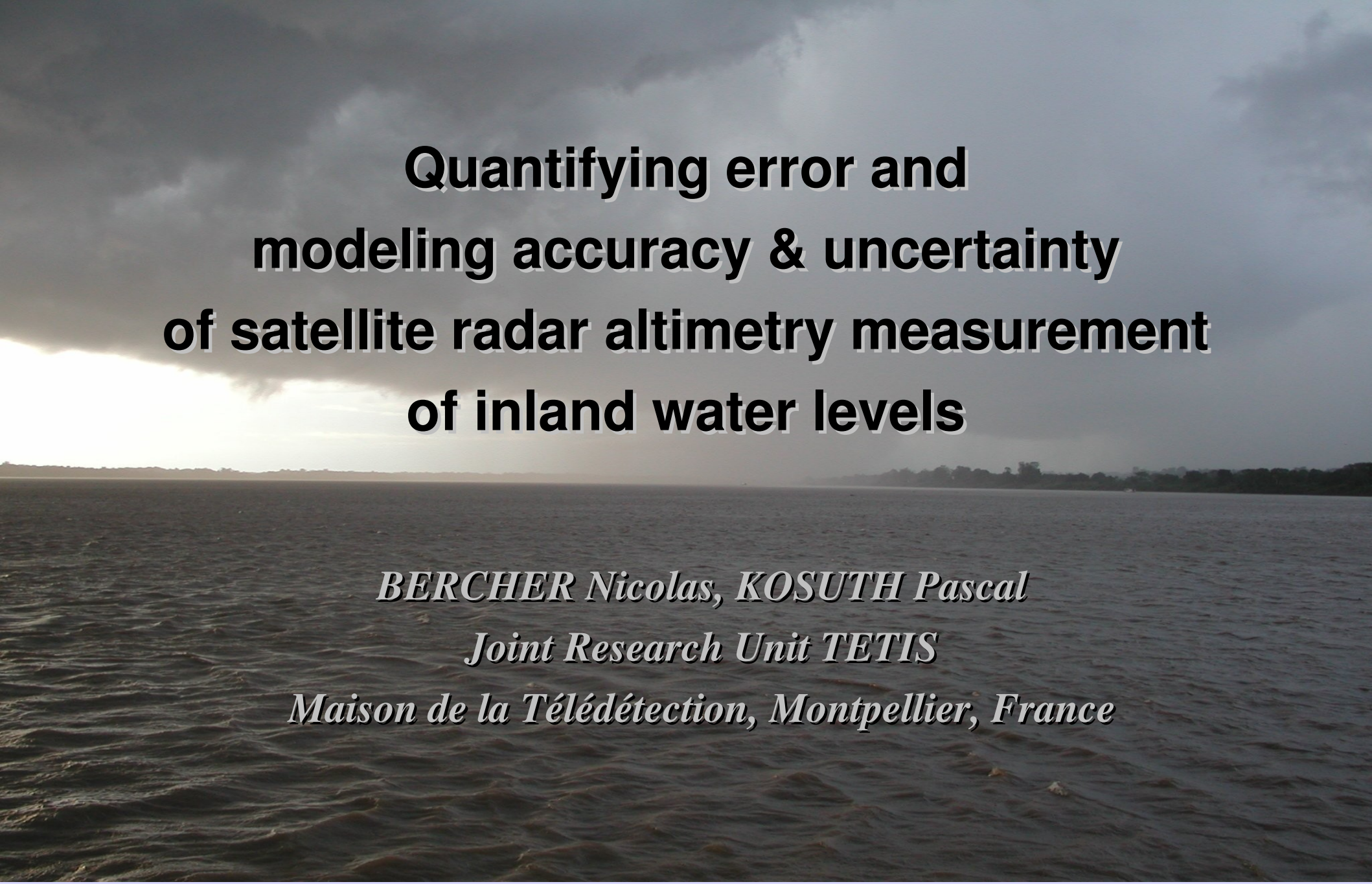

Quantifying error and modeling accuracy & uncertainty of satellite radar altimetry measurement of inland water levels

BERCHER Nicolas, KOSUTH Pascal
Joint Research Unit TETIS
Maison de la Télédétection, Montpellier, France

Cemagref cnes ALCATEL ALENIA SPACE
An Alcatel/Finmeccanica company

Presentation plan

- Introduction
- Building of time series of satellite radar altimetry water levels
- Quantification of satellite measurement error
- Modeling of accuracy & uncertainty
- Statistical analysis of accuracy (77 test sites on the Amazon basin)
- Conclusion & perspectives

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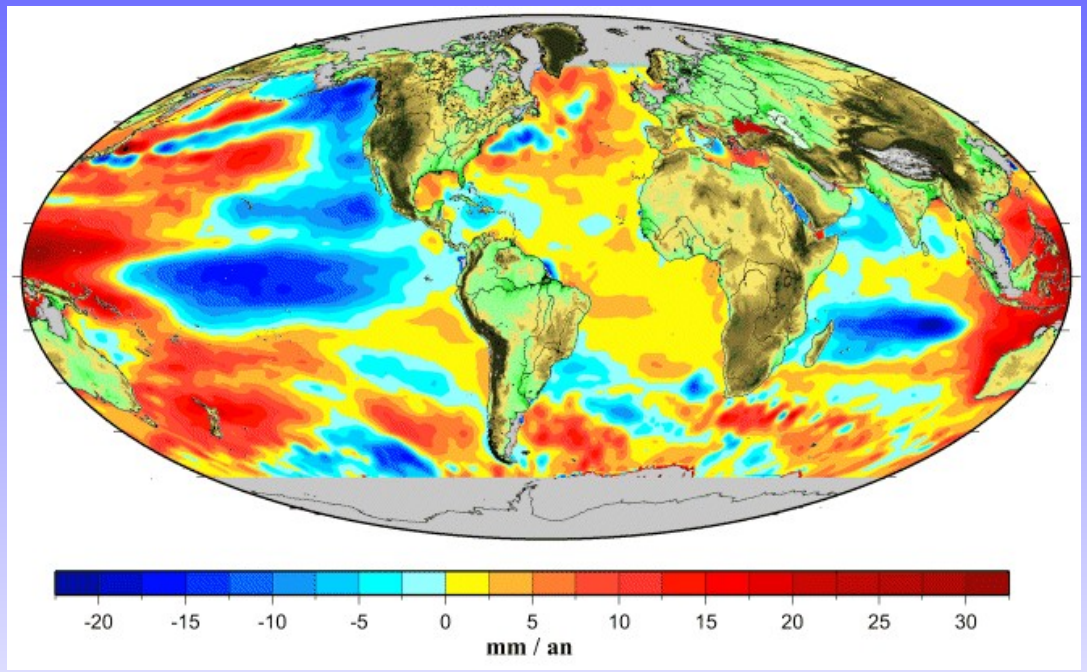
Introduction to satellite radar altimetry

- Originally designed for ocean applications

  Land topography, ocean bathymetry, sea mean height, etc.

- Multiple missions launched since early 80' (ERS, Topex/Poseidon, ENVISAT, JASON-1)

