# Ocean Surface Topography Science Team Meeting

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**Introduction**

The 2007 Ocean Surface Topography Science Team (OSTST) Meeting was held in Hobart, Australia, on March 12-15. Australia's Commonwealth Scientific and Industrial Research Organization (CSIRO) hosted the meeting with support from the Australian Bureau of Meteorology Research Centre (BMRC) and the Royal Australian Navy (RAN). The Governor of Tasmania**, His Excellency the Honorable William Cox**, officially opened the meeting and welcomed the participants to Hobart. **Neville Smith** [BMRC—*Chief Scientist*] also welcomed the group and noted that this was the first OSTST meeting ever held in the southern hemisphere. **Commander Andrew McCrindell** [RAN] delivered a keynote presentation on applications of satellite altimetry to Australian naval operations.

In his opening remarks, **Lee-Lueng Fu** [NASA/Jet Propulsion Laboratory (JPL)—*Jason-1 Project Scientist*] recognized the strong participation of Australian oceanographers in precision altimetry over the past two decades and expressed appreciation for the opportunity to meet in Hobart and interact with local participants. He also acknowledged the excellent assistance of **David Griffin** [CSIRO—*Research Scientist*] in the planning of the meeting and logistics support.

**Program and Mission Status**

**Eric Lindstrom** [NASA Headquarters—*Physical Oceanography Program Scientist*] and **Eric Thouvenot** [Centre National d'Etudes Spatiales (CNES)] spoke on the status of altimetry and oceanography programs at NASA and CNES. Lindstrom discussed the overall NASA program and the role of Earth sciences including the next two oceanography missions: Ocean Surface Topography Mission (OSTM)/Jason-2 to be launched in 2008 and Aquarius scheduled for 2009. He also addressed the plan to renew the OSTST in 2008 as announced in NASA's Research Opportunities in Space and Earth Sciences (ROSES) Program.

**Thouvenot** reported on the CNES altimetry program focusing on OSTM/Jason-2 and the *AltiKa* altimeter (Ka band altimeter). *AltiKa* is to be launched on the Satellite with ARgos and *ALtika* (SARAL) Mission, a joint mission with the Indian Space Research Office (ISRO) in 2009-2010. CNES is also committed to contribute a Proteus spacecraft and project team support to Jason-3, planned as a joint mission involving CNES, the European Organisation for the Exploitation of Meteorological Satellites (EUMETSAT), and NOAA. The contemplated launch date is 2012. CNES is also planning to participate in a future wide-swath altimetry mission.

**Sophie Coutin-Faye** [CNES] presented the CNES status of Jason-1, which has delivered 95% of science data since the last OSTST meeting. The payload status is very good. CNES and NASA signed a five-year mission extension agreement in December 2006.

**Glenn Shirtliffe** [JPL—*Jason-1 Project Manager*] presented the status of the NASA portion of Jason-1. Since the 2006 OSTST meeting in Venice, Italy, no science or engineering data have been lost due to NASA ground-system anomalies or command errors. Excluding the two-week safe hold event in October-November 2006, the total data recovery rate exceeds 99.97% of all available science data. Geophysical data records (GDR)-B data reprocessing is going well and is near completion. Both Turbo Rogue Space Receiver global positioning system (GPS) receivers have failed to function properly, and the quality of GPS-based orbit determination has been deteriorating since mid 2006. However, Jason-1 precision orbit determination continues meeting science requirements based on the Determination d'Orbite et Radiopositionement Integre par Satellite (DORIS) and Laser Retroreflector Array (LRA) instruments.

**Nicolas Picot** [CNES] reported on the status of Service d'Altimétrie et de Localisation Précise (SALP), a multi-mission altimetry and orbit data processing center, and the GDR reprocessing. SALP archives data from TOPEX/Poseidon (T/P), and processes data from Jason-1, Envisat, and Satellites Pour l'Observation de la Terre (SPOT). Preparations for Jason-2 and *AltiKa* are underway. For Jason-1 the focus is on GDR-B reprocessing that should be completed in a few weeks. GDR-C reprocessing is expected to start in early 2008 for cross-calibration of OSTM/Jason-2.

