Report of the

2010 Ocean Surface Topography Science Team (OSTST) Meeting

edited by R. Morrow, LEGOS

Organised by CNES, EUMETSAT & IDS

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Executive Summary

The 2010 OSTST Meeting was held in Lisbon, Portugal on October 18-20. The meeting was the central part of a 10-day program of altimetry workshops, starting with the Coastal Altimetry Workshop in Porto, Portugal on October 14-15, and then three events at the Lisbon International Fair: the Ocean Surface Topography Science Team (OSTST) meeting on 18 – 20 October 2010, followed by two workshops on 21 – 22 October 2010 : an altimetry Workshop "Towards High-Resolution of Ocean Dynamics and Terrestrial Surface Waters from Space", and in parallel, the International Doris Service Workshop (IDS).

The **three events** at Lisbon were co-hosted by the CNES, EUMETSAT and the IDS, with the support of LEGOS. 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) review the progress of science research, (3) conduct splinter meetings on the various corrections and altimetry data products, (4) discuss the science requirements for future altimetry missions, and (5) make recommendations on the choice of orbit for the End-of-Life period of Jason-1, and for the Jason-CS series of altimeters. This report along with all the presentations from the plenary, splinter, and poster sessions are available on the AVISO website : http://www.aviso.oceanobs.com/ /ostst/ .

OSTM/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 the Jason-2 GDR data show that all the missions meet the requirements. However, some discrepancies have been highlighted, in terms of mean geographically correlated errors or mean sea level trend, and need to be further investigated. Moreover, the need for improved long-term wind speed time series for climate studies highlighted that this quantity should be more carefully calibrated and validated with homogeneous standards for the different missions. The long-term stability of on-board radiometers continues to be a key issue for high accuracy altimetry.

The origin of the relative range bias between Jason-1 and Jason-2 (~85 mm) has been discovered recently and presented at the Seattle OSTST (see "Summary of the in situ analysis key findings" in section 9.1.2): it comes from an error in some parameterization files on Jason-1 and Jason-2 discovered by the project. Correcting these errors will increase the absolute Jason-1 bias from 85 mm to 205 mm and that of Jason-2 from 170 mm to 195 mm. This needs further investigation (notably on the C band) but, if confirmed, both satellites are measuring sea surface consistently; within 1 cm of each other. Both are about 20 cm higher than T/P. The biases to be applied to both Jason-1 and Jason-2 will not be included in the current products (GDR-C and GDR-T respectively for Jason-1 and Jason-2) to maintain continuity. **So for the moment, Jason-1 will be maintained with its 85 mm bias with respect to T/P, and Jason-2 with its 170 mm bias.** However, the reprocessed Jason-2 products (GDR-C : to be issued in mid 2011) will be corrected for the 25 mm bias found (sea level will increase by 25 mm). CNES has ongoing work analysing the root cause of the 195 mm Jason-2 absolute bias with respect to Topex MSL. If this absolute bias can be explained before the Jason-2 GDR_C implementation, it will be corrected as part of this reprocessing. The absolute bias values used in the different versions of the Jason-2 and Jason-1 products will be communicated to the OSTST and to the end users before the reprocessing starts. Concerning the Jason-1 bias, the 120 mm correction will be applied to the next generation of the products (GDR-D).

The Jason-2 orbit comparisons between CNES and JPL or GSFC solutions show minor differences which are under investigation, and the EnviSat/Jason-1 geographically correlated signals emphasize the importance of having good communication between the CalVal and POD communities for all altimeter missions.

Jason-1 continues to exceed all Level-1 Science Requirements on its interleaved orbit, despite the loss of a reaction wheel in 2003, the loss of the backup Processor Module B (PMB) in 2005, and the loss of a Gyro in March 2010. Both GPS receivers (TRSR) have now failed, however, Jason-1 POD continues to meet the mission requirements based on DORIS and LRA. Although the mission lifetime is uncertain, the thermal, power and propulsion systems all have significant margins remaining.

One problem for Jason-1 is that it is in the same orbit plane as TOPEX/Poseidon (T/P) (non-operational), OSTM/Jason-2 (operational) & Jason-3 (planned). T/P is inoperable, and has a nearly-full tank of hydrazine (~200kg) that cannot be depleted. Since Jason-1 is single-string on several key component systems, the permanent loss of one of these key components would end the mission and could possibly leave Jason-1 adrift, with ~22 kg of hydrazine onboard. Under joint agency direction, an End/Extension-of-Life (EOL) Joint Working Group was established in early-2010 to study future options for Jason-1.

The following actions and strategies were approved by the Joint Steering Group in July 2010:

- That Jason-1 should remain in its current interleaved orbit until another high-accuracy repeat-track altimeter is launched and validated. (Most likely to be SARAL/AltiKa in June 2011 + 9 months Cal/Val), with a science recommendation to be provided by the OSTST meeting in October.
- To immediately begin a fuel depletion campaign to mitigate the intrinsic explosive breakup risks.
- To develop and implement emergency decommissioning procedures to move to graveyard orbit in the event of a sudden mission-ending failure.

In line with this, in July 2010, a series of maneuvers were performed to deplete the Jason-1 tanks. 70% of the desired depletion goal had been achieved, when a problem occurred with one thruster. The depletion campaign was suspended, and the thruster problem is currently being evaluated. Jason-1 continues to provide excellent quality science data on its interleaved orbit.

The results of the End/Extension-of-Life (EOL) Joint Working Group, whose task was to study future orbit options for Jason-1, were presented for discussion by the OSTST on Wednesday 20 October. The OSTST endorsed the actions and strategies approved by the JSG in July, with the science recommendation to remain in its current interleaved orbit until another high-accuracy repeat-track altimeter is launched and validated, and then move to an appropriate geodetic orbit. An overview of the presentation and discussion are provided in detail in section 5. The formal recommendations are given below.

A series of discussions were also undertaken concerning the choice of a future orbit for the **Jason-CS** series of altimeters. During the OSTST meeting, this topic was discussed in the different splinter sessions, a special townhall meeting was held on 19 October to discuss the different Jason-CS orbit options, and the results were presented with a final discussion in a plenary session on 20 October. After much discussion, the majority of the OSTST supported the overriding importance of maintaining the precise climate record of sea surface height time series, and agreed that Jason-CS should stay on the 1336 km reference orbit flown by TOPEX/Poseidon and Jason-1, 2, & 3. Secondary considerations included the lack of a clear net scientific benefit of a change of orbit, and the challenges of calibrating & validating a precise climate record without the formation flight period between Jason-3 & Jason-CS. The formal recommendations are given below.

At the 2009 OSTST Meeting in Seattle, the radiometer was identified as the largest source of error in the estimate of global mean sea level, and a recommendation was made that future altimetric missions work on improving the **radiometer stability**. The OSTST considered the mean sea level requirements and performed an assessment of current techniques to meet the long term radiometer stability requirement. JPL is performing a feasibility study to address long-term radiometer stability for Jason-3, which is currently under development. This study and others were discussed in the plenary session on 20 October, and the recommendations are given below.

Seven **keynote lectures** were given during the meeting, on a wide range of altimetric subjects. Three talks addressed a variety of different altimetric programmes and projects. Charles Elachi, the Director of JPL, gave an overview of present and future satellite oceanography projects at JPL. Jacques Verron, Project Scientist for SARAL/AltiKa, presented the status of the CNES/ISRO SARAL/AltiKa Ka-band altimeter project. This mission is to be launched in 2011, and will provide finer alongtrack resolution measurements over the oceans, and coastal and hydrological surfaces. Joanna Fernandes, then gave an overview of the main results discussed at the 4th coastal altimetry workshop.

In preparation for the upcoming altimeter missions, Jean-Claude Souyris presented an overview talk explaining the technical aspects of Ka-band altimetry, and the SAR and interferometric SAR modes which will be used on the upcoming missions (e.g., SARAL/Altika and SWOT in Ka-band, SAR mode on ENVISAT and Cryosat-2, interferometric SAR on SWOT). Two science talks presented some recent results on Indian Ocean sea level change in a warming climate (W. Han) and an example of an operational prediction of the regional ocean circulation near the Mid-Atlantic Bight (J. Zavala-Garay). A plenary keynote talk from high-school students in the Midi-Pyrénées region demonstrated how altimetry was being used in school projects to help track drifting buoys, including buoys that were built by the students.

A special presentation was made of the annual **COSPAR International Co-operation medal**, given jointly to Lee-Lueng Fu and Yves Menard. This medal is awarded to scientists who has made distinguished contributions to space science and whose work has contributed significantly to the promotion of international scientific cooperation. The presentation was made by J.L. Fellous, Executive Director of COSPAR, in the presence of their families. Felisa Menard accepted the award on behalf of Yves.

Recommendations from OSTST in Lisbon, Oct 18-20, 2010

Recommendations concerning Jason-1 Extension of Life:

During the OSTST meeting, the science recommendations for the Jason-1 end-of-life orbit were discussed in the different splinter sessions, and in the plenary meeting on 20 October. These discussions considered the scientific value of Jason-1 in its tandem mission, the errors induced by moving Jason-1 away from its long-term repeat track, and Jason-1's role in the present and future constellation of altimeters. The following recommendations were adopted by the entire OSTST :

1) Jason-1 Recommendation :
In light of the move of ENVISAT to a new orbit, and the current gap in exact repeat, high inclination altimeter data, moving Jason-1 to an alternative orbit would cause unacceptable errors for users of high-resolution SSH observations due to a combination of asynchronous sampling with Jason-2 and errors in gridded mean sea surface products. The Ocean Surface Topography Science Team therefore recommends that Jason-1 be maintained on its current orbit until data from the upcoming SARAL/AltiKa mission can be validated. However, because the Science Team recognizes the broad scientific value of a geodetic mission for Jason-1, we further recommend that Jason-1 be moved to a geodetic orbit in the range of 1286 +/- 2 km, or a suitable geodetic orbit in line with the spacecraft's capabilities at the time, after data from SARAL/AltiKa is validated.

2) Altimeter Constellation Recommendation : CryoSat2
Although it is recognized that CryoSat2 is primarily a cryosphere mission, the OSTST recommends that all efforts be made to make available validated Cryosat2 GDR and IGDR data over ocean surfaces to scientific users, for their crucial use in multi-mission altimetric ocean applications, and for improving the ocean mean sea surface.

3) Altimeter Constellation Recommendation : SARAL/Altika
The OSTST recognizes that the SARAL/Altika mission will be an essential component of the altimetry constellation from 2011 onwards, re-occupying the long-term ERS and ENVISAT ground track. SARAL/Altika will also provide the first demonstration of Ka-band altimeter capabilities for fine resolution alongtrack applications, including for coastal and inland water applications, which will be further developed for the future SWOT mission. The OSTST recommends that all efforts be made to launch SARAL/AltiKa as soon as possible in 2011.

Radiometer Drift Requirements :
The error budget analysis presented at the OSTST 2009 Seattle meeting showed that the radiometer drift was the largest contributor to overall stability. At Lisbon, the discussion on the radiometer drift requirement was presented in terms of goals or requirements, depending on the mission advancement. The objective is that future altimeter missions shall measure globally averaged sea level relative to levels established during the cal/val phase with zero bias +/- 1 mm (standard error) averaged over any one year period.

4) Jason-3 Drift Requirement Recommendation

The OSTST recommends that the Jason-3 project continue to study the feasibility of improving the AMR stability through on board calibration for the Jason-3 mission.

5) Jason-CS Drift Requirement Recommendation

The OSTST also recommends that Jason-CS meet the following requirement at the mission level:

Requirement: Jason CS shall measure globally averaged sea level relative to levels established during the cal/val phase with zero bias +/- 1 mm (standard error) averaged over any one year period.

6) Recommendations concerning Jason-CS future orbit

Given the overriding importance of maintaining the precise climate record of sea surface height, the challenges of calibrating & validating without formation flight between Jason-3 & Jason-CS, and the lack of a clear net scientific benefit of a change of orbit: the OSTST recommends that Jason-CS maintain the 1336 km reference orbit flown by TOPEX/Poseidon and Jason-1, 2, & 3.

1. Introduction

The 2010 OSTST Meeting was held in Lisbon, Portugal on October 18-20. The meeting was the central part of a 10-day program of altimetry workshops, starting with the Coastal Altimetry Workshop in Porto, Portugal on October 14-15, and then three events at the Lisbon International Fair: the Ocean Surface Topography Science Team (OSTST) meeting on 18 – 20 October 2010, followed by two workshops on 21 – 22 October 2010 : an altimetry Workshop "Towards High-Resolution of Ocean Dynamics and Terrestrial Surface Waters from Space", and in parallel, the International Doris Service Workshop (IDS).

The meeting was opened by Lionel Suchet of CNES and François Parisot of EUMETSAT, who welcomed the participants, and noted the long international co-operation of the OSTST group, and their work in maintaining precise sea level observations for scientific and operational applications, and the extension to the 4-partner agencies. They also introduced the celebrations for the 20^{th} anniversary of the DORIS measurements, which were the focus of the IDS meeting discussions on 21-22 October. Rosemary Morrow, LEGOS, and Sophie Coutin-Faye, CNES, presented the meeting overview and the practical planning.

2. Program and Mission Status

L. Suchet introduced the programme managers to speak on the status of altimetry and oceanography programs at NASA, CNES, EUMETSAT, NOAA and ESA.

Peter Hacker represented Eric Lindstrom for the NASA program status. Amongst the NASA altimetry program events, the SWOT partnership is now settled between NASA and CNES, with an expected launch date in 2019. The 4-party MOU has been signed between NASA, NOAA, CNES and EUMETSAT for the upcoming Jason-3 mission, with an expected launch date in June 2013. Jason-CS orbit and the Jason-1 end-of-life orbit requirements are to be discussed at the present OSTST meeting in Lisbon. The call to construct the new OST Science Team for the next 4 years will likely appear in NASA's 2011 ROSES solicitation, with proposals due in March 2012.

Eric Thouvenot reported on the CNES altimetry program with a focus on the operational outcome of altimetry, with CNES/SALP supporting the Jason-1, Jason-2 series and preparing for the future SARAL/Altika, Jason-3, Jason-CS, and SWOT. CNES also contributes DORIS and data processing for the ESA altimeters ERS-2, ENVISAT and Sentinel-3, and for the future HY-2A (with the Chinese Space Agency CNSA). In addition support is given to operational oceanography groups such as Coriolis and Mercator. He noted that SARAL/AltiKa is tentatively scheduled for launch in mid 2011. The CNES payload module is ready and waiting for the delivery of the ISRO platform. The PI selection process has been undertaken, and 64 teams were selected, and the Cal/val plan and science plan are drafted. An international workshop is planned in 2011 in India (TBC by ISRO)

F. Parisot and S. Wilson discussed EUMETSAT and NOAA's involvement in altimetry programs with a focus on Jason-3 and it potential follow-on, Jason-CS. For Jason-3, the 4-agency partnership is the same as for Jason-2, but with NOAA and EUMETSAT – operational agencies

– taking the lead. The launch date in mid 2013 is to allow at least a 6-month overlap with Jason-2. After Jason-3, the Continuity of Service program (Jason-CS) will be the follow-on Reference Mission, spanning a 15- to 20-year period, but with a new satellite bus based on the ESA Cryosat-2 platform. The choice of altimeter may be changed to take into account the most recent technology, and the choice of orbit also needs to be decided. The scientific requirements for the orbit will be discussed during the OSTST in Lisbon, and the final decision will be made by the agencies in early 2011.

J. Benveniste gave a presentation on the status of ESA missions. GOCE was successfully launched March, 2009, and is working well. First science assessment shows good results, three gravity field solutions are already available on the ESA website, and a user toolbox is also available, see: http://earth.esa.int/goce. Cryosat was launched in Apr 2010. The priority is to provide data over the cryosphere, but early results from the SAR Altimeter Ocean Retracker are promising. Data may be available to users in early 2011. A validation workshop for Cryosat data will be held in ESRIN/ESA 1-3 February 2011. SMOS was launched in November 2009. Preliminary results of ocean salinity show an accuracy of 0.5 psu at 25 km resolution, though the validation phase is still ongoing.
ENVISAT, now 8-years old, will enter a new orbit in Oct 2010, and has been financed for a further 3 years. The new orbit will be at 30 day repeat, with a slowly drifting inclination. First data products on the new orbit will be available from early November, with validated products available in January 2011. Sentinel-3 is under development. ESA has started the "Climate Change Initiative" in response to requirements set out by the Global Climate Observing System reports. One of the essential variables to be monitored is sea level change, and the altimetry component is essential. A brief outline of this is presented later.

3. Jason-1/2 project and program status

T. Guinle provided an overview of Jason-2 status. The second Jason-2 REVEX was held in May 18-20, 2010 at the Toulouse Space Center. The satellite is operating well and all instruments are fully operational after two years of the mission. The core payload is fully operational, and the passengers are behaving well. 100% of the IGDR and GDR products have been archived, and distributed via CNES AVISO and NOAA data services to users (from mid January, 2009 for the IGDRs, from 5 August 2009 for the GDRs). All satellite and system performances requirements are fulfilled with large margins.

G. Shirtliffe provided an overview of Jason-1 status. Jason-1 continues to exceed all Level-1 Science Requirements on its interleaved orbit, despite the loss of a reaction wheel in 2003, the loss of half-satellite (PMB) in 2005, and the loss of a Gyro in March 2010. Both GPS receivers (TRSR) have now failed, however, Jason-1 POD continues to meet the mission requirements based on DORIS and LRA. Although the mission lifetime is uncertain, the thermal, power and propulsion systems all have significant margins remaining. In Sept 2009, the NASA Senior Review Panel recommended that funding for Jason-1 be extended to 2013, with another review scheduled for 2011. OGDR-SSHA products, providing near-real-time (NRT) sea surface height anomaly (SSHA) measurements, have been reinstated, with orbits based on the DORIS and

Laser tracking rather than GPS. An enhanced JMR Data Product is also now available in the coastal region, similar to the J2 product.

Some data outages occurred in September 2009 when the satellite went into safehold mode, in cycle 305 from a gyro anomaly, in cycles 310 & 315 from attitude control excursions, and during July-August 2010 during the fuel depletion campaign.

One potential problem for Jason-1 is that it is in the same orbit plane as TOPEX/Poseidon (T/P) (non-operational), OSTM/Jason-2 (operational) & Jason-3 (planned). T/P is inoperable, and has a nearly-full tank of hydrazine (~200kg) that cannot be depleted. Since Jason-1 is single-string on several key component systems, the permanent loss of one of these key components would end the mission and could possibly leave Jason-1 adrift, with ~22 kg of hydrazine onboard. Under joint agency direction, an End/Extension-of-Life (EOL) Joint Working Group was established in early-2010 to study future options for Jason-1.

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4. Keynote Talks

Seven keynote lectures were given during the meeting, on a wide range of altimetric subjects. Three talks addressed a variety of different altimetric programmes and projects. Charles Elachi, the Director of JPL, gave an overview of present and future satellite oceanography projects at JPL. Jacques Verron, Project Scientist for SARAL/AltiKa, presented the status of the CNES/ISRO SARAL/AltiKa Ka-band altimeter project. This mission is to be launched in 2011, and will provide finer resolution measurements over the oceans, and coastal and hydrological surfaces. Joanna Fernandes, then gave an overview of the main results discussed at the 4th coastal altimetry workshop.

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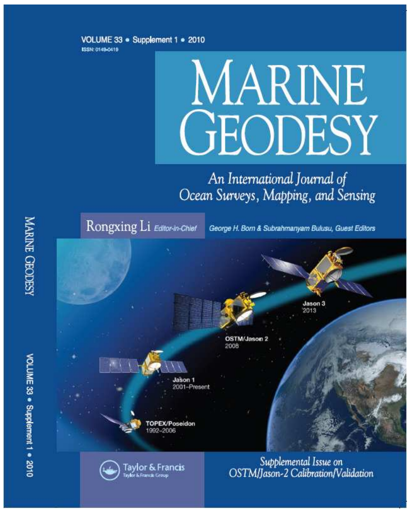
The Keynote talks can be found on the AVISO website at : [http://www.aviso.oceanobs.com /ostst/](http://www.aviso.oceanobs.com/ostst/) .

	MONDAY 18 OCTOBER 2010 : **Keynote Talks**	
11:00	JPL & satellite oceanography	C. ELACHI (JPL)
11:15	SARAL/AltiKa – Ka-band altimetry over oceans, coastal and hydrology surfaces	J. VERRON (LEGI)
11:30	Indian Ocean Sea level Change in a Warming Climate	W. HAN (University of Colorado)
11:50	Coastal Altimetry Meeting Report	J. FERNANDES (Universidade do Porto)
14:00	Upcoming altimeter measurements : explaining Ka-band, SAR mode, interferometric SAR.	J.C.SOUYRIS (CNES)
	TUESDAY 19 OCTOBER 2010 : **Keynote Talks**	
8:45	Operational prediction of the Mid Atlantic Bight ocean circulation	J. ZAVALA-GARAY (IMCS, Rutgers the State University of New Jersey)
14:00	School presentations on altimetry applications	

A special presentation was made of the annual COSPAR International Co-operation medal, given jointly to Lee-Lueng Fu and Yves Menard. This medal is awarded to scientists who has made distinguished contributions to space science and whose work has contributed significantly to the promotion of international scientific cooperation. The presentation was made by J.L. Fellous, Executive Director of COSPAR, in the presence of their families. Felisa Menard accepted the award on behalf of Yves.

R. Morrow presented an introduction to the splinter sessions, and an overview of the different discussion points to be addressed during the meeting, mainly concerning the potential change of orbit for Jason-1 End-of-life phase (discussion in section 5), Jason-CS (see section 6), and the radiometer drift requirements for future missions (see section7).

The first special issue on OSTM/Jason-2 Cal/Val results has just been published in *Marine Geodesy,* dedicated to the late Dr. Yves Menard. George Born and Subrahmanyam Bulusu were Guest Editors. Twenty-five papers addressing early CalVal and science results with Jason-2 data were included, and copies are being distributed to authors.



A second OSTM/Jason-2 special issue is planned, and 28 letters of intention have been received. The deadline for submission is Nov 15, 2010, and publication is scheduled for mid 2011. Due to popular demand, **Volume 3** is also being planned, with a deadline next year.

5. Plenary Session on Jason-1 end of Life orbit

Chairs : J. Willis and R. Morrow

Jason-1 continues to meet and exceed all Level-1 Science Requirements on its interleaved orbit, and is providing valuable science returns.

Concern had developed at both CNES and NASA that, given its age, the Jason-1 spacecraft could fail in a way that it could become uncontrollable. If this happens in its present orbit there is a risk that the spacecraft could collide with a piece of debris, with Jason-2, or with TOPEX/Poseidon, which shares a similar orbit and is also no longer controllable. In fact, Jason-1 and TOPEX/Poseidon have already had one close encounter since the end of the TOPEX/Poseidon mission. Although it is not certain that such a collision would result in a catastrophic break up, if it did the resulting debris could jeopardize the Jason-2 mission as well as any future altimeter missions in this same orbit. So under joint agency direction, an End/Extension-of-Life (EOL) Joint Working Group was established in early-2010 to study future options for Jason-1. Within the Jason-1 EOL Joint Working Group, a Science Subgroup was established in April 2010 with the following goals:

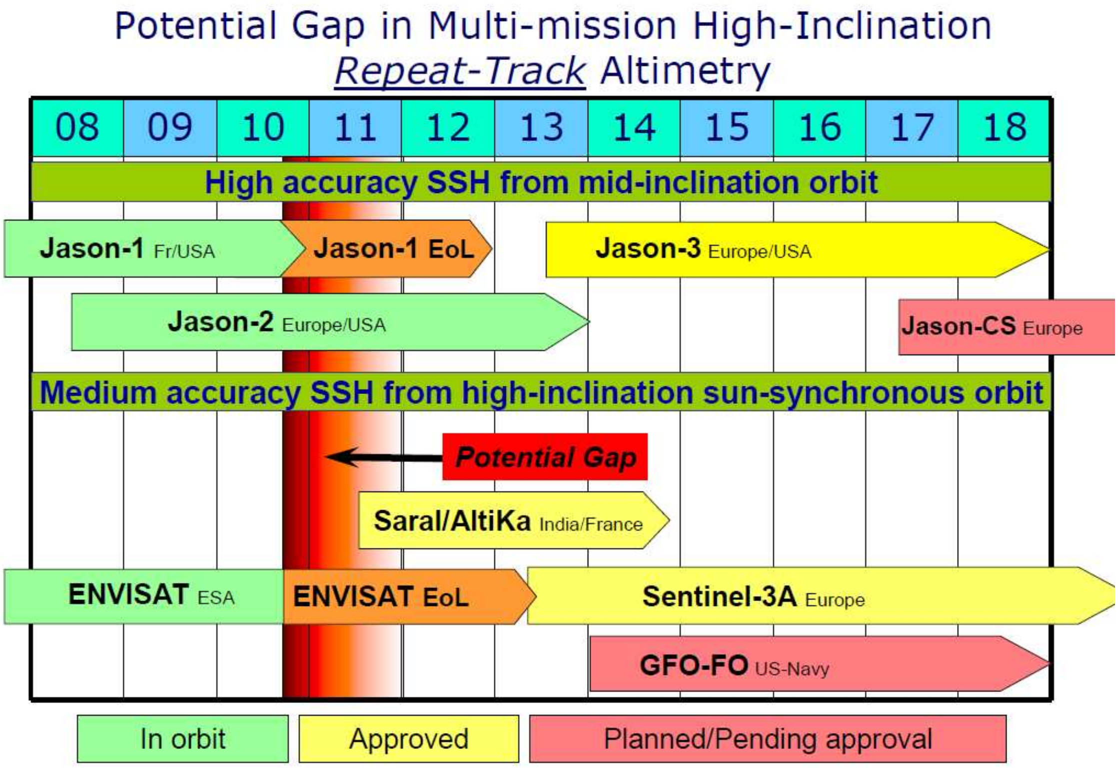
- To summarize the scientific value of Jason-1 in the current tandem orbit
- To solicit US and French agency assessments of the science and operational value of the current tandem orbit
- To investigate alternate mesoscale and geodetic ocean science orbit options and limitations within the range of possible Jason-1 orbit change (1336 ± 180 km)
- To provide science recommendations on the timing and duration of future mission activities

The subgroup members were : Ole Andersen, Jean-Paul Berthias, Pierre Brasseur, Don Chambers, Gerald Dibarboure, Dudley Chelton, Gilles Larnicol, Eric Leuliette, Pierre-Yves LeTraon, John Lillibridge, Florent Lyard, Laury Miller, Steve Nerem, David Sandwell, Remko Scharroo, Detlef Stammer, Lee Fu, Juliette Lambin, Rosemary Morrow, Josh Willis.

In terms of science priorities for Jason-1, the primary goal is to provide high-resolution SSH observations for both science and operational needs. The 2009 NASA Senior Review Panel noted that the science value of Jason-1 was outstanding, and that the operational and applied utility was very high. In addition, they also noted "*the unique orbit of Jason-1, currently flying in formation with Jason-2/OSTM, and expressed concern that the value of the orbit may justify a conservative approach to mission extension and decommissioning.*" For a synoptic view of the ocean mesoscale signal, at least 3 co-ordinated altimeter missions are needed (Jacobs et al., 2001), with 2-3 altimeters necessary for delayed mode studies, and 3-4 for operational applications (Pascual et al., 2006). Jason-1, on its interleaved track, provides optimal sampling of the mesoscale field with respect to Jason-2, and is also an integral part of the present constellation of altimeters.

Members of the science subgroup identified a potential secondary goal for Jason-,1: to improve the marine geoid. The present resolution of altimetric bathymetry maps do not resolve small scale bathymetric features and fail to identify areas that may excite mixing and baroclinic tides, or generate turbulence and dissipation. As an example, present maps resolve only a few thousand seamounts, whereas there are probably between 50 000 and 100 000 seamounts that are currently invisible in the existing geodetic maps. GRACE and GOCE resolve only large-scale anomalies (spherical harmonic degree < 200, or wavelength > 200 km). This is because they measure the gravity field at the satellite orbital altitude. Satellite altimeters measure the effect of the gravity field on sea level, so they can resolve much shorter scales.

The best resolution of marine gravity anomalies comes from using the along-track sea surface slope, rather than using the height directly [Sandwell, *JGR*, 1984; Olgiati et al., *Bull. Geod.*, 1995]. The gravity calculation requires two horizontal components of sea surface slope, north and east. The accuracy with which these can be obtained from an altimeter depends on the latitude and the orbital inclination of the satellite. Because Jason-1 is in a lower inclination, its track crossing angles near the equator are better than those from the previous geodetic altimetric missions, such as ERS-1 or CryoSat2, and are about equal to those of Geosat. So the Jason-class altimeters present a unique data set for improving maps of marine gravity anomalies.



With these two science objectives in mind, the third consideration was the role of Jason1 in the present constellation of altimeter missions. Jason-2 & Jason-1 provide precise repeat track data on the long term reference orbit, and on the interleaved orbit, respectively. At the end of October 2010, Envisat was moved off the long term high-inclination orbit established by ERS1&2, and started a new 30-day orbit. Cryosat-2 data are not yet available over the oceans. Saral/AltiKa will be launched in mid-2011 on the ENVISAT groundtrack, and the validated data will only be available ~6 months after launch. So there is a potential gap in the altimetry constellation (See Figure below). During 2011, precise repeat data will be available from Jason-2, but less precise data will be available from the new Envisat orbit. The J1-EOL science group also investigated the potential impact of having non-repeat J1 altimeter data versus the more precise repeat-track data for the altimeter constellation.

