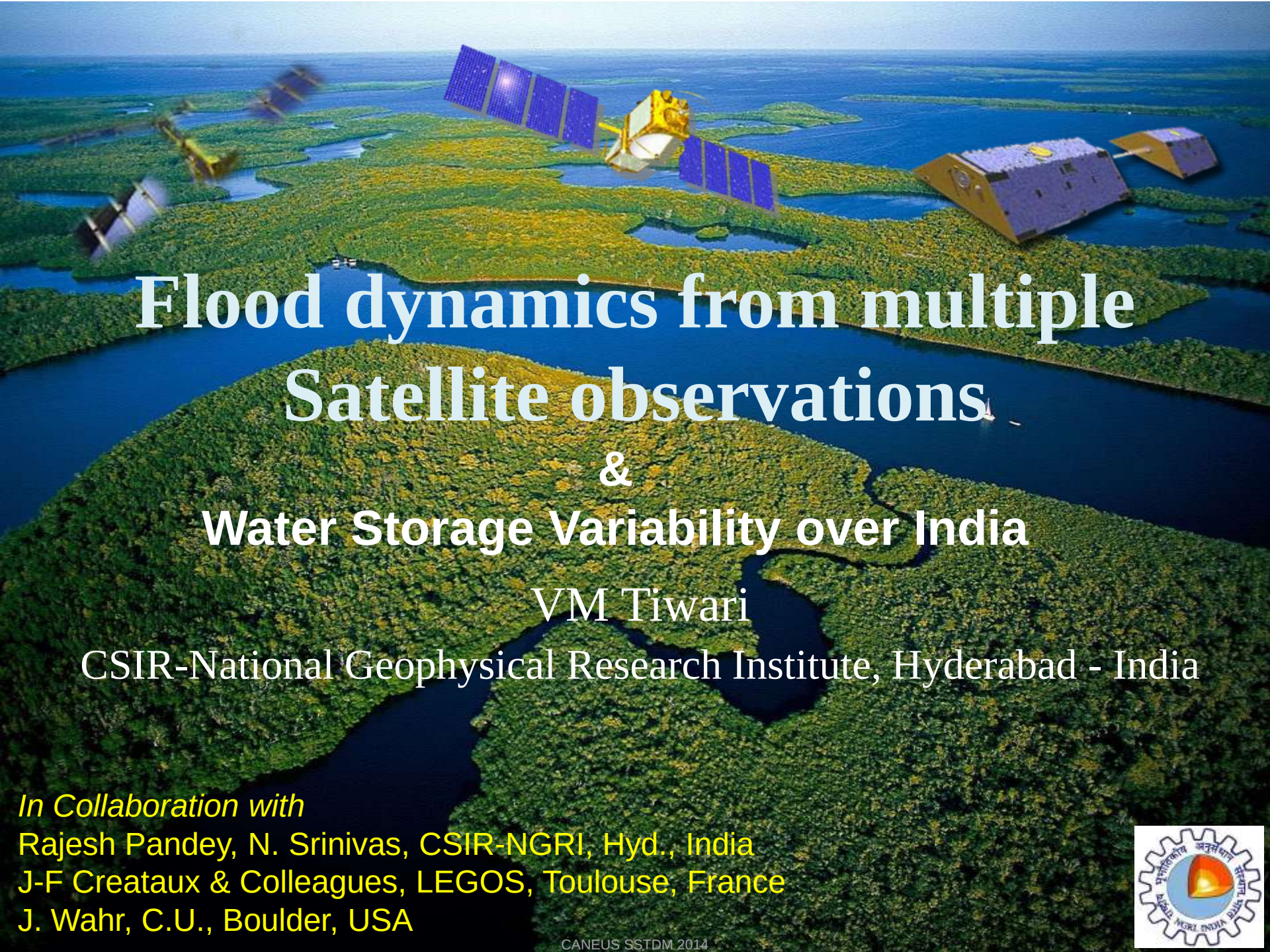


Flood dynamics from multiple Satellite observations

&

Water Storage Variability over India

VM Tiwari

CSIR-National Geophysical Research Institute, Hyderabad - India

In Collaboration with

Rajesh Pandey, N. Srinivas, CSIR-NGRI, Hyd., India

J-F Creataux & Colleagues, LEGOS, Toulouse, France

J. Wahr, C.U., Boulder, USA

Outline

- Introduction
- Data and Methods
- Case Study
  - Kosi flood in 2008
  - Indus flood in 2010
- Inferences
- Water Storage variability over India

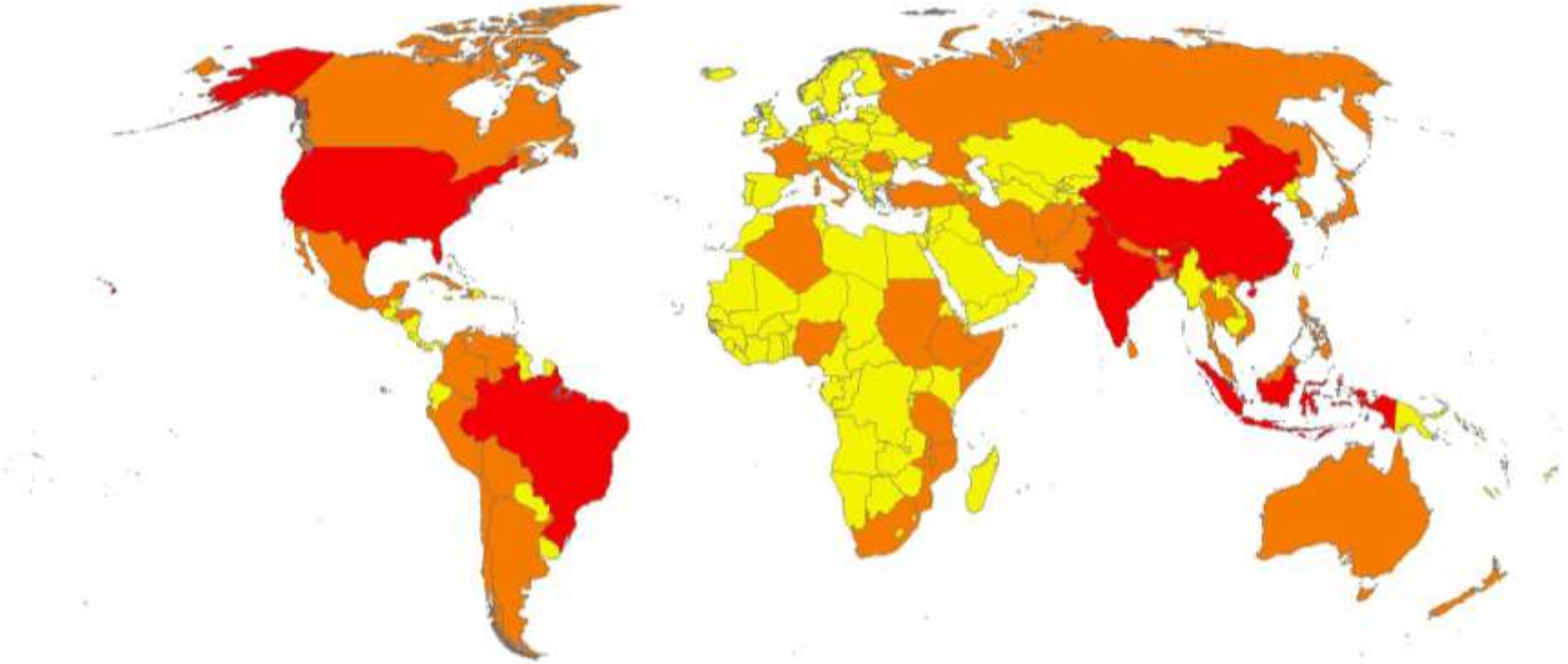
Outline

- **Introduction**
- Data and Methods
- Case Study
  - Kosi flood in 2008
  - Indus flood in 2010
- Inferences

Key Issues

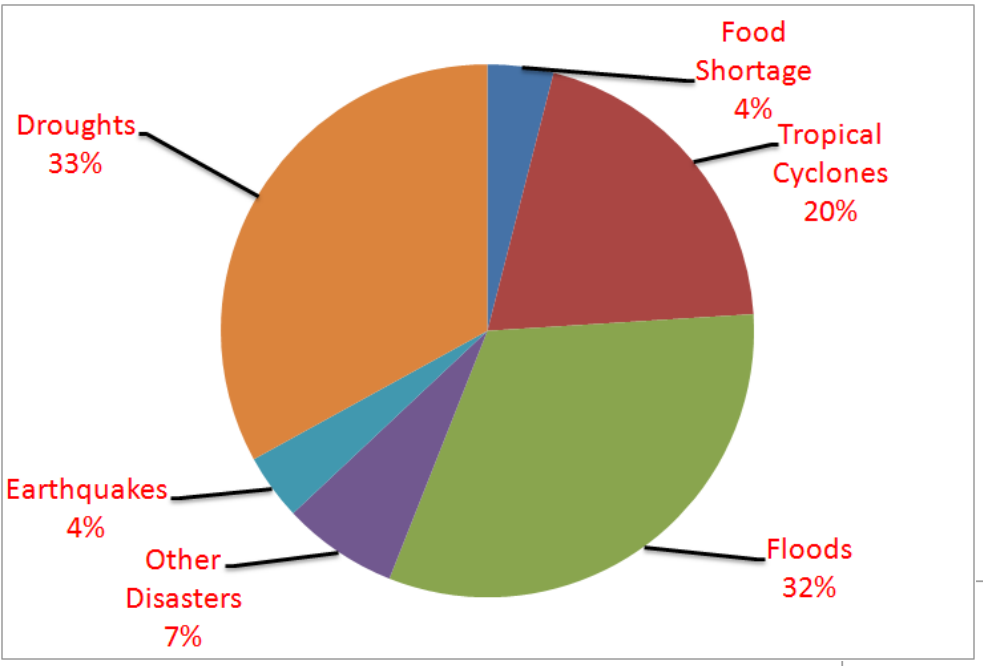
Reduction of damages due to flood: Monitoring, Research, Forecasting and warning

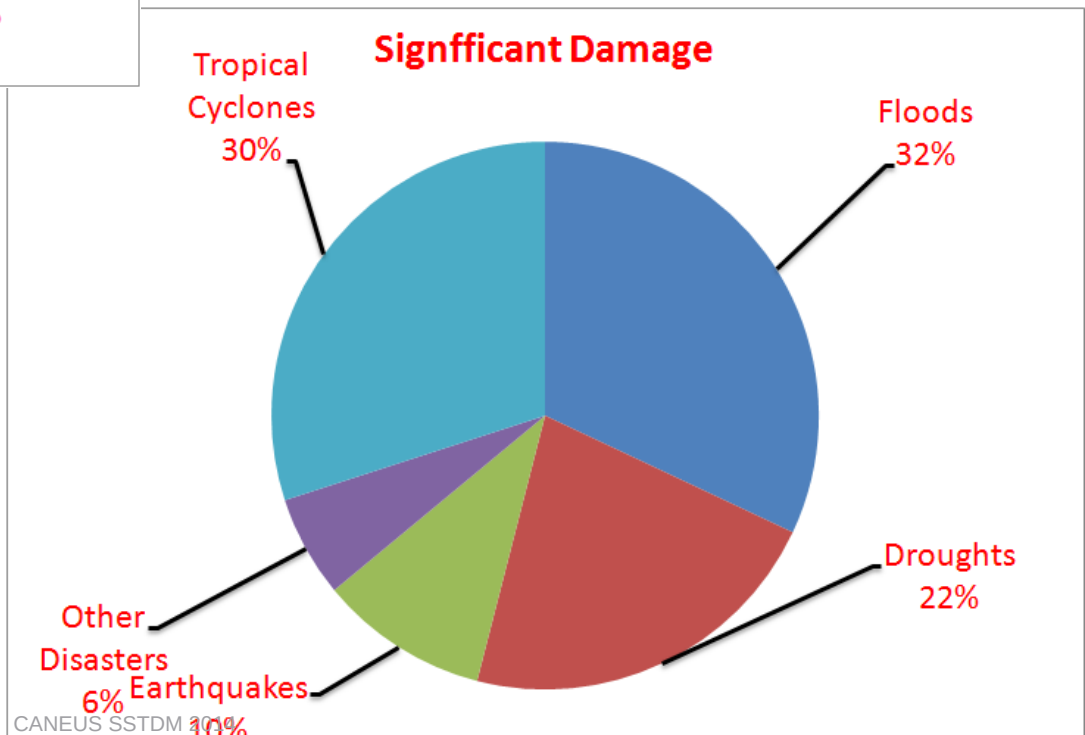
Flood Disasters During 1974 - 2003



EM-DAT: The OFDA/CRED International Disaster Database
www.em-dat.net - Université Catholique de Louvain - Brussels - Belgium

Damages due to Natural Disasters





Impact of Disasters

		Effect on:			
		GDP growth	Agricultural growth	Industrial growth	Service growth
From median intensity of severe:	Droughts	–1.0%***	–2.2%***	–1.0%*	0.3%
	Floods	0.3%	0.6%	0.1%	0.4%
	Earthquakes	–0.0%	–0.1%	0.3%	0.0%
	Storms	–0.9%**	–0.8%**	–0.9%	–0.9%

*significant at 10%; **significant at 5%; ***significant at 1%.

