Report of the

Ocean Surface Topography Science Team Meeting

Steigenberger Inselhotel

Lake Constance, Germany

October 28-31, 2014

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and
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Organized by NASA, CNES, NOAA and EUMETSAT

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1 Executive Summary

The 2014 Ocean Surface Topography Science Team (OSTST) Meeting was held at Lake Constance, Germany, October 28-31. The meeting was held alongside the IDS and SARAL/AltiKa workshops, all three events being part of the "New Frontiers of Altimetry" congress. The 8th Coastal Altimetry Workshop (CAW) was held the week before (October 23-24) in the same location.

The primary objectives of the OSTST Meeting were to (1) provide updates on the status of OSTM/Jason-2 (hereafter, Jason-2), (2) conduct splinter meetings on the various corrections and altimetry data products, and (3) discuss the science requirements for future altimetry missions. The meeting lasted 3.5 days, to accommodate time for discussions during dedicated round tables for each splinter. This report, along with all of the presentations from the plenary, splinter and poster sessions are available on the AVISO website: http://www.aviso.altimetry.fr/en/user-corner/science-teams/ostst-swt-science-team/ostst-2014-lake-constance.html.

Jason-2 was launched in June 2008 on the former ground track of Jason-1 and TOPEX/Poseidon. All systems are in good condition and the satellite is operating nominally after 6 years in orbit. The mission has been approved to be extended up to 2017 on the CNES/EUMETSAT side and a similar approval is anticipated in 2015 on the NASA/NOAA side. No major events occurred this year on the platform side and the 2013 safe hold modes (SHMs) have been better understood and patches have been successfully developed and uploaded to avoid the same kind of situation. There was a major payload event this year with the GPSP-A, which required switching to GPSP-B on September 8, 2014. Some degradation of the GPS performance has been identified from the GPSP-B instrument, which is currently being investigated. However, from a global point of view, Jason-2 continues to collect data that meets all mission and level-1 science requirements. Although Jason-2 is performing well, the project requested consideration of an "Extension of Life" phase when the risk of losing control of the satellite becomes high. This was one of the main key points considered by splinters, who were each given the opportunity to express their scientific and/or operational needs. ***A Jason-2 EOL Working Group will be re-established to consider different options for science given operational limitations, which must be provided by the agencies.***

Jason-3 development is nominal at satellite, instruments and ground levels, and the integration is completed. Next steps are the Satellite Qualification Review in November and the "Satellite Final Preparation" before shipment to VAFB in Feb 2015. At the time of the meeting, the planned launch date remained set for March 31st, 2015. However, there were still uncertainties about the NOAA funding needed for the launch (2015 Continuing Resolution from Congress). As a consequence, the Ocean Surface Topography Science Team (OSTST) adopted the following recommendation regarding the scheduled launch: ***Continuity being of the utmost importance, the Ocean Surface Topography Science Team strongly recommends that space agencies strive to maintain the current launch date of Jason-3.*** After the OSTST meeting, NOAA announced that the March 31st launch date could not be met due to budget constraints as well as issues involving production and certification of the new SpaceX launch vehicle, and that the Jason-3 launch would slip into the summer of 2015. In December 2014, President Obama signed the FY15 omnibus appropriations bill into law, providing Jason-3 with the funding needed to launch in 2015. The project teams continue to work on the launcher issues, but it is a very positive development that the mission now has secure funding.

The transition from Jason-2 to Jason-3 was also discussed and the following recommendation has been raised: ***Move Jason-2 to the interleaved orbit with a 5-day delay (as for Jason-1) after 6 months of Formation Flight with Jason-3.***

The Jason-CS mission — now named Sentinel-6/Jason-CS following a request of the European Commission — will continue the Jason series of research and operational oceanography missions and will embark a Ku/C-band radar altimeter, a K/Ka band passive microwave radiometer, GNSS equipment and DORIS as part of its payload. Progress on planning and development of Jason-CS is ongoing. As recommended by the OSTST in previous meetings, an interleaved altimeter mode is now the baseline for the mission, which will simultaneously provide both low-resolution mode (LRM) and high-resolution synthetic aperture radar (SARM) mode data. In addition, implementation of a radiometer with long-term stability (likely to be maintained through the use of an on-board calibrator) is now also included in the baseline mission, as recommended by the OSTST. The OSTST expressed its appreciation for the responsiveness of the Jason-CS project in all of these instances (see section 7). However, securing funding for Jason-CS remains a significant hurdle and is now driving the schedule, with launch unlikely before 2020. As a consequence, ***the Ocean Surface Topography Science Team strongly recommends that space agencies strive to avoid further slippage of the Jason-CS launch date***

Five keynote talks were given during plenary sessions of the OSTST (see section 4).

Reprocessing of data from the TOPEX/Poseidon mission was discussed in the closing plenary session of the meeting. The current plan is to make a new Re-tracked GDR, consistent with GDR-C processing, which should become available in early 2015. While TOPEX reprocessing remains a top priority, plans to reprocess Jason-1 and Jason-2 data to a new GDR-E standard are underway and Jason-1 reprocessing will start early 2015. An upgrade of SARAL/AltiKa products is also foreseen in 2015.

Finally, it was noted during the closing plenary that the ongoing accuracy of globally averaged sea level as observed by the Jason series of altimeters is partly maintained and verified by the global tide gauge network. In light of this, the Cal/Val Splinter noted that cross-agency efforts are needed to maintain the global tide gauge network, and to co-locate GPS stations to detect ground motion at many key tide gauges.

2 Introduction

The 2014 Ocean Surface Topography Science Team (OSTST) Meeting was held at Lake Constance, Germany October 28-31. The meeting was held alongside the IDS and SARAL/AltiKa workshops, all three events being part of the “New Frontiers of Altimetry” congress. On Monday 27th Jean-Yves Le Gall (CNES president) made the introductory talk of the congress, followed by 2 welcome talks from Marc Cohen (Associate Director for LEO Programmes at EUMETSAT) and A. S. KIRAN KUMAR (Director of SAC/ISRO). The 8th Coastal Altimetry Workshop (CAW) was held the week before (October 23-24) in the same location.

On behalf of the Project Scientists (Lee-Lueng Fu and Josh Willis, NASA; Rosemary Morrow and Pascal Bonnefond, CNES; John Lillibridge, NOAA; Hans Bonekamp, EUMETSAT), the meeting was opened by Pascal Bonnefond who presented the agenda and discussed logistics.

3 Program and Mission Status

The program managers presented the status of altimetry and oceanographic programs at NASA (Eric Lindstrom), CNES (Juliette Lambin), EUMETSAT (François Parisot), NOAA (Laury Miller) and ESA (Jérôme Benveniste).

Juliette Lambin (CNES) first reported on the "CEOS Ocean Surface Topography Virtual Constellation" initiative and reiterated two of the requirements expressed in CEOS OST-VC Document "The Next 15 Years of Satellite Altimetry" (http://www.ceos.org/images/OST/SatelliteAltimetryReport_2009-10.pdf): (i) a constellation of at least 4 satellites with careful intercalibration and (ii) level 3-4 products transforming 4-satellite profiles into maps. As of today, 4 altimetry missions are operating (OSTM/Jason-2, Cryosat-2, HY-2A, SARAL/AltiKa) and in spite of heterogeneous programmatic set-up, multi-mission products are freely available in NRT through AVISO/DUACS. Juliette Lambin also reported on the CNES Ocean program status by illustrating the current and future constellation in which CNES is involved at various level of contributions (Figure 1). Thanks to cooperation with the China National Space Administration (CNSA) and to the CNES processing effort, HY-2A data has been integrated in DUACS system and is available in AVISO maps since May 2014. CFOSAT, which is dedicated to wind and waves measurement, is also a collaboration with China and is currently in phase C/D with a launch expected in 2018. Another fruitful collaboration with India (ISRO), is the SARAL/AltiKa mission, which meets and even exceeds the mission requirements. This has been highlighted during the SARAL/AltiKa workshop (Monday October 27th) and reported by Jacques Verron in its summary: "*The Ka-kid is acknowledged to be in the constellation of the big Ku-guys…*" In March 2014, CNES held a "science prospective seminar", to request recommendations for future missions from the scientific community. The first priority raised was OCAPI: ocean color from the geostationary orbit over Europe and Atlantic Ocean (with interest from land surfaces community). Other or longer term recommendations raised included: THIRSTY (High resolution surface temperature), AltiKa-2 (follow-on from the SARAL mission), SWORD (Radar mission dedicated to surface currents / wind / wave monitoring) and SMOS-Next (SMOS new generation, with much higher resolution). Implementation of those recommendations will depend on international cooperation opportunities.

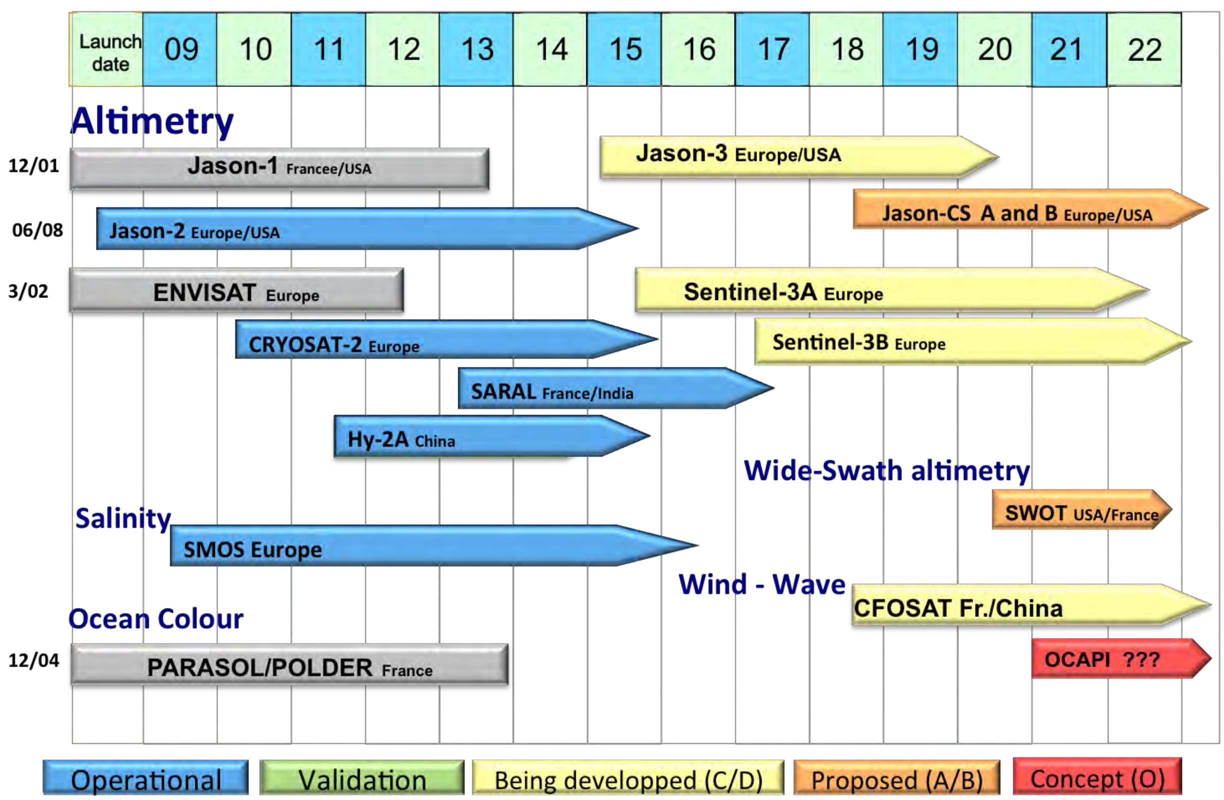

Figure 1. Ocean missions in which CNES is involved at various levels of contributions

François Parisot (EUMETSAT) reported on Jason-3 status for EUMETSAT. Progress of satellite and ground system preparation activities is nominal for the launch on March 31st, 2015. EUMETSAT will fund the launch campaign preparation and the launch campaign activities. All build up for operations and operations cost (European part) for the full lifetime of the mission will be funded by the European Commission. François Parisot noted that the decision to go ahead needed to be made soon and was conditional to: (i) In Europe, signature of the EUMETSAT-EU Delegation Agreement (document has been approved by EUMETSAT Council, waiting for EU approval), (ii) Confirmation by NOAA of March 31st launch date. Concerning Jason-CS (Continuity of Service for Topography, also named Sentinel-6 following a EC request)), François Parisot noted the prime mission objective: “Continue high-precision global sea level time series with an error on sea level trend < 1 mm/year”. This will provide an unprecedented 40 year systematic measurement and will be a great boon for climate and sea level rise monitoring. The partnership involves: EUMETSAT, ESA, NOAA, European Community, CNES and NASA. EUMETSAT hopes to open the program for subscription at end of November and begin the program in mid-2015. After briefly describing the Sentinel-6 System Elements, François Parisot reported on technical aspects. From a scientific point of view, Jason-CS altimeter “Interleaved” mode is expected to be a breakthrough to access to sub-mesoscale variability of currents. Moreover, Jason (as a reference) and Sentinel-3 orbits complement each other for optimum sampling of variability of ocean circulation. François Parisot also provide a brief status of Sentinel-3 and the EUMETSAT implication, notably the Marine Centre in EUMETSAT.

Laury Miller (NOAA) reported on NOAA Jason-3 Program Status. The NOAA internal ground segment testing is completed and the 4-Partner ground segment testing is progressing well. Space-X Falcon 9 v1.1 has now completed 8 successful launches and NASA certification is ongoing. NOAA will control and down-link telemetry for both Jason-2/OSTM and Jason-3 at Fairbanks, Barrow, Wallops, Usingen-1 & Usingen-2 ground stations. At the time of the meeting, Laury Miller noted that the scheduled March 31st launch was unchanged. Concerning NOAA Jason-CS Program Status, a 5-partner ground operations planning meeting was hosted at NOAA/NSOF, July 2014. A follow-on is planned for January 2015. Level 1 requirements document is in final stages of review and NOAA is participating in Phase B and System Requirement Reviews. JPL, on behalf on NOAA, is continuing the development of AMR-C radiometer, including external calibrator. Advanced planning for GPS Radio Occultation (RO) secondary mission is underway: Radio Occultation will provide ~1000 vertical atmospheric profiles of temperature & humidity per day for use in operational numerical weather prediction models. Finally Laury Miller reported that the NOAA FY16 Jason-CS budget initiative is in preparation.

Eric Lindstrom (NASA HQ) gave a summary of NASA Ocean Program. On Oct 14-16, 2014, the Scripps Institution of Oceanography hosted the NASA Sea Level Change Team (N-SLCT) PI Meeting. The aim of this team is: (i) Tackle major problems and scientific questions limiting the accurate projection of future regional sea level change, (ii) Address the interdisciplinary nature of these problems (e.g. ocean-ice sheet interaction, interannual land hydrology-sea level fluctuations) and (iii) Use a web portal to enable communication and research activity across the team. A NASA Sea Level “Road Map” has been defined. Eric Lindstrom then reported on SWOT Mission Overview and status. The “Implementing Arrangement” was signed by CNES and NASA on May 2nd 2014. CSA and UKSA are also now in partnership with NASA and CNES. The Target Launch Readiness is Oct 2020. Concerning the SWOT Science Team, the present team finishes end of 2015, so NASA ROSES and CNES TOSCA in 2015 will invite proposals for a SWOT Science Team: it is likely that proposals will be due in late spring 2015 and selected projects will start on 1/1/16 with a four year duration. AirSWOT continues instrument check-out flights in 2014 and plans validation in both ocean and hydrological experiments in 2015. Next SWOT SDT Meeting in San Diego (13-15 January 2015). Finally Eric Lindstrom reported on Jason-2/3 & Jason-CS/Sentinel-6 missions.

NASA continues its support of OSTM/Jason-2 operations and building of Jason-3, and its support of OSTST (next call for proposals in ROSES 2016). This will be balanced, however, against growing support for SWOT. NASA will continue scientific and technical support of the Jason series.

Jérôme Benveniste (ESA) presented the ESA Programmes by first recalling the status of the ERS-1&2 and Envisat reprocessing. REAPER reprocessed data represents 17 years in total for ERS-1&2, for both altimeter and microwave radiometer, and is now freely available through a fast registration (eohelp@esa.int). For Envisat, the next reprocessing is getting prepared with tens of algorithm improvements planned for the future products. However, a current homogeneous dataset is available on: ftp://diss-nas fp.eo.esa.int. Moreover, Envisat corrected SSH products are also now available on ODES portal: http://odes.altimetry.cnes.fr. Concerning CryoSat, the mission is extended until February 2017 but, thanks to the excellent status of platform and payload after four years, operations can continue until 2020 without major impact on mission performance. The ground segment is continuously evolving to accommodate new products and demand from worldwide community. The ocean chain (IOP, GOP) was released in 2014 with more than 15% of open sea covered in SAR. CryoSat is seen as the precursor mission of Sentinel-3 and Sentinel-6 and fundamental for their development and for user ramp-up to SAR. Release of Baseline C (which will include improved over-ocean products) is foreseen by January 2015, followed by reprocessing campaign. Jérôme Benveniste then reported on Sentinel-3 status. The readiness of the Sentinel-3A platform and the instruments integration and testing are on track with some technical issues to solve. The launch window is foreseen for June to September 2015. All ground segment facilities supporting the S-3 operations are in place and the Mission Performance Centre for Sentinel-3 has been kicked-off in mid-October. Data access will follow same route as for Sentinel-1. A 2nd Sentinel-3 validation workshop will hold on 3-4 December at EUMETSAT. Sentinel-3B will be placed in the same orbit with an offset of 180°, with ground track in the middle of the tracks of the first satellite (inter-track separation of 52 km at the equator), thus optimizing payload coverage while maintaining a balance between topography and optical mission coverage. The launch of Sentinel-3B is foreseen some 12–18 months after Sentinel-3A. About GOCE, the mission is accomplished but the exploitation continues. Release 5 gravity field products (models and grids) are available, with full error information (complete error covariance matrix available. Extremely low orbit operations proved to be extremely successful, approximately doubling the information content and quality of the GOCE products. The 5th INTERNATIONAL GOCE USER WORKSHOP will be held on 25-28 November 2014 at UNESCO (Paris, France).

The Project Managers reviewed the status of the Jason missions. Jason-2 Project status was given by Thierry Guinle. All systems are in good condition and the satellite is operating nominally after 6 years in orbit, and the passengers perform satisfactorily. The mission has been approved to be extended up to 2017 on the CNES/EUMETSAT side and a similar approval is anticipated in 2015 on the NASA/NOAA side. No major event occurred this year on the platform side and the 2013 safe hold modes (SHMs) have been better understood and patches have been successfully developed and uploaded to avoid recurrence. A major payload event was caused by an issue on GPSP-A, which was switched to GPSP-B on September 8, 2014. Some degradation of the GPS performance has been identified from GPSP-B instrument and is currently being investigated. However, overall Jason-2 continues to collect data that meets all mission and level-1 science requirements: the global Jason-2 system availability is 99.9 %, exceeding the 95 % requirement. Moreover, the near real-time product (OGDR) latencies also largely exceed the requirements (75 % within 3 hours and 95 % within 5 hours) as measured by EUMETCast (90% and 97% respectively) and NOAA ESPC (96% and 99% respectively). The accuracy for real-time orbit from DIODE (DORIS) over the period is ~2.8 cm (radial rms). Concerning the AMR, with ARCS processing, the residual drift of GDR-D wet path delay (PD) is estimated to be < 1mm/year over mission life. Although Jason-2 is performing well the project requested the OSTST to consider an “Extension of Life” phase when the risk of losing control of the satellite becomes high.

Status of the Jason-3 Project was discussed by Gerard Zaouche. The development of Jason-3 is nominal at satellite, instruments and ground levels, and the integration is completed. The next steps are the Satellite Qualification Review in November and the “Satellite Final Preparation” before shipment to VAFB in Feb 2015. Following the 2010 (Lisbon) OSTST recommendation and 2011 (San Diego) OSTST decision, planning for the AMR in-flight cold-space calibration using satellite pitch maneuvers (80° off nadir) has been completed and tested in 2014. Concerning Poseidon-3B altimeter, a single mode with on-board automatic transitions between DIODE/DEM tracking and autonomous tracking, with respect to the satellite position, has been implemented; Moreover, Poseidon-3B DEM upload is now possible without mission interruption. Although GPSP is not mission critical, further updates for radiation hardened parts and shielding has been applied. The new generation DORIS DGXX-S takes into account lessons learned from Jason-2 and new data in Telemetry allows “pole product” generation. For the ground System, Barrow (NOAA) and Usingen2 (EUM) stations have been added to operate simultaneously Jason-2 and Jason-3 and operations will be merged after the launch. Formation flight with Jason-2 is planned for both altimeters cross-calibration purposes (between 1-10 minutes ahead/behind Jason-2). The injection orbit will be 25 km below the nominal Jason-3 orbit to avoid polluting the operational orbit and to avoid crossing the Jason-2 orbit (and Jason-1). The duration for station acquisition and number of maneuvers depends on the launch date (day number in the Jason cycle) and on the launcher dispersion: max 1 month but evaluation is in progress. At the time of the meeting, the planned launch date remained set for March 31st, 2015. However, since that time NOAA announced that although adequate funding was available, launch would likely be delayed due to NASA qualification and production of the SpaceX launch vehicle.

Richard Francis (ESA) also gave a brief update on the status of the upcoming Jason-CS mission. Jason-CS will continue the Jason series of research and operational oceanography missions and will embark a Ku/C-band radar altimeter, a K/Ka band passive microwave radiometer and GNSS equipment (compatible with Galileo constellation) including DORIS as part of its payload. Progress on planning and development of Jason-CS is ongoing. As recommended by the OSTST in previous meetings, an interleaved altimeter mode is now the baseline for the mission, which will simultaneously provide both low-resolution mode (LRM) and high-resolution synthetic aperture radar (SARM) mode data. In addition, implementation of a radiometer with long-term stability (likely to be maintained through the use of an on-board calibrator) is now also included in the baseline mission, as recommended by the OSTST. System Phase B activities are ongoing, the System Requirement Review (SRR) Part 1 took place in February 2014, SRR Part 2 is planned for Q1 2015. The ESA PDR (Preliminary Design Review) is planned for December 2014 and the System Preliminary Design Review is planned in Q3 2016. The EUM Initial Ground Segment development team is in place. The partnership and responsibility sharing involves: EUMETSAT, ESA, NOAA, European Community, CNES and NASA. Securing funding for Jason-CS remains a significant hurdle and is now driving the schedule, with launch unlikely before 2020.

4 Keynote Talks

Before the Keynotes, Lofti Aouf (Meteo-France) made a dedication to Jean-Michel Lefevre (Meteo-France) who passed away on April 5th 2014. Jean-Michel was a great scientist with exceptional communicative good humor. He was among the first in the adventure of altimetry and its application on the waves. This is a great loss to the oceanographic community and in particular for the waves community.

Five keynote talks were given during the opening plenary session of the OSTST on Tuesday 28th morning. The first one concerned the sea level initiatives for both NASA and ESA sides and was split into two parts: First Steve Nerem gave an overview of the activities of the NASA Sea Level Change Team (N-SLCT) and then Benoit Meyssignac (on behalf of Gilles Larnicol) reported on two decades of global and regional sea level observations from the ESA Climate Change Initiative Sea Level Project. The three other keynotes serve as introduction for the three "Science Results from Satellite Altimetry" splinters: Dean Roemmich reported on the development of the Deep Argo Program, Ruoying He on the impact of mesoscale eddies on the Gulf Stream and shelf ecosystem in the southeastern United States and Stephane Calmant on satellite altimetry over rivers (from the data processing to thematic applications, with focus on the Amazon basin). Finally, Lee-Lueng Fu presented SWOT Status and Challenges.

Two other keynotes were given in the closing session on Friday 31st by our emerging new scientists. In the framework of the CNES Argonautica project (http://www.cnes.fr/web/CNES-fr/7161-argonautica.php) two groups of students were selected to present their results. The first one was on "the plastic islands in the Atlantic ocean" by "Collége Esquinance (la Réole, France)" in which they analyze of buoys trajectories to help to find the main sites of aggregation of marine debris. The second one was on "Théthys investigation in the Mediterranean sea" by "Lycée Monteil (Rodez, France)" where they presented a driven buoy built by the students in order to study the Ligure current.

5 Poster Sessions

A poster session was conducted on Thursday and the posters were on view during the coffee breaks throughout the entire meeting. Links to the posters are available on the meeting website: http://www.aviso.altimetry.fr/en/user-corner/science-teams/ostst-swt-science-team/ostst-2014-lake-constance.html.

The posters were grouped into the following categories:

- Precise Orbit Determination
- Near Real Time Products & Applications and Multi-Mission, Multi-sensor Observations
- Tides, internal tides and high-frequency processes
- Regional and Global CAL/VAL for Assembling a Climate Data Record
- Science Results from Satellite Altimetry: Finer scale ocean processes (mesoscale and coastal)
- Science Results from Satellite Altimetry: Regional and basin-scale processes and sea level rise
- Instrument Processing: Corrections
- Instrument Processing: Measurement and retracking (SAR and LRM)
- Science Results from Satellite Altimetry: Inland waters (multi-mission and long-term monitoring)
- Outreach, Education & Altimetric Data Services
- The Geoid, Mean Sea Surfaces and Mean Dynamic topography
- Quantifying Errors and Uncertainties in Altimetry Data
- Others

6 Splinter Sessions

The splinter sessions were organized as follows:

Tuesday, October 28:

- Instrument Processing (Part I): Corrections
- Instrument Processing (Part II): Measurement and retracking (SAR and LRM)
- Outreach, Education and Data Services
- Science (Part I): Inland waters (multi-mission and long-term monitoring)

Wednesday, October 29:

- Precision Orbit Determination
- Near Real Time Products and Applications and Multi-Mission, Multi-Sensor Observations
- Tides, internal tides and high-frequency processes
- Regional and Global CAL/VAL for Assembling a Climate Data Record
- Science (Part II): Finer scale ocean processes (mesoscale and coastal)
- Science (Part III): Regional and basin-scale processes and sea level rise

Thursday, October 30:

- Geoid, Mean Sea Surface
- Quantifying Errors and Uncertainties in Altimetry Data
- Round tables for each splinter

Links to the presentations are available on the meeting website: http://www.aviso.altimetry.fr/en/user-corner/science-teams/ostst-swt-science-team/ostst-2014-lake-constance.html.

6.1 Instrument Processing

6.1.1 Measurement and retracking (SAR and LRM)

Chairs: François Boy, Phil Callahan, Robert Cullen (Marco Fornari) and Walter Smith

The Instrument Processing splinter included 9 presentations.

6.1.1.1 Low Resolution Mode Missions

P. Callahan (JPL) presented the status of TOPEX retracking, mainly to correct Alt-A point target response (PTR) changes. Work has focused on correcting the systematic defects of the 2009 version of the retracked data. It has been determined that less of the TOPEX calibration data than previously thought is usable for determining PTR changes. The retracking code has been upgraded to allow the use of a fixed skewness. Results suggest that retracking with the original waveform weights, a revised PTR fitting procedure, and a fixed skewness of 0.1 (Figure 2, green curve) give the most consistent results. Several new retracked data sets with various approaches will be provided for evaluation soon.

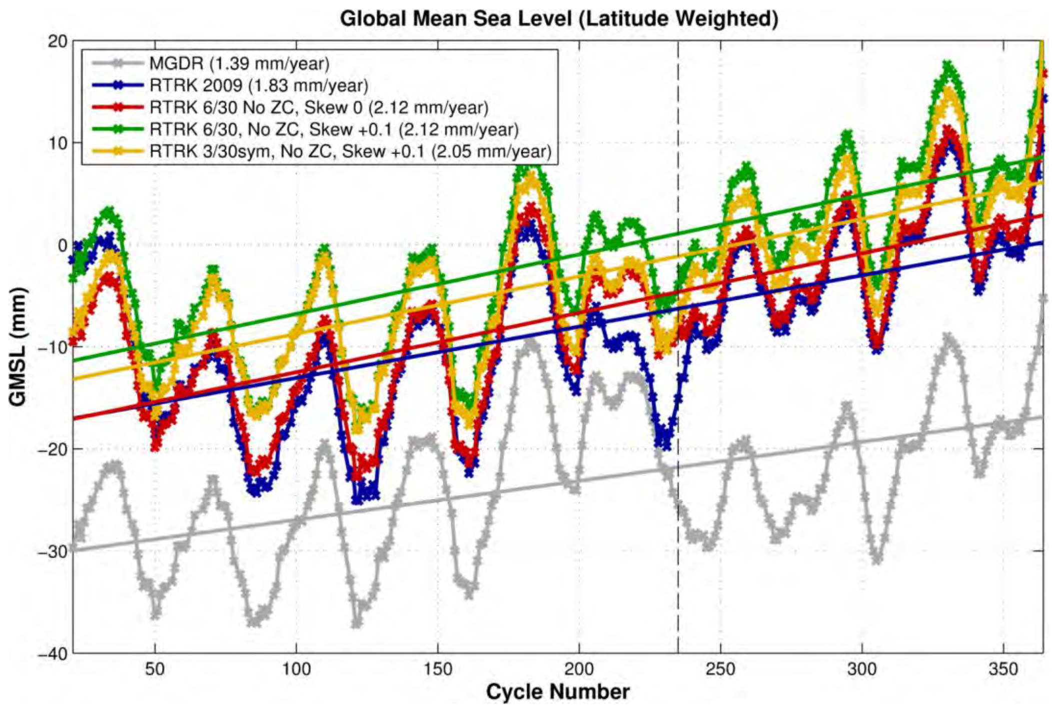

Figure 2. Different versions of TOPEX retracking compared to original MGDR.

CNES (F. Boy et al.) presented a numerical retracking technique for a Low Resolution Mission like Jason-3. The method takes into account the instrument impulse response directly in the echo model whereas current retracking estimates must be corrected using a look up table. This method is also very robust to any instrument degradation because it accounts for all instrument features, in real time, during the retracking. Applied on Poseidon-3 waveforms (very stable instrument), the numerical retracking provides very similar results compared to operational MLE4 outputs, which indicate its capability to ensure data quality continuity with past missions. This new retracking will be applied to Jason-3 data through a processing prototype developed by CNES. A delta product, provided separately from the operational products, will be delivered to experts for assessment.

