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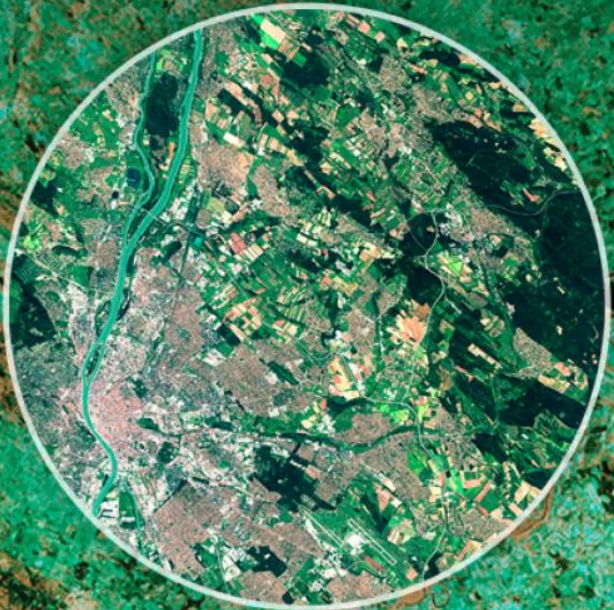
→ 7th ADVANCED TRAINING COURSE ON LAND REMOTE SENSING

4–9 September 2017 | Szent István University | Gödöllő, Hungary



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RIVER DISCHARGE AND LAKE VOLUME VARIATION USING RADAR ALTIMETRY AND IMAGING SENSORS

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Research Institute for Geo-Hydrological Protection
National Research Council

Summary

- *Satellite data: Radar altimetry*
    - *Principles*
    - *Missions and technologies*
    - *Applications*
    - *Data access and toolboxes*

- *Satellite data: Optical and multispectral sensors*
    - *Missions and technologies*
    - *Data access*

- *Hydrological Applications*
    - *River Discharge (from altimetry, from multispectral sensors, from multi-mission)*
    - *Lake Volume variation (from multi-mission)*

Summary

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  - ***Principles***
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- ***Satellite data: Optical and multispectral sensors***
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- ***Hydrological Applications***
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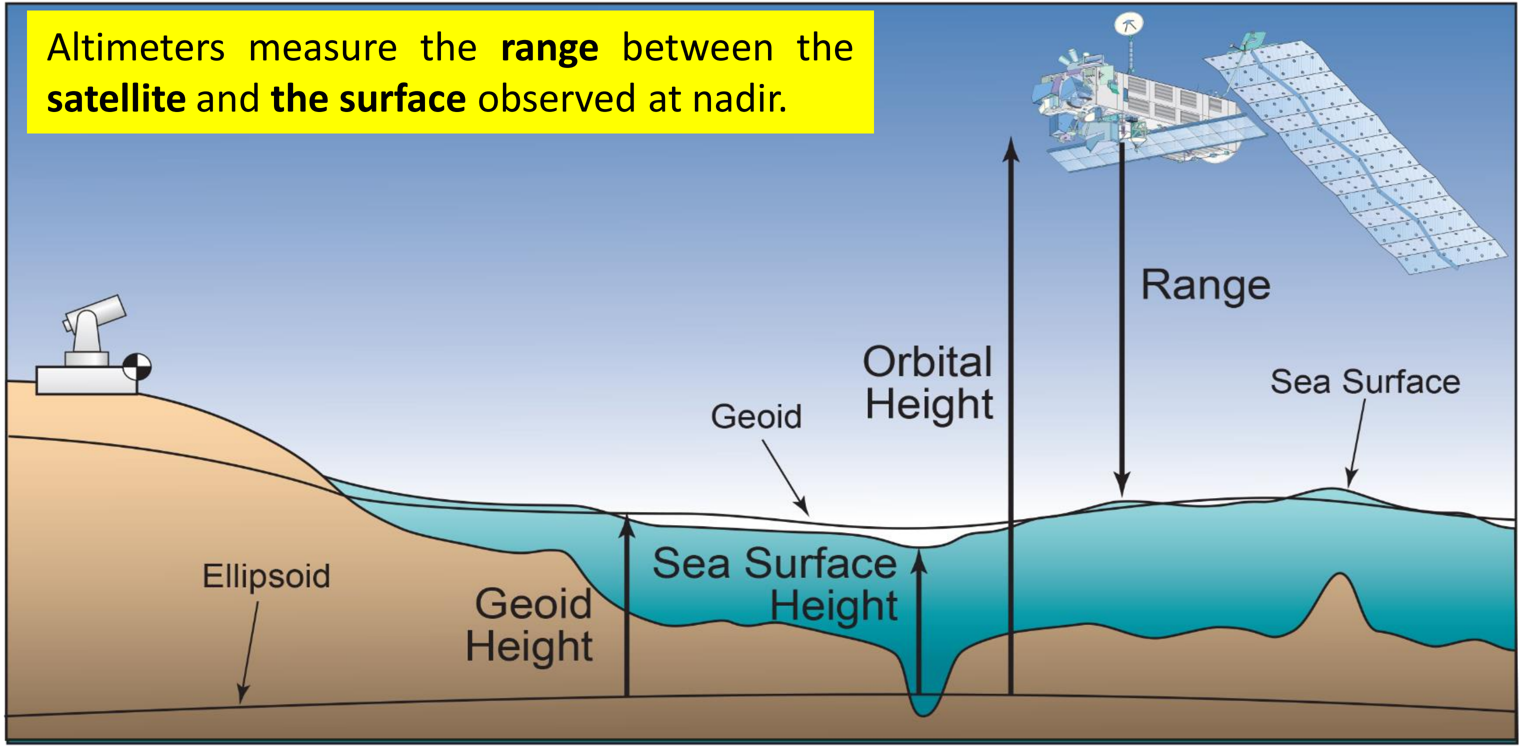
  - ***Lake Volume variation (from multi-mission)***

Radar altimetry principles

Altimeters measure the **range** between the **satellite** and **the surface** observed at nadir.



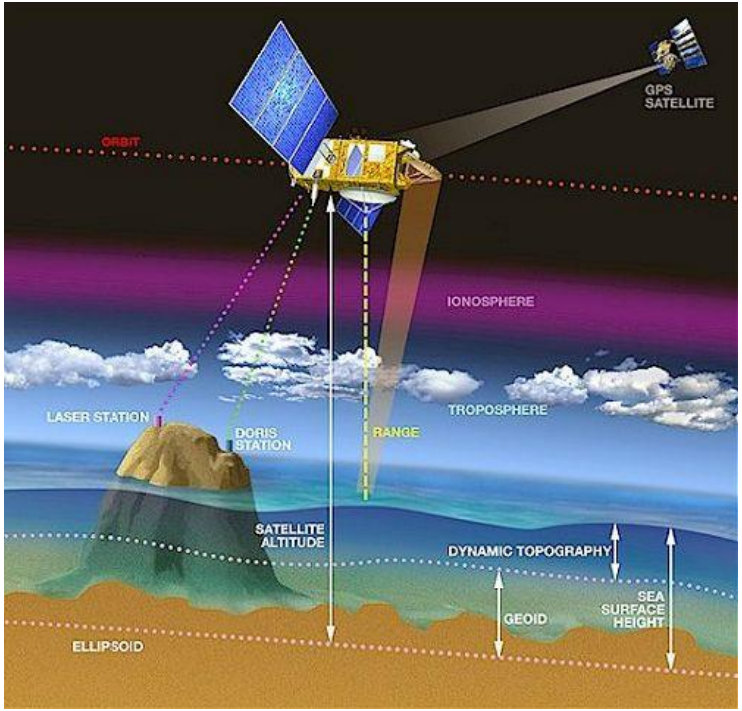
Radar altimetry principles

- The **orbit** is typically determined with an accuracy (radial orbit error) of <2 cm (NTC products) by using SLR, GPS (20,180 km orbit) and DORIS data (10-100 m in '50s-'60s with optical data, 5-10 cm in NRT/STC L2 products).

- **Geoids** (i.e. the ocean surface excluding the influence of wind and tides) are obtained from geodetic or gravity missions (e.g. CHAMP, GRACE, GOCE and including Starlette/Stella, LAGEOS-1/2 data).

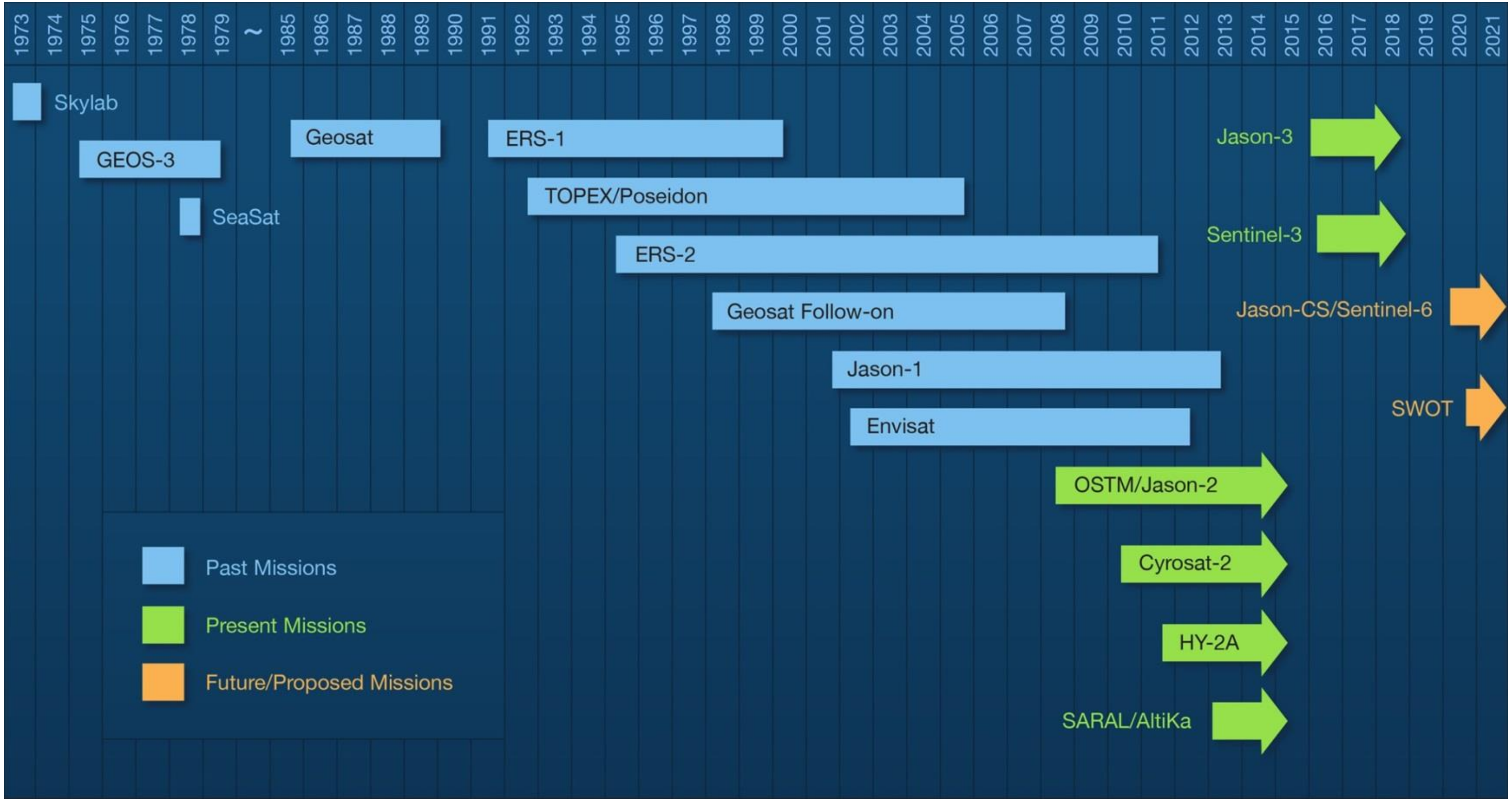
- A reference **ellipsoid** shall be considered as baseline Datum (e.g., WGS84). It is an arbitrary smooth surface designed to be close to the Earth's surface.

- The **range** measurement shall be corrected for a series of effects related to both the propagation into the **Ionosphere/Troposphere**, the **reflection** and **geophysical forcing** on the ocean.