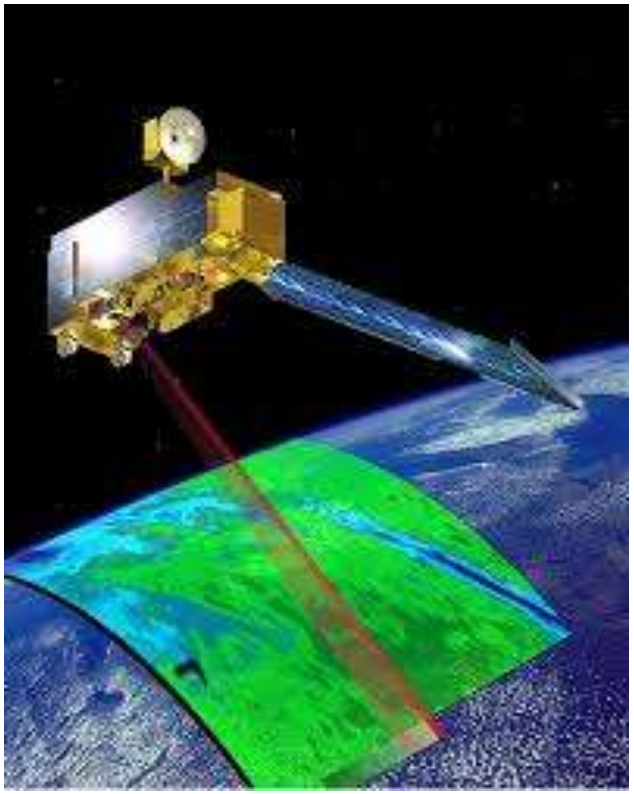
Source: Loayza and others 2009.

Outline

- Introduction
- **Data and Methods**
- Case Study
  - Kosi flood in 2008
  - Indus flood in 2010
- Inferences

Datasets …

- Imagery (daily/weekly)
  - Land cover classification
  - Inundation mapping



❑Parameters for MODIS /TERRA mission

- Operating Spectral bands (µm)

  0.412-0.551 (VS); 0.650-0940 (NIR); 1.240-4564 (SWIR/MWIR); 6.715-14.235 (LWIR) ==36 spectral bands

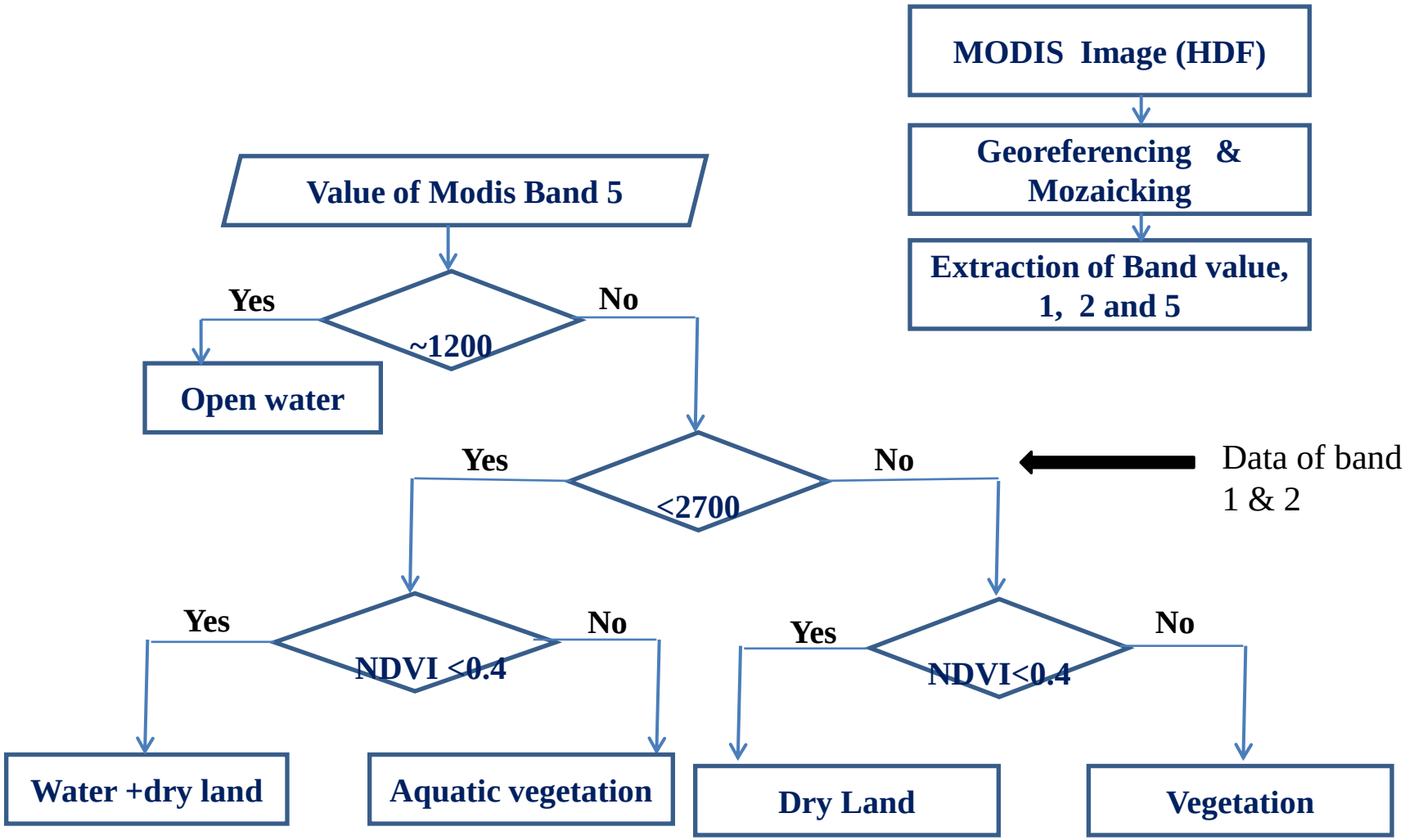
- Ground Resolution (m)

  250, 500, 1000

- Product in study: surface reflectence

  MOD09A1 (8 days) ; MOD09GHK (daily)

Methodology: Land surface categorization from MODIS images



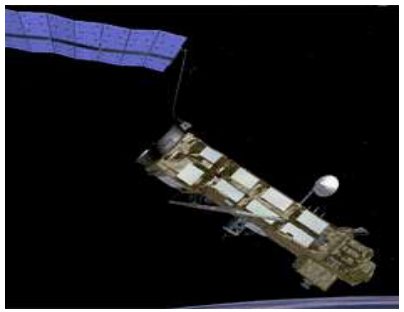
Estimate open water surface extent from MODIS observations

Datasets …

➢ Radar Altimetry data (10/35 days)

- Measure water stage variation with accuracy of few cm/dm
- Can detect water stage over bodies of width 100 m
- Provides water stage data for remote area

	T/P (10 days)	**Envisat** (35 days)	**Jason 2** (10 days)
Altitude/inclination	1336 km /66°	800 km/98.55°	1336 km /66°
Operating frequency (GHz)	18, 21, 37, 13.65	13.575 , 3.2	13.575 , 3.2
Freq./ Ground Coverage	10 Hz/580m	20 Hz/350m	20 Hz/350m
Inter-track dist @ Equator	315 km	80 km	315 km
Tracking Instruments	Microwave Radiometer; laser tracking; DORIS		

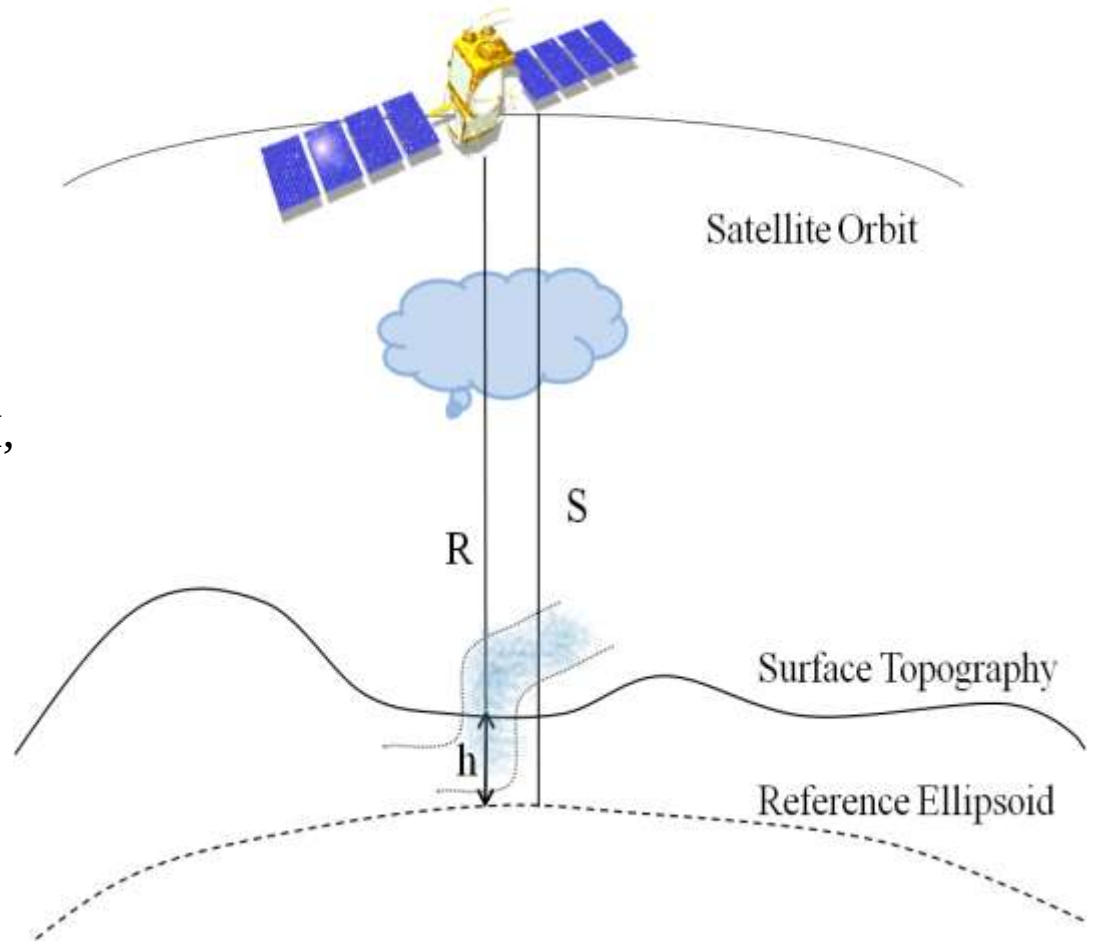




Methodology: water height estimation

$$R = ct/2$$

$$h = S - R + \Delta R_{corr.}$$

R is one way distance travelled by EM,
c is speed of light in vacuum,
t is two-way travel time ,
S is altitude of satellite ,
ΔRcorr. Corresponds to atmospheric and geophysical corrections



