Variability of Terrestrial Freshwater Storage from Multi-Satellite Observations in the Ganges-Brahmaputra river system

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F. PAPA [1,9,10] , F. FRAPPART [2], F. JORDY [1], V. MARIEU [4], M. SHAMSUDDUHA [5], V. VENUGOPAL [6], M. SEKHAR [9], G. RAMILLIEN [2], C. PRIGENT [10] , F. AIRES [8], R. KUMAR[7], S. CALMANT [1,10]

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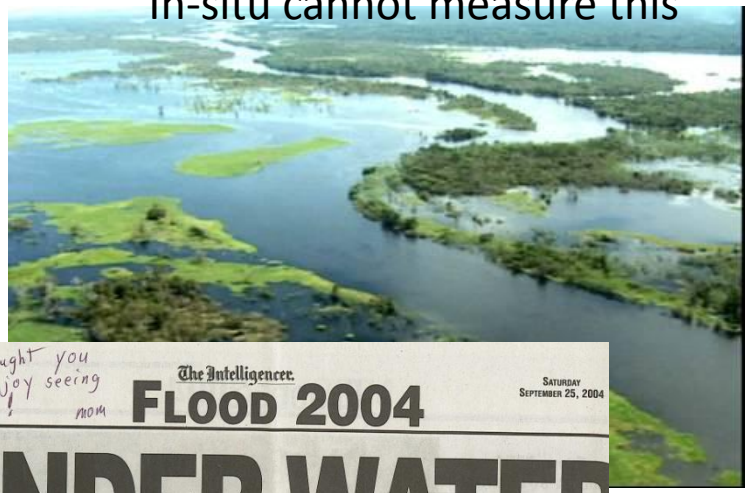
INTRODUCTION

1. The Problem

In-situ cannot measure this



Floods are the number one hazard

2. The Question

What is the spatial and temporal variability of freshwater stored in the world's terrestrial water bodies?

3. Study Region

Ganges-Brahmaputra-Meghna River Basin

- *Trans-boundary* rivers
  India, China, Nepal, Buthan and Bangladesh
- Host of more than *700 millions people*
- Strong Climate variability (*Flood / Drought*)
- ~25% of freshwater received by the Bay of Bengal (*Impact on the climate* of the area)
- 2 in situ Gauge stations with public access

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Lake Constance

Dataset : GIEMS product

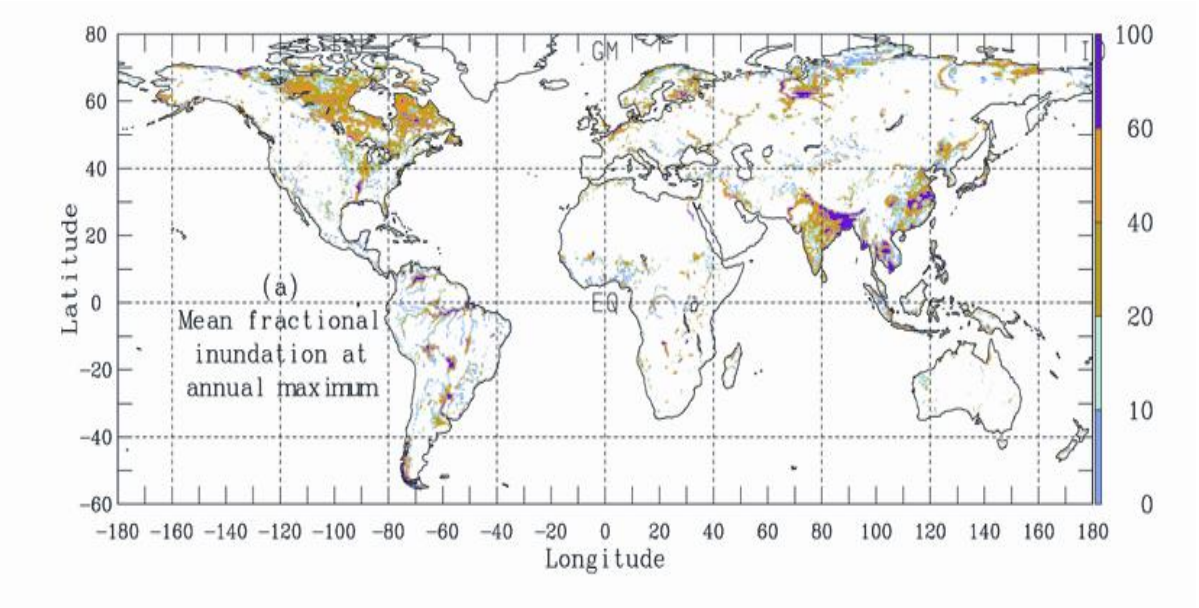
Merging of satellite data with different wavelengths (surface classification, NN, vegetation)

Passive microwave
SSM/I emissivities

Active microwave
ERS scatterometer

Visible and near infrared
AVHRR NDVI (reflectances)

Mean fractional surface water extent at annual maximum



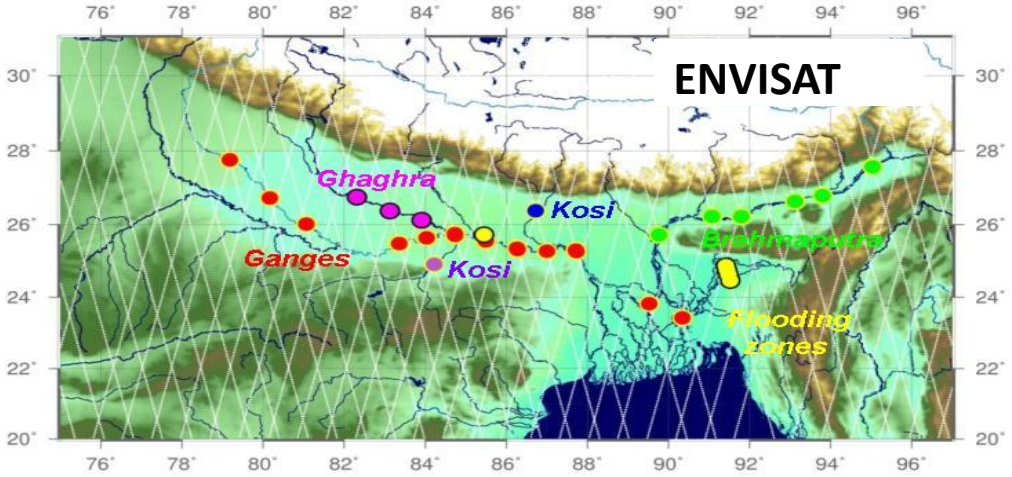
[Prigent et al., *J. Geophys. Res.*, 2007; *Geophys. Res. Lett.*, 2012
Papa et al., *Geophys. Res. Lett.*, 2006; 2008; *J. Geophys. Res.*, 2010]