SSH = ORBIT – (RANGE – CORRECTIONS)

Radar altimetry missions



Radar altimetry missions

Satellite	Agency	Launch	Altitude	Altimeter	Frequency (band)	Revisit Time (days)	Inter track (km)	Inclination
Skylab	NASA	1973	435 km	S193	-	-		50°
GEOS 3	NASA	1974	845 km	ALT	-	-		115°
Seasat	NASA	1978	800 km	ALT	Ku	17	165	108°
Geosat	US Navy	1985	800 km		Ku	17	165	108°
ERS-1	ESA	1991	785 km	RA	Ku	35	80	98.5°
Topex/ Poseidon	NASA /CNES	1992	1336 km	Topex	Ku and C	10	315	66°
				Poseidon-1	Ku			
ERS-2	ESA	1995	785 km	RA	Ku	35	80	98.5°
GFO	US Navy /NOAA	1998	800 km	GFO-RA	Ku	17		108°
Jason-1	CNES /NASA	2001	1336 km	Poseidon-2	Ku and C	10	315	66°
Envisat	ESA	2002	800 km	RA-2	Ku and S	35	80	98.5°
Jason-2	CNES /NASA/ Eumetsat/NOAA	2008	1336 km	Poseidon-3	Ku and C	10	315	66°
Cryosat	ESA	2010	720 km	SIRAL	Ku	369	7	92°
Saral	ISRO/CNES	2009	800 km	AltiKa	Ka	35	90	92°
HY-2	China	2010	963 km		Ku and C	14	200	99.3°
Sentinel-3 A/B/C/D	ESA	2016 (A)	814 km	SRAL	Ku and C	27	52 (A+B)	98.5°
Jason-3	CNES /NASA/ Eumetsat/NOAA	2016	1336 km	Poseidon-3B	Ku and C	10	315	66°
SWOT	NASA	2021	970 km	KaRIn	Ka	22	120	78°

Radar altimetry missions

Topex/Poseidon . . . Jason-3 : 315 km– 10 days

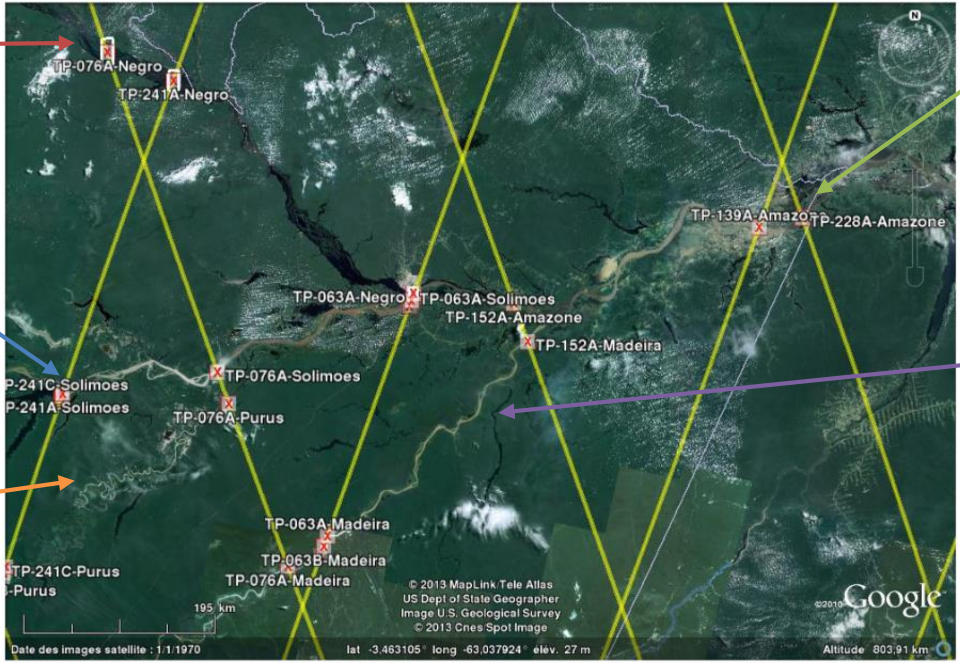
3 VSs in Negro river

3 VSs in Amazon river

4 VSs in Solimoes river

4 VSs in Madeira river

2 VSs in Purus river



The virtual station, VS, is the location where the radar satellite track intersects the river reach

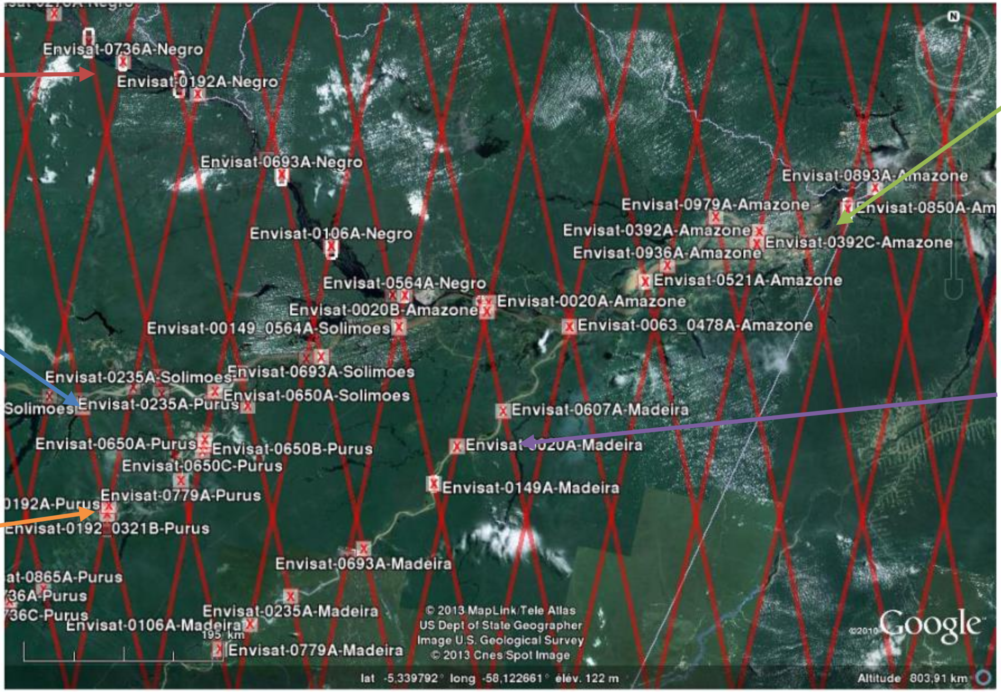
Radar altimetry missions

ERS, ENVISAT, SARAL : 80 km– 35 days

10 VSs in Negro river

9 VSs in Solimoes river

8 VSs in Purus river

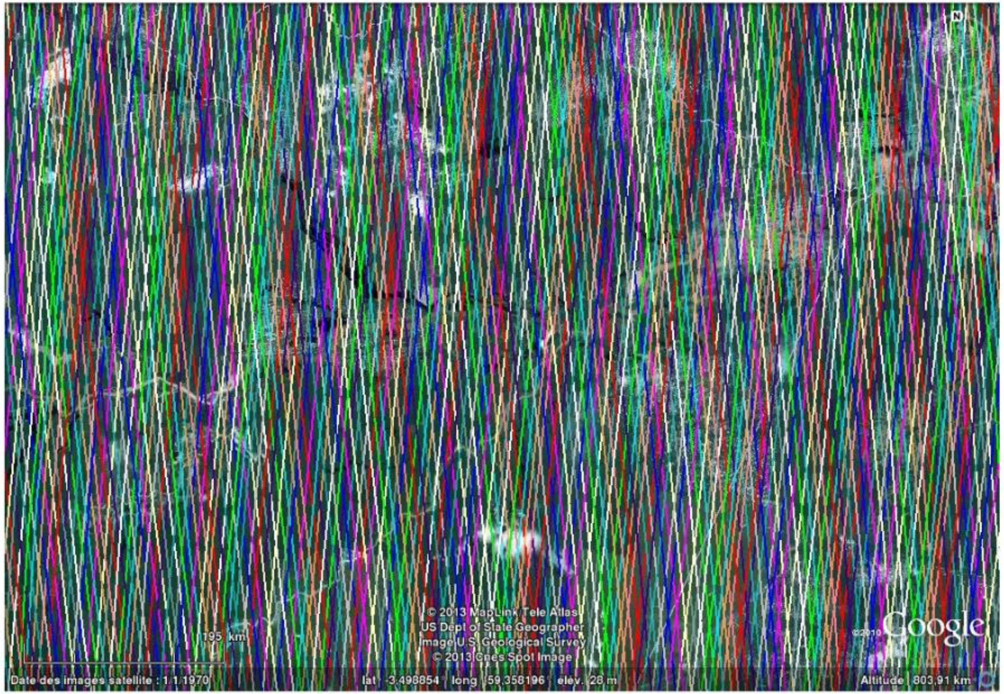


13 VSs in Amazon river

8 VSs in Madeira river

Radar altimetry missions

CryoSat-2 : 7 km– 369 days (colours : “12.7 subcycles”)



Typical altimeter technologies

- **Envisat**: **Low Resolution Mode** (8 Km along track resolution by averaging 20 measurements acquired every 400 m), **Ku Band (13.6 GHz),** vertical resolution of 0.5, 2 or 8 m (adaptable to the scenario, 320 MHz, 80 MHz, 20 MHz). 800 km orbit.

- **Sentinel-3** (SRAL): **SAR Processor** (spatial resolution of 250 m in the along-track direction), Onboard Radiometer, vertical resolution of 0.4 m (350 MHz bandwidth). 814.5 km Orbit .

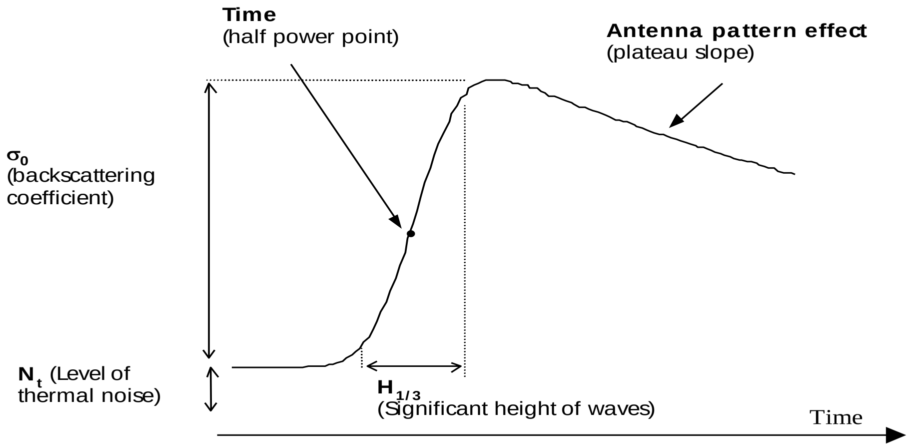
- **CryoSat-2**: 2 Antennas, **LRM/SAR/SARin Processors** (spatial resolution of 250 m in the along-track direction), No Onboard Radiometer. Vertical resolution of 0.47 m (320 MHz bandwidth). 732 km orbit (high latitude coverage: 88°).

- **SARAL/AltiKa**: Single Antenna, **Ka band (35.75 GHz),** 0.3 m vertical resolution (500 MHz chirp bandwidth). Smaller footprint than Ku band due to higher frequency. 800 km orbit (same as Envisat).

Typical altimeter technologies

Processing schemes: Low Resolution Mode

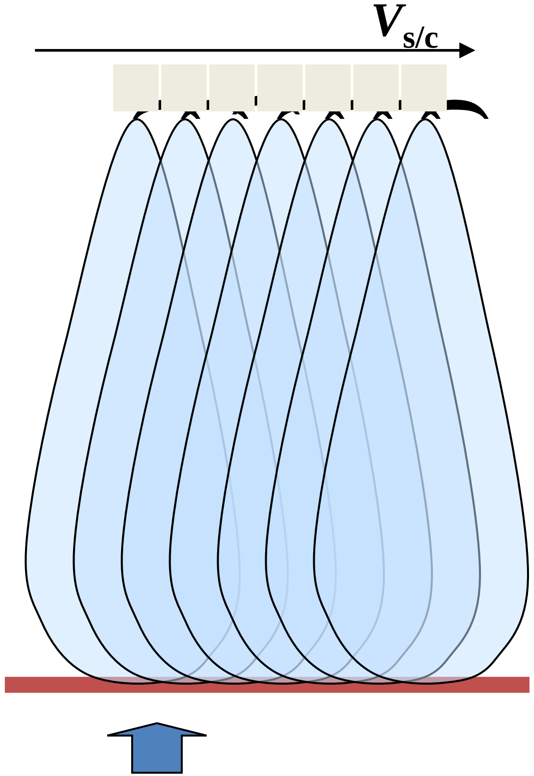
The radar altimeter transmits a short pulse of microwave radiation with pre-defined power toward the target surface. The pulse interacts with the rough surface and part of the incident radiation reflects back to the altimeter.



Animation by Keith Raney

1800-2000 Pulses Transmitted per second

After averaging all the measured ranges over 1/20 second (90 - 100 looks), we have the Brown's Echo over ocean.

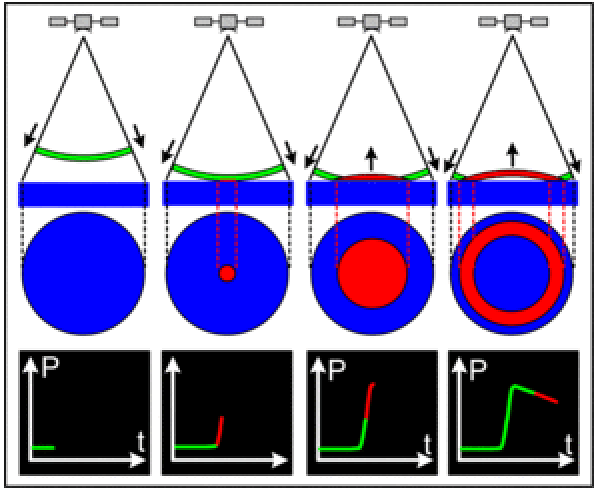


Ground Resolution Cell (around 3-5 km)

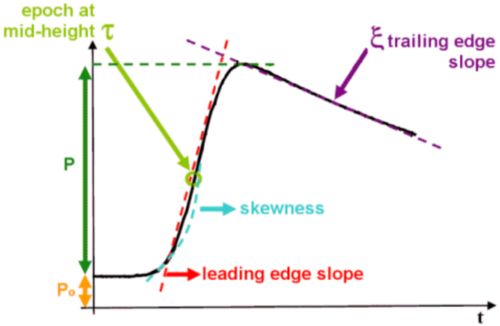
Typical altimeter technologies

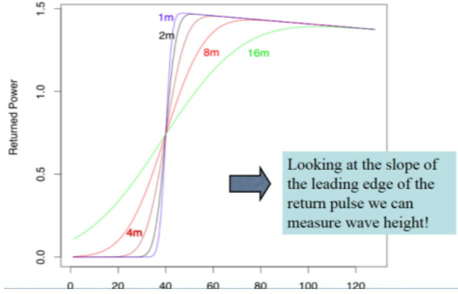
Processing schemes: Low Resolution Mode

When the incident pulse strikes the surface, it illuminates a circular region that increases linearly with time. Correspondingly, a linear increase in the leading edge of the return waveform occurs. The signal reaches the water surface, and it keeps increasing, until power becomes maximum value.



