Water level change detection

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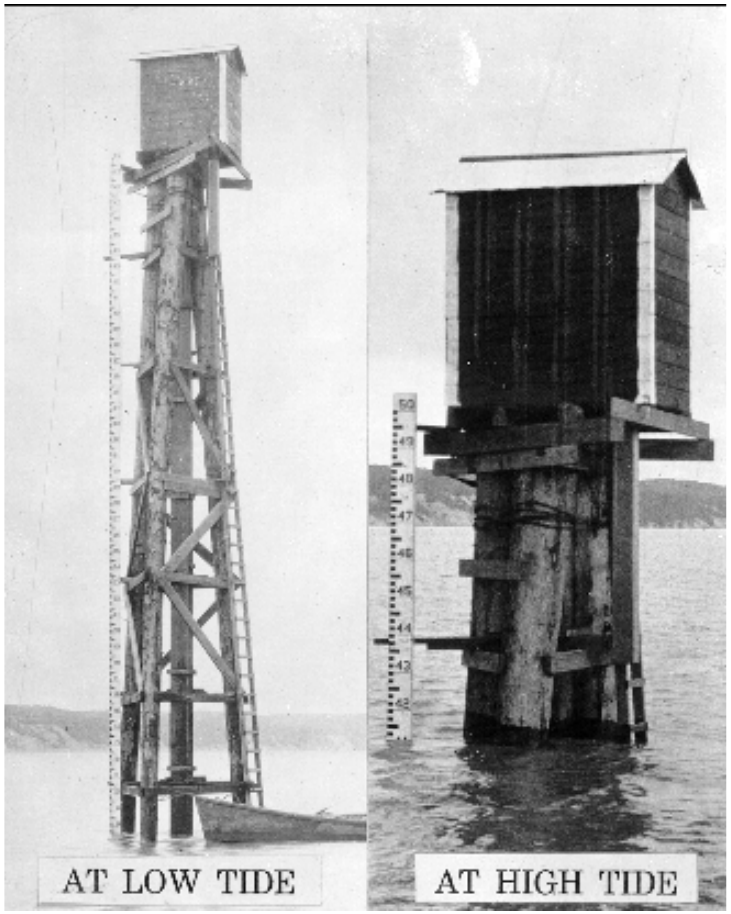
ESA Land Training 2023
12th Advanced Training Course on Land Remote Sensing
Hydrology and Hazards

Objective of the talk = history of satellite altimetry

To show when satellite altimetry:

- **was not good enough to meet requirements of oceanography**
  $\longrightarrow$ before TOPEX/Poseidon
- **began to be a useful tool in measuring water levels for oceanography**
  $\longrightarrow$ from TOPEX/Poseidon onwards
- **began to be a useful tool in measuring water levels for hydrology**
  $\longrightarrow$ from CryoSat-2 onwards

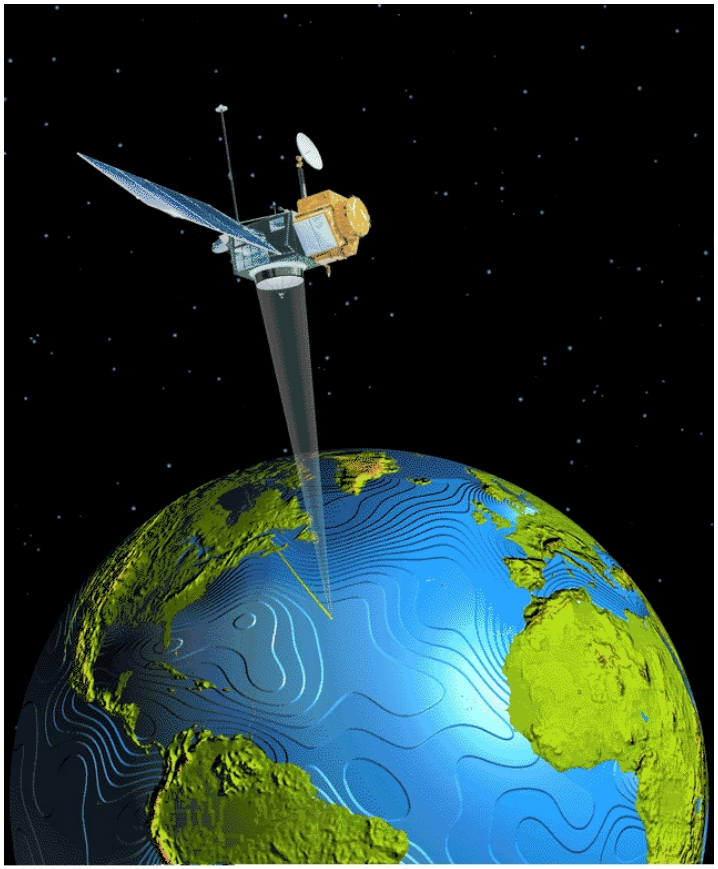
Before altimetry and also now (tide gauges)



Source: NOAA, http://co-ops.nos.noaa.gov/

RELATIVE OBSERVATIONS!

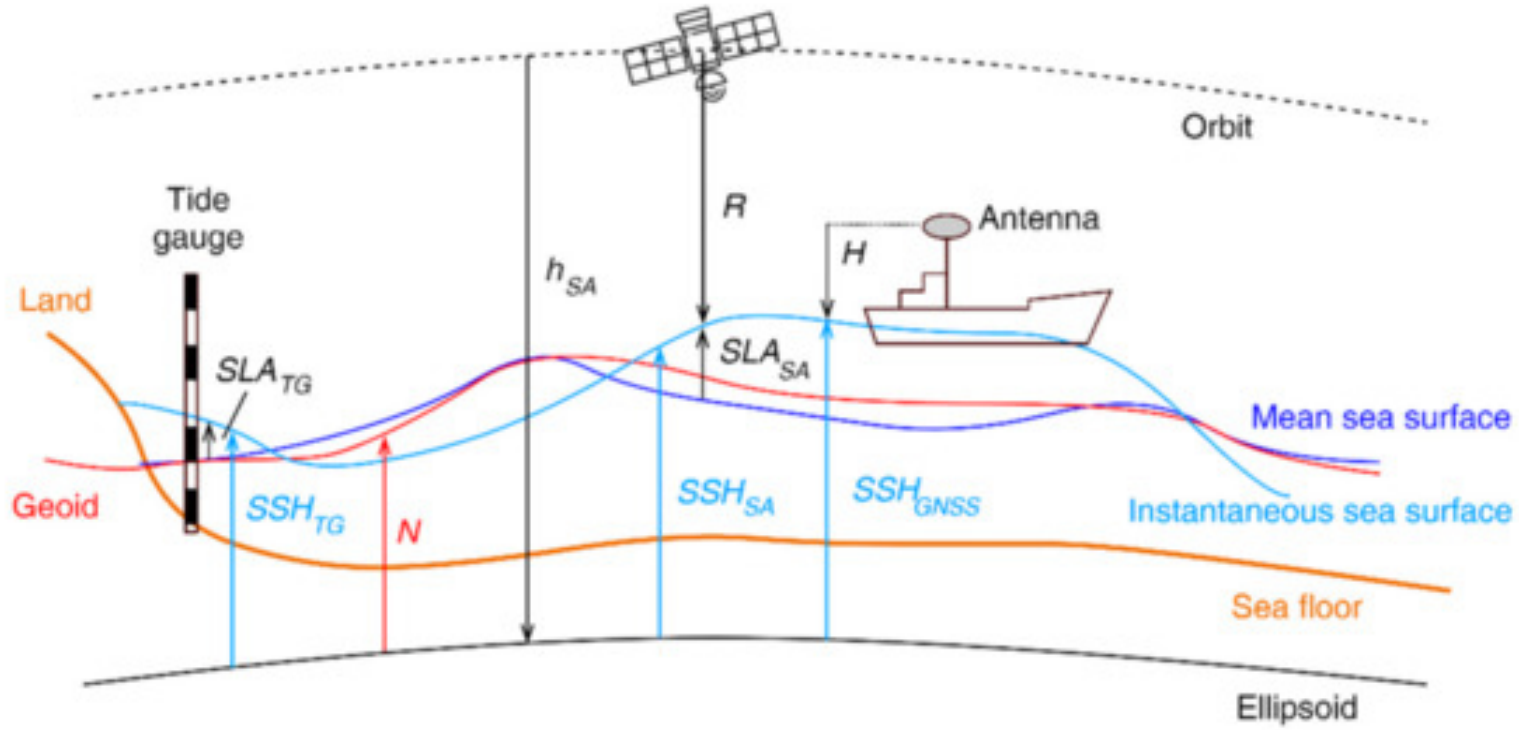
Idea behind altimetry



Źródło: http://www.jpl.nasa.gov

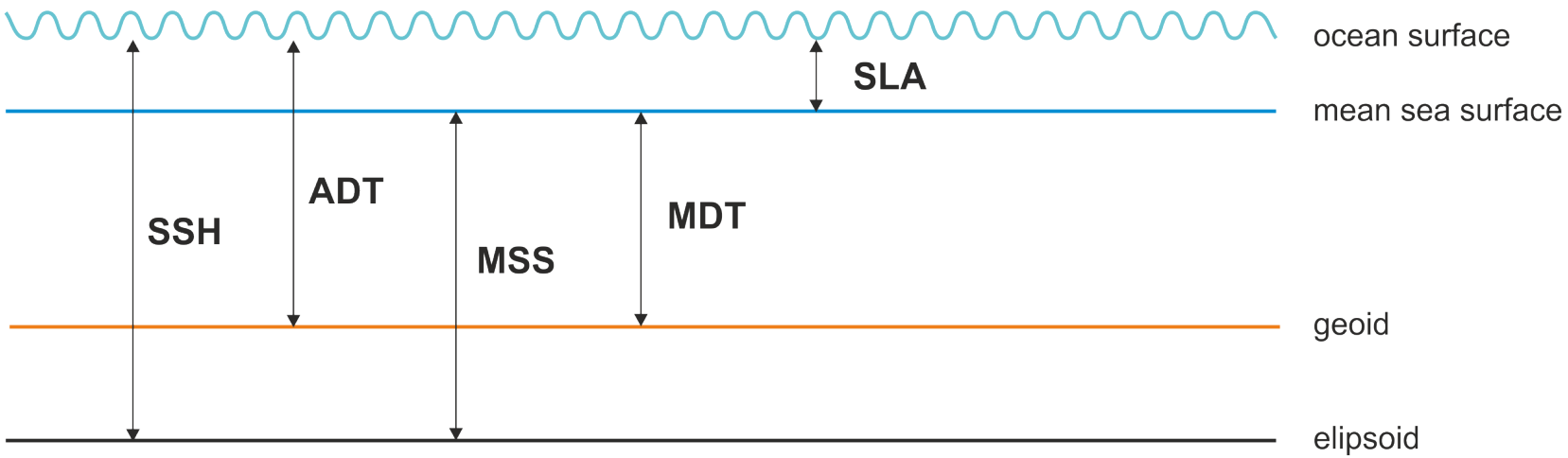
ABSOLUTE OBSERVATIONS!

What is measured and calculated?



Source: Liibusk A, Kall T, Rikka S, Uiboupin R, Suursaar Ü, Tseng K-H. Validation of Copernicus Sea Level Altimetry Products in the Baltic Sea and Estonian Lakes. Remote Sensing. 2020; 12(24):4062.

