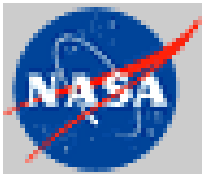# Multi-Satellite Remote Sensing of Global Surface Waters Extent, 1993-2004

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1. Surface Waters and their Roles

Terrestrial water ~1% of the total amount of water on Earth

Surface Waters (rivers, lakes, inundations,wetlands, snow pack, SM….)
  ~ 4% to 6% of the ice-free Earth surfaces

They play a crucial role in the global biochemical and hydrological cycles

  ● The largest methane source (~ 20-40%), a powerful greenhouse gaz
     The only CH_4 source dominated by short-term climate variations

  ● Regulate the local river hydrology
     Part of the fresh water input in the ocean via river discharges
     Sources for recharching ground water supplies.

     Surface Waters extent is a crucial parameter to measure
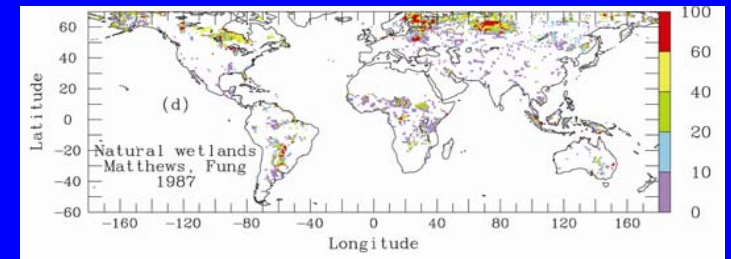However:
  ● Lack of reliable estimates of Surface Water extent
  ● Dynamics (seasonal, inter-annual) poorly understood

2. Existing Surface Water database (non exhaustive list)

Static estimates

- based on vegetation and soil distribution
- no seasonal or inter-annual variations
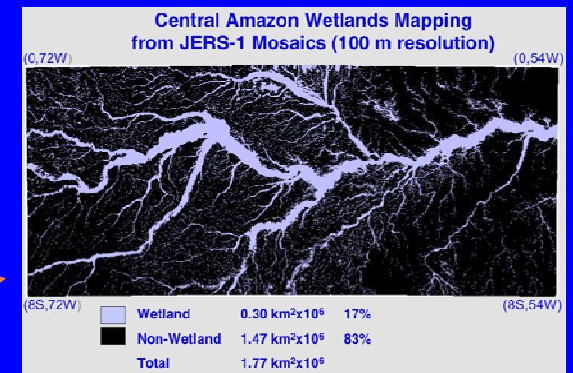   - Ex: wetlands global scale, [Matthews et al., 1987], IGBP

Satellite-derived estimates

Active microwave (SAR)

- very high spatial resolution
- large data volume: difficult to handle for global analysis
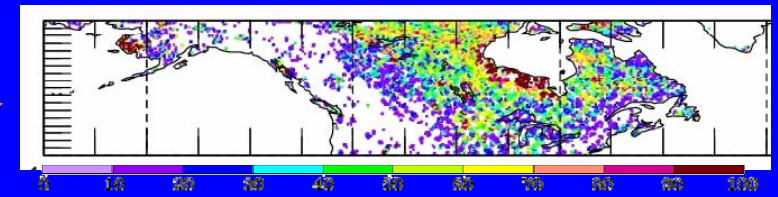- few time samples: difficult to assess the dynamic
    - Ex: the Amazon, [Hess et al., 2003,RSE]

Active microwave (altimeter)

- usually used for river and lake water levels
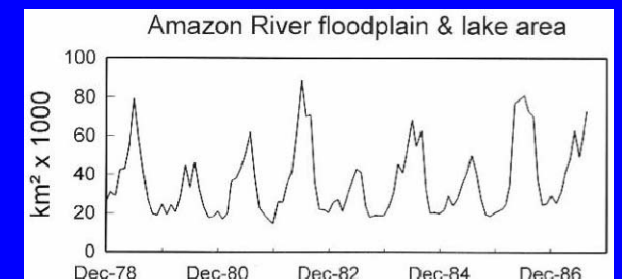- thin track: not total coverage except over boreal regions
    - Ex: the Boreal regions, [Papa et al., 2006, IJRS]

Passive microwave (SSMR, SSM/I…)

- water reduces emissivities in both linear polarizations
- difficult to account for vegetation contribution when used alone
- low spatial resolution (~ 20 km)
    - Ex: The Amazon, [Sippel et al., 1998, IJRS]

3. A multi-satellite method to monitor land surface water extent

The idea:
To merge satellite data from different wavelengths

- to benefit from their different sensitivities
- to help separate the contributions of the various parameters within a pixel (standing water, dry soil, vegetation…)

It includes satellite data:
- available on a global basis with spatial resolution compatible with climatological applications
- available on long time series (at least 10 years)

Passive microwaves
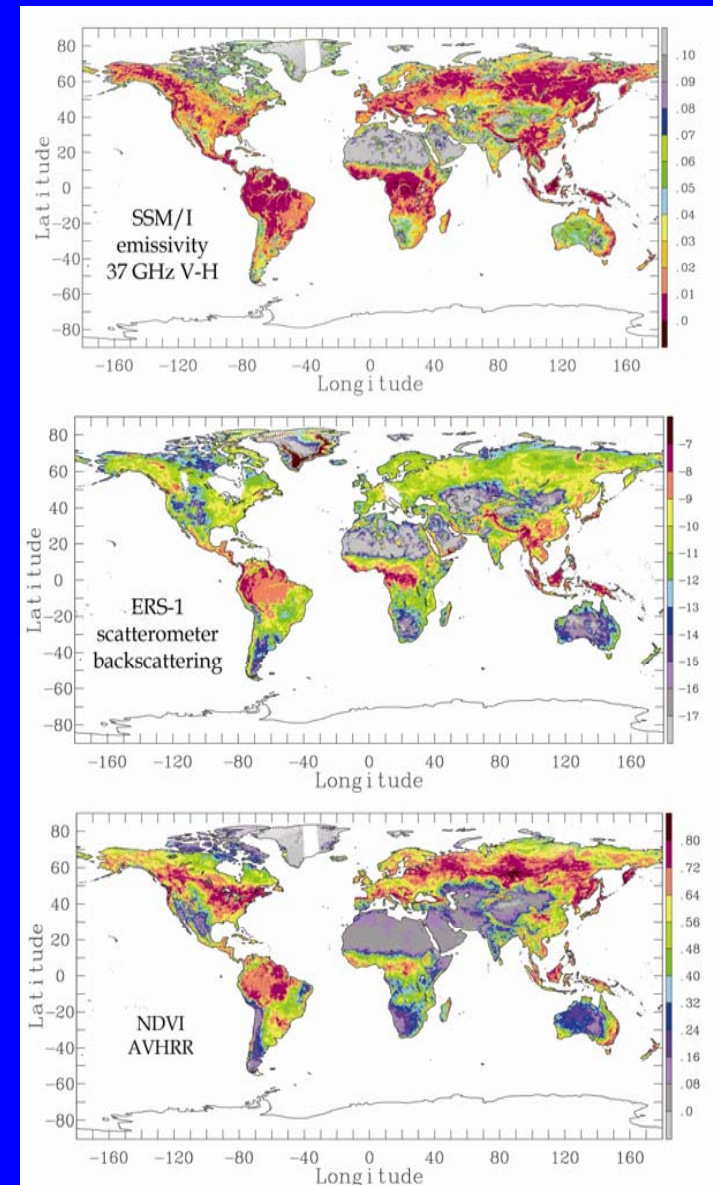SSM/I emissivities at 19, 37 GHz, H and V polarizations
Active microwaves
ERS scatterometer backscattering coefficient at 5.25 GHz
Visible and near infrared
AVHRR NDVI (visible and near-infrared reflectances)

[Prigent et al, 2001]

# 3. A multi-satellite method to monitor surface waters extent

The methodology (3 steps):

Pre-processing
> • when relevant, cloud-screening and subtraction of the atmospheric effects Emssivities calculated from SSM/I obs. by removing the atmosphere contribution (clouds, rain), the modulation by Ts (IR, visible from ISCCP, NCEP) [Rossow et al., 1999; Prigent et al, 2006, BAMS]
> • data sets mapped on an equal-area grid 0.25°x0.25° resolution at equator

Clustering of the merged satellite data to detect inundated pixels (NN)

Fractional coverage of flooding then estimated from a linear mixture
> model with end members calibrated with active microwave observations to
account for vegetation
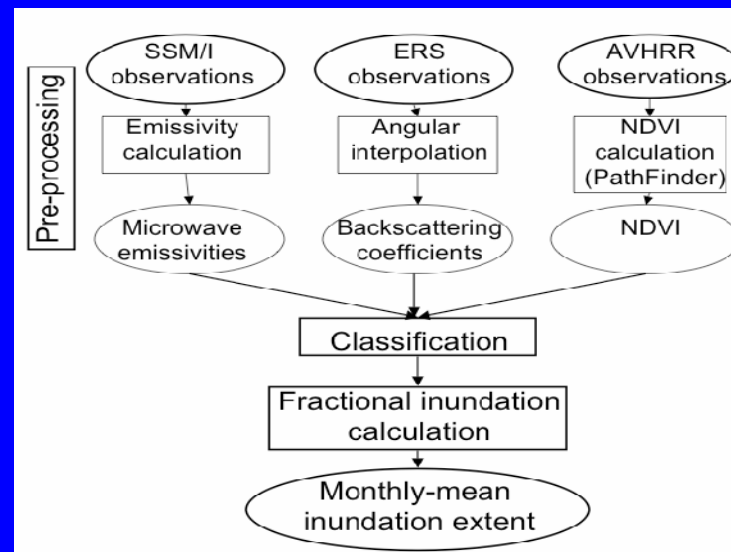
4. Results and Evaluation

