Technical aspects of coastal altimetry data processing

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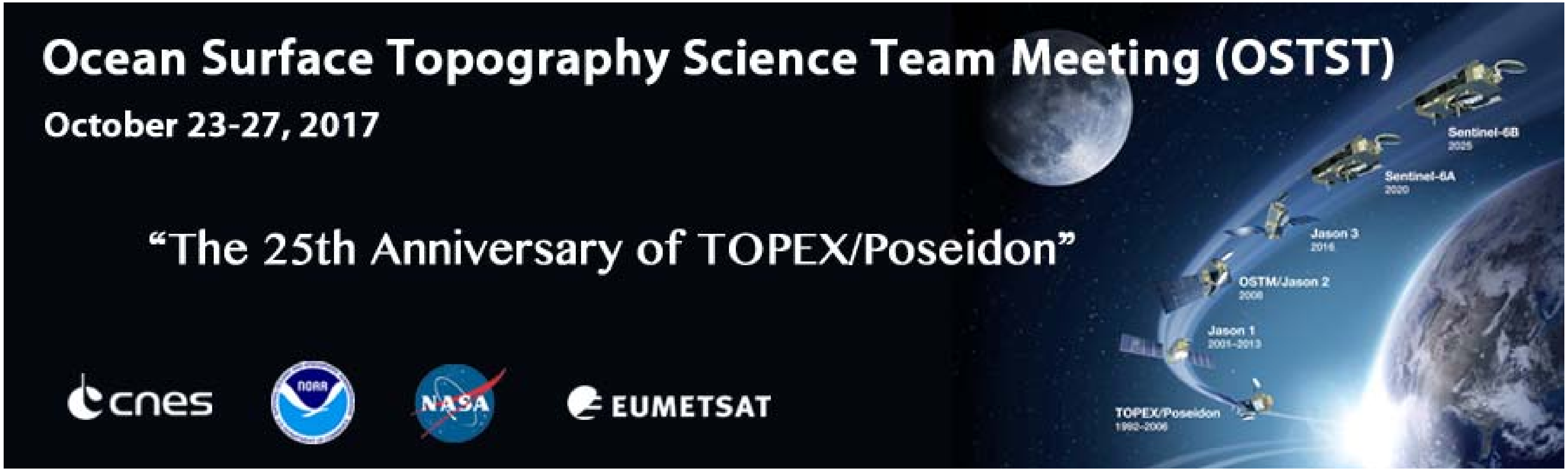


New capabilities

New technology – Making better measurements

- SAR mode altimetry (CryoSat-2, Sentinel-3)
- Open loop altimetry with onboard DEM (OLTC)

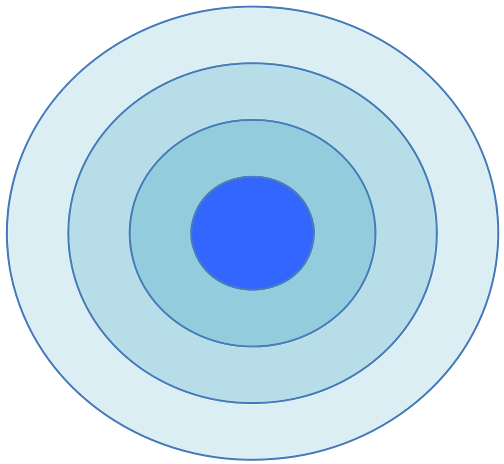
New Level 1 processing – Obtain better waveforms

- Zero padding

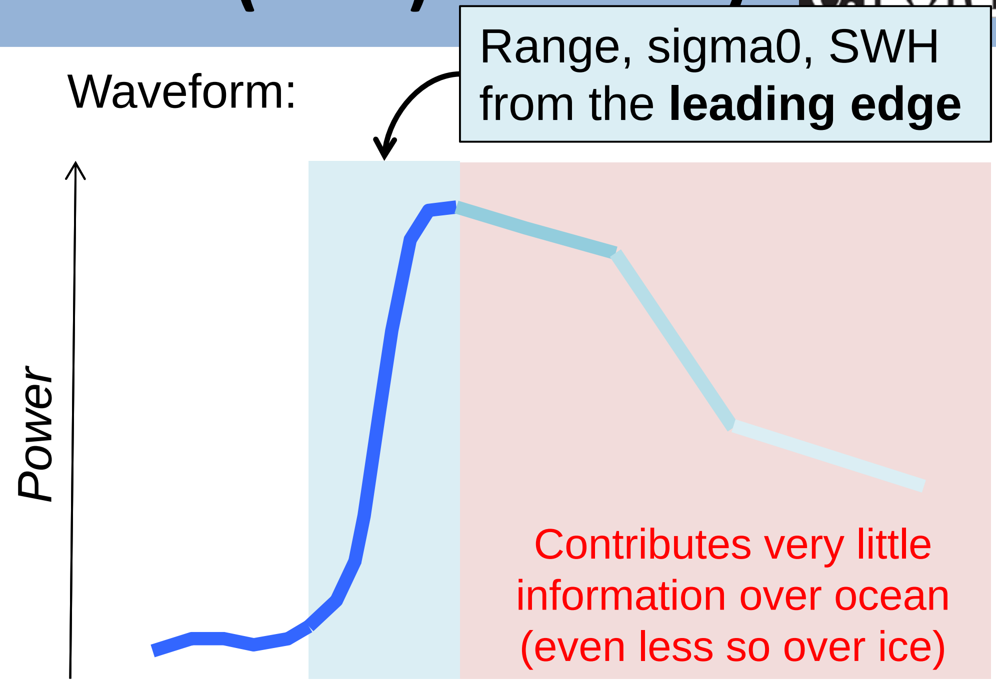
(red)	Strong coastal effects
(orange)	Moderate effects or effects only in some coastal conditions
(green)	No coastal effects

Principle of conventional (LRM) altimetry

Illuminated surface:



Waveform:

