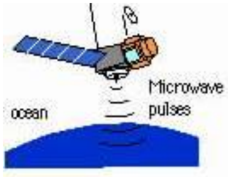

Coastal Altimetry: past, present an future - A Review

Presented by

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With invaluable help (and material) from
COASTALT and eSurge Projects

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particular thanks also go to Ron Abileah (jomegaK) and to the Coastal Altimetry Community

Outline of my talk

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- Introducing Coastal Altimetry
  - Closer to coasts – why
  - A look back – key milestones
  - A lively community
- Coastal Altimetry in action
  - A little on fundamentals of satellite radar altimetry
  - What the re-analysis tells us
  - More, better and closer to coasts – how
  - Error budget
- Moving from research to routine use
  - Coastal altimetry products
  - Showcase of emerging applications
- A summary
  - What we have learned
  - Recommendations from Coastal Altimetry Workshop series

The "Google Earth" effect: from global to local

Why “Coastal Altimetry” now?

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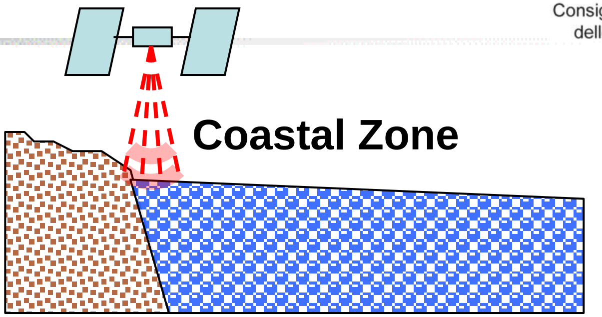

- **Coastal Zone uncharted domain**
  - ~20 yrs multi-mission archive
- **Coastal Zone of strategic importance**
  - most people live there
  - source of food and raw materials
  - vital link to transport and trade
  - host valuable habitats and landscape
  - favored destination for leisure

Key impacts are where policy decisions are usually made

- **There is much interest in bringing altimetry to the coastline**
  - Not only for using in synergy with modelling tools and other data sources,
  - but also to understand the error budget in global sea level rise when altimeters are tied to coastal tide gauges for calibration.
- **A hope at horizon: progresses in technology**
  - New techniques (Delay-Doppler, Interferometry, Reflectometry)
  - New concepts (Constellations)

New missions (AltiKa, CryoSat-2, Sentinel-3, SWOT) will have much greater coastal capabilities

What do we mean by "Coastal Altimetry" ?

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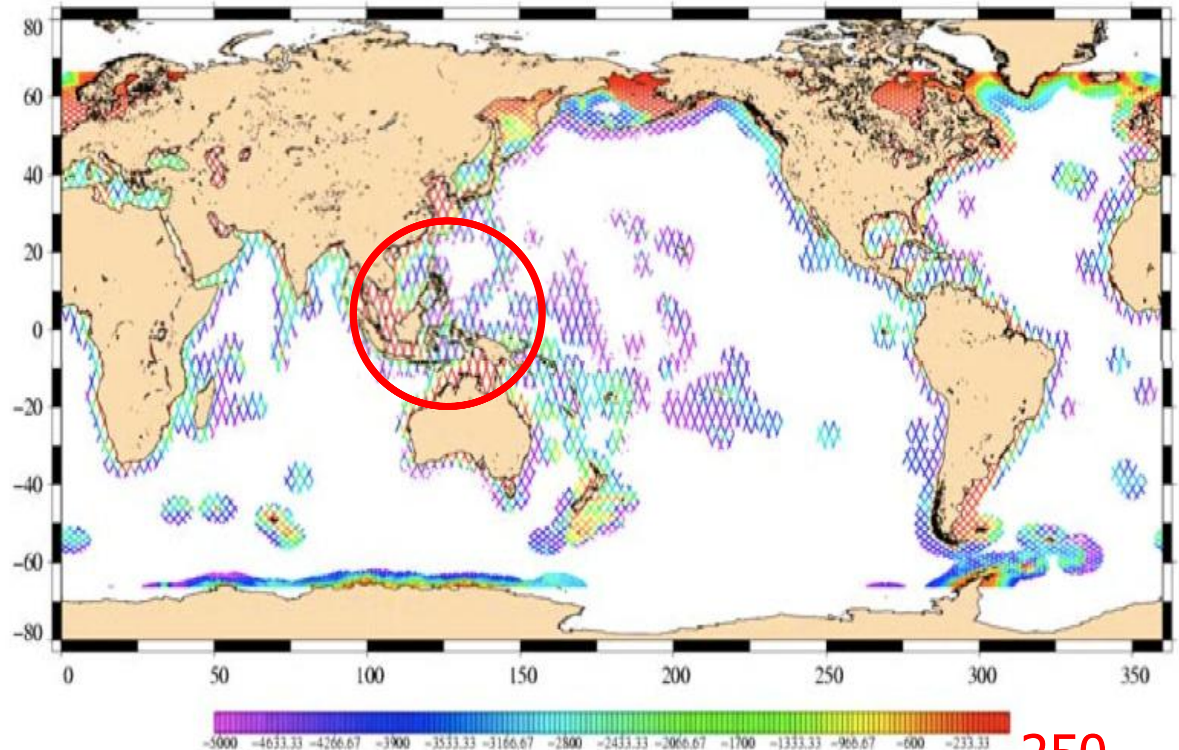
- We define **coastal altimetry** as altimetry over that ocean domain close to land where standard processing is problematic (information is somehow hidden)
- These data are normally **flagged as 'bad'** in official products for a number of reasons
  - non-standard waveforms,
  - inaccurate corrections, etc.

Coastal domain based on Jason-1 tracks (courtesy: PISTACH)



-5000 Bathymetry (m) -250

These data can – and should - be recovered!

and users are actually asking for them!

Coastal Altimetry – a bit of history

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- **Some seminal papers**
  - Manzella et al. 1997 - custom wet tropospheric correction
  - Crout 1998 - could recover data when coastal topography is flat
  - Anzenhofer et al. 1999 – retracking waveforms
  - Vignudelli et al. 2000 - Signal recovered consistent with in situ data

ALBICOCCA
France-Italy-UK 2001/04
Feasibility

ALTICORE-EU
EU/INTAS 2006/08
Capacity building

MAP/XTRACK/MARINA
CNES/LEGOS/CTOH
Integrated approach

DATA available

ALTICORE-India
ALTICORE-Africa

PRODUCT DEVELOPMENT STUDIES INCLUDING RETRACKING

PISTACH
CNES 2007-present
For Jason-2

COAST
ESA 2008-
For Envisat

→ now following with **eSurge** (*multimission, 2011-2014*)

…plus several OSTST Projects funded by NASA and CNES

Coastal Altimetry – at centre of the community

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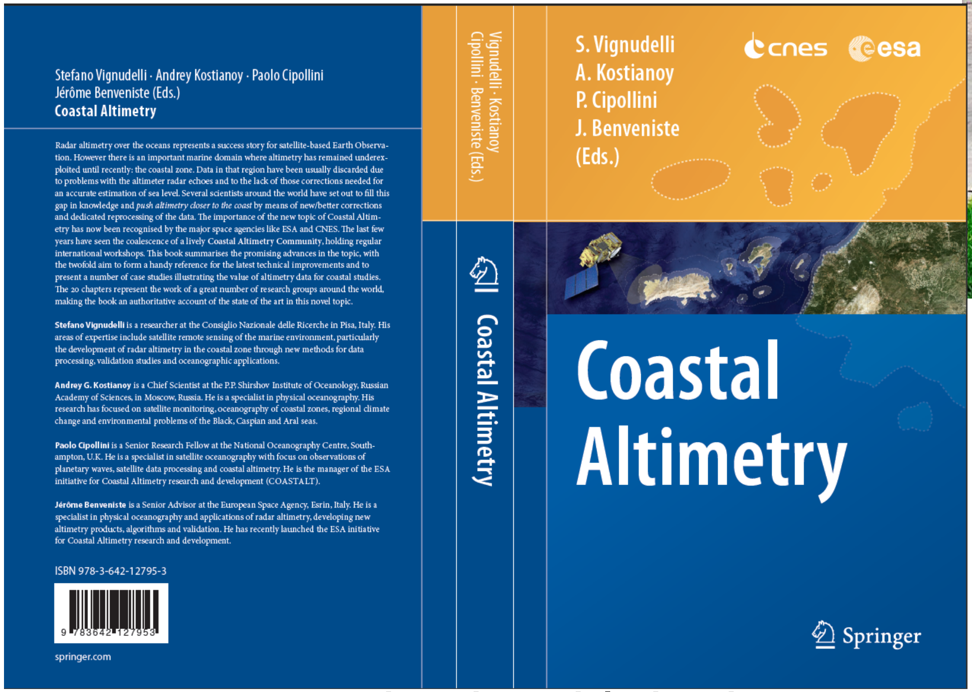
Regular workshops (Silver Spring 2008, Pisa 2008, Frascati 2009, Porto 2010, San Diego 2011, Riva del Garda, 2012, Boulder 2013, Lake Constance 2014) – see at www.coastalt.eu)



Springer book published
(see TOC at http://www.springer.com)

Recap – how satellite altimetry works

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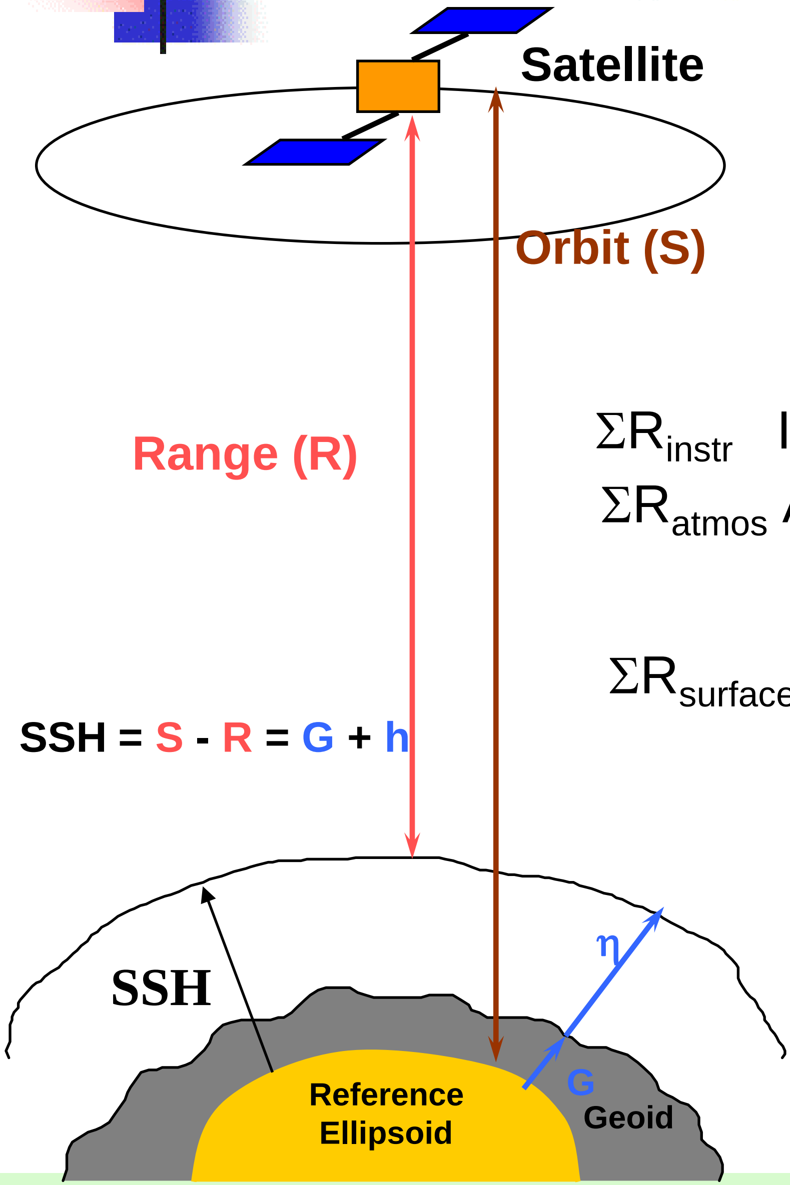

$SSH = S - R_{corr}$

Range (R) must be corrected for various effects, with equation of form:

$$R_{corr} = R_{altimeter} + \Sigma R_{instr} + \Sigma R_{atmos} + \Sigma R_{surface}$$

ΣR_{instr} Instrument dependent (e.g. USO, Doppler)

ΣR_{atmos} Atmospheric path corrections given by:

$$\Sigma R_{atmos} = R_{iono} + R_{wet\ tropospheric} + R_{dry\ \ tropospheric}$$

$\Sigma R_{surface}$ Surface dependent given by:

$\Sigma R_{surface} = R_{SSB}$ Sea Surface Bias

Some applications require correction of high-frequency signals (tides, wind and air pressure)

$$\Sigma R_{surface} = R_{SSB} + R_{tides} + R_{wind\text{-}pressure}$$

But the Sea Surface Height (SSH) contains the geoid signal!!

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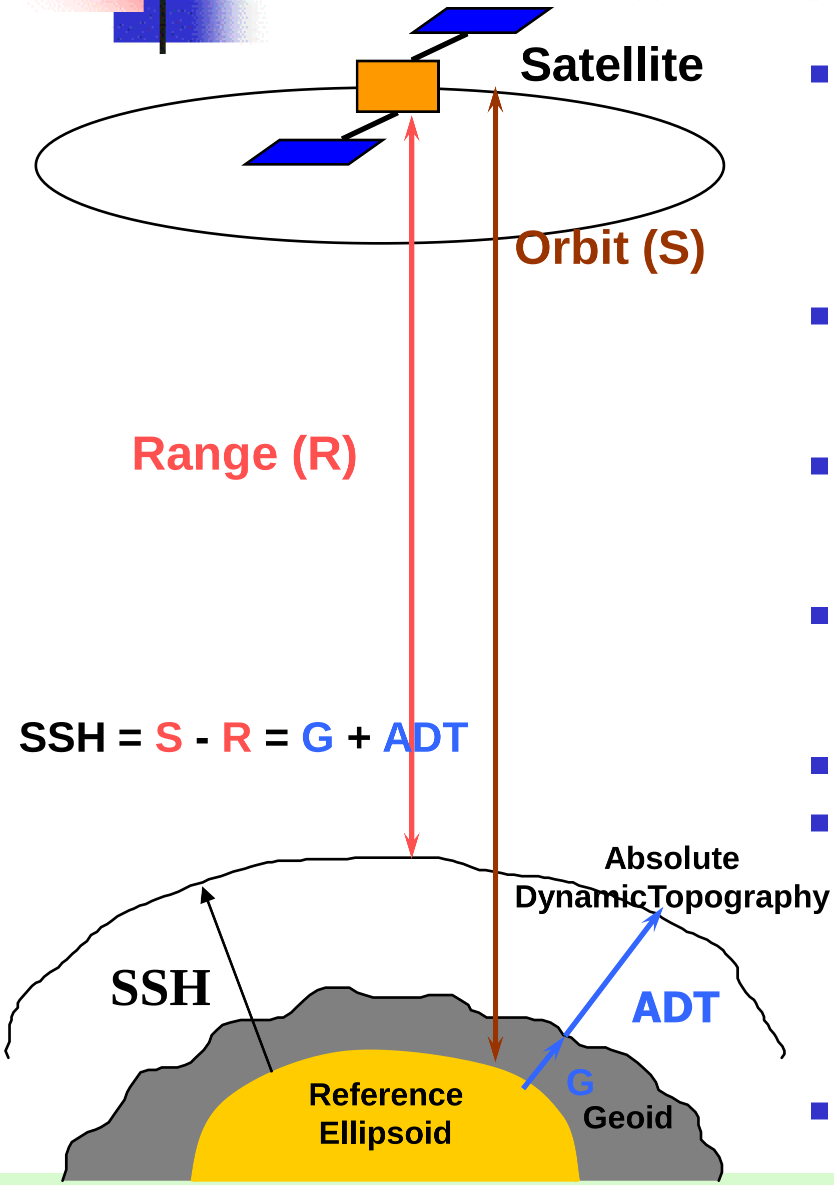
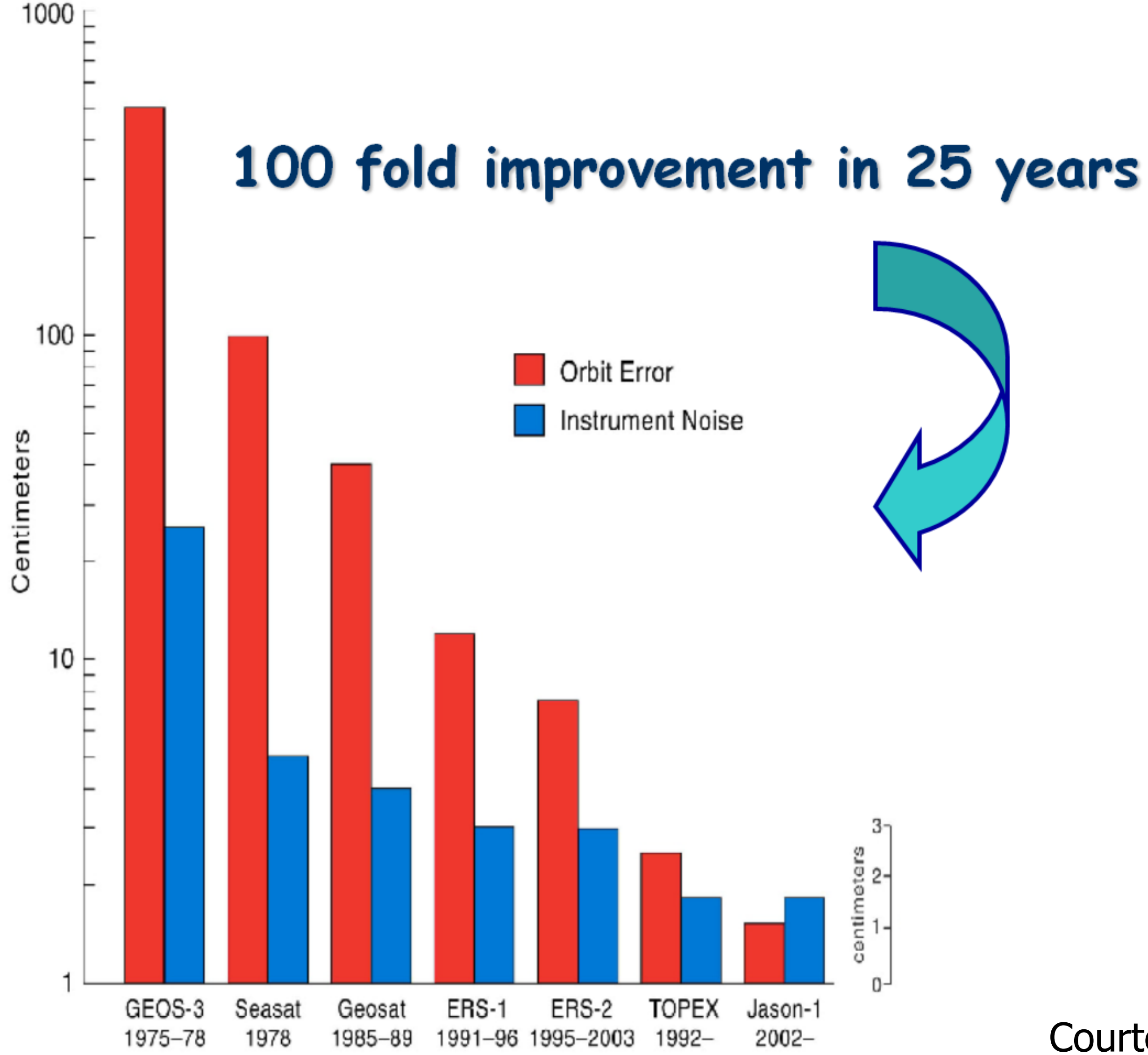


- SSH is composed of a variable oceanic part, the Absolute Dynamic Topography (ADT), and of a geophysical constant the Geoid. These latter deals with the position of the ocean at rest.
- Its small scales are not known with enough accuracy to permit the separation of the two components of the SSH.
- Consequently, SSH is decomposed into a Mean Sea Surface (MSS) and a Sea Level Anomaly (SLA)
- SLA which takes into account the variation of height around the MSS due to the variability of the ocean currents:
- *SSH =MSS + SLA =G+ADT*
- The MSS contains then both the Geoid and the permanent part of the ADT called the Mean Dynamic Topography (MDT) which deals with the stationary part of the ocean currents. Its knowledge permits to bypass the Geoid to study the ADT of the ocean:
- *ADT = MDT + SLA*

History of satellite altimetry accuracy in open ocean



Courtesy by L.L. Fu, NASA

TOPEX Latest Error Budget

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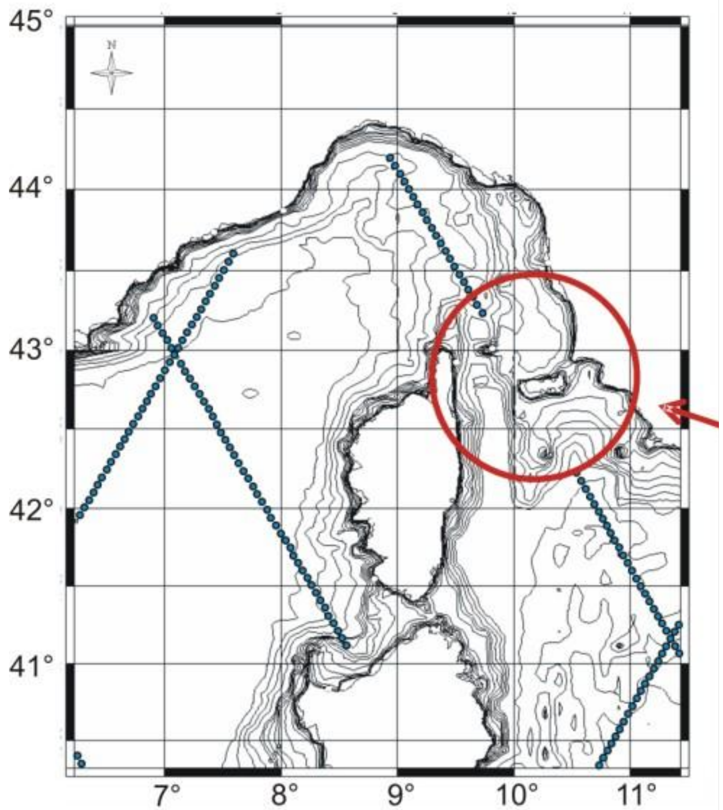
for 1-Hz measurement - from Chelton et al 2001

Source	Error
Instrument Noise	1.7cm
Ionosphere	0.5cm
EM Bias	2.0cm
Skewness	1.2cm
Dry Troposphere	0.7cm
Wet Troposphere	1.1cm
Orbit	2.5cm
Total	4.1cm

One picture is worth 1000 words - Starting point … really no data ?

