Splinters summaries

- **09:00** Regional and Global CAL/VAL for Assembling a Climate Data Record
- **09:10** Precision Orbit Determination
- **09:20** Instrument processing: Corrections
- **09:30** Instrument processing: Measurement and retracking
- **09:40** Application development for Operations
- **09:50** Outreach, Education & Altimetric data services
- **10:00** The Geoid Mean Sea Surfaces and Mean Dynamic Topography
- **10:10** Quantifying Errors and Uncertainties in Altimetry Data
- **10:20** Tides, internal tides and high-frequency processes

Coffee break

- **11:00** Science Results from Satellite Altimetry

Regional and Global CAL/VAL for Assembling a Climate Data Record Splinter summary

Chairs: P. Bonnefond, S. Desai, B. Haines, E. Leuiliette, N. Picot

Regional Calibration/Validation

Wednesday, October 21, 2015

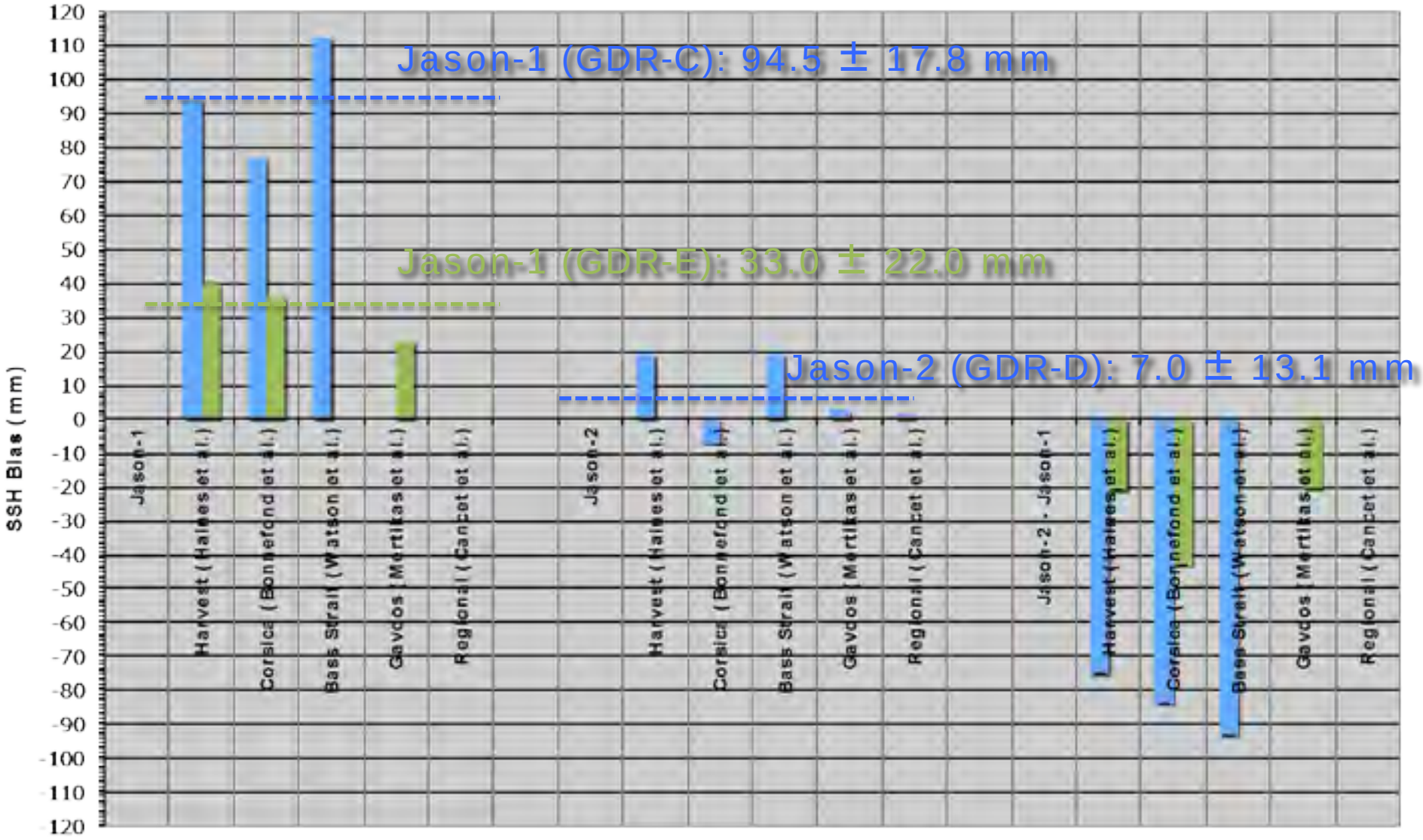
6 oral presentations.

10 posters (for both sessions).

Local Cal/Val Summary report

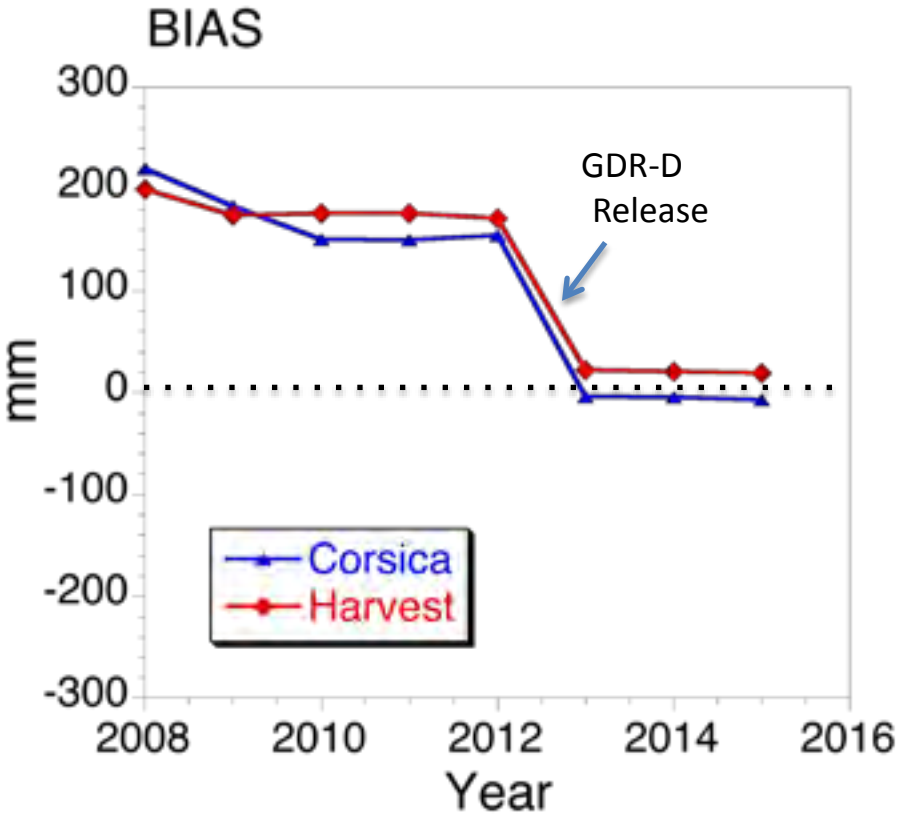
- **Ensemble results from dedicated sites and regional campaigns indicate**:
  - Current Jason-2 (GDR-D) SSH unbiased or slightly biased (questionable significance).
  - Current Jason-1 (GDR-C) SSH bias high by 9 cm.
  - Preliminary analysis of Jason-1 GDR-E SSH confirms significant reduction in SSH bias, due mainly to correction for Poseidon-2 internal path delay. The residual SSH bias (+3 cm) is larger than predicted at last year's meeting, due mainly to the selection of the SSB model.
  - Legacy (T/P) systems unbiased. However RGDR diverges significantly with MGDR and tide gauges prior to mid-1995 and warrants investigation.
  - SARAL/AltiKa results support that the SSH measurements are biased low by 4 cm.
- **Jason-2 drift estimates from dedicated sites continue to improve**
  - Harvest and Bass Strait now yield estimates ≤ 1 mm/yr (statistically indistinguishable from zero), but….
  - Systematic patterns in calibration series from all sites remain, and drift at Corsica is -4 mm/yr.
  - Raises questions on regional stability of altimetric measurements, and on the stability of the in-situ observations (of water level and vertical land motion).
  - Spurious drift in Jason-2 C-Band range at Harvest warrants investigation.

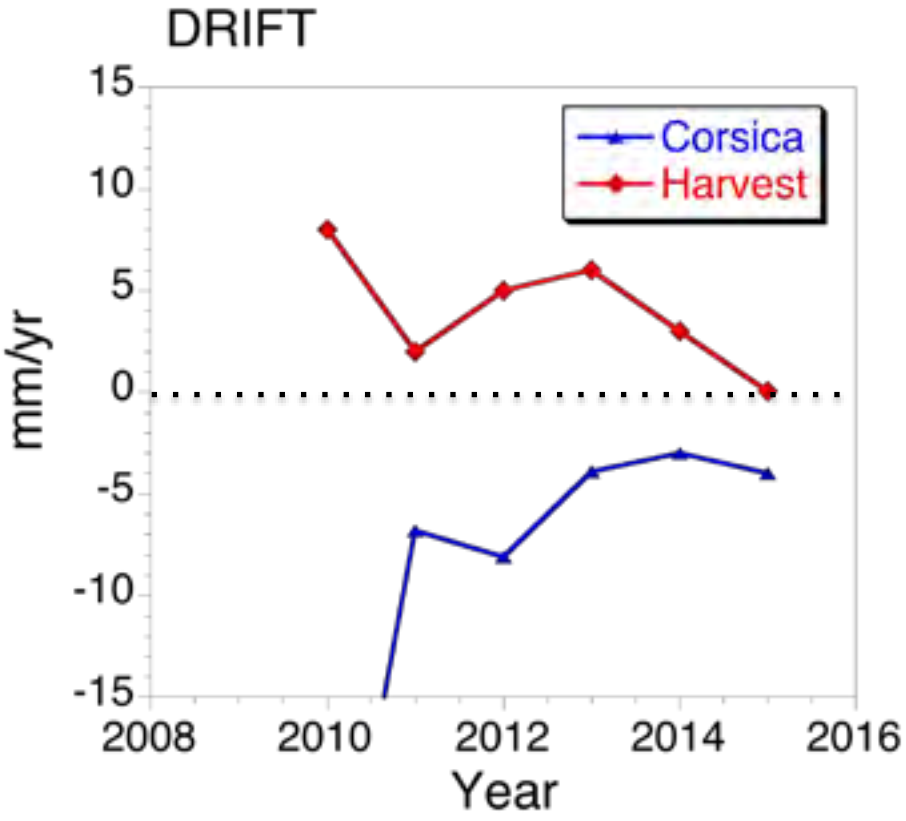
In-Situ Bias Estimates for Jason-1 and Jason-2



Evolution of Jason-2 Estimates of SSH Bias and Drift

AS REPORTED AT OSTST MEETINGS





Regional Cal/Val summary report

- **Regional calibration methods (Cancet et al.)**
  - **Employed for the first time at all three historical calibration sites (Corsica, Harvest and Bass Strait). This technique shows great promise for reducing errors (through increasing numbers of overflights), expanding the calibration footprint of each site and improved linking of in-situ and global calval results.**
- **Evolution of tide gauge/altimeter comparisons has led to new insights**
  - **Leads to lower estimate for GMSL in one study, due principally to TOPEX Side A.**
  - **Questions on the Jason-2 drift have been largely resolved (close agreement between all teams).**
  - **Highlights importance of accurate land motion estimates.**
  - **Underscores importance of developing rigorous error budgets for competing solutions.**
  - **Different approaches also desirable to expose errors.**
- **Comparisons to ARGO and GRACE providing valuable new insights on stability - A good 'closing budget' is available for 2004-2014 period but there are still open questions on :**
  - **Impact of the deep layer thermal content – future ARGO network will improve the sampling of the deep layers content.**
  - **Sensitivity to the GRACE geoid solution has been emphasized**

Global Calibration/Validation
Wednesday, October 21, 2015

6 oral presentations.

10 posters (for both sessions).

Global Cal/Val summary report

- **Jason Missions**
  - Jason-1 **GDR-E processing ongoing:**
    - Improves (reduces) SSH crossover variance.
    - Improves consistency with Jason-2.
      - Relative bias expected to be < 1 cm when using consistent SSB.
    - Two anomalies identified, and will be fixed:
      - Applied ranges biases
      - GOT ocean tide model.
  - Jason-2 **data coverage and quality remain excellent.**
    - Sea surface height error 3.5 cm for temporal scales less than 10 days.
    - GMSL stability < 0.5 mm/yr
    - Version E orbit standards reduce errors on regional sea level rise.

Global Cal/Val summary report

- **SARAL Mission**
  - Excellent data coverage and quality, even slightly better than Jason-2.
    - Missing measurements due to rain are significantly fewer than anticipated.
  - Crossover performance is similar to Jason-2.
  - No significant drift relative to Jason-2.
  - Range bias of ~-5 cm still remains to be explained.
  - Improvements to current product standard foreseen in 2016 (TBC).
    - Sea state bias, wind LUT, radiometer wet troposphere correction, sigma0 atmospheric attenuation, orbit, ice2 retracking, … . Those are already implemented in PEACHI products.

- **Crysosat**
  - Excellent data quality in both LRM and SAR modes from all data centre (ESA GOP ie GDR like products are now routinely available, still processed on CNES side for SAR studies and DUACS needs)

- **HY2A**
  - Routinely processed on CNES side to allow data use in SALP/DUACS but …
  - Not a stable mission on the long-term basis

Cal/Val round-table discussion

- **Tide gauge/altimetry comparisons**
  - **It is recommended that the groups involved in the tide gauge/altimetry comparisons work collectively to further understand and document the strengths and limitations of the techniques, with the goal of reporting back to the community at OSTST 2016**. The group involved will agree on a set of milestones to achieve this undertaking.
  - The tide gauge/altimeter comparison group will work to define a set of sensitive tests including investigating site weighting strategies, network effects, and approaches for dealing with vertical land motion.
  - **We encourage the work of the IAG Joint Working Group 3.2 (Vertical motion of the Earth's crust and sea-level change) and tide gauge/altimeter group plan to work alongside them to provide a prioritized list of gauges that are most critical to the altimetry comparisons.**
  - We support efforts to investigate tide gauge / GNSS deployments and their optimization for current and future missions.
  - **We look forward to the release of ITRF2014 and continued efforts by the reference frame community to reduce the reference frame errors and improve the long-term stability.**

Cal/Val round-table discussion

SWOT preparation: From 1D to 2D Cal/Val

- How should we validate the along track SSH at scales from 30-150 km - with spatial distribution of in-situ observations or global analyses?
- Review of the existing means
  - In Situ measurements
    - Tide gauges, ADCP, drifters, CTD, GPS devices, moorings, gliders, transponders, air flight data, radar HF, …
    - Complementarity of these different measurements => multi-platform experiments (see Alborex experiment keynote by Ananda Pascual)
    - But a detailed description of each instrument is needed (advantages/disadvantages, error budget, how to link altimeter SSH and in situ, …)
  - Global Cal/Val
    - SAR measurements can help to increase the spatial resolution
    - Promising LRM processing (Dcore, Two pass, Filtering, …) should be analyzed
- An OSTST session dedicated to this in 2016?

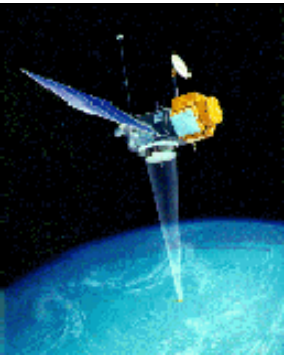
Cal/Val round-table discussion

Other items

- Make a living document including all the altimetry (products, events, ...) history to defend the importance of continuity
- In situ data: make a recommendation to release the data (and the documentation …) to all to allow different groups to make their own study

POD Splinter Summary

Frank Lemoine (NASA GSFC
Sean Bruinsma (GRGS/CNES)
Alexandre Couhert (CNES)



OSTST 2015 POD Splinter
Reston, Virginia, USA
October 20-23, 2015

Session Summary (1)

- 9 oral talks; 4 posters.
- Updates by CNES, GSFC, JPL & GFZ
- Evaluation of orbit quality for new orbits (GDR-E, std1504); New project orbits offer significant improvements.
- Other detailed topics:

1. New Time series of GRACE+SLR-based TVG solutions available from GRGS (*Richard Biancale, GRGS/CNES*).
2. Recomputed South Atlantic Anomaly (SAA) model for Jason-1 DORIS data using Jason-2 payload (CARMEN). Validated previous results (Hugues Capdeville, CLS)
3. Analysis of Satellite laser ranging data using geodetic satellites fof multiple stations illuminates station-specific performance issues *(Sean Bruinsma, GRGS/CNES)*
4. *Two papers looked at integrated treatment of geocenter, one in context of adjustment of reference frame (WIB) and the other in context of DORIS orbit (FM). Both showed that Jason-2 orbit centering can be improved.*

Session Summary (2)

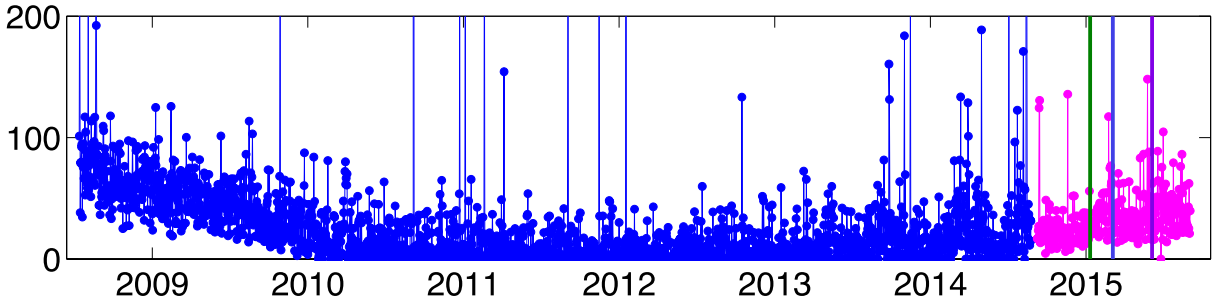
1. **SLR data is now independent for GDR-E orbits. Orbit computations based on DORIS (Saral, Cryosat-2), DORIS+GPS (Jason-2). (Core network RMS SLR residuals, high elevations (< 1cm RMS)** [*Jalabert et al.,, CNES*].

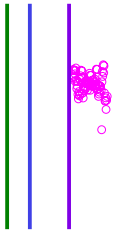
2. **CNES, JPL, GSFC orbits all agree to < 8 mm radial RMS, but signatures remain in geographic representations of error, and at specific periods** (*Bertiger et al., JPL; Lemoine et al., NASA GSFC*).

3. **GPS for Jason-2 operates on Side B since 2014-08-23; Performance initially not as good as Side A, but now has improved. (***Bertiger et al.,* JPL**).**

4. **We are monitoring performance of DORIS data on Jason-2. We see quasi-secular increase in RMS of fit since ~2012. Investigations are underway. (***Lemoine et al., NASA GSFC***)**

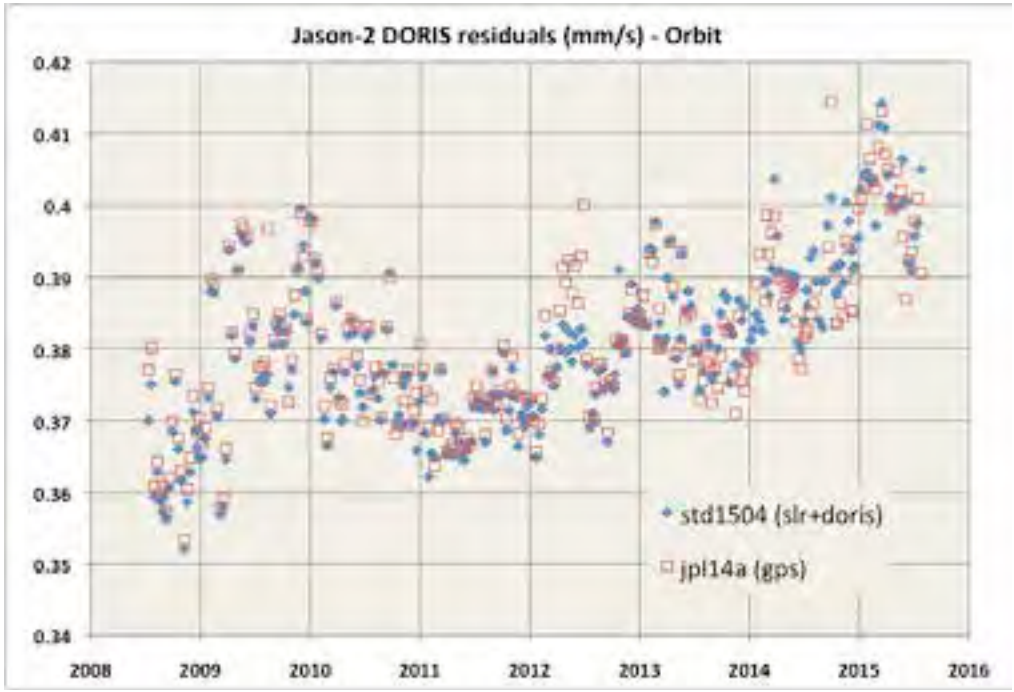
Jason-2 GPS Receiver Performance





(Bertiger et al. 2015)

Jason-2 DORIS Residuals



DORIS Residuals for NASA GSFC POD (SLR+DORIS) and using independent JPL/GPS orbits

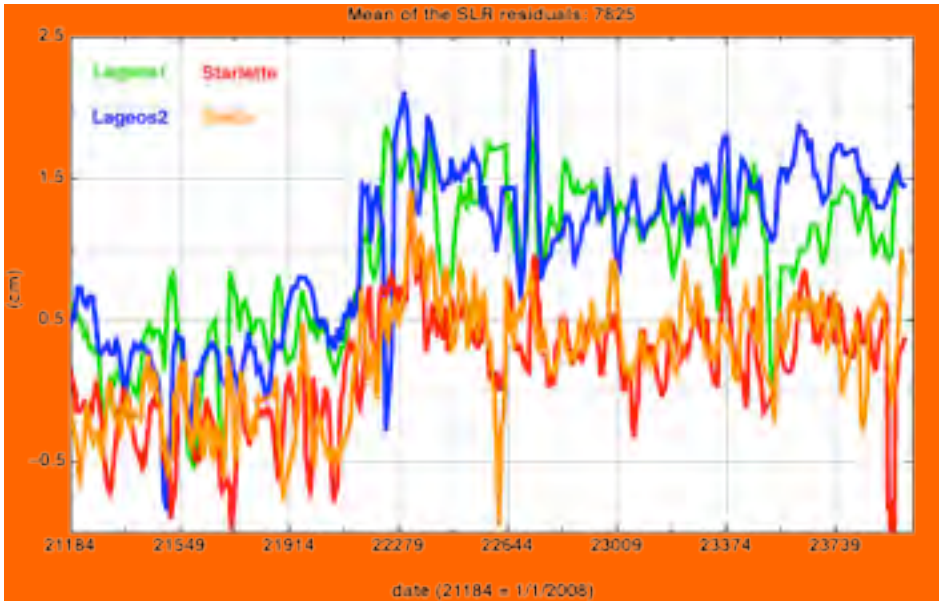
POD team will monitor this behavior.

