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→ 10th COASTAL ALTIMETRY WORKSHOP

SAR Altimetry Training Course

Radar Altimetry - Introduction to missions and applications

M. Restano[1] & J. Benveniste[2]

[1]SERCO c/o ESA/ESRIN [2]ESA/ESRIN

21–24 February 2017 | Florence, Italy

Summary

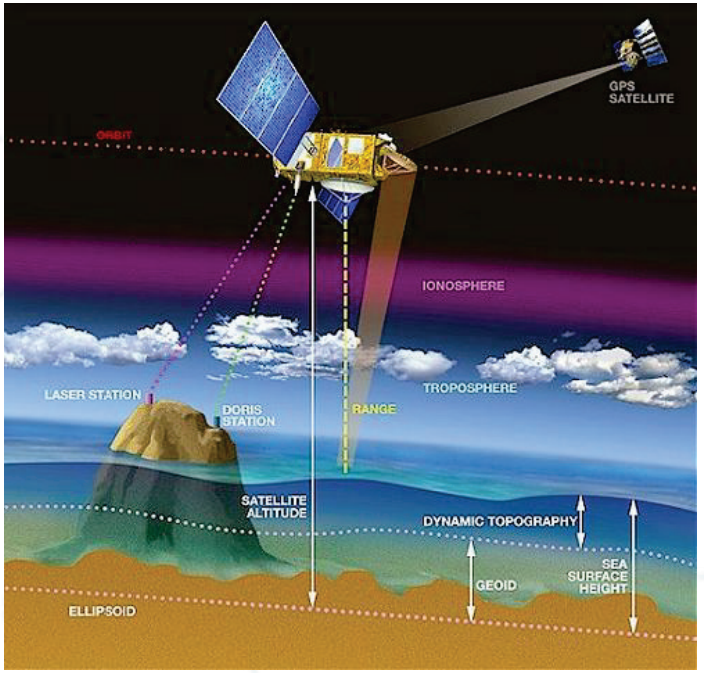
- *Radar Altimetry fundamentals*
- *Missions & Technologies*
- *Applications*

Summary

- *Radar Altimetry fundamentals*

Radar principles

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

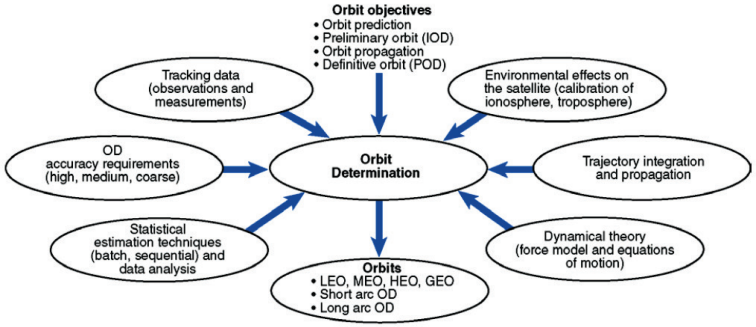


Sea Surface Height (SSH): Satellite_Altitude – Corrected_Range

Sea Level Anomaly: SSH – Mean SSH (=geoid)

Table 2
Nature and source of geophysical corrections

Correction	Source	Typical winter magnitude at 80°N, averaged over 1 month and 10^4 km^2.	Reference
Ocean tide	FES 02	0.03 m	Le Provost et al. (1998)
Ocean loading tide	FES 02	0.002 m	Francis and Mazzega (1990)
Long-period tide	FES 02	0.0075 m	Le Provost et al. (1998)
Solid Earth	Cartwright Edden	0.015 m	Cartwright and Edden (1973)
Polar tide	Wahr	0.0025 m	Wahr, 1985
Dry troposphere	Meteo France/ECMWF	2.3 m ±0.02 m	Saastamoinen, 1972
Inverse barometric correction	Meteo France/ECMWF	0.03 m	Ponte (1991)
Wet troposphere	Meteo France/ECMWF	0.01 m	Saastamoinen (1972)
Ionosphere	Bent model	0.015 m	Llewwllyn and Bent (1973)



Credits: (right, top) AVISO, (left) Wingham et. al. (2006), (right, bottom) Vetter (2007)

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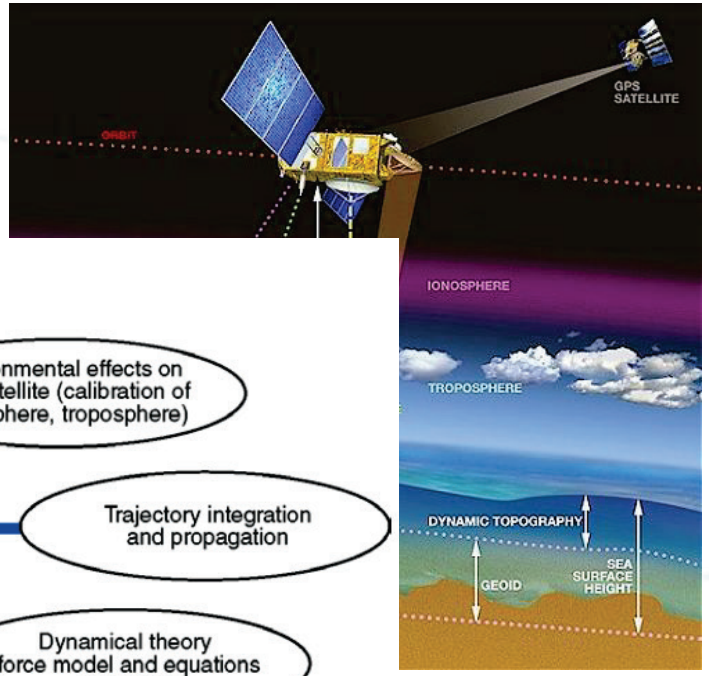

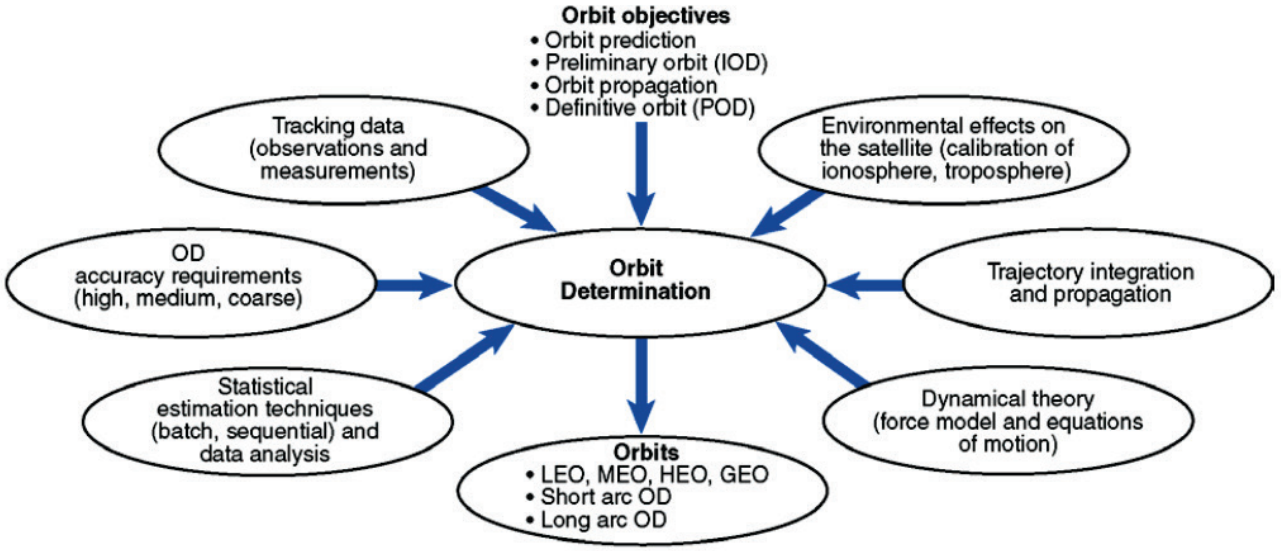

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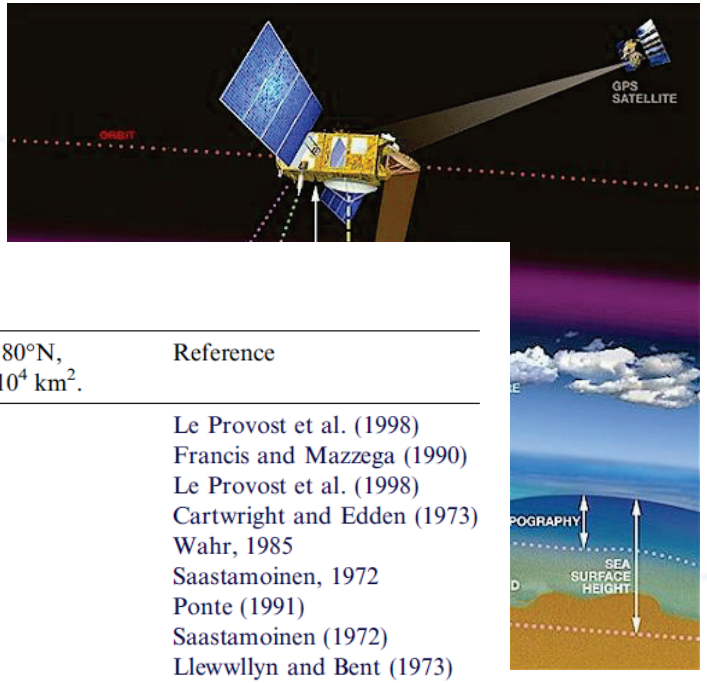

