Report of the 2007 OSTST Meeting (edited by L-L. Fu)

Executive Summary

The 2007 OSTST Meeting was held in Hobart, Australia, on March 12-15. The meeting was hosted by CSIRO with support from the Australian Bureau of Meteorology Research Centre and the Royal Australian Navy. The primary objectives of the meeting were to (1) provide updates on the status of Jason-1 and OSTM/Jason-2, (2) review the progress of science research, (3) evaluate the quality of GDR version B, (4) discuss the plan for GDR version C, (5) make recommendations on future mission requirements, (6) conduct splinter meetings on various topics, among which a theme 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), which have failed to deliver quality data in a consistent manner. However, Jason-1 POD continues meeting the mission requirements based on DORIS, LRA, and reduced TRSR-2 tracking data. OSTM/Jason-2 development and implementation is on track for launch in June, 2008. It will be launched into the same orbit as Jason-1 but one minute ahead. An initial cross-calibration phase is planned for 6 months before Jason-1 is maneuvered into an interleaving orbit for a science tandem mission with OSTM/Jason-2.

Overview of science progress was presented by 12 invited talks on subjects ranging from global sea level rise, internal and coastal tides, to water levels of lakes and rivers. New estimates of the decadal variability in global mean sea level rise and acceleration were reported. New maps of global ocean general circulation have been constructed from the combination of surface drifter and satellite altimetry observations, revealing remarkable zonally-oriented narrow currents. New findings of the properties of ocean eddies and their propagation have raised questions on the roles of Rossby waves versus eddies in ocean's response to atmospheric forcing. Modelling and data assimilation is responsible for remarkable progress in the understanding of climate variability from seasonal, interannual, to decadal time scales, as well as in the operational applications of altimetry observations. The application to the study of inland waters is a growing field with rich potential for breakthroughs utilizing future wide-swath observations.

The quality of GDR B was evaluated by various splinter groups. The bias of sea surface height (SSH) of Jason-1, although somewhat reduced, still remains at the order of 10 cm (+84 mm at Corsica; +115 mm at Harvest). A significant drift in GDR A SSH was much reduced as a result of re-calibration of JMR in GDR B. The discrepancies between Jason-1 and T/P SSH measurements during the cross-calibration have also been much improved.

The POD group has produced a new complete error budget for both T/P and Jason-1, including breakdown into components ranging from noise, time varying gravity (including hydrological effects), to geocenter motion. The RSS error for POD in Jason-1

GDR B has been reduced to sub-centimeter level (9 mm). T/P POD error has also been reduced to 1.5 cm. New POD standards have been proposed for GDR-C processing scheduled for early 2008.

The continuation of precision altimetry data record beyond OSTM/Jason-2 is a prime concern expressed by the team during the meeting. Although missions like AltiKa and Sentinel-3 have been approved and proceeding, these missions are not designed for large-scale climate studies. Jason-3 and SWOT are the next missions for extending the climate data record. However, these missions have not yet been approved by space agencies. To address the concern, the OSTST made the following recommendation:

To continue the precision altimetry data record for monitoring and understanding global ocean circulation and sea level variability in relation to global climate variability, the OSTST recommends that Jason-3 be a high priority mission for NOAA and EUMETSAT and that, as recommended by the NRC Decadal Survey, the Surface Water and Ocean Topography Mission (SWOT) be a high priority mission for NASA. Jason-3 is vital for continuing the existing climate data record by bridging the gap between the present high-precision missions and future wide-swath altimetry missions, of which SWOT is the first.

No consensus was reached for a recommendation on Jason-3 orbit, but it was agreed that ***if a change of orbit (from T/P, Jason-1, and OSTM/Jason-2) was to take place, all future precision altimetry missions must fly in the same new orbit.***

Regarding the impact of a sun-synchronous orbit for SWOT on meeting oceanography objectives, a unanimous consensus was reached: ***A sun-synchronous orbit will alias many surface and internal tidal components as well as all diurnally-varying signals into highly undesirable frequencies that overlap with important time scales for ocean circulation and climate studies. Therefore, such orbits for SWOT are not acceptable for meeting oceanography requirements.***

1. Introduction

The 2007 OSTST Meeting was held in Hobart, Australia, on March 12-15. The meeting was hosted by CSIRO with support from the Australian Bureau of Meteorology Research Centre and the Royal Australian Navy. The meeting was opened by the Governor of Tasmania, His Excellency the Honorable William Cox, who officially welcomed the meeting participants to Hobart. Neville Smith then spoke on behalf of BMRC as its Chief Scientist to welcome the meeting participants, noting that the meeting was the first OSTST meeting ever held in the southern hemisphere. As a keynote for the meeting, Commander Andrew McCrindell of RAN delivered a presentation of the applications of satellite altimetry to Australian naval operations.

In his opening remarks, L-L. Fu, the NASA Project Scientist for the Jason Mission, recognized the strong and long-lasting participation of Australian oceanographers in the enterprise of precision altimetry over the past two decades and expressed the appreciation of the opportunity to have the meeting in Hobart and interaction with local participants. He also acknowledged the excellent assistance of David Griffin in the planning of the meeting and the logistics support.

2. Program and Mission Status

L-L. Fu and D. Griffin gave a brief overview of the meeting's technical programs before introducing E. Lindstrom and E. Thouvenot to speak on the status of altimetry and oceanography programs at NASA and CNES, respectively. Lindstrom showed the overall NASA program and the role of earth sciences, including the next two oceanography missions: OSTM/Jason-2 launch in 2008 and Aquarius in 2009. He also addressed the plan to renew the OSTST in 2008 as announced in NASA's ROSES Program.

Thouvenot reported on CNES altimetry program with focus on OSTM/Jason-2 and AltiKa. AltiKa is to be launched as part of the SARAL Mission (joint mission with the Indian Space Research Office) in 2009-2010. 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 2012. CNES is also planning for participation in wide-swath altimetry (SWOT).

S. Coutin-Faye presented the CNES status of Jason-1, which delivered 95% of science data since the last OSTST meeting. The problem of the cross-track excursion outside the +/- 1 km nominal repeat track boundaries (lasted for about 40 days) was fixed. The payload status is very good. CNES and NASA signed an agreement for a 5-year mission extension in December 2006.

G. Shirtliffe presented the status of the NASA portion of Jason-1. In the period since the last OSTST Meeting in Venice, no science or engineering data has been lost due to NASA ground system anomalies or command errors. Excluding the two-week safe hold event in Oct.-Nov. 2006, the total data recovery rate exceeds 99.97% of all available science data. The support of GDR-B reprocessing is going on well and near completion. Recalibration of the JMR performed to correct the anomalies in Version A GDRs. The TRSR1 GPS receiver has failed completely and the TRSR2 receiver has been suffering from degraded performance and reduced operational periods since mid-2006, affecting the quality of GPS-based orbit determination and near real-time data products. However, Jason POD continues to meet science requirements based on DORIS, LRA and reduced-availability TRSR2 tracking data.

N. Picot reported the status of SALP (a multi-mission altimetry and orbit data processing center) and the GDR reprocessing. The current tasks of SALP are to support T/P, Jason-1, ENVISAT, and SPOT satellites. Preparations for Jason-2 and AltiKa are underway. The focus of Jason-1 is GDR-B reprocessing, which is expected to be completed in a few weeks. GDR-C reprocessing is expected to start in early 2008 for cross-calibration of OSTM/Jason-2.

G. Zaouche reported the status of OSTM/Jason-2. The responsibility sharing among the four partners (CNES, EUMETSAT, NOAA, and NASA) was described. Near-real-time OGDR will have 10-cm orbit with re-tracked sea surface height with improved resolution near coasts. Special data products for coastal and in-land water applications will be available. OSTM/Jason-2 will be launched into an orbit with 1 minute ahead of Jason-1 along the same ground tracks for cross-calibration. Payload integration started in December 2006. Satellite integration and test will be conducted from June 2007-January 2008. End-to-end ground system test is scheduled for completion before May 2008. Launch is scheduled for mid June 2008.

3. Other On-going and Future Mission Status

J. Noubel reported on the status of the joint CNES/ISRO AltiKa/SARAL mission. It is a gap filler mission between ENVISAT and Sentinel-3. It will carry a Ka band (35.75 GHz) radar altimeter, a two-frequency (23.8 and 37 GHz) microwave radiometer, DORIS receiver, and a laser retroreflector. The launch date is in 2009-2010.

L-L. Fu presented the status of the development of a wide-swath altimetry mission. The recently released NRC Decadal Survey recommended the combination of the concepts of WaTER and Hydrosphere Mapper into a single mission to address the objectives of both the land hydrology and oceanography communities. After last year's Venice Meeting, the two communities already held two joint meetings (a workshop in October and an AGU session in December) leading to a consolidated mission concept. This new mission concept is called SWOT (Surface Water and Ocean Topography). A key mission design issue is the choice of orbit. A question posed to the OSTST is the impact of a sun-synchronous orbit on the oceanography objectives. This question was addressed in the Tide/HF splinter session.

