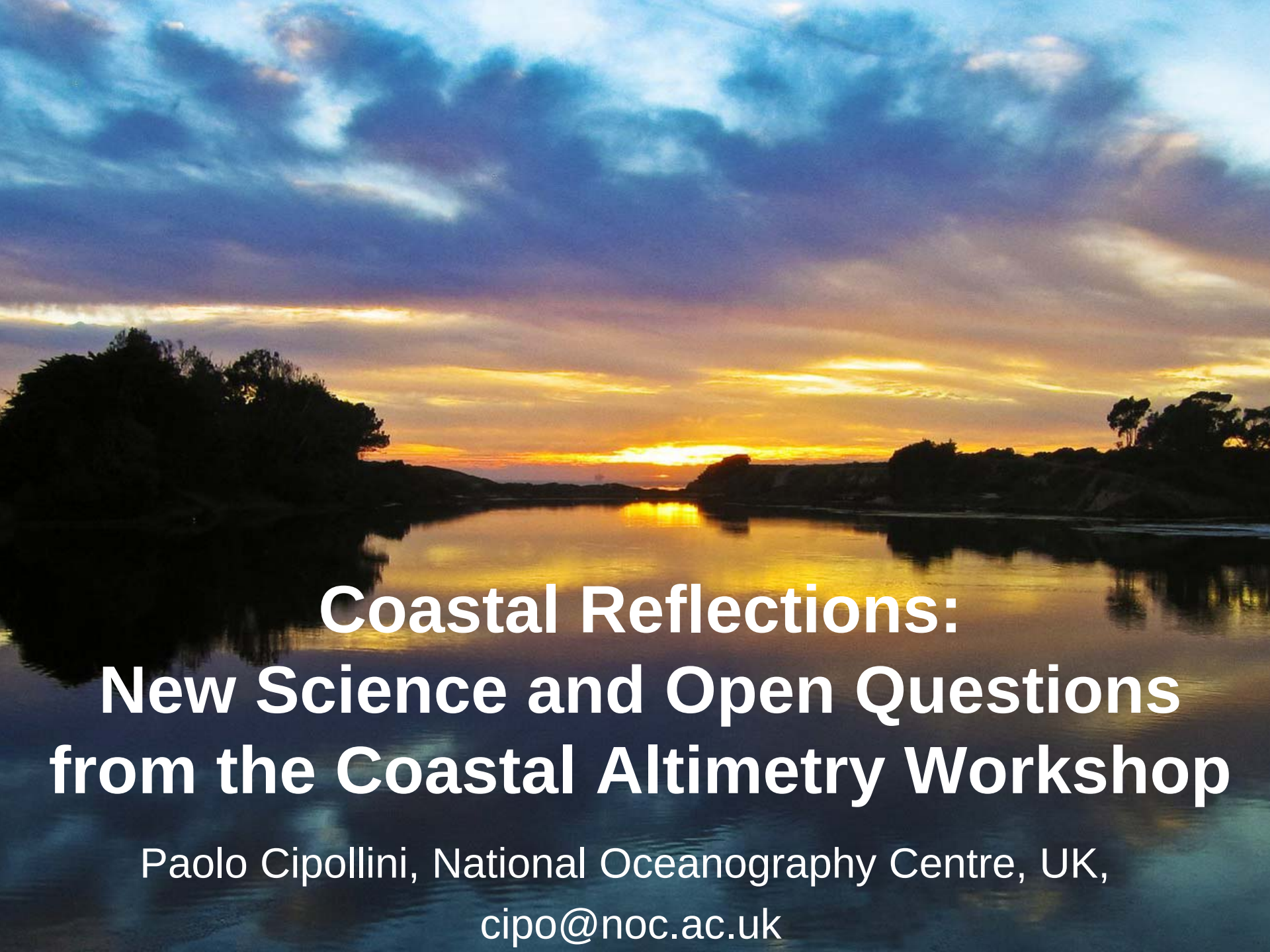


Coastal Reflections: New Science and Open Questions from the Coastal Altimetry Workshop

Paolo Cipollini, National Oceanography Centre, UK,
cipo@noc.ac.uk

Acknowledgements

Org Comm

Jérôme Benveniste
Paolo Cipollini
Laury Miller
Nicolas Picot
Remko Scharroo
Ted Strub
Doug Vandemark
Stefano Vignudelli

Sci Comm / Session Chairs

Lifeng Bao, **Florence Birol**, **Emanuel Coelho**, **Xiaoli Deng**, **William Emery**, **Luciana Fenoglio**, **Jesus Gomez Enri**, **David Griffin**, **Joana Fernandes**, **Guoqi Han**, **Jessica Hausman**, **Kaoru Ichikawa**, **Andrey Kostianoy**, **Villy Kourafalou**, **Sylvie Labroue**, **Gilles Larnicol**, **Richard Ray**, **Martin Saraceno**, **Frank Shillington**, **C. K. Shum**, **Pierre Thibaut**, **John Wilkin**, **Somayajulu Yenamandra**.

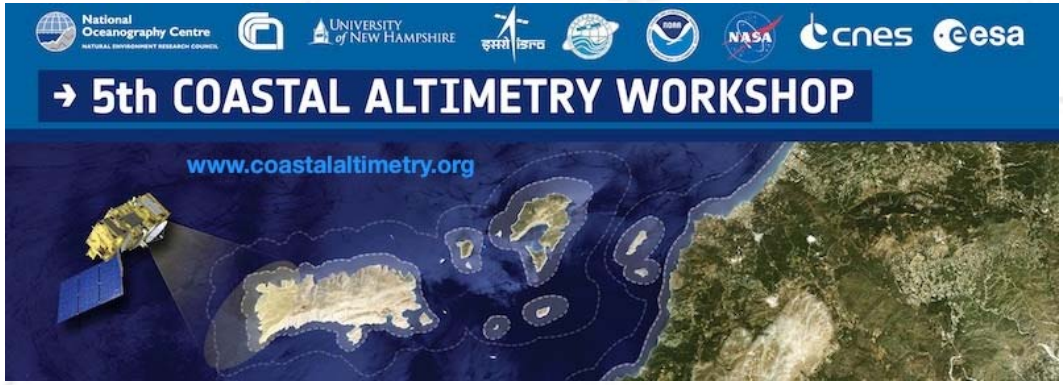
Why Coastal Altimetry?

- Coastal altimetry is extending the frontiers of altimetry
  - previously uncharted domain (the coastal strip)
  - reprocessed data now available (CTOH, PISTACH, COASTALT)
  - many novel applications
- Linked to high-resolution altimetry
- Important for absolute calibration of altimeters

The Coastal Altimetry Community

- 5th Coastal Altimetry Workshop
  - 2.5 days, 37 talks, 30 posters, 136 participants
- A special kind of ‘splinter’
  - big community: 100+
  - cuts across the splinter disciplines
- we want to report here on:

1. How things are improving in coastal altimetry
2. the refreshing **diversity of applications**, with examples
3. **recommendations** (internal / external) & open questions