Possibilities:

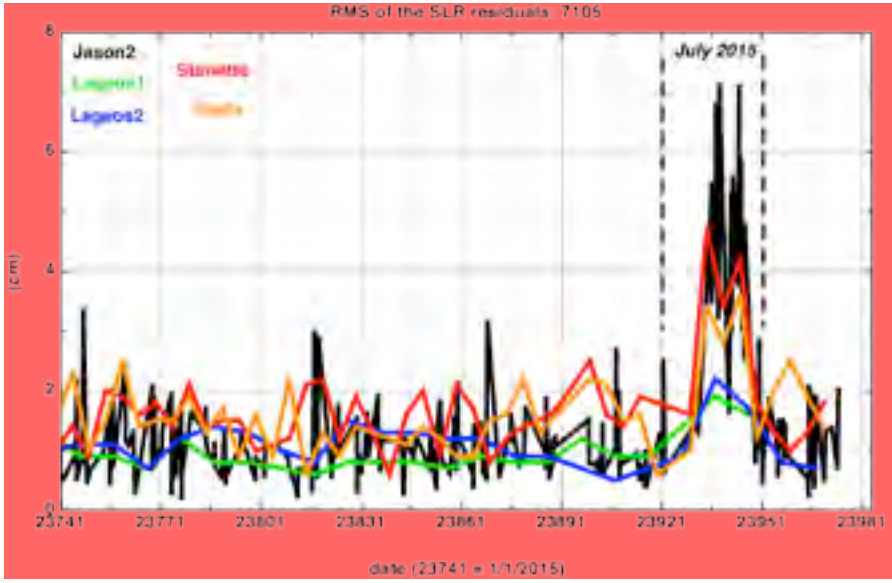
- **ITRF2008 degradation (test with ITRF2014).**
- **Time-variable gravity modeling**
- **performance issues with receiver;**
- **Correlate with DORIS performance on other satellites.**

(Lemoine et al. 2015)

SLR Station Performance Issues



Mean of SLR station bias (Mt Stromlo, station 7825)

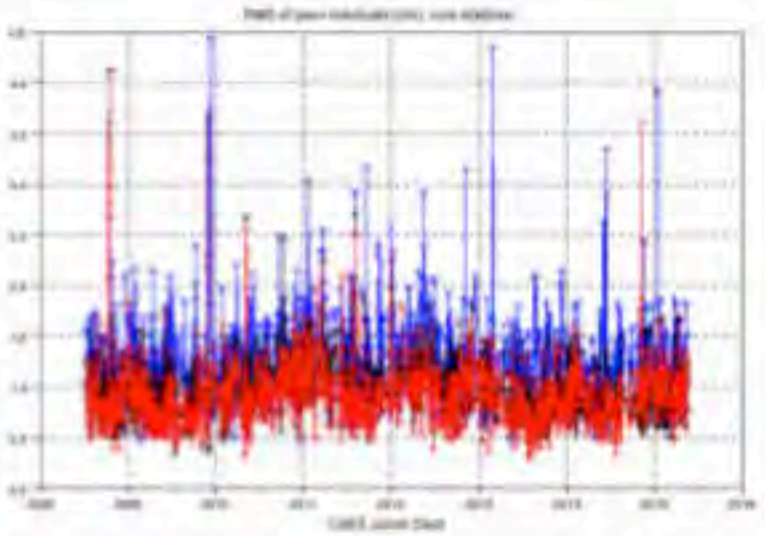


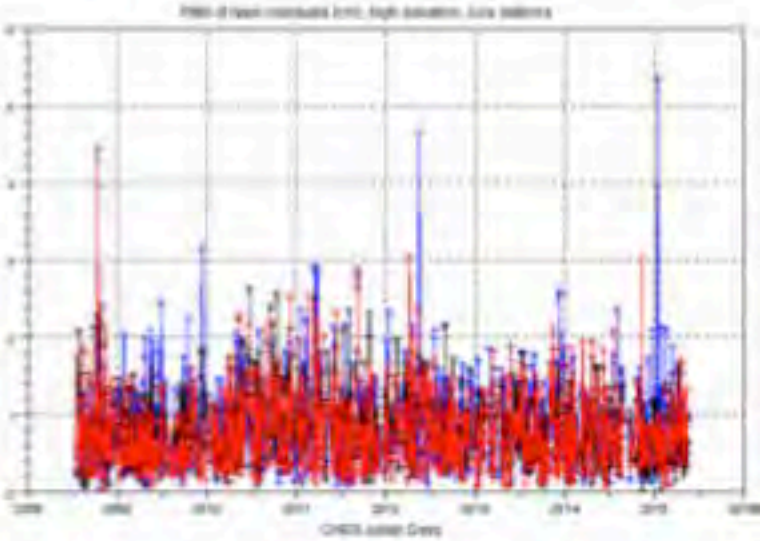
RMS of SLR Residuals (Greenbelt, station 7105)

(Bruinsma et al. 2015)

JASON2 – COMPARISON WITH JPL AND GSFC SLR RESIDUALS

Core network ✦ RMS SLR residuals	GDR-E : Reduced dynamic orbit	GSFC : Dynamic orbit	JPL : Reduced dynamic orbit
All elevation	0,95cm	1,19 cm	0,87 cm
High elevation	0,76 cm	0,77 cm	0,66 cm

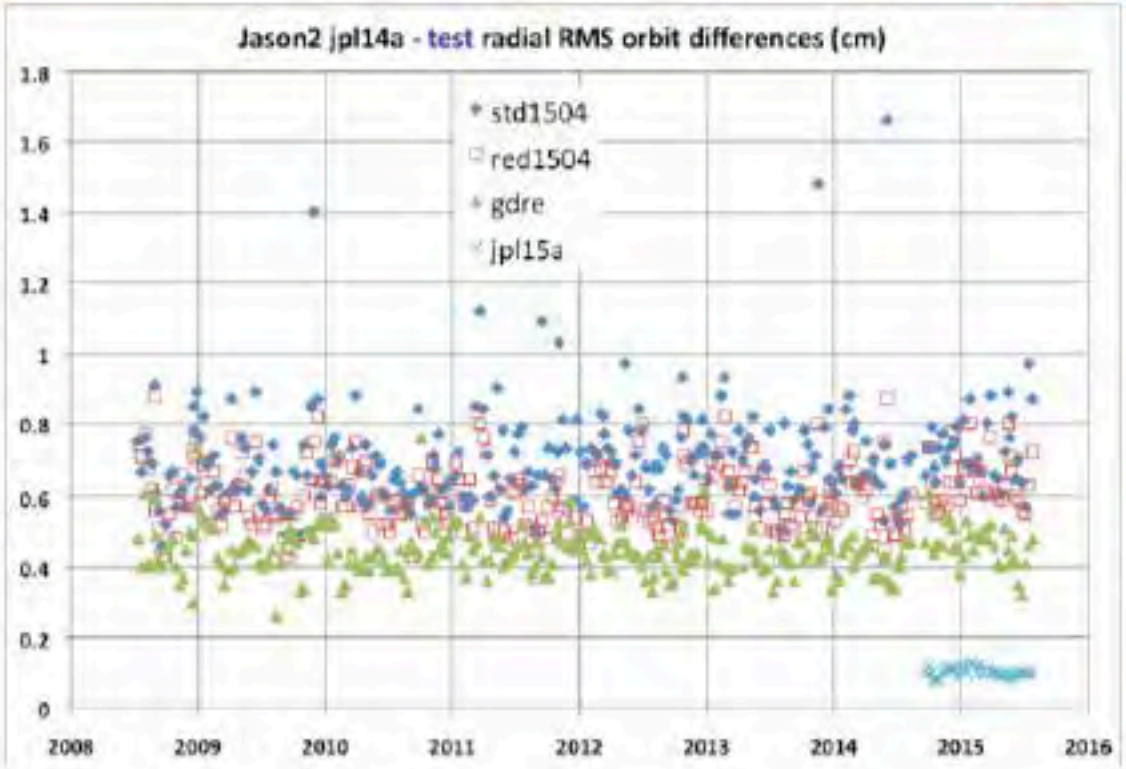




✦ *Core network* : L7090 L7105 L7810 L7839 L7840 L7941

(Jalabert et al. 2015)

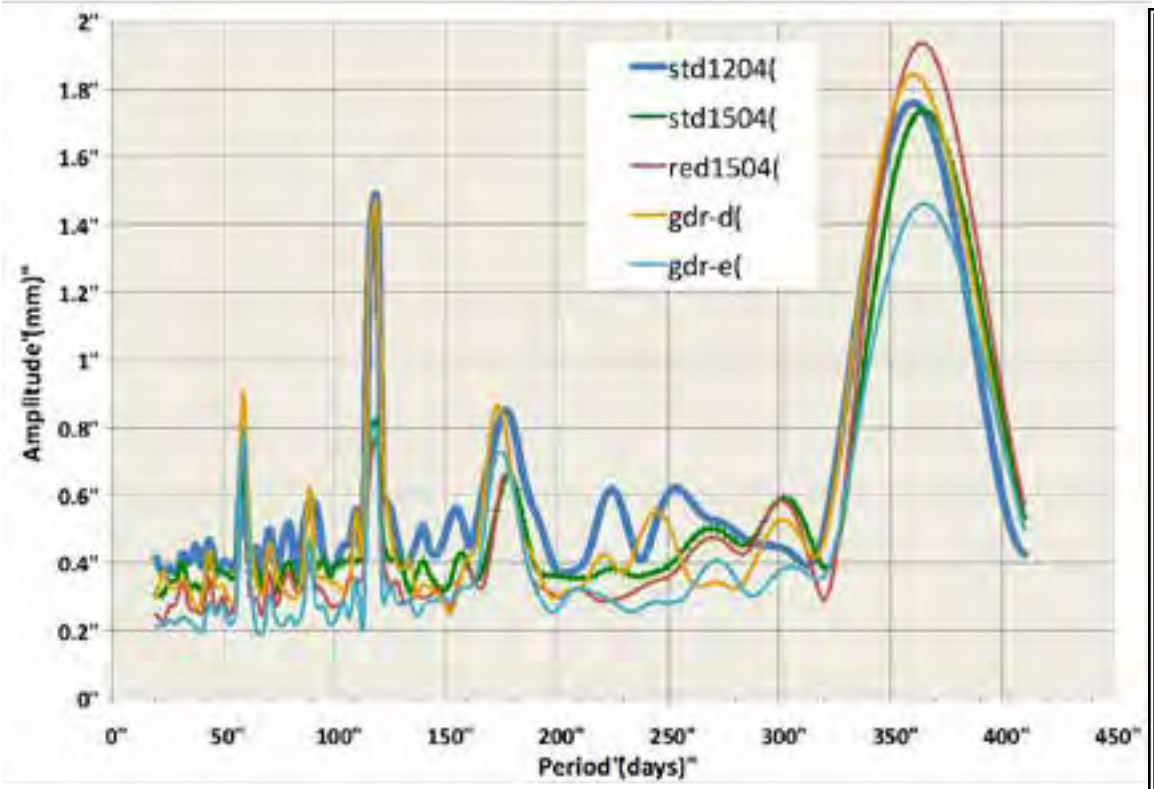
Jason-2 Orbit Difference Summary (2)



Lemoine et al., 2015; New POD Standards (std1504), OSTST, Reston, VA, U.S.A.

All orbits agree in radial direction at < 8 mm RMS.
(Different data, POD software and techniques)

2D projection spectral analysis jpl14a-"*test*" radial orbit differences sampled at fixed geographic locations

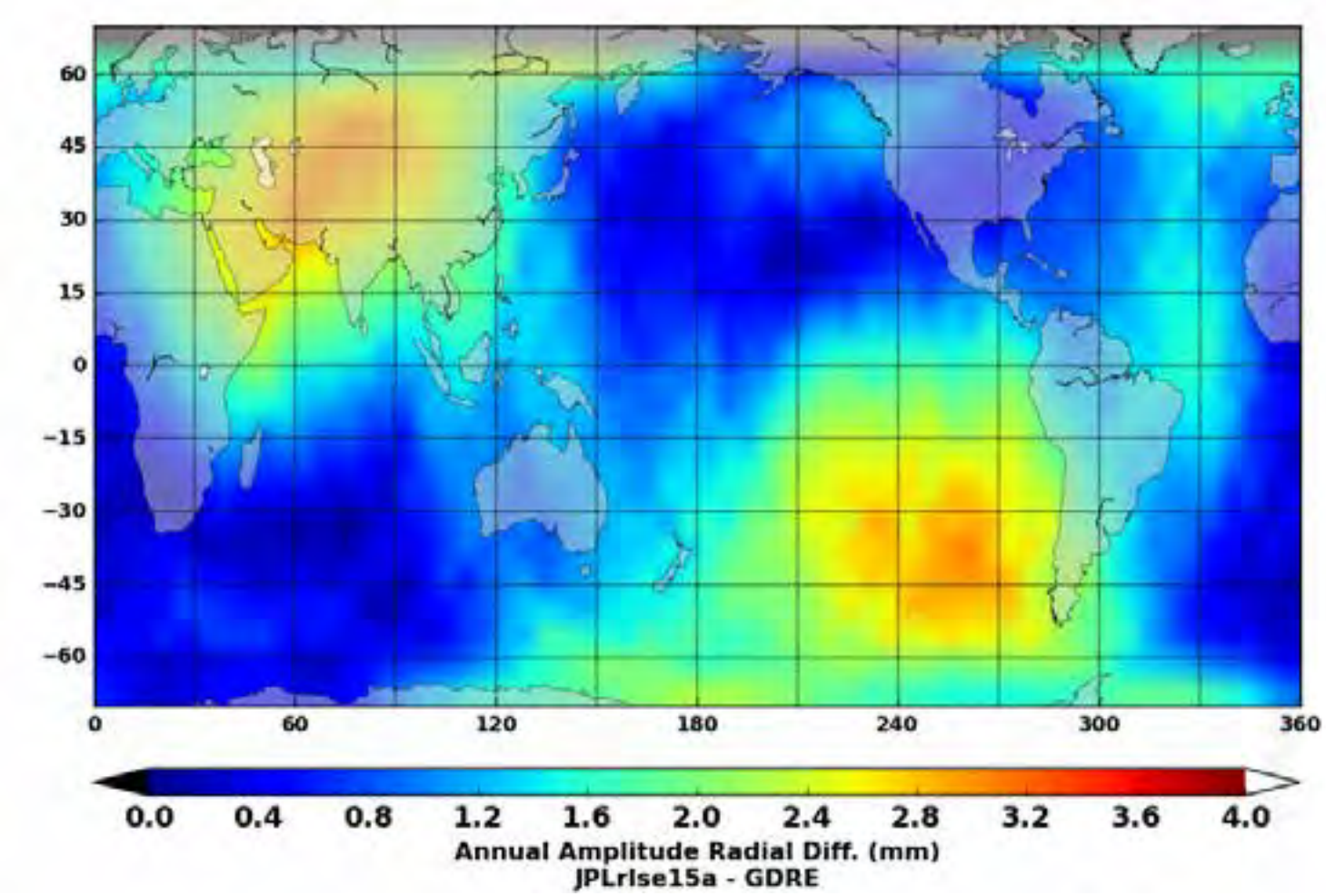


Both GDRE/CNES and NASA/GSFC std1504 show big reduction in signal at ~118 days.
(1.4-1.5 mm à ~0.8 mm)

Remaining signals are at 59 days & 118 days (~0.8 mm) and at annual period (~1.5-2.0 mm).

(Lemoine et al. 2015)

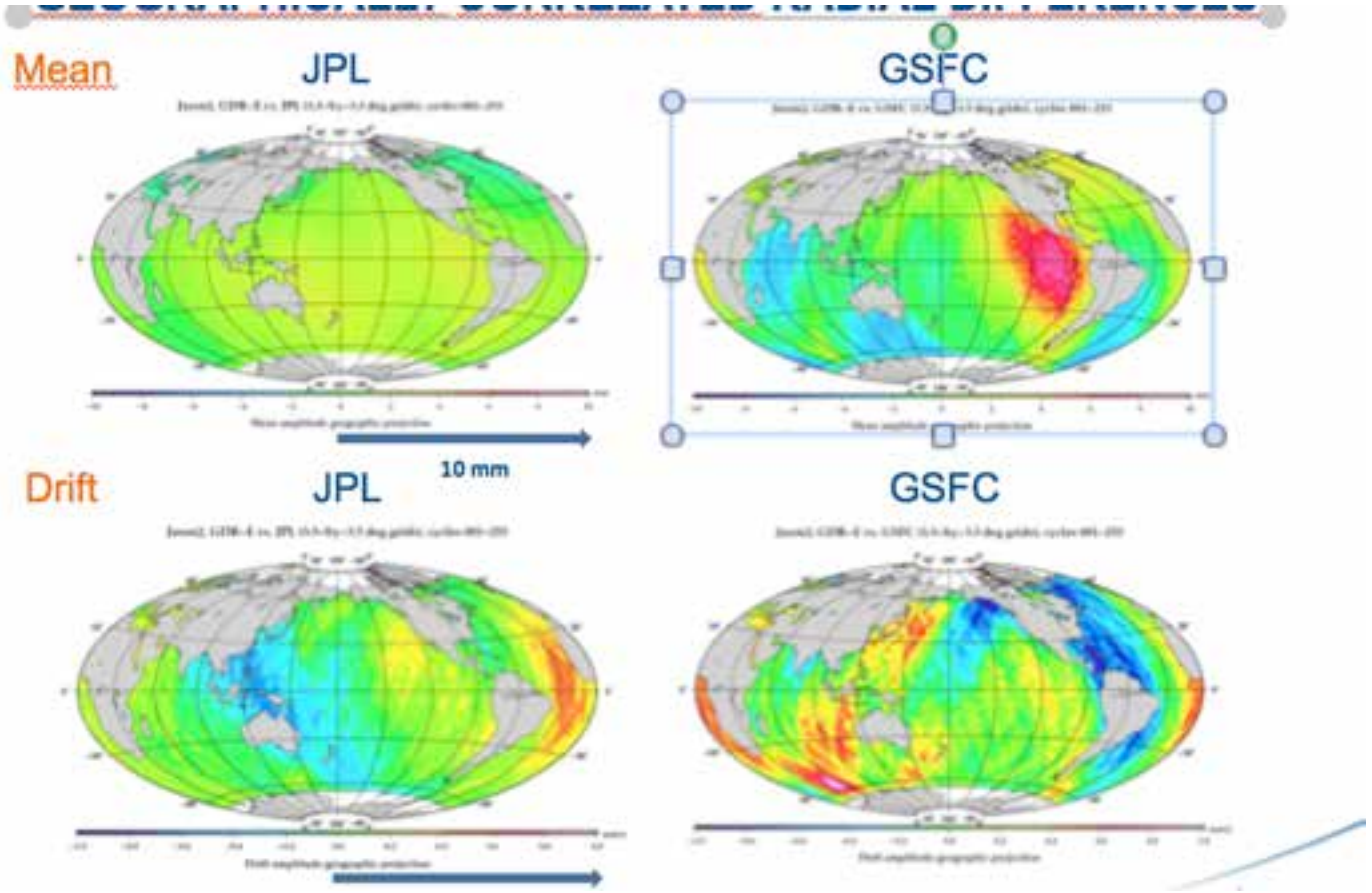
Radial Difference Annual Amplitude, JPLrlse15a – GDRE, 6°x6° Bin Average



(Bertiger et al. 2015)

- Differences in Geocenter realization?
- GPS/Bias fixing, DORIS?

JASON2 – Comparison for CNES/GDRE with JPL/jpl14a and GSFC/std1504
geographically correlated radial differences



(Jalabert et al. 2015)

Summary from POD Round Table (1)

1. Continue to monitor performance of DORIS on Jason-2 and ascertain cause of increase in RMS of fit.(an “SAA-effect” is not excluded; but there are other possibilities).
2. Continue to monitor and diagnose SLR station performance. Can exhibit biases – some that are even episodic in nature. (GRGS, CNES, and NASA GSFC will look at this issue).
3. Jason-CS. Questions about RUAG/GPS performance due to issues on Swarm and GOCE. Solution: Team members will analyze Sentinel-3 data to understand updated RUAG receiver; POD team members will compile list of questions based on experience with GOCE & Swarm for Jason-CS project.

Other POD Issues

4. Jason-CS: Center-of-mass (COM) modeling due to large propellant tank (200 kg). Questions about specifications.

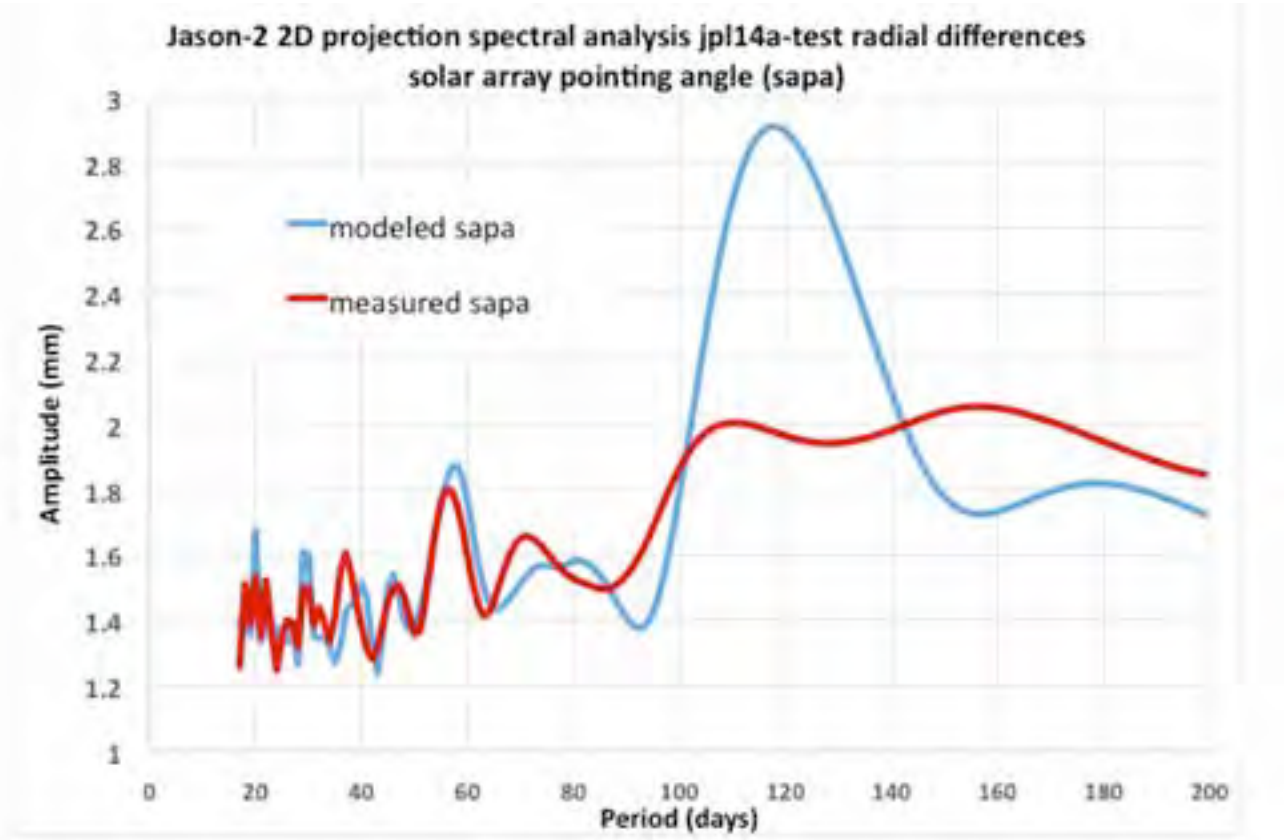
5. Perform Detailed Tests on all realizations of ITRF2014 (IGN, JPL, DGFI). At some point the GDRE/std1504 orbits will need to be updated with the new reference frame.

Other POD Issues

"The POD team of the OSTST recommends for all existing (Saral, HY2A…**) and future altimeter missions (**Sentinel-3, Jason-CS, SWOT**) that the quaternions of the spacecraft bus and movable appendages (e.g. solar panels) be made available to the community.**

The availability of quaternions is beneficial for altimeter data evaluation since it offers an independent way to estimate the pitch roll and yaw of the platform, moreover this data helps to model solar radiation pressure effects which are relevant during Precise Orbit Determination."

Jason-2 jpl11a/GPS – GSFC/SLR+DORIS test orbits 118-day signal (cycles 5-45)



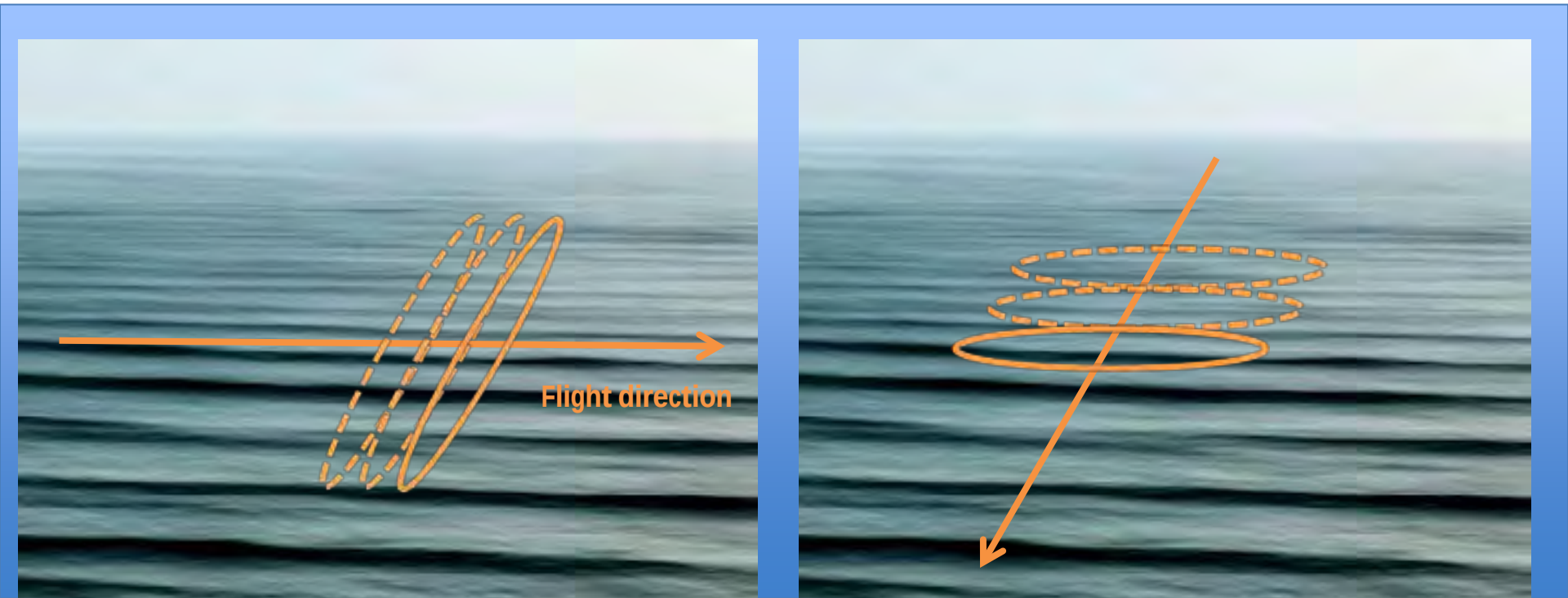
Improvements for NASA GSFC orbits arise solely from correcting few degree misorientation of solar arrays from nominal model. This is why solar array orientation knowledge is critical.

Instrument Processing Corrections Splinter Summary

- Session focused on SSB correction wet tropo corrections
- Corrections for new altimeter modes (e.g. SAR mode, InSAR)

SAR mode altimetry and sea state bias, Bellingham et al

- No current SSB models developed for SAR
- SAR altimetry footprint is strongly asymmetric
  - LXT ~ O(2-10 km) & dAT ~ O(300 m)
  - introduces uncertainty as to possible effects on SAR mode waveforms by ocean swell and swell direction, and possible swell induced biases in SSH.
- 8 months study started 21 September 2015 to develop SAR SSB
  - Limited data available - Cryosat

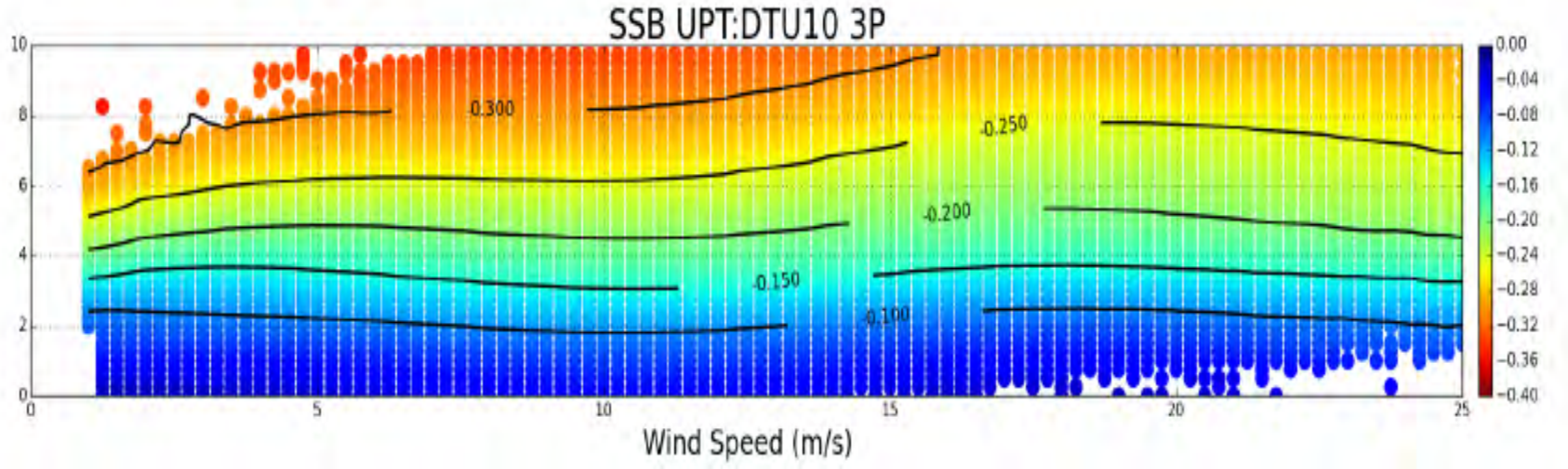


A new proposal for SSB modelling with three parameters exclusively derived from altimetric data (Pires et al)

- Development of a new global and multi-mission SSB model based on parameters solely derived from altimetric data
- Regional studies of SSB for different sea state regimes
- Planned to implement in the forthcoming missions.

