Report of the
2011 Ocean Surface Topography Science Team (OSTST) Meeting

Edited by J. Willis, Jet Propulsion Laboratory

Organized by NASA, CNES, NOAA and EUMETSAT

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Executive Summary

The 2011 Ocean Surface Topography Science Team (OSTST) Meeting was held in San Diego, CA on October 19-21. The meeting closed out a weeklong program of altimetry-related workshops in San Diego, starting with the Coastal Altimetry Workshop Oct 16-18, a SWOT Science Working Group Meeting Oct 17, and a Joint Argo and Altimetry Workshop Oct 18.

The primary objectives of the OSTST Meeting were to (1) provide updates on the status of Jason-1 and OSTM/Jason-2 (hereafter, Jason-2), (2) review the progress of science research, (3) conduct splinter meetings on the various corrections and altimetry data products, and (4) discuss the science requirements for future altimetry missions. This report, along with all of the presentations from the plenary, splinter and poster sessions are available on the AVISO website: http://www.aviso.oceanobs.com/ostst/ .

Jason-2 was launched in June 2008 on the former ground track of Jason-1 and TOPEX/Poseidon. All systems are in excellent condition and the satellite is operating nominally. The calibration and validation of Jason-2 data has shown that all mission and level 1 science requirements continue to be met. The cause of the 20 cm absolute bias in Jason-2 data has finally been identified as resulting from a discrepancy in the antenna reference points. After correction of this, along with an error discovered in the altimeter characterization files, the absolute sea surface height bias for both the Jason-1 and Jason-2 missions is statistically indistinguishable from zero. The range bias correction will be applied in the Geophysical Data Record, Release D (GDR-D), which will begin production in early 2012. Finally, both Jason-2 and Jason-1 were approved for extended mission operations after agency-level reviews at both NASA and CNES.

Jason-1, after celebrating its tenth year on orbit, continues to meet all of its level 1 science requirements delivering high quality sea surface height observations along an interleaved ground track, which provides enhanced spatial and temporal resolution in conjunction with Jason-2. After considering recommendations made by the OSTST regarding the ongoing operation of Jason-1, NASA and CNES agreed to continue operating Jason-1 in its present orbit until the launch and validation of a new altimeter mission such as SARAL/AltiKa (scheduled for launch in 2012). After this (or at the end of 2013, whichever comes first), Jason-1 will be maneuvered into a geodetic orbit (a very-long period repeating orbit, with finely spaced ground tracks) at an altitude of 1324 km. There, Jason-1 will provide sea surface height observations that give new information about marine gravity and will be safely removed from its current orbit, where the inoperable TOPEX/Poseidon satellite remains an important collision risk. In order to reduce any risk posed by a potential collision, and to remain in compliance with international laws designed to mitigate space debris, Jason-1 was maneuvered over a period of several weeks in order to deplete excess fuel aboard the spacecraft. These maneuvers were successfully completed on October 18 with only minor impact on the science data.

Work on the Jason-3 mission is now underway. Although the satellite is scheduled for launch in early 2014, selection of the launch vehicle and budget constraints remain critical elements for achieving a timely launch. At present, the 2014 launch will require Jason-2 to remain in operation for 6.5 years in order to have a 6-month overlap for cross calibration. Long-term stability of the radiometers remains a concern for the Jason missions and in response to previous recommendations by the OSTST, the Jason-3 Project has proposed instituting a periodic pitch maneuver of the satellite once it is on orbit that would allow the radiometer to be calibrated by looking at the cold sky. The implications of this proposal were considered by the relevant splinter sessions as well as the OSTST as a whole, which adopted the following recommendation: **The Jason-3 Project should proceed with plans to perform a maneuver during flight in order to periodically calibrate the Jason-3 radiometer. In addition, the Jason-2 Project should study the feasibility of performing a similar calibration maneuver on Jason-2.**

One of the primary themes of this OSTST meeting was the future of satellite altimetry. Along these lines, a special plenary session was held on Friday, Oct 21 that highlighted observations from existing and upcoming altimetry missions beyond the TOPEX/Poseidon and Jason series. During the meeting, considerable attention was also given to new data from CryoSat-2 over the oceans in splinter sessions such as Instrument Processing. These interactions were considered to be mutually beneficial to both the OSTST and the CryoSat-2 Project. In light of this, and of the recommendation adopted by the OSTST at the 2010 Meeting in Lisbon concerning availability of CryoSat-2 data, **the OSTST further recommended that ESA and the CryoSat-2 Project make all efforts to:**

1. **Allow distribution of currently generated value-added science products made on a free and open basis.**
2. **Provide a global seamless product over the ocean (LRM & SAR regions) as soon as possible.**

Six invited Keynote Lectures were given during the meeting, on a wide range of topics relevant to the OSTST. On Wednesday, Oct 19, Dean Roemmich, the co-chair of the Argo Steering Team, presented an overview of the Argo program and its synergy with the Jason satellites. Caroline Katsman discussed projections of sea level change over the 21st Century driven by anthropogenic climate change. Pierre-Yves Le Traon presented science and operational advances made possible by the constellation of satellite altimeters. Paolo Cipollini reported on new science and open questions from the coastal altimetry workshop held 16-18 Oct 2011, immediately prior to the OSTST. On Thursday, Oct 20, Shannon Brown presented scientific results based on the 19-year record of water vapor and cloud liquid water based on altimeter radiometers. On Friday, Oct 21, Josh Willis presented a summary of scientific highlights based on data from the Jason-1 satellite in honor of its 10th anniversary.

1. Introduction

The 2011 OSTST Meeting was held in San Diego, CA on October 19-21. The meeting closed out a weeklong program of altimetry-related workshops in San Diego, starting with the Coastal Altimetry Workshop Oct 16-18, a SWOT Science Working Group Meeting Oct 17, and a Joint Argo and Altimetry Workshop Oct 18.

On behalf of the Project Scientists (Lee-Lueng Fu and Josh Willis, NASA; Rosemary Morrow and Pascal Bonnefond, CNES; John Lillibridge, NOAA; Hans Bonekamp, EUMETSAT), the meeting was opened by J. Willis who presented the agenda and discussed logistics. In addition, R. Morrow announced that P. Bonnefond would be taking over her responsibilities as Projects Scientist for the Jason missions and OSTST meeting organization for the coming year.

2. Program and Mission Status

J. Willis introduced the program managers to speak on the status of altimetry and oceanographic programs at NASA, CNES, EUMETSAT, NOAA and ESA.

Eric Lindstrom reported on the NASA program status, noting the launch of Aquarius on June 10 and the upcoming SPURS in situ salinity campaign in 2012. He noted that the NASA Mission Concept Review for SWOT would occur in March 2012, and that the Jason-3 launch date had been moved to Spring 2014. Finally, Lindstrom noted that the next NASA ROSES solicitation for the Ocean Surface Topography Science Team would have proposals due March 23, 2012.

Juliette Lambin reported on the CNES program status. J. Lambin described the extensive involvement that CNES has in the current and upcoming constellation of satellite altimeters. These include the Chinese mission HY-2A, and the upcoming missions SARAL/ALtiKa and SWOT, as well as the CFOSAT (China-French Oceanography Satellite) which will make wind and wave observations and launch in 2014. J. Lambin also announced that CNES Project Scientist Rosemary Morrow would be transferring her OSTST duties to Pascal Bonnefond, and that she (J. Lambin) would be taking over as CNES Oceanography program manager from Eric Thouvenot. Finally, she noted that the CNES OSTST solicitation would be scheduled to be in phase with that of NASA.

Francois Parisot and Laury Miller reported on the status of the EUMETSAT and NOAA programs together. The slip of the Jason-3 launch date was discussed and it was noted that the delay until April, 2014 would require Jason-2 to achieve a 6.5 year life in order to have 6 months of overlap. Launch of Jason-CS is planned for 2017 with a bus based on the CryoSat mission. Areas for potential US cooperation on Jason-CS were also discussed. Finally, the retirement of Stan Wilson from NOAA was noted and he was thanked for his 35 years of service to the oceanography community. A special issue of Oceanography Magazine on sea level rise published this year and edited by J. Willis and L. Miller was also noted.

Jerome Benveniste reported on the status of the ESA program. J. Benveniste noted the passivation of ERS-2 in September as well as the upcoming symposium entitled “20 Years of Progress in Radar Altimetry” to be held in conjunction with the next OSTST Sept 24-29, 2012 in Venice Italy. The status of ENVISAT and GOCE was presented, and both missions continue to operate successfully. GOCE operations are expected to continue in its present altitude until at least April, with updated gravity fields continuing to be released.

3. Jason-1/2/3 Project Status

Glenn Shirtliffe provided an overview of Jason-1 status. Jason-1 continues to exceed all Level-1 science requirements in its present interleaved orbit, despite loss of reaction wheel #1 in Nov 2003, loss of half-satellite (PMB) in Sept 2005, a switch to Gyro #3 in April 2010, after an anomaly on Gyro #1 on March 2010, and loss of both GPS payload receivers. In May 2011, Jason-1 went through its fourth NASA Senior Review and was approved and funded for operation through 2013. Consistent with a similar REDEM Review process by CNES, the guidance given to the Jason-1 project was to continue operation in its present orbit through the end of 2013, or until data from another mission such as SARAL/ALtiKa can be validated, unless the spacecraft experiences additional technical anomalies. After this time, it will be maneuvered into a geodetic orbit at 1324 km altitude, which will serve as both a graveyard orbit and provide observations of sea surface height that will be of high value for marine geodesy. These directions were in line with the consensus recommendation for Jason-1 that were adopted by the OSTST in Lisbon in 2010:

At present, moving Jason-1 to a new orbit would create unacceptable error levels for users of high-resolution SSH observations. However in the long run, many will benefit from a geodetic mission, and programmatic pressure to move will likely continue to grow.

<u>We therefore recommend that Jason-1</u>:

- **Remain in its current orbit until SARAL/ALtiKa data can be validated.**
- **After validation of SARAL/ALtiKa data, move to a new repeat-cycle or geodetic orbit in the range 1326 to 1286 km, or another suitable geodetic orbit within an appropriate range.**

The project was also directed to resume fuel depletion activities, in order to minimize the risk of catastrophic break-up, should a collision occur. These maneuvers were completed on 18 Oct 2011, affecting Science Cycles 358, 359 and 360. Three auto-initializations of the on-board DORIS navigator led to gaps in the NRT products, however, first assessments of the IGDRs showed that less than 10% of ocean data were impacted due to maneuvers, which was less than anticipated. Jason-1 has retained 3.7 kg of hydrazine to continue its mission.

It was also announced that JPL has developed an NRT SSHA product that combines data from Jason-2, Jason-1 and ENVISAT, which is now available from PODAAC.

The Jason-2 project status was also presented by G. Shirtliffe on behalf of Thierry Guinle. The Jason-2 status is nominal, with the spacecraft and its core payloads remaining fully operational after more than 3 years in orbit. 100% of all OGDR, IGDR and GDR products are being archived and distributed by CNES, AVISO and NOAA data services to users. All satellite and system performance requirements are being fulfilled with large margins.

Gerard Zaouche provided an overview of the Jason-3 mission status. The Jason-3 mission will provide continuity of the observations begun by TOPEX/Poseidon, and carried on by Jason-1 and Jason-2 in support of oceanographic, climate, and operational applications. The program is led by the operational agencies EUMETSAT and NOAA, with CNES making a significant in-kind contribution and acting as the system coordinator. NASA in conjunction with EUMETSAT, NOAA and CNES will support science team activities. The satellite will be nearly a carbon copy of Jason-2, with improvements to the OGDR orbital accuracy (5 cm as opposed to 10 cm orbital accuracy with 3-hour latency). The project continues to consider the possibility of improving AMR stability through on board calibration, as recommended by the OSTST in 2010 in Lisbon. Finally, the Jason-3 satellite development is nominal at satellite, instrument and ground system levels. However, 2012 will be a key year for Jason-3 project due to the need to select a launch vehicle and the impact of this decision on the associated project schedule.

4. Keynote Talks and Discussion Points for Splinters

Six invited keynote lectures were given during the meeting on a wide range of topics of interest to the altimeter community. On Wednesday, Oct 19, Dean Roemmich, the co-chair of the Argo Steering Team, presented an overview of the Argo program and its synergy with the Jason satellites. Caroline Katsman discussed projections of sea level change over the 21st Century driven by anthropogenic climate change. Pierre-Yves Le Traon presented science and operational advances made possible by the constellation of satellite altimeters. Paolo Cipollini reported on new science and open questions from the coastal altimetry workshop held 16-18 Oct 2011, immediately prior to the OSTST. On Thursday, Oct 20, Shannon Brown presented scientific results based on the 19-year record of water vapor and cloud liquid water based on altimeter radiometers. On Friday, Oct 21, Josh Willis presented a summary of scientific highlights based on data from the Jason-1 satellite in honor of its 10th anniversary.

All of the Keynote talks can be found on the AVISO website at:
http://www.aviso.oceanobs.com/en/courses/sci-teams/ostst-2011/ostst-2011-presentations/index.html

	Wednesday 19 October 2011: **Keynote Talks**	
11:00	Observing climate variability and change in the global oceans: The Argo Program	D. Roemmich (SIO)
11:20	Towards regional projections of twenty-first century sea-level change	C. Katsman (KNMI)
11:40	Science and operational applications from the altimeter constellation	P.-Y. Le Traon (IFREMER)
12:00	Coastal Reflections: New science and open questions from the Coastal Altimetry Workshop	P. Cipollini (NOC)
	Thursday 20 October 2011: **Keynote Talks**	
8:30	Tracking water above the oceans: A 19-year water vapor and cloud water climatology from the altimeter radiometers	S. Brown (JPL)
	Friday 21 October 2011: **Keynote Talks**	
8:30	The road to continuity: Redefining success on the 10th anniversary of Jason-1	J. Willis (JPL)

Prior to the beginning of the splinter sessions, two brief presentations were given to provide key information for consideration in certain splinter sessions. The first presentation was given by Shannon Brown (JPL) and Veronique Couderc (CNES) and concerned a recommendation for a potential satellite maneuver for calibration of the AMR instrument on Jason-3. A periodic pitch maneuver (approximately once every 2 months) would provide a cold sky target for absolute calibration and aid in identification of any long-term drifts in the radiometer. Simulations suggest that drift uncertainty could approach 1 mm/yr with an 8 month record.

A second brief presentation was given by Richard Francis, the project manager for the CryoSat-2 mission. R. Francis briefly described the operational modes of the CryoSat-2 altimeter, which include a mode that mimics conventional pulse-limited operation (LRM), an along-track "Delay-Doppler" synthetic-aperture mode (SAR), and an interferometric SAR mode that provides a narrow across-track swath by utilizing two antennas (SARIN). Selection of the SAR mode operation areas over the ocean remains somewhat flexible and R. Francis requested input from the science team on selection of these areas.

5. Plenary Session on New Frontiers in Satellite Altimetry

A special plenary session was held on Friday, Oct 21 highlighting upcoming and existing altimeter missions outside of the TOPEX/Poseidon and Jason family, and including a discussion on the future roles of the OSTST.

Duncan Wingham (CryoSat PI, CPOM, University College London) provide an update on the mission status of CryoSat-2. Although the primary science objectives of CryoSat-2 involve observing the cryosphere, ocean observations are collected and ocean data products should be released by ESA sometime during 2012.

Jerome Benveniste (ESA) presented the status of Sentinel-3, which will launch in the first quarter of 2014 and provide continuity of SSH observations as good as ENVISAT on a 27 day repeat, sun-synchronous orbit near 800 km altitude, along with ocean color and surface temperature observations. Like CryoSat, it will have SAR capabilities near the coastline.

Richard Francis (ESA, CryoSat/Jason-CS Project Manager) provided an update on the status of Jason-CS, which will be the follow-on mission to Jason-3, scheduled for launch in 2017. Jason-CS will use the same bus as CryoSat and include an altimeter capable of both standard LRM-mode observations as well as a SAR-mode (similar to CryoSat and Sentinel-3). Calibration targets for the radiometer are under consideration in order to improve its long-term stability. It will be operated in the same orbit used by TOPEX/Poseidon, and Jasons-1, 2 and 3, with an increased design lifetime of 5 years (as opposed to 3).

Pierre Sengenes (CNES) presented the status of the SARAL/AltiKa program. This joint French and Indian mission will occupy the same ground track as ENVISAT with a 35 day repeat period. The satellite is scheduled for launch in 2012.

Charon Birkett (ESSIC/UMD) discussed the ICESat-2 Mission. ICESat-2 will carry a laser altimeter and measure cross-track slope in addition to along-track height, and launch in 2016. Ocean water science requirements have not yet been defined.

Finally, Lee-Lueng Fu (JPL, SWOT Project Scientist) gave an overview of the SWOT Mission, which is scheduled to launch in 2019 and will provide centimeter accuracy SSH observations at a resolution of 1 km. Aircraft campaigns called AirSWOT will provide a platform for testing the instrumentation in the coming years, with observations off the coast of Southern California and in the Mediterranean Sea. A Joint NASA/CNES solicitation for the formation of a Science Definition Team is scheduled for release through NASA ROSES in Feb 2012.

All of these talks are available on the AVISO website at:
http://www.aviso.oceanobs.com/en/courses/sci-teams/ostst-2011/ostst-2011-presentations/index.html

In addition to the talks on future and current missions, Program Scientists Eric Lindstrom (NASA) and Juliette Lambin (CNES) led a discussion on the future of the OSTST. The growing importance of missions other than the TOPEX/Poseidon and Jason series, and the need to evolve the topics handled by the splinter sessions were discussed. It was proposed that the OSTST consider a proposal to the Committee on Earth Observation Satellites (CEOS) to become the "Ocean Surface Topography Virtual Constellation". This would broaden the scope of the OSTST to include other missions and give it a larger international presence. Although no formal recommendation was adopted at this meeting, it was generally agreed by the members of the OSTST that the move to broaden its scope and apply for "Virtual Constellation" status with CEOS was in the best interest of the team.

