Satellite Hydrology

R. P. Singh
(rpsingh@sac.isro.gov.in)

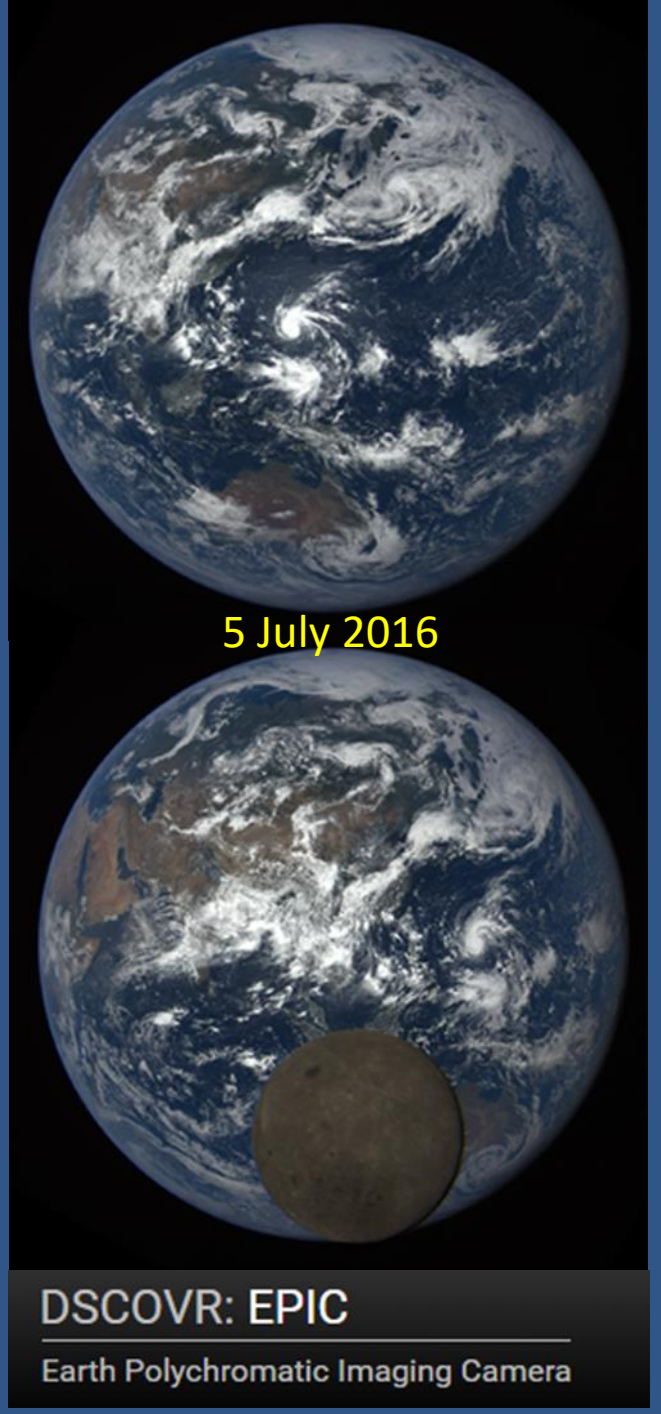
Space Applications Centre, ISRO,
Ahmedabad

Introduction

Water is one of the prime elements responsible for climate and life on any planetary system (earth)

Hydrology is the science that deals the occurrence, distribution, movement and properties of the waters of the earth and their relationship with the environment within each phase of the hydrologic cycle.

It involves development of scientific knowledge, Instruments and mathematical principles to solve water-related problems in society:

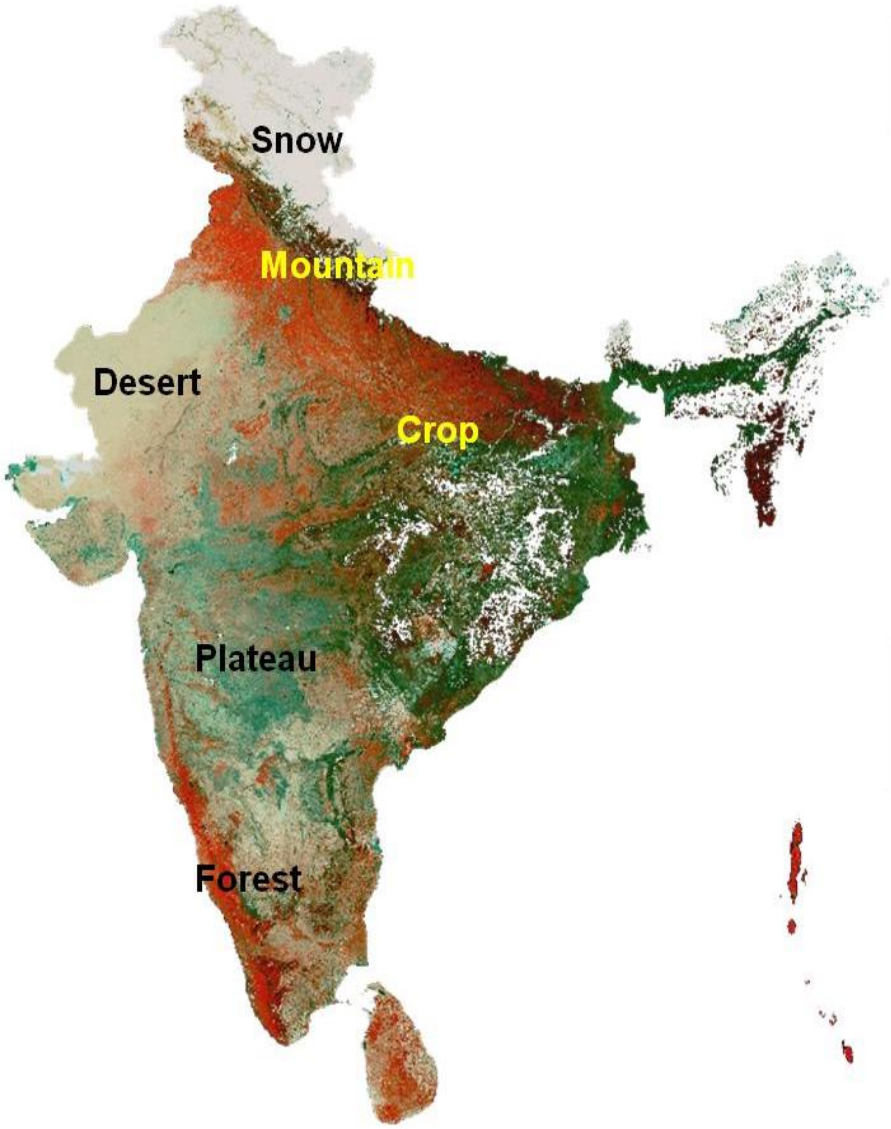


Content

- India Resources and Challenges
- Basics concepts in Remote Sensing
- Methods of estimation of Hydrological Parameters
- Some Hydrological Applications
- Future Direction

INDIA: RESOURCES & CHALLENGES

- 3.27 M sq km Geographical Area
- 1.41M sq km Net Sown Area
- 88 cm (+/- 85 mm) rainfall (LTA)
- 8500 km^3 Glaciers
- 20.64 % Forest Cover
- >7% of world's biodiversity
- 7516 km long Coastline
- 7.6 M ha Wetlands
- 1.2 B Population



- Declining water availability
- Low Agricultural Productivity
- Accelerated Land Degradation
- Reducing forest cover, biodiversity
- Degrading Coastal Resources
- Disaster-prone
- Glacier Retreat

Increasing population and demand from various sectors including agriculture, consumption of water is going to increase in coming decades and require scientific management to cater the increasing demand of water.

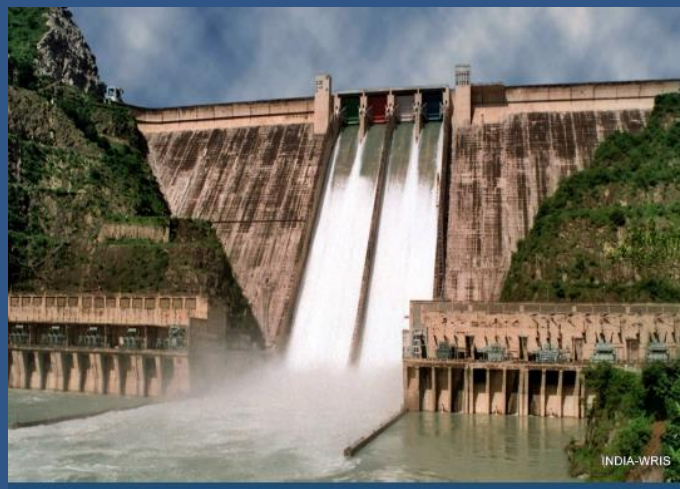
India : Water Resources

Area : 2.4 % (World's Area)
Population : 17.1 % (World's Population)
Water : 4% (World)

Water Resources per year in BCM (%)

Average Rainfall (inc. Snowfall): 4000* (100%)
Potential Flow in Rivers: 1869** (46.7 %)
Utilizable Water Resources: 1123 (28.1%)
Surface Water : 690 (17.3%)
Replenishable GW : 433 (10.8%)
Water need in 2050 : 1450 (129%)
Deficit (2050) : 327 (29%)
River interlinkages : 200 (17.8%)

Revised Estimates
*Mean annual Rainfall:3880 BCM
**Avg. annual water Resource: 1999.20 BCM

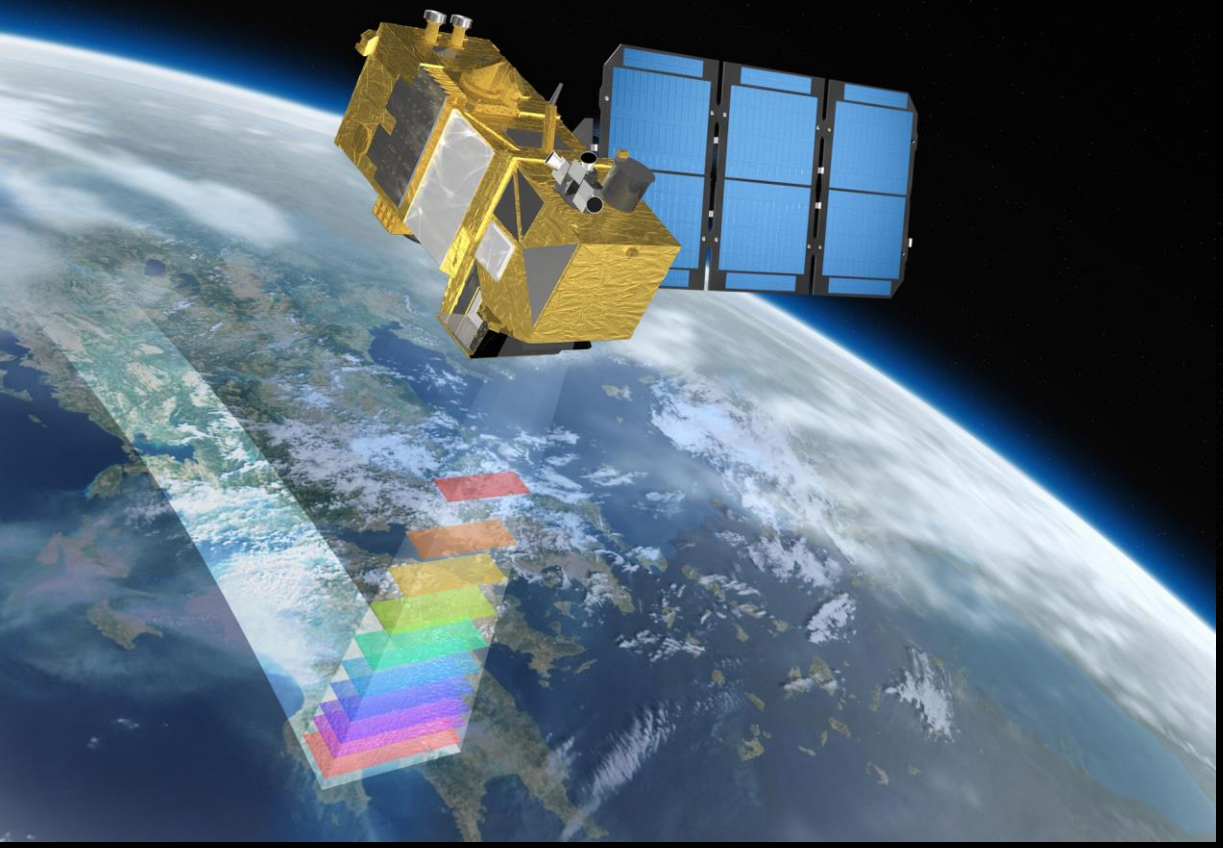


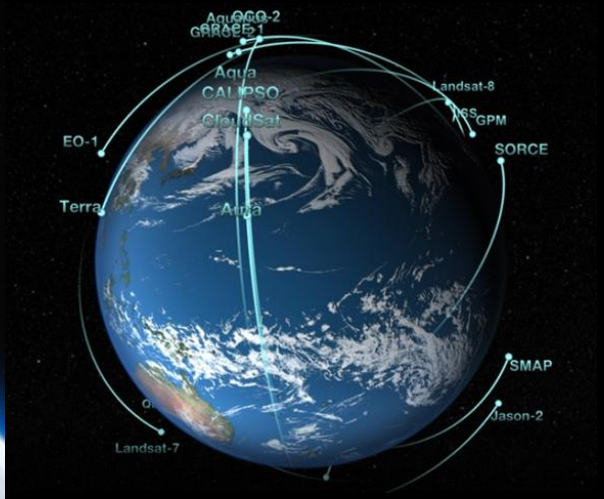
Water need in India
(2010:**813** bcm, 2025: **1093** bcm)

Remote sensing

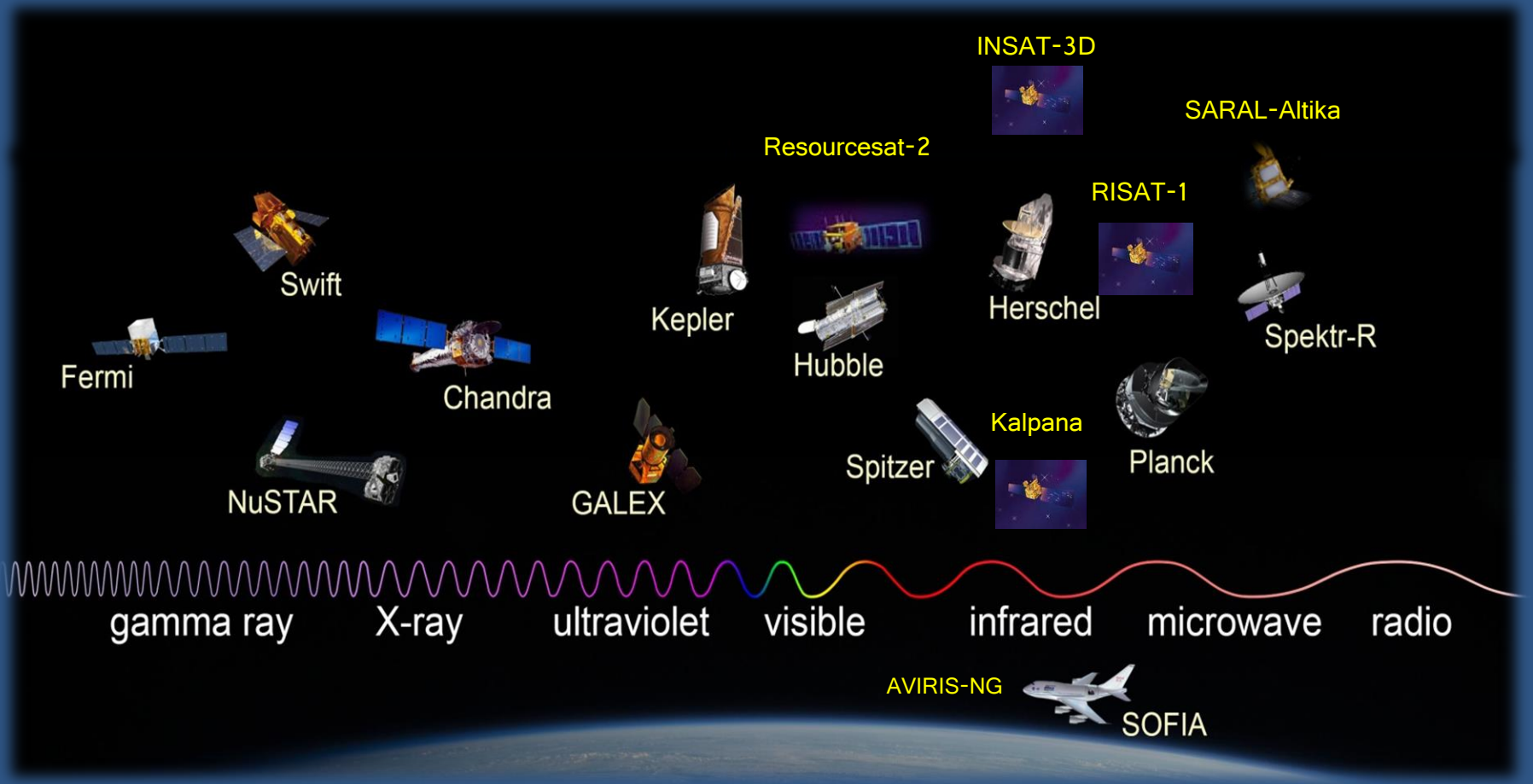
Science and Technology of obtaining the physical properties of an area from a distance.

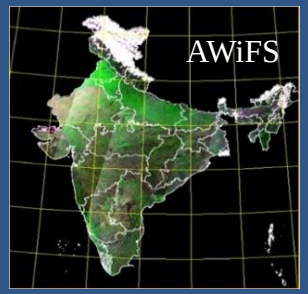
Synoptic global coverage, Calibrated, Historical long term gridded products.

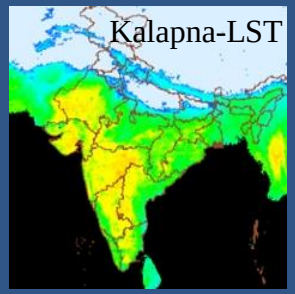


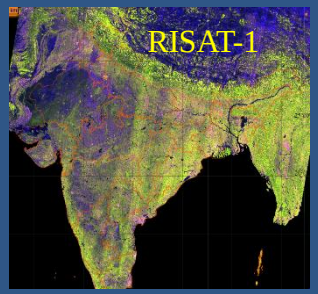


Measurements in Different Electromagnetic Spectrum

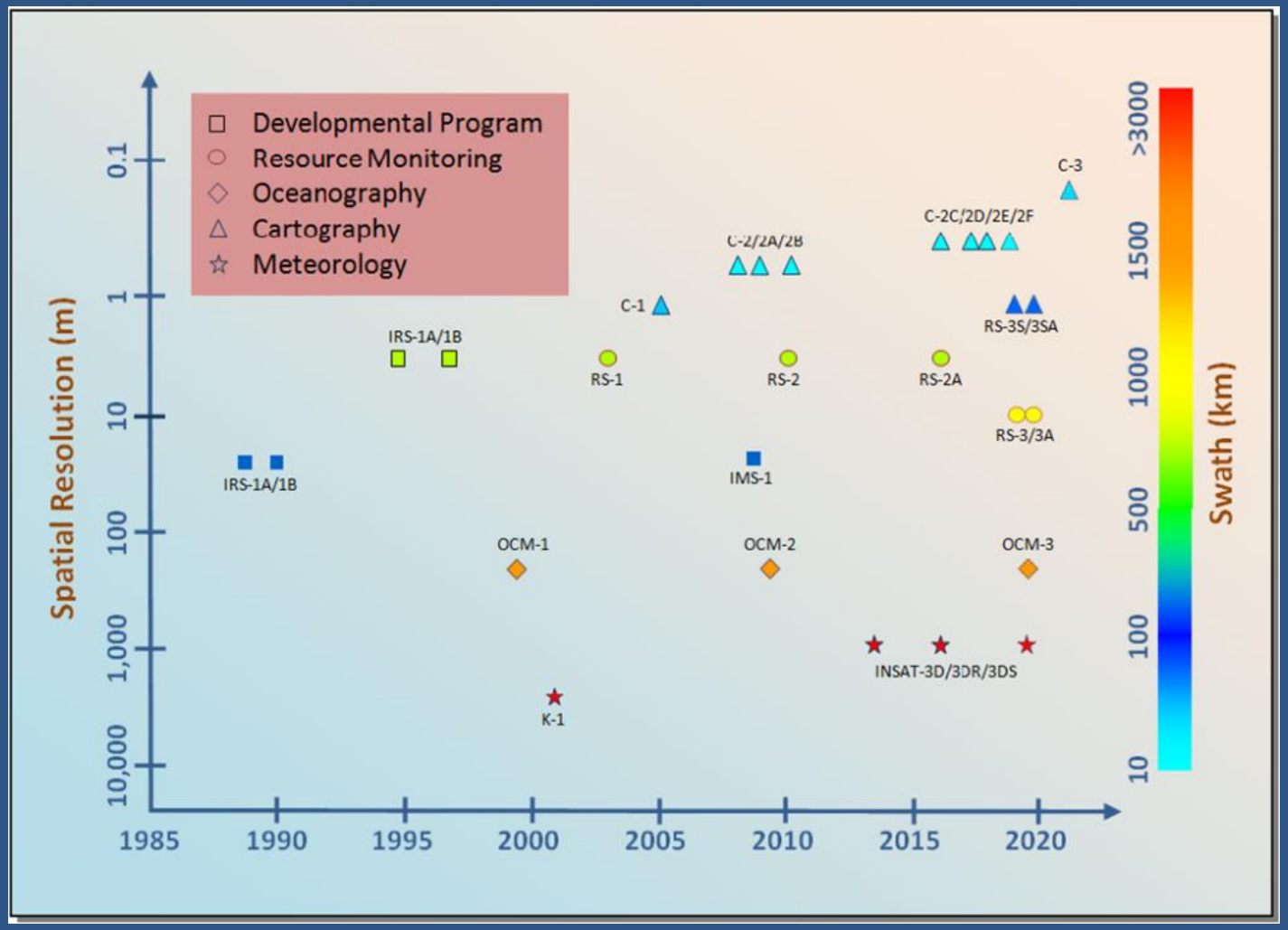






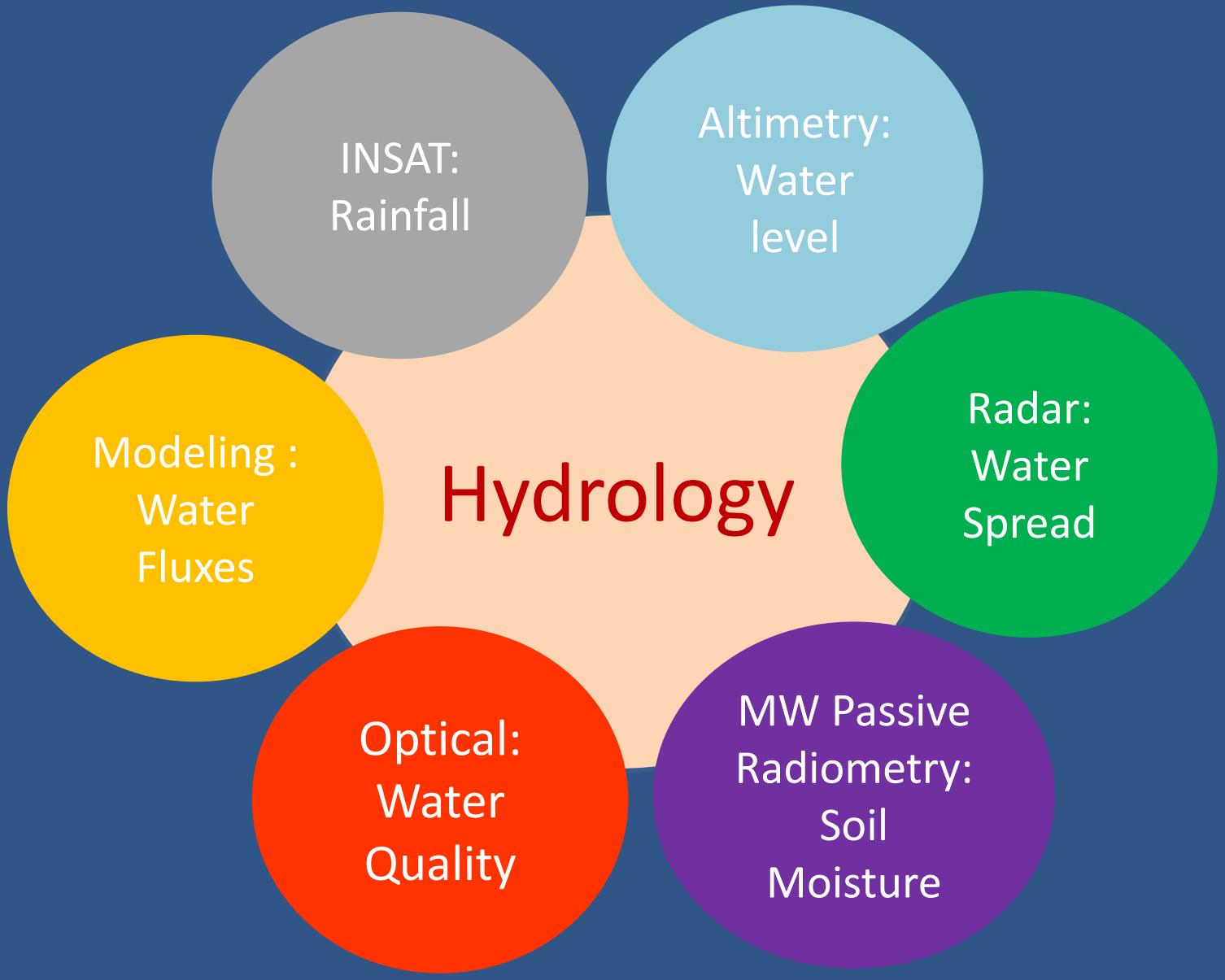


Indian Earth Observation System



Currently, many operational satellites are in Sun-synchronous orbit – RESOURCESAT-1, 2, 2A CARTOSAT-1, 2, 2A, 2B, OCEANSAT-2, Megha-Tropiques, SARAL and SCATSAT-1, and in Geostationary orbit- INSAT-3D, & INSAT -3DR

Dimensions of Satellite based Hydrology

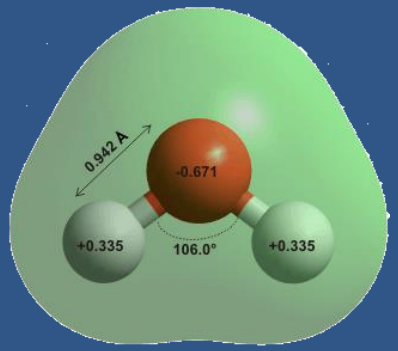


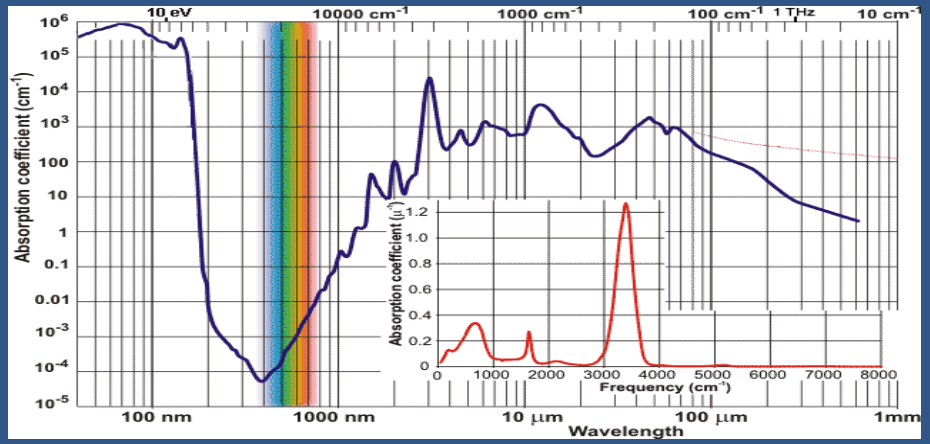
Physical Principle of detection

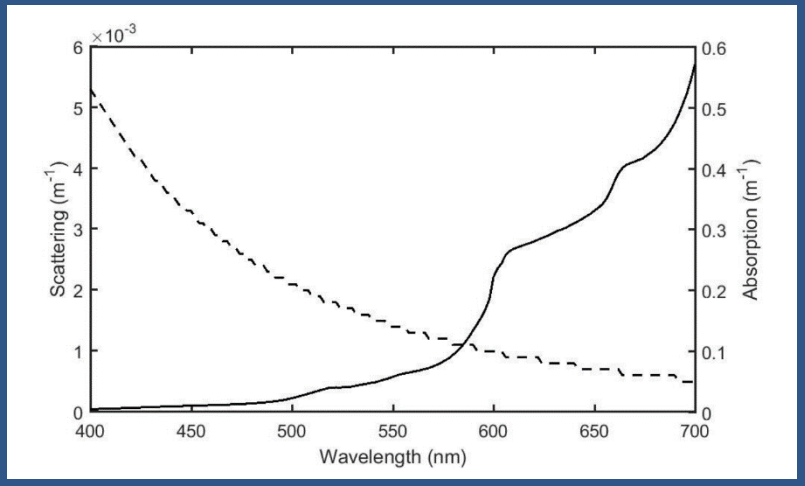
- Reflection/Absorption of Water in Optical Region
  - Delineation of wetlands, Turbidity, Veg. NDVI , ET …
- Emission in Thermal Infrared Region
  - Temperature of cloud top and land surface, Rain …
- Backscattering in Microwave Region (Radar)
  - Water spread, Flood, Soil Moisture ….
- Microwave Emission (Passive Radiometer)
  - Soil Moisture, Rain rate…
- Detection of time delay of Radar signal (Altimetry)
  - Water level, River Discharge …..
- Detection of Gravity (GRACE)
  - Ground water ..
- Hyperfine Spectroscopy (TES)
  - Isotopic Measurements..