The Science Subgroup carried out several studies to determine possible alternative science orbits

- Over 17,000 alternate repeat-track and geodetic orbits were considered
- CNES identified 8 repeat-track orbits
  - Fast repeat, low spatial resolution (5 day)
  - Near-present repeat cycle (11 day)
  - Long repeat, higher spatial resolution (20 day)
- Thousands of possible geodetic (very-long repeat) orbits were analyzed

The Science Subgroup agreed that for oceanographic purposes (the primary science objective for Jason-1), sampling characteristics should mimic current configuration as closely as possible

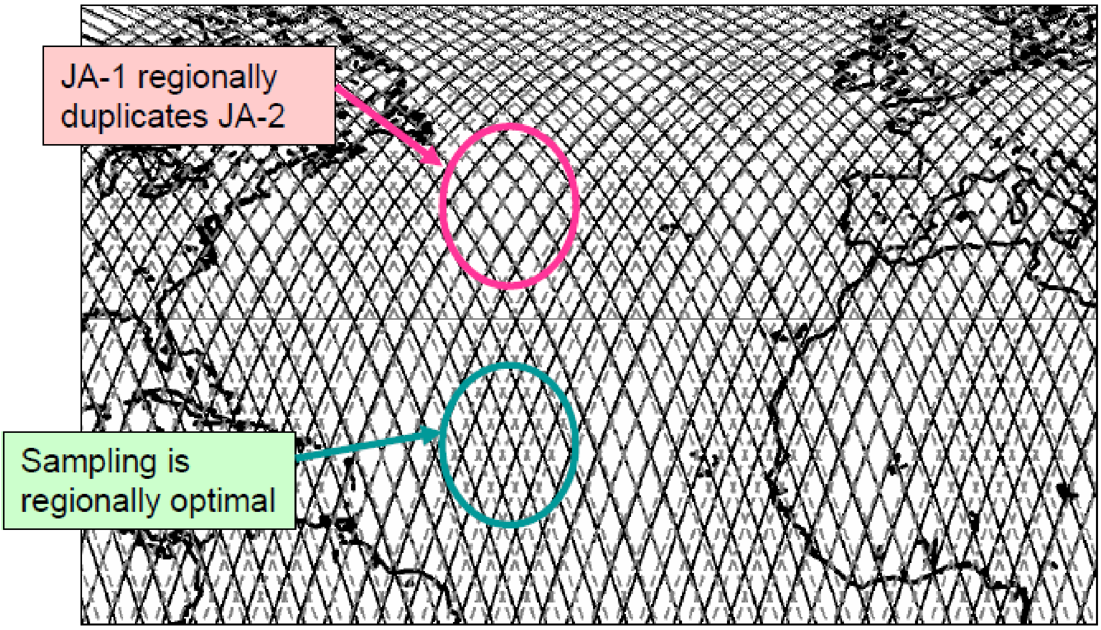


Figure 5.1 *: Moiré sampling pattern for one example : an 11-day repeat EOL orbit (dashed gray) and Jason-2 (Black). Blue shows regions where both satellites are optimally interleaved, rose shows regions where both satellites duplicate the space coverage. Temporally, the satellites also move in and out of phase. (G. Dibarboure, OSTST 2010)*

The present Jason-1/2 configuration was chosen to give optimal sampling of a wide range of oceanographic signals. Any new J1 orbit which is not at the same altitude will have a sampling pattern which is sub-optimal in either space, time or both (see Figure 5.1 above). All EoL are largely inferior to the current tandem with at least a 30% increase in mapping error from sampling alone (Dibarboure et al., OSTST, 2010).

The J1-EOL science group also considered the potential errors in sea level anomaly induced by moving to a non-repeating groundtrack, or by moving to a new repeat orbit (it may take 1-3 years to construct a stable alongtrack mean sea surface, depending on the repeat period). For these orbits, the SLA can be calculated from a gridded mean sea surface, and two new MSSHs have recently become available (DTU10, CLS10). In any case, there is additional error from using a gridded mean sea surface, from either product :

- Error in the Alongtrack Mean Profile

  The gridded MSSHs are based on historical altimeter data from geodetic and repeat-track missions. The different missions may include uncorrected mesoscale signals, different interannual variability, and obsolete altimetry standards
- Error in gridded estimate <SSH>

  The different gridded products may have discrepancies across mean profiles, different smoothing/interpolation scales, unresolved small scales (< 100 km), un-accounted for mesoscale (esp. in geodetic data)
- Dynamic SSHA error (mismatch between SSH and <SSH>)

Different studies were carried out to test the new generation of gridded MSS products, and to estimate the different sources of error (Smith & Scharroo, Dibarboure, OSTST 2010). Based on internal MSS coherency estimates, the optimistic error range was 1cm (100 to 500km) and 2.5 cm (at shorter scales). The comparison between independent MSS and datasets gave a more pessimistic error range of 3 to 5 cm.

The theoretical formal error on the gridded MSS was 3 cm. The average error (3cm) is coherent with theoretical estimates, whereas error peaks and outliers are geographically correlated and can be > 10cm. For the 50% of the globe with low eddy energy, the error is 50 % of the variability. Only 20% of the world oceans had error less than 25 % of the oceanic variability.

In summary, the different studies highlighted that the combined MSS error and sampling error were both important. Moving to a new orbit introduced a 30% observation error globally (with multi-satellite maps) due to the sampling degradation alone, and up to +50% if the MSS error is a realistic 3cm. Furthermore, the sampling degradation is uneven in time and goes through cyclic pulses of best/worst case phases particularly detrimental to near real time applications.

These results were presented in detail to the entire OSTST at the meeting, after which a vigorous discussion ensued. The scientific merits of both the geodetic and oceanographic missions were carefully weighed against the potential accuracy degradation of moving to a new orbit and the potential for losing the satellite too early to make a major advance in marine geodesy. Given all of these considerations, the OSTST judged that at present, moving Jason-1 to a new orbit would create unacceptable error levels for users of high-resolution SSH observations. However in the long run, many will benefit from a geodetic mission, and programmatic pressure to move will likely continue to grow. The compromise position adopted by the OSTST was that Jason-1 should be maintained in its present orbit in 2011, thus maintaining two precise repeat-track missions (J1 & J2) with optimal ocean sampling, to balance the loss of precision and change of sampling from the move of Envisat, and while waiting for the arrival of validated CryoSat-2 data over the oceans. However, once Saral/AltiKa is launched into the old ERS and Envisat groundtrack and its data can be validated, J1 should be moved from its present orbit onto a geodetic orbit, with a subcycle chosen to allow the best restitution of ocean signals.

At the end of the discussion, the following recommendation was officially adopted by the OSTST:

The OSTST recommends that Jason-1:

- Remains in its current orbit until repeat-track data from the SARAL/AltiKa can be validated

- However, because the Science Team recognizes the broad scientific value of a geodetic mission for Jason-1, we further recommend that Jason-1 be moved to a geodetic orbit in the range of 1286 +/- 2 km, or a suitable geodetic orbit in line with the spacecraft's capabilities at the time, after data from SARAL/AltiKa is validated.

6. Plenary session & Townhall meeting on science requirements for the Jason-CS orbit

Chairs : Hans Bonekamp, with J. Lillibridge, R. Morrow, J. Willis

Preparation:
In preparation of Jason-CS orbit discussions at the 2010 OSTST meeting in Lisbon, in July 2010, the results of the two related EUMETSAT studies done by Collecte Localisation Satellite (CLS) and the University of Hamburg (UHH), together with an overall and agreed summary written by Hans Bonekamp and Francois Parisot have been conveyed to on the OSTST via its email list. First results of the CLS study were already reported on a poster [Carrere et al. 2009] at the OSTST meeting in Seattle in 2009. In addition, after the Jason-CS Working Group meetings on partnership with NOAA and CNES end of August 2010 a note with the programmatic context by Francois Parisot and Stan Wilson was forwarded to the OSTST early September 2010. The various splinter sessions chairs of the OSTST meeting were approached before and during the meeting to address the issue of a potential orbit change from their splinter session perspective.

Programmatic context and agencies request: (Monday 18 October 2010):
At the OSTST meeting in the programmatic session on Monday, Francois Parisot and Stan Wilson (as CEOS OST VC co-chairs) gave a status overview of the Jason-3, Jason-CS (proposed) programs and how they were linked in the so-called ‘hybrid solution’. They highlighted that the continuity and consistency of the 20 years sea level climate record was the most compelling argument for decision makers to approve the Jason-3 program. They stressed that with phase B studies for Jason-CS starting now, there was an urgent need for a scientific recommendation on the orbit choice. This was formulated as a request for an acceptance of a change of orbit to meet the definition of a reference climate mission or for a justification for keeping the current Jason orbit. When changing orbit a ranking of preference for orbit candidates (as resulting from the CLS and UHH studies) was also asked for.

Town hall style OSTST discussion meeting: (Tueday 19 October 2010)

- The town hall style discussion meeting on science requirements for the Jason-CS mission orbit addressed only the orbit choice issue. After an introduction by Hans Bonekamp including highlighting again the request for a recommendation, Richard Francis provided an overview on scientific aspects of potential reduction in launch cost; potential extended life due to reduced radiation; potential improved instrument performance; better prospects for orbital debris mitigation. From this presentation it was concluded that technical solutions are in hand, but that the higher current Jason orbit implies additional complexity, mission costs and programmatic risks.

- Subsequently, Hans Bonekamp summarized the two studies by showing several metrics that underpinned the combined conclusions from the studies: It was understood that the combined CLS and UHH studies considered sampling aspects only, not calibration and validation aspects. From the sampling perspective in relation to the key applications of the missions (including sea level trends) no showstoppers were found for moving to an alternative orbit. The small impact on regional sea level trend from orbit change was noted by the OSTST and apart from slight advantage from higher inclination orbit as dominantly expressed in the UHH study, no compelling orbit choice was forwarded by the studies.

- Before going into the audience discussion, the splinter sessions chairmen summarized the feedback from their sessions. The feedback of the splinters was summarized as follows: A change of orbit is feasible from the near real time applications (operational oceanography, wind/wave applications) and also from the precise orbit determination perspective. A weak recommendation to change orbit was forwarded from the tides splinter, whereas a weak recommendations to stay in the same orbit was given by the near real time application splinter. The 'Mean Sea Surface and Geoid' splinter was divided over the advantages and disadvantages of an orbit change. The calibration and validation splinter, however, issued a strong recommendation to stay on the current Jason orbit.

- The following plenary discussion was lively and addressed the important issues at stake. There was a strong recommendation not to "break" the climate science record by moving the measurement position, but to extend the climate record on the same orbit. There was similarly a strong recommendation to stay on the reference orbit from the calibration and validation aspects, with an emphasis on the notion that Jason CS mission as a reference mission in the constellation of nadir altimeter missions is critical to maintain global sea level climate record; GCOS principles for climate monitoring demand continuity and consistency which may not be met with a change of orbit. No compelling scientific reason for a change orbit was found as well as no compelling technical reason preventing the Jason-CS mission from flying in the current orbit

Summary and consolidation: (Wednesday 20 October 2010)

The project scientist summarized the feedback and came up with a proposed recommendation (see below). There was an additional discussion with the same nature as that of the town hall style discussion meeting. It did not result in a divergence of points of view. The OSTST settled on providing dominantly a justification to keep the same orbit and endorsed the following recommendation:

Given the importance of maintaining the precise climate record of sea surface height, the challenges of calibrating & validating without formation flight between Jason-3 & Jason-CS, and the modest scientific benefits from a change of orbit: the OSTST recommends that Jason-CS maintain the 1336 km reference orbit flown by Topex/Poseidon and Jason-1, 2, & 3.

Richard Francis and Francois Parisot stressed that given additional costs for staying in the same orbit, a ranking of orbits is still needed for the case that an orbit change may become critical for the approval of the Jason-CS program, however, this "plan-B" option was not further discussed by the OSTST.

7. Plenary session discussion on radiometer drift requirements

Chair : Josh Willis

Context:

At the 2009 OSTST Meeting in Seattle, a plenary session was held on sea level error budgets. During that session, the wet path delay correction was identified as the largest source of error for estimating global sea level rise from satellite altimetry. The result of this session was a recommendation that an effort be made on Jason-3 to improve the long-term stability of the radiometer in order to improve both the accuracy and timeliness of global sea level rise observations.

Presentations:

For the splinter session in Lisbon, Josh Willis recapped the scientific argument for improving the accuracy and reducing the latency of global mean sea level estimates based on the Jason series of high-precision altimeters. In particular, two radiometer jumps in Jason-1 produced a spurious downturn in global sea level between 2003 and 2005, and it took years for the science team to detect and correct these errors. For Jason-2, a ground calibration system, termed the Autonomous Radiometer Calibration System (ARCS), was implemented on a best-effort basis to improve the timeliness of these radiometer on-orbit calibration corrections.

A brief outline of the Jason-2 radiometer on-orbit calibration techniques and ARCS (the operational segment of the on-orbit calibration) and their performance was presented by Shannon Brown. ARCS uses regions of the Amazon basin as a pseudo-blackbody warm brightness temperature (TB) reference and stable ocean regions as a cold TB reference to determine within 60 days if the AMR calibration had changed and if so, updates the AMR calibration coefficient file prior to GDR production In addition, AMR data are compared with radiometer data from other microwave sensors and outputs from Numerical Weather Prediction (NWP) models. Shannon showed that the ARCS system, supplemented by additional off-line recalibrations, was probably capable of achieving the desired 1 mm/yr uncertainty in the wet path delay long term stability for time spans longer than 3 years, but it was noted that with this approach, the long term radiometer calibration relies on the stability of ancillary data sets. On decadal time scales, the assumption of no drift in the ground truth may not be valid due to changes in the type and quality of the ancillary data that are available.

Shannon also recapped the discussion on this topic from the Instrument Processing splinter. In the Instrument splinter, it was noted that the NOAA and CEOS requirements of 1 mm/yr over 5 years and 0.5 mm/decade, respectively, insure only global stability and not regional stability of the sensor. The splinter recommended that future missions such as Jason-3 and Jason-CS should consider including radiometers that are capable of achieving long term stability by design without reliance on ancillary data in order to facilitate climate quality measurements of the global wet path delay correction and hence global sea level rise.

Recommendations and Requirements:

Finally, Josh Willis presented a recommendation for updating the requirement for stability on the global mean sea level measurement. The OSTST agreed upon the following language for the global sea level stability requirement on future missions:

Requirement: Jason-3 shall measure globally averaged sea level relative to levels established during the cal/val phase with zero bias +/- 1 mm (standard error) averaged over any one year period.

Verification: Accuracy will be verified by comparison with no less than 50 tide gauges that provide the widest possible geographic coverage.

Latency: As a goal, the project will attempt to design Jason-3 to meet this level of accuracy with a latency of 2 months, in time for production of the GDR.

Explanation: Given the small autocorrelation and the 4.9 mm RMS variability in altimeter – tide gauge time series the above requirement is intended to achieve a drift accuracy over different durations as follows:

error on mean = 4.9 mm / sqrt(23 - 1)
slope error= mean square error / sqrt(sum (ti - tmean)^2)

duration	***error***
1 year	***3.5 mm/yr***
2 years	***1.3 mm/yr***
3 years	***0.68 mm/yr***

It was recommended by the OSTST that this language be adopted as a goal for Jason-3 and as a strict requirement for Jason-CS.

Finally, it was noted that NOAA has commissioned JPL to perform a study to determine the feasiblity of adding an on board absolute calibration reference to the AMR for Jason-3. This study is proceeding and will be independently reviewed and discussed between the four partners (EUMETSAT, NOAA, CNES and NASA) in the coming months. In light of this, the OSTST adopted the following recommendation:

The OSTST recommends that the Jason-3 project continue to study the feasibility of improving the AMR stability through on board calibration for the Jason-3 mission.

In addition, the following recommendation was adopted with regard to Jason-CS:

The OSTST also recommends that Jason-CS meet the following requirement at the mission level:

Requirement: Jason CS shall measure globally averaged sea level relative to levels established during the cal/val phase with zero bias +/- 1 mm (standard error) averaged over any one year period.

8. Poster Sessions

A poster viewing session was conducted on Monday evening, and posters were also viewed during coffee breaks during the 3-day meeting. Links to the posters are available on the meeting website: http://www.aviso.oceanobs.com/ostst/ .

The posters were grouped into the following categories:

- Splinter session I.1: Local CalVal
- Splinter session I.2: Instrument Processing : sea state bias and retracking
- Splinter session II.1: Geoid and mean sea surface products
- Splinter session II.2: Near real-time products validation and application
- Splinter session III.1: Precision orbit determination
- Splinter session III.2: Instrument processing 2
- Splinter session III.3: Global and basin-scale science results
- Splinter session IV.1: Global and in-situ calibration and validation
- Splinter session IV.2: Outreach, education & altimetric data services
- Splinter session V.1: Tides, internal tides & high-frequency processes
- Splinter session V.2: Global and Regional Mean Sea Level studies
- Splinter session VI.1: 60-day variations in J1 & J2
- Splinter session VI.2: Ocean general circulation
- Poster session I: Coastal processes
- Poster session II: Hydrology processes
- Poster session III : Past & Future missions

9. Splinter Sessions

The theme for the splinter sessions (in particular for cal/val, POD/geoid, tides/HF aliasing, sea-state bias/retracking) was the evaluation of the Jason-2 GDR product. The splinter sessions were organized as follows:

Monday 18 afternoon :

- Splinter session I.1: Local CalVal
- Splinter session I.2: Instrument Processing : sea state bias and retracking

Tuesday 19 :

- Splinter session II.1: Geoid and mean sea surface products
- Splinter session II.2: Near real-time products validation and application
- Splinter session III.1: Precision orbit determination
- Splinter session III.2: Instrument processing 2
- Splinter session III.3: Global and basin-scale science results
- Splinter session IV.1: Global and in-situ calibration and validation
- Splinter session IV.2: Outreach, education & altimetric data services
- Splinter session V.1: Tides, internal tides & high-frequency processes
- Splinter session V.2: Global and Regional Mean Sea Level studies

Wednesday 20 :

- Splinter session VI.1: 60-day variations in J1 & J2

- Splinter session VI.2: Ocean general circulation

9.1 Local and global calibration/validation Splinter Report

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

Introduction

The primary goals of this session were:

• Validation of all available Jason-2 version "T" (test) GDRs, including data collected after the end of the verification phase. We are particularly seeking insight on any potential emerging trends in the data on local, regional or global scales.

• Validation of the complete set of the Jason-1 GDR-C products. Definitive calibration time series are needed, along with estimates of geographically correlated errors, in order to reconcile local and global results and arrive at a unified error assessment.

• Validation of Jason-1 GDR-C data on the interleaving ground track.

• Validation of available reprocessed T/P data. Of particular interest is the impact of these products on reducing relative geographically correlated errors (GCEs) observed in the Jason-1/TP (2002) tandem verification phase.

• Validation of EnviSat GDR data

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, however, if they help to explain errors in the official products.

Discussions were conducted on the following subjects:

- Possible change of orbit for Jason-1 End of Life,
- Possible change of orbit for the upcoming Jason-CS mission,
- How to maintain a 1-mm/yr drift accuracy for the Jason series, particularly in preparation for Jason-3.

9.1.1 Results from in-situ calibration sites

<u>Absolute calibration of TOPEX/POSEIDON, JASON-1 and JASON-2 altimeters in Corsica, *Bonnefond et al.*</u>

The analysis of the whole data sets available for T/P, Jason-1 and Jason-2 was presented as well as a detailed study of the land contamination of radiometer measurements on approach to the Corsica site (Figure 9.1.1): for more details about this study, notably the location of measurements relatively to the coast, please refer to *Bonnefond et al*. (2010) in *Marine Geodesy* 33:1 (special issue on OSTM/Jason-2). One of the main results presented concerns the Enhanced Path Delays for JMR and AMR (*Brown et al*.): both reduce the land contamination and show better agreement with GPS-derived wet tropospheric corrections. Results are summarized below:

<u>Absolute biases over the whole data sets:</u>

Jason-2:	+150 ±5 mm
Jason-1:	+64 ±2 mm
T/P ALT-B:	-16 ±4 mm

Relative biases over common overflights:

Jason-2 - Jason-1: +87 mm (+87 mm from orbit-range)

Jason-1 – T/P: +84 mm (+80 mm from orbit-range)

Corrections:

- Wet tropospheric correction from radiometers shows a bias of -5 mm (JMR dryer than AMR), but close to 0 when using Enhanced Path Delays
- GPS shows that both AMR and JMR are dryer at the Corsica approach
- No significant drift detected from JMR/GPS and AMR/GPS comparisons.
- Better agreement between GPS and Enhanced Path Delays (EPD, *Brown et al.*) from AMR and JMR (differences reduced to zero for JMR/EPD and AMR/EPD).
- Using EPDs for both JMR and AMR makes Corsica closer to other in situ results:
  - ⇨ Jason-2 bias increases by ~10 mm (=> +160 mm, vs. +176 mm from Harvest)
  - ⇨ Jason-1 bias increases by ~13 mm (=> +77 mm, vs. +87 mm from Harvest)

Orbits:

The latest orbit solution sets (std0905 and std1007 from GSFC and rlse10a from JPL) agree well with one another at Corsica, impacting the bias estimates at the millimeter level.

T/P MGDR+ (MGDR + TMR replacement products + std0905 orbits (GSFC)):

9 mm decrease of the T/P ALT-B bias compared to MGDR (-4 mm from TMR and -5 mm from orbit). Using LSE retracked products increases T/P ALT-B bias by 16 mm (=> zero bias) and induces a slope of 9 mm/yr which needs to be analyzed further.

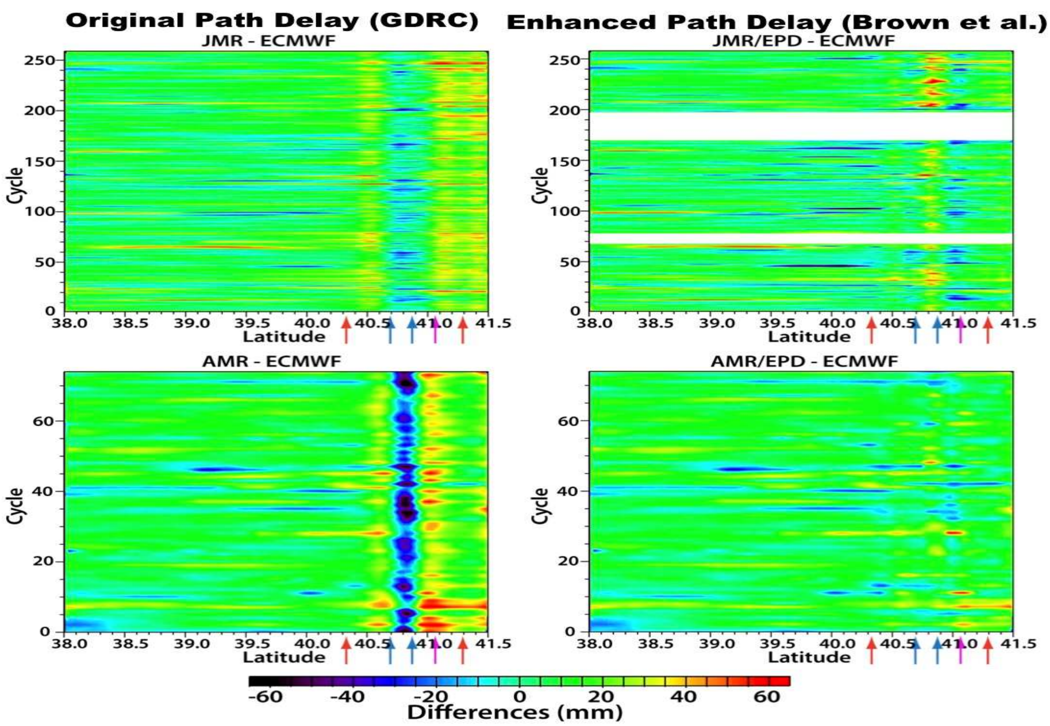


Figure 9.1.1. AMR & JMR wet tropospheric correction differences with ECMWF model. Original correction from GDR-C at left and Enhanced Path Delay at right. The colored arrows on the latitude axis correspond to: 30 km from coast (red), Sardinia overflight (blue) and end of Asinara island (magenta).

Use of the Corsica site to compute altimeter biases for EnviSat, JASON-1 and JASON-2/OSTM : absolute and regional CalVal methods, *Chimot et al.*

Usually, the in-situ calibration is done at the vertical of a specific CalVal site by direct comparison of the altimeter data with the in situ data. NOVELTIS has developed a regional CalVal technique, which aims at increasing the number of the altimeter bias assessments by determining the bias also on satellite passes located far away from the Senetosa CalVal site (Figure 9.1.2).

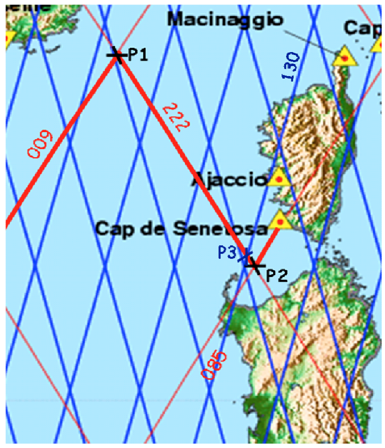


Figure 9.1.2. Configuration of the calibration site in Senetosa (Jason-2 groundtracks in red, EnviSat in blue).

The strong interests of this method are to extend the single site approach to a wider regional scale as well as to be able to estimate the bias for satellite missions flying in the neighborhood of the calibration site. (Jason-1 on the interleaved orbit for example)

Nevertheless, the ocean dynamics (tide and atmospheric effects) may influence the altimeter bias estimations at crossover points located far from the calibration site. The computation of the Jason-2 bias correcting either the tide or the dynamical atmospheric effects proved that both corrections have an impact of only a few mm on the bias in Senetosa. This result is confirmed by Figure 9.1.3, where the amplitude and the phase of the M2 wave, the main tide component in this area, appear to be very homogeneous in this part of the Mediterranean basin. With this method, the Jason-2 mean bias reaches 17.5cm (74 cycles), using models for the ionosphere and wet troposphere corrections.

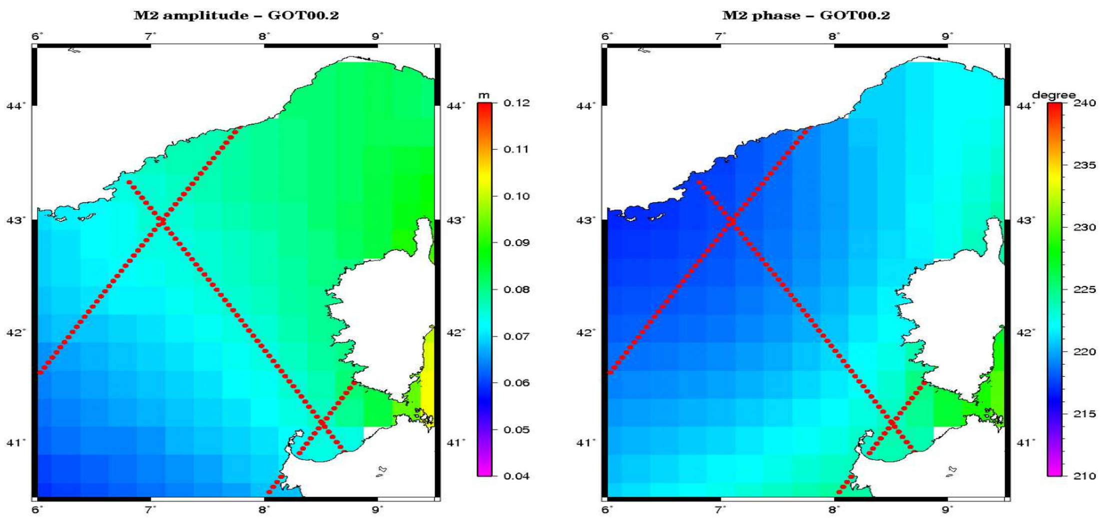


Figure 9.1.3. Amplitude and phase of the M2 tide wave from the GOT00.2 atlas in the Senetosa area. The Jason-2 ground tracks are superimposed in red dots

Finally, the NOVELTIS regional CalVal method was applied on the Jason-1 interleaved orbit, and the results show that the bias of the Jason-1 mission remained stable after the orbit change (Figure 9.1.4), with mean biases of 8.5cm on the initial orbits (259 cycles), and 8.3cm on the interleaved orbits (45 cycles).

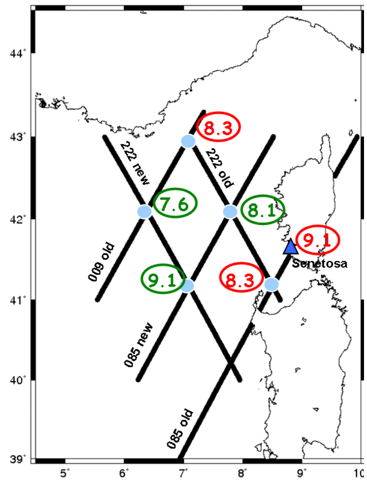


Figure 9.1.4. Bias estimation for the Jason-1 mission in Senetosa: on the initial orbits in red and on the interleaved orbits in green

The Harvest Experiment: Current Results from the 18-year Altimeter Calibration Record, *Haines et al.*

Haines et al. presented the 19-yr altimeter calibration record at Harvest, which includes results from the combined T/P, Jason-1 and Jason-2 missions. The main evolution since the last OST/ST meeting is a re-estimation of the platform vertical (1992–2010) from GPS. This time series is derived using reanalyzed orbit and clock products for the GPS constellation (Desai et al., 2009), and exhibits better long-term stability, as well as day-to-day repeatability. Also new is significant additional calibration data on Jason-2, which continues to pass over the platform every 10 days (Figure 9.1.5). The sea-surface height (SSH) data from the legacy T/P altimeter measurement systems continue to yield bias estimates (≤10 mm) that are statistically indistinguishable from zero. In contrast, both Jason-1 and Jason-2 are measuring SSH too high, by +87 and +176 mm respectively. The repeatability of the individual bias estimates is the range of 26–33 mm, depending on the altimeter system. A spectral analysis of the SSH bias estimates was undertaken to lend insight on possible error sources (Figure 9.1.6). Results from the B Side of the NASA radar altimeter on T/P show a significant (~2 cm) variation at 59 days (S2 alias period), while those from the A Side do not. This was further addressed as part of the ’60 days signal’ splinter meeting.