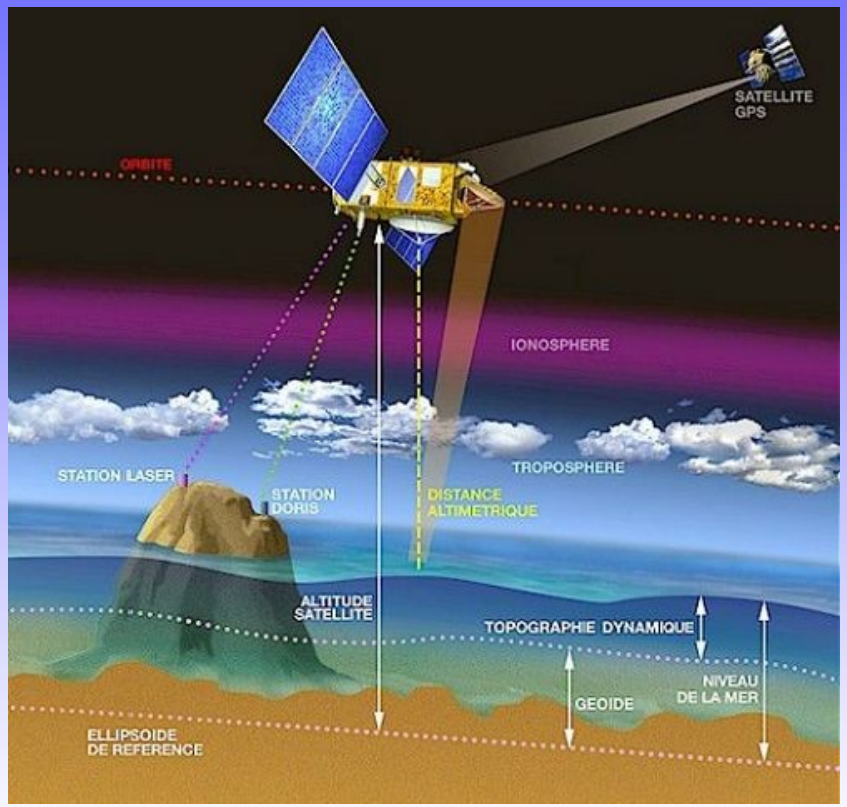
Topex/Poseidon
CNES/NASA

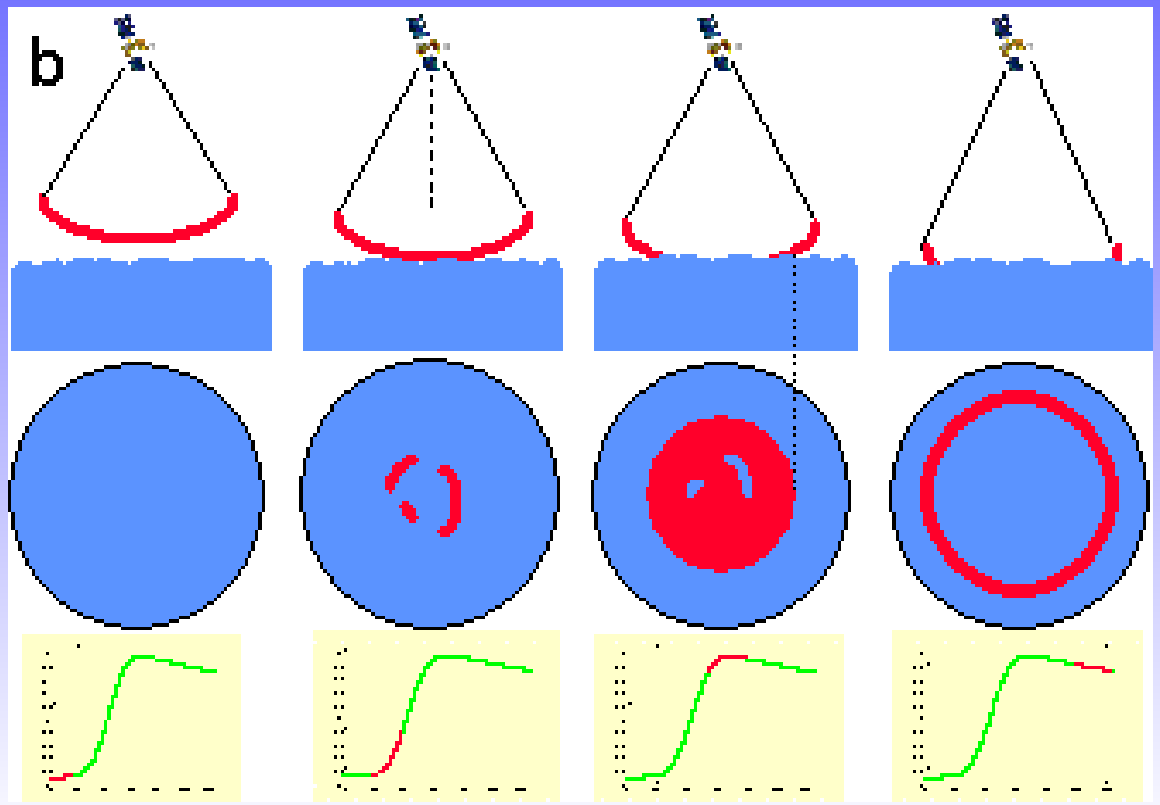


Ocean level variation 1993-2000
CNRS/Legos

Satellite radar altimetry principle

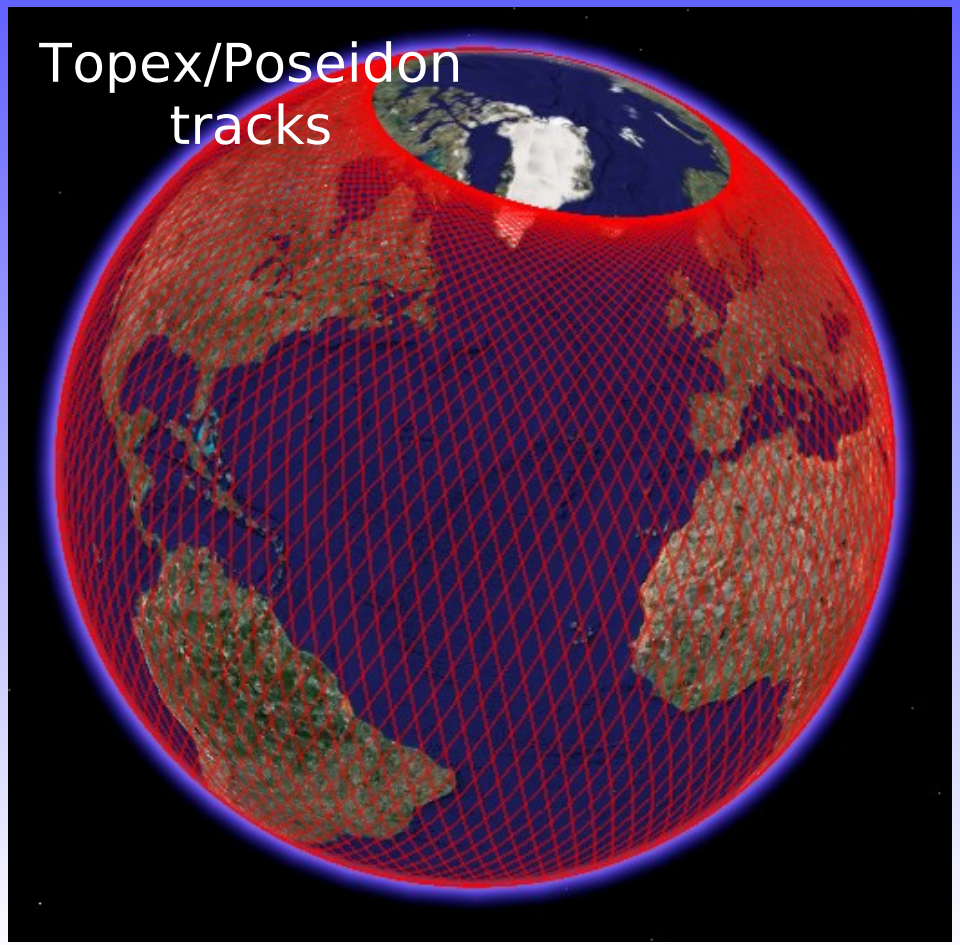
- Measurement of satellite/water surface distance by radar echo analysis (on board tracker, can be retracked later)
- Highly accurate 3D localization of satellite (GPS, DORIS)
- Water level referenced to an Earth ellipsoid, translated to geoid





Satellite characteristics

- Orbit: inclination, periodicity, equatorial inter-track distance (compromise spatial/temporal on-site resolutions)
- Radar sensor: along-track sampling frequency



Examples:

T/P: 66°/10 days/300km/10Hz

ENVISAT: 98°/35days/70km/18Hz

Different satellite characteristics lead to different performances in river level monitoring...

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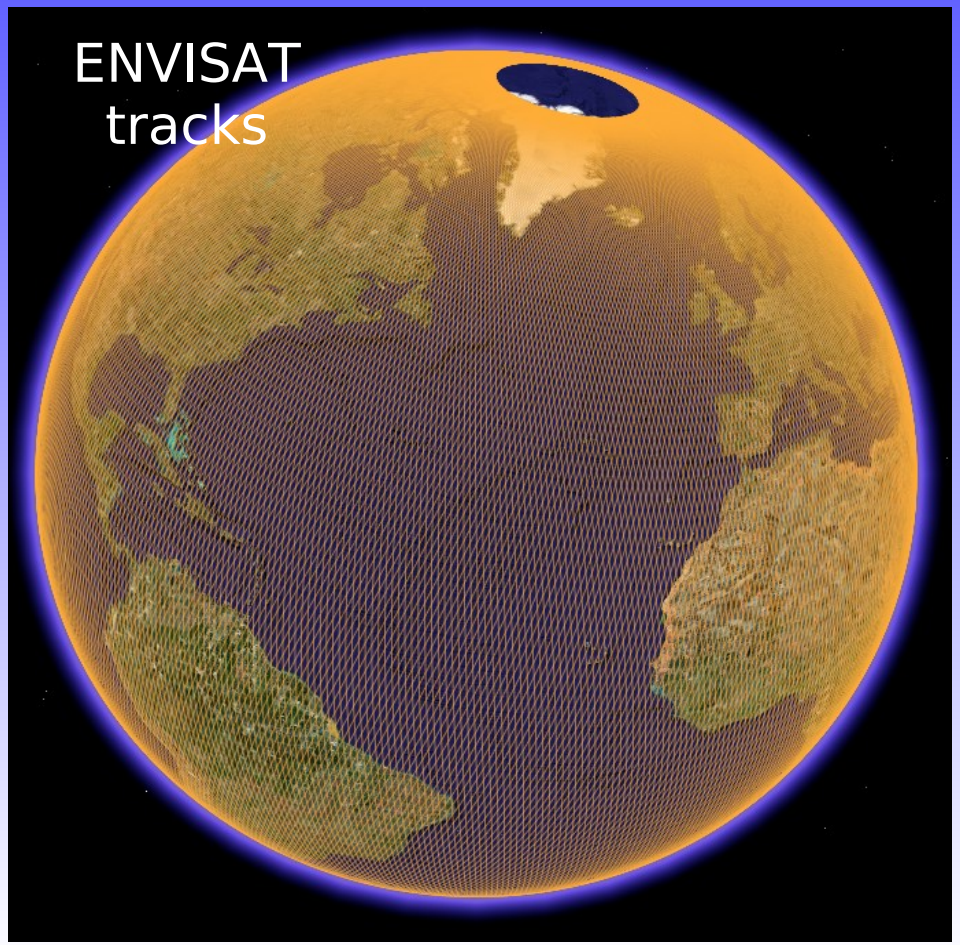

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Different satellite characteristics lead to different performances in river level monitoring...

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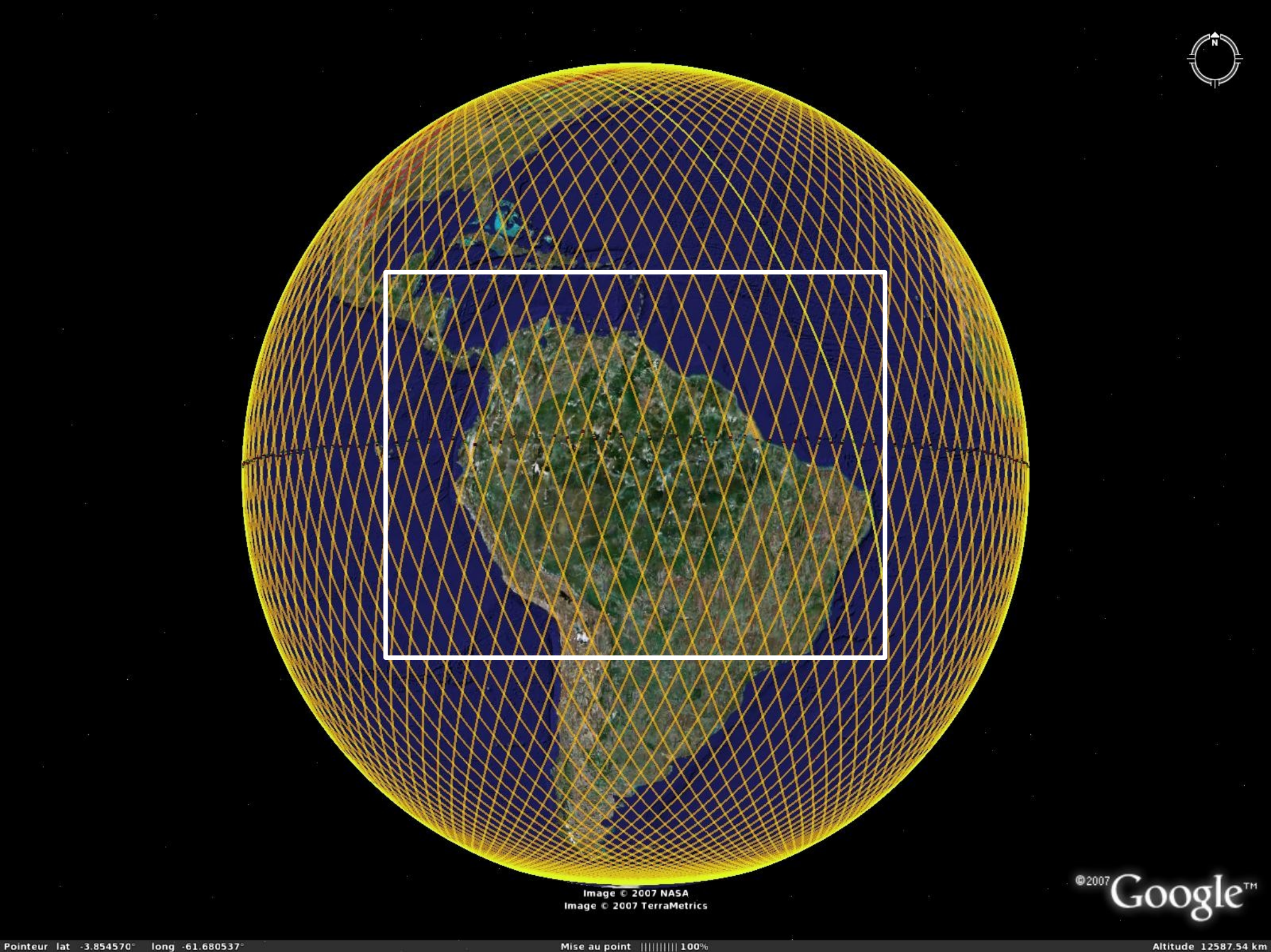
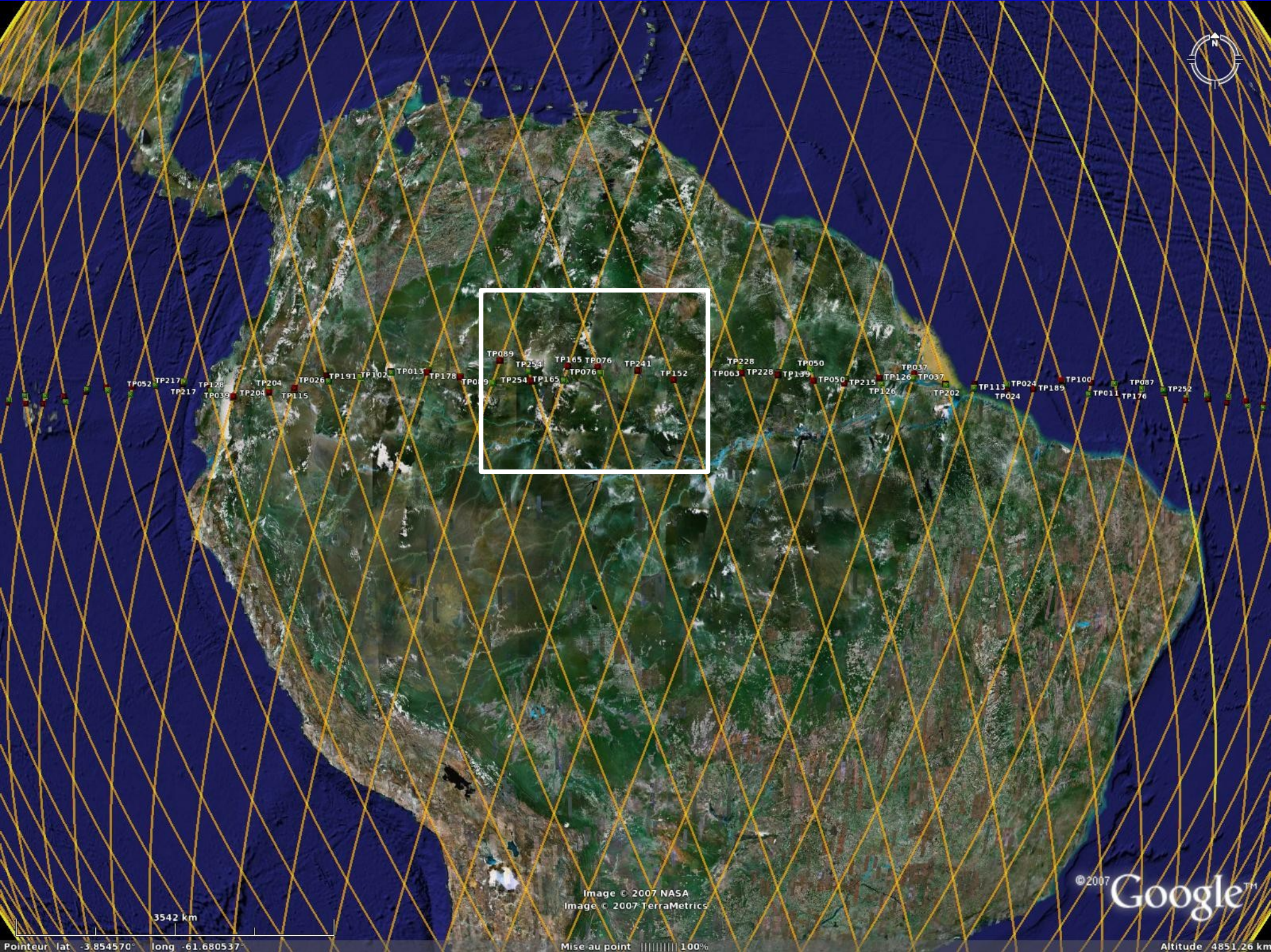