Global fractional inundation extent (0.25 deg, monthly, 1993-2000)
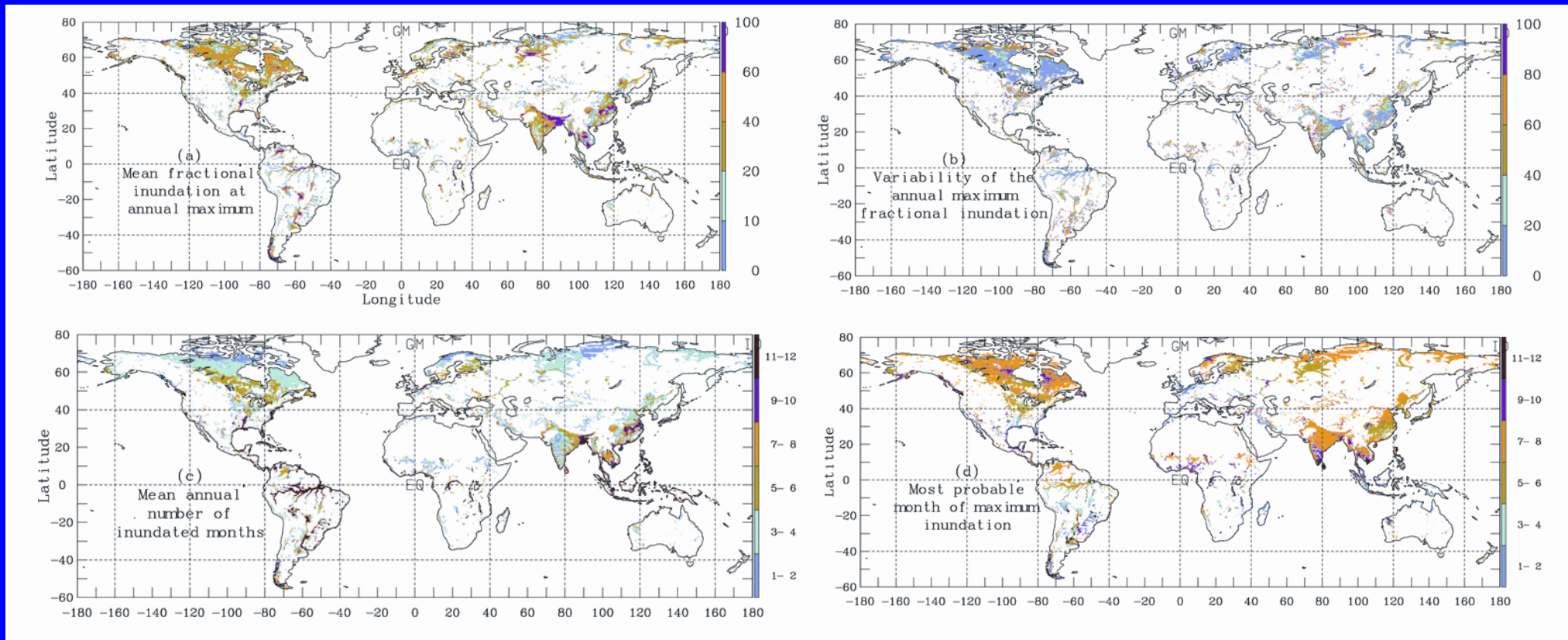
➤ On the large scale, estimates show realistic structures in good agreements with static estimations

➤ Results capture well major inundated areas
Ob river, Amazon basin, North of Canada, India, China…

4. Results

Global and zonal temporal variations of inundated surfaces extent

General good agreement with static estimates

Satellite estimate
Wetlands, Matthews
Wetlands, Cogley
Lakes ,Cogley
Rice fields, Matthews
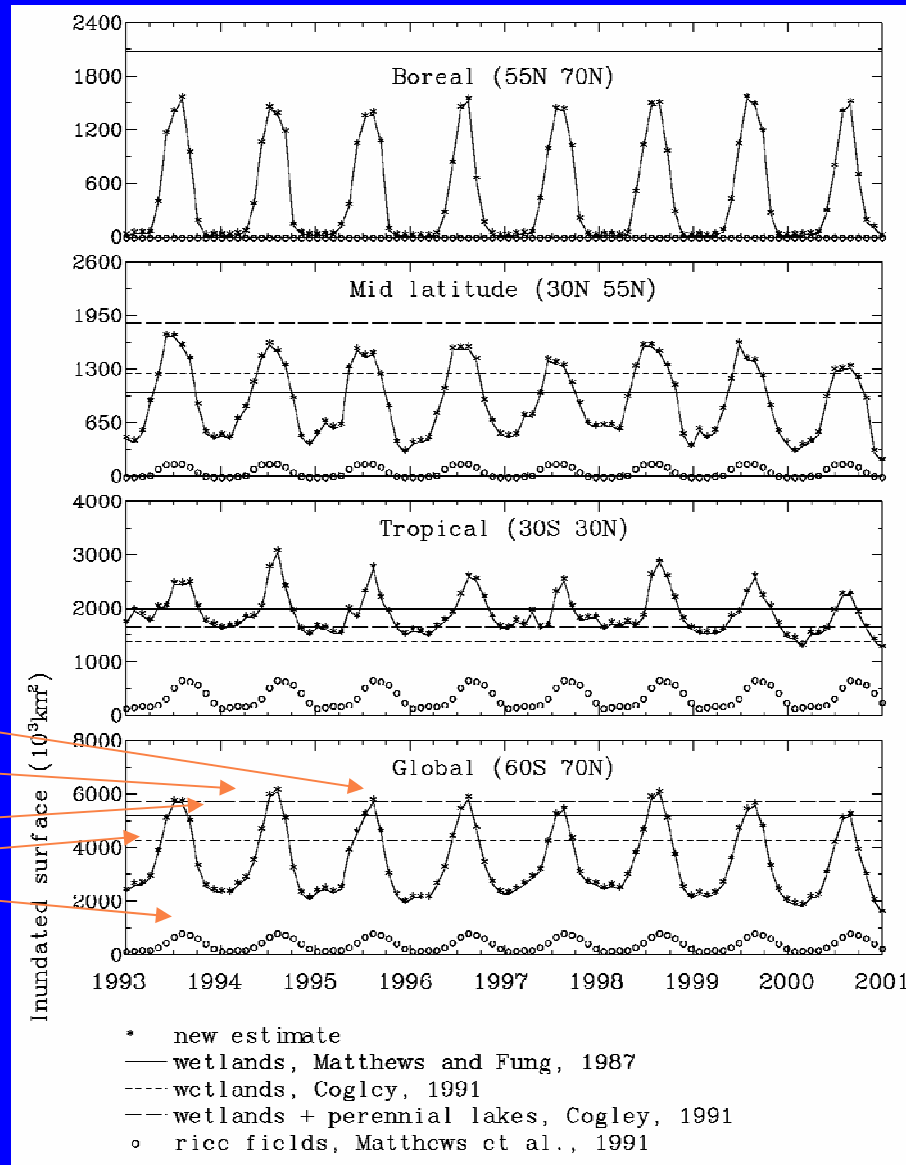
Boreal region
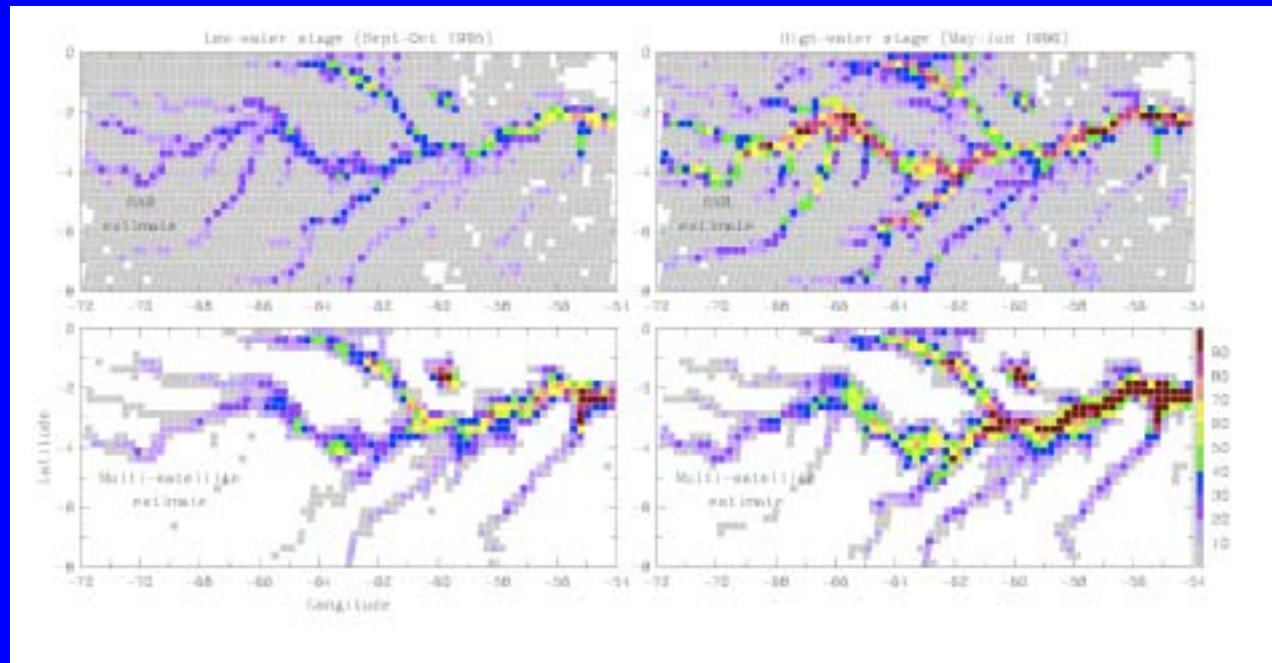max: 1.5 million km²
seasonal cycle, max. in summer