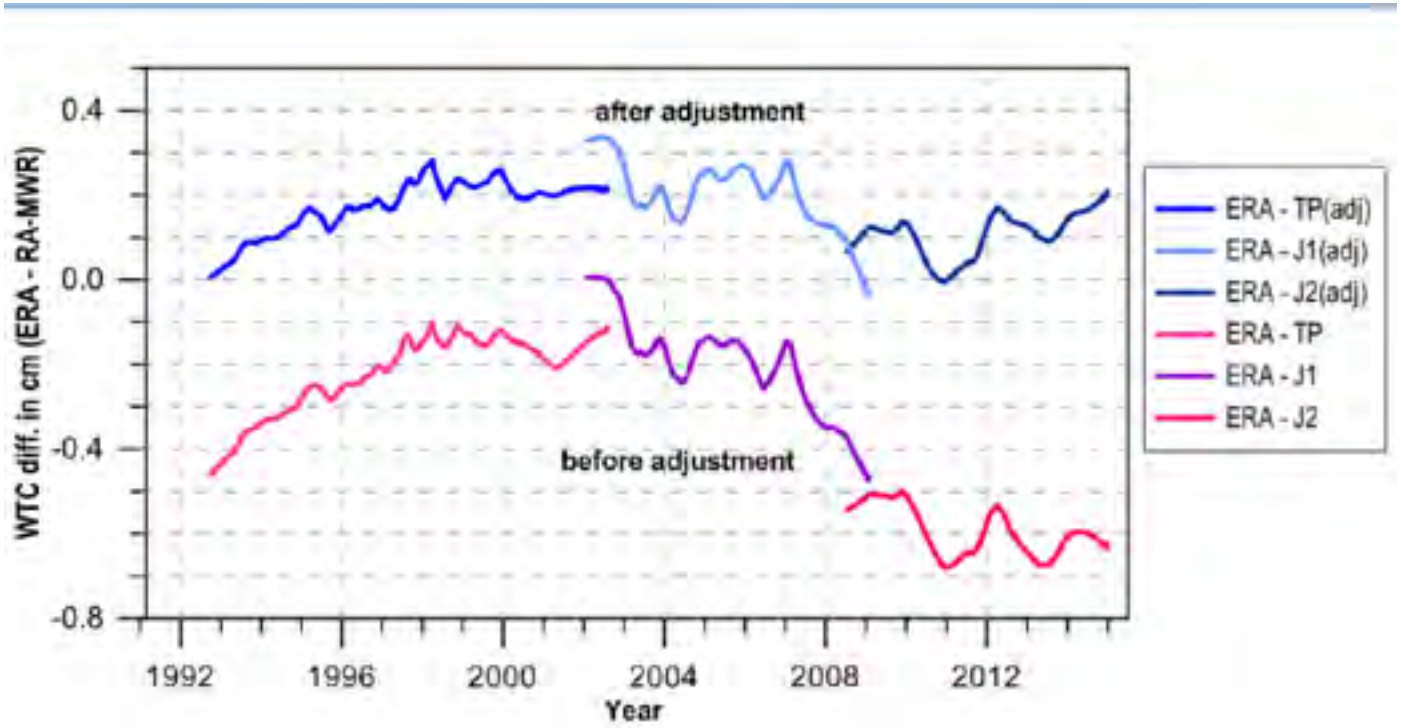
$$SSB_i = \beta_0 + f_1(SWH_i) + f_2(U10_i)$$

$$SSB_i = \beta_0 + f_1(SWH_i) + f_2(U10_i) + f_3\left(SWH_i, \sigma^0_{Ku}\right)$$



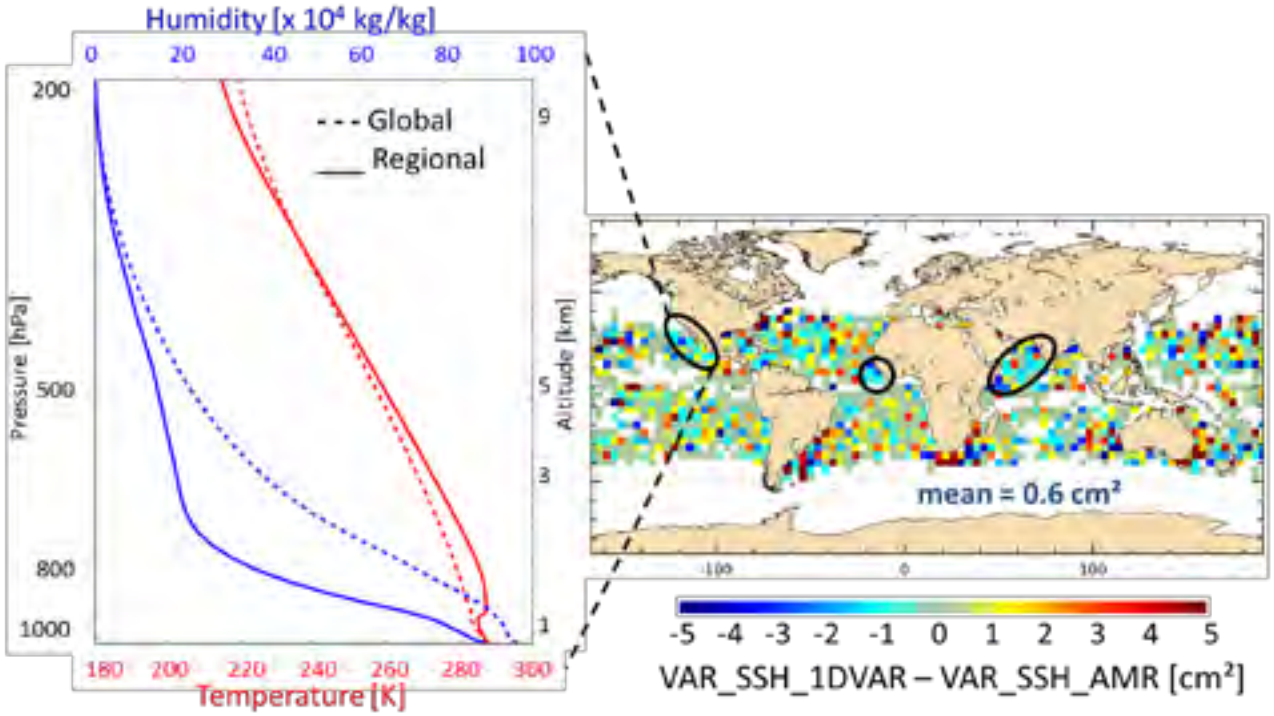
Inter-calibrated wet path delays for eight altimetric missions (Fernandes et al)

- GPD+, combines coastal GPS-based processing with open ocean objective analysis processing to provide global data for any altimeter mission
- All available microwave derived PD data inter-calibrated using SSMI sensors and applied to eight altimetry missions
  - Useful for missions without a radiometer and also for data gaps



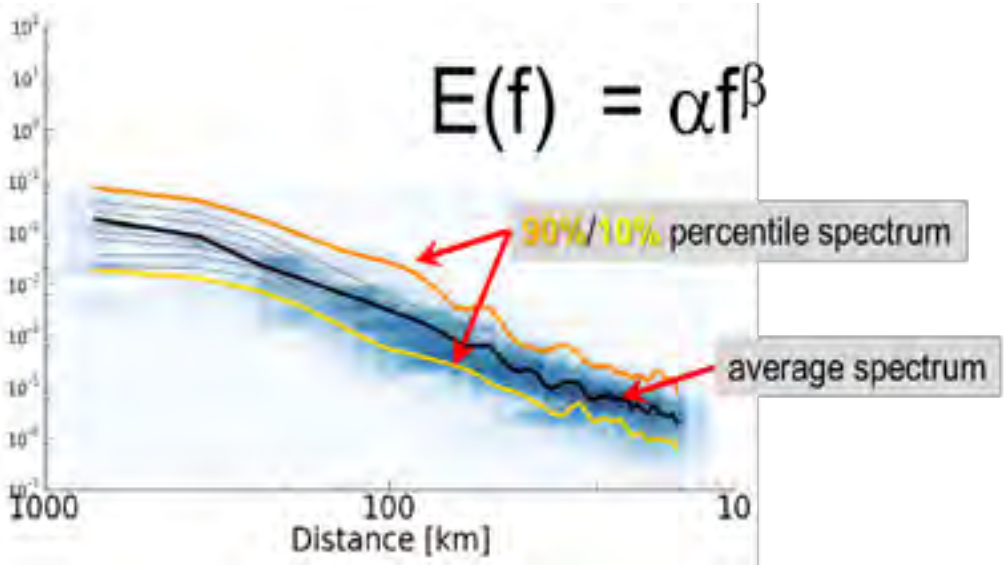
Towards a unique method for a global and multi-surface Wet Tropospheric Correction retrieval : a 1-D Variational approach (Hermozo et al)

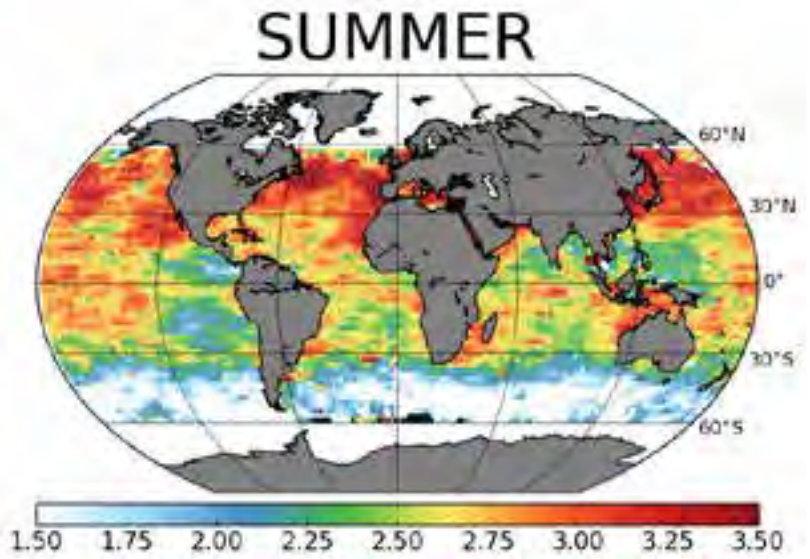
- Development of one single method for retrieval of WTC over all types of water covered surface
- Population of the background error covariance matrix for use of ECMWF inputs
- Earlier test show encouraging results over upwelling areas



Spatial and seasonal variability of the Wet Tropospheric Correction Spectral characteristics (Picard et al)

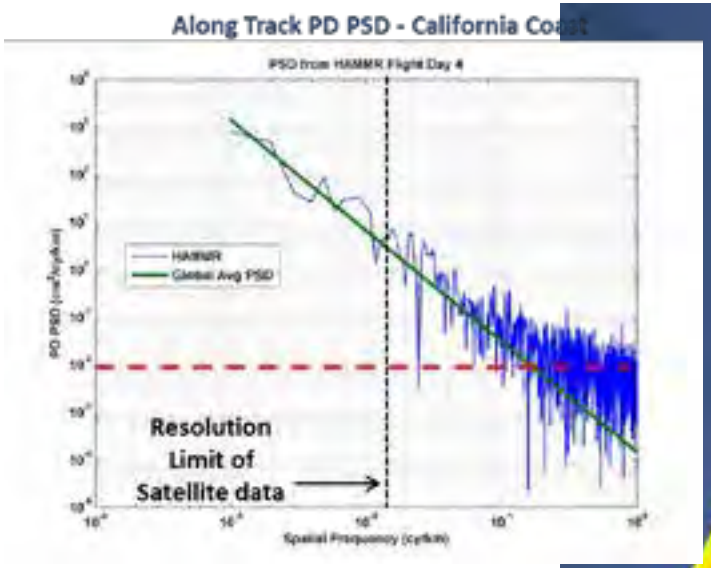
- To expand the « 1D » analysis of WTC spectra to a « 2D » geographical analysis
- To assess the impact of rain on the geographical patterns of the linear fit slope of the average spectrum = scaling exponent
- To quantify the seasonal and spatial variability of the scaling exponent

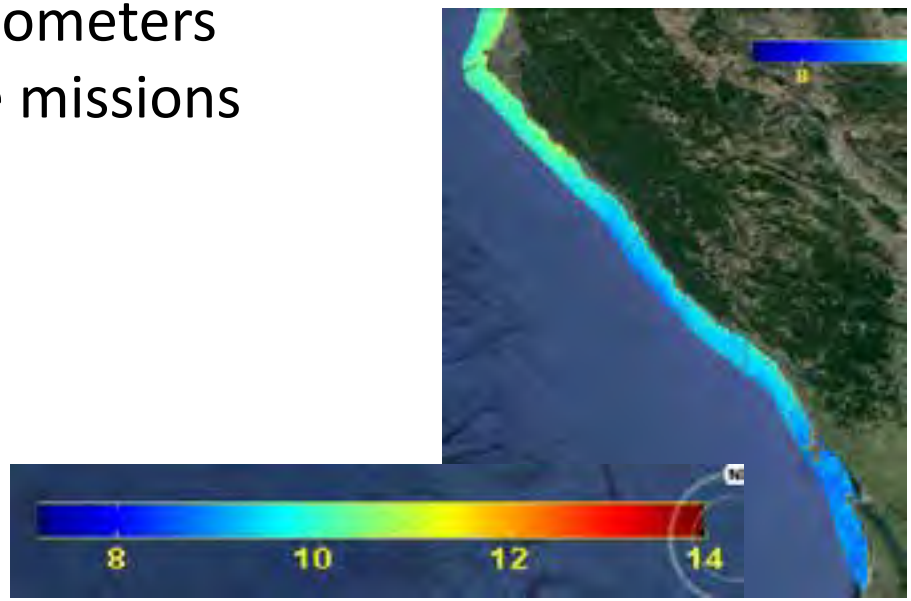


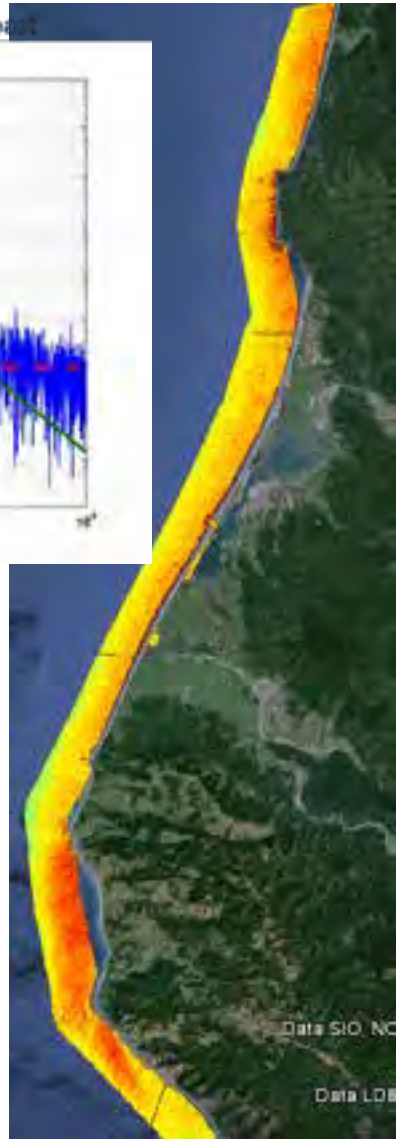


Evaluation of High-Resolution Path Delay Data from the Airborne HAMMR Instrument (Brown et al)

- Analyzed small-scale PD variability with high-resolution next-generation airborne radiometer for altimetry
- Evaluated improvement possible in coastal regions with high-frequency radiometers proposed for future missions

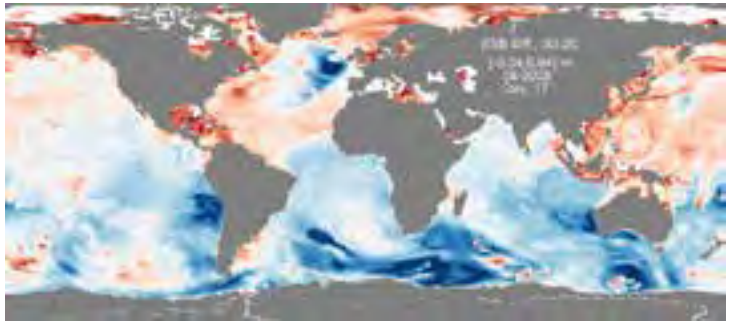


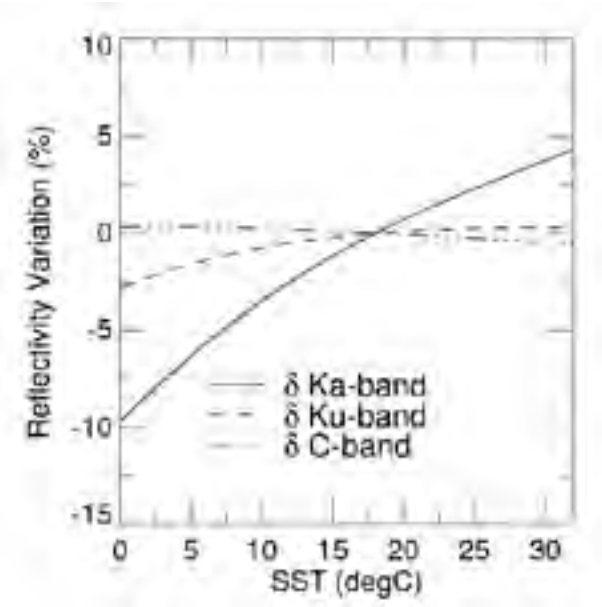


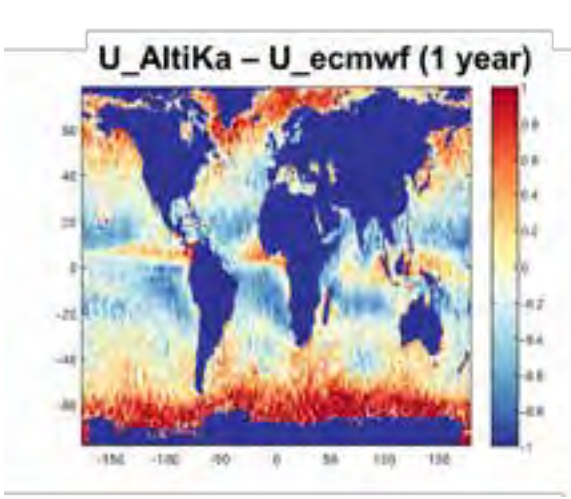


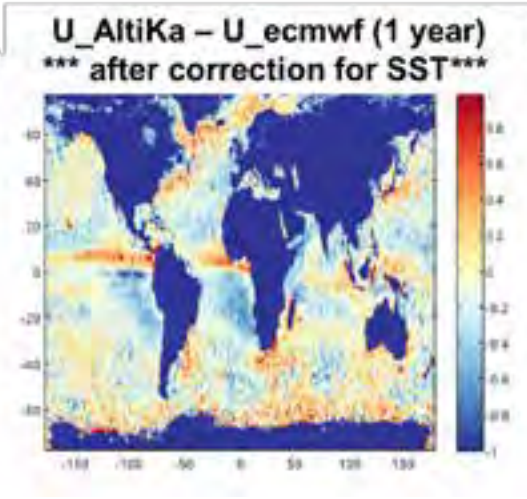
Issues involved in global wave model application to routine SSB range correction (Vandemark et al)

- 1-2 cm^2 of gain still possible in sea state geophysical corrections (SSB)
  - Work on-going to include wave information in SSB corrections
- Ka-band reflectivity varies with SST, not currently accounted for in AltiKa, results in regional bias









Recommendations/Key Points:

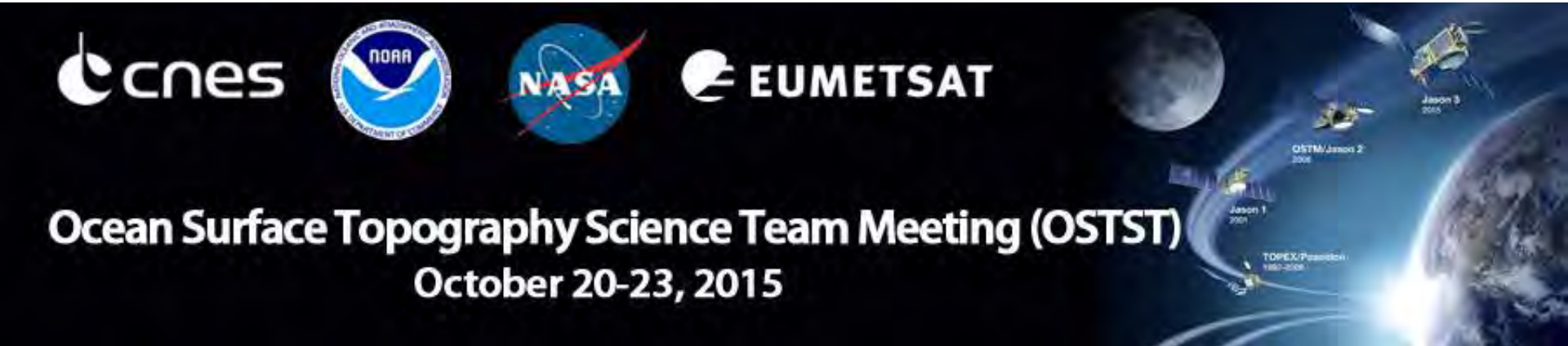
- Ka-band altimeter missions should account for the SST dependence of backscatter to avoid regional biases in products (e.g. wind speed)

- On-going and future altimeter projects should consider additional airborne measurements to study small-scale water vapor variability and test the performance of enhanced high-frequency radiometers under diverse weather conditions

- If wet path delay stability is critical to the Jason-2 EOL mission, then routine cold sky maneuvers should be considered

Report from Instrument Processing: Measurement and retracking (SAR & LRM)

Phil Callahan, Rob Cullen, Jean-Damien Desjonqueres, and Walter Smith

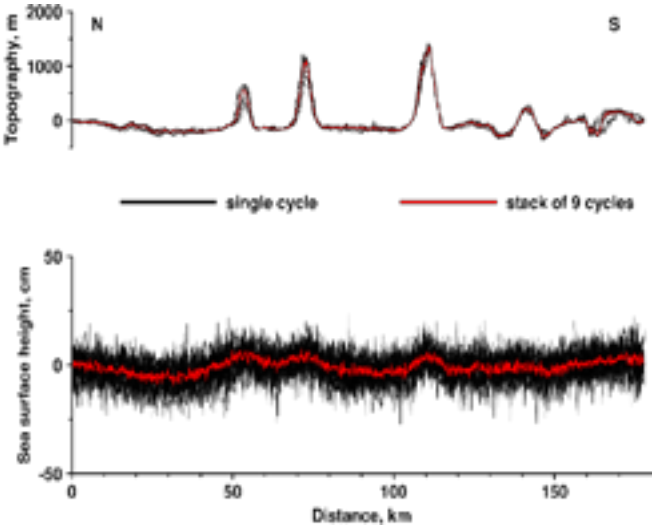


Answers to posed questions, 1

- The IP Measurement/Retracking splinter takes no position on the Geodetic Mission EoL for Jason-2 or SARAL, or the COP21 statement.
- We do note that Geodetic Mission EoL data are needed to improve the marine geoid at sub-mesoscale (30 – 150 km) and shorter scales. At these scales, LRM retracking issues are important.

Answers to posed questions, 2

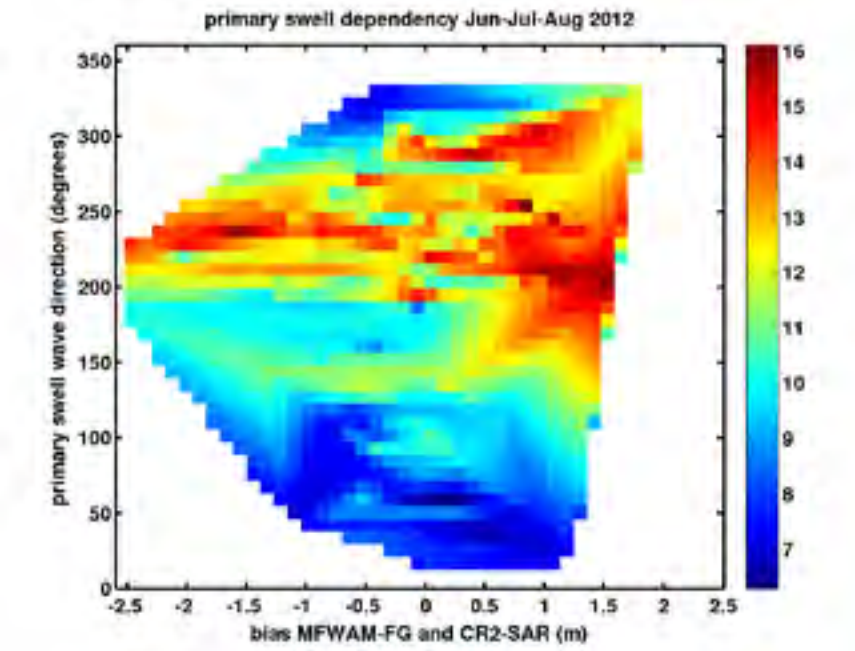
- Sub-mesoscale (30 to 150 km) SSH is measured. Retracking can introduce correlated errors (LRM; “spectral bump”) or remove them (specialized retracking and editing; SAR processing).
- Geoid in this band is correlated with bathymetry, and improving geoid:bathymetry coherence provides a quasi-validation.
- Improving the geoid at these scales requires new Geodetic Mission altimeter data.



Sea State Bias and Long Swell

- CryoSat SAR mode has not sampled all the oceans. We look forward to complete coverage from Sentinel-3.
- Studies of SAR-mode SWH resolution and Sea State Bias are on-going and will benefit from S-3.

Global wave model forecast skill improves when assimilating Cryosat data, except where very long-wavelength swell propagates along-track. (L. Aouf, Meteo France)

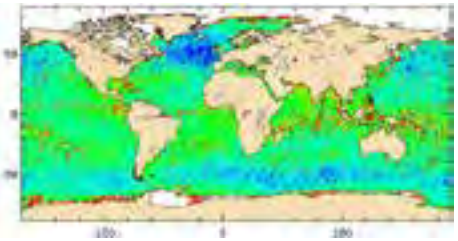


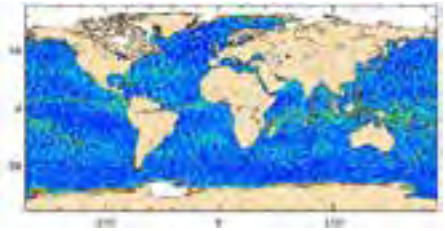
Retracking

- Improved retracking, particularly over coastal regions, is an area of active research effort.
- TOPEX RGDR (retracked GDR) product has been upgraded again in 2015. Some issues will continue to be worked between JPL and CNES.
- Global, full-mission, within 50 km of coast, coastal retracker product ("ALES") is available from PO-DAAC for Jason-2. [J-1 & Env to come.]

LRM processing continues to improve

- Antenna pattern corrections are particularly important for Ka band. (AltiKa is beam limited as well as pulse limited)
- Numerical retracking
- Fast convolution retracking





Simple retracking(MLE-like) intrinsically introduces correlation in errors in geophysical retrievals. Simple averaging to 1 Hz has side lobes that leak errors.

The goal is that the retracker should not produce errors that must then be compensated in the SSB correction. The SSB should become more physical, less retracker-dependent.