Image © 2007 NASA
Image © 2007 TerraMetrics
©2007 Google™
Pointeur lat -3.854570° long -61.680537°
Mise au point ||||||||| 100%
Altitude 12587.54 km


TP089
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TP039
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TP204
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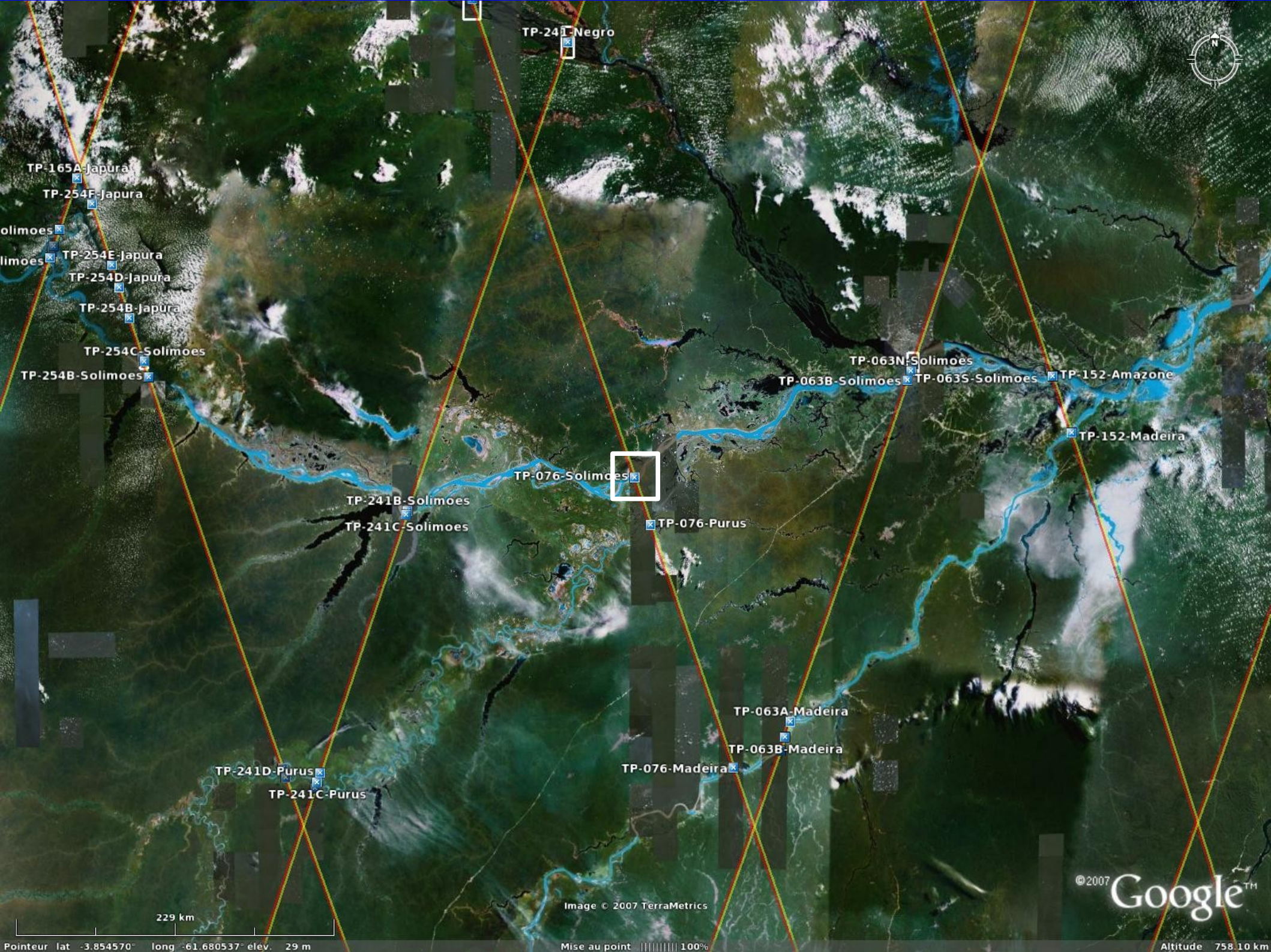
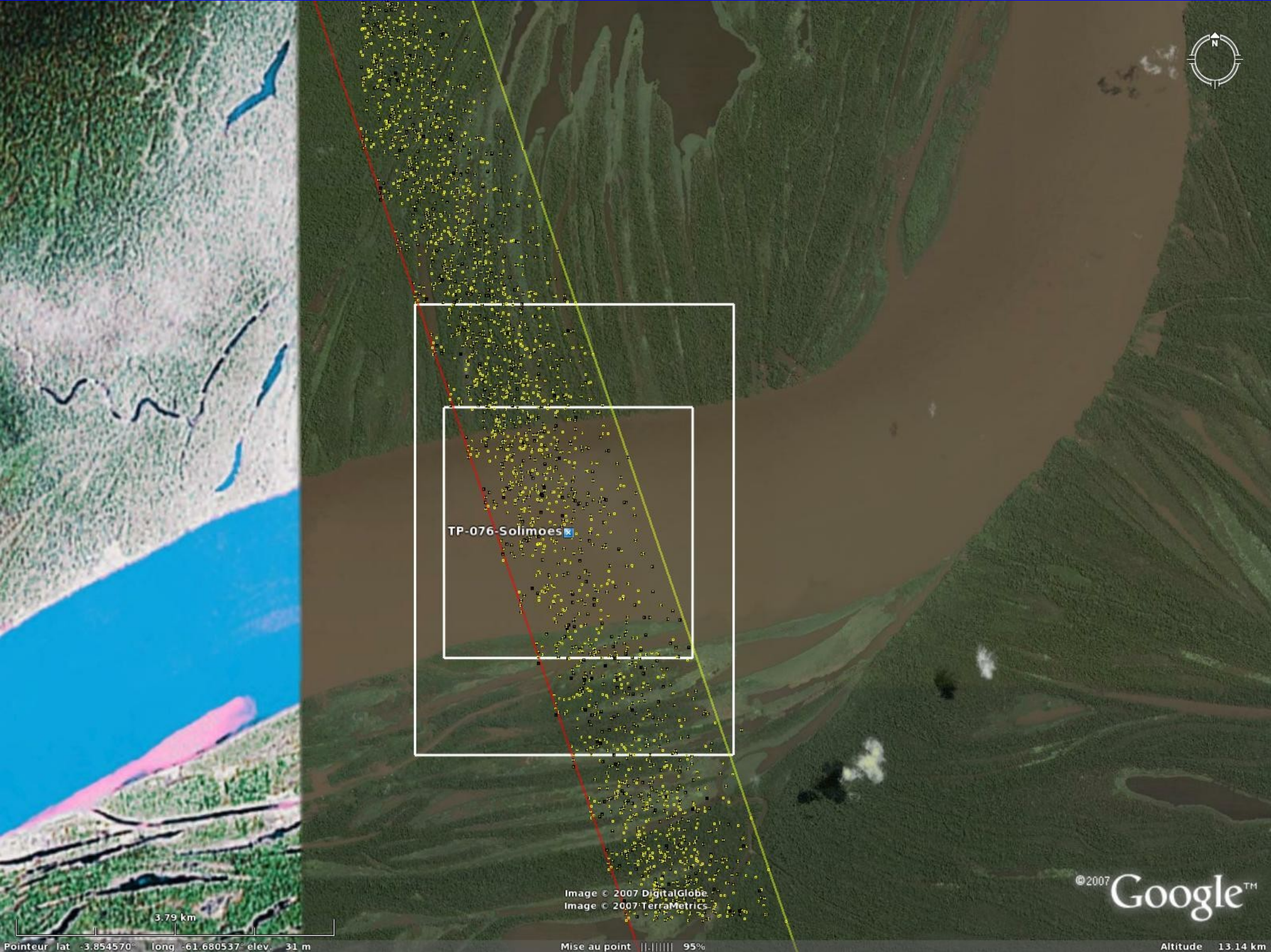
TP026
TP191
TP102
TP013
TP178
Image © 2007 NASA
Image © 2007 TerraMetrics
©2007 Google™
3542 km
Pointeur lat -3.854570° long -61.680537
Mise au point 100%
Altitude 4851.26 km

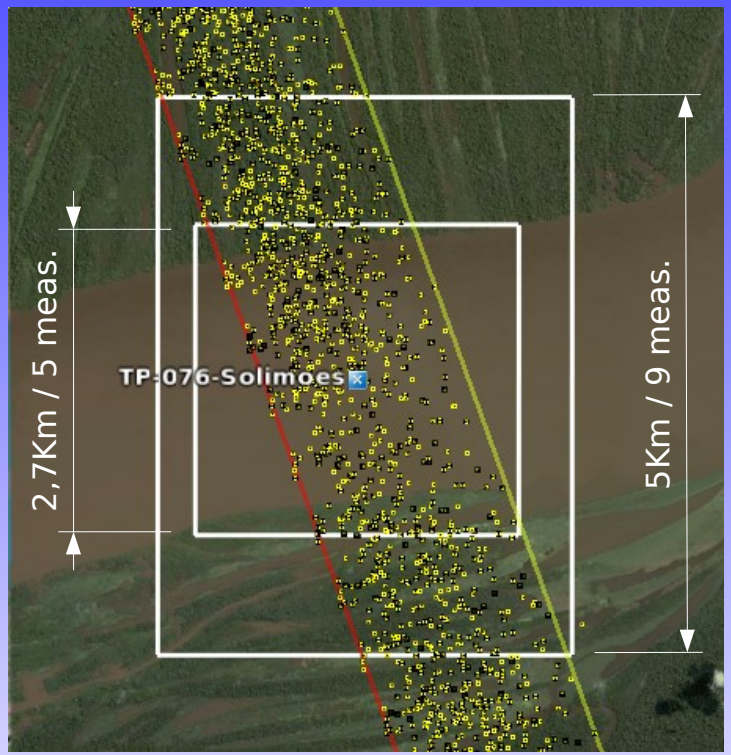

TP-241-Negro
TP-165A-Japura
TP-254F-Japura
olimoes
limoes
TP-254E-Japura
TP-254D-Japura
TP-254B-Japura
TP-254C-Solimoes
TP-254B-Solimoes
TP-063N-Solimoes
TP-063B-Solimoes
TP-063S-Solimoes
TP-152-Amazone
TP-152-Madeira
TP-076-Solimoes
TP-241B-Solimoes
TP-241C-Solimoes
TP-076-Purus
TP-063A-Madeira
TP-063B-Madeira
TP-076-Madeira
TP-241D-Purus
TP-241C-Purus
229 km
Image © 2007 TerraMetrics
©2007 Google™
Pointeur lat -3.854570° long -61.680537° elev. 29 m
Mise au point 100%
Altitude 758.10 km


TP-076-Solimoes
Image © 2007 DigitalGlobe
Image © 2007 TerraMetrics
©2007 Google™
3.79 km
Pointeur lat -3.854570° long -61.680537° elev. 31 m
Mise au point 95%
Altitude 13.14 km

Building time series of satellite radar altimetry water levels: a 5 step method

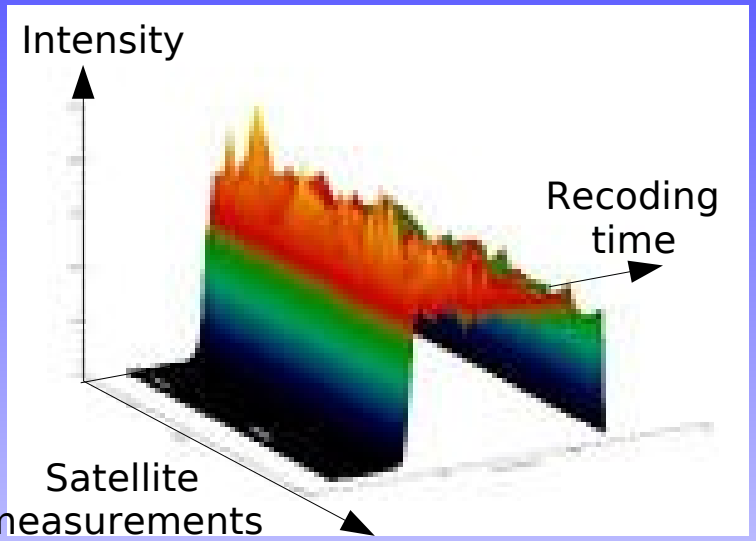
Processing time series derived from satellite altimetry