After the trailing edge of the pulse has intersected the surface, the region back-scattering energy to the satellite becomes an expanding annulus of constant area. At this point, the return waveform has reached its peak and then begins to trail off due to the reduction of the off-nadir scattering by the altimeter’s antenna pattern. **The one way travelling time of signal is actually the mid-point of leading edge.**

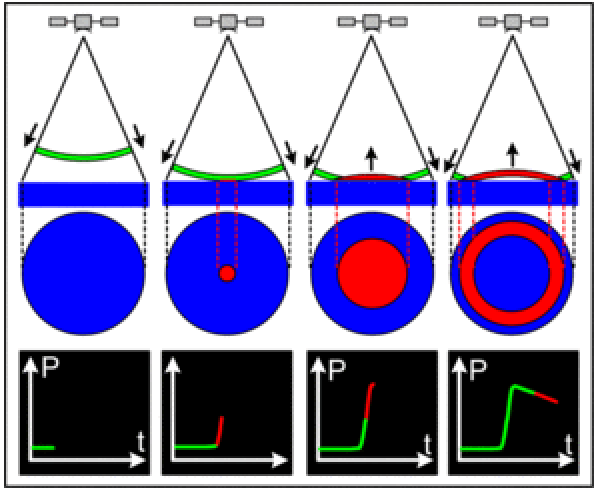


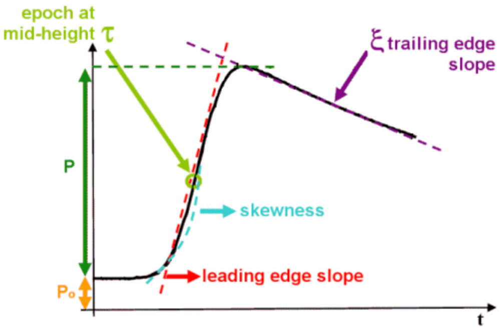


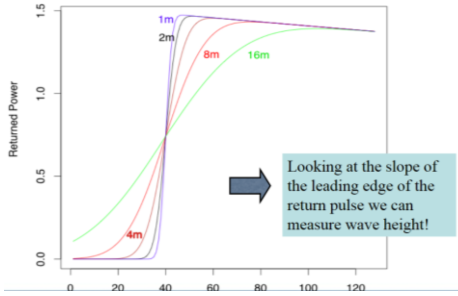
Typical altimeter technologies

Processing schemes: Low Resolution Mode

- Pulse limited acquisition. The time spent observing a punctual target within the beam footprint is not exploited.
- **Observed parameters:** Significant Wave Height (SWH), Wind Speed, Range
- **Typical specs:** Along/Across track resolution: several km depending on SWH.
- **Pros:** easy to implement, typically adopted on the open ocean
- **Cons:** poor usage of the scattering information, poor resolution in both directions.



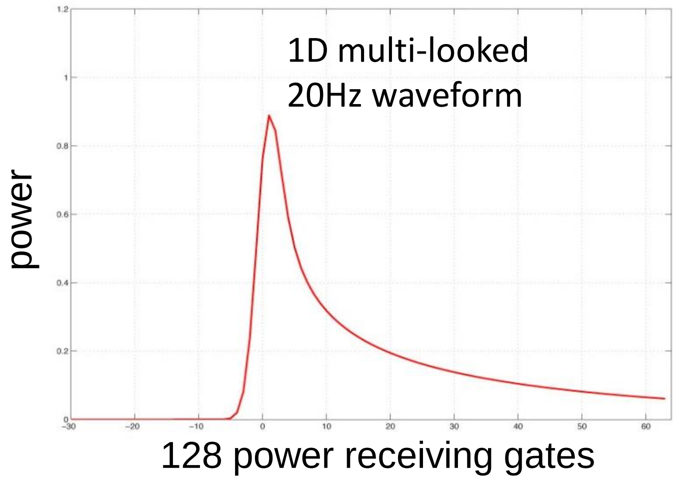




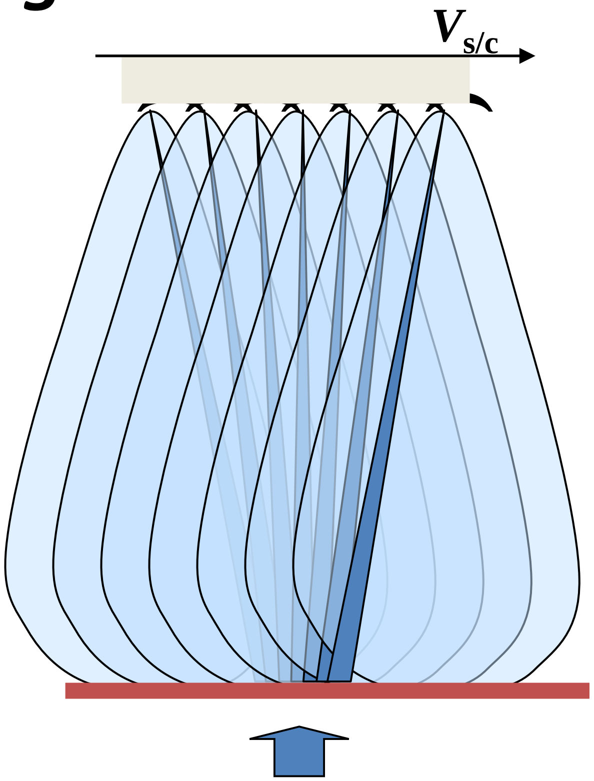
Typical altimeter technologies

Processing schemes: Unfocused Delay-Doppler

Delay Doppler/SAR altimeter "stares" at each resolved along-track cell as the radar passes overhead for as long as that particular cell is illuminated. Each cell is viewed over a larger fraction of the antenna beam than the pulse-limited; thus more data is gathered, which leads to substantial benefits (e.g. it uses most of the power received).



In SAR Altimetry, we average around 250 looks whereas in pulse limited we average around 90 looks: that makes SAR altimetry more precise than classic altimetry



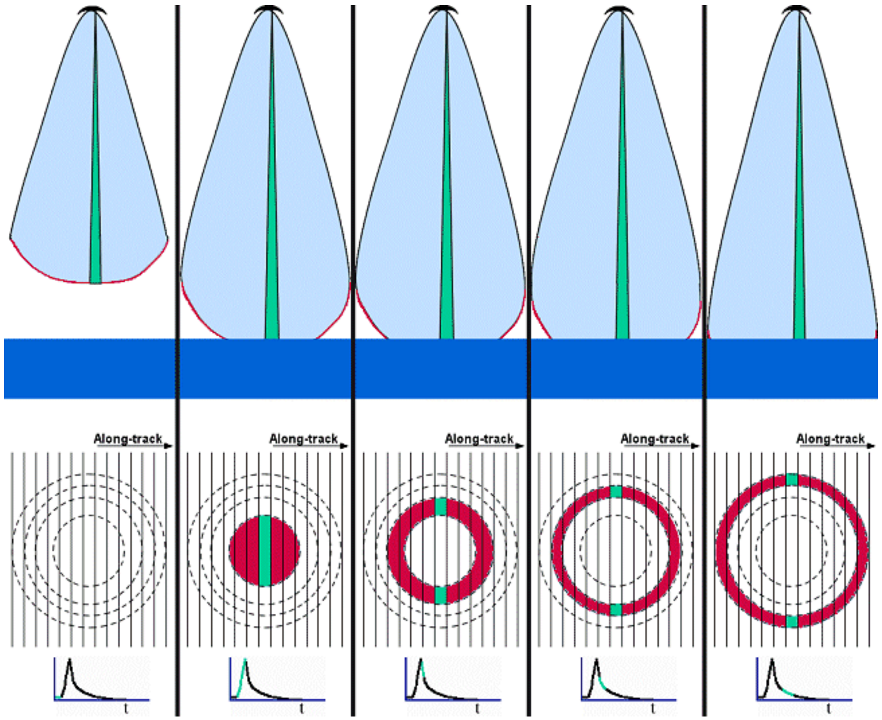
Typical altimeter technologies

Processing schemes: Unfocused Delay-Doppler

Contrary to the classical altimeter, the lighted area is not a surface-constant ring, but only part of it, which explain the peakier shape of the echo. Several such beams are used at the same time.

In Figure, the conventional altimetry range rings are shown together with the division of along-track Doppler cells, which make the footprint for each waveform significantly smaller. Consequently, land contamination is avoided or, at least, reduced. CryoSat-2, for example, has a footprint with a diameter of around 20 km. When using DDA, the along-track resolution is narrowed down to 300m.

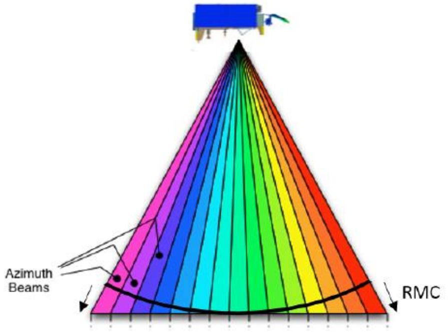
The Delay Doppler/SAR altimetry processes the data such that they could be seen as having been acquired from a synthetic aperture antenna. This along track processing increases resolution and offers a multilook processing with the two independent dimensions: along-track and across-track.



Typical altimeter technologies

Processing schemes: Unfocused Delay-Doppler

The time spent observing a punctual target within the beam footprint is exploited thanks to the high PRF permitting coherent measurements and the exploitation of the Doppler frequency shift using the speed of the spacecraft (along-track only). Pulses are transmitted in bursts.



Typical specs:

Along track resolution: around 300 m

Across track resolution: same as LRM

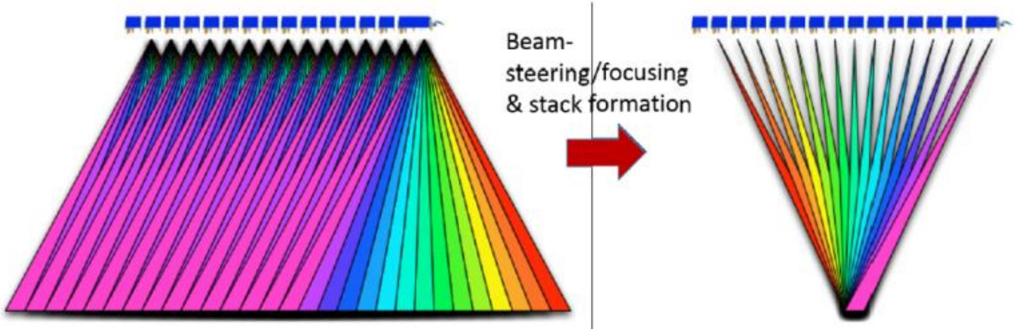
Pros:

Improved along track resolution (300 m)

Higher SNR due to extended time on target

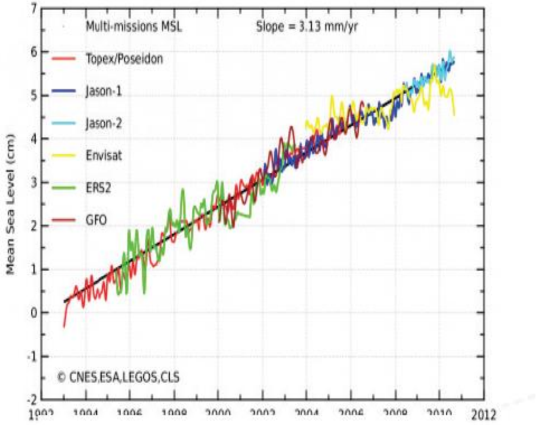
RDSAR (pLRM) waveforms can be obtained by compressing SAR and SARin waveforms.

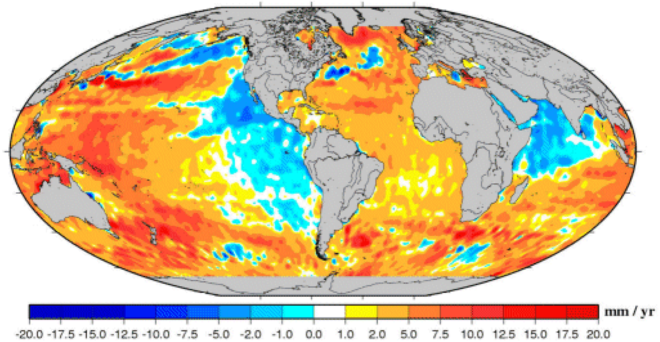
Cons: Across track resolution is not improved



Applications: Sea Level Monitoring

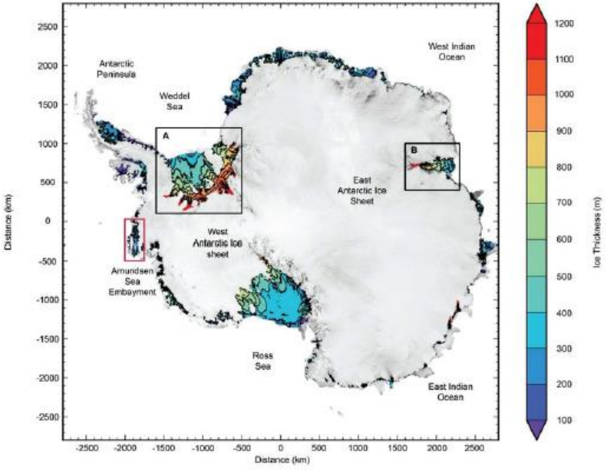
- **The global mean level of the oceans is an indicator of climate change** (ocean temperature warming, mountain glaciers/melting).
- Mean Sea Level is an average over all the oceans of sea surface height with respect to a reference.
- Recently, the **Sea Level CCI team** has released a full reprocessing of the **Sea level products** (v2.0 ECV).
- Mean Sea Level trends computed from altimetry, from January 1993 to 2005. Regional variations were sometimes more than ten times the average (West Pacific, Indian Ocean), whereas in other regions sea level actually decreased.