New ways of processing SAR data

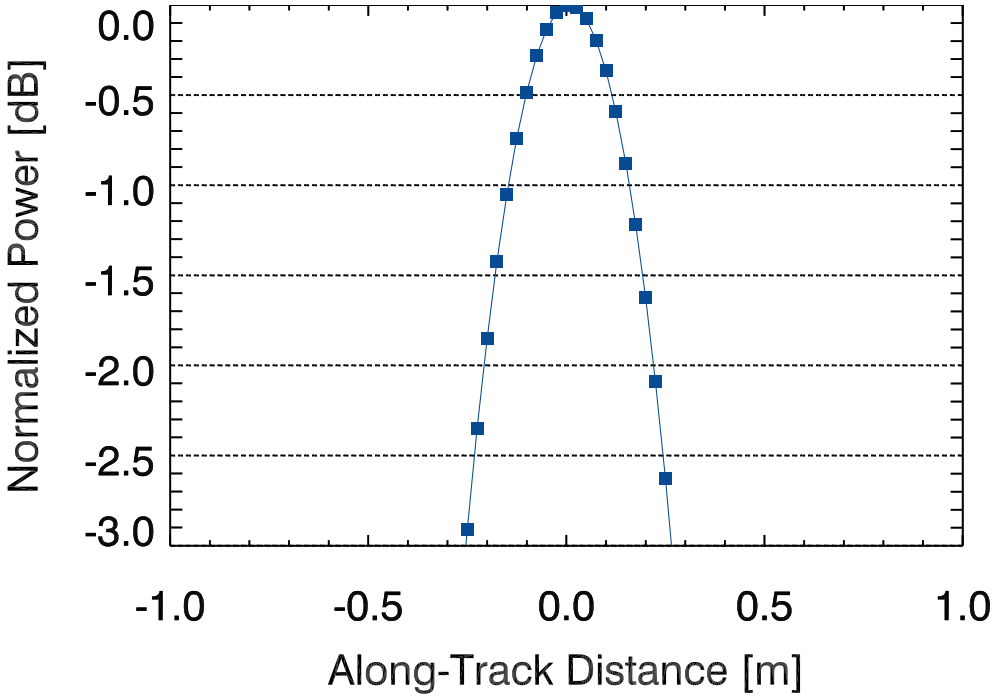
- Modifying the stack (reduced stack, antenna gain compensation of the stack, others).
- Increased along-track sampling (“84 Hz”, 80 m along-track), shows benefit in coastal zone. [The “20 Hz” notion is now artificial. Should future processors provide data at 84 Hz or some other rate?]

SAR sensitivity to mispointing

- The impact of uncertainty in pointing knowledge on SWH and range retrieval can be made very small (sub mm in range) [C. Ray]
- However this needs to be independently assessed. [Recommendation for further and independent study.]

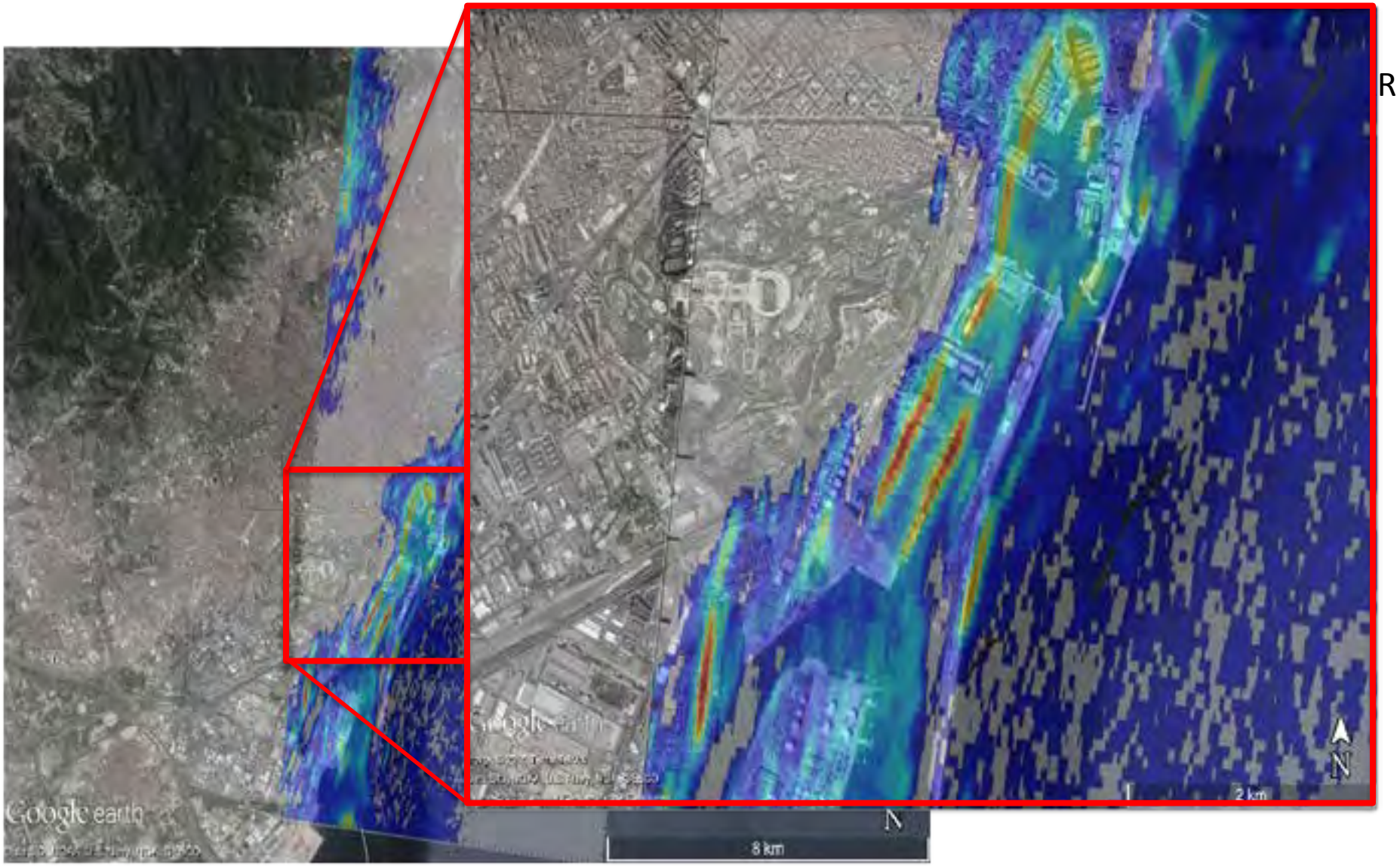
Fully focused aperture synthesis

- Standard “SAR” mode processing creates unfocused beams about 300 m wide.
- The same radar echoes can also be processed to focus on a strip 0.5 m wide (along-track only).



This processing also increases the effective number of independent looks (signal to noise) by approximately a factor of 2.

Barcelona CryoSat-2 ***Focused*** SAR



Recommendations

- Algorithms, including calibration, need to be open and documented, to facilitate climate studies.
- TOPEX had a requirement for no geographically correlated errors. Other missions haven't made this an explicit requirement. Should they?
- Sentinel-3 commissioning phase should make a specific effort to collect and analyze data to calibrate biases in pitch and roll. Due care must be taken not to rush this process. (Collect data both at beginning and end of commissioning phase, both in LRM and SAR?)
- CryoSat attitude biases need to be re-analyzed with Baseline-C and discordant results need to be understood.

Recommendations, 2

- The dependence of sigma0 on Sea Surface Temperature (because of reflection coefficient) needs to be included for Ka band and considered for other cases. (see IP Corrections summary)
- The perennial question of whether SSB should use sigma0 or wind speed came up again.
- Can the Crete transponder be used to make an absolute calibration of sigma0? [Should do if possible.]

Application Development for Operations (Oral)

Are SAR wave spectra from Sentinel-1A ready for operational use in the wave model MFWAM?
Lotfi Aouf (Département Marine et Océanographie Météo-France, France), Alice Dalphinet (Département Marine et Océanographie, Météo-France, France)

Improved Representation of Eddies in Fine Resolution Forecasting Systems Using Multi-Scale Data Assimilation of Satellite Altimetry
Zhijin Li (JPL, US)

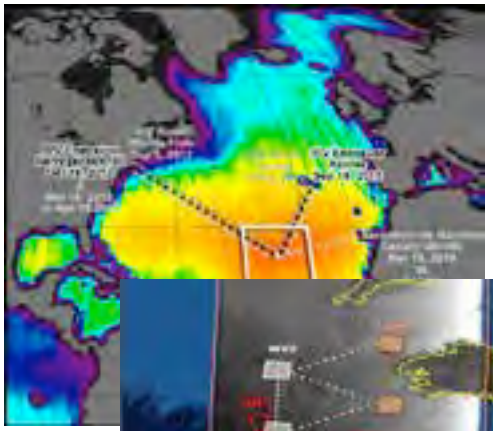
NOAA Operational Satellite Derived Oceanic Heat Content Products
Eileen Maturi (NOAA/NESDIS/STAR, US), David Donahue (NOAA/NESDIS/OSPO, US), Nick Shay (RSMAS - University of Miami, US), Jodi Brewster (RSMAS - University of Miami, US), Jerry Guo (MAXIMUS, US)

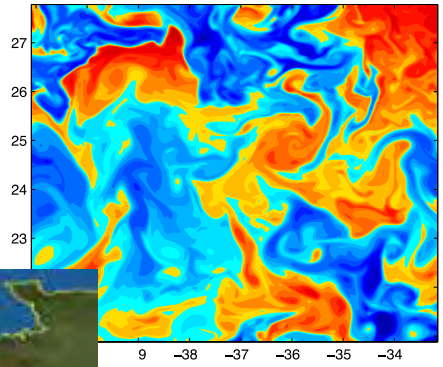
On the use of recent altimeter products in NCEP ocean forecast system for the Atlantic (RTOFS Atlantic)
Liyan Liu (NOAA, US), Carlos Lozano (NOAA, US), Avichal Mehra (NOAA, US), Dan Iredell (NOAA, US)

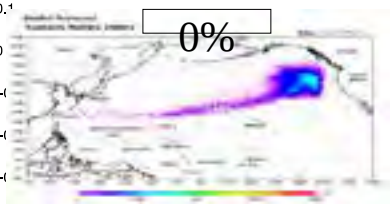
Operational Oceanography in support of the search for MH370
David Griffin (CSIRO, Australia)

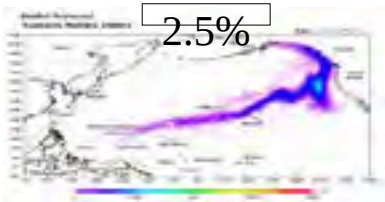
Predictability of marine debris motion, simulated with numerical models and diagnosed using oceanographic satellite data
Nikolai Maximenko (IPRC/SOEST, University of Hawaii, US), Jan Hafner (IPRC/SOEST, University of Hawaii, US), Amy MacFadyen (NOAA Emergency Response Division, US), Masafumi Kamachi (Meteorological Research Institute, Japan Meteorological Agency, Japan)

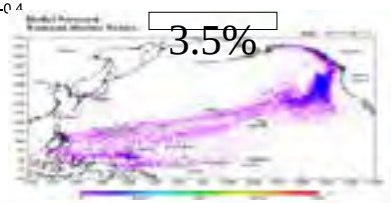
Applications to Operations

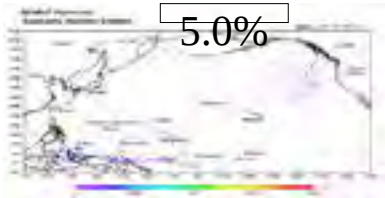


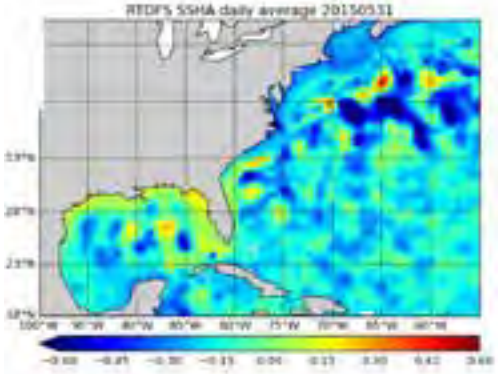


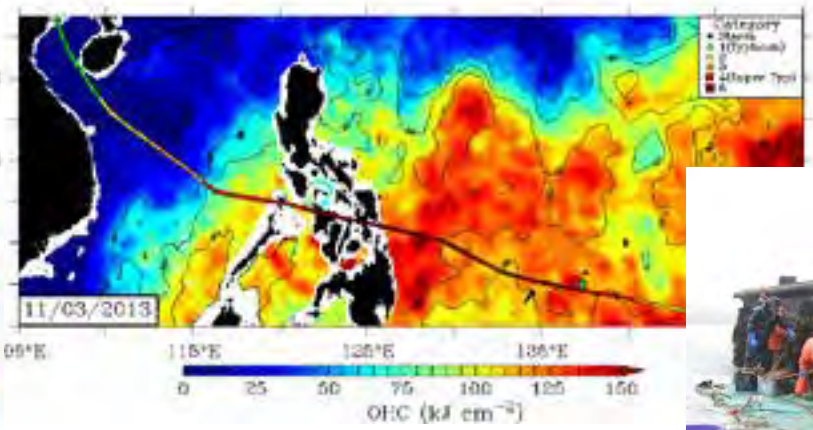












Application Development for Operations (Poster)

DUACS sea level products, a step beyond with Jason-3 and Sentinel-3
Yannice Faugere (CLS Space Oceanography Division), Isabelle Pujol (CLS), Frederic Briol (CLS), Claire Dufau (CLS), Antoine Delepoulle (CLS), Gerald Dibarboure (CLS), Damien Desjonquere (CNES), Nicolas Picot (CNES)

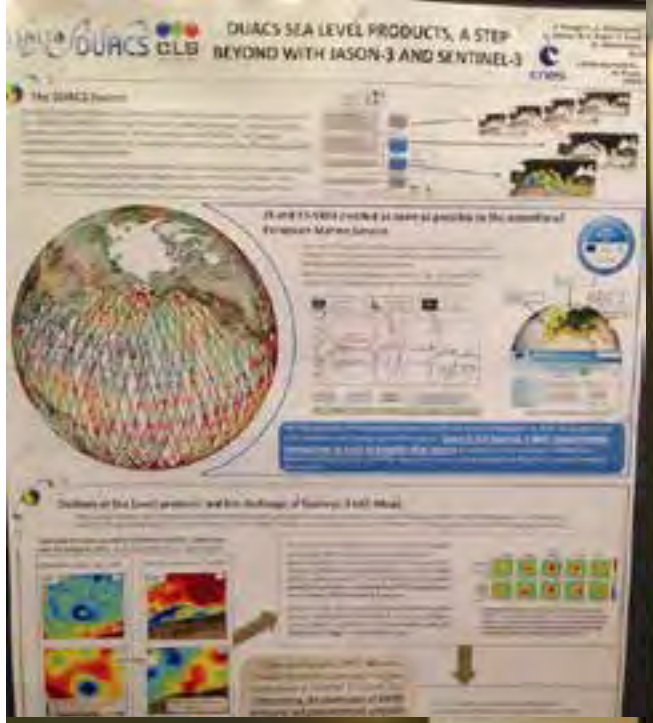
20 years of reprocessed Lyapunov exponents from altimetry available on Aviso
Marie Isabelle Pujol (CLS), Yannice Faugere (CLS), Francesco d'Ovidio (LOCEAN - IPSL), Rosemary Morrow (LEGOS), Jean-Damien Desjonquères (CNES), Nicolas Picot (CNES)

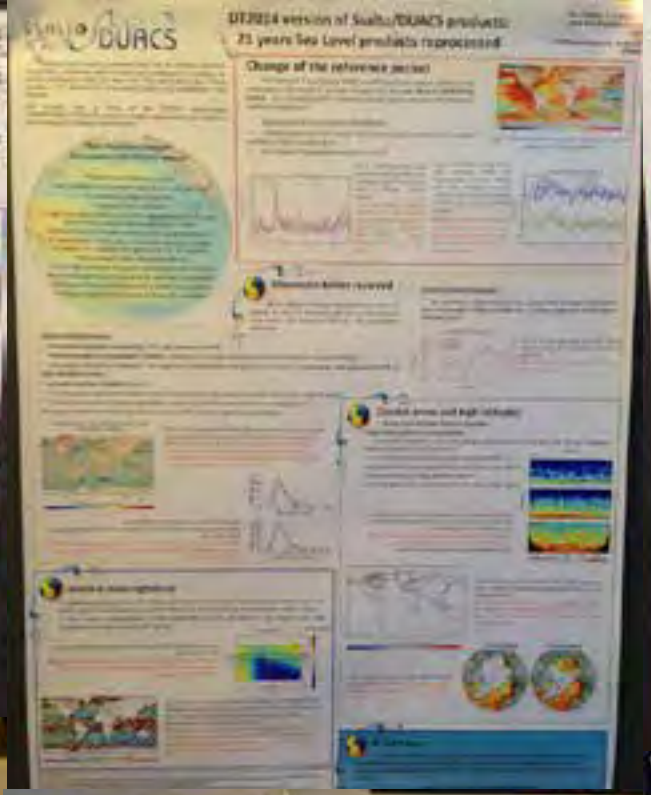
DT2014 version of Ssalto/DUACS products: 21 years Sea Level products reprocessed
Marie Isabelle Pujol (CLS), Yannice Faugere (CLS), Guillaume Taburet (CLS), Jean-Damien Desjonquères (CNES), Nicolas Picot (CNES)

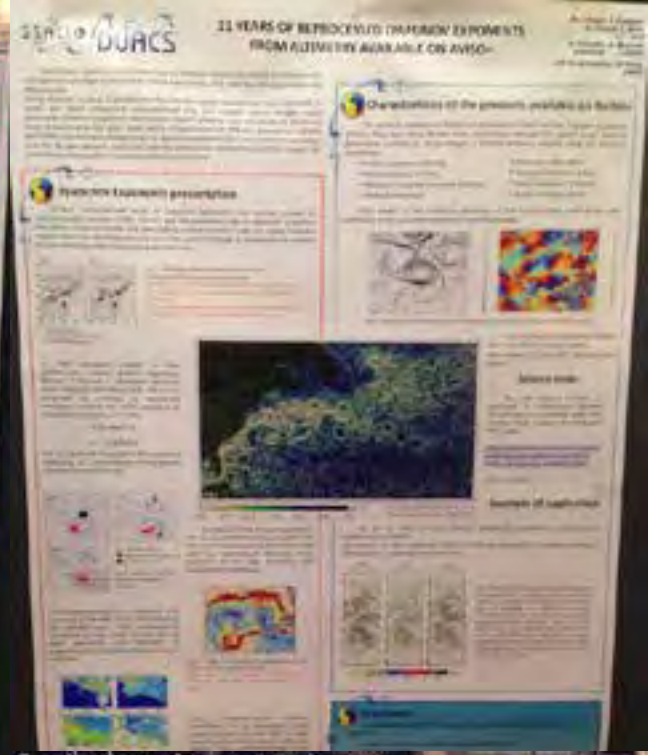
Validation of Cryosat-2 SAR Wind and Wave Products
Saleh Abdalla (European Centre for Medium-Range Weather Forecasts (ECMWF)), Salvatore Dinardo (Serco/ESRIN), Jérôme Benveniste (European Space Agency/ESRIN)

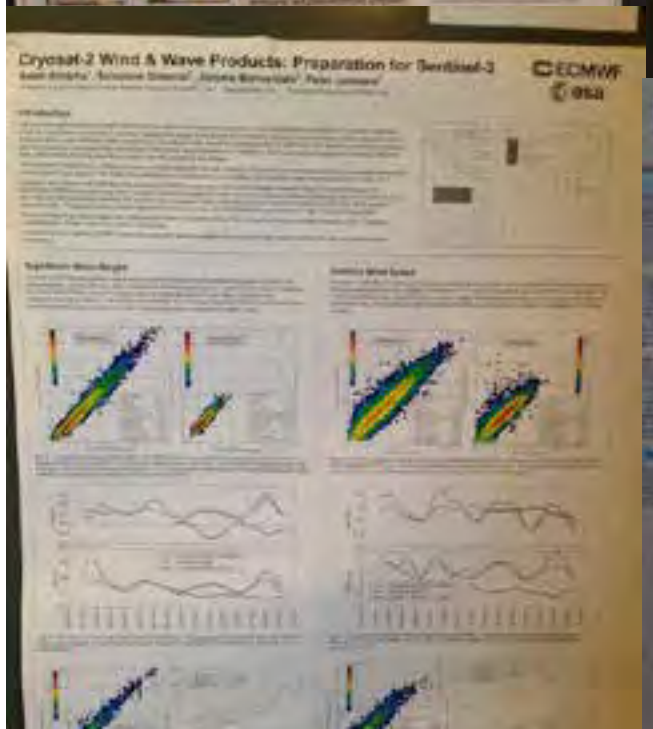
Satellite Altimetry Sea Surface Height Anomaly Processing at the Naval Oceanographic Office's Altimetry Data Fusion Center
Carolyn Cooper (Naval Oceanographic Office)

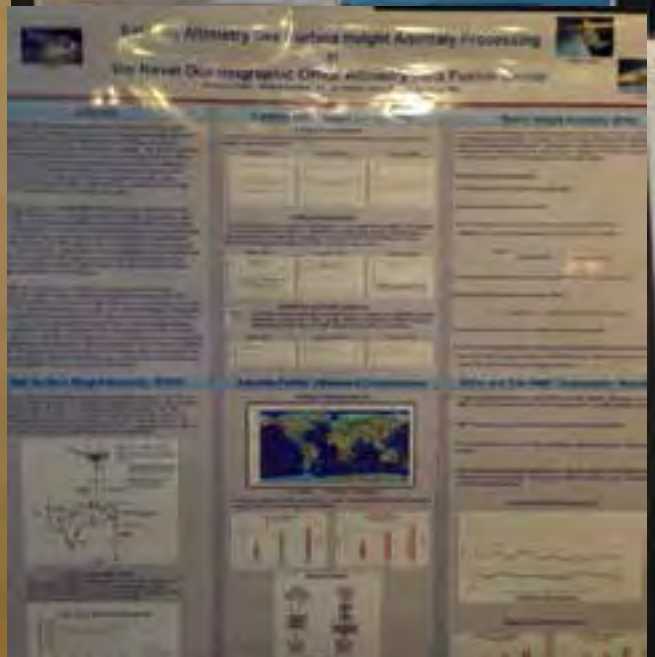
Operational ocean data assimilation/prediction system for the western North Pacific at JMA
Toshiyuki Sakurai (Japan Meteorological Agency), Mikitoshi Hirabara (Japan Meteorological Agency), Masakazu Higaki (Japan Meteorological Agency), Norihisa Usui (Meteorological Research Institute), Yosuke Fujii (Meteorological Research Institute), Hiroyuki Tsujino (Meteorological Research Institute)

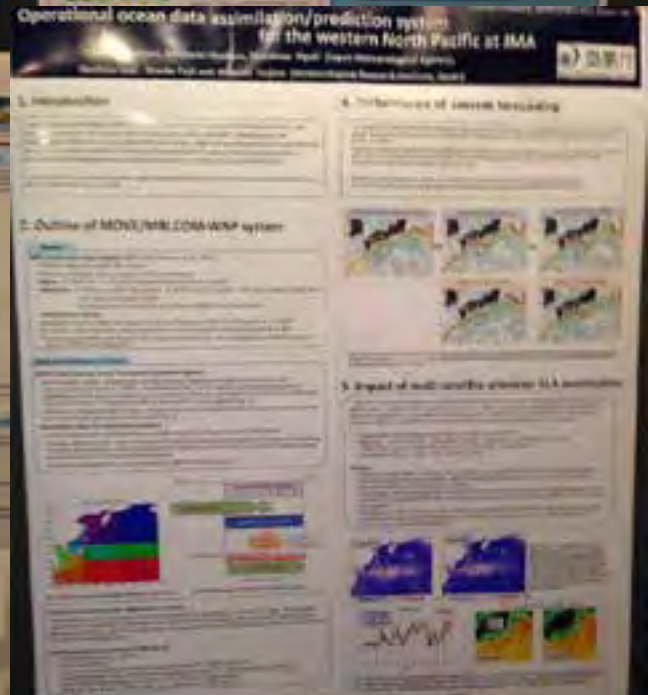

DUACS SEA LEVEL PRODUCTS, A STEP BEYOND WITH JASON-3 AND SENTINEL-3


DUACS


DUACS


Cryosat-2 Wind & Wave Products: Preparation for Sentinel-3
ECMWF
esa




Operational ocean data assimilation/prediction system for the western North Pacific at JMA

APOP/NRT Round Table

1. Jason-2 Extension of Life

- For operations the best scenario is to stay on interleaved track as long as possible.
- Geodetic data may benefit NRT SWOT thru improved MSS. By how much do we expect J-2 EoL to contribute to reducing MSS errors?
- In terms of orbit selection, we endorse G. Dibarboure's selection.
- When we have 6 operational satellites, the incremental benefit of Jason-2 will be less, but this will still not be oversampling the ocean.

2. **Altika Drifting Orbit**

- AltiKa has a bigger influence on ocean forecasts than J2 (perhaps even J2+J3).
- Drifting orbit will be sub-optimal, but would be desirable if it ensures significantly longer mission.
- When it's time to move, try to optimize the drifting orbit to benefit the MSS.
- Is there any possibility that the fuel will be consumed prematurely due to station keeping?
- If possible maintain the +/-1km orbit until Jason-3 is launched.

3. **Other Issues**

- Jason-3 Launch Delay
  - Sooner we get Jason-2 into interleaved orbit the better.
  - It isn't a matter of bridging a gap: we will lose the operational capability all together.
  - We are living in fear of a losing ocean forecasting: J2 beyond design life; SARAL has health issues; C-2 sampling isn't sufficient for ocean predictions.
  - However, do NOT launch Jason-3 until it is absolutely safe to do so!
- COP21 Recommendation
  - We support the altimetry for climate recommendation, but recommend stressing regional as well as global sea level rise, and understanding extreme events.
  - We should also be putting forward recommendations to operational satellite group, such as WMO, IOC,…
- We need to reduce data latency from current 2.5 hours to ~1 hour for wind/wave applications.

