Report of the 2009 OSTST Meeting (edited by J. K. Willis)

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Executive Summary

The 2009 OSTST Meeting was held in Seattle, Washington on June 22-24. The meeting was co-hosted by the University of Washington with support from NASA and the Jet Propulsion Laboratory. The primary objectives of the 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) approve the release of the Jason-2 GDR, (4) conduct splinter meetings on various topics, a theme among which was the error budget of altimetry data products. This report along with all the presentations from the plenary, splinter, and poster sessions are included in a DVD which is to be distributed to all meeting participants.

Jason-1 is doing well except for the GPS receivers (TRSR), both of which have now failed. However, Jason-1 POD continues meeting the mission requirements based on DORIS and LRA. In February 2009, Jason-1 was maneuvered onto an interleaved orbit with a five day lag relative to Jason-2.

OSTM/Jason-2 was launched in June 2008 and flew approximately 55 seconds behinds Jason-1 for six months during the calibration/validation phase of the Jason-1/Jason-2 tandem mission. It now occupies the former ground track of Jason-1 and TOPEX/Poseidon. All systems are in good condition and the satellite is operating nominally.

Six keynote talks were presented during the meeting on subjects ranging from an update on science results of the tandem missions, to the status and prospects of other satellite altimeter, sea surface salinity and gravity missions, and the challenges of understanding and observing global sea level change. The Jason-1/TOPEX and Jason-2/Jason-1 tandem missions, in addition to providing critical periods of cross-satellite calibration, have provided improved sampling and resulted in numerous breakthroughs in understanding mesoscale variability in the ocean and its interaction with the large scale circulation, improvements of shallow water tides and increased operational use of altimeter wind/wave observations. Given the scientific and operational needs for better coverage and reduced errors, there will be an ongoing need for a constellation of altimeter satellites as well as a concerted effort to quantify errors across the numerous existing and upcoming missions. The Aquarius and SMOS satellites, to be launched in 2010, will provide observations of surface salinity. Combined with altimeter observations and estimates of ocean circulation, these will provide important insight into the marine freshwater budget. Launched in March 2009, the GOCE satellite is operating well and will soon provide estimates of the geoid that will be used to estimate the time-mean ocean dynamic topography with centimeter accuracy at 100 km scales. Knowledge of the geoid with sufficient accuracy could eventually pave the way for non-repeat altimeter missions.

Two of the keynote talks addressed observations of global mean sea level rise and served to open a plenary session on understanding errors related to global sea level rise. It was noted that rate of sea level rise during the altimeter era is significantly larger than the historical rate estimated for most of the 20th century. Furthermore, evidence suggests that the rate of mass loss in the cryosphere has accelerated since the early 1990s. It was also emphasized that relevance of sea level rise to society demands a careful accounting of the uncertainties in the numerous and complex measurement systems involved in the altimeter observations.

The plenary session on the sea level error budget contained several presentations highlighting the need for a more comprehensive understanding of both systematic and random errors in the altimeter data sets. Numerous sources of error were discussed, but of particular concern were the need to understand and reduce errors caused by inaccuracies in the reference frame as well as errors resulting from drifts and jumps in the radiometers onboard all of the satellite altimeters. After a discussion of the need for improvement of the radiometer data, the following recommendation was adopted by the OSTST:

> **Given the societal relevance and scientific importance of global sea level rise, and given the climate focus and operational nature of the Jason-3 mission, the Science Team recommends that the Project take steps to improve the accuracy of the global mean sea level measurement. This will ensure that global signals such as the ongoing rise of 3 mm per year and the 4 to 5 mm interannual fluctuations associated with ENSO will continue to be observed with sufficient accuracy and that data be released in a timely manner to facilitate monitoring of these signals. Although a Level 1 science**

requirement for global mean sea level accuracy was placed on Jason-2, only the radiometer design was updated from Jason-1 to achieve this capability. As a result, exhaustive scientific calibration activities have been required to ensure sufficient accuracy of the global sea level record. Furthermore, the Jason-2 radiometer is presently calibrated using natural Earth targets. This risks contamination by other climate signals and reduces the independence of the mean sea level measurement

Therefore, the science team recommends that a study be initiated immediately to identify all components of the measurement system whose drift could affect the globally-averaged sea level estimate. The study should indicate those components under Project control, and determine the cost and feasibility of complying with the Level 1 science requirement that existed for Jason-2: to "Maintain the stability of the global mean sea level measurement with a drift less than 1 mm/year over the life of the mission." The project should coordinate with the science team during and after the study, so that instrument stability requirements can be set before mission development begins and to ensure that Jason-3 meets this Level 1 science requirement.

The quality of the Jason-1 GDR-C and Jason-2 GDR-T were evaluated by several splinter groups. The analysis of the formation flight phase between Jason-1 and Jason-2 clearly show very good agreement between the measurement systems of the two satellites. The origin of the relative range bias between Jason-1 and Jason-2 (~70 mm) has been discovered recently (see “Summary of the in situ analysis key findings” in section 7.1.2). This needs further investigation (notably on the C band) but, if confirmed, both satellites are measuring sea surface consistently, but too high by about 20 cm. Investigations are in progress to explain the difference between Jason-1/2 and TOPEX.

After reviewing the status and accuracy of the Jason-2 GDR, the OSTST also made the following recommendation regarding its public release:

The Ocean Surface Topography Science team recommends that the OSTM/Jason-2 Geophysical Data Records, version T, be released to the general public. This recommendation is based on evidence presented at the OSTST meeting in Seattle that demonstrates the data on this product meets all mission requirements and has accuracy as good as, or better than, data from the Jason-1 Geophysical Data Records.

A splinter session was also devoted to analysis and discussion of altimeter data from inland and coastal regions. Several large efforts to improve altimeter data quality in these regions are underway. Results suggest that these data can be highly valuable and energetic participation in this splinter underscore that there is still considerable interest in continuing to improve and exploit altimeter data in these regions.

Finally, a summary of the status of development of the SWOT mission was presented by Doug Alsdorf. After discussion, the OSTST adopted the following recommendation regarding SWOT:

Recognizing the urgency of making new observations for fundamental understanding of

1. **the vertical transfer of heat and nutrients in the ocean for improving ocean climate prediction models,**
2. **the storage and discharge of land water for improving the prediction of the shifting freshwater supplies in a changing climate,**
3. **the interaction between ocean currents, sea ice, ice shelf, and ice sheets for improving the prediction of polar ice melting, the Ocean Surface Topography Science Team recommends that NASA and CNES allocate the necessary resources for a speedy development of the SWOT mission including prelaunch campaigns for collecting field data supporting the validation of the measurement approach.**

1. Introduction

The 2009 OSTST Meeting was held in Seattle Washington, on June 22-24. The meeting was hosted by the University of Washington with support from NASA and the Jet Propulsion Laboratory.

The meeting was opened by L-L Fu, the NASA Project Scientist for the Jason Mission. In his opening remarks, Fu noted that the following last OSTST meeting in Nice, the decision to move Jason-1 into an interleaved orbit with a 5 day lag had been successfully carried out and the two satellites are now providing improved spatial and temporal coverage. He also presented the agenda for the present meeting and charged the Science Team with evaluating the Jason-2 GDR and coming to a decision on its public release. Finally, he introduced Rosemary Morrow, Juliette Lambin and Josh Willis as new Project Scientists.

2. Program and Mission Status

L-L. Fu introduced E. Lindstrom and E. Thouvenot to speak on the status of altimetry and oceanography programs at NASA and CNES, respectively. Lindstrom noted that 26 U.S. PIs had been selected to for the new OST Science Team for the next 4 years. The next solicitation will likely appear in NASA's 2011 ROSES solicitation with proposals due in March 2012. He also noted that a 4-party MOU has been drafted between NASA, NOAA, CNES and EUMETSAT for the upcoming Jason-3 mission.

Thouvenot reported on the CNES altimetry program with a focus on Jason-1, Jason-2 and SARAL/AltiKa. AltiKa is to be part of the SARAL Mission (joint mission with the Indian Space Research Office) and is tentatively scheduled for launch in late 2010. CNES also committed to the contribution of a Proteus spacecraft and project team support to Jason-3, which is being planned as a joint mission involving CNES, EUMETSAT, and NOAA. The launch date is being contemplated for 2013. CNES is also planning for participation in wide-swath altimetry (SWOT).

F. Parisot discussed EUMETSAT's involvement in altimetry programs with a focus on Jason-3 and it potential follow-on, Jason-CS. EUMETSAT is seeking to contribute 60 M Euros to Jason-3. Program approval is expected by the end of 2009 and launch of Jason-3 by mid-2013. A 4-party MOU between NASA, CNES, NOAA and EUMETSAT is under development with the program being led by NOAA and EUMETSAT. Preliminary discussions have begun for planning the follow-on to Jason-3: Jason-CS (continuity of service). Finally, EUMETSAT will be involved in the operation of Sentinel-3, and will also support SARAL.

J. Lillibridge and L. Miller discussed NOAA’s roles in the Jason-2 and Jason-3 missions. For Jason-2, NOAA is providing satellite command and control and is producing and distributing the OGDR. Data recovery is good (~99.9%) and NOAA is meeting distribution requirements. NOAA has proposed $210M budget for Jason-3, to pay for launch, radiometer, GPS, satellite command and control, telemetry, near real-time data processing, data archiving and distribution. Although, the budget is not final, Congress has proposed $20M for an FY2010 start for Jason-3. NOAA has also identified sea level rise as a major theme of any new U.S. Climate Service. Finally, NOAA is developing a radiometer calibration project to ensure smooth transition of Jason-3 from research to operations.

J. Benveniste gave a presentation on the status of ESA missions. GOCE was successfully launched march, 2009, and is working well. First science assessment will occur at the end of June, and a workshop will be planned for the beginning of 2010. Cryosat will launch in Nov 2009 and provide classical altimetry data over land. SMOS is scheduled for launch on 9/9/09. ENVISAT, now 7-years old, will enter a new orbit in Oct 2010. Sentinel-3 is under development. Finally, ESA has initiated the “Global Monitoring of Essential Climate Variables” program element. This will include reprocessing of ERS-1/2 & ENVISAT data to improve quality.

3. Jason-1/2 project and program status

G. Zaouche provided an overview of Jason-2 status. The first Jason-2 REVEX was held Apr 28-30, 2009 in Toulouse Space Center. The satellite is operating well and all instruments are fully operational after one year of the mission. OGDR is now being delivered, beginning Dec 15. 2008, IGDR since mid-Jan 2009, and the GDR has been made available to PIs. The Poseidon-3 altimeter has had 100% data availability since the last OSTST; the only losses have been due to software updates. A new DEM has been uploaded, but final tracker mode still to be selected. The DORIS system is working well. Most of the 8.3 cm absolute altimeter bias between Jason-1 and Jason-2 in the Ku band has been related to differences in the characterization parameters set during ground measurements. The remaining difference between Jason-1 and Jason-2 is about 1 cm, but investigations are still in progress to explain the difference between Jason-1/2 and TOPEX.

G. Shirtliffe provided an overview of Jason-1 status. As agreed at the previous OSTST meeting in Nice, Jason-1 was maneuvered into a new orbit that is interleaved and has a 5 day lag relative to the Jason-2 orbit. Jason-1 continues to meet and exceed all Level 1 science requirements. Jason-1 has a 67% probability to live to April 2011, and sufficient fuel to go back to its original orbit if needed. In Sept 2009, the NASA Senior Review Panel recommended that funding for Jason-1 be extended to 2013, with another review scheduled for 2011. Because TOPEX can no longer be maneuvered, Jason-1 and OSTM/Jason-2 must monitor the drift of TOPEX/Poseidon and possibly initiate avoidance maneuvers. Furthermore, CNES and JPL have agreed to set up a joint working group in order to plan an orderly decommissioning and disposal of the Jason-1 satellite in order to minimize the collision risks to current and future OST missions. Despite loss of both TRSR 1 and 2, Jason-1 is still meeting Level 1 POD requirements with 1.5 cm RMS precision.

4. Keynote Talks

An overview of tandem mission results, the status of other missions, including altimeters, ocean salinity missions and gravity missions were presented in a series of keynote talks. In addition, two keynote talks addressed issues regarding the observation of global sea level rise from space and preceded a plenary session on error budgets for altimeter observations. Links to the keynote talks are available on the meeting website: http://sealevel.jpl.nasa.gov/OSTST2009/index.html.

Jason1 Tandem Mission: Early results – J. Willis

Status of other altimetry missions: Altika, Cryosat, Sentinel-3, Jason-3, Chinese programs, etc – J. Lambin

Linking ocean circulation, the water cycle and climate: New science opportunities with salinity satellite missions – G. Lagerloef

Absolute ocean circulation from altimetry: Current status and prospects for the upcoming GOCE era. – M.-H. Rio

Sea Level Change: Past, Present, and Future – S. Nerem

Sampling and systematic errors in the global sea level change problem – C. Wunsch

5. Plenary Session on Altimeter Sea Level Error Budgets

A Plenary session on Wednesday was devoted to sea level error budgets, emphasizing the current status as well as the need for future improvements. The session was chaired by R. Ponte, J. Dorandeu and A. Lombard.

There were 8 formal talks and 5 poster contributions on a wide variety of issues. Full details of the talks and posters can be found on the meeting website.

The topic of the session was briefly introduced by Ponte, followed by an overview given by Dorandeu, both emphasizing the need for a vastly expanded treatment of the errors across the range of available altimeter datasets. Details on the systematic and random components of the errors, their spatial and temporal characteristics, correlations structures, and other properties, are needed to allow for best use of the data by the diverse user community and provide insight on how to improve error budgets of future altimeter missions.

A particular focus of the session was the uncertainty underlying altimetric estimates of global mean sea level (GMSL), following the two keynote talks by Nerem and Wunsch on the subject. Ablain reviewed the impact of several altimeter corrections on the determination of trends in GMSL, showing that possible biases and trends in those corrections can amount to uncertainties larger than the formal errors derived from trend residuals. The talk by Mitchum revisited the calibration of altimeter GMSL values based on tide gauge records. A major uncertainty in these calibrations results from land motions affecting the tide gauges. Mitchum pointed out that reference frame issues can impact the quality of GPS-derived land motion corrections and need to be better understood, before tide gauge calibrations can be improved.

Still related to the GMSL topic, talks by Chambers and Brown highlighted the poor stability of the radiometers that have been flown in current and previous altimeter missions and addressed the need to have tighter (as well as more timely) constraints on the wet tropospheric path delay corrections, if major problems with determination of GMSL are to be avoided. Brown discussed new internal calibration procedures for the radiometer to be flown in Jason-3 that would eliminate much of the problems experienced with previous missions. A recommendation to tighten the requirements for the Jason-3 radiometer was proposed by Chambers. Final drafting of the text was discussed at the end of the session, and a consensus was reached to recommend that study should start immediately on the feasibility of maintaining stability of the Jason-3 measurements to better than 1 mm/yr in GMSL over the lifetime of the mission. See the Executive Summary or Appendix for the text of the recommendation.

Tide corrections are very important for altimetry and errors in available barotropic tide models were addressed by Ray. Comparisons with tide gauge records and formal uncertainties associated with inverse tide solutions provided roughly consistent error estimates, amounting to ~2 cm RMS in the deep ocean but much larger and with considerable spatial structure in shallow and coastal regions. Contributions from errors of omission as well as comission, especially related to compound tides in shallow areas, were both deemed important. Still on the topic of tides, Lyard addressed the contributions of data errors, e.g., caused by non-tidal oceanic variability and land contamination near the coasts, to the uncertainties in present tide corrections that are derived from data-constrained hydrodynamic models. He discussed various methods to improve assessment of uncertainties in altimeter-derived tidal constants for better assimilation results. Future plans to patch regional and global tidal solutions were also discussed.

Another important altimetric correction deals with the sea state bias (SSB). Vandemark reviewed the empirical basis of the SSB correction, stressing the lack of independent ground truth and the intricate relation between SSB, climate variables such as significant wave height and wind speed, and all issues affecting altimeter range measurements (orbits, tides, etc.). He described possible improvements in the SSB correction from using wave models as an extra input, which can explain some of the spatial differences in bias seen for example at calibration stations like Corsica and Harvest. Vandemark summarized the present estimates of SSB errors over various spatial and temporal scales and discussed possible refinements for SSB corrections in the future.

One final topic, covered by Kaplan, was that of errors in gridded altimeter surface height fields, which are commonly used in many data applications. Kaplan described error parameterizations in terms of the sampling errors involved in the grid box averages and verified results by comparisons with tide gauge records. The method provides spatial error maps that can be physically interpreted in terms of short-scale (mesoscale) variability. Examples of errors in monthly gridded altimetry fields and along-track 1-deg averages of T/P data were presented with regards to "true" 4-deg longitude by 1-deg latitude monthly means. These error maps can be readily used to appropriately weight such types of sea level data in assimilation procedures for models with equivalent grid resolutions.

6. Poster Sessions

Two poster viewing sessions were conducted. Links to the posters are available on the meeting website: http://sealevel.jpl.nasa.gov/OSTST2009/index.html. The posters were grouped into the following categories:

- General ocean surface topography science results (modeling/data assimilation, mean dynamic topography, tropical ocean, coastal ocean, sea level, ocean circulation/air-sea interaction, ocean eddies, land/ice/hydrology)
- Sea level error budgets: current status and future improvements
- Global and in-situ calibration and validation
- Precision orbit determination and geoid
- Instrument processing
- Near real-time products validation and application
- Coastal and inland altimetry
- Outreach

7. Splinter Sessions

The theme for the splinter sessions (in particular for cal/val, POD/geoid, tides/HF aliasing, sea-state bias/retracking) was evaluation of the Jason-2 GDR product with a goal of recommending it for public release by the end of the meeting. The splinter sessions were organized as follows:

- Local and Global Calibration and Validation

- Instrument Processing
- Precision Orbit Determination and Geoid
- Near Real-Time Products Validation and Application
- Outreach/Education
- Inland/Coastal Altimetry
- General Ocean Surface Topography Science

7.1 Local and Global Calibration and Validation (P. Bonnefond, S. Desai, B. Haines, S. Nerem, N. Picot)

7.1.1 Introduction

The primary goals of this session were:

- Joint analysis of Jason-1 and Jason-2 data from the tandem verification phase. Emphasis was placed on unique insight afforded by the cancellation of common mode errors in formation flight.
- Validation of all available Jason-2 test GDRs, including data collected after the end of the verification phase. We were 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 were 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 was the impact of these products on reducing relative geographically correlated error (GCE) observed in the Jason-1/TP (2002) tandem verification phase.

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.

7.1.2 Results from In Situ Calibration Sites

Haines et al. presented the whole altimeter time series of the T/P, Jason-1 and Jason-2 missions using updated GDR data (see Figure 1). While T/P remains statistically unbiased (< 2 cm), both Jason-1 and Jason-2 are measuring SSH too high, by +10 and +17 cm respectively. He also presented the calibration of Jason-1 and Jason-2 altimeter on the C-band: this study demonstrated that for Jason-2 the bias is higher by about 5 cm on the C-band compared to the Ku-band and explains the ~1 cm discrepancy on the dual frequency ionospheric correction. *Haines et al.* also presented the long series of radiometer monitoring using GPS data (Figure 2): the radiometers show good stability (better than 1 mm/yr); JMR and AMR appear to be biased by 6.5 and 4 mm, respectively. At this level, however, the systematic errors in the GPS-determined path delays (e.g., from the radome) cannot be discounted.

