Report of the

Ocean Surface Topography Science Team Meeting

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Organized by NASA, CNES, NOAA and EUMETSAT

1. Table of Contents

2. Executive Summary

The 2012 OSTST Meeting was held in Venice, Italy on September 27-28. The meeting closed out a weeklong program of altimetry-related workshops in Venice, starting with the "20 Years of Progress in Radar Altimetry" Symposium (Sept 24-26), the "4th Argo Science" Workshop (Sept 27-29) and the IDS Workshop (Sept 25-26). This week was also preceded by the "6th Coastal Altimetry" Workshop (Sept 20-21) that was held in Riva del Garda, Italy.

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 scientific contributions have been removed from oral talks (only posters) as OSTST members have been requested to submit them to the "20 Years of Progress in Radar Altimetry" Symposium. 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-2012.html.

Jason-2 was launched in June 2008 on the former ground track of Jason-1 and TOPEX/Poseidon. All systems are in excellent condition and the satellite is operating nominally. The calibration and validation of Jason-2 data has shown that all mission and level 1 science requirements continue to be met. The GDR-D reprocessing is now completed and thanks to the errors discovered by the project in the altimeter measurement system (see OSTST 2011 report), **the altimeter bias is no longer distinguishable from zero. This reconciles the Jason-2 time series with the T/P one**.

Year 2012 has been an important milestone in the Jason-1 life as the satellite was successfully place into its geodetic orbit. Removing Jason-1 from the altimetry reference orbit accomplishes the primary goal of the Jason-1 End-of-Mission decommissioning plan: that of safeguarding the 1336-km altimetry reference orbit by minimizing the collision and debris risks to that orbit. Jason-1 continues to make an essential contribution to ocean surface topography and to geodesy (see section 6.3).

The Jason-3 development is nominal at satellite, instruments and ground levels. Even if minimal there are some changes and new features with respect to OSTM/Jason-2, e.g.: AMR on-board calibration following Lisbon OSTST recommendation and San Diego OSTST decision. An important milestone has been made with the launcher selection mid July 2012: Falcon 9 from SpaceX. **OSTST wants however to stress the importance of maintaining the December 2014 launch date for Jason-3 in order to preserve the continuity of the sea level record** (*postponed to March 2015 at the time of report writing*)**.**

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. At this stage of development two important issues (see § 5.2) were raised and intensively discussed in the various splinters: MicroWave Radiometer Configuration Option and Altimeter Mode of Operation. This lead to important recommendations (see § 9.5) that are summarized below:

1. **Jason-CS radiometer(s) instrument enhancements to enable long-term stability from the radiometer, eliminate dependence on ancillary data sources and reduce the latency of the final calibrated product. The Jason-CS system will also benefit significantly from a three-frequency radiometer. Finally, the most significant benefit from the embarkation of a second**

radiometer would be for the second radiometer to operate at high frequencies to improve coastally altimetry and inland hydrology applications

2. **The OSTST strongly recommends that the Jason-CS altimeter shall deliver both backward-compatible ("LRM") and high-resolution ("SAR") range measurements over all the ocean, seamlessly and simultaneously (interleaved mode).**

During this meeting but already beginning at San Diego last year, there were a lot of studies and discussions about SAR mode of measurement (see § 8.6). This not only linked to Jason-CS issues but also to current (CryoSat-2) and future (Sentinel-3) missions. The potential of such measurement system has been clearly noted (e.g. possible improvement in spectra between about 7 and 50 km wavelength) but on the contrary there are issues to be studied further notably concerning the link between LRM and SAR mode (possible biases) and also the SSB correction that has no history in the case of SAR mode. One of the raised issues concerns also the Calibration/Validation activities that can be difficult to realize in the case of missions using masks (coastal & inland waters versus open ocean) because in situ data are mostly located in coastal areas. As a consequence some recommendations have been made for CryoSat-2 and Sentinel-3 missions (see § 9.5):

<u>CryoSat-2:</u> Allow distribution of currently generated value-added science products made on a free and open basis. Provide a global seamless product over the ocean (LRM & SAR regions) as soon as possible.

<u>Sentinel-3:</u> the OSTST recommends that the area of Sentinel-3 SAR altimeter acquisitions be maximized over the ocean to include all open ocean, coastal regions and marginal seas.

3. Introduction

The 2012 OSTST Meeting was held in Venice, Italy on September 27-28. The meeting closed out a weeklong program of altimetry-related workshops in Venice, starting with the "20 Years of Progress in Radar Altimetry" Symposium (Sept 24-26), the "4th Argo Science" Workshop (Sept 27-29) and the IDS Workshop (Sept 25-26). This week was also preceded by the "6th Coastal Altimetry" Workshop (Sept 20-21) that was held in Riva del Garda, Italy.

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

4. Program and Mission Status

Pascal Bonnefond introduced the program managers to speak on the status of altimetry and oceanographic programs at NASA (Peter Hacker), CNES (Juliette Lambin), EUMETSAT (François Parisot), NOAA (Laury Miller) and ESA (Jérôme Benveniste). This year a common talk was leaded by François Parisot but given by each program manager and has been greatly appreciated for its efficiency.

François Parisot made the introduction by recalling the current status of the different missions (past, current and future). Figure 1 clearly shows that with the lost of Envisat (April 8th) the constellation is in a critical situation and the launch of SARAL/AltiKa, which is scheduled for December 12th (*postponed to February 2013 at the time of report writing*), is highly welcomed.

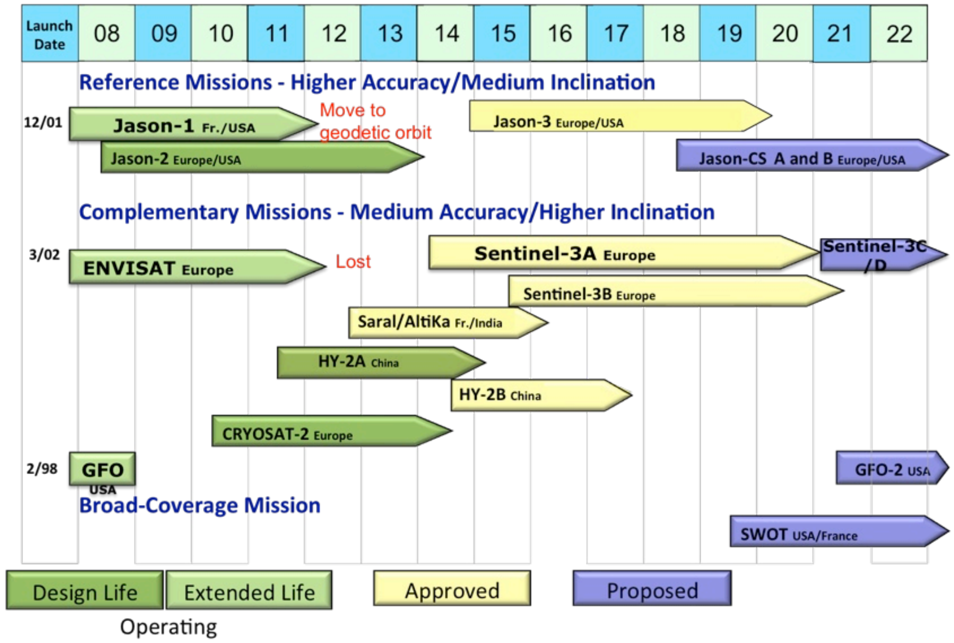

Figure 1. Missions' status.

Jérôme Benveniste reported on the status of the ESA program. He first reported on CryoSat mission status: the space and ground segment are very stable and instruments are functioning very well with no sign of major degradation (expected life time > 5 years); around 3 GB of data/day are delivered to the international community which has increased by 65% since launch and so the mission performance (i.e. mission data return) is greater than 97%; CryoSat mission is delivering high quality data to various user communities (i.e. ice, ocean, marine gravity) and to operational services (i.e. DUACS, NOAA); Baseline B was released on the 1st Feb 2012 and first reprocessing campaign has started: on Friday afternoon, Jérôme Benveniste also gave a short presentation on the CryoSat data access where he reported that all level 1b and level 2 (LRM, SAR, SARIN) as well as FDM (NRT Marine Product) are a "free dataset" available with a simple registration while a "restrained dataset" is available on request (FBR: SAR, SARIN; al FDM). CryoSat continues to meet and exceed its engineering specifications in all modes (LRM/SAR/SARIN) proving to be a precursor for future altimetry missions. Preliminary results show that the mission will meet its geophysical specifications and primary mission goals. The experimental verification of the scientific requirements must take into account a number of challenges some of which are constantly being tackled since the launch and even beforehand. A road map has been established by ESA with the support of expert teams to assess, by the end of next year, to which extent CryoSat has met its scientific requirements. By that time, the first estimation of the residual uncertainty and of the trend of sea ice mass in the Arctic will have been shown. The assessment of mission objectives for land ice will follow. Oceanographers and Marine Geodesists have shown that CryoSat will significantly contribute to their field (e.g. SAMOSA Project final report). Concerning the Sentinel-3 status, Jérôme Benveniste reported that phase C/D is ongoing with significant technical progress (completion of platform integration expected Oct. 2012) and that Preliminary Mission Analysis Reviews (PMAR's) with A- and B-unit launch providers (Eurockot and Arianespace) has begun and expected launch dates are respectively April 2014 and 2015. The two main issues are SLSTR and OLCI development schedules that remain on "critical path" (i.e. driving the schedule) and an anomaly during Solar Array Deployment Mechanism testing that is under investigation.

Juliette Lambin then reported on missions where CNES is involved. First on the HY-2A satellite that is a physical oceanography satellite from China National Space Administration (CNSA), embarking a Ku-C altimeter, a Ku/K/Ka radiometer, and LRA, GPS, DORIS for tracking systems. Its payload is also composed of a Ku-band Wind scatterometer and a 5-frequency radiometer (SST°). The CNES participation consists in POD processing and inclusion of altimetry data into AVISO multimission product (after validation); The orbit data are of good quality but for the moment, a limited set of altimetry data has been received at CNES; a dedicated presentation on "Altimeter Products Quality Assessment" was given on Friday afternoon by Peng HaiLong from NSOAS: HY-2 altimeter data are stable but further work is on-going to improve data quality and accuracy. Secondly, Juliette Lambin gave the status of SARAL/AltiKa mission that is a cooperation with ISRO (India Space Research Organization). It is a new technology mission (new Ka-band altimeter, higher precision, compact design, integrated radiometer/altimeter, with DORIS and SLR for POD) that will be also very useful as a gap filler between Envisat & Sentinel-3 sharing the same orbit than Envisat (35 days, Sun Synchronous Orbit); the other CNES payload are the Argos-3 instrument and a X-band telemetry. The current status is that the payload module arrived in ISRO mid-july, the bus-payload module mating is completed; Final testing is on-going and a launch is scheduled on December 12th (*postponed to February 2013 at the time of report writing*). The data policy will be the same as Jason missions and the PI is Jacques Verron (LEGI). Juliette Lambin then reported on CFOSAT that is a China-France Cooperation, currently in phase C/D with a launch date end of 2014. It will embark SWIM (Surface Waves Investigation and Monitoring), a new spaceborne instrument that has technology innovations (antenna, on-board digital processing) and SCAT, a new concept of wind scatterometer (Ku-band, rotating fan-beam). CFSOSAT will permit to have access to 2D wave spectrum with high angular resolution and with global scale and will perform joint measurements of winds and waves. Finally, Juliette Lambin reported on a phase 0 study that concerns an altimetry microsat constellation: The Iridium-NEXT study, that aims to embark 12-24 altimeters as passengers, showed that such concept could provide a very viable and interesting approach to altimetry constellation. However, the study, constrained by the Iridium constellation design, could not explore other orbital configurations, payload concepts then require new technological developments. As SWOT will provide very high resolution over a relatively small swath, and a fairly long revisit, this is an "extreme" in the resolution-coverage/revisit trade space, then other altimetry missions in constellation ("operational constellation" Jason-2/3/CS + SARAL/Sentinel-3A&B … or other) will be needed to provide the revisit capability. The current "virtual constellation" concept is not sufficient for a variety of applications that are not mainstream altimetry (real-time, coastal/inland/ice, sea state…) then it is needed to reopen some of the user requirements in a constellation design. As there is no imminent programmatic opening on CNES side to really decide such a constellation, this phase 0 study is more intended to define different scenarios and what would be the steps to achieve for their realization. This needs to define a "mission group" representing different potential user of such constellations.

François Parisot followed by reporting on Jason-CS Programme status: satellite Phase B is on going with some key trade off (see section 0 for details): a Preliminary Programme Proposal was approved by last EUMETSAT Council. Two letters of NOAA are confirming the U.S. Interest to participate in the programme with the contributions defined by the Preliminary Programme Proposal (14 December 2011 and 9 May 2012). A letter of comfort from the European Commission confirmed that EC shares the common baseline (4 April 2012) but cannot commit on its funding now. The next milestone is ESA C-MIN in November this year for a decision for Phase B2/C0, decision on phase B/C/D will be in 2014: this needs a coordinated and timely aligned decision process by all partners (commitment by March 2014 at the latest). Currently there is also a need to work at System and Ground System level: documentation tree, End User Requirement Document, Mission Requirement Document, System Requirement

Document, products definition, Ground System Architecture, Earth terminal network, Operation Concept.

Peter Hacker reported on the SWOT mission status. In July 2012 there was a Science Definition Team review of the 41 proposals submitted to NASA. Results will be announced in Oct. 2012. On Sep. 13-14, 2012 a successful Mission Concept Review (MCR) of SWOT was held at JPL. The next milestone is on October 31, 2012 for a KDP-A (Key Decision Point) review at NASA HQ.

Concerning the status of the Joint Research Announcement for OSTST renewal, it was issued on 31/01/2012 in full alignment with NASA ROSES call for OST: in July 2012, 60 proposals were reviewed at NASA while over 50 proposals have been received by EUMETSAT and CNES. The selection process is ongoing and outcome will be released after OSTST meeting, but before Jan 2013. The Joint Research Announcement covers the period from Jan-2013 to Dec-2016 (Jason-3). After that perhaps a new future for the OSTST (Jason-CS period) with wider agency participation will be elaborated: link between OSTST and "OST Virtual Constellation" but also look at the Virtual Constellation for Sea Surface Temperature, Ocean Surface Winds, Ocean Color, …

5. Jason missions Project Status

5.1. Jason-1/2/3

5.1.1 Jason-1

Glenn Shirtliffe provided an overview of Jason-1 status and notably on the move to its geodetic orbit. Jason-1 completed 50,000 orbits on 18 September 2012 and continues to exceed all Level-1 Science Requirements , despite the loss of reaction wheel #1 in November 2003, the loss of half-satellite (PMB) in September 2005 (Tx), the gyro #1 anomaly in March 2010 and switch to Gyro #3 in April 2010, the loss of double reconfiguration capability in safe hold mode, the ageing of the RAM: following this two last events, on 12 April 2012, the CNES—NASA Joint Steering Group (JSG) determined that due to the state of the spacecraft after the safe hold events of early 2012, Jason-1 should immediately be moved to the planned geodetic orbit. The operations began on 23 April and Jason-1 returned to NOMINAL mode on 24 April. An over consumption was detected on maneuvers 4 & 5 and then decision was taken to stop the operations at -12 km after validation that the current orbit was a "geodetic" one: the lesson learn is to define new hydrazine margins for other missions (Jason-2) based on the Jason-1 in-flight experience. Finally, Jason-1 was verified to be in a usable geodetic orbit (see Table 1) on 4 May and POSEIDON-2 altimeter restarted on 7 May (first restart was unsuccessful on 4 May). The Product generation restarted on 9 May. As Jason-1 is now below Jason-2, operation team must monitor impacts of Jason-2 overflights every 33 days: Jason-1 altimeter does not transmit when passing under Jason-2 (In INIT mode for ~3 hours) and Jason-2 altimeter will not transmit if passing directly over Jason-1.

The project team has decided to keep a GDR sub-cycle of 11 days (full cycle = 406 days) to avoid major upgrades in the processing centers: no changes to product nomenclature neither in data latency (3h, 2-3 days, 30 days). Routine OPS procedures for the geodetic mission are in place at CNES & NASA/JPL and decommissioning plans and procedures for the final Jason-1 end-of-mission are also in place.

A Technical Note about the Jason-1 Geodetic Mission was issued on 24 May 2012, by E. Bronner (CNES) and G. Dibarboure (CLS) (SALP-NT-MA-16267-CNv1.0). This document describes the motivations for the orbit change and impacts and constraints of the new geodetic orbit. It also provides important user information and FAQs. This Technical Note is available from:

http://www.aviso.oceanobs.com/fileadmin/documents/data/duacs/Technical_Note_J1_Geodetic_Mission.pdf

The move to a long-repeat orbit will result in a substantial improvement in resolution of the marine geoid. This will result in significant improvements in estimates of deep ocean topography, resolving many presently unknown seamounts and other geologic features on the ocean bottom. This will be a new and important contribution from Jason-1. Improvements in bottom topography will be of value in ocean modeling (e.g., allowing improved representation of topographically induced mixing), in naval operations, and in solid Earth dynamics. Improvements in the geoid will also increase the value of historical altimetry data, such as from GEOSAT, and be useful (at least initially) for interpretation of the planned SWOT mission. Removing Jason-1 from the altimetry reference orbit accomplishes the primary goal of the Jason-1 End-of-Mission decommissioning plan: that of safeguarding the 1336-km altimetry reference orbit by minimizing the collision and debris risks to that orbit.

Jason-1 continues to make an essential contribution to ocean surface topography and to geodesy (see section 6.3).

Table 1. Orbital elements of Jason-1 on its geodetic orbit.

Semi major axis	7702.437 km
Eccentricity	1.3 to 2.8 E-4
Altitude at Equator	1324.0 km
Orbital Period	6730s (1h 52’ 10’’)
Inclination	66.042°
Cycle	406 days
Sub-Cycles	3.9, 10.9, 47.5, 179.5
Type	12+299/410

5.1.2 Jason-2

Thierry Guinle reported on Jason-2 status: Jason-2 satellite has an excellent behavior and all satellite and system performances requirements are fulfilled with large margins. Jason-2 satellite is then fully operational after more than 4 years in orbit and has successfully passed the REView of EXploitation (REVEX, May 9-11, 2012). The Operational Routine Phase is nominal and all products are now produced in GDR-D standard: the performances in term of OGDR data latency exceed the requirements (75% of OGDR data within 3 hours from sensing / 95% of OGDR data within 5 hours from sensing) as measured either at EUMETCast end user level (91 % in less than 3 hours / 98 % in less than 5 hours) and NOAA ESPC production level (94 % in less than 3 hours / 98 % in less than 5 hours). Global Jason-2 system availability is 99.9 % and also exceeds the requirement: the GDR shall contain 95% of all possible over-ocean data (acquisition and archive) during any 12 month period, with no systematic gaps.

The Jason-2 GDR-D reprocessing was on going at the time of the meeting and has been completed in November this year. Systematic cross-checked validation is realized by CNES and JPL and for each cycle and a full validation report is produced by CNES (see ftp://avisoftp.cnes.fr/AVISO/pub/jason2/gdr). The reprocessed and validated cycles are available on AVISO ftp server.

As proposed and accepted in San Diego, a new release of DIODE software (v11) is now on-board. Main evolutions are: PAPEETE as a Master Beacon, Hill along-track acceleration and OAP formula change. This issue has been activated on September 19th and the expected performance for real-time orbit accuracy (OGDR) is 2.7 cm (radial rms) (18% improvement): this will be confirmed with flight data by comparison with POE orbit.

AMR continues to provide excellent performance and exceeds all requirements. However, without ARCS processing, Path Delays derived from AMR measurements would exhibit 7 mm/yr drift. ARCS processing mitigates large Brightness Temperature drift on operational GDRs. In term of Path Delay the improvement thanks to GDR-D permits to estimate that the drift is far below 1 mm/yr while it was just below 1 mm/yr for GDR-T products. GDR-D product also includes new processing to produce valid Path Delay in the coastal zone in addition to radiometer rain and sea ice flags: AMR enhanced product is also currently available via PO.DAAC.

5.1.3 Jason-3

Véronique Couderc on behalf of Gérard Zaouche gave the report of the Jason-3 project. The objective of the Jason-3 Mission is to provide continuity to the unique accuracy and coverage of the TOPEX/Poseidon, Jason-1 and OSTM/Jason-2 missions in support of operational applications related to extreme weather events and operational oceanography and climate applications and forecasting. The Jason-3 Programme is led by the operational agencies EUMETSAT and NOAA, with CNES making a significant in-kind contribution and acting at technical level as the system coordinator. NASA in conjunction with EUMETSAT, NOAA and CNES will support science team activities.

The Jason-3 development is nominal at satellite, instruments and ground levels. Even if very close some changes and new features wrt OSTM/Jason-2 have been realized, e.g.: AMR on-board calibration following Lisbon OSTST recommendation and San Diego OSTST decision using satellite pitch maneuvers (80°off nadir), change of DORIS antenna location for compliance with each potential launch vehicle while waiting for the selection.

An important milestone has been made with the launcher selection mid July 2012: Falcon 9 from SpaceX. Next step is to deeply assess the compatibility between the new launcher and the satellite. The selection of a new launcher must also be taken into account in the safety process. Intensive work is needed to consolidate the interfaces definition and coordinate the launcher development plan with regard to the satellite integration milestones: Jason-3 Launch is planned in December 2014 (*postponed to March 2015 at the time of report writing*). Payload AIT (Integration and Tests) and then Satellite AIT will be the key events of 2013. Technical Qualification of the Ground System will also be demonstrated in 2013.

5.2. Jason-CS issues highlights (altimeter & radiometer)

Hans Bonekamp presented the two important Jason-CS issues to be discussed inside the splinters:

1. MicroWave Radiometer Configuration Option
2. Altimeter Mode of Operation

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. The radar altimeter, known as Poseidon-4, is adapted from the Sentinel-3 SRAL with heritage from CryoSat's SIRAL and Jason-1 (Poseidon-2), Jason-2 (Poseidon-3a) and Jason-3 (Poseidon-3b).

5.2.1 MicroWave Radiometer Configuration Option

For programmatic reasons, one of the satellite configuration options under feasibility study is the embarkation of both US and EU radiometers either as entirely separate payload elements or by sharing the antenna of one of the radiometers (the JPL antenna has been considered to date). The reasoning behind this decision comes from the outcome of a recent ESA satellite review that concluded in Feb. 2012. The Design Consolidation Review (DCR) concluded that since the US contribution to the Jason-CS programme will not be determined before mid-2014 (for financial year 2015) then there will be a need for a European radiometer solution in the unfortunate event that the AMR-C is not contributed. If the AMR-C is funded then the EU-MWR will remain as part of the payload, since will have been agreed by ESA member states and the satellite design will be such that it will not be simple to remove the instrument.

The concept will be to operate both radiometers simultaneously, unless satellite power margins reduce after the end of nominal mission lifetime to levels that would constitute a selection of either radiometer to be switched off periodically or completely. However, it must be stressed the mission is being designed such that it will meet mission requirements with the operation of either radiometer.

For the same programmatic reason the EU option is undergoing a feasibility study for the addition of a third frequency channel that would be implemented in the event the US contribution does not cover the embarkation of the AMR-C within the Jason-CS payload.

Although the programmatic reasons are clear there are some key science questions to be raised. Namely:

1. Are the scientific benefits of a three-frequency radiometer over a two-frequency system clear enough to recommend one or the other for Jason-CS?

2. Is there any science benefit to having two radiometers on-board? In particular:

    a. Could the simultaneous operation of two radiometers be an asset in terms of estimation and effective minimization of radiometer drift in wet tropospheric path delay retrievals?

    b. Would there be any science benefit in having different centre frequencies for the two radiometers, considering the frequency channel used to estimate the cloud water content is already different between the MWR and AMR-C?

5.2.2 Altimeter Mode of Operation

The current baseline instrument design, planned to be implemented is based on the Sentinel-3 SRAL and allows operation in either LRM or SARM separately over different geographical regions (in the same manner of operation to CryoSat-2), with LRM being operated over open ocean and SARM over coastal regions. Though this baseline is designed to meet mission requirements, there are strong concerns as to how one can calibrate the open ocean LRM retrievals based on coastal SARM retrievals whilst the knowledge of the sources of uncertainty between the two modes are limited and majority of tide gauges are located only where SARM data will be acquired.

An improved design that allows continuous bursts of pulses to be transmitted and received that would allow an on-ground processing to either generate Brown echoes, or SAR echoes from measurement data acquired simultaneously over the same ground track. Based on the outcome of the project Design Consolidation Review (DCR) completed in Feb. 2012, this mode of operation is currently under an extended feasibility study until February 2013. The study covers handling at instrument and system level and will also determine impacts to the programme in terms of cost.

In both cases, the designs will meet the mission requirements as they stand today. However, there are arguments as to why one configuration may be chosen over another. There are a number of fundamental questions relating to the baseline mode of operation that need answering over the next few years covering and that have been addressed to this OSTST meeting and among them:

a. Where does one operate SARM and LRM as a function of geophysical location?

- In order to size the system the geographical choice SAR operation was chosen, for Jason-CS to be over regions where the ocean is <1000 meters deep around the major continents.

- It is recognized that this approach is not be the optimum choice for eventual in-orbit operations and thus if the baseline is adopted for implementation then there will need to be a consultation in order to focus the regions for which LRM and SAR modes would be operated. That consultation will then need to be consolidated with system constraints (data, thermal and power budgets) similar to CryoSat-2 mode mask changes implemented following the OSTST 2011 meeting.

b. Is there a consistent understanding of the uncertainties between LRM and SARM if one wants to validate with tide gauges and thus how does one calibrate LRM retrievals against calibrated SARM retrievals?

c. If one generates Brown echoes from the SARM data stream then how do errors compare with those from the LRM data?

d. How are SAR mode retrievals sensitive to, for example:

- Platform pointing: SAR retrievals have been shown to be sensitive to pointing.

- SWH

- Directional waves

e. Can SAR mode bursts be processed in a pulse-width limited manner to generate Brown model echoes effectively?

6. Discussion Points for Splinters

Prior to the beginning of the splinter sessions, three presentations in addition to the Jason-CS issues one (see section 0) were given to provide key information for consideration in certain splinter sessions.