Key variables



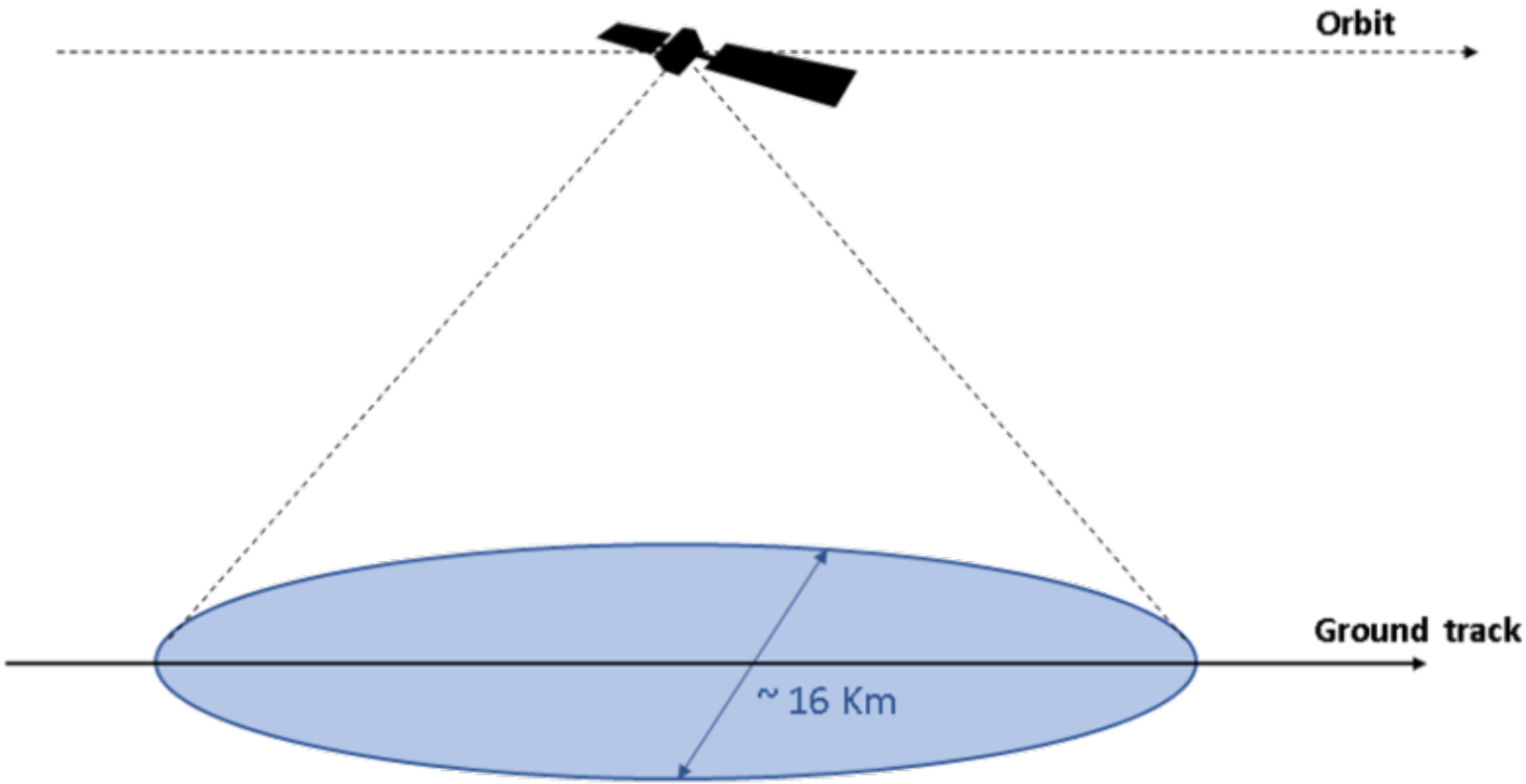
ADT: Absolute Dynamic Topography
SSH: Sea Surface Height
MSS: Mean Sea Surface
MDT: Mean Dynamic Topography
SLA: Sea Level Anomaly

$$SSH = MSS + SLA$$
$$SSH = Geoid + MDT + SLA$$
$$SSH = Geoid + ADT$$
$$SLA = SSH - MSS$$

Data products are usually published after applying tropospheric and ionospheric corrections, tidal corrections, correction for waves and the inverted barometer effect.

Conventional satellite altimetry

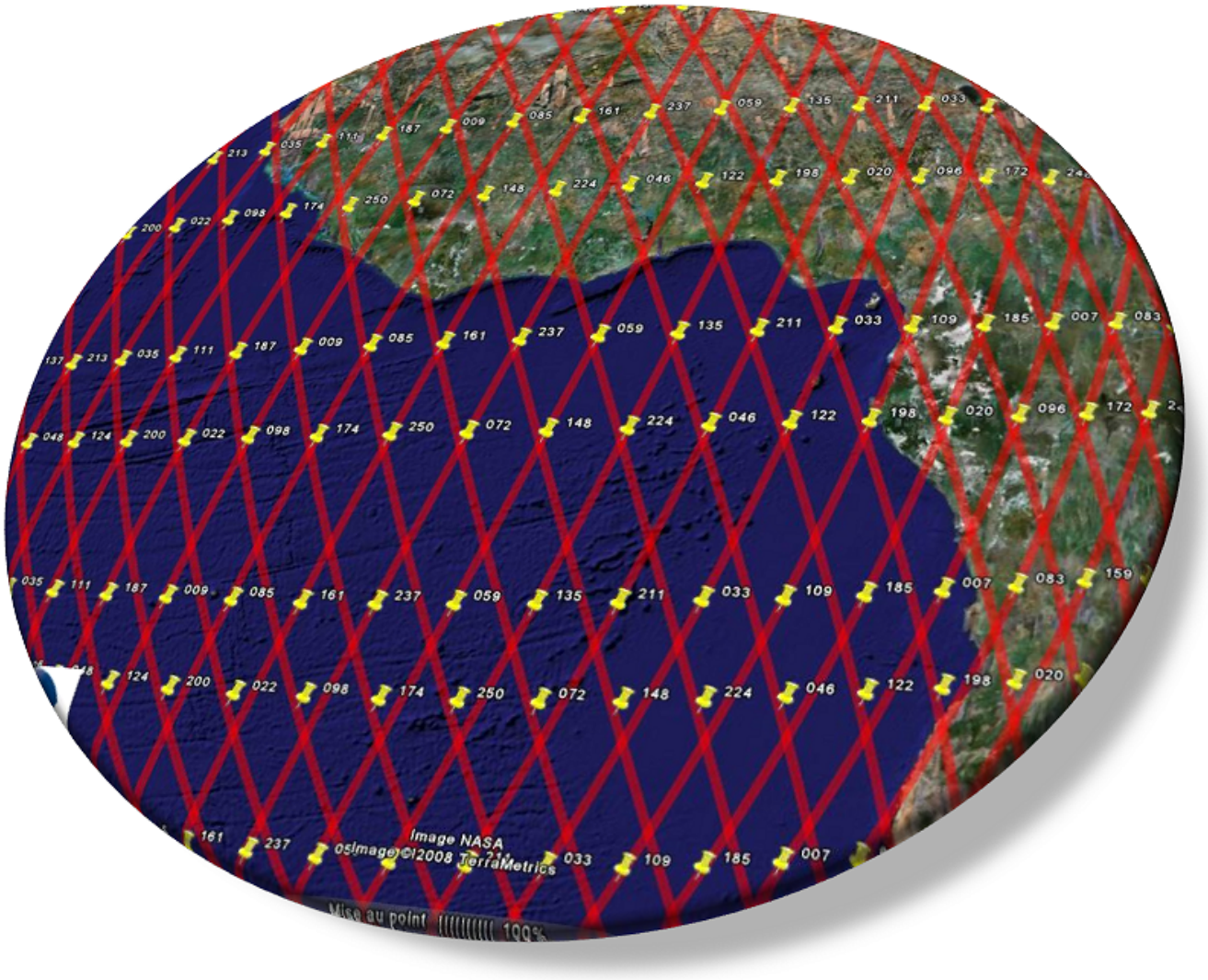
LOW RESOLUTION MODE (LRM)



Source: www.aviso.altimetry.fr

Conventional satellite altimetry

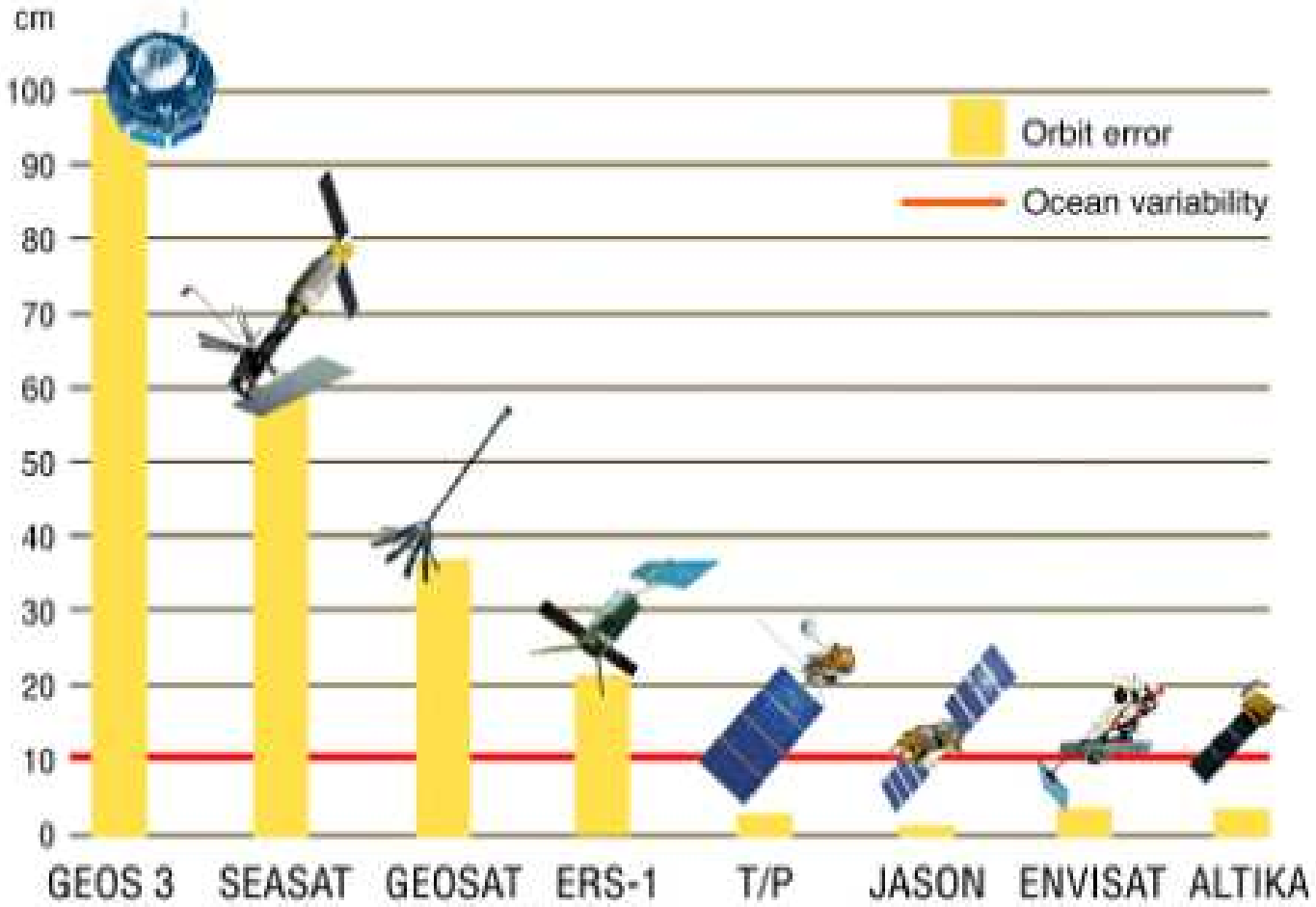
EXAMPLE GROUND TRACKS (spacing and repeat cycle)