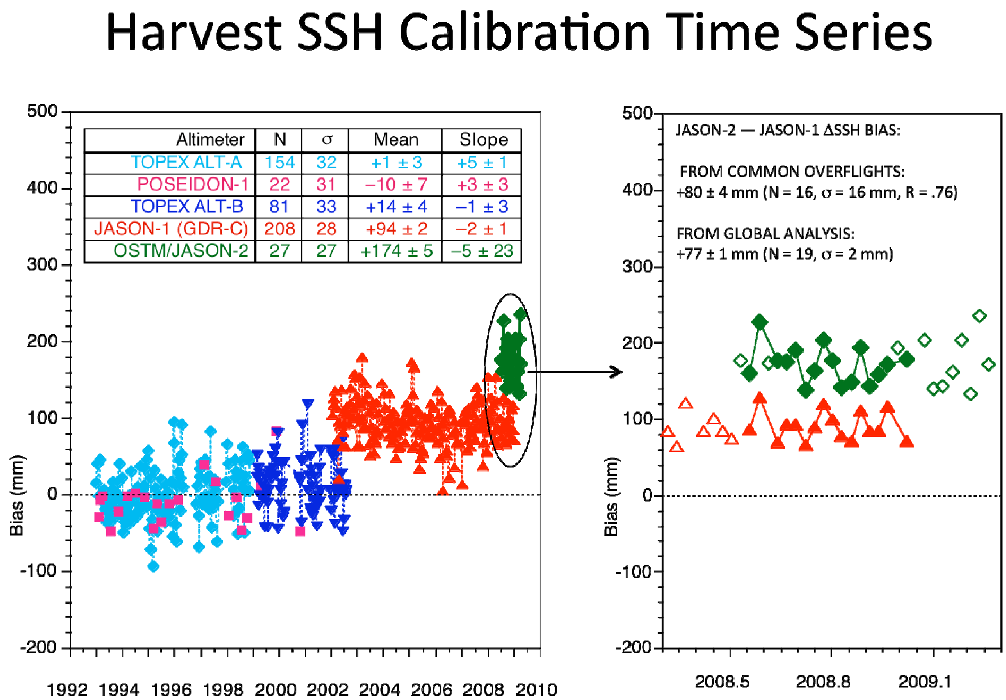


Figure 1. *Absolute bias time series for TOPEX/Poseidon, Jason-1 and Jason-2 from Harvest calibration site (left). Zoom on the Jason-1 and Jason-2 formation flight phase (right).*

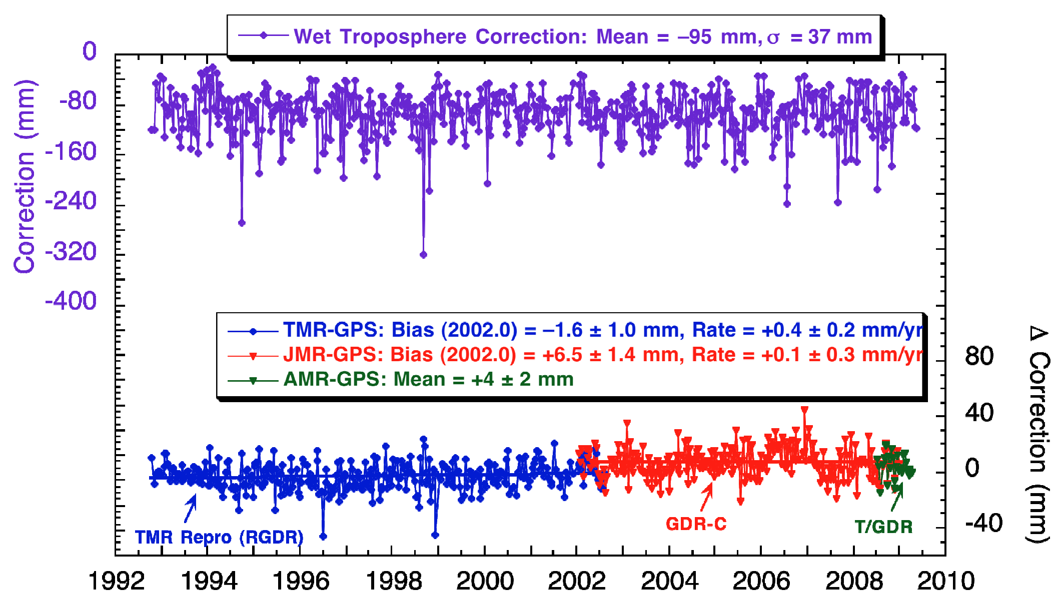


Figure 2. *Time series for TOPEX/Poseidon (TMR), Jason-1 (JMR) and Jason-2 (AMR) of the radiometer wet tropospheric correction differences with the GPS derived one.*

Based on similar analysis and with the same data products (see Figure 3) *Bonnefond et al*. also showed these time series for the Corsica calibration sites. He also presented a study of the wet tropospheric correction at the Corsica approach, which demonstrated that the new AMR coastal path delay algorithm significantly reduces land contamination. As shown in Figure 4, an external validation using wet tropospheric corrections derived from GPS shows better agreement with this new correction (+2 mm) compared to the wet tropospheric corrections on the standard GDR-T (13 mm).

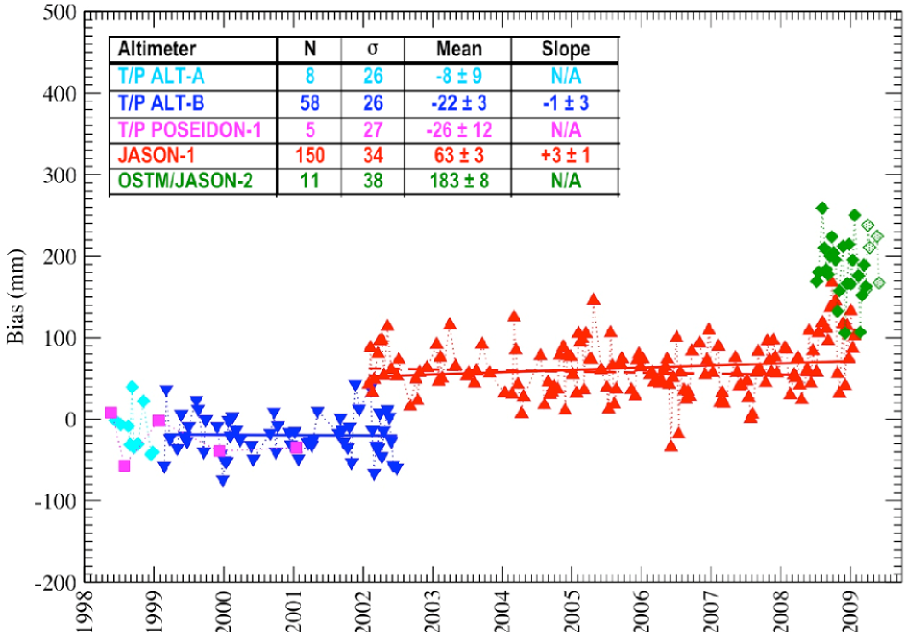


Figure 3. *Absolute bias time series for TOPEX/Poseidon, Jason-1 and Jason-2 from Corsica calibration site.*

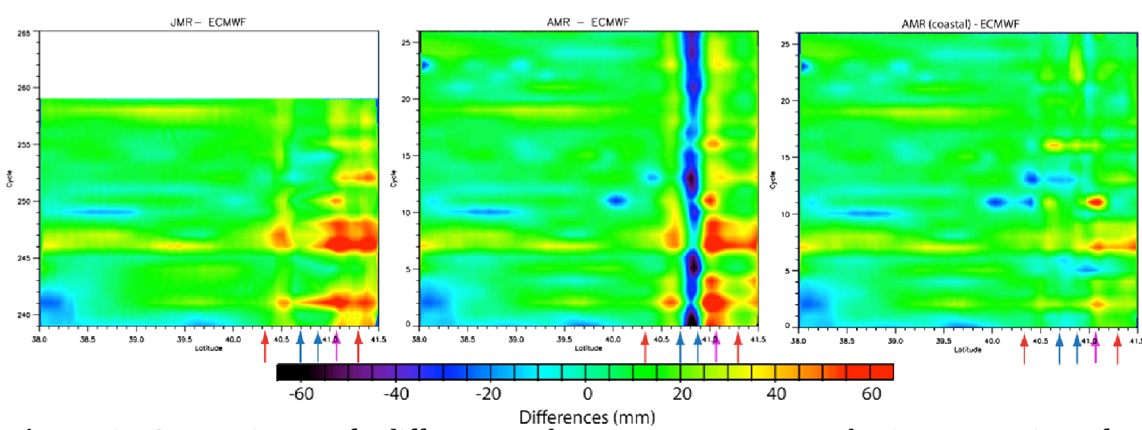


Figure 4. *Comparison of differences between wet tropospheric correction from radiometers and ECMWF model at Senetosa (Corsica calibration site); for (a) Jason 1/JMR (cycle 239 to 259), (b) Jason 2/AMR and (c) Jason 2/AMR coastal (cycle 0 to 26); the Formation Flight Phase (FFP) correspond for Jason 1 of cycle 239 to 259 and for Jason 2 to cycle 0 to 20. The colored arrows on the latitude axis correspond (from left to right) to: 30 km off Sardinia coast for the first red one, the overflight of Sardinia etween the two blue ones, the end of the small Asinara Island is illustrated by the purple one, the last red one corresponds to 30 km off the coast of Corsica.*

N. White presented *Watson et al*. results for the Bass Strait calibration site. The presentation was mainly dedicated to Jason-1 and Jason-2, and summarized the local infrastructure changes: new comparison point, new GPS buoy design, new CGPS sites and FTLRS laser station campaign. Results for Jason-1 and Jason-2 based on GDR-C data are very consistent with other in situ data (see Figure 8). The analysis of the correction differences (Figure 5) between Jason-1 and Jason-2 during the formation flight is consistent with those conducted at Harvest and Corsica, and shows that the main and constant part of the differences comes from the ionospheric correction.

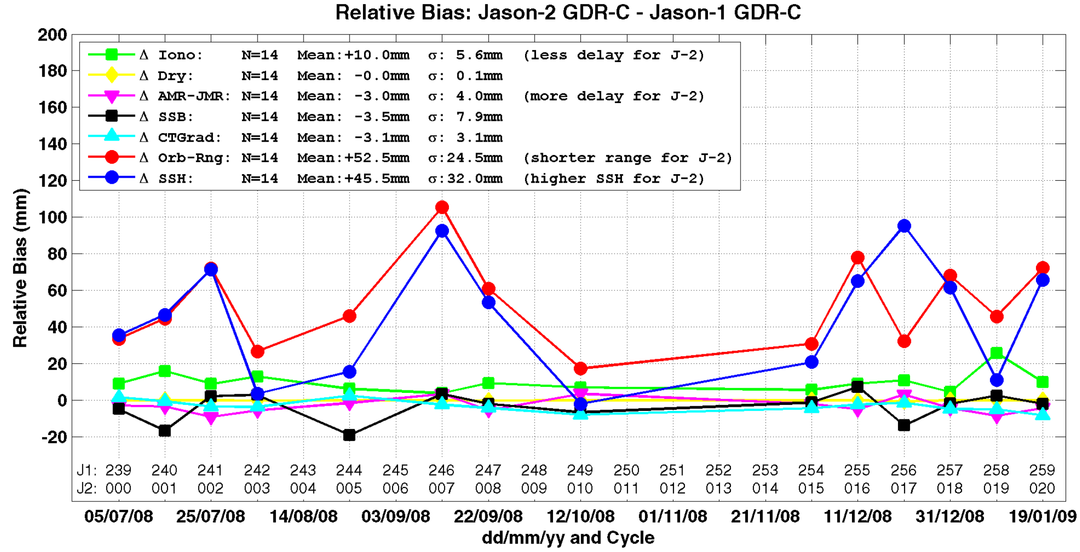


Figure 5. *Details of the corrections differences between Jason-1 and Jason-2 during the formation flight phase from Bass Strait calibration site.*

Mertikas et al. gave also a presentation on Gavdos results for Jason-1 and Jason-2 using their recently upgraded analysis. The absolute altimeter bias of Jason-2 has been determined using cycles 2 to 20 (Figure 6). Results for Jason-1 and Jason-2 are very coherent with those from other in situ calibration sites (Figure 8).

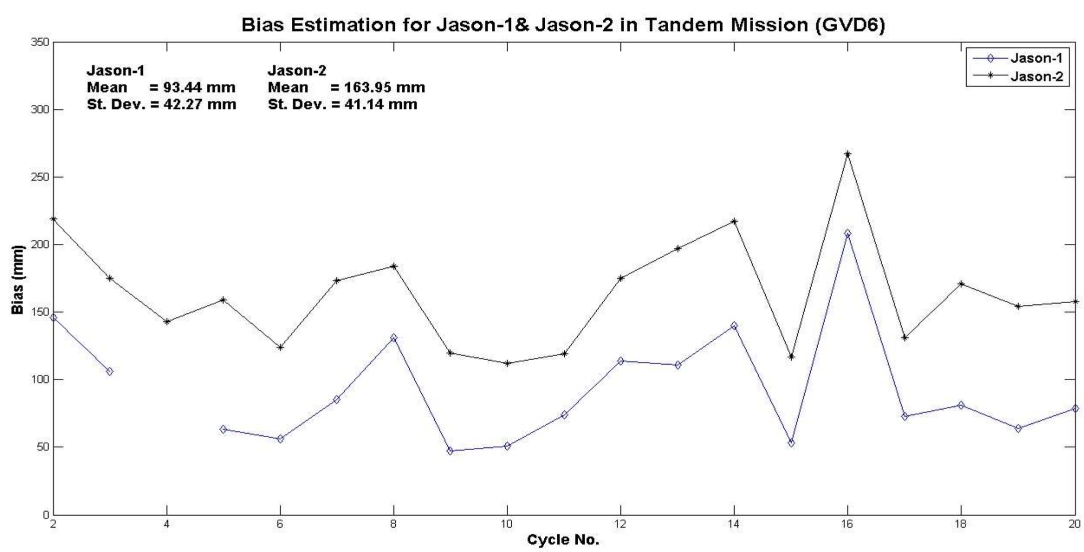


Figure 6. *Absolute biases time series for Jason-1 and Jason-2 from Gavdos calibration site during the formation flight phase.*

Jan et al. presented the results of the altimeter calibration using in situ data from the Corsica calibration site but not only for the pass #085 which over-flies the site but also for 2 other passes (#009 and #222) at distances of up to 200 km (Figure 7). Results for these 3 passes and for Jason-2 are coherent at the cm level with a mean value of 174 mm for the altimeter bias. The study for Jason-1 was conducted for pass #085 only and shows coherent results with the other in situ calibration sites (Figure 8).

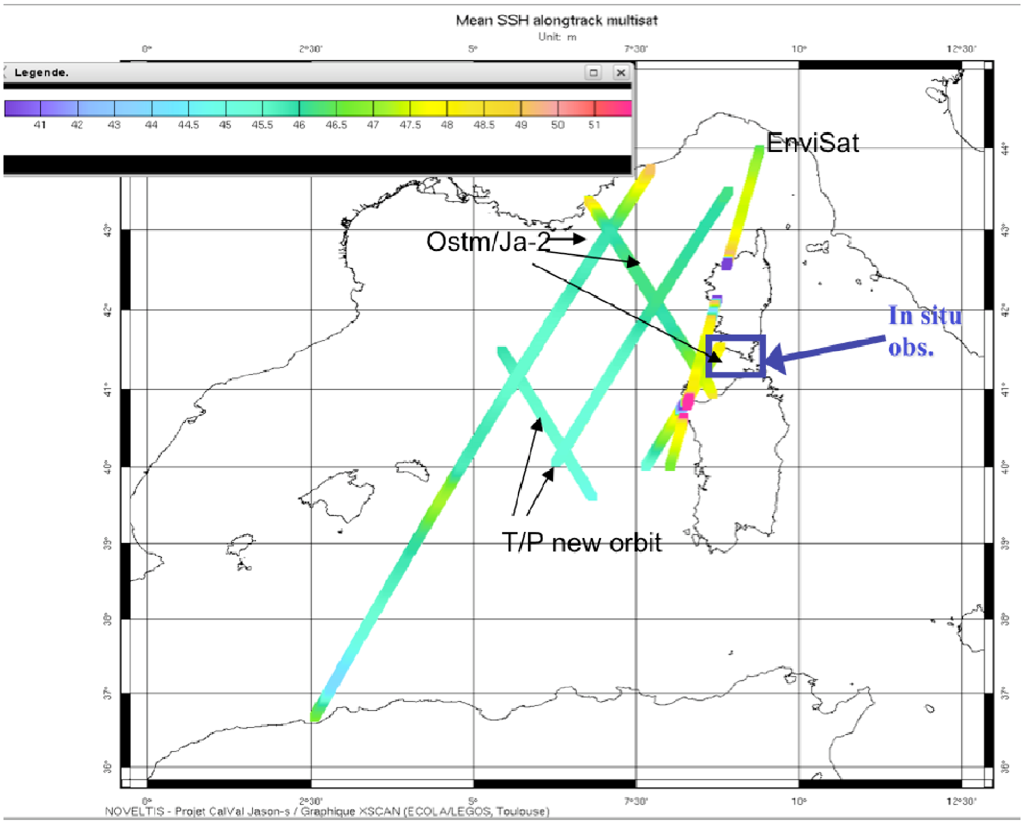


Figure 7. *Configuration of the regional in situ CALVAL technique.*

Summary of the in situ analysis key findings:

- Coherence of Jason-1 and Jason-2 SSH bias time series for all calibration sites reveals similar behavior of the two measurement systems (*Haines et al.*, *Bonnefond et al.*, *Watson et al.*, and *Mertikas et al.*).
- New coastal AMR product clearly improves agreement with GPS-derived path delay for coastal approaches; waiting for this improvement for JMR; from in situ studies this new correction increases the Jason-2 bias by 5 to 11 mm (*Haines et al.*, *Bonnefond et al.*, and *Watson et al.*).
- Differences between absolute biases have been observed at the various calibration sites of up to 15 and 30 mm respectively for Jason-1 and Jason-2. This probably reflects geographically correlated errors, but it is not clear which ones. Orbit errors seem unlikely, but wet tropospheric correction and SSB (see D. Vandemark presentation) surely contribute. In situ effects also contribute.
- ~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 (*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 (73 mm, see Figure 8) seems to come from an error in some parameterization files on Jason-1 and Jason-2 recently discovered by the project (purple lines in Figure 8). 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 73 mm to -22 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 of the order of -15 mm. 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.

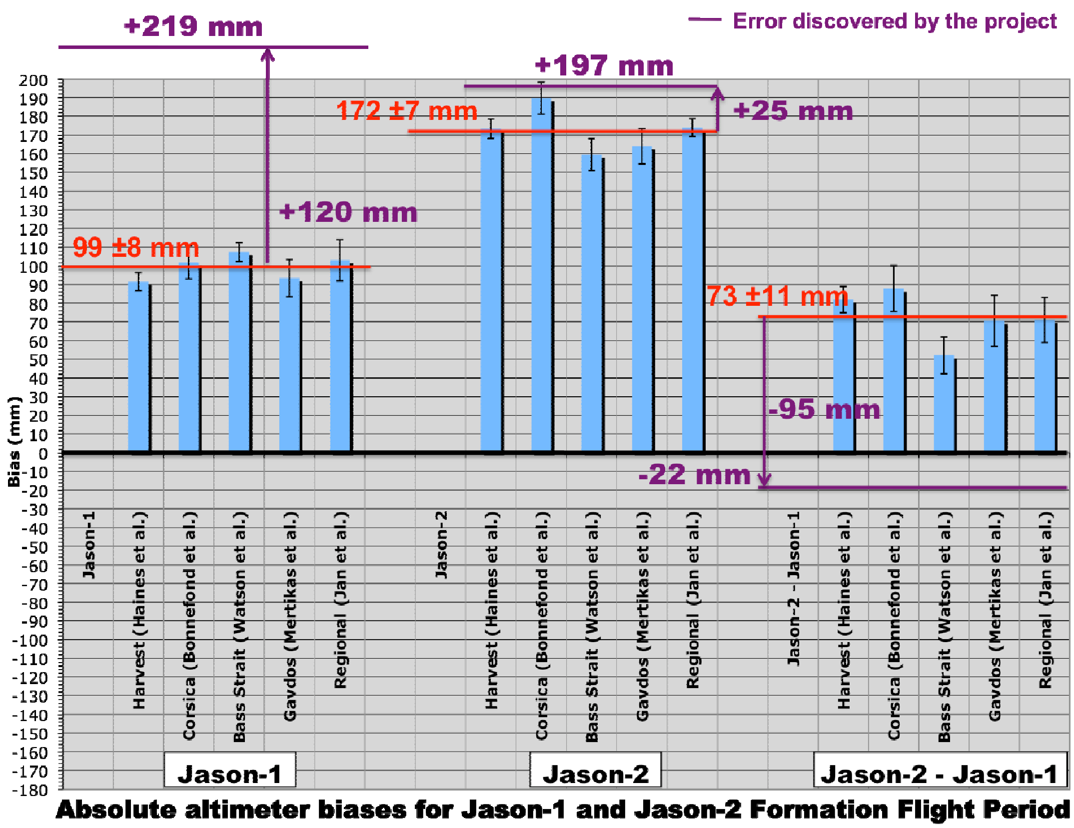


Figure 8. *Absolute bias values for Jason-1 and Jason-2 from the different calibration sites during the formation flight phase. Red lines and associated numbers correspond to the average of all individual sites values. Purple lines and associated numbers correspond to the absolute biases if corrected from the error recently discovered by the project.*

7.1.3 Results from Global Comparisons of Tide Gauges and Altimetry Sea Level Records

Han et al. presented comparisons of satellite altimeter data, reconstructed sea level, and tide gauge observations in the Indian Ocean.