6. Poster Sessions

A poster session was conducted on Wednesday evening and the posters were on view during the coffee breaks throughout the entire three day meeting. Links to the posters are available on the meeting website: http://www.aviso.oceanobs.com/en/courses/sci-teams/ostst-2011/ostst-2011-posters/index.html

The posters were grouped into the following categories:

- Regional and Global CAL/VAL for Assembling a Climate Data Record
- Instrument Processing
- The Geoid, Mean Sea Surfaces and Mean Dynamic topography
- Near-Real Time Products and Applications
- Precise Orbit Determination
- Science Results from Satellite Altimetry
- Outreach, Education & Altimetric Data Services

7. Splinter Sessions

The splinter sessions were organized as follows:

Wednesday, Oct 19:
- Splinter Session I
    - Regional and Global CAL/VAL for Assembling a Climate Data Record (part I)
    - Instrument Processing

Thursday, Oct 20:
- Splinter Session II
    - The Geoid, Mean Sea Surfaces and Mean Dynamic Topography
    - Near Real Time Products and Applications
- Splinter Session III
    - Precision Orbit Determination (Part I)
    - Science Results from Satellite Altimetry (Part I)
- Splinter Session IV
    - Regional and Global CAL/VAL for Assembling a Climate Data Record (Part II)
    - Outreach, Education and Altimetric Data Services

- Splinter Session V
    - Instrument Processing (Part II)
    - Science Results from Satellite Altimetry (Part II)

Friday, Oct 21:

- Splinter Session VI
    - Precision Orbit Determination (Part II)
    - Science Results from Satellite Altimetry (Part III)
    - Advanced Altimetry Modes (SAR/SARIN)

7.1 Regional and Global CAL/VAL for Assembling a Climate Data Record

Chairs: Pascal Bonnefond, Shalien Desai, Bruce Haines, Steve Nerem, Nicolas Picot

7.1.1 Introduction

The primary goals of this session were:

- Validation of all available Jason-2 version "T" (test) GDRs, including data collected after the end of the verification phase. We particularly sought insight on any potential emerging trends in the data on local, regional or global scales.
- Validation of the complete set of Jason-1 GDR-C products. Definitive calibration time series were solicited, along with estimates of geographically correlated errors, in order to reconcile local and global results and arrive at a unified error assessment.
- Validation of Jason-1 GDR-C data collected on the (current) interleaving ground track.
- Validation of EnviSat GDR data, especially from the more current reprocessing ("GDR-C" standards)

In order to facilitate comparisons among various results, contributors were asked to focus on results from the official data products. Complementary results from alternative sources were sought, however, if they helped to explain errors in the official products.

7.1.2 Results from in-situ calibration sites

Table 7.1.1. Averaged values of the altimeter biases from absolute calibration experiments.

Mission, Altimeter	Bias (mm)	Contributors
T/P, ALT-A	0 ± 5	*Haines et al., Bonnefond et al., Watson et al.*
T/P, ALT-B	+3 ± 3	*Haines et al., Bonnefond et al., Watson et al.*
T/P, POSEIDON-1	-4 ± 8	*Haines et al., Bonnefond et al.*
Jason-1, POSEIDON-1	+91 ± 4	*All* see Figure 1
Jason-2/OSTM, POSEIDON-2	+172 ± 6	*All* see Figure 1

Results from in-situ studies—whether linked to dedicated sites or regional campaigns—reveal good agreement for the absolute bias estimates. For each of the five altimeter measurement systems (Table 7.1.1), the bias estimates from competing investigations agree at the 10–15 mm (RMS) level. Moreover, the overall bias estimates (Table 7.1.1) show excellent (mm-level) stability from one OSTST meeting to another. As data from T/P mission yield unbiased SSH (Table 7.1.1), the relative calibration performed by *Dettmering et al.* gives similar results to those from in situ studies (Figure 7.1.1).

CNES investigators recently discovered two types of errors in the Jason-1 and Jason-2 altimeter ranges (*Desjonquères et al*., 2009; 2011). Correcting these errors strongly impacts the absolute bias estimates:

- Altimeter characterization file differences: These bias errors include an unexplained inconsistency between the Jason-1 and Jason-2 characterization files, as well as round-off error for the value of the altimeter pulse repetition frequency for Jason-2. After correcting the altimeter ranges for errors (biases) from the altimeter characterization files, both altimeters (Jason-1 and Jason-2) are biased by ~20 cm
- Different definition of antenna reference point (ARP): An inconsistent interpretation of the ARP (antenna mechanical plane vs. antenna focal plane) resulted in an additional bias of ~20 cm, common to both Jason-1 and Jason-2.

After applying these corrections, the sea surface height biases for Jason-1 and Jason-2 are no longer significantly different from zero. Preliminary results from both Harvest and Corsica calibration sites confirm this. A provisional version of the GDR-D for Jason-2 (cycles 1–8) reflects these adjustments to the altimeter range measurements. Analyses of this data product further supports that ***the Jason-2 bias has been reduced to insignificance.***

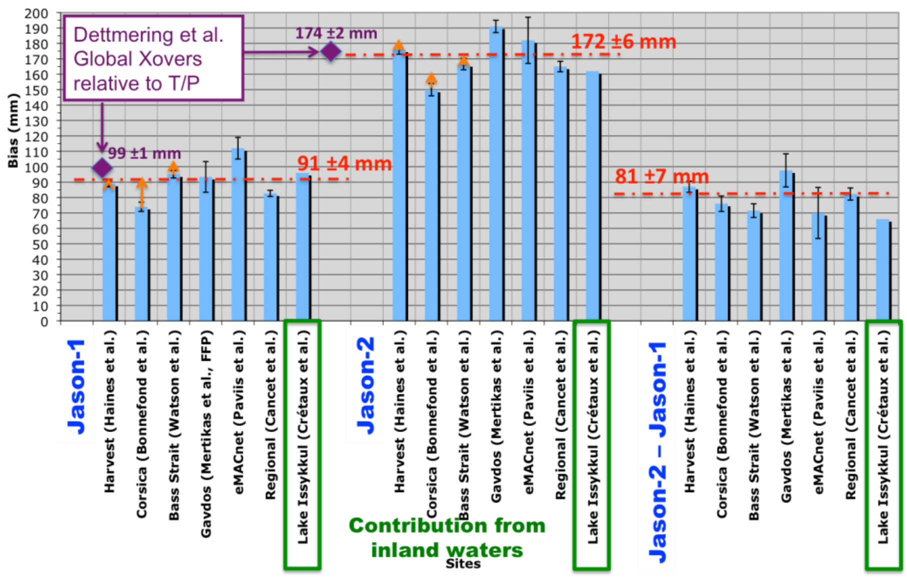

Figure 7.1.1. Absolute bias values for Jason-1 and Jason-2 from the different calibration sites, ***prior to the most recent corrections***. Red lines and associated numbers correspond to the average of all individual sites values. Orange arrows show the impact of using the Enhanced Path Delay for the wet tropospheric corrections (*Brown et al*., JPL)

While important progress has been made in the understanding of the overall biases of the altimeter measurement systems, significant periodicities remain unexplained. A frequency analysis of the long-term calibration time series from the Bass Strait experiment shows a clear 60-day signal for T/P ALT-B, which is less prominent for ALT-A (Figure 7.1.2). A similar result is observed at Harvest. The source of discrepancies in other signals (e.g. energy near Chandler wobble frequency at Bass Strait) requires further investigation.

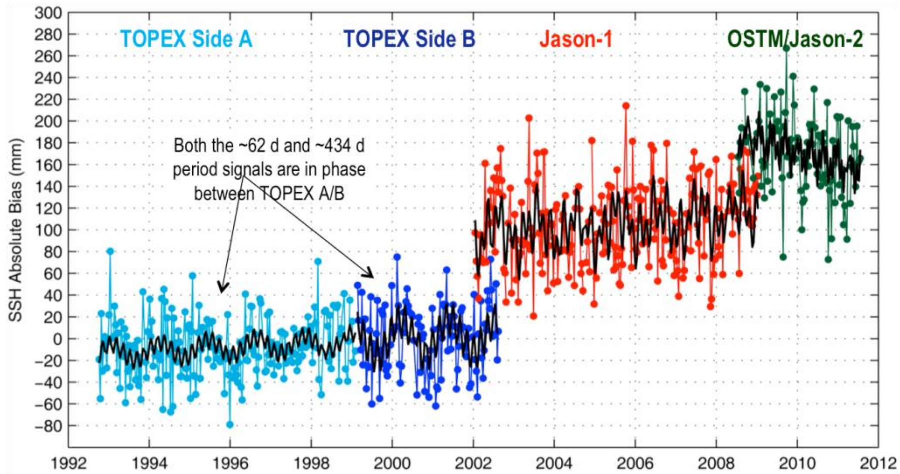

Figure 7.1.2. Frequency analysis of the Bass Strait altimeters biases time series (*Watson et al*.)

To complement the traditional in-situ approach to cal/val, a transponder was installed at the Gavdos calibration site (*Mertikas et al*.) to illuminate Jason-1. It has emerged, however, that the Jason-1 altimeter modes are not well suited for the proper receipt of a transponder signal. Dedicated operations to support a configuration change on Jason-2, however, have resulted in the first acquisitions of a transponder signal from Gavdos (*Desjonquères et al.*). The estimated range biases are stable (20 mm RMS), but the absolute value needs to be revisited after further calibration of the transponder. Moreover, a datation bias of 40 ms has also been derived. A new transponder is currently under development by the Technical University of Crete (*Mertikas et al*.).

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

Global in situ data analysis (tide gauges and/or ARGO) has proven to be very important to both the altimeter missions and the in situ data sets (*Ablain et al*., *Beckley et al.* and *Leuliette et al*.).

Preliminary results from *Beckley et al.* provide an explanation for the apparent drift of OSTM/Jason-2 relative to tide gauges (Figure 7.1.3). This apparent drift has been reduced to +0.28 mm/yr after appropriate exclusion of tide gauges affected by large earthquakes (e.g., Pago Pago), new orbit solutions (with improved handling of time-variable gravity) and AMR calibrations (Enhanced Path Delay, *Brown et al*., JPL).

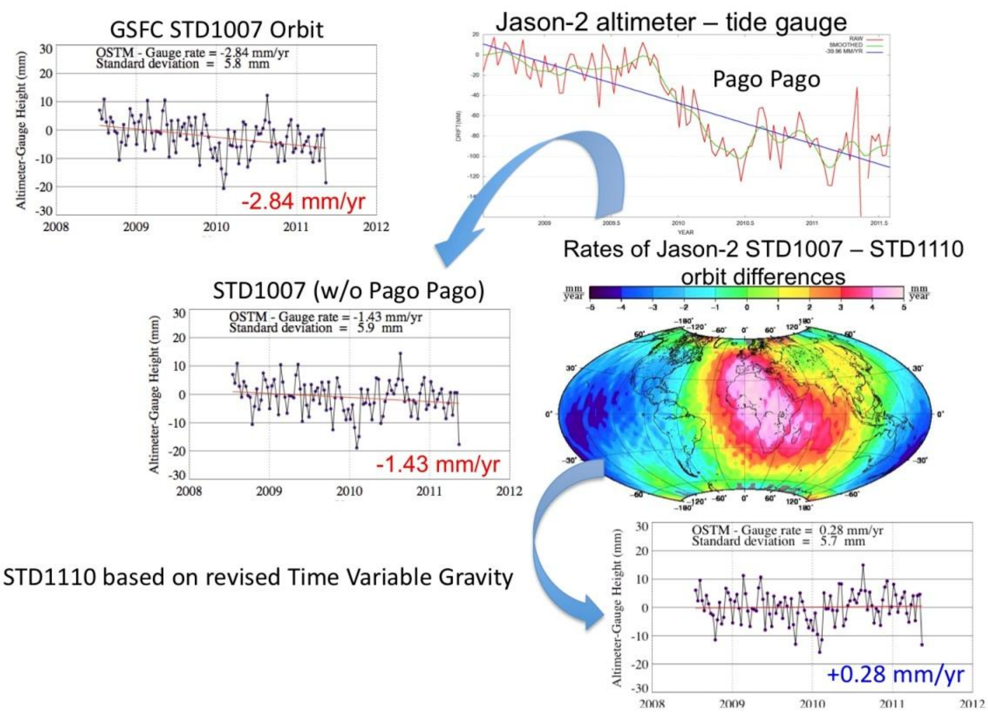

Figure 7.1.3. Towards Resolving Apparent Jason-2/OSTM Drift (*Beckley et al*.)

7.1.4 Global validation studies

All papers demonstrated the very good data quality for both Jason-1 and Jason-2 missions, using crossover and SLA metrics. Investigations of the overall stability of the reference missions have also been undertaken, and show that the radiometer wet tropospheric correction has some remaining instabilities (Figure 7.1.4) that need to be monitored carefully (*Philipps et al*.).

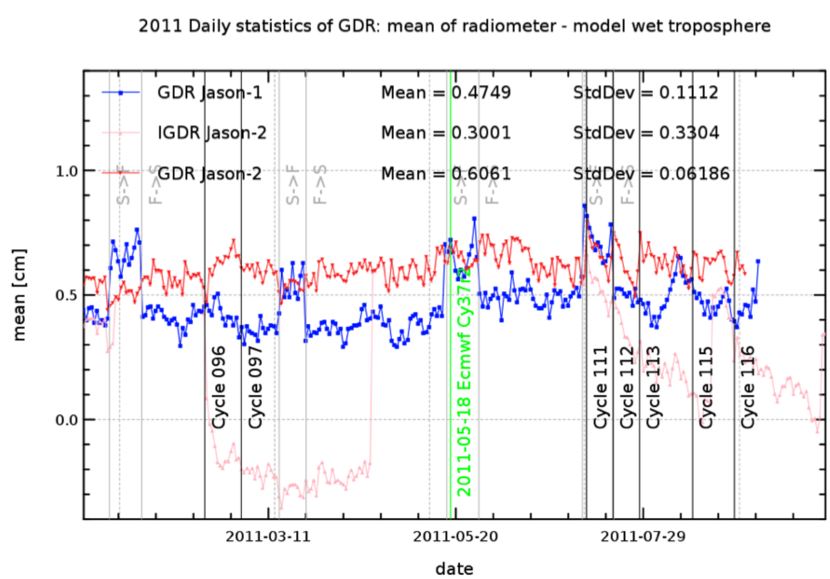

Figure 7.1.4. Daily Radiometer – ECMWF model wet troposphere correction (*Philipps et al*.)

Retracking of CryoSat-2 low-resolution model (LRM) altimeter data has been performed and evaluated by several groups. Current results demonstrate good performance: NOAA is ready to distribute Cryosat-2 products through RADS (*Scharroo et al*.), pending approval by ESA. If the large apparent secular drift can be corrected, Cryosat-2 data may be useful for Mean Sea Level studies (*Leuliette et al*.).

EnviSat 'GDR-C' reprocessing is ongoing, and is already yielding improvement in overall data quality. In particular, the correction for the Point Target Response (PTR) was not applied with the correct sign in this most recent reprocessing. Correcting this sign error results in a significant improvement in the Mean Sea Level trends observed by EnviSat relative to the Jason-1 reference (Figure 7.1.5). However, some remaining drifts are evidenced, mainly for the period 2002–2003.

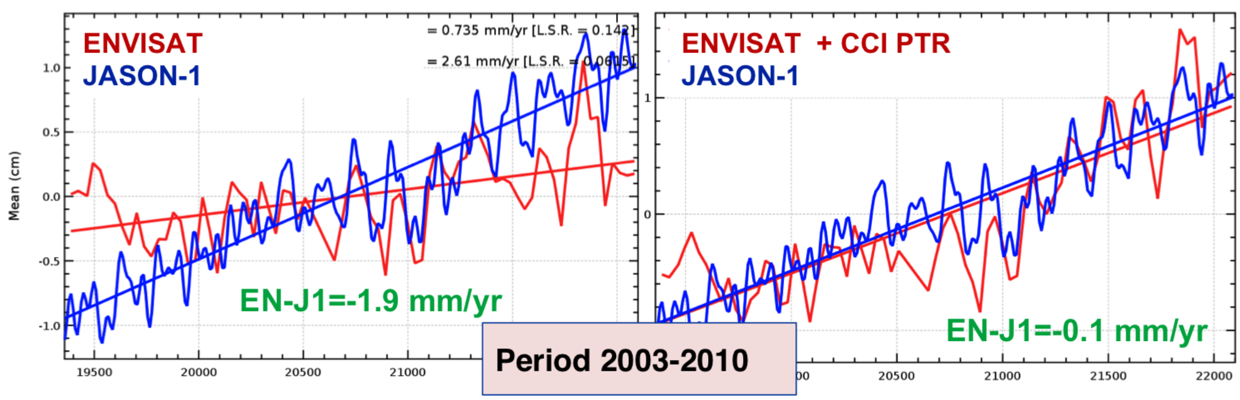

Figure 7.1.5. MSL time series for Jason-1 and EnviSat (*Ollivier et al*.): original time series for EnviSat at left and with the correct sign of the Point Target Response correction at right.

Using POE GDR-D quality orbits improves the coherence between EnviSat and Jason-1/2 missions. Large east-west geographically correlated errors (Figure 7.1.6) shown at the Lisbon OSTST meeting are significantly reduced (*Ollivier et al*., *Ablain et al*. and *Leuliette et al*.). This reinforces the need for routine multi-mission CalVal activities.

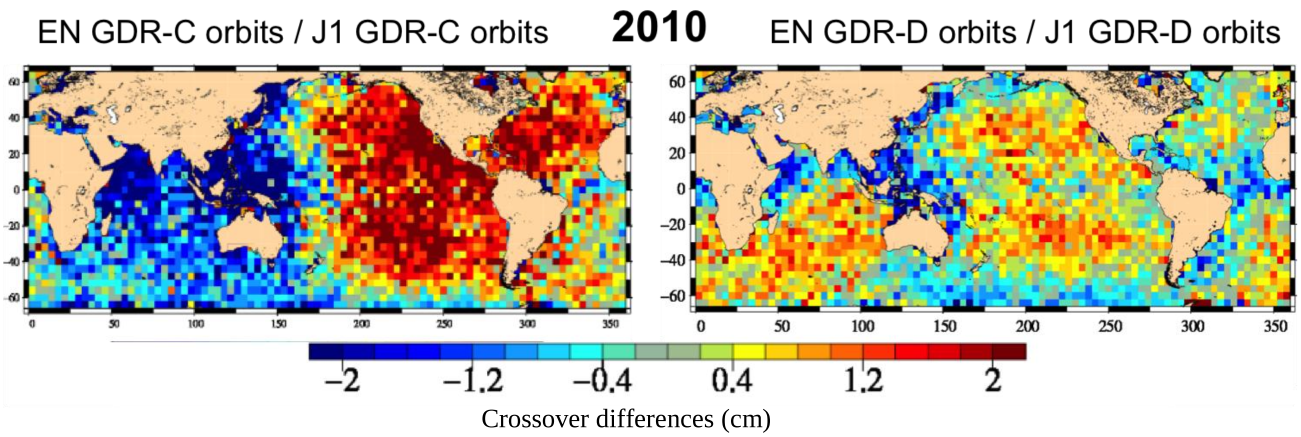

Figure 7.1.6. Crossover differences between Jason-1 and EnviSat for year 2010 (*Ollivier et al*.): GDR-C orbits for EnviSat at left and GDR-D orbits for EnviSat at right.

7.1.5 Conclusions

From the global analysis, the Jason-1 and Jason-2 missions are meeting the mission requirements. Discrepancies in mean sea level trends and geographically correlated errors observed on EnviSat mission, as compared to the Jason-1/2 missions, have been largely removed after adopting the correct sign for the EnviSat PTR correction and using GDR-D standards for the EnviSat precise orbit ephemeris.

