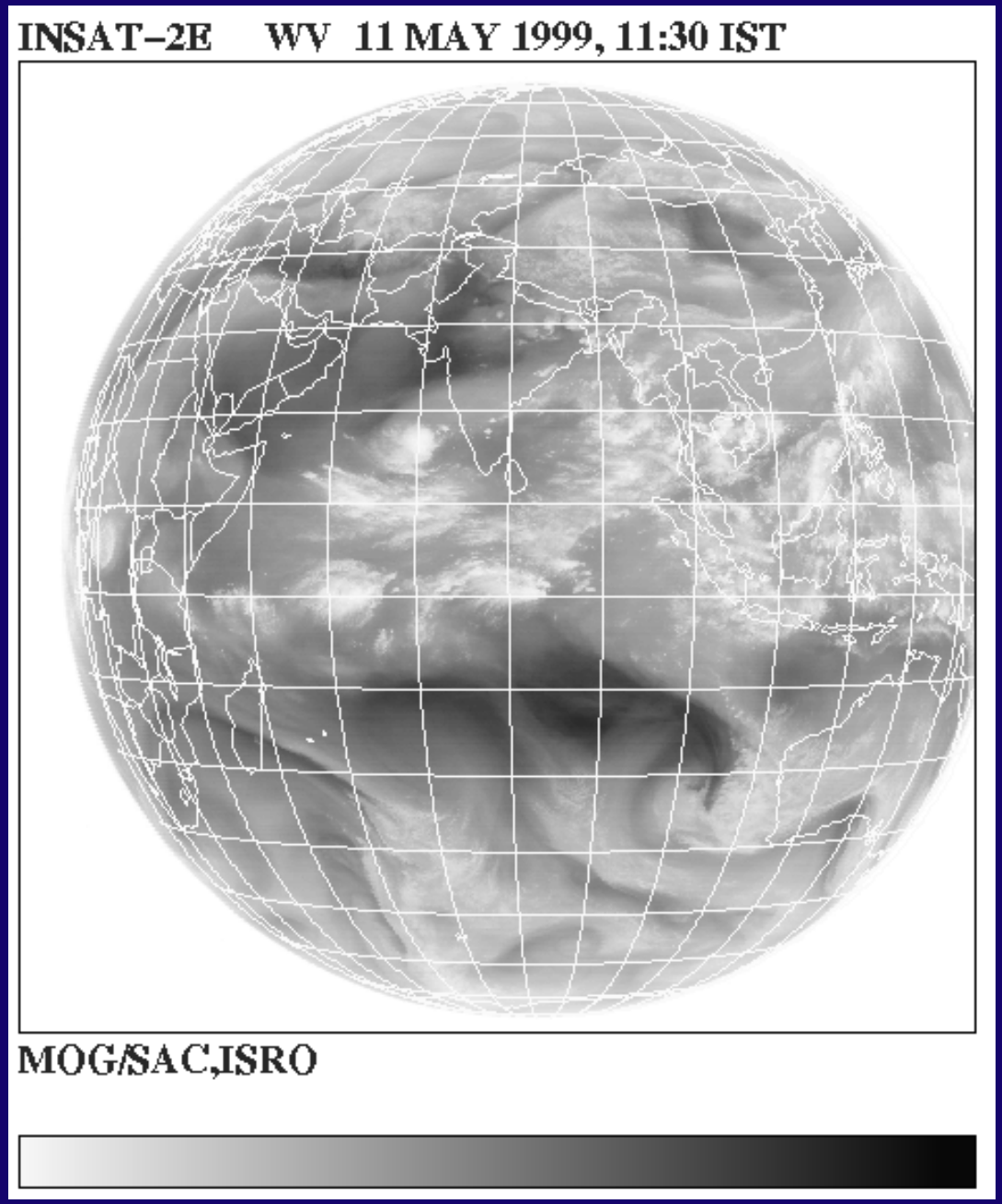
INSAT 2E - VHRR

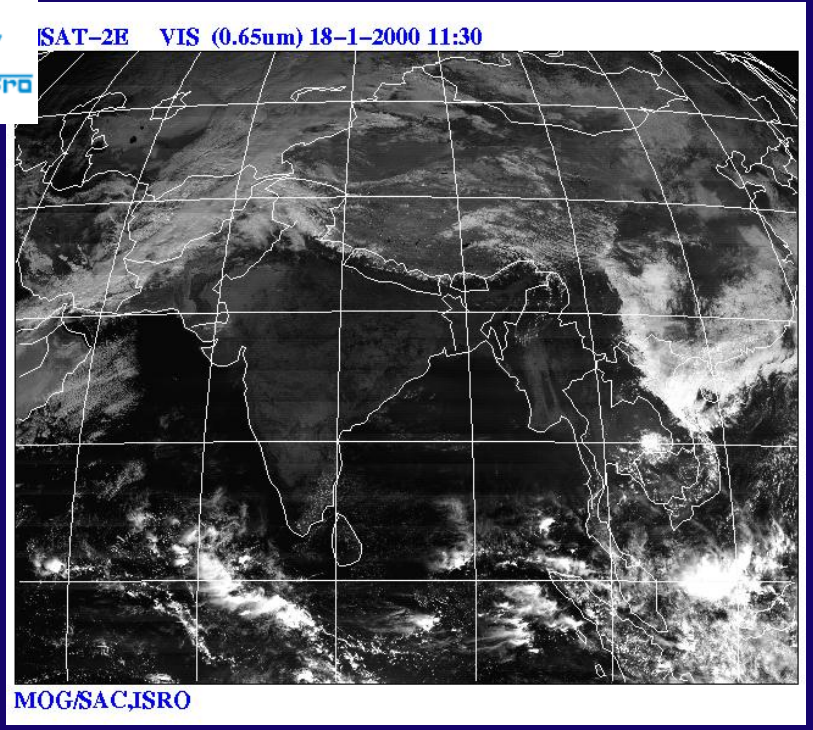
Detectors	Spectral Band (μm)	Resolution (km)
Visible	0.55-0.75	2 x 2
Infra Red	10.5-12.5	8 x 8
Water Vapour	5.7-7.1	8 x 8

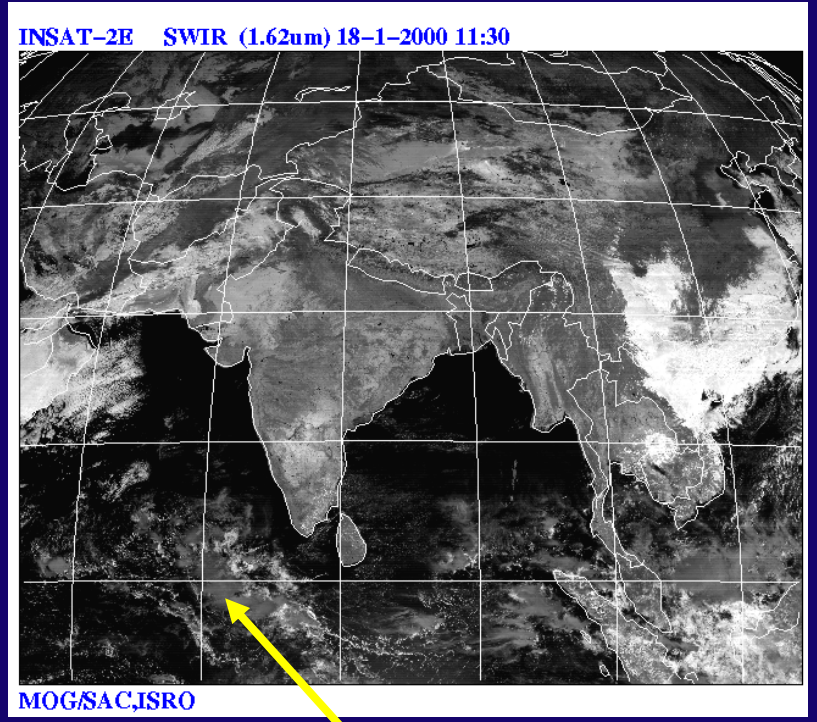
INSAT 2E - CCD

Detectors	Spectral Bands (μm)	Spatial Resolution
Visible (Vis)	0.63-0.68	1 Km
Near Infrared (NIR)	0.77-0.86	1 Km
S W Infrared (SWIR)	1.55-1.7	1 Km

