Report of the

Ocean Surface Topography Science Team Meeting

Millennium Harvest Hotel

Boulder, CO, USA

October 8-11, 2013

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Organized by NASA, CNES, NOAA and EUMETSAT

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1 Executive Summary

The 2013 Ocean Surface Topography Science Team (OSTST) Meeting was held in Boulder, CO on October 8-11. The meeting was held alongside the 7th Coastal Altimetry Workshop (CAW). A joint session between OSTST and CAW was held on Tuesday, Oct 8, to specifically focus on results from new Synthetic Aperture Radar Mode (SARM) data from the CryoSat-2 mission. This year's meeting was complicated by the ongoing shutdown of the US Federal Government. The shutdown prevented several key participants from attending the meeting, including Program Managers from both NASA and NOAA.

The primary objectives of the OSTST Meeting were to (1) provide updates on the status of Jason-1 and OSTM/Jason-2 (hereafter, Jason-2), (2) conduct splinter meetings on the various corrections and altimetry data products, and (3) discuss the science requirements for future altimetry missions. This year, the meeting was extended to 4 days, in part to accommodate a synergistic joint splinter session with the Coastal Altimetry Workshop (CAW) on new, high-resolution, along track altimeter observations (Synthetic Aperture Radar Mode, or SARM data), which will eventually become commonplace on future altimetry missions. This report, along with all of the presentations from the plenary, splinter and poster sessions are available on the AVISO website: http://www.aviso.oceanobs.com/en/courses/sci-teams/ostst-2013.html.

The year 2013 saw the end of the Jason-1 mission due to a failure of its last remaining transmitter. Jason-1 completed 11.5 years of service and finished one complete 406-day geodetic (or marine-gravity related) orbit. After the transmitter failure, **Jason-1 was successfully decommissioned in this orbit at an altitude of 1324.0 km, where it poses no collision risk to TOPEX/Poseidon, or Jason-2 or any future Jason missions**. A special presentation was given by Rosemary Morrow on the many scientific accomplishments of Jason-1 during the Wednesday morning plenary session and is available here: http://www.aviso.oceanobs.com/fileadmin/documents/OSTST/2013/oral/Morrow_v2.pdf

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. Jason-2 experienced 3 safe hold modes (SHMs) in 2013, the first such events of the mission. These events involve the satellite moving to a sun pointing orientation due to any kind of error or upset in routine operation. Recovery to nominal operation was successful and Jason-2 continues to collect high-quality science data. The cause for these SHMs remains under investigation and apart from the short periods where science data was not collected, Jason-2 continues to collect data that meets all mission and level 1 science requirements.

Jason-3 development is nominal at satellite, instruments and ground levels, and complete integration of the satellite is expected during 2014. At the time of the meeting, the planned launch date remained set for March of 2015. Since the meeting, however, the US Congress passed a budget for fiscal year 2014 that cut the Jason-3 budget in half (a reduction of approximately $18 million) for this fiscal year. At present, NOAA management and NASA, as NOAA's acquisition agent for the U.S. instruments and launch services, are working together to determine the impact and develop options to maintain the current March 2015 launch date. Recently, NOAA announced that it does not expect approval of its FY15 budget request for a new-start for Jason-CS and that it is now working on a FY16 request. This automatically introduces a 1-year delay into the start of development for the JPL payload instruments. With these new factors the readiness for launch is now moved from the Q4 2019 to the second half of 2020. This reinforces the Ocean Surface Topography Science Team (OSTST) adopted recommendation regarding the scheduled launch: **The OSTST strongly recommends that space agencies strive toward an earlier launch date for Jason-CS and to maintain the current launch date of Jason-3 to ensure that there is overlap with the expected 5 year lifetime of Jason-3.**

The Jason-CS mission will continue the Jason series of research and operational oceanography missions and will embark a Ku/C-band radar altimeter, a K/Ka band passive microwave radiometer and GNSS equipment including DORIS as part of its payload. Progress on planning and development of Jason-CS is ongoing. As recommended by the OSTST in previous meetings, an interleaved altimeter mode is now the baseline for the mission, which will simultaneously provide both low-resolution mode (LRM) and high-resolution synthetic aperture radar (SARM) mode data. In addition, implementation of a radiometer with long-term stability (likely to be maintained through the use of an on-board calibrator) is now also included in the baseline mission, as recommended by the OSTST. The OSTST expressed its appreciation for the responsiveness of the Jason-CS project in all of these instances (see section 7). Securing funding for Jason-CS remains a significant hurdle and is now driving the schedule, with launch unlikely before 2020.

Six keynote talks were given during plenary sessions of the OSTST (see section 4). In a talk on recent results from the Intergovernmental Panel on Climate Change (IPCC) by Don Chambers and Steve Nerem, it was noted that satellite altimeter data provides an important measure of global climate change by monitoring global sea level rise (see Figure 1.1).

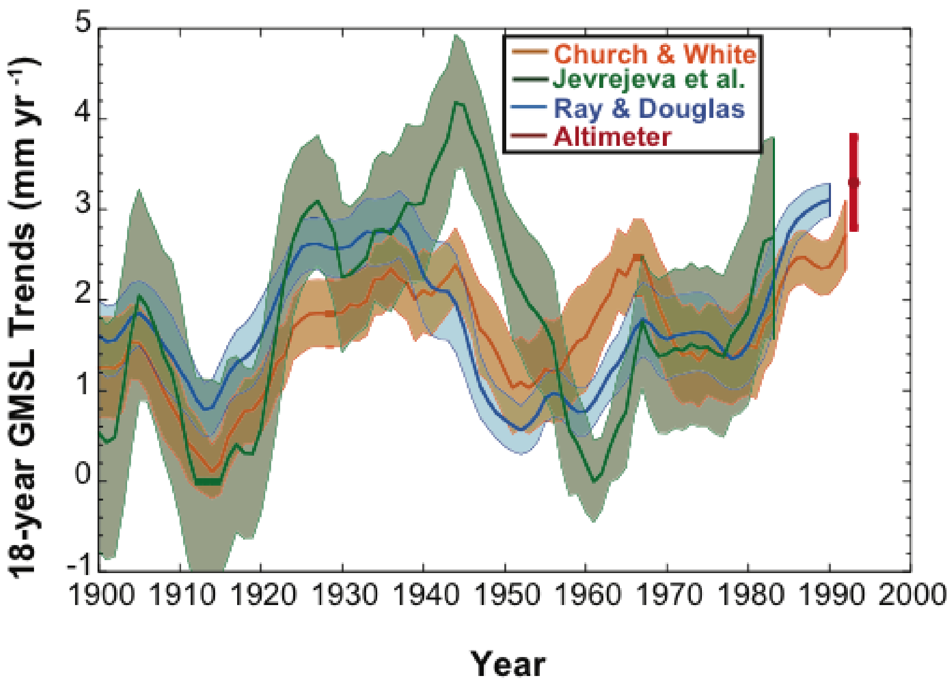


Figure 1.1: Altimetry data was highlighted as an important tool for monitoring climate change in the most recent report from the IPCC (the 5th Assessment report)

Splinter sessions included Precision Orbit Determination, Global and Local Calibration and Validation, Instrument Processing, Near Real Time Products, Applications and Multi-Mission, Multi-Sensor Observations, Outreach, Education and Altimetric Data Services, Quantifying Errors and Uncertainties in Altimetry Data and Science Results from Satellite Altimetry. In several splinter sessions, including a joint session with the Coastal Altimetry Workshop, focus was on use of new high-resolution altimetry data from along-track SAR processing of altimetry data. SAR data from CryoSat-2 shows that at wavelengths shorter than 100 km, Low Resolution Mode (LRM) data has higher variance. Work presented in the

Errors Splinter (see section 6.2) suggested that the "spectral bump" in Jason-2 data was due to waveform contamination and depends on the along-track footprint of the altimeter (Figure 1.2).

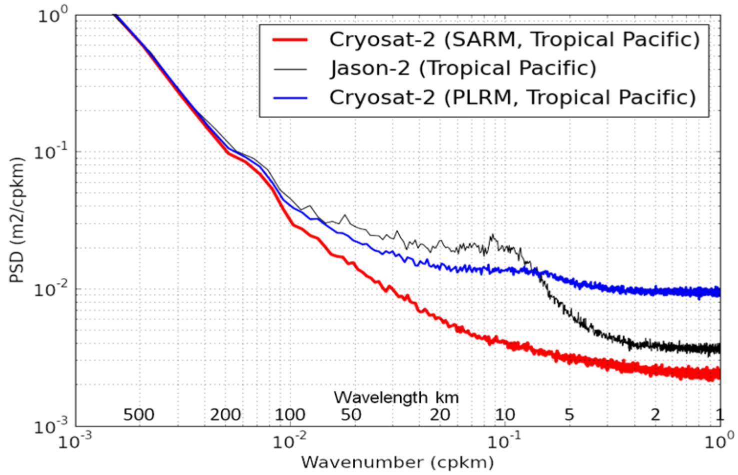


Figure 1.2: 20 Hz SSH spectra for LRM and SARM data (from Thibaut et al.). See Section 6.2.4.

Satellite altimeter data continues to be refined as a tool for measuring ocean currents. Combined with satellite gravity observations from GOCE and other tools used to estimate the time-averaged, dynamic ocean topography, multi-mission satellite altimetry can now provide a much higher resolution look at surface currents in the ocean. As an example, figure 1.3 shows a single week of surface currents estimated using satellite altimeters.

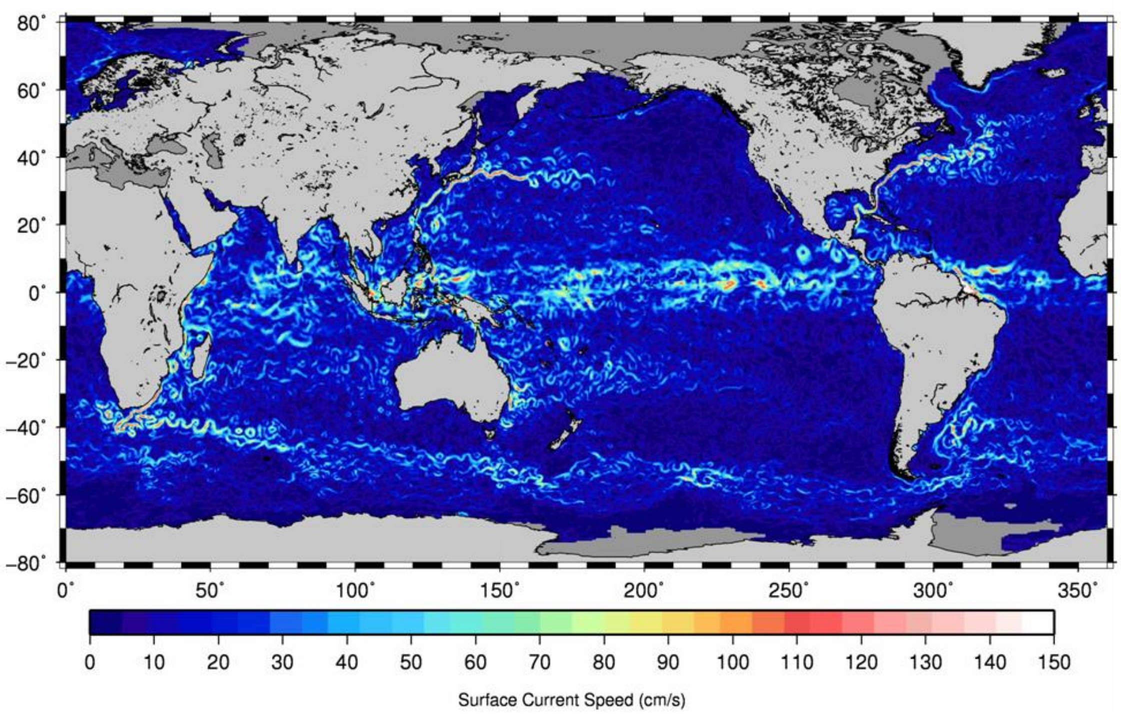


Figure 1.3: Example of Absolute velocities using the new version of CNES/CLS MDT (see section 6.3)

Reprocessing of data from the TOPEX/Poseidon mission was discussed in the closing plenary session of the meeting. Concern over the changing point target response of the TOPEX altimeter has prevented reprocessing to date. Recent work to analyze data over lakes has been used to help understand the point target response in the face of leakage. The current plan is to make a new Re-tracked GDR, consistent with GDR-C processing, which should become available in early 2015. While TOPEX reprocessing remains a top priority, plans to reprocess Jason-1 and Jason-2 data to a new GDR-E standard are underway and Jason-1 data should be completely reprocessed by the end of 2014.

2 Introduction

The 2013 Ocean Surface Topography Science Team (OSTST) Meeting was held in Boulder, CO on October 8-11. The meeting was held alongside the 7th Coastal Altimetry Workshop (CAW). A joint session between OSTST and CAW was held on Tuesday, Oct 8, to specifically focus on results from new Synthetic Aperture Radar Mode (SARM) data from the CryoSat-2 mission. This year's meeting was complicated by the ongoing shutdown of the US Federal Government. The shutdown prevented several key participants from attending the meeting, including Program Managers from both NASA and NOAA and the NOAA Program and Project Scientists.

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

3 Program and Mission Status

The status of the Jason missions was reviewed by the Project Managers. Glenn Shirtliffe reported on the status of Jason-1. After losing its last remaining transmitter in June of 2013, Jason-1 was decommissioned. Over its entire operational life, Jason-1 exceeded all Level-1 Science requirements and completed 50,000 operational orbits. It was decommissioned in its geodetic orbit at an altitude of 1324 km, which was chosen to have a > 400 day repeat cycle. It completed one full geodetic cycle before decommissioning and in its present orbit, does not pose a collision risk to either TOPEX/Poseidon or Jason-2. Jason-1 data will be reprocessed one final time for mission close out. Lessons learned during Jason-1 End of Life planning will be used to plan similar activities for Jason-2.

Jason-2 Project status was given by Thierry Guinle. This year, Jason-2 suffered its first 3 safe hold modes (SHMs) in March, April and September of 2013. Four, five and seven days of data were not collected as a result of these safe holds, and satellite operation was switched to Processing Module B (PMB, the redundant side). Analysis of these SHM events is ongoing. Despite the SHMs, the satellite bus is OK and the satellite continues to perform very well overall with all payloads continuing to meet all Level 1 science requirements. Finally, funding and continued operation has been extended through June of 2015.

Status of the Jason-3 Project was discussed Gerard Zaouche. The development of the Jason-3 spacecraft and instruments is nominal and complete integration of the spacecraft is anticipated before the end of 2014. Development of the ground system is also nominal and operational qualification will occur during 2014. Compatibility of the launch vehicle, a SpaceX Falcon 9.1, will be assessed and confirmed during 2014. At the time of the OSTST Meeting in October 2013, funding for Jason-3 was expected to be nominal and the current launch date remains March of 2015. Since the meeting, however, the US Congress passed a budget for fiscal year 2014 that cut the Jason-3 budget in half (a reduction of approximately $18 million) for this fiscal year. At present, NOAA management and NASA, as NOAA's acquisition agent for the U.S. instruments and launch services, are working together to determine the impact and develop options to maintain the current March 2015 launch date.

Richard Francis also gave a brief update on the status of the upcoming Jason-CS mission. Progress on planning and development of Jason-CS is ongoing. As recommended by the OSTST in previous meetings, an interleaved altimeter mode is now the baseline for the mission, which will simultaneously provide both low-resolution mode (LRM) and high-resolution synthetic aperture radar (SARM) mode data. In addition, implementation of a radiometer with long-term stability (likely to be maintained through the use of an on-board calibrator) is now also included in the baseline mission, as recommended by the OSTST. Securing funding for Jason-CS remains a significant hurdle and is now driving the schedule, with launch unlikely before 2020.

Josh Willis introduced the program managers/scientists to speak on the status of altimetry and oceanographic programs at NASA (Eric Lindstrom), CNES (Juliette Lambin), EUMETSAT (François Parisot), NOAA (Laury Miller) and ESA (Jérôme Benveniste). This year, Josh Willis presented the NASA and NOAA portions of the program status on behalf of Eric Lindstrom and Laury Miller, who were unable to attend because of the shutdown of the Federal Government. In addition, Hans Bonekamp presented on behalf of Francois Parisot, and Pierre Femenias presented on behalf of Jérôme Benveniste. Finally, a talk on the program status of SARAL/AltiKa was presented by Vivek Singh on behalf of Kiran Kumar from ISRO (the Indian Space Research Organization).

On behalf of Eric Lindstrom, Willis discussed the recent re-competition of the NASA portion of the OSTST. Of 59 proposals received, 28 were selected (roughly half). Areas with increased support include coastal altimetry, tides and mesoscale eddies. Grants will run from 2013 through 2016. NASA also selected PIs for the SWOT Science Definition Team and is in the process of reviewing proposals for a new Sea Level Science Team. NOAA reported that the Jason-3 Ground segment is making good progress and that FY14 funding for Jason-3 was in the President's proposed budget. Jason-CS funding remains uncertain. Planned launch date for Jason-3 remains March 2015 and will happen on a SpaceX Falcon 9.1 launch vehicle.

EUMETSAT reported that funding for Jason-2 has been approved through 2015 and extended funding through 2017 was planned. The Jason-3 EUMETSAT ground system is ready and system tests have begun. Planning for Jason-CS is under way. The current plan is to have the Poseidon-4 radar altimeter (on Jason-CS) operate in an interleaved mode that would provide both high-resolution along-track observations (SARM), as well as lower along-track data set (Low Resolution Mode, or LRM) that is compatible with Jason-1, 2 & 3. It was also noted that Jason-CS may be renamed Sentinel 6. CNES reported that SARAL/Altika is meeting or exceeding all observational requirements. CNES also reported that SWOT will enter phase B in 2014 and the airborne instrument AirSWOT had a first successful campaign in March-April of 2013.

ESA reported that Sentinel-3 is scheduled for launch near the end of 2014 and will provide high resolution, along-track SAR coverage over the ocean. A Validation Team for Sentinel-3 is being formed and was scheduled to have its first meeting in Frascati, Italy on 26-29 November 2013. ESA also reported that Cryosat-2 is now producing ocean products that will be released in January of 2014.

