Combination of radar altimetry and satellite imagery for the monitoring of flood events in arid zone: application to the Inner Niger Delta

J-F. Crétaux, M. Bergé-Nguyen,
S. Calmant & P. Maisongrande

Lisbon, Ocean and hydrology applications, October 21,22, 2010

Framework and field applications of the methodology

Targets:

Floodplain and highly variable lakes
In arid zones

Objectives:

Mapping water extent and level variations
On high temporal resolution
Medium spatial resolution

→

Understanding the linkage of water surface with regional and global climate variability
Assimilation in hydrodynamic model
Estimating water volume variations

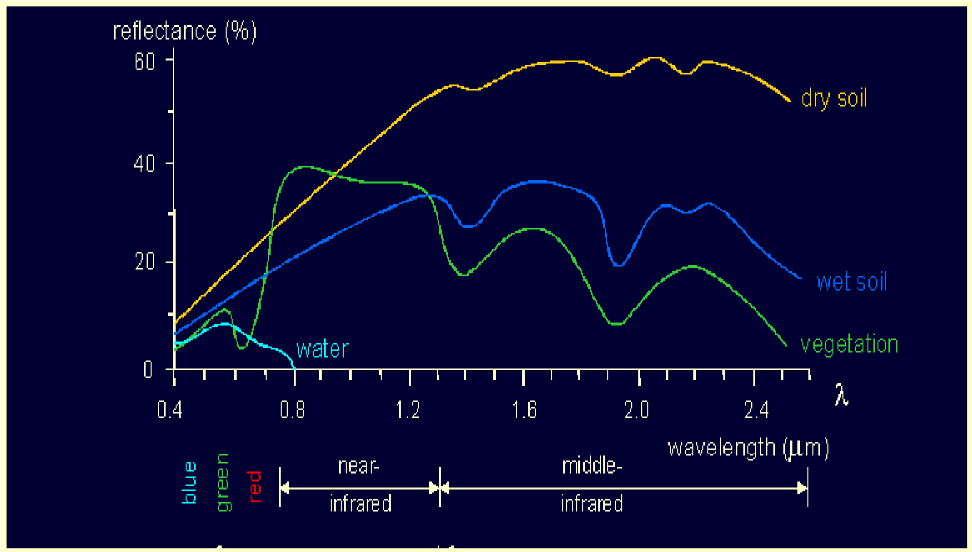
Instruments:

Modis sensor
Radar altimetry

Ancillary data:

Global gridded precipitation data (TRMM, GPCP, PERSIAN …)

Multispectral satellite imagery: what do we measure?

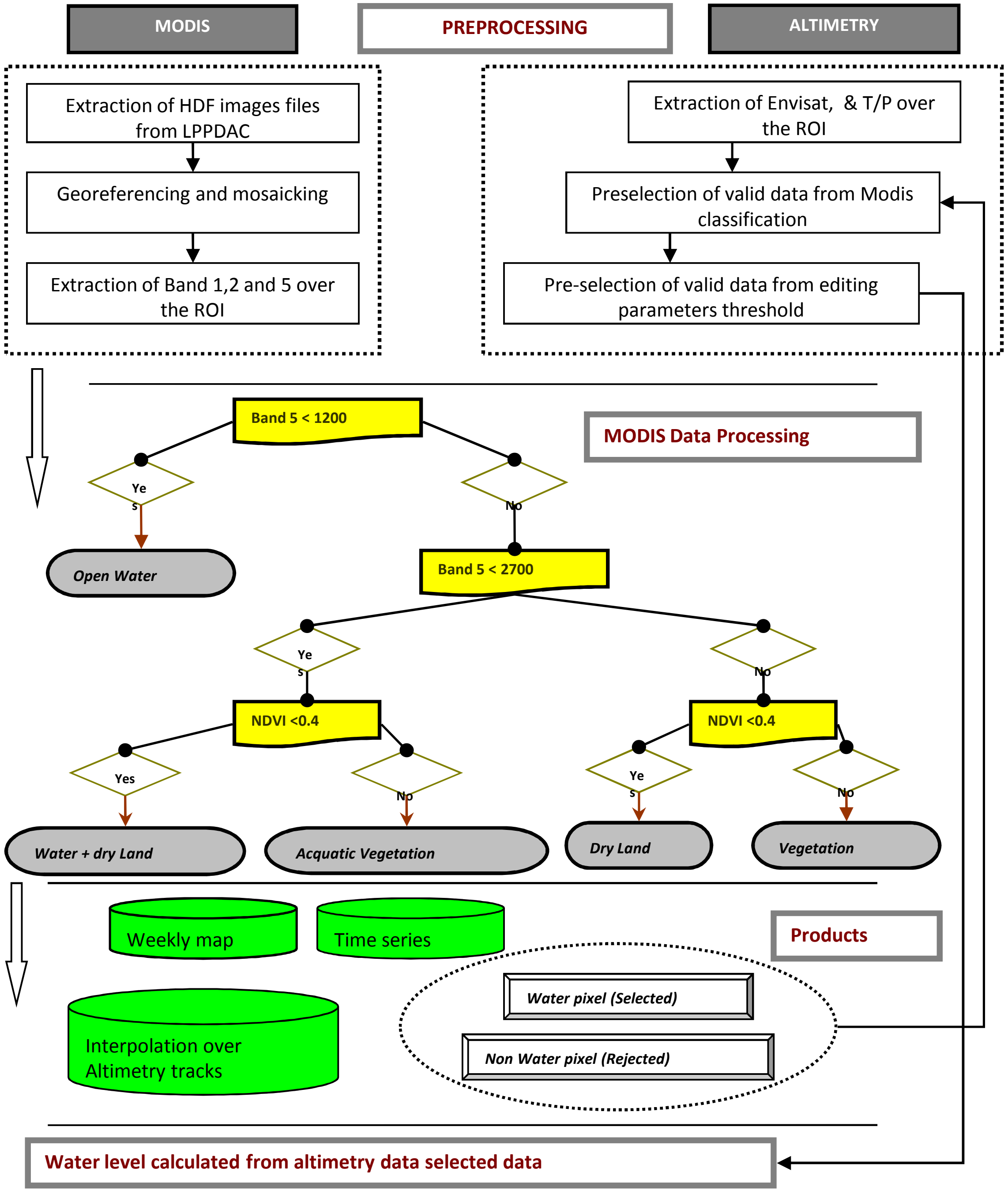


MODIS

Bande 1 (620 – 670 nm)
Bande 2 (841 – 876 nm)
Bande 3 (459 – 479 nm)
Bande 4 (545 – 565 nm)

Bande 5 (1230 – 1250 nm)
Bande 6 (1628 – 1652 nm)
Bande 7 (2107 – 2155 nm)

Classification by combination of spectral bands


MODIS
PREPROCESSING
ALTIMETRY
Extraction of HDF images files from LPPDAC
Georeferencing and mosaicking
Extraction of Band 1,2 and 5 over the ROI
Extraction of Envisat, & T/P over the ROI
Preselection of valid data from Modis classification
Pre-selection of valid data from editing parameters threshold
Band 5 < 1200
MODIS Data Processing
Yes
No
Open Water
Band 5 < 2700
Yes
No
NDVI <0.4
NDVI <0.4
Yes
No
Yes
No
Water + dry Land
Acquatic Vegetation
Dry Land
Vegetation
Weekly map
Time series
Products
Water pixel (Selected)
Non Water pixel (Rejected)
Interpolation over Altimetry tracks
Water level calculated from altimetry data selected data

Case study: Flood monitoring over the Inner Niger Delta (IND)

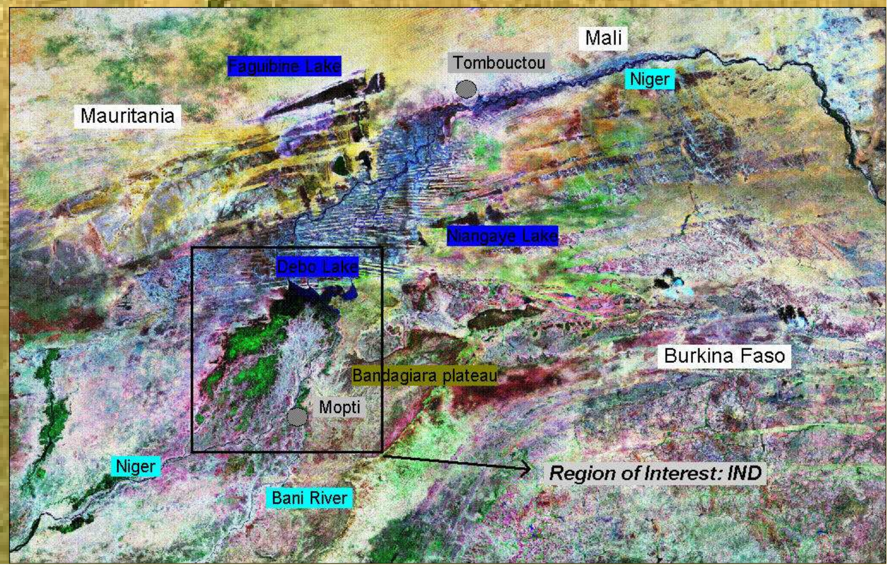
From Modis

Inter-annual Monitoring of inundated areas, aquatic vegetation and vegetation
Tool for selection of altimetry data

- The IND is a shallow area of 40,000 km2
- Niger and Bani rivers supply to the IND with annual inundation which occur between August and October
- It is lowland constituded by channels, swamps and lakes

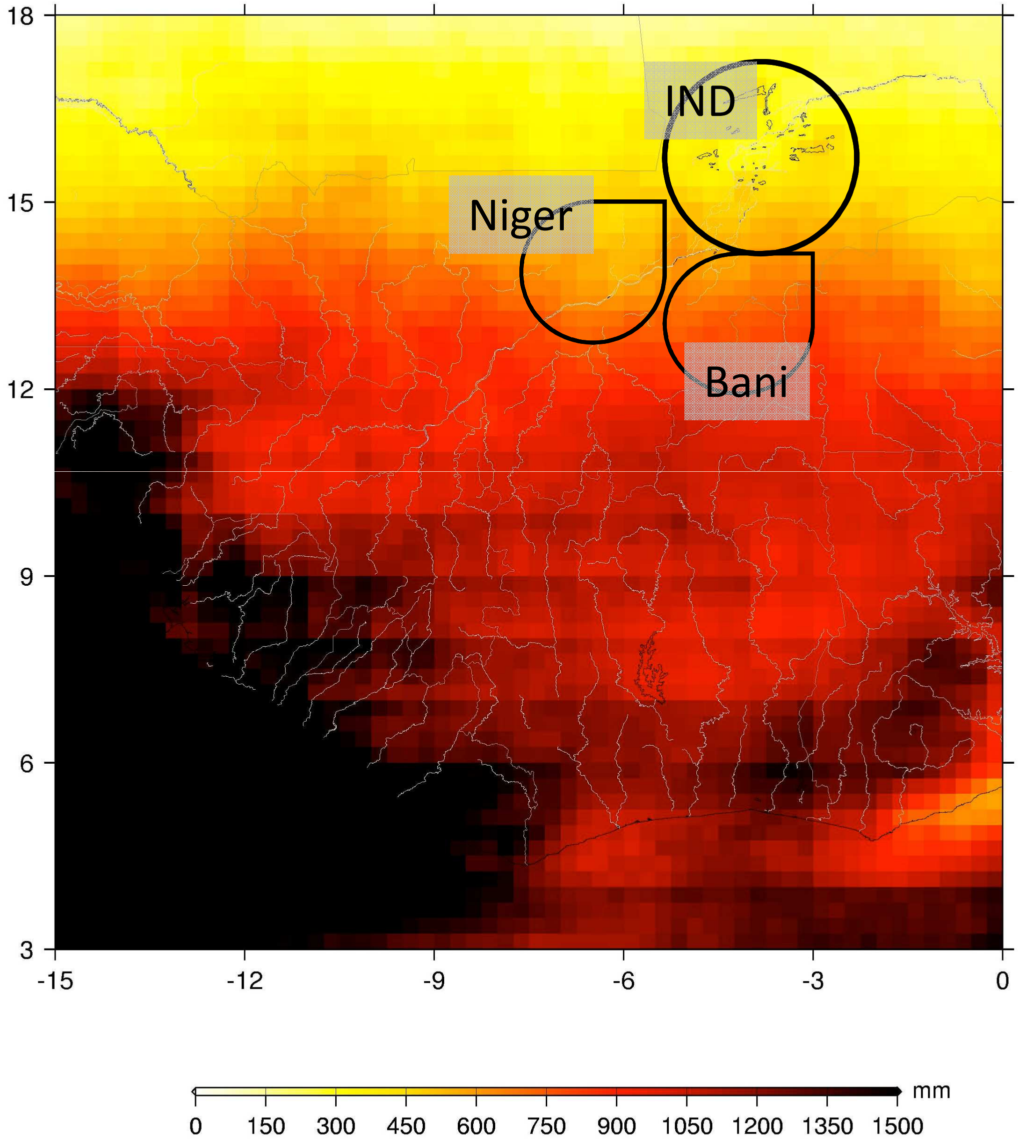
From Altimetry

Water level variations along satellite tracks over the IND



Analysis of Precipitations over the IND and upstream watershed of Niger and Bani rivers