L. Amarouche (CLS) presented DCORE Retracking, a new algorithm for processing LRM waveforms. This approach is based on a new model which provides a less correlated relationship between parameters which are assumed to be responsible for the spectral hump in SLA when using a Brown model to retrack the data). This new model is used through a weighted MLE retracking and is combined with a 2 pass retracking technique (Sandwell and Smith 2005 in Geophys J. Int'l., http://gji.oxfordjournals.org/content/163/1/79.full). Applied on Jason-2 waveforms, L. Amourache demonstrated the DCORE retracking removes the spectral hump and reduces the level of noise (see Figure 3). The OSTST community asked that DCORE retracking be included in the J3 processing prototype for assessment. CNES took the action to analyze its feasibility in coordination with CLS.

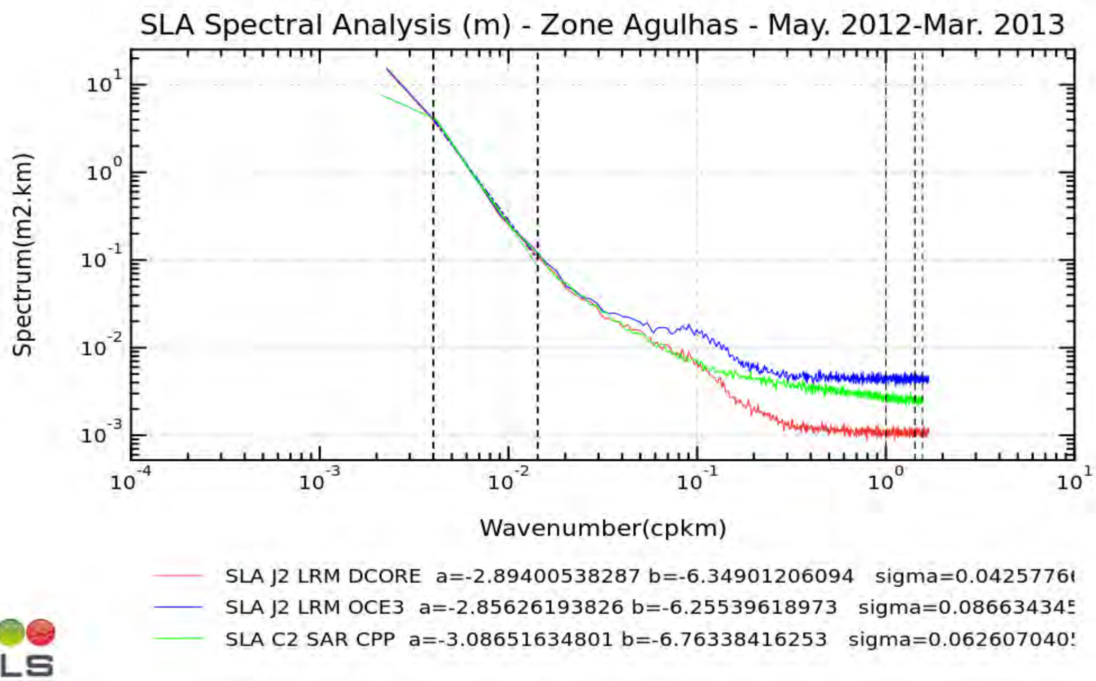

Figure 3. Spectral Analysis over Agulhas region with different retrackers

6.1.1.2 SAR Mode missions:

D. Cotton presented the latest results of the CryoSat Plus For Ocean: an ESA project for Cryosat-2 Data exploitation over ocean. The project covers different themes such as Open, Coastal and Polar Ocean, Sea Floor Topography and Geophysical Corrections. The main conclusions were:

- CryoSat is working well and providing improved precision and along track resolution in SAR mode.

- CP40 provided significant improvements over the first SAMOSA model. Moreover, the comparison between analytical (SAMOSA) and numerical (CPP) SAR processing shows very good agreement and demonstrates that the relationship between the 2 methods is now understood (see Figure 4).

- Several presentations and posters were given concerning all CP40 topics.

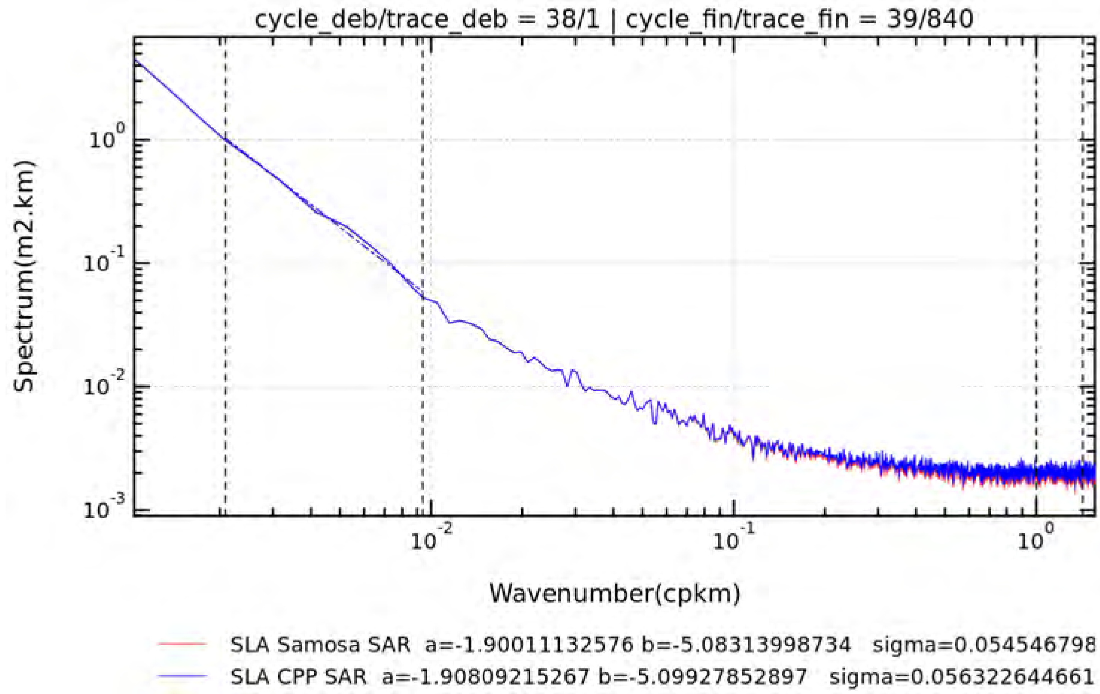

Figure 4. Comparison between analytical (SAMOSA) and numerical (CPP) SAR ocean retracker.

IsardSAT presented the Jason-CS Altimeter Ground Prototype Processor (JCS GPP), which is now ready in its first version. The JCS GPP accounts for the innovative features of the Jason-CS altimeter and is capable of processing the instrument source packets in the 3 baseline modes (LRM, SAR, RMC).

A first Test Data Set has been released for the user community in October 2014. The TDS includes 4 different products in netCDF format (see example in Figure 5): L1A, L1B-S, L1B LR and HR (SAR), which can be retrieved at the following ESA ftp:

FTP server:	ftp.eopp.esa.int
Login:	sentinel6-science
Password:	yot7+scart

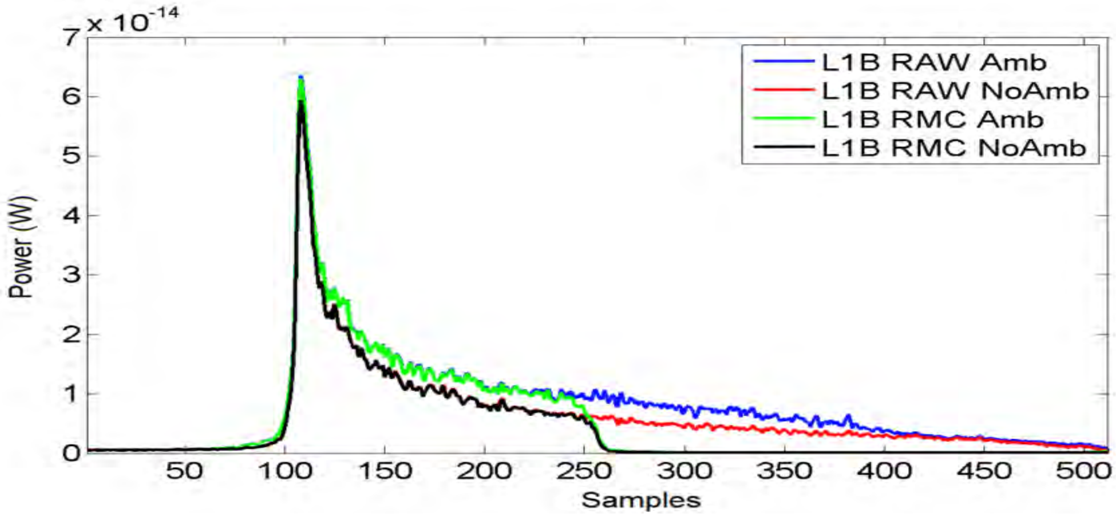

Figure 5. Examples of Jason-CS GPP L1B SAR waveforms in different configurations

In the framework of the JCS GPP, C. Martin-Puig presented a new SAR retracker, developed in order to validate the JCS GPP output (L1B HR). The retracker is a revision of the SAMOSA retracker, including several improvements, which ensure compatibility with current and forthcoming SAR missions. The importance of adapting the SAR re-tracker (and *any* SAR re-tracker) to the L1b processor in order to achieve optimum performance was stressed. The new re-tracker has been validated using CryoSat2 data against CNESS GPP and results on JCS GPP simulations are provided in the above ftp as separate netCDF products.

Different solutions for SAR stack exploitation and improvement were presented:

- M. Scagliola showed the improvement of compensating the stack with antenna pattern in terms of speckle reduction in the SAR L1B waveform. Results were presented in terms of ENL: the Effective Number of statistically independent Looks. The method proposed by M. Scagliola requires pitch estimation from the stack (as already published in literature) and shows an improvement of ENL up to 30% for Cryosat2 data. This promising method requires validation at level 2 to assess the SLA variance reduction.

- Chris Ray presented a further step to SAR stacking, involving the reshaping of each look in the stack: the ACross-track Dilation Compensation. The ACDC technique reshapes all the looks in the stack into a power waveform that is identical for all Dopplers (see Figure 6). The result of this new technique is a multi-looked waveform, represented by an extremely simple equation, which simplifies re-tracking. Moreover the noise level is reduced by up to a factor of 5, leading to higher precision measurements.

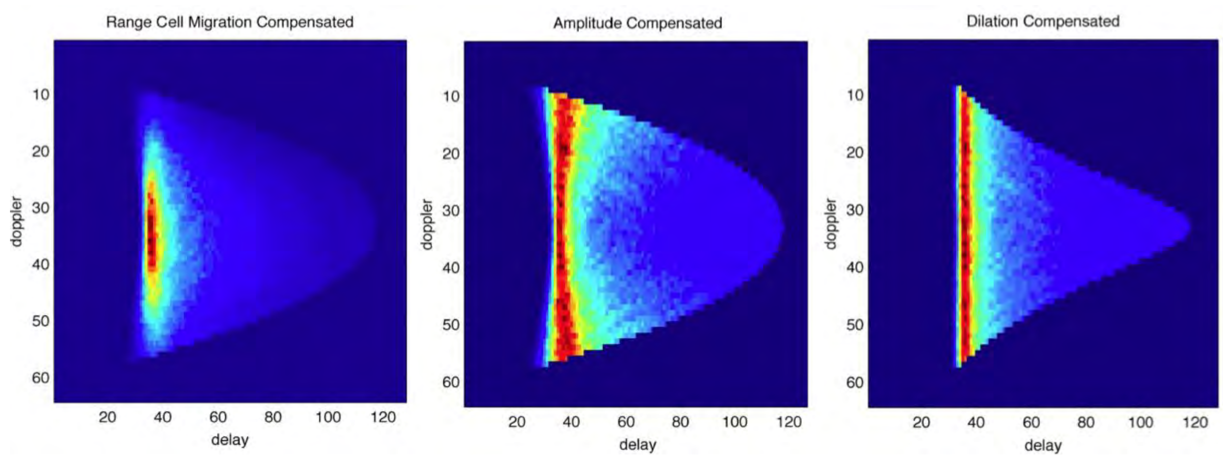

Figure 6. Steps of ACDC techniques. Right figure: stack with only range cell migration applied. Center figure: stack with amplitude compensated with antenna pattern. Left figure: stack reshaped with ACDC algorithm.

T. Moreau from CLS analyzed the Power Distribution in the Stack (PDS) over ocean and other surfaces. The PDS is the mean power observed in each Doppler look (before performing the multi-look process). T. Moreau showed that the PDS characteristics vary depending on the surface type and roughness (standard deviation and skewness of the PDS) and also depending on the mispointing angle (position of the PDS maximum). Using a Gram-Charlier series (distorted Gaussian-shape model), T. Moreau retracked several months of Cryosat-2 PDS and estimated the PDS standard deviation, skewness, kurtosis, and the position of the maximum that directly gives the altimeter pitch angle. He demonstrated that using this method, the estimation of pitch angle is in a very good agreement with the mispointing information coming from StarTrackers.

6.1.1.3 Round Table and Recommendations

Jason-2/Jason-3 tandem phase:

- Recommendation to not shorten the tandem phase from initial plan (6 months).

Numerical Retracker for Jason-3:

- Available later as a "delta product" for experts on demand
- Will be delivered separately from operational products
- Objectives:
  - Assess the numerical retracker performances
  - Decide by the end of assessment period which one to use for operational products
    - Several iterations may be needed
    - Input/validation from OSTST members welcome (notably from Instrument Processing splinter)

TOPEX Processing:

- Recommendation to deliver the TOPEX waveforms (SDRs, PTRs, weights) to the users

SAR-LRM continuity:

- Current status: SAR and LRM continuity has been assessed on CryoSat2 data:

    - PLRM-LRM within 1 cm
    - SAR-PLRM differences about 0,5%SWH
- DECORE Retracking could be used on PLRM waveforms to reduce the noise level and make easier SAR-LRM-PLRM comparison
- For Sentinel-3, SAR-LRM continuity will be assessed during commissioning phase by switching modes over oceans
- Sea State Bias for Doppler Altimetry: Need to be addressed
    - ITT from EUMETSAT
    - Current studies from ESA and CNES

6.1.2 Corrections

Chairs: Shannon Brown and Estelle Obligis

The instrument processing splinter for corrections featured four presentations focusing on wet tropospheric correction and rain rate products and one on sea state bias.

SARAL radiometer processing and validation (Frery et al.)

This presentation focused on the performance of the SARAL/AltiKa radiometer. The data presented showed excellent performance of the instrument. A comparison was done between AltiKa and other instrument over the Amazon rainforest, over cold ocean scenes (vicarious cold reference) and at cross-over points between instruments with common channels. The comparison shows a low bias, less than 1K. But an interesting observation is found, that the brightness temperature difference between Jason-2 and AltiKa/AMSU has a scale dependent bias.

Larger residual errors were initially observed with the AltiKa wet path delay retrieval algorithm. This was due in part to uncertainty in the Ka-band backscatter model function. To improve the retrievals, an empirical algorithm has been developed and the expected performances of the geophysical products should be even better (Figure 7). These products will be made available in the Peachi dataset through the ODES portal http://odes.altimetry.cnes.fr. The same approach is planned for the atmospheric attenuation correction algorithm as well. It is suggested that more work be invested in the modeling of the backing scattering coefficient at Ka band to improve knowledge on atmospheric and surface interaction at this frequency and to continue to improve understanding of the statistics of the sigma0 for upcoming Ka-band missions, including SWOT.

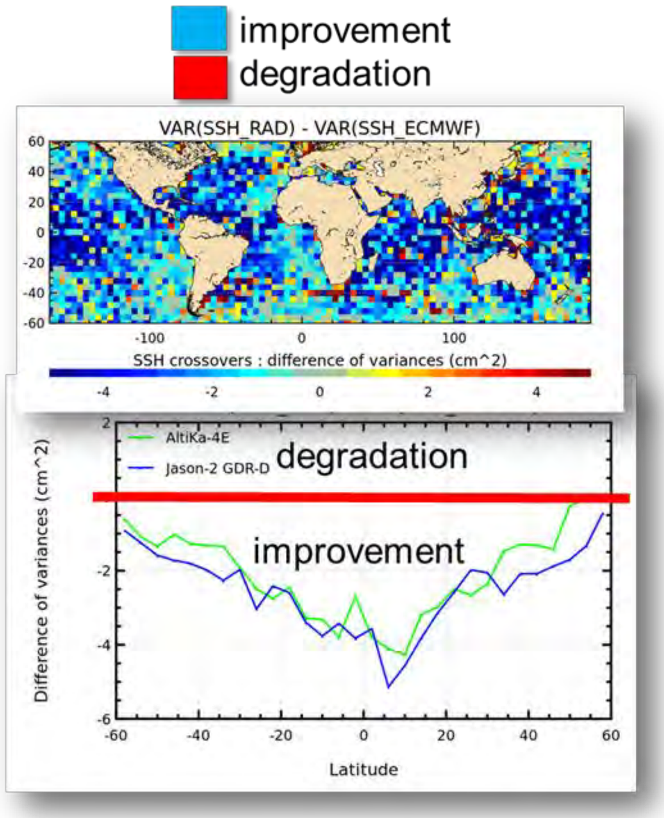

Figure 7. SSH cross-over variance improvement using the new empirical retrieval algorithm for AltiKa.

Development of a combined wet tropospheric correction product (Fernandes et al)
The data combination (Dcomb) algorithm is developed to provide accurate wet path delay estimates for missions that do not include an on-board radiometer, such as Cryostat. The Dcomb product optimally combines all sources of wet path delay information using objective analysis of three path delay sources; imaging satellite microwave radiometers, coastal GNSS measurements and ECMWF model path delays. The Dcomb product was computed for Jason-2 and compared to the actual AMR measurements. The Dcomb product is shown to be an improvement over using the model alone, but not a replacement for a dedicated radiometer on-board the satellite.

JMR end-of-mission climate record (Brown et al)
An end-of-mission calibration was performance for the Jason-1 Microwave Radiometer and a new product developed. The long term calibration was constrained by using inter-sensor TB matchups to the SSM/I Fundamental Climate Data Record. A similar technique was previously used for AMR on Jason-2. In addition to the long term calibration, residual yaw-dependent (~60-day) biases were observed in the geophysical retrieval comparisons (e.g. path delay and wind speed). Comparisons of the path delay to the model and wind speed to the altimeter were used to back out the residual temperature dependence to remove these yaw-dependent (hence temperature dependent) signals. The recalibrated dataset is characterized by an uncertainty better than 2 mm/yr for any year of the mission and much better than 1mm/yr for the mission lifetime (Figure 8). In addition to the calibration, the processing algorithms are updated to Jason-2 GDR-D standard. This includes the coastal algorithm for path delay, the radiometer sea ice and rain flags and the all-weather attenuation correction algorithm.

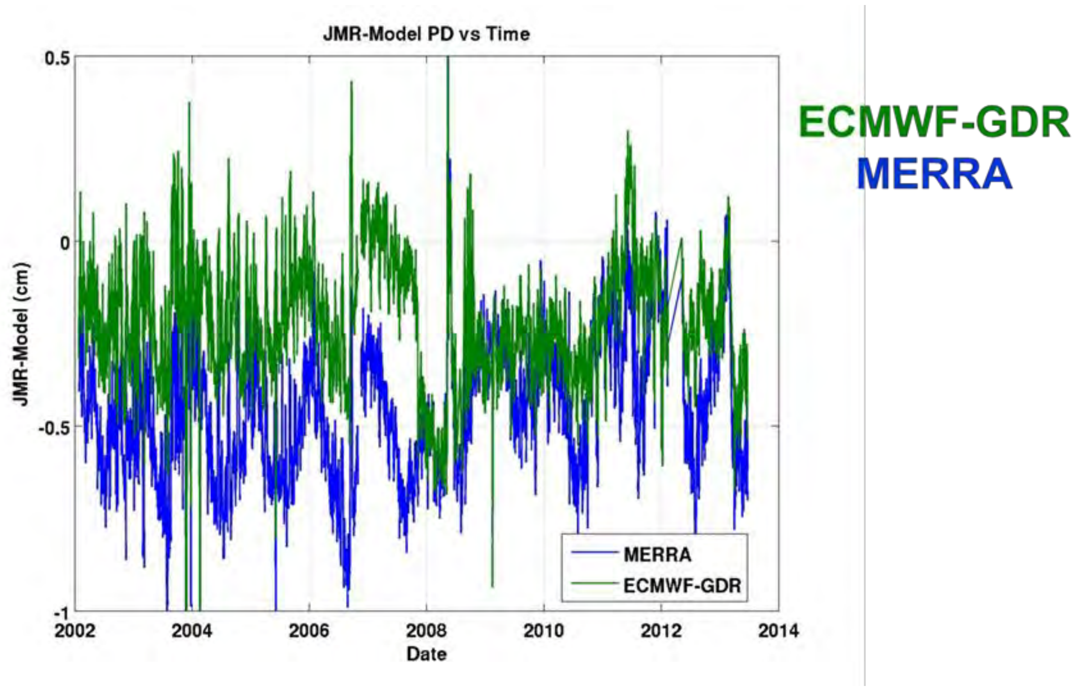

Figure 8. Comparison of the global mean PD difference between JMR and MERRA and JMR and ECMWF.

<u>AltiKa rain rate product (Picard et al)</u>

A new rain rate product is proposed for the AltiKa mission. It is based on the use a 'closest' rain rate product, which is obtained by combination between SSMIS and Windsat rain rate products (Figure 9). The product includes the rain rate, the time lag from the external measurements and a confidence flag. The confidence flag is based on the observed cloud liquid water from AltiKa, with those cases where the closest product indicates rain, but AltiKa indicates clear being flagged as bad. This product allows sensitivity of AltiKa waveforms to rain. The 'closest' rain rate will be available on PEACHI dataset on: ttp://odes.altimetry.cnes.fr.

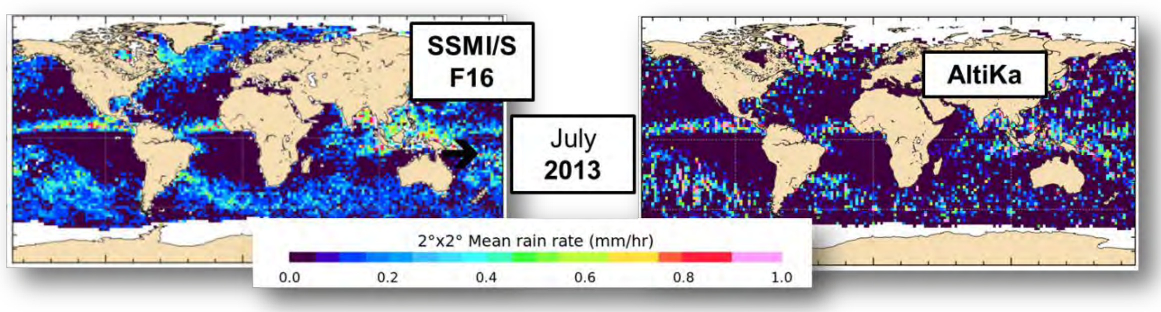

Figure 9. Comparison between the SSMIS F16 rain rate and the AltiKa closest rain product.

<u>Potential of High Frequency Radiometers on Future Altimetry Missions (Brown et al)</u>

High frequency radiometer channels if integrated into future high resolution altimetry missions will improve observations in the coastal regions and potentially improve observations over land. A study was conducted to quantify the improvement offered by high-frequency radiometers using both simulation and real data from the recently launched, high resolution GPM Microwave Imager (GMI). Two algorithms are evaluated, a coastal algorithm and over-land algorithm. The coastal algorithm works by dynamically training high frequency radiometer channels and using the open ocean low-frequency

PDs and then using that dynamic fit to retrieve PDs in the coastal zone using only the high frequency channels. The results of the simulations and the application to GMI data were consistent, showing that these high frequency channels can be used to keep the PD errors below 8mm up to the coastline (Figure 10). Overland, 183 GHz sounding channels can be used along with model data to reach 2-3 cm level accuracy. Missions such as Jason-CS and SWOT will benefit from these systems. An airborne high-frequency radiometer for wet PD has been built by CSU/JPL and first flights took place in November.

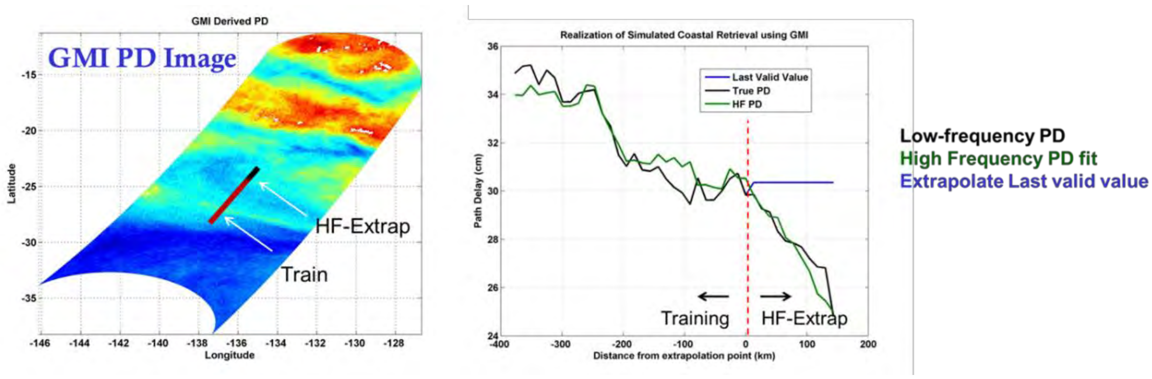

Figure 10. Demonstration of the high-frequency extrapolation data using GMI.

Multi-mission sea state bias modeling: development and assessment (Feng et al)

Metrics for sea state bias (SSB) correction were evaluated for inter-comparing models (Figure 11). Three methods were compared, direct SLA data evaluation, collinear differences and cross-over differences. The direct SLA data evaluation shows that in terms of variance reduction the 3D SSB outperforms 2D SSB in the range of 0.5-1.5cm2. This evaluation test may be not related only to SSB model performance (due to spurious correlation with SLA). Collinear difference data evaluation shows the largest absolute variance reduction measures for 3D SSB correction, with 3D SSB outperforming 2D SSB in the range of 1-2.5cm^2. This is very stable from year to year and in zonal evaluation. This is viewed as the best evaluation metric even though a 10 day difference may yet be sub-optimal. Crossover difference data evaluation shows much less variance reduction gain in the 3D vs. 2D evaluation. This test is sub-optimal for evaluating SSB performance. The crossover test might be useful for many geophysical corrections, but it is a relative measure at best for sea state dependent SSB performance testing.

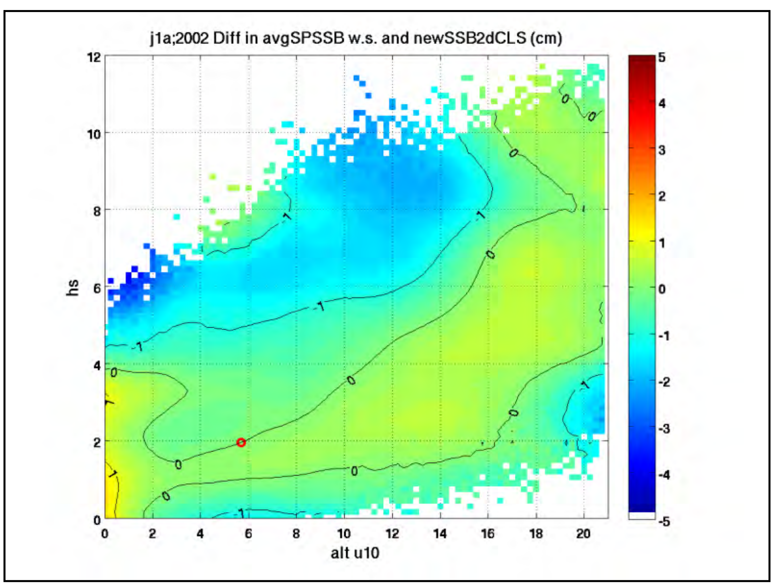

Figure 11. Improvement of new SSB correction algorithm.

6.2 Near Real Time Products & Applications and Multi-Mission, Multi-sensor Observations

Chairs: Emilie Bronner, Gregg Jacobs, John Lillibridge and Julia Figa Saldana

There were 6 talks and 11 posters presented and the session was well attended (~100 attendees).

Interest in this session from operational users of delayed (i.e., non NRT) data is increasing, and so, in general, is the interest of users developing operational services from altimetry at all time scales. The most notable example in this year's NRT splinter is a very interesting contribution on the use of altimeter products for operational climate monitoring. It is for this reason that we propose a new name for this splinter for future OSTST meetings: **'Application development for Operations'**.

A noted absence in the splinter this year was the inland water users, because there was a dedicated splinter in this year's OSTST for this set of applications.

6.2.1 Talks summary

The talk from **D. Chelton et al.**, 'The Spatial Resolution of AVISO Gridded Sea Surface Height Fields' was presented by co-author **I. Pujol** and assessed the improvements of the new AVISO grids DT-2014 with respect to DT-2010, looking at SSH wavenumber spectra and maps of the SSH difference statistics for the period between October 2002 and September 2005, where four altimeters were available. The comparison was done in two steps: first considering the grids update (from 1/3°Mercator to 1/4° and then considering the addition from 2 to 4 altimeters.

The spectra show that the resolution improvement (from 40 to 35 km) comes primarily from the grid change, while the addition of altimeters does not contribute to this, because the same OI method (same co-variance scales) is used in both cases.

The variance analysis shows that the grid change to DT-2014 brings mean differences of over 5 cm and RMS differences of 1-4 cm on average, but exceeding 10 cm in the most energetic regions, showing more eddies and of bigger amplitudes and smaller radii, of longer lifetimes and propagation distances (Figure 12).