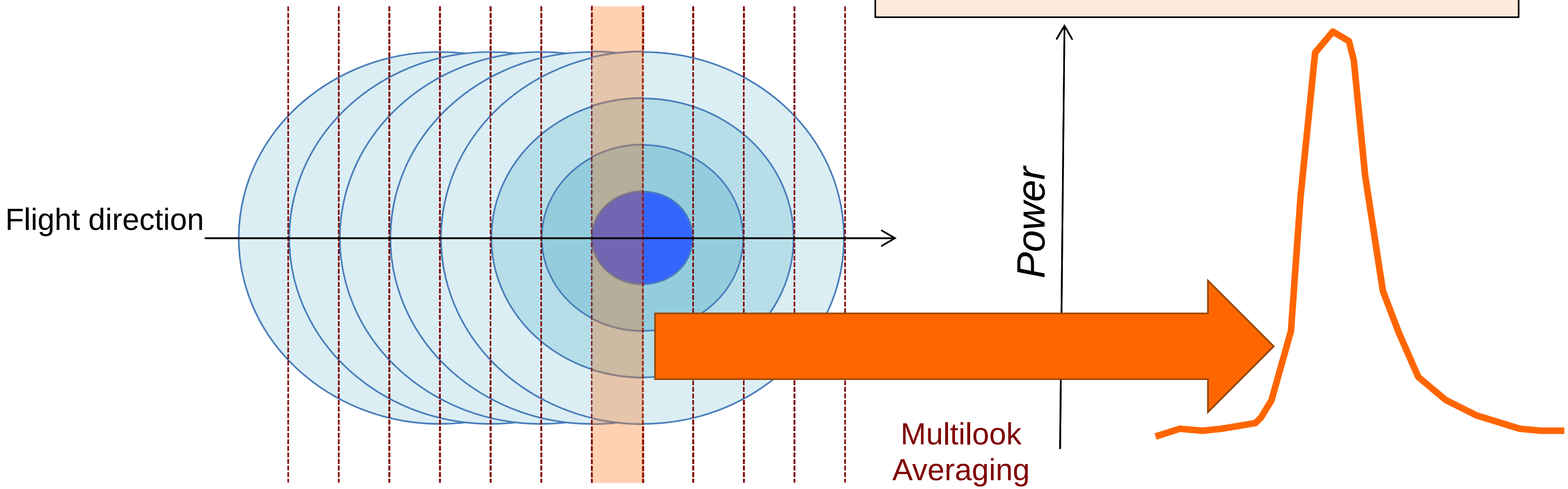


– Relatively large footprint, prone to contaminations in trailing edge

– Ocean and sea-ice retracking focuses on leading edge only

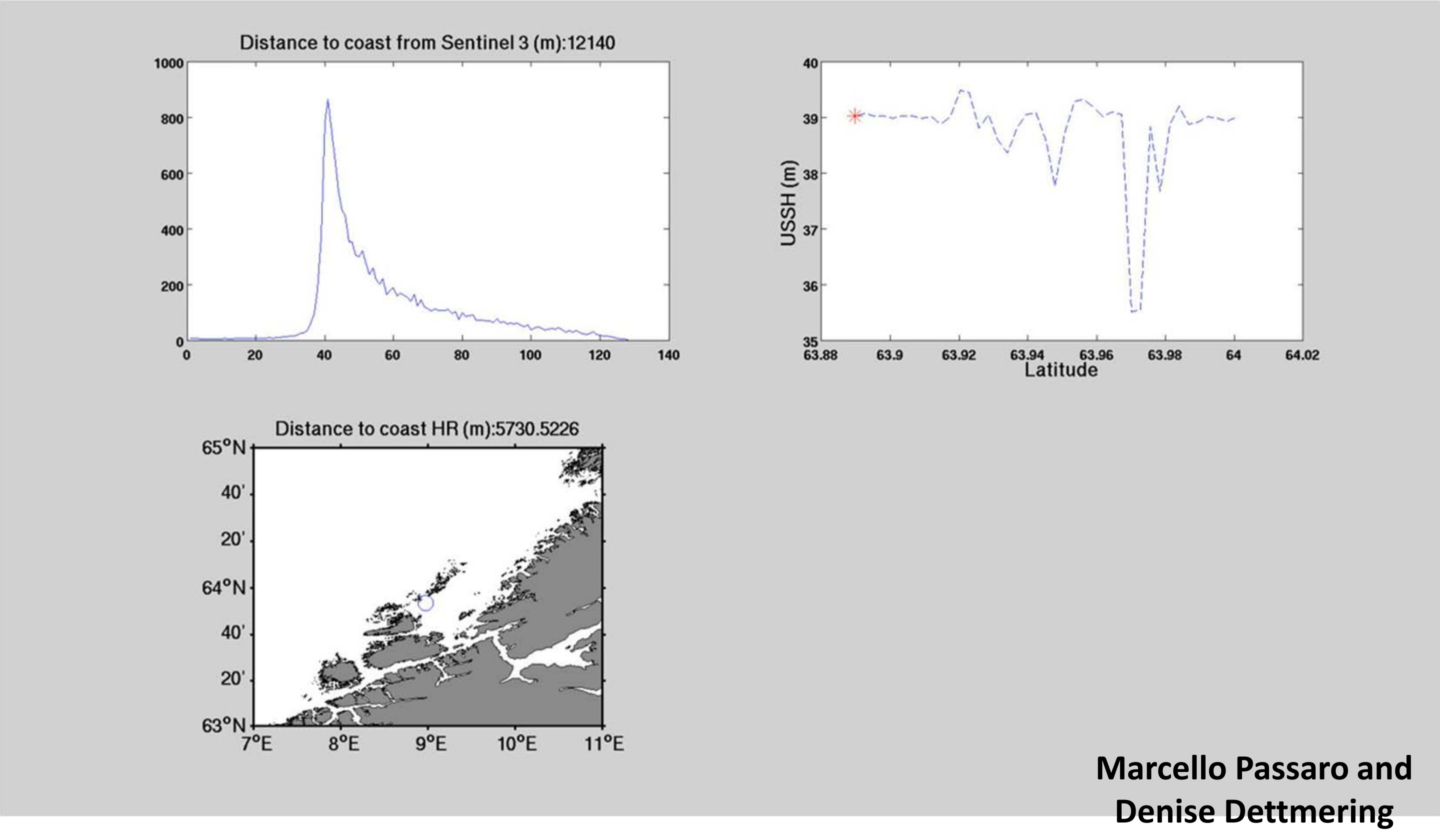
Principle of SAR a

In SAR mode we split the footprint along-track, and align multiple looks over the same resolution cell