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 found. It is due to errors (biases) in the altimeter characterization files (*Desjonquères*, 2009) for both satellites. After correcting for this error, the two missions are measuring sea surface consistently, but too high by about 20 cm. The origin of this 20 cm absolute bias has also been found by *Desjonquères et al*., and is due to an inconsistent definition of the antenna reference point for both satellites. With this additional correction, the absolute sea surface height bias for both the Jason-1 and Jason-2 missions is statistically indistinguishable from zero.

All these corrections will be applied for Jason-2 GDR-D reprocessing. Given that full reprocessing of Jason-1 is a huge task, there was a recommendation for CNES and JPL to study the feasibility of an intermediate (and simple) approach to generate a Jason-1 product that is in line with Jason-2 GDR-D standards.

Some questions were raised during discussions:

- As the GDR is the data set for the climate record, is the 60-d latency used for Jason-2 a good compromise?
    - One proposal is to enforce a mandatory reprocessing of the GDR (every 2 years??), keeping in mind the need to ensure the long-term stability (radiometer, orbit, ….) of the climate data record.
- Jason 1&2 error budget figures
    - The error budget for these missions should be assessed regularly: there are still issues with the figures available today (mainly on wind speed and SWH)
- Analysis of other key parameters?

    - This should be reinforced (wind, water vapor, etc.), with expert support from other communities.
- Add quality metrics on the operational products (OGDR and IGDRs)?
    - There is a need to provide more data quality metrics to end users: this should addressed in future OSTST CAL/VAL meetings
- Assessment of CryoSat SAR data quality?
    - It will be challenging taking into account the small areas covered. It was noticed, however, that the Mediterranean Sea provides a good target (low variability) and that it is better to keep the current SAR acquisition in place (long term analysis). It was also recommended to plan more SAR acquisitions over in situ sites (tide gauges, …)
- Orbit centering and reference point?
    - Do oceanographers prefer to have the orbit referenced to the center of mass of the whole Earth system, or to the origin of the terrestrial reference frame? On the long term (periods > 1 yr), the two should agree. At annual frequencies, however, the two disagree at the 5-mm level. Note that there is no consensus model for the annual geocenter motion.

7.2 Instrument Processing

Chairs: Shannon Brown, Phil Callahan, Emilie Bronner

The Instrument Processing splinter included 12 papers and 15 posters. There were substantial contributions on the processing of both LRM (Low Rate Mode) and SAR data from CryoSat-2 as well as traditional topics such Sea State Bias (SSB) and processing improvements, particularly for radiometers.

Three types of data are available from CryoSat-2 as shown in Figure 7.2.1 Low Resolution Mode (LRM, standard pulse limited data); (2) SAR Altimetry over selected ocean (mainly coastal) and sea ice areas; (3) SAR Interferometry over selected land and ice areas. A separate splinter was held on CryoSat-2 data collection and features. There were several detailed presentations on processing CryoSat-2 waveforms in addition to a number of posters on CAL/VAL of CryosSat-2 data. The main points of the session on CryoSat-2 processing were:

1. Processing of SAR data reemphasizes the need for correct modeling of waveforms in all retracking. Furthermore, retracking should use information on platform attitude when it is stable and accurate in order to reduce the number of parameters solved for.
2. With proper processing the SAR data can be reduced to regular waveforms and retracked to give results with reduced range noise, typically about 1 cm, about 30% better than standard pulse-limited altimetry. Useful SWH values can also be recovered. One key point is that the elliptical antenna pattern must for accounted for; for most purposes, using a harmonic mean of the two axes is adequate.
3. CryoSat-2 data need additional corrections and validation before they are ready to augment Jason SSH measurements.
4. New methods in retracking that take advantage of increased computer resources are being developed and should be tried on larger data sets so that error structure can be fully understood.

SAR seems to be very promising as it offers noise reduction. But that is not directly a proof of better quality, as unexplained biases or geophysical variations can exist, so comparison with geophysical data is needed to assess real performance.

General new retracking approaches were also discussed. Given current computer capacity new methods involving numerical, non-parametric, or tabularized methods may now be feasible and should be further developed so that the error structure and suitability for operational use can be fully evaluated.

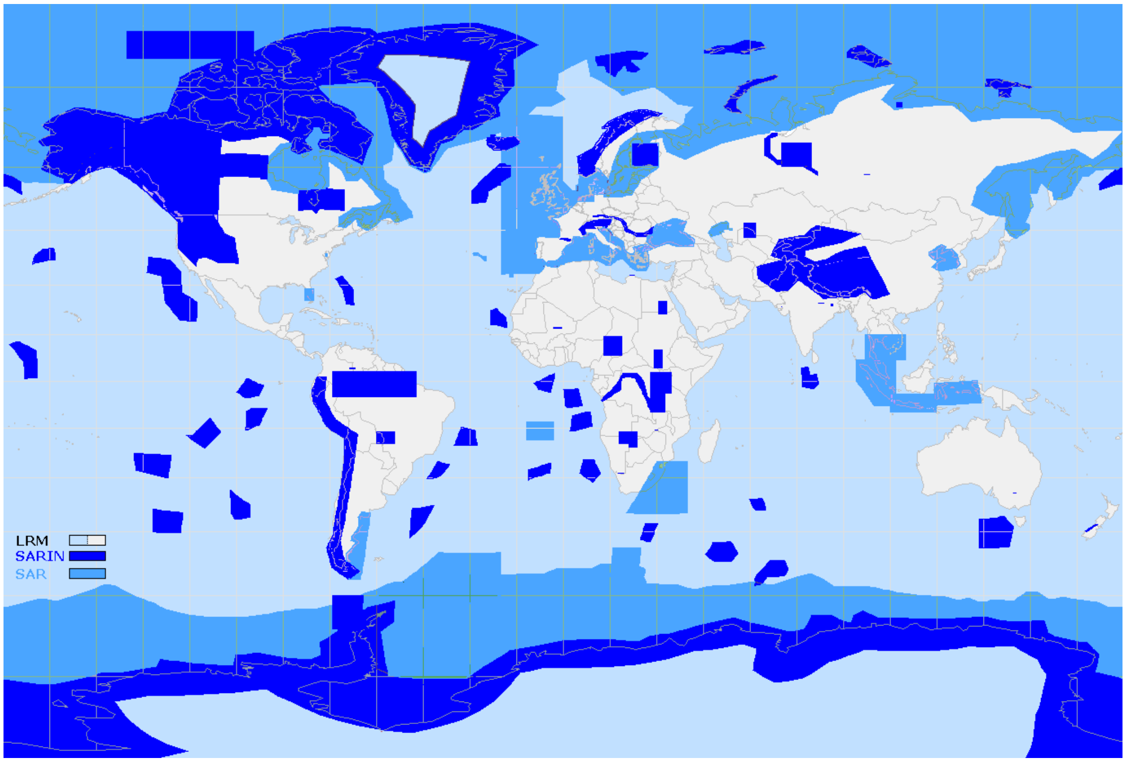

Figure 7.2.1. Data coverage of CryoSat-2. Pale blue – LRM; Middle blue – SAR; Dark blue – Interferometric SAR.

The main points regarding SSB were:

1. A three parameter model using wave period from WaveWatch III was shown to reduce along-track repeat RMS differences by 1.25 cm^2. Previous studies have shown similar improvement with three parameter models. The main issue is routinely integrating the wave model information into the processing stream.
2. A long-term trend in SSB was shown that is a significant fraction of the sea level trend, especially south of -40 degrees latitude. This effect and a recent article on long term wind speed drift in altimeter data need further investigation.

The main points regarding radiometer processing were:

1. Calibration, both semi-automated for the IGDR and multisensory analysis for the long term, is crucial to providing climate-quality wet troposphere corrections (< 1 mm/yr drift).
2. Rain and ice flagging must be done carefully when data sets are compared.
3. Significant improvements have been made for coastal processing and will be incorporated in GDR-D reprocessing (Jason-2).

The standard and plans for the Jason-2 GDR-D were discussed both in the splinter and in the plenary by N. Picot. First, the main points of GDR-C that was recommended last year were reviewed. Jason-2 GDR-C includes (N. Picot, p 3):

- New J2 AMR processing (coastal area + new flags) and updates to work around the 34 GHz VFC anomaly
- Use of a null mispointing value in input of the C band retracking algorithm
- Use of LTM information filtered over 10 days
- New tide model: GOT00.2 → GOT 4.7
- Pole tide anomaly correction
- Long period non equilibrium tide anomaly correction
- SSHA on OGDRs computed when meteo grid are extrapolated
- NRT orbit quality flag in OGDR products
- Update of the altimeter characterisation file and impacts
- Ice Flag in SSHA products
- New parameters in SGDR products (including all MLE3 derived parameters).

Since reprocessing to GDR-C has not begun, it was proposed to make some additional improvements (N. Picot, p 6):

- Absolute bias correction: The origin of this 20 cm absolute bias has also been found by Desjonquères et al., and is due to an inconsistent definition of the antenna reference point for both satellites. With this additional correction, the absolute sea surface height bias for both the Jason-1 and Jason-2 missions is statistically indistinguishable from zero.
- Datation bias correction (a datation bias of about 250 microsec is observed on current Jason-1&2 products and will be corrected in Jason-2 GDR-D products)
- Use of GOT 4.8 version instead of GOT 4.7
- New atmospheric correction algorithm provided by JPL
- Include MLE3 key parameters in both GDRs and SGDRs datasets, following what has been implemented for MLE4 (there is an unusual feature in the MLE3 sigma0 near 12 dB)
- New altimeter instrumental corrections tables (LUT) have been generated and delivered.

Jason-2 cycles 1-8 were processed in mid-September for an assessment of the new product by the OSTM partners. New SSB tables were computed based on preliminary data for inclusion. After some additional checks and corrections, it is recommended that production of GDR-D for Jason-2 start in early 2012 with the Jason-1/2 tandem phase to more carefully estimate the Jason-1/2 bias. GDR-D will not be produced for Jason-1 at this time, but the derived corrections will be widely publicized.

7.3 The Geoid, Mean Sea Surfaces and Mean Dynamic Topography

Chairs: Marie-Helene Rio, Ole B. Andersen

The Geoid, Mean Sea Surface and Mean Dynamic Topography are three key reference surfaces for altimetry. For the second time the OSTST meeting dedicated a splinter session for scientists to present the state of the art in computing these three reference surfaces. A number of important improvements and exciting perspectives have emerged from this session.

7.3.1 The Geoid

Regarding the geoid, many presentations were dedicated to the use of the recent data from the ESA GOCE mission. A new global gravity field based on 6.5 years of GRACE data and 6.7 months of GOCE data was presented by (Biancale et al). Both a satellite-only and a combined solution are available. The impact of the combined solution compared to EGM2008 is mainly visible over parts of the continents that suffered from bad terrestrial data coverage (Figure 7.3.1). The use of this solution was also shown to improve the orbit computation compared to the use of GRACE models. For consistency sake it was therefore recommended that the same geoid model should now be used both for orbit computation and geoid reference.

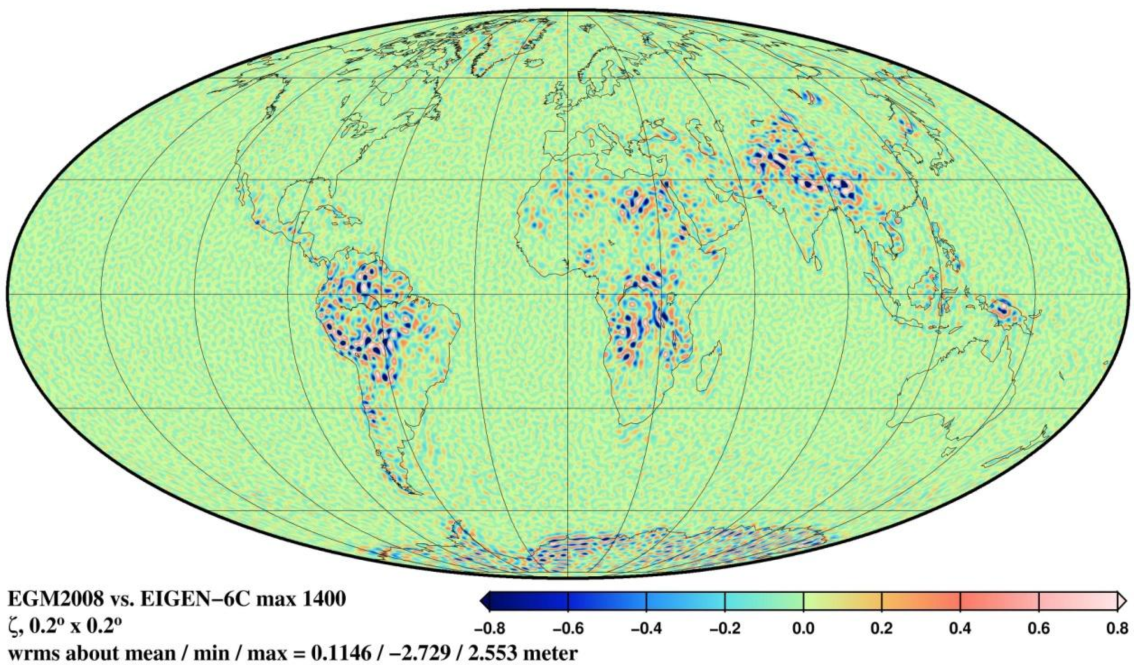

Figure 7.3.1. Difference between the EGM2008 geoid model and EIGEN-6C at degree/order 1400.

The improvements of recent GOCE geoid models over GRACE solutions were characterized over large lakes by (Schwatke et al.), where the difference between the altimetric elevation and the geoid is expected to be null.

Over the ocean, validation of the new geoid models based on GOCE data has been done by (Mulet et al.). Geoid models are used together with an altimetric Mean Sea Surface to compute the ocean Mean Dynamic Topography, and by geostrophy, mean surface currents. Figure 7.3.2 shows the Root Mean Square (RMS) difference between the mean surface currents obtained at various spatial lengths and independent velocity observations of mean surface currents measured in-situ by drifters. Significant improvements over GRACE are seen in the resolution range between 100km and 200km.

The additional use of 4 months of GOCE data in the second release made by ESA compared to the first release is also proven to improve significantly the estimation of mean surface currents at 100 km.

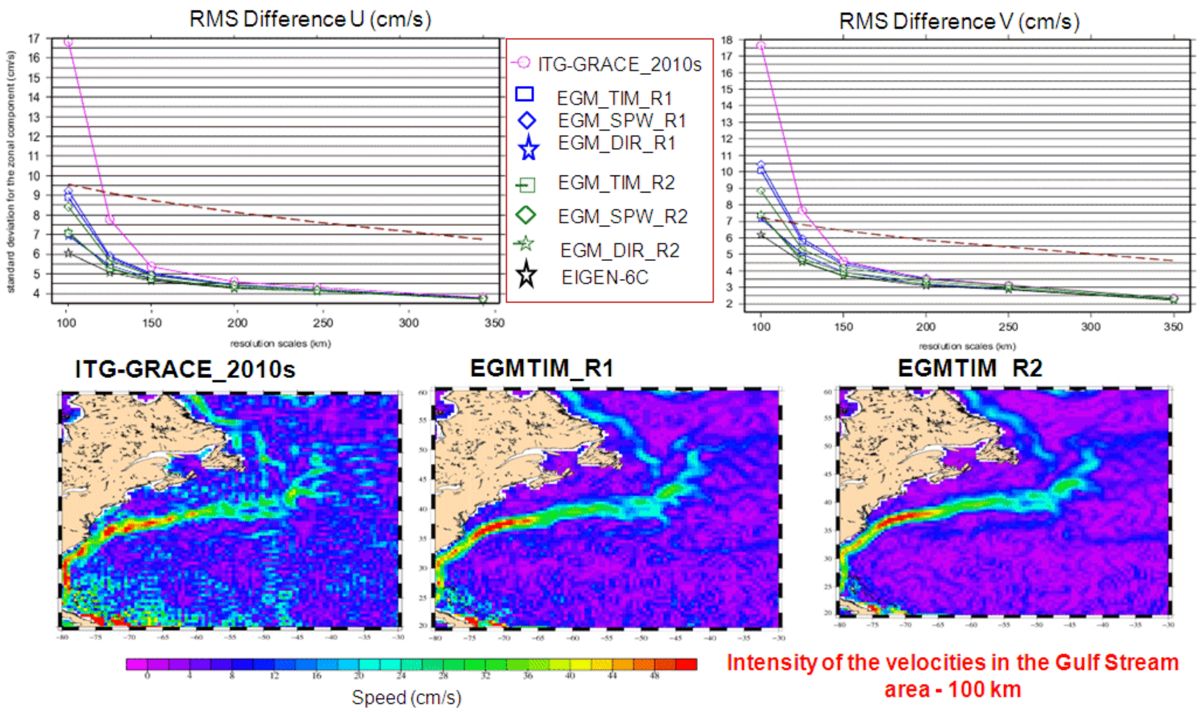

Figure 7.3.2. Top panel: Root Mean Square differences between mean geostrophic velocities computed using the CNES-CLS11 Mean Sea Surface and different geoid models and in-situ mean geostrophic velocities at spatial scales ranging from 100km and 350 km. bottom panel: Intensity of the mean velocity in the Gulf Stream obtained at 100km using GRACE data (left), 71 days of GOCE data (middle) and 6 months of GOCE data (right).

Further improvements of the Earth Gravity field are expected with the future release of the third version of the GOCE geoid models by ESA in November of this year (just released).

In addition, external information from other satellites may contribute to the better determination of the geoid. In particular, while twice better gravity is expected with Cryosat-2, the geodetic Jason1 data are expected to improve the East-West slope component of the gravity field as was discussed by (Sandwell et al.).

In addition, the first ever measurement of across track slopes of the marine geoid seen from the SARIN mode of CRYOSAT was shown by Galin et al. After a careful calibration of the interferometer is performed, the across-track slope estimate of the marine geoid can be estimated with an accuracy of 26 microradians at 10 km, which is very promising.

7.3.2 The Mean Sea Surface

Regarding the Mean Sea Surfaces (MSS) results, the new CNES/CLS11 MSS was presented (Schaeffer et al.) and its improvement to the previous CNES/CLS10 solution was discussed. Once the interannual signal is removed, differences between the CNES-CLS11 and the DTU10 MSS of the order of 1 to 3 cm RMS are obtained in most part of the ocean (Figure 7.3.3). However, locally (high latitudes, strong variability areas) differences can exceed 10cm. These differences between the two most recent MSS available still need to be further understood. They provide a good indicator of the consistency and relative accuracy of present day MSS models.