Northern Mid latitude
max: 1.8 million km²
seasonal cycle, max. in summer

Tropics
max: 2.6 million km²
strong seasonal cycle
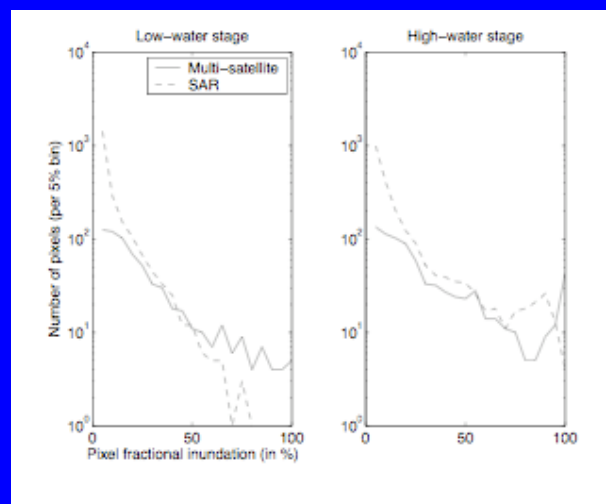and inter-annual variability

Global results
max: ~6.3 million km²

[Prigent et al, 2007, JGR]

5. Comparison of the WSE estimates with other RS estimates
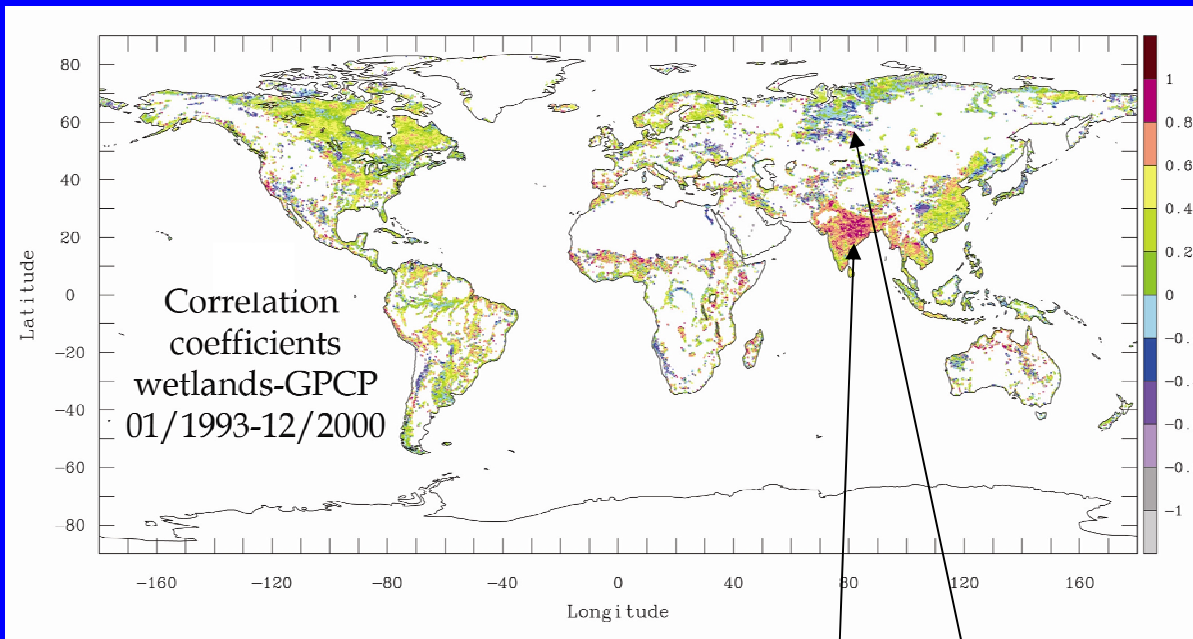

SAR estimates

Multi-Satellites derived estimates

Good agreement between the SAR-derived estimates and the Multi-Satellites derived estimates

Some differences at higher and lower stage for small and large extents (<10%; >90%)
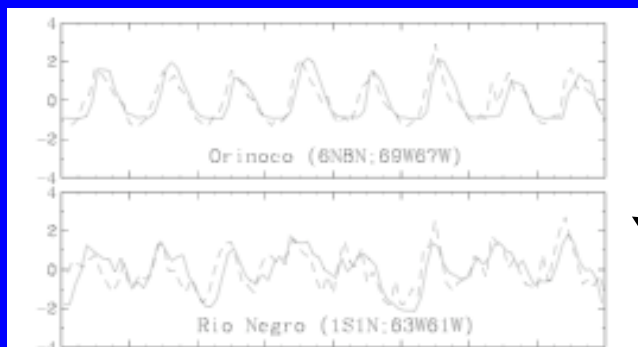
[Prigent et al, 2007, JGR]

5. Comparison of the WS estimates with related variables

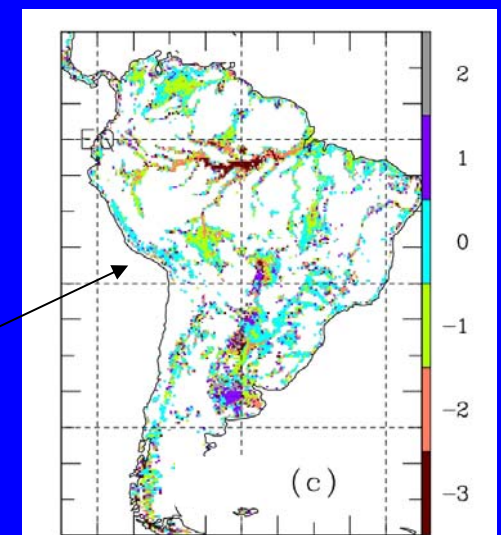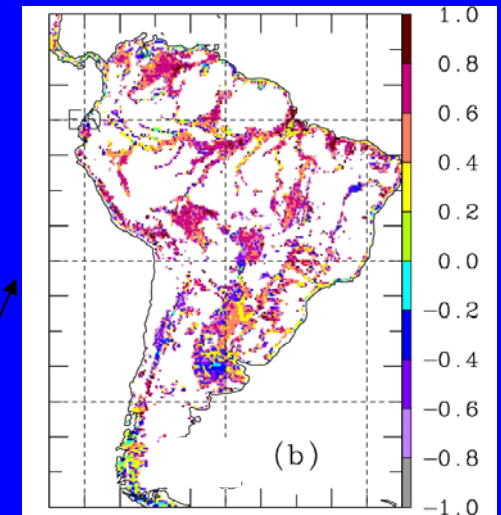Correlation between wetland extents and GPCP rain estimates over 8 years

Different regimes:
- rain-fed inundation (direct rain at the location)
- inundation related to snow-melt or rain upstream location

Time-lagged maximal correlation between inundation estimates and GPCP and the time lag in month over South America
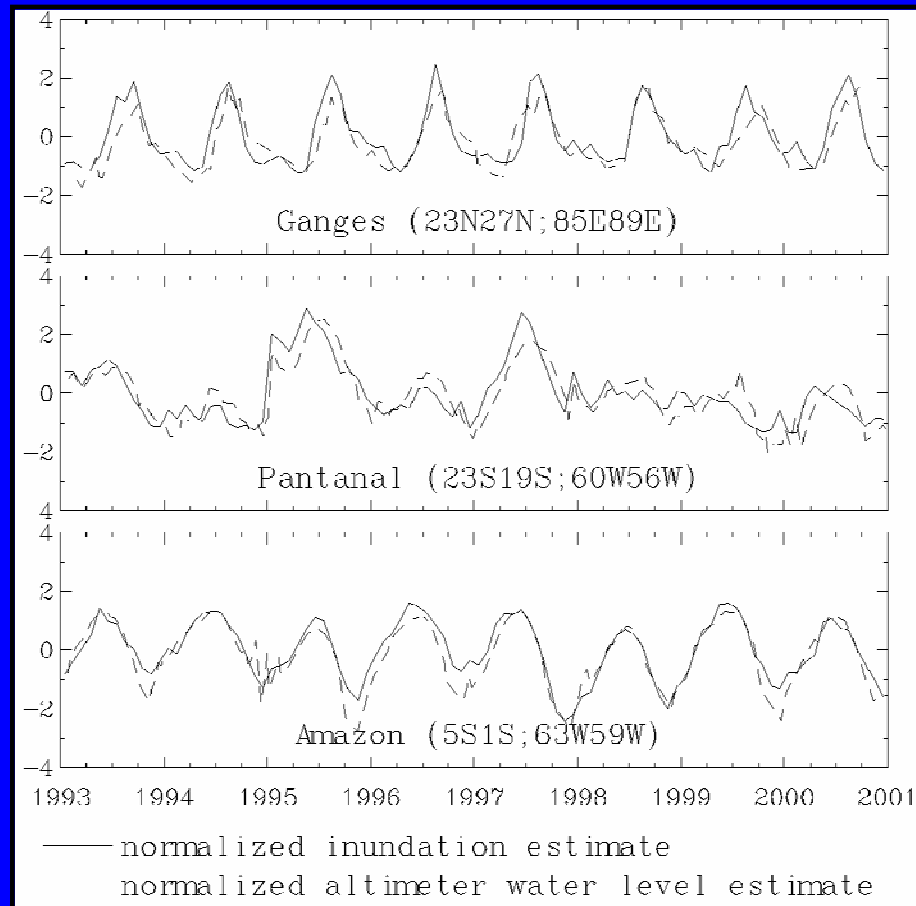
Time series of anomalies (normalized)

