Report of the

Ocean Surface Topography Science Team Meeting

Espace Encan

La Rochelle, France

November 1-4, 2016

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Organized by CNES, NASA, NOAA and EUMETSAT

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1 Executive Summary

The 2016 Ocean Surface Topography Science Team (OSTST) Meeting was held in La Rochelle, France, November 1-4. The meeting was held alongside the SAR Altimetry and IDS Workshop in the same location respectively on October 31 and October 31 – November 1, in the frame of the "New era of altimetry, new challenges" symposium. The primary objectives of the OSTST Meeting were to (1) provide updates on the status of Jason-2, and Jason-3 (2) conduct splinter meetings on system performance (orbit, measurements, corrections), altimetry data products, science outcomes, and outreach, (3) preliminary analysis of data from the Jason-3 altimeter, which was launched on January 17th 2016. 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://meetings.aviso.altimetry.fr.

Jason-3 was successfully launched from Vandenberg Air Force Base on January 17, 2016 aboard a Falcon 9 launch vehicle built by SpaceX. All of Jason-3's systems and instruments are operating nominally and as of February 12, it was maneuvered into position approximately 80 seconds behind Jason-2 where it spent six months while the data was evaluated relative to Jason-2. After that, Jason-2 was moved into an interleaved orbit in October 2016 on an adjacent ground track with a 5-day lag, identical to the one flown by Jason-1. ***Based on the quality of the GDR data, the OSTST endorses the immediate public release of the GDR products for Jason-3***.

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 more than 8 years in orbit. The mission has been approved to be extended up to 2017 at both CNES/EUMETSAT and NASA/NOAA. No major events occurred this year on the platform side. From a global point of view, Jason-2 continues to collect data that meets all mission and level-1 science requirements. After consideration by the splinters and a dedicated "Extension of Life" working group (referred to as the "EoL subgroup"), the OSTST adopted the following recommendations: ***The OSTST recognizes the importance of both mesoscale applications, which benefit from a repeat orbit, and the need to improve mean sea surface estimates which require a drifting, or long-term repeat orbit. As a compromise between these needs, the OSTST recommends moving Jason-2 into a Long Repeat Orbit ("Long Repeat Orbit (LRO)" mission) after two years in the interleaved orbit, in October 2018. Based on its favorable subcycles (12+284/371 at 1309 km) for both mesoscale sampling and improvement of the mean sea surface, the OSTST recommends the Jason-2 long-repeat orbit to be at –27 km.*** However, the timing can be changed if the health of Jason-2 requires moving sooner to the LRO orbit in order to preserve the reference orbit. ***Regardless of when Jason-2 is moved, the OSTST strongly recommends that all requirements on latency, accuracy and data availability be maintained as long as the satellite can collect data***.

In order to improve long-term stability of global mean sea level estimates based on altimeter data, the Jason-3 project has implemented a calibration maneuver, designed to point the Advanced Microwave Radiometer (AMR) toward deep space, approximately once per 2 months. ***In light of the demonstrated improvement in accuracy and stability of the wet-path delay correction, the OSTST recommends cold sky calibration for Jason-2 and Jason-3 be continued, and the projects should study the feasibility of performing these maneuvers more frequently than once every 60 days***. The current time lag between the cold sky calibrations implies that the GDR latency should be relaxed to account for these calibrations. ***Given the improved quality of the IGDR product and the likelihood of improved accuracy and stability of AMR data in the GDR, the OSTST is willing to accept relaxation of the GDR latency requirement to a maximum of 90 days on Jason-3 and Jason-2***.

Last year, the OSTST recommended that future altimetry missions should consider adding additional higher-frequency radiometer channels in order to improve coastal and inland water wet path delay corrections. During the plenary session, ESA announced the implementation of such a radiometer on board Jason-CS/Sentinel-6 with three additional channels (90GHz, 130GHz and 166GHz). Even if experimental and non-redundant, the OSTST greatly appreciated this initiative.

On Jason-CS/Sentinel-6, there is a small probability that the external calibrator can fail in a position that renders the AMR unusable for the remainder of the mission. Pierrik Vuilleumier (ESA) presented this issue and stated that with all the efforts made, a very small likelihood (but non-zero) risk for in flight failure exists. However, the OSTST recognizes the importance of maintaining the climate record of sea level change. ***Because long-term stability of the AMR is required in order to achieve this, the OSTST is willing to accept the additional risk of loss of AMR functionality as reported by the project in order to improve long-term stability on Jason-CS/Sentinel-6.***

Three keynote talks were given during the opening plenary session of the OSTST (see section 4).

2 Introduction

The 2016 Ocean Surface Topography Science Team (OSTST) Meeting was held in La Rochelle, France, November 1-4. The meeting was held alongside the SAR Altimetry and IDS Workshop in the same location respectively on October 31 and October 31 – November 1, in the frame of the "New era of altimetry, new challenges" symposium. On behalf of the Project Scientists (Josh Willis, NASA; Pascal Bonnefond, CNES; John Lillibridge, NOAA; Remko Scharroo, EUMETSAT), Pascal Bonnefond opened the meeting, 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 (Philippe Escudier), EUMETSAT (François Parisot), NOAA (Laury Miller) and ESA (Jérôme Benveniste).

Eric Lindstrom (NASA HQ) gave a summary of the NASA Ocean Program. The SWOT Mission Science Team was competed through NASA's ROSES program in 2015. 67 proposals were reviewed on the US side and 56 proposals have been selected. The first SWOT science team meeting was held in Pasadena in June 2016. The OSTST renewal was part of the 2016 ROSES call. The OSTST proposals have been reviewed and the new team for 2017-2020 will be announced by the end of 2016.

Philippe Escudier (CNES) reported on the CNES Ocean Program status by illustrating the current and future constellation in which CNES is involved at various levels of contributions (Figure 1). The main priorities were identified in terms of support for altimetry: long term monitoring, guaranteed product accuracy, cross calibration between missions and high-level products. The first is support for high-quality nadir altimetry for medium-resolution oceanography through multiple partnerships, as is the case for Jason-2, Jason-3, Sentinel-3, HY-2, SARAL/AltiKa, and Jason-CS/Sentinel-6. The second is to support high-resolution oceanography through programs such as SWOT. On a longer-term perspective, CNES works on the definition of the appropriate space measurement system to support the next phase of high-resolution oceanography through an on going phase 0 study. This should be done in the framework of international cooperation through CEOS OST VC. CNES also support measurement system for Ocean/Atmosphere interactions with CFOSAT (China-France Oceanography SATellite, Wave directional spectrum and wind) on a short-term and SKIM (Ocean currents and Waves) for the mid-term. CNES reaffirmed its strong support of science. The SWOT Science Team is now in place with 19 teams selected by CNES for ocean applications including 4 mixed (Ocean + Inland waters or Ice) and 7 Non French teams. Concerning the OSTST renewal, 45 proposals have been received (13 non French). The selection will be announced by the end of 2016 jointly with NASA. An international AO for CFOSAT is expected to be released in 2017.

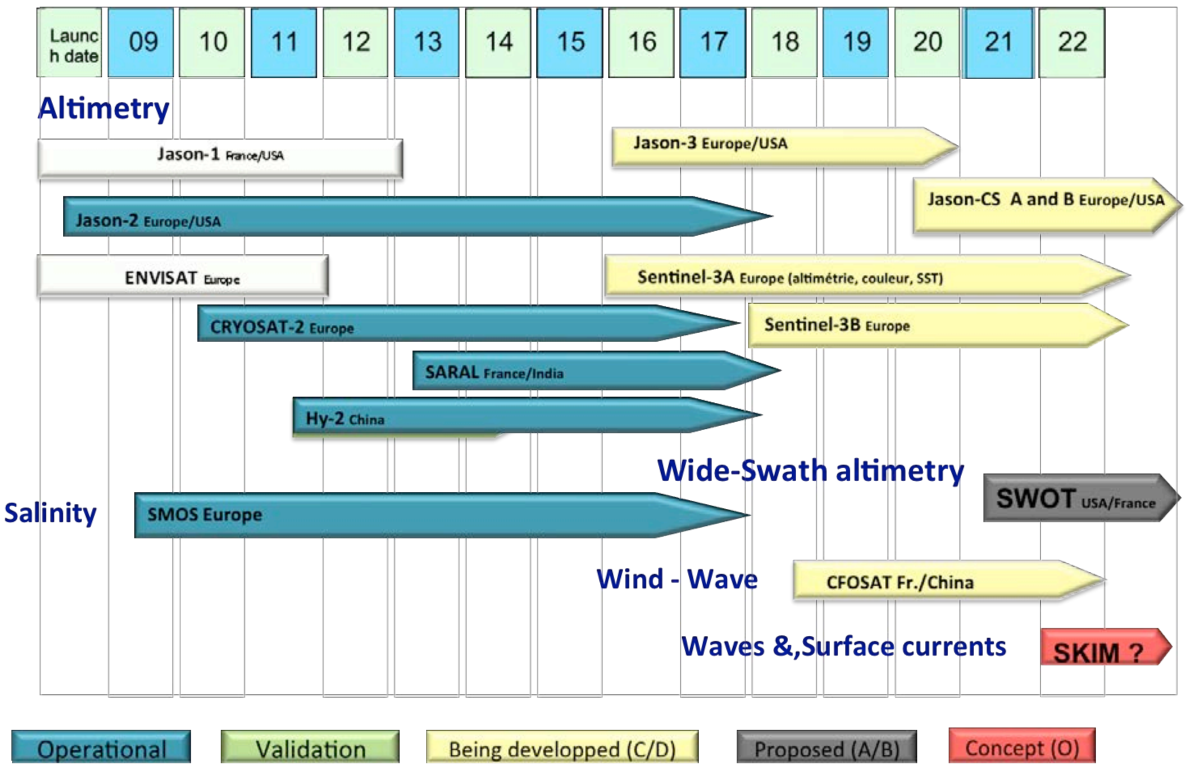


Figure 1. Ocean missions in which CNES is involved at various levels of contributions

François Parisot (EUMETSAT) reported on the status of EUMETSAT Marine Programmes. EUMETSAT is today involved in: Sentinel-3 (but also Jason-3, Jason-CS/Sentinel-6) operations and Cal/Val activities, Performance on SAR in coastal regions, Jason-3 operations and Cal/Val activities, Jason-CS/Sentinel-6 Products and Performance definition. It delivers operational data and supports services to the Copernicus Marine Service. The Achieved Milestones/current activities for Sentinel-3 are: Satellite under EUMETSAT control since July 2016, Marine Payload Data Ground Segment (PDGS) is now running at EUMETSAT and under corrective and evolving maintenance, activities to prepare for the launch of Sentinel 3B in 2017. On December 5th, SRAL L1A, L1B and L2 NRT and STC products will be distributed to all users following the confirmation of the readiness and product validation status on November 29. In February 2017 a SRAL/MWR Quality Working Group will held at ESA-ESRIN. Concerning Jason-CS/Sentinel-6, EUMETSAT's Programme is now fully approved, addressing two Jason-CS satellites. EUMETSAT Operations in Europe will be funded by the European Commission, as for Jason-3 and Sentinel-3. All Agreements (multi partner and bilateral) are signed or under final agencies approval process. The system support and services from CNES is secured through a dedicated agreement. System Readiness Review key point held on September 27 with partners' teams to close residual points moving forward towards to Mission/System PDR planned in early 2017. The End User Requirement / System Requirement Document is mature and traces to lower levels are under finalization. The Mission Performance and System Engineering work are in place. Eight years after the Assmannhausen workshop, all recommendations are implemented or will be in the coming years: (1) Maintain continuity of high-accuracy Jason altimetry, (2) In addition to a highly accurate Jason-class altimeter, maintain continuity with altimeters on at least two and preferably three complementary, high-inclination satellites, (3) In addition to the above, extend the capability of altimetry to denser observational coverage through wide swath altimetry, (4) Maintain an open data policy including near-real time data for operational purposes, (5) Maintain a continuing partnership with the scientific community, and (6) Maintain a broad collaboration between engineering and science, research and operations, and international partners.

Laury Miller (NOAA) reported on the NOAA Jason-mission Program Status. NOAA successfully managed the tandem mission: while Jason-2 and -3 flew 80 seconds apart, NOAA managed ground operations for both, a first for the same agency. This was done thanks to a new remote antenna at Barrow, AK (working jointly with Fairbanks antenna) and a new ground system design. NOAA organized a Jason-3 Near Real-Time Workshop in June 2016 (hosted at College Park, MD) to approve the public release of OGDRs and define the date to move Jason-2 to Interleaved Orbit (October 2016). NOAA also presented Jason Data Assimilation Projects, which will upgrade National Weather Service (NWS) ocean data assimilation systems through the NWS Climate Prediction Center: (1) MOM-5 model/ Climate Forecast System (for improved seasonal and ENSO predictions) and (2) NWS Environmental Modeling Center (HYCOM model for improved hurricane intensity forecasting). John Lillibridge is retiring at the end of 2016 and so Laury Miller announced that NOAA's new Jason Measurement System Engineer (MSE) will be Alejandro Egido and its new Project Scientist will be Eric Leuliette.

Jérôme Benveniste (ESA) presented the ESA Programmes by first recalling the status of the ERS-1&2 and Envisat reprocessing. Envisat RA2&MWR V3.0 data set delivery after validation is planned for Q3-Q4 2017. Reprocessing of ERS-1 and ERS-2 Altimetry data for alignment with Envisat v3.0 dataset is intended to be released in 2017. Concerning CryoSat, the Space and Ground Segment are in very good status and well fitted to continue mission exploitation until 2025. The operations are reliable, stable and performing well. Jérôme Benveniste also announced the North-American CryoSat Science Meeting (20-24 March 2017, Banff, Alberta, Canada - www.cryosat2017.org). This meeting will be held in parallel with a SWARM meeting (www.swarm2017.org) and a GOCE meeting (project to bridge geoid and ocean communities). A CryoSat Special Issue on Advances Space Research is planned for Spring 2017 (abstract submission is still opened). He also recalled that any new requests for Cryosat-2 mask changes over the ocean and coastal zones (SAR or SARin) could be sent to ESA; SWATH Processing from SARIN data could also be exploited in preparation for SWOT. Sentinel-3A was successfully launched on 16 February 2016, all instruments are switched on and are working well; the commissioning phase was successfully completed in July 2016. SRAL is now in 100% SAR Mode with Closed-Loop/Open-Loop transitions. Sample data products for expert users are available and the official data release will be: SRAL L1A, L1B and L2 NRT and STC in early Dec 2016 and SRAL L1B-S on January 16, 2017. The access is through the ESA Sentinel Data Hub and through EUMETSAT's EO Portal (EUMETSAT's ODA, Data Centre, EUMETCast). The request for an orbit shift between S3A and S3B is in process to be implemented. Anyone who wants to join the S3 Validation team (S3VT) can submit a proposal in the Rolling Call on ESA Earth Online. The Next S3VT meeting planned for 15-17 February 2017 in ESA-ESRIN, Frascati, Italy. Finally a list of on-going activities in R&D, Training and Outreach was presented (SCOOP, SHAPE, SPICE, DEDOP, SARvatore, SARINvatore, S3SARvatore, BRAT, GUT …)

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 more than 8 years in orbit, and the passengers perform satisfactorily even if getting "old" (CARMEN2 is off and LPT experienced some issues). Both CNES/EUMETSAT and NASA/NOAA approved the extension of the mission up to 2017. The main event this year is the orbit change to reach the interleaved orbit from October 2 to October 14. The operation was successful and shows the very good performance of the thrusters even after more than 8 years in orbit, almost 20 kg of hydrazine remain available. During this orbit change a new DEM has been uploaded to be in line with Jason-3. Following the OSTST 2015 recommendation two Cold sky calibration maneuvers were performed on 12 July and 5 Sept 2016 and will be continued with a ~60-days period. Overall Jason-2 continues to collect data that meets all mission and level-1 science requirements: the global Jason-2 system availability is 100%, 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 (95.8% and 99.2% respectively) and NOAA ESPC (96% and 99% respectively). Although Jason-2 is performing well, the Project requested the OSTST to endorse a specific Extension of Life Orbit.

Thierry Guinle gave an update on the status of the SARAL/AltiKa Mission. The SARAL/AltiKa mission continues to perform nominally after more than 3 years on orbit and provides data with accuracy comparable to Jason-2. Some concerns about reaction wheels have been reported during OSTST 2015 and because the long-term ground track maintenance after three years on orbit (Feb 2016) could be uncertain it has been decided to find a suitable drifting orbit. In early 2016, CNES made a study for determining the optimum orbit (+1 km in altitude) to preserve the mesoscale sampling for at least 3 years. In April 2016, ISRO and CNES decided to implement a new phase for SARAL, the SARAL Drifting Phase (SARAL-DP) and the maneuvers were performed to start this new phase on July 4, 2016.

Status of the Jason-3 Project was discussed by Gerard Zaouche. He told, in fantastic detail, the fabulous and tumultuous history of the launch (see online presentation for details). Finally, Jason-3 was successfully launched on January 17, 2016 aboard a SpaceX Falcon 9 launch vehicle. The launch and orbit injection was successful, and as of February 12, 2016, Jason-3 was maneuvered into an orbit approximately 80 seconds behind Jason-2. Regarding the chronology, he noted the incredible speed with which data acquisition and diffusion was achieved: Poseidon-3B was switched on January 19 at 16:12 and the first OGDR was available only 3 hours later. On Feb 15, 2016 the OGDR started to be delivered to PIs followed on Mar 9 by the IGDR. In April, the In Flight Assessment meeting main conclusion was: "*The assessed performances of the spacecraft and the payload are compliant with requirements and comparable to Jason-2 ones*". Moreover, all the new features and activities on Jason-3 are performing very well: DORIS start "Auxiliary" packets, POS3B mode Diode+DEM with automatic transitions, AMR on-board calibrations, "Altimeter mispointing" maneuver, etc. This was followed by the Jason-3 NOAA "Hand-Over Review" (4 partners) in Suitland, MD on May 24, 2016 with effective operations handover on June 1, 2016. Then, as a result of the excellent quality of Jason-3 data, the public release of OGDR (and IGDR) was decided during the Jason-3 Near Real-Time Workshop in June 2016 (hosted by NOAA at College Park, MD), the timeline was compliant with the "5 months after launch" requirement. This OSTST meeting will serve as the final verification workshop to authorize the public release of GDR (also compliant with the "10 months after launch" requirement). In conclusion, Jason-3 is operational at satellite, instruments and ground levels and after nine months in orbit the system is running fine, with an excellent availability and quality level. Following the Jason-2 new orbit (interleaved) that was reached on October 14, Jason-3 has been declared to be the reference mission.

Pierrik Vuilleumier (ESA) also gave an update on the status of the upcoming Jason-CS mission. Jason-CS will continue the Jason series of research and operational oceanography missions. Two satellites will be commissioned, with the first launching in November 2020 and the second launching in 2025. Good news concerning the funding for two satellites was: (1) ESA GSC-3 + EC MFF programmes are already in place, (2) entry into force of the EUMETSAT programme and (3) FY16 NASA budget approval (AMR-C, RO, LRA, Launcher). There are also inter-agencies agreements through a three party/four partner MOU to be finalized, with text to be approved by ESA/NASA/NOAA/EUM. There are some remaining open points concerning the Mission Advisory Group (MAG). The ESA/EUMETSAT implementing arrangement planned a fixed contribution to the Satellite-A model and about one third of the Satellite B model. An ESA/CNES cooperation agreement has also been defined through a support agreement for Jason-CS (system, topography, POD). Concerning the project status, a full space segment consortium is under contract for the two Satellites A & B procured at the same time. Upcoming Satellite CDR: review kick-off on March 29 at ESTEC and review collocation on May 16-18. One of the mission improvements is that the altimeter and POD will be driven by the same USO allowing easier error budgeting and capability to monitor the new USO against the GPS system. Pierrik Vuilleumier also announced a high-frequency radiometer add-on. This follows a previous OSTST recommendation in order to improve coastal and inland water wet path delay corrections. On Jason-CS/Sentinel-6, there is a small probability that the external calibrator can fail in a position that renders the AMR unusable for the remainder of the mission. Pierrik Vuilleumier presented this issue and stated that with all the efforts made, a very small likelihood (but non-zero) risk for in flight failure exists. On the last day of the meeting, the OSTST expressed an endorsement of the science utility of this enhancement outweighing the residual risk. This is a key aspect for continuing the development and flight of this important capability (see "1 Executive Summary" and "7 Closing Plenary" sections).

Finally, Lee Fu provided an update on the SWOT mission (Surface Water and Ocean Topography mission). Launch of the SWOT mission is scheduled for April, 2021. The mission will carry an interferometer as well as a traditional nadir-altimeter and operate at a 21-day repeat. Mission science objectives include observation of mesoscale and submesoscale ocean process. The Mission has passed Preliminary Design Review (April 2016) and been in Phase C since May 2016 (NASA) & July 2016 (CNES). A new Science Team (ST) has been established via a joint ROSES and TOSCA selection process. The first ST meeting was held in Pasadena, June 13-16, 2016. The team is composed of 53 investigation teams with 25 in oceanography, 21 in Hydrology, and 7 in synergistic sciences. Approximately 40% of the new members are from the previous Science Definition Team (SDT). The ST is rich in international participation: 22 in US, 18 in France, 6 in Brazil, 2 in UK, 1 in Spain, Japan, Canada, Greece, Australia, and Colombia. The planning of calibration/validation and development of science algorithms are the main contributions from the Science Team in the next year. Finally, he announced that in order to devote time to SWOT, he was stepping down as the NASA Jason-2 Project Scientist with Josh Willis succeeding him in that role.

Before the splinter sessions Shannon Brown gave a presentation on the benefits of the Cold Sky Calibrations and the counterpart of increasing the GDR latency to fully benefit from this calibration for maintaining the climate record of sea level change. Then, Gerald Dibarboure gave an overview of the study of a new possible Extension Of Life (EoL) orbit (12+284/371 at 1309 km, ~-27 km) and the timing of this EoL for Jason-2. He presented the possible tradeoff between the length of the interleaved phase (important for operational activities) and the need to have enough time for at least 2 years of a Long Repeat Orbit (for MSS improvement in preparation of SWOT but also providing good mesoscale sampling). Finally Pierre-Yves Le Traon presented the Copernicus Marine Environment Monitoring Service and the role of altimetry. He pointed out the essential role of Jason-2 in its interleaved orbit.

On behalf of the other Project Scientists, John Lillibridge (NOAA) presented discussion topics for consideration by the splinter sessions. These included evaluation of the EoL orbit and timing for Jason-2, the AMR calibrator issue on Jason-CS/Sentinel-6 and the possible relaxation to 90 days for Jason-2/3 GDR latency to account for the benefits of the Cold Sky Calibrations.

4 Keynote Talks

During the opening plenary session, three keynote talks were also given. These included Marta Marcos, who discussed the progress in reconstructing long-term global sea level changes. This new GMSL curve is now more consistent with the historical CMIP5 modeling attempts especially between the 1930s and 1970s. Acceleration in GMSL is stronger than in any other reconstruction and recent rates of GMSL are higher than earlier recorded periods. Thierry Penduff discussed the fingerprints of oceanic chaos and atmospheric forcing on altimeter/in-situ data and its observational consequences. These investigations provide the community with quantitative estimates of the chaos-related uncertainties associated with individual and integrated observational information, and of the observed part of observed signals that may be explained by atmospheric causes. Finally, Angelica Tarpanelli discussed the use of radar altimetry and its integration with other satellite sensors for river discharge estimation and forecasting. The integration of different sensors, including altimetry, represents an added value to the information derived from single sensor data and widens the possibilities of increasing the accuracy of river discharge estimates.

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://meetings.aviso.altimetry.fr

The posters were grouped into the following categories:

- Application development for Operations [7 posters]
- Instrument Processing: Corrections (Troposphere and Ionosphere, Wind Speed and Sea State Bias) [7 posters]
- Instrument Processing: Measurement and retracking (SAR and LRM) [14 posters]
- Outreach, Education & Altimetric Data Services [6 posters]
- Precise Orbit Determination [12 posters]
- Quantifying Errors and Uncertainties in Altimetry Data [6 posters]
- Regional and Global CAL/VAL for Assembling a Climate Data Record [23 posters]
- Science Results from Satellite Altimetry: Current and past mean sea level observations [9 posters]
- Science Results from Satellite Altimetry: From large-scale oceanography to coastal and shelf processes [43 posters]
- Science Results from Satellite Altimetry: Two decades of continental water's survey from satellite altimetry - From nadir low-resolution mode to SAR altimetry, new perspectives for hydrology [12 posters]
- The Geoid, Mean Sea Surfaces and Mean Dynamic topography [1 poster]
- Tides, internal tides and high-frequency processes [12 posters]
- Others (poster only) [7 posters]

6 Splinter Sessions

The splinter sessions were organized as follows:

Tuesday, November 1:

- Instrument Processing (Part I): Corrections [7 orals]
- Instrument Processing (Part II): Measurement and retracking (SAR and LRM) [7 orals]
- Outreach, Education and Altimetric Data Services [5 orals]
- Science (Part I): Current and past mean sea level observations [7 orals]

Wednesday, November 2:

- Precision Orbit Determination [9 orals]
- Application development for Operations [6 orals]
- Tides, internal tides and high-frequency processes [7 orals]
- Regional and Global CAL/VAL for Assembling a Climate Data Record [12 orals]
- Science (Part II): From large-scale oceanography to coastal and shelf processes [7 orals]
- The Geoid, Mean Sea Surfaces and Mean Dynamic topography [5 orals]

Thursday, November 3:

- Quantifying Errors and Uncertainties in Altimetry Data [6 orals]
- Science (Part III): Two decades of continental water's survey from satellite altimetry - From nadir low-resolution mode to SAR altimetry, new perspectives for hydrology [6 orals]
- Side meeting with European tide gauges operators: What needs in term of in situ sea level observation? [1 oral]
- Round tables for each splinter

Links to the presentations are available on the meeting website: http://meetings.aviso.altimetry.fr

6.1 SAR Altimetry Workshop

Chairs: François Boy and Paolo Cipollini

The SAR Altimetry Workshop, at the start of the OSTST week, had a good participation of scientists (about 200 throughout the day). Forty-four abstracts had been submitted; eighteen contribution were presented as talks organized in 4 sessions, and preceded by a keynote by R. K Raney, while the rest were presented as posters (which remained up on display throughout the entire week).

The main objective of the Workshop was to provide a forum for experts and users to display technical progress, discuss outstanding issues and showcase applications of SAR altimetry over water surfaces and sea ice. The Workshop was undoubtedly successful in achieving this objective, by allowing the sharing and exchange of a great deal of information; the final discussion was dense and went on until late, suggesting that in future editions more time should be allocated for discussion throughout the day, perhaps distributed after each session.

The picture of SAR altimetry that emerged from this Workshop is that of a rapidly expanding field. On one side SAR altimetry observations over the oceans, inland waters and sea ice, first remarkably demonstrated by CryoSat-2, are fully consolidated and moving towards operationalization thanks to the availability of global SAR mode data from Sentinel-3A; on the other side the SAR altimetry community remains an incubator of novel ideas on further technical improvements to the data processing that could result in a step change in observational accuracy – or even yield new parameters.

6.1.1 Keynote talk "SAR altimetry: precedent, present, and prospects (fifty years following Apollo 17)" by R. Keith Raney

The Workshop was opened by a keynote talk by R. Keith Raney (2kR LLC) who revisited a number of milestones in the development and consolidation of the technical knowledge leading to SAR altimetry, and provided for each milestone the relevant theoretical context. The early lessons learned from the Apollo and Seasat missions and from X-band airborne radars were multifold: there was more attainable from SAR processing than just a finer resolution; a high number of looks is desirable and coherence of the raw signal is needed; spurious Doppler signals due to altitude rate must be eliminated. While fully focused SAR mode is desirable, as already shown by the 1972 Apollo Lunar Sounder Experiment, unfocused SAR (aka delay-Doppler altimetry) is a reasonable (and computationally much simpler) starting point. CryoSat has met all expectation and fully demonstrated the capabilities of Unfocused SAR. Dr Raney explained in detail the derivation of the unfocused and focused (one-look) resolutions at the CryoSat and Jason-CS orbital altitudes: the focused resolution is better than half the antenna diameter. For CryoSat two limiting characteristics are the closed burst (listening time only 1/3 of the radar cycle) and the Doppler resolution of 300 m, worse than the theoretical unfocused resolution of 168 m. Maximizing the performance requires the open/interleaved mode; this yields 5 to 6 times more looks, but there is an upper bound on the number of looks per resolution cell (SAR measurement uncertainty principle) depending on the Doppler bandwidth, in line with Shannon's theory. Fully focused SAR mode is necessary and sufficient to establish this upper bound while unfocused processing of interleaved data can achieve near-maximum performance. Future design must support coherent processing [as reiterated in session 1, see below] while processing must manage ambiguity and increase the sample rate before the computation of the power waveform.

6.1.2 Session 1: Innovative SAR processing

Session chairs: Robert Cullen, Salvatore Dinardo, Walter H.F. Smith

Paolo Cipollini opened the session with a review of the many topical issues in SAR altimetry, including weighting of the multi-look stack, exploitation of power distribution in the stack, retracking of individual Doppler bins, computation on a finer ground step, fully-focused SAR altimetry processing, Amplitude Compensation and Dilation Compensation (ACDC), improvements in SAR waveform models, coastal-specific retracking, and the improvements in the wet tropospheric correction that benefit altimetry as a whole.

Some remarkable characteristics of the fully-focused SAR altimetry technique were described by Walter Smith. In this synthetic aperture processing technique, looks over a surface element are collected during its entire illumination time by the radar (around 2 sec). The technique can reach half meter along-track resolution and as such may have direct applications to hydrology and sea-ice monitoring, while for ocean applications SAR data focused to half meter can then be incoherently averaged along-track resolution to provide SSH, SWH and sigma0 noise reduction by up to a factor of sqrt(2) wrt unfocused SAR.

Mònica Roca presented some results from the ESA funded projects CryoSat+ for Topography and CryoSat+ for Mountain Glaciers concerning L1 and L2 processing enhancements for SARin, including the so called "swath processing" that improves the spatial resolution of the elevation measurements.

David Cotton summarized the scope and early results of the ESA SCOOP project aiming at developing, testing and implementing modifications to the processing of the L1B-S product (e.g. zero-padding, multi-looking, antenna pattern compensation, stack beam weighting), and improving to the implementation of the model in the re-tracking of the SAR echo to generate the L2 product. SCOOP includes an activity to develop an improved wet tropospheric correction for Sentinel-3.

Christine Gommenginger presented the results from a EUMETSAT-funded study on the impact of swell on SAR mode altimetry. While theoretical consideration indicate that swell effect could distort waveforms when swell height are larger than 4 metres (which is rare), empirical investigations with Cryosat-2 SAR data collocated with Envisat ASAR found no evidence of swell effects, neither in L1B waveforms, nor in L2 SSH. Further investigations are recommended, in particular for the parallel swell case that only had swell height < 2m in this dataset.

Finally, Mònica Roca presented DeDop, a tool for self-processing of altimetry data, composed of open source libraries, fully configurable to suit research and application needs (tool and documentation are available from http://dedop.org).

6.1.3 Session 2: SAR mode performances: SAR CALVAL from Cryosat-2 and Sentinel-3

Ssession chairs: Pierre Féménias, Mònica Roca, Pierre Thibaut

The main focus of this session was on the quality of the new SAR altimetry data coming from Sentinel-3 SRAL, with some complementary findings based on Cryosat-2 SIRAL.