J. Benveniste gave a presentation on the status of ESA missions:

- ESA's Living Planet Programme has a series of approved missions of direct interest to OSTST. See: www.esa.int/livingplanet
- Earth Explorers have focused scientific objectives - and each will address key questions about the Earth System
- GOCE, SMOS and CryoSat in the next 2 years
- The 6 short-listed "7th Explorer" are subject of a feasibility study now in call for Tender.
- Sentinels on-going development
- Several studies and algorithm development in support of missions are on-going and planned this year.
- ENVISAT RA-2/MWR in good health, monitored and drift corrected

S. Wilson and F. Parisot reported on the status of Jason-3:

- Jason-3 has been clearly identified as priority 1 in Europe for satisfying the needs of the Marine Core Services within the GMES initiative.

- EUMETSAT/NOAA approach has been endorsed at high level
  - Several exchanges of letters between EUMETSAT, NOAA and CNES confirm the commitment of these agencies on Jason-3.
- Focus group and Application and Implementation Groups have been established by EUMETSAT and NOAA with participation of CNES, NASA and others.
- In order to ensure continuity with Jason-2 and minimize cost and risk, the Jason-3 mission is proposed to be based on a maximum of recurrence with Jason-2, with an orbit choice still open.
- What orbit does the OSTST recommend for Jason-3 ?

4. Science Plenary Sessions

The progress in science investigations conducted by OSTST was reviewed by 12 invited talks:

Global observations of westward energy propagation: Rossby waves or nonlinear eddies? - D. Chelton

Eddy-mean flow interaction: insights from satellite altimetry measurements – B. Qiu

Understanding sea-level rise - J. Church

Observing decadal variability in the oceans – D. Roemmich

Seasonal to interannual variability of global sea level: recent progress in monitoring and prediction – T. Busalacchi

Large-scale subseasonal sea level variability over the global ocean – R. Ponte

Combining ocean velocity observations and altimeter data for OGCM verification – P. Niiler

Ocean surface topography applications to circulation mapping in the coastal ocean – W. Emery

Internal tides, tides in shallow seas, and altimetry – G. Egbert

Monitoring terrestrial surfaces waters by satellite – A. Cazenave

Ocean state estimation for studies of climate variability –T. Lee

Operational oceanography- Eric Dombrowski

Before the start of the plenary science session, L-L. Fu presented a brief tribute to Roman Glazman, an OSTST member who passed away last April.

5. Poster Sessions

Two poster viewing sessions were conducted. The posters were grouped into the following categories:

- Science results (modeling/data assimilation, mean dynamic topography, tropical ocean, coastal ocean, sea level, ocean circulation/air-sea interaction, ocean eddies, land/ice/hydrology)
- Local and global calibration/validation
- Precision orbit determination and geoid
- Multi-satellite/operational applications
- Tides and high-frequency aliases
- Sea-state bias and re-tracking analysis
- Outreach

6. Splinter Sessions

The proposed theme for the splinter sessions (in particular for cal/val, POD/geoid, tides/HF aliasing, sea-state bias/retracking) is the error budget of altimetry products. R. Ponte, who proposed the theme, made a brief introduction to the subject before the start of the splinter sessions. He stressed the following points:

- Basic errors/Jason+TP
  - radar noise
  - orbit error
  - environmental corrections (wet and dry troposphere, ionosphere, sea state bias,…)
  - models (tides, inverted-barometer effect, high-frequency correction)
- Basic errors/other missions, combined products, etc.
- Special topics
  - methodologies to estimate errors
  - characterizations of spatial, temporal behavior
  - errors in time-mean ocean topography, mean sea level trends,…
  - correlation structures

6.1 Cal/Val (P. Bonnefond, S. Nerem, B. Haines)

The splinter "Local and Global Calibration/Validation" focused on an assessment of the new data products available for Jason-1 (GDR-B) and for TOPEX/Poseidon (RGDR-LSE&MAP). The temporal coverage of these data products has been significantly improved since the Venice (2006) OSTST meeting, although neither span the duration of the respective missions. (At this writing, however, the GDR-B reprocessing is nearly complete.)

The Jason-1 sea-surface height (SSH) measurements on the GDR-B product remain biased (high). Estimates from the dedicated calibration sites and a Mediterranean regional campaign range from +84 mm (Corsica) to +115 mm (Harvest). The overall magnitude of the bias is somewhat smaller than experienced using the older (A) version of the GDR. Still, the Jason-1 SSH bias is clearly non-zero (order 10 cm), and the underlying cause remains a subject of investigation. For T/P, estimates of the Side B (ALT-B) SSH bias using the LSE retracking option of the RGDR fall between –9 and +3 mm, depending on the calibration site. In consideration of the systematic errors (both in-situ and altimetric), these numbers are not significantly different from zero.

In prior OSTST meetings, a significant negative drift in the Jason-1 SSH (GDR-A) measurements was a source of concern. As more cycles of the improved GDR-B product are released, the evidence increasingly supports that this drift has been dramatically reduced. At Harvest, for example, the magnitude of the drift has been reduced from 10.2 mm/yr (using GDR-A) to 0.3 mm/yr (using GDR-B). Similar improvement was noted at Senetosa (Corsica). As pointed out at the Venice meeting, much of the drift was due to spurious jumps in the JMR wet-path delay correction, which have been corrected in GDR-B. Based on the results from the calibration sites, the current SSH drift estimate is not statistically different from zero. Results from the global-tide gauge network (pending completion of the complete GDR-B data set) will be necessary to confirm this at the level of 1 mm/yr level or better.

Global evaluations of the Jason-1 GDR-B data also provide evidence of important improvements in the data quality. For example, the use of GDR-B leads to a 35% reduction in the SSH variance (crossovers) compared to GDR-A. An attendant reduction in geographically correlated errors (GCE) is also observed.

A particularly demanding goal of the cal/val effort is to reduce (to insignificance) the GCE observed in the Jason-1 – T/P SSH differences from the Jason-1 tandem verification phase. Use of the Jason-1 GDR-B in combination with the T/P RGDR (LSE) reduces the global variance of the sea level anomaly (SLA) by 2 cm^2. More important, it removes a large fraction of the hemispherical (NS) pattern observed in prior releases of the data. A large contributor to this improvement is the LSE retracking of the ALT-B waveforms underlying the RGDR ranges. Furthermore, new orbits and SSB solutions improves the overall (mean) GCE (Jason-1 – T/P). Despite the improvement in the overall (mean) GCE (Jason-1 – T/P), important differences (NS) remain when the data are segregated according to the sense of approach (ascending or descending). The effects of waveform leakages on TOPEX (ALT-B) are probably responsible, and will be targeted in upcoming versions of the RGDR data. The effects of waveform leakages on TOPEX ALT-A needs to be analyzed

Wet path delay (WPD) measurements from both JMR and TMR have been rigorously recalibrated, the results of which have led to comprehensive reprocessing of both data sets. The TMR recalibration (reflected on the RGDR) is considered the “end of mission” calibration. However, this does not preclude reprocessing of the TMR data if significant advances to the TMR algorithms or calibrations become available. Comparisons of both TMR and JMR with independent data (e.g., GPS, SSMI) yield excellent long-term stability and depict much smaller systematics (e.g., yaw state dependencies). An additional recalibration of the JMR is forthcoming for the next (C) version of the Jason-1 GDR, and will reflect a slight scale shift (2%).

A central question that emerged from the session was “What is the best approach for aligning the T/P and Jason-1 SSH time series?” It was agreed that better efforts need to be directed at developing an integrated approach that harmonizes the global differences (including the tide-gauge analysis) with point results (coastal) from the dedicated calibration sites. To succeed in this goal, it is incumbent on the investigators from the calibration sites to better reconcile their results with expectations for global, open-ocean comparisons. A particular priority is the reduction of land contamination of the JMR/TMR corrections at the calibration sites, or alternatively the use in situ (e.g., GPS) WPD measurements. The use of GPS-derived WPD delays at Harvest and Corsica improved the agreement between the respective SSH biases by 40%. Similar efforts should be made to reconcile geographically correlated orbit, SSB, and retracking errors (e.g., waveform leakages) as well as other potential sources of inhomogeneity between the coast and open ocean. A list of potential tasks to support this effort is being developed and circulated among the in-situ investigators.

Regarding the duration of the Jason-1/OSTM tandem verification phase, it was generally agreed that six months would be long enough (in view of the urgency of placing the missions in interleaving tracks to support mesoscale studies). Also, the cal/val team needs to further evaluate the implications of a possible change in orbit for the Jason-3 mission. There are obvious implications on ensuring the measurement continuity of the precision series of altimeters (e.g., T/P, Jason-1, OSTM…). Overflying only a single calibration site may not be reasonable.