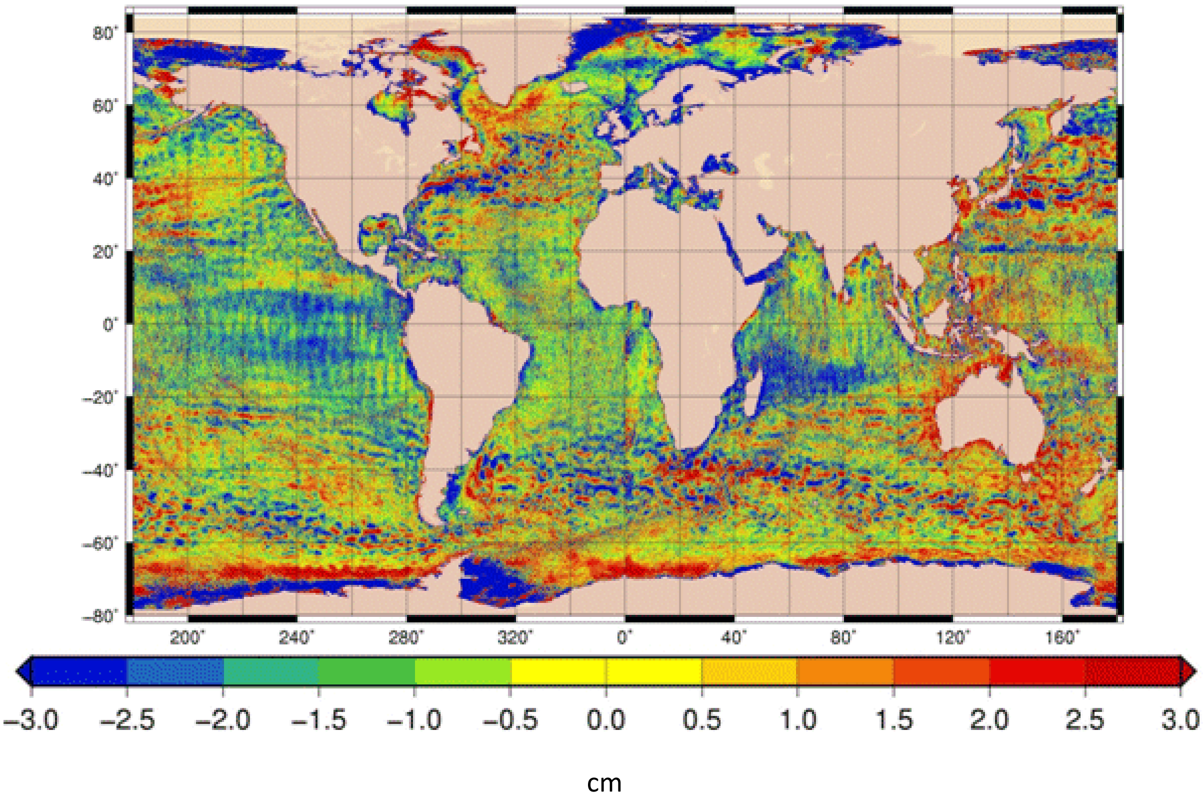

Figure 7.3.3. Differences between the CNES-CLS11 Mean Sea Surface and the DTU10 Mean Sea Surface.

The accuracy of the different MSS was also assessed looking at the impact of using different altimetric corrections on mean profiles (Andersen et al.)

Further improvements of the MSS are expected including data of missions with new ground tracks (Envisat drifting Phase, Cryosat, HY2) In particular, preliminary work is ongoing to assess the improvement of the MSS in the Arctic thanks to the use of Cryosat data (poster by O. Andersen and Stenseng). Improving the MSS accuracy is essential for the optimal use of future altimetric missions on non-repetitive or new orbits.

7.3.3 The Mean Dynamic Topography

Finally, both the MSS and the geoid may be combined to compute the third key reference surface for altimetry, i.e. the ocean Mean Dynamic Topography (MDT).

Global MDT from a preliminary GOCE model were presented by (Knudsen et al.) and (Mulet et al.). The present accuracy of the GOCE geoids implies that the ocean MDT needs to be filtered at 150-200 km. This resolution should be improved in the future with the release of new GOCE geoid models. (The maximum resolution expected with the delivery of new GOCE solutions (satellite only) is 100 km)

To improve the resolution provided by the use of GOCE data and create a MDT with higher spatial resolution, a new high resolution MDT (1/8°) using the GOCE model, altimetric data and oceanographic in-situ data (drifters, T/S profiles) around the Kerguelen Island was presented by Rio et al.. Significant improvements are obtained at short scales using the in-situ observations (Figure 7.3.4). For the optimal use of altimetric data, it is recommended to extend the high resolution computation of the MDT to the global ocean.

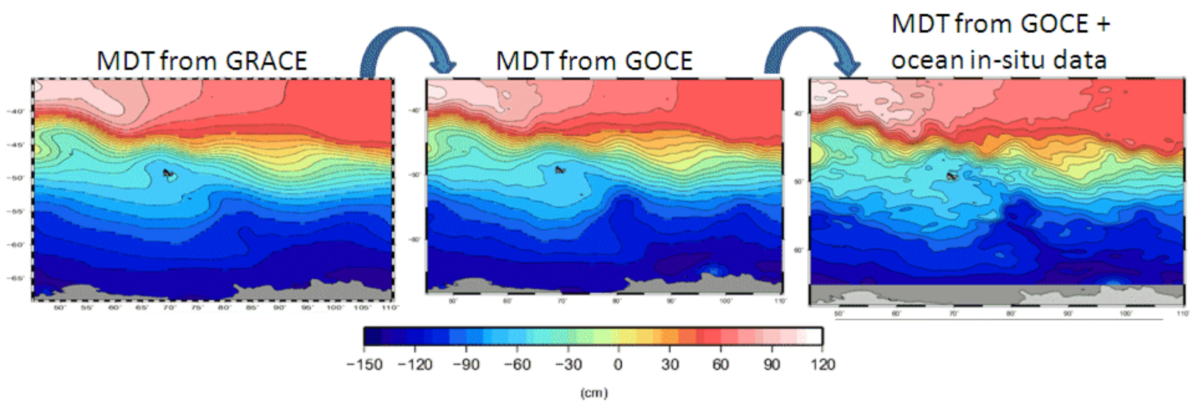

Figure 7.3.4. Left Mean Dynamic Topography obtained from the CNES-CLS11 Mean Sea Surface and the ITG-GRACE2010s geoid model in the Kerguelen island area at 400 km resolution. Middle MDT obtained at 200km resolution using GOCE data. Right: 1/8° resolution MDT obtained combining GOCE derived MDT to ocean in-situ data (ARGO floats and drifting buoys)

The ocean Mean Dynamic Topography is needed to reconstruct the ocean absolute dynamic topography (ADT) from the altimetric Sea Level Anomalies. Alternatively, the ocean ADT may be computed as the difference between the altimetric Sea Surface Height above the ellipsoid minus the geoid. This approach of course is limited by the accuracy and the resolution of the geoid models, which explains why it could not be used so far. With the new GOCE data, it is tempting to study the feasibility of such an approach for scales greater than 100-200 km. In this session, preliminary results of using this approach were presented using Cryosat-2 (A. Horvath et al.) and using multi-mission satellite altimetry (R. Savcenko et al.).

7.4 Near Real Time Products and Applications

Chairs: *John Lillibridge, Gregg Jacobs, Julia Figa Saldana*

On Thursday 20 October 2011 the near real-time (NRT) product validation and applications splinter session was held. The session consisted of 6 oral presentation and 6 posters. There was a short discussion after the talks, to **recommend uploading the latest version of DORIS/DIODE software on Jason-2 to further reduce orbit errors in the OGDRs**. The session encompassed a wide variety of topics, demonstrating the broad use of satellite altimetry data in near real time, illustrating that altimetry data are now being utilized by decision makers as end users. Topics included NRT product improvements, ocean circulation modeling in the wake of the 2011 Japanese tsunami, enhanced monitoring of global lakes and reservoirs, observations during extreme events, and inclusion of Cryosat-2 data for NRT operational monitoring.

7.4.1 NRT Processing and Multi-mission products

- Jayles et al. (poster) discussed the new version V11 DORIS/DIODE navigation software. The new DORIS/DIODE orbits have a radial RMS of 2.7 cm, compared to the final Precise Orbit Ephemeris (POE) orbit. This improves the OGDR SSH products by 18% compared to the current on-board software (V8, Figure 7.4.1). The splinter session recommended that the version V11 DIODE software be uploaded for operational use on Jason-2 as soon as possible.

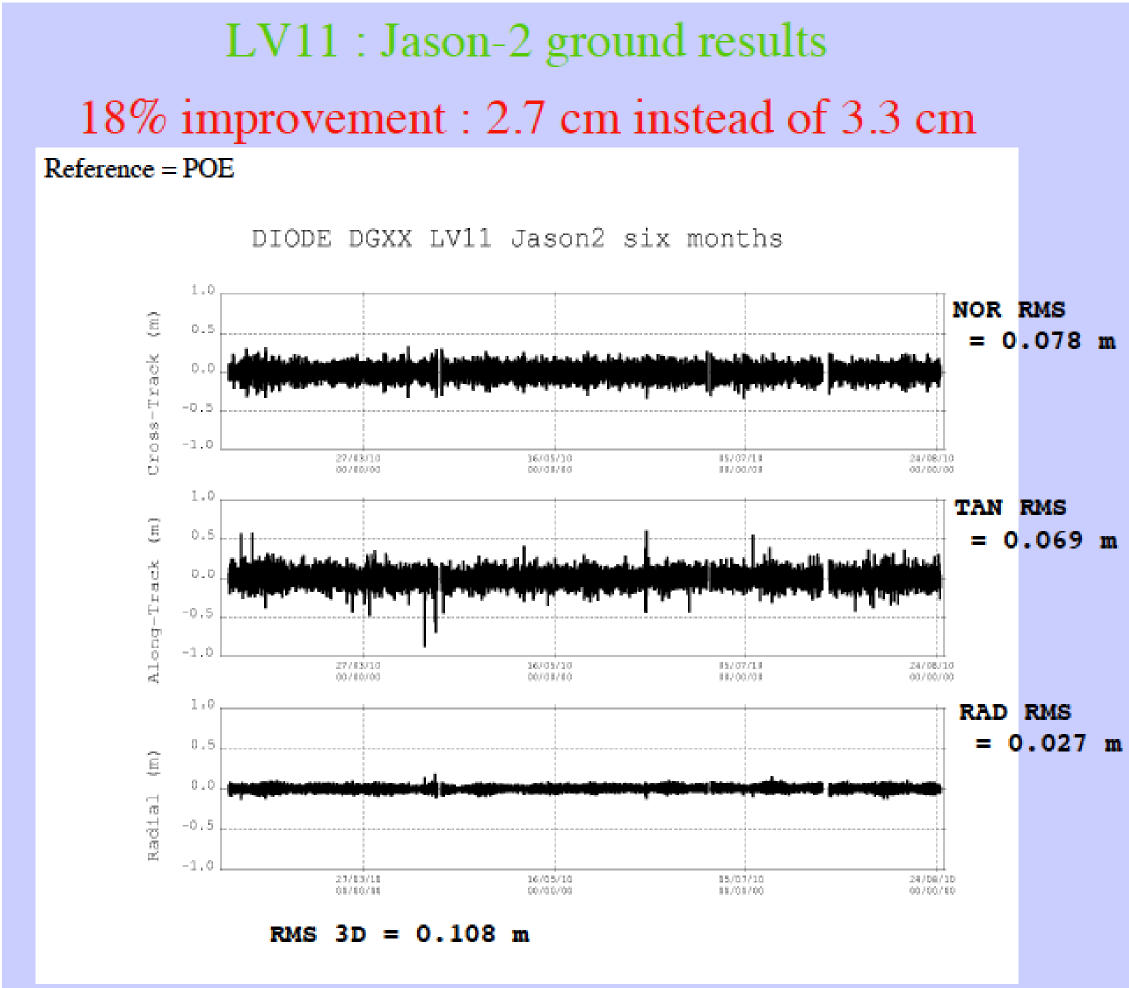

Figure 7.4.5. Orbital differences along-track (top), across-track (middle), and radially (bottom) from the Jason-2 DORIS/DIODE system compared to the final POE orbits. Radial errors are reduced by 18% for V11 software relative to POE orbit, compared to current V8 software.

- Desai et al. (oral) described the Jason-1 OSDR-SSHA, Jason-2 GPS-OGDR-SSHA and Envisat FDGDR-SSHA NRT products. These 1-Hz NRT SSHA measurements have accuracies of 3 cm or better (RMS), with latencies of 3-5 hours (Jason-2) and 7-9 hours (Jason-1 & Envisat). There are no GPS data from Jason-1 and Envisat to support precision orbit determination, so the SSHA differences at ground-track crossing locations with Jason-2 can be used to improve the NRT orbits for both missions. The data from all 3 missions are shown in Figure 7.4.2, and are available online individually and as merged products as well.

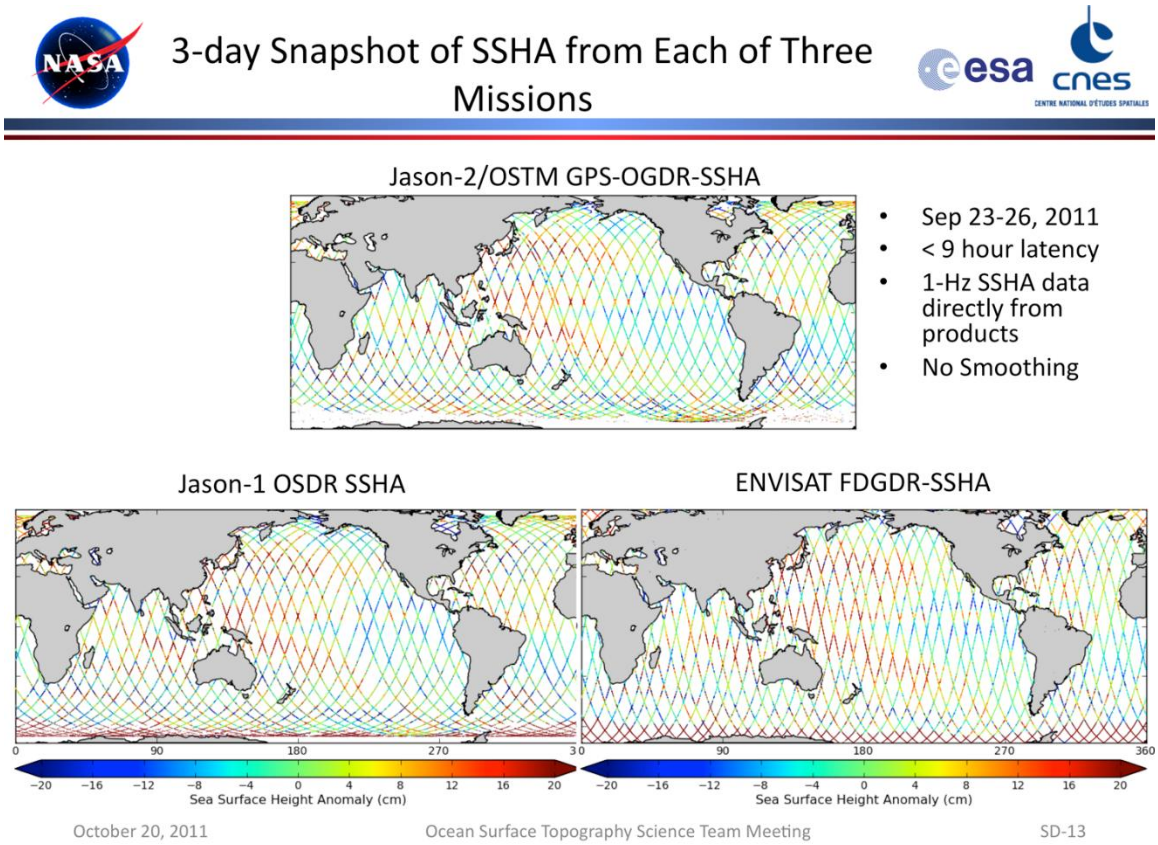

Figure 7.4.6. Near Real-Time Jason-1, Jason-2 and Envisat products based on JPL GPS orbits.

- Smith et al. (oral) showed that Cryosat-2 fast delivery mode (FDM) data could be exploited for oceanographic applications by retracking the conventional mode (LRM) waveforms from the level-1b products. Excellent agreement with both Jason-2 and Envisat measurements were found for significant wave height (Figure 7.4.3), sigma-0/wind speed and for sea surface height anomalies, given a sufficiently accurate MOE orbit. A recommendation was made in the final plenary session that the Cryosat-2 project make the CNES MOE orbits available, so that NOAA could produce an IGDR-like dataset for the community.

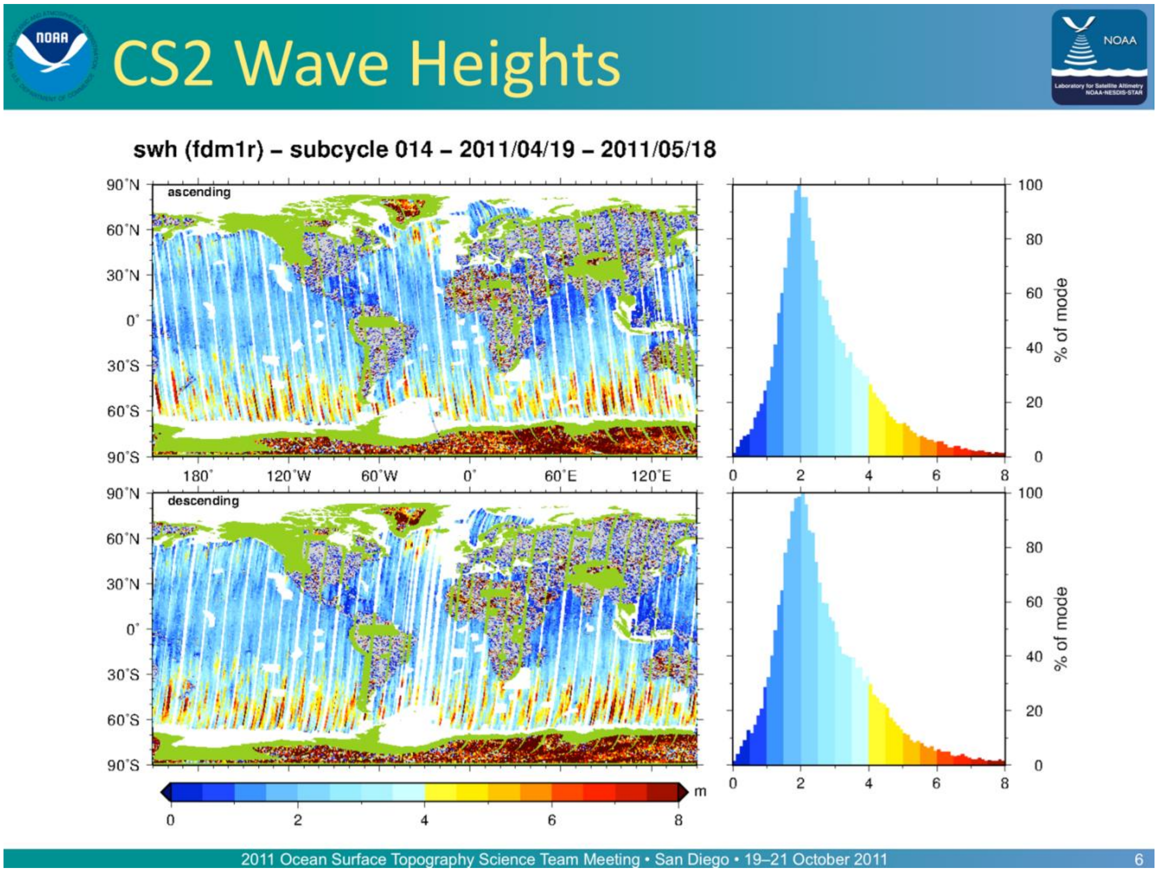

Figure 7.4.7. Cryosat-2 SWH data for subcycle 14, based on retracking of ESA FDM/L1B datasets.