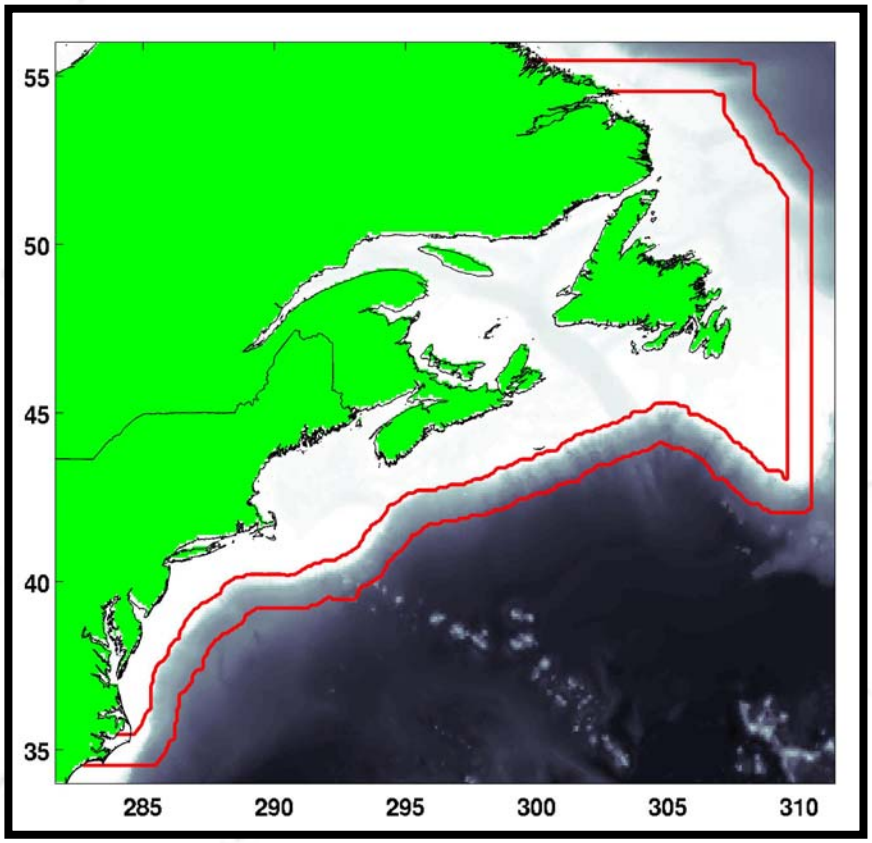
Improving the error budget

- Three main areas of improvements continue to be highlighted in our workshops
- **Retracking** (dedicated session – more later)
- **Wet Tropo** correction (dedicated session – more later)
- **Tides:**
- Global tidal models undoubtedly getting better and better even in the coastal zone but…
- Egbert & Erofeeva's review talk showed huge improvements with a Nested High-Resolution Data Assimilation Modeling + a simple scheme to merge the HR solution with regional and global models

Recommendation: ***make along-track tidal analysis widely available to the community***

Merging high-resolution solutions with regional and global solutions (TPXO7.2-atlas, AO-atlas, etc.)

- Modify land mask on coarse grid: only cells that are completely on land in the HR solution are masked
- Replace coarse-grid tidal solution with averaged high-resolution model in shallow zone
- Retain coarse grid solution outside of this zone
- Smooth transition over boundary zone by blending coarse-grid, averaged high-resolution solutions



Egbert & Erofeeva

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				

T. Strub et al.

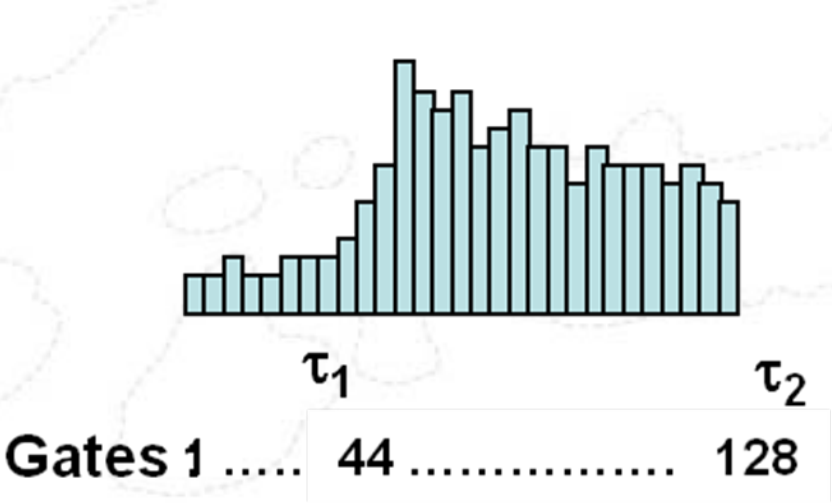
Retracking

- Pervaded several talks /posters
- Main achievements in last 5 years:
  - development of a number of new/improved retrackers
  - identification of some retrackers better performing at the coast (e.g. RED3 in PISTACH Project; but BAG/ BAGP are even more promising)
- Remaining issues:
  - Intercalibration of retrackers is still an issue
  - Validation remains a challenge

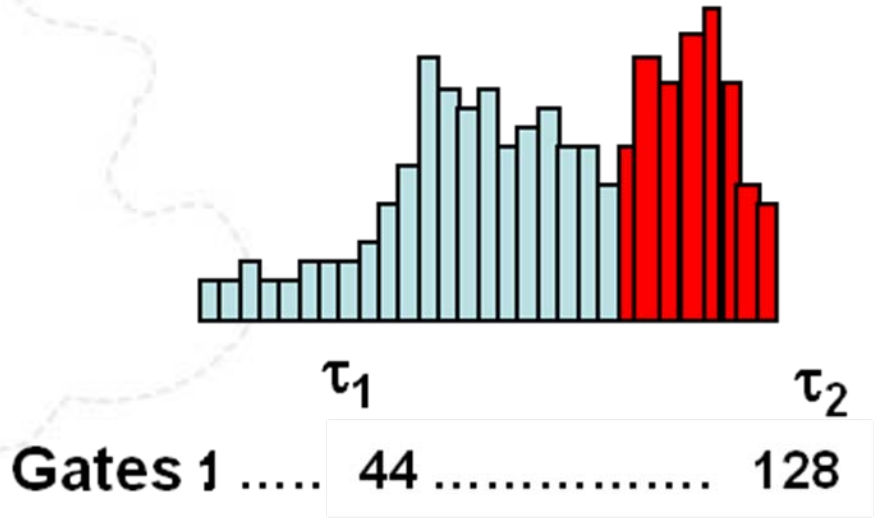
  (Geostrophy, height versus slope, etc.)

***Rec:* further efforts are needed on retracking; both on development, intercalibration and validation**

Retracking solutions (P. Thibaut)



Brown ocean waveforms



Brown corrupted ocean waveforms

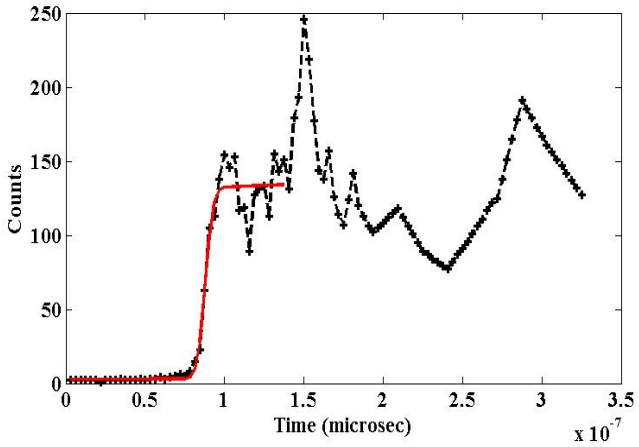
❑ Current ocean retracking
MLE3 or MLE4

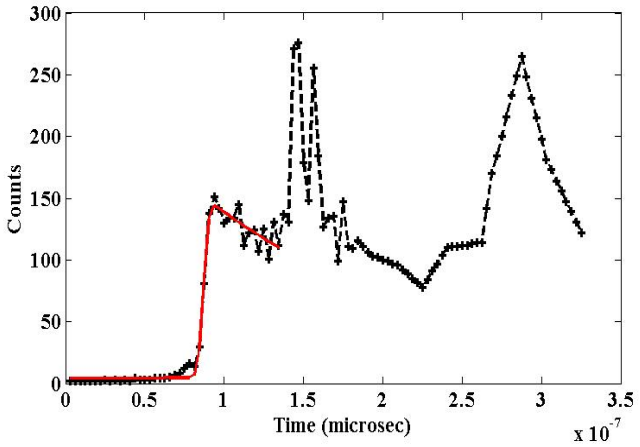
❑ SVD before MLE3/4
to de-noise the estimations
Oce3 in PISTACH products

RED3 Retracking
on truncated window

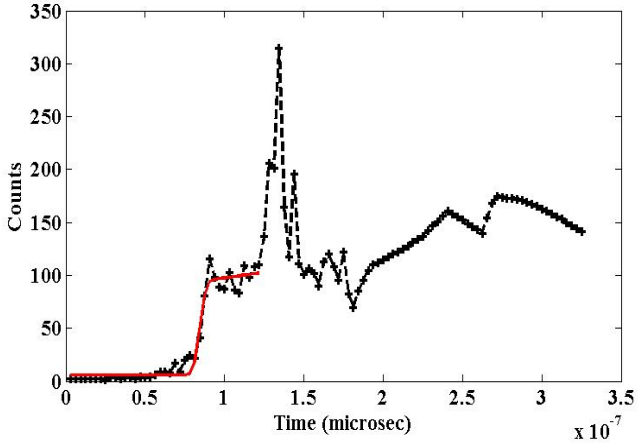
Brown + Gaussian Peak

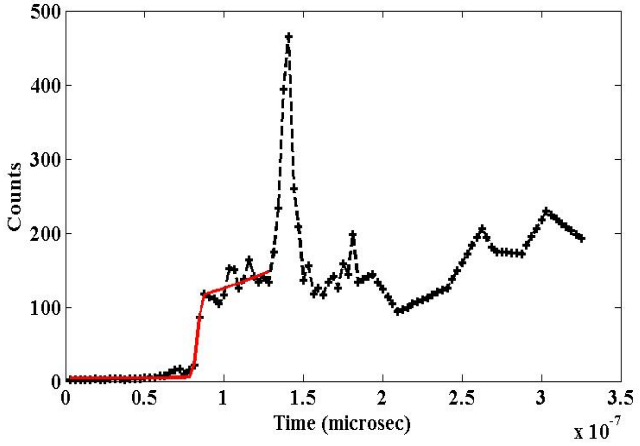
Retrack real Jason-1 waveforms





The Brown Model is successfully fitted to the sub-waveforms.