ISRO reported that the SARAL/AltiKa altimeter was providing observations of sea surface height as well as sea state that are being assimilated to improve ocean circulation model and monitor water levels of inland lakes and rivers. In addition, comparisons with Jason-2 sea surface height measurements and significant wave height from buoys show good agreement with data from AltiKa. Analysis of data near the coasts suggests that it is possible to get useful altimeter returns from AltiKa within 2 to 3 km of the coast.

4 Keynote Talks

Six keynote talks were given during plenary sessions of the OSTST. Four keynote talks were presented on Wednesday morning. A joint talk on recent results from the Intergovernmental Panel on Climate Change (IPCC) was presented by Don Chambers and Steve Nerem. Chambers presented results from the recently published 5th Assessment Report of the IPCC on observations of climate change in the oceans. Nerem presented results from the chapter on Sea Level Rise, which included projections over the next Century. Rosemary Morrow presented a keynote talk highlighting the accomplishments of the 11.5 years of data collected by the Jason-1 satellite, which was decommissioned this year. Jacques Verron presented results from the new altimeter, SARAL/Altika, which launched this year. Finally, Lee-Lueng Fu presented updates on the mission design of the upcoming Surface Water/Ocean Topography (SWOT) mission.

Keynote talks continued on Thursday morning with Patrice Klein presented a talk on the impact of mesoscale and sub-mesoscale dynamics on sea level. The talk provided context for Splinter IX – Science: Mesoscale, Sub-Mesoscale Oceanography. A second keynote talk Thursday morning was given by Kevin Trenberth, who discussed the Earth's energy imbalance and ocean heat content change. This talk served to introduce Splinter VII – Science: Climate Change in the Ocean and Sea Level Rise.

5 Poster Sessions

A poster session was conducted on Tuesday Afternoon and the posters were on view during the coffee breaks throughout the entire four-day meeting. Links to the posters are available on the meeting website: http://www.aviso.oceanobs.com/en/courses/sci-teams/ostst-2013/ostst-2013-posters.html

The posters were grouped into the following categories:

- *Regional and Global CAL/VAL for Assembling a Climate Data Record*
- *Quantifying Errors and Uncertainties in Altimetry Data*
- *The Geoid, Mean Sea Surfaces and Mean Dynamic topography*
- *Instrument Processing*
- *Near-Real Time Products and Applications*
- *Others*
- *Outreach, Education & Altimetric Data Services*
- *Precise Orbit Determination*
- *Science Results from Satellite Altimetry*

6 Splinter Sessions

The splinter sessions were organized as follows:

Tuesday, October 8:

- Splinter Session I
    - Precision Orbit Determination (Part I)
    - Joint CAW/OSTST SARM Splinter (Part I)
- Splinter Session II
    - Precision Orbit Determination (Part II)
    - Joint CAW/OSTST SARM Splinter (Part II)

Wednesday, October 9:

- Splinter Session III
    - Regional and Global Cal/Val (Part I)
    - Science (Part I): Large Scale Oceanography
- Splinter Session IV
    - Regional and Global Cal/Val (Part II)
    - Outreach, Education and Data Services

Thursday, October 10:

- Splinter Session V
    - Science (Part II): Climate Change in the Ocean and Sea Level Rise
    - Instrument Processing (Part I): Wet Troposphere
- Splinter Session VI
    - Science (Part III): Mesoscale, Sub-Mesoscale Oceanography
    - Instrument Processing (Part II): Ka-band, Wind Speed and Sea State Bias
- Splinter Session VII
    - Science (Part IV): Large Scale Oceanography
    - Near Real Time Products and Applications
- Splinter Session VIII
    - Geoid, Mean Sea Surface
    - Quantifying Errors and Uncertainties in Altimetry Data

Friday, October 11:

- Round tables for each splinter

Links to the presentations are available on the meeting website:
http://www.aviso.oceanobs.com/en/courses/sci-teams/ostst-2013/ostst-2013-presentations.html

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

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

6.1.1 Introduction

CAL/VAL activities are conducted based on dedicated in-situ observations but also larger in-situ networks (ARGO, tide gauges, etc.), statistics, cross comparisons between models, different algorithms, and external satellite data. 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. These ongoing efforts are essential to ensure the integrity of the long-term climate record at the 1-mm/year level and to support the 'closing budget' analysis performed by different group (ARGO and GRACE compared with altimetry).

In order to facilitate comparisons among various results, contributors were asked to focus on results from the official data products. Complementary results from alternative sources were sought in order help to explain errors in the official products (Jason-2 GDR version D, Jason-1 GDR-C, SARAL GDR-T, and Envisat "GDR-C").

The primary goals of this session were:

- to assess the performance of the measurement system, including the altimeter, radiometer and orbit-determination subsystems
- to improve ground and on-board processing; and
- to enable the development of a seamless and accurate climate data record from the current (OSTM/Jason-2) and legacy (TOPEX/Poseidon and Jason-1) time series.

6.1.2 Results from in-situ calibration sites

Absolute bias estimates from dedicated sites and also from regional experiments continued to show a good coherence of results with 10–20 mm RMS differences for T/P, Jason-1, and Jason-2.

- The Jason-2 SSH bias for GDR-D is slightly biased (~ 1 cm) but with questionable significance. Differences in results from Corsica, Harvest, and Bass Strait are perhaps exposing regional effects (Figure 6.1.1 and Table 6.1.1). Results were based on the first complete time series of GDR-D products.
- While the Jason-1 SSH bias for GDR-C is ~9 cm for the dedicated sites, reprocessing Jason-1 data in GDR-E is expected to reduce the bias to insignificance. We note that this result is provisional, and is based in part on the assumption that the two altimeters (Jason-1 and -2) should have similar internal path-delay corrections due to uniform instrument design (Desjonquères et al.).
- The legacy Topex/Poseidon systems continue to show biases that are statistically insignificant.
- The dedicated calibration sites reflect unusual estimates of Jason-2 SSH drift (using GDR-D products) that warrant further investigation. For example, drifts of +6 mm/yr are observed at Harvest, -4 mm/yr at Corsica, and -6 mm/yr at Bass Strait. These results raise questions on the regional stability of altimetric measurements, but also on the stability of the in-situ observations (or water level and vertical land motion).
- Early results at the two primary calibration sites (Corsica and Harvest) from SARAL GDR-T products suggest a SSH bias of ~-6 cm (SARAL measuring low).

Table 6.1.1. Averaged values of the altimeter biases from absolute calibration experiments.

Mission, Altimeter	**Bias (mm)**	**Contributors**
T/P, ALT-A	3.0 ± 4.3	Haines et al., Bonnefond et al., Watson et al.
T/P, ALT-B	7.0 ± 3.6	Haines et al., Bonnefond et al., Watson et al.
T/P, POSEIDON-1	–7.0 ± 8.0	Haines et al., Bonnefond et al.
Jason-1, POSEIDON-2, GDR-C	96.1 ± 2.3	Haines et al., Bonnefond et al., Watson et al.
Jason-2, POSEIDON-3, GDR-D	9.1 ± 2.9	Haines et al., Bonnefond et al., Watson et al.

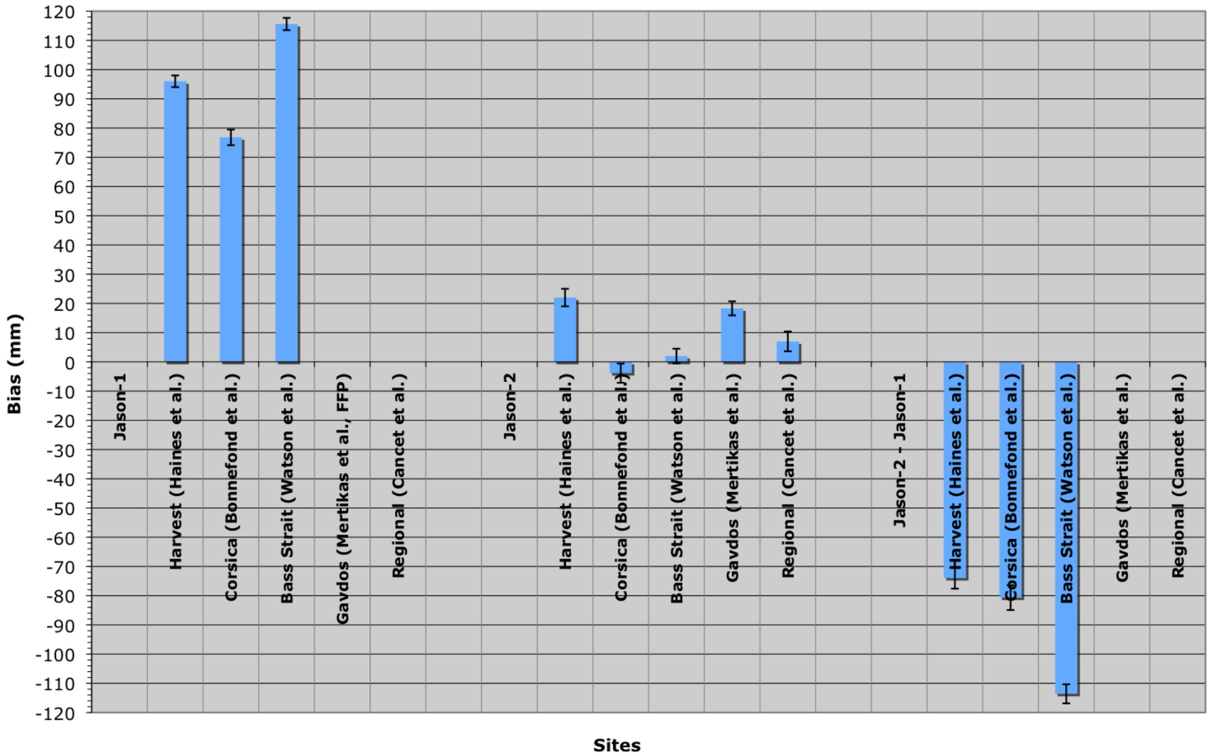


Figure 6.1.1. Absolute bias values for Jason-1 and Jason-2 from the different calibration sites using the latest versions of the official products (Jason-1 GDR-C and Jason-2 GDR-D).

Enhanced wet path delay (EPD) corrections continue to prove valuable for (land-contaminated) calibration sites. Such enhanced correction is now fully integrated in Jason-2 GDR-D products and available from external files for Jason-1.

Emerging calibration programs (e.g., Gavdos, Regional, Tide gauges, Argo profiles) are now routinely delivering results. These sites are contributing strongly to refining of bias estimates and characterization of geographically correlated errors, while supporting other missions (*Bonnefond* et al.). For example, *Cancet* et al. presented an approach to performing regional cal/val, where dedicated calibration sites can be used for missions that do not have direct over-flights of those sites. *Prandi* et al. showed improved consistency between Argo profiles and Jason-1 data when precise orbit determination solutions do no underweight DORIS stations located in areas where the onboard USO is affected by the South Atlantic Anomaly (SAA). Further investigation is needed into determining the appropriate weighting of DORIS stations in the SAA for Jason-1 precise orbit determination. Finally, *Watson* et al. described an improved tide-gauge validation of the combined 20-yr global mean sea level (GMSL). Featuring new treatments of the altimeter data and updated estimates of vertical land motion from GPS, the analysis suggests that the current altimeter GMSL is overestimated by ~0.7 mm/yr. This result underscores that the tide-gauge calibration technique warrants further investigation but also that the different groups should cross-compare their methods, assumptions because of different results obtained (see also *Prandi et al.* and *Beckley et al.*).

6.1.3 Global validation studies

6.1.3.1 Jason-2 and Jason-1 Missions

Reprocessing of Jason-2 GDRs to version D (GDR-D) standards is 100% complete. Global validation studies support that data quality for GDR-D is noticeably better than GDR-T (*Phillips* et al.). SSH measurement system error for Jason-1 and Jason-2 is < 4 cm for temporal scales less than 10 days (Figure 6.1.2).

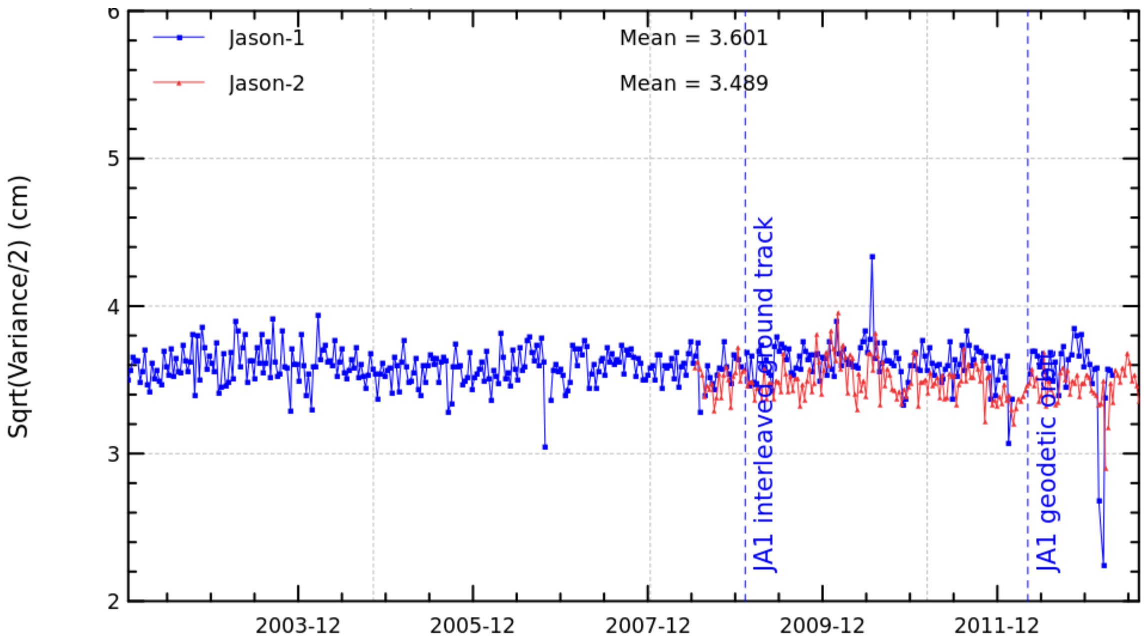
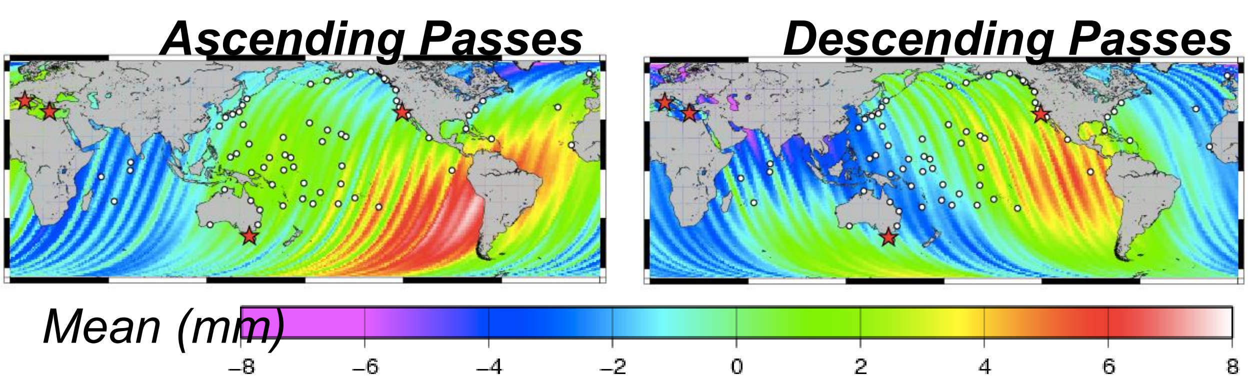


Figure 6.1.2. Jason-1 and Jason-2 SSH system error based upon RMS of SSH crossover differences (Phillips et al.)

Radial orbit errors remaining in GDR-D are < 1 cm (RMS), but have geographically correlated errors that are important at regional scales (Figure 6.1.3), and important to the dedicated calibration sites. Additional improvements in orbit accuracy are nevertheless achievable. For example, the JPL GPS orbit solution reduces SSH crossover variance by 44 mm^2 on average relative to GDR-D orbit solutions (Figure 6.1.4).



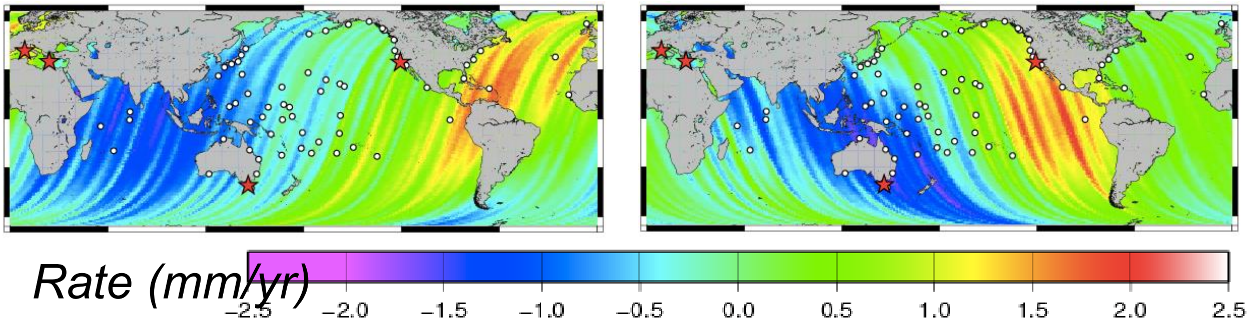


Figure 6.1.3. Jason-2 radial orbit differences between GDR-D and JPL GPS orbit solutions. Red stars indicate dedicated calibration sites, and white circles indicate tide gauges typically used for monitoring stability. Units are respectively mm and mm/yr for the mean and the rate (Haines et al.).