- Labroue et al. (oral & poster) illustrated recent improvements to the AVISO/DUACS multi-mission processing in terms of reduced latencies (Figure 7.4.4) and for coastal applications (Figure 7.4.5). The concept of "OGDR-on-the-fly" processing reduces the data latency of Jason-2 data in the DUACS system from the current > 24-hour level to ~ 4 hours (Figure 7.4.4). The level-3 PISTACH products, with improved editing of 20 Hz measurements, dedicated retracking, and higher spatial resolution, perform better in coastal applications such as the Florida Strait example shown in Figure 7.4.5.

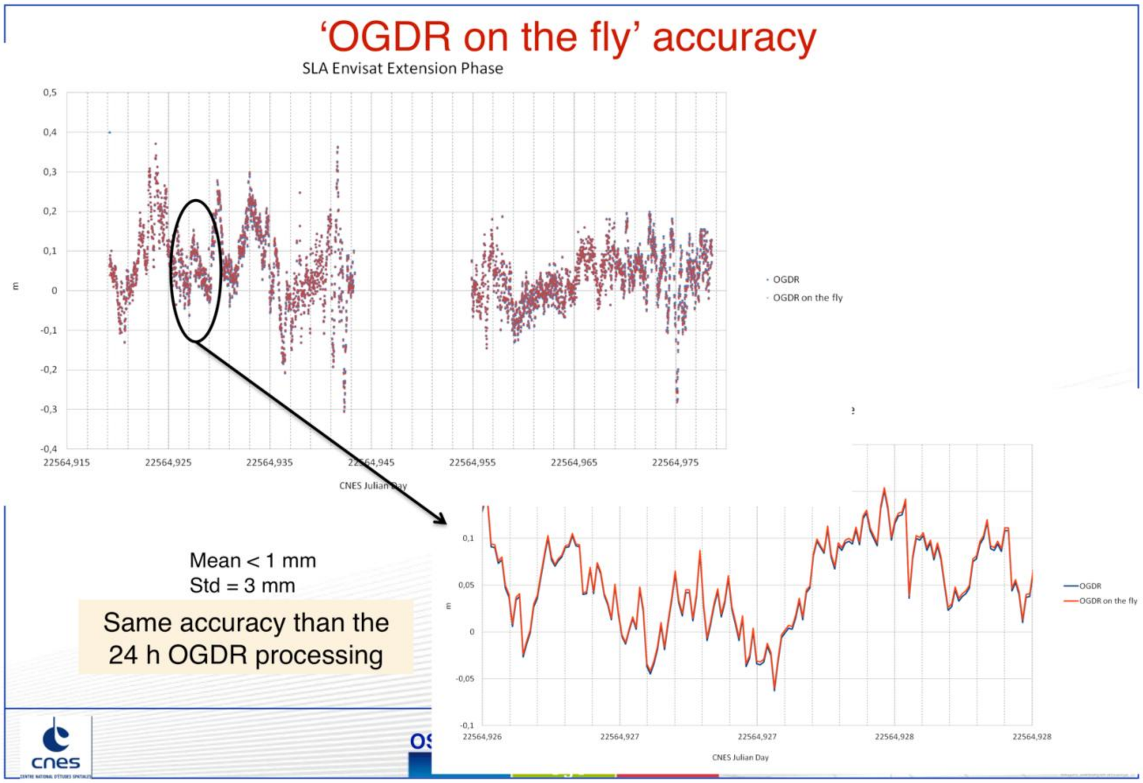

Figure 7.4.4. Improvement in DUACS latencies via 'OGDR-on-the-fly' processing. Latency is typically reduced from the current 24-hour level to a few hours.

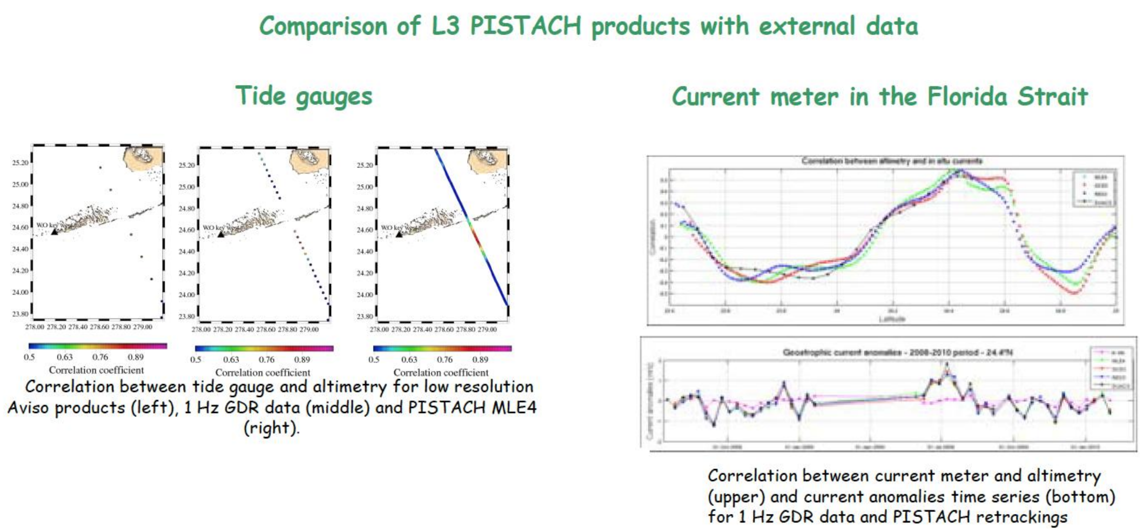

Figure 7.4.5. Improvements in NRT coastal altimetry products provided by the PISTACH project. The alongtrack resolution and correlation with nearby tide gauge and current meter measurements are improved with the dedicated processing compared to both 1 Hz and 20 Hz data in the original level-2 products in this example from the Florida Strait.

7.4.2 Extreme Event Monitoring and Applications

- Lefevre et al. (oral) explained how the Meteo-France wave modeling system (MFWAM) had been enhanced to provide early warnings for high waves and coastal flooding. An example event is shown for French Polynesia in Figure 7.4.6, which was based solely on satellite data (no wave buoy information). Another example was given for the coast of France after cyclone ‘Xynthia’ in 2010. This illustrates that near real-time altimetry are now being used operationally by international decision makers.

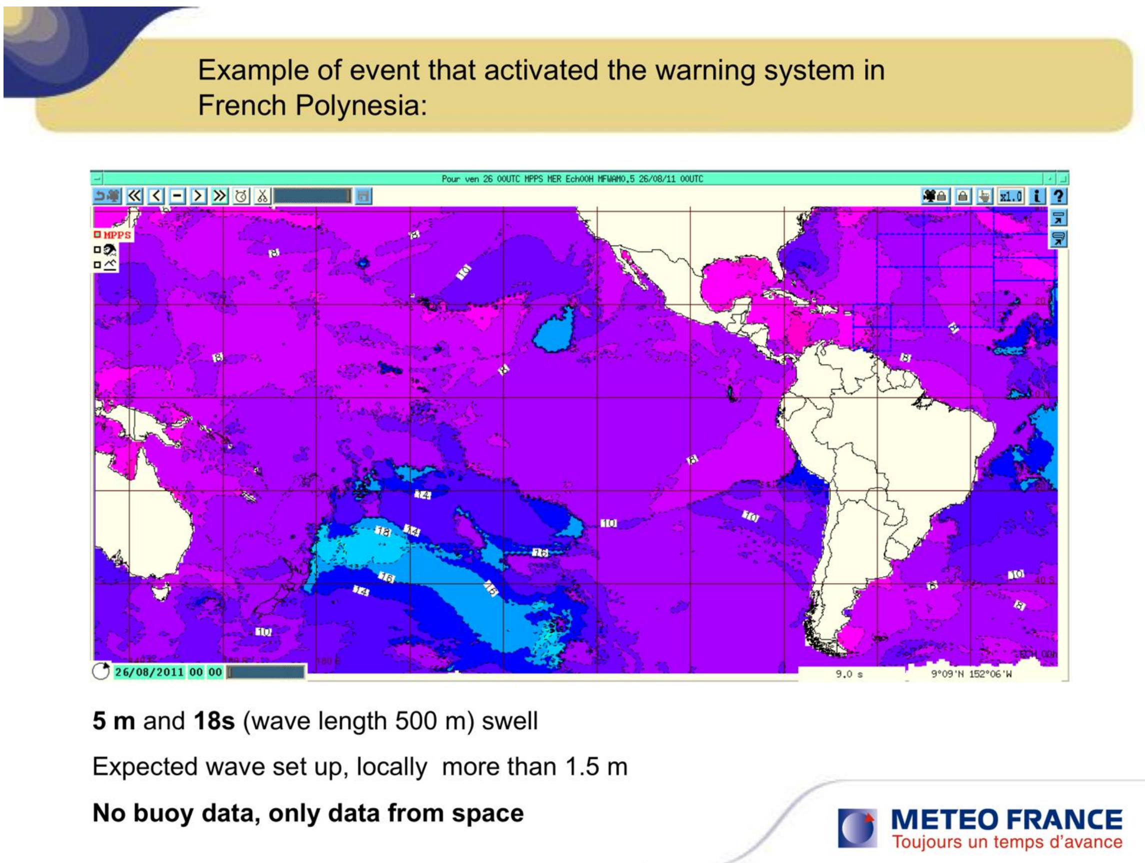

Figure 7.4.6. Example of a near real-time warning for French Polynesia after detection of high swell-dominated waves based on altimetry, from the Meteo-France MFWAM wave monitoring system.

- Griffin et al. (oral) provided a new method for monitoring extreme events based on percentile statistics of sea surface height anomalies and velocities in the East Australian Current (EAC). Very often, extreme values in NRT data are due to errors, so quality control is critical. This methodology of comparing to historic extrema (vs. spatially invariant limits) looks very promising. As stated in the conclusions: “For operational oceanography to become a reality, we must build systems that do not fail when they are most needed.” An example of an unusually large warm-core eddy, and associated strong flows in the EAC is shown via percentile plots of velocity and SLA in Figure 7.4.7.

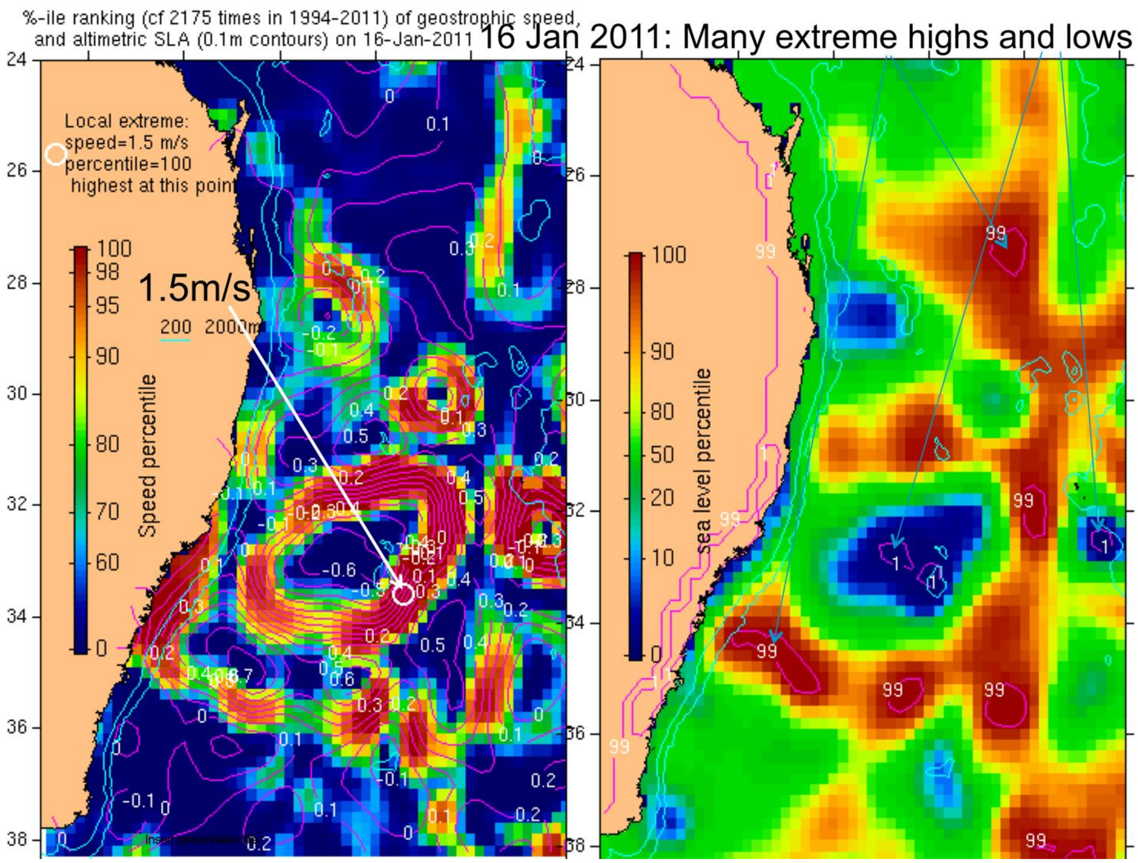

Figure 7.4.7. Percentile ranking of geostrophic velocities (left) and sea level anomaly (right) for 16-Jan-2011 in the East Australia Current (EAC) region. Extreme highs (> 99%) and lows (1%) are observed which are associated with extreme currents > 1.5 m/s. This resulted in a record breaking warm-core eddy in the EAC.

- Mertz et al. (poster) addressed the issue of monitoring extreme events, such as cyclones and tsunamis, which are both high frequency and rare – making them difficult to observe with traditional nadir-only altimetry. They have developed automated tools to detect such events, and specific processing code is utilized to fully exploit the observations. An example for hurricane Katia in the NW Atlantic is shown in Figure 7.4.8.

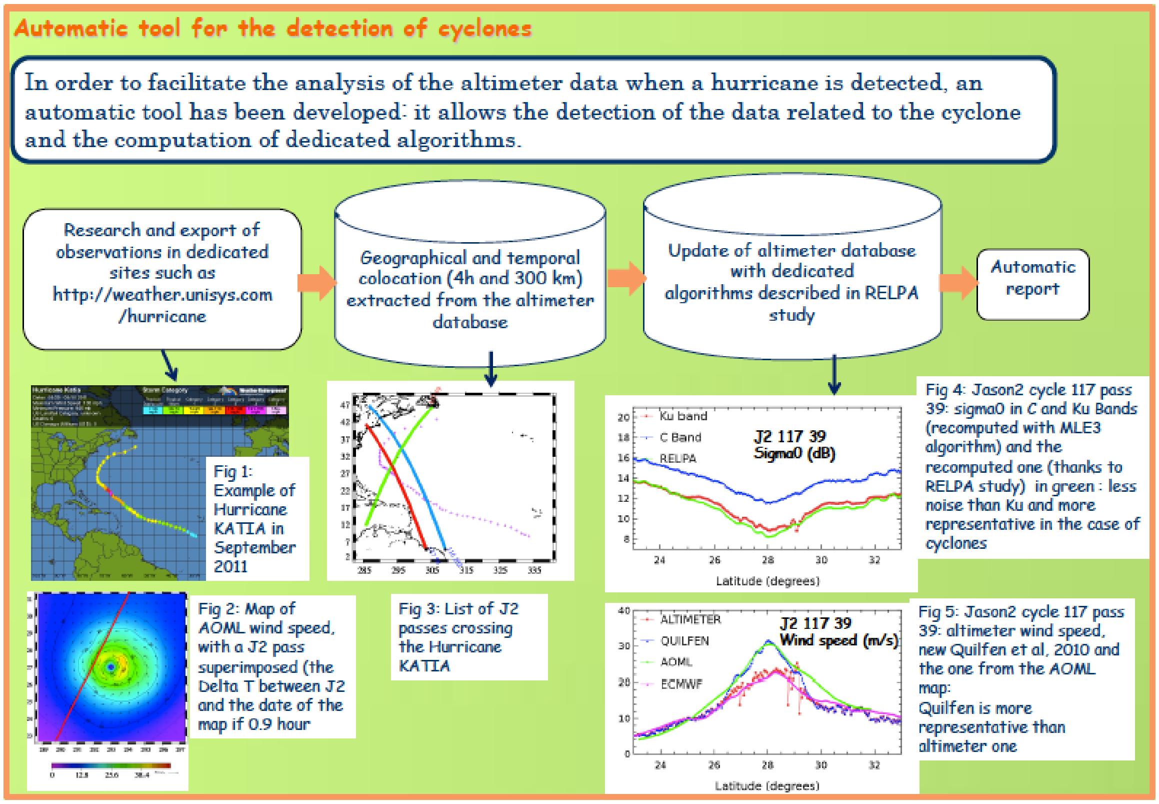

Figure 7.4.8. Detection and analysis of tropical cyclone Katia in Sep-2011 with dedicated CLS system.

- Maximenko et al. (oral) reported on a very interesting application of their ocean surface current model (SCUD), to predict advection of the massive debris field from the 11-Mar-2011 Japanese tsunami. Simulations from their model have already shown that there are five large-scale gyres where flotsam and jetsam will converge (e.g. the "Great Pacific Garbage Patch"). Their model predicts that the debris field associated with the Japanese tsunami would largely avoid the U.S. West Coast, but would have significant impacts on the Hawaiian Islands ~ 5 years after the event. This is illustrated in Figure 7.4.9.