TOPEX/Poseidon - Ground Track Reference Mask



Standard Product

From this…

Beyond flags: new editing strategy

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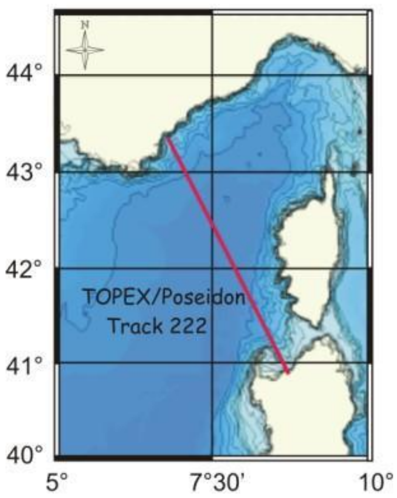
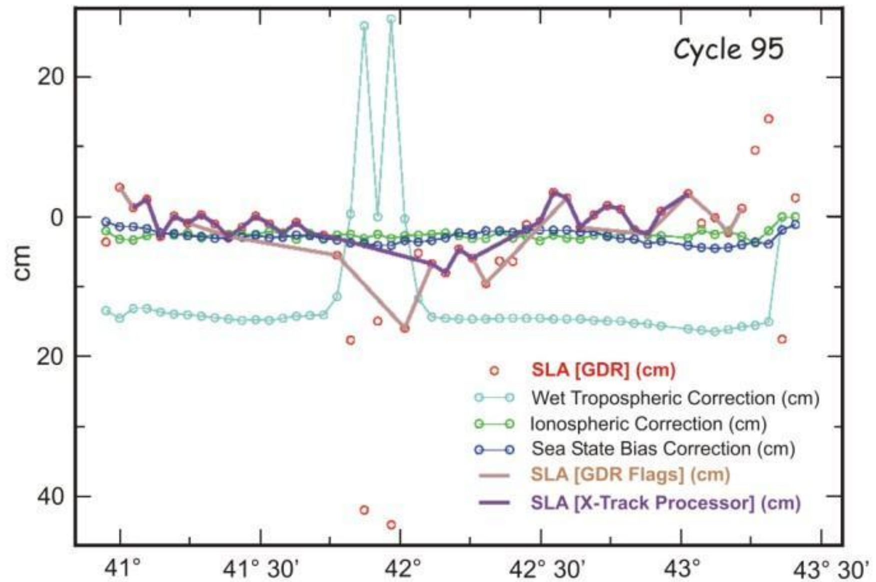




***Circles**: uncorrected sea level anomalies (SLA) and original corrections from the AVISO Geophysical Data Records (GDR).*

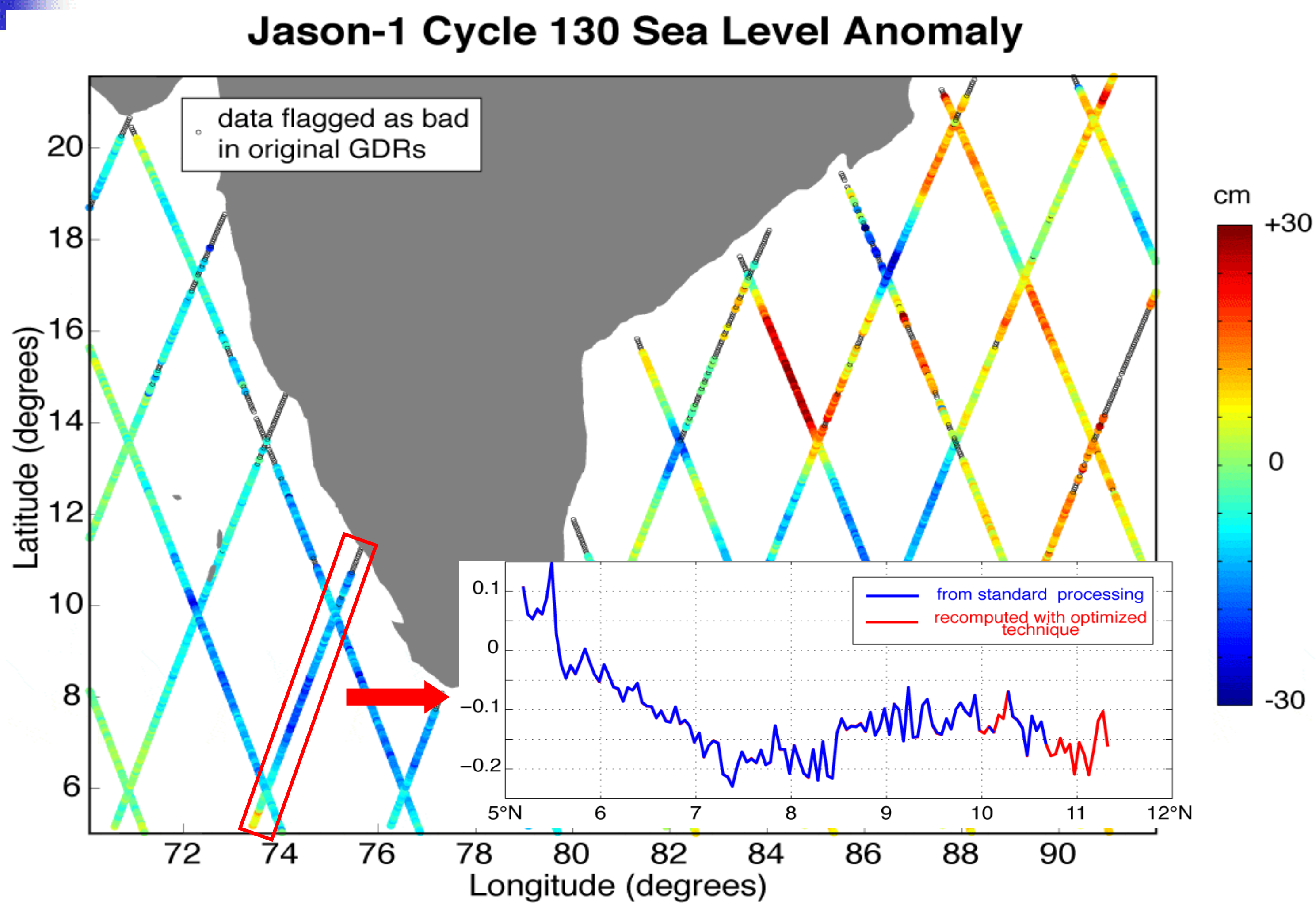
***Brown line**: SLA after application of the standard corrections from the GDR.*

***Purple line**: the new SLA profile computed*

- Screening profiles rather than single values
- Reconstructing /extrapolating profiles where possible

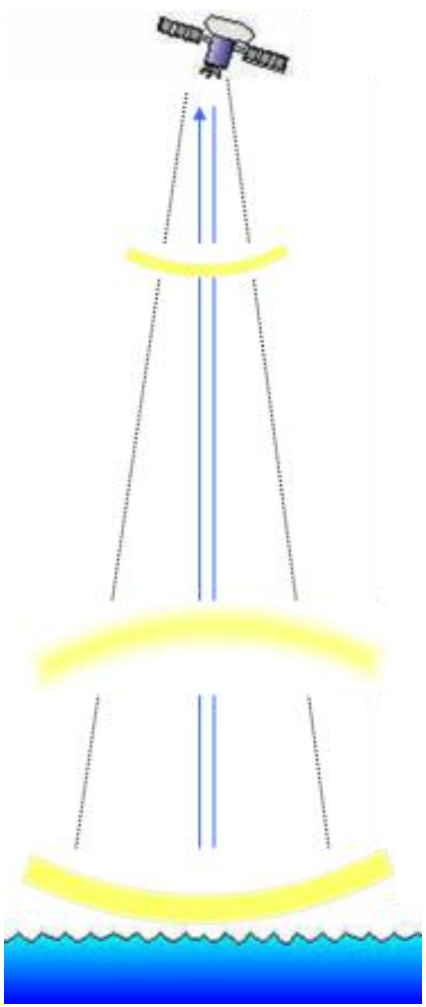
Much more data on average than using standard editing

Lesson learned I - Reprocessing standard along-track products



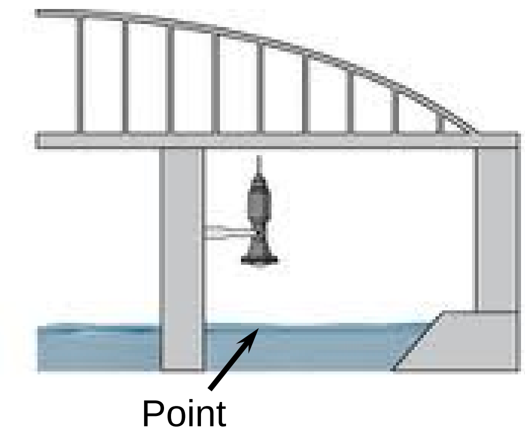
A significant part of data is recoverable just de-flagging, filtering, editing, re-interpolation of corrections

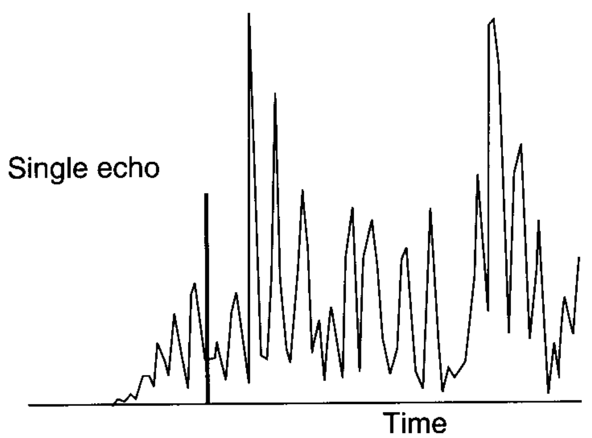
Recap - What are we measuring?



- The altimeter system is just a more complicated radar tide gauge mounted on satellite
  - Need of additional data (e.g. orbits and corrections)
  - But more uses (waves, winds, currents, bathymetry in addition to sea level)
  - Averages over footprints vs point-wise
  - Sampling of order of days vs min/hour

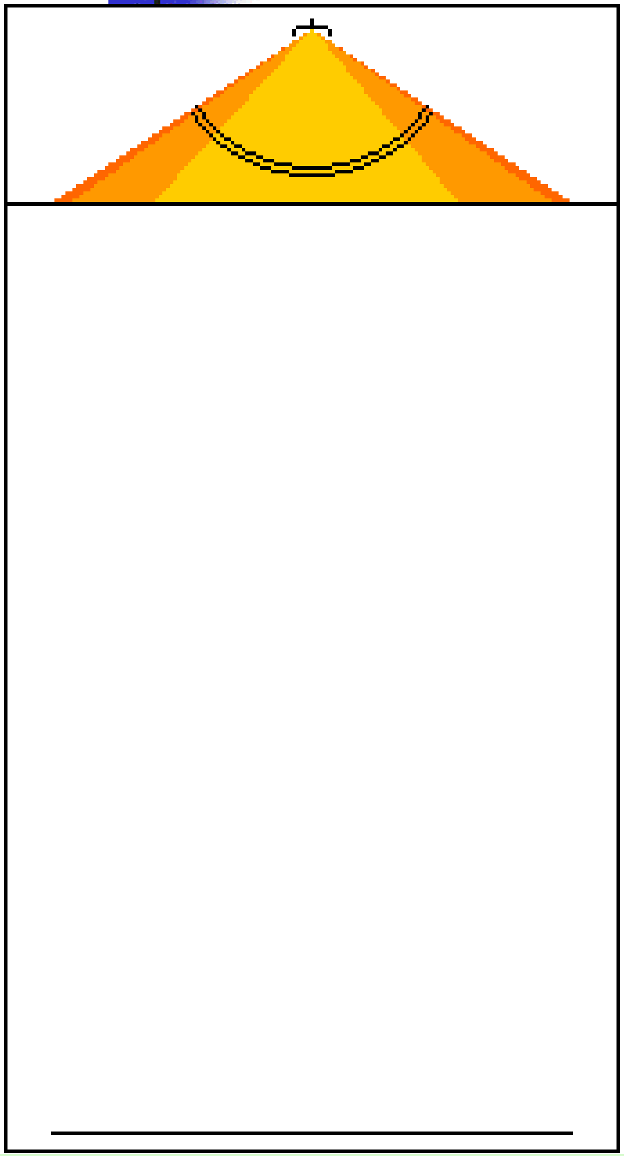
In situ

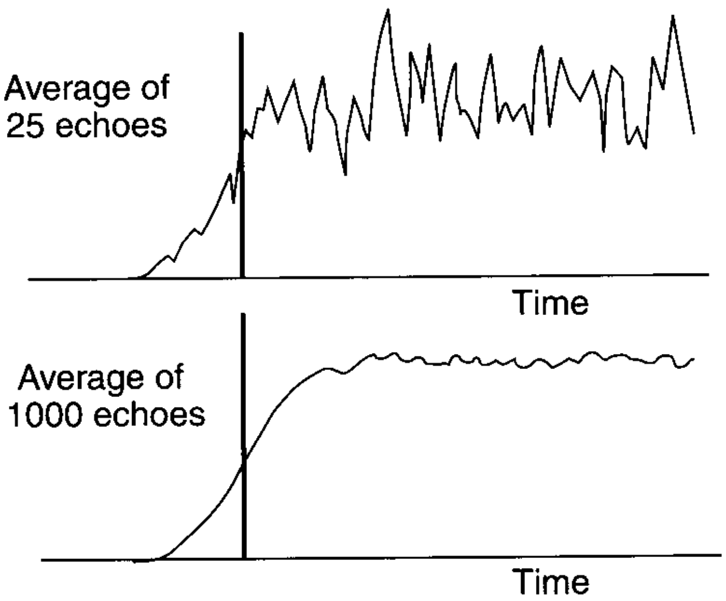




- It sends a microwave pulse towards the ocean surface, f = 13.5 Ghz
- Each individual return signal or echo (known as **waveforms**) is very noisy
- This is a result of random distribution of the ocean wave facets at any instant

Averaging many successive pulses can reduce noise





- Envisat is averaging 100 echoes on board
- then trasmitted on ground over 1/18 second of flight
- This means measurements every 350 m along track
- However, data are furtherly averaged on ground over 1 second of flight
- This means measurements every 7 km along track

7 km is the standard resolution for use in open ocean

Source: ESA

Real radar return signals (waveforms) in open ocean

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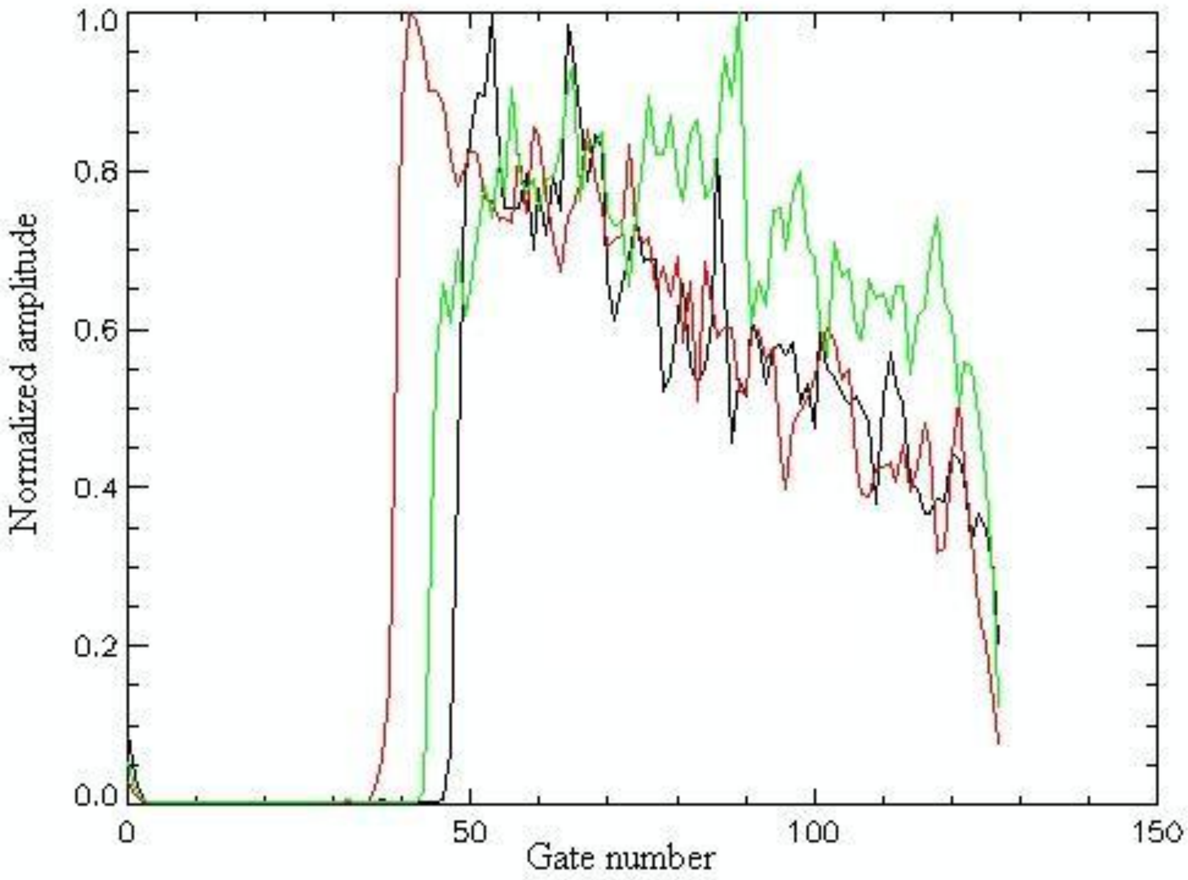
RA-2 altimeter on ESA's Envisat