Source: www.aviso.altimetry.fr

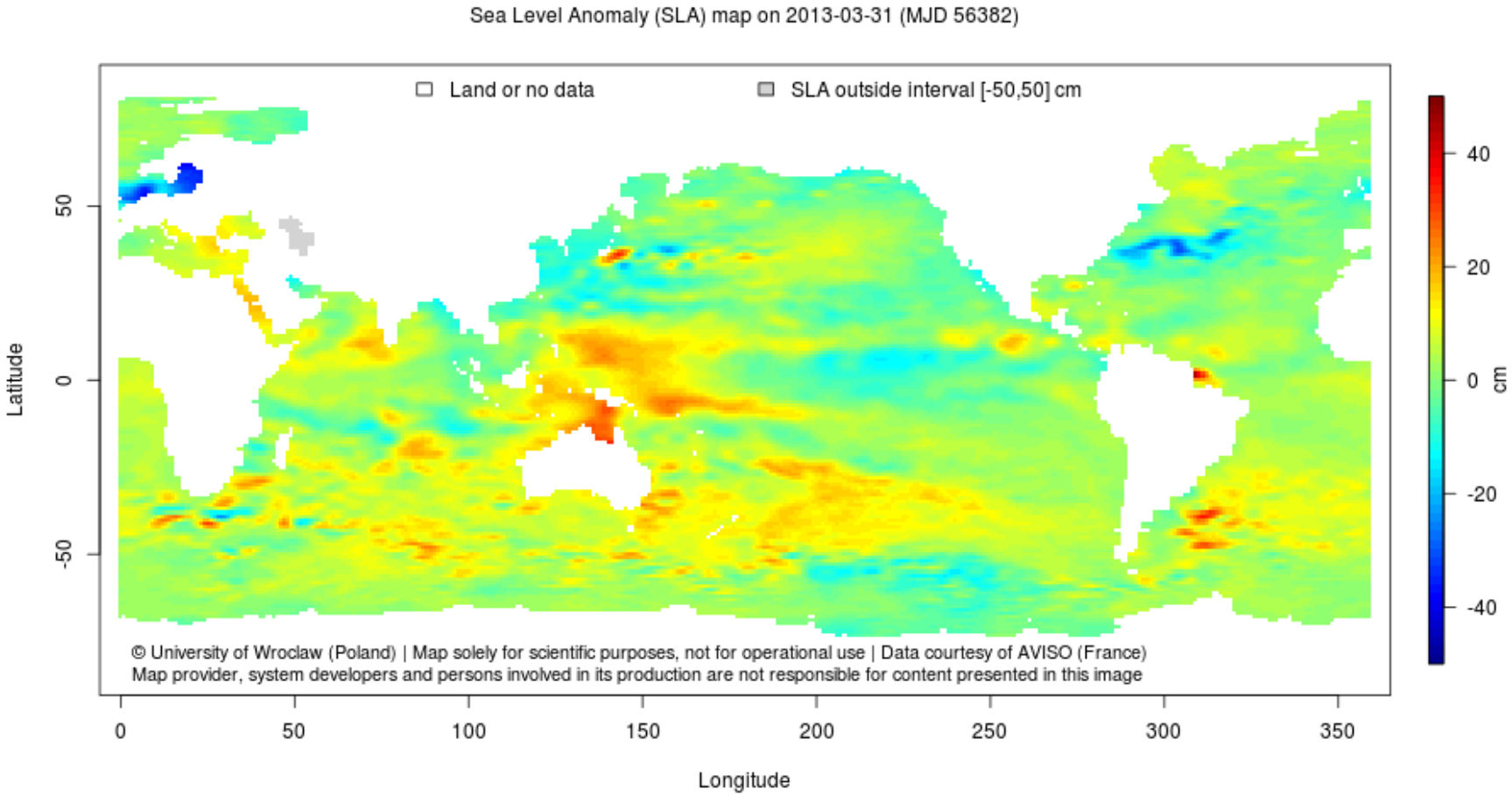
Before TOPEX/Poseidon

Oceanographic requirements (10 cm)

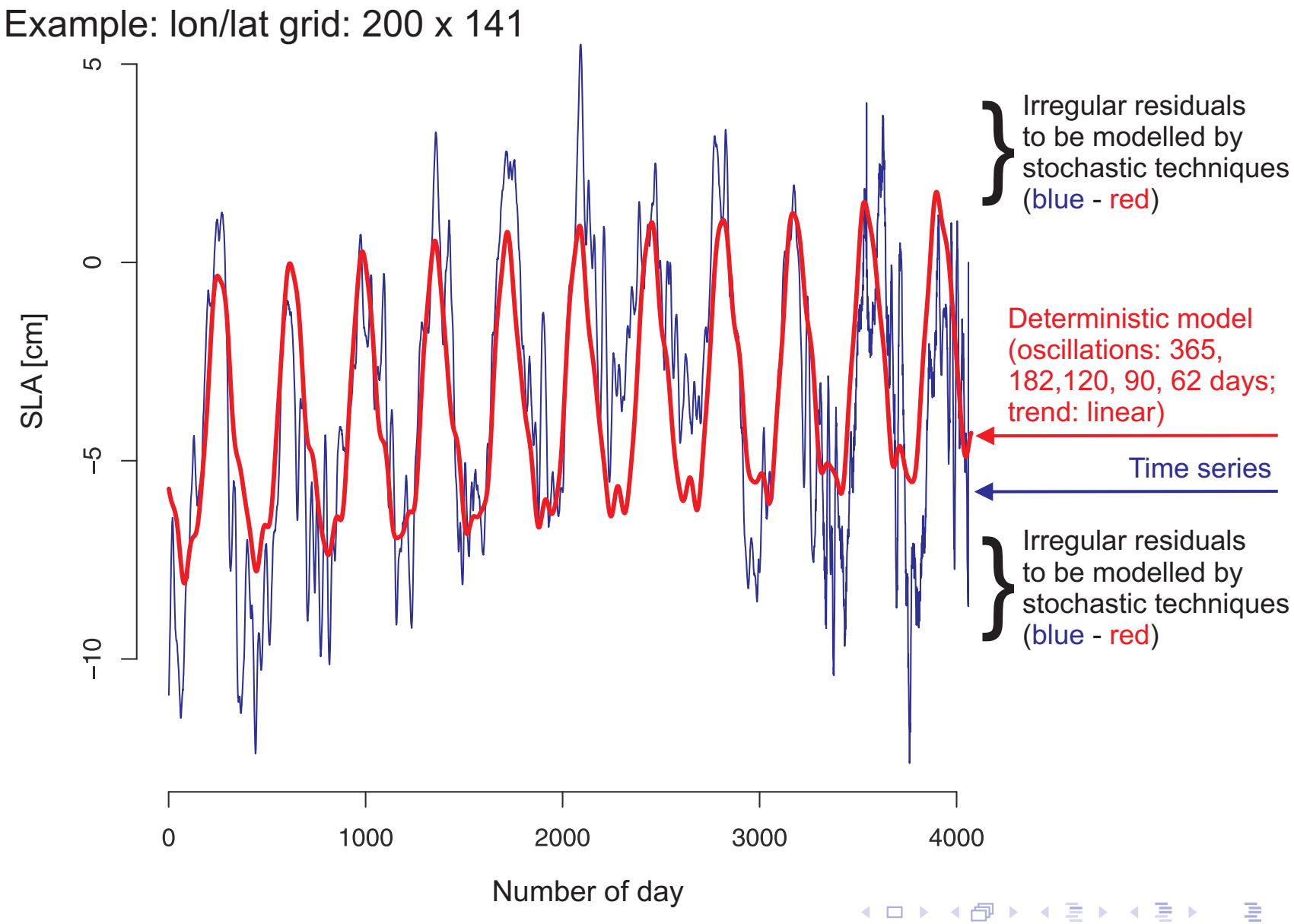


Source: http://www.altimetry.info/

Oceanographic requirements (in space)



Oceanographic requirements (in time)



Accuracy offered by some pre-TOPEX satellites

- **Geos-3 (1975–1978)**
  $\longrightarrow \approx$100 cm accuracy
- **Seasat (1978)**
  $\longrightarrow$ 50–60 cm accuracy
- **Geosat (1985–1990)**
  $\longrightarrow$ 30–40 cm accuracy
- **ERS-1 and ERS-2 (1991–2000 and 1995–2011)**
  $\longrightarrow \approx$25 cm accuracy

These accuracies did not meet expectations of oceanography.

What about hydrology?

Geosat applied in the Amazon River

Water Resources Research

Technical Reports

Measurement of river level variations with satellite altimetry

C. J. Koblinsky, R. T. Clarke, A. C. Brenner, H. Frey

First published: June 1993 | https://doi.org/10.1029/93WR00542 | Citations: 158

"The overall level of comparison is 0.7 m rms when the technique is applied manually, and 1.2 m rms when an automated version of the method is applied. At one location the average difference is 0.2 m rms. **This level of accuracy may not be useful for routine hydrological measurements**."

From TOPEX/Poseidon onwards

Seminal paper by Fu et al. (1994)

JOURNAL OF GEOPHYSICAL RESEARCH, VOL. 99, NO. C12, PAGES 24,369–24,381, DECEMBER 15, 1994

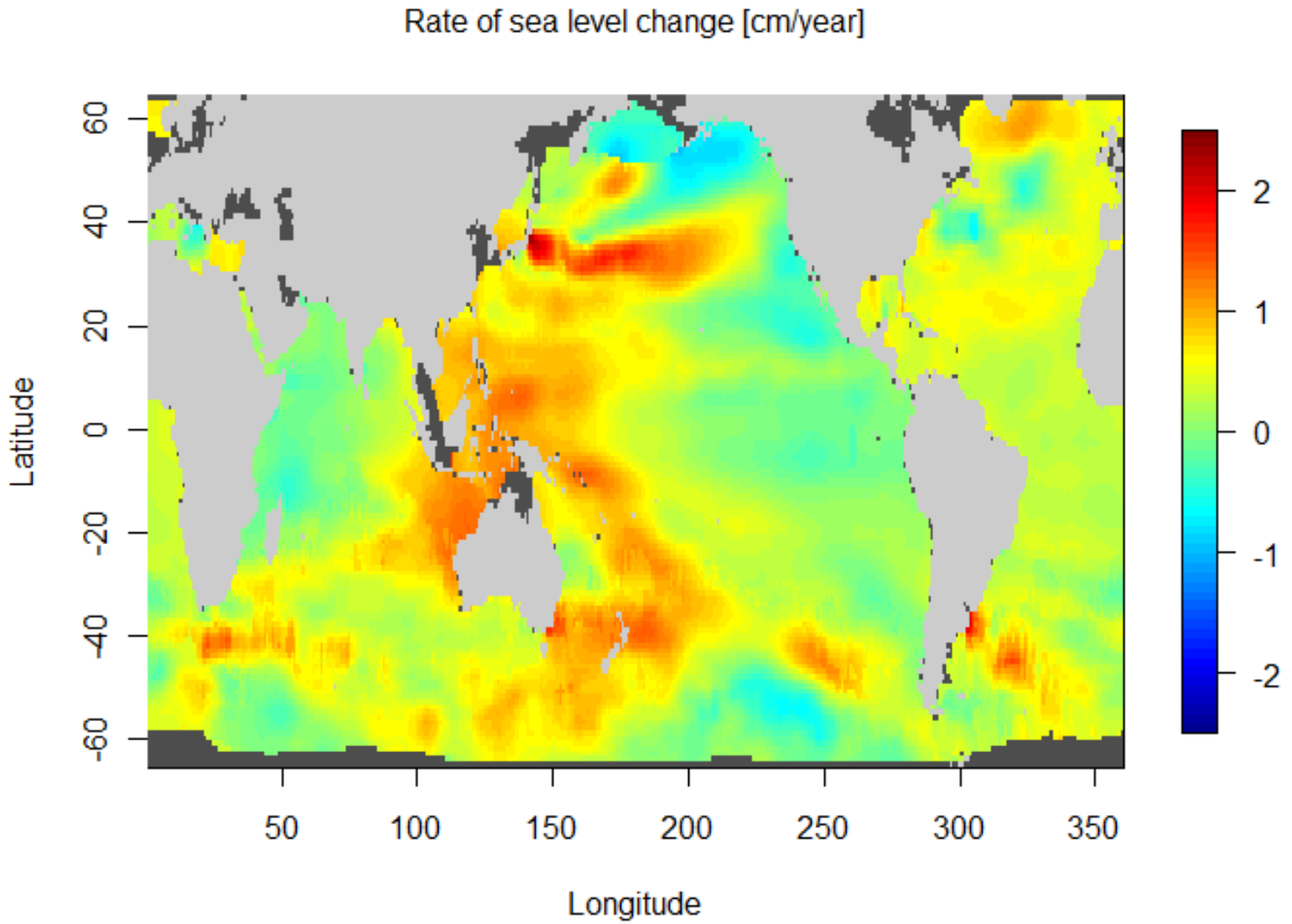
TOPEX/POSEIDON mission overview

Lee-Lueng Fu, Edward J. Christensen, and Charles A. Yamarone Jr.
Jet Propulsion Laboratory, California Institute of Technology, Pasadena