6.1. Remaining geographical or seasonal correlations in the errors (Dorandeu et al.)

This presentation gave meaningful examples of altimeter error characterization but also served as an introduction to the splinter session "Quantifying Errors and Uncertainties in Altimetry Data". The "conventional" error budget that try to answer to the question "is the altimeter system within specifications?" mixes white noise, media errors, long wavelength errors, HF/LF errors in a single RSS calculation. The answer is more complicated: it depends on targeted applications (needs) and on the considered wavelengths/frequencies. For each specific application domain, a dedicated global altimeter System error should be derived trying to estimate how much does each error term alter the observation of each ocean process. For example, climatologists want to know MSL errors (global, local…), oceanographers need precise and complete error estimates as entry of ocean model assimilation. Moreover, not only static (estimated once), but dynamic error estimates are necessary (accounting for sensor evolutions, geophysical variations). In conclusion the new "Quantifying Errors and Uncertainties in Altimetry Data" splinter should focus on:

- A cross-cutting activity among all the splinter sessions: thematic and CALVAL
- A specific effort for defining error estimation protocols
- Going further than the "simple" error budget table
- Separating spatial and temporal errors
- Characterization of the errors according to wavelength/frequencies to address specific applications
- Users, applications should be engaged in defining the requirements, depending on their domain:
  - Climate scientists are pushing a lot: good improvements in error characterization in the last few years
  - Other applications should also be more engaged: e.g. assimilation into ocean models

6.2. Seamless transition from ocean to coastal retracking algorithms (Quartly, Cipollini et al.)

Graham Quartly gave a presentation showing the variety of the waveform encountered in relation to coastal contamination but also local sea state conditions. As for the moment no retracker is able to account for all situations, it is important to minimize the effect of switching retrackers. One parameter is to evaluate at what distance (coastal proximity or some property of waveform) does the open ocean retracker variability increase but also how coastal retracker is variable in open ocean and how it is biased relatively to open ocean tracker. In summary the raised points for discussion are:

- There is a clear need for specialist retrackers
- Mean offset can be removed but there is a need to minimize the variability of offset: model offset as f(Hs,σ_0)
- Characterize r.m.s. of the tracker change: 20 Hz?, 5 Hz?, Spectral description
- Characterize the transition: how near to coast? Sharp or fade?
- Characterize non-oceanic returns in open ocean: storms, slicks, sea-ice, …

6.3. Future scientific outlook for Jason-1: geodesy and oceanography (Sandwell, Dibarboure et al.)

Gerald Dibarboure for the oceanographic part and David Sandwell for the geodetic part shared this presentation. The Jason-1 SSH error budget is mostly unchanged (payload status is ok, see § 5.1.1) but the new drifting ground track imply that T/P-based history is no longer usable then the temporal average for SSHA is now based on a gridded Mean Sea Surface model. Even if static and correlated error on Jason-1 GM SSHA remains at good precision level (2 to 3 cm RMS), the main risk is that false stationary eddies in SSHA should be injected in ocean models. Such an artifact was already detected on Envisat where the SLA variance increased when Envisat left the charted ERS track for a geodetic drifting orbit: +11 cm RMS with 2001 MSS model and +2.5 cm RMS with 2011 MSS model. This reinforces the need of very precise fine scale MSS models. However, the added value of higher spatial resolution from the additional geodetic missions probably outweighs the errors in MSS references. In term of sampling, there is no more coordination with Jason-2 leading to Moiré patterns (2800 km bands) between Jason-2 and Jason-1 tracks and the temporal desynchronization implies a drift of the relative sampling patterns. As a results also, a fraction of the Jason-1 GM sampling is lost (duplication with Jason-2). Concerning the mesoscale monitoring, Gerald Dibarboure recalled that 2 altimeters are needed for delayed time and 3 for near real time. As Envisat was lost last Spring only Jason-2 and Cryosat-2 are available but the sampling/orbit of the latter is not optimal for mesoscale. Jason-1 GM thus remains a strong asset until SARAL/AltiKa or Jason-3 (or HY-2A) are validated and available in NRT: Jason-1 data have been then routinely re-ingested by AVISO/DUACS since May and routinely assimilated into global and nested systems from NRL, CSIRO, Mercator and most GODAE-OV models. On the other hand, the new sampling does not affect Jason-1's ability to monitor MSL as the global & regional trends are barely affected by the sampling pattern. However, the new phase could introduce a bias in the Jason-1 GM series that should be handled with care (e.g. TOPEX A/B transition) and measured through comparisons with Jason-2, tide gauges, or ARGO. In conclusion, oceanographers are still successfully using Jason-1 GM and they probably will until its very last measurement. Moreover, Jason-1 is still a valuable source of data for wind and wave.

For the geodetic part of the presentation, David Sandwell first recalled the numerous applications of non-repeat altimetry that can be divided into two main groups: Gravity/SSH (average SSH for variability, plate tectonics, planning ship surveys, inertial guidance, petroleum exploration, …) and Topography (seafloor roughness, linear volcanic chains, tsunami models, tide models, tidal friction, thermohaline circulation, planning undersea cables, law of the sea, education and outreach, …). He also recalled that achieving 1 mGal gravity accuracy (1 cm over 10 km) requires:

- Improved range precision: a factor of 2 or more improvement in altimeter range precision, with respect to Geosat and ERS-1, is needed to reduce the noise due to ocean waves.
- Fine cross-track spacing and long mission duration: a ground track spacing of 6 km or less is required.
- Moderate inclination: current non-repeat-orbit altimeter data have high inclination and thus poor accuracy of the E-W slope at the equator. Indeed orbit inclination controls error anisotropy (orthogonal tracks are optimal)
- Near-shore tracking: for applications near coastlines, the ability to track the ocean surface close to shore is desirable.

Without Jason, the error in the east slope component is large and so N-S features such as the East Pacific Rise will be poorly resolved. One 409-day cycle provides about 25% improvement in east slope and two cycles provides about a 33% improvement. Most of the area of the earth is at latitude less than 60 degrees where Jason will make the largest improvement. Pre-Jason-1/CryoSat gravity accuracy was 2-4 mGal with large EW errors. The lower inclination of Jason-1 will result in gravity accuracy 1-2 mGal if 406 days are collected. An additional 406 days could result in ~1 mGal global marine gravity accuracy.

7. Poster Sessions

A poster session was conducted into two parts on Thursday morning and evening and the posters were on view during the coffee breaks throughout the entire two-day meeting. Links to the posters are available on the meeting website: http://www.aviso.oceanobs.com/en/courses/sci-teams/ostst-2012/ostst-2012-posters.html

The posters were grouped into the following categories:

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

8. Splinter Sessions

The splinter sessions were organized as follows:

Thursday, September 27:

- Splinter Session I
    - Regional and Global CAL/VAL for Assembling a Climate Data Record (Part I)
    - Tides, internal tides and high-frequency processes
    - Outreach, Education & Altimetric data services
- Splinter Session II
    - Regional and Global CAL/VAL for Assembling a Climate Data Record (Part II)
    - Near Real Time Products and Applications
    - The Geoid, Mean Sea Surfaces and Mean Dynamic Topography

Friday, September 28:

- Splinter Session III
    - Instrument Processing (Part I): Wet and Dry troposphere, Ionosphere and Sea State Bias
    - Instrument Processing (Part IIa): LRM/SAR, retracking
    - Precision Orbit Determination (Part I)

    - Quantifying Errors and Uncertainties in Altimetry Data (Part I)
- Splinter Session IV
    - Instrument Processing (Part IIb): LRM/SAR, retracking
    - Precision Orbit Determination (Part II)
    - Quantifying Errors and Uncertainties in Altimetry Data (Part II)
- 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-2012/ostst-2012-presentations.html

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

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

8.1.1 Introduction

CAL/VAL activities are conducted based on dedicated in-situ observations, 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.

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, and Envisat "GDR-C"). While not the emphasis of the session, comparisons involving other missions (e.g EnviSat and HY-2A) were also solicited.

The primary goals of this session were:

- to assess the performance of the measurement system, including the altimeter 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.

8.1.2 Results from in-situ calibration sites

Absolute bias estimates from dedicated sites and also from regional experiments showed a good coherence of results with 10–15 mm RMS differences for T/P, Jason-1, and Jason-2. ***For the first time since Jason-1 launch, none of the altimeter measurement systems show any unexplained biases.***

- The Jason-2 SSH bias for GDR-D is statistically indistinguishable from zero with consistent results from Corsica, Harvest, and Bass Strait (Figure 2 and Table 2). The elimination of the bias present in GDR-T has been primarily due to corrections to Ku range (~15 cm bias) and a secondary contribution (~3-cm bias) from the sea state bias correction.
- While the Jason-1 SSH bias for GDR-C is ~9 cm for the dedicated sites, application of GDR-D standard corrections to Jason-1 data is expected to reduce 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.).

Table 2. Averaged values of the altimeter biases from absolute calibration experiments.

Mission, Altimeter	Bias (mm)	Contributors
T/P, ALT-A	3.4 ± 4.4	Haines et al., Bonnefond et al., Watson et al.
T/P, ALT-B	5.2 ± 3.5	Haines et al., Bonnefond et al., Watson et al.
T/P, POSEIDON-1	–3.1 ± 7.9	Haines et al., Bonnefond et al.
Jason-1, POSEIDON-2	89.9 ± 2.3	Haines et al., Bonnefond et al., Watson et al.
Jason-2, POSEIDON-3, GDR-D	2.9 ± 3.7	Haines et al., Bonnefond et al., Watson et al.

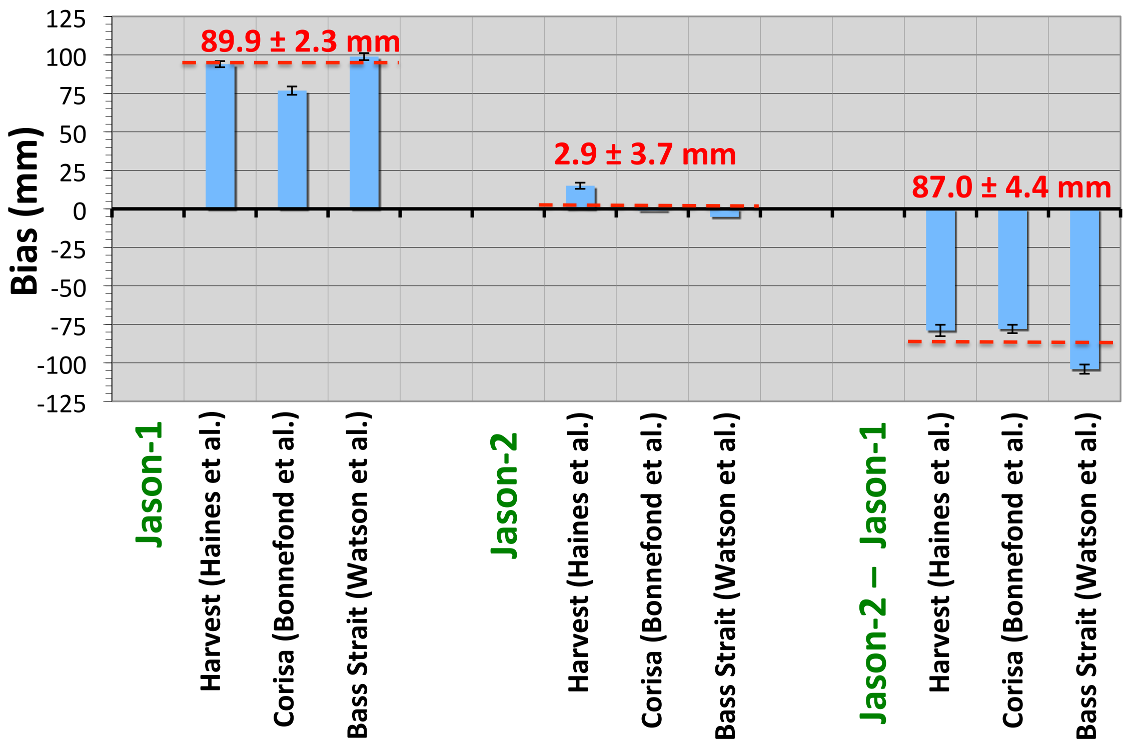

Figure 2. Absolute bias values for Jason-1 and Jason-2 from the different calibration sites using the latest versions of the official products (Jason-1 GDR-C and Jason-2 GDR-D).

Emerging calibration programs (e.g., Gavdos, ACTION, FOAM) 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.).

Enhanced wet path delay (EPD) corrections continue to prove valuable for (land-contaminated) calibration sites.

The nominal (MLE4) retracker on Jason-2 GDR-D yields the best results at Harvest and Corsica. MLE3 leads to a higher scatter and ~3 cm upward shift in SSH bias as compared to MLE4 (*Haines* et al.). The 3-cm SSH bias between MLE3 and MLE4 is due primarily to a corresponding bias between the respective sea state bias corrections.

The transponder deployed at Gavdos yields outstanding (cm-level) repeatability in bias determinations for Jason-2. A ~6 cm bias, possibly due to transponder calibration, remains unexplained. Improved geoid models have extended the calibrating regions. Calibration of HY-2 in Crete has been commenced. Further deployments of the transponder for Cryosat-2, Jason-2, Sentinel-3, and HY-2 are pending. There are plans for installing a HF radar to verify ocean circulation and for measuring absolute gravity at Gavdos (*Mertikas* et al.).

8.1.3 Results from global comparisons tide gauges and altimetry sea level records

Comparisons to Jason-1 and Jason-2 interleaved data produce different stabilities depending on which gauges are used. Recent land motion at some gauges may be affecting stability estimates.

8.1.4 Global validation studies

JASON-2 MISSION

Reprocessing of Jason-2 GDRs to version D (GDR-D) standards is 70% complete (completed since end of 2012), and global validation studies support that data quality for GDR-D is noticeably better than GDR-T (*Phillips* et al.). SSH crossover variance is lower than GDR-T by 200 mm^2 (Figure 3), primarily from improvements in precise orbit ephemeris (*Desai and Haines*). Radial orbit errors remaining in GDR-D are below 1 cm (RMS) but continue to show some geographically correlated patterns. The application of improved time variable gravity in dynamic orbit solutions leads to better long-term stability, as shown in comparisons with the tide gauge network (Figure 4).

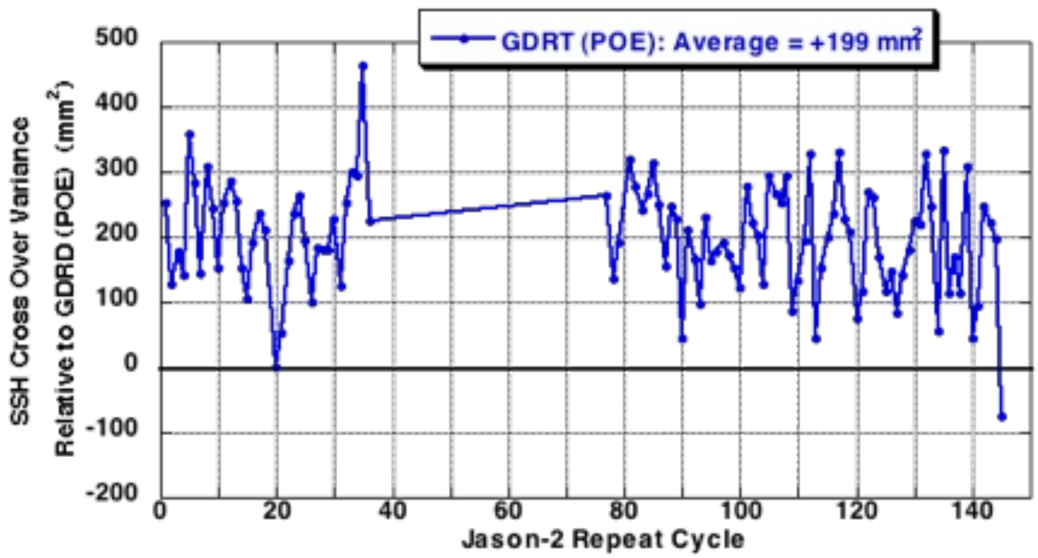

Figure 3. Crossover variance in SSH between GDR-T and GDR-D.

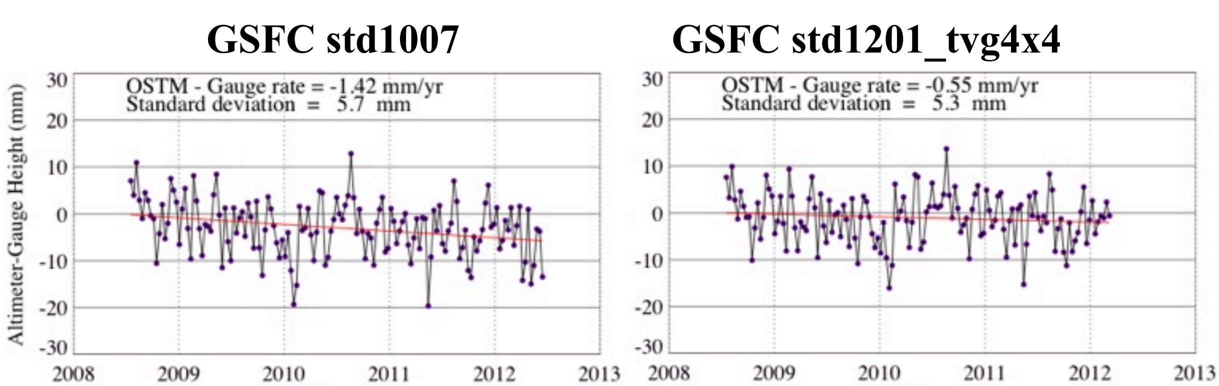

Figure 4. Impact of revised time-varying gravity on Jason-2 SSH stability assessment. The time-varying gravity model std1007 uses annual and linear terms derived from SLR and GRACE data. The model tvg4x4 uses the gravity coefficients to degree and order x4 derived weekly from SLR/DORIS tracking to 10 satellites from 1993.

Biases in the SSH, time tag, ionosphere delay, and wind speed have been resolved through application of:

- Correct antenna reference point.
- Improved precision on Pulse Repetition Frequency
- Sigma0 calibration bias of 0.32 dB to align to Jason-1 and facilitate continued use of Jason-1 wind speed model.
- Updated sea state bias model that also improves the consistency between Jason-1 and Jason-2 ionosphere path delays.
- Time-tag processing anomaly correction.
- Climate quality radiometer calibrations for cycles 1-113.

Compared to MLE4, the MLE3 altimeter data have lower 20-Hz noise, but SSH crossover variance is higher (23 mm^2) on average (Figure 5) (*Desai and Haines*). MLE3 and MLE4 data provide slightly different regional sea level, which is attributable to differences in sea state bias models (Figure 6) (*Leuliette* et al.).

The JPL GPS orbit reduces SSH crossover variance by 60 mm^2 on average (Figure 5) (*Desai and Haines*).

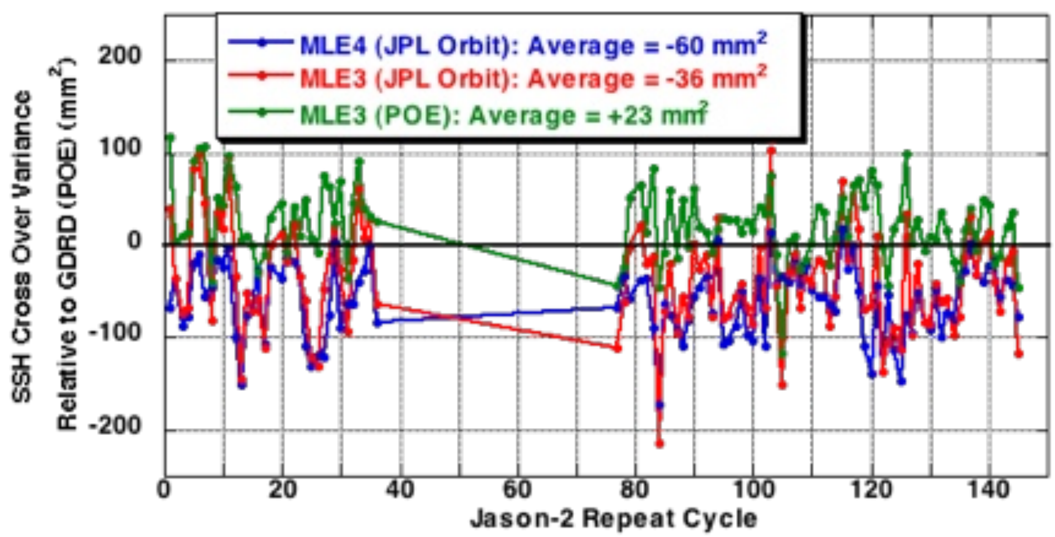

Figure 5. SSH crossover variance (mm2) relative to GDR-D.

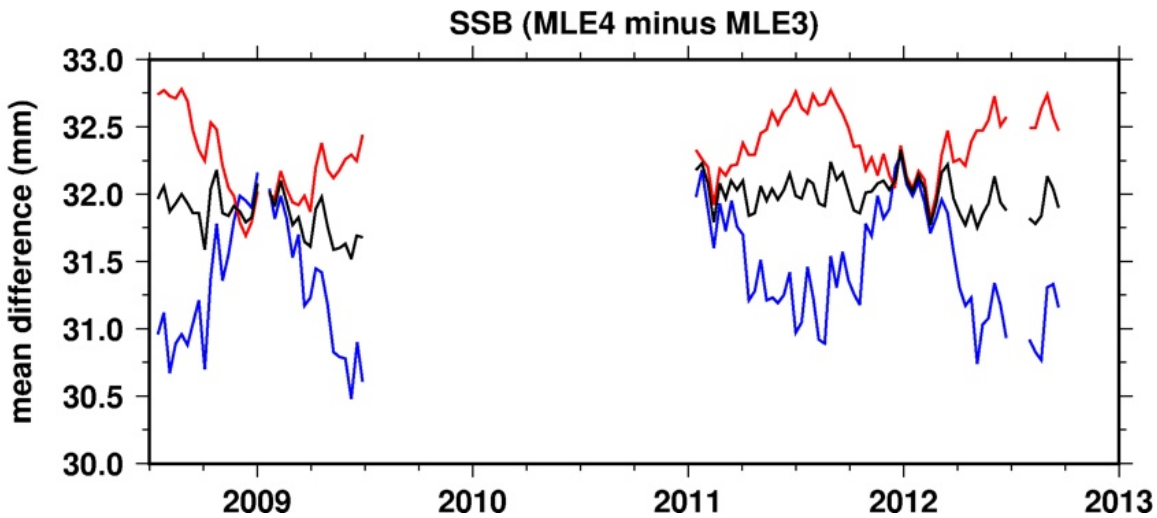

Figure 6. Mean difference in the sea state bias corrections from MLE3 and MLE4 retracking for global (black), Northern Hemisphere (blue), and Southern Hemisphere (red) averages.

JASON-1 GEODETIC 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). After calibrations related to changes in the Jason-1 orbital altitude and altimeter pulse repetition frequency, GDR production resumed in September 2012. The Jason Microwave Radiometer (JMR) continues to experience episodic bias shifts. Unlike for the Jason-2 microwave radiometer (AMR), calibrations are not performed regularly for the wet troposphere path delay included on the Jason-1 GDR-C (*Roinard* et al.),

ENVISAT

While the Envisat mission ended 8 April 2012, reprocessing continues to improve historical data quality. Reprocessing of Envisat data to Version 2.1, which has shown significant improvements in data quality, was completed in January 2012. Additional upgrades after V2.1 reprocessing continue to improve data quality, particularly for providing stable measurements of the global mean sea level for climate applications. These upgrades include reprocessing orbits to GDR-D standards, additional improvements to the wet troposphere correction, and new point-target response (PTR) corrections. Comparisons with Jason-1 and Jason-2 show improved consistency, however there are unresolved differences for first year (2003) of Envisat (*Ollivier* et al.).

CRYOSAT-2

Conventional retracking of low-rate mode (LRM/Level 1B) CryoSat-2 over the ocean data shows excellent quality: Despite the lack of a radiometer on board CryoSat-2, the crossovers differences in SSH and SWH with Jason-2 are comparable to those between Jason-1 and Jason-2 (Table 3) (*Scharroo* et al.).

For the ocean regions where CryoSat-2 operates in delay-doppler/"SAR" mode, retracking using a pseudo-LRM (PLRM) algorithm that stacks SAR echoes was demonstrated. SSH and SWH from pseudo-LRM retracking was shown to produce data with higher levels of 20-hz noise (√3) than conventional retracking of LRM mode, as expected. For 1-Hz pseudo-LRM retracking, the quality is comparable to the results from LRM mode with no apparent bias with regions of LRM data (Table 3), allowing for a seamless coverage (Figure 7) (*Scharroo* et al.).

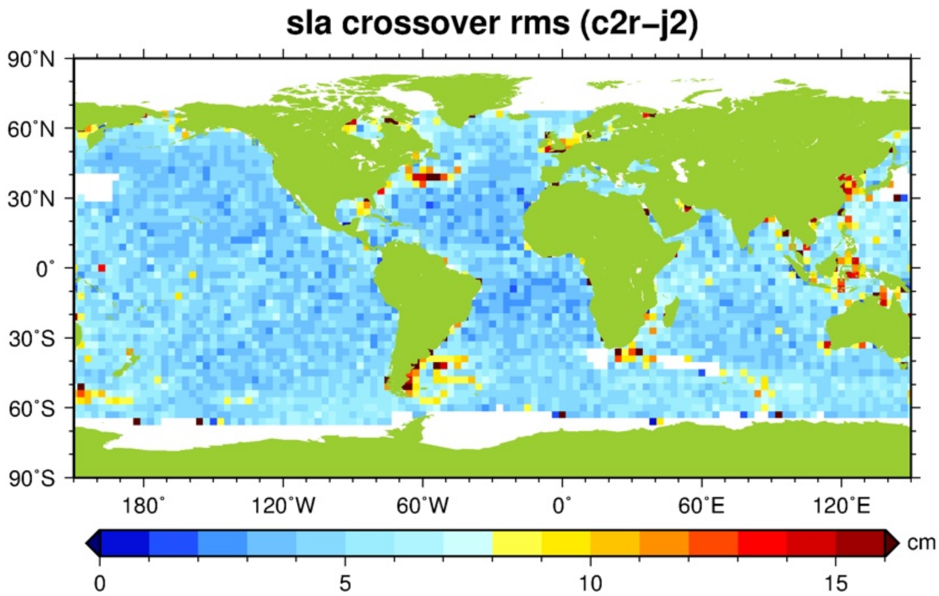

Figure 7. Sea level crossovers in cm between Jason-2, and CryoSat-2 from conventional retracking of low-rate mode (LRM) and pseudo-LRM (PLRM) retracking during SAR mode.

Table 3. Sea level crossovers between Jason-1, Jason-2, and CryoSat-2 from conventional retracking of low-rate mode (LRM) and pseudo-LRM (PLRM) retracking during SAR mode.

	SSH mean (cm)	**SSH std. dev. (cm)**	**SWH mean (m)**	**SWH std. dev. (m)**
CryoSat-2 LRM – Jason-1	–0.96	6.35	+0.12	1.23
CryoSat-2 PLRM – Jason-1	–1.73	6.27	–0.04	1.24
CryoSat-2 LRM – Jason-2	–0.57	5.30	+0.10	1.20
CryoSat-2 PLRM – Jason-2	–1.46	5.87	–0.03	1.22
Jason-1 – Jason-2	+0.37	6.40	–0.01	1.21

HY2-A

HY2-A was launched in August 2011 and an evaluation of instrument performance indicates a potential for good data quality. Preliminary IGDR data are available to the altimetry community for evaluation. The IGDR data quality appears to have significant potential for improvements and at present do not seems to represent true instrument data quality. Crossover differences and the accuracy of sea level anomalies are slightly worse than Jason standards. Including HY2-A IGDR data can provide valuable information for mesoscale variability (*Legeais* et al.).

ARGO AND GRACE

The comparison of altimeter measurements with combined in-situ Argo profiles and GRACE data in the open ocean is accurate enough to detect global and regional altimeter MSL drifts and other anomalies and to assess the impact of new altimeter standards (*Leuliette* et al. and *Legeais* et al.).