[Prigent et al, 2007, JGR]

5. Comparison of the WS estimates with related variables

Comparison with altimeter water level estimates
(Generro et al., Surface water monitoring by satellite altimetry,
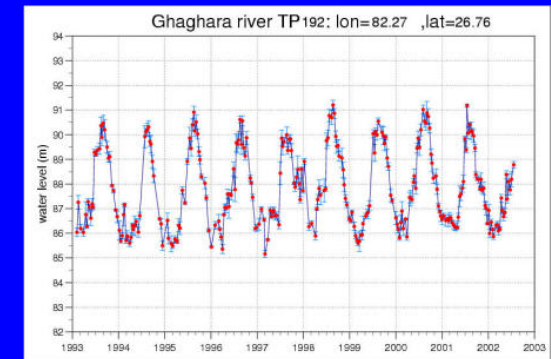www.legos.obs-mip.fr/soa/hydrologie/hydroweb)

The Ganges

[Papa et al., 2006,GRL]

The Pantanal in South America

The Amazon

Very good correspondence in the cycles between the altimeter-derived water
level and the satellite-derived inundation extent estimates

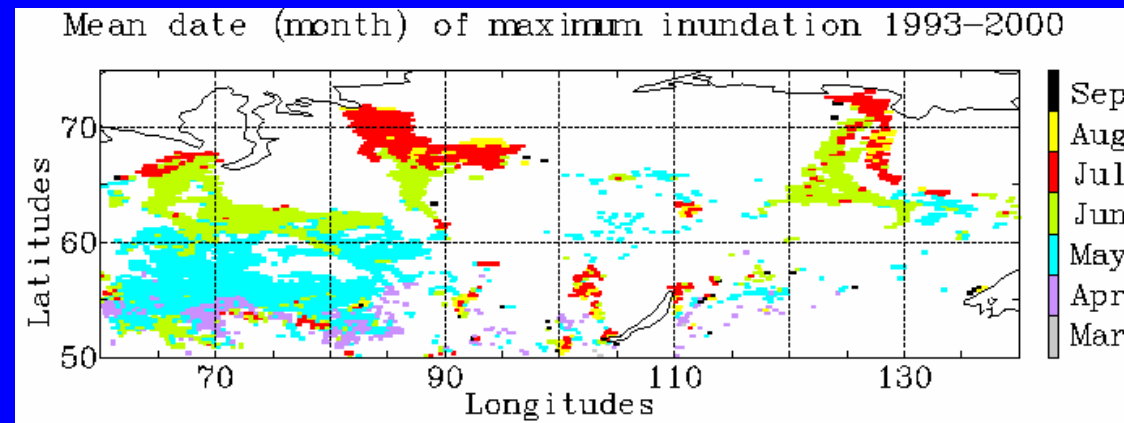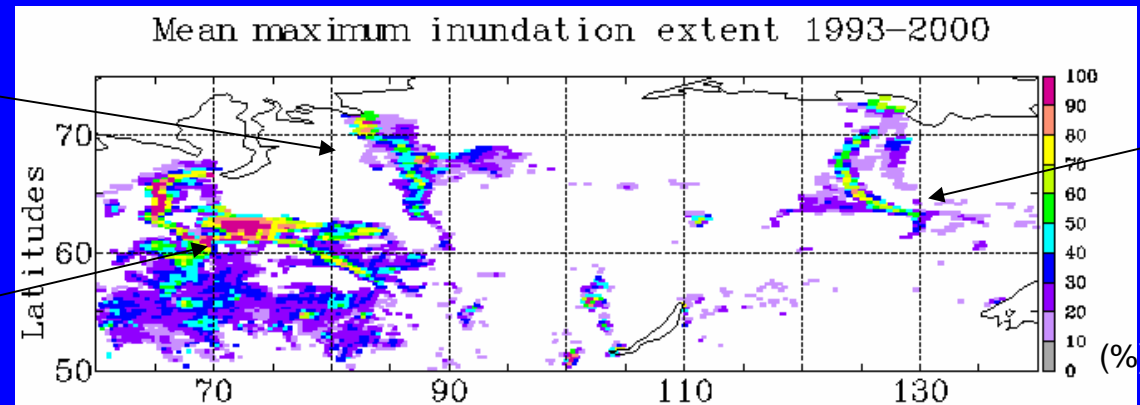# 6. Application: Case study: the large Siberian watersheds

Mean maximum inundation extent 1993-2000

Yenissey

Ob

Lena

(%)

[Papa et al., 2007, JGR]
[Papa et al., 2007, SIG]

Mean date (month) of maximum inundation 1993-2000
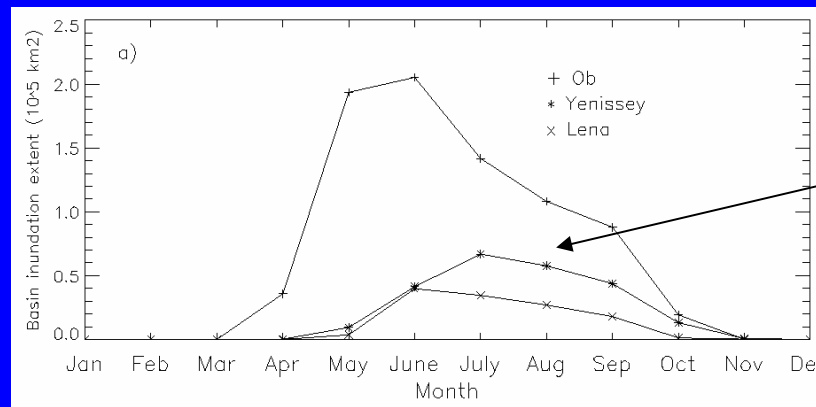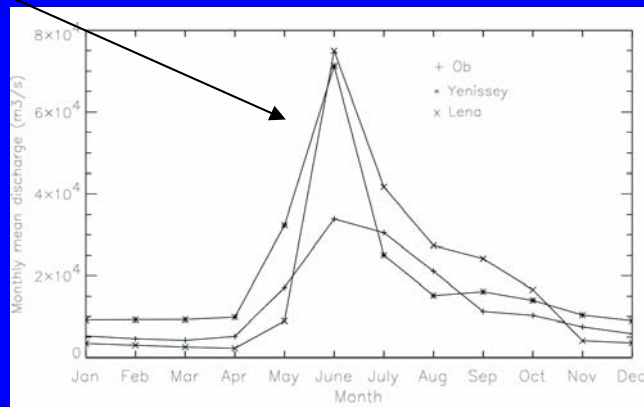
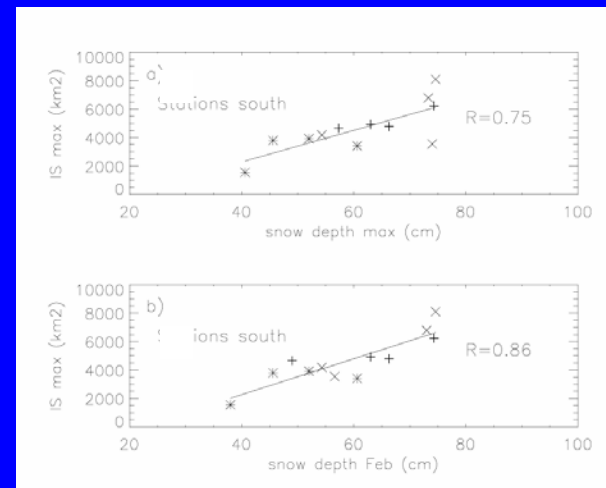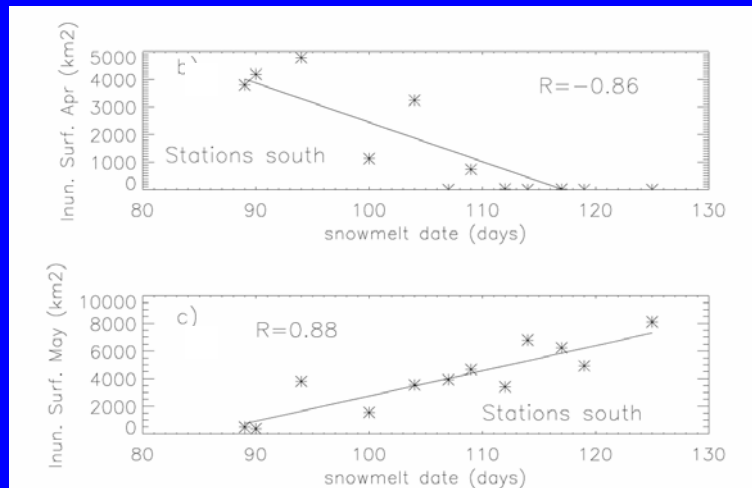Latidunal dependence on gradual snow melting