6.2 POD and geoid (J-P. Berthias, J. Ries)

A. Introduction

The release of the ITRF 2005 reference system was an important event during the year 2006 for precision orbit determination (POD). The work needed to evaluate this new reference system mobilized the energy of all the POD groups for months. The other significant event was the reprocessing of the whole history of Jason-1 with the GDR-B orbit standards. Even though the GDRs themselves have not all been produced and released, the corresponding orbits are already available. These new orbits have been evaluated by various POD groups. No new major gravity model or geoid was released since the last OSTST meeting.

The goal of the 2007 POD/Geoid splinter meeting was therefore to summarize the evaluation of the GDR-B orbits and the new ITRF 2005 reference frame, as well as refine the GDR-C standards that were discussed at the Venice meeting. With the new goal of switching from GDR-B to GDR-C standards before the launch of Jason-2, the target date for selecting GDR-C standards is the end of 2007. For the geoid, the objective was only to review current work.

In addition, the POD working group was asked to provide an estimate of the contribution of the orbit error to the overall altimeter system error budget. Based on the various contributions, it is possible to provide a new, more detailed look at the orbit error components. This approach has been adopted to summarize the contribution of the POD groups to the POD effort.

B. GDR-B orbits

GDR-B orbits are based on the "intermediate standards" that were implemented in September 2005 to replace the old TOPEX/Poseidon standards. The GDR-B standards are not as "sophisticated" as those discussed during the 2006 OSTS meeting; however, they include a recent GRACE gravity model and many up-to-date models. They also combine GPS, DORIS and SLR tracking data in the orbit estimation.

To help validate the GDR-B orbits, B. Haines and W. Bertiger (JPL) have computed a new set of GPS reduced-dynamics orbits (JPL 07a) using a very advanced set of standards (including the ITRF 2005 reference system, JEM03 static GRACE gravity model, GRACE AOD1B Release-04 atmospheric gravity) and new correction maps for the GPS antennas, both on Jason-1 and on the GPS constellation. The RMS radial difference of GDR-B orbits with these new orbits is only 9 mm and stable with time (see Figure 1).

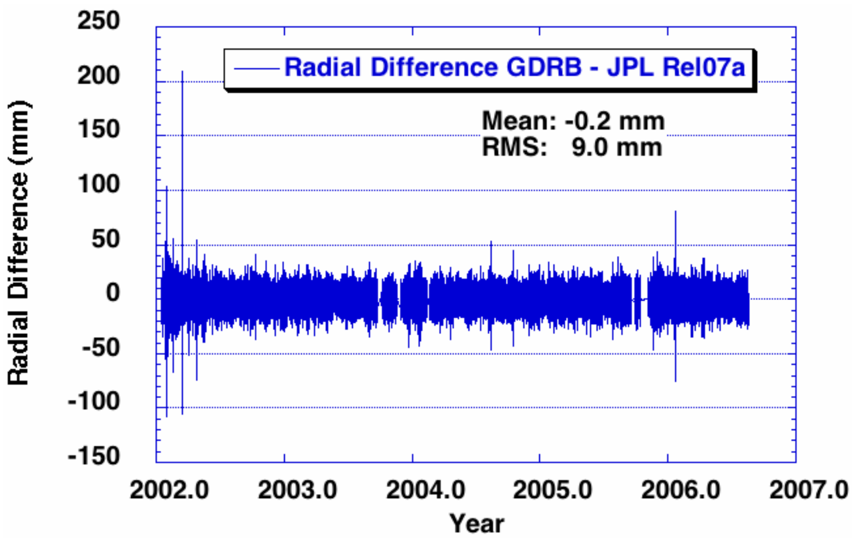


Figure 1. RMS Radial Difference between JPL 07a and GDR-B (courtesy W. Bertiger & B. Haines)

This demonstrates the good quality of the GDR-B and JPL orbits. However, some systematic differences can be observed. Figure 2 shows the mean orbit difference between the JPL 07a and GDR-B orbits over two sets of cycles. The difference over the early cycle is due to the difference in gravity modeling; this difference is small with an RMS value less than 2 mm. There is also a clear increase in the geographically correlated orbit difference between the early and the late cycles. The North-South signature seen on the late cycles is typical of a shift between orbits along the polar axis (Z-shift). This is the result of the use of different reference systems, ITRF2005 for the JPL orbits, ITRF 2000 for the GDR-B orbits.

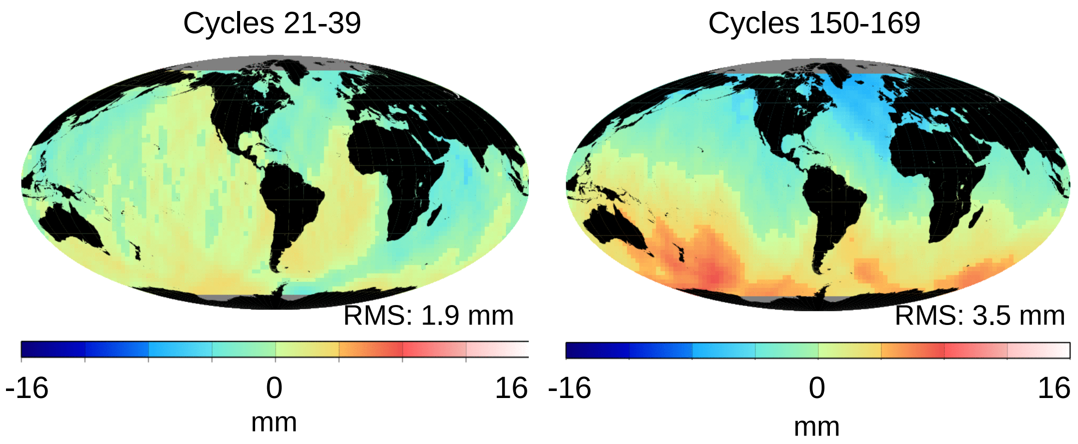


Figure 2. Geographic Radial Comparison of JPL 07a and GDR-B (courtesy W. Bertiger & B. Haines)

This type of time-varying geographically correlated orbit differences translates into differences in the mean sea level drifts computed with the two sets of orbits. It is therefore an important error type that needs to be properly evaluated.

C. Orbit error budget

The previous example shows that two orbits can agree very well in the RMS radial sense and still exhibit systematic differences, which are significant for users. For this reason, the orbit error budget needs to account properly for the nature of the error associated with each contributor. The focus now is more on the slowly varying systematic contributions to the geographically correlated orbit error.

C.1. Orbit determination “noise”

The traditional orbit error signal, at the orbital period, is still present in the orbits because of limitations in the dynamical models, primarily the surface force models, and the tracking data. However, much of the residual error in the dynamical models is accommodated by adjusting empirical accelerations at the orbital period. The dense and permanent GPS tracking supports a high level of parameterization (reduced-dynamics orbits) that significantly attenuates this error source. The less dense DORIS tracking performs very well, but retains more of the dynamical error.

This shows up as orbit differences when comparing orbits computed by different POD centers. Differences in strategies in applying the empirical parameterization lead to orbit differences at the orbital period. For Jason-1, these differences are now around 9 mm RMS for all orbits involving GPS data, and about 12 mm RMS when only DORIS and SLR are included in the orbit solution. Even though this is not a measure of absolute orbit accuracy, it does provide a likely upper bound to the orbit error. Furthermore, comparisons with the very accurate GPS-only orbits with the independent SLR tracking also indicate a radial accuracy around 9 mm.

C.2. Geographically correlated orbit error

The other key contributions to the orbit error budget are the geographically correlated errors, both static and time variable. These need to be scrutinized on a model-by-model basis.

C.2.1. Static gravity field

Static gravity model errors have been very significantly reduced with the latest GRACE gravity models. The only significant impact of differences between models on the T/P and Jason-1 orbit is limited to an East –West (order-1) signature at the 1-2 millimeter level. These differences can expected to be further reduced with newer gravity models, but the current model is more than adequate.

C.2.2. Tides

Tide model error, as evaluated by the impact on the Jason-1 orbit of the difference between contemporary models, is limited to millimeter level East –West (order-1) signatures. Contrary to static gravity, these differences vary slowly with time.

C.2.3. Time variable gravity:

The variations in the Earth gravity due to the fluctuations in the distribution of the mass of the atmosphere are the largest contributor to time variable gravity. They are also the most difficult to model, as these fluctuations reflect complex meteorological phenomena. In practice, the atmosphere contribution to the Earth gravity is computed by converting pressure fields derived from meteorological models into gravity. There are many approaches to perform this transformation, with increasing levels of precision.