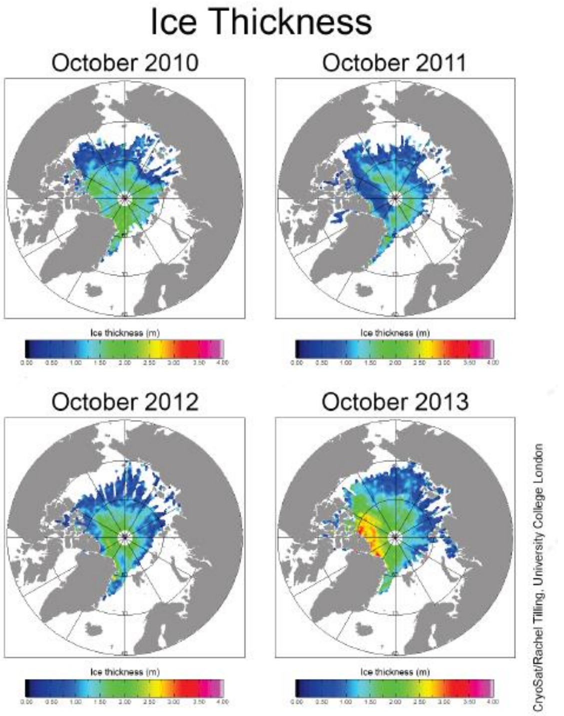


Applications: Ice Cap and Sea-Ice Thickness Monitoring

- CryoSat-2 monitored changes in surface elevation of Earth's ice sheets, sea-ice thickness and extent.
- Routinely monitoring since November 2010.



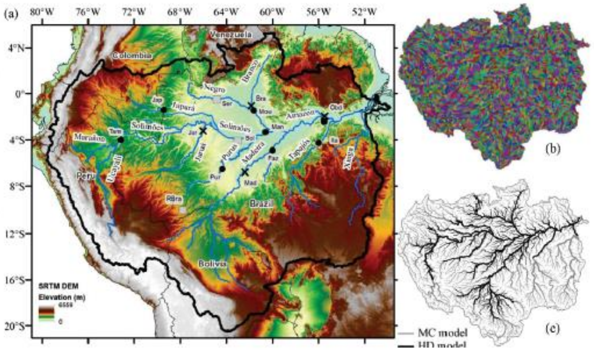
Antarctic ice shelf thickness Derived from CryoSat-2 radar altimetry (Credit: subset of fig S1 from Chuter and Bamber, 2015).



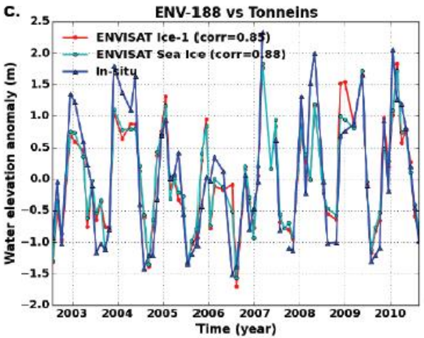
Applications: River Level Monitoring & Hydrological modelling

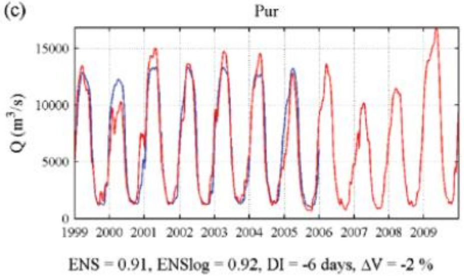
The radars on altimetry satellites, even those optimised for the ocean, continue to emit pulses while flying over land. Reception of the return echoes is more complex, since a field or a forest does not reflect radar pulses as well as water, but some conclusions can still be drawn.

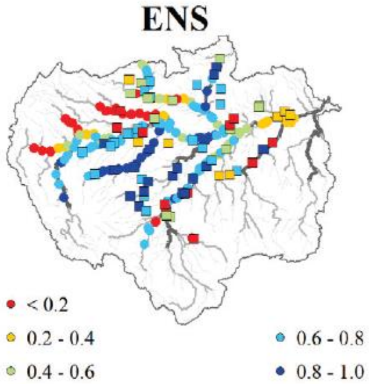
Hydrological products from satellites are unaffected by political and logistical considerations and can provide accurate height measurements not only for lakes but also for large/medium rivers.



The assimilation of altimetry data in hydrodynamic models should also lead to advances in knowledge and ultimately even in forecasting hydrological systems.







Credit: S. Biancamaria et al. (2016) , Paiva et al. (2013)

Applications: River Level Monitoring & Hydrological modelling

Applications: River Level Monitoring & Hydrological modelling

***In-situ* data**

(from January 2002 to December 2008)

[red box] Water level

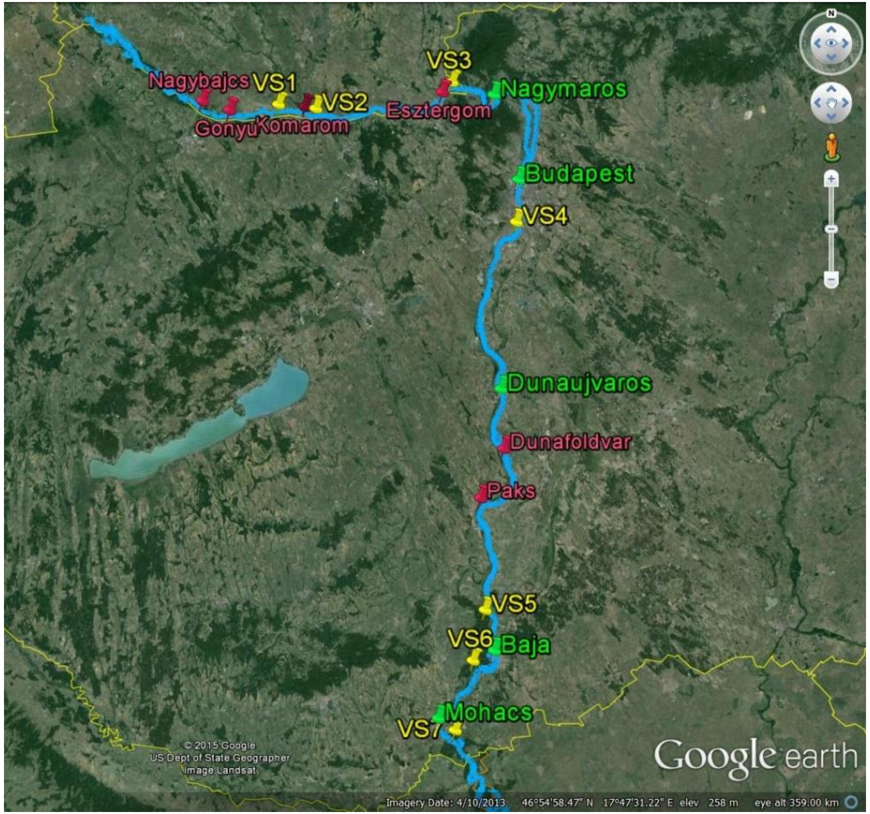
[green box] Water level / Discharge / Cross sections

Satellite altimetry data

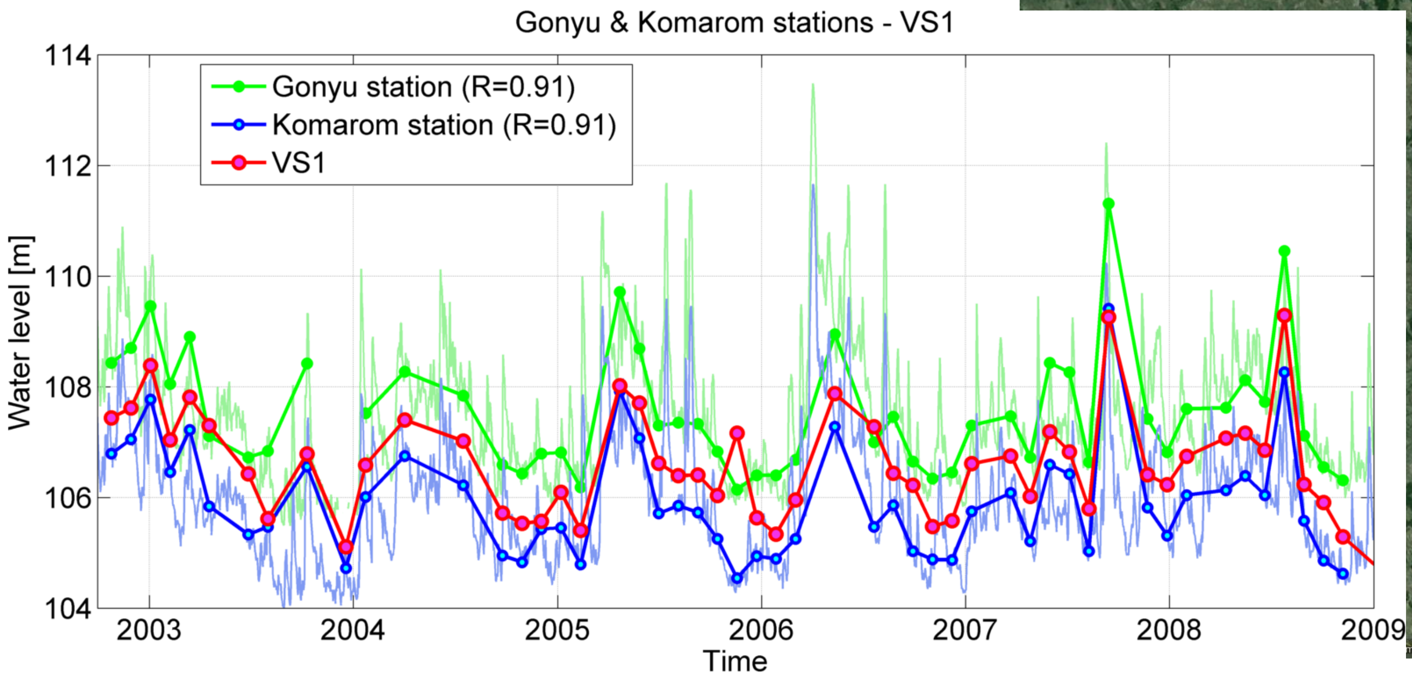
provided by ESA River&Lake website

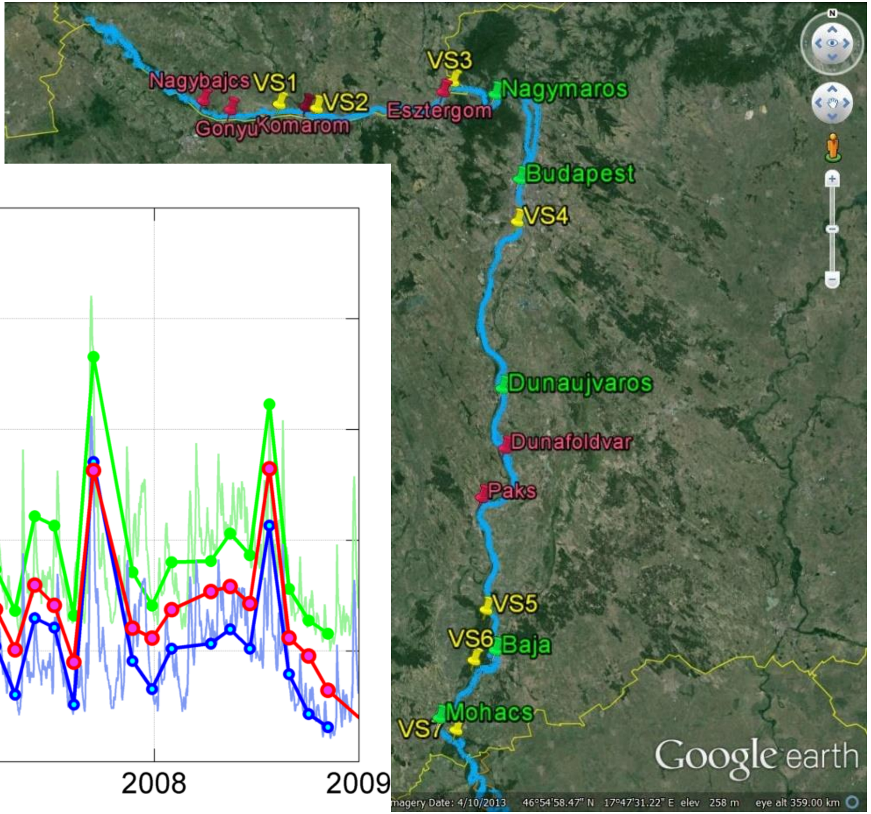
(***http://earth.esa.int/riverandlake***)