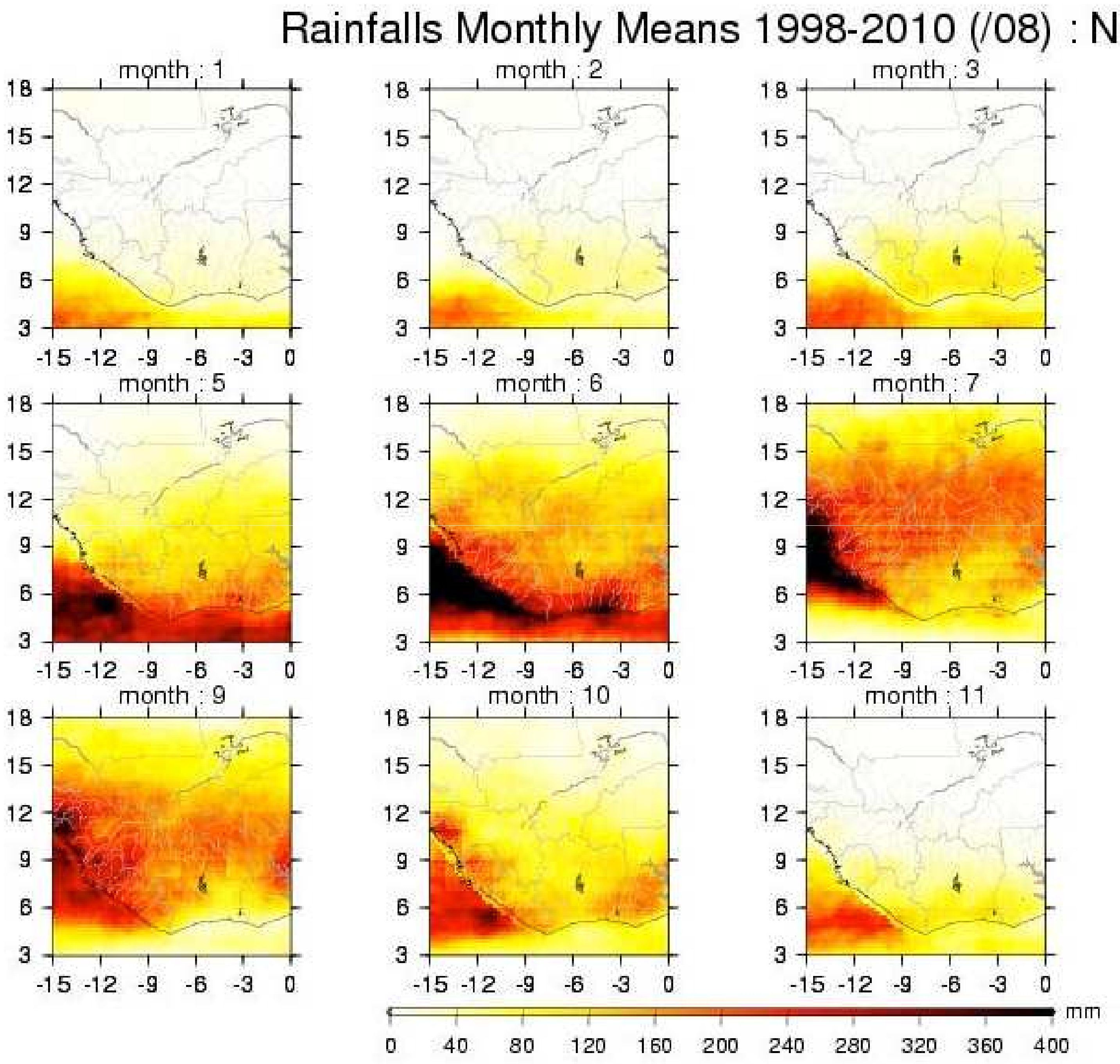
Average rainfall over 1998-2009 from TRMM

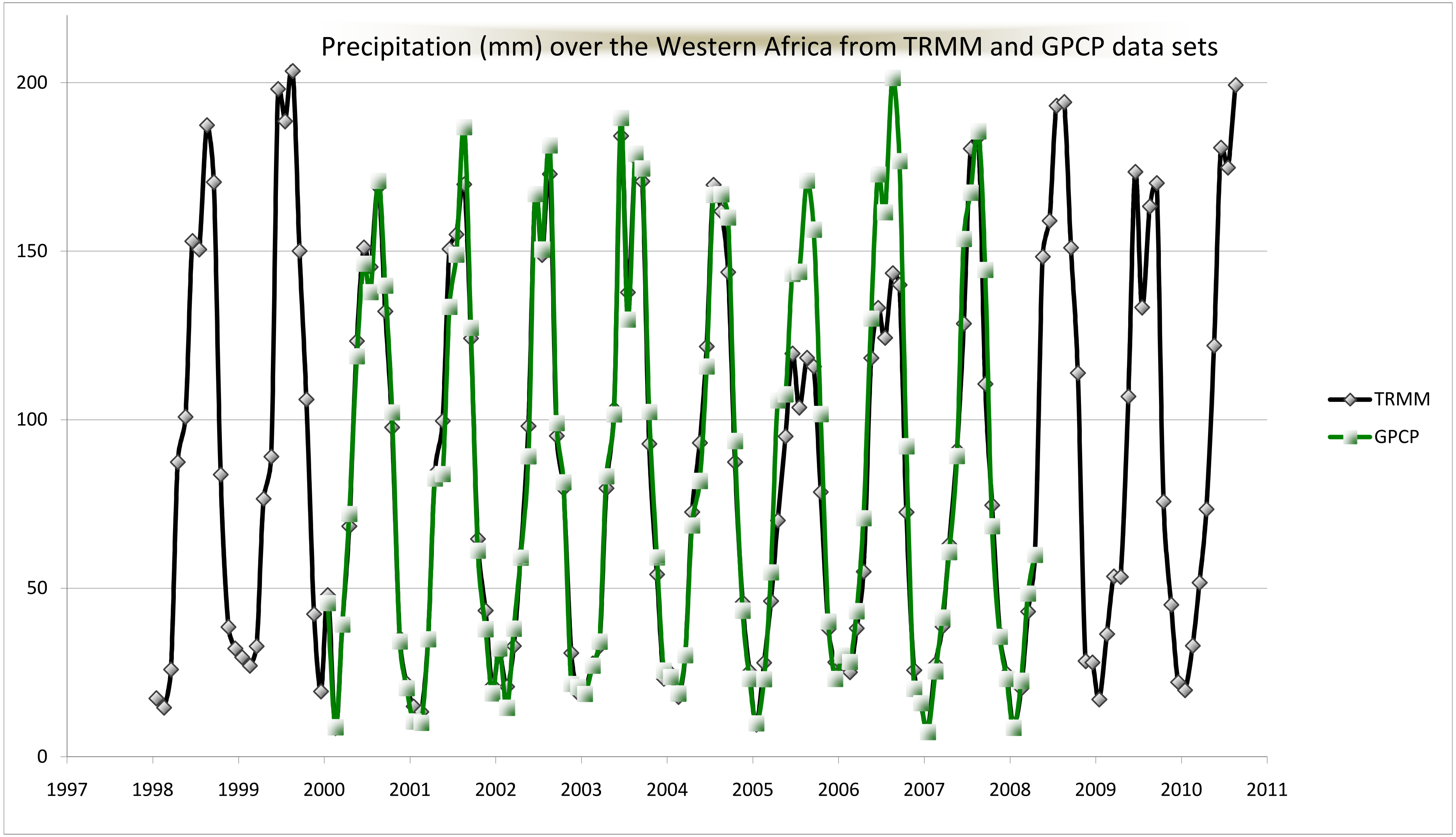


Longitudinal patterns with marked gradient from South to North.

1200 to 1500 mm/yr at the source of Niger and Bani rivers, to about 300 mm/yr over the northern part of the IND

Over the IND the main contributor of flooding will therefore be the surface water flow from upstream rivers with time shift that should be detected from Modis images analysis

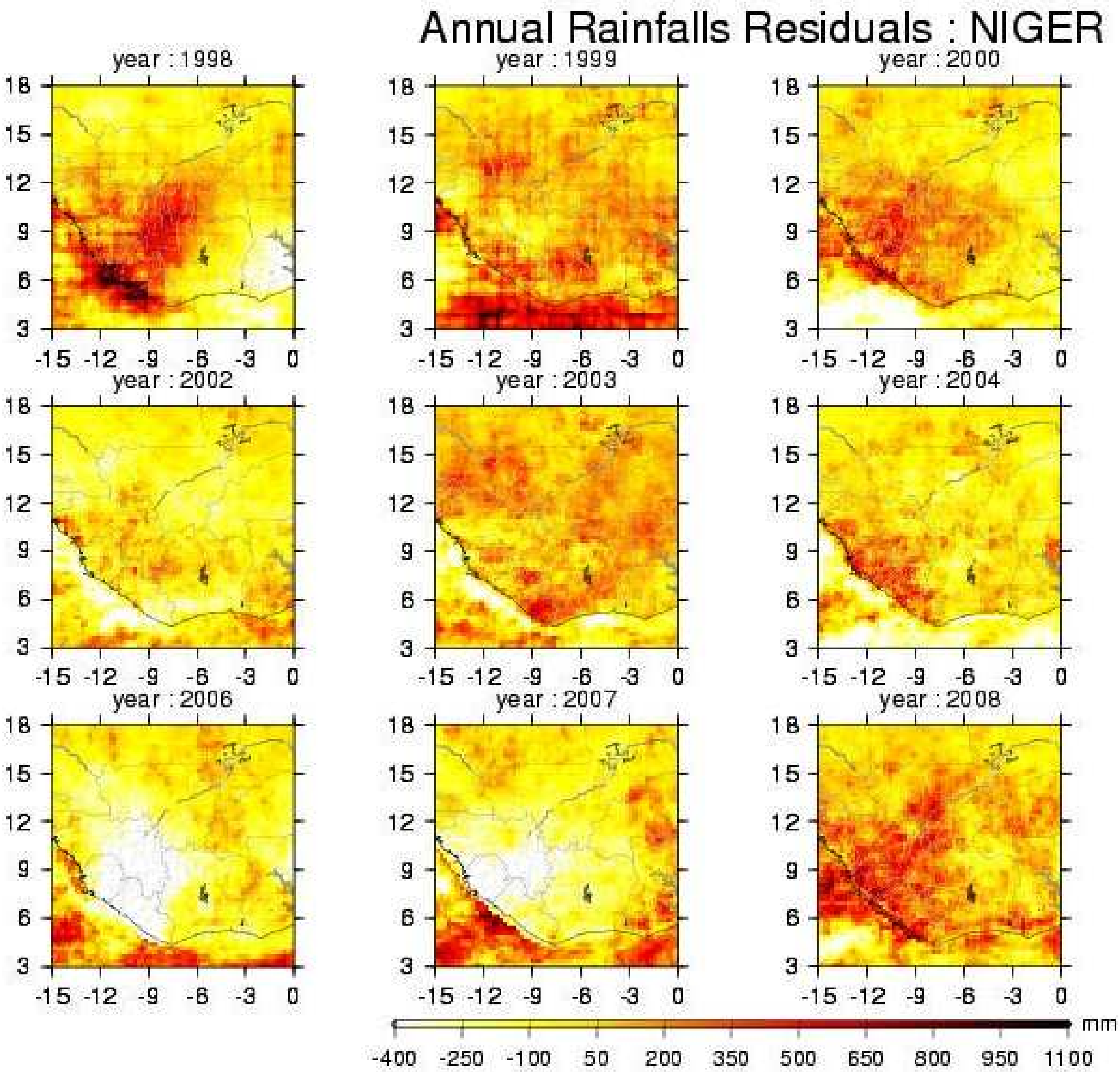

Rainfalls Monthly Means 1998-2010 (/08) : NIGER
month : 1
month : 2
month : 3
month : 4
month : 5
month : 6
month : 7
month : 8
month : 9
month : 10
month : 11
month : 12
18 15 12 9 6 3
-15 -12 -9 -6 -3 0
mm
0 40 80 120 160 200 240 280 320 360 400



Quite good correlation of interannual precipitation from GPCP and TRMM exept for 2005-2006

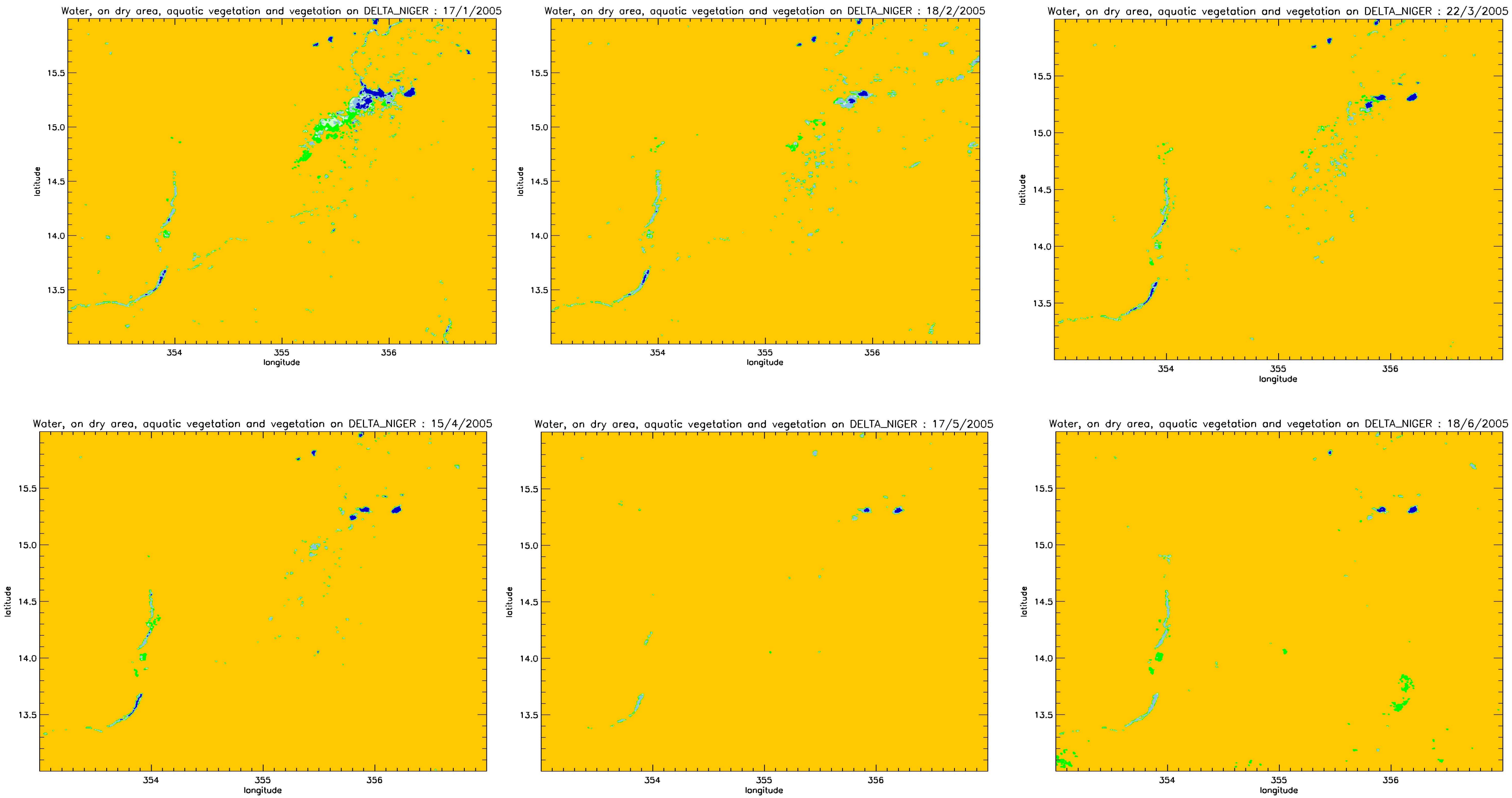
TRMM exibits significant internannual variability