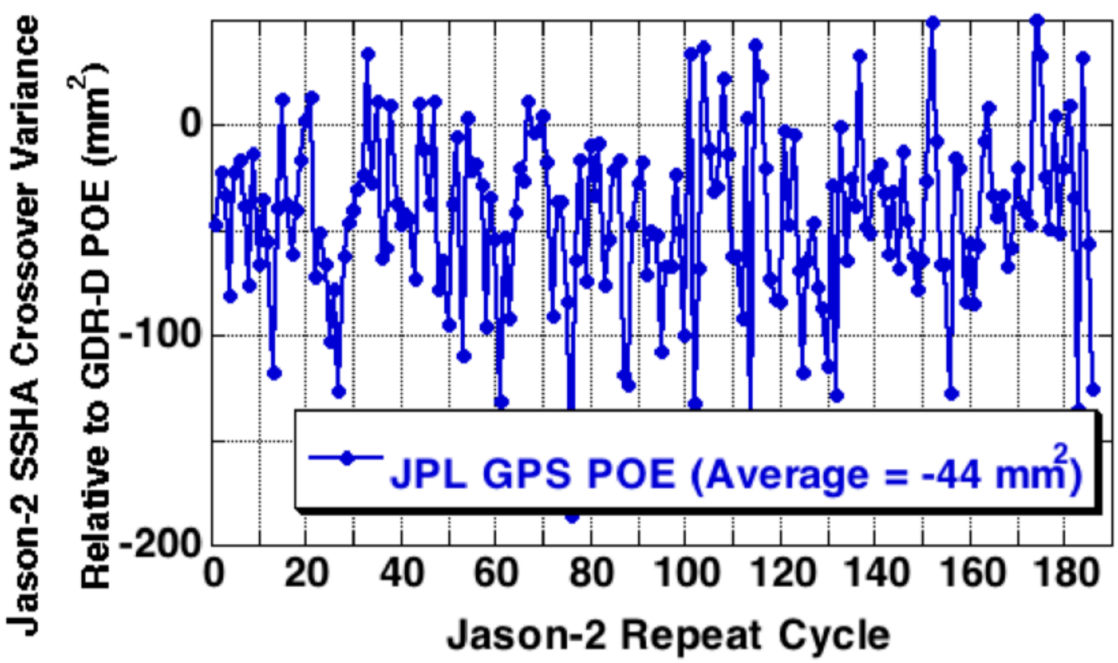


Figure 6.1.4. SSH crossover variance (mm2) relative to GDR-D POE (Phillips et al).

6.1.3.2 Jason-1 Mission

Data quality and availability for the Jason-1 geodetic phase are comparable to those of the repeat ground track phases (both reference and interleaved). A potential relative range bias of 6 mm during the geodetic mission was reported, and shown in Figure 6.1.5 (e.g., *Phillips* et al, *Dettmering and Bosch*) and deserves more investigation. The Jason Microwave Radiometer (JMR) continues to experience episodic calibration errors. In particular, the JMR wet troposphere correction has increased attitude dependent errors after the February 2013 satellite safehold event. As additional evidence that a dedicated recalibration of the JMR is necessary, *Phillips* et al showed that consistency between Jason-1 and Jason-2 global mean sea level rise observations is improved from 0.7 to 0.2 mm/yr when the Jason-1 wet troposphere correction is determined from a meteorological model instead of the JMR. *Brown and Misra* have started a dedicated end-of-mission recalibration of the Jason-1 microwave radiometer. This recalibration effort will include improved algorithms that have already been applied to the Jason-2 AMR, including a coastal path delay algorithm and the radiometer rain and ice flagging algorithms.

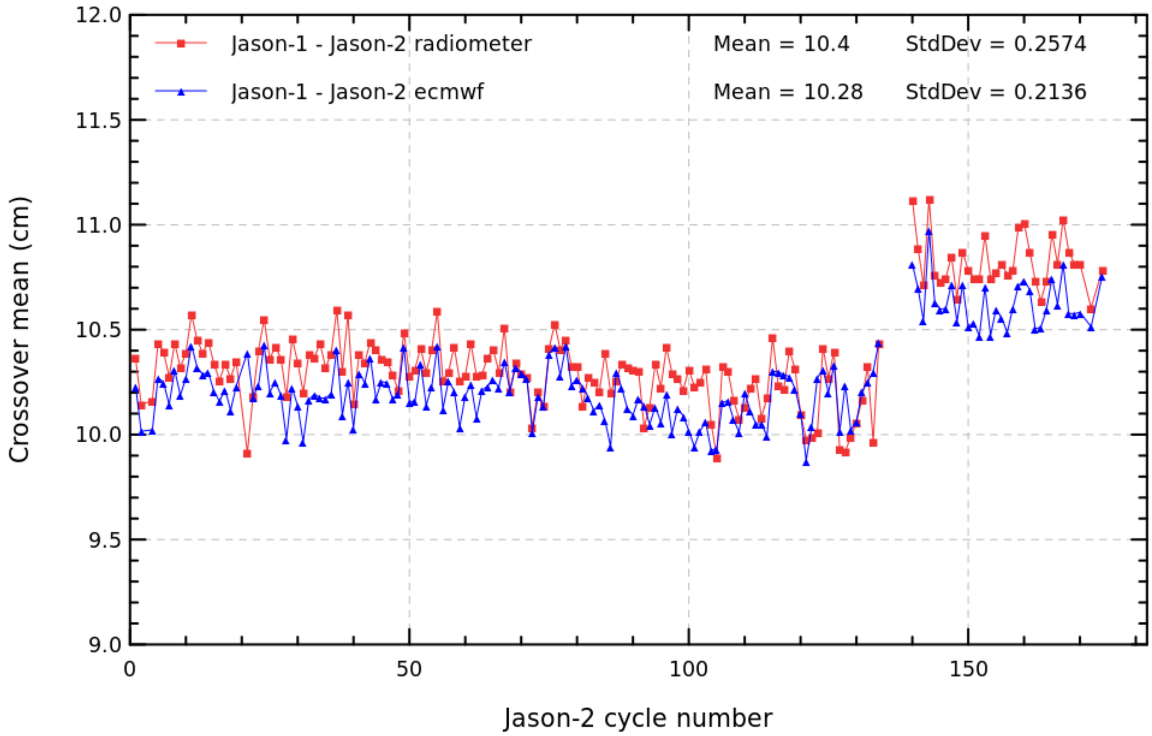


Figure 6.1.5. Average of SSH crossover differences (Phillips et al.)

6.1.3.3 SARAL/AltiKa Mission

Early results from the SARAL mission are impressive and demonstrate the data are meeting mission requirements. Data coverage is excellent with the impact from rain at Ka-band lower than expected. Range noise for the AltiKa altimeter is lower than for Jason-1 and Jason-2 (Figure 6.1.6). The sea level anomaly spectrum for SARAL shows that the well-known “hump” is shifted to shorter wavelengths (primarily due to a smaller footprint), and is closer to the theoretical ocean spectrum at wavelengths of 50-90 km (Figure 6.1.7). It was emphasized that the “hump” can be reduced through appropriate data editing and processing techniques. Global results also show a SARAL SSH bias of ~-6 cm. Additional improvements in SARAL data are expected after calibration and improvements of the orbit solution, sea state bias model, radiometer wet troposphere correction, and altimeter wind speed model. A number of preliminary models for altimeter wind speed and sea state bias are already available (e.g., *Scharroo* et al., *Picot* et al.).

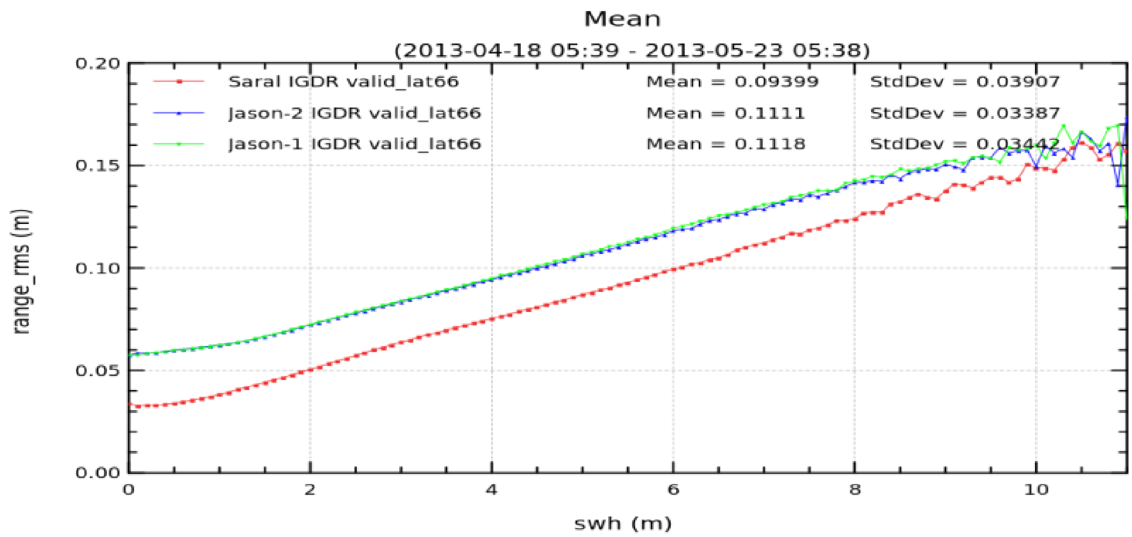


Figure 6.1.6. Range noise for Jason-1, Jason-2, and SARAL (Picot et al.)

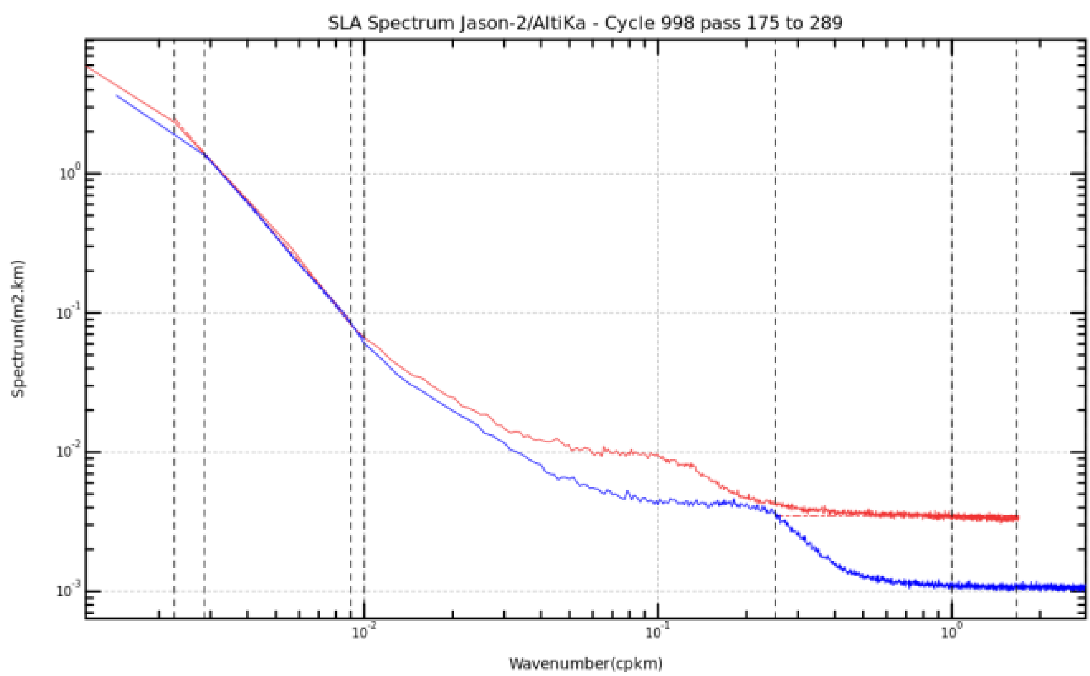


Figure 6.1.7. Sea level anomaly spectrum for Jason-2 and SARAL. Jason-2 is shown in red, and SARAL in blue.

6.1.4 Round table summary

The following recommendations were made:

- **TOPEX reprocessing is high priority to benefit from 20-year record.**
- Cal/Val should be approached from a multi-mission perspective.
  - Provides means to develop new standards for data products.
    - Precise orbit determination, retracking, sea state bias.

- Further development of regional calibration techniques.
  - Include other missions.
  - Expose errors impacting calibration of reference (Jason) missions.
- Continue to develop approaches to improve long-term stability of radiometer wet troposphere delay measurements.
  - Significant source for limitations in long-term stability.
- Concerted effort to characterize and reduce systematic in-situ errors.
  - Working group for in-situ measurements, and exchange of data.
- Further investigation of potential altimetric sources for unusual Jason-2 drift estimates.

6.2 Quantifying Errors and Uncertainties in Altimetry Data

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

6.2.1 Overview

To introduce the session, Joël Dorandeu described the main objectives of this splinter. The first one is to establish the link between altimetry experts and applications describing new insights about errors in the altimeter system. And the second one is to establish the link from experts to application, providing the users need 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 13 abstracts were submitted to the splinter session, resulting in 6 oral presentations, and 7 posters. They can be classified in 3 parts relative to mean sea level applications, ocean circulation & mesoscale, and analysis and formalism of errors.

6.2.2 Mean Sea *Level* applications

The studies presented by Henry et al. (talk) and Masters et al. (poster) allowed to address the issue raised at last OSTST (Venice, Sept 2012) which was "to enhance the Global Mean Sea Level (GMSL) intercomparison between several groups in order to better understand GMSL differences".

Master at al., showed that altimetry correction standards used in the GMSL calculation do not explain the GMSL differences over the Jason-1 and Jason-2 period (from 2002 onwards). On the other hand, it is not the case on TOPEX period where few corrections as the sea-state bias have a significant impact on the GMSL evolution, mainly due to instrumental instabilities on TOPEX data.

Henry et al. focused their study in the processing methodology differences between AVISO and the University of Colorado. In order to estimate the error of the method, they used GLORIS Ocean reanalyses (provided by Mercator Océan) as a reference, and they interpolated these reanalyses along the Jason-1 ground track. The GMSL directly derived from GLORYS (from grids) with the along track GMSL calculated using different averaging methods were compared. They showed that significant differences on the order of 0.3 mm/yr in the MSL rate were obtained depending on latitude bands (tropical band < 30°, medium latitudes [30, 60], high latitudes > 60°). Further investigations highlighted that both methods made some approximations that should be corrected in the future. For instance, for the AVISO method, the binning currently performed (2°x2°) is not optimal for medium latitudes, and for the University of Colorado, the weighting of altimeter measurements by the cosine of latitudes should be revisited for high latitudes.

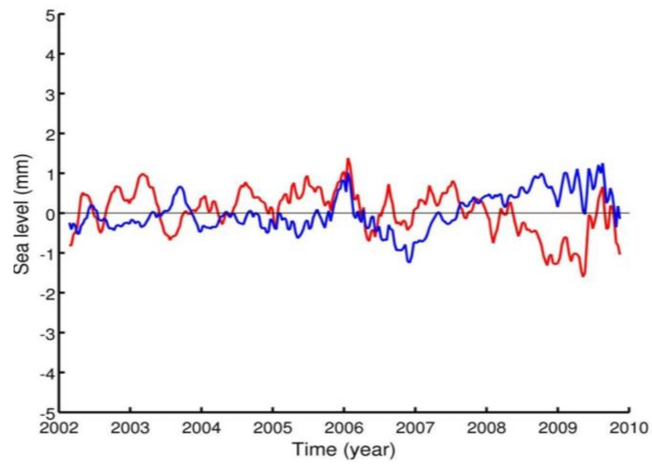


Figure 6.2.1: Differences in GMSL estimates from GLORYS gridded products (provided by Mercator Océan) and the estimates obtained by interpolating the same fields on Jason-1 ground tracks using two different methods: AVISO in blue and University of Colorado in red. (From Olivier et al.).

Others posters were dedicated to the long-term errors of altimetry measurements. Ablain et al, explained why the altimetry error budget error is higher in the first altimetry decade [1993, 2002] than in the second one [2003,2012]. The main reasons are: instrumental instabilities in TOPEX measurements but also on ERS-1 and ERS-2 data, larger errors in orbit solutions and atmospheric corrections and a stronger uncertainty to estimate the errors in the first decade. The main conclusion for users is that the altimetry error budget in the first altimetry decade must be carefully considered (e.g. in sea level budget closure studies). Thao et al. provided a study dedicated to the long-term errors of wet troposphere correction and their impact on the MSL calculation by comparison with ERA-interim reanalyses (from ECMWF) and AMSR products. They showed that ERA-interim is currently the best model to allow the identification of errors such as microwave radiometer drifts.

6.2.3 Ocean circulation & mesoscale

Dufau et al. presented a study dedicated to the spatial spectral analysis of SSH with the objective to characterize the small scales observability. This is particularly important for data assimilation systems in order to better take into account altimetry errors for short wavelengths. By intersecting the slope and the noise level of SSH spectra, the authors deduced the minimum observable scales and also maps of the remaining SSH observation errors to be used in entry of assimilation process instead of the current constant value (see Figure 6.2.). This map could be further improved taking into account seasonal variability of the errors.

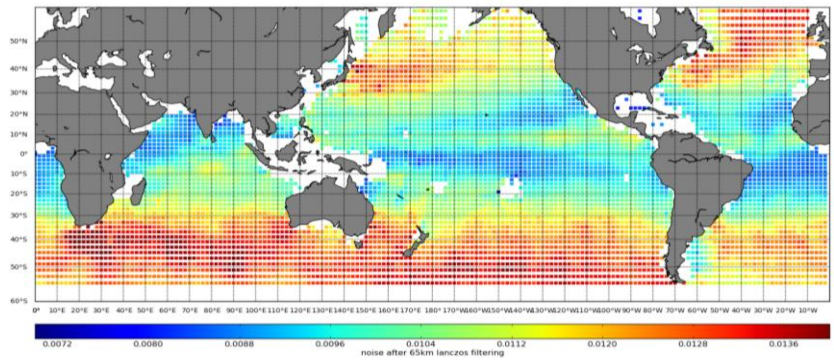


Figure 6.2.2: Map of SSH observation errors (from Dufau at al.)

6.2.4 Analysis and formalism of errors

The 3 talks given by Thibaut et al, O. Andersen et al., and G. Jacob et al. were focused on the analysis of altimetry errors.