Back to the Future…

- More operational centers than in prior years: JMA, NAVO, NOAA, Meteo-France, ECMWF
- 100+ participants in oral session
- New operational products: OHC from NOAA; Lyapunov exponents from DUACS
- Real-world applications: MH370 & tsunami debris
- We are pushing envelope with operational models to submesoscale
- Synergy with altimetry from Sentinel-3 & Jason-2/3 with SAR wave information from Sentinel-1
- Expand operational outreach & education for users

Outreach & data services

In summary

- Data Services: 4 presentations, 3 showcase, 8 Posters
- Outreach: 2 presentations, 3 showcases, 2 Posters

- The short format of the “outreach showcases” went quite well
- About 40 attendees

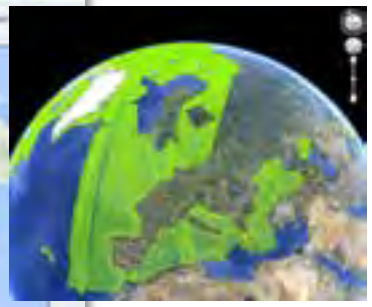
Data services

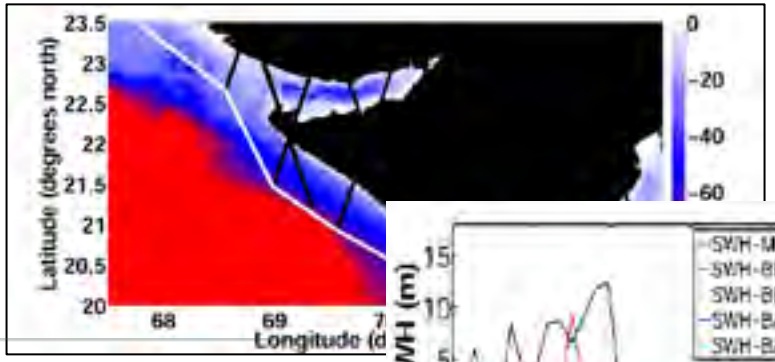
- Some new products distributed
- Upated/upgraded services (online, interactive including web services) to distribute them
- Upgraded tools

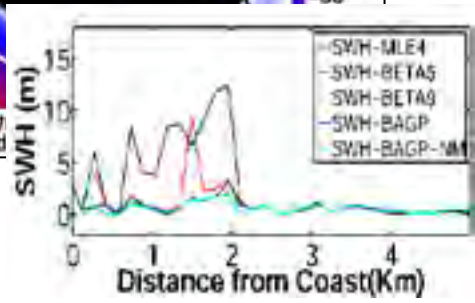
- Discussion : more and more data available all around
  BUT : what are each of them is good for?

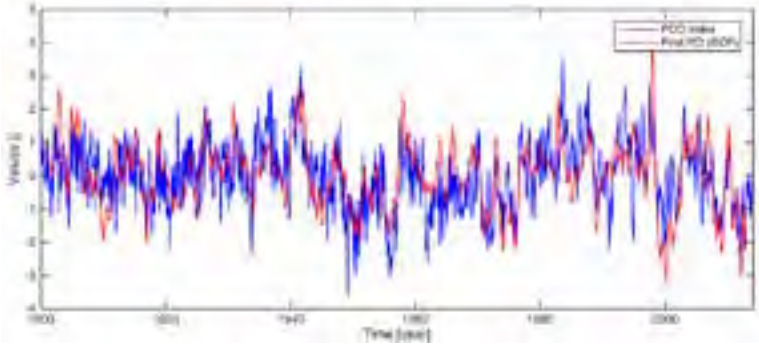
è Need of a user guidance about the best product for his/her use

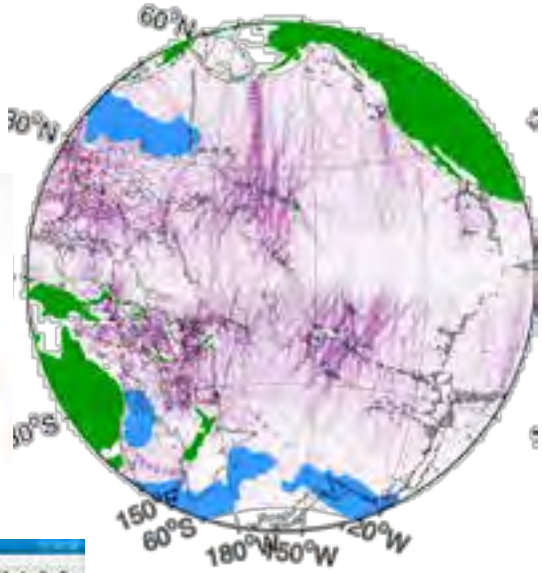

Map

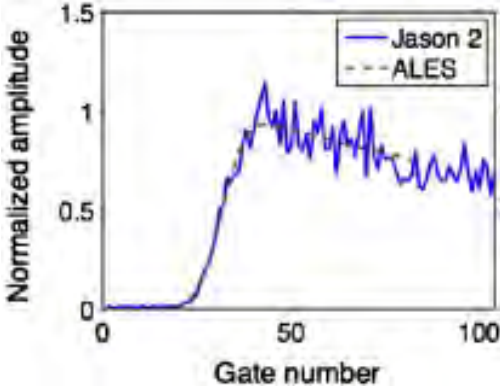



Latitude (degrees north)
23.5
23
22.5
22
21.5
21
20.5
20
68
69
0
-20
-40
-60


SWH (m)
SWH-MLE4
SWH-BETA5
SWH-BETA9
SWH-BAGP
Distance from Coast(Km)




60°N
30°N
0°S
30°S
60°S
150°E
180°W
150°W
120°W


Normalized amplitude
Jason 2
ALES
Gate number


AVISO+

Outreach

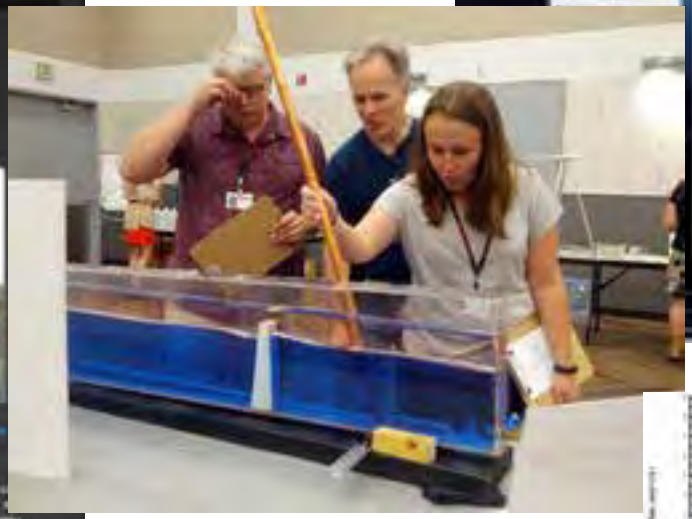
- Jason-3 / Sentinel-3 launch scheduled soon
- COP21 Climate conference in Dec. 2015
- El Niño brewing

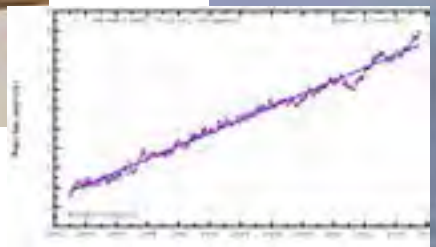
Ú preparing for those launches
AND the climate conference
+ El Niño

- Storm surges another subject with potential public impact
- Hands-on experiments very often a successful way of outreaching
- Web site accessibility to be taken into account

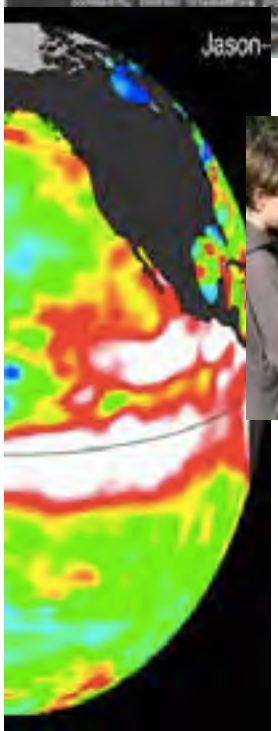

AVISO+
MISSIONS


cnes
ARGONAUTICA DATA





SPACEX
T+00:00:00


Jason-

Recommendations / perspectives

- A number of resources (figures, maps, movies, animations, schemes…) available
  - On the web e.g. www.aviso.altimetry.fr/gallery , sealevel.jpl.nasa.gov/gallery/
  - On our computers / databases
- don’t hesitate to ask for general material or a specific theme / figure
  (at worst, we can think about having it made for future uses)
- If you have “hands-on” activities, try to write a rough description to share it (and/or send a movie?)

Recommendations / perspectives

- Prepare to talk about climate, climate and climate…(and Jason-3)

è preparing for the launches, El Niño and the climate conference.

- Plan for mobile/simple interfaces/navigation for web sites, at least as alternate possibility; consult with an accessibility expert

- Jason-CS, SWOT outreach AND data services to be prepared

The Geoid,Mean sea surface and mean dynamic topography

Splinter summary & recommendations

Y. Faugere and O. Andersen

The Session.

- **6 oral presentations (geoid/MSS/MDT)**
- **2 Posters (on MDT)**
- GEO_001 – Müller, Dettmering and Bosch

  Pointwise comparison of geostrophic currents of altimetry-derived instantaneous Ocean Dynamic Topography with in-situ measurements

  GEO_002 – Knudsen,

  The updated geodetic mean dynamic topography model – DTU15MDT.

S. Bruinsma et al: The POD gravity field model for GDR-E: EIGEN-GRGS.RL03-v2.MEAN-FIELD

EIGEN-GRGS.RL03-v2.MEAN-FIELD: summary

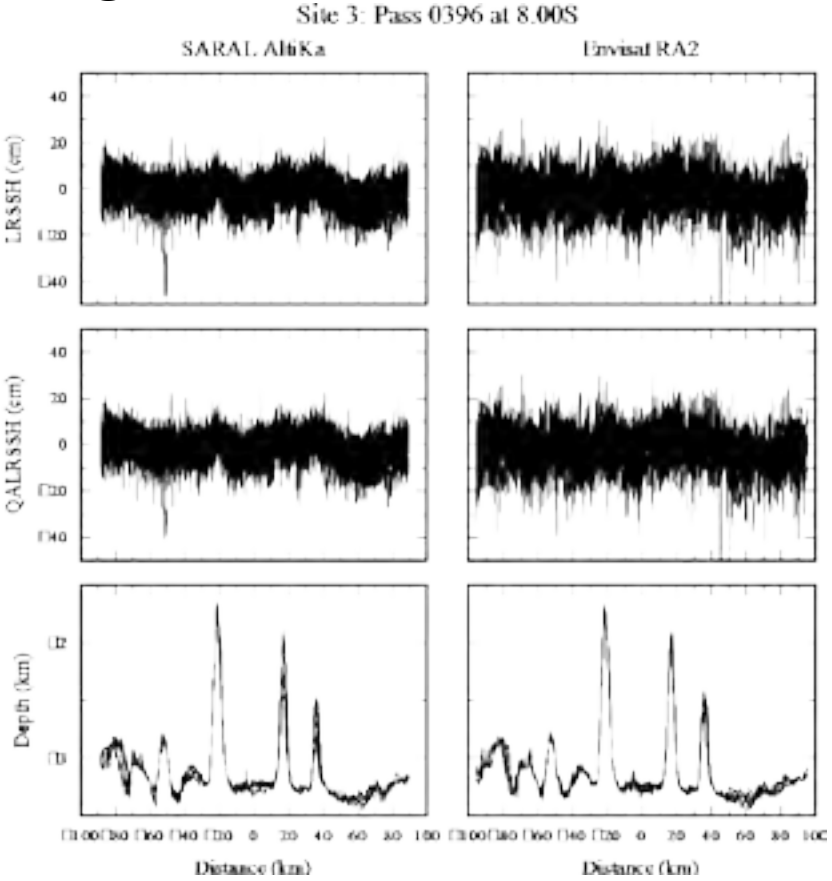
- Model to d/o 300 constructed with LAGEOS, GRACE and GOCE data;
- Time-variable coefficients to d/o 80 (bias, slope and periodic terms were adjusted per year). Better agreement with JPL red. dyn. orbits, *but still room for improvement*;
- Best satellite-only model when comparing with GPS/leveling data, POD, and geostrophic current velocities;
- Formal accumulated geoid error at degree 200 (100 km): 0.8 cm (mission objective: 1.0 - 2.0 cm). Estimation over Germany: 1.8 cm;
- The geostrophic current comparisons reveal that GOCE can provide accurate current information at 100 km scale; at 80 km, only the zonal component is accurate enough.

Smith and Marks: Stacking repeat cycles of 40-Hz AltiKa data resolves the geoid anomalies of very small seamounts Walter Smith

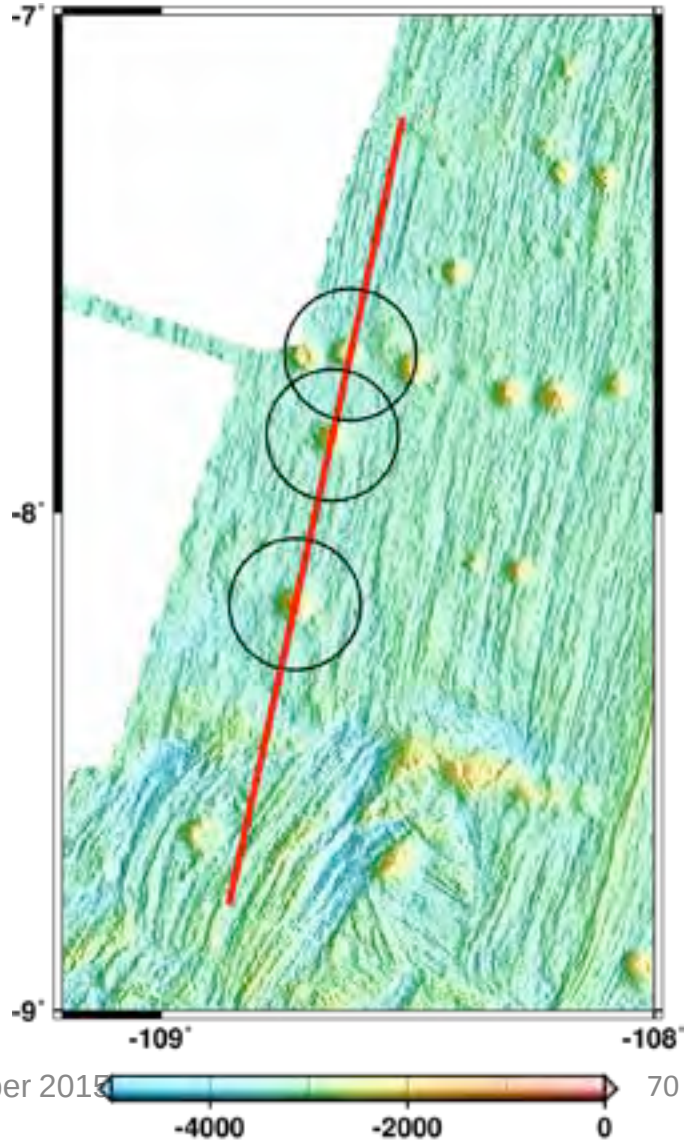
Sea level (geoid) anomaly over Seamounts. 12 repeat tracks.

AltiKa samples @ 40 Hz rate

Ku samples @ 18 Hz rate



Left: Figure from Smith, doi:10.1080/01490419.2015.1014950.
Right: bathymetric survey by Cochran et al., image by Karen Marks.



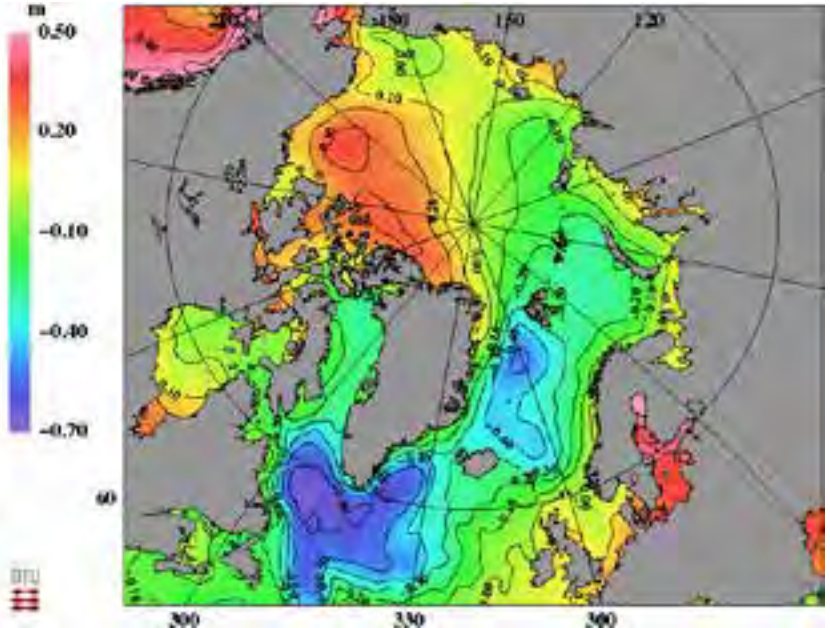
Andersen et al. DTU15 MSS and MDT

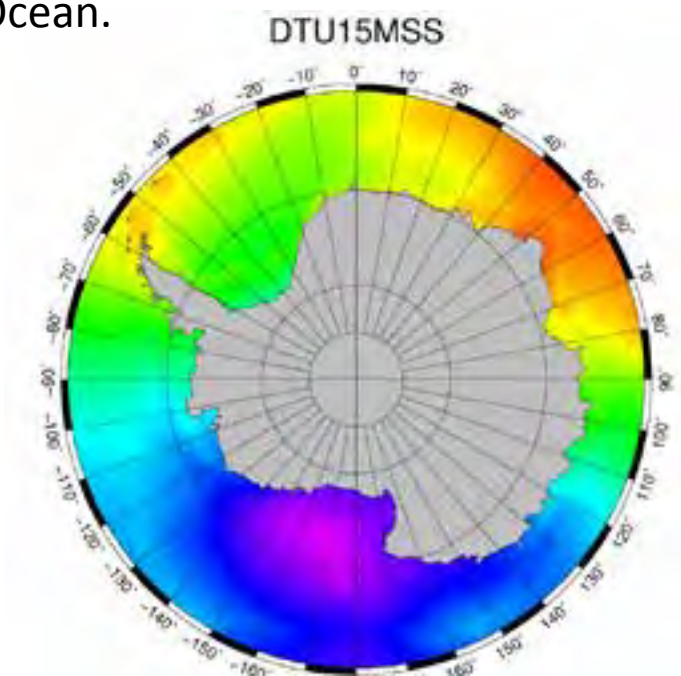
What is NOT NEW….

- **MSS is STILL based on 20 year Mean T/X-J1+J2 profiles (1992-2012)**
- **Identical reference time period to DTU13.**
- **Corrections consistent to RADS V.3**

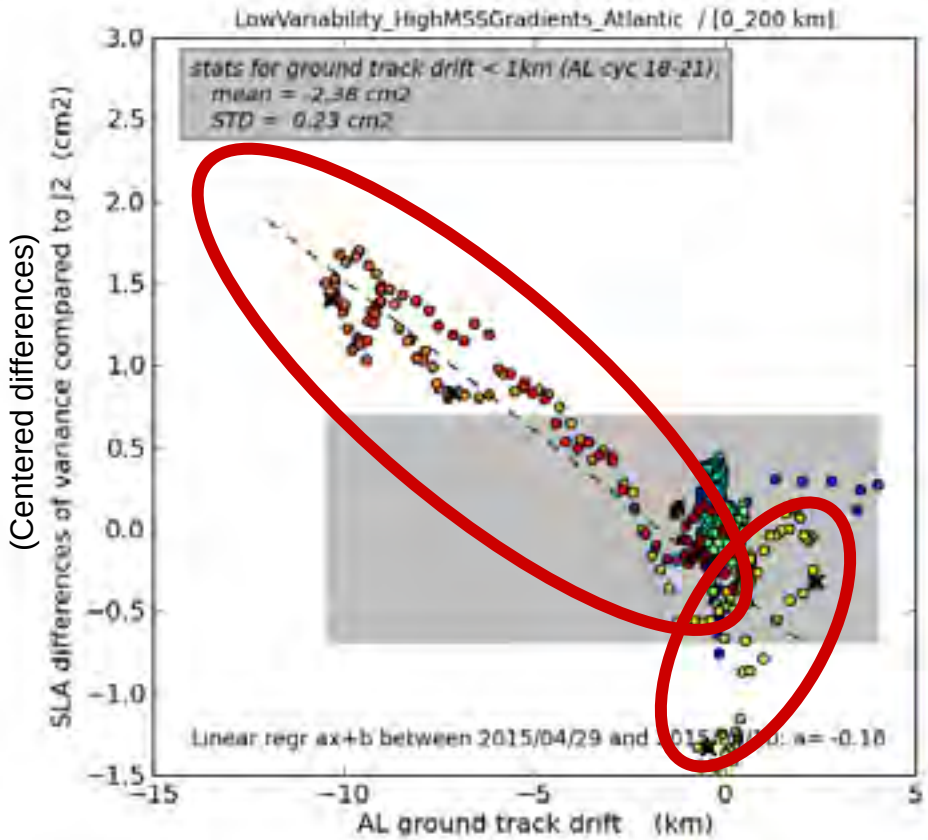
Whats new:

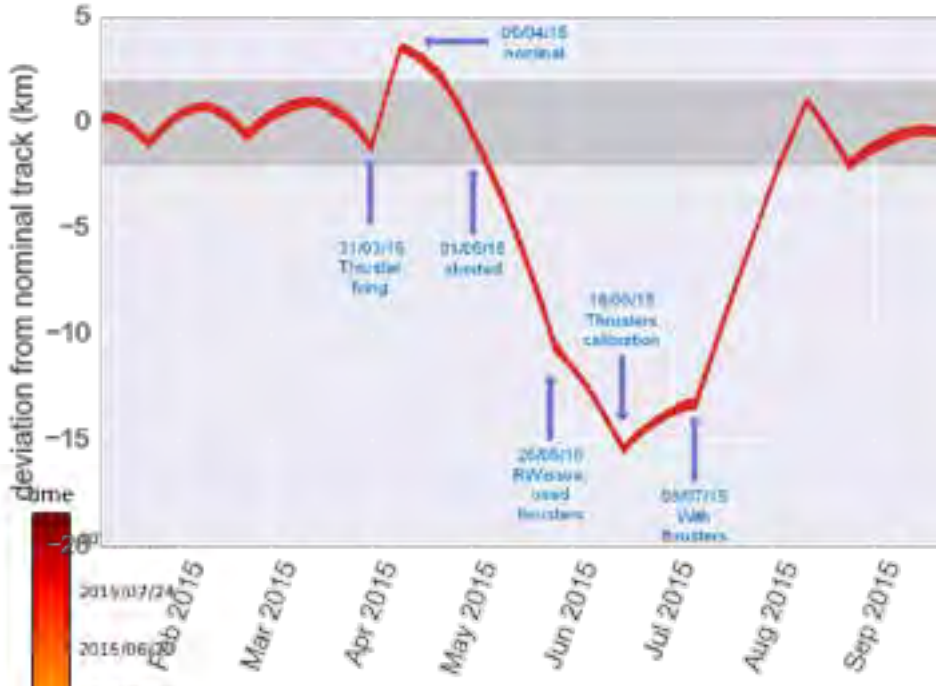
- **Old Geodetic mission of ERS-1 and GEOSAT have too low range precision**
- **Compared to C2 and J-1. Hence they are not used at mid/low latitudes.**
- **SARAL/AltiKA and ENVISAT(phase C) drifting orbits incorporated.**
- **Update of short wavelength in** Arctic and Antarctic Ocean.





Pujol et al.: The recent drift of SARAL: an unexpected MSS experiment





MSS error evolution with AL ground-track position:

à **Err = 4.2 mm rms / km**

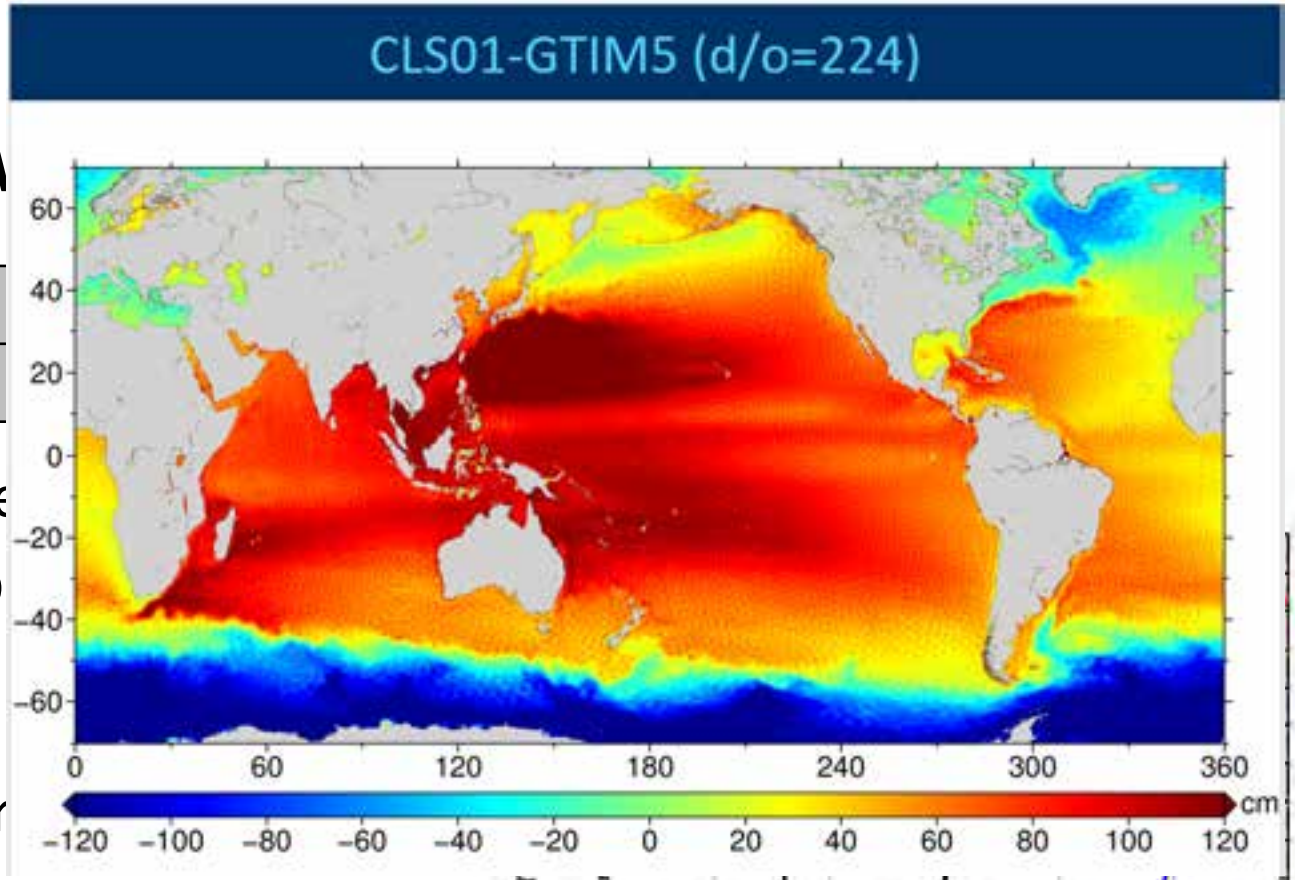
à Mixed with ocean variability between 0-4 km

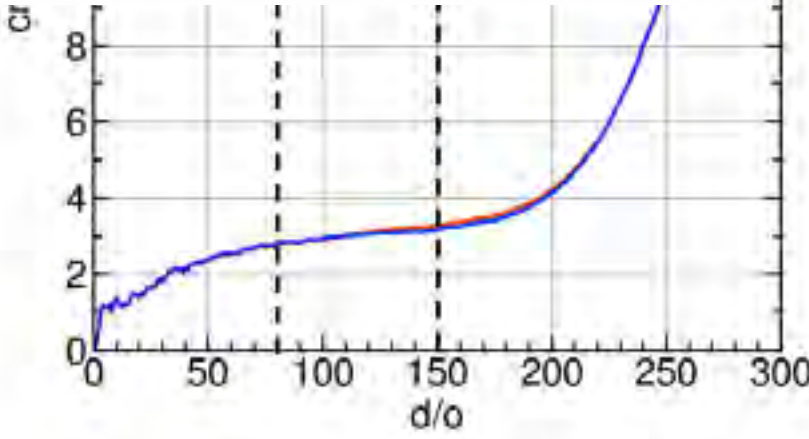
à **Err significant for ground-track distance > 5km** (low variability & high MSS gradients area)

- **How well can w**

resolution (km)	
error (cm)	

- Little difference be
- TIM (GOCE) and D
- Compared to DIR,
- have shown the gr
- in the LW and MW components
- Different MSS (CLS/DTU) products
- have little overall impact:
  - Swamped at LW by residual geoid omission error
  - Swamped at SW by geoid commission error



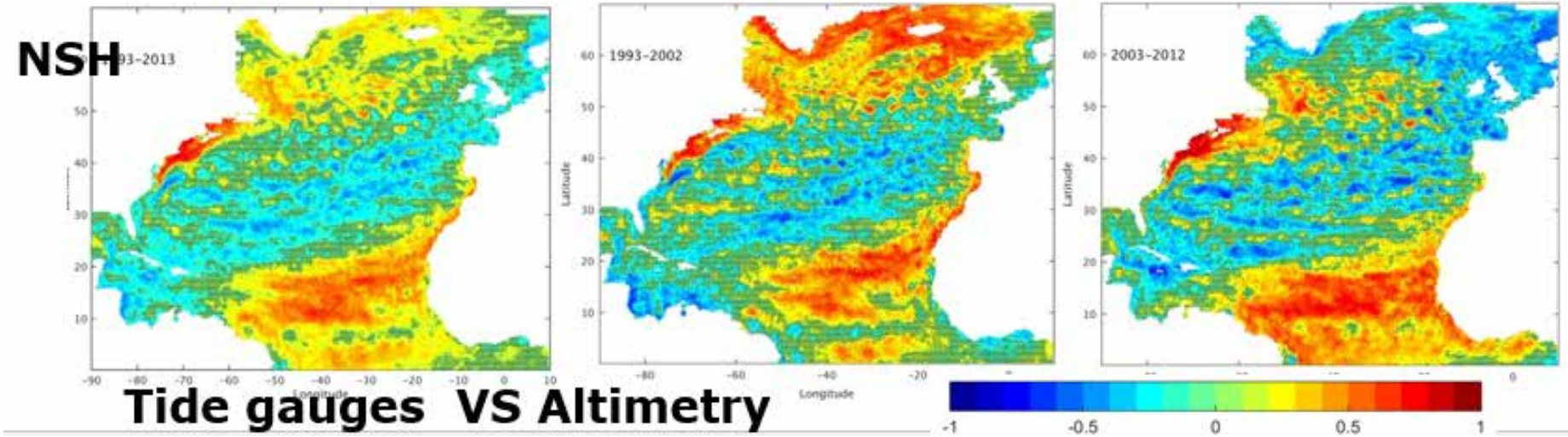


Cheng et al. Variations of observed correlations between satellite altimetry and tide gauge data along the U.S. east coast

Significant correlations and the correlation variations between tide gauge data north of Cape Hatteras and altimeter data in the subpolar and tropical North Atlantic Ocean in the last two decades.