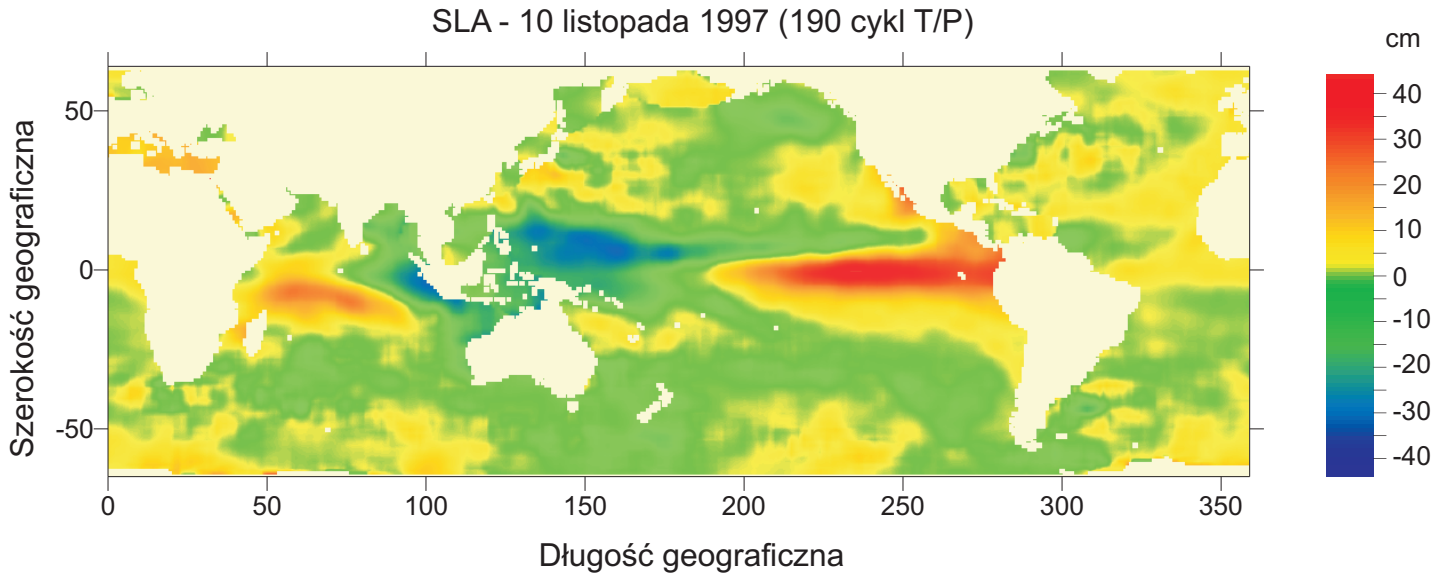
Michel Lefebvre, Yves Ménard, Michel Dorrer, and Philippe Escudier
Centre National d'Etudes Spatiales, Toulouse, France

"The results indicate that the root-sum-square accuracy of a single-pass sea level measurement is **4.7 cm** for the TOPEX system and **5.1 cm** for the POSEIDON system; both are more than a factor of 2 better than the requirement of 13.7 cm. This global data set is being analyzed by an international team of 200 scientists for improved understanding of the global ocean circulation as well as the ocean tides, geodesy, and geodynamics, and ocean wind and waves."

Rate of sea level change



Sea level change driven by El Niño 1997/1998



These accuracies met expectations of oceanography.

But what about hydrology?

TOPEX/Poseidon over large rivers

WATER RESOURCES RESEARCH, VOL. 34, NO. 5, PAGES 1223–1239, MAY 1998

Contribution of the TOPEX NASA radar altimeter to the global monitoring of large rivers and wetlands

Charon M. Birkett[1]
Department of Space and Climate Physics, University College London, England

"Here, it is shown that the NASA radar altimeter (NRA), currently operating on board the TOPEX/POSEIDON satellite, can successfully track both large wetlands and **rivers of >1 km width**. [...] Validation shows the results can be accurate to ∼11 cm rms, offering the potential to observe these regions as part of a long-term hydrological monitoring program."

Limitations of TOPEX/Poseidon over large rivers

JOURNAL OF GEOPHYSICAL RESEARCH
Atmospheres
AN AGU JOURNAL

Climate and Dynamics | Free Access

Surface water dynamics in the Amazon Basin: Application of satellite radar altimetry

C. M. Birkett, L. A. K. Mertes, T. Dunne, M. H. Costa, M. J. Jasinski

"This constraint does allow observation of the main stem (Solimões/Amazon) and the larger tributaries, but **rugged terrain** in the vicinity of the target additionally places severe **limitations on data retrieval**. [...] Overall, the altimetric results demonstrate that the T/P mission is successfully monitoring the transient flood waves of this continental-scale river basin."

Limitations over medium and small rivers

Tarpanelli and Benveniste (2019) in their chapter entitled "Extreme Hydroclimatic Events and Multivariate Hazards in a Changing Environment" wrote:

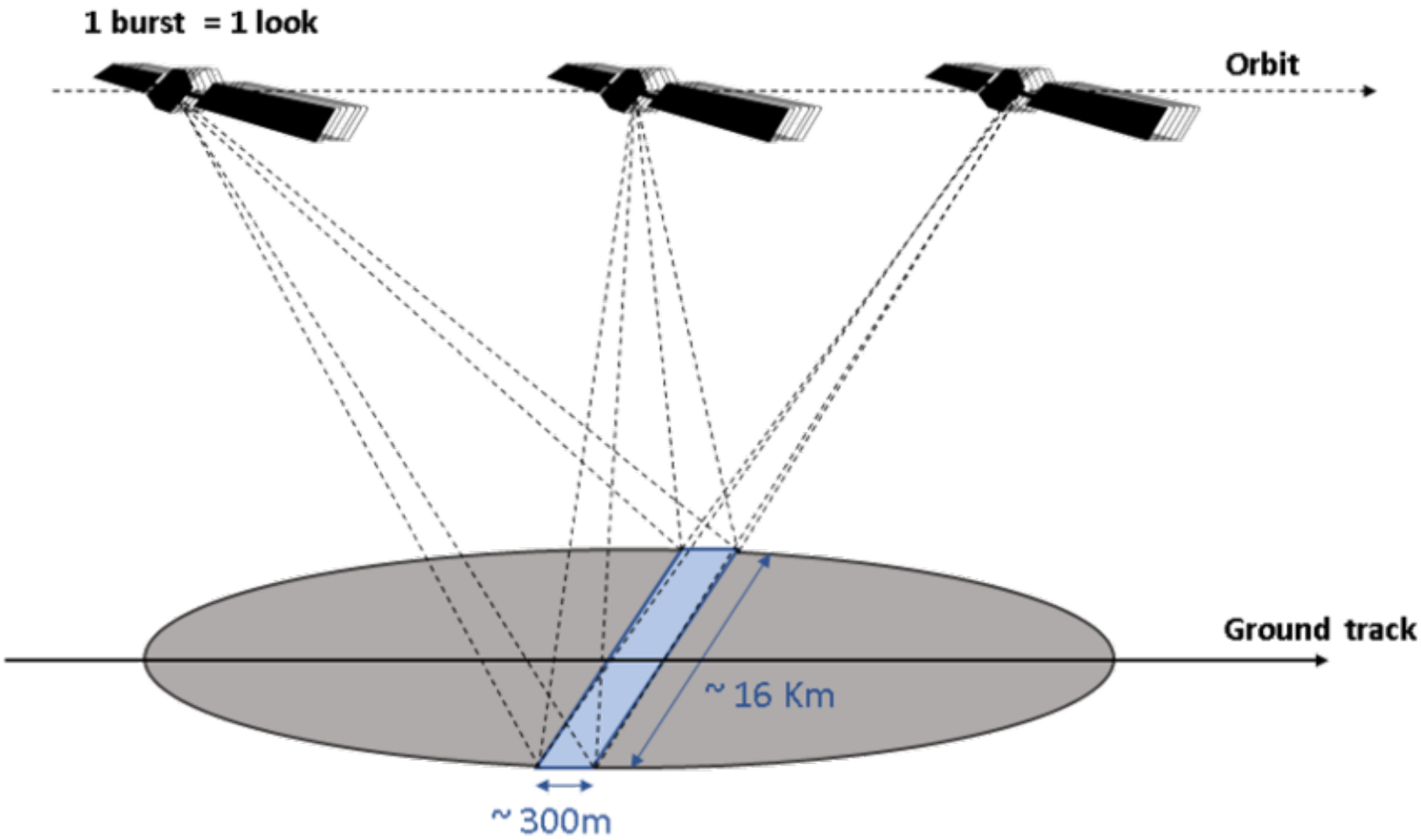
"Due to the size of the footprint, which is larger than the water bodies of small-medium rivers (width of 40–800 m), the surrounding topography often contaminates the returned radar signal.".