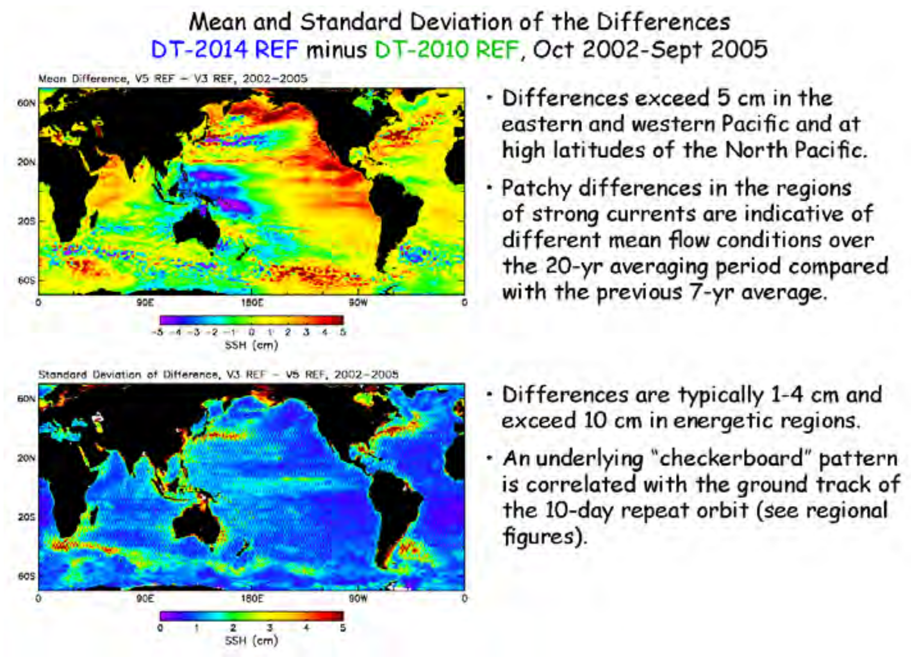

Figure 12. Improvements of the new AVISO grids DT-2014 with respect to DT-2010

Ongoing work is in the direction of improving the OI for the exploitation of 4 altimeters, in order to improve the spatial resolution.

The talk from **Willis et al.** 'JPL Gridded Altimetry Products' was presented by co-author **V. Zlotnicki** and presented their work exploring new interpolation grids (1/6°) and methods, as part of the MEaSUREs program (1 week map, period 2010-2012, 2 altimeters used: ENV and J2, GSFC products). Validation of the methods is done by withholding data and comparing the interpolated grid with the data not used. The final grids will include all data. The analysis is done on spectral content and on RMS differences. This is done globally but also for different ocean areas with different characteristic correlations. A map of JPL gridded altimetry product is shown on the Kuroshio region (Figure 13). Twenty-two years of data will be reprocessed.

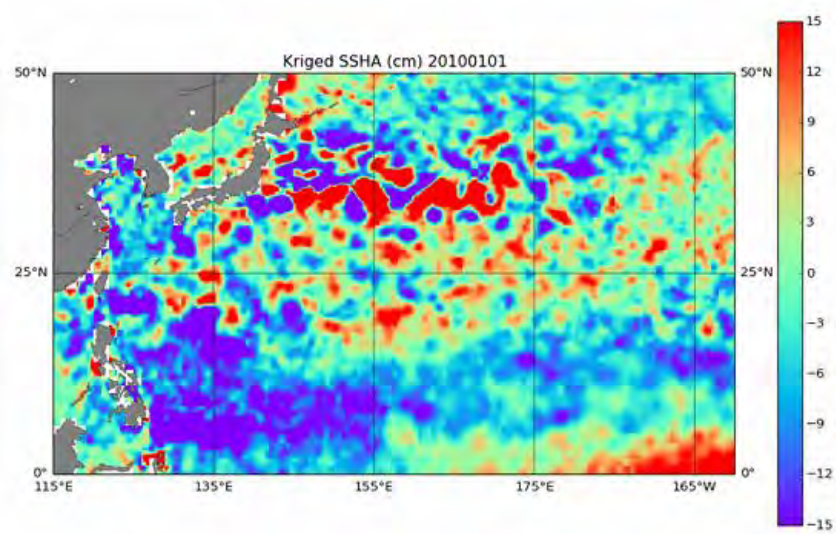

Figure 13. Map of JPL gridded altimetry product is shown on the Kuroshio region.

The talk from **Z. Li et al.**, 'Improved Representation of Eddies in Realtime Fine-Resolution Forecasting Systems Using Multi-Scale Data Assimilation of Satellite Altimetry' was on SSH data assimilation and its impact on representing meso-scale eddies for spatial scales smaller than 200 km. The assimilation approach is a multi-scale 3DVar, the model grid is at 1 km and the validation takes as a reference several in situ observations, among them from the SPURS field campaign in the Atlantic Ocean (during this experiment, many observations were assimilated twice a day: altimeter data, Spurs salinity observations, Argo profiles, SST). Models and AVISO maps can well resolve eddies (200 km) but smaller eddies will need additional data (Figure 14) as may be obtained by Airswot, SWOT, denser T/S profiles, etc.

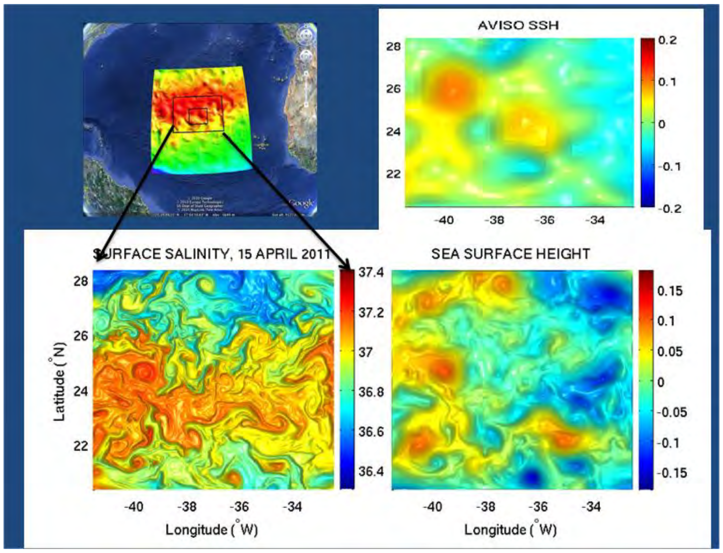

Figure 14. Eddies spanning a spectrum of Meso-Scales.

The talk from **K. Madsen et al.**, 'Near Real Time altimetry measurements of the storm surge Bodil, Denmark - comparison with model and in-situ observations' presented the use of altimeter data within the eSurge project, which aims to improve the modeling and forecasting of Storm Surges. A case study was presented over the North Sea – Baltic Sea region, where the availability of high quality tide gauge information has allowed validation of coastal re-trackers, which currently provide data that can be used at 1-3 km of the coast. She demonstrated this by examining the re-tracked coastal data from a Cryosat pass during the Bodil/Xavier storm in 2013. She further discussed the pros and cons of assimilating altimeter and tide gauge data in storm surge forecast models and reported that the best results at DMI have been from assimilating, in an Ensemble Optimum interpolation context, a blended product (see her poster in session '*Science Results from Satellite Altimetry: Finer scale ocean processes (mesoscale and coastal)'* for more details). A 2-year experimental simulation scenario demonstrated that assimilation reduced forecasted sea level RMS by 34% in the North Sea / Baltic Sea area (Figure 15).

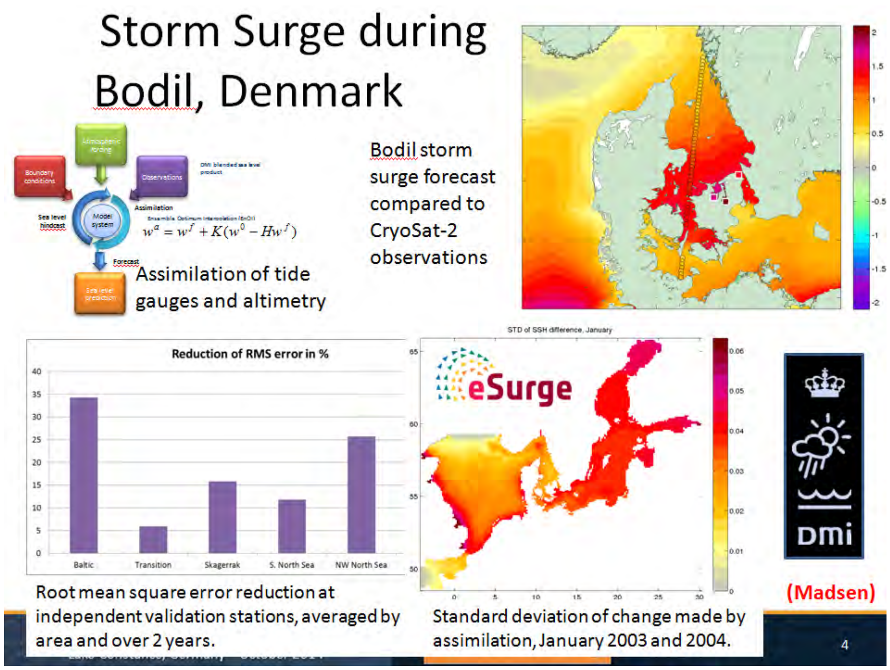

Figure 15. Bodil/Xavier storm in 2013 analyzed through eSurge project.

The talk by **L. Aouf et al.**, ‘The impact of the assimilation of altimeters and ASAR data in the wave model MFWAM’ provided a status update of ocean sea state forecast capabilities at Météo-Fance, taking into account recent improvements in the MFWAM model physics and assimilation system, in preparation for the assimilation of Sentinel-1 wave spectra. Several experiments were done assimilating ASAR wave spectra, and Jason-1 and RA-2 SWH, and leaving Jason-2 SWH out, for validation purposes. The addition of a new dissipation term, including the effect of damping induced by air friction at the surface, results in a reduced impact from ASAR and makes more prominent the impact of assimilating the altimeter SWH data (Figure 16). However, the impact of ASAR wave data on the wave period is significant for the swell part of the wave spectrum.

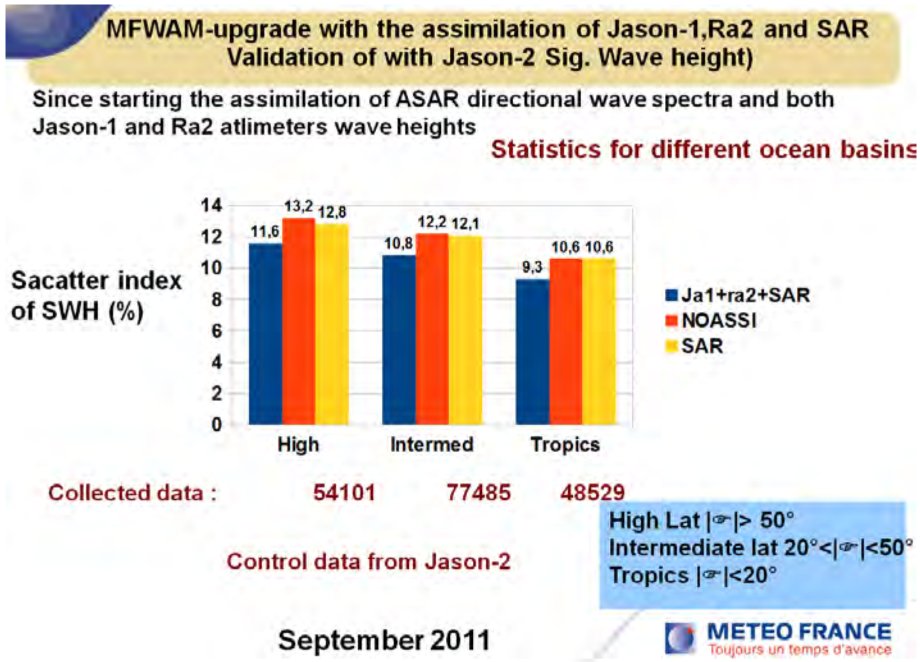

Figure 16. Impact of the assimilation of altimeters and ASAR data in the wave model MFWAM.

Finally, the talk of **B. Leben et al.**, ‘Near Real Time Monitoring of Earth's Climate Using Satellite Altimetry and Reconstructed Sea Level’, was given by **B. Hamlington** and provided a fresh concept of the term “Near Real-Time” in the context of operational climate monitoring. Climate indices based on monthly or seasonal data are established, which relate the current situation to a historical mean, usually reporting on anomalies with respect to the mean or on measured slow changes. The talk analyzed how sea level is being incorporated into climate monitoring efforts. Most of the openly available websites hosting climate indices do not consider SSH or even mention SSH as a climate variable. Three documented sources of SSH-based climate indices were examined and compared in terms of frequency, timeliness, length of the time series, methodology (data or model-based). At the moment, they do not provide a clear and consistent idea of the state of the climate and some effort is recommended to reconcile these differences by producing a consistent set of NRT and historical ocean climate indices based on satellite altimetry and sea level reconstructions (for extension of the time series back to 1900). The plan is to release the first set of SSH-based climate indices at the beginning of 2015.

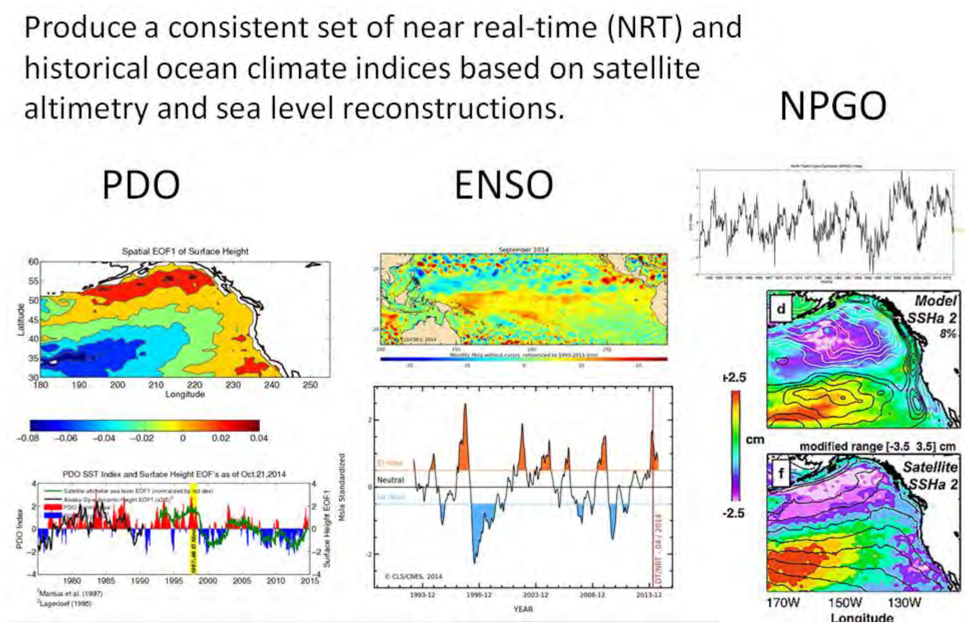

Figure 17. Produce a consistent set of NRT and historical ocean climate indices based on satellite altimetry and sea level reconstructions.

6.2.2 Round table summary

During the round table, and to close an action from the 2012 OSTST meeting in Venice, **J. Figa-Saldaña** presented the results of a joint activity with several operational users attending the NRT splinter, towards establishing an inventory of operational applications of the different altimeter parameters: SSH, SWH, and wind, and how the data is expected (latency) and exploited in each application (see the poster for more details).

With respect to the subjects proposed by the OSTST project scientists for discussion

Jason-2/3 transition:

- The proposal to alternate DIODE/DEM mode for the Jason-2/3 formation phase was accepted, noting however that this scheme may impact inland water users.
- The Jason-2 interleaved orbit was seen as a good baseline after the formation flight, although the option of a 3-day vs. 5-day interleaved lag was discussed

Jason-2 Extension of Life:

- The needs for geodesy vs. operational oceanography were discussed and it was noted that improvements of the MSS benefits coastal/shelf operational oceanography. Exact repeat/subcycles were considered, but the general view is that no move from the interleaved orbit should be made until we must.
- Protection of the reference & interleaved orbits was indeed considered important

Other topics:

- With respect to the LRM/SAR continuity, the need for Sentinel-3 SAR/LRM ascending/descending (or alternating cycles) was highlighted, as well as requesting to have data available ASAP.
- With respect to the Jason-1 GDR-E upgrade, it was requested to provide Jason-2/3 OGRD-E with NRT MOG2D DAC as an additional field, as the review of operational applications highlighted this as one of the

main reasons why the OGDRs are not used for certain applications (e.g., storm surge forecasting applications, see poster)

- With respect to the Jason-2 numerical retracker, it is recommended to consider adding Dcorr to the OGDRs, but also to be careful with product size increase. The need to resolve as much as possible the question of the optimum retracking solution for operational applications was suggested, which would avoid the need to add many re-tracking solutions to the OGDRs.

6.2.3 Posters summary

P. Cipollini et al., 'New altimetry products over shelf and coastal zone from the eSurge processor' provided an overview of specifically developed coastal re-tracker to respond to the eSurge altimeter data needs and on the availability of a database of over 200 storm surge cases. For LRM a specific re-tracker (ALES) was developed, while for SAR data (e.g. Cryosat) the SAMOSA re-tracker was used. SSH corrections from RADS were used.

D. Donahue et al., 'NOAA Operational Satellite Derived Oceanic Heat Content Products' presented a synergetic application of altimeter SSH and SST data which generates operational Oceanic heat Content estimations for the North Atlantic and North Pacific, with current efforts to extend the coverage to the South Pacific and Indian Ocean.

D. Donahue et al., 'NOAA Jason-2/OSTM Products' provided and overview of the Jason-2 operational products portfolio.

I. Pujol et al., 'Ssalto/DUACS 2014 upgrades: 4 satellites in the Real time system and a new processing' provided a status overview of the operational Multi-mission Ssalto/DUACS product suite, highlighting as the latest development the inclusion of HY-2A altimeter data, which provides an important robustness to the system. The availability of the re-processed 21 years of along-track and map products was also highlighted.

J. Figa-Saldaña et al., 'Characterization of current operational altimetry applications' presented the results of a survey among the NRT splinter participants towards the characterization of different operational applications in terms of data timelines requirements, critical SSH corrections, data latency and update frequency, showing that the Mog2D correction would add value to the OGDR products and that with the advent of coupled ocean/atmosphere models, the synergetic use of SWH and SSH is becoming important for many applications. The difference between 'operational' and 'NRT' concepts was also addressed.

N. Fuller et al., 'Altimetry data for regional applications: the CTOH database' presented a status update of the CTOH database for coastal altimetry data and the specific processing applied for the data generation.

D. Griffin et al., 'Oceanography and the search for Malaysia Airlines MH370' introduced an interesting use of altimeter SSH data to analyze and forecast surface trajectories, where CSIRO participated as a member of the Drift Working Group. The poster presented how the debris trajectories were calculated, together with the uncertainly estimation.

N. Picot et al., 'Operational Use of HY-2A in SSALTO/Duacs' addressed specifically how the HY-2A altimeter data was integrated in the SSALTO/DUACS products, the quality monitoring activities associated to it and the consequent current performances of the SSALTO/DUACS system.

G. Quartly et al., 'GlobCurrent: What's it all about?' provided a review of the progress of the project in its first year, which aims at identifying tailored solutions for application needs of ocean current information, based on simple models and satellite data assimilation. The solutions are based on a general geotropic circulation based on altimeter SSH data and adds specific components by using other satellite data forcing (e.g. surface winds)

R. Scharroo et al., 'Altimeter products for the Sentinel-6/Jason-CS mission' presented an overview of the Jason-CS product suite definition, based on the operational Jason series of products, but also emphasizing the new features that the new SAR altimetry technology will offer and the potential for improved products. He invited participants to evaluate and provide feedback for future refinement.

C. Tison et al., 'Signal processing simulations of the SWIM wave data' provided an overview of the SWIM instrument capabilities and processing challenges. The data simulations consist of forward modeling the backscattering coefficient from sea state scenes, adding instrument noise and retrieving wave spectra (including automatic partitioning of the 2D spectra).

6.3 Outreach, Education & Altimetric Data Services

Chairs: Vinca Rosmorduc and Margaret Srinivasan

Session presentations:

- New datasets for ODES (Online Data Extraction Service) (Bronner et al.)
- New Datasets and Updated Tools at PO.DAAC (Hausman et al.)
- NOAA archive and access services for Jason-2/3 products (Byrne et al.)
- SAR Processing on Demand Service for CryoSat-2 at ESA G-POD (Dinardo et al.)
- Sea Level and Climate Change Outreach for High School Students (Hamlington et al.)
- Recent Advances in NOAA Altimetry Outreach and Education (Miller et al.)
- SHOWCASE of altimeter outreach
  - *SatiSphere: an interactive sphere to demonstrate satellites view (Rosmorduc et al.)*
  - *Search for MH370 – media (Griffin et al.)*
  - *NASA-CNES SWOT Applications (Srinivasan et al.)*
  - *Multi-Mission "Pull-up" Display (Richardson et al.)*
  - *GlobCurrent project (Danielson et al.)*
  - *Cooperative Product Development – Scientists & Commercial Fishermen (Duncan et al.)*
  - *Wavechaser (Alford et al.)*
  - *High School Climate Science (L-A. Thompson)*
  - *SWOT in the GLOBE Program: Hydrology science in the classroom (Srinivasan et al.)*
  - *Oceanography in the future Grenoble Science Museum (Penduff et al.)*

- Feedback from La Reole Middle School: What participating to the Argonautica project brought the students? (movie)

Posters

- AVISO+, the new reference web portal for altimetry (Rosmorduc et al.)
- Aviso products & services: what's new? (Rosmorduc et al.)
- CTOH altimetry products (L1 to L4) for ocean and continental surfaces applications (Fleury et al.)

- NASA and NOAA Collaborative Altimetric Data Information and Access Webpage (Hausman et al.)
- OpenADB: An Open Altimeter Database providing high-quality altimeter data and products (Schwatke et al.)
- SWOT in the GLOBE Program: Hydrology science in the classroom (Srinivasan et al.)
- Satellite Altimeter Demonstration Experiments for Outreach and Education (Leben et al.)
- Sentinel-3 SAR Altimetry Toolbox - Scientific Exploitation of Operational Missions (SEOM) Program Element (Lucas et al.)

6.3.1 2013-2014 Highlights

Figure 18. Middle-school students from La Réole (near Bordeaux, France) had the whole Science Team playing with their board game during the late afternoon poster session on Thursday

New and innovative data services, mostly interactive online interfaces, were shown this year, with a new trend of processing on remote computers (cloud).

The outreach activities presented were varied, including contributions to exhibitions, hands-on educational activities, as well as feedback from students.

The short format of the "outreach showcases" a great success this year. It allowed OSTST members to share an outreach activity they participated in but which was not the subject of a full-fledged presentation.

6.3.2 Data services

Data Services provide a way of exchanging information and linking projects and users together so users can benefit from the wide variety of altimetry-derived data available.

CNES has opened its “Online Data Extraction Service” with new, including experimental, datasets provided (see http://odes.altimetry.cnes.fr). Plans to develop and strengthen this tool were shown by E. Bronner (Figure 19).

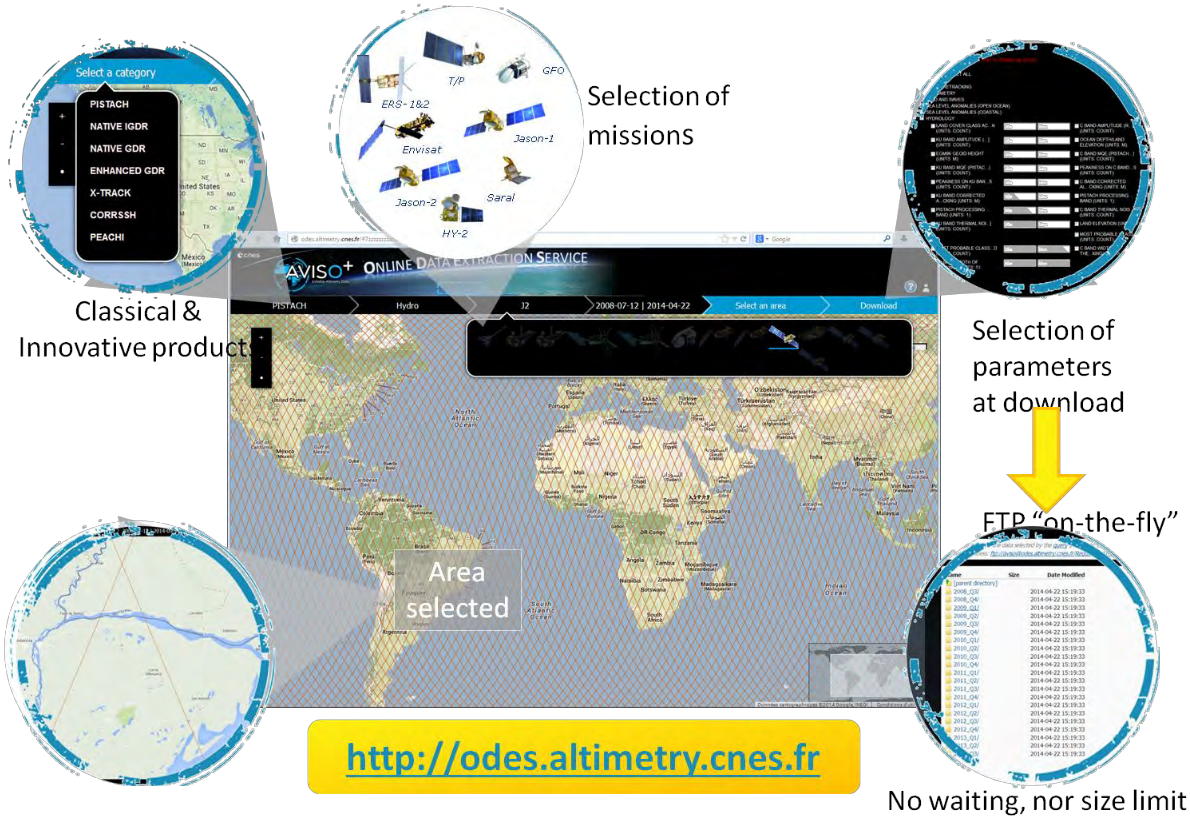

Figure 19. Synoptic view of the Online Data Extraction Service (ODES) developed by CNES

NOAA detailed some metrics, centering on authenticated/anonymous access statistics. They showed that given the choice, most users chose not to register (even if a large number, not given the choice, will do so). But registration is a mean to know them better, and better serve them.

JPL/PODAAC is developing new datasets (NRT SARAL/AltiKa GPS orbit corrections, OSCAR 1/4°, Integrated Multi-Mission Ocean Altimeter V3, Jason-1 GDR-E), new pages on their web site, with a forum and links with NOAA and other data services. Web services, and a focus on Data management best practices, with also the use of DOI are being put in place.

ESA opened a new service dedicated to SAR altimetry-specific processing, with the capability to process remotely and on demand CryoSat-2 SAR data, from L1a (FBR) data products until SAR Level-2 geophysical data products (available on ESA G-POD web portal at https://gpod.eo.esa.int/services/CRYOSAT_SAR/).

The ESA Globcurrent project is computing and releasing current data computed from (among other sources) altimetry.

CTOH, Aviso and DGFI showed their new data and services in posters.

The round table discussed the scripting ability of the different tools to retrieve data “en masse”.

6.3.3 Outreach

Some of our usual mechanisms for Outreach include:

- Exhibitions
- Public lectures and conference presentations
- Supporting classroom activities
- Writing and editing books
- Producing educational and outreach handout materials
- Generating animations and images
- Engaging journalists and the media
- Updating web sites
- Providing easy access to data products
- Teaching tutorial courses
- Developing dedicated tools (e.g. the Basic Radar Altimetry Toolbox)
- Highlighting research results

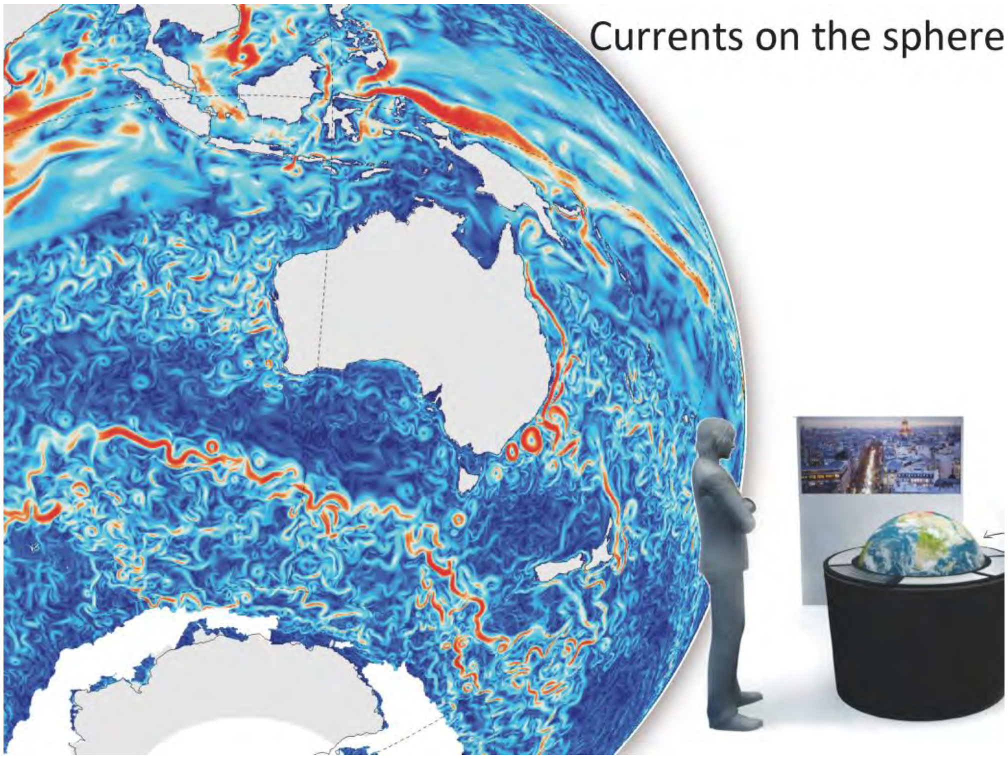

Figure 20. Interactive globe screen interface at the Grenoble science museum

Outreach and educational activities of the past year include continued promotion of the societal benefits of ocean altimetry data, highlights of the Jason-1/OSTM-Jason-2 tandem mission, and anticipation of the Jason-3 and SWOT missions. The team has generated several products (handout materials and web-based informational products) to promote the science and applications of the data. In addition, our emphasis on climate literacy has been used to engage our target audiences (public and educational) with outreach and education products and events.

Useful resources (figures, maps, movies, animations, schemes…) are now available on the web or on the computers and in databases of the outreach team. We remind OSTST participants that they should not hesitate to ask for general presentation material or a specific theme or figure. If it does not exist, we can consider having it made for future uses.

A restyled AVISO web site, including CTOH information and activities (AVISO+) opened on Feb. 26, 2014. The "meeting" web site where the OSTST abstracts were submitted opened a little later on.

D. Griffin (CSIRO), as well as NOAA, contributed to the search for the Malaysia Air Line lost flight, and this made its way to the Newspapers.