Water height estimation from altimetry over open water

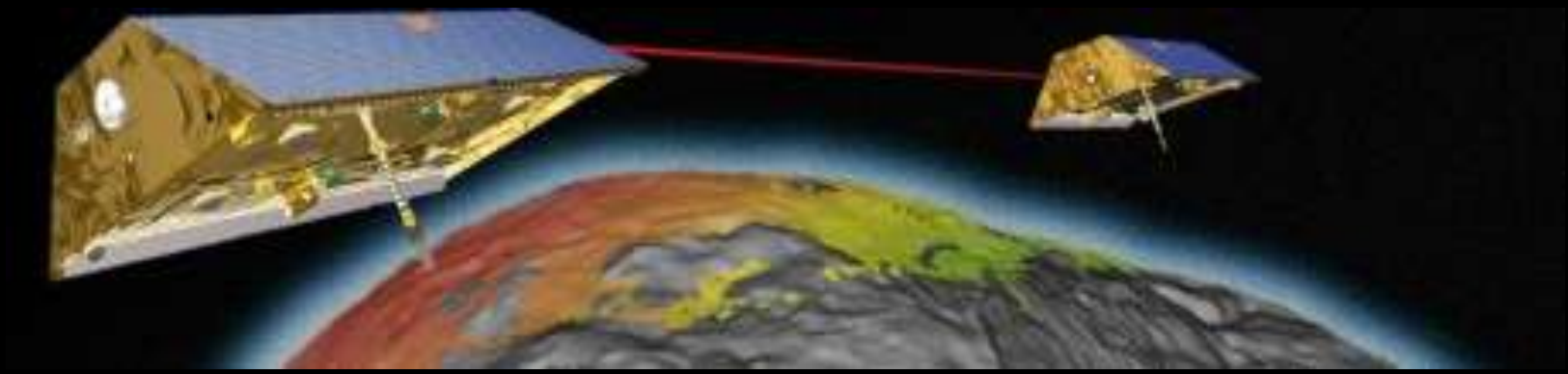
Datasets: TRMM

Measuring instruments:

- TRMM Microwave Imager (TMI),
- Visible Infrared Scanner (VIRS)
- Precipitation Radar (PR)
- Cloud and Earth Radiant Energy Sensor (CERES)
- Lightning Imaging Sensor (LIS)

Altitude	**403 km**
Horizontal resolution	**5 km**
Dialy passes	**16 (92 minute period)**
Vertical rain profile	**20 km from surface**
Rain rate accuracy	**0.7 mm/h**

Gravity Recovery & Climate Experiment (GRACE)



Observations of subtle variations in distance between orbital motions of twin satellites are used to measure Earth's gravity field

Provides gravity response of mass changes

$$\delta N(\theta,\phi) = \frac{G}{\gamma}\iiint_V \frac{dm}{|r-s|}$$

$$N(\theta,\phi) = a\sum_{l=2}^{\infty}\sum_{m=0}^{l} P_{lm}(\cos\theta)(\Delta C_{lm}\cos m\phi + \Delta S_{lm}\sin m\phi)$$

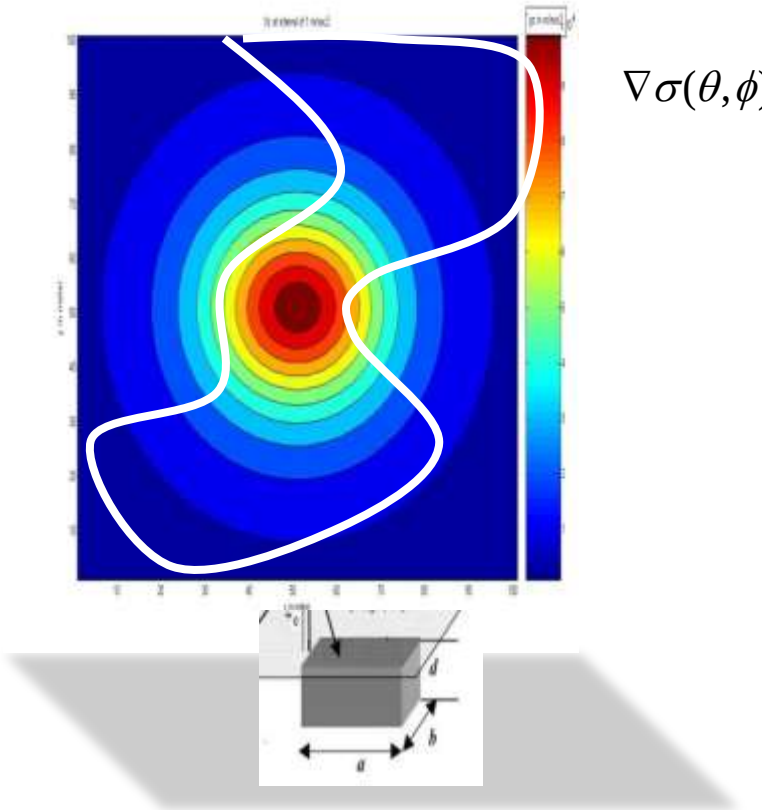
Global influences integrated at each location

Attenuation or smoothing with altitude

Often quoted:
Complex problems: simple solutions

"SIMPLE CAN BE HARDER THAN COMPLEX."
STEVE JOBS

Complex Solution to a Simple Problem



$$\nabla\sigma(\theta,\phi) = \frac{a\rho_w}{3}\sum_{l=2}^{\infty}\sum_{m=0}^{l}\frac{2l+1}{1+k_l}P_{lm}(\cos\theta)(\Delta C_{lm}\cos(m\phi)+\Delta S_{lm}\sin(m\phi))$$

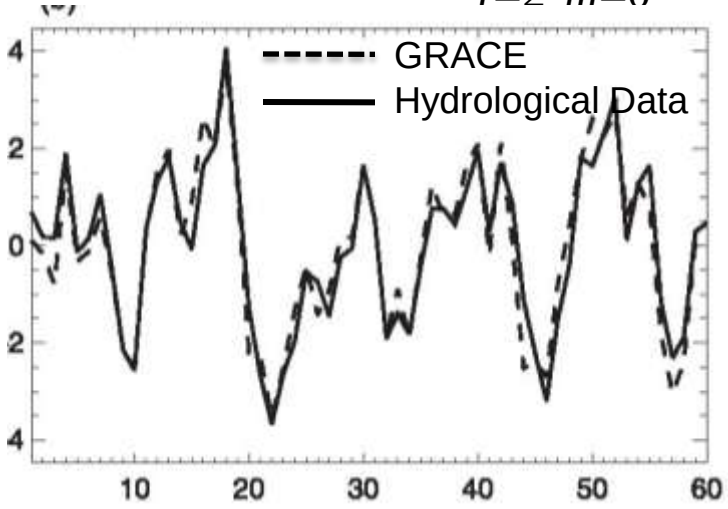
Gravity Anomaly → Mass

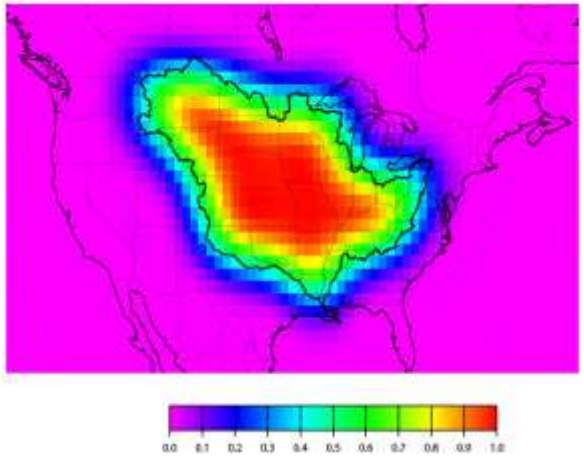
Total mass estimate: Unique

Intricacy in regional mass estimates

Mass Estimates: Averaging Kernel Functions

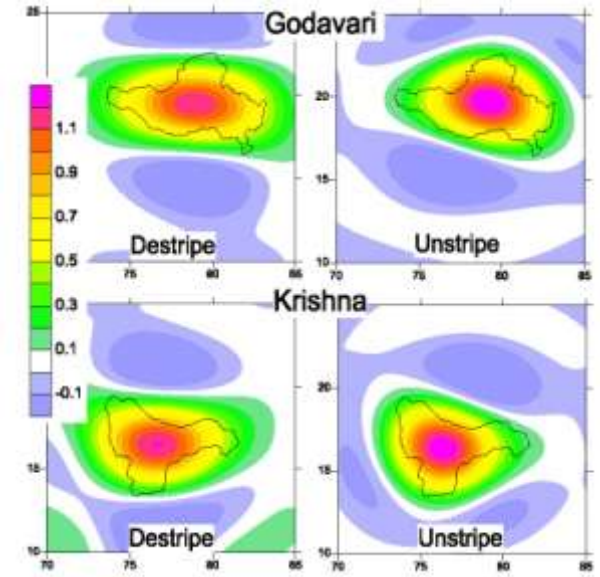
$$\nabla\tilde{\sigma}_{region} = \frac{a\rho_{ave}}{3}\sum_{l=2}^{\infty}\sum_{m=0}^{l}\frac{1}{\Omega_{region}}\frac{2l+1}{1+k_l}(W_{lm}^{c}\Delta C_{lm} + W_{lm}^{s}\Delta S_{lm})$$





Swenson & Wahr JGR, 2002

Mass Solution



M = W(θ,φ)×σ(θ,φ)

σ(θ,φ), surface mass distribution

θ and φ are latitude and longitude

And M : mass sum over all (θ,φ)