8.1.5 Round table summary

Jason-CS operating mode recommendation (SARM versus LRM)

- The pros and cons of different operating modes (SARM, LRM, and interleaved) were discussed. There was consensus that in order to provide continuity of service, Jason-CS measurements should be globally compatible with previous reference missions and then the interleaved mode is clearly required.
- With no high-quality dataset of SAR-mode results publicly at the time of the OSTST, concern was expressed that the Cal/Val community could not adequately address questions about the value of SARM versus LRM mode. However, it was suggested that the Cal/Val team could describe the methods and data needed to assess benefits and risks of SAR modes (e.g., during the commissioning phase). It was suggested that global SARM coverage over a long period (all sea state conditions, in-orbit conditions) would be ideal, but smaller datasets in space or time, such as those provided by Cyrosat, might suffice.
- Because SAR mode will give measurements closer to the coast where current standard retracking fails, it was suggested that the new coastal retracking algorithm for current LRM missions needs to be cross compared with SARM in coastal areas.

Jason-CS radiometer recommendation

- There was a suggestion that the most significant benefit for including a second radiometer would be for it to include high frequencies able to resolve km-scale water vapor to improve coastal observations.

Structure of the splinters

One proposal was for dedicated project meetings before the OSTST to allow for more detailed discussions at the meeting and more feedback from users at the OSTST.

Other questions discussed at the round table:

- Is it possible to reduce the latency of GDR production?
    - *Discuss the possibility of increasing the latency of the GDRs to 6 months to improve the radiometer stability. Reducing the GDR latency could increase the risk of errors.*
    - *Differences between the IGDR and the GDR are smaller than in the past.*
    - *Agencies should work on new methods to provide altimeter data (database, …)*
- Is it useful to provide alternate orbit solution (e.g. JPL GPS-based reduced dynamic) on the GDR?
    - *The cal/val community has an interest to evaluate differences and has access to other solutions.*
    - *JPL orbits are a research product. To routinely include JPL orbits in the GDR, additional resources would be needed. However this JPL orbit tends to be of a better quality and the differences with the operational orbit solution are large enough to require this implementation to the Agencies.*
    - *New instrument corrections and different orbit solutions and software should be made available from a single site to evaluate by the OSTST.*
- Need for radiometer climate data record? (Once per year update)
    - *For past and current missions we need an accurate and stable wet troposphere corrections, and we need regular updates.*

    - *A yearly update of Jason-1 and Jason-2 radiometer path delay corrections provided month before the OSTST meeting would be very valuable.*
- Is it useful to improve MSL consistency between research groups? What are some ways to improve the MSL consistency between all groups at least to explain the differences including differences in tide gauges comparisons? How can we explain the differences to public?
    - *We should be able to explain the differences global mean sea level time series. The differences among the global mean sea level time series produced by different groups are large. Some progress has been made understanding the differences, and the cooperation should be continued.*
    - *Looking only at global mean sea level time series, it can be difficult to understand differences. Regional map differences, standardized grids should be used to regularly identify differences between groups (see Henry et al., section 8.8).*
- Is there a need for tandem phases between missions (Jason-3, Jason-CS), and if so what is the appropriate duration?
    - *Because we are flying a new instrument and platform, to maintain the continuity between Jason-3 and Jason-CS the period of formation flying-calibration should be long enough to complete a calibration.*
    - *Continued US/European cooperation is important for independent analysis and calibration-validation.*

8.2. Tides, internal tides and high-frequency processes

Chairs: Florent Lyard, Rui Ponte, Richard Ray

During the OSTST part of the Venice meeting there was a standard Tides/High-frequency splinter group meeting, as well as a round-table discussion the next day. The splinter meeting was chaired by B. Arbic (Michigan) and R. Ray (GSFC); the round-table was chaired by R. Ponte (AER) and F. Lyard (CNES). The splinter meeting consisted of five oral presentations and one poster, somewhat fewer than usual because of other presentations earlier in the week, which were part of the 20-year celebration. All presentations can be found at the meeting website (http://www.aviso.oceanobs.com/fr/courses/sci-teams/ostst-2012.html)

8.2.1 Splinter summary

Two presentations were by L. Carrère (CLS) on (a) possible improvements to the so-called dynamic atmospheric correction (DAC) now used on T/P and Jason GDRs and (b) improvements to the FES tidal modeling, also used on current GDRs. An especially noteworthy improvement to the DAC was obtained when atmospheric forcing was based on the ECMWF re-analysis product (ERA-Interim) rather than the currently used ECMWF operational product. As might be expected, maximum improvement was found during early years of the T/P mission when the ECMWF operational product was not as accurate as nowadays (Figure 8). Issues regarding the quality of DAC fields were also addressed in the poster by K. Quinn.

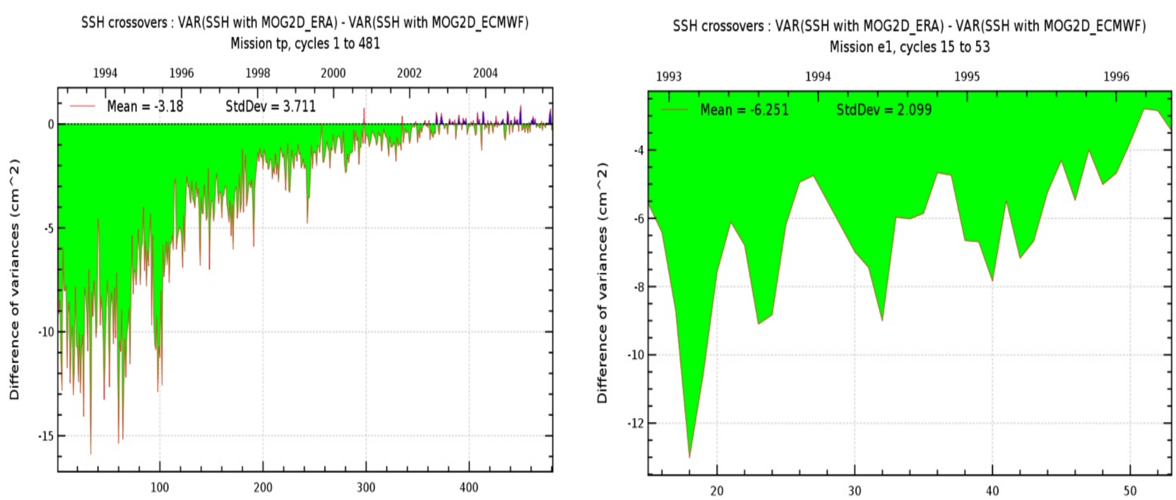

Figure 8. Temporal evolution of the mean variance difference at crossovers when using ERA-interim DAC instead of operational DAC, for T/P (left) and Envisat (right) (in cm²)

The other presentation by Carrère on FES2012 highlighted the remarkable increase in spatial resolution over the already high resolution (for a global model) of FES2004 (Figure 9). Considerable work has also been done to incorporate improvements in bathymetry. FES2012 also includes a number of minor tidal constituents by direct solution, rather than by inference as before. The new solutions considerably reduce certain S2 errors in FES2004, errors that have been rather over-emphasized in the GRACE community.

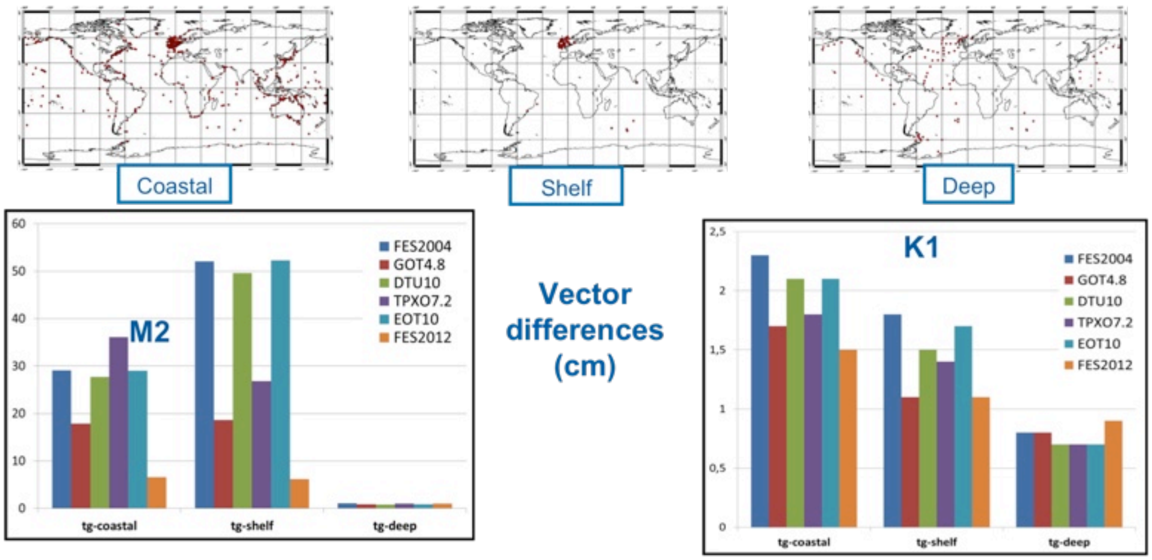

Figure 9. Performances of global tides models versus tide gauge databases.

L. Roblou (CNES) presented analysis of an improved along-track tidal database. Along-track approaches have long been used to explore high-wavenumber tidal phenomena (including internal tides). Roblou also emphasized improved mapping in the English Channel (Figure 10) relative to that obtained with available global models (especially relative to GOT4.7, which at 0.5° resolution is much too coarse to map the English Channel).

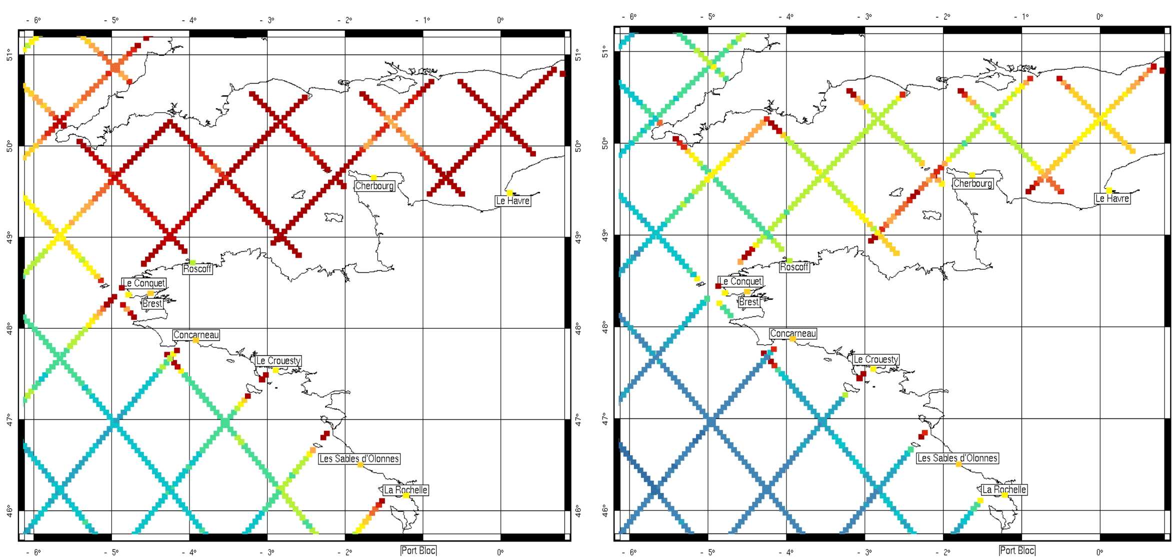

Figure 10. SLA standard deviation with GOT4.7 correction (left) versus standard deviation with empiric correction (right)

R. Ray (GSFC) presented further analysis on the notorious 59-d oscillations in global mean sea level and how these are tied up with the adopted S2 tide model and with center-of-mass corrections for T/P. A new series of GOT4.x solutions was used to explore some of these problems (Figure 11). The center-of-mass correction was further shown to be still anomalous. A tidal solution based only on T/P data (GOT4.8) and one based only on Jason data (GOT4.10) further emphasized an inconsistency between the two missions for S2, at the level of 5-10 mm.

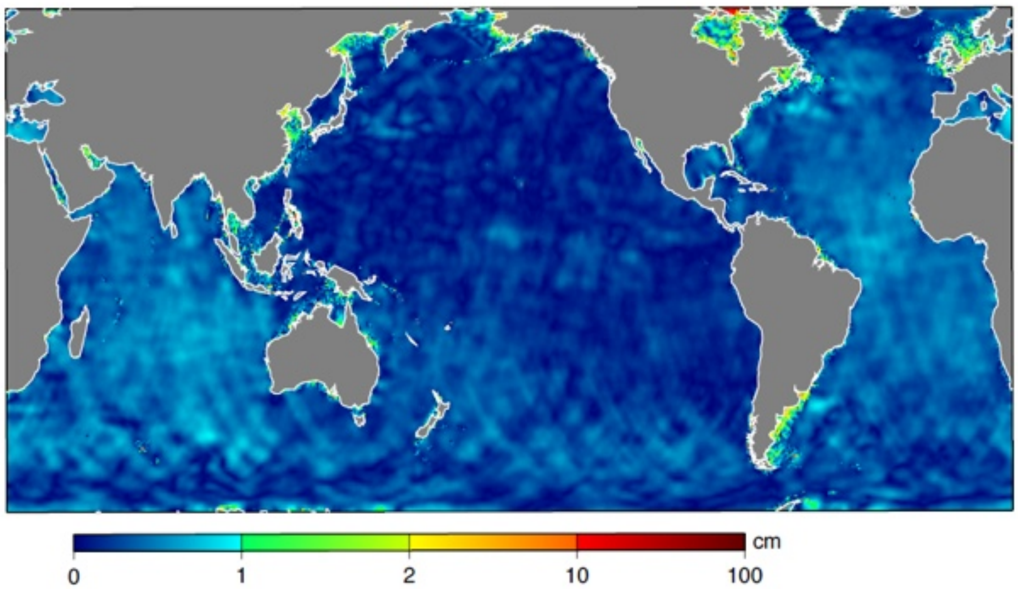

Figure 11. S2 vector differences for GOT4.8 – GOT4.10; Basin-scale differences approaching 1 cm.

C.-K. Shum (Ohio State), and also L. Carrère as part of her FES2012 discussion, presented some comparisons of new global tide models against various "ground truth" datasets (Figure 12). Some of this material will presumably find its way into a more extensive comparison study now underway under the general direction of D. Stammer (Hamburg), which includes most of the altimeter tidal community.

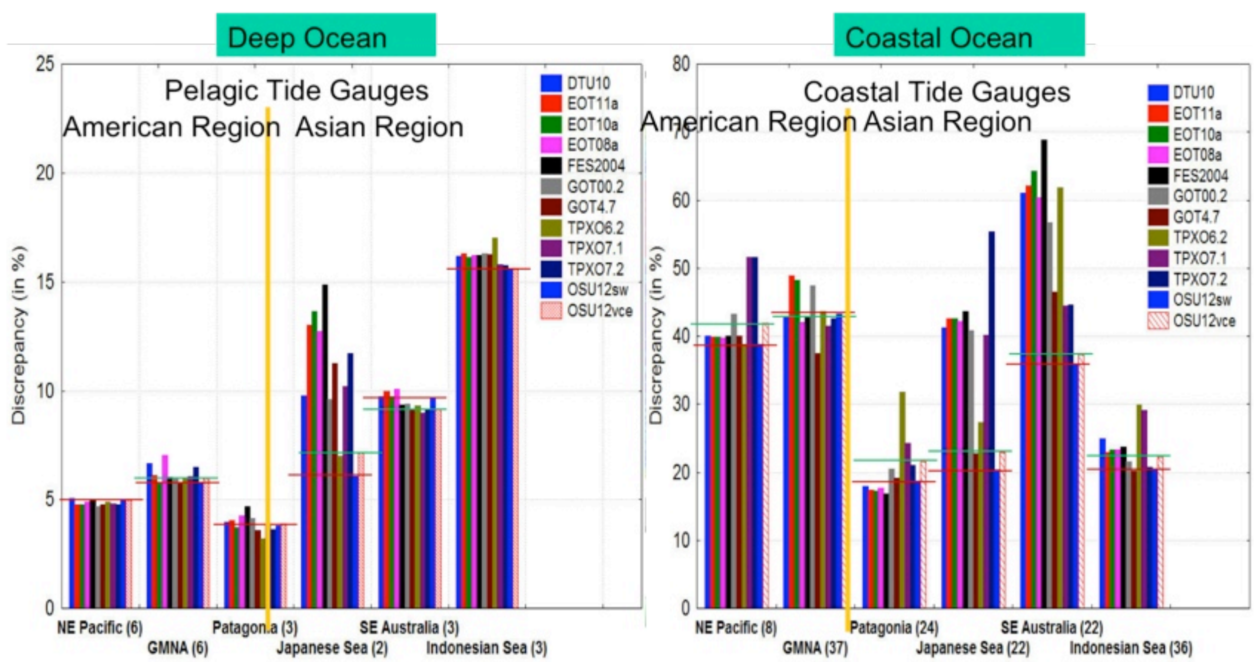

Figure 12. Regional accuracy assessment using tide gauge data in deep ocean (left) and coastal areas (right).

8.2.2 Round-table Discussions

Round-table discussions were fairly wide-ranging but for the most part emphasized some of the still outstanding issues for both tidal and (high-frequency) non-tidal corrections for altimetry. This included the expected further testing of tidal models, following Shum's and Carrére's presentations the previous day, but in addition some outstanding research issues.

The problem of internal tides is expected to be more critical for the SWOT mission, and some discussion noted some of the various ways that current altimetry data can be used to help generate, or at least help test, global models of internal tides. The issue of temporal variability further complicates this issue. The extent to which low-mode internal tides are temporally coherent with the tidal potential is still an open research question; there have certainly been examples now discovered where little coherency is maintained, but these may not be representative of the global picture, or at least representative of regions where internal tides are large enough to be of greatest concern.

The 59-d problem with T/P and Jason is still outstanding. In light of the small inconsistency between Jason and T/P, and the inability to know for certain which is the more accurate, it is not clear at this point which altimeter dataset should be more heavily weighted in new global solutions.

Non-tidal issues were also discussed. Concerning the dynamical ocean corrections, some outstanding questions are:

1) How effective are current corrections at removing non-tidal aliased variance?

2) Do we understand the structure and type of errors in this modeling? Do these stem mainly from forcing errors or representation errors (e.g., lack of baroclinic processes)?

3) How can these errors be reduced?

Concerning the latter, a number of approaches were mentioned: improved forcing fields, additional physics (baroclinicity, self-attraction and loading, improved dissipation modeling), and enhanced methodologies (e.g., data constraints, use of GRACE).

8.3. Outreach, Education and Altimetric Data Services

Chairs: *Margaret Srinivasan, Vinca Rosmorduc*

Session presentations:

- ARGONAUTICA, an educational project using Jason data (De Staerke, et al.)
- The 7th Continent Expedition: International Student Participation in a Voyage to the "Great Pacific Garbage Patch" (Vernieres, et al.)
- Education, Outreach, and Societal Benefits of Ocean Altimetry Missions: 20 Years of Communication & Collaboration (Richardson, et al.)
- Climate Science Education for Underrepresented Students through Collaboration with CABPES (Hamlington, et al.)
- Indonesian Throughflow Proxy from Satellite Altimeters (Susanto et al.)
- Jason-1 Geodetic Datasets at PO.DAAC and the Impact on its Users and Services (Hausman)
- SHOWCASE of altimeter outreach
    - *'Oceanez-vous' book (M. Lefebvre)*
    - *Ocean Data Extraction Service (Aviso)*
    - *AvisOcean Iphone/Ipad application (Aviso)*

Posters:

- LearnEO!: an ESA Learn Earth Observation Project (Byfield, et al.)
- A new interface to download altimetry data in Toulouse (Rosmorduc, et al.)
- Reaching Operational Users: A JPL/CCAR collaboration (Srinivasan, et al.)
- Sea Level Experiments for Climate Science Education of High School Students (Fitzpatrick, et al.)
- CTOH: 20 years of altimeter data (Fleury, et al.)
- Ssalto/Duacs: Preparation of the next products version (Pujol, et al.)

8.3.1 2011-2012 Highlights

The NASA/JPL-CNES collaborations in outreach, education, and applications have celebrated 20 years of cooperation 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. Among them, English-French, French-English, and English-French-Spanish translations were completed on several outreach products and educational materials. Some notable examples include the Jason board game, and the "BT Publication, "Topex-Poseidon and Jason-1; Surveyors of the Ocean".

Outreach and educational activities of the past year include a 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.

8.3.2 Outreach

Some mechanisms for Outreach are:

- Exhibitions

- Public lectures and conference presentations
- Supporting classroom activities
- Writing & 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

8.3.3 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. Aviso, collaborated with Legos/CTOH, and CLS and CNES developed an "Online Data Extraction Service" which was on demo during the meeting. An online version is planned to be available in 2013.

A question arose about statistics/metrics of users (Jason-1 geodetic phase GDRs). What is the trend of data usage amongst the different missions and phases of those missions? In order to understand this on a mission wide level, metrics from all the data centers would need to be collected. So is it feasible to compile joint, multi-service, metrics to provide "total" number of users to the agencies?

All centers are working continuously to improve the data quality and the relevance of the data with respect to the operational applications and science. CLS, in particular, is working from its expertise in altimetry to build up 'downstream' application services in offshore oil operations, ship routing, sail races, etc.

CSIRO has developed a new web site, "Oceancurrent" (oceancurrent.imos.org.au), with data distribution and information (including news, animations and glossary). The JPL/CCAR collaboration has highlighted real-time uses of altimetry, with real-time data distributed through a dedicated CCAR web site.

8.3.4 Education

The now annual presentation by students in the Argonautica program was, again, a highlight of both the plenary (in the 20 Years Symposium) and the Outreach session (in the OSTST meeting). The students won a **real** appreciation from the attendees for the quality of science content, use of the scientific method, and presentation skills. We strongly endeavor to continue this part of the program in future OSTST meetings (on both sides of the Atlantic).

The Argonautica presentation during the outreach session provided examples of what the student participants did with the data provided or when building their own buoys (presented by French high school students themselves). Still 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 California school joined in. OSTST members are welcome and encouraged to join in too!

Ben Hamlington of CCAR presented their CAPBES (Colorado Association of Black Professional Engineers and Scientists) initiative, "Sea Level Education For Underrepresented Students". Ben and Bob Leben organized an after-school sea level and climate science course, introducing students to Matlab and to the experimental process. 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.

8.3.5 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. Some success was demonstrated by ESA with a press release about the Venice symposium and the release of a new mean sea level dataset.

We feel that the OSTST members can make a significant difference in their local communities by organizing training sessions and classes for 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. The Outreach team is willing and available to facilitate these interactions. The development of international collaborations between students is another area that could be more developed via shared resources and communication. Translating educational materials into other languages could be a 'low hanging fruit' on resource-sharing trees.

Linking efforts between data centers is an area that can be further developed. This would also better serve the users by providing them with the data best fitted for their needs.

At the Data Services level, old missions never die: at least the data reprocessing aspect does not! The suggestion was made that it would make sense to transfer the data processing and reprocessing activities to data centers, and away from the projects that currently fund these activities. This holds true for data distribution, as well. Many users are highly interested in the longest (most homogeneous) time series possible.

8.3.6 New Planned Efforts

The focus of the outreach team for the coming year will be on education and public outreach, as well as applications outreach for all of the existing and upcoming ocean altimetry missions—Jason-1, 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?
- AvisOcean Iphone/Ipad application expansion
- Aviso Online Data Extraction Service to be opened online (2013) with full database
- JPL's annual Climate Day event (continued)

8.4. Near Real Time Products and Applications

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

On Thursday 27 September 2012 the near real-time (NRT) products and applications splinter session was held at the Venice OSTST. The session consisted of 8 oral and 10 poster presentations. There was a round table discussion the following afternoon, and NRT recommendations were gathered for the final plenary session. This splinter session encompassed a wide variety of topics, demonstrating the broad use of satellite altimetry data for operational applications. Topics included NRT product improvements and operational quality assessment, enhanced monitoring of global lakes and reservoirs, observations during extreme events such as hurricanes and tsunamis, and inclusion of data from new missions such as Cryosat-2, SARAL/AltiKa and CFOSAT.

8.4.1 Oral Presentations (in session order):

1) SSALTO/DUACS: STATUS ON THE REAL TIME SYSTEM UPGRADES AND IMPACT OF THE ALTIMETRY CONSTELLATION EVENTS (FAUGERE ET AL.)

This presentation discussed upgrades to the CLS/CNES developed SSALTO/DUACS altimetry processing system. The loss of Envisat on Easter, 2012, and the movement of Jason-1 to a new geodetic orbit on 07-May-2012 has required changes to the processing of altimetry constellation data, notably the inclusion of Cryosat-2 data for NRT processing (Figure 13). The criticality of the upcoming AltiKa and Sentinel-3 missions was stressed, and the possibility of inclusion of Chinese HY-2A data was discussed. Several important updates are planned for 2013: real-time on-demand (regional?) products, a DUACS high-frequency dynamic ocean correction (DAC) for real-time SLA products, and a complete reprocessing based on a 20-year reference period.

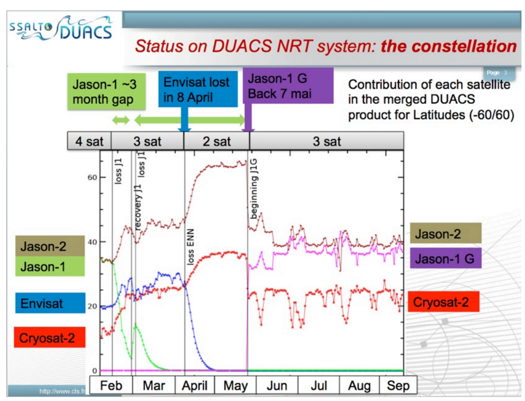

Figure 13. Contribution of each operational altimetry mission to the SSALTO/DUACS system in 2012.

2) THE USE OF NRT ALTIMETER WIND AND WAVE PRODUCTS AT ECMWF (ABDALLA ET AL.)

This presentation discussed the use of Jason-1, Jason-2 and Envisat data in the ECMWF WAM wave model, for both assimilation and verification. Latency of the data is a key issue given the runtime schedule of the models at ECMWF. Presently only Jason-2 data are being assimilated, after the loss of Envisat and movement of Jason-1 to a geodetic orbit, but Jason-1 data will begin to be assimilated again next year. Assimilation of the NRT SWH has a positive impact on the WAM model (Figure 14). Comparisons of ECMWF model wind speeds vs. altimetry was also discussed.

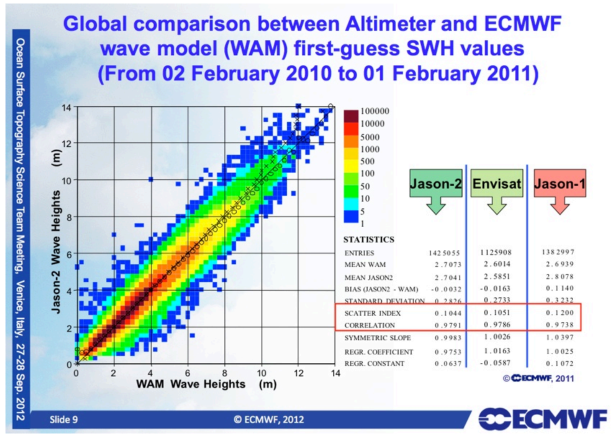

Figure 14. Comparison of SWH data from ECMWF WAM model vs. Jason-1, Jason-2 and Envisat.