WAVEFORM ANALYSIS AND RETRACKING

BUT IT WILL NOT SOLVE THE PROBLEM OF MEDIUM OR SMALL RIVER WIDTH

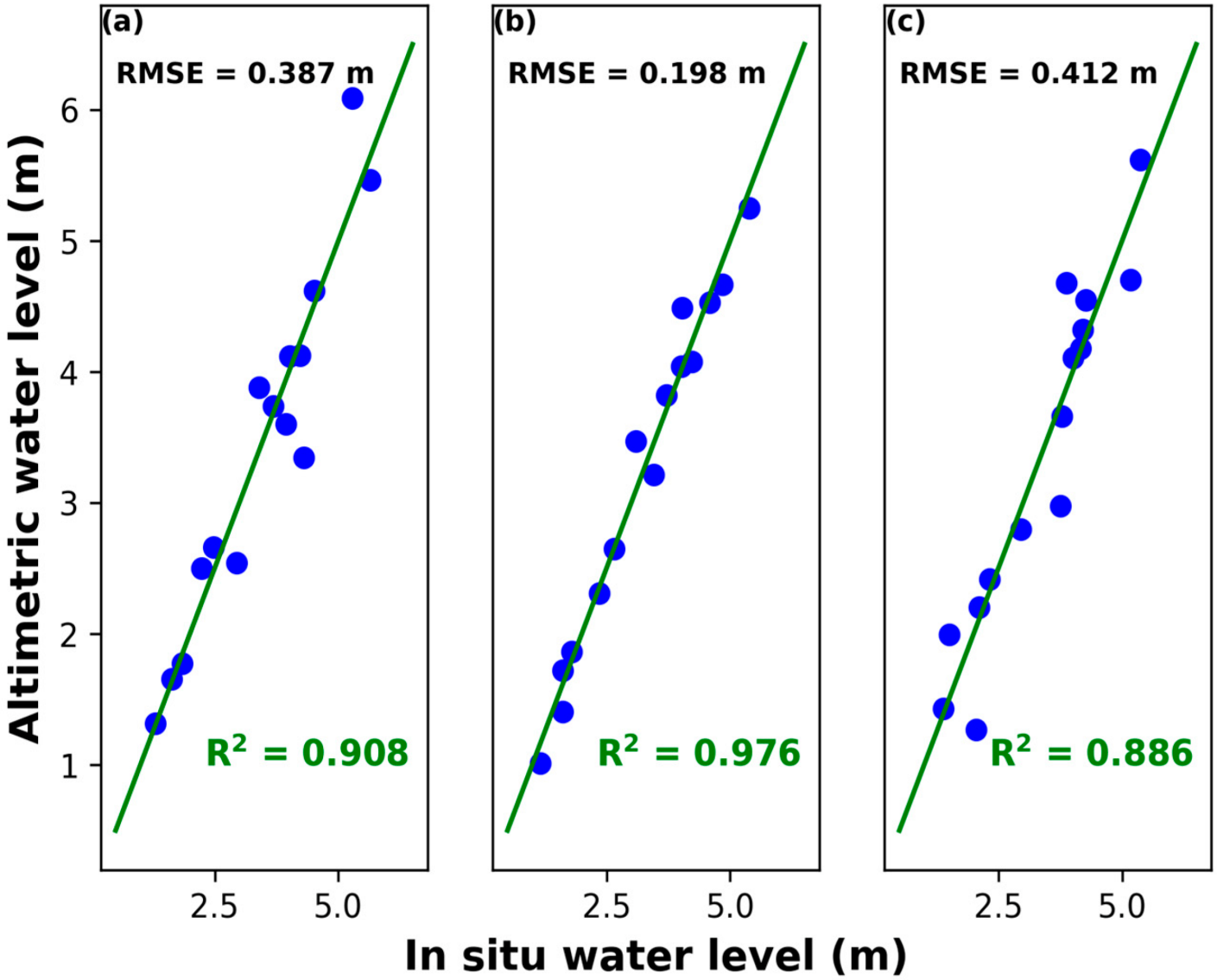
From CryoSat-2 onwards

The solution is brought by SAR altimetry



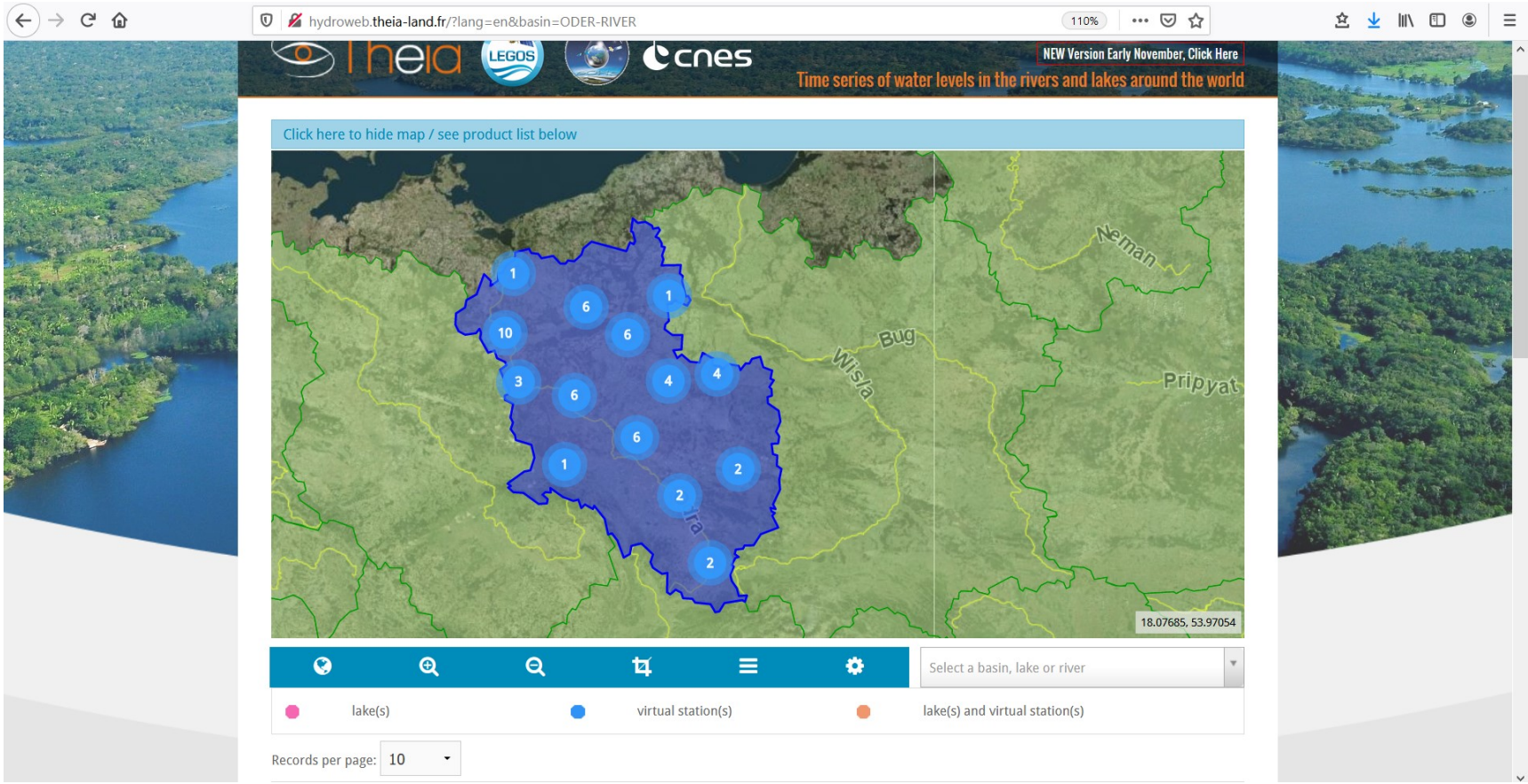
Source: www.aviso.altimetry.fr

Sentinel-3A over the Ogooue river



Source: Remote Sensing 2018, 10(2), 350

Hydroweb database



Source: http://hydroweb.theia-land.fr

DAHITI database

Source: https://dahiti.dgfi.tum.de

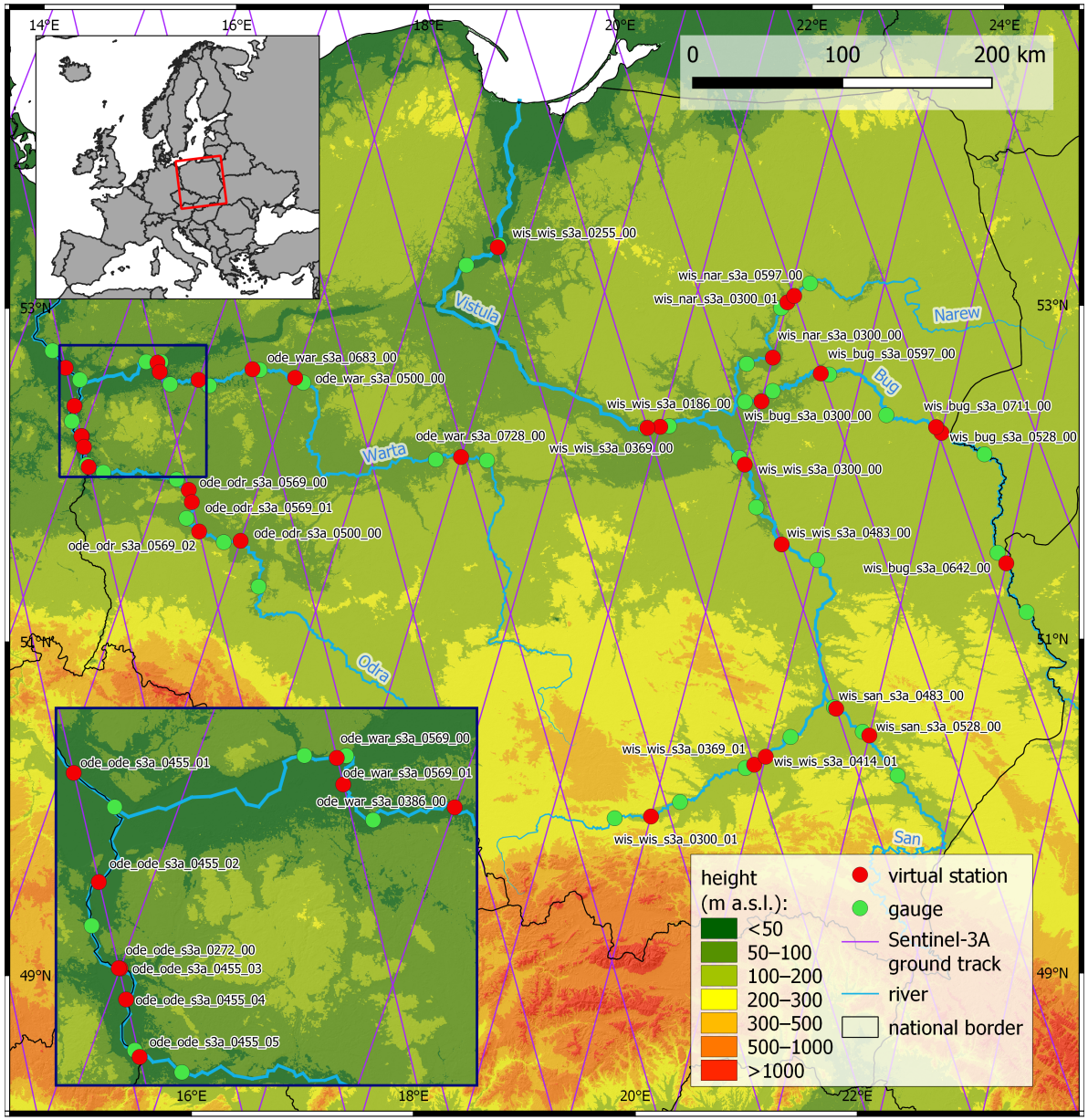
Satellite altimetry over Polish rivers

Halicki M., Niedzielski T., 2022. The accuracy of the Sentinel-3A altimetry over Polish rivers. Journal of Hydrology 606, 127355 (1–14).

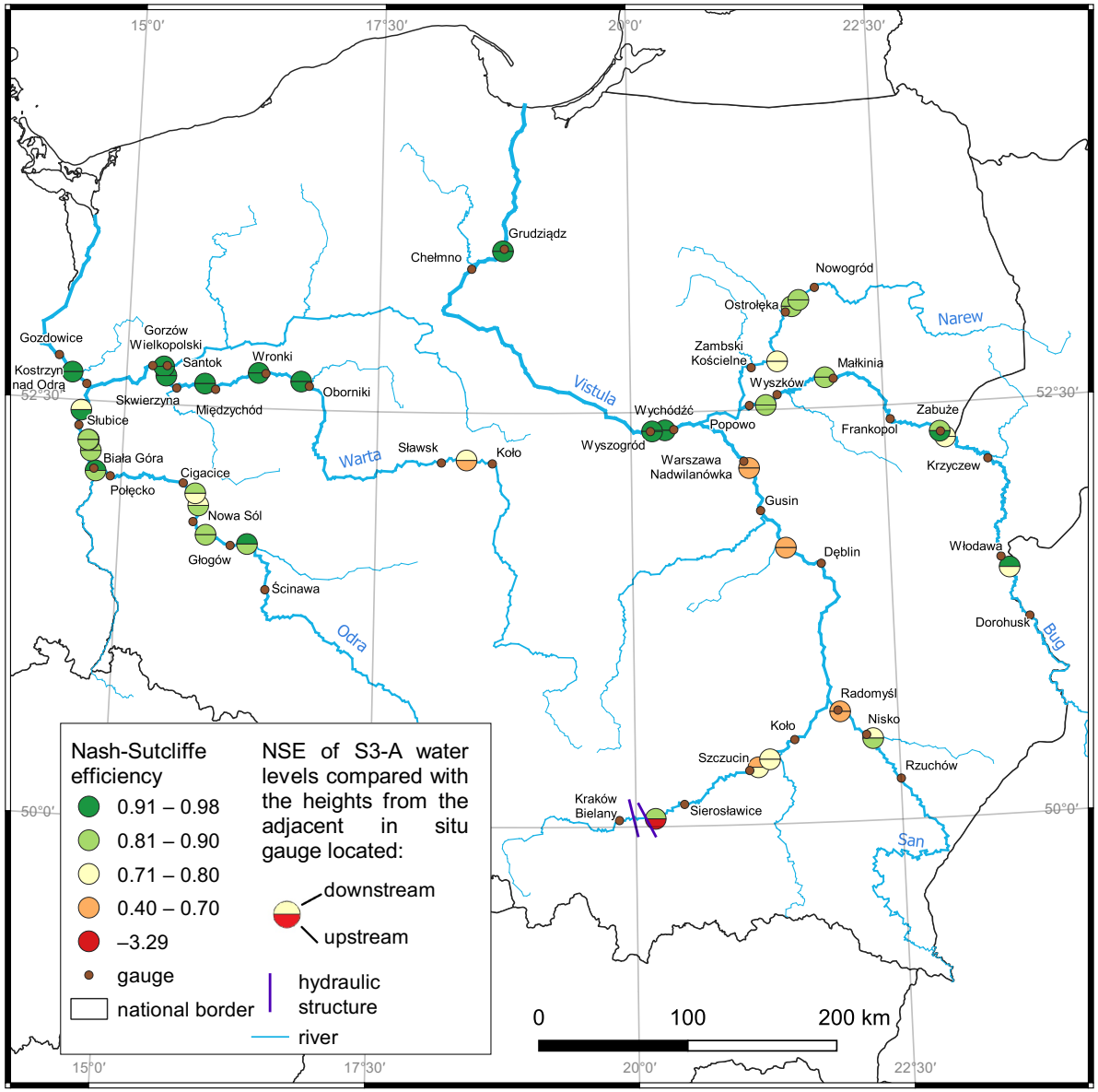
Objectives:

- examine the accuracy of water levels of the selected Polish rivers based on altimetric data from the Sentinel-3A satellite,
- study the influence of several factors (river width, river channel morphology, geographical setting of the VS and the land cover in its vicinity) on the altimetric measurements.