(1) Defining an extraction window



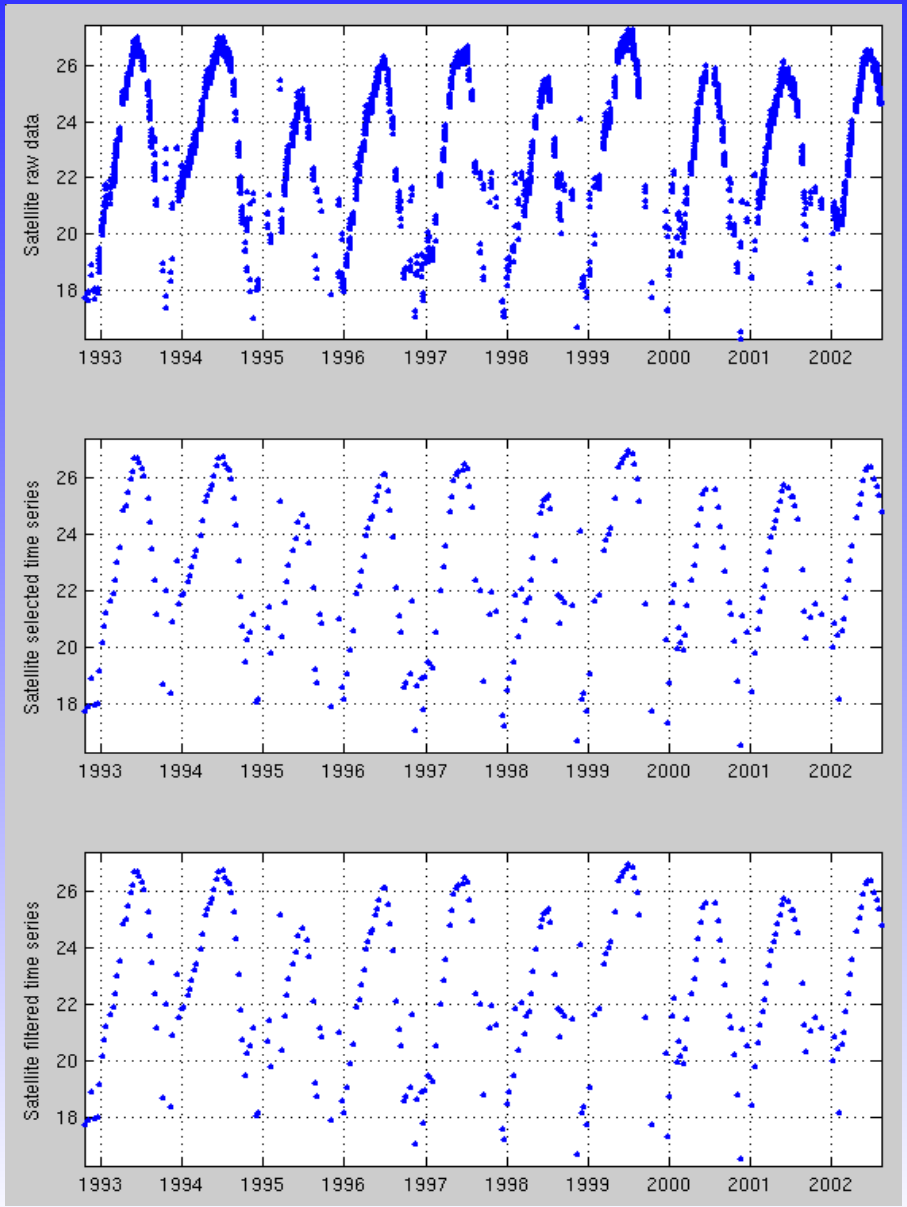
Extraction windows can be fitted on river width or enlarged for narrow rivers

(2) Waveform tracking



Waveform tracker algorithm developed for oceans are not optimized for inland applications

Building time series of satellite radar altimetry water levels: a 5 step method



(3) Translation to geoid referential:

Geoid undulation is calculated for each satellite measurement (WGS84/EGM96)

(4) Water level time series:

Choosing a unique representative measurement for each satellite overflight over the water body

(5) Filtering the time series:

Removing erroneous measurements

Presentation plan

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Quantification of satellite measurement error

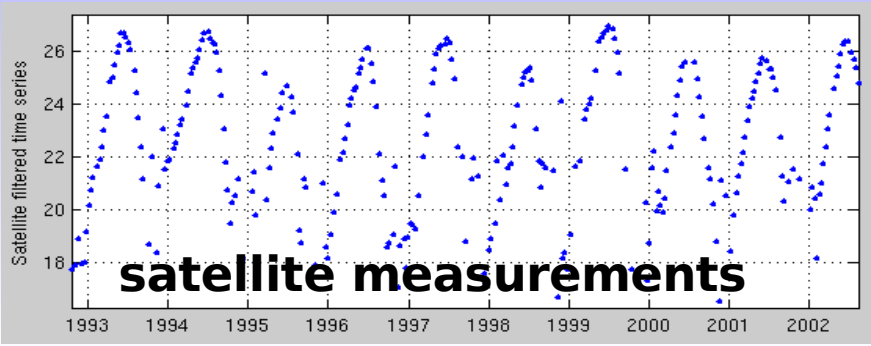
Definition of a virtual gauging station (Solimões river, Amazon basin)

Quantification of satellite measurement error through comparison between:

Quantification of satellite measurement error

Definition of a virtual gauging station (Solimões river, Amazon basin)

Quantification of satellite measurement error through comparison between:



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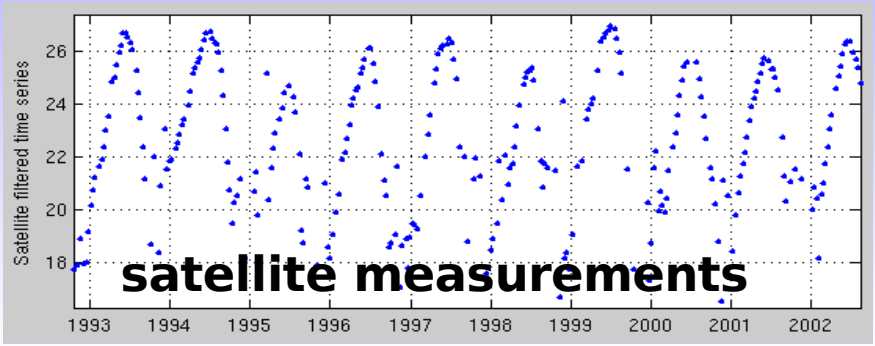
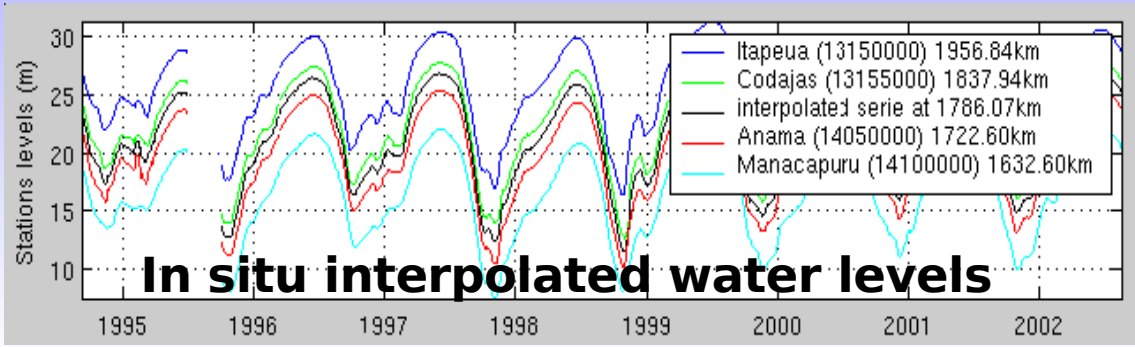
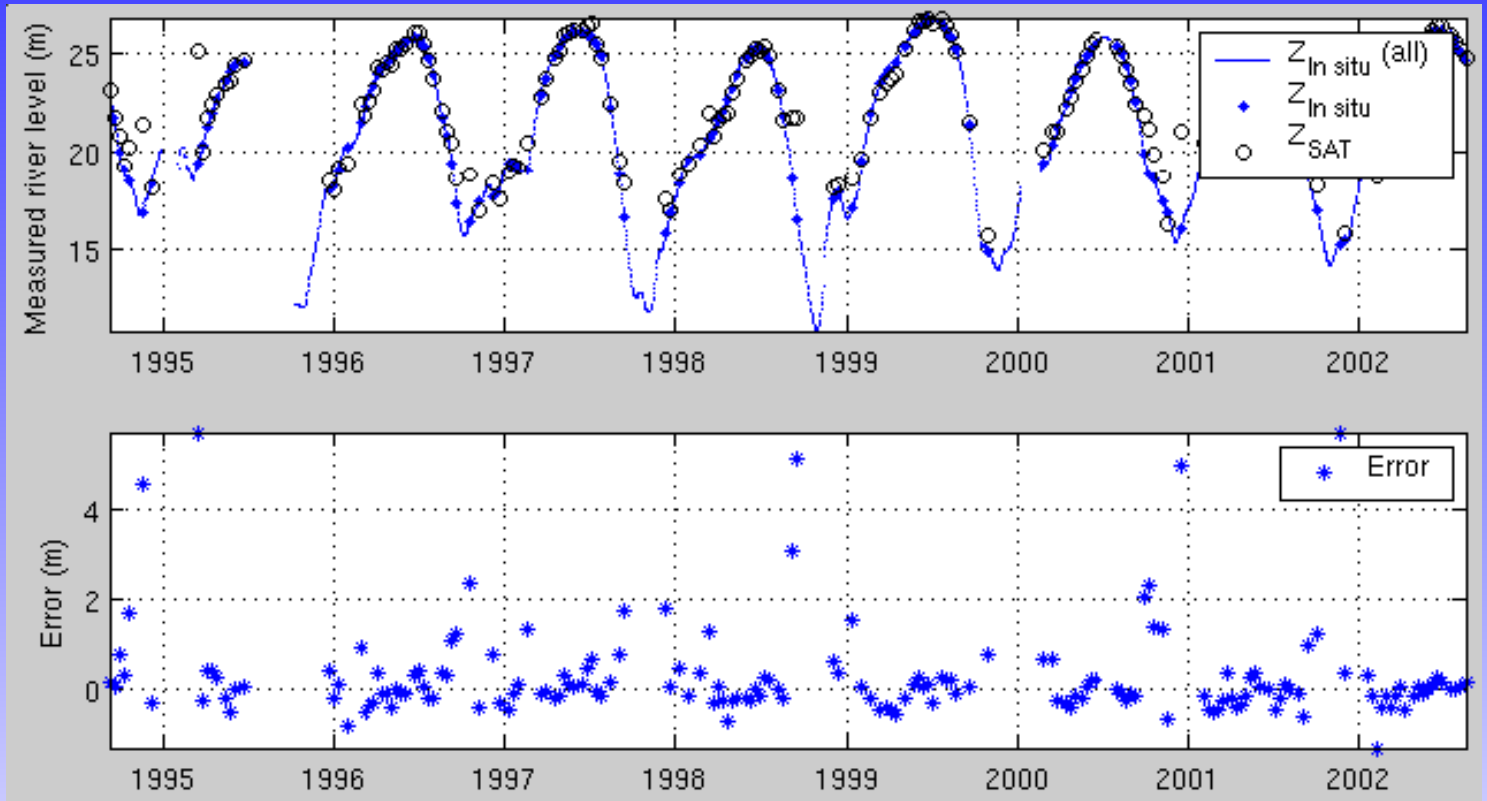




Quantification of satellite measurement error

Error time series, **RMSE** & **effective sampling period**



Global RMSE (m):	**1.10**
Effective sampling period (days):	**16** (10days theoretically)
	(37% loss rate)

