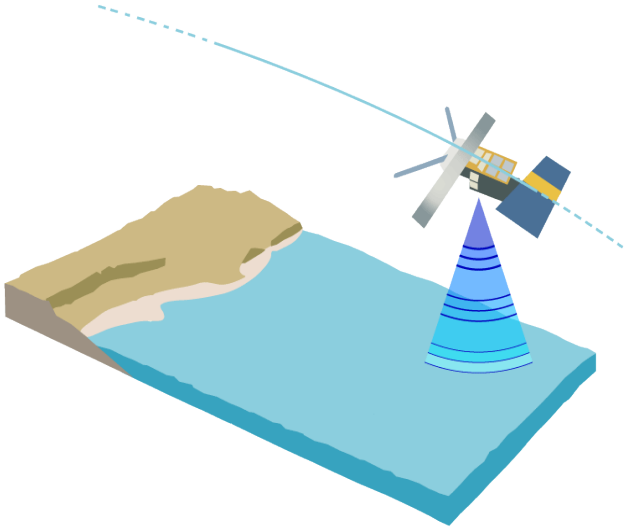
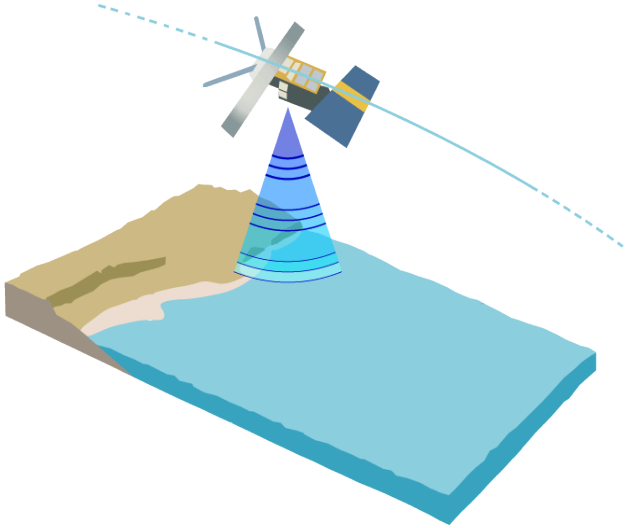
COASTALT
Executive summary and recommendations

Paolo Cipollini,
National Oceanography Centre,UK

Rationale for coastal altimetry





- Satellite altimetry works well for open ocean
- Near coasts however..
  - land contamination, calm water effects on waveform shape, poorer corrections, etc
  - data normally flagged as 'bad' in the official products - **but they can be recovered!**
- Coastal region has enormous strategic importance
- Almost **20 years of data** over the coastal ocean are waiting to be processed

Need for Coastal altimetry

- The need for extra attention on **coastal altimetry** is now widely recognized:
  - science topic of great relevance to monitor the coastal environment and assess the impact of global change on the coasts!
  - several space agencies and institutions are supporting its development (e.g. the ESA COASTALT project, CNES' PISTACH Project and centers like CTOH)
  - New and forthcoming missions have even better coastal capabilities:
    - **delay-Doppler altimeters** (e.g. Cryosat-2 and Sentinel-3 STM)
    - **altimeters in Ka-band** with smaller footprint (AltiKa mission)

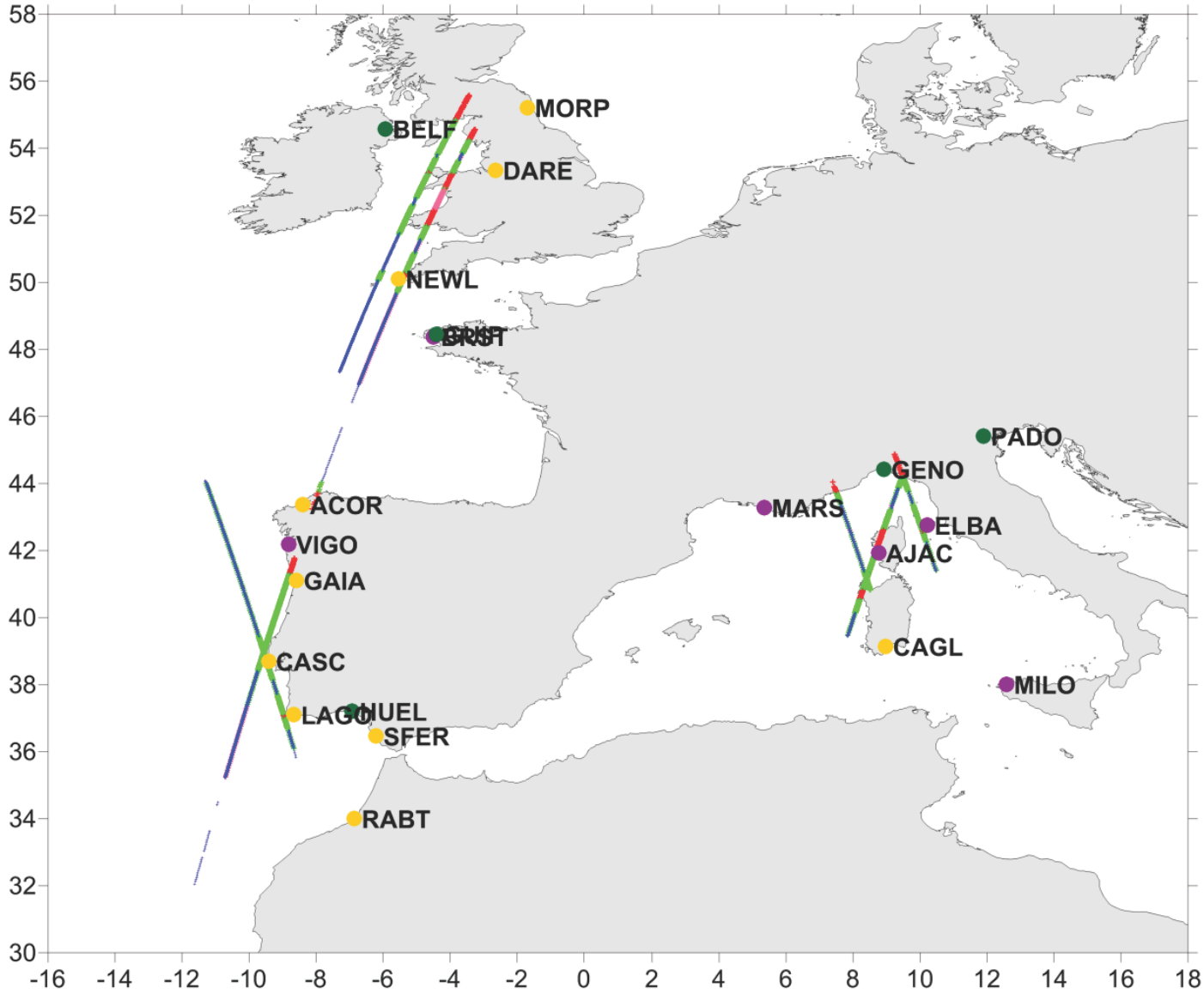
COASTALT: ESA's development of Coastal Altimetry for Envisat

- Phase 2 (2010-2011)
  - **NOC Southampton**: P. Cipollini (project manager), V. Byfield, P. Challenor, S. Gleason, C. Gommenginger, G. Quartly, H. Snaith, M. Tsimplis. L. J. West
  - **NOC Liverpool**: P. Woodworth, J. Wolf
  - **CNR Pisa**: S. Vignudelli, A. Scozzari
  - **Univ. Cadiz**: J Gomez-Enri
  - **Starlab Barcelona**: C. Martin-Puig, M. Caparrini, L. Moreno
  - **Univ. Porto**: J. Fernandes, L. Bastos, C. Lázaro, A. Nunes. N. Pires, M. Bos (CIIMAR), I. Araujo (CIIMAR)
  - **Univ. Lisbon**: S. Barbosa
- In Phase 1 (2008-09): Hidromod (H. Coelho)
- **ESA Support Team**: J. Benveniste (scientific officer), S. Dinardo, B. M. Lucas

COASTALT - objectives

- COASTALT aims to lead to the **definition, specification and prototyping** of a new pulse-limited radar altimetry coastal zone **product**.
- In COASTALT this has been done over **three study regions**:
  - NW Mediterranean (incl Corsica Channel)
  - West Britain
  - West Iberia Coast (and Gulf of Cadiz)
- This new product will hopefully be **the seed for future routine reprocessing** of coastal altimetry data by ESA
  - including the reprocessing **of whole ESA Radar Altimetry archive** (ERS-1, ERS-2, ENVISAT)
  - exploitation of **CryoSat** and **Sentinel**-3 over the coastal zone
  - PISTACH focuses on NASA/CNES missions (Jason-2) instead

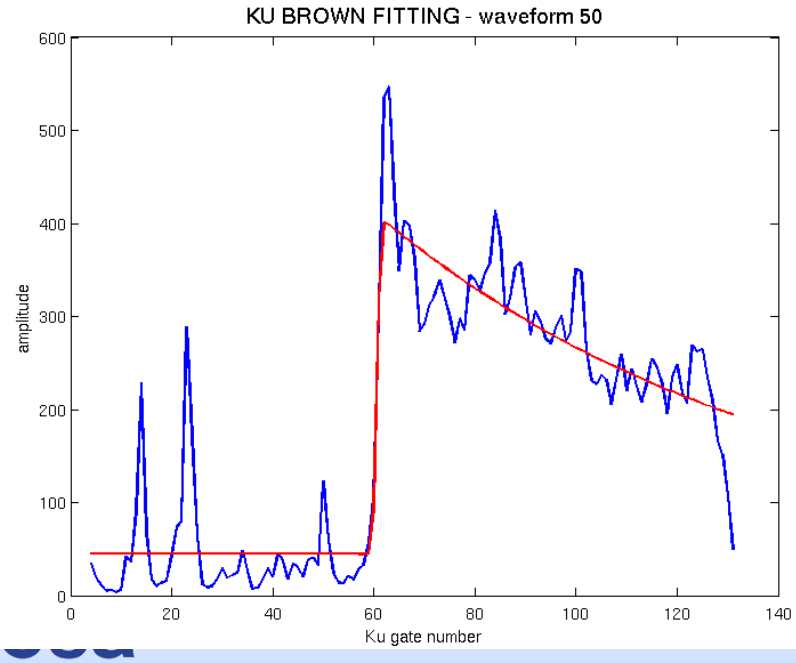
COASTALT pilot tracks



How we recover more valid data

0-10 km

A. Specialized **retracking**
   - Use better waveform models, accounting for change of shape in coastal environment
   - Use specialized (2-D or sequential) retracking techniques