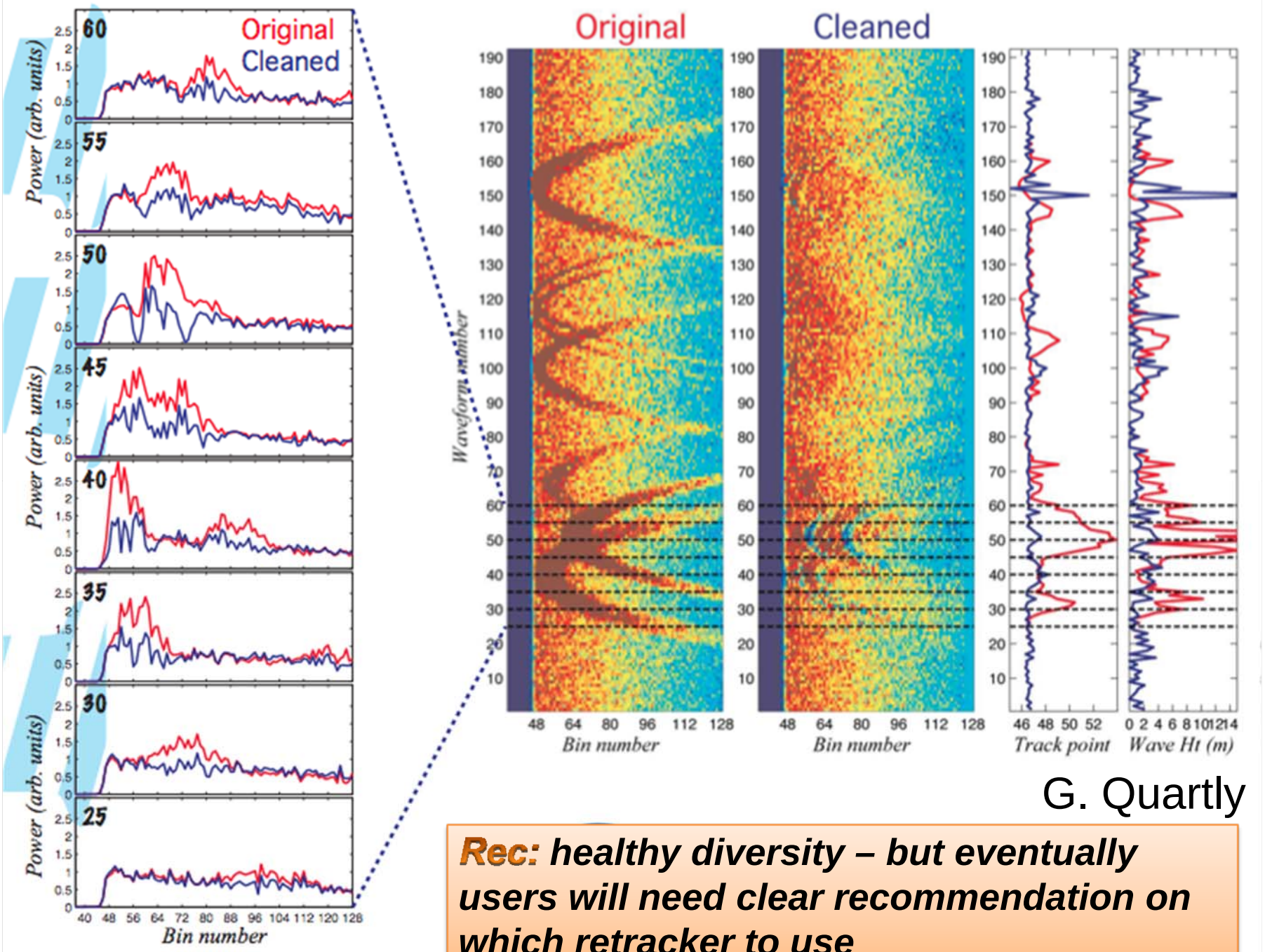


Idris and Deng

Innovative retrackers

- Use information in adjacent waveforms
- Denoised estimations with Singular Value Decomposition(PISTACH)
- Hyperbolic ‘Pretracker’, Bayes Linear Retracker (COASTALT Project)

Rec: ***these are very promising but need further R&D***



G. Quartly

Rec: ***healthy diversity – but eventually users will need clear recommendation on which retracker to use***

Path Delay

- High spatial variability
- Several techniques developed in recent years, promising results, but difficult to validate

✓ GNSS Path Delay + combination with models and radiometer products (Joana Fernandes in COASTALT)

  ✓ GNSS network still not enough for operational correction, but crucial for validation and comparision

✓ land's proportion in the pixel introduced in the radiometer processing (Estelle Obligis, Shannon Brown)

- What about Wet Tropospheric Correction for the new altimeter missions (Altika, CryoSat, etc.)
- Are the proposed methods applicable to hydrology?

***Rec:* An intercalibration of the various wet tropo algorithms is needed**

Other corrections - SSB

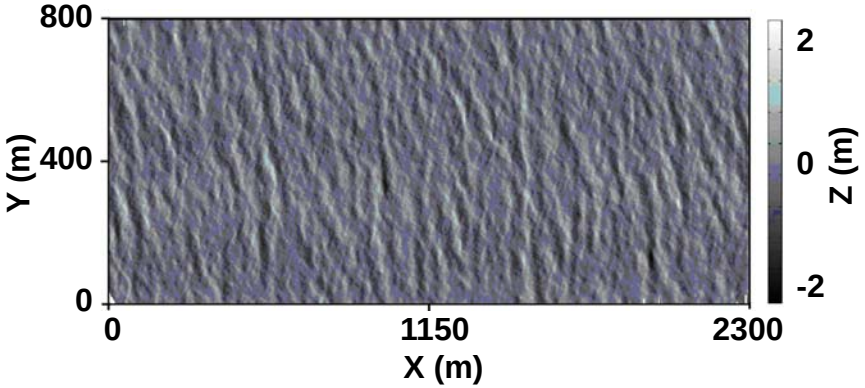
- SSB – still an issue! and we need a SSB correction for SAR altimetry