- T/P, Jason-1 and Jason-2 (GDR) data have comparable agreements with the tide gauge observations in the Indian Ocean, with correlation coefficients generally exceeding 0.84, except in the northern Bay of Bengal (BOB) and Persian Gulf, where correlation coefficients are low (~0.6) or even negative and RMSE is large (121 cm at station 138a);

- The temporal variations and linear trends of basin-averaged SLA from AVISO and TPJ1 gridded data (1992-2008) agree very well; the RMSE of (AVISO-TPJ1), however, shows regular spatial patterns with large errors (~8 cm) south (north) of 20S (10N) and near the western boundary (Figure 9);
- The reconstructed sea level reproduces the mean seasonal cycle well; its linear trend of basin-mean sea level, however, is much larger than that of the satellite data; its temporal variability and amplitude do not seem to agree well with the tide gauge data.

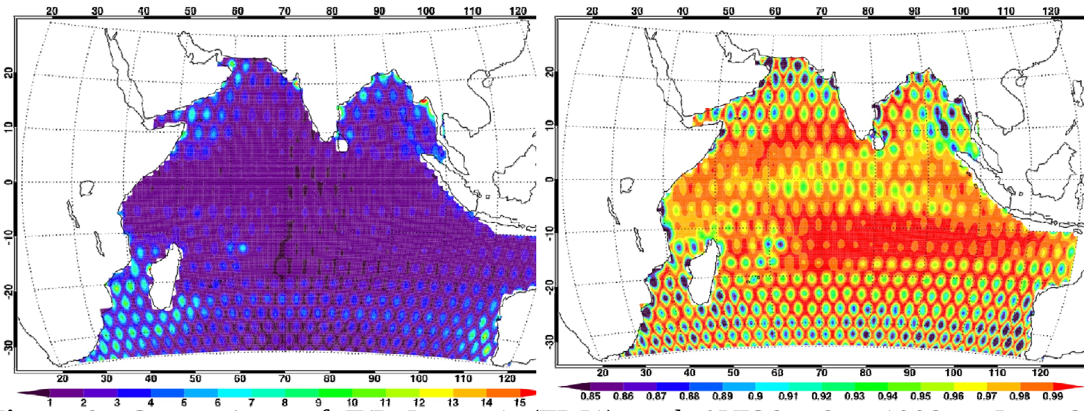


Figure 9. *Comparison of T/P-Jason 1 (TPJ1) and AVISO: Oct 1992 - June 2008, Weekly, 1/3 x 1/3 degree; RMS difference at left and correlation coefficient at right.*

Ablain et al. presented a quality assessment of tide gauge and altimeter measurements through sea surface height comparisons. This study demonstrates the ability of the method to detect an altimeter drift:

- Envisat MSL drift = -2.2 mm/yr: consistent with global Cal/Val analyses, and is mainly due to inhomogeneous products,
- TOPEX A drift = +1.3 mm/yr (Figure 10): this result has to be analyzed thoroughly, especially testing the impact of retracked T/P data,
- No significant drift for Jason-1 with tide gauges is observed: -0.1 mm/yr, but the errors of the method are also significant,
- The formal error of the adjustment (on the order of 0.2 mm/yr),
- The uncertainty to take into account the vertical land movements,
- Sensitivity to the numbers of tide gauges, which impacts the drift at the ± 0.2 mm/yr level.

The overall uncertainty in the drift estimate is close to ± 0.5 mm/yr over the whole altimeter period. It is larger than the drift estimate itself (altimeter vs tide gauge) from the combined Jason-1 and T/P record (+0.2 mm/yr). The accuracy of the method could be improved using tide gauges corrected for jumps, using an extended GPS station network, and improving the collocation method.

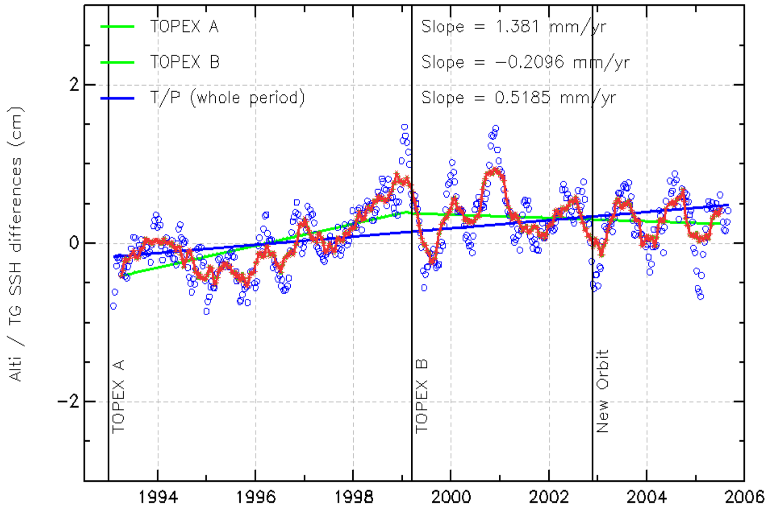


Figure 10. *T/P – tide gauges sea surface height time series.*

Leuliette et al. presented a study about tide gauge and inter-satellite calibrations of Jason-1 and Jason-2 geophysical data records. The relative biases from tide gauge calibration (Figure 11) are very close to those derived from the absolute biases computed from in situ sites (Figure 8).

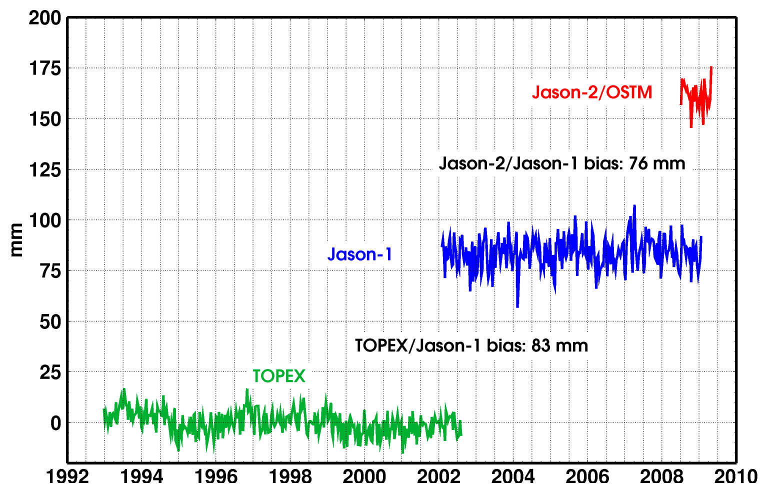


Figure 11. *Relative biases from tide gauge calibration.*

The conclusions of the inter-satellite calibration studies are:

- Jason-2 – Jason-1 1-sec. residuals have a 1.0 mm RMS when averaged over a repeat cycle.
- The Jason-2 – Jason-1 bias depends on off-nadir angles (Figure 12).
- Concerning the tide gauge calibration, the studies show:
    - JMR correction product reduces drift rate of Jason-1 to less than the error of calibration.
    - Jason-1 mean sea level has a significant 58-day signal (Figure 13). Comparisons with the TOPEX interleaved mission shows that the sea level residuals are correlated with solar intensity

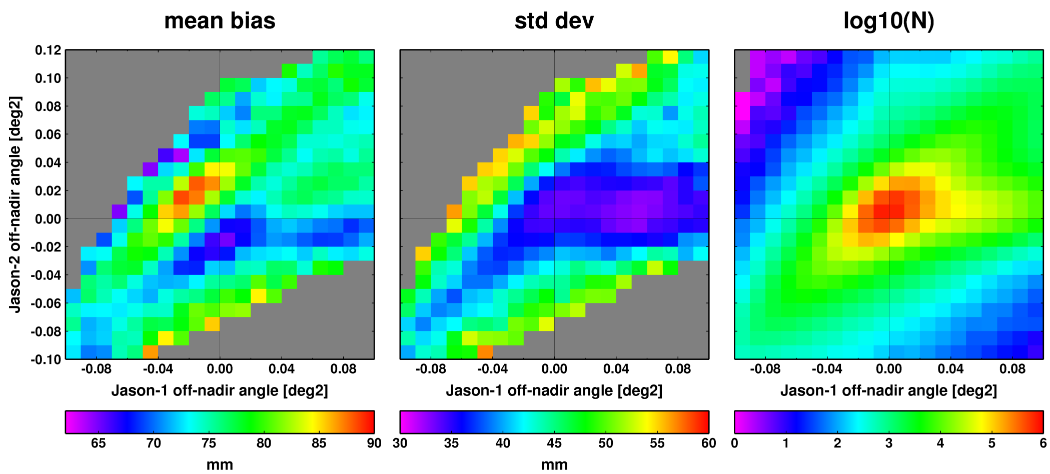


Figure 12. *Jason-1/Jason-2 bias tracker bias dependence on nadir angle.*

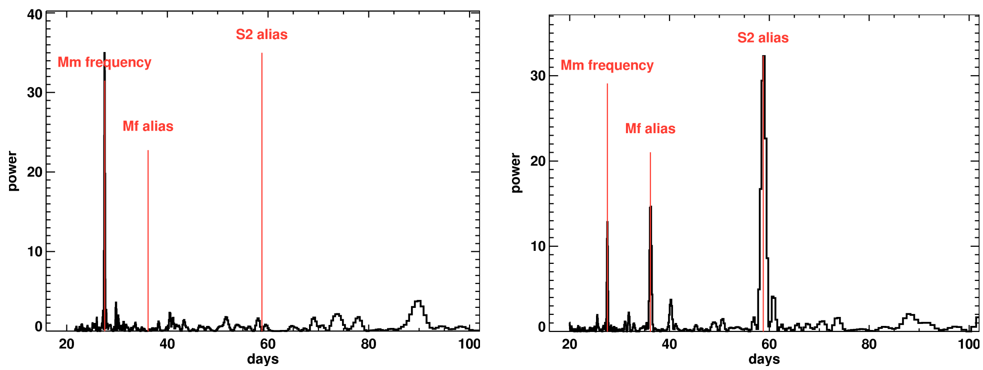


Figure 13. *Power spectrum of altimeter – tide gauge time series: left for T/P and right for Jason-1.*

Beckley et al. presented the assessment of Jason-1 and OSTM global verification phase through sea surface height collinear residuals. The conclusions of this study are:

- GDR-C JMR replacement product more consistent with OSTM/Jason-2 AMR wet troposphere correction (Figure 14).
- Excellent agreement between OSTM/Jason-2 and Jason-1; STD < 1 cm for both project GDR and GSFC orbit revealing low tracker bias (Figure 15). SLR/Doris more than adequate for Jason-1 extended tandem mission.
- OSTM/Jason-2 SSH bias of 76 ± 9 mm with respect to Jason-1 (Figure 16).
- OSTM/Jason-2 relative range bias (compared to Jason-1) in both Ku (84 mm) and C band (131 mm) results in ~ 1 cm ionosphere correction bias.
- Jason-1 drift rate with respect to tide gauge network reduced with revised GDR-C, though variance still higher than TOPEX benchmark. Bias estimates from tide gauge comparisons agree well with bias estimates derived from verification phase collinear SSH residuals.

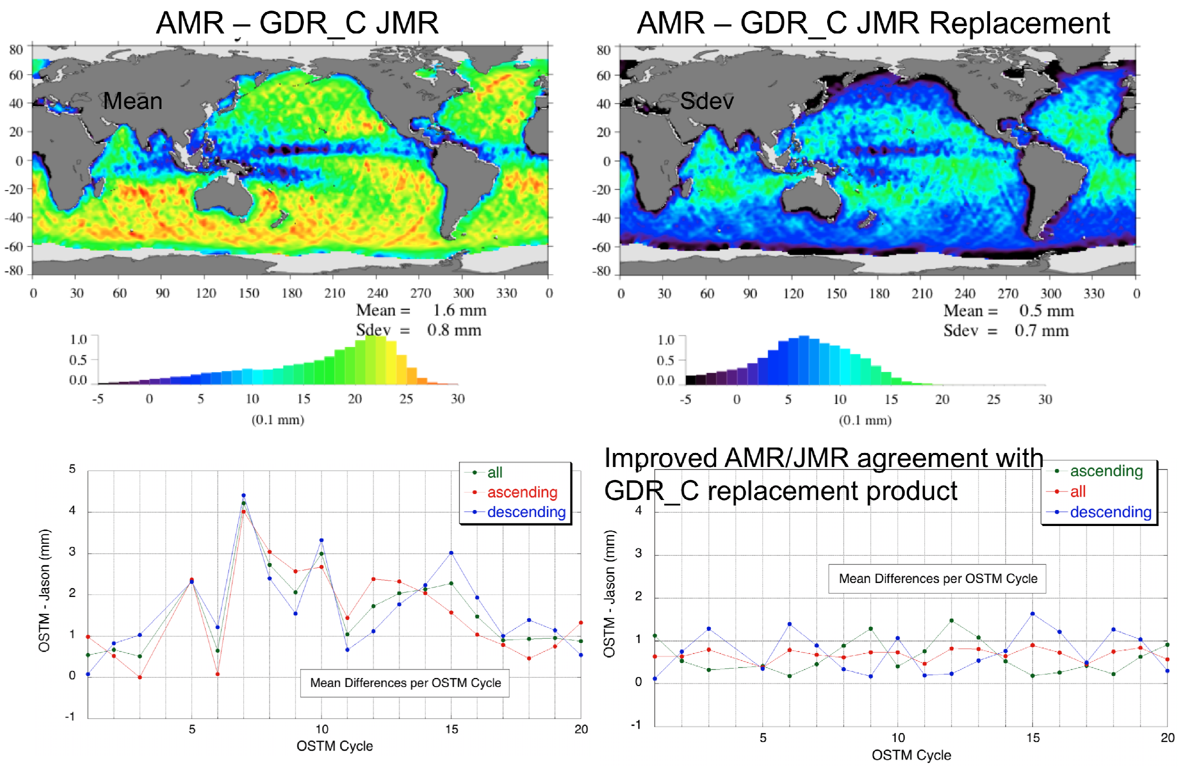


Figure 14. *Improvement of the AMR/JMR differences thanks to the JMR replacement.*

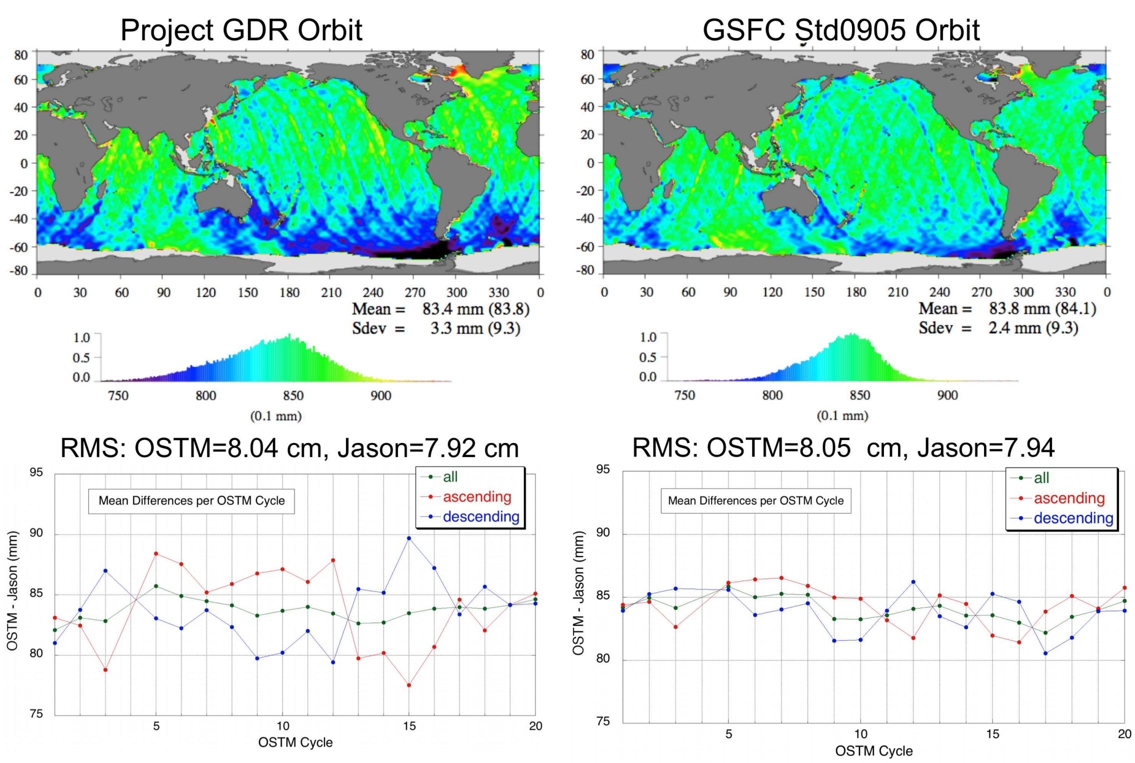


Figure 15. *Impact of GSFC SLR/Doris Replacement Orbits.*

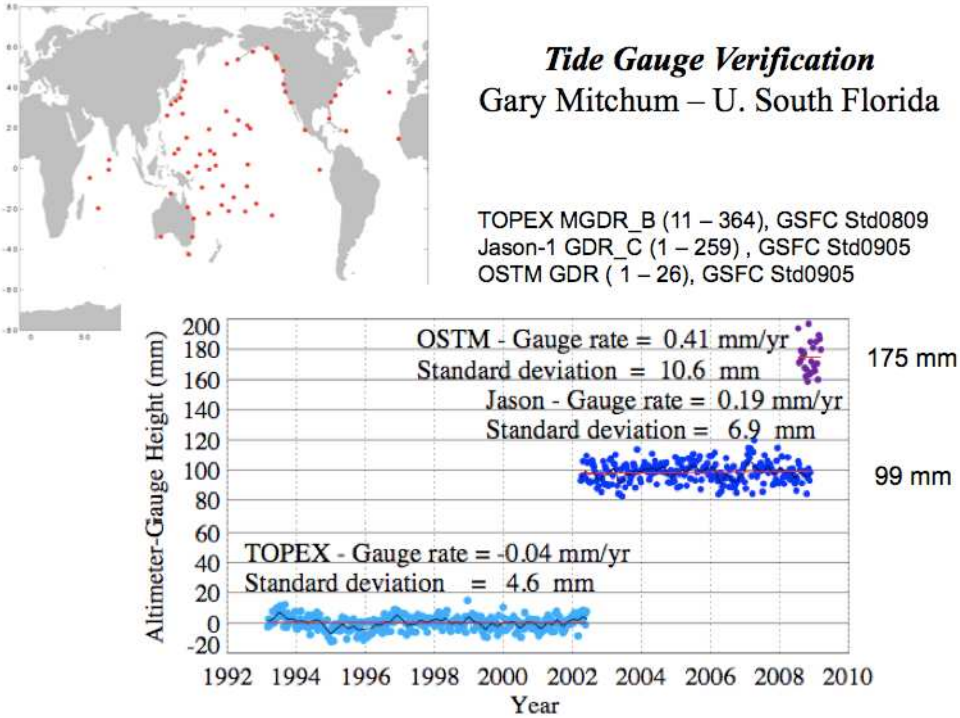


Figure 16. *Tide gauge calibration using the latest orbits from GSFC (std0905).*

Summary of tide gauges versus altimetry global analysis key findings:

- No clear drift of the Jason-1 measurement system (with new JMR replacement product, *Ablain et al.*, *Beckley et al.* and *Leuliette et al.*)
- No clear drift of the T/P measurement system over the whole mission (differences between ALT-B and ALT-A should exist, see Figure 10 from *Ablain et al.*)
- Relative range between Jason-2, Jason-1 and T/P (reference) is in very good agreement with the absolute mean derived from in situ analysis: 175 mm (172 mm from in situ, see Figure 8) for Jason-2 and 99 mm (99 mm from in situ, see Figure 8) for Jason-1 (*Beckley et al.*)
- The Jason-2/Jason-1 relative SSH bias depends on off-nadir angles (*Leuliette et al.*)
- Ionospheric correction bias on Jason-2 confirmed to come from different biases on Ku and C band (*Beckley et al.*)
- Jason-1 mean sea level has a significant 58-day signal. Comparison with the TOPEX interleaved mission shows that the sea level residuals are correlated with solar intensity (*Leuliette et al.*).
- No clear impact of new set of orbits, standard GDR-C ones from CNES are already very good (*Beckley et al.*).