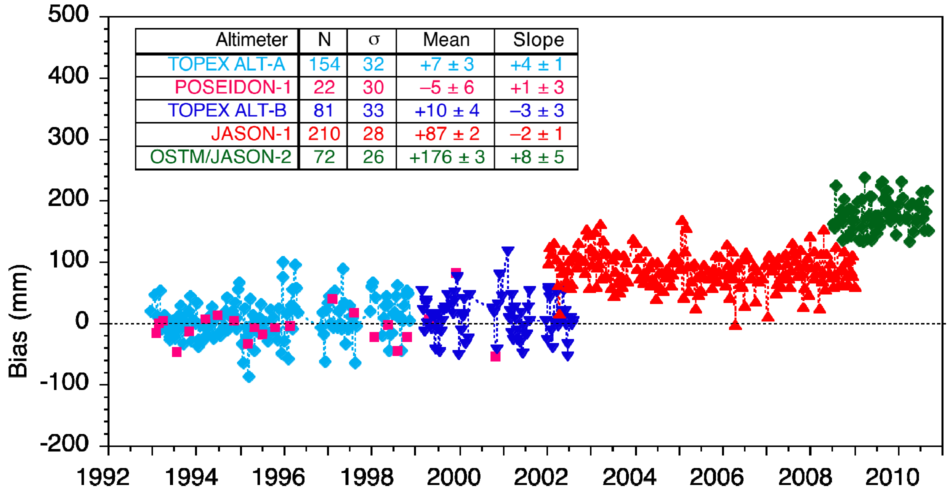


Figure 9.1.5. Absolute biases time series for TOPEX/Poseidon, Jason-1 and Jason-2 from Harvest calibration site.

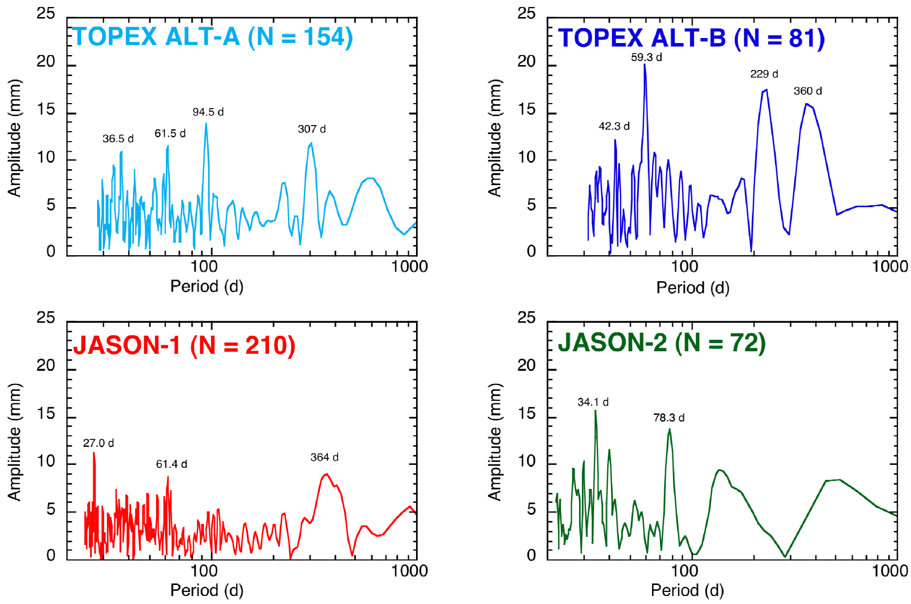


Figure 9.1.6. Periodograms of SSH bias estimates (T/P, Jason-1 and Jason-2) from the Harvest calibration site. For T/P, the MGDR correction for CG_CORR (center of gravity motion) was not applied.

Determination of the absolute bias for the Jason satellite missions using the Gavdos facility, *Mertikas et al.*

The Gavdos calibration site has determined the absolute bias for Jason-2 over Pass No. 109 (cycles 2-60) and Pass No. 018 (cycles 1-40).

The bias using Pass No. 109 has been estimated to be +171.19 ± 4.54 mm in the Ku-band in a region from 12 to 21 km south of Gavdos. Cycle 27 has been identified as an outlier (large sigma0 values) and excluded from processing. Figure 9.1.7 shows the altimeter bias as a function of cycle number over Pass No. 109.

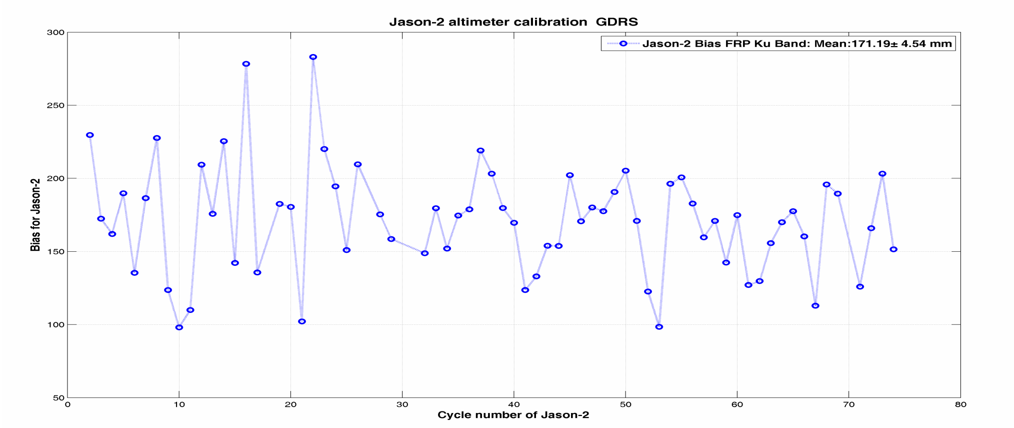


Figure 9.17. Jason-2 absolute bias for Jason-2 Pass No. 109, Cycles 2-60.

For Pass No. 018, the bias has been estimated to be +172.9 ± 5.9 mm in the Ku-band in the area from 8 to 18 km, south of Gavdos for cycles 1 to 40. Cycles 3 and 32 have been identified as outliers (large sigma0 values) and excluded from processing.

In cooperation with CNES and the Austrian Space Research Institute of the Austrian Academy of Sciences (AAS), the transponder installed on Gavdos island was used to perform Jason-2 range calibration experiments. This requires moving the tracking window of the altimeter to 200 m above sea level, and therefore impacts the coverage of the altimeter products over the sea surface along Pass No. 018. Therefore, cycles No. 41 and thereafter could not be used in our analysis. Figure 9.1.8 depicts the altimeter bias over Pass No. 018 with the conventional technique.

In both passes No. 109 and No.18, the new *Brown* (2010) enhanced model has been used for the determination of the Wet Tropospheric Delay.

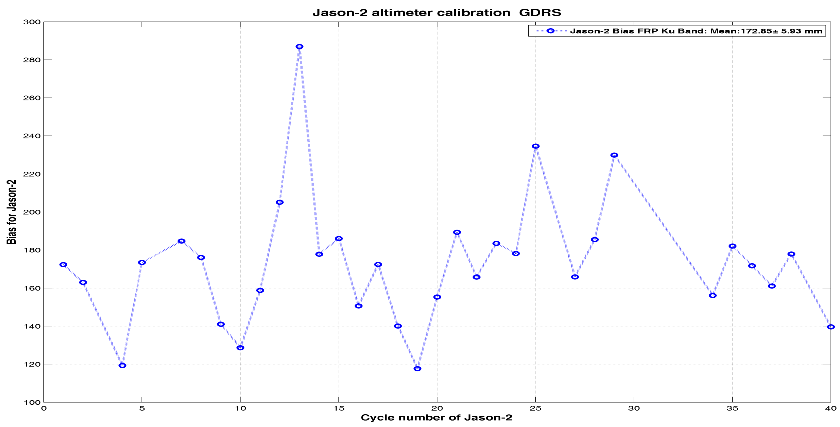


Figure 9.1.8. Jason-2 absolute bias for Jason-2 Pass No. 018, Cycles 1-40.

The ionosphere and the wet troposphere delays from altimetry were compared with those determined from GPS analysis. The differences are +5.4 ± 0.4 mm and -8.1 ± 1.5 mm respectively for the ionosphere and wet troposphere corrections (GDR minus GPS) for Pass 109.

The MSS technique, using the CLS01 model as reference, produced an altimeter bias of +151 ± 6.8 mm over Pass No. 109.

Studies from the transponder deployment (Sept 2009 – pr.) are ongoing, and are being undertaken in close cooperation with CNES and the Austrian Space Research Institute of the Austrian Academy of Sciences (AAS).

The eastern Mediterranean altimeter calibration network – eMACnet: anticipating JASON-3 and SWOT, *Pavlis et al.*

Accomplishments:

- Six sites operational, one with two tide gauges (a radar and a float)
- Three sites with CORS GNSS receivers (GAVDOS, KASTELI, PALEKASTRO)
- Two more GNSS receivers purchased for installation at CHIOS & MANI (2010)
- THASOS and a new site in central-north Greece to be equipped with GNSS receivers in early 2011
- JASON-2 passes covered now: 18, 33, 94, 109 (185)
- The AQUATRAK tide gauge (operational since 2003 at KARAVE) was relocated to the HNHS instrument shack on the new KARAVE harbor (east of old location)
- A new CORS GNSS receiver installed and operational at the new location, along with the MET3A sensor and communications equipment for local and satellite transmission of data
- JASON-1 (from GDR-C) bias estimate: 107.5 ± 8 mm (41 events)
- JASON-2 (from GDR-T) bias estimate: 177.1 ± 18 mm (35 events, Figure 9.1.9)

Future plans:

- Connect new KARAVE/GAVDOS to EUMETCAST, enable data collection with 15 min latency
- Complete GNSS installations at CHIOS and MANI in 2010, and THASOS by early 2011 (GEST & NTUA have purchased instruments)
- Re-analysis of GPS data with ITRF2008 back to 2003
- Redo/extend calibration series with new GDRs for JASON 1 & 2
- Pursue redeployment of mobile SLR (FTLRS?) at Dionysos satellite tracking station (NTUA) in the next 1-2 years (will cover all tracks and all sites!!!)

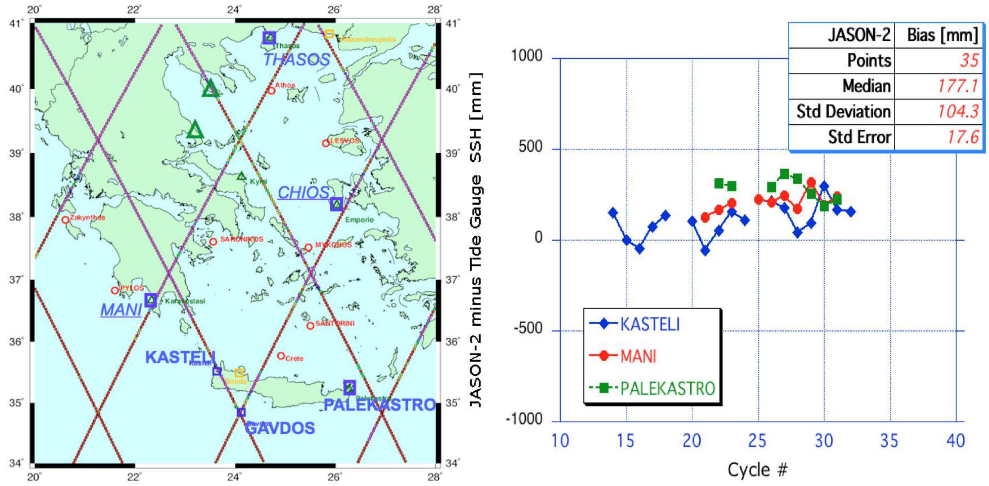


Figure 9.1.9. Configuration of the eMACnet network (Left) and Jason-2 bias time series (Right)

<u>Updated results from the in-situ calibration site in Bass Strait, Australia, *Watson et al.*</u>

- Updated absolute bias estimates from the Bass Strait calibration site for the Jason-1 and OSTM/Jason-2 missions are provided below and illustrated in Figure 9.1.10:

Altimeter Data	**Cycles**	**N**	**Mean Bias ± Std Error**
Jason-1 GDR-C Jason-1 GDR-C (enhanced JMR)	001-259 120-259*	211 88	**+96.7 ± 2.6 mm**** increase by 9.6 mm
Jason-2 GDR-T Jason-2 GDR-T (enhanced AMR)	001-076 001-076	66 66	**+175.2 ± 4.0 mm**** increase by 2.7 mm

* No data available at time of writing for cycles 169-198
** Standard errors about the mean are quoted but do not take into account likely systematic contribution to the error budget. The likely error floor for absolute bias estimates is at the ± 10-15 mm level.

- The enhanced JMR and AMR products from Shannon Brown were shown to outperform the standard GDR wet delay estimates at the Bass Strait comparison point. The enhanced near-coast product shows less land contamination and mitigates the requirement to extrapolate from more distant GDR samples. Marginal increases in the Jason-1 (~9.6 mm) and OSTM/Jason-2 (~2.7 mm) absolute biases were noted with the enhanced radiometer product.
- As part of its commitment to ocean remote sensing infrastructure, the Australian Integrated Marine Observing System (IMOS) has committed support to the Australian contribution to altimetry calibration and validation in the OSTST. This contribution will extend the bias estimates from Bass Strait to Storm Bay (on the same pass, yet in a different wave climate) in addition to computing bias drift from the global tide gauge and GPS network.

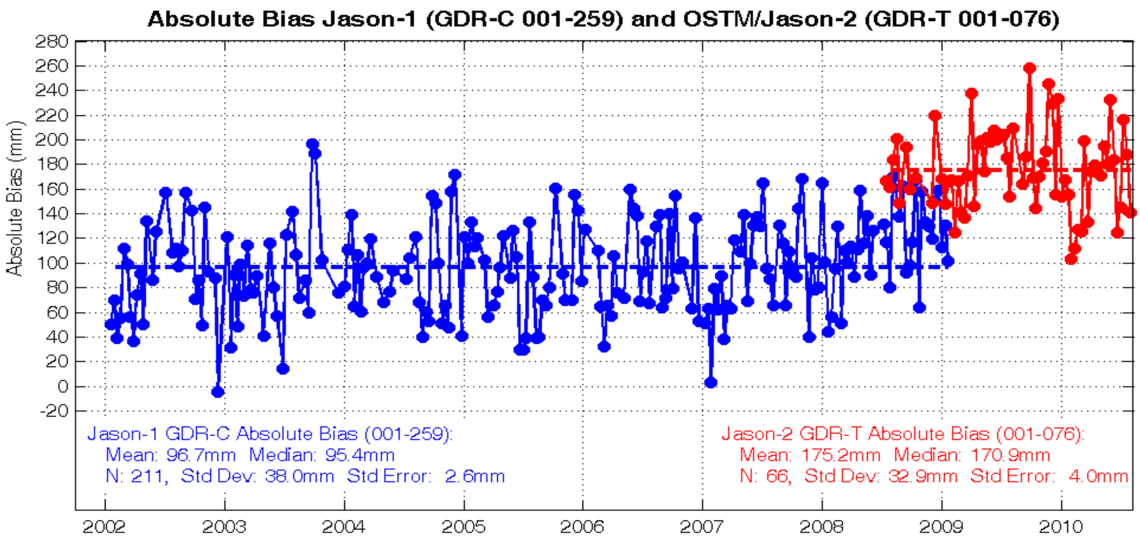


Figure 9.1.10. Absolute bias time series for Jason-1 (blue) and Jason-2 (red) for the Bass Strait calibration site.

Summary of the in situ analysis key findings:

- There is good coherence of the Jason-1 and Jason-2 SSH bias estimates from all calibration sites (Figure 9.1.11).

- New coastal AMR and JMR products (EPD) clearly reduce the land contamination and improve agreement with GPS-derived path delay for coastal approaches; from in situ studies this new correction increases (except at Gavdos) the Jason-1 and Jason-2 bias and then reduce the discrepancies between in-situ calibration sites (*Haines et al., Bonnefond et al. and Watson et al.*).
- ~10 mm average for differenced ionospheric correction (Jason-2 – Jason-1) due to different range bias for Ku and C bands for Jason-2; this reinforces the need to calibrate both bands and to conduct detailed studies on the errors discovered by the project on the C-band (*Haines et al.*).
- No clear drift of the measurement systems (T/P and Jason-1) revealed by the longest time series (*Haines et al., Bonnefond et al. and Watson et al.*).
- Most of the Jason-1/Jason-2 relative range bias (85 mm, see Figure 9.1.11) comes from an error in some parameterization files on Jason-1 and Jason-2 discovered by the project before the Seattle OSTST meeting in June 2009 (purple lines in Figure 9.1.11). Correcting this error will increase the Jason-1 bias by 120 mm and that of Jason-2 by 25 mm. This results in an overall decrease of the relative bias by 95 mm (from 85 mm to -10 mm), based on the average of estimates from the in situ calibration sites. Accounting also for the 10 mm bias on the ionospheric correction, the relative bias between Jason-1 and Jason-2 would be close to zero. This needs to be further investigated (notably on the C-band) but, if confirmed, both satellites are measuring sea surface consistently high by about 20 cm.

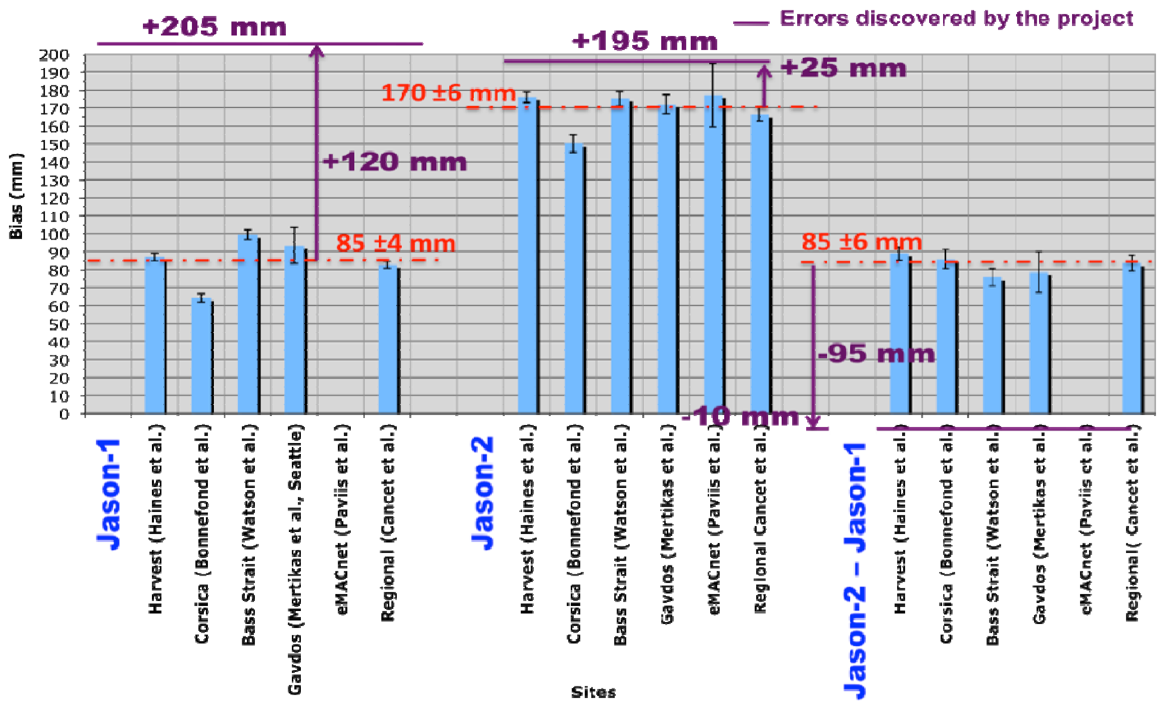


Figure 9.1.11. Absolute bias values for Jason-1 and Jason-2 from the different calibration sites. Red lines and associated numbers correspond to the average of all individual sites values. Purple lines and associated numbers correspond to the absolute biases if corrected from the error recently discovered by the project.

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

Data quality assessment of in-situ and altimeter measurements through SSH comparisons, *Ablain et al.*

In this study, we presented the main results obtained from comparisons between these in-situ measurements and altimeter data from TOPEX, Jason-1, Jason-2 and EnviSat through the 3 following objectives linked together. The first consists of detecting drifts or jumps in altimeter SSH by comparison with in-situ measurements. The second goal is the analysis of the SSH consistency improvement between altimeter and in-situ data using new altimeter standards (orbit, geophysical corrections, ground processing...). The last objective is the detection of anomalies on in-situ time series thanks to the cross-comparison with all available altimeter data. In-situ measurements can thus be corrected or even removed in order to further improve the SSH comparison with altimeters. In this study we focused on the drift detection of the MSL.

For Jason-1 MSL (Figure 9.1.12), we do not detect drift, but a parabolic signal seems to be highlighted with an amplitude close to 5 mm. The origin of this potential anomaly has to be investigated. On Jason-2 MSL, a negative drift is observed, but the data duration is too short to consider this result as reliable. For TOPEX (Figure 9.1.13), a positive drift is estimated (+0.7 mm/yr) but it is partly explained by a significant jump (7 mm) in 1996 (under investigation). Finally, for EnviSat (Figure 9.1.14 & 9.1.15), a negative drift (-1.4 mm/yr) and a strong regional drift dependent on longitude (East/West) likely related to orbit calculations have been highlighted. The EnviSat GDR-C reprocessing (on-going) should improve the EnviSat long-term stability.

To conclude, it’s important to underline the synergy of both in-situ and altimetry comparison methods using tide gauges and T/S profiles to estimate the altimetry MSL drift: while tide gauge measurements provide long time series but limited spatial sampling, T/S profiles provide global coverage but are available on a shorter time period. Thanks to the cross-comparisons between results provided by different approaches (global comparison between altimetry missions, Alti/TG and Alti/TS comparisons), the estimate of the MSL drift from altimetry is more and more reliable and accurate (globally and regionally).

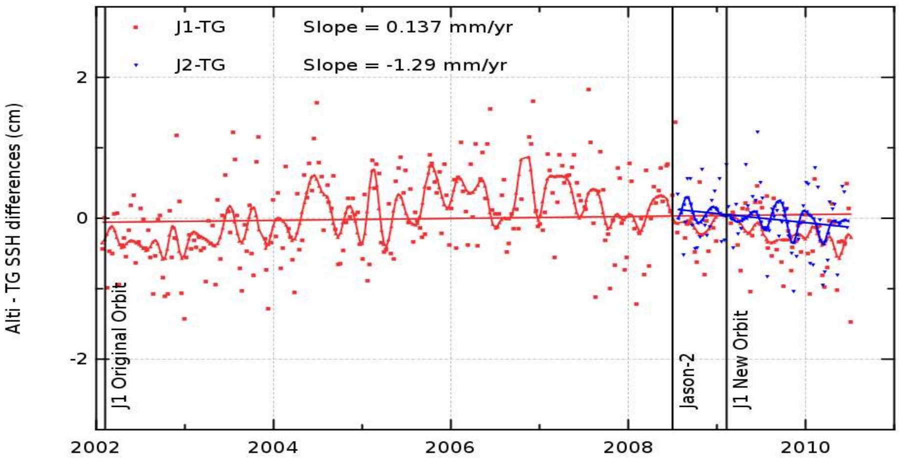


Figure 9.1.12. Long-term differences between Jason-1/Jason-2 and Tide Gauges SSH

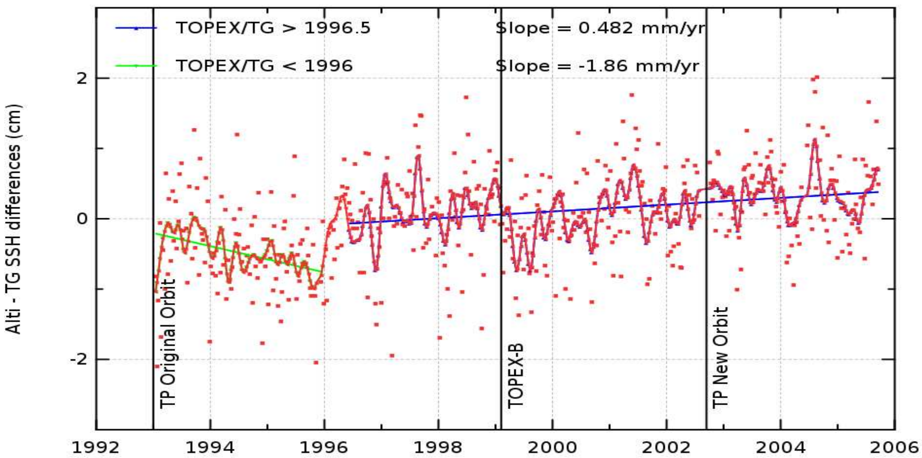


Figure 9.1.13. Long-term differences between TOPEX and Tide Gauges SSH

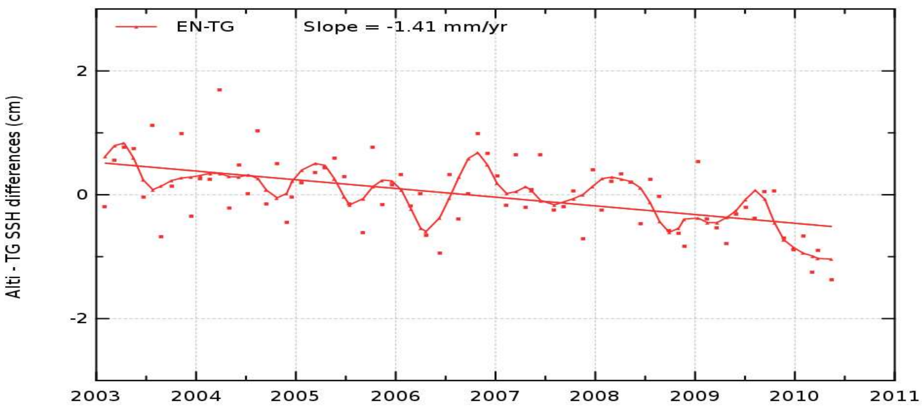


Figure 9.1.14. Long-term differences between EnviSat and Tide Gauges SSH

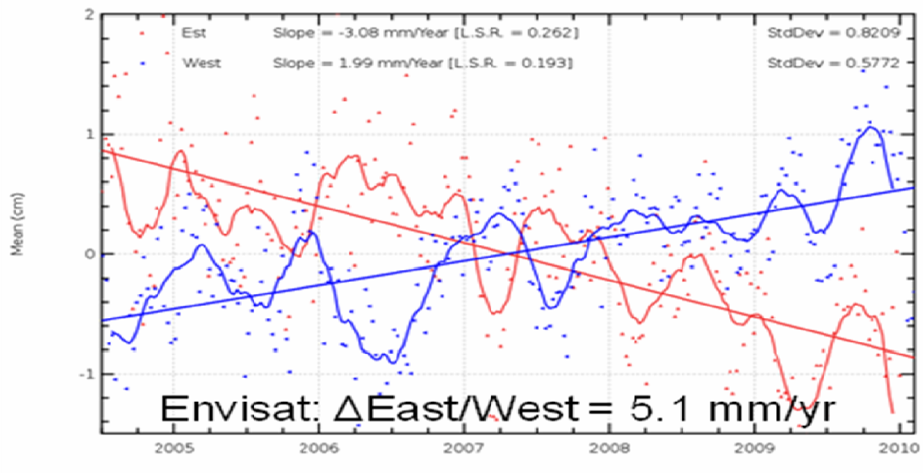


Figure 9.1.15. Long-term differences between EnviSat and T/S profiles separating the East [0°,180°] and West part [180°,360°] of the ocean

Evaluating and interpreting the global and regional sea level climate record, *Leuliette et al. (from « Global & Regional Mean Sea Level studies » splinter)*

The drift estimate from the tide gauge calibration of the current climate data record from TOPEX/Jason-1/Jason-2 time series is consistent with no drift within the uncertainty in the tide gauge calibration (–0.16 ± 0.4 mm/yr), which for the 18-year record is dominated by the uncertainties in the land motion correction. However, recently, Jason-1, Jason-2, and EnviSat have exhibited recent offsets or drifts around November 2009 (Figure 9.1.16) using the Mitchum [2000] method of calibration using a global network of 64 tide gauges. The Jason-2 offset begins in November 2009 and is roughly a 1 cm offset.

Three relatively large earthquakes struck near gauges at roughly the time of the offset (M 8.1, Samoa, 29 September 2009; M 7.3, Suva, Fiji, 9 November 2009; and M 6.8, Tonga, 24 November 2009). In particular, a large change in vertical land motion is apparent at Pago Pago in both GPS data and altimeter/tide gauge differences (Figure 9.1.17). However, excluding these gauges from the analysis does not completely eliminate the offsets in Figure 9.1.16. For example, excluding the gauge at Pago Pago appears to reduce the offset set by only ~2 mm.

While an analysis of the relative contributions of each gauge to the offset suggests that it is seen by the entire tide gauge network (Figure 9.1.18), no offset is apparent in the global mean of the troposphere or ionosphere correction applied to each mission. Only the ECMWF dry troposphere correction is common to data from the three missions calibrated with the tide gauges.

The source of the offset(s) is under investigation.

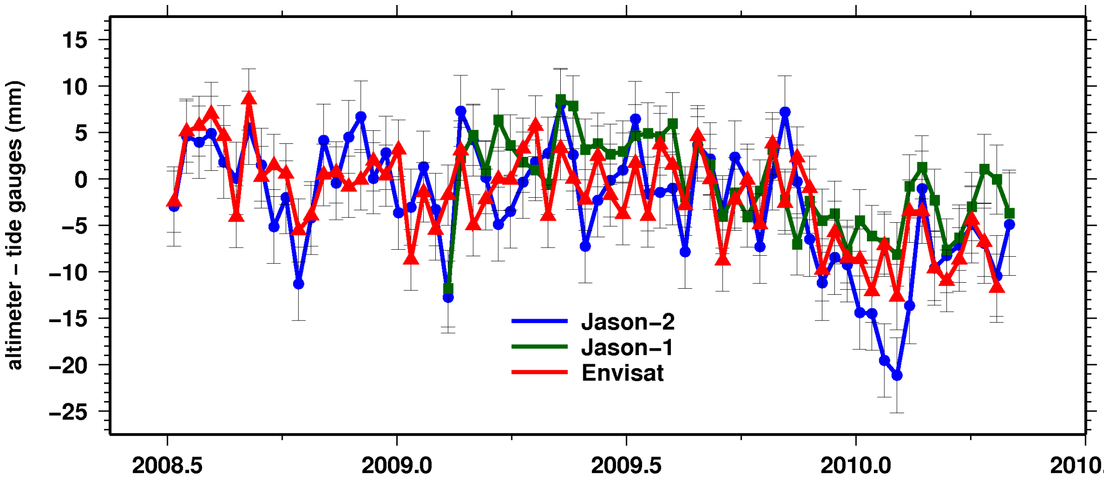


Figure 9.1.16. Drift series from Jason-2, Jason-1 interleaved mission, and EnviSat since mid-2008. All three operating altimeters have exhibited recent offsets or drifts. The Jason-2 offset begins in November 2009 and is roughly a 1 cm offset.