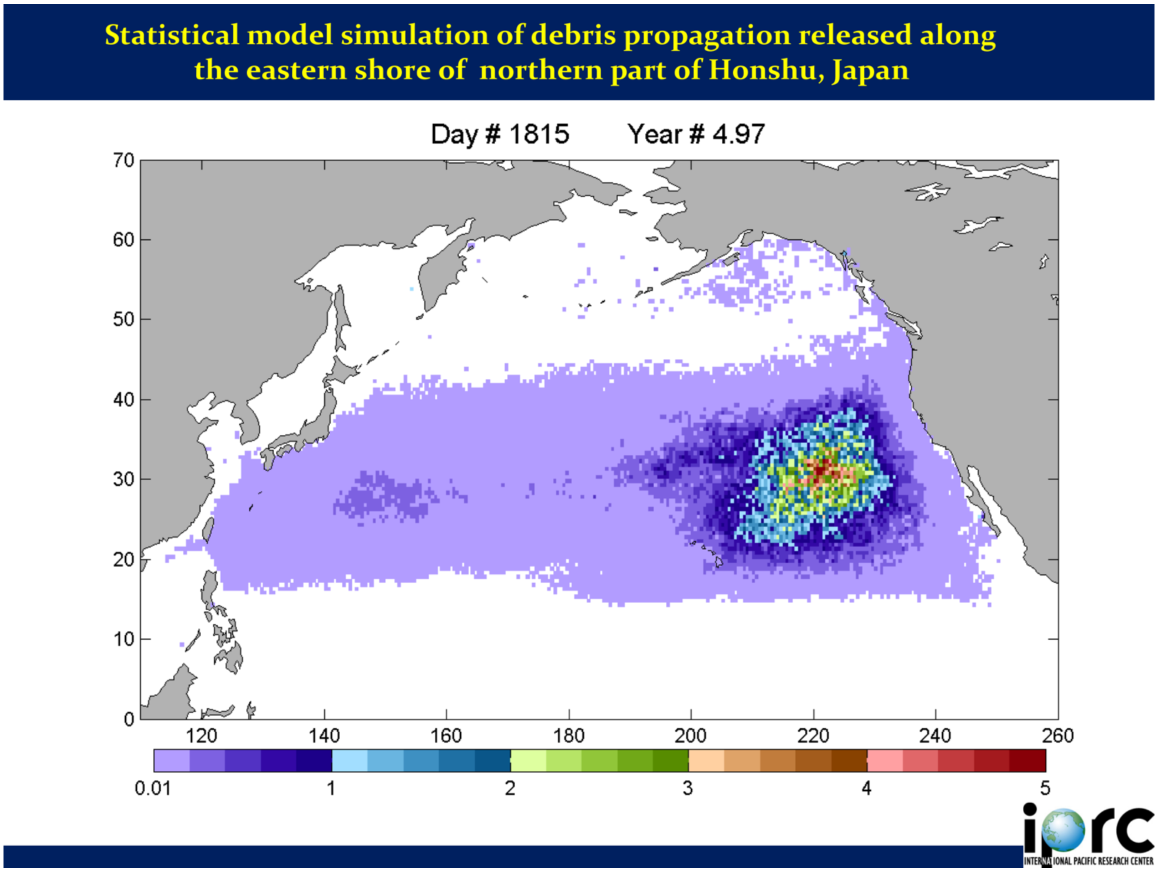

Figure 7.4.9. Location of debris associated with the 11-Mar-2011 Japanese tsunami five years after the event, impinging on the Hawaiian Islands, from the U.H. SCUD surface current model.

7.4.4 Hydrology & Regional Oceanography applications

- Birkett et al. (poster) showed the application of NRT monitoring of global lakes and reservoirs. They highlighted the addition of Envisat data to their Global Reservoir & Lake Monitoring system (GRLM). This will ultimately result in an additional 500 or so inland water bodies being monitored in near real-time. An example of the Envisat data record over Lake Victoria is shown in Figure 7.4.9.

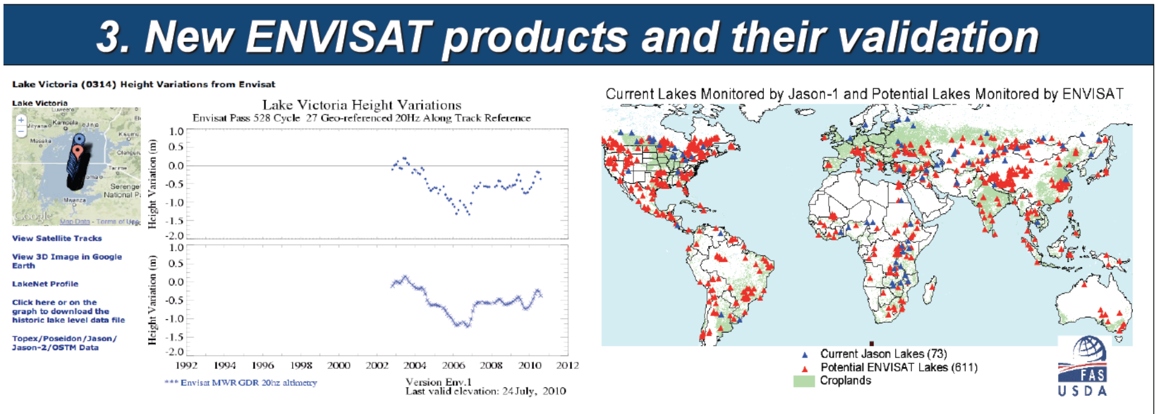

Figure 7.4.9. NASA/USDA Global Reservoir & Lake Monitoring system over Lake Victoria, Africa, from ENVISAT.

- Pujol et al. (poster) presented a regional sea level product developed specifically for the Kerguelen Island region near Antarctica. This specialized altimetry product was provided to oceanographic cruise members for biogeochemical studies in this region during the KEOPS2 campaign. The altimetric products support the field campaign by providing more detail via a regional mean dynamic topography field, as shown in Figure 7.4.10.

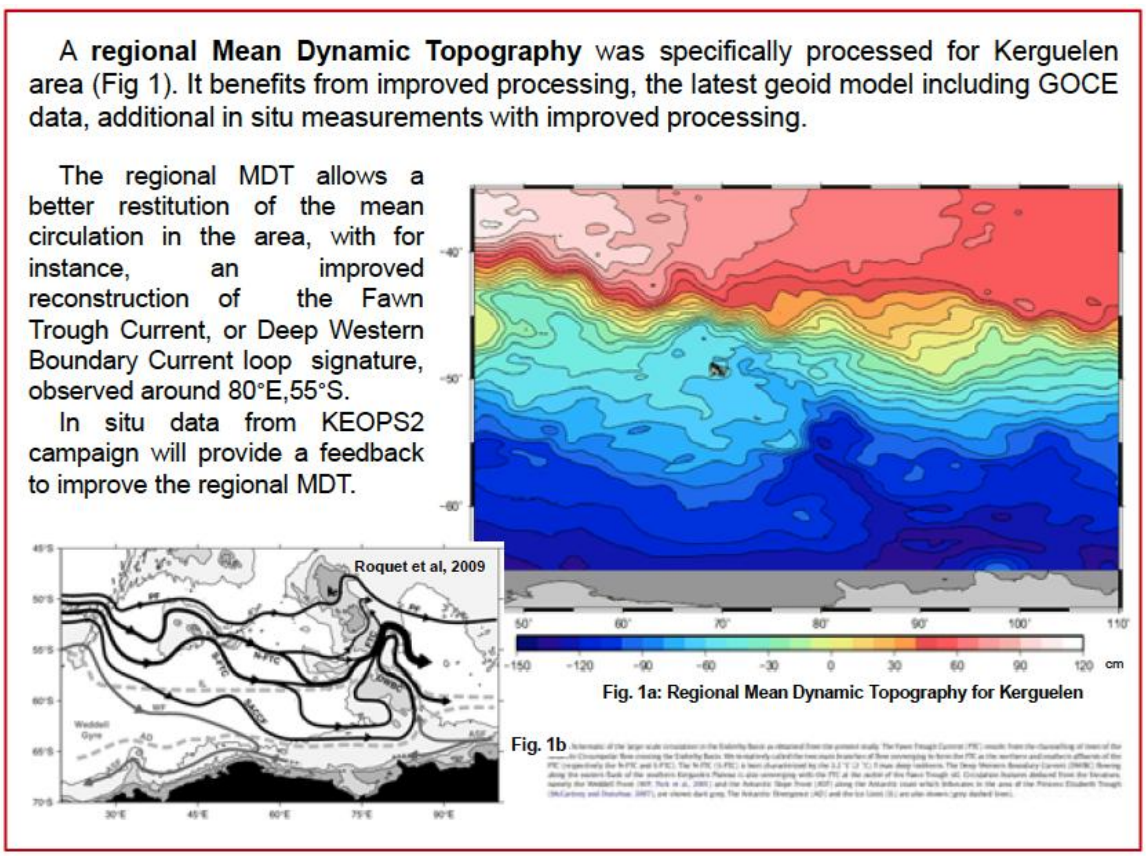

Figure 7.4.10. Regional Mean Dynamic Topography for the Kerguelen region provided by CLS in support of the KEOPS2 campaign.

7.4.5 Discussions

- The NRT splinter specifically recommended that the V11 DORIS/DIODE software be uploaded to Jason-2 as soon as possible, to further reduce radial orbit errors in the OGDR products. This was approved at the final plenary session on Friday, October 21st.
- No specific recommendations were made with regard to AMR pitch calibration maneuvers, nor on the issue of Cryosat-2 sampling via SAR/SARIN 'polygons'.

A related Cryosat-2 recommendation was made in plenary that the CNES MOE orbit be provided to facilitate NOAA's efforts to produce an IGDR-like product.

7.5 Precision Orbit Determination

Chairs: *Luca Cerri, Frank Lemoine*

7.5.1 Status of Jason-2 GDR orbits

Jason2 GDR orbit has been extensively compared with the solutions of other groups, including GSFC, JPL, and ESOC. All these solutions are obtained using similar though not identical models, different combinations of tracking techniques and different parameterizations. Overall, the radial orbit comparison is stable and close to 1 cm RMS (cf. Figure 7.5.1). Classic performance metrics like SLR residuals and altimeter crossover residuals (Table 7.5.1 and Figure 7.5.2) also indicate accuracy at the 1 cm level. The best performance is achieved by reduced-dynamic orbits, JPL GPS-based in particular, indicating that the force models that drive the error of dynamic solutions have still some margin for improvement. In particular, most of the splinter session was dedicated to the assessment of improvements in modeling of the non-tidal component of time-varying gravity field on the long term.

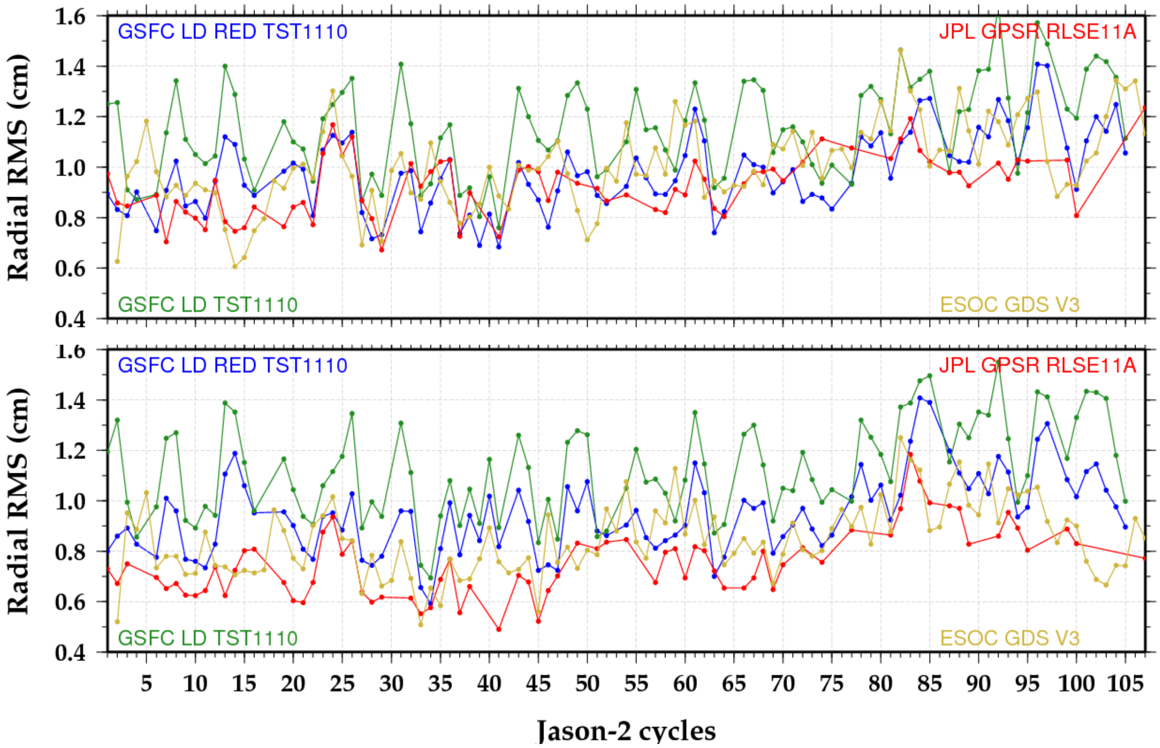

Figure 7.5.8. (From Couhert et al., 2011) Top : RMS per cycle of the radial orbit difference between Jason-2 CNES GDR-C orbit and GSFC DORIS+SLR dynamic orbits (green), GSFC (DORIS+SLR) reduced-dynamic orbits (blue), JPL GPS reduced-dynamic orbits (red), ESOC DORIS+SLR+GPS dynamic orbits. Bottom: same comparison but with respect to the CNES preliminary GDR-D orbit. Notice CNES preliminary GDR-D orbit gets closer to reduced-dynamic solutions, which generally perform better.

Jason2 Orbit Comparison Summary over Cycles 1 -105							
orbit	average RMS residuals			jpl11a -test orbit (mm)			
	DORIS (mm/s)	SLR (cm)	Xover (cm)	radial rms	ECF Mean X	ECF Mean Y	ECF Mean Z
std1007_cr	0.3704	1.148	5.449	9.2	1.3	-3.4	2.6
std1110	0.3705	1.143	5.421	9.1	3.3	0.5	3.5
red_std1110	0.3696	1.060	5.378	6.9	2.3	-1.3	2.3
gdrc	0.3705	1.160	5.483	9.6	2.3	-4.0	7.3
gdrd	0.3703	1.139	5.441	7.6	2.2	1.4	2.4
esa	0.3702	1.480	5.386	6.6	3.8	0.1	1.8
jpl11a	0.3700	1.139	5.323	---	---	---	---
tst1110	0.3705	1.126	5.422				
red_tst1110	0.3696	1.049	5.382				

Table 7.5.1. Jason-2 POD Performance Summary (from Lemoine et al., 2011). Left: Jason-2 SLR, DORIS and independent altimeter crossover fits for GSFC orbits (std1007_cr, std1110, red_std1110, tst1110), CNES orbits (GDR-C, GDR-D), ESA, and JPL orbits. For GSFC, std1110 refers to ITRF2008-based orbits; tst1110 refers to the orbits determined based on GGM03S and augmented with a weekly 4x4 coefficients determined from nine SLR & DORIS satellites. The CNES & ESA orbits are based on SLR+DORIS+GPS. The JPL orbits are reduced-dynamic and based on GPS only. Right: Earth-Centered-Fixed mean orbit differences in X,Y,Z between the JPL reduced-dynamic orbits and the other analysis centers' orbit series. The mean radial RMS difference between the orbit series is 6.6 to 9.2 mm.

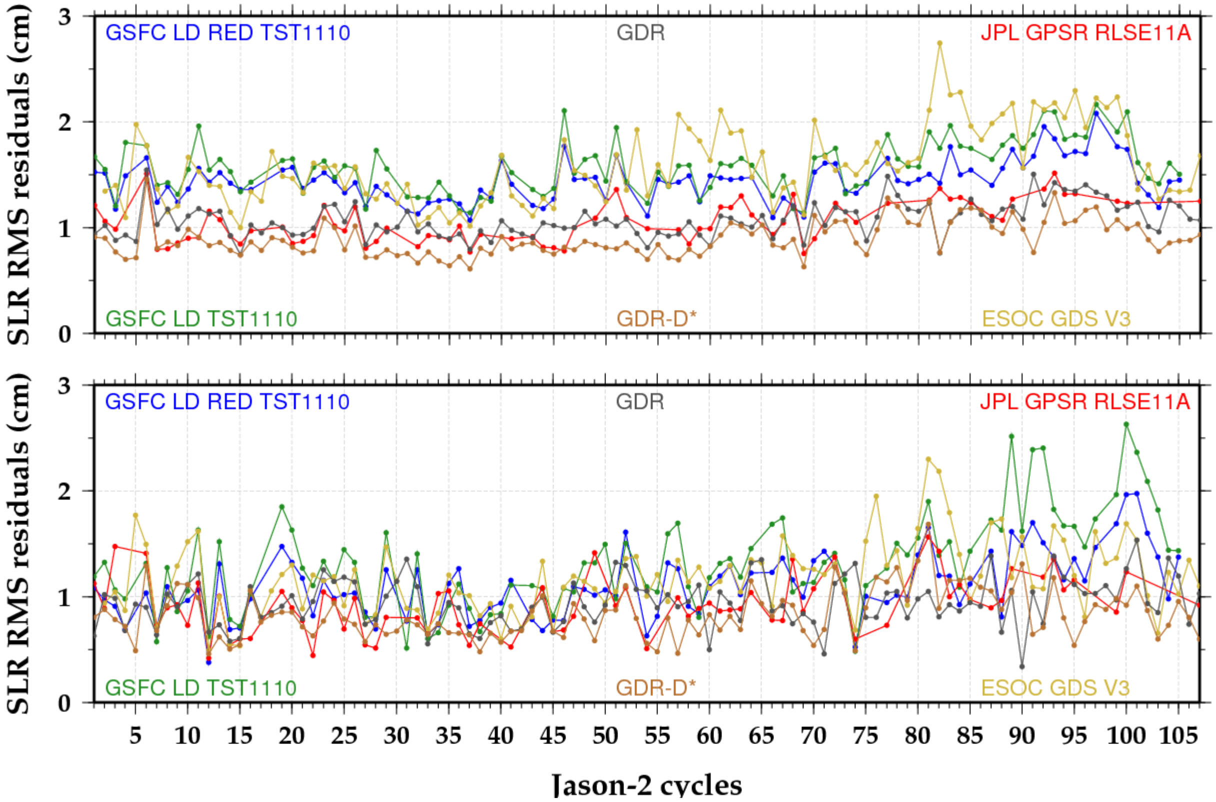

Figure 7.5.2. (Couhert et al., 2011): Top: SLR residuals on the core network at all elevations; Bottom: same for elevations above 70° degrees in order to better capture a metric of the radial orbit error.