The most significant impact of atmosphere gravity on the Jason orbit is again a time varying East –West (order 1) pattern with a few millimeter amplitude. Figure 3 shows how the difference between GDR-B and JPL06b GPS orbits is reduced when various atmospheric gravity inputs are used (the GRACE product AOD1B is more sophisticated than the SHDP product). Note that the JPL06b GPS reduced-dynamics orbits do not contain any atmosphere gravity model; it is only through the reduced-dynamics process that these fluctuations in Earth gravity are accommodated. This result thus demonstrates both the physical impact of the atmosphere gravity on Jason-1 orbits and the efficiency of the reduced-dynamics approach.

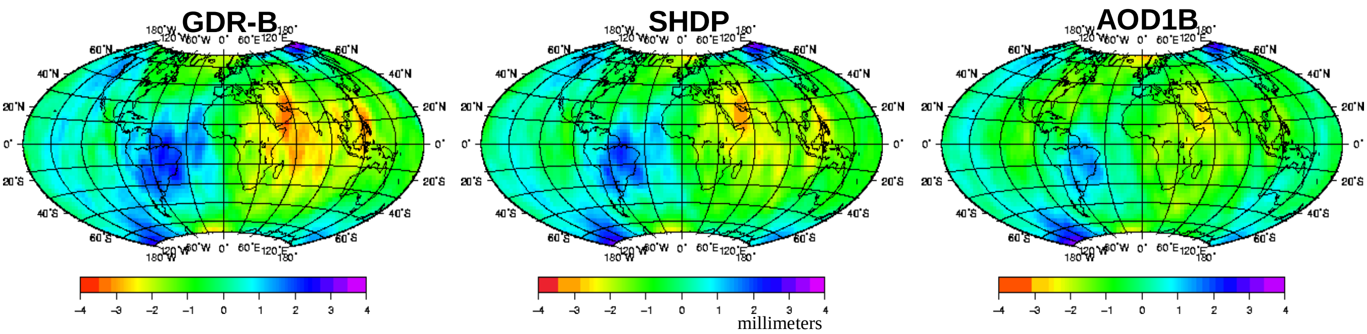
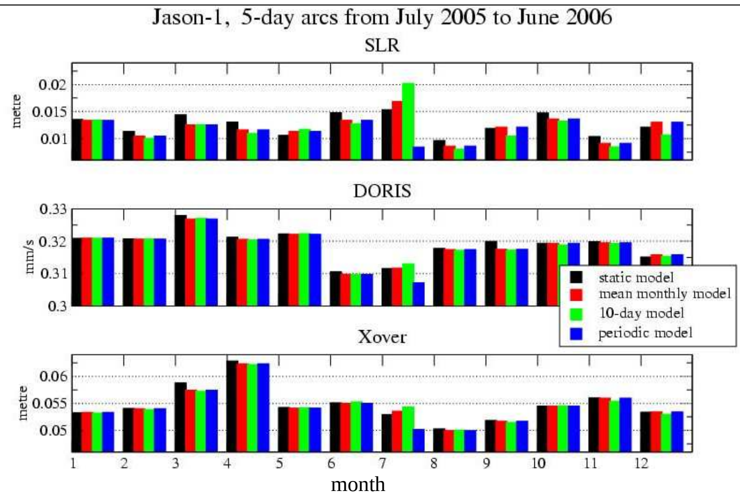


Figure 3. Geographic radial comparison of JPL 06a and GDR-B with various atmosphere gravity models (GDR-B = no model) (courtesy L. Cerri)

In addition to the atmosphere, there are other physical effects, which generate large fluctuations in the Earth gravity. The largest contributor is hydrology. Given the seasonal nature of these phenomena, empirical models limited to annual and semi-annual variations of the Earth gravity have been derived from the GRACE monthly (or sub-monthly) gravity fields.

Slight reductions in tracking data and altimeter crossover statistics when using these models prove that there is a small sensitivity of the Jason-1 orbit error to these effects.



	SLR (mm)	DORIS (mm/s)	Xover (mm)
No annual	12.7	.3219	54.7
Monthly fields	12.2	.3185	54.6
10-day fields	11.9	.3185	54.6
Annual model	11.5	.3181	54.3

Figure 4. RMS values of observation residuals for one arc per month after orbit adjustment
using various time variable gravity solutions (courtesy C. Foerste)

Overall, the contribution of the time variable gravity to the orbit error budget can be estimated at 2-3 mm with a complex time variable geographical pattern.

C.2.4. Solar radiation pressure:

A bias in the solar radiation pressure model interacts with the estimated empirical 1/rev accelerations to create a periodic Z-shift correlated with the Sun angle (beta-prime). This

Z-shift translates into a North-South geographically correlated orbit error. Hence, the impact of an error in the solar radiation pressure model is a North-South geographically correlated error that varies with a 120-day period. The amplitude is larger at high latitudes as shown on Figure 5.

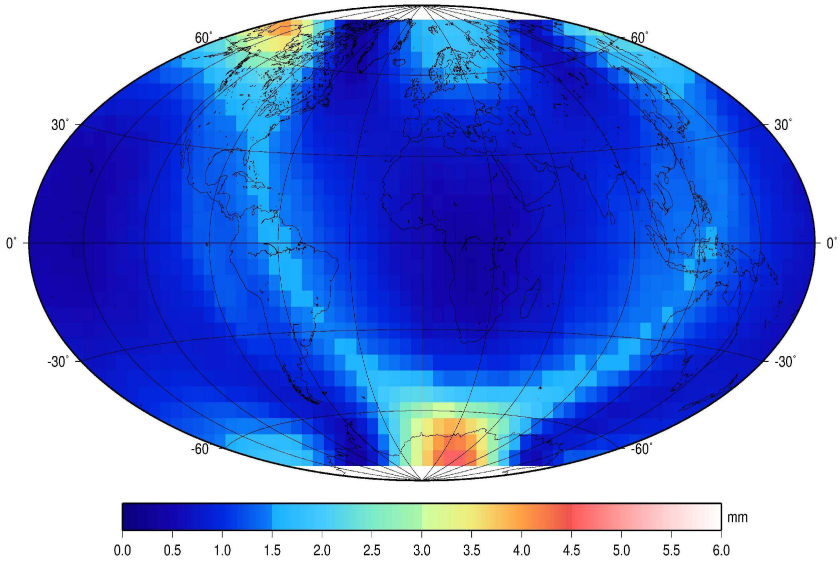


Figure 5. Amplitude of the 120-day variation in geographically correlated orbit error induced by
a change in the scale of the solar radiation model from 1 to 0.914 (courtesy N. Zelensky)

This plot assumes a reduction of nearly 10 % of the solar radiation force (comparing scale factors of 1 and 0.914). Currently there is no consensus between the POD centers on the scale factor to apply, with values ranging from 0.914 to 0.97. The impact is thus about half of what is seen on Figure 5, that is, around 3 mm amplitude at 120 days period at high latitudes.

C.2.5. Reference system

Over the last few years, the POD report has emphasized the importance of the stability of the reference system for precision altimetry applications. In particular, drifts and variations in the Z component of the reference system can translate into drifts and variations in the North-South geographically correlated orbit error. Results of the 2006 OSTST in Venice clearly established incoherences in ITRF2000 between DORIS/SLR and GPS, with both long-term drifts and 120-day variations in Z.

The new reference system ITRF 2005 clearly reduces the drift in Z between techniques. It also improves the tracking data fit results.

Jason Orbits SLR/DORIS cycles 1-177	DORIS RMS (mm/s)	SLR RMS (cm)	SLR mean (cm)	Altimeter crossover RMS (cm)
ITRF 2000	0.3740	1.440	-0.058	5.578
ITRF 2005 (SLR rescaled)	0.3734	1.365	-0.030	5.576

Table 1. Fit residual improvements with ITRF 2005 (courtesy N. Zelensky)

There was some discussion following the pre-release of ITRF 2005 on the scale of the SLR solution. It is now clearly established that the SLR solution should be rescaled for Jason POD. This rescaled solution is now an official product associated with ITRF 2005.

The switch from ITRF 2000 to ITRF 2005 is very significant for DORIS/SLR orbits. The Z-shift between the two solutions drift is more than 1.2 mm/year and reaches over a centimeter at the present date as illustrated on Figure 6 (looking only at the pink curve which corresponds to the rescaled SLR solution).