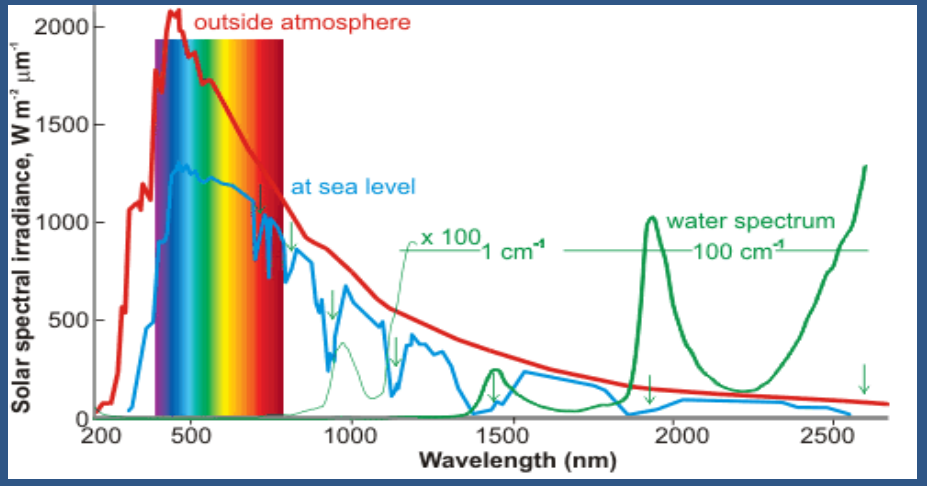
Spectroscopy of Water Molecules

Water absorbs a wide range of electromagnetic radiation with rotational transitions and intermolecular vibrations responsible for absorption in the microwave (~1 mm - 10 cm wavelength) and far-infrared (~10 μ - 1 mm), intramolecular vibrational transitions in the infrared (~1 μ- 10 μ) and electronic transitions occurring in the ultraviolet region (< 200 nm).









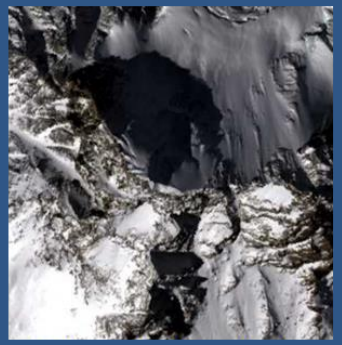
Colours of Water through Airborne AVIRIS-NG


Ahmedabad


Surendranagar


Desalpar

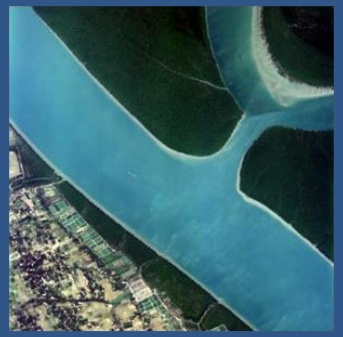

Patna


Himachal Pradesh


Bhagalpur


Muddumalai

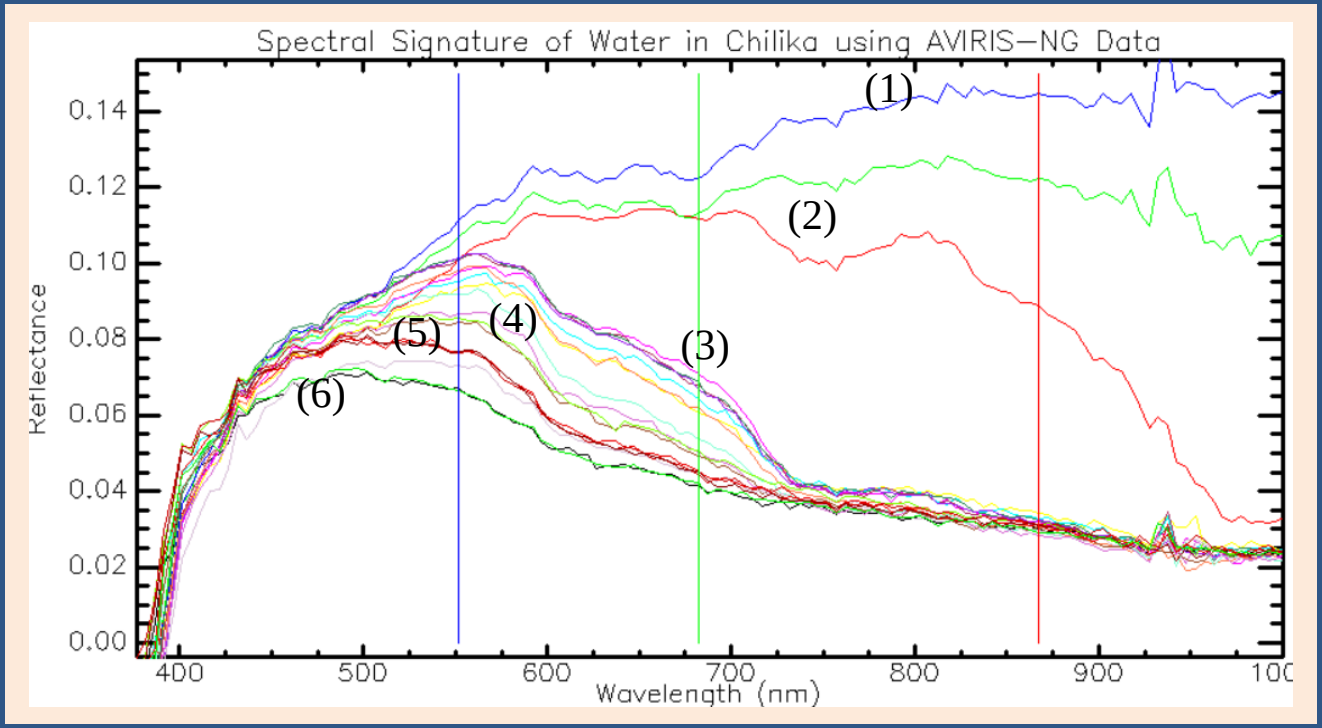

Hoogli


Sundarban

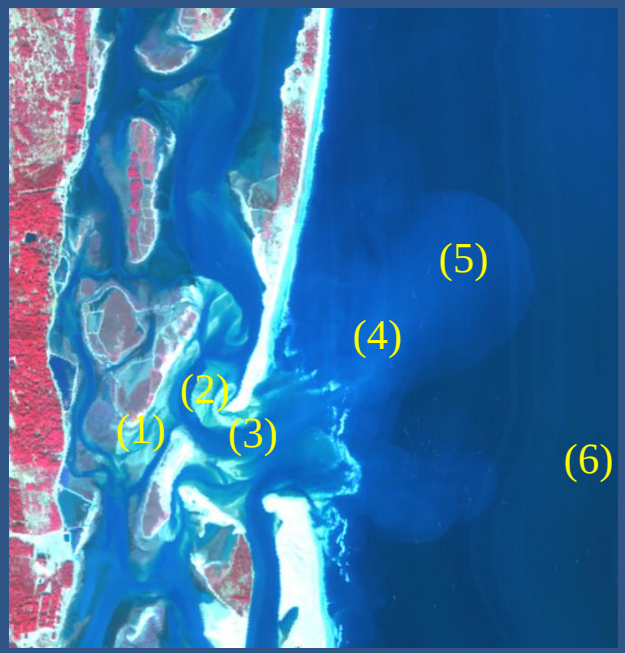

Bhitarkanika


Chilika


Veeraval

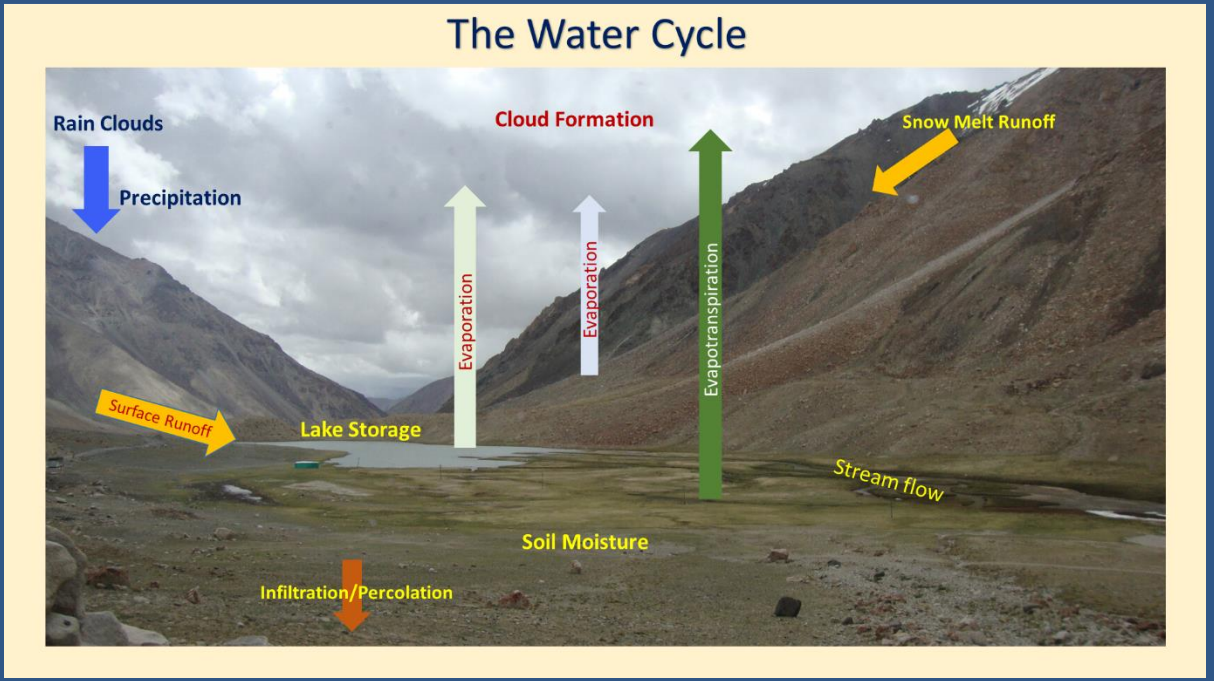


AVIRIS-NG Data
27-12-2015



Water Cycle and Hydro-meteorological Parameters

- Rainfall
- Snow melt Runoff
- Evapotranspiration
- Surface Runoff
- Soil Moisture
- Surface Water level
- River Discharge
- Ground Water



Water and Energy Balance

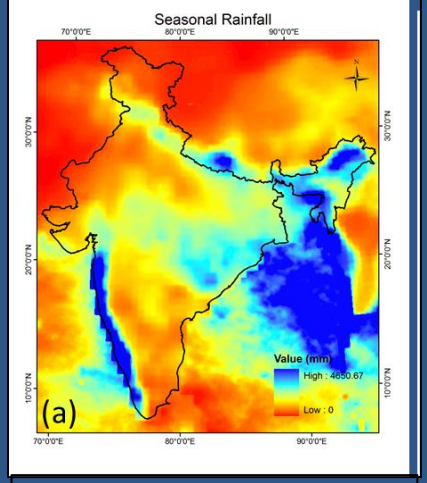
The land water balance is over all change of water storage (ΔS) and difference between incoming amount of precipitation (P) and subtracted amount of water in the form of ET and Runoff (R) with respect to time.

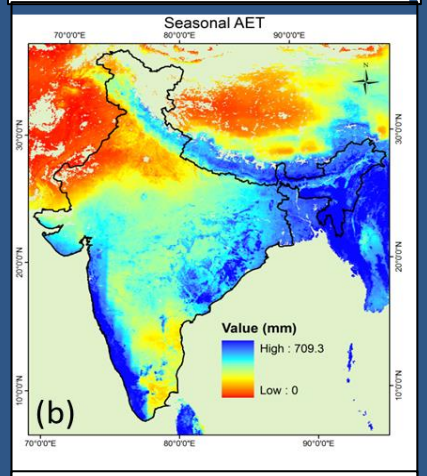
$$\Delta S = P - ET - R$$

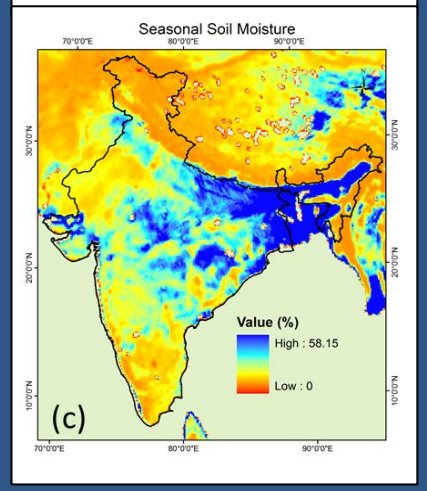
The process can also be described in energy balance term as

$$Rn - G = H + LE$$

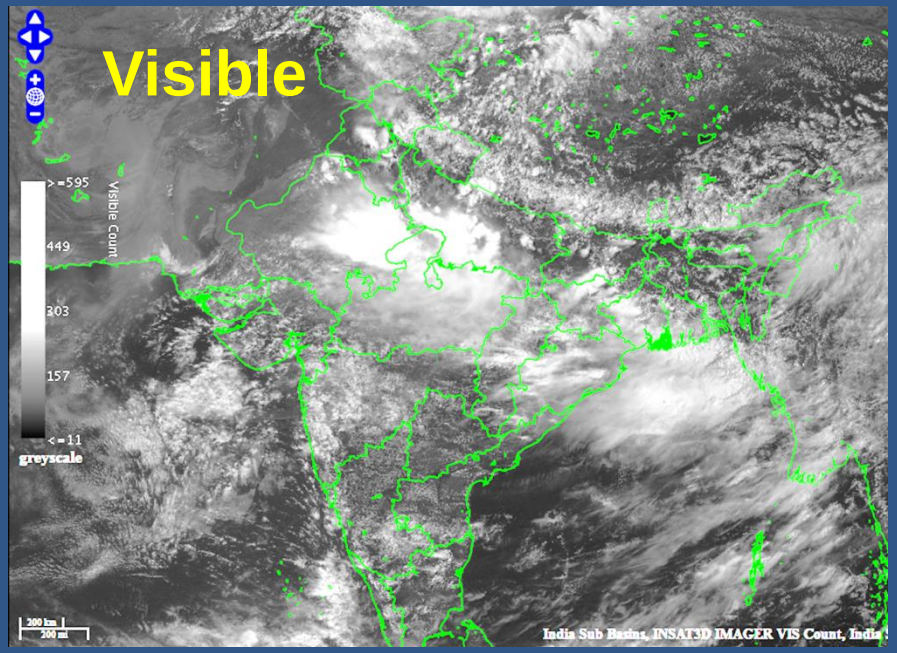
Where Rn is the net radiation, G is the soil heat flux, H is the sensible heat flux and LE is the latent heat flux. The quantity Rn-G is known as available energy

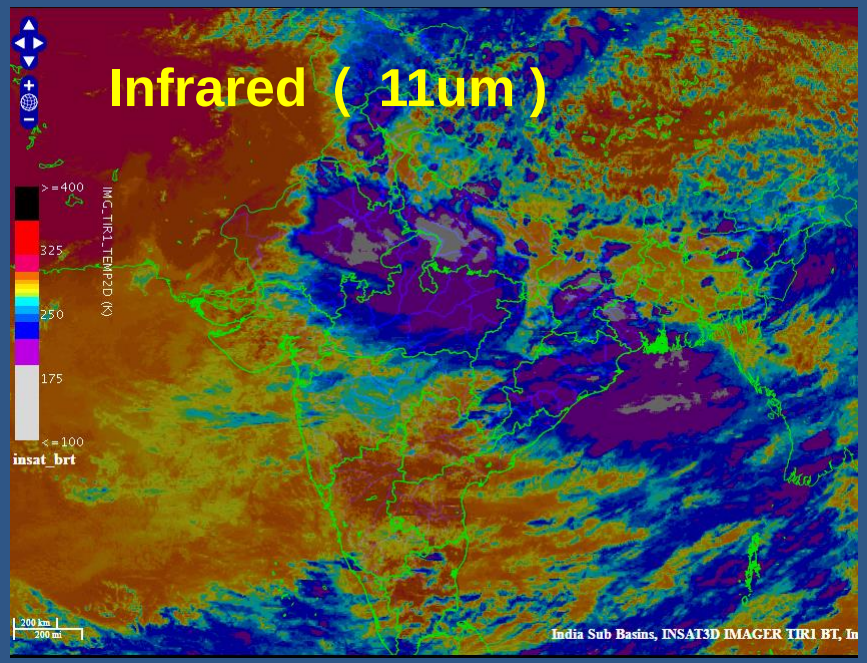




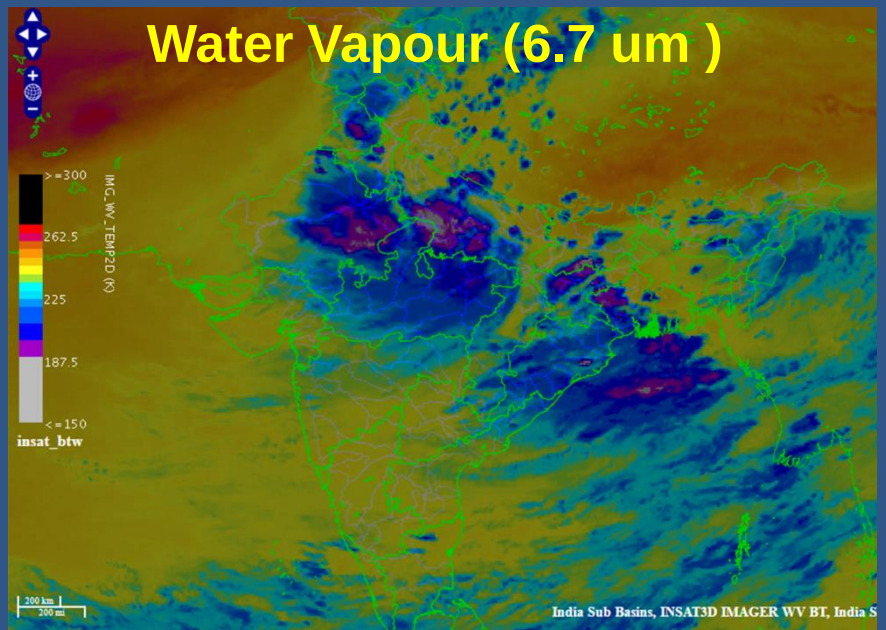


Rainfall Estimation



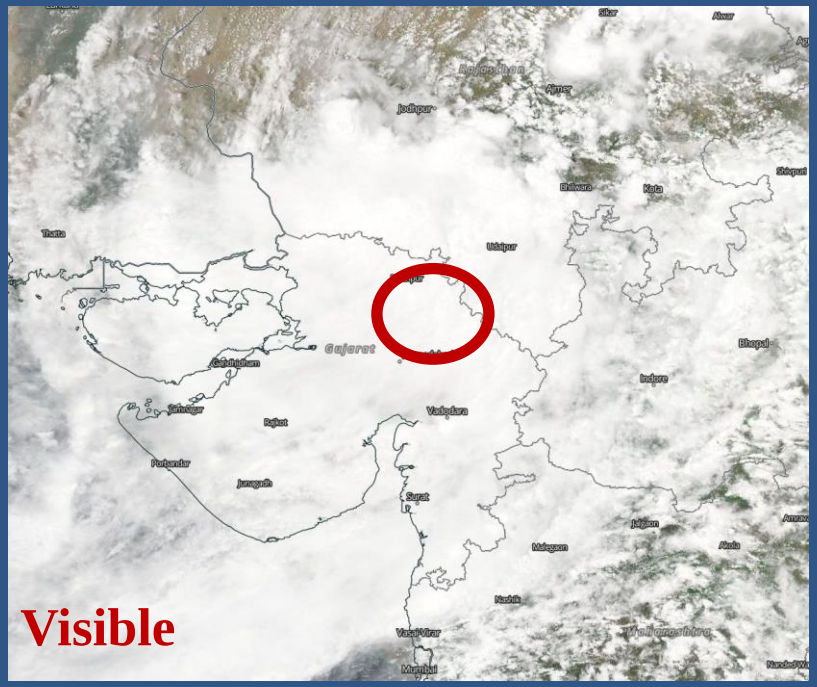


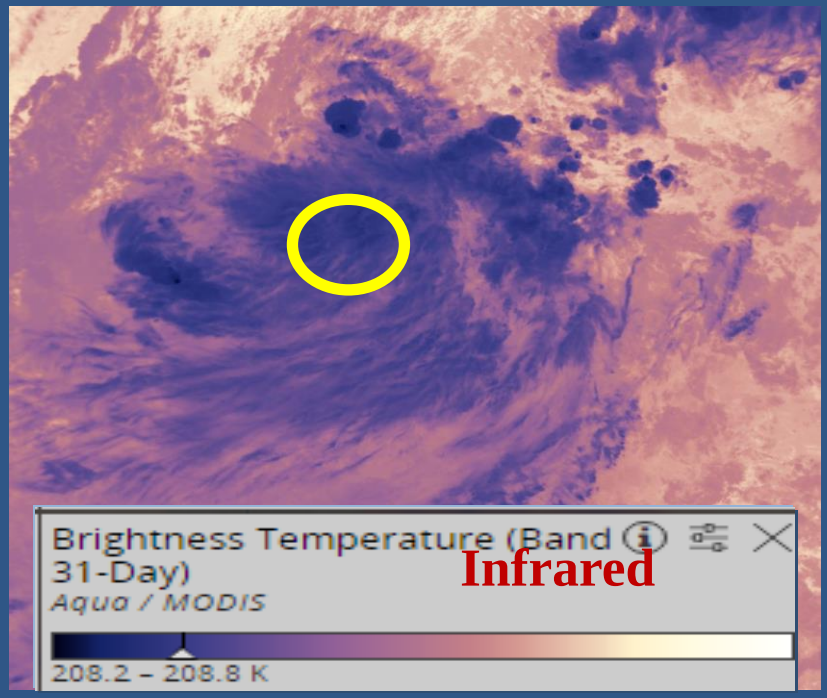
Heavier rainfall is associated with cold cloud top and generally seen as thick cloud in visible imagery