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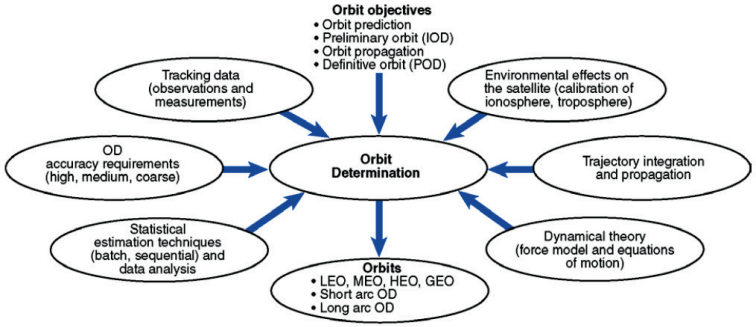

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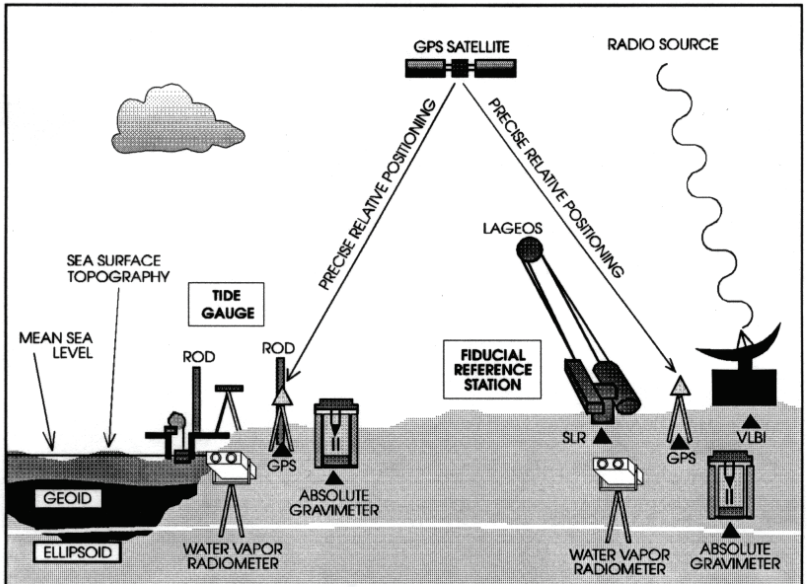
Other useful products: Tide Gauge Data

- Gauges locally measure relative sea level, absolute level if they are referenced to an ellipsoid (e.g. WGS84) with a GPS.
- Tide gauge measurements (e.g. every 10 min) are made with respect to a local fixed reference level on land.
- Local vertical land motion can be corrected by using GPS data or glacial isostatic adjustment (GIA) models.
- When referencee datums are different, a de-meaning (subtracting the mean from each set of observations so that they are zero--mean) shall be applied when comparing TG and Altimeter dataset.



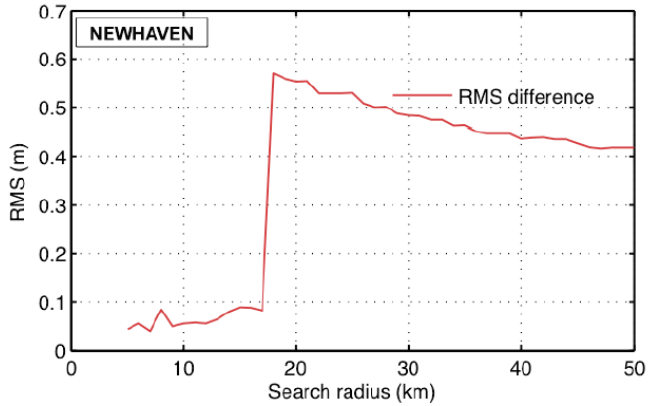


Figure 19: RMS difference between de-meaned time series of TWLE from altimetry and from the tide gauge at Newhaven, as a function of the search radius around the tide gauge. No outlier was removed. Note the sharp increase when search radius goes from 17 km to 18 km.

Credit: ESA CP4O/CCN1 project.

Summary

- *Missions & Technologies*

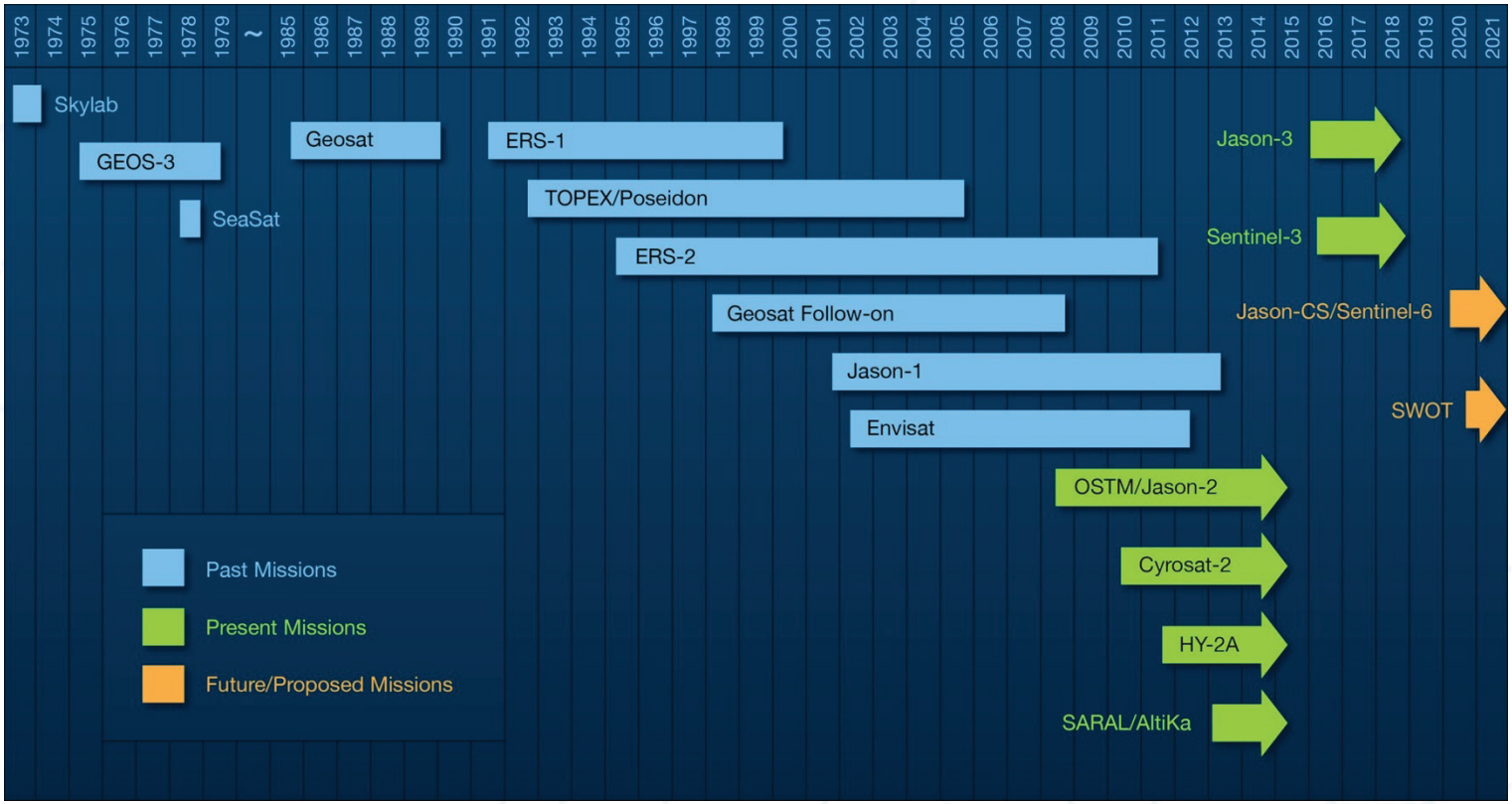
DAY 1 **Tuesday 21 February 2017**

8:30–8:35	**Welcome to the SAR ALTIMETRY TRAINING COURSE**	J. Benveniste
8:35–8:55	Radar Altimetry - Introduction to missions and applications	M. Restano; J. Benveniste
8:55–9:35	Overview on LRM, SAR, SARin & RDSAR Altimetry	M. Roca
9:35–10:55	SAR and SARin L1A to L2 processing; Strategies for different applications; options in SARvatore	S. Dinardo
10:55–11:25	**Coffee Break**	
11:25–11:45	Delay Doppler Altimeter Instrument Calibration	M. Scagliola
11:45–12:10	Overview on corrections to be applied & on validation against TG and other datasets	P. Cipollini; M. Passaro
12:10–12:35	ESA projects on Radar Altimetry	M. Restano; J. Benveniste
12:35–13:00	Fully focused SAR processing / Swath Processing	W. Smith
13:00–14:00	**Lunch**	

