meeting/workshop summaries

Ocean Surface Topography Science Team Meeting

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Introduction

The 2010 Ocean Surface Topography Science Team (OSTST) meeting was held in Lisbon, Portugal. The meeting was the central part of a 10-day program of altimetry workshops, starting with the Coastal Altimetry Workshop in Porto, Portugal on October 14–15, followed by three events at the Lisbon International Fair that included the Ocean Surface Topography Science Team (OSTST) meeting, and two workshops that took place on October 21–22: an altimetry workshop entitled *Towards High-Resolution of Ocean Dynamics and Terrestrial Surface Waters from Space*, and in parallel, the *International Doppler Orbitography and Radiopositioning Integrated by Satellite (DORIS) Service (IDS)* workshop.

The primary objectives of the OSTST meeting were to:

- provide updates on the status of Jason-1 and Ocean Surface Topography Mission OSTM/Jason-2 (hereafter Jason-2);
- review the progress of science research;
- conduct splinter meetings on the various corrections and altimetry data products;
- discuss the science requirements for future altimetry missions; and
- make recommendations on the choice of orbit for the end-of-life period for Jason-1, and for the Jason-CS (continuation of service) series of altimeters.

The full OSTST report, along with all the presentations from the plenary, splinter, and poster sessions, are available on the AVISO website: *www.aviso.oceanobs.com/ostst/*.

Program and Mission Status

Lionel Suchet [CNES] and **François Parisot** [EUMETSAT] opened the meeting and welcomed the participants. They noted the long international co-operation of the OSTST group, its work in maintaining precise sea level observations for scientific and operational applications, and the extension of the Memorandum of Understanding (MOU) that now includes four-partner agencies—NASA, the Centre National d'Études Spatiales (CNES), the National Oceanic and Atmospheric Administration (NOAA), and the European Organisation for the Exploitation of Meteorological Satellites (EUMETSAT). They also introduced the celebrations for the 20th anniversary of the DORIS measurements, which were the focus of the IDS meeting discussions. **Rosemary Morrow** [Laboratoire d'Etudes en Géophysique et Océanographie Spatiale (LEGOS)] and **Sophie Coutin–Faye** [CNES] presented the meeting overview and meeting logistics.

Lionel Suchet [CNES] introduced the program managers who spoke on the status of altimetry and oceanography programs at NASA, CNES, EUMETSAT, NOAA, and the European Space Agency (ESA).

Peter Hacker [NASA Headquarters (HQ)—*Oceanography Program Scientist*] represented Eric Lindstrom and spoke about the NASA program status. Amongst the NASA altimetry program events, the Surface Water Ocean Topography (SWOT) mission partnership has now been established between NASA and CNES, with an expected launch date in 2019. The four-party MOU has been signed by NASA, NOAA, CNES, and EUMETSAT for the upcoming Jason-3 mission, with an expected launch date in June 2014. The Jason-CS orbit and the Jason-1 end-of-life orbit requirements are to be discussed at the current OSTST meeting in Lisbon. The call to construct the new OST Science Team for the next four years will likely appear in NASA's 2011 ROSES solicitation.

Eric Thouvenot [CNES—*Ocean Program Manager*] reported on the CNES altimetry program, with a focus on the operational altimetry outcome, with CNES/Service d'Altimetrie et Localisation Precise (SALP) supporting the Jason-1, Jason-2 series, and preparing for the future Satellite with ARgos and ALtika (SARAL)/Altika, Jason-3, Jason-CS, and SWOT. CNES also contributes DORIS and data processing for the ESA altimeters on the Earth Research Satellite (ERS-2), ENVISAT, and Sentinel-3, and for the future HY-2A (with the Chinese Space Agency). In addition, support is given to operational oceanography groups, such as Coriolis and Mercator. Thouvenot noted that SARAL/AltiKa is tentatively scheduled for launch in mid 2011. The CNES payload module is ready and waiting for the delivery of the Indian Space Research Organization (ISRO) platform. In other supporting work, the Principal Investigator (PI) selection process has been completed; 64 teams were selected; and the calibration/validation (cal/val) plan and science plan are being drafted. An international workshop is planned in 2011 in India, to be confirmed by ISRO.