L. Miller (NOAA) detailed other outreach action they participated to, e.g. New Satellite Altimetry Web Pages (Jason Program, Sea Ice, Bathymetry, Sea Level Rise), contribution to the NOAA View web site, Facebook & Twitter and NOAA Science on a Sphere.

OSU is working with computer scientist undergraduate students to adapt their interface for the fishermen to retrieve model data in a friendly way, adapted to their needs.

The LGGE in Grenoble, France (T. Penduff), is participating to a project of science museum. They will provide animations for an interactive globe screen interface (Figure 20) (CNES also bought one of those, with a number of ocean-related animations made for it by CLS).

The round table discussed the impact and outreach possibilities of having both the Climate conference in 2015 and the Jason-3 (and Sentinel-3) launch the same year.

6.3.4 Education

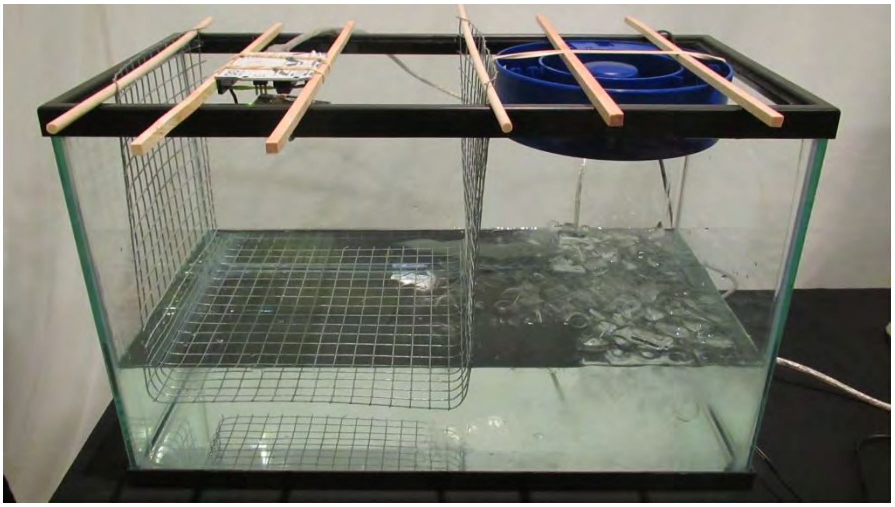

Figure 21. Hands-on experiments for education in primary to high school

B. Hamlington (CCAR) showed some hands-on experiments (Figure 21), including a sealed box to have students feel their way around an object by measuring its "height" to the top of the box. Such experiments are always a hit for education in primary to high school, since they are working on everyday material.

Two groups of French students participated in the plenary session on Friday. Their presentations were much appreciated, with a high level of scientific content (and English). Middle-school students from La

Réole (near Bordeaux, France) had the whole Science Team playing with their board game during the late afternoon poster session on Thursday. (Games may be purchased directly from the students. See their presentation online for contact information).

Ideas for SWOT education through the GLOBE project were shown by JPL and CNES. In particular, a good opportunity on French side could be the AirSWOT campaign on the Garonne River (flowing through Toulouse). The Argonautica project continues on CNES side, with a number of students (from 5 to 20 years old) involved and enthusiastic.

High school education included climate-related classes by L-A. Thompson –see http://uwpcc.washington.edu http://www.uwhs.washington.edu/uwhs/courses/sci.asp.

A teacher workshop might be linked to the Jason-3 launch activities.

6.3.5 Recommendations

Jason-3 and Sentinel-3 launches are planned next year, while the COP21 Climate conference will take place in Dec. 2015 in Paris. This is an opportunity to promote altimetry and its uses in climate study and monitoring (cf. e.g. indices as shown by B. Hamlington in the NRT session). OSTST members should thus prepare for those launches AND the climate conference. We recommend that OSTST attendees support applications user communities and applications science, and advise us about their activities related to the applied and operational uses of individual and multimission data sets.

OSTST members are also involved in a number of training courses.

Collectively, we would like to:

1) advertise activities of the OSTST more widely (i.e. on the Aviso, JPL, etc. web sites), and
2) share material and methods. One example is “kitchen experiment” descriptions, which are often informative and useful experiments that share scientific concepts with the general public using familiar materials from home (or at least easily bought). If you have “hands-on” activities, try to write a rough description to share it, and send it to the outreach team.

OSTST members can make a significant difference in their local communities by participating in school activities, supporting local events involving climate science and science educations, and volunteering (or agreeing to support) training sessions or class visits at local schools and general public venues. The work done by other team members can make this task more accessible to both the scientists and their audiences. If we are aware of your activities, we can support you by facilitating these interactions. The development of international collaborations between students is another area that can be more developed via shared resources and communication. Translating educational materials into other languages could be a ‘low hanging fruit’ on resource-sharing trees.

6.3.6 New Planned Efforts

The focus of the outreach team for the coming year will be on climate and global change education and public outreach, as well as applications outreach for all of the current and especially the upcoming ocean altimetry missions— OSTM/Jason-2, Saral/AltiKa, Jason-3, Sentinel-3 and SWOT. The anticipated elements of this focus (not withstanding new opportunities) will include:

- Jason-2/OSTM, SWOT, Saral/AltiKa and Jason-3 education & public outreach and applications outreach

- Jason-3 launch activities, including movies
- Altimetry and multisensor applications promotion
- Coverage of science team research and other applications on the Web
- Development of a SWOT GLOBE program (NASA, CNES, U. North Carolina, GLOBE Program collaboration)
- Presentations about altimetry and applications made available to the community?
- Specific climate-related material?

6.4 Precise Orbit Determination

Chairs: Sean Bruinsma, Alexandre Couhert and Frank Lemoine

6.4.1 Status of Jason-2 GDR orbits

The current release of GDR orbits, referred to as version ‘D’, continues to achieve the targeted radial accuracies of 1 cm RMS over a 10-day repeat cycle, as shown by comparisons with Jason-2 ephemerides computed independently by CNES, NASA GSFC, and JPL (Figure 22). The compared solutions use different combinations of tracking techniques and different parameterizations: JPL produces GPS-based, reduced-dynamic solutions, while the GSFC orbits and the CNES GDR-D are dynamic orbits based on DORIS+SLR and GPS+DORIS+SLR tracking respectively. The POD analysis centers produced new time series of using updated modeling standards: GSFC STD1404/RED1404, CNES GDR-E (GPS+DORIS reduced-dynamic), and JPL RLSE14A. The major modeling updates include updated dynamic/measurement models and improved parameterization. As can be seen in Figure 22 and Table 1, the CNES preliminary GDR-E orbits (using a more reduced-dynamic parameterization than in the GDR-D) is closer to the JPL RLSE14A and GSFC RED1404 reduced-dynamic solutions, less sensitive to modeling errors than the dynamic orbits. The mean radial RMS difference between the new reference orbit series is now between 4 and 8 mm.

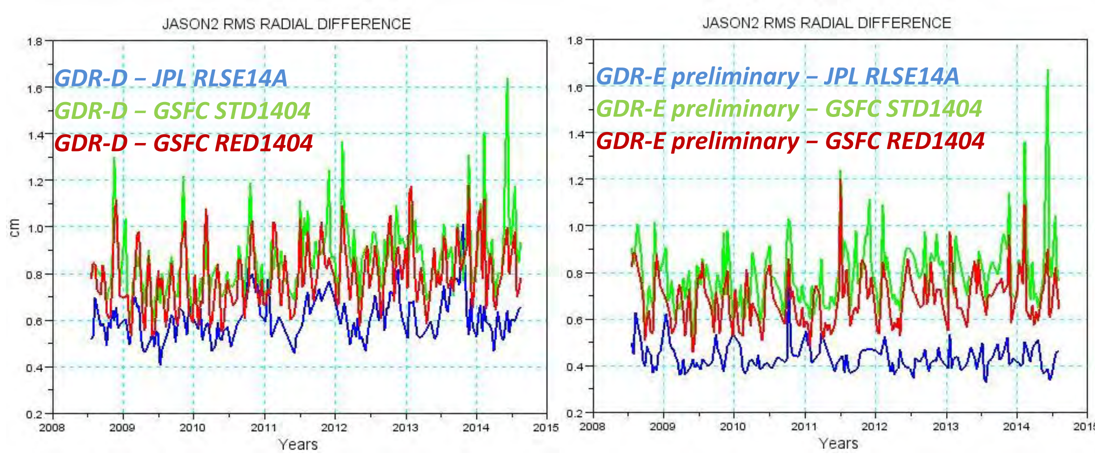

Figure 22. (Moyard et al.) Left: RMS of radial orbit differences between Jason-2 CNES GDR-D GPS+DORIS+SLR dynamic orbits and GSFC STD1404 DORIS+SLR dynamic orbits (green), GSFC RED1404 DORIS+SLR reduced-dynamic orbits (red), and JPL RLSE14A GPS-only reduced-dynamic orbits (blue). Right: Same comparison but with respect to CNES preliminary GDR-E GPS+DORIS reduced-dynamic orbits

Table 1. (Lemoine et al.) Jason-2 POD performance summary. Mean RMS and Earth-Centered-Fixed orbit differences between JPL RLSE14A orbits and other analysis centers’ orbit series: GSFC orbits (STD1007, STD1204, STD1404, RED1404), CNES orbits (GDR-D, preliminary GDR-E). GSFC, STD1007 (resp. STD1204) is comparable to the

generation of CNES GDR-C (resp. GDR-D) orbits; STD1404 refers to the orbits determined based on a TVG harmonic piece-wise fit to 5x5 weekly coefficients determined from twenty SLR & DORIS satellites.

Jason2 jpl14a-*test* orbit differences cycles 1-224	Mean RMS TOD (mm)			Mean ECF (mm)		
	radial	cross-trk	along-trk	X	Y	Z
std1007	10.7	24.1	35.6	2.4	-4.8	3.0
std1204	8.0	23.1	30.5	1.4	-2.2	3.1
std1404 (prelim)	7.6	22.2	29.3	3.1	0.3	2.9
red1404	6.5	18.9	24.8	2.0	0.8	2.5
gdrd	6.2	13.0	17.5	1.1	2.7	1.5
gdre	4.3	13.0	15.4	0.5	1.4	1.4

The statistics of the altimeter crossover residuals show an average 35 mm^2 of variance reduction for the GDR-E preliminary solutions compared to the GDR-D orbits (Figure 23). Better accounting for Time-Varying Gravity (TVG) field effects and improving Solar Radiation Pressure (SRP) model for Jason-2 explain ~10 mm^2 and 10-15 mm^2, respectively, of the overall gain. Although small (~3 mm^2), the contribution from direct modeling of the annual signal in the geocenter motion to decreasing the altimeter crossover residuals should be noted. The bulk of the variance reduction for the GDR-E (preliminary) orbits comes from the implementation of the reduced-dynamic parameterization in the orbit determination computations.

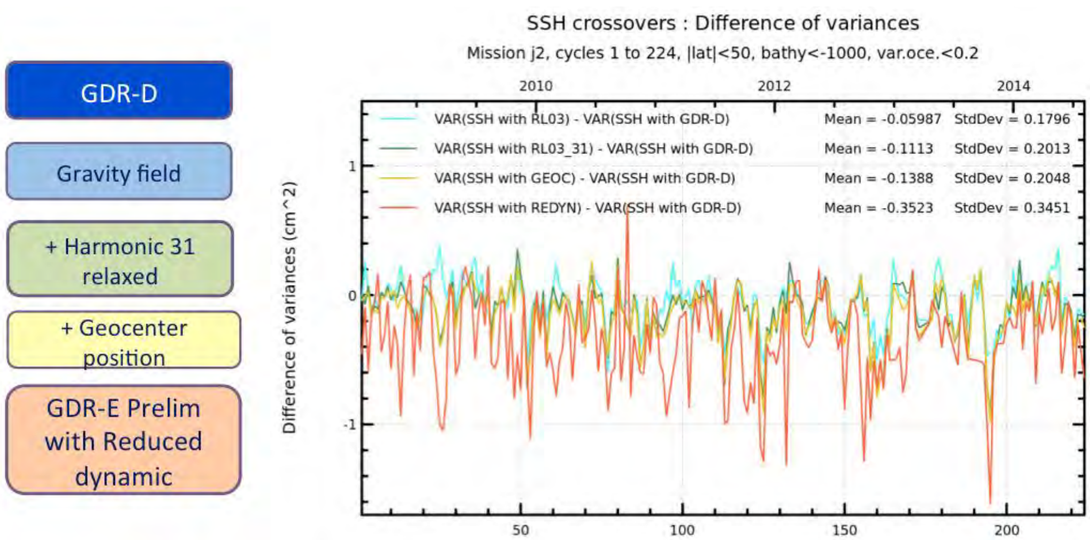

Figure 23. (Ollivier et al.) Evaluation of model improvements with respect to Jason-2 GDR-D orbits through analysis of independent crossover residuals.

The new orbit standards in the GDR-E preliminary orbits reduce the geographically correlated radial orbit drift rate, from 1 mm/y (for GDR-D solutions) to less than 0.5 mm/y over ~6 years, with JPL RLSE14A orbits (Figure 24). Although CNES GDR-E preliminary solutions use both GPS and DORIS measurements in their reduced-dynamic process, these orbits are mainly GPS-driven, and thus are expected to compare well with the JPL RLSE14A GPS-only reduced-dynamic orbits. Still, there is good constancy between the CNES GDR-E preliminary orbits and the GSFC RED1404 DORIS+SLR reduced-dynamic solutions at the mm/y level on a regional scale.

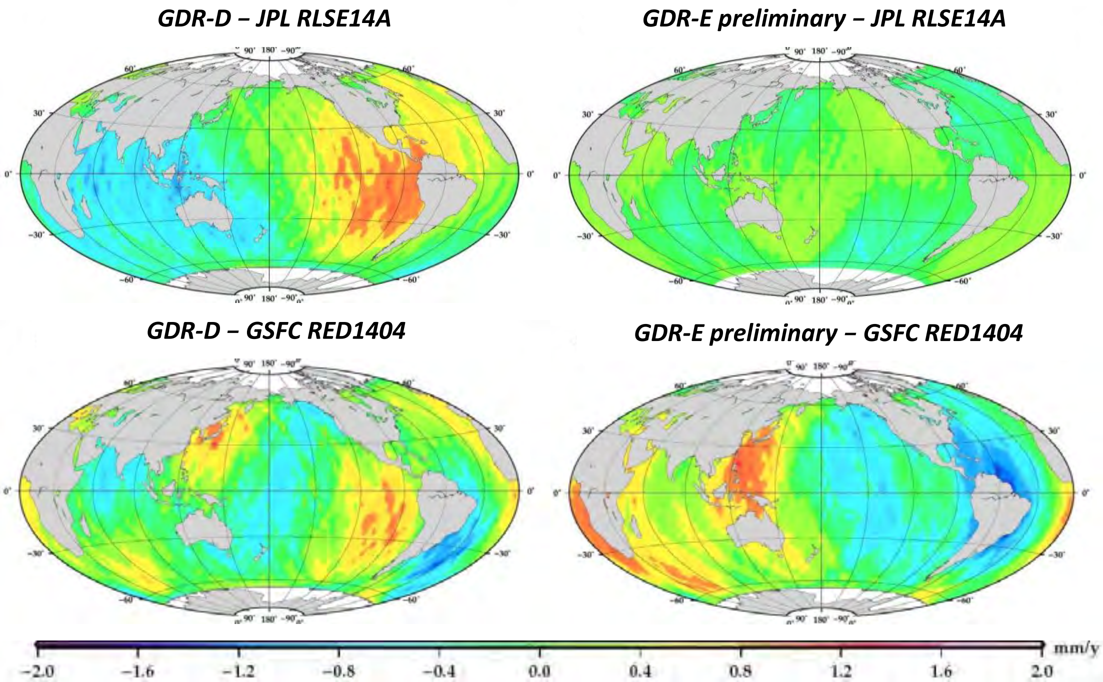

Figure 24. (Moyard et al.) Jason-2 geographically correlated radial orbit difference drifts of CNES GDR-D (left) or GDR-E preliminary (right) and GSFC RED1404 or JPL RLSE14A orbits.

Mercier et al (2014) developed a calibrated SRP model for Jason-2, by adjusting the solar array optical properties, and by estimating a harmonic model for the central box function of the satellite angular position with respect to the subsolar point. With respect to the GDR-D (dynamic-based) orbits, this new SRP model reduces both the Sea Surface Height (SSH) crossover variance (by 10-15 mm^2 on average and 40 to 100 mm^2 per orbit cycle, for periods of high beta-prime), and the once-per-revolution (OPR) empirical accelerations (from 4×10^{-9} $m.s^{-2}$ to less than 1×10^{-9} $m.s^{-2}$) (Figure 25). The same procedure of SRP calibration could be applied to other altimeter missions when switching from the current GDR-D to new GDR-E orbit standards.

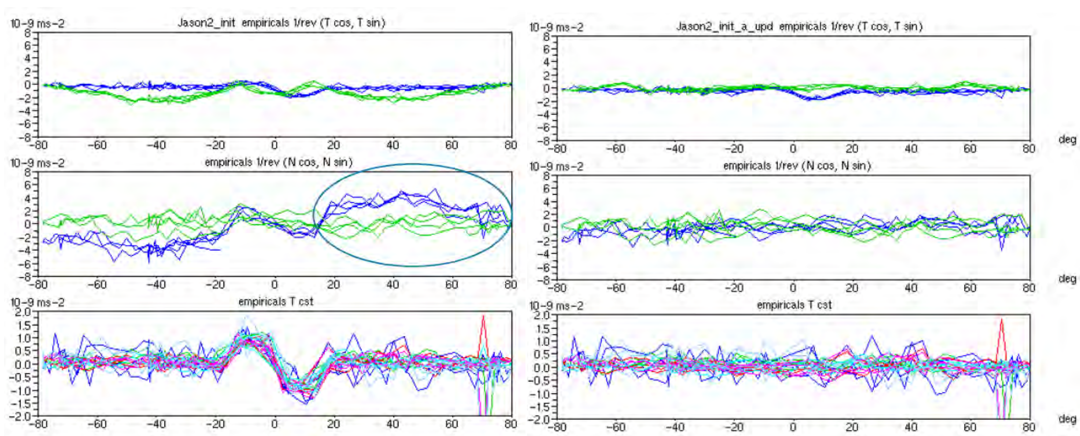

Figure 25. (Mercier et al.) Estimated empirical accelerations when using the standard GDR-D configuration for Jason-2 (left) and when using the new calibrated SRP model (right).

6.4.2 Tracking system status (GPS, SLR, DORIS)

6.4.2.1 GPS

The GPS Receiver A (GPSP-A) has operated in a stable manner since 2008 (exceeding its design lifetime of three years) (Figure 26), but experienced an anomaly on Aug. 23, 2014. The cause of the anomaly is unknown, and diagnostic tests have been made on the ground copy of GPSP-A._The GPS Receiver B (GPSP-B) was activated on Aug. 26, 2014, but only started returning data on Sept. 10, 2014. The GPSP-B returns adequate data for orbit determination, but the receiver exhibits an increase in daily data loss and a slight decrease in the number of GPS satellites tracked, compared to the former GPSP-A receiver. A degradation of the L2 frequency in association with small temperature increases is under investigation. An increase in the pseudo-range (+5 cm) and phase residuals (+2 mm) was observed and may be at least partially attributed to the need to derive an antenna phase map specific to the GPSP-B.

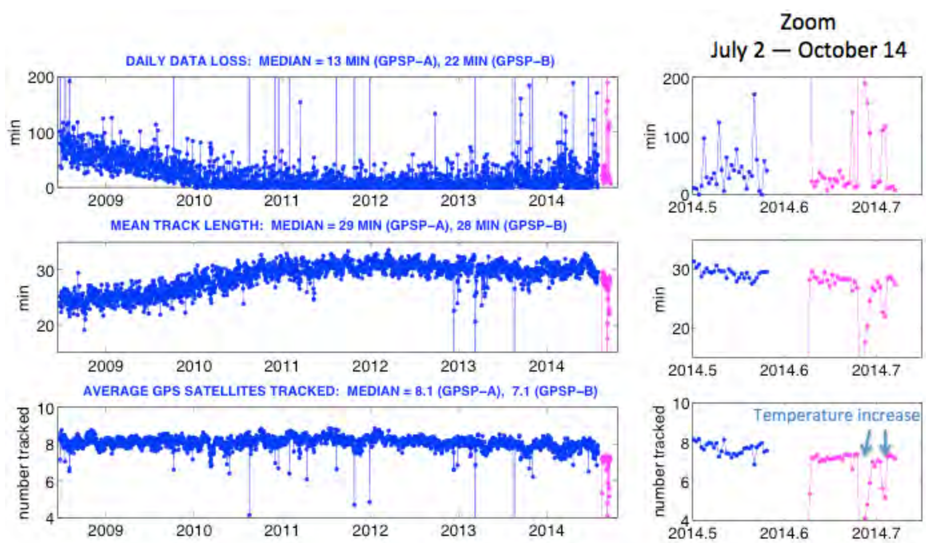

Figure 26. (Bertiger et al.) Jason-2 GPS tracking performance: GPSP-A (blue), GPSP-B (pink).

6.4.2.2 SLR

The acquisition of SLR tracking data for Jason-2 is without any issues. Over 2013-Nov. 2014, the five stations that returned more than 1000 tracking passes were Yarragadee (Australia), Changchun (China), Zimmerwald (Switzerland), Grasse (France), and Mt. Stromlo (Australia). An item of concern is that two of the best performing stations of the network, show a degradation of residuals: over the year 2012 for Greenbelt (L7105) and from 2010 for Yarragadee (L7090) (corresponding to a positive bias of ~1 cm). This was noticed in their residual statistics for LAGEOS-1, LAGEOS-2, and Jason-2 orbit solutions and other altimeter satellites. The high-elevation mean SLR residuals per cycle on independent Jason-2 GPS-derived orbits are shown for Yarragadee in Figure 27. Un-modeled effects in the station position (atmospheric and hydrological loading) were investigated to explain the 1-centimeter bias, but these loading effects could only reduce the amplitudes of annual signals in the residuals. This anomaly in station performance is under investigation.

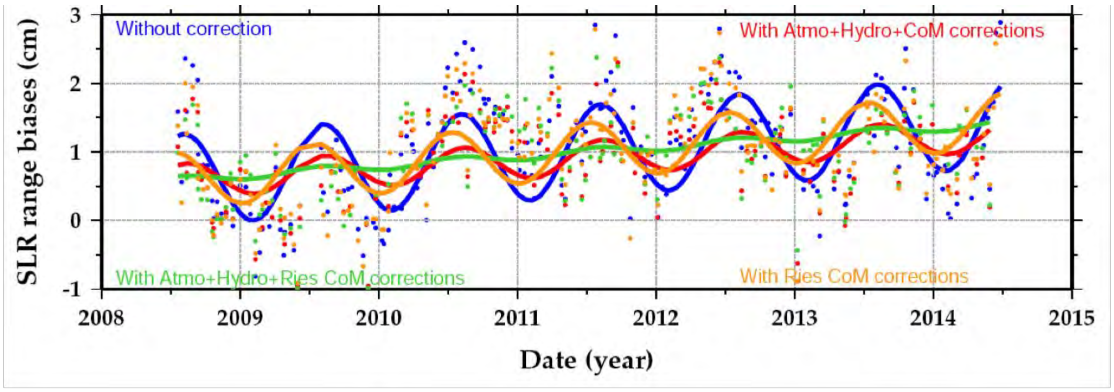

Figure 27. (Couhert et al.) Mean SLR Yarragadee reference station residuals by cycle above 70° elevation from 2008 to 2014 for Jason-2 independent GPS-based GDR-D-like dynamic orbits. The solid curves are the results of the least squares fit to the mean SLR residuals of a bias, drift and annual periods.

6.4.2.3 DORIS

The tracking performance of the DORIS measurement system remains stable over time. Jason-2 benefits from the continued effort to maintain and upgrade the DORIS station network. The CNES provided to the DORIS community a phase map for the ground Starec antenna, determined from measurements in an anechoic chamber. The use of the phase map improved the RMS of fit to the DORIS satellites (including Jason-2), but had an inconsequential impact on the orbit determination. Its primary influence will be in the determination of the new station coordinate set associated with the new realization of the terrestrial reference frame (ITRF2013).

6.4.3 Non-tidal TVG modeling strategies for altimeter satellites

POD analysis centers have tried different strategies to account for modeling long-term time-variable-gravity (TVG) effects: GRACE-dependent and "GRACE-free" approaches.

6.4.3.1 GRACE-dependent

6.4.3.1.1 GRACE-derived mean gravity field models

GSFC (6x20 annual terms), JPL (JPLRL05M) and CNES (EIGEN-GRGS.RL02bis.MEAN-FIELD) now all use a background GRACE-derived mean gravity field model. Their successive modeling improvements drove the evolution of the GDR orbit standards:

- EIGEN-GL04S-ANNUAL (GDR-C): **annual and semi-annual periodic terms** (based on 2 years of GRACE+LAGEOS data => drift terms ignored).

- EIGEN-GRGS.RL02bis.MEAN-FIELD (GDR-D): inclusion of **secular drift terms** (based on 8 years of GRACE+LAGEOS data).

- EIGEN-GRGS.RL03.MEAN-FIELD (proposed for GDR-E): refinement with **yearly bias+drift** (Figure 28) **to account for interannual variability** (based on 10 years of GRACE+LAGEOS data).

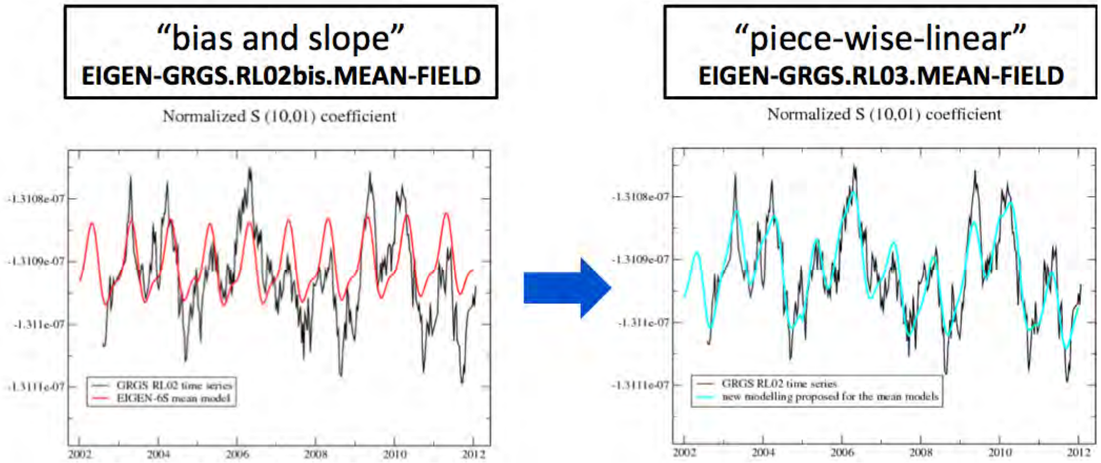

Figure 28. (J.M. Lemoine et al.) The new "piece-wise-linear" modeling for the GRACE-based mean field EIGEN-GRGS.RL03.MEAN-FIELD (right) provides better agreement with the 10-day series of gravity fields than the previous "bias and slope" modeling used in the GRGS.RL02.MEAN-FIELD (left).

A strong advantage of these GRACE-based mean models is their compatibility with the low-latency requirement for routine delivery of precise orbits for altimeter satellites. The main disadvantage is that as mean models, they are extrapolated in operational POD and thus diverge from the time series after some time and need to be updated. The use of time series of GRACE-derived gravity solutions is not seen as a reliable option for routine altimeter satellite POD, since there is a long-latency (several months) associated with the GRACE data, and Level-2 product delivery. In addition, GRACE-based solutions are not available for certain months due to aging of the spacecraft, and a concern exists over the projected continuity of the time series before the launch of the GRACE-Follow-On mission.

6.4.3.1.2 GRACE time series

Monthly GRACE solutions from the different analysis centers (CSR, GFZ, JPL, CNES/GRGS) were thoroughly tested by the POD groups (GFZ, GSFC, CNES) and discussed in several splinter presentations. Jason-2 GDR-D-like dynamic orbits were reprocessed using the different GRACE monthly solutions (instead of the mean gravity field model) and compared to reduced dynamic orbits (CNES GDR-E preliminary and JPL RLSE14A solutions) to assess their accuracy. The major observation that came out of these comparisons is that the GRACE RL05 time-series of monthly time-variable gravity field estimates from CSR make dynamic orbits more consistent with reduced-dynamic orbits than the other monthly GRACE solutions.

The differences between the low degree and order terms (below 20x20) of GRACE monthly gravity field solutions from the four processing centers (CSR, GFZ, JPL and GRGS) was also analyzed to gauge their "internal" error. Figure 29 reveals that the dispersion between the different analysis centers is quite high for the degree 2/3, as well as for the sectorial harmonics (degree l = order m). The higher dispersion of the sectorial terms may be attributed to the high inclination of the GRACE twin-satellite orbits.

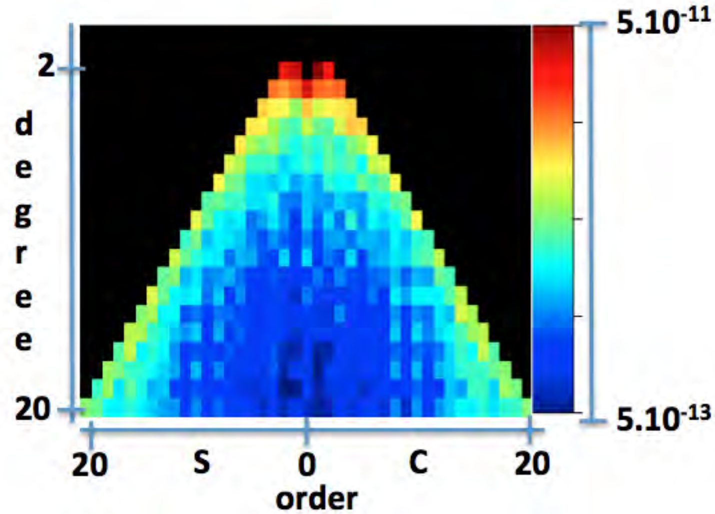

Figure 29. (Couhert et al.) Standard deviation values of the low degree and order C/S spherical harmonic coefficients (below 20x20) representative of the dispersion between the four GRACE time-series of monthly time-variable gravity field estimates from CSR, GFZ, JPL and CNES/GRGS.