DAY 3 **Friday 24 February 2017** **SAR ALTIMETRY TRAINING COURSE**

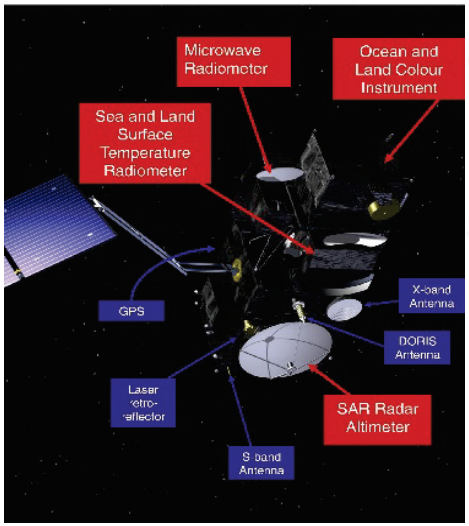
13:30–14:30	SARvatore Demo and Hands-On	S. Dinardo and M. Restano
14:30–15:30	DeDop Demo and Hands-On	M. Roca
15:30–16:00	**Coffee Break**	
16:00–16:45	BRAT Demo	R. Capote
16:45–17:15	GUT Demo	A. Ambrózio
17:15–17:45	Future Missions: Sentinel-6, SWOT, CryoSat Follow On	M. Roca and J. Benveniste
17:45–18:45	**Wine & Cheese**	

Altimetry Missions (1973-2017)



- Low Resoluton Mode (LRM) missions up to Jason-3.
- Other missions include SAR mode. CryoSat-2 includes SARin mode (two antennas for interferometry).
- The interleaved mode designed for Sentinel-6/Jason-CS allows to obtain simultaneously SAR and LRM waveforms.

Typical Altimeter Technologies



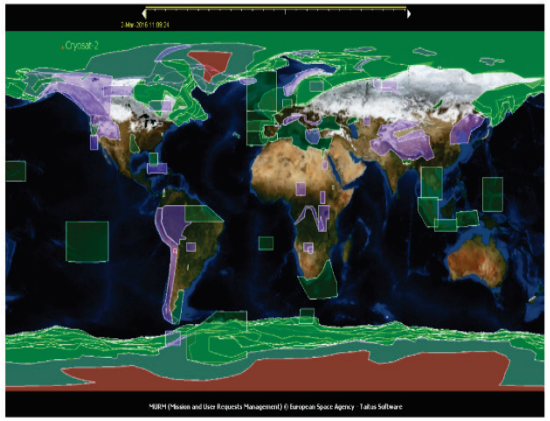
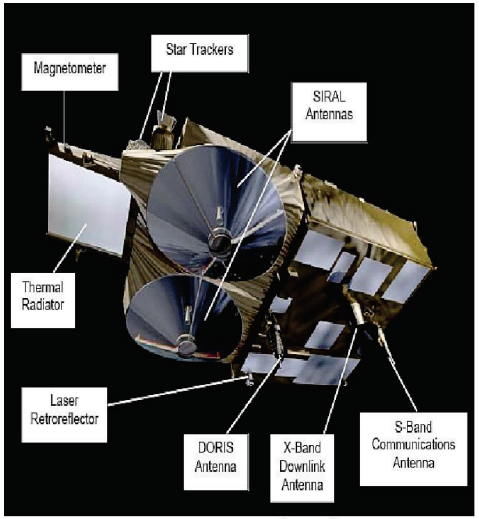
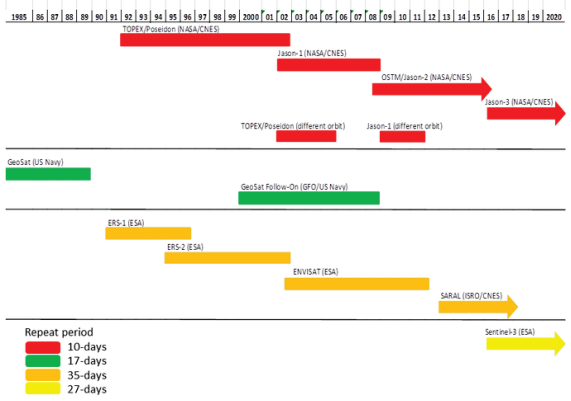


Figure 3.1-1 The current CryoSat-2 mode mask (version 3.8). Green is SAR mode, purple is SARin mode, and other areas are in LRM mode.



- **Envisat**: Low Resolution Mode (8 Km along track resolution by averaging 20 measurements acquired every 400m), Ku Band **(13.6 GHz),** vertical resolution of 0,5, 2 or 8 meters (adaptable to the scenario). 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 mt (320 MHz bandwidth). 732 kilometres orbit (high latitude coverage: 88°).
- **SARAL/AltiKa**: Single Antenna, SAR Processor, **Ka band (35,75 GHz),** 0,3 mt vertical resolution (500MHz chirp bandwidth). Better sea roughness determination than Ku band (higher frequency). polar orbit at 800 km altitude (same as Envisat).

Inter-track distance at the equator: 8 km (Cryosat-2), 80 km (ENVISAT), 104 km (Sentinel-3), 315 km (Jason 1-3).



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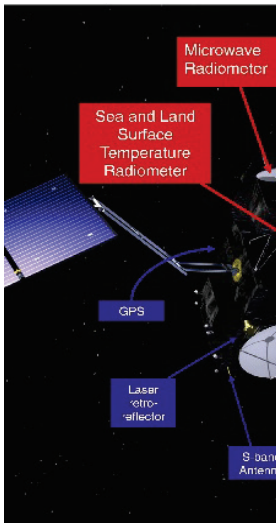

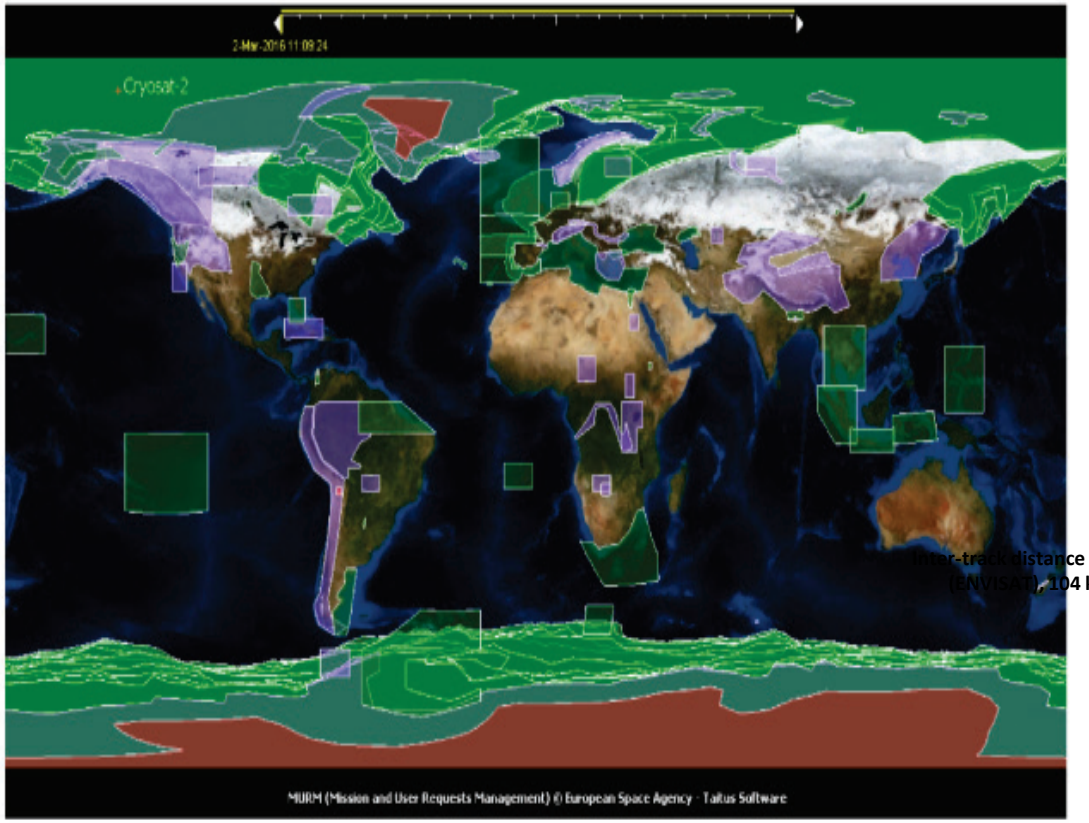

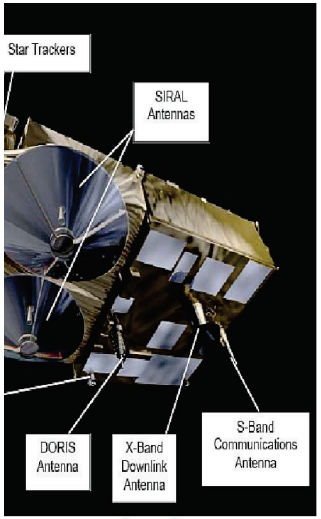

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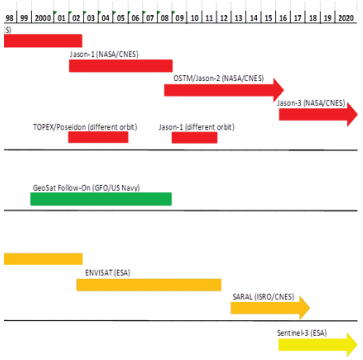