**Gerard Zaouche** [CNES] reported on the status of OSTM/Jason-2 and described how mission responsibilities are shared by the four partners: CNES, EUMETSAT, NOAA, and NASA. Near-real-time operational geophysical data records (OGDR*)* products will have a 10-cm orbit with re-tracked sea surface height and improved resolution near coasts. Special data products for coastal and inland water applications will be available. OSTM/Jason-2 will be launched into an orbit one minute ahead of Jason-1 along the same ground tracks for cross-calibration. Payload integration started in December 2006. Satellite integration and testing will be conducted from June 2007 to January 2008. End-to-end ground system testing is scheduled for completion before May 2008. Launch is scheduled for mid-June 2008.

**Other Ongoing and Future Missions Status**

**Jocelyne Noubel** [CNES] provided more details on the joint CNES/ISRO *AltiKa*/SARAL mission, a gap filler mission between Envisat and Sentinel-3 that will carry a Ka band (35.75 GHz) radar altimeter, a two-frequency (23.8 and 37 GHz) microwave radiometer, a DORIS receiver and a laser retroreflector. The launch date is in 2009-2010.

**Lee-Lueng Fu** [JPL] presented the status of the development of a wide-swath altimetry mission. The recently released National Research Council's Decadal Survey recommended combining the concepts of the Water And Terrestrial Elevation Recovery (WaTER) and the Hydrosphere Mapper missions into a single mission to address the objectives of both the land hydrology and oceanography communities. Since last year's OSTST meeting, the two communities held two joint meetings, a workshop in October and an American Geophysical Union session in December, leading to a consolidated mission concept—called the Surface Water and Ocean Topography (SWOT) mission. A key mission design issue is the choice of orbit, and the OSTST discussed the impact of a sun-synchronous orbit on the oceanography objectives. (The Tides and High Frequency Aliases splinter session discussed this issue in greater detail—see below.) The conclusion was that a sun-synchronous orbit was not acceptable for meeting oceanographic objectives.

**Jerome Benveniste** [ESA] gave a presentation on the status of the European Space Agency (ESA) missions. He reported that:

- ESA's Living Planet Programme has a series of approved missions of direct interest to OSTST. See: *www.esa.int/livingplanet*.
- The Earth Explorer missions address key questions about the Earth system.
- The Gravity Field and Steady-State Ocean Circulation Explorer (GOCE), the Soil Moisture and Ocean Salinity (SMOS) mission and CryoSat-2 are all scheduled for launch within the next 2 years.
- The six short-listed "7th Explorer" are the subject of feasibility studies.
- Sentinel's development is ongoing. Sentinel 3 will focus on medium-resolution ocean monitoring with wide-swath ocean color and surface temperature sensors and a synthetic aperture radar altimeter.
- Studies and algorithm development in support of missions are ongoing and planned this year.
- Envisat Radar Altimeter (RA)-2 Ultra-Stable Oscillator (USO) is in good health, monitored and drift corrected.

**Stan Wilson** [NOAA—*Senior Scientist, NOAA Satellite & Information Services*] and **Francois Parisot** [EUMETSAT] reported on the status of Jason-3:

- Jason-3 has been clearly identified as priority one in Europe for satisfying the needs of the Marine Core Services within the Global Monitoring for Environment and Security (GMES) initiative.
- The EUMETSAT/NOAA approach has been endorsed at high level. Letters between EUMETSAT, NOAA, and CNES confirm the commitment of these agencies on Jason-3.
- EUMETSAT and NOAA have established a focus group and application and implementation groups with participation of CNES, NASA, and others.
- To ensure continuity with Jason-2 and minimize cost and risk, the proposed Jason-3 mission is to be based on a maximum of recurrence with Jason-2, with the choice of orbit still open.
- The question of an appropriate orbit for Jason-3 was raised to the OSTST.

**Science Plenary Sessions**

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

Twelve invited talks in the plenary session reviewed the progress in OSTST science investigations to date.