3) ASSIMILATION OF ALTIMETERS AND ASAR WAVE DATA IN THE WAVE MODEL MFWAM: PREPARATION STUDY RELATED TO CFOSAT MISSION (AOUF ET AL.)

This presentation examined the benefits of both altimetry and ASAR data in the Météo-France wave model (MFWAM) and a look ahead to the type of wave spectral data that the SWIM instrument in CFOSAT will provide. Analyses based on Envisat's ASAR wave spectra in the new MFWAM model demonstrate the benefit to SWH predictions (Figure 15). Assimilation of directional wave spectra improves the estimation of peak period by > 20%, comparing the model to buoy data.

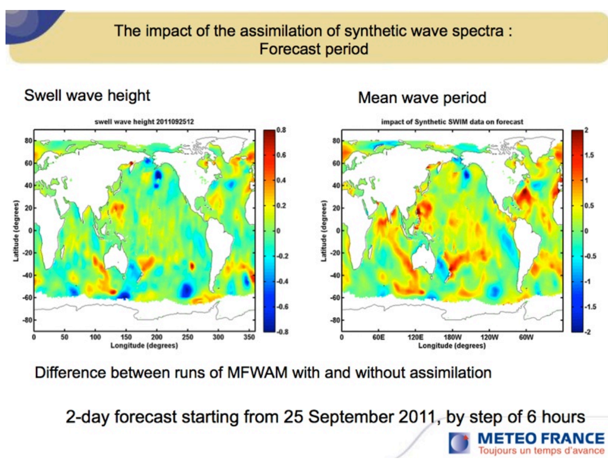

Figure 15. Differences between MFWAM model with/without assimilation of synthetic CFOSAT spectra: impact on wave height and wave period.

4) SSH IMPLICATION FOR OPERATIONAL PREDICTION (JACOBS & LILLIBRIDGE)

This presentation illustrated the importance of altimetry in numerical ocean modeling, compared to in situ measurements alone. SSH data from altimetry influence the subsurface temperature, salinity and geopotential fields much more strongly than SST, sea surface salinity, and even XBT temperature profiles (Figure 16). Basically, with no altimetry data the ocean models have no skill. However, in order to properly capture mesoscale features a minimum of 3 nadir-only altimeters are required, particularly for estimates of mixed layer depth. In that sense the contribution of Cryosat-2 was acknowledged, with the loss of Envisat and sub-optimal sampling from the Jason-1 geodetic mission.

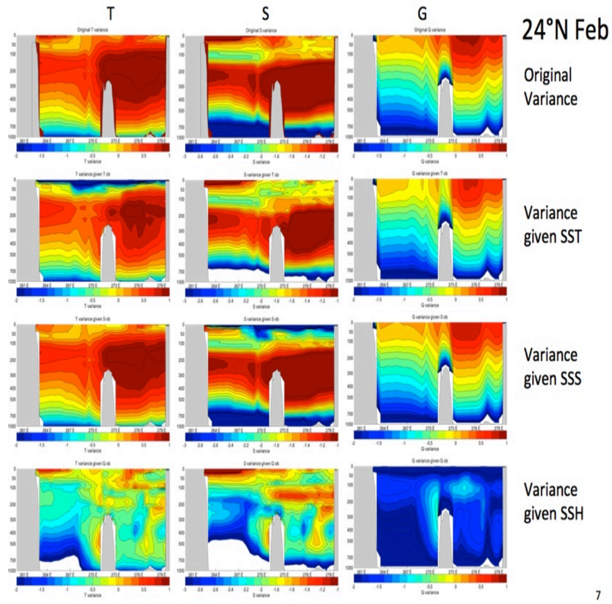

Figure 16. Variance reduction in Navy HYCOM model: vertical sections of Temperature, Salinity and Dynamic Height (Geopotential) showing largest improvement from assimilation of SSH.

5) PREDICTABILITY OF THE MIDDLE ATLANTIC BIGHT SHELF BREAK FRONT GIVEN SATELLITE DATA (ZAVALA-GARAY ET AL.)

The NW Atlantic Shelf/Slope front, and forecasts for its position based on the Rutgers ROMS model, were discussed in this presentation. Altimetry data are reprocessed to recover as much as possible approaching the coast in the Mid-Atlantic Bight region. Total SSH, including a regional mean dynamic topography, are assimilated along with satellite SST data into the 4DVar model. An important step in the assimilation is the reduction in biases attained by replacing the HYCOM seasonal signal with one based on local observations. Increased correlations and reduced RMS differences between the altimetry and model are achieved with assimilation of SSH & SST (Figure 17).

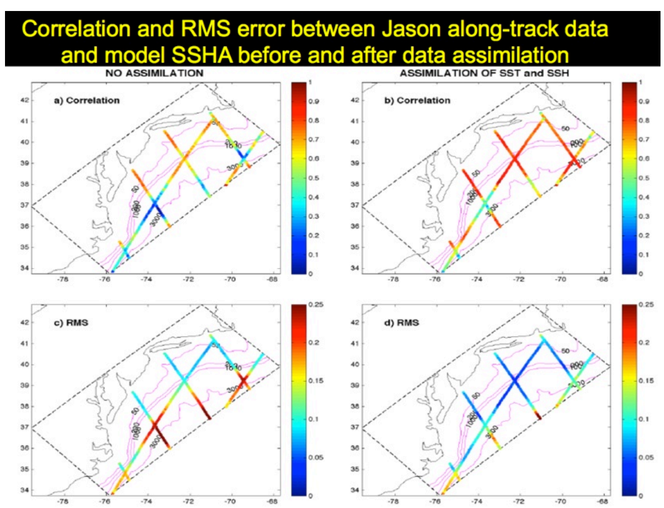

Figure 17. Correlation and RMS differences between Jason altimetry and ROMS model SSHA with/without assimilation.

6) APPLICATION OF NEAR-REAL TIME SATELLITE ALTIMETRY FOR INITIALIZING THE OCEAN COMPONENT OF COUPLED TROPICAL CYCLONE-OCEAN FORECAST MODELS (YABLONSKY & GINIS)

The utility of NRT altimetry data in a coupled ocean/atmospheric hurricane model was shown in this presentation. The tropical cyclone model is forced by the oceanic boundary conditions below, and the inclusion of altimetry data improves the accuracy of the SST field in the ocean model (here the Princeton Ocean Model). The negative feedback of ocean surface cooling due to evaporative heat losses to the hurricane need to be included (vs. a static SST field). Vertical mixing and upwelling in the surface mixed layer both cool the ocean during the storm's passage. This was illustrated by a striking animation based on Hurricane Katrina (Figure 18). Plans are underway to move from the current 'feature-based' model initialization to a HYCOM-based model such as NOAA's RTOFS-Global.

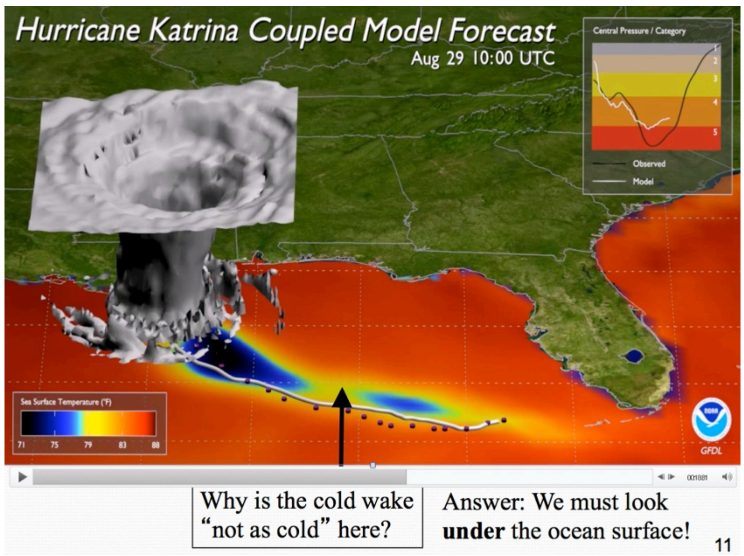

Figure 18. SST field from coupled POM-TC model for Hurricane Katrina, illustrating 'cold wake' after passage of the tropical cyclone.

7) ASSESSMENT OF CRYOSAT SEA LEVEL ANOMALY USING HF RADAR AND SST IMAGERY (GRIFFIN & CAHILL)

In this presentation the benefit of Cryosat-2 altimetry in the CSIRO IMOS ocean monitoring system was assessed by comparisons with coastal radar data and SST fields. The sampling pattern of Cryosat-2 leads to a 'moving spotlight' of high density measurements half the time, and nearly no measurements otherwise. Nonetheless, when present the SLA data from Cryosat-2 increases the ability of the system to monitor mesoscale features, as illustrated by comparisons with coastal HF radar and drifters off SW Australia (Figure 19).

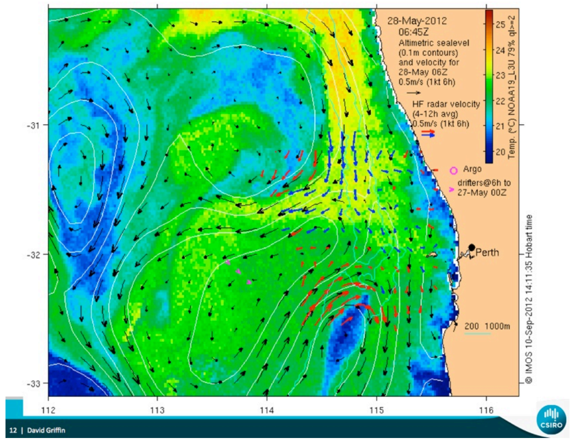

Figure 19. SSH (contours) from Jason-1/Jason-2/Cryosat-2 overlaid on SST from IMOS system off SW Australia. Red & Blue arrows show surface current as measured by Coastal HF radar.

8) COULD SATELLITE ALTIMETRY HAVE IMPROVED EARLY DETECTION AND WARNING OF THE 2011 TOHOKU TSUNAMI? (HAMLINGTON ET AL.)

In the final oral presentation for our splinter session, the application of altimetry data to the tsunami detection problem was examined. Although the current constellation of nadir altimeters is insufficient to provide an early warning system for tsunamis, this study examines the role that altimetry could play in augmenting the existing system of models and DART buoys. For large tsunamis, the signal can be discerned from the background mesoscale field, and the question becomes when, not if, that signal can be detected by the altimetry constellation. SSHA data relative to a smoothed average of the previous 2 cycles were compared with NOAA's MOST tsunami model for the case of the 2011Tohoku tsunami (Figure 20). Along track measurements provide a larger, cross-sectional view of a propagating tsunami, providing information that cannot be obtained from DART buoys alone.

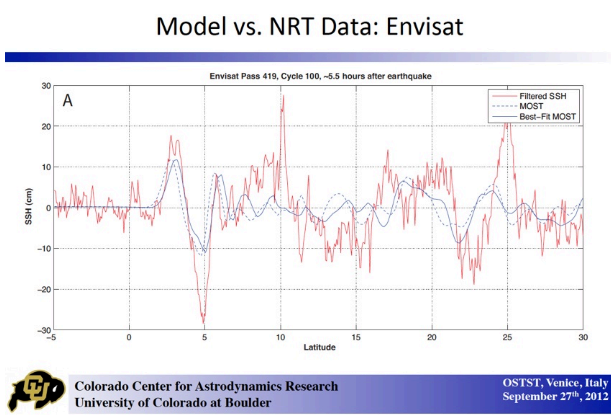

Figure 20. Envisat SSH data vs. MOST tsunami model after 2011 Japanese earthquake

8.4.2 Poster Presentations:

P1) MONITORING MARINE DEBRIS FROM THE MARCH 11, 2011 TSUNAMI IN JAPAN WITH THE DIAGNOSTIC MODEL OF SURFACE CURRENTS (MAXIMENKO ET AL.)

Mean dynamic topography, NRT altimeter SLA and wind data from scatterometers were used in the diagnostic SCUD model to simulate motion of heterogeneous marine debris from the 2011 tsunami in Japan. The effect of wind forcing on objects with high profile was simulated by adding a windage component to he SCUD-estimated drift velocities. Model results were confirmed qualitatively by the Summer 2012 survey of the North Pacific and adequately reflect the timeline of tsunami debris landfall on the US/Canada west coast and its recent arrival in Hawaii (Figure 21).

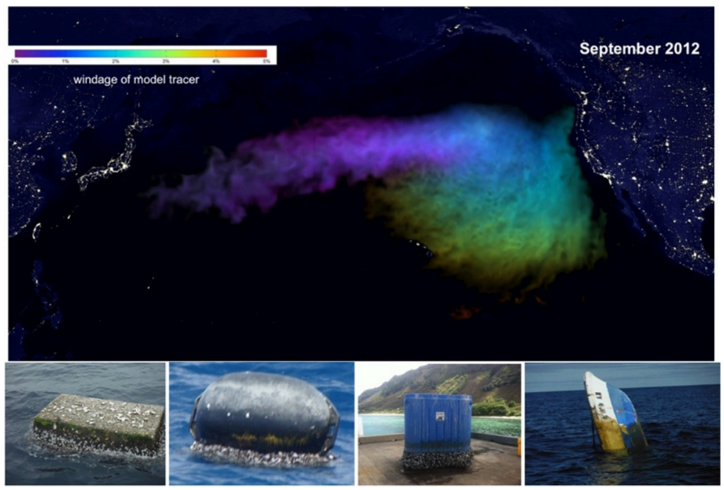

Figure 21. Above, windage of model tracer for September 2012, below some examples of debris objects

P2) OBSERVATORY AND RESEARCH ON EXTREME PHENOMENA OVER THE OCEANS (ORPHEO) (QUILFEN ET AL.)

The project ORPHEO aims to help better characterizing and forecasting extreme phenomena through the use of multi-satellite and in-situ measurements and the development of demonstration tools. A case study was shown in this poster looking into hurricane signatures in the Amazon-Orinoco plume, specifically for hurricane Igor (September 2010, Figure 22). The wakes of different parameters were monitored using different sensors: SST (TMI/AMSR), SSH (Jason-1 and 2) and SSS (SMOS) and contrasted with in-situ vertical information, showing how this fresh water pool is affected. It was shown that the SSH wake shows as a large through along the hurricane track, which can persist for months and modify the course of the hurricane season.

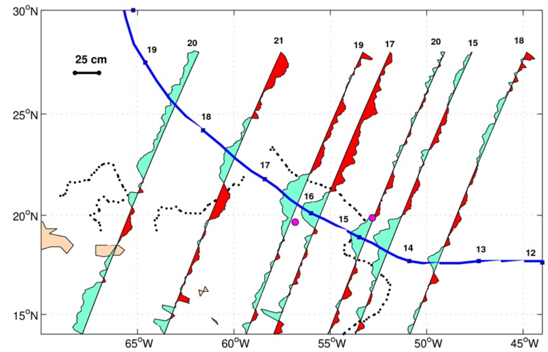

Figure 22. SSH wake from Jason1 and Jason2 measurements on the Amazon-Orinoco plume, after the passage of Igor (2010).

P3) THE NEAR REAL-TIME GLOBAL RESERVOIR AND LAKE MONITOR (BIRKETT ET AL.)

This poster covered a system for NRT altimetric monitoring of the largest lakes and reservoirs around the world, using NRT data from the Jason-2/OSTM mission, plus historical time series from Topex/Poseidon, Jason-1 and GFO/ENVISAT missions. For validation, radar lidar and ground-based data sets are used for relative or absolute validation exercises. The poster reported on performance evaluations of the different input data sets, as well as future steps based on additional science requirements and end-user needs.

P4) CONTRIBUTION OF THE SARAL/ALTIKA MISSION FOR SEA-STATE ANALYSIS AND PREDICTION AT MESOSCALE AND IN COASTAL ZONES (LEFEVRE ET AL.)

Work at Météo-France shows that SARAL/Altika wind and wave measurements are expected to provide an important contribution, especially in coastal areas, in three ways. First, they will be a very good reference for validation of high spatial resolution winds from atmospheric models (AROME-Western Mediterranean). Second, they will be used in the validation of model waves (MFWAM with new physics). Finally, they are expected to contribute with other altimeters to better understanding how waves have an impact on turbulent fluxes.

P5) NEAR REAL-TIME JASON-2 PRODUCT OPERATIONS (FIGA-SALDAÑA ET AL.)

This paper discussed the driving factors and challenges at NOAA and EUMETSAT, of near real-time product processing, dissemination and monitoring for Jason-2. The most important aspects/drivers of the Jason-2 operations are timeliness, near real-time monitoring of product quality (i.e., detection of changes) and generic tools suitable for many current altimetry missions. Examples of these tools are (a) NRTAVS (Figure 23), a multi-mission product quality display and monitoring system, (b) the Metscript, which provides path delay corrections for Jason-2 and other altimetry missions and (c) a GPS-based POD service providing an independent accurate orbit determination for LEO missions, including specifically Jason-2. The emphasis is on sustainable operations, continuous development and learning.

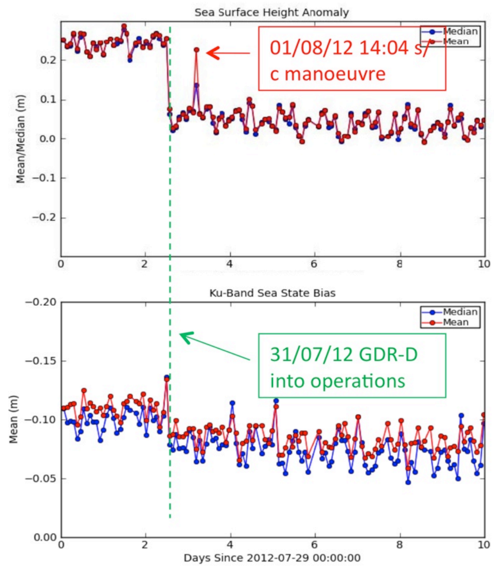

Figure 23. Example of impact of a spacecraft manoeuvre and of the implementation of the GDR-D standard in the near real time products (OGDR), as seen the SSHA and SSB orbit statistics, displayed by the NRTAVS operational product quality monitoring system.

P6) JASON-2 GPS BASED OGDR PRODUCTS (ANDRES ET AL.)

EUMETSAT has established a near real-time POD environment designed initially for METOP and instantiated experimentally for Jason-2. It benefits from operational GRAS GSN data provided by ESA. The system allows the near real-time monitoring and validation of the OGDR orbit computed on-board by the DORIS/DIODE system. Examples of scenarios where it was particularly useful were given, e.g., spacecraft maneuvers (Figure 24). For Jason-2, the accuracy of the EUMETSAT GPS orbits compare well with the JPL GPS orbits and with the MOE. This is a multi-mission tool suitable for current and future altimetry missions (JA3, JACS, S3) and the option exists to provide this orbit to users in near real-time.

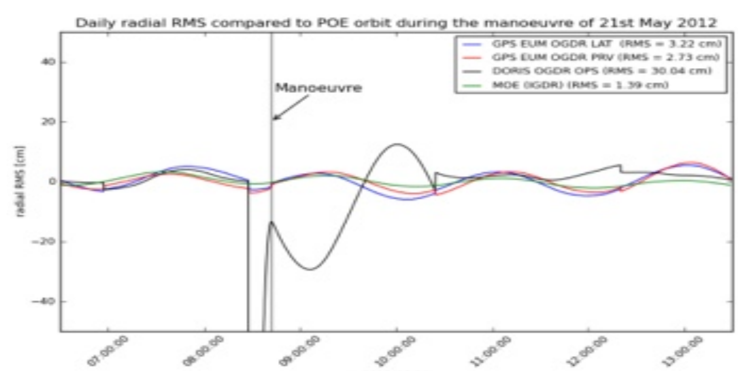

Figure 24. Comparison of different radial orbit solutions in the event of a Jason-2 spacecraft manoeuvre.

P7) SSALTO/DUACS – TOWARDS REGIONAL PRODUCTS (PUJOL ET AL.)

After years of very successful multi-mission global products, DUACS is going regional, starting with a few selected areas. Level 2/3/4 products are tuned for specific areas, in particular optimizing several geophysical corrections, using customized editing criteria and mapping correlation scales. These products make possible a better restitution of mesoscale phenomena, which is better suited for regional data assimilation.

P8) A KERGUELEN REGIONAL SEA LEVEL PRODUCT TO SUPPORT THE KEOPS2 EXPERIMENT (PUJOL ET AL.)

The KEOPS2 campaign in November 2011 was a multi-disciplinary oceanographic campaign relying on high quality satellite data. Optimized DUACS products were generated for this area for MDT, along-track and gridded SLA and ADT, as well as other derived products such as geostrophic currents and total surface currents. The products were used before and during the campaign in real time, for planning purposes (providing the synoptic view). Campaign in-situ measurements are furthermore being used to validate and improve these specific products.

8.4.3 NRT Round table summary:

- Jason-CS issues:
    - 2 radiometers / 3 frequencies
        - If 2 radiometers, a cross-calibration is possible in NRT between both radiometers. But a NRT cross-calibration of two instruments, each with its own drift and drift corrections might not be straight forward to resolve in operations. Regardless of the number of radiometers, what would be more important for NRT applications is that at least one has an on-board external calibration system (hot/cold sources). Another argument to consider is that 2 radiometers ensure redundancy, but it is also true that one good radiometer with appropriate redundancy may be the optimal engineering solution.
        - 2 frequencies are acceptable only if it meets requirements for accuracy, precision and drift. Otherwise, **3 frequencies** are recommended. Moreover, a 3rd frequency would add accuracy.
    - Interleaved / LRM exclusive?
        - Strong recommendation for **interleaved mode**. SSH and SWH must meet accuracy and precision specifications at all points along ground tracks. And it is important for NRT, that the interleaved mode do not affect data availability and latency.
- In NRT session, **many applications** are presented each year (assimilation of altimetric products in meteo/wave/ocean forecasting model, multi-mission products, tsunami detection, hurricane monitoring, reservoir and lake monitoring, marine debris, etc.). These applications benefit from accuracy/timeliness/revisit time/coverage in very diverse ways and it is important to assess for each of them, when the application breaks, in order to understand what the minimum requirements are. For each NRT application, a table should be established defining and

quantifying requirement in terms of sampling, products latency, etc. This is a **new challenge to quantifying sensitivity** for NRT session next year.

- NRT applications being very dependent of the number of operational satellites flying simultaneously, we strongly **support continued / expanded coverage in NRT** with SARAL/AltiKa, Sentinel 3, CryoSat2, HY-2A, wave spectra from CFOSAT, Jason-CS and SWOT in the future and explore alternative solutions (microsats could provide possibility of greater payoff to have an altimeter constellation).

- As product differences become smaller, we suggest a **review of latency vs. accuracy strategies of O/I/GDR products**. Indeed, Jason-2 O/IGDR orbits are very similar, as the DIODE navigator has great performance compared to MOE. Furthermore, GPS orbits in NRT are suggested as a backup for scenarios that the DIODE orbit does not completely cover (e.g., maneuvers, DORIS s/w updates, etc.) and for NRT monitoring purposes. The only remaining large differences concern the dynamic atmospheric correction that is not available for the moment in NRT (testing expected to start in 2013) and the calibration of the radiometer (thanks to ARCS for GDR products). Can advancing accuracy and precision lead to a latency reduction, a new product creation or a products merge? Official products will certainly remain and, although their formats are not easy to change frequently, some adaptations are possible. In preparation for that, new ways of disseminating the altimetric data can help reviewing the data latency by distributing new corrections, new orbits and auxiliary data as soon as available (RADS, AVISO OnLine Data Extraction Service, etc.).

- It is important to have **wind, wave, SSH products within 3 hours**. There is a need of CryoSat2 latency within 3 hours for many applications. No RT product for the moment, only NOAA wave product available in 3H and some work under way within ESA to bring CryoSat2 to this point (a new Fast Delivery product should be released in January 2013 where 98% of data should be processed in 3H. The 3H latency (~OGDR) is sufficient for assimilation in meteo model but for regional application the spatial coverage is a problem. For extreme events, there is a need of direct-broadcasting and local real time processing capability, as it is currently available for example for some key missions on board NOAA/METOP satellites (e.g. HRPT system combined with the AAPP ground processing package for ATOVS).

8.5. The Geoid, Mean Sea Surfaces and Mean Dynamic Topography

Chairs: Marie-Hélène Rio, Ole B. Andersen

This splinter had a total of 7 oral presentations and 6 posters

The 7 oral presentations were:

- DETTEMERING ET AL: The geodetic mission phase of Jason-1: Benefits for regional marine gravity field modeling
- SANCHEZ_REALES et al. Assessment of the first three generations of GOCE geoid models through their induced surface geostrophic currents
- GALIN et al. CryoSat-2 SARIN Mesoscale Observations of the Kuroshio Current
- MULET et al., Mapping of the Absolute Dynamic Topography from multi-satellite along track Sea Surface Height and GOCE geoid height: a direct method
- MENENEZ et al. Dominance of Eastward Currents in Southern Hemisphere Oceans: the Impact of GOCE Data
- ZAJACZKOVSKI et al. Southern Ocean 4-D circulation: combining altimeter and Argo float data
- GRAYEK et al. Observing System Evaluation for the Black Sea: Focus on ARGOfloats and altimetry during 2005-2012

The 6 posters were:

- BOSCH et al. Error assessment of dynamic ocean topography profiles (iDOT)
- ALBERTELLA et al. High resolution dynamic ocean topography in the Southern Ocean from GOCE
- SCHRÖTER et al. Evaluating an ensemble of global ocean circulation estimates using satellite altimetry, gravity field models and ARGO data
- JANJIC et al. Dynamical ocean topography from satellite measurements and its impact on Southern Ocean circulation estimates
- SANCHEZ-REALES et al. Anisotropic filtering to improve the geodetic determination of the Surface Geostrophic Currents: Edge Enhancing Diffusion
- SANCHEZ-REALES et al. Ocean Geostrophy from Satellite Altimetry and GOCE Data

During the round table discussion several challenges were discussed within the 3 subthemes, Mean Sea Surface (MSS), Geoid and Mean Dynamic Topography (MDT) and the impact of GOCE and Cryosat-2 for ocean studies. The different contributions from this session highlight that the newly available datasets from recent missions (Jason-GM, Cryosat-2, GOCE) show a great potential that still needs to be further explored. Many results indeed were only preliminary and further work is planned for the coming year.

8.5.1 Summary/discussion within the MSS subtheme

The challenge of residual effect of ocean variability (Figure 25) remains one of the largest challenges to the Mean Sea Surface determination. The challenge of digesting the JASON-1 GM into the MSS and particularly the challenge of inter-annual variability with the new mission being decades from each other remain another large challenge.