[yellow box] Water level

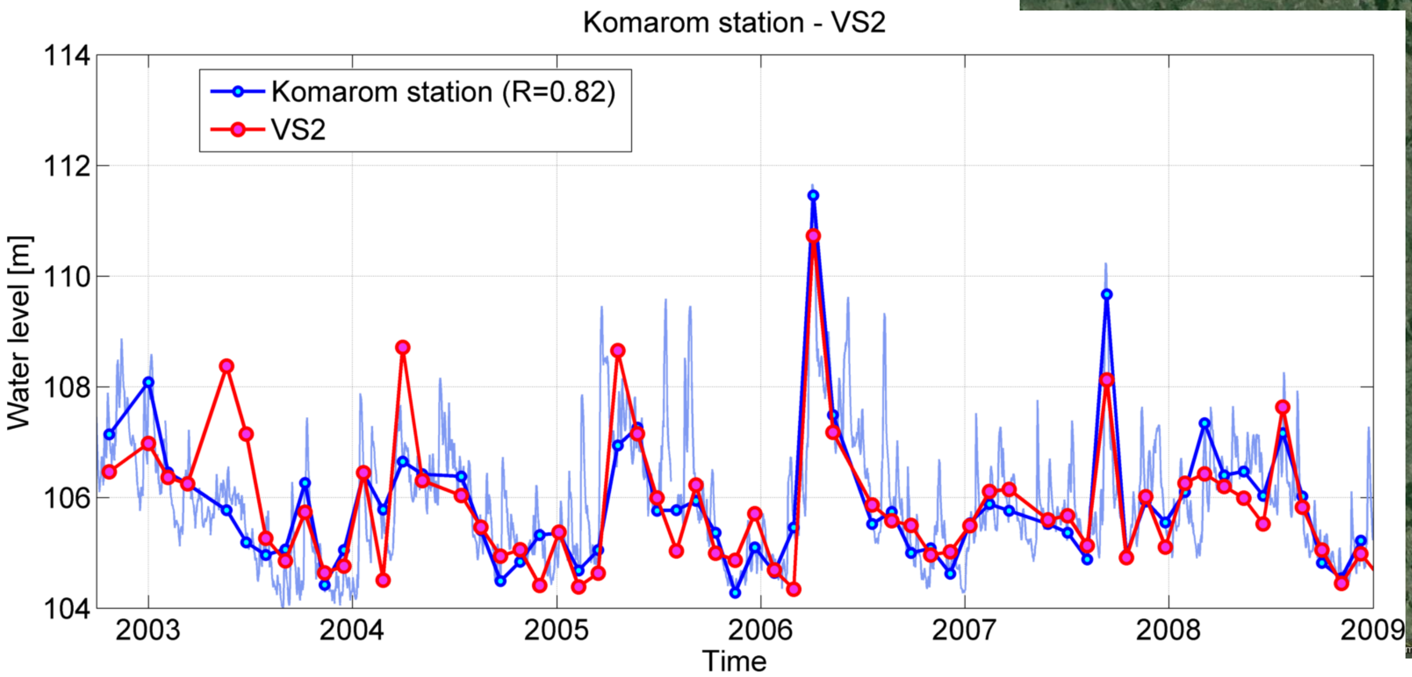


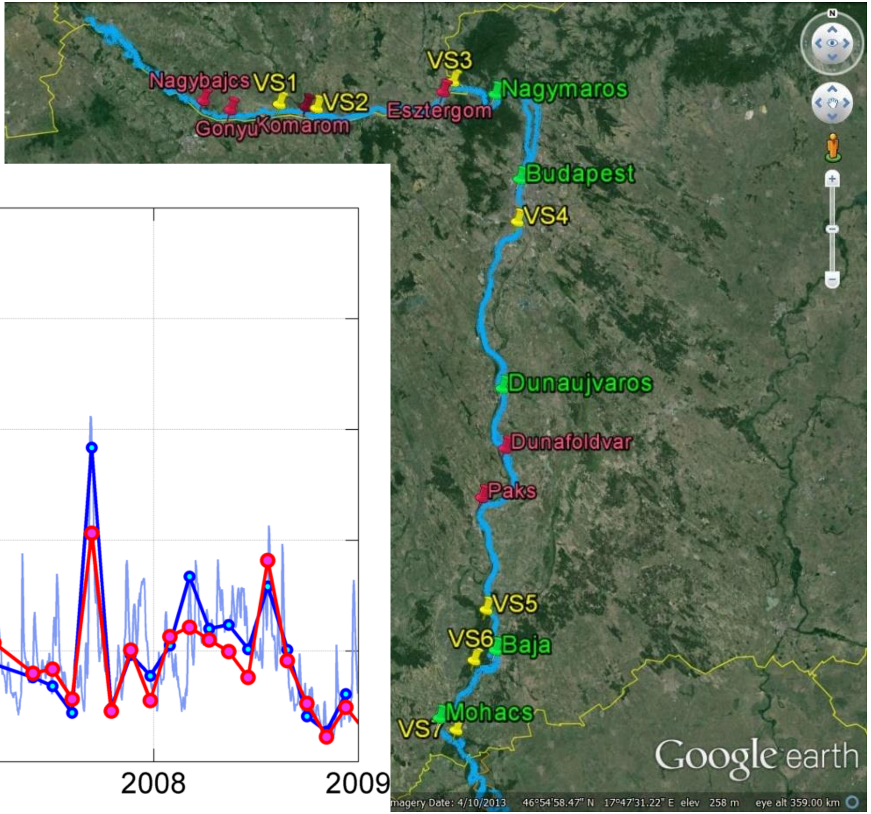
Applications: River Level Monitoring & Hydrological modelling



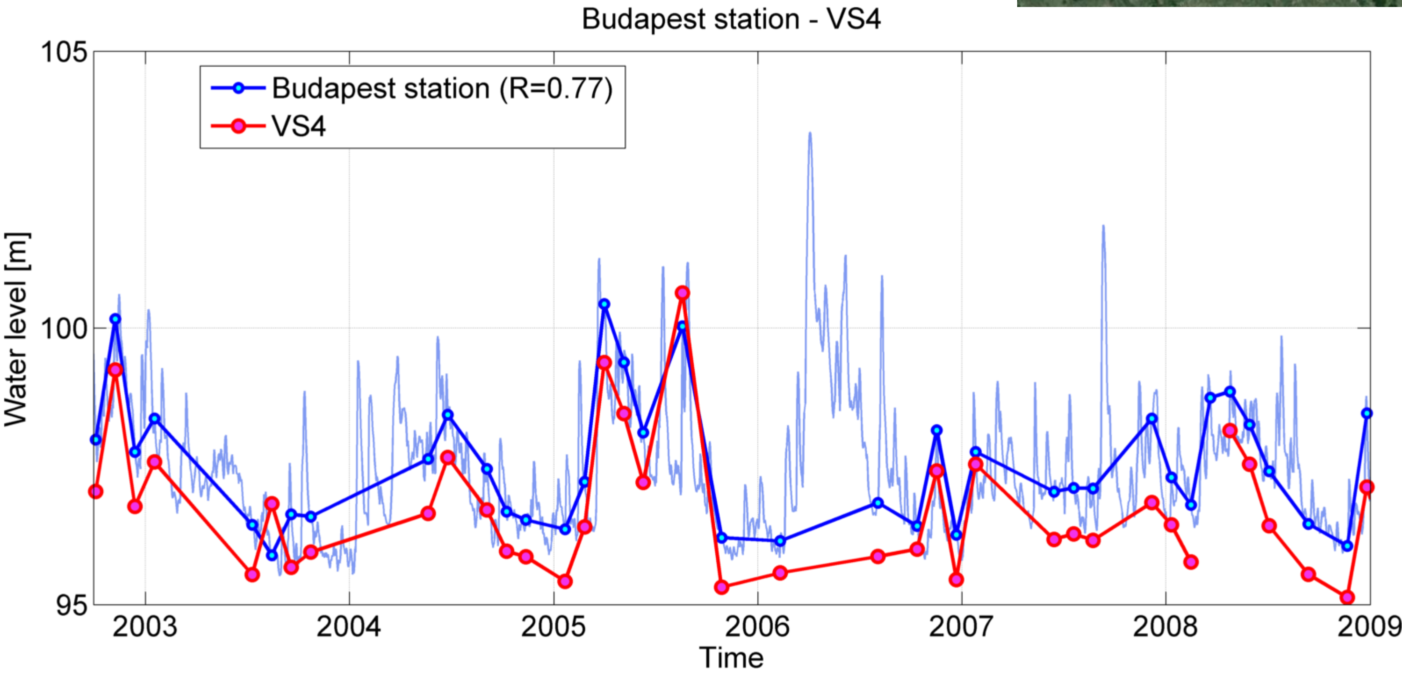


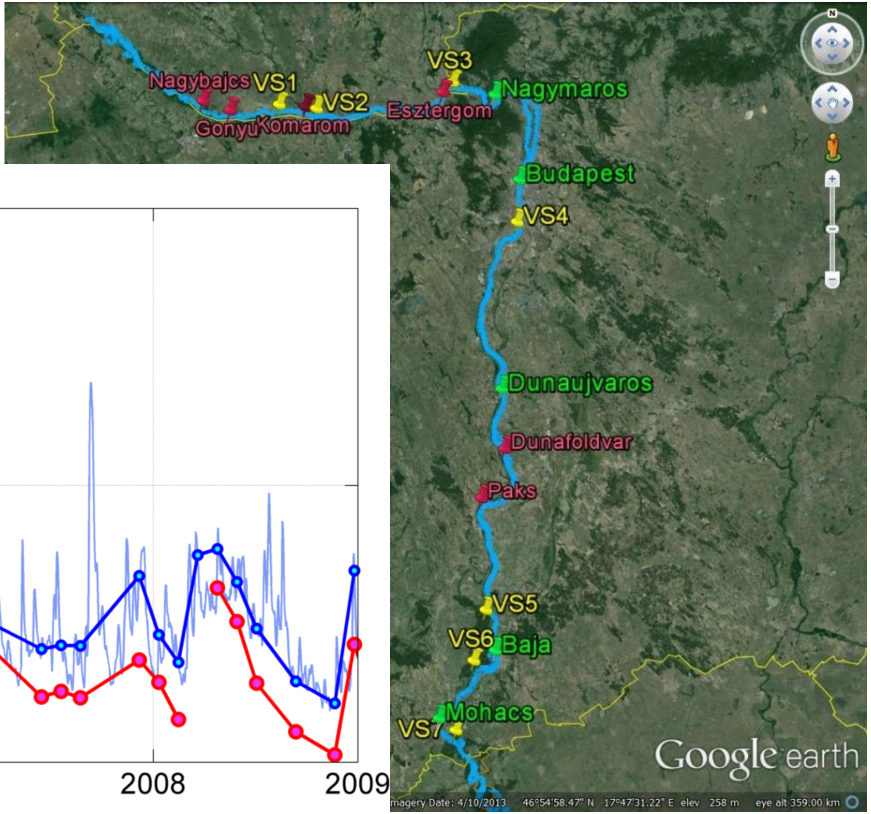
Applications: River Level Monitoring & Hydrological modelling



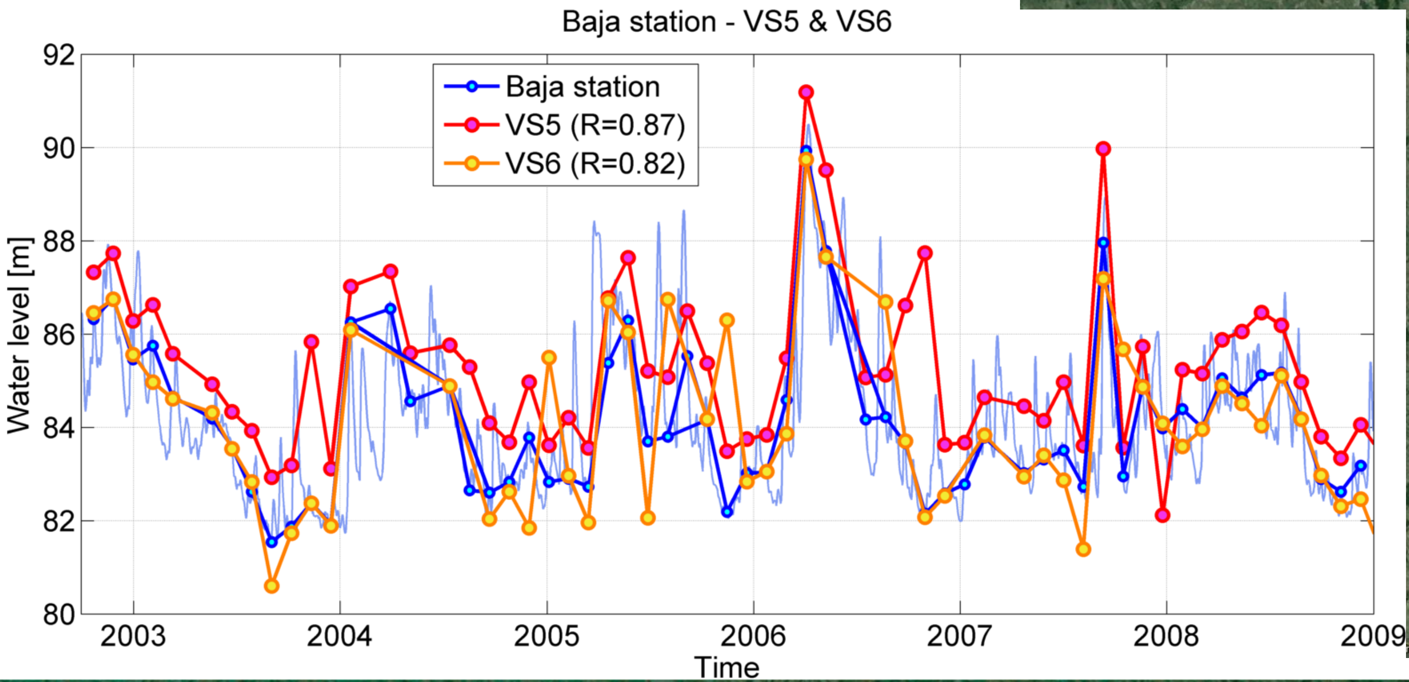


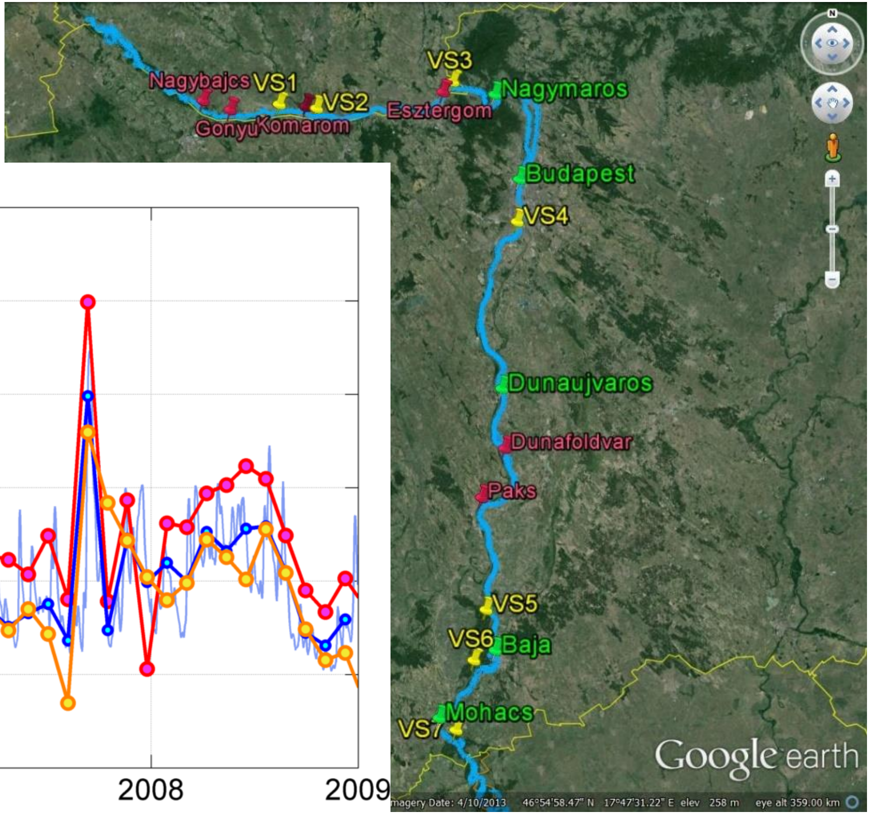
Applications: River Level Monitoring & Hydrological modelling