How can we turn 'return radar signal' into useful data

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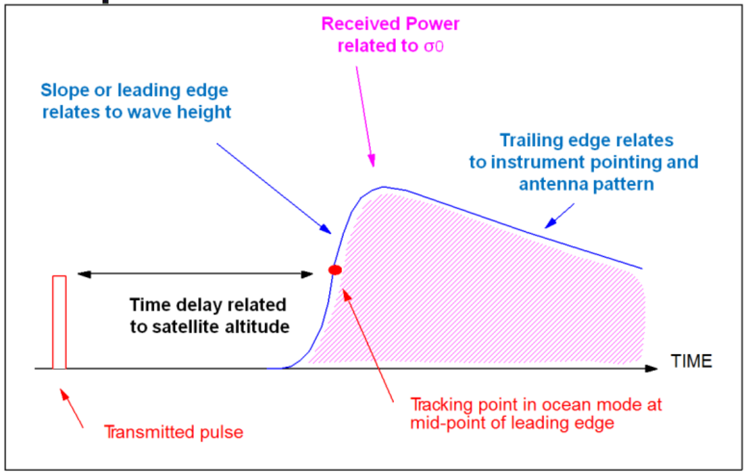
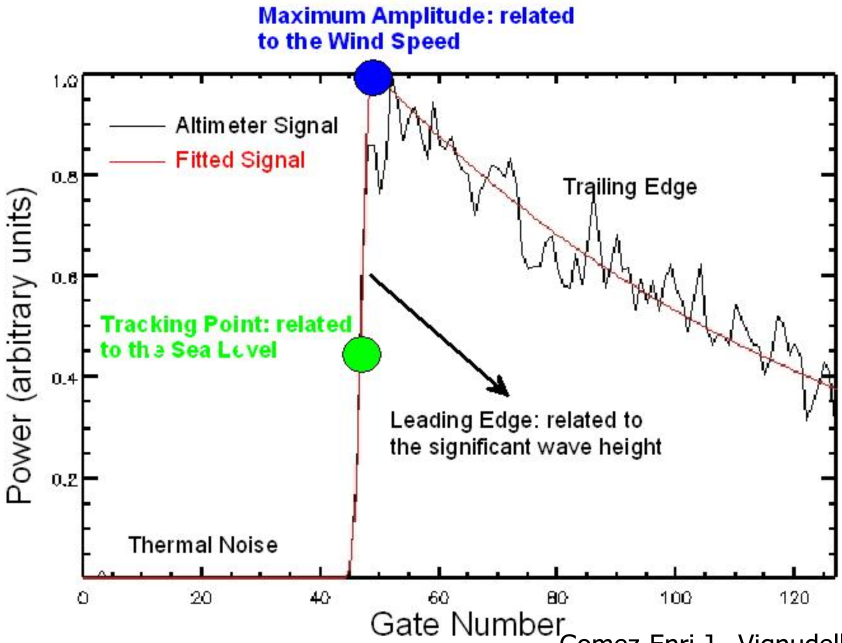


- The shape of the waveform can be described analytically through the Brown model over the ocean
- But it assumes that the sea surface is a perfect mirror which reflects only at specular points



- We use a procedure called retracking to fit the Brown model (red line) to the waveform (black line)
- Then we can estimate the time required for two-way travel of signal (2T)
- The time is then converted to a measurement of distance, known as **range**
- $h = T/c$ ($c = 3 \times 10^8$ m/s)

but what happens when satellite approaches coasts ?

Gomez-Enri J., Vignudelli S., et al., Bringing satellite radar altimetry closer to shore, In SPIE (Society of Photo-Optical Instrumentation Engineers), 2009

This is to illustrate how complicated the waveforms get

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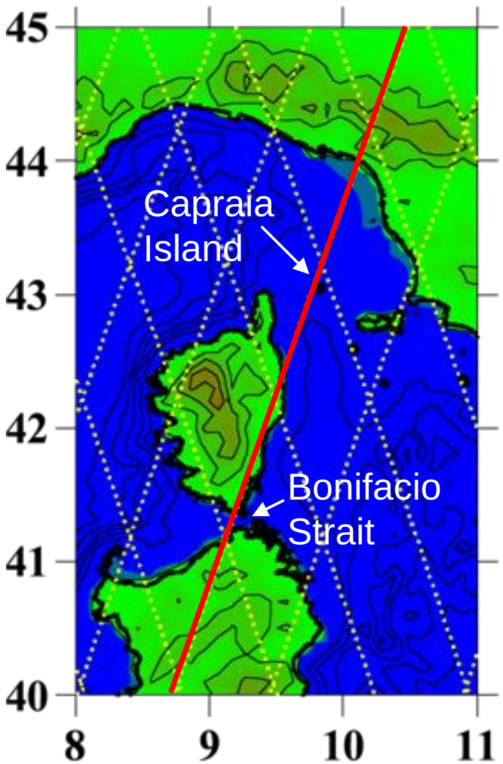
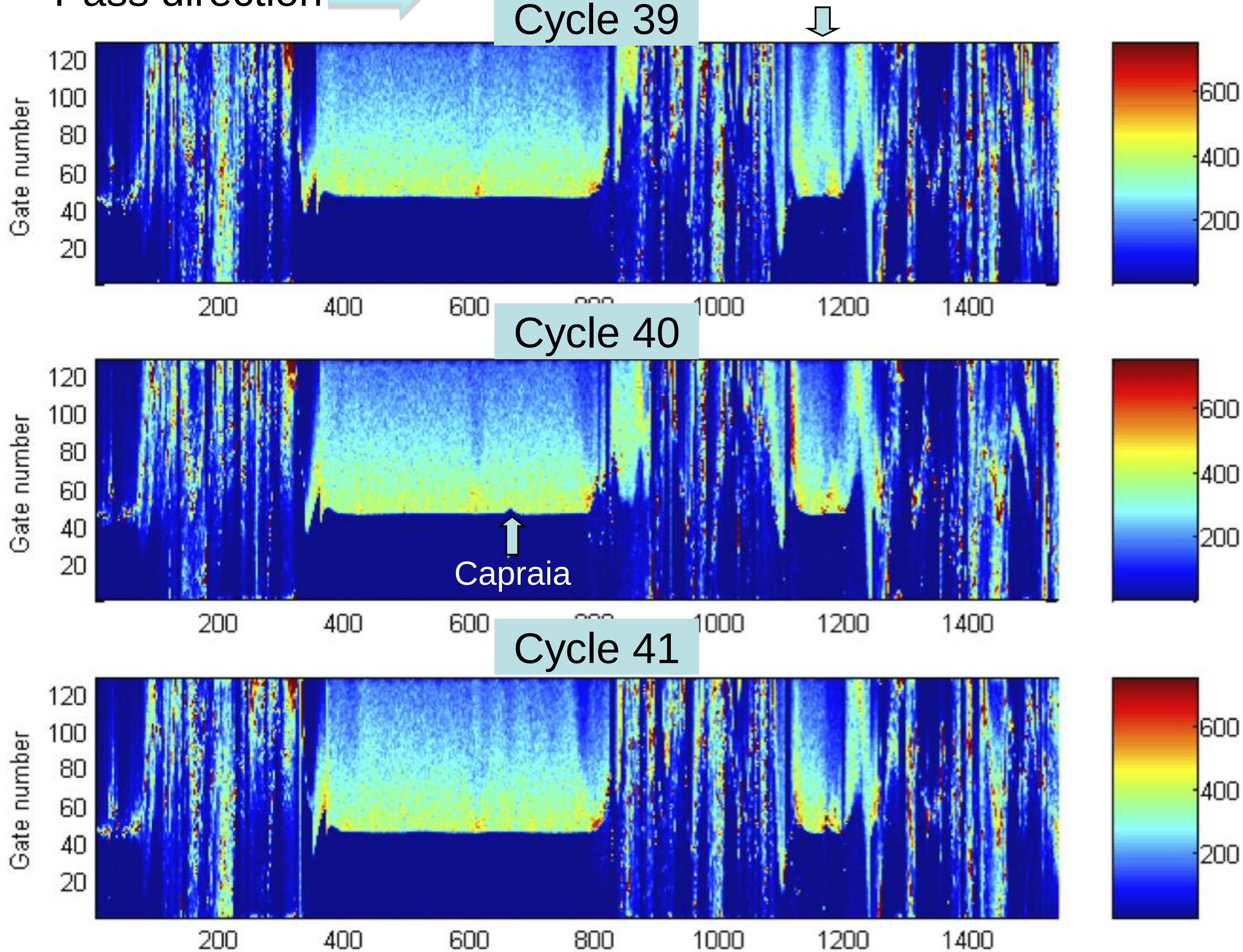
ENVISAT **pass 294** (descending)



Pass direction



But if we zoom locally ....

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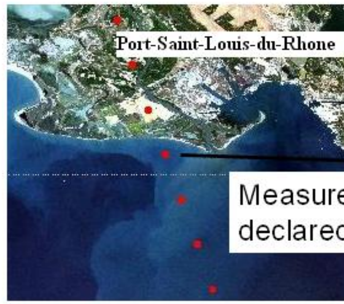
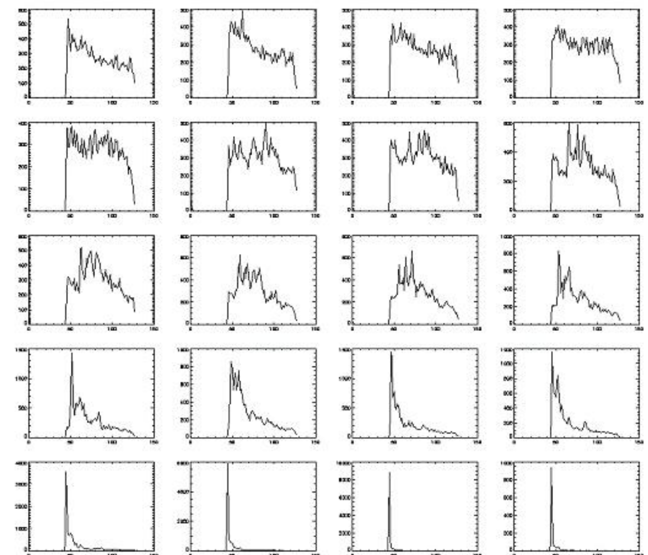
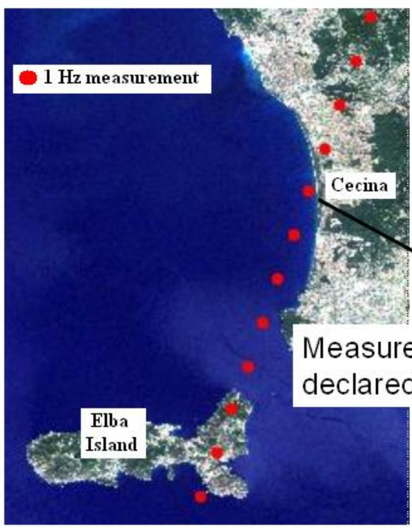
Envisat Ascending Track



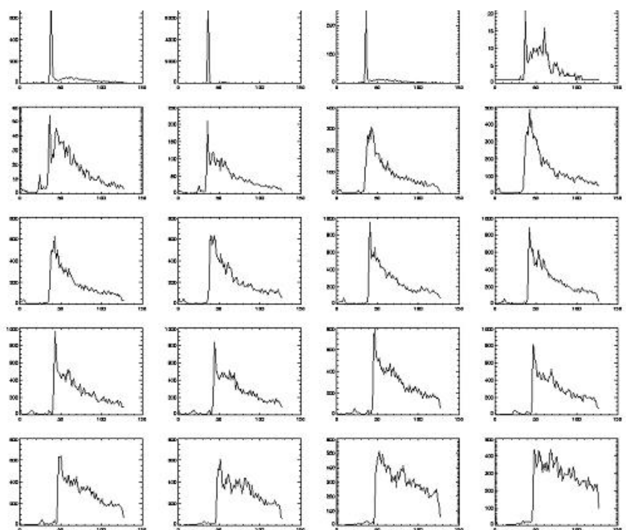
Measurement at 1-Hz declared as LAND

18-Hz waveforms



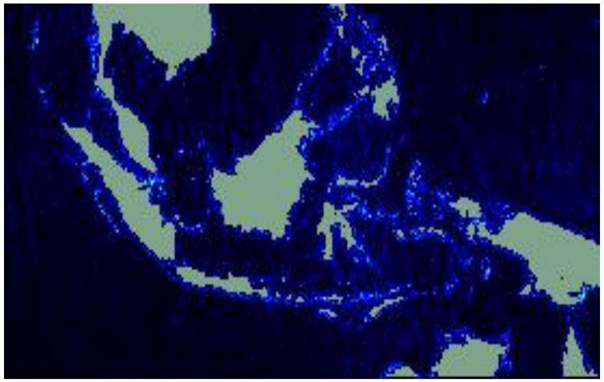


Measurement at 1-Hz declared as LAND

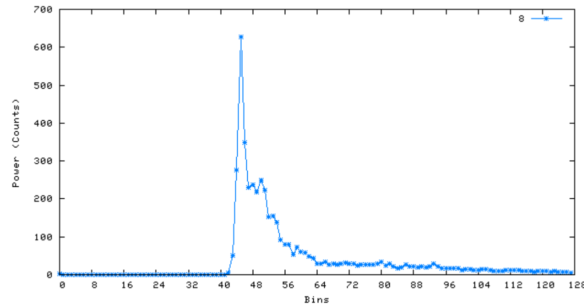


Envisat Descending Track

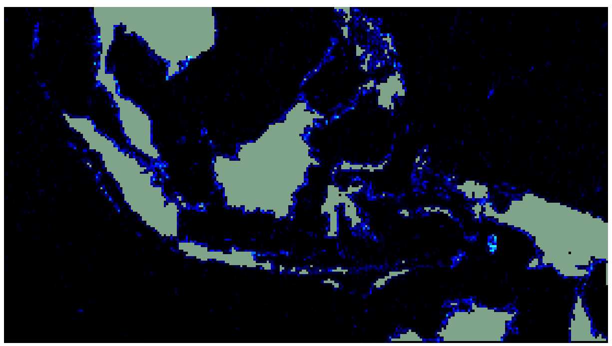
Indonesia is a challenging area



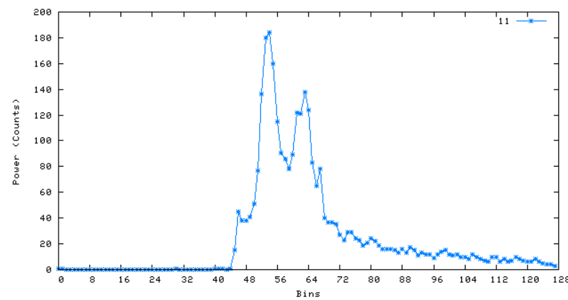
Flat patch echoes



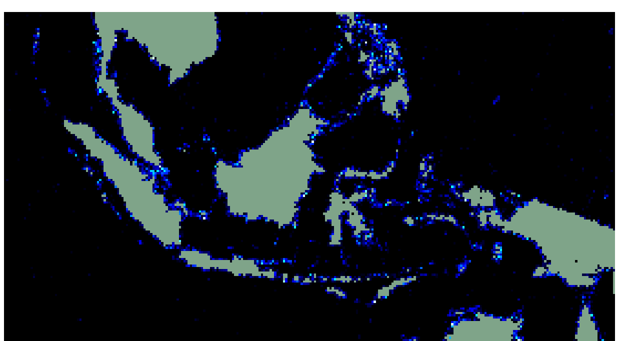
Calm water in coastal regions or with the presence of small islands.



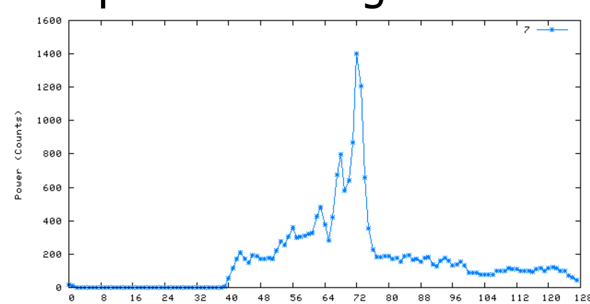
Simple Multi-target echoes



Multiple brightly surfaces reflecting within the altimeter footprint.



Complex Multi-target echoes



Combination of ocean component and rough terrain.

Courtesy by P. Berry, DMU

Lesson learned II – Re-thinking retracking

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- We learnt that retracking waveforms in the coastal zone is challenging work
  - How close to the coast? – depends on how much high ground can affect tracking window too much
  - 90% of waveforms are Brown-like seaward of 10 km from the coast.
  - Standard (Brown model) retracking should be adequate seaward of 20 km from the coast.
- Identification of some retrackers better performing at the coast
  - e.g. RED3 in PISTACH Project
  - but BAG/ BAGP are even more promising (PISTACH)
- Use better waveform models, accounting for change of shape in coastal environment
  - e.g. scattering from non-linear surfaces.
  - e.g. by including the effect of white caps
  - e.g. by mixing different models – Brown, Specular and Mixed (COASTALT)
- Use innovative techniques
  - Denoised estimations with Singular Value Decomposition(PISTACH)
  - Cleaning waveforms (COASTALT)
  - Avoid treating each waveform in isolation but using info from adjacent ones – 2D Hyperbolic Pre-tracker and Bayes Linear Reatracker (COASTALT)

Retracking – mixing different models

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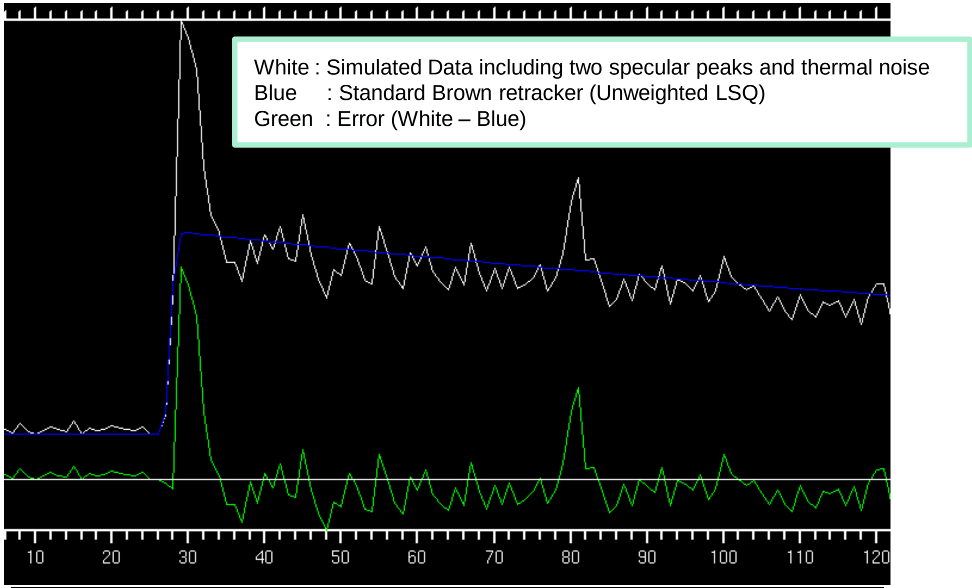
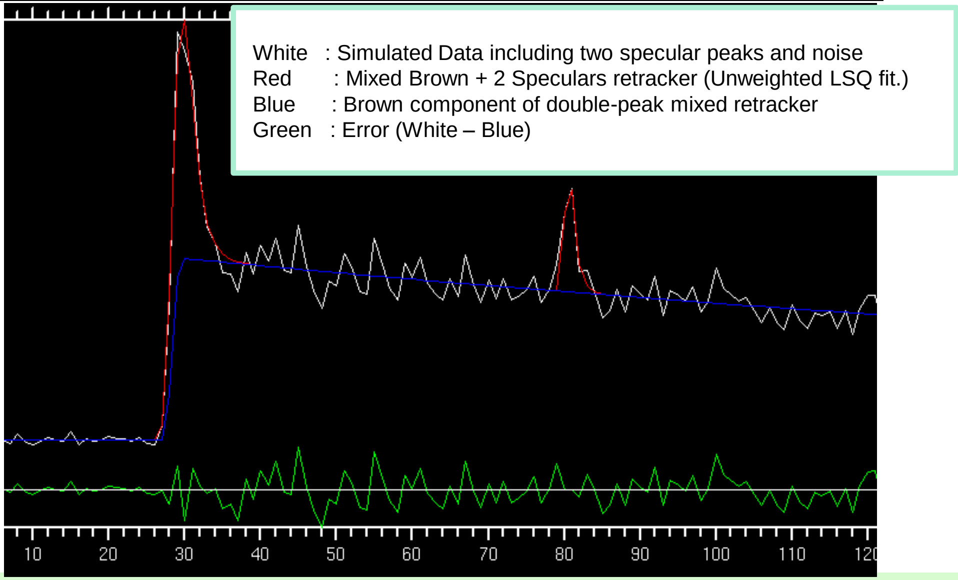
- In many cases there are one (or more) non-Brown component(s) – e.g. A “specular” one superimposed on a Brown-like echo
- This can be tackled with models fitting different waveforms, e.g. one fitting sums of different Brown and non-Brown waveforms (a ”mixed” retracked)