Matthias Raynal presented an assessment of SAR mode data from the S3PP processor, showing good consistency with Jason-2 at global scales after only 7 months of full SARM (No mean bias on Sea level/ Reduced noise/No spectral bump). Noise differences between SAR and PLRM are not homogenous over Ocean but highlight regional patterns that may be correlated with swell period (but not only). There is also a remaining 20cm bias on SAR SWH wrt LRM (observed both in C-2 and S-3)

The very good quality of the S-3 L2 operational products (PDGS) was illustrated in a talk by Sylvie Labroue. Excellent S-3 SARM performances are observed at global scales. The latest operational SAR processor (delivered to ESA on 14 Oct, waiting for the installation on ESA and EUMETSAT processing centres, reprocessing already started) is very close to S3PP processing. Further improvements are expected from the SAMOSA 2.5 retracker that will be implemented in the ground segment early next year (following recommendation from CP4O project). In agreement with the previous talk, SAR observations appear to be sensitive to the swell (in terms of increase of 20-Hz range noise)

The impact of swell on SWH from SAR altimetry was analysed in some detail by Saleh Abdalla using C-2 data from the SARvatore processor (run on ESA GPOD) over the NorthEast Atlantic and South Pacific SAR box, and S-3 data over the same regions. Abdalla showed a few clues that swell has a negative impact on SWH from SAR altimetry: as far as SWH is concerned, it seems that altimetry in general performs better in swell dominated regimes compared to wind-sea dominated. But SAR altimetry is less successful at swell regimes.

An assessment of the coastal performance of SAR Altimetry from CryoSat-2 and Sentinel-3 was presented by Paolo Cipollini, who looked at both SSH and SWH and highlighted the beneficial effect of data screening based on retracking misfit. S-3 with no specific coastal processing (i.e. no zero padding, no hamming windowing) already shows coastal precision comparable to C-2 with specific coastal processing, and it seems possible to use SAR altimetry data to characterize the coastal wave field, for instance by observing sheltering and shoaling effects.

Eduard Makhoul presented a detailed performance comparison of the S-3 and C-2 SAR processing baselines over the open ocean and the coastal zone, carried out within the ESA SCOOP project. C-2 baseline processing provides an improved estimation noise for SWH

Retrieval, and slightly better performance in estimation noise for SSH w.r.t. S-3. The absence of windowing in S-3 processing results into side-lobe contamination and therefore some performance degradation.

Finally, Pascal Bonnefond presented the calibration activities for S-3A at Corsica, linking it with historical and current missions, and the plans for further improving the calibration site. The S-3 SSH is «unbiased » in the PDGS products (SARM and PLRM mode), without clear dependency with SWH. A –34 mm PLRM/SAR bias in the S3PP products has been identified and is being corrected in the reprocessing)

Discussion in the session allowed ESA and EUMETSAT to clarify the S-3 data release plan: the data set from April onward is already accessible to expert data users (members of the S3VT. The Official S-3 STM data release to the user community (L1A, L1B, L2WAT & L2LAN products) is planned for early December 2016 [data now released since December 13rd]. The L1B-S will still have to be quality-controlled before official data release. This will nominally happen Q1 2017.

6.1.4 Session 3: Applications, SAR for science

Session chairs: Jérôme Benveniste, David Cotton, Remko Scharroo

This session showcased a number of applications that exploit the potential of SAR altimetry for different parameters or over different targets.

Marcello Passaro kicked off the session showing the use of Cryosat-2 stack data for nadir-lead detection in sea-ice regions. One important motivation to isolate leads is to improve sea level records in those regions. The combination of a new parameter, the stack peakiness, and multi-stack analysis is promising to detect the leads, as shown against Sentinel-1 SAR images. This application highlights the importance of L1b-stack data, so far only available from the SARvatore/GPOD processor.

Jérémie Aublanc showed a promising first study of SAR altimetry over the Antarctic ice sheet with both C-2 and S-3A data. The retrieved elevations are very consistent with previous DEMs; the waveform leading edge is weakly impacted by volume scattering and the technique has negligible sensitivity to along-track slopes and so it should be able to retrieve fine scale topographic variations.

Moving on to a different target, Pierre Fabry presented some work on the characterization of SAR mode altimetry data over inland waters, that is being carried out within the ESA SHAPE Project. A range of water classes have been investigated and found to be very heterogeneous without clear distinctions between them. Skewness, kurtosis and standard deviation of the Range Independent Power seems to be inter-dependent parameters, nevertheless they might still help estimate the Water Fraction classes as a self standing method from the altimetry data only.

Alejandro Egido complemented the work on fully-focused SAR altimetry introduced by W. Smith in Session 1 with an overview of the scientific applications of this promising technique, with examples. These range from hydrology (FF-SAR can detect small ponds and monitor river levels) to sea ice (SSH measurements from ice leads) to coastal (where coastal scatterers can in principle be seen and located, but the sea return is still not completely understood) to open ocean (where the focused SAR multi-looked waveforms @ 1 Hz show an increase in the effective number of looks by a factor of 2 with respect the delay/Doppler processing, i.e. a reduction in noise by a factor sqrt(2))

Lotfi Aouf described the methodology and results of assimilation of S-3A SAR mode wave data in the wave model MFWAM. Assimilation of S-3A shows a positive impact in the analysis and forecast, but geographically variable. A bias of S-3A significant wave height is well identified, more pronounced in southern winter ocean regions, and confirmed by comparison with both other altimeters and buoys. This bias seems to be linked to a swell wave regime.

Luciana Fenoglio concluded the session with a study using 3 years of SAR Altimetry from C-2 over the coastal zone of the Bay of Bengal. Over the open ocean they find good consistency PLRM & SAR ocean SSH and SWH (SSH STDD of 4-5 cm, SWH STDD 18 cm, no biases). In the coastal zone standard deviation of differences are significantly higher but SAR shows a better agreement with the model near the coast. SAR allows a good recovery of the climatic signal (monthly sea level), with geographical patterns matching the model.

6.1.5 Session 4: Future missions, recommendations and round table

Session chairs: Craig Donlon, Lee-Lueng Fu, Nicolas Picot

This session was opened by Lee-Lueng Fu with a short overview of the status and the challenges of the SWOT mission. The Mission has passed Preliminary Design Review (April 2016) and been in Phase C since May 2016, and a new Science Team has been established. Mission launch is scheduled for April 2021.

Then, Nicolas Picot presented the CFOSAT mission, especially the SWIM payload. SWIM is a Ku-band real aperture radar. It illuminates the surface sequentially with 6 incidence angles: 0°, 2°, 4°, 6°, 8° and 10° with an antenna aperture of approximately 2°. In order to acquire data in all azimuth orientations, the antenna is rotating at a speed rate of 5.6 rpm. The six beams enable measurements of several geophysical parameters: backscattering coefficient profiles from 0° to 10° of each surface, SWH and wind sea surface (from nadir beam), and 2D wave spectra (from 6, 8, 10° beams). Those data could help understanding the impact of swell in conventional and SAR altimetry.

Craig Donlon introduced the discussion on the current international constellation of altimeters and its future additions, presenting the status and main characteristics of Sentinel 3-C/D and Jason-CS/Sentinel-6, and then the plans for a future polar monitoring mission (Ku+Ka SARin altimeter with new generation MWR, complementary orbit to operational system, focus on high latitudes) to follow on CryoSat-2. Issues under discussion included optimization of SAR chronograms to maximise the performance (looks) over different surfaces (ocean, sea ice, coastal, land, rivers lakes), constellation of low-cost altimeters or other techniques swath altimeters and GNSS-Reflectometry, linking altimetry to the local datum on land and specific action to improve relationship to tide gauges (better siting for improved correlations). A possible larger grouping International Satellite Altimeter Science Team was mentioned with more countries (for instance China, India, Japan) and coverage of all Earth surfaces (ocean, inland waters, ice).

The Workshop ended with some recommendations:

From the Cal/VAL session:

> Agencies should provide in the data the variable "distance from coast" from a precise, higher resolution map than currently used, and provide across-track distance from coast, which is a crucial parameter in SAR altimetry. An estimate of the 'angle of attack' of the track would also be useful.

From the SAR processing methods session:

> Recognizing that "fully focused SAR processing" has new capabilities and applications that improve precision and resolution of Earth surface properties, the OSTST recommends that SAR altimeter missions provide, insofar as possible, characterization information needed to support coherent processing throughout the time when a point on the ground is visible. More R&D is required to consolidate our understanding of fully-focused SAR processing performance. (see also OSTST IPM summary, W. Smith)

6.2 Application development for Operations

Chairs: Hans Bonekamp, Emilie Bronner, Gregg Jacobs and John Lillibridge

This is a summary of the Application Development for Operations splinter session for the 2016 OSTST. It took place on Wednesday November 2.

There were 6 talks and 7 posters presented, and the oral session was very well attended (> 100 attendees).

6.2.1 Oral presentation summary

The first talk by Alice Dalphinet, 'On the validation of the high resolution wave model with altimeter data under hurricanes and storm conditions for the West Indies' discussed recent advances with high spatial-resolution wave models being run at Meteo-France. The hi-res model, based on WAVEWATCH III®, is nested within the global 0.5° MFWAM model, assimilating altimetry observations. The model benefits from inclusion of coastal physical processes (such as wave refraction) and a very fine (200m minimum) irregular mesh (Figure 2). When altimetric SWH is assimilated in the bounding 0.1° (regional) MFWAM model, the validation of the WW3 model with altimetry data is improved. It was noted that the WW3 model tended to underestimate wave heights in the Caribbean Sea, west of the island arc. Future work will focus on better bathymetry and adjustment of dissipation source terms in the model.

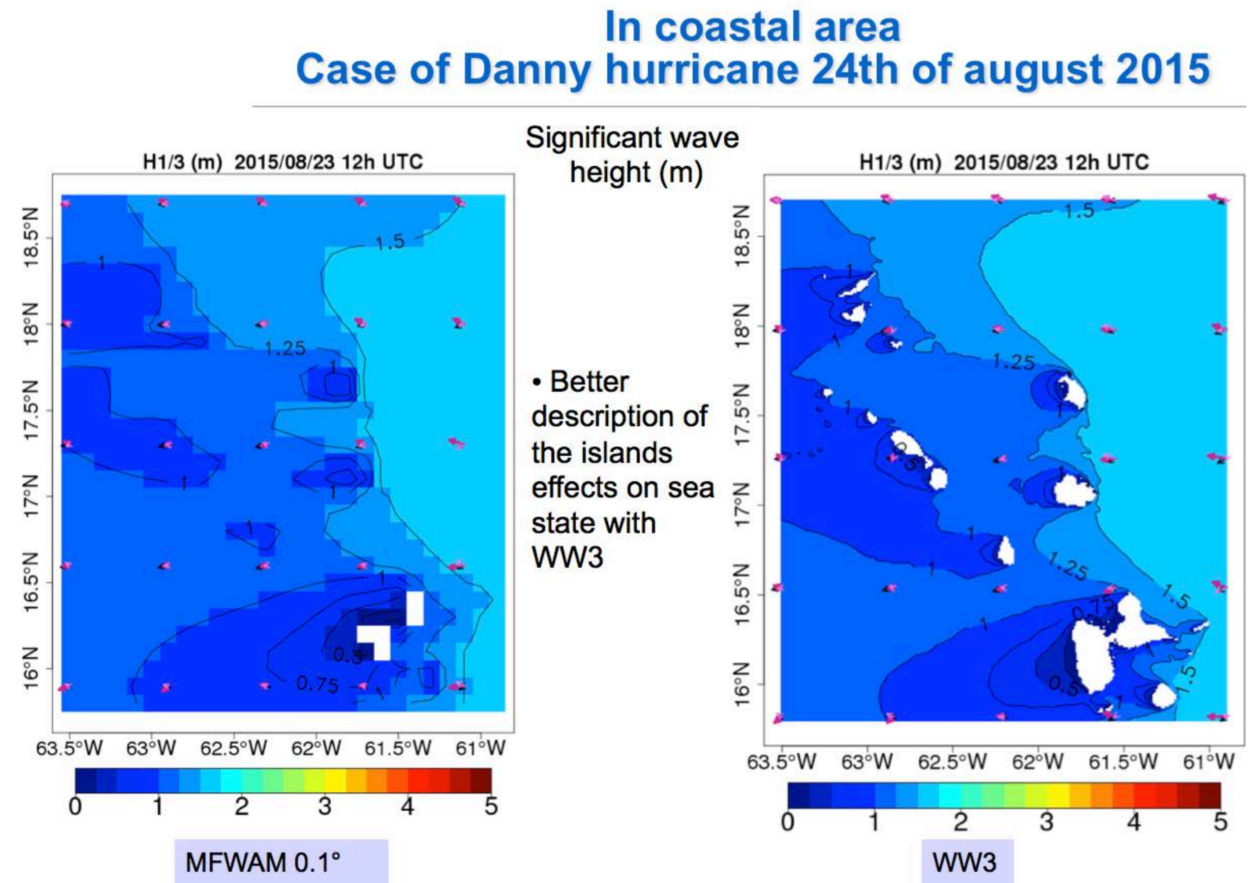


Figure 2. Example of hi-res WW3 model (right) vs. MFWAM (left) for Hurricane Danny in the W. Indies

The next talk by Fabrice Ardhuin 'Wave height variations at scales under 100 km: Small-scale currents have large effects on ocean wave heights' looked at the interplay between ocean currents and surface waves, and their effect on each other. It is well known that surface currents modify the wave field through refraction, advection, dissipation, etc. but the converse is also true – waves can affect currents and sea level at small spatial scales. At scales > 20 km, refraction of the wave field tends to dominate, whereas at shorter scales advection is more important (Figure 3). The talk concluded with a descript of the "SKIM" mission concept, which would simultaneously measure both significant wave height *and* surface currents to advance studies of the interaction of the two phenomena.

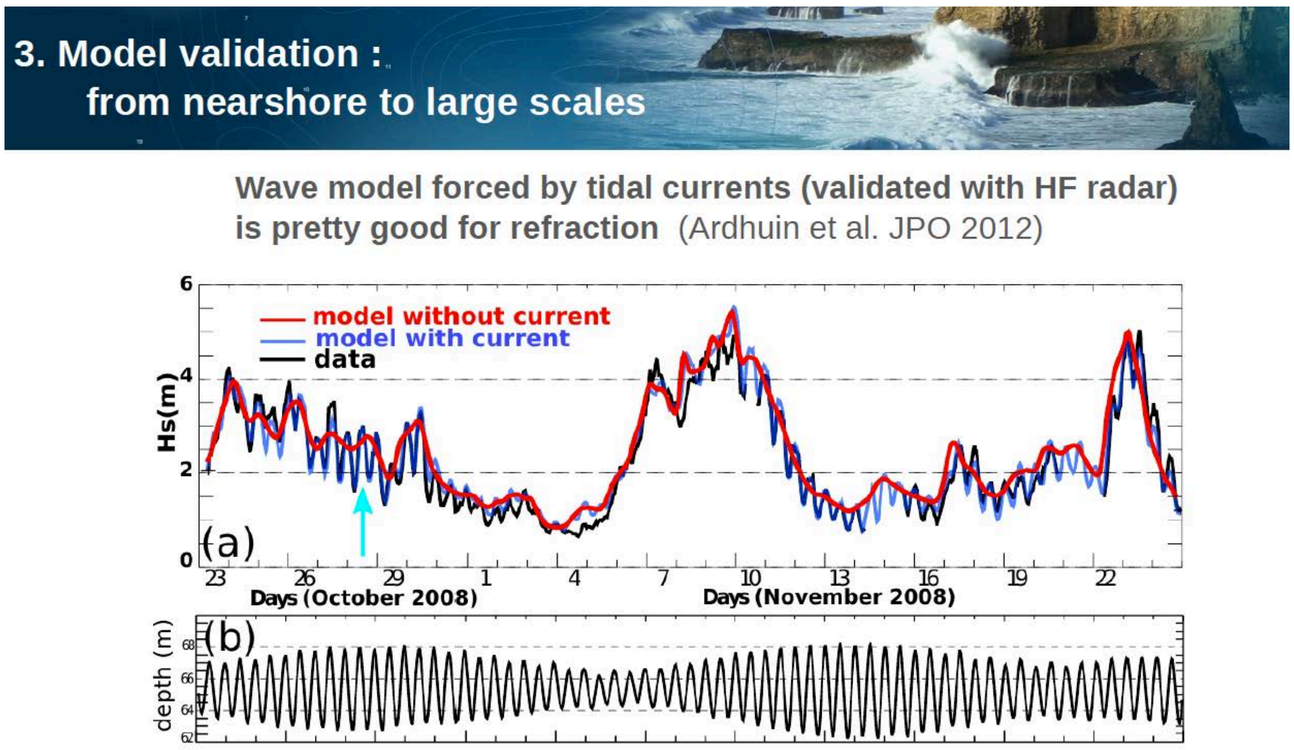


Figure 3. Improvements in wave model after inclusion of tidal currents, as validated by coastal HF radars

The third talk by Zhijin Li 'Improved Representation of Submesoscale Flows Using Multiscale Data Assimilation of Satellite Altimetry' provided an update on improving the model resolution of submesoscale features, this time in the Salinity Processes in the Upper Ocean Regional Study (SPURS-2) field campaign in the salinity minimum in the eastern equatorial Pacific. The SPURS-2 data assimilation and forecasting system predicted observed mesoscale eddies due to the assimilation of multi-satellite altimetry measurements (Figure 4). The assimilation of multi-satellite altimetry measurements helped constrain model biases. It was evident that submesoscale flows make a major contribution to near-surface salinity balance.

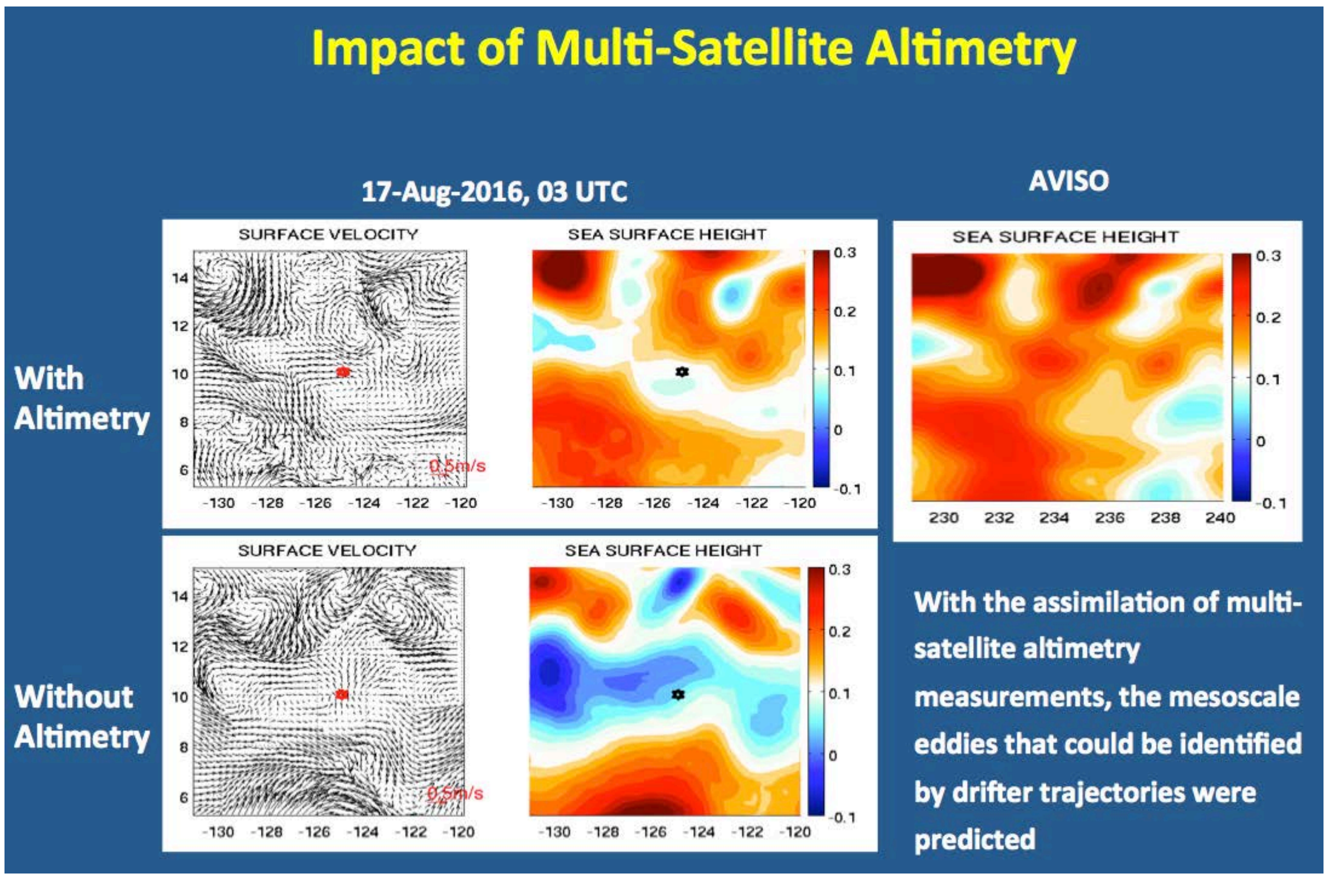


Figure 4. Improvement in mesoscale eddy modelling after assimilation of altimetry data in the SPURS-2 region

The next talk by Cédric Tourain 'SWIM NRT products - Focus on the nadir beam processing' described the SWIM wave measurement system on the upcoming CFOSAT mission (China & France; launch mid-2018). After introducing the mission and instruments (Figure 5), examples of the near real-time products coming from the wind and wave scatterometers were presented. Retracking of the nadir beam products will be optimized for backscatter (wind speed) and SWH estimation, benefiting from recent advances in numerical retracking, Nelder-Mead convergence criteria, etc. The 'wave products' (from 6/8/10° incidence angles) will provide directional 2-D wave spectra as well as estimates of wave period. The 'backscatter products' will provide σ^0 information across 0-10° of incidence angle.

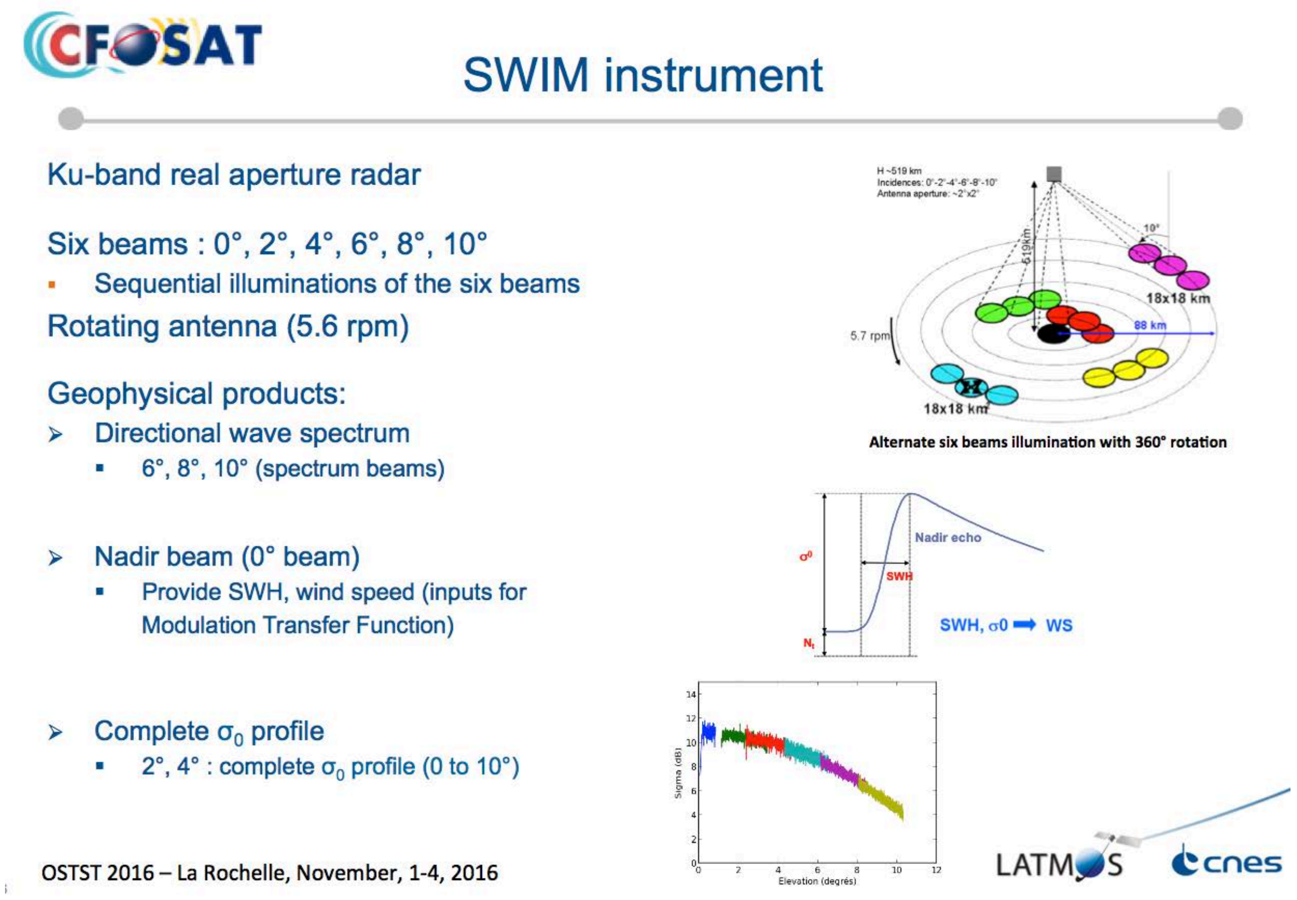


Figure 5. Measurement principle of the SWIM system on-board CFOSAT

The fifth talk by Jean-Michel Lellouche 'Performance and quality assessment of the new CMEMS global ocean monitoring and forecasting real-time system' described a new forecasting and global ocean monitoring system being run by Mercator as part of the Copernicus initiative in Europe. The new system recently went operational (2016-10-19) with 10-day daily forecasts, assimilation of sea-ice concentration (in addition to SLA and SST as before), with adaptive tuning of the altimeter and SST observations. The adaptive tuning of SLA measurements (Figure 6) reduced the median value of the model error by half, from 5 cm to 2.5 cm resulting in more realistic model results. Similarly, SST estimations were improved by adaptive tuning as shown by an EOF analysis with better mode-1 (seasonal) and mode-3 (El Niño) error reduction. The overall result for mean sea level was better agreement between the model and recent estimates for the mass and thermosteric components of sea level rise. Finally, a stark real-world example of the improved model performance demonstrated that the search for AF-447 in the South Atlantic would have found the missing plane sooner than the model available at that time.

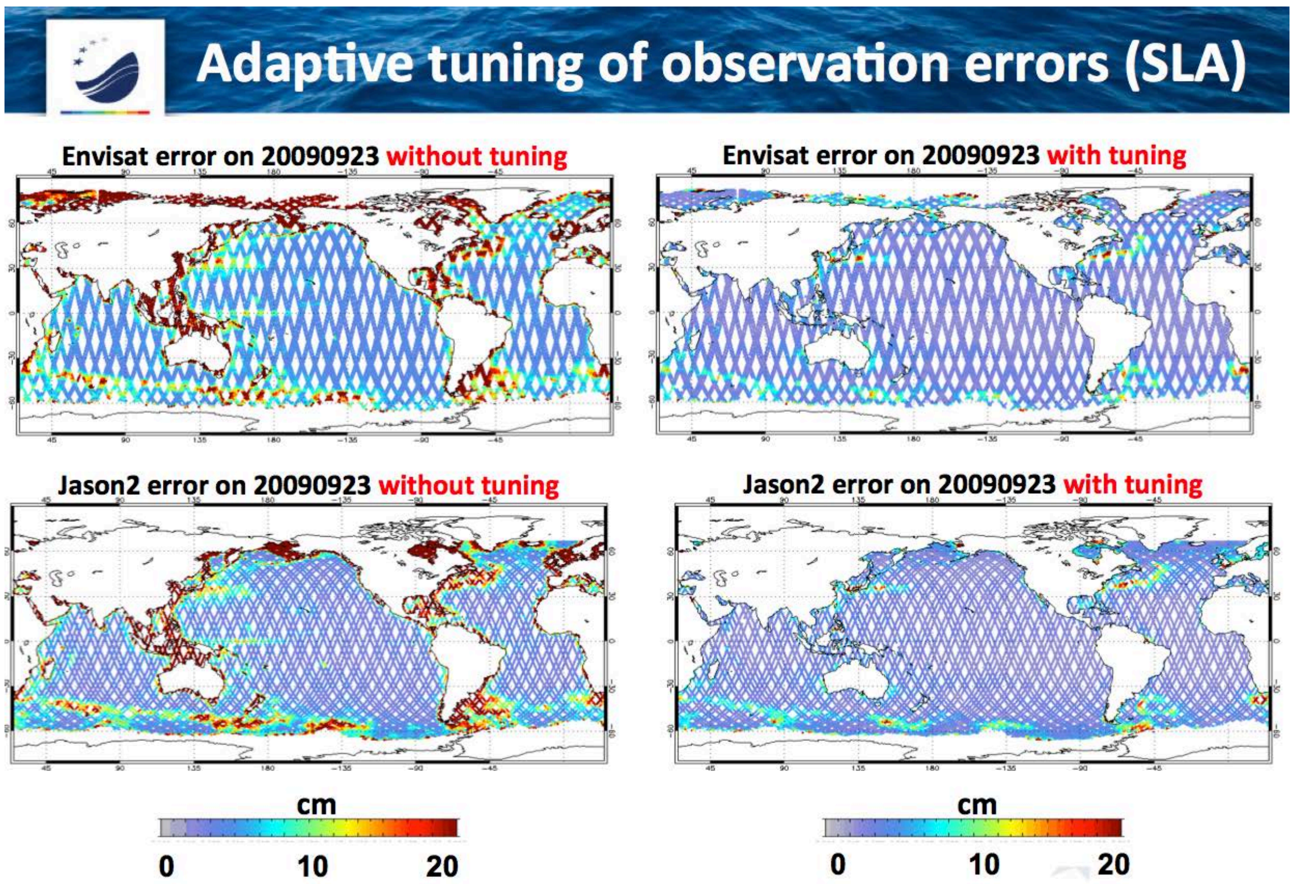


Figure 6. Example of improvement in CMEMS Sea Level Anomaly errors after adaptive tuning

The final talk by Yannice Faugère 'DUACS sea level products: (soon) 6 missions in the system' gave us an update on the DUACS multi-mission altimetry system, with the inclusion of Sentinel-3A data (as soon as STC/IGDR products are available) along with Jason-3, Jason-2 interleaved, SARAL/AltiKa drifting-phase, Cryosat-2, and HY-2A (geodetic) measurements. The Topex/Jason reference missions are crucial for determination of the large-scale climate signals, and the transition from Jason-2 to Jason-3 is in progress after Jason-3 data were added on 2016-09-13. Jason-2 interleaved data are planned to return to the system on 2016-11-22. Preliminary results from Sentinel-3A look very promising (Figure 7) and those data will also be added to DUACS in the near future. Several updates to the system are planned, including the new MSS_CNES_CLS 2015 mean sea surface, which is important for non-repeat track AltiKa, Cryosat-2 and HY-2A measurements. Additional updates include utilization of the 20-Hz data, dynamic interpolation vs. OI, and the provision of a new 'eddy atlas' at the AVISO+ site.