Thibaut et al. gave new insight into altimetry errors at short wavelengths and explained the origin of these errors. A hump-shaped artifact is indeed observed on all LRM altimeter spectra (10-60+ km) (see Figure 6.2.) preventing or limiting the observation of the sub-mesoscale. It is not the result of a minority of outlier segments or sloppy processing (long uncontaminated segments are very rare). The phenomenon is more intense in zones of severe rain and bloom events, but it is also present for other ocean conditions (though with lower amplitude). This anomaly is due to waveform contamination by the heterogeneity of the sea surface (depending on the footprint size). Thibaut et al. also showed that this artifact is removed using SARM data derived from Cryosat-2 thanks to the thinner synthetic footprint of SARM technology compared LRM (see Figure 6.2.4). In order to improve LRM data, decontamination would require revisiting the editing of 20 Hz altimeter measurements. The challenge is to find a trade-off between data coverage and data quality depending on each application.

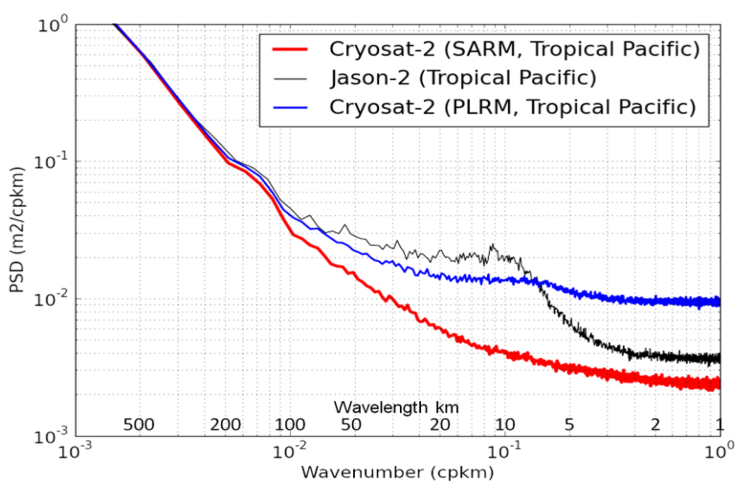


Figure 6.2.3: 20 Hz SSH spectra for LRM and SARM data (from Thibaut et al.)

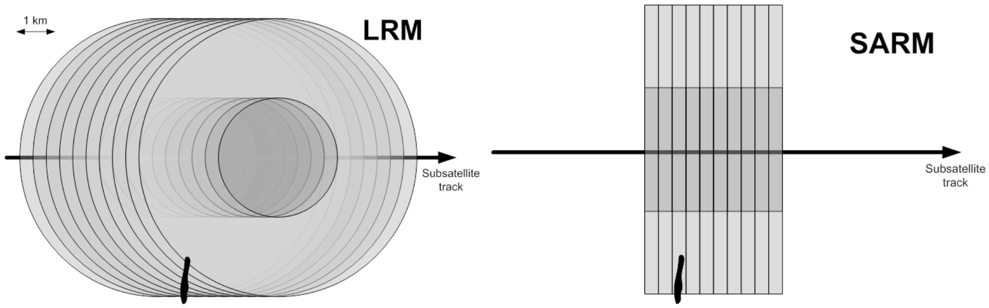


Figure 6.2.4: Synthetic footprint of LRM and SARM technologies (from Thibaut et al.)

Andersen et al. performed an exhaustive cross-comparison of several ocean tidal models in terms of performances. The originality of this study is this evaluation of tides is made on Arctic and Antarctic areas (see Figure 6.2.) and the assessment of tidal currents available from models is also performed by comparing against tidal velocities estimated from current meters located in the deep ocean and from acoustic tomography.

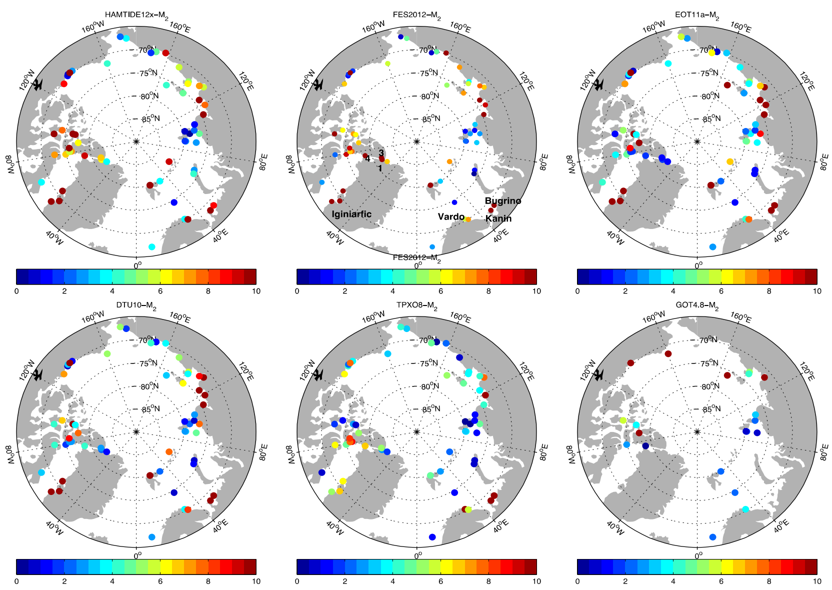


Figure 6.2.5: Vector differences between in situ and interpolated M2 tide amplitude for 60 tide gauges (from O.Andersen et al.)

Jacob et al. gave a talk about sampling errors in the decomposition of vertical modes from current meter data estimated using an eddy-resolving ocean circulation model with embedded tides. Though few tidal current observations are available, an attempt to estimate barotropic/barocilinic tidal velocities from current meters observations has been made. But the ability to estimate the barotropic velocity is affected by the number and distribution of the current meters and the internal tide variability.

The talk given by Ubelmann et al. addressed the improvement of the altimetry error formalism. C. Ubelmann presented a new statistical approach to improve the characterization of the high frequency errors providing spectra for each altimeter correction (e.g. the wet troposphere correction as in Figure 6.2.). From the equation below with assumptions on signal and error uncorrelation, the authors are able to derive the altimeter correction error spectrum from the altimeter correction spectrum and from the spectra of the SSH corrected or uncorrected for the studied correction:

$$s^2(E) = \langle H_C, C \rangle = \frac{1}{2}\left(s^2(C) + s^2(H_C) - s^2(H_{NC})\right)$$

This study presented first attempts and the method has to be tuned/improved with the possibility of doing regional analysis in order to provide maps of errors.

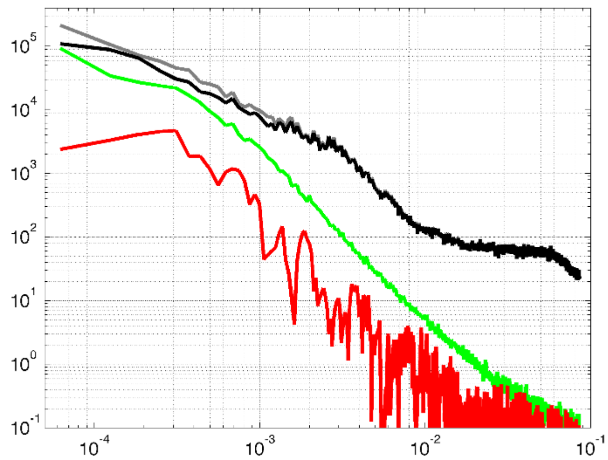


Figure 6.2.6: Error Characterization of the radiometer wet troposphere correction on red curve (from Ubelmann et al.)

6.2.5 Conclusion

From the last OSTST, several improvements have been performed on altimeter error characterization: a huge work to better understand the GMSL differences between each group has been performed. New insights in altimeter error at short wavelength have been characterized and understood. Also a better characterization of orbit and geophysical corrections errors (tidal models, atmospheric corrections, wet troposphere corrections, etc.) has been presented in other splinters. Finally improvements in the error formulation continue to be done.

In terms of recommendations, the splinter highlighted the need for the user community and altimetry experts to work together. The feedback from users should be enhanced by more sophisticated requirements about the error characterization (for model assimilation in particular). The splinter also highlighted the need to continue to characterize the altimetry errors depending on wavelengths and frequencies and to provide a synthetic error budget of altimetry data for each altimeter standards (e.g. : wet troposphere, instrumental processing, etc.).

6.3 The Geoid, Mean Sea Surfaces and Mean Dynamic topography

Chairs: Ole Andersen and Yannice Faugere

This splinter had a total of 6 oral presentations as follows:

- (Andersen Et al.) The DTU13 Global Marine gravity field First evaluation
- (Sandwell Et al.) New Marine Gravity From Jason-1 And CryoSat-2 Reveals Tectonics, Seamounts, And Abyssal Fabric

- (Andersen Et al.) The DTU13 Global mean sea surface from 20 Years of satellite altimetry
- (Pujol Et al.) A 20-year Reference period for SSALTO/DUACS products
- (Mulet et al.) New Global Mean Dynamic Topography from a GOCE Geoid model, altimeter measurements and oceanographic in-situ data
- (Gille et al.) Assessing Mean Dynamic Ocean Topography Using State Estimation Constraints

The session had 2 posters as follows:

- (Bosch et al) Instantaneous profiles of dynamic ocean topography (iDOT)
- (Knudsen et al.) A Global mean ocean circulation estimation using GOCE

Among the interesting results shown and discussed in this session, the group strongly recognized the importance and impact of GOCE, Jason-1 EOL Geodetic Mission and Cryosat-2 (near Geodetic Mission) for developing more accurate MSS, MDT and Geoid models. The three examples bellow illustrates this conclusion.

As an example of the importance of Jason-1 EOL and Cryosat-2 for gravity the presentation by Sandwell and Garcia highlighted that new geophysical features can be seen using the new data.

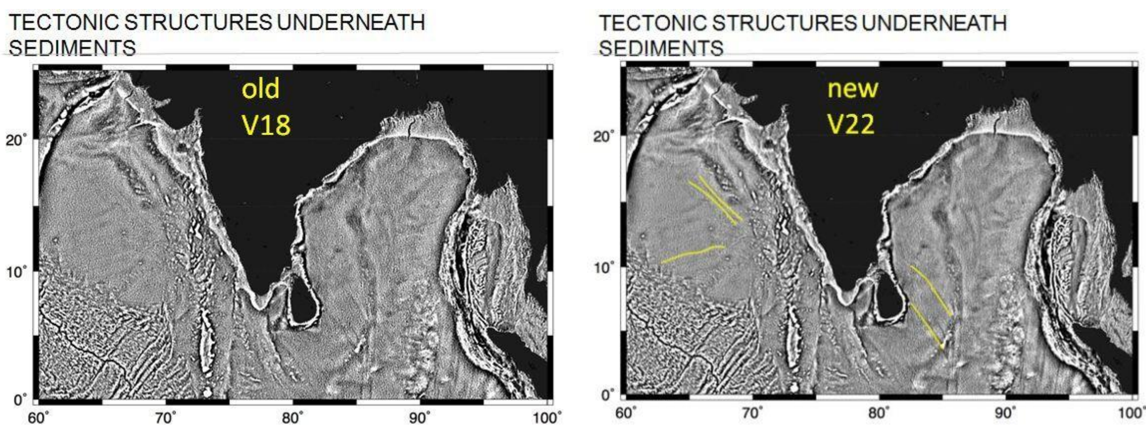


Figure 6.3.3: map of tectonic structures underneath sediment deduced from the old altimetry dataset (left). Adding Cryosat-2 and Jason-1 dataset, new fine structures are revealed (right).

As an example of the importance of Cryosat-2 and GOCE for MSS and MDT in the Arctic was presented by Andersen demonstrating the improved MDT in ice-covered regions.

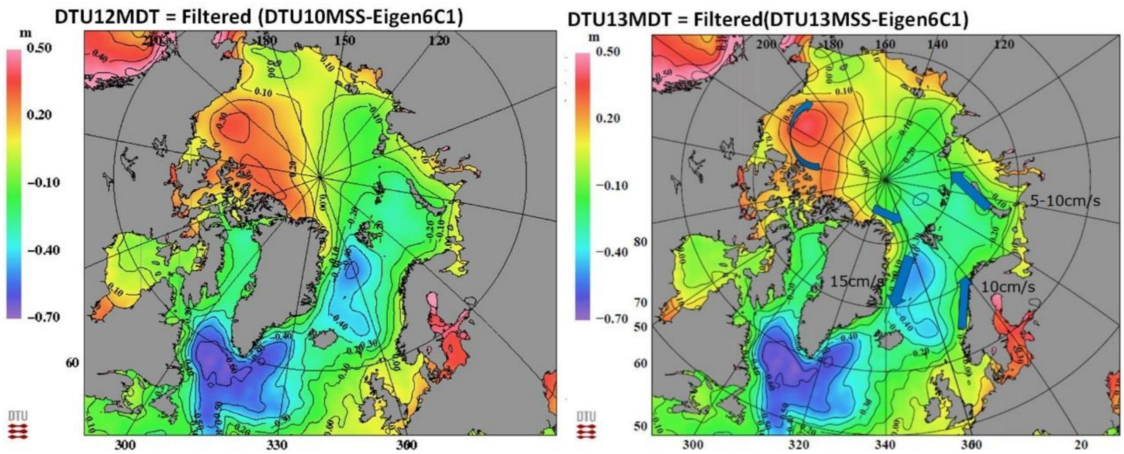


Figure 6.3.2: Map of MSS-Geoid using the DTU10 model (left) and the new DTU13 model (right)

As an example of the importance of the GOCE geoid for ocean circulation was presented in a movie by Mulet showing on 20 years of absolute surface currents relative to the CLS/CNES MDT.

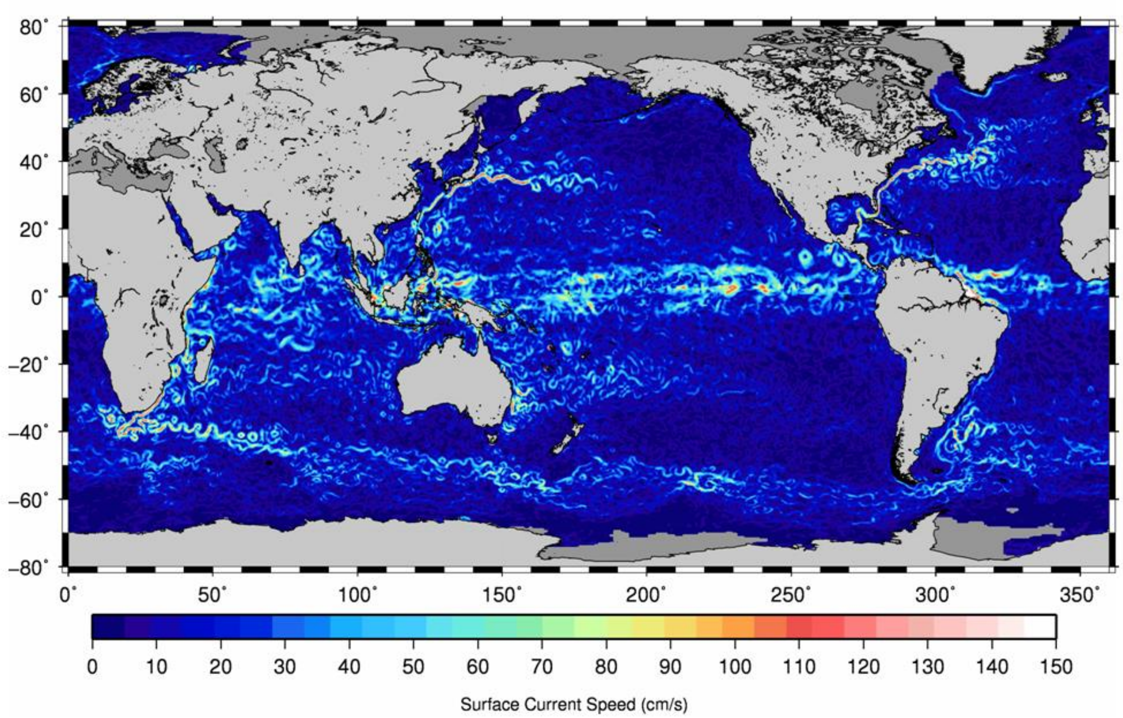


Figure 6.3.3: Example of Absolute velocities modulus using the new version of CNES/CLS MDT

Another important topic discussed was the reference period on which are based MSS and MDT. With 20 year of altimetry, there is a strong interest to use the whole time period as a reference, and thus computing more meaningful anomalies. As an example Figure 6.3.4 shows the change that will occur on SSALTO/DUACS products in 2014.

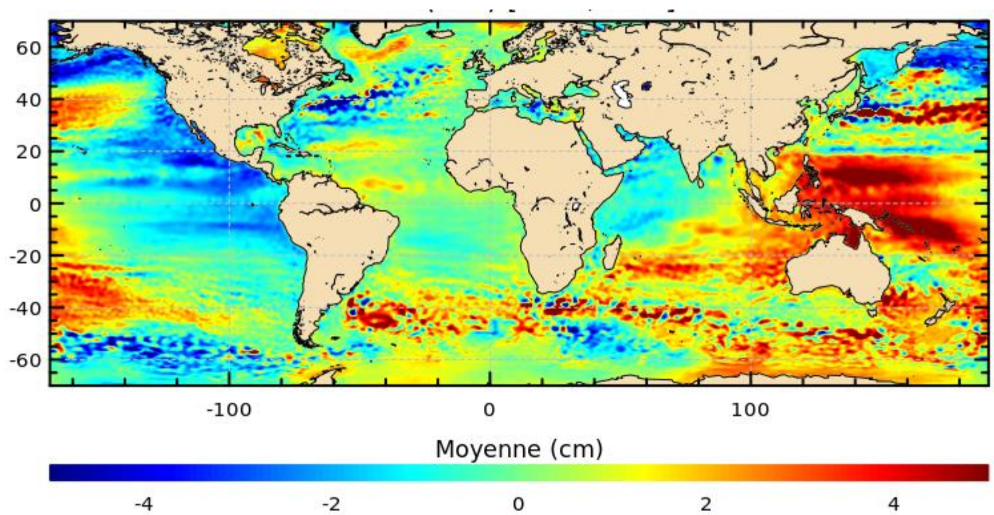


Figure 6.3.4: Impact of a 7 yrs [93-99] to 20 years [93-2012] reference period change for SSALTO/DUACS SLA products (cm)

During the round table discussion several challenges were discussed within two themes:

- *Data acquisition*
- *Modeling/techniques.*

Within these a number of subthemes were identified. This lead to the following recommendations within the following sub-theme:

The reprocessing of the historical altimetry dataset is crucial, notably:

- The reprocessing of old missions. Geosat, ERS-1, T/P – Jason1
- The importance of SSB / Retracking - spectral hump
- The continuity between regional and global products / Tide correction when considering regional products (CoastAltetc).