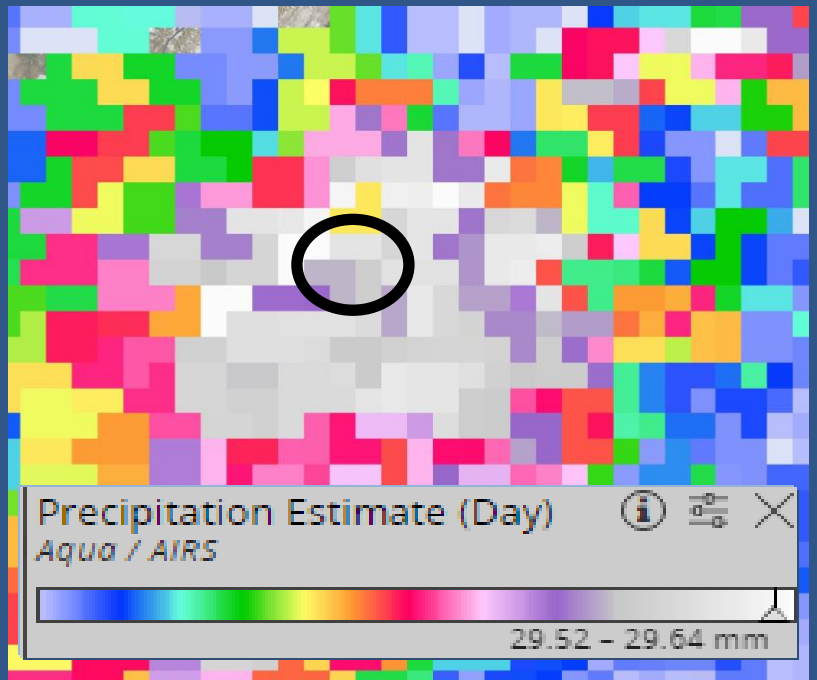


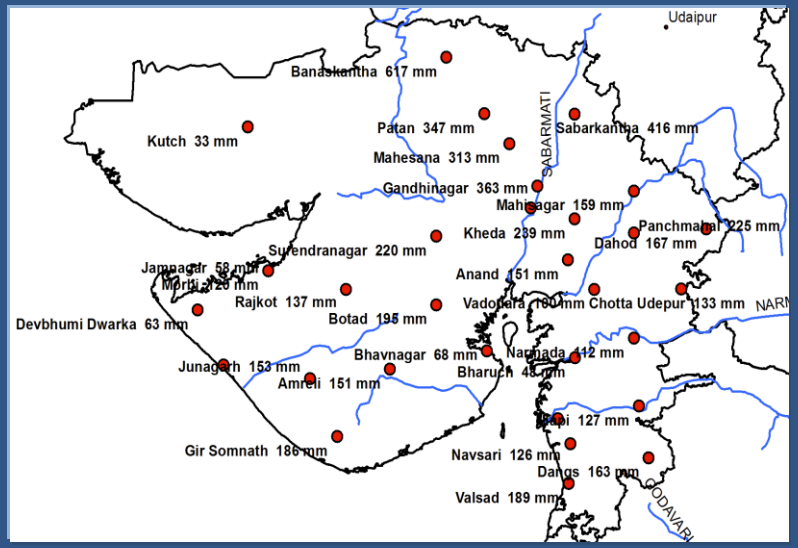
INSAT-3D
15 July
0200 Hrs

Gujarat Heavy Rain (23 July 2017) Observed from MODIA (AQUA) Satellite



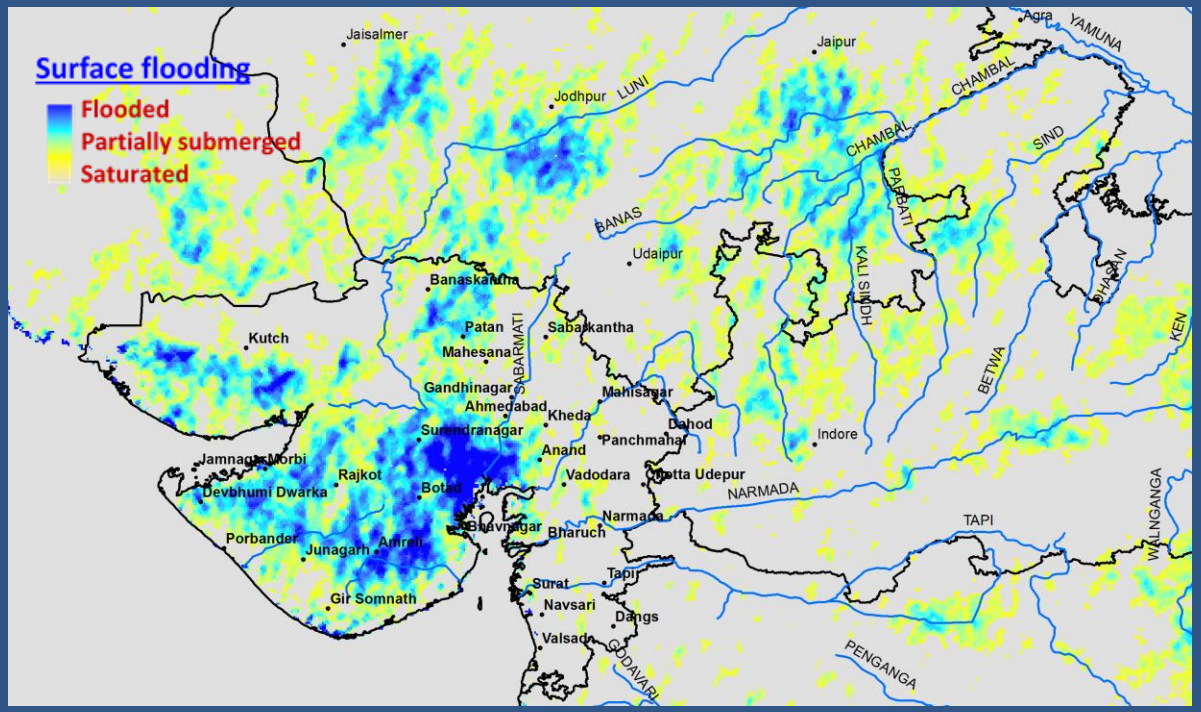






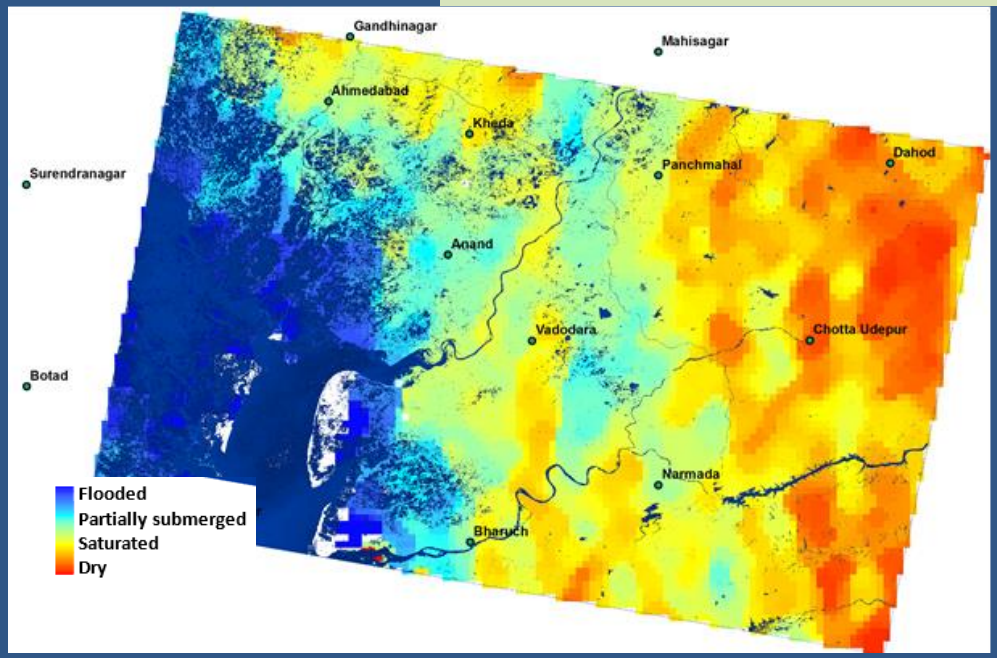
Observed Cumulative Rainfall (mm) in Gujarat during 21-26 July 2017

Floods

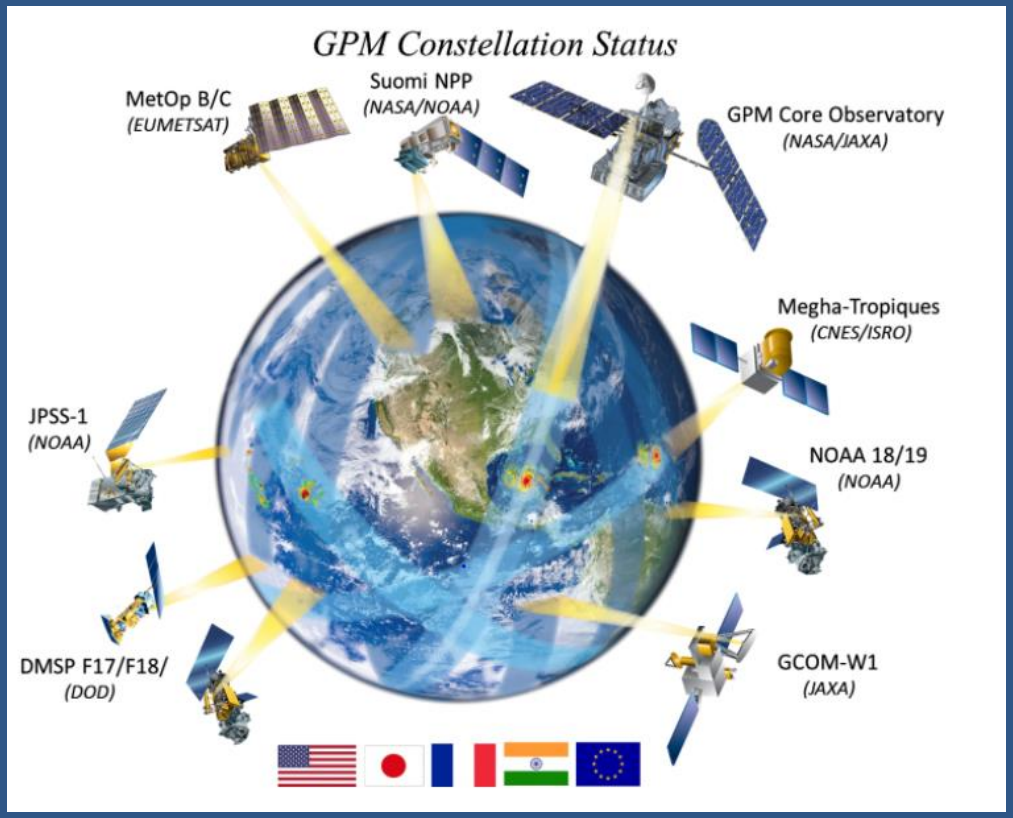


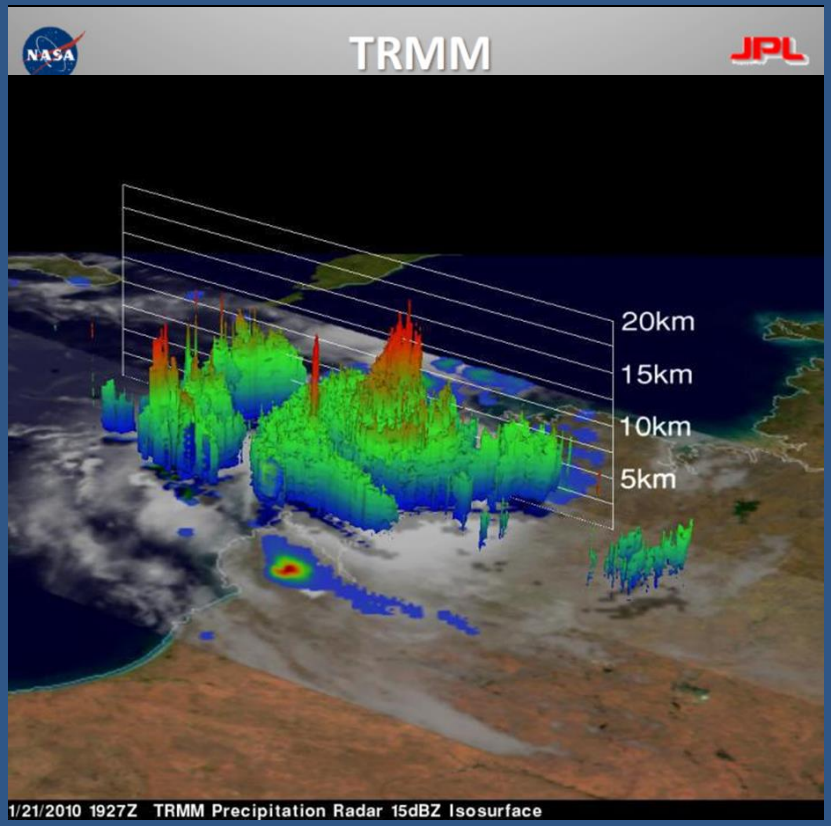
Merged inundation information from Scatsat-1 (Ku band, coarse resolution) and Sentinel-1A (C-band, high resolution) for 24th July 2017 in parts of Gujarat.

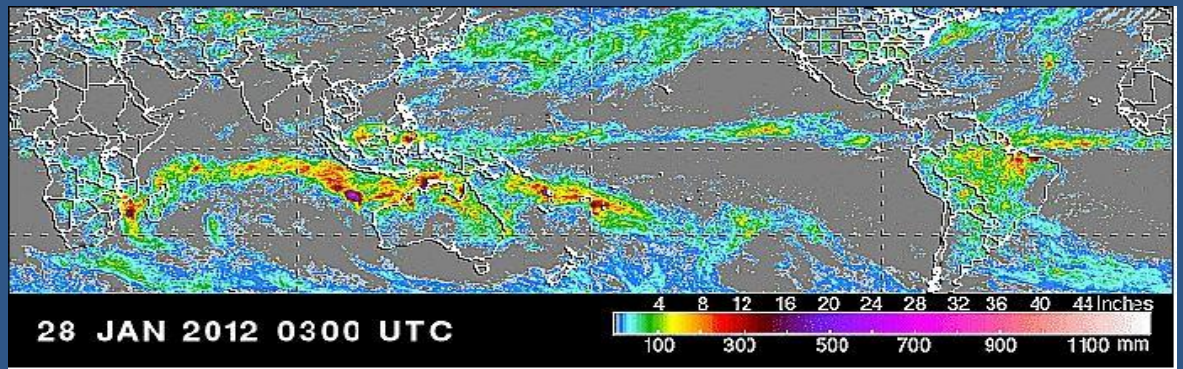
Flood inundation change analysis (6-10 July Vs 22-26 July 2017) over Gujarat and neighboring regions using Scatsat-1.



Rainfall Estimation







Soil Moisture

Soil moisture is the water stored in the soil and is affected by precipitation, temperature, soil characteristics.

Soil moisture influences meteorological and climatic processes as it is an important component in land water balance

Remote sensing Methods

Visible : Albedo (Less sensitive)

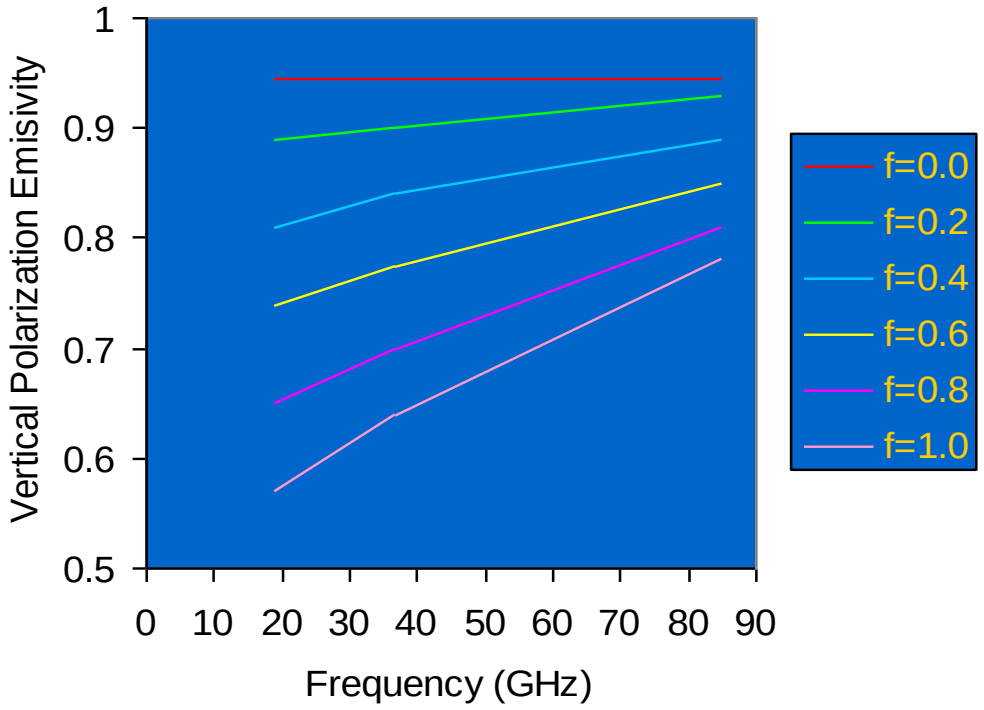
Thermal Infrared: Temperature, Thermal Inertia (Cloud cover)

Active Microwave: Backscatter Coeff. Dielectric Prop. (Limited Swath, Roughness, Veg. cover)

Passive Microwave: Brightness Temp. Dielectric Prop. (Low Resolution, Veg. cover)

Multi Frequency Based Surface Wetness Estimation

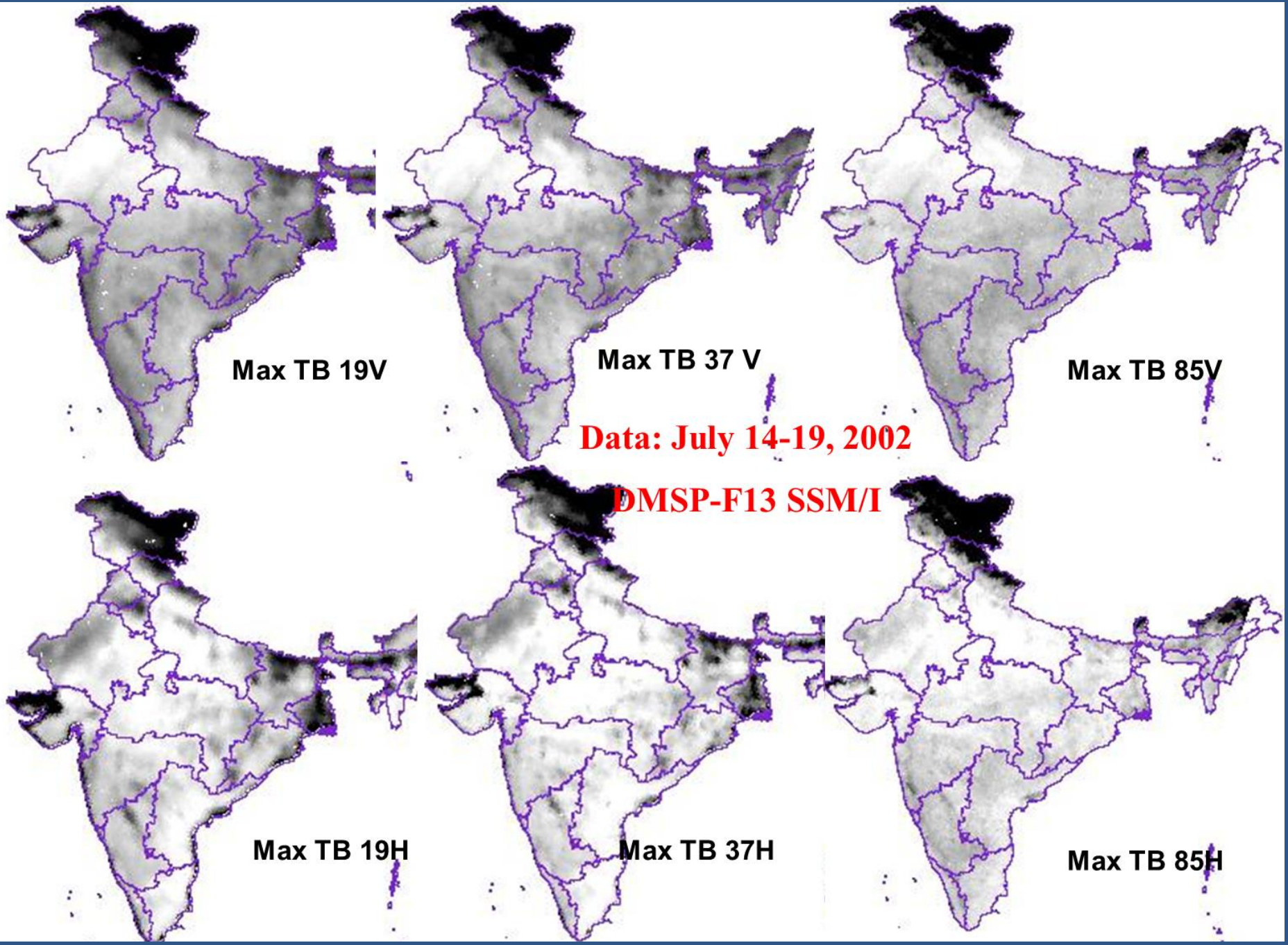
Relationship of emissivity over spectrum of microwave frequencies for different fraction (f) of surface water content (Source: Basist et al. 1998)



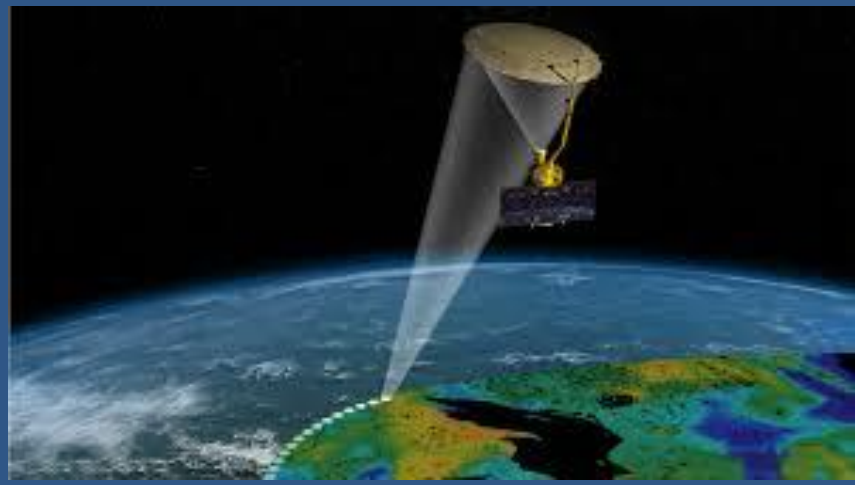
Source: Entekhabi D. et al. 2010

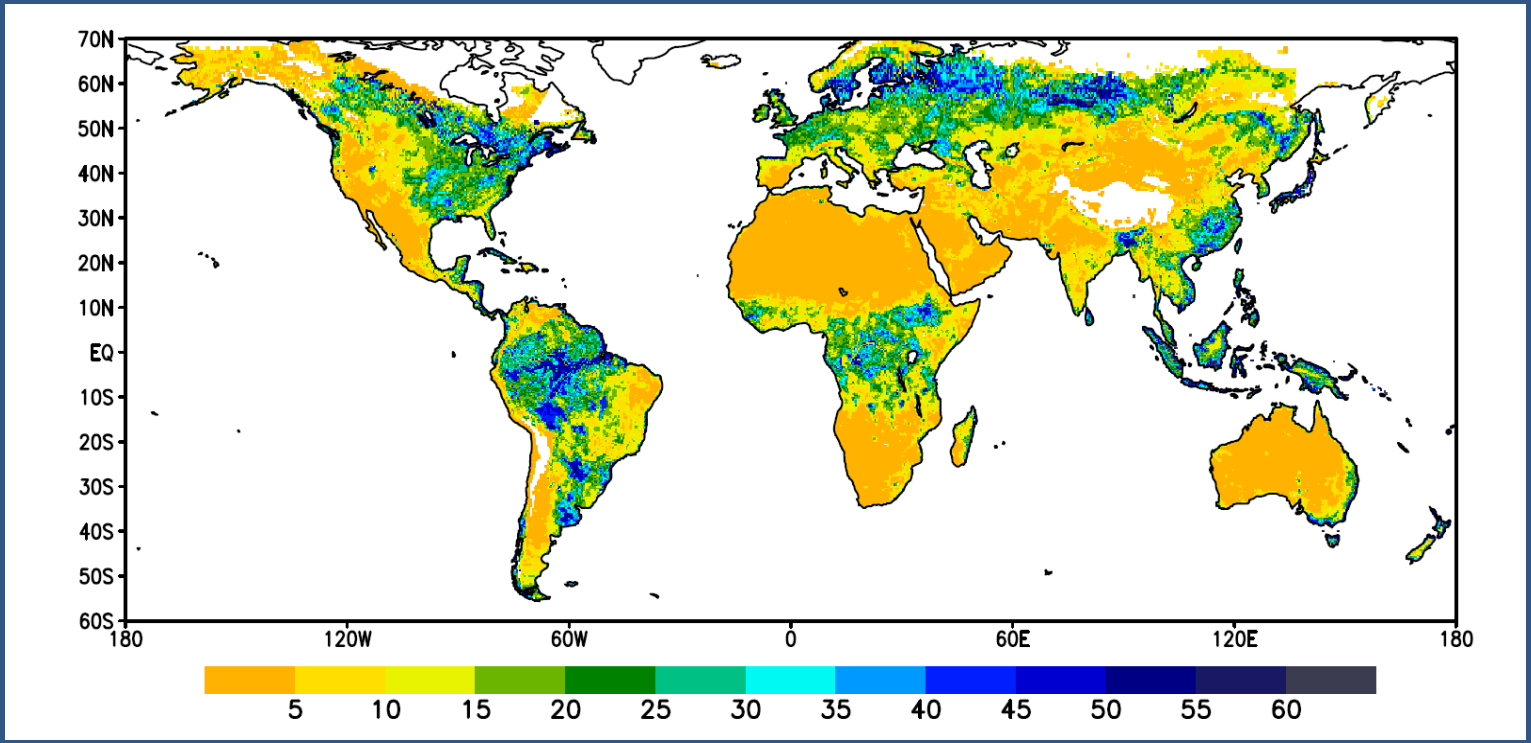
Surface Wetness $= \beta_0 \, [T_B(\nu_2) - T_B(\nu_1)] + \beta_1 \, [T_B(\nu_3) - T_B(\nu_2)]$

ν_1, ν_2 and ν_3 are 19, 37 and 85 GHz Frequency


Max TB 19V
Max TB 37 V
Max TB 85V
Data: July 14-19, 2002
DMSP-F13 SSM/I
Max TB 19H
Max TB 37H
Max TB 85H

SMAP Mission

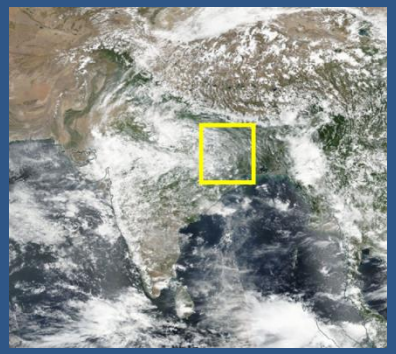




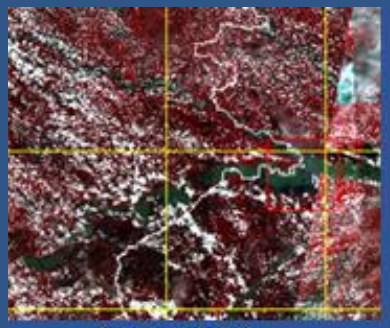
Global soil moisture map from SMAP's combined radar and radiometer instruments, averaged between 4 May and 11 May 2015,