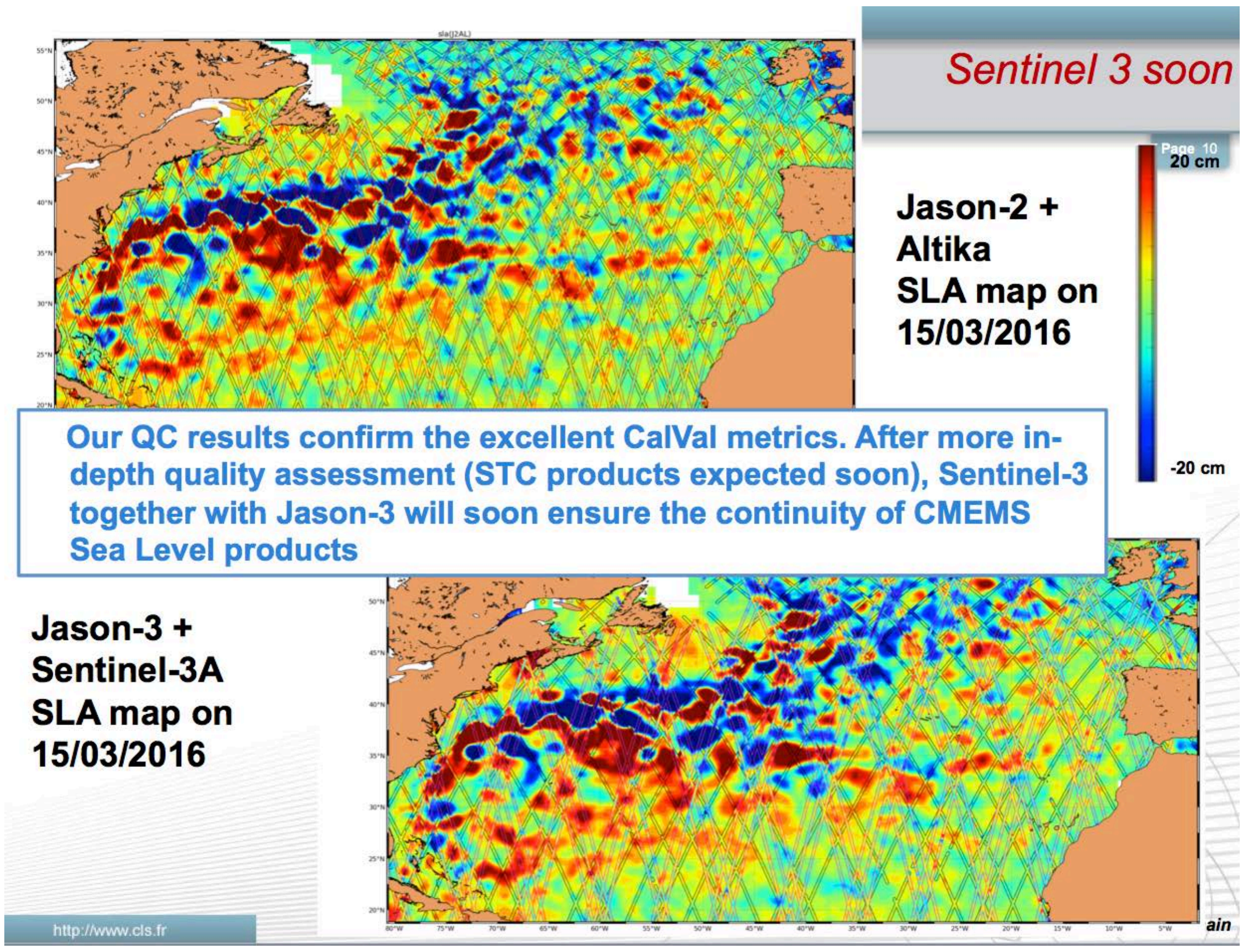


Figure 7. SLA maps of J2+AltiKa vs. J3+Sentinel-3A in preparation for inclusion of S-3A data in DUACS

6.2.2 Round table summary

With respect to the subjects proposed by the OSTST project scientists for discussion, the following points were noted and presented in the final closing plenary:

1 - Assess the Jason-3 data quality: GDR notably - this is the Final Verification Workshop.

Universal concurrence for Jason-3 GDR public release. Jason-3 GDR is of equal quality to Jason-2 GDR. What is the timing for the next evolution of Jason-3 GDR (to GDR-E)? Processing groups would like to be ready.

2 - Jason-2 EoL orbit: discussion between -27 and +35 km orbit.

Concur with recommendation of -27 km. Keep final orbit (graveyard) in mind after EoL orbit for future Jason-3 use of same orbit.

3 - Jason-2 EoL time: trade-off between “soon” vs. waiting for Sentinel-3B.

Consensus recommendation: minimum of 2 years of Jason-2 interleaved. Regardless of orbit, all operational requirements continue to apply. Given: any problem implies immediate graveyard. Continue present operations (exact repeat orbit). Alternative strategy: after S-3B acceptance (~1.5 year J2 interleaved).

4 - Cold sky calibration for Jason-2 as well as Jason-3 (frequency).

Universal concurrence to calibrate both Jason-2 and Jason-3. Frequency is dictated by orbit and solar geometry. Jason-2 reprocessing may consider methods to extrapolate backwards to correct prior AMR data.

5 - Extend the 60-day requirement to 90 days for GDR latency (Jason-3 & Jason-2) to improve the AMR stability via the cold sky calibration.

Universal concurrence. The criteria must be relaxed in system requirement to accommodate this change. GDR processing need not be tied to a particular time, but processing may be triggered on readiness of all necessary available inputs.

6 - AMR on Jason-CS: there is a small probability that the external calibrator can fail. Do we accept the risk?

Universal concurrence: Accept risk and maintain drift requirement. Very small risk of AMR being unusable for the remainder of the mission. Loss of radiometer degrades but does not end mission for NRT applications (but strong effect on climate observations). ECMWF model improvements should be investigated including higher frequency (presently 6-hourly; switch to 3-hour or even 1-hourly). Would benefit present data sets as well.

7 - Full-time open-loop (DIODE/DEM) tracking mode for Jason-2 (already done for J-3).

Evaluate for 1-2 cycles prior to full time operation. Evaluate hydrological, coastal and sea ice application impacts. Would benefit coastal applications.

6.2.3 Poster summary

APOP_001: Value added Sentinel-3A sea level products by the Marine Altimetry L2P-L3 Service (Philipps et al.)

In the frame of the Copernicus Programme funded by the European Union, CNES with its subcontractor CLS are in charge of the development and operation of the Sentinel-3 Marine Altimetry L2P-L3 Service. A first phase has developed the service in order to process L2P and L3 products. L2P products are along-track mono-mission products (over global marine surfaces), providing as much as possible the same corrections and models for several altimeter missions. They have homogenized format and content in order to facilitate inter-mission comparisons. For S3, NRT L2P products have been developed and processed on an operational basis, short time after availability of L2 products. L3 products are along-track products containing time and sea level anomaly for valid marine surfaces, after a multi-mission cross-calibration process versus a reference mission. Additional editing steps, filtering and subsampling are used. A second phase will operate the service during 30 months for S3-A and S3B. L2P products will be disseminated through AVISO+ and L3 products will be disseminated through CMEMS portal.

APOP_002: Sentinel-3A Impact on Numerical Ocean Prediction (Jacobs et al.)

This poster examined the contribution of Sentinal-3A to the multi-mission ocean modelling system being run by the U.S. Navy and developed by NRLSSC. Sentinel-3A provides a new opportunity to advance ocean prediction with a unique sampling pattern in which successive subcycles producing ground tracks that progressively sample toward the east. Comparison of S3A SAR to PLRM observations indicates much lower noise level in the SAR data (1.37 cm RMS for SAR vs. 2.47 cm RMS for PLRM). The addition of Sentinel-3A or AltiKa provides much more spatial structure and higher amplitude peaks.

APOP_003: On the update of the assimilation in the operational wave model MFWAM with Jason-3, Sentinel-3A, and Sentinel-1A and 1B satellite missions (Aouf et al.)

The assimilation of Jason-3 altimetry data improves the Météo-France wave forecasting system (MFWAM). Since 19 October 2016 the assimilation system operationally uses wave data from Jason-3, Jason-2 (interleaved), SARAL/AltiKa and Cryosat-2. The second objective of this effort is to utilize SAR wave spectra from Sentinel-1A in the wave forecasting system. The first validation shows the improvement from the move of Jason-2 to its interleaved orbit, with the 4-altimeter assimilation leading to reduced scatter index of SWH.

APOP_004: Four-dimensional variation ocean reanalysis for the western North Pacific over 30 years (FORA-WNP30) (Kuragano et al.)

A coastal forecasting system around the Seto Inland Sea was developed by Japan’s Meteorological Institute, and was put in operation April 2016. A key aim was to predict abnormal high tides caused by variations in the Kuroshio current. The system consists of an eddy-resolving analysis model for the western North Pacific with a 2 km coastal model. This study documents a long-term ocean reanalysis based on this model, showing success even in the pre-altimetry era largely due to the satellite altimetry providing invaluable ocean statistics in the assimilation system. The state of the Kuroshio extension has decadal variability between stable (low EKE) and unstable (high EKE) states. The variability is remotely forced by the large-scale wind stress field in the North Pacific and was well modeled in the reanalysis.

APOP_005: Developments and new challenges for altimetric data assimilation into high-resolution ocean circulation models (Brasseur et al.)

During the past four years, a variety of advanced assimilation methods have been explored and developed with the objective of improving our capacity to incorporate altimetric data into high-resolution ocean models. Well established methodologies such as variational methods and ensemble-based filters/smoothers have been implemented, expanded and enhance to take into account non-Gaussian error statistics or non-linear model dynamics. Generic methods such as particle filters have been explored to cope with the huge dimensions of realistic ocean models. In the framework of the OSTST and EU-funded SANGOMA project (2012-2015), the NEMO modelling framework was used in eddy-resolving configurations of ocean basins (North Atlantic) and regional seas at low latitude (Salomon Sea) with altimetric products (Envisat, Jason, SARAL/AltiKA), in situ profile data, and surface imagery (SST, ocean colour). This provides a unique approach to (i) improve our scientific understanding of the role of the mesoscale ocean dynamics, (ii) develop our capability to monitor and forecast the mesoscale/submesoscale features of the ocean circulation, (iii) provide added-value information on the space-time variability of the sea-surface topography including error statistics and advanced diagnostics, (iv) demonstrate the capability of coupled physical-biological systems for the monitoring of living resources and carbon dioxide storage and fluxes. This poster reviewed the progress made in altimetric data and image assimilation for science as well as operational applications, and discussed the new assimilation challenges that will have to be addressed looking forward to SWOT and hybrid high-resolution altimetric constellations.

APOP_006: Withdrawn.

APOP_007: Calibration, validation and advanced applications of ocean drift models, forced with ocean satellite data, using marine debris reports from natural disasters (Maximenko et al.)

This final poster examined the use of ocean drift models, particularly looking at the spread of marine debris in the North Pacific as a result of the tragic Japanese tsunami in 2011. Near-surface currents are difficult for numerical models to predict due to problems estimating vertical shear in the mixed layer and modeling processes associated with wind forcing and buoyancy flux. For a broad range of spatiotemporal scales, a surrogate, diagnostic model known as SCUD (Surface Currents from Diagnostic model) has been built and used for a variety of marine applications. These include the drift of the 2011 tsunami debris and verification of a fisherman's 430-Day drift across the Pacific. The IPRC Ocean Drift Model helped to identify regions of the World Ocean where marine debris accumulates over long periods of time. Finally, the Ocean Drift Model has simulated the drift of fragments identified from flight MH370 in the Indian Ocean.

6.3 Instrument Processing

6.3.1 Corrections

Chairs: Shannon Brown, Estelle Obligis

6.3.1.1 Instrument Processing – Corrections: Results Summary

The instrument-processing splinter on corrections featured several presentations on the wet tropospheric path delay correction, flags and the sea state bias correction. Since this was the first OSTST after the launch of the Jason-3 satellite, a focus was on the Jason-3 performance relative to Jason-2 during the tandem phase. Overall, the Jason-3 AMR was shown to be providing a wet tropospheric path delay correction with equivalent accuracy as Jason-2 almost from day 1. Figure 8 shows the wet path delay from Jason-2 and Jason-3 for a representative pass. Globally, the Jason-3 AMR PD agreed with the Jason-2 AMR to 0.3cm after post-launch calibration. One issue noted with Jason-3 was a long-term drift in the noise diodes. A drift correction using the new cold sky maneuvers is implemented for the GDRs to mitigate any impacts on the global mean sea level record.

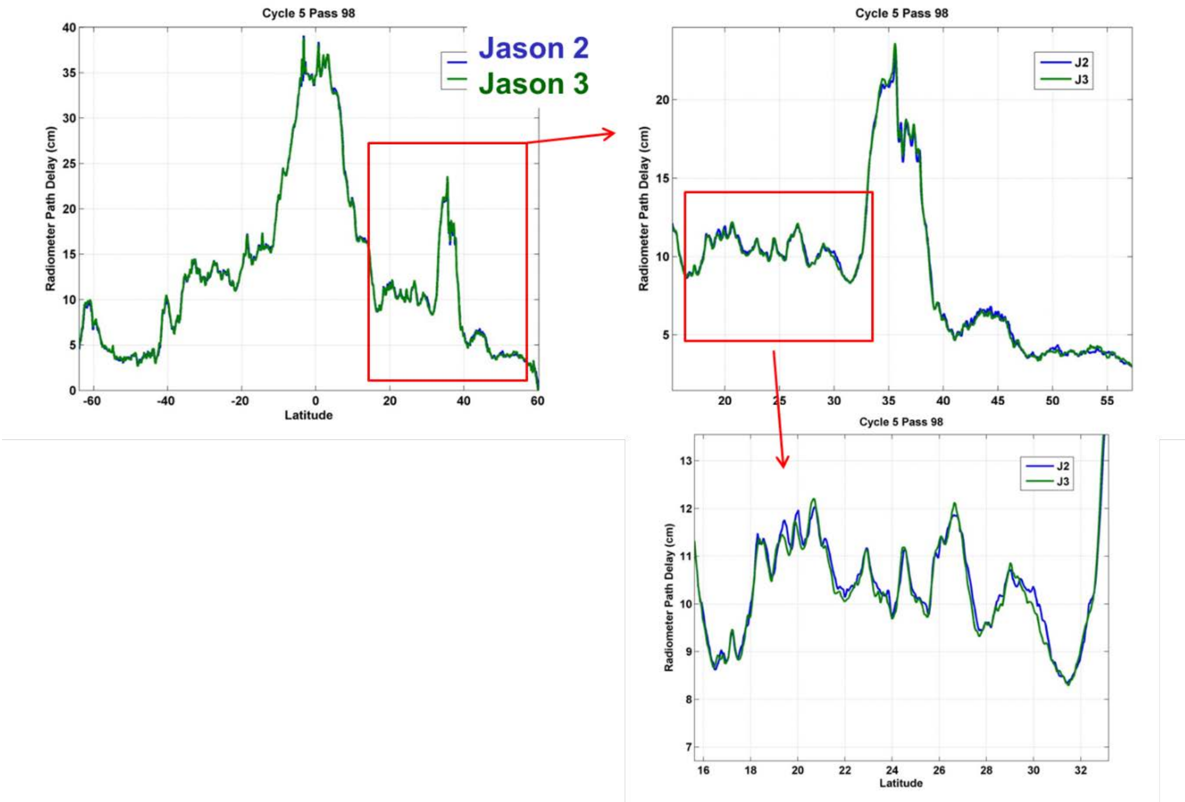


Figure 8. Jason-2 and Jason-3 wet path delay from cycle 5 pass 98. The two agree to better than 3mm (1-sigma).

The rain flag, as currently implemented, was discussed in two presentations. An anomalously large number of flagged values were observed. This was found to be due to a few issues:

- The rain flag seemed to be only based on cloud liquid water
- Biases were observed between expected values from a lookup table and measured values of sigma0
- The rain flag is set when rad_surf_type > 0 (coastal zones) & qual_alt_1hz_ku > 0

An updated algorithm that fixed these issues was tested and resulted in a more reasonable amount of flagged values, as shown in Figure 9. Future improvements will consider adding a SST dependence of differential backscatter at Ku and C-bands for more accurate flagging.

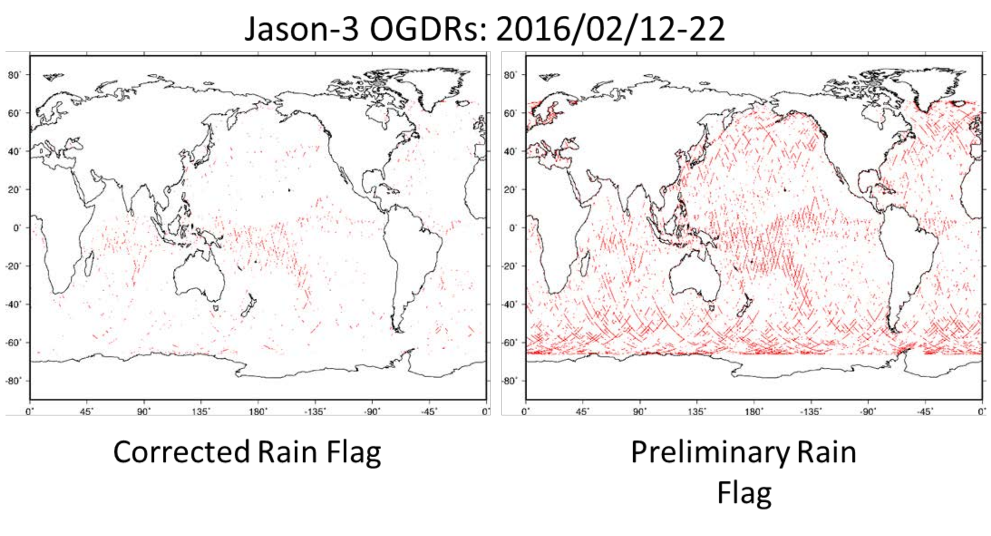


Figure 9. Flagged values before (right) and after (left) the rain flag algorithm issues were corrected.

In addition to the Jason-3 AMR, another recent addition to the altimeter family was the Sentinel-3 system. This system features a two-frequency radiometer termed the MWR. Overall, good agreement is found in inter-comparisons with other radiometers. The hot end TB calibration was found to be unbiased (within the uncertainty of the comparison), but a small bias was observed for cold TBs. Calibration adjustments have been proposed to mitigate the observed bias. The wet tropospheric correction is produced using a neural network algorithm and shows good agreement relative to ground truth, as shown in Figure 10.

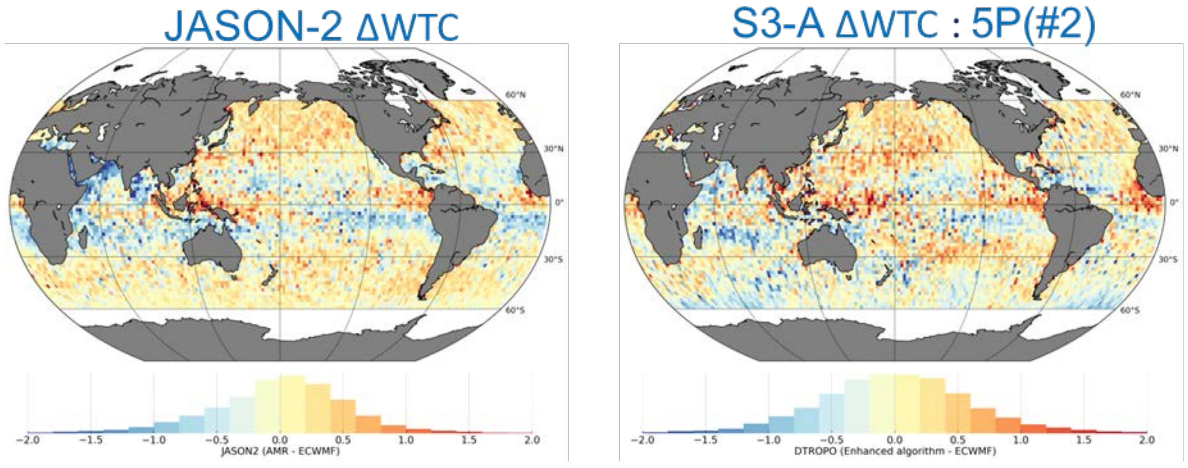


Figure 10. Comparison of Jason-2 and Sentinel-3 wet PD biases relative to ECMWF.

In addition to evaluating the performance of current microwave radiometers, there was discussion on future radiometer systems. A report was presented from an on-going study on optimal radiometer configurations for future altimetry systems. The study focused on how future instruments could provide improvement in coastal areas, using high-frequency channels. The study identified the optimal set of radiometer channels based on retrieval performance and instrument design constraints (e.g. cost, feasibility, resources). The optimal set was found to be: 23.8, 36.5 50.3, 53.596, 89, 183+/-11 GHz. An initial study of the performance enhancement shows that a combination of high-frequency channels and a 1D-var retrieval approach promise to the capability to downscale retrievals not limited by instrument resolution, as illustrated in Figure 11.

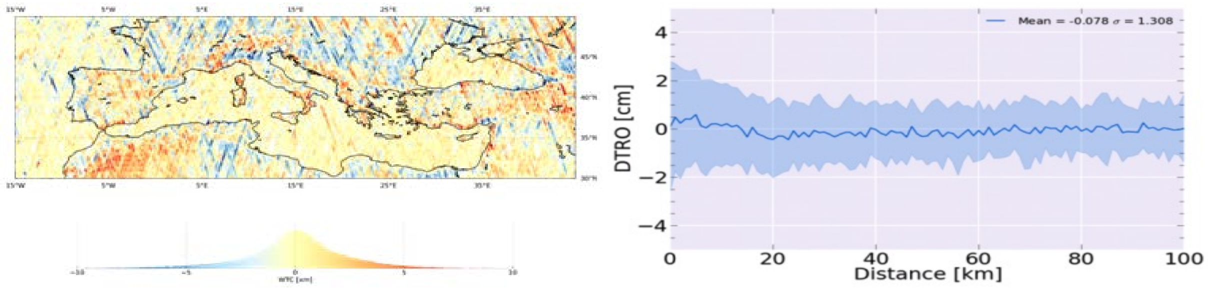


Figure 11. Demonstration of high-frequency radiometer capability for improving retrievals near land.

The initial Jason-3 SSB model has been developed and is implemented on the GDR. It will be re-derived after 1-year when more data is available. Some progress has been made in new 3D SSB models which show reductions in SSH cross-over variances, as shown in Figure 12. These models are derived from collinear SSH differences. They show some differences with standard 3D models derived from SLA data and further comparisons are planned.

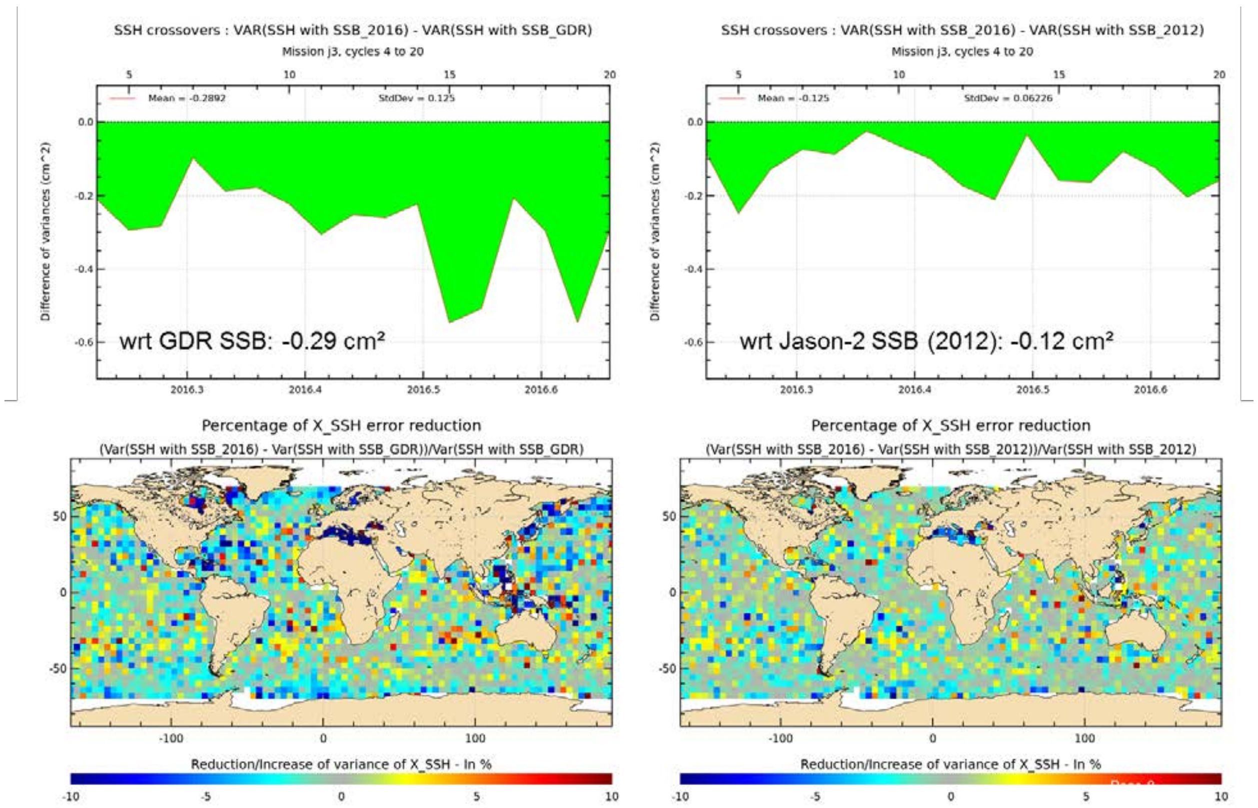


Figure 12. Cross-over variance reduction with new SSB models.

6.3.1.2 Recommendations

A round table discussion was held and several recommendations to the questions posed in the opening plenary were generated.

Should Jason-2 continue cold sky maneuvers?

The cold sky maneuvers have proved valuable for Jason-3 and **should be continued** for Jason-2, at least for inter-leaved mission. The cold sky calibration provide data to stabilize long term record and provide additional insight into calibration behavior which may benefit first 8 years of the mission.

Should a change in GDR production schedule allowing up to 90-day latency for optimal use of cold sky data be implemented?

The IPC **fully supports** changing the GDR latency to 90-days to achieve the best quality calibrated product on the GDR. The benefits are a lower potential for large changes to GDR later on which extends the time between reprocessing. Additionally, all GDRs will have equal uncertainty since the calibration will be interpolated between cold sky measurements instead of extrapolated. Its noted that the median latency for the GDR will only increase by +5 days (65 days compared to 60).

Calibrator for Jason-CS (Sentinel-6)

To meet the long-term stability requirement for Jason-CS, the radiometer needs to implement a calibrator that adds an additional, but extremely low likelihood, failure point in the design. The IPC was asked to comment on the importance of the long-term stability requirement. The IPC **strongly supports** long term stability requirement and need for calibrator on Jason-CS and thanks the project for seeking OSTST comment on this important issue. The radiometer calibration is largest source of error in the measured GMSL trend and a new requirement for stability on Jason-CS ensures stable measurement for next decade. The radiometer design for Jason-CS, which includes calibrator and new risk compared to Jason-2/3, will still meet equivalent reliability standards as other operational instruments, including prior Jason radiometers. The risk of failure is no different than any other part on spacecraft (all components meet operational reliability requirements).

6.3.2 Measurement and retracking (SAR and LRM)

Chairs: Phil Callahan, Robert Cullen, Jean-Damien Desjonquères & Walter Smith

6.3.2.1 TOPEX Retracking

In an effort to secure the use of TOPEX data for the climate data record a new retracking of the data has been undertaken. The new retracking used a point target response (PTR) fit to the first six sidelobes measured by the Cal-1 as these had been previously found to be the only reliable ones and extended to plus/minus 30 sidelobes with an adjusted sinc. The preflight waveform weights used. A fixed skewness of 0.1 (as for Jason) was used. The new feature for this retracking was that the noise estimate was moved earlier in the waveform (gates 5-7 scaled vs 7-12) to avoid contamination as the Alt-A PTR changed beginning from as early as cycle 100.

The new results reproduce the signature observed in the WFF range correction from about cycle 50 onwards. This WFF range correction has been included in the MGDR distributed by PODAAC even though it was not included in the original project-provided GDRs. The new results continue to be somewhat anomalous for cycles 21-50 during which the first sidelobe is elevated for unknown reasons. A simple version of global mean sea level comparing various retracking versions is shown in Figure 13.

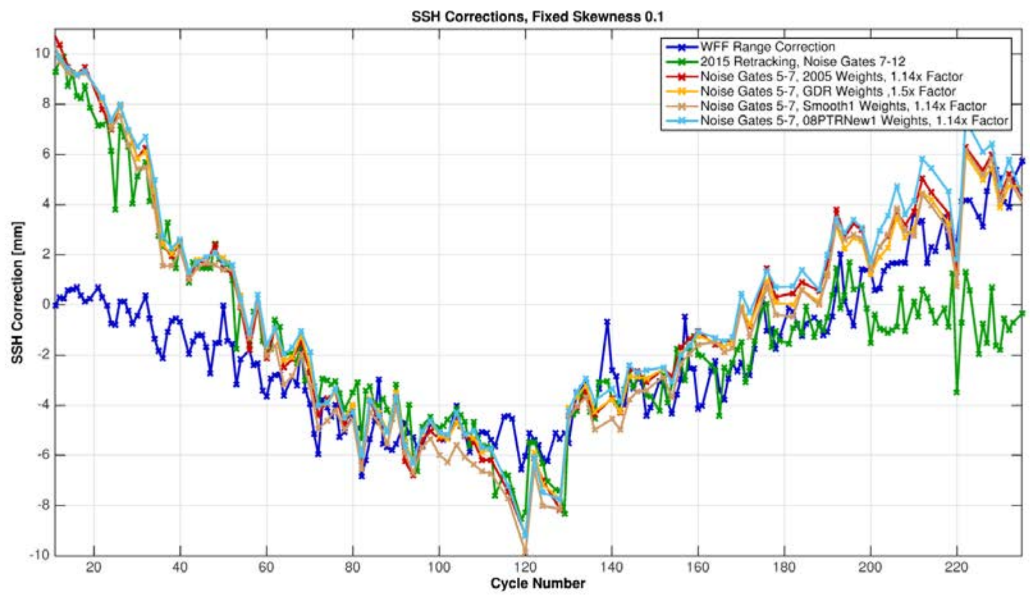


Figure 13. TOPEX retracking results with various noise gates and waveform weights compared to the WFF range correction (blue). The current best estimate is the gold line.

Beckley et al. (this meeting) showed that including the WFF range correction in the calculation of sea level gives a signature relative to global tide gauges. An initial evaluation of the new retracked data indicates that it does not have this signature even though Figure 13 shows that these data following the WFF range correction. A final analysis will have to await the production of a fully reprocessed and corrected TOPEX GDR expected in the spring of 2017.

6.3.2.2 Jason-3 Altimeter Performance

All Jason-3 instruments are functioning normally. Performance is as expected (range noise ~1.6 cm at 2 m SWH; SWH noise ~0.1 m; sigma0 noise ~0.08 dB) and consistent with Jason-2. An initial analysis of the bias between Jason-2 and Jason-3 shows of ~2.3 cm for Ku band and ~8-9 mm for C band. In order to reduce noise in products the low pass filter calibration (Cal-2) is now averaged over 30 days. An early evolution of 0.36 dB/yr of the PTR total power is observed, but it is corrected in the final products. A small anomaly in the estimated off nadir angle was noted following a fine tuning of the spacecraft pointing. The problem was traced to a small error in the Cal-2 gain setting. The error briefly affected only OGDR and IGDR products, but is corrected in all GDRs and future products. An altimeter calibration of range and power was done over three full orbits to test the thermal stability. It was found to be better than 0.1 mm in range and 0.001 dB in power.

The POSEIDON3B altimeter has both autonomous (median tracker) and DIODE/DEM tracking modes and can switch automatically between them depending on position. The former is the previous standard, while the latter provides instant acquisition which can benefit coastal and inland water applications so long as the DEM is accurate to better than 10 m. The onboard DEM v2.0 uploaded in cycle 8 has lakes and rivers from the LEGOS Hydroweb database and a dedicated river database for France and the Congo basin as well as some transponder locations for calibration. Data acquisition from cycle 21 is in DIODE/DEM mode even over the ocean. Noise performance is not affected by DEM errors less than 10 m. An additional improvement to altimeter performance was made by adjusting the AGC operation for peaky waveforms which can occur over inland water and ice.