Tiwari et al, 2009

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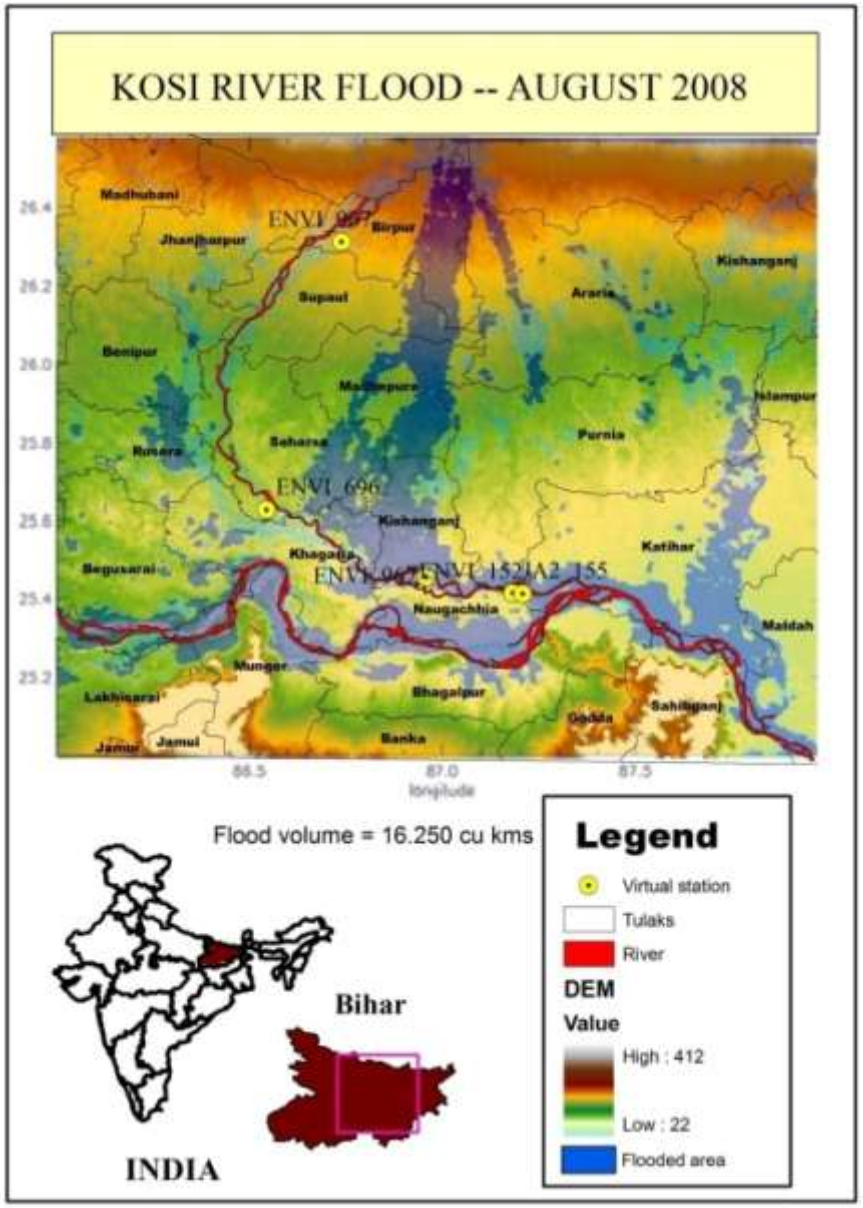
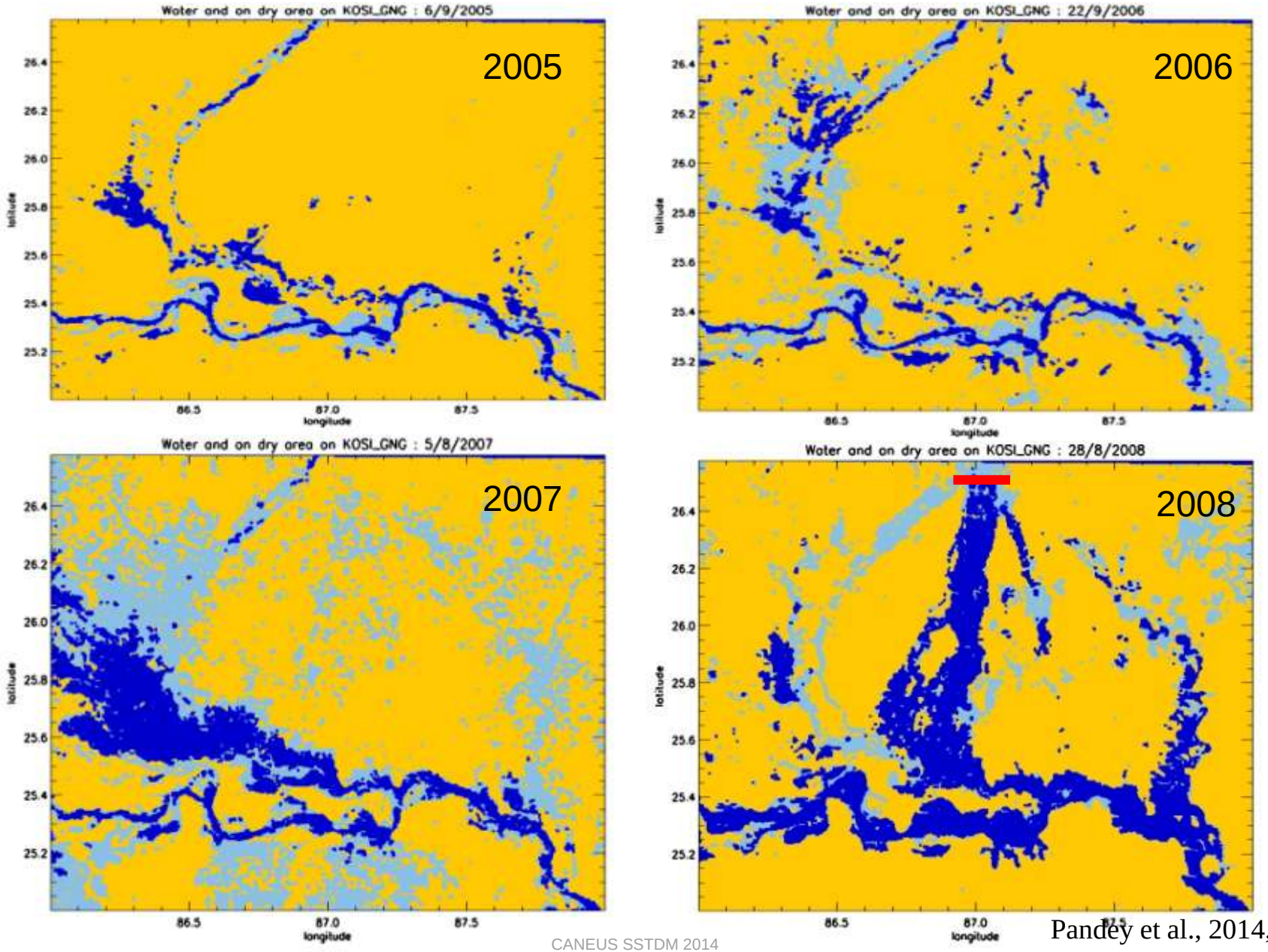
Flooding in Kosi sub-basin (Ganga)



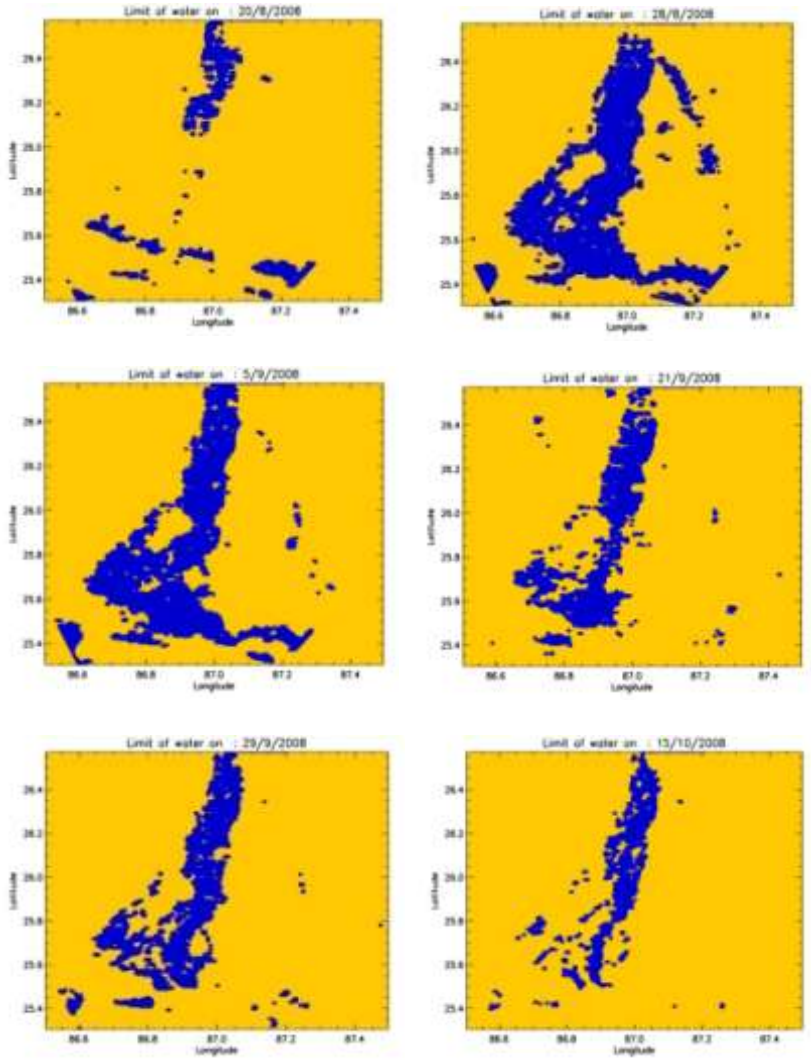
[One Million People Cut Off By Monsoon Floods In India](#) (Huffington Post, 25/08/2008)