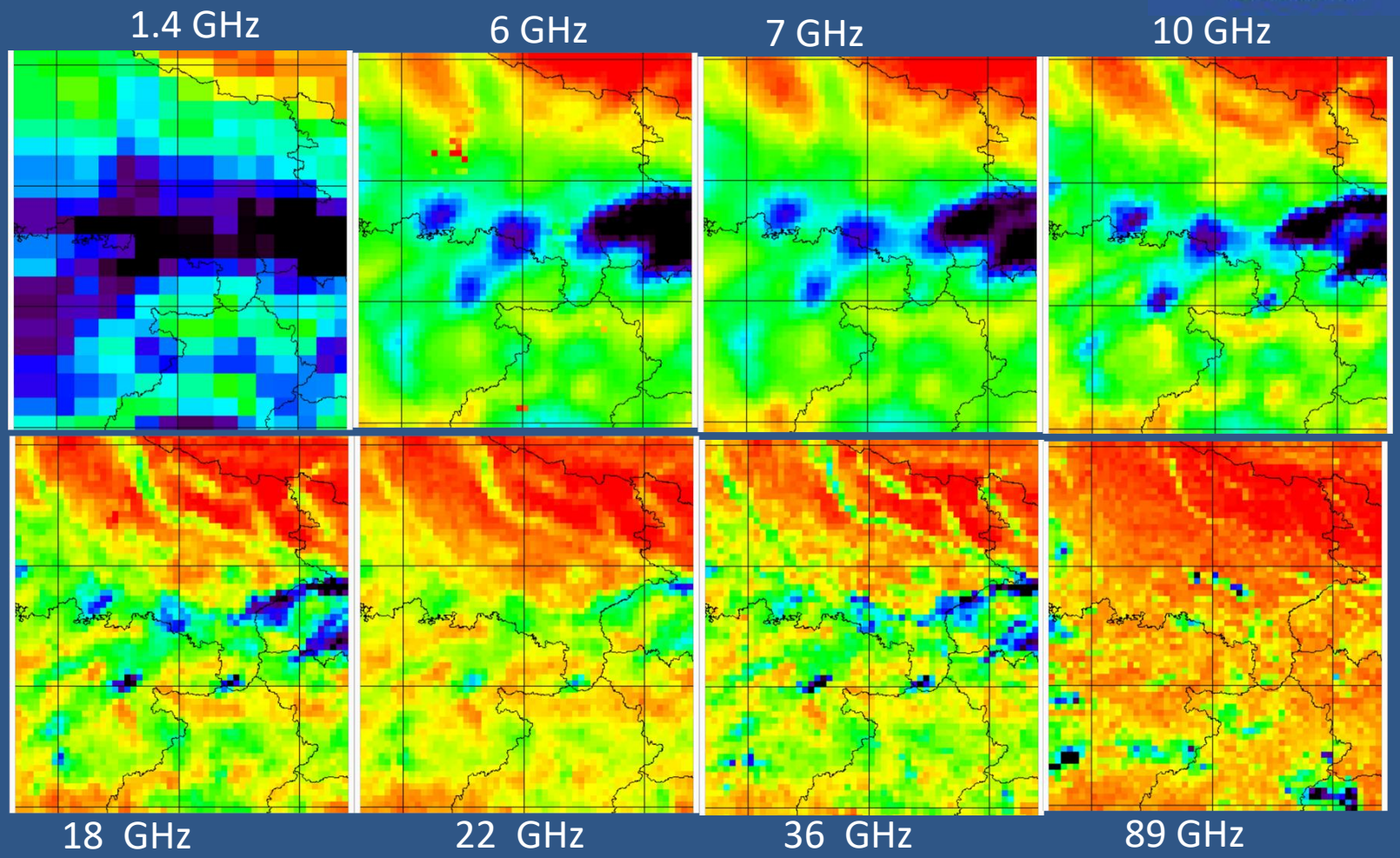
Source: Lettenmaier, D. P. et al. 2015

GANGA RIVER FLOOD 2016



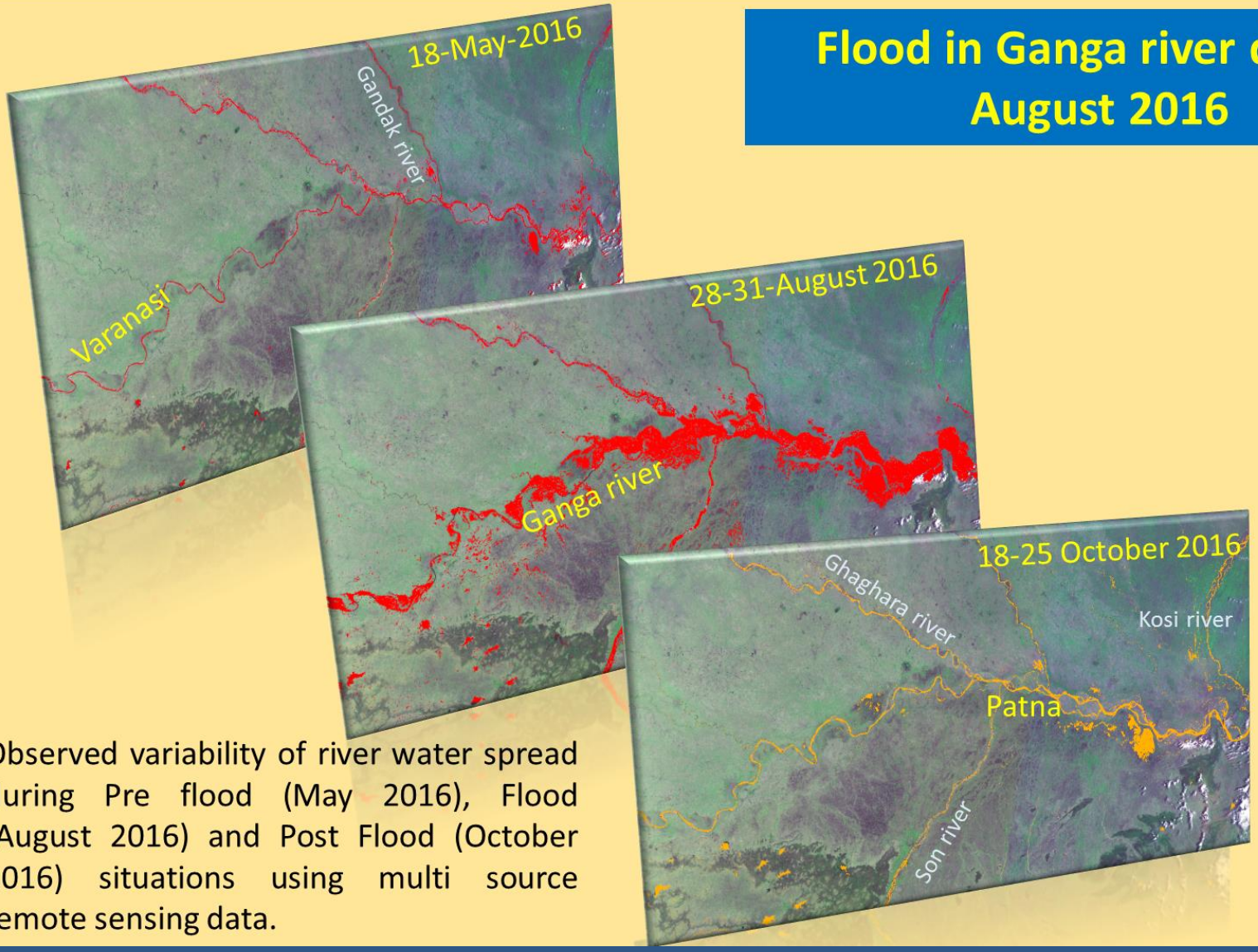
SMAP and AMSR-2 Observation of Brightness Temperature (Horizontal Polarization) on 23 August 2016 over Flooded region of Ganga River in Northern India





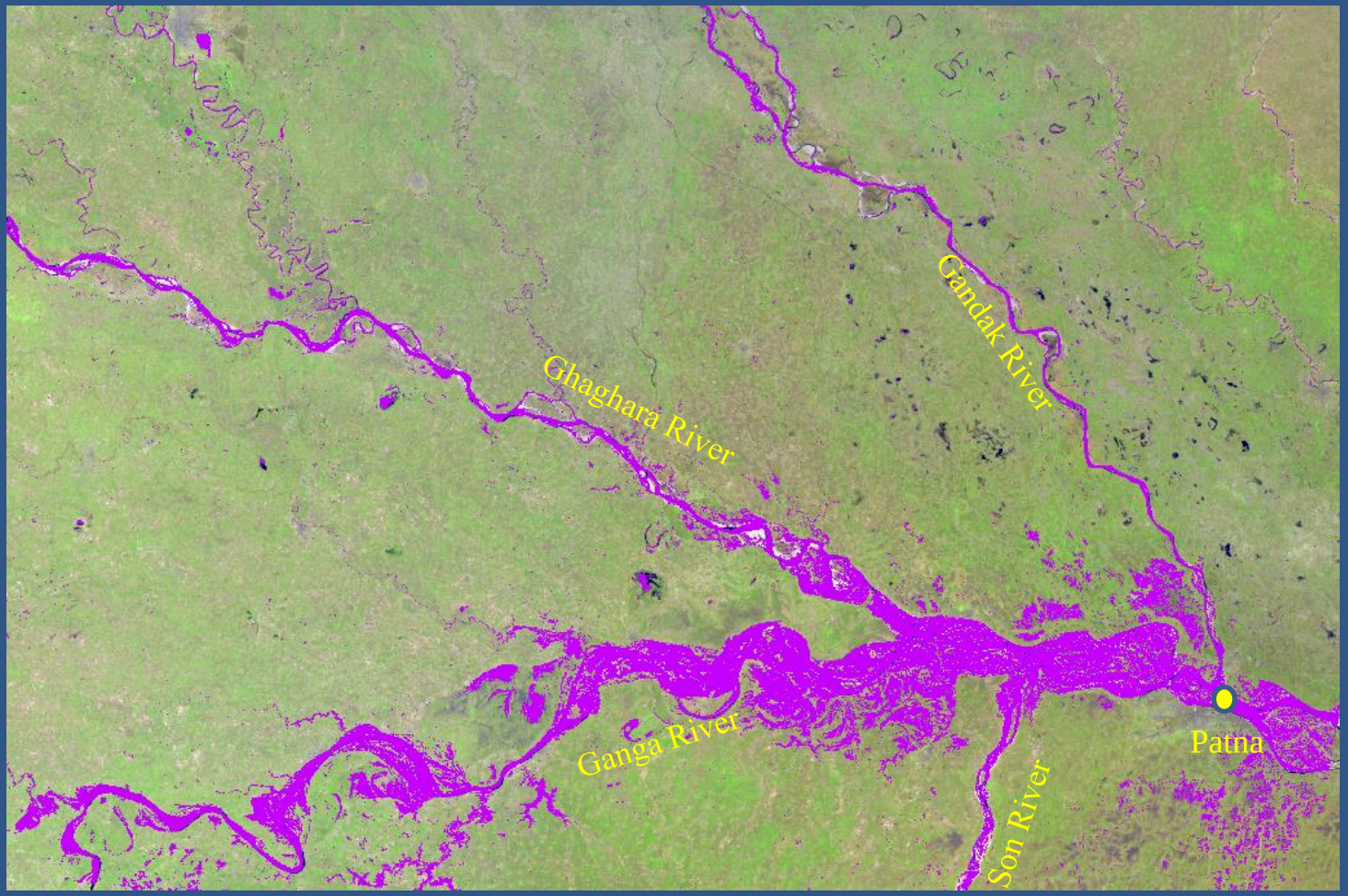
Floods

Flood in Ganga river during August 2016



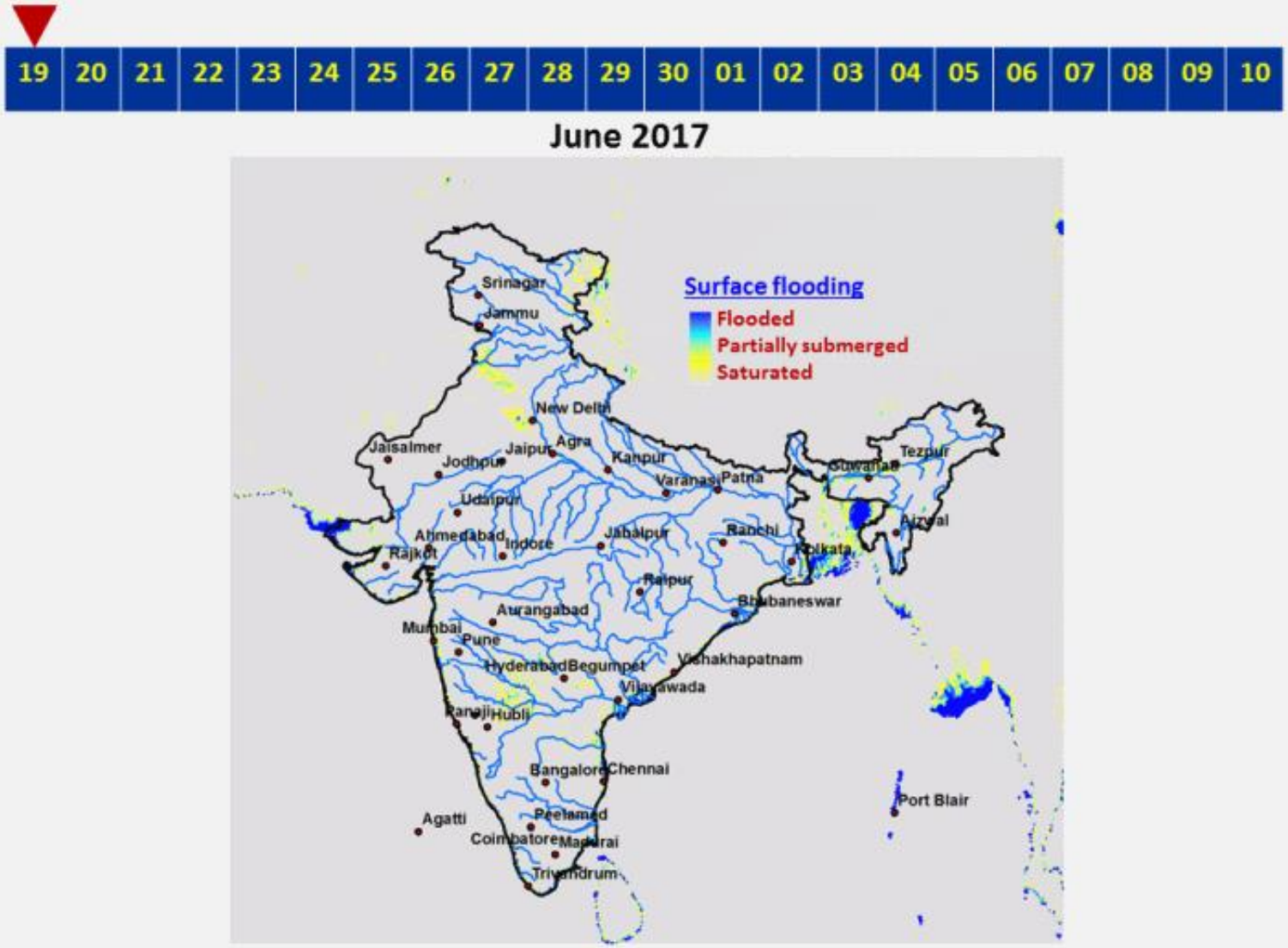
Observed variability of river water spread during Pre flood (May 2016), Flood (August 2016) and Post Flood (October 2016) situations using multi source remote sensing data.

Water spread in Ganga river in 2016



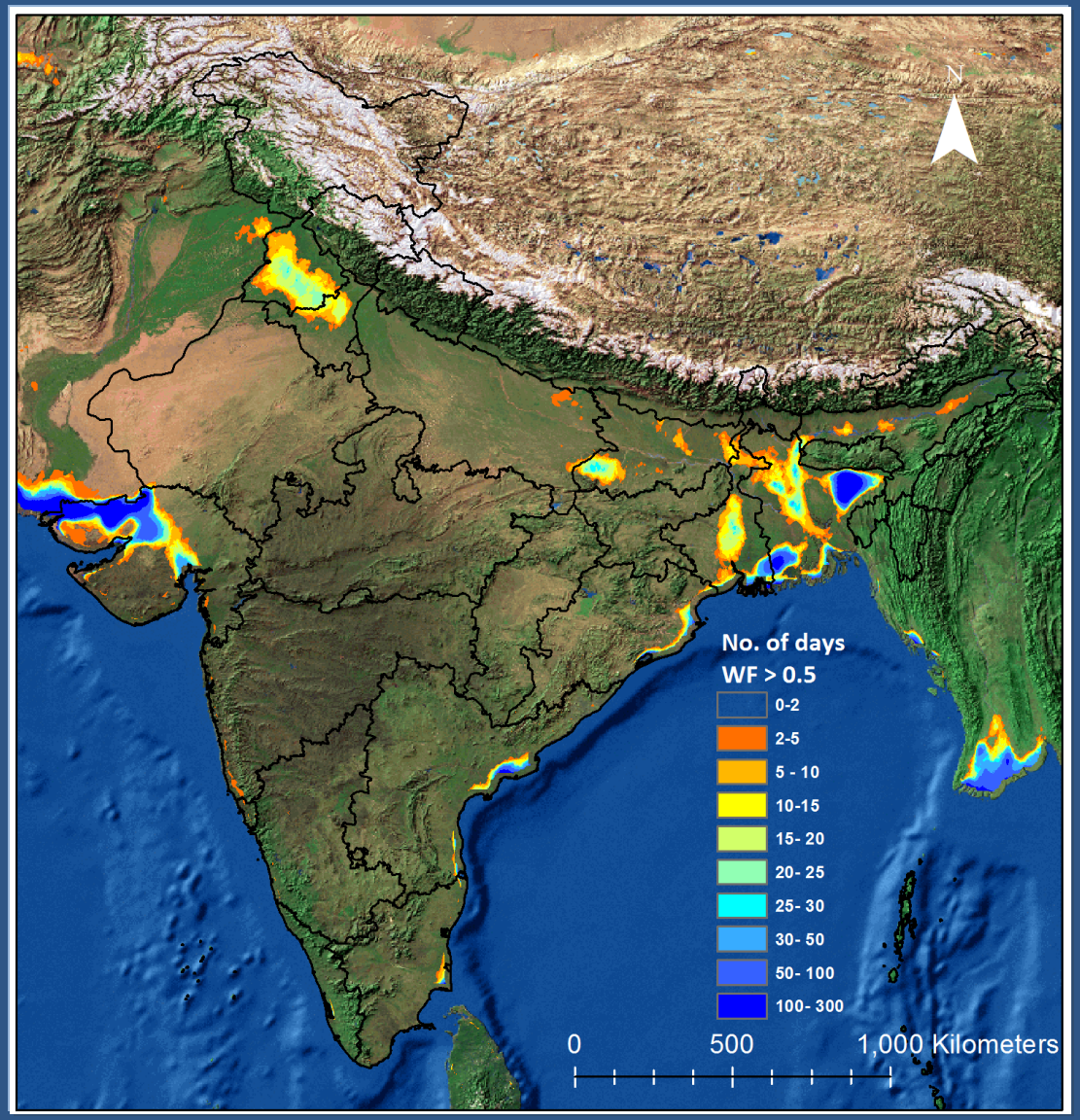
Sentinel-1 SAR Data, 21-August 2016

Surface Flooding as Observed from Passive Microwave Measurements from SCATSAT-1 Satellite

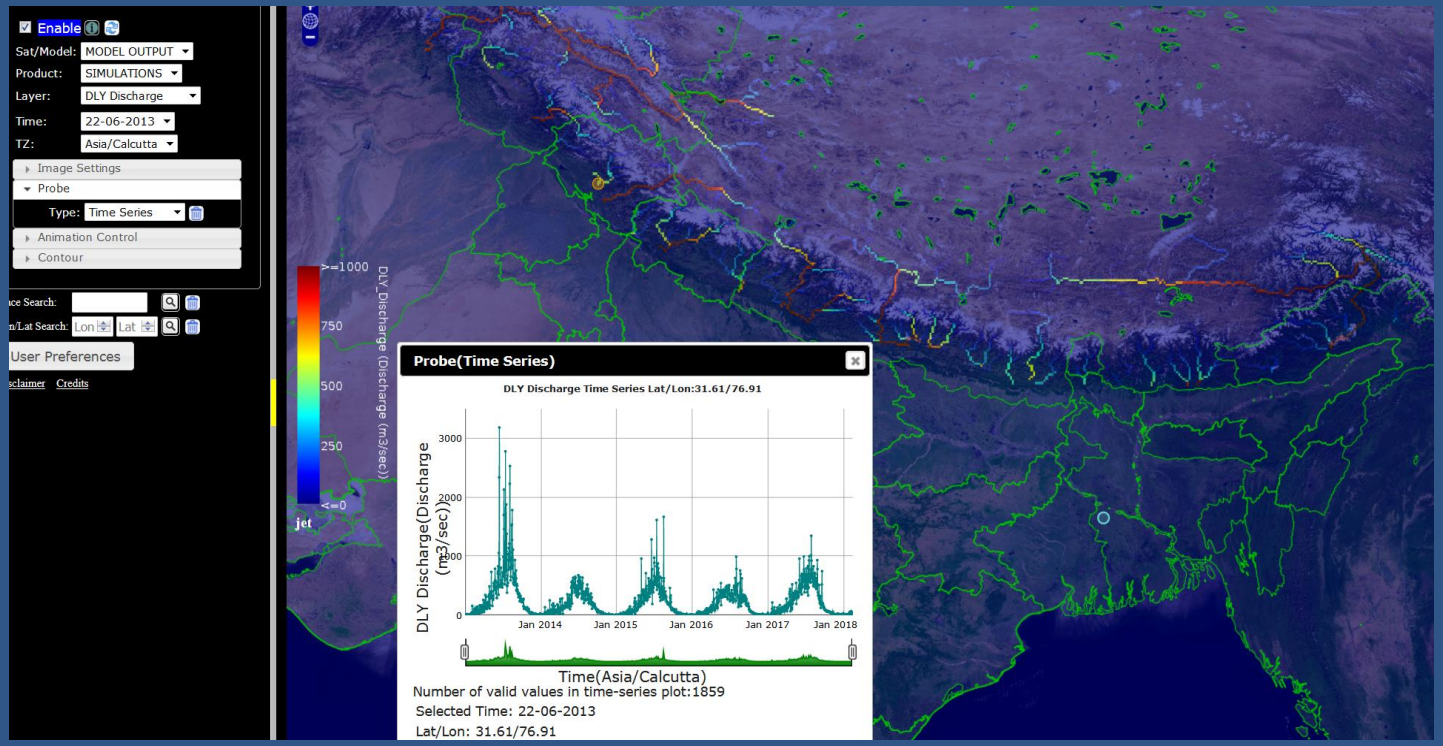


Source: ISRO Story of the week (01 Aug. 2017)

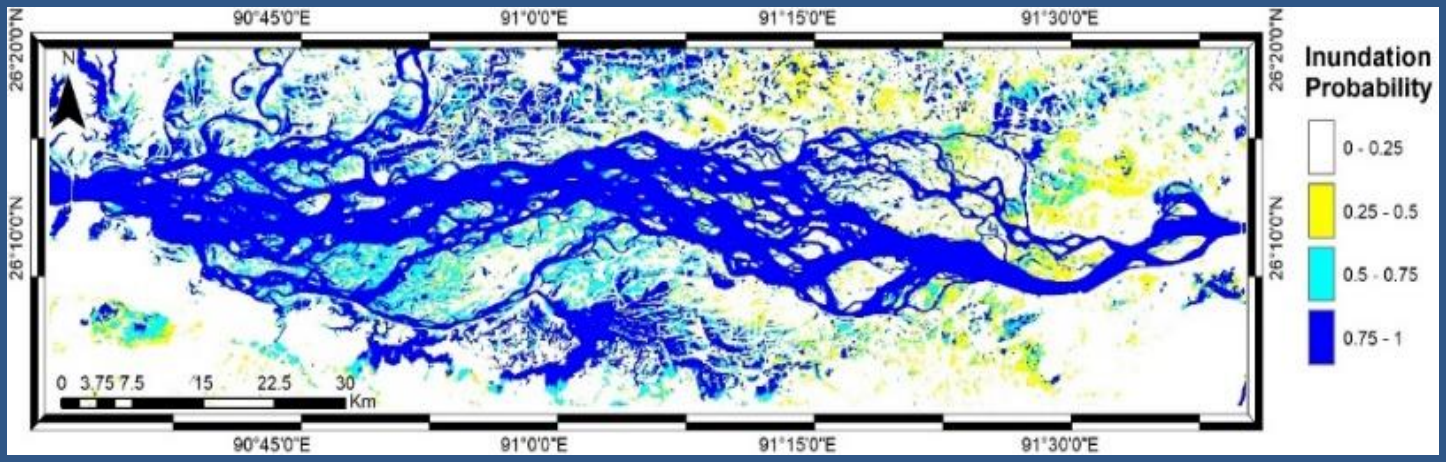
Surface Flooding as Observed from SCATSAT-1 Satellite during 2017



Flood Forecasting



Spatial variability of River Discharge



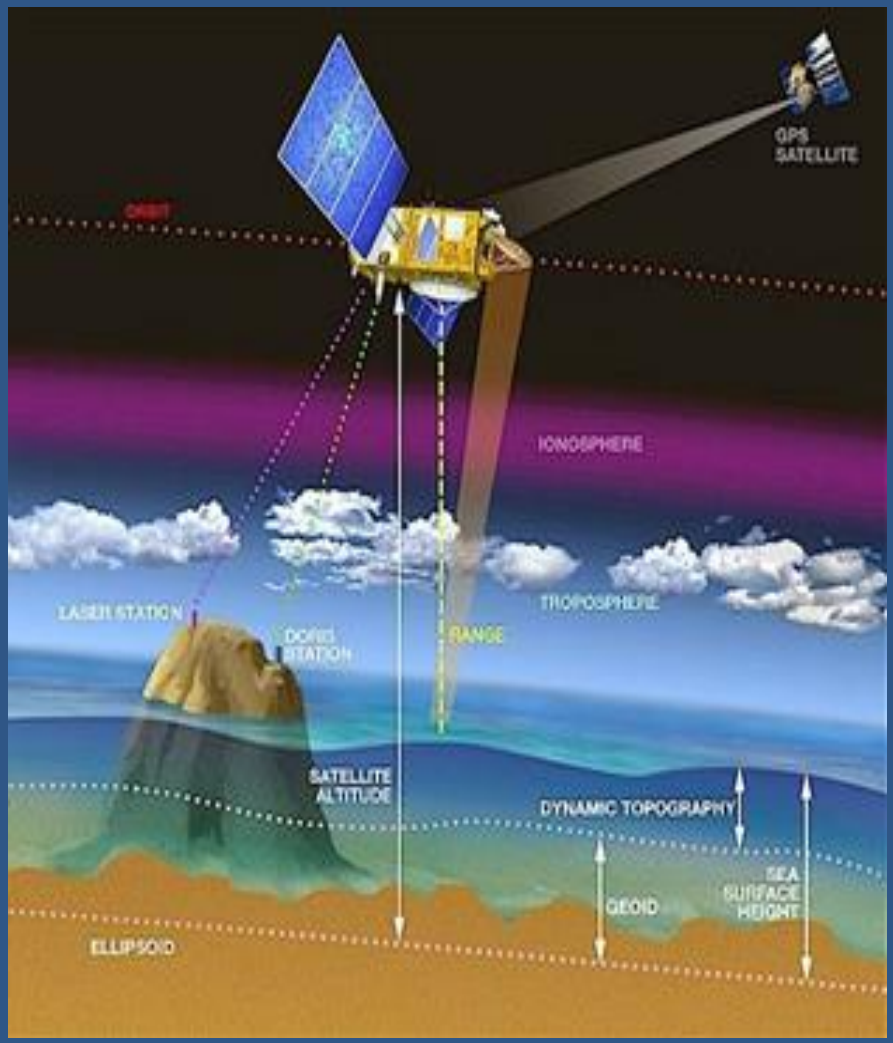
Forecasting (72 hours) Brahmaputra river Inundation using WRF-Hydro

Surface Water Level

Radars onboard satellite emit pulses towards nadir and receive the echo by water surface. The half time span for pulse reflected back to mission corresponds to distance (ρ) between satellite and earth surface. The height H of the reflecting water body with reference to geodetic reference is given as

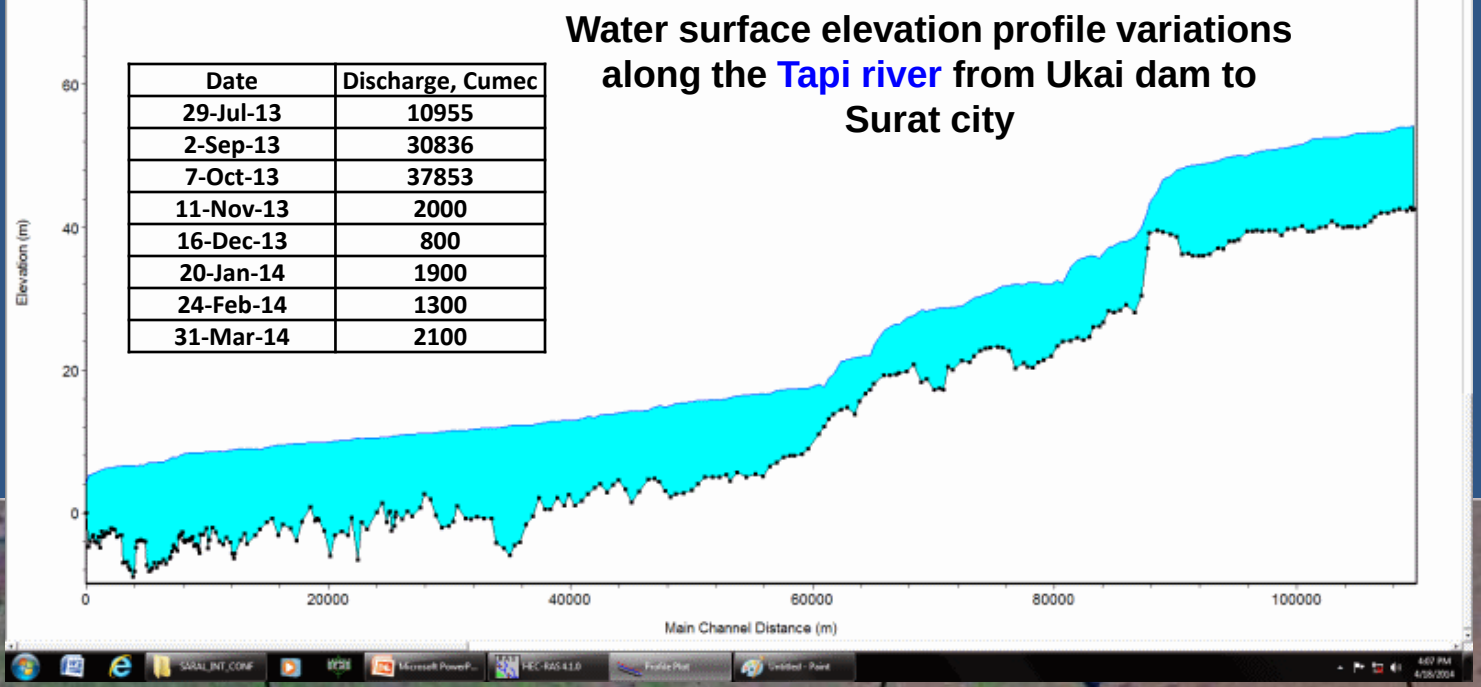
$$H = a_s - \rho + C_{iono} + C_{dry} + C_{wst} + C_{st} + C_{pt}$$

Where a_s is the satellite altitude with reference to reference ellipsoid. Other terms reference to corrections related with delayed propagation through the atmosphere (C_{dry} and C_{wet}), the interaction with ionosphere (C_{iono}) and solid earth tides (C_{st} and C_{pt}).