- Data mapped on equal-area grid with **0.25°x 0.25°** resolution at equator (773 km²)
- Monthly resolution for **1993-2007**

Dataset : ENVISAT

1. Hydroweb

- Data base: About **1400 sites** on large rivers are available
- **Time series** over water levels of large rivers, lakes and wetlands
- Based on altimetry data from Topex/Poseidon, **Envisat**, Jason-2
  - ► *http://www.legos.obs-mip.fr/fr/soa/hydrologie/hydroweb/*



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► *http://www.legos.obs-mip.fr/fr/soa/hydrologie/hydroweb/*

2. Hydrology from space

French Observation Service dedicated to satellite altimetry studies

Distribution of Geophysical data records provided by the space agencies with additional parameters

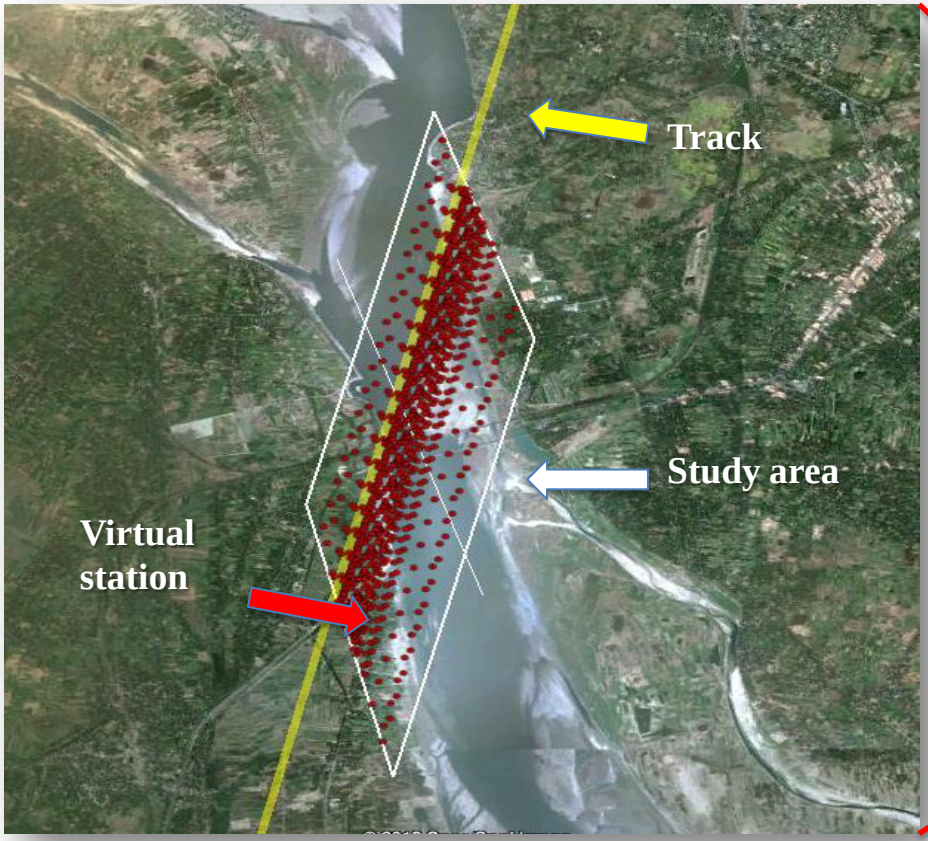
► *http://ctoh.legos.obs-mip.fr/products/*

Dataset : Complementary data

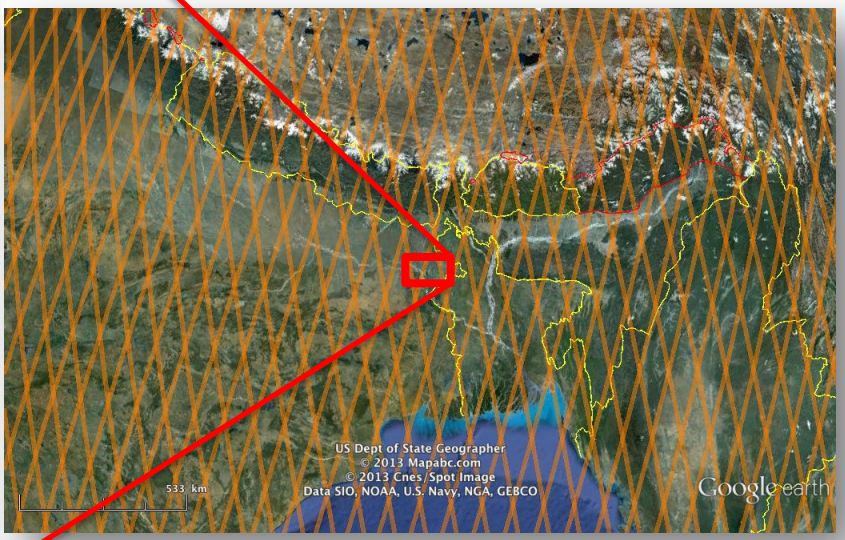
Sources	Parameters
Flood Observatory (USA – Darmouth College)	Maximal inundation maps (MODIS) 2000 - 2012 0,10° resolution
Rainfall (TRMM 3B43)	Cumulative monthly rainfall 0,25° resolution
Total water storage (GRACE)	Sum of liquid water reservoirs (surface waters + soil moisture + groundwaters) and snow pack contributions 4° resolution
in-situ data (Bangladesh Water Development Board)	Water levels and discharges