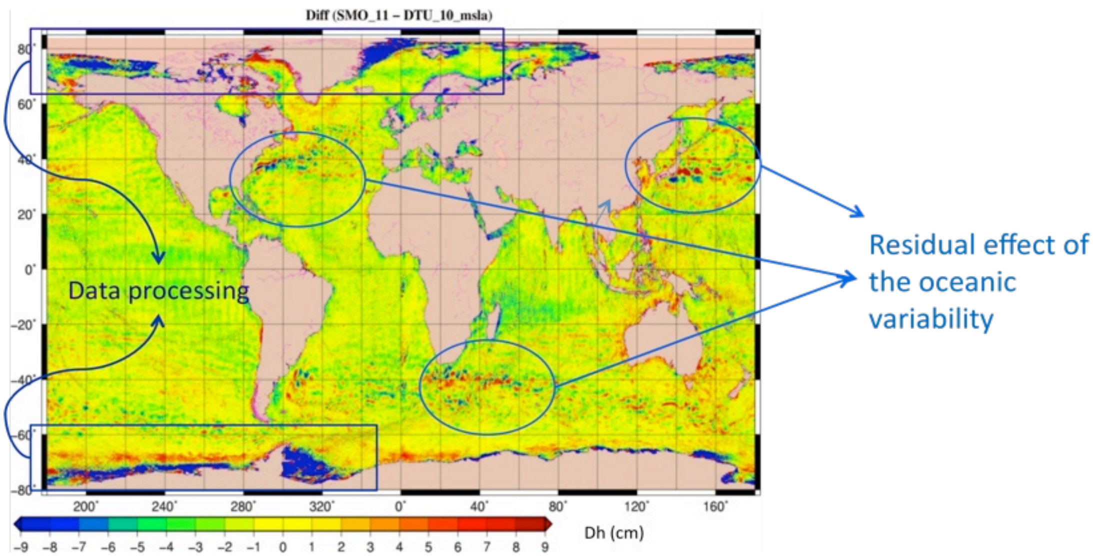

Figure 25. Residual effect of ocean variability

In particular, Dettenmaier et al. showed that Jason-1 EOL geodetic mission provides valuable input for regional marine gravity modeling although the data distribution is not yet able to provide high resolution gravity field information without combination with other missions. As shown below, Regional gravity model approach for the central Atlantic Ocean provides good results (Figure 26), which are close to EGM2008.

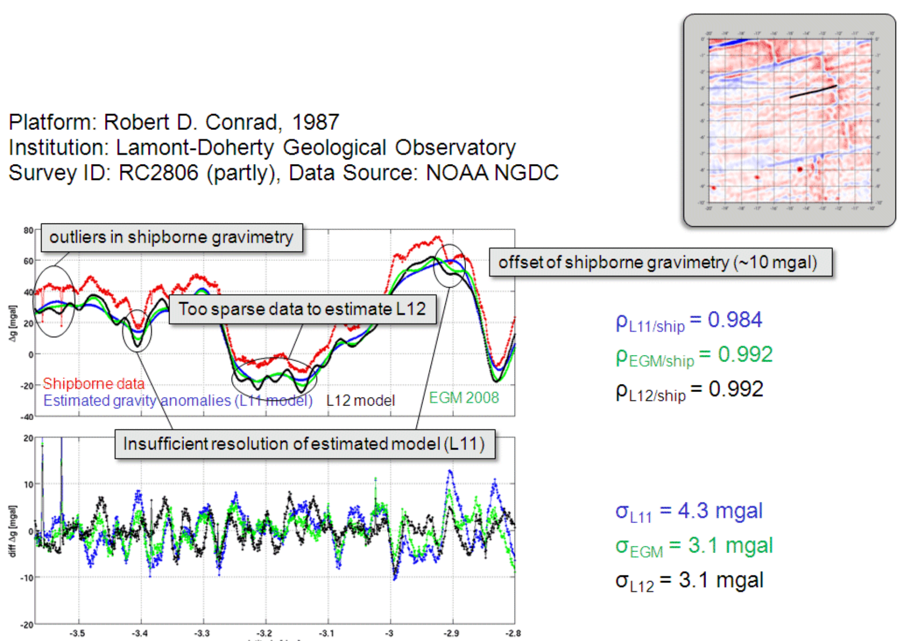

Figure 26. Regional gravity model approach for the central Atlantic Ocean.

8.5.2 Summary/discussion within the subtheme of GOCE geoid and Mean dynamic Topography determination.

Many talks and posters presented results from the use of the recent GOCE-based geoid models. They all showed strong improvements over GRACE for the computation of the Mean Dynamic Topography and the corresponding mean geostrophic currents. Complex filtering methods are now used to extract the maximum information from GOCE as the anisotropic diffusive filter (Bingham et al.), the enhancing edge diffusion (Sanchez-Reales) or the Singular Spectrum Analysis based filter (Menezes).

A new mapping method of the Absolute Dynamic Topography directly from multi-satellite along track Sea Surface Height and GOCE geoid height was presented by Mulet et al. This method is especially relevant in the Arctic where the determination of the Mean Sea Surface from altimeter data suffers from the seasonal Ice coverage. The right plot in Figure 27 shows the map of absolute dynamic topography for September, 5th 2007, that was computed from along-track estimated of the absolute dynamic height (altimeter Sea Surface Height minus EIGEN-6C geoid model). It shows good consistency with the map obtained from the classical approach (left plot) consisting in adding the map of Sea Level Anomalies computed for the same day to an estimate of the Mean Dynamic Topography (the DNSC08 MDT is used here).

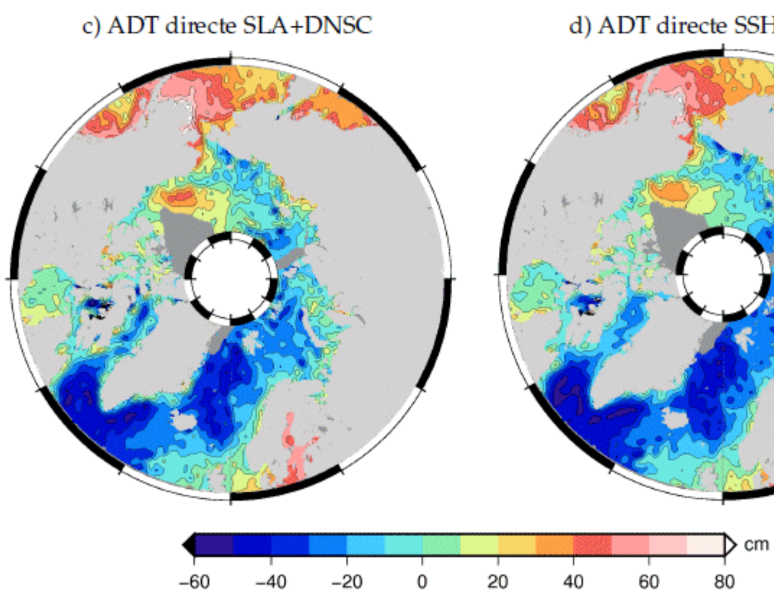

Figure 27. New mapping method of the Absolute Dynamic Topography directly from multi-satellite along track Sea Surface Height and GOCE geoid (right) compared to the classical approach (left).

In particular a long time series of ADT could be used instead of SLA to look at the mean/regional Sea Level trend (Arctic is a region where results on this topic differ a lot from one study to the other)

This presentation was also related to the presentation by Bosch who suggests a slightly different approach to this.

8.5.3 Summary/discussion for the subtheme of impact of GOCE and Cryosat-2 for ocean studies

Galin et al presented a study on application of Cryosat-2 (C-2) interferometric data (SAR-in) for mesoscale observations in the Aghulas current. However their preliminary results were not conclusive, but it is very much work in progress and more results will follow. The Figure 28 illustrates the first surface slope vector gradients from C-2.

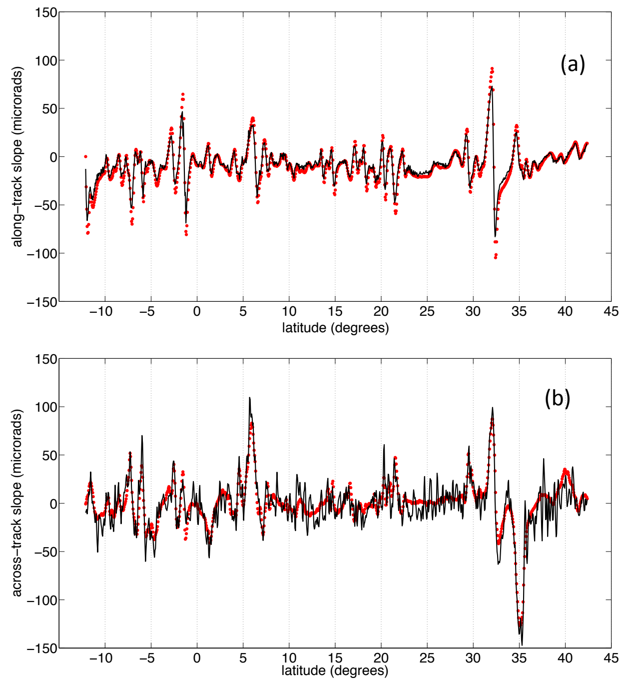

Figure 28. First surface slope vector gradients from CryoSat2.

The presentations of MENENEZ et al., ZAJACZKOVSKI et al. and GRAYEK et al. highlighted the effect of the use of satellite altimetry, ARGO floats and GOCE for ocean and circulation studies during the altimetric era for different regions. In particular, ZAJACZKOVSKI et al. showed that the use of different pre-GOCE MDT together with a 3D density field shows inconsistent transport values at key sections of the ACC current. GOCE based MDT may help improve this issue in the near future. Also, the authors suggested to compute a mass-balanced MDT using a Quasi Geostrophic vorticity equation.

8.6. Instrument Processing

Chairs (Part I): Shannon Brown, Estelle Obligis

Chairs (Part II): François Boy, Phil Callahan, Robert Cullen, Walter Smith

The Instrument Processing Splinter focused on two topics – radiometer issues and processing of SAR mode data based on two documents prepared in advance of the meeting for discussion and recommendation at the OSTST. Based on these and presentations made during the splinter and subsequent round table discussion the team made recommendations on two issues: the Jason-CS the radiometer configuration and Jason-CS. In addition, the question of Sentinel-3 SAR mode coverage was discussed and the recommendation made during the 6th Coastal Altimetry Workshop was endorsed (see § 9.5). The latter generated a great deal of both pre- and post-meeting email discussion. In addition to the oral sessions there were posters on related topics including several on coastal altimetry.

The main new result regarding the radiometer wet tropospheric correction was (E. Obligis) that an objective analysis of all available (note that 92% of the Earth is covered in 4 hours) radiometer data for 3 days to 1 day before the time of interest could meet the CryoSat-2 NRT requirements. Analysis of data from June 2012 showed a 1.25 cm RMS between the proposed analysis scheme and the Jason-2 AMR. The performance of the technique in coastal areas needs to be evaluated.

N. Tran provided an update on the Sea State Bias correction for Jason-1 and Jason-2. For Jason-1 it is not necessary to change the SSB model for either a new solution technique or for GDR-D orbits as each gives mainly a bias of about 5-7 mm with no significant SWH/wind speed (WS) dependence in the main data region. Users may wish to use a new Jason-1 model in order to be consistent with Jason-2. For Jason-2 the story is more complex. A change of about 3 cm between GDR-C and GDR-D has been observed by a number of groups. The SSB model that was used to generate GDR-D was derived without some sigma0 instrument corrections and atmospheric attenuation (There were significant discrepancies in the Jason-2 WS histogram before the corrections were made.). Thus, when the new WS is used with the model there are differences of about 3 cm between the SSB for Jason-1 and Jason-2. It is not planned to update the Jason-2 SSB on GDR-D. New (consistent) models for both Jason-1 and Jason-2 are available from N. Tran. The difference between the Ku and C band SSBs should be revisited with the newest methods and data.

Several papers were presented on new or improved methods of retracking. D. Sandwell presented results on double retracking to improve the high frequency noise characteristics of data. The double retracking improves the noise by reducing the number of parameters in the second pass and thus "noise" from the correlation of parameters in the waveform model. To the extent that the removed parameter is constant over the span of the retracking error is reduced. Sandwell uses the method to improve geoid models. He used 3 and 2 parameter models and found an improvement in SSH noise of 1.56 but noted that the method does not improve the results for SAR-mode waveforms. Reduced noise was also the reason for including both the MLE3 and MLE4 results on the Jason-2 GDRs; however, it was noted in the report from the Cal/Val splinter that MLE3 has higher crossover variance in spite of reduced along-track noise.

P. Thibaut presented a numerical retracking approach. It is part of a study on the development of SAR processing for which the Brown/Hayne model that can be simplified with Gaussians does not apply. In addition to validating the current retracking methods, the numerical approach will be useful for assessing the changes from the TOPEX Alt-A PTR degradation. The "cal sweeps" of the TOPEX PTR can be used directly in the numerical method for comparison with the multiple-Gaussian method. The numerical method produces significantly reduced waveform residuals, generally more uniform results, and improved results at low SWH. Currently, the method is too computer intensive to be used for routine processing.

A number of papers were presented on CryoSat-2 processing, in particular comparing Low Rate (LRM) and SAR Mode (SARM) data. There has been significant progress in processing approaches and general agreement among groups. There appears to be good agreement between the two modes although it cannot be directly assessed, as they are not on at the same time. It is also difficult to compare SARM to Jason-2 as there are few crossovers. Thus, "pseudo-LRM" (pLRM) or "reduced SAR" (RDSAR) data are processed. These data are noisier than real LRM (~sqrt(3)) because they do not use all the pulses. Full SAR data have an improvement in noise performance of about a factor of 1.5 – 2 (there are some variation among processing methods/groups but results are converging since OSTST 2011), though, not quite as much as expected. In assessing the comparison of LRM, pLRM, and SARM, one must ask what constitutes "good" agreement at his stage of development, i.e., is agreement to 2-3 cm good enough? Nevertheless, verification of the theoretical and retrieved 0.8 cm range noise (for a 2 m SWH) result presented by L. Phalippou during OSTST 2011 has not yet been independently achieved yet and remains to be a key issue. W. Smith presented a detailed analysis of the waveforms (18 kHz) over a few bursts of SARM (burst interval = 11.8 msec) showing pulse rates higher than the 2 kHz used for conventional LRM may have reduced noise.

A number of issues remain with understanding the SAR data which require further research, including:

- the optimal weighting of Doppler beams needs to be included as the width of the response function broadens for off nadir beams;
- problems remain for SWH < 1 m (sensitivity of waveform leading edge);
- the possibility of sensitivity to swell and wave direction has not been fully evaluated;
- an SSB model has not been derived.

In the course of doing comparisons between conventional data and processing of SAR data, the spectra of high rate sea level anomalies (SLA) was investigated. The main result is shown in the Figure 29 from F. Boy. The "bump" in the spectra between about 7 and 50 km wavelength of all the data types except the fully processed SAR was the subject of much discussion and does not have a complete explanation. Post-meeting work suggests that the effect is less prominent, but not completely absent, in TOPEX data. Work will continue to understand this result.

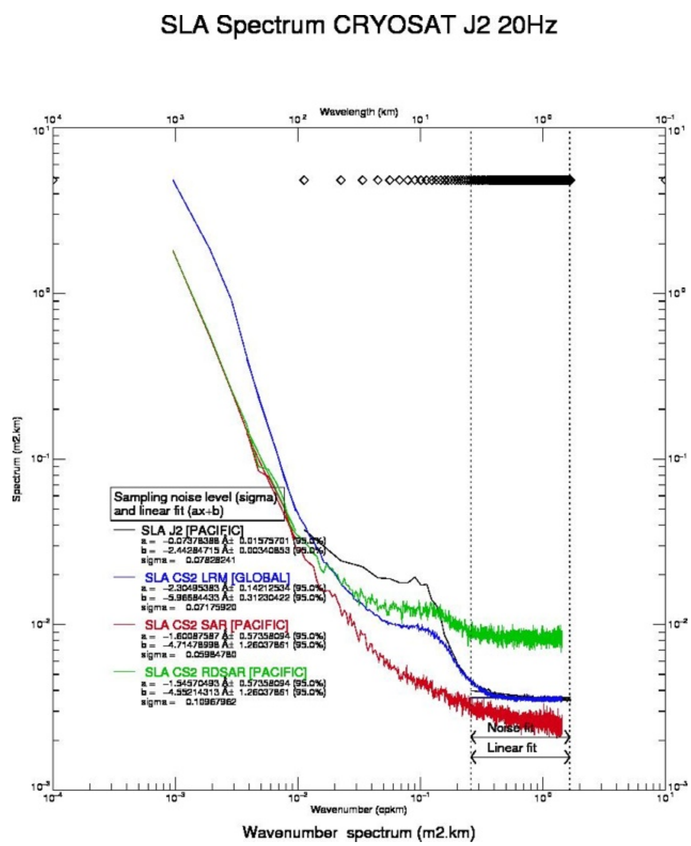

Figure 29. Sea Level Anomaly (SLA) spectra from several missions. Note that all "low rate" type (~ 1/sec related to 20 Hz) altimeter data has a spectral feature near 10 km before a drop found in the 20 Hz data. The CryoSat-2 SAR data (Red) do not show this feature.

8.6.1 Jason-CS Discussion

RADIOMETER

The Jason-CS team has been active in studying the options for the core payloads including the radiometer. Prior to the OSTST, a document titled "Jason-CS Microwave Radiometer Design Configuration Options," was provided to the team by Robert Cullen [JC-TN-ESA-MI-0034, 16 September 2012] describing the current design options under consideration by the Jason-CS team and is summarized below.

Currently, there are two systems being considered for the radiometer on Jason-CS. One system is a European funded radiometer with heritage from ERS-1/2, EnviSat, and Sentinel-3, which is termed EU-MWR. The other system is a US funded radiometer with heritage from Jason-2/3, which is termed AMR-C. The EU-MWR is a noise injection radiometer (NIR) operating at two-frequencies and uses an internal switch to a cold sky horn for calibration. A study is underway to investigate the addition of an 18.7 GHz channel to the EU-MWR. The AMR-C is a Dicke-radiometer operating at three-frequencies and uses both internal calibration sources (reference load and noise diode) for short time scale calibration (< 30 days) and periodically viewed external blackbody calibration targets for long time scale calibration (> 30 days) the latter of which is expected to significantly improve the stability of the wet path delay on long time scales. The two concepts are shown in Figure 30.

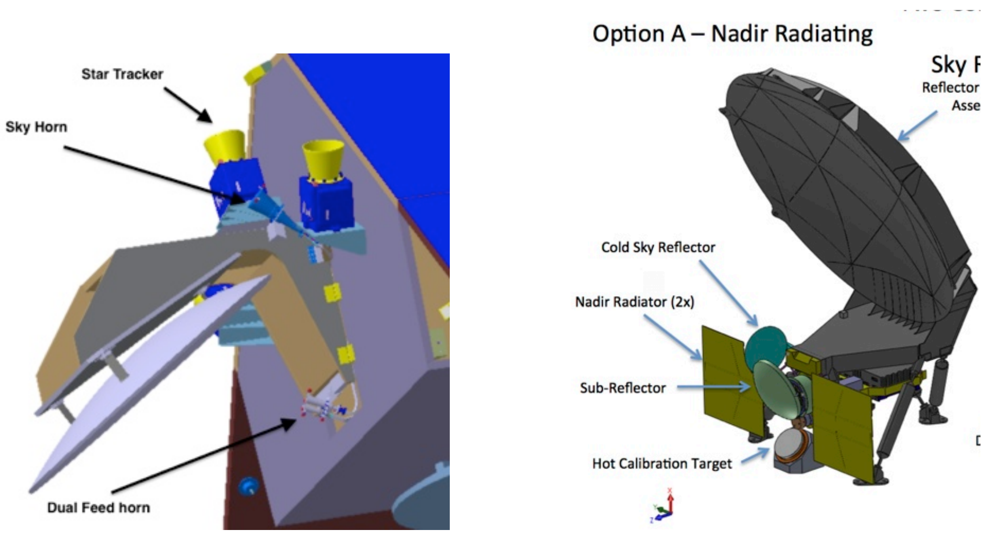

Figure 30. EU-MWR concept drawing (left) and AMR-C concept drawing (right).

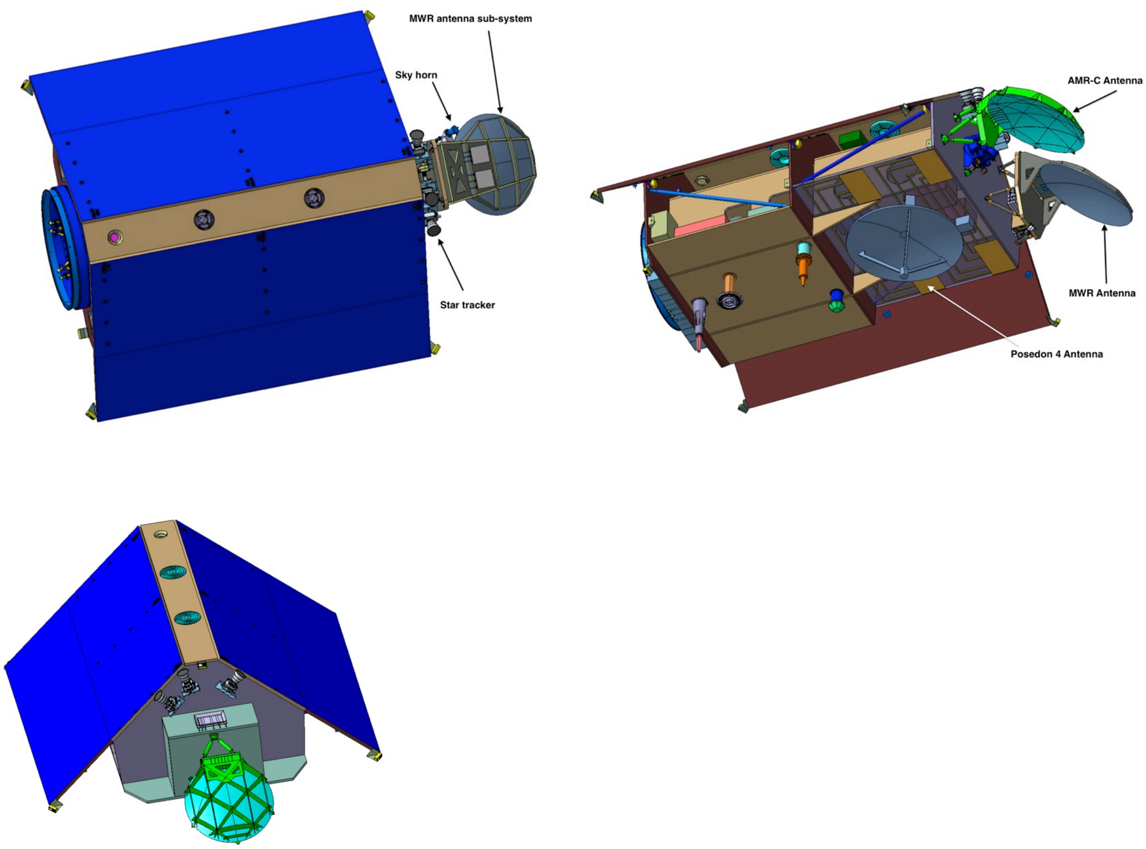

Figure 31. Jason-CS radiometer configuration options. Option-A (top left) includes the EU-MWR, Option-B (top right) includes both the EU-MWR and AMR-C as stand alone systems and Option-C (bottom left) includes the EU-MWR and AMR-C electronics and a single shared antenna.

Several satellite configurations for Jason-CS have been studied and three radiometer accommodation options have been identified. Option A includes only the EU-MWR, Option B includes both the AMR-C and EU-MWR as standalone instruments, and Option C includes both the AMR-C and EU-MWR sharing a single antenna aperture. These options are pictured in Figure 31.

Of these three options, Option-A would nominally embark a three-frequency radiometer; Option-B would embark two independent radiometers with the EU-MWR operating at 23.8/36.5 GHz and the AMR-C operating at 18.7/23.8/36.5 GHz and Option-C would be equivalent to Option-B except that the independence between the systems is reduced due to the shared aperture. The Jason-CS team presented the OSTST with the following questions:

1. *Are the scientific benefits of a three-frequency radiometer over a two-frequency system clear enough to recommend one or the other for Jason-CS?*
2. *Is there any science benefit to having two radiometers on-board? In particular:*
    a. *Could the simultaneous operation of two radiometers be an asset in terms of estimation and effective minimisation of radiometer drift in wet tropospheric path delay retrievals?*
    b. *Would there be any science benefit in having different centre frequencies for the two radiometers, considering the frequency channel used to estimate the cloud water content is already different between the MWR and AMR-C?*
3. *Lastly, as a result of OSTST 2010 meeting, the Jason-CS Mission Requirements Document states as a requirement,*

    "Jason-CS shall measure globally averaged sea level, relative to levels established during the calibration and validation phase, with zero bias ±1 mm (standard error) averaged over any one year period."
    Consultation is requested in order to clarify the meaning of this requirement since it can be interpreted, as the system shall have no drift, which is difficult to verify. The consultation should help identify how the requirement can be broken down in order that partner agencies can supply the hardware requirement to industry. Also, consideration should be given whether this drift requirement must be met through instrument design or characterization or whether it can be left to the science team as a post-launch calibration effort.

Prior to the meeting, a technical report titled "What type(s) of microwave radiometer for Jason-CS" was provided by Estelle Obligis et al. providing a response to these questions. This report was summarized and presented during the afternoon round table discussions on September 28th. A set of recommendations based in part upon this report was drafted by the splinter chairs. After discussion, the splinter session attendees and the greater OSTST concurred with these recommendations. These recommendations are as follows:

The recommendations regarding the Jason-CS radiometer were

1. **The main improvement the OSTST community could expect from the Jason-CS radiometer(s) is instrument enhancements to enable long term stability from the radiometer, eliminate dependence on ancillary data sources and reduce the latency of the final calibrated product.**

2. The Jason-CS system will benefit significantly from a three-frequency radiometer by reducing variance in the tropospheric path delay correction and maintaining continuity with the 20+-year record.

3. The most significant benefit from the embarkation of a second radiometer would be for the second radiometer to operate at high frequencies to resolve km-scale water vapor to improve coastal altimetry and inland hydrology applications.

The motivation for these recommendations is as follows.

1. The wet tropospheric correction provided by the radiometer on altimeter missions is the largest source of error in the estimation of the global mean sea level (GMSL) trend. This is in part because the radiometers on heritage missions have relied on internal calibration and not necessarily been designed for long term stability. The long-term calibration is typically derived from ancillary data sources (e.g. models, other sensors). Because the long-term calibration relies on ancillary data sources that are not under project control, climate quality calibration stability can only be a mission goal and not a requirement. An alternative would be to embark a system that utilized stable external blackbody calibration targets for the long-term calibration, similar to those used for the primary calibration on imaging sensors like SSMI, WindSat and AMSU.

2. An analysis was performed by CLS for ESA in the context of Sentinel-3 preparations to study the benefits of a two- versus three-frequency radiometer. In this study, TOPEX/Poseidon data were processed using a two-frequency and three-frequency version of the wet path delay retrieval algorithm. The two-frequency algorithm included the altimeter sigma-0 to aid in the surface roughness correction. The difference in the variance of the along track sea surface height anomalies (SSHA) at crossover points was used as a metric to assess the difference between the algorithms. A map of the crossover variance difference between the two-frequency+sigma0 and three-frequency algorithm is shown in Figure 32. In this plot, red indicates an increase in variance from the two-frequency algorithm and blue indicates a decrease in variance. The improvement observed with the three-channel algorithm is significant: a 1 cm^2 or 1% of total SLA variance reduction. Locally the improvement can reach 10% of the SSHA variance.