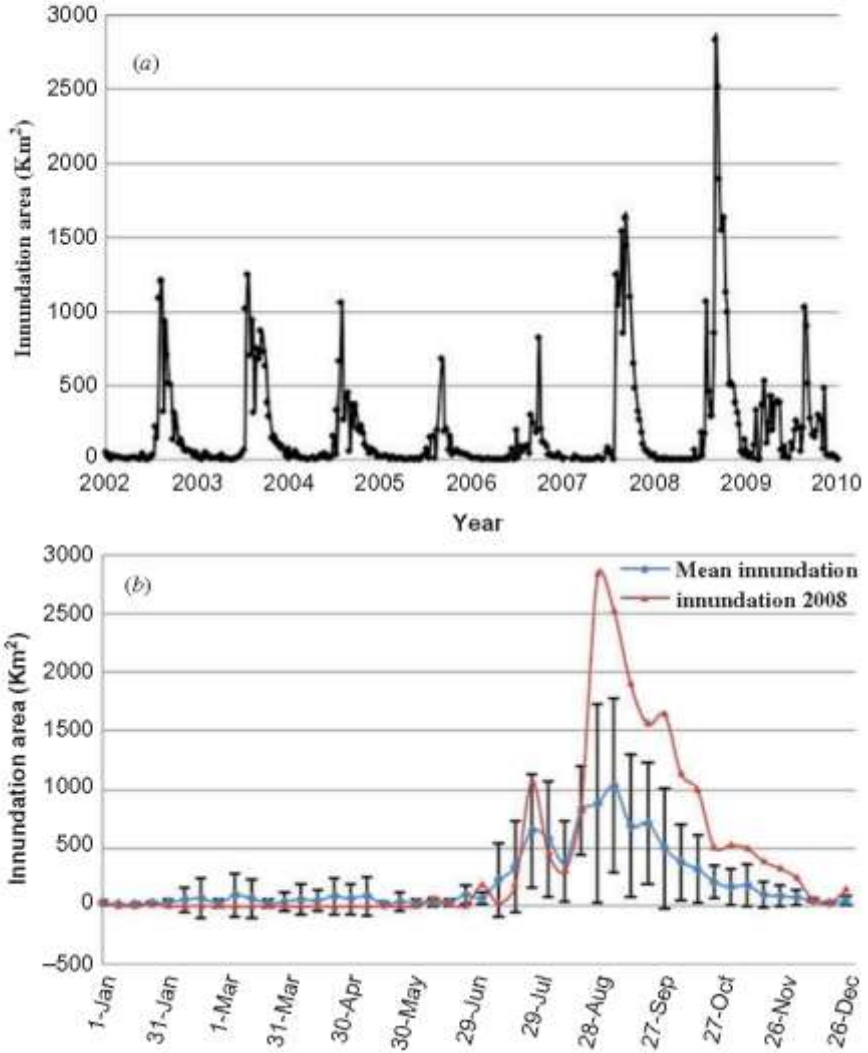
Recent floods in Kosi Sub-basin



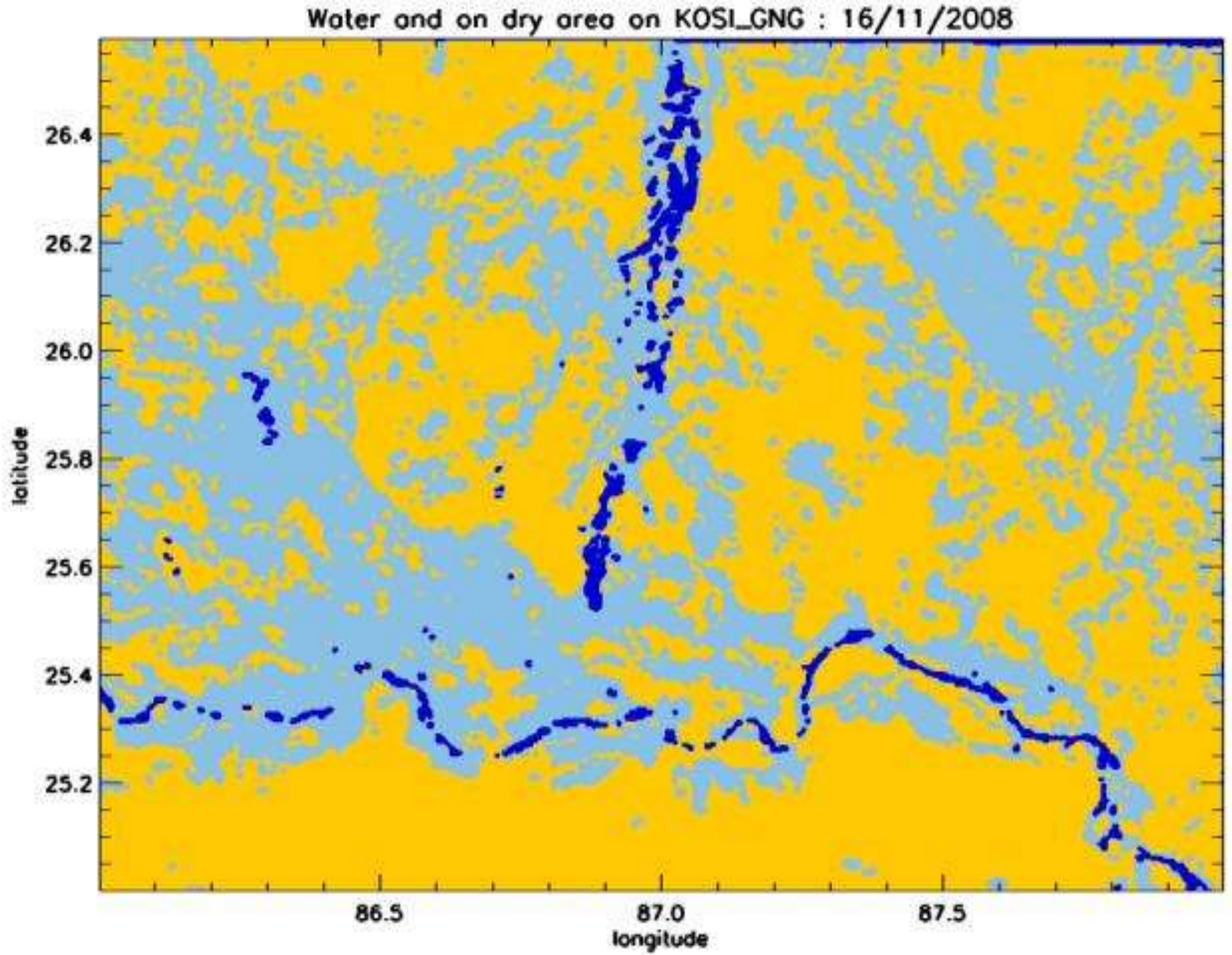
Pandey et al., 2014, IJRS

Flood dynamics of 2008 Kosi flood

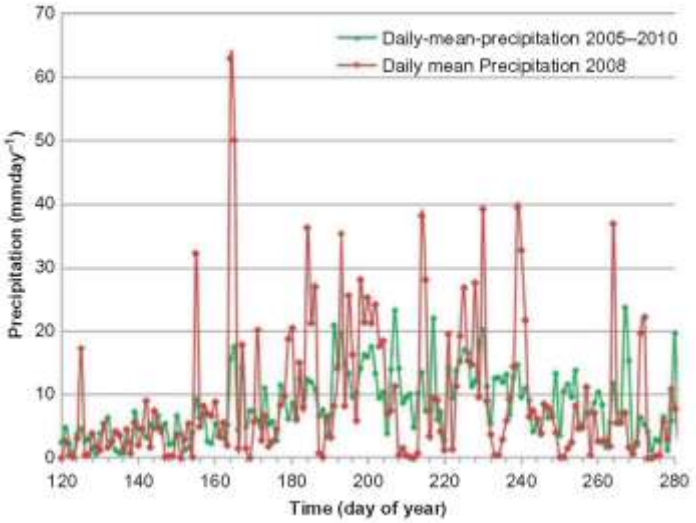


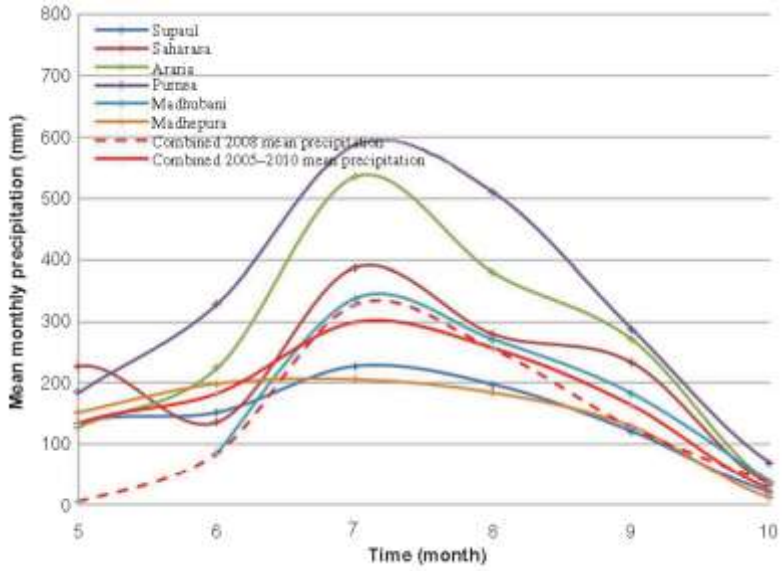


Pandey et al., 2014, IJRS


Water and on dry area on KOSI_GNG : 16/11/2008
26.4
26.2
26.0
25.8
25.6
25.4
25.2
latitude
86.5
87.0
87.5
longitude