Methodology : VALS

Virtual **AL**timetry **S**tation Sofware (2010)



Data selection



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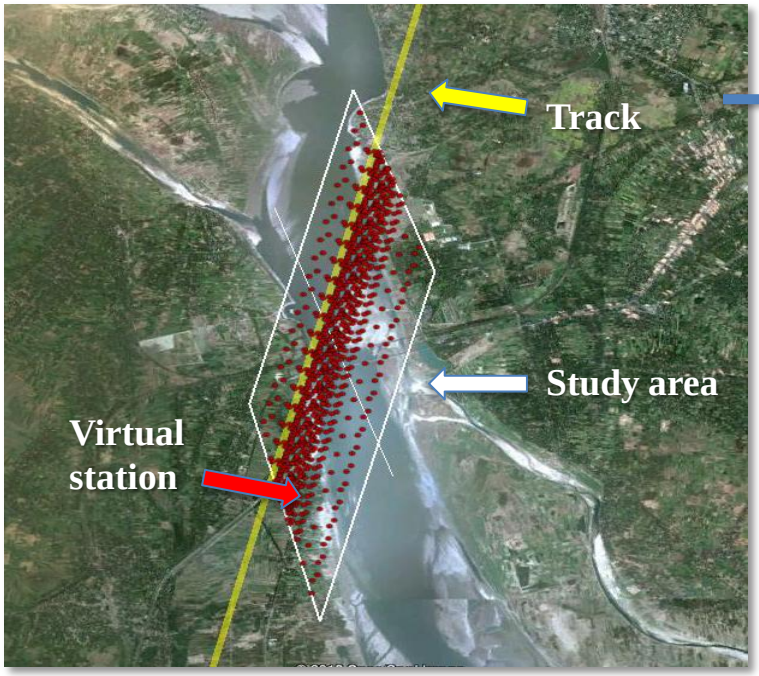
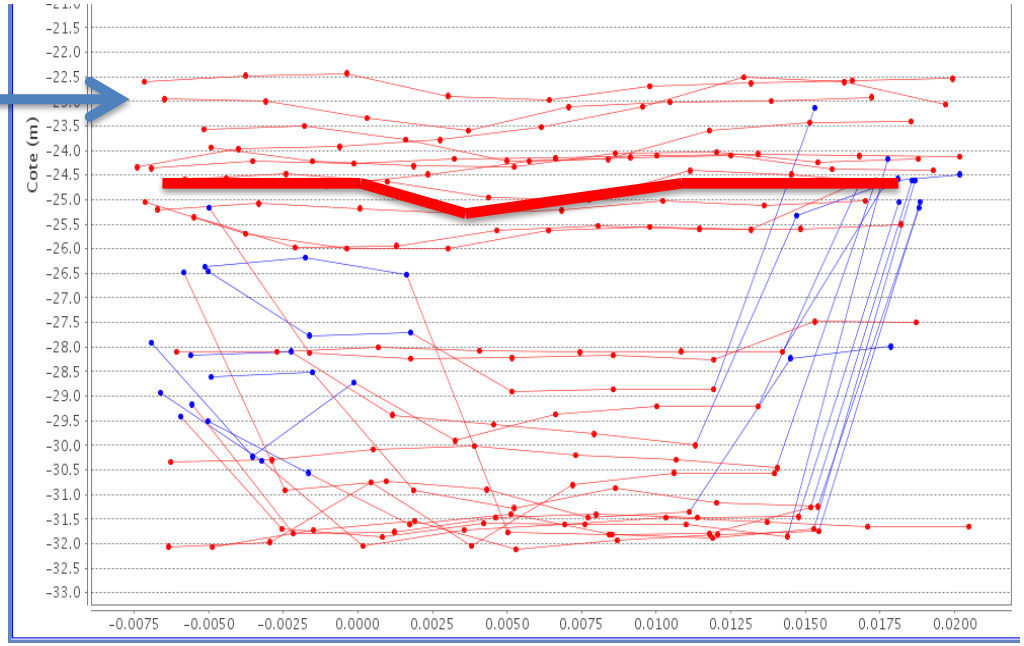