=> Effect on inundation over the IND should be marked

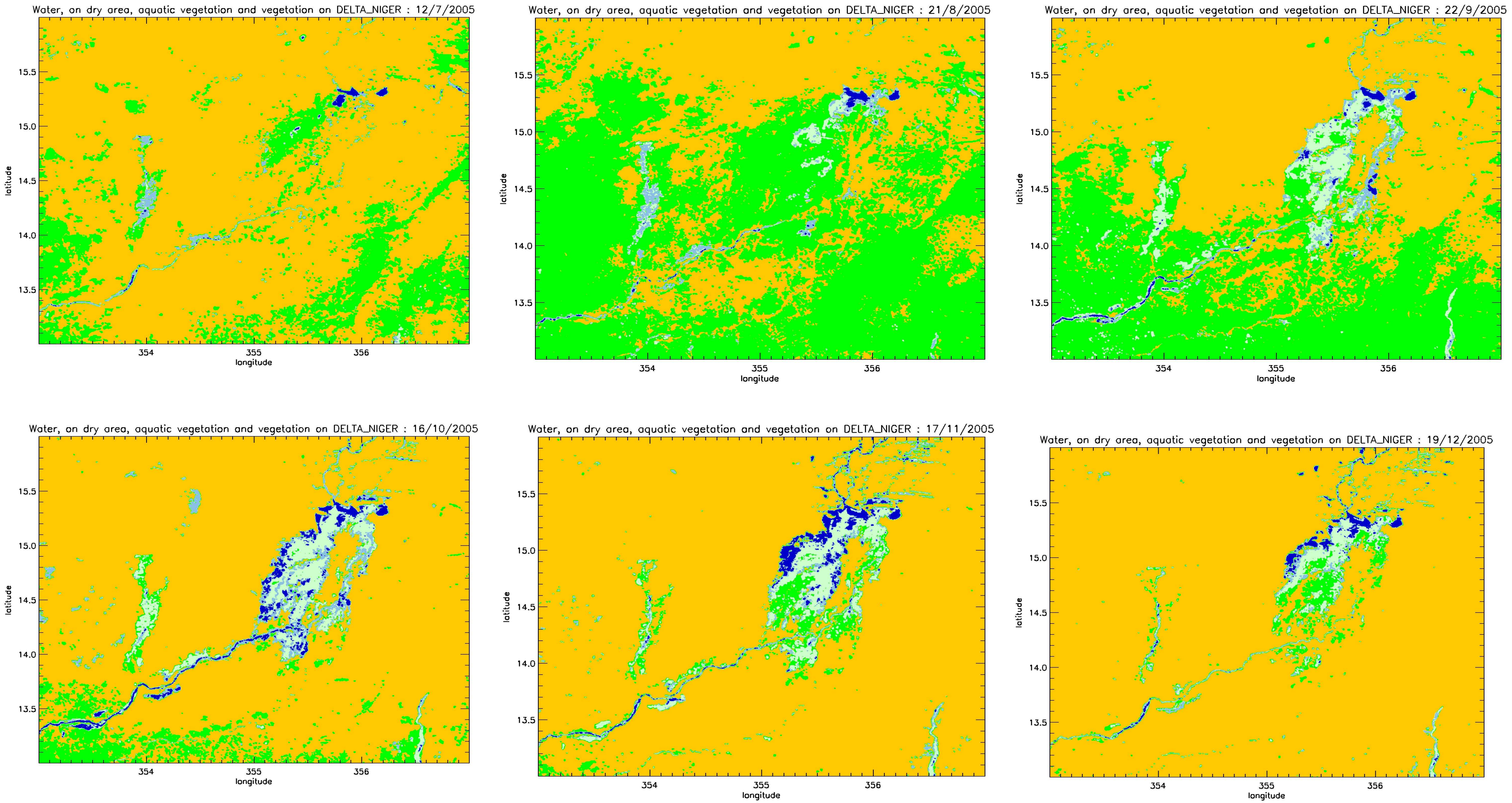


Annual Rainfalls Residuals : NIGER
year : 1998
year : 1999
year : 2000
year : 2001
year : 2002
year : 2003
year : 2004
year : 2005
year : 2006
year : 2007
year : 2008
year : 2009
mm
-400
-250
-100
50
200
350
500
650
800
950
1100

Modis data processing over the IND

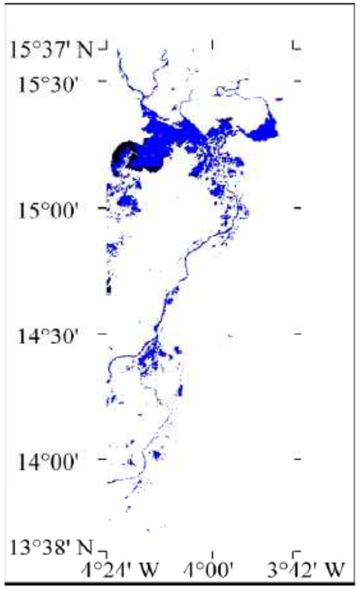


- In absence of rainfall for the first semester of a usual year the IND is totally dry except some permanent small lakes
- Vegetation is also absolutely not present



- ➢ Vegetation appears in July, and aquatic vegetation in August in the IND
- ➢ September is marked by increasing flow over the IND with peaks in mid October
- ➢ From September to December the vegetation around the IND disappears
- ➢ In December the water on the IND starts to evaporate

Comparison of Modis classification with Meris (Seiler & Csaplovics 2003)



24. August 2002

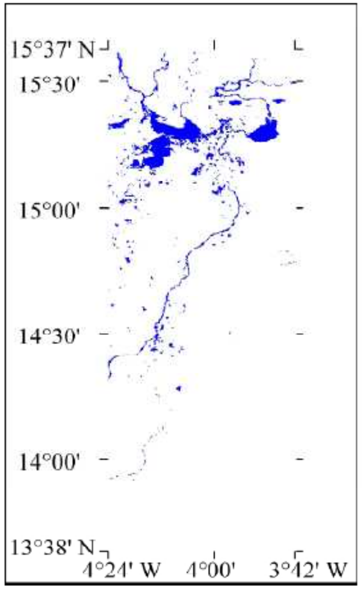
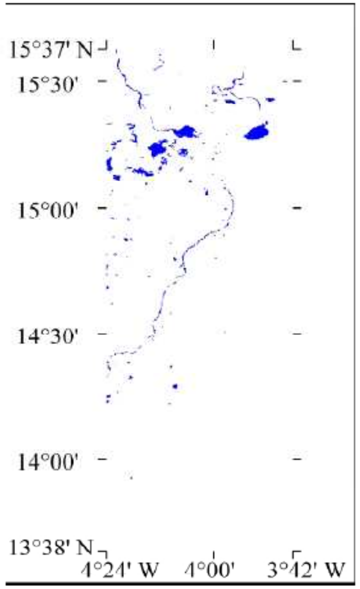
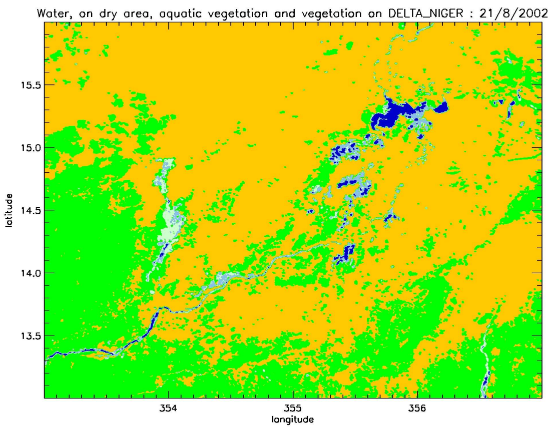


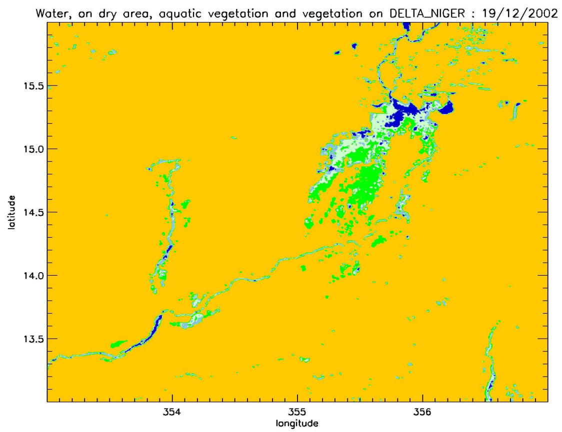
Fig. 6a – c. open water aereas for
20. December 2002