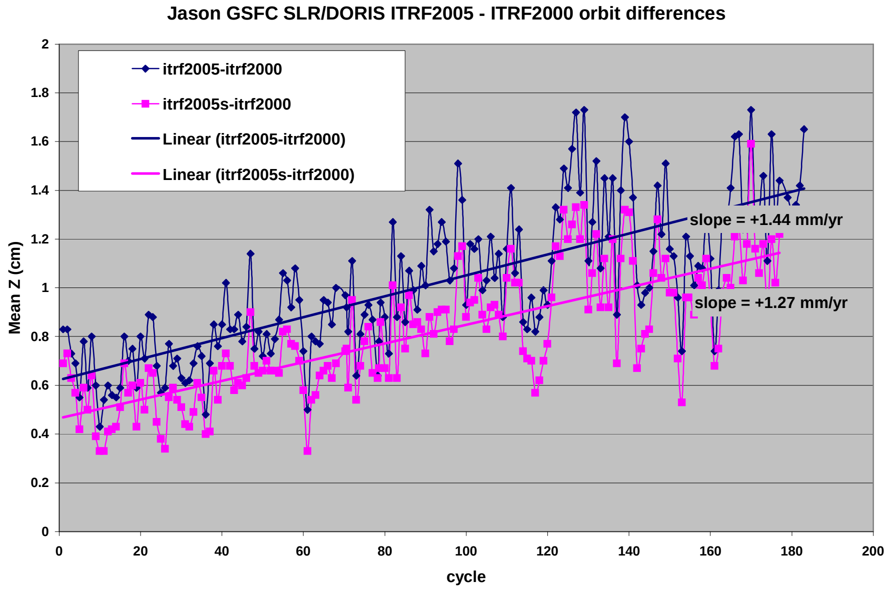


Figure 6. Z-shift between DORIS/SLR orbits referenced to ITRF 2005 and 2000 (courtesy N. Zelensky)

The GPS-based orbits appear less sensitive to this change in ITRF. Possible explanations are that there is a weaker tie to the reference system through the GPS constellation, that the IGS adopted a slightly different set of station velocities in IGS00, or that the GPS tracking is less strongly tied to the geocenter due to the estimation of the phase ambiguities. In any case, GDR-B orbits will probably not change as much as the DORIS/SLR orbits when going from ITRF2000 to ITRF2005. However, there will still be a shift in Z.

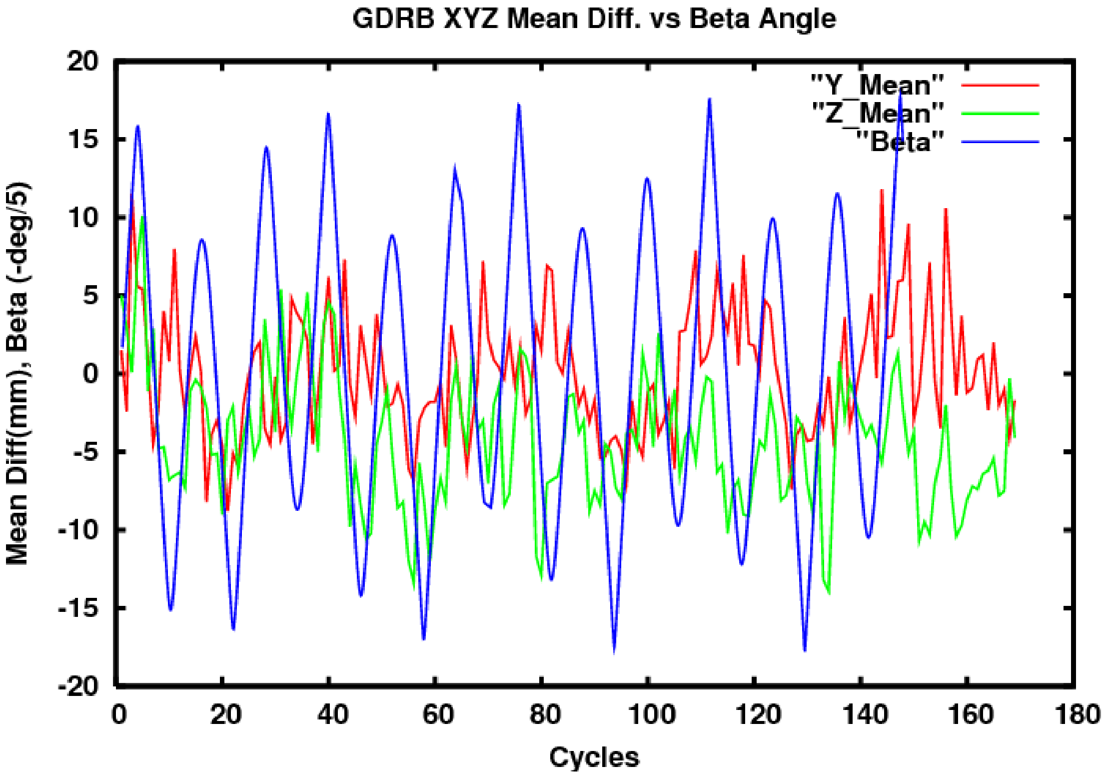


Figure 7. Y- and Z-shift between GDR-B and JPL 07a orbits (courtesy B. Haines)

Figure 7 shows the shifts in Y and Z between the GDR-B and JPL 07a orbits. GDR-B orbits are referenced to ITRF 2000, JPL 07a to ITRF 2005. The Z-shift (green curve) exhibits variations as a function of beta-prime (blue curve) as well as a small drift. The Y-shift (red curve) contains annual variations. The origin of these signals is not yet clear. Geocenter motion could play a part, since this is not modeled in any technique.

C.2.6. Geocenter motion

Geocenter motion is the motion of the Earth's center of mass relative to the origin of the terrestrial reference frame defined by the set of tracking station coordinates. This motion is dominated by a seasonal variation of 2-3 mm in X and Y, with an estimated uncertainty around 30%. For Z, the uncertainty is significantly larger, with the estimates of the seasonal variation ranging from 2 to 8 mm. In light of these uncertainties, a consensus model for geocenter motion is not yet available, and research in this area continues.

C.3. Radial orbit error budget

Preliminary estimates of the contributions to the radial orbit error budget are summarized in the following table. The contributions to the T/P orbit error can be expected to be larger than for Jason-1 since the tracking systems on T/P are less precise (the DORIS receiver has higher noise and the large laser reflector array (LRA) introduces larger biases in the laser ranging). Relying only on SLR and DORIS, the orbit fits for T/P must use a coarser level of empirical force parameterization than is possible with the GPS tracking on Jason-1. As the GPS receiver on Jason-1 degrades, the orbit error for Jason-1 is likely to increase, though probably not to T/P levels since the tracking systems on Jason-1 are more precise.

Source	T/P (mm)	Jason-1 (mm)	Dominant Systematic Signal	Rationale
Orbit determination 'noise'	13	8	One-cycle-per-orbit revolution, variable in phase and amplitude	Intercomparison of similar orbits
Static gravity field	1	1	1-2 mm 'order 1' pattern	Comparison GIF31a vs EIGEN-GL04C
Tide model	3	2	1-2 mm slowly varying 'order 1' pattern	Comparison CSR3.0 vs FES2004
Atmosphere/ocean/hydrology	3	2	1-2 mm varying 'order 1' pattern	GRACE RL04 atmosphere/ocean
Solar radiation pressure	4	2	Few mm 120-day Z-variation	3% scale error, T/P more complex due to solar array tilt
Station/data errors	3	2	Z-drift of a few to several tenths of a mm/yr are possible	ITRF2000 vs ITRF2005
GPS satellite orbits	0	2	Uncertain	Uncertain
Reference frame (origin)	0	2	Few mm bias, 0.5-1 mm/yr drift in Z	Geocenter time series estimates
Geocenter motion	2	2	2-3 mm annual variation in X and Y, 2-6 mm annual variation in Z	Geocenter time series estimates
RSS	15	9	Z-variations due to SRP probably dominate; variations with 'order-1' patterns at the few mm level	

Table 2. Preliminary revised orbit error budget (courtesy J. Ries)

D. GDR-C standards

All the issues left open have been addressed during the splinter. This provides a consistent set of standards to use for GDR-C orbit production

- The models are principally based on the IERS2003 Conventions with the addition of the ocean pole tide model.
- The gravity model is still currently EIGEN-GL04C truncated to degree and order 120 but it could switch to EIGEN5 or GGM03C if these models are available before the end of the year. At the current level of precision, there is no significant effect due to differences between gravity models.
  The models include linear time variations for C20, C30 and C40. The C21 and S21 values from the model will be used; the rates for these harmonics will be set to the IERS 2003 standard values (this has become the standard for EIGEN5).
- The tide model is the revised FES2004 model (with the K2 wave of the FES2002 tide model instead of the original K2 wave from FES2004).
- Atmospheric gravity obtained by converting the ground surface pressure into degree and order 20 gravity harmonics is taken into account; the inverse barometer is assumed to compensate for pressure over the oceans. The origin of

the data (either GSFC's service of the atmospheric contribution to geopotential or SSALTO's own conversion of ECMWF pressure fields into gravity harmonics) is still to be decided.