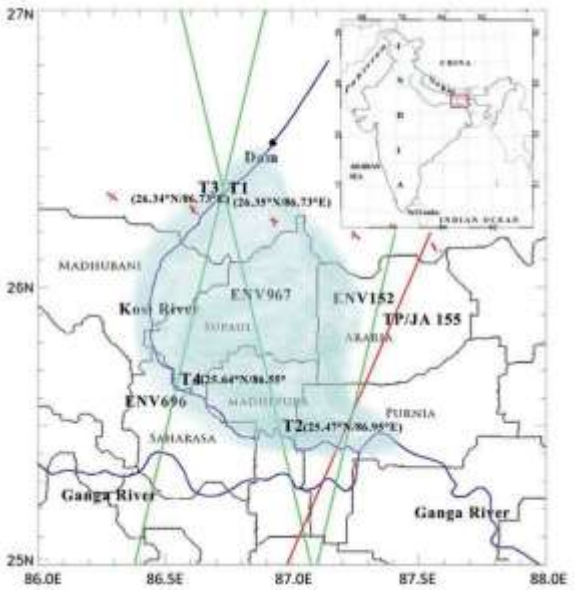
Rainfall

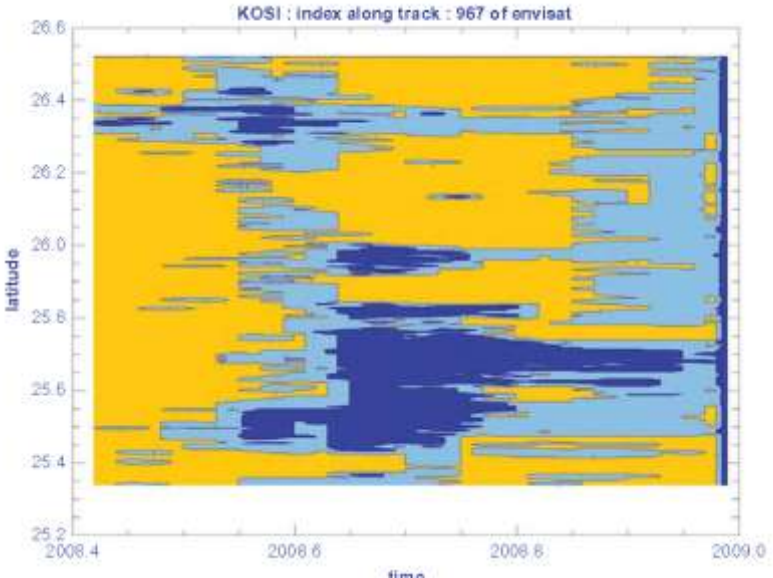




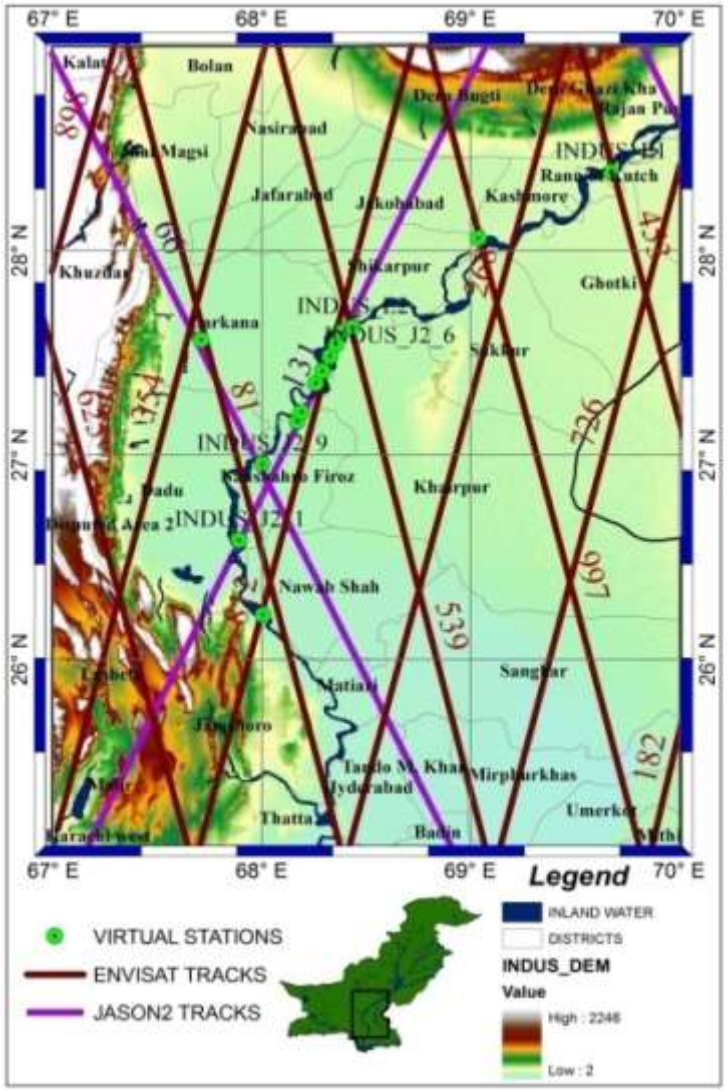
Pandey et al., 2014, IJRS

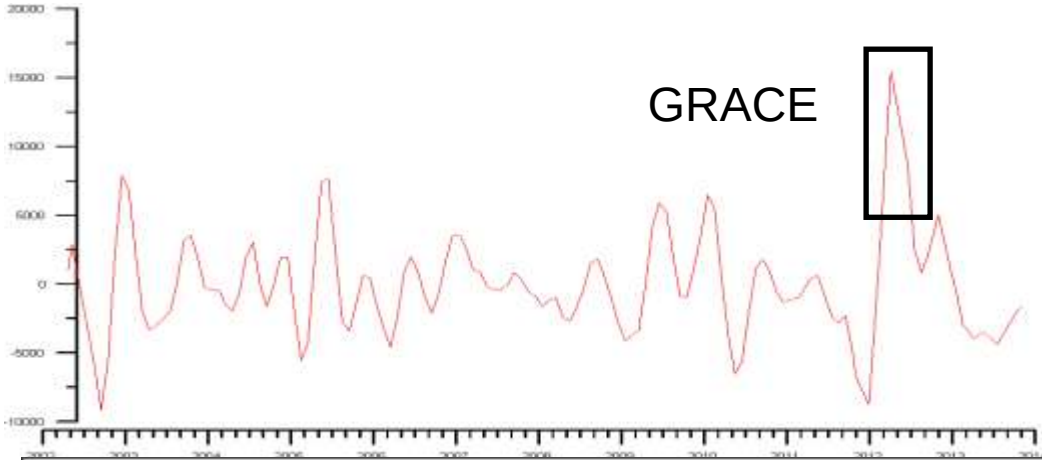
Inundation

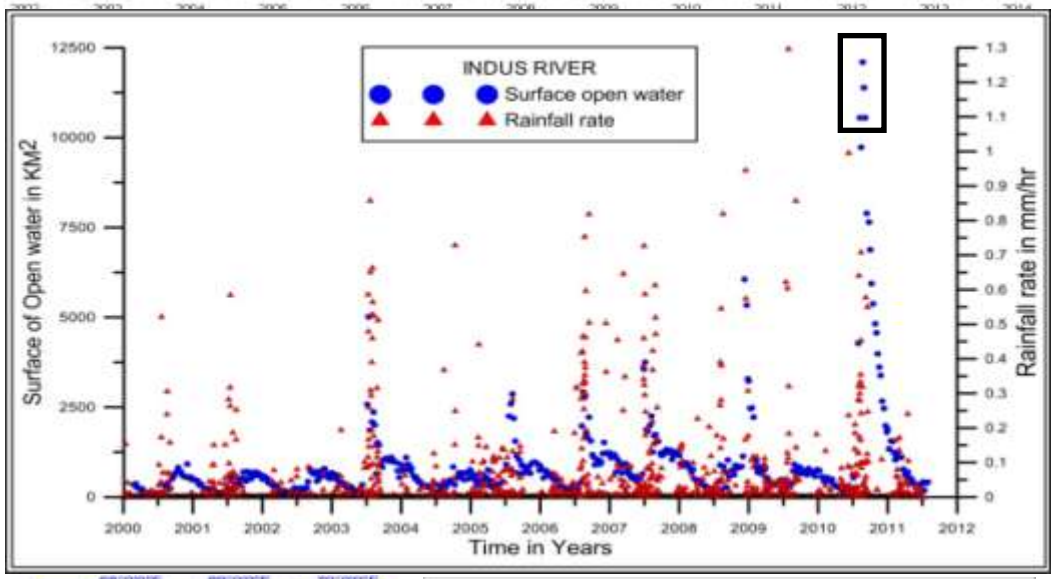


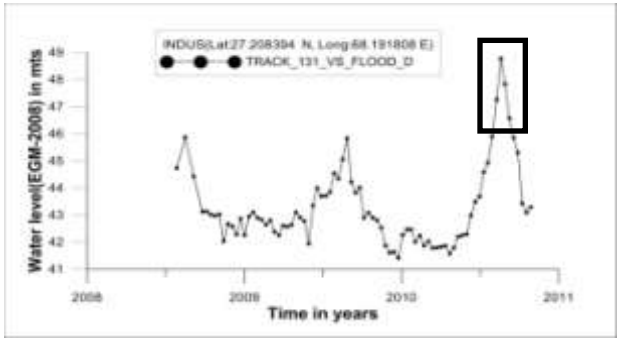


Pakistan flood 2010

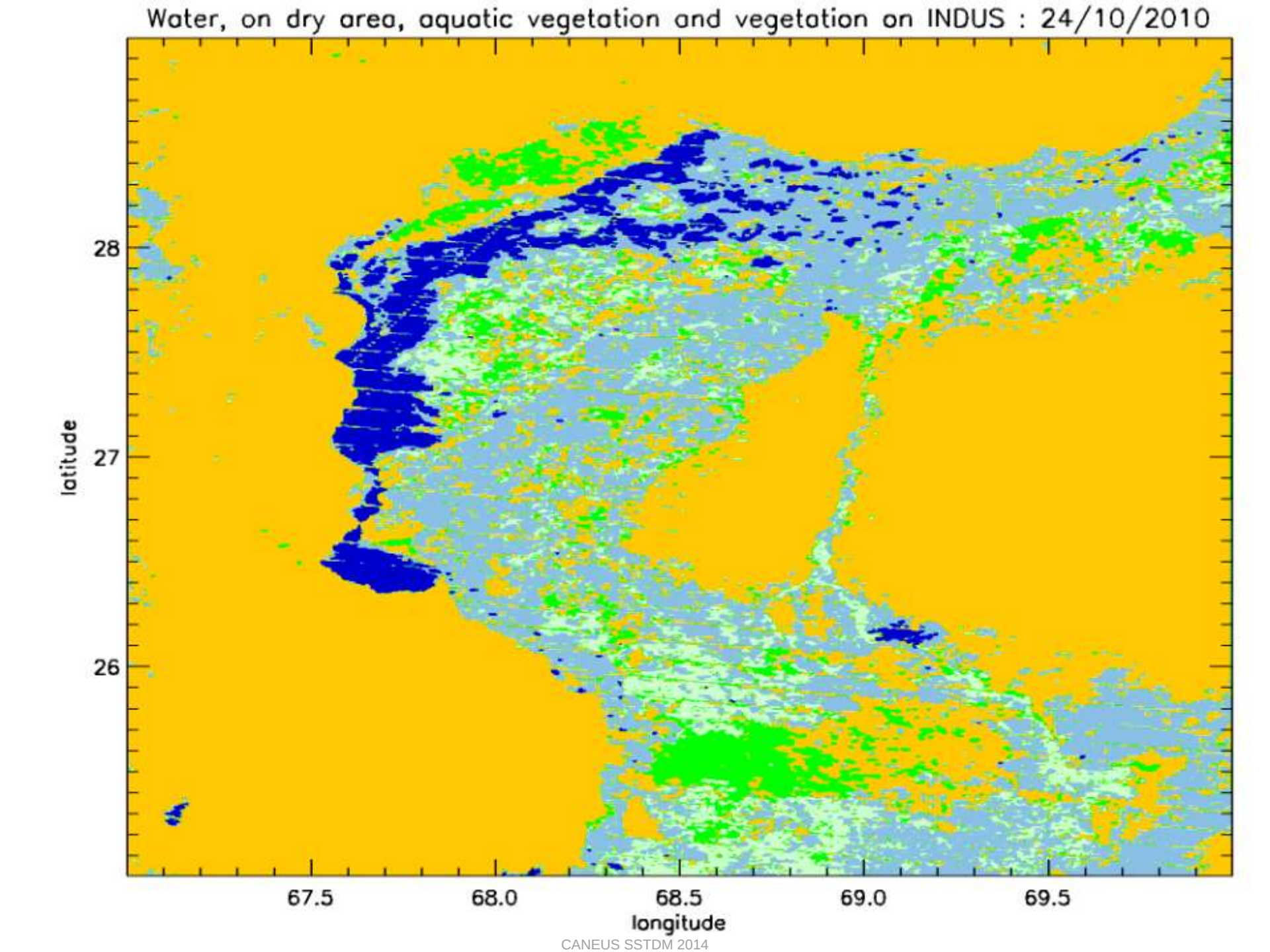








Srinivas et al., 2014


Water, on dry area, aquatic vegetation and vegetation on INDUS : 24/10/2010
28
27
26
latitude
67.5
68.0
68.5
69.0
69.5
longitude

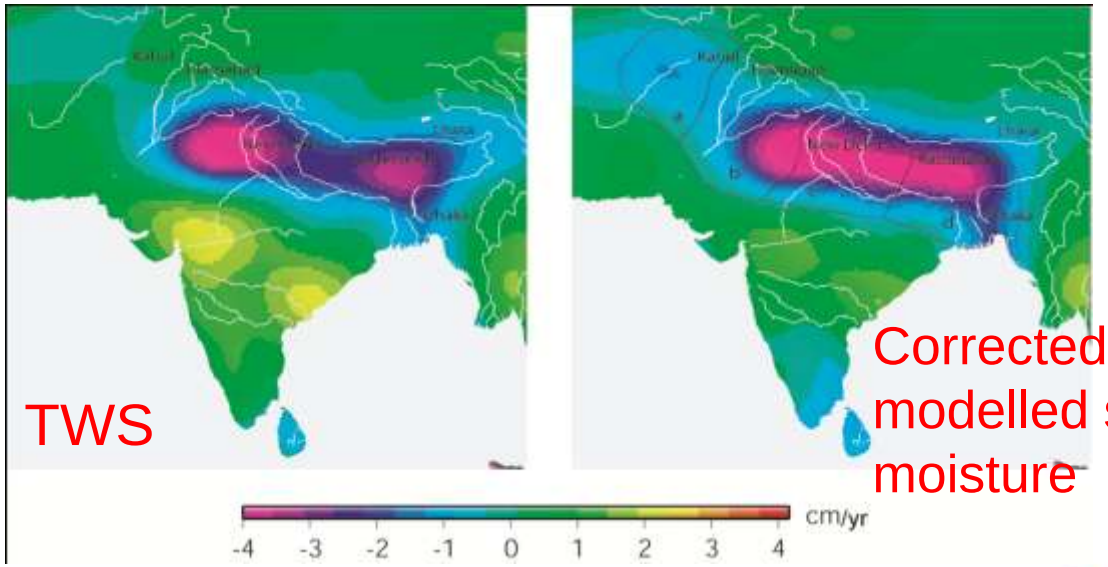
Inferences

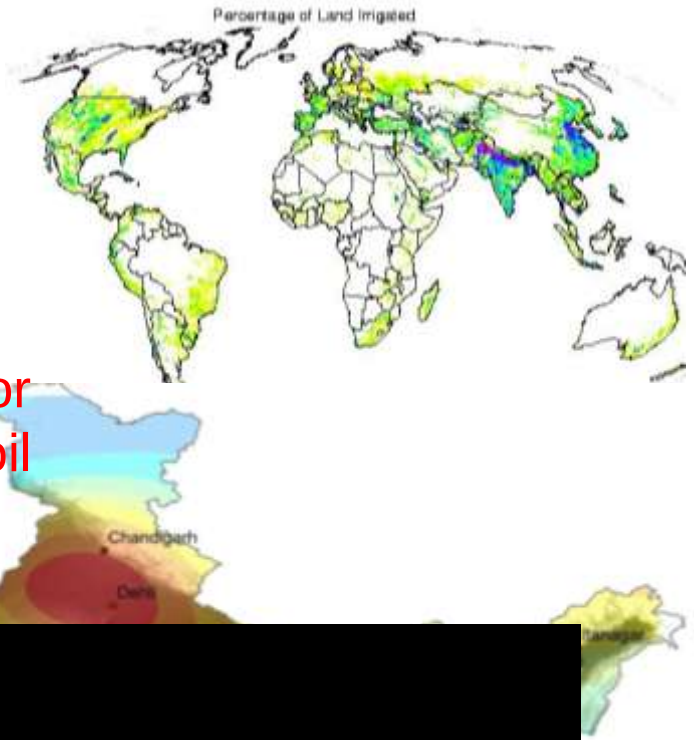
- **Kosi Flood 2008 : Inundation area is 2900 km^2, 1-1.5 m of water height and away from river course**.
- **Indus Flood 2010: Inundated area is ~ 12000 km^2 with ~ 1m height. GRACE data shows ~ 12 km^3 excess water during flood period, which corroborate with MODIS and altimetry data.**
- **Retention time for both the floods is about 2 months.**

Water Storage Variability over India

Northern Indian Mass Loss: Story Continues..