6.3.2.3 PEACHI products for Jason-3

CNES/CLS is making PEACHI (Prototype for Expertise in Altimetry, Coastal, Hydrology, Ice) products available for Jason-3 GDRs. The PEACHI output is appended to the Jason-3 SGDR product. PEACHI, which has also been used on AltiKa, allows the user to evaluate:

- Weighted versus Unweighted Retracking
- Numerical PTR versus Analytical Approximation
- Improved corrections

Initial evaluation by CNES and CLS of PEACHI weighted retracking ("Nelder Mead") and the numerical PTR shows improved performance with respect to MLE4 unweighted (see next section).

In addition to the latest models for tides, mean sea surface, etc., the corrections include a neural network wet tropospheric correction and a 3 parameter SSB. The neural network gives an improvement of about 0.2 cm^2 in crossover variance. The SSB model uses the mean wave period from a Wave Watch III model as the third parameter to achieve a crossover variance improvement of about 1.5 cm^2. Both models need to be evaluated with a full year of data to check for seasonal effects.

External review of the product quality from expert and general users' perspective is welcome to confirm CNES&CLS assessment. The products are available on Jason-3 oceanobs FTP server. One may access the products with the pi_jason3 login/password at ftp://ftp.jason3.oceanobs.com/peachi/ . Initially this directory contains SGDR PEACHI-Jason-3 products, for complete cycle 5, one pass per file. Comments and questions can be sent to sophie.legac@cnes.fr and francois.boy@cnes.fr .

6.3.2.4 Processing methods

Several authors addressed improvements to processing including

- Weighted and unweighted retracking
- Spectral windows
- Sub-waveform pattern recognition in groups of waveforms

Retracking improvements under development for PEACHI were presented that include use of a numerical model of the PTR (rather than the current CNES MLE method with a single Gaussian) and the Nelder-Mead method for optimization. Use of the improved PTR results in significant reduction in the look up table (LUT) correction to the SWH; additionally, the Nelder-Mead optimization reduces the LUT correction to the range. Overall, the improved method reduces biases in both range and SWH to near zero and noticeably reduces the noise – improvements in noise of 10% for range and 60% for SWH at 20 Hz are shown. The improvement is particularly large for small SWH.

The higher pulse repetition frequency (PRF) of POSEIDON-4 on Jason-CS (9 kHz vs the usual ~2 kHz) was discussed with regard to averaging independent samples of the waveform for noise reduction. It was noted that the equivalent number of independent samples (looks, ENL) around the leading edge of the waveform is not significantly different for the higher PRF but does increase in the tail of the waveform. Also, the ENL increases for higher SWH. The latter does lead to some advantage in the leading edged for higher PRF. Thus, the higher PRF will lead to some noise reduction, although not nearly a factor of 4-5 compared to current altimeters.

A poster by Smith emphasized the importance of using data windows and representing them correctly in digital methods. In selecting a window function one should consider other criteria such as resolution (central peak broadening) and integrated sidelobe power besides just the lowest sidelobe level.

Uebbing et al. gave an interesting presentation on the use of "sub-waveforms" for coastal processing. The method attempts to find "spatial (within one waveform) and temporal (successive waveforms along the satellite groundtrack) information from neighboring range gates to derive a comprehensive partitioning of the total waveform into individual sub-waveforms". The individual sub-waveforms are processed with any standard retracker to give an SSH point cloud. The final result is found by using Dijkstra's algorithm, which finds the "best (shortest) path" through a graph, on the point cloud. The approach gives much smoother results approaching coasts than other algorithms and similar results to standard processing over the open ocean.

6.3.2.5 "Fully-focused SAR"

Egido has investigated fully focused SAR processing that processes pulses across bursts to reach the theoretical resolution limit of antenna size/2 (~0.5 m). This processing goes beyond that of the standard delay/Doppler processing for CryoSat-2 and Sentinel-3 that processes the 64 pulses in a burst to achieve along track resolution of approximately 300 m. The full SAR processing also has the advantage of creating a beam strictly at nadir so that the waveform is sharpened and retracking time is reduced. Of course, the very fine slices from the full SAR processing are extremely noisy, but they are independent so that they can be averaged to various scales to achieve a noise/resolution balance appropriate to the phenomena being studied. A factor of square root of 2 improvement with respect to standard products is found for the open ocean.

6.3.2.6 Recommendations

Based on discussion in the IP splinter and SAR splinter, the following recommendation is made:

> *Recognizing that "fully focused SAR processing" has new capabilities and applications that improve precision and resolution of Earth surface properties, the OSTST recommends that SAR altimeter missions provide, insofar as possible, characterization information needed to support coherent processing throughout the time when a point on the ground is visible.*
>
> *More research and development is required to consolidate our understanding of fully-focused SAR processing performance.*

6.4 Outreach, Education & Altimetric Data Services

Chairs: Jessica Hausman, Vinca Rosmorduc and Margaret Srinivasan

Session presentations:

- The Latest and Greatest in Datasets and Services at PO.DAAC (Hausman et al.)
- The Online Data Extraction Service (ODES): great new features and attractive products (Bronner et al.)
- Scientific Stewardship for Jason-2/3 products: NOAA Archive and Access Services (Baker-Yeboah et al.)
- Outreach at La Rochelle Aquarium (Dell'Amico et al.)
- SHOWCASE of altimeter outreach
  - *Avisoviz interface (Rosmorduc et al)*
  - *Aviso web mobile version (Rosmorduc et al)*
  - *Argonautica "Vendée Globe" operation (De Staerke et al)*
  - *Jason-3 mini-web site contest (De Staerke et al)*
  - *Three new products from CTOH: ERS-2 Mission Reprocessing for Continental Surfaces, X-TRACK Regional Product Release 2016, CryoSat-2 ESA Baseline C: NetCDF Edition (Fleury et al)*
  - *Eumetsat Observing the Ocean from Space MOOC (Scharroo et al)*
  - *Internal Tide Animations (Girton et al)*
  - *Bill Patzert NASA's Jet Propulsion Laboratory Science Communication*
  - *Argo Profiling Floats Field Trip LEARNZ program -- National Strategic Goals from New Zealand – Technology (Piotrowicz et al)*

Posters

- Sar altimetry processing on demand service for cryosat-2 and sentinel-3 at esa g-pod (Benveniste et al.)
- Aviso+ products & services: what's new? (Rosmorduc et al.)
- Transition Aviso+ towards CMEMS for SSALTO/Duacs products (Mertz et al.)
- CTOH altimetry products (L1 to L4) for ocean, ice and continental surfaces applications (Fleury et al.)
- Broadview radar altimetry toolbox (Escolà et al.)
- SWOT in the GLOBE Program: Hydrology science in the classroom (Srinivasan et al.)

2015-2016 Highlights

Updates of data services and tools were shown this year.

New datasets distributed. Some changes in data distribution.

Few outreach & education activities.

The short (1 to 2 slides) format of the "outreach showcases" successful this year. It allows OSTST members to share an outreach or data service activity they participated in but which was not the subject of a full-fledged presentation.

Data services

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

PO.DAAC & NOAA showed evolutions in their services and data. CNES showed evolutions in its extraction service.

A visualisation interface has been opened within Aviso data access services (with sample data), named "AvisoViz".

Outreach

The "MOOCs," or, Massive Open Online Courses, format is on the rise as outreach approach. Building a MOOC entails defining an audience and a learning objective, and identifying a platform, a repetition scheme (scheduled at given time, or open at any time), and supplementary materials, etc. We will consider participation in the development of new MOOCs relevant to ocean altimetry science as opportunities arise.

Outreach and educational activities of the past year include continued promotion of the societal benefits of ocean altimetry data, highlights of the Jason-3 mission especially for its launch, Sentinel-3A, and anticipation of the SWOT and Jason-CS/Sentinel-6 missions. The team has generated several products (handout materials and web-based informational products) to promote the science and applications of the data.

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 use.

A mobile version of the Aviso+ web site was released in March.

Education

Argonautica is focused on the Vendee Globe around the world sail race this year, with skippers launching buoys along the way.

A Jason-3 contest is launched by CNES, with the making of web sites around climate and the environment for students at different school levels (in French and in English).
http://concoursjason3cnesedu.org/

NOAA is participating to educational activities in New Zealand around the Argo floats, as showed by S. Piotrowicz

Recommendations

We would like the OSTST organizers to consider the possibility of proposing a "demonstration" format during next OSTST in addition to posters & orals, i.e. an area with tables / some tables scattered within the session poster, showed during poster sessions, ideally with a screen each on the wall or at least high enough, so that it is easy to show things to more than one person, and on something bigger than a laptop screen. This would give the opportunity of really showing interactive services (data services as well as some outreach material, or even applications)

We recommend OSTST members to consider MOOC & webinars, as well as online tools for outreach and data dissemination

We consider inviting people working at science centers/museums/aquariums close to OSTST future meetings to participate in the outreach session (e.g. F. Dell'Amico from Aquarium La Rochelle this year), so as to broaden the outreach activities introduced to the OSTST, as well as the local community of the meeting location. If OSTST members have ideas and/or contacts, please share them with the Outreach Leads.

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.

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, Jason-CS (Sentinel-6), and SWOT. The anticipated elements of this focus (not withstanding new opportunities) will include:

- Jason-2/OSTM, SWOT, Saral/AltiKa, Jason-CS/Sentinel-6 and Jason-3 education & public outreach and applications outreach
- Jason-3 launch activities, including movies and animations
- 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

6.5 Precise Orbit Determination

Chairs: Sean Bruinsma, Alexandre Couhert and Frank Lemoine

6.5.1 Status of Jason-2 and Jason-3 GDR orbits

Jason-3 was launched on January 17, 2016 and later maneuvered into the same orbit as Jason-2, so that the two satellites would fly in formation, approximately 80 seconds apart, for a seven- month tandem phase. During the tandem mission, the SLR stations were requested to track both spacecraft with equal priority, alternating rapidly between the two satellites in the same pass. Two examples of successful application of this strategy are shown in Figure 14 for Herstmonceux and Yarragadee.

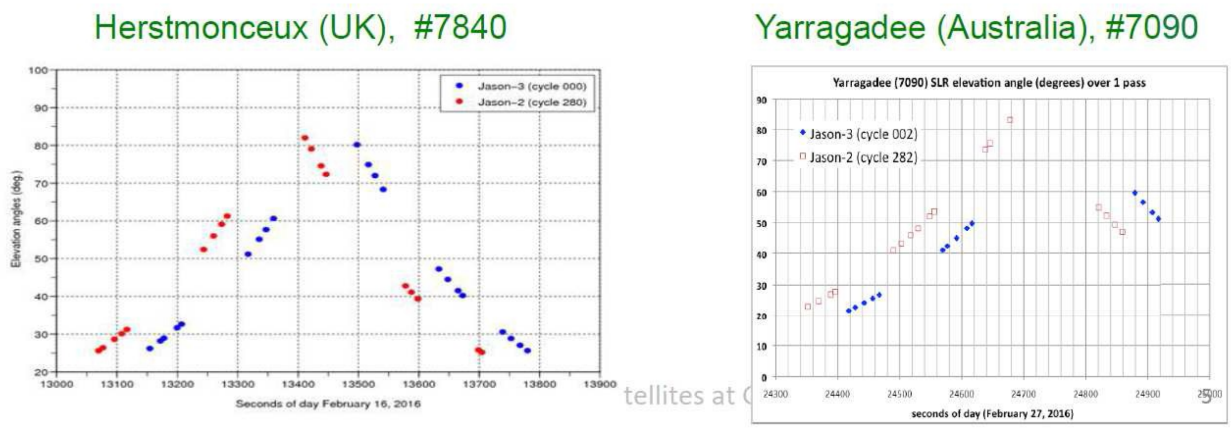


Figure 14. (Lemoine et al.) Jason-2 (blue) and Jason-3 (red) tandem flight tracking on common passes over Herstmonceux (left) and Yarragadee (right).

For Jason-3, we observe that the DORIS RMS of fit increases by 10-20% for stations in vicinity of the SAA (South Atlantic Anomaly). The increased sensitivity of the Jason-3/USO to radiation becomes visible on DORIS-only or DORIS+SLR orbits. GPS+DORIS solutions are not affected. While waiting for a SAA-DORIS data correction model, two solutions were proposed to mitigate this effect:

- For the CNES orbits, additionally to the frequency bias estimated per pass over each DORIS beacon, a frequency drift was solved for per SAA station to cope for the on-board frequency drift,
- whereas for the GSFC orbits, the DORIS SAA beacons were downweighted by a factor of about three compared to the non-SAA stations.

Both approaches give comparable results, removing the East/West geographic pattern visible in Figure 15, despite the fact that network effects do not degrade the orbit solution when no station downweighting is performed.

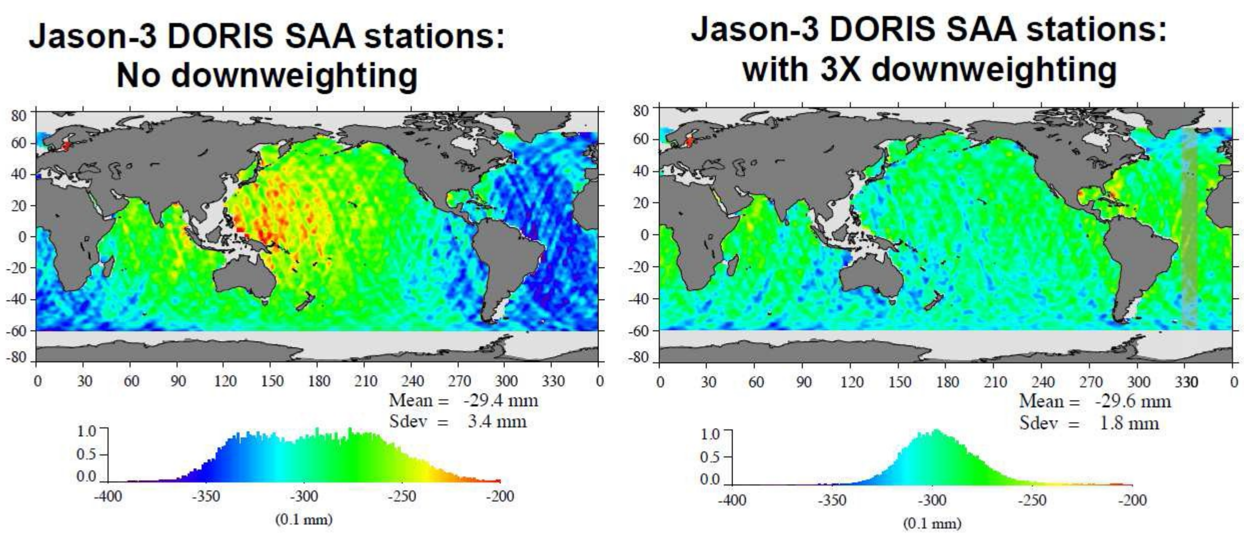


Figure 15. (Lemoine et al.) Jason-3 – Jason-2 SSH differences over intercalibration period for SLR+DORIS orbits without downweighting (left) and with 3X downweighting (right) DORIS SAA stations.

As can be seen in Figure 16, the Jason-3 GPS receiver behaves better than the Jason-2 GPS receivers (A or B side), while delivering more data (higher number of satellites in view, much less data loss, longer mean track length). In addition, the availability of more low elevation measurements may explain the slightly higher residuals.

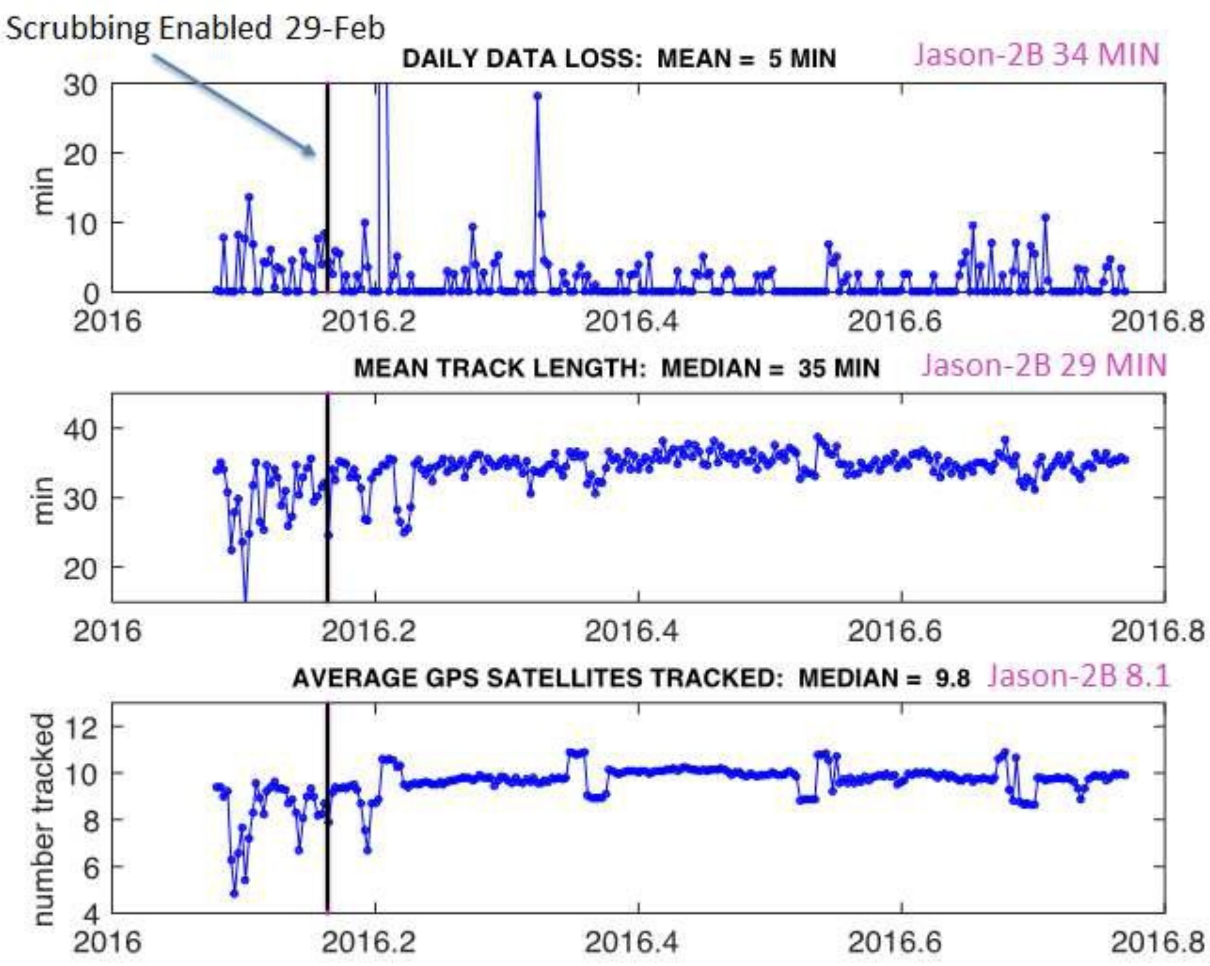


Figure 16. (Bertiger et al.) Jason-3 GPS tracking performance.

Mercier and Couhert (OSTST, 2016) presented a status on the feasibility of fixing ambiguities for the Jason-3 satellite. Contrary to the Jason-2 GPS receiver, almost no half-cycle slips are observed, enabling the computation of fixed ambiguity solutions. Unexplained differences between the pseudo-range and phase clocks create spurious along-track biases (depending on the weight given to pseudo- range measurements) in floating solutions. These biases are removed when fixing ambiguities, and there is no longer any drift between the average phase and pseudo-range residuals (pseudo-range and phase clocks are aligned correctly. The complete impact on the derived orbit performance will now need to be further assessed with a longer time series.

Table 1 summarizes the performance of the currently available Jason-3 orbits at CNES (GDR-E GPS+DORIS reduced-dynamic), GSFC (STD1504 DORIS+SLR dynamic), and JPL (RLSE16A GPS- based reduced-dynamic). The NASA GSFC POD team also produced new time series of DORIS+SLR dynamic and reduced-dynamic solutions updating their terrestrial reference frame modeling to ITRF2014. The mean radial RMS difference between the different orbit series is between 5 and 8 mm.

Table 1. (Lemoine et al.) Jason-3 orbit evaluation summary. Mean DORIS, SLR, Xover RMS residuals for JPL RLSE16A, GSFC (STD1504_SAA, ITRF2014_AUG_SAA, REDDYN_ITRF2014_AUG_SAA), and CNES GDR-E orbits. GSFC STD1504 is comparable to the generation of CNES GDR-E orbits.

Test Orbit	DORIS RMS (mm/s)	SLR RMS (cm)	Xover * RMS (cm)	Comment
GSFC std1504_saa (SLR +DORIS)	0.4425	1.022	5.327	Dynamic: ITRF2008
GSFC itrf2014_aug_saa	0.4426	1.074	5.325	Dynamic: ITRF2014
GSFC reddyn_itrf2014_aug_saa	0.4424	1.237	5.297	Reduced-dynamic
CNES gdre (GPS+DORIS)	0.4426	1.269	5.261	
JPL jpl16a (GPS)	0.4433	1.116	5.252	

Jason-2 geographically correlated radial orbit drift rates agree at the 0.4 mm/y level between the two GPS-driven solutions (CNES GDR-E GPS+DORIS and JPL RLSE16A GPS-derived reduced- dynamic orbits), at the 0.8 mm/y level for GSFC STD1504 DORIS+SLR dynamic solutions (Figure 17, top). Annual patterns are no longer visible between the CNES and the GSFC orbits. Yet, ~3 mm 365-day signatures on a regional scale can be seen with respect to the JPL solutions (Figure 17, bottom), which seem to be explained by orbit centering differences.

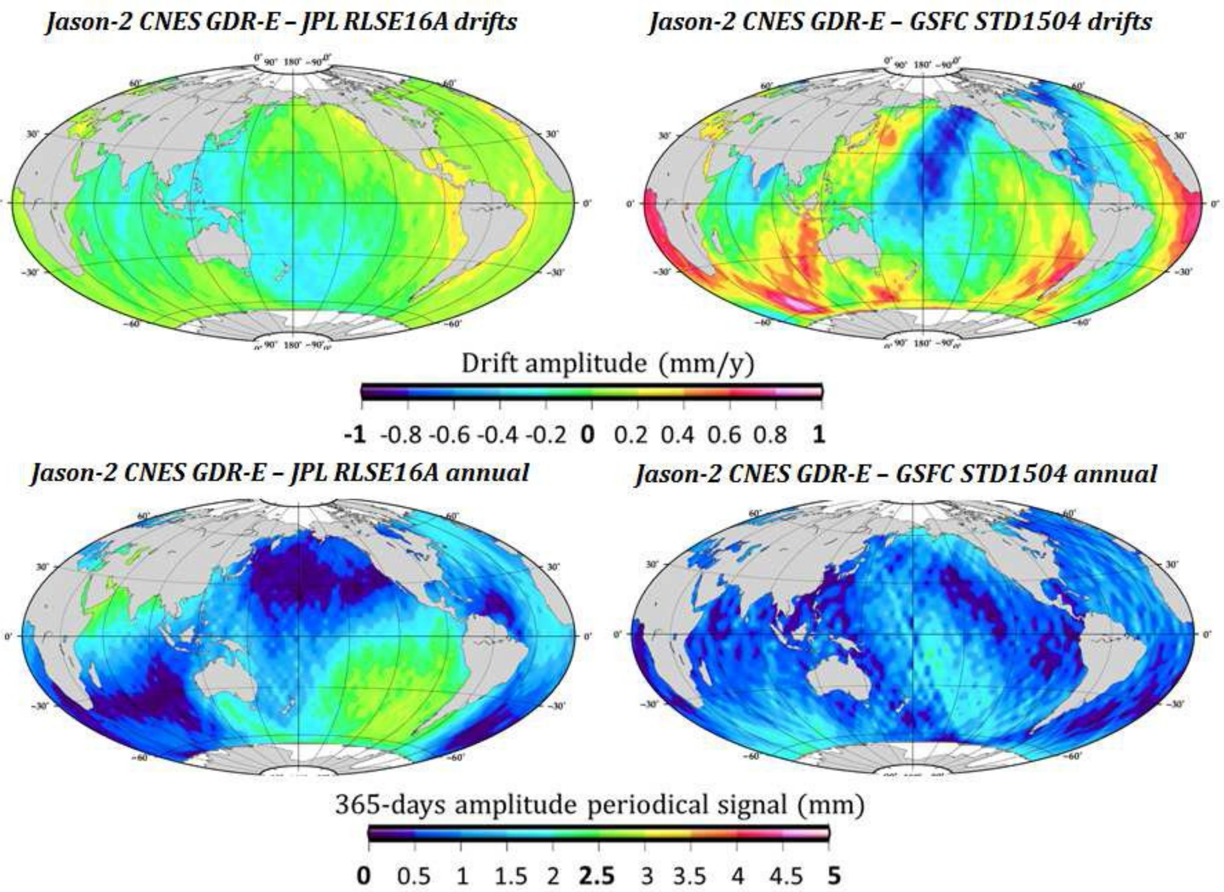


Figure 17. (Jalabert et al.) Jason-2 geographically correlated radial orbit difference drifts (up) and annual signatures (bottom) of JPL RLSE16A (left) and GSFC STD1504 (right) with respect to CNES GDR-E orbits.

As time-variable gravity (TVG) modeling errors no longer appear to be reflected in the orbit comparisons (at least at annual time scales), we must now concentrate on elucidating orbit centering differences.

6.5.2 Analyses of Sentinel-3A

A new fully-equipped altimeter satellite (carrying onboard the three POD instruments: GPS receiver, DORIS instrument, and laser retro-reflector), Sentinel-3A, was successfully launched on February 16th 2016. The current operational solutions (Near Real Time (NRT): 30 min latency – cf. Andres et al., Short Time Critical (STC): 1.5 days, and Non Time Critical (NTC): 25 days) are computed by the Copernicus POD Service (GPS-based dynamic orbits) and CNES (GPS+DORIS reduced-dynamic orbits). Independent groups (AIUB, DLR, ESOC, TU Delft, and TUM) provide external GPS-derived solutions computed offline for validation purposes, using different parameterization choices (from dynamic to close to kinematic) and various modeling options (for gravitational and non-gravitational forces, see Hackel et al., OSTST, 2016). Additional solutions from JPL and CNES/CLS IDS analysis center were also presented. Radial orbit differences between the different groups are below 1 cm RMS. Though, an unexpected radial bias of ~5 mm, between GMV, CNES, ESOC solutions and the other external ones, needs to be understood (Figure 18). The GMV, CNES, and ESOC orbits are lower than the combination of the solutions.

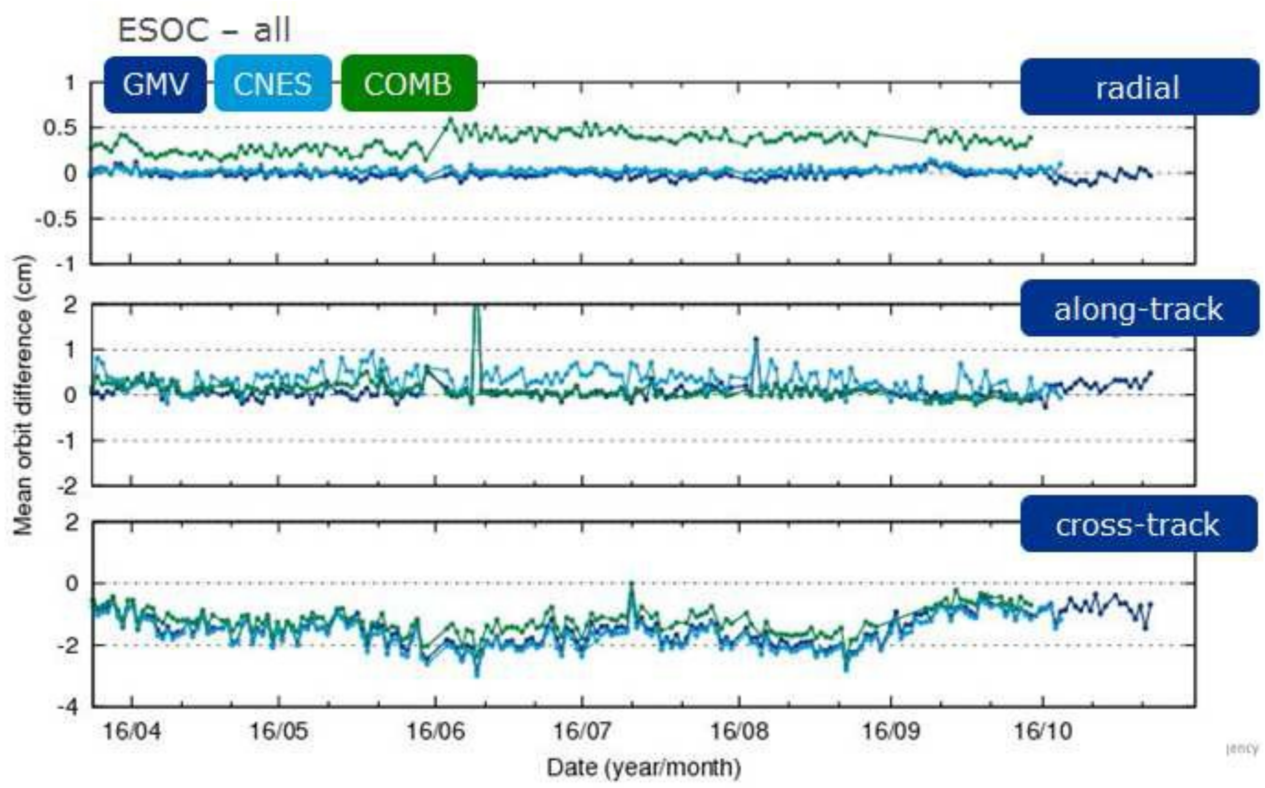


Figure 18. (Otten et al.) Daily mean of Sentinel-3A orbit differences with respect to ESOC orbits in the radial, along-track, and cross-track directions for the GMV (dark blue), CNES (light blue), and combined (green) solutions.

Independent evaluations of Sentinel-3A CPOD and CNES orbits were presented by Ollivier et al. , OSTST, 2016, using the Sea Surface Height estimation criteria, corroborating the good agreement between the two solutions. SLR data are another independent tool because its fundamental asset is that it enables an absolute validation of the orbit accuracy. As shown in Figure 19, CNES, CPOD, and ESOC solutions exhibit small SLR biases between 4 and 5 mm, not seen in AIUB, DLR, and TUDF orbits. Center of mass location and/or SLR optical center offset issues could explain such discrepancies (assuming that the mean radial component of the solutions is not sensitive to GPS phase center and phase map models). On-going analyses will also investigate if the culprit has to do with the ~1 cm along-track bias seen by the SLR data in GPS-based (and DORIS-only) orbits, pointed out in Couhert et al.' (OSTST, 2016).