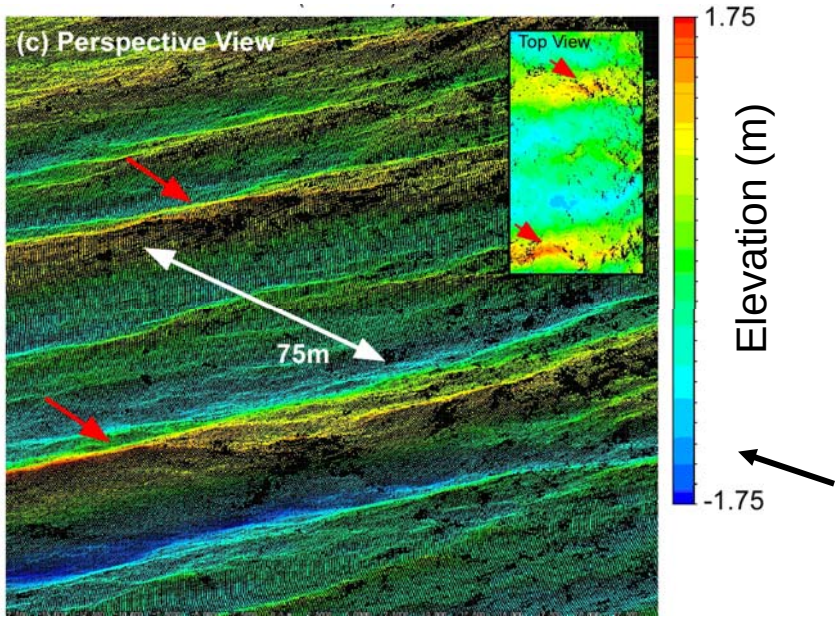
***Rec:* more efforts on SSB**

- full waveform airborne LIDAR (Reineman et al) might help a lot

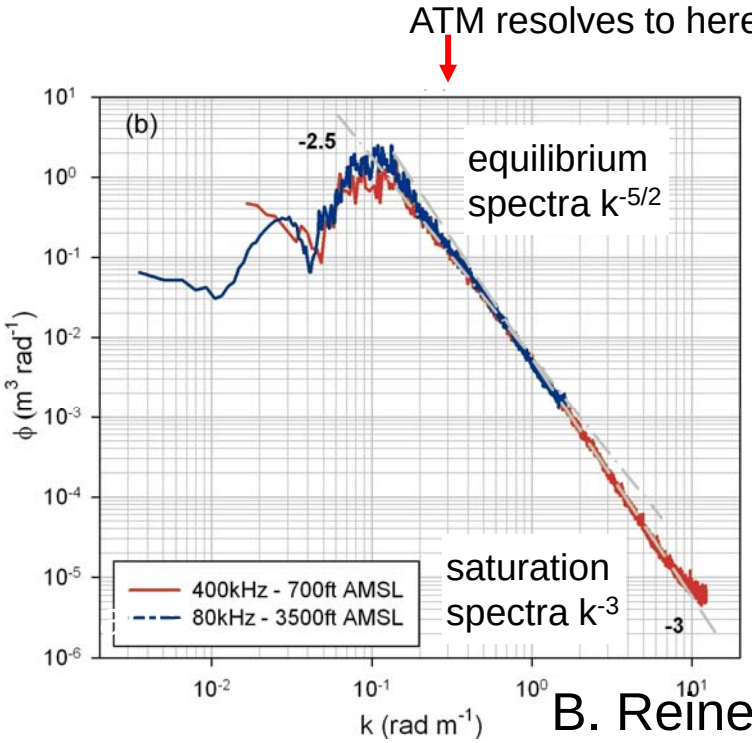
Sea surface topography, omnidirectional surface wavenumber spectra

a) Segment from previous slide, 4 Aug 2011, 1100 m AMSL





b) Omnidirectional wavenumber spectra
- 1100 m AMSL (blue) 800-1000-m swath width, 1.2-m resolution
- 200 m AMSL (red) 200-m swath width, 12-25-cm resolution



B. Reineman et al

c) Perspective view example of raw point cloud color coded for height above MSL. Insert: top view of the same wave field

Other corrections - HF

- short-term atmospherically-loaded signal. Over coastal and shelves seas, residual errors ranges from 12-20 cm rms.
- regional model have been developed for the European seas. However, there are still lots of shelves to deal with and this intensive work need to be supported.

- we should recommend the production of regional modelling archives to provide coastal altimetry data suppliers with.

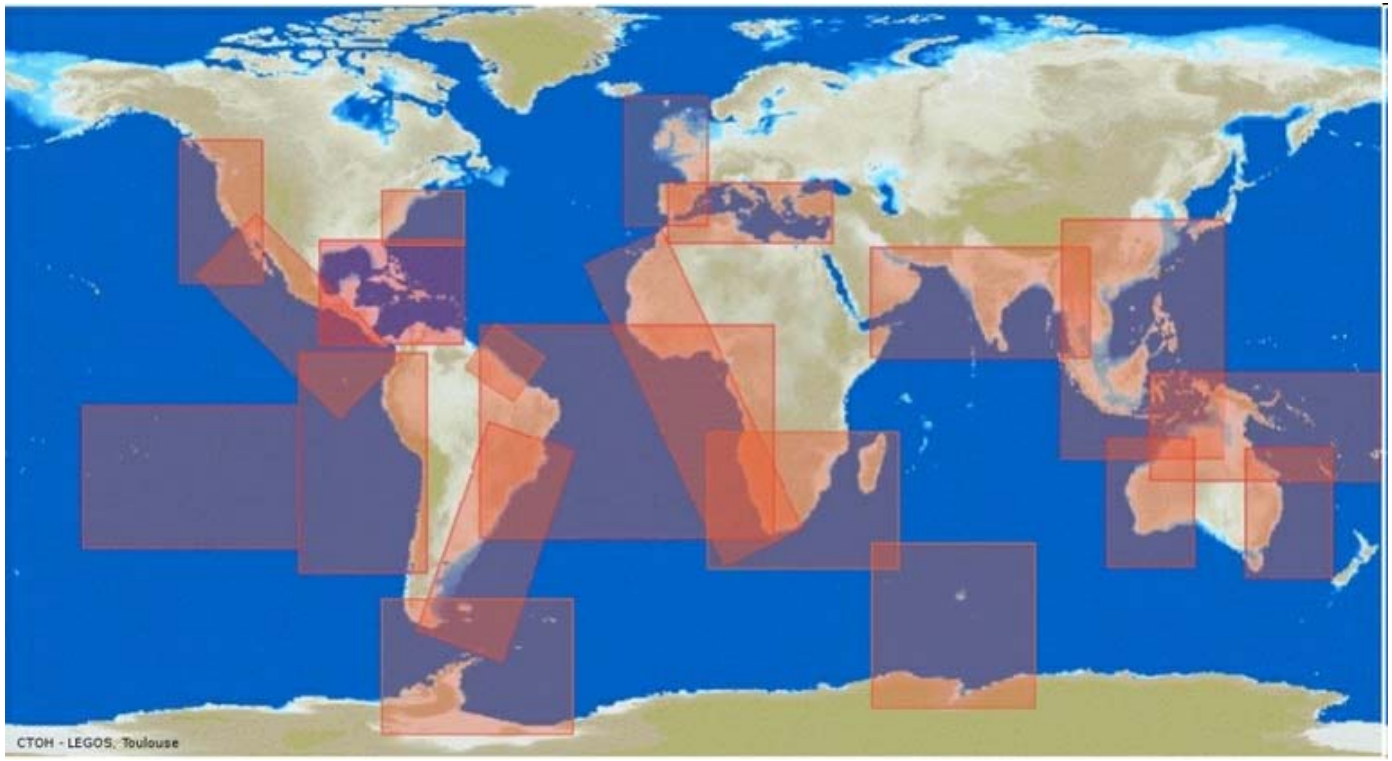
Rec: ***more on HF – need production of regional modelling archives to provide this correction for coastal altimetry***

CTOH regional products: what's new in 2011

F. Birol et al

- **1 Hz products, Netcdf format:**
  - **SLA time series along a nominal ground-track,**
  - **MSSH consistent with SLA**
  - **geophysical (tidal and DAC separetely) corrections included**
  - **distance to nearest coast (Leuliette)**