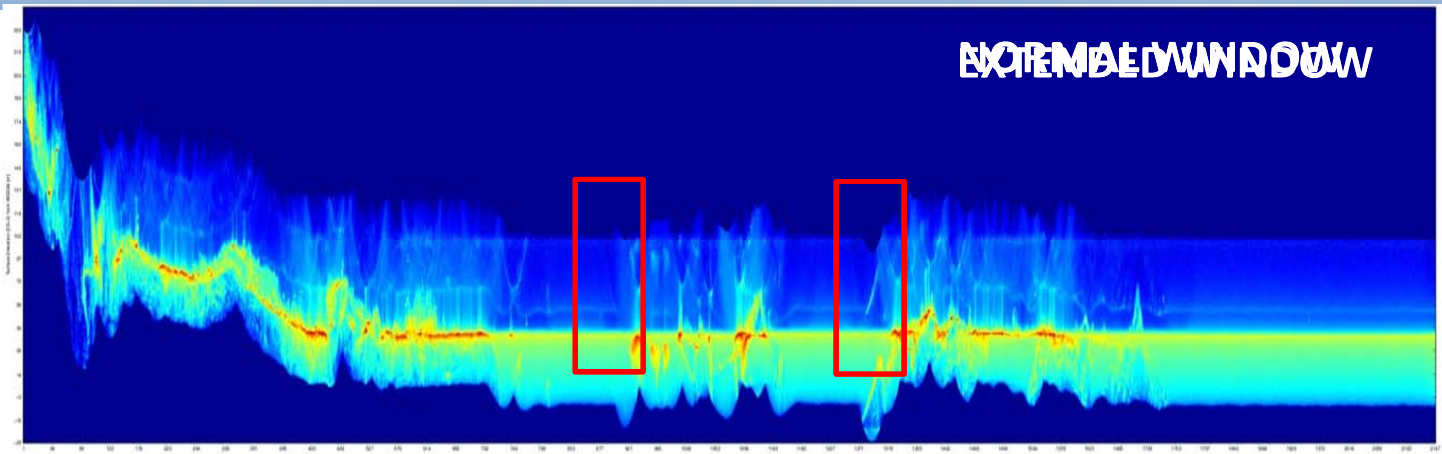
- Narrow footprint (~300 m) avoids a lot of contamination
- Retracking can use entire waveform, reducing noise

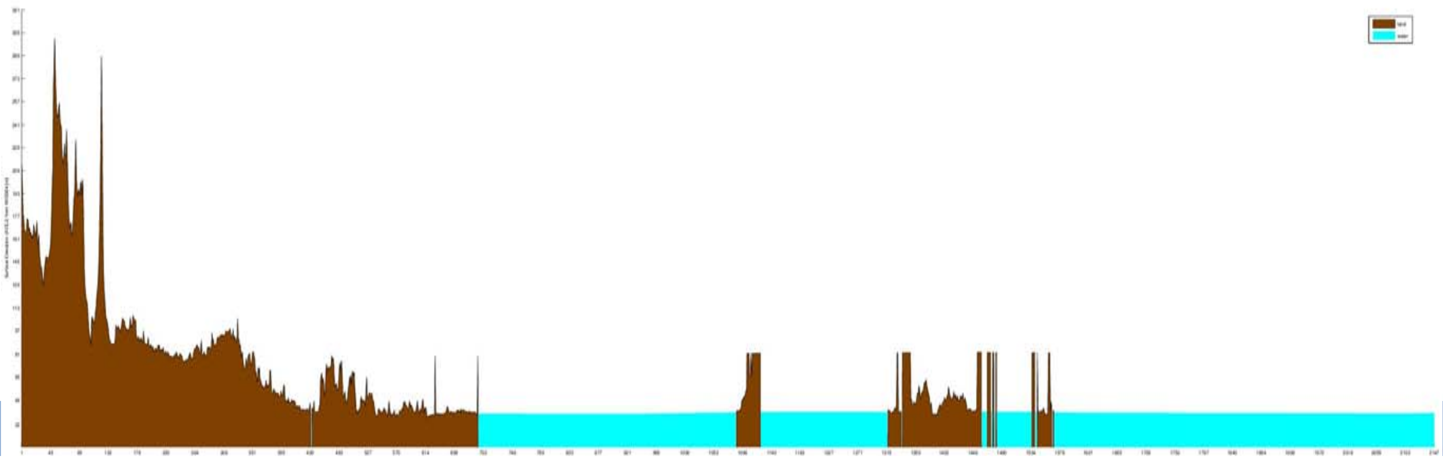
Case Study: North Sea and Norwegian Coast