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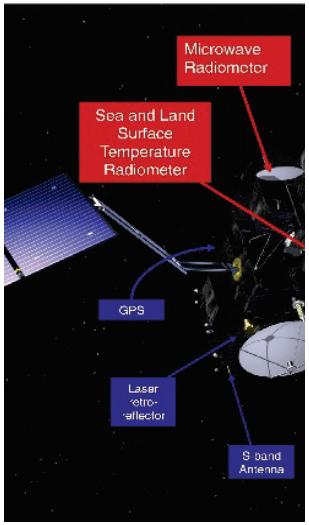

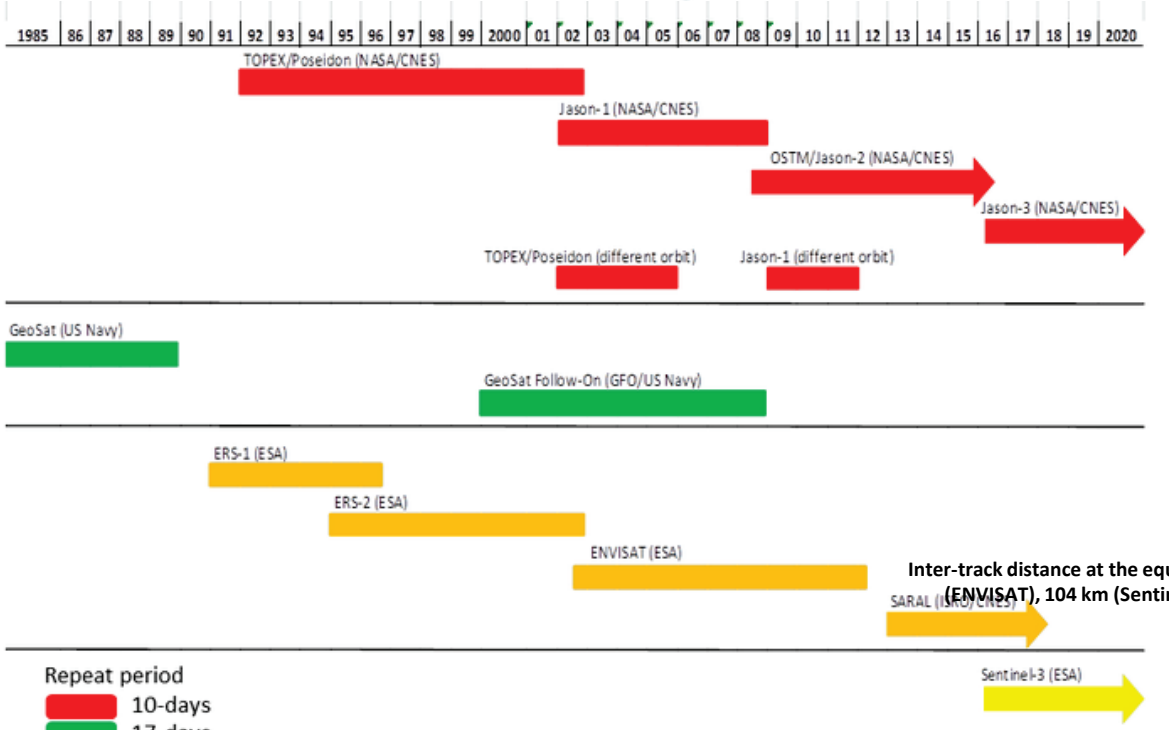

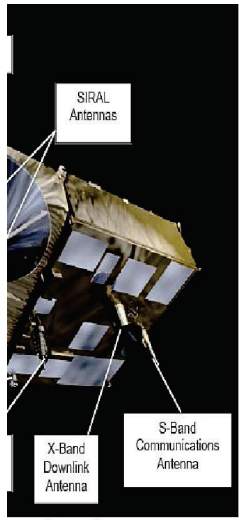

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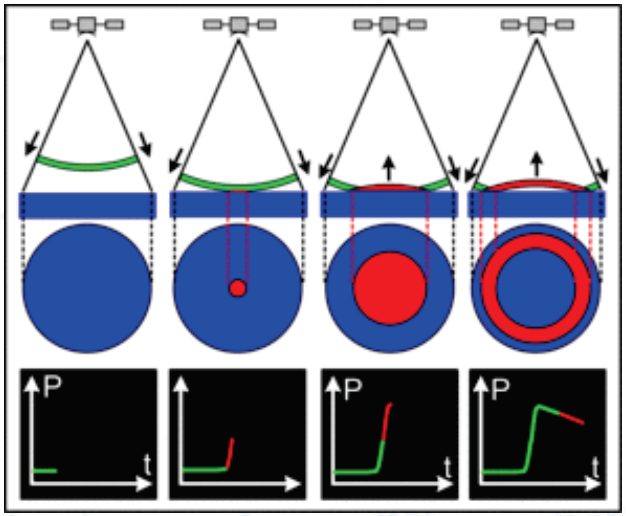
Processing schemes: Low Resolution Mode

- Pulse limited acquisition. The time on target dictated by the beam illumination is not exploited.



- **Observed parameters:**

  Significant Wave Height (SWH)
  Wind Speed
  Range (altimeter to mid-height of sea level)

- **Typical specs:**

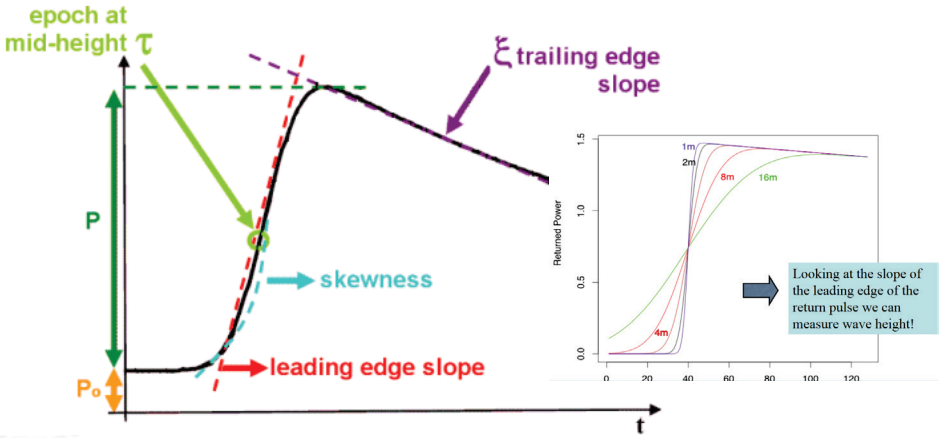
Along/Across track resolution: several km depending on SWH.

- **Pros:**

  Easy to implement.
  Typically adopted on the open ocean.
  Can be obtained from SAR or SARin waveforms (RDSAR)

- **Cons**

  Poor usage of the scattering information.
  Poor resolution in both directions.