- **Complete reprocessing, 20 different regions available (12, last year)**



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

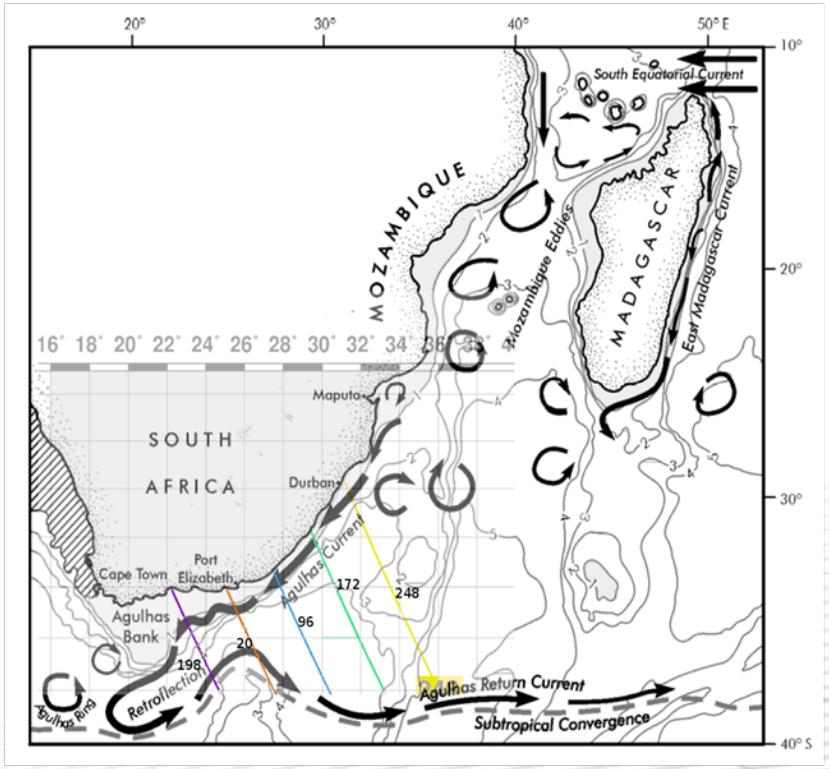
Products

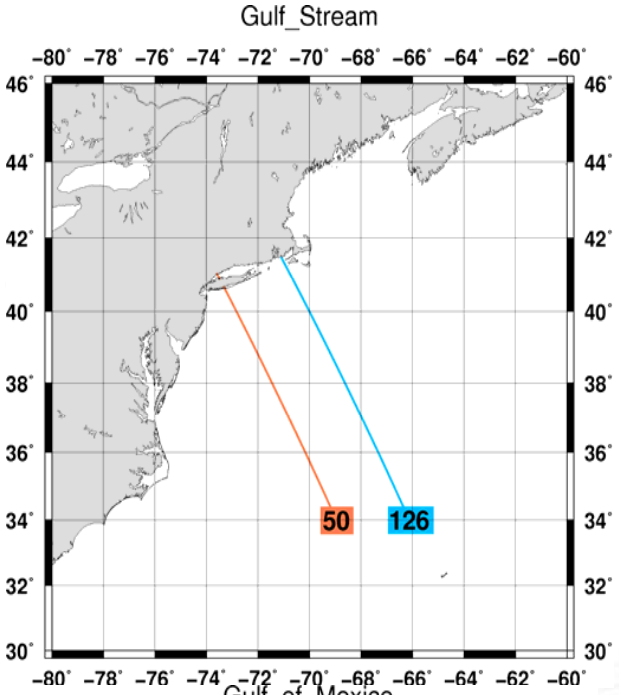
- PISTACH – Jason-2 - distributed since 2008
- a call in June 2011 for reprocessing over selected areas – 3 selected
  - Agulhas (Beal + Collard SAR), Florida Straits (kourafalou) East US (Vandemark)
  - L3 for 3 zones computed by CLS + Noveltis and Legos
- 3 more to be selected in 2012
- COASTALT also providing data (over a few selected tracks in validation areas)
- Users need multi-mission coastal products. For the moment PISTACH provides Jason-2 data products only.

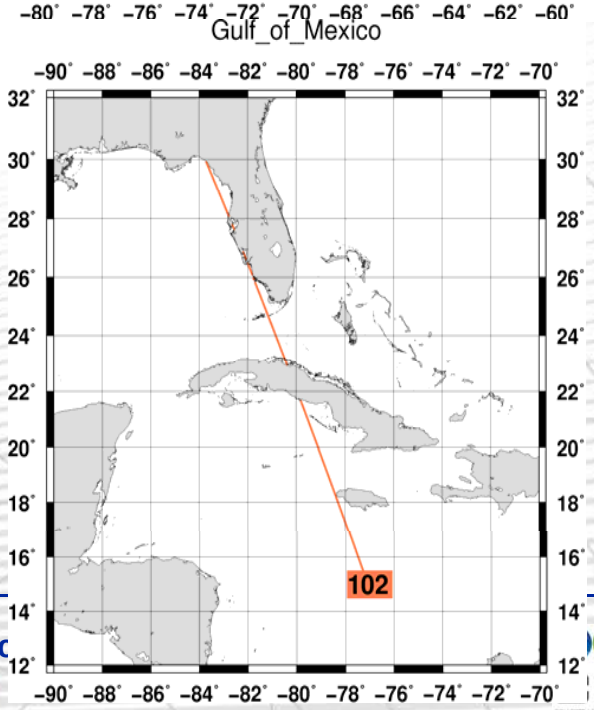
***Rec:* need to move to multi-mission processing**

L3 PISTACH Project

- Choice of 3 zones
  - Agulhas current with the support of Beal (in situ) and Collard
  - Florida Strait with the suuport of Kourafalou
  - East US coast with the support of Vandemark







S. Labroue et al

Processing/Products

PISTACH has done a good job of providing retrackers and retracked data along with all the information to utilize these retrackers.

PISTACH and CTOH demonstrate that careful treatment/editing of 20Hz data (SLA not only range) is crucial

If we are to expand the use of altimetry in the coastal ocean we need to be able to provide well documented products to new users, with case studies , as done in the COASTALT Handbook

***Rec:* need documentation and case studies**

Data dissemination

No data centers specifically for coastal altimetry – users may not know where to go to find products

Rec: ***need single point of access to coastal alt data – also calls for outreach***

Cal/Val Issues

1) Compare impact of wet tropo correction on absolute calibration at coastal calibration sites.
2) Relevance of coastal biases (drop or rise) due land interference in the waveform.
   Applies to range and SWH.
3) Impact of dynamic topography on range calibration near coastal sites.

Coastal Altimetry and CryoSat

Keynote (D Sandwell) on improvement in marine geoid, plus 4 talks

- More focusing on the actual ”first results” of CryoSat than actual coastal zone applications.

The Wonders of CryoSat

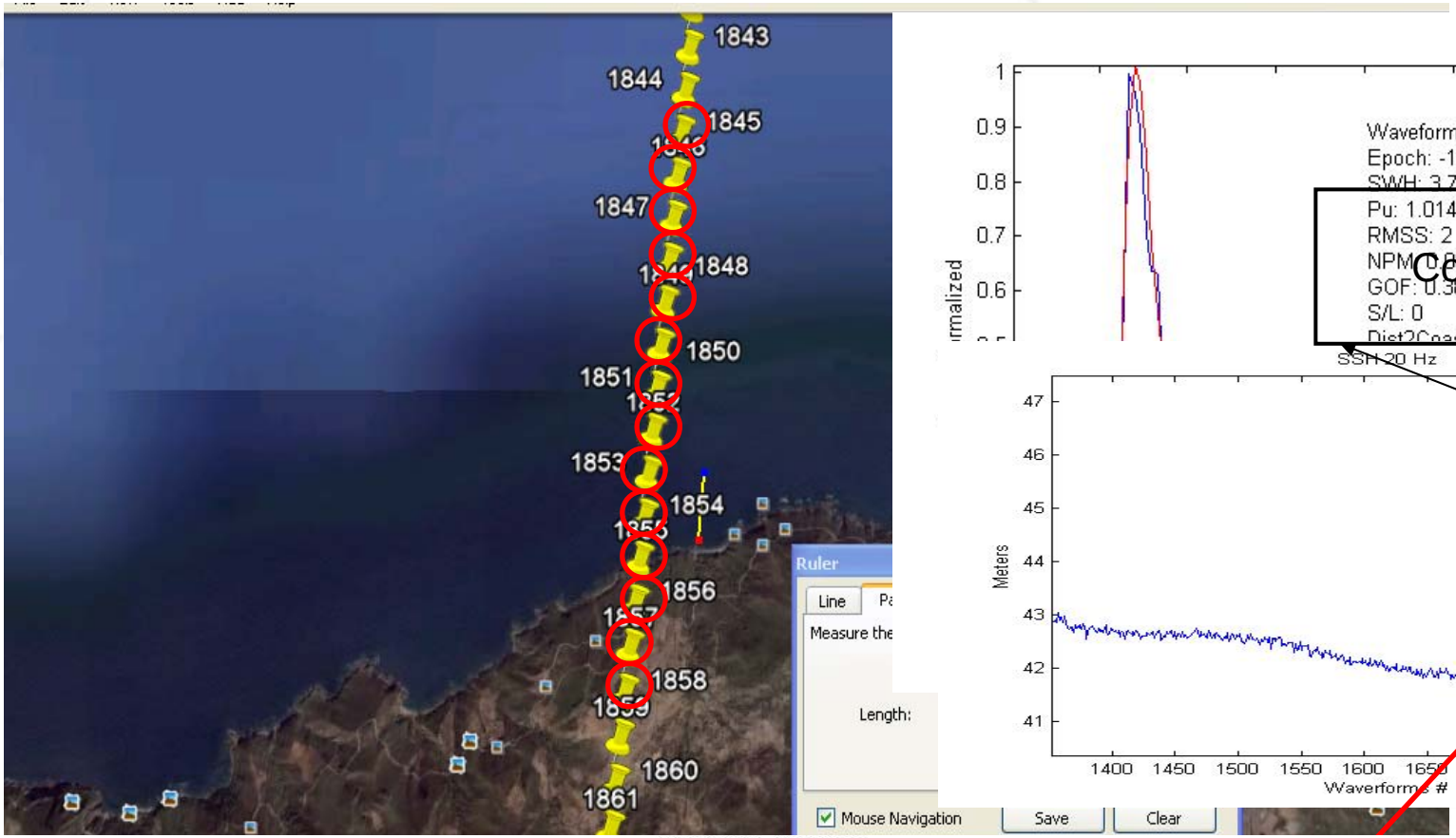
- CryoSat already performs equally well to conventional altimeters even without some of the corrections (and using a tentative SSB) (Scharroo)
- CryoSat waveforms are well behaved all the wave all the way to the coast. (Dinardo)
- Possibility of Fast Delivery CryoSat ”SGDR” quality data (Smith).