In-situ discharge (m3/s)
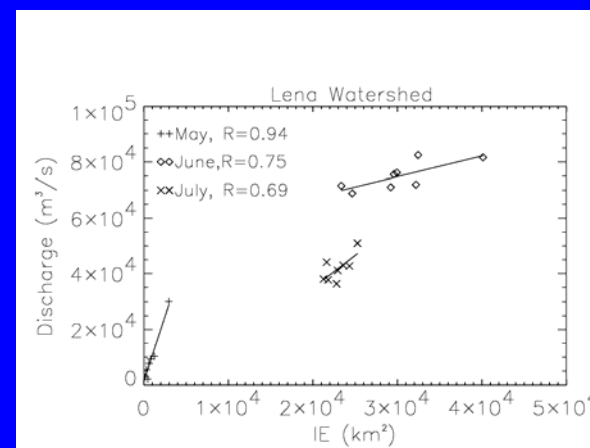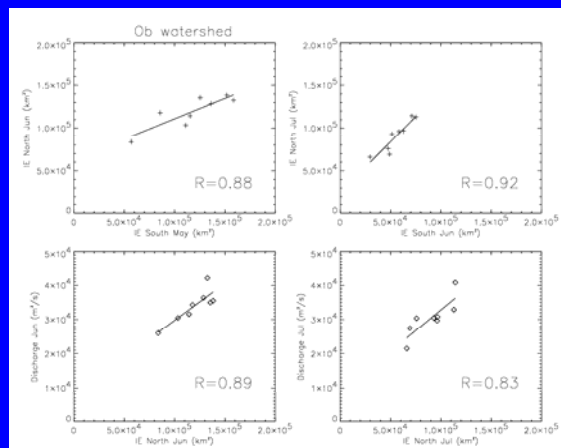
Basin inundation Extent (km2)

6. Application : Case study: the large Siberian watersheds

1. Evaluation with in-situ snowmelt date and snow depth over the southern Ob river [Papa et al., 2007, JGR]

Good relation between the inundation extent and in-situ snow snowmelt date and snow depth in the Southern area
In the Northern part of the basin, no such relation were found: inundation is regulated also by the water coming from downstream basin

2. Evaluation with in-situ run-off and discharge at the Ob estuary [Papa et al., 2007, SIG]

Good relation between the inundation extent and in-situ runoff parameter at the Ob, Yenissey, Lena estuaries
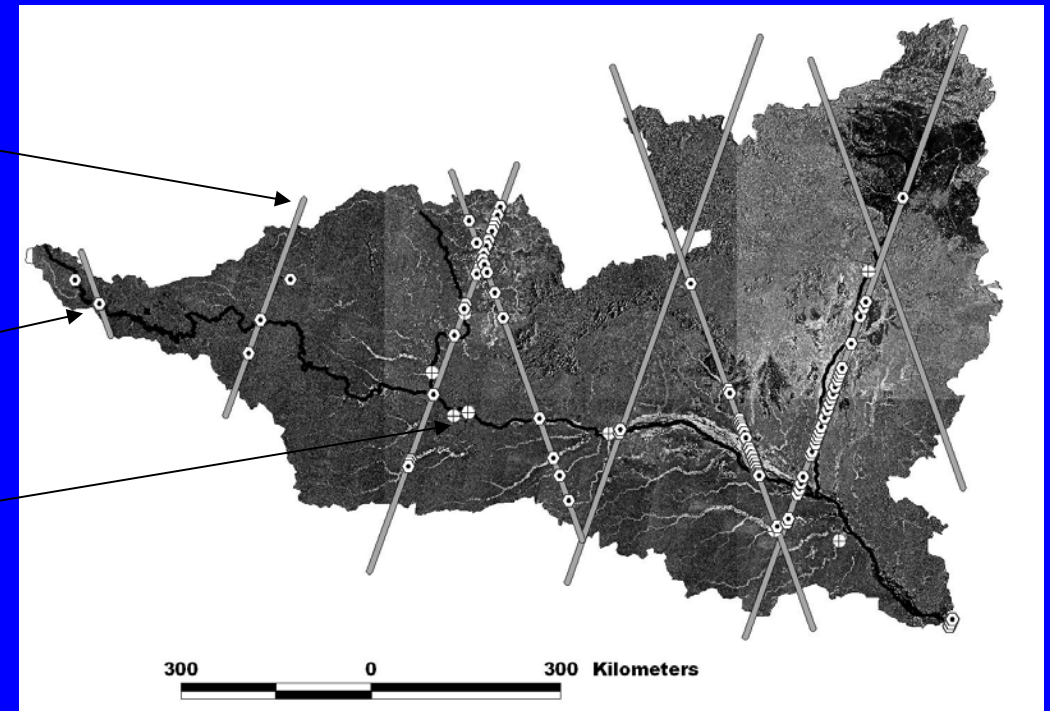
7. Application: A combination of multi-satellite derived WSE with water level variations from altimetry (Topex-Poseidon) over the Rio Negro River

Identification of floodplains/inundation using multi-satellite technique

Construction of water level time series (TP)

Estimation of water level maps

Computation of water level variation maps

Computation of surface water volume variations
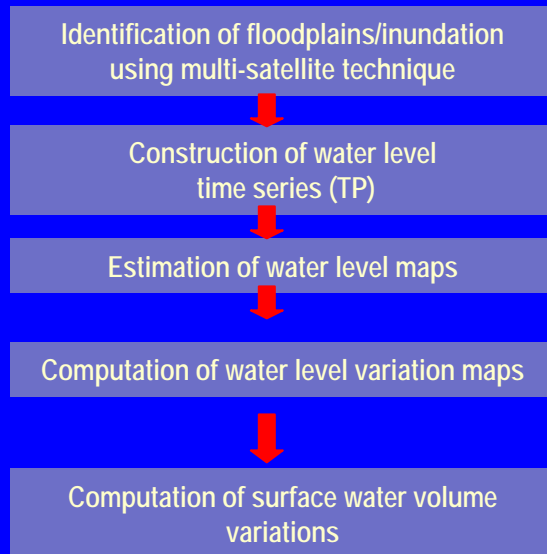
Topex-Poseidon tracks

Topex-Poseidon virtual stations

In-situ stations

300   0   300 Kilometers

Map of water level (m)

Water Level (m) - 1/1996

Water Level (m) - 6/1996
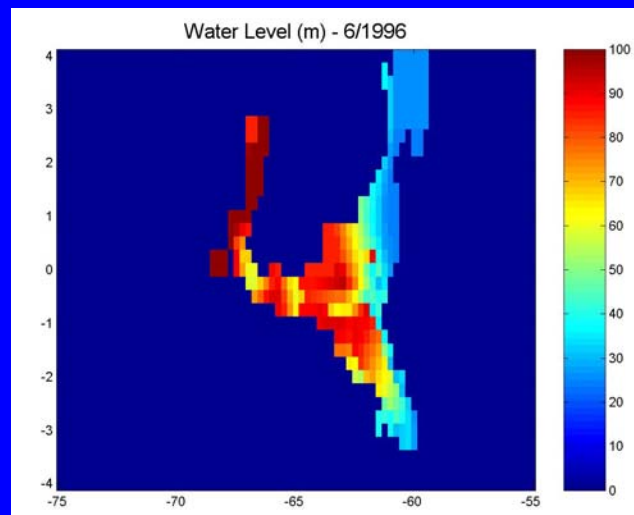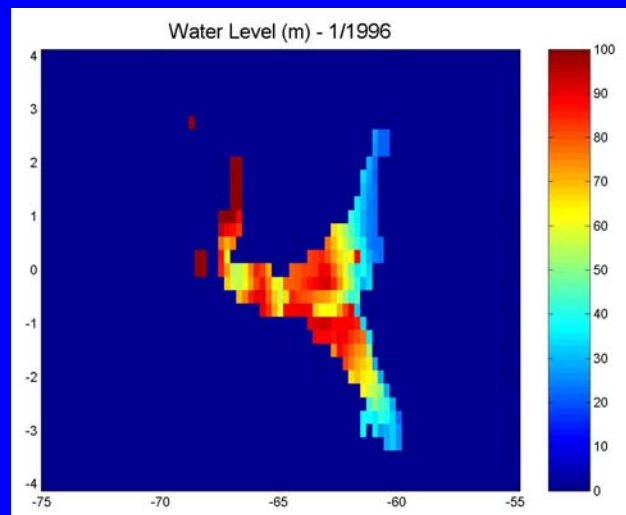
[Frappart et al., 2007, JGR]

See the poster
Frappart et al., on Tuesday
11am-12pm

Results: surface water volume variations (1993-2000)
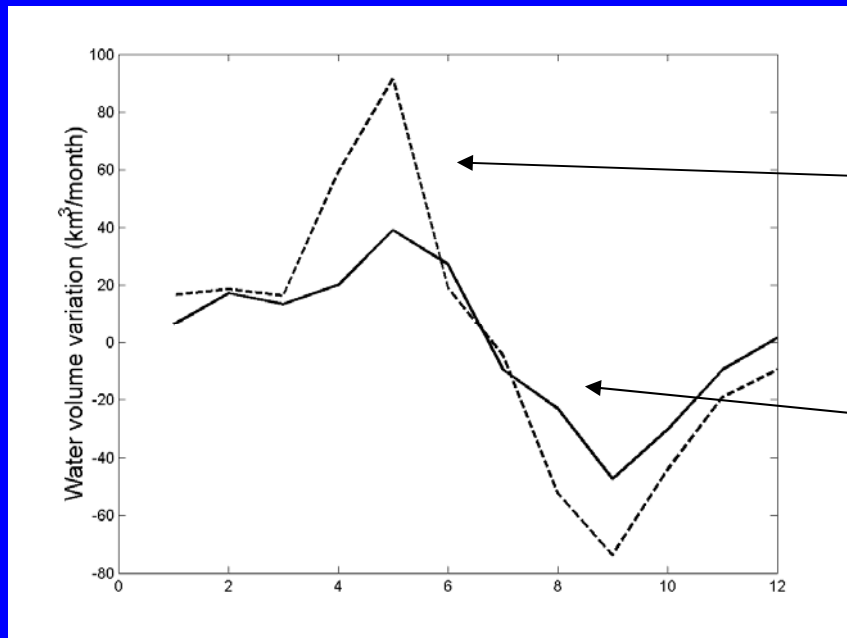
Good agreement in the seasonal cycle between new estimates and the Grace estimates