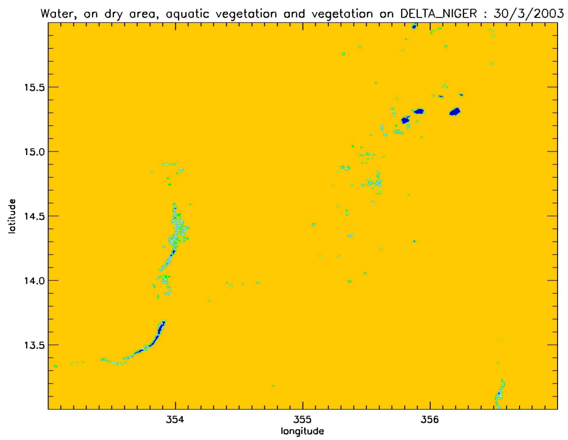
01. April 2003



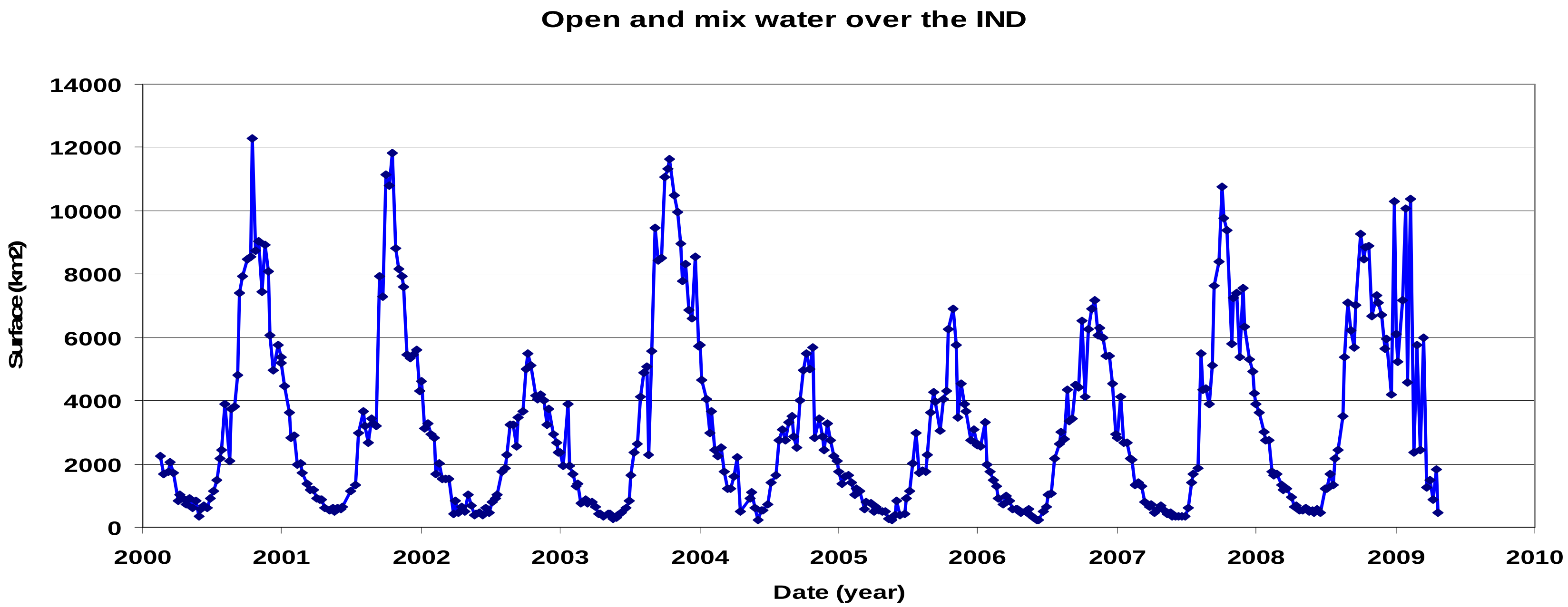
Modis August 21, 2002



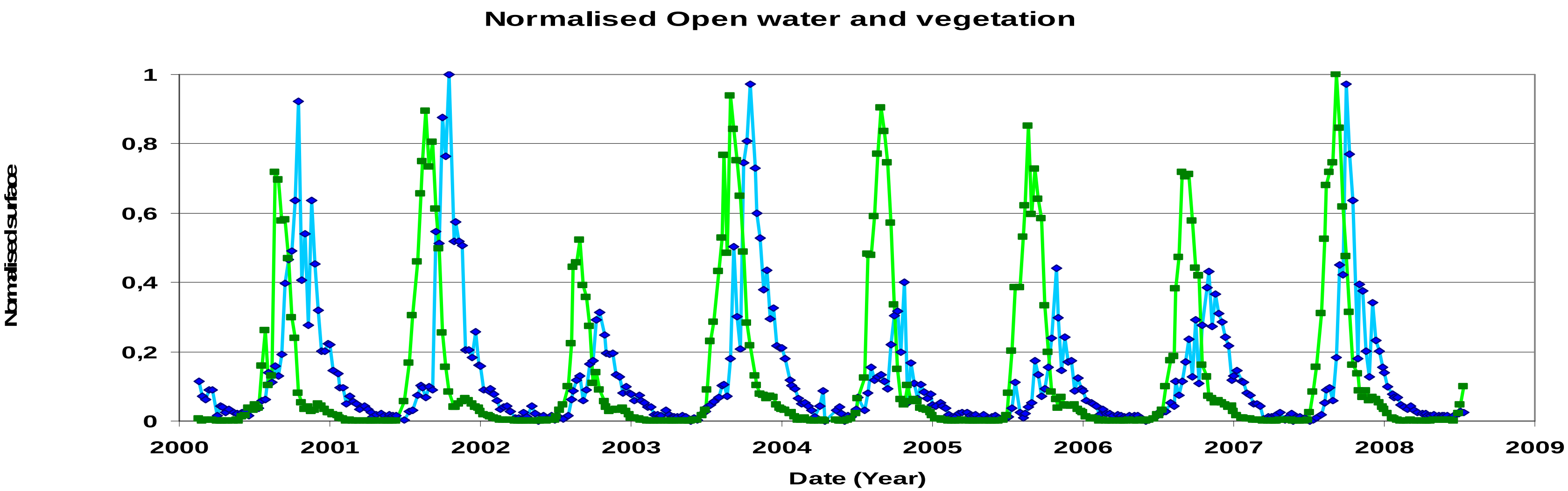
Modis December 19, 2002



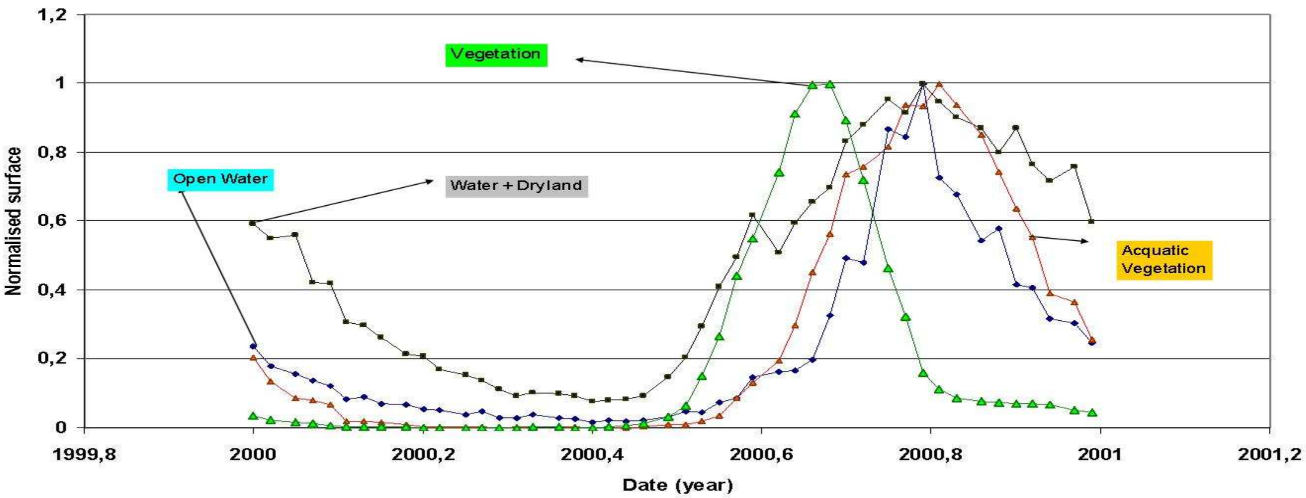
Modis march 30, 2003



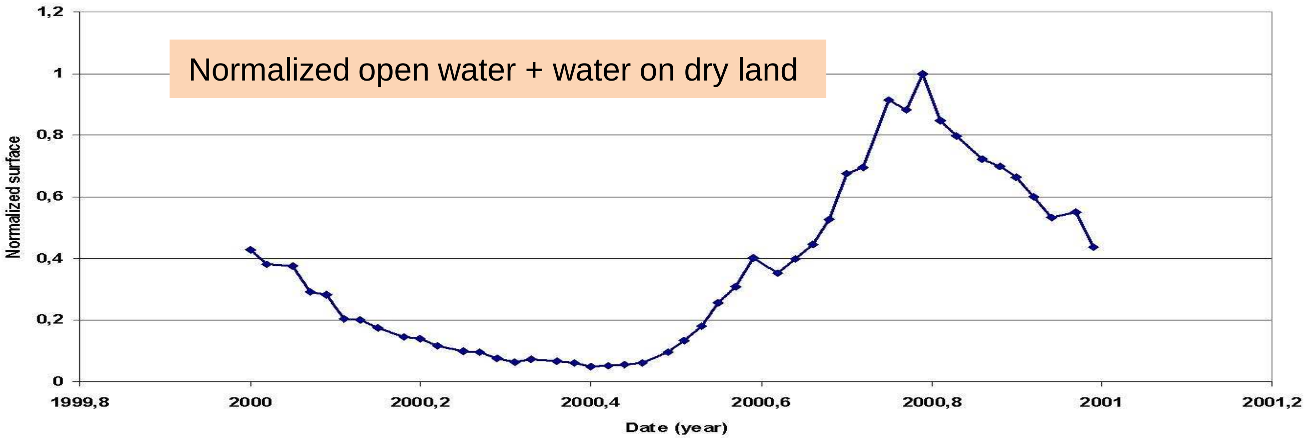
High inter-annual variability
Double peak on water (June/July then October)
Végétation is in phase with first peak

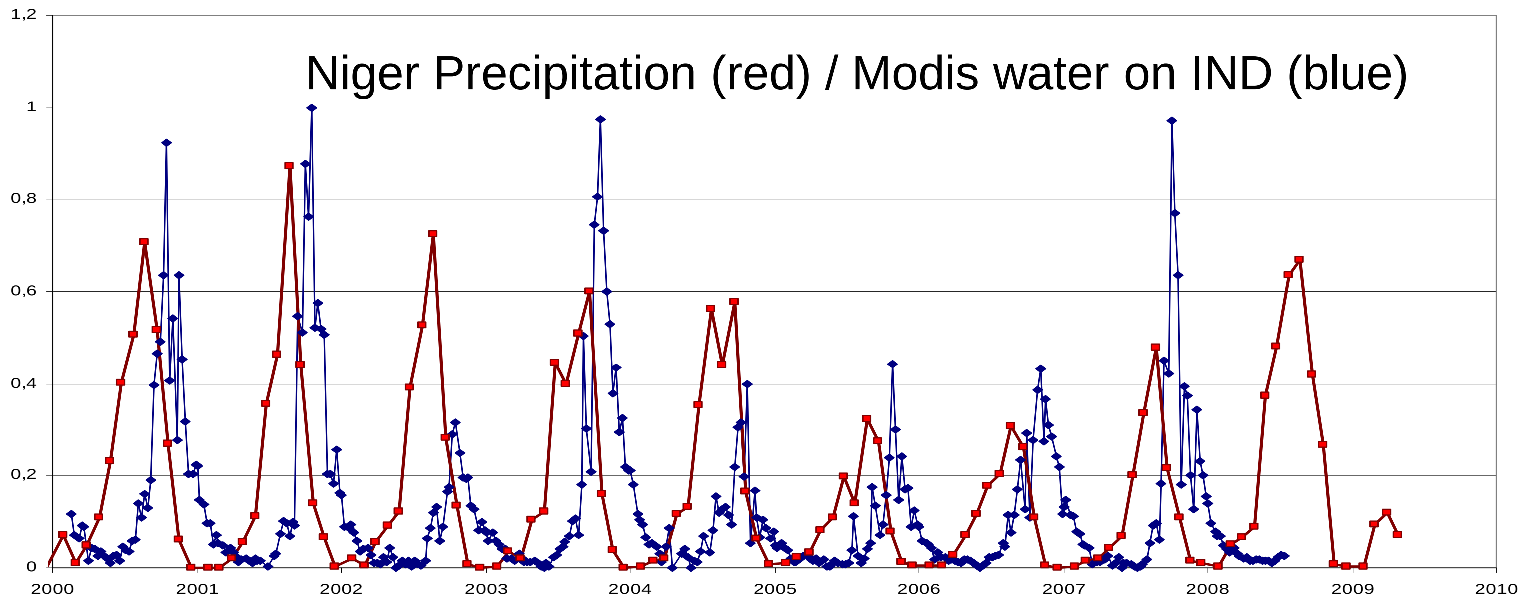


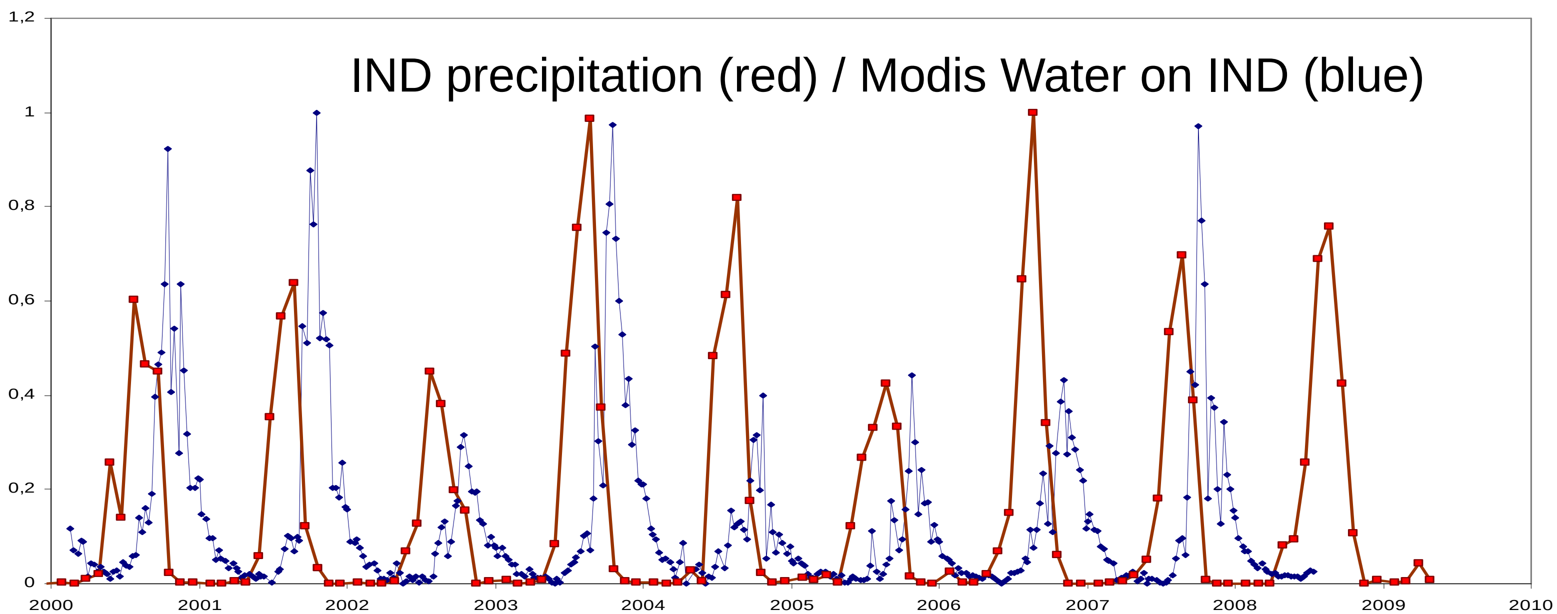
Normalized average surface from Modis over the IND



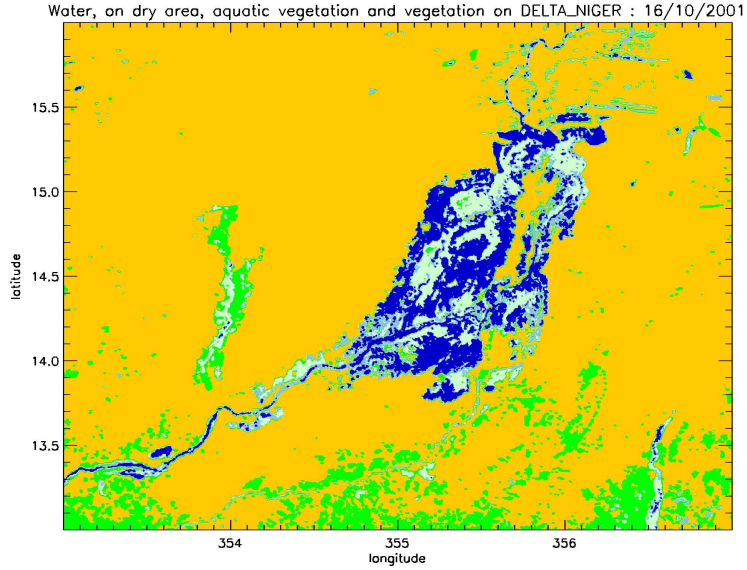
- Peak of vegetation occurs in beginning of September => after the first rainfall in July / August
- starts of water over the IND in end of July => due to direct precipitation
- Main peak of water and aquatic vegetation occur 1.5 month later, and open water peak is narrow => Surfaces inundated are shallow with relatively flat topography, and presence of vegetation slow down the flow in the IND inducing quick evaporation of open water in the IND