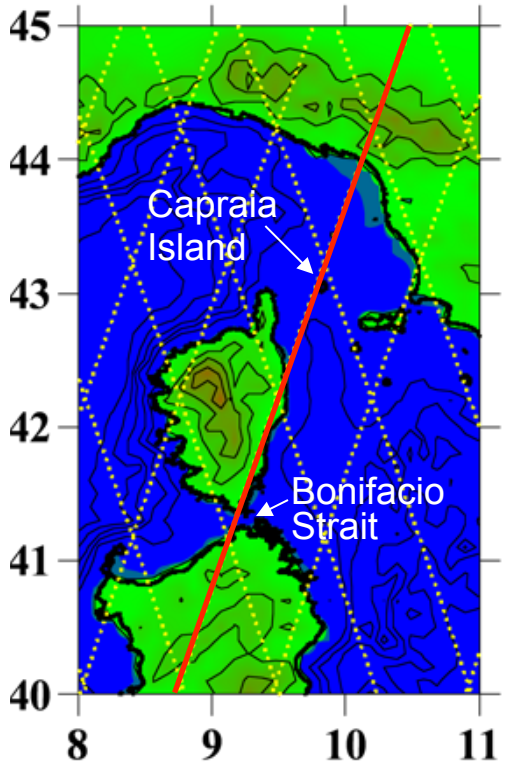


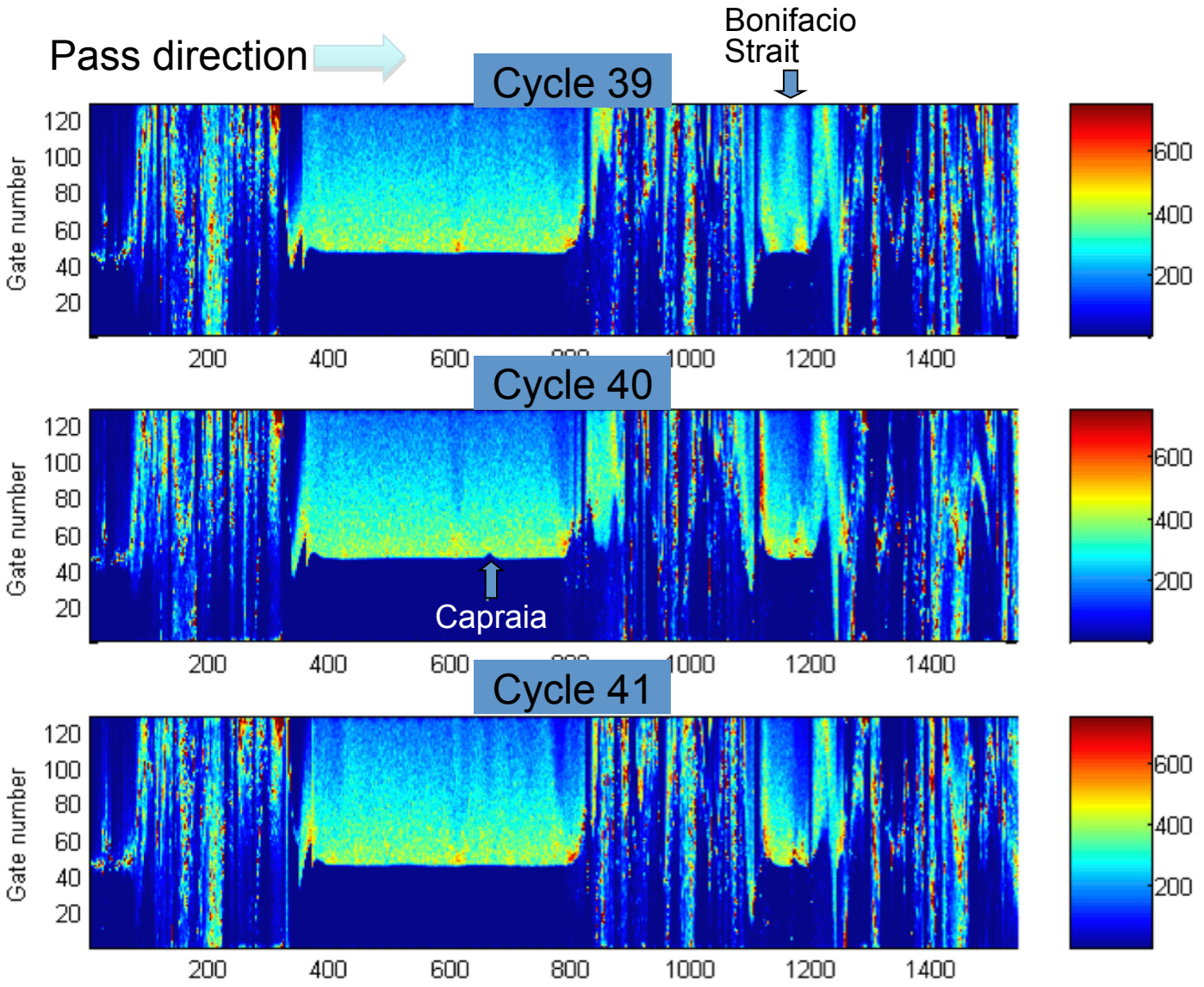
0-50 km

B. Improved **Corrections**
   - Most crucial is the correction of path delay due to **water vapour** (“wet tropospheric” correction)
   - Some applications require correction of **tidal** and **high-frequency** signals, which are also difficult to model in the coastal zone

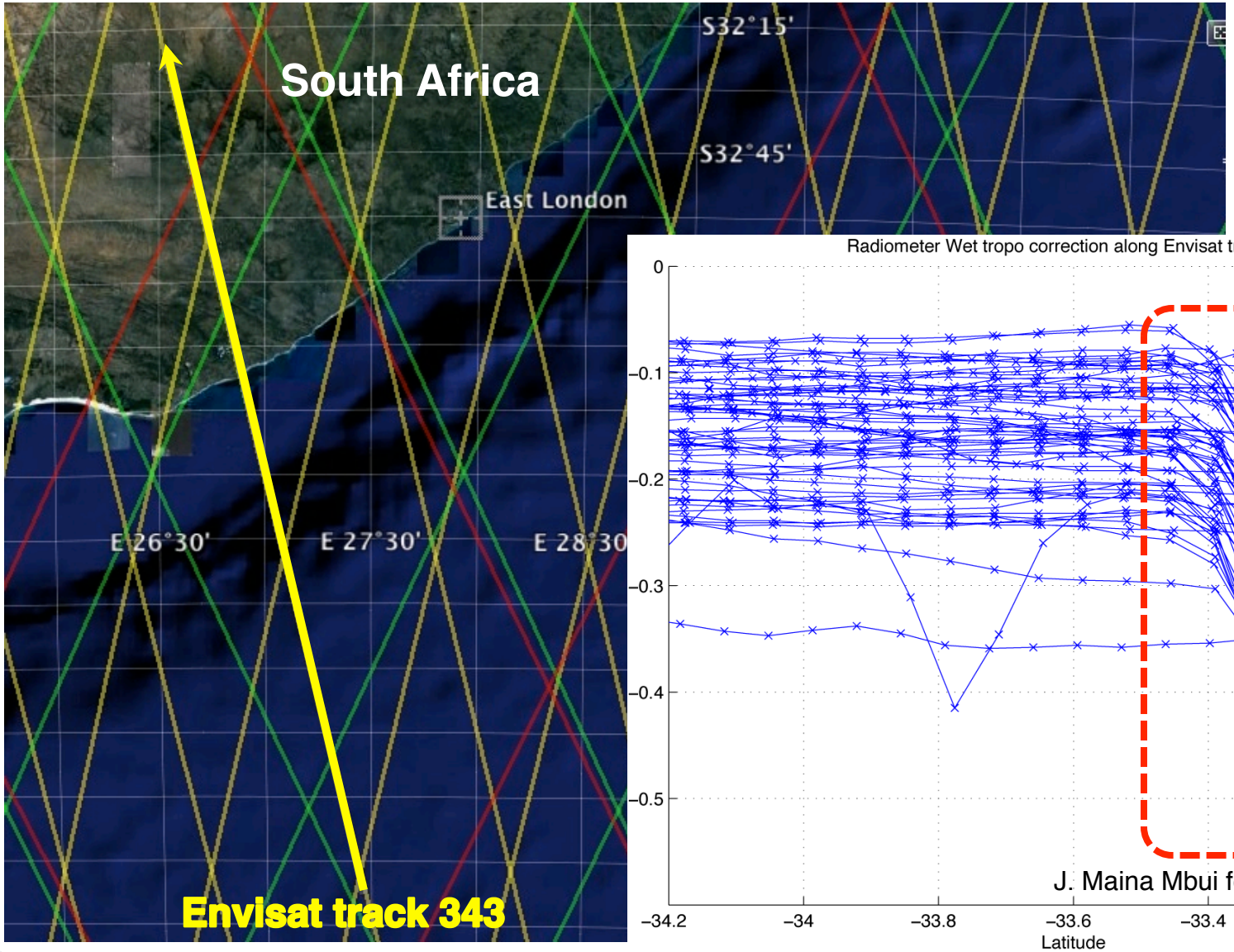
Example of coastal waveforms

ENVISAT **pass 294**
(descending)