7.5.2 Improvements in the modeling of the geopotential proposed for the GDR-D standards

The current POD models that have been applied in the GDR orbits since July 2008, are referred to as the GDR-C standards. (Sometimes the GDR-C' naming convention has been used, because final orbits were reprocessed removing the drifts in the EIGEN-GL04S-Annual model selected for initial standards, due to a lack of confidence in these drifts that were estimated over only two years of data (2003-2005) at that time). GDR-C orbits are dynamic solutions consistent with ITRF2005 and are the first GDR solutions that attempt to model the non-tidal periodic component of the time-varying gravity field (annual and semi-annual component from the GRACE/LAGEOS EIGEN field and atmospheric gravity from the AGRA service at GSFC, based on NCEP pressure fields).

Nevertheless it is evident that long term variations of the geopotential are still the most significant contributors in error budget of the GDR orbit solutions; this type of error is of particular interest for the analysis of mean sea level trends on both the local and global scale, because of its geographic coherence (order-1 patterns) and temporal behavior (seasonal variations and significant rates). Also, errors in the gravity field are transferred to the radial component of the orbit error in a way that depends on the orbit geometry (altitude and inclination), leading to different effects between the Envisat and the Jason orbits, and on the parameterization of the solution (for instance reduced-dynamic orbits are certainly less sensitive to such type of errors).

The availability of more recent geopotential models and the release of ITRF 2008 (which was already discussed in the Lisbon 2010 POD splinter report) represent the main motivation to change the standards of GDR orbits.

Figure 7.5.3 shows the geographical distribution of the trend in the radial difference (mm/year) between Jason-2 solutions from different groups and the GDR-C orbit (top) or the preliminary GDR-D orbit (bottom). Table 7.5.2 summarizes the various gravity fields used by different groups, except for JPL release 11a solution, which can be considered to be significantly less dependent on the adopted field.

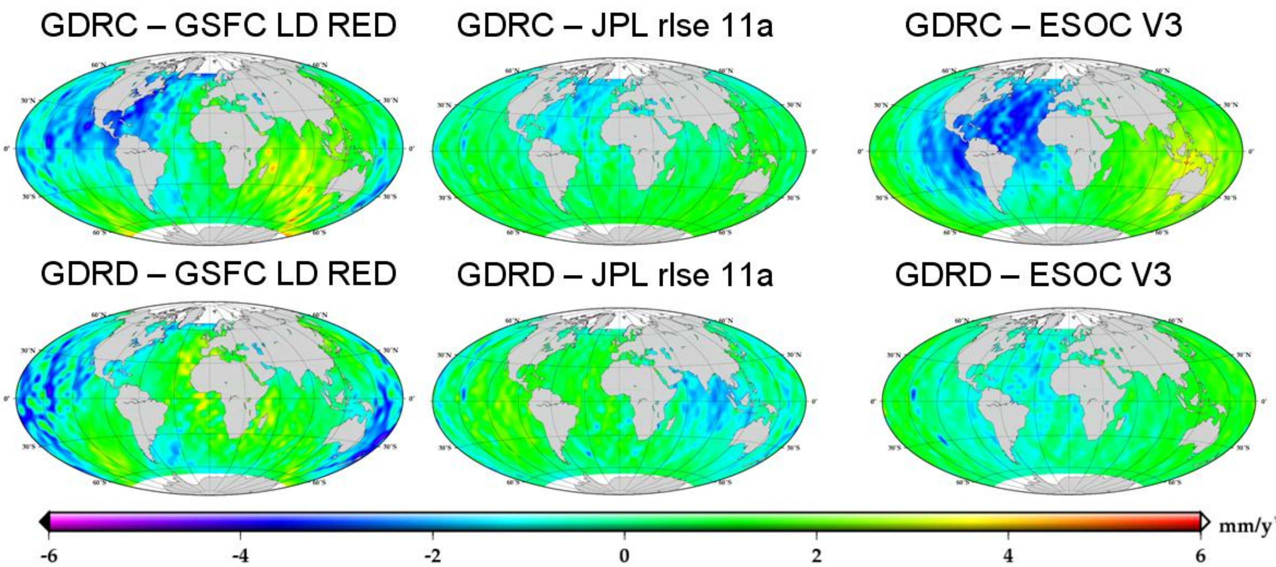

Figure 7.5.3. (Couhert et al., 2011). Mean geographically correlated radial orbit difference drifts, GDR-C vs. GDR-D orbits vs. GSFC, JPL and ESOC. The use of the orbit standards in the GDR-D reduces the orbit drift rate with other analysis centers over those of the GDR-D.

GSFC LD RED std1110 (exp.)	Linear rates for C20, C30, C40, C21, S21+ 20x20 annual field derived from 4 years of GRACE data. **Updated 4x4 gravity coefficients per week** obtained from GSFC weekly solution series determined from SLR/DORIS tracking of 9 satellites. **The base model beyond degree four is GGM03S**.
ESOC V3	**Eigen6s**: GFZ/GRGS 50x50 annual, semi-annual and linear terms estimated simultaneously with a 240x240 static field determined over 6.5 years of GRACE+LAGEOS data (2003-2009.5), and includes GOCE data.
CNES GDR-C	**EIGEN-GL04S-ANNUAL** from CNES/GRGS without drifts (except for zonal terms up to degree 4 and C21/S21): from GRACE and LAGEOS data only. Uses exactly 2 years of GRACE + LAGEOS data (between 2003/02/24 and 2005/02/23). It includes annual and semi-annual terms up to degree and order 50.
CNES GDR-D	**EIGEN-GRGS.RL02bis.MEAN-FIELD**: based on 8 years of GRACE and LAGEOS data. It includes time-variable terms (linear trend+annual+semi-annual) up to degree and order 50.

Table 7.5.2. Summary of static and time-variable gravity modeling standards for GSFC, ESOC and CNES GDR-C and CNES GDR-D orbits.

Although all metrics indicate that orbit solutions including trends in the geopotential model perform better for all satellites (Jason-1, Jason-2, Envisat), especially in recent years, it is actually on Envisat that the results are most relevant. The impact of this improvement in the multi-mission CAL/VAL analysis has been thoroughly discussed in the "Regional and Global CAL/VAL for Assembling a Climate Data Record" splinter session.

GRACE-based solutions determined over as long a period as possible are the best candidates to use for Jason and Envisat GDR production. Figure 7.5.4 shows that the new mean model proposed for the GDRD standards (EIGEN-GRGS.RL02bis.MEAN-FIELD) is able to capture most of the variability over 2003-2011, as no significant trends remain in the radial orbit difference with respect to solutions obtained using a time series of 10-day fields. Nevertheless, any secular and periodic model will not be able to capture all the variations in the gravity field that are observed.

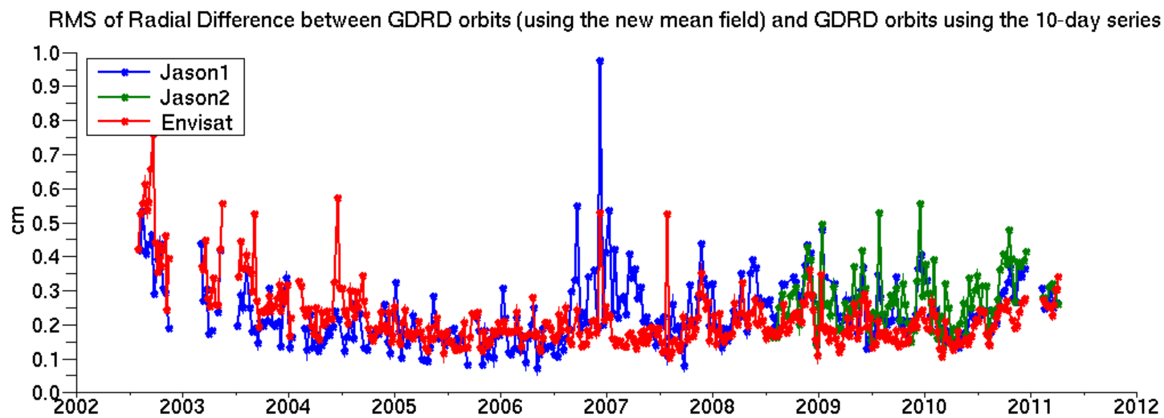

Figure 7.5.4. (Cerri et al., 2011): Comparison of GDR-D orbit (using the new mean model) with a GDRD-like test orbit in which the 50x50 part of the mean model is replaced by the 10-day series of GRACE-derived gravity fields (CNES/GRGS product not available for operational orbit production)

Linear trends obtained using GRACE data cannot be extrapolated back to the TOPEX/Poseidon period, as made evident in Figure 7.5.5. In order to maintain the orbit series outside the time span of the GRACE mission, Goddard approach of using a time series of smoothed gravity coefficients to degree/order 4x4 determined weekly from SLR & DORIS data to 9 satellites proves to be a valuable option, which should certainly be further explored.

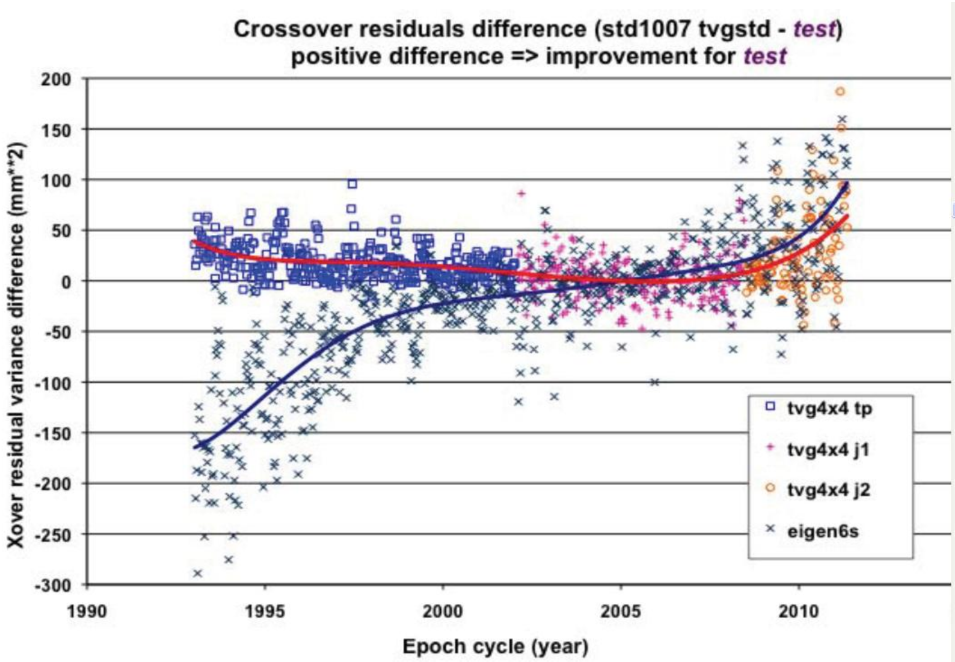

Figure 7.5.5. (Lemoine et al., 2011) tvg4x4 Shows Orbit Improvement Across TP, J1, J2; Eigen6s only after about 2005

7.5.3 Tracking performance

The tracking performance of both SLR and DORIS systems is stable and allows orbits to be obtained that have comparable level of accuracy to GPS. Concerning SLR, the need for careful monitoring and eventual data editing or solving for biases in few stations in the ILRS network has been reported (Couhert et al., 2011).

As far as the GPS receiver is concerned, it was highlighted in last year's report that "… a decrease in the accuracy of the JPL GPS-only orbits that seems correlated with a receiver software change is currently being investigated." JPL analysis (Carvalho et al., JPL memorandum, 2011) led to detection of an increase over time in the absolute number of half-cycle slips that were highlighted soon after launch (Mercier et al., Nice OSTST 2008). This increase came along with a global improvement of other receiver metrics (increasing mean track length and decreasing data gaps as shown in Figure 7.5.6), and made it necessary to review the JPL's data editing strategy by introducing phase brakes more frequently (whenever L1-L2 > 1.5cm over 10 seconds). This more conservative approach was sufficient to restore the continuity of the performance metrics of the JPL orbit solutions. No conclusive sign of degradation has been observed so far in the CNES GDR solution (Couhert et al., 2011), nor in the CNES GPS-only solution, as both solutions use conservative data editing approach and are likely more constrained by dynamic models.

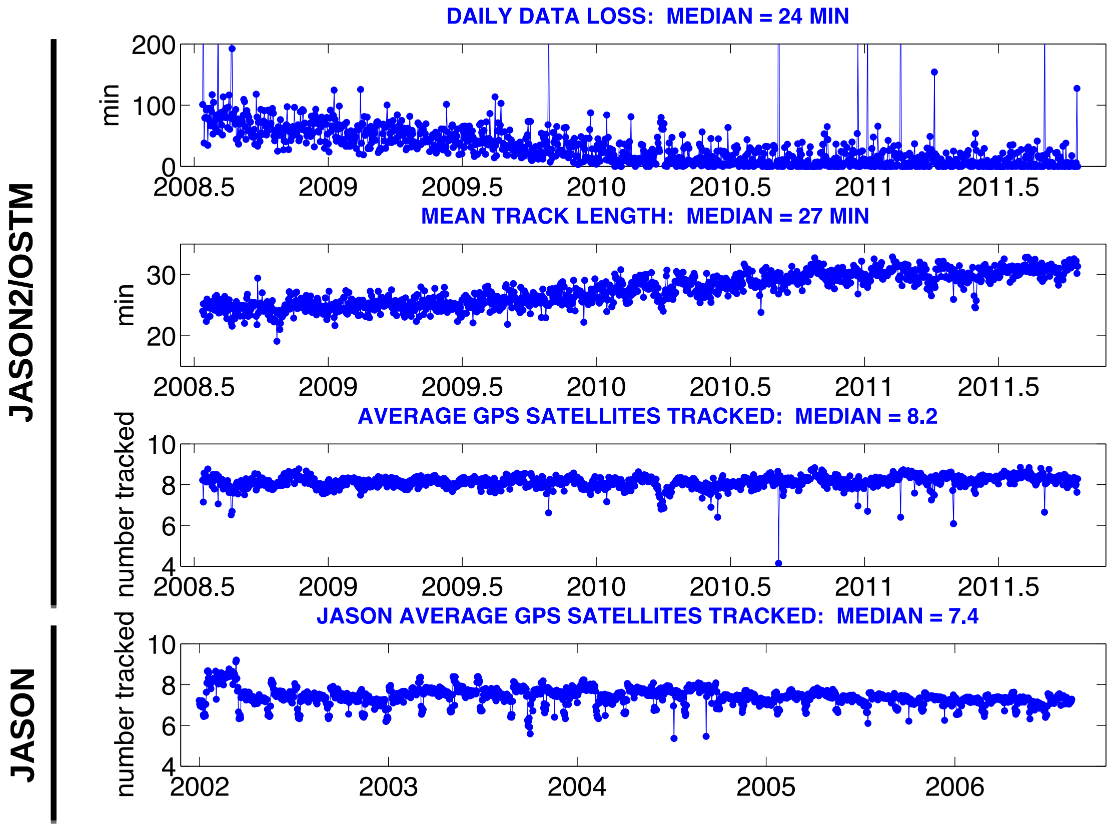

Figure 7.5.6. (Bertiger et al., 2011): Improvement in GPS data quality over time

7.5.4 Other issues

- **Updates to ITRF2008**: Although the POD teams have adopted ITRF2008 as the new standard, this new realization of the terrestrial reference frame only includes data from geodetic satellites through the end of December 2008. Hence, for both SLR and DORIS, updates are necessary for newer stations, and for those stations with known modeling issues in ITRF2008. To satisfy POD needs, the ILRS has developed SLRF2008, as an extension to ITRF2008. Willis et al. (2011) are developing an extension to ITRF2008, DPOD2008. The latest update (DPOD2008 v1.3) contains coordinates for the latest DORIS stations that have been recently deployed. Whereas ITRF2008 contains solutions for only 130 stations, DPOD2008 (v1.3) contains coordinates for 166 DORIS stations, and is the solution of choice to use for any GDR-D processing, or any retrospective reprocessing of orbits for TOPEX, Jason-1, Jason-2 and Envisat.
- **Radiation Pressure Modelling**: Mismodelling of radiation pressure on Jason-2 remains one of the most serious problems affecting the dynamic orbits. In the case of some dynamic solutions, the typical local signature at 120 days can reach one cm (cf. Figure 7.5.7). The use of reduced-dynamic orbits can mitigate the error. In the longer term, the POD team will need to continue to work to improve radiation pressure modeling. The macromodels at present do not include self-shadowing, or thermal re-radiation, and the planetary radiation pressure models are still based on the simplified model of Knocke et al. (1988). The University College London (UCL) has initiated a study to develop a tuned (finite-element-based) model for Jason-2 and the POD team will evaluate this model once it becomes available. The potential inclusion of an accelerometer

on the Jason-CS satellite is quite encouraging in that this could provide a tool not only for aeronomy studies but also to better handle nonconservative force model error for altimetry satellite POD.

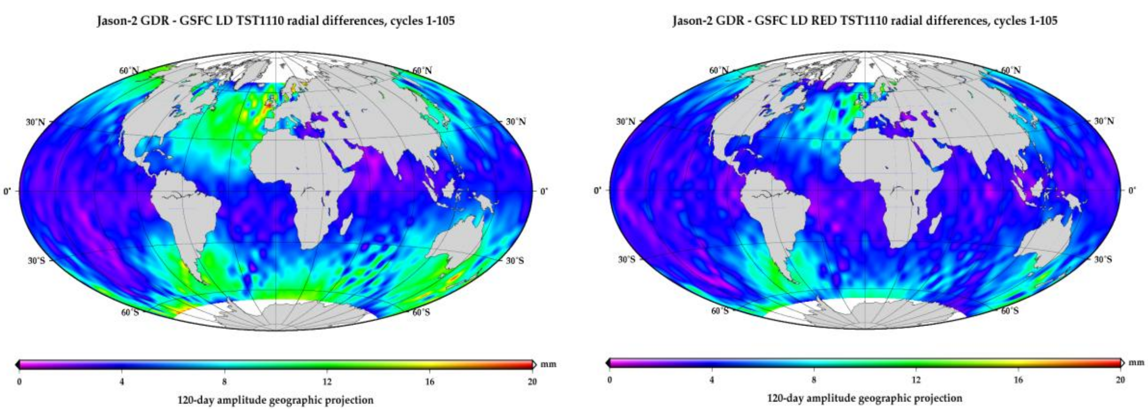

Figure 7.5.7. (Couhert et al., 2011): 120-day geographically correlated radial signal. Left from differences between GDR and GSFC SLR+DORIS Dynamic orbits (TST1110), and Right from differences between GDR and GSFC SLR+DORIS reduced-dynamic orbits (TST1110) for Jason2 cycles 1-105.