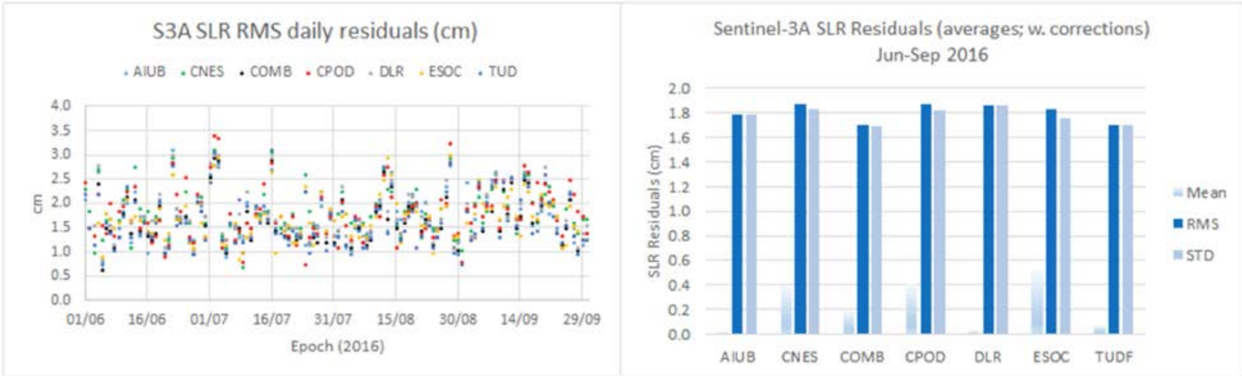


Figure 19. (Fernandez Sanchez et al.) Daily RMS of independent SLR residuals (left) for the different Sentinel-3A POD analysis centers: AIUB (light blue), CNES (green), CPOD (red), DLR (gray), ESOC (yellow), TUD (dark blue). Mean and RMS SLR residuals over the June-September 2016 period (right).

ESOC presented their processing strategy of resolving integer ambiguities for the Sentinel-3A satellite. An unexplained larger number of ¼ cycles exhibits in the GPS residuals. The ambiguity- fixed orbits show close performances to the corresponding float orbits, but still no significant improvement can be put forward.

6.5.3 Investigating biases in SLR observations

Rodriguez et al. (from Herstmonceux SLR observatory, U.K), representing the International Laser Ranging Service (ILRS), was invited to discuss the issue of systematic errors in SLR observations. At the few-mm level, range biases become difficult to detect by station operators. In addition, their estimation may be confounded by correlations with station height and sometimes appear to be target-specific (as reported by Bruinsma et al., OSTST, 2015), when CoM inaccuracies and possibly return strength issues come into play.

The level of accuracy needed for POD validation on short time scales for high elevation SLR residuals should be better than 5 mm RMS over a pass or a day (typical length of an orbit arc). Indeed, SLR measurement errors should be smaller than the orbit errors we want to determine (center of mass offsets, dynamic modeling errors …). On long time scales, weeks to years, drift errors in SLR measurements (that could be seen in mean SLR residuals) should be of a few tenths of a mm/y, for validating long-term regional orbit errors (which are of a few mm at annual time scales and below 1 mm/y over a few years). Figure 20 stresses the fact that further progress is necessary: no SLR station achieves short-term stability of less than 5 mm RMS (although Herstmonceux and Graz are close).

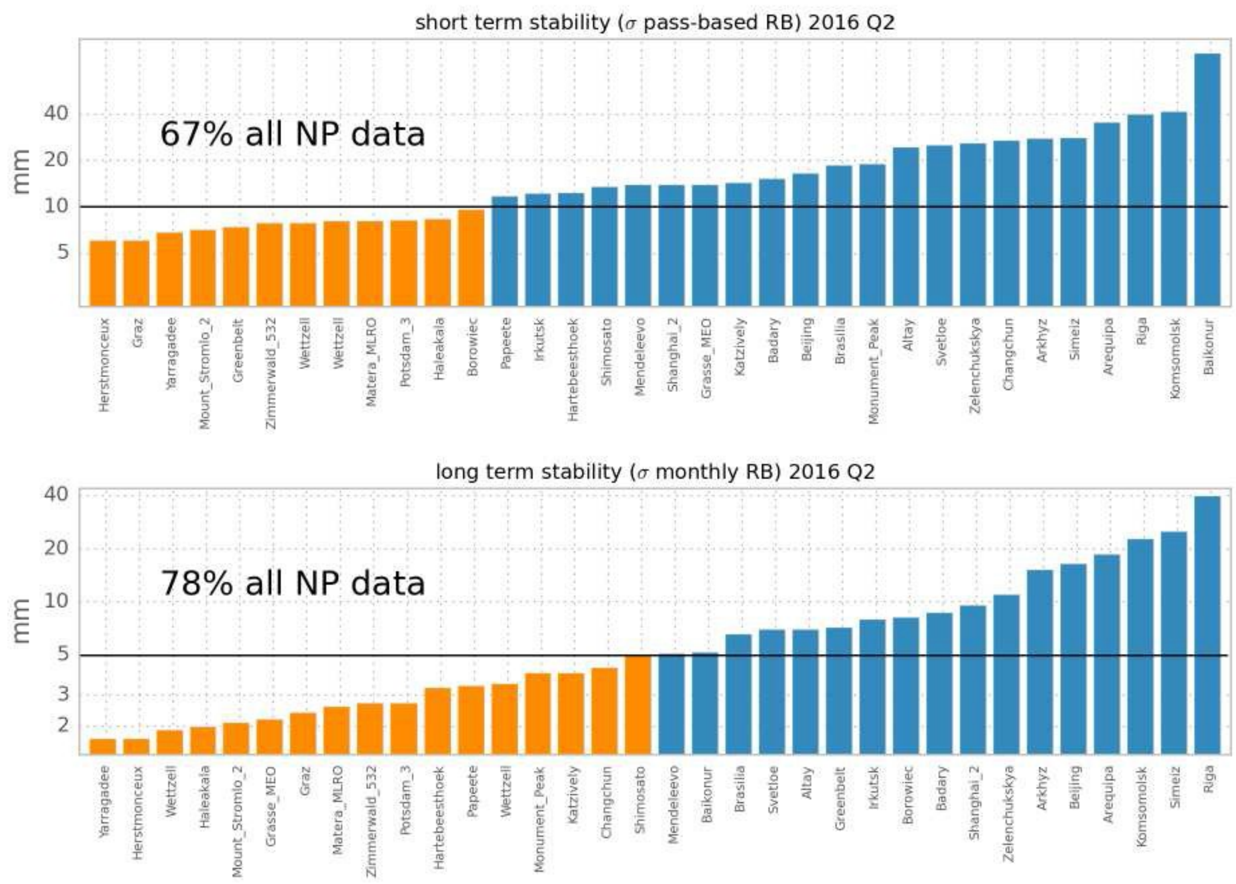


Figure 20. (Rodriguez et al.) Short- (top) and long-term (bottom) stability of SLR stations.

Moyard et al. investigated un-modeled hydrological loading effects in the Yarragadee SLR station position (e.g., from the Yarragadee Aquifer) to explain the degradation of residuals observed between 2010 and 2013 (compatible with a vertical bias of ~-1 cm in the station position). To this end, local mass variations were derived from all available DORIS altimeter satellites (Jason-1, OSTM/Jason-2, Envisat, CryoSat-2), to benefit from the diverse inclinations of the missions, where an improved observability in the East-West direction is expected over polar-only orbits. Despite the similarity between CNES DORIS-only and GSFC GRACE-based mascon solutions at continental scales, the separation between the three basins (Eastern, Center, and Western Australian basins) is more challenging, when comparing to GRACE-derived results, especially over the Western Australian region (Figure 21). The subsequent inclusion of GPS observations (from the Jason-1 and Jason-2 satellites) may be useful as an additional validation of these DORIS-only preliminary results. The achieved results do not enable yet to confirm the hydrological loading hypothesis.

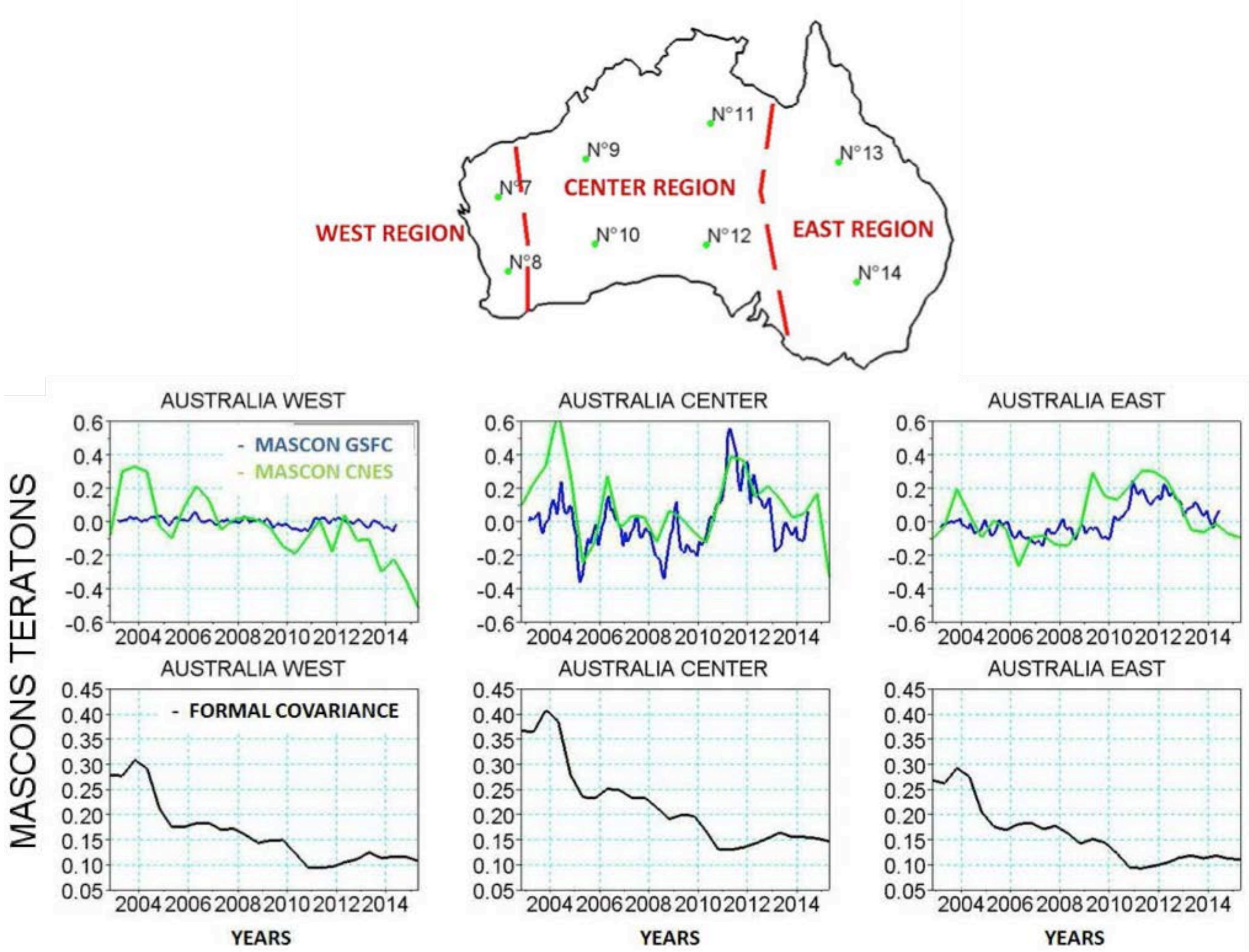


Figure 21. (Moyard et al.) Regional comparisons between CNES DORIS-only and GSFC GRACE-derived mascon solutions over Australian basins.

6.5.4 Non-tidal geocenter motion modeling strategies for altimeter satellites

The currently delivered CNES (GDR-E) and GSFC (STD1504) orbits apply an annual geocenter model (Ries 2013), derived from LAGEOS-1 & LAGEOS-2 SLR data. The geocenter model corrects the DORIS and SLR station positions so that they are properly referenced to the true center of mass of the Earth. However for several reasons, the CNES and GSFC POD analysis centers have tried different strategies to refine the modeling of the geocenter variations:

- due to inconsistency, the Ries Earth "CN-CM" model cannot be used in combination with Atmospheric Pressure Loading (APL) station corrections,
- annual signatures change in amplitude and phase over time, thus an annual geocenter model may not be sufficiently precise for an accurate determination of the mean sea level (MSL) rise,
- independently determined geocenter time series are necessary to validate the accuracy of the CM motion observability.

Zelensky et al. (OSTST, 2016) estimated a preliminary geocenter model from the LAGEOS-1/2 SLR satellites, enabling to consistently apply atmospheric loading corrections into new time series of altimeter satellite orbits (Table 2. (Zelensky et al.) GSFC annual SLR-based CM models compared to Ries 2013 CM model.).

Table 2. (Zelensky et al.) GSFC annual SLR-based CM models compared to Ries 2013 CM model.

Model	X (amp)	X (phase)	Y (amp)	Y (phase)	Z (amp)	Z (phase)
Ries 2013 (15+ years) no APL	**2.7**	**41**	**2.8**	**321**	**5.6**	**27**
L1+L2 (8 yrs) no APL	**3.3**	**50**	**2.4**	**303**	**5.8**	**46**
L1+L2 (4 yrs) no APL	**4.0**	**51**	**2.4**	**305**	**6.6**	**40**
L1+L2 (4 yrs) with APL	**3.5**	**60**	**2.0**	**289**	**5.1**	**61**

Couhert et al. (OSTST, 2016) presented mitigation strategies to yield competitive DORIS-based geocenter variations from the Jason-2 satellite, while taking benefit from the more numerous and better uniformly distributed DORIS stations across the globe. Figure 22 shows the qualitative agreement between the DORIS-derived and independent SLR-based estimates of the CM motion in the Z direction.

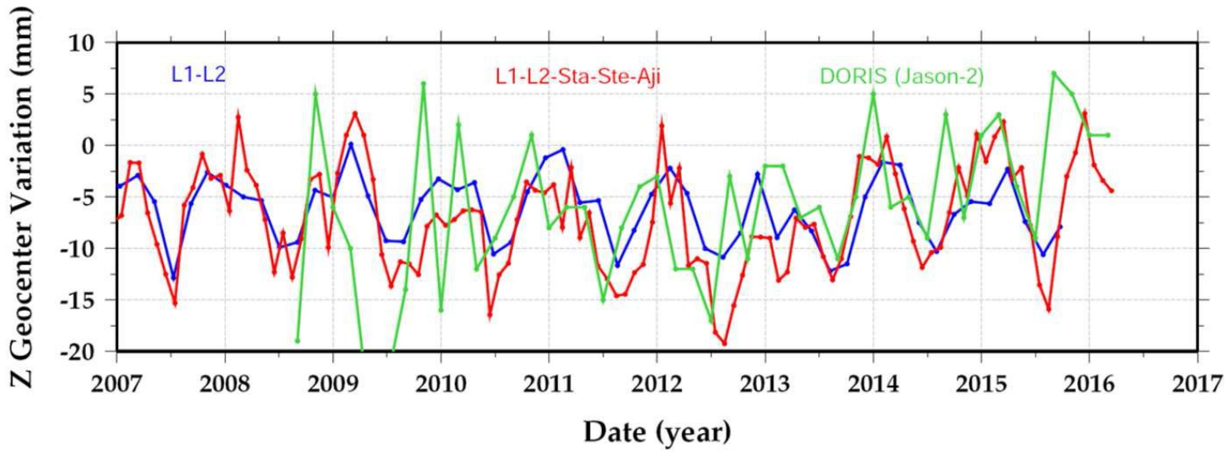


Figure 22. (Couhert et al.) CNES Jason-2 DORIS-only (green) North-South CM variation compared to independent CSR L1+L2 and L1+L2+Starlette+Stella+Ajisai SLR-based estimates.

Ollivier et al. (OSTST, 2016) introduced tentative metrics to validate orbit accuracy when the computed orbit origin is better aligned with the instantaneous center of mass, using altimeter data and ARGO (+GRACE) in-situ measurements (Figure 23). Yet, the task remains challenging as the geocenter variations are at the cutting edge of what the current validation methods are able to detect.

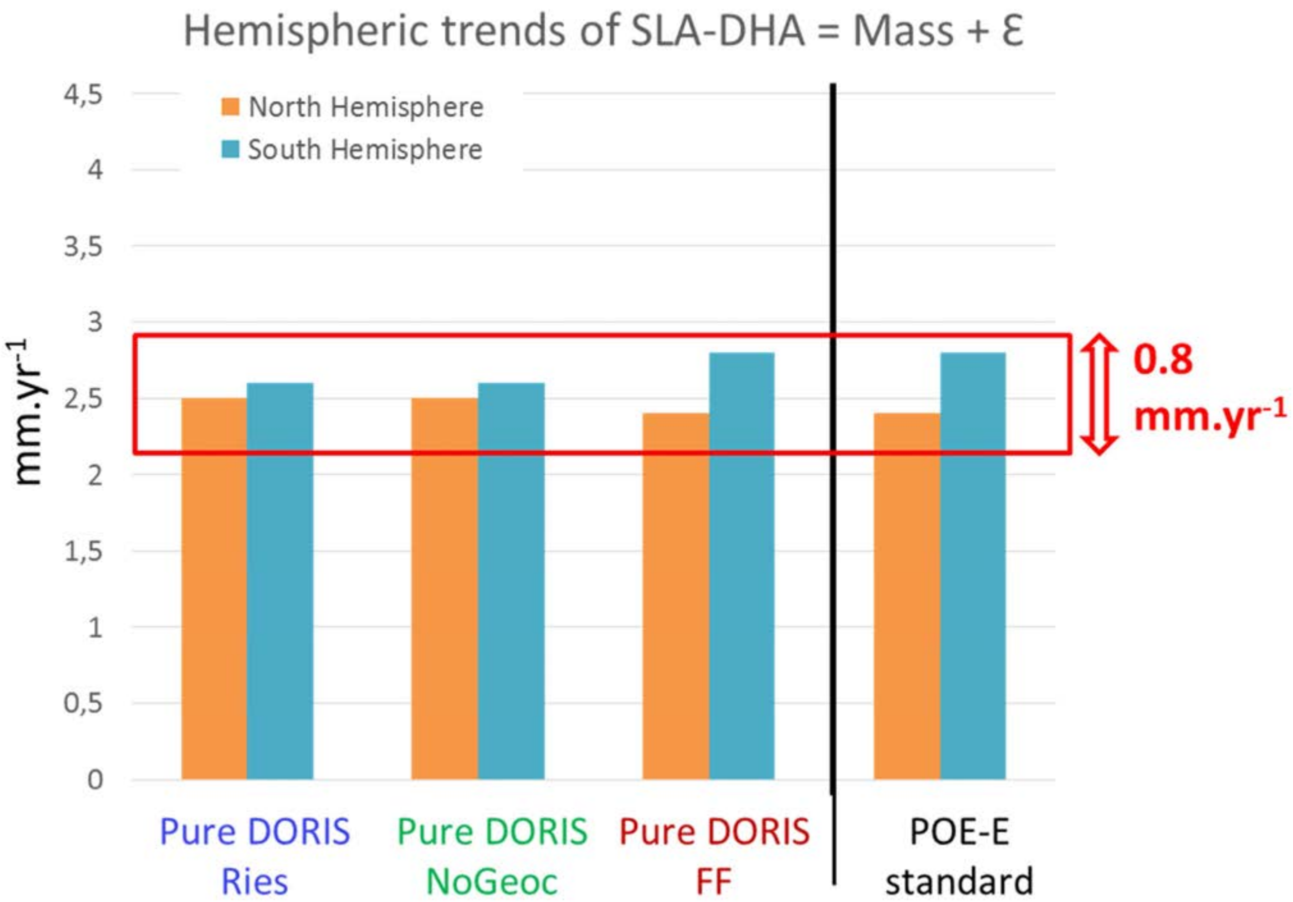


Figure 23. (Ollivier et al.) Consistency between North/South mass-height-equivalent regional trends for different geocenter modeling and associated uncertainty of the in-situ comparison method (~0.8 mm/y).

6.5.5 ITRF2014/DPOD2014 evaluations

The newly-released International Terrestrial Reference Frame realization (ITRF2014) has been evaluated by two POD groups (DGFI-TUM and GSFC who also contributed to the validation of DPOD2014, see Moreaux et al., OSTST, 2016); thus enabling ITRF2014-based orbits to be publically released for the TOPEX/Poseidon, Jason-1, Jason-2 and Jason-3 missions. A general improvement in the orbit performance was observed for all the above-cited altimeter missions when using ITF2014 in place of ITRF2008. The improvement revealed in a reduction of DORIS, SLR, and altimeter crossover residuals, as well as radial orbit overlaps. When analyzing the associated effect in terms of regional sea level trends, a North-South bias peaking at 0.2 mm/y at high latitudes can be seen over the time period of Jason-2 (Figure 24).

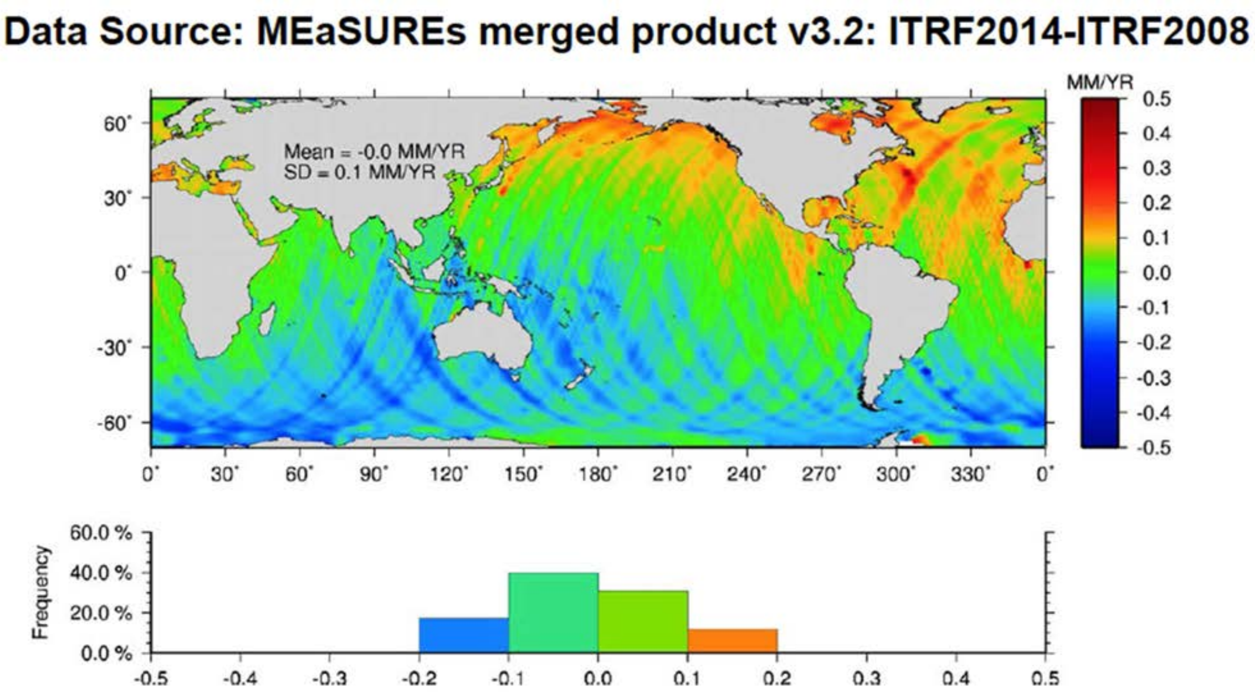


Figure 24. (Lemoine et al.) Impact of updating terrestrial reference frame from ITRF2008 to ITRF2014 on regional sea level trends over the time period of Jason-2.

6.5.6 Current work and future improvements

6.5.6.1 TOPEX/Poseidon orbits reprocessing at CNES

T/P orbits were reprocessed in the GDR-E standards and analyzed in Aït-Lakbir et al. (OSTST, 2016). In order to overcome the lack of GRACE time-varying gravity (TVG) observations for a major part of the mission (between 1992 and 2002), two strategies were investigated: solving for the degree 3 order 1 spherical harmonic (which the Jason orbit is most sensitive to) in dynamic orbits or computing reduced-dynamic solutions. Comparisons to the GSFC STD1504 DORIS+SLR dynamic orbits show a good agreement ranging from 1.0 to 1.5 cm RMS in the radial direction, depending on the parameterization strategy and the measurements used (DORIS-only vs. DORIS+SLR). The geographically correlated radial orbit difference drifts are found below 1 mm/y and only 4-5 mm annual signatures over the North Pacific and South Atlantic coming from orbit centering differences (in X and Z axes) are visible. Independent altimeter crossover residuals conclude the GSFC and CNES DORIS-only reduced-dynamic orbits are of similar performance.

Further analyses will be performed to confirm the impact of not using SLR observations, especially before 2000 (before the DORIS network renovation program started), while improving laser measurements modeling and carefully handling SLR station biases.

6.5.6.2 Multi-technique (GPS, DORIS, SLR) combination with the Jason-2 satellite

Zoulida et al. (OSTST, 2016) presented a study of the impact of including Jason-2 multi-technique observations (DORIS, SLR, GPS) when determining GPS satellite orbits, GPS station ambiguities, and ground network positions. The benefit from adding Jason-2 observations is not conclusive from the preliminary results, but the approach deployed here looks promising.

6.5.7 Conclusions and recommendations

The primary purpose of the 2016 OSTST meeting was to evaluate the performance of Jason-3 as a successor mission to Jason-2. From all the data presented, the tracking systems, SLR, GPS, DORIS are performing well, although an SAA effect is observed in the DORIS data on Jason-3, different mitigation strategies can be used to minimize the impact on the POD. The Sea Surface Height differences using the available orbit averaged over the tandem mission period show no visible instrument or orbit-related biases. This result is a testimony to the assiduous work by instrument teams preparing the interim-altimeter data products, and to the high quality of the Jason-3 tracking data and derived orbit products. We demonstrated that the Jason-3 orbits from different groups agree to a level of 5-8 mm radial RMS over the tandem mission period.

Although ITRF2014 has been evaluated in a preliminary sense by different groups (DGFI-TUM, NASA GSFC), in order to completely apply the new reference frame realization, we need to ‘fill- out’ the missing stations (SLR & DORIS, for example). For the present we have relied on a Helmert transformation from ITRF2008-derived solutions for these stations, but clearly we need to adopt the updates provided by the technique services (DPOD2014 by DORIS, and SLRF2014 for SLR). We note that the CNES GDR-E orbits are based on ITRF2008, but will switch to ITRF2014 when the GPS orbits become available in the new reference frame, probably in 2017.

Accuracy of modeling the geocenter remains one of the limiting error sources in POD. It is important to continue efforts improve geocenter modeling by various methods.

SLR retains a central role for altimeter satellite POD, both as a primary POD tool, and as a means to evaluate POD quality. A major concern remains the stability and accuracy of the SLR station data over short and long time scales. The POD team should continue to work with the ILRS on this issue.

At the POD Round Table, and in the final presentation, the POD team expressed concerns regarding the fundamental error in the IERS2010 model of the mean pole of the Earth. This model of the mean pole underpins the derivation of the reference frames (ITRF2010) and the POD products. We pointed out that following King and Watson (2014, Geophys. J. International), that the secular deviation of the true pole from the modeled mean pole results in a secularly increasing error in the calculation of the pole tide, which affects the geometric corrections at the tracking stations and the derived geopotential coefficients (primarily but not exclusively C21 & S21). Following the OSTST 2016, the POD team relayed these concerns to the IERS, and we look forward to the elucidation and adoption of a new model. The magnitude of the errors pointed out by Watson and King (2014) amount to 3 mm of anomalous (mismodeled) deformation, and affects the calculation of vertical rates at tide gauge sites as well precise orbit determination of all altimeter satellites. The present IERS2010 pole model is not adequate for altimeter satellite POD, and we look forward to the derivation and presentation of a new model which the Jason-2/Jason- 3 POD team will be pleased to implement and test.

Also at the POD Round table, the latest results from the Jason-2/T2L2 instrument were presented and discussed. Based on presentations and results shown at the IDS Workshop, the T2L2 instrument has provided quite important information on the behavior of the DORIS/Ultra Stable Oscillator (USO) on board Jason-2. It has allowed the derivation of an improved model of the DORIS USO performance, which we can use to improve Jason-2 POD, and to improve the DORIS reference frame for all altimeter satellites that carry a DORIS receiver. An additional application has also come to light, and that is the latest results (in a manuscript under preparation by the Grasse SLR station team) is that the T2L2 has permitted the elucidation of hitherto unknown and un-accounted for time biases in the SLR stations. For example persistent time biases of up to 2µsecs have been observed at Yaragadee, the most important and prolific station of the Satellite Laser Ranging network. The POD team strongly recommends that the T2L2 experiment continued to be supported and should be operated until the end of the mission life of Jason-2. In addition, the POD team strongly recommends support for efforts to explore the geodetic implications of the T2L2 results.

6.6 Quantifying Errors and Uncertainties in Altimetry Data

Chairman: Michael Ablain, Joel Dorandeu and Remko Scharroo

6.6.1 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 11 abstracts were submitted to the splinter session, resulting in 5 oral presentations, and 4 posters. This year, a focus on short wavelength errors has been performed with 5 talks dedicated and complementary to this subject.

The main issues of the session are listed hereafter.

6.6.2 Issue #1

Need to continue to improve LRM data to better observe small ocean scales (< 100 km): editing and new retracking are the main source of improvement expected. (M. Raynal et al).

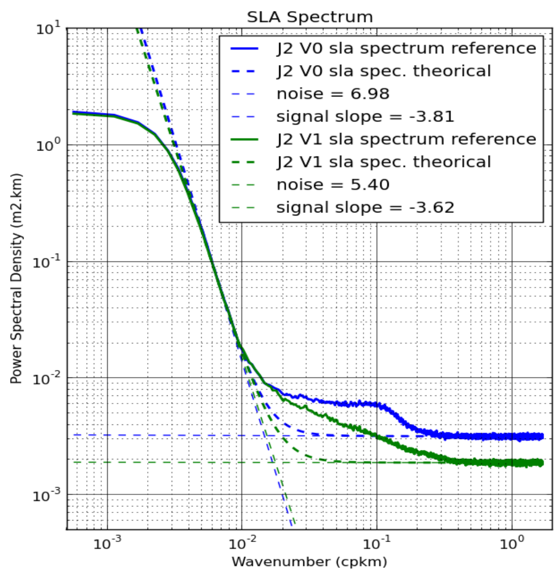


Figure 25: Improvement of Jason-2 LRM data at small ocean scales applying adapted editing algorithm and Zaron's empirical method to reduce the correlated noise between altimeter range and SWH (M. Raynal et al.)

6.6.3 Issue #2

Ability of Sentinel-3 data to observe small ocean scales (between 30 and 100 km) is very promising after removing MSS errors on the new ground track. (M. Raynal et al., M.I. Pujol et al.)

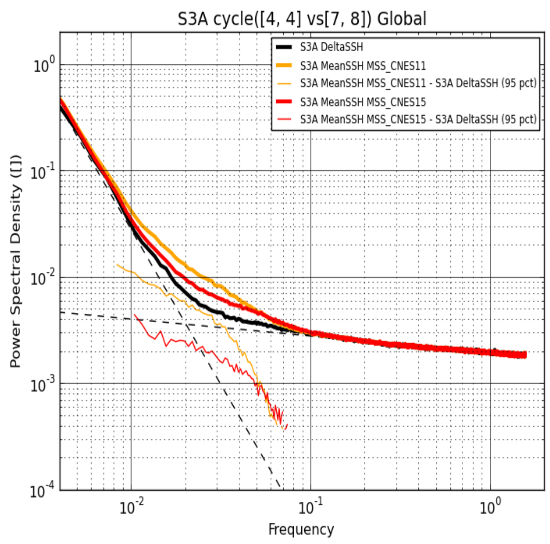


Figure 26: Sentinel-3A SLA spectrum is reduced after removing the MSS error comparing 2 consecutive cycles N and N-1 (M.I. Pujol et al.)

6.6.4 Issue #3

MSS errors at high resolution will be reduced:

- using geodetic missions
- improving the mean profile along track resolution based on high rate altimeter measurements
- improving the correction of the ocean variability (especially along geodetic tracks)
- using geodetic missions over an extended period
- improving the reduction of the LRM measurement errors (M.I. Pujol et al.)