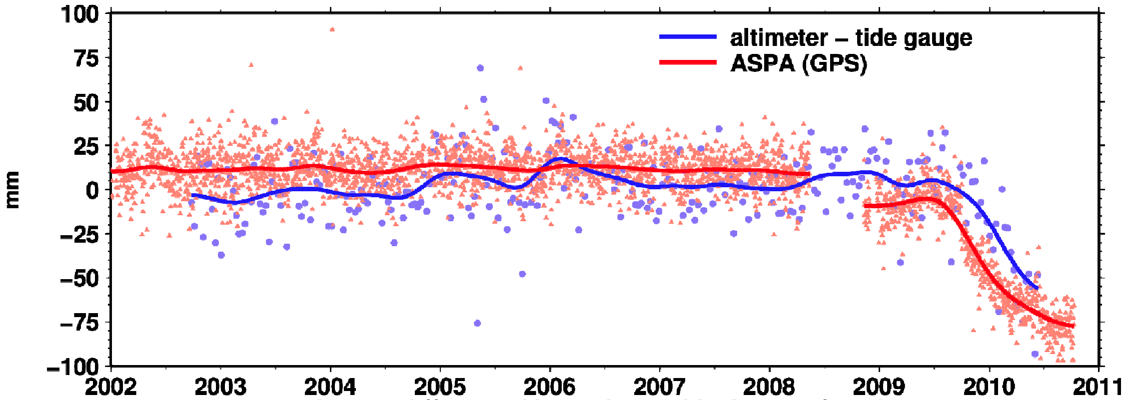


Figure 9.1.17. Jason-2 minus tide gauge differences (blue) and vertical land motion from the ASPA GPS station at Pago Pago (red). The effect of post- seismic vertical land motion is apparent after the September 29, 2009 earthquake. The solid lines are 1-year Gaussian smoothed.

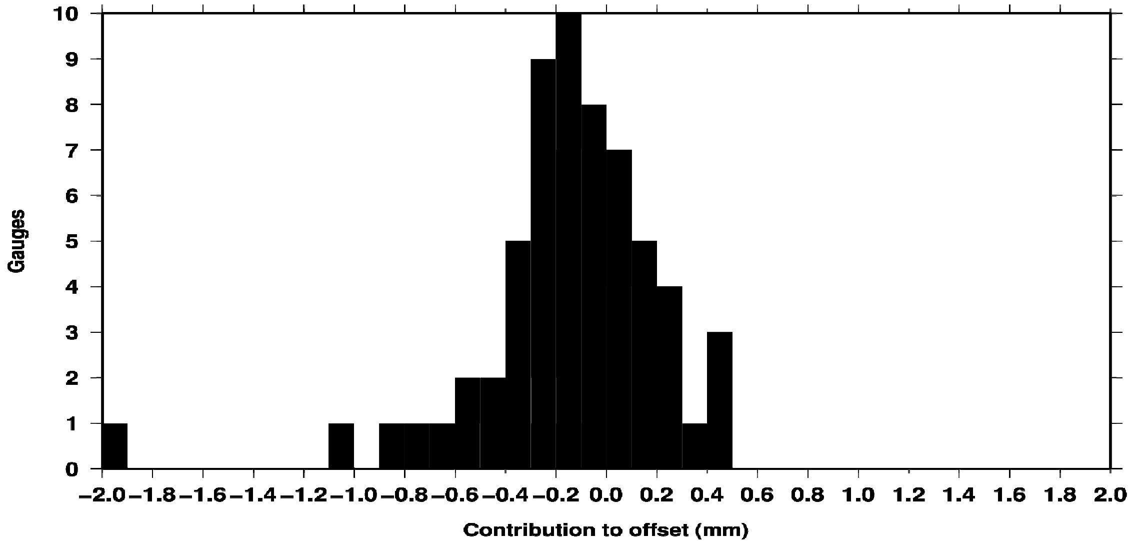


Figure 9.1.18. Contribution to Jason-2 offset from individual tide gauges, estimated by weighting the differences in mean bias for the 5 months before and after Nov. 2009 ± 5.

Summary of tide gauges versus altimetry global analysis key findings:

- No clear drift of the Jason-1 measurement system (GDR-C, *Ablain et al., and Leuliette et al.*)
- No clear drift of the T/P measurement system over the whole mission: however, a clear difference in the drift was identified by *Ablain et al.* before and after a jump in 1996 but do not correspond to the ALT-B/ALT-A transition (Figure 9.1.13)
- A negative drift (-1.4 mm/yr) for EnviSat (Figure 9.1.14 & 9.1.15), and a strong regional drift dependent on longitude (East/West). However, this is not confirmed by *Leuliette et al.* who found a much smaller drift (-0.5 mm/yr).
- The strange drop in Jason-1, Jason-2 and EnviSat reported by *Leuliette et al.*, is not as obvious in Ablain's results, but cannot be completely ruled out in view of the systematic variations in the various time series. This has to be further investigated to insure that such 1-2 month drop is only a statistical anomaly.

9.1.3 Global validation studies

Jason-2 DATA QUALITY assessment and cross-calibration with Jason-1, *Ablain et al.*

1 Hz Jason-2 (GDR-T) and Jason-1 (GDR-C) data are used to assess Jason-2 data quality and system performances.

Data coverage and editing: Jason-2 has excellent data availability with only few missing measurements (due to planned uploads or calibrations), whereas Jason-1 had several data outages during 2010 (altimeter incidents, lost of tracking due to high mispointing). Due to its new tracker algorithms (Median), Jason-2 has more data available over ice, coastal and hydrological zones than Jason-1 (SGT tracker). These additional measurements over ice explain the higher percentage of edited measurements for Jason-2 than for Jason-1.

Parameter Analysis: Jason-2 altimeter and radiometer parameters are routinely monitored and compared to Jason-1's (Figure 9.1.19).

Mispointing	Very stable, about 0.01 deg2 (due to antenna aperture)
Ionosphere	Similar to Jason-1, bias of about 8.5 mm
Sigma0	Similar to Jason-1, bias of about 0.1 dB
Altimeter wind speed	Similar to Jason-1, bias of about 0.4 m/s, different shape of histogram
SWH	Good agreement with Jason-1, small increase during 1 semester of 2010
Radiometer wet troposphere	Less impacted by yaw maneuvers, but radiometer/model difference shows some evolution up to 2 mm amplitude (application of calibration coefficients)

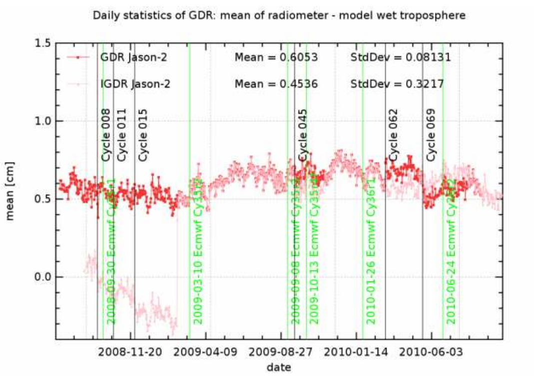


Figure 9.1.19. Daily mean of radiometer - ECMWF model wet troposphere correction for Jason-2 GDR (red) and IGDR (pink). Vertical green lines show ECMWF model version changes. Vertical black lines show changes in AMR calibration coefficients.

SSH performance at cross-overs: SSH performance at crossovers is good, but shows geographically correlated patterns up to +/- 2 cm amplitude, which are similar to those from Jason-1. This is related to the orbit solution, as using GPS-only orbits (such as JPL09a, Figure 9.1.20) and correcting for pseudo datation bias, eliminates these patterns. Cyclic monitoring of mean SSH differences at crossovers reveals a 120-day signal, also reduced when using GPS JPL09a orbits.

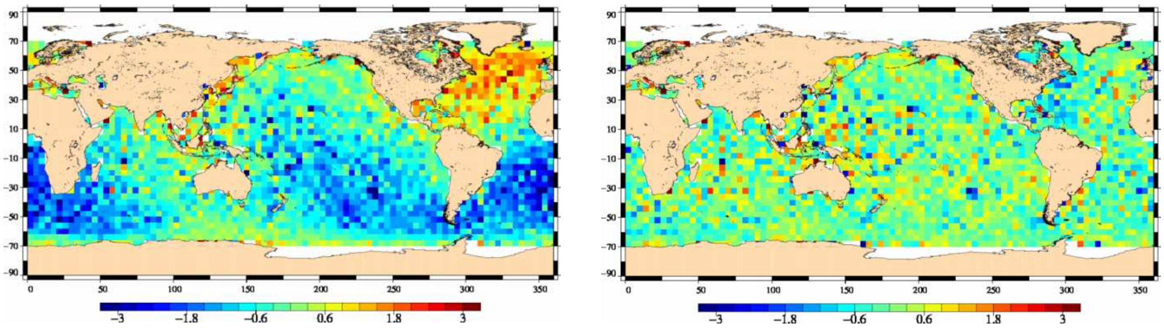


Figure 9.1.20. Mean of asc/dsc SSH differences at crossovers for Jason-2. Using GDR-C orbit (left) or JPL GPS 09a orbit (right).

<u>SLA along-track performances:</u> Mean difference of SLA between Jason-2 and Jason-1 is about 7.4 cm. SLA standard deviation is close to 10.5 cm (in average).

<u>JASON-2 / EnviSat cross-calibration, *Faugere et al.*</u>

Results from cross calibration between EnviSat and JASON-1/2 show that Ra-2 altimetry system performances are consistent with Jason-1/2. Very good availability and good metrics at crossovers, at the same level as Jason series, are observed.

The EnviSat/Jason dual crossovers analysis, using the reprocessed CNES orbit for EnviSat (GDRC standards), highlights a strong East/west signal between the two missions (Figure 9.1.21). Comparison to independent in situ data showed that the error, increasing from 2007 onwards, is on EnviSat side. The sensitivity of EnviSat orbit solution to time variable gravity terms is a possible explanation. This should be analyzed by, for instance, testing other orbit solutions.

On 26 October 2010, the EnviSat ground track will change. For this new mission phase, no mean profile will be available anymore to compute the Sea Level Anomalies. MSS will be used instead, which will increase the error budget of EnviSat data.

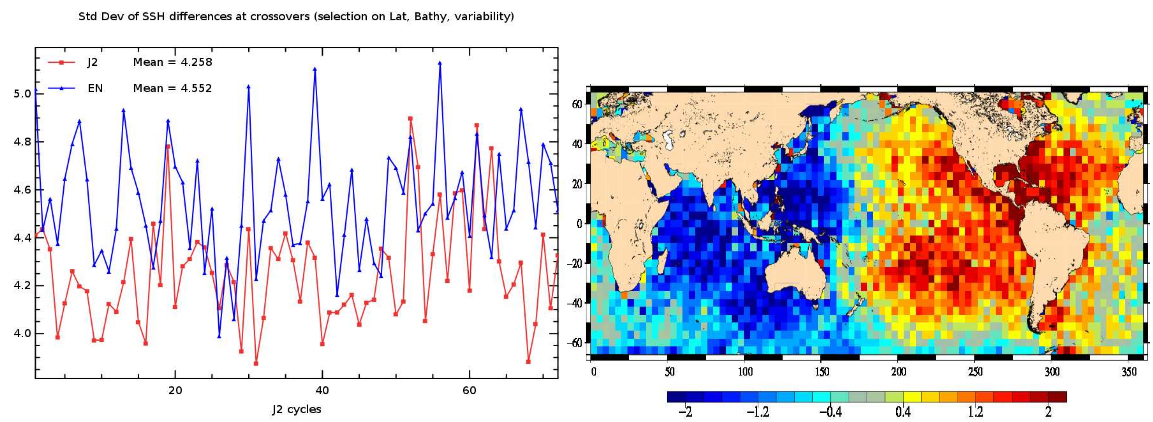


Figure 9.1.21. EnviSat /Jason-2 GDR crossovers analysis over 2 years. Std of SSH differences(cm), box averaged (left), mean (EnviSat –Jason-2) SSH (right)

Global evaluation of the JASON data products, *Decarvalho et al.*

We reported two interesting features in the AMR data. First, the variance on all three brightness temperature channels is increasing as a function of time (Figure 9.1.22). The cause for this is not yet understood. Secondly, we observe an anomalous spike in the distribution of the 34.0 GHz brightness temperatures near 163K. This is due to a hardware anomaly in the voltage to frequency converter (VFC). A work-around has been implemented to mitigate the impact on the measurement system and will be applied to the Jason-2/OSTM GDR-C products.

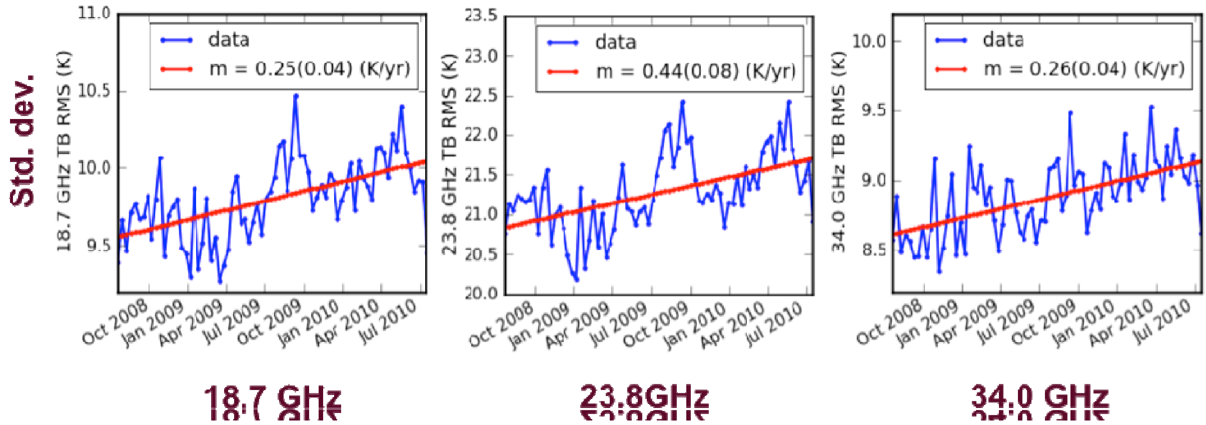


Figure 9.1.22. variance on all three brightness temperature channels.

Consistent with other investigations, we observe a 2.7 mm, 58.77-day oscillation in the global sea surface height measurements from Jason-1 and Jason-2, coinciding with the S2 tidal alias period (refer to the dedicated splinter focusing on the 60 days signal analysis). We presented results from our investigation into the possibility that this feature is caused by artifacts in the GOT00.2 ocean tide model. In particular, we considered the inconsistencies in the treatment of the S1/S2 atmospheric tide effects on the dry troposphere correction applied to the Topex data versus the Jason-1 and Jason-2 data. This inconsistency manifests itself through the empirical ocean tide models that are derived from the Topex data. We also considered the impact of the center of gravity correction in the Topex data. We showed that the amplitude of the 58.77-day oscillation was reduced to < 1 mm by simultaneously forcing consistency in the dry troposphere correction and applying the Topex center of gravity correction with the opposite sign to that recommended in the Topex handbook (Figure 9.1.23). Additional work is needed to fully investigate possible Topex-related artifacts that could be introducing artifacts into the ocean tide models.

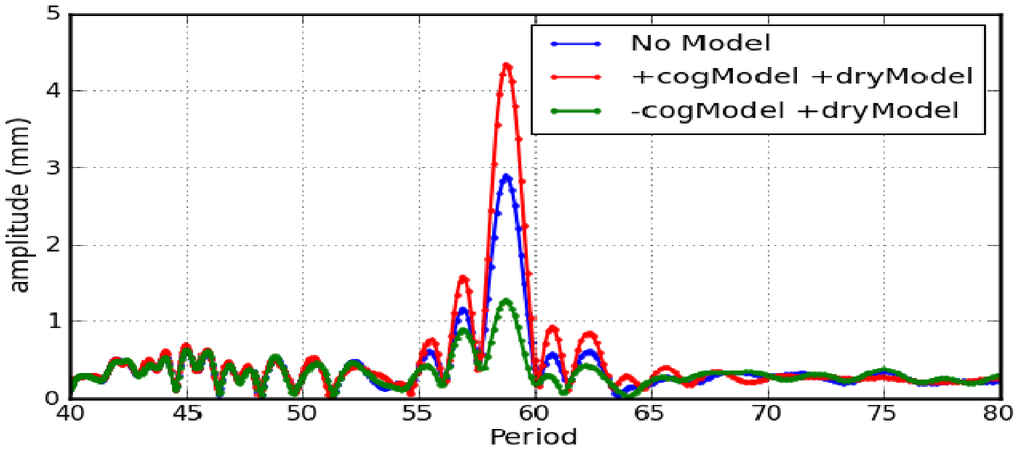


Figure 9.1.23. amplitude of the 58.77-day oscillation in the global sea surface height measurements from Jason-1 using different models.

Systematic differences in the center-of-origin realizations of Jason-1 and EnviSat, *Dettmering et al.*

A global calibration of all available altimeter missions has been performed by means of a multi-mission crossover analysis (MMXO). In addition to differences of the range bias of the missions, this method reveals information on geographically correlated errors as well as on center-of-origin offsets between the missions.

The investigation shows systematic differences in the realization of the center-of-origin between Jason and EnviSat, even if the latest reprocessed orbit solutions for both missions are used. For Jason-1 and EnviSat nearly the same standards for precise orbit determination are applied (GDR-C standard) and the EnviSat reprocessing solutions from CNES and ESA do not differ significantly. Nevertheless, the differences in the y-component (Figure 9.1.24) between Jason and EnviSat show a drift of about -2 mm/year and lead to temporal variations of geographically correlated errors and to differences in the mean sea level trend estimations from both missions.

The reasons for the differences are not fully understood yet. Probably they are due to orbit determination and caused by effects of the time variable gravity field (which is handled in the same way for both missions but may have different effects because of the different orbit heights of the satellites). This is under investigation.

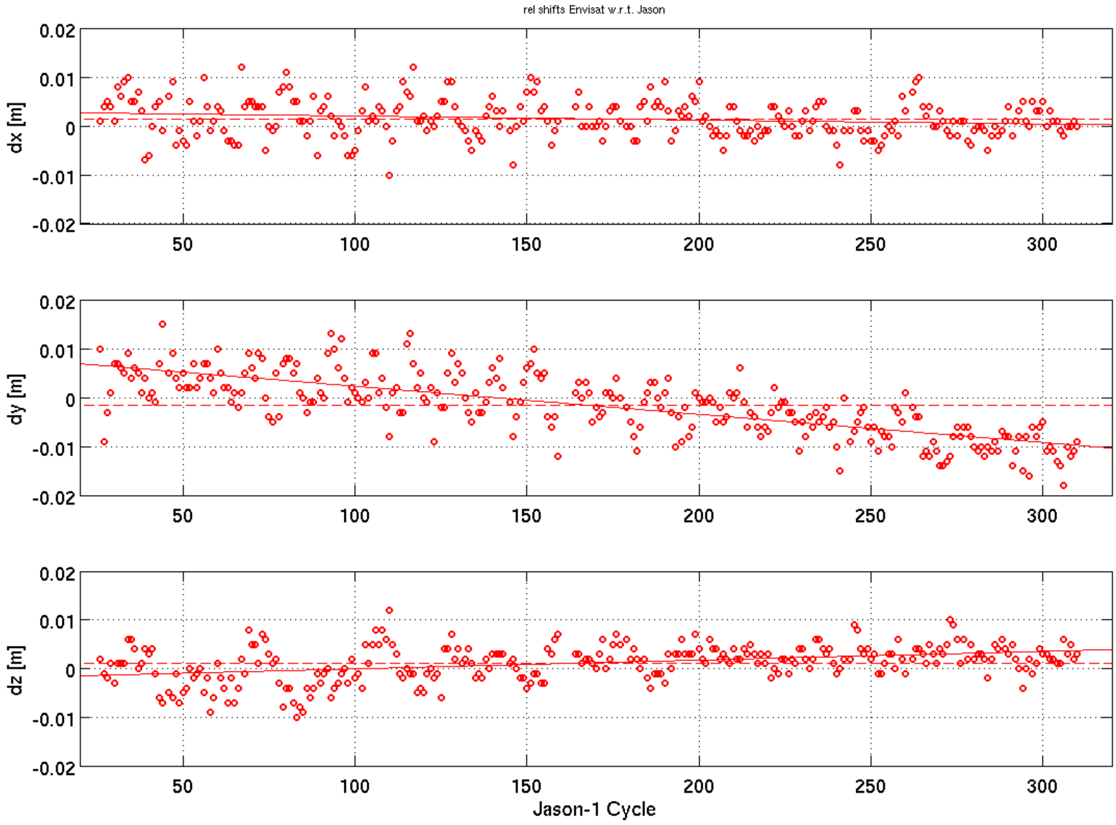


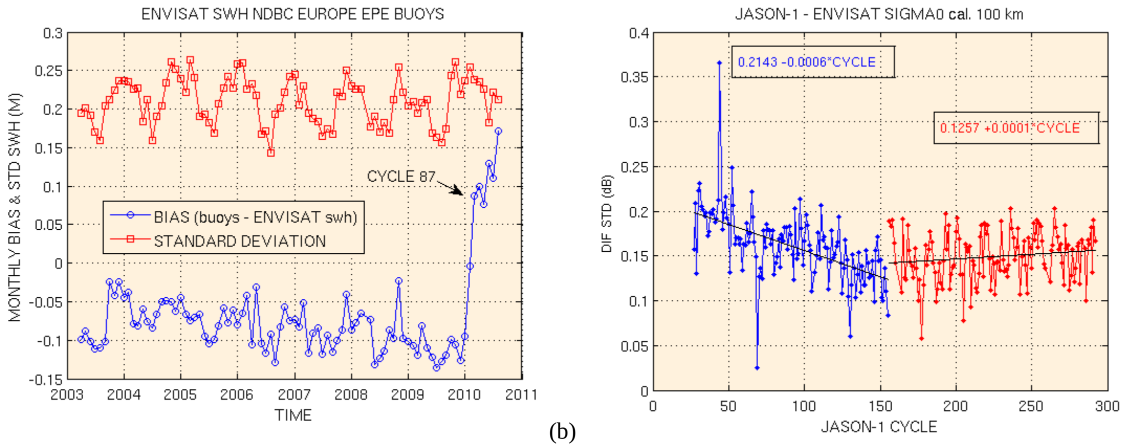
Figure 9.1.24. Relative center-of-origin shifts of EnviSat w.r.t. Jason-1. In the y-component of the earth fixed system a significant drift of about -2 mm/year is visible.

Validation status of a global altimeter wind & wave data base, *Queffeulou et al.*

The "*Laboratoire d'Océanographie Spatiale*" (LOS/IFREMER) develops an altimeter wind and wave data base consisting of homogeneously calibrated measurements from various altimeter missions, with unique format. Thus, the significant wave height (SWH) measurements have been monitored for several years, and corrected data are available. Recently, work has been extended to the altimeter wind speed retrievals.

Concerning SWH, the proposed corrections enable generation of homogeneous and well-calibrated SWH data from the all altimeter missions. An exception has been observed on EnviSat RA-2 SWH, which exhibits a change in the SWH bias (relative to buoy data), after cycle number 86 (Figure 9.1.25a). This change is linked to a ground processing update and the ongoing ground reprocessing will provide a consistent series of GDR products.

Cross-calibration of Ku-band sigma0 (backscatter coefficients) is difficult. Some changes in sigma0 as a function of time are not well understood, nor monitored. This is particularly the case for Jason-1 Ku-band sigma0, as shown by comparisons with buoy and QuickScat wind speed measurements, and by comparisons with EnviSat RA-2 Ku-band sigma0 (Figure 9.1.25b).



(a) (b)

Figure 9.1.25. (a) EnviSat SWH differences with Europe EPE buoys. (b). Jason-1 – EnviSat σ_0 differences time series.

<u>Analysis of the wind speed evolution over ocean derived from altimeter missions and models, *Ablain et al.*</u>

This study aims at analyzing and comparing wind speed evolution derived from altimeter missions and different models (ECMWF, ERA-interim, NECP reanalysis) over the entire altimeter period and over the ocean surface. We especially focused on Jason-1 and EnviSat altimetry missions, but we also performed comparison to other altimeter missions, such as TOPEX and ERS-2. Thanks to these cross-comparisons between the different models and missions, the main objective is to assess altimeter wind speed stability directly deduced from the Sigma-0 parameters.

The main results obtained highlight jumps or drift for all the altimeter wind speeds derived from Jason-1, EnviSat, TOPEX and ERS-2. For Jason-1 wind speed (Figure 9.1.26), a +10 $cm.s^{-1}$ ramp is detected from 2004 to 2005 by comparison with NCEP and ERA-interim wind speed. In the meantime, it is not observed on EnviSat and model wind speeds (Figure 9.1.27). This corresponds to a 0.025 dB sigma0 ramp, but the origin of this potential anomaly is unknown at the moment. It might be linked to the high mispointing values observed from 2004 onwards on Jason-1. For EnviSat (Figure 9.1.28) a ramp (-10 $cm.s^{-1}$) is also detected at the beginning of the period in 2003. Concerning TOPEX, we observed stronger oscillations and ramps close to 20 $cm.s^{-1}$ (Figure 9.1.29) impacting the global wind speed drift by 2.5 cm.s-1/yr.

Of course, such small jumps are inside sigma0 stability requirements but they impact the MSL accuracy through the SSB correction (especially concerning TOPEX) and also the wind speed calculation and long-term evolution for climate studies. Concerning the MSL, the impact is low but not negligible: the 10 $cm.s^{-1}$ jason-1 wind speed ramp in 2004/2005 corresponds to a +0.6 mm jump on the Jason-1 global MSL, and the +2.5 $cm.s^{-1}$/yr wind speed drift detect on TOPEX corresponds to a +0.15 mm/yr drift on the TOPEX global MSL.

Thanks to this study, we can also characterize the ocean wind speed evolution better: a positive global trend seems to be highlight from 1993 onwards close to +1 cm.s-1/yr within 0.5 cm.s-1/yr differences (+0.5 $cm.s^{-1}$/yr for ERA-interim, +0.9 $cm.s^{-1}$/yr for NCEP, +1.5 $cm.s^{-1}$/yr after correcting anomalies). But, local wind speed trends do not indicate the same spatial structures between altimetry and models together: +/- 5 $cm.s^{-1}$/yr wind speed differences Finally, given these differences between models and considering the wind speed evolution as an indicator of the climate change, it seems important to improve the long-term stability of altimeter wind speed and therefore the sigma0 parameter for climate studies.

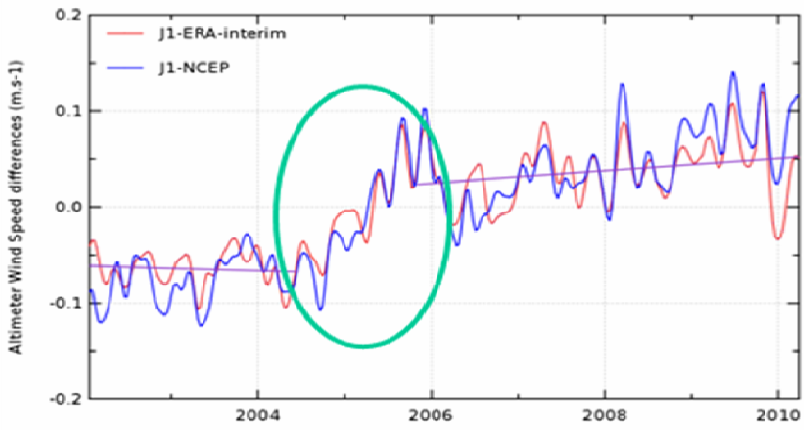


Figure 9.1.26. Long-term differences between wind speeds derived from Jason-1 and models (ERA-interim and NCEP)

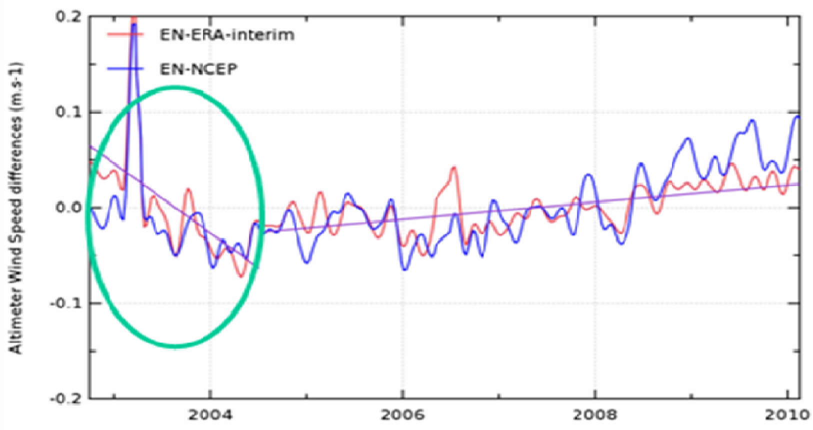


Figure 9.1.27. Long-term differences between wind speeds derived from EnviSat and models (ERA-interim and NCEP)

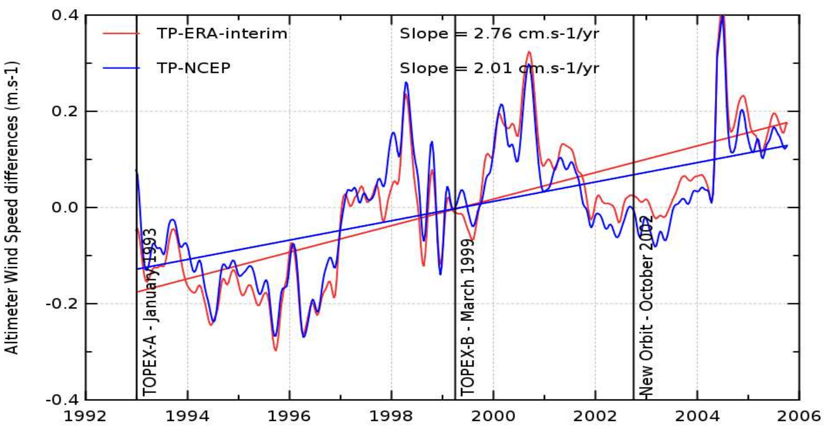


Figure 9.1.28. Long-term differences between wind speeds derived from TOPEX and models (ERA-interim and NCEP)

Summary of the global analyses key findings:

All speakers reported that Jason-2, Jason-1 and EnviSat missions have high data availability and quality, meeting mission scientific requirements. They also noticed that following EnviSat orbit change maneuvers, ERS-2 is once again becoming of interest. From November 2010, 4 altimetry missions (5 if we consider CryoSat) will be available.