Marcello Passaro and
Denise Dettmering

Implications of zero-padding



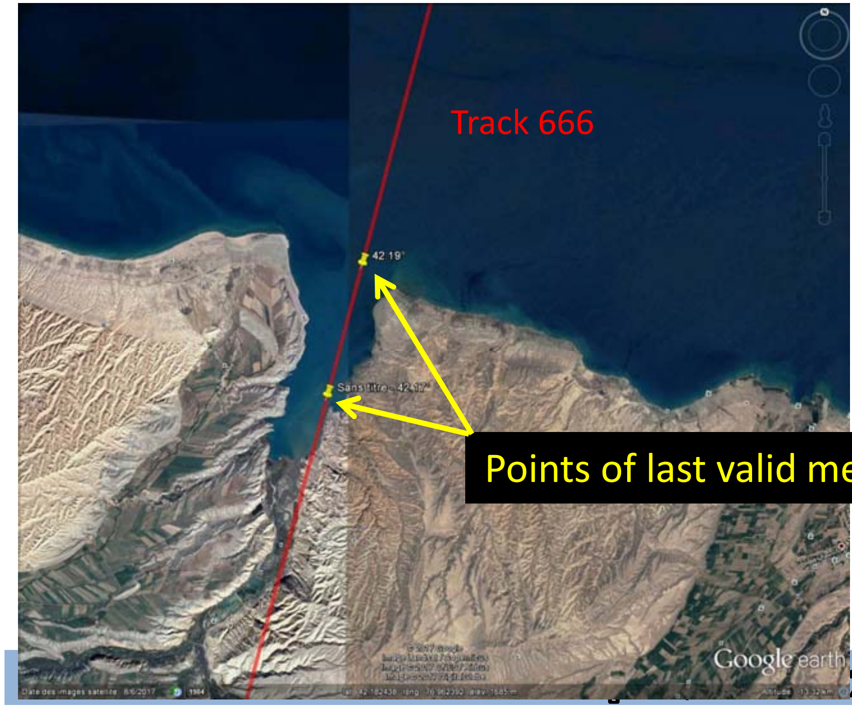


S-3A STM Inland Water Results

➔ How S-3A SRAL SAR mode behave close to the shore line?

S3A track 666, **valid measurements up to 1 km to the coast line '**

Pierre Féménias



Points of last valid measurements for Cy 5&6

Retrieval Algorithms

Updated retrackers – Better fit the waveform at high resolution (SAR)

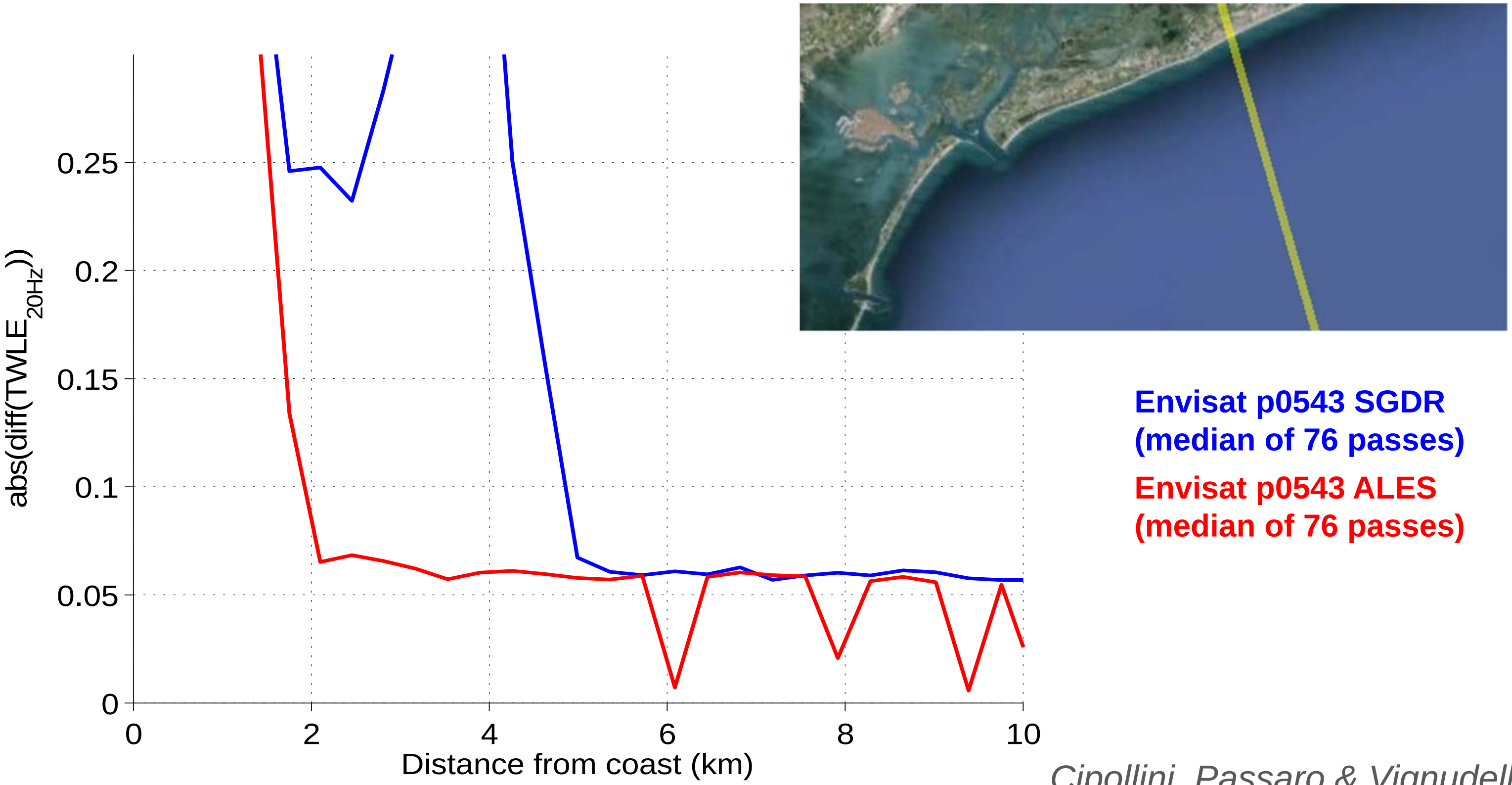
- Updates to current retrackers (like SAMOSA)