Couhert et al. computed the radial orbit sensitivity of the four current altimeter missions (Jason-2, CryoSat-2, HY-2A, Saral) to individual variations in spherical harmonics corresponding to the standard deviations derived from the dispersion in the GRACE analysis center solutions. The projected errors from dispersion in GRACE TVG solutions affect altimeter satellites at specific orders and sets of coefficients. Figure 30 shows that Jason orbit is most sensitive to GRACE gravity field errors in the degree 3 order 1 harmonic, while CryoSat-2 orbit is more affected by inaccuracies in the degree 3 order 2/3 and resonant degree 14 order 14 harmonics. Such errors can affect Mean Sea Level (MSL) rate significantly, especially regionally.

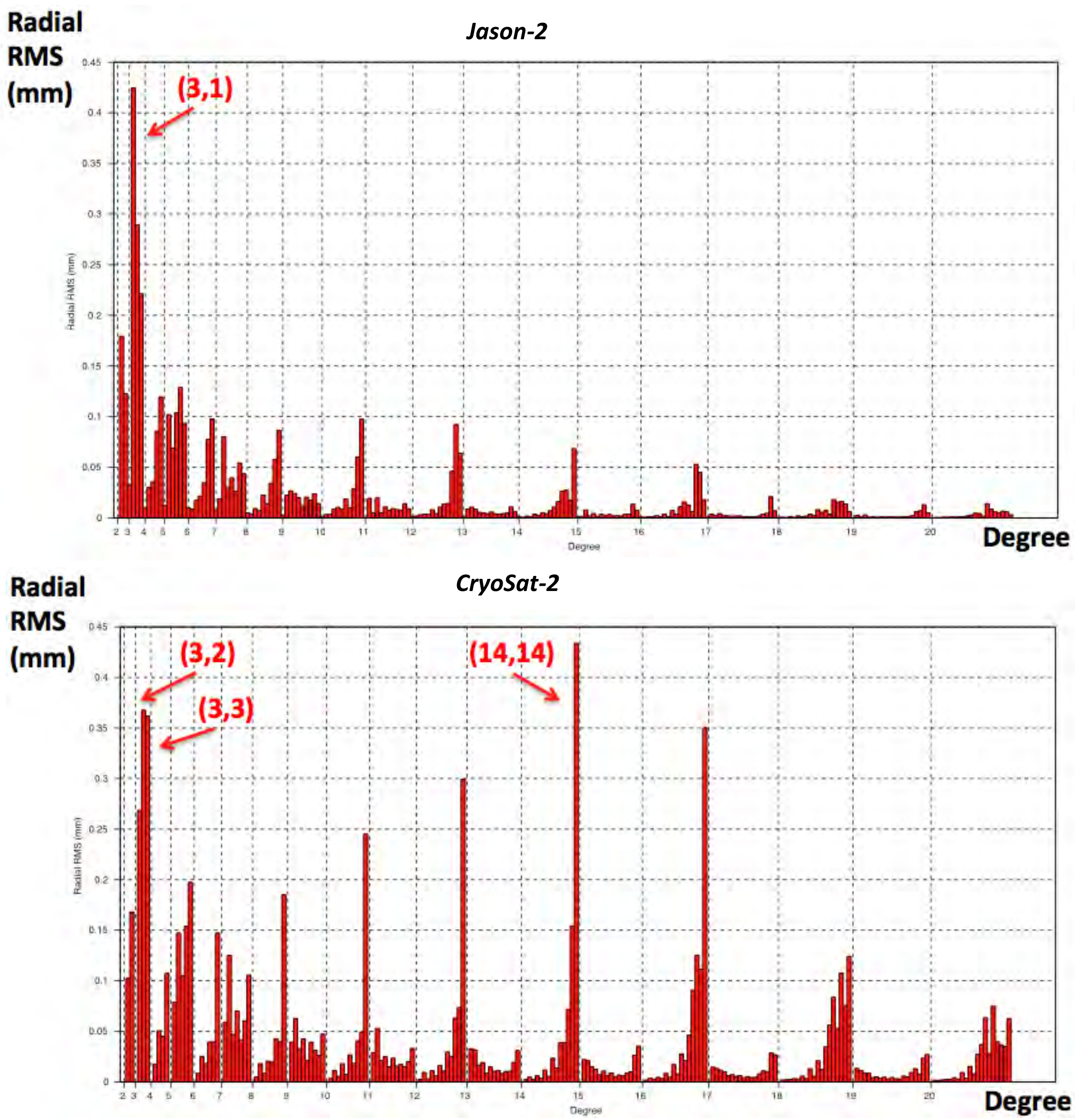

Figure 30. (Couhert et al.) Radial orbit sensitivity to individual variations in spherical harmonics corresponding to their associated GRACE internal error estimates, for Jason-2 (top) and CryoSat-2 (bottom).

As previously mentioned, despite the fact that the monthly GRACE solutions better represent the instantaneous geopotential than the mean gravity field models, their latency and questions about their routine availability make them difficult to use in operational multi-mission POD production. With the identified errors in GRACE TVG solutions in mind (cf. Figure 29 & Figure 30), some other strategy may also be needed.

6.4.3.2 ***"GRACE-free"*** *(using POD tracking data alternative to GRACE)*

6.4.3.2.1 GPS-driven reduced-dynamic solutions

Reduced-dynamic orbit determination based on GPS-driven orbits offer the advantage of smaller sensitivity to dynamic model errors. Thus, sensitivity to errors in modeling time-variable gravity (for example in deviations from an extrapolated mean GRACE model) can be mitigated. However since the Jason-2 GPS receiver is (officially) not considered mission critical, we must bear in mind the possibility of losing the ability to compute reduce-dynamic (GPS-based) orbits if there is a gap in GPS tracking. Still, such reduced-dynamic orbits (JPL RLSE14A GPS-only and CNES GDR-E preliminary GPS+DORIS solutions) are quite useful in improving precise orbit quality and assessing dynamic model errors.

6.4.3.2.2 5x5 Spherical harmonics complement

GSFC has developed direct use of low-degree and order spherical harmonic coefficient time series (up to degree 5 and order 5) estimated using SLR/DORIS tracking data to 20 satellites (Figure 31), and a harmonic piecewise "fit" model of time-variable corrections fit to the 5x5 gravity coefficient series (used in the latest GSFC STD1404 dynamic SLR+DORIS orbits for routine TVG computations).

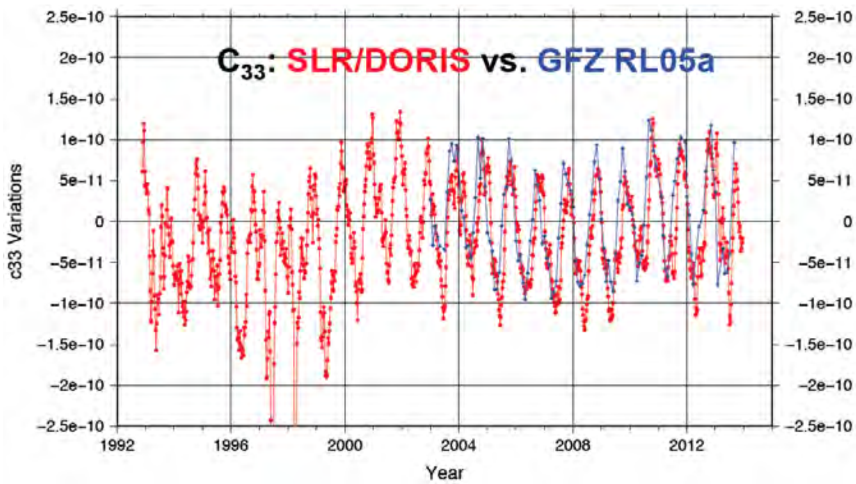

Figure 31. (Lemoine et al.) Example of very good correlation between two C_{33} gravity terms: one estimated from SLR and DORIS data of up to 20 satellites (red) and one from GRACE GFZ RL05 monthly time-series.

6.4.3.2.3 Estimate in the orbit determination process of the low degree TVG coefficient the satellite orbit is most sensitive to

Satellite POD tracking data ((GPS+)DORIS+SLR) can thus be used to account for TVG effects and/or absorb residual errors in the GRACE-based TVG models. Figure 32 shows an example of use of all the available tracking data on-board the Jason-2 satellites (GPS, DORIS and SLR) to capture time variations of the gravity field that are not present in the GRACE RL05 JPL low-degree and order spherical harmonics monthly solution. The GDR-D-like (using the GRACE JPL RL05 monthly time-series) dynamic orbit gets closer to the JPL RLSE14A reduced-dynamic orbit when estimating for the C_{31} and S_{31} gravity terms (cf**.** Figure 32) in the orbit determination solutions.

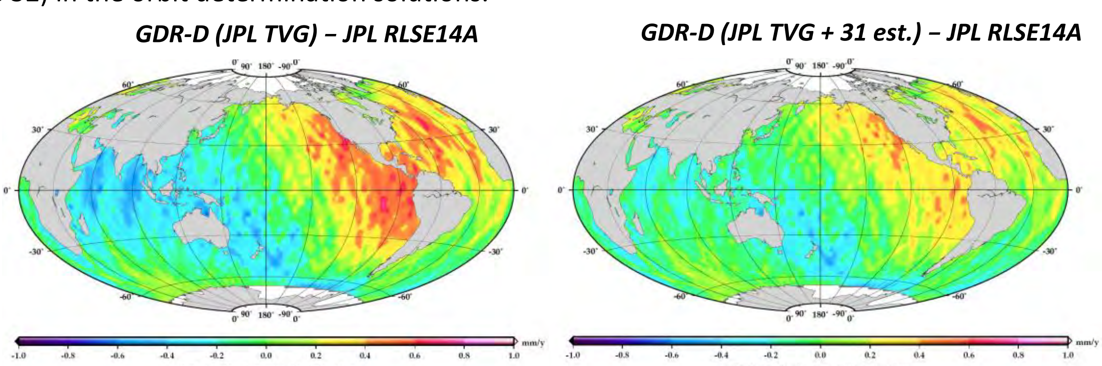

Figure 32. (Couhert et al.) Jason-2 geographically correlated radial difference drifts between CNES GDR-D-like (left) or CNES GDR-D-like + tuned gravity fields (right) orbit series and JPL RLSE14A solutions.

6.4.4 Current work and future improvements

6.4.4.1 ITRF2013

The new release of the International Terrestrial Reference Frame (ITRF2013) has been delayed and is now expected in late 2015. Two POD groups (LCA, GSFC) presented their ITRF2013 orbits, as part of the IDS contribution. A good agreement for all altimeter satellites was observed between the analysis centers' orbit series and the CNES GDR-D orbits. A 1-cm radial orbit agreement is found (Figure 33), which augurs well for the quality of the ITRF2013.

LCA – GDR-D ***GSFC STD1404 – GDR-D***

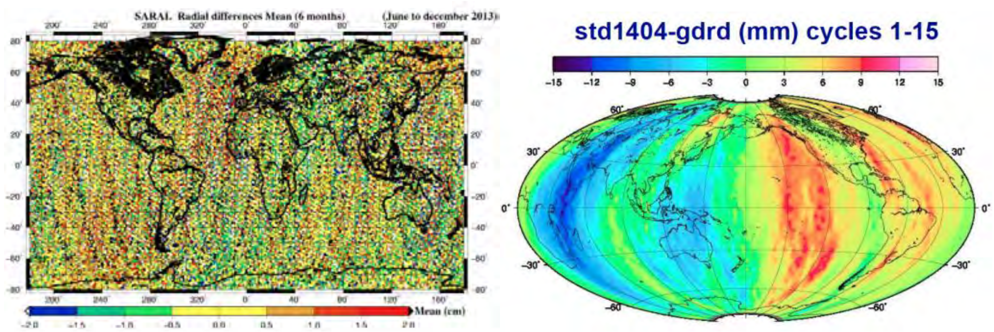

Figure 33. SARAL mean geographically correlated radial difference of CNES GDR-D orbits with respect to LCA (left: Capdeville et al.) and GSFC (right: Lemoine et al.) ITRF2013 orbits.

6.4.4.2 Integer ambiguity fixing

ESOC presented their processing of Jason-2 under development using ambiguity fixing. The ambiguity-fixed orbits have currently unexplained higher variations than with their SOL4 standard DORIS+SLR+GPS dynamic solution, but the results are promising **(**Figure 34).

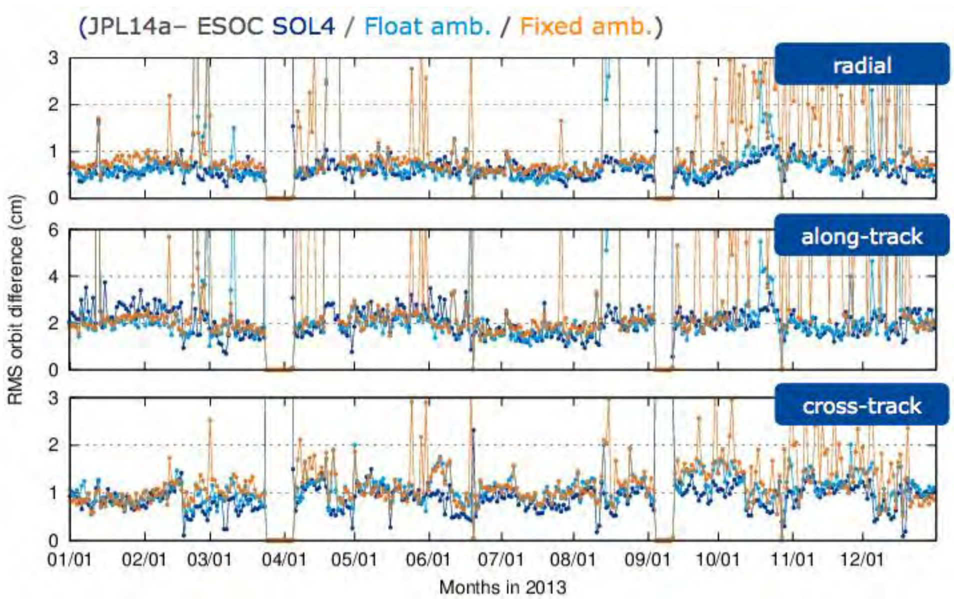

Figure 34. (Otten et al.) Daily RMS of orbit differences between JPL RLSE14A Jason-2 orbits and ESOC SOL4 DORIS+SLR+GPS dynamic orbits (dark blue), floating (light blue) and integer (orange) ambiguity resolved orbits.

6.4.4.3 Validation of new released models

The increased participation of other POD groups (GFZ, ESA, LCA), though not directly involved in the NASA/CNES/EUMETSAT/NOAA Jason-2 mission, was very encouraging and welcome. Their altimeter satellite orbits aid a further validation of orbit quality. It also enhances the possibility of validating new released models, like the tropospheric model VMF-1 implemented and tested at GFZ (Figure 35).

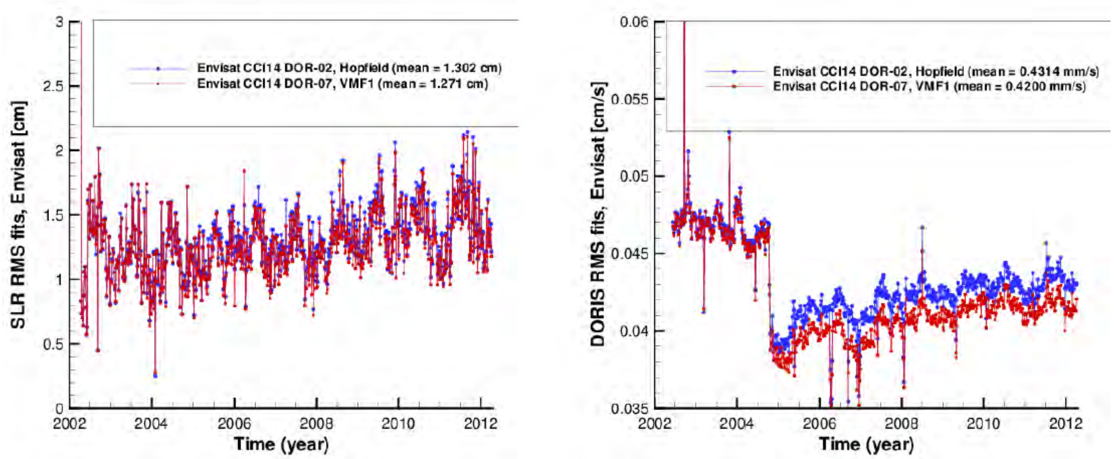

Figure 35. (Rudenko et al.) Impact of different tropospheric models (Vienna Mapping Function-1 vs. Hopfield model) for DORIS troposphere refraction correction on Envisat SLR (left) and DORIS (right) fits.

6.4.4.4 Relative orbit centering stability

The use of a seasonal non-tidal geocenter correction ("Climatological model" SLR-only; from J. Ries, Fall AGU 2013) was already discussed at the 2013 OSTST meeting in Boulder, Colorado. The orbit produced this year by CNES (GDR-E), GSFC (STD1404) and JPL included this annual geocenter model.

The estimated geocenter motion as seen by the GPS constellation agrees quite well with the one estimated by SLR in the X and Y directions, but differs reasonably in the Z direction (Figure 36). When applying the CSR SLR CM correction model to the GPS stations network, the estimated geocenter motion is reduced, but the transfer function is complex (not equal to the difference between the red and blue curves). Bias fixing also provides a different geocenter estimate from allowing the biases to float.

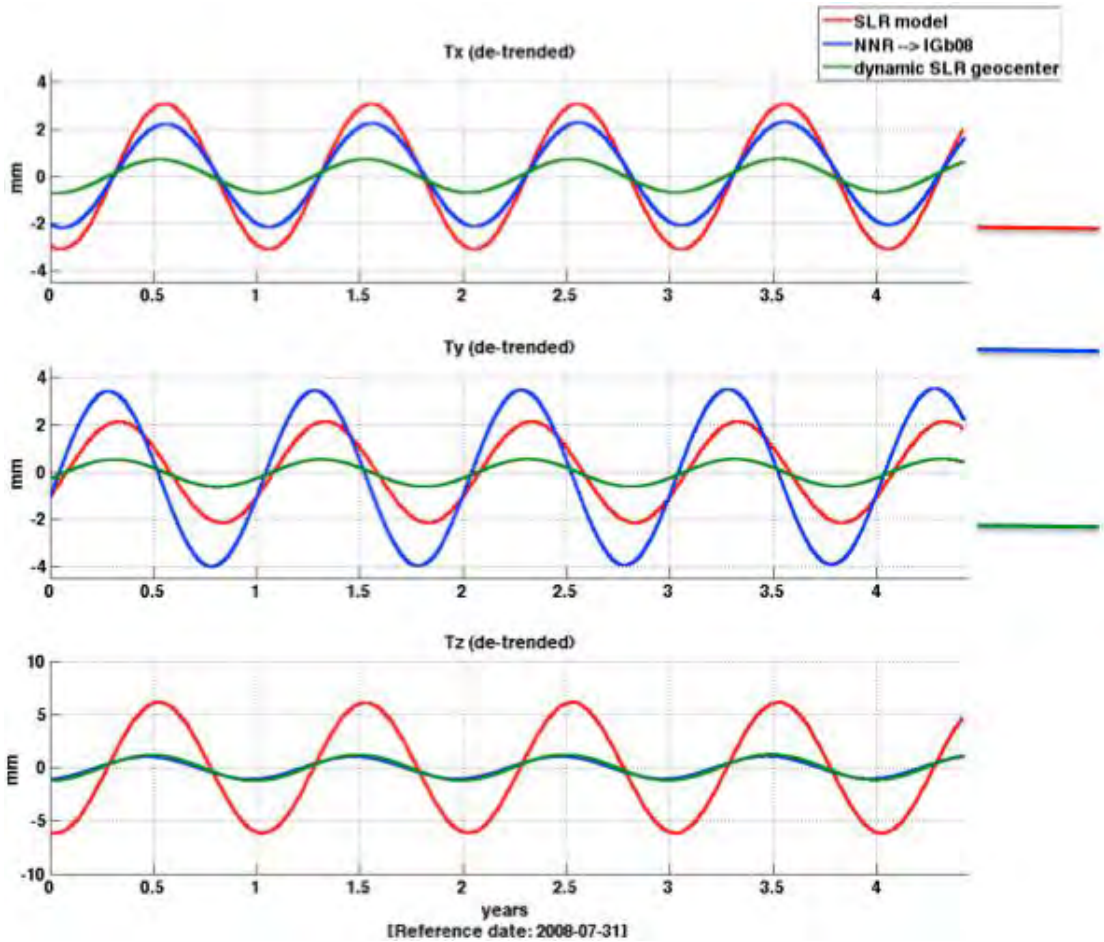

Figure 36. (Bertiger et al.) Components of the CSR SLR CM correction model (red), the estimated annual components of the translation vector for the GPS stations network determined simultaneously with the GPS constellation (blue), the same translation vector but estimated after applying the CSR SLR CM correction model to the GPS stations network (green).

The CSR Earth CM correction model largely reduces annual Z difference signature with the JPL RLSE13A orbits and improves the consistency between independent DORIS+SLR and GPS-only orbits, as noted by Melachroinos et al. (2013). The CSR Earth CM model should NOT be used in combination with Atmospheric Pressure Loading (APL) station corrections, as the CSR CM correction model was estimated without considering APL (Figure 37).

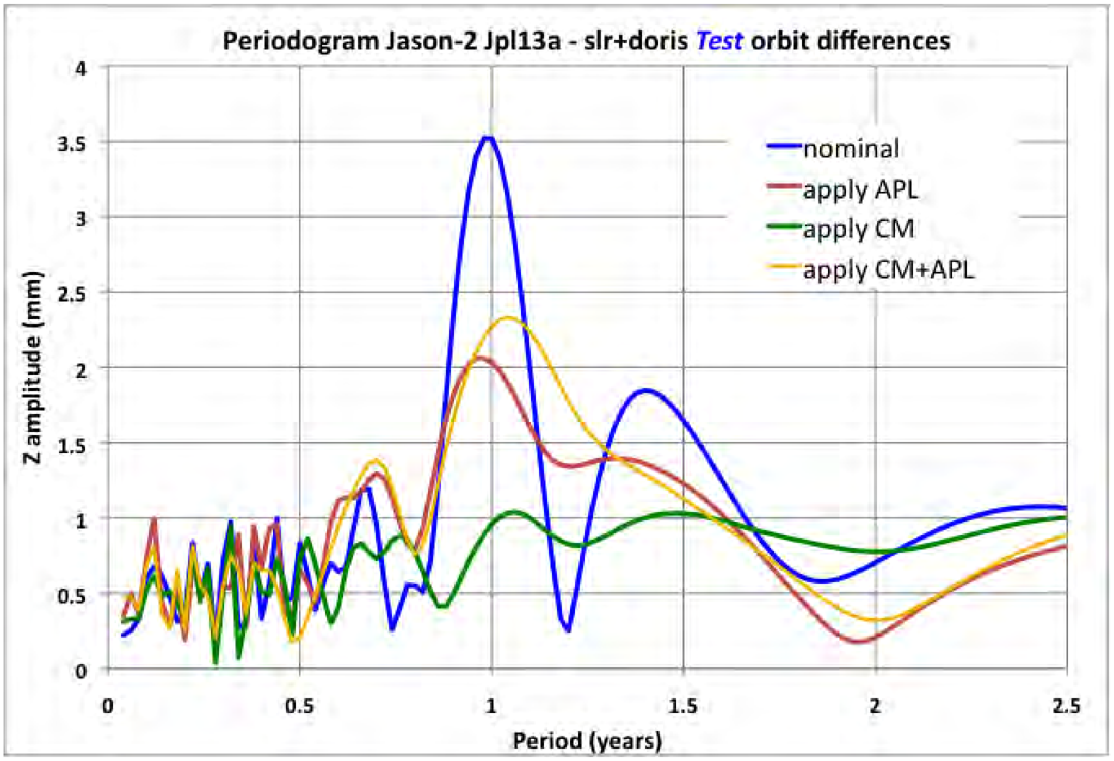

Figure 37. (Zelensky et al.) Periodogram, Jason-2 orbit mean Z differences: GSFC SLR+DORIS orbits, applying or not the CSR SLR CM and APL station deformation model, w.r.t. JPL RLSE14A solutions.

When estimating the annual components of the translation vector for the DORIS stations network determined simultaneously with Jason-2 GDR-D-like DORIS-only orbit (Figure 38), one also gets stable and consistent X and Y components but Z is affected by the elevation cut-off angle (tropospheric delay modeling error?). The reason for the odd behavior of the Z component estimates - from DORIS or GPS measurements - remains to be determined.

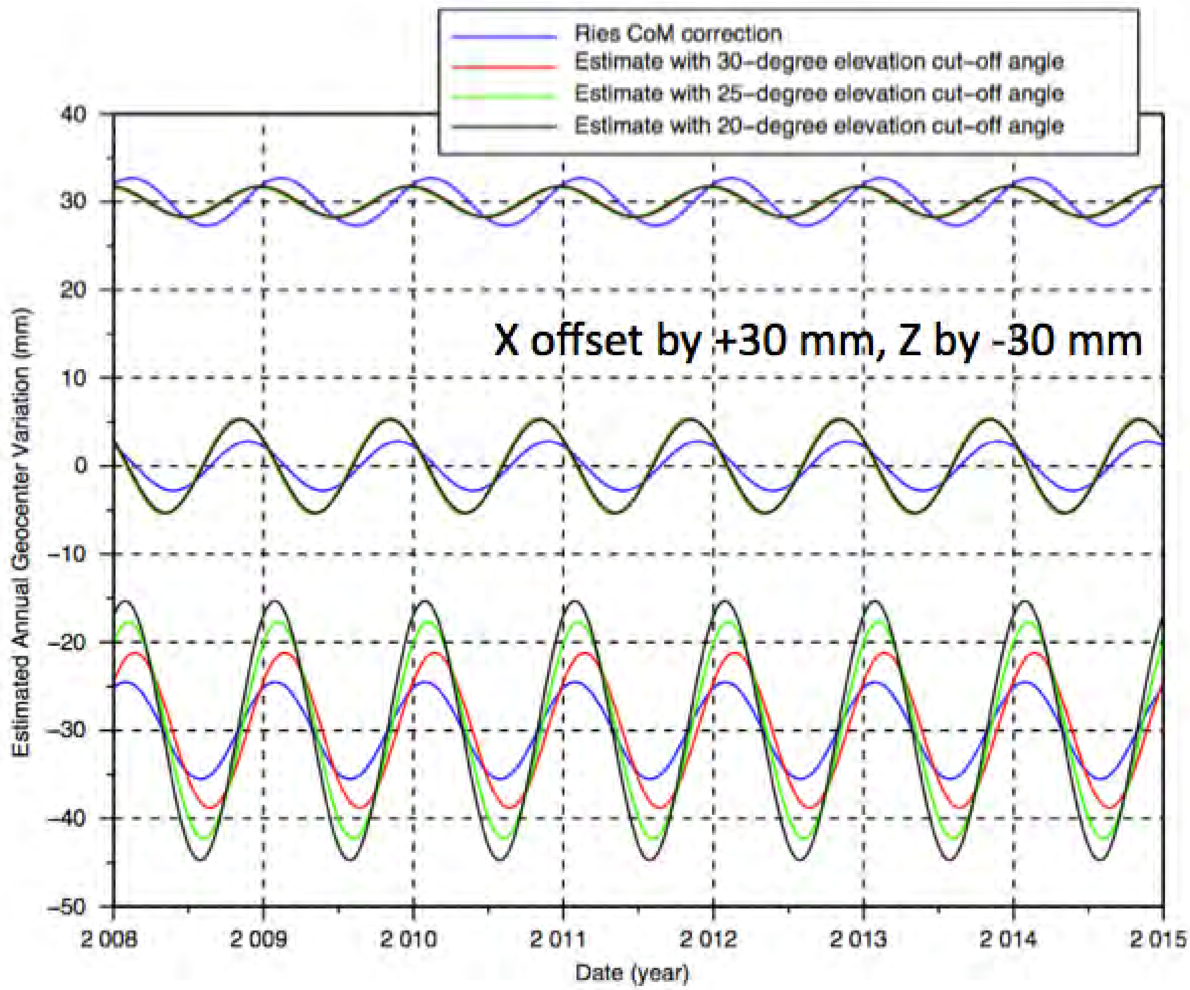

Figure 38. (Couhert et al.) Components of the CSR SLR CM correction model (blue), the estimated annual components of the translation vector for the DORIS stations network determined simultaneously with Jason-2 GDR-D-like DORIS-only orbit with different elevation cut-off angles (30°: blue, 25°: green, 20°: black).

6.4.5 Conclusions and recommendations

It is important to understand that the process of orbit determination for Jason-2 is operationally dependent on the derivation of models of time-variable gravity over the altimeter dataset period. The availability of such models should be viewed as a fundamental mission requirement to reach the required radial orbit accuracy and stability.

Presently these TVG-models are derived from GRACE analyses, in combination with other data (e.g. LAGEOS). The use of a time series of GRACE-based solutions provides the highest orbit accuracy, but from the perspective of meeting operational delivery requirements for Jason-2, is not feasible. Thus we rely on GRACE+LAGEOS-based solutions that are extrapolated by at least a year. The use of time-series either from GRACE or from alternate sources (derived from analysis of data to batch of low-orbiting SLR+DORIS satellites) can provide TVG models for orbit determination – but this issue of TVG modeling will be a recurring issue for Jason-2 and Jason-3.

We continue to observe orbit-centering discrepancies between the different POD analysis centers. The nature, and origin of these differences (examples listed below) remains to be elucidated.

- X bias of 2-3 mm (and drift?) between CNES GDR-E and GSFC STD1404.

- Y drift of ~0.5 mm/y between CNES GDR-E and GDR-D or GSFC STD1404.

- Z annual signal from 1 to 4 mm between all orbits.

While we have chosen to include a seasonal (annual) model of Earth Geocenter variations in the orbit standards, we note that these have complex transfer function to the orbit, and may not even be a pure harmonic function, as the geocenter variations which are climatologically driven exhibit a non-stationary behavior as well as secular trends.

The trend of increasing SLR residuals for the most important SLR stations – those that provide substantial amounts of data (e.g. Yarragadee, Greenbelt, as cited in this report) must be elucidated. We recommend the POD team continue their investigations, and if necessary solicit the input of the International Laser Ranging Service (ILRS) to elucidate this issue.