7.1.4 Global Validation Studies

Phillips et al. presented a detailed study of all the parameters using Jason-2 cycles 1-20, during the formation flight configuration with Jason-1; this study shows:

- Very good consistency between altimetric parameters of Jason-2 and Jason-1
- Near the coasts Jason-2 radiometer (AMR) is more stable than JMR

- AMR drift observed in IGDR is removed for GDR (ARCS), Jason-2 radiometer wet troposphere is therefore much more stable than Jason-1, but risk exists for real geophysical signal to also be removed by the ARCS calibration (which would have an impact on MSL).
- Model and Jason-1, Jason-2 altimeter wind speed histograms have different shapes (due to differences in backscatter coefficients)
- Parameter analysis reveal no particular behavior linked to use of different tracking modes (Median, Diode/DEM)

Phillips et al. further focused on system performance through the analysis of sea level anomaly and crossover differences:

- After 20 cycles of verification phase, Jason-2 shows good SSH performance:
    - Of the same order as Jason-1 for GDR
    - Better than Jason-1 for IGDR
- SLA consistency between both missions is very good and quite stable in time with a mean value of 83 mm (Jason-1 – Jason-2 Orbit – range – MSS differences, see Figure 17)
- Very good consistency between both POE, there is only a weak (+/- 1 cm) hemispheric bias between them (Figure 18); for IGDR: geographically correlated patterns (+/- 3 cm amplitude, Figure 18)
- Jason-2 enables continuation of study of mean sea level evolution and allows an accurate seamless transition with Jason-1

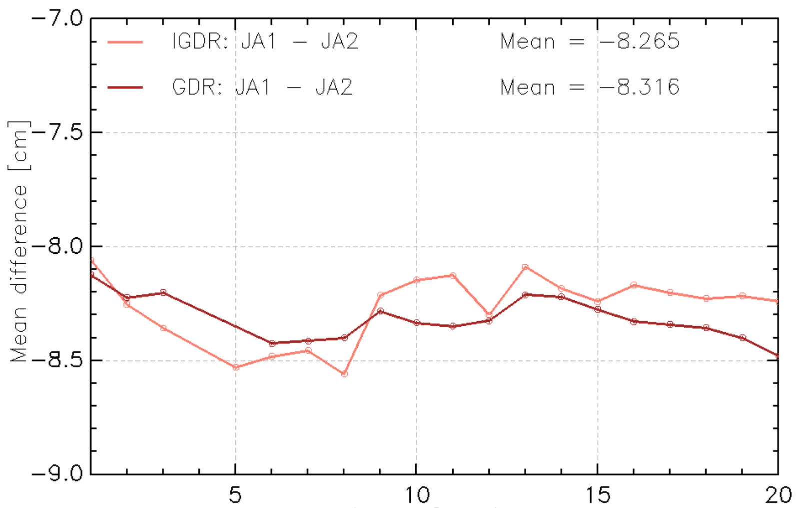


Figure 17. *Time series of the Jason-1 – Jason-2 global differences using Orbit – range – MSS (IGDR and GDR).*

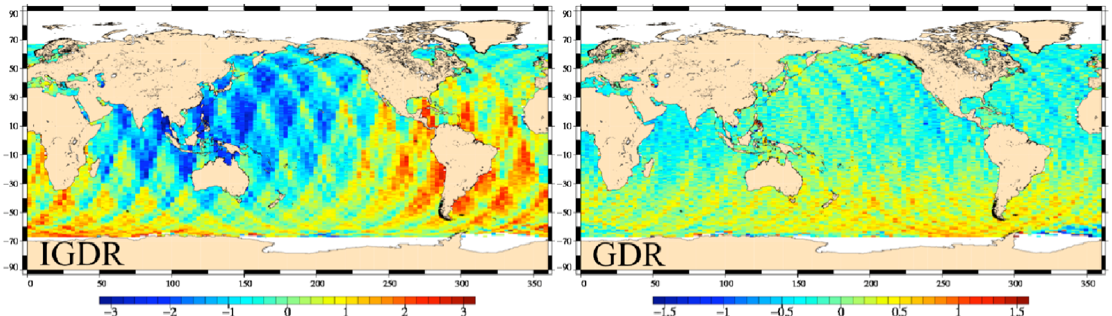


Figure 18. *Map of the Jason-1 – Jason-2 global differences using Orbit – range – MSS (IGDR at left and GDR at right).*

Dettmering et al. presented a global cross calibration of Jason-1/2 GDR-C data based on a discrete crossover analysis. The main results are summarized bellow:

- Comparison of Jason-1 GDR-B and GDR-C:
  - More valid crossovers with GDR-C
  - Slightly better consistency of crossovers
  - Mean bias between GDR-B and GDR-C of 3.9 cm
  - Significant differences in dz realization (~ 5 mm)
  - Same magnitude for geographically correlated errors (up to 2 cm)
- Comparison of Jason-1 GDR-C before and after orbit change:
  - Last 4 cycles show a slightly different behavior than before orbit change
  - Maybe just uncertainties because of the interruption
  - More data needed for significant result
- Relative calibration of Jason-2:
  - Relative Range Bias of 74 mm with respect to Jason-1 (Figure 19)
  - No significant differences in center-of-origin realization for x and z
  - Small, but significant dy of 5 mm
  - Geographically correlated errors up to 2 cm (Figure 20)

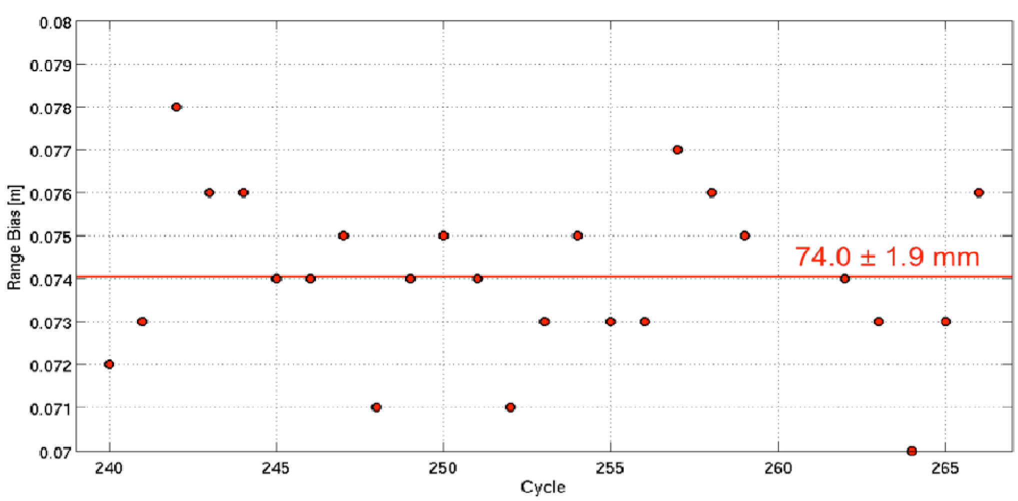


Figure 19. *Jason-2 range bias per Cycle (with respect to Jason-1).*

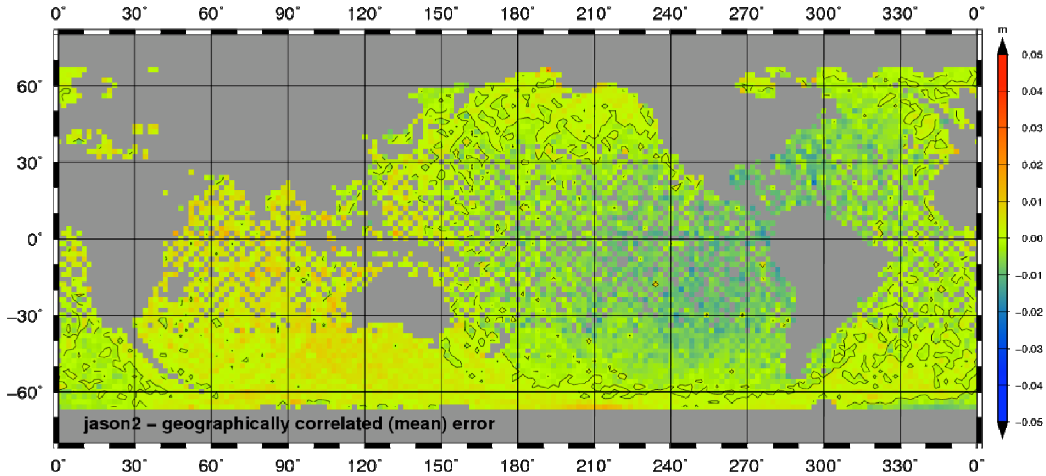


Figure 20. *Jason-2 geographically correlated errors.*

DeCarvalho et al. presented the global cross calibration and validation of the Jason-1 and Jason-2/OSTM data products. The talk was mainly focused on the ionospheric correction, the impact of sigma0 bias and the radiometer wind speed drift. Results are summarized bellow:

- Jason-2 – Jason-1 ionosphere correction is biased by 8.5 mm due to different relative biases in Ku and C band ranges.
  - Ku-Band: 84 mm
  - C-Band: 131 mm
- Jason-2 has a ~ 4.5 cm bias between Ku and C band ranges
- Apparent scale error in Jason-2 – Jason-1 ionosphere differences is statistical artifact of current low ionosphere conditions (solar minimum).
- AMR wind speed appears to be drifting at 1.2 m/s/yr (Figure 21)
  - Still under investigation
  - Negligible impact on wet path delay / sea level anomaly
- Jason-2 – Jason-1 sigma0 bias observed to be -0.15dB
  - Likely contributing to Jason-2 – Jason-1 altimeter wind speed bias/scale peculiarities.
  - Likely contributing to observed Jason-2 – Jason-1 differences in the sea state bias.

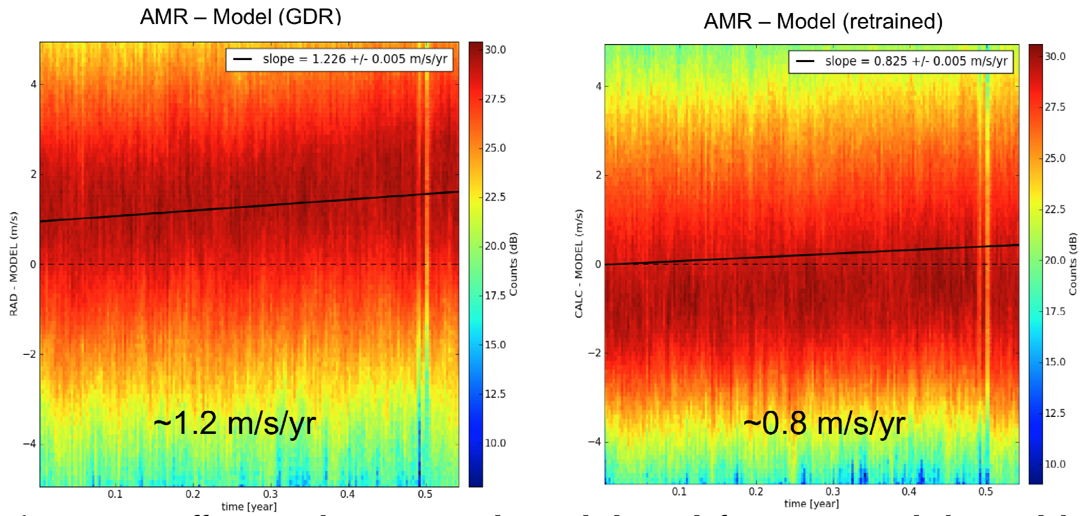


Figure 21. *Differences between wind speed derived from AMR and the model: from GDR at left and from a retrained wind speed algorithm at right.*

Ollivier et al. presented the Jason-2 cross-calibration with Jason-1 and Envisat; Results show a good consistency between these three missions and are summarized below:

- Geographic/temporal coverage difference:
  - The performances of the 3 missions can be compared after averaging by boxes
  - Can also be completed by crossing results from 10 day cyclic observations (based on J2 cycles) to 35 day observations (based on EN cycles).
- Envisat/Jason-2/Jason-1 are very precise missions:
  - Standard deviation of mono-mission crossover differences around 4 cm (GDR), which enables a precise cross calibration
- Jason-1 and -2 comparisons with Envisat GDR are very consistent (Figure 22):
  - The geographical biases observed on IGDR products disappear in the GDR thanks to the POE improvement compared to MOE.
- In the GDRs, Jason-2/Envisat has the same level of consistency as Jason-2/Jason-1
  - This consistency is even more relevant considering that its orbit configuration is different from Jason-1 and 2
  - Envisat provides a very important means for quantifying Jason-2 altimetric performance

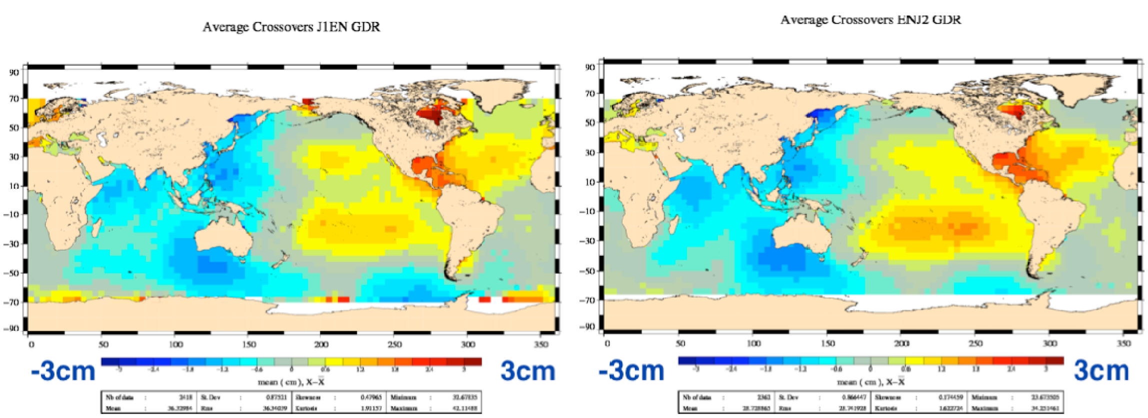


Figure 22. *Map of the dual crossovers: at left between Jason-1 and Envisat and at right between Jason-2 and Envisat.*

Labroue et al. presented the CalVal analysis of latest release of TOPEX retracked data. Results are summarized bellow:

- Non regression results:
  - Comparisons with MGDR and Jason-1 data show that 2009 RGDR products are different from 2006 and 2007 releases (Figure 23)
  - 2009 retracking does not change Range/SWH correlation. The 2009 SSB is the same as the SSB correction derived from MGDR data. The 2009 SSB no longer agrees with Jason-1 SSB, whereas the SSB derived from the 2006/2007 RGDRs had good agreement with the Jason-1 SSB.
  - This change in SSB behavior clearly demonstrates that the Topex retracking changes the Topex tracker bias
- Analysis of the side A time series :
  - The PTR drift appears to be well corrected for SWH but not for the range measurement.
  - The MSL trend obtained with the 2009 RGDR appears incorrect with a negative trend of -0.8 mm/year (Figure 24).
- Analysis of the side B time series:
  - SWH is OK
  - Strange trend on the range in the year 2002
  - The MSL trend obtained with 2009 RGDR is ~3 mm/year, which makes a difference of 0.6 mm/year compared to MSL obtained with MGDR data. This discrepancy is significant since side B altimeter is known to be very stable (calibration with tide gauges, comparison with Jason-1)

The recommendations from this study are:

- From the presented results, 2009 RGDR release is not recommended for MSL studies, especially the side A time series
  - These results should be confirmed by other teams (global CalVal and calibration with in situ data)
  - The only way to validate the PTR correction is to recompute the whole time series on side A
- Further work is needed on Topex retracking:
  - Change in the SSB behavior is of minor impact (leaving aside our understanding about tracker bias issue) since it can be corrected by a suitable SSB correction
  - Correcting for PTR drift is a critical issue since MSL studies are very sensitive to the PTR variations included in the retracking processing
  - PTR drift also impacts the sigma0 and thus the MSL trend (by way of wind speed and SSB correction). The sigma0 is not corrected in the RGDR data. Even this error is of second order compared to range error and SWH error (0.2 dB drift = 1 mm/year error on MSL), efforts should be done in the view of a final Topex reprocessing.

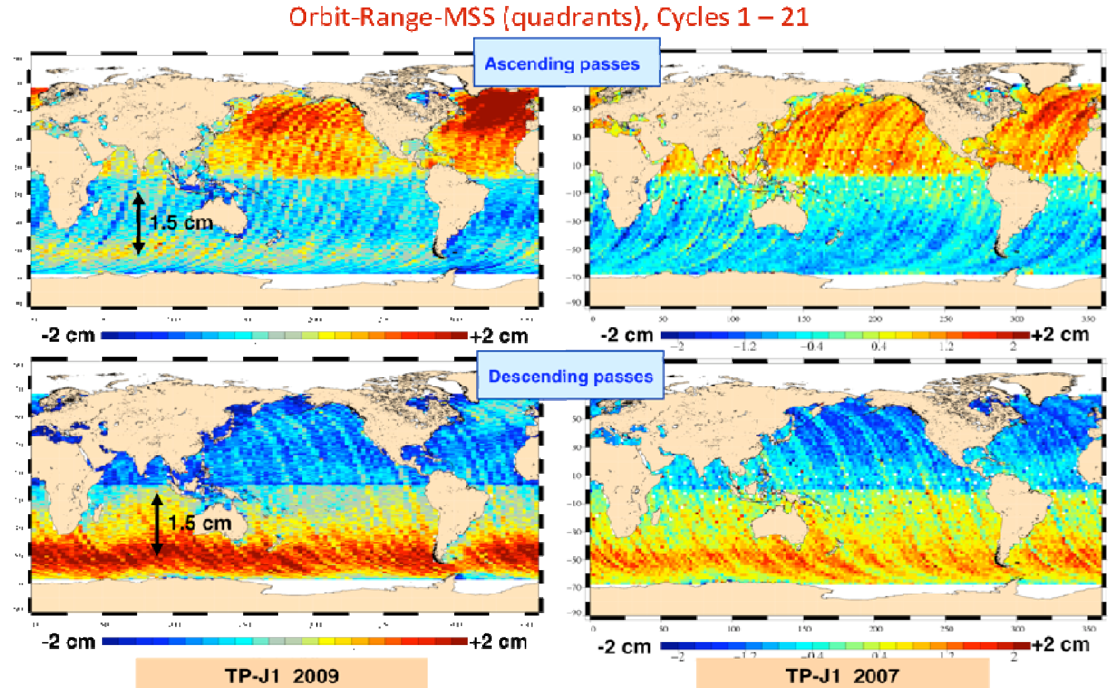


Figure 23. *T/P – Jason-1 Orbit-Range-MSS differences during their formation flight phase (2002) for new retracked products at left and the 2007 release at right.*

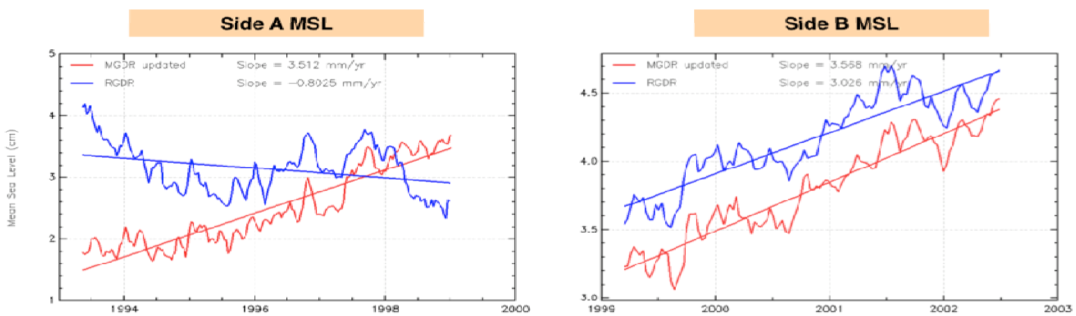


Figure 24. *Time history of Sea Level for Alt-A (left), Alt-B (right) from GDR (red) and 2009 RGDRs (blue). Note that retracking produces a very different variation for Alt-A.*

Summary of the global analyses key findings:

- AMR meets its requirements and is better than JMR when approaching the coast. Also more stable than JMR
- Jason-2 has a ~4.5 cm bias between Ku and C band ranges: causes a ~8.5 mm bias in the ionosphere correction
- POE (GDR-C) improves standard deviation of SSH biases compared to GDR-C (from 40 to 35 mm)
- Good agreement of all parameters between Jason-1&2 (with the exception of relative range biases).
- Jason-1&2 show a very stable relative bias of 75 mm in terms of SSH and 83 mm in terms of range (without corrections); the ~8 mm difference comes from the erroneous Jason-2 ionospheric correction; this is also compatible with mean value from in situ studies (73 mm for SSH)

- Jason-1 and -2 comparisons with Envisat GDR are very consistent
- Use of the T/P retracked products is not recommended at the moment, notably for MSL studies; future work is needed especially on side A.