Sea level variations in the Labrador Sea are highly correlated to local sea level variations north of Cape Hatteras with phase leading of about 3 years over 1993-2002 time period.

Spatial distribution characteristics of the correlation variations are linked to the slowing down of AMOC and the variations of NAO winter, atmospheric forcing and Ocean Heat Content in the North Atlantic Ocean.



Tide gauges VS Altimetry

Recommendations: Jason-2 EoL

RECOGNISE that it's a great achievement that J-2 is IN VERY GOOD SHAPE(full redundancy), and RECOMMEND early investion of possible/various EoL scenarios

RECOMMENDATION is linked to the expected altimeter constellation in upcoming years.

Assuming we have two operational repeat satellite (J-3 & S-3A) +

2 additional satellites (Altika and/or C2 and/or HY2A and/or S-3B) flying.

RECOMMEND to move J-2 to a GM mission as soon as possible in preparation for SWOT

RECOMMEND to plan for TWO interlaced GM cycles to reduce cross track sampling to 4 km in order to Improve resolution and generate next GENERATION MSS/Gravity/Bathymetry.

RECOMMEND THAT TIMING IS CONSIDERED: Two interlaced GM cycles will take 800 days or3 years. If SWOT will launch in Dec 2020 a J-2 EoL GM should be initiated no later than Dec 2017

RECOMMEND two Interlaced GM because we can not use interleaved orbit with J-1 GM

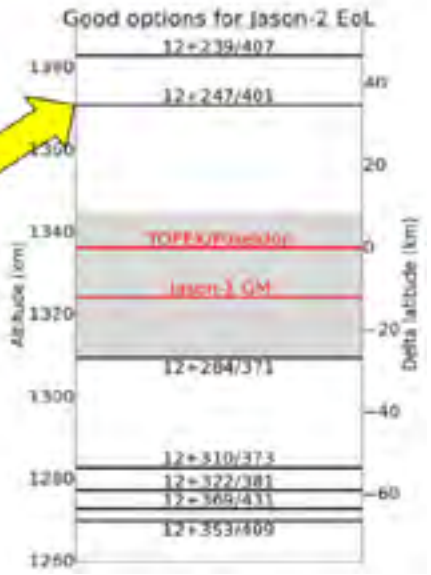
RECOMMEND study if first GM can be phased to maximize info with J-1GM in case of J-2 failure (near interleaved but at other altitude)

Recommendation: J-2 EoL orbit choice.

Following presentation by Dibarbure

- Best contender: codename 12+247/401
  - 35km above Jason-3
  - Minimizes mesoscale sampling duplication
  - Good geodetic grid
- Gains (geodesy) and losses (mesoscale) of geodetic phase will be the same as for Jason-1

Priority	Revs per day	Sub-cycles
1	12+247/401	3, -5, 13, 138, 401
2	12+369/431	-7, 146, 431
3	12+353/409	-7, 22, -73, 168, 409
4	12+310/373	-6, -77, -148, 373
5	12+284/371	-4, 17, 81, 145, 371
6	12+322/381	-6, 13, -71, 155, 381
7	12+239/407	-2, 5, -17, -63, -172, 407



RECOMMEND to investigate the orbits (higher RECOMMEND THAT orbit with highter altitude than nominal orbit - codename 12+247/401 (1) and 12+239/407(2) is further investigated as it seems optimal withrespect to optimal sea state and oceangoraphic use.

RECOMMEND a study of orbit wrt sampling of oceangraphic signals.

RECOMMEND choice of with intermediate sub-Cycle in case of failure of the satellite

SARAL/Altika “Extension of Life”

- Due to technical problems two future orbit choices were outlined (35 or drift)

- RECOMMEND the not-maintained (drifting) orbit for MSS/Grav/Bath.

- RECOMMEND this phase to start as soon as possible (awaiting 3 years project meeting in early 2016)

- RECOMMEND to start investigating possible scenarios of drifting orbit (decrease) and investigate consequence for oceanographic signal (tides, mesoscale)

- RECOMMEND TO perform (i.e. 1 year) orbit simulation for 2 scenarios (low and high solar activity) for AltiKa drifting orbit

- RECOMMEND to consider timing and investigate consequence of several simultaneous geodetic missions

Other topics

- Discussed having a dedicated MSS meeting in 2016
- (accuracy/future needs/ processing/ assesment/
- impact of various future Geodetic missions)
  - possible outside/adjacent to OSTST
  - Possible phased with SWOT meeting.

Quantify Errors and Uncertainties in Altimetry Data

Chairman: R.Scharroo, J.Dorandeu, M.Ablain

q **Objectives:** Establish the link between Altimetry experts and applications (MSL, mesoscale, etc)

- New insights about errors in the altimeter system

Þ From experts to applications

- User needs and requirements in terms of errors, including formalism of errors

Þ From applications to experts

q Splinter divided into 2 parts :

1) Mea Sea Level errors: 3 talks / 2posters
2) Short wavelength errors : 2 talks / 2 posters
3) Instrumental errors : 1 talk

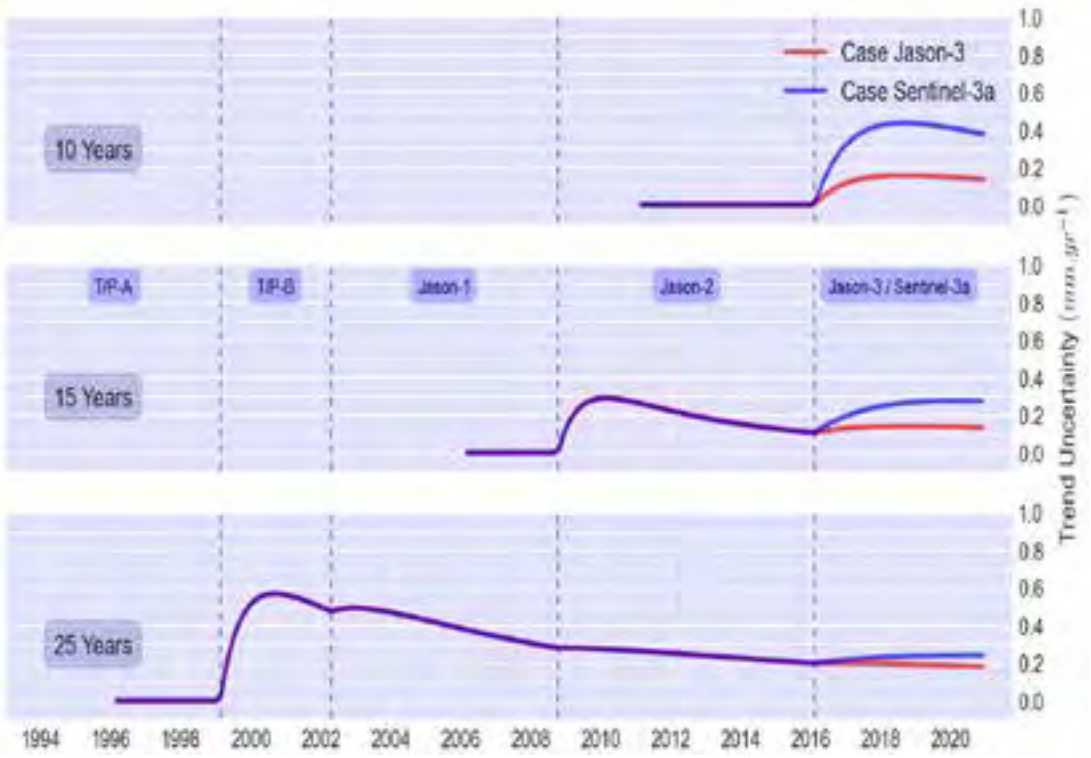
Mean Sea Level errors

q **L. Zawadzki et al.** : Accuracy of the mean sea level continuous record with future altimetric missions: Jason-3 versus Sentinel-3a

Þ What would be the impact on the GMSL of using S3-A instead of Jason-3 as reference mission ?

•Linking Sentinel-3 MSL time series to Jason-2 has a strong impact on the global (and regional) MSL uncertainty, mainly due to the absence of a calibration phase.

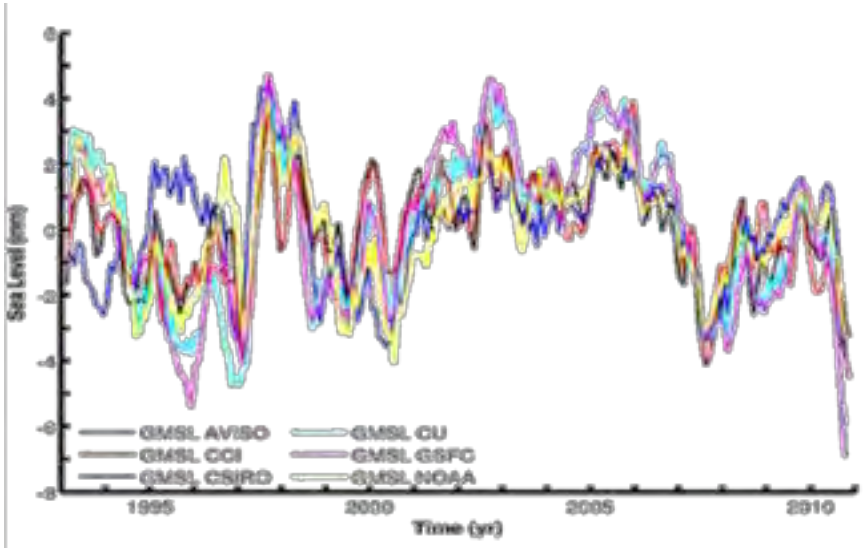
• Changing the historical TOPEX/Jason orbit for Sentinel-3a orbit would therefore exceed user requirements over 10 years even though it is only one component of MSL error budget (Ablain et al. 2015).

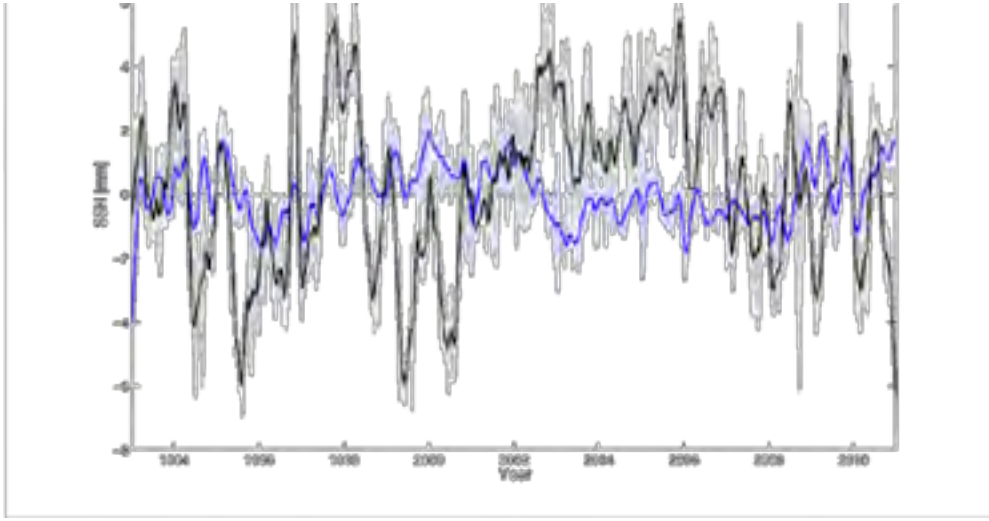


Mean Sea Level errors

q **M. Scharffenberg et al. :** Uncertainty estimates of altimetric Global Mean Sea Level timeseries

Þ Impact of the STORM/NCEP model [von Storch et al. 2012] as synthetic truth to test the effects of applying different averaging methods.





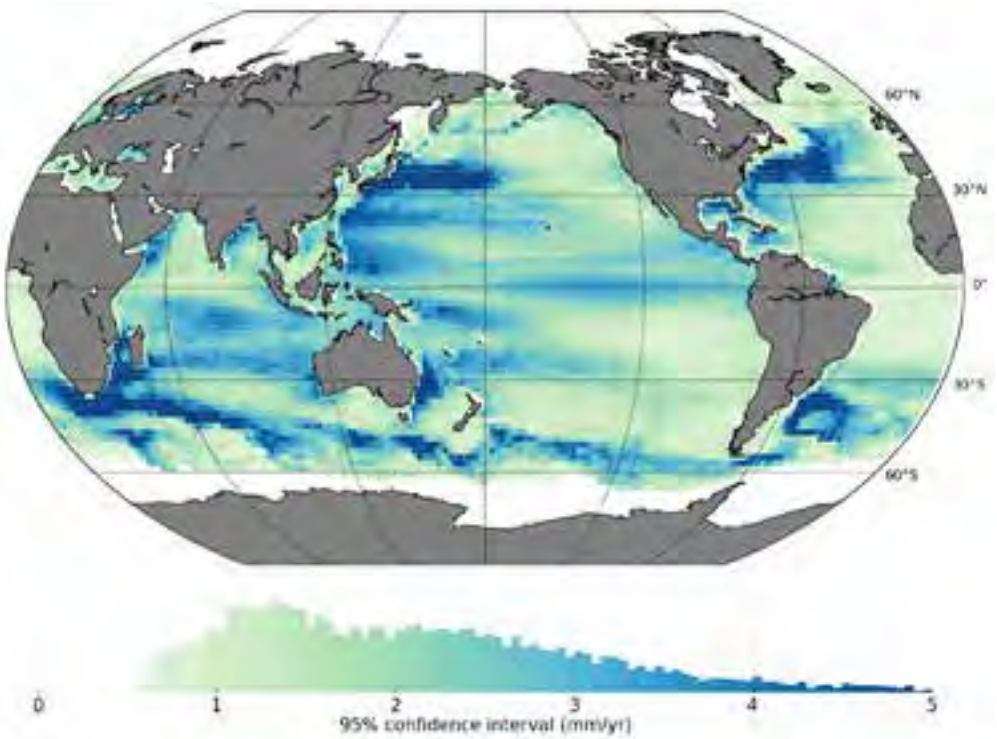
Þ This work is an update of O. Henry et al., 2013

Þ depending on the method used, the uncertainties of the GMSL estimates needs to be considered larger by up to +6 mm

Mean Sea Level errors

q **P. Prandi et al. :** How reliable are regional sea level trends ?

Þ Objective: provide a map of uncertainties of regional MSL trends trends



• Systematic uncertainties range between 1 to 3 mm/yr

• Results depend on the *a priori* description of errors : if the error model is wrong, the results are

Þ Accurate error covariance description is crucial

• With time, the CI will reduce

Providing this map was a recommendation of last OSTST

Short wavelength errors

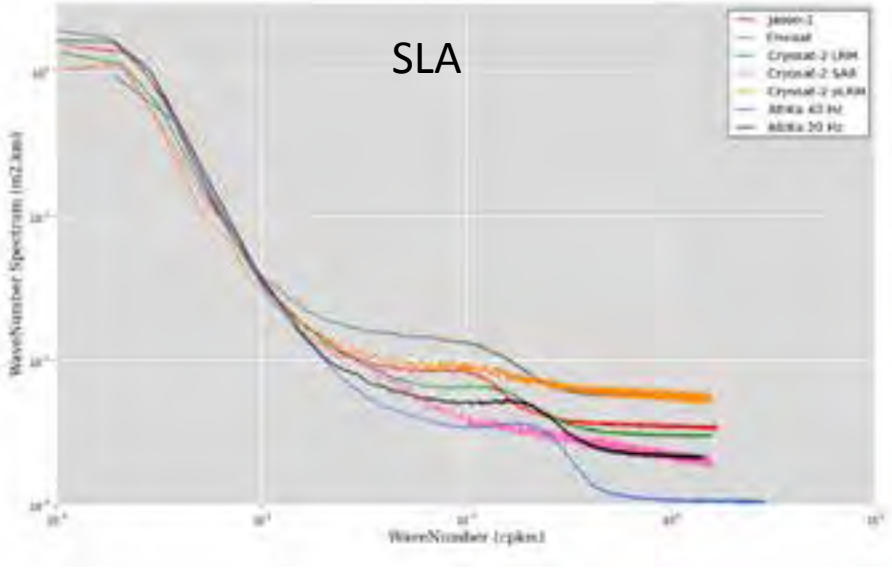
q **P. Thibaut et al. : Characterization of the Altimeter Mission Performances over Ocean: Comparison and Interpretation**

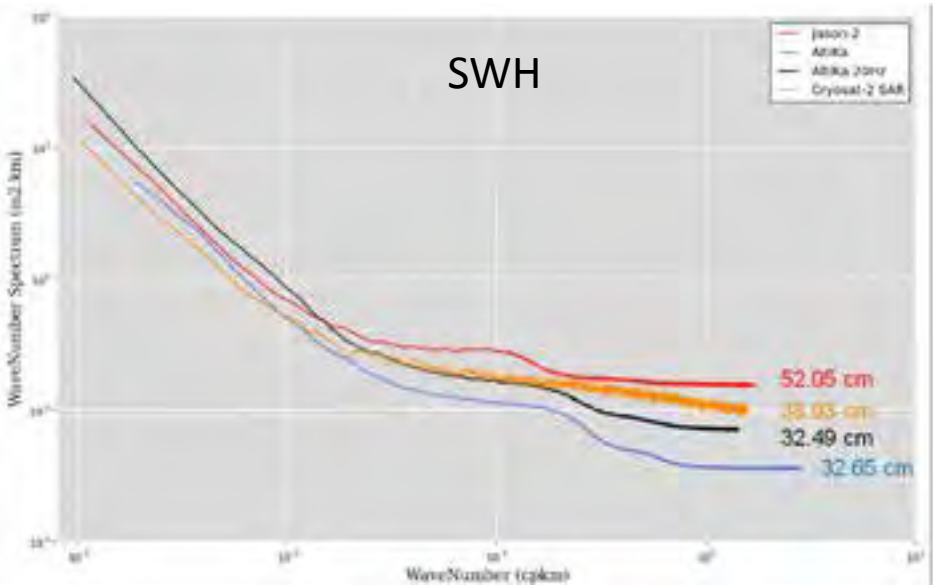
Þ Most of past/present altimeter missions have been looked at and compared with the same processing applied: Performances have been derived using different metrics

Þ 20Hz std and PSD noise level are strictly equivalent at low SWH and coherent with simulations

Þ PSD noise level for high SWH doesn't represent the instrumental noise. Does SWH/Swell introduce correlated errors in the estimates ?

Þ Very good SLA performances of CS-2 SAR but also of SARAL (Ka band / 40 Hz), even better SWH performances with Saral



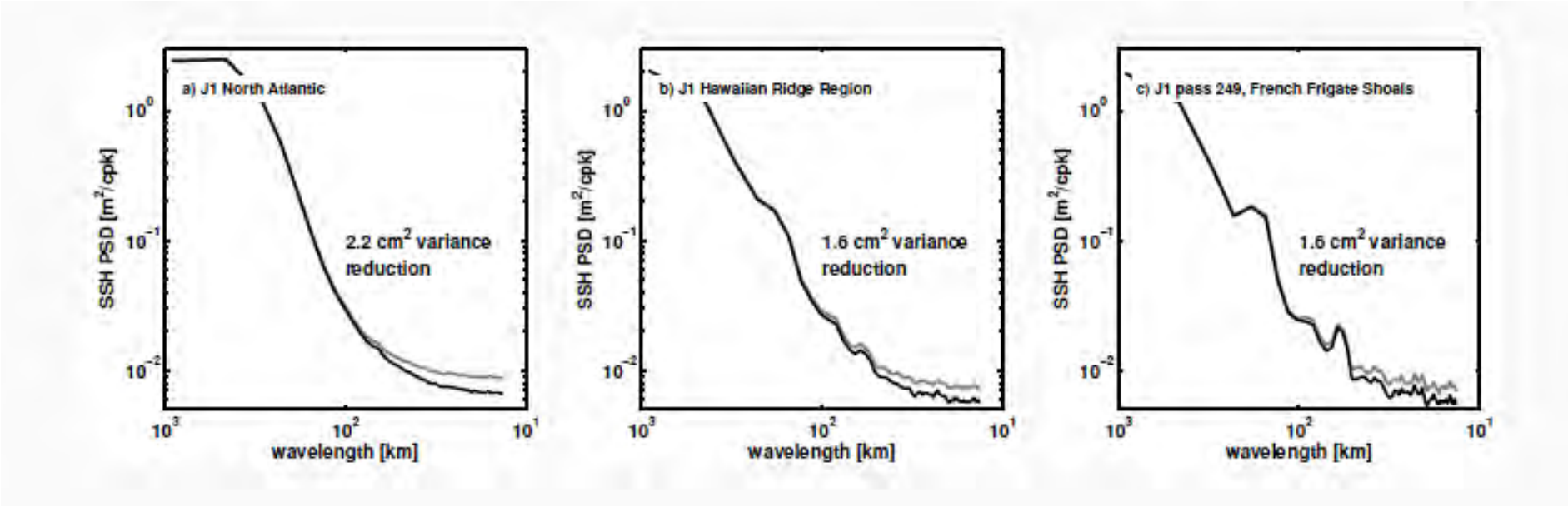


Short wavelength errors

E.D. Zaron et al. : identification and reduction of retracker-related noise in altimeter-derived sea-surface height measurements

Þ An empirical approach to reducing the retracker-related SSH error was implemented, based on analysis of J1-J2 during the J2 cal/val orbit phase.

Þ The high-wavenumber SSH noise floor is reduced by about 2cm$_2$, depending on SWH.



Instrumental errors

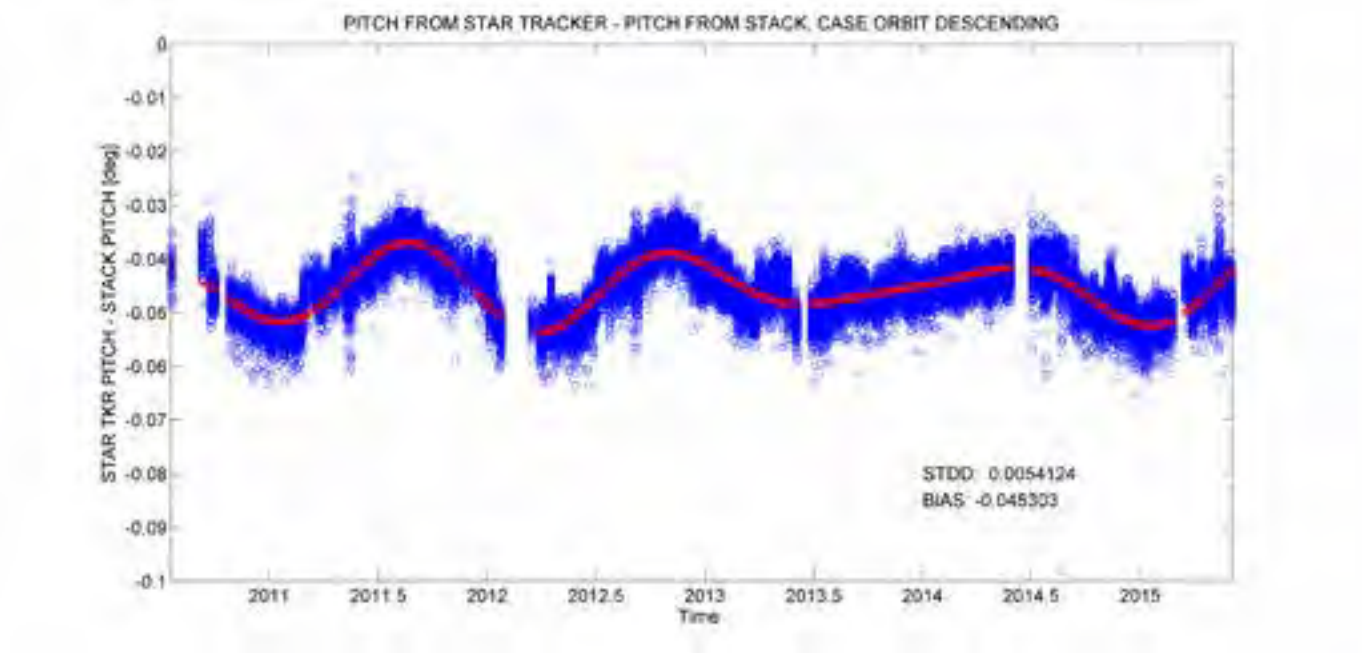
q **D. Salvatore et al. : Seasonal Effects on the Pitch Measurements for Cryosat-2**

Þ Thanks to pitch mispointing computed from Stack, a sinusoidal pattern in the Star Tracker estimation of the pitch mispointing has been detected (potentially correlated to sun illumination conditions).