There is a need to improve the altimetry data at high resolution, notably in the context of SWOT preparation:

- Higher resolution for the altimetric product in general (20Hz/40Hz processing).
- Study Limitation of the current MSS for SWOT?
- High latitudes / sea ice coverage
- Concerning the improvement of the MSS at High Resolution, the interest of SAR altimetry is now demonstrated: need of a timely back reprocessing of C2 SAR for the entire C2 mission to Baseline-B and following baselines.
- Need to keep some of the current C2 SAR regions to insure long term SAR observations crucial for MSS
- Need to enhance the consistency between LRM/SAR/SAR-in -> MSS Sensitivity to gradients.

Concerning future missions, additional data from new Geodetic Missions would still allow us to improve the resolution of the MSS/Geoid/MDT, and in particular the Geoid Splinter recommends:

- A Jason-2 geodetic End of Life phase
- A HY-2 geodetic Mission
- A SAR geodetic mission

The following were also discussed as a means of ensuring the development/continuation of MSS as vertical reference:

- Focusing on estimating MSS/MDT accuracy/error -> future OSTST
- Arctic/Antarctica (different averaging period north/south 66˚)

The following were discussed as a means of ensuring the MDT development:

- Need of good in-situ data -> work on processing of auxiliary data
- Coastal region (broader coast vs near-shore) - tidal errors
- Deriving currents. Directional filtering/adaptive filtering

6.4 Instrument Processing

Chairs: François Boy, Robert Cullen, Walter Smith, Paolo Cipollini, Jerome Benveniste, Phil Callahan, Shannon Brown, Estelle Obligis

Instrument processing had three sessions including one shared with the Coastal Altimetry Workshop. The sessions covered

- SAR Mode and high resolution altimetry
- AltiKa performance
- Wet Troposphere processing
- Other processing topics including Sea State Bias.

6.4.1 SAR Mode Processing

SAR Mode (SARM) processing, including retracking, is now fairly well understood. A. Halimi reviewed modeling of the two-dimensional SARM signal including both along-track and cross-track off-nadir angles (see also the ESA/ESRIN document “Guidelines for the SAR Delay-Doppler L1b Processing” by S. Dinardo, Issue 2 R2, 2013/05/02).

S. Dinardo et al. investigated processing SARM data to a finer scale than the nominal 300 m. The approach appears to have benefits over inland waters and other inhomogeneous scenes. W. Smith considered a similar issue regarding resolution and signal to noise for processing of SAR data over relatively homogenous ocean scenes where somewhat coarser sampling/resolution consistent with the surface correlation time might result in a significant improvement in SNR.

It should be noted that the full rate SARM data can be processed to give a range to any point chosen, which may have benefit for coastal or inland water measurements.

CNES (F. Boy, et al) has generated a full year of SAR product. Initial comparisons of SARM with LRM, Reduced SAR (SARM reduced to LRM), and Jason-2. It would be very valuable for users to provide feedback on these data.

S. Dinardo et al. found good agreement between SARM, pseudo-LRM (PLRM), and in situ data over the German Bight. For SSH, the SARM vs. PLRM (no SSB corrections) have a bias of < 1 cm, standard deviation of 6 cm, and slope of 0.97 (SARM "low"). For SWH the SARM histogram is noticeably tighter. Both data types have similar statistics with respect to nearby buoy data.

Labroue et al. found particularly interesting results in examining the Agulhas current with SARM and other data types. They found that 25 km SARM data gave velocities approximately 50% higher than 50 km data. The finer SARM data were also able to observe near-shore current inversions that were confirmed by AltiKa data.

It was noted that a Sea State Bias (SSB) model for SARM data is still needed.

It was stated that the recommendation to take all Sentinel-3 data in SARM is technically accepted but the issue of cost, e.g., for the large data volume, still needs to be worked out among the partners.

It is recommended that the projects/agencies assess the user desire for having the same products from Jason-CS as Sentinel-3, including lower level products.

6.4.2 AltiKa Performance

Several speakers reviewed the performance of AltiKa to date. The higher frequency (35.75 GHz) and larger bandwidth (480 MHz) provide better spatial (5.7 km footprint) and range resolution. The instrument is functioning well and is meeting all performance expectations. The CNES Cal/Val and processing teams have done an outstanding job in producing data products and providing an initial assessment of performance. Data are already being publicly released.

The effects of rain and atmospheric attenuation in the AltiKa data are much less than feared. Over all surfaces 96% of data are being acquired. A map of data flagging shows that generally more than 90% of ocean data are unflagged. The pattern of flagging suggests that much less than 10% of data may be flagged for rain, with only about 0.1% are lost entirely. The typical atmospheric attenuation is about 0.8 dB, although this is subject to revision as the radiometer and related algorithms are further calibrated.

The backscatter at Ka band is about as expected, approximately 2.5 dB larger than at Ku band. A new wind speed model function, particularly including SWH, will need to be developed. A new SSB model will also need to be developed in conjunction with the wind speed. Initial results suggest that the SSB is similar to Ku for wind speeds < 7 m/s and less than Ku for wind speeds > 7 m/s.

6.4.3 Wet Troposphere

Two speakers discussed the algorithm for the two-frequency radiometer (MWR) flying with AltiKa. The MWR operates at 23.8 and 37 GHz, very similar to the upper two frequencies of JMR/AMR. The MWR is performing well in terms of measurement accuracy and stability. The initial AltiKa algorithm using a neural network with the two brightness temperatures (Tb) and altimeter sigma0 did not perform as well as the EnviSat one because the Ka-band sigma0 could not be well simulated in the learning database. A new algorithm using the ECMWF wind speed as the third parameter gave improved performance but has issues of model accuracy and spatial/temporal resolution. When wind speed is available from AltiKa performance should improve (but see below regarding the utility of wind speed).

S. Thao et al. compared retrieval algorithms starting from the basic premise of the wet tropospheric correction measurement: use of two or three brightness temperatures in either a two-step log-linear regression or neural network algorithm. When only two frequencies (~23, 34 GHz) are available, the altimeter sigma0 is used in place of the ~18 GHz Tb. This substitution is justified on the basis that Tb18 helps to remove the wind roughening of the sea surface, although it also contains other background radiometric effects (e.g., sea surface temperature, different physics between sea surface emission and backscatter). Using simulated data, the three frequency linear regression and two frequency neural network perform similarly (global RMS ~ 4.4 mm). However, a three frequency neural network performs much better with a global RMS of 2.5 mm and no bias as a function of total delay. The authors then explored the importance of the inputs to the neural network to understand the difference between the two and three frequency results. A principal component analysis shows that wind speed (sigma0) is nearly "orthogonal" to the wet path delay. Of surface pressure and surface temperature, the surface temperature is moderately aligned with wet path delay. Again from simulated data, a neural network with two Tbs, sigma0 Ku, and surface temperature had a global RMS of 2.2 mm. Whether surface temperature would help three frequency algorithms and results with real data should be explored.

It was suggested that an integrated altimeter-radiometer wind speed algorithm be investigated. Rather than use the data to first determine an atmospheric attenuation and then use the attenuation-corrected sigma0 in the wind speed determination, an integrated wind speed algorithm that inputs directly the measured sigma0 and the brightness temperatures could be developed.

The 2012 Instrument Processing splinter made recommendations on improving radiometers for Jason-CS. As a follow on to those recommendations, the benefits of higher frequency channels (typically 80-200 GHz) were discussed. Benefits include: supporting AMR-C retrievals, providing a method for cross calibration with the AMR-C, providing path delay retrievals over coastal regions since the footprints will be much smaller, and potentially providing retrievals over land for hydrology studies.

6.4.4 Other Processing Issues

SARM and AltiKa data strongly support the explanation developed by Dibarboure and collaborators that the "spectral hump" found in Sea Level Anomaly (SLA) spectra is due to instrument footprint size effects: larger footprints contain more diverse ocean scenes and in particular include perturbations in the waveform tail that affect the height through correlations in the retracking. The best processing of CryoSat2 SARM, Jason-2 (PISTACH), and AltiKa are largely unaffected by noise and agree well down to scales of about 30 km. For smaller scales the conventional altimeters show the spectral hump followed by the noise floor while the SARM data go smoothly to the noise floor at about 10 km.

W. Smith and R. Scharroo used CryoSat2 FBR data to confirm a point original raised by Jensen (IEEE TGRS, ***37***, 651, 1999) who noted that conventional altimeters alias the waveform when the power is created by squaring the original samples. Oversampling the original data before forming the power could reduce the range noise by up to 10% and the SWH noise by 20%. The effect is larger at lower SWH.

D. Vandemark et al. reviewed Sea State Bias models including consideration of Ka band. Their findings for Ka band agree with those reported above for AltiKa. SSB issues include: number of parameters (2 available from altimeter data vs. additional model parameters); along-track difference vs. "direct" data generation; sampling variability (temporal, spatial). In particular, the non-uniform sampling in space and/or time of the difference method because of infrequent/irregular extreme conditions gives less robust solutions. Also, as previously known, one must use full years of data in order to avoid sampling effects; one year of data provides barely adequate sampling of the more extreme conditions for the direct method (probably not for difference).

6.5 Near-Real Time Products and Applications

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

6.5.1.1 Overview

- 7 talks
- 10 posters
- Large audience for the splinter session (~100 attendees)

6.5.1.2 Talks Summary

The talk given by N. Picot from CNES (*Towards an operational use of HY-2A in SSALTO/DUACS: evaluation of the altimeter performances using NSOAS S-IGDR data*) presents HY-2A official products. They do not have the accuracy of Jason like mission, but the altimeter system show promising performances, HY-2A can complement the sampling of current missions and it can provide valuable information on the ocean mesoscale variability particularly in regions of strong ocean variability. CNES has developed the HY-2A Processing Prototype with specific evolutions on the ground processing of the altimeter data (retracking of S-IGDRs) (see Figure 6.5.4). HY-2A could provide very promising results concerning the observation of the sea level within the multi-mission SSALTO/DUACS system. It will be integrated soon.

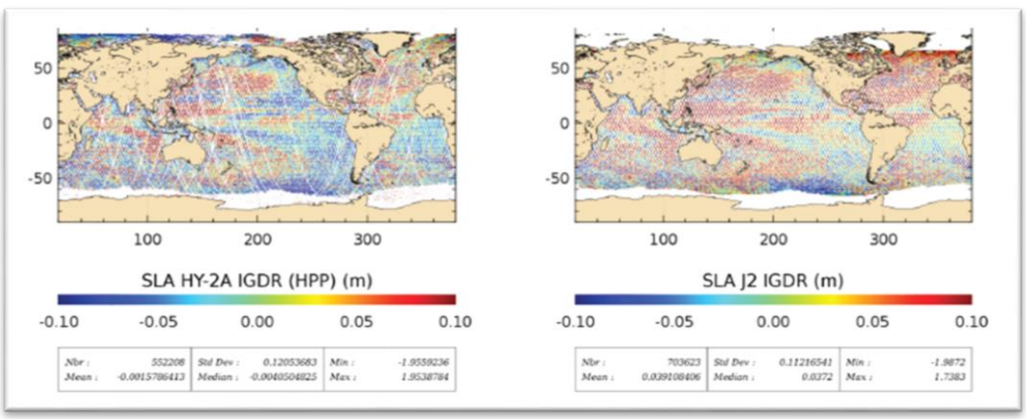


Figure 6.5.4. Maps display the HY-2A CNES Retracked S-IGDR sea surface height anomalies compared to Jason-2. Both missions provide very similar signals.

In the presentation of C. Schwatke from DGFI (*Use of multi-mission altimetry data for height estimation of inland waters (DAHITI database)*), the DAHITI database containing about 180 water level time series over lakes, rivers, reservoirs, and wetlands is presented. It is available in free access via Open Altimeter Database (OpenADB) (http://openadb.dgfi.badw.de). The method used to reprocess altimetric data is presented and deals with classification, retracking, height estimation, website dissemination.

Figure 6.5.2. "Database for Hydrological Time Series of Inland Water"

In the J. Dorandeu talk's from Mercator (*Altimetry impact studies on global ocean analysis and forecasts at Mercator Océan*), the assimilation of ocean observations into the Mercator ocean operational systems is presented. He also gives an overview of Mercator and MyOcean in the operational oceanography context (see Figure 6.5.). The MyOcean products catalogue is recalled and dedicated impact studies such as OSE and OSSE detailed. Finally, he presents benefits of the assimilation of SARAL/Altika data in the Mercator operational system.

Figure 6.5.3. Mercator ocean in the MyOcean European integrated system

J. Wilkin from the Rutgers University (*Data Assimilative Modeling of the U.S. Mid-Atlantic Bight Shelf*) presents the Espresso Real Time ROMS system detailing the model surface and boundary forcing, assimilation datasets such as altimetry and in situ data (HF radar, glider, drifter, ADCP, XBT, etc.). Preprocessing and workflow is explained. Finally, MARACOOS (assets.maracoos.org) is a server providing maps of Near Real Time data and models (see Figure 6.5.4).

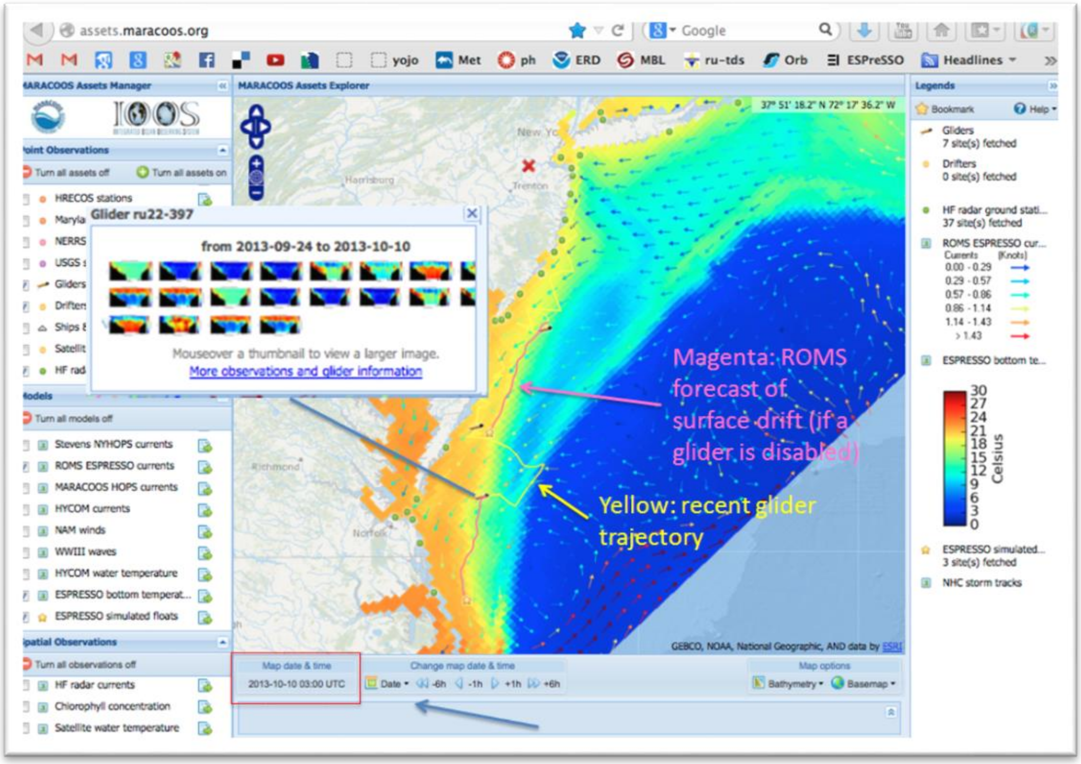


Figure 6.5.4. MARACOOS map server displays Near Real Time data and models

The talk given by Z. Li from JPL (Improved Representation of Eddies in Regional Real-Time Forecasting Systems Using Multi-Scale Data Assimilation of Satellite Altimetry) presents Regional Ocean Modeling System (ROMS) model for the representation of eddies. He explains that assimilation of multi-satellite altimetry data significantly improved the representation of mesoscale eddies during SPURS. The multi-scale data assimilation scheme is effective to assimilate existing altimetry data into high-resolution models (see Figure 6.5.).

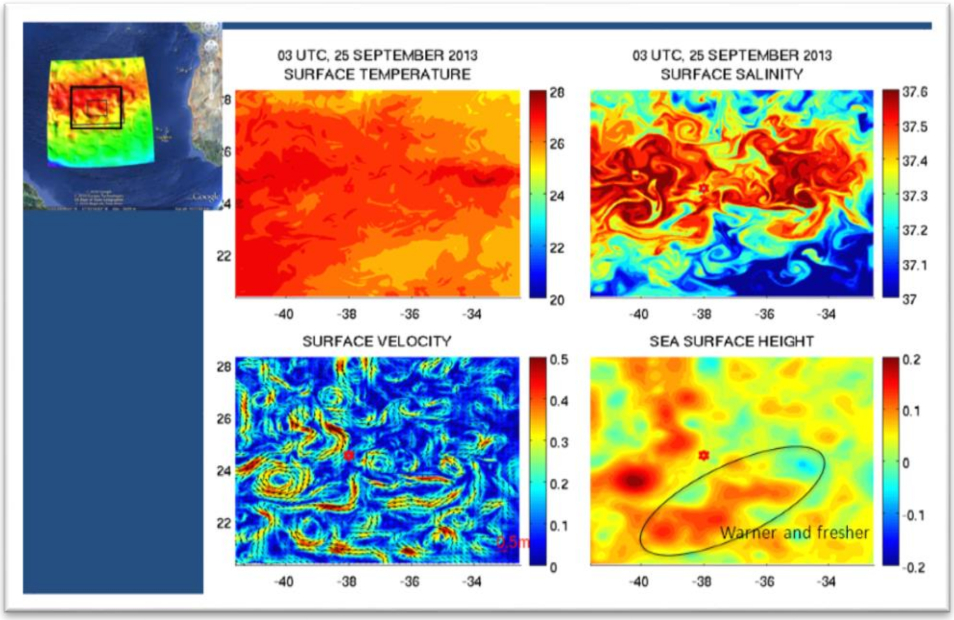


Figure 6.5.5. Real time high resolution forecast

E. Obligis from CLS (*An objective analysis derived water vapour path delay correction for altimetric missions: NRT application to Jason-2 and Cryosat-2 over the ocean*) presented a new wet tropospheric correction based on in-flight radiometers, that could be useful for altimetry when no radiometer is on board or if the wet path delay correction given by meteorological models is not enough accurate. Water vapour observations given by in-flight radiometers such as space borne scanning microwave radiometers can be used to calculate a wet tropospheric correction using an objective analysis method. Application to Jason-2 and Cryosat-2 NRT has demonstrated the applicability of the method to operational altimeter data processing. The new correction performs significantly better than the ECMWF one (see Figure 6.5.) and its accuracy is limited by the number and accuracy of the input sensors.