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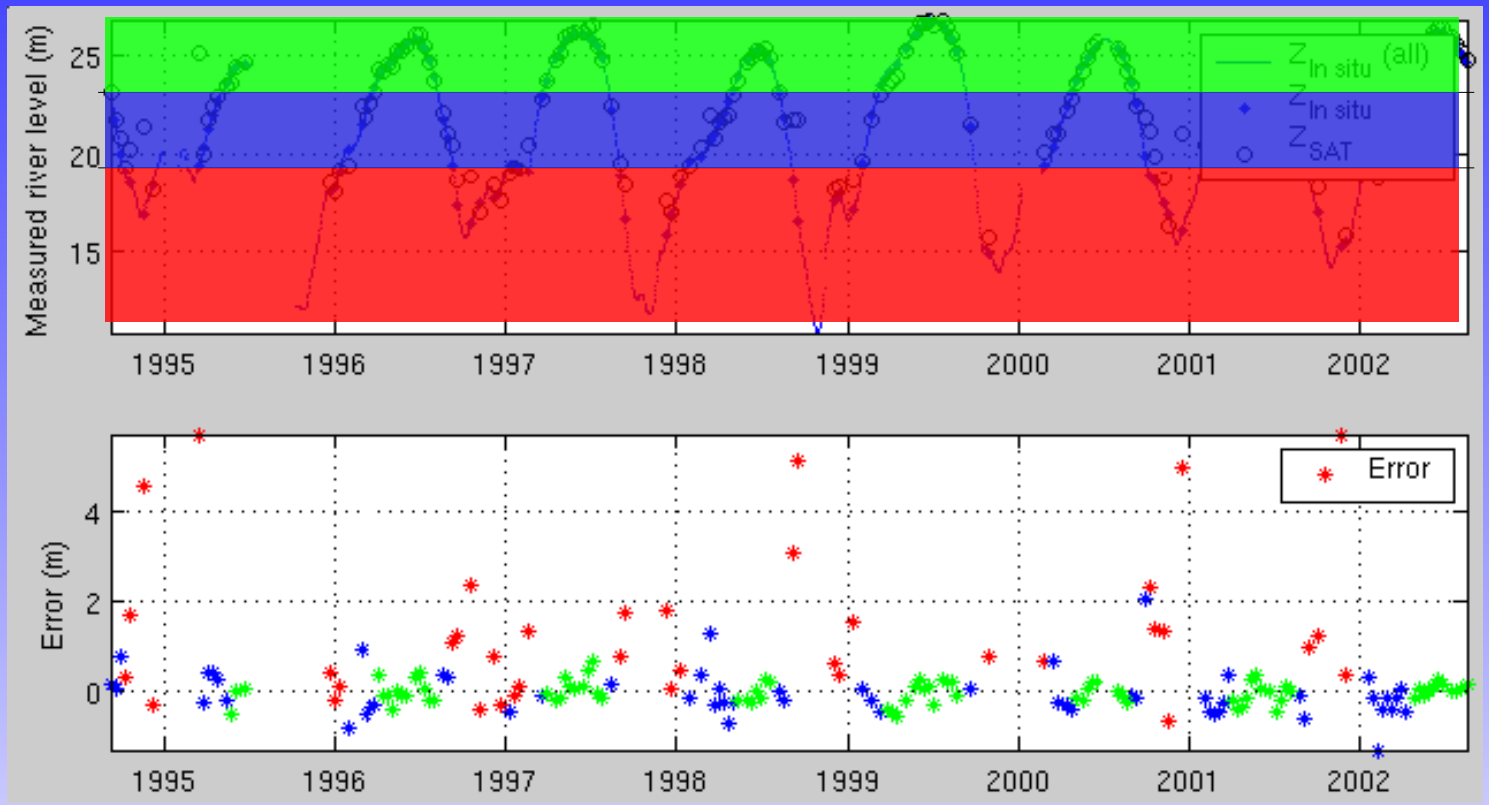
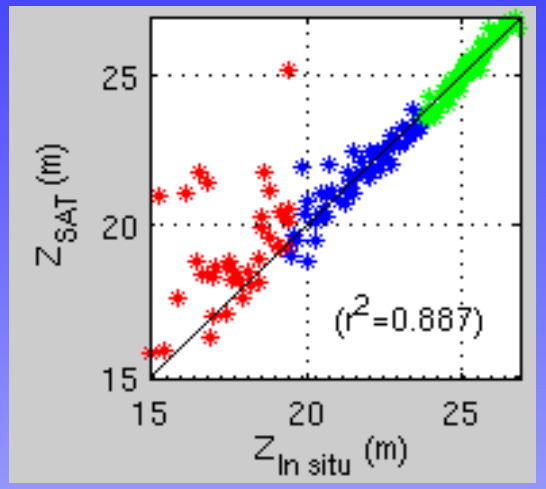
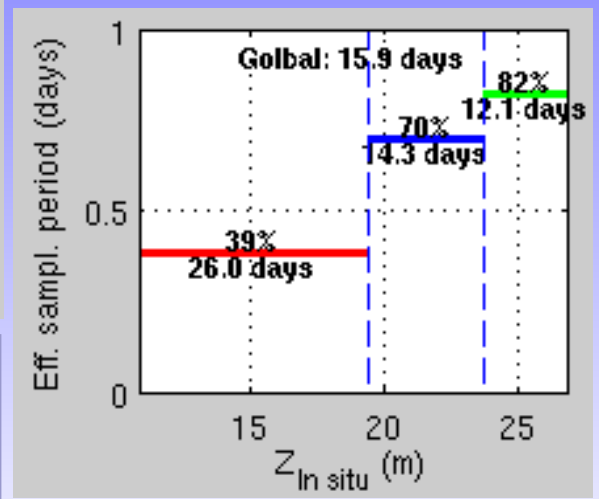
Modeling accuracy & uncertainty

Error is not gaussian : it is structured according to the hydrological regime => Modeling error : 3 complementary modeling approaches



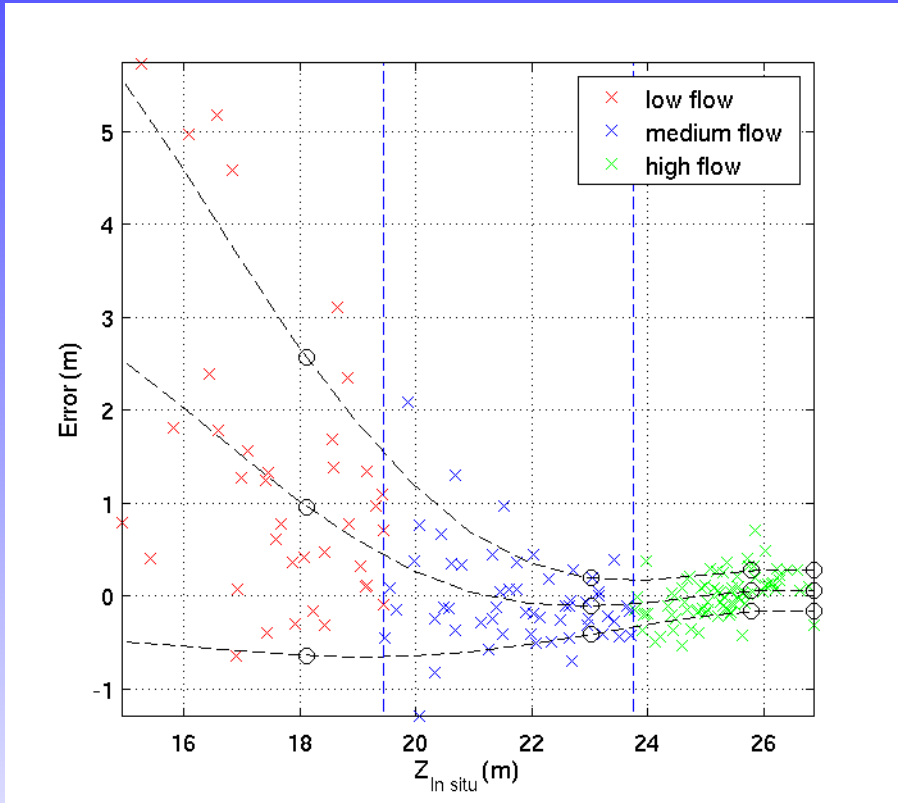




Stages RMSE (m):	**0,24**	/ **0,52**	/ **2,21**	/ **1,10**
Eff. sampl. Period. (days):	**12**	/ **14**	/ **26**	/ **16**

Modeling accuracy & uncertainty

(1) Modeling error structure according to the river level (in situ): quantifies variable accuracy



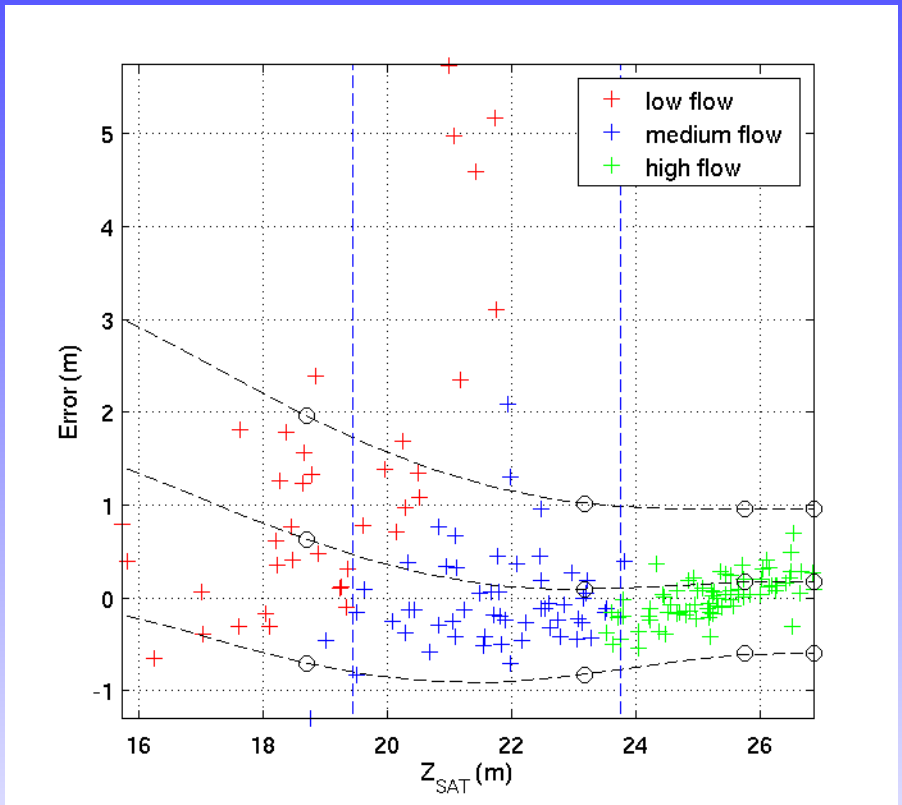
	$Z_{in\ situ}$ (m)	RMSE (m)	Mean (m)	STD (m)	Teff (days)
Global	$10,9<Z_{in\ situ}<26,8$	1.10	0.30	1.06	15.90
High	$23,8<Z_{in\ situ}<26,8$	0.24	0.00	0.24	12.10
Medium	$19,5<Z_{in\ situ}<23,8$	0.52	-0.04	0.52	14.27
Low	$10,9<Z_{in\ situ}<19,5$	2.21	1.41	1.73	26.00

Systematic bias

- Takes into account past years measurements
- Provides an information of satellite performances according to the river level

Modeling accuracy & uncertainty

(2) Modeling error structure according to the radar altimetry river level: quantification of uncertainty



	Z_{SAT} (m)	RMSE (m)	Mean (m)	STD (m)
Global	$15,7<Z_{SAT}<26,9$	1.10	0.30	1.06
High	$24,7<Z_{SAT}<26,9$	0.79	0.18	0.78
Medium	$21,7<Z_{SAT}<24,7$	0.92	0.09	0.92
Low	$15,7<Z_{SAT}<21,7$	1.46	0.63	1.33

Application:

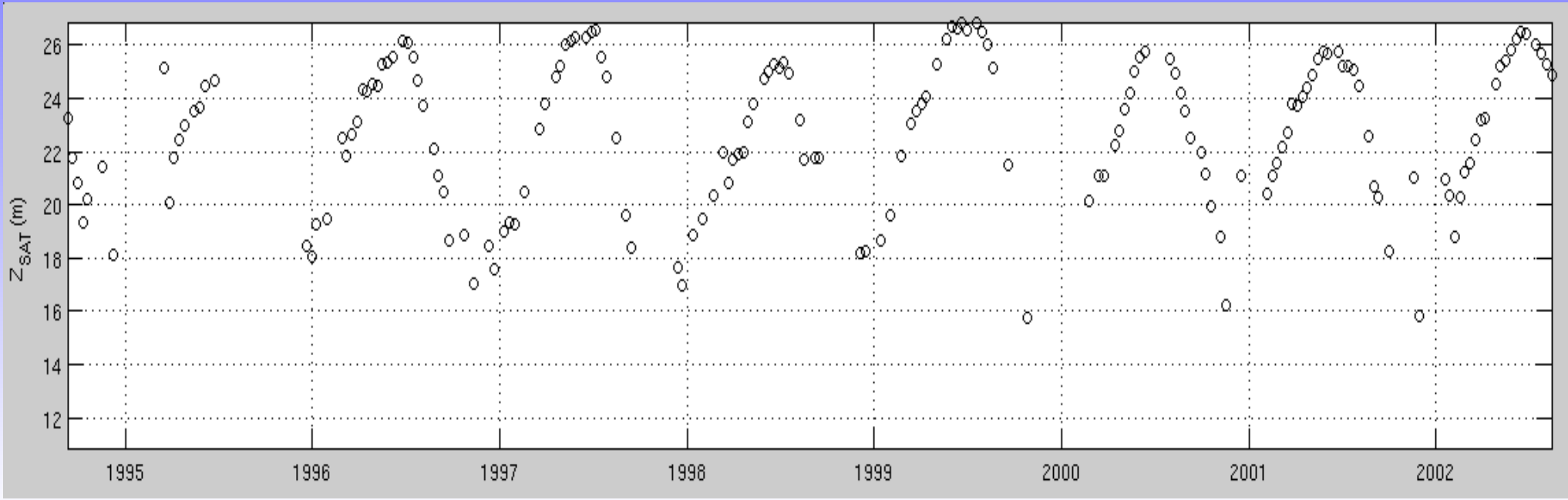
- Model uncertainty based on previous measurements (past years)
- Quantifies the uncertainty of new incoming radar altimetry measurements **without any in situ information**