Mass loss of four sub-regions





Question ?

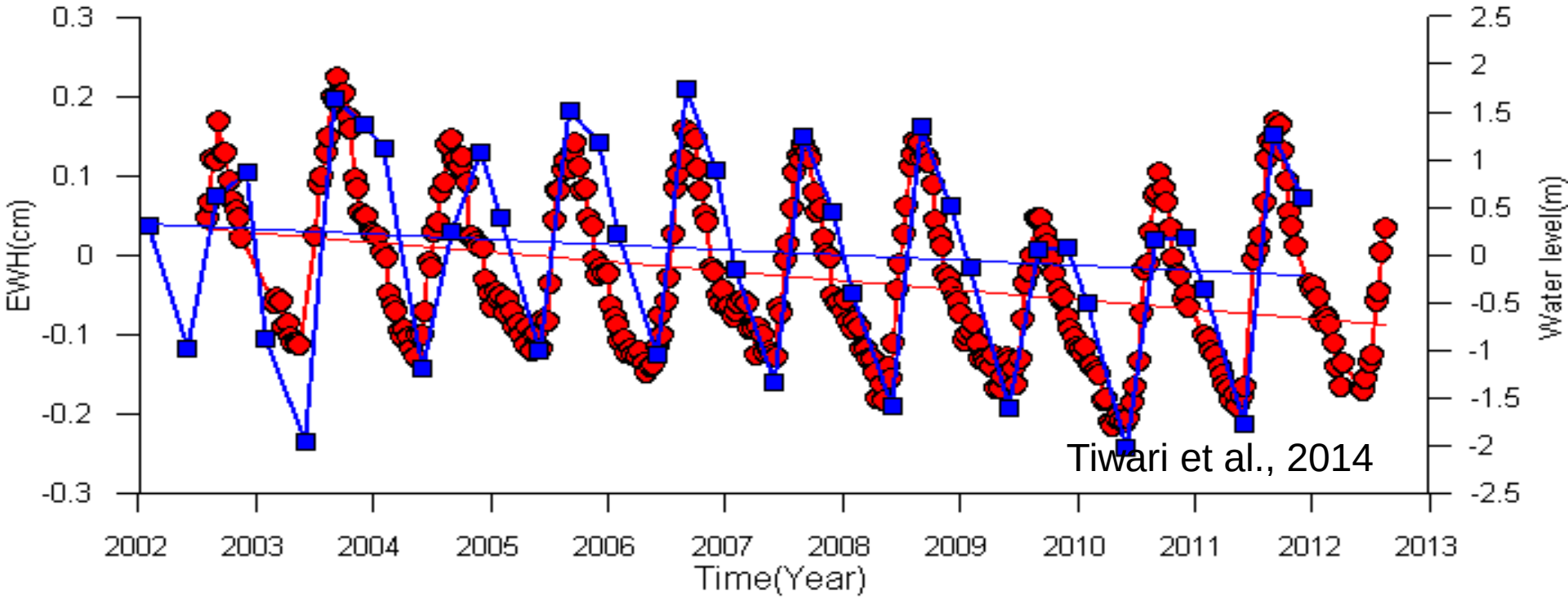
Inter-annual variability or long term changes

Ground Validation ?

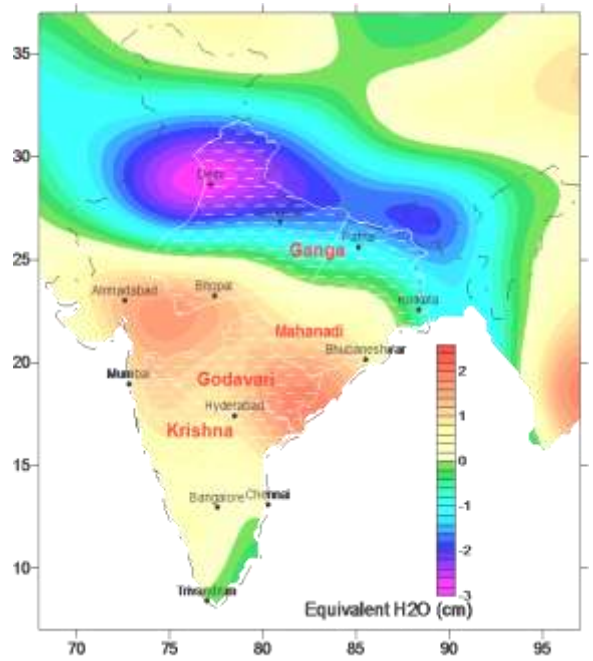
Tiwari et al, 2009

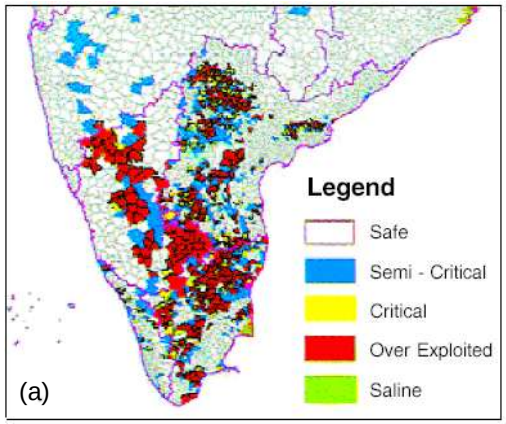
Trend of total storage water 2002-2012

Groundwater Level Fluctuations: Bore well records

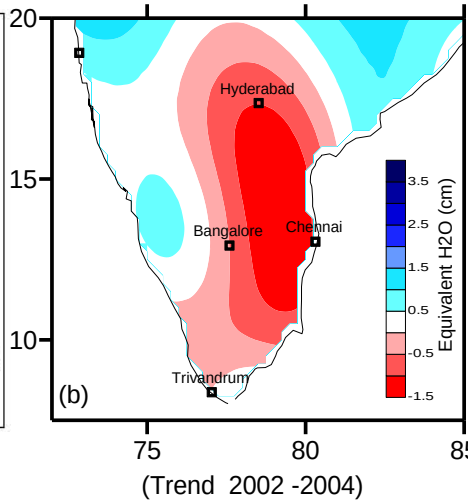


Inter-annual Variation

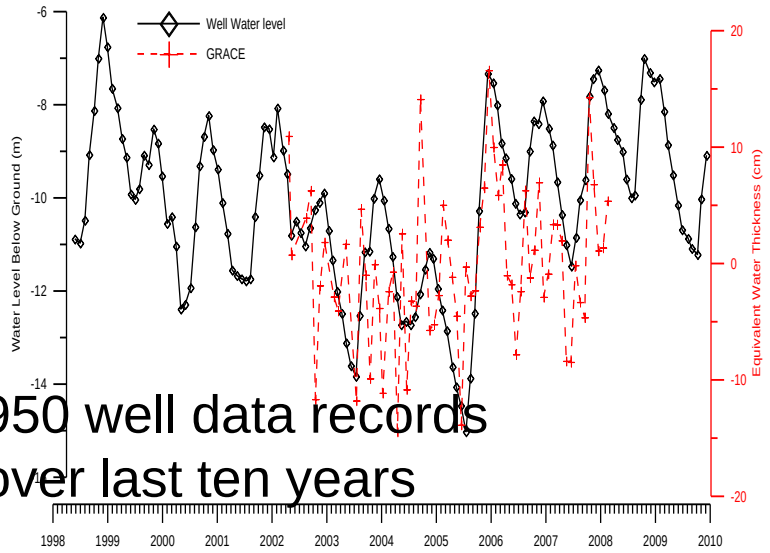




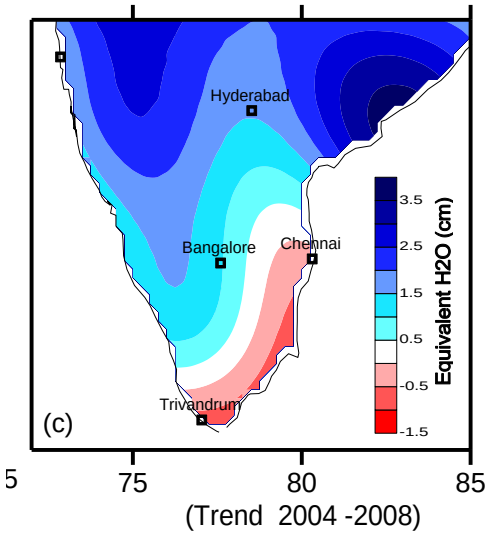
(After CGWB as on 2004)



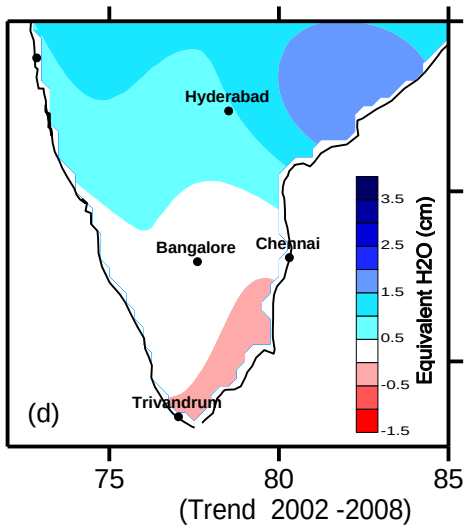
(Trend 2002 -2004)



950 well data records over last ten years

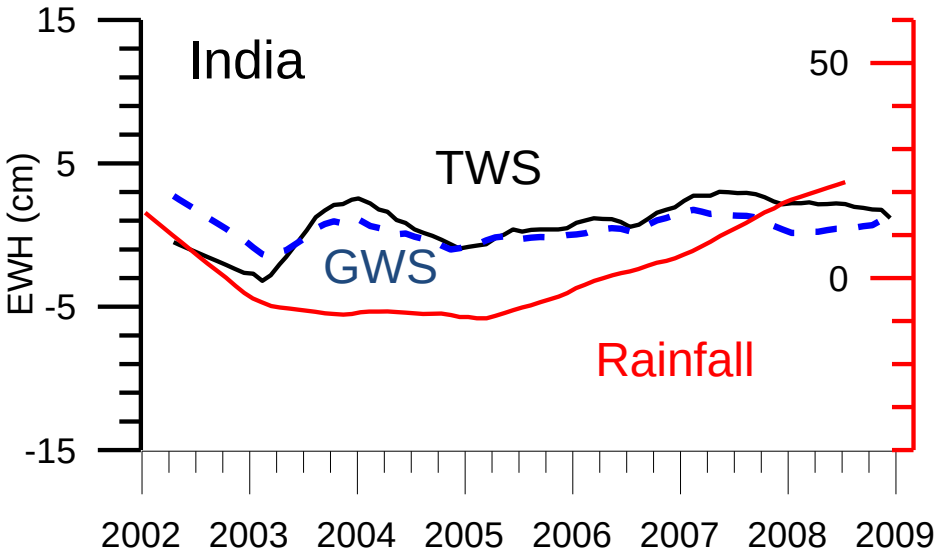


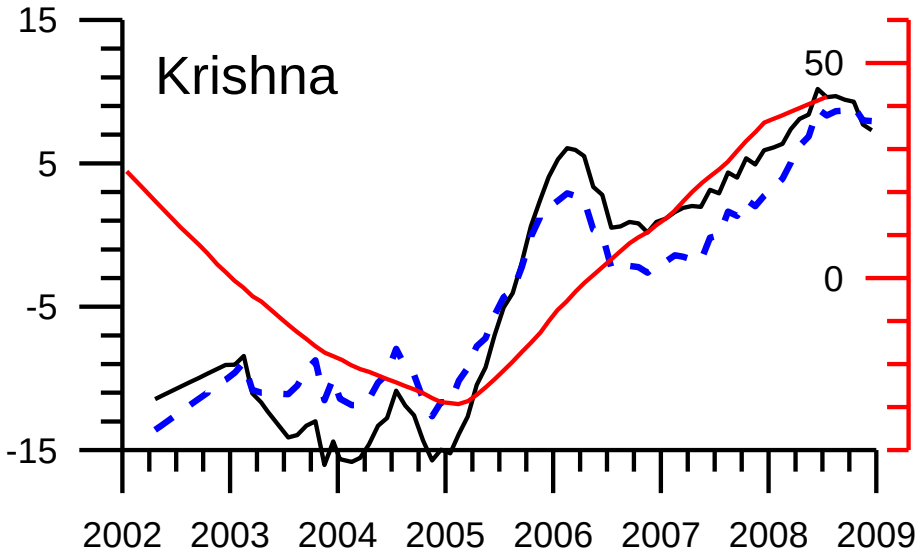
(Trend 2004 -2008)