6.6.5 Mean Sea Level errors

L. Zawadzki et al. presented a study on the accuracy of the mean sea level continuous record with future altimetric missions: Jason-3 versus Sentinel-3a. The objective is to answer the question: what would be the impact on the GMSL of using S3-A instead of Jason-3 as reference mission? The main conclusion is linking Sentinel-3 MSL time series to Jason-2 has a strong impact on the global (and regional) MSL uncertainty, mainly due to the absence of a calibration phase. Therefore changing the historical TOPEX/Jason orbit for Sentinel-3a orbit would therefore exceed user requirements over 10 years even though it is only one component of MSL error budget.

Figure 27: Impact of global Mean Sea Level inter-mission linking bias uncertainties on the estimation of the MSL trend over 10 years (Upper panel), 15 years (middle panel), 25 years (lower panel), in the cases of Jason-3 and Sentinel-3a.

Martin Scharffenberg et al. gave a talk about the uncertainty estimates of altimetric Global Mean Sea Level time series. The STORM/NCEP model [von Storch et al. 2012] has been used as synthetic truth to test the effects of applying different averaging methods. This work is an update of O. Henry et al., 2013. Depending on the method used, the uncertainties of the GMSL estimates needs to be considered larger by up to +6 mm.

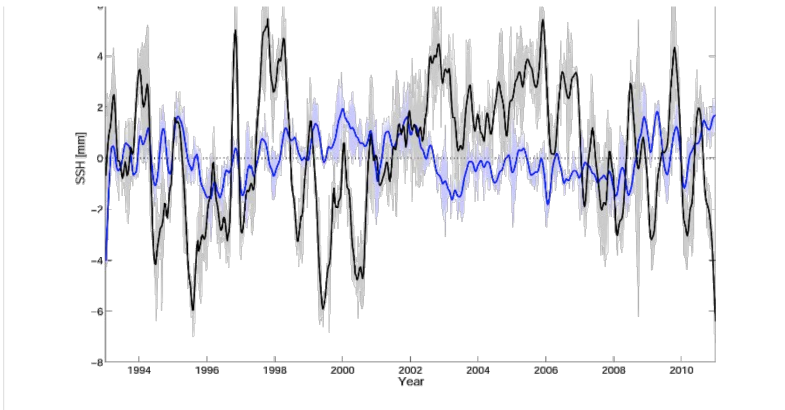


Figure 28: GMSL evolution (after removing the global trend) from altimetry (black) and STORM/NCEP model (blue): due to the smaller variablity in STORM as compared to satellite data the uncertainties for GMSL estimates serve as a lower bound

P. Prandi et al. gave a talk about the estimation of regional sea level trends accuracy. The objective is to provide a map of uncertainties of regional MSL trends (see figure below). Systematic uncertainties ranging between 1 to 3 mm/yr have been displayed. Results depend on the a priori description of errors: if the error model is wrong, the results are. It is worth noting that accurate error covariance description is crucial.

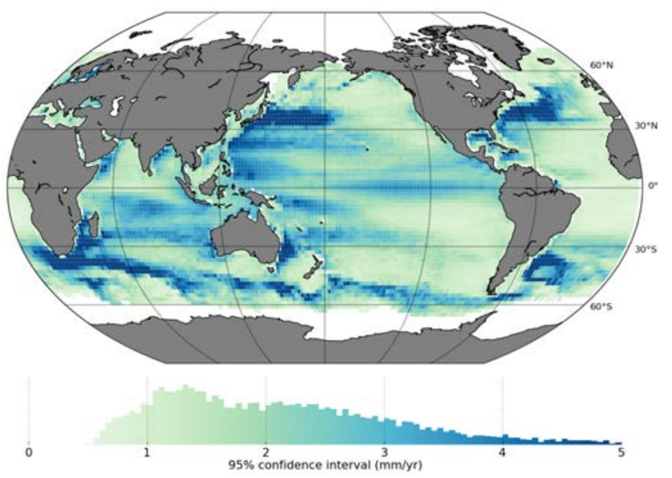


Figure 29: Map of MSL trend uncertanties

6.6.6 Short wavelength errors

P. Thibaut et al. presented the characterization of the altimeter mission performances over ocean. Most of past/present altimeter missions have been looked at and compared with the same processing applied: performances have been derived using different metrics. 20Hz standard deviation and PSD noise level are strictly equivalent at low SWH and coherent with simulations. PSD noise level for high SWH doesn't represent the instrumental noise. The following question is raised: does SWH/Swell introduce correlated errors in the estimates ? Very good SLA performances of CS-2 SAR are highlighted but also of SARAL (Ka band / 40 Hz), even better SWH performances with Saral.

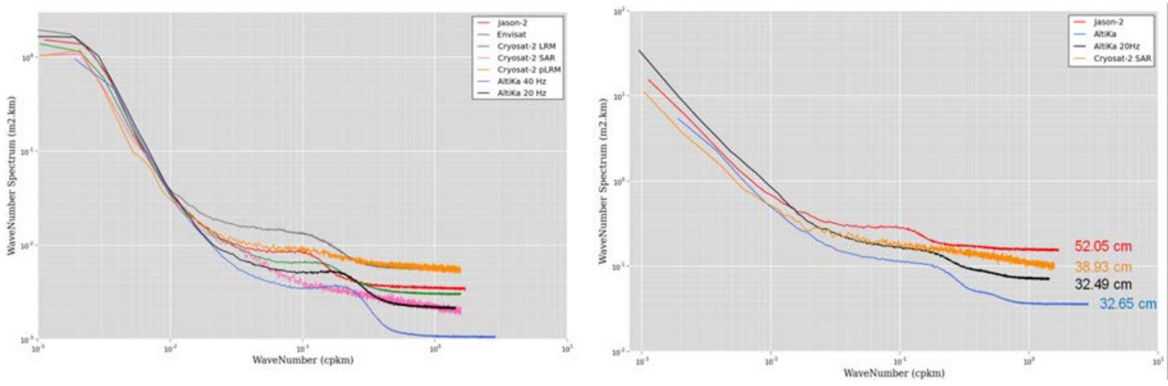


Figure 30: SLA and SWH spectra for several altimeter missions

E.D. Zaron et al. gave a talk about the identification and reduction of retracker-related noise in altimeter-derived sea-surface height measurements. An empirical approach to reducing the retracker-related SSH error was implemented, based on analysis of J1-J2 during the J2 cal/val orbit phase. Thanks to this approach, the high-wavenumber SSH noise floor is reduced by about 2cm², depending on SWH. It is worth noting that the correction uses conventional 1 Hz data; although, it was inspired by 2-pass retrackers, the correction is not independent of the sea-state bias correction. This kind of method would be useful to better estimate the short wavelengths of ocean scales.

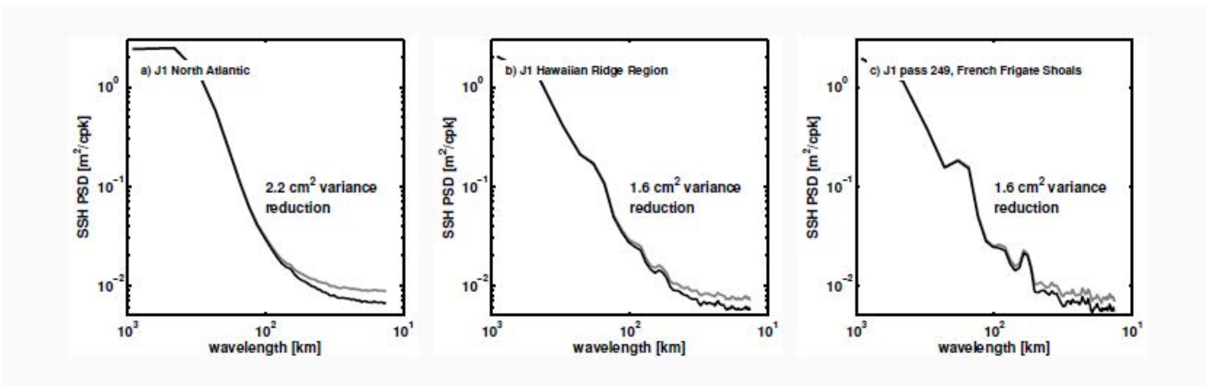


Figure 31: SLA spectra applying the Zaron et al.' s correction

6.6.7 Instrumental errors

S. Dinardo et al. presented the seasonal Effects on the Pitch Measurements for Cryosat-2. Thanks to pitch mispointing computed from Stack, a sinusoidal pattern in the Star Tracker estimation of the pitch mispointing has been detected (potentially correlated to sun illumination conditions). After removal of the sinusoidal pattern, the estimation of the pitch from Star Tracker and Stack are pretty consistent (around 3 millideg). It is essential to calibrate also the roll mispointing (that can be affected in the same way by solar illumination). We recommend performing the same exercise routinely for Sentinel-3, as long as for the roll.

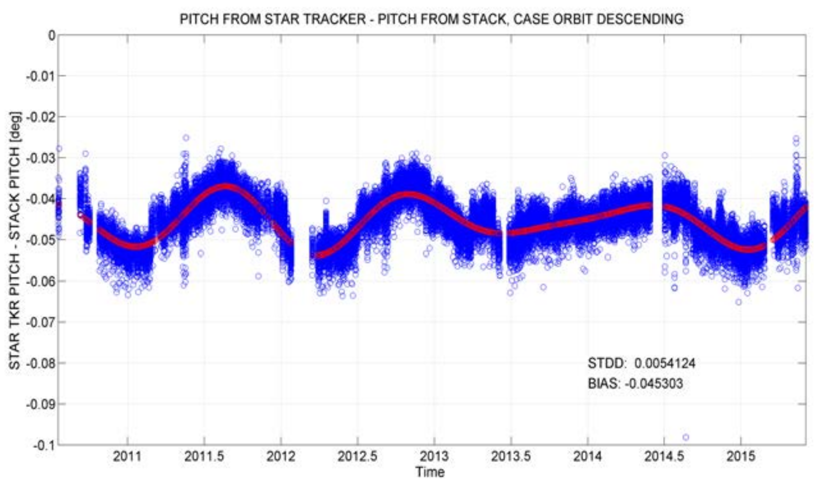


Figure 32: Evolution of the pitch mispointing on Cryosat-2

6.6.8 Conclusion

From the last OSTST, several improvements have been performed on altimeter error characterization: new insights in altimeter error at short wavelength and at climate scales have been characterized and understood, new method to characterize the error for climate scales has been developed.

In terms of recommendations, the splinter encourages feedbacks from end-users to better characterize the error for their studies. Moreover, the propagation of measurements errors into the final products should be further studied.

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

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

6.7.1 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.
3. Enable a seamless and accurate connection between the current (OSTM/Jason-2 and Jason-3) and legacy (TOPEX/Poseidon and Jason-1) time series.

To succeed in these objectives, the general approach is to pool the talents and resources of the project and science teams. Engaging the science team in the continuous CALVAL effort has been one of the hallmarks of success for the TOPEX/Poseidon and Jason altimeter programs.

Apart from the traditional in-depth analyses of the TOPEX/Poseidon and Jason-series missions, cross-calibration with other missions (e.g., Sentinel-3A and SARAL) are also of interest with the goal of a self-consistent multi-mission global data set.
CALVAL results from Jason-3 and Sentinel-3A were of particular interest since this was the first OSTST meeting after their successful launches. During the first 6 months of each new mission, an intensive verification effort is conducted by all members of the Verification Team in order to verify the integrity of the system—and to make adjustments where necessary—before starting the routine GDR production. However, the verification effort continues afterwards on a routine and permanent basis.
CALVAL 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. They also encompass issues related to data return, such as data editing and flagging. CALVAL presentations on specific areas, for example on the Arctic ocean and on the impact of El Niño phenomena on data were also especially encouraged.
Because of the usual large number of contributions, the CALVAL splinter was separated into two parts:

1. Local calibration/validation (focusing on in-situ bias estimates).
2. Global calibration/validation (focusing on corrections quality assessment and error budget assessment).

6.7.2 Results from in-situ calibration sites

Ensemble results from the dedicated in-situ calibration sites and regional campaigns are provided in Table 3, and show good consistency across legacy and current missions. The TOPEX/POSEIDON (T/P) and Jason-1 systems are no longer in operation, but are subject to ongoing evaluation as procedures and data products are enhanced. Calibration records continue to support that the sea-surface height (SSH) biases of the T/P measurement systems are indistinguishable from zero. However, the T/P CALVAL results will need to be updated when the next version of the TOPEX Retracked GDR (RGDR) is released.

SSH from the current (E) version of the Jason-1 GDR products is biased high by ~33 mm, with differences at the 20–30 mm level among the different calibration sites. SSH from the current (D) version of the Jason-2 GDR products is unbiased, or slightly biased with questionable significance (~+6 mm on average for all the calibration sites). However, differences at the 20-30 mm level also exist among the different calibration sites. Concerning Jason-3, the studies consistently support that all data products (OGDR, IGDR and GDR-T) are of very good quality with very small differences compared to Jason-2. However, the Jason-3 SSH is slightly lower (by ~26 mm) than comparable values from Jason-2. Detailed analysis shows that this relative SSH bias is due mainly to the Ku-band range, but probably also to the C-band range. Together, they lead to smaller ionosphere delays for Jason-3 (by 5–10 mm).

The in-situ sites also provide results for the SARAL/AltiKa system, showing that its SSH measurements are biased low by 49 mm. Preliminary results for Sentinel-3A suggest that the current product is unbiased, or slightly biased with questionable significance.

Thanks to the transponder (TRP) installed in Crete at a crossover point between Jason and Sentinel-3 (A&B), new results in terms of absolute calibration have been derived. The results presented by Mertikas et al. and illustrated in Table 4 are coherent with those derived from in situ SSH measurements. (A positive range bias is equivalent to a negative SSH bias.) Similar results from a temporary transponder installed in Lauragais (close to Toulouse, France) were presented by Desjonqueres et al. They show that this technique has great potential for monitoring stability and is straightforward for relative calibrations (especially during tandem calibration phases). However, absolute calibration needs an accurate measurement of the TRP system (including antenna) and is more difficult.

In addition to results from Harvest, Haines et al. also presented a new calibration experiment based in the summer of 2016 at a Jason crossover location near Daisy Bank (off the Oregon coast). The absolute calibration used a new GPS buoy for SSH measurements but also for atmospheric corrections. The results showed that retrievals of SSH, SWH, wet path delay and ionosphere are competitive with Harvest for all altimeter calibration metrics. Bonnefond et al. and Watson et al. also presented the planned extension of their respective sites (Corsica and Bass strait) to allow monitoring of Sentinel-3 and later SWOT.

Table 3. Absolute SSH bias values (in mm) for different missions and from the different calibration sites (using in situ SSH measurements)

Mission	**Bass Strait**	**Harvest**	**Corsica**	**Gavdos**	**Average**
TOPEX-A	+7	+8	0		**+5**
TOPEX-B	+19	+11	0		**+10**
Poseidon-1		-11	-12		**-12**
Jason-1 GDR-E	+47	+25	+19	+39	**+33**
Jason-2 GDR-D	+19	+20	-8	-8	**+6**
Jason-3 GDR-T	+1	-9	-38	-31	**-20**
HY-2				+287	**+287**
SARAL/AltiKa		-37	-63	-47	**-49**

Sentinel-3A			+5	+20	**+13**

Table 4. Transponder range calibrations from CDN1 compared to those from in situ SSH (Gavdos)

Satellite	**Descending**		**Year**
JA-2 (Gavdos)	+ 15.6 mm		2011-2012
JA-2 (CDN1, Crete)	+ 15.0 mm		2015-2016
JA-3(CDN1, Crete)	+ 38.0 mm	**J3-J2=23mm**	2016

Meanwhile, regional calibration methods from Cancet et al. have been employed at all three historical calibration sites (Corsica, Harvest, and Bass Strait) for the first time. This technique shows great promise for reducing errors by increasing the number of available overflights, thus improving the link between in-situ and global calibration and validation results.

Finally, Leuliette et al. presented comparisons of TOPEX/Jason with tide gauges. Differences between TOPEX and ERS-2 are reduced when TOPEX's Beta-prime dependence is removed, which also reduces the bias error between T/P ALT-A and ALT-B. This important result needs to be confirmed by other independent assessments. Concerning the comparisons with tide gauges, they showed that the range of drifts in TOPEX/Jason-gauge results using different strategies to remove vertical land motion from the gauges is consistent with an uncertainty of ±0.4 mm/year. Using the VLM strategy with the smallest distribution of altimeter–gauge residuals shows a drift in the TOPEX/J1/J2 time series of –0.03 mm/year. Finally they provided an estimate of the Jason-3 SSH bias with respect to the 24 year GMSL time series of –26.7 ± 1 mm.

6.7.3 Global validation studies

In preparation for the OSTST meeting, 20 cycles of Jason-3 version T (test) GDR products were released to the science team in October, 2016. These GDR-T products incorporate minor modifications to the science processing to reflect cal/val results from the OGDRs and IGDRs since the launch of Jason-3 in January 2016. The GDRs also reflect ground calibration of the radiometers on both Jason-2 and Jason-3. The GDRs were evaluated by all four project partners prior to their release to the science team. Global calibration and validation of the Jason-3 data products take advantage of the first 23 exact repeat cycles of Jason-3 where it was flying on the same ground track as Jason-2 but just 82 seconds apart.

Global cross-comparison of the Jason-3 GDR-T and Jason-2 GDR-D products indicate that the Jason-3 GDR products satisfy mission requirements and have similar quality to those from Jason-2. Direct comparisons between Jason-2 and Jason-3 measurements reveal the following:

1. The sea surface height measurements from Jason-3 are biased 29 mm lower than Jason-2 as a result of the range, ionosphere delay correction, and wet troposphere delay correction biases, as described below.
    a. Jason-3 is measuring Ku-band range longer than Jason-2 by approximately 22 mm. This is fully inline with ground calibration error budget.
    b. Jason-3 is measuring C-band range shorter than Jason-2 by approximately 9 mm.
    c. The dual-frequency ionosphere delay correction from Jason-3 is biased higher than Jason-2 by 6 mm, when using identical sea state bias models. This is a consequence of the relative Ku- and C-band range biases noted above.
    d. The radiometer wet troposphere delay correction from Jason-3 is biased higher than Jason-2 by 1 mm, after ground calibration. A residual Jason-2 versus Jason-3 relative drift in the radiometer wet troposphere delay corrections of 2.4 mm between Jason-3 cycles 1 to 12 remains in the GDR data after ground calibration.
2. The Jason-3 and Jason-2 measurements of sigma0 have good consistency, with Jason-3 measurements biased higher by approximately 0.27 dB.
3. The Jason-3 and Jason-2 measurements of significant wave height have good consistency and have a negligible bias.
4. The Jason-3 data are impacted by mispointing of the platform during the first three cycles. This platform mispointing resulted from incorrect star tracker parameters during cycles 1-3. There is a small but detectible impact on altimeter and radiometer parameters during these first three cycles. Precision users are advised to use the first three cycles of Jason-3 data with caution.
5. The standard deviation of internal crossover differences for Jason-2 and Jason-3 are a strong indicator of similar data quality from the two missions (Figure 33).
6. Geographically correlated differences between Jason-3 and Jason-2 are within +/- 1cm (Figure 34) when using the precise orbit ephemeris from the respective GDRs. These geographical patterns are reduced when using other orbit ephemeris solutions (e.g., GSFC, JPL).
7. Early results indicate that Jason-3 is providing a near seamless transition of observation of the Global Mean Sea Level after accounting for the relative bias observed during the tandem phase (Figure 35).

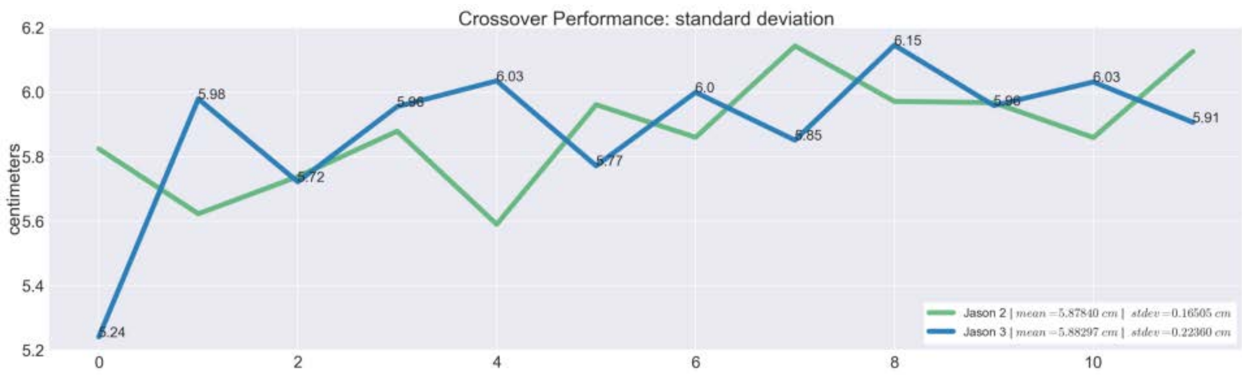


Figure 33. Standard deviation of internal sea surface height crossover differences from Jason-2 and Jason-3 during the first 11 cycles of Jason-3 indicate similar data quality from the two missions (Picot et al.). Similar results were also presented by Dettmering et al.

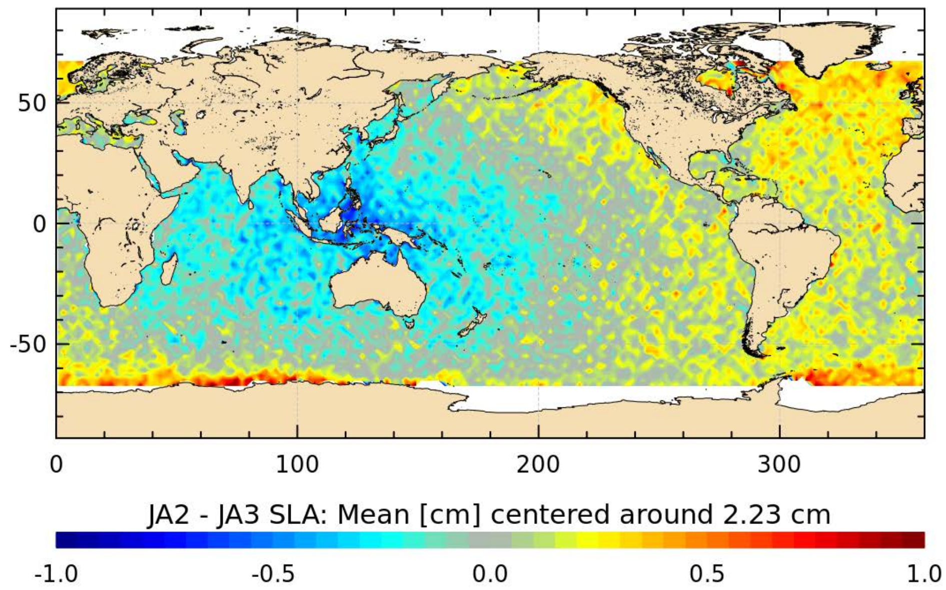


Figure 34. Averages of differences in sea level anomaly (SLA) observations from Jason-2 (JA2) and Jason-3 (JA3) reveal small (+/- 1 cm) geographically correlated features that are most likely caused by remaining errors in the precise orbit ephemerides (Picot et al.).

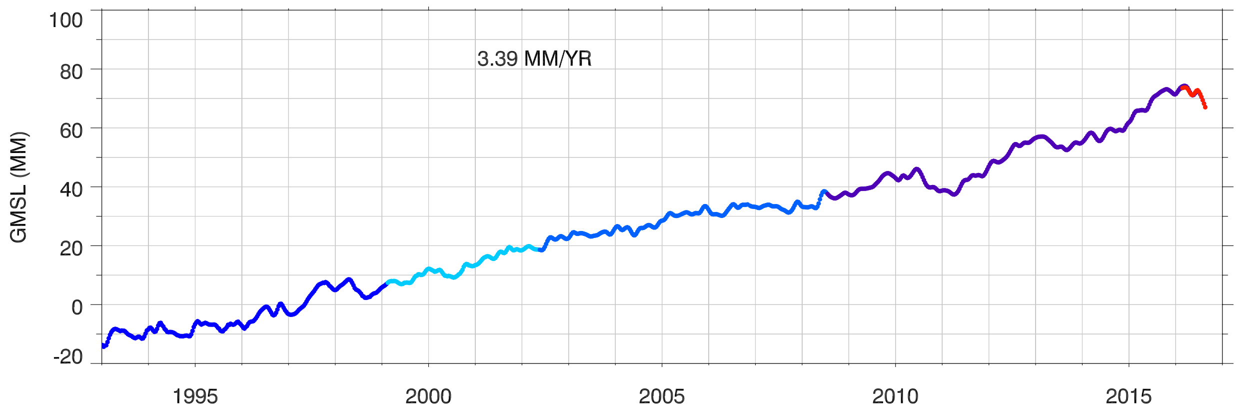


Figure 35. Satellite altimeter observations of global mean sea level from the Topex/Poseidon, Jason-1, Jason-2, and Jason-3 missions (Beckley et al.) show near seamless transition from Jason-2 to Jason-3.

A complete reprocessing of the Jason-1 data into version E GDRs was performed in 2016 and released to users in May 2016. The primary changes compared to the preceding version C GDRs included:

1. Correct accounting for altimeter range biases due to the internal path delay and Pulse Repetition Frequency truncation.
2. Correct accounting of the difference between the time of the emitted and received echoes that impacts the time tag of the measurements.
3. Improved precise orbit ephemeris solutions following version E standards.
4. An improved end-of-mission recalibration of the Jason-1 Microwave Radiometer data.
5. The addition of wet troposphere, dry troposphere, inverse barometer, and dynamic atmosphere correction fields derived from the ECMWF Reanalysis products.
6. Improved models for the sea state bias, the ocean tides, the mean sea surface, mean dynamic topography, and the geoid.
7. Adopting the NetCDF product format standards used by Jason-2 and Jason-3.

The Jason-1 version E GDRs have better quality than the version C GDRs, as demonstrated by lower variance of sea surface height crossover differences (Figure 36). The various improvements also reduce geographically correlated errors. The improved ocean tide models on the version E products reduce the amplitude of the 60-day signal observed in the sea level anomaly measurements. The relative sea surface height bias observed in the difference of Jason-2 GDR-D and Jason-1 GDR-E products is reduced to –25 mm, from –105 mm in the difference of Jason-2 GDR-D – Jason-1 GDR-C (Roinard et al., Dettmering et al.) products. The remaining relative bias between Jason-1 and Jason-2 is likely due to the SSB tables used and can be reduced by improving the SSB model for both missions. An anomaly has been highlighted on the dry tropospheric correction close to the coast for cycles 1-150 (related to Gibbs oscillations), this anomaly will be corrected in the future release of the products.

Early results suggest good SRAL data quality from the Sentinel-3A mission, with sea level anomaly measurements performing close to those from Jason-2 (Scharroo et al.). Public release of the Sentinel-3A SRAL data products is expected by mid-December, 2016. Some issues are still under investigation, including the wet troposphere retrieval algorithm, the ionosphere delay correction, and a small drift in in sea level anomaly measurements relative to Jason-2 and Jason-3 observations (Figure 37). The wind speed and significant wave height measurements from the Sentinel-3A are considered to be suitable for operational applications after some tuning. These measurements appear currently to be noisier than from other altimeter missions, and there may be some adverse effects of swell on the significant wave height measurements (Figure 38).

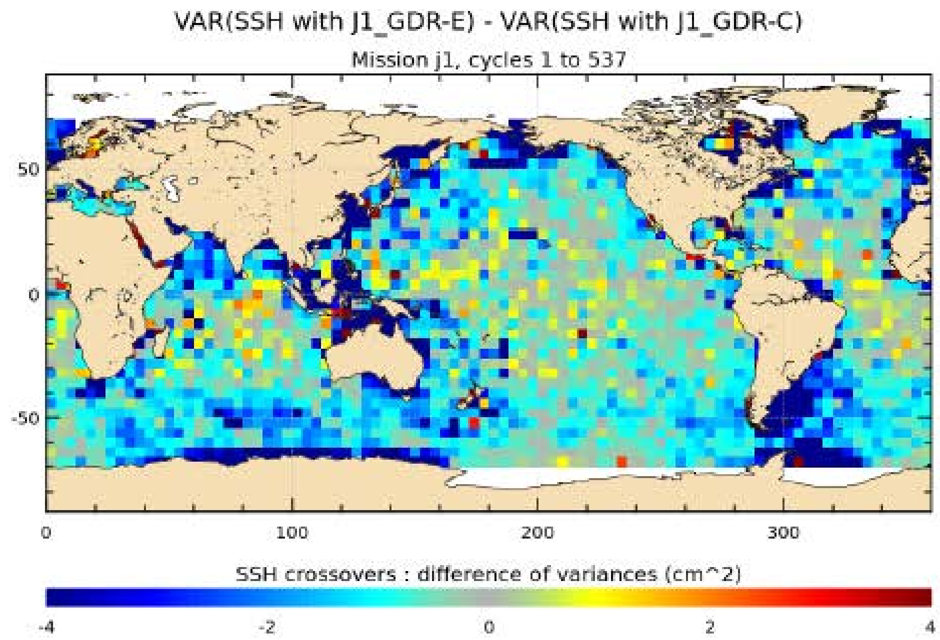


Figure 36. Jason-1 version E GDRs provided lower variance of sea surface height crossover differences compared to version C GDRs by an average of 1.3 cm2. The improved ocean tide models contribute most significantly to this improvement, followed by the improved precise orbit ephemeris solutions (Roinard et al.).

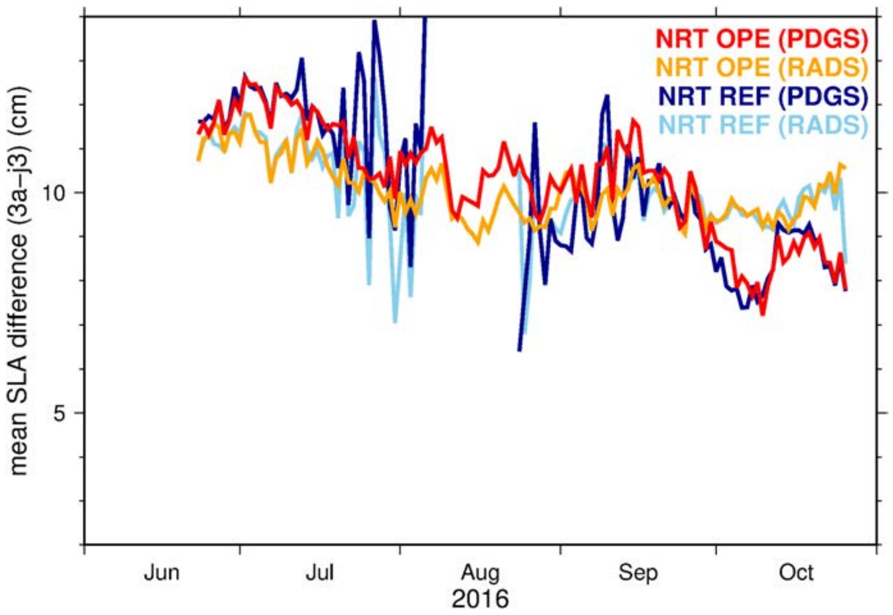


Figure 37. Inter-satellite crossover differences of sea level anomaly from Sentinel-3A and Jason-2/Jason-3 reveal a small relative drift (Scharroo et al.).