7.1.5 Conclusions

The analysis of the formation flight phase between Jason-1 and Jason-2 clearly show very good agreement between the measurement systems of the two satellites, both in terms of observed sea surface height and the individual contributions to sea surface height. The origin of the main differences has been identified to be the ionospheric correction (difference of range bias between the C and the Ku band for Jason-2) affecting the measurement system by ~10 mm at the global scale. At a more local scale, the land contamination of the radiometer could have induced some biases which have been considerably reduced by using the enhanced path delay product for the Advanced Microwave Radiometer (AMR) on Jason-2 developed by Shannon Brown at JPL.

The origin of the relative range bias between Jason-1 and Jason-2 (~70 mm) has been discovered recently (see "Summary of the in situ analysis key findings" in section 7.1.2). This needs further investigation (notably on the C band) but, if confirmed, both satellites are measuring sea surface consistently, but too high by about 20 cm. The constants to be applied to both Jason-1 and Jason-2 (see Figure 8) will not be included in the current products (GDR-C and GDR-T respectively for Jason-1 and Jason-2) to maintain continuity. However, the reprocessed Jason-2 products (GDR-C, planned to be completed by June 2010) will contain the 25 mm bias found (sea level will decrease by 25 mm). Concerning Jason-1 bias, it should be applied in the next generation of the products (GDR-D).

Concerning the T/P retracked products (RGDR, 2009 release) some critical problems have been identified and further investigation is recommended. As a consequence, the use of the T/P retracked products is not recommended at the moment, notably for MSL studies.

7.2 Instrument Processing (P. Callahan, S. Brown, J. Lambin)

7.2.1 Jason Instrument and Algorithms

There were three talks on Jason processing and performance. Desjonqueres reported that Jason-2 is currently operating in DIODE-acquisition (tracker window set by orbit height estimate) median tracking mode to provide improved acquisition coming off land. Recently the DIODE-DEM had the DEM table updated; new tests of the mode will be conducted. With two corrections to Jason-2 process – PRF truncation and calibration from ground testing – the Jason-1/2 difference is reduced to 1.5 cm. Jason-2 tracking has been improved by resetting thresholds so that it will not track low amplitude, distorted waveforms.

Thibaut reported on several issues raised at the November OSTST meeting. The antenna beam width will be adjusted to 1.28 deg (from 1.26) to improve estimation of the off-nadir angle. Jason-1 and Jason-2 agree on a skewness value of -0.1 (The comments in

November from Callahan on differing skewness were incorrect due to not accounting for different onboard waveform variations between the two instruments.). No changes to Jason-2 filter weights or PTR have been detected, but it is recommended to use a longer average of the filter weights to improve stability. It is proposed to change the Jason-2 retracking to take advantage of the more stable spacecraft pointing. The proposal is to estimate the off-nadir angle with MLE4 only for Ku band, and for C band to use MLE3 with platform attitude (not Ku band MLE4 as now). This will provide less noisy sigma0s for C band, with no loss in range accuracy. It is also proposed to develop a Jason rain flag based on MLE3 tracking to get a stable C-K sigma0 relationship. Developing this will require 1 yr of data. Also, a new wind speed based on new wind speeds is being determined. This will result in re-solving for the SSB.

Thibaut reported on a new method under development to improve retracking by reducing WF noise with a singular value decomposition (SVD) method. The SVD allows for removal of the high frequency components of the WF. Retracking the filtered WF allows for either a lower noise level or improved along-track resolution.

7.2.2 TOPEX Retracking

Callahan reported on retracking TOPEX data for cycles 021-480. Retracked GDRs with improved GSFC POE and GOT4.7 tides have been produced. The retracking eliminates for most obvious effects, e.g., SWH change (up to about 0.5 m), of Alt-A PTR degradation. The range change is about 1.6 cm (see Figure 25). Skewness continues to absorb WF leakages. The 2009 RGDRs have a 1 cm bias and different SWH behavior than those produced in 2007. The SWH behavior is more like that of the original GDRs and thus differs noticeably from that of Jason. The new RGDRs appear to have more symmetric variations and errors. However, as shown in Figure 24 from *Labroue et al.* in section 7.1.4, the Alt-A sea level variation is radically changed by the retracking, while Alt-B shows mainly the 1 cm offset. The source of the differing time variation must be investigated.

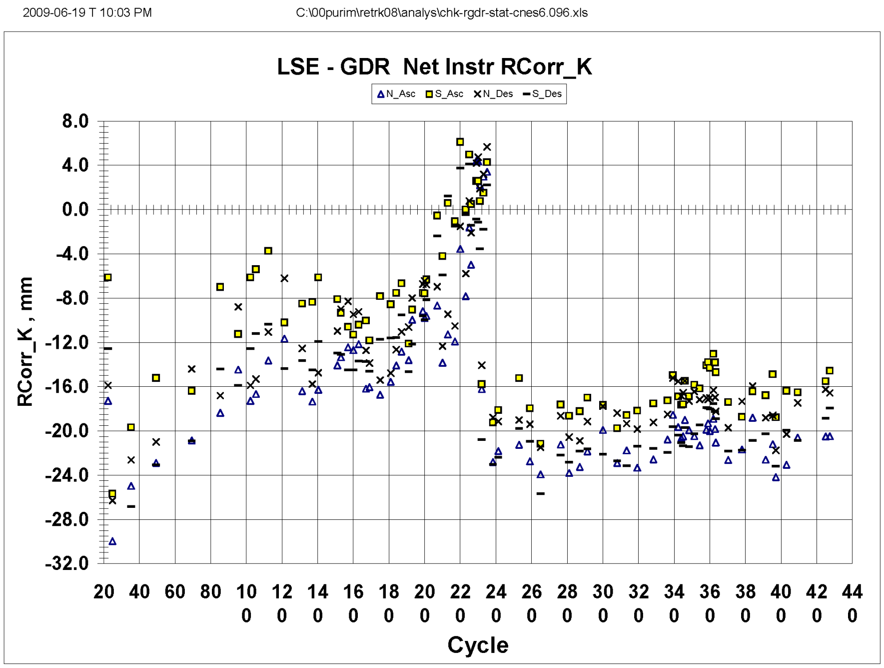


Figure 25. *Effective retracking correction to range.*

7.2.3 Sea State Bias

Naenna reported on work on a physical optics analytical EMB model. While the work is not yet complete, under some simplifying assumptions it reproduces the well-known *Jackson* (1979) physical optics result.

Tran noted that Jason-1/2 differences do not have an obvious SWH dependence and that SSB solutions for them are consistent at the 1-2 cm level over the full range of SWH and wind speed. Tran also reported on continuing work on SSB models involving additional parameters, e.g., swell and wave period from a wave model, and separating varied wave age and steepness regimes (swell-dominated, you, intermediate/mixed). Figure 26 shows the improvement in explained variance from the different models. The last model (black dashes) uses different fits for different classes.

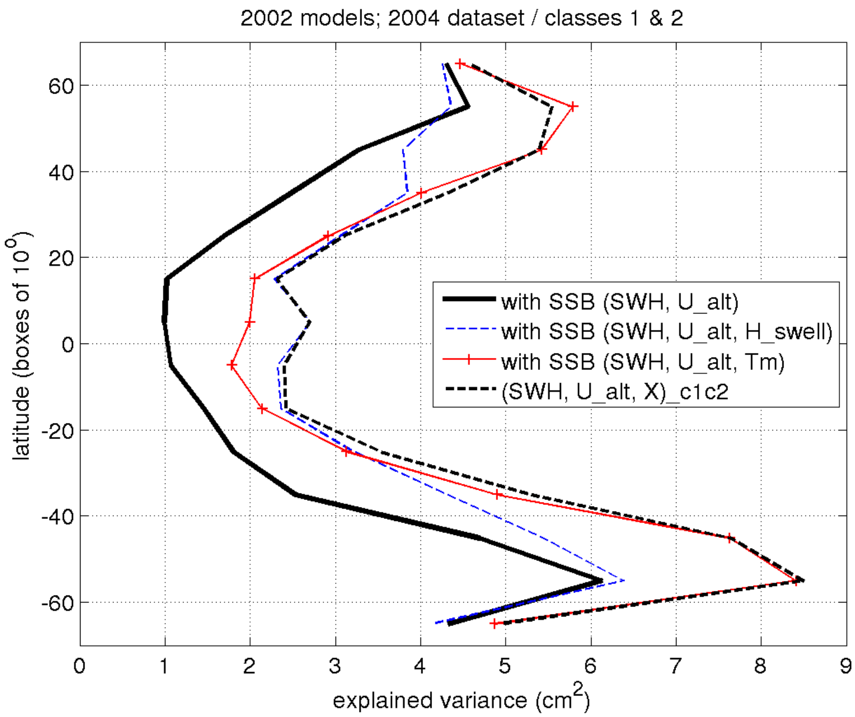


Figure 26. *Explained variance for SSB models with various parameter sets.*

7.2.4 Wet Tropospheric Correction

E. Obligis presented results from a study to evaluate systematic geographically correlated error in wet path delay retrieval algorithms. Traditional statistical retrieval algorithms are derived by finding a set of retrieval coefficients that minimize the global RMS error between simulated observations and wet path delay. The residual algorithm error has structure that is geographically and temporally correlated. Several algorithm types were evaluated using ECMWF meteorological profiles and simulated brightness temperatures. New parameters, such as sea surface temperature (SST) and atmospheric temperature lapse rate were also included in some of the algorithms. Both traditional log-linear type algorithms and neural network type algorithms were evaluated. Figure 27 shows examples of the geographical structure of four types of retrieval algorithms: (1) 2-frequency log-linear, (2) 2-frequency neural network, (3) 3-frequency log-linear, (4) 3-frequency neural network. In general, the errors are significantly lower for the 3-frequency algorithm as compared to the 2-frequency algorithm. Also, the neural network reduces the overall retrieval residual. Figure 28 shows that including lapse rate and sea surface temperature in a neural network algorithm further reduces the geographically correlated structure of the residual.

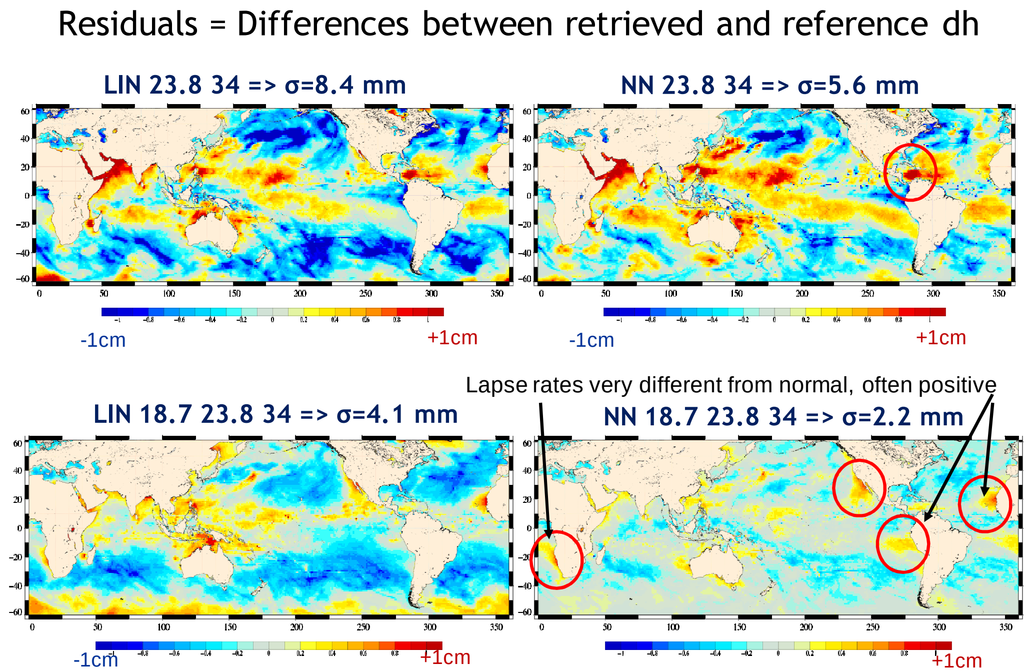


Figure 27. *Residual geographically correlated wet path delay error for different retrieval algorithm types.*

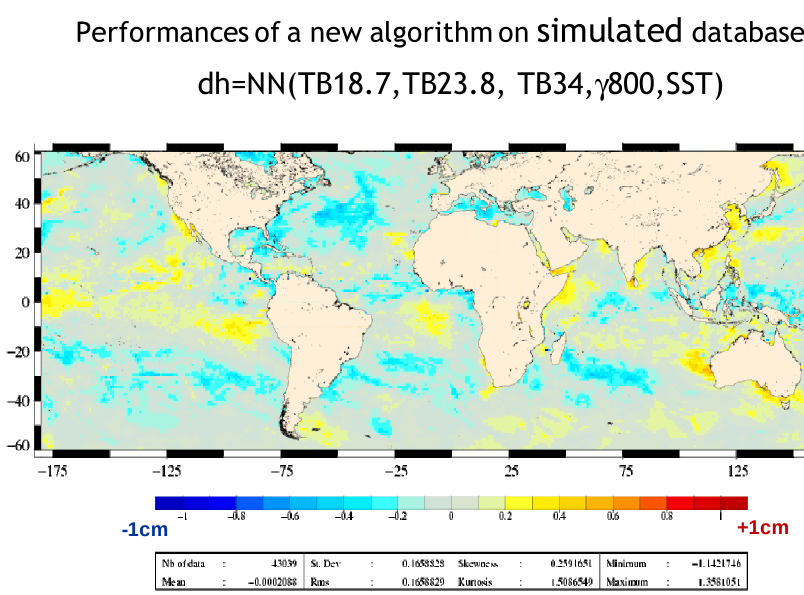


Figure 28. *Residual geographically correlated wet path delay error for a 3-frequency neural network algorithm that includes information about temperature lapse rate and sea surface temperature.*

S. Brown presented a performance assessment of the Advanced Microwave Radiometer performance on Jason-2. Several new algorithms were developed and presented. Two of the algorithms are a new radiometer specific sea ice flag and rain flag. It was shown that the statistical distribution of the sea ice flag was consistent with sea ice extent data from the National Snow and Ice Data Center (NSIDC) and the average rain flag was consistent with a rainfall climatology produced using TRMM data. These algorithms are simple and can be implemented by the user using GDR products, can be acquired from the AMR enhancement product available by restricted access to the OSTST on PO.DAAC and will be on the next evolution of the GDRs. The other new algorithm presented was the new AMR coastal path delay retrieval algorithm. This algorithm was demonstrated to improve the wet path delay retrieval in the coastal zone. The error is estimated to be below 1.2 cm to within 5 km from land. An independent comparison between the AMR new coastal PD product and coastal GPS derived PD estimates shows no excess error near land with the new algorithm, compared to a significant increase in error with the current GDR algorithm. This is shown in Figure 29.

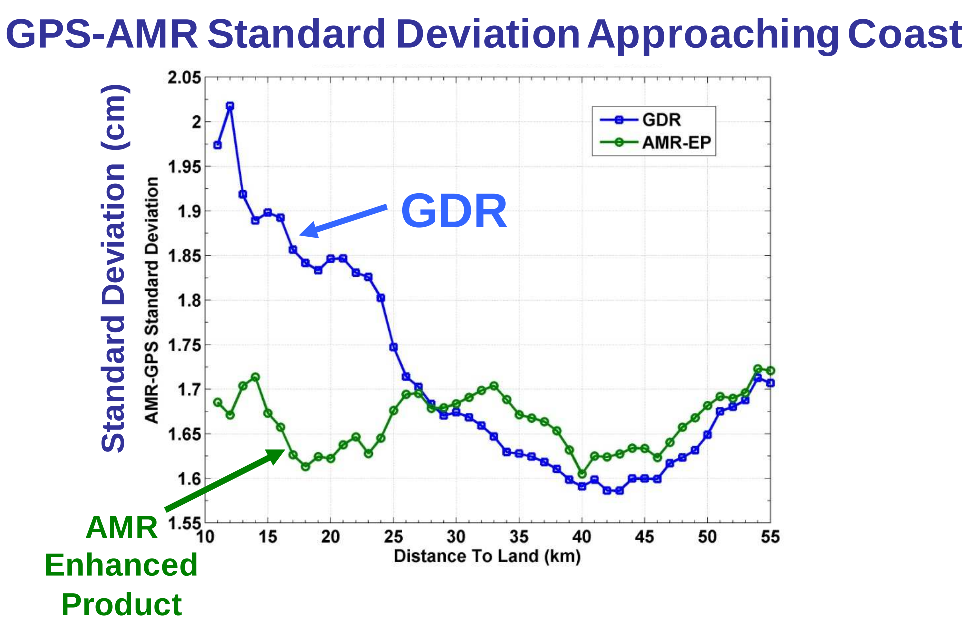


Figure 29. *Comparisons between AMR and GPS derived wet path delay approaching the coast for the current PD algorithm and the new coastal PD algorithm.*

An assessment of the AMR long-term calibration stability of the first year of the mission was also presented. The AMR Autonomous Radiometer Calibration System (ARCS) is used to operationally monitor calibration and detect and correct changes prior to GDR production. The GDR will be different from IGDR if calibration is performed. Two jumps in the AMR 34 GHz channel, occurring in September and November 2008, were detected and corrected for the GDR product. This removed what would have been a 6 mm/yr drift in the path delay, had it not been corrected. Figure 30 shows the AMR global mean PD compared to ECMWF, AMSR-E and TMI. There is no conclusive evidence from these comparisons of instability in the AMR > 1mm/yr. A JMR replacement product has also been generated and is available via PO.DAAC. This product periodic 5 mm shifts in the JMR PDs after August 2008 safehold. The JMR replacement product also shows negligible residual bias from AMR and lower variance compared to JMR on GDR-C.