Innovative Retracking – Cleaning waveforms in advance

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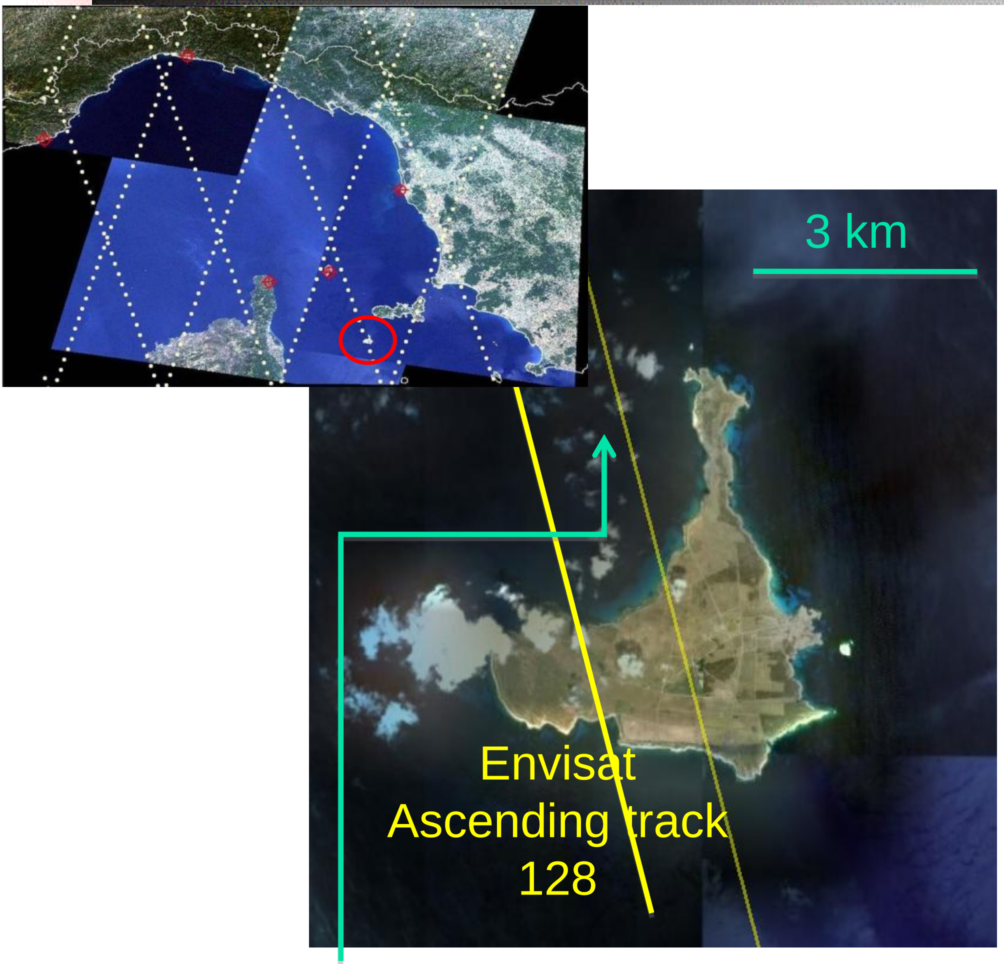
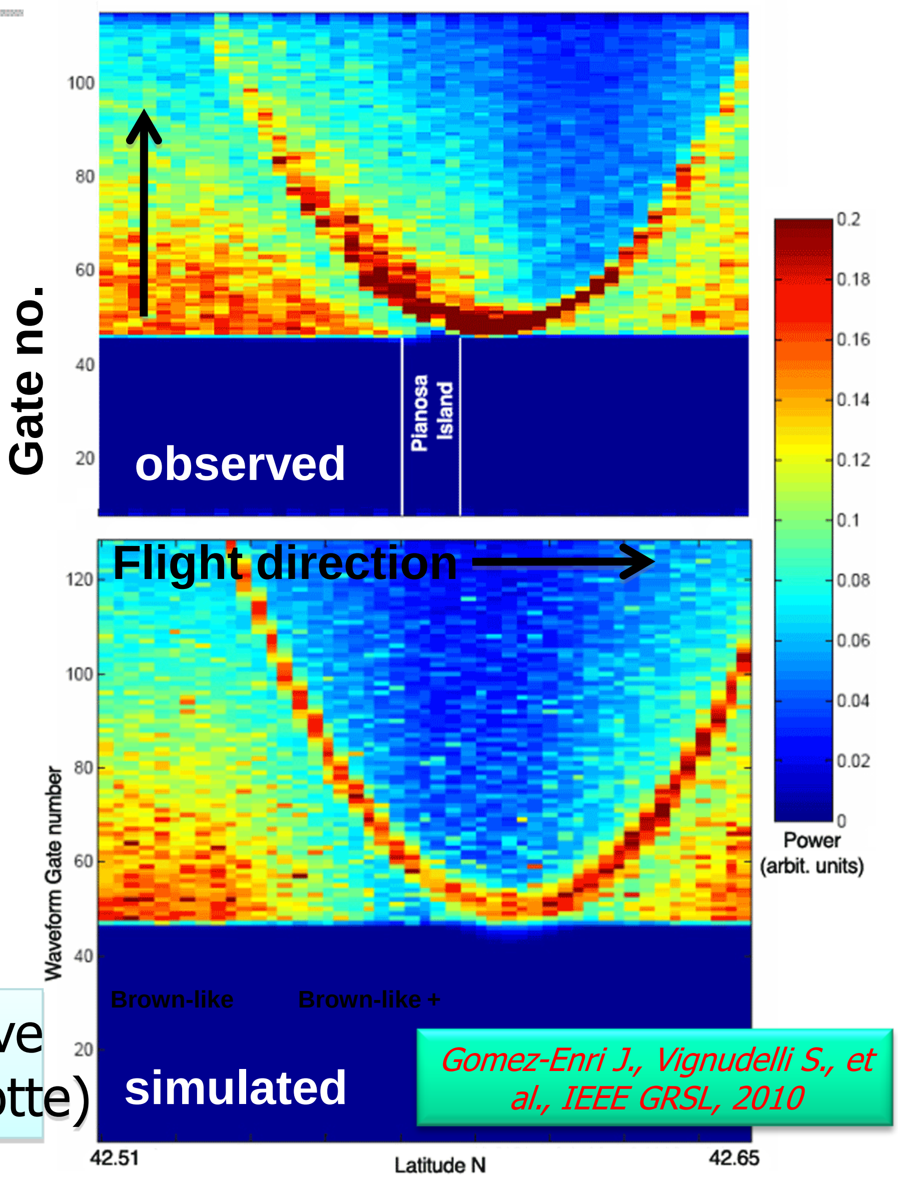
- We observed effects of land and effects of calm waters in the coastal strip
  - Land normally gives ‘dark’ features (less signal)
  - Calm water cause quasi-specular reflections giving peaky waveforms
- These features migrate in the waveform/gatenumber space following hyperbolae (a parabolic shape is usually a good approximation)
- Because we know the form of the hyperbolae (the speed of the satellite) we can accurately predict its position across a set of waveforms
- Features are reproduced by a simple model of the land/ocean/calm waters response
- The idea is that this should allow removal of the land/calm waters contamination prior to retracking

Example of Pianosa Island





In cycle 49, bright target due to wave sheltering in NW bay (Golfo della Botte)

Gomez-Enri J., Vignudelli S., et al., IEEE GRSL, 2010

Innovative Retracking concept – using information in adjacent waveforms

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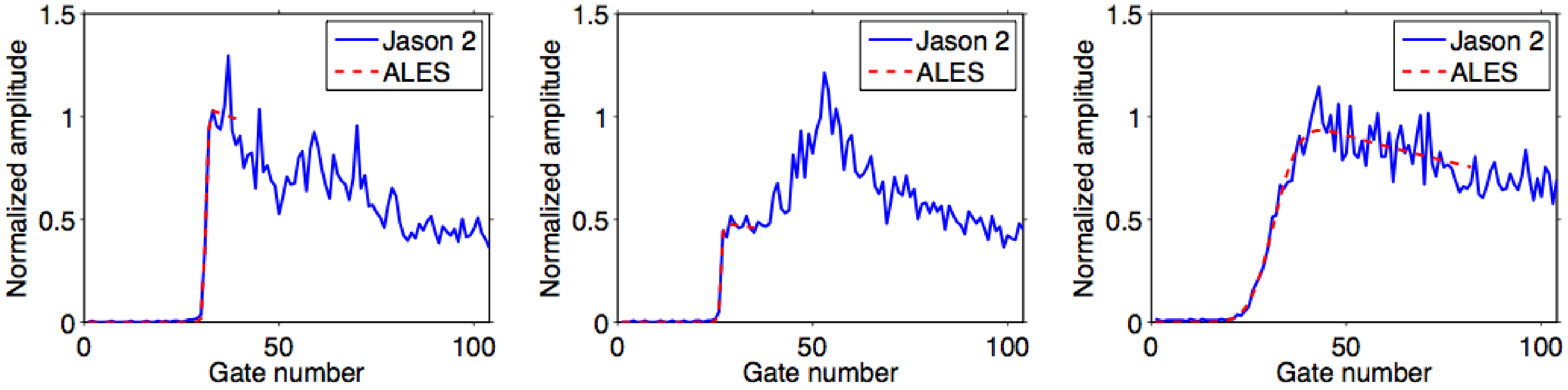
- The hyperbolic "Pre-tracker" to fit and remove bright/dark targets is an example
- Another example is the Bayes Linear retracker
  - Based on the application of Bayesian methods
  - The idea is to treat the posterior from one waveform as the prior for the next
- Both these have been designed within COASTALT and prototyped but not still optimized
- This is a most promising field, already identified in Phase 1 and the difficulties in the development and implementation of some of the ideas tested (Bayes Linear Retracker, 2-D retracker) should not deter from pursuing further development, with the hope of achieving a full validation of these innovative techniques.

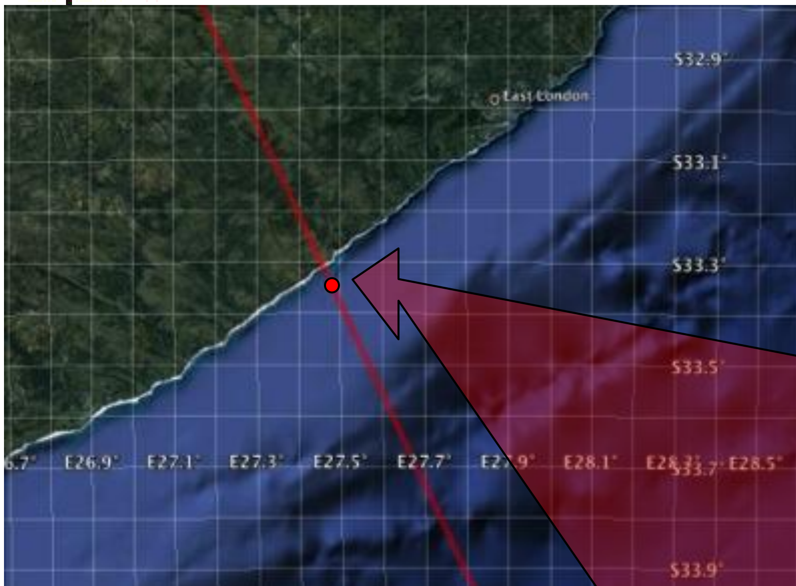
ALES: a new subwaveform retracker

- 1) Leading Edge detection (based on difference of consecutive gates)
- 2) First pass: retracking of subwaveform until the end of the leading edge
- 3) Adaptation of subwaveform depending on initial estimation of SWH
- 4) Second pass: retracking of new subwaveform and precise estimation of Epoch, SWH and Sigma0

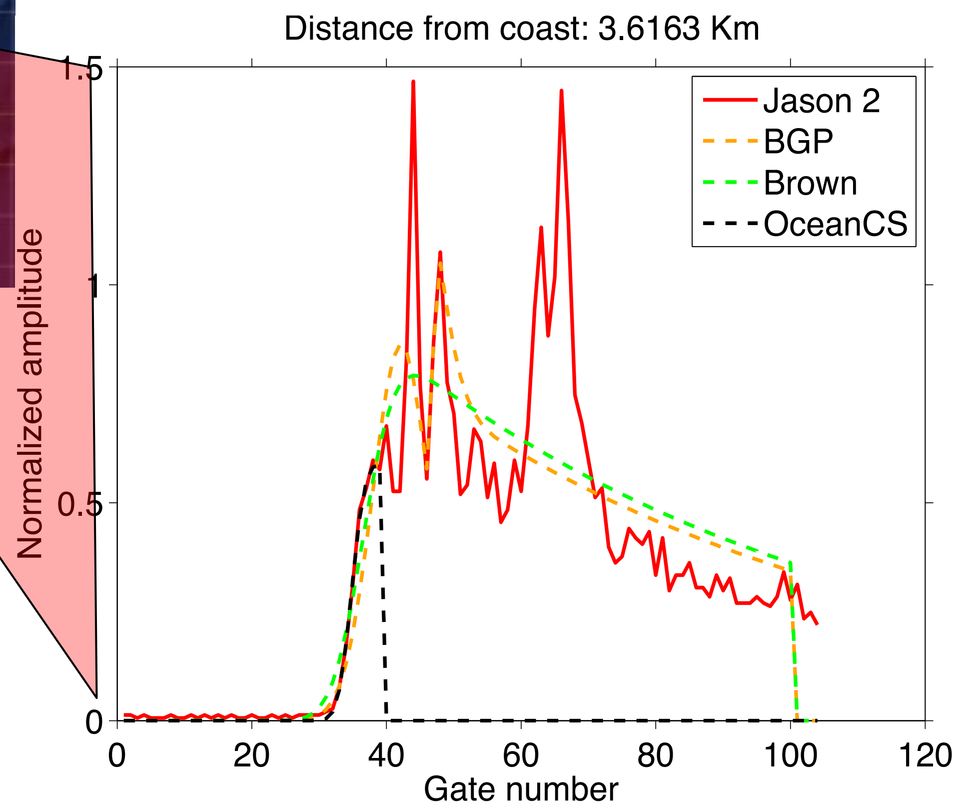
Estimation: Least-Square Estimator, convergence found through Nelder-Mead algorithm [(Nelder & Mead, 1965), Halimi (2013)]



Retracking – an example



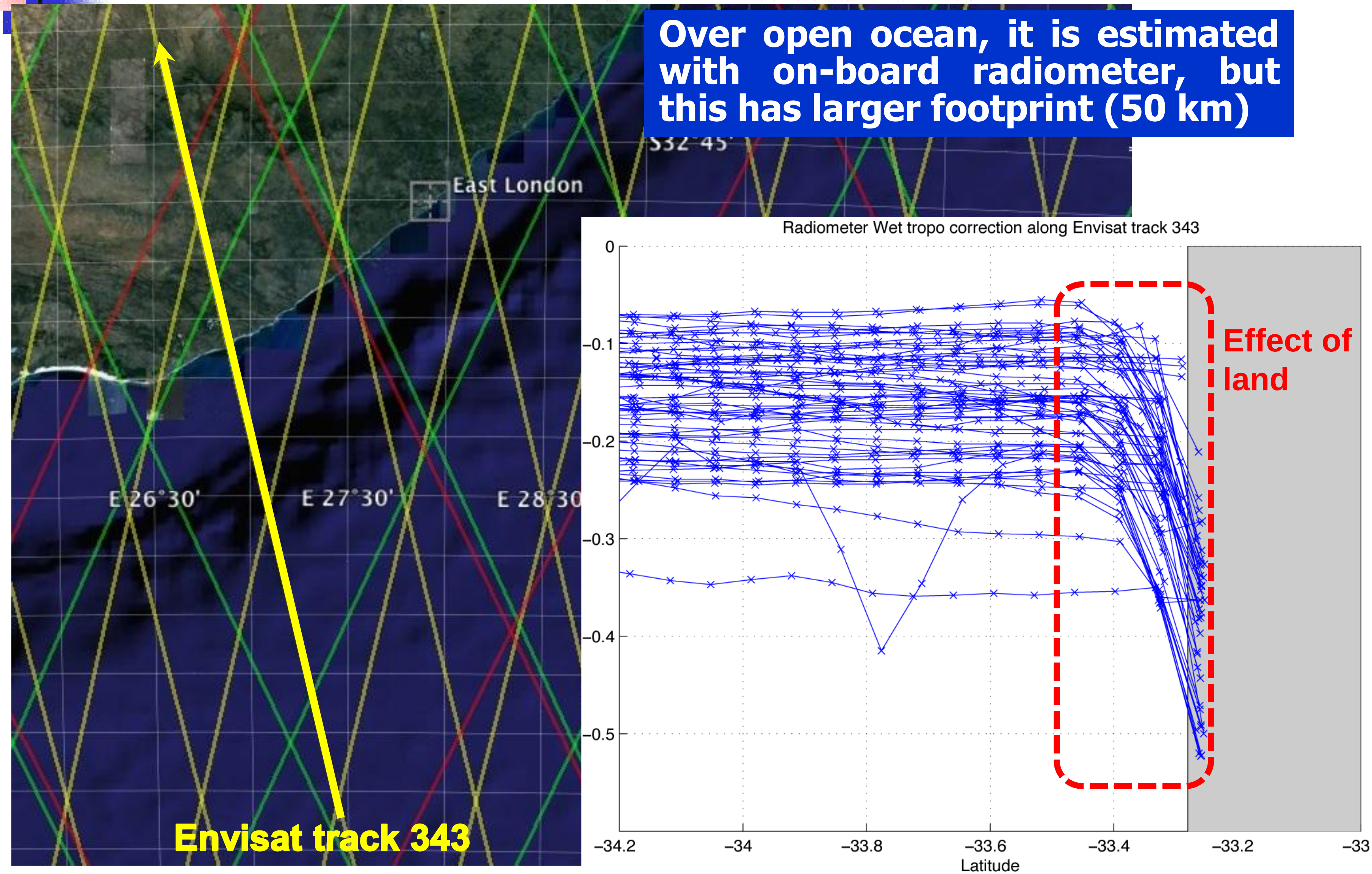
Jason-2 Example



Jason-2 pass 096 over the coast of South Africa and example of **coastal waveform** for cycle 83 and its retracking with various models: **BGP (Halimi et al., 2013)**, **Brown (1977)**, **OceanCS (Yang et al., 2012), ALES (Passaro et al., 2013)**