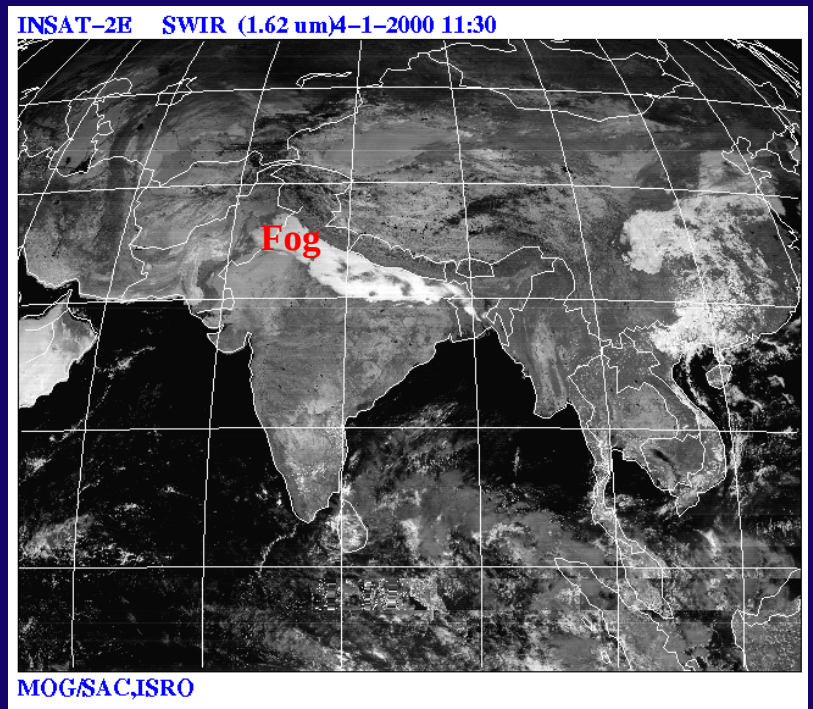
INSAT-2E VHRR WV Channel Image





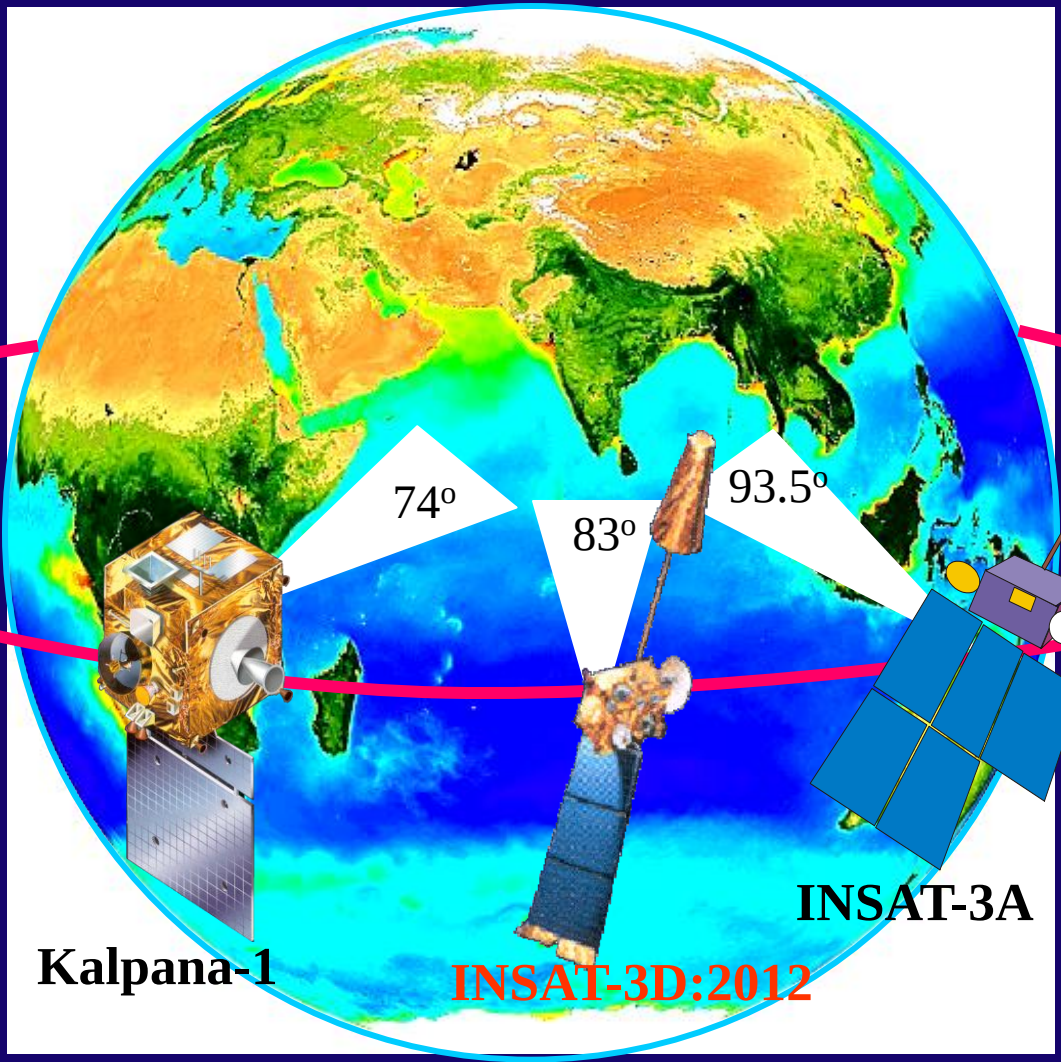


Cirrus clouds



INSAT-2E
CCD Image

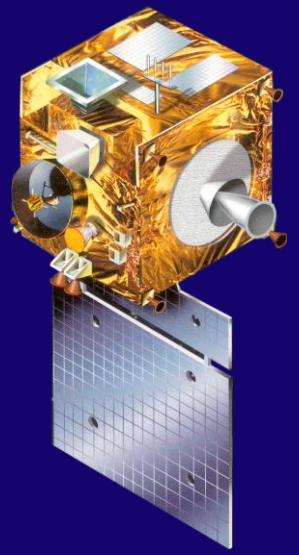
Present and Future INSAT Satellites



INSAT-3A & Kalpana-1

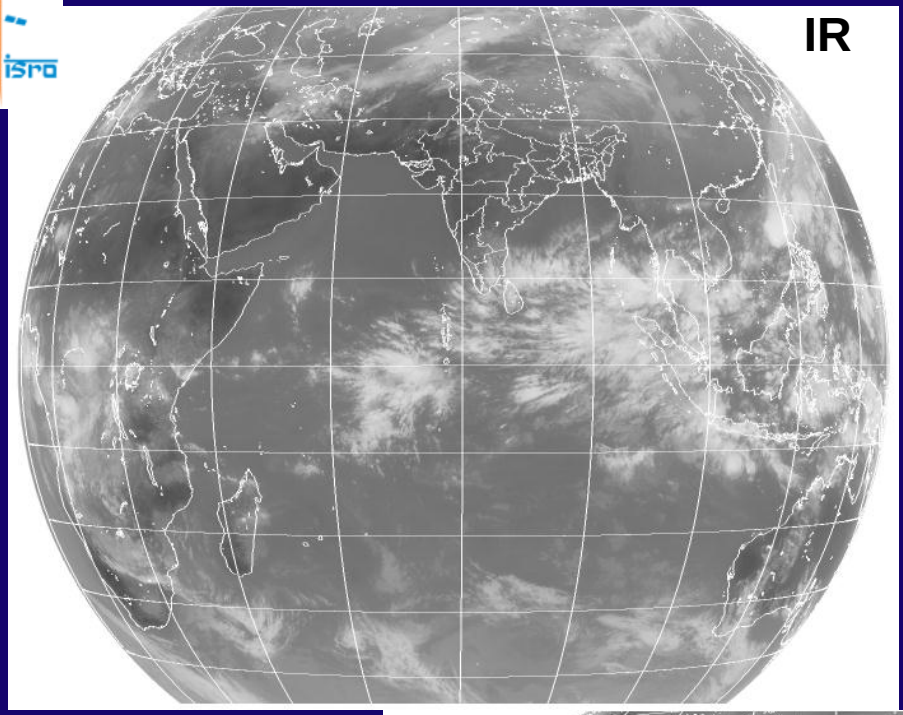
Location : INSAT 3A : 93.5ºE
Kalpana-1 : 74ºE

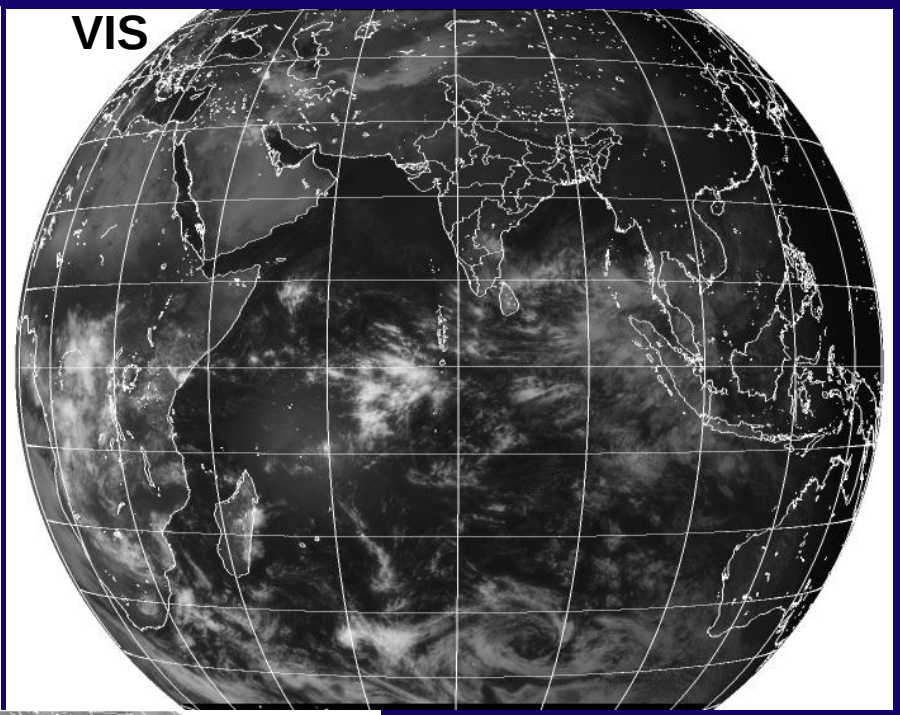
Payload : (i) VHRR & CCD camera in INSAT 3A
(ii) VHRR in Kalpana-1

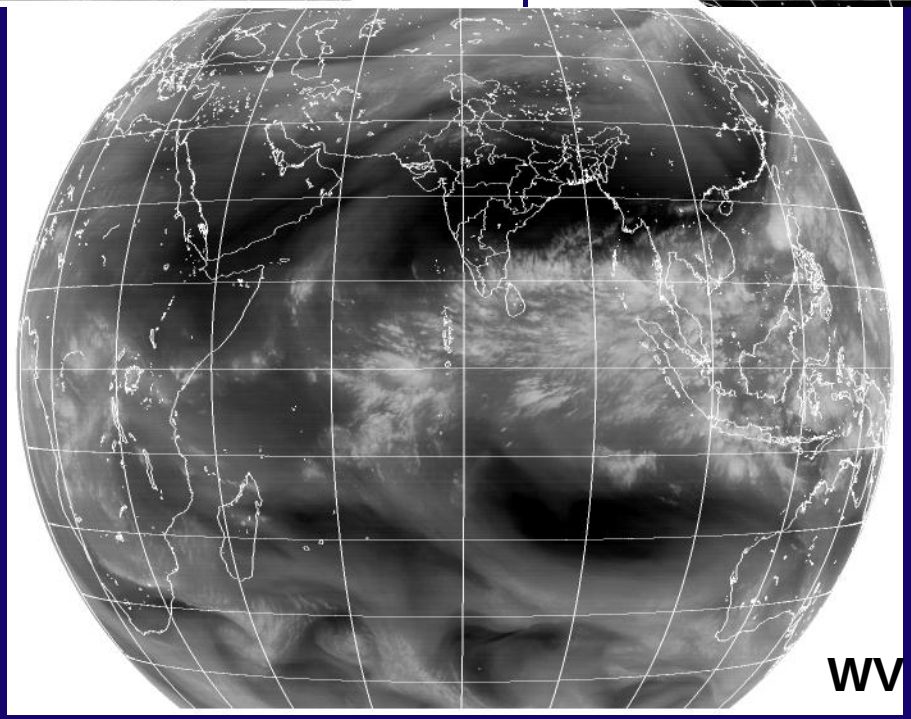


- **VHRR Bands (μm)**
  - Visible : 0.55 – 0.75
  - Water vapour : 5.70 – 7.10
  - Thermal Infra Red : 10.5 – 12.5
- Resolution (km) : 2 X 2 for Visible
  8 X 8 for TIR

- **CCD Camera Bands (μm)**
  - Visible : 0.62 – 0.68
  - Near Infra Red : 0.77 – 0.86
  - Short Wave Infra Red : 1.55 – 1.69
- Resolution (km) : 1 X 1 for all bands



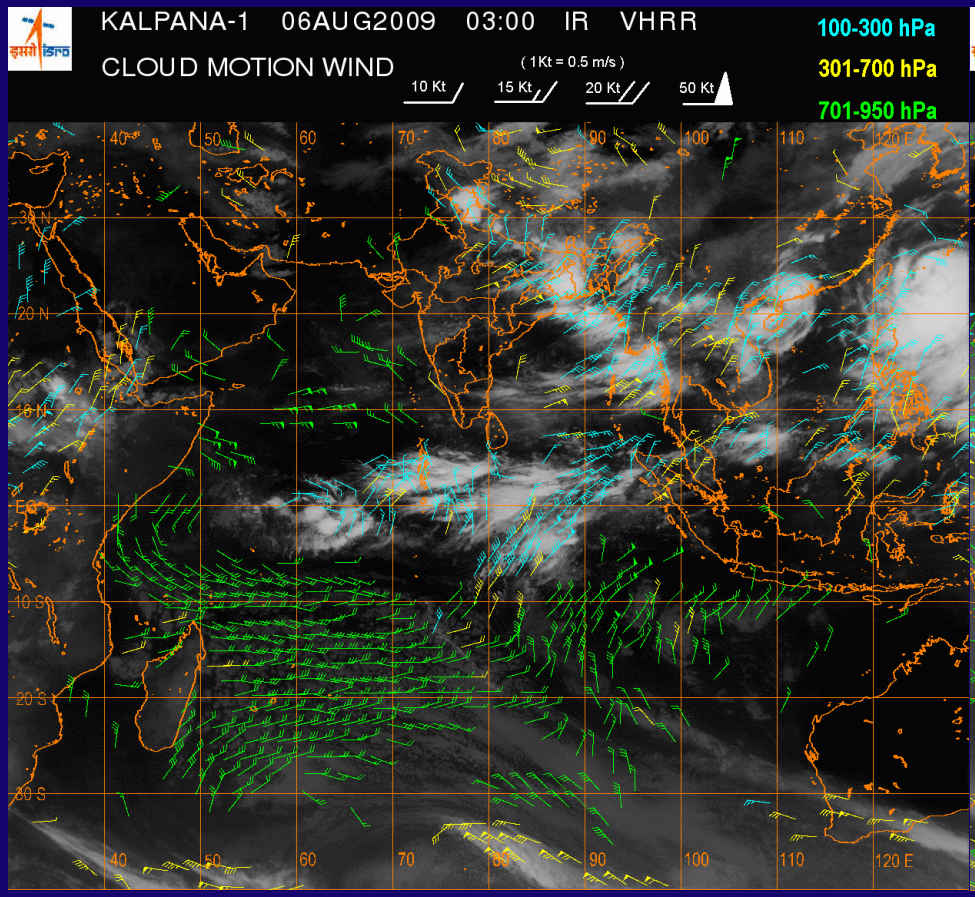


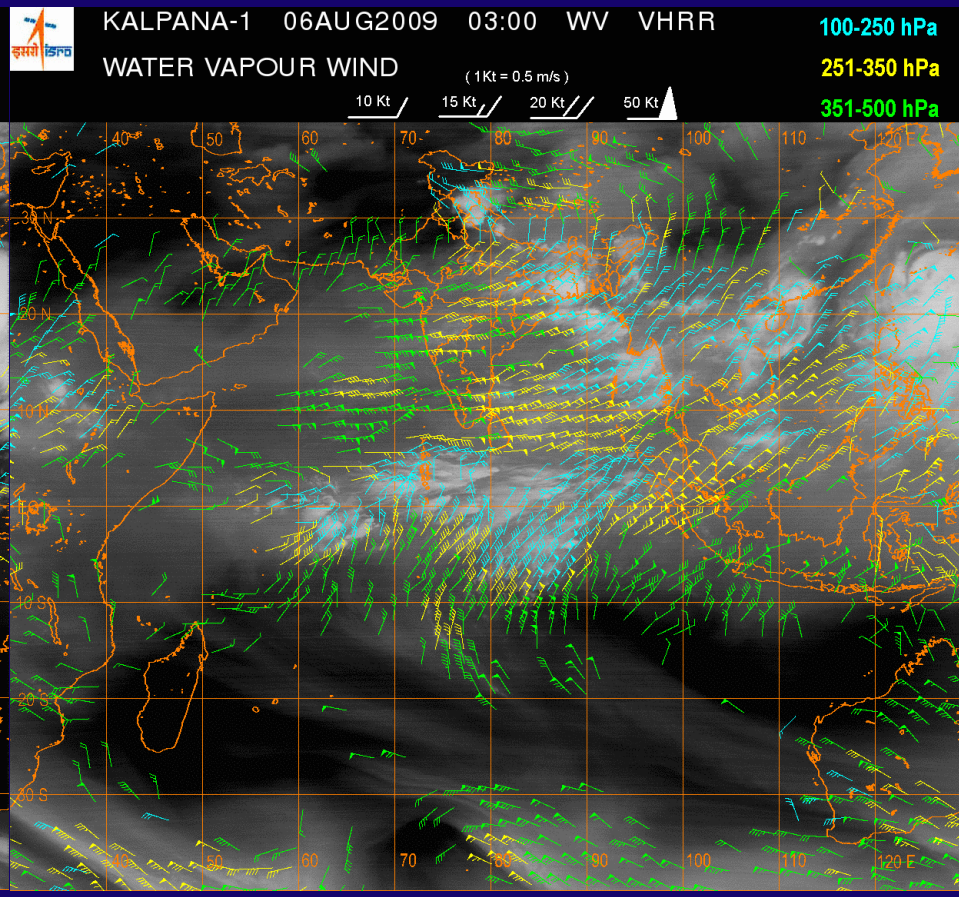


Kalpana-1 VHRR
10 Nov 2008 0900Z

INSAT-3A / Kalpana Products

AMV (Winds)





INSAT-3A / Kalpana Products

Outgoing Longwave Radiation

- Important model diagnostic parameter
- Kalpana, INSAT-3A, INSAT-3D half-hrly
- Accuracy: ~5 W.m^{-2}