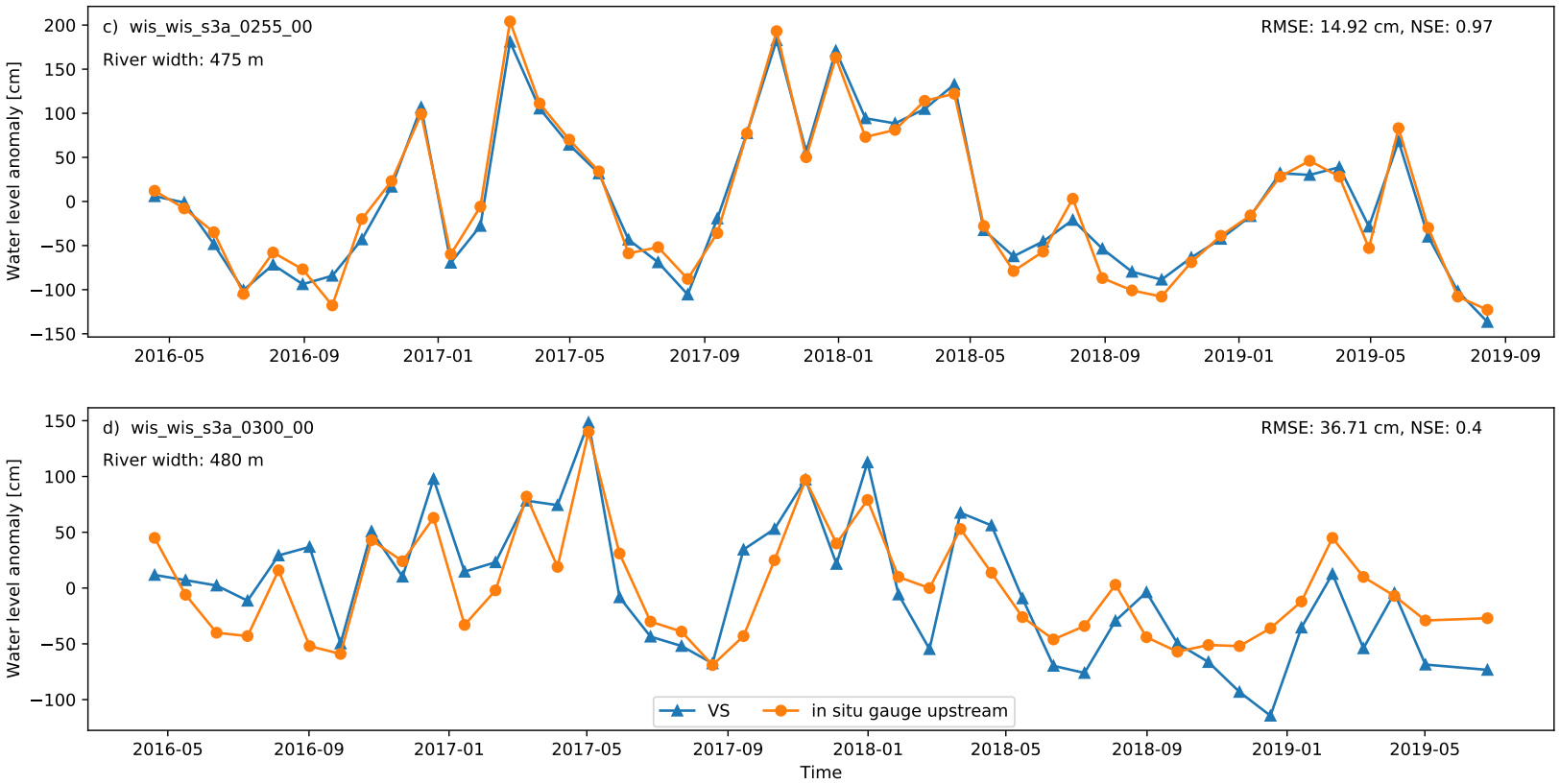
Study area (virtual stations and gauges)



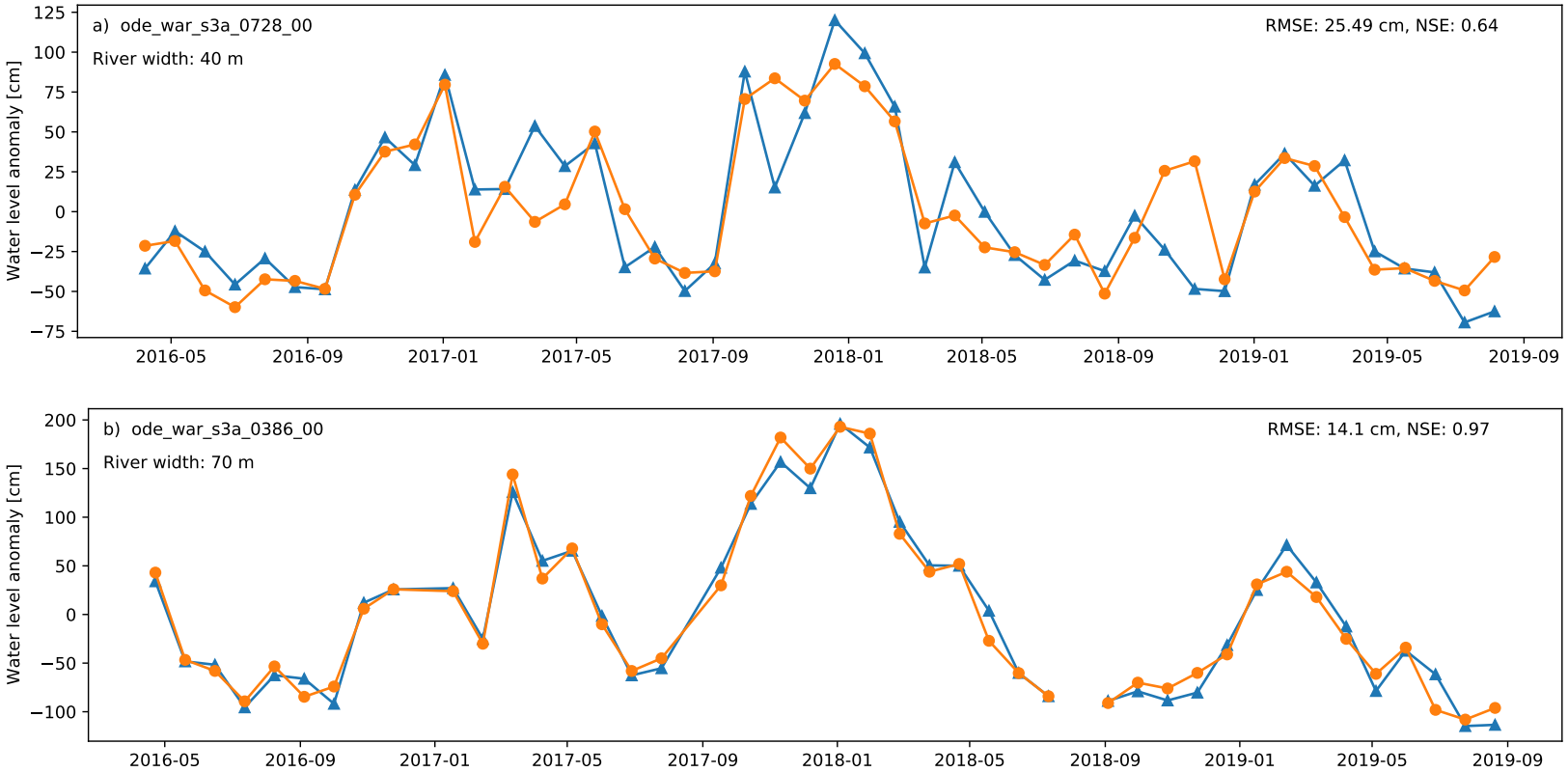
Nash-Sutcliffe Efficiency (NSE)



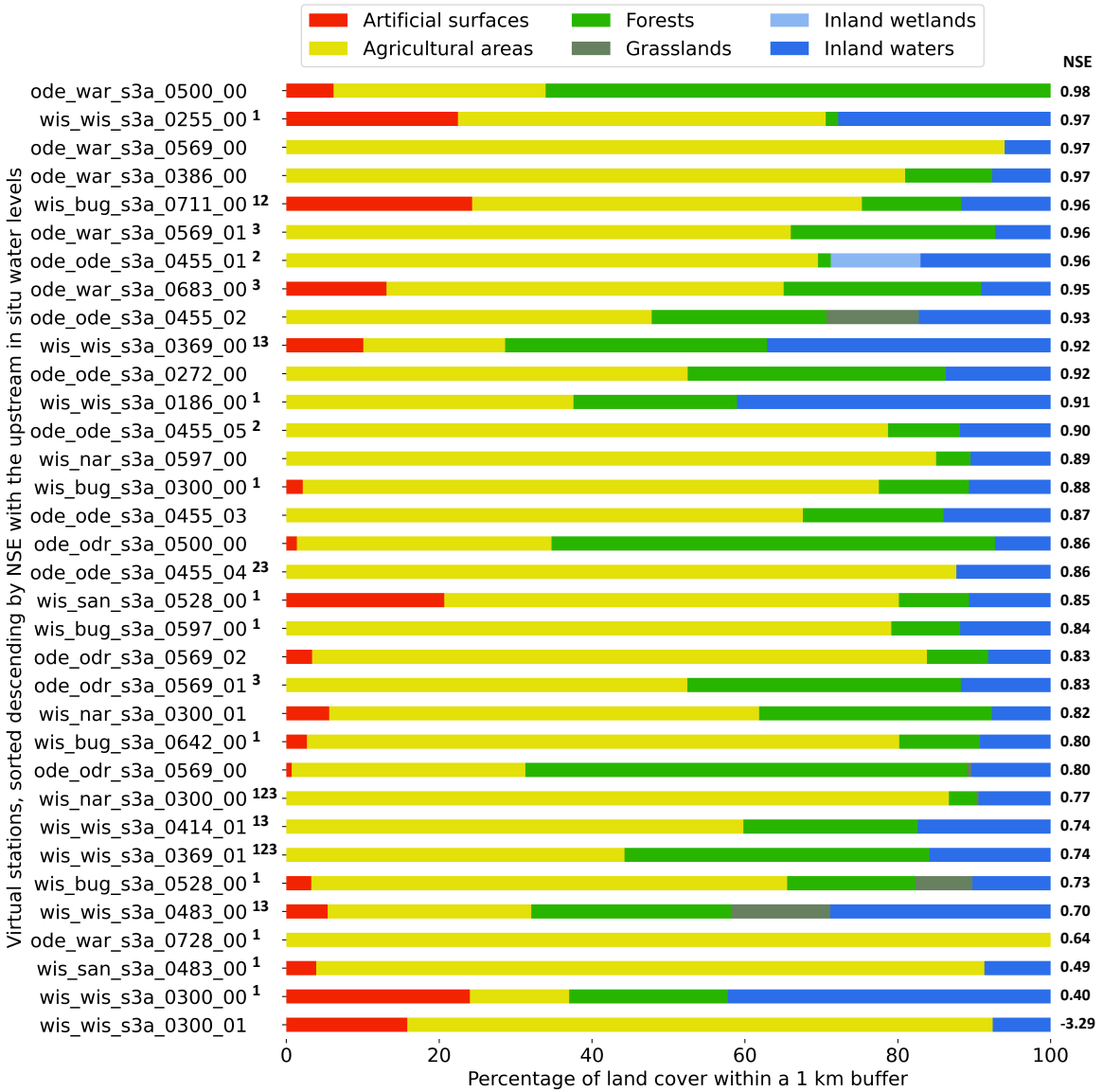
Sentinel-3A vs. gauges (medium river)



Sentinel-3A vs. gauges (narrow river)



Environmental factors



Environmental factors

	NSE $>$ 0.8	NSE $\leqslant$ 0.8
Mean % of artificial land cover	4.75	5.07
Mean % of agricultural land cover	60.92	60.43
Mean % of forest land cover	19.7	18.04
Mean % of grassland land cover	0.52	1.93
Mean % of inland wetland land cover	0.51	0.00
Mean % of inland water land cover	13.59	14.54
% of virtual sites with the complex river channel morphology or unfavourable geographical setting of the VS	56.52	81.82

Summary (Polish rivers)

- For the studied Polish rivers (40–610 m in width), mean RMSE of water levels was of 0.22 m.
- Neither the river width nor the land cover revealed any impact on data accuracy.
- Poorer skills in computing stages are linked to sandbars and azimuth of rivers at VS.