- **Dudley Chelton** [Oregon State University] *Global observations of westward energy propagation: Rossby waves or nonlinear eddies?*
- **Bo Qiu** [University of Hawaii] *Eddy-mean flow interaction: insights from satellite altimetry measurements*
- **John Church** [CSIRO] *Understanding sea-level rise*
- **Dean Roemmich** [Scripps Institution of Oceanography, University of California San Diego (USCD] *Observing decadal variability in the oceans*
- **Tony Busalacchi** [University of Maryland] *Seasonal to interannual variability of global sea level: recent progress in monitoring and prediction*
- **Rui Ponte** [Atmospheric and Environmental Research, Inc.] *Large-scale subseasonal sea level variability over the global ocean*
- **Peter Niiler** [Scripps Institution of Oceanography, UCSD] *Combining ocean velocity observations and altimeter data for OGCM verification*
- **William Emery** [University of Colorado] *Ocean surface topography applications to circulation mapping in the coastal ocean*
- **Gary Egbert** [Oregon State University] *Internal tides, tides in shallow seas and altimetry*
- **Anny Cazenave** [Laboratoire d'Etudes en Géophysique et Océanographie Spatiales (LEGOS)-CNES] *Monitoring terrestrial surfaces waters by satellite*
- **Tony Lee** [JPL] *Ocean state estimation for studies of climate variability*

- **Eric Dombrowski** [Mercator Océan] *Operational oceanography*

**Poster Session**
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 (POD) and geoid;
- Multi-satellite/operational applications;
- Tides and high-frequency aliases;
- Sea-state bias and re-tracking analysis; and
- Outreach.

**Splinter Sessions**
The proposed theme for the splinter sessions—in particular for the calibration/validation, POD/geoid, tides/high frequency aliasing, and sea-state bias/retracking groups—is the error budget of altimetry products. **Rui Ponte**, who proposed the theme, made a brief introduction to the subject before the start of the splinter sessions. He stressed several areas he felt the splinter groups should consider during their discussions.

- Basic errors in Jason-1 and T/P data resulting from such sources as radar noise, orbit error, environmental corrections (e.g., wet and dry troposphere, ionosphere, sea-state bias), and models (e.g., tides, inverted barometer (IB), high frequency correction).
- Basic errors in data from other missions, from combined data products, etc.
- Special topics such as methodologies to estimate errors, characterization of spatial and temporal behaviors, errors in the time-mean topography and mean sea-level trends, and correlation structures.

**Calibration/Validation**
General conclusions of the splinter session are that:

- The Jason-1 GDR sea surface height (SSH) remains biased (high);
- there is no significant drift in Jason-1 bias (GDR-B);
- there is no detectable drift in Jason Microwave Radiometer (JMR) path delay;
- the sea surface height (SSH) bias in T/P altimetric measurement has decreased; and
- there is no significant drift in altimeter-B in T/P altimeter measurement systems.

**POD and Geoid**
Conclusions for this splinter group are subdivided into POD and Geoid.

General conclusions from the **POD** discussion are that:

- The Jason-1 GDR-B orbits are centimeter level orbits;
- new standards should be ready by the end of the year to support the GDR-C reprocessing—and Jason-2;
- at the current level of precision, geocenter motion should probably be taken into account, but there is a lack of consensus on which model to use; and
- margins of improvement appear limited for the future.

General conclusions from the **Geoid** discussion are that:

- The next generation of geoid models will continue to increase the resolution of gravity as seen from space;
- the emphasis of combination solutions tends to minimize 'striations' and other data artifacts;
- some smoothing of the implied ocean topography will always be required, if only due to truncation, but we hope to reduce the smoothing radius from the current ~400 kilometers; and
- it is important to continue to refine methods to extract the best estimates of the mean dynamic topography considering the accuracy and limitations of the Gravity Recovery and Climate Experiment (GRACE) geoids.

**Sea-state Bias (SSB) and Retracking**
General conclusions from this splinter group are that:

- The algorithm MLE4 for retracking is ready;
- SSB processing is ready. A new version will be computed as soon as other information—e.g. the final CNES orbit—becomes available; and
- T/P re-tracking should be completed within about one year and will require extension of the present OSTST task into fiscal year 2008.

**Tides and High-frequency Aliasing**
The following topics were highlighted in this splinter group's discussion.

- The group continued the discussion of sun-synchronous orbits for SWOT begun in the earlier plenary session and concluded that there were strong arguments against sun-synchronous orbit—e.g., not useful for tides, corruption of climate signals by diurnal errors, corruption of mean absolute dynamic topography, corruption of the seasonal cycle—and far fewer strong arguments for sun-synchronous orbit other than engineering and cost issues.
- The group discussed a slight upgrade in FES2004 to correct some problems with S1 and K2 tides.
- The group also had discussions about:
  - A new validation data set from Richard Ray [NASA Goddard Space Flight Center] that

requires consideration of the contribution of shallow water tidal impacts, especially from Australia;
- improvements in high frequency or dynamic atmospheric correction from a much higher resolution *MOG2D* version;
- the status of current Aviso products wherein the S1 tide solution is not optimal and some technical issues related to the filtering of the pressure forcing need to be addressed;
- the use of baroclinic models and data assimilation methods may provide further improvements for dynamic atmospheric correction; and
- surface atmospheric pressure errors provided from comparisons of surface atmospheric pressure analyses and data, important for uncertainty in dry tropospheric, IB and dynamic atmospheric corrections.