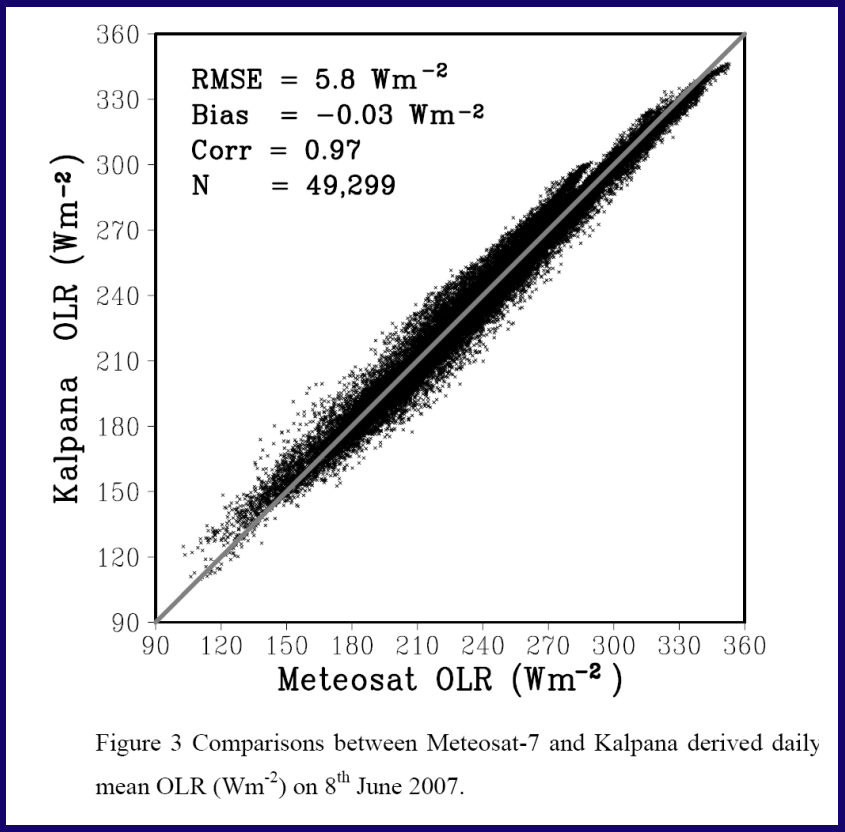
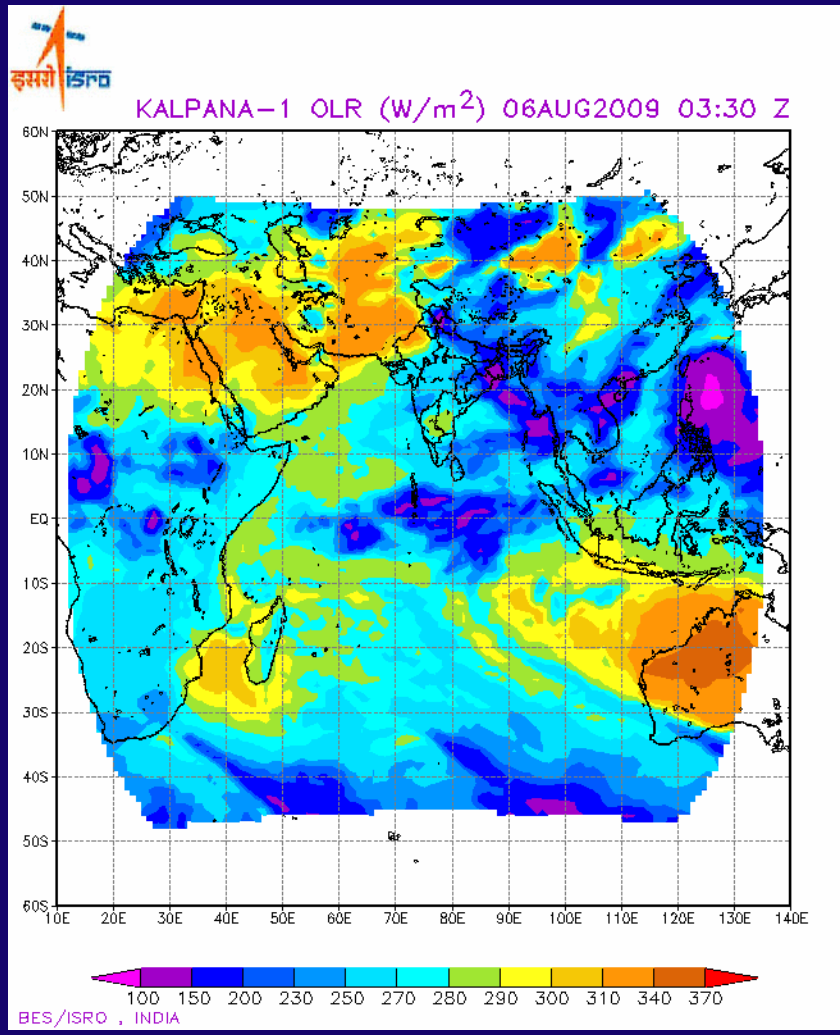
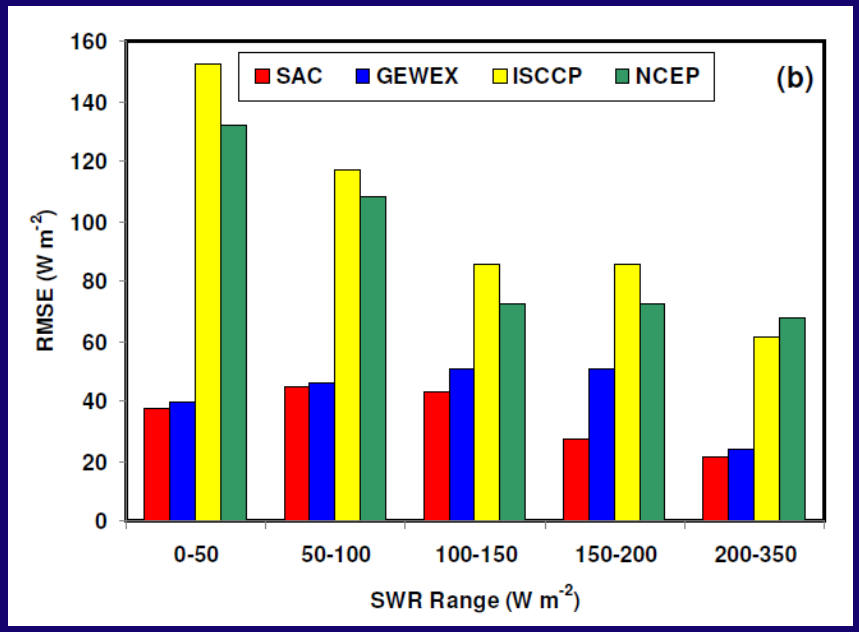
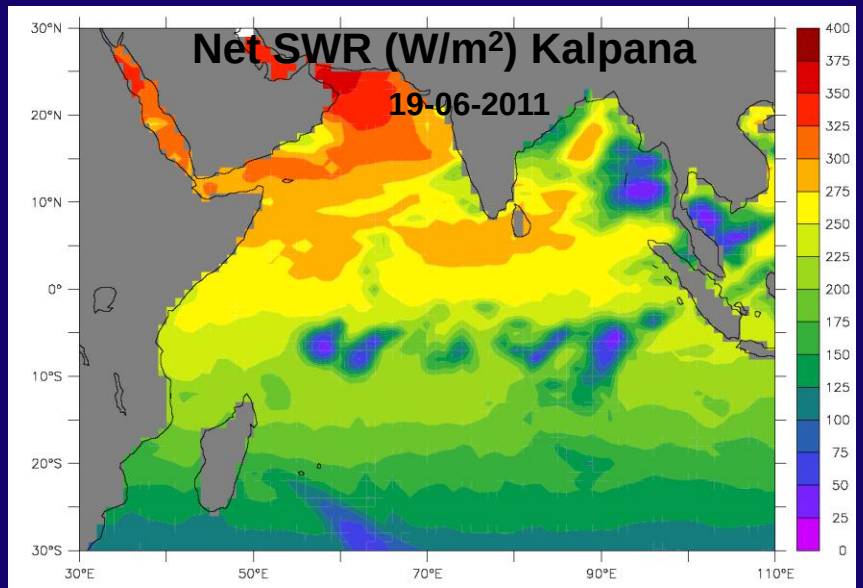


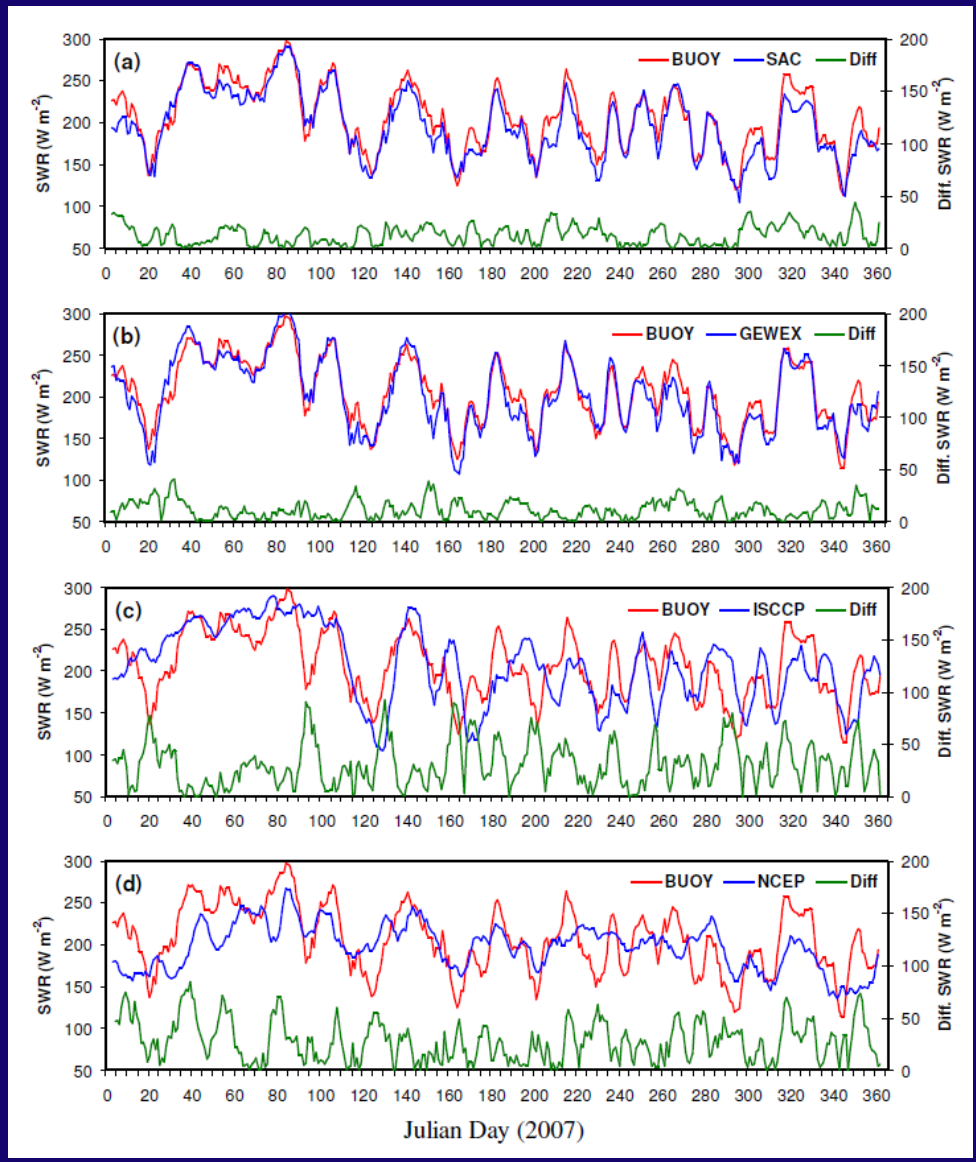
Figure 3 Comparisons between Meteosat-7 and Kalpana derived daily mean OLR (Wm^{-2}) on 8th June 2007.



Net SWR over Indian Ocean warm-pool from Satellite derived OLR Observations



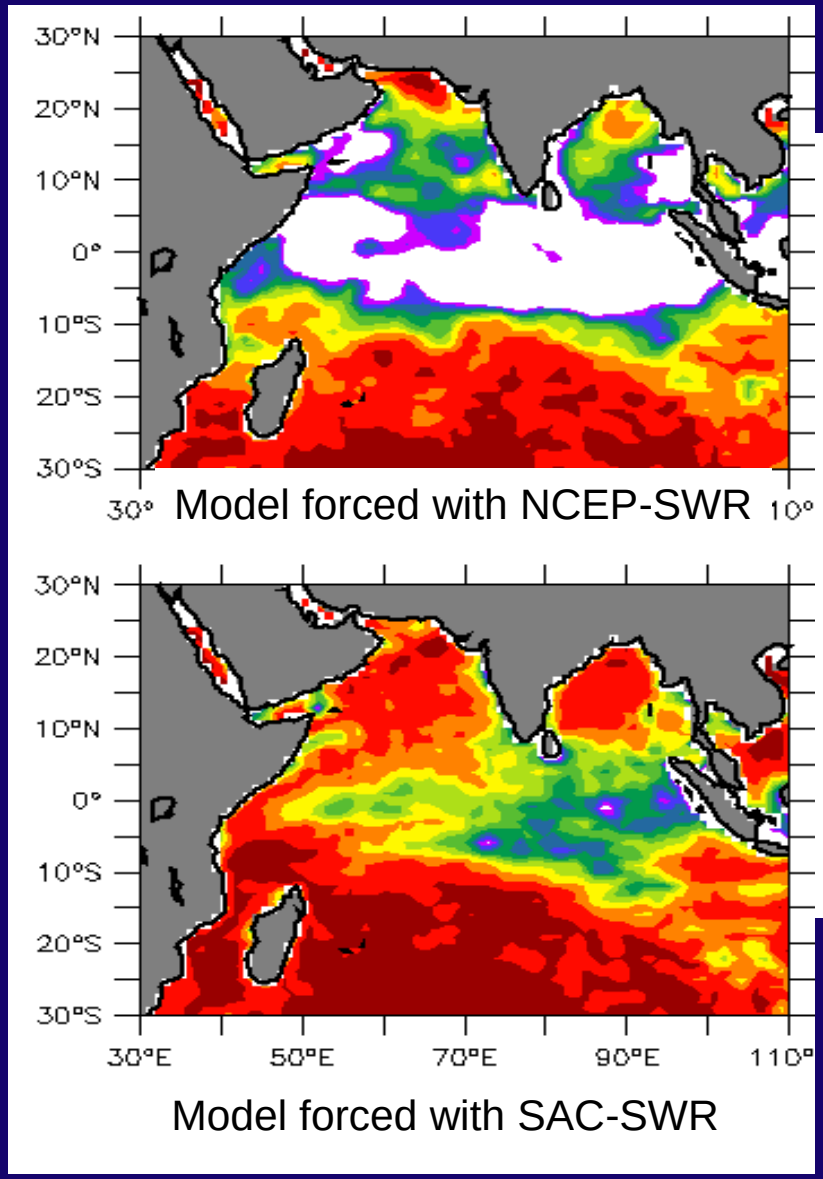




JGR-Ocean (Accepted)