Grace
(2003-2006)
(ground water
+soil moisture
+surface water)

Multi-satellite
and altimeter
(1993-2000☐☐)
(surface water)

Good agreement between water volumes change and the total GPCP rain over the basin

…lack of in-situ measurements…

7. Application: A combination of multi-satellite derived inundation with water level variations from altimetry (Topex-Poseidon) over the Rio Negro River
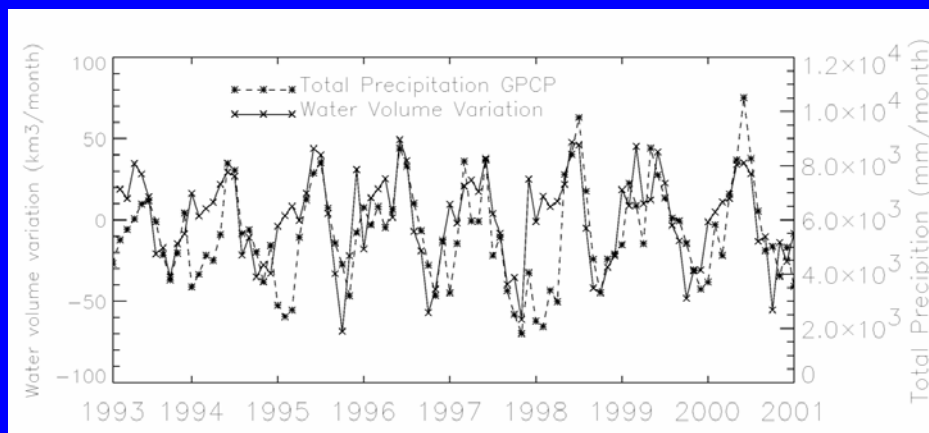
Perspectives: Estimation of "Ground water+ Soil moisture"

"Ground water+ Soil moisture"=Total water (Grace)- Surface Water (Multi-Alti)
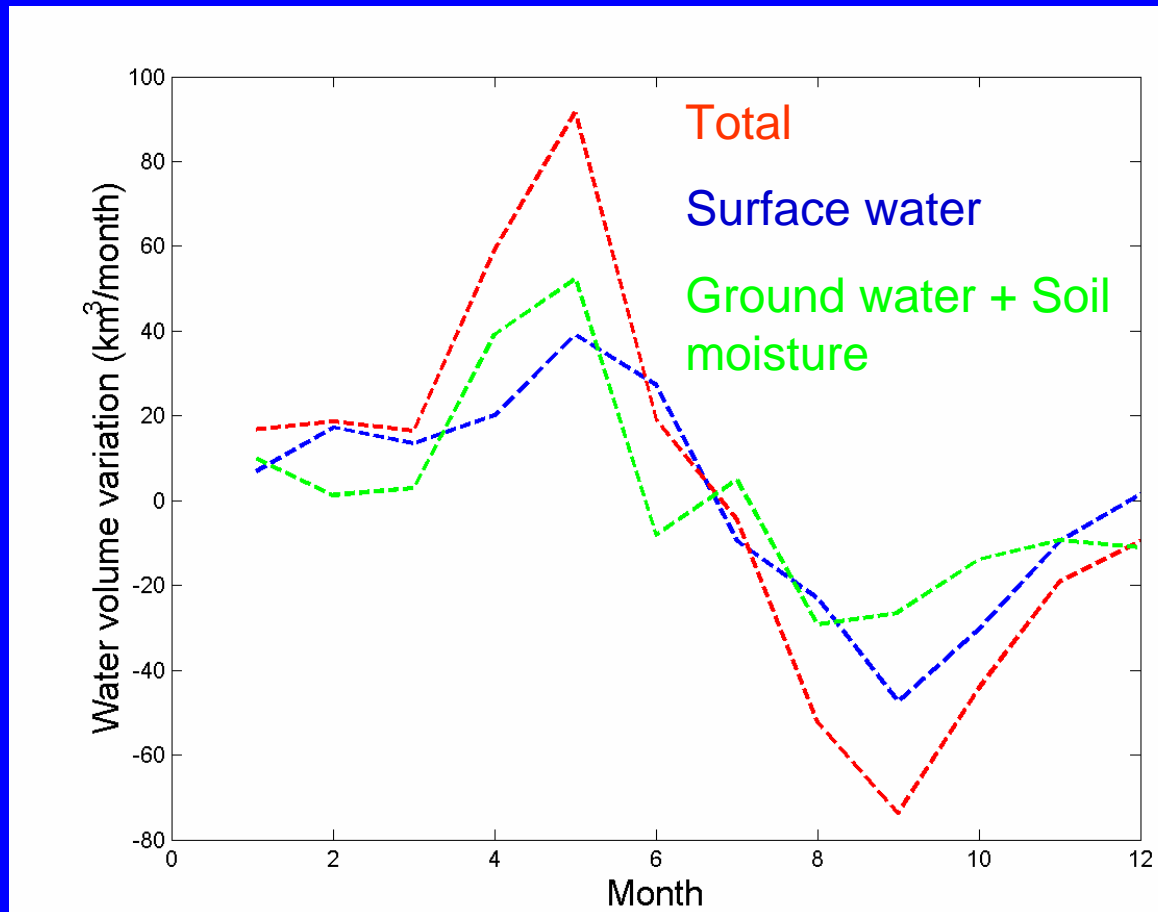
[Frappart et al., 2007, JGR]

Soil moisture coming soon with SMOS….. And soon direct comparison with Grace…

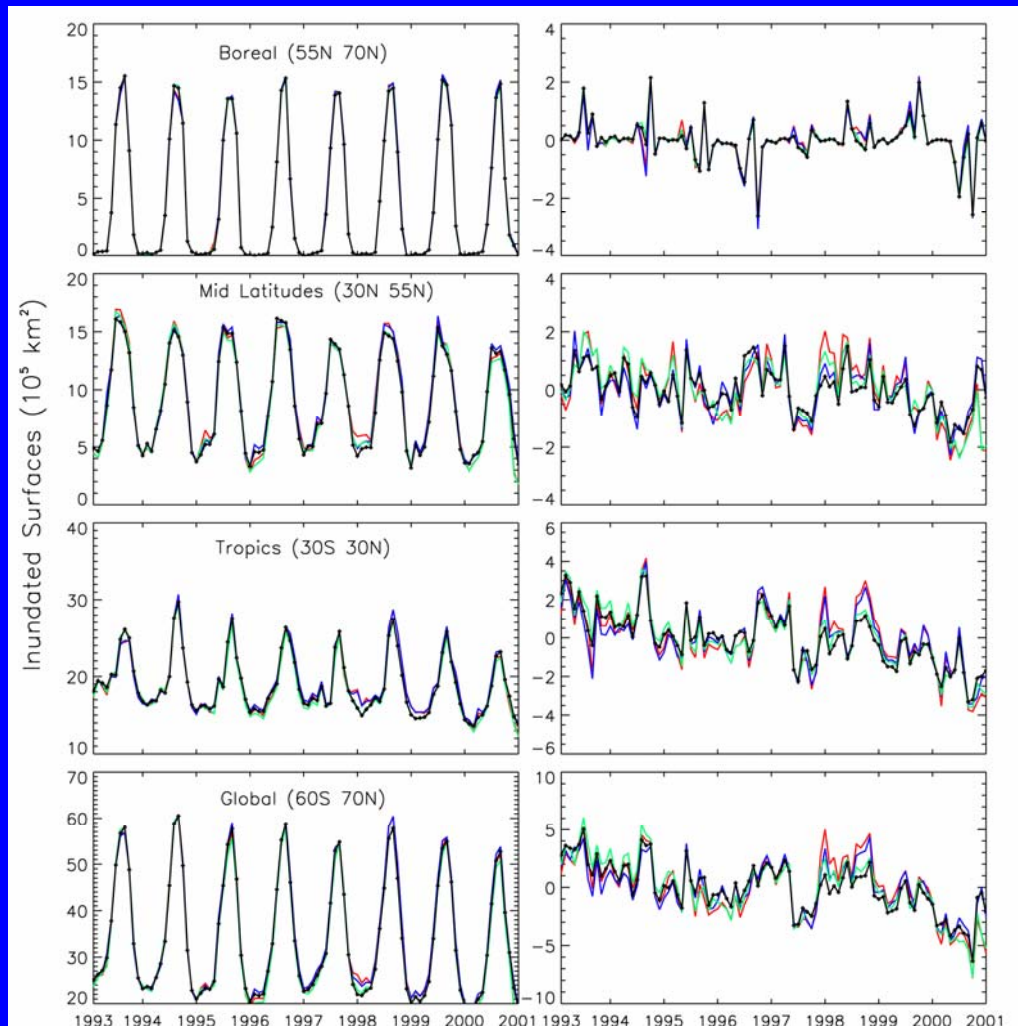# 8. Global Surface Water Extent Dynamic, 1993-2004

After 2001, no more ERS scatt. data… alternative solution: using Quicscatt (not simple… because of difference in frequency) : Use of ERS mean monthly climatology to extent the dataset

Global and zonal temporal variations of water surfaces extent Over 8 years:

Comparison:
- ⬤ Using both ERS and AVHRR temporal Signal (red)

- ⬤ Using ERS temporal signal and NDVI mean monthly climatology (green)

- ⬤ Using NDVI temporal signal and ERS mean monthly climatology (blue)

- ⬤ Using both ERS and NDVI mean monthly climatology (black)