Water surface elevation profile variations along the Tapi river from Ukai dam to Surat city

Date	Discharge, Cumec
29-Jul-13	10955
2-Sep-13	30836
7-Oct-13	37853
11-Nov-13	2000
16-Dec-13	800
20-Jan-14	1900
24-Feb-14	1300
31-Mar-14	2100



Tapi River

Ukai reservoir

Altika_track_367

Altika_track_926

Water depth, m

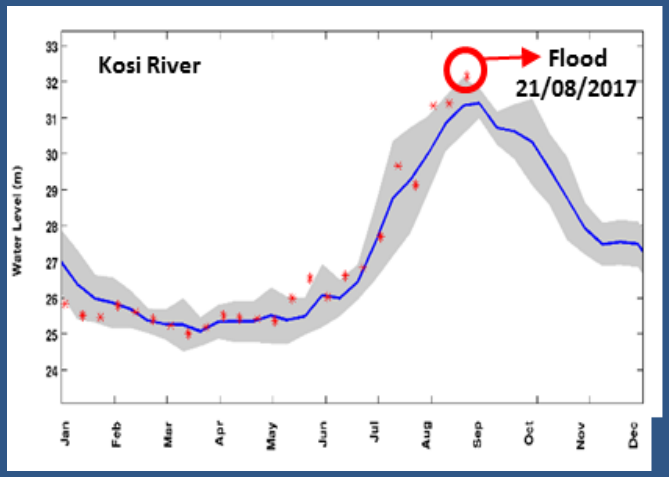
20.0

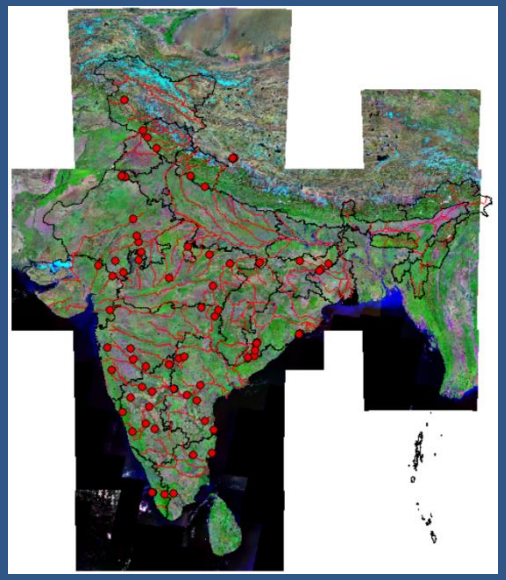
0.1

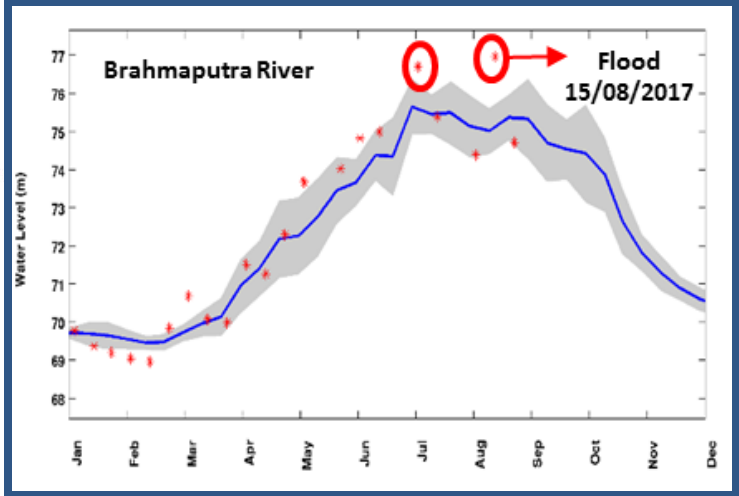
Water surface depth spread for various discharge patterns

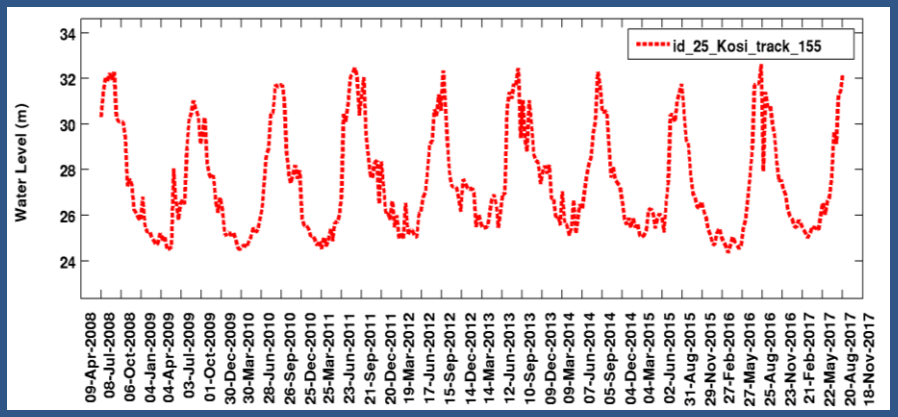
JUL 29, 2013

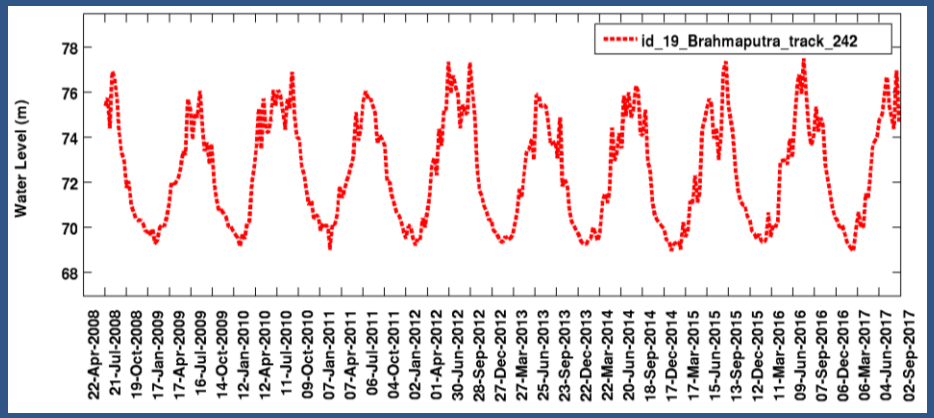
Solutions from Radar Altimetry





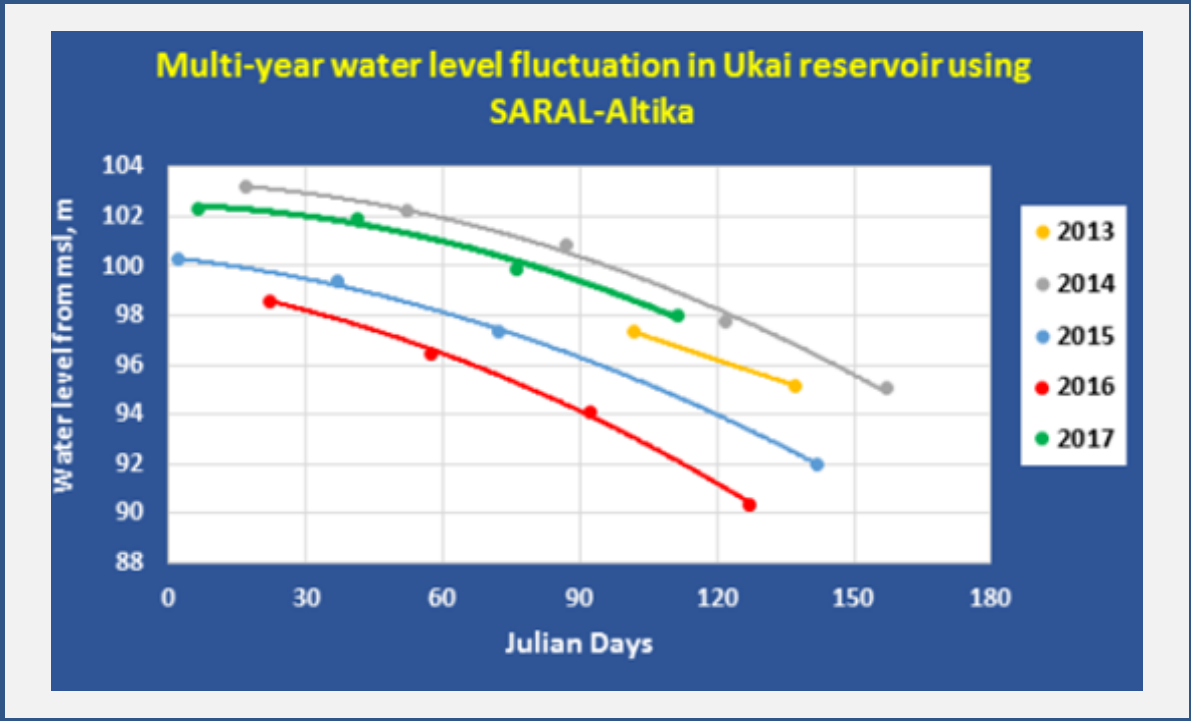


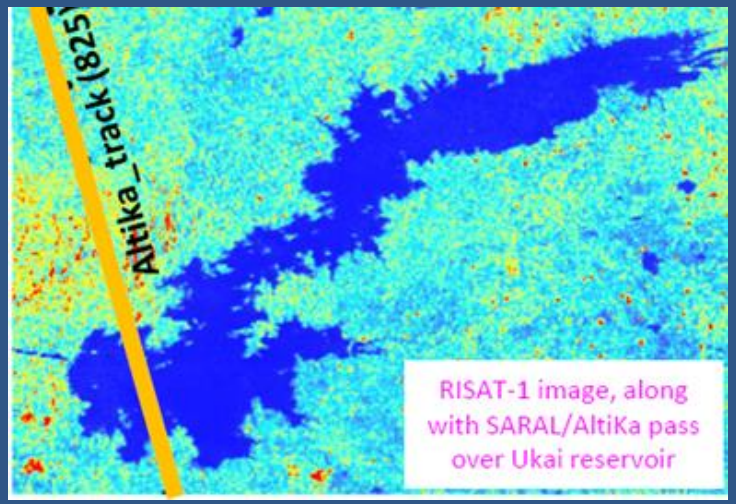




Flood wave in Ganga, Kosi, Brahmaputra rivers retrieved using Jason – 3 altimeter
And its comparison with decadal measurements from Jason-2 dataset (2008-2016)

Reservoir Water Availability from Radar Altimetry

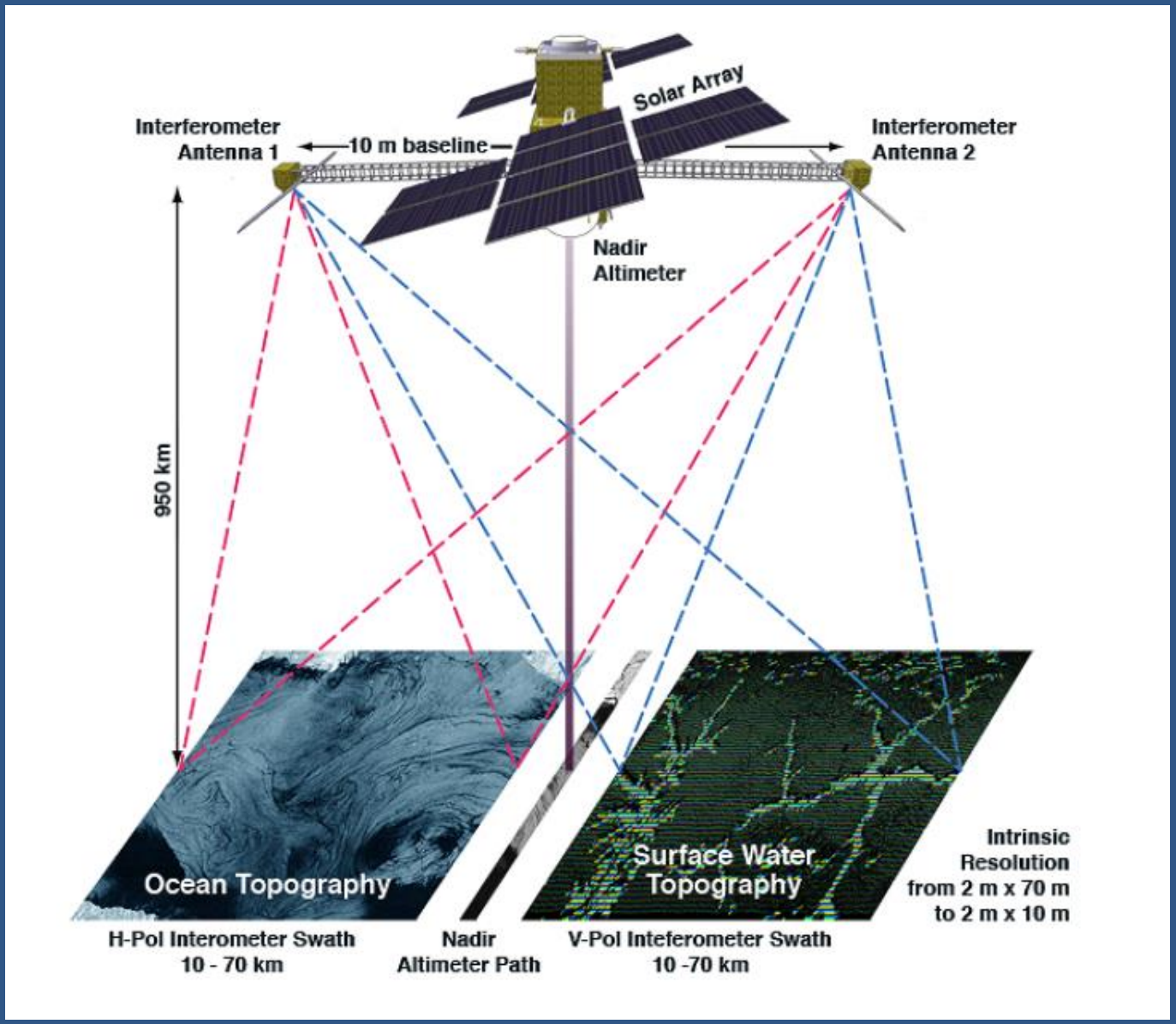




Assessment of water levels and volume (million cubic metre; MCM) for Ukai reservoir

Date	Water level (meter)	Capacity (MCM)
12-Apr-13	97.31	3347.75
01-Apr-14	100.48	4570.81
01-Apr-15	95.89	2905.15
01-Apr-16	94.12	2424.73
01-Apr-17	98.5	3819.261

The SWOT satellite

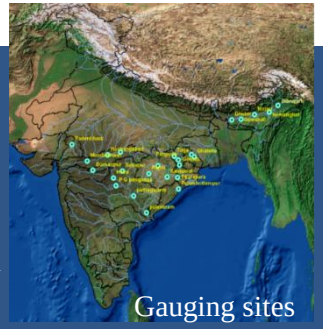


River Water Level Estimation using SCATSAT-1

Water Level (m)

Days since 01-12-2016

Water level retrieved over **18** virtual gauging stations using SCATSAT-1 backscatter data (01-12-2016 to 22-12-2017) :
(a) Adityapur (b) Basantpur (c) Panposh (d) Purushotampur (e) Ghatsila
(f) Gomali (g) Kantamal (h) Kashinagar (i) Tikarapara (j) Tilga (k) Pathagudem
(l) Polavaram (m) Mancherial (n) Burhanpur (o) Mandleshwar (p) Hoshangabad
(q) Satrapur (r) PG Penganga.


Gauging sites


Catchment areas

Evapotranspiration Estimation

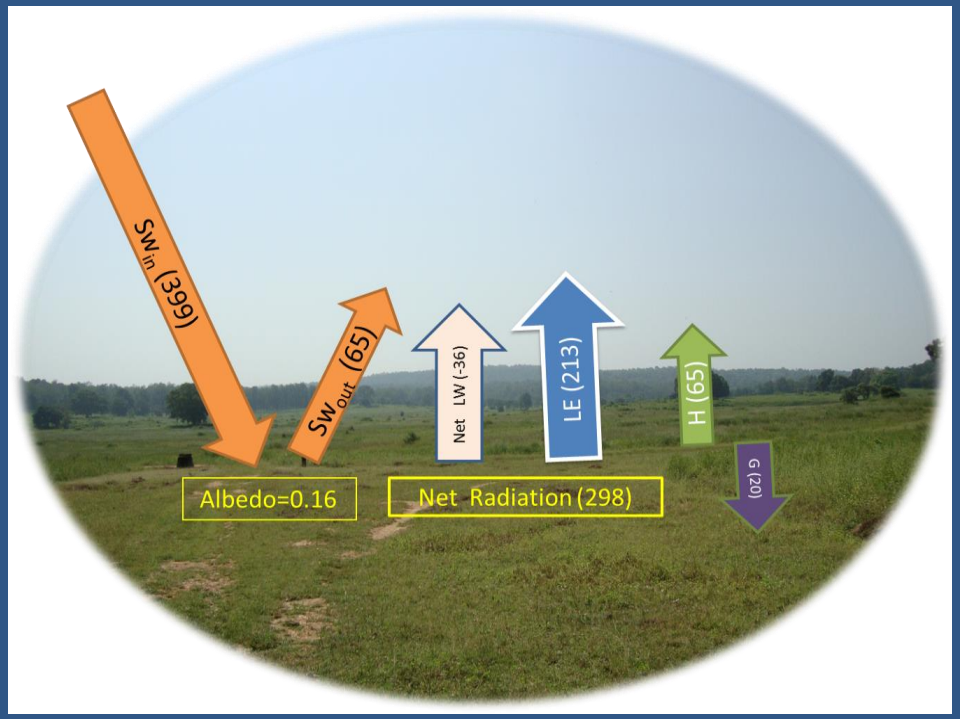
Energy balance

$$Rn = H + G + \lambda E + M$$

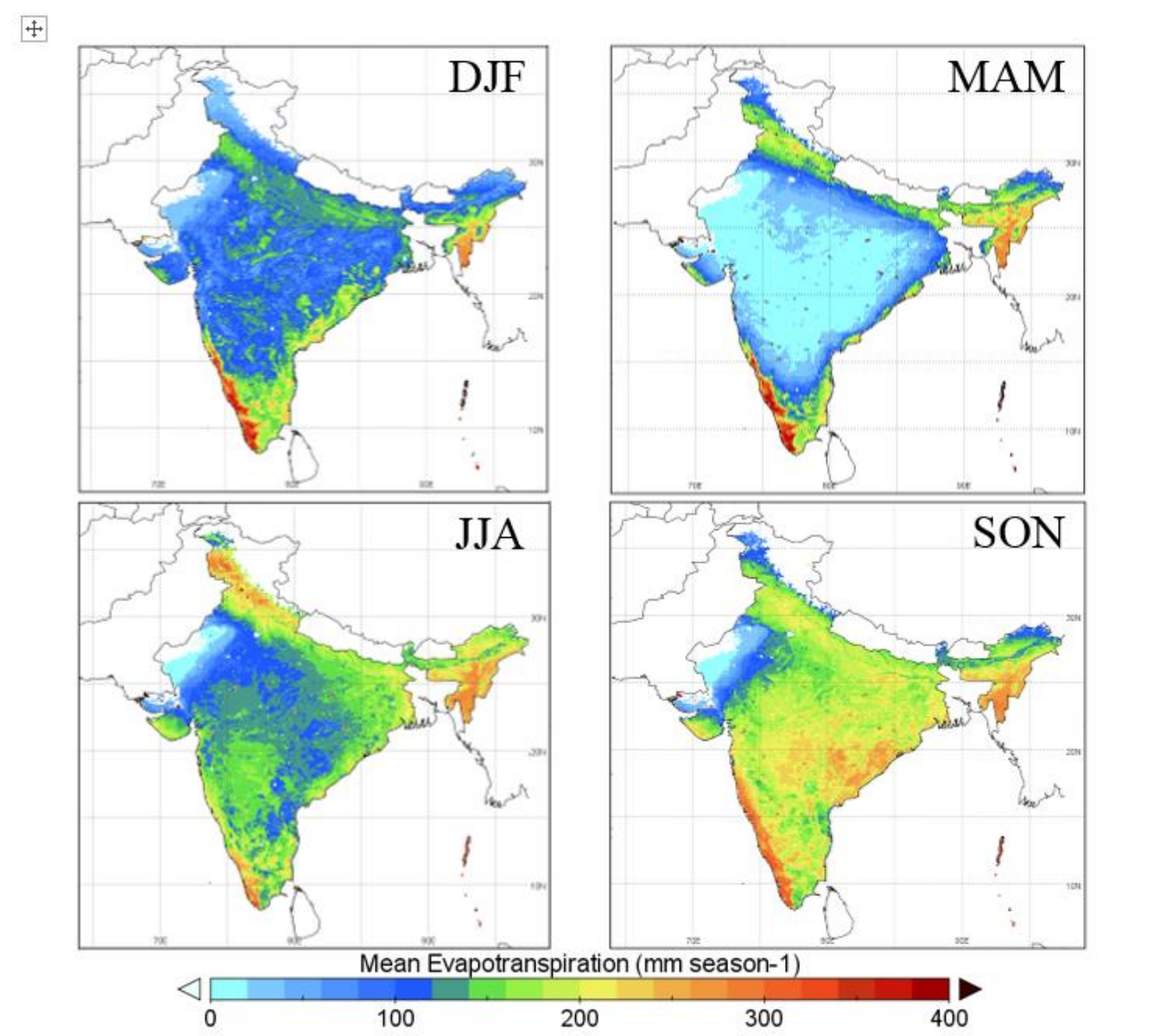
Net radiation (R_n) = Sensible (H) + soil heat (G)+ latent heat flux or ET (LE)

$$Rn = S\downarrow - \alpha S\uparrow + \sigma\varepsilon_a T_a^4\downarrow - \sigma\varepsilon_s T_s^4\uparrow$$

net radiation = net shortwave + net longwave

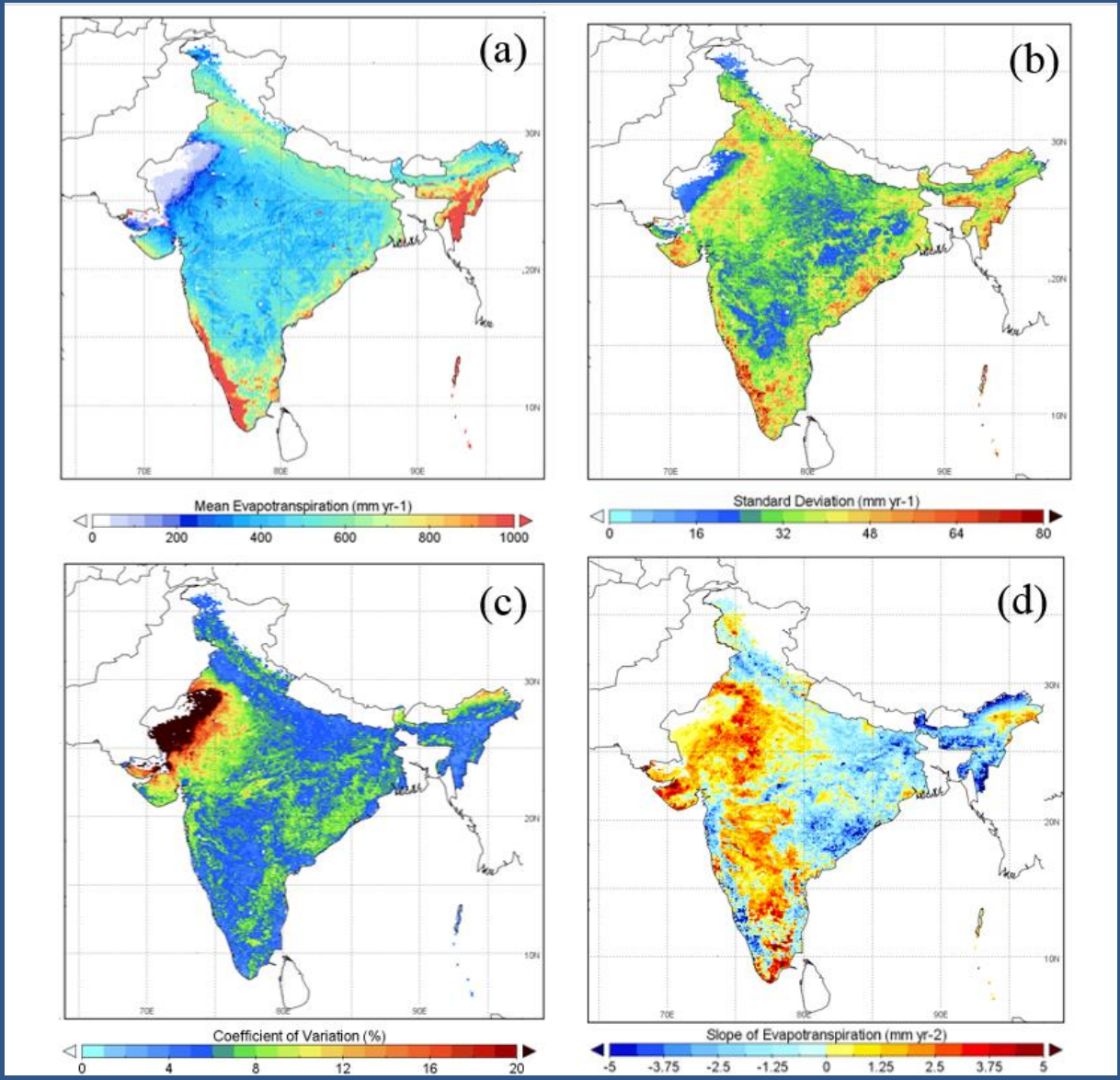


Evapotranspiration



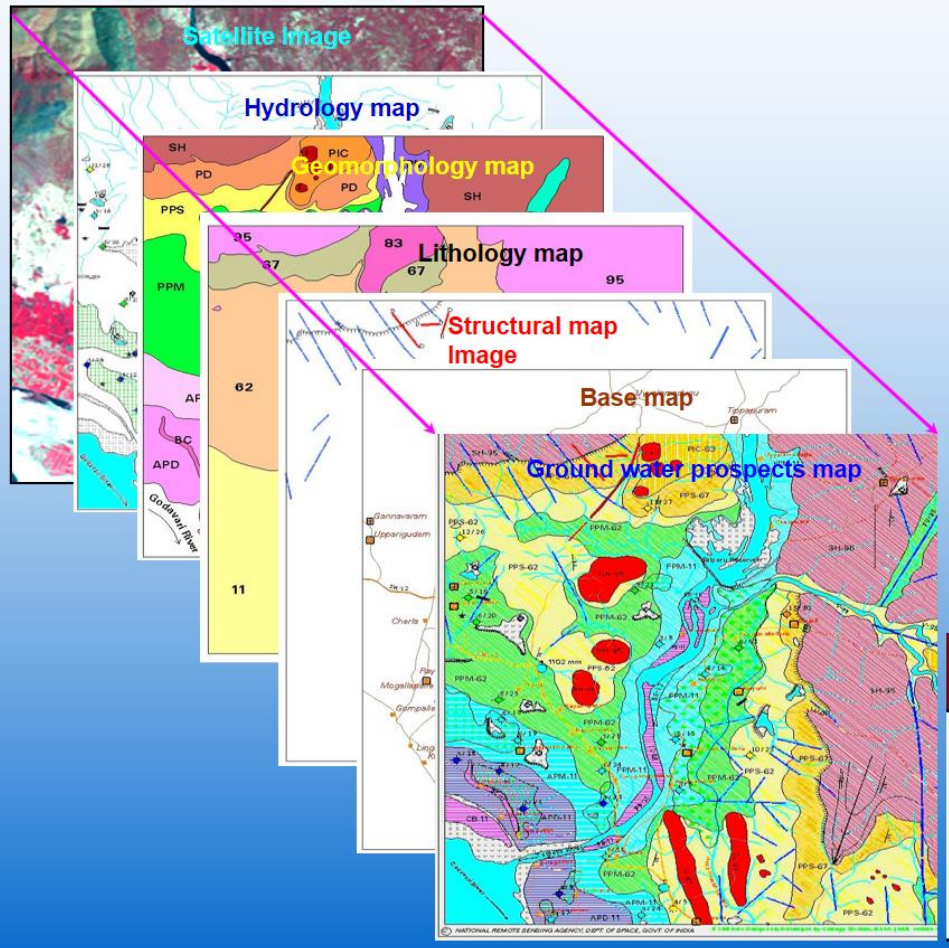
Source: Goroshi et al. 2017

Evapotranspiration



Source: Goroshi et al. 2017

Ground Water
Rajiv Gandhi National Drinking Water Mission



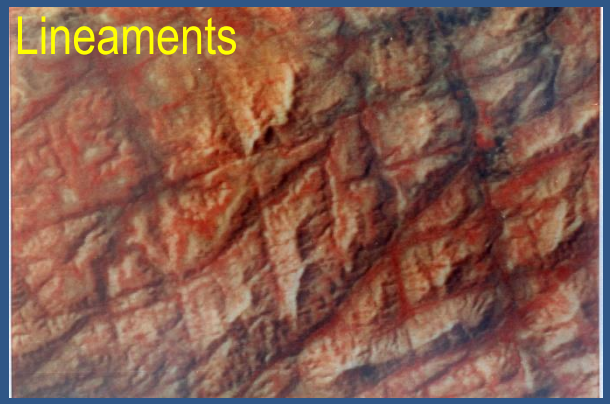
YIELD RANGE	DEPTH RANGE		
	SHALLOW <20 m	MODERATE 20-80 m	DEEP >80 m
EXCELLENT >200 lpm			
GOOD 100-200 lpm			
MODERATE 50-100 lpm			
LIMITED 20-50 lpm			
POOR <20 lpm			
NIL			