Example of “wet tropospheric” problems



A selection of COASTALT results

User requirements & products

- Joint PISTACH/COASTALT Survey in 2008
- **Modelling community** is an important user community
- **Wind and Waves** matter to a good share of the users in addition to SSH
- Some scope for **near-real-time** or even **real-time** delivery of coastal altimetry
- Need clear quality **flags** together with **all the separate corrections**
- Need good documentation → doing **NetCDF product specification** and **user handbook**

Corrections: the way forward

- COASTALT reviewed the whole spectrum of corrections. Two are crucial in coastal zone:
- **Wet Tropospheric correction**:
  - **DLM (Dynamically Linked Model) approach**: Use models to extend radiometer observations
  - Model/remove land effect (developed by PISTACH)
  - **GPD (GNSS-derived Path Delay)** - dry and wet tropo from GNSS (GPS/Galileo) measurements (Univ. Porto → see 'highlight talk' by J. Fernandes next).
- **Tides**
  - Investigated and used local models (UPorto/CIIMAR, WITM local tidal model for W Iberian shelf)

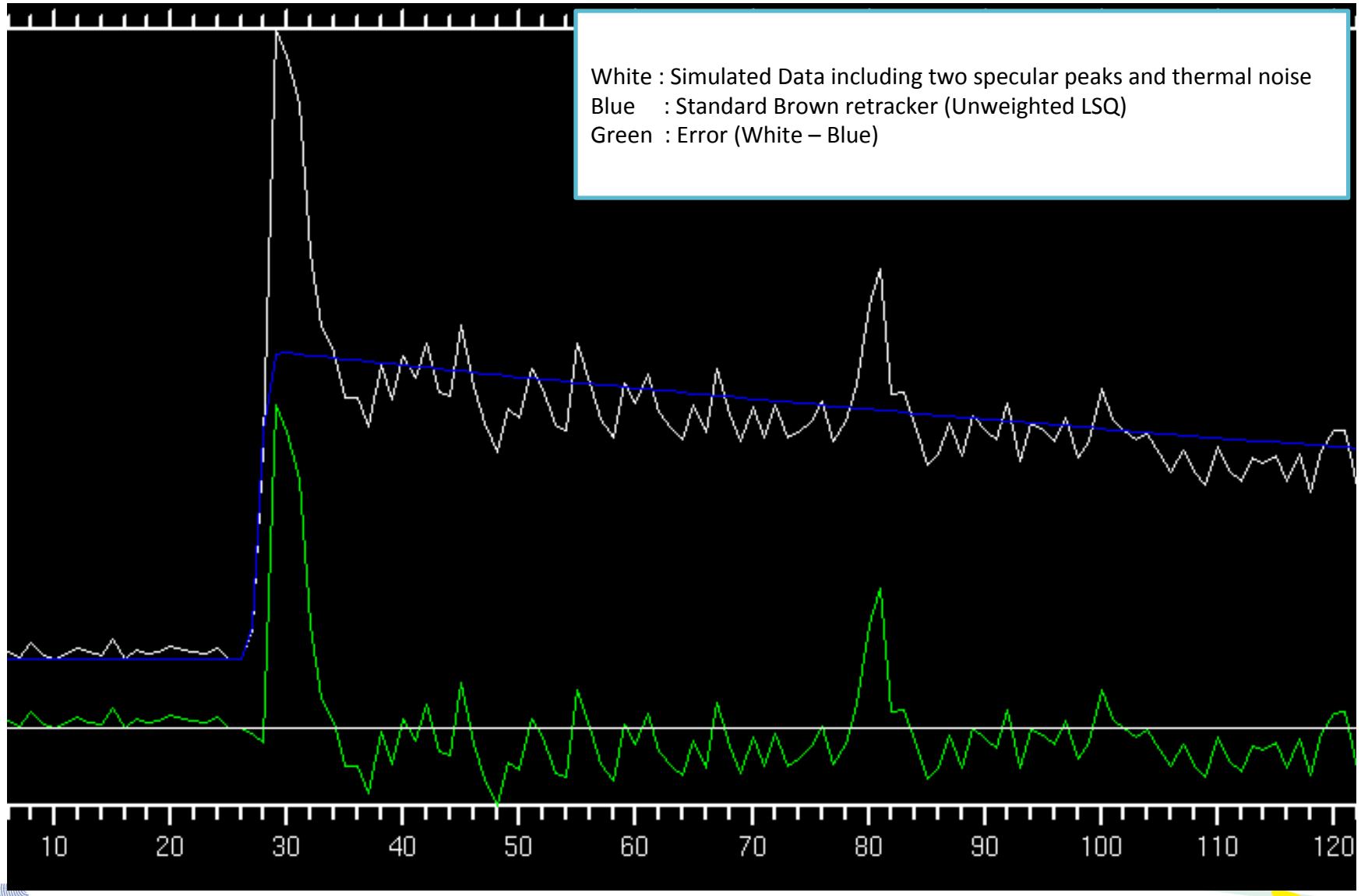
The COASTALT Processor

- Core deliverable and solid legacy of the Project
  - Flexible, user-configurable and modular software
- Baseline processor
  - Read ENVISAT L2 SGDR files
  - Retracks all waveforms with different models
    - **Brown, Specular and Mixed,** plus innovative retrackers (see later)
  - Generates corrections at 18Hz
  - Generate **Coastal Geophysical Data Records (CGDRs)** output files in NetCDF
- User-defined Geophysical Corrections module ("addcorr")
  - Allows addition of any user-generated corrections

Retracking – crucial!

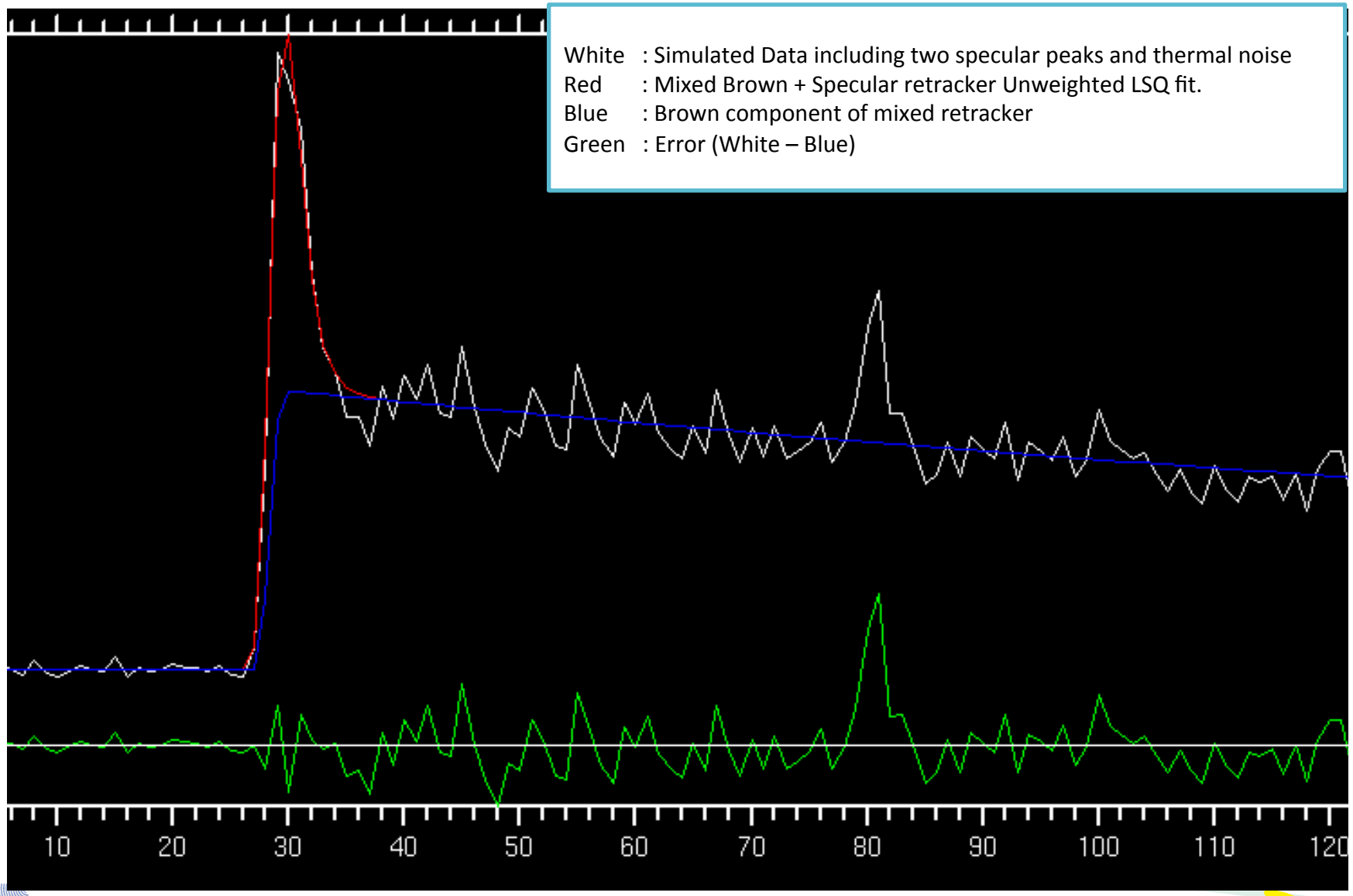
- The COASTALT processor (open, flexible, modular) is an approprate tool for further research and development work on retracking techniques and corrections;
- We learnt that retracking in the coastal zone is hard work – needing a lot of effort for the optimization of the retrackers
  - work still very much ongoing.