Data selection



Refining the selection in a cross sectional view

Methodology : VALS

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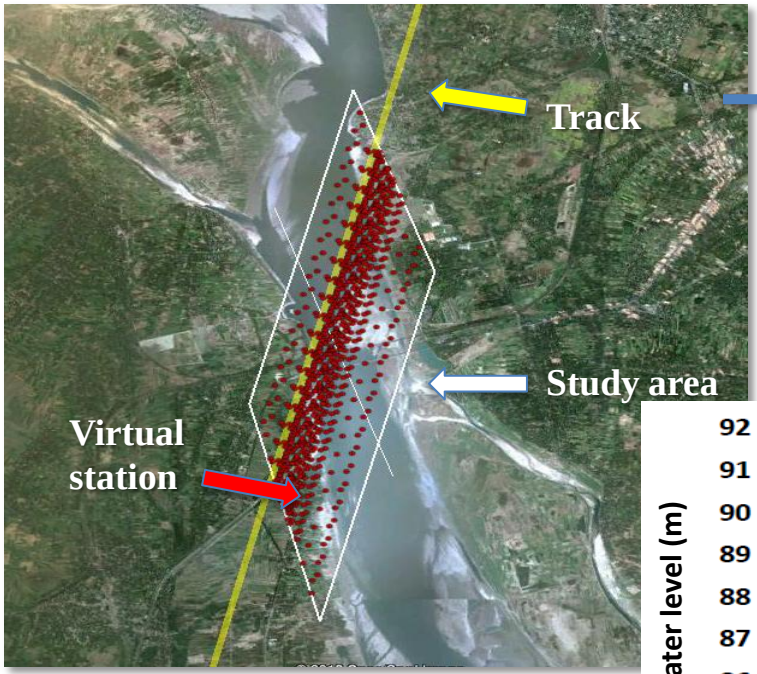
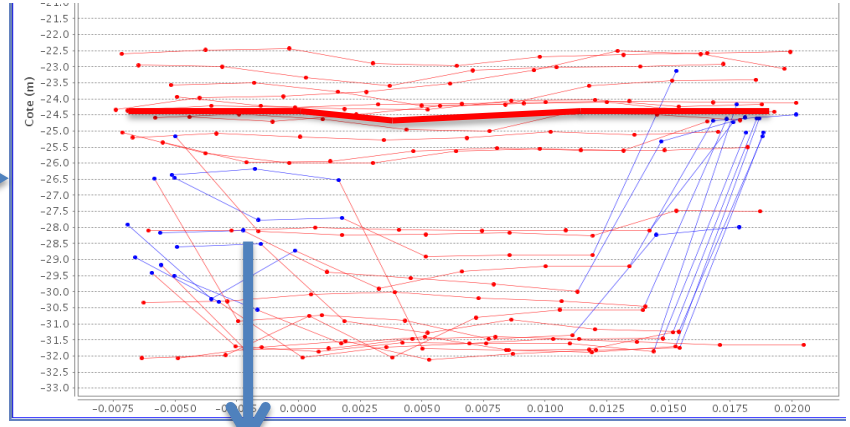
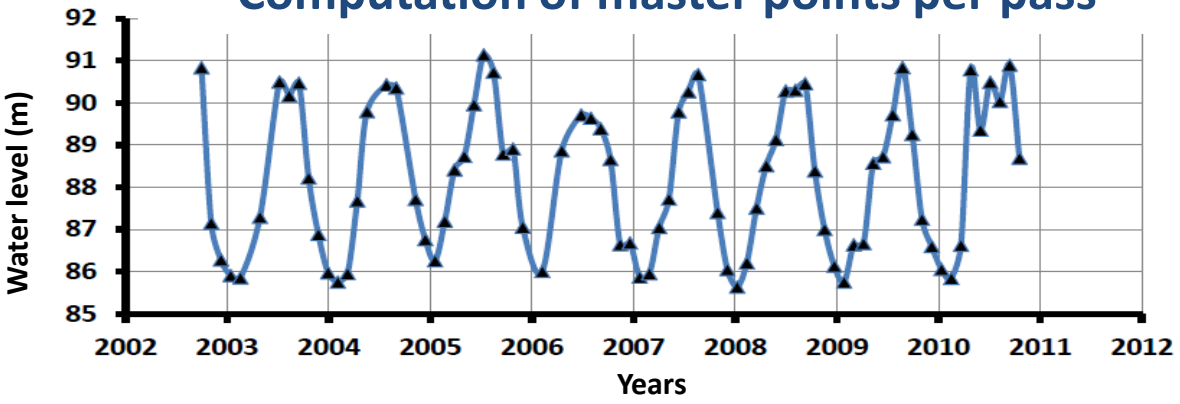


Data selection

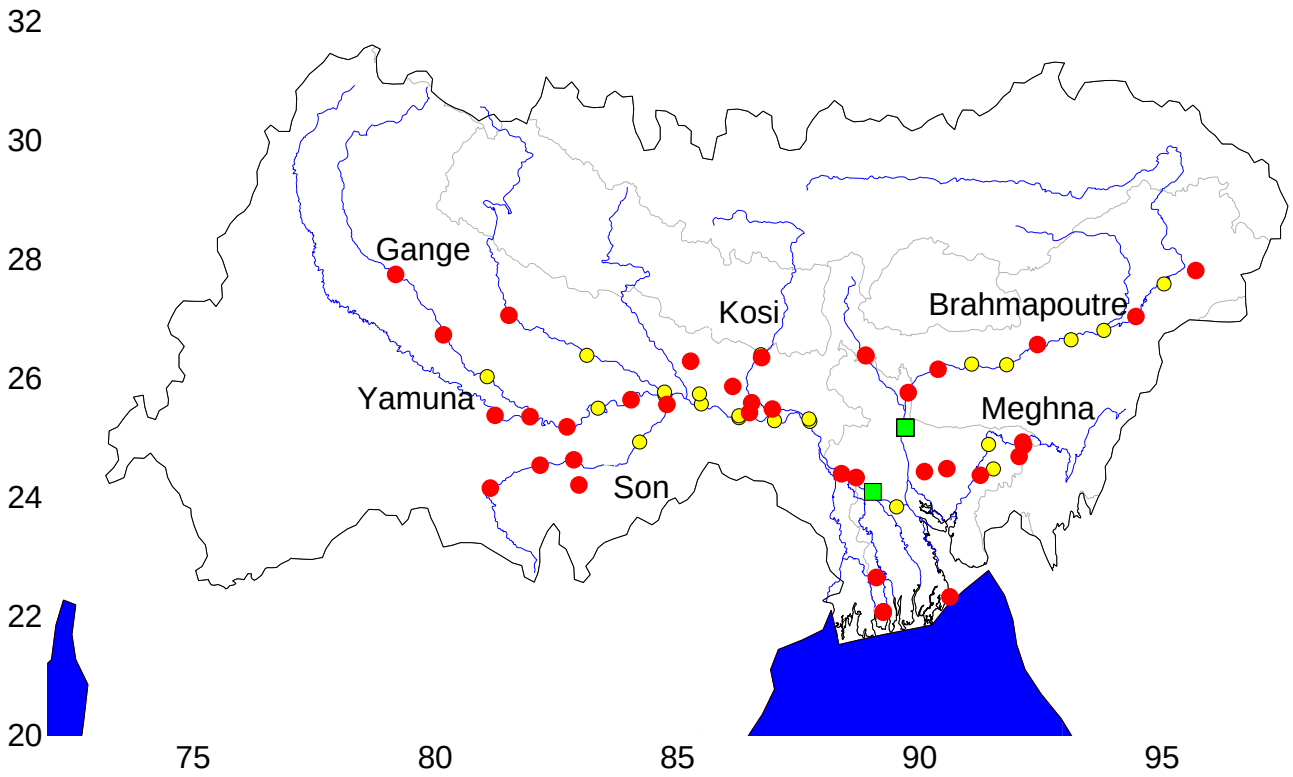
Refining the selection in a cross sectional view