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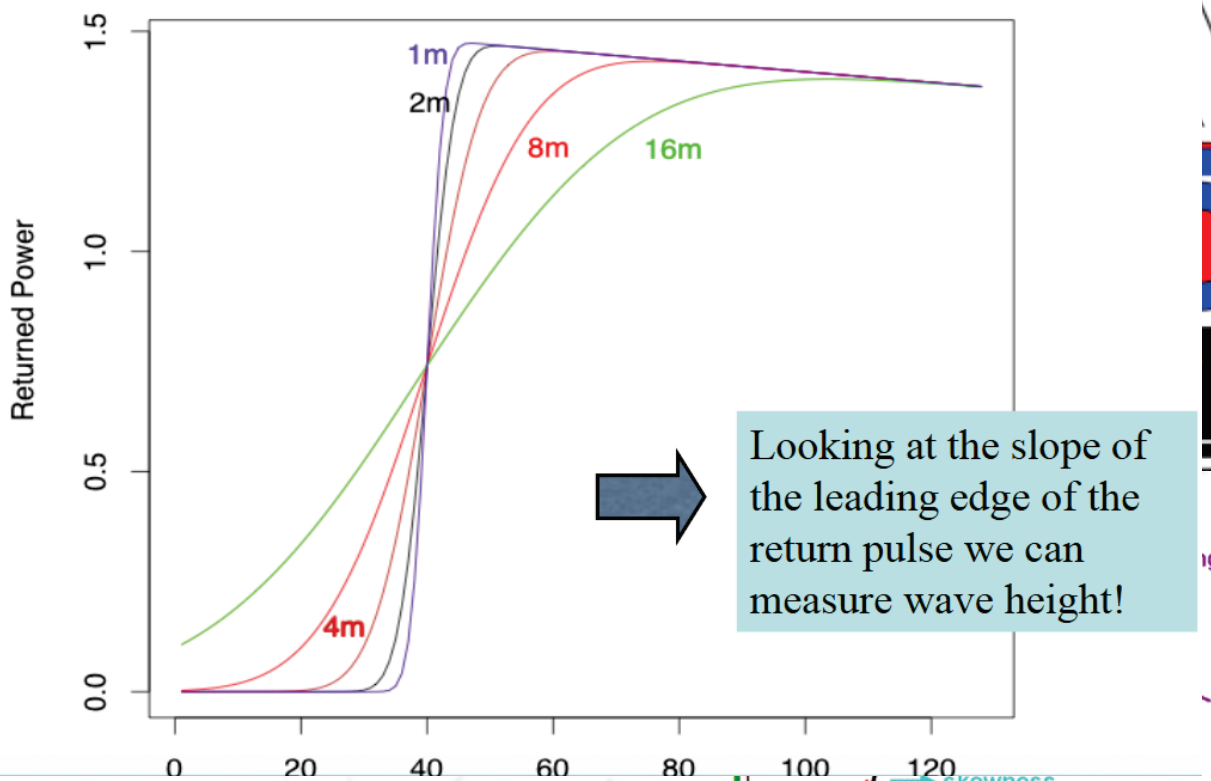

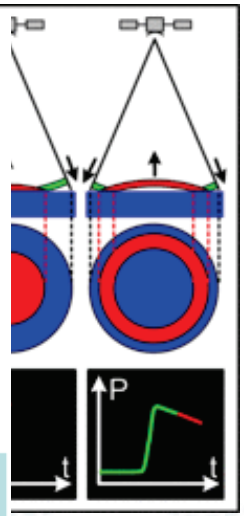

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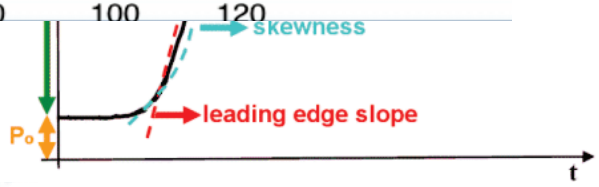
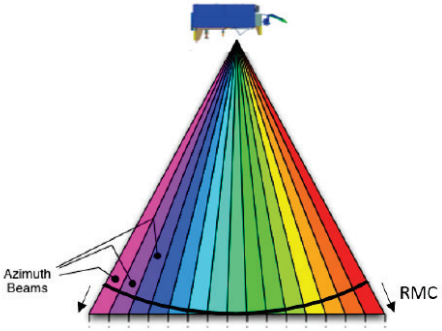


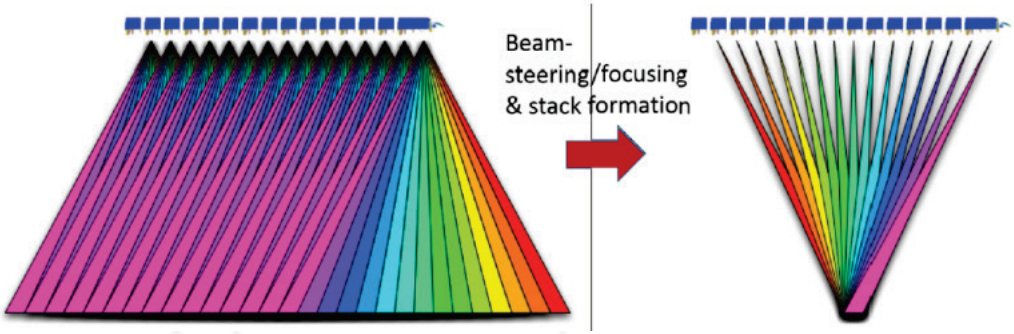
Processing schemes: Unfocused Delay-Doppler

- The time on target dictated by the beam illumination is exploited. Burst of pulses are transmitted (Sentinel-3, 66 pulses: 1 C-band pulse / 64 Ku-band pulses / 1 C-band pulse).



- **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.

Transmission Schemes

- **Possibility to obtain both LRM and SAR waveforms if the interleaved transmission mode is adopted.**

- The statistical equivalence to native LRM waveforms is not given by RDSAR waveforms.

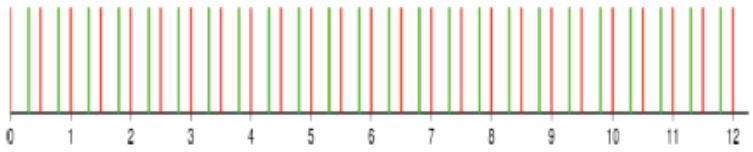
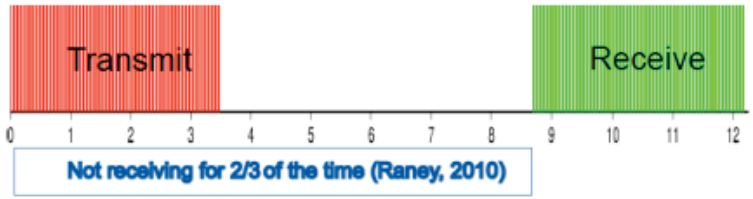
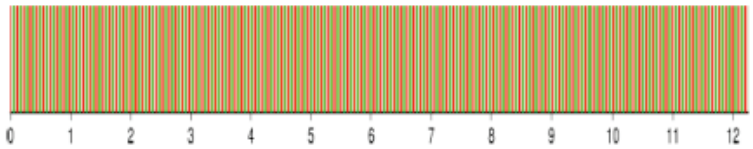
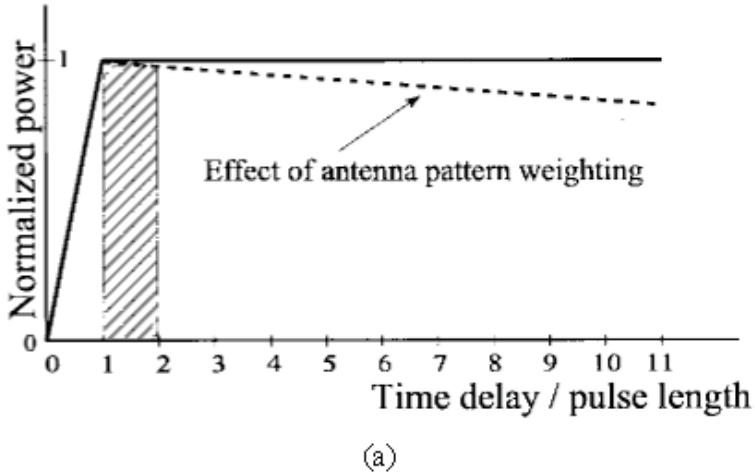
OPERATION MODE	CHRONOGRAM	ALTIMETRIC MISSIONS
Low Resolution Mode (LRM) Low PRF (1-4kHz) Continuous Tx/Rx		All past ocean altimeter missions Cryosat-2 LRM AltiKa Jason-3
SAR Closed-Bursts High PRF (~20 kHz) Tx/Rx in bursts		Cryosat-2 SAR Sentinel-3
SAR "Interleaved" Moderate PRF (~ 9 kHz) Continuous Tx/Rx		Jason-CS

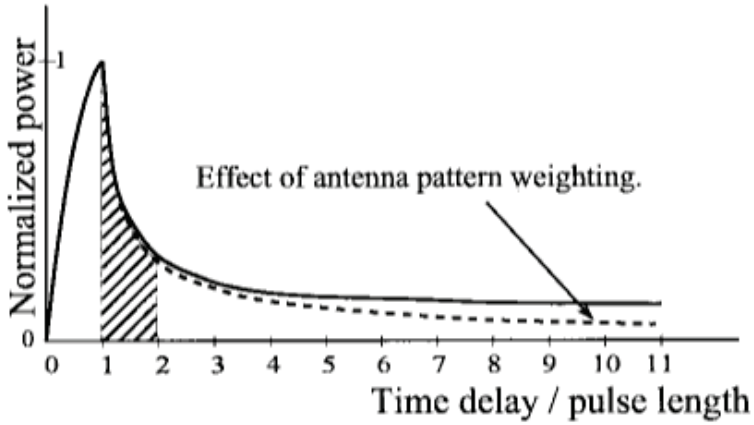
FIGURE 2: CHRONOGRAMS FOR LRM (TOP), SAR CLOSED BURST MODE (MIDDLE) AND SAR INTERLEAVED MODE (BOTTOM) (SOURCE: ADAPTED FROM SMITH ET AL., 2013)