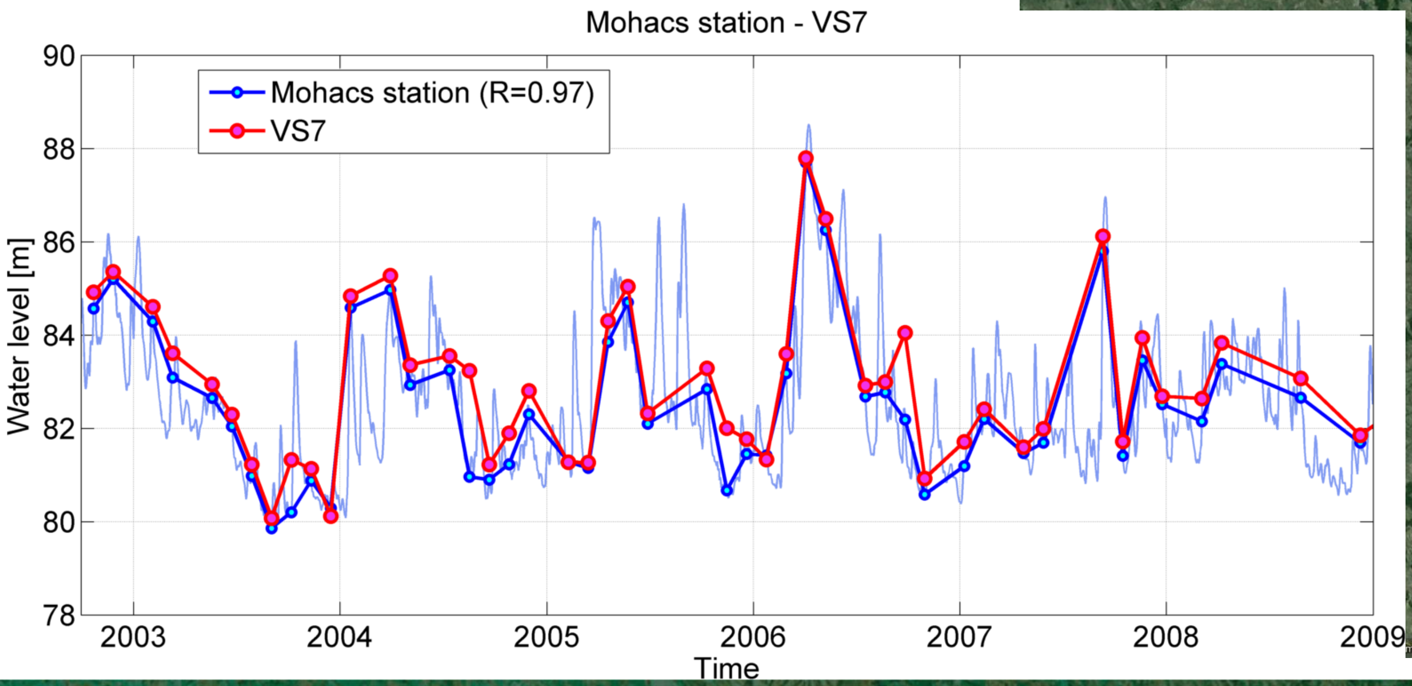


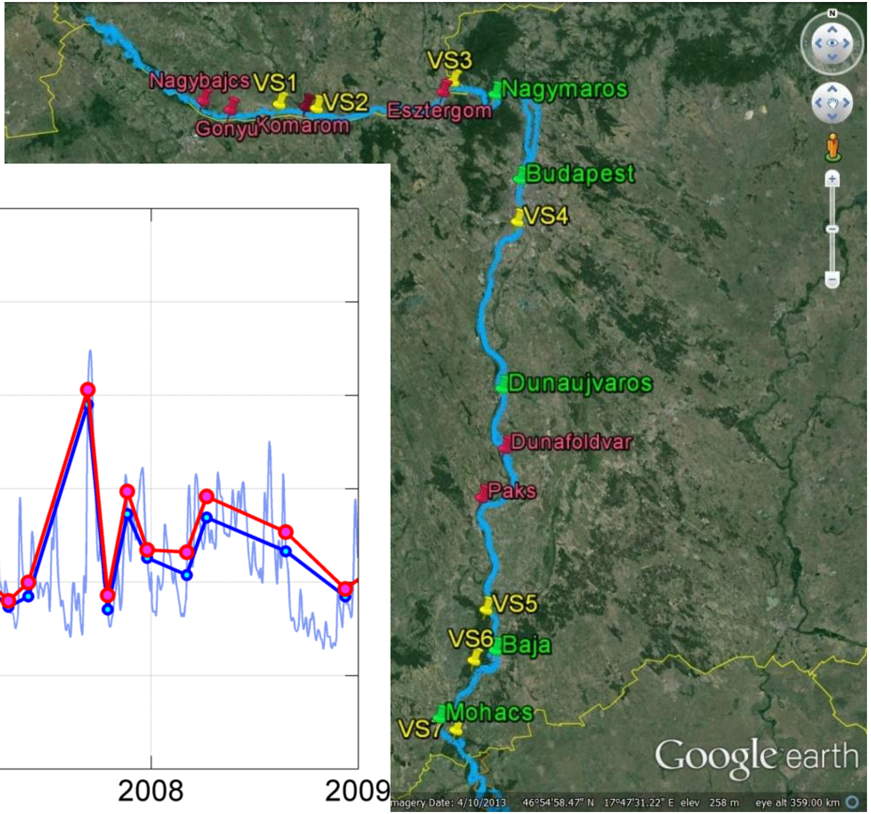
Applications: River Level Monitoring & Hydrological modelling





Applications: River Level Monitoring & Hydrological modelling





Altimetry data download

Data access:

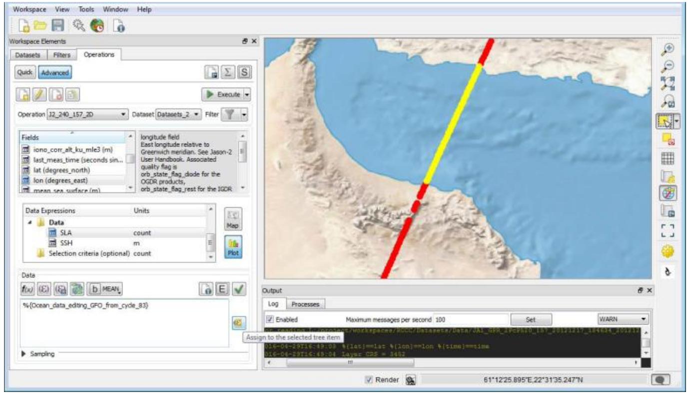
- ESA
- AVISO+ (incl. PEACHI)
- LEGOS/CTOH
- NASA/PO.DAAC
- PISTACH

Alti-Hydro portals:

- HydroSat (**http://hydrosat.gis.uni-stuttgart.de**)
- DAHITI (**http://dahiti.dgfi.tum.de**)
- HydroWeb (**http://hydroweb.theia-land.fr**)
- River&Lake (**http://tethys.eaprs.cse.dmu.ac.uk/RiverLake**)

Broadview Radar Altimetry Toolbox (BRAT)

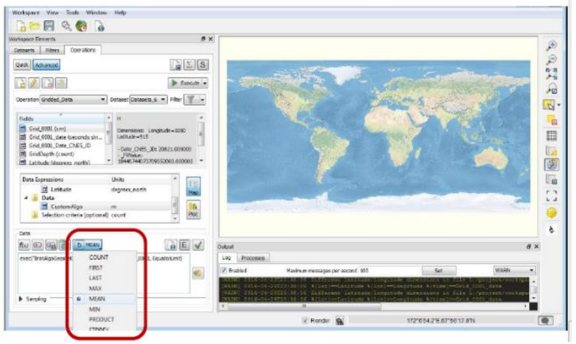
- The project started in 2005 from the joint efforts of ESA (European Space Agency) and CNES (Centre National d'Études Spatiales).
- BRAT is a collection of tools and tutorial documents designed to facilitate the reading, manipulation and visualization of radar altimetry data.
- It can read all altimetry missions' data, from ERS-1 (1991) to Sentinel-3 (2016).
- BRAT can be used in conjunction with MATLAB/IDL or C/C++/Python/Fortran, allowing users to obtain the desired data, bypassing the data-formatting hassle.



Broadview Radar Altimetry Toolbox (BRAT)

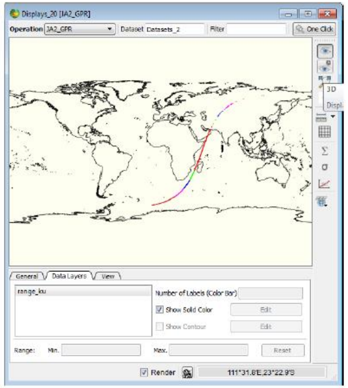
- Several kinds of computations can be done within BRAT, involving both user defined combinations of data fields that can be saved for posterior use and BRAT's predefined formulas from oceanographic altimetry.
- Easy access to altimeter data from RADS (**http://rads.tudelft.nl/rads**) and display of RADS variables included in BRAT.
- BRAT can be used to simply visualise data quickly, or to translate the data into other formats (NetCDF, ASCII text files, KML and raster images from the data (JPEG, PNG, etc.)).

Operations – Data computation

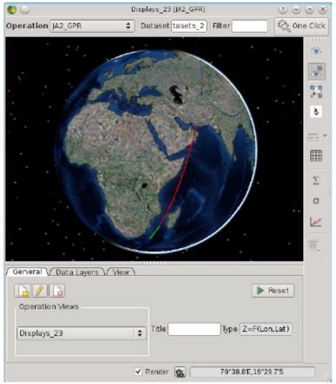


	NEW FEATURES	NEW DATASETS
09.2015	• CODA Library Upgrade • NetCDF 4 Upgrade • Porting to 64 bits • KMZ/KML Export Update • Python API Upgrade • Import to GPOD analysis	• Sentinel-3 L1B and L2 • Jason-3 • CryoSat-2 Baseline C • CryoSat-2 Ocean Products • SARAL AltiKa • HY-2A
09.2016	• Visualisation functions improvement	• Sentinel-3 L1A and L1B-S • ERS REAPER
08.2017	• Coastal / inland waters formulas update • Dataset interpolation improvement • ASCII export improvement • CFI libraries inclusion	• River and Lake products • Geosat GDR • EnviSat reprocessed

Views - Map

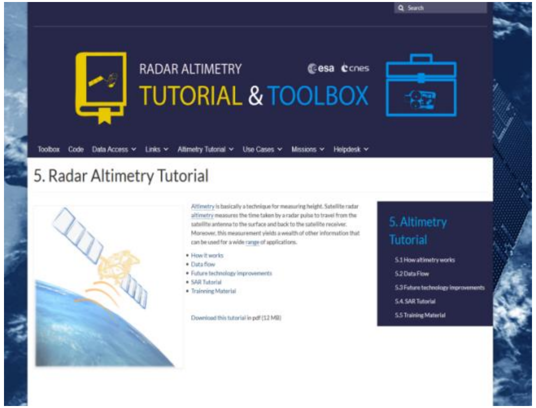


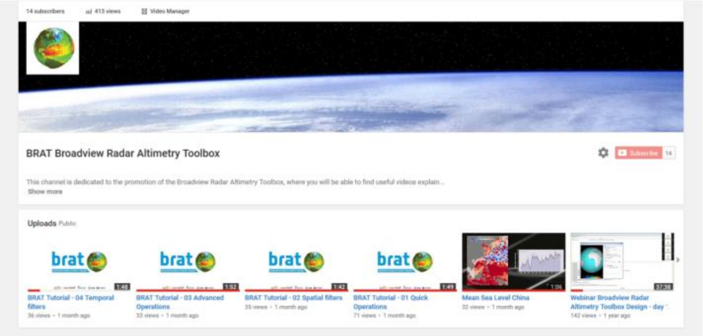
Views - Globe



Broadview Radar Altimetry Toolbox (BRAT)

- BRAT also includes the Radar Altimeter Tutorial, which contains an extensive introduction to altimetry. As part of it, you can find:
  - Examples of usages of altimetry data
    http://www.altimetry.info/thematic-use-cases
  - Didactic material
    http://www.altimetry.info/radar-altimetry-tutorial/training-material
  - Community forum
    http://www.altimetry.info/?forum=altimetry-forum-2
  - Step-by-step instructional videos
    http://bit.ly/bratvideo





Broadview Radar Altimetry Toolbox (BRAT)