François Parisot [EUMETSAT] and **Stan Wilson** [NOAA] discussed their respective organizations' involvement in altimetry programs with a focus on Jason-3 and its potential follow-on, Jason-CS. For Jason-3, the four-agency partnership is the same as for Jason-2, but with NOAA and EUMETSAT—the operational agencies—taking the lead. The planned early 2014 launch is to allow for at least a six-month overlap with Jason-2. After Jason-3, the Continuity of Service program (Jason-CS) will be the follow-on reference mission, spanning a 15- to 20-year period, but with a new satellite bus based on the ESA Cryosat-2 platform. The choice of altimeter may be changed to take into account the most recent technology, and the choice of orbit also needs to be decided. The scientific requirements for the orbit will be discussed during the OSTST in Lisbon; the final decision will be made by the agencies in early 2011.

Jerome Benveniste [ESA] gave a presentation on the status of ESA missions. The Gravity field and steady-state Ocean Circulation Explorer (GOCE) was successfully launched in March 2009, and is working well. First science assessment shows good results; three gravity field solutions are already available on the ESA website, and a user toolbox is also available (see: *earth.esa.int/goce*). Cryosat was launched in April 2010. The priority is to provide data over the cryosphere, but early results from the Synthetic Aperture Radar (SAR) Altimeter Ocean Retracker are promising; data may be available to users in early 2011. A validation workshop for Cryosat data will be held at the ESA Center for Earth Observation (ESRIN) in Frascati, Italy, February 1-3, 2011. The Soil Moisture and Ocean Salinity (SMOS) mission was launched in November 2009. Preliminary results of ocean salinity show an accuracy of 0.5 practical salinity units [psu] at 25 km resolution, although the validation phase is still ongoing.

ENVISAT, now eight-years old, will enter a new orbit in October 2010, and has been financed for a further three years. The new orbit will be at 30-day repeat, with a slowly drifting inclination. First data products on the new orbit will be available from early November, with validated products available in January 2011. Sentinel-3 is under development. ESA has started the "Climate Change Initiative" in response to requirements set out by the Global Climate Observing System reports. One of the essential variables to be monitored is sea level change, for which the altimetry component is essential. A brief outline of this is presented in the full OSTST report referenced above.

Current Altimetry Missions

Thierry Guinle [CNES] provided an overview of Jason-2 status. The Ocean Surface Topography Mission on Jason-2 (OSTM/Jason-2) was launched in June 2008 on the former ground track of Jason-1 and TOPEX/Poseidon (T/P). All systems are in excellent condition and the satellite is operating nominally.

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

The origin of the relative range bias between Jason-1 and Jason-2 (~70 mm) has been discovered recently and presented at the Seattle OSTST (see *Summary of the in situ analysis key findings* in **Section 9.1.2** of the full summary report). This needs further investigation (notably on the C-band). If confirmed, both satellites are measuring sea surface consistently, but are both about 20 cm higher than T/P. The biases to be applied to both Jason-1 and Jason-2 will not be included in the current Geophysical Data Record (GDR) versions[1] to maintain continuity. However, the reprocessed Jason-2 products (to be issued in mid-2011) will be corrected for the 25-mm bias found (sea level will increase by 25 mm). Concerning the Jason-1 bias, it should be applied in the next generation of the products that should be available before the end of the Jason-1 mission.