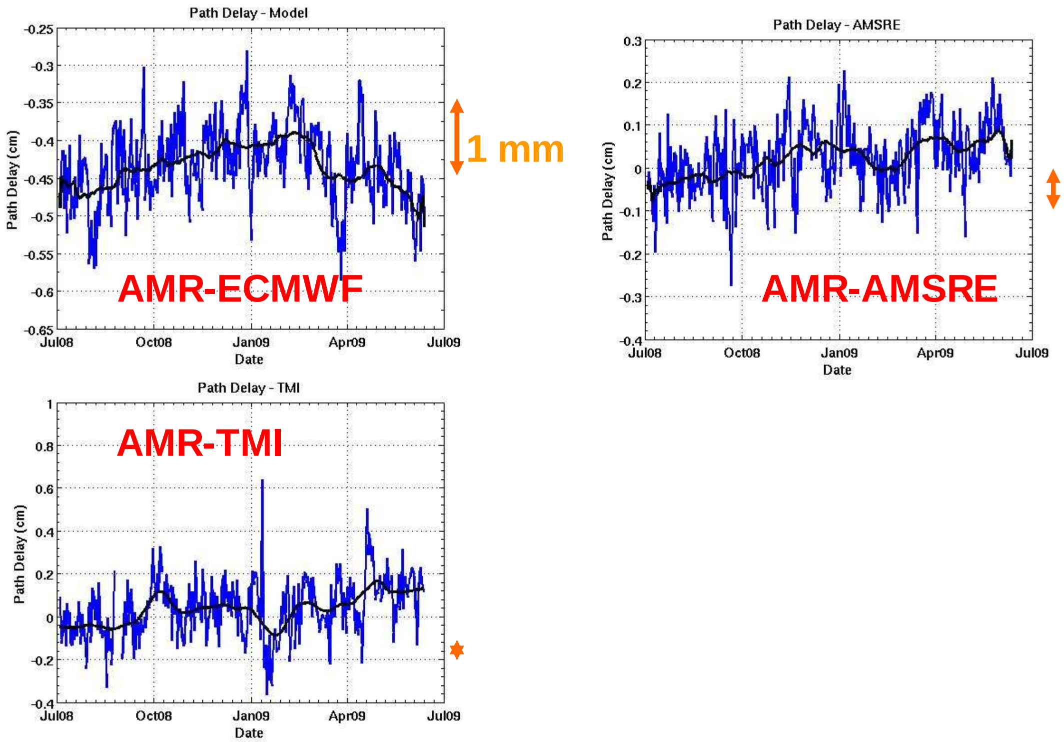


Figure 30. *AMR path delay compared to EMCWF, AMSR-E and TMI over the first year of the mission.*

7.3 POD/Geoid (L. Cerri, F. Lemoine)

7.3.1 Status of Jason-1 and Jason-2 GDR orbits

7.3.1.1 Jason-2

The accuracy of Jason-2 GDR orbits has been evaluated by means of standard POD quality criteria, such as inter-comparison of orbits obtained by different groups and statistics of both SLR and altimeter cross-over residuals.

Figure 31 shows the RMS of the radial difference between the orbits produced for this meeting and the GDR POE (including with DORIS, SLR and GPS measurements). This plot includes solutions obtained with different tracking techniques, and different level of parameterization, ranging from DORIS and GPS only dynamic solutions (CNES), to reduced-dynamic DORIS/SLR (GSFC) and GPS solutions (JPL). Most of these orbits compare to better than 1 cm RMS in the radial direction to the GDR POE, indicating an excellent overall agreement.

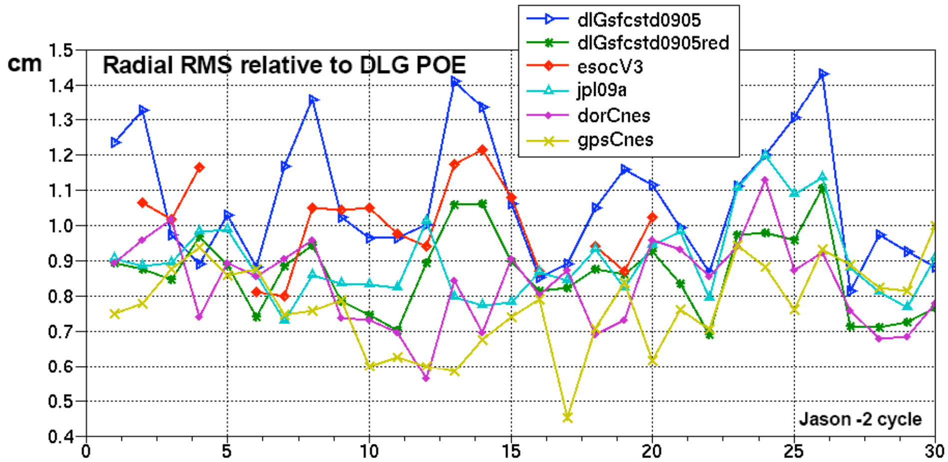


Figure 31. *Radial RMS comparison between different orbits and GDR POE (L. Cerri)*

A clear 60-day pattern is visible in some of the orbits, indicating that the Jason-2 surface force model has some margin for improvement; the impact of this error seems to be stronger on GSFC dynamic orbits, while the comparison with reduced-dynamic orbits (JPL, GSFC), which are by construction less sensitive to such modelling errors, doesn't highlight the same signature and suggests in turn that GDR orbit is also less sensitive to such errors.

Table 1 summarizes how the various orbits fit to the available tracking data. Altimeter crossover residuals are an independent measure of the radial orbit accuracy, indicating a somewhat better performance for reduced dynamic orbits in general, as expected. Another measure of the radial orbit accuracy is provided by high elevation SLR residuals (Figure 32) showing a similar fit for the GDR orbits and the JPL/GSFC reduced dynamic orbits above 60° of elevation. When GPS data are not included in the solution, the cross-track and along-track orbit error are higher, and as a consequence the SLR low-elevation fit is degraded.

Jason2 orbit evaluation cycles 1 -20	doris (edit cyc 18)		slr (edit cycles 18)			xover rms (cm) (edit cyc 18,20)	
	points	rms (mm/s)	points	mean (cm)	rms (cm)	points	rms (cm)
gsfc ld std0905	169900	0.3719	2764	-0.020	1.288	4814	5.512
gsfc ld srp0906	169900	0.3718	2764	-0.017	1.290	4814	5.505
gsfc ld red_std0905	169900	0.3711	2764	-0.075	1.242	4814	5.460
cnes ldg gdrc	167553	0.3719	2718	0.000	1.215	4812	5.523
cnes ldg gdrc tune00	167553	0.3718	2718	-0.019	1.209	4812	5.532
jpl gps rlse09a	162291	0.3720	2662	0.015	1.307	4414	5.362

Table 1. *DORIS, SLR and crossover fit on different Jason-2 orbits (F. Lemoine)*

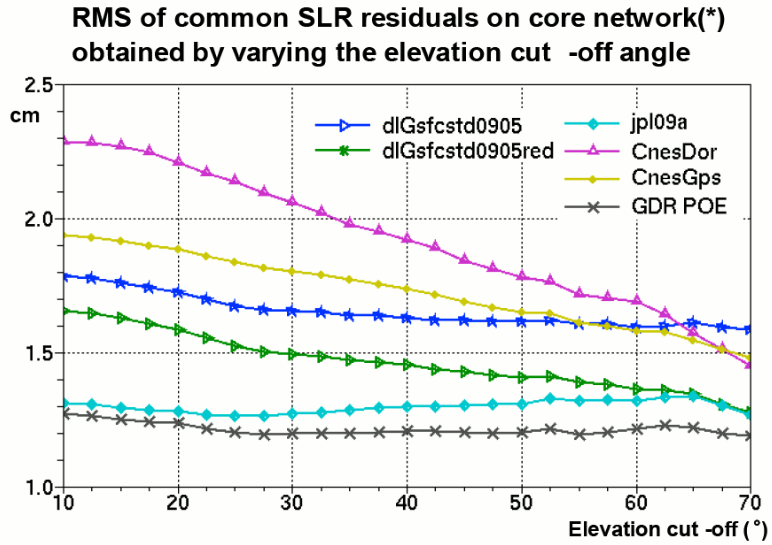


Figure 32. *RMS of SLR residuals as a function of increasing minimal elevation (L. Cerri)*

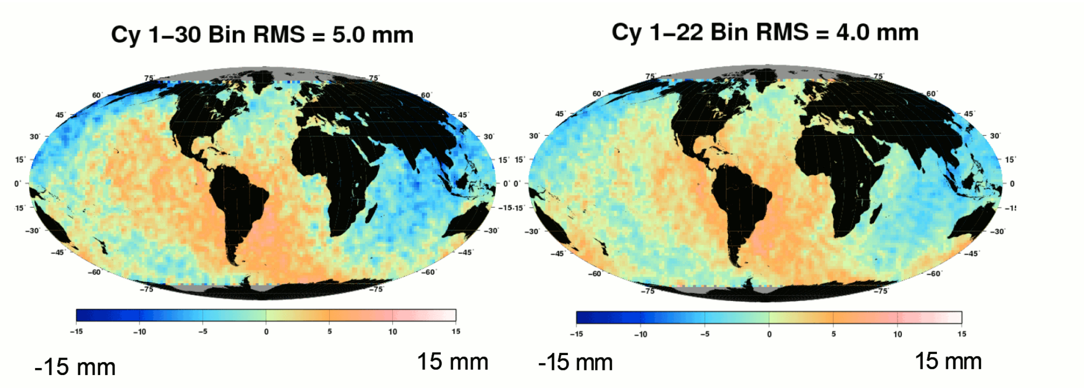


Figure 33. *Mean geographically correlated radial difference of JPL orbits with respect to GDR POE (left) and GSFC reduced dynamic (right) orbits (W. Bertiger)*

Figure 33 depicts the mean geographically correlated radial difference between the JPL orbit and the GDR and GSFC orbits. Although the pattern is variable from cycle to cycle, the mean over many cycles reflects the common modeling of CNES and GSFC orbits with respect to JPL. As far as the quality of tracking data is concerned, the direct comparison of D/L and GPS reduced dynamic orbits shows an average agreement on the order of 7 mm RMS, proving that the different tracking systems on board Jason-2 provide very consistent orbits (Figure 34). No conclusive sign of degradation due to South Atlantic Anomaly (SAA) effects has been detected in the DORIS measurements. It was pointed out that the GPS receiver exhibits some data outage over the SAA region that needs to be further investigated (Figure 35), although no clear impact on the orbit quality has been assessed at this time. One consequence of the SAA sensitivity of the receiver, besides a concern over the Jason-2 GPS receiver longevity, is that the parameterization for the reduced dynamic orbits cannot be as aggressive as it might be to take advantage of the robust tracking of the GPS receiver.

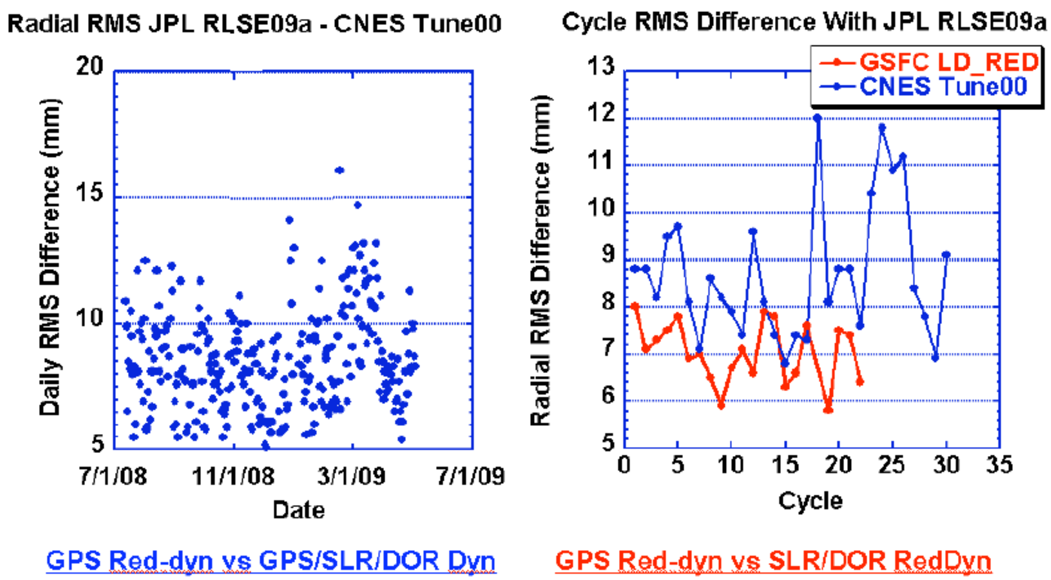
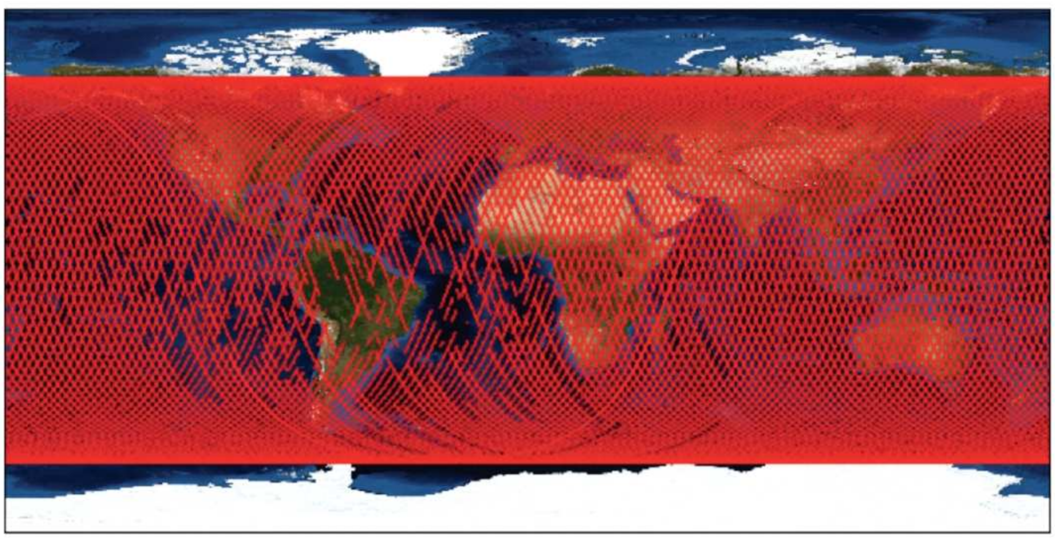


Figure 34. *Radial comparison with respect to JPL reduced dynamic orbits (W. Bertiger)*



Points on map indicate locations where 4 or more GPS satellites are being tracked for the dates, Aug 10-19, 2008

Figure 35. *GPS receiver data gaps around South Atlantic Anomaly (W. Bertiger)*

7.3.1.2 Jason-1

The consequences on POD of the orbit change and of the failure of TRSR GPS receiver needed to be verified. The model used to correct the DORIS measurements over the SAA region has been adapted for the new ground track and implemented in the GDR POE without any noticeable degradation of the orbit's performance. The definitive loss of the GPS data on board Jason-1 occurred in April 2009 has no evident impact on the accuracy of GDR POE as GPS tracking was already significantly reduced since August 2006.

The reprocessed Jason-1 DORIS+SLR orbits from GSFC (version std0905) show a good agreement with CNES DOR/SLR/GPS GDR-C orbits, prior and post the GPS receiver degradation (Figure 36). In terms of radial RMS per cycle, most of the remaining difference is correlated with the beta-prime angle, indicating problems in surface force modeling that still need to be solved. In terms of the geographically correlated error, most of the difference between the two orbit series is before the change of DORIS instrument (cycle 90). In particular, even when SAA model is applied, the behavior of the first DORIS oscillator produces N-S orbit differences that have non-negligible impact on the mean sea level trend estimate (Figure 37). More confidence should be given to the GDR orbit before cycle 90 because it includes GPS in solution. The radial difference rate between the two orbit series is negligible if the trend is computed over the entire mission lifetime.

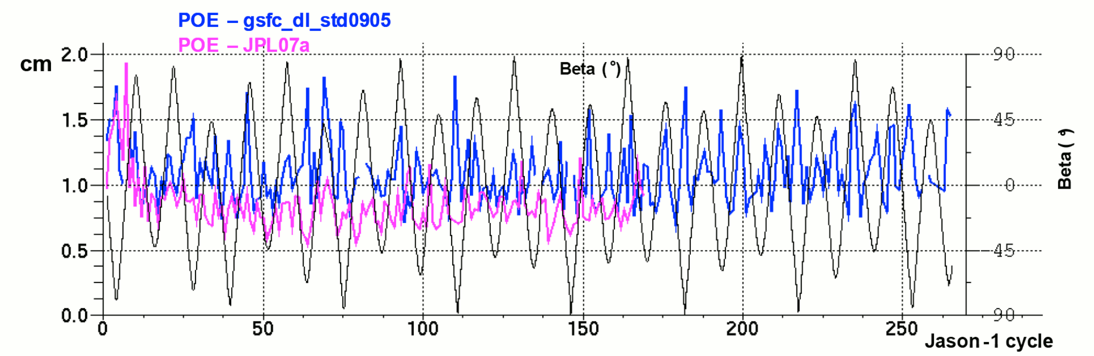


Figure 36. *RMS of radial difference between GSFC/JPL Jason-1 orbits and GDR-C orbit (L. Cerri)*

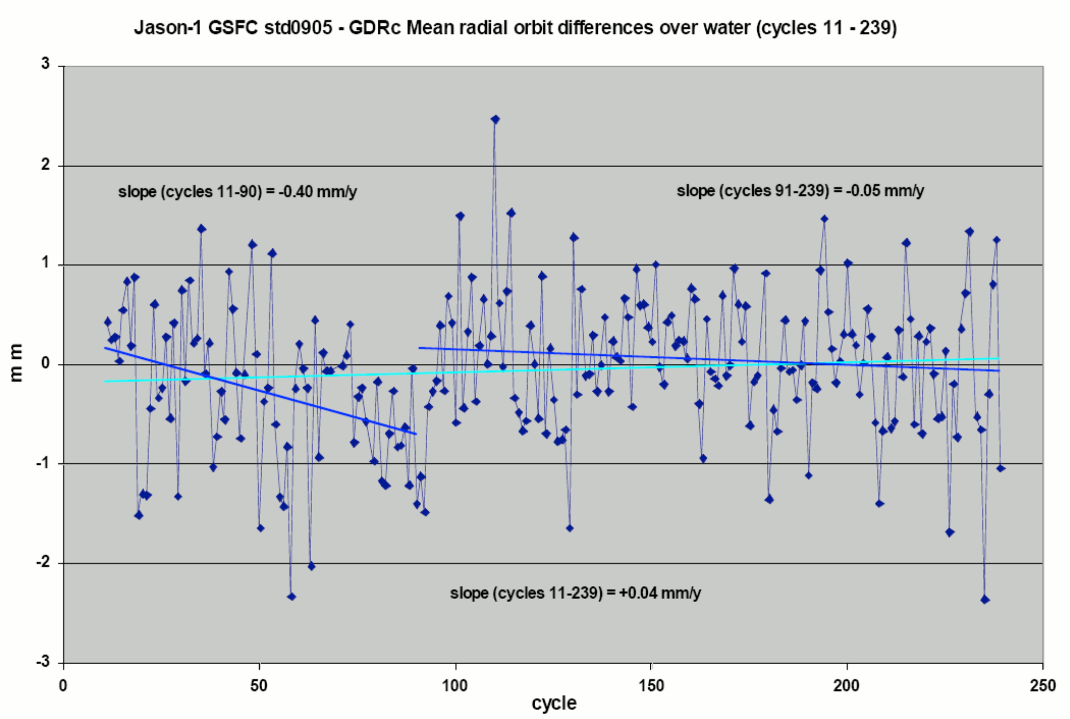


Figure 37. *Mean radial difference over water (F. Lemoine)*

7.3.2 Impact of non-tidal variations of the gravity field on Jason orbit

Current POD standards include time varying gravity effects from the annual and semi-annual terms contained in the EIGEN-GL04S-ANNUAL gravity model (primarily due to hydrology) and from the interpolation of 6-hour-sampling atmospheric gravity fields derived from NCEP atmospheric pressure fields, assuming an inverted barometer ocean response.