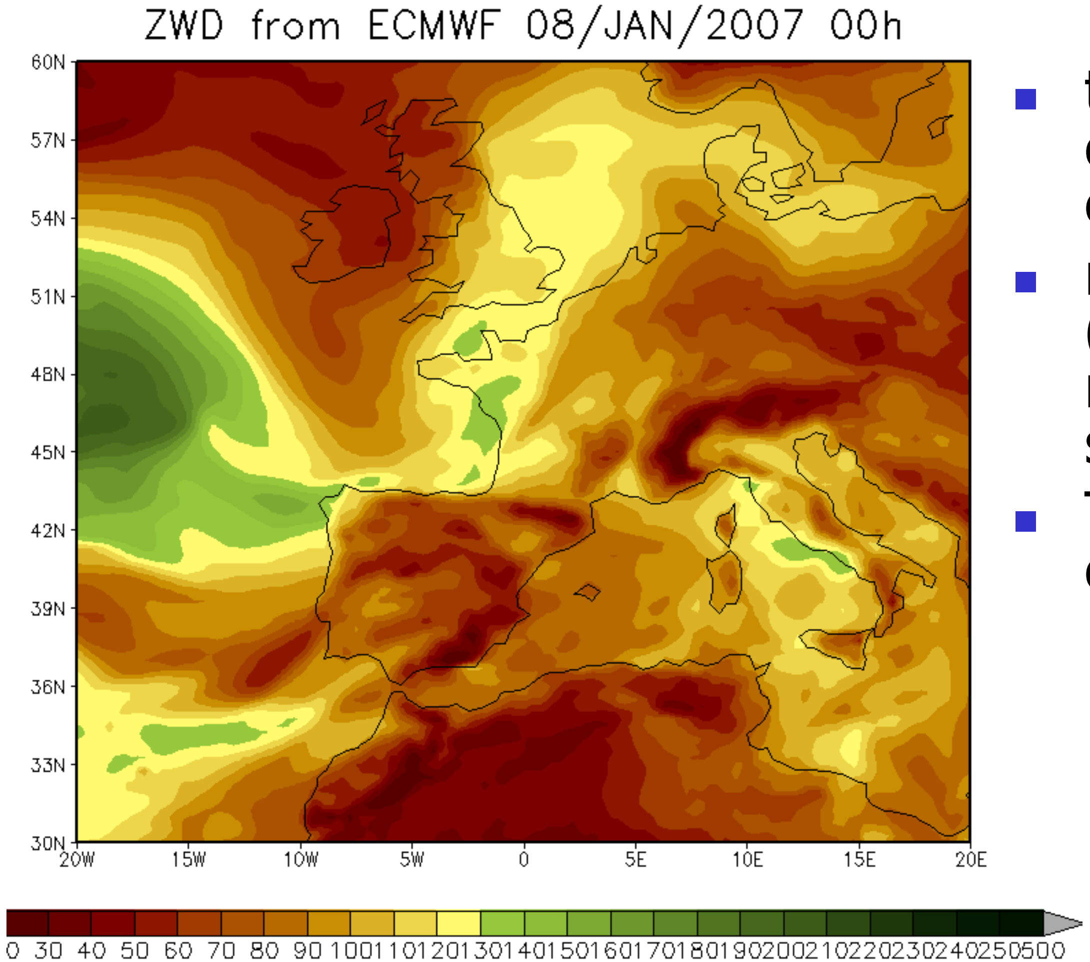
Wet Tropospheric Correction corrects for path delay due to water vapour

Over open ocean, it is estimated with on-board radiometer, but this has larger footprint (50 km)



Source: Alticore-Africa

We can use the model but ....



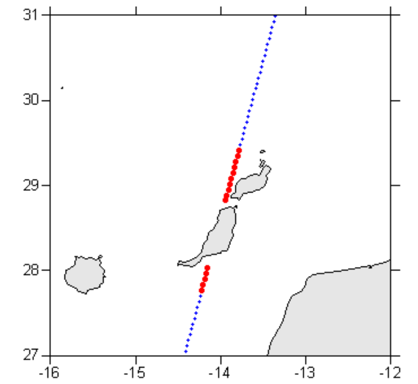
- the wet tropo varies rapidly especially in the coastal environment
- models like this from ECMWF (ZWD=Zenith Wet Delay) may not capture its dynamics and short-scale variability.
- This figure illustrates an example from the model.

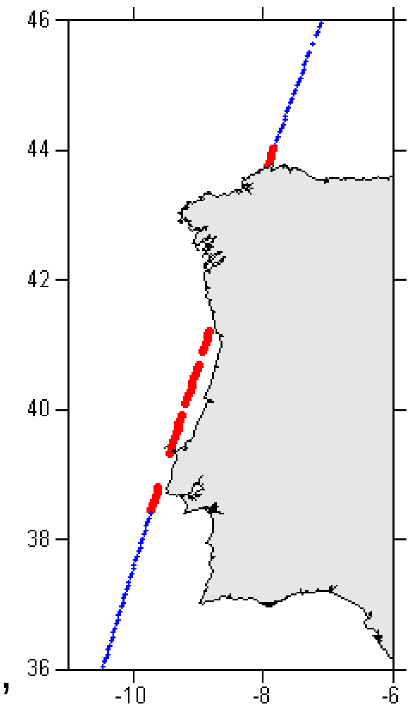
Lesson learned III – Re-visiting Wet Troposphere correction

- Three approaches to improve this correction
  - Extending (linking) models with radiometer observations (this is the so-called Dynamically Linked Model approach) - implemented in COASTALT processor
  - Modelling/removing land effect (being developed by PISTACH and NASA)
  - GNSS (GPS) based, develop by Univ. Porto – implemented in COASTALT processor

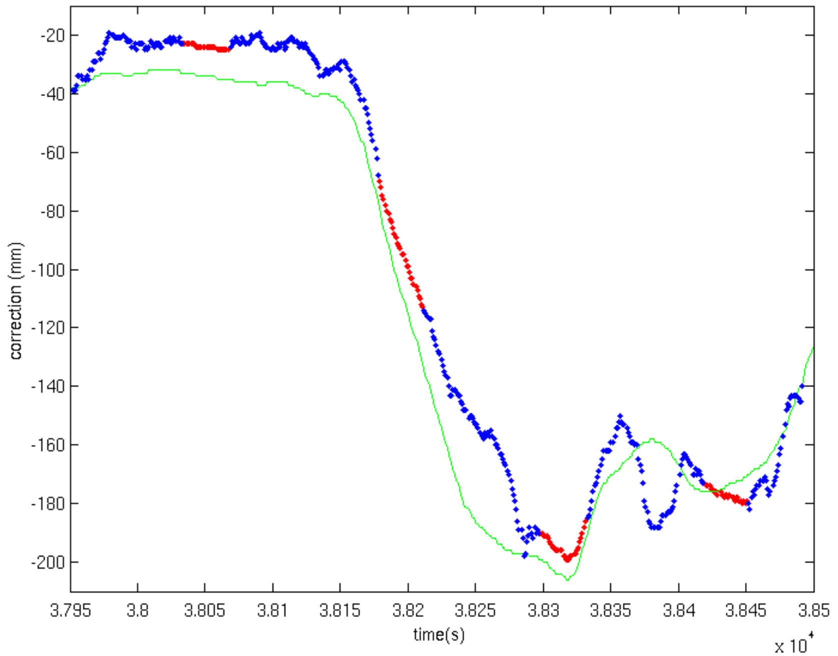
Linking radiometer and model : DLM Approach

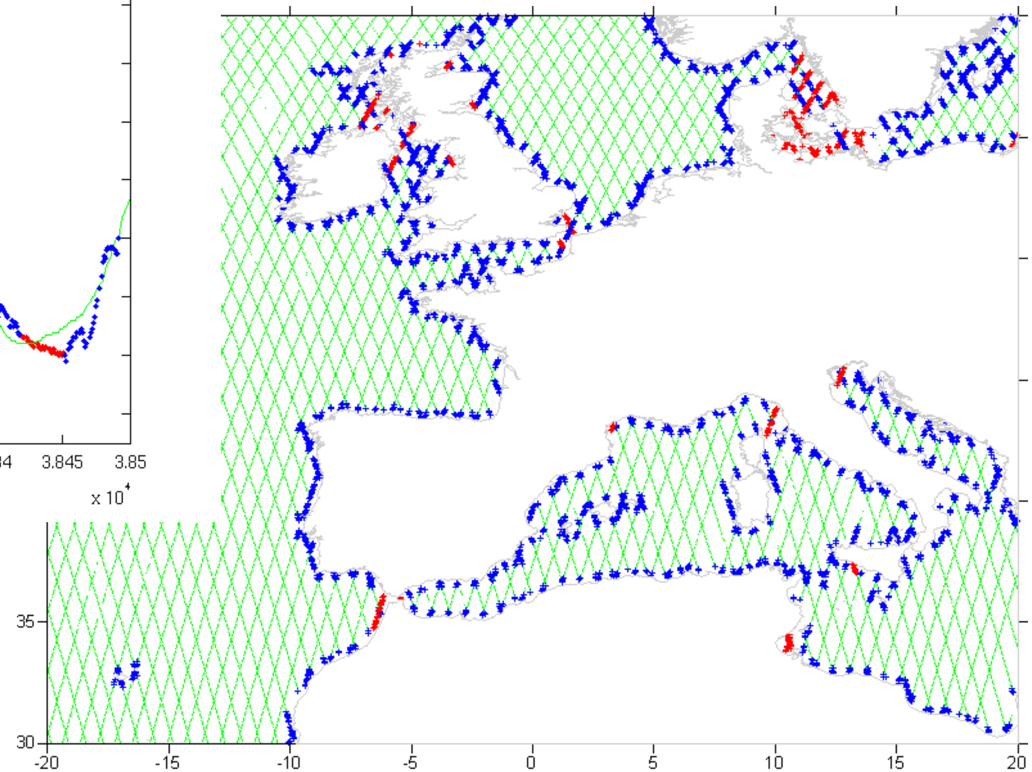
- Simple method requiring only GDR fields:
  - Radiometer and ECMWFderived wet corrections
  - MWR flags (LAND flag + MWR QUAL flag for Envisat)
  - Optional information: distance to land
- Data are split into segments
- In each segment identifies “land contaminated zones”
  - Flags only
  - Flags + distance to land
- Two types of algorithms:
  - Island type or ‘double-ended‘ algorithm
    - valid radiometer points on each side of the segment
    - Model field is adjusted to the radiometer field, at the beginning and end of the land contaminated segment, by using a linear adjustment (using time as interpolation coordinate)
  - Continental coastline type algorithm (‘single-ended’)
    - only valid radiometer points on one side of the segment
    - Model field is adjusted to the radiometer field, at the beginning or at the end of the land contaminated segment, by using a bias correction





DLM Approach - Results





- Bue – corrected points
- Red - uncorrected points

Wet tropo - GPD technique

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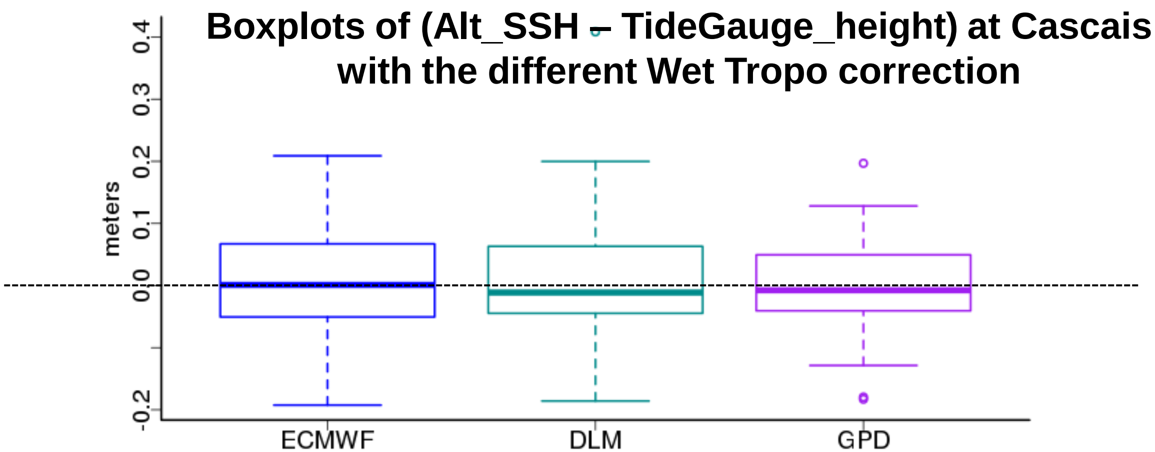
- First, estimate STD - Slant Total Delay from GPS observations
- Then, map into ZTD - Zenith Total Delay using MIT GAMIT software and Vienna mapping functions
- Estimate 'dry' component (ZHD) from meteo data · derive 'wet' component (ZWD)
- Needs a good network of coastal stations, and possibly coincident meteo observations
- ZTD accuracy – currently ~3 mm. Wet accuracy depends on how good the 'dry' is – but we can get to less that 1 cm.



M.J. Fernandes et al., IEEE GRSL, 2010

Big discrepancies between LOCAL and GLOBAL tidal models

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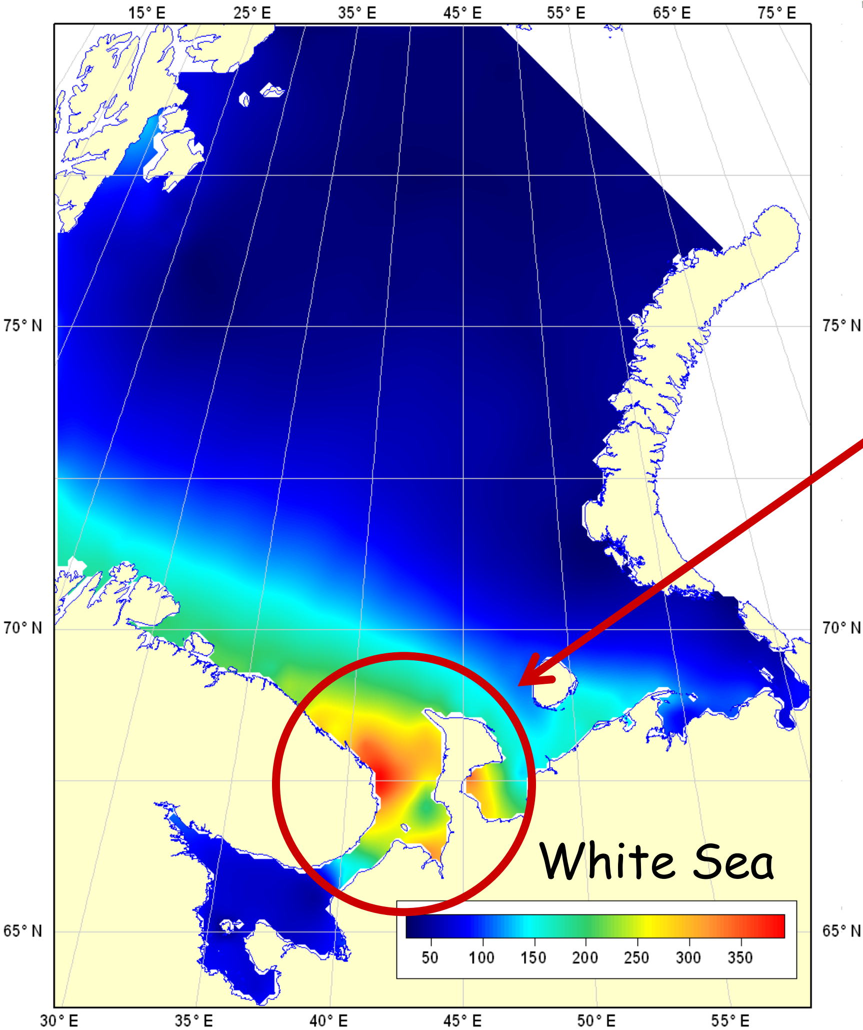

Example: Difference between a local tidal model and a global one (GOT00) over the White Sea
(courtesy of S. Lebedev / A. Sirota for ALTICORE)

- Example of regional tidal model from HRC (Russia)
- Difference of order of meters when compared with GOT00 (global)
- Accurate tidal predictions are usually difficult in shallow waters
  - Amplitudes are large
  - Wavelengths are short
  - Nonlinear processes generate many new constituents
- Note that some users may not want this correction to be applied to the SSH fields for their applications.

Lesson learned IV – Improving or replacing global tidal models

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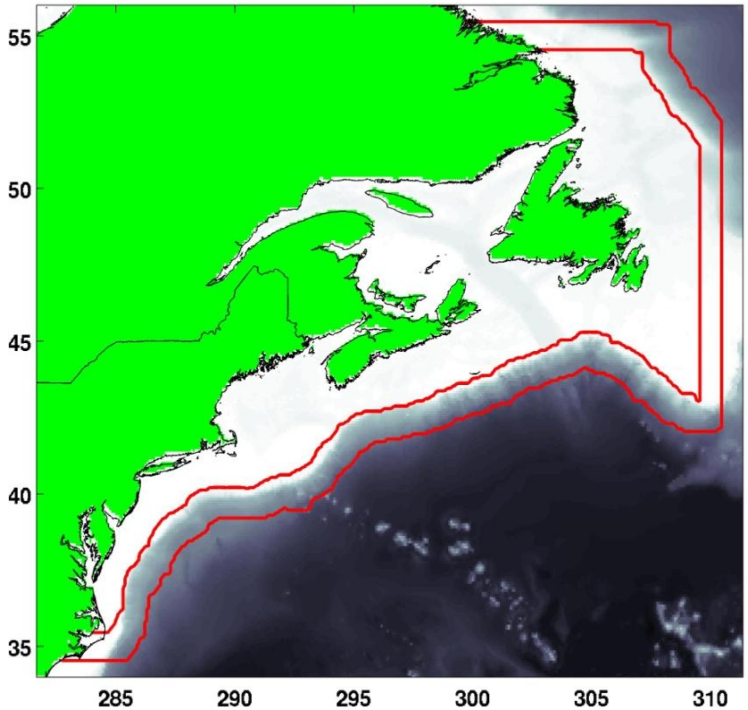
- One approach for the tidal correction is to use local models
  - Hydrodynamical modelling + data assimilation of tide gauge and high resolution altimeter data and use of regional bathymetry, e.g. T-UGOm code (ex- Mog2D) in NW Mediterranean
- Another approach is to improve global tidal models
  - Quasi-empirical analyses of altimeter data, e.g. EOT10a, GOT4.7



- A novel approach Egbert & Erofeeva's review talk at 5th Coastal Altimetry
  - Huge improvements with a Nested High-Resolution Data Assimilation Modeling + a simple scheme to merge the HR solution with regional and global models

Courtesy by Egbert, OSU

Aliasing due to short-period ocean response to meteorological forcing

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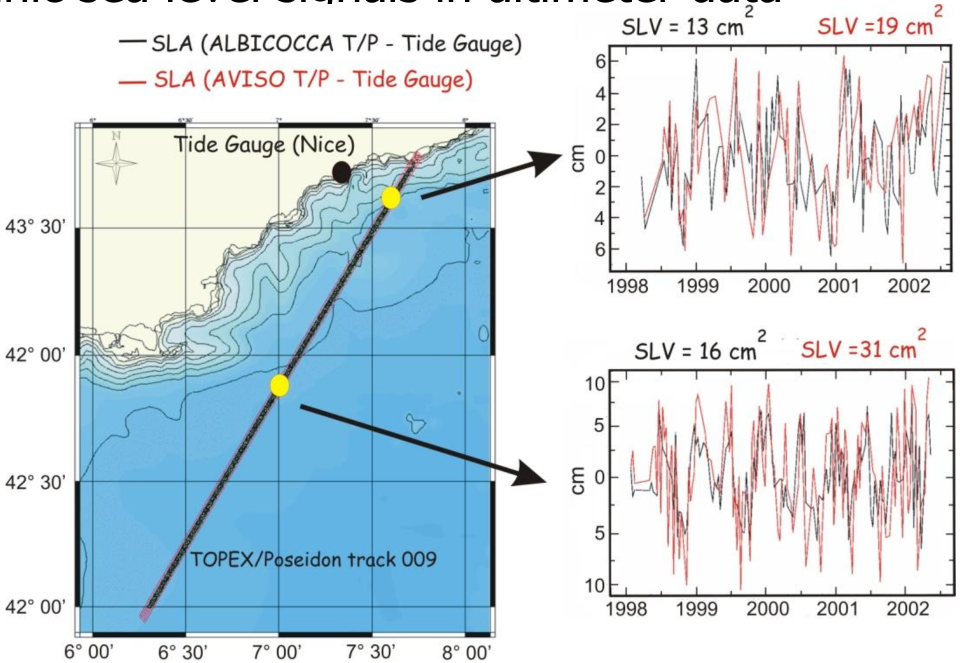
- The sea surface rises and falls due to changes in air pressure and winds
- IB approximation used in open ocean
  - formulates merely the hydrostatic equilibrium between the sea level and the applied atmospheric pressure gradients.
  - It totally ignores wind-forced sea level variations
- Significant departures can be observed over continental shelves and marginal seas.
- This is a major problem when estimating the seasonal or longer time scales of oceanic sea level signals in altimeter data



The variance of the residual time series indicates that the model performs systematically better than the IB to explain the tide gauge observations, and that the reduction is significant even in the shelf area

Lesson learned V – De-aliasing using models

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- IB correction to be modelled dynamically, correcting high-frequency component
- Option 1: Use archived regional surge fields based on the most recent forecast met information typically a few hours old
  - Problem is that large regions would not be represented
- Option 2.: Use hindcast information several weeks later (or however later is considered acceptable for the altimeter data processing)
  - Assuming that the hindcast data are by then of higher quality than the stored forecast information (probably unlikely as meteorological re-analyses are usually performed over a considerable time later).
- Option 3: Use a global barotropic model forced with global met information.
  - Models presently available include T-UGO (MOG2D)
  - finite element model with a high spatial resolution at the coastline
  - e.g. 15 km elements for the global model, 4 km for regional models)

Sorting out coastal altimetry – in three steps!