Caution : This estimation of uncertainty is limited to a given virtual station. It cannot be transfered to other stations

Modeling accuracy & uncertainty

Application to satellite time series

- Allows future measurements to be qualified with their uncertainty
- Useful method in near real time applications
- Provide uncertainty used by hydrological models



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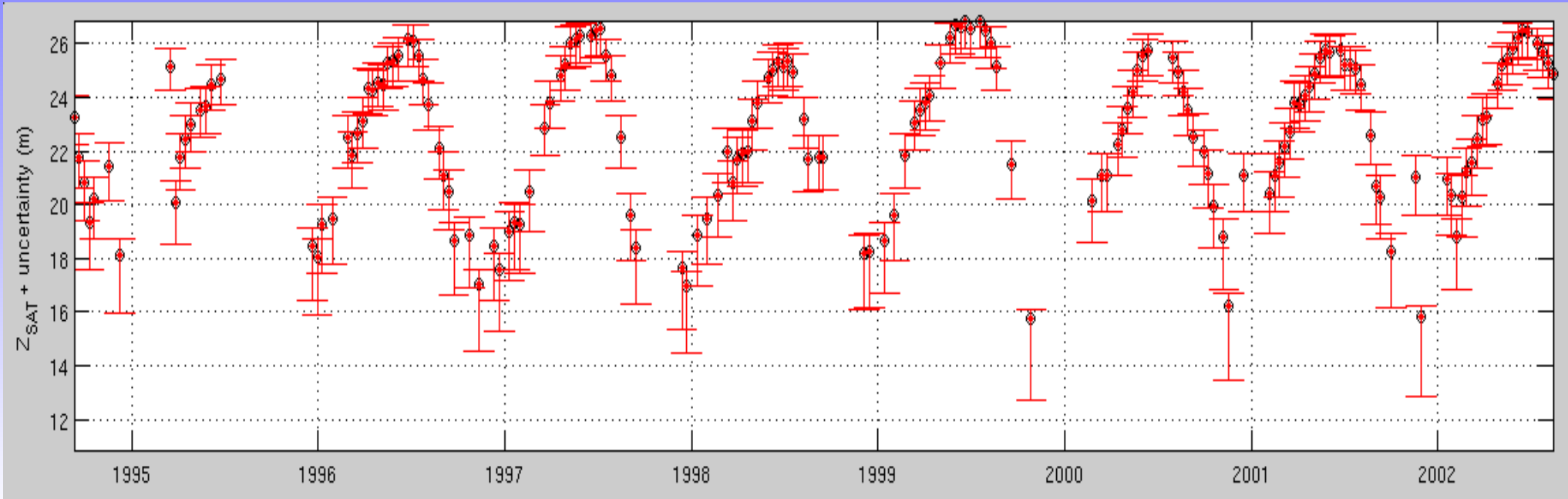

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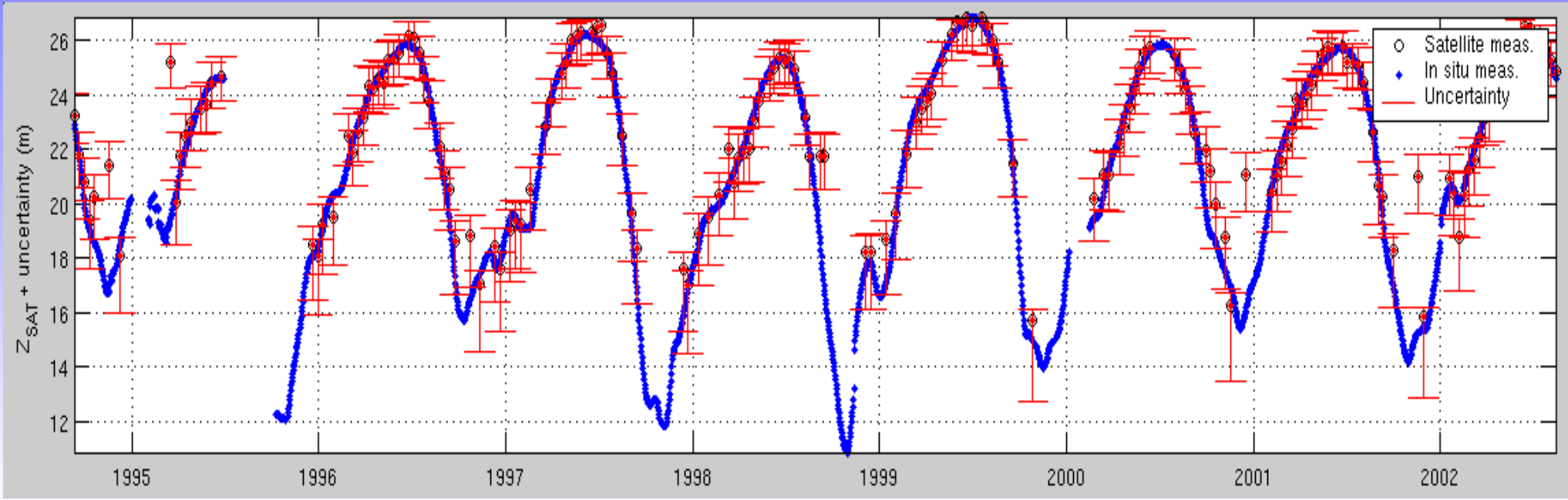
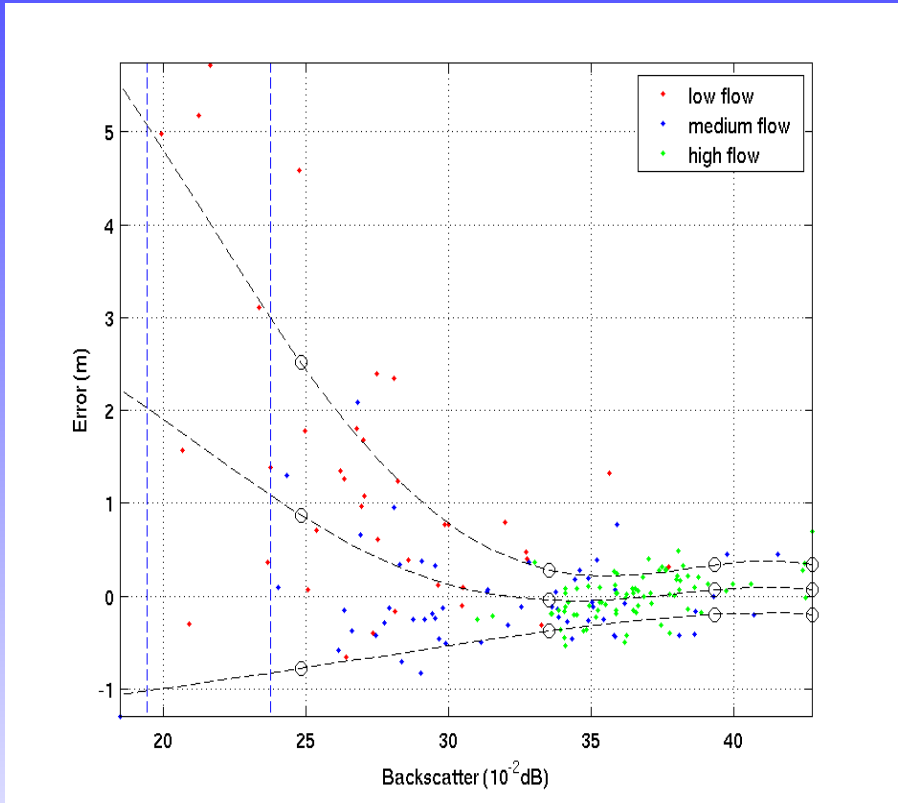


Modeling accuracy & uncertainty

Question: Modeling uncertainty according to the backscatter coefficient...?



	Backscatter (10^{-2} dB)	RMSE (m)	Mean (m)	STD (m)
Global	18,5<Bck<42,8	1.10	0.30	1.06
High	35,9<Bck<42,8	0.27	0.07	0.24
Medium	31,1<Bck<35,9	0.33	-0.04	0.33
Low	18,5<Bck<31,1	1.85	0.87	1.73

- **Model that is usually closer to the accuracy model**
- **Can we merge every virtual stations errors into a global model?**
  - **Would be useful when no in situ data is available...**

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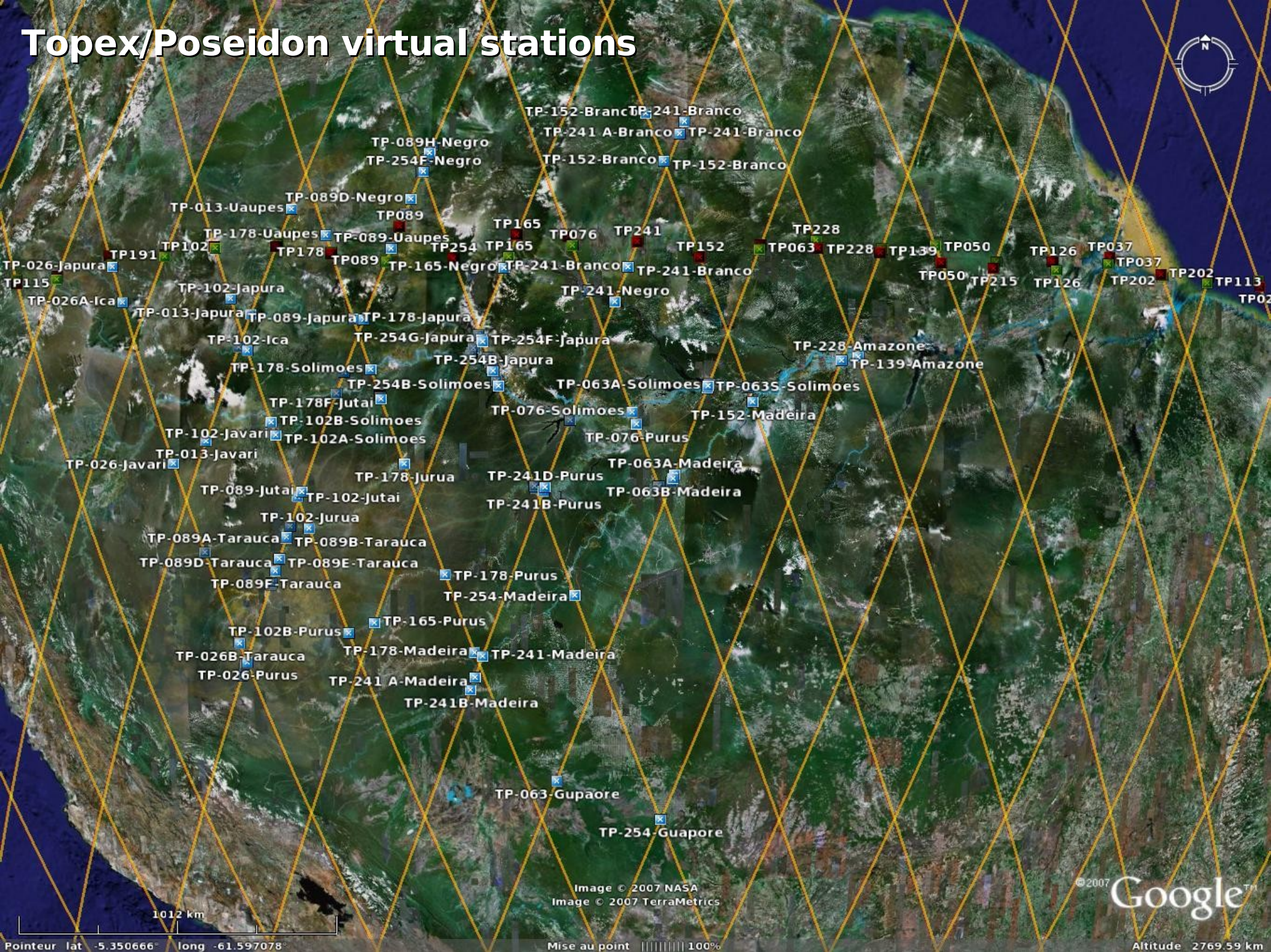
Statistical analysis over 77 study sites on the Amazon basin