Credit: Gommenginger et al. (2013)

Processing schemes: Unfocused Delay-Doppler (2)

- The SAR waveform is substantially different requiring different waveform models for retracking.
- **Retracking**:
- Processing required for improving the range precision of existing measurements guaranteeing a very accurate Sea Surface Height (SSH).
- It involves the fitting of the returned echo to a waveform model corresponding to the observed target.
- **Input: L1b data:** LRM or SAR processed obtained from calibrated FBR (L1A) data.
- **Output: L2 data**





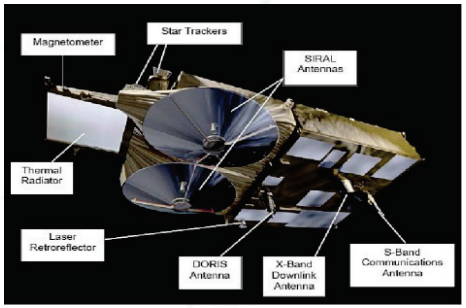
Credit: Raney (1998)

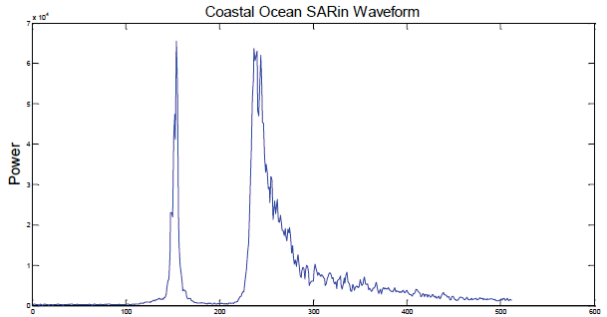
Processing schemes: Synthetic Aperture Radar (SARin) mode

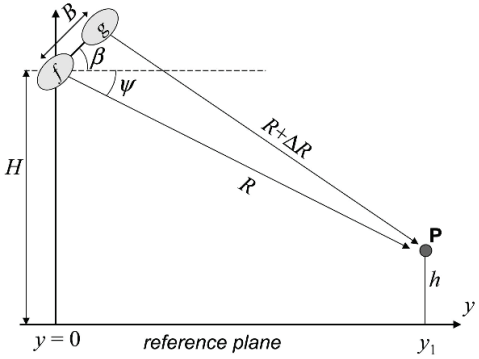
- SIRAL on CryoSat-2 is the only radar altimeter implementing the SARin processing by collecting data with two antennas.
- **Typical specs:**
- Along track resolution: same as SAR.
- Across track resolution: same as LRM but the Angle of Arrival (AoA) can be determined.

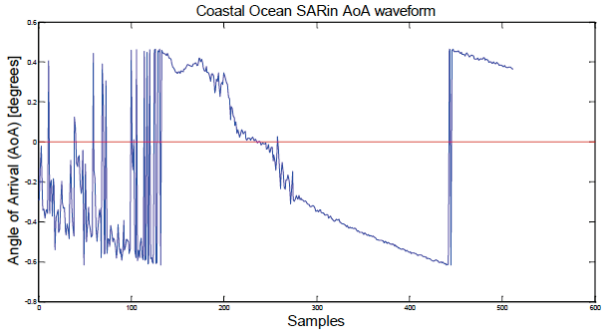
Pros

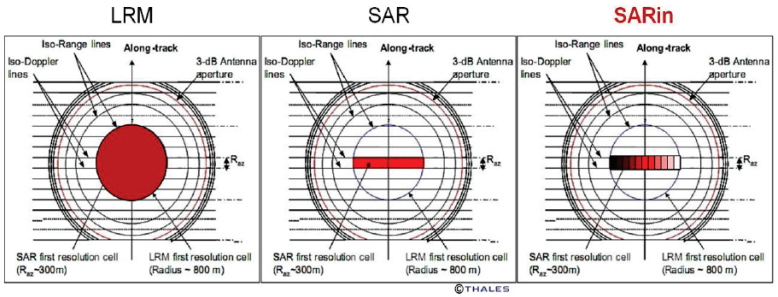
- Operated over the marginal regions of the Earth's ice sheets and regions of mountain glaciers allowing the elevation retrieval.
- Useful for coastal regions as well as on inland water to identify clutter return to be excluded from the analysis.











Credit: ESA CP4O/CCN1 project

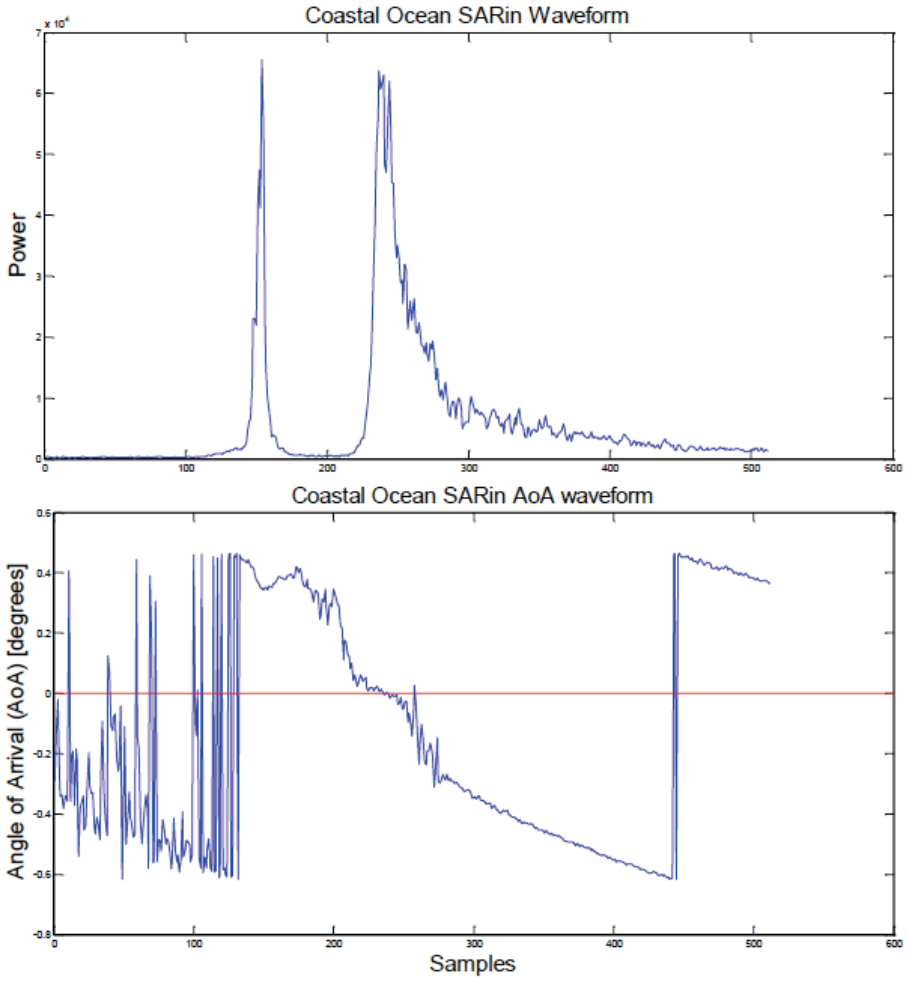
Figure 2-1. The three CS2 possible modes: LRM, SAR & SARin (courtesy of Thales Alenia Space).

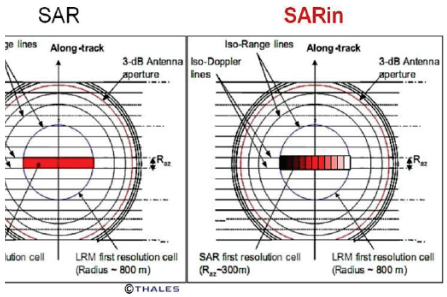
Processing schemes: Synthetic Aperture Radar (SARin) mode

- SIRAL on CryoSat-2 is implementing the collecting data with t
- **Typical specs:**
- Along track resolutior
- Across track resolutic Angle of Arrival (AoA)

Pros

- Operated over the Earth's ice sheets ar glaciers allowing the
- Useful for coastal reg water to identify clut from the analysis.