The main outcome of the round table was to proceed with recomputations (new standards: GSFC/STD1404, CNES/GDR-E) early in 2015 (before the launch of Jason-3), without waiting for the release of ITRF2013. When the new ITRF2013 will be validated (probably in 2016), a new time series of orbits will be planned. If an updated version of the EIGEN-GRGS.RL03.MEAN-FIELD TVG model becomes available and is validated by early 2015, then it would be used in the new orbit standards. Otherwise, the current version will be used for the GDR-E orbit computations.

6.5 Quantifying Errors and Uncertainties in Altimetry Data

Chairman: Remko Scharroo, Joel Dorandeu and Michael Ablain

6.5.1 Overview

Objectives of this session are to strengthen the link between altimetry experts and applications regarding errors in the altimetry system. This covers information exchange in both directions: the exports informing the end-users about new insights about errors in altimetry, and the end-users providing their needs and requirements in terms of errors but also in terms of error formulation.

The splinter was fruitful given the number and diversity of talks and posters, each of them tackling the error topic with a different approach. A total of 12 abstracts were submitted to the splinter session, resulting in 6 oral presentations, and 6 posters. They can be classified in 3 parts relative to mean sea level applications, ocean circulation and mesoscale, and analysis and formalism of errors.

6.5.2 Mean Sea Level applications

Eric Leuliette et al. presented “What do errors between altimeters tell us about the length of the Jason-3/Jason-CS calibration phase?” (Figure 39). The main conclusion was that global and regional biases in sea level can be determined with a 6 month tandem Cal/Val phase. Others interesting results were presented: Jason-2/CryoSat global biases are well determined after 6 months without tandem data; the radiometer calibration doesn’t benefit significantly from an extended tandem phase because of long-period errors; the seasonal, geographic variations of sea state make the SSB vulnerable to geographically-correlated errors; if the geographically-correlated errors between Jason-3 and Sentinel-6/Jason-CS were sufficiently small, 6 months would be sufficient to determine the SSB; the Jason-2/Jason-3 Cal/Val (as scheduled) will poorly sample high waves in the Northern Hemisphere, as they would be sparse at the time.

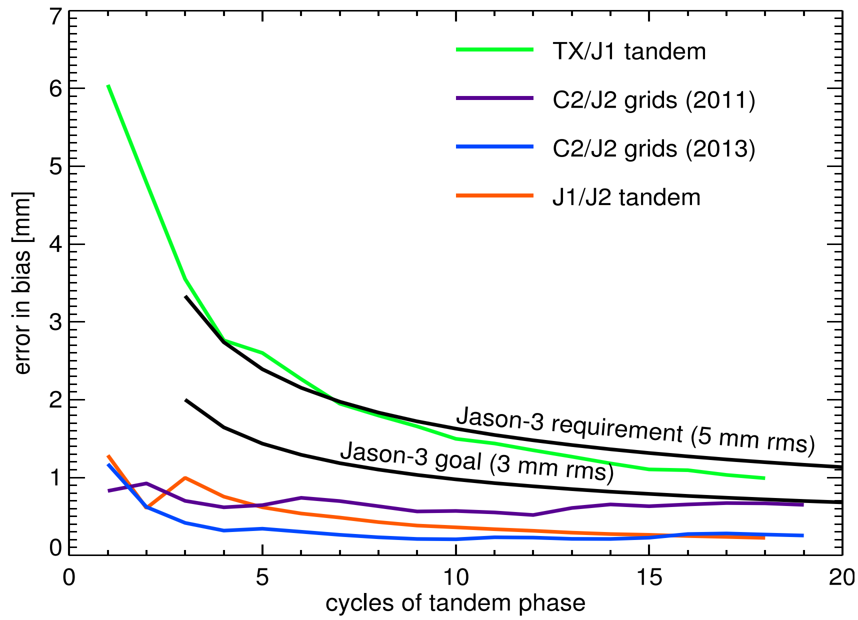

Figure 39. Bias error (= rms of cycle biases/sqrt(# cycles)) versus the cycle number of tandem phase

Martin Scharffenberg et al. gave a talk about the “Sea Level ECV quality assessment via global Ocean model assimilation”. He presented the work performed in the framework of the CCI project (ESA), in which the Sea Level ECV from AVISO (2010 version) and the Sea Level CCI (V1.1 version) are compared (Figure 40). The main conclusions are that currently errors of the model are larger than altimetry errors, but also that the description of altimetry errors (at climate scale) is very useful for the validation of model outputs.

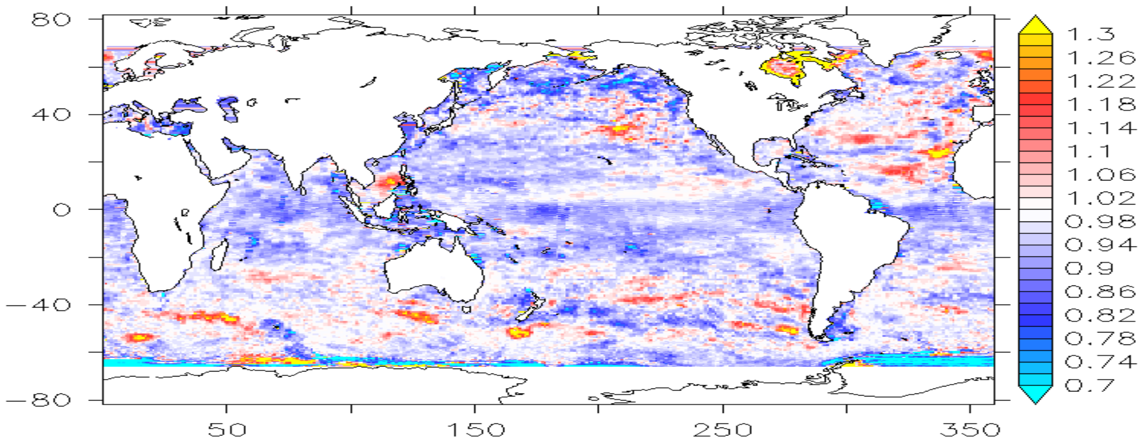

Figure 40. Ratio of the RMS differences RMS_AVISO and RMS_SL_cci between the GECCO model and the satellite time series of ERS-1, ERS-2 and ENVISAT in percent improvement.

Lionel Zawadzki al. (poster) provided the envelope errors of the global MSL time series for Jason-1 and Jason-2 missions. Similar work is ongoing for the other missions.

6.5.3 Ocean circulation and mesoscale

Isabelle Pujol et al. provided a better evaluation of errors in merged DUACS/AVISO Sea Level products at the mesoscale (Figure 41): the formal mapping error (e.g. instantaneous error associated with space-time sampling and gridding); the upper bound error estimation at the mesoscale (based on comparison between maps and independent along-track data).

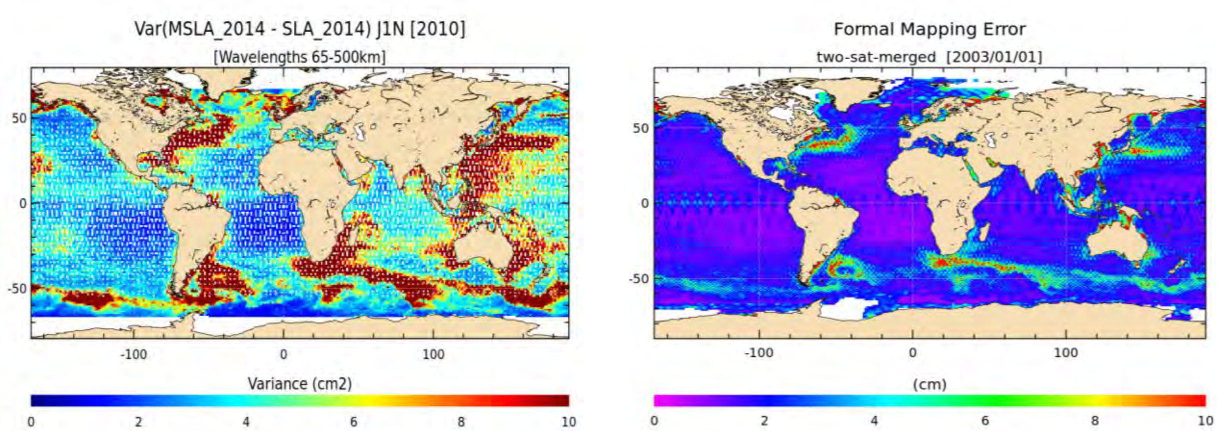

Figure 41. map of formal mapping error (on left) and upper bound error estimation at the mesoscale (on right)

Isabelle Pujol presented on behalf of Mounir Benkiran the impact of the assimilation of SLA along-track observations on the high-frequency signal in the IBI operational ocean modeling system (Figure 42). Model errors are reduced when assimilating data consistent with the model resolution. The main message is that each different assimilation purpose requires tailored measurement products with their associated error budget.

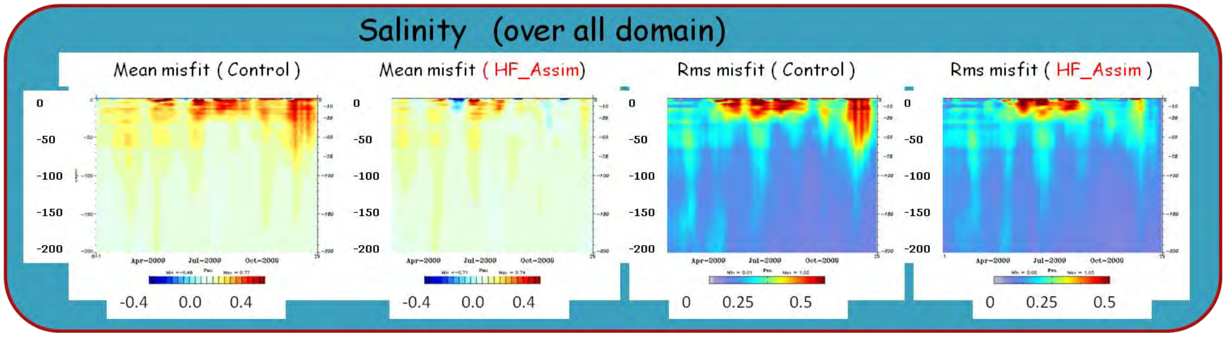

Figure 42. Assessment of the model outputs (for the salinity here) analyzing the "misfit" (⇔ data minus model forecast differences) in several configurations.

In addition to these talks, Simon Verrier et al. (Poster) tested the impact of present and future altimetric missions on ocean forecasts as a result of the change in error budget from LRM to SAR measurements. They showed no impact is detected on the model assimilation since currently errors of the model are significantly larger than the altimetry errors.

Overall, a carry-away message is that the altimeter errors have dropped significantly below those of the models. Operational ocean models and assimilation schemes have to be improved to take full advantage of the extraordinary accuracy of altimeter data.

6.5.4 Analysis and formalism of errors

Jean-Christophe Poisson et al. presented a new approach to improve the detection of ocean surface heterogeneities of SARAL/AltiKa measurements based on wavelet analysis (Figure 43). The Continuous Wavelet Transform (CWT) is a powerful tool to detect short scale coherent variations in a time series. Applied to the slope of the waveform trailing edge, it allows flagging of backscattering variations in the waveform footprint like rain cells, sigma-0 blooms or modifications of the sea state. Rain and bloom measurements (~15%) are not sufficient to explain the SLA spectral hump presented by Pierre Thibaut in the previous OSTST (Boulder, 2013). The spectral hump is greatly reduced by a drastic threshold on the wavelet power spectrum, which leads to edit almost 50% of data all over the globe. New retracking algorithms are needed to decorrelate backscattering heterogeneities in the footprint from the range estimation (cf Laiba Amarouche's talk about the DCORE retracking) and to be able to reach smaller scales. Note that the information on the ocean surface heterogeneities of altimeter measurements could be determined for other altimeter missions and provided to users (via ODES).

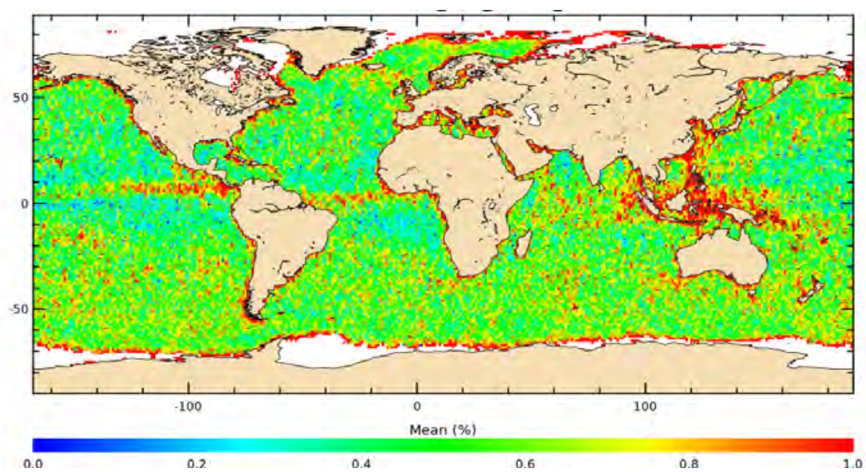

Figure 43. Percentage of edited data by 1°x1° boxes

Annabelle Olivier et al. presented a spectral error budget of Nadir Altimetric missions. The characterization of the errors has been improved by performing a spectral analysis of altimetric signal and errors for Jason-2 measurements (Figure 44). The spectral analysis of the SLA corrections gives information on their distribution of energy relative to the spatial scales; the error of each correction is supposed to be below the correction itself. As it is an upper bound, multiple alternatives for similar geophysical corrections can be compared. The envelope around the cumulative spectrum is expected to better describe all the temporal/spatial variations of the error and its correlations. This work is ongoing and the objective is to provide a spectral error budget of sea level. Furthermore, the method is complementary to other error estimation techniques and should be carried on jointly with them. For this, multiple observation systems for each correction must be carried on; the method can also be applied to other missions during cross-calibration phases.

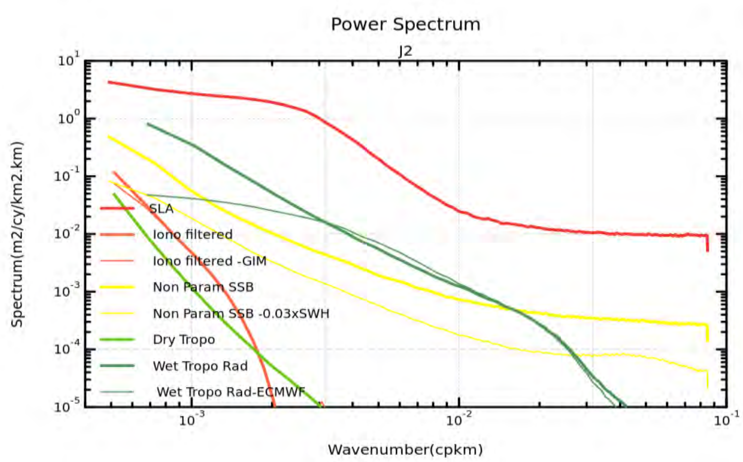

Figure 44. Error spectra of all the altimeter corrections and the sea level estimations for Jason-2

In addition to these talks, two posters were presented by Graham Quartly et al. concerning the improvements of the sea level estimates in the Arctic by filtering out better the waveforms impacted by sea ice, and another one by Gérald Dibarboure who pointed out the interest of a new approach based on the Radon transform to detect anisotropic error sources.

6.5.5 Conclusion and recommendations

From the last OSTST, several improvements have been performed on altimeter error characterization: better interaction between end-users and altimeter groups are observed during the splinter as well as during the round table, new insights in altimeter error at short wavelength have been characterized and understood, new methods to characterize the error for climate scales have been developed. Finally, improvements in the error formulation continue to be done.

In terms of recommendations, the splinter encourages feedbacks from end-users to better characterize the error for their studies. Furthermore, errors should not only be in the form of a static table; instead they should consist of errors as function of wavelength and conditions (e.g. sea state).

We also need to characterize the errors on regional sea level trends and to provide these errors (e.g. in peer review papers, inclusion into products). Moreover, the propagation of measurements errors into the final products should be further studied.

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

Chairs: Pascal Bonnefond, Shailen Desai, Bruce Haines, Eric Leuliette, and Nicolas Picot

6.6.1 Introduction

Determining the random and systematic errors in the fundamental instrument observations and in the Level-2 geophysical data products is a continuing process that involves participation of both the project teams and the OSTST investigators. The principal objectives of joint verification are to:

1. Assess the performance of the measurement system, including the altimeter and orbit-determination subsystems;
2. Improve ground and on-board processing; and
3. Enable a seamless and accurate connection between the current (OSTM/Jason-2) and legacy (TOPEX/Poseidon and Jason-1) time series.

CAL/VAL efforts are essential to ensure the integrity of the long-term climate record at the 1-mm/yr level. These activities are conducted based on dedicated in-situ observations, statistics, cross comparisons between models, different algorithms and external satellite data. The studies go well beyond validation of the overarching error budget underlying the mission requirements. They focus in particular on the temporal and geographically correlated characteristics of the errors. Reduction of this class of errors is critical, since they are conspicuously damaging to estimates of ocean circulation and sea level. Because of the usual huge number of contributions it has been decided to separate the CALVAL splinter into two parts:

1. Local calibration/validation (focusing on bias); and
2. Global calibration/validation (focusing on corrections quality assessment and error budget assessment)

The primary goals of this session were:

- to assess the performance of the measurement system, including the altimeter, radiometer and orbit-determination subsystems
- to improve ground and on-board processing; and

- to enable the development of a seamless and accurate climate data record from the current (OSTM/Jason-2) and legacy (TOPEX/Poseidon and Jason-1) time series.

6.6.2 Results from in-situ calibration sites

Absolute bias estimates from dedicated sites and also from regional experiments continue to show good agreement, with ~1 cm (RMS) differences for T/P, Jason-1 and Jason-2. For the first time, results from the three longest-recording sites—Corsica, Harvest and Bass Strait—were combined into a single time series (Watson et al.). Shown in Figure 45, this time series is based on nearly 2000 combined overflights, and testifies to the good coherence of the results. Figure 46 provides the breakdown of the SSH bias estimates per site providing additional estimates from other in-situ calibration programs.

While the overall Jason-2 SSH bias for GDR-D is slightly positive (~ 1 cm), the estimate is considered statistically indistinguishable from zero. At this level, site-dependent in situ errors and geographically-correlated errors in the altimeter measurement system are important contributors.

The Jason-1 SSH bias estimate from the dedicated sites remains at ~10 cm, based on the currently available (C) version of the GDR. The 2015 transition to the GDR-E standard, however, is expected to reduce the residual bias to insignificance (Figure 47). Most of the anticipated bias reduction will come from the well-documented corrections to the Poseidon-2 ranges (Desjonquères et al.), but also from updates to the sea-state bias model, orbit solutions, and wet troposphere corrections. The legacy TOPEX/Poseidon systems also show small (1-cm level) SSH biases, implying that the bias estimates are now insignificantly different from zero across all three missions and five altimeter measurement systems spanning the last two decades (Figure 47).

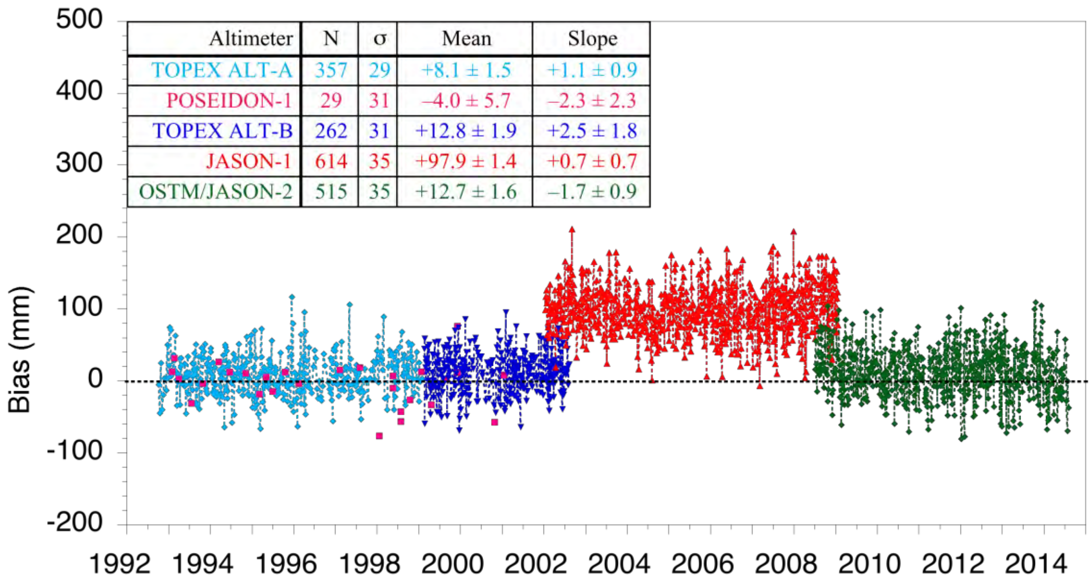

Figure 45. Combined time series of absolute SSH bias estimates from Harvest, Corsica and Bass Strait, dating to the launch of TOPEX/Poseidon in 1992 (Watson et al.). The most current versions of the official GDR products are used.

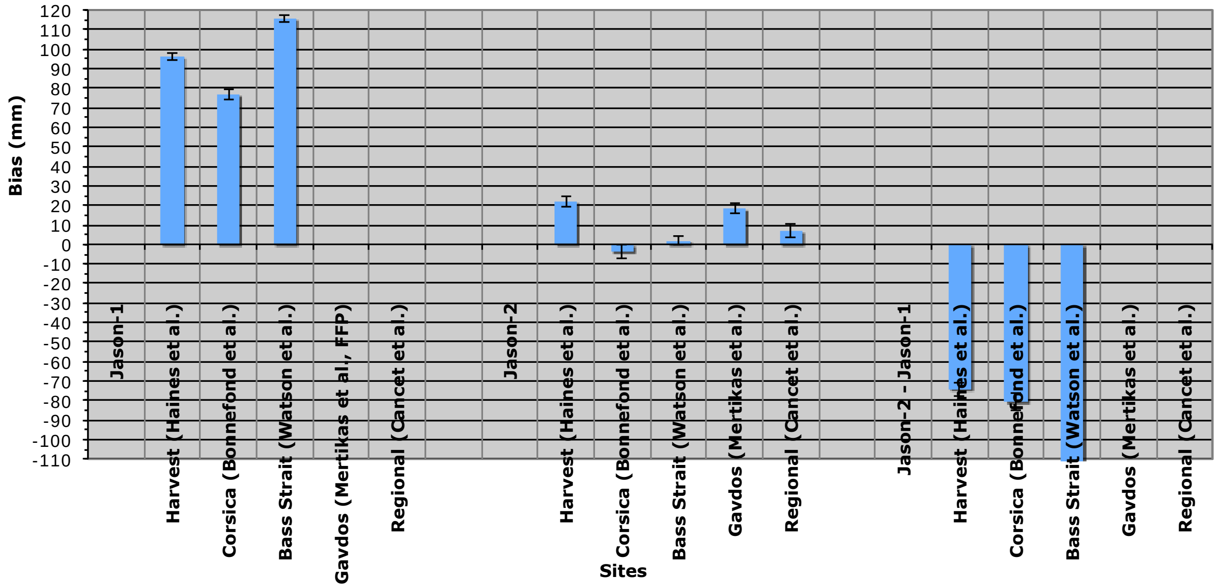

Figure 46. Absolute bias values for Jason-1 and Jason-2 from the different calibration sites using the latest versions of the official products (Jason-1 GDR-C and Jason-2 GDR-D).

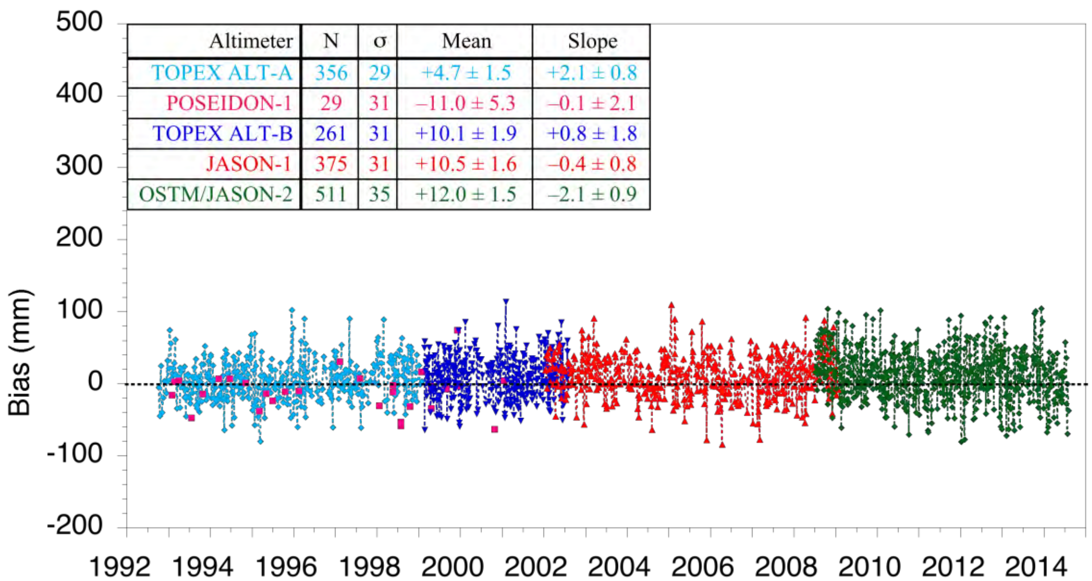

Figure 47. Combined time series of absolute SSH bias estimates from Harvest, Corsica and Bass Strait, dating to the launch of TOPEX/Poseidon in 1992 (Watson et al.). Expected updates to the official products are used in order to illustrate anticipated improvements, notably for Jason-1 due to the upcoming GDR-E release.

In terms of drift, the combined results (Figure 45 and Figure 47) shows estimates from 1–2 mm/yr, depending on the altimeter measurements system. The range of Jason-2 drift estimates among the three sites has been significantly reduced over the past year—from ± 6 mm/yr to ±3 mm/yr—but the discrepancies underscore that challenges remain. Estimating drift from a single site pushes all components of the measurement system to the limit: geodetic positioning, water level, altimetry, orbits, troposphere, reference frames etc. Uncertainty in vertical land motion (VLM) is a particularly important error source, especially at Bass Strait and Harvest. Corsica is the only site among the three with negligible land motion.

The impact of land contamination, notably of the radiometer wet path delay correction but also of the altimeter, warrants additional research. Understanding land contamination informs the calibration connection between the open ocean and coast, but also enhances emerging applications in coastal altimetry. Among the three primary sites, Corsica suffers the most from land contamination. Enhanced wet path delay (EPD) corrections continue to prove valuable for (land-contaminated) calibration sites. Such enhanced corrections are now fully integrated in Jason-2 GDR-D products and will be included in the upcoming GDR-E product. A pre-release of the GDR-E JMR correction yielded promising results at Harvest, where JMR–GPS instabilities were decreased and a ~1 cm JMR–AMR relative bias during the Jason-2 formation flight phase was reduced to insignificance.

Other important calibration initiatives (e.g., Gavdos, Issykul, Kavaratti) are now routinely delivering results. Mertikas et al. reported new SSH bias estimate results for Jason-2 and HY-2 from Gavdos, but also provided news on a permanent altimeter transponder site currently supporting Cryosat-2, with plans for both the Jason and Sentinel series of missions. New insights on the behavior of the altimeter system biases over inland waters were provided by Cretaux et al., and the regional calibration technique developed by Cancet et al. has been extended for the first time from Corsica to both Harvest and Bass Strait. A new site at Kavaratti Island in the Arabia Sea is supporting both Jason and SARAL (Babu et al.). These programs are contributing to refining of bias and drift estimates, and to characterizing the behavior of the altimeter systems over different land and water surfaces, while supporting other missions.

6.6.3 Global validation studies

6.6.3.1 Jason-2 Mission

More than 6 years of Jason-2 measurements are now publicly available as version D (O/I) GDR products. Validations activities on these products are performed as a joint effort between the CNES and JPL Cal/Val teams prior to their release. Data availability continues to be excellent, with 99.9% of over-ocean data available when excluding calibration and platform incidents. Sea surface height error, as determined from crossover analysis, is 3.5 and 3.6 cm for the Jason-2 GDR (version D) and Jason-1 (version C) data products. (*Ablain et el*.).

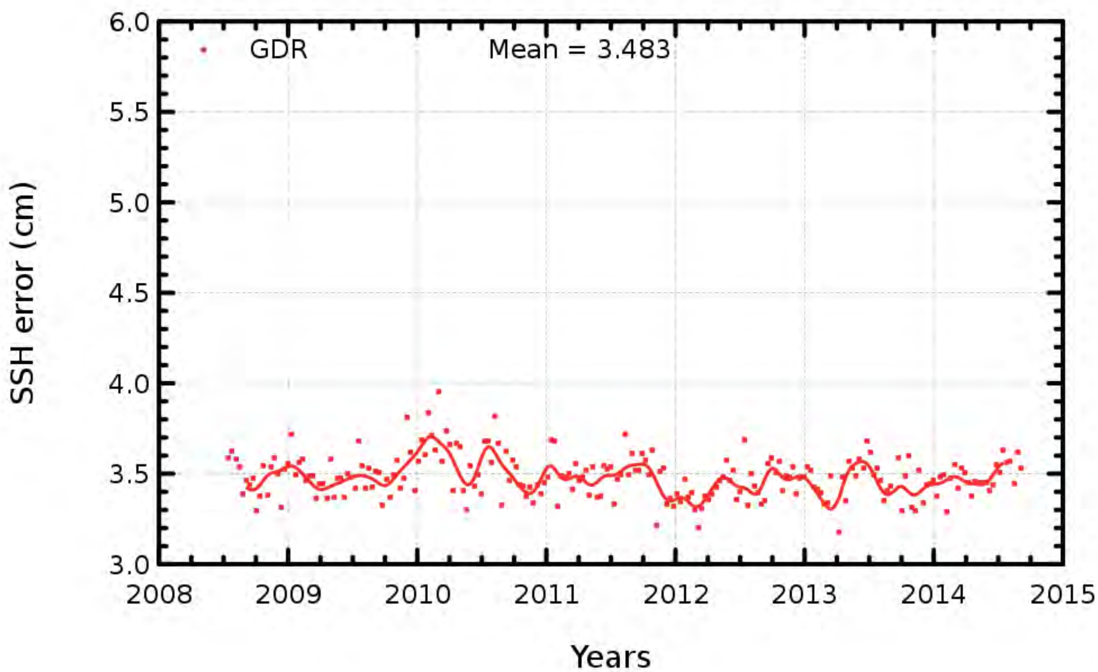

Figure 48. Jason-2 SSH system error based upon RMS of SSH crossover differences (Ablain et al.)