New retrackers – Better fit subsamples of waveforms

- ALES, ALES+
- Adaptive retrackers

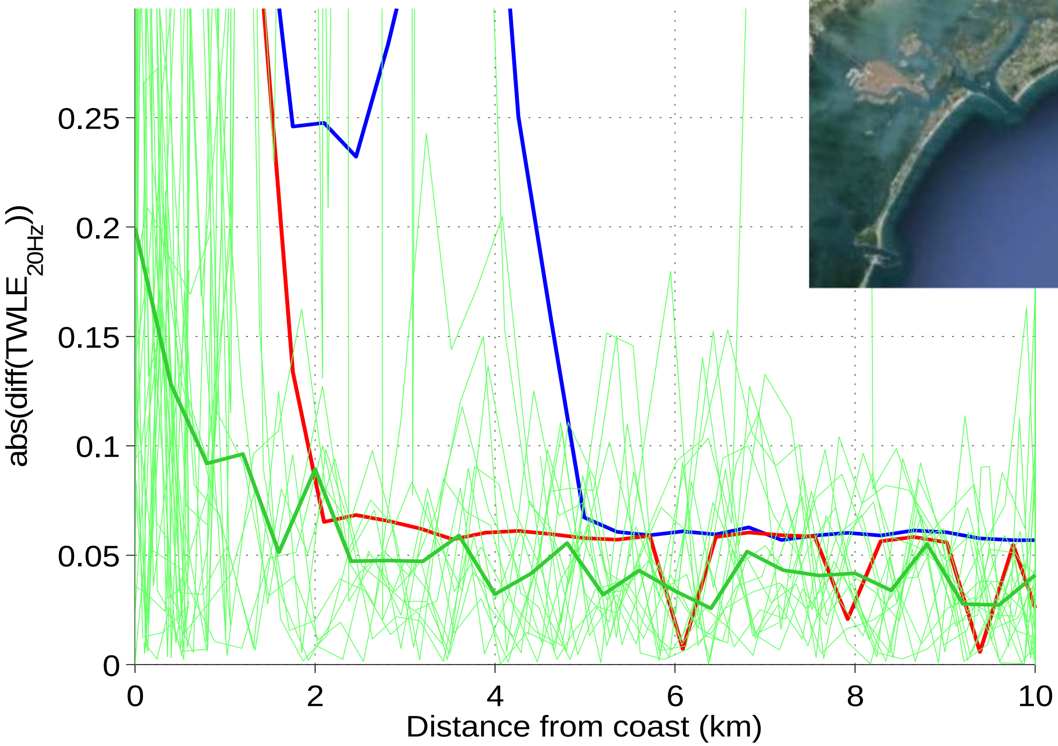
Strong coastal effects
Moderate effects or effects only in some coastal conditions
No coastal effects

Coastal performance: a case study



Cipollini, Passaro & Vignudelli

Coastal performance: a case study



Envisat p0543 SGDR (median of 76 passes)

Envisat p0543 ALES (median of 76 passes)

CryoSat–2 SAMOSA (single passes)

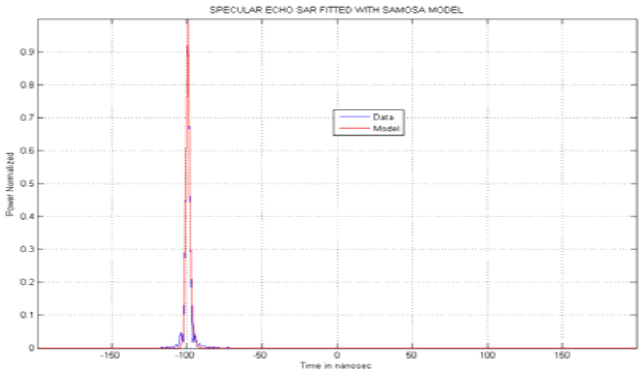
CryoSat–2 SAMOSA (median of 11 passes)

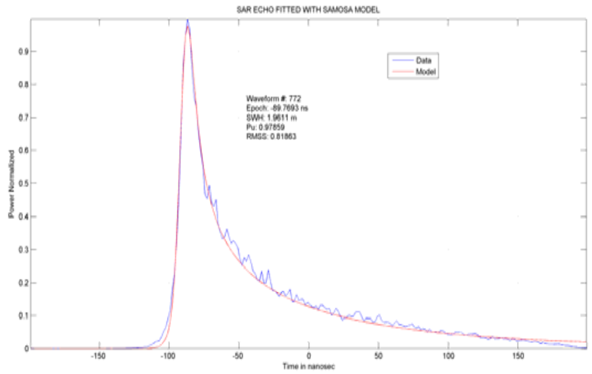
Cipollini, Passaro & Vignudelli

SAR Coastal Retracker

- Echo not contaminated/weakly contaminated/not specular, → SAMOSA 2.5 Model (C. Ray et al. 2014)
- Echo contaminated by land contamination → SAMOSA 2.5 Model with Mean Square Surface Slope (mss) as free parameter and SWH set to zero (SAM+)

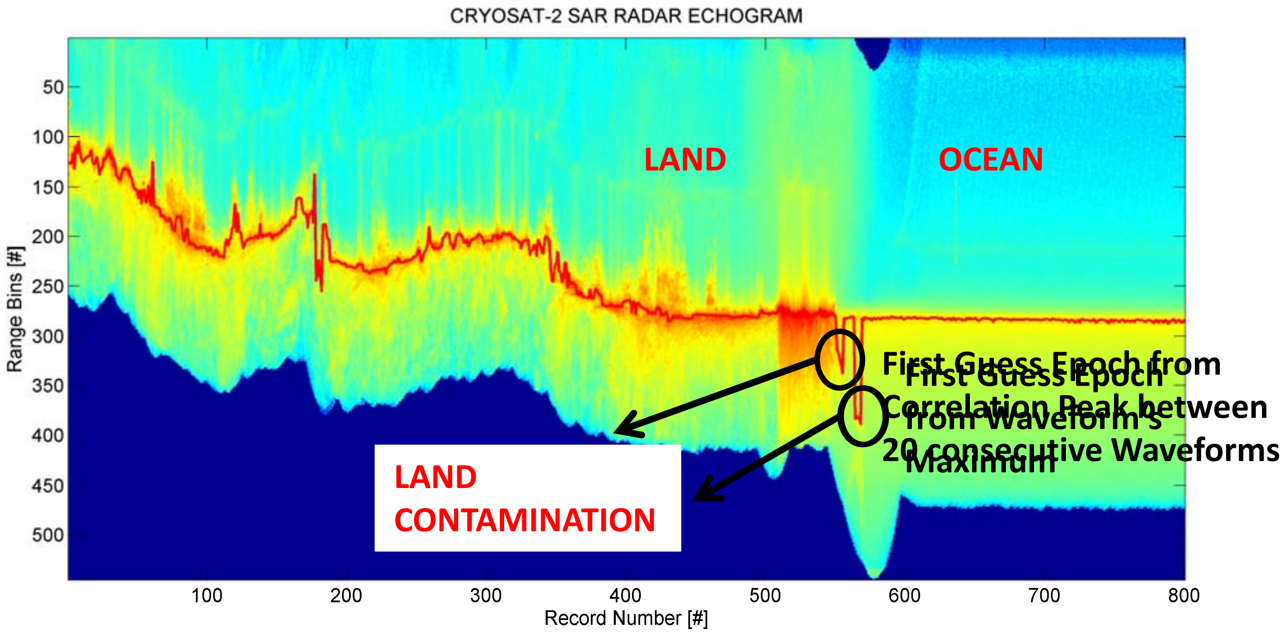
$$P_r^{SAR} = f_{SAMOSA}\left(t_0, SWH, P_u, mss\right)$$