High confidence in using both ERS and NDVI mean monthly climatology

8. Global Surface Water Extent Dynamic, 1993-2004

12 years time-serie

Anomaly
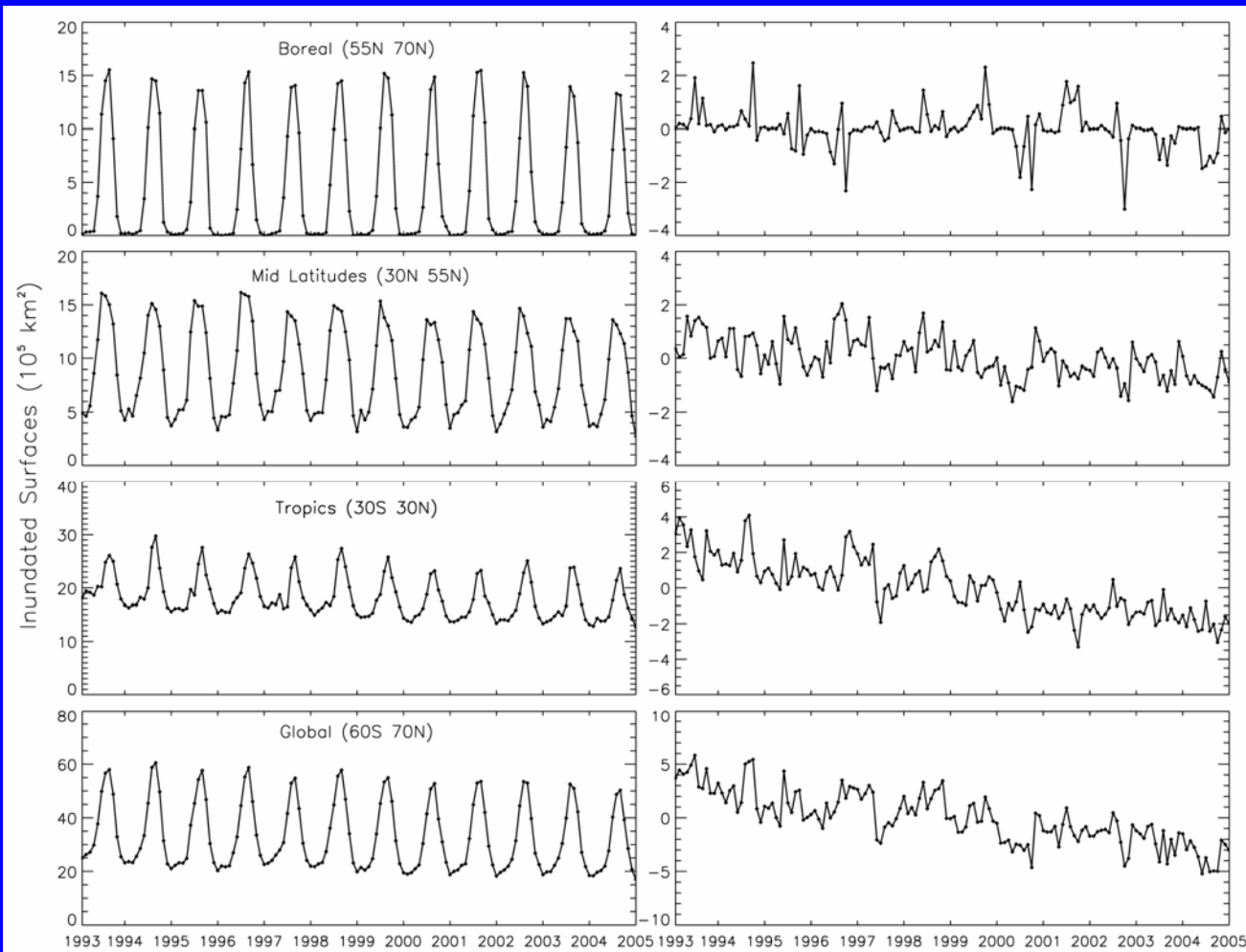
Boreal region

Northern Mid latitude
Slightly decrease

Tropics
Decrease in ~15% in 12 years

Global results
Decrease in ~10-15%
in 12 years

Need to understand and interpret these results and to compare them with other variables

8. Global Surface Water Extent Dynamic, 1993-2004

Trend in the Water Surface Extent 1993-2004

(b) Trend in the wetland extent from 1993 to 2004 when the uncertainty in the trend is less than 50%
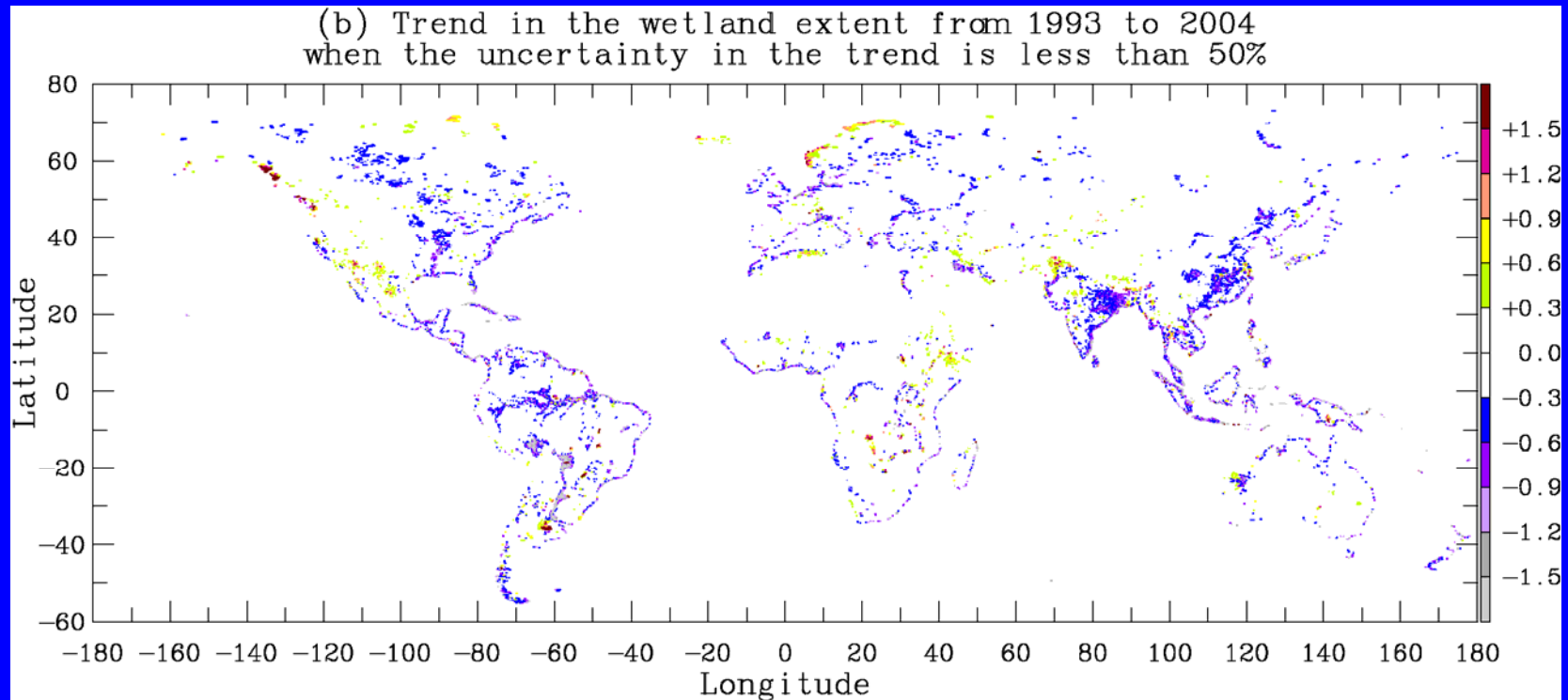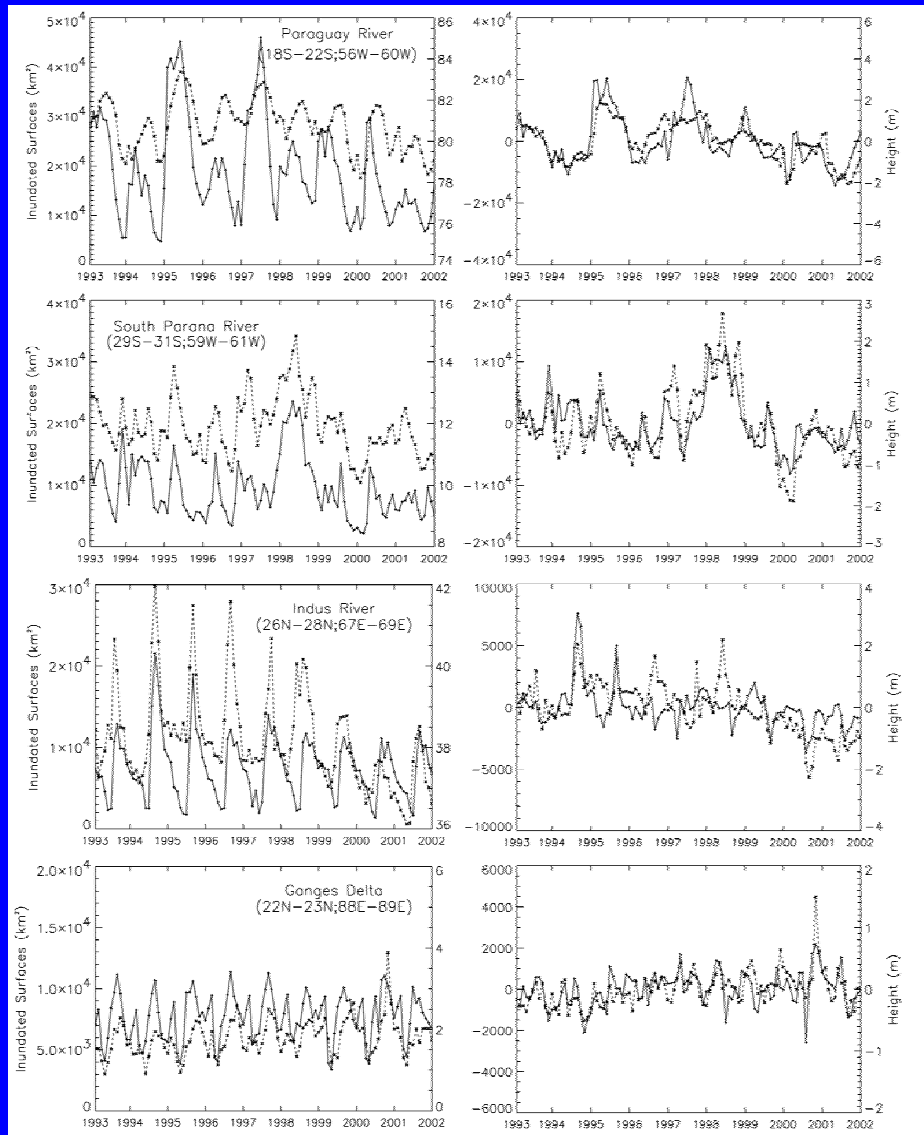
- Mostly negative trend in inland water bodies (few positive as well)
  Pantanal, Ganges, Central China, have significant negative trends
  North Indus, East Africa have positive trends