- **New ERS-1/ERS-2 orbits**: Otten et al. (2011) presented a poster summarizing the recalculation of orbits from ERS-1 and ERS-2 in ITRF2005. This was the culmination of an effort between a number of groups, including ESOC, GFZ and DEOS. The geographically correlated errors are now of the same order as on TOPEX and Jason (2-3 mm RMS) (Dettmering et al., 2011). The new orbits are available from ftp://dgn6.esoc.esa.int/reaper.
- **Geocenter**: The POD assumes that the center of the coordinate system of the Earth is in fact the center of mass. In actual fact, the fluid motion in the atmosphere, hydrosphere and cryosphere causes the actual center of mass to deviate from the center of the ITRF reference frame. This is referred to as geocenter motion. The geocenter motion is known to have an amplitude of 4-6 mm in Z (North/South), and a few mm in X and Y on annual basis. No consensus model for the geocenter exists, so forward modeling of the geocenter cannot be accommodated at the present time, however bounds can be placed on the impact this mismodelling might have on the altimeter satellite orbits. When a geocenter model is not applied, Doris+SLR based orbits are centered at the origin of the ITRF along Z, while GPS orbits appear to be closer to the instantaneous center of mass, in a way which depends on the parameterization of the solution. One of the principle uncertainties is also the extent, if any, of any geocenter drift—which would map directly into an error in the secular rate of change of mean sea level. Papers in the literature bound the geocenter rate at ~0.6 mm/yr (cf. Métivier et al., 2010) which would map into an error in the mean sea level rate of ~0.12 to ~0.18 mm/yr from this phenomenon.

7.5.5 Conclusions

The Jason-2 radial orbit accuracy remains at 1 cm radial RMS, as established by comparisons between different types of orbits produced by the different analysis centers. The tracking systems on Jason-2 all appear to be operating normally and without incident. The problem previously identified in the performance of the GPS system appears to be related to an increase in the number of half-cycle slips—whereas all metrics of system performance (pass length, quantity of data) are nominal or show improvement. Rigorous editing in the pre-processing is necessary to mitigate the impact of these half-cycle slips on the POD. The principle sources of orbit error and concern remain the radiation pressure modeling, the stability of the reference frame, and the adequacy of the modeling for the time-variable gravity field of the Earth. The gravity models deduced over a limited period over the beginning of the GRACE mission are not adequate when extrapolated to recent years since the launch of Jason-2. This is one of the strongest reasons why a new gravity model must be adopted for GDR-D, which better handles the changes in the Earth's gravity field from 2003 to 2011. While the model selected is adequate at present, it cannot reliably be projected backward in time to the start of the TOPEX mission, nor is there any guarantee that the secular rates (or annual and semi-annual terms) will remain adequate long into the future. Furthermore, the ITRF realization requires periodic updating – so that the latest realization – ITRF2008 will be used in the GDR-D. The ITRF and geodetic community may soon be gearing up to compute a new realization – however this new solution will likely not be available for evaluation and use until 2013 to 2014. Given the need to maintain a coherent and stable time series of orbits for all the altimeter satellites and the issues just discussed, the project should consider whether periodic reprocessing should be accommodated every few years, so that the latest gravity model and reference frame updates are always used by the scientists making use of altimeter data.

7.5 Outreach, Education and Altimetric Data Services

Chairs: *Margaret Srinivasan, Vinca Rosmorduc*

7.6.1 Session Presentations:

- Aviso users: what about them? (*V. Rosmorduc*)
- NOAA archive and access services for Jason-2/OSTM (*D. Byrne*)
- Ocean surface topography datasets and services at PO.DAAC (*J. Hausman*)
- Argonautica, an educational project (*D. De Staerke*)
- Experiences with informing the public about sea level science (*S. Nerem*)
- JPL ocean surface topography program EPO updates: JPL and NASA climate day (*A. Richardson*)
- Showcase Of Altimeter Outreach
  - NOC outreach activities – SEOS (*P. Cipollini, V. Byfield*)
  - NOC outreach activities – EuroArgo (*P. Cipollini, V. Byfield*)
  - U. Washington outreach activities (*L. Thompson*)
  - Understanding Sea Level Variability & Rise (*J. Church*)
  - Oceanography Special Issue on sea level (*L. Miller*)
  - If You Build It (*T. Strub*)
  - Aviso Accordion-folded flyer (*V. Rosmorduc*)
  - Aviso Altimetry images & tools USB-key (*V. Rosmorduc*)
  - CNES Fifty Years anniversary (*J. Lambin*)
  - Tsunami debris tracking (*N. Maximenko*)

The Outreach session now includes data services topics. Six oral presentations, ten activities in the annual "Outreach Showcase" element, and eleven posters made up the joint Outreach/Data Services session. Approximately 60 science team members attended the 20 October 2011 afternoon session.

The Outreach Showcase portion of the session is becoming a popular and essential feature of the session, with no fewer than 11 outreach activities presented each year. We will actively pursue additional contributions from science team members at future meetings and expect even more. We are investigating archive options for past Outreach Showcases, and approaches for encouraging science team members to contribute throughout the year. In this way we can build a permanent database of outreach activities shared by science team members.

7.6.2 2010-11 Highlights

The focus of outreach and educational activities of the past year included continued promotion of the societal benefits of ocean altimetry data, highlights of the Jason-1/OSTM-Jason-2 tandem mission, as well as the Jason-3 mission, and generating products to promote the science and applications of the data. In addition, an emphasis on climate literacy has been engaged in outreach and education products and events. JPL held the third of an anticipated annual Climate Day event in October 2011 in Pasadena, California.

An important outreach focus this year has been on the mission partner and supporting organizations data services, highlighting their different roles and approaches.

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

- JPL Earth mission science results posters (including Ocean Surface Topography) CNES/SALP 2011 wall calendar
- 2 Hydrology Data Use cases ("PISTACH" data)
- CNES's Argonautica 2010-2011
- Aviso Newsletter #6 and 7 (#8 to come)
- Aviso "altimetry tools & images" USB key
- Animation made within the CNES/MyOcean/Mercator Océan collaboration (different parameters/techniques used—SST, model, altimetry…) (look at them on the "altimetry tools & images" USB key)
- Update of the "Monitoring the ocean from space" accordion-folded flyer
- Two pages about science results from altimetry written for CNES 50 year anniversary (El Niño, Mean Sea Level) (CNES science & technology web site – in French only)

7.6.4 Data Services

Several presentations/posters from the mission partner data service groups (Aviso, NOAA, NASA, CTOH, RADS) highlighted their activities. Each data service has different objectives, scopes, roles, and approaches.

Statistics and metrics on data users were provided by Aviso and NOAA. Data quality indicators in the respective systems provide easy quality checks. A question was raised after the session: is there interest within the Project teams in compiling joint, multi-service, metrics to provide "total" number of users to the agencies? The data teams should assess the feasibility.

7.6.5 Education

The Argonautica presentation gave examples of what the student participants (from 6 to 20 years-old) are doing with the data provided or when building their own buoys. Mock-up, theater, board games, etc. are among the many projects that are shown each year during the annual meeting (taking place in La Rochelle, France). There might be an opening to US students in 2011-2012.

ESA, CLS, and CNES have developed the Basic Radar Altimetry Tool as a training aid for new and existing users. Benefits of this tool can extend to new and more traditionally isolated users without formal access to processing techniques and capabilities. It is quite often used in an education frame (remote sensing classes for at least graduate level). The "GOCE User Toolbox" has largely the same approach, but for GOCE geoid data.

Climate is a major focus for the general public and in particular for students. This 'hot' topic can be an incentive for engaging young people who are on science or policy-oriented educational paths and are concerned about climate issues and implications for their own future and who are enthusiastic in their approach to learning.

7.6.6 Media and Public Outreach

Steve Nerem discussed his interactions with climate skeptic bloggers and the Fox News channel. A confluence of web site modifications and the addition of a correction to the sea level rise time series for GIA set off a firestorm of accusations of data 'doctoring'. A process of valid and standard scientific methodology was exploited in an attempt to discredit valid science indicators of global warming. The attackers were quite vindictive on this topic. This type of experience shared among science team members, especially when it involves media outlets, can be very instructive for the rest of the team.

Ted Strub showed an example of bottom-to-top outreach (a fisherman doing a tutorial on how to use their coastal SST model outputs). This kind of spontaneous initiative demonstrates a real interest in ocean data time series, in this case, near real-time data. That this tutorial was created by an "end-users" gave the activity all the more importance.

Nikolai Maximenko presented aspects of his science presentation on tsunami debris crossing the Pacific Ocean. This phenomenon is an important issue for people living on the North Pacific islands and coasts that lie in the path of this debris train over the next few years. Outreach efforts can provide essential information to those affected in order to help mitigate the effects of this potential catastrophe.

7.6.7 New Planned Efforts

The focus of the outreach team for the coming year will be on education and public outreach, as well as applications outreach for all of the existing and upcoming ocean altimetry missions—Jason-1, OSTM/Jason-2, Jason-3, SWOT and SARAL/AltiKa. The anticipated elements of this focus (not withstanding new opportunities) will include:

- Altimetry and multi-sensor applications promotion
- Coverage of science team research and other applications on web, posters, products
- New animations made within the collaboration CNES/MyOcean/Mercator Océan
- 2012 CNES/SALP wall calendar
- Jason-1 10th anniversary (e.g. Aviso Newsletter special issue, web news)
- Argonautica 10th anniversary
- Presentations about altimetry and applications made available to the community?
- 20th anniversary of this ocean altimetry time series (TOPEX/Poseidon to OSTM/Jason-2)
- 20 years of altimetry symposium, including a possible "beautiful images from altimetry" exhibition in Venice in 2012.
- Annual NASA/JPL Climate Day

7.7 Advanced Altimetry Modes (SAR/SARIN)

Chairs: *Walter H. F. Smith, Duncan J. Wingham, Richard Francis*

Unlike other splinter sessions, this splinter was primarily a "break out" session for discussion of the exploitation of SAR and SARIn mode altimetry from CryoSat-2 and future missions such as Sentinel-3 and Jason-CS.

The splinter was asked to discuss the following four questions:

1. Where and when might the SAR mode be most useful over the open ocean?
2. Where and when might the SARIn mode be most useful over the open ocean?
3. What priority might be placed on SAR versus SARIn over the open ocean?
4. Should Jason-CS use the SAR mode as the default mode over the open ocean?

Most of the discussion focused on the possibilities for exploiting the present capabilities of CryoSat-2's SAR and SARIn modes. During that discussion it became clear that the results from CryoSat-2 are still evolving and its capabilities as an ocean altimeter are still an active area of research. Therefore, splinter participants advise the OSTST that it is premature for OSTST to make recommendations about Jason-CS at this time. It was noted that, ideally, Jason-CS would be able to support both LRM and SAR operations throughout the ocean, if possible.

The other three questions remain open topics for research and further discussion. The splinter recommends that the OSTST express its thanks to Prof. Dr. Duncan Wingham, Principal Investigator for the European Space Agency's CryoSat-2 mission, for offering the OSTST science community the opportunity to exploit CryoSat-2's new altimeter modes.

The splinter did agree that users interested in having CryoSat-2 acquire SAR or SARIn data over the ocean should send a request to Prof. Wingham by email, containing a KML (Google Earth Keyhole Markup Language) polygon indicating the area of interest, and a brief text describing the time (season, duration) of desired acquisition, and the science rationale behind the request. Prof. Wingham will forward these to the CryoSat-2 Mission Mangement Team, and the team will evaluate which requests can be met within the resources of the mission.

It was also noted that European Space Agency policy calls for full public access to Level-1b and Level-2 data products from CryoSat-2 in all its operating modes. ESA also expects product quality to improve after upgrades to the ground segment software, scheduled to be operational in February 2012.

The following is a brief introductory sketch to the CryoSat-2 altimeter's operating modes, and the constraints on exploitation. Prof. Wingham explained these in an introductory talk that opened the splinter session.

CryoSat-2 carries a Ku band Synthetic Aperture Interferometric Radar Altimeter (SIRAL). It is a single frequency instrument, capable of operating in three distinct modes:

- "LRM", the "Low Rate Mode", is so-called because it generates data at a modest rate. In this mode the instrument operates as a conventional pulse-width limited altimeter, transmitting pulses continually at a pulse repetition frequency (PRF) of 1950 Hz, averaging the power received from 92 consecutive pulse-limited echoes to form averaged waveforms at 21.4 Hz. In this mode, performance is essentially similar to the "20 Hz" Ku-band measurements from other ocean altimeters such as Jason and Envisat, although the signal-to-noise ratio of CryoSat-2 is somewhat better, as it transmits more power in order to measure snow and ice surfaces. This LRM mode is used over most of the ice-free ocean.

- In the "SAR" mode, or Synthetic Aperture Radar mode, SIRAL transmits a "burst" of pulses every 11.8 milliseconds. Each burst contains 64 individual pulses transmitted at a PRF of 18.18 kHz. This rapid pulse rate allows along-track aperture synthesis to narrow the radar footprint to approximately 290 meters in the along-track direction, and to "multi-look" the waveforms, improving the precision in range and SWH estimates.
- In the "SARIn" mode, bursts are also employed, and are received by two antennas and receivers, one each on the left and right sides of the spacecraft. This allows aperture synthesis for footprint narrowing and noise reduction, and also allows differential phase interferometry between the two antennas to measure the tilt of reflecting surfaces in the across-track direction. SARIn is designed for altimetry over rough and tilted ice surfaces, and so the range window is lengthened by a factor of 4. As a consequence, to keep data rates manageable, the burst repetition frequency is decreased by a factor of 4 relative to SAR mode. When SARIn is used over the ocean, the use of 2 antennas for SARIn versus one antenna for SAR, combined with the four times lower burst rate, means that SARIn waveforms should have a range precision roughly a factor of two less precise than SAR.

In SAR and SARIn mode, all the received echoes are digitized (in-phase and quadrature) and stored on board, then periodically downlinked for later processing on the ground. (The LRM averages echoes autonomously on board, and downlinks only the averaged waveforms, as is routine in other ocean altimeters.) Therefore use of SAR or SARIn mode significantly increases the burden on data storage, downlink, and ground processing. CryoSat-2 employs only one downlink station, at Kiruna, and storage and downlink capacity are significant constraints.

The system was designed to allow SAR and SARIn mode over ice-covered areas, with additional capacity so that SAR and SARIn could be deployed over some land and ocean areas for research and calibration purposes. The possibility that OSTST scientists might use some of this capacity prompted this splinter session.

The instrument switches among its 3 operating modes as it executes a plan uploaded to the instrument from the ground. The plan instructs mode changes to occur at various times that have been pre-computed and uploaded. These times are selected by "driving" a predicted future orbit ephemeris through a geographical polygon mask and computing the times at which it is anticipated that the subsatellite nadir point will enter and leave the polygons. An example polygon mask is shown here.

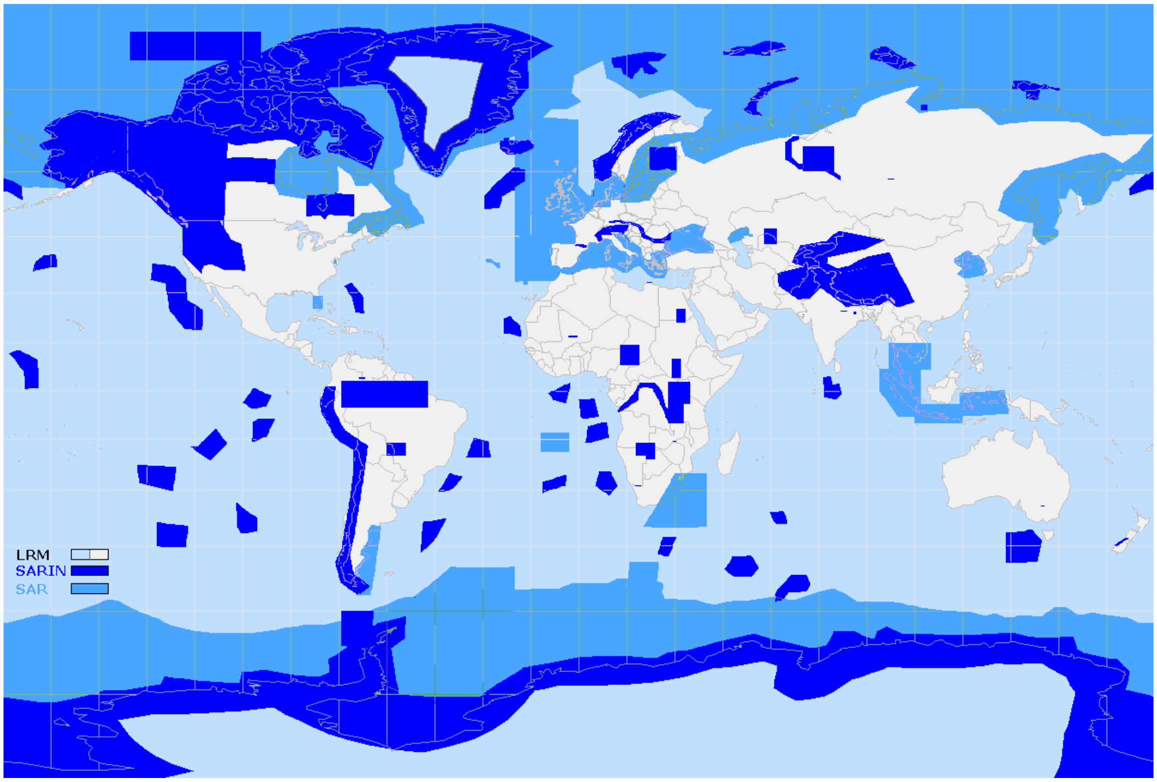

Figure 7.7.1. Example map showing CryoSat-2 operating modes.

Mode change timing commands are generated weekly and uploaded the following week. The polygon mask is cycled fortnightly within a pre-defined library of masks. This allows the mission to follow changes in the extent of sea ice (based on historical data), and so to allocate more data capacity to the northern or southern hemispheres as the seasons change.

The map above shows a typical set of polygons, but with the maximal sea-ice extent in both northern and southern hemispheres. Prof. Wingham explained that some polygons are intrinsic to the mission in order to carry out its primary ice measuring function. Other polygons, called below "PI polygons", were created at the request of various investigators who demonstrated particular need for SAR or SARIn data for a specific research purpose in response to one of the several Announcements of Opportunity. And a few polygons are also at the disposal of the mission operators and have been deployed to collect data for calibration or other test purposes, called “calibration polygons” below.

Prof. Wingham now proposes that interested OSTST investigators could propose new SAR or SARIn polygon deployments, with specific times (season, duration), and a justification of the potential science benefit