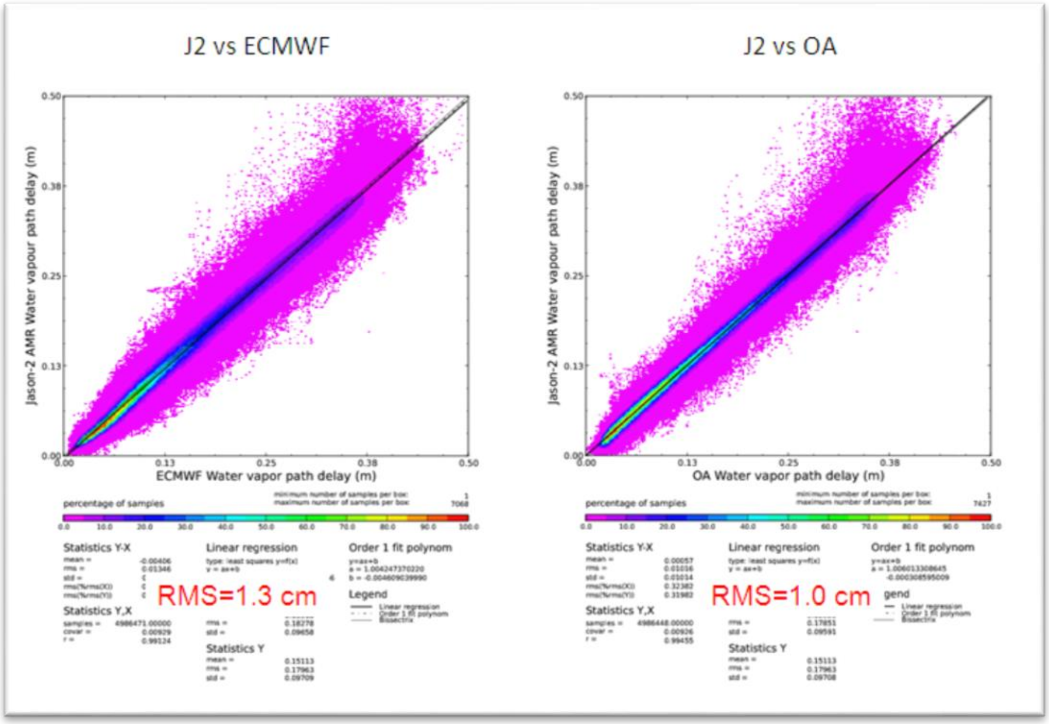


Figure 6.5.6. Scatter plot between Jason-2 AMR water vapor path delay and correction provided by ECMWF and Objective Analysis method

The conclusive talk of L. Aouf from Meteo-France (*On the impact of SARAL/AltiKa wave data on the wave forecasting system of Météo-France*) gives a presentation about the improvement of MFWAM wave model forecasts due to assimilation of SARAL/AltiKa data. Small changes in Quality Control procedure are implemented to prepare the data. Impacts on regional wave models have been measured and global results are compared to buoy data (see Figure 6.5.).

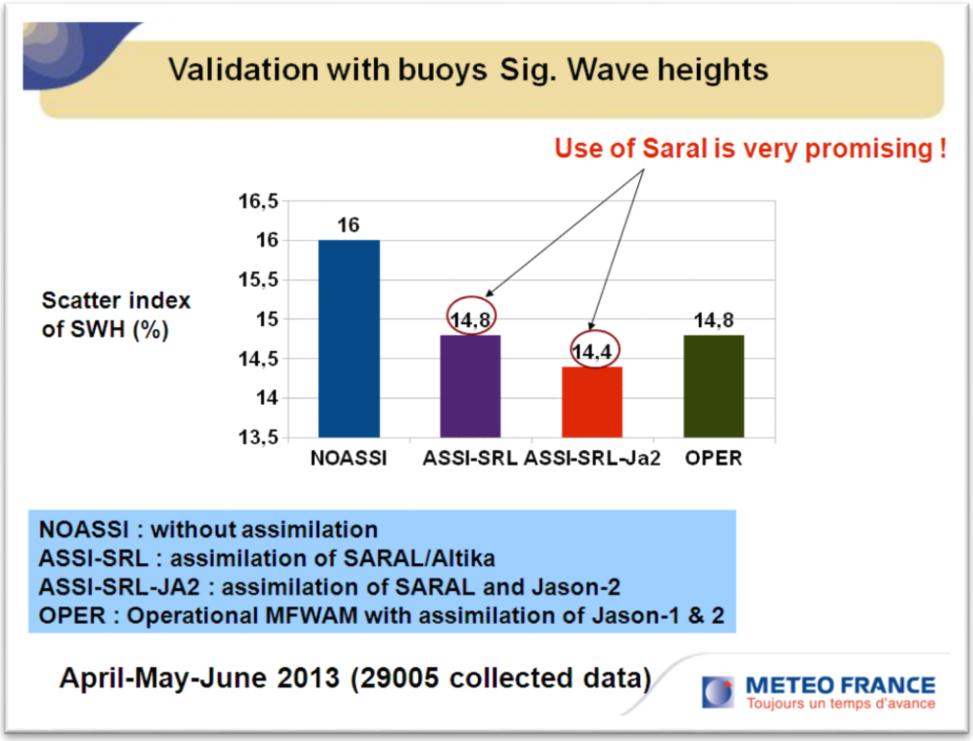


Figure 6.5.7. The use of Saral with Jason-2 showed very promising results. The SWH errors are greatly reduced SI<9% in the tropics)

In summary, the "NRT products and applications" addressed the following topics:

- New data used in multi-mission analysis and forecast systems (AltiKa, HY-2)
- New corrections (wet troposphere for CryoSat-2 or others without radiometer)
- New retracking and datasets (DAHITI for hydrological monitoring)
- New sensitivity analysis through MERCATOR (quantification of data volume impact)
- New impact on waves (AltiKa reduces scatter index to <10%)
- New impact to science studies (NASA equatorial salinity and eddy effects)
- New real time applications (MARACOOS)

6.5.2 Round Table Summary

- NRT applications are critically reliant on altimeter observations and increasing independent observations has highest priority. Severe degradation in NRT products occurs with less than 3 sensors. There is perceived risk of time periods with only 1 sensor through Sentinel. The NRT round table recommends that space agencies ensured future satellites and constellations to maintain a number of sensors sufficient for NRT applications (moreover, make easier the use or access to HY-2 or CFOSAT data).
- For the Jason-2/Jason-3 interleaved orbit, the 5 days gap is recommended. The formation flight phase should be as short as possible (e.g. 3 months). As differences between TOPEX/Poseidon and Jason-1 or Jason-1 and Jason-2 are not fully understood, the NRT round table recommends that the Jason-2 / Jason-3 interleaved phase occurs as soon as differences

are sufficiently characterized between the 2 satellites during formation flight / tandem phase.

- Trade-offs of future sampling under various orbit configurations could provide added value for NRT applications. The impact of sampling provided by different options for future missions should be quantified.
- Progress is impeded by lack of clear data sources for ocean observations. While altimeter data sources have some defined availability (GTS, RADS, EUMETCAST, AVISO), other data sources are scattered (QC is inconsistent, formats are inconsistent, duplication of effort in research community, etc.). The NRT roundtable recommends that data dissemination coordination should be defined at national level (Mercator, NOAA/NCEP/NOS, etc.).
- Finally, the NRT Round Table has concern regarding the maturity of SAR / LRM consistency. Sentinel 3A will provide SAR information that will aid progressing processing but there is a risk of gap in ability to use Sentinel 3A data. The NRT round table recommends to ensure that SAR / LRM consistency is well understood and Sentinel 3A processing is ready.

6.6 Outreach, Education & Altimetric Data Services

Chairs: Vinca Rosmorduc, Margaret Srinivasan

6.6.1 Session presentations:

- The 7th Continent Expedition: International Student Participation in a Voyage to the "Great Pacific Garbage Patch" – De Staerke et al.
- Outreach in a Changing Budget Climate: More or Less, Doing More with Less – Richardson
- AVISO: online data extraction service for all altimetry users – Briol et al.
- NOAA Archive and Access Services for Jason---2/3 Products – Byrne et al.
- Reformatted SEASAT Data and Improved Tools at PO.DAAC – Hausman
- SHOWCASE of altimeter outreach
    - *Real Time Ocean Circulation Forecasts: Along the Oregon Coast (Kurapov et al., OSU)*
    - *SWOT on Aviso web (Aviso)*
    - *Aviso Gallery (Aviso)*
    - *Planetarium show about tides (Rosmorduc)*

6.6.2 Posters

- AVISO: online data extraction service for all altimetry users – Briol et al.
- Argonautica: behind the scenes – Rosmorduc et al.
- Enhancing science and promoting practical applications of high-resolution altimetry measurements – Srinivasan et al.
- Sea Level Course and Experiments for High School Students – Hamlington et al.
- CTOH: from L1 to L4 altimeter data – Fleury et al.
- The ESA LearnEO! Project for Stimulating Earth Observation Education – Rosmorduc et al.
- Aviso products & services: what's new? – Mertz et al.
- Basic Radar Altimetry Toolbox: Saral examples – Rosmorduc et al.
- OpenADB: An Open Altimeter Database providing high---quality altimeter data and products – Schwatke et al.

6.6.3 2012-2013 Highlights

The NASA/JPL-CNES collaborations in outreach, education, and applications have celebrated more than 20 years of cooperation and collaboration over the multi-mission lifetimes. A fruitful partnership has developed, and now includes participation by Eumetsat, NOAA, and ESA. Joint products and activities, including Argonautica in the US, have been fostered, and continue to be developed.

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

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

The question arose of more visible and accessible ways of distributing Outreach materials. A database of existing material might be a viable solution, which could also include past outreach activities. In this way, materials developed or presented by others doing similar work or events in the past may be a benefit to others.

6.6.4 Outreach

Some of our usual mechanisms for Outreach include:

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

6.6.5 Data Services

Data Services provide a way of exchanging information and linking projects and users together so users can benefit from the wide variety of altimetry-derived data available. CNES is developing an “Online Data Extraction Service” which was demonstrated during the outreach session, to be used by Aviso, and which also distributes LEGOS/CTOH products.

We generally understand that metrics from the data centers would provide useful information about the community of data users, trends of data usage amongst the different missions and phases of those missions. Perhaps compiling joint, multi-service, metrics to provide “total” number of users to the agencies on one or all partner web sites would be a viable approach. A joint “user report” might be a way of making the wide audience of altimetry more visible.

JPL/PODAAC is developing a new web site, with new visualization interfaces to promote altimetry and its other datasets.

6.6.6 Education

There was no participation by local students in the plenary session due to logistical constraints of distance, timing and permissions. We hope to include this aspect of the Education portion of the session in future meetings.

Within the Argonautica framework, the "7th Continent" Expedition" is a French project designed to study and collect data in the Pacific Ocean "garbage patch" or "plastic island", via an ocean voyage coupled with the use of satellite data). JPL and a school in San Diego, California participated. OSTST members are welcome and encouraged to join in this type of activity too!

The NASA/JPL presentation summarized activities throughout the past year hosted at JPL including; Girl Scout Earth Patch, an engineering workshop for women and minority engineering undergrad students, and a JPL Summer Educator Institute hosted collectively by the JPL-involved Earth missions. A celebration at JPL featured both the 5th anniversary of launch of the OSTM/Jason-2 satellite, and the 35th anniversary of the SeaSat mission.

Other OSTST members are also involved in a number of training courses. Collectively, we would like to 1) advertise them 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.

6.6.7 Recommendations

There is a heightened interest by the general public concerning climate issues. We feel that more effort can be made in making altimetry more visible in this framework. We recommend that OSTST attendees support applications user communities and applications science, and advise us about their activities related to the applied and operational uses of individual and multimission data sets.

OSTST members 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.

We seek to further develop collaborations between data centers. This would also better serve the users by providing them with the data best fitted for their needs. Data user services recommend that all data be processed in self-describing, homogeneous universal format following acknowledged standards, so as to help users by (at least) freeing them of format challenges.

6.6.8 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 upcoming ocean altimetry missions— OSTM/Jason-2, Jason-3, SWOT and Saral. The anticipated elements of this focus (not withstanding new opportunities) will include:

- Jason-2/OSTM, SWOT, Saral and Jason-3 education & public outreach and applications outreach
- Altimetry and multisensor applications promotion
- Coverage of science team research and other applications on the Web
- Presentations about altimetry and applications made available to the community?
- Continuing the "beautiful images from altimetry" project?
- A restyled AVISO web site, including CTOH information and activities (AVISO+)
- Aviso Online Data Extraction Service already open online (2013) with full database (2014)
- JPL's annual Climate Day event

6.7 Precise Orbit Determination

Chairs: Lu Cerri, N. Zelensky, A. Couhert, F. Lemoine

6.7.1 Status of Jason-2 GDR orbits

The RMS of GDR-D radial orbit error is close to 1-cm and stable throughout the mission, as indicated by the comparison with orbits from different groups (Figure 6.7.1) and the statistics of core-network SLR residuals at high elevation (Figure 6.7.2). In particular, the difference between GDR-D dynamic orbits and JPL reduced dynamic orbits is close to 6 mm on average. It should be noted that both orbits are GPS-driven (GDR orbits include all available tracking data and JPL is GPS-only), while GSFC reference solutions only include DORIS and SLR.

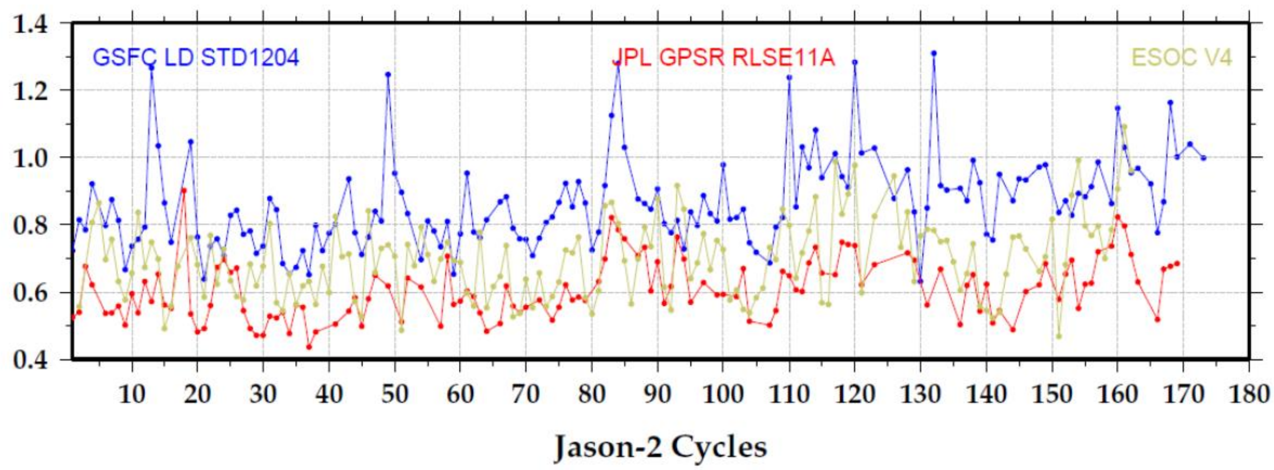


Figure 6.7.1 (Couhert et al.) RMS of radial orbit differences (units: cm) between GDR-D orbits and alternative solutions from different groups. GSFC LD STD04 are DORIS+SLR dynamic orbits, JPL RLSE11A are GPS-only reduced dynamic orbits, ESOC V4 and CNES GDRD are DORIS+SLR+GPS dynamic orbits.

As far as the SLR statistics are concerned (Yarr7090, Graz7839, Greb7105), the degradation of residuals after cycle 70 (mid 2010), and the returning at 1-cm level value after cycle 150 (mid 2012), is common to all Jason-2 orbit solutions and is noticed in Yarr7090-only statistics of Jason-2 and other altimeter satellites (Cerri et al.). This result outlines some problem in the processing of Yarr7090 data over this 2-year time span. This is particularly unfortunate, as Yarr7090 is generally the best performing station of the network and its location is useful in detecting geographically correlated errors induced by reference frame and the geopotential model. It should also be noticed that the Greenbelt station (Greb7105) shows an almost-1-year data gap in 2010.

As already noted in previous splinters, the statistics of altimeter crossover residuals indicates that JPL reduced dynamic orbits are the most accurate, with an average gain of 40 mm^2 over GDR-D (Figure 6.7.3). As explained later in the splinter summary, this metric can be significantly improved by calibrating the solar radiation pressure model used in dynamic orbit solutions (Mercier et al.).