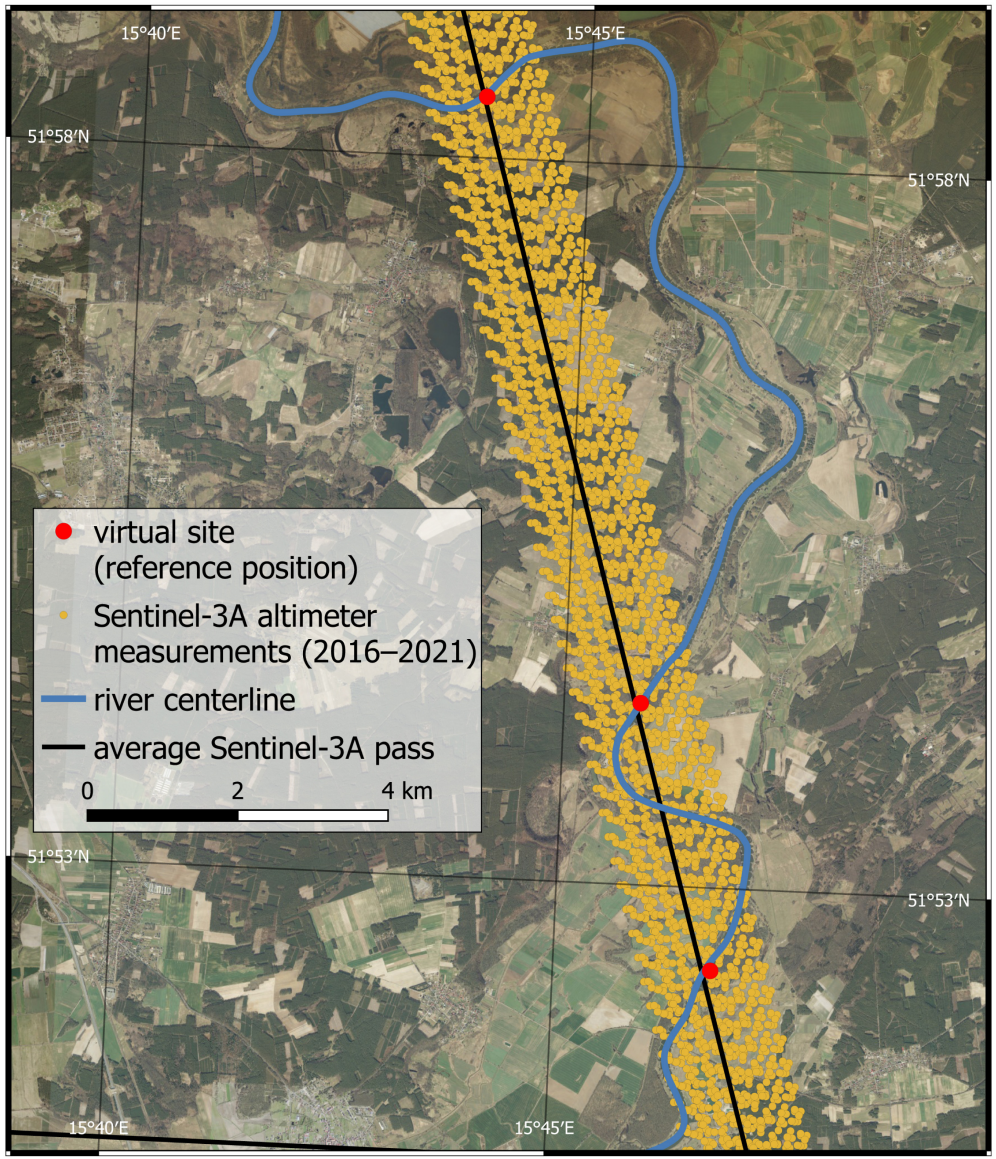
Correcting for slope over the Odra river

Halicki M., Niedzielski T., 2023. The impact of the satellite ground track shift on the accuracy of altimetric measurements on rivers: A case study of the Sentinel-3 altimetry on the Odra/Oder River. Journal of Hydrology 617, 128761 (1–15).

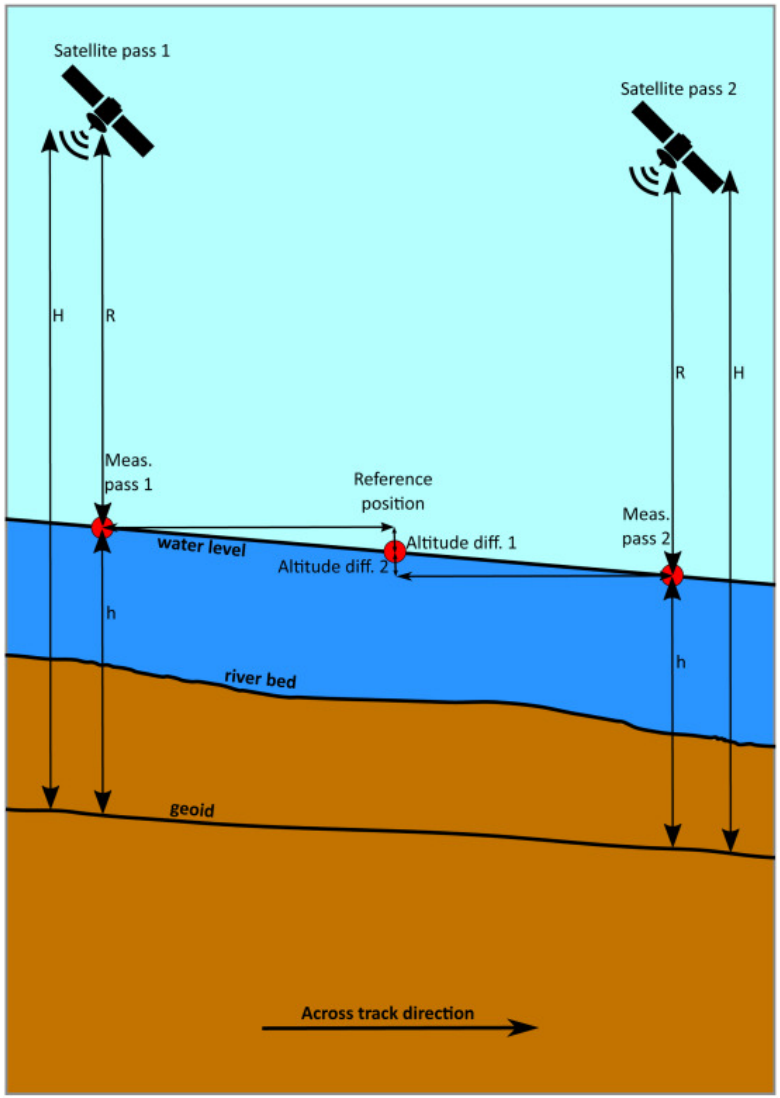
Objectives:

- quantify the impact of river slope (due to satellite ground track shift) on the accuracy of altimetric measurements at virtual stations,
- propose a new method for correcting altimetric measurements.

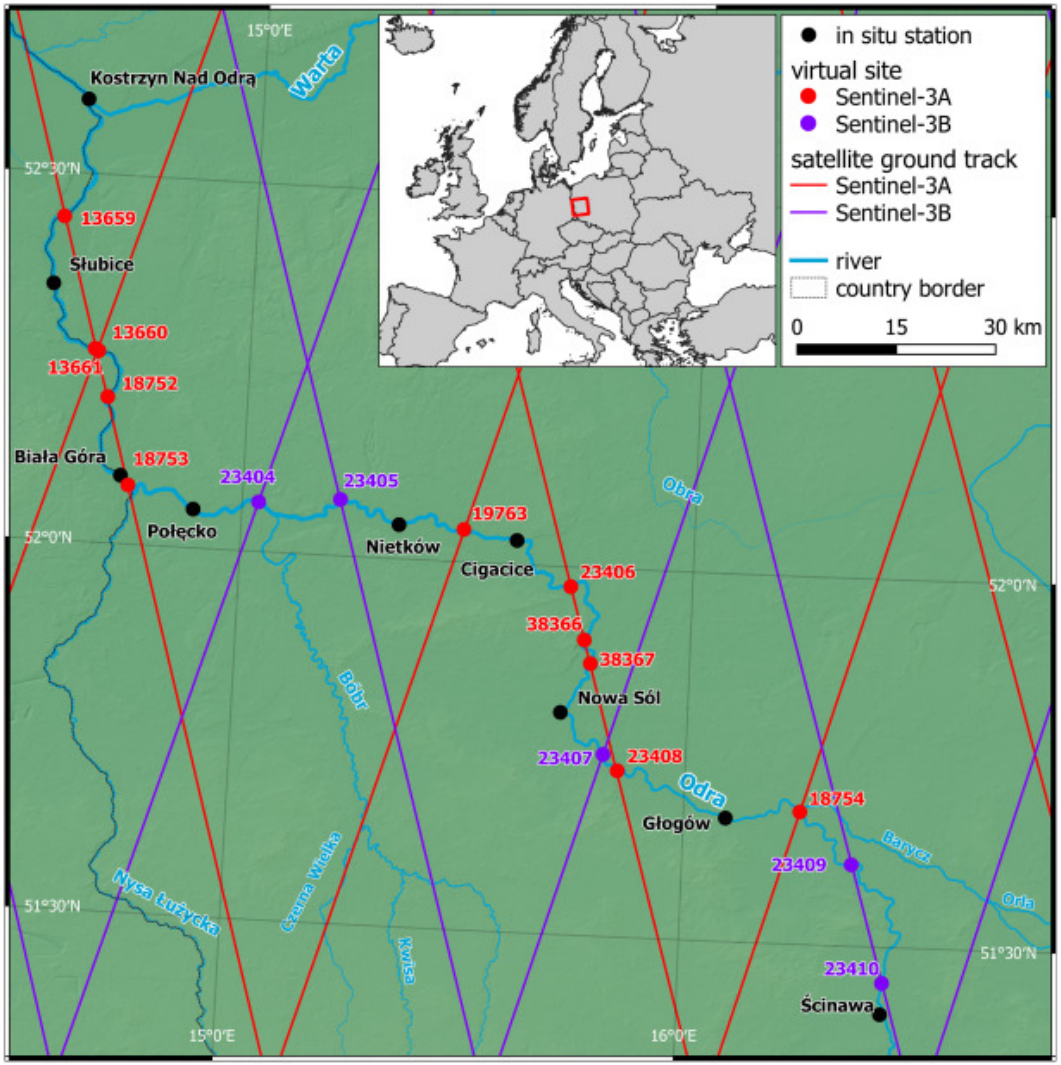
Problem


15°40′E
15°45′E
51°58′N
51°58′N
51°53′N
51°53′N
15°40′E
15°45′E
virtual site
(reference position)
Sentinel-3A altimeter
measurements (2016–2021)
river centerline
average Sentinel-3A pass
0
2
4 km