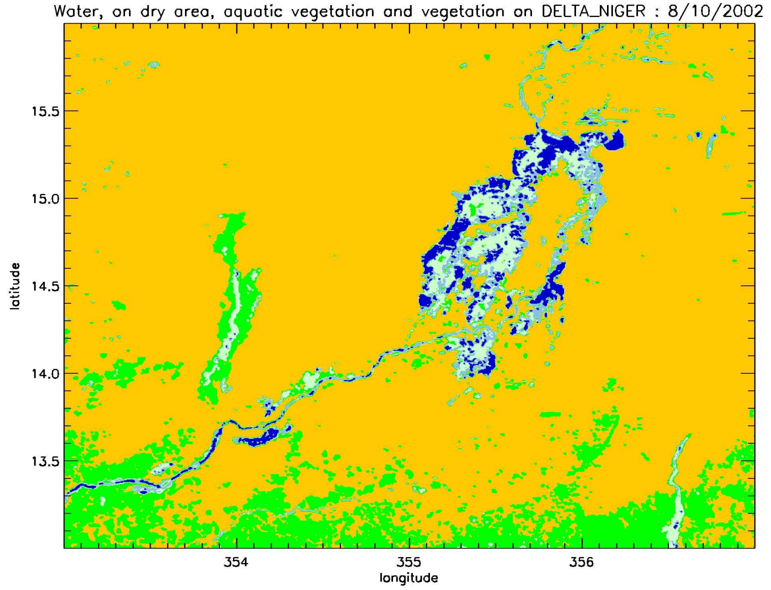


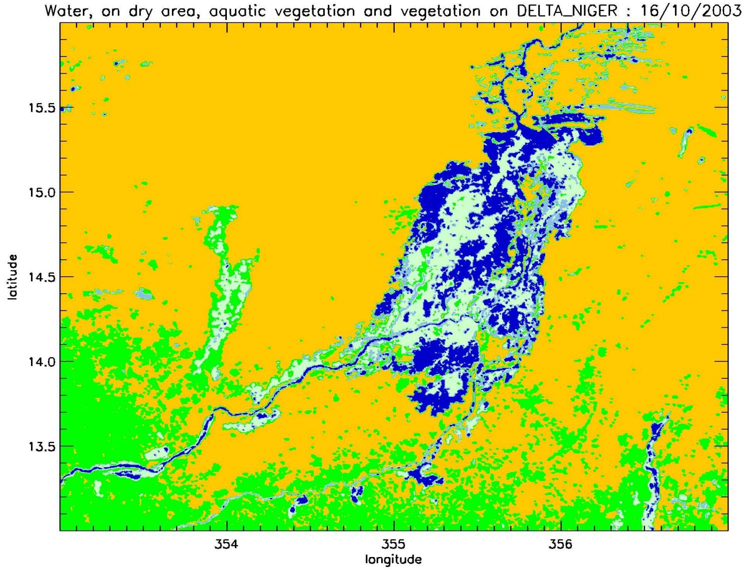

Niger Precipitation (red) / Modis water on IND (blue)
1,2
1
0,8
0,6
0,4
0,2
0
2000
2001
2002
2003
2004
2005
2006
2007
2008
2009
2010

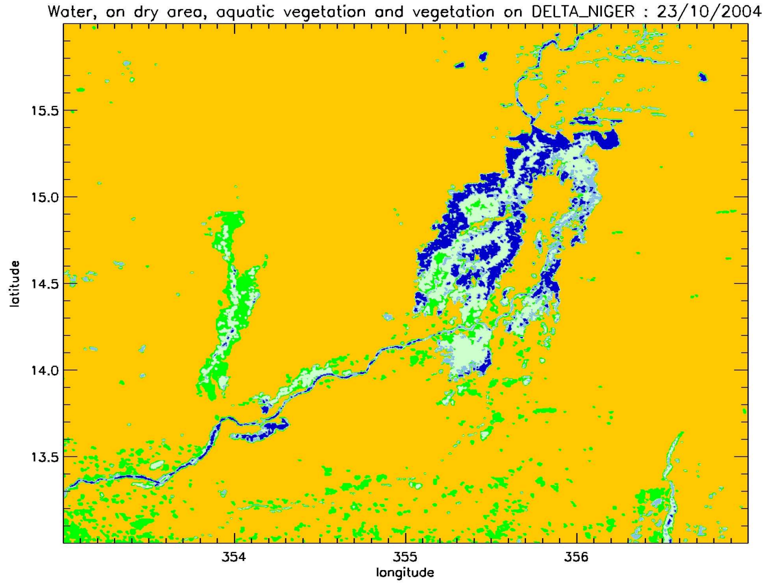

IND precipitation (red) / Modis Water on IND (blue)
1,2
1
0,8
0,6
0,4
0,2
0
2000
2001
2002
2003
2004
2005
2006
2007
2008
2009
2010

Map of Modis classification over the IND at the maximum of inundation of 4 different years
High inter-annual spatial variability of the water extent is pronounced
=> This enhance the interest and capability of Modis to monitor flood in Arid zone

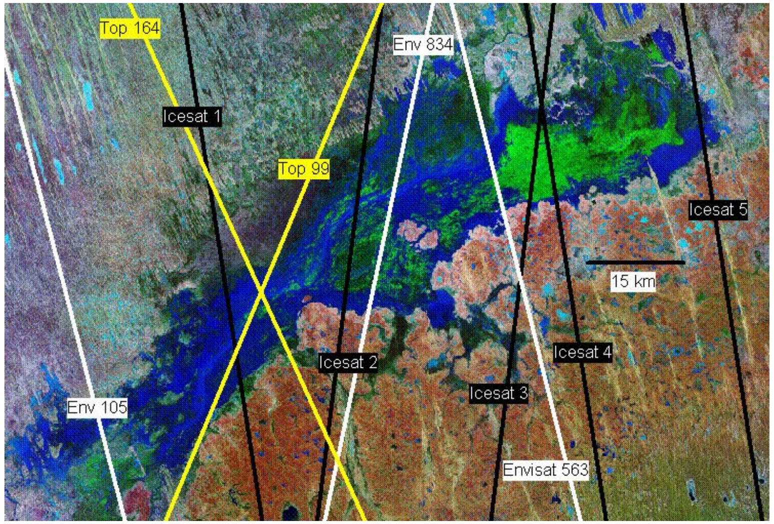


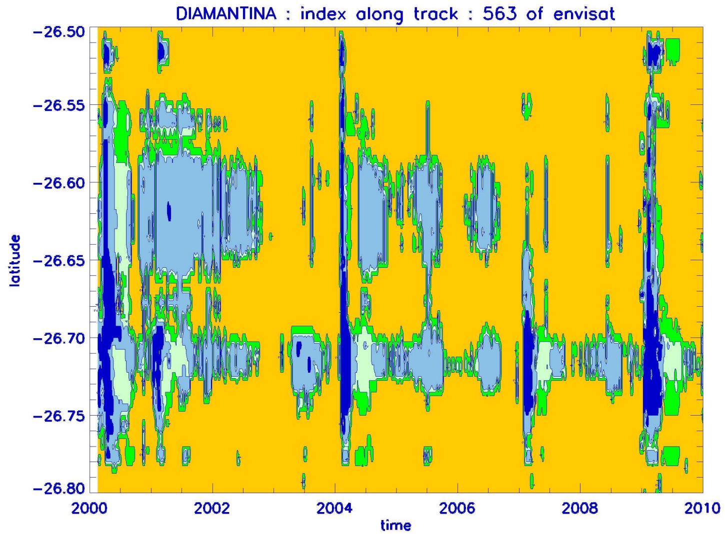


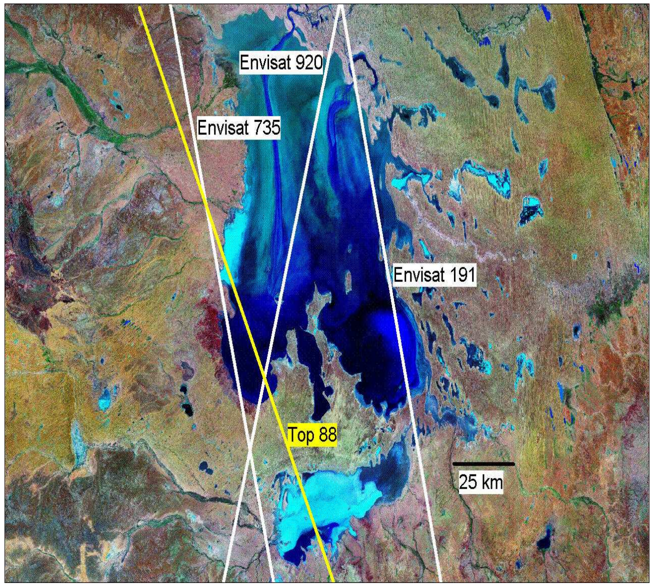


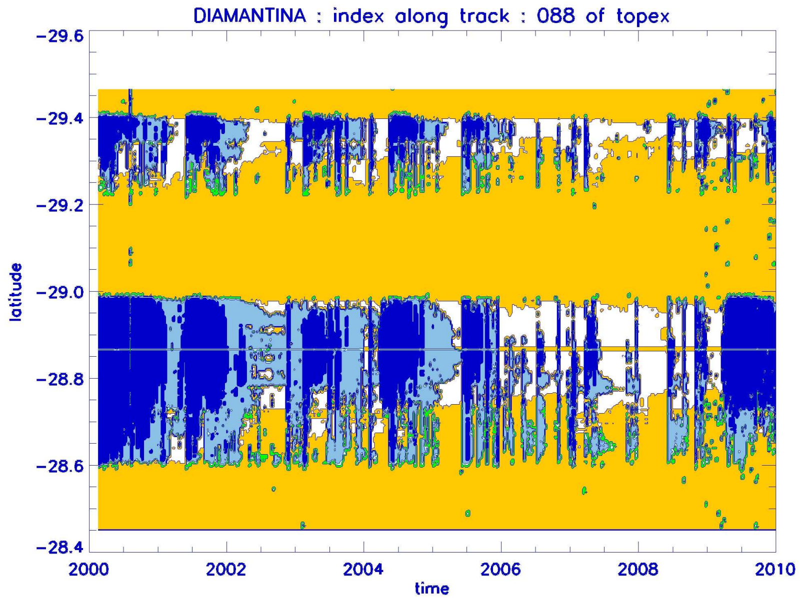


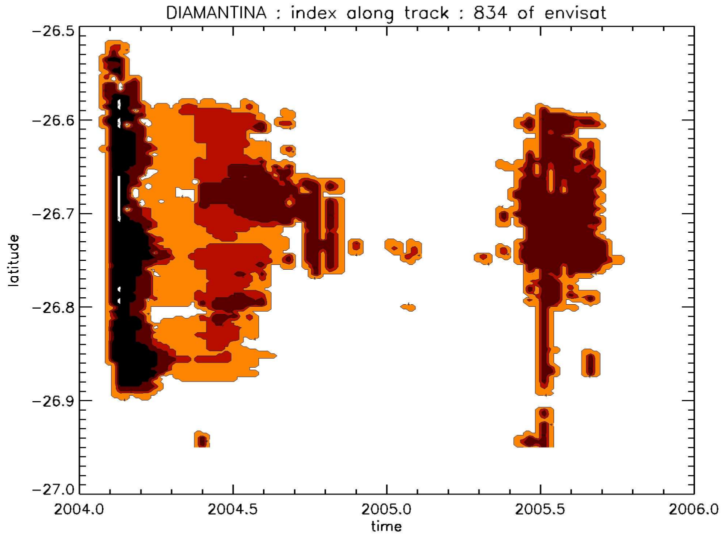
How Modis classification may be used for altimetry data analysis? Example over the Diamatina River and Lake Eyre in Australia



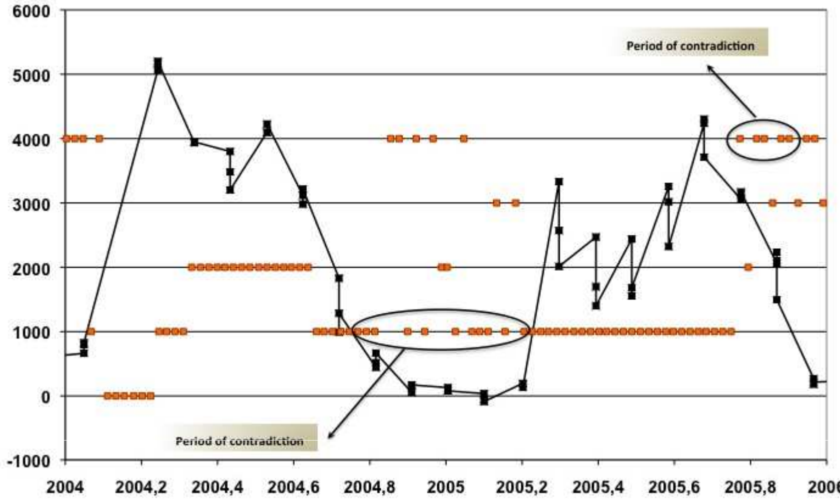


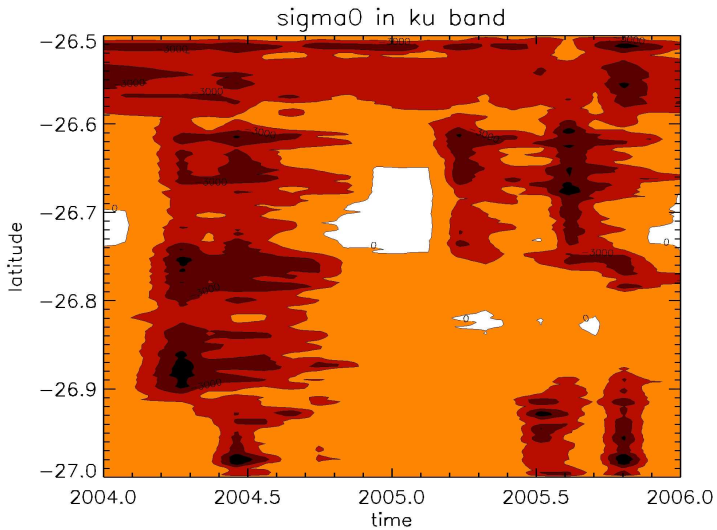


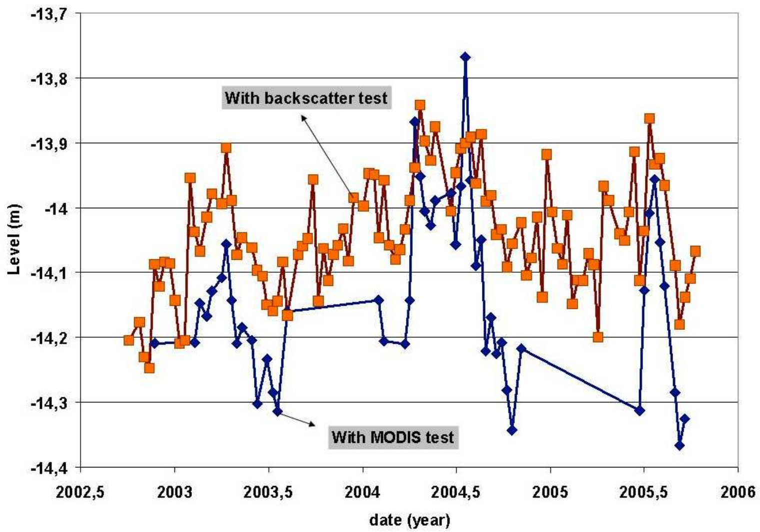




Why usual tests made on the backscatter coefficient is not valid over floodplains ?