Topex/Poseidon virtual stations
TP-152-Branco
TP-241-Branco
TP-241 A-Branco
TP-241-Branco
TP-089H-Negro
TP-254F-Negro
TP-152-Branco
TP-152-Branco
TP-089D-Negro
TP-013-Uaupes
TP089
TP165
TP076
TP241
TP228
TP-178-Uaupes
TP-089-Uaupes
TP102
TP254
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TP115
TP-102-Japura
TP-241-Negro
TP-026A-Ica
TP-013-Japura
TP-089-Japura
TP-178-Japura
TP-102-Ica
TP-254G-Japura
TP-254F-Japura
TP-228-Amazone
TP-254B-Japura
TP-139-Amazone
TP-178-Solimoes
TP-254B-Solimoes
TP-063A-Solimoes
TP-063S-Solimoes
TP-178F-Jutai
TP-076-Solimoes
TP-152-Madeira
TP-102B-Solimoes
TP-102-Javari
TP-102A-Solimoes
TP-076-Purus
TP-013-Javari
TP-026-Javari
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TP-178-Jurua
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TP-102-Jutai
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TP-165-Purus
TP-102B-Purus
TP-026B-Tarauca
TP-178-Madeira
TP-241-Madeira
TP-026-Purus
TP-241 A-Madeira
TP-241B-Madeira
TP-063-Gupaore
TP-254-Guapore
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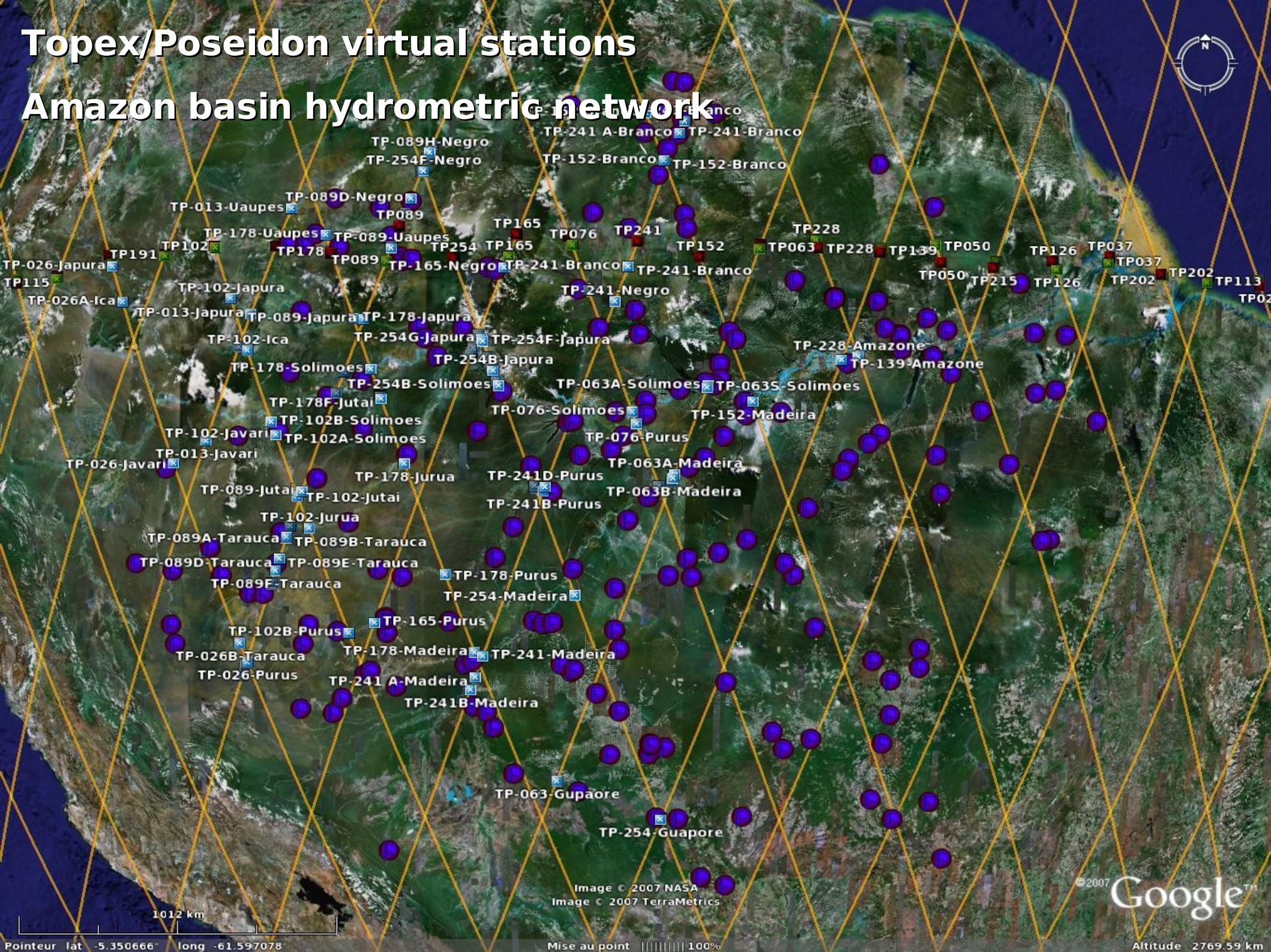
Image © 2007 TerraMetrics
©2007 Google
1012 km
Pointeur lat -5.350666° long -61.597078°
Mise au point 100%
Altitude 2769.59 km


Topex/Poseidon virtual stations
Amazon basin hydrometric network
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TP-241-Branco
TP-089H-Negro
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TP-152-Branco
TP-089D-Negro
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TP-241 A-Madeira
TP-241B-Madeira
TP-063-Gupaore
TP-254-Guapore
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Image © 2007 TerraMetrics
©2007 Google
1012 km
Pointeur lat -5.350666° long -61.597078°
Mise au point 100%
Altitude 2769.59 km

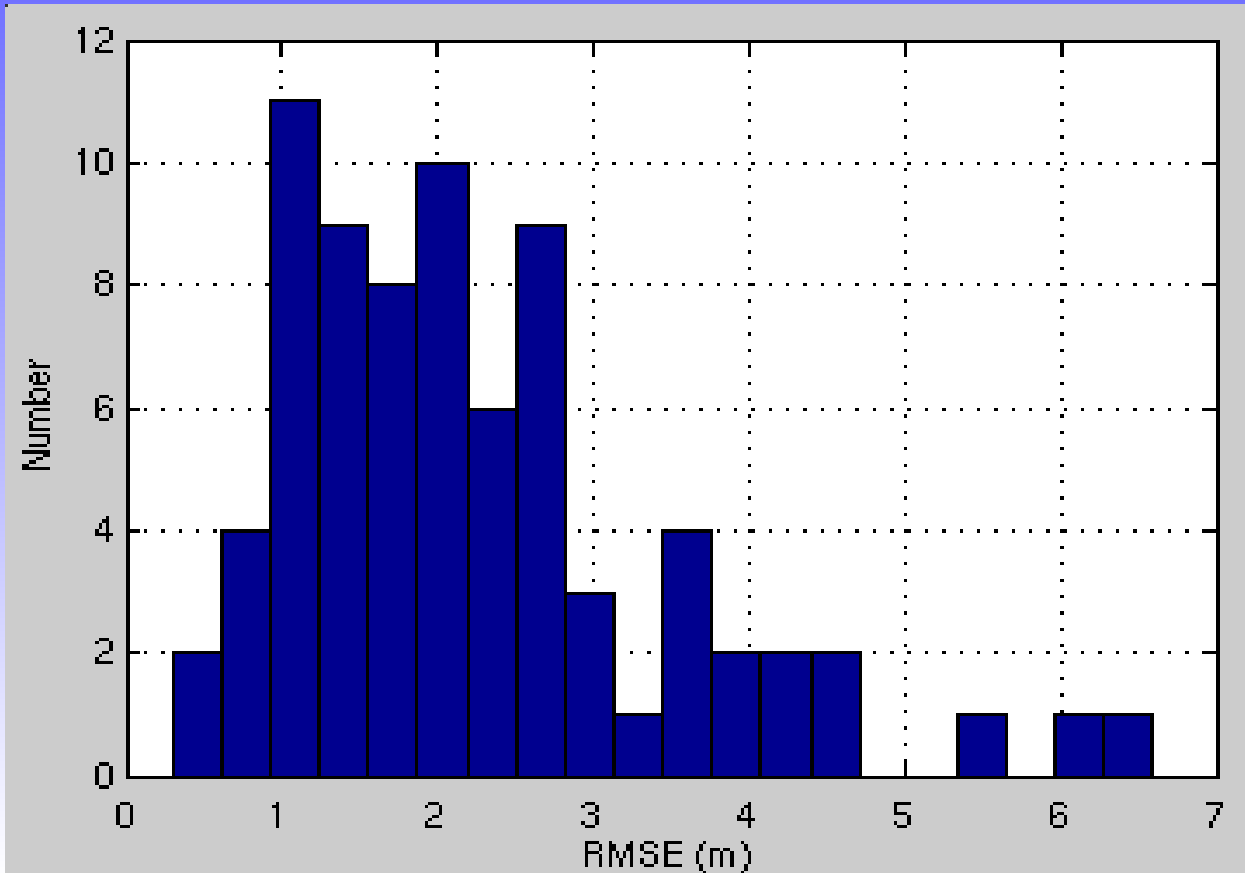
Statistical analysis over 77 study sites on the Amazon basin

- **Satellite data:**
  - Provided by CNES/AVISO: Topex/Poseidon M-GDR product
  - Whole satellite mission (1993-2006)
  - Global coverage (up to 75Gbytes)
  - Waveforms tracked: 10 Hz water level measurements
- **In situ data:**
  - ANA (Agência Nacional de Águas), Brazil
  - ~320 in situ gauging stations
  - Daily measurements

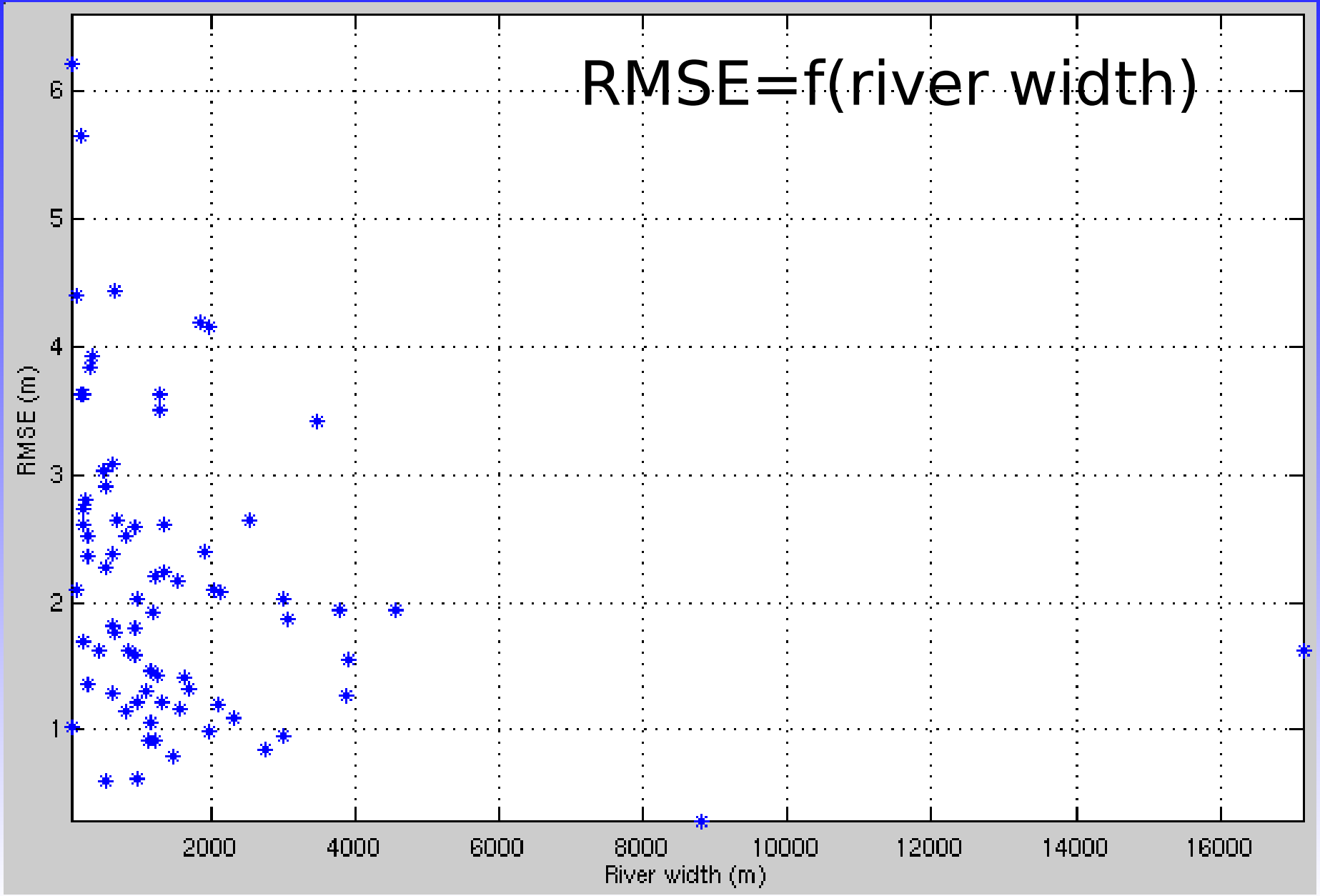
Statistical analysis over 77 study sites on the Amazon basin

Global analysis results:

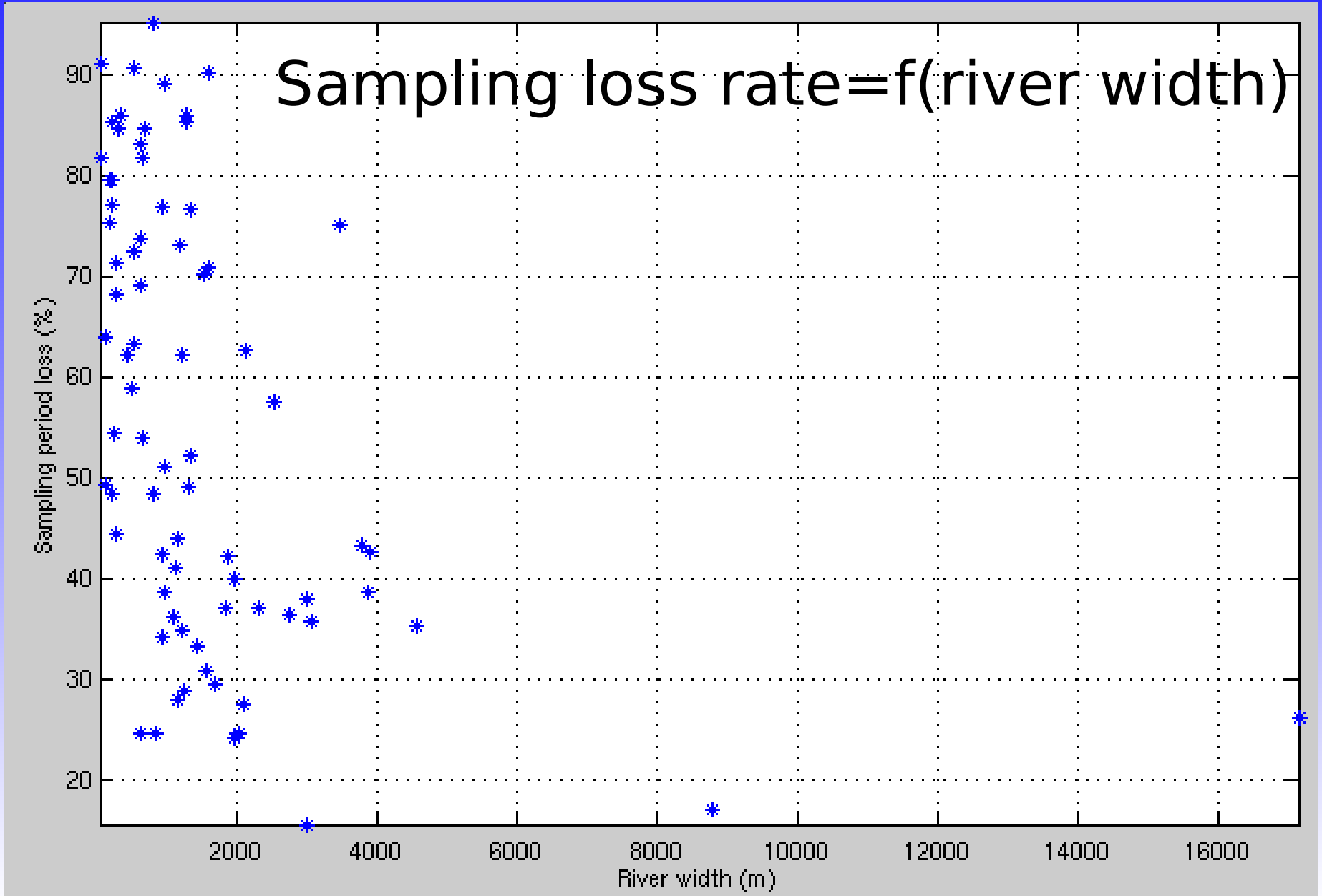
- **rivers width: 80m to 17,000m**
- **Global RMSE ~2.2m (from 0,25m to 6.5m)**
- **RMSE < 1.1m for 21%**
- **RMSE > 3.2m for 20%**



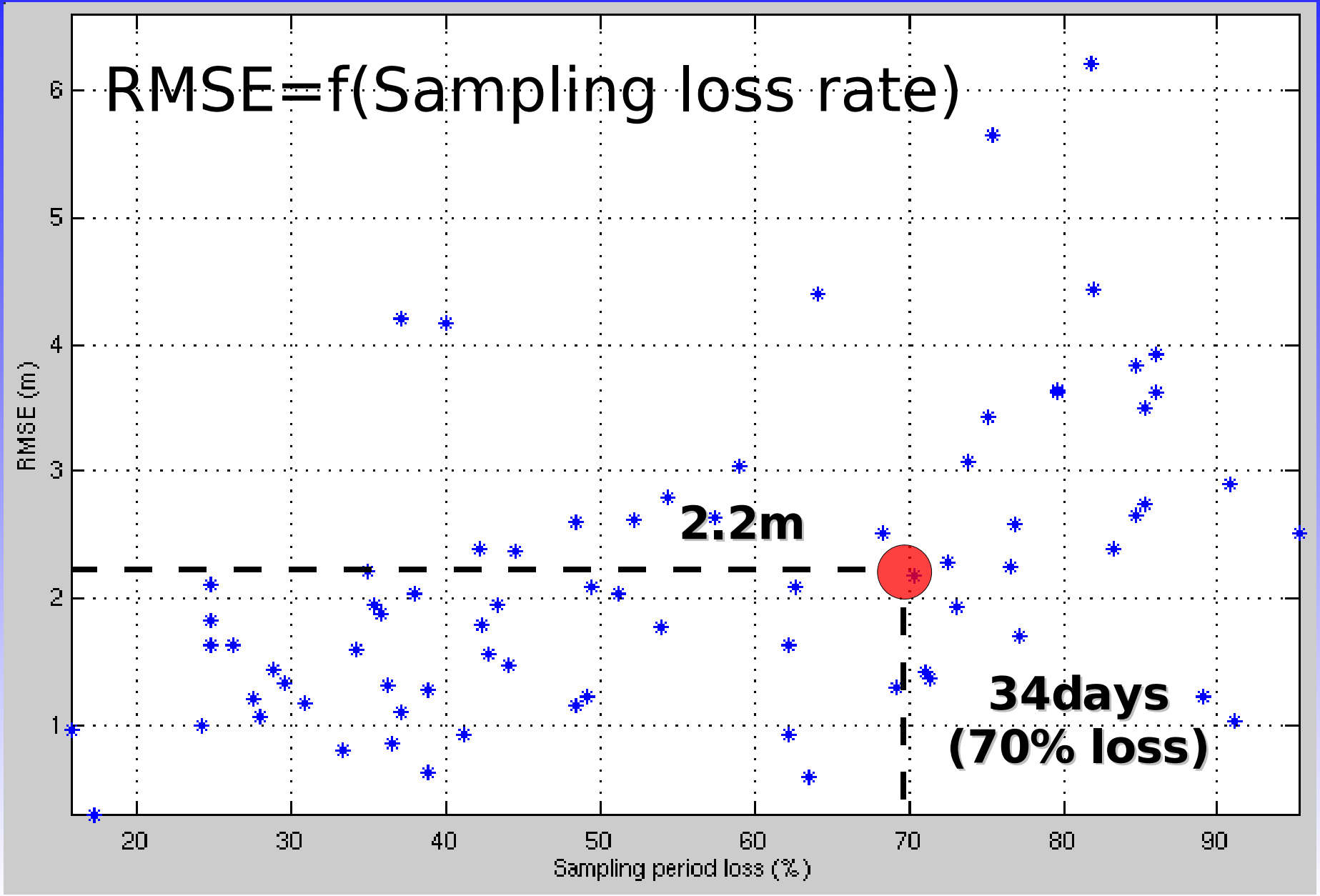
Statistical analysis over 77 study sites on the Amazon basin



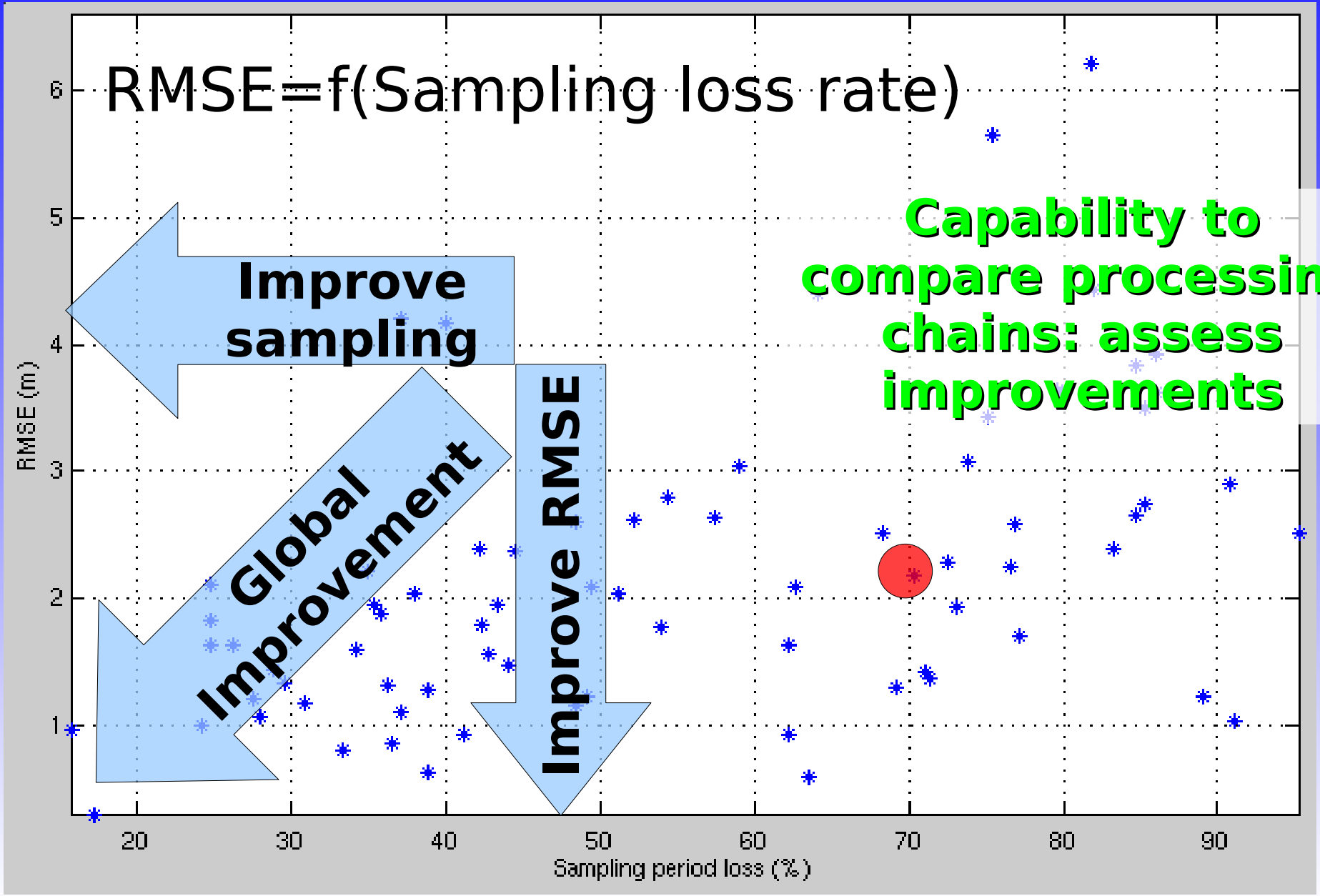
Statistical analysis over 77 study sites on the Amazon basin



Statistical analysis over 77 study sites on the Amazon basin

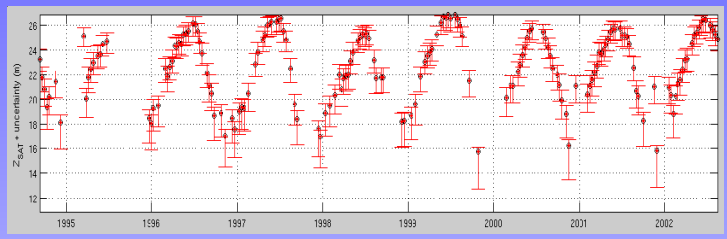


Statistical analysis over 77 study sites on the Amazon basin



Conclusion & perspectives

- A method is available to quantify the Accuracy and Uncertainty of satellite altimetry water level products:
  - **Topex Poseidon AVISO GDR products:**
    2.2m mean accuracy ; Teff = 34days (70% loss)
  - **The radar altimetry water level can be characterized by its uncertainty**



- The method will help to assess product improvements
  - Allows **satellite products comparison**
    (satellite, extract. window, retracking algorithms, filtering methods, etc.)

Conclusion & perspectives

- Compare 4 different products (4 retracking algorithm applied on Topex/Poseidon data) (EGU symposium 2007, Vienna)
- Understand the relation between river geomorphology and satellite measurement error
- Improve Uncertainty modeling according to backscatter
- Develop a method for spatio-temporal interpolation of river water levels Z(X, t) based on radar altimetry sampling Z (Xi; Ti0+k.T)

Questions ?

Gauging stations (ANA hydrometric network)