During the previous meeting in Nice, an action was then taken by the POD group to assess the impact of omission/commission errors in time varying gravity modeling, by comparing the operational GDR orbit with solutions obtained using a GRACE-derived time series of gravity fields over the longest possible time interval. It is important to remember that such series cannot be used operationally, but can eventually be used a posteriori to evaluate modeling errors. The Goddard group test included an ocean model (MOG2D) response to atmospheric forcing, GLDAS-derived hydrology model, and 60x60 GRACE-derived gravity fields over the 2004-2005 time-span. The geographically correlated difference with respect to the orbit obtained with the operational model shows mainly annual signal whose amplitude (< 3 mm) is shown in Figure 38.

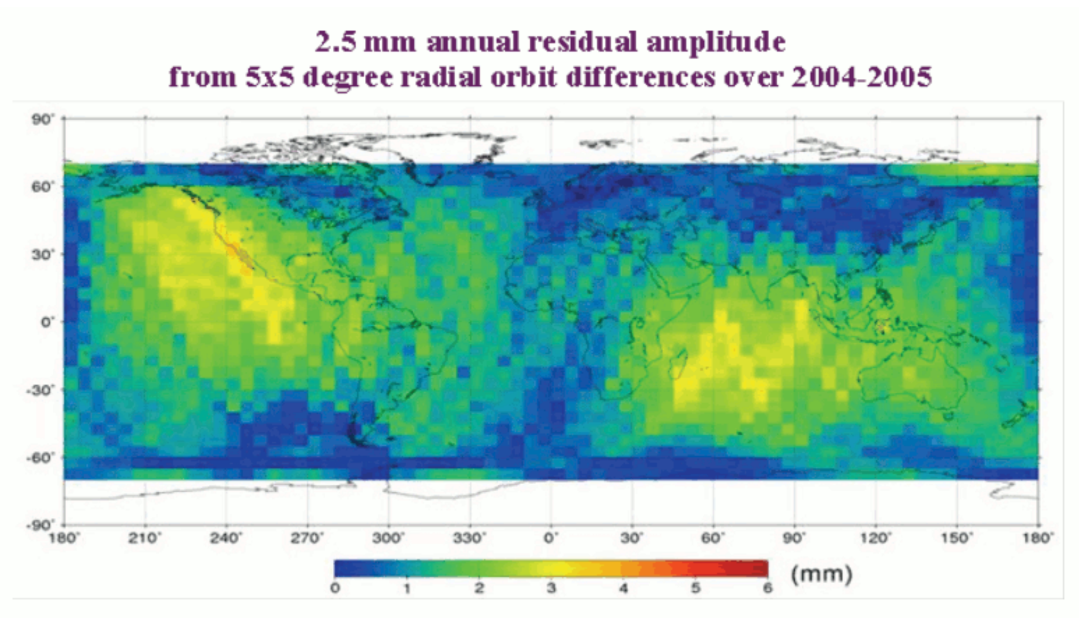


Figure 38. *Effect of residual TVG on J1 orbit: operationally modeled – atgrav + mog2d + gldas + 60x60/month form GRACE (N. Zelensky)*

CNES performed a similar test by using the latest release of GRACE-derived 10-day gravity fields over the time interval 2002-2008 (Figure 39), highlighting the yearly mean radial difference between the GDR orbit and the test orbit.

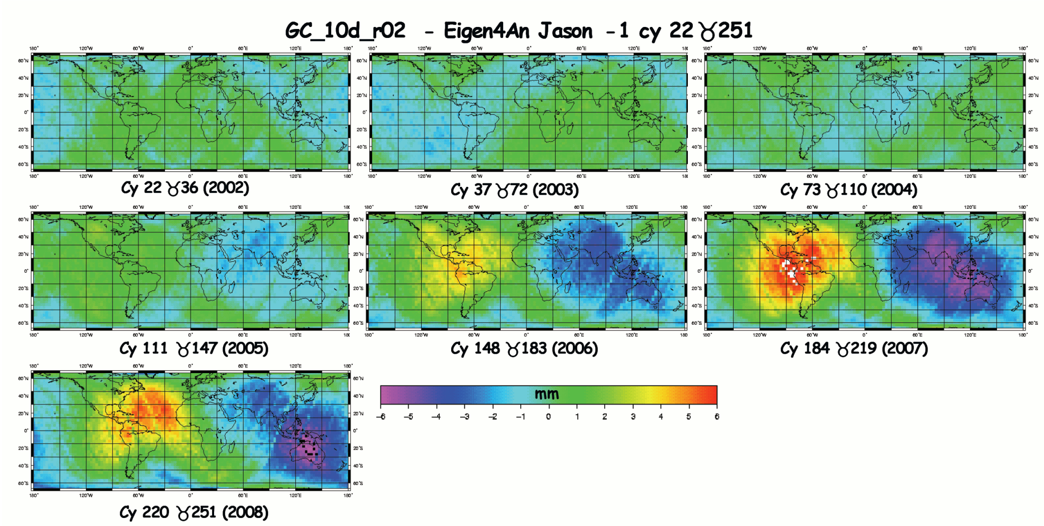


Figure 39. *Effect of residual TVG on Jason-1 orbit: GDR-C – 50x50/10days from GRACE (from CNES-GRGS release 02) (L. Cerri) Color scale range is-6 to 6 mm*

In general, the orbit differences seem to be well correlated with variations of the degree 3, order 1 harmonic, which seem to be stronger in 2007 (Figure 40). The impact of these variations depends on the orbit parameterization. In particular, the loss of the GPS receiver slightly amplifies this effect as the DORIS/SLR orbits are processed adjusting a lower number of empirical parameters.

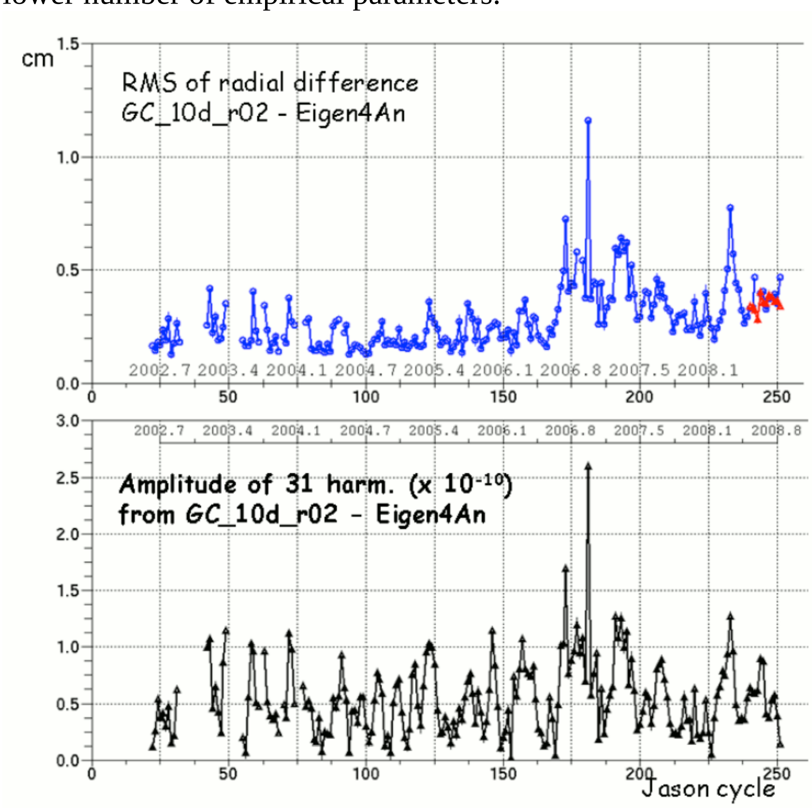


Figure 40. *Jason-1 radial orbit differences from tests of GRCS 10-day gravity fields vs. the GDRC standards*

7.3.3 Current Work and Future Improvements

The current calendar still forecasts the release of ITRF2008 by the end of the current year. At present the Jason/OSTM POD group has not yet tested the new set of coordinates, although Z. Altamimi's presentation indicated that the origin and scale of the new reference frame are likely to be close to ITRF2005 (still under investigation). Jason-2 JPL orbits benefit from a new technique based on the resolution of the integer phase ambiguity that further improves the radial orbit accuracy (overlap radial RMS reduction of 3 mm).

7.3.4 Conclusion

Jason-2 and Jason-1 POD performs very well and no critical issue has been raised. The principal residual modeling errors affecting Jason-1 and Jason-2 orbits concern surface forces in general (including radiation pressure) and the time-variable gravity omitted in the operational model. The annual component of the geographically correlated error caused by remaining TVG was shown to have 3 mm amplitude. Longer-term variations are more difficult to assess, but the analysis performed over the Jason-1 lifetime indicates that the yearly average of the orbit error has an order-1 pattern reaching 7 mm between 2006 and 2007. One of the main objectives of the next meeting should be to make the orbit more robust to these types of small but significant variations. Maintaining the reference frame stability remains a major objective in order to improve the accuracy of the global mean sea level measurement, and the upcoming release of ITRF2008 will give the POD group the opportunity to evaluate the impact of current reference frame errors on Jason orbits.

A common theme of the POD splinter session was the importance of having a three-instrument system in order to achieve the highest accuracy orbits. Data from the GPS are presently being used to generate orbit solutions with 1-cm radial RMS accuracy within 5 hours of real time. This capability is facilitating the availability of measurements of sea surface height that have better accuracy than those from the IGDR with a latency of ~5 hours. A recommendation was discussed to consider including a radiation-hardened GPS instrument, in addition to DORIS and SLR, on future missions that require cm level orbit precision. This recommendation should be considered by the operational agencies as they assume responsibility for future high-precision altimetry missions and the need for operational sea surface height products grows.

7.3.5 Publication Plans

Recent progress in Jason POD is discussed in detail in the following publications, already submitted for the DORIS special issue in Advances in Space Research (ASR) or under preparation for the Jason-2/OSTM special issue in Marine Geodesy (MG).

- F. Lemoine et al. *Towards Development of a Consistent Orbit Series for TOPEX/Poseidon, Jason-1, and Jason-2* - in preparation for ASR.
- L. Cerri et al., *Precision Orbit Determination Standards for the Jason series of altimeter mission*, - in preparation for MG.
- N. Zelensky et al. *DORIS/SLR POD Modeling Improvements for Jason-1 and Jason-2* – in preparation for ASR.

- F. Mercier et al. *DORIS phase measurement processing for Jason~2 precise orbit determination* - submitted to ASR.
- W. Bertiger et al. *Sub-centimeter Precision Orbit Determination with GPS for ocean altimetry*, in preparation for MG.

7.4 Near Real-Time Products Validation and Application (H. Bonekamp, J. Lillibridge, G. Jacobs)

This splinter session covered topics related to the production, validation, and applications of the Jason-2 OGDR and Jason-1 OSDR products. The status of the products and their cal/val was presented. The NRT products differ in accuracy from the offline IGDR and GDR data sets. This session assessed the sources of these differences, e.g. in terms of orbit determination and applied sea surface height corrections. Operational applications of the data for monitoring and model assimilation were also highlighted.

The presentations and posters discussed opportunities for improving the NRT products (for example enhanced use of the GPS system for improved NRT orbits). Examples were given showing exploitation of SWH and wind information in wave models and marine meteorology, the use of OGDR's in multi-mission (NRT) SSH products, and assimilation of the NRT products in ocean models.

7.4.1 Session Highlights

The oral presentations from this session, along with a few highlights, are summarized below:

Jacobs, Lillibridge, Tabor, May & Russell: *Jason-2 OGDR accuracy and precision validation for ocean forecasting*

- The Jason-2 OGDR meets the NPOESS IORD-II threshold requirements for precision & accuracy: Precision = 1.96 cm RMS (threshold = 3 cm); Accuracy lower bound = 2.26 cm & upper bound = 5.49 cm RMS (threshold = 5 cm basin scale & 6 cm global scale)
- Latency of the Jason-2 OGDR for assimilation in operational Navy models is up to 48 hours better than Jason-1 OSDR observations

Scharroo, Lillibridge & Leuliette: *Good, Better, Best: A Comparison of Jason-2 O/I/GDR Products*

- Comparisons of Jason-2 OGDR vs. IGDR show unexplained range differences dependent on SWH as well as overland discrepancies related to convergence of the ground-based retracking
- Lingering issues in the OGDR/IGDR/GDR data for Jason-2 were identified: noise in sigma-0; SSB model differences with Jason-1; MLE-4 derived rain flag is never set; errors in long-period non-equilibrium tide & pole tide over inland water; AMR measurements have a 1-second time tag error

Jayles, Chauveau & Chaillou: *Quality of the DORIS/DIODE orbits for Jason-1, Envisat, Jason-2… and potential improvements*

- The onboard DORIS/DIODE orbits for Jason-2 have radial orbit errors of < 8 cm RMS

- Improvements in Jason-2 DIODE orbits were made early in the mission; Jason-2 DIODE orbits surpass both Jason-1 & Envisat

Desai, Bertiger, Haines, Harvey, Lane & Weiss: *An Introduction to the GPS-OGDR-SSH product for OSTM/Jason-2*

- Near real-time GPS orbits for Jason-2 may be better than current IGDR MOE orbits, e.g: RMS of difference over cycle 34 - DIODE: 40.9 mm, IGDR/MOE: 12.9 mm, OGDR/NRT-GPS: 4.8 mm
- Compromise between orbit precision and product latency yields best choice for a 1-hour orbit cutoff resulting in a typical lag by one OGDR for the NRT-GPS orbits (2.9 mm RMS with the final GDR/POE orbit).

Abdalla, Janssen & Bidlot: *Jason-2 OGDR Wind and Wave Products: Monitoring, Validation and Assimilatio*n

- Jason-2 SWH product replaced the corresponding Jason-1 product in the ECMWF system on 10 March 2009
- Impact of Jason-2 SWH assimilation in WAM model has smaller bias for all forecast intervals compared to Jason-1
- Assimilation of Jason-2 SWH data in coupled model leads to slight but significant improvement in meteorological fields as well

Ji, Chawla, Sienkiewicz, Tolman, Vandemakr, Feng, Callahan & Zlotnicki: *Near Real Time SWH Applications at NCEP*

- Jason-1 OSDR (interleaved) and Jason-2 OGDR being used operationally for high seas wind/wave forecasts at NCEP's Ocean Prediction Center
- N-AWIPS display used operationally to validate NCEP WaveWatch-3 wave model

Dibarboure, Pujol, Pascual & Bronner: *Using short scale content of OGDR data to improve DUACS' near real time products*

- New near real-time processing module for the DUACS system now includes Jason-2 OGDR SSH measurements, filtered to removed long-wavelength orbit error
- RMS of differences between traditional IGDR and experimental IGDR+OGDR analysis is equal to ~40% of the difference between offline (GDR) and NRT (OGDR) products: variability, Äúlost, Äù in traditional DUACS NRT products is partially restored by the OGDRs

Dohan, Gunn, Lagerloef & Mitchum: *Assessment of near real-time OSCAR surface currents*

- Comparisons of ocean surface drifters with OSCAR currents (derived from altimetry-derived geostrophic + Quickscat-derived Ekman currents)
- Using AVISO/DUACS gridded fields vs. NRL model fields as input results in better agreement with drifters
- OSCAR currents agree best with drifter data in strong current systems with largest SSH gradients

The following posters were also a part of the NRT splinter session, and are available on the AVISO website at http://www.aviso.oceanobs.com/en/courses/ostst/ostst-2009-seattle/posters/index.html:

- Poster: Callahan, Wilson, Xing, Raskin & Oslund: *Web-based altimeter service*

- Poster: Lefevre, Aouf, Queffeulou, Bentamy & Quilfen: *Improving operational wave modeling from altimetry*
- Poster: Stathoplos, Donahue, Lillibridge, Throwe, Zhang & Casey: *NOAA's Jason 2/OSTM products*

7.4.2 Conclusions

- Jason-2 OGDR meets or exceeds expectations for NPOESS accuracy, precision and latency requirements
- Smaller problems in all products need to be considered before final GDR release
- Upload new v4.01 navigation DIODE software
- GPS-based NRT-POD for OSTM/Jason-2 demonstrating < 1 cm (RMS) radial orbit accuracy (operational centers requesting inclusion in operational products)
- Jason-2 OGDR has positive impact on SWH forecast and meteorological forecast accuracy
- Jason-2 OGDR is used operationally by marine forecasters for ship warnings by evaluating both model forecasts and altimeter SWH
- The improvement observed in actual products (consistency with offline maps) is consistent with predictions from simulations (OGDR error budget reasonably controlled)
- OSCAR is moving analysis forward in time with more timely data & higher spatial resolution
- Jason-2 OGDR products are presently used in operational centers
- Performance improvements in data stream and center products are demonstrated
- There is continued demand for further development

7.5 Outreach and Education (M. Srinivasan, V. Rosmorduc)

7.5.1 Introduction

Outreach session topics:

- *Plotting Altimeter Data: GMT and Google Earth*, R. Scharroo
- *Outreach Using Web Map Service*, R. Leben
- *CTOH altimeter data service: data & products*, R. Morrow
- *Basic Radar Altimetry Toolbox: Tools for all altimetry users*, V. Rosmorduc
- *Reaching the public through the media: In with the new, but not out with the old*, R. Sullivant
- *Promoting OSTST Research*, M. Srinivasan
- J*ason-2 contest (Un canard sur l'océan),* A. Richardson, D. De Staerke
- *Using the Jason-1 board game to reinforce ocean literacy principles,* A. Richardson
- *Adopt a buoy to study plastic Island*, D. De Staerke

The Outreach session was well-attended by meeting participants, indicating satisfactory support by the OSTST. An average of 40 participants were present at any given time. In fact, several members of the outreach team gladly forfeited their presentation opportunity in order to allow for more presentations by scientists.

This year, the “outreach showcase” portion of the session consisted of presentations by outreach team members only. We encourage OSTST scientists to present opportunities they have had throughout the year to focus on outreach or participate in an outreach activity or outreach product development. It is helpful for us to know what kind of activities OSTST members are involved in and what the impact of those activities/products is. Next year we will begin soliciting inputs on this standard feature of the outreach splinter session early and vigorously!

It must be noted that several OSTST members regretted that no students were presenting as in Nice. Unfortunately, at this time the Washington state school year was already finished. We will keep this interest in mind, and will schedule student presentations at future meetings when possible.

7.5.2 Altimetry data visualization & Google Earth

Several presentations addressed the visualization of altimetry data. Compelling images and pictures are a major asset in outreach. So the question of “how to produce effective and efficient plots from altimetry data” is certainly of interest to the outreach teams. Moreover, providing easy-to-use visualization tools is an integral part of outreach and promotion of altimetry: On-line tools can be used by a large number and wide range of people (Aviso LAS was used by students for Jason-2 contest).

Several participants demonstrated the use of Google Earth to browse maps or other results (R. Scharroo, R. Leben, V. Rosmorduc). This tool is indeed becoming a standard in Earth science visualization and outreach, and can therefore be an important tool in altimetry. It should be noted that the Google Earth “Ocean” gallery includes global SST and ocean color maps, but currently, not altimetry data. Several efforts to fill this gap are underway, including the NOAA AOML Tropical Cyclone Heat Potential NRT Data site, which is not yet live, or Aviso Google Earth applications features (but with not much success for the latter).

7.5.3 Data access

Data access, particularly for novice users, can be considered to be within the realm of outreach, as it is relevant for both researchers and educators. The era of “one data set fits all” is definitely past: new users have different areas of interest and different skills. The more value we add through data processing, for example (filaments [R. Morrow], indicators such as Mean Sea Level [V. Rosmorduc]), the more new altimetry users we can attract since those data will be closer to their needs and interests than are the raw, or minimally processed altimetry data. Such a user-dedicated approach to data definition and distribution is becoming more and more necessary, and several teams are working on this [R. Morrow (CTOH Toolbox) and V. Rosmorduc in outreach; but also P. Callahan, Y. Faugere, J. Hausman, and L. Stathoplos in other sessions].

Providing tools to facilitate the use of altimetry data is also a way to help new users. There is a demonstrated interest in this, as there were more than 700 on-line requests registered between June 2007 and June 2009 for the Basic Radar Altimetry Toolbox [V. Rosmorduc].