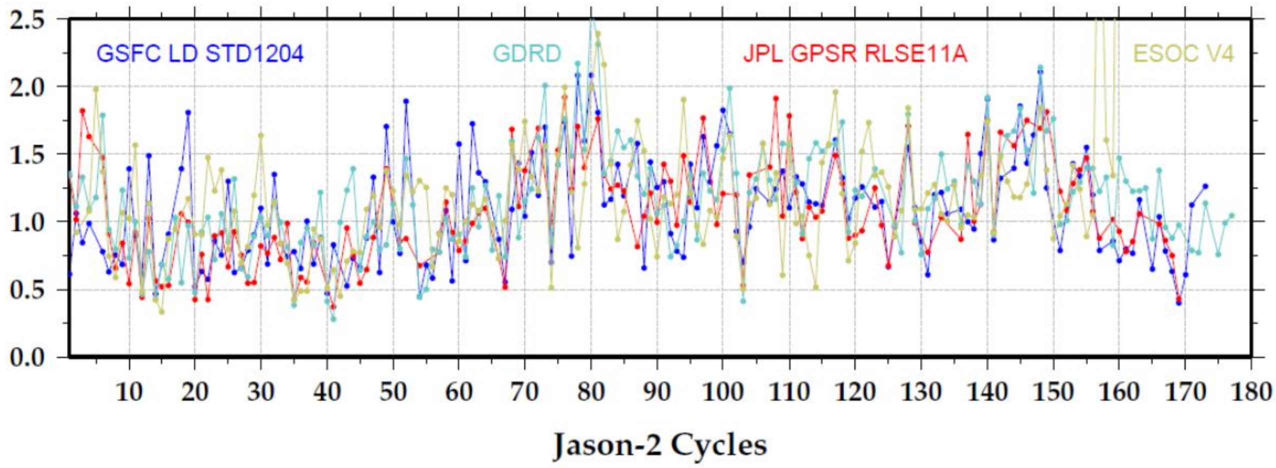
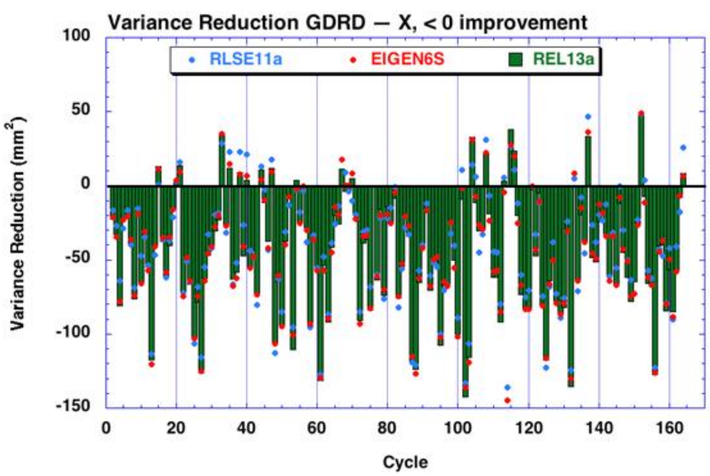


Figure 6.7.2. (Couhert et al.) RMS of SLR residuals (units: cm) above 70° elevation for a 3-stations core-network (Yarr7090, Graz7839, Greb7105).



J2 summary cycles 1-169 (7/08-5/13) *external ephemeris*	SLR RMS average residuals (cm)	Xover RMS average residuals (cm)
std1007	1.194	5.448
std1204	1.071	5.376
std1204_iers2010	1.074	5.378
tvg5x5_wd20	1.053	5.364
red_tvg5x5_wd20	1.087	5.353
gdrd	1.312	5.378
jpl11a	1.201	5.301
jpl13a	1.175	5.307

Figure 6.7.3. (Left - Bertiger et al.) Variance reduction of JPL GPS – based reduced dynamic orbits with respect to GDRD. (Right – Lemoine et al.) Statistics of SLR and crossover residuals for several orbit solutions.

Although stable in terms of RMS, radial orbit differences exhibit geographically correlated patterns with amplitude of few mm that are of interest for the analysis of mean sea level, especially at the regional scale. In regard to this, Couhert et al. prepared an error budget of the Jason GDR-D orbit solutions in terms of seasonal signals and trends (Figure 6.7.4). As expected, the budged identifies the non-tidal component of the gravity field as the most significant contributor to the regional orbit error. As far as the linear rates are concerned, this contribution is estimated to not exceed 2 mm/year over the 5-year lifespan of the Jason-2 mission, and manifests itself mainly as a longitudinal "order-1" pattern. The rationale for this upper bound is given by comparison between GDR-D and reduced dynamic orbits or orbits using different models as shown in Figure 6.7.5 and discussed in more detail in next section.

Error Source	Global	Regional
Tracking Data residuals consistency (SLR Vs GPS/DORIS orbits)	/	Annual term: SLR range biases oscillations from *3* to *9 mm* Long-term evolution: Drifts in SLR range biases (5-10 years) *< 2 mm/y*
Reference Frame	GMSL long-term trend (ITRF2008 – ITRF2005): Drifts (10 years) < *0.05 mm/y*	Annual term: North/South oscillations < *8 mm* Long-term evolution: - Jason2 (5 years) < *0.6 mm/y* at extreme latitudes - Jason1 (10 years) < *0.3 mm/y* at extreme latitudes
Time Variable Gravity (TVG)	GMSL long-term trend: Jason-1 (10 years) , Jason-2 (5 years) < *0.10 mm/y*	Annual term: East/West patterns < *4 mm* **Long-term evolution:** **East/West patterns < *2 mm/y***

Figure 6.7.4. (Couhert et al.) Error budget of Jason GDRD orbits for MSL applications.

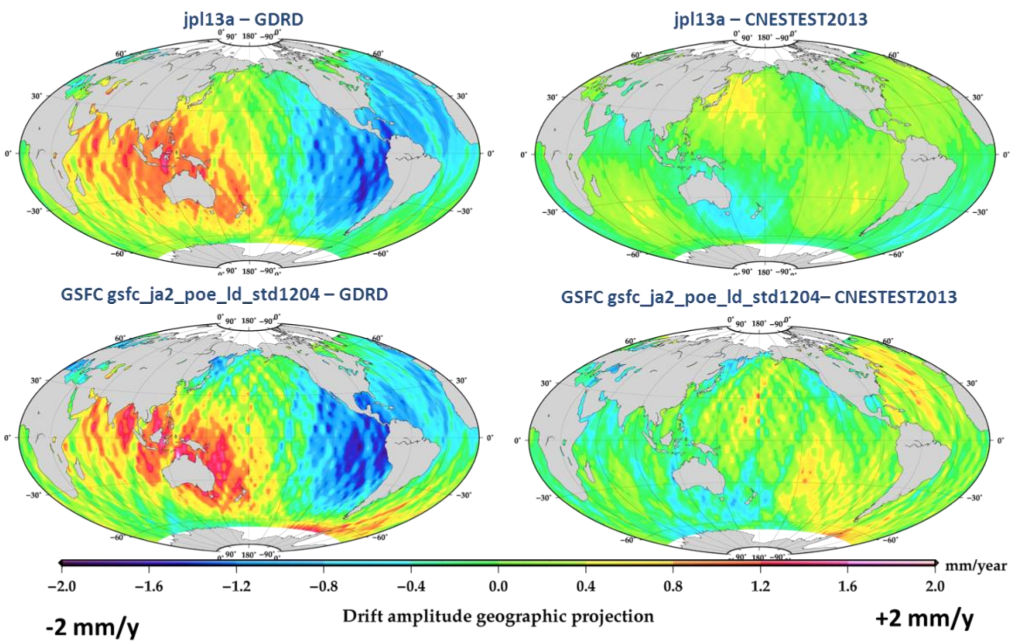


Figure 6.7.5. (Cerri et al.) Linear rates of the radial orbit difference between CNES GDR-D (left) or TEST2013 (right) and GSFC or JPL reference orbit solutions. GDR-D orbits are dynamic orbits relying on a mean field whose trends are based on 8 years of GRACE data, while GSFC, JPL13a and TEST2013 accommodate for large scale TVG errors using Jason data, although in different ways, as explained in section 2.

6.7.2 Modeling options for the Non Tidal Time Varying Gravity (TVG)

Several options exist to accommodate TVG effects in POD solutions:

1) use of GRACE-based mean models

2) use of “GRACE-free” complements to the GRACE-based static field (where “GRACE-free” means that the time varying part is not obtained from GRACE data), or
3) use of GPS-based reduced dynamic solutions. Each option presents some advantages and drawbacks.

6.7.2.1 GRACE-based mean models – testing of EIGEN6S2

GDR-D orbits include annual, semi-annual, and linear rates derived from the time series of 10-day GRACE potentials (Rlse02) from CNES/GRGS team (Bruinsma et al., 2010, doi: 10.1016/j.asr.2009.10.012). This “mean” model (EIGEN-GRGS_RL02bis_MEAN-FIELD) spans eight years of GRACE and LAGEOS data (2003-2010) and has shown to significantly improve the orbits of all altimeter satellites with respect to the previous generation of mean models (GDR-C), as reported in the summaries of 2011 and 2012 OSTST meetings.

A new mean model has been recently made available and proposed for the ITRF2013 analysis, EIGEN6S2, resulting from the cooperation between CNES/GRGS teams and GFZ. A large part of POD splinter presentations has been dedicated to the evaluation of EIGEN6S2 as a possible mean field for next standards. All tests have consistently indicated some degree of improvement with respect to GDR-D model:

- Instead of a unique linear rate for the entire time span, EIGEN6S2 adopts a bias and rate per year, to account for the inter-annual variability that is naturally present in the time series. The radial orbit difference is now below 2 mm RMS with respect to solutions using the time series for all altimeter satellites (Figure 6.7.6 and 6.7.7).

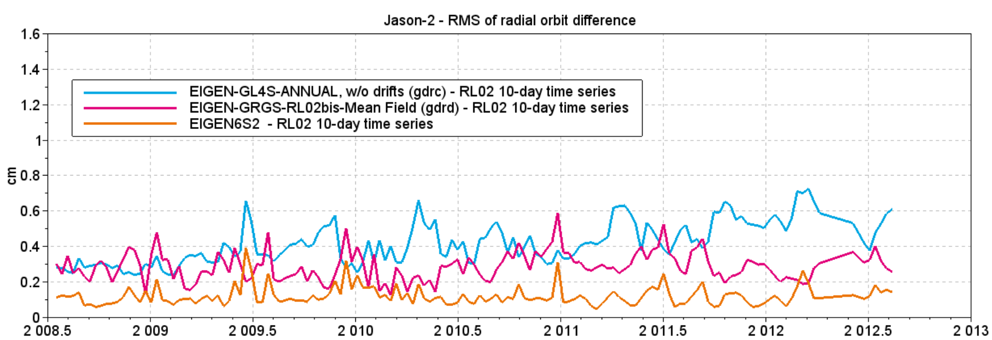


Figure 6.7.6. (Cerri et al.) RMS of radial orbit difference between orbits using the mean models and the reference orbits using the time series. EIGEN6S2 is conceived to minimize the discrepancies with respect to the time series.

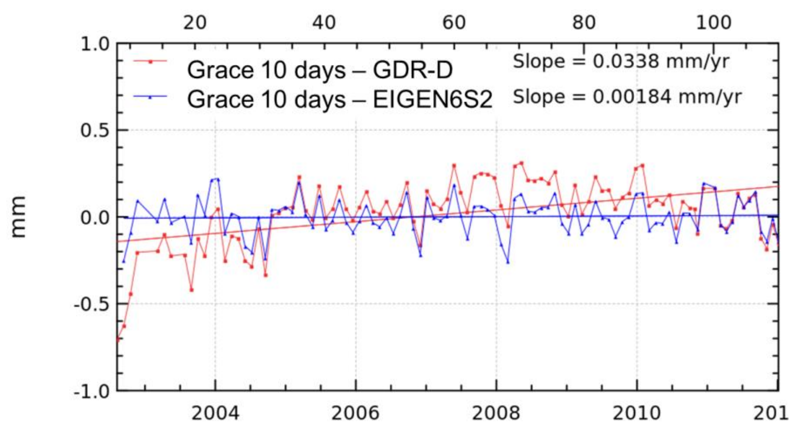


Figure 6.7.7. (Ollivier et al.) Envisat MSL Difference between orbits using a mean model (GDR-D or EIGEN6S2) or the time series.

- SLR residuals are generally slightly improved when EIGEN6S2 is used instead of GDRD (Figure 6.7.8)

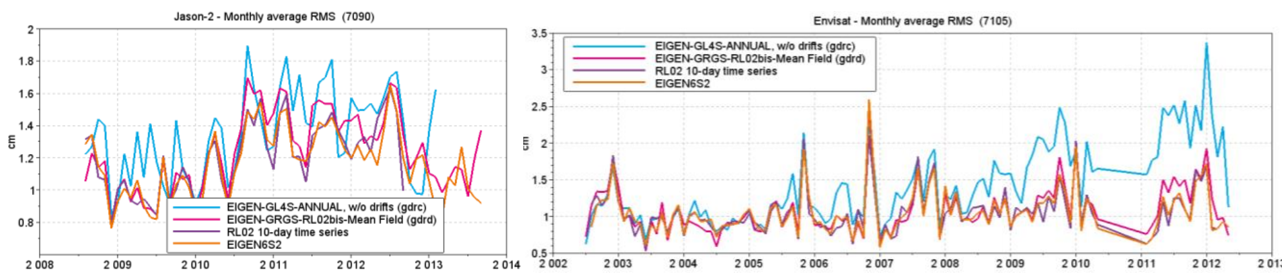


Figure 6.7.8. (Cerri et al.) Monthly average RMS of SLR residuals in final POE solutions using different mean models and the time series.

- EIGEN6S2-based dynamic orbits are closer to GPS based reduced dynamic orbits than GDRD (Figure 6.7.9)

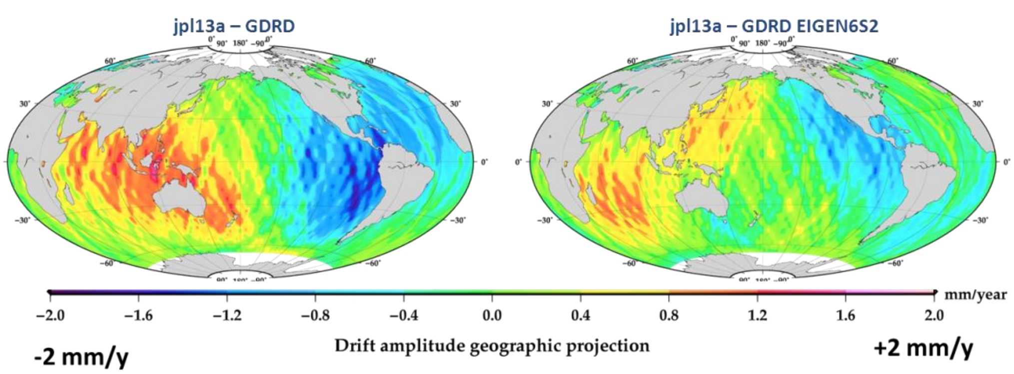


Figure 6.7.9. (Cerri et al.) Monthly average RMS of SLR residuals in final POE solutions using different mean models and the time series.

- The consistency between the Sea Surface Height measured by different missions is improved (Figures 6.7.10, 6.7.11)

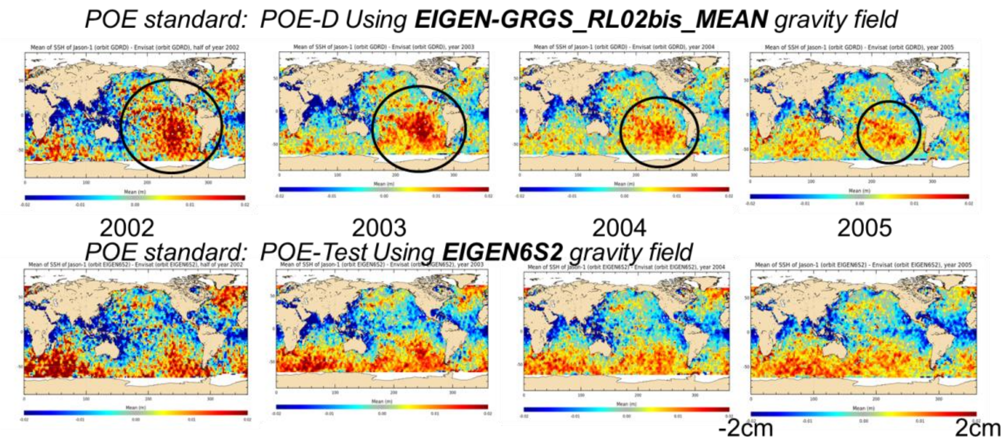


Figure 6.7.10. (Ollivier et al.) Interannual signal remaining on EN-J1 mean difference per year at crossovers are efficiently removed by EIGEN6S2; remaining signals now dominating between those missions are most probably due to a mix of other sources (wet tropospheric correction, SSB solutions, etc.).

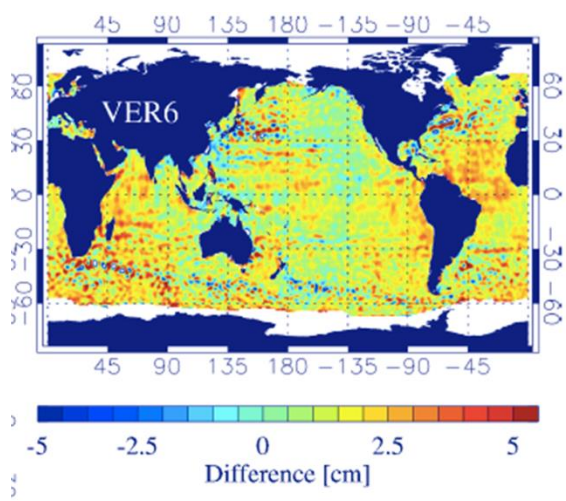


Figure 6.7.11. (Rudenko et al.) Differences of the mean sea level calculated from ERS-2 and TOPEX (June 1995 – June 1996) when EIGEN6S2 is extrapolated with zero drifts before 2003.

GRACE-based mean models perform well on all altimeter missions and can be easily implemented in operational multi-mission POD production but present some drawbacks with respect to the capability of orbit solutions to maintain the 1 mm/year stability over 5 years at regional scales. The first is that any mean model used in operational POD is extrapolated and will likely diverge from the time series after some time. The second is that there would be no possibility to update the field in case of GRACE demise or to represent TVG effect before the GRACE mission. To overcome both limitations, POD groups have worked out alternative solutions since the 2011 meeting in San Diego when the GDR-D standards were originally presented. The status of these alternative options, that accommodate TVG effect using tracking data alternative to GRACE, and in particular including Jason, is outlined in the next paragraphs.