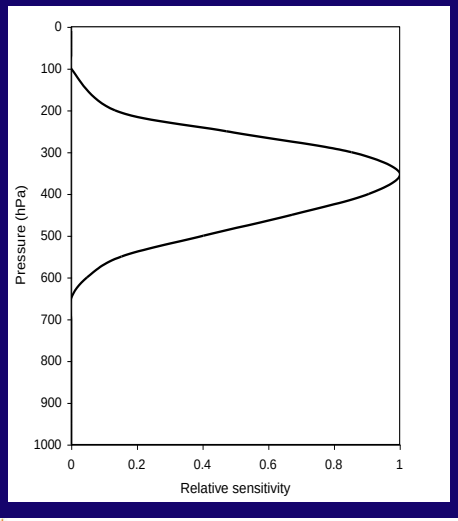
Impact of Satellite derived Net SWR on SST Simulation

Impact of satellite SWR on SST simulation: Correlation of TMI SST with SST from Model forced with NCEP SWR (upper panel) and that with satellite-SWR forced in the model (lower panel)



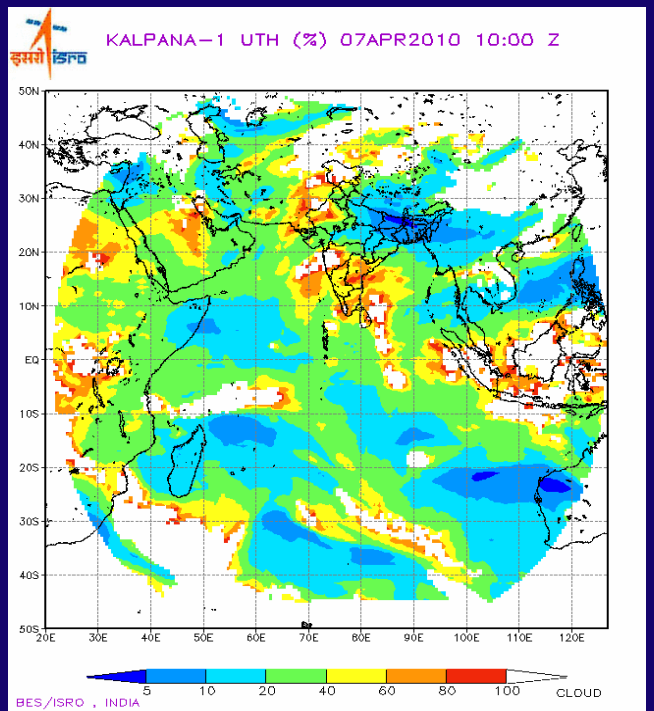
INSAT-3A / Kalpana Products

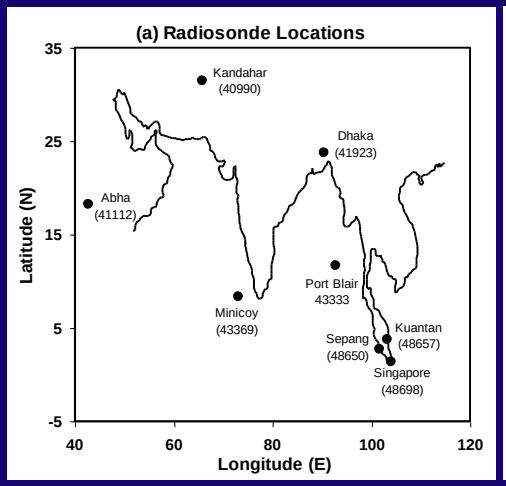
Upper Tropospheric Humidity (UTH)

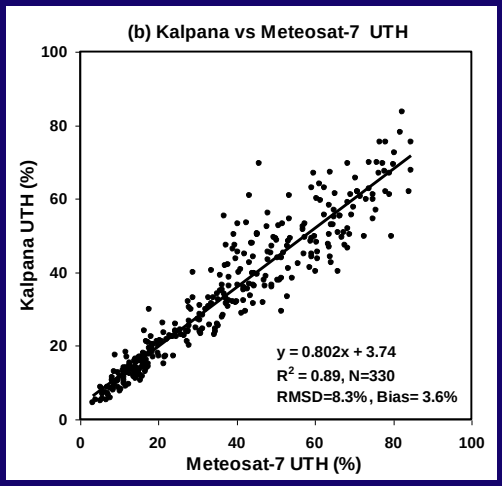


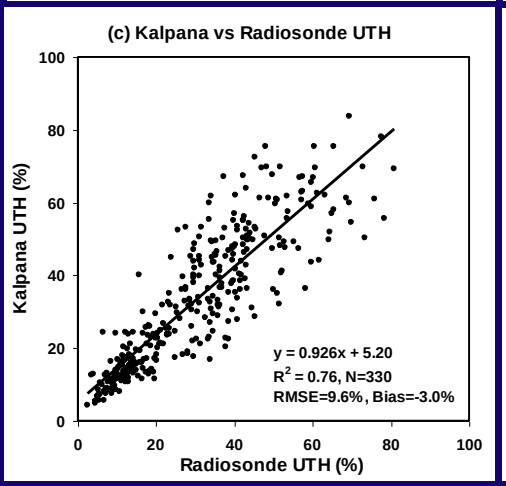
$$\ln\left(\frac{p_0.(UTH)}{\cos(\beta)}\right) = a + b.T_b$$

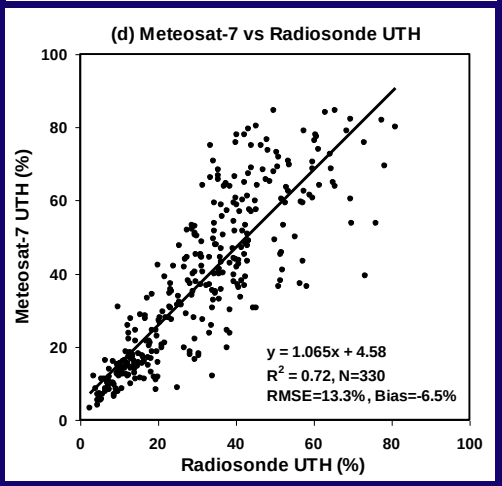
JGR, 2011



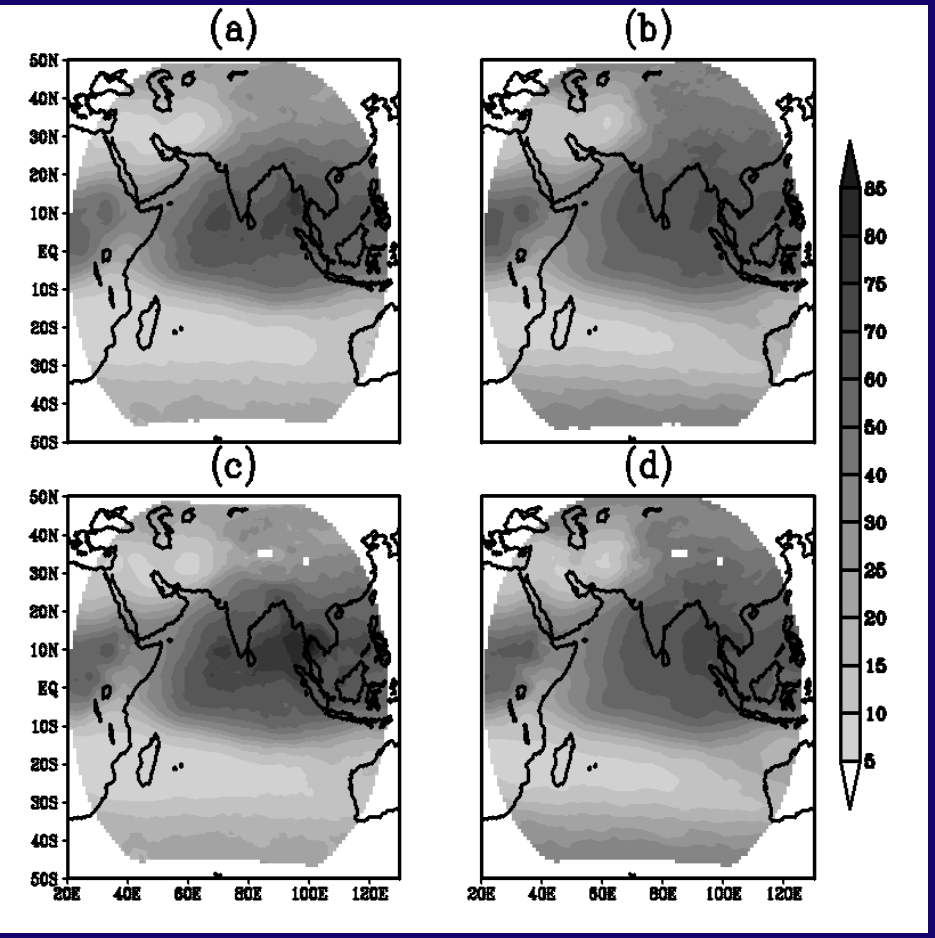




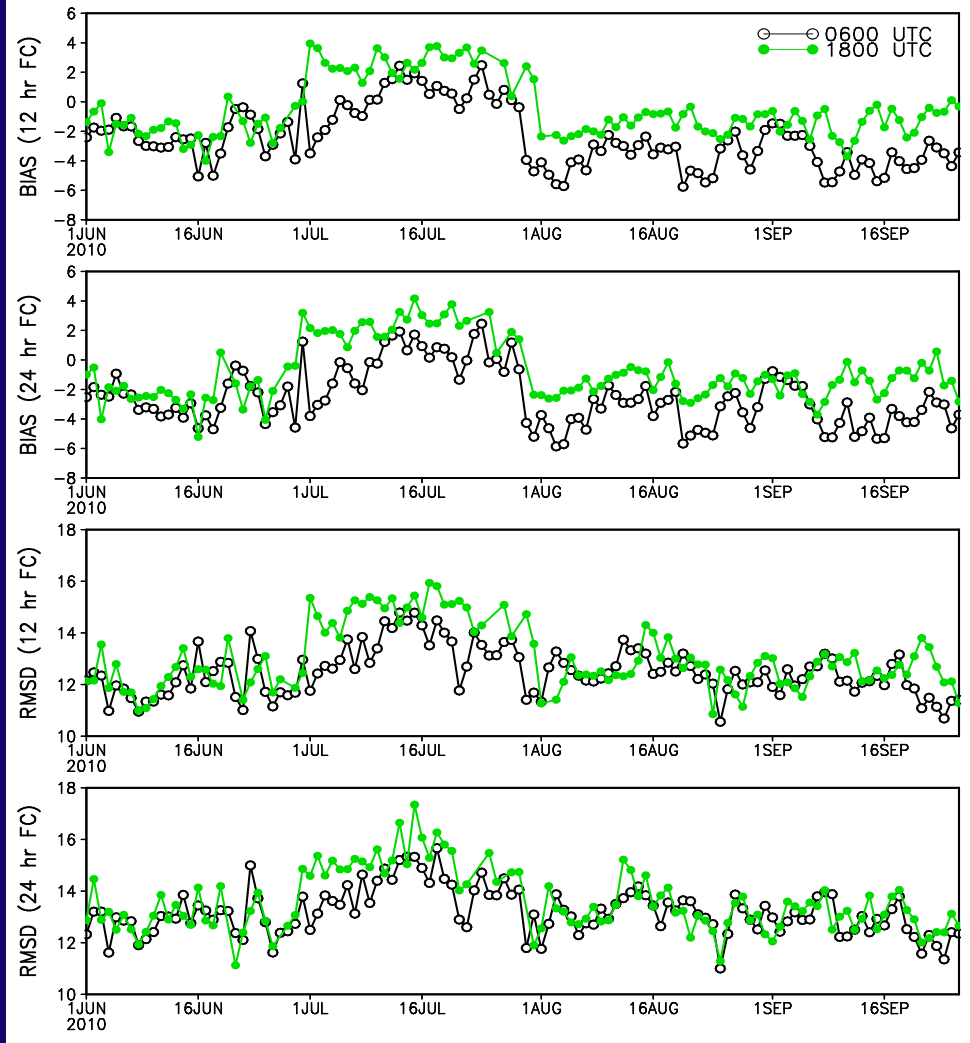




UTH Applications



Seasonal Mean UTH (a) Kalpana 06Z (b) NCEP 06Z (c) Kalpana 18Z (d) NCEP 18Z

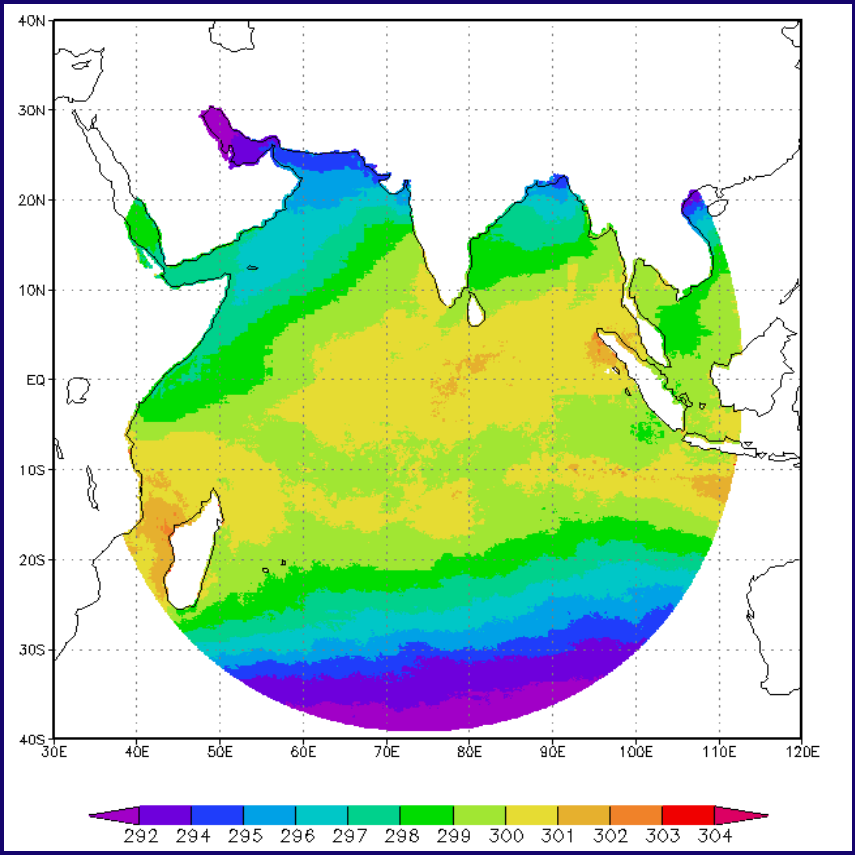


Temporal distribution of Bias and RMSD for 12 and 24 hr predicted UTH valid at 06 and 18Z during Jun-Sep.