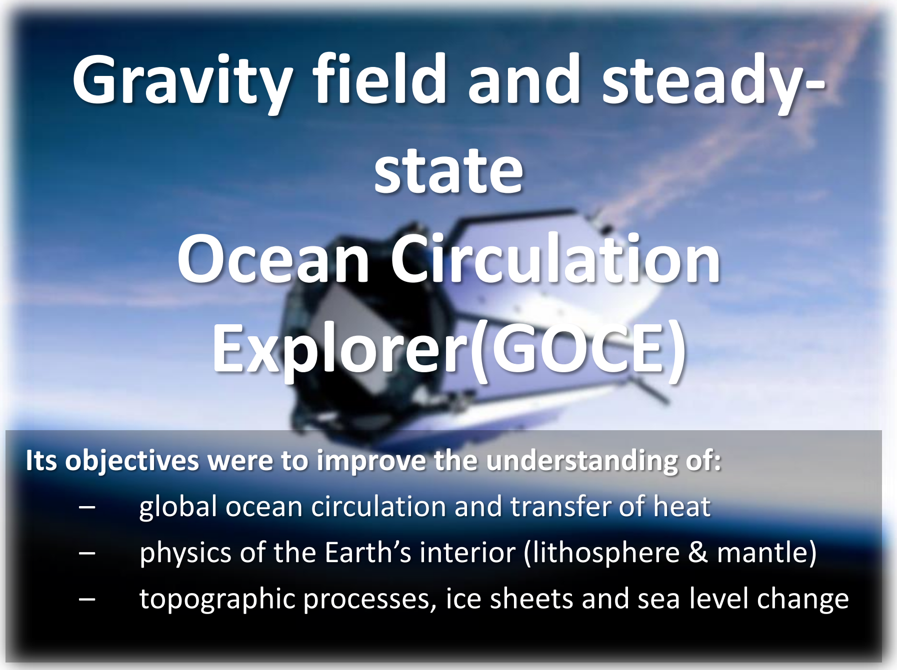
- Current version is 4.1.0, with version 4.2.0 expected to be released in October 2017.
- BRAT is available at **http://www.altimetry.info/toolbox**: installers for Windows, macOS and Linux.
- BRAT is open-source: released under the GNU Lesser General Public License (LGPL).
- The source code is available at **https://github.com/BRAT-DEV/main**, where users can submit bug reports, requests for features or even contribute to the development.

http://www.altimetry.info

brat
BASIC RADAR ALTIMETRY TOOLBOX

GOCE User Toolbox (GUT)

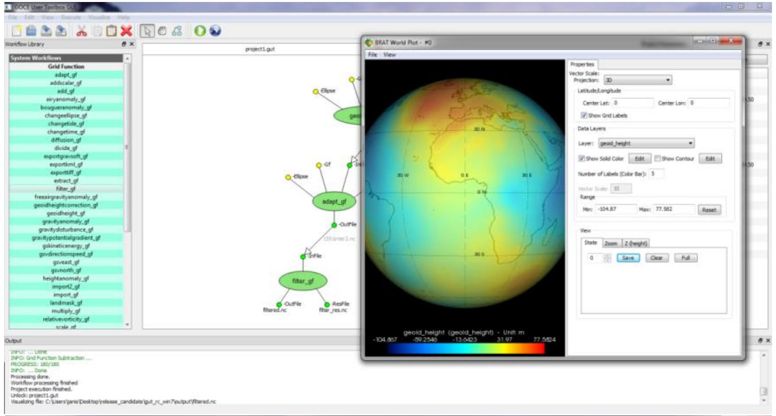
GUT is a toolkit to facilitate the use, viewing and post-processing of GOCE's Level-2 gravity field data products.

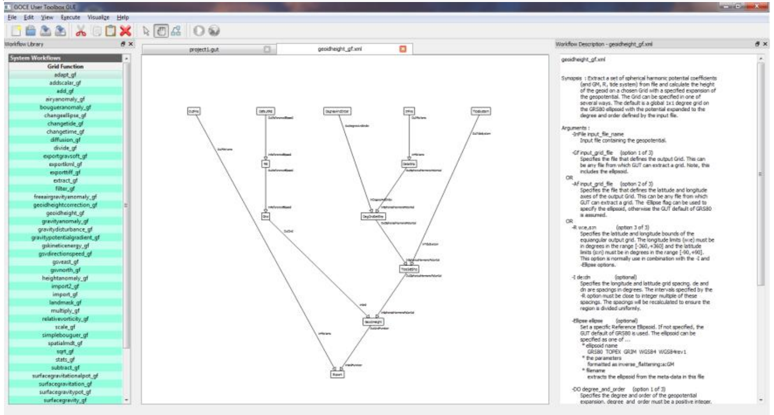


GOCE User Toolbox (GUT)

- It is also able to process GRACE and SWARM data products.
- Fully open-source, built with Python over C++ command lines tools.
- Users can interact with it by dragging and dropping workflow nodes, user-friendly dialogs, and colour coded feedback.
- As a companion document, we have a very extensive tutorial, focused on the theory behind GOCE and how to use GUT, that guides users:
  - From using pre-built tools to calculate gravity anomalies
  - To step-by-step instructions of how to build your own tools with GUT

https://earth.esa.int/gut





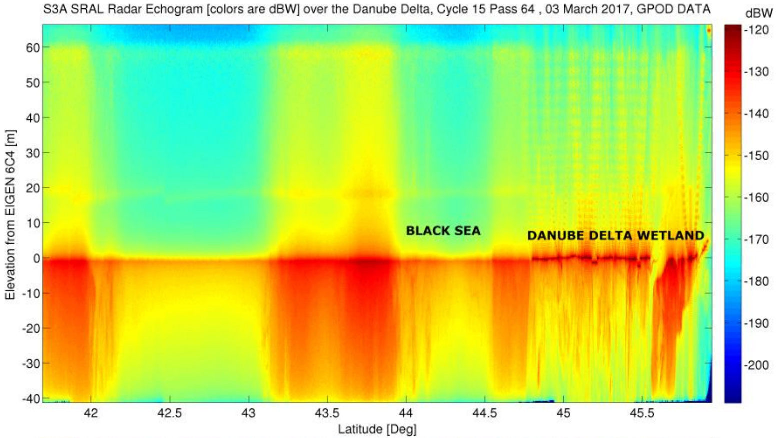
SAR Versatile Altimetric Toolkit for Ocean Research & Exploitation (SARvatore)

- SARvatore is a SAR and SARin altimeter data processing on demand service available on the ESA-RSS processing platform (**G-POD**).
- Users can process, on line and on demand, low-level CryoSat-2 and Sentinel-3 Altimetry data products (FBR, Level-1A) up to Level-2 geophysical products.
- The service provides self-customised options, which are not available in the default processing of CryoSat-2 and Sentinel-3 Ground Segments.
- As one of the options for Level-2 processing, users can choose SAMOSA+, a SAMOSA2 model tailored for inland water, sea ice and coastal zone domain.
- SARvatore for Sentinel-3 provides default profiles with the most suitable processing options for **inland water**.

http://gpod.eo.esa.int/services/SENTINEL3_SAR/

http://gpod.eo.esa.int/services/CRYOSAT_SAR/

http://gpod.eo.esa.int/services/CRYOSAT_SARIN/



Summary

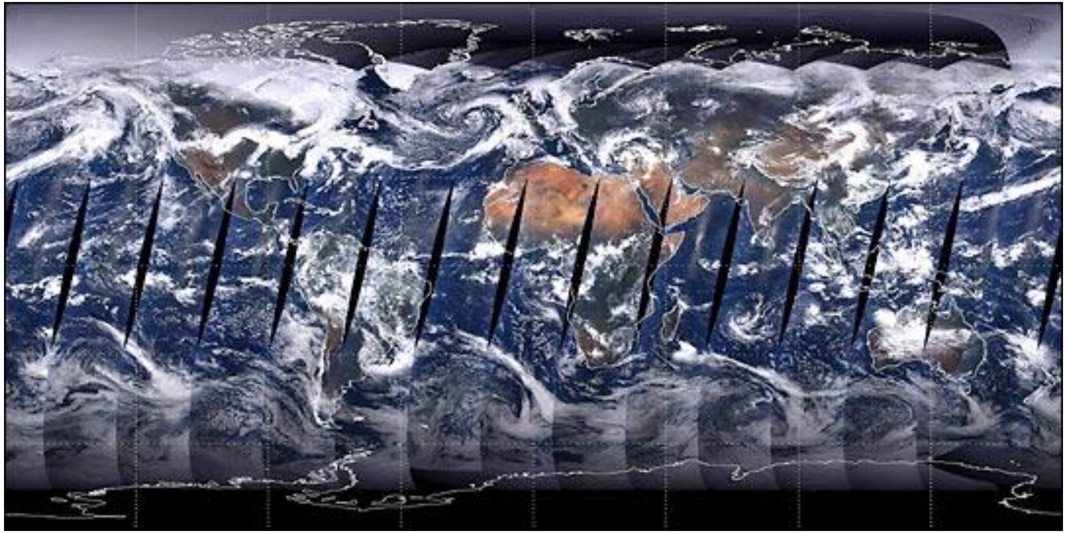
- *Satellite data: Radar altimetry*
  - *Principles*
  - *Missions and technologies*
  - *Applications*
  - *Data access and toolboxes*

- ***Satellite data: Optical and multispectral sensors***
  - ***Missions and technologies***
  - ***Data access***

- *Hydrological Applications*
  - *River Discharge (from altimetry, from multispectral sensors, from multi-mission)*
  - *Lake Volume variation (from multi-mission)*

Optical and multispectral sensors

Multispectral remote sensing is generally based on acquisition of image data of Earth's surface **simultaneously in multiple wavelengths**. As different types of surfaces reflect the light of different wavelengths with various intensity, different spectral behavior is leading to detailed classification of specific types of land surfaces (depending on the spatial, spectral and radiometric resolution of the used sensor).



Optical and multispectral sensors

Nowadays, there are many systems for the acquisition of multispectral image data:

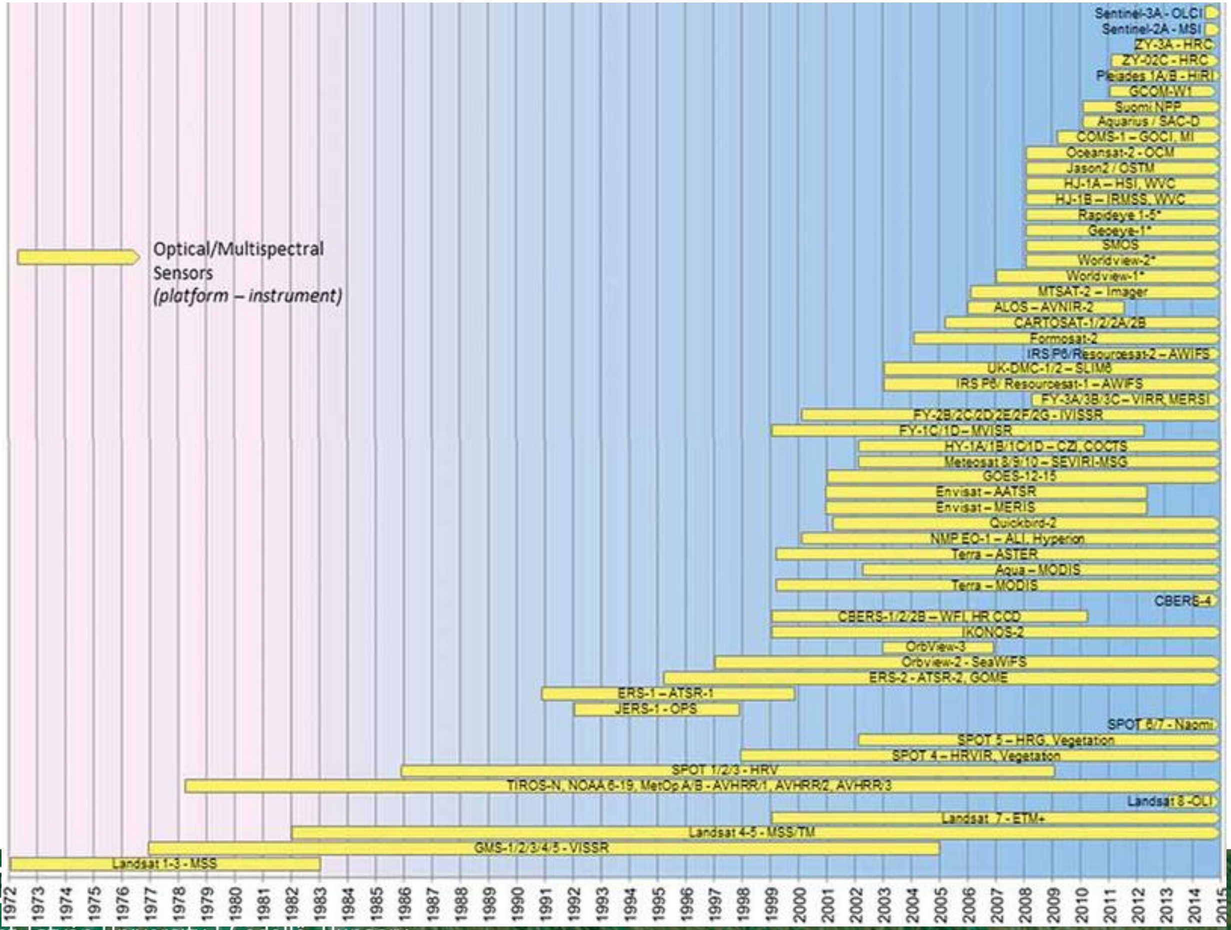
- meteorological satellites with **low spatial resolution** (e.g. Meteosat, NOAA, GOES) used in particular for global analysis at the level of entire countries or continents,
- **medium resolution** data (e.g. Landsat, SPOT, ASTER, MERIS, MODIS, OLCI) used especially for studies at the regional level,

  - visible bands (RGB)
  - near Infra-Red (NIR)
  - shortwave Infra-Red (SWIR)
  - thermal Infra-Red (TIR)