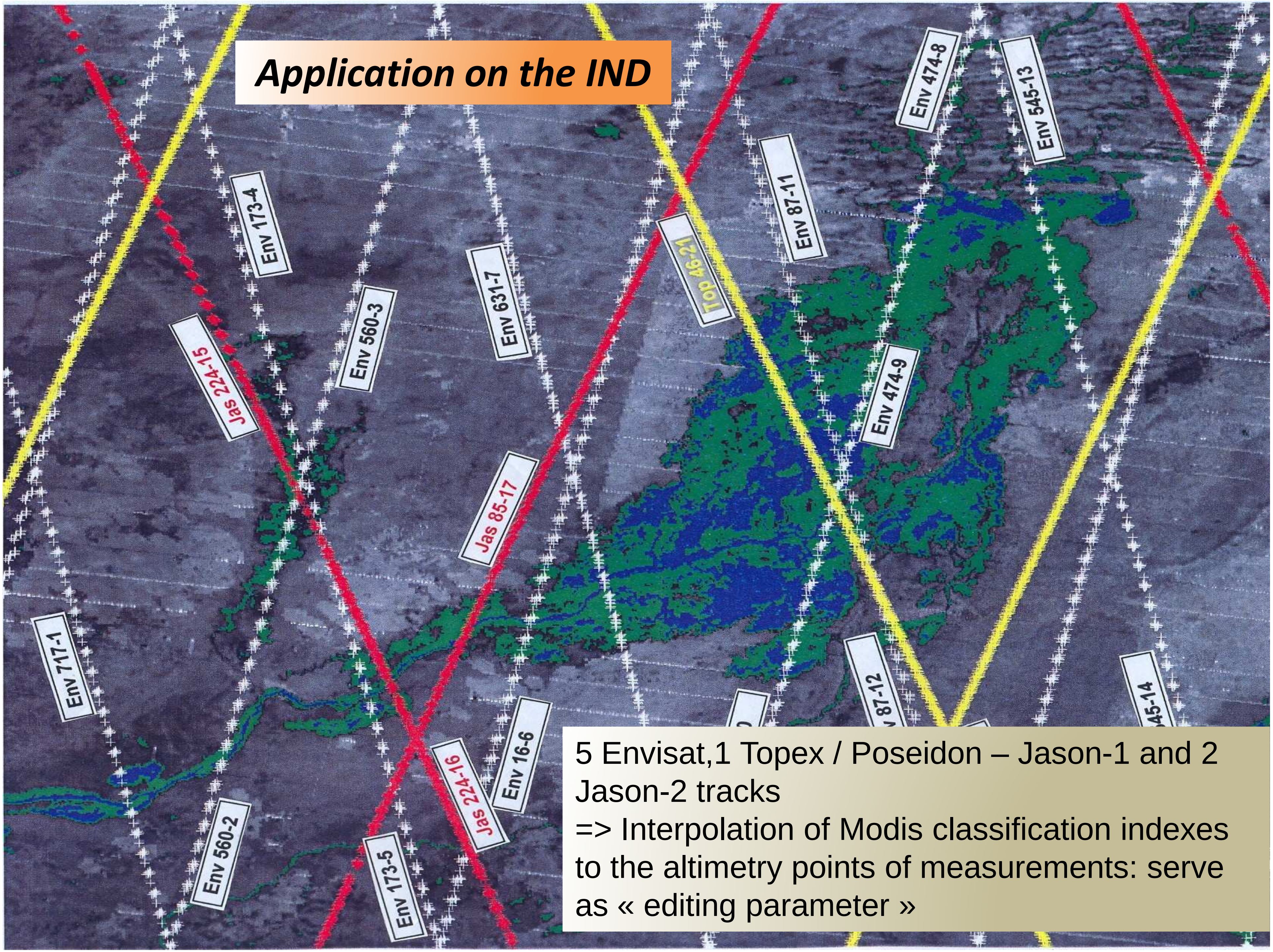




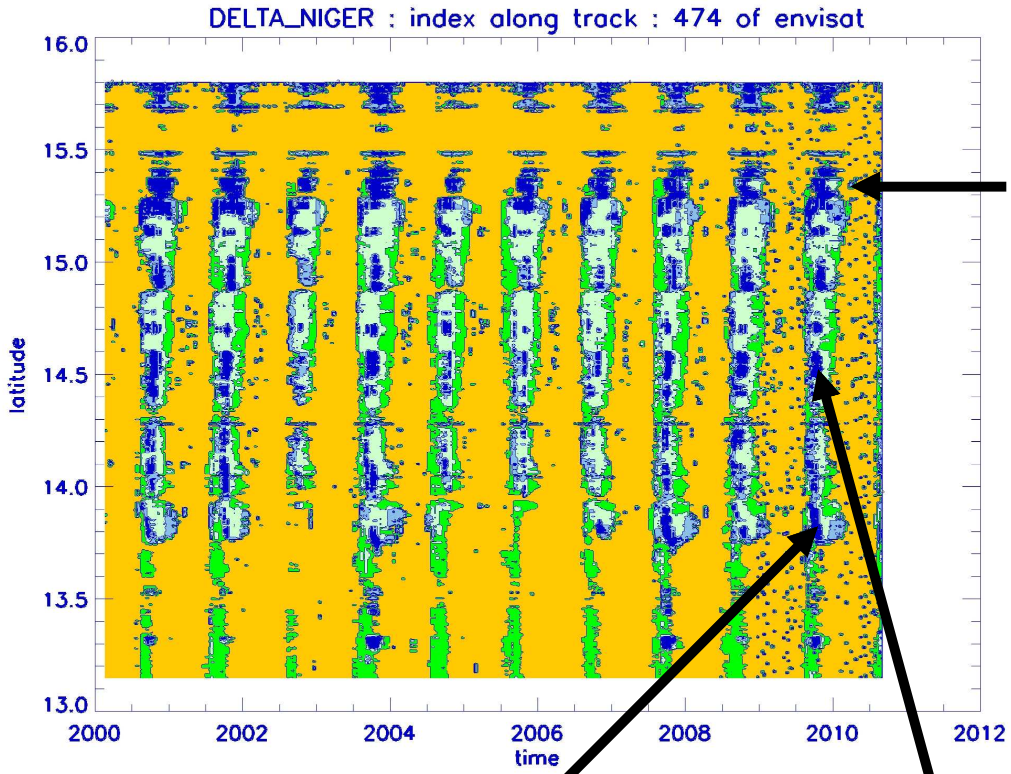
- ➢None correspondance can be found between the backscatter coefficients (in KU, C and S band and combination of them) with Modis classifications.

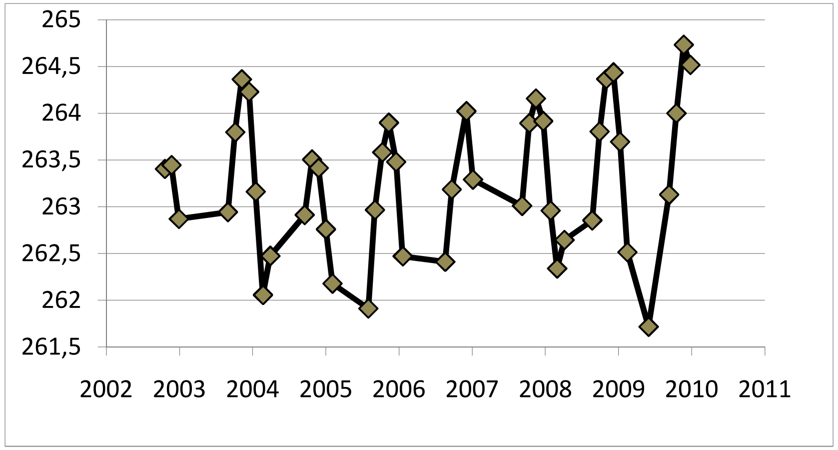
- ➢In some cases, the backscatter coefficient lead to error in water level estimation as for Lake Eyre due to salt crust on the bed lake

Application on the IND



5 Envisat,1 Topex / Poseidon – Jason-1 and 2
Jason-2 tracks
=> Interpolation of Modis classification indexes to the altimetry points of measurements: serve as « editing parameter »

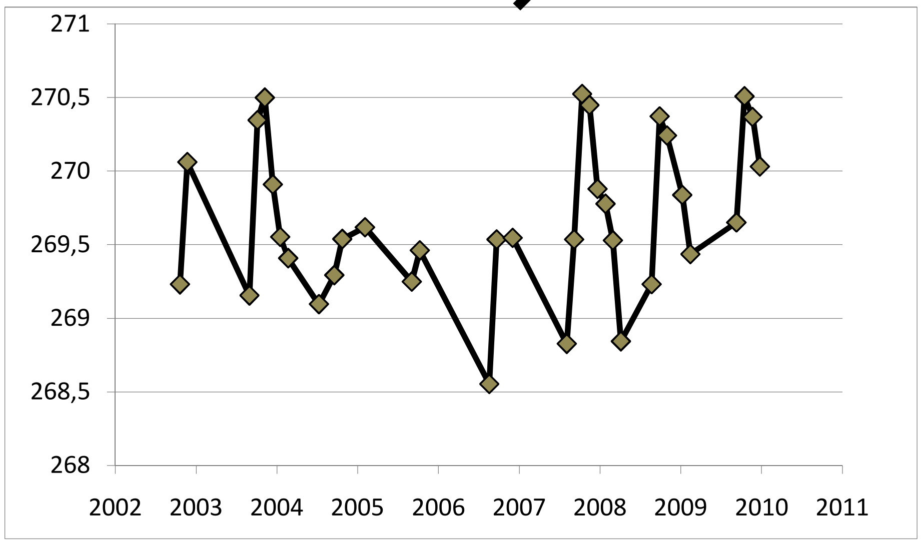


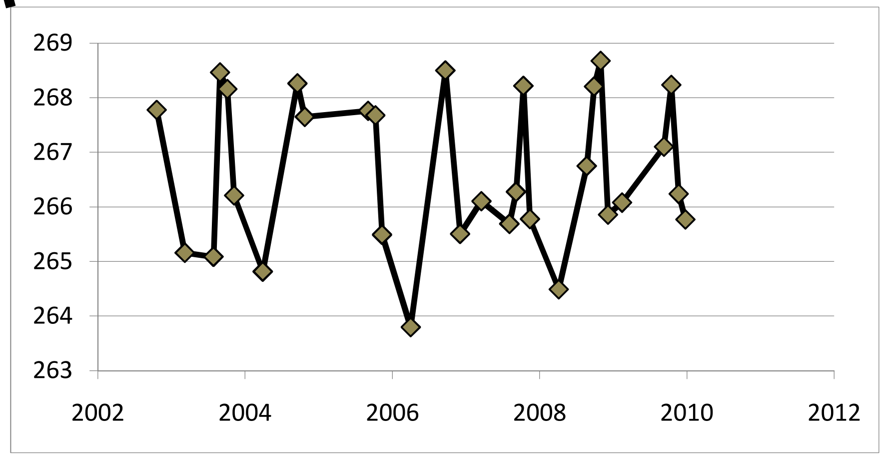


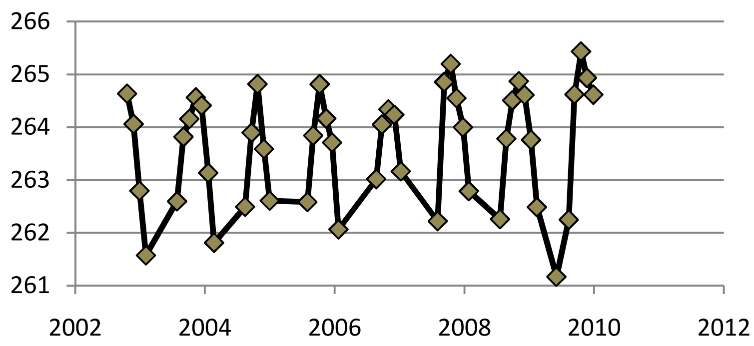
- **Poor time sampling of Envisat**

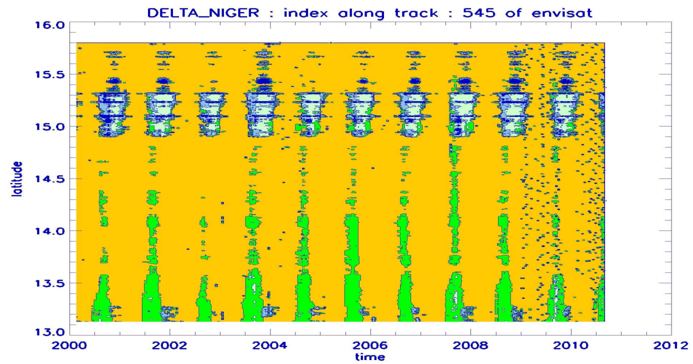
- **Relative maximum level between zones on the IND**