INSAT3A/ Kalpana Products

Sea Surface Temperature

- **IR measurements –**
  - **Higher accuracy (~0.5K), Higher spatial resolution (~8 km)**
  - **Insensitive to surface roughness and salinity**
  - **Cloud limited Cloud detection and cloud clearing crucial**
  - **Water Vapor correction from Model Forecast/ Analysis**



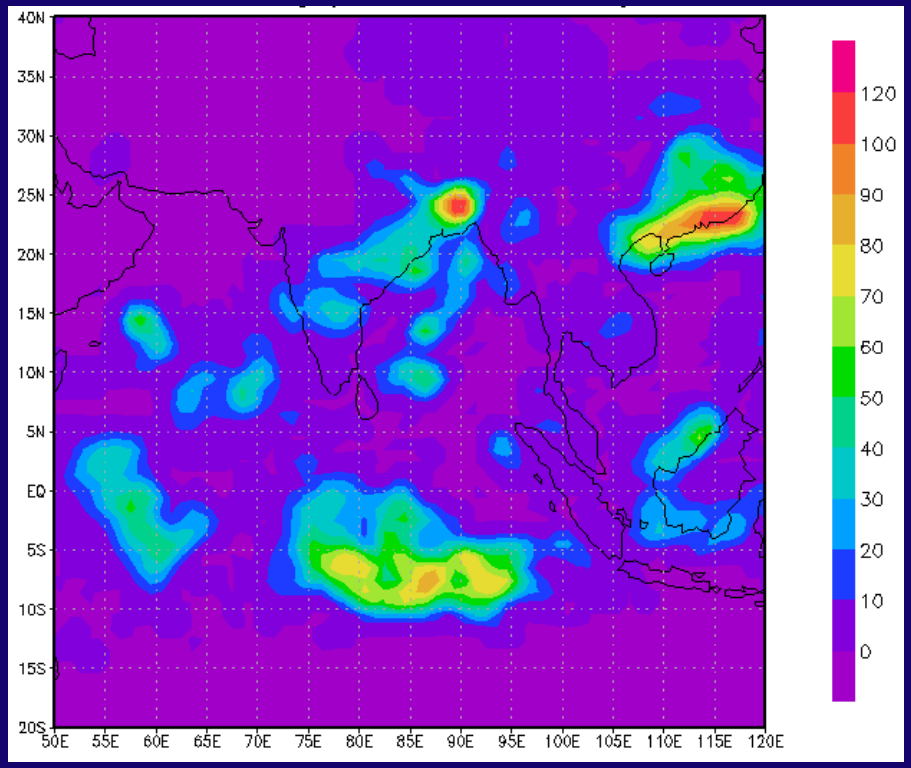
INSAT3A/ Kalpana Products

Rainfall Estimates

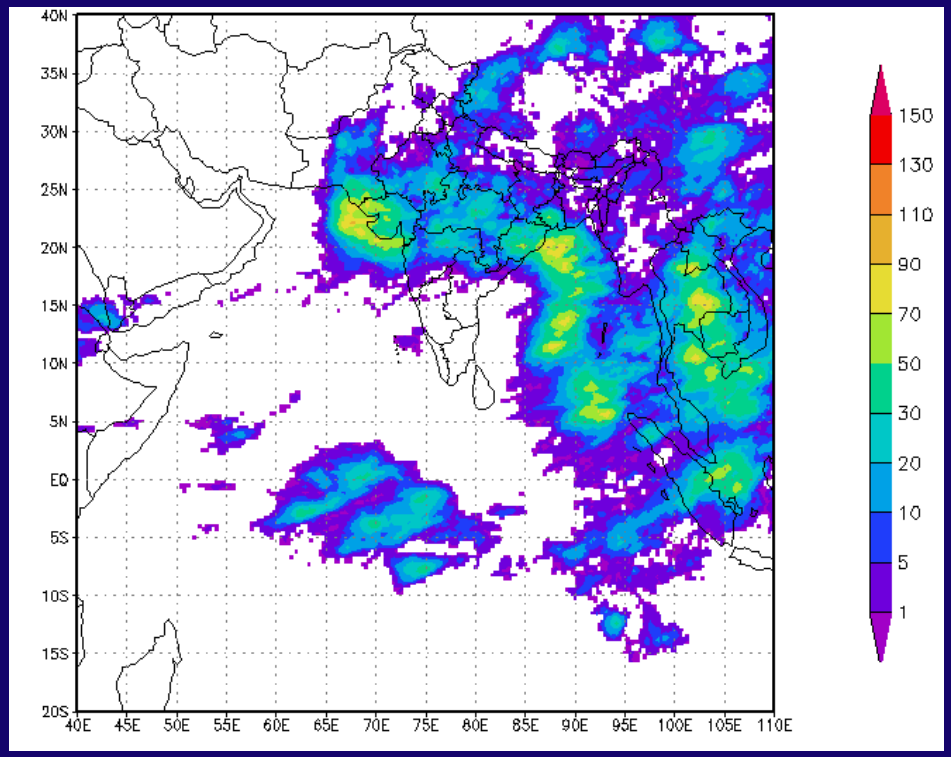
Modified GPI improved QPE (MGPI) using GFS relative humidity and TPW for correction

INSAT Multi-Spectral Rainfall Algorithm (IMSRA)

- Cloud Classification using IR/ WV
- Calibration with MW Radiometer

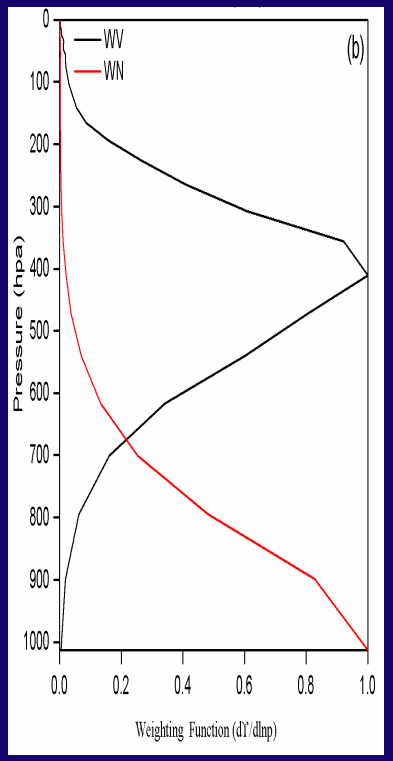


Daily Rain(mm) from KALPANA (Aug. 1, 2010)

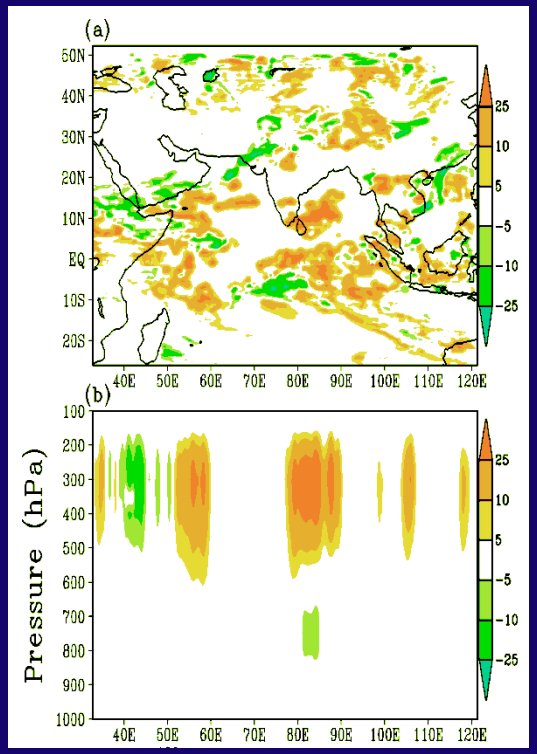


INSAT3A/ Kalpana Products

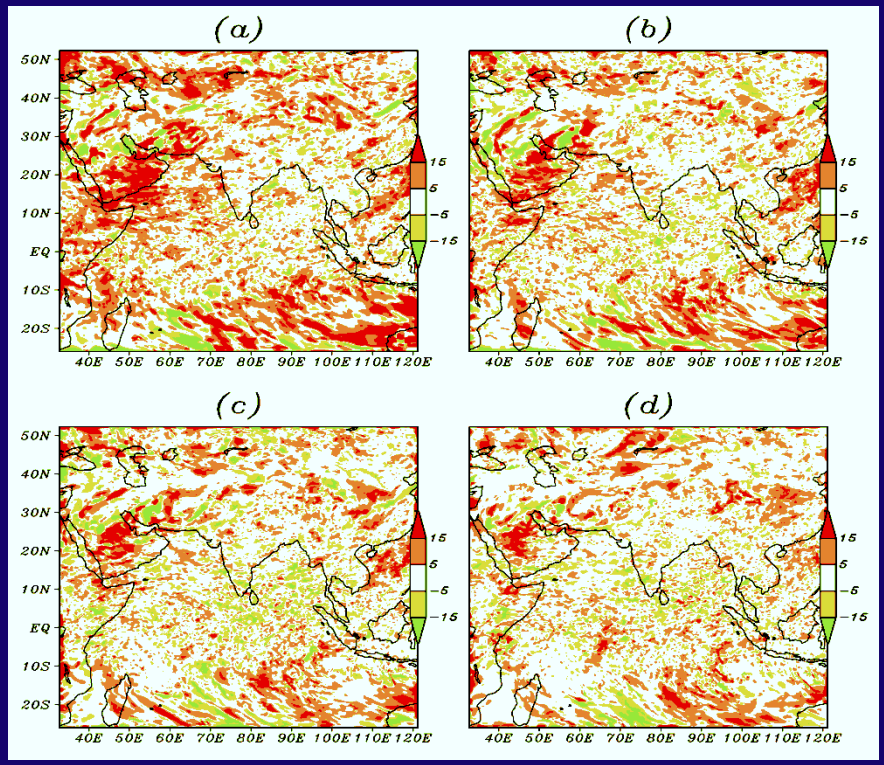
Radiances



EXP-CNT Analyzed RH (%) 350 hPa



Forecast improvement parameters (%) for 350 hPa relative humidity; (a) at 6-h forecast, (b) 12-h forecast, (c) 18-h forecast and (d) 24 h forecast.