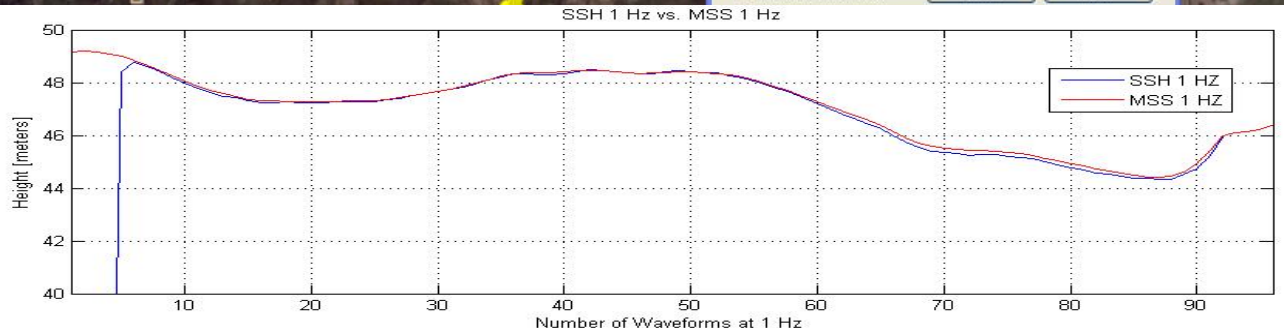
***Rec:* fast delivery data**

- Development of RDSAR pseudo LRM data (Puig)
- CryoSat is optimized for ice-surfaces. The community would like an ocean-optimized SAR altimeter for J-CS.
- The importance of higher waveform sampling for improved waveform retracking.
- The importance of high resolution easy accessible CS data.

Effect of the Land In SAR mode

Waveforms at 20 Hz, one waveform each 300 meters – Optimal Conditions



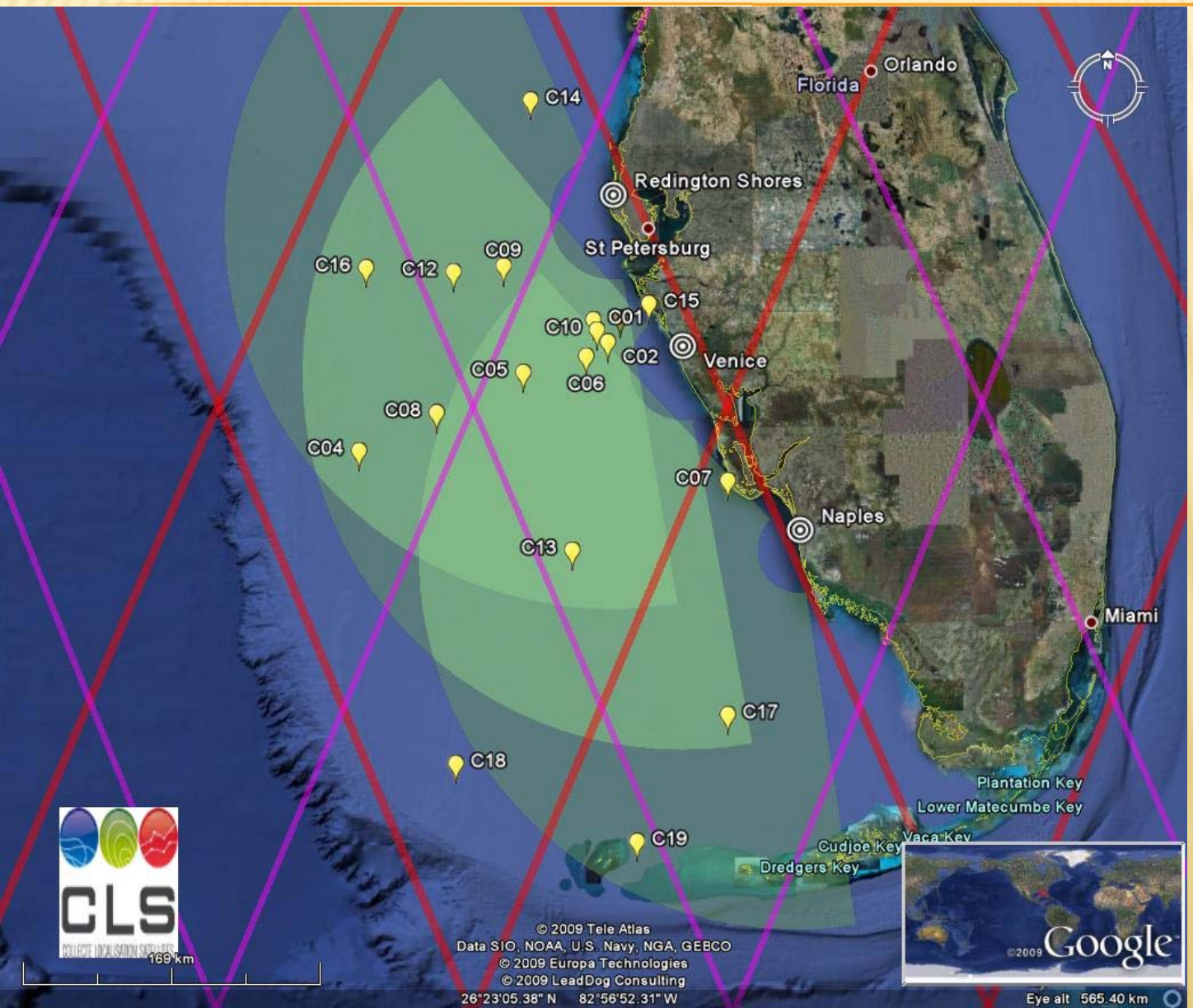


S. Dinardo et al

Applications

- The range of applications presented was impressive…
- some areas are emerging as scientifically popular.

A Platform for Coastal Altimetry Validation



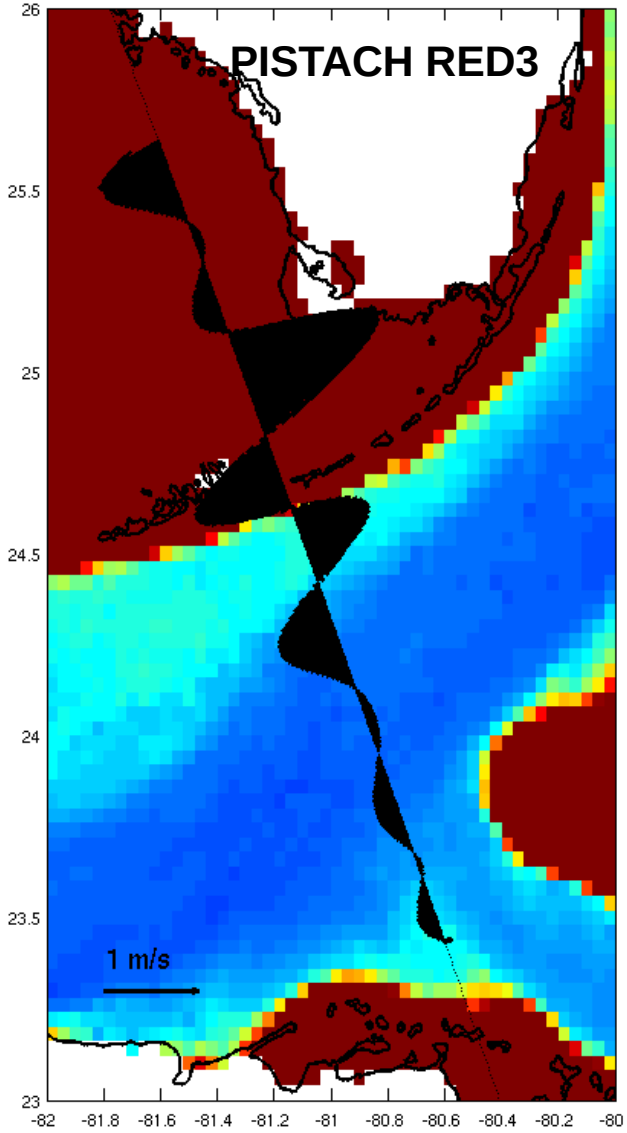
- **ADCP array**
- **HF radar array**
- **Satellite tracks**