Þ After removal of the sinusoidal pattern, the estimation of the pitch from Star Tracker and Stack are pretty consistent (around 3 millideg)

Þ It is essential to calibrate also the roll mispointing (that can be affected in the same way by solar illumination).

Þ We recommend to perform the same exercise routinely for Sentinel-3, as long as for the roll.



Posters

• Labroue et al. Sentinel-3 Delay Doppler Altimeter: a New Insight on High Resolution Ocean Dynamics

•M. Scharffenberg: Sea level ECV quality assessment via global ocean model assimilation

• H. Dieng et al. : Sea level budget over 2005-2013: Missing contributions and data errors

• Laura A. R. Etcheverry et al.: Satellite altimetry data validation in San Matias Gulf, Argentina

Conclusions

- from last OSTST :
  - new insights allowing a better description of the altimeter errors
  - 2 recommendations of last OSTST have been answered:
  - errors are provided as function of wavelength
  - the errors on regional sea level trends have been characterized and a map has been provided

- Recommendation for the next OSTST:

  - feedbacks from end-users to better characterize the error for their studies are very encouraged !
  - the total propagation of measurements errors into final products should be further studied.

Tides / High-frequency Summary

2 talks on new CNES/CLS/LEGOS/Noveltis and ESA/Noveltis/DTU barotropic tide models:

FES2014 (global) + regional model of Arctic

The notorious 59-day problem in mean sea levels

Topex and Jason are inconsistent at β' period (S_2 alias)

Zawadzki et al., in preparation

3 talks on internal tides and 1 on internal waves

motivated especially to prepare for SWOT

first cut at new global internal-tide models

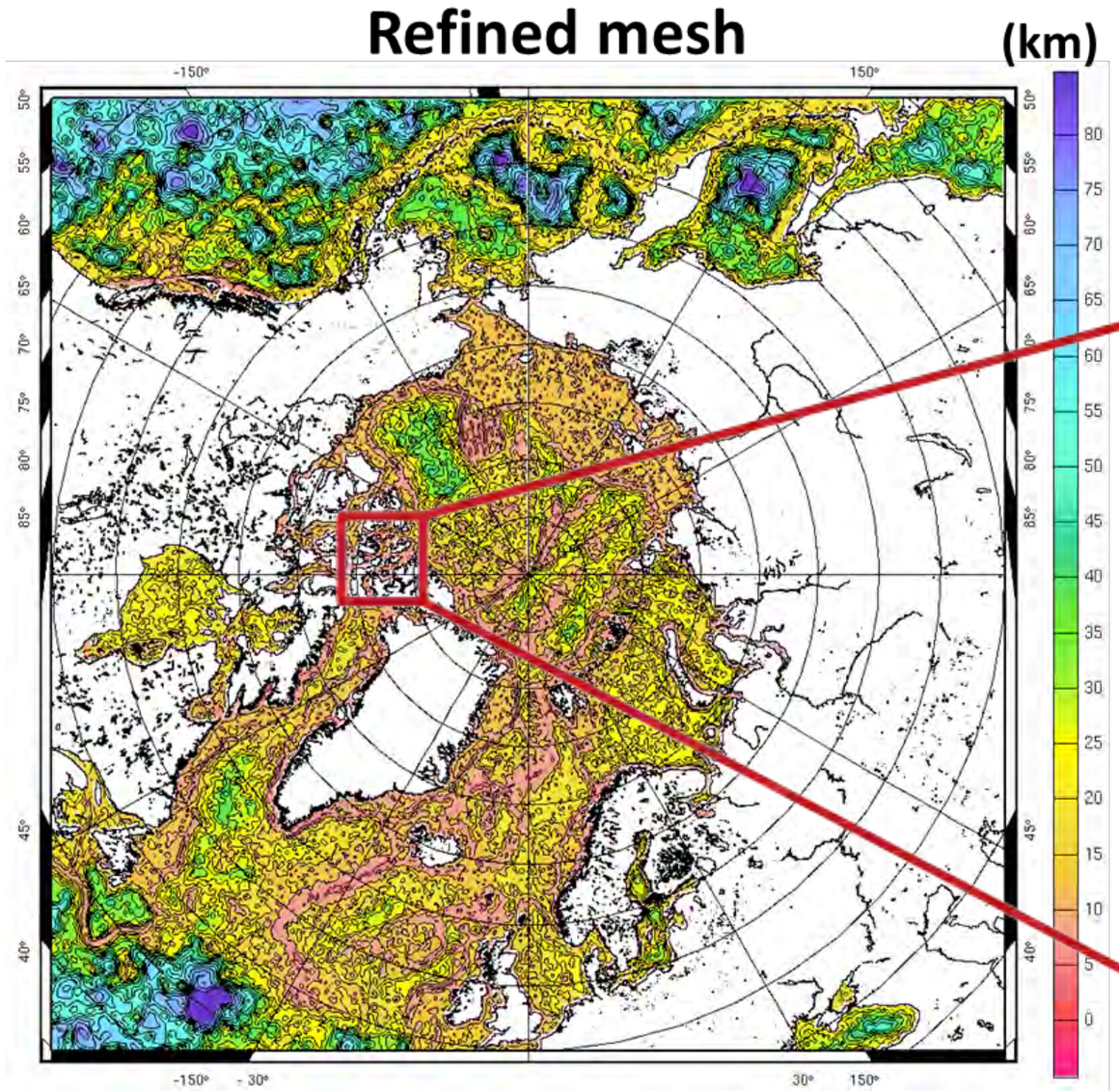
5 posters

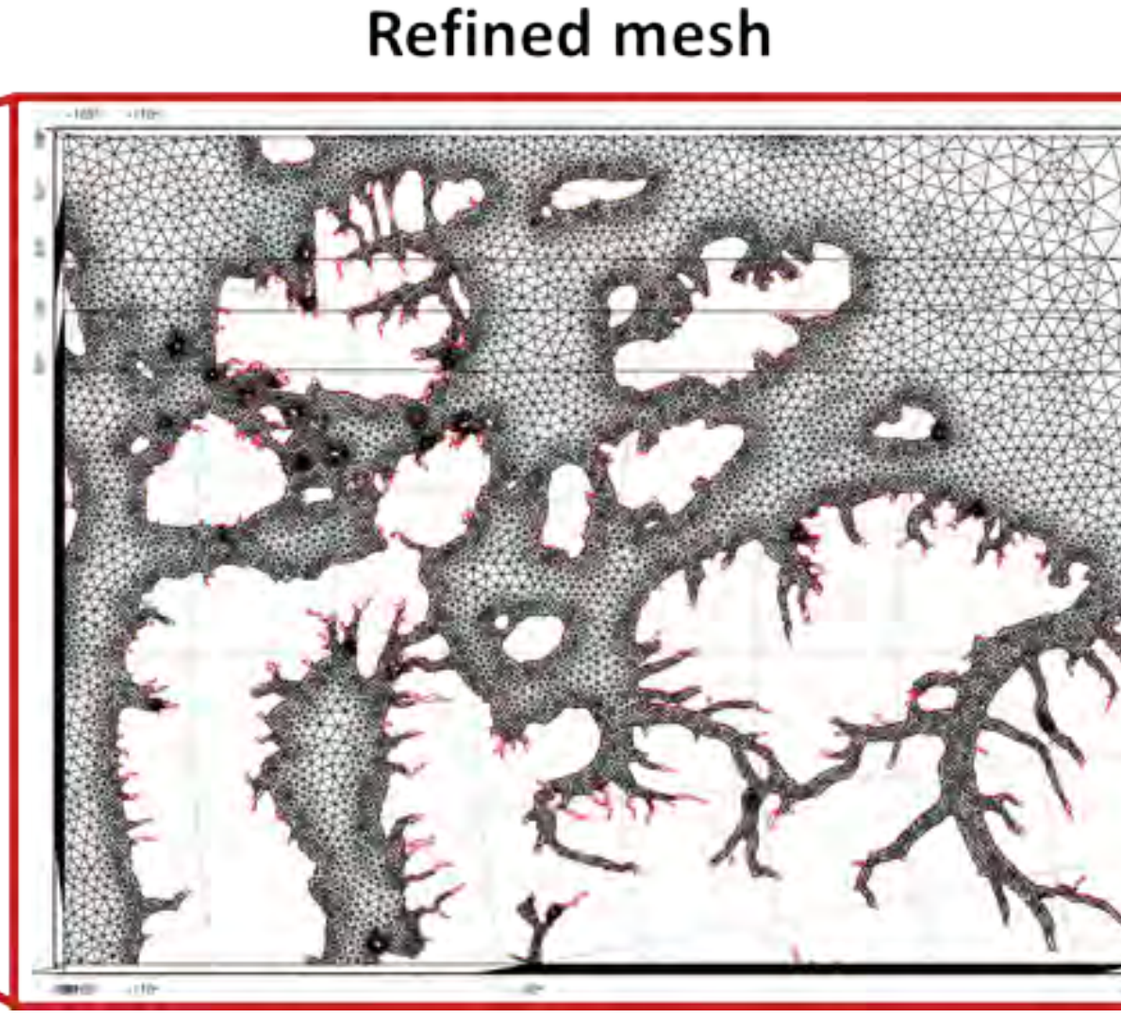
– improvements to dynamic atmospheric loading model

– surface & internal tides (including another global model)

– revised pole-tide correction

Finite-element mesh – Arctic Ocean
Cancet et al.



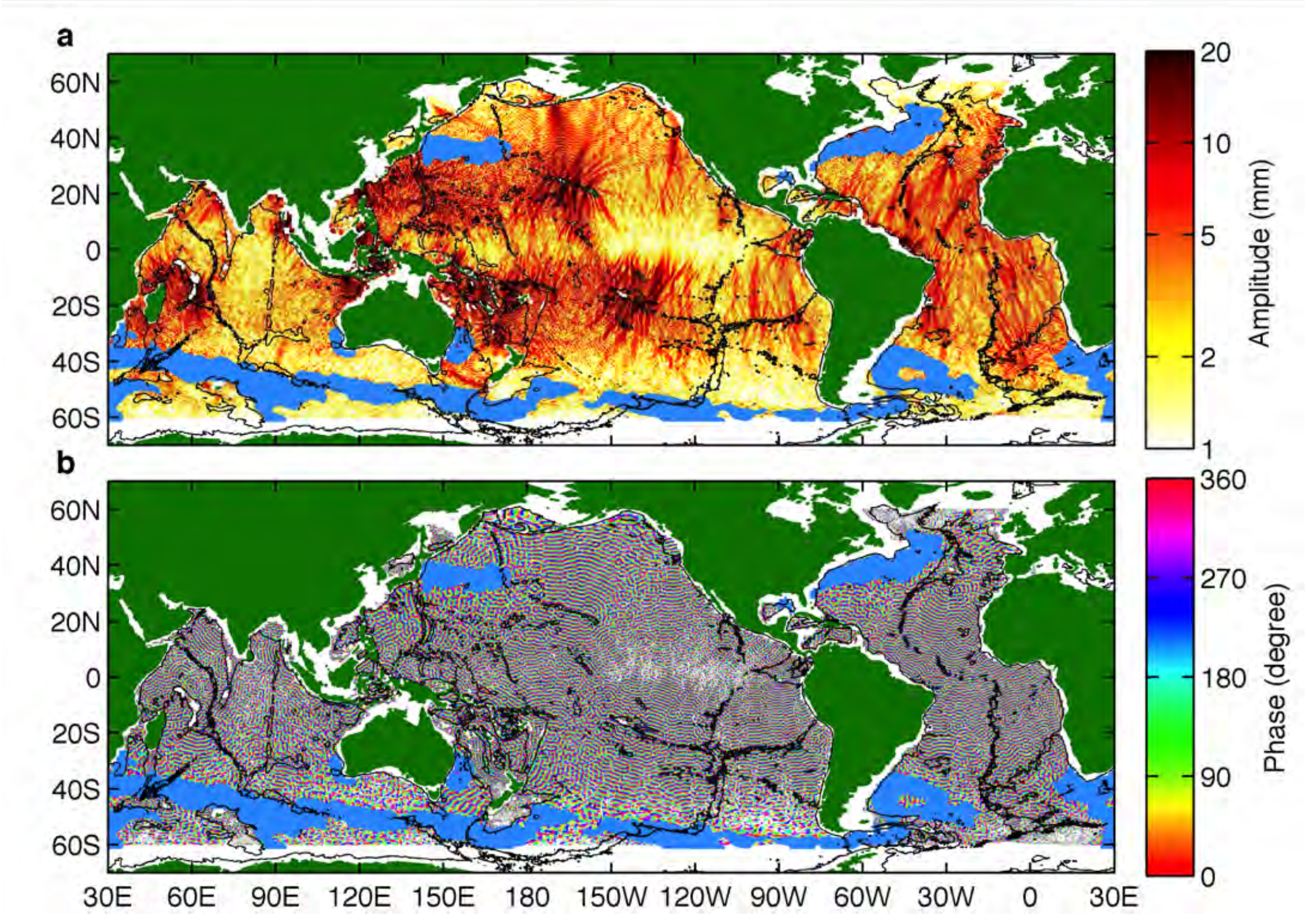


Coast: ~4 km

Offshore: ~8 km

Global mode-1 M2 internal tide

Zhongxiang Zhao



Tides Round Table Discussion

Jason-2 EOL orbit:

No strong preference, but we should check aliasing

SARAL orbit:

Some in favor of letting it drift

Some in favor of staying ± 5 km

Loren Carrère: CNES SWOT managers desire testing of new internal tide models early next year.

Too soon? Current models are fledglings.

How to do it?

- **independent altimetry (if there is any)**
- **PIES (but often deployed in boundary currents)**
- **many subtleties (e.g., coupling with surface tide)**

Science I: Mean sea level monitoring: how to reconcile altimetry, tide gauges, land motion and other in situ observations?

Chairs: Eric Leuliette, Christopher Watson

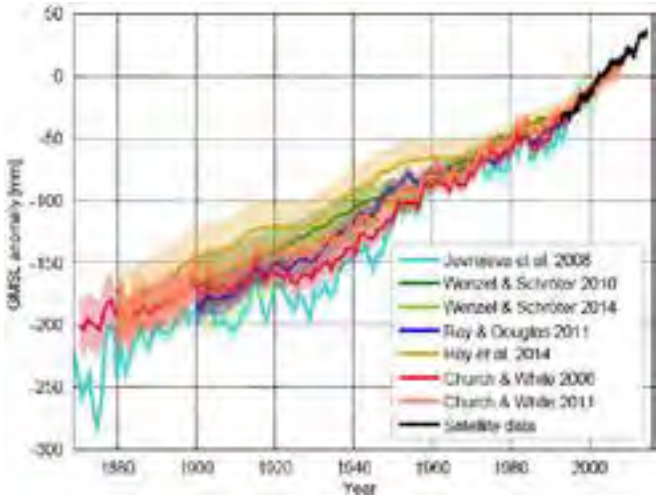
Science 1: Session Summary

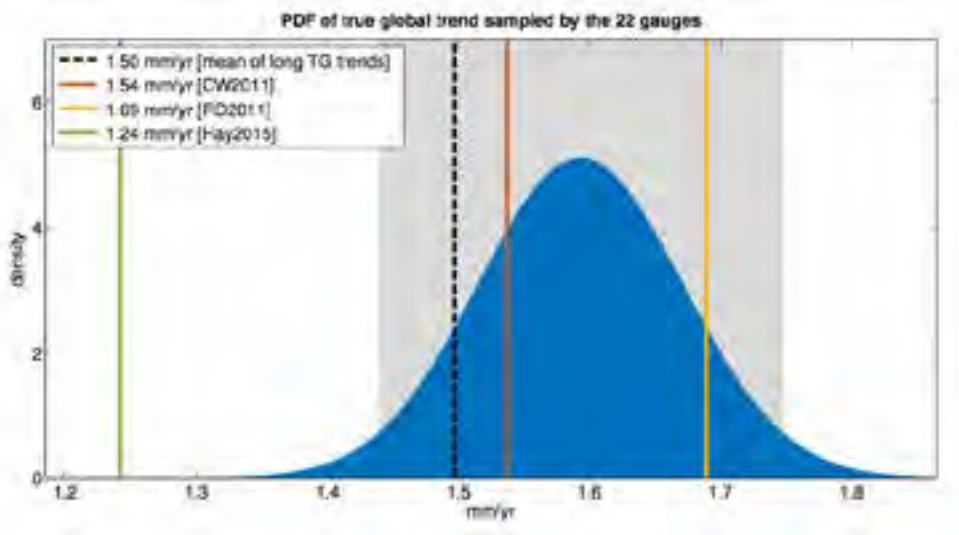
- The session had the goal of showcasing research that has a focus on using altimetry, tide gauges, land motion and other in situ measurements for the purpose of estimating changes in global mean sea level.
- **1 keynote presentation, 7 oral presentations and 7 posters, all well attended!**

Selected Highlights:

20th Century GMSL: (Keynote by Ben Hamlington)

Interesting investigation into what the tide gauge network can tell us about GMSL change over the 20th C, with a focus on investigating the effects of network selection and land motion.

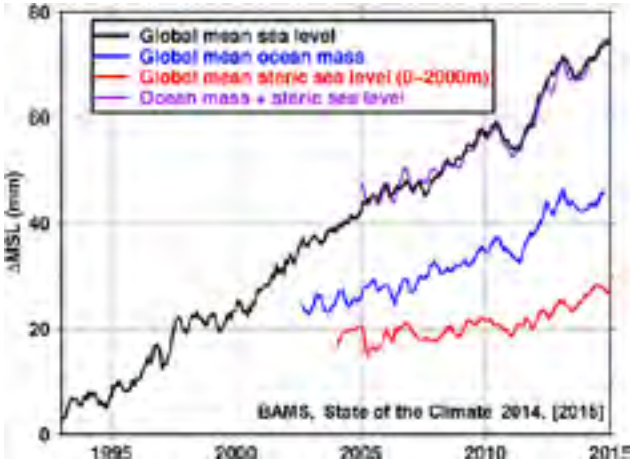




Budget / Altimeter / Tide Gauge Comparisons:

(Talks by Prandi, Watson, Leuliette, Pragge)

- Leuliette presented work on the closure of the sea level budget since the ARGO and GRACE observations began
- Pradi / Watson / Pragge presented some of the subtleties (including land motion uncertainties) behind the altimeter v tide gauge comparison technique used to assess systematic error in the altimetry. See further in the cal/val summary.



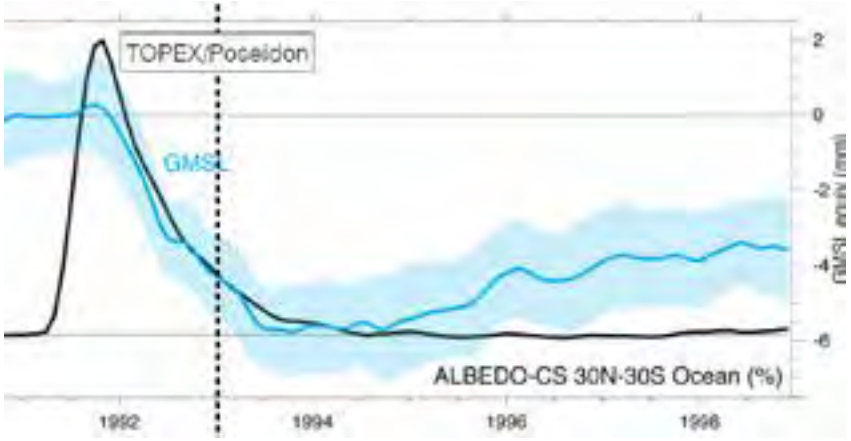
Vertical Land Motion (VLM): (Talk by Santamaría-Gómez)

- ULR6 to be released on the SONEL site soon. Insight into the evolving ability to infer VLM at tide gauges using satellite positioning techniques.
- **New IAG Joint Working Group 3.2** on "Vertical motion of the Earth's crust and sea-level change". Alvaro.SantamariaGomez@utas.edu.au

Decadal variation in GMSL:

(Talks by Fasullo and Fu)

- Interesting work by Fasullo et al on the potential effect of the eruption of Mt. Pinatubo in masking the acceleration in GMSL over the altimeter era.
- Fu highlighted some salient points about the level of uncertainty in decadal trends in GMSL.



Science II: Mesoscale and sub-mesoscale ocean processes: current understanding and preparation for SWOT

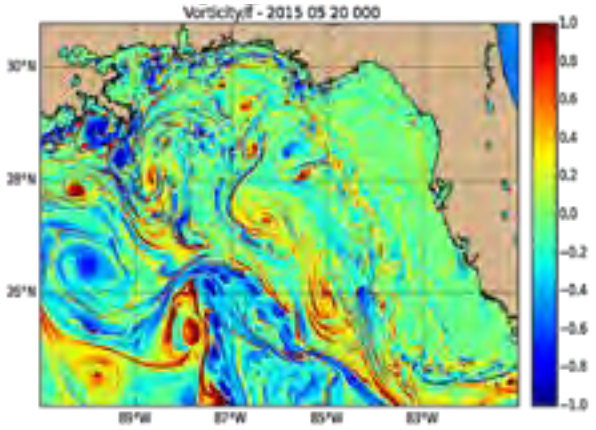
Chairs : Lee-Lueng Fu, Rosemary Morrow

7 oral presentations , 15 posters

1) Observational capabilities of meso-submesoscale: Towards SWOT

Understanding the SSH observational capabilities at submesoscales using OGCMs

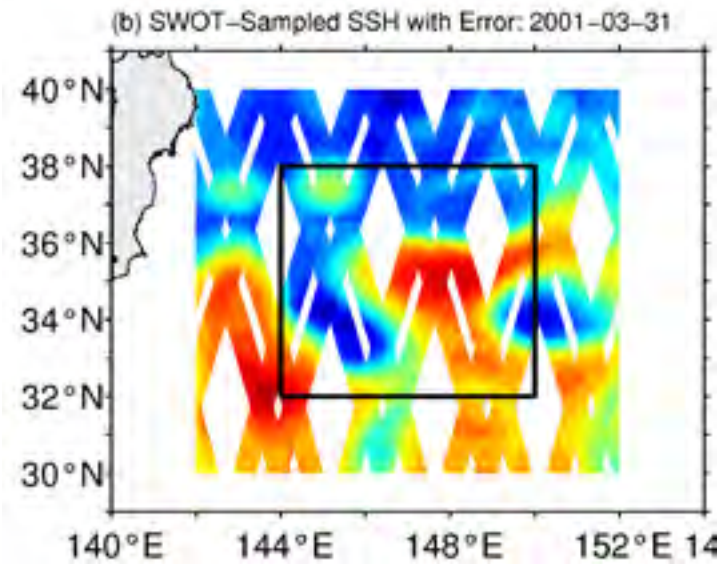
- Different dynamical operators to link subsurface structure (T,S, V, z) to SSH (sQG, balance operators, …) *(Jacobs, Qiu)*
- 2D reconstruction *(Ubelmann)*



Credit : G. Jacobs

Understanding the impact of errors

- Impact of 3D velocity field reconstructions using the SWOT simulator sampling and errors *(Qiu)*
- Impact of SWOT errors limits SSH resolution (15 km); velocity (40 km) & Relative vorticity (50-60 km) *(Chelton)*



Credit : B. Qiu

+ Posters (Toublanc, Girton, D'Ovidio, Le Sommer)

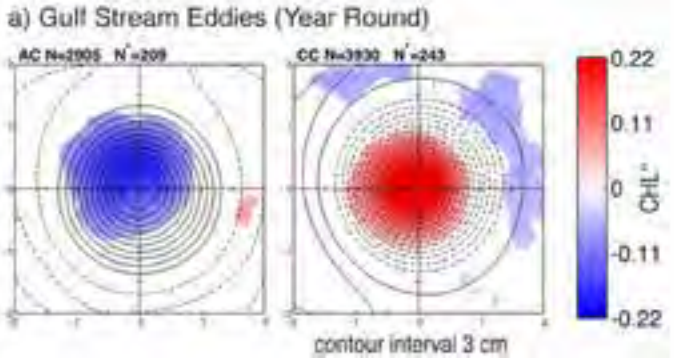
2) Today's Mesoscale observability & applications

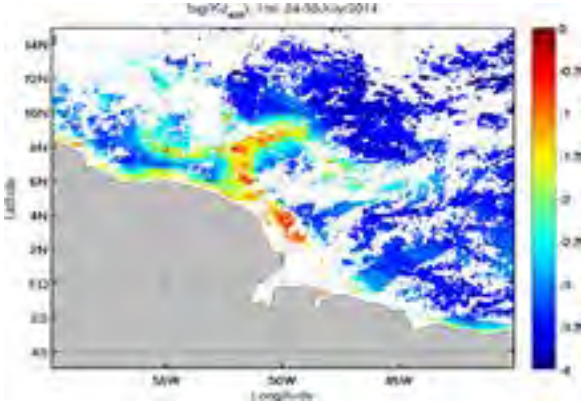
- Composites of Mesoscale eddies reveal **physical-biological interactions** in different regions, based on satellite observations and eddy resolving models. *(McGillicuddy)*

- **Regional data assimilation** schemes resolving mesoscale dynamics : example in the Luzon Strait: (*Zavala-Garay*)

- Role of mesoscale dynamics in **Amazon freshwater plume** extension & their role in modulating hurricanes (*Carton*)

- A **frontal eddy** intensively sampled at sea and overflown by SARAL (*Griffin*)