July 2008

INSAT - 3D

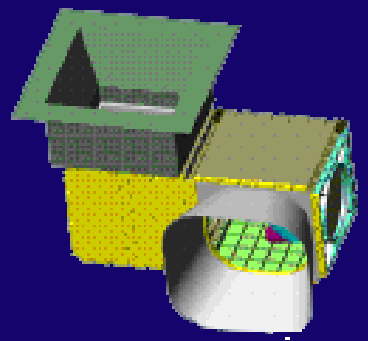
Improved Understanding of Mesoscale Systems

6 Channel IMAGER

- Spectral Bands (μm)

Visible	: 0.55 - 0.75
Short Wave Infra Red	: 1.55 - 1.70
Mid Wave Infra Red	: 3.70 - 3.95
Water Vapour	: 6.50 - 7.10
Thermal Infra Red – 1	: 10.30 - 11.30
Thermal Infra Red – 2	: 11.30 - 12.50

- Resolution : 1 km for Vis, SWIR
  4 km for MIR, TIR1&2
  8 km for WV



19 Channel SOUNDER

- Spectral Bands (μm)

Short Wave Infra Red	: Six bands
Mid Wave Infra Red	: Five Bands
Long Wave Infra Red	: Seven Bands
Visible	: One Band

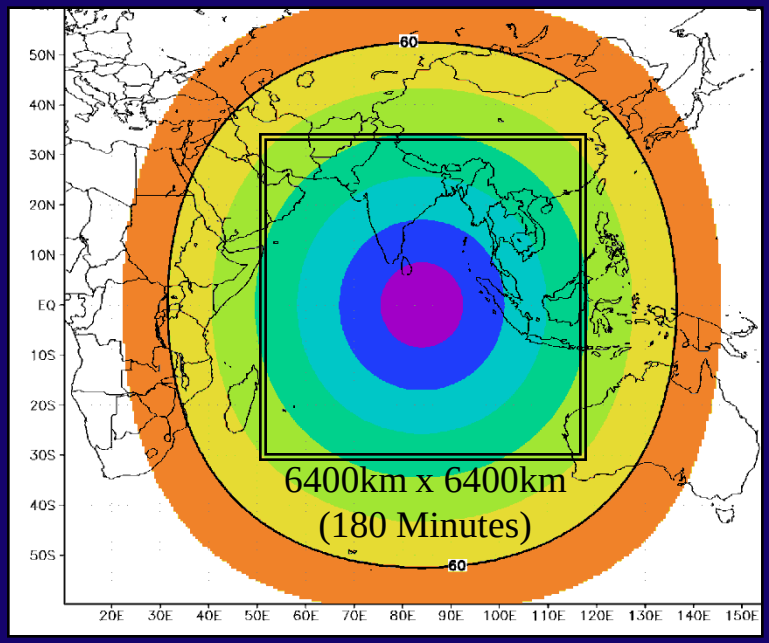
- Resolution (km) : 10 X 10 for all bands
- No of simultaneous sounding per band : Four

Sounder Channels

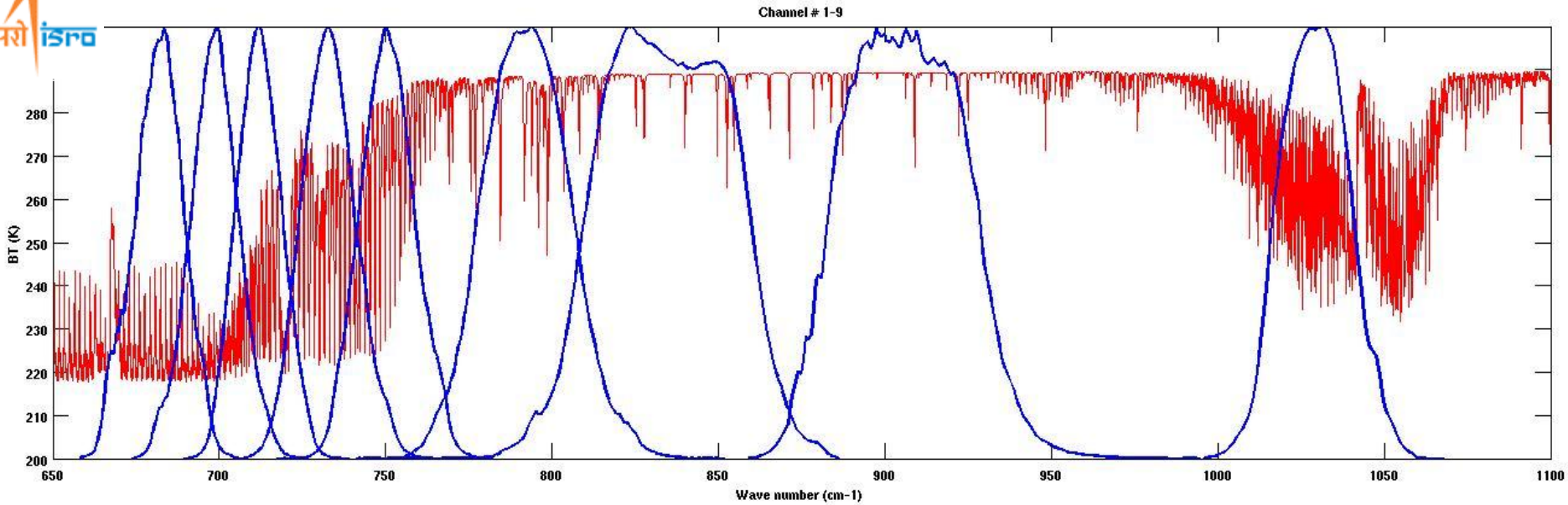
Ch	λ_c (μm)	$\Delta\lambda$ (μm)	Principal absorbing gas	Purpose
1	14.71	0.281	CO_2	Stratosphere temperature
2	14.37	0.268	CO_2	Tropopause temperature
3	14.06	0.256	CO_2	Upper-level temperature
4	13.64	0.298	CO_2	Mid-level temperature
5	13.37	0.286	CO_2	Low-level temperature
6	12.66	0.481	water vapor	Total precipitable water
7	12.02	0.723	water vapor	Surface temp., moisture
8	11.03	0.608	window	Surface temperature
9	9.71	0.235	ozone	Total ozone
10	7.43	0.304	water vapor	Low-level moisture
11	7.02	0.394	water vapor	Mid-level moisture
12	6.51	0.255	water vapor	Upper-level moisture
13	4.57	0.048	N_2O	Low-level temperature
14	4.52	0.047	N_2O	Mid-level temperature
15	4.45	0.0456	CO_2	Upper-level temperature
16	4.13	0.0683	CO_2	Boundary-level temp.
17	3.98	0.0663	window	Surface temperature
18	3.74	0.140	window	Surface temp., moisture
19	0.695	0.05	visible	Cloud

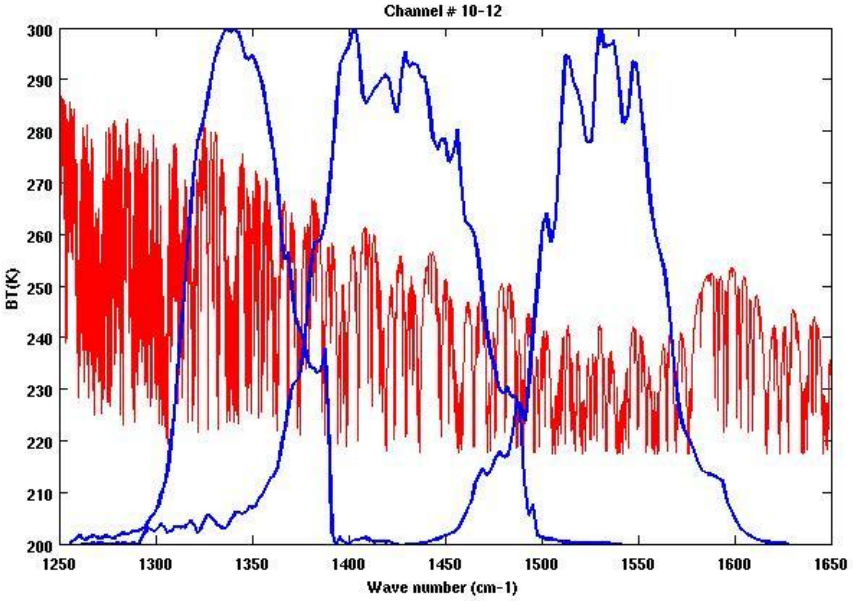
Sounder Products

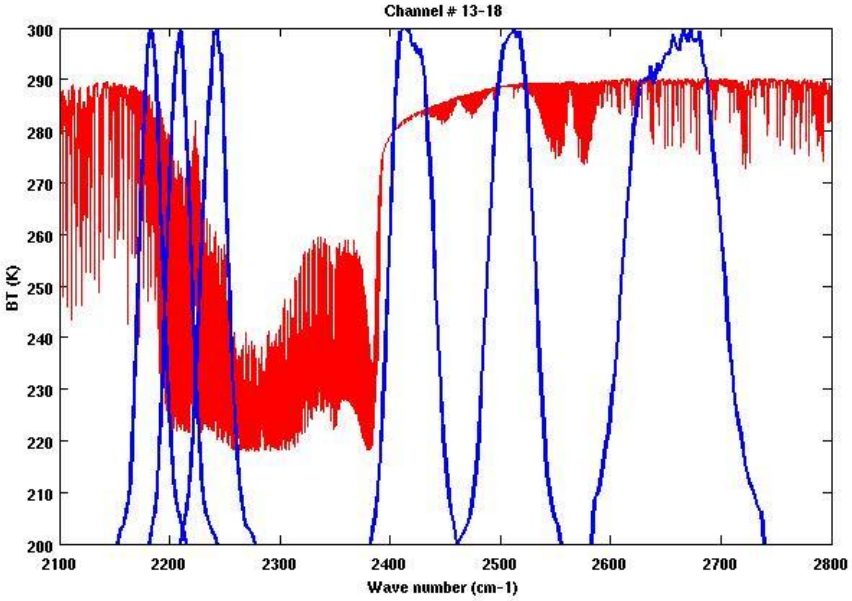
- Atmospheric Profiles
  - Temperature
  - Water vapor
  - Ozone
- Surface skin temperature (TS)
- Total column integrated ozone
- Total column water vapor (TPW)
- Cloud Properties



Observation zenith angle, INSAT-3D at 84E


Channel # 1-9
BT (K)
Wave number (cm-1)

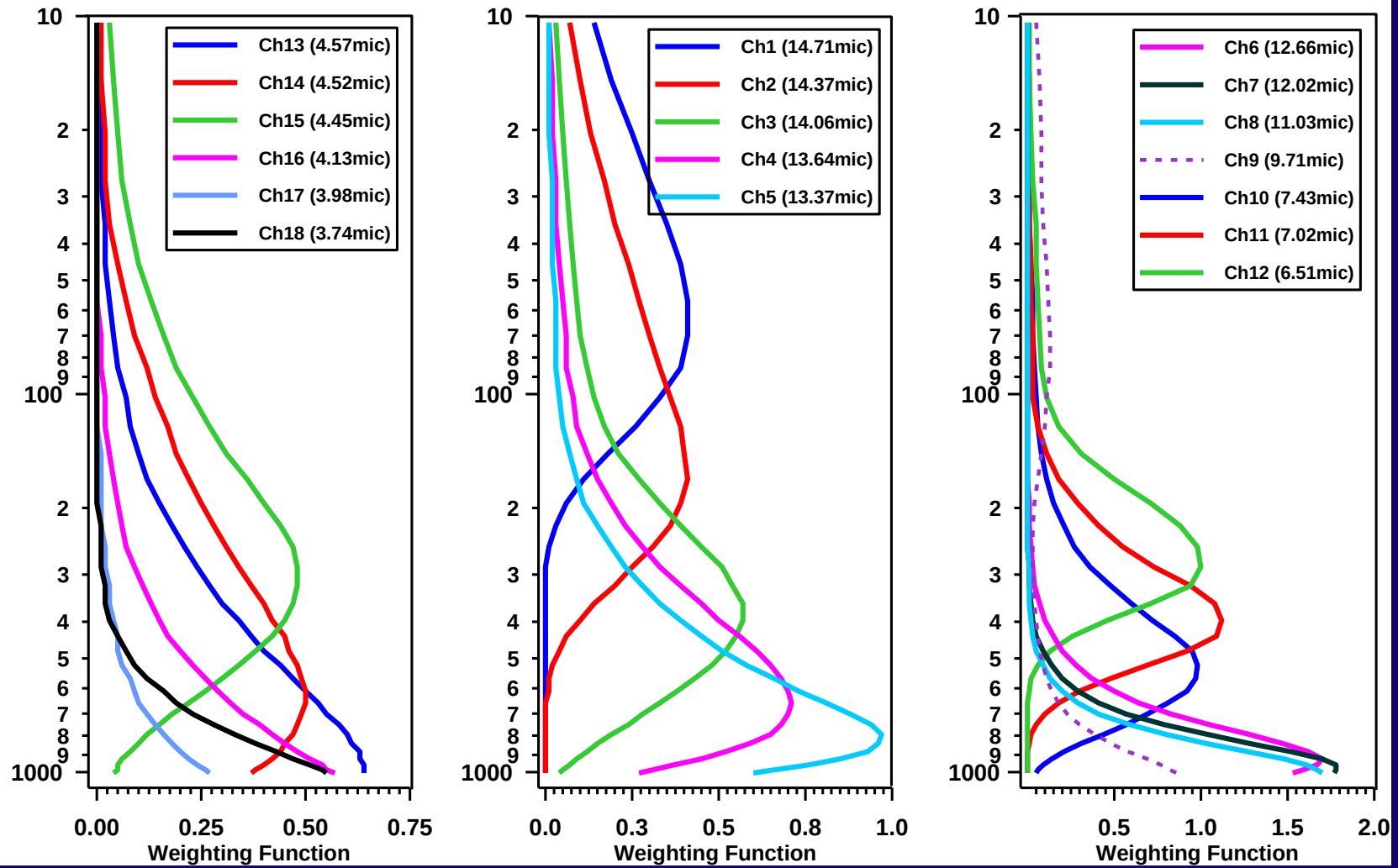

Channel # 10-12
BT(K)
Wave number (cm-1)


Channel # 13-18
BT (K)
Wave number (cm-1)