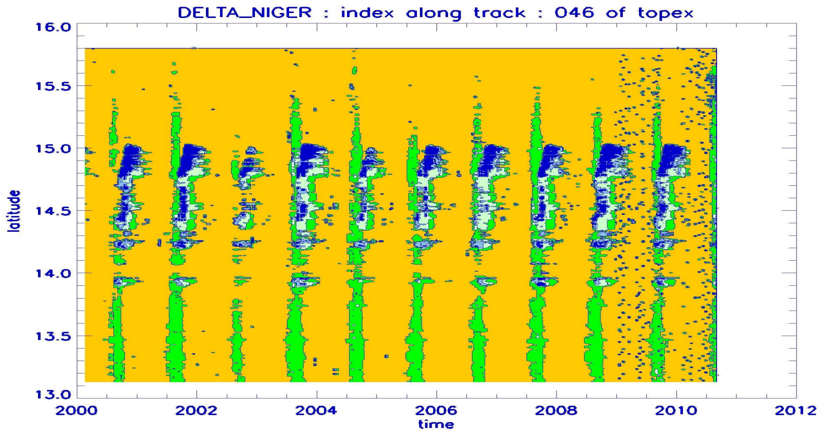
- **Could serve as control measurements for hydrodynamical model of the IND**

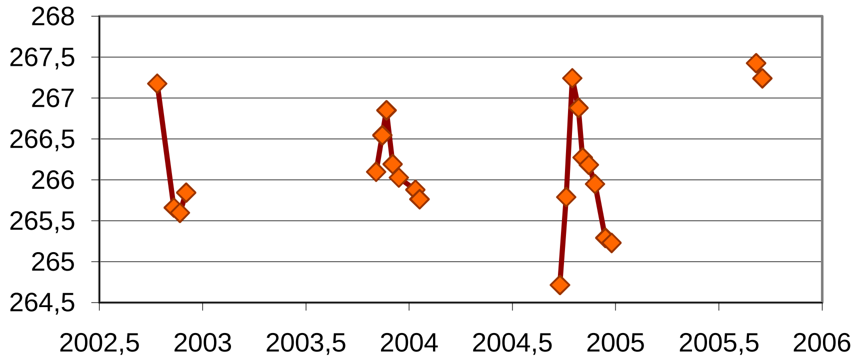


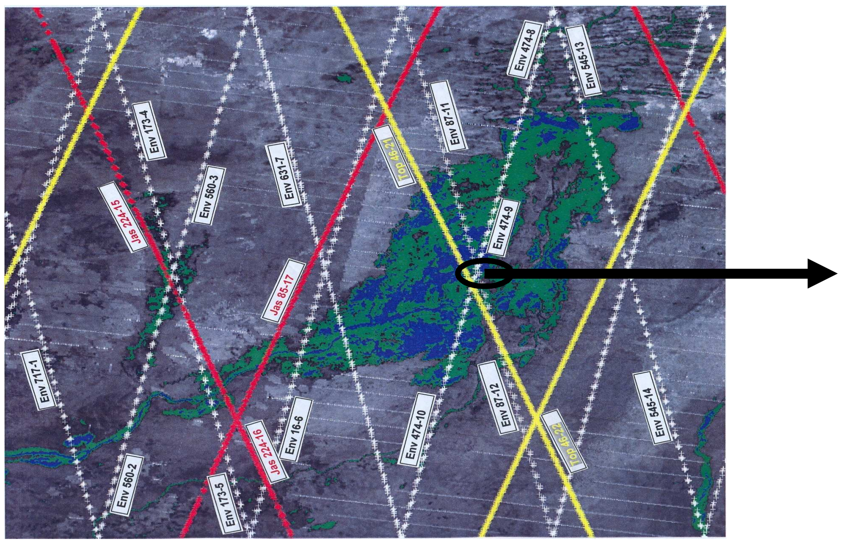




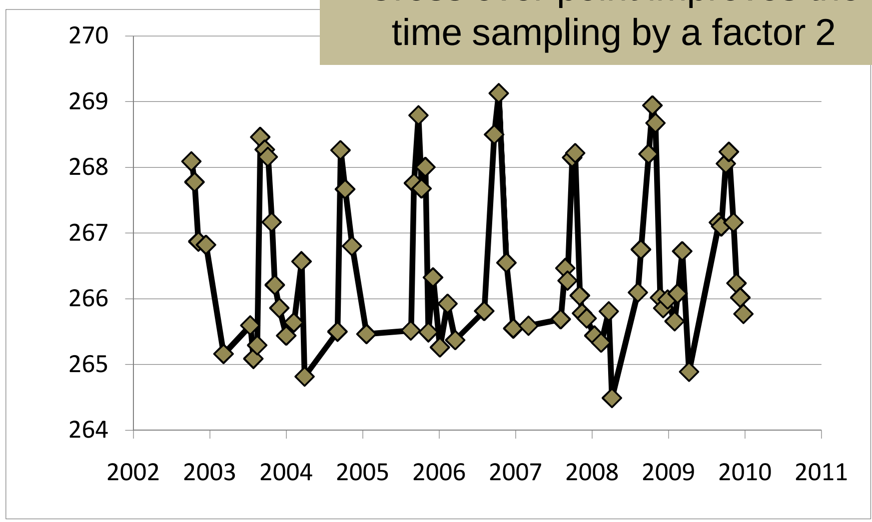








Cross over point improves the time sampling by a factor 2



Why monitoring the IND water surface and level from RS is important ?

✧ The Sahel is one of the most endangered zones worldwide

✧ The IND serves as crucial source of economic activity in Mali, with more than one million inhabitants strongly dependant on water resources in the IND (agriculture, fishing, pastoralism)

✧ The interaction among pre-flood, flood and post-flood conditions strongly affect land use patterns in and around the delta

✧ Need to examine how vulnerable is the IND to climate change

✧ Need to investigate the linkage between IND flooding, the river systems, and the Western African moonsoon (AMMA program)

✧ The IND can serve as a good natural laboratory to study climate change impact on surface water resources in semi-arid region

✧ Development of a modern system of survey/alert/prediction for inundation in the IND is an ongoing challenge.

A *condition sine qua non is the availability of homogenised and standardised time series of remotely sensed data.*

And what are the perspective ?

Remote Sensing future missions for surface waters

Satellite imagery

- Modis/Terra but still how long?
- Sentinel-2 but will the data be freely and easily available?

Satellite radar altimetry

- Jason-2 and Jason-3 (mid 2013) but cover the IND only at the mouth of the delta
- Altika but When? Will the CNES/ISRO consortium follow the agenda? However very interesting perspectives of improvement on floodplains thanks to Ka Band.
- Sentinel-3 (2013) but will the data be freely and easily available?
- HY2 but will the data be freely and easily available?

2019-2020: will SWOT be THE solution?

- Ka-Band SAR interferometric system with 2 swaths, each 60 km wide

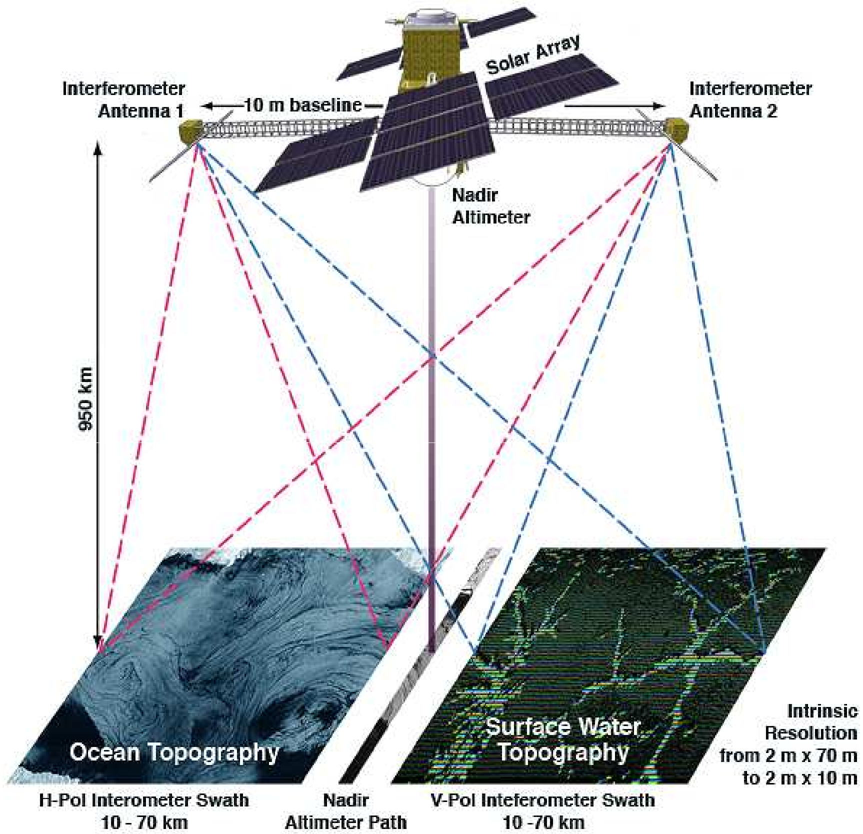
- Noise is uncorrelated thus averaging further improves height accuracy by sqrt(n)

- Produces heights and co-registered all weather imagery

- Height accuracy: 10cm w.r.t land over 1 km2 and slope of 1cm/km over 10 km

- In case study like IND it will considerably improve the understanding of flood process

- The potential of SWOT measurements will be enhanced if coupling with other RS data (SMOS like, radar altimetry, imagery, gravimetry and meteorological satellite data sets)



Graphics: Karen Wiedman


Thanks for attention

Classification over shallow lakes and floodplains

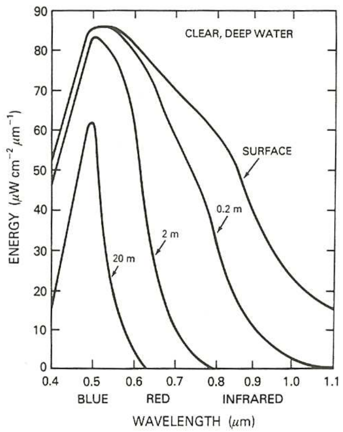


Figure 9.1 An illustration of how light is attenuated by clear water. Note that in the infrared region there is very little penetration into the water.

$\Rightarrow$ **Use of NIR is required**

$\Rightarrow$ **Resolution of 500 meters**

178 REMOTE SENSING IN HYDROLOGY

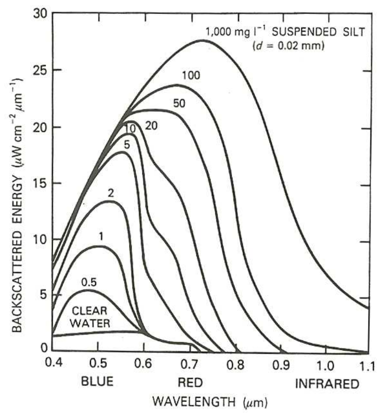
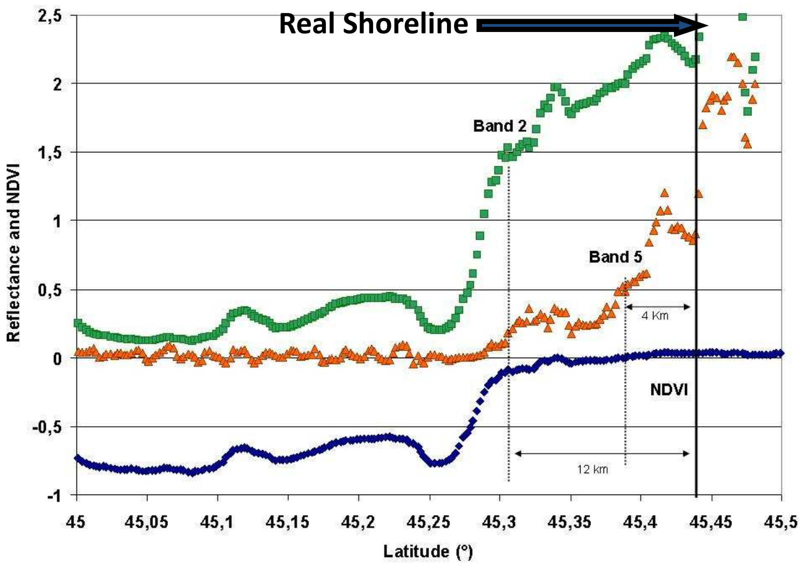
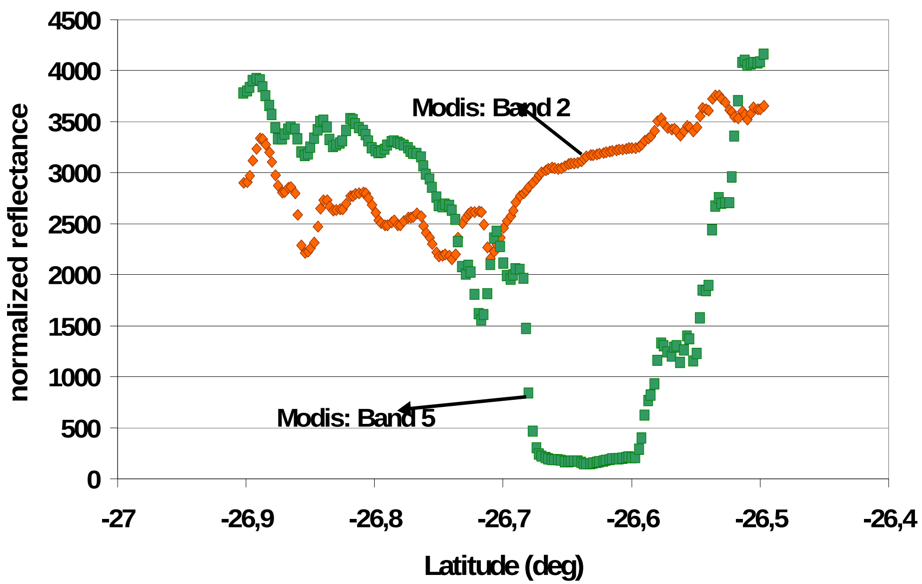


Figure 9.2 An illustration of the increase in backscattered energy as the sediment concentration increases.