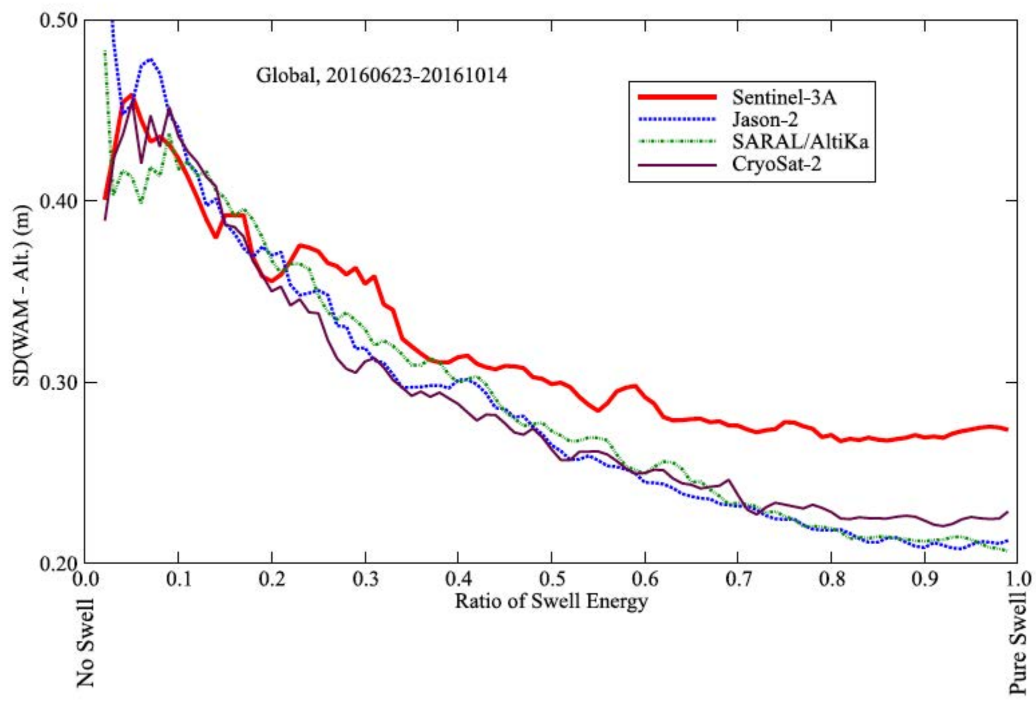


Figure 38. Variation of relative difference between wave model and altimeter measurements suggests that Sentinel-3A measurements of significant wave height may be susceptible to adverse effects from swell (Abdalla).

6.7.4 Round table summary

Key points raised by the Project Scientists:

1. **Assess the Jason-3 data quality: GDR notably – this is the Final Verification Workshop:**

- The consensus within the cal/val group is that the Jason-3 GDR products meet or exceed the requirements. The group therefore endorses the public release of Jason-3 GDR data products.

2. **Jason-2 End-of-Life orbit: Discussion between -27 and +35km orbit:**

– The group finds that the 17-day sub-cycle of the -27 km option is arguable better for cal/val studies.

3. **Cold-Sky radiometer calibration for Jason-2 and Jason-3 (frequency):**

The group recommended:

1. Perform cold-sky calibrations on both Jason-2 and Jason-3.
2. Perform cold-sky calibrations on both missions at least every 60 days.
3. Recommend feasibility studies for increasing the frequency of the Jason-2 and Jason-3 cold-sky calibrations.

4. **Extend the latency requirement on GDR production from 60 to 90 days on Jason-2 and Jason-3 to improve stability of radiometer measurements from use of cold-sky calibrations:**

• The group is convinced that the longer latency will contribute towards reducing radiometer stability errors through the use of the cold-sky calibrations. The longer latency on GDR production would also provide other potential benefits such as improved precise orbit determination solutions via usage of time-varying gravity fields, and availability of ERA-interim solutions.

5. **AMR on Jason-CS: There is a small probability that the external calibrator can fail in a position that renders the AMR unusable for the remainder of the mission. Should we accept this risk and keep the strong requirement on wet tropospheric correction drift that is very important for the climate data record:**

– The group accepts the risk if it is in-line with other inherent risks of the mission.

6. **Full-time open-loop (DIODE/DEM) tracking mode for Jason-2 (already done for Jason-3):**

The project clarified that Jason-2 is unable to switch between modes automatically like Jason-3 and Sentinel-3A, and that the proposal was to use open loop when flying over transponders and over other specific strategic targets. The group recommends that this needs to be weighed against the needs of the inland water community and operational constraints.

7. **Other:**
    1. The group showed an interest in having a special issue or collection of peer-reviewed papers covering Jason-3 and Sentinel-3A calibration and validation studies.
    2. The group recommends that the project inform the OSTST of progress of TOPEX reprocessing efforts because of the impact on mean sea level and other studies.
    3. The group recognizes that the transponder is an interesting and valuable tool, and recommends continued discussion about the challenges and value to long-term stability monitoring and use for absolute calibration, with potential expansion to C-band range and sigma0.

6.8 The Geoid, Mean Sea Surfaces and Mean Dynamic topography

Chairs: Ole B. Andersen and Yannice Faugere

This splinter had a total of 5 oral presentations and 1 posters

The oral presentations were the following:

- (Ole Andersen) Update to the DTU15 global marine gravity field and new DTU15 bathymetry
- (Xiaoli Deng[1]) The altimetry-derived gravity field for resolving hidden geological features around Taiwan
- (P Schaeffer) The CNES CLS 2015 Global Mean Sea surface
- (P Knudsen) A preliminary mean dynamic topography model – DTU16M
- (Simon Williams) GNSS at tide gauges for Mean Dynamic Topography: Conventional measurements and Multipath Reflectometry

The posters were the following

- (P Knudsen) The Goce toolbox

As the previous years the session covered the three topics of the session, Geoid, Mean Sea Surfaces and Mean Dynamic Topography. First, the accuracy of the altimetry derived Marine gravity and Mean Sea Surface fields has been discussed at global scales and regional scales. Figure 39 (left) shows an example of the contribution of geodetic missions (Cryosat-2 and Jason-1G) on the quality of MSS at global scale. The error reduction is huge, up to 90%, and strongly correlated with topographical structures. Regional improvements are also highlighted in Figure 40 and Figure 41 both illustrating the performance of these products using ship data in respectively North Atlantic and Taiwan region. Both analyses highlight the importance of Cryosat-2 contribution to resolve the fine scales of the marine Geoid. Though the reference field coastal regions accuracy has improved (Figure 39 right) improvements in those areas remains a challenge, and require further work notably improved altimeter coastal retracking. Applying fine editing process on situ marine gravity campaign is also necessary as the quality of certain dataset (pre GNSS) is now not sufficient to be used to assess altimetry derived fields. Progress has also been made in mean dynamic topography thanks notably to the latest GOCE geoid, and the latest MDTs such as DTU16 (GOCO05C-EIGEN-6C4 hybrid) exhibits improved performances (Figure 42). Finally promising new technics will allow us to improve coastal MDT such as GPS reflectometry, using GPS receivers as tide gauges (Figure 43).

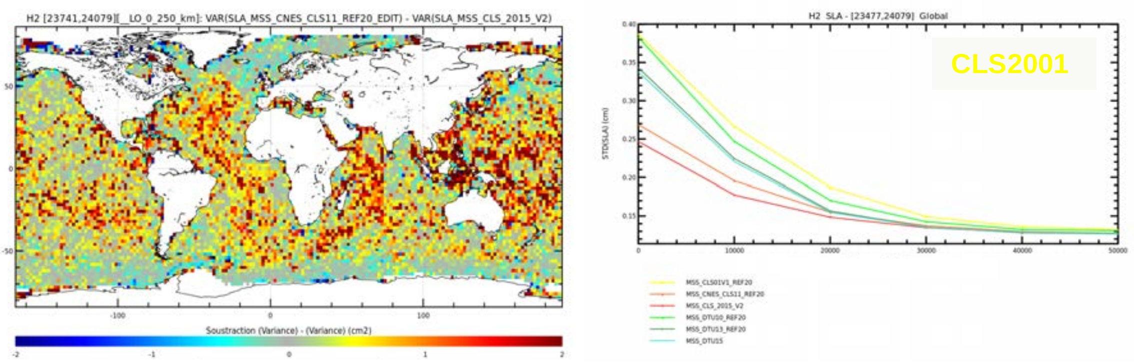


Figure 39. Illustration from (Schaeffer et al) on the CNESCLS15 MSS performances using an independent dataset, HY2A: (left) Dif of SLA variance using MSS_CNES_CNES_CLS_2011 and MSS_CNES_CLS_2015 (right) STD of the SLA along HY-2A tracks as a function of the distance to the coast, and using different MSS solution. (Latitudes > 60° are excluded).

2015 Recon 2.4mill obs	Std (mGal)	Mean (mGal)	Max (mGal)
DTU15	**2.65**	0.5	33.9
DTU13	2.83	0.5	32.2
DTU10	2.90	0.5	32.2
SS 23.1	3.13	0.7	43.4

Figure 40. Illustration from Andersen et al on Comparisons between several generation of Marine Gravity fields and Survey in NW Atlantic (specific editing)

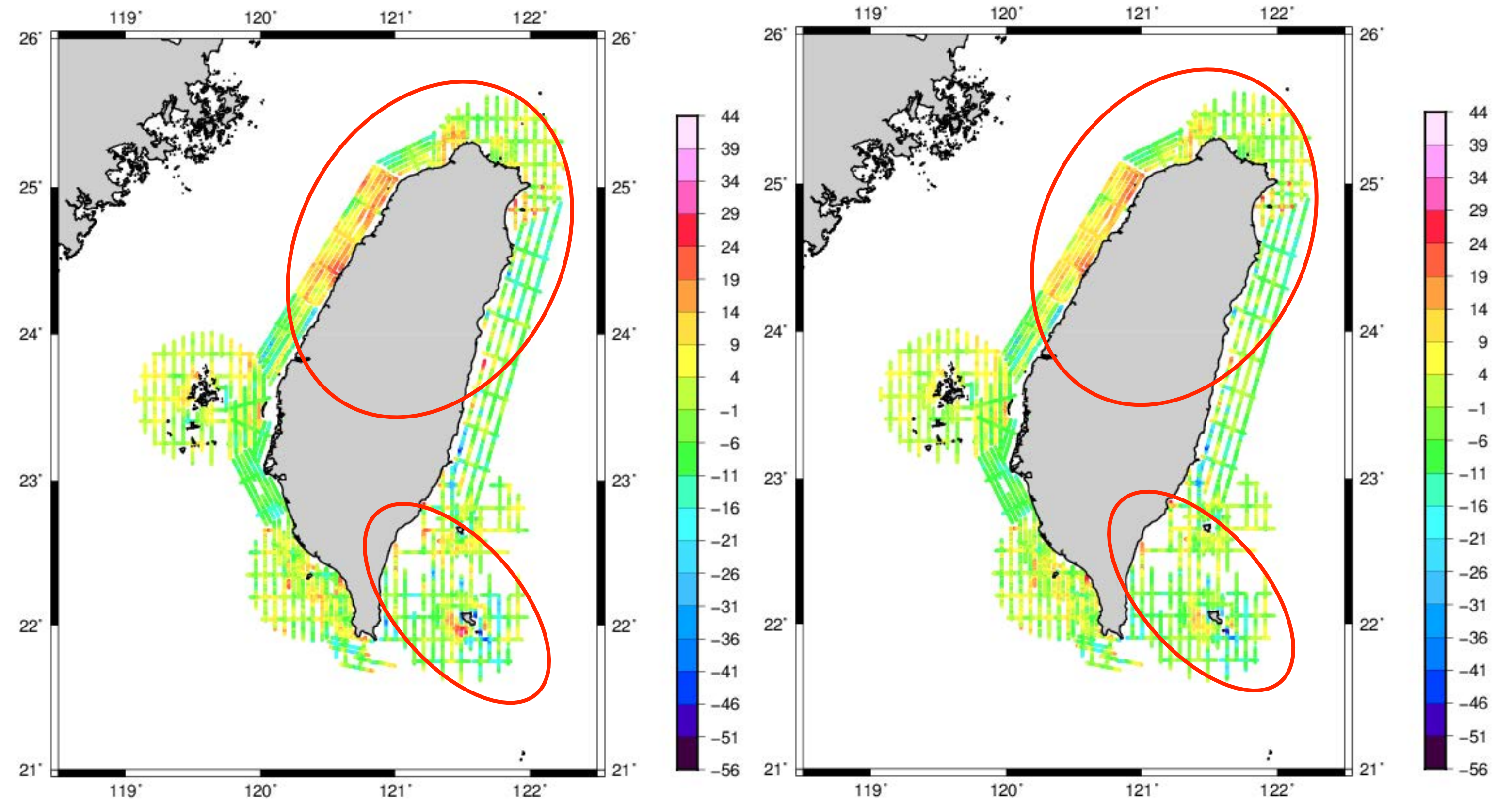


Figure 41. Illustration from (Deng et al) Comparison altimetry based free-air gravity anomalies to Ship-track (mGal) around Taiwan: (left) Jason-1 standard retracking from GDR (right) sub-waveform retracked Jason-1 + Cryosat-2 SSHs

	lat 10-30		lat 30-50	
	u	v	u	v
DTU15MDT	5	5.9	5	4.9
DTU16MDT	4.9	5.6	4.7	4.7

Figure 42. Illustration from (Kundsen et al) on the new DTU16 MDT performances compared to drifters (cm/s)

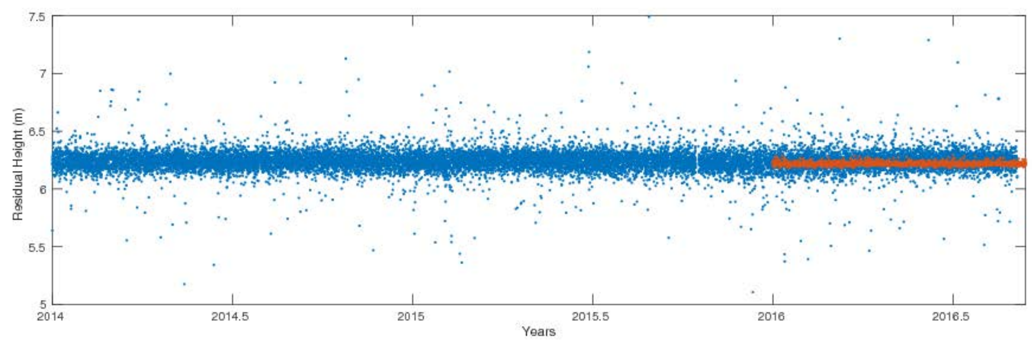


Figure 43. Illustration from Smith et al on the performances of the L5 GNSS signal (red) instead of of L1 and L2. Mean dynamic topography from tide gauges is consistent with ocean models/open ocean MDT at the 5-8 cm RMS level. New analysis techniques offer significant improvements. 1-2 cm RMS is certainly possible

Additionally to the presentation, a round table was also organized with a focus on the End of life of Jason-2.

Jason-2 End of life Recommendations:

- RECOGNIZE the great achievement that J-2 is IN SUCH GOOD HEALTH
- RECOGNIZE the value of J1-GM for high quality of current MSS/Geoid i.e., to the benefit of operational use of i.e. Cryosat-2 and SARAL/AltiKA, HY-2A
- RECOGNIZE that accuracy of current altimeter product is affected by remaining error in MSS.
- RECOGNIZE that Jason-2 is unique in potentially providing a 4 or 2 km “exact” sampled MSS
- RECOMMEND to have AT LEAST 2 interleaved repeat GM lasting 2.2 years.
- RECOMMEND to follow the suggestion of Dibarboure with an orbit 27 km lower than Jason-3 as it ALSO gives the highest value to Oceanography.
- Jason-2 Extension of Life Orbit: -27 km is the best option
  - **It has a 17-day sub-cycle that is good for mesoscale monitoring because it blends well with the 10-day cycle of Jason-3.**
  - 2. It has a 145-day sub-cycle and a 371-day repeat cycle that are good for geodesy: the final grid is close to the Jason-1 GM grid. If Jason-2 EoL was to die after only half the repeat cycle, it would still provide a coarser but globally homogeneous dataset for geodetic users.
  - 3. It has a 4-day sub-cycle that is favorable for sea state applications (e.g. assimilation in operational wave models) and that blends well with Jason-3's 3-day sub-cycle.
  - 4. It generates overlap events with Jason-3 that are well distributed at all time scales. There are no empty bins for the 10-day criterion, and only 3 empty bins for the 1-day criterion. This orbit yields a high probability of collecting an overlap sample in any region, season, and for any time difference.
  - 5. IT HAS A BENEFITIAL SUBCYCLE IN CASE OF EARLY FAILURE
- RECOMMEND that (if possible) the GM is extended into 4 years (2 km)
- RECOMMEND to further study the impact of 4 years extended GM (2 km)
- RECOMMEND that the timing is not being linked to the launch of i.e. S-3B as this might potentially compromise the GM – i.e. by delay of S-3B launch.
- RECOMMEND to move J-2 to a GM mission RELATIVELY SOON while J-2 is still healthy and while 2 years of GM can be “safely” ensured. Two Years GM is considered THE MINIMUM to ensure significant MSS improvement – 4 years the preferred.

- RECOGNIZE that an EARLY improved MSS will ALSO lead to Improved SSH values as well as global bathymetry and gravity and that improved MSS will highly benefit SWOT and enhance the value of (SARAL+C2) in operational/climate use.

6.9 Tides, internal tides and high-frequency processes

Chairs: Loren Carrere, Florent Lyard and Richard Ray

This year the Tides/HF splinter counted 7 oral presentations and 8 posters dedicated to barotropic and baroclinic tides and to high-frequency corrections.

Presentations

Two talks focused on the new barotropic tides results: a regional model on Arctic Ocean and estimation of minor tidal constituents. One presentation focused on the foreseen evolutions of the high frequency corrections for altimetry and the four other talks focused on internal tides and internal waves, motivated especially to prepare for SWOT mission.

M. Cancet presented the final results of the regional tidal model for Arctic Ocean developed in collaboration with ESA/NOVELTIS/DTU/LEGOS. The mesh has been refined to 4 km on coasts. Results show that the regional purely hydrodynamic model shows equivalent performances to global data-assimilated models for main waves. Assimilation of a specific high latitudes dataset based on CRYOSAT-2 and ENVISAT data, and also some tidal gauges, still allows improving model performances (cf. Figure 44).

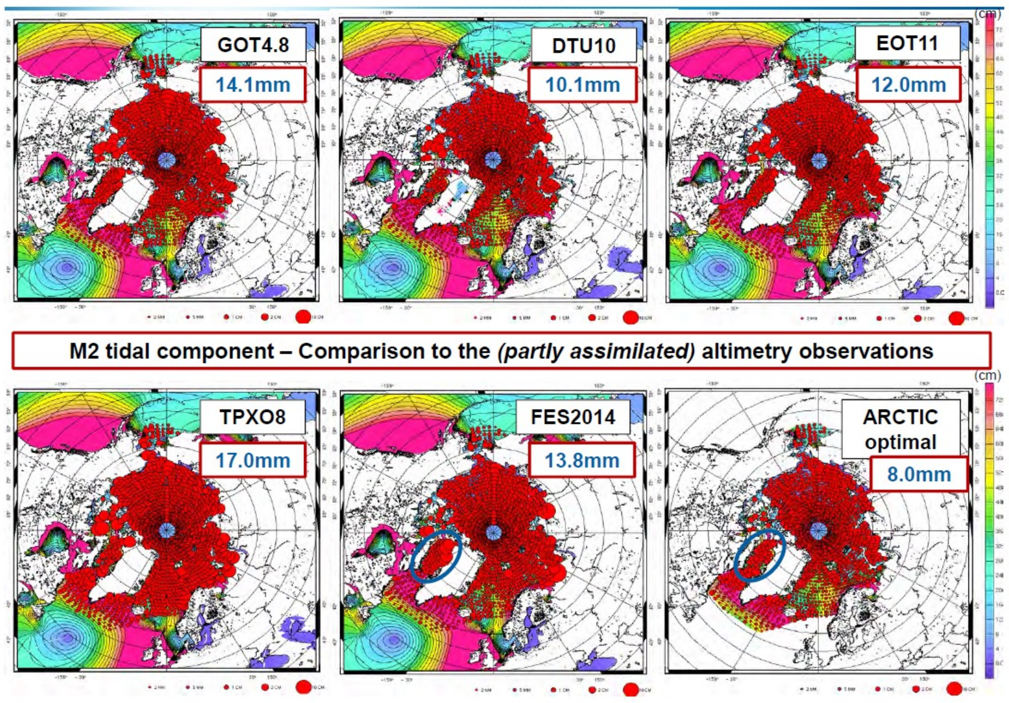
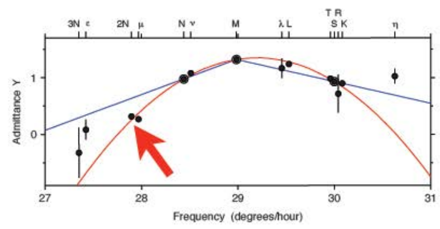


Figure 44. Comparison of the M2 tidal component from different models to altimetry observations in Arctic region.

R. Ray presented some results about the minor tidal constituents'computation. Generally the tide prediction softwares account for minor tides "on the fly" by inferring their constant from major tides, exploiting the smoothness of admittances in deep water. A network of 150 bottom-pressure stations (Ray, 2013) was used to test some aspect of tidal inference and comparing with direct solutions (free or assimilated) provided by new tidal atlases. For small tides near larger, well-determined tides (e.g., nu2), inference may be more accurate than direct estimation. For "large" tides on the edges of tidal bands (2N2, J1), direct solutions can be more accurate than inferred solutions (cf. Figure 45). For the large P1 tide, inference is more accurate than direct estimation for all models except TPXO8, if the Free Core Nutation (FCN) is accounted for. FCN has a positive impact on diurnal tides estimation. Some of these results are to be published in JTech paper: Ray, "On tidal inference in the diurnal band," under review.

Tests of $2N_2$



RMS Difference (mm) with BPR Tides

	FES04	FES14	EOT11a
Direct	1.22	0.83	1.15
Inferred (linear)	2.54	2.70	2.71
Inferred (fourier)	2.81	3.08	3.10

Bootstrap standard error on RMS is ~0.15 cm; RMS signal is 8.0 mm.

Figure 45. Inference test for 2N2 tidal component.

F. Lyard showed a comprehensive presentation of the foreseen evolutions of the high frequency (HF) corrections for altimetry, including ocean waves, storm surges, ocean tides and internal tides surface signatures. Present concerns are open oceans high mesoscale energy regions, insufficient resolution and higher error budget for coastal ocean, higher error budget at high latitudes, no correction yet used for internal tide surface signatures and an overall weaker accuracy out of TP/Jason reference ground-track. Future requirements are thus to improve data homogeneity particularly between open ocean and coastal region and between low and high latitudes, improve data coverage on coast and in estuaries, predict internal tide signatures and propose a proper ocean wave de-aliasing. Keeping improving models' realism and accuracy is essential, and we need to redefine the corrections' production systems, to propose new archiving and delivery formats and still promote science collaboration. Some perspectives are to include the LSA forcing in non-tidal simulations (cf. Figure 46), and work on the new FES20XX atlas.

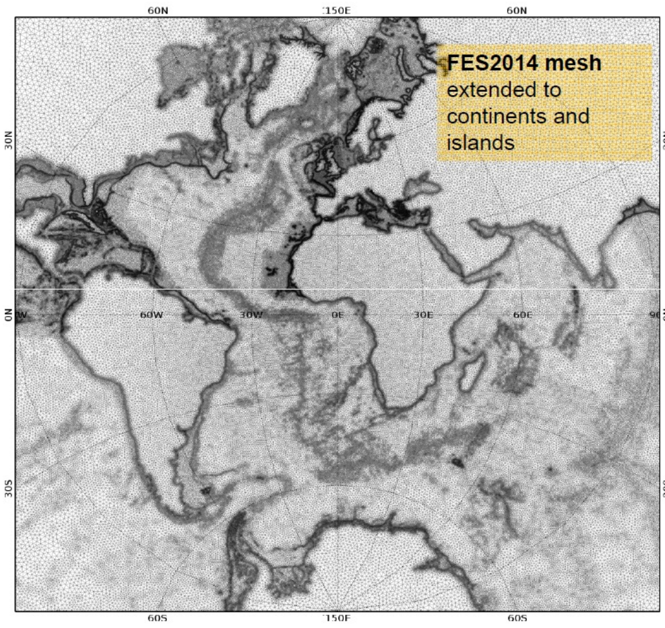


Figure 46. FES2014 mesh extended on continents and islands to compute the LSA effects.

J. Girton first presented new global estimations of the open-ocean mode-1 M2 and S2 internal tides from Zhao et al. (2016) analysis based on a wave-fitting approach of satellites measurements; some estimations of the diurnal components K1 and O1 were also shown, but with a geographical pattern restricted to the diurnal critical latitudes. The approach allows identifying distinct beams coming from different generation sources and thus proposing diagnostics of multi-waves interference on global ocean and maps of global M2 energy fluxes divergence (cf. Figure 47). Then some estimations of the near inertial kinetic energy were proposed from drifters, mooring, profiling float velocity data and from ARGO vertical displacement data. Finally some spectrum analysis showed that the SSH contribution from internal waves (and observability from satellites) is dominated by internal tides, but the background (Garrett-Munk) continuum may be visible where other contributions are small.

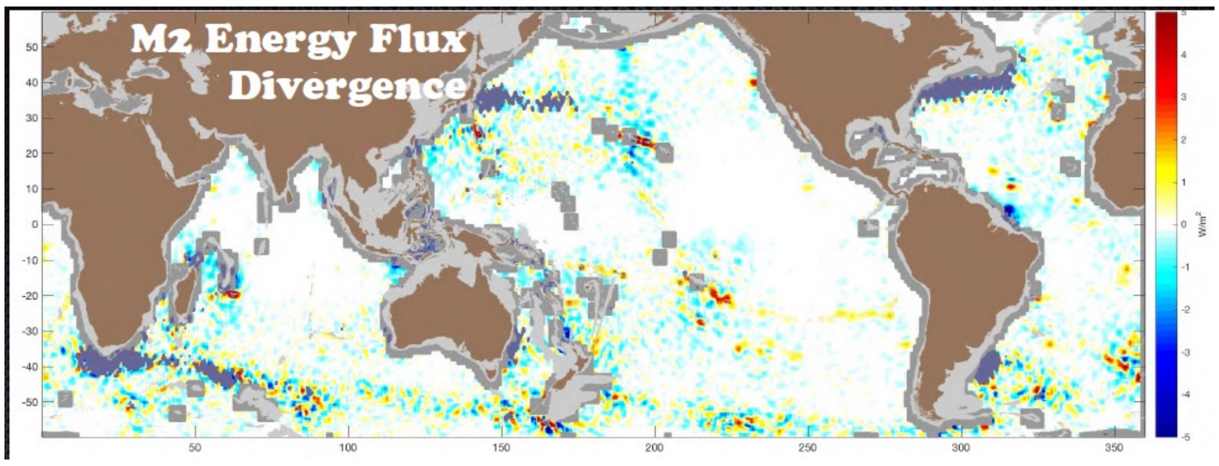


Figure 47. Estimation of the M2 energy flux divergence (W/m²)

L. Carrere presented a comparison study of five internal tides (noted IT) models focusing on coherent internal tides. Models from B. Dushaw, G. Egbert and L. Erofeeva, R. Ray, Z. Zhao and E. Zaron have been used. The analysis is based on altimetry variance reduction diagnostics for three missions Jason-2, AltiKa and Cryosat-2, and on a 2D spectral analysis of SLA. Results point out the very good performances of Ray model on global ocean for M2 frequency (cf. Figure 48). Egbert and Zaron models give similar results for K1 but Zaron's one need to be improved in shallow waters. A first IT correction can thus be envisioned for nadir altimeters and for SWOT mission, using M2 from Ray model. Some complementary investigations are needed for K1.

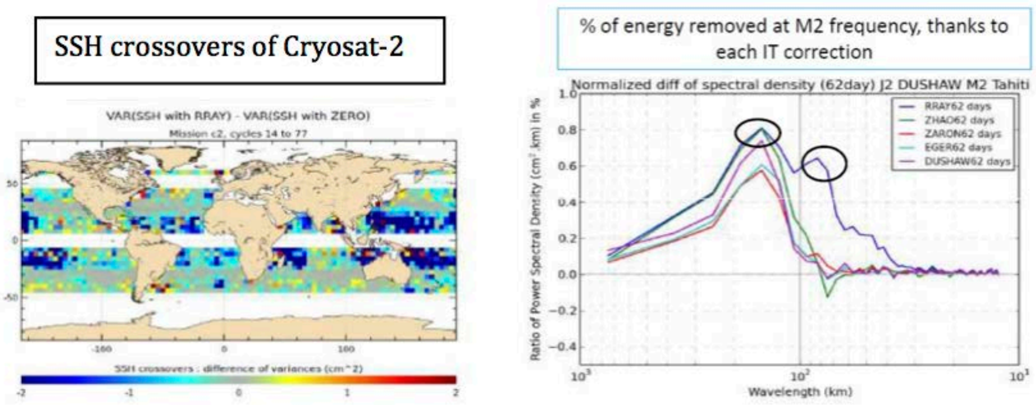


Figure 48. Left: variance reduction for SSH crossovers of Cryosat-2 mission when using Ray's internal tide correction (cm²). Right: percentage of SLA energy removed at M2 frequency, when using each IT model.

E. Zaron presented some results about non-stationary tides inferred from along-track altimetry and particularly from a global analysis of along-track wavenumber spectra of Topex-Poseidon/Jason-1/Jason-2 SSH. After removing the barotropic tide, the large-scale mesoscale SLA, and the coherent internal tide, the incoherent mode-1 semidiurnal internal tide is evident in the along-track power spectrum at many locations. Quantitative measures of the incoherent tide are influenced by the choice of the bandwidth and the model for the broadband non-tidal spectrum. Main results show that the incoherent internal tide is spatially variable, but in much of the Tropics it is as large or even larger than the coherent internal tide (cf. Figure 49).

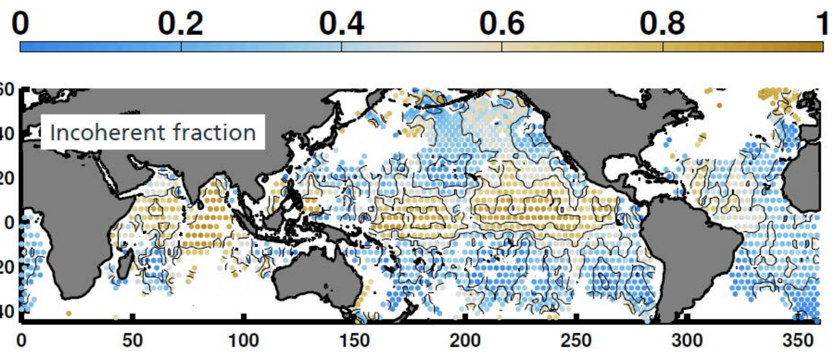


Figure 49. ratio of non-coherent to total semi-diurnal variance. Not plotted where the total variance is less than twice the standard error of the coherent M2 signal.

J. da Silva presented results from a synergetic approach between radar altimetry and SAR or other high-resolution optical sensors, enabling identification of large amplitude, short-period internal waves in high-rate Jason-2 altimeter data. The Brown model assuming homogeneity over the surface backscatter altimeter footprint is no more valid when Internal Solitary Waves (noted ISW) or slicks occur; tests show that MLE4 algorithm performs better than MLE3 for inhomogeneous surfaces affected by internal waves. ISW signatures are detected in the 20Hz-rate Jason-2/3 altimeter products, showing parabolic-like features in the radargram, radar power (sigma0), "off-nadir angle", SWH, and an inversion of altimeter waveforms (cf. Figure 50).