No drift in the Jason-2 sea surface height measurements is apparent when compared to tide gauge observations (*Prandi et al*. and *Leuliette et al.*). Nevertheless, additional improvements to the CNES POE, referred to at POE version E, demonstrate impact on regional mean sea level trends at the level of +/- 1 mm/year. These improvements primarily arise from upgrades to the gravity field and use of geocenter models.

Comparisons of the 22-year record of TOPEX/Jason-1/Jason-2 with tide gauges (*Valladeau et al.*, Leuliette et al., Watson et al.) are consistent with no significant drift (e.g. Figure 51) or suggest a significant overestimate of GMSL (*Watson et al*.), depending on the analysis technique applied. These results underscore that tide-gauge comparison techniques warrant further investigation, and that the different groups should cross-compare their methods (*Mitchum et al.*). A comparison framework could include comparison methodologies, altimetry processing, station selection, vertical land motion estimates (*Schöne et al.)*, and error analyses.

While GRACE mass fields and Argo profiles continue to be used to constrain global and regional drifts, the technique is sensitive to the reference depth used for Argo analyses and the GRACE solution employed (*Legeais et al.*). The comparison should improve as more Argo profiles report from 1900 dbar and as the Argo network evolves to include some deep Argo (4000 dbar) profiles.

Applying a GDR version E tide model, like GOT4.10c (based only on Jason data), to Jason and CryoSat-2 reduces inter-satellite differences and eliminates most spurious variations in global mean sea level at 59-days in Jason-2 and 244-days in CryoSat-2 (*Leuliette et al.*).

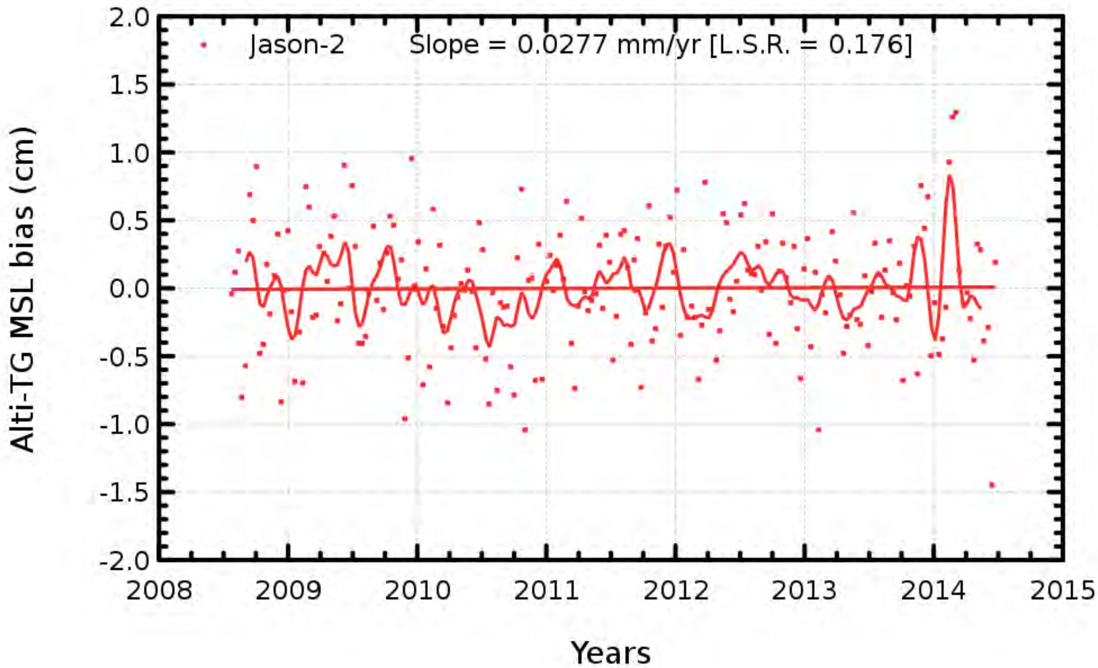

Figure 49. Comparison of sea surface height observation between Jason-2 and tide gauge observations (Prandi et al.)

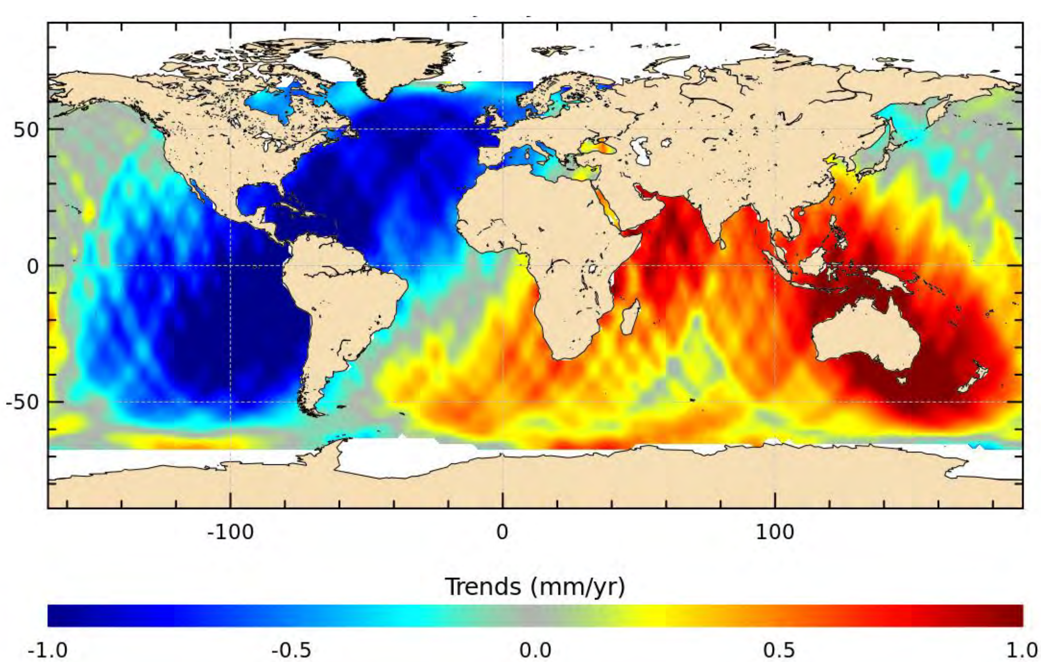

Figure 50. Long-term trend between the version E and D precise orbit ephemerides for Jason-2 (POE-E – POE-D) (Ablain et al.)

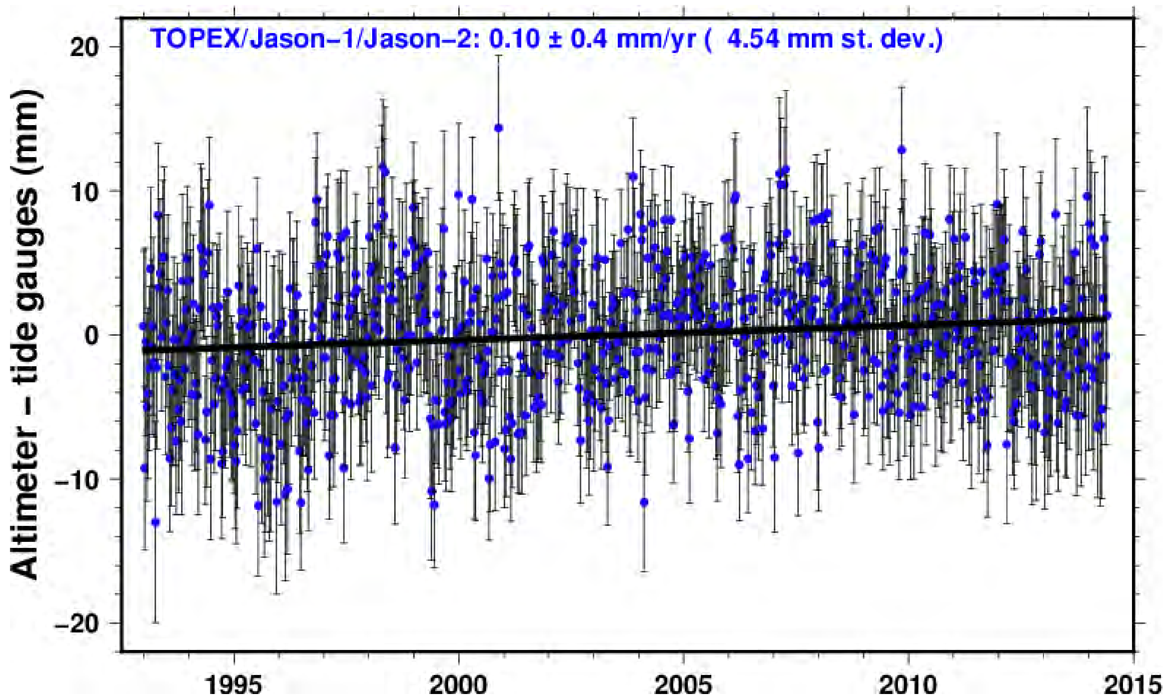

Figure 51. Comparison of sea surface height observations between TOPEX/Jason-1/Jason-2 and tide gauge observations (Leuliette et al.)

6.6.3.2 SARAL Mission

The use of short-latency (<6 hours) crossovers between the Jason-2 and SARAL measurement systems also provides a measure of the remarkable precision available from both systems (*Desai et al.,* Table 2). The SARAL data demonstrate slightly better mono-mission sea surface height crossover measurement performance than Jason-2, as well as better performance with regards to the sea level anomaly spectrum (*Prandi et al*). Global analysis suggests that the SARAL sea surface height measurements are biased low, relative to Jason-2, by 4-6 cm (*Prandi et al., Desai et al*.). There are ongoing efforts to further improve the SARAL (Ka-band) models for altimeter wind speed and sea state bias that can facilitate additional improvements to the SARAL measurement system.

Table 2. Standard Deviation of Short-Latency (< 6 hours) Cross-Over Measurement Differences Between Jason-2 and SARAL (Desai et al.).

Parameter	Standard Deviation of Cross Over Differences
Significant Wave Height	0.10 m
Backscatter Coefficients	0.22 dB
Radiometer Wet Troposphere Correction	0.68 cm
Sea Surface Height (Jason-2 GDR-D and SARAL GDR-T)	3.08 cm

Sea Surface Height (Jason-2 GDR-D and Calibrated SARAL)	2.81 cm

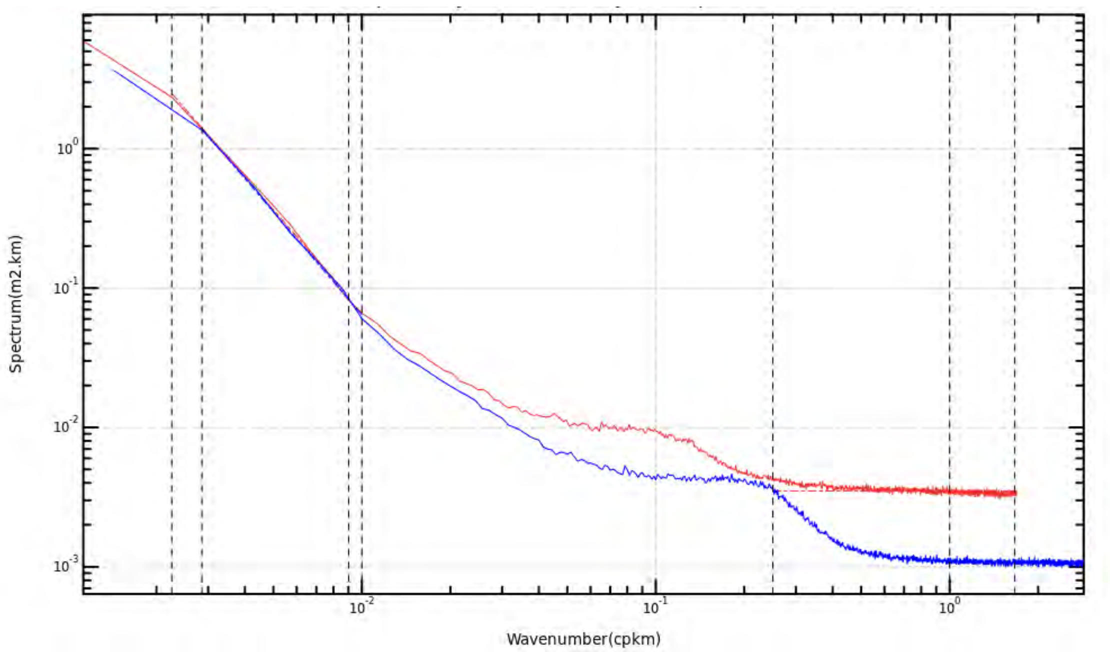

Figure 52. Sea level anomaly spectra for the Jason-2 (red) and SARAL (blue) missions (Prandi et al.)

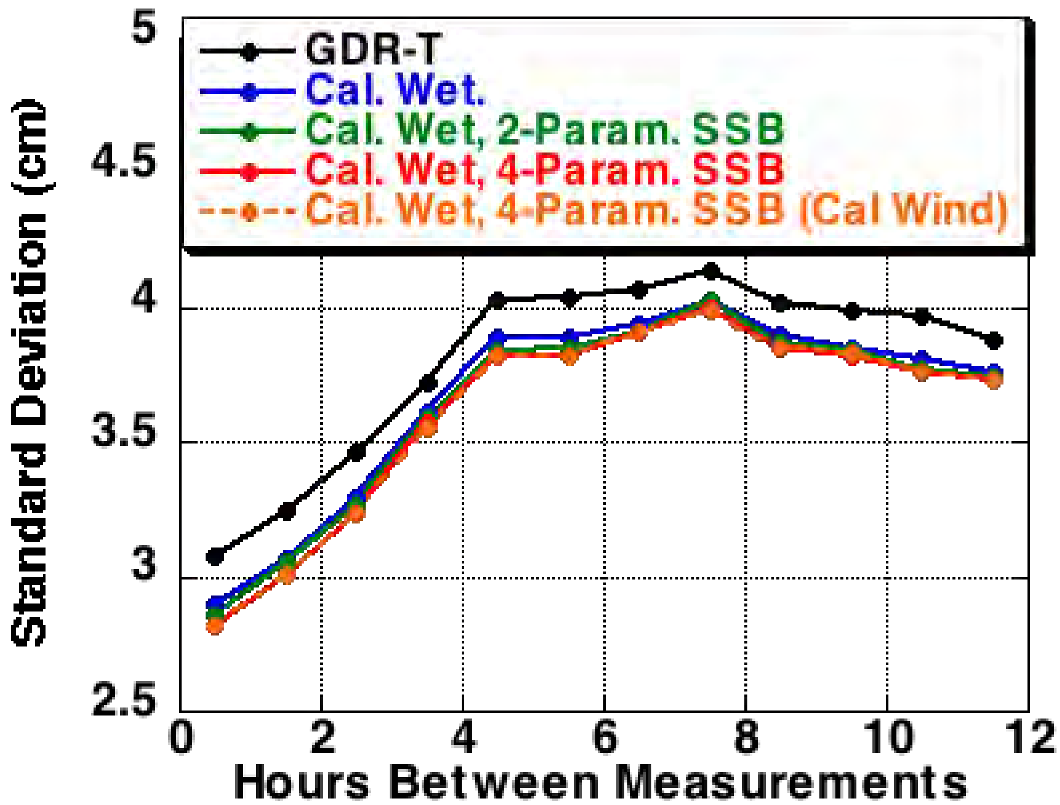

Figure 53. Standard deviation of short-latency inter-satellite cross-over differences between Jason-2 GDR-D and SARAL GDR-T sea surface height (Desai et al.). Improvements to the SARAL measurements are achieved through additional calibration of the altimeter wind speed and sea state bias models.

6.6.3.3 Cryosat and HY-2A Missions

The Cryosat mission continues to demonstrate that it can provide valuable measurements of sea surface height for mesoscale studies. The additional benefit of Cryosat is its ability to provide sea surface height measurements at high latitudes (> 66 degrees) (*Olivier et al.)*. *Olivier et al.* showed that dedicated tuning of data selection on approach to land (coasts) and ice using external geophysical information has the potential to recover more observations in these areas.

Picot et al showed that CNES is continuing to evaluate measurements from the HY2A mission. Data availability over the ocean is ~90%, with missing data primarily related to telemetry incidents. While the original HY2A data are negatively impacted by a variety of errors (e.g., USO drift, ground processing errors), cross-calibration with the reference Jason-2 mission is capable of significantly improving the HY2A data quality. Accurate and daily monitoring of the data quality from HY2A is necessary, and additional improvements require additional information from NSOAS.

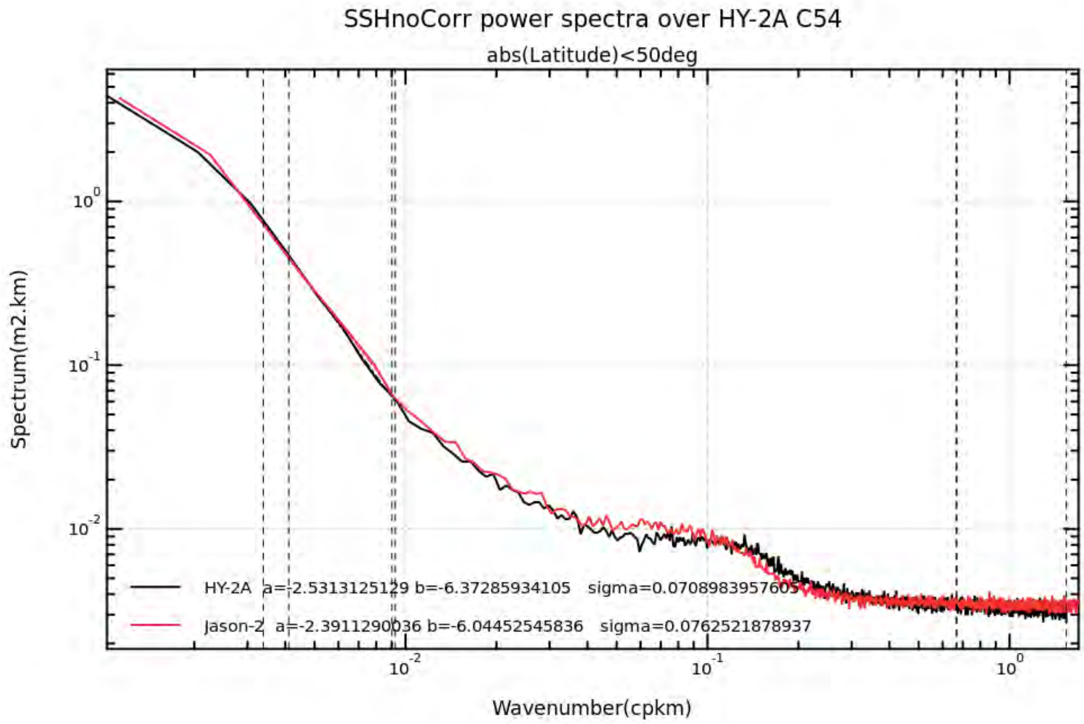

Figure 54. Spectral content of HY2A sea surface height shows similar performance to Jason-2, after improved processing is applied to HY2A data.

6.6.4 Round table summary

Key points raised by the Project Scientists:

1. **Jason-2/Jason-3 transition:**
   - DIODE/DEM mode for Jason-2 &/or Jason-3 during formation phase

   Proposal from the project is approved (median tracking for Jason-2 and change to DEM mode every other cycle for Jason-3), recalling that Jason-3 offers the required flexibility (on-board commanding enabled by the so-called ‘bit mode’, implying easy updates to the tracking mode without mission impacts)

   More information on this mode is required … Action on the project side to provide to OSTST a technical note describing the DIODE/DEM mode.

   Review of the product flag values is required (not linked to the Diode/DEM mode)

2. **Other topics:**
   - LRM/SAR

   CP4O project results provides **good confidence of SAR data quality over ocean**. PLRM mode also provides valuable inputs.

   Additional studies required on SSB, swell, sigma naught events… Also on other surfaces (inland water, sea-ice, land ice)

   Sentinel-3: **proposal to implement a SAR/LRM geographical box** like the one implemented on CryoSat-2. Duration to be assessed.
   - Jason-3 Numerical Retracker

Prototype implementation is approved, tentatively with additional algorithms (DCOre retracking, 3 parameter SSB…) if feasible.

<u>Seed Questions :</u>

1. **Following Venice 2012 discussions**: how to develop/promote a high accuracy/stability tide gauge network to be able to monitor altimetry?
   - Are we able to define such a subnetwork?

   G. Mitchum thinks that we must let the different groups define their own criteria to select the reliable network.

   At least a "benchmark" network could be interesting to cross-compare results from different groups.

   For the monitoring of the altimeter system **additional networks (in land water)** should also be used
   - Which kind of instrumentation (radar, pressure, CGPS, …)

   A lot of evolutions have been performed on the instrumentation since 1850 without impacts on the long term monitoring (G. Mitchum). However, recent instruments improves the accuracy and stability but with shorter time series.

   Recommend that OSTST endorse the 2012 The Global Sea Level Observing System Implementation Plan
   - Which accuracy/stability is needed?

   Better vertical land motion monitoring (long lasting open point …) is required – GPS and/or other means should be implemented (we cannot rely on 'close GPS' sites). This would also provide additional GPS information in coastal areas for radiometer correction analysis

   PIs to provide the expected impacts on the long-term monitoring accuracy.

2. **How to better insure external monitoring of the radiometer behavior (coastal contamination, long-term stability, …)?**
   - GPS? Ground radiometers?...
   - Radiometer remains a large source of uncertainty (refer to Shannon presentation) – use of model reanalysis (ERA Interim, others…) is very valuable.
   - GPS @ tide gauges coastal network would be valuable
   - Jason-3 will improve the long term stability – Jason-CS will be even better
   - **Bathymetry**: key information for SWOT mission
   - Resume the work on the computation of bathymetry on European side
   - **Long term stability of the wind/waves retrieval:** current status? can it be improved? what is the system limitation?
   - Wind is an essential variable: project to analyze the system capability on this variable

The following recommendations were made:

- **TOPEX reprocessing is a high priority to improve the 20-year record.**
- Cal/Val should be approached from a multi-mission perspective.
  - Provides means to develop new standards for data products.
    - Precise orbit determination, retracking, sea state bias.
- Further development of regional calibration techniques.
  - Include other missions.
  - Expose errors impacting calibration of reference (Jason) missions.

- Continue to develop approaches to improve long-term stability of radiometer wet troposphere delay measurements.
  - Significant source for limitations in long-term stability.
- Concerted effort to characterize and reduce systematic in-situ errors.
  - Working group for in-situ measurements, and exchange of data.
- Further investigation of potential altimetric sources for unusual Jason-2 drift estimates.

6.7 The Geoid, Mean Sea Surfaces and Mean Dynamic topography

Chairs: Ole Andersen and Yannice Faugere

This splinter had a total of 6 oral presentations and 9 posters

The oral presentations were the following:

- *(Knudsen at al.)* Combining a Global GOCE Derived MDT with In-situ Observation for Regional Enhancement of the Mean Dynamic Topography
- *(Maximenko et al.)* How well can we measure the ocean's mean dynamic topography from space?
- *(Bruinsma and Mulet)* The new ESA/GOCE geoid model from the direct method and its impact on the
- *(Smith)* Slope Correction for Ocean Radar Altimetry
- *(Labroue)* Linking Conventional and SAR Altimetry with Cryosat-2: An assessment over the whole mission
- *(Andersen et al.)* What Cryosat-2 revealed about existing MSS models in coastal regions

The 9 posters were the following

- *(Bosch et al.)* Validating space-based time-variable dynamic ocean topography by surface currents observed by ARGO floats and surface drifters
- *(Gille et al.)* Improving the geoid: Combining altimetry and mean dynamic topography in the California Coastal Ocean
- *(Knudsen et al.)* Combining a Global GOCE Derived MDT with In-situ Observation for Regional Enhancement of the Mean Dynamic Topography.
- *(Knudsen et al.)* GOCE User Toolbox and Tutorial
- *(Kosempa et al.)* Southern Ocean Velocity and Geostrophic Transport Fields Estimated by Combining Jason Altimetry and Argo Data
- *(MULET et al.)*Assessment of the Dynamic Topographies in the Arctic Ocean by comparing different methods (direct versus classical method)
- *(Rio et al.)*Potential use of HF radar and SAR velocities for regional High Resolution Mean Dynamic Topography Estimation
- *(Sandwell et al*.)New Global Marine Gravity from CryoSat-2 and Jason-1 Reveals Buried Tectonic Structure
- *(Vigo et al.)* Seasonal variations of the geostrophic ocean surface circulation inferred from the combination of altimetry and GOCE data

The importance of the GOCE geoid was highlighted in several of the poster/presentation. The last release of ESA/GOCE geoid model EGM-DIR-5 and EGM-TIM-5 still present improvements in terms of accuracy (Figure 55) and impact on MDT determination (

Figure 56). Additional information was shown to be important to refine the MDT. The use of in situ data improves the fine scales of the field but the calibration of these data is crucial. As an example, the correction of the effect of the drogue loss for drifting buoys was described. The interest of other sources of data like SAR interferometer or HF radar data has also been demonstrated (Rio et al., Figure 57)

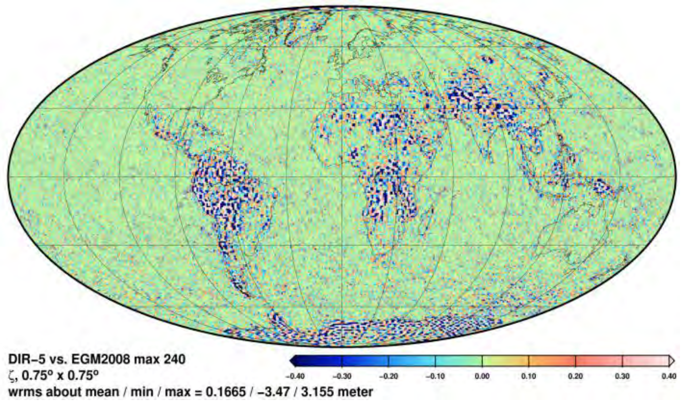

Figure 55. Illustration from Bruinsma et al. on height differences (meter) EGM2008 vs. DIR5.

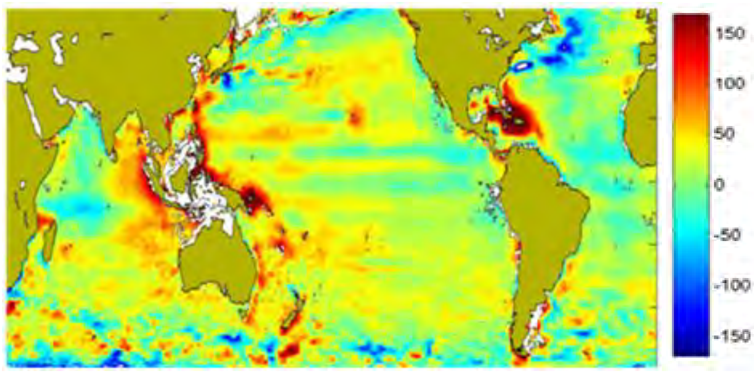

Figure 56. Illustration from Maximenko et al. on differences between the new MDOT/MDT solution and CNES/CLS09 solution.

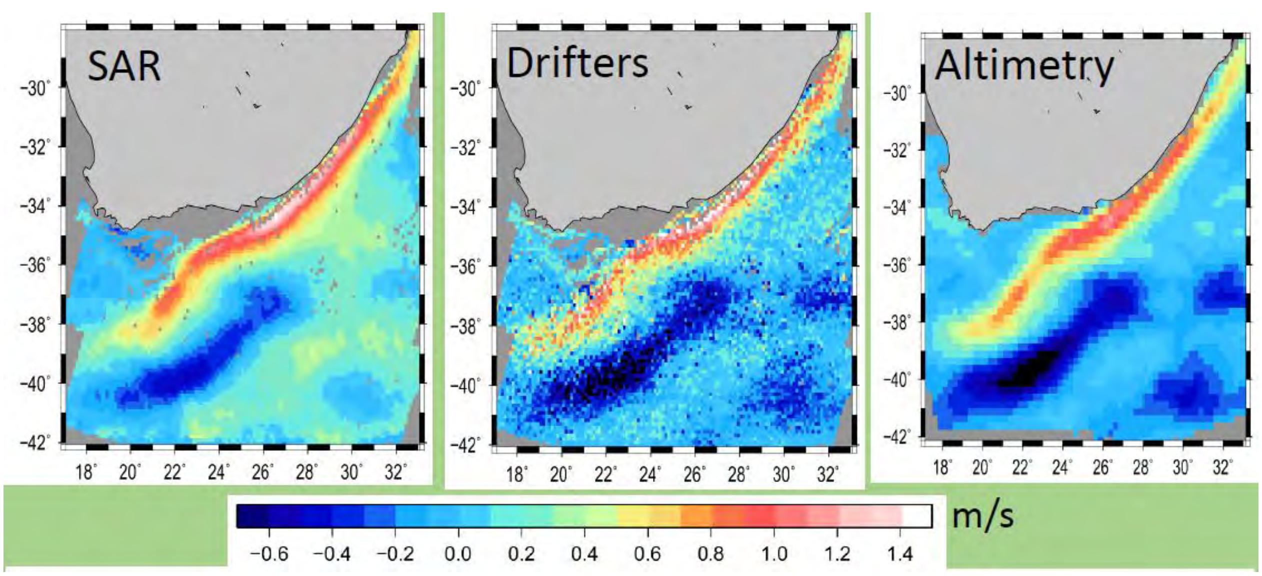

Figure 57. Illustration from (Rio et al.) on the good consistency of the circulation derived by between 3 sources of data.

The mean sea surface (MSS) was also discussed in half of the presentations, focusing notably on the current limitation of MSS at small scales and potential source of improvement. Smith et al. described the error currently committed in computing sea surface height in regions of strong mean sea surface slope. This error reaches 4 cm for a satellite at 1000 km of altitude in the Aleutian Trench (Figure 58). The error is important for geodesy but can in principle be ignored for ocean application when referencing to repeat tracks.