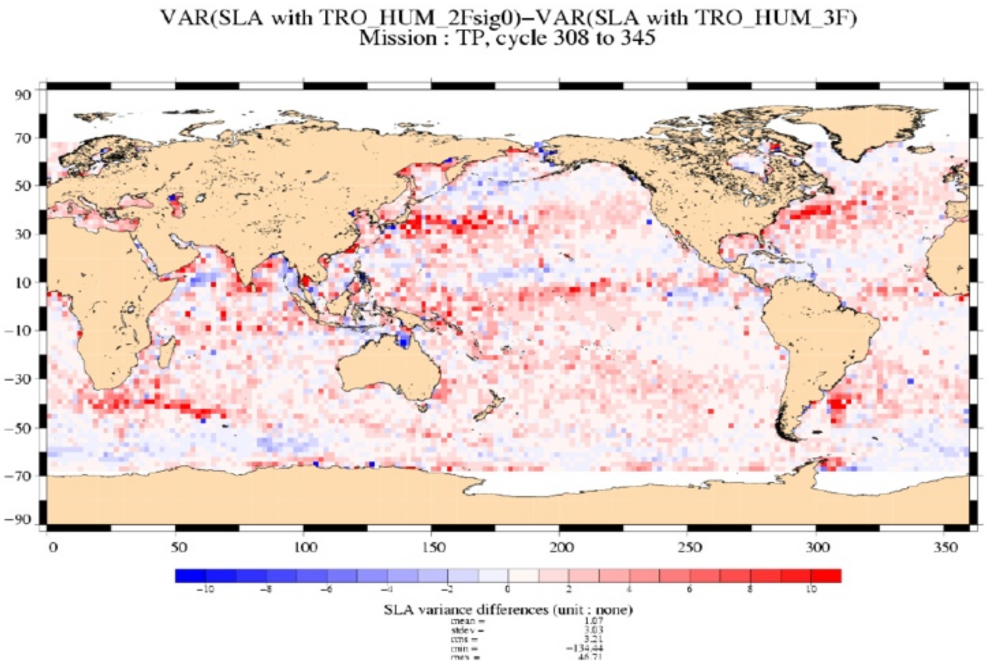

Figure 32. Difference in the SSHA variance at crossover points between the 2 and 3 frequency PD retrieval algorithms. The scale is -10 to 10 cm.

3. The question posed regarding the deployment of two radiometers was (a) whether having two systems would be an asset in the identification or minimization of the drift in the PD retrievals and (b) whether there would be a benefit to having difference center frequencies for the two systems.

    a. The simultaneous operation of two <u>independent</u> radiometers is great for identifying relative drifts and anomalies between the two. Two examples were cited from the TOPEX/Jason-1 and Jason-1/Jason-2 tandem phases and shown in Figure 33. In these cases, small 0.1 K level calibration anomalies were observed between the radiometers, but it is only a relative difference and ancillary data sources are required to identify the contribution from each radiometer to the observed relative difference. Since ancillary data sources cannot be relied upon for absolute stability, as illustrated in Figure 34 which shows 5 independent PD times series and no agreement in trends, having two radiometers on board will not necessarily help the Jason-CS system reach the required stability.

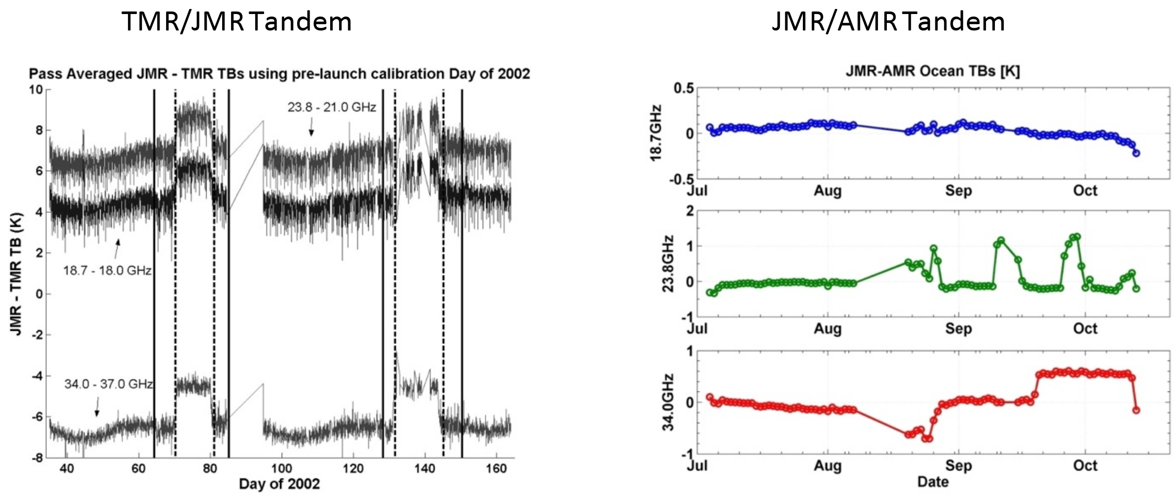

Figure 33. Relative differences between independent radiometers (TMR and JMR left) and (JMR and AMR right). Relative offsets are clearly observed, but without additional information, it is ambiguous as to which radiometer is contributing.

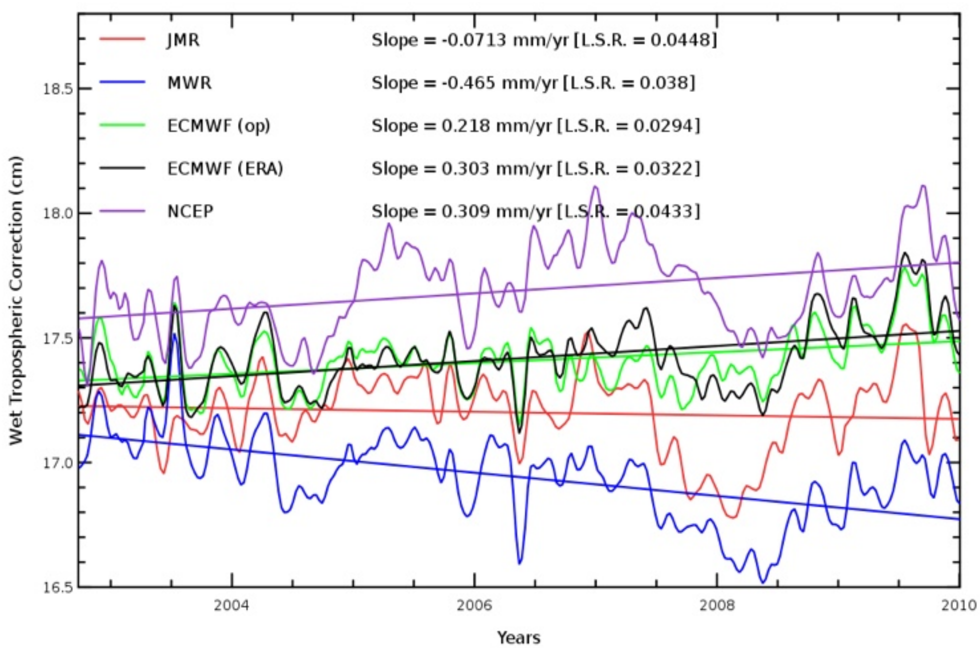

Figure 34. Wet PD trends from 5 sources. Differences in slope of up to 0.75 mm/yr are observed.

b. The EU-MWR and AMR-C have different Ka-band channels (36.5 and 34 GHz respectively). Because the atmospheric window is centered at 35 GHz, having both frequencies is not expected to add significant information that will lead to improved PD retrievals. Detailed simulations can confirm this. If one Ka-band channel is chosen, it is recommended that this channel be 36.5 GHz for consistency with other planned and existing altimeter radiometers and to operate the radiometer in a radio frequency protected band. But, there would be a significant benefit if the second radiometer operated a higher frequencies (> 90 GHz), enabling it to resolve shorter scales of the atmospheric variability (with the same antenna aperture size as the low-frequency system) to significantly improve the quality/resolution of the wet tropospheric correction in coastal areas and for hydrology (smaller footprint, less corrupted by land emissivity).

8.6.2 Altimeter

Prior to the OSTST, a document titled "Jason-CS Poseidon-4 Modes of Operation" was provided to the team by Robert Cullen [JC-TN-ESA-MI-0036, 10 September 2012] that described the various options being considered by ESA and partner agencies for the altimeter based on heritage "LRM" and the "SAR" mode (SARM) for which science benefits for oceanography are becoming clearer since OSTST 2011. The main advantages are reduced instrument noise and smaller effective footprint as discussed during the Instrument Processing splinter. Some of the issues remaining to be resolved for SARM were also noted during the splinter.

The recommendations regarding the Jason-CS altimeter were

1. **The OSTST strongly recommends that the Jason-CS altimeter shall deliver both backward-compatible ("LRM") and high-resolution ("SAR") range measurement over all the ocean, seamlessly and simultaneously.**

2. **Backward compatibility will ensure continuity of service in operational oceanography, climate, and wind & wave services.**

3. **The high-resolution data will enable sampling of sub-mesoscale features associated with high-velocity currents, vertical flow and mixing in the ocean. These will benefit both the operational and research communities.**

4. **To enable near-real-time applications, LRM (at least) and SAR (if feasible) shall be delivered with latency similar to that in previous Jason missions.**

5. **Land and inland water applications shall be enabled to the fullest extent possible under the constraint that sea level measurement must be the primary mission.**

The specific implementation of LRM and SARM, e.g., timing as "closed burst" like CryoSat or "interleaved", is covered by implication in recommendation 1 as only interleaved operation allows "seamless and simultaneous" comparison of LRM and SARM. The technical and cost implications of this implementation will need to be evaluated by the project. The relative performances of the different implementations were shown by R. Cullen in Figure 35.

Recommendations regarding the Sentinel-3 altimeter were discussed extensively on email following the meeting, but no final conclusion was reached. It was noted that Sentinel is not a research mission but is aimed at ESA GMES services. However, a strong scientific recommendation on the coverage of SAR data would be reviewed by the project.

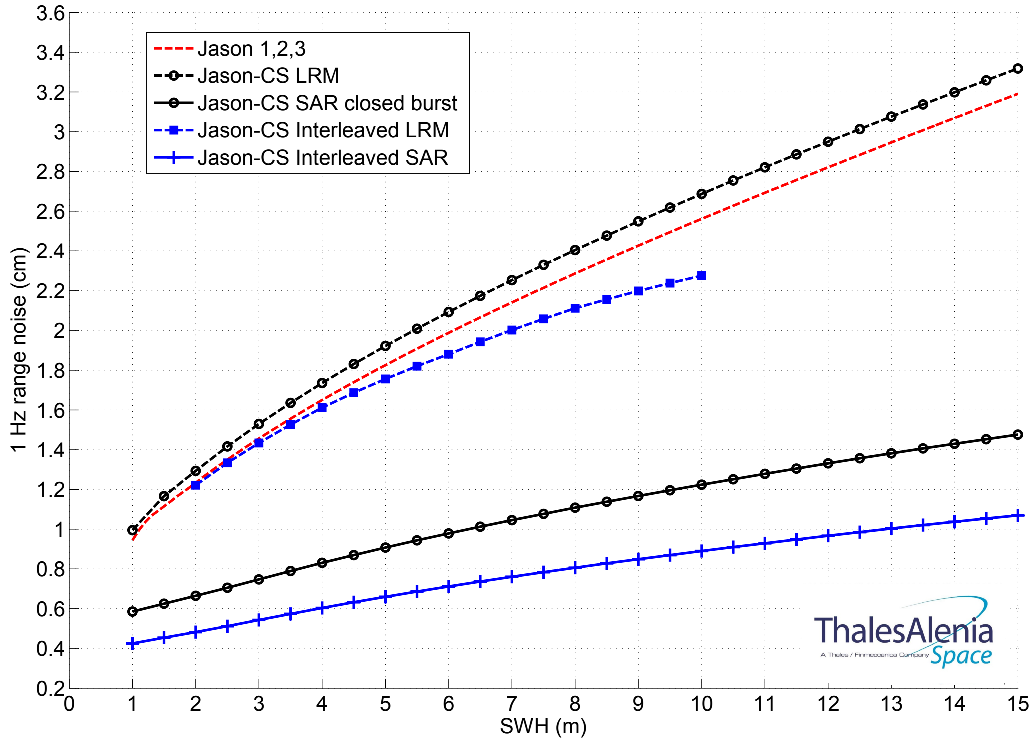

Figure 35. Theoretical performance of various modes and timing implementations discussed for the Jason-CS altimeter. (Courtesy Thales Alenia Space)

8.7. Precision Orbit Determination

Chairs: *Luca Cerri, Nikita Zelensky (on behalf of Frank Lemoine)*

8.7.1 Status of Jason-2 GDR orbits

Significant progress in the orbit accuracy has been achieved since 2010 in orbit solutions from all analysis centers. Jason-2 GDR orbits have been reprocessed with updated standards referred to as GDR-D. A preliminary version of GDR-D orbits had been presented by CNES at the 2011 OSTST meeting in San Diego. With respect to this preliminary version, final GDR-D orbits include updated JPL Phase Center Origin and Variation maps for the Jason receiver (rlse11a) and increased weight of GPS data in the solution with respect to DORIS and SLR. These changes bring the latest GDR orbits slightly closer to the JPL orbits (Figure 36 and Figure 37) and significantly improve the crossover variance (Figure 38 and Figure 39). Comparison of GDR orbits to other reference solutions indicates stable radial RMS differences, generally well below 1-cm.

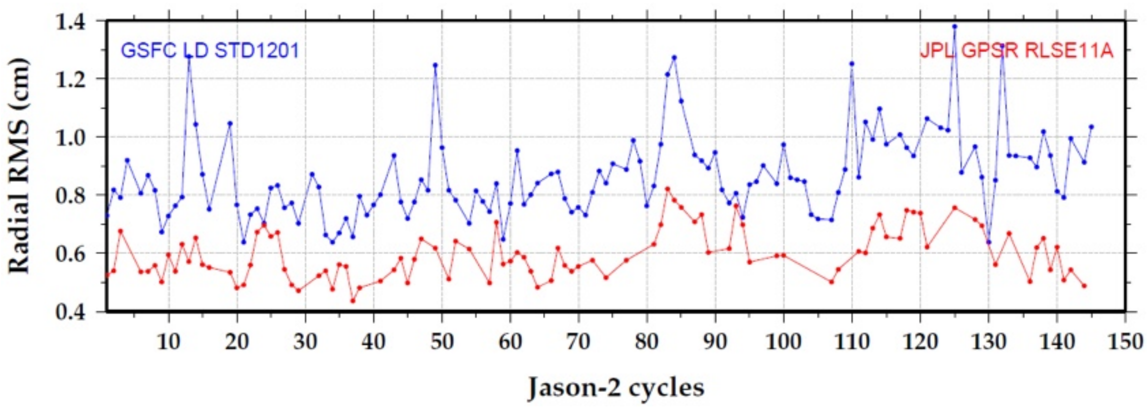

Figure 36. (Couhert et al.) Comparison of two different orbit solutions (GSFC_LD_STD1201 and JPL_GPSR_RLSE11A) solutions with respect to Jason-2 GDR-D orbits. GSFC_LD_STD1201 is a DORIS+SLR-based dynamic solution using un updated gravity field model (as explained later), JPL_GPSR_RLSE11A is a reduced-dynamic GPS-only orbit.

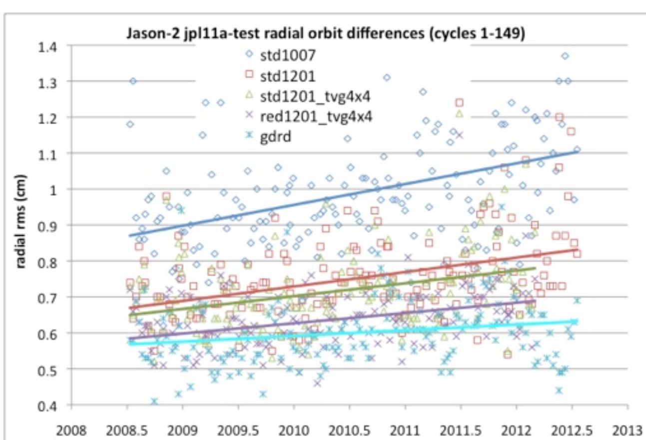

Figure 37. (Lemoine et al.) Comparison of several orbit solutions with respect to JPL_GPSR_RLSE11A. GSFC std1007 orbits are similar to GDR-C. Orbits using updated gravity fields (std1201, std1201_tvg4x4, gdrd) and/or higher (red1201) parameterizations significantly get closer to JPL GPS reduced dynamic reference.

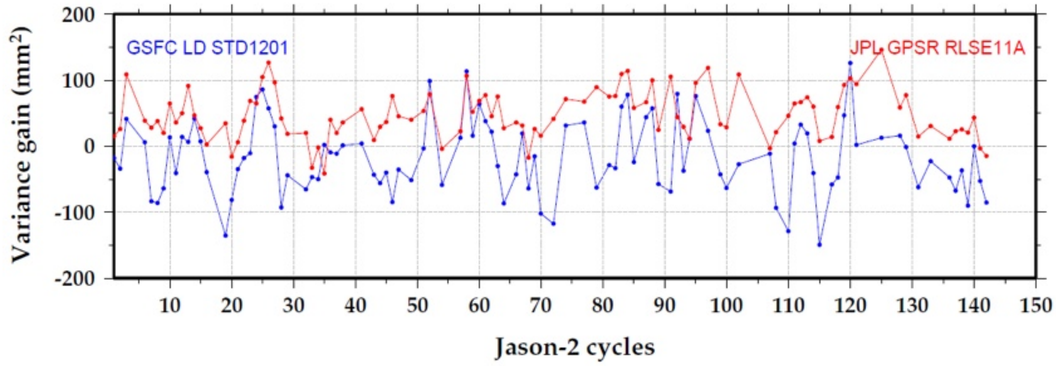

Figure 38. (Couhert et al.) Change in variance of cross-over residuals (GDR-D – other) between different Jason-2 orbits. Crossover residuals are sensitive to the geographically anti-correlated part of the orbit error.

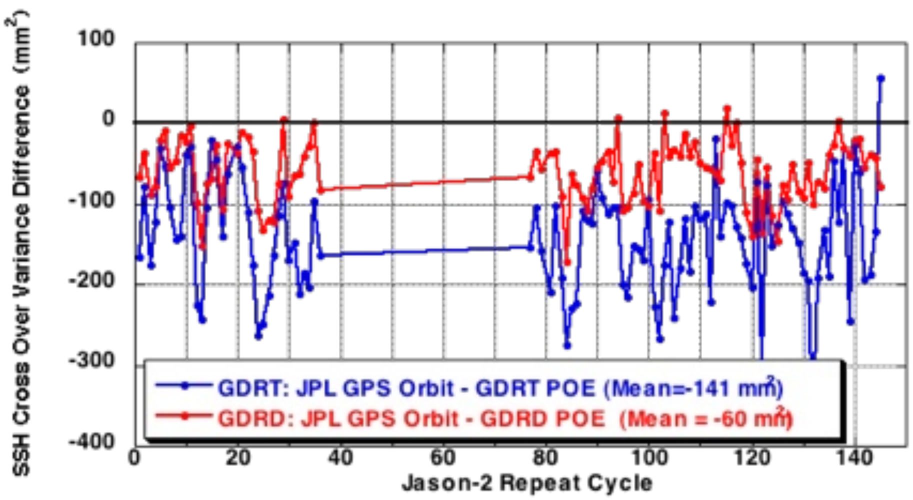

Figure 39. (Bertiger et al.) Gain in cross-over residuals of JPL reduced dynamic GPS-only orbits with respect to GDR D+L+G dynamic orbits. GDRT is the name of the initial release of Jason-2 GDR products, making use of CNES GDR-C orbits.

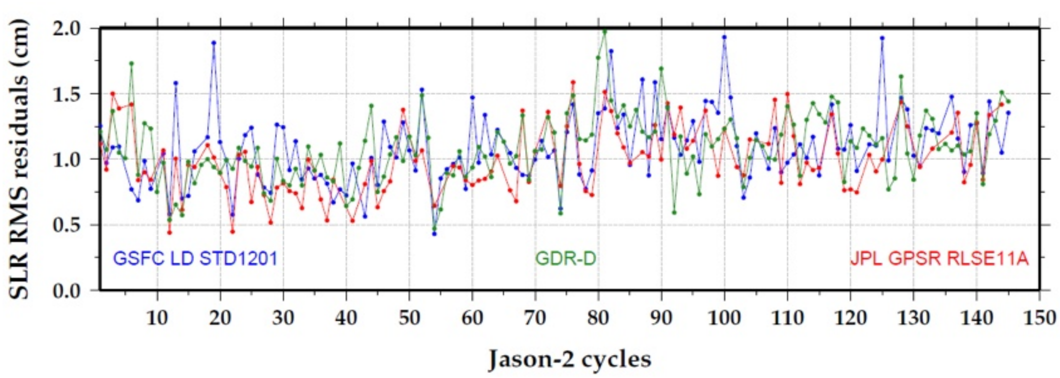

Figure 40. (Couhert et al.) SLR residuals above 70 degrees are similar for all orbit solutions (GDR-D and GSFC LD STD1201 include laser data in orbit determination solutions).

Jason-2 residuals summary cycles 1-135 July 2008 – March 2012 test using external ephemeris having a common span across Analysis Center orbits			
orbit	doris (mm/s)	slr (cm)	xover (cm)
gsfc std1007 (Measures)	0.3812	1.188	5.469
cnes gdrd	0.3804	1.313	5.408
gsfc std1201	0.3808	1.058	5.404
std1201_tvg4x4noj2	0.3808	1.076	5.401
gsfc std1201_tvg4x4	0.3806	1.020	5.395
gsfc red1201_tvg4x4	0.3801	1.086	5.381
jpl11a gps	0.3807	1.199	5.328

Figure 41. (Lemoine et al.) Residuals summary of different orbit solutions. More details concerning the modelling changes of different orbit solutions is given in the next section.

In summary, the comparison with external orbits, the statistics of tracking data and altimeter crossover residuals indicate that the accuracy of GDR-like dynamic orbits (CNES, GSFC) is significantly improved (Figure 40 and Figure 41). This improvement is mainly due to the updated gravity field models that now account for long-term trends in the geopotential, as explained in next section with more detail. Moreover, we observe that orbits using this improved time-varying gravity models get significantly closer to reduced dynamic GPS-only solutions from JPL. GPS-based reduced dynamic orbits are by construction less sensitive to errors in dynamical models, although there isn't yet compelling evidence that these solutions are completely independent from these effects, time varying gravity in particular. Finally, even though significantly reduced, residual radial orbit differences still exhibit geographically correlated drifts that can reach 2 mm/year with respect to JPL11a orbit over the 4 year lifespan of Jason-2 (Figure 42).

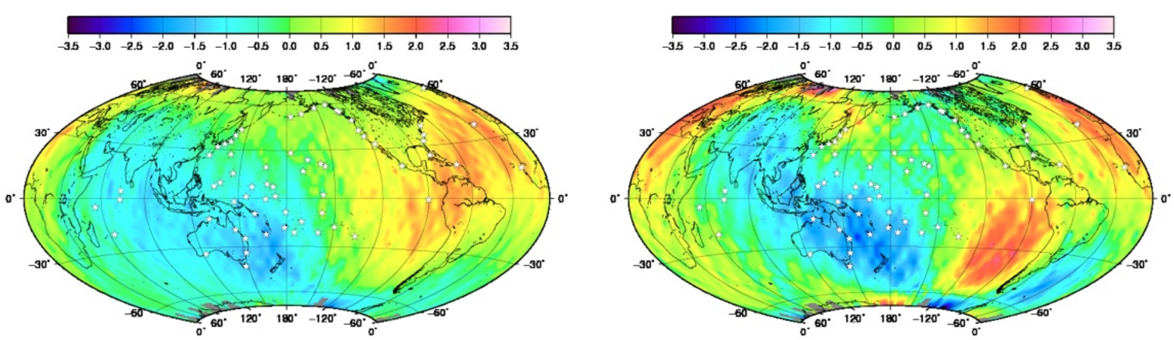

Figure 42. (Lemoine et al.) CNES_GDR-D – JPL11a (left) and GSFC_STD1201tvg4x4 – JPL11a (right) rates of radial differences in mm/year, once annual, semi-annual and 118-day signals are removed from the comparisons. Stars indicate locations of the 64 tide gauges currently used by Gary Mitchum for altimeter validation analysis.

8.7.2 Time Varying Gravity field models: status and prospects

GDR-D POD standards include linear rates in the geopotential up to degree and order 50 to account for secular variations in the geopotential (EIGEN-GRGS_RL02bis_MEAN-FIELD model). CNES constantly monitors any divergence of this mean linear model with respect to the time series of 10-day GRACE-derived fields. Figure 43 shows the radial difference RMS remains small between DORIS-only dynamic orbits of different missions using the GDR-D field and the same orbits using the time series, up the January 2012.

In Figure 44 the impact on MSL trends is shown for Envisat, which has proven to be significantly more sensitive than Jason to these geopotential effects. Globally over about 10-years the impact is less than 0.04mm/yr surpassing the goal of 0.5mm/yr precision, while regionally the impact is less than 0.5mm/yr for a goal of 3mm/yr precision (Phillips et al.). Over shorter time intervals (like the Jason-2 4-year lifespan) local trends can be higher (2-3 mm/year).

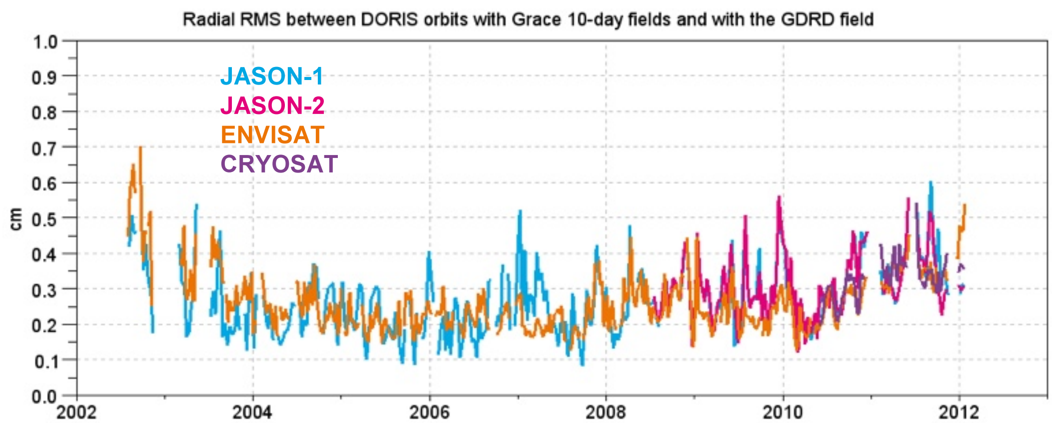

Figure 43. (Cerri et al.) Radial RMS between dynamic DORIS-only orbits using the 10-day time series of GRACE-derived fields and the mean model including rates, annual and semiannual terms of the GDR-D standards

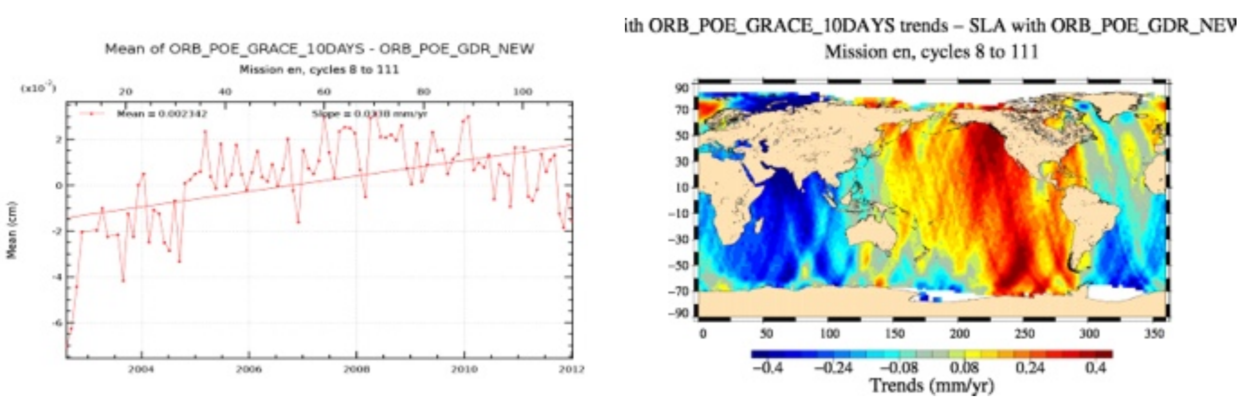

Figure 44. (A. Ollivier et al.). Impact on Envisat Mean Sea Level trends between Envisat orbits using the time series of 10-day GRACE-derived geopotential and the GDR-D orbits.