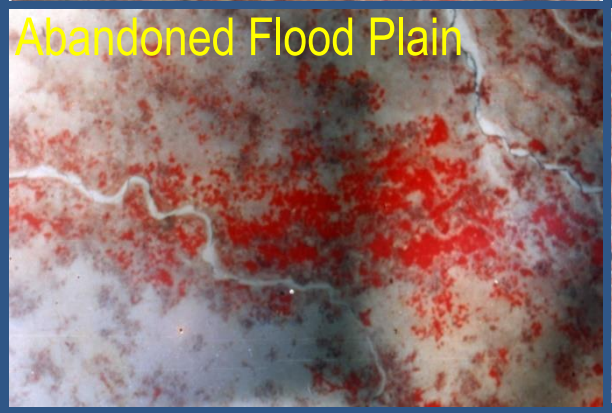
FRACTURE ZONES
GROUND WATER IRRIGATED AREA
FRACTURE/LINEAMENT
GEOLOGICAL/GEOMORPHOLOGICAL BOUNDARIES

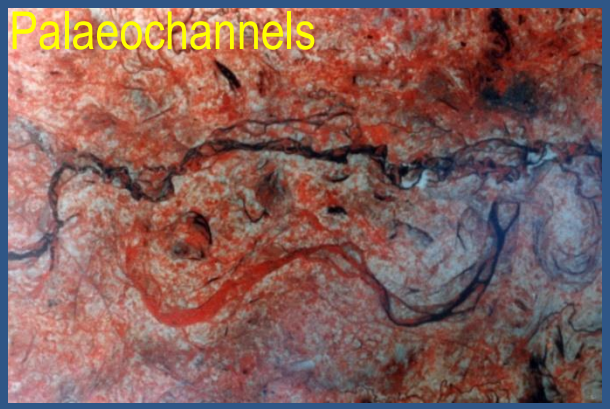
State	No. of Wells Drilled as per Ground Water Prospect Maps	Success Rate (%)
A. P.	29873	90.0
Chattisgarh	19,503	90.0
Gujarat	34	100.0
Karnataka	5213	93.0
M. P.	7730	92.0
Kerala	10,430	90.0

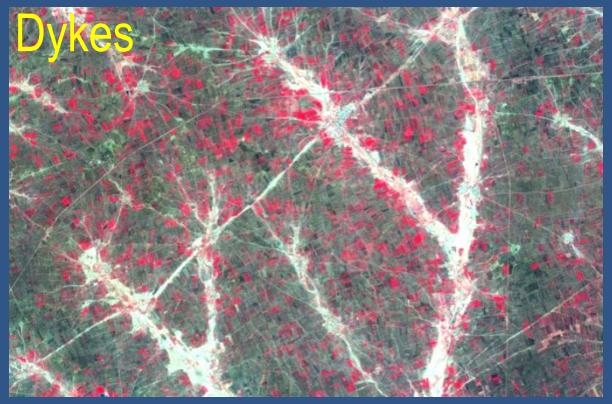
The remote sensing data along with ground survey information provides information on the geology, geomorphology, structural pattern and recharge conditions which ultimately define the groundwater regime.

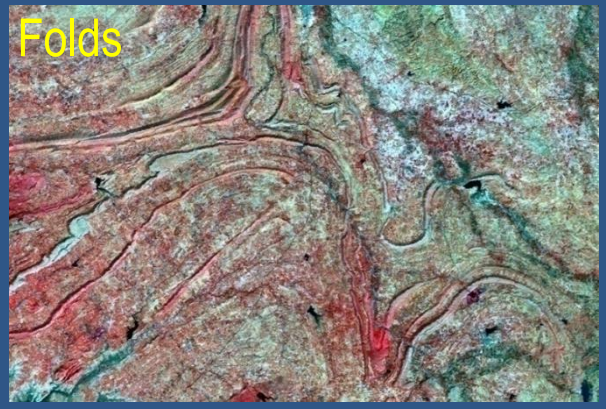
Water Resources







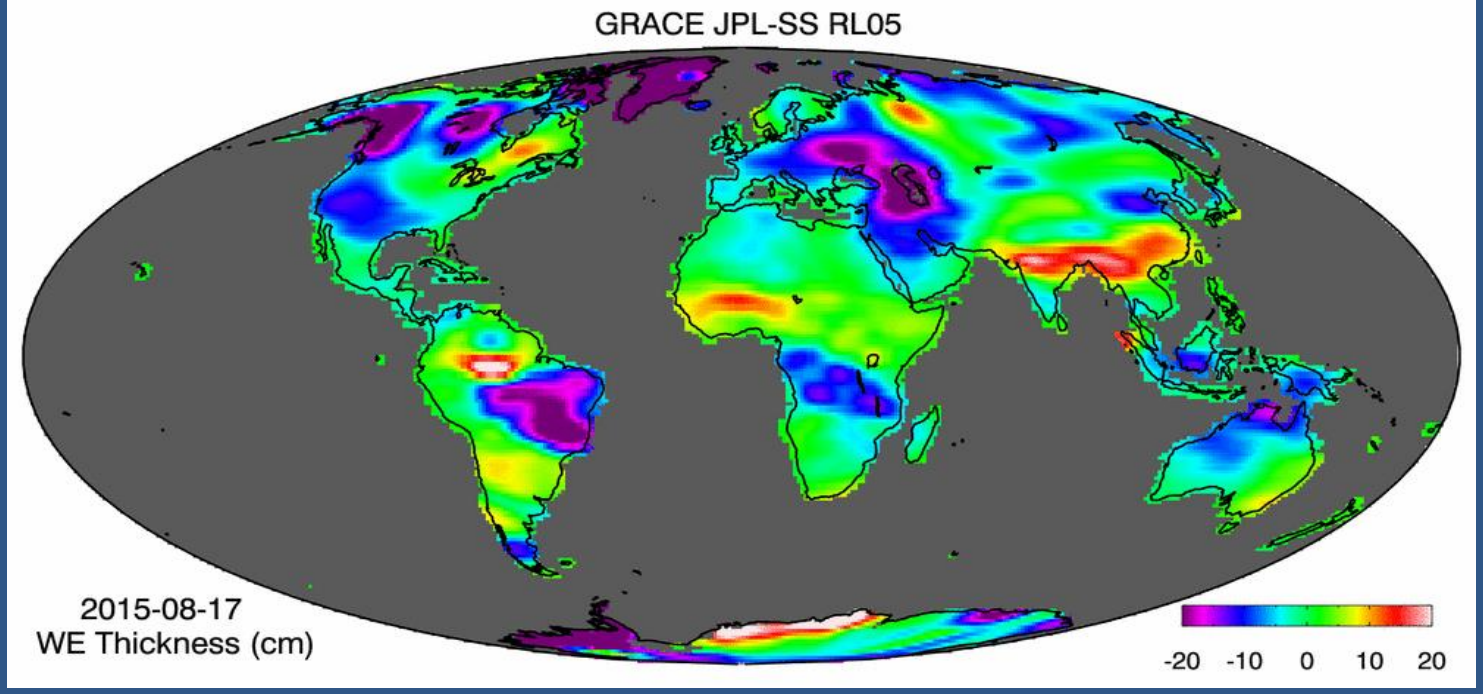


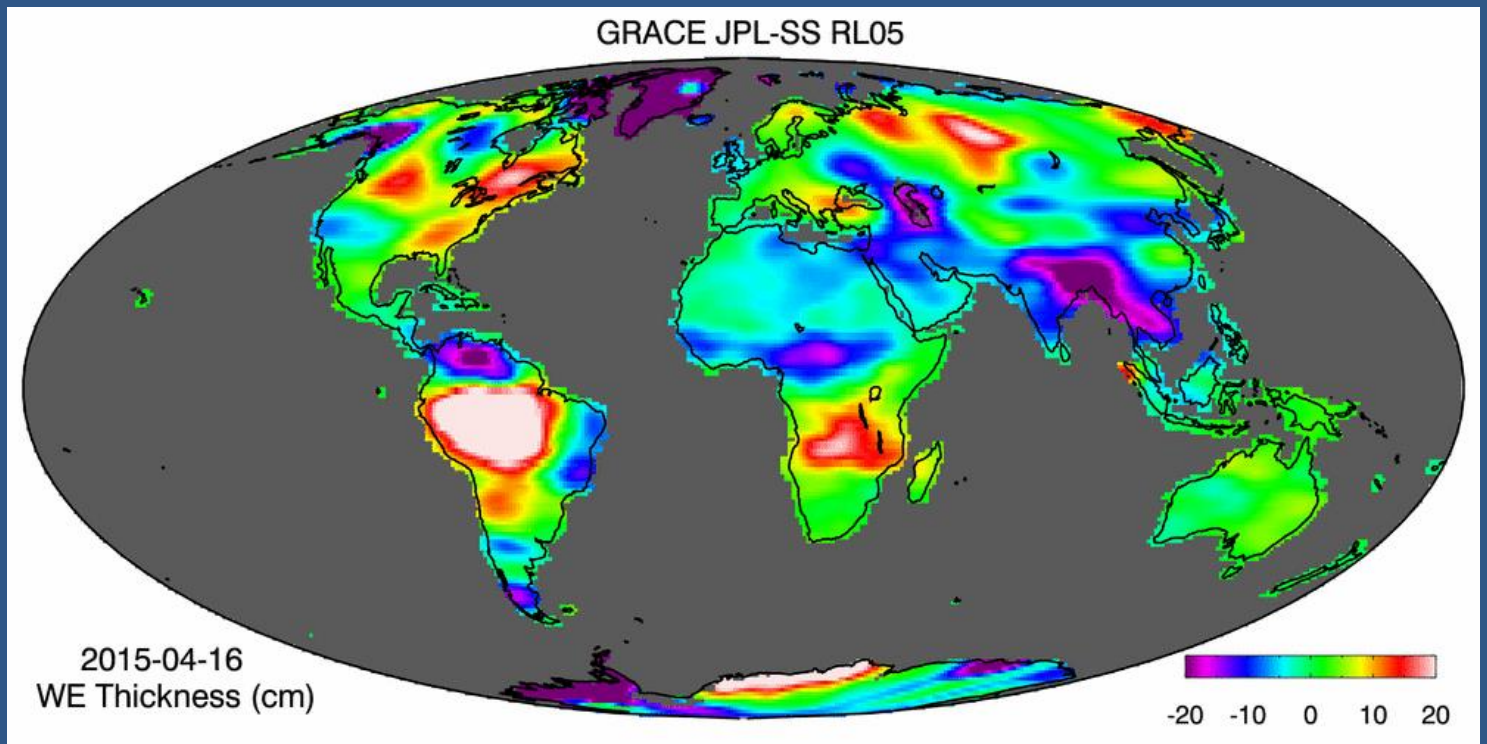


Gravity Recovery And Climate Experiment (GRACE) Mission

The time varying gravity field mapping helps in monitoring of hydrological mass redistribution through their integrated gravitational effect. GRACE Mission sense changes in gravity field by the twin GRACE satellites, and GPS networks.

GRACE observations provides changes in vertically integrated stored water, which includes variations from snow pack, glaciated areas, surface water, soil moisture, and ground water at different depths


GRACE JPL-SS RL05
2015-08-17
WE Thickness (cm)
-20 -10 0 10 20


GRACE JPL-SS RL05
2015-04-16
WE Thickness (cm)
-20 -10 0 10 20

GRACE data application: Groundwater

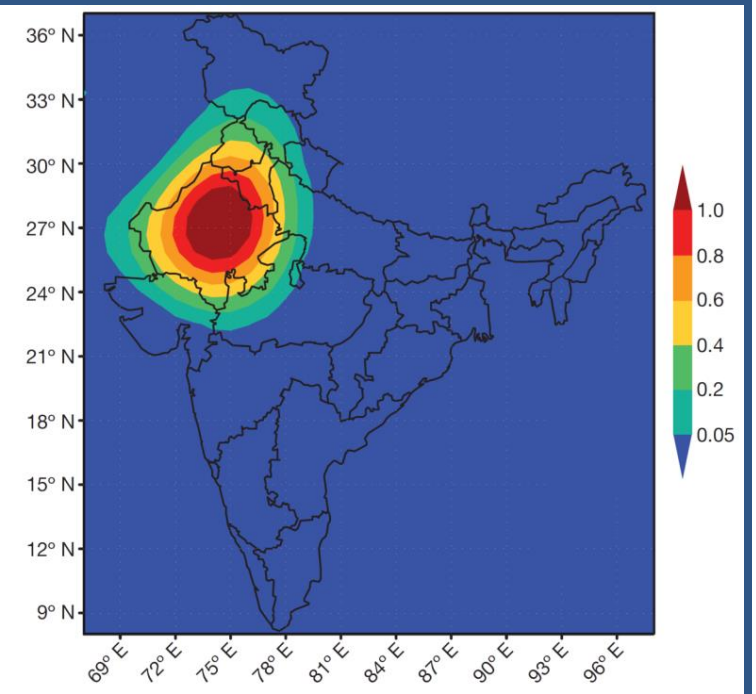


Figure 2 | GRACE averaging function. The unscaled, dimensionless averaging function used to estimate terrestrial water storage changes from GRACE data is mapped.

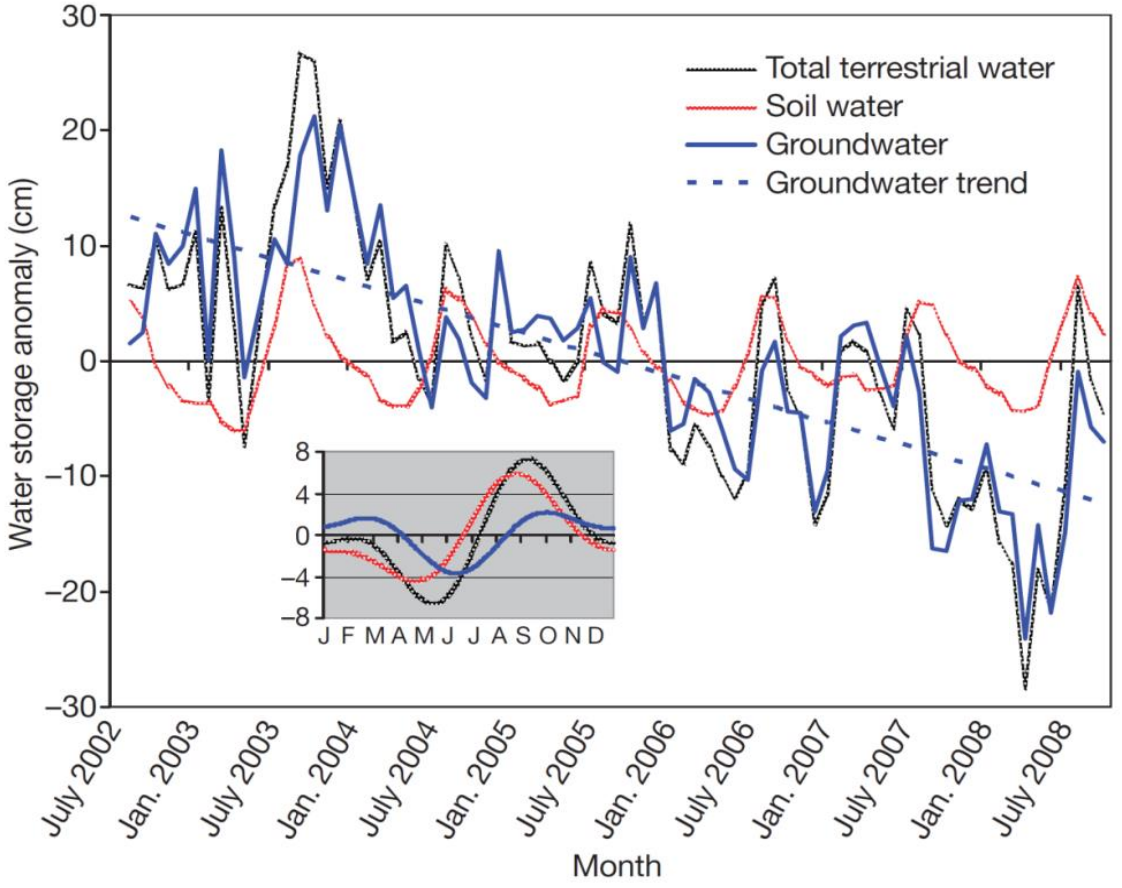


Figure 3 | Monthly time series of water storage anomalies in northwestern

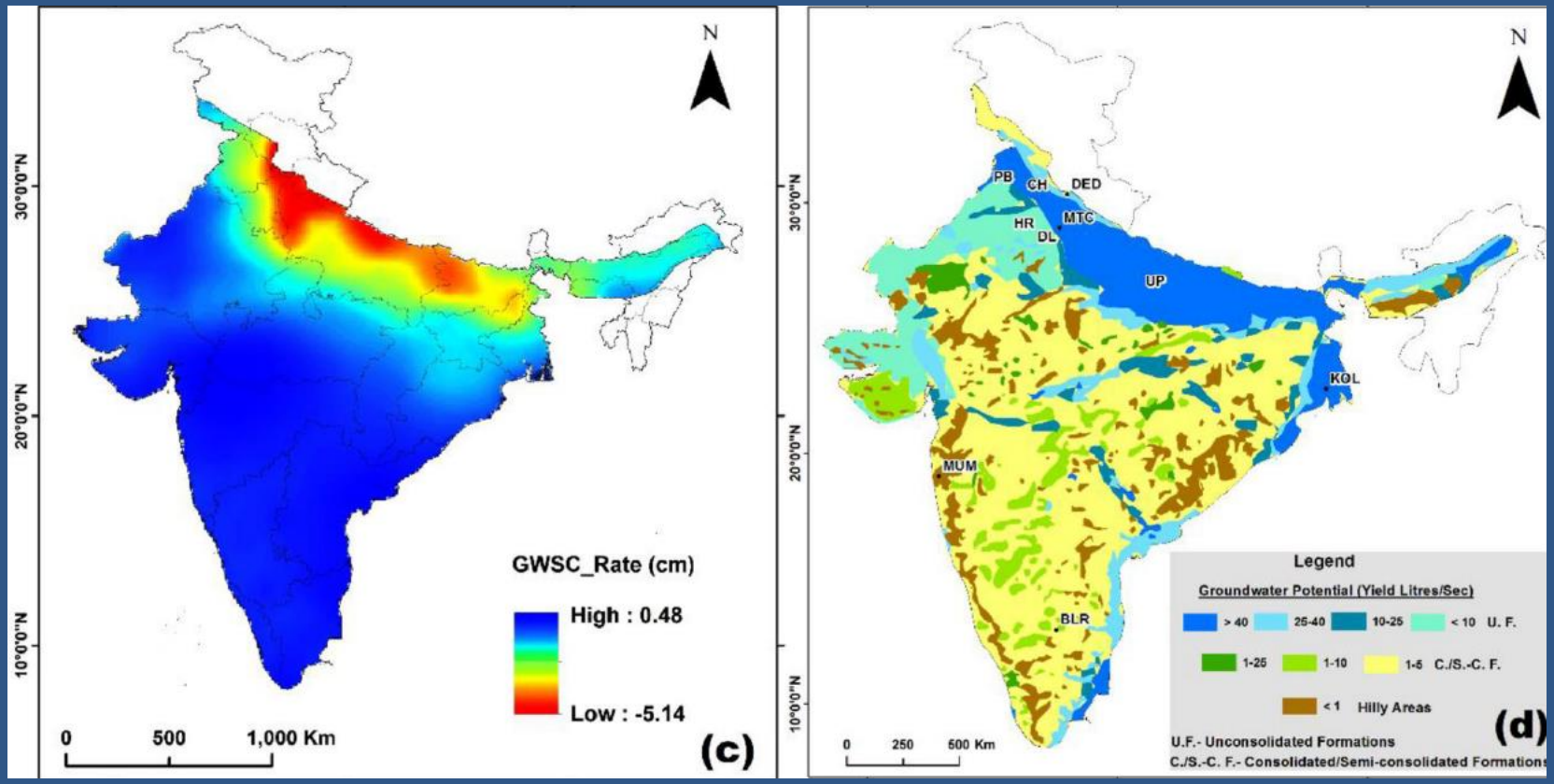
- **Withdrawals for irrigation and other uses are depleting the groundwater reserves of Rajasthan, Punjab and Haryana at a rate of 4.0 ± 1.0 cm yr^{-1} equivalent height of water, or 17.7 ± 4.5 km^3 yr^{-1}.**

- **During the study period, 2002-08, 109 km^3 of groundwater was lost.**

Research paper

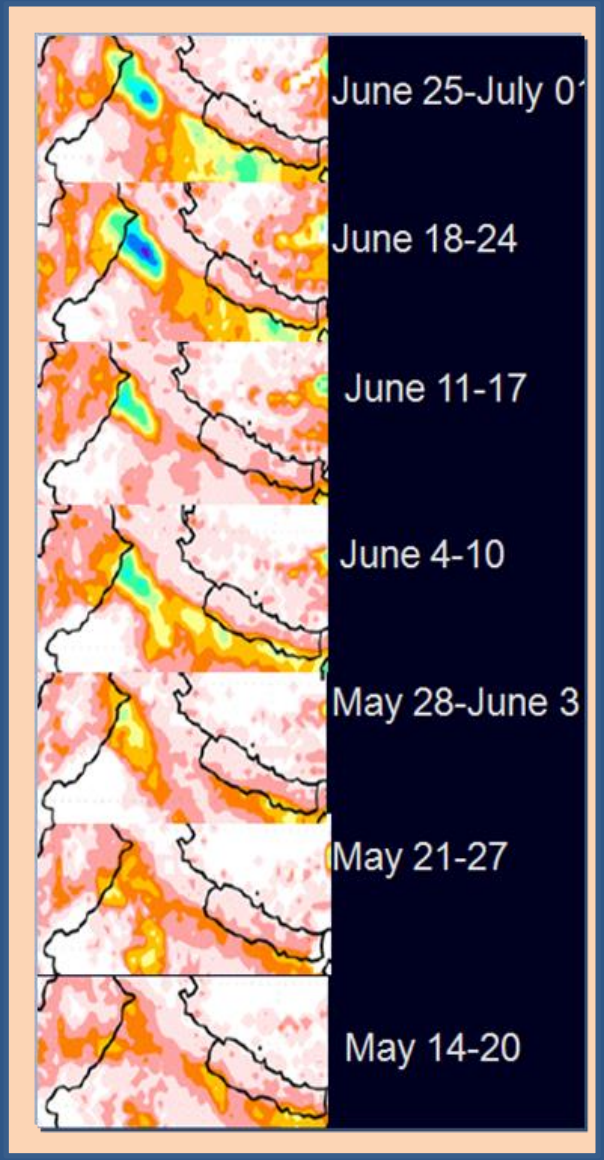
Integrated study of GRACE data derived interannual groundwater storage variability over water stressed Indian regions

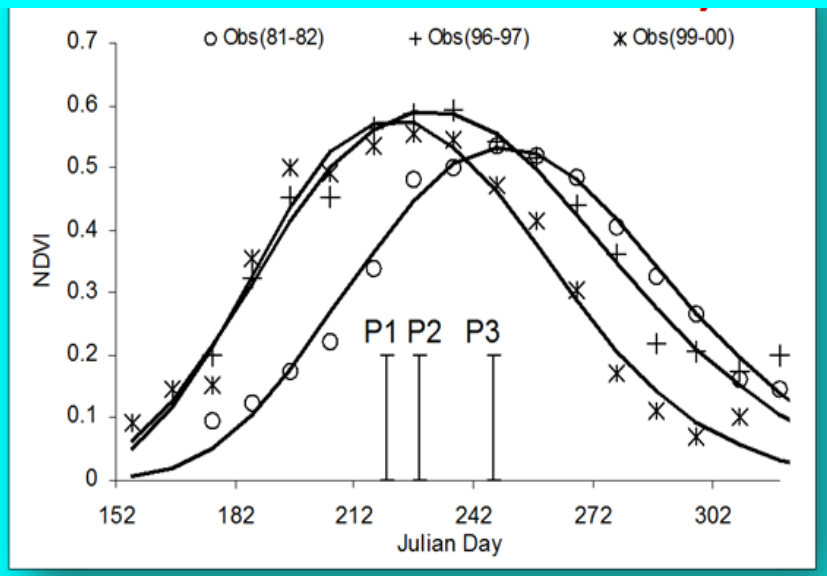
Tandrila Sarkar [a], Suresh Kannaujiya [b,*], Ajay Kumar Taloor [c], Prashant Kumar Champati Ray [b], Prakash Chauhan [d]

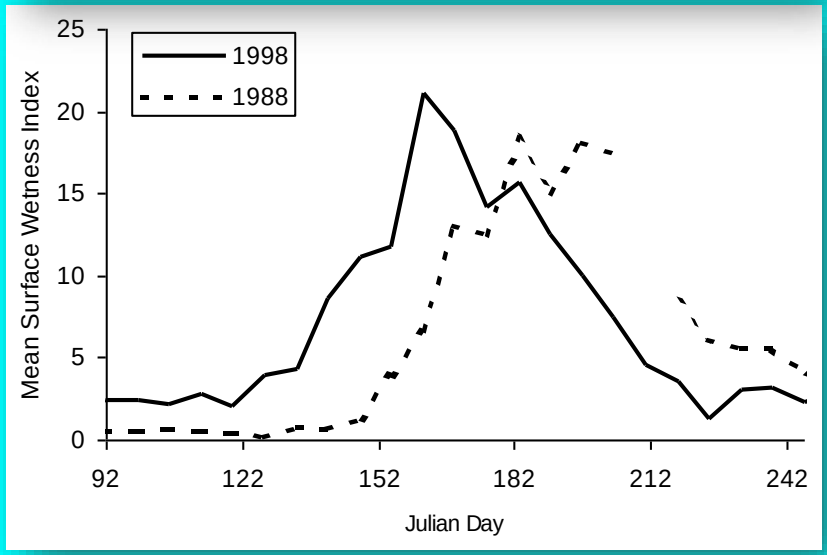


Overall groundwater storage change rate across India (2003–2016) and Hydrogeological map of India (modified after Central Ground Water Board, 2002).