However, they also reported the following concerns:

- Jason-1&2 orbit solutions from GDRs depict geographically correlated patterns of the order of 2 cm, « peak-to-peak », and a signal at 120 days on the crossover mean values.
    - Jason-2 JPL GPS-based orbit solution appears to have smallest geographically correlated errors.
    - JPL GPS orbit solution could be considered for additional orbit altitude field, at least for GDR (and perhaps IGDR?) products.
- Jason-1 and EnviSat underline East/West discrepancies that increased in time. Cross comparison between those missions is a key for long-term studies.
- Growing interest in wind speeds measured by altimeter missions for climate studies.
    - Increased effort to monitor stability of wind speeds.
    - Define reference for sigma0, and use identical algorithms for wind speed computation.
    - Jason-1 pointing stability has an impact on the wind speed long-term drift.
- Long term stability of radiometer wet troposphere correction should be insured with more precision.

9.1.4 Conclusions

The calibration and validation of the Jason-2 GDR data show that all the missions meet the requirements. However, some discrepancies have been highlighted, in terms of mean geographically correlated errors or mean sea level trend, and need to be further investigated. Moreover, the need for improved long-term wind speed time series for climate studies highlighted that this quantity should be more carefully calibrated and validated with homogeneous standards for the different missions. The long-term stability of on-board radiometers continues to be a key issue for high accuracy altimetry.

The origin of the relative range bias between Jason-1 and Jason-2 (~85 mm) has been discovered recently and presented at the Seattle OSTST (see "Summary of the in situ analysis key findings" in section 9.1.2): it comes from an error in some parameterization files on Jason-1 and Jason-2 discovered by the project. Correcting these errors will increase the absolute Jason-1 bias from 85 mm to 205 mm and that of Jason-2 from 170 mm to 195 mm (see Table below). This needs further investigation (notably on the C band) but, if confirmed, both satellites are measuring sea surface consistently; within 1 cm of each other. Both are about 20 cm higher than T/P. The biases to be applied to both Jason-1 and Jason-2 will not be included in the current products (GDR-C and GDR-T respectively for Jason-1 and Jason-2) to maintain continuity. **So for the moment, Jason-1 will be maintained with its 85 mm bias with respect to T/P, and Jason-2 with its 170 mm bias.** However, the reprocessed Jason-2 products (GDR-C : to be issued in mid 2011) will be corrected for the 25 mm bias found (sea level will increase by 25 mm). CNES has ongoing work analysing the root cause of the 195 mm Jason-2 absolute bias with respect to Topex MSL. If this absolute bias can be explained before the Jason-2 GDR_C implementation, it will be corrected as part of this reprocessing. The absolute bias values used in the different versions of the Jason-2 and Jason-1 products will be communicated to the OSTST and to the end users before the reprocessing starts. Concerning the Jason-1 bias, the 120 mm correction will be applied to the next generation of the products (GDR-D).

Satellite	**GDR Release**	**Absolute bias included in GDR release**	**Additional bias to be applied by user to GDR release**	**Total absolute bias**
Jason-1	GDR-C	85 mm	120 mm	205 mm
Jason-2	GDR-T	170 mm	25 mm	195 mm
Jason-2[*]	*GDR-C*	*195 mm*	*0 mm*	*195 mm*

[*]future release (mid 2011)

The Jason-2 orbit comparisons between CNES and JPL or GSFC solutions show minor differences which are under investigation, and the EnviSat/Jason-1 geographically correlated signals emphasize the importance of having good communication between the CalVal and POD communities for all missions.

There were very limited discussions regarding the possible change of orbit for Jason-1 End of Life during the CalVal splinter and the 1mm/yr drift accuracy. Those topics were widely addressed as part of other splinter meetings. All the discussions about the possible change of orbits for Jason-CS have concluded with a recommendation to keep the current reference orbit. Among the different arguments the following points were raised:

- T/P – Jason-1 as well as Jason-2 – Jason-1 comparisons during the Formation Flight Phase: There is very strong benefit of these phases to link 2 different missions. Not clear that CalVal will ensure this without such overlap.
- Possible degradation on a new ground track (even if there is a strong debate ...)
- The dedicated calibration sites have accumulated up to 18 years of continuous monitoring. Is there an orbit that will overfly all of them?…

9.2 Instrument Processing

Chairs: Emilie Bronner, Shannon Brown, Phil Callahan

➔ **Sea State Bias**

- There is **no SSB difference between Jason-2 and Jason-1** when these solutions are derived from homogeneous data and in similar ways. This is not the case today between TOPEX-A and TOPEX-B.
- It is recommended **to derive Jason-2 wind from MLE-3 sigma0 instead of MLE4** value to get better estimates **and recalculate the SSB model.** (See comments below.)

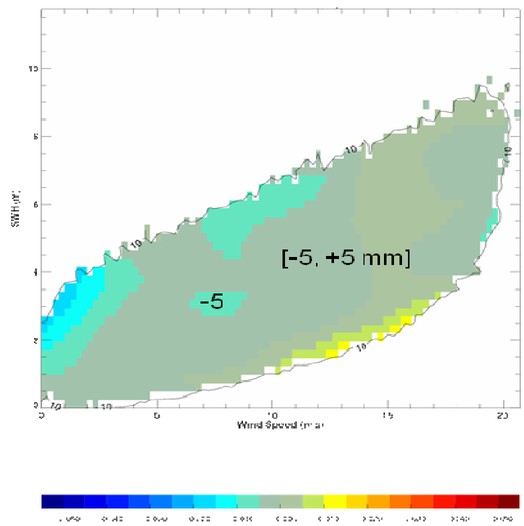


Figure 9.2.1 Difference between Jason-2 and Jason-1 SSB derived using the same estimation approach, the same data version and a similar wind speed histogram. Jason-2 uses MLE4.

- There is an alternate **spline method for SSB fitting** that is less sensitive to data weighting than the current non-parametric method and can be used for higher dimensional models.

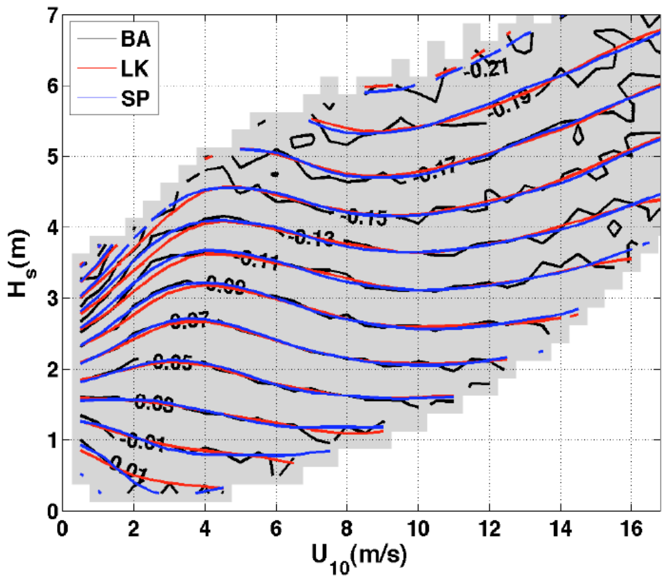


Figure 9.2.2 SSB spline nonparametric model using Jason-1 & WAVEWATCH data from 2002. Shown are the Local linear kernel (LK) and the spline method (SP) run on same yearlong data sets and compared to the high resolution bin average response.

- Investigations about **wave-model-enhanced SSB models** show improvement, and steps towards future GDR implementation are being taken.

➔ **Sigma0 and wind speed**

- For wind and SSB it has been decided during the OSTST meeting to think about the question in a working group (Doug Vandemark, Ngan Tran, etc.) to choose the best wind and SSB solutions before J2 GDR-C reprocessing (wind speed using sigma-0 MLE3, which SSB solution?, etc). The expert working group should give an answer.
- Concerning wind speed, it is important to provide users with the sigma-0 used to calculate it because they generally recomputed the wind speed themselves.
- Mixing information coming from MLE3 and MLE4 in SSB could be strange for some users but the aim is only to find the best parameter estimation.
- We should investigate alternative methods to MLE3 to estimate sigma0. For example, an alternative approach has been implemented for rain flag calculation.

➔ **Wet Troposphere**

- Objective-analysis can provide a wet tropospheric correction for altimeter missions without a dedicated radiometer that is better than a model alone, but not better than a dedicated radiometer

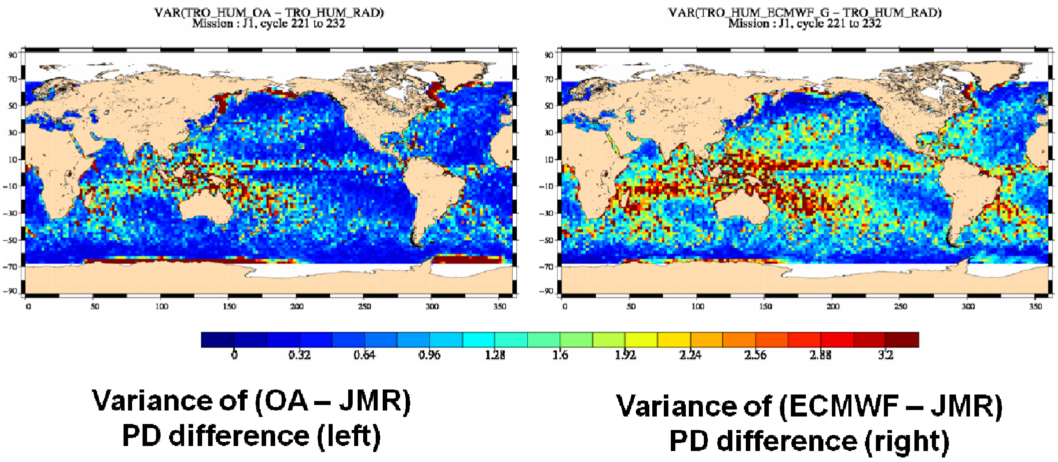


Figure 9.2.3 Wet path delay variance between the objective analysis solution and the JMR path delay (left) and the variance between the model and the JMR. The OA solution has a lower variance than the model.

- Inter-sensor calibration between AMR and AMSU radiometers showed good results for 23.8 GHz inter-calibration, indicating a negative trend in the AMR 23.8 GHz TBs and also in the 34 GHz TBs.
- Specific cases highlight the weakness of the on-orbit calibration approach needed to stabilize the radiometer PD on long time scales. Inconsistency in model inter-

comparisons and the potential for geophysical signals to alias into the record were shown.

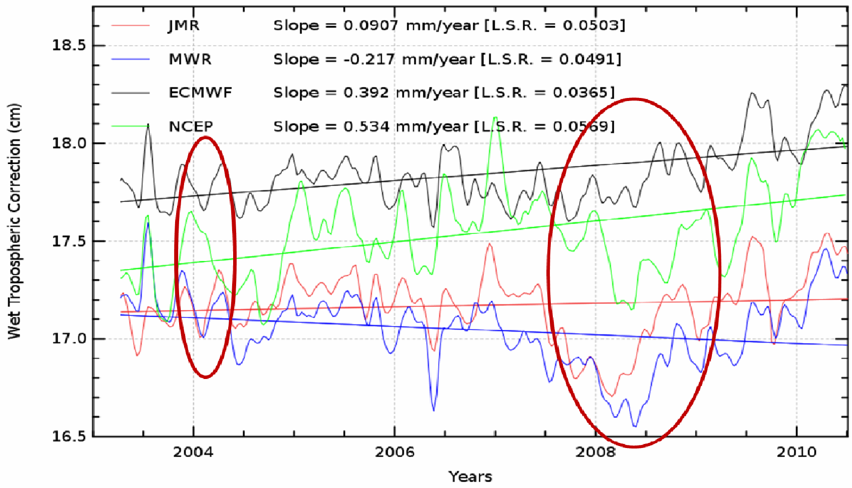


Figure 9.2.4. Time series of wet path delay from JMR, Envisat MWR, ECMWF and NCEP. This plot illustrates the weaknesses of models to represent the inter-annual variability of path delay and climatic events, like the 2008 drying associated with La Nina. Use of the model alone would alias these climate signals into the SSH record.

- For long-term stability, it is important to intercompare all possible radiometers (on-board altimeter satellites and others).
- **Analysis of AMR calibration stability:** Residual drift in GDR product estimated to be -1mm/yr which is removed in new GDR-C calibration. ARCS processing successfully reduced drift on GDR product from 3mm/yr to 1mm/yr.

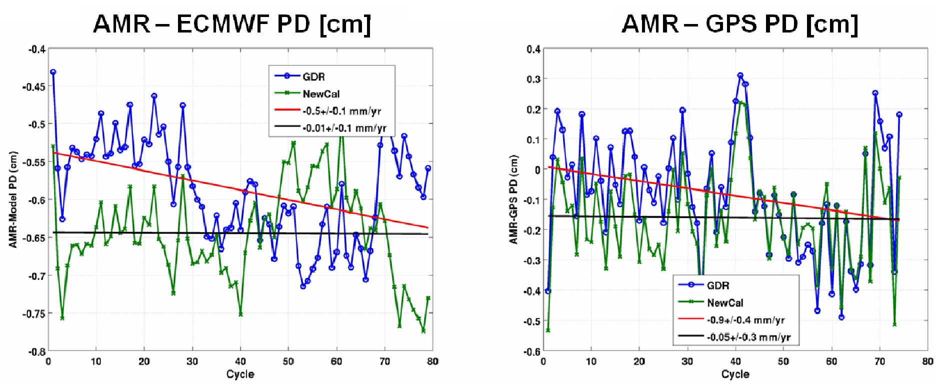


Figure 9.2.5 Cycle averaged AMR-Model (left) and AMR-GPS (right) wet path delay differences for GDR-T (blue) and for GDR-C (green). A residual -1mm/yr PD drift exists in GDR-T which is removed with the updated radiometer calibration.

- The new radiometer algorithms proposed by JPL (Shannon Brown) would be useful and applicable to other altimeters. Discussions are on going to derive these algorithms for ENVISAT and SARAL to have good data closer to the coast.

➔ Jason DIODE/DEM Mode

- Performance was re-evaluated on cycle 34 after new DEM upload. Performance is excellent in most cases, but careful validation of DEM is recommended.
- On Jason-2, the DIODE/DEM mode is a demonstrator but studies have shown that it has the same performance than median mode on ocean; it acquires more waveforms near coasts (not always exploitable). It has proven better performance on specific areas such as embanked lakes. In conclusion, the median and DIODE/DEM modes have both a regional interest that is why it impossible to evaluate one better than the other at global scale.

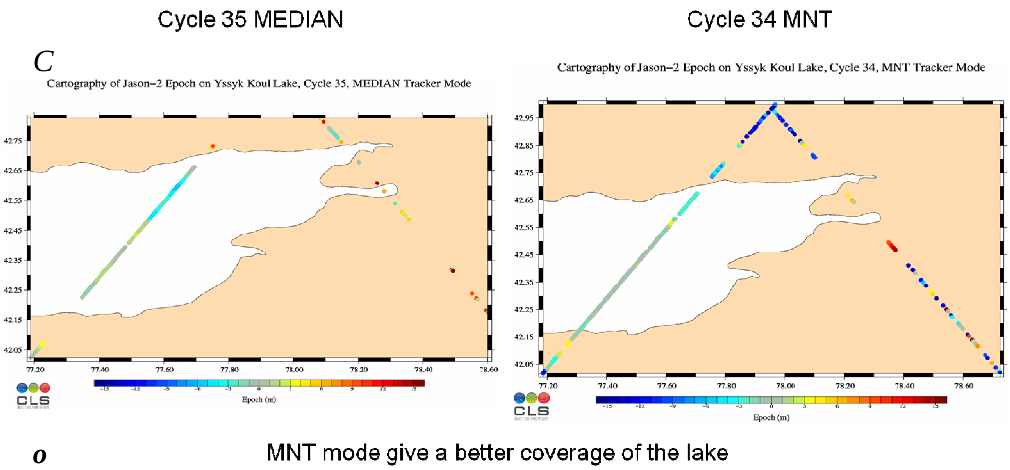


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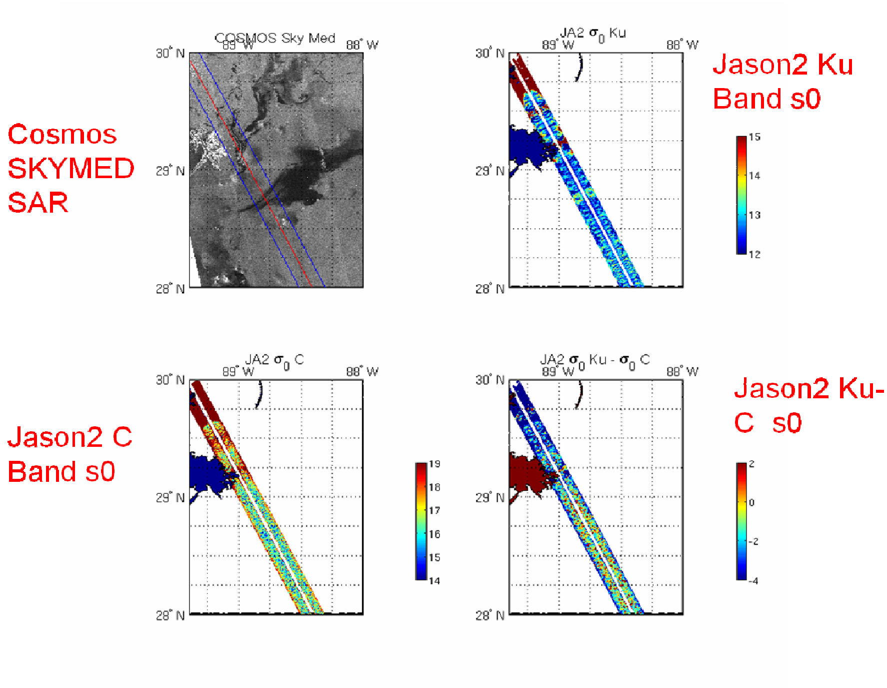
Figure 9.2.6 Median tracker and the diode DEM tracker over a lake. The Diode DEM tracker has better performance near the lake.

- On Jason-2 MSEs level in Lisbon, the DIODE/DEM mode seems very interesting to follow the Amazon River. Moreover, it has been decided to switch in DIODE/DEM mode (using time-tagged TC) on Andean and Tibetan lakes.
- It was suggested to test the DIODE/DEM mode each 2 Jason-2 cycles during one year. It would provide some interesting data, but with the current DEM model on-board J2, we will degrade hydrological performance in some areas.
- Efforts should be pursued to improve the Jason-2 DEM model (using experience of AltiKa DEM) and about the zones of interest for the DIODE/DEM mode.



- Concerning Jason-3, the DIODE/DEM mode will be used. The constraint is still 1MB to store the DEM but efforts will be pursued to upload a precise DEM where the median is known to be less efficient. POSEIDON3B will be designed to switch between the 2 modes automatically.

➔ Other Topics and further discussion

- **SWOT Simulation:** Two presentations on detailed simulators were given. The simulators will allow estimation of performance and will be useful for instrument trade studies.
- A new application to **transform waveforms into surface images** was presented. It provided interesting images of the Gulf oil slick.

Figure 9.2.7 Retrieved surface backscatter image over the 2010 Gulf Oil Spill. Note, the images have a left/right ambiguity.

- **A Bayesian retracking algorithm** was presented. It provides better performance for noise reduction, but currently requires a great deal of processing time.
- N**ew techniques such as SVD** (single value decomposition) should not be forgotten because they present a great interest for J2 and Sentinel-3 (studies are on-going).
- **TOPEX reprocessing** was not discussed during the OSTST meeting, but it was discussed at a separate meeting in Toulouse. A plan for JPL to investigate the 59-day variations in TOPEX data and to revisit the TOPEX retracking was made.

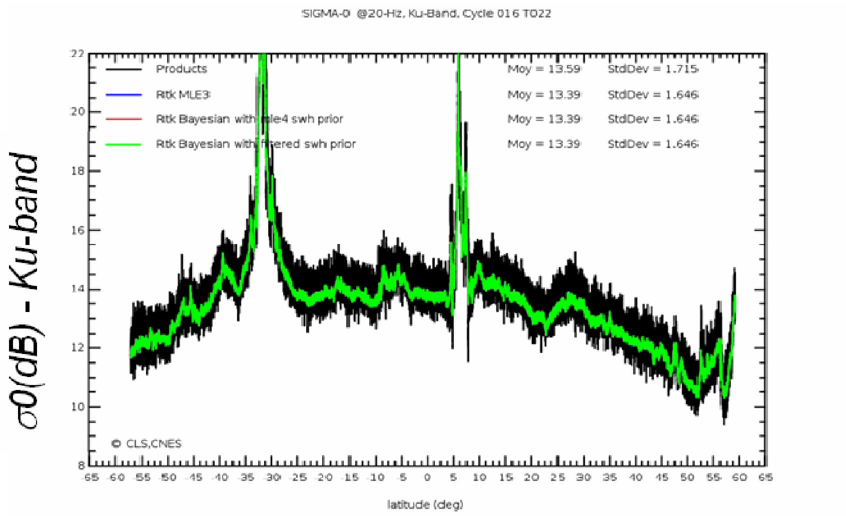


Figure 9.2.8 Comparison of sigma0 using the standard processing and the new baysian algorithm (green line). The strong noise reduction is evident for the baysian algorithm.

Splinter session recommendations

- Since Jason-1 Jason-2 are now very similar in SSB and bias, they should be treated the same in terms of retracking, SSB, etc.
- To maintain measurement system calibration to highest level (< ~ 1 mm/yr) it is important that instrument, algorithm, and cal/val teams be in close communication
- On-orbit radiometer calibration techniques have limitations. Instrument stability for future missions (e.g. Jason-CS) should not rely on on-ground processing but should be provided by instrument design

9.3 Precise Orbit Determination

Chairs : Luca Cerri & Frank Lemoine

Status of Jason-2 GDR orbits

The Jason-2 GDR orbit has been compared to solutions obtained using either different models, or different combinations of tracking data or different parameterization techniques. The result of this comparison in terms of radial RMS per cycle is shown in figure 9.3.1, indicating an agreement at the 1-cm level for all solutions. In particular, the RMS of the radial orbit difference with respect to reference reduced-dynamic solutions from JPL (JPL10A) and GSFC (GSFC LD RED STD1007) is generally below 1 cm. A similar radial accuracy is indicated by the RMS of high elevation SLR residuals computed using a reference network of stations (figure 9.3.2).

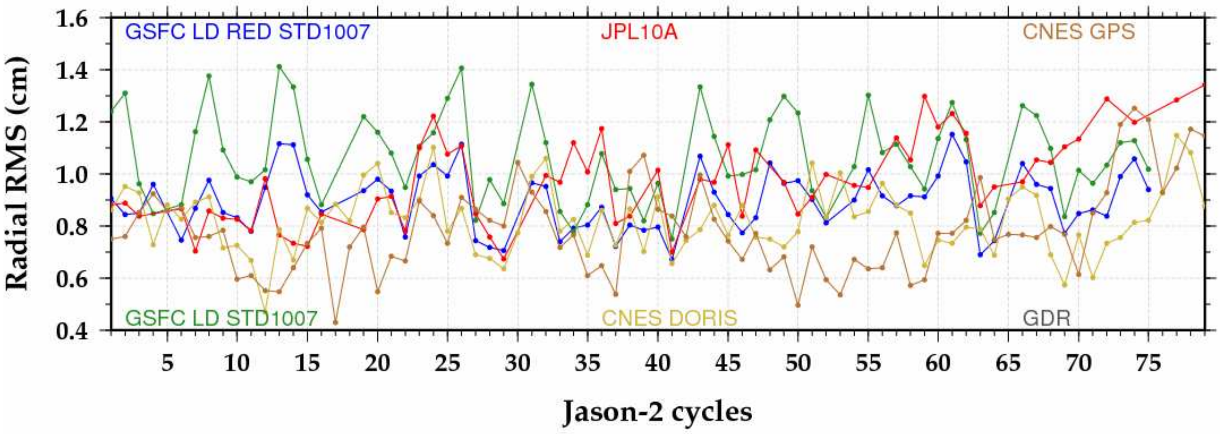


Figure 9.3.1 Radial RMS per cycle of various JASON-2 orbit solution with respect to GDR orbit, which is a DORIS+SLR+GPS orbit using a dynamic parameterization. GSFC LD STD1007 is a DORIS+SLR dynamic orbit, while GSFC LD RED STD1007 is a reduced dynamic solution sharing identical models as its dynamic counterpart. JPL10A is GPS-only reduced dynamic orbit. CNES GPS and CNES DORIS are respectively GPS-only and DORIS-only dynamic solutions sharing the same force models of the GDR orbit (from Couhert et al.).

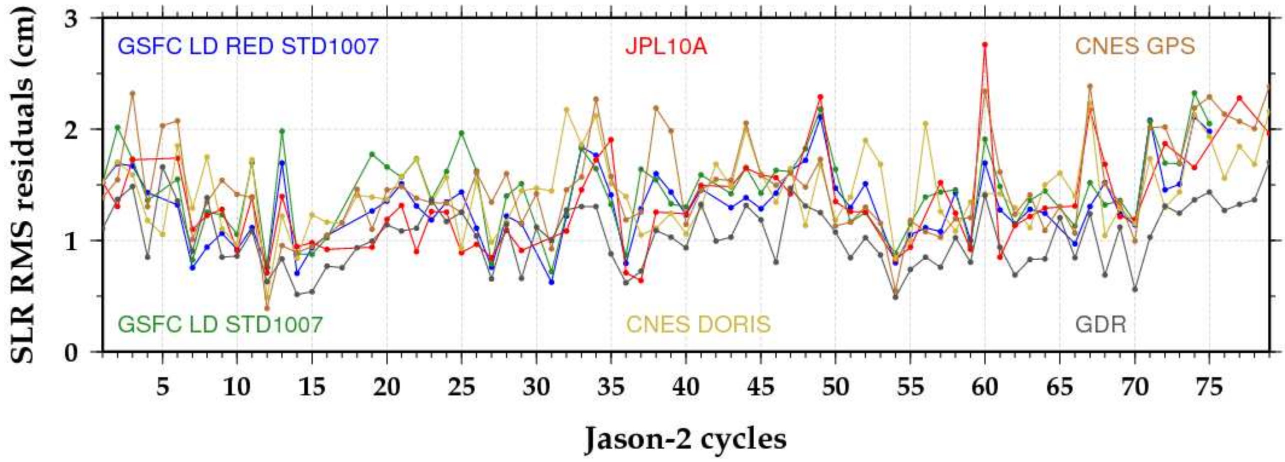


Figure 9.3.2 RMS of SLR residuals above 70 degrees elevation on reference network per cycle for different orbit solutions (from Couhert et al.).

Although orbit solutions from different groups remain close in terms of RMS, the radial orbit differences are characterized by a temporal and spatial coherence which is of interest for the altimeter data analysts. In particular, the following systematic errors have been observed

- a geographically correlated signal at 120-day period, mainly affecting the comparison between GSFC D+L Dynamic orbits and other orbits (figure 9.3.3). This type of signature is typical of solar radiation pressure modeling differences, and is reflected in the 60-day variation of the radial RMS shown in figure 9.3.1. It is significantly reduced when the GSFC D+L reduced-dynamic orbit is considered instead of its dynamic counterpart, suggesting that the Jason-2 solar radiation pressure model used in GSFC solution can probably be improved.

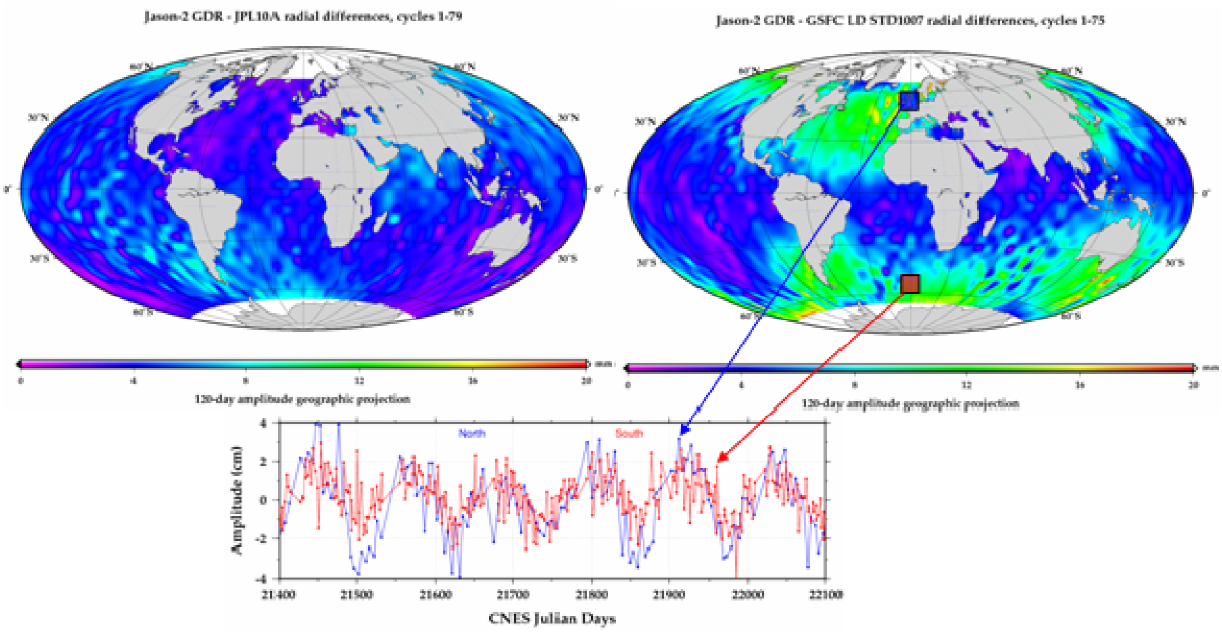


Figure 9.3.3 (from Couhert et al.) Amplitude of the 120-day signal in the radial orbit differences between Jason2 GDR orbit and other solutions. The amplitude of the signal reaches 1.5 cm at high and low latitude in the comparison with respect to GSFC dynamic orbit. This signal is greatly reduced when comparing GDR orbit to reduced dynamic solutions (from either JPL or GSFC).