7.5.4 Education & training

Education and training at all levels is a focal point of our ocean outreach efforts, whether it be scientist or graduate student training, or educational projects for students from kindergarten through undergraduate levels. As Annie Richardson said, “Teaching young people about the ocean and altimetry ensures that [you, the OST science team member] will have graduate students in the future.”

Training
Training in the use of satellite altimetry data is a recurrent outreach topic. Since it is clearly recognized that not all scientists and engineers, including oceanographers, are necessarily familiar with the use of ocean altimetry data, outreach team members have developed several training tools for scientists and engineers who are new to the use of satellite data in general and radar altimetry data in particular [V. Rosmorduc, M. Naeije].

Educational projects
CNES organized an educational contest to coincide with the Jason-2 launch called “Un canard sur l’océan” (“A duck/newspaper over the ocean,” as canard, in French, means both "duck” and, colloquially, “newspaper”). The contest challenged student groups to create newspapers about climate, oceans and satellites [D. De Staerke, A. Richardson]. Results of this contest were interesting in several ways:

- Interest in the contest itself was quite high: a large number of people visited the dedicated web site for information about the contest. More than 200 student newspapers were submitted; with 60 being accepted. An e-mail survey was sent to all participant teachers; 70% responded; all very enthusiastically. They wrote that the contest provided motivation for students, including at-risk students. Some classes even created follow-on activities (musical production, astronomy club, etc.)
- Young people are concerned about climate change, protection of the environment, and, sustainable development
- Jean Louis Fellous, who served as a member of the judging panel, was quoted as saying, “50 years ago there were no more than five people in the world aware of ocean altimetry. Today more than 1,500 students participated in this ocean altimetry contest.”

In another project, two classes from France were working independently and both became intrigued with a “plastic island” in the Pacific. The two groups met at the Argonautica annual meeting in La Rochelle, France. Since then, working together, they advocated the launch of three Argonautica buoys last year in this area of the Pacific. The team studied their paths to see if there were any similarities between the motion of the buoys and that of the plastic. They would now like to work with U.S. students on this issue [D. De Staerke].

“Voyage on the High Seas”, the Jason-1 board game continues to be a popular and useful tool for developing an interest in the ocean environment. Over the years, the game has been effective in formal and informal settings, particularly among students age 9-14. Supplemental activities for using the game to reinforce the seven essential ocean literacy principles are being investigated [A. Richardson].

7.5.5 Promoting OSTST

Climate change and environmental protection are central themes in recent news stories, and are a common focus in student activities and public discussions. The science results from ocean altimetry satellite data can be an important element in this dialogue and, used along with data from other satellite and in situ sources, can be a highly relevant component in developing solutions for action and change in environmental stewardship. Through our mission and organizational web pages, outreach activities, and products, we seek opportunities to expose the relevance of our data and research in public, educational, and academic settings [M. Srinivasan].

7.5.6 Continued Activities

Activities are continuing on developing mission and science web pages, issuing press releases for major mission milestones and new research findings, feature stories on PI science, image releases, and mission activities. Other activities include developing products such as science writer’s guides, videos, and animations to promote OST science.

A strong focus at JPL is in the area of “new” media and social networking, such as Facebook, Twitter, blogs, and 3D and interactive technology (see features on JPL’s new climate website, http://climate.nasa.gov). JPL is also working to update and correct entries in the online informational web site, Wikipedia [R. Sullivant].

The new SWOT website at JPL (http://swot.jpl.nasa.gov) is an opportunity to disseminate information on this important new mission, and includes links to relevant mission documents.

7.5.7 New Planned Efforts

Promoting OSTST science and educating students and the public on ocean literacy will remain the focus of our outreach efforts. Training of new data subscribers and novice users in optimizing satellite altimetry data for their specific application will continue. In addition, we will focus efforts on the following topics:

- Jason-2/OSTM, SWOT, Saral and Jason-3 education & public outreach and applications outreach
- Altimetry and multi-sensor applications promotion
- Coverage of science team research and other applications on web
- Aviso Google Earth altimetry application browser with a series of new images

7.6 Inland/Coastal Altimetry (F. Mercier, T. Strub, S, Calmant)

7.6.1 Introduction

The goal of this splinter session was to review progress in the use of altimeter data to investigate processes at work in the coastal ocean and inland waters. The session was comprised of 28 (7 oral and 21 poster) presentations. We asked authors to address: (1) methods used to retrieve and/or analyze altimeter data in these regions, assess the quality/reliability of the different components entering in the determination of the height/altitude products (range trackers, geophysical corrections, geoid models, etc....); (2) descriptions of operational systems that use altimeter data, in conjunction with other satellite, in situ and model fields, to address problems of societal concern; and (3) basic scientific studies that use altimeter data (along with other types of data or model fields) to examine processes affecting inland waters and the coastal ocean.

The fairly large number of abstracts submitted for this session reflects the growing community of research scientists engaged in the use of altimeter data in coastal ocean studies. Two workshops have been held on this topic in: Silver Spring, Maryland (February, 2008); and Pisa, Italy (November, 2008). A third workshop is scheduled to be held in Frascati, Italy, during September 17-18, 2009. Summaries of the first two workshops and information on the third can be found at http://www.congrex.nl/09C32. The splinter session at the OSTST meeting provided another venue for this community to get together. It also added a larger group of researchers applying altimetry to inland waters than had attended the coastal altimetry workshops.

7.6.2 Coastal and Inland Reprocessed Data Sets

At least three efforts are underway to produce altimeter data sets that are specifically processed to enhance use of the data in coastal ocean areas and over inland waters.

PISTACH: This project is supported by CNES, involving many CLS investigators (ftp://ftpsedr.cls.fr/pub/oceano/pistach/). Its focus is presently on producing an enhanced set of Jason-2 IGDR data for the period beginning in November 2008. Modifications to the data set include enhanced tracking and geophysical corrections for both coastal ocean and terrestrial inland water data retrieval. The first phase of PISTACH ends in late 2009. In future phases, it may reprocess the historical Jason-1 and TOPEX/POSEIDON data sets.

COASTALT: This ESA-funded project (http://www.coastalt.eu/) is producing enhanced data for the Envisat altimeter over coastal ocean regions, complementing the Jason-2 data set from PISTACH. It does not have an inland water focus. Like PISTACH, the first phase of COASTALT ends in late 2009. In future phases, it may reprocess the historical ERS data sets and may continue into the future with CryoSat and Sentinel-3 data sets. A book on coastal altimetry is nearing completion (see the URL above).

CTOH: This project (http://www.legos.obs-mip.fr/en/observations/ctoh/originalite) is a French national service that applies new methods that make possible new uses for altimeter data, over both open and coastal ocean regions, as well as over inland waters and the cryosphere. It uses all of the available altimeters to produce consistent, multi-altimeter data sets, building on the previous X-Track methodology. It has reprocessed the altimeter data in a number of global regions and is testing applications in those regions.

Data sets for Inland Waters are usually focused on specific regions, although there are plans to enlarge some of their target areas.

Global Terrestrial Network for Lakes (GTN-L): Genero et al. (LEGOS/CNES) reported on initial efforts to develop a lake center through collaborations between LEGOS and the Russian Academy of Sciences. The eventual goal is a global data set of lake levels, based on remote sensing techniques. Work on the Amazon and Congo Rivers was also described.

Amazon Basin Alert Network: Sousa et al. and Calmant et al. reported on use of altimeter data over the Amazon River, along with efforts to establish a network of water level estimates from Jason-2 IGDR data over the extended Amazon basin. If water levels in the upper basin can be provided with no more than a 2-week delay, they can be used in hydrodynamic models to provide flood warnings for the lower basin. Presently, a sparse system of 20 gauges provides observations with a 2-day delay, but observations from the rest of the basin have a 6-month delay.

Hulun Lake: Guo et al. analyzed a 10-year data record of altimeter-derived lake levels for Hulun Lake in northern China. The seasonal cycle was the dominant time scale, with a weak El Niño signal also present.

7.6.3 Specific Methods and Algorithms

In ***coastal ocean regions,*** aspects of the **wet troposphere** correction are being investigated in several studies. Off the U.S. West Coast, Haack and Strub are using water vapor fields from a high-resolution atmospheric model (COAMPS, from the U.S. Navy) to characterize sharp gradients in fields of IWV. The COAMPS model fields are also being used to compute PD estimates, in comparison to PD values from improved radiometer (TMR, JMR) algorithms (Brown). In the same region, multi-channel IR algorithms that correct estimates of SST for atmospheric attenuation are being used to estimate the integrated water vapor (IWV) path delay (PD) by Emery et al. The IR methods can only be used in cloud-free regions of images, which are not necessarily coincident in time with the altimeter data. Data from dual-frequency GNSS receivers along the coast are being combined with offshore microwave data from the altimeters and atmospheric models by Fernandes et al. to provide IWV PD estimates with 1 cm accuracy in some locations. They recommend increasing the network of coastal GNSS locations to provide coverage with 100 km separation (or less) between sensors. Looking at other corrections in coastal regions, **tidal** and **high-frequency** ocean signals are the subject of ongoing investigations by Lyard and Roblou, using an improved finite element model (T-UGOm).

Considering **tracking** over and near land, a (possibly) unique example of **waveform** anomalies was described by Quartly et al., caused by a small (10 square km) island under the altimeter track. The waveforms were also affected by patches of calm waters (bright spots) near the island. More general advances in **re-tracking,** using the POSEIDON Diode/DEM tracking model, were presented by Desjonqueres and Lombard. This experimental method is being applied to a subset of the global continents during cycle 34.

The retrieval of water levels over **inland waters** is also making progress. Seyler et al. and Calmant et al. demonstrated the ability of altimeter data to follow the range of water levels (0-10 meters) over the Amazon River. The general use of Jason-2 data over U.S. inland waters was presented by Birkett and Beckley, while Lee et al. found that re-tracked 10-Hz TOPEX data over Louisiana wetlands appeared to follow fine scale (660 m) dynamics of water levels in the wetlands.

7.6.4 Coastal Oceanographic Applications

The combination of altimeter and in situ data with coastal ocean models is felt by many oceanographers to be the form that operational coastal ocean "observation" systems will take in the future. Approximately a third of the splinter presentations discussed this topic.

Data from altimeters and subsurface gliders were combined by Pascual et al. and Ruiz et al. in the Western Mediterranean Sea. The gliders provide hydrographic fields of temperature and salinity, from which dynamic heights and geostrophic velocities are calculated, for comparison to the altimeter SSHA and surface geostrophic velocities. In addition, the "integrated" horizontal water velocity can be calculated by tracking (with GPS fixes) the sequential displacement of the glider's surface positions. Using higher frequency altimeter data (10-20 Hz) helps in the comparison. Around the island of Corsica, Roublou et al. described a more complete integrated observing system, consisting of reprocessed coastal altimeter data, several in situ sources of data, an improved geoid and high resolution meteorological model fields.

Along the margins of the Western North Atlantic, Han presented results from a 3-D finite element model, which agreed with altimeter observations over the continental slope and deep-ocean but not in the coastal ocean over the shelf. The model fields were also used to estimate a local marine geoid. In the Gulf of Maine (GOM) and Mid-Atlantic Bight (MAB), Feng et al. compared variances in the altimeter fields using different geophysical corrections. They inferred which corrections were better from changes in the variances. Also in the MAB, Zavala-Garay et al. used variational data assimilation (DA) with the Regional Ocean Modeling System (ROMS) to test the effect of assimilating SST and SSHA. Surface velocities from coastal HF radars and hydrographic fields from gliders provide independent checks of the improvements in the model fields gained through the DA.

Along the U.S. West Coast, another modeling study was carried out by Kurapov et al., assimilating the alongtrack SSHA data into ROMS. Using their own tangent linear and adjoint codes, the variational approach was modified to include dynamics unique to the coastal ocean. For example, alongshore propagation of coastal-trapped waves (CTW) create larger alongshore decorrelation scales than found farther offshore. These must be included in the covariance statistics used to adjust the initial conditions. The results demonstrated that the assimilation of alongtrack SSHA improved comparisons between model and satellite SST fields (which were not assimilated). Coastal HF radar and subsurface glider data are also being used in these studies.

CTW dynamics were also investigated using model and altimeter data in the Tropical Atlantic by Peter and Lazar. Kelvin waves propagate across the Atlantic at the equator and then down the South Atlantic's eastern coast as CTW's. These affect the local dynamics and heat budgets of the coastal ocean.

In a very different application, combinations of altimeter, in situ (bottom pressure and other) data and model fields were used to calculate volume transport through the Indonesian Throughflow by Song et al. Data from the GRACE gravity mission were also used in the study.

7.6.5 New Altimeter

A poster by Steunou et al. presented the approach of the future AltiKa altimeter, which will be a collaboration between CNES and the Indian Space Research Organization. This is a Ka-band altimeter, meant to follow Envisat and complement Jason-2. It includes a bi-frequency radiometer for the IWV PD and a DORIS/DIODE navigator, building on experience with Jason-2 tracking modes.

7.6.6 Discussion and Conclusions

In discussions during the oral and poster sessions, several suggestions were made for coastal ocean and inland water splinters during the next OSTST meeting.

- A longer period is needed for these topics, given that this splinter had the largest number of abstracts submitted to it (with the exception of the "general" topics session). There is enough interest to have separate splinters for Coastal Ocean and Inland Waters. These should be made permanent splinter topics for OST meetings and should not conflict in time, since there is overlap in topics and interests.
- Since initiatives such as COASTALT and PISTACH will have finished their initial phases, the oral sessions for the coastal and inland altimetry splinters should be used to highlight and summarize the important results from those initiatives. Ongoing plans for these and other initiatives (CTOH, etc.) should also be presented.

7.7 General Ocean Surface Topography Science

General science contributions were presented in a poster session. Links to these presentations can be found on the meeting website: http://sealevel.jpl.nasa.gov/OSTST2009/index.html.

8. Conclusions

The closing session was chaired by L-L. Fu and J. Willis. Before summaries from the splinter session chairs, L-L. Fu presented plans for a special issue on Jason-2 Cal/Val results in *Marine Geodesy* that would be dedicated to the late Dr. Yves Menard. The deadline for submission is Oct 1, 2009, accepted papers are due by Feb 10, 2010 and publication is scheduled for June of 2010. The Chief Guest Editor for the issue will be Dr. George Born. An announcement was also made for a special session on ocean surface topography to be held at the 2010 Ocean Sciences Meeting, Feb 22-26 in Portland Oregon, USA.

A final plenary talk was given by D. Alsdorf of Ohio State University on the status of the SWOT mission. Alsdorf emphasized the importance of SWOT to both the oceanographic and hydrological communities. The primary oceanographic objectives of the SWOT mission are to characterize the ocean mesoscale and submesoscale circulation at spatial resolutions of 10 km and larger. The hydrologic science objectives of the SWOT mission are to measure the storage change in lakes, reservoirs, and wetlands larger than 250m by 250m and to estimate discharge in rivers wider than 100 m (50 m goal) at sub-monthly, seasonal, and annual time scales. The instrument will be a Ka-band SAR interferometric system with 2 swaths, 60 km each. Onboard data compression will provide 1 km resolution over the ocean. No data onboard data compression will occur over land allowing for 50 m resolution. The SWOT Science Working Group has meet several times over the past 2 years and determined that the orbit inclination will be 78° with and repeat exactly every 22 days yielding global coverage with 2 samples each repeat period. Finally, Alsdorf noted that the Mission Science Document was nearing completion and would be ready for public release soon.

8.1 Evaluation of the Jason-2 GDR

The quality of the Jason-2 GDR-T was evaluated by several splinter groups. The POD splinter reported that Jason-2 POD performance is close to or better than 1 cm for all POE orbit solutions. In the instrument processing splinter, Tran noted that Jason-1/2 differences do not have an obvious SWH dependence and that SSB solutions for them are consistent at the 1-2 cm level over the full range of SWH and wind speed. The AMR was reported to be meeting is requirements and performing better than the JMR, particularly near the coast. However, Brown reported that the new Autonomous Radiometer Calibration System has detected and corrected two jumps in the AMR so far. After correction, the radiometer calibration appears to be stable at around the 1 mm/yr level over the first year of the mission. Finally, a retracked GDR for TOPEX has been produced, but use of this product is not recommended until addition work is done to improve it.

The analysis of the formation flight phase between Jason-1 and Jason-2 clearly show very good agreement between the measurement systems of the two satellites, particularly with Jason-1 GDR-C. The origin of the relative range bias between Jason-1 and Jason-2 (~70 mm) has been discovered recently (see “Summary of the in situ analysis key findings” in section 7.1.2). This needs further investigation (notably on the C band) but, if confirmed, both satellites are measuring sea surface consistently, but too high by about 20 cm.

It was stressed by N. Picot during the summary of the Jason-2 GDR analysis that although improvements may be available, it is important to provide a consistent and seamless data product across all altimeter records. He further recommended that although the current GDR met all requirements, a number of improvements remain to be included. Therefore, he recommended that the current version be released as version "T", with a more complete release to follow. After reviewing the status and accuracy of the Jason-2 GDR, the OSTST also made the following recommendation regarding its public release:

The Ocean Surface Topography Science team recommends that the OSTM/Jason-2 Geophysical Data Records, version T, be released to the general public. This recommendation is based on evidence presented at the OSTST meeting in Seattle that demonstrates the data on this product meets all mission requirements and has accuracy as good as, or better than, data from the Jason-1 Geophysical Data Records.

8.2 Future Missions

The importance of maintaining the accuracy and continuity of the precision altimeter record was emphasized several times during the meeting. With transition of responsibility for the altimeter missions to the operational agencies and the development of Jason-3 drawing near, considerable discussion was given to the need for a more comprehensive understanding of both systematic and random errors in the altimeter data sets. The plenary session on sea level error budgets identified several potential error sources that must continue to be studied an addressed to ensure accuracy of the long-term record of sea level rise. The most immediate of these were the need to maintain the accuracy of the terrestrial reference frame, and a need to improve the long-term stability of the on-board radiometer corrections. Following the error budget session a lengthy discussion lead to the adoption of the following recommendation by the OSTST:

Given the societal relevance and scientific importance of global sea level rise, and given the climate focus and operational nature of the Jason-3 mission, the Science Team recommends that the Project take steps to improve the accuracy of the global mean sea level measurement. This will ensure that global signals such as the ongoing rise of 3 mm per year and the 4 to 5 mm interannual fluctuations associated with ENSO will continue to be observed with sufficient accuracy and that data be released in a timely manner to facilitate monitoring of these signals. Although a Level 1 science requirement for global mean sea level accuracy was placed on Jason-2, only the radiometer design was updated from Jason-1 to achieve this capability. As a result, exhaustive scientific calibration activities have been required to ensure sufficient accuracy of the global sea level record. Furthermore, the Jason-2 radiometer is presently calibrated using natural Earth targets. This risks contamination by other climate signals and reduces the independence of the mean sea level measurement

Therefore, the science team recommends that a study be initiated immediately to identify all components of the measurement system whose drift could affect the globally-averaged sea level estimate. The study should indicate those components under Project control, and determine the cost and

feasibility of complying with the Level 1 science requirement that existed for Jason-2: to "Maintain the stability of the global mean sea level measurement with a drift less than 1 mm/year over the life of the mission." The project should coordinate with the science team during and after the study, so that instrument stability requirements can be set before mission development begins and to ensure that Jason-3 meets this Level 1 science requirement.

After the closing plenary talk given by D. Alsdorf, the OSTST discussed the importance of the SWOT mission and adopted the following recommendation regarding SWOT:

Recognizing the urgency of making new observations for fundamental understanding of

1. **the vertical transfer of heat and nutrients in the ocean for improving ocean climate prediction models,**
2. **the storage and discharge of land water for improving the prediction of the shifting freshwater supplies in a changing climate,**
3. **the interaction between ocean currents, sea ice, ice shelf, and ice sheets for improving the prediction of polar ice melting, the Ocean Surface Topography Science Team recommends that NASA and CNES allocate the necessary resources for a speedy development of the SWOT mission including prelaunch campaigns for collecting field data supporting the validation of the measurement approach.**

8.3 Future meetings

The next meeting is proposed to be held in Europe in October 2010. The meeting will be held in conjunction with the annual IDS meeting as well as a workshop for the upcoming SWOT mission. As a theme, the meeting will focus on high resolution remote sensing of ocean dynamics and hydrology.