SAR Coastal Retracker

Fitting First-Guess epoch (retracker initialization) taken as position of the peak in correlation between 20 consecutive waveforms (to mitigate land contamination problem)



Range and Geophysical Corrections

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Range corrections – delay caused by the interaction of the radar signal wit the atmosphere and with the sea surface

- Dry tropospheric correction (DTC)
- Wet tropospheric correction (WTC)
- Ionospheric correction (IC)
- Sea state bias (SSB)

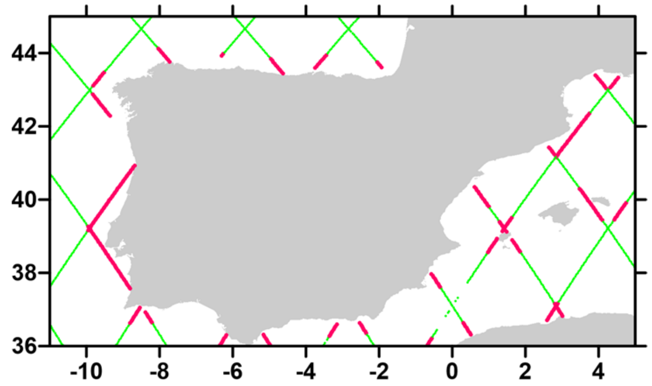
Geophysical corrections – due to geophysical phenomena, which must be accounted for in order to separate them from the signals of interest

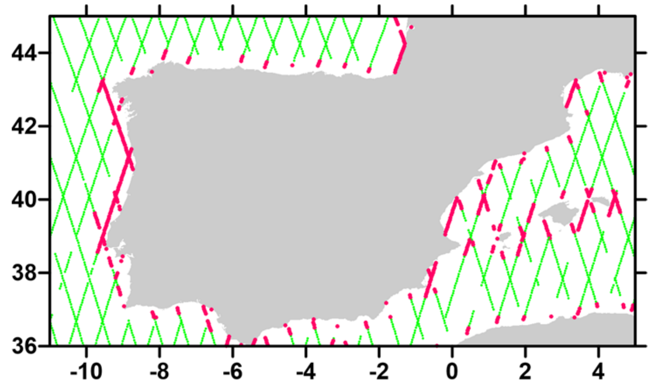
- Dynamic atmospheric correction (DAC)
- Tides:
  - Ocean tide
  - load tide
  - solid Earth tide
  - pole tide

Red	Strong coastal effects
Orange	Moderate effects or effects only in some coastal conditions
Green	No coastal effects

Wet Tropospheric Correction

- Due to its high variability (in space and time), the most accurate way to model the WTC is by means of collocated measurements from on-board microwave radiometers (MWR)
- MWR have footprints (10-40 km, depending on frequency) larger than the altimeter footprint
- Coastal effects depend on instrument (frequency and number of channels) and retrieval algorithm; stronger effects on 2-band MWR on ESA and SARAL than on 3-band MWR aboard the reference missions.



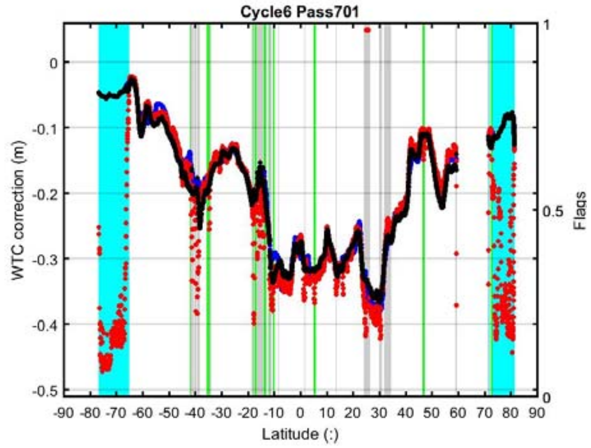


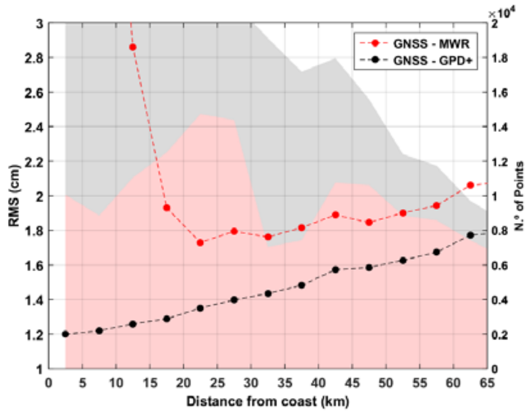
*Altimeter points with **valid** and **invalid** MWR measurements for a T/P (top) and anEnvisat (bottom) cycle*

Wet Tropospheric Correction

- Various methods have been derived to improve the MWR-derived WTC in coastal regions:
  1) Basic extrapolation of the last valid measurement over the ocean (in Envisat, AltiKa Peachi)
  2) Dynamically-Linked Model – DLM - or Composite approach (in COASTALT, AVISO) – replaces invalid MWR by geometric adjustment of last valid MWR to model values.
  3) Land Contamination Algorithm - LCA – corrects the TBs from land fraction before using them in the WTC retrieval
  4) Mixed-Pixel Algorithm - MPA – applicable only to 3-band missions but very efficient; in Jason-1/2/3 GDR.
  5) GNSS derived Path Delay (GPD) approach – developed for almost all missions; in CS2 GOP baseline C and Envisat GDR V3.0; from UPorto, CTOH.
  6) Variational method: retrieves specific humidity and temperature profiles, from which the WTC is computed, in combination with surface emissivity.