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- On the Shelf (100-0 km): main problem is the correction of **tides** (and HF atmospheric effects)
  - NEED **GOOD TIDAL & HF MODELS**
- Coastal strip (30-0 km): radiometer-derived **wet tropospheric correction** affected by land vicinity
  - NEED GOOD TIDES/HF + SOME **OPTIMIZED COASTAL WET TROPO**
- Up to the shore (10-0 Km): the altimetric echoes **waveforms** affected by land & specular reflections
  - NEED TIDES+WET TROPO+ **DEDICATED WAVEFORM RETRACKING**

Coastal Altimetry is progressing in processing /products

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- More/better (and new) datasets are being produced
  - New/improved retrackers
  - New/improved corrections
  - Reprocessed products now available (PISTACH, XTRACK, COASTALT (now eSurge))
  - Validation and quality control started

Coastal Altimetry Product (1)

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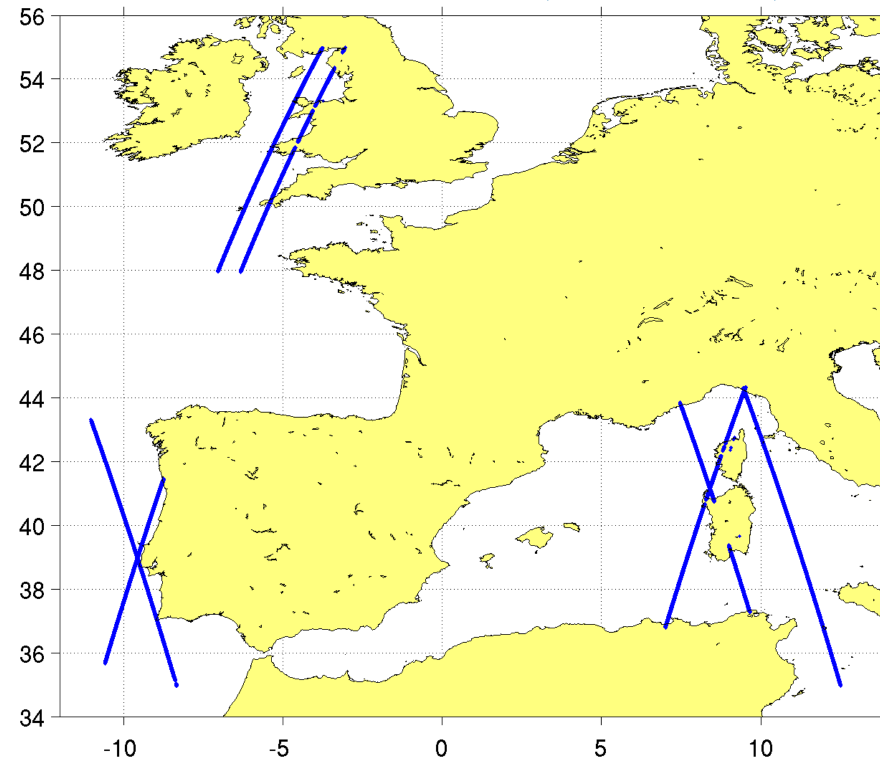
COASTALT/ESA

- Developed a baseline processor for Envisat
  - User-configurable and modular software in view of a global reprocessing, expandable to future missions
  - Useful tool for further research and development work on retracking techniques and corrections
  - Reads ENVISAT L2 SGDR files
  - Retracks all waveforms with different models
  - Generates corrections at 18Hz
  - Allows addition of any user-generated corrections
  - Fully Documented
  - Now at Revision 73 ! (just to give an idea of the complexity of this software)
- Coastal geophysical Data Records (CGDRs)
  - Output files in NetCDF
  - Contain output of all retrackers (h, swh, sigma0) and full range of corrections at 1 Hz and 18 Hz
  - Product Specification and User handbook document available
  - v2.0r3 (latest) freely available from web site - www.coastalt.eu
- Retracking & Corrections
  - Optimizing and validating specialized Brown, Specular and Mixed, plus innovative retrackers to get closer to coast
  - Making operational the new approach to Wet tropospheric correction using GNSS/GPS data



http://www.coastalt.eu

We tested selected tracks around Indonesia within RESELECASEA Project

Coastal Altimetry Product (2)

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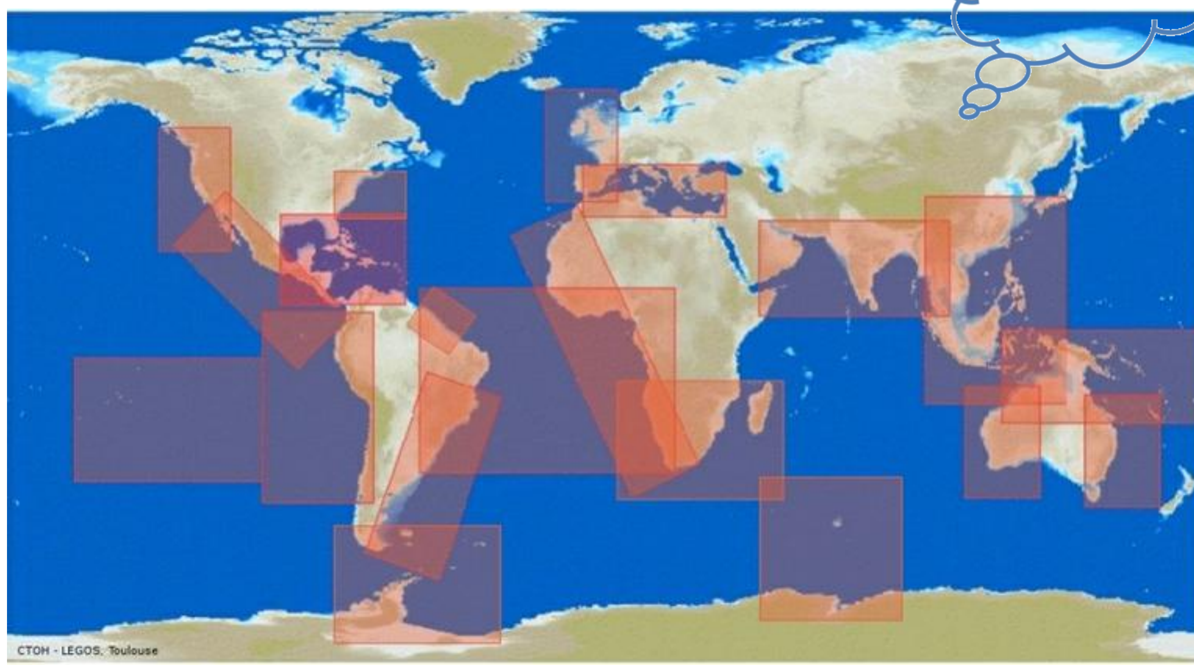
XTRACK/CTOH

CTOH
Legos

- SLA time series along a nominal ground-track
- MSSH consistent with SLA
- Geophysical (tidal and DAC separetly) corrections included
- Distance to nearest coast
- Non-retracked products
- Access to simple diagnostics

- 1 Hz (7 km) regional operational products
- T/P & Jason 1/2 everywhere, Envisat and GFO on request
- 20 different regions available

Indonesia is one of the region covered!!



NEW!

- Experimental Product 20 Hz (350 m) now available on request for expert users

http://ctoh.legos.obs-mip.fr/products/coastal-products/

Coastal Altimetry Product (3)

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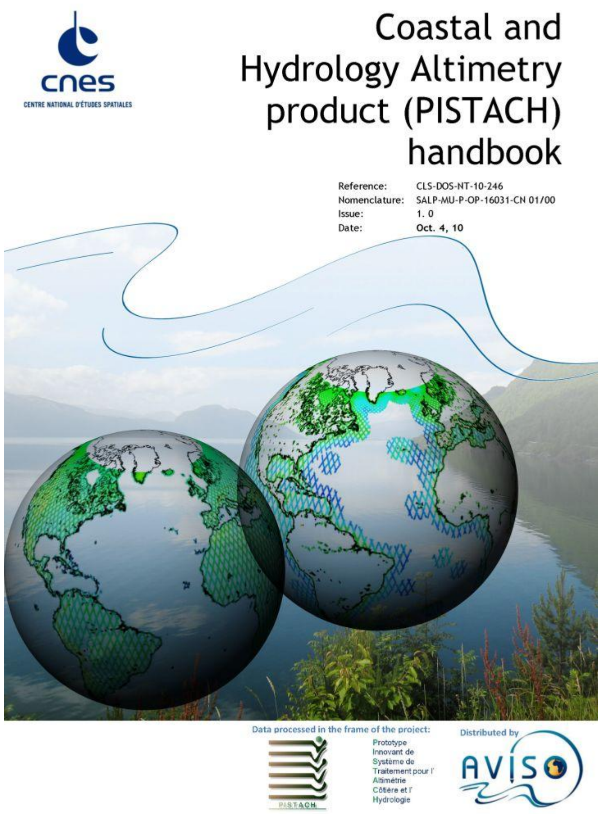
PISTACH/CNES

- Global product distributed since 2008
- at both 1 HZ (7 km) and 20 Hz (350 m) in Netcdf format
- Only Jason-2
- No SLA time series (left to the user choice of corrections, re-trackers, etc.)
- Several MSSH
- New/improved Geophysical corrections included
- Retracked products
- Handbook



- A call in June 2011 for reprocessing over selected areas – 3 selected
  - Agulhas current with the support of Beal (in situ) and Collard (SAR)
  - Florida Strait with the support of Kourafalou
  - East US coast with the support of Vandemark
- SLA time series for 3 zones computed by CLS + Noveltis and Legos
  - Calculated from 20 Hz measurements and provided with a final sampling of 5 Hz
  - Editing + low pass filtering
- 3 more areas selected in 2012

http://www.aviso.oceanobs.com/en/data/products/sea-surface-height-products/global/coastal-and-hydrological-products/index.html

Coastal Altimetry is progressing towards applications

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- These recent data products (either retracked or reprocessed) are closer to the coast with high resolution than previous AVISO data.
- They are exploited by scientists and other users
- Mostly used IN COMBINATION with other techniques, or in assimilation schemes, where they can successfully integrate in situ and/or model data.
- Results are coming out, applications are pioneered
- I will show some examples

Coastal altimetry is a legitimate component of a coastal ocean observing system!

Cipollini P., Benveniste J., Gommenginger C., Griffin D., Madsen K., Mercier F., Miller L., Pascual A., Ravichandran M., Shillington F., Snaith H., Strub T., Vignudelli S., Wilkin J., Vandemark D., Woodworth P., **The Role of Altimetry in Coastal Observing Systems**, In Proceedings of Conference OceanObs'09 on Sustained Ocean Observations and Information for Society (J. Hall, D.E. Harrison and D. Stammer Editors), Venice, Italy, 21-25 September 2009, ESA Publication WPP-306, Vol. II, doi:10.5270/OceanObs09.cwp.16 2010.

Improved Coastal Altimetry for better Monitoring of Regional Sea Level Trends

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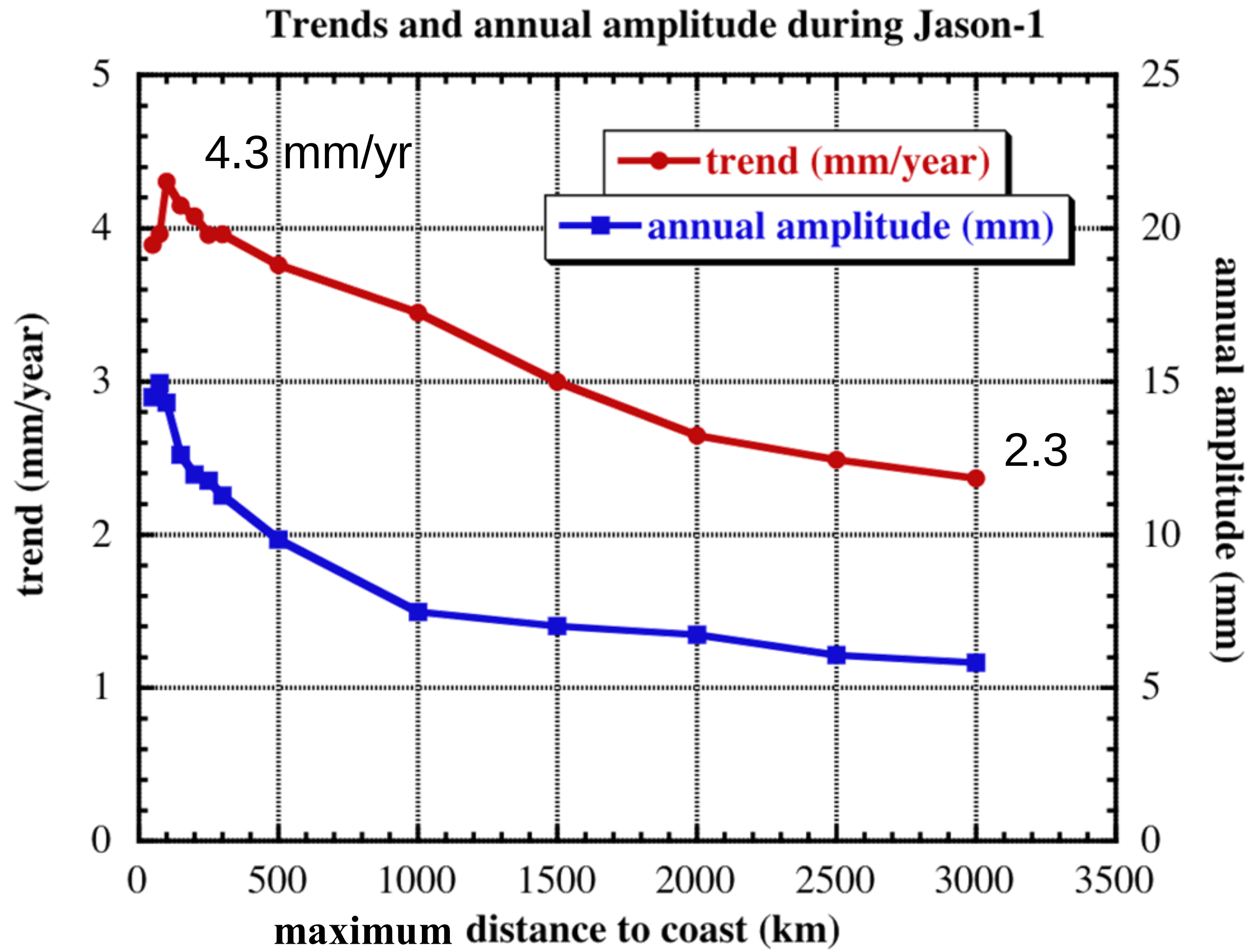
Fernandes, M. J., J. Benveniste, and S. Vignudelli (2011), *Eos Trans. AGU*, 92(16), doi:10.1029/2011EO160004



Courtesy by R. Scharroo, Altimetrics

Improved Coastal Altimetry for better understanding of coastal/shelf dynamics

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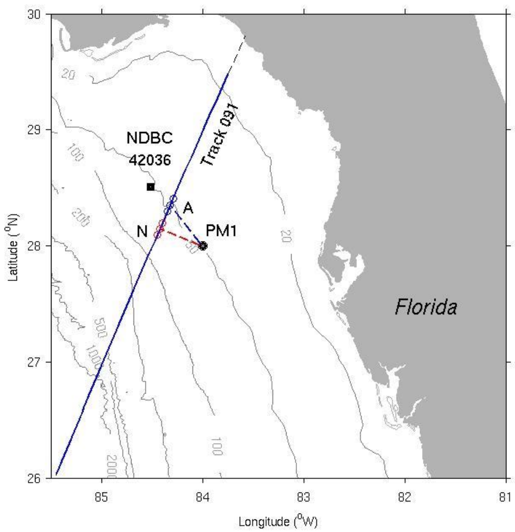
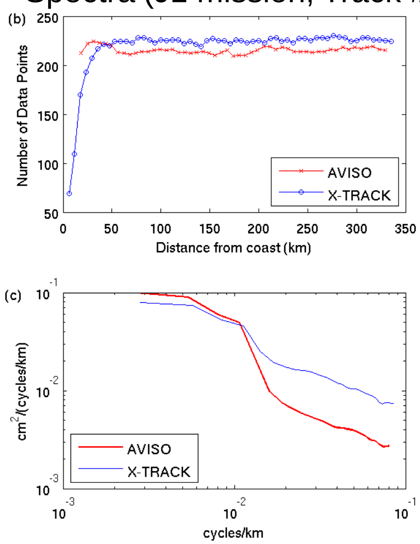
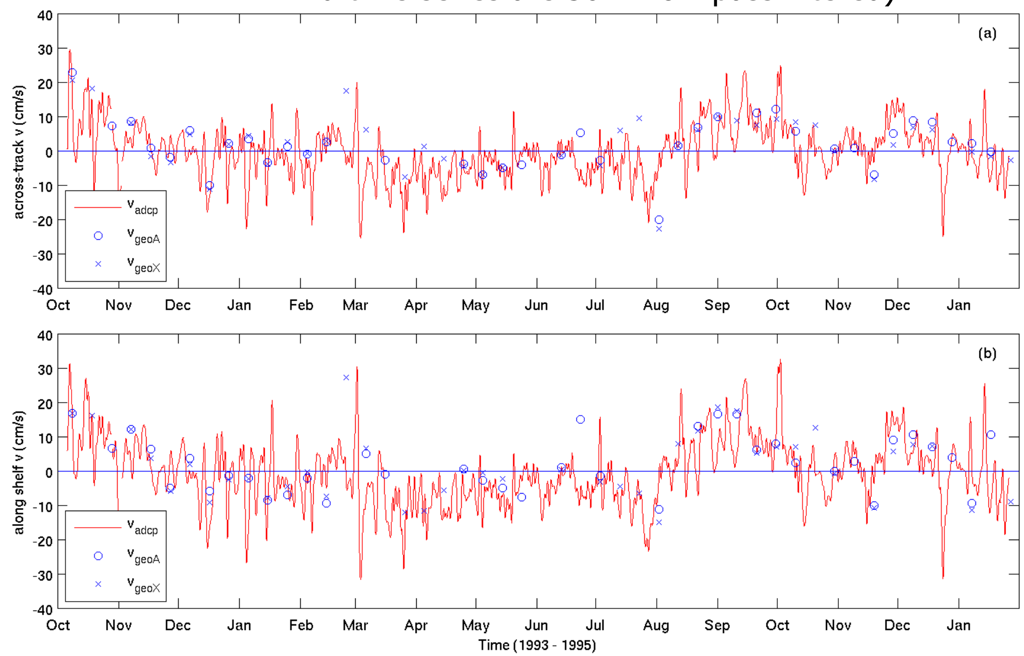
- Case-study of the West Florida Shelf (Gulf of Mexico)
- More data points than the AVISO product, especially near the coastlines.
- More energy in mesoscale activities as seen from the along-track power spectra.
- The rmsd of the estimated and observed velocities range from 7 to 10 cm/s, which is encouraging.