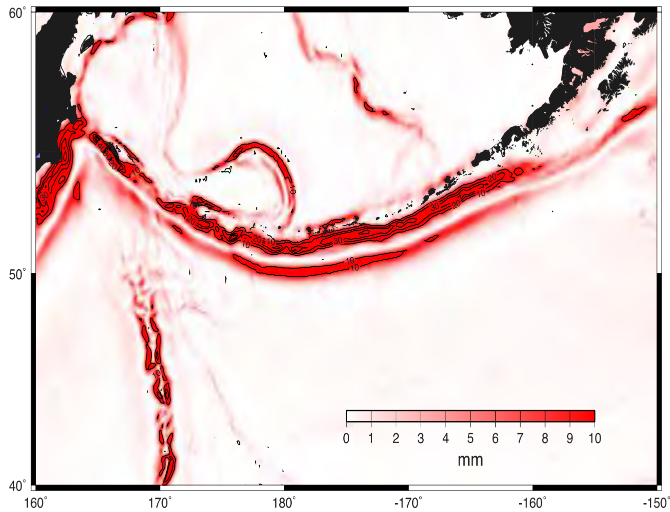

Figure 58. Illustration from (Smith et al.) on the error induced by the MSS slope.

The impact of SAR altimetry data in MSS, was also discussed last year, but the issue has been revisited by (Labroue et al., Figure 59). It was demonstrated, based on a few examples, that reprocessed Cryosat-2 SAR data (CPP processor) allows us to better resolve gradient of the MSS than conventional altimetry. With a 2 Hz resolution, sharper gradients are obtained. Finally, (Andersen et al.) recalled the coastal issue for MSS, and notably the criticality of the editing procedure.

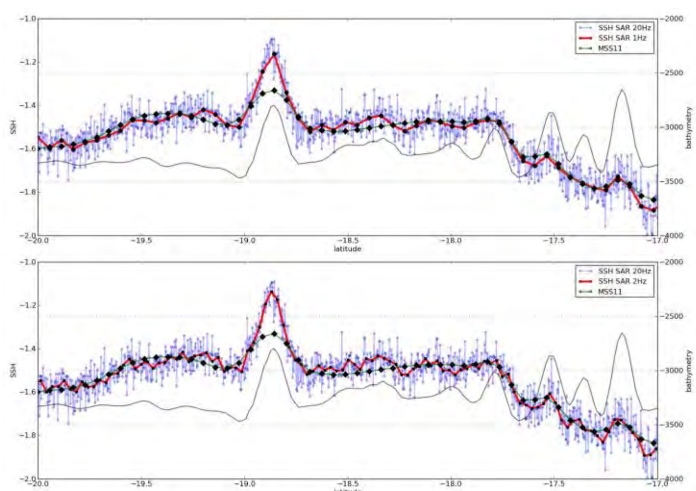

Figure 59. Illustration from (Labroue et al.) on the good estimation of seamounts using Cryosat-2 SAR dataset.

During the round table, several topics were discussed, including input data necessary to improve the Geoid, MSS and MDT, as well as the methodology to process the data. In addition, Jason-2 end of life was discussed. For MSS and Geoid application there is a strong need to use the next Jason-2 phase to improve the SSH sampling. A preferable scenario would be to use an orbit that interleaved the Jason-1 geodetic (406 day) orbit to enhance the sampling of the MSS. This would indeed allow us to reach a 4 km across-track resolution instead of 8 km obtained with the 1 year of Jason-1 geodesic phase. The SSH derived from this dataset would thus represent a good opportunity to drastically improve the MSS accuracy before the SWOT launch. The recommendation of this session is to initiate a study to find the optimal orbit allowing us to reach the 4 km resolution.

Another important topic discussed was the reference period on which MSS and MDT area based. SSALTO/DUACS products reference has been changed to a 20 year period in 2014. As several products are now referenced to this period (DTU, Aviso), it was discussed if this period should become a standard in the future, however the most of the two decades are seen under the same Pacific Decadal Oscillation phase.

6.8 Tides, internal tides and high-frequency processes

Chairs: Loren Carrere, Florent Lyard and Richard Ray

This year the Tides/HF splinter was mostly dedicated to tides, with 6 oral presentations and 10 posters.

Presentations

Three presentations focused on barotropic tides and three others on baroclinic tides.

S. Desai talked about the impact of tidal variations of the geocenter on satellite observations of ocean tides. This signal should be considered by oceanographers and geodesists as it impacts significantly the ocean tide observation, particularly K1 and O1 waves (Figure 60). No correction is needed for altimeter users, which use a geocentric tide correction (ocean+ load tidal components).

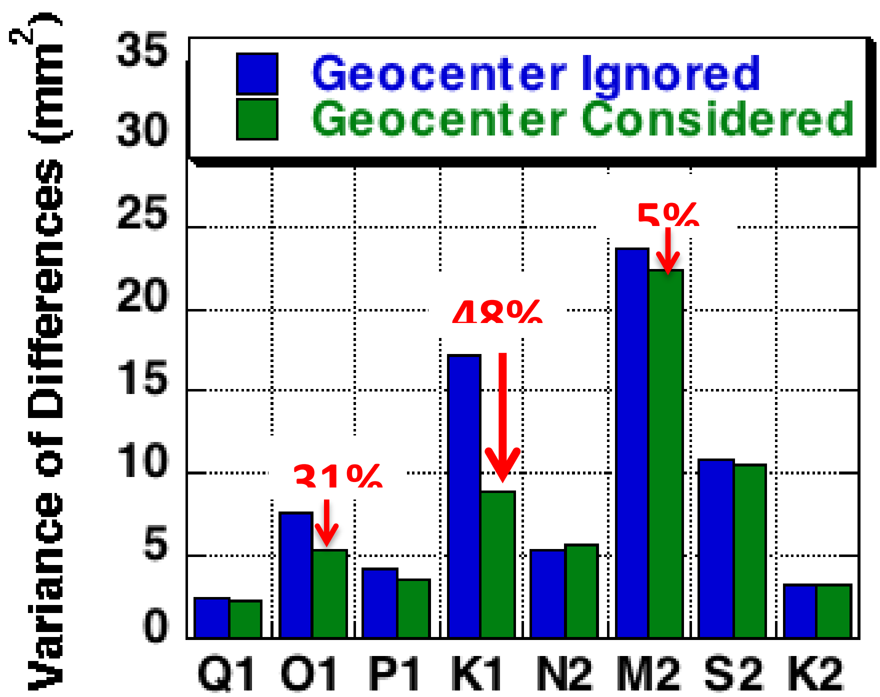

Figure 60. Comparison of Altimeter Model GOT4.10 to In-Situ Bottom Pressure Recorder Observations (Ray 2013)

L. Carrere presented the preliminary results of new FES2014 tidal model, which is an improvement of FES2012 model on the global ocean (Figure 61): results are significantly improved in many places, in deep ocean, at high latitudes and in shallow waters, although the model does not assimilate tidal gauges yet. The final version of the model will be available by the end of 2014.

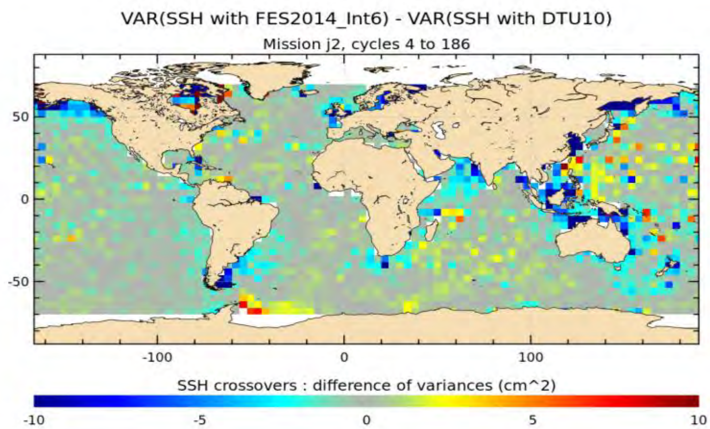

Figure 61. Variance reduction for Jason-2 crossovers when using FES2014 tidal model instead of DTU10 (cm²)

E. Zaron presented some results about the estimation of the seafloor topography in Okhotsk sea using ocean tides simulations and satellite altimetry (OTIS model). Analysis shows that small corrections to bottom topography can explain a significant fraction of the discrepancy between observed and modeled tides (Table 3 and Figure 62). But the issue is complex because the inversion problem is strongly non-linear, and the estimation of the spatial error covariance of the bathymetry is not well characterized.

Table 3. Topographic adjustments explain about 50% of the SSH error variance.

	M2 Prior	M2 Optimal (ETOPO1+Altimetry)
RMSE	4.1 cm	2.8 cm

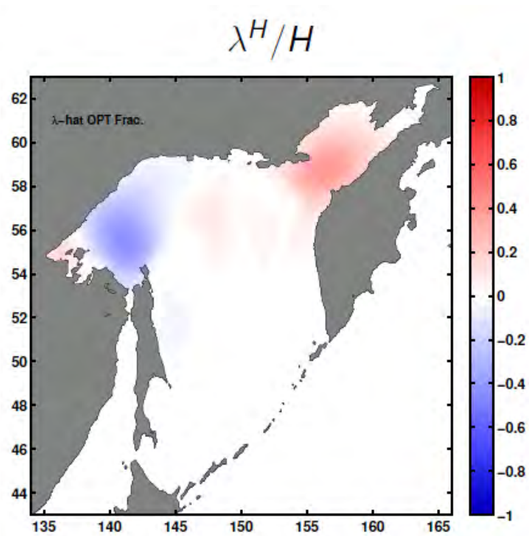

Figure 62. Sea of Okhotsk Topographic correction in %

Then F. Lyard made the transition to 3D modeling, talking about TUGO. He described first 2D-modeling improvement made within the frame of FES2014 model (Figure 63) and then presented some tests done with the 3D model (sigma-layer model with non-permeable layers) concerning the modeling of internal waves: he used plane waves (Figure 64), as done by other teams, and pointed out some limitations of this approximation and he used Kelvin waves which allow IW crossing the critical latitudes of tides.

wave	FES2012	FES2014
M2	24 / 93 mm	**13 / 53 mm**
S2	10 / 28 mm	**8 / 18 mm**
K1	11 / 30 mm	**9 / 23 mm**
O1	12 / 30 mm	**7 / 20 mm**

Figure 63. Strong improvement of the hydrodynamic tidal solution on global ocean: comparisons against TPJ1J2 crossovers database (deep/shelf)

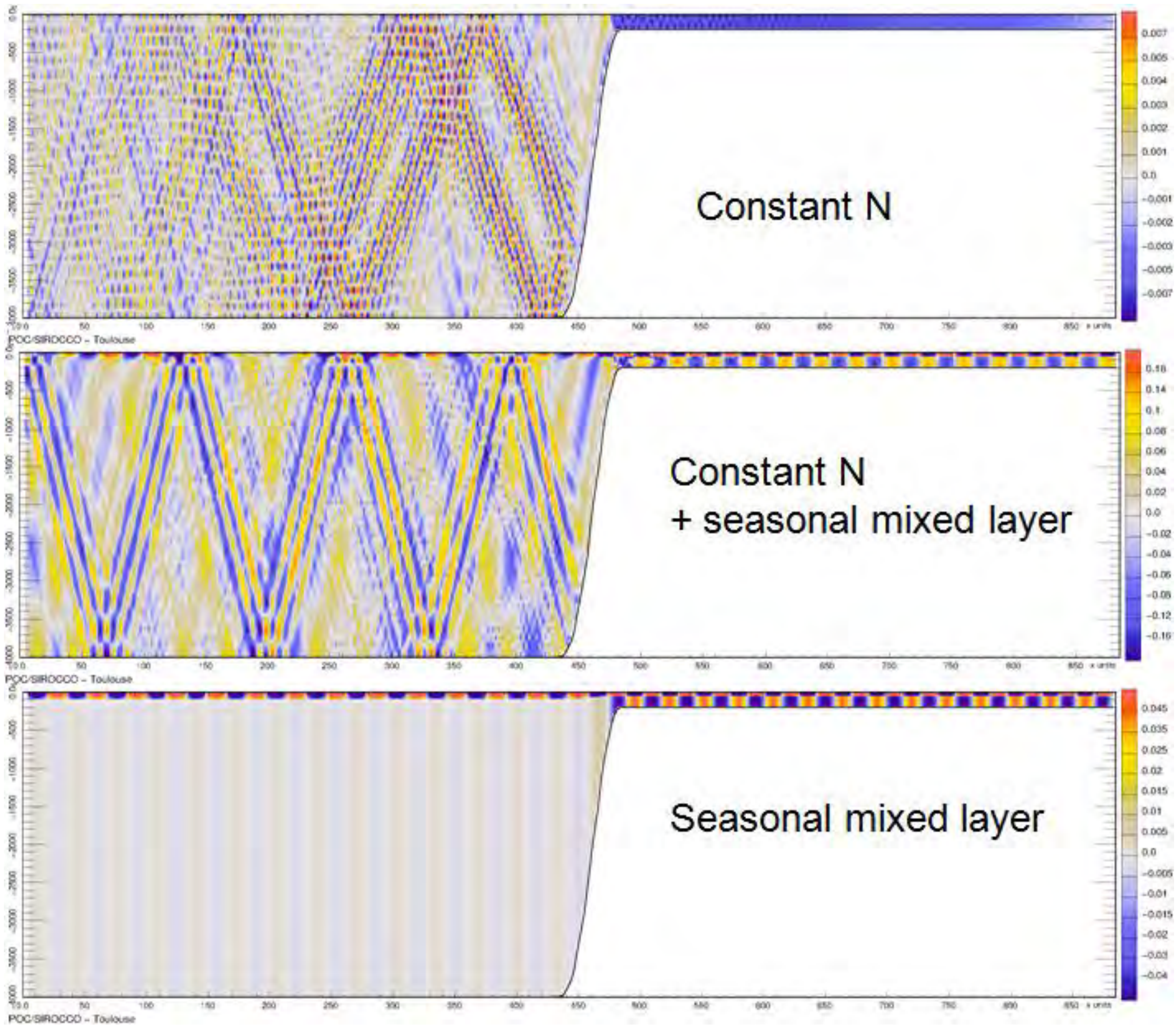

Figure 64. Simulation of internal tides : plane wave experiment

Z. Zhao presented results about global internal tides estimation for mode-1 M2, O1, K1, from multi-satellite altimetry, using plane waves fit (Figure 65). He uses an iterative process to get a varying number of waves. Northbound and Southbound beams are computed and comparison to several models and in situ data is positive. The method needs to be refined, particularly to reduce noise, add more waves and regional processing, and try to map mode-2/3 components. Tide estimations from each altimeter should also be compared. These internal tides maps may work as a prototypical empirical internal tide model for all altimeter missions (Figure 66).

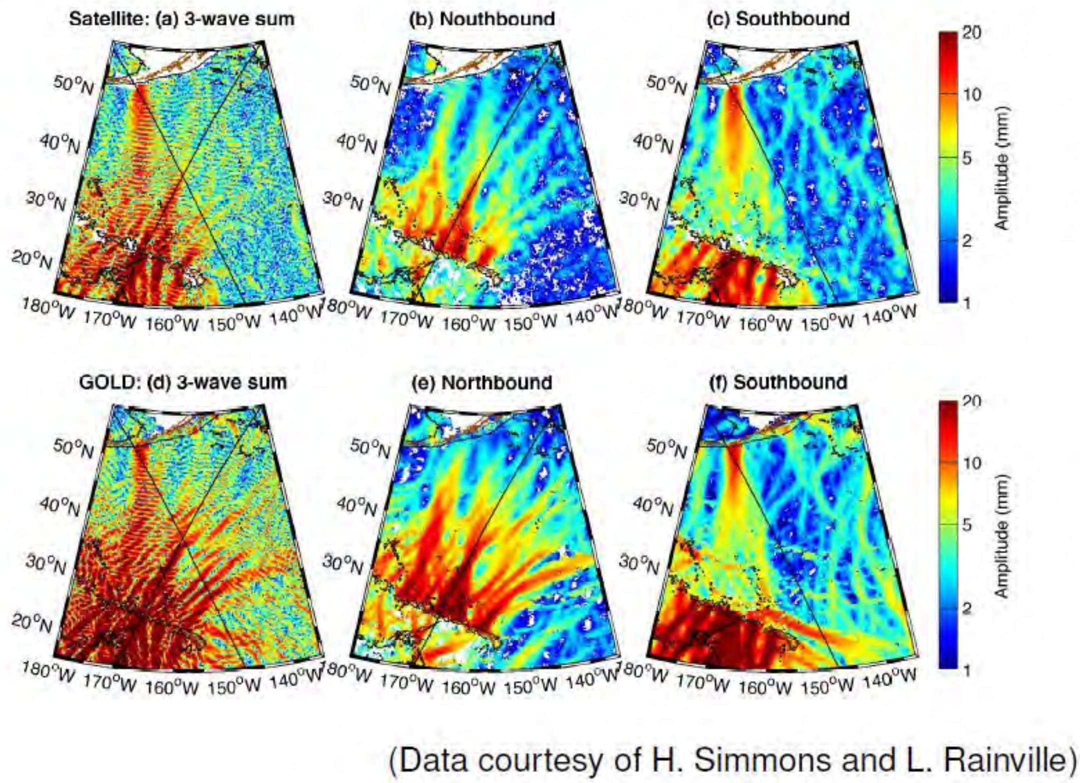

Figure 65. Comparison between internal waves maps from altimetry and GOLD model in the North Pacific region.

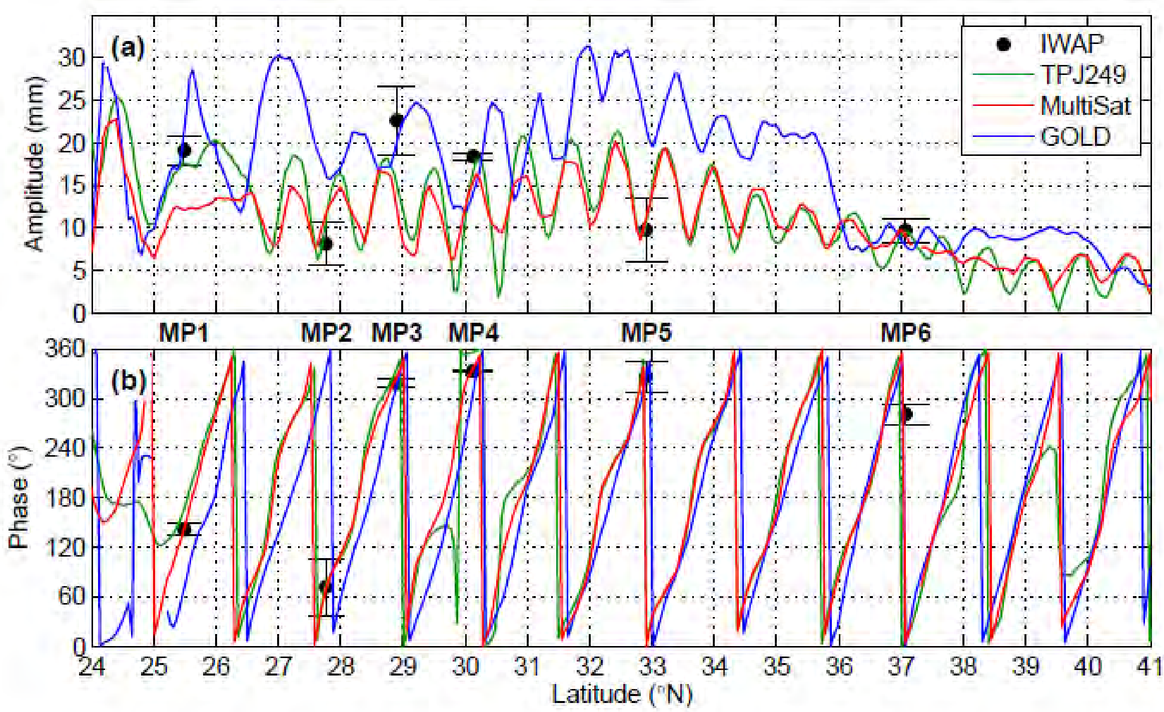

Figure 66. Comparison with IWAP moorings for TP-Jason track n° 249 in North Pacific.

M. Alford showed results about internal tides refraction and attenuation in North Pacific, using GOLD model (GCM + tides) and altimetry. The aim of this work is to better understand the spatial distribution of IW dissipation, focusing on mode-1 M2 internal tide coming from 3 major generation sites (Aleutians, Hawaiian ridge, and Mendocino escarpment). The model is used to compute coherent fraction of the signal, which decreases due to refraction by time-varying mesoscale eddies. Results show that the strongest attenuation of IW appends over rough topography patterns and when PSI (parametric Subharmonic Instability) is possible; in their absence IW can propagate nearly loss-free across the basins (Figure 67).

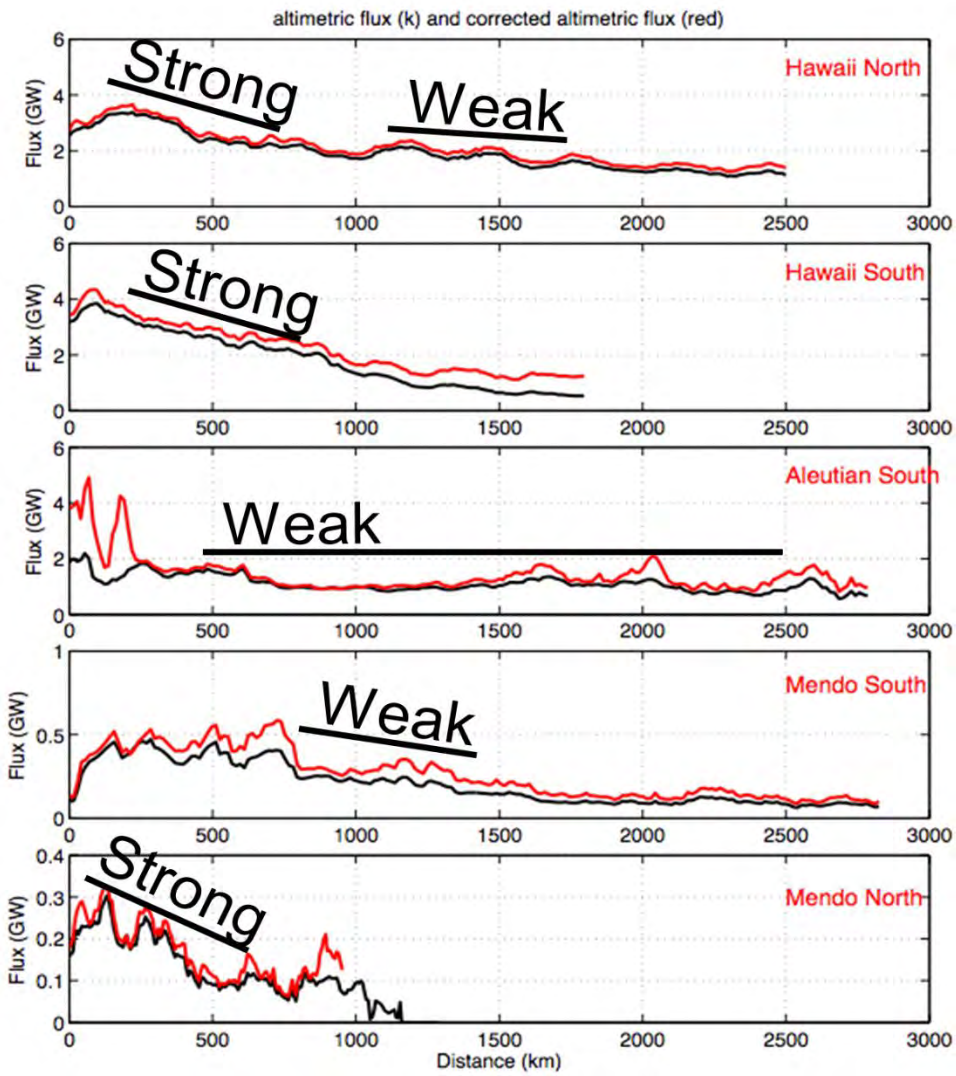

Figure 67. Attenuation of the internal tides fluxes derived from altimetry for five main generation sites in North Pacific. Attenuation is strongest on rough topography and when PSI is possible.

<u>Posters</u>:

Six posters presented several initiatives about IW, dealing with estimating/mapping IW signals from altimetry, the understanding of interaction of IW with mesoscale patterns, the geographical/temporal variability of IW theoretical eigen-modes, and an analysis of the impact of IW signature and a tentative correction on the frequency-wavenumber SSH spectra.

Concerning barotropic tides, four posters presented results about a new regional model on west coast of India, simulations about ENSO-related tidal modulations in the eastern Pacific, a case study about minor tides and the best estimation method, and new results about the reduction of 58.77 days signals observed on the TOPEX and Jason MSL using new tidal models available.

From splinter and round table, several important topics have been raised:

- Internal tides are a big issue for new HR/SWOT missions. Several teams work on the subject and different initiatives should be continued: estimating and mapping the IW surface signatures using altimetry and/or models (coherent part), quantifying and understanding the incoherent part of the internal tide signal, identification of processes which lead to loss of coherency of IW.
- Coastal tides are still an issue as the error of barotropic models in shallow waters/coastal regions remain stronger than in deep ocean. We need better bathymetry fields, higher resolution mesh, and also regional models.
- New results of FES2014 barotropic tidal model are very good on global ocean, in deep and shallow waters and at high latitudes. This model is recommended to be used for altimetry products.
- Concerning J2 EOL, the recommendation of tidal experts is to keep J2 on its optimized tandem orbit (same as TPN and J1N) as long as possible in order to improve significantly tidal estimations from the TPN-J1N orbit, and reach the accuracy of the TP-J nominal track estimations.
- Concerning the coming J3-J2 joint phase, tidal experts ask for the possibility of a specific tandem phase for tides: having J3 and J2 flying on the same orbit with only a few hours apart (delay between 3 and 5 hours), would greatly help in the understanding of non-coherent IW and checking the noise level. Unfortunately, this would require moving the J2 ascending node by 45° or more, which appears totally unfeasible.
- S3 SAR-mode will also be interesting to study IW.

Concerning other HF signals, the recommendation of OSTST is to deliver a DAC for OGDR products.

7 Closing Plenary

The closing plenary took place on Friday morning. In addition to the splinters summaries Paolo Cipollini reported on the 8th Coastal Altimetry workshop and Jacques Verron gave a summary of the SARAL/AltiKa workshop. Two special keynotes were also given by students (see section 4).

The meetings ended with the status of reprocessing. Phil Callahan discussed the TOPEX Reprocessing and update to GDR-C standards. The current plan is to make a new Re-tracked GDR, consistent with GDR-C processing, which should become available in early 2015. Nicolas Picot discussed the current GDR status for Jason-1 and Jason-2. Plans to reprocess Jason-1 and Jason-2 data to a new GDR-E standard are underway and Jason-1 reprocessing will start early 2015. An upgrade of SARAL/AltiKa products is also foreseen in 2015. For the CalVal phase, Jason-3 will be based on GDR-D standard with orbit in GDR-E, fully inline with Jason-2 standard. The next product version will be defined after the CalVal phase.

The closing plenary session also had a discussion time slot, notably about the following key points that were addressed to the splinters during the opening session:

1. **Jason-2/Jason-3 transition:**

   – DIODE/DEM mode for J-2 &/or J-3 during formation phase

   The proposed strategy from the project:

   - Jason-2 remains in nominal median tracking throughout
   - Jason-3 alternates median/DEM cycles (after validation of DEM mode)

   The proposed scenario is adopted by the OSTST but more information needs to be given by the project about Jason-3 DEM mode specificities. OSTST members should give detailed feedback (notably for inland waters) to better define the mask that can be updated in Jason-3.

   – Jason-2 interleaved orbit at end of formation flight

   *A recommendation was issued; see below in the "*Recommendations and Appreciations*" section. Before the Jason-2 interleaved phase, there is request issued by the "*Tides, internal tides and high-frequency processes*" splinter:*

   > *Concerning the coming Jason-3-Jason-2 joint phase, tidal experts ask for the possibility of a specific tandem phase for tides: having Jason-3 and Jason-2 flying on the same orbit with only a few hours apart (delay between 3 and 5 hours), would greatly help in the understanding of non-coherent Internal Waves and checking the noise level. Unfortunately, this would require moving the Jason-2 ascending node by 45° or more, which appears totally unfeasible.*

2. **Jason-2 Extension of Life:**

   – Needs for geodesy vs. operational oceanography

   – Protection of reference & interleaved orbits

   *This was the main key point discussed during the closing session. Because Jason-2 must ultimately be moved from the altitude of the reference orbit, a Jason-2 EOL Working Group will be re-established to **consider different options for science given operational limitations, which must be provided by the agencies**. The Jason-2 EOL Working Group will provide recommendations on:*

   - *a graveyard orbit for Jason-2 in the case of failing performance in its end of life*
   - *science priorities for J2-EOL (Geodesy? Operational oceanography? Preparation for SWOT?)*

   Some preliminary recommendations were issued from different splinters and can be found in their respective summaries.

3. **Other topics:** LRM/SAR; Jason-1 GDR-E updates: orbits, JMR,…; Jason-3 Numerical Retracker

Output of these different key points can be found in the splinters summaries

Recommendations and Appreciations

- In recognition of the response of the Space Agencies and Project Teams to its prior recommendations, the Ocean Surface Topography Science Team expresses its thanks for the following:
    - Approval of extended funding for Jason-2 up to 2017.
    - SARAL/AltiKa fast delivery of high quality data products to the community.
    - The OSTST appreciates the recognition by the agencies of the ongoing need to continue processing of Jason-1 and TOPEX/Poseidon data.
- Recommendations
    - ***Continuity being of the utmost importance, the Ocean Surface Topography Science Team strongly recommends that space agencies strive to maintain the current launch date of Jason-3 (31st March 2015).*** After the OSTST meeting, NOAA announced that the March 31st launch date could not be met due to budget constraints as well as issues involving production and certification of the new SpaceX launch vehicle, and that the Jason-3 launch would slip into the summer of 2015. In December 2014, President Obama signed the FY15 omnibus appropriations bill into law, providing Jason-3 with the funding needed to launch in 2015. The project teams continue to work on the launcher issues, but it is a very positive development that the mission now has secure funding.
    - Nominally, the current and projected launch dates for Jason-3 (March, 2015) and Jason-CS (2020) may not leave sufficient margin for cross calibration between missions, and further slips will jeopardize continuity of the sea level record. ***The Ocean Surface Topography Science Team strongly recommends that space agencies strive to avoid further slippage of the Jason-CS launch date*** to ensure that there is overlap with the expected 5 year lifetime of Jason-3.
    - ***Move Jason-2 to the interleaved orbit with a 5-day delay (as for Jason-1) after 6 months of Formation Flight with Jason-3.***