Instead of directly looking at the orbit differences, an alternative measure of the radial orbit error is observed by means of multi-mission altimeter crossover analysis (Dettmering & Bosch). When the observed radial error for GDR and GSFC orbits is represented by a displacement of the orbit centre in the Earth-fixed reference frame, the equatorial Tx,Ty components of such displacement oscillate with a 120-day period and an amplitude higher in GSFC orbit (figure 9.3.4.).

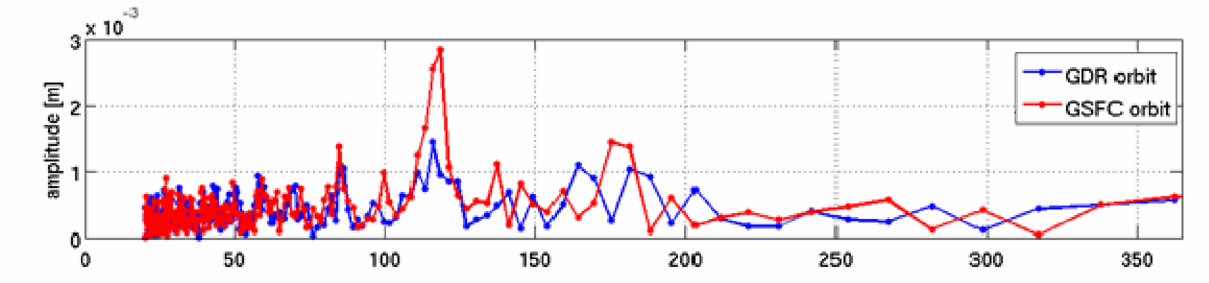


Figure 9.3.4 (from Dettmering & Bosch) Spectral analysis of the TY component of the radial orbit error estimated from the multi-mission crossover analysis (units are abscissa shows period in day). Although this plot has been obtained with Jason-1 orbits, a similar result is obtained with Jason-2.

- a geographically correlated signal at annual period, between reduced dynamic solutions from JPL and other orbits (figure 9.3.5). As this is an order-1 type of signature, a possible explanation is that GPS-based reduced dynamic orbit are able to capture part of the gravity field temporal variability which is not included in the current GDR and GSFC standards.

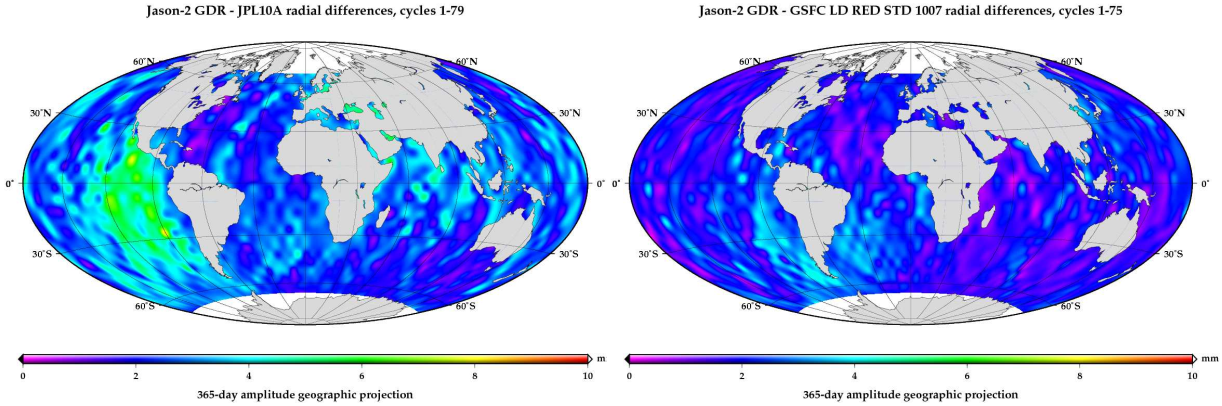


Figure 9.3.5 (from Couhert et al.) Amplitude of the annual signal in the radial orbit differences between Jason2 GDR orbit and other solutions. The amplitude reaches 6 mm with an order-1 pattern in the comparison with respect JPL GPS-based reduced dynamic orbit.

- it was noted that the radial orbit differences of the latest release of JPL orbits increases with respect to other solutions (figure 9.3.1). As shown in figure 9.3.6, there seems to be a correlation between the degradation observed on JPL orbit and the GPS receiver software change occurred on Dec. 16, 2009. However the reason for this degradation is still being investigated by the JPL team. No conclusive sign of degradation could be observed on GDR orbit, which includes GPS data (as well as DORIS and SLR).

Station	Before Dec '09 Mean(cm)	After Mean(cm)	Cycles 1-79 Mean(cm)	Before Dec '09 Sigma(cm)	After Sigma(cm)	Cycles 1-79 Sigma(cm)
Monument	0.37	1.91	0.81	1.17	0.90	0.90
Yaragadee	1.03	1.00	0.75	0.66	1.15	0.77
Graz	-1.33	-1.12	-1.06	0.76	1.07	0.81
McDonald	0.49	-0.15	0.37	0.77	1.15	1.12
ALL WEIGHTED	0.38	0.51	0.31	0.72	1.16	0.83
	ALL GDRC, includes SLR:			0.68	0.75	0.74

SLR Data is not used in POD for JPL RLSE10a

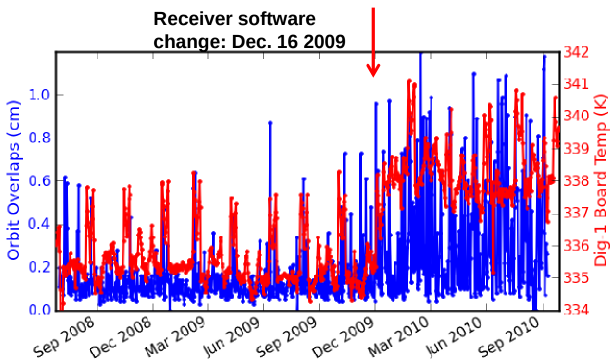


Figure 9.3.6 (from Bertiger et al.) Left: SLR residuals on reference stations before and after Dec. 2009. Right plot: the increase in the orbit overlap radial RMS seems correlated with the receiver software change occurred in Dec. 2009.

ITRF 2008

The latest release of the ITRF has been extensively tested in order assess the impact on the Jason and TOPEX orbit series, indicating a small but significant improvement in the fit of SLR and

DORIS data, and in the overall orbit quality as indicated by a smaller RMS of the altimeter crossover residuals (figure 9.3.7).

The most significant impact on the orbit geometry is a shift towards the north of less than 5 mm, as shown in figure 9.3.8. This reduces the mean N/S difference of DORIS+SLR orbit with respect to GPS only orbits.

Evaluate ITRF2008 SLR/DORIS orbit performance for TP, J1, J2 [1]				
Mission	dynamic orbit test	average RMS tracking data residuals		
		DORIS (mm/s)	SLR (cm)	Crossover (cm) (independent)
TP cycles 1-446 xover: 30 cycles	std0905 (itrf2005)	0.4989	1.751	5.482
	std1007 (itrf2008)	0.4985	1.663	5.477
J1 cycles 1-259	std0905 (itrf2005)	0.3857	1.076	5.460
	std1007 (itrf2008)	0.3851	1.055	5.457
J2 cycles 1-75 xover cycles 1-52	std0905 (itrf2005)	0.3618	1.095	5.564
	std1007 (itrf2008)	0.3609	1.032	5.550

1) 1.5 cm radial accuracies have been achieved with the dynamic TP std0905 (itrf2005) orbits (Lemoine et al. 2010 , ASR, Towards development of a consistent orbit series for TOPEX, Jason-1, and Jason-2)

Figure 9.3.7 (Zelensky et al.) Improvement in the RMS of SLR and DORIS post-fit residuals and in the RMS of altimeter crossover residuals.

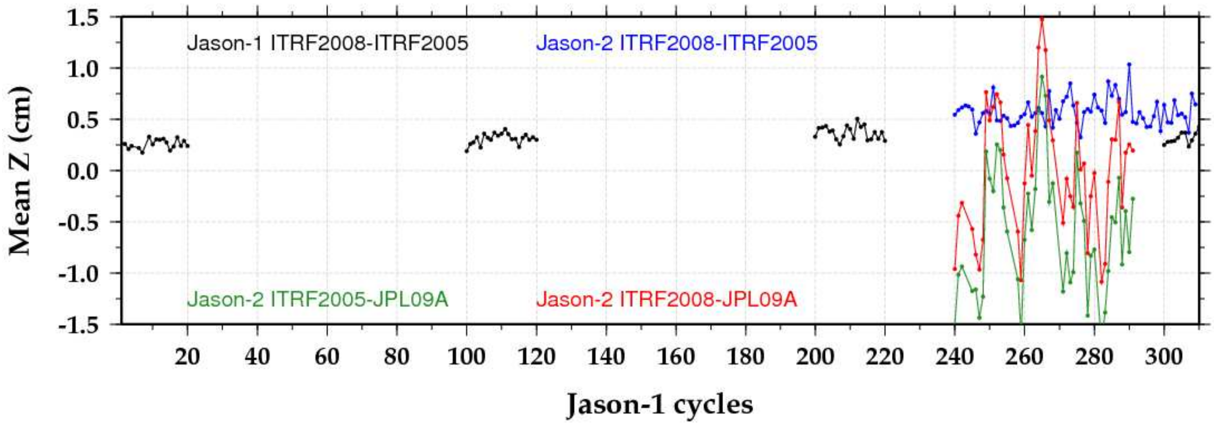


Figure 9.3.8 (Couhert at al.) Mean displacement along the north/south direction (Tz) of ITRF2008 DORIS+SLR orbits with respect to ITRF2005 orbits.

The drift along the North/South direction, which has an impact on the global mean sea level estimate due to the asymmetry of ratio between ocean and continental surfaces in the northern and southern hemispheres, is small (figure 9.3.8 and 9.3.9).

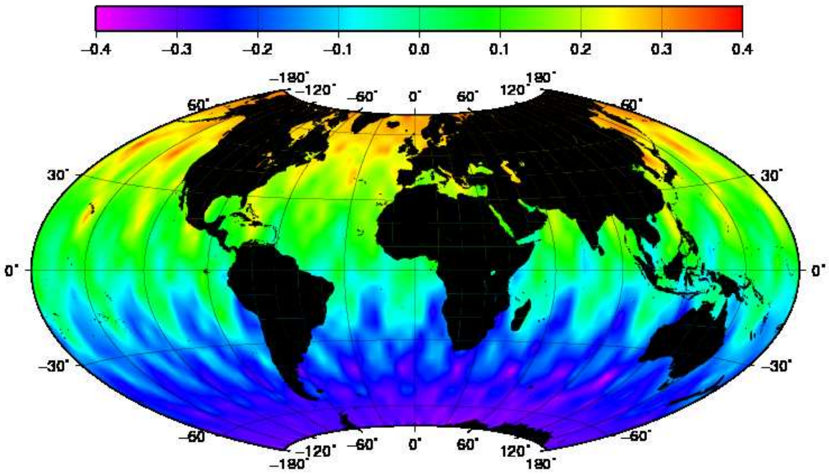


Figure 9.3.9 (Zelensky et al.) Estimated trends of radial orbit differences between ITRF2008 and ITRF2005 Topex orbits. Units are mm/year. The global radial orbit change over oceans is 0.06 mm/yr.

This is consistent with the fact that nominally there is no global drift along the N/S direction between ITRF2008 and ITRF2005 coordinates. The mean radial drift over water has been estimated by Zelensky et al. to be 0.06 mm/yr from the comparison between ITRF2005 and ITRF2008 DORIS+SLR TOPEX orbits the 1992-2004 interval.

Conclusion and prospects

All tracking systems on Jason-2 are operating at comparable levels of precision and support 1-cm radial precise orbit determination. The Jason-2 DORIS Ultrastable Oscillator (USO) is stable and shows no sensitivity to passage through the SAA (South Atlantic Anomaly) like the DORIS USO on Jason-1. The SLR tracking on Jason-2 is robust with the caveat that the bulk of the high-quality tracking is provided by a core network of 10-12 stations, and the performance of these stations must be monitored closely. A decrease in the accuracy of the JPl GPS-only orbits that seems correlated with a receiver software change is currently being investigated. A longer-term issue remains the fact that the GPS/Jason-2 antenna was not radiation hardened, and that there is the possibility like on Jason-1 that in the future this might affect the Jason2 GPS performance.

The Jason-2 GDR orbit accuracy is at the 1-cm level as shown by the comparison between different solutions and by the fit of high elevation SLR residuals. Systematic errors remain present in the various orbit differences, the most notable of which have a variability at 120-day period (comparison of all orbits to GSFC D+L dynamic orbits) and at annual period (comparison of all orbits to JPL GPS reduced dynamic orbits).

The recently released ITRF2008 has been tested and it was shown that it slightly improves the orbit accuracy and the consistency in terms of North/South centering between orbits obtained using different tracking techniques. The impact on the mean sea level estimates remains well below 0.1 mm/year. ITRF2008 will be part of the next POD standard update together with the latest generation of GRACE-based gravity fields, whose impact has been discussed at the 2009 OSTST POD splinter session.

A small fraction of the splinter was dedicated to assess the status of the short-latency orbit products. In particular, it was shown (Jayles et al.) that the on-board real-time Jason-2 DORIS orbit is now at less than 5 cm RMS with respect to the final POE orbit included in the GDR product; in addition, short-latency ground MOE orbits have been routinely produced for test purpose over a period of about 3 months, using the DORIS data flow available every 2 hours. The radial accuracy of this orbit is equivalent to that of the standard MOE used in the IGDR product, but with a delay compatible with the OGDR processing needs (Houry et al., poster). For recent progress concerning the Jason-2 GPS-based rapid orbits, refer to the Near Real-Time Product Validation and Application summary report.

Future issues that are of concern and/or will be studied by the POD team include the following:

1. **Jason-2 radiation pressure modeling improvement**: Although the reduced-dynamic approach can mitigate these errors, some efforts need to be made to improve these models for Jason-2 since this remains the largest source of radial orbit difference between different POD solutions.

2. DORIS station coordinate improvement: Although ITRF2008 is a notable improvement over ITRF2005, there remain individual issues for the newest stations with a short (or non-existant) time history in ITRF2008. In addition some of the coordinates and velocities of the South American DORIS stations may have been contaminated by the use of data from the SPOT-5 satellite whose DORIS USO might have been perturbed by passage through the South Atlantic Anomaly (SAA) like on Jason-1. Pascal Willis (IGN, IPGP) is leading an effort to develop refinements of ITRF2008 for POD applications.

3. **SLR system performance:** Since we rely mostly on a core network of 10-12 station to provide the bulk of the SLR data, we must monitor carefully the station performance for unexpected changes that might occur to equipment breakdowns at the stations, or due to changes in system configurations.

4. **Intertechnique orbit consistency in Z:** We shown that the radial orbit agreement between the different sets of orbits is close to 1 cm radial RMS, however we must monitor these different orbits (SLR/DORIS/GPS, SLR/DORIS, DORIS-only, GPS-only) for any long-term drifts in the Z-centering that could be indicate of reference system error.

5. **Improvements to Time-variable gravity modeling:** The secular rates of the geopotential coefficients in the current GDR standards wre determined over a short time span, and may not be reflective of all the variations (secular, interannual, annual) that occur. More detailed models have become available that would better handle these sorts of geopotential variations and their use will be investigated for application in the next set of GDR standards.

6. **IERS2010**: The IERS has published the next revision of the geodetic modeling standards, IERS2010. Improvements to geodetic modeling are advocated in a number of areas, such as troposphere refraction delay, second-order ionosphere effects, S1/S2 atmospheric tidal loading and other areas. The POD team will evaluate these suggested model changes for ease of implementation and applicability to Jason-1 and Jason-2 POD.

9.4 Geoid and Mean Sea Surface Products and impact on SLA

Chairs : Ole Andersen and Yannice Faugere

This splinter on **Geoid and Mean Sea Surface Product and impact on SLA had a total of** 5 presentations with 3 main subjects

Two presentations devoted to the presentation of 2 new Mean Sea Surface.

Two presentations were devoted to presentation of geoid and Mean dynamic Topography results.

One presentation reported on the Potential improvement of geoid/MSS using a geodetic mission – related to J1 end of life

New Mean Sea Surfaces

The two MSS presentations introduced the two new MSS which have been released this year: CNES_CLS10 and DTU10. Dramatic improvements are evident in the new MSS modelling, notably

- Extended temporal coverage
- Resolution refinement for both MSS
- Ocean variability: it is important to remove properly the ocean variability (noise for MSS) for geodetic data but also for mean profiles: extensive work has been performed in CLSCNES10 to optimally remove the ocean variability
- Strong improvement near the coast and in polar regions. DTU10 uses ERS-1 retracked data and Icesat data to improve these regions and the DTU10 covers the entire Arctic Ocean.

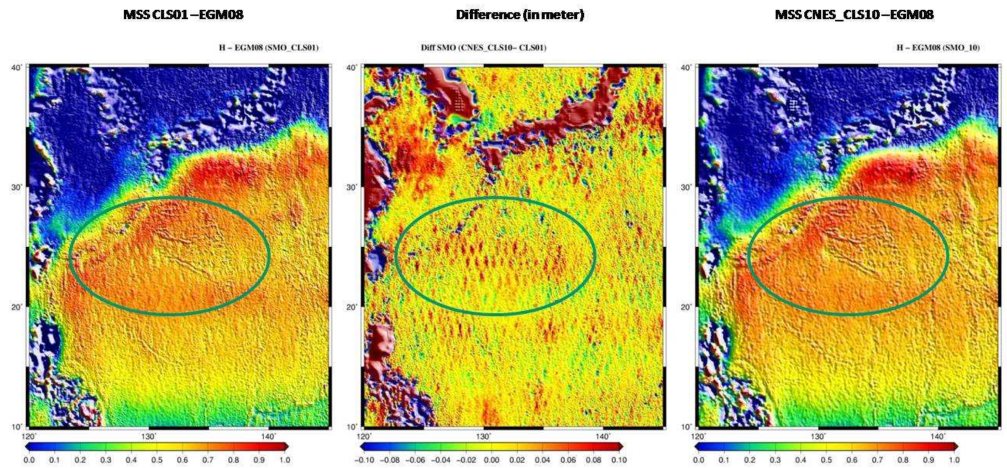


Figure 9.4.1: CLS01 (left), difference CLS01-CLS10 (middle) and CLS10 left.

The intercomparison between the two MSS demonstrated that collaborations should continue between the MSS development teams in order to help us characterize the MSS error. There are good perspectives for MSS improvement in the coming year, with the upcoming missions with geodetic or slowly-evolving groundtracks (CRYOSAT, HY2). In the session discussions, the importance of the choice of a geodetic J1-EOL track was stressed for MSS applications.

New Mean Dynamic Topography Products

Exciting improvements to Mean Dynamic Topography was obtained using the preliminary GOCE geoids and was presented in two presentations. Three GOCE solutions based on 71 days of data have been released, based on different methodology.

- Quantitative assessment of direct MDT (MSS-Geoid) is obtained with GOCE data
- Expecting the next release of GOCE for further results

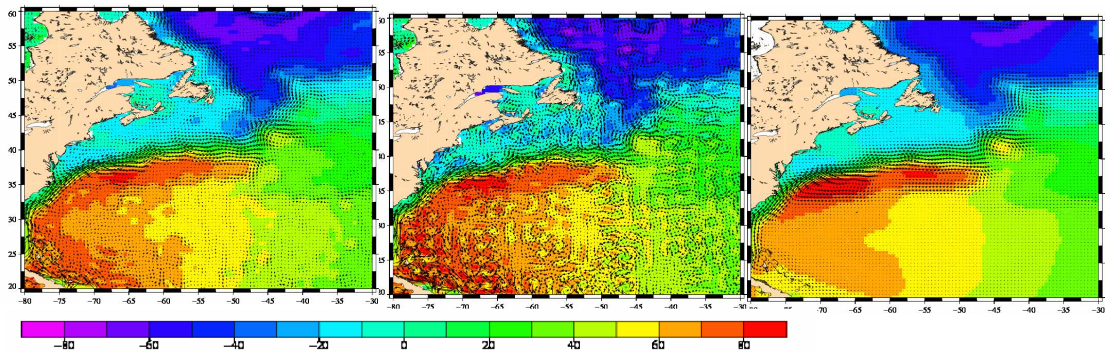


Figure 9.4.2: MDT derived using GOCE geoid (left), GRACE geoid (middle) and CNES/CLS09 MDT (right) for the Gulf Stream.

The final presentations related to the potential improvement of geoid/MSS using a geodetic mission – related to the End of Life discussion of J1. Some points raised were:

- Big interest for a Jason-1 geodetic mission. For both MSS and geoid improvement and also from other communities (like biology)
- J1's inclination is fundamental for improving the geoid modeling, because of the increased angle of the tracks near the equator (Cryosat's inclination is 98°).
- 1 year of Jason-1 GM would improve MSS + Geoid determination and possible uncover > 50000 unknown seamounts
- Would benefit future satellite missions (like Jason CS with new orbits)
- Recommendation: A possible GM configuration (320-400 days) will result in 10 km track resolution – so two interlaced repeats are required (5 km)

But it will degrade the SLA restitution (important to oceanographers). By how much?

- Recent MSS error study should be carefully re-analysed with new CLS10 : First results show that the problem found on MSS CNES-CLS10 does not impact the global performance estimations (local impact only)
- Several presentations demonstrated the MSS error is 3 -5 between historical tracks
- Recommendation : initiate exercise of "Envisat new ground track" assimilation in model to validate if data on new tracks are adequate enough for oceanography

9.5 Near real-time products, validation and applications

Chairs: Hans Bonekamp, J. Lillibridge, G.Jacobbs

On Tuesday 19 October 2010 the near real-time (NRT) product validation and application session was held. The session consisted of 5 oral presentation and 10 posters. In addition, there were short discussions on the end-of-life orbit for the Jason-1 Mission and the orbit choice for the proposed Jason-CS (Continuity of Service) mission. The session encompassed a wide variety of topics demonstrating the broad use of satellite altimetry data in near real time: It included contributions on ocean circulation modelling, wave modelling, NRT processing , multi mission products, monitoring of global lakes and reservoirs, the 2010 Chile tsunami , observations during extreme events, and iceberg detection.

Processing, Multi-mission NRT products:

- Jayles et al. (oral presentation) discussed the new version of the DIODE (DORIS Immediate Orbit on-board Determination) Navigation Software (DGXX v8_00 flight software ,including Diode v4.02 version) as uploaded on-board DORIS/Jason-2 in February 2010. Since then the accuracy of the on-board DORIS/DIODE orbits has been oscillating between 1 and 5 cm radial RMS as compared to the final Precise Orbit Ephemeris (POE) orbit, significantly enhancing the OGDR SSH products (Figure 9.5.1). In the future, a one-centimeter radial RMS accuracy is possible with further updates of DIODE. For cryosat-2 first POD results with the DORIS system (without optimisation) show a Radial RMS (just) below 10 centimeters.

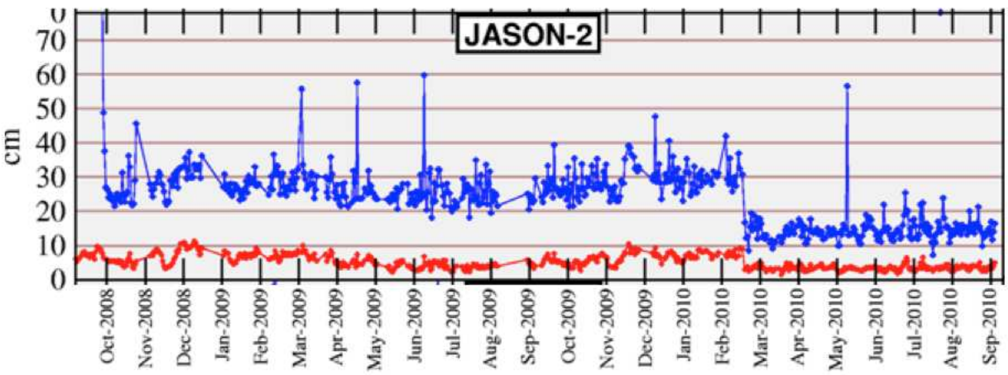


Figure 9.5.1. Radial RMS error from Jason-2 DORIS/DIODE system. Errors reduced significantly after upload of new onboard DIODE software in February, 2010.

- Desai and Haines (oral presentation) described the OSDR-SSHA and GPS-based GPS-OGDR-SSHA products, respectively. These 1-Hz NRT SSHA measurements have accuracies of 4 cm or better (RMS), with latencies of resp. 7 and 4 hours. Recent advances in GPS technology have enabled the achievement of 1-cm orbit accuracies (radial RMS) for Jason-2 within 4 hours of real time (Figure 9.5.2). There are no current GPS data from Jason-1 to support POD, but the near SSHA differences (Jason-1 vs.

Jason-2) at ground-track crossing locations (crossovers) can be used to improve NRT orbit altitudes for Jason-1 reviving NRT OSDR SSHA product.

Median of Daily RMS of Orbit Differences

OGDR DIODE	IGDR MOE	GPS-OGDR
38.0 (30.5) mm	14.1 mm	11.2 mm

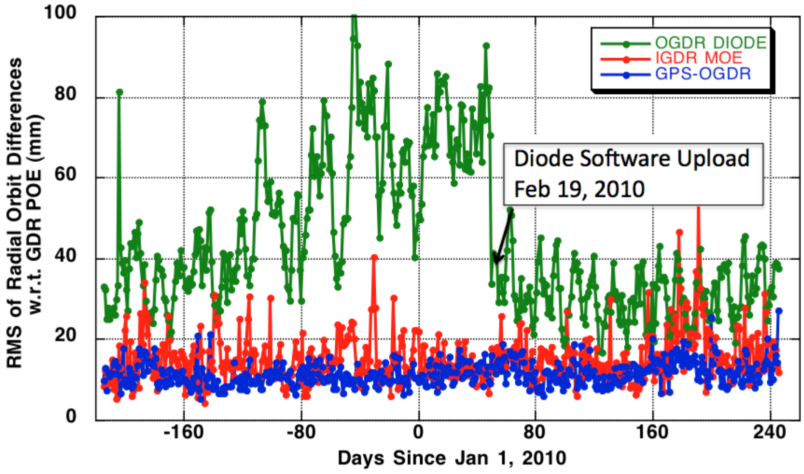


Figure 9.5.2. Comparison of RMS radial orbit errors for NRT products: DORIS/DIODE and GPS-OGDR vs. the Interim GDR Medium-precision Orbit Ephemeris (MOE).

- Leben et al (poster) explained the CCAR NRT multi mission product and its use in a NRT Web Map Service (WMS) using Google Earth and dynamical color scaling to reveal relevant ocean eddy features at all scales (Fig. 9.5.3).

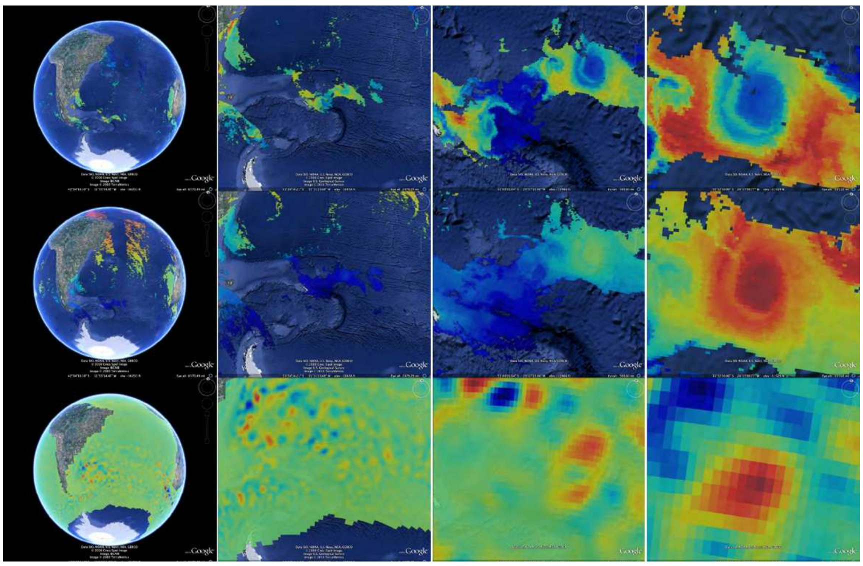


Figure 9.5.3. Sample Google Earth/Ocean dynamic zooms of imagery are shown above of a "very cold warm-core eddy" in the Southern Ocean in October 2003 that was highlighted in the Goddard Earth Sciences Data and Information Services Center Science Focus Webpage. Aqua MODIS ocean color (upper panels) and MODIS SST (middle panels) images near South Georgia Island from a rare cloud-free time period on 19 October are shown along with the AVISO merged sea level anomaly

from 23 October. A 3°C warm-core eddy with very low chlorophyll concentration "pops" into view in the highest resolution zoom.

- Dibarboure et al (poster) demonstrated how the individual missions are contributing to the AVISO/DUACS multi-mission product by applying the Degrees of Freedom of Signals (DFS) technique. It was shown with the DFS analysis that a third mission (e.g. Jason-1) added in the assimilation scheme to the first two (Jason-2 and ENVISAT) is bringing nearly full extent contribution to the product. The level of duplication (oversampling) is only a few percent (Fig. 9.5.4).