Standard Brown Retracker



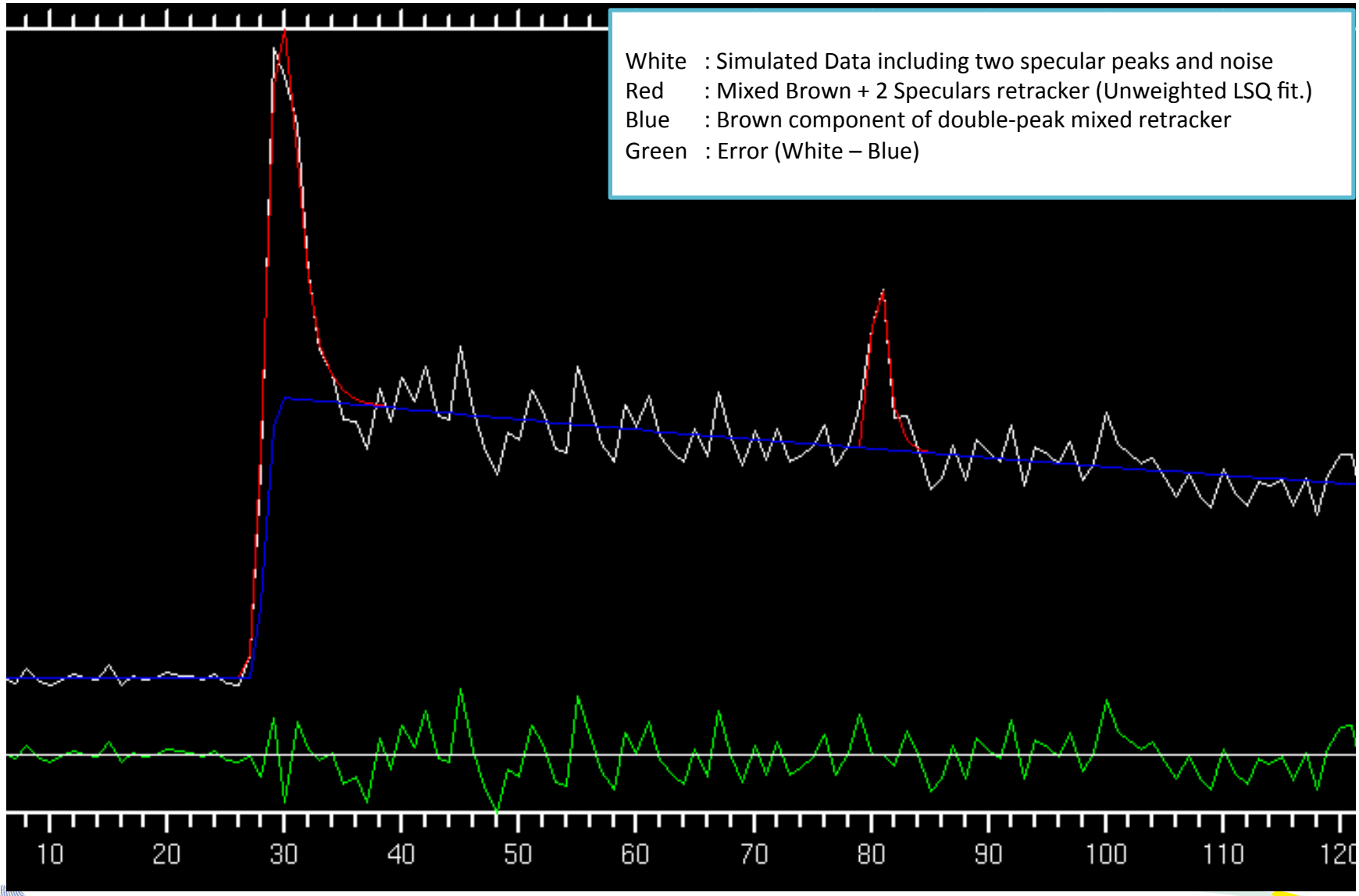
Brown range bin number: **27.66**

Brown + Specular Mixed Retracker



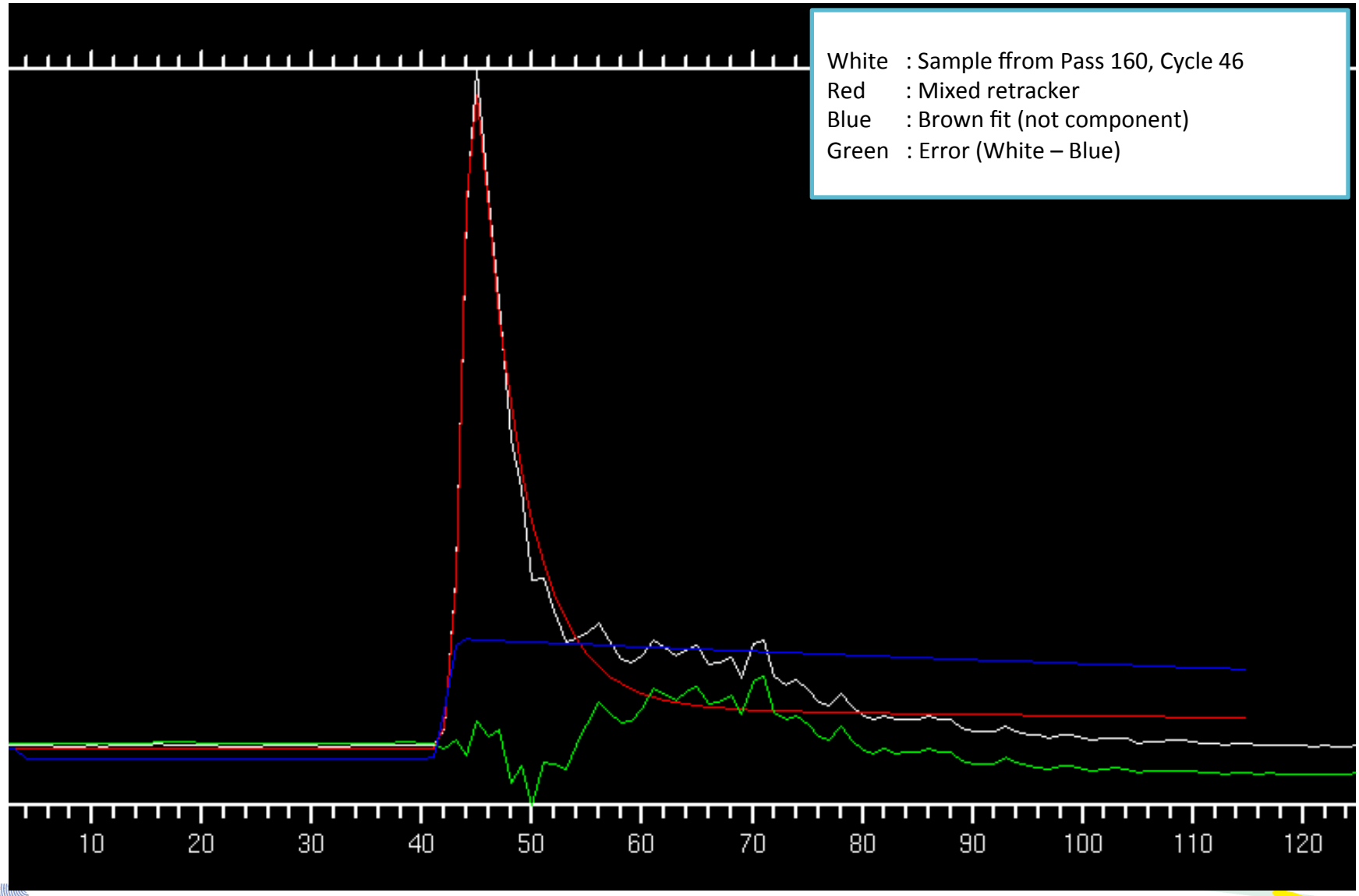
Brown range bin number: **28.36**

Brown + 2 Speculars Mixed Retracker



Brown range bin number: **28.35**

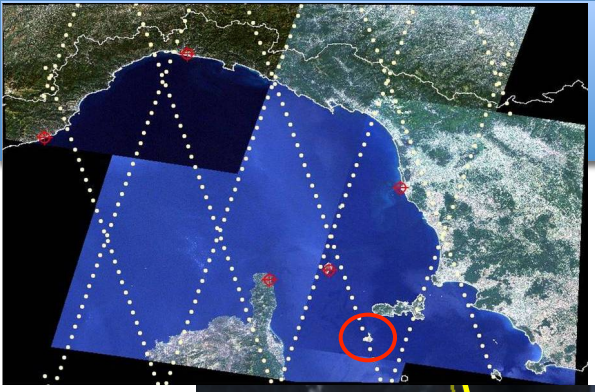
Mixed Retracker for a Pass 160 Cycle 46 Sample