6.7.2.2 Use of POD tracking data from several missions ("GRACE-free" long-term TVG)

Both CNES and GSFC have tried different approaches to account for long term time-varying gravity without using GRACE. This effort has so far been conducted without the use of GPS data from Jason as this is not a mission critical instrument (although it continues to perform very well on Jason-2) and in theory most current and past altimeter missions should be capable of relying only on DORIS+SLR. The solution of point mascons based on Doris data only has proven to effectively remove most of the TVG-induced geographically correlated signatures on Envisat and Jason orbits, although the use of the low Earth orbit, high inclination satellite remains essential for this method to work (Cerri et al. doi: 10.1016/j.asr.2013.03.023). In order to rely only on Jason data to account for TVG effects, CNES_TEST2013 orbits let the degree3/order1 harmonics free to adjust in each POD run, as the sensitivity of Jason orbits to this particular harmonic has been demonstrated in several occasions (Cerri et al. OSTST 2009, Cerri et al. doi: 10.1080/01490419.2010.488966, Couhert et al OSTST 2013). Results are promising, as shown in Figure 6.7.5.

The GSFC team (Lemoine et al.) extended the series of 4x4 spherical harmonics complement to the GOCO-2S static field up to degree/order 5. This complement is obtained from SLR and DORIS data of up to 15 satellites. The improvement has been clearly demonstrated with respect to orbits that do not attempt to model long term TVG effects (Figure 6.7.12), and the residual relative radial drifts with respect to JPL11A and CNES-TEST2013 are generally below the 1 mm/year level over 5 years (Figures 6.7.5 and 6.7.13). It is important to note that Jason-2 (and TOPEX) data are included in the determination of this spherical harmonics complement.

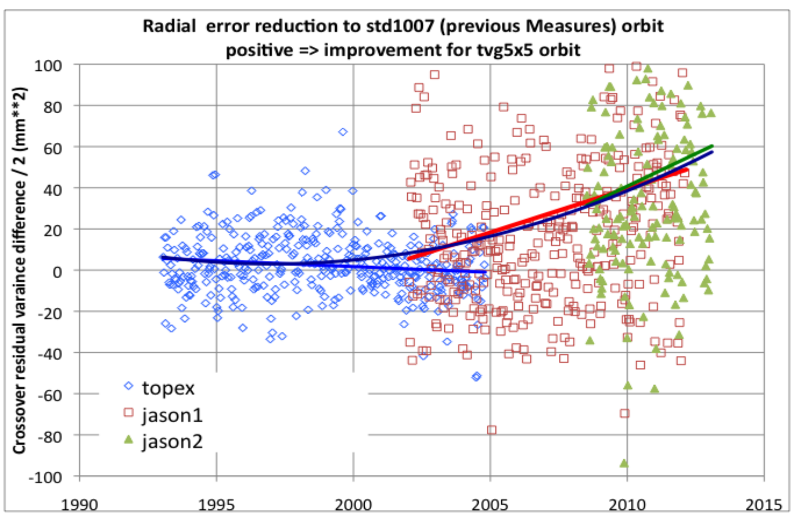


Figure 6.7.12. (Lemoine et al.) Gain in the variance of altimeter crossover residuals when the new GSFC 5x5 SH complement is applied with respect to orbits that do not model long term TVG (std1007).

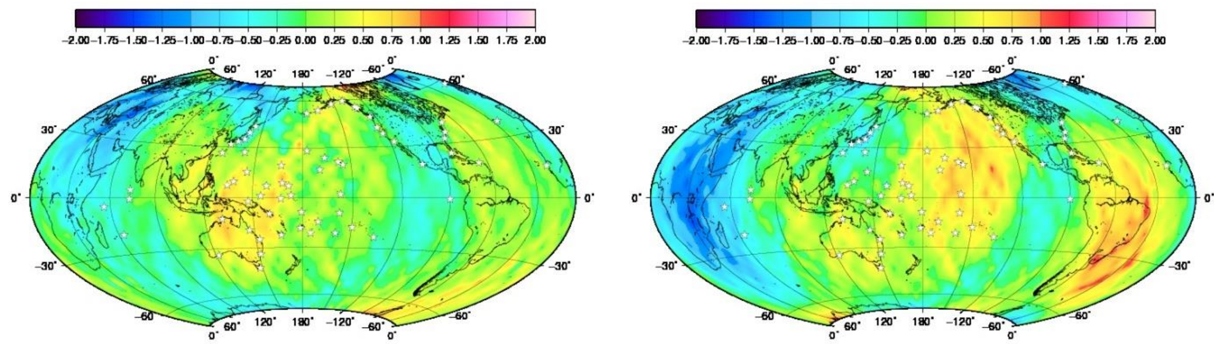


Figure 6.7.13. Linear rates of the orbit radial difference between GSFC orbits and JPL11A GPS-based reduced dynamic orbits; left: 4x4 SH complement (std1204, the current Measures orbit, Lemoine et al., doi: 10.1016/j.asr.2010.05.007); right: using 5x5 complement, which is still an experimental series.

6.7.2.3 Reduced dynamic GPS-based orbit solutions

The JPL POD team investigated the effects of time varying gravity on their reduced dynamic solution, and it appears that even these orbits are sensitive to the geopotential variations, at least to some extent (Figure 6.7.14). Although the large scale patterns are effectively removed by the reduced dynamic filtering process, some smaller scales in the radial orbit differences appear where the TVG signal is known to be stronger: the Amazon basin for the seasonal component, Greenland and West Antarctica for the rates.

As shown in Figure 6.7.5, JPL13A and CNES-TEST2013 orbits are very close (4 mm radial RMS on average, radial difference rates in below 0.6 mm/year), as it could be expected for GPS-driven reduced dynamic solutions. GPS tracking is not considered mission critical and so the potential risk for losing this capability may be higher than for the DORIS. Also it should be noted there are some gaps in the GPS tracking.

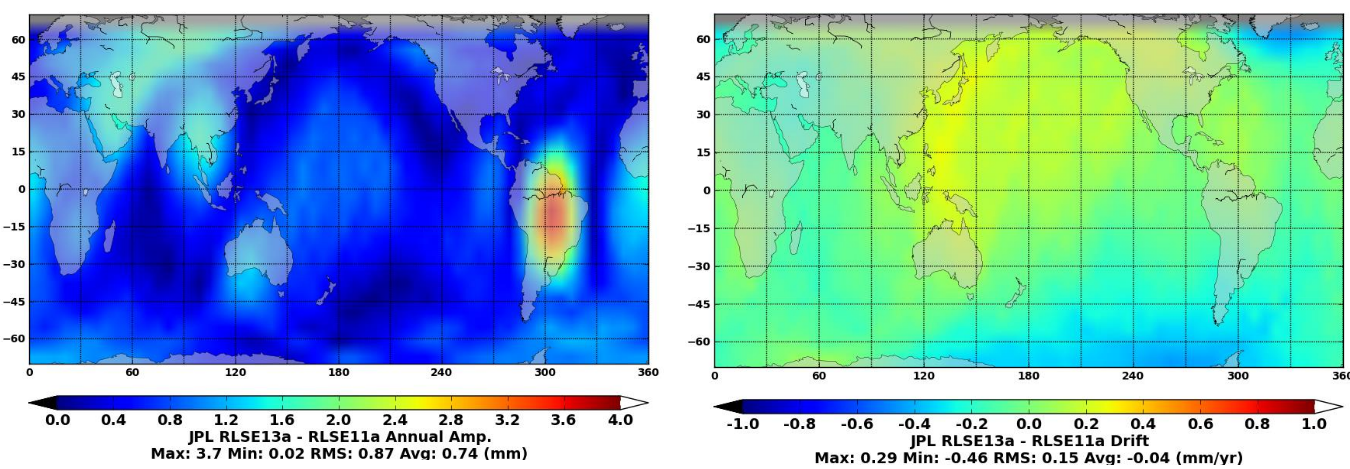


Figure 6.7.14. Sensitivity of JPL's GPS-only reduced dynamic orbits to TVG effects: RELSE11A does not include TVG models, while JPL13A includes JPLR05 TVG model. The left plot shows the amplitude of the annual component in the radial difference, while the right plot shows the linear rate.

6.7.3 Prospects for next POD standards

This splinter has not only addressed TVG-related issues but also outlined what could be the basis for the future POD standards updates.

6.7.3.1 TVG

Given the discussion in section 2, one of the main outcomes of this splinter is the fact that the reference orbit solutions from CNES, GSFC, JPL agree to the sub-mm/year level over 5-years if Jason tracking data is used to accommodate large scale TVG effects (Figure 6.7.5). Residual radial difference rates with respect to the best available GRACE-based dynamic orbits are below 1.5 mm/year (Figure 6.7.9). Inputs from CalVal teams are needed to help understanding which is the best approach to be used for POD reprocessing.

6.7.3.2 ITRF

The new release of the International Terrestrial Reference Frame (ITRF2013) is expected in late 2014. All altimeter orbits will be reprocessed to be consistent with the new frame.

6.7.3.3 SOLAR RADIATION PRESSURE

Mercier and Cerri have presented the benefits of calibrating the SRP model using the available tracking data for Jason1 and Jason2. The a-priori box-and-wing model has been replaced by a plate model for the solar array and a harmonic expansion of the satellite angular position with respect to the sub-solar point for the central box. The coefficients of this semi-empirical model have been estimated using several months of GPS data, the results being presented in Figure 6.7.15 (significant reduction in the altimeter crossover residuals with respect to GDR-D orbits). This new model will be the basis for next GDR POD standards.

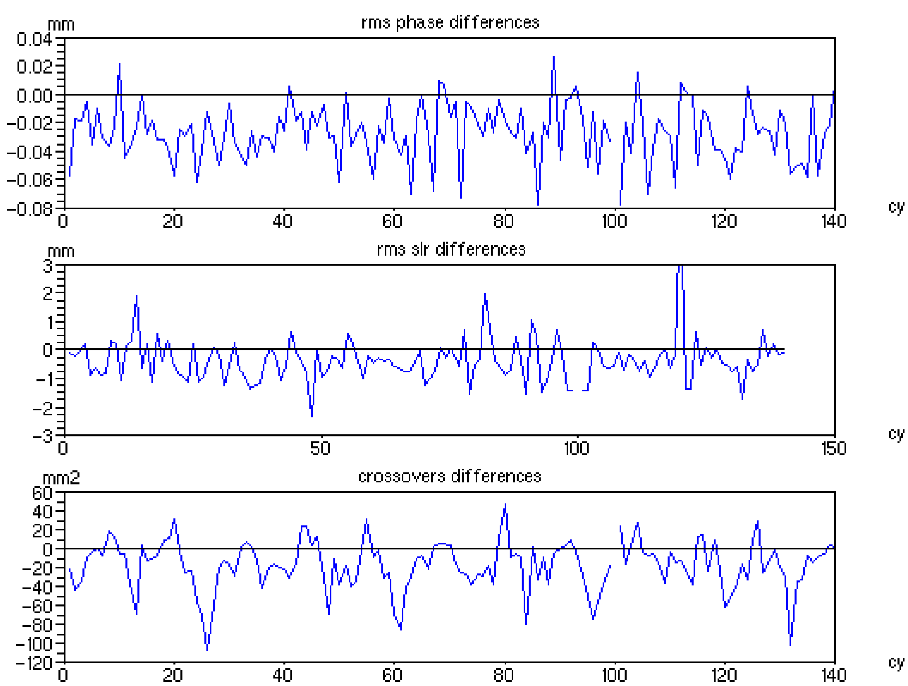


Figure 6.7.15. Difference in several metrics when using the calibrated SRP model in GDR-D solutions. Negative means improvement with respect to the standard GDR-D configuration.

6.7.3.4 GEOCENTER MOTION

Mass transfers in Earth surface layers are responsible for the seasonal variations in the motion of solid Earth in a reference frame whose origin is the center of mass of the total Earth system, which is the convenient origin for precision orbit determination solutions. As the tracking stations are fixed to the solid Earth, their instantaneous position should be corrected for this motion, which has not been done so far due a lack of a consensus model to be used in the standards. This omission error manifests differently in DORIS+SLR solutions than in GPS-based solutions along Z, which leads to annual differences between both types of orbits (Lemoine et al., OSTST 2007, Cerri et al. OSTST 2011, Melachroinos et al. doi: 10.1016/j.asr.2012.06.004).

The POD group wishes to include geocenter motion in next POD standards, as this will improve the consistency between orbits based on different tracking techniques and ensure the delivery of orbits whose origin is the whole Earth center of mass (at least to the best of our modeling knowledge).

6.7.3.5 OTHER

The weighting strategy of South Atlantic Anomaly DORIS stations in Jason-1 GDR solutions should be reviewed as this has proven to have an impact on the SSH consistency between Jason-1 and Jason-2 (Ollivier et al.).

6.7.4 Conclusions and recommendations

The sensitivity of the altimeter orbits to Time Varying Gravity is demonstrated, and the use of highest fidelity geopotential models is essential to achieve the 1 mm/year stability of radial orbit errors at the regional scale. As enhanced geopotential models have been released, a new ITRF will be available in 2014, and other improvements to surface forces models and the solution parameterization have already been tested, GDR orbits should be reprocessed and the operational standards be changed before end 2014.

One of the main outcomes of the 2013 POD Splinter session is that the agreement between different Jason-2 orbits is now well below 1 mm/year when Jason tracking data is used to accommodate long term TVG effects. This result is achieved over the 5-year lifespan of the Jason-2 mission, which is characterized by strong variations in the gravity field especially due to the melting of the Greenland and Antarctica ice sheets.

However, these orbits differ from GRACE-based dynamic solutions to the level of <1.5 mm/year (when using the new EIGEN6S2 field, and this figure is raised to 2 mm/year with the GDR-D orbits). It is then important to know if the GRACE-derived low degree/order harmonics are known with sufficient accuracy to be fixed in next POD standards, for both the reprocessed and the routine GDR orbits. This analysis is even more important as in case of GRACE demise, POD would need operational TVG models using SLR, DORIS and GNSS data from other satellites anyway.

It should be noted that given the paucity of the current set of tracking stations and occasional biases or data gaps, the ability of the SLR system to detect orbit regional drifts at the 1 mm/year level over 5 years remains questionable. CalVal analysis allowing to reveal trends in the geographically correlated orbit errors using alternative measurements of Sea Level (Argo T/S + GRACE, Tide Gauges) are a fundamental complement to internal POD analysis and should be pursued as much as possible.

Given the above, the POD team recommends:

- That any effort is made to improve the SLR stability and station distribution
- That accurate GNSS receivers are made a mission critical instrument for ocean topography missions, as GPS-based reduced dynamic solutions remain an indispensable tool to validate POD performances

- That a "best effort" commitment is made by the GRACE teams to provide time series of geopotentials in a more timely manner (applies especially to GRACE FO) for operational altimeter POD

For the future, operational POD groups and project teams should think of the possibility of orbit products more suitable than GDR for long term analysis, to the level of accuracy required by current climate applications (better than 1 mm/year regional stability over <= 5 years), even if this required the delivery of orbit products with a higher delay than the current GDR orbit. In parallel, the accuracy of short latency orbit products (IGDR) could be improved, making use of all the available tracking data and models, providing the best available interim solution while waiting for the final orbit.

7 Closing Plenary

The closing plenary began after lunch on Friday afternoon with Phil Callahan discussing TOPEX Reprocessing and update to GDR-E standards. Concern over the changing point target response of the TOPEX altimeter has prevented reprocessing to date. Recent work to analyze data over lakes has been used to help understand the point target response in the face of leakage. The current plan is to make a new Re-tracked GDR, consistent with Jason-1 GDR-E processing. Systematic point target response generation should be developed by the end of December 2013, and begin bulk reprocessing in January. Re-computation of sea state bias should begin by fall 2014, with products available in early 2015.

Nicolas Picot discussed the current GDR status for Jason-1 and Jason-2. TOPEX data remains in Merged GDR product developed in 1996. Jason-1 data remains in GDR-C format, developed in 2006. Jason-1 will undergo a full reprocessing to GDR-E standards, which should be completed by the end of 2014. Official products are not available in a consistent GDR standard across all missions. Jason-3 data will be produced in a GDR-E standard, which will be similar to GDR-D, but with small updates to orbit calculation, tides, mean sea surface. A numerical retracking solution will be used on Jason-3, in parallel with MLE4, to allow comparison between these two standards. Finally, the sea state bias solution will be based on Jason-2 from 2012. Jason-2 is now in GDR-D standard since March 2013, but will be updated to GDR-E standards (except for numerical retracking) for comparison with Jason-3 during its calibration phase. TOPEX reprocessing remains the top priority.

Recommendations and Appreciations

- In recognition of the response of the Space Agencies and Project Teams to its prior recommendations, the Ocean Surface Topography Science Team expresses its thanks for the following:
    - Acceptance of interleaved mode as the baseline for Jason-CS
    - Acceptance of a climate-quality, three frequency radiometer as baseline for Jason-CS
    - Investigation of an additional high frequency radiometer for Jason-CS
    - Acceptance of all ocean and land coverage in SAR mode as baseline for Sentinel-3
    - Release and processing of over-ocean CryoSat-2 data.

        - OSTST members are encouraged to download, analyze and provide feedback on reprocessed data from CNES

    - Congratulations for an extremely successful 11.5 year mission for Jason-1

    - Approval of extended funding for Jason-2

    - Successful launch and commissioning of SARAL/AltiKa and fast delivery of high quality data products to the community

    - The OSTST appreciates the recognition by the agencies of the ongoing need to continue processing of Jason-1 data,

- Recommendation

    - Nominally, the current and projected launch dates for Jason-3 (March, 2015) and Jason-CS (2019 or later) may not leave sufficient margin for cross calibration between missions, and further slips will jeopardize continuity of the sea level record. Continuity being of the utmost importance, **the Ocean Surface Topography Science Team strongly recommends that space agencies strive toward an earlier launch date for Jason-CS and to maintain the current launch date of Jason-3 to ensure that there is overlap with the expected 5 year lifetime of Jason-3.**

Recently, NOAA has announced that it does not expect approval of its FY15 budget request for a new-start for Jason-CS and that it is now working on a FY16 request. This automatically introduces a 1-year delay into the start of development for the JPL payload instruments. With these new factors the readiness for launch is now moved from the Q4 2019 to the second half of 2020.