- Other contributions to time variable gravity (hydrology for example) will be taken into account in the form of annual and semi-annual corrections to the gravity model, derived from monthly GRACE solutions. The actual series is not yet selected; it will be the object of a comparative study during the second semester of 2007.
- The solar radiation pressure will be modified to reduce the level of empirical accelerations (both the box and wing and the UCL model need to be revised); this work will be conducted during the second trimester of 2007.
- The reference system is ITRF 2005, extended with new or "repaired" coordinates for the stations not included in ITRF 2005 (DPOD2005 and LPOD2005); these extended solutions will be available by mid-2007.
- The orbits for the GPS constellation are ITRF 2005 orbits computed by JPL; clocks are those provided by JPL (at a 5 minutes sampling rate).
- The antenna maps provided by JPL both for Jason-1 and the GPS constellation are applied for phase (not required for pseudo-range).
- An elevation-dependent correction map for the LRA is applied.
- The DORIS, SLR and GPS tracking data are combined with weights that remain to be tuned.
- The phenomenological model designed to mitigate the effect of the South Atlantic Anomaly on DORIS data is used for both instruments on Jason-1.
- No consensus currently exists on a model for geocenter motion. The impact is expected to be only at the few mm level, but research in this area is ongoing.

The current goal is to be ready to start producing orbits with GDR-C standards at the beginning of 2008, or at the latest, a few months before the launch of Jason-2. The open questions regarding the choice of specific models are not likely showstoppers, as each of the available models are sufficiently good choices. The only issue that appears to require a significant amount of work is the tuning of the solar radiation pressure model.

E. Marine geoid

The GRACE mission continues to produce high quality data, with five years on orbit and with an expected lifetime of at least another four years. Mission support has been approved through 2009, and a review is underway regarding funding an additional two years beyond that.

No new gravity models were introduced since the last OSTST meeting, although at least two new solutions, EIGEN-GL05 and GGM03, are expected shortly. At this point, additional improvements in the GRACE-based geoid models will be less dramatic, and the current emphasis is on reducing the meridional 'striations' or other artifacts that appear upon detailed examination (the current models require a smoothing radius of roughly 400 km for marine applications). It will also be important to continue to refine methods to best extract estimates of the Mean Dynamic Topography considering the accuracy (and limitations) of the GRACE-based geoids.

6.3 Sea-state bias and retracking (P. Callahan, O. Zanife)

D. Vandemark et al. have made excellent progress on SSB model refinement. A first approach relies on objective clustering which classifies sea state conditions into distinct gravity wave provinces using wave model information as well as altimeter data; they then derive province-specific SSB models based on standard parameterization. They have also explored in parallel numerous two-parameter models besides the standard wind speed-SWH model. The best parameter to use in place of wind speed is pseudo-wave age (= b * (SWH/U^2) ^0.62) which uses only altimeter measurements and swell height from the wave model. Measurable improvements are expected through optimization and combination of these two approaches.

Y. Faugere et al. investigated high frequency altimeter noise. They found that TOPEX LSE, Jason MLE4 and Envisat MLE3 have very similar high frequency noise. This reinforces the conclusions of other groups on the similarity in processing characteristics between LSE and MLE4. They also find that, as expected, TOPEX MAP has lower high frequency noise. Unfortunately, other work shows that MAP has large-scale biases and/or SWH dependence that currently make it unsuitable for general use. Finally they found out that, for all the missions, the remaining suspicious high energy in the 0.1-0.4Hz bandwidth is due to perturbed data with high mispointing values.

Rodriguez and Callahan retracked two years of TOPEX Alt-B data with both the Least Squares Estimator (LSE) and Maximum a Posteriori (MAP) algorithms. They also retracked Jason cycles 1-21 during the collinear period. The Jason data were retracked with skewness set to 0 (Jason MLE processing has skewness set to 0.1) and solving for skewness. TOPEX data show large spurious skewness related to waveform leakages in LSE processing. Unfortunately, MAP solutions return values of skewness very near 0 so that leakage affects appear in other parameters.

Thibaut et al. presented an extensive analysis of the LSE and MLE4 retracking of Jason data, in order to determine whether the retracking algorithms are responsible for differences observed between Jason and Topex sea state bias. They found that the LSE solving for skewness (average skewness ~ 0.06) agreed well with the Jason MLE4 while the other results had biases or SWH and pseudo-attitude dependence. They conclude that the cause of Jason and Topex SSB differences may be found in waveforms themselves (leakages on Topex) rather than in retracking algorithms. They also showed that MAP algorithm is not yet ready to provide users with reliable estimates.

S. Labroue et al. solved for new SSB models for the retracked TOPEX data and the Jason MLE4 data. They found that the models are now very similar for the two data sets. It is necessary to solve for TOPEX models in each “quadrant” (North/South, Ascending/Descending) in order to get TOPEX-Jason differences with less than 1 cm of SWH dependence.

These presentations led to the main conclusions regarding SSB and Retracking:

- The MLE4 algorithm being used for Jason GDR-B works as expected and produces good results.
  - The LSE algorithm with skewness solution applied to Jason does not differ significantly from MLE4.
  - Jason MLE4 and TOPEX LSE are now very consistent: no apparent SWH dependence, similar SSB models, although a quadrant adjustment will still need to be applied to TOPEX to remove residual waveform leakage effects.

- SSB processing is ready. A new Jason version will be computed as soon as other information, e.g., final CNES orbit, becomes available. A new TOPEX version will be completed when final C-band retracking is available so that dual frequency ionospheric effects can be properly accounted for.

- TOPEX re-tracking is expected to be completed by about June 2008 (P. Callahan).
  - The LSE solving for skewness will be the primary data type. The effect of not solving for skewness for SWH < 1m should be checked.
  - An empirical quadrant SSB adjustment of a form to be determined (e.g. A+B*SWH) will be needed to remove residual waveform leakage effects after the application of a global SSB model. Additional work should be done to better quantify the errors from the waveform leakages.
  - Alt-A alignment with Alt-B will be done by comparing a 1-3 year average of SSH and SSB. Some attention should be paid to adapt PTR description of Alt-A, as it has been observed that it was not stable in time.

6.4 Tides and high-frequency aliasing (R. Ray, R. Ponte, F. Lyard)

At the request of Y. Menard and L.-L. Fu, the first part of the splinter meeting was devoted to a discussion of the issue of sun-synchronous altimetry. This was prompted by the continuing cost and engineering pressures that future missions face, especially power-hungry missions such as SWOT. Sun-synchronous orbits can simplify both spacecraft design and operations. The splinter was to address whether a sun-synchronous mission could be adopted for future satellites, in light of the remarkable progress in model improvements made possible by T/P. Two presentations, by R. Ray and J. Dorandeu (given by his colleague Y. Faugère), were followed by a general discussion.

R. Ray presented an overview of the altimeter problems associated with sun-synchronous orbits. The primary issue for most altimeter users is that any error of a diurnal nature gets aliased into generally undesirable periods, either into the zero-frequency (the mean sea-surface), into long periods that potentially mimic climate signals, or into the seasonal cycle. Examples involving both tidal errors and non-tidal errors were discussed.

Because diurnal errors can be subtle and difficult to detect, the errors that sun-synchronous altimetry is vulnerable to can be difficult to anticipate. An example is the mean SSH difference between Topex and Jason-1 that is observed during the Jason cal/val period; that difference has a local-time dependence, which is clearly the result of some kind of diurnal error (*not* tides), but whose source is currently unknown. However, the mean SSH difference is seen to change over the course of the cal/val period, so a sun-synchronous altimeter could sample this error in such a way as to generate a false climate-like signal in implied mean sea level, whereas T/P and Jason-1 simply map this error into a near 60-day period, which is easily recognized as error.

While these kinds of errors concern most altimeter users, it is also obvious that sun-synchronous altimetry prevents serious tidal investigations. This is of particular concern if a primary mission goal is to study oceanography in shallow seas and coastal zones. In such regions, accounting for nonlinear, compound tides can be especially challenging, and any compound tides involving S_2 become hopelessly entangled by sun-synchronous sampling—for example, the tides MSf, $2SM_2$, MS_4 (usually the second largest compound tide), $2SM_6$, etc., are all aliased to the same period as M_2.

The presentation by Y. Faugère and J. Dorandeu emphasized further difficulties associated with sun-synchronous altimetry by examining some results from Envisat altimetry. They notice that discrepancies between ascending and descending tracks have a clear annual periodicity, with amplitudes varying spatially from about 1 cm to nearly 3 cm. The discrepancies are dependent on which tide model was used to correct the data, and they are apparently related to the coupling between the K_1 and P_1 tides and the annual cycle as sensed by Envisat.

The general discussion during the splinter offered no support for sun-synchronous missions, other than the obvious cost benefits. The consensus was that for missions such as SWOT, sun-synchronous sampling is not acceptable.

Other issues involving tides that were addressed in the splinter meeting included a short presentation by F. Lefevre on some minor errors in the FES2004 model, now used for GDR processing, involving the K_2 and S_1 tides. These errors have now been corrected in a new release of FES2004. Finally, R. Ray gave a brief presentation about some on-going work on compiling a new "ground truth" dataset to be used in testing shallow-water tide models. He asked for help, especially from Australian colleagues, in compiling such data.