Credit: ESA CP4O/CCN1 project

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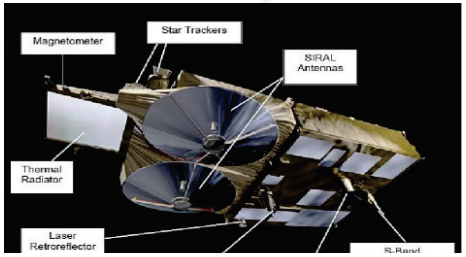
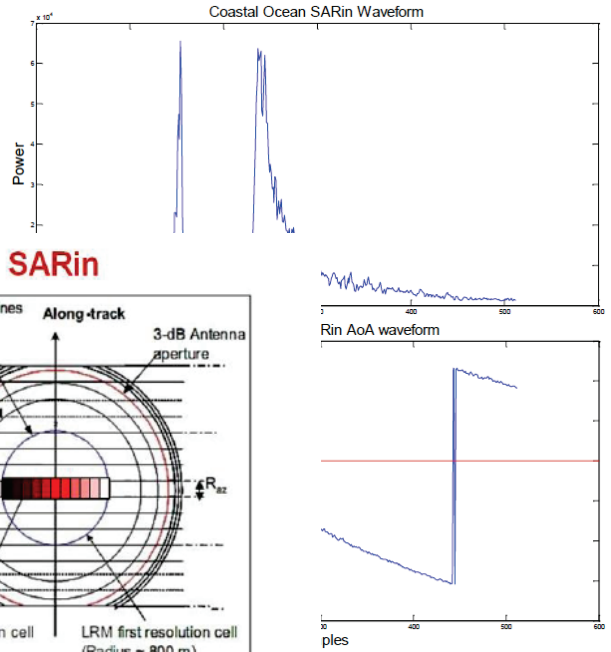




- **Typical spec**

- Along track r

- Across track
  Angle of Arri

Pros

- Operated o
  Earth's ice s
  glaciers allo

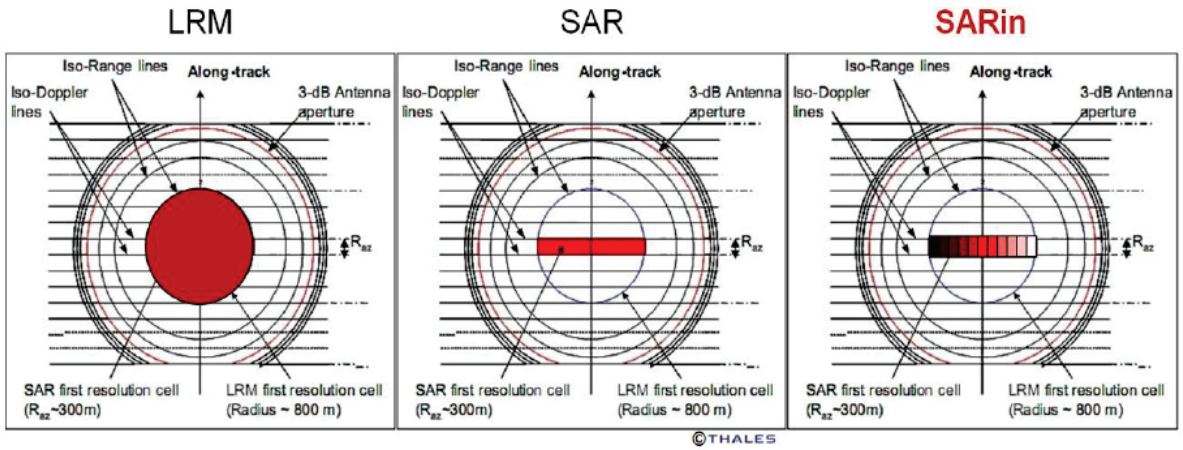


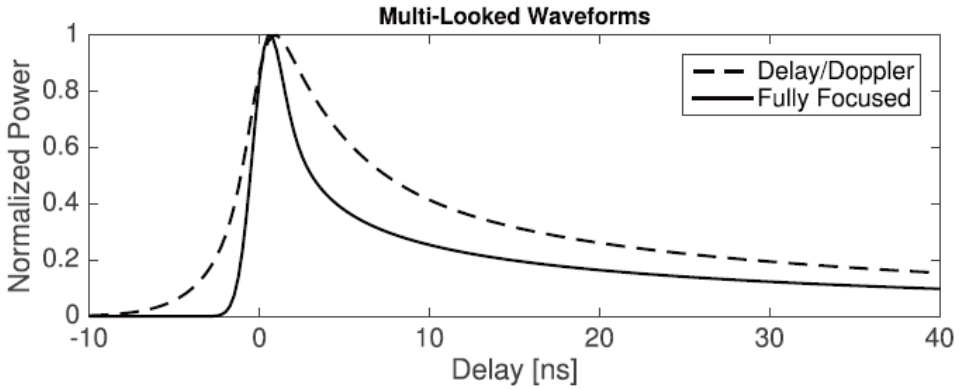
Figure 2-1. The three CS2 possible modes: LRM, SAR & SARin (courtesy of Thales Alenia Space).

- Useful for coastal regions as well as on inland water to identify clutter return to be excluded from the analysis.

Credit: ESA CP4O/CCN1 project

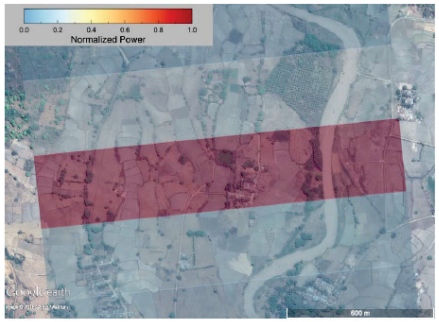
Processing schemes: Fully Focused SAR altimetry

- FF SAR processing reduces the along-track resolution down to the theoretical limit equal to half the antenna length.
- The footprint of an FF-SAR altimeter measurement is a narrow strip on the surface, which is pulse limited across track and SAR focused along track.
- It was demonstrated by obtaining an along-track resolution of 0.5 m (in contrast to the approximately 300-m resolution of the unfocused delay/Doppler processing).



Credits: Egido and Smith (2016)

(a)



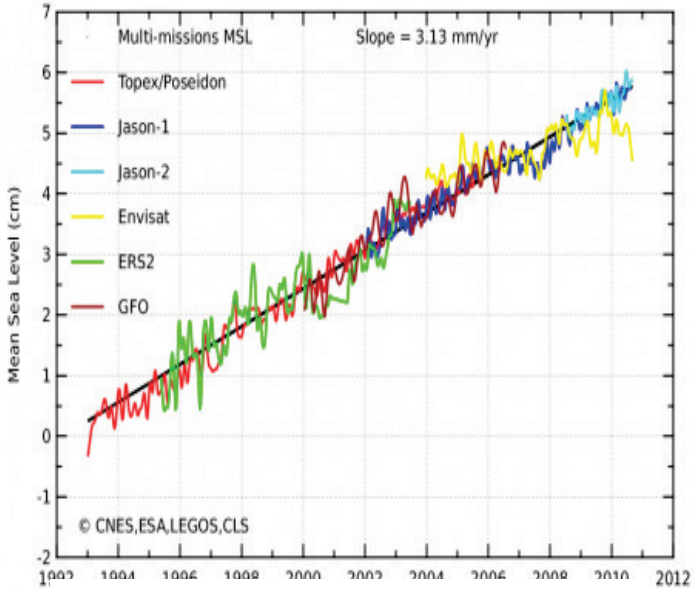
Summary

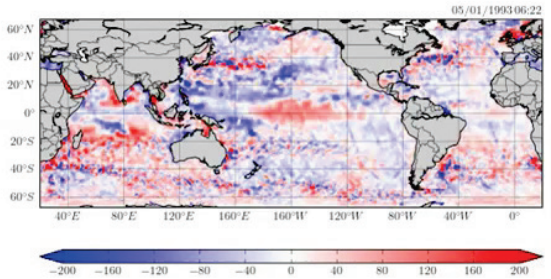
- *Applications*

DAY 3	Friday 24 February 2017	SAR ALTIMETRY TRAINING COURSE
9:00–9:40	SAR Altimetry Processing for Open Ocean, Sea Level Monitoring,/SLCCI Multi Mission datasets	L. Fenoglio-Marc
9:40–10:20	SAR Altimetry Processing for Coastal Oceanography	L. Fenoglio-Marc
10:20–10:50	SAR Altimetry Processing for Sea Level in Polar regions (e.g. CS-2 data as input to Tide Models)	O. Andersen
10:50–11:20	**Coffee Break**	
11:20–11:50	SAR Altimetry Processing for Inland Water: Lakes	N. Bercher
11:50–12:30	SAR Altimetry Processing for Inland Water: Rivers	N. Bercher
12:30–13:30	**Lunch**	
13:30–14:30	SARvatore Demo and Hands-On	S. Dinardo and M. Restano
14:30–15:30	DeDop Demo and Hands-On	M. Roca
15:30–16:00	**Coffee Break**	
16:00–16:45	BRAT Demo	R. Capote
16:45–17:15	GUT Demo	A. Ambrózio
17:15–17:45	Future Missions: Sentinel-6, SWOT, CryoSat Follow On	M. Roca and J. Benveniste
17:45–18:45	**Wine & Cheese**	