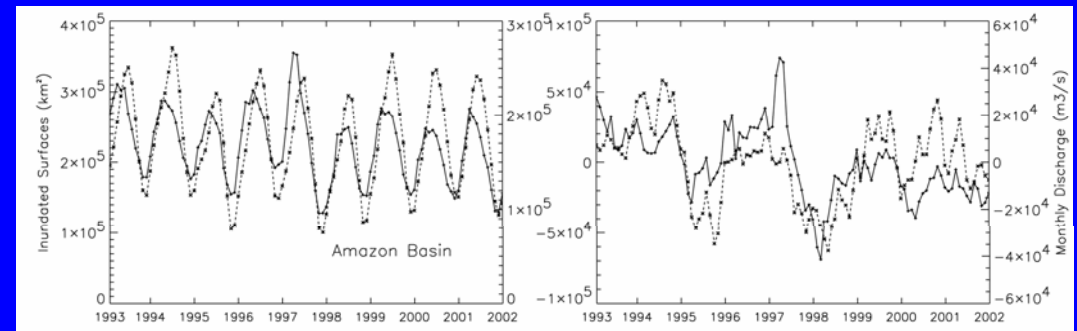- Most striking features: strong negative trend over the coastal regions
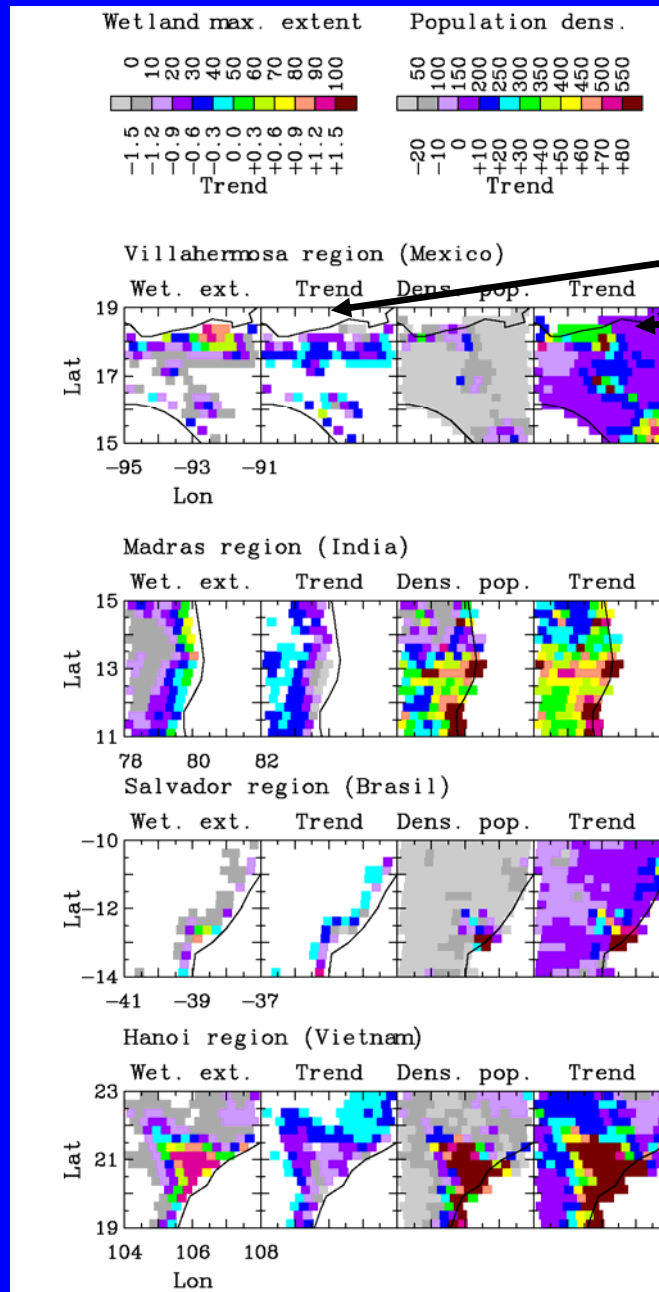
Comparison with Radar Altimeter

Good agreement with other variables

Comparison with in-situ river discharge

Comparison against GPCP, Air Temperatures were also checked

8. Global Surface Water Extent Dynamic, 1993-2004

Wetland max. extent
Population dens.

Villahermosa region (Mexico)
Wet. ext. Trend Dens. pop. Trend

Madras region (India)
Wet. ext. Trend Dens. pop. Trend

Salvador region (Brasil)
Wet. ext. Trend Dens. pop. Trend

Hanoi region (Vietnam)
Wet. ext. Trend Dens. pop. Trend

Over the Tropics, comparison with **the trend in the density of population** 1990-2005 for coastal regions

Trend in Water Surface extent

Trend in the population density

South Mexico

Madras, India

Salvador, Brazil

Hanoi, Vietnam

Good spatial agreement between the decrease in WSE and the increase in the density of population (this has been checked for other locations)

No particular trend was found on the NDVI or ERS signal over 8 years

Need to compare against other socio-economical parameters such as the agriculture change, land use change, and other climatic parameters

9. Conclusions

Existing satellite observations have potential to estimate inundation dynamics at global scale with spatial resolution of ~ 25km and temporal sampling of 1 month 1993-2004 (8 years dataset available upon request)

Work in progress to a weekly, daily basis

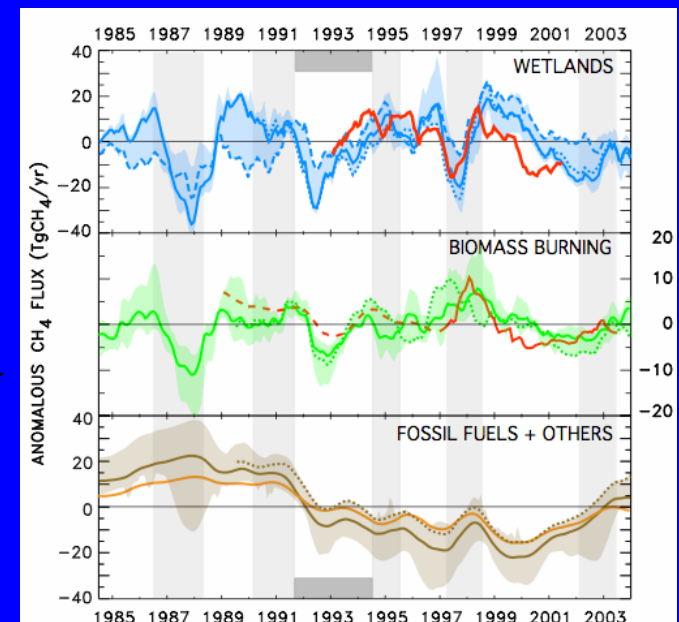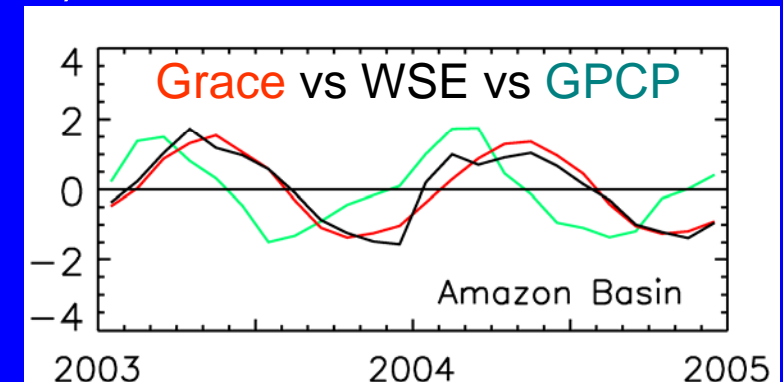Evaluation of the inundation dynamic estimates still in progress:
- difficult given the lack of independent global data sets

Limitations of the method:
- small surfaces likely to be missed

Use of the inundation dataset:
- in methane emission models
- in hydrological models
- land hydrology

[Bousquet et al., 2006 Nature]