A presentation by F. Lefevre, filling in for L. Carrere, described plans to improve the dynamic atmospheric correction (DAC), which is provided operationally for purposes of dealiasing atmospherically-driven (non-tidal) high frequency signals in the altimeter data. Among the latest developments, a much higher resolution version of the barotropic model (MOG2D) has been tested with positive results. The new model can account for more observed variance, especially in coastal regions. Plans to update the operational DAC product with the latest model are being considered. Changes in the implementation of the atmospheric pressure forcing will also be included, to resolve a problem with the current filtering of the S_1 air tide, as briefly discussed by F. Lyard.

The current DAC uses a barotropic model and includes no data assimilation. R. Ponte discussed the use of baroclinic models and data assimilation techniques to improve estimates of high frequency signals, and the possibility of applying those tools for dealiasing procedures. Preliminary tests based on the optimized, data-constrained sea level estimates produced at MIT/AER under the ECCO-GODAE project showed promising results, particularly in tropical latitudes. Careful comparisons with the performance of the current DAC products were proposed, in order to further evaluate the different dealiasing methodologies.

Surface atmospheric pressure errors can lead to errors in the dry tropospheric, inverted barometer and dynamic atmospheric corrections. R. Ponte presented estimates of pressure errors, based on comparisons of surface atmospheric analyses from NCEP and ECMWF and in situ data. Errors seem to have decreased since the launching of TOPEX/POSEIDON and can have substantial spatial dependence as well. Results were discussed in the context of providing more detailed error budgets for altimeter data products.

The session closed with two science talks by C. Maraldi and A. Wang (filling in for C.-K. Shum) on the general subject of modeling tides. For summaries of these talks, please consult the respective abstracts included in the general meeting program.

6.5 Multi-satellite and operational applications (P. Oke, C. Birkett)

The multi-satellite and operational applications splinter was comprised of 16 oral presentations and 15 poster presentations. Topics covered under this splinter include:

- issues in data assimilation,
- waves,
- applications to fisheries,
- data provision,
- coastal and regional studies and
- various aspects of the Global Ocean Observing System.

A common opinion in many of the presentations was that satellite altimetry is a corner-stone of ocean monitoring and forecasting, particularly for applications that resolve the mesoscale. Escudier and Larnicol demonstrated that for their applications, a minimum of 2 altimeters are required to monitor mesoscale variability for delayed-mode applications, and a minimum of 3 or 4 satellites are required for near real time applications. This conclusion was drawn by comparing fields of mapped sea-level anomalies and eddy kinetic energy derived from mapped products using different combinations of altimeters (Jason, Envisat, T/P and GFO). Notably, these applications involve the mapping of altimetry to $1/3^o$ grids. It was noted in the plenary session, when the splinter summaries were being presented, that one might expect that for higher resolution applications the addition of more satellites would be beneficial and would reveal more detailed ocean variability. The requirement for more altimeters for near real time applications is a reflection of both the reliability and timeliness of delivery of the altimeter observations.

Larnicol also highlighted the reduction in skill of near real time mapped altimetry that arises due to data delays.

Presentations by both Wilkin and Oke demonstrated the positive impact of assimilating sub-surface observations, in addition to altimetry, on the skill of an ocean forecast/hind-cast. These presentations implied that the assimilation of different types of observations (e.g., altimetry, in situ or synthetic temperature and salinity and sea surface temperature) significantly increases the redundancy in the Global Ocean Observing system (GOOS). This may be particularly important for near real time applications, where the timeliness of data delivery is often compromised.

Verron presented results from a series of observing system simulation experiments that were intended to assess the most appropriate orbit for Altika. Verron considered various scenarios that included a 10, 17 and 35 day repeat cycle for Altika. From these Verron concluded that a 35 day Altika cycle seems like a good compromise for mid-latitudes.

Lagerloef presented results from a study that was intended to provide insight into the likely benefits of the future Aquarius mission for observing sea surface salinity from satellite. The expectation from this presentation was that this would fill an important gap in the Global Ocean Observing System.

Presentations at this splinter included a number of coastal and regional studies (e.g., Bouffard, Chao, Griffin, Garcia, Vandemark). Chao presented results from a forecast system for the Californian coast, where observations from a range of observation platforms, including HF radar, gliders and moorings, are assimilated. Forecasts from Chao's forecast system are delivered to the public via the internet and have attracted a lot of interest. Griffin presented a series of case studies where interesting oceanic features (e.g., strong upwellings, intrusions of large eddies on the shelf) that are evident in altimetry-derived products have been publicized through media-releases. Many of these media releases have sparked significant public interest and have found themselves the basis of many media articles around the world. Griffin noted that the state of ocean monitoring has significantly advanced in recent decades.

Queffaulou and Lefevre both presented results from projects that have used altimetry to validate and subsequently improve the formulation and configuration of wave models. These studies identified deficiencies in existing models, based on model-observation comparisons and subsequent improvements.

This splinter saw 2 presentations in the field of fisheries research (Hobday and Alpine). Both of these studies use value-added products, relevant to fisheries management, that are derived from altimetry. The result of these applications is more flexible ocean management. Both presentations provided evidence of the positive impact of the utilization of these products on fisheries management decisions leading to reduced illegal by-catch, for example.

Several poster presentations addressed the issue of data provision (Perry, Birkett and Dorandeu). Birkett presented results on the data provision for near real time monitoring of sea-level in lakes and reservoirs. Applications referred to in this presentation include agriculture, water resources, irrigation potential and long-term drought. Other topics that were covered in poster presentations include the estimation of representation error for data assimilation (Kaplan and Oke). These presentations presented new methods for the estimation of this error term.

6.6 Outreach (V. Rosmorduc, M. Srinivasan)

The outreach splinter session highlighted activities targeting the three main categories of outreach audiences: data users, education, and general public through the media.

We began with an update and summary of activities since the Venice OSTST meeting, and continued with participant talks on the ESA/CNES Basic Radar Altimetry Toolbox (BRAT) and Radar Altimetry Tutorial (RAT), teaching undergraduate oceanography, an update on operational applications, ocean literacy support efforts, news and public interest in ocean altimetry, and a discussion of using visual aids to promote public understanding of climate change, sea level rise and polar science. An "altimetry product showcase" of outreach activities from nine members of the science team was presented at the end.

Current OSTST outreach is being linked to a national, multi-organizational ocean literacy effort in the U.S. Robert Stewart (Texas A&M) presented information about the web-based oceanography textbook he is writing, which is organized around real-life problems that emphasize the connections among Earth systems and the contributions of NASA to understanding oceans.

Future plans include launch-related public and educational outreach activities as well as a focus on new operational applications, emphasis on ocean literacy efforts, and tying science team research to these and other relevant and timely issues (climate change, global warming, polar science, etc.).

Past & future outreach activities

Outreach activities since the OSTST meeting in Venice include;

- Argonautica: 20 beacons are currently in operation, Google Earth visualizations are now available, and two fact sheets (in French, with animations) are online.
- CNES/Aviso products: 2007 Wall calendar, 3D images and animations web site, BRAT and RAT online altimetry toolbox and tutorial.
- NASA/JPL products: Jason 5th anniversary/ocean literacy bookmark, OSTM fact sheet, Jason-1 fact sheet update, new science results poster.

Future projects in development;

- Jason-2/OSTM education and public outreach and applications outreach
- Altimetry applications, including multi-sensor/multi-satellite applications
- Coverage of science team research and other applications on web
- Refurbishment of the Aviso web site with increased news frequency beginning before Jason-2
- Expanding the Argonautica program near the Jason-2 launch
- Participation in the International Polar Year activities
- OSTM/Jason-2 Launch 2008, Eumetsat

Basic Radar Altimetry Toolbox & Radar Altimetry Tutorial

V. Rosmorduc demonstrated the Basic Radar Altimetry Toolbox & Radar Altimetry Tutorial. This "all-altimeter" set of tools development was supported by ESA and CNES. They include:

- A general Radar Altimetry Tutorial (RAT) taking into account 16 years of efforts in outreach on satellite altimetry, as well as new users' need for information
- An "Open Source" Basic Radar Altimetry Toolbox (BRAT). The Basic Radar Altimetry Toolbox is a collection of tools able to read most distributed radar altimetry data, from ERS-1 & 2, Topex/Poseidon, Geosat Follow-on, Jason-1, Envisat, and the future Cryosat missions, capable of doing some processing, data editing and statistics, and displaying the results.

The toolbox & tutorial overall objective is to facilitate the use of satellite altimetry products for altimetry users and answer to particular needs of specific applications (cryospheric science, oceanography, marine meteorology, land process studies including hydrology and geodesy.).

Teaching undergraduate oceanography:

R. Stewart demonstrated outdated methods and formats of historic oceanography text books based on fixed attributes of the physical ocean (animals, currents, bathymetry of the sea floor) and static systems that constrained the understanding of oceanography. New emphasis on marine microbes, the carbon cycle, long term climate events, robotic exploration of the oceans, and dynamic, interacting systems drives the effort to promote an ocean literate society. Dr. Stewart's online textbook is based on problems that emphasize the connections among earth systems and the contributions of NASA to understanding the oceans.