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

Glenn Shirtliffe [JPL] provided an overview of Jason-1 status. The mission continues to exceed all Level-1 Science Requirements on its interleaved orbit, despite the loss of a reaction wheel in 2003, the loss of half-satellite (PMB) in 2005, and the loss of a gyro in March 2010. Both GPS receivers (Turbo Rogue Space Receivers) have now failed; however, Jason-1 POD continues to meet the mission requirements based on DORIS and Laser Retroreflector Array (LRA). Although the mission lifetime is uncertain, the thermal, power, and propulsion systems all have significant margins remaining.

One problem for Jason-1 is that it is in the same orbital plane as T/P (now non-operational), OSTM/Jason-2 (operational), and Jason-3 (planned). T/P is inoper-

[1] The current Geophysical Data Record (GDR) for Jason-1 is referred to as *GDR-C*, the current Jason-2 product is called *GDR-T*, and the next generation data product (set to debut near the end of the Jason-1 mission) will be called *GDR-D*.

able, and has a nearly-full tank of hydrazine (~200 kg) that cannot be depleted. Since Jason-1 is single-string on several key component systems, the permanent loss of one of these key components would end the mission and could possibly leave Jason-1 adrift, with ~22 kg of hydrazine onboard. Under joint agency direction, an End/Extension-of-Life (EOL) Joint Working Group was established in early 2010 to study future options for Jason-1.

As background, the following actions and strategies were approved by the Jason Steering Group (JSG)[2] in July 2010:

- That Jason-1 should remain in its current interleaved orbit until another high-accuracy repeat-track altimeter is launched and validated. [Most likely to be SARAL/AltiKa in June 2011 + nine months calibration/validation (Cal/Val)], with a science recommendation to be provided by the OSTST meeting in October.

- To immediately begin a fuel depletion campaign to mitigate the intrinsic explosive breakup risks.

- To develop and implement emergency decommissioning procedures to move to graveyard orbit in the event of a sudden mission-ending failure.

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

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

Future Altimetry Missions

A series of discussions was also undertaken concerning the choice of a future orbit for the Jason-CS series of altimeters. During the OSTST meeting this topic was discussed in the different splinter sessions. A special town hall meeting was held on October 19 to discuss the different Jason-CS orbit options, and the results were presented with a final discussion in a plenary session on October 20. After a lot of discussion, the majority of the OSTST supported the overriding importance of maintaining the precise climate record of sea-surface-height time series, so that Jason-CS should stay on the 1,336 km reference orbit flown by T/P and Jason-1, 2, and 3. Secondary considerations included the lack of a clear net scientific benefit of a change of orbit, and the challenges of calibrating and validating a precise climate record without a formation flight period between Jason-3 and Jason-CS.

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

Keynotes

Seven keynote lectures were given during the meeting, on a wide range of altimetric subjects. Three talks addressed a variety of different altimetric programs and projects. **Charles Elachi** [JPL—*Center Director*] gave an overview of present and future satellite oceanography projects at JPL. **Jacques Verron** [Centre National de la Recherche Scientifique (CNRS)—*Project Scientist for SARAL/AltiKa*] presented the status of the CNES/ISRO SARAL/AltiKa Ka-band altimeter project, to be launched in 2011. This mission will provide finer-resolution measurements over the oceans and coastal and hydrological surfaces. **Joanna Fernandes** [University of Porto—Portugal] then gave an overview of the main results discussed at the 4th Coastal Altimetry Workshop, held in Porto in October 2010.

In preparation for the upcoming altimeter missions, **Jean-Claude Souyris** [CNES] presented an overview, explaining the technical aspects of Ka-band altimetry, and the SAR and interferometric SAR modes which will be used on the upcoming missions (e.g., SARAL/Altika and SWOT in Ka-band, SAR mode on ENVISAT and Cryosat-2, interferometric SAR on SWOT). Two science talks followed: **Weiqing Han** [University of Colorado] presented recent results on Indian Ocean sea-level change in a warming climate, and **Javier Za-**

[2] The Jason Steering Group is the decision-making body for Jason-1.

vala-Garay [Rutgers University] gave an example of an operational prediction of the regional ocean circulation near the Mid-Atlantic Bight. A plenary keynote talk from a group of high-school students in the Midi-Pyrénées region of France demonstrated how altimetry was being used in school projects to help track drifting buoys, including buoys that were built by the students.