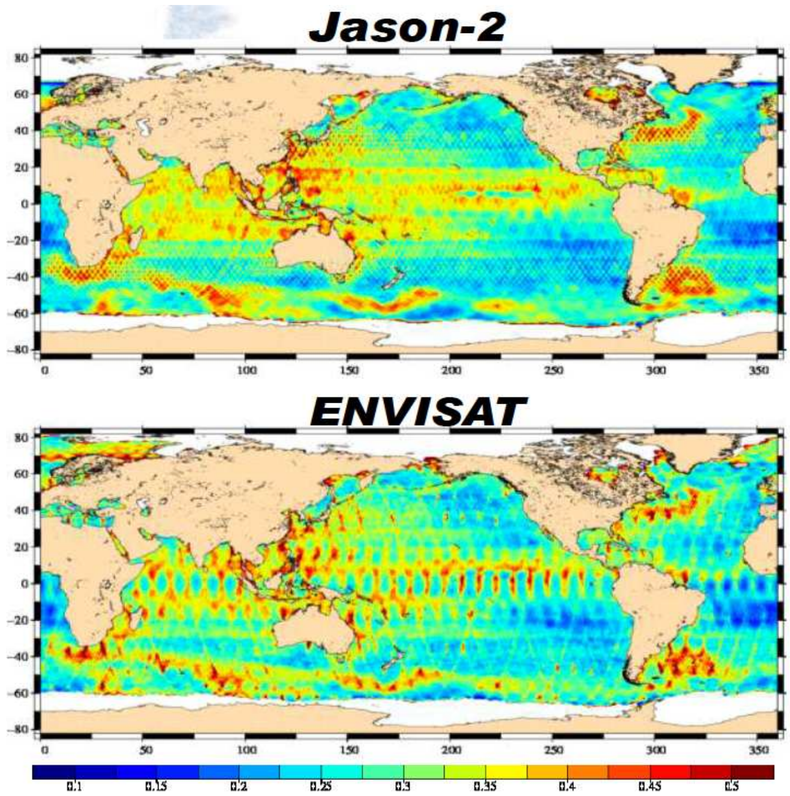


Figure 9.5.4. Fraction of the satellite-specific information content actually used by the Optimal Interpolation for a Jason-1 + Jason-2 + ENVISAT map. Top map for Jason-2 and bottom for ENVISAT.

Wind and Wave data and wave model applications:

- Lefevre et al (poster) showed assessments of the behaviour of the updated version of the wave prediction system at Meteo-France (MFWAM) in extreme conditions. Periods of availability of two altimeter missions demonstrated the largest reduction in analysis errors. In terms of forcing, the best performances were achieved with blended (Numerical Weather Prediction + scatterometer) surface wind products (Fig. 9.5.5).

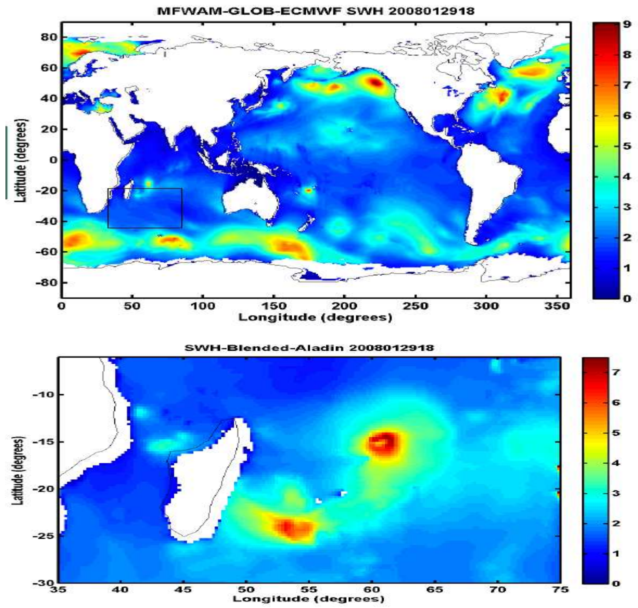


Figure 9.5.5. A limited area Numerical Weather Prediction model, ALADIN/REUNION, was implemented at La Reunion in 2006 with hurricane bogusing and has been improved in 2008 with the introduction of a 3D wind vortex based on hurricane advisories issued by the La Reunion Hurricane Center. A regional MFWAM wave model nested in the global model has been implemented recently, covering part of the Indian Ocean with ¼° resolution.

- Quilfen et al (poster) addressed the issue of high winds (> 18 m/s) from altimeter data. Currently these are inaccurate for Jason-1 and Jason-2 due to lack of calibration. A dedicated high wind algorithm was proposed based on work with QuikSCAT data. This algorithm was also presented in the oral presentation by Vandemark et al. Furthermore, an outreach was made to the upcoming CFOSAT mission (Fig. 9.5.6).

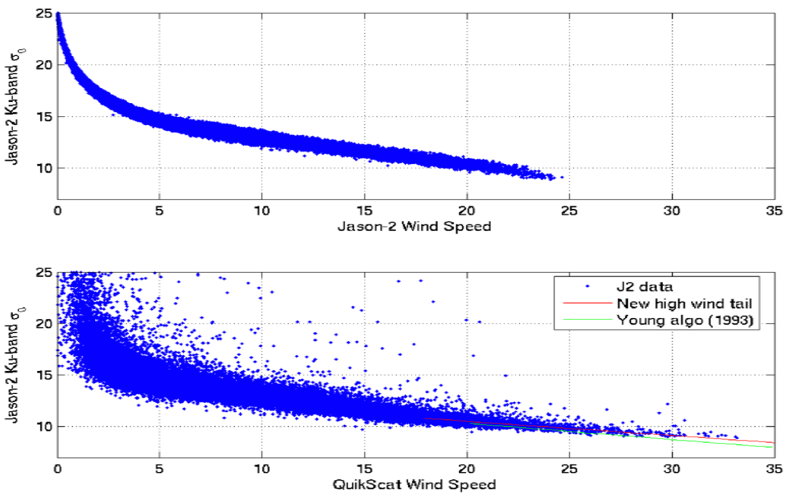


Figure 9.5.6. Behavior of altimeter backscatter as a function of QuickScat wind speed. New high wind algorithm: $U = 96.98 - 7.32 * \sigma_0$ (Ku band, in dB) for U > 18 m/s.

- Vandermark et al. (oral presentation) gave an overview of wind and wave data use at NCEP and the current project to enhance it. Altimeter wind and wave data are forwarded to operational forecast desks and displayed using the N-AWIPS tool. The algorithm based on Young 1993 for gale to storm force as discussed also at Quilfen et al (poster) has been delivered to the NCEP Ocean Prediction Center in summer 2010. Publication in JAOT is under review. They also recalled the IOC/IODE/WMO (EUMETSAT/NOAA) forecaster workshop held Dec. 2009, work that is going to be continued (Fig. 9.5.7).

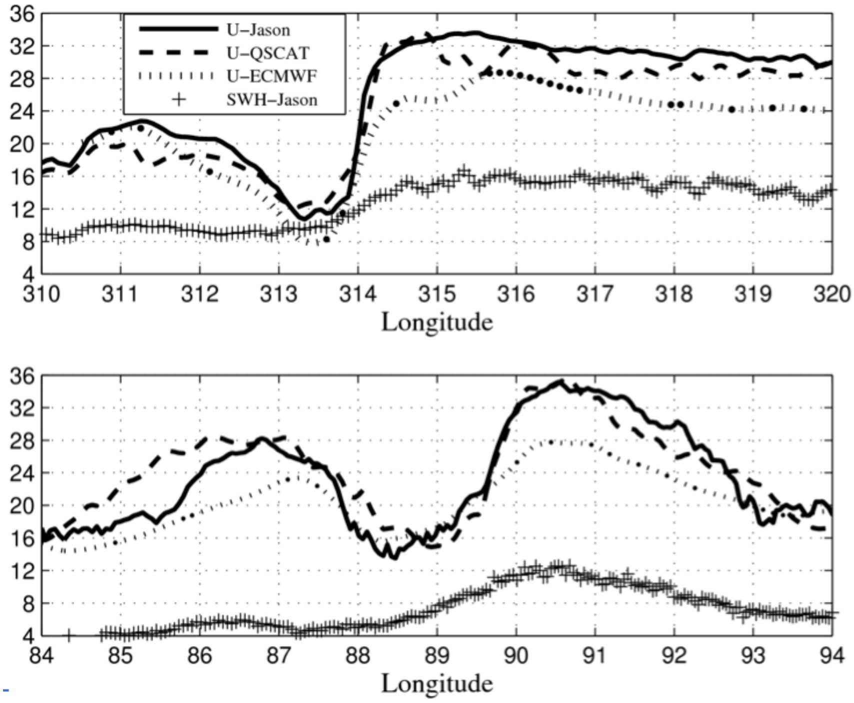


Figure 9.5.7. High altimetric wind speed algorithm: linear and similar to Young (1993); easy to apply to Jason-1, Jason-2, or ENVISAT. To be published in: Quilfen, Vandemark, Chapron, Feng, Sienkiewicz, Estimating gale to hurricane force winds using the satellite altimeter, JAOT in review, 2010.

- Tournadre et al (oral presentation) presented work of the IOWAGA project to improve wave modelling. They showed the example of how a new parameterization for wave dissipation has been investigated from altmeter (and SAR) data. In particular, small icebergs as observed in altimeter data act as breakwaters in the middle of the ocean. A new parameterization including this effect has been proposed. In this new scheme most of the improvements result from the enhanced wave dissipation from breaking. The better quality of the wave models with these parametrizations (e.g. better 3rd and 4th moments) can be exploited to derive better sea state bias corrections in altmeter processing (Fig. 9.5.8)

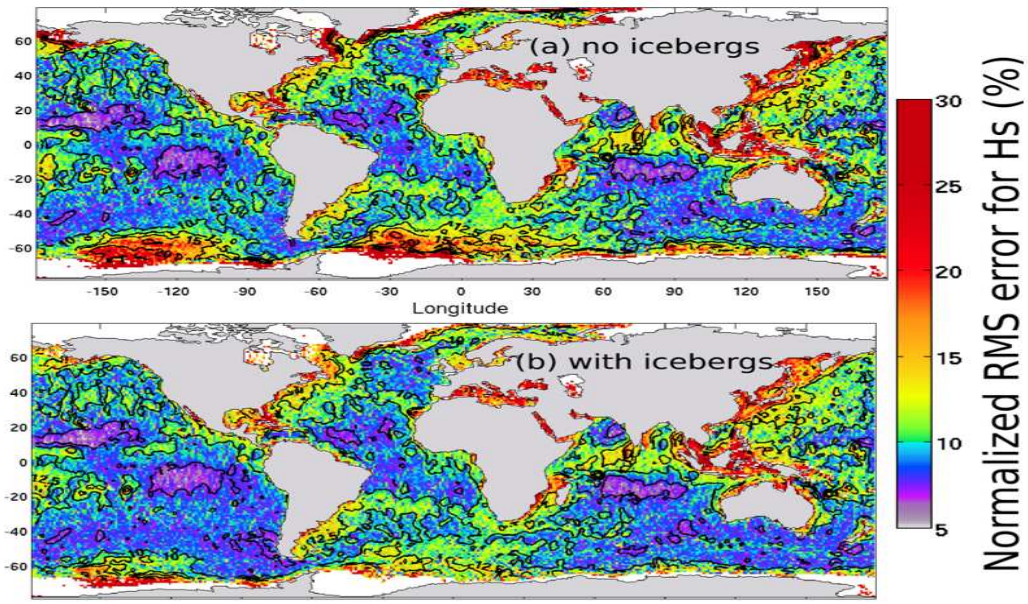


Figure 9.5.8. Model errors without and with icebergs, year 2008: note the impact in the south Pacific, very particular for that year. Figure from Tournadre et al., in revision with GRL.

<u>Ocean model assimilation applications:</u>

- Dombrowsky et al. (oral presentation) explained the real-time use of altimeter data in the Mercator Océan forecasting and reanalysis systems. He highlighted some Observing System Experiments for the North Atlantic and Mediterranean. These experiments were showing strong degradation of the model analyses with decreasing number of missions. In fact there was no model forecast skill without assimilation of altimeter (even with the assimilation of SST and T/S profile data), Fig. 9.5.9.

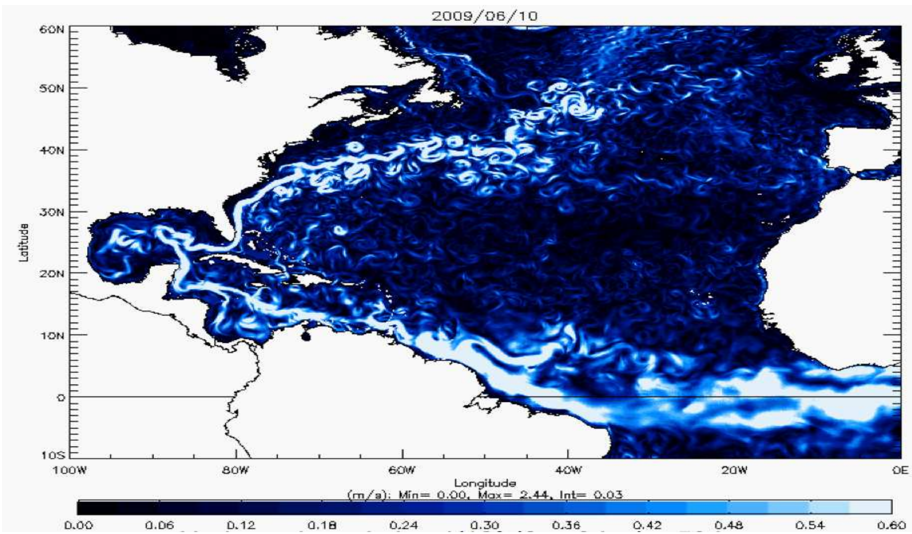


Figure 9.5.9. Example of the Mercator Ocean model system, with a horizontal resolution of 1/12° and 50 vertical layers. The animation exhibits strong mesoscale variability as well as the high frequency barotropic response of the ocean to passing atmospheric pressure systems.

- Brankart et al. (poster) addressed the parameterization of the observation error covariance matrix in an ocean model data assimilation system (Kalman Filter) and demonstrated its applicability in analysis with the NEMO ocean model for the North Brazil current. These parameterizations did show to help in dealing with correlated noise resulting in further minimisation of analyses errors (Fig. 9.5.10).

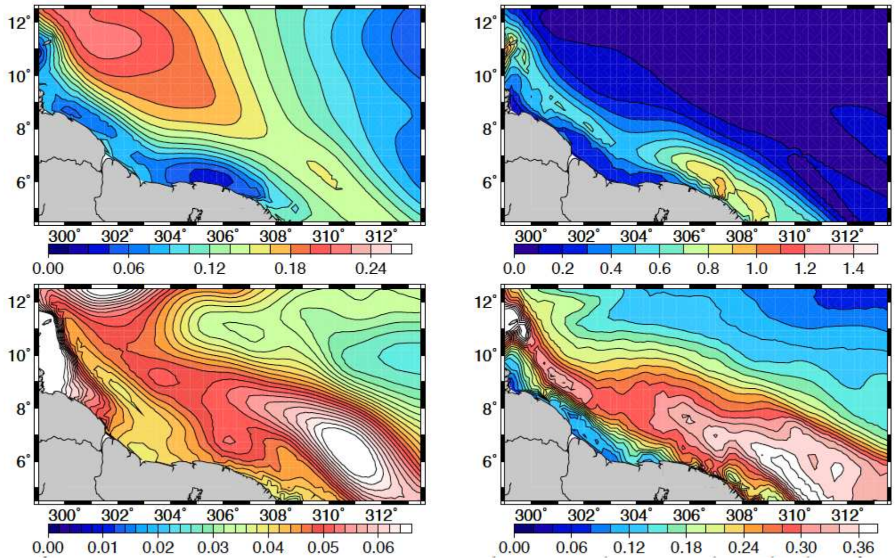


Figure 9.5.10. Mean (top) and standard deviation (bottom) of the 5 year simulation in the Brazil Current for sea surface height (in m, left panel) and sea surface velocity (in m/s, right panel).

- Chao et al. (poster) demonstrated a system to do NRT model forecasting along the Californian coast. The Regional Ocean Modelling System (ROMS) is now running 24/7 in real time off the Californian Bight the Monterey Bay and in Alaska's Prince William Sound (Fig. 9.5.11).

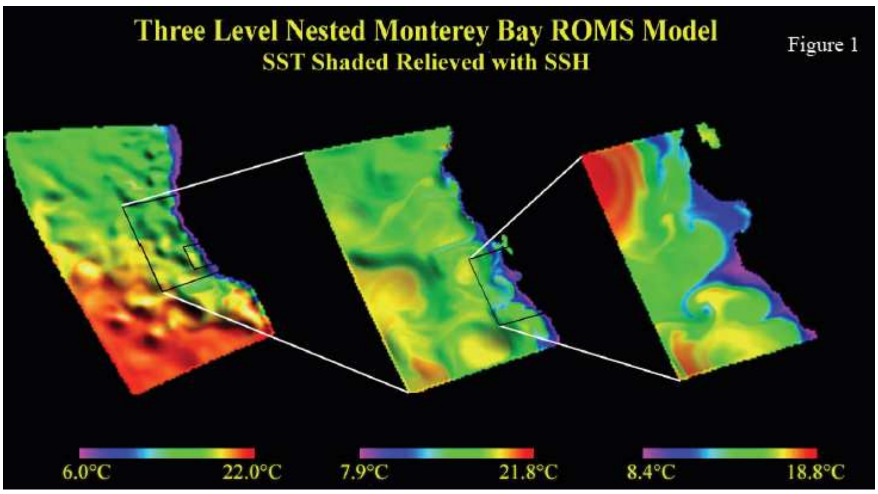


Figure 9.5.11. The nested ROMS Multi-Scale 3D Variational data assimilation system has the ability to assimilate both in situ data (vertical profiles of temperature & salinity from ships, moorings, gliders, and profiling floats) and remotely sensed data (satellite SST and land-based HF radar).

- Dohan et al (poster) explained the use of the AVISO/DUACS near real time and delayed time products in the Ocean Surface Current Analyses Real-time (OSCAR) system, which combines altimetry measurements with wind information to produce geostrophic + Ekman surface current estimates. Traditionally NRL/MODAS SSH products were used, but the DUACS system if providing very good results (Fig. 9.5.12).

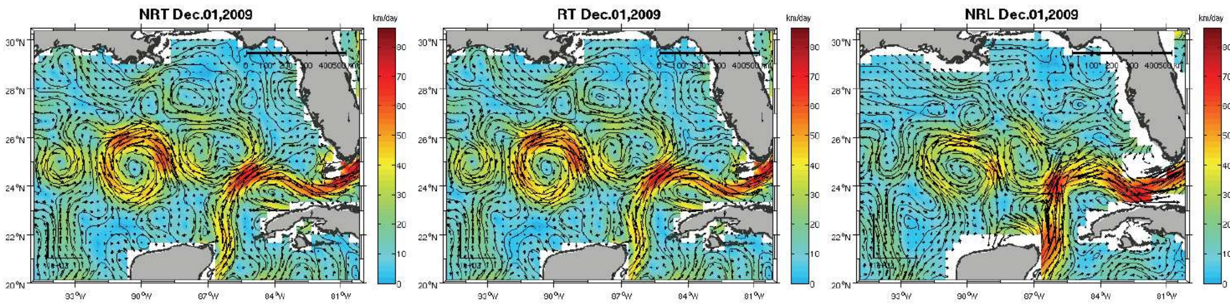


Figure 9.5.12. Sample OSCAR fields in the Gulf of Mexico using AVISO NRT, RT and NRL fields. A daily OSCAR version for real time uses is in development, with preliminary results in the Gulf presented at: www.esr.org.

Land/Hydrology applications

- Birkett et al. (poster) showed the application of NRT monitoring of global lakes and reservoirs. Validations are made using gauge data and cross-platform data sets. It was concluded that with ENVISAT and Jason-2 an excellent performance has been achieved (Fig. 9.5.13).

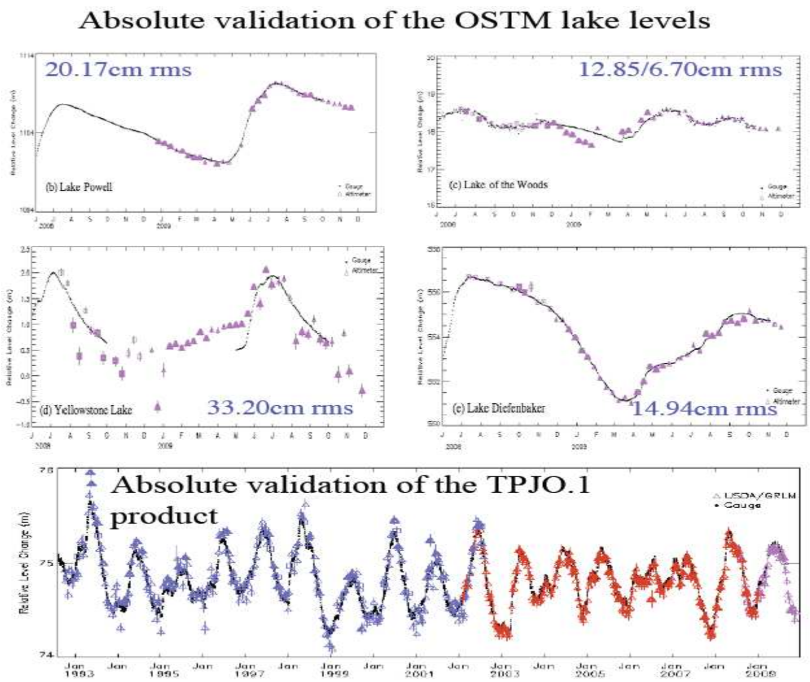


Figure 9.5.13

Catastrophic Events:

- Smith et al. (poster) examined radar altimeter waveforms over the DeepWater Horizon 2010 oil spill in the Gulf of Mexico. They found both in C and Ku band bright (specular) reflectors over the spill area with power levels much exceeding the normal ones. These findings can be used to further develop oil discrimination methods.

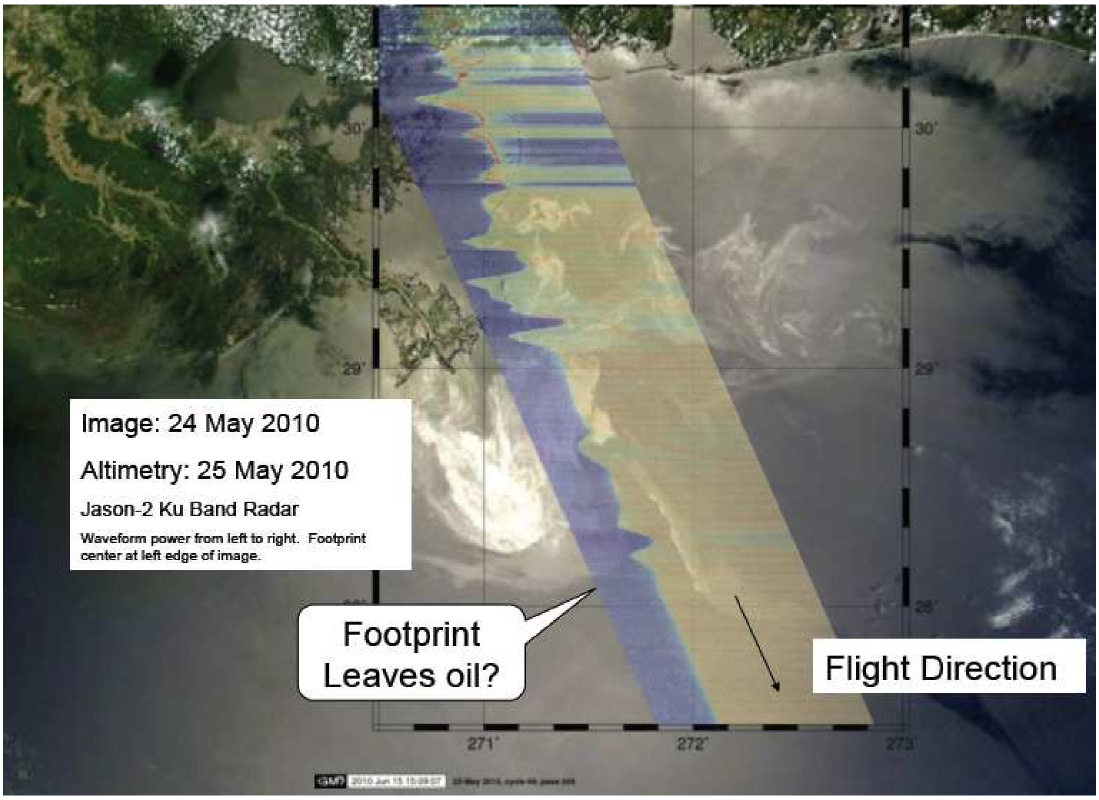


Figure 9.5.14. Oil on the ocean surface makes the surface unusually reflective at Ku and C band, causing a "bloom" of sigma-0 and a disruption of the waveform's shape and track point. This affects all geophysical tracker outputs (range, sigma-0, SWH, etc.) and also other parameters (MQE, pulse peakiness, etc.) These parameters, and waveforms, are available at 20 Hz for both Ku and C band in Jason-1 andJason-2.

- Song et al. (poster) showed that the Chilean tsunami generated by the February 27, 2010 earthquake was observed on Jason 1 and Jason 2 tracks. Synchronisation analyses were made with a tsunami model to investigate the propagation patterns of the leading waves. (Fig. 9.5.15).

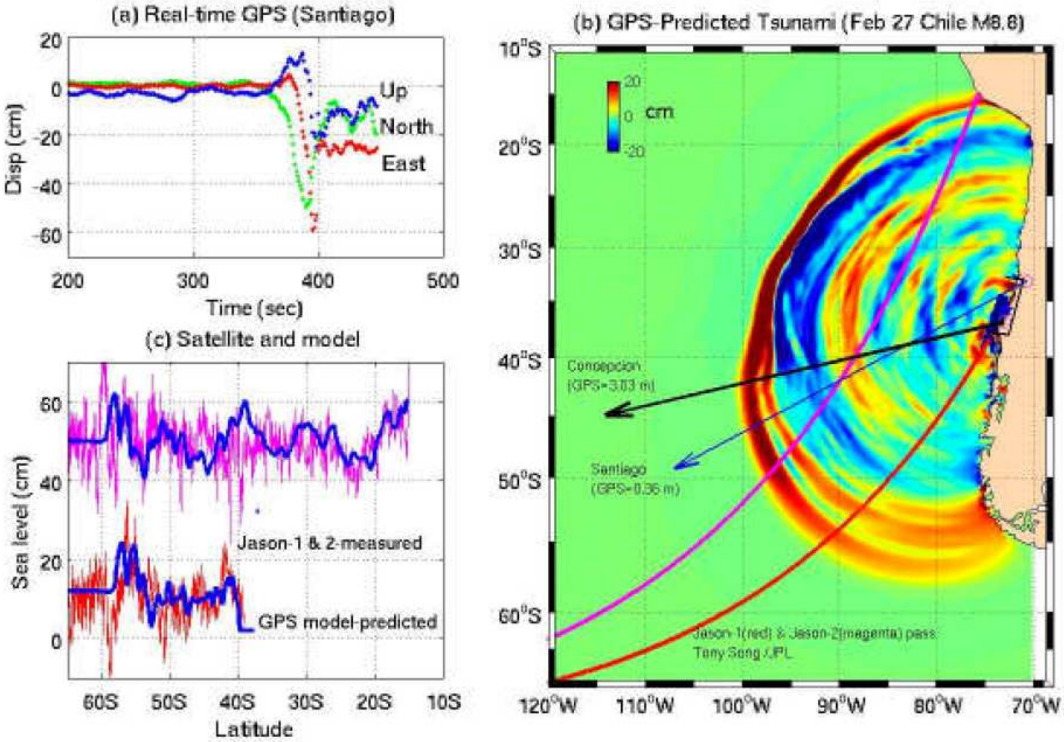


Figure 9.5.15. GPS data were used successfully in estimating the size of the Chile tsunami and altimeter data were used to confirm the estimation after the event: (a) GPS-forced real-time GPS displacement data obtained from NASA/JPL global differential GPS system on 27-Feb-2010; (b) GPS data were used in the earthquake source model and forced an ocean model for simulation of the Chile tsunami; (c) the model tsunami compared with Jason-1 and Jason-2 altimetry data, confirming the tsunami's size.

Discussions:

- Jason-1 EOL orbit: there was little discussion. Wind/wave applications are basically immune (orbit error and MSS are not an issue…) From the operational oceanography perpective: Good services depend on three good functioning nadir altimeters. ENVISAT is moving to new orbit in October 2010: Having Jason-1 in same orbit would avoid further degradation in services. Hence the recommendation from the splinter was to delay a move from reference orbit.

- Jason-CS Orbit. Little discussion. Wind/wave applications: No input NRT POD: Impact of an orbit height change on NRT POD with DORIS system is negligible. See very good first results of DORIS/DIODE on Cryosat-2. Operational Oceanography: In addition to temporal and spatial sampling (with +3 missions), accuracy of missions (reference mission) is very important. The need for a good inter-mission cross-calibration. Hence a weak recommendation was to stay on in the T/P orbit. It was remarked that schedule is important for Jason-3/Jason-CS Cal/Val. With a move, a long overlap in time is needed to tune MSS.

- No recommendations were made on future Jason drift requirements

9.6 Outreach, education & altimetric data services

Chairs: Vinca Rosmorduc, Margaret Srinivasan

Due to scheduling constraints for the 3-day OSTST meeting this year, the Outreach session was expanded to include data services. Six oral presentations, eleven activities in the annual 'Outreach Showcase' element, and ten posters made up the joint Outreach/Data Services session. The Tuesday (10/19/2010) afternoon session was attended by about 50 science team members, students from a French junior high and high school, and others.

This year, the "outreach showcase" portion of the session consisted of eleven presentations by OSTST scientists, data services personnel, and outreach team members. We encourage OSTST scientists to present the outreach activities and events they have had throughout the year, or to discuss any outreach-focused product development they have been involved in. It is beneficial for us to be aware of public and educational outreach activities that OSTST members are involved in and what the impact of those activities/products is. We are interested in learning about any and all outreach activities and products that OSTST members are involved with, and it was quite gratifying to see just how much our science team members support education and public outreach.

Once again, as at the 2008 OSTST meeting in Nice, France, the CNES Education Lead brought a group of junior high and high school students and their teachers to participate in the meeting. They reported with great enthusiasm on the science activities linked to altimetry they conducted during the school year. The junior high school students used altimeter and other data to examine the so-called "plastic island" occurring in the North Pacific. The high school students constructed a buoy equipped with temperature sensors, which they tracked using satellite data, and planned to compare with altimetry maps. Both groups will continue using ocean data in 2010-2011. High school students will build a new buoy, for release in the Liguro-Provencal current (along the French coast of the Mediterranean). Ocean data, including altimetry will be used to monitor and analyze the buoy's path.