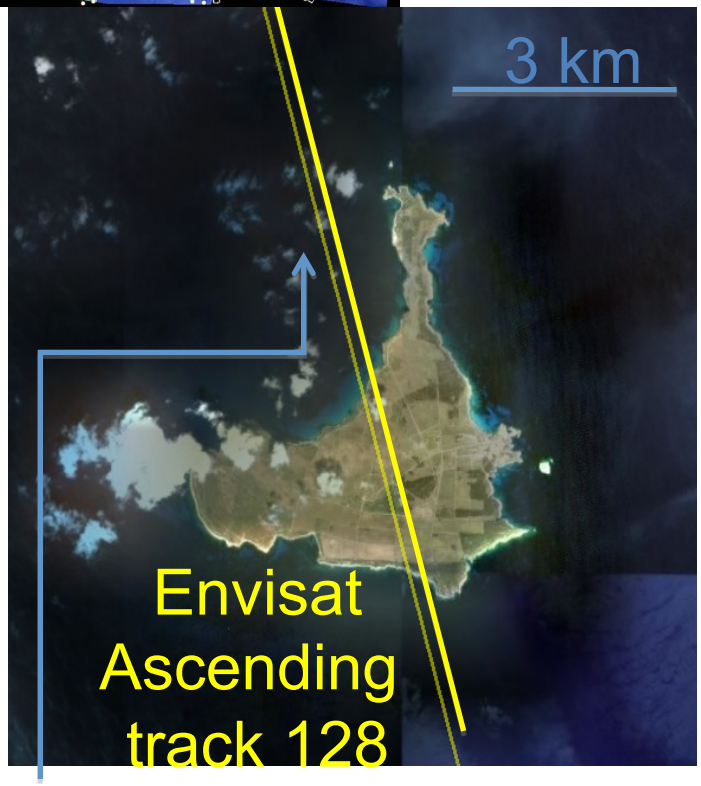


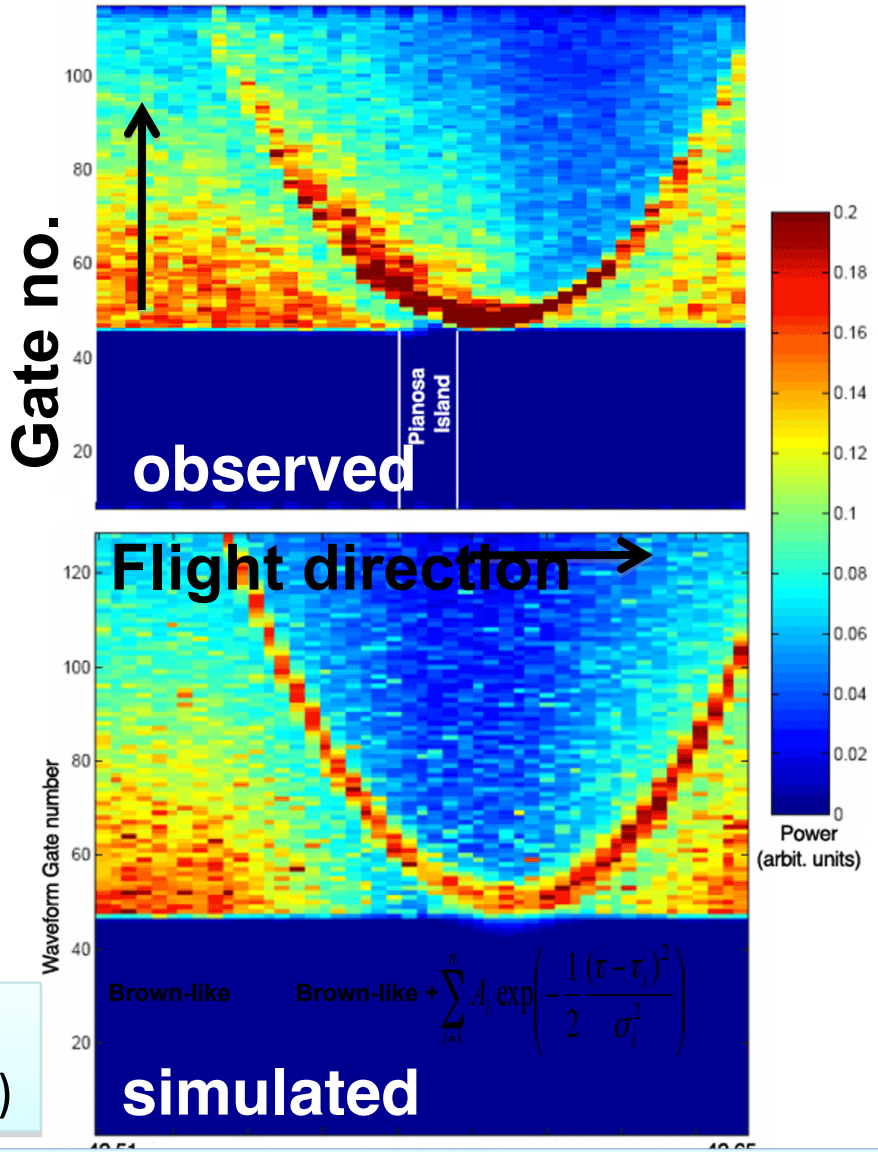
Retracking – Coastal waveforms

- Study of waveforms in coastal zone and island passes
- 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 → bright features or **“bright targets”**
  - These features migrate in the waveform/gatenumber space following hyperbolae (a parabolic shape is usually a good approximation)
- 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 – Pianosa Island







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

esa

J. Gómez-Enri et al., IEEE GRSL 2010 → next talk

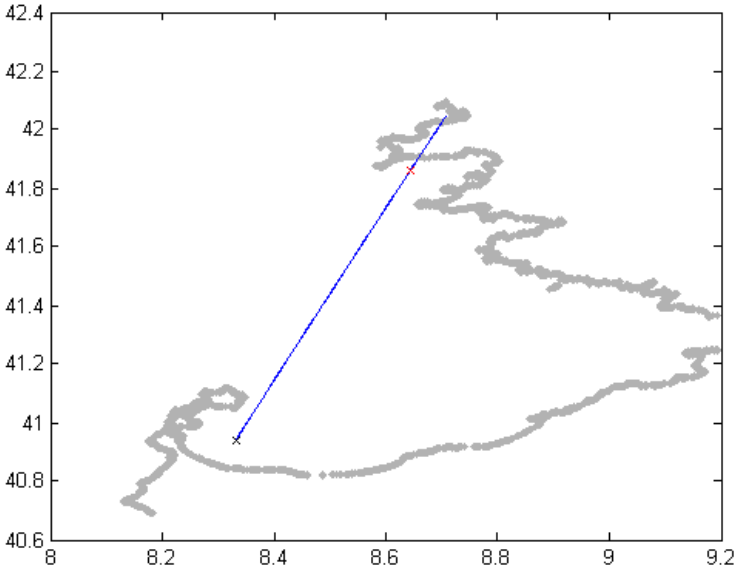
Innovative retrackers

- Innovative retrackers: retrack each waveform not in isolation but using info from adjacent ones
- The parabolic/hyperbolic retracker 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 are being prototyped

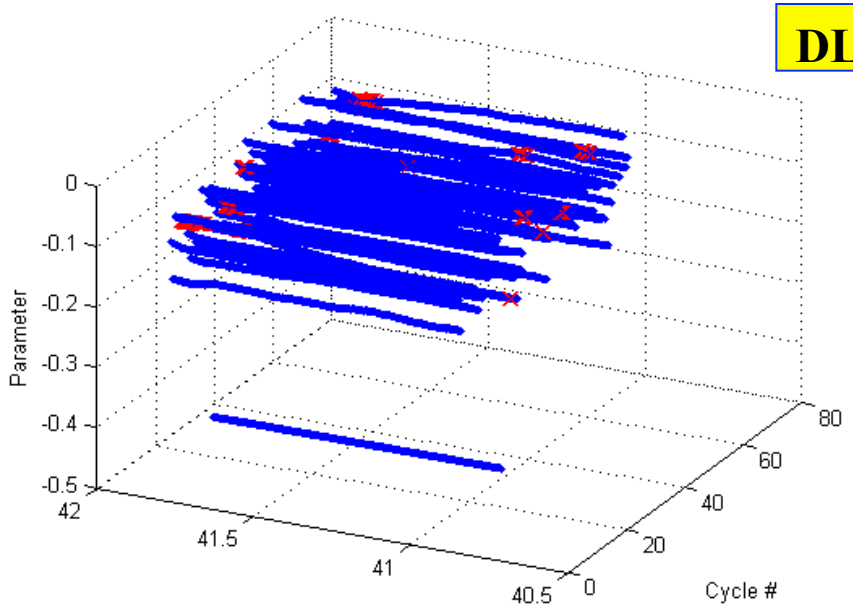
visualization & validation

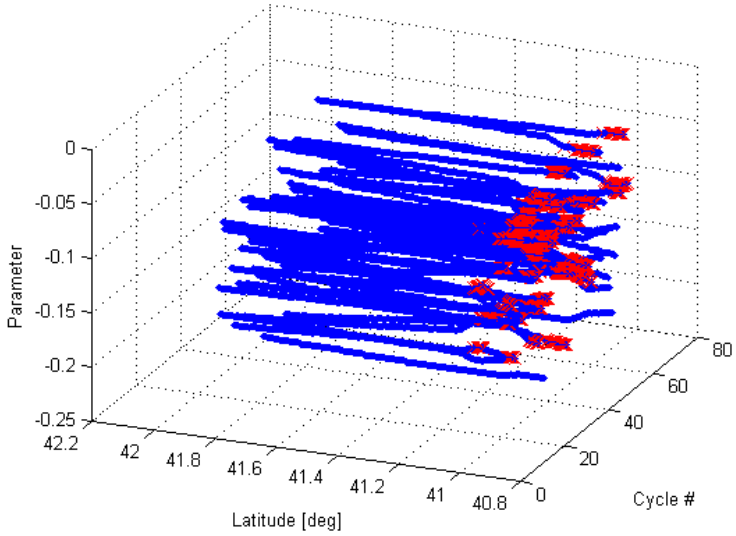
- valuable work on the **techniques for visualization and validation** of altimetric data in the coastal zone, including the development of a suite of analysis routines for MATLAB;