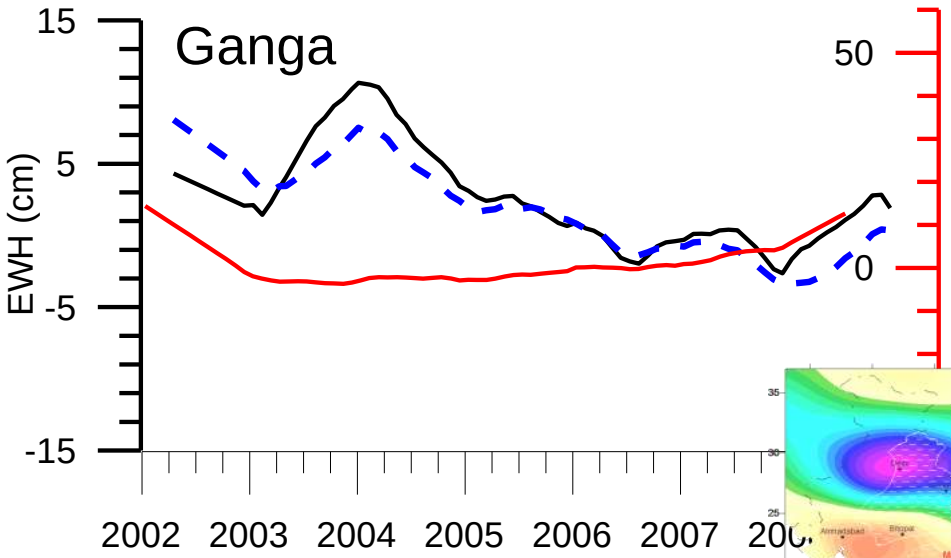


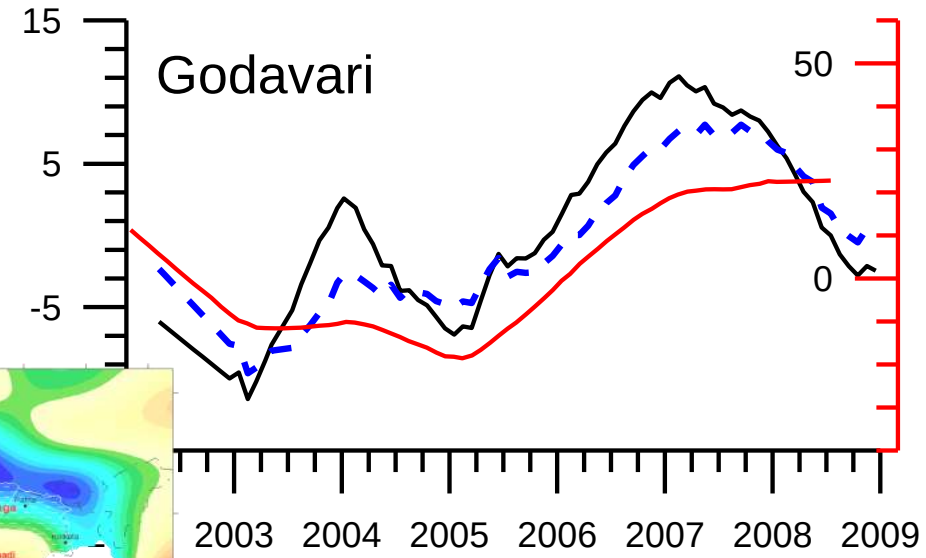
(Trend 2002 -2008)

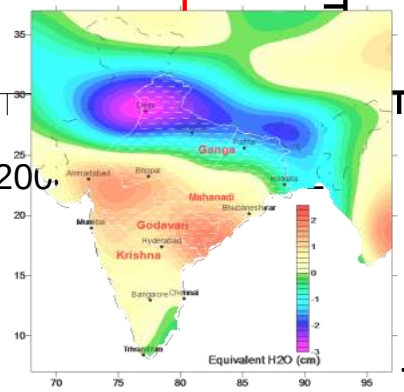
Tiwari et al., 2011











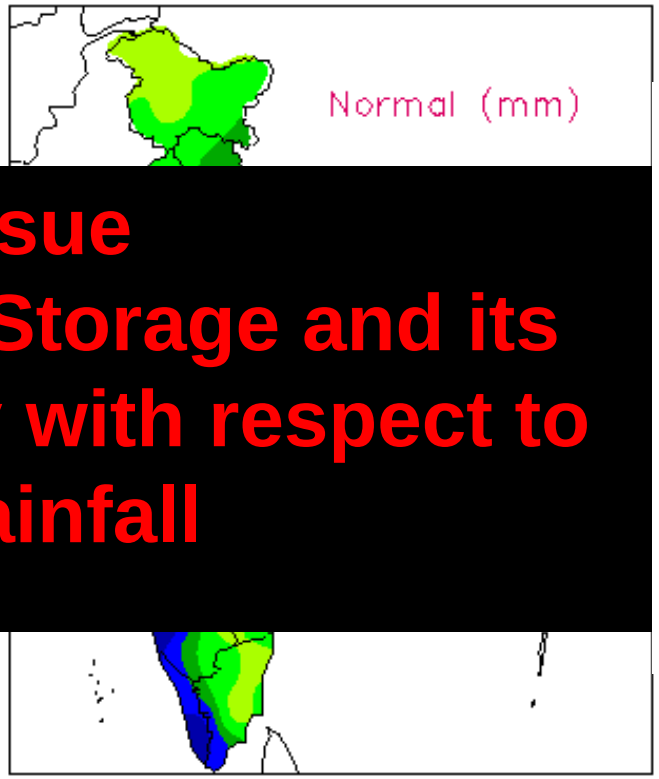
Tiwari et al., 2014 (Under Revision)

Water Budget

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

Diverse hydrologic regimes

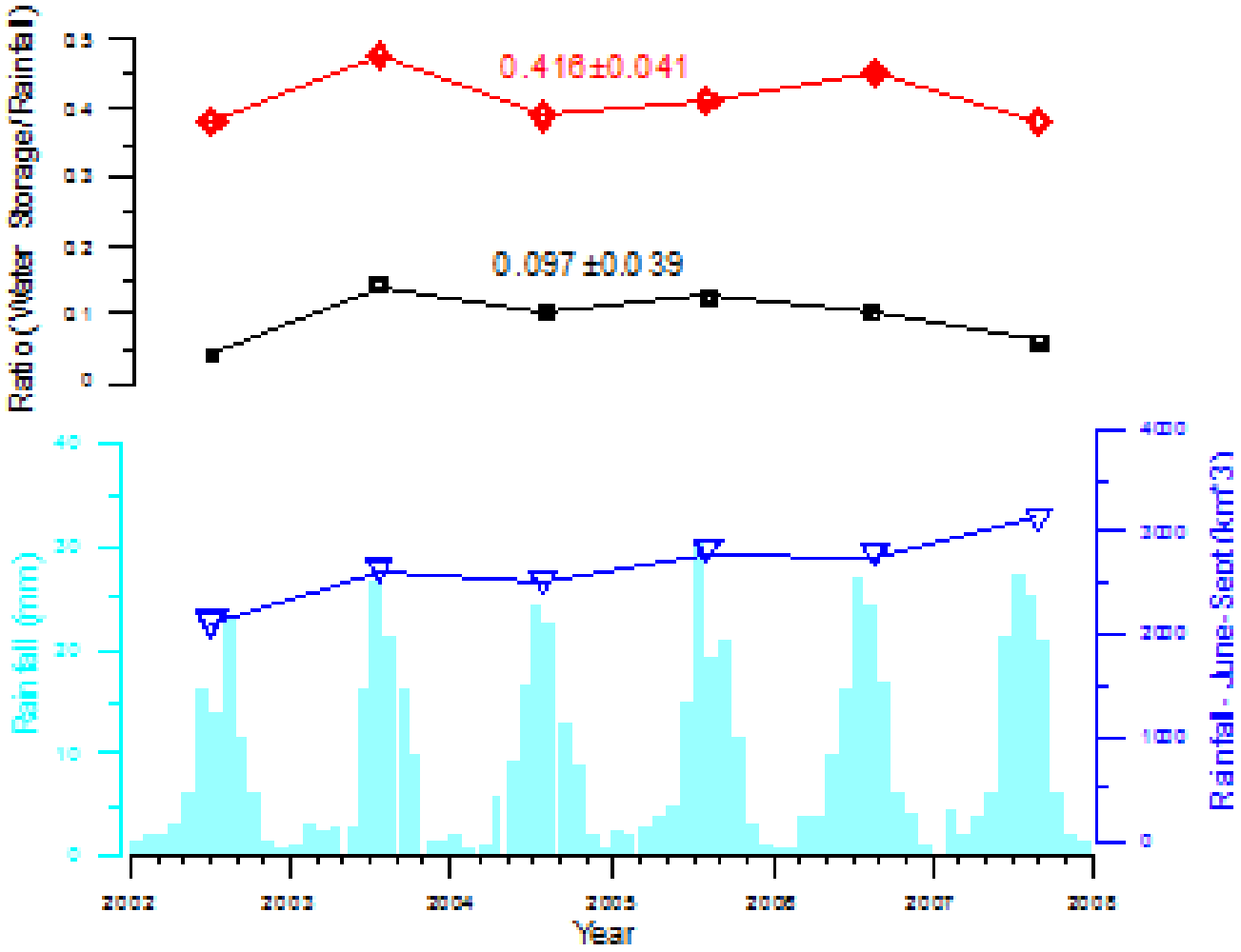
Large Variation in precipitation pattern



Science Issue
Replenishable Water Storage and its Inter-annual Variability with respect to Monsoon Rainfall

Groundwater storage estimates are based on empirical relations between Precipitation & Recharge

Storage Estimates



Tiwari et al., 2014 (Under Revision)

Concluding Remarks

- **GRACE is useful in estimating dynamic water storage over tropical regions like India. 12%-16% of total precipitation is retained as groundwater**

- **Water budget compares well with ground based estimates for all India. However, it differs on basin scale**

- **Hard rock region has strong inter-annual variability and thus would be influenced most by climatic changes**

The Future

NASA is considering a GRACE follow-on mission, which will be able to obtaining mass variability down to scales of ~100 km.

Thank you !