Computation of master points per pass



Methodology : Envisat-based Virtual stations



Virtual station (VALS)
Virtual station (Hydroweb)
In situ station

38 new virtual stations from VALS (●)

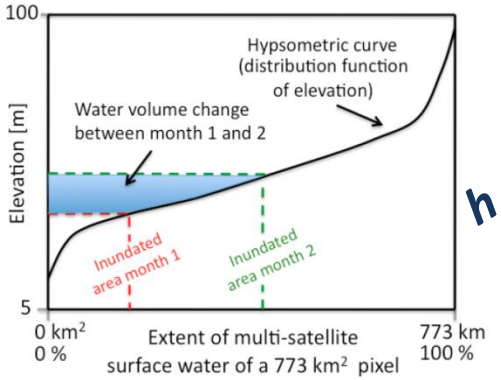
20 from hydroweb database (○)

Papa et al., J. Hydrol., under revision

Methodology : Monthly water level maps

Lake Constance

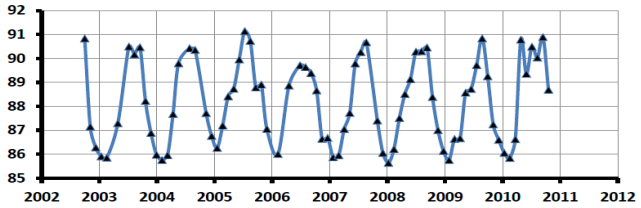
Elevation of each pixel
(minimum water level estimated)



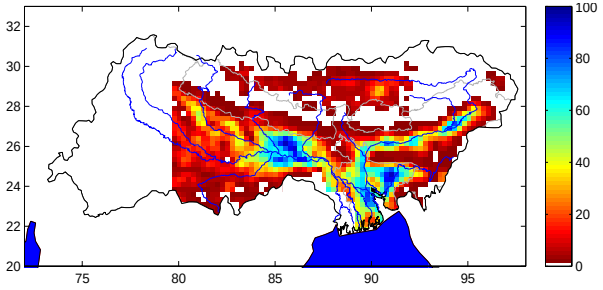
$h_{minimum}$

$$h_{min}(\lambda_i, \varphi_i, \alpha, \Delta T) = min\left(h(\lambda_i, \varphi_i, t)\right)_{P(\lambda_i,\varphi_i,t)\leq\alpha; t\in\Delta T}$$

Water levels



GIEMS
(inundated pixels estimate)



Frappart et al., Environ. Res. Lett., 2012

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Lake Constance

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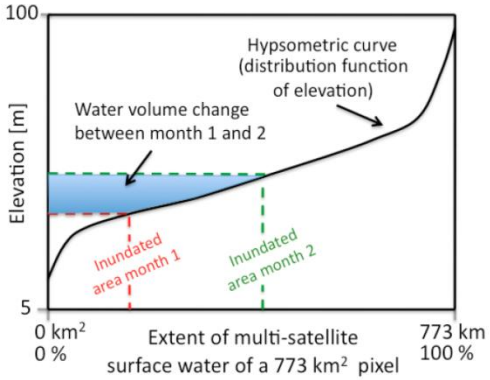

Estimated error: 10%

(Frappart et al., 2008;2011)

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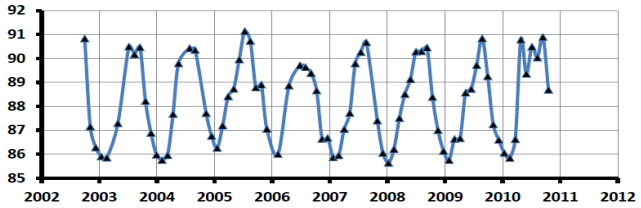
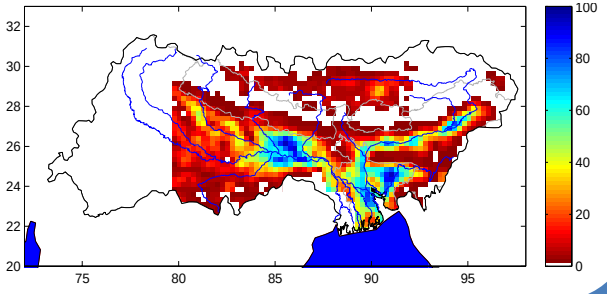
$h_{minimum}$

Water levels

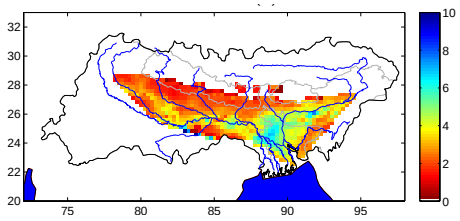


linearly interpolated over

GIEMS
(inundated pixels estimate)



Monthly water level maps



Frappart et al., Environ. Res. Lett., 2012

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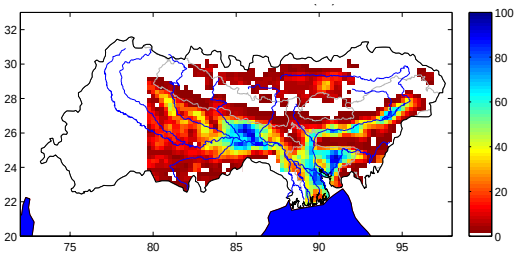
Lake Constance

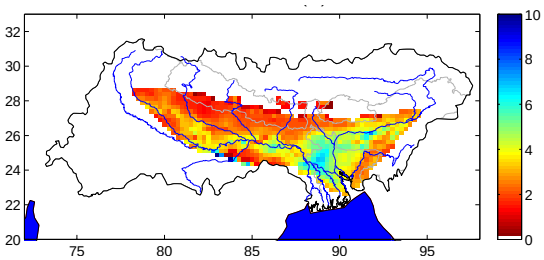
Methodology : Time-series of water volume variations

$$V_{sw} = Re^2 \sum_{j \in S} P(\lambda_j, \varphi_j, t) \left[h(\lambda_j, \varphi_j, t) - h_{\min}\left(\lambda_j, \varphi_j, P(\lambda_j, \varphi_j, t)\right) \right] \cos(\varphi_j) \Delta\lambda \Delta\varphi$$