Porto Torres – Track 065 – Retracker



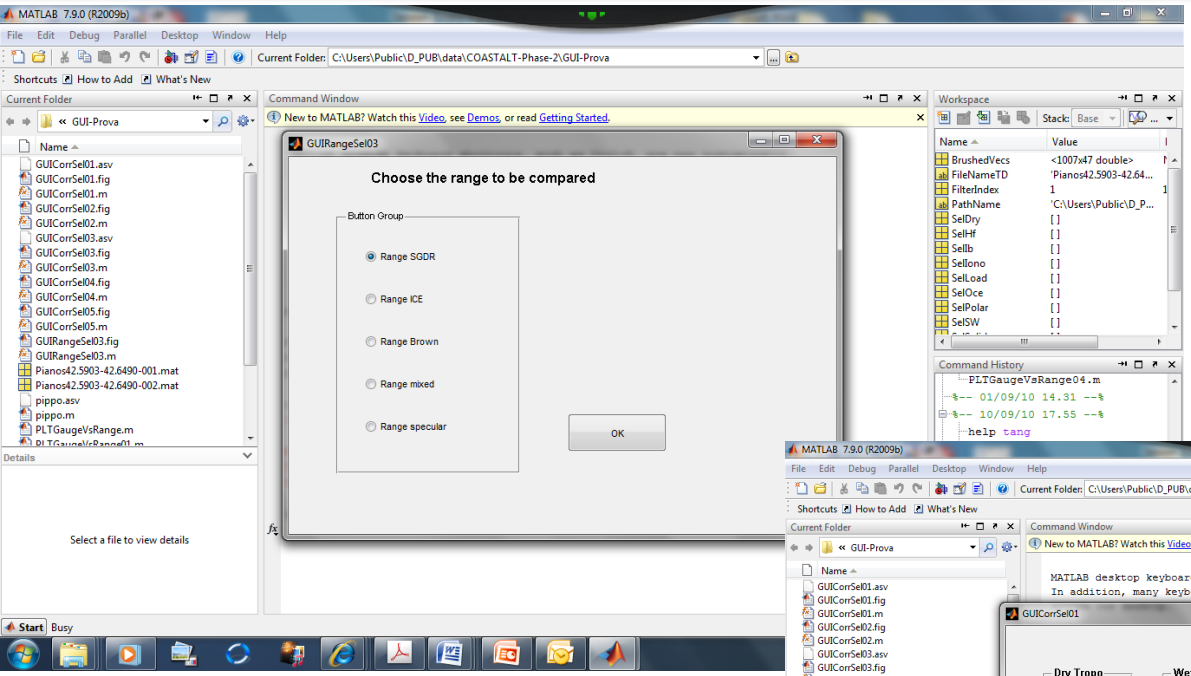
DLM

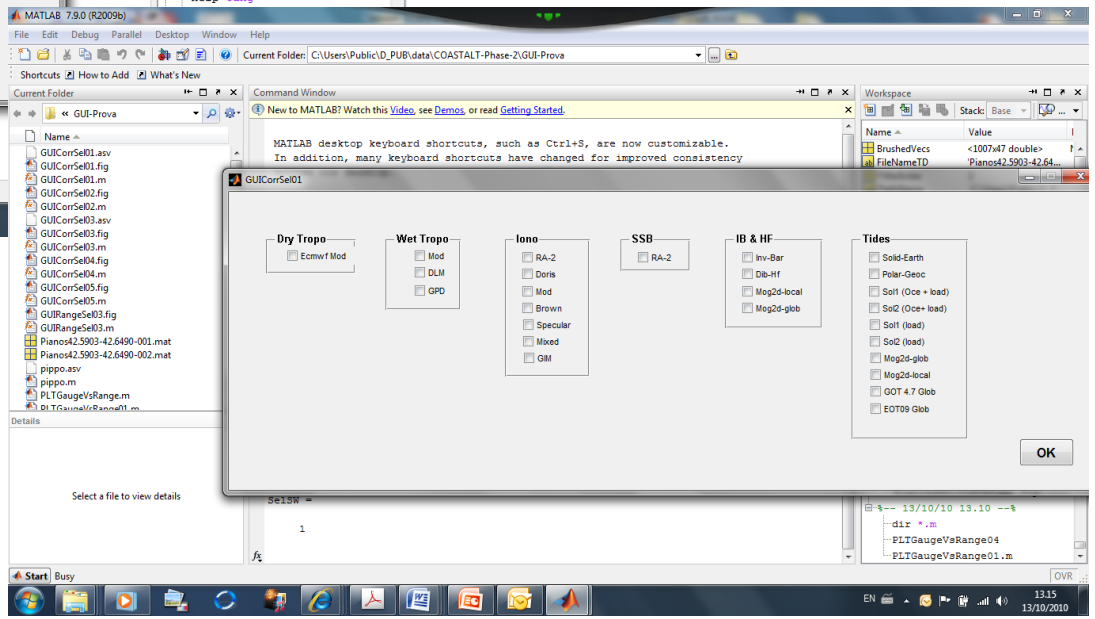




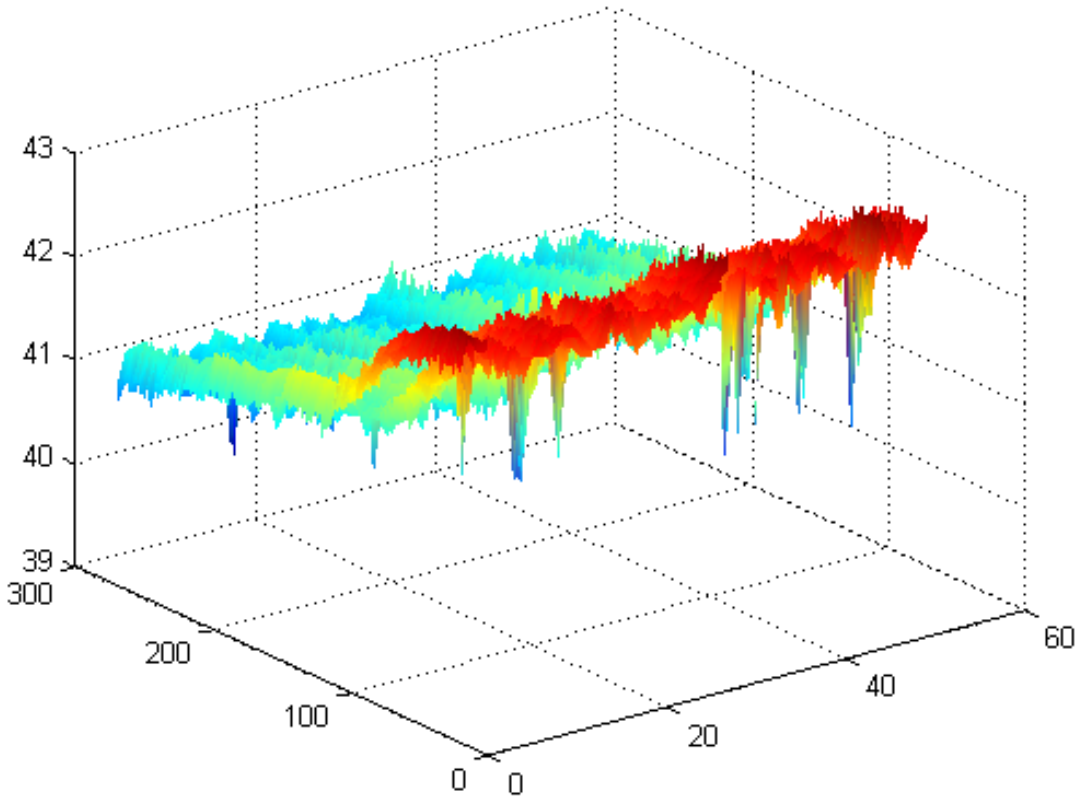
GPD

Selecting ranges and corrections on the fly





SSH in a 3-D View (all cycles) – track 443



SSH corrected = orbit - (range + iono + dry tropo + wet tropo + loading tide + SSB + solid tide + pole tide + wind and pressure effects

Several combinations !!!! But we like to measure of how closely the altimeter-derived sea level estimates correspond to the in situ values

Catalyst for the community

- COASTALT has been crucial for the **coordination and moderation of a new, lively international community of coastal altimetrists**:
  - via the COASTALT-SWT list
  - leadership of the OceanObs'09 paper on Coastal Altimetry,
  - organization of the highly successful **2nd, 3rd and 4th Coastal Altimetry Workshop**,
  - plus the 5th edition of the CA-WS now in preparation for October 2011,
  - and last but not least the co-editorship and contribution to the first ever **refereed book** on coastal altimetry.

Stefano Vignudelli · Andrey Kostianoy · Paolo Cipollini
Jérôme Benveniste (Eds.)
Coastal Altimetry

Radar altimetry over the oceans represents a success story for satellite-based Earth Observation. However there is an important marine domain where altimetry has remained underexploited until recently: the coastal zone. Data in that region have been usually discarded due to problems with the altimeter radar echoes and to the lack of those corrections needed for an accurate estimation of sea level. Several scientists around the world have set out to fill this gap in knowledge and *push altimetry closer to the coast* by means of new/better corrections and dedicated reprocessing of the data. The importance of the new topic of Coastal Altimetry has now been recognised by the major space agencies like ESA and CNES. The last few years have seen the coalescence of a lively Coastal Altimetry Community, holding regular international workshops. This book summarises the promising advances in the topic, with the twofold aim to form a handy reference for the latest technical improvements and to present a number of case studies illustrating the value of altimetry data for coastal studies. The 20 chapters represent the work of a great number of research groups around the world, making the book an authoritative account of the state of the art in this novel topic.

Stefano Vignudelli is a researcher at the Consiglio Nazionale delle Ricerche in Pisa, Italy. His areas of expertise include satellite remote sensing of the marine environment, particularly the development of radar altimetry in the coastal zone through new methods for data processing, validation studies and oceanographic applications.

Andrey G. Kostianoy is a Chief Scientist at the P.P. Shirshov Institute of Oceanology, Russian Academy of Sciences, in Moscow, Russia. He is a specialist in physical oceanography. His research has focused on satellite monitoring, oceanography of coastal zones, regional climate change and environmental problems of the Black, Caspian and Aral seas.

Paolo Cipollini is a Senior Research Fellow at the National Oceanography Centre, Southampton, U.K. He is a specialist in satellite oceanography with focus on observations of planetary waves, satellite data processing and coastal altimetry. He is the manager of the ESA initiative for Coastal Altimetry research and development (COASTALT).

Jérôme Benveniste is a Senior Advisor at the European Space Agency, Esrin, Italy. He is a specialist in physical oceanography and applications of radar altimetry, developing new altimetry products, algorithms and validation. He has recently launched the ESA initiative for Coastal Altimetry research and development.