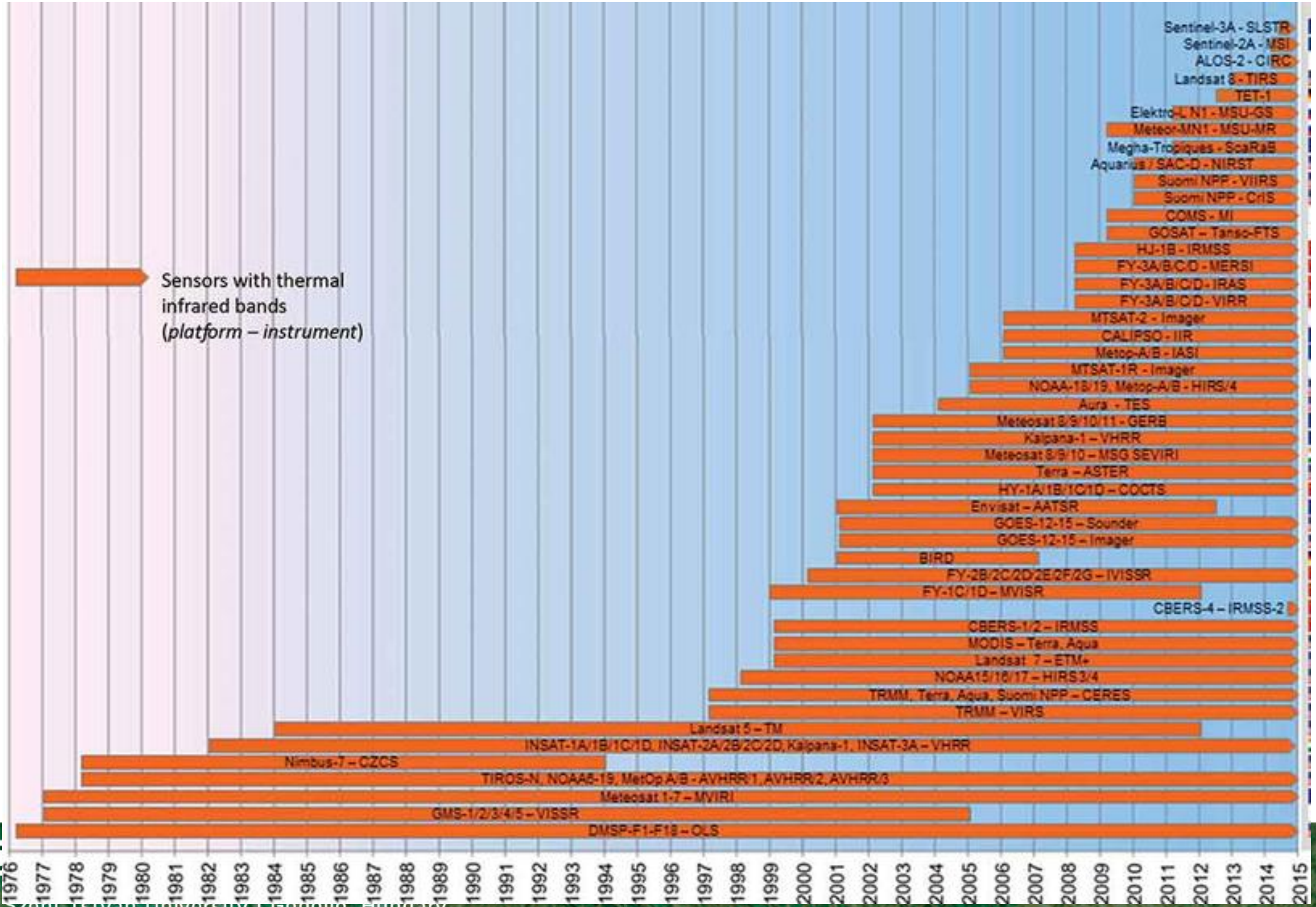
- **very high spatial resolution** data (e.g. Quickbird, Ikonos, WorldView, GeoEye and Rapid Eye), characterized by a spatial resolution of about 0.5 - 1 m, used for detailed local studies.

  - visible bands (RGB)
  - near Infra-Red (NIR) (sometimes)

Optical and multispectral sensors



Optical and multispectral sensors



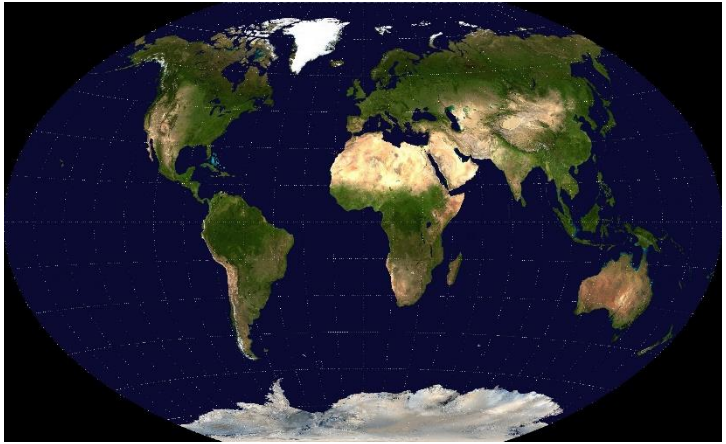
Optical and multispectral sensors

MODERATE RESOLUTION IMAGING SPECTRORADIOMETER- MODIS

Onboard the satellites **TERRA** (lunched in December 1999) and **AQUA** (lunched in May 2002) and ongoing

BANDS	Spatial Resolution	Temporal Resolution
1-2	250 m	1-2 days
3-7	500 m	
8-36	1000 m	

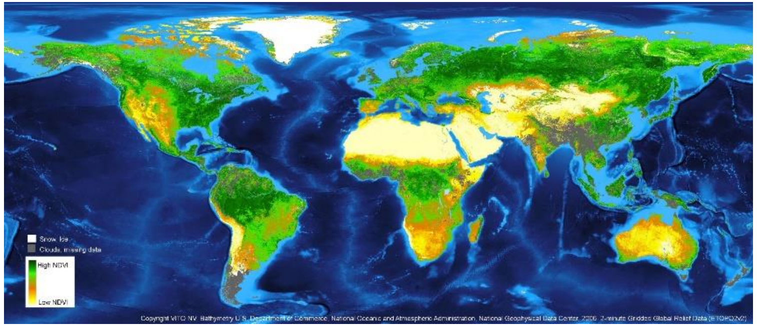
Used for different purposes: *Land Cover, Vegetation, Clouds, Snow, Chlorophyll, sediments, atmosphere, Aerosol, surface temperature, total ozone, forest Fires and volcanoes.*



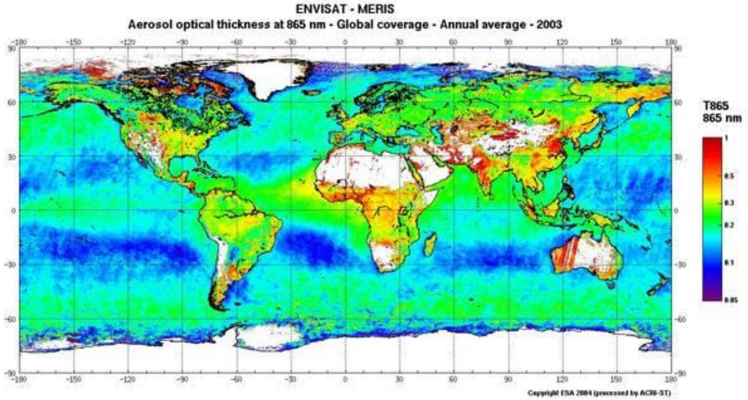
Optical and multispectral sensors

MEDIUM RESOLUTION IMAGING SPECTROMETER - MERIS

Onboard the satellites **ENVISAT** lunched in March 2002 until April 2012.

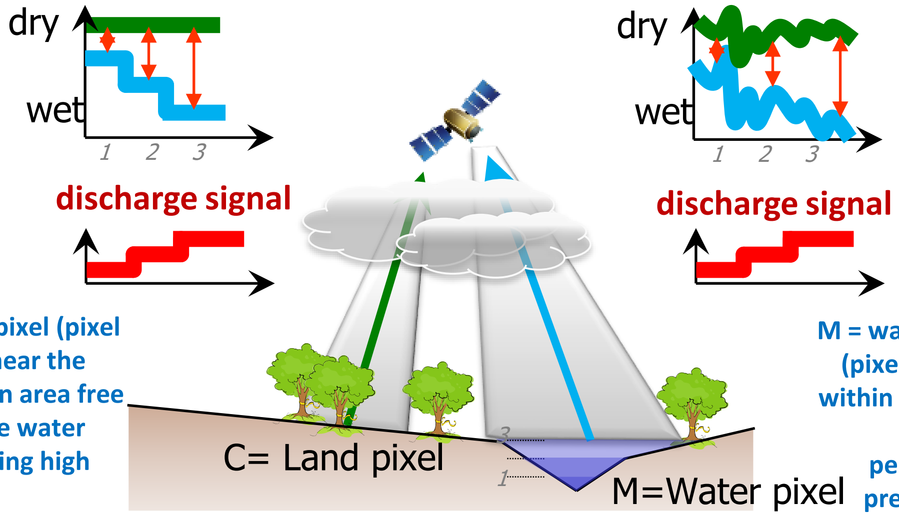


BANDS	Spatial Resolution	Temporal Resolution
15	260x300 m	3 days



Used for different purposes: *Red tides, Land Cover, Vegetation, Clouds, Chlorophyll, suspended sediments, atmospheric correction, water vapor*

Water signal by in NIR

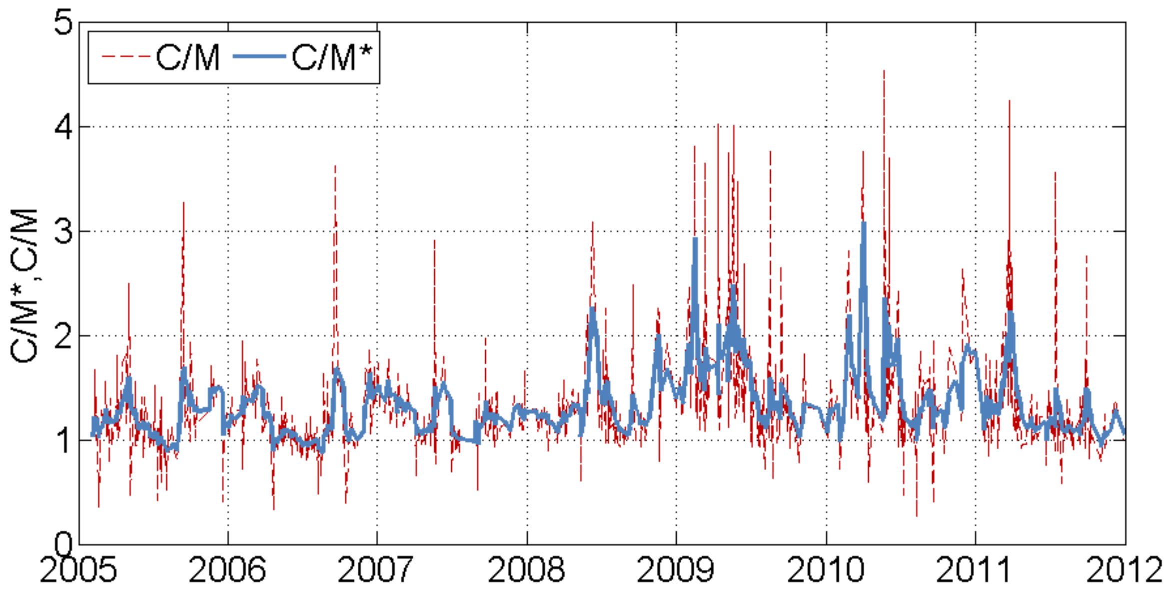


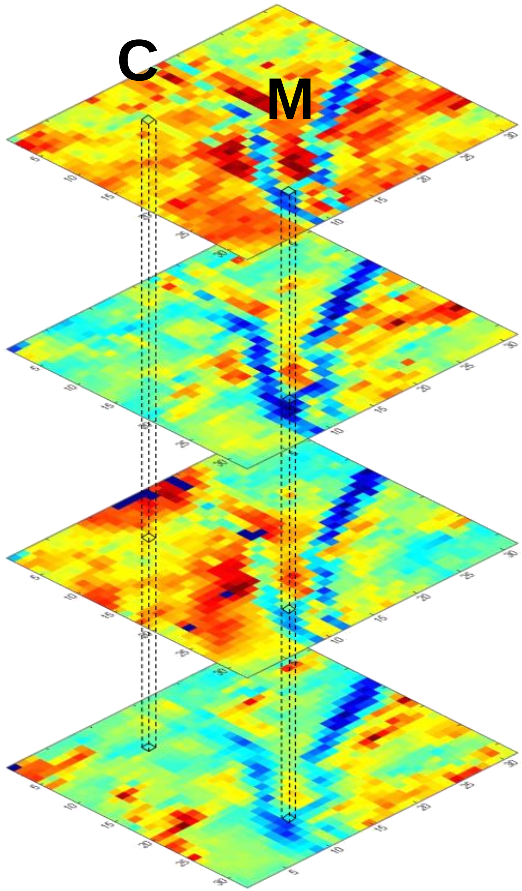
C = land pixel (pixel located near the river in an area free of surface water even during high floods)

M = water pixel (pixel located within the river with permanent presence of water)

Brakenridge, G.R., Nghiem, S.V., Anderson, E., Mic, R. (2007). Orbital microwave measurement of river discharge and ice status. *Water Resour. Res*. 43, W04405.

Water signal by in NIR





Data access

PORTALs:

USGS EarthExplorer (**https://earthexplorer.usgs.gov**)

SENTINEL data hub (**https://scihub.copernicus.eu**)

MODIS land products (**https://lpdaac.usgs.gov**)

GloVis (**https://glovis.usgs.gov**)