Shift in phenology due to early irrigation in Punjab (1981-2000)

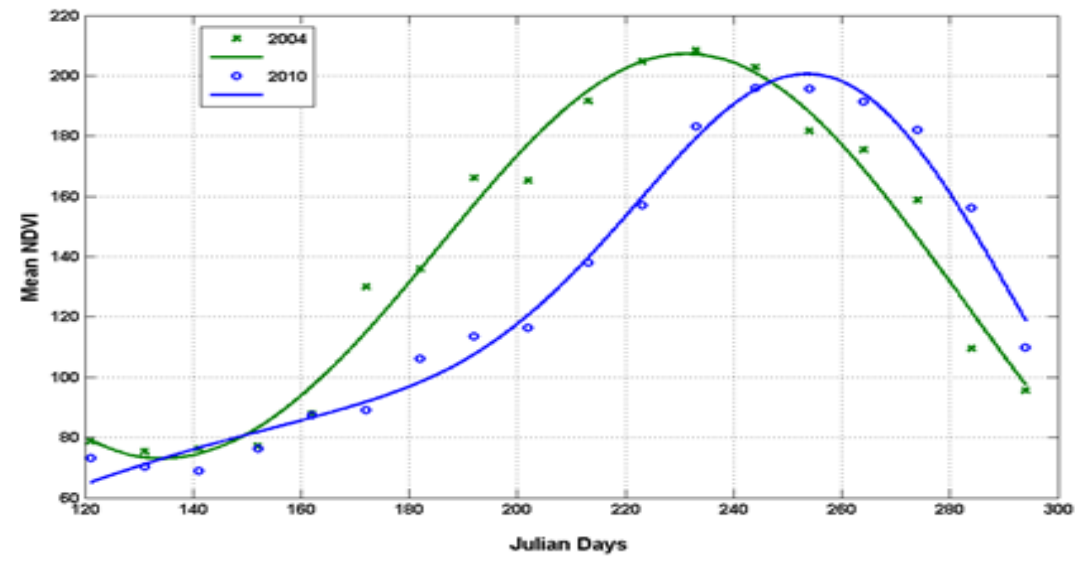


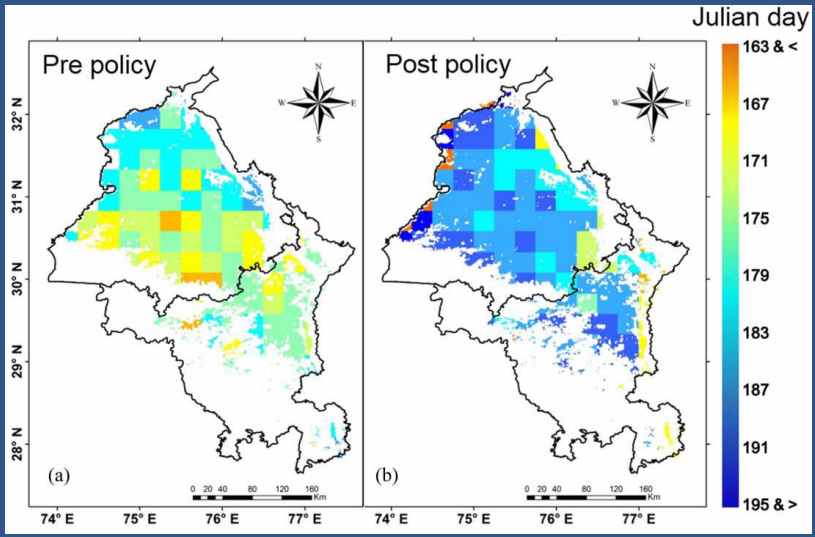


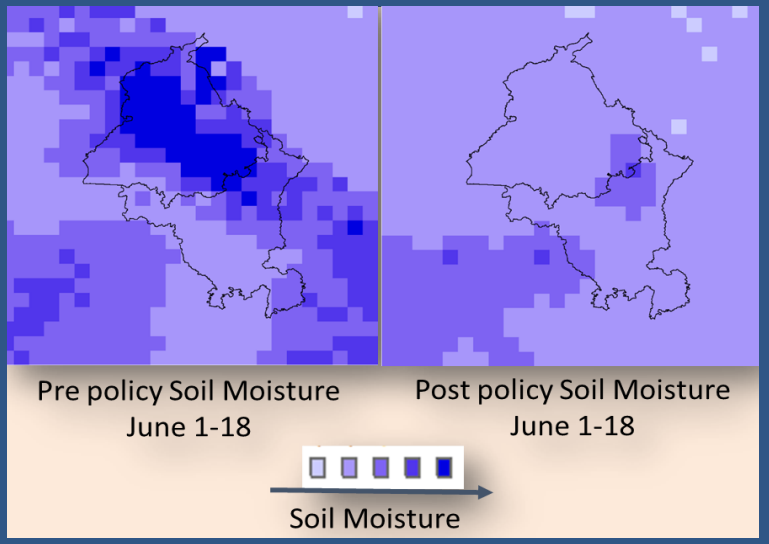


(Singh et al. 2006, Current Science)

Shift in phenology due to Govt. Policy and Water Act. 2009 induced delay in irrigation in Punjab (2001-2010)

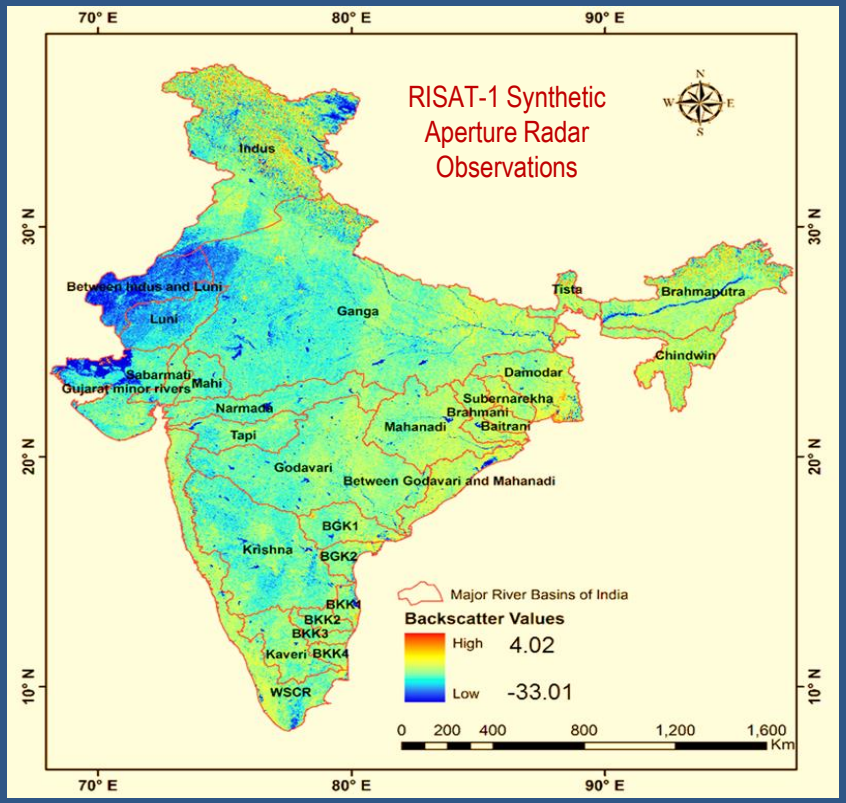


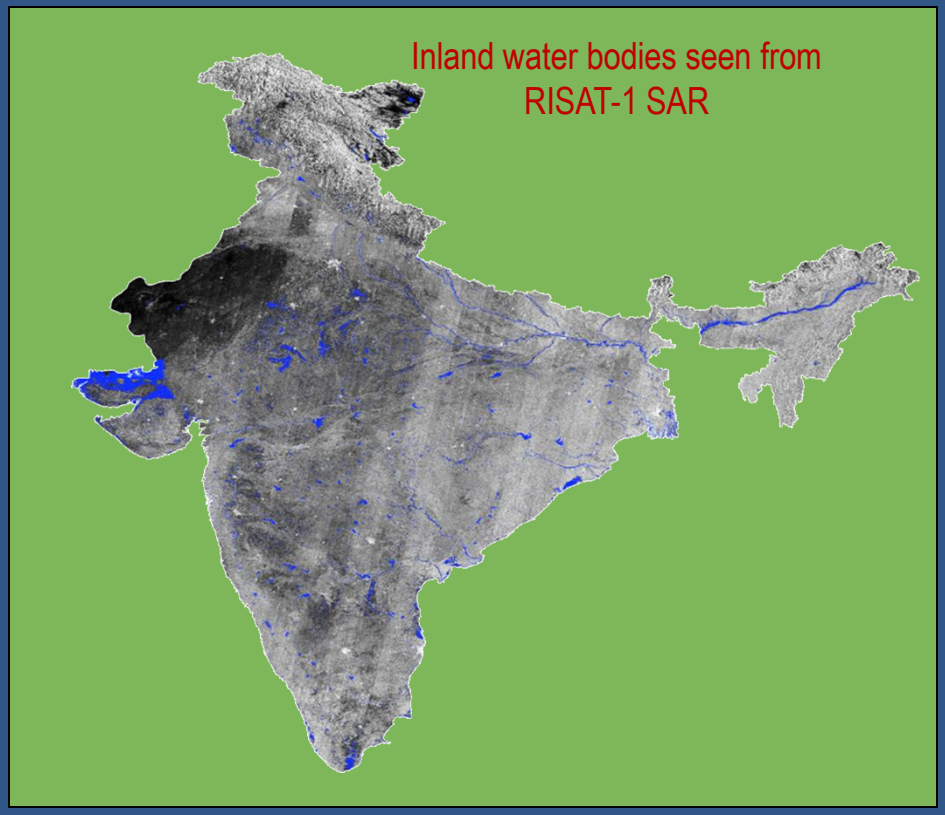




(Singh et al. 2017 Journal of Water and Climate Change)

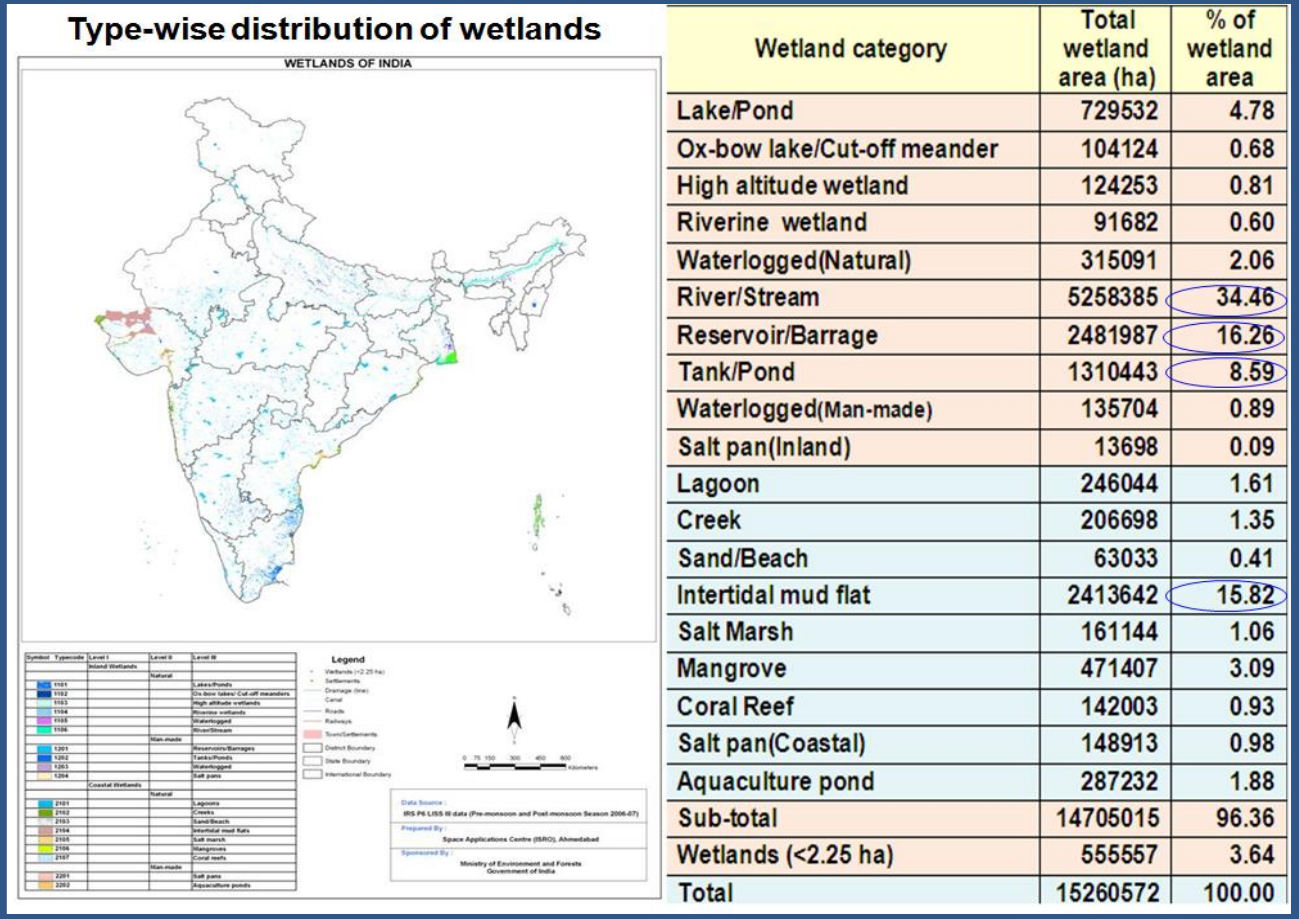
Water Spread Delineation



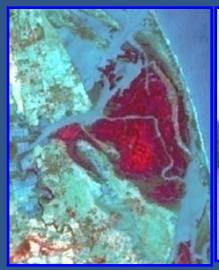


WETLANDS

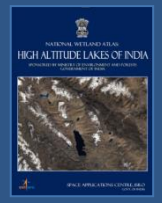
- Wetland (of > 2.25 ha) maps of entire country has been generated at 1:50,000 scale using IRS Satellite data.



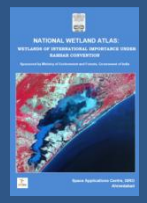
Wetland category	Total wetland area (ha)	% of wetland area
Lake/Pond	729532	4.78
Ox-bow lake/Cut-off meander	104124	0.68
High altitude wetland	124253	0.81
Riverine wetland	91682	0.60
Waterlogged(Natural)	315091	2.06
River/Stream	5258385	34.46
Reservoir/Barrage	2481987	16.26
Tank/Pond	1310443	8.59
Waterlogged(Man-made)	135704	0.89
Salt pan(Inland)	13698	0.09
Lagoon	246044	1.61
Creek	206698	1.35
Sand/Beach	63033	0.41
Intertidal mud flat	2413642	15.82
Salt Marsh	161144	1.06
Mangrove	471407	3.09
Coral Reef	142003	0.93
Salt pan(Coastal)	148913	0.98
Aquaculture pond	287232	1.88
Sub-total	14705015	96.36
Wetlands (<2.25 ha)	555557	3.64
Total	15260572	100.00



National Wetland Atlas

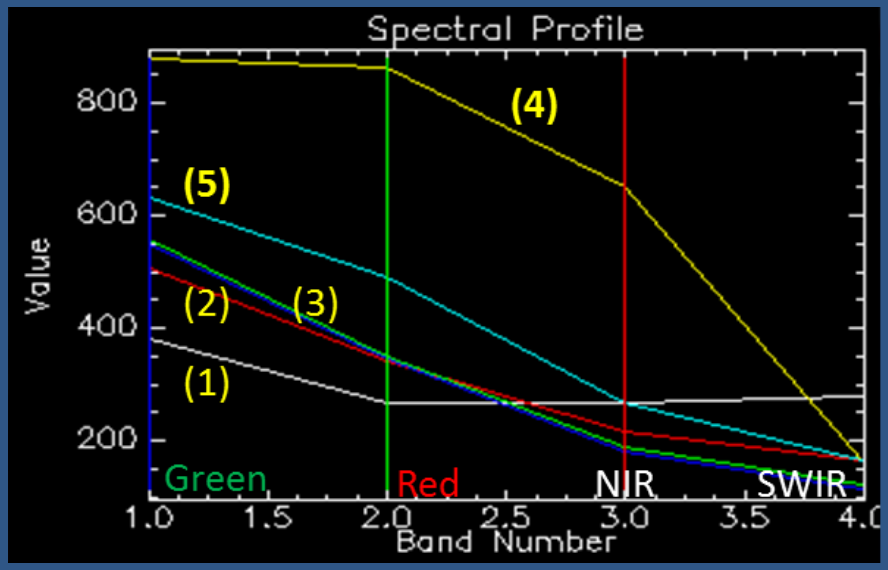


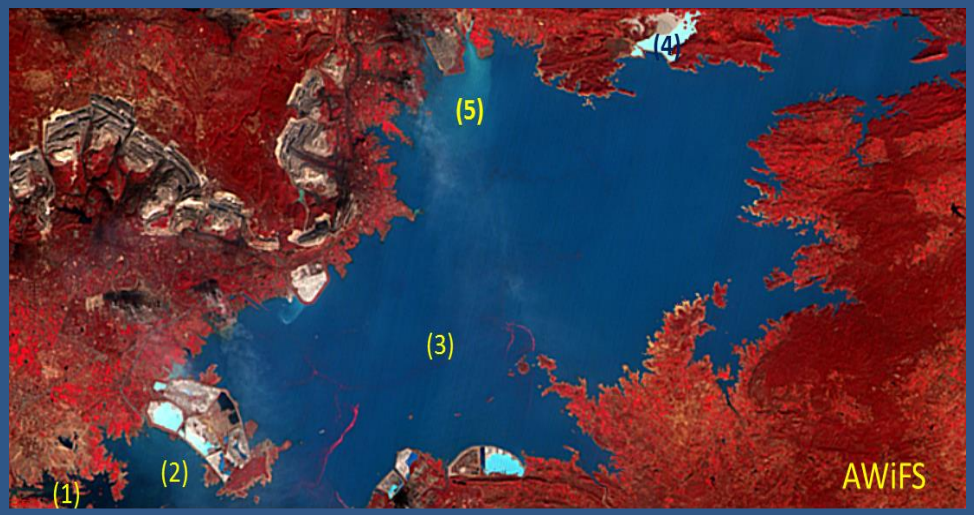
Atlas on HALs



Atlas on Ramsar Sites of India

Water Quality Assessment

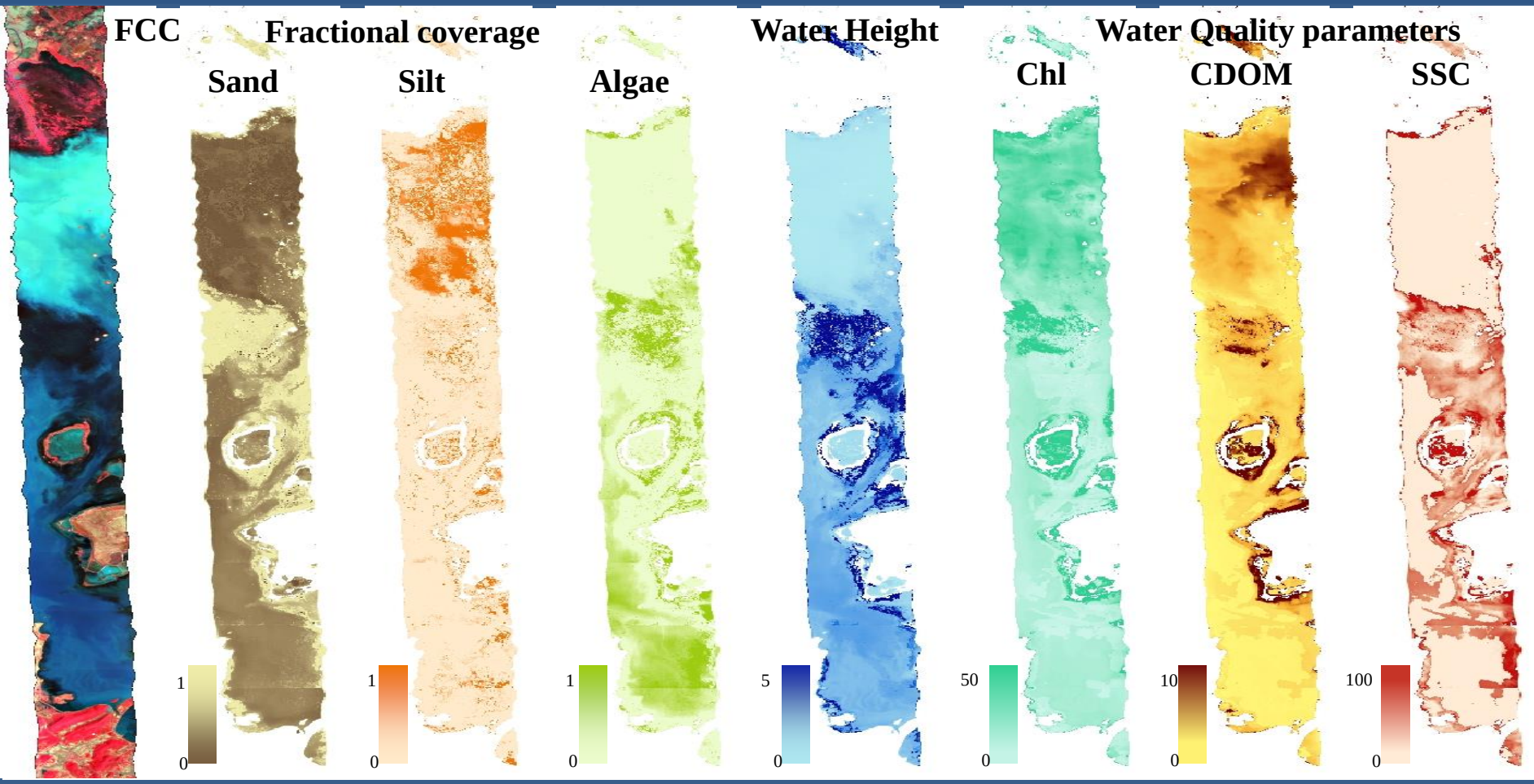




(Govind Sagar Dam: AWiFS 14 Jan 2013)

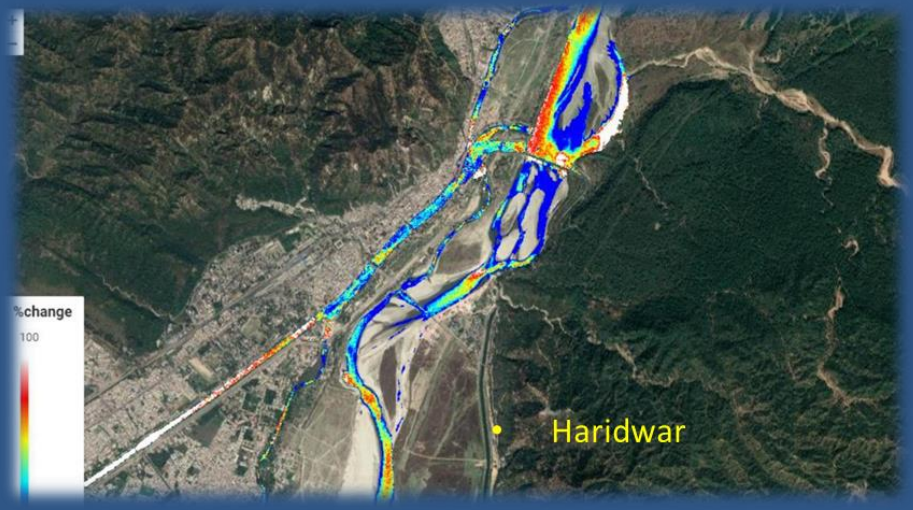
(Indira Sagar Dam: Landsat 19 Jan 2018)