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Coastal Altimetry

S. Vignudelli
A. Kostianoy
P. Cipollini
J. Benveniste
(Eds.)

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Coastal Altimetry

Springer

Outputs

- **seven refereed publications**
  - 2 papers in refereed journals, one more in preparation
  - 5 book chapters (refereed)
- coastal altimetry book!
- OceanObs CWP
- 11 conference and other non-referred papers
- ~50 presentations
- 11 posters

- All on the web site.. http://www.coastalt.eu

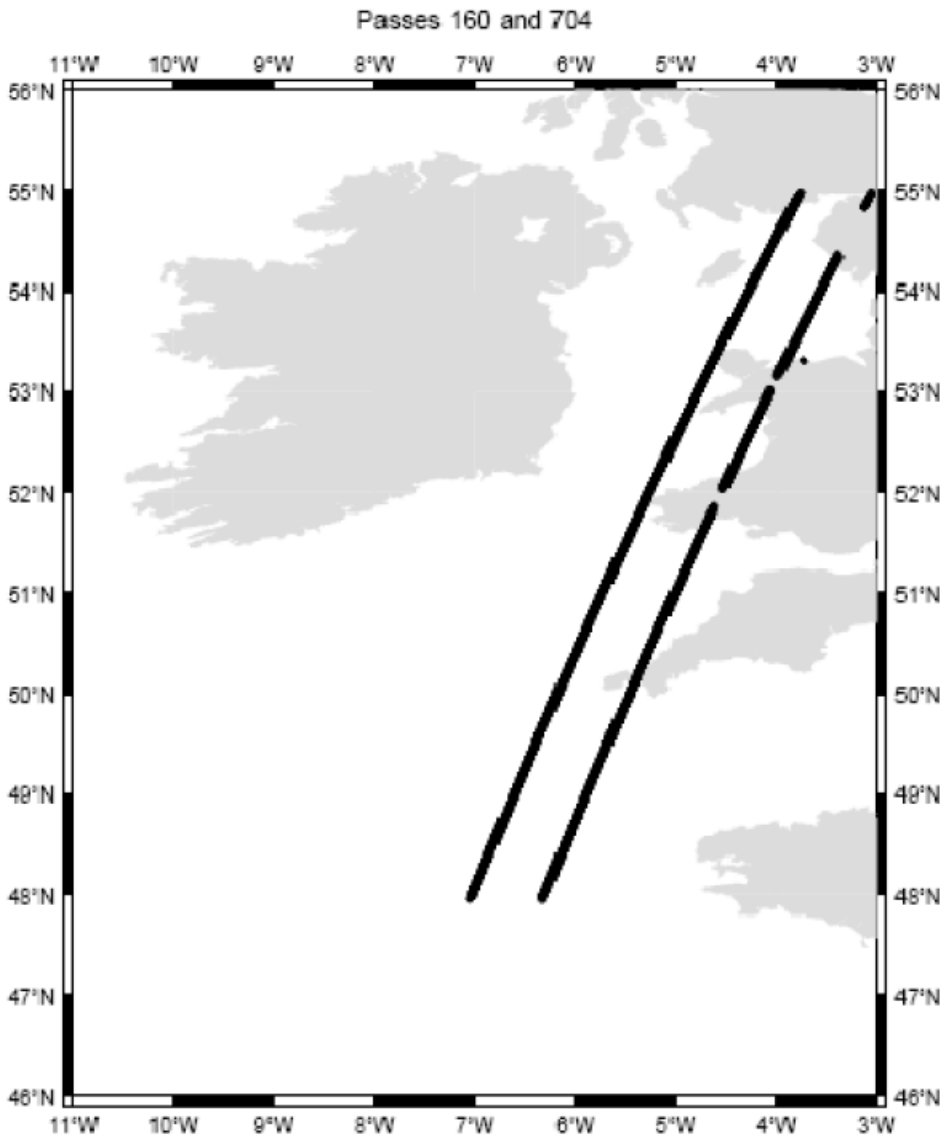
A look at the data

CGDRs

- The Coastal processor produces Coastal Geophysical Data Records – CGDRs
  - contains output of all retrackers (h, swh, sigma0) and full range of corrections
- Fully Documented:
  - Product Specification document
  - Product User handbook
- Validation so far has focused mainly on traditional (Brown) retrackers and GPD correction
- We can show a few results
  - Alt heights w.r.t. Tide Gauges over west of Britain
  - Significant Wave Height over Gulf of Cadiz
  - see also GPD talk nextn

West of Britain passes

704

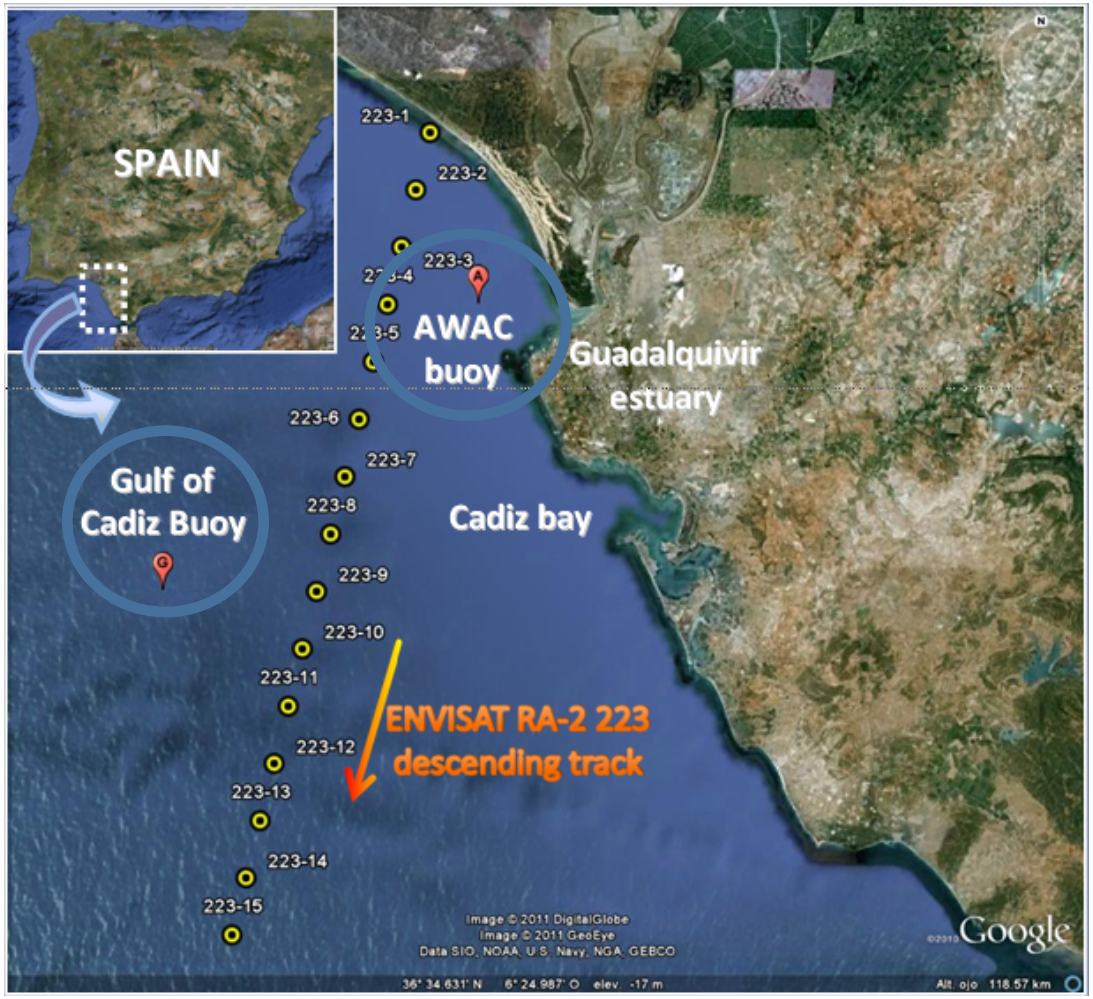


160

Comparisons to Tide Gauges

- Pass 160 compared to Newlyn and Pass 704 to Holyhead
- In this case only load tide correction (and no ocean tide or IB) correction applied to the altimetry
- Pass 160/Newlyn with Selection A has rms of **6.8 cm from 49 passes**
- Use of DORIS for iono reduces this to **3.7 cm**
- Use of DORIS + GPD for Wet tropo reduces **further to 3.2 cm** – so GPD may indeed have some benefit in some situations

STUDY AREA: THE GULF OF CADIZ



VALIDATION WITH IN-SITU DATA: offshore buoy

•Buoy at a distance of 55 km to the coast.

•Altimeter data averaged to1Hz rate.

•High correlation for both datasets GDR (N=797) and COASTALT (N=787) statistically significant at the 95% level.