Recommendations from OSTST

Recommendations concerning Jason-1 Extension of Life

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

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

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

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

Radiometer Drift Requirements

The discussion on the radiometer drift requirement was presented in terms of goals or requirements, depending on the mission advancement. The objective is that future altimeter missions shall measure globally-averaged sea level relative to levels established during the cal/val phase with zero bias +/- 1 mm (standard error) averaged over any one-year period.

4) Jason-3 Drift Requirement Recommendation: The OSTST recommends that the Jason-3 project continue to study the feasibility of improving the Advanced Microwave Radiometer (AMR) stability through on-board calibration for the Jason-3 mission.

Lee-Lueng Fu and Yves Menard Honored

The annual **COSPAR International Cooperation medal**, was presented jointly to **Lee-Lueng Fu** [JPL] and (posthumously) to **Yves Menard** [CNES]. This medal is awarded to scientists who have made distinguished contributions to space science and whose work has contributed significantly to the promotion of international scientific cooperation. **J.L. Fellous** [COSPAR—*Executive Director*] presented the award in the presence of the awardees' families. **Felisa Menard** accepted the award on behalf of her husband.

Lee-Lueng Fu

Yves Menard

5) Jason-CS Drift Requirement Recommendation: The OSTST also recommends that Jason-CS meet the following requirement at the mission level:

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

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

Three plenary sessions provided a forum for formulation of recommendations from the science team on: 1) the potential change of orbit for Jason-1 end-of-life phase; 2) the optimal orbit for Jason-CS; and 3) the radiometer drift requirements for future missions. The full discussion can be perused in the final report (*www.aviso.oceanobs.com/fileadmin/documents/OSTST/2010/oral/final%20report/10_lisbon_OSTST_meeting_report.pdf*).

In summary, the OSTST recommendations are:

1) Jason-1 end-of-life orbit:

- Jason-1 should remain in its current orbit until repeat-track data from the SARAL/AltiKa can be validated.
- Because the OSTST recognizes the broad scientific value of a geodetic mission for Jason-1, we further recommend that Jason-1 be moved to a geodetic orbit in the range of 1286 +/- 2 km, or a suitable geodetic orbit in line with the spacecraft's capabilities at the time, after data from SARAL/AltiKa are validated.

2) Optimal orbit for Jason-CS:

- Given the importance of maintaining the precise climate record of sea-surface height, the challenges of calibrating and validating without formation flight between Jason-3 and Jason-CS, and the modest scientific benefits from a change of orbit: the OSTST recommends that Jason-CS maintain the 1,336 km reference orbit flown by T/P and Jason-1, 2, and 3.

3) Radiometer drift requirements:

- Jason-3 shall measure globally averaged sea level relative to levels established during the cal/val phase with zero bias +/- 1 mm (standard error) averaged over any one-year period.
- The Jason-3 project should continue to study the feasibility of improving the Advanced Microwave Radiometer (AMR) stability through on-board calibration for the Jason-3 mission.
- Jason-CS shall meet the following requirement at the mission level: Jason-CS shall measure globally-averaged sea level relative to levels established during the cal/val phase with zero bias +/- 1 mm (standard error) averaged over any one-year period.

Presentations and detailed summaries of the splinter sessions can be found in the full report at: *www.aviso.oceanobs.com/en/courses/sci-teams/ostst-2010/index.html.* ■

Special Issue of Marine Geodesy Highlights OSTM/Jason-2

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

A second OSTM/Jason-2 special issue is planned, and 28 letters of intention have been received. The deadline for submission was November 15, 2010, and publication is scheduled for mid-2011. Due to popular demand, **Volume 3** is also being planned, with a deadline sometime in 2011 (exact date TBD).