Thanks to an extensive analysis including ERS-1, ERS-2, TOPEX and Envisat, Rudenko et al. at GFZ have confirmed that the drift terms of recent GRACE-derived mean models (EIGEN-6S and similar) cannot be extrapolated before 2002, which is consistent with what Lemoine et al. had shown for Topex in 2011 POD splinter. Again, GFZ orbits are generally improved for ERS and Envisat over 2002 and 2010 using these rates, as they are on CNES and GSFC orbits for Jason. The improvement is further corroborated by Dettmering et al., which have outlined significant geographically correlated errors on a previous generation of GFZ orbits (using the EIGEN-GL04S field, no model for long term time-varying gravity) obtained by GFZ within Sea Level project of the European Space Agency (ESA) Climate Change Initiative (SLCCI).

Although satisfactory over the 2002-2012 time interval, modeling these inter-annual variations using constant rates has several limitations, as we cannot safely extrapolate linear trends if the underlying geophysical processes are not linear. Moreover, we need a solution for POD in case GRACE data were lost, as the mission is already operating well beyond its nominal lifetime. It should be mentioned also that several potential contributors to MSL trends estimates (Cryosat-2 and SARAL/AltiKa) will rely on DORIS+SLR data, which have not proven so-far to offer the necessary observability for an effective reduced-dynamic approach.

Three strategies to overcome this problem have been outlined during the POD splinter session

1) Build a **spherical harmonics complement** to the nominal GRACE-based static field using available DORIS and SLR data; two methods using this approach have been undertaken by the GSFC team, which has released 1) a series of experimental orbits (tvg4x4) using a time-series of 4x4 geopotential coefficients (7-day time series from 1993 estimated using SLR/DORIS tracking up to 10 satellites) and 2) orbits based on a TVG model derived from the 4x4 geopotential coefficient time series (std1201). For the TVG model annual, semi-annual and linear terms estimated from the 19-year tvg4x4 time series are applied depending on the coefficient (Figure 45); together with the GOCO2S static gravity fields, this complement constitutes the basis of the std1201 GSFC standard. The TVG model could also be tailored for example, to the apparent recent significant changes in the geopotential, by just fitting over the most recent 6-10 year period. As shown in the previous metrics, the new orbits represent a significant improvement with respect the previous std1007 orbit, whose model of the secular variations of the gravity field was limited to the IERS2010 recommendations. Both POD methods show promise accounting for changes in the Earth's geopotential in the absence of available GRACE data (Lemoine et al., Zelensky et al. poster)

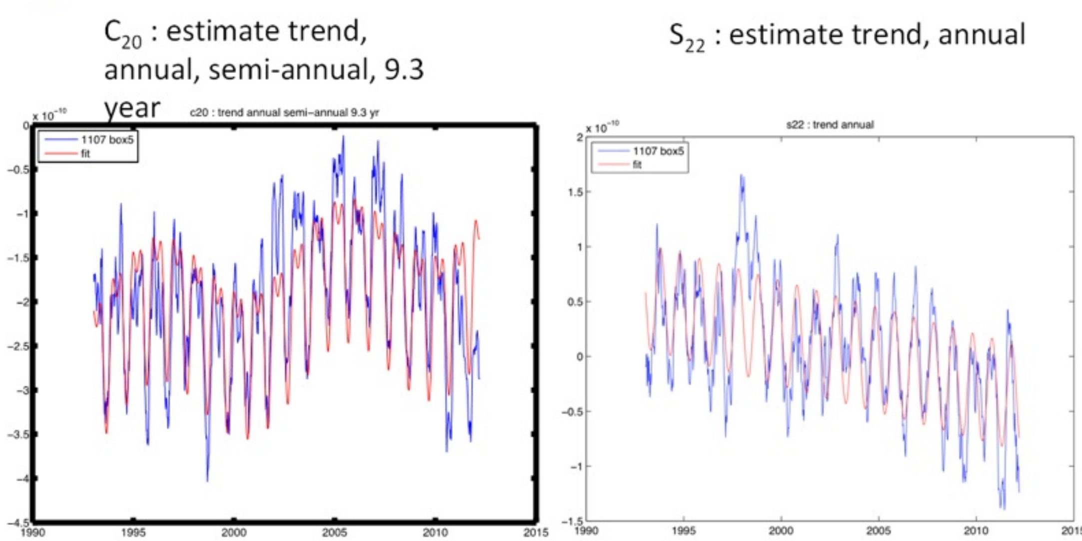

Figure 45. (Lemoine et al.) Examples of temporal behavior of two spherical harmonics coefficients. The blue curves represent the time series, the red curves the model fit.

2) Build a **point-mascon complement** to the nominal GRACE-based field (Figure 46). CNES Team has generated a time-series of 6-point-mascon values that are interpolated to complete the gravity field model used in dynamic POD solutions. These point mascons are located where significant long-term signatures are expected, at high and low latitudes, where either glacier melting (negative mass

trend) or GIA (positive mass trend) dominate. The point mascon complement is obtained using only DORIS data from current and past altimeter missions. The implementation (extension of the time series at weekly intervals) is compatible with the operational production of POE orbits from all missions. To the extent that locations where the strongest long-term variations occur remains (Figure 47) known over a 3-4 year time-span, the mascon empirical approach is promising in maintaining and monitoring the DORIS-based orbit performance in case of loss of the GRACE time series (Cerri et al.)

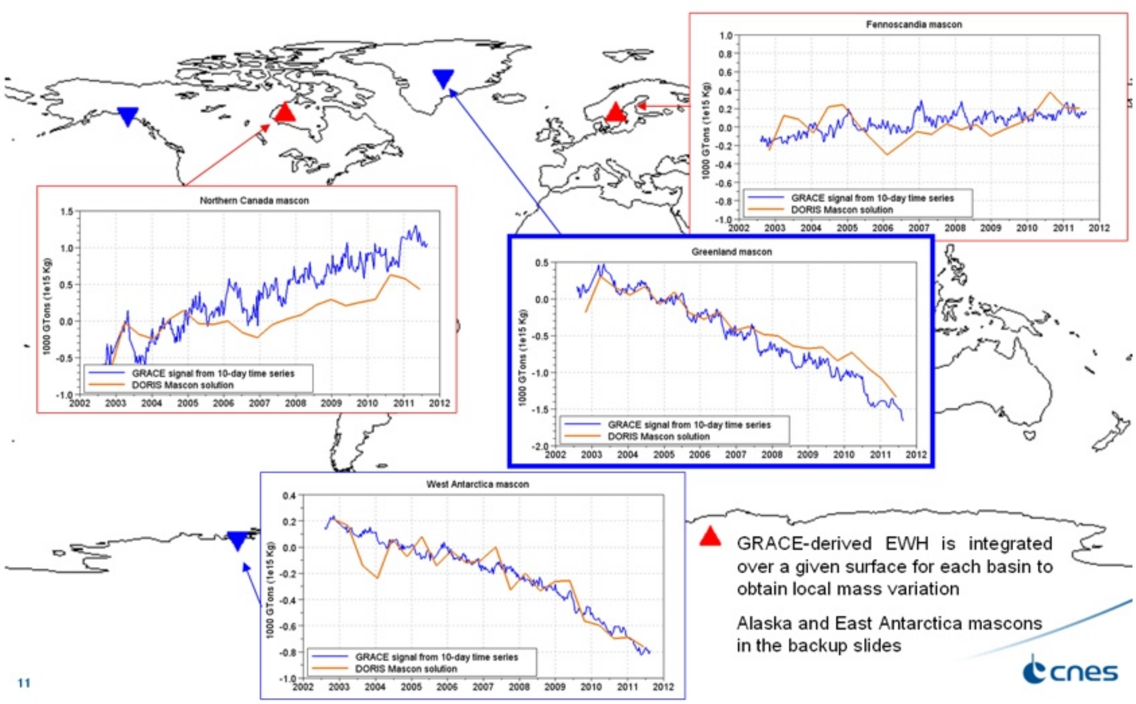

Figure 46. (Cerri et al.) Validation of DORIS-based point mascon models using GRACE data

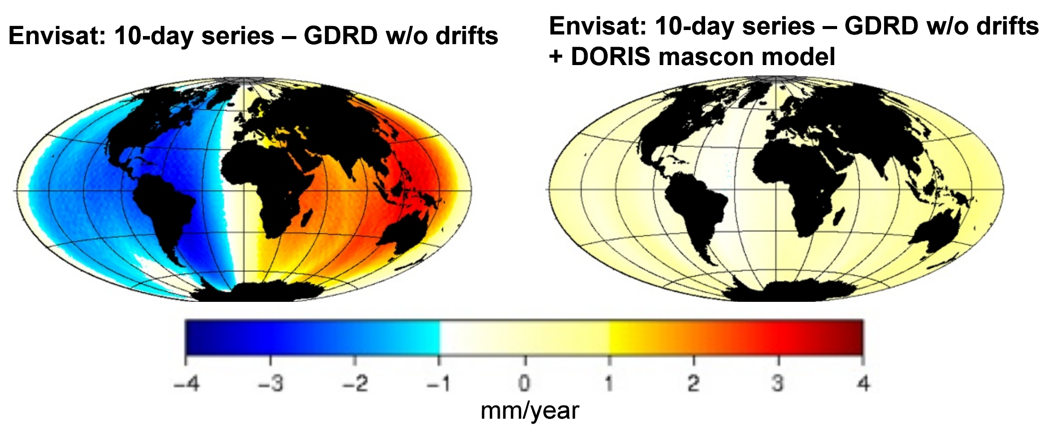

Figure 47. (Cerri et al.) Impact of point mascon model on Envisat DORIS-only orbits

3) **Reduced-dynamic GPS-based orbits**. The JPL Team is currently the only group providing this type of orbits, using GGM02C static field, no TVG nor any forward modeling of atmospheric gravity. As this type of solution strongly relies on GPS tracking alone and only very weakly on the accuracy of

dynamic models, it may not be able to respond adequately to possible significant future changes in the geopotential. However the JPL orbits continue to show the lowest crossover variance and remain a highly valuable tool to assess the limits of current dynamic orbit solutions. We should further investigate the extent to which these solutions are free from errors induced by the geopotential and especially time varying gravity.

In regard to this, all POD groups should continue their effort to improve their processing of GPS measurements to maximize the observability, and using independent constellation solutions. This effort will ultimately result in an error budget for the reduced dynamic GPS orbits and will prepare the way for future missions, for which the POD team recommends to make GNSS receivers a mission critical instrument.

For the time being, a dynamic orbit solution based on a set of "consensus" models expressed in a well defined and stable reference frame should remain the basis of long term mean sea level analysis, on either the global and the regional scale.

It is now clear that a model for the inter-annual variability of the geopotential needs to be used in particular over the 2005-2012 period; however, external validation of the orbit error induced by different TVG models, which is obtained by comparison of altimeter-based MSL to that derived from tide gauges or Argo's T/S profiles, has not yet produced a conclusive statement on which modeling approach minimizes the geographically correlated error (Figure 48).

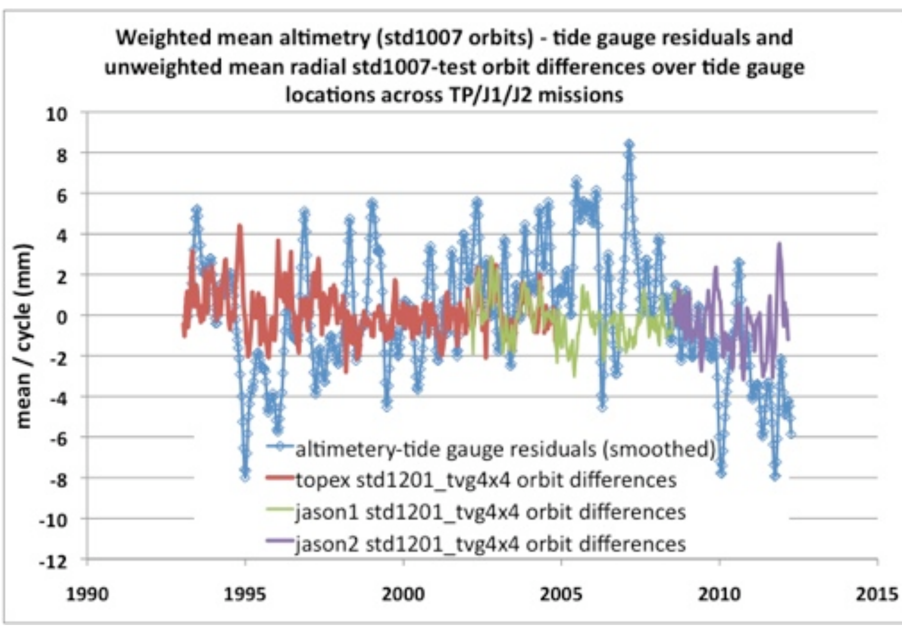

Figure 48. (Lemoine et al.) Comparison of altimeter based mean sea level with that derived from tide gauges. Radial orbit differences are averaged at tide gauge locations.

8.7.3 Tracking performance and improvements in the processing of the tracking data

DORIS

DORIS residuals are stable for all satellite missions. A small increase has been observed by Couhert et al. in Jason-1's residuals after orbit change (Figure 49). CNES is adopting a preliminary version of the updated SAA model used to correct the frequency of the on-board oscillator for GDR solutions on the new orbit. A more recent version is now available and will be tested. No conclusive sign of degradation in the POE metrics has been observed so-far.

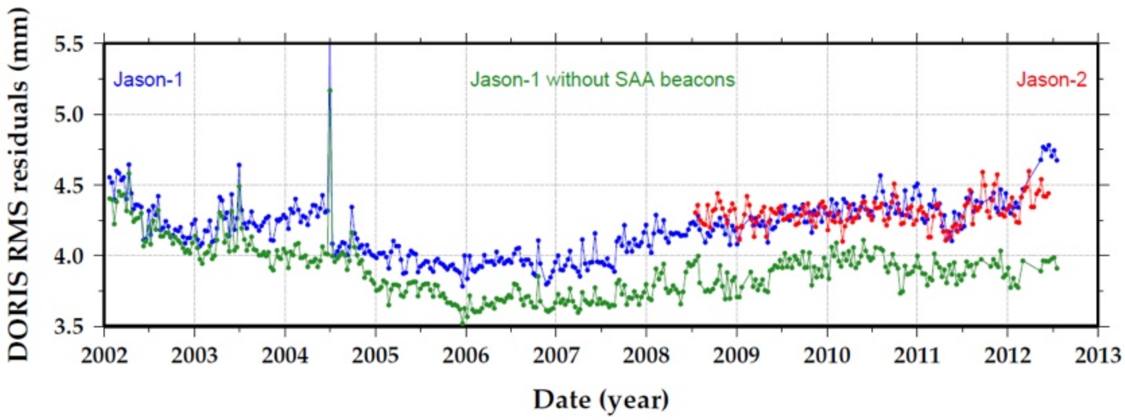

Figure 49. (Couhert et al.) DORIS post-fit residuals across Jason-1 and Jason-2 missions.

SLR

The SLR residuals on the core network of stations are generally stable, although increased scatter is sporadically observed on some stations usually considered as part of the core network (in particular Mount Stromlo last year, see Figure 50). The weight of SLR residuals has been reduced with respect to DORIS and GPS and this type of degradation has no significant impact on the accuracy of POE solutions. Nevertheless, the analysis of the statistics of high elevation SLR residuals remains the primary way to confirm that the orbit accuracy meets the mission requirement.

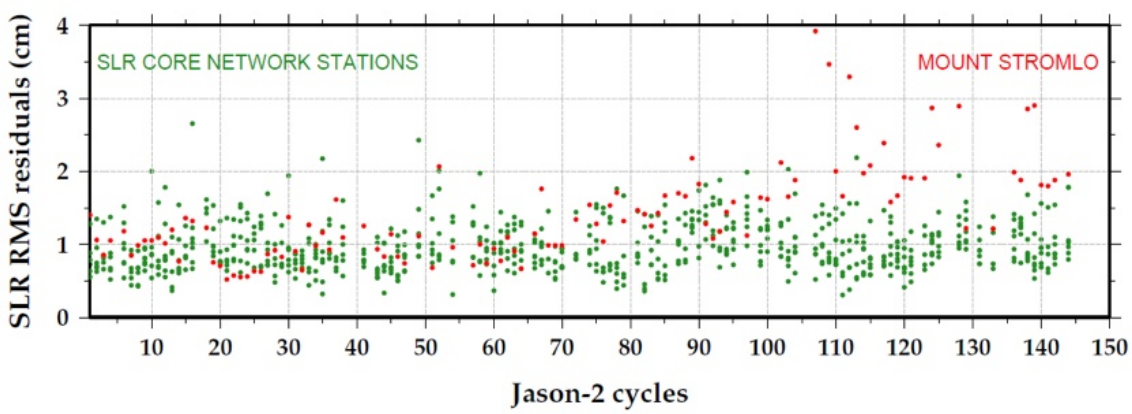

Figure 50. Statistics of SLR residuals above 70 degrees on JPL rlse11a Jason-2 orbits.

GPS

As explained earlier, the processing of GPS measurements is particularly valuable for altimeter missions because the observability of the tracking system allows to produce orbits that are weakly dependant on errors in the force models, the gravity field in particular. The observability of the GPS tracking system is maximized when the carrier phase ambiguities are fixed to their integer values. However these reduced dynamic solutions are potentially more sensitive to the quantity and quality of the tracking data, and to errors in the processing of measurements, as orbits are only weakly constrained by dynamic models.

In regard to this, it had been shown early after the Jason-2 launch (Mercier et al., OSTST 2008) that the GPS-P receiver phase measurements were subject to half-cycle slips. This problem was preventing the CNES zero-difference ambiguity fixing process from working properly on Jason-2, although it had proven to be successful on Jason-1 and GRACE (Laurichesse et al.). Notice that fixing integer ambiguities at half-wavelength is challenging because of 3D orbit errors at the few cm level.

It turned out that these half-cycle slips were causing a degradation in the JPL10a reduced-dynamic solutions (Bertiger et al., OSTST 2010), which was later solved by JPL (Bertiger et al., OSTST 2011) with introduction of phase brakes whenever the 10 second increment of $\lambda_1 L_1 - \lambda_2 L_2$ combination is beyond a given threshold. This approach allowed excellent reduced dynamic orbits with no sign of degradation over the time span of Jason-2 mission. These orbits take advantage of the single receiver integer ambiguity resolution scheme already presented by Bertiger et al. in Seattle, OSTST 2009.

Nevertheless, it can be expected that the fact of introducing phase breaks somewhat degrades the observability of the system, which led Mercier et al. for this year's splinter to try an alternative approach based on the preliminary reconstruction of the half cycle slips. Once the phase discontinuity is removed, the zero-difference integer ambiguity fixing scheme is applied using the CNES-CLS "GRG" constellation solution, with success rate which is often beyond 90%. Jason-2 integer-ambiguity orbits compare well to the standard POE (~ 8 mm RMS) but further work is needed to fully validate these solutions and to make the overall process more robust. Mercier et al. have also shown that the same widelane ambiguity fixing process works extremely well for the HY2A receiver and that reduced dynamic integer ambiguity GPS-only orbits are feasible in the operational orbit production.

The ESOC team (Otten et al.) is also engaged in the effort of creating integer ambiguity solutions for Jason-2; they used the recommended technique by JPL to pre-process the GPS observations to detect cycle slips, and included Jason-2 observables into an IGS like scenario (including GPS station data) where the orbiting receiver is treated together with the ground network, and the integer ambiguities are resolved at the double difference level together with the station ambiguities. The results are encouraging although further work is needed to outline a clear improvement of integer solutions with respect to classic floating solutions.

Finally, this year the JPL POD team (Bertiger et al.) has ambitiously tried to resolve half cycles over the lifespan of the TOPEX/Poseidon Motorola Monarch demonstration receiver, in 1993. It should be noted that at that time the GPS constellation was not fully operational, and the tracking system, occasionally engaged in anti-spoofing and individual satellites tests, was composed of only 23-24 satellites and 30-50 ground receivers. Although not successful in resolving the half-cycle ambiguities, this effort has demonstrated that the simultaneous solution of T/P and the GPS constellation using a fiducial approach (ground stations fixed to IGS08) improves significantly the precision of the GPS constellation solution (reduced overlaps), especially in February 1993, before the deployment of a larger ground network.

8.7.4 Remaining issues from last years

Non-conservative force models have not been improved in the last standard updates. As far as Jason-1 and Jason-2 are concerned, some evidence of systematic errors at 60-day and 120-day signatures still exists (Otten et al., Couhert et al.). Grey et al. (poster) have communicated the UCL plans to continue their effort on a-priori solar radiation, Earth radiation and atmospheric drag models. Dynamic solution GSFC orbit error due to solar radiation pressure mis-modeling was shown to be significantly reduced upon estimation of opr accelerations over 12-hour spans compared to the previously employed 24-hour spans (Lemoine et al.)

Significance of geocenter motion in POD has been further confirmed - though a consensus model for this correction has yet to be reached (Melachroinos et al., poster).

8.7.5 Conclusions

The GDR-D POD standards have been applied to Jason-1, Envisat, Jason-2, Cryosat and HY2A precise orbits, showing consistent improvements across all missions.

These improvements are due to the inclusion of GRACE-derived constant rates in the geopotential that account for the interannual evolution of the gravity field between 2002-2010, and are confirmed by the analysis of several groups who provided orbits with similar standards.

Promising results have been shown by both GSFC and CNES techniques who proposed respectively a DORIS/SLR-based spherical-harmonic complement to the static field and a DORIS-based mascon complement to model the geopotential outside the GRACE time interval.

The extent to which external validation systems (Tide Gauges, Argo T/S profiles, …) are able to monitor the geographically correlated orbit errors affecting altimeter based regional mean sea level estimates remains to be assessed.

JPL's GPS-based reduced dynamic orbits (which have the lowest variance of altimeter crossover residuals) remain an alternative valuable approach to the full modeling of the time varying gravity field. In particular, the POD group recommends to make GNSS receivers mission critical instruments for future altimeter missions. In regard to this, several groups (JPL, CNES, ESOC) are constantly improving their processing of GPS tracking data using independent solutions for the constellation orbits and clocks, which will prepare the way for future missions and eventually lead to a better understanding of the error budget applicable to reduced dynamic GNSS-based solutions.

8.8. Quantifying Errors and Uncertainties in Altimetry Data

Chairs: *Gerald Dibarboure, Joel Dorandeu, Rui Ponte*

The splinter was introduced by a plenary talk from J. Dorandeu who gave an overview of the necessity to provide a more precise altimetry error characterization for various applications (e.g. ocean modelers who need to setup covariance error matrixes), and the limited knowledge of the error correlation and wavelengths in the literature. This introduction emphasized the cross-cutting nature of the error analysis among OSTST splinters and altimetry users.

The splinter itself was quite 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 9 oral presentations, and 4 posters. Different domains (wavelengths and frequencies) were covered, from climate to mesoscale; focus was on sea surface height but wind and wave errors were also mentioned. Both sides of the error characterization were presented: altimetry experts reported their new findings on the error quantification while oceanography end-users explained why and how they used the altimetry error description.

The splinter started with a focus on climate scales and Henry et al showed the discrepancies between MSL trend estimates from different groups (e.g. Univ. Colorado and Aviso). The differences were large and up to 0.8 mm/yr in 2005-2011, which is a key period for the MSL closure budget. Their analysis highlighted that replacing the JMR correction on AVISO could reduce the differences by 0.3 mm/yr. Moreover, they showed that a difference in the processing methodology (e.g. gridding, weighting, editing) could explain as much as 0.5 mm/yr, thus resolving the disagreement between the AVISO GMSL (overestimated) and the CU GMSL (underestimated) with a corrected trend of 2.5 mm/year in 2005-2010 (Figure 51).

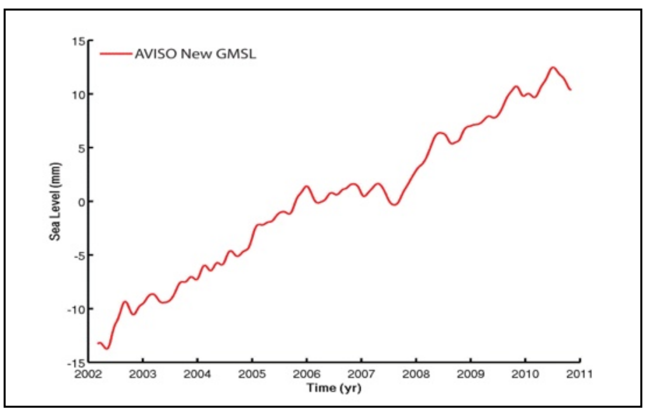

Figure 51. Global mean sea level trend with the corrections from Henry et al

Leuliette et al used a comparison of the altimetric data record with tide gauges to derive a drift estimate for each mission and each basin, thus improving our regional understanding of the limits of the 20-year altimetric record. They also investigated a possible time tag bias depending on the difference between the yaw control laws used for TOPEX and Jason-1 (centre of mass – centre of antenna) as the control used is also linked with the beta prime angle (i.e. unexplained 60-day errors discussed during the 2010 OSTST meeting). They showed that empirical corrections related with time tagging could improve the consistency between both missions (Figure 52).