Surface inundated



Water levels map



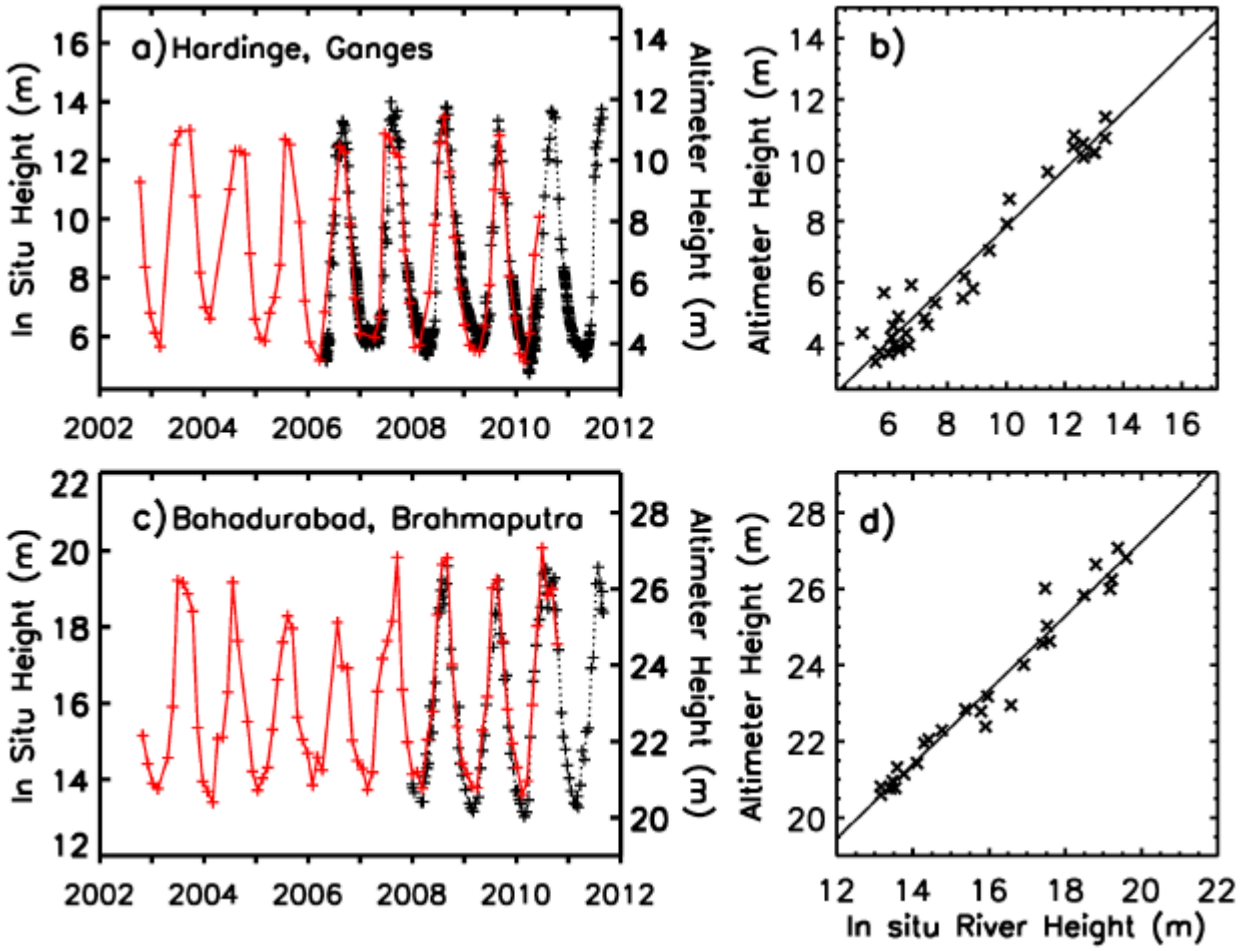
Water volume variation

0.25°Resolution

elementary surface in spherical coordinates
(Re : radius of Earth)

Frappart et al., Environ. Res. Lett., 2012

Results : Evaluation of ENVISAT



Ganges

RMSE : 0.36 m
R : 0.98
N : 38

Brahmaputra

RMSE : 0.29 m
R : 0.99
N : 29

Papa et al., J. Hydrol., under revision

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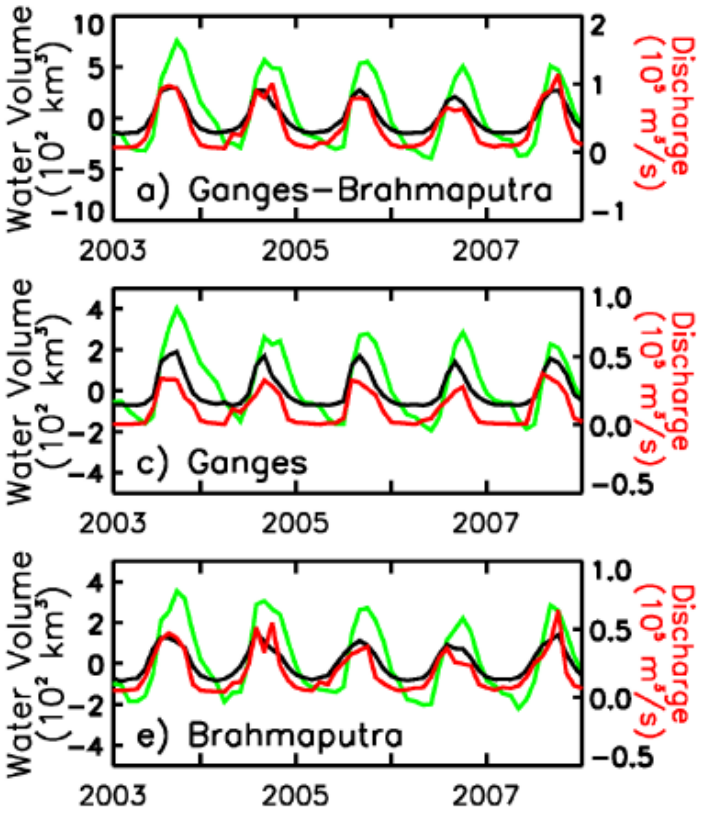
Lake Constance