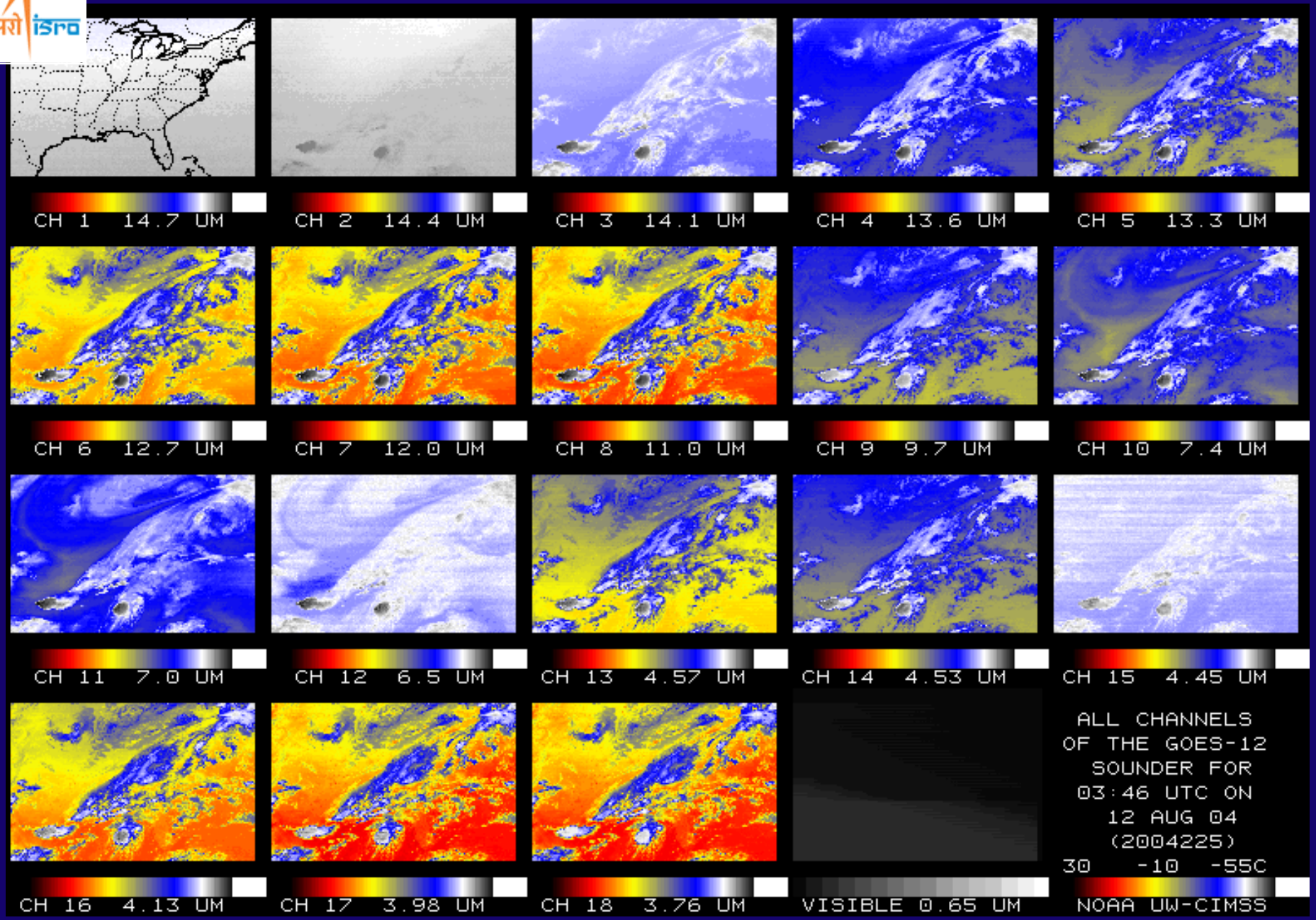
INSAT-3D Weighting function

$$I_\nu(p=0) = \varepsilon_\nu . B_\nu(T_s) . \tau_\nu(p_s \to 0) + \int_{p_s}^{0} B_\nu[T(p)] . \frac{\partial \tau_\nu(p \to 0)}{\partial p} . dp + (1-\varepsilon_\nu) . \tau_\nu(p_s \to 0) . \int_{0}^{p_s} B_\nu[T(p)] . \frac{\partial \tau_\nu(p \to p_i)}{\partial p} . dp$$

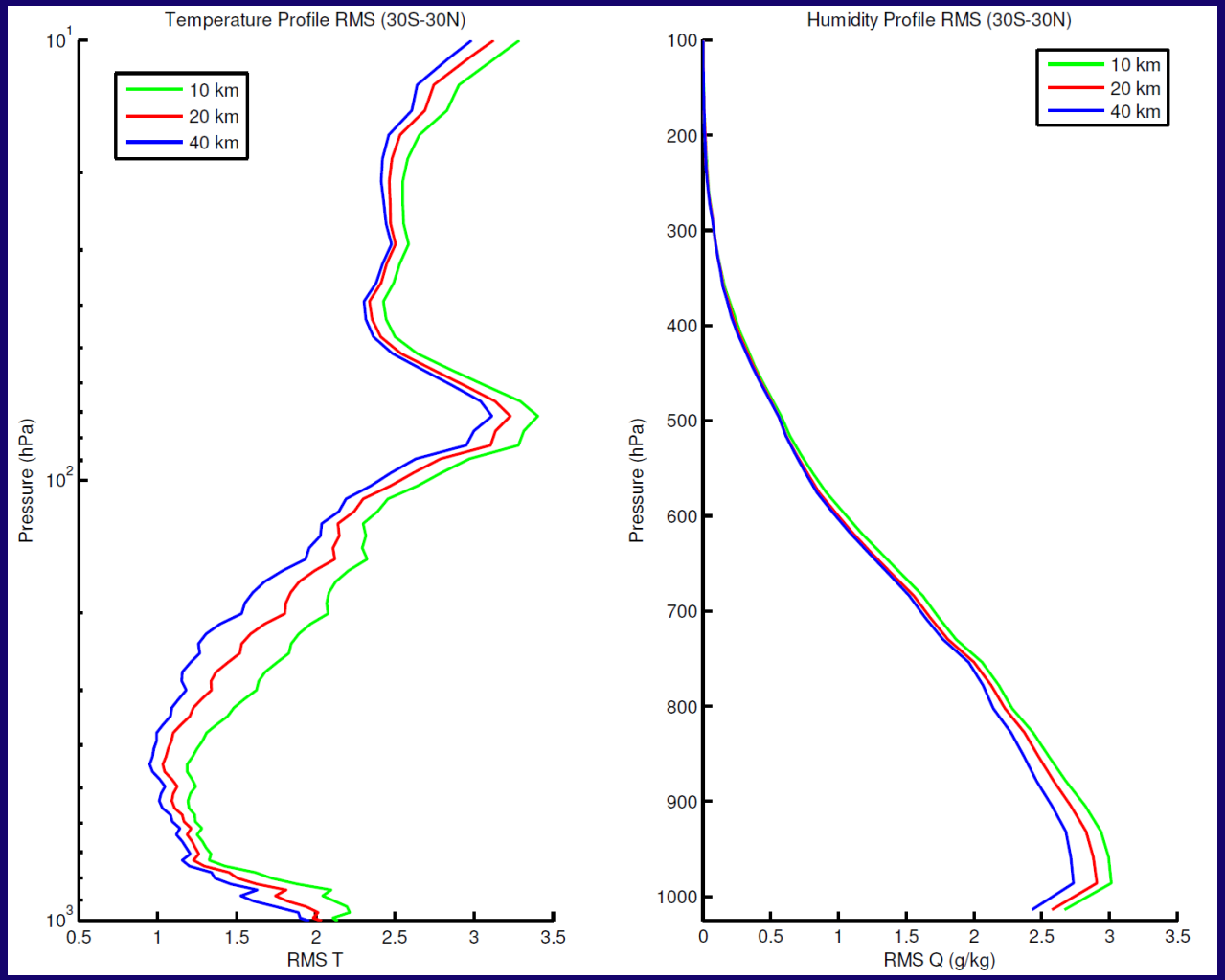
INSAT-3D Weighting Function over Indian Region (July)



19 channel sounder observations



Atmospheric Profiles RMSE



RMSE

TS = 0.42K, TPW = 0.41cm, TOZO = 8.0 Dob

INSAT-3D Imager Products

Imager Channels

Channel No.	Wavelength Band	Resolution (Km)
1	0.55 - 0.75 μm	1
2	1.55 - 1.70 μm	1
3	3.7 - 3.95 μm	4
4	6.5 - 7.1 μm	8
5	10.3 - 11.3 μm	4
6	11.3 - 12.50 μm	4

Imager Products

- Atmospheric Motion Vector (AMV)
  - Cloud Motion Vector (CMV)
  - Water Vapor Winds (WVW)
- Outgoing Longwave Radiation (OLR)
- Upper Tropospheric Humidity (UTH)
- Rainfall (QPE) – GPI, IMSRA
  – Hydro-Estimator (H-E)
- Sea Surface Temperature (SST)
- Cloud Mask
- Fog
- Snow Cover
- Aerosol
- Fire
- Smoke

Future Geostationary Satellites

- **INSAT 3D Repeat (~ 2013)**
- **Follow-up of INSAT-3D (~2015)**
- **Geo – HR (~2012)** [name yet to be frozen]
  - Visible – 50 m
  - 3 Channel IR – 1.5 Km
  - Visible and SWIR Hyper-spectral – 500 m
    - ❑ 50 – 60 channels in VIS
    - ❑ 50 – 60 channels in SWIR
  - For general remote sensing, can also be used for meteorological purpose

Polar Orbiting Indian Satellites

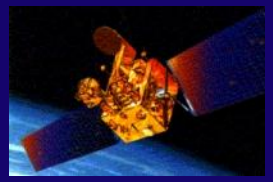
L
E
O

OCEANSAT–1/2 (1999/2009)

MSMR, OCM, Scatterometer ROSA (GPS)

Vector Winds, Aerosol, T&h Profile

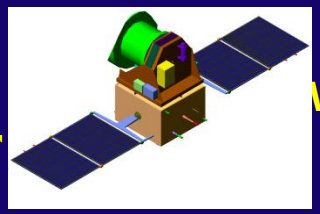
SARAL (2011)



Altimeter

SSH, Waves, Winds

MEGHA-TROPIQUES (2011)



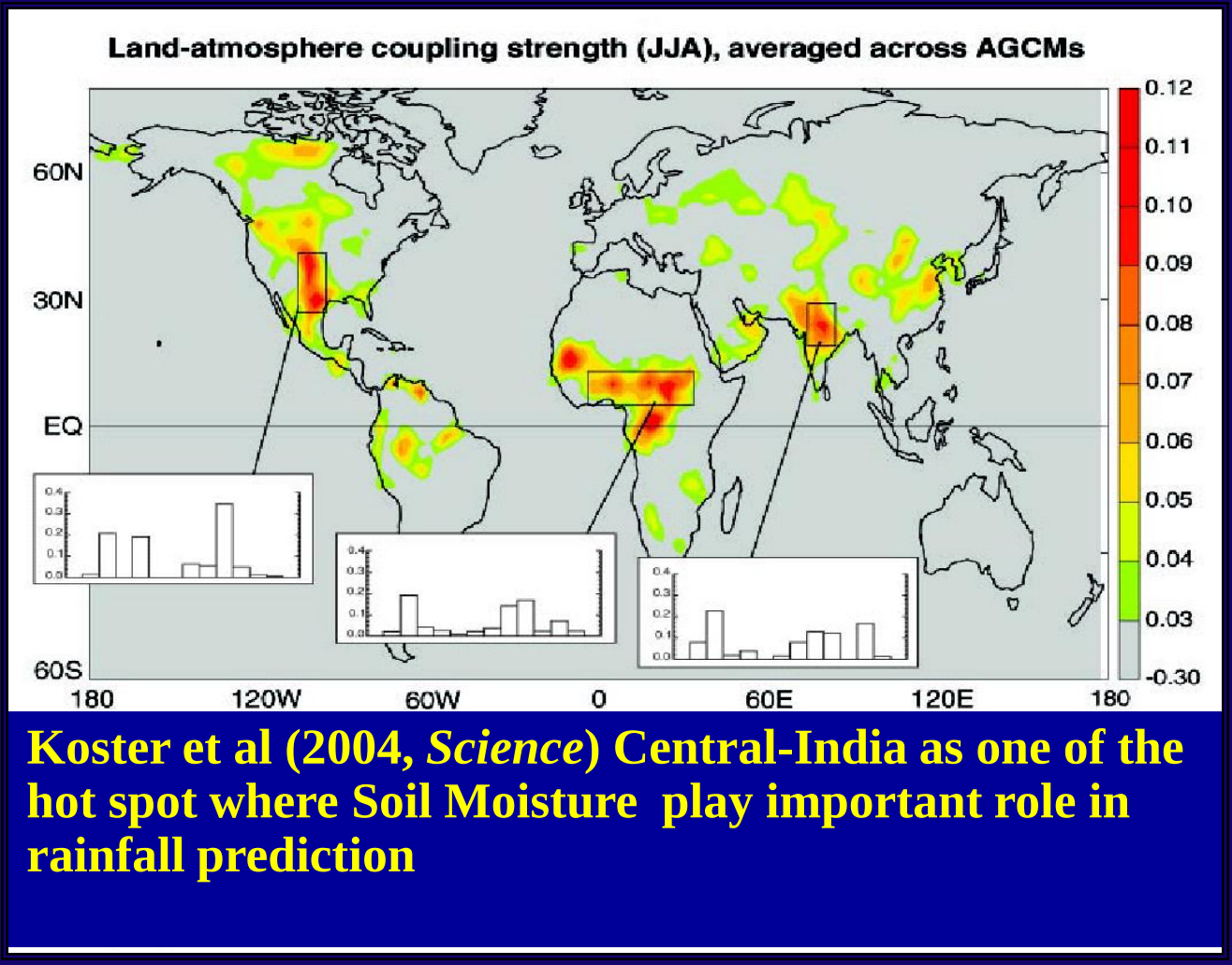
MW Imager, WV Sounder, ScaRaB ROSA

SS Wind, TWV, Rainfall
T, h Profile,
Radiation Budget

Microwave Temperature and humidity sounder

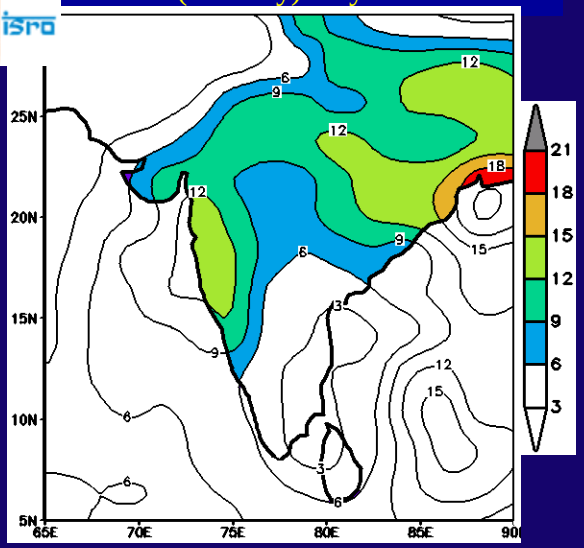
Oceansat-1 MSMR (1999)