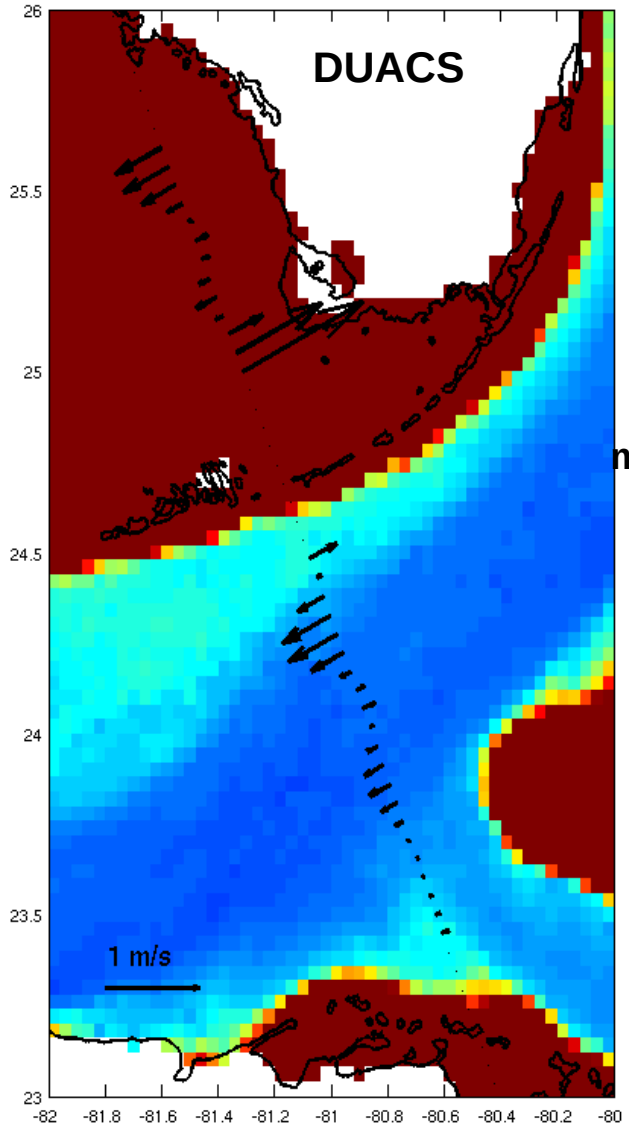
T/P & J1 tracks

T/P interleaved tracks

Liu (USF) et al

Comparison of the current anomalies

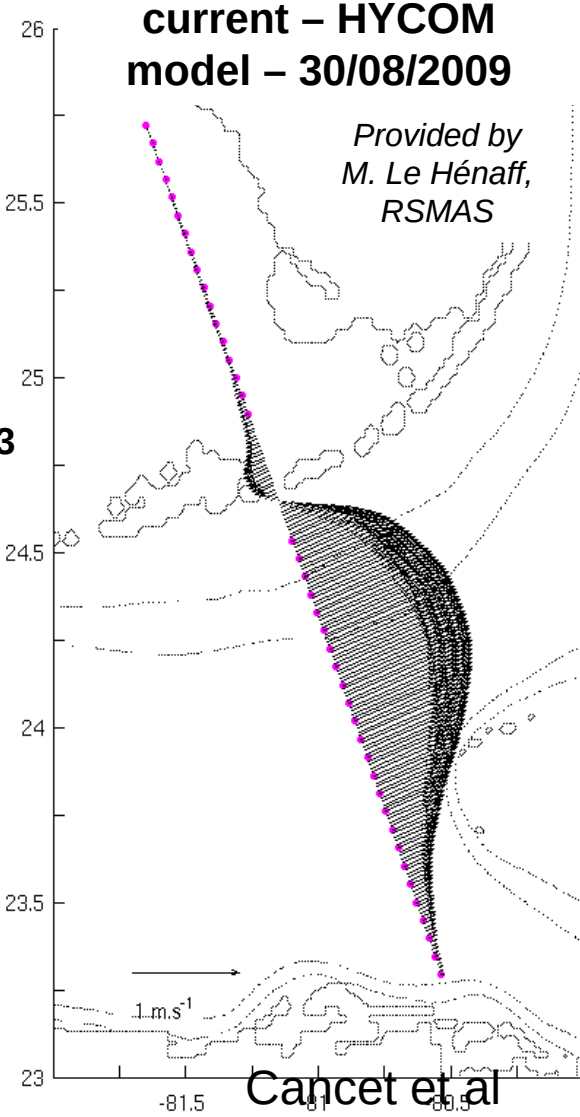




mg/m3

Mean geostrophic current – HYCOM model – 30/08/2009

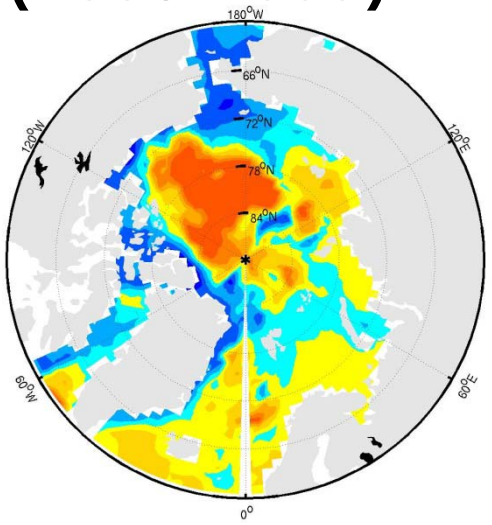
Provided by M. Le Hénaff, RSMAS



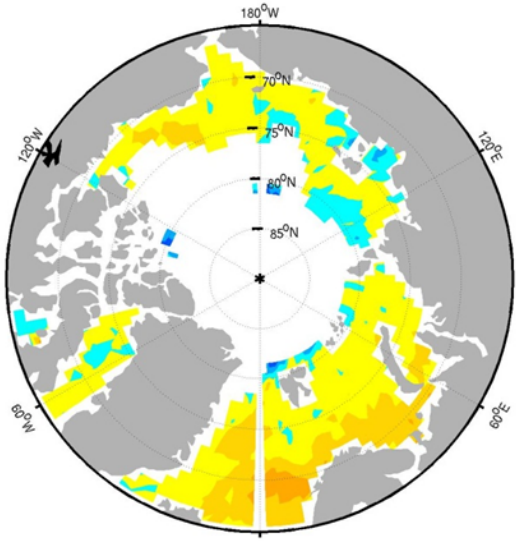
Cancet et al

Linear Sea Level Trend: (GIA NOT applied)