2009-2010 Highlights

The focus of outreach and educational activities of the past year included continued promotion of the societal benefits of ocean altimetry data, highlights of the Jason-1/OSTM-Jason-2 tandem mission, and products to promote the science and applications of the data. In addition, an emphasis on climate literacy has been engaged in outreach and education products and events. JPL held the second of an anticipated annual 'Climate Day' event in March 2010 in Pasadena, California.

An important outreach focus this year has been on data improvement with respect to quality, user-dedicated and high level processing, and for data retrieval tools that provide easier access to altimetry data for all levels of user.

The JPL Ocean Surface Topography and the AVISO pages are regularly updated to feature and highlight science and outreach activities. The following are some of the activities and products developed this year:

- JPL Earth mission science results posters (including Ocean Surface Topography)

- New banner stand displays featuring OST, SWOT and GRACE
- CNES/SALP 2010 wall calendar
- Google Earth browse through altimetry applications (AVISO)
- Coastal Data Use case ("PISTACH" data)
- CNES' Argonautica 2009-2010
- JPL's 2010 Revision "Discovering the Ocean" book cover
- Aviso Newsletters 4 and 5
- OST missions in NASA Web "Eyes on the Earth"
- New SWOT brochure
- DORIS "20 years" material (leaflet, Rollup, movies, new logo
- Animation made within the CNES/MyOcean/Mercator Océan collaboration (different parameters / techniques used – SST, model, altimetry)
- "VIGIE" educational project (High school students from Toulouse plus retired and active scientists/engineers)

User-dedicated approach of data & tools
There are many activities ongoing in the area of data improvement,; for data quality, for user-dedicated/high level processing, as well as for data retrieval tools (providing tools to ease the access of altimetry data, at all levels).

The era of "one data type fits all" is certainly over in oceanography. New and potential users have a wide variety of concerns, and have different skills and capabilities with respect to processing and interpreting data. New, highly refined, data can help gain more new users and thus prove the interest in and use of altimetry. The outreach and data services efforts are focusing on:

- Developing systems to distribute data that is better suited to user needs (including data bases, data mining...),
- Providing increasingly refined products (filaments, indicators– e.g. MSL, ENSO, coastal, hydrology products, etc.),
- Developing tools to aid new users with data products and interpretation tools and knowledge.

Different services are planned /in development / in service (CNES, JPL, LEGOS, NOAA, Delft Technical University…), to enable users to define and download their own products.

Education
ESA, CLS, and CNES have developed the Basic Radar Altimetry Tool as a training aid for new and existing users. A wide variety of data products and levels for access to ocean altimetry data is a recurring concern. This tool can be an aid for education:

- In formal classroom settings (universities, for both students and teachers),
- In developing countries, for scientists and engineers with very little, or even no experience in satellite data use.

Benefits of this tool can extend to new, and more isolated users who traditionally have had no formal access to processing techniques and capabilities.

Science Team members continue to contribute to outreach by conducting altimeter data trainings in developing countries, e.g., in Indonesia and in countries in Africa. Science Team members who are contacted to teach or help during these trainings, which are now being organized all around the world, are encouraged to provide information on training schedules and content to either PODAAC or AVISO so that the information can be easily provided to new, and prospective users in isolated regions.

Climate is a major focus for the general populace and in particular for students. This 'hot' topic can be an incentive for engaging young people who are on science or policy-oriented educational paths and are concerned about climate issues and implications for their own future and who are enthusiastic in their approach to learning. Some of the tools from the altimetry outreach effort that can support students include:

- Argonautica
- JPL Climate Day
- Media activities; web, press releases, features, etc.
- Promotion of OST science & applications

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;

- France/US joint education activity
- Altimetry and multi-sensor applications promotion
- Coverage of science team research and other applications on web, posters, products
- Google Earth altimetry application browser with a series of new images
- Development of more "Data Use Cases" with coastal and hydrology data
- Development of more "Data Use Cases" for BRAT frame (Cryosat, geostrophic velocities, GOCE/altimetry)
- New animations made within the collaboration CNES/MyOcean/Mercator Océan
- VIGIE2 (High school students plus retired and active scientists/engineers)
- Saral movie
- 2011 CNES/SALP wall calendar

9.7 Tides, internal tides and high-frequency processes

Chairs : Florent Lyard, Rui Ponte, Richard Ray

A total of 11 abstracts were submitted to the splinter session, resulting in 6 poster and 5 oral presentations. A full listing of the contributions, including titles and authors, can be found in the meeting program. The oral session took place on Tuesday, October 19 (16:30-18:00) and was chaired by Ponte and Lyard. A brief summary of the oral session is given here. For further details, copies of the posters as well as the slides from the oral presentations are available at the meeting website:

http://www.aviso.oceanobs.com/ostst

The oral session started with a talk by Legeais on the relevance of altimeter observations for tsunami detection and monitoring. Although the large 2004 Sumatra tsunami was well observed, more extensive altimeter data analysis, in relation to all large tsunami-generating earthquakes in the altimeter era, revealed considerable difficulty in capturing the generation and propagation of tsunamis in their initial stages, even with several altimeters flying at the same time. The altimeter observations were deemed important, however, for post-event validation and improvement of tsunami generation and propagation models.

The following talk by Cherniawsky dealt with the effects of seasonal modulation of tides in shallow seas. As the length of the altimeter record continues to increase, it is now possible to investigate temporal variability of the tides. The results presented focused on the modulation of M_2 and O_1 potentially related to changes in stratification and other ocean parameters at the seasonal period. Comparison of hydrodynamic (3-D) model solutions with altimeter data for a couple of shallow seas yielded mixed results, as expected given that the modulation effects under consideration are small and the data still considerably noisy.

The presentation by Cancet (filling in for Lux) focused on regional tide solutions and high frequency dynamical atmospheric corrections (DAC) for the Northeast Atlantic and Mediterranean Sea. These are prototype products under development with the goal of improving coastal altimetry data processing. The recently produced tidal atlases (COMAPI CNES project) do strongly improve the tidal prediction needed for de-aliasing correction in coastal regions, while scoring similarly to global atlases such as GOT4.7 in deeper regions. Consistent tidal loading computation is still needed to reach the optimal accuracy from regional tidal model corrections. Regional “storm surge” models (needed for the DAC) have been validated through tide gauge comparison, but estimates of regional versus global expected improvements are still to be processed. Efforts towards improving regional corrections in altimetry processing will continue, especially in the perspective of the SWOT mission.

A similar topic was discussed in the talk by Lyard on the methodology and validation of regional tidal atlas in coastal and shelf seas. Compared to the deep ocean tide spectrum, many more constituents need to be included in the prediction spectrum, often with significant but relatively weak amplitudes. Those constituents are barely observable from altimetry in most places, making assimilation extremely challenging. The need for data cleanup before assimilation was emphasized, particularly regarding contamination from internal tides, as well as the need for better characterization of errors for minor constituents. The production of future regional, high resolution and accurate tidal atlases will still demand the improvement of the direct hydrodynamic solvers (the most crucial parameter being the model's bathymetry, and thus the accuracy of available ocean bottom topography databases) and of the assimilation procedure (such as multi-constituents simultaneous assimilation).

The final talk by Lyard (filling in for Lamouroux) focused on a new methodology for handling the S_1 and S_2 tides in the altimeter data processing and their appropriate treatment in the tide correction and DAC. Those two tides have a strong atmospheric pressure-forced contribution (radiational component), whose stability with time is questioned. In the S_1 case, the infra-annual variability pleads for not including S_1 in the tidal spectrum, but instead to take it into account as part of the DAC (including the high frequency response to atmospheric wind and pressure forcing). In the S_2 case, present global tidal atlases used for tidal signal decontamination in sea level anomalies already include a kind of average radiational contribution because of the use of observations in their construction (assimilation or direct empirical analyses). This average must be consistently removed from the DAC to avoid double correction. Given the newly released ECMWF products at 3-hour sampling, the direct modeling of the S_2 radiational tide is now feasible. Due to seasonal variability and inter-annual stability, the proper extraction of an average S_2 radiational tide, i.e. consistent with tidal atlases, seems feasible and might provide the basis for an improved high frequency de-aliasing (as shown for a limited set of tide gauges). However, additional investigations are still needed before proposing an operational methodology based on this approach.

The session ended with a brief discussion of the issues related to the definition of (1) the Jason-1 end-of-life orbit and (2) the future Jason-CS orbits, in the context of the tides and high-frequency aliasing topic. With regard to (1), the importance of regular sampling and long records for best determination of tides, as well as for assessing non-tidal aliasing signals, provided a strong consensus to keep Jason-1 in its current interleaved orbit for as long as possible. Alternative drifting orbits are difficult to use for tidal purposes, although it was recognized that improved bathymetry resulting from these orbits could be useful for the study of tidal dissipation and related ocean mixing, particularly in the deep ocean. With regard to issue (2), a move to a different orbit could help fill data holes in many regions (particularly important issue in coastal regions), as well as cover more of the high latitude regions. Thus, a change of orbit from the TOPEX and Jason orbits was preferred, as long as proper tidal aliasing periods were observed. Preference for orbits with shorter repeat periods was also mentioned, because baroclinic dynamics become more and more important at longer periods, and dealiasing (non-tidal) models that account for those processes would need to be implemented.

9.8 59-day variations in J1 & J2

Chairs: N. Picot, R. Scharroo

For per-cycle global means, the **J1-TX bias is highly corrected with the amount of time TX/J1 spent in the Sun.**

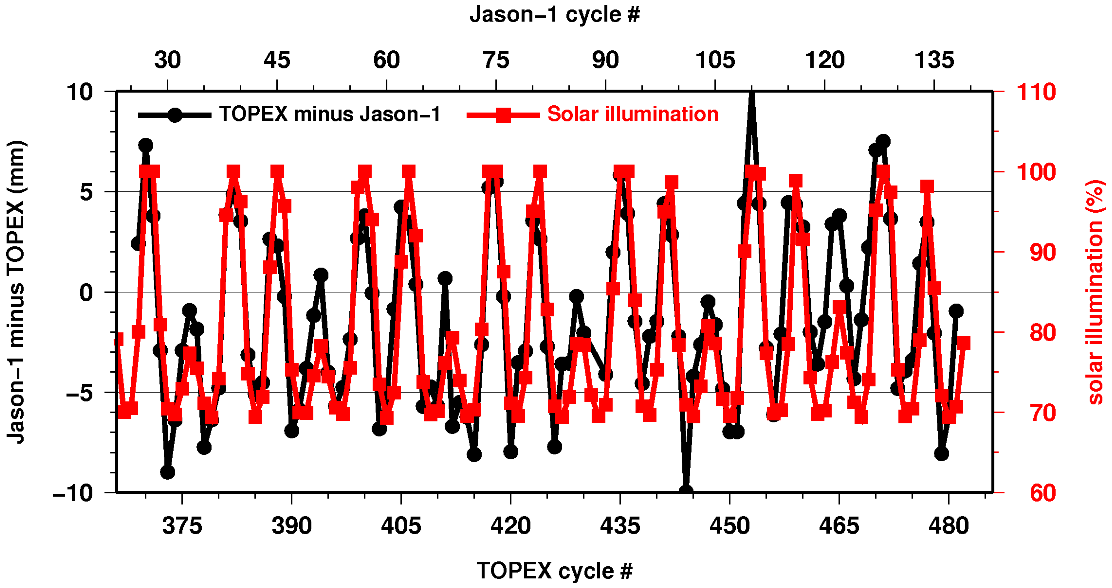


Figure 9.8.1 *Temporal evolution of the bias between Jason-1 and Topex (black) compared to the amount of time TX/J1 spent in the Sun (red).*

TOPEX CoG Correction :

- Analysis of algorithm and SLR residuals confirms existence and sign of CoG variation of TOPEX
- No such variations exist on J1 and J2
- CoG variation seen in TOPEX attitude
- Need to analyse SA deployment error
- Need to find design of or actual SA part

Jason-1 instrument/platform behaviour :

- No significant temperature 59-day variation measured at altimeter
- Should also be evaluated along orbit
- Similar studies to be conducted for TOPEX and Jason-2
- No significant orbit error at 59-day cycle
- No CoG variation observed nor expected in Jason because of design

Tide solutions :

- Clear indication that not applying or wrongly applying CoG correction on TOPEX leaks into empirical S2 tide model
- FES2004 model should be less sensitive to this error (hydrodynamic)

- Tide model differences can explain some, but certainly not all of the observed 59-day cycle

Impacts :

- 59-day cycle does not impact sea level trend at long time periods, but doesimpact the confidence level
- Not solving the causes will affect / has affected tide modelling
- More studies required to identify other impacts and possible causes

Other suggestions:

- Time tag bias (TX), sigma0 variations, off-nadir pointing (J1) might be related to the observed 59-day variations
- Difference between TOPEX A and B suggests instrumental causes
- Evaluations best conducted both on cycle averages (4 mm) and along-orbit (20 mm)

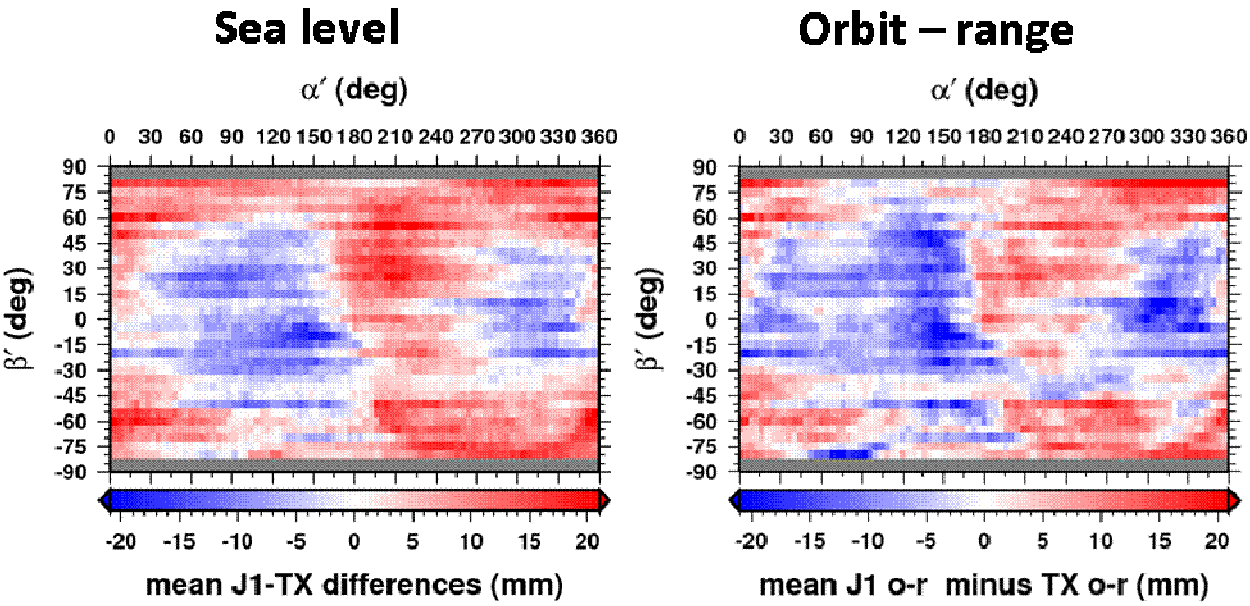


Figure 9.8.2 *(left) Mean Jason-1 and Topex sea level difference, plotted as a function of orbit angle (alpha') and solar aspect angle (beta'). (right) Mean orbit – range difference between Jason-1 and Topex, as a function of orbit angle and solar aspect angle. Note : orbit angle, alpha', is the angular separation of the spacecraft from the orbital 6 a.m. position. The solar aspect angle, beta', is the angle between the Earth/Sun position vector and the orbital plane.*

Conclusions:

The **error seems to come from TOPEX** (but maybe not from CoG correction) but it is difficult to find information. The thermal sensitivity of the altimeter should be studied (PTR, USO, time base evolution, etc.).

9.9 Ocean circulation science results

Chairs: R. Morrow, J. Willis

In addition to a large number of quality poster presentations, we were able to have two splinter sessions dedicated to scientific studies using altimetry for ocean applications. There were also dedicated poster sessions for the coastal, terrestrial surface waters, and future altimetric missions, as these subjects were discussed in separate Workshops each side of the OSTST meeting.

The first splinter session dealt with basin-scale processes, where altimetry was used jointly with other oceanographic data sets and atmospheric forcing terms to monitor the upper ocean heat budget in the North Atlantic and the North Pacific, or to study circulation changes in the tropical Atlantic or between the North Atlantic subtropical and subpolar gyres. Talks also addressed the impact of assimilating altimetry into a high resolution model of the North Atlantic, and on the intrinsic variability of the ocean revealed by global simulations, and validated with altimetry.

The second splinter session dealt with the circulation of regional current systems observed with altimetry and other observations, with talks on the bifurcation of the north equatorial current off the Philippines, on the western boundary currents in the Soloman Seas and off the East Australian coast, and on the Antarctic Circumpolar Current. Two final talks presented an analysis of the temporal spectrum in the ocean and its regional variations, and discussed the impact of these changes for calculating sea level trends from limited time series. A final talk discussed a statistical technique for deriving ocean mixing parameters from multi-satellite altimetry measurements, - a theme which was discussed in greater detail in the following Workshop on 21-22 October.

The oral and poster presentations for this session can be found on the AVISO website : http://www.aviso.oceanobs.com/ostst

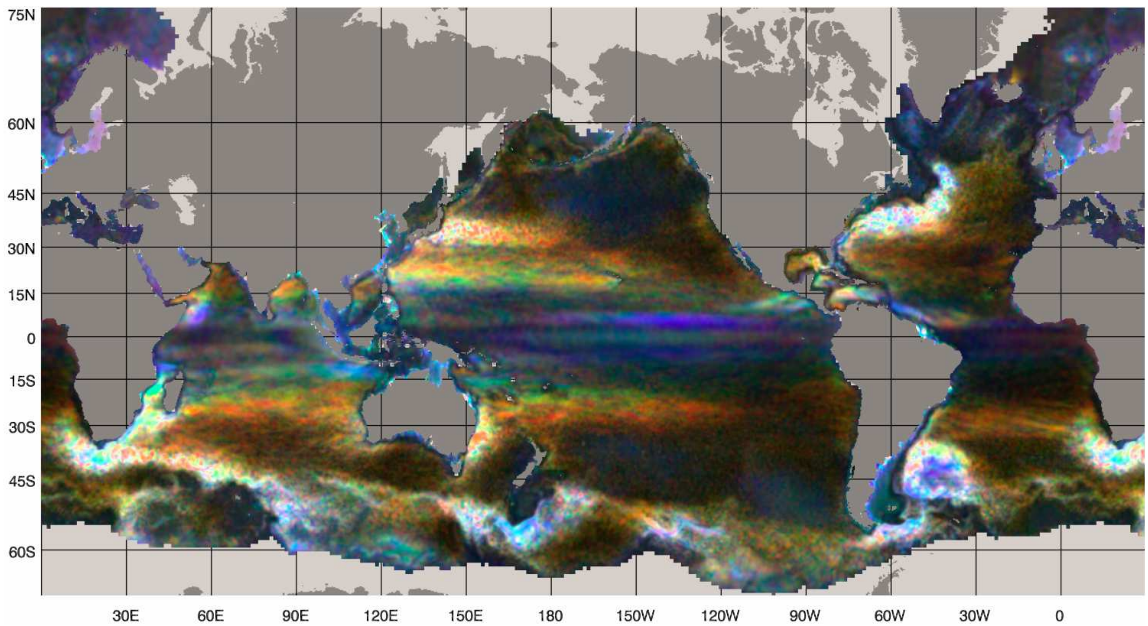


Figure 9.9.1: *The sea level spectrum – the rainbow effect is related to Rossby wave dynamics. Rossby waves have a maximum possible frequency, which depends on stratification and latitude, and can be mapped. Regions in white need a long time series to derive significant sea level trends. (after Hughes).*

Oral presentations :

Estimates of the Ocean Heat Budget in the North Atlantic: the role of ocean heat transport convergence
L. THOMPSON (University of Washington)

North tropical Atlantic ocean circulation from altimetry and ARAMIS data
S. ARNAULT (LOCEAN/IRD)

Subtropical-subpolar exchange in the n Atlantic: atmospheric forcing, SSH structure, carbon, AMOC, AMV
P. RHINES (University of Washington)

Impact of assimilating SSH on the dynamics of the Gulf Stream
J. RICHMAN (Naval Research Laboratory)

Satellite-observed changes in the upper ocean heat Budget of the Northeast Pacific during 1993-2004
S. SPRINGER (Earth and Space Research)

Intrinsic interannual variability in the ocean : global simulations and altimeter observations (107)
T. PENDUFF, (LEGI-CNRS and FSU,)

Interannual-to-decadal variability in the bifurcation of the north equatorial current off the Philippines
B QIU (University of Hawaii at Manoa)

The LLWBCs of the Solomon Sea depicted by altimetry
L. GOURDEAU (IRD/LEGOS)

Structure of the Antarctic Circumpolar Current in Drake Passage observed from satellite altimetry
N. BARRE (LOCEAN)

Decadal Changes in the East Australian Current system determined from XBT transects, satellite altimetry and a high-resolution ocean model
K. RIDGWAY (CSIRO)

Colour of the sea level spectrum: when are observed trends statistically significant?
C. HUGHES (National Oceanography Centre)

Surface ocean mixing inferred from different multisatellite altimetry measurements
F. BERON-VERA (RSMAS, University of Miami)

9.10 Global and Regional Mean Sea Level studies

Chair : J. Willis

In addition to two splinter sessions on ocean circulation science results, a splinter session on global and regional mean sea level studies was held. The session included 5 oral talks and 12 poster presentations. These studies focused on regional and global sea level changes and their causes, and included efforts to reconstruct sea level changes in the global oceans as well as in marginal seas prior to the satellite altimeter record. Several authors also focused on the overall accuracy of global sea level estimates based on the satellite altimeter record. Finally, several authors considered the causes of regional variations in sea level change.

The oral and poster presentations for this session can be found on the AVISO website : http://www.aviso.oceanobs.com/ostst

Oral presentations :

Reconstructing global mean sea level from tide gauges using satellite altimetry
B. HAMLINGTON (Univ. of Colorado)

Comparison of altimeter-based global mean sea level time series
R.S. NEREM (Univ. of Colorado)

Reconstruction of the Mediterranean sea level variability over 1970-2006 derived from altimetry and 2 long OGCM runs
B. MEYSSIGNAC (CNES)

Reconstruction of recent sea level changes in Pacific islands region
BECKER Melanie (LEGOS/CNRS)

Evaluating and interpreting the global and regional sea level climate record
E. LEULIETTE (NOAA)

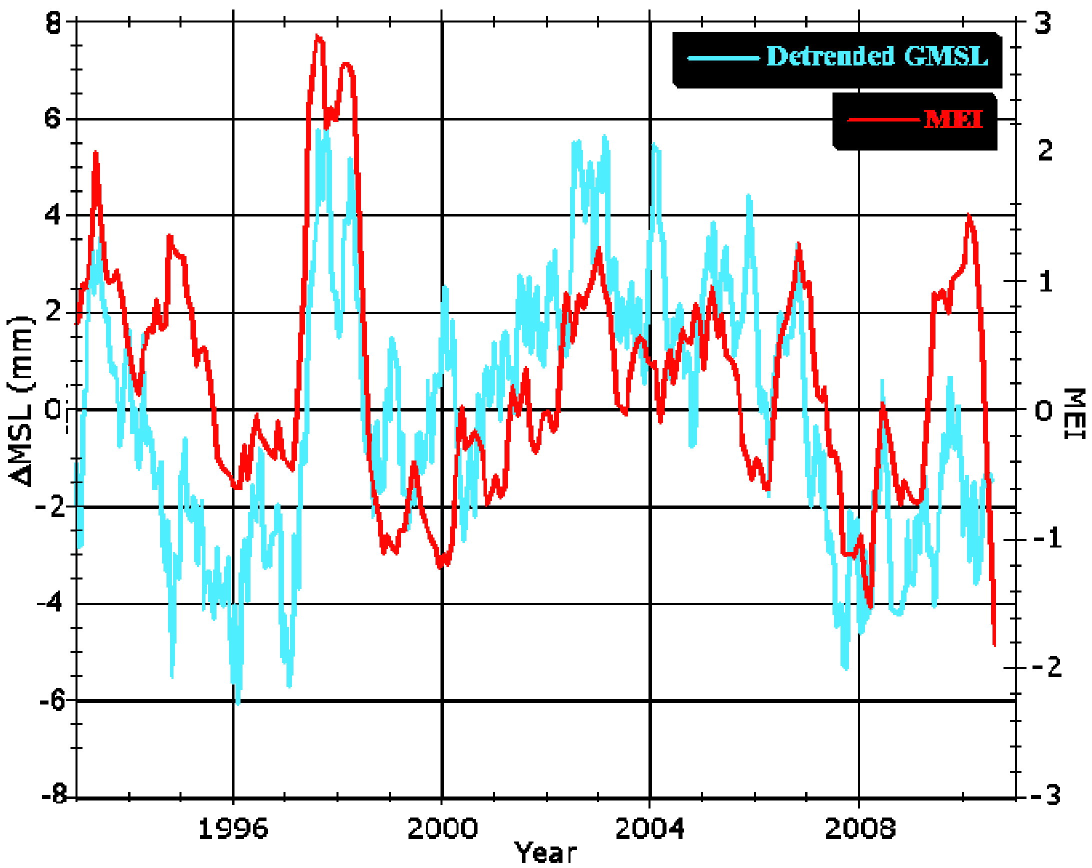


***Figure 9.10.1** : Global mean sea level from altimeter data with a linear trend removed (blue). Also shown is the Multivariate ENSO Index. The close correspondence between the two suggests a that El Nino may play a role in year to year fluctuations in global sea level (from Nerem).*

10. Conclusions

The closing session was chaired by R. Morrow and J. Willis.

10.1 Jason-2 GDR-C Reprocessing

After the summaries from the splinter session chairs, N. Picot presented a summary of the J2 GDR-C reprocessing status and standards, on behalf of the four project partners.

Jason-2 GDR-C standards : evolutions already implemented :
(3 cycles were reprocessed before the OSTST)

- New J2 AMR processing and updates to work around the 34 GHz VFC anomaly
- Use of a null mispointing value in input of the C band retracking algorithm
- Use of LTM information filtered over X days
- New tide model (GOT00.2 replaced by GOT 4.7)
- Polar tide anomaly correction
- Long period non equilibrium tide anomaly correction
- SSHA on OGDRs computed when meteo grid are extrapolated
- NRT orbit quality flag in OGDR products
- Some complementary evolutions (specifications updates, typos in the products, etc.)
- Update of the altimeter characterization file and impacts
- Ice Flag in SSHA products
- New parameters in SGDR products (including all MLE3 derived parameters)

However, some additional evolutions should be implemented before Jason2 GDR_C processing starts:

- The wind is overestimated, and the SSB could/should be computed with a wind derived from MLE3 estimates.
  => N Tran has proposed a solution that will be reviewed by a dedicated sub group in the coming weeks to provide final advice to the project
- The ionospheric correction is underestimated.
  => the C band internal path delay will be reviewed to try to explain this bias. No artificial bias will be applied to align JA2 ionospheric correction to JA1
- An additional correction is needed to account for the pseudo datation bias and the reference plan bias, which will be implemented on JA2 GDR-C
- MLE3 parameter estimates are required in the GDRs products (not only in the sensor products)

Other improvements may be included before the Jason2 GDR_C processing starts, depending on their availability after validation :

- Update tide model with GOT 4.8 or 4.9
- Use high horizontal resolution ECMWF met files (N640)
- Include JPL GPS altitude information in GDRs products

The **tentative schedule for reprocessing :** beginning **after March/April 2011**. The JA2 GDR-C reprocessing should be completed before summer 2011. The reprocessing will start with the JA1/JA2 tandem phase in order to derive relative bias estimates between both missions. This relative bias shall be widely published by all projects communication means, in response to users complaints about the lack of available information on that topic.

A final point was to clarify the biases between the JA1(Poseidon 2) and JA2 (Poseidon 3) range measurements, which was originally discussed at the Seattle OSTST meeting in June 2009. N. Picot presented an overview of work done to better understand these biases, which should be small since both instruments (Poseidon2 and Poseidon3) are very close in term of hardware.

The CalVal studies show a JA1-JA2 range difference for the Ku Band of 8.3 cm during the tandem phase, obtained from global analyses or from the in-situ CalVal sites. Most of this relative range bias comes from an error in some parameterization files on Jason-1 and Jason-2 discovered by the project before the Seattle OSTST meeting in June 2009. There are 2 main components which contribute to this bias :

- A wrong altimeter PRF is applied today in the ground segment (Truncation effect) for both missions
- A wrong altimeter internal path delay value is used on JA1 (derived from ground measurement)

Parameter	**JASON1**	**JASON2**	**JAS-1/JAS-2 Difference**
PRF truncation effect	-0.316 cm	-2.471 cm	-2.156 cm
Alti correction for Ku band	4.151466 m	4.268487142 m	11.70211423 cm

The sum of these two errors creates a total difference for the Ku band of 9.5 cm, which explains a large part of the observed bias. The remaining difference in Ku Band is only ~ 1.2 cm.

If we also take into account the 10 mm bias on the ionospheric correction, the relative bias between Jason-1 and Jason-2 would be close to zero. This needs to be further investigated (notably on the C-band) but, if confirmed, both satellites are measuring sea surface consistently, and both are higher than T/P by about 20 cm.

The bias in the JA2 data from both sources will be corrected in the upcoming JA2 GDR-C reprocessing. The bias in the JA1 GDR-C data will not be corrected until JA1 GDR-D reprocessing is undertaken. Efforts will be made to clearly communicate a point on these biases, when the JA2 GDR-C data are released.

Satellite	GDR Release	Absolute bias included in GDR release	Additional bias to be applied by user to GDR release	Total absolute bias
Jason-1	GDR-C	85 mm	120 mm	205 mm
Jason-2	GDR-T	170 mm	25 mm	195 mm
Jason-2[*]	*GDR-C*	*195 mm*	*0 mm*	*195 mm*

[*]future release (mid 2011)

10.2 Future meetings

The OSTST meeting was followed on 21-22 October 2010 by a workshop entitled “Towards High-Resolution of Ocean Dynamics and Terrestrial Surface Waters from Space”, and by the IDS Workshop.

The next OSTST meeting is proposed to be held in the United States in October, 2011. The meeting venue will be confirmed by NASA in early 2011.