Profile over the Aral Sea

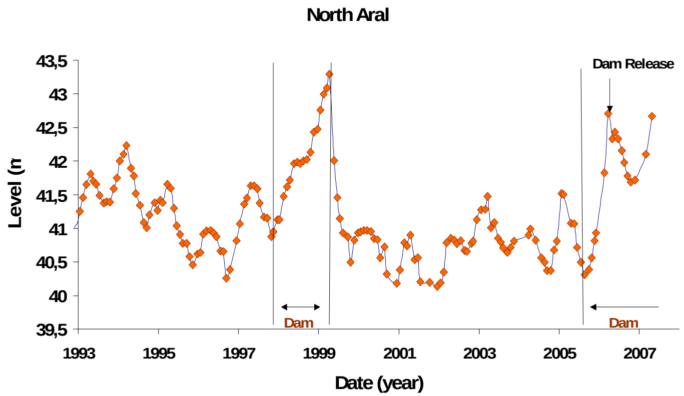


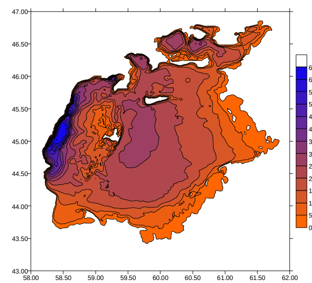
Profile over the Diamantina River

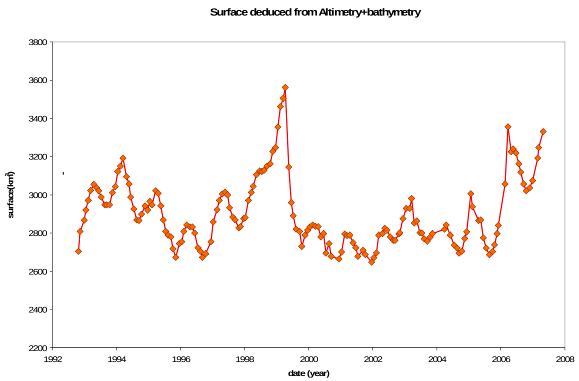


Validation of the methodology over the Aral Sea

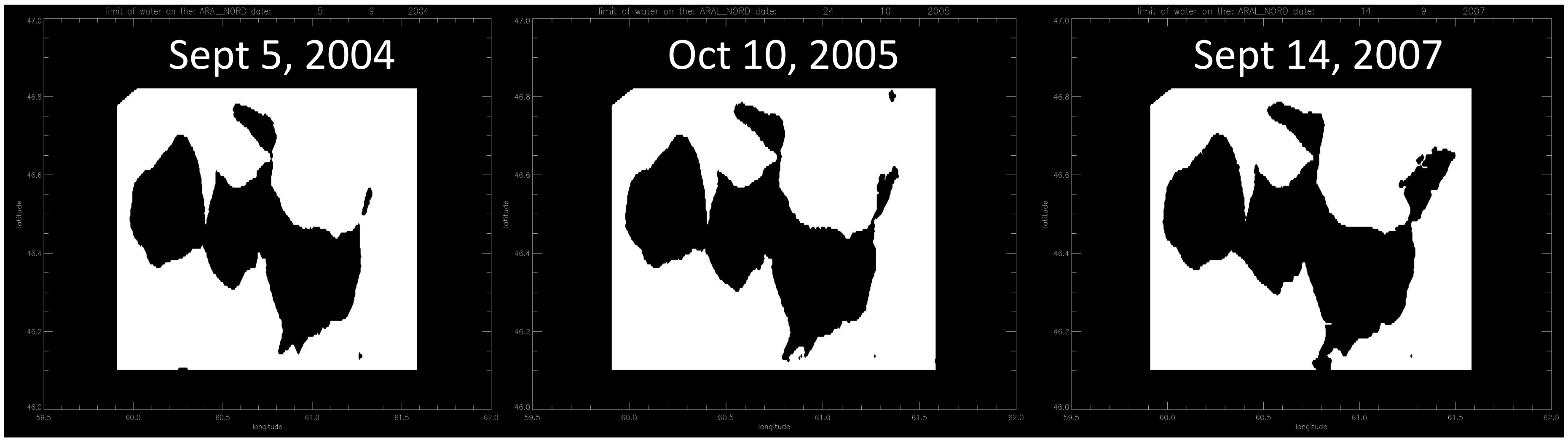
From altimetry + bathymetry = > variation of surface



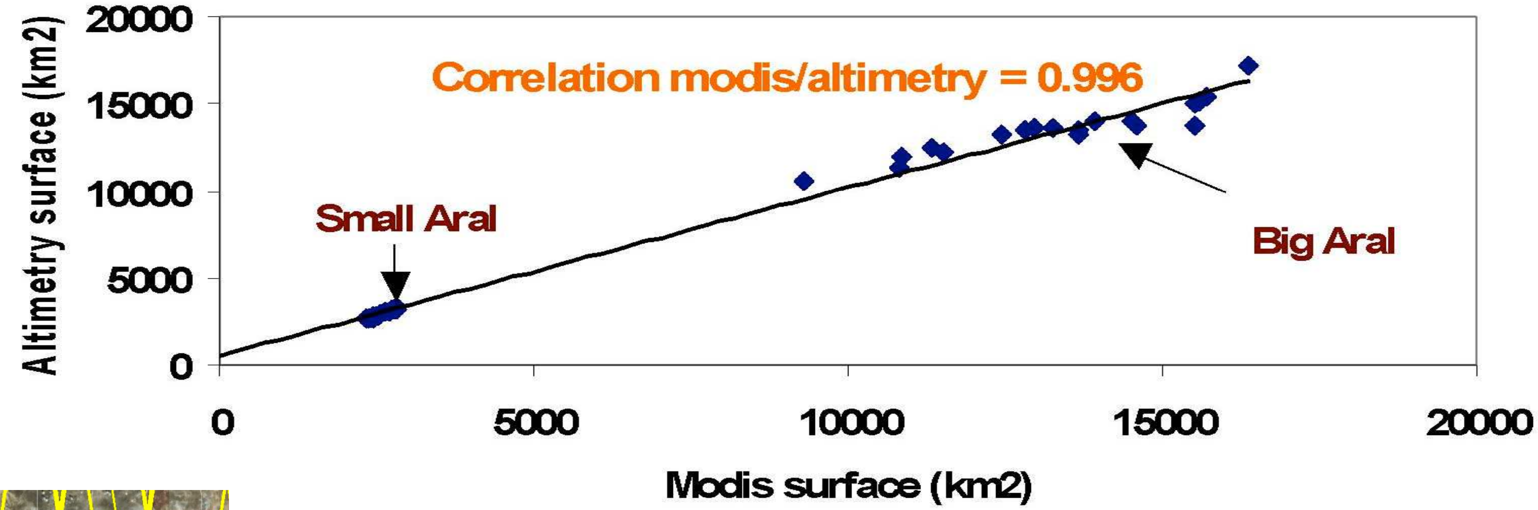


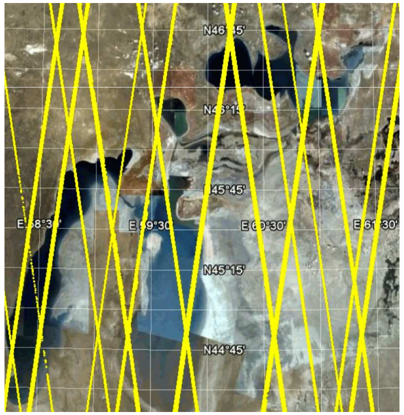


Direct measurement from analysis of the Modis images

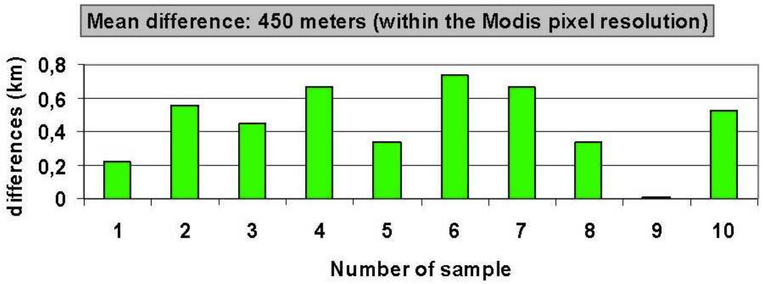


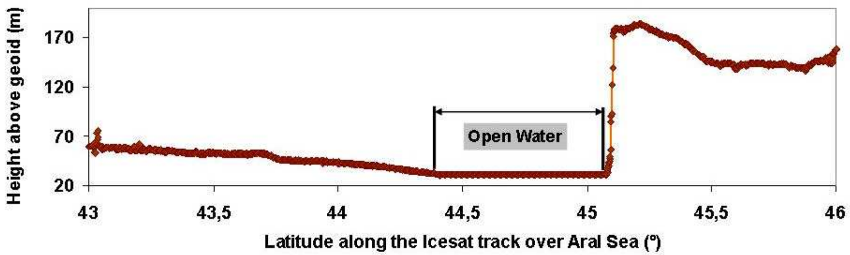
Modis / altimetry Aral surface variations

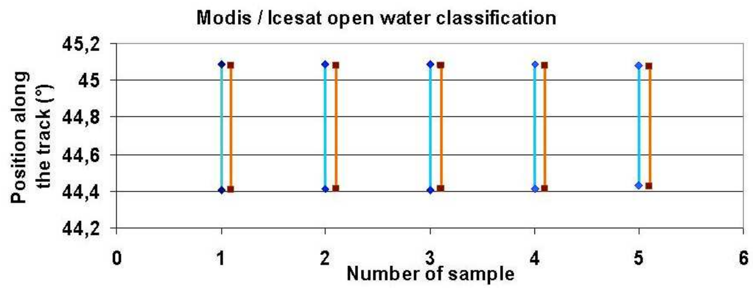


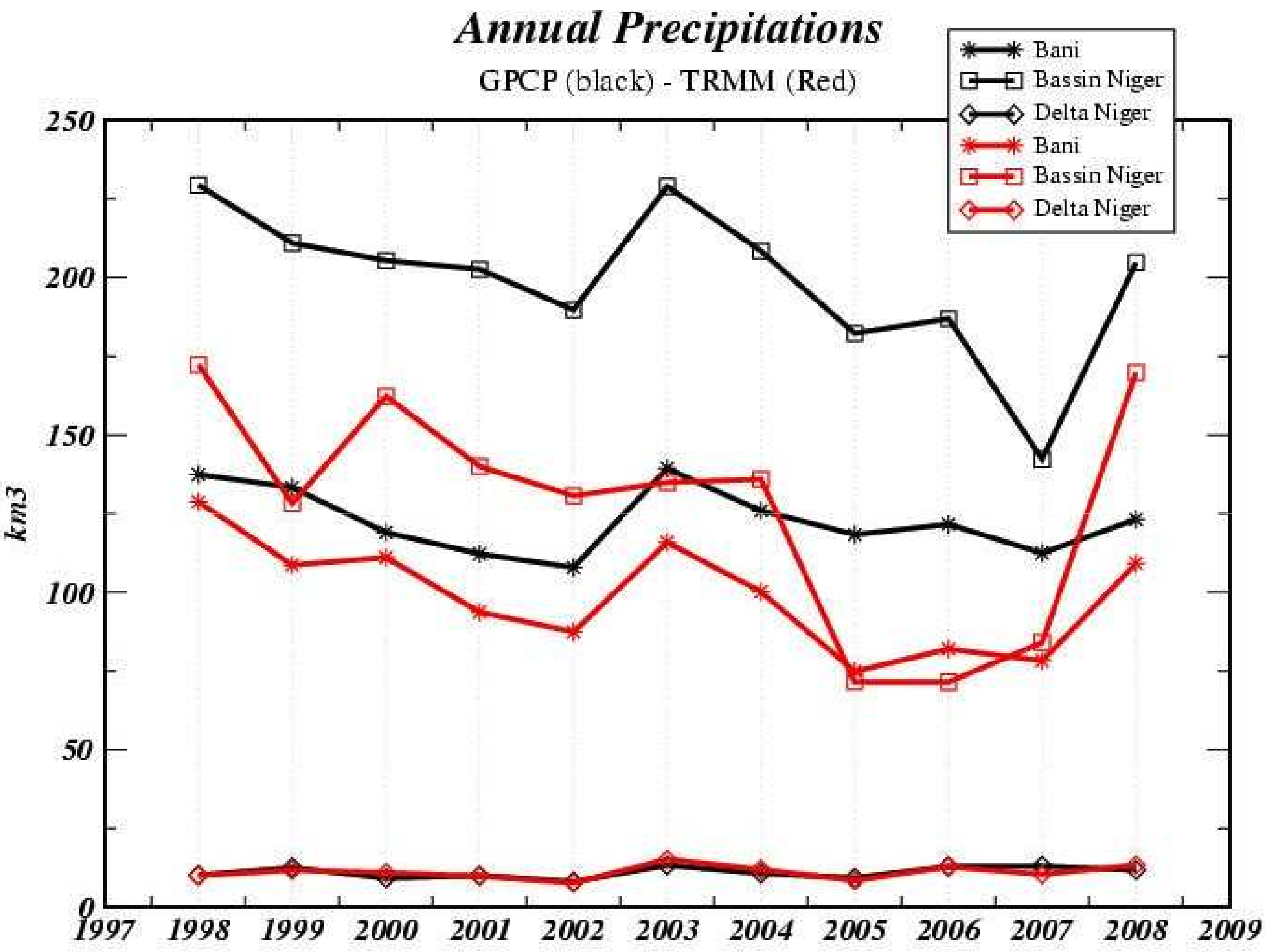


- From Icesat Laser altimetry mission one may detect presence of water through determination of height level above geoid.
- Comparison over 5 years of Icesat data on Aral Sea allow assessment of Modis classification of open water.









Total annual water supply by precipitation (GPCP & TRMM) on the IND from direct precipitation and flow on Niger and Bani rivers

Comparison of Modis classification with Landsat 7

October 22, 2003 ***February 27, 2004*** ***November 15, 2006***