Data Availability and Along-track Power Spectra (J1 mission, Track # 091)



Surface Geostrophic vs. ADCP (4 m) Velocity Anomalies (ADCP and wind time series are 36-hr low-pass filtered)

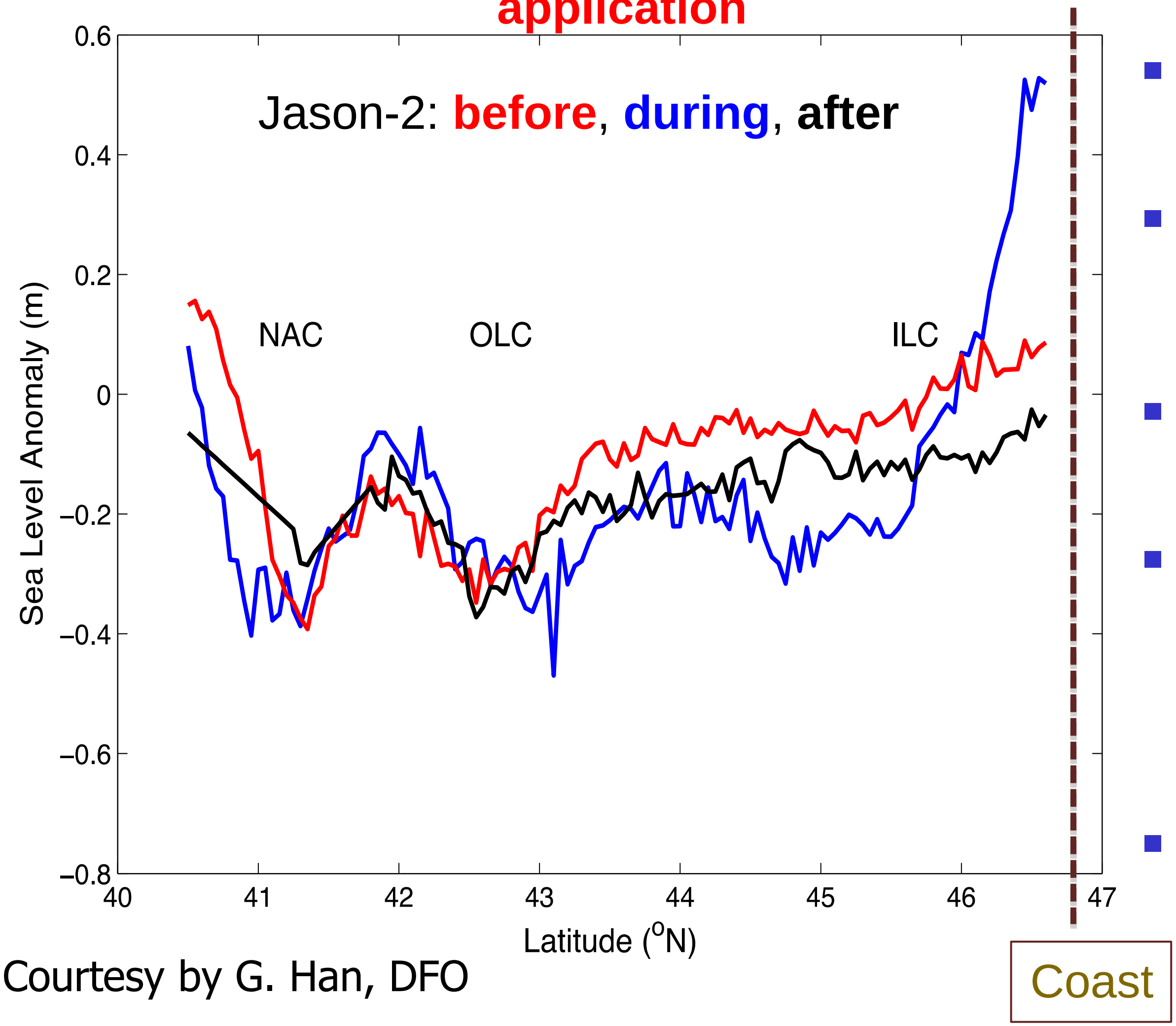


Liu Y., Weisberg R. H., **Vignudelli S.**, Roblou L., Merz C. R.: **Evaluation of the X-TRACK Coastal Altimetry Estimated Currents with Moored ADCP and HF radar Observations on the West Florida Shelf,** in Special Issue “COSPAR Symposium”, Journal of Advances in Space Research, doi:10.1016/j.asr.2011.09.012, 2011.

Improved Coastal Altimetry for storm surge forecasting

Consiglio Nazionale delle Ricerche

storm surges now emerging as crucial application

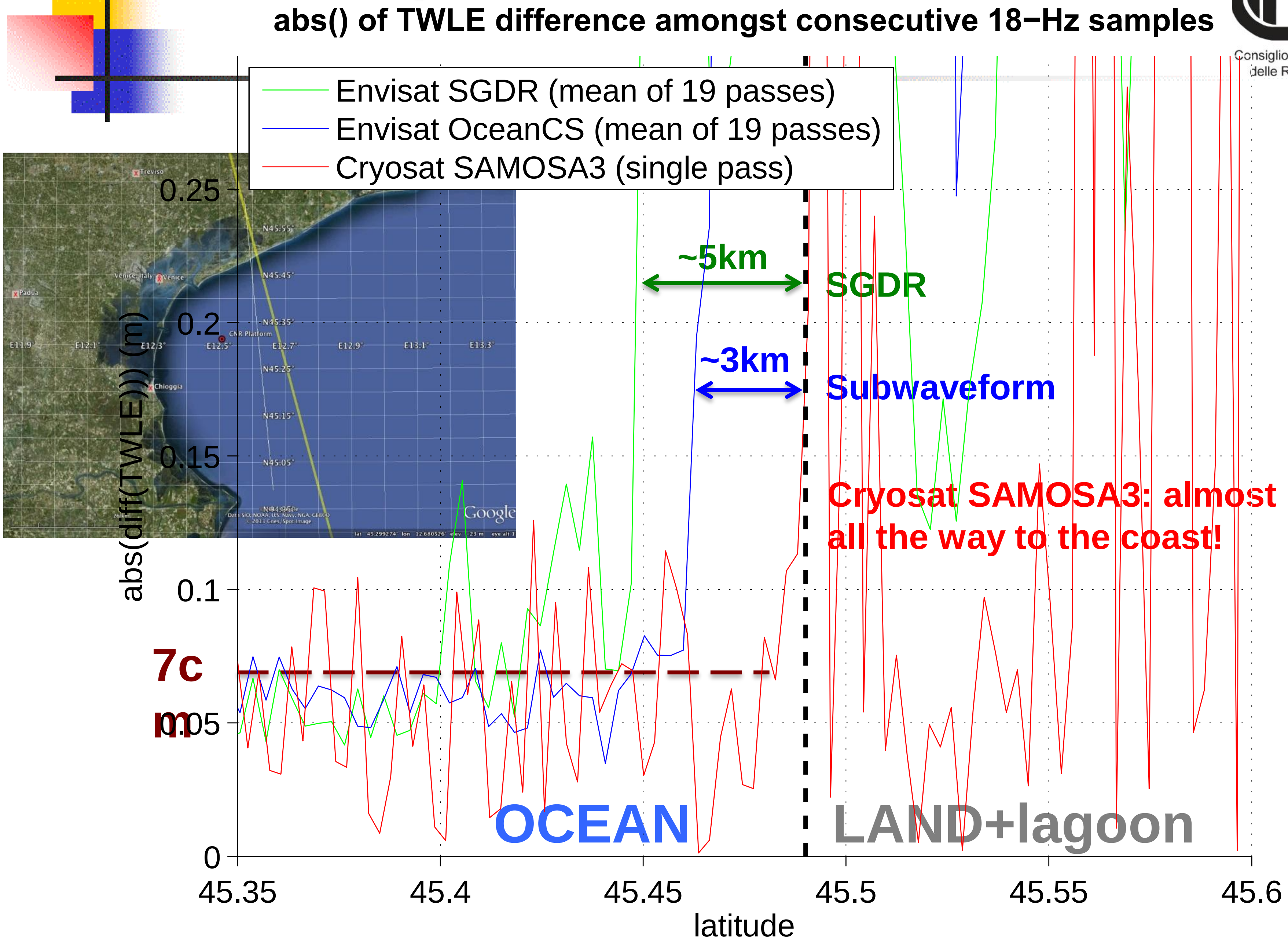


Courtesy by G. Han, DFO

- Coastal altimetry is important as it measures the Total Water Level Envelope (TWLE)
- That's the level you get – inclusive of tides, HF atmospheric effects, wave setup, etc…
- key quantity required by storm surge applications and services
- Of course there is a sampling issue – but altimetry is still useful, in combination with Tide Gauges, to ascertain the modes of variability of the coastal ocean
- ESA has recognized the above needs with two projects:
  - eSurge (Coordinator: P. Cipollini, NOCS, UK)
  - eSurge Venice (Coordinator S. Zecchetto, CNR, Italy)

http://www.storm-surge.info/ http://www.esurge-venice.eu/

Case-study of Venice



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Case-stufy of Venice (cont’d)

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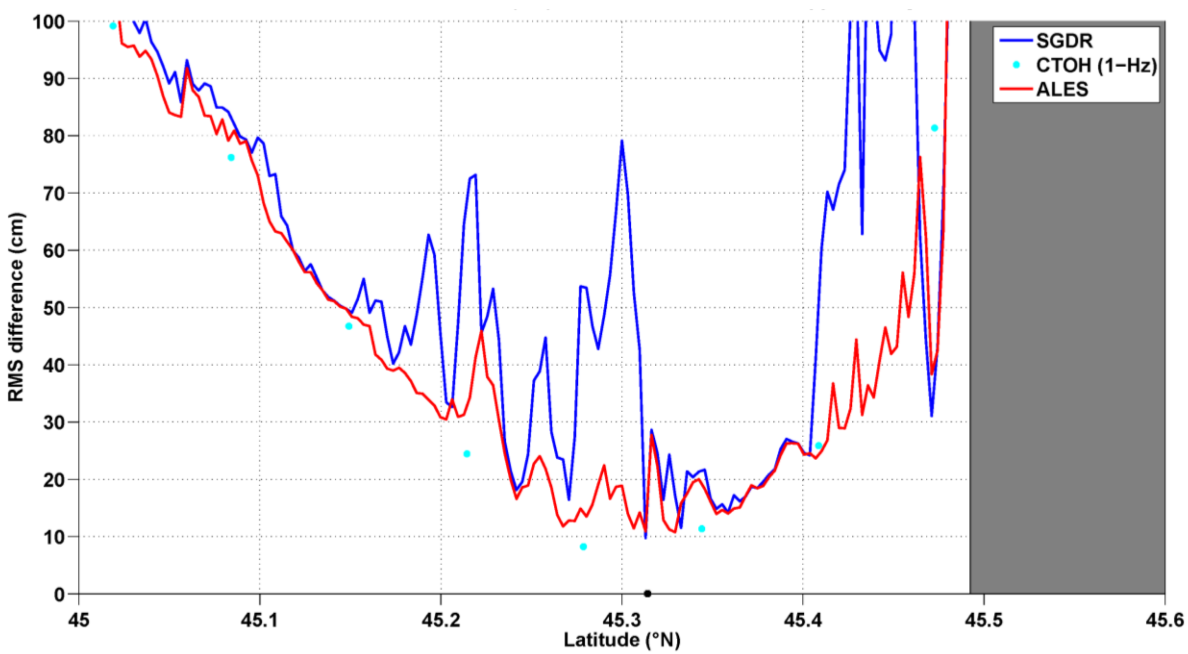

Absolute RMS difference between “Acqua Alta” tide gauge off Venice and Envisat 543 for 3 altimetric datasets

Improved Coastal Altimetry for better evaluation of hydrocarbon basins

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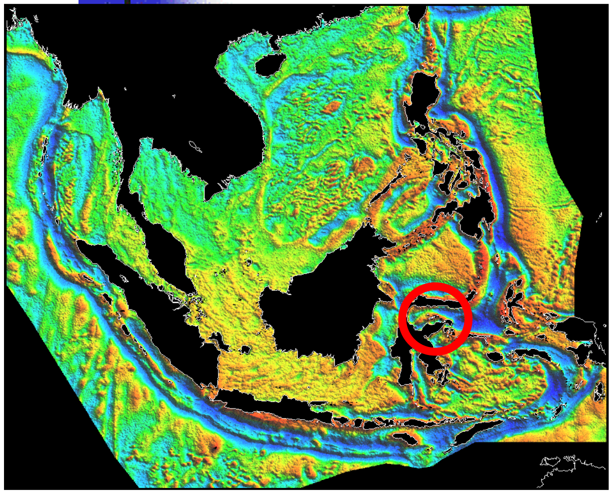

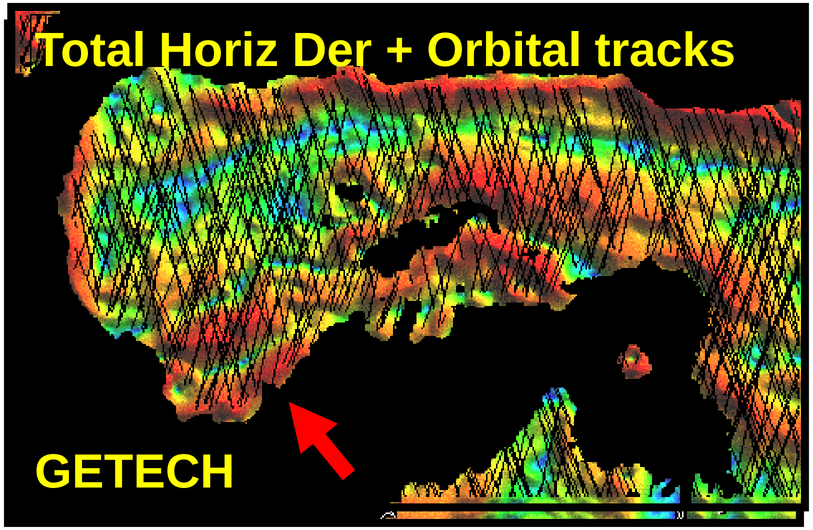

Courtesy by D. Fairhead,

- Free Air Gravity (FAA) is derived from the first vertical derivative of the Sea Surface Height (SSH).
- GETECH Ltd developed a specific processing to resolve gravity anomalies down to 10 km wavelength and to within 5 km of the coast.
- An improved coastal gravity map helps to:
  - better define the extent and structure of offshore basins, especially where little or no other data are available
  - identify subtle but important lineations running from the deep water onto the shelf plan and assist the interpretation of 2D seismic surveys
- The above example in Indonesia shows the existence of possible structures close to the shore.

Revised Error Budget for Coastal Altimetry

Parameter	0-10 km From coast	10-20 km From coast	20-50 km From coast	>50 km From coast
Wet Tropo PD SSH	2 cm	1-2 cm	1 cm	1 cm
SSH Slope	?	?	?	?
SSH spatial scale	10 km	20 km	20 km	20 km
SSH temporal scale	6 hrs	6 hrs	6 hrs	6 hrs
Tidal Correction SSH	15 cm	Over shelf 15 cm		Open Ocean 2 cm
SSH Slope	?	?		?
SSH spatial scale	10-20 km	40 km		50-500 km
SSH temporal scale	6 hrs	6hrs		6hrs
Tracking SSH				
SSH Slope				
SSH spatial scale				
SSH temporal scale				

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Exploiting the synergies between radar altimeters and multi-spectral imaging satellites

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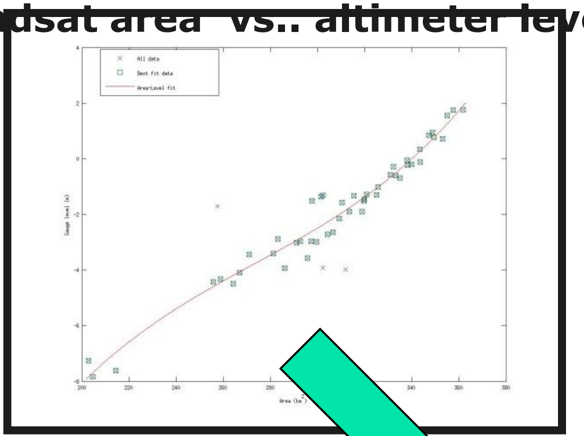
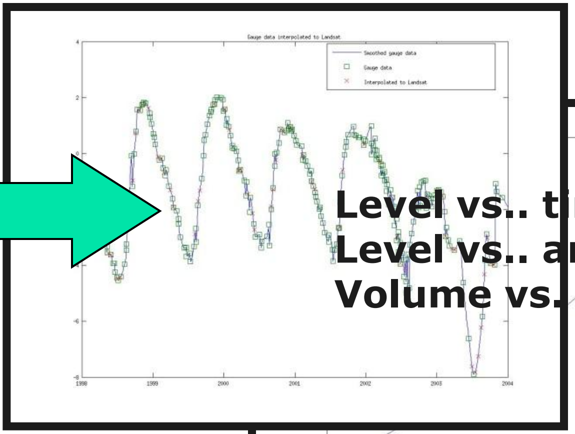
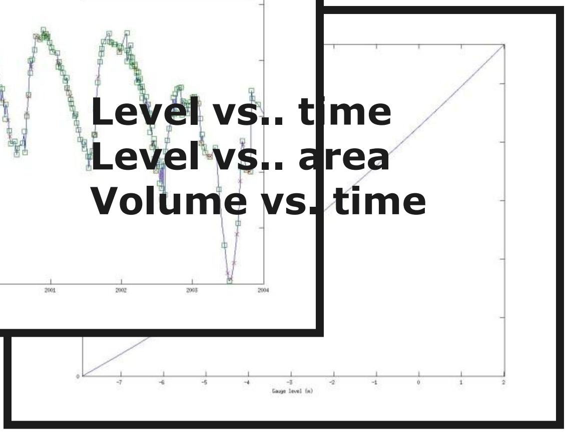
Landsat area vs.. altimeter level