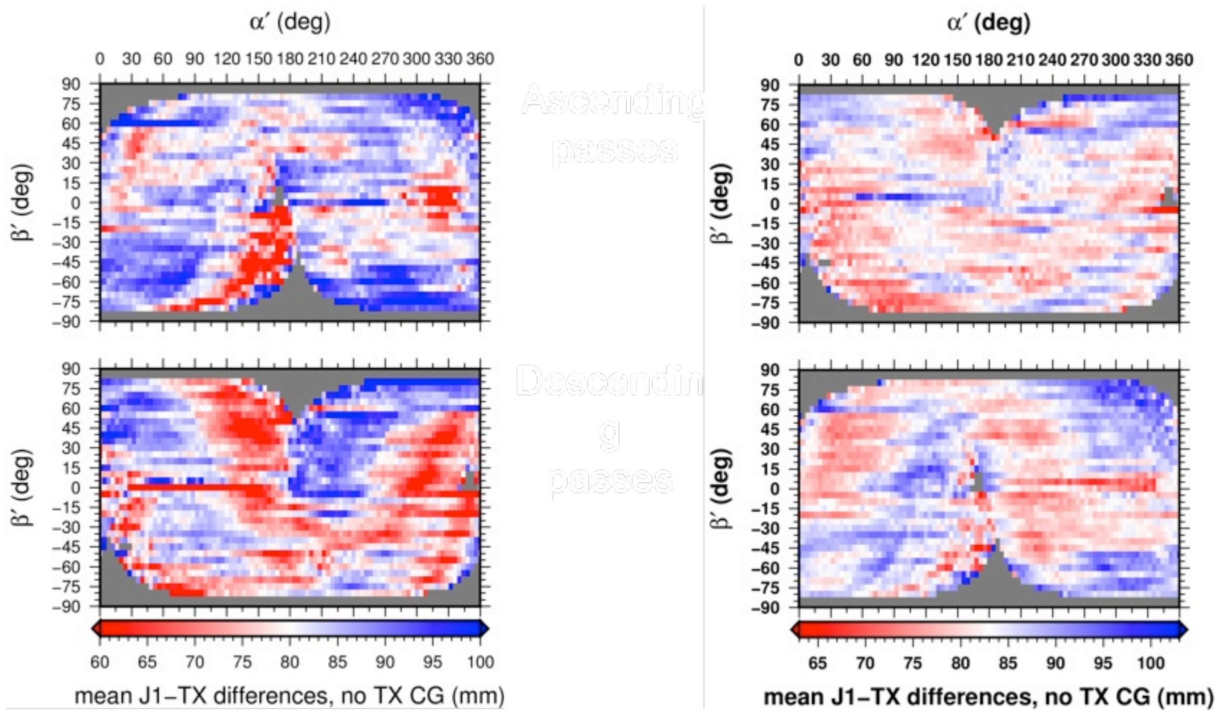

Figure 52. Jason-2 / Jason-1 difference with and without the time tag bias correction from Leulliette et al.

Ablain et al revisited the estimation of the MSL budget error and user requirements at multiple climate scales (Figure 53), presenting a decomposition of the errors according to the different contributions (orbit, altimeter, etc) with total error bars of the order of 0.5 mm/yr for the global mean sea level and 3 mm/yr for the regional (or local) mean sea level.

Spatial Scales	Temporal Scales	Altimetry errors	User Requirements
Global Mean Sea Level (10-day averaging)	Long-term evolution (> 10 years)	≤ 0.5 mm/yr	0.3 mm/yr
	Inter annual signals (2-5 years)	≤ 3 mm	0.5 mm over 1 year
	Periodic signals (Annual, 60-days,…)	Annual ≤ 1 mm 60-day ≤ 5 mm	Not defined
Regional Mean Sea Level (2x2 deg boxes and 10-day averaging)	Long-term evolution (trend)	≤ 3 mm/yr	1 mm/yr
	Inter annual signals (> 1 year)	Not evaluated	Not Defined
	Periodic signals (Annual, 60-days,…)	Annual ≤ 1 cm 60-day ≤ 2 cm	Not Defined

Figure 53. Revised mean sea level error budget and GCOS user requirements from Ablain et al.

Esselborn and Schöne investigated the orbit uncertainties by computing radial differences between several orbit solutions. They also performed a sensitivity study for time varying gravity fields, i.e. a major contributor of the error in POD. Their analysis shows that POD could locally explain as much as 2.5 mm/yr and 1-year correlated errors with an amplitude of the order of 1 cm. The signature is the same for all missions analyzed, thus highlighting the value of using different independent solutions in multi-mission Cal/Val analyses.

The error splinter then tackled the topic of the error characterization for wavelengths smaller than 100 km, which are difficult to use with Jason-class missions. Fu et al described the SSH errors at the mesoscale using the Jason1/Jason2 formation flight phase. They investigated the wavenumber spectrum slope (after removing the white noise background) and the implications for oceanographic mesoscale and turbulence studies (e.g. Figure 54).

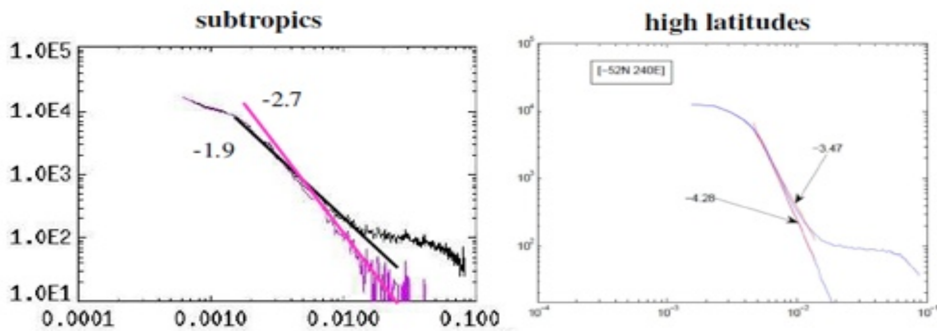

Figure 54. The effects of noise on the spectrum at long wavelengths from Fu et al.

Similarly, Ponte and Quinn analyzed short scale altimetry error estimates and described their geographical variations using differences between Jason1 and Jason2 (e.g. Figure 55). Their regional error estimate might prove to be an asset to better control the assimilation process of ocean models. These talks also highlighted the user-oriented benefit of improving the signal-to-noise ratio in the 10 - 100 km wavelengths with future technology (e.g. new retrackers, SAR altimetry and SWOT).

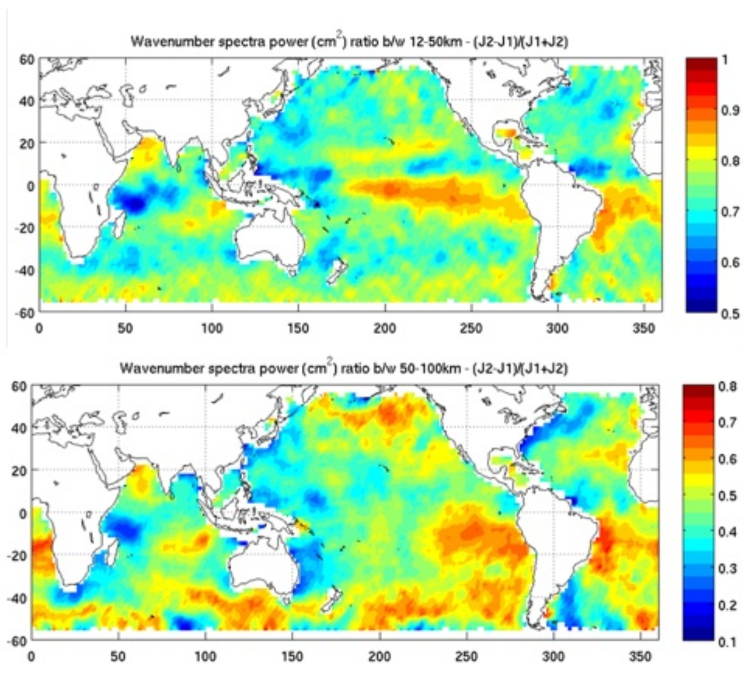

Figure 55. Signal to noise map from Ponte and Quinn.

The splinter expanded on the topic of ocean modeling and altimeter data assimilation with the talk from Oke who explained how different types of errors (instrument error, representation error, age error) are set up in typical assimilation procedures. Oke also discussed what might be still incorrect in their altimetry content (IB correction, MOG2D, Tidal, etc). Furthermore, Remy et al (Figure 56) described the main challenges in taking into account a realistic error description in the assimilation (i.e. improving from a simple diagonal covariance matrix) and showed different metrics used to quantify the impact of observations.

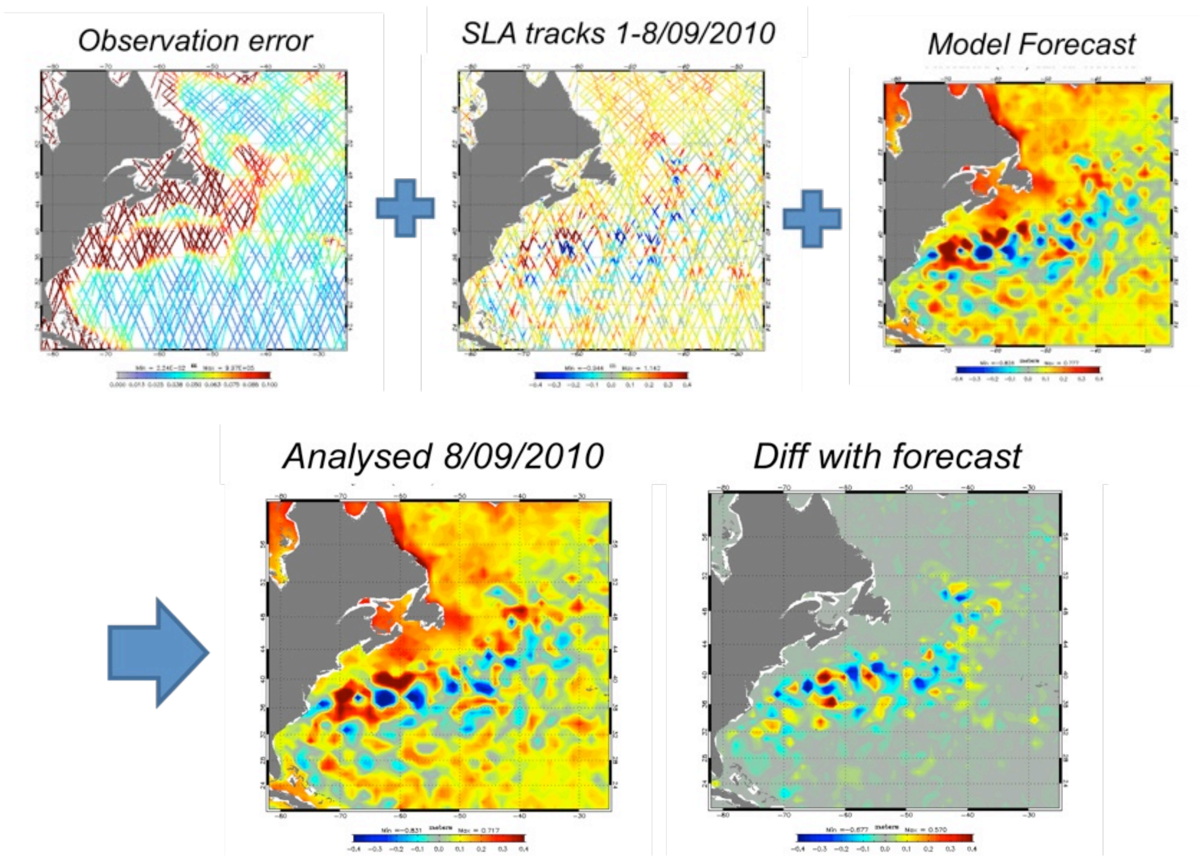

Figure 56. Weekly analysis and forecasts produced with an assimilation scheme from Remy et al.

Lastly, winds and waves were discussed by Abdalla and Janssen (Figure 57) who showed how robust error estimates could be derived from triple collocations (several missions and buoys). Their method provides wind and wave errors estimates on all altimetry missions, including a description of the variation of the error as a function of wind/wave values. Their analysis should be soon introduced as an input for improved assimilation of altimeter-derived wind and wave products in the ECMWF model.

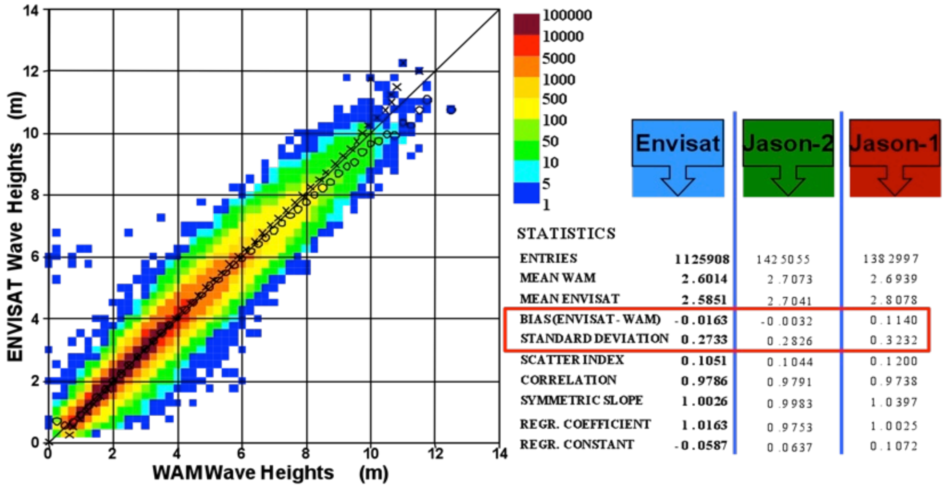

Figure 57. Global comparison between Altimeter and ECMWF wave model (WAM) first-guess SWH values from Abdalla and Janssen.

During the poster session, two posters provided new error estimates and two altimetry users explained how they used or reduced the altimetry error description in their application.

Philipps et al revisited the Jason-2 error budget for time scales shorter than 10 days, looking at OGDR, IGDR and GDR products with detailed values for each parameter (Figure 58). Similarly, Horvath and Pail showed their mean dynamic topography error budget analysis with two contributors: geoid and mss. And they used complex filters (e.g. anisotropic diffusive filter) to ensure a good spectral consistency.

	Error budget	Specifications			Error (<10 days)			GOAL
		OGDR	IGDR	GDR	OGDR	IGDR	GDR	
Parameters and corrections for raw sea surface height calculation	Altimeter range	>1.7 cm[a,b,c]			>1.6 - 1.7 cm			1.5 cm[a,b,c]
	Ionosphere	1 cm[d,c]	0.5 cm[d,c]		>1 cm[h] / >0.2 cm[i]			0.5 cm[d,c]
	Sea State Bias	3.5 cm	2 cm		>0.4 cm			1 cm
	Dry troposphere	1 cm	0.7 cm		0.4-0.7 cm	0.3-0.7 cm		0.7 cm
	Wet troposphere	1.2 cm			>0.2 cm			1 cm
	Rms Orbit (radial component)	10 cm[e]	2.5 cm	1.5 cm	>3.7 cm	>1.7 cm	>1.0 cm	1.5 cm
Altimeter parameters	Significant wave height	10% or 50 cm[f]	10% or 50 cm[f]		13 cm			5% or 25 cm[f]
	Wind speed	1.6 m/s	1.5 m/s		1 m/s			1.5 m/s
	Sigma0 (absolute)	0.7 dB			0.11 dB			0.5 dB
Raw sea surface height		11 cm[A]	3.9 cm[A]	3.4 cm[A]	> 4.2 cm[A]/-	> 2.6 cm[A] - 2.8 cm[B]	>2.1 cm[A] - 2.4 cm[B]	2.5 cm[A]
Final sea surface height		?	?	?	< 5.0 cm[C]	< 4.1 cm[C]	< 4.0 cm[C]	

a Ku-band after ground retracking
b Averaged over 1 sec
c Assuming 320 MHz C-bandwidth
d filtered over 100 km
e real time doris onboard ephemeris
f whichever is greater
h non filtered value
i filtered over 300 km
A Computed with , Assuming that errors in the table are uncorrelated (which is not the case).
B from formation flight phase (jason-1/ Jason-2)
C from cross-over computations of jason-2 data

Figure 58. Revisited Jason-2 error budget for time scales shorter than 10 days from Philipps et al.

Cosme et al explained how they accounted for the spatial correlation of altimetric errors in their model assimilation and how the model outputs were improved with non diagonal covariance matrixes. Lastly

Birol et al reported their progress in using altimetry at full 20 Hz rate in the Mediterranean Sea to improve coastal coverage and accuracy (Figure 59).

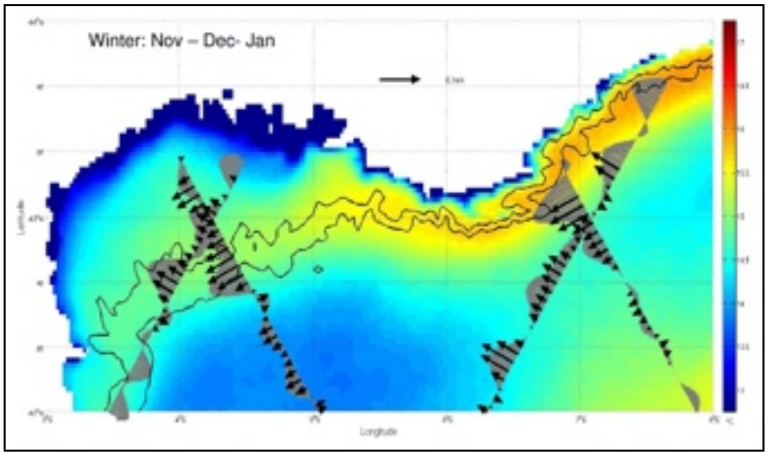

Figure 59. Climatology of the cross-track geostrophic currents derived from 1 Hz altimeter data (black arrows) and 20 Hz rate (grey envelope) from Birol et al.

In terms of recommendations, the splinter highlighted the need for the user community and the Instrument Processing splinter to work together and to provide more sophisticated end-to-end error assessments that could be used -among others- by the climate and ocean modeling communities. Furthermore, the discussion about SARM altimetry during the IP splinter highlighted that large datasets (ideally global) and independent assessments of SARM errors at all scales would be a desirable contribution to future error splinters.

More generally, the OSTST community needs to maintain (in the long run) independent teams striving to improve the end-to-end error estimates in a precise and complete way, notably by comparing different standards and processing methodologies. The climate talks also showed the necessity to converge to a common and official set of algorithms and processing (e.g. gridding) even if alternatives are still explored.

Lastly, the upcoming TOPEX reprocessing was shown to be crucial for MSL estimation in the first decade: new retracked parameters are needed, as well as tentative corrections for possible drifts stemming from PTR change, time tag bias, center of gravity, or other instrumental parameters.

9. Summaries and Recommendations

The closing session was chaired by P. Bonnefond, H. Bonekamp, J. Lillibridge, and J. Willis. In addition to the presentation of summaries by the splinter session chairs Paolo Cipollini gave a short summary of the 6th Coastal Altimetry Workshop and Nicolas Picot gave a short presentation on GDR products, notably Jason-2 GDR-D standards and reprocessing status. Moreover, two presentation were added prior to the splinters summaries: “HY-2A altimeter quality assessment” by Peng Hailong and “Information on the Cryosat ocean data availability” given by Jerome Benveniste (on behalf of Tommaso Parrinello). Finally, a number of recommendations were discussed by the OSTST and adopted.

9.1. HY-2A altimeter quality assessment (P. Hailong)

After a brief recall of the satellite payload, P. Hailong showed statistical assessment of different parameters (SSH, SWH, wind speed, sigma0, radiometer correction). When compared to Jason-2 the HY-2 altimeter data is stable but further work is needed to improve data quality and accuracy. HY-2A data can be obtained from website http://www.nsoas.gov.cn or songxingai@mail.nsoas.gov.cn.

9.2. Information on the Cryosat ocean data availability (J. Benveniste)

On behalf Tommaso Parrinello, Jerome Benveniste recalled the CryoSat Data Access policy:

- "Free Dataset": simple registration
  - All Level 1b: LRM, SAR, SARIN
  - All Level 2: LRM, SAR, SARIN
  - ALL FDM: NRT Marine Product
- "Restrained Dataset": on-request
  - FBR: SAR, SARIN
  - ALL FDM: NRT Marine Product

The next steps of the CryoSat mission are:

- Get mission extension (2013-2016): Nov 2012
- Release FDM: Jan 2013
- CryoSat 3rd Workshop: Dresden, 12-14 March 2013
- Complete reprocessing all Cryosat Data: July 2013
- Release IOP and GOP: July 2013
- Release new baseline (C): January 2014

9.3. Summary of the 6th Coastal Altimetry Workshop (P. Cipollini)

Paolo Cipollini gave a brief summary of the 6th Coastal Altimetry Workshop, details can be found at: http://www.coastalt.eu/.

First of all, thanks to the great investment of the coastal community these last years dedicated data set are available and people are using them:

- CTOH: many regions, multimission, also 20Hz in specific areas
- PISTACH: global Jason-2 coastal & hydrology product and now also L3 over specific tracks (Florida, Agulhas, MAB,…)
- COASTALT: few pilot Envisat tracks
- CryoSat–2 SAR data are being produced (no release yet)

Using such data set, now integration is the keyword and notably how best to assimilate the new data into models but also how they can be compared to other in situ observations. Cal/val issues remain crucial and must be supported.

Research & Development is also needed even more than before:

- There has been a gear shift in analysis of waveforms but:
  - SAR opened a whole new set of problems

- still no consensus on retracking notably on continuity issues (open ocean vs. coastal)
- Substantial improvements in corrections and wet tropospheric is a case in point

Future looks bright but challenging. SAR altimetry is already a revolution for the coastal zone (first results with CryoSat-2) and Sentinel-3 will probably be the first operational coastal altimetry mission. AltiKa is very promising too and we have to be prepared for 2-D altimetry. An important point is that the techniques we developped in the coastal zone have feed back into open ocean applications (non-Brown WFs, sigma0 blooms, slick, submesoscale, sharp fronts…).

Finally, Paolo Cipollini summarized the recommendations made during the 6th Coastal Altimetry Workshop that can be found at: http://www.coastalt.eu/news/recommendations-6th-coastal-altimetry-workshop

9.4. GDR Product discussion & recommendations (N. Picot)

Nicolas Picot gave a presentation of the GDR status for the different past, present and future missions. Jason-1 is distributed in GDR-C since 2006 and no new reprocessing is planned. POE GDR-D is delivered to all users but agencies should work on a more flexible way to update the standards, as already discussed past year: it was recommended by the OSTST that an intermediate (and simple solution) should be studied by both CNES and JPL to allow users to generate a Jason-1 product that is in line with Jason-2 GDR-D standards. SARAL/Altika products will be delivered in GDR-D standard. Efforts on TOPEX/Poseidon reprocessing should be increased and not limited to the retracking (COG correction, 60 days sensitivity, radiometer processing, …).

For Jason-2 GDR-D was implemented as planned, reprocessing started mid April 2012 and is expected to be completed by end of the year, going smoothly. The conversion to BUFR format could be considered by EumetSat (depending on users needs) in order to remove the jump that occurred between 'C' and 'D' versions (mainly on the wind speed). The importance of the 4 partners expertise has been emphasized during this phase, in particular the support from NASA/JPL is very important (POD, radiometer monitoring & algorithms, routine CalVal, …). Globally data shows a very good quality but there is already some questions on SSB, orbit and several standards (tide, MDT, MSS, DAC, ..) that could, should or have to be updated in the coming months or years. This leads to the same conclusion: agencies should work on a more flexible way to update the standards. Users are encouraged to evaluate MLE3 for the individual applications. MLE3 altimeter data have a lower 20 Hz noise but SSH crossover variance is higher in average.

Finally, "In Orbit Performances meetings" are envisaged: it might be organized in between OSTST meetings to better monitor the overall performances of the systems and to help preparing the OSTST meetings more in advance.

9.5. Recommendations

Jason-1&2

- The Jason-1 geodetic mission has proven valuable for both oceanographic and geophysical applications. We recommend continued operation for as long as is feasible.
- The Jason-2 mission continues to provide crucial observations for oceanography, climate and operational applications. We recommend continued operation for as long as is feasible.

Jason-CS – LRM/SARM

1. **The OSTST strongly recommends that the Jason-CS altimeter shall deliver both backward-compatible ("LRM") and high-resolution ("SAR") range measurements over all the ocean, seamlessly and simultaneously (interleaved mode).**
2. Backward compatibility will ensure continuity of service in operational oceanography, climate, and wind & wave applications.
3. The high-resolution data will enable sampling of sub-mesoscale features associated with high-velocity currents, vertical flow and mixing in the ocean. These will benefit both the operational and research communities.
4. **To enable near-real-time applications, LRM (at least) and SAR (if feasible) shall be delivered with latency similar to that in previous Jason missions.**
5. Land and inland water applications shall be enabled to the fullest extent possible under the constraint that sea level measurement must be the primary mission.

Jason-CS – Radiometer

1. The main improvement the OSTST community could expect from the Jason-CS radiometer(s) is **instrument enhancements to enable long term stability from the radiometer, eliminate dependence on ancillary data sources and reduce the latency of the final calibrated product.**
2. **The Jason-CS system will benefit significantly from a three-frequency radiometer by reducing variance in the tropospheric path delay correction and maintaining continuity with the 20+ year record.**
3. **The most significant benefit from the embarkation of a second radiometer would be for the second radiometer to operate at high frequencies to resolve km-scale water vapour to improve coastally altimetry and inland hydrology applications.**

CryoSat-2

The OSTST further recommended that ESA and the CryoSat-2 Project make all efforts to:

- **Allow distribution of currently generated value-added science products made on a free and open basis.**
- **Provide a global seamless product over the ocean (LRM & SAR regions) as soon as possible.**
- The OSTST greatly appreciates the efforts made by ESA to allow the inclusion of CryoSat-2 data in the operational products such as DUACS and NOAA's wind/wave service since the 2011 meeting.
- In order to provide better feedback to the CryoSat-2 Project on CryoSat-2 ocean data, we recommend that level 2 data products based on LRM, SAR and SARIN that have been reprocessed by all parties be made available to the broader community.
- We hope that SARM data (raw telemetry, FBR and retracked data) be made available to experts in the OSTST in order to prepare for future SAR missions like Jason-CS and SWOT. Such data will also help to understand 10 to 100 km scale features in existing altimeter observations.

Sentinel-3

- Several presentations during the Venice symposium and OSTST showed the potential of SAR altimeter for oceanography. Moreover, there were many discussions concerning the risk of discontinuity between LRM and SAR mode (see Jason-CS recommendations). As a result, **noting the potential benefits of SAR mode data to improve the precision and resolution of the**

measurements for all ocean applications, the OSTST recommends that the area of Sentinel-3 SAR altimeter acquisitions be maximized over the ocean to include all open ocean, coastal regions and marginal seas.

OSTST Appreciations

- We are grateful for the selection of the Jason-3 Launch Vehicle and stress the importance of maintaining the December 2014 launch date in order to preserve the continuity of the sea level record (*postponed to March 2015 at the time of report writing*).
- We are also grateful for the advance of Jason-CS mission definition and notably the issues raised (altimeter and radiometer) that can lead to very important improvements for such a reference mission.
- We are pleased that the launch date for SARAL/AltiKa has been set at 12/12/12 (*postponed to February 2013 at the time of report writing*).
- We also want to express our appreciation to the National Satellite Ocean Application Service (NSOAS) for the effort made on the communication of the quality of HY2-A data and for the advances made in the data policy to provide to the scientific community with such an important data set.
- We are also pleased that SWOT has passed MCR, and development is on pace for a 2020 launch.