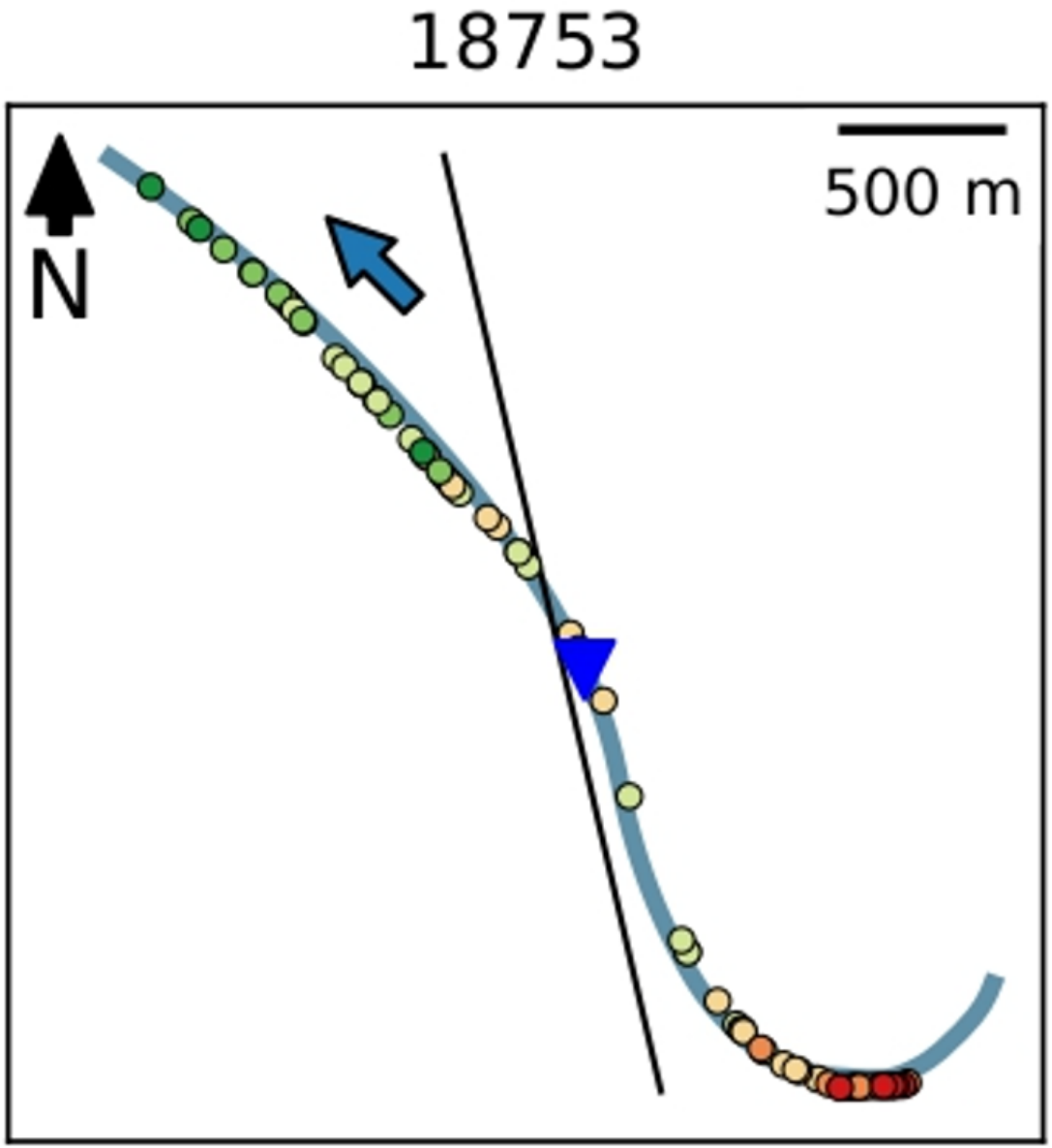
Problem


Satellite pass 1
Satellite pass 2
H
R
R
H
Meas.
pass 1
Reference
position
Meas.
pass 2
water level
Altitude diff. 1
Altitude diff. 2
h
h
river bed
geoid
Across track direction

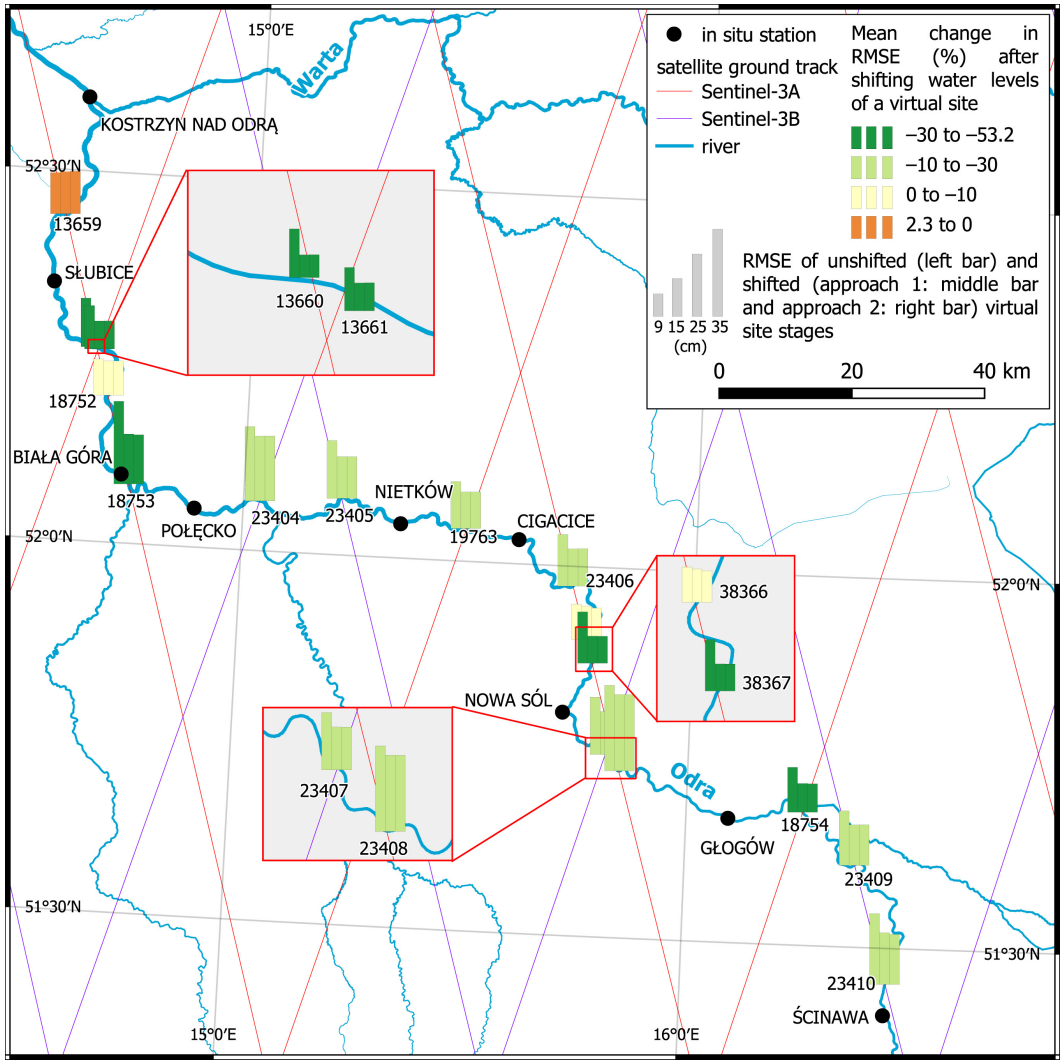
Study area


in situ station
virtual site
Sentinel-3A
Sentinel-3B
satellite ground track
Sentinel-3A
Sentinel-3B
river
country border
0
15
30 km
Kostrzyn Nad Odrą
Warta
Słubice
13659
13660
13661
18752
Biała Góra
18753
23404
23405
Połęcko
Nietków
19763
Cigacice
23406
38366
38367
Nowa Sól
Obra
Bóbr
23407
23408
Odra
Głogów
18754
23409
Barycz
Orla
23410
Ścinawa
Nysa Łużycka
Czarna Wielka
Kwisa
15°0'E
16°0'E
52°30'N
52°0'N
51°30'N

Effect along the river



Results

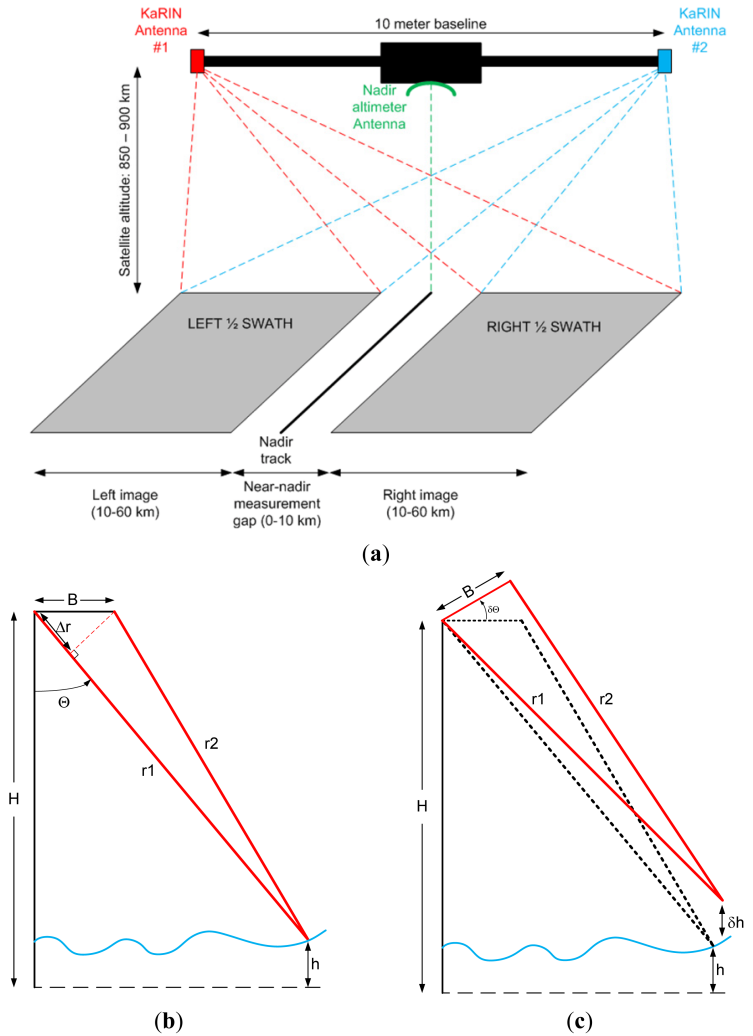

in situ station
satellite ground track
Sentinel-3A
Sentinel-3B
river
Mean change in RMSE (%) after shifting water levels of a virtual site
−30 to −53.2
−10 to −30
0 to −10
2.3 to 0
RMSE of unshifted (left bar) and shifted (approach 1: middle bar and approach 2: right bar) virtual site stages
9 15 25 35 (cm)
0 20 40 km
Warta
Odra
KOSTRZYN NAD ODRĄ
SŁUBICE
BIAŁA GÓRA
POŁĘCKO
NIETKÓW
CIGACICE
NOWA SÓL
GŁOGÓW
ŚCINAWA
13659
13660
13661
18752
18753
23404
23405
19763
23406
38366
38367
23407
23408
18754
23409
23410
52°30′N
52°0′N
51°30′N
15°0′E
16°0′E

Summary (slopes along the Odra river)

- The correction with the gauge-based slope allowed for a mean reduction in RMSE by 5.64 cm, which is an improvement of about 25%.
- The correction with the VS-based slope performed very similarly, reducing RMSE by 5.74 cm.
- The decrease in RMSE for the 16 VS is statistically significant for both approaches.

Instead of overall summary

SWOT HAS JUST BEEN LAUNCHED



Source: Remote Sensing 2014, 6(6), 4831-4869

Acknowledgements

Thank you for your attention!

European Space Agency is acknowledged for inviting this contribution and support.

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