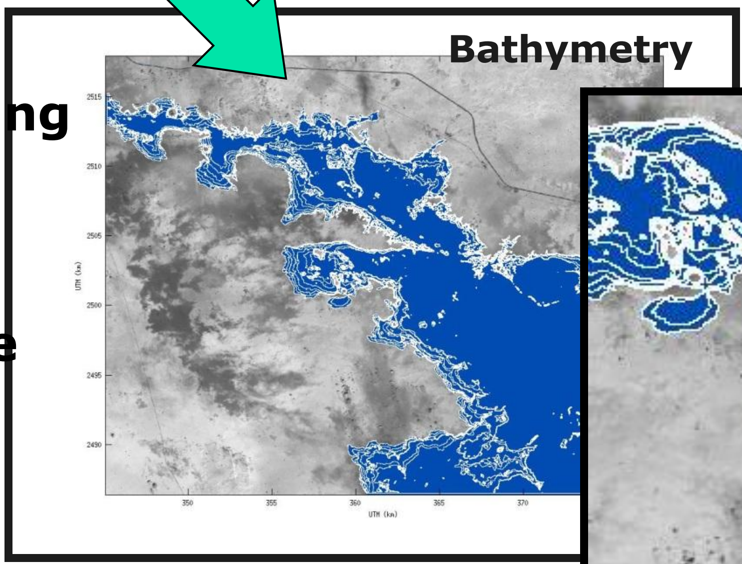


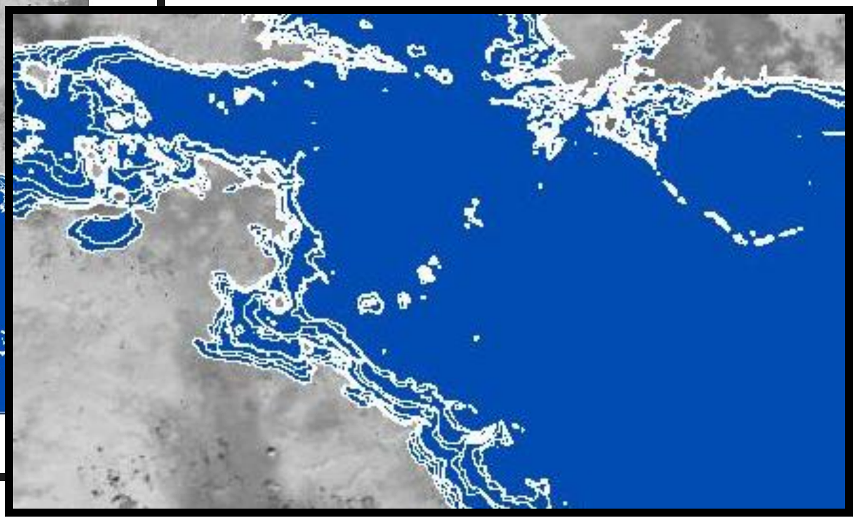


Level vs.. time
Level vs.. area
Volume vs. time

A Completely Remote Sensing Approach To Monitoring Reservoirs Water Volume

Bathymetry





The Near-Specular Altimeter Waveforms of Small Inland Water Bodies

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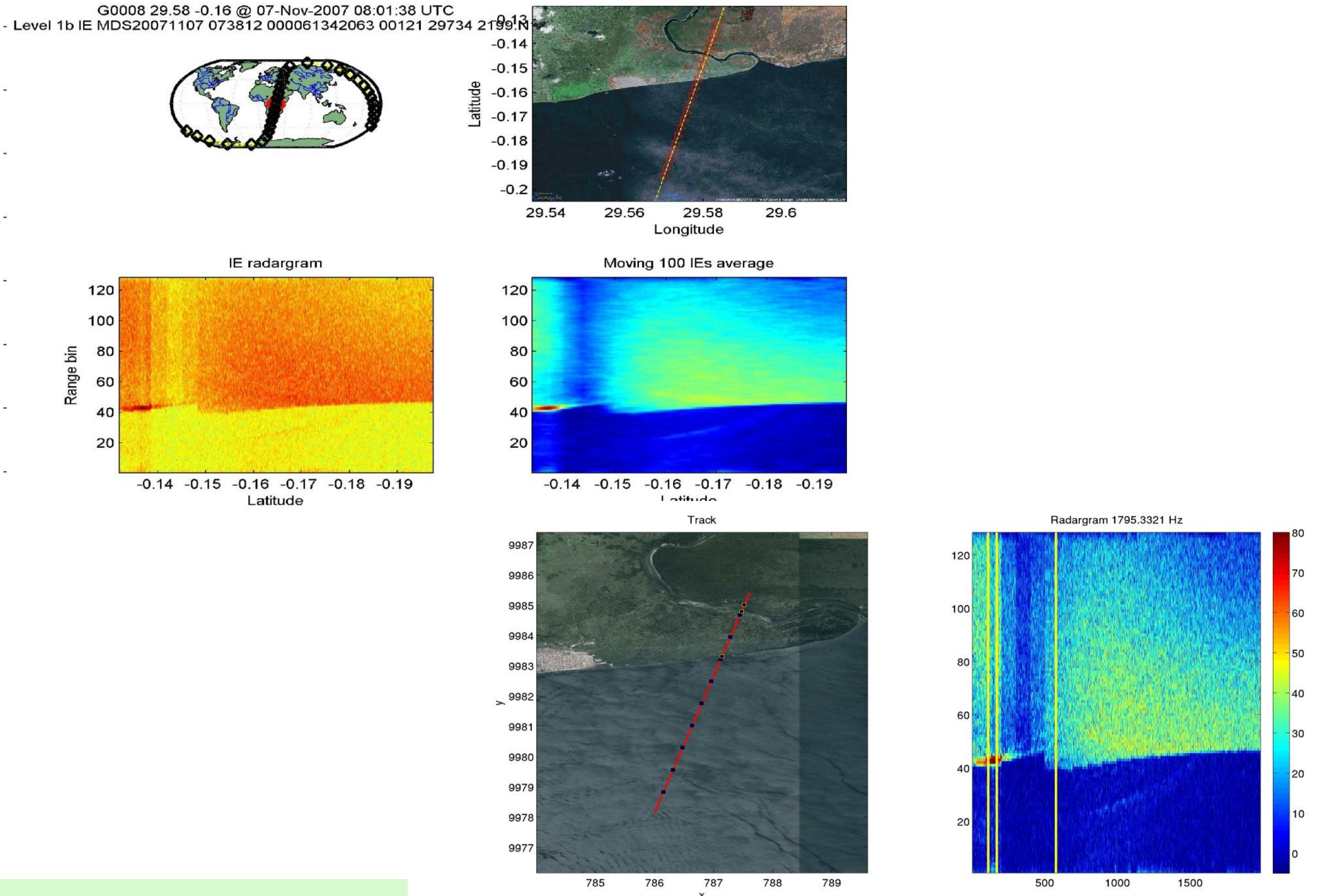

The SAR data revolution: CryoSat-2

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- delay-Doppler (SAR altimeter) allows a much better characterization of short scales
- This is not only useful at the coast: think of areas of strong submesoscale activities, (filaments, very intense fronts across storms), major oil slicks, etc
  - cross-fertilization of ideas with open-ocean scientists (and also inland, ice margins); technical improvements will benefit altimetry in general
- Cryosat-2: designed to measure ice thickness, but collects data in some selected oceanic regions
- Launched 8 April 2010 and carries aboard the SAR/Interferometric Radar Altimeter (SIRAL)
- It uses a new Synthetic Aperture Radar (SAR) Technique which gives 250 m along-track resolution, much higher than conventional altimeters (ERS-2/Envisat RA-2) -
- SAR mode provides high res data over ocean, inland water and coastal zone

CryoSat-2 in the Coastal Zone

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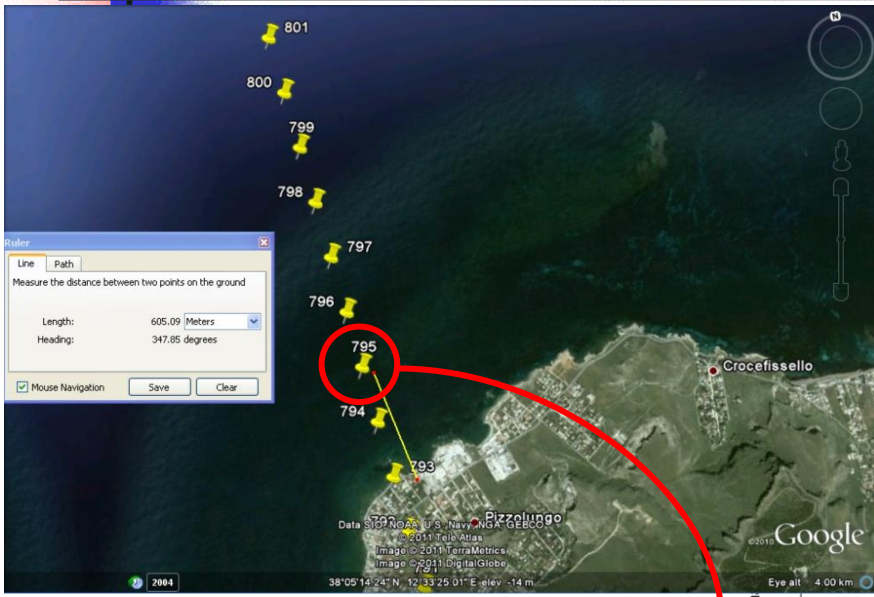

When the track approaches the coast almost orthogonally, the waveforms conform well to the delay-Doppler Altimetry model (and give sensible results when retracked), up to 500m from the coast or even closer.

Summary

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Coastal Altimetry: One topic, many challenges

- Coastal altimetry is an important new field of research
  - A lively international community has quickly gathered around it
  - It needs constant interaction with engineers on technical side and hydrographers, ocean modellers on the application side
- Much progress reported…
  - Springer book is a good account of all that
  - Reprocessed coastal altimeter data sets now available (e.g. PISTACH, CTOH, COASTALT)
  - An official AVISO coastal product is coming soon
  - Applications using improved (new) coastal altimetry data are emerging
- COASTALT has contributed a lot
  - Incubator of ideas now developed in follow-on projects
  - Processor – up and running with work in progress to ensure multi-mission and multi-domain capability and move to NRT (e.g. eSurge)
  - Specialized retracking to get closer to coast
  - Much improved global corrections now possible (e.g. DLM and GPD innovative approaches for wet troposphere)
- A main point is that there is still much to do
  - Many challenges but room for improvement remains
  - New CryoSat-2 data look like very promising in the Coastal Zone
  - Forthcoming future missions both nadir viewing (Sentinel-3 sporting the novel delay-Doppler altimeter; SARAL/AltiKa (India), HY-2 (China)) and wide-swath (SWOT), which should improve both quantity and quality of coastal altimetry data

Recommendations from the Coastal Altimetry Workshop series

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- Do more with the data we've got already
  - But a single point of access to coastal altimeter datasets would be welcome
- Further work is needed on the existing and innovative retrackers (which use information in adjacent waveforms)
  - Both theoretical and in terms of optimization and inter-calibration
  - Important to ensure consistency from the offshore to the inshore
  - Further R&D for innovative algorithms to move from concepts to simulations and eventually confrontation with real data
- The issue of filtering of the various corrections needs to be revisited
  - Correlation scales must be clearly identified and data screening and filtering schemes clearly recommended [these may depend on the application to some extent]
  - We need to quantify the improvement of the new/improved algorithms
  - The SSB correction should be reassessed in the coastal zone, with investigation of specific models

Recommendations from the Coastal Altimetry Workshop series

Consiglio Nazionale delle Ricerche

- Validation is crucial and should be supported further
  - Developing consistent validation protocols and assessments that can be applied to a number of locations with varying geographical and oceanographic conditions
  - We need to quantify the improvement on a regional basis
- The techniques developed in COASTALT, PISTACH and similar projects, and the relevant processors, should be extended to ensure multi-mission and multi-domain capability
  - Making processors open, flexible, expandable, easily upgradable and fully documented
- Coastal Altimetry applications should be supported and encouraged, with easy data access, outreach and training activities, and demonstration studies
  - The eSurge project is a clear example of the transition to applications
  - The RESELECASEA project is a clear example of transferring know-how and best practices

Altimetry: exceptional impact…

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Timespan=All Years. Databases=SCI-EXPANDED, SSCI, A&HCI, CPCI-S, CPCI-SSH.

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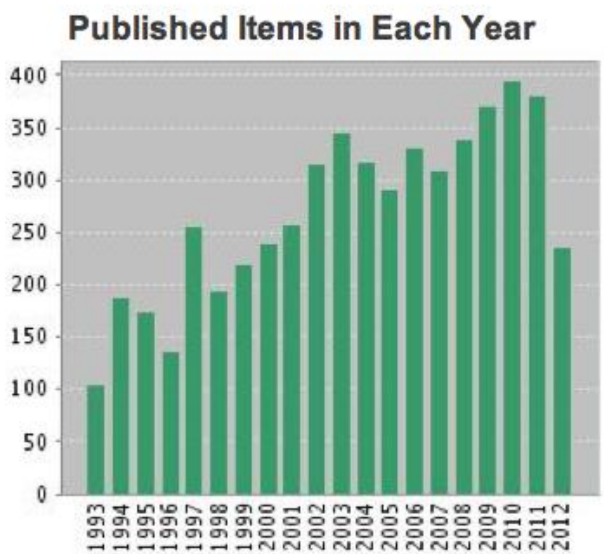
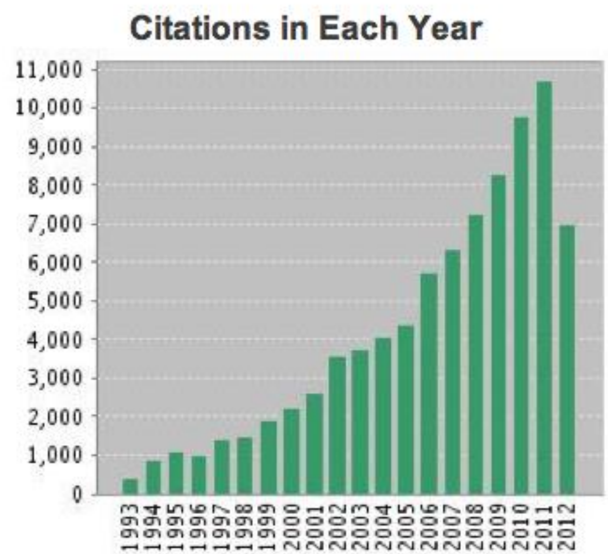


The latest 20 years are displayed.
View a graph with all years.



The latest 20 years are displayed.
View a graph with all years.

Results found:	5827
Sum of the Times Cited [?] :	85638
Sum of Times Cited without self-citations [?] :	58098
Citing Articles[?] :	36427
Citing Articles without self-citations [?] :	31815
Average Citations per Item [?] :	14.70
h-index [?] :	103

Results: **5827** Page 1 of 583 Go Sort by: Times Cited -- highest to lowest

...but we must do better at the coast!

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Refined by: Topic=(coast)

Timespan=All Years. Databases=SCI-EXPANDED, SSCI, A&HCI, CPCI-S, CPCI-SSH.

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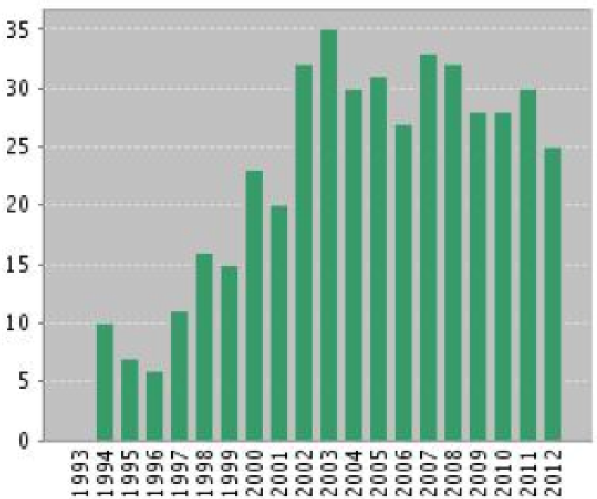
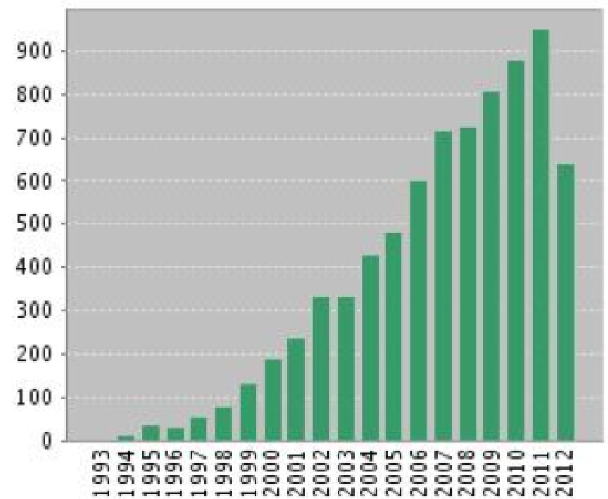
Published Items in Each Year



The latest 20 years are displayed.

View a graph with all years.

Citations in Each Year



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Sum of Times Cited without self-citations [?] : 7248

Citing Articles[?] : 5769

Citing Articles without self-citations [?] : 5553

Average Citations per Item [?] : 17.30

h-index [?] : 47

Results: **444** Page 1 of 45 Go Sort by: Times Cited -- highest to lowest

Thank you for your attention!

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http://www.coastalaltimetry.org/
http://www.coastalt.eu/

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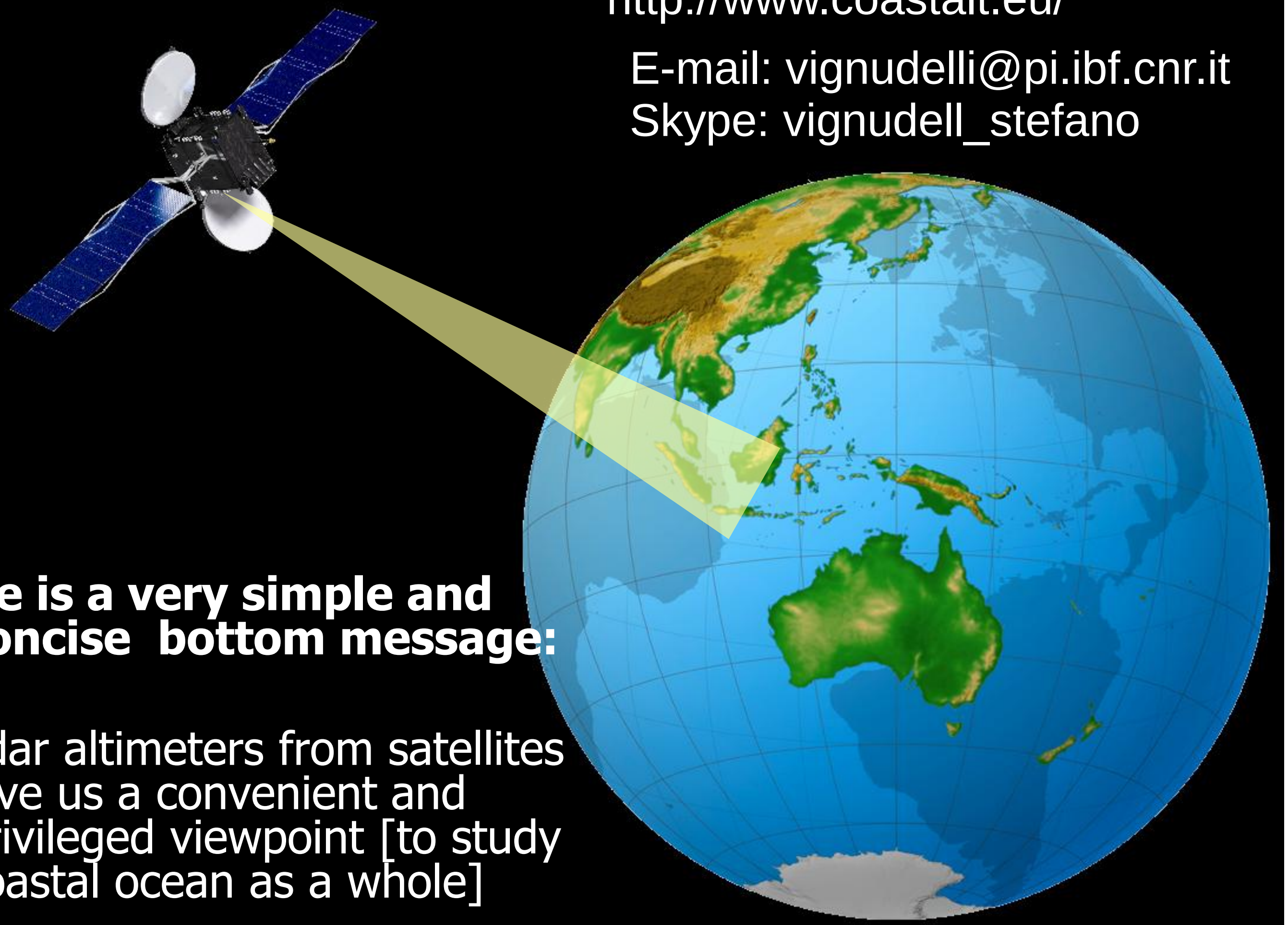

There is a very simple and concise bottom message:

….radar altimeters from satellites give us a convenient and privileged viewpoint [to study coastal ocean as a whole]