Ocean Altimetry Data: Operational Users and Applications

M. Srinivasan outlined methods used to highlight and feature the scientific and operational applications of ocean altimetry data. Routine updates to the JPL and Aviso web sites include features on science results and new applications, as well as press and image releases. Special operational applications sessions at the semi annual AGU Oceans meeting offer another opportunity to learn about new applications and multisensor/multisatellite uses of ocean data. A 12-year partnership between the TOPEX/Poseidon and Jason-1 projects at JPL and the University of Colorado Center for Astrodynamics Research (CCAR) in Boulder provides a valuable resource for near real-time and archived altimetry data. CCAR has developed a data web site (http://argo.colorado.edu/~realtime/welcome/) which provides data and images from Jason-1, Envisat , Geosat Follow On, TOPEX/Poseidon and ERS (historical), as well as sea surface temperature and ocean color data. The newest CCAR effort in this area is a Google Earth overlay of the data stream that is in development. Science team members were encouraged to consider the potential and operational applications of their research, and to estimate the economic/practical effects/benefits to facilitate dissemination of their work and efforts into the public domain.

Ocean Literacy and JPL Ocean Surface Topography EPO Support

A. Richardson summarized the outreach team's focus this year on ocean literacy, described as "an understanding of the ocean's influence on you, and your influence on the ocean". A multi organizational ocean literacy network of education, government and non-governmental groups is committed to establishing an ocean-literate public. JPL is focusing outreach efforts in this area as two of the seven essential principles of ocean literacy can be related to Jason/altimetry assets that support these principles;
1. Earth has one big ocean with many features, and
3. The ocean is a major influence on weather and climate.

In an effort to promote an ocean-literate society, our efforts will be guided by the notion that literate people understand the essential principles and fundamental concepts about the functioning of the ocean, can communicate about the ocean in a meaningful way; and are able to make informed and responsible decisions regarding the ocean and its resources. U.S. national science education standards currently lack ocean-related content so using ocean literacy principles and concepts allow an ocean-oriented approach to science education. Jason science objectives can be directly related to ocean literacy principles and concepts and can provide content for ocean literacy educational products.

Ocean Altimetry: Anticipating News and Public Interest
R. Sullivant summarized the new NASA strategic communications framework, which identifies audiences important to NASA, the key messages NASA wishes to emphasize, and some of the strategies the agency will be using to communicate these messages. She also discussed the growing public and media interest in Earth science, noting that we can anticipate more stories on climate change, global warming, El Nino, hurricanes, sea level rise, etc. in the coming year. JPL media outreach activities continue to include press and image releases as well as web-based news and feature stories on the NASA, JPL, and NASA's Earth Observatory's websites. Topics for these stories are influenced by current events, new scientific discoveries, and institutional activities, such participation in the ocean literacy program.

Use of satellite and ocean images to inform the Australian community
S. Zicus discussed the use of imagery and animations in communicating science and scientific concepts to the public. The presentation focused on recent climate change communication efforts including sea level, an evaluation of communication opportunities during the 2007-2008 International Polar Year (IPY), and included animations developed for education and public outreach by the Australian climate Change Science Program.

Showcase of altimetry outreach activities
The "outreach product showcase" was an opportunity for OSTST members to present their outreach activities in a short, easy, format (one slide during presentation, which is included in the outreach poster session with other showcase slides). It provided outreach session participants with a quick-view of ongoing and new outreach activities, including activities that may not have been developed enough for a full-scale talk. A broad range and scope of ideas and activities were presented, reaching many varied public audiences:

- IDS outreach product, DORIS Special Issue in Journal of Geodesy, P. Willis
- IDS outreach product, New IDS web site, G. Tavernier
- Outreach Activities at the University of Washington, L. Thompson

- Jason 5th Anniversary/Ocean Literacy Bookmark, JPL Outreach team
- “Courants d’air, courants d’eau”, a public exhibition held in Noumea, C. Maes
- OSCAR surface currents, G. Lagerloef
- NOAA/AOML Near Real-Time Altimetry Products, G. Goni
- Ocean Weather Forecasting; An Integrated View of Oceanography, E. Chassignet
- Mean Sea Level web site, CLS/Cnes/Legos

We will continue the outreach showcase during each OSTST outreach splinter session in the future to expand the view on existing outreach efforts by the science team.

6.7 Conclusions

Science

L-L. Fu briefly summarized the outstanding science progress reviewed in the meeting. The data record from T/P, Jason, and ERS has provided unprecedented views of ocean variability on decadal scales, revealing interesting large-scale patterns of ocean circulation and air-sea interactions in all ocean basins. Such decadal variability was used to simulate the variability of global sea level change in the past 100+ years, revealing interesting decadal variability in global mean sea level rise and acceleration. New maps of global ocean general circulation have been constructed from the combination of surface drifter and satellite altimetry observations, revealing remarkable zonally-oriented narrow currents. New findings of the properties of ocean eddies and their propagation have raised questions on the roles of Rossby waves versus eddies in ocean’s response to atmospheric forcing. The study of the interaction between eddies and large-scale circulation and its variability has been significantly advanced by merged T/P, ERS, Jason, and GFO data. Challenges still remain in the study of coastal tides and circulation, but significant progress has been made and future promise has been identified. Modeling and data assimilation is responsible for remarkable progress in the understanding of climate variability from seasonal, interannual, to decadal time scales, as well as in the operational applications of altimetry observations. The application to the study of inland waters is a growing field with rich potential for breakthroughs utilizing future wide-swath observations.

Altimetry error budget

Tremendous progress has been made in reducing errors in altimetry measurements. For example, the “two centimetre challenge” posed by Michel Lefebvre before the launch of T/P has been met by the POD effort. However, remaining instrument errors (sea-state bias, T/P-Jason bias, etc.) still pose challenges for future work. The details of the error budget of the state-of-the-art altimetry products are beyond the scope of the meeting. L-L. Fu proposed that all the splinter group leaders consider working together on a review paper summarizing the current state of understanding. Such an effort is timely considering the growing importance of altimetry in wide-ranging applications discussed in the meeting.

Future missions

The continuation of precision altimetry data record beyond OSTM/Jason-2 is a prime concern expressed by the team during the meeting. Although missions like AltiKa and Sentinel-3 have been approved and proceeding, these missions are not designed for large-scale climate studies. Jason-3 and SWOT are the next missions for extending the climate data record. However, these missions have not yet been approved by space agencies. To address the concern, the OSTST made the following recommendation:

To continue the precision altimetry data record for monitoring and understanding global ocean circulation and sea level variability in relation to global climate variability, the OSTST recommends that Jason-3 be a high priority mission for NOAA and EUMETSAT and that, as recommended by the NRC Decadal Survey, the Surface Water and Ocean Topography Mission (SWOT) be a high priority mission for NASA. Jason-3 is vital for continuing the existing climate data record by bridging the gap between the present high-precision missions and future wide-swath altimetry missions, of which SWOT is the first.

The orbit choices for the two missions were discussed during the meeting. Regarding the Jason-3 orbit, several practical advantages have been identified for changing to an orbit different from T/P/Jason/Jason-2 (such as shared launch, less radiation damage, etc.). However, these advantages do not appear to overwhelm the disadvantages (such as different sampling errors, absence of cross-calibration, time to build new reference surface for computing temporal changes, etc.). No consensus was reached for a recommendation, but it was agreed that ***if a change of orbit was to take place, all future precision altimetry missions must fly in the same new orbit.***

Regarding the impact of a sun-synchronous orbit for SWOT on meeting oceanography objectives, a unanimous consensus was reached: ***A sun-synchronous orbit will alias many surface and internal tidal components as well as all diurnally-varying signals into highly undesirable frequencies that overlap with important time scales for ocean circulation and climate studies. Therefore, such orbits for SWOT are not acceptable for meeting oceanography requirements.***

Future meetings

L-L. Fu noted the evolution of altimetry from technical challenges to science challenges. There has been a disconnect between oceanographers and technologists in some of the splinter meetings. Although continuously pushing the envelope of measurement accuracy is always a charge to a measurement team like OSTST, technical splinters like sea-state bias, POD, and tides need to evaluate the accomplishments already made and develop future foci to proceed. Topical science workshops (e.g., eddy science, general circulation, etc) are to be considered for future meetings. In any case, the balance between science and technical issues is a challenge. Suggestions from the team members for the structure of future meetings are welcomed.

The next meeting is proposed to be held in France in November, 2008, with the first results from OSTM/jason-2 as the main objective. The meeting is considered to be jointly conducted with the final symposium of GODAE. A follow-on meeting in U.S. with emphasis on OSTM/Jason-2 cal/val is being contemplated for April-May, 2009.