- MWR with high frequency channels, with smaller footprints are being designed for some of the future missions (e.g. AMR-C on Sentinel-6)





*Top: WTC for S3A cycle 06 pass 701- **ECMWF Op**. , **MWR** and **GPD** solely based on SI-MWR and GNSS. Bottom. RMS diff. between **WTC from S3A MWR and WTC from GNSS** at coastal stations. Same for **GNSS-GPD.***

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Ocean Tides

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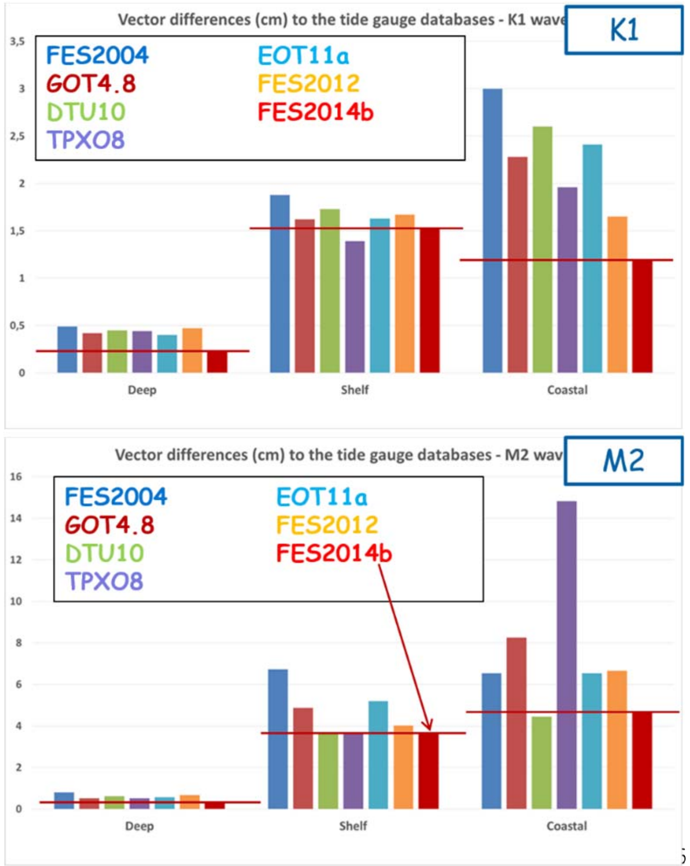
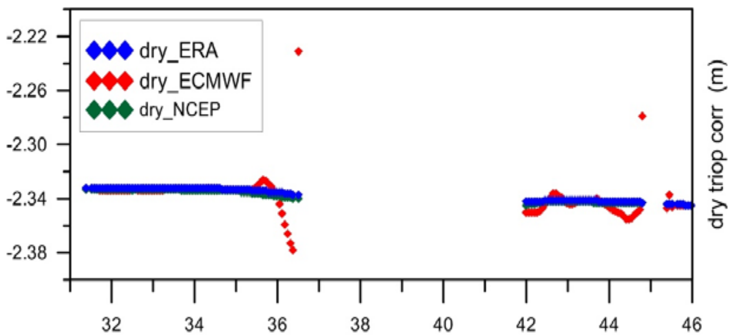
- While in open ocean the ocean tides rarely exceed ±1 m, in coastal regions may reach e.g. 10 m or more.
- Various global ocean tide models have been developed:
  - **GOT 4.8, GOT4.10** – large grid size (0.5°) is problematic in coastal zone
  - **TPX08, DTU10**
  - **FES models: FES2004, FES2012, FES2014.**
- Coastal tides tend to be larger, more complex and with shorter periods, often requiring local modelling.
  Main problem in some regions: lack of good bathymetry.
- Presently, in most coastal regions, ocean tides are the major uncertainty in the range and geophysical corrections



Vector differences in the frequency domain for the two main tidal constituents (M2 and K1) from various ocean tide models and tide gauge data.

Dry Tropospheric Correction

- About -2.3 m ± 0.2 m, the DTC is the largest range correction but with small variability. Retrieved from SLP or surface pressure from e.g. ECMWF with an accuracy, in open ocean, better than 1 cm.
- It has a strong height dependence (1 cm per 40 km height). For coastal altimetry it should be provided at sea level, e.g. from SLP.
- In altimeter products It is provided as along-track interpolated values derived either from SLP or from surface pressure grids. In the first case, if provided at sea level, it is appropriate for coastal areas, having the same accuracy as in the open ocean.
- In the last case, in steep coastal areas surrounded by land with elevations of e.g. 500-1000 m, errors in the DTC up to 5 cm or more increasing linearly as the coast is approached, may occur.



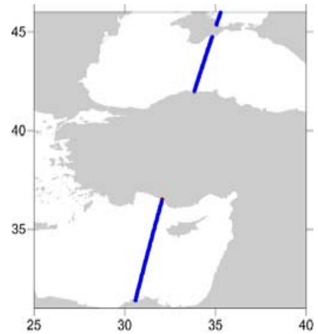


Illustration of DTC errors along Envisat cycle 12, pass 128 over the Mediterranean Sea and the Black Sea. The **DTC from ERA-Interim** is provided at sea level while **ECMWF Op.** is provided at the height of model orography