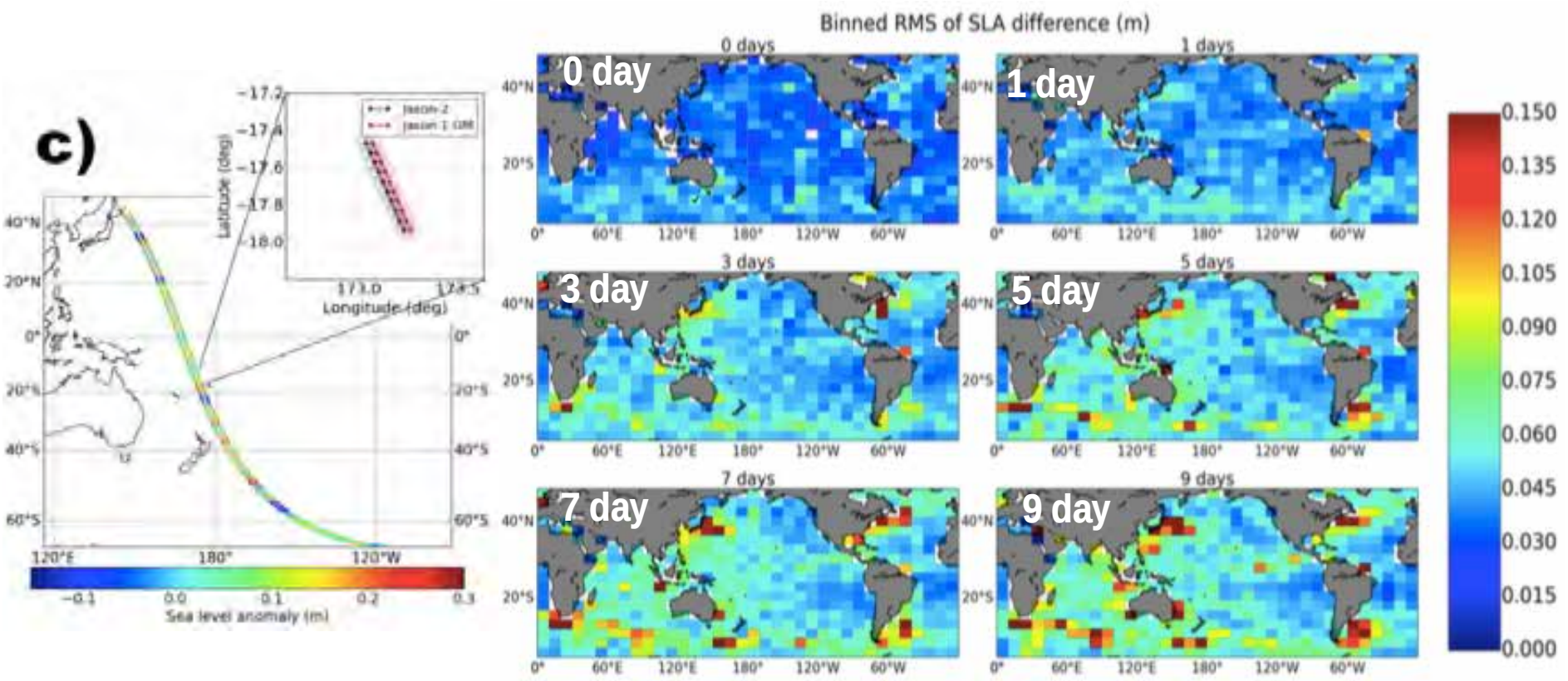




+ Posters (Dohan, Beron-Vera, Maximenko, Melnichenko, Strub, Morrow, Pascual, Quilfen)

3) Rapid meso and submesoscale processes

- Barotropic Rossby waves (*Farrar*)
- Data set of J1G-J2 overlapping tracks at 0-10 days (*Dibarboure*)



Recommendation : Set up an OSTST CalVal group to discuss spatial validation of alongtrack data from 50-100 km wavelength (J2-J3, S3-SAR, CR2-SAR, Saral,…) & in preparation for J-CS & SWOT 2D CalVaL

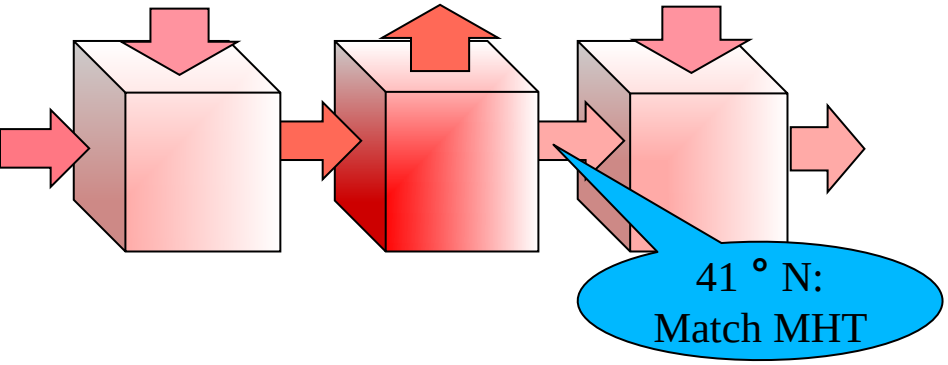
Science III: Large scale and global change ocean processes: the ocean's role in climate

Chairs : Dean Roemmich, Thierry Penduff

1 keynote — 6 talks — 20 posters

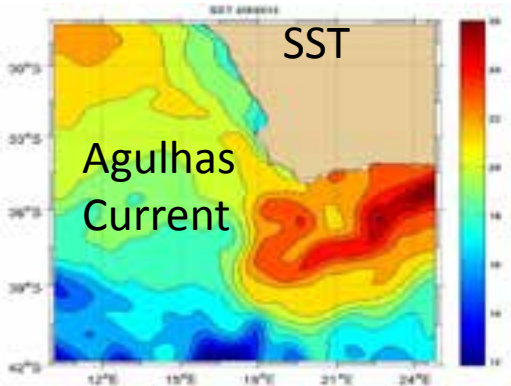
Heat and Freshwater Convergence Anomalies in the Atlantic Ocean Inferred from Observations

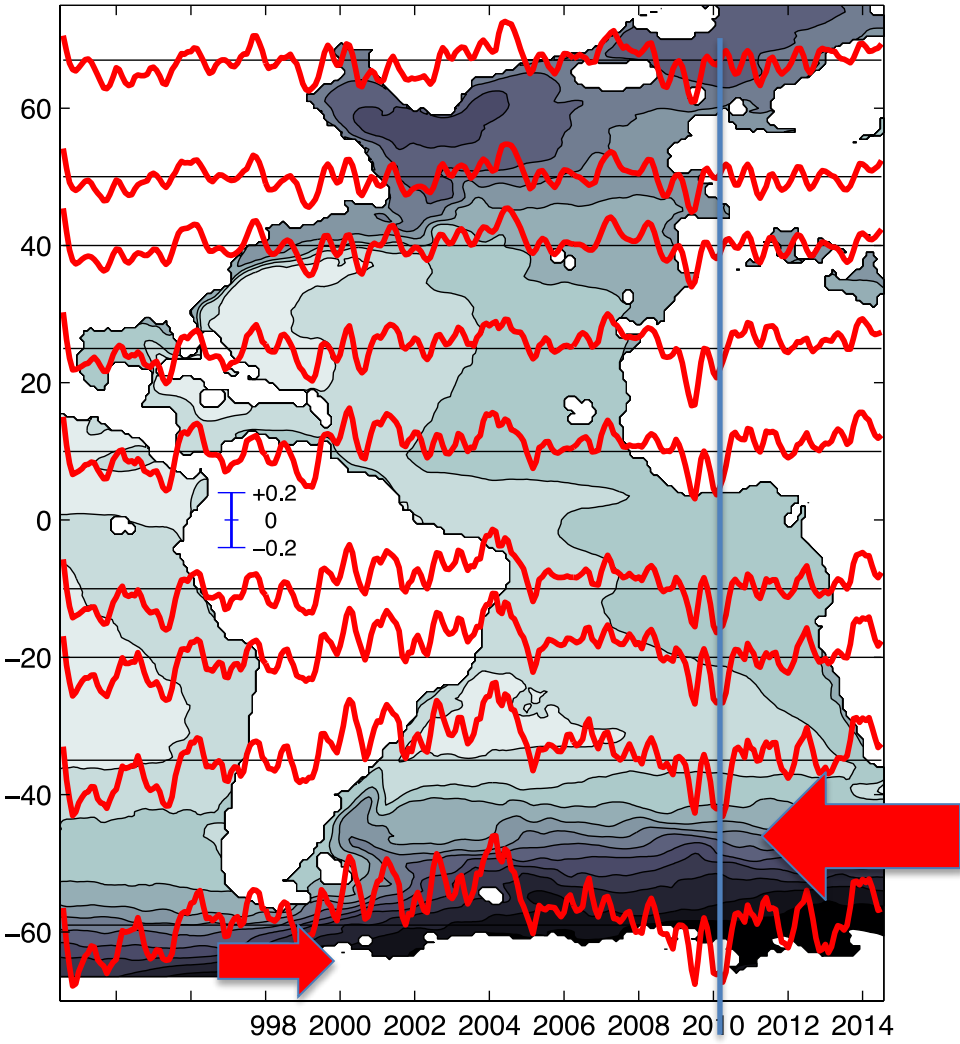
Kathryn Kelly
Kyla Drushka
LuAnne Thompson



MHT anomalies derived from Qnet & T.
Latitudinally-coherent signals.
Where do interannual MHT anomalies originate?

- no obvious propagation
- South Atlantic?

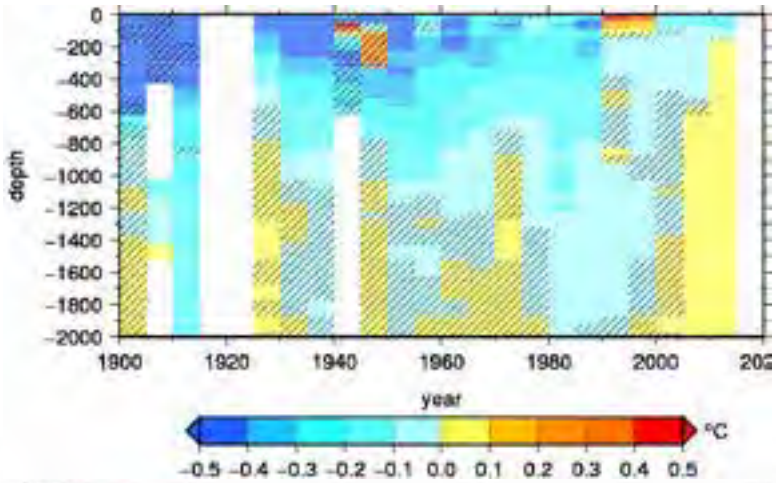


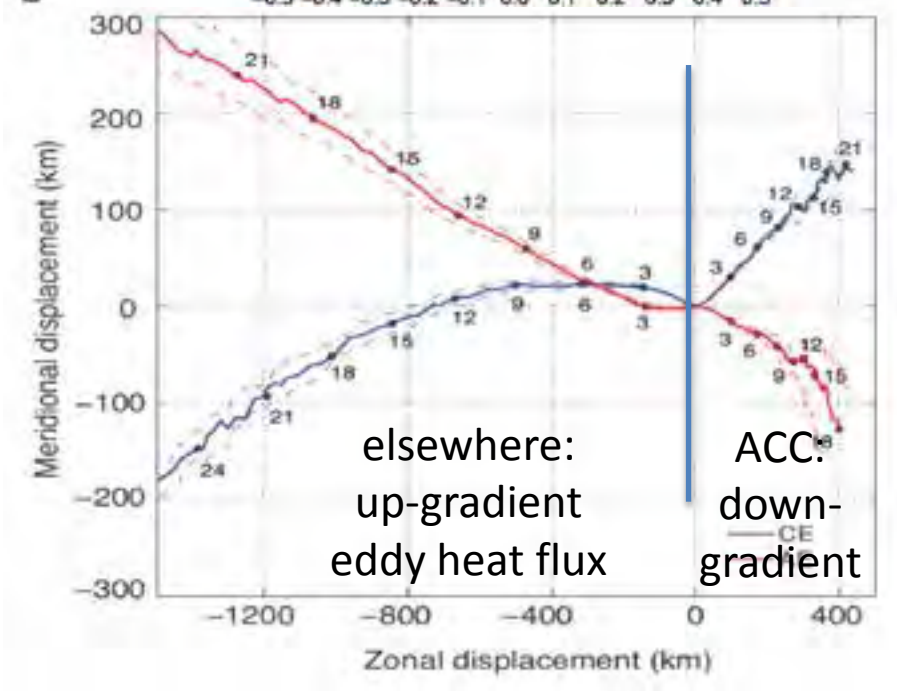


Mean structure, long-term change and eddy motions in the Southern Ocean: A perspective from altimetry, Argo and state estimation

Sarah Gille
Uriel Zajaczkovski
Matt Mazloff

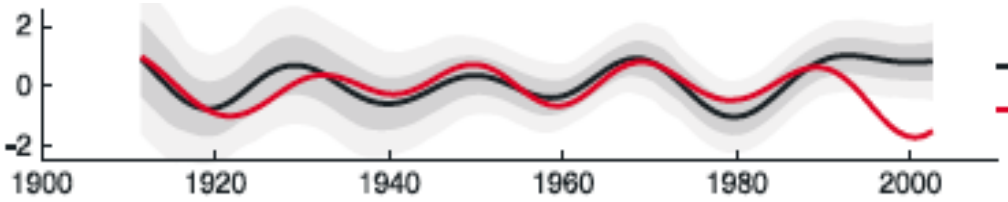
- SSH anomalies well correlated with sub-surface anomalies, in principle provide a means to refine reference mean field against which century-scale temperature changes are evaluated, albeit possibly introducing more noise than benefit....
- Southern Ocean warming persistent throughout 20th century.
- Eastward-moving Southern Ocean eddies result in poleward heat transport across the ACC—may help to explain mechanisms governing observed warming in Southern Ocean.

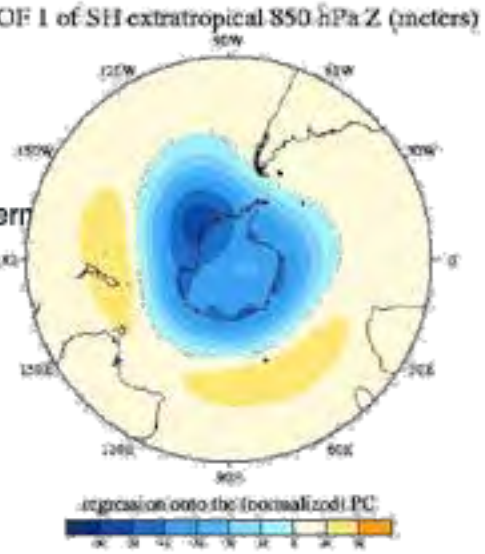


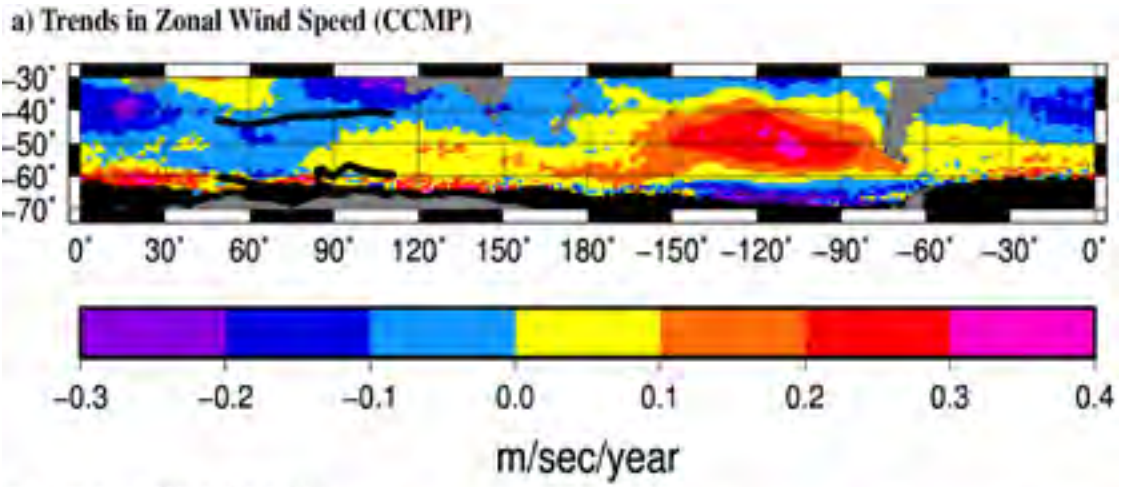


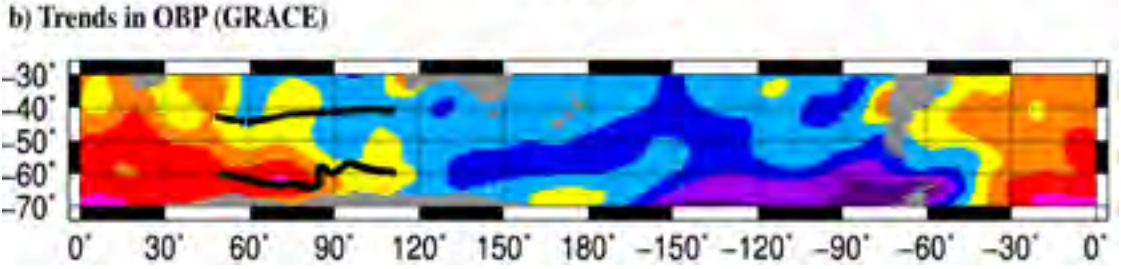
Low-Frequency Transport Variability in the Southern Ocean: The Importance of Regional Variations

Don Chambers,
Michael Kosempa
Jessica Makowski





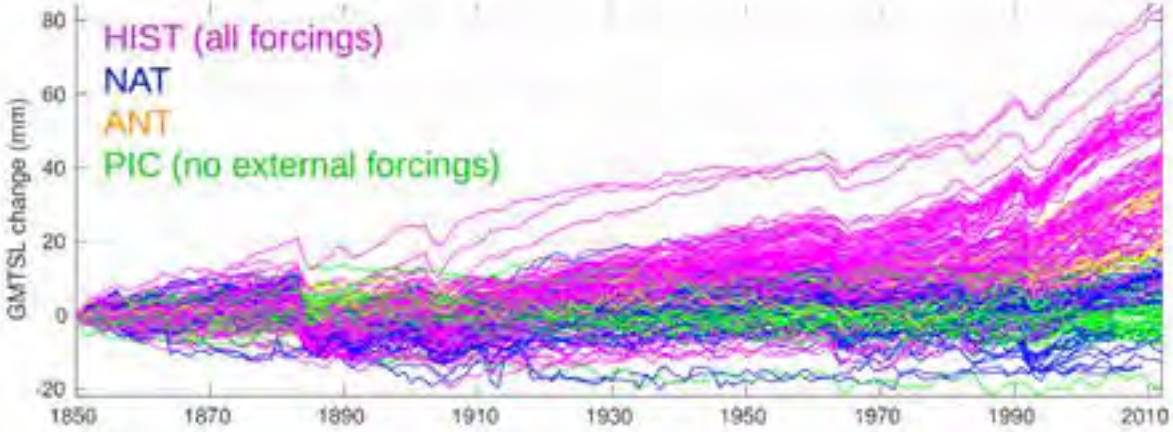


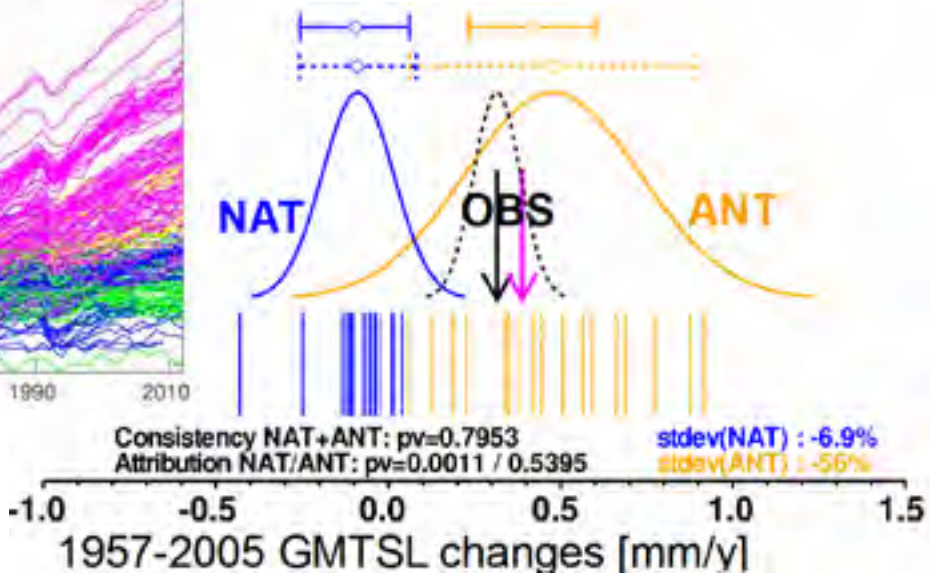


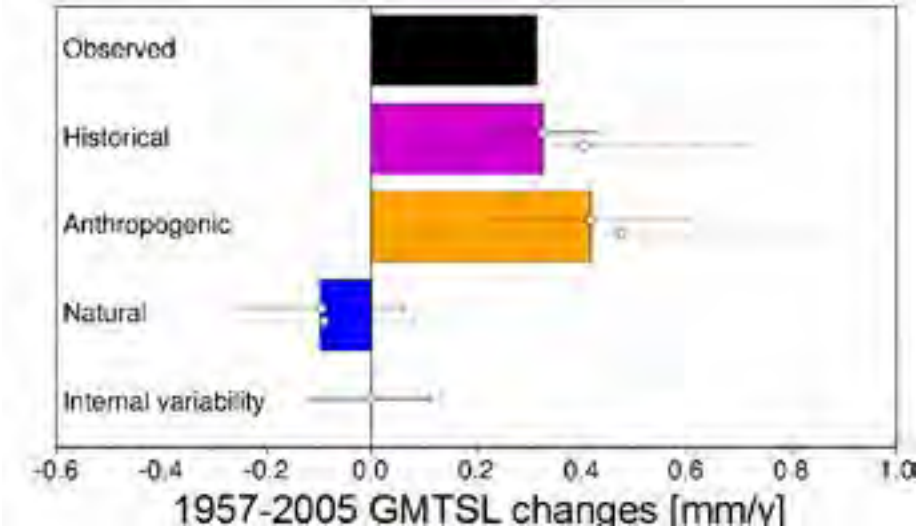
- Significant decadal-scale variability in Southern Ocean
- Different sign of trend in Indian Ocean, South Pacific
- Can we really measure climate-related transport change in the ACC using only repeat hydrogr. transects across Drake Passage?

A new approach to detection and attribution of ocean thermal expansion

E. Charles,
B. Meyssignac
A. Ribes







Contribution of each forcing and associated uncertainties issued from multi-model mean (dotted lines) and from D&A best estimators (continuous lines)

Is anthropogenic sea level fingerprint already detectable in the Pacific Ocean over the altimetry era?

H. PALANISAMY, B. MEYSSIGNAC, A. CAZENAVE
T. DELCROIX
LEGOS, Toulouse, France

The role of anthropogenic forcing??

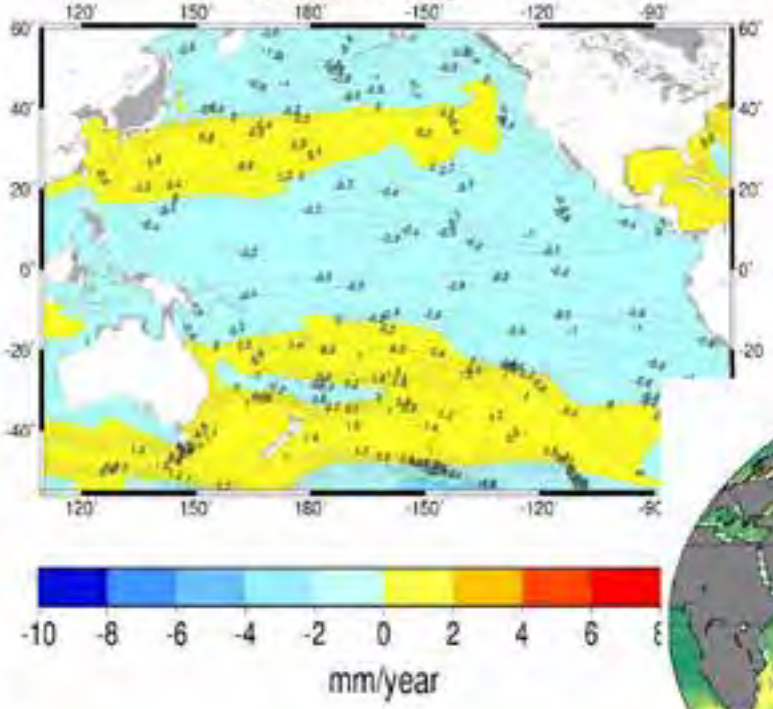
53 RCP8.5 coupled CMIP5 runs

21 models

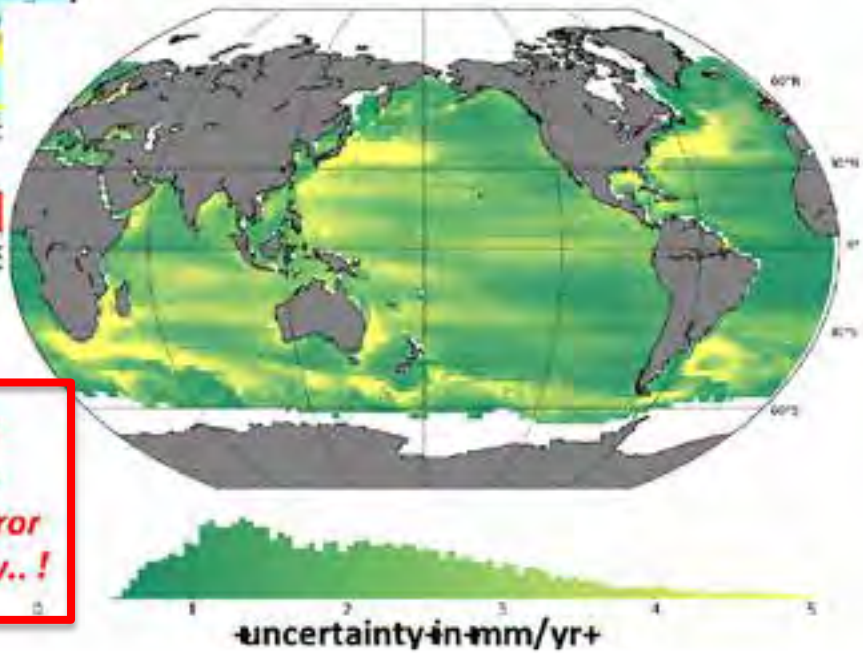
Remove PDO footprint

Remove Modoki El Niño

CMIP5 regressed ensemble



Expected uncertainty in altimetry trend
see talk of Prandi et al.



CMIP5 based externally forced sea level trend amplitude in the tropical Pacific is significantly lower than the expected error in trend patterns from satellite altimetry.. !

The impacts of ENSO/PDO on regional sea level change: After 20 years, are we finally seeing a change in the pattern of Pacific sea level change?

R. S. Nerem
B. Hamlington
Mark Merrifield
Phillip Thompson

- Tropical Pacific 1993-2013 sea level change pattern is changing.
- Ongoing ENSO or also a switch in PDO phase ? won't be known for a few years.
- If the latter, rates of sea level rise along the coast of California are expected to increase dramatically over the next decade as it recovers from an ~7 cm sea level deficit.
- If the PDO switches phase and we begin to average out decadal variability in Pacific sea level, there will likely be a residual pattern of sea level change due to climate change.