PSMSL (1993-2009): **3.22 mm/yr**



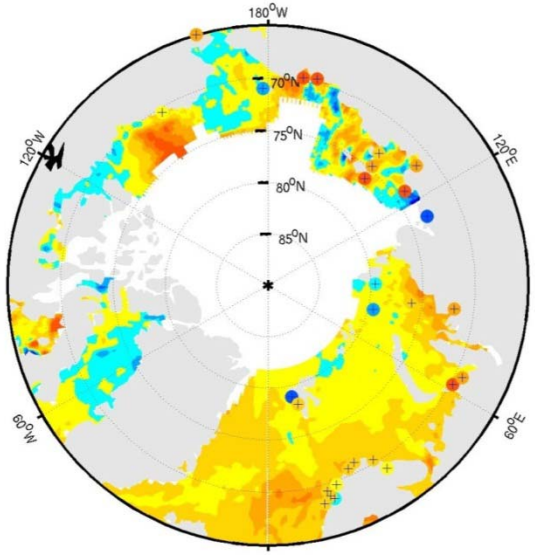
Cheng and Andersen



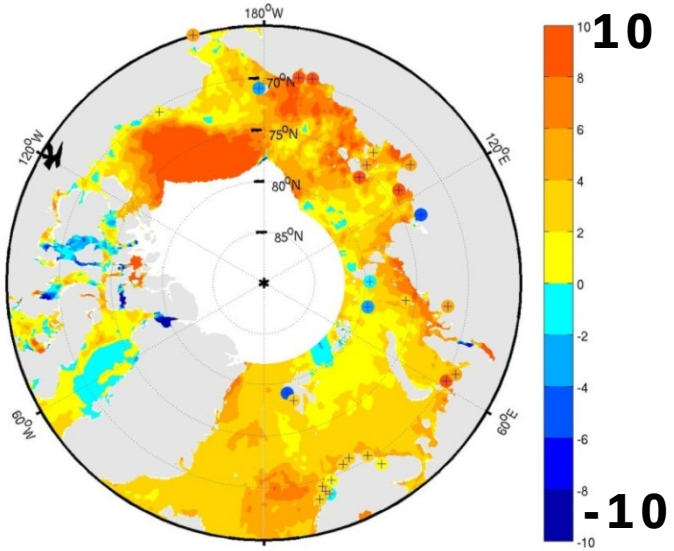
Resolution: 1°*3°

SODA (1993-2008) **0.39 mm/yr**

RADS(1993-2009) **0.89 mm/yr**



DUACS V3.0.0 **1.75 mm/yr**

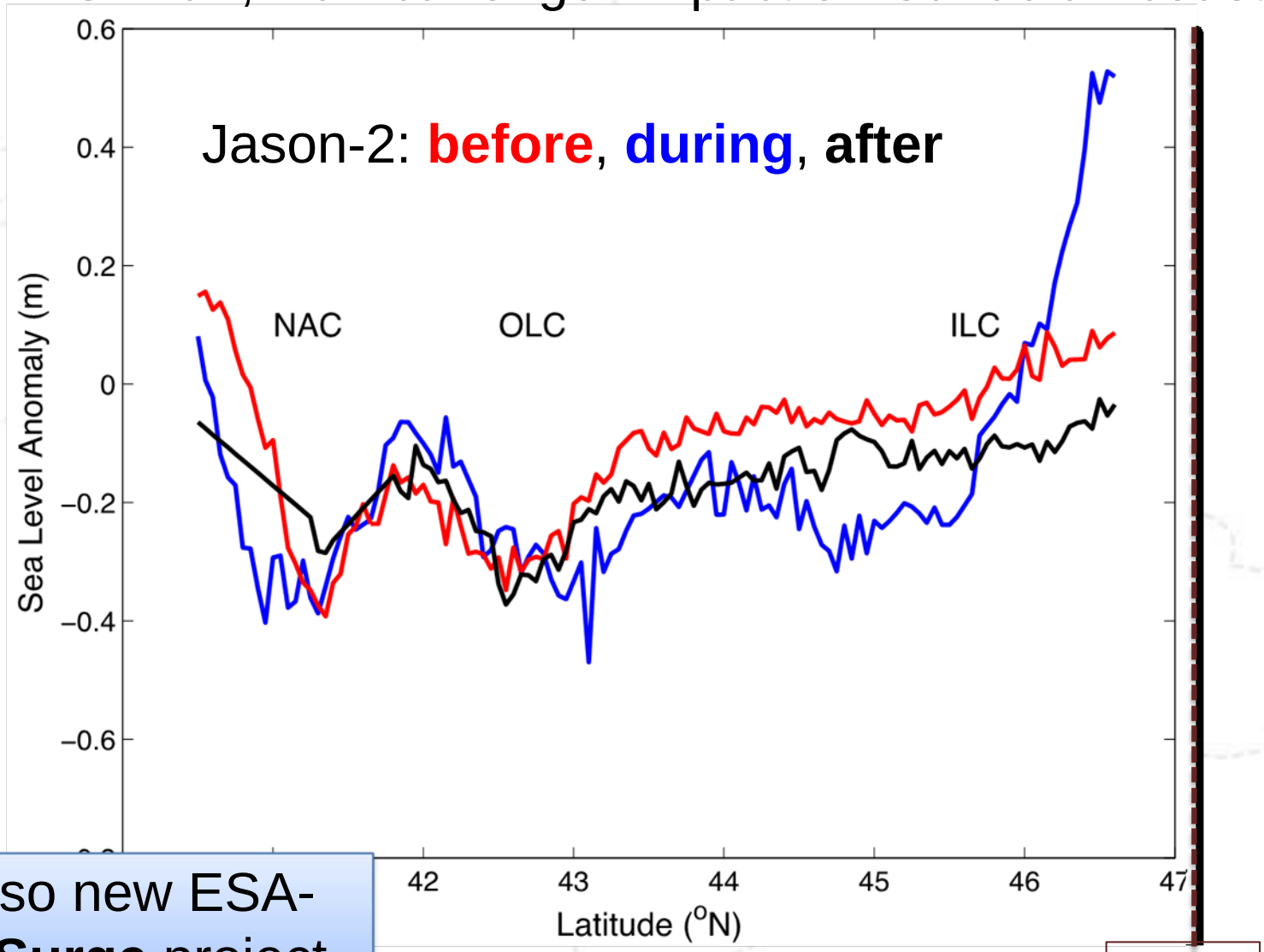


Arctic V2p **3.64 mm/yr**

Application to trajectories of jellyfish (Bouffard et al)

Application to Extreme events: surges

G. Han, Hurricane Igor impact on Canadian coast



See also new ESA-DUE **eSurge** project

Application Highlights – Further Steps

- Expand the user groups, promote collaborations among user groups and with the data providers, toward methodologies that result in data products suitable for broad applications.
- Design experiments that can quantify the data value (such as Observing System experiments and Observing System Simulation Experiments)
- **Demonstrate benefits to the SWOT mission** by providing the highest long track resolution (combined with validation form other data sets and high resolution coastal and shelf modeling)
- Assimilate coastal altimetry data to high resolution models *(related issues to be addressed by the modeling summary -> J Wilkin/K Ichikawa)*

High resolution current/dynamics

- Need to resolve the submesoscale features so need to use high frequency signal and use better retracking
- There is no "one size fits all" solution due to different physics of different regions.
  - We need to better resolve ageostrophic currents and wet troposphere, carefully edit and smooth waveforms when retracking, and subsample appropriately the retracked data.
- Find the right filter/smoothing scale so SSHA is not noisy due to the high frequency from a small radius but does not wash out physics from a large radius

Rec: ***decorrelation scales of data and corrections (and relevant smoothing scales) need to be investigated further***

Coastal Altimetry and Modelling

- Data assimilation (via variational methods) integrates remotely sensed observations and dynamical constraints to improve ocean state estimation
- Using all data (SSH, SST, HF-radar) gives greatest analysis skill; assimilating only one data type degrades the analysis of unconstrained variables.
- Adjoint-based methods quantify forecast uncertainty without computing large ensembles
- Multi-scale hierarchy of models, using altimetry processed to differing levels, acknowledges the range of model and data covariance scales.
- High-resolution models reveals submesoscales at the limit of nadir altimetry.

Coastal Altimetry and Modelling

Recommendations:

- Model-based analysis (assimilation; statistical covariance analysis) are promising approaches to infer subsurface circulation from surface-only observations
- Coastal oceanographers need guidance on “best practise” to match corrections appropriate to dynamical processes.
- To utilize high sample rate SSH model development required ~ multi-scale nesting and data assimilation is recommended.
- Coastal modelers/assimilators need a test-bed/comparison framework (complementary to CAW process) to exchange developments in assimilation methodology, data pre-processing, and verification.

CA-WS: A Community Science Review

- Coastal Altimetry is a relatively new field
  - BUT a science topic of great relevance to monitor the coastal environment and assess the impact of global change on the coasts!

- a **vibrant international community** has quickly gathered around it!

- Datasets are being produced, results are coming out, applications are pioneered
  - our *Coastal Altimetry* book is a good account of all that!

The Workshop reviewed and steered this new science

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.

ISBN 978-3-642-12795-3

springer.com

Vignudelli · Kostianoy
Cipollini · Benveniste (Eds.)

Coastal Altimetry

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

cnes esa

Coastal Altimetry

Springer

Community Goals – a simple view

- do more with the **data we've got already**
  - exploit PISTACH, XTRACK, COASTALT (selected tracks)
  - near future: eSurge, CryoSatPlus Projects

- get **more/better (and new!) data**
  - new/improved retrackers
  - new/improved corrections
  - new missions (CryoSat, AltiKa, HY-2)

- This community is well placed to **express the coastal zone user requirements for future missions** (e.g. Jason-CS)

Next CA-WS: 19-21 Sept 2012, in some place close to Venice!