**Multi-satellite and Operational Applications**

Science team members covered a wide range of topics in the session including: data assimilation, waves, fisheries applications, data provision, coastal and regional studies, and observing systems. The splinter group concluded that:

- At least two satellites are required to be able to address mesoscale variability;
- assimilation of different data types increases redundancy in the Global Ocean Observing System;
- altimetry is considered the foundation of operational applications; and
- the extension of altimetry towards the coast is an essential requirement for the future.

**Outreach**

This session highlighted activities targeting the three main categories of outreach audiences: data users, education, and general public through the media. Participants reported on the outreach highlights of the previous year and current activities. Discussion 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. Outreach team members encouraged OSTST members to submit examples of their efforts to inform the public about ocean science research and applications.

The splinter group also discussed future plans including:

- 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 the web;
- refurbishment of the Aviso web site with increased news frequency beginning before Jason-2;
- expanding the *Argonautica* program near the Jason-2 launch; and
- participation in the International Polar Year activities.

**Conclusions**

**Science**

**Lee-Lueng Fu** briefly summarized the outstanding science progress reviewed in the meeting. The data record from T/P, Jason-1 and the European Remote Sensing satellite (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 reconstructed from the combination of surface drifter and satellite altimetry observations, revealing remarkable zonally-oriented narrow currents. New findings on ocean eddies and their propagation raise questions on the roles of Rossby waves versus eddies in the 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-1 and Geosat Follow-On (GFO) data.

Challenges still remain in the study of coastal tides and circulation, but significant progress has been made

and future promise identified. Modelling and data assimilation are responsible for remarkable progress in the understanding of climate variability from seasonal, to interannual, to decadal time scales, as well as in the operational applications of altimetry observations. A growing field of study is applications of altimetry to the study of inland waters, which seems to offer great potential for breakthroughs using future wide-swath observations that could also have practical benefits for society.

**Altimetry Error Budget**

Tremendous progress has been made in reducing errors in altimetry measurements. For example, the *two-centimeter challenge* posed by Michel Lefebvre (CNES, retired) led by the United Kingdom Meteorological Office before the launch of T/P has been met by the POD effort. However, remaining instrument errors—e.g., sea-state bias, T/P-Jason-1 bias, etc.—still pose challenges for the future. The details of the error budget of the state-of-the-art altimetry products are beyond the scope of the meeting. 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 the many wide-ranging applications discussed in the meeting.

**Future Missions and Recommendations**

One of the teams biggest concerns is that the precision altimetry data record established over the past two decades continue beyond OSTM/Jason-2. Although missions like AltiKa and Sentinel-3 have been approved and are proceeding, these missions are not designed for large-scale climate studies. Jason-3 and SWOT are the next missions capable of extending the climate data record. However, these missions have not yet been approved by space agencies. To address this 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 Jason-3 and SWOT were also discussed at the meeting. Regarding Jason-3, several practical advantages have been identified for changing to an orbit different from T/P, Jason-1 and Jason-2—i.e., shared launch, less radiation damage, etc. However, these advantages do not appear to outweigh the disadvantages—i.e., different sampling errors, absence of cross-calibration, time needed to build new reference surface for computing temporal changes, etc. The science team did not reach a consensus for a recommendation but agreed that ***if a change of orbit was to take place, all future precision altimetry missions must fly in the same new orbit.***

The science team was unanimous in regard to the impact of a sun-synchronous orbit for SWOT on meeting oceanography objectives: ***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**

Fu noted the evolution of altimetry from technical challenges to science challenges. He discussed the apparent 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 the OSTST, he suggested that technical splinters, such as those on 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 remains 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 being considered to coincide with the final symposium of the Global Ocean Data Assimilation Experiment (GODAE). A follow-on meeting in the United States with emphasis on OSTM/Jason-2 calibration/validation is being contemplated for April-May 2009. ■