SST, SSWS, TPW, CLW, SM

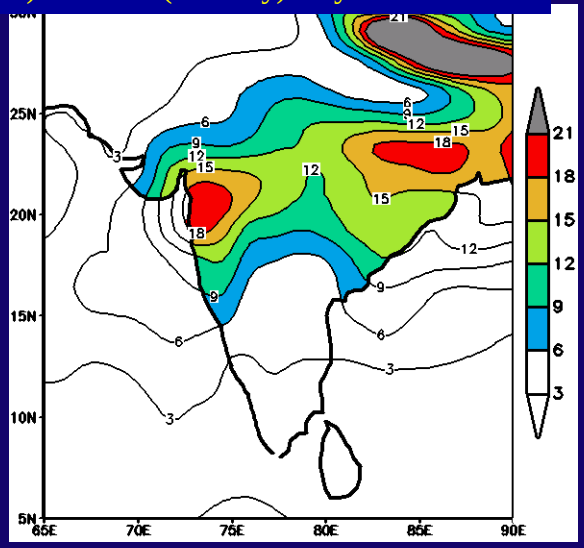


Koster et al (2004, *Science*) Central-India as one of the hot spot where Soil Moisture play important role in rainfall prediction

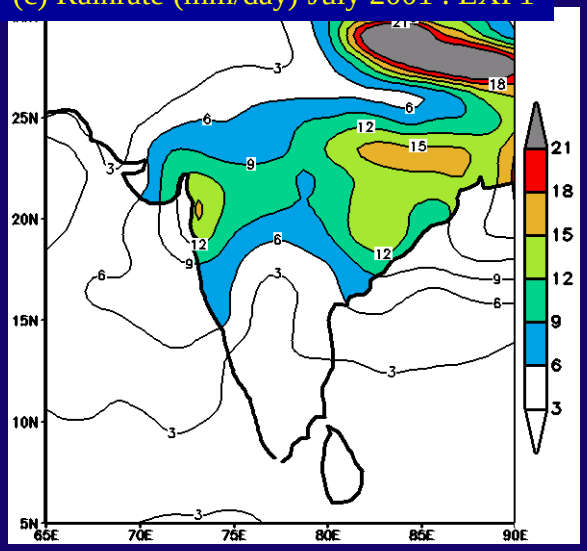
Rainrate (mm/day) July 2001 : NCEP



b) Rainrate (mm/day) July 2001 : CNTL



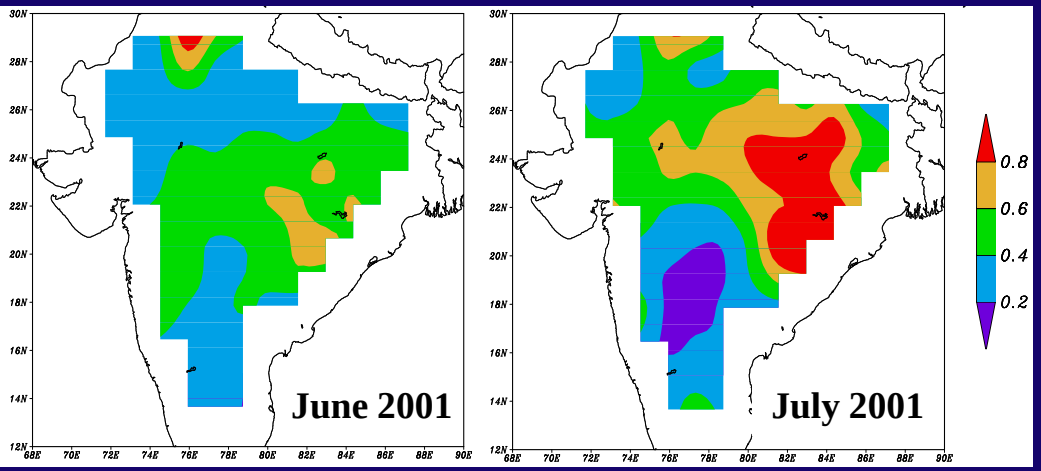
(c) Rainrate (mm/day) July 2001 : EXP1



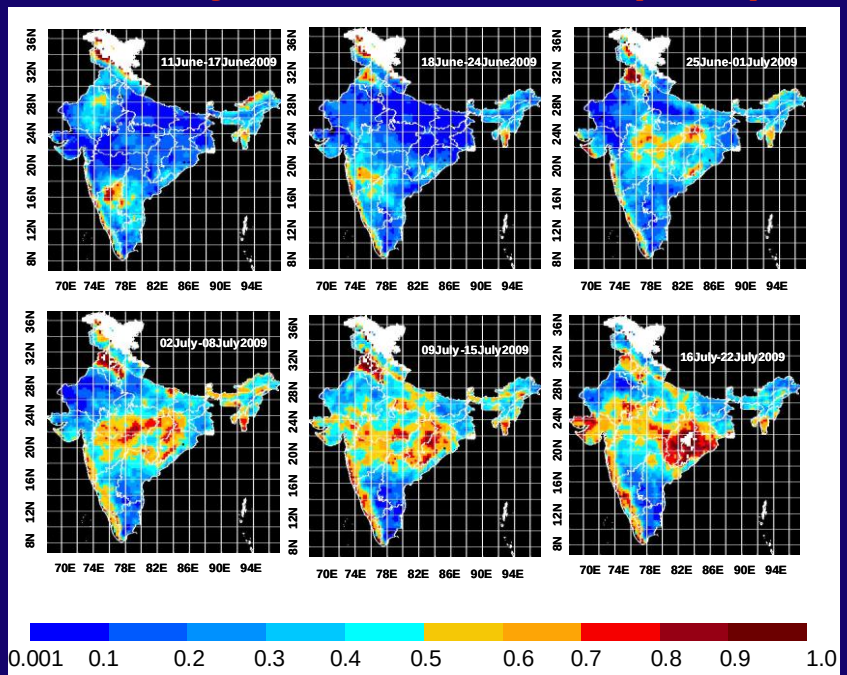
Observed and simulated rainrate (mm/day) for July 2001: a) NCEP analysis: b) CNTL, and c) MSMR-derived soil moisture assimilation

Monthly SWI from MSMR

(Thapliyal et al JAM, 2003)

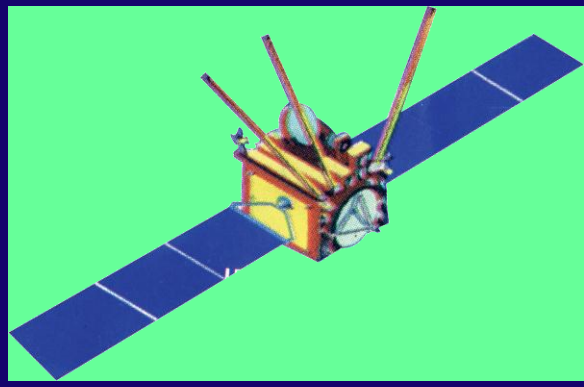


Weekly SWI from AMSR (2009)



Oceansat -II

- **Instruments:**
  - Scatterometer Ku band (13.515 GHz)
  - Ocean Colour Monitor (8 bands 0.4- 0.885 µm)
  - Radio Occultation ROSA



- **Launched**
  - 23 September 2009

- **Applications:**
  - Sea State Forecast: Waves, Circulation and MLD
  - Monsoon and Cyclone Forecast
  - Antarctic Sea Ice
  - Fisheries and Primary productivity estimation
  - Detection and monitoring of Phytoplankton blooms
  - Sediment dynamics

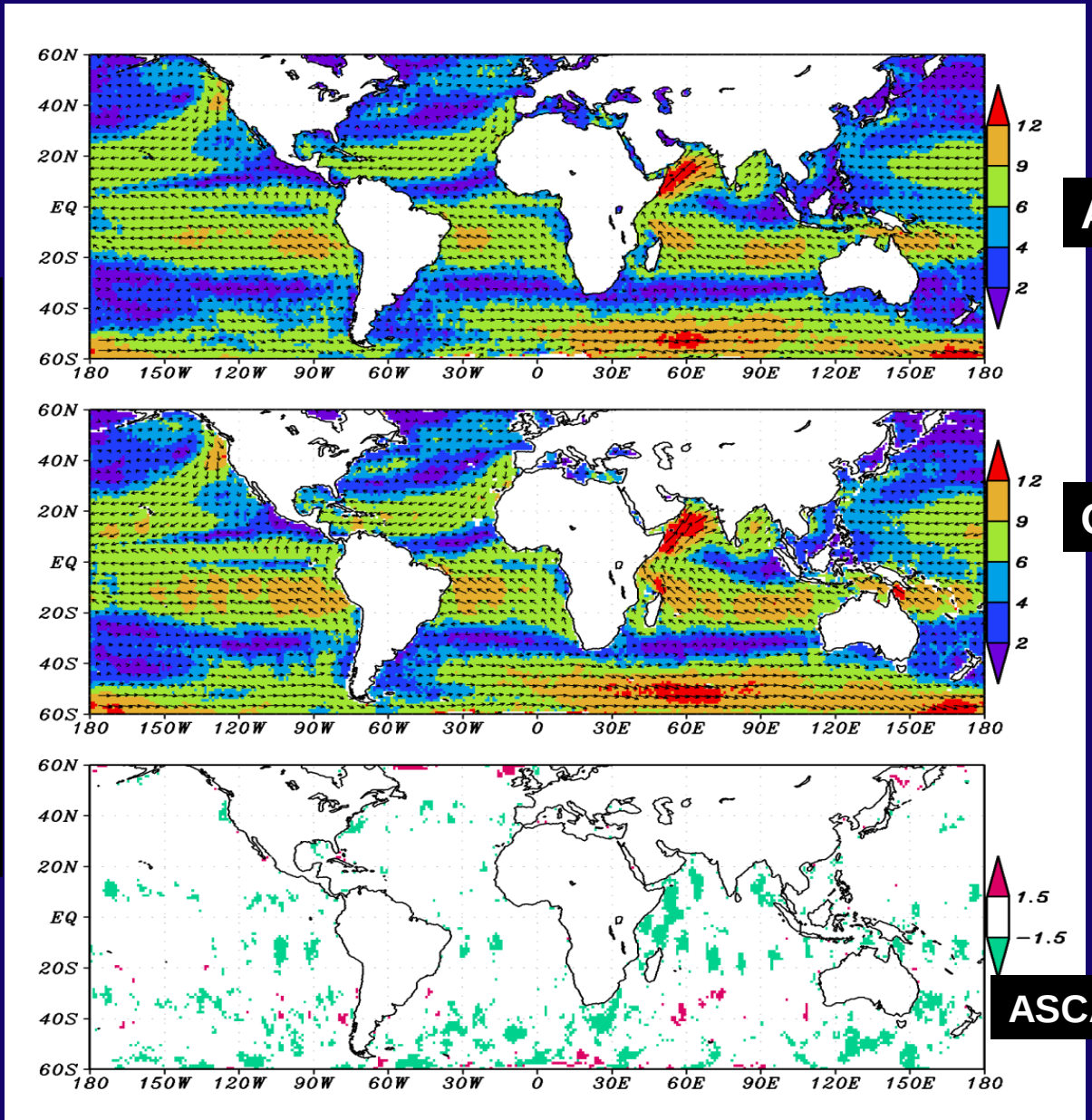
Comparison of Sea Surface Winds derived from Scatterometer

Buoys

5100 Match-ups
2 m/s; 35 Deg

For wind speeds
> 4 m/s

4500 Match-ups
1.9 m/s; 23 Deg



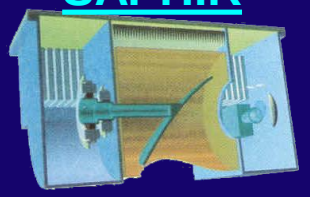
Megha Tropiques

For studying water cycle and energy exchanges in the tropical belt

Low inclination (20º) for **frequent simultaneous** observations of tropics

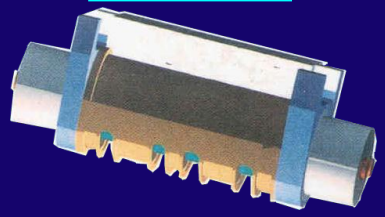
- Water vapour
- Clouds
- Cloud condensed water
- Precipitation
- evaporation

SAPHIR



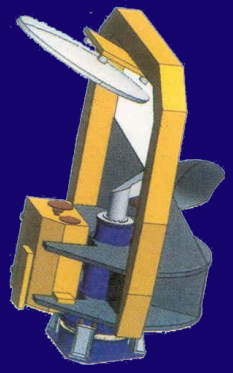
- 183 GHz WV Sounder
- Six atmospheric layers upto 12 km height
- 10 km Horizontal Resolution

SCARAB



- Outgoing fluxes at TOA
- 40 km Horizontal Resolution

MADRAS



ROSA

- Precipitation and cloud properties
- 89 &157 GHz : ice particles in cloud tops
- 18 & 37 GHz: cloud liquid water and precipitation
- 23 GHz : Integrated water vapour
- T & q profile

Contributing to GPM and GEWEX

SARAL-AltiKa (ISRO-CNES)

- **AltiKa Mission:** Global altimetry system for the precise and accurate observations of ocean topography, circulation and sea surface monitoring
- **launch Date: 2011**
- **AltiKa Payload :**
  - A Ka-band (35.75 GHz, BW 500 MHz) radar altimeter
  - A dual-frequency MW radiometer (23.8 and 37 GHz), for tropospheric range correction
  - DORIS: For achieving adequate orbitography performances
  - LRA: For Orbitography and system calibration

AltiKa/SARAL central objective :

Ocean meso-scale variability: Sea state Monitoring & Now Casting
Data assimilation: Sea state forecasting
Coastal altimetry: Bathymetry, coastal upwelling, Circulations etc.

Satellite Description :

- Sun-synchronous, polar orbiting
- inclination: 98.38 Deg.
- Altitude: ~800 km,
- Repeat cycle: 35 days

Data availablity

www.mosdac.gov.in
www.nrsc.gov.in

Thank You