Results : Seasonal and interannual variability



Satellite-derived surface water storage

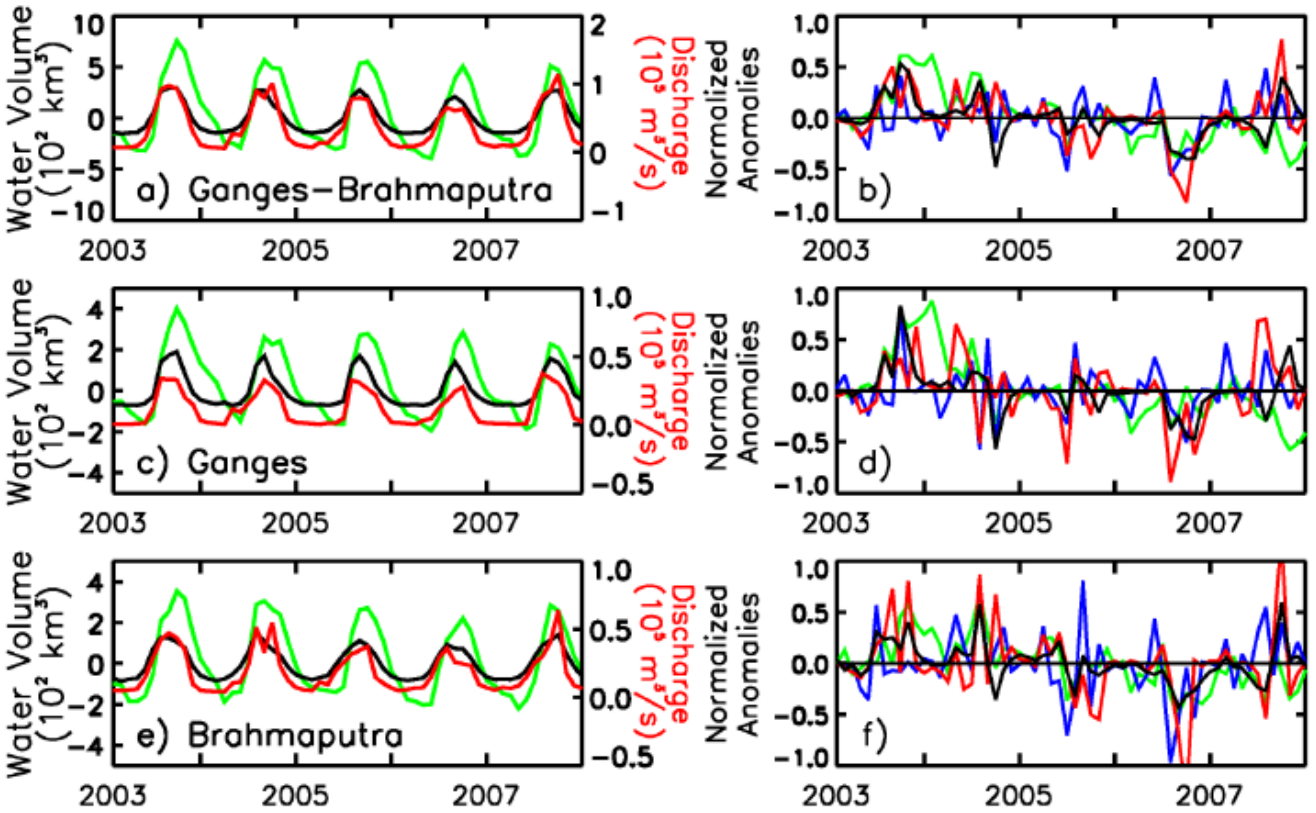
GRACE-based total water storage

Altimeter-derived river discharge

Papa et al., J. Hydrol., under revision

Lake Constance

Results : Seasonal and interannual variability



Satellite-derived surface water storage

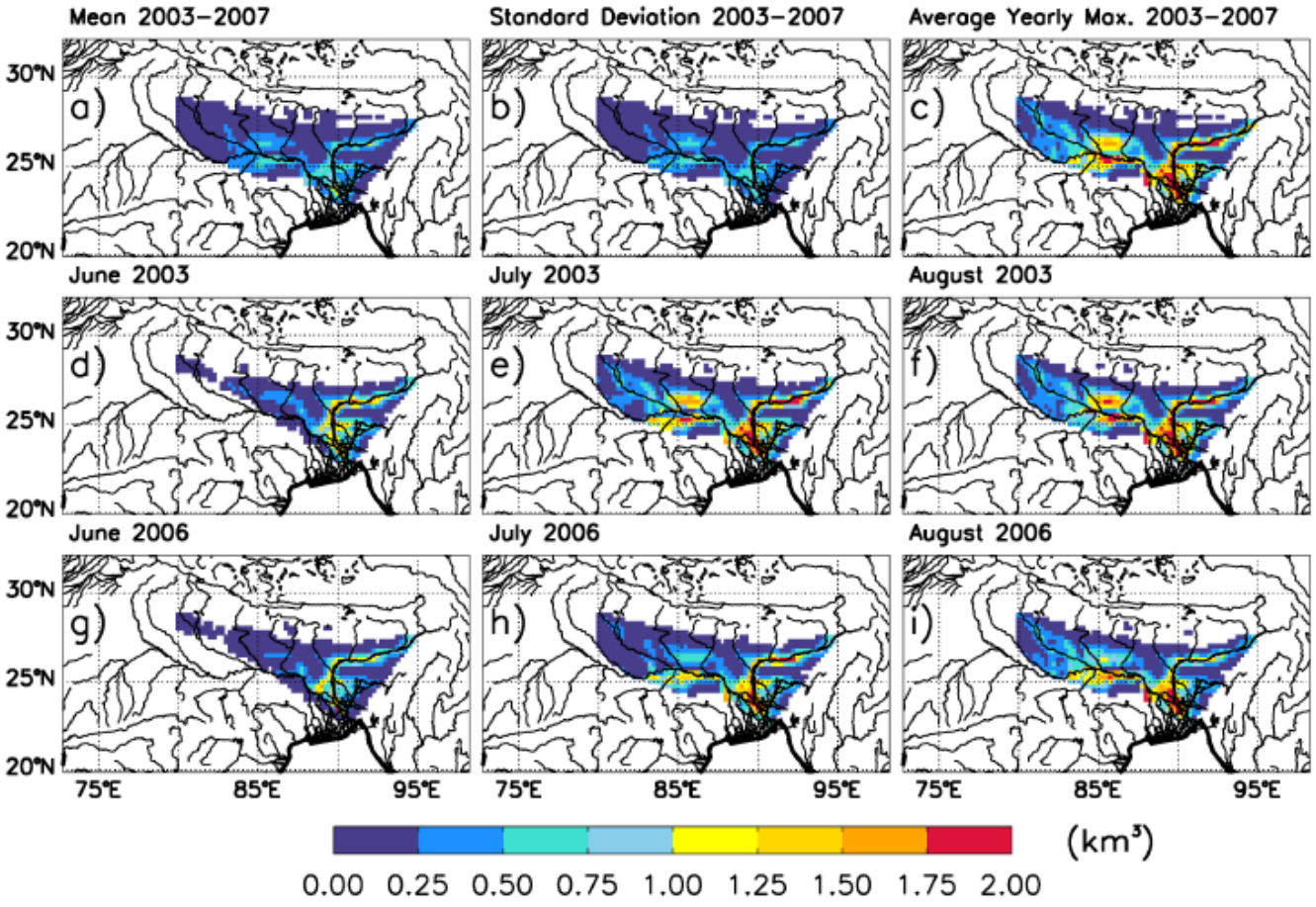
GRACE-based total water storage

Altimeter-derived river discharge

Mean precipitation from TRMM

Papa et al., J. Hydrol., under revision

Results : Maps of Ganges-Brahmaputra



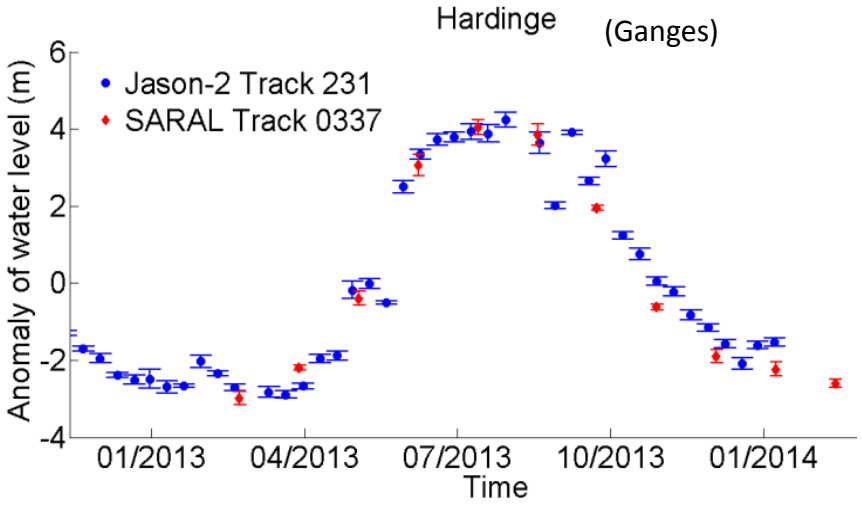
surface freshwater volume variations

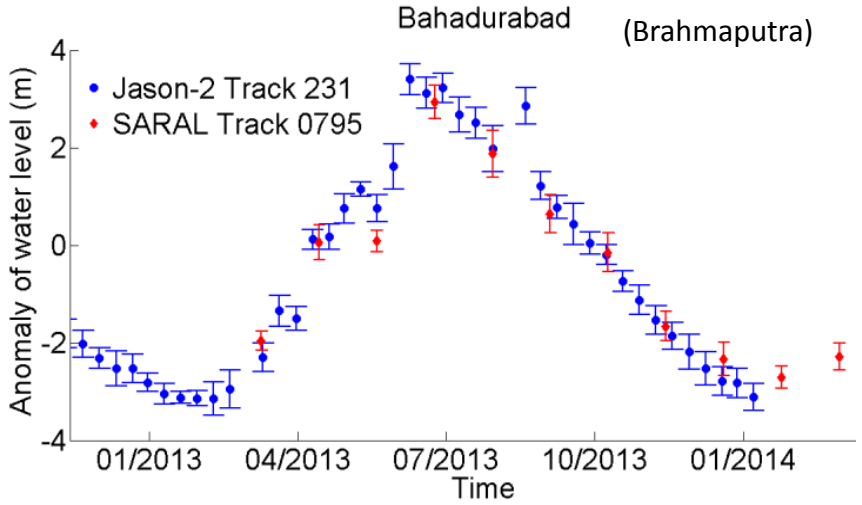
Wetter year

Dryer year

Papa et al., J. Hydrol., under revision

Results : A first assessment of SARAL-ALTIKA observations





	RMSE	
Jason-2/SARAL	0.37	(Ganges)
	0.45	(Brahmaputra)
Jason-2/ENVISAT	1 .00	(Ganges)
	0.83	(Brahmaputra)

cross calibration with Envisat and Jason-2

Frappart et al., Marine Geod., submitted

Conclusion and perspectives

Unique and new dataset of Surface Water Storage (period 2003-2007)

Ganges-Brahmaputra Basin : Mean annual amplitude of **410 km^3**

Orinoco Basin : Mean annual amplitude of **170 km^3**

Amazon Basin : Mean annual amplitude of **900 km^3**

Applying over large-scale tropical river basins (Congo, Yangtze …)

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Applying over large-scale tropical river basins (Congo, Yangtze …)

A better understanding of **the complex dynamics** of surface water in large basin

A better understanding of **hydrological and climate processes** in the Indian region

The opportunity to better quantify fluctuations in **freshwater flux to the ocean**

Extending using SARAL, JASON-2, JASON-3, Sentinel 3A ….

Thank you


Cryosat
Jason-1
Envisat
Jason-2
ERS
Spot
Geosat
GFO
TOPEX/POSEIDON