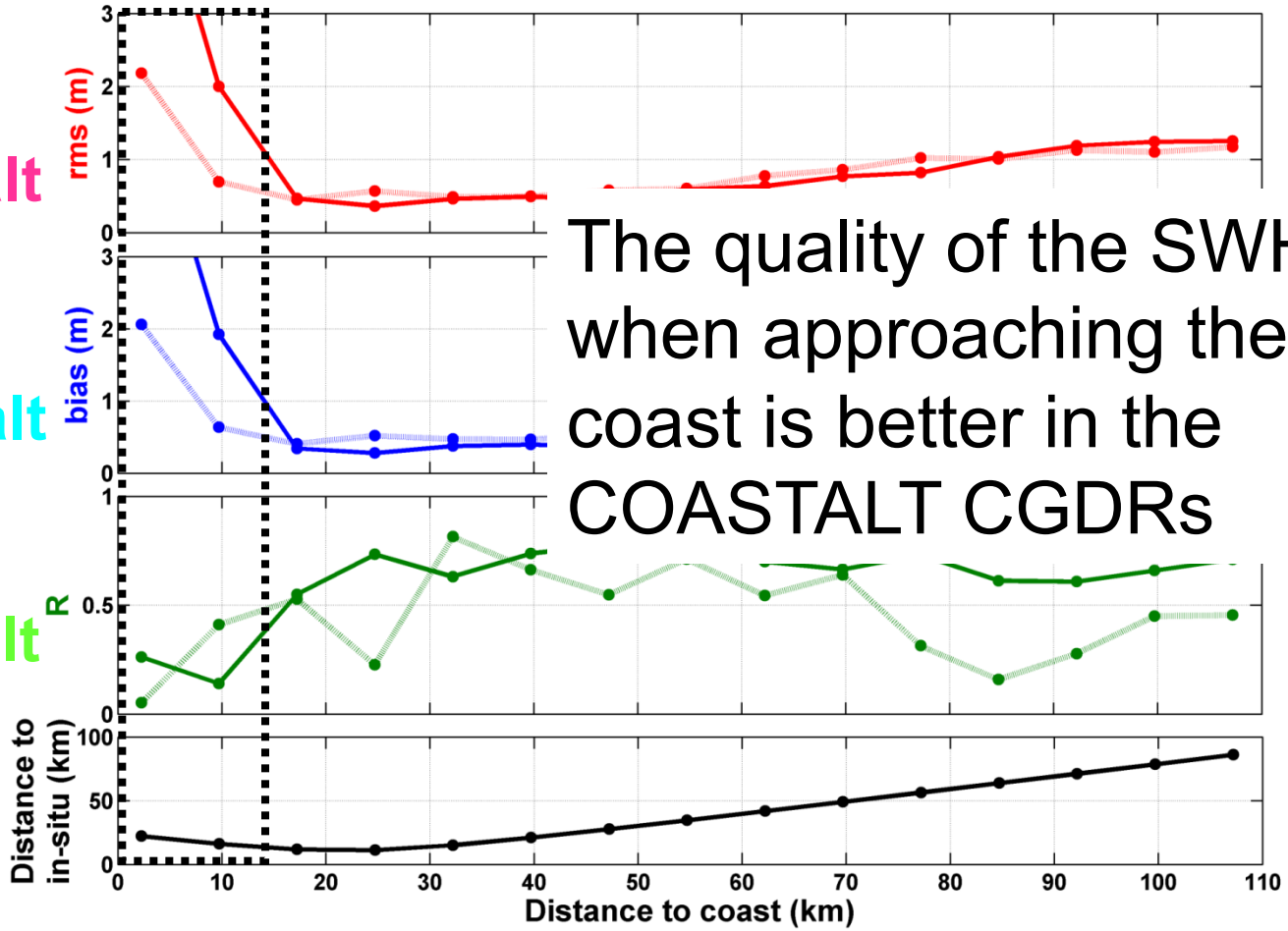
•The closest 1Hz track point to the buoy (20 km) offered the best fit in both data streams: 0.17 m rms, 0.006 m bias and R=0.97 (GDR) and 0.15 m rms, 0.007 m bias and R=0.96 (COASTALT).

VALIDATION WITH IN-SITU DATA: coastal buoy

GDR
Coastalt

GDR
Coastalt

GDR
Coastalt



The quality of the SWH when approaching the coast is better in the COASTALT CGDRs

(draft) Final Recommendations from COASTALT

Final Recommendations: 1

- **Further work is needed on the retrackers, both theoretical and in terms of optimization and inter-calibration**
  - "Theoretical" means improvement of the existing models (eg, by including the effect of white caps) or the development of new models (eg scattering from non-linear surfaces).
  - "Optimization and intercalibration" includes not only runtime optimization, but, most importantly, an assessment of biases and other differences amongst different retrackers, and the development of a criteria for retracker selection

Final Recommendations: 1 (cont.)

- **We believe that an international exercise for the intercalibration of the various retrackers would be extremely beneficial and that the Space Agencies should support this**

Final Recommendations: 2

- **Innovative retrackers (which use information in adjacent waveforms) need further R&D to move from concepts to simulations and eventually confrontation with real data**
  - 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.

Final Recommendations: 3

- **To facilitate the work of developers, testers, and the uptake of the data by 'expert users', coastal altimetry processors must be open, flexible, expandable, easily upgradable and fully documented.**

Final Recommendations: 4

- **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]**
  - A good example is the work carried out in D2.4 regarding the correlation scales for the tropospheric corrections. But other corrections that crucially need a better assessment of the optimal filtering scheme are the ionospheric and the SSB.
  - A related issue is to see which corrections, if any, need to be computed at full rate (18Hz) and which can be interpolated from lower rate data

Final Recommendations: 5

- **The SSB correction should be reassessed in the coastal zone, with investigation of specific models**

  – This is a recommendation is the outcome of agreement at the various Coastal Altimetry workshops and is perceived as scientifically challenging, but conducive to very useful results.

Final Recommendations: 6

- **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.

Final Recommendations: 7

- **The techniques developed in COASTALT and similar projects, and the relevant processors, should be extended to ensure multi-mission and multi-domain capability.**
  - In particular to the new and forthcoming Delay-Doppler altimetry missions (Cryosat-2, SRAL on Sentinel-3) and to AltiKa, which have intrinsically better capabilities in the coastal zone.
  - This multi-mission capability is one of the objectives, for instance, of the follow-on work to COASTALT in the ESA DUE eSurge project, which has just started (June 2011).
  - we need to work closely with the ice & inland waters communities

Final Recommendations: 8

- **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, but several other possible applications are listed and described in the OceanObs'09 Community White Paper on Coastal Altimetry (Cipollini et al, 2010)

-

Possible Applications

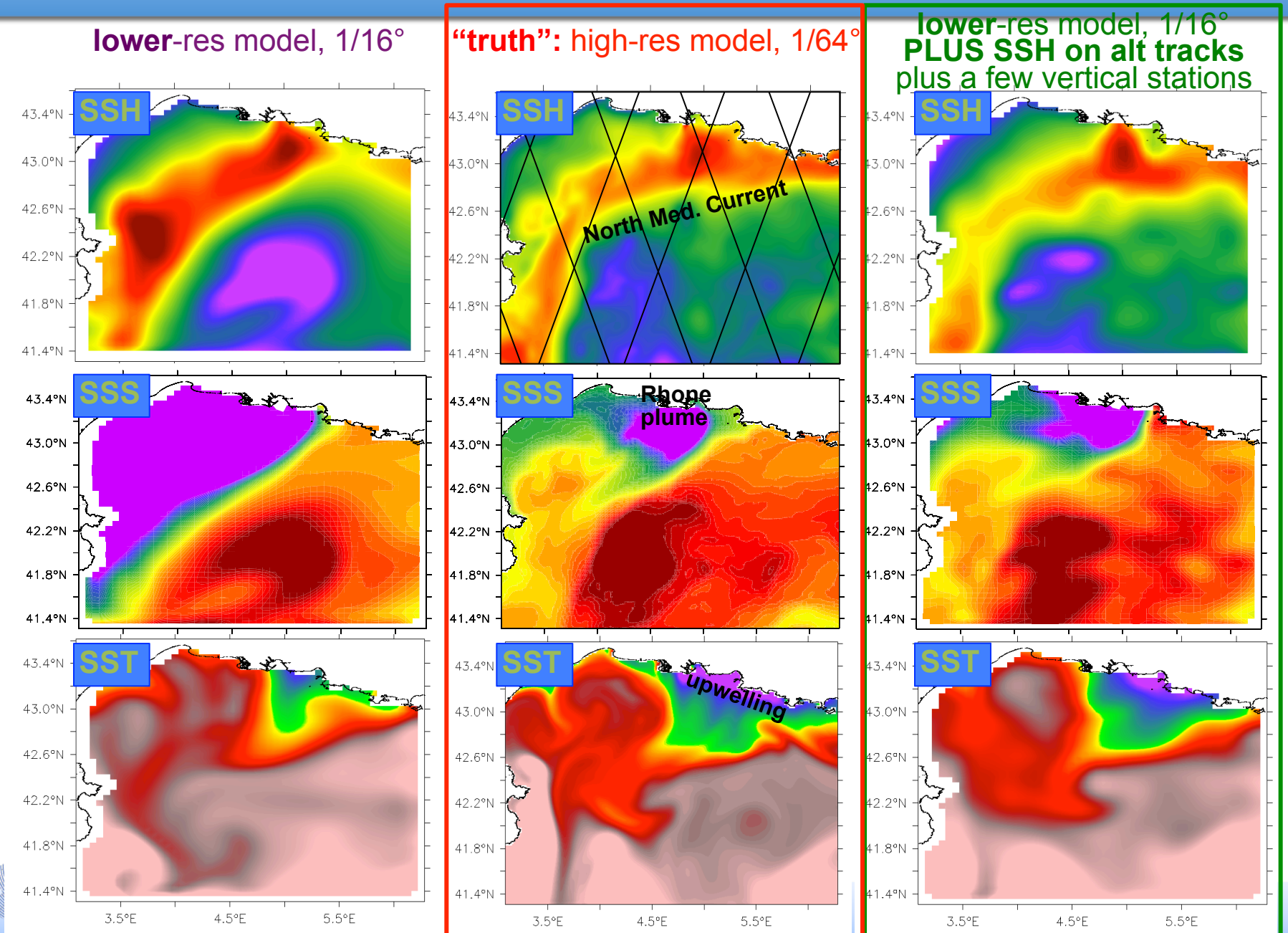
- Multifold:
  - Sea Level, tides - not only long term studies and climatologies, but also specific hazardous/extreme events (storm surges)
  - Near-shore currents and waves
  - Assimilation into coastal models (see **Mediterranean example** in next slide)
  - Fisheries, shipping, sediment transport

Altimetry is a **legitimate component of any coastal observing systems**

  - See Cipollini et al OceanObs'09 Community White Paper

Example of expected impact of coastal altimetry

over Gulf of Lions, by Aurélie Duchez, LEGI Grenoble (now @ NOC), paper in prep.



Conclusions

- Significant international efforts underway to "*make satellite altimetry sailing closer to the coast*"
  - should have significant impact on numerous applications
- **ESA COASTALT: Flexible software processor, Innovation in corrections and retracking, well-documented NetCDF products, scientific papers**
- **COASTALT has been a catalyst of the new Coastal Altimetry community and remains at its very centre.**
- The final COASTALT results will be also showcased at the 5th Coastal Altimetry workshop in San Diego, California, 16-18 October 2011

www.coastalt.eu
www.CoastalAltimetry.org