Sea Level Monitoring

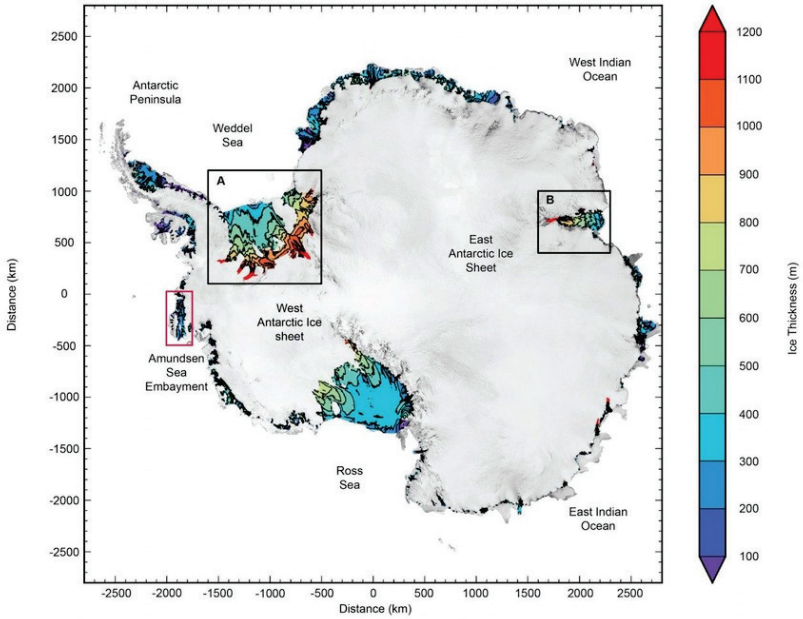
- **The global mean level of the oceans is an indicator of climate change** (ocean temperature warming, mountain glaciers/ melting).
- Mean Sea Level is an average over all the oceans of sea surface height, with respect to a reference.
- Recently, the **Sea Level CCI team** has released a full reprocessing of the Sea Level **products (v2.0 ECV)**.
- The monthly maps of **sea level anomalies (actual sea level-mean sea surface, [mm] in the video)** are now available over the **1993-2015** period.



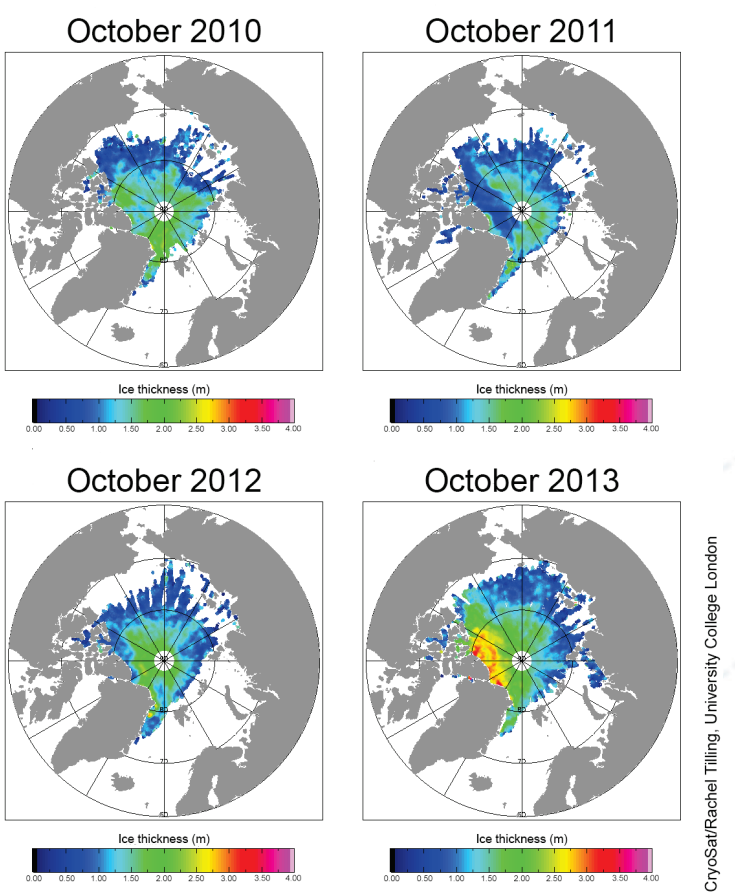


Glaciers Monitoring

- 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).

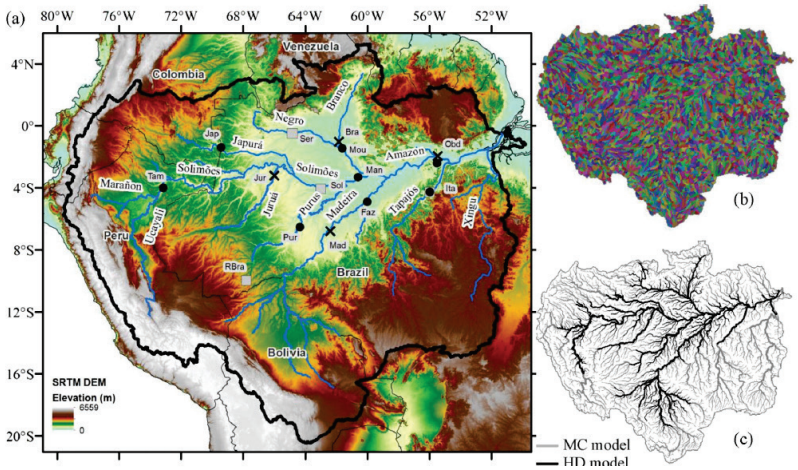


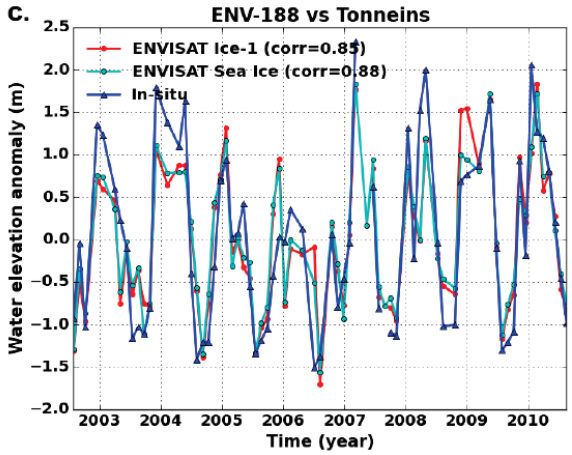
CryoSat/Rachel Tilling, University College London

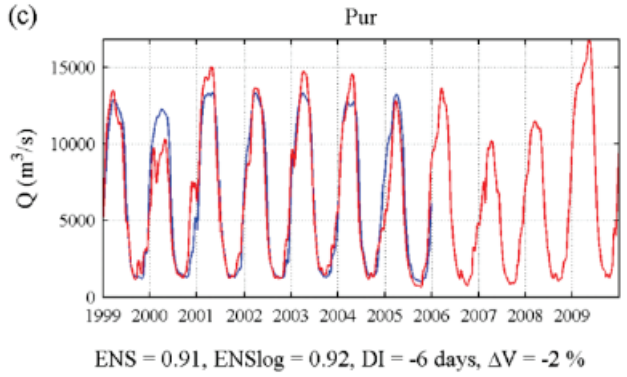
River Level Monitoring &Hydrological modeling

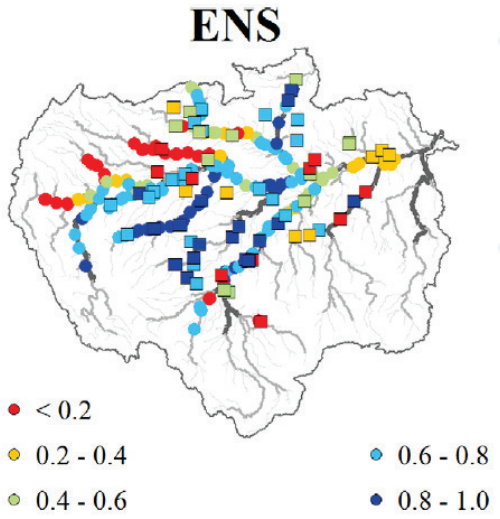
- Hydrological models are used to understand and quantify processes such as evapotranspiration, soil and groundwater storages, and river-floodplain hydrodynamics.

- The Nash–Sutcliffe **(NS)** coefficient can be adopted for validation. The closer to 1 the NS coefficient is, the closest to the in situ time series match the water level predictions. NS above 0.5 can be considered skillful.









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

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- "Fully Focused SAR Altimetry: Theory And Applications" by Egido And Smith (2016) Doi: 10.1109/Tgrs.2016.2607122
- ESA CP4O/Ccn1 Project, Wp1000 Deliverable (Http://Www.Satoc.Eu/Projects/Cp4o/Cp4o_ccn.Html)
- "Jason-CS SAR Mode Error Budget Study Review Of State Of Knowledge For Sar Altimetry Over Ocean" By Gommenginger Et Al. (2013)
- "Cryosat: A Mission To Determine The Fluctuations In Earth's Land And Marine Ice Fields" By Wingham Et Al. (2006) Doi:10.1016/J.Asr.2005.07.027.
- "Satellite Radar Altimetry Water Elevations Performance Over A 200 M Wide River: Evaluation Over The Garonne River" By Biancamaria Et Al. (2016), Http://Dx.Doi.Org/10.1016/J.Asr.2016.10.008
- ESA CCI sea level website: www.esa-sealevel-cci.org/

For any question, contact us at: altimetry.info@esa.int