Sea State Bias

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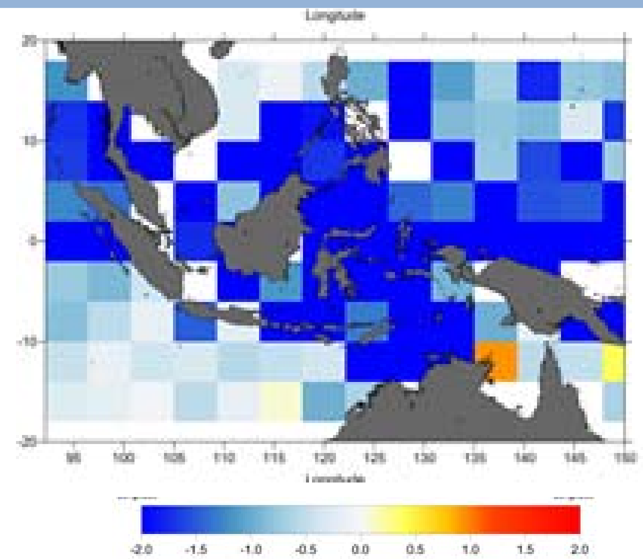
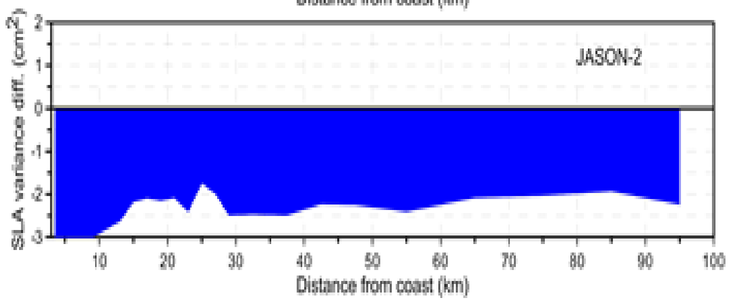
- The SSB is presently estimated by means of empirical models (parametric and non-parametric) using 2 parameters (SWH and $\sigma\theta$ or WS) or 3 parameters by adding e.g. the mean wave period. Examples: **CLS (2D), Tran, UPorto (3D)**
- In the coastal regions, the SSB is expected to have larger uncertainty due to:
  - Increasing errors in the estimated parameters (SWH and sigθ) as the coast is approached
  - Poor knowledge of the underlying physical processes that affect sea state and their effect in the altimeter observations for the various measurement modes
  - Larger complexity due to non-linear wave interactions; Need additional information to model coastal SSB effects.





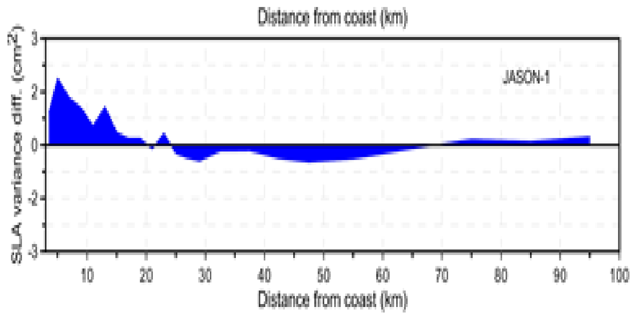
SLA variance difference at crossovers (top) and function of distance from coast (bottom) between SSB Tran and CLS for Jason-2 cycles 1 to 280, for the Indonesia region.

Other Corrections

Ionospheric correction (IC)

- Effect is frequency dependent, inversely proportional to f^2. Best determined from the combination of dual-frequency measurements: Ku (13.6 GHz) and C/S bands (5.3/3.2 GHz).
- Near the coast it is affected by the degradation of altimeter measurements; this effect is partly removed by the smoothing applied to the original correction.
- Smaller effect on Ka band (AltiKa) due to its larger frequency (35.7 GHz) and smaller footprint

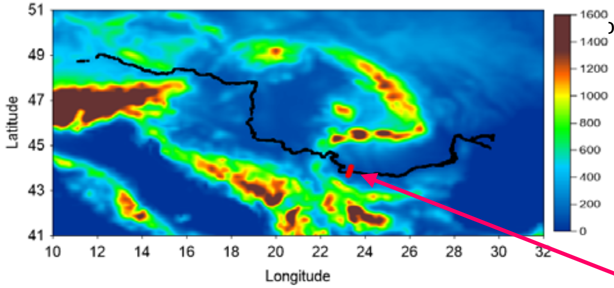
SLA variance difference function of distance from coast between smooth dual frequency and GIM model IC, present in RADS, for Jason-1 cycles 1 to 259. for the Indonesia region.



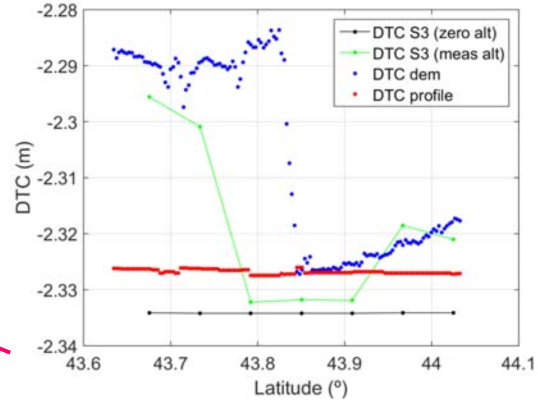
Dynamic atmospheric correction (DAC)

- The DAC accounts for the change in sea level induced by the change in atmospheric pressure (i.e., inverted barometer effect) and to the high-frequency atmospheric forcing. It is provided by global models.
- T-UGO is an evolution of the MOG2D model
- SL_cci DAC -> based on ERA Interim

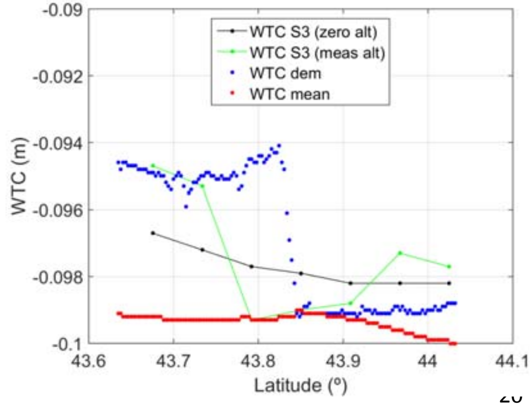
Importance of high data rate for IW and coastal regions



…or S3 cycle 11, pass 214.



- S3 provides model DTC/WTC **at sea level** and **at measurement level**, both at 1 Hz.
- Figs show their comparison with corrections computed at 20 Hz **at ACE2 DEM level** and **at mean river profile**.
- Over inland water regions with large height gradients or steep coastal regions this causes large errors, particularly in the DTC.
  This cannot be corrected with interpolation



Important to provide the DTC/WTC at 20 Hz!

THANK YOU FOR YOUR INTEREST