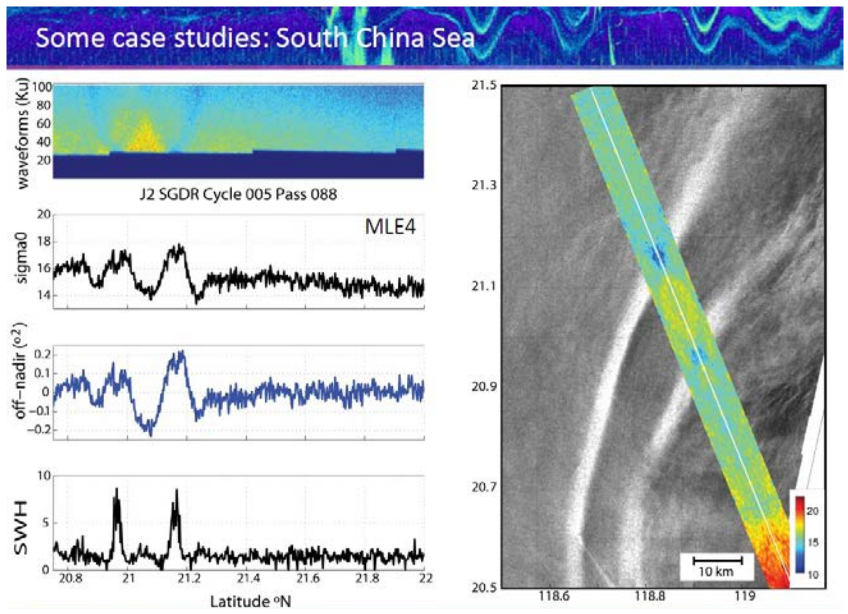


Figure 50. example of ISW detection from Jason-2 HR altimeter data and SAR image n the South China Sea.

Posters:

A.R. Tazkia et al. presented some results on the seasonal modulation of M2 tide in the Bay of Bengal from a modeling and data analysis approach; they point out strong M2 amplitude changes between winter and summer seasons.

J. D'Addezio and G. Jacobs presented how optimizing numerical models for submesoscale eddy prediction, comparing the forward integration of the primitive equations with the quasi-geostrophy and semi-geostrophy approximations within a high-resolution regional model of Golf of Mexico area.

Last results of FES2014b global tidal model have been presented by L. Carrere et al.: new loading and self-attraction FES2014 solutions have been computed and then used to estimate the new FES2014b tidal model version. The performances of FES2014b solution still show some improvement in shelf regions, in some deep ocean areas and at high latitudes.

D. Einspigel presented a new global tide model named DEBOT, with a purely hydrodynamic or an assimilative modes, both solved in time-domain; validation results show encouraging performances compared to some of the state-of-the-art tidal models.

F. Toublanc et al. showed results for tidal downscaling in a regional 3D circulation model (SYMPHONIE) of the Bay of Biscay and Gironde estuary, using tailored 2D unstructured simulations. Complex error are reduced by more than 75% when using a regional 2D forcing (TUGO or SYMPHONIE) compared to a global forcing, due to the better consistency of bathymetry and grid resolution between the large scale and the coastal models.

Results of the assessment of the FES2014 tidal currents atlas around Australia have been shown by M. Cancet et al., showing a very good agreement between the FES2014 tidal currents and the in-situ currentmeter observations available around Australia, at most locations. The validation was performed for the five main tidal components, M2, S2, K1, O1, N2. Some large discrepancies were also identified at a few stations, mainly due a local lack of resolution of the global model mesh.

J. Wang and L-L. Fu presented a study focusing on designing an in-situ observing system for the SWOT ocean Cal/Val, to validate the SSH measurement error wavenumber spectrum. Performance of Underway CTD (UCTD), Pressure-Inverted-Echo-Sounder (PIES), and moored measurement of temperature and salinity have been explored using the global 1/48th degree resolution ECCO2 simulation. The results show that only a mooring-based SSH reconstruction can meet the SWOT ocean CalVal baseline requirement.

E. Zaron et al. presented a validation study of 3 internal tides models using Cryosat-2 altimeter data and also steric height measured from XBT transects and ARGO profiles. R. Ray's model for M2 internal tide exhibits positive variance reduction for all comparisons except in regions of highest mesoscale SSH variability; other models are still being improved.

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

- Jason-2 EoL Time: trade-off between "soon" vs. waiting for Sentinel-3B
  - No unanimous consensus was raised from tide community but most people prefer to stay on interleaved orbit as long as possible. Indeed, 7-years time series is much better than 5 years for wave separation; for example, 5-years time series still yields a 30% correlation between M2 and S2 main waves. Longer time series will help improve tide models on shelves, which will then help improving the new MSS …
- EoL Jason-2 Orbit choice:
  - no specific recommendation was raised from tide community;

- Evolution of high-frequencies corrections for altimetry:
  - HF de-aliasing corrections include ocean waves, storm surges, ocean tides and internal tides surface signatures;
  - Recommendations raised are to improve data homogeneity between open ocean and coastal region and between low and high latitudes, improve data coverage on coast and in estuaries, predict internal tide signatures and propose a proper ocean wave de-aliasing;
  - We need to keep improving global and regional models' realism and accuracy and to propose new archiving and delivery formats;
  - Still promote science collaboration is fundamental.
- Internal tides :
  - Promising products have been tested, and particularly M2 from R. Ray's model exhibits very good performances on the global ocean. More tests are needed as some products are still being improved to take higher modes into account, to deal properly with shallow water regions and new frequencies are being computed (K1, O1, S2) and should be available soon for the tests …
  - A recommendation raised is to use an IT correction for the next version of the AVISO gridded products. Indeed R. Ray and E. Zaron (2016) have pointed out the leakage of the internal tide signal in the last AVISO PVA2014 product and this is a problem for some users.
- Regional modeling:
  - Very interesting regional tide models have been presented for Arctic and Bay of Bengal regions. We recommend continuing developing regional tidal models as it allows very high resolution mesh locally and thus to improve significantly tides on shore or even in estuaries.
- Bathymetry :
  - Bathymetry remains a critical parameter for tide and surge modeling, particularly in shallow waters and estuaries.
  - So we keep needing bathymetry data to improve such models: critical regions are Argentina, Siberian Plateau, Yellow seas … We need new bathymetry surveys and to make these data available for scientists.
- GDR tide product:
  - There is no objection to store the LP ocean+load solution in the *ocean_tide_sol_2* field for FES2014 solution.
  - A recommendation is to still be able to use either LP equilibrium or LP static, so we need to keep the *neq_tide* field in the GDR product.
  - We also need to have a clear description of each tide solution and the way to use them in the GDR's Handbook.

6.10 Science (Part I): Current and past mean sea level observations

Chairs: Benjamin Hamlington and Guy Woppelmann

Summary

There were two main scientific themes in this session: 1) disagreements between historical reconstructions of sea level, and 2) the estimate of acceleration in GMSL during the satellite altimetry era. Phil Thompson presented a new study trying to reduce the uncertainty and complexity of GMSL reconstructions and establishing a "likely range" of 20th century rates of GMSL rise. He found that estimates above 1.85 mm/year and below 1.4 mm/year are highly unlikely given the best available tide gauge data (Figure 51). While this does narrow the range, it does underscore the ongoing issues associated with estimating 20th century GMSL. This was followed up by two presentations looking at sea level reconstructions on regional levels. Significant disagreements were found between widely used sea level reconstructions, with the quality of the reconstructions varying dramatically across the globe (Figure 52). This raises questions about the best practices of reconstructing sea level and how robust these techniques actually are.

The second half of the session focused on current GMSL estimates. In particular, a focus was placed on the use of tide gauges in correcting the altimetry data and the impact this has on GMSL. Both the corrections used and way in which those corrections are used were found to have an impact on GMSL trend estimates. Steve Nerem concluded the session by attempting to estimate an acceleration in satellite-measured GMSL, tentatively identifying a statistically significant acceleration in GMSL since 1993.

Conclusions

- By simplifying the process of reconstructing GMSL, a likely range of GMSL rise from 1901 to 2000 was found to be 1.4 to 1.85 mm/year.
- Significant disagreements exist between sea level reconstructions, especially on regional levels, necessitating further investigation into the best practices for reconstructing past sea level.
- Further investigation is needed into the bias drift correction applied to the altimetry data and - with particular regard to this session – the impact it has on GMSL trend estimates.
- It may now be possible to identify a statistically significant acceleration in GMSL. This needs to be investigation further in a detailed study.

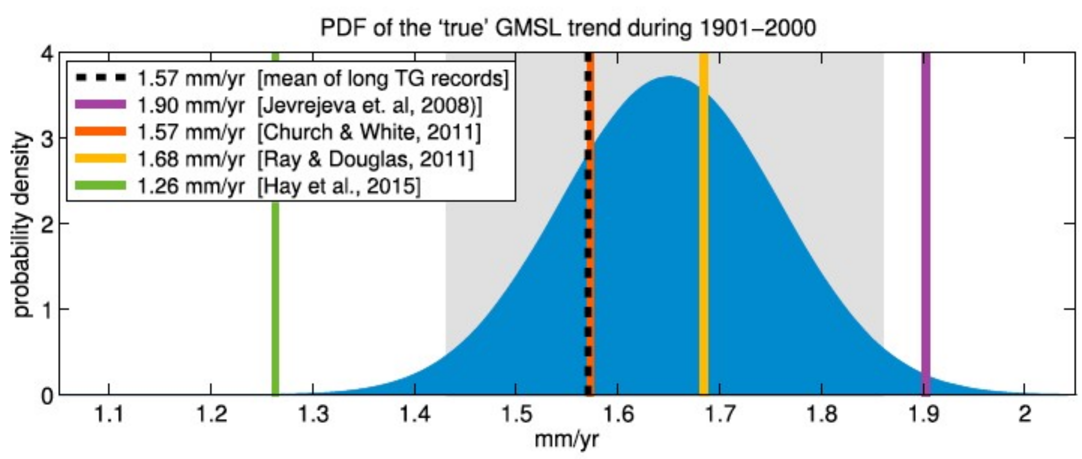


Figure 51. Probability density function (PDF) for the true rate of twentieth century GMSL rise given how the tide gauges sample spatial structure in sea level change (blue). Gray shading represents 95% confidence intervals (°¿0.23 mm/yr) about the central value of the distribution (1.66 mm/yr). The black dashed line shows the sample mean of the observed GIA-corrected (ICE-6G VM5a) trends from the tide gauge records; solid lines denote the linear rate of GMSL rise during 1901–2000 from four prominent twentieth century sea level reconstructions [Jevrejeva et al., 2008; Ray and Douglas, 2011; Church and White, 2011; Hay et al., 2015].

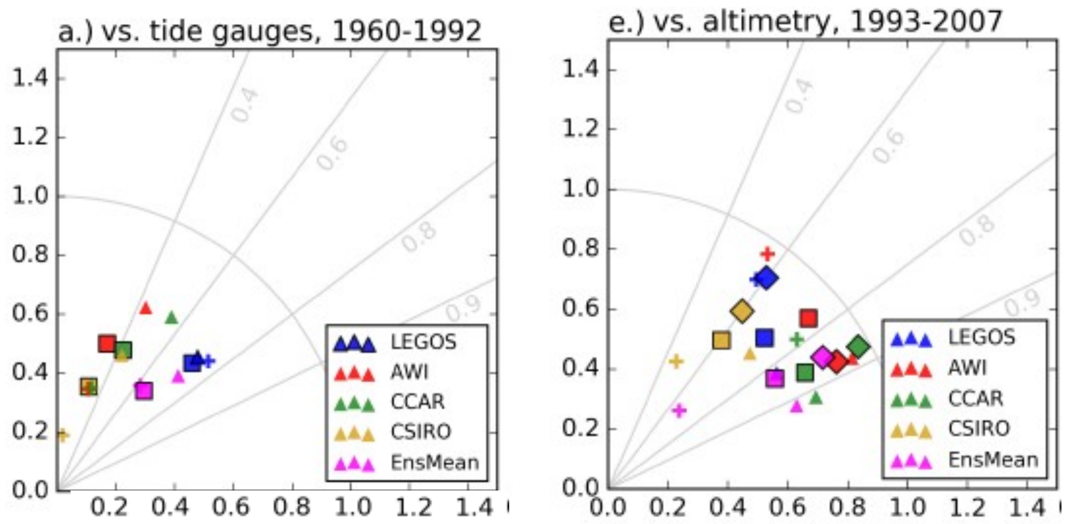


Figure 52. Taylor diagrams of correlations (the angle) vs. the ratio of standard deviations (the radius) between the various products and the tide gauges and altimetry, all from detrended, 5-yr-smoothed data. Squares represent mean correlation and RMS mean variability ratio for the products over all TG locations, even for the comparison to altimetry. Triangles and plus signs are the means over only the North Pacific and North Atlantic, respectively. The diamonds in panel e are the means over all locations for a global comparison of the products to altimetry (i.e., not just at TG locations).

Presentations

- Phil Thompson: Are long tide gauge records in the wrong place to measure global sea level rise?
- Mark Carson: Sea level variability and trends reconstructed for the period 1960 - 2007
- Sonke Dangedorf: Spatio-temporal evolution of 20th century regional mean sea level rise
- Gary Mitchum: Vertical land motion errors at the tide gauges and sensitivity of altimeter drift estimates to these errors
- Brian Beckley: On the 'cal mode' correction to TOPEX altimetry and its effect on the global mean sea-level time series
- Steve Nerem: Has the Rate of Sea Level Rise Accelerated During the Altimeter Era?

6.11 Science (Part II): From large-scale oceanography to coastal and shelf processes

Chairs: Florence Birol and David Griffin (replaced by John Wilkin)

In the Science 2 splinter the following oral presentations were made:

- *Connections between AMOC, meridional heat transport, and heat content in the North Atlantic from satellite altimetry*. LuAnne Thompson, Kelly Kathryn, Frajka-Williams Eleanor.
- *An Ongoing Shift in Pacific Ocean Sea Level.* Benjamin Hamlington, Se-Hyeon Cheon, Philip Thompson, Mark Merrifield, Robert Nerem, Robert Leben
- *Sea Surface Height retrieval in the ice covered Arctic Ocean from waveform classification to regional sea level maps*. Pierre Prandi, Lionel Zawadzki, Jean-Christophe Poisson, Vincent Debout, Pierre Thibaut, Michael Ablain, Graham Quartly, Jérôme Benveniste, Nicolas Picot
- *An Analysis of the Southern Ocean's barotropic response to the wind during the past 20 years: Contributions to Sea-Surface Height variations and to the variability of the ACC transport across the Kerguelen Plateau*. Frederic Vivier, Wilbert Weijer, Young-Hyang Park
- *Deep ocean influence at ocean boundaries*. Chris Hughes, Joanne Williams
- *Characterizing submesoscale variability in the southern California Current System.* Teresa Chereskin, Rocha Cesar, Gille Sarah, Dimitris Menemenlis
- *Seasonality of submesoscale dynamics in the Kuroshio Extension*. Cesar B Rocha, Sarah T. Gille, Teresa K. Chereskin, Dimitris Menemenlis

In addition, the following posters were presented:

- *Altimetry in a regional tropical sea: benefits from the SARAL/ALtiKA mission*. Lionel Gourdeau et al.
- *Quantifying the impact of mesoscale eddies on precipitation and SSS changes in the tropical Pacific Ocean*. Dodji Sovadian et al.
- *Altimetry and biologging in support of pelagic marine protected areas.* Francesco d'Ovidio et al.
- *Can we map the interannual variability of the whole upper Southern Ocean with the current database of hydrographic observations?* Céline Heuzé et al.
- *Inter-decadal modulations in the dynamic state of the Kuroshio Extension system: 1905- 2016*. Bo Qiu et al.
- *Comparing the energy content and resolution capability of numerical simulations and alongtrack altimetry at meso and submesocales.* Angelique Melet et al.
- *Investigation of the intra-annual variability of the North Equatorial Counter Current eddies and of the instability waves of the North tropical Atlantic Ocean*. Sabine Arnault et al.
- *Impact of slowdown of Atlantic overturning circulation on heat and freshwater transports*. Kathryn Kelly et al.
- *High-wavenumber variability in the California Current from new altimeters*. Sarah Gille et al.
- *Detecting coastal currents in the Antarctic Sea-ice Zone*. Rosemary Morrow et al.
- *Inter-comparison between different along track altimeter products, numerical ocean models and in situ measurements: development of a dedicated software*. Isabelle Soleilhavoup et al.

- *Radar altimetry backscattering signatures at Ka, Ku, C and S bands over the ocean*. Fabien Blarel et al.
- *Comparisons of coastal ocean wavenumber spectra for surface velocity estimated from Hfradar (CODAR) and sea surface height estimated from CryoSat*. John Wilkin et al.
- *Heaving and/or isopycnal advection: two main processes responsible of thermohaline anomalies within coastal Californian mesoscale eddies.* Cori Pegliasco et al.
- *Dynamic interpolation of Sea Surface Height from the present 6-satellite constellation: reconstruction of the Gulf Stream eddies and comparisons with objective mapping*. Clement Ubelmann et al.
- *Refined altimetry products in support of scientific cruises*. Marie Isabelle Pujol et al.
- *Diagnosing Mechanisms of Mesoscale Physical/Biological Interaction using Satellite and In Situ Observations in Concert with a Global Coupled Physical/Biological Simulation.* Peter Gaube et al.
- *Impact of vertical and horizontal advection on nutrient distribution in the southeast Pacific*. Bàrbara Barceló-Llull et al.
- *Characteristics of mesoscale eddies in the Southwest Pacific based on observations from satellite altimetry, Argo floats and moorings*. Lydia Keppler et al.
- *Separation of steric sea level and ocean bottom pressure in the Tropical Asian Seas*. Marcel Kleinherenbrink et al.
- *On the Connection Between the Mediterranean Sea Level and the Atlantic Meridional Overturning Circulation*. Denis Volkov et al.
- *Integrated monitoring of the rivers-estuaries-ocean continuum combining satellite altimetry and hydrodynamical modeling: a case study for the Bengal delta*. Yann Krien et al.
- *Validation of ESA Sea Level CCI in the coastal zone* . Kristine S. Madsen et al.
- *Synergies between Sentinel-3A altimetry and in-situ multi-platform observations in the western Mediterranean*. Antonio Sánchez Román et al.
- *Towards quantifying the relative information content of sea surface data relative to interior data in constraining ocean state estimates*. Remi Tailleux et al.
- *Tropical Connections Along the Eastern Pacific During the 2014-16 El Niño and "Warm Anomaly" Events*. Ted Strub et al.
- *Deep Ocean contributions to sea level and heat content variability in the Subtropical South Pacific: Early insights from a pilot deep Argo array*. Nathalie Zilberman et al.
- *Forcing of recent decadal variability in the Equatorial and North Indian Ocean*. Philip Thompson et al.
- *Comparison between high resolution altimetric products and in situ observations to guide oceanographic cruises*. Louise Rousselet et al.
- *Accurate coastal altimeter products in the Strait of Gibraltar: ready for exploitation*.
- Jesus Gomez-Enri et al.
- *Volume transport variations in the Taiwan Strait in relation with the cross- and along-strait pressure gradients*. Kaoru Ichikawa et al.
- *Sea level predictions from tide gauges and satellite altimetry around the coast of Northern Australia*. Xiaoli Deng et al.
- *CASSIS-MALVINAS: Aviso altimetry and mooring data across the continental slope of Argentina at 41S in 2015: Jason ground track #26 and Brazil Malvinas Confluence*. Ramiro Ferrari et al.
- *CASSIS-MALVINAS: Performance of MERCATOR operational model at the Brazil Malvinas confluence, comparison with in situ data (mooring and hydrography), AVISO gridded products, and new altimetric products from CLS*. Camila Artana et al.
- *Malvinas Current variations: dissipation of mesoscale activity over the Malvinas Plateau and recurrent blocking events in the Argentine Basin*. Camila Artana et al.
- *CASSIS-Malvinas: Southwestern Atlantic currents from in-situ and satellite altimetry data project*. Martin Saraceno et al.
- *Improving OSCAR Currents with Level 2 Fields.* Kathleen Dohan et al.
- *CASSIS-Malvinas: Dynamics of currents on the continental shelf and shelfbreak in the southwestern Atlantic, Argentina*. Guillermina Fernanda Paniagua et al.
- *Upper ocean mixing processes and circulation in the Arabian Sea during monsoons*, Subrahmanyam Bulusu et al.
- *Airborne Lidar Altimetry in support of Radar Altimetry*. Ken Melville et al.
- *Using dynamical interpolation to map high-resolution altimeter data in the Western Mediterranean Sea.* Marine Rogé et al.

The presentations and posters have shown sustained synergies:

- Through merging multiple satellites, different types of in situ data (mooring arrays, the Florida Current cable, CalCOFI shipboard ADCP and CTD, CODAR HF-radar), and proxies to study ocean and climate processes - AMOC, past sea level variability, polar processes, submesoscale vorticity/strain and divergence.

- Through renewed analysis founded on dynamical principles (coastal-trapped waves, infra-gravity waves, internal waves, QG and SQG dynamics) to extract coherent signals at increasingly smaller scales that reveal ocean dynamic signals that were previously unresolvable with earlier altimeters.

The discussion/recommendations that emerged from the round table session are:

- Contemporary coastal and high resolution data (both altimetric and in situ) could be used to develop robust methods for downscaling conventional open deep ocean mesoscale and longer scale variability to coastal zones.

- Methods could then be applied to historical altimeter data sets to infer more reliable estimates of coastal variability over the past 25 years that is possible with direct observations alone.

- They could then add value to tide gauge time series, or other coastal monitoring time series data, for numerous retrospective coastal scientific studies.

- This effort would make better synergistic use of existing in situ networks; it would be facilitated by greater regional and international coordination in making coastal data sets available for analyses of more global scope based on satellite missions.

6.12 Science (Part III): Two decades of continental water's survey from satellite altimetry - From nadir low-resolution mode to SAR altimetry, new perspectives for hydrology

Chairs: Charon Birkett and Jean-Francois Crétaux

The Science III splinter session received 19 submitted abstracts. The focus of the presentations was diverse, from the determination of river discharge to preliminary trials of soil moisture estimation, from the estimation of river delta storage fluxes to the monitoring of lakes, reservoirs and inland seas. While acquiring accurate altimetric surface height remained a priority, the utilization of other altimetric parameters (radar backscatter coefficient), remotely sensed data sets (Gravimetry, SMOS, Optical and Passive Microwave Imaging), and tools (hydrological theory, assimilation, and modeling) was in evidence across the varying projects. Many presentations discussed methods for refining the altimetric height and backscatter estimates via retracking, subwaveform analysis, point cloud detection, or fully-focused SAR techniques. Others looked to improving surface height estimates via the application of enhanced atmospheric height corrections, or via novel target-surface detection techniques. The problem of multi-platform data set or data product mergers was also discussed with focus on how to improve current spatial and temporal resolutions. A number of presentations served to remind the inland water community of the availability of specialized on-line databases offering both enhanced (over IGDR or GDR capabilities) data sets or operational/archive higher-level lake and river products including surface water level, areal extent, storage variability, and river reach discharge. The number of on-line data product services serving various stakeholders and end users raised the question as to whether the SWT community should adopt a set of standards to conform to, which should be re-visited in 2017 as the Jason-3 mission progresses.

The Science III session provided some response to the SWT in terms of Jason-2/Jason-3 performance, orbits, and tracking modes.

- The question of whether Jason-2 should now be switched permanently to DIODE/DEM mode raised one objection that highlighted the failure of this mode (in comparison to the improved Jason-3 DEM) to acquire many of the lake and reservoir surfaces.
- The group was in favor of keeping Jason-2 in the 10-day repeat interleaved mode for as long as possible to assist projects already utilizing the earlier T/P and Jason-1 Interleaved phase data at the same temporal resolution. The group noted that Cryosat-2 could already provide a drift orbit data set if required.
- Where data is available, the Jason-3 altimeter is performing as well as Jason-2 in terms of acquisition speed and accuracy.
- The Jason-3 DIODE/DEM mode is performing very well over many lakes/reservoirs with few failures noted to date. However, it was noted that there are persistent data gaps over some of the major river basins and it was not clear whether this was due to DEM inaccuracy or instrument calibration issues. Several members of the Inland Water community will integrate Jason-3 successes/failures and report back to the SWT, noting a limited DEM size but the option to perform some DEM upgrades and satellite uploads.

6.13 Side meeting with European tide gauges operators: What needs in term of in situ sea level observation?

Chairs: Begoña Pérez Gómez and Laurent Testut

A side meeting on *Altimetry and tide gauge for sea level* was hosted by the annual OST/ST International congress on Satellite Altimetry, on 3 November 2016, at the Espace Encan of La Rochelle. The meeting, convened by the EuroGOOS Tide Gauge Task Team, had the objective of presenting this task team activities to the altimetry community. Tide gauges and altimetry are the basic technologies used for measuring sea level. Both techniques are needed and complementary and will always require exchange of information and products for validation, and communication between both communities. The session was chaired by Laurent Testut (EuroGOOS TGTT member) and Begoña Pérez Gómez (EuroGOOS TGTT co-chair) and attended by several altimetry experts from the OST/ST congress and by tide gauge experts attending the EuroGOOS TGTT workshop of November 4th. It started with two introductory presentations and was followed by an open discussion. Médéric Gravelle (University of La Rochelle) presented an exercise about optimal distribution of tide gauges for calibrating multiple satellite altimetry missions, based on just a geometric approach. Begoña Pérez Gómez presented the objectives, terms of references and activities of the EuroGOOS Tide Gauge Task team, explained the objective of the session and the need of discussion and asked for answers to the question:

How could the European TG network be improved for altimetry calibration / exploitation in terms of instrumentation, network coverage, data sampling and quality, data availability, co-location (GNSS, met stations, etc)?

After a first debate on the meaning and objectives of a tide gauge network focused on altimetry calibration, the final consensus was that tide gauge and altimetry data must always be compared, and that coastal and dense tide gauge networks will be needed to validate the quality of altimetry data near the coast. The main concerns of the altimetry community were still the lack of information about vertical land motion at many tide gauge stations, the quality of the tide gauge data (datum or reference changes) and the remaining gaps in the time series. Michaël Ablain (CLS) discussed a proposal on requirements for an appropriate tide gauge network for global validation of Sentinel missions (Sentinel 3 Validation Team: S3VT, CAL/VAL requirements), and mentions for example the benefits of increasing the number of tide gauge stations (and better chosen locations) in the global validation analysis, to reduce uncorrelated errors.

From the different comments and suggestions received from the audience during the session, we confirm that the altimetry community recognizes the need of tide gauge stations for altimetry validation and interpretation. Based on previous analysis (e.g. the one of S3VT) and the input of this side meeting, we can compile the following list of recommendations from the altimetry community to the tide gauge community:

List of recommendations from the altimetry community:

1. *Vertical land movements: they request more co-location of GNSS stations with existing tide gauges to monitor vertical land motion*
2. *Tide gauges are needed in the open ocean for validation of altimetry in ocean circulation studies*
3. *There is a demand also of coastal tide gauges, including estuarine gauges to the extent of the tidal influence, for validation of altimetry near the coast*
4. *Quality controlled time series to minimize undocumented datum or reference changes and clock errors: datum control within a month (or less for near-real time validation in altimetry) and metadata with information about the origin of the error.*
5. *A homogenous product, with standard format (e.g. CF compliant) and a one-click download data bottom is required. Someone also asked for tidal predictions in the data*
6. *Homogeneous sampling: hourly data should always be provided, independently of what other high frequency samplings are available for other applications*
7. *Whenever possible, optimizing the location of stations with respect to altimetry ground-tracks and improving the spatial coverage of the in-situ network*
8. *Redundancy (double or multiple) of sea level sensors would be appreciated for avoiding gaps in the historical tide gauge time series*

The session was closed with the recommendation of the EuroGOOS TGTT being represented in future altimetry meetings for reporting on the status of the in-situ networks and the feasibility of the mentioned requirements for the altimetry users. The EuroGOOS TGTT thanked the OST/ST Congress organization (Pascal Bonnefond) for facilitating the organization of this side meeting and the audience for their comments and participation.

7 Closing Plenary

The closing plenary took place on Friday morning. In addition to the splinter summaries, François Boy reported on the SAR Altimetry workshop. A group of students from “Lycée Charles De Gaulle, Muret” gave a presentation of their project conducted in the frame of Argonautica that was greatly appreciated.

The meetings ended with the status of reprocessing. Phil Callahan discussed the TOPEX Reprocessing and update to Jason GDR-E standards. Initial evaluation of retracked data has been completed and will be made available on the PODAAC server soon. Geophysical corrections still require updating and applicability of some corrections remains uncertain. Work on reprocessing will continue into 2017, with stronger help and collaboration with CNES notably for the updated geophysical corrections (GDR-E standards). Nicolas Picot discussed the current GDR status for Jason-1, Jason-2 and SARAL/AltiKa. The whole set of Jason-1 data is now available in GDR-E standards. Plans to reprocess Jason-2, Jason-3 and SARAL/AltiKa data to the new GDR-E standard are underway. For the CalVal phase, Jason-3 was based on GDR-D standard with orbit in GDR-E, fully in line with the Jason-2 standard.

The closing plenary session also had a discussion time slot, notably about the key points that were addressed to the splinters during the opening session. After discussion, the following Recommendations and Appreciations were adopted (other specific recommendations can be found in the splinters summaries):

Recommendations:

- **Based on the quality of the GDR data, the OSTST endorses the immediate public release of the GDR products for Jason-3.**
- **Based on its favorable subcycles (12+284/371 at 1309 km) for both mesoscale sampling and improvement of the mean sea surface, the OSTST recommends the Jason-2 long-repeat orbit to be at -27 km.**
- **The OSTST recognizes the importance of both mesoscale applications, which benefit from a repeat orbit, and the need to improve mean sea surface estimates which require a drifting, or long-term repeat orbit. As a compromise between these needs, the OSTST recommends moving Jason-2 into a Long Repeat Orbit (“Long Repeat Orbit (LRO)” mission at -27 km) after two years in the interleaved orbit, in October 2018.**
- **Regardless of when Jason-2 is moved, the OSTST strongly recommends that all requirements on latency, accuracy and data availability be maintained as long as the satellite can collect data.**
- **In light of the demonstrated improvement in accuracy and stability of the wet-path delay correction, the OSTST recommends cold sky calibration for Jason-2 and Jason-3 be continued, and the projects should study the feasibility of performing these maneuvers more frequently than once every 60 days.**
- **Given the improved quality of the IGDR product and the likelihood of improved accuracy and stability of AMR data in the GDR, the OSTST is willing to accept relaxation of the GDR latency requirement to a maximum of 90 days on Jason-3 and Jason-2.**
- **The OSTST recognizes the importance of maintaining the climate record of sea level change. Because long-term stability of the AMR is required in order to achieve this, the OSTST is willing to accept the additional risk of loss of AMR functionality as reported by the project in order to improve its long-term stability on Jason-CS/Sentinel-6.**

OSTST Appreciations:

- OSTST appreciates that CNES and NASA have completed the Jason-1 reprocessing begun in 2013 as well as the funding and support provided by CNES & NASA for this activity
- OSTST appreciates the Jason-3 project’s efforts to succeed launching of Jason-3 in early 2016
- OSTST appreciates the work of the operational team for the successful execution of Jason-2/3 Formation Flight Phase (also called tandem phase) and the move of Jason-2 to the interleaved orbit
- OSTST appreciates the work of the operational team for the smooth transition to drifting phase for SARAL/AltiKa
- OSTST appreciates the Jason-CS/Sentinel-6 mission improvements: (1) altimeter and POD will be driven by the same USO allowing easier error budgeting and capability to monitor the new USO against GPS system, (2) a high frequency radiometer add-on. This later follows a previous OSTST recommendation in order to improve coastal and inland water wet path delay corrections. Even if experimental and non redundant, the OSTST greatly appreciates this initiative.
- OSTST appreciates the ESA work for successful launch of Sentinel-3A in February 2016
- OSTST recognizes the high value of CryoSat Ocean Products for science

Finally, the 2017 OSTST meeting will be held in Miami, Florida, USA, October 23-27.