Inversion for Water quality parameter retrieval over Chilka lake using AVIRIS

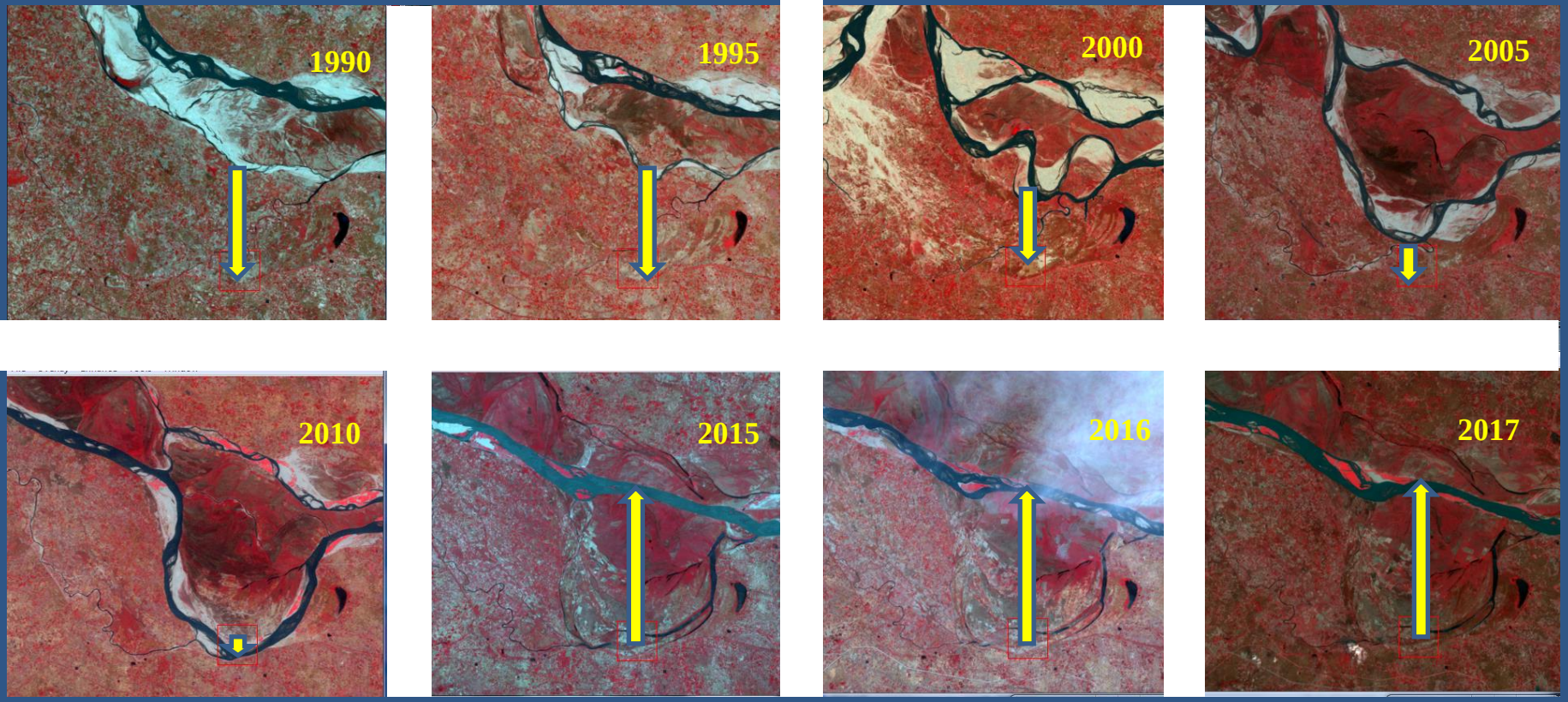


Water Turbidity Changes in Ganga River during Pre and Post Lockdown

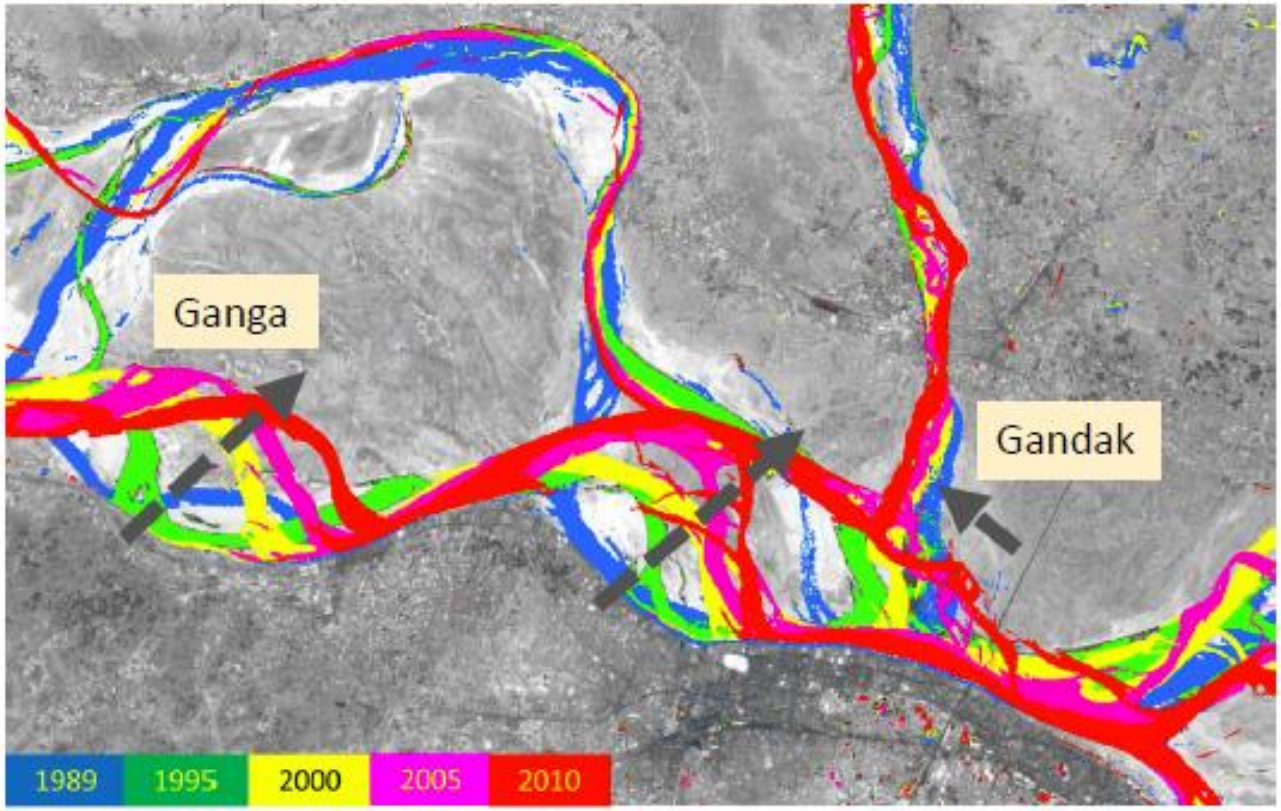
Water Turbidity Changes in Ganga River during Pre and Post Lockdown



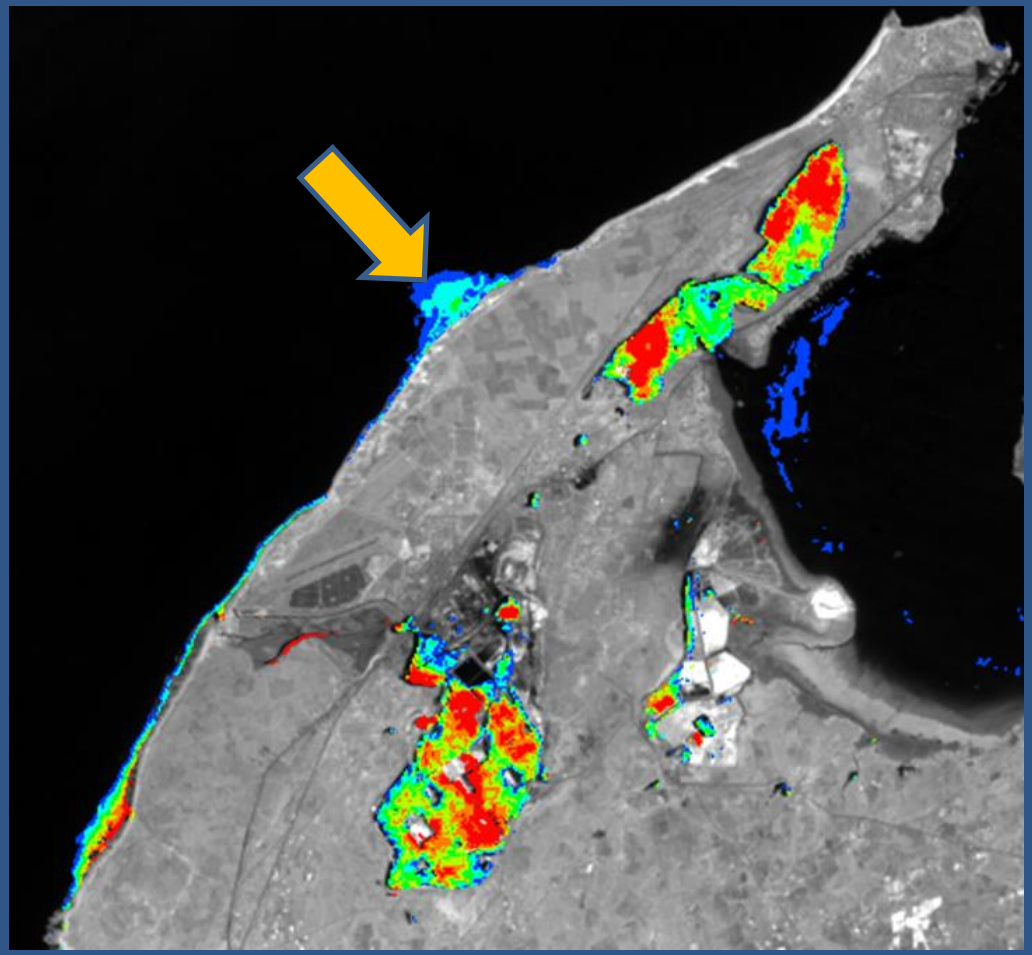
Long term changes in Gandak river (Data: April, Landsat series)



Shifting Course of Ganga and Gandak Rivers (1989-2010) near Patna, India

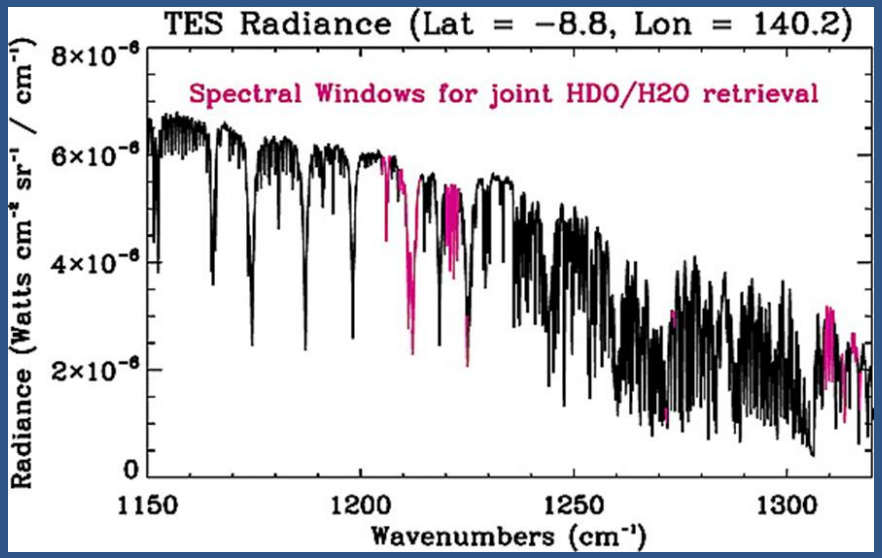


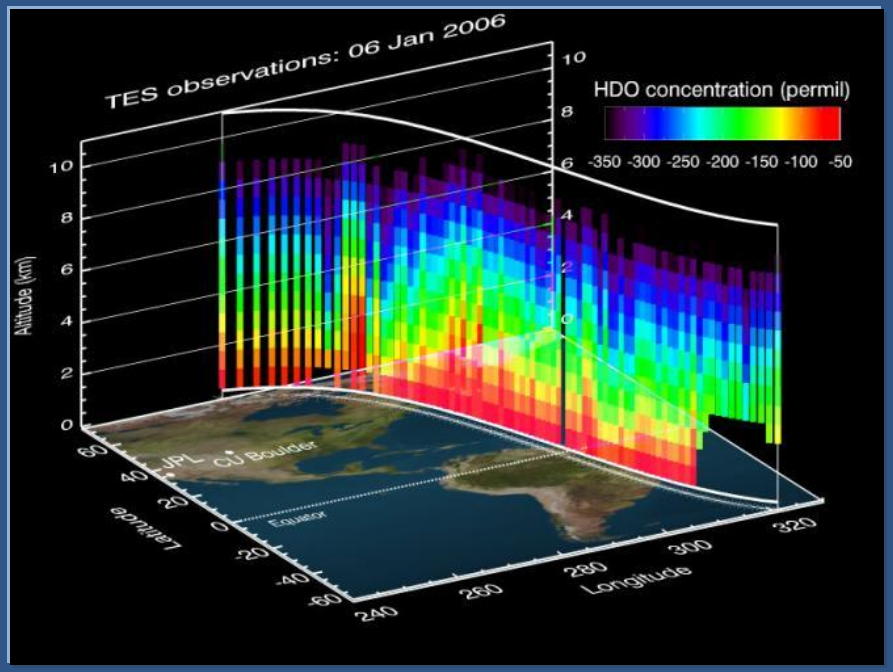
Detection of SGD near Okha Region, Gujarat



New study shows the Amazon makes its own rainy season

SATELLITE BASED ISOTOPE HYDROLOGY





(Jonathon and Team , PNAS , 2017)

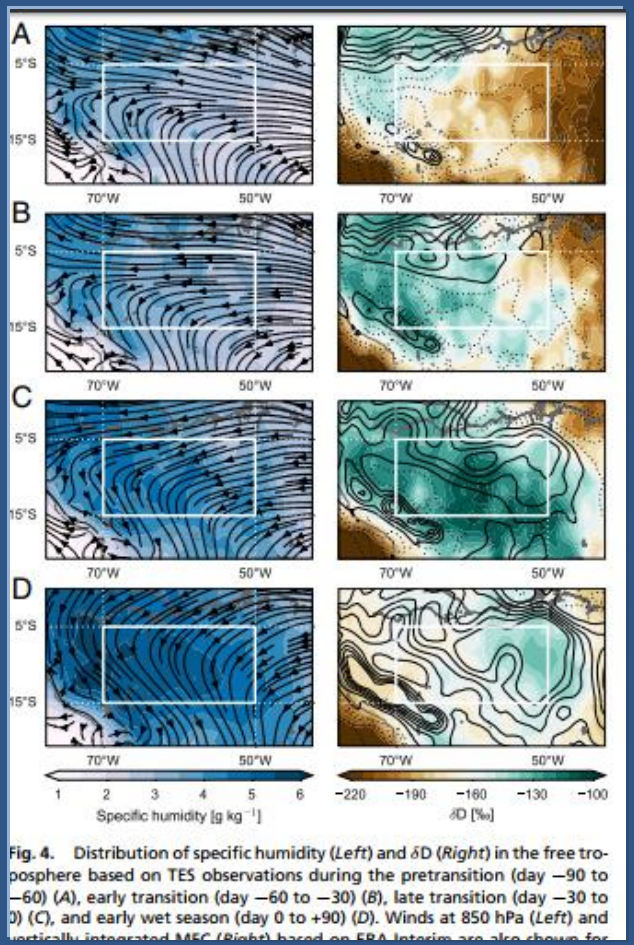
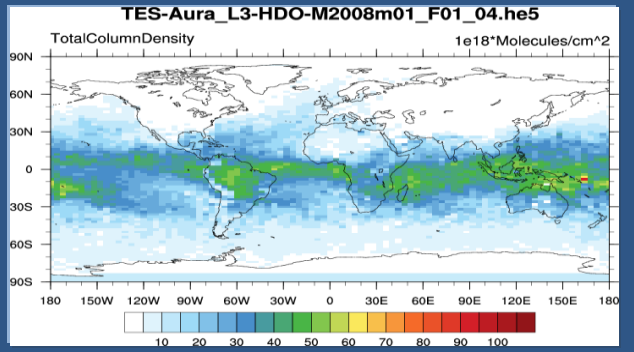


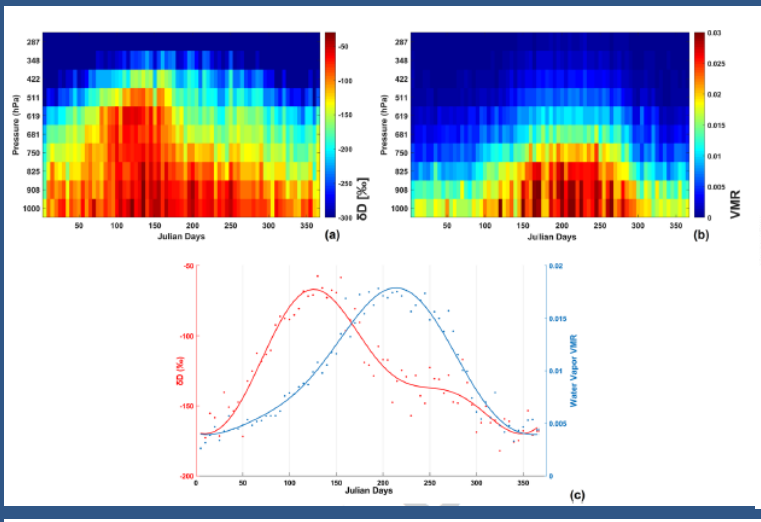
Fig. 4. Distribution of specific humidity (*Left*) and δD (*Right*) in the free troposphere based on TES observations during the pretransition (day −90 to −60) (*A*), early transition (day −60 to −30) (*B*), late transition (day −30 to 0) (*C*), and early wet season (day 0 to +90) (*D*). Winds at 850 hPa (*Left*) and

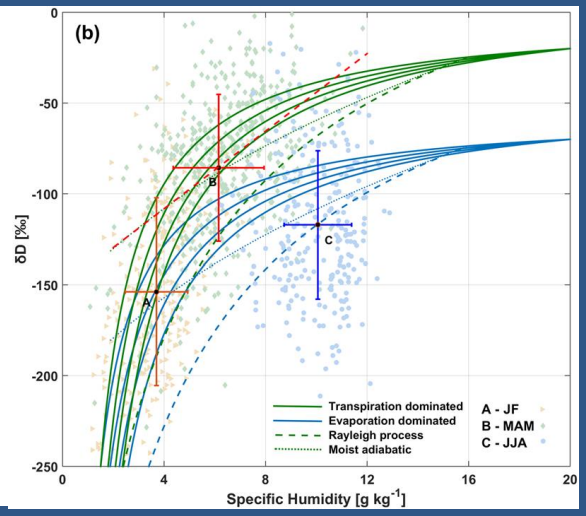


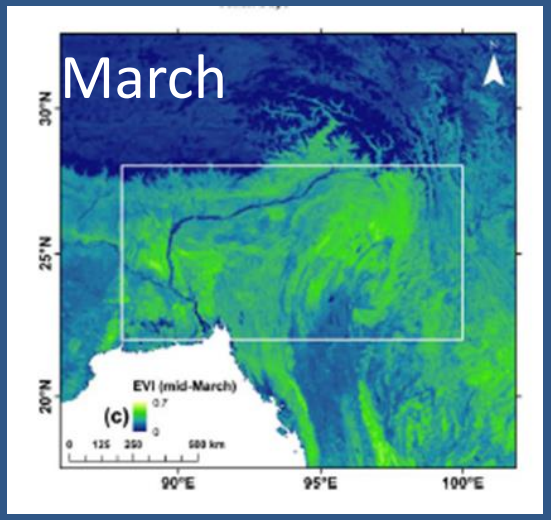
Onset of summer monsoon in Northeast India is preceded by enhanced transpiration

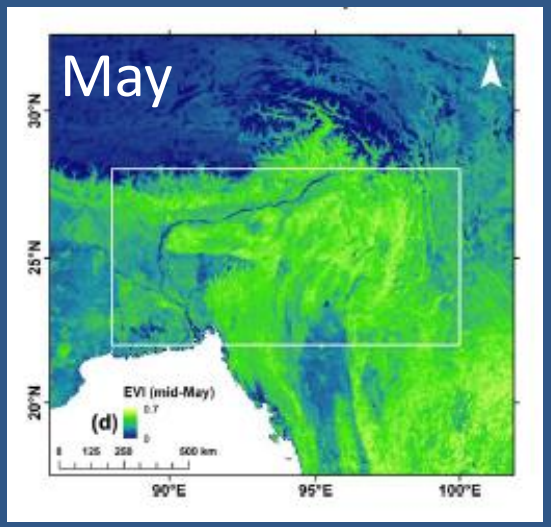
Rohit Pradhan*, Nimisha Singh & Raghavendra P. Singh

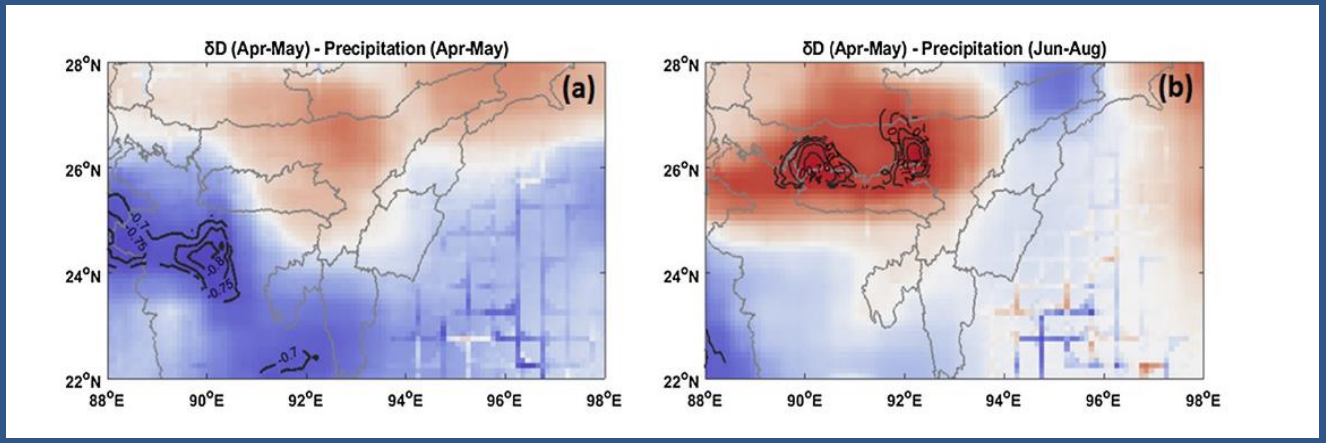
SCIENTIFIC REPORTS
nature research

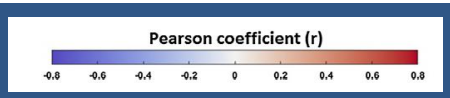








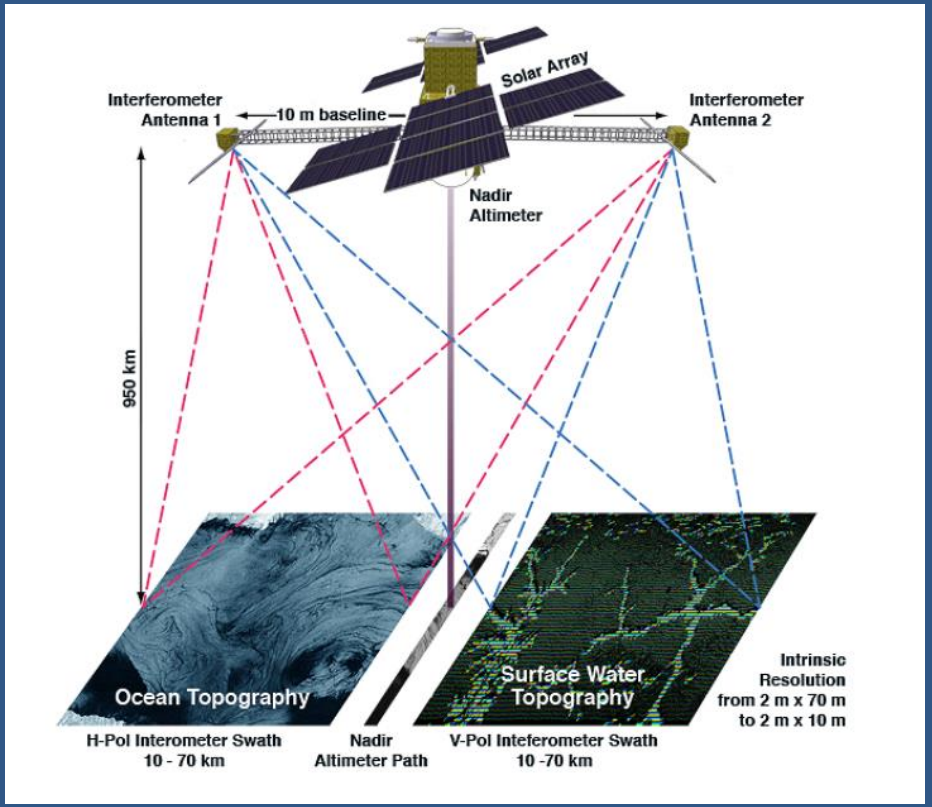




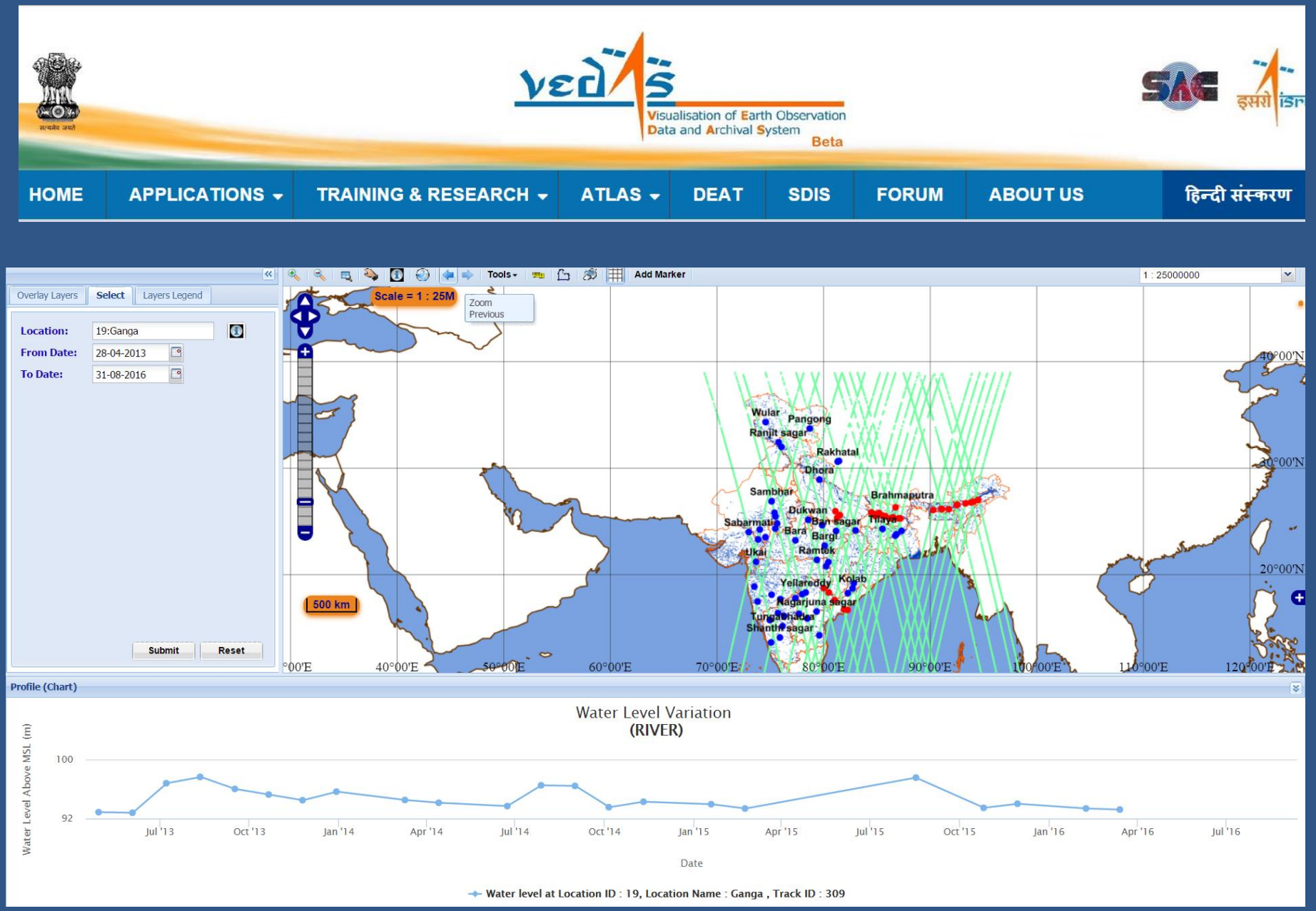
Pradhan et al. J. Earth Syst. Sci (2019)

Future Direction

- Development of dedicated constellation of Hydrological satellites.
- Improved methodologies for retrieval of various hydrological parameters from satellite data.
- Assimilate the information in physically based distributed hydrological models
- Near Real time Monitoring and Forecast of extreme events and Web based Data dissemination.



The SWOT satellite


VEDAS
Visualisation of Earth Observation Data and Archival System
Beta
HOME
APPLICATIONS
TRAINING & RESEARCH
ATLAS
DEAT
SDIS
FORUM
ABOUT US
हिन्दी संस्करण
Overlay Layers
Select
Layers Legend
Location:
19:Ganga
From Date:
28-04-2013
To Date:
31-08-2016
Submit
Reset
Tools
Add Marker
1 : 25000000
Scale = 1 : 25M
Zoom Previous
Wular
Pangong
Ranjit sagar
Rakhatal
Dhora
Sambhar
Brahmaputra
Dukwan
Ban sagar
Tilaya
Sabarmati
Bara
Bargi
Ukai
Ramtek
Yellareddy
Kolab
Nagarjuna sagar
Tungabhadra
Shanthi sagar
500 km
40°00'N
30°00'N
20°00'N
40°00'E
50°00'E
60°00'E
70°00'E
80°00'E
90°00'E
100°00'E
110°00'E
120°00'E
Profile (Chart)
Water Level Variation
(RIVER)
Water Level Above MSL (m)
100
92
Jul '13
Oct '13
Jan '14
Apr '14
Jul '14
Oct '14
Jan '15
Apr '15
Jul '15
Oct '15
Jan '16
Apr '16
Jul '16
Date
Water level at Location ID : 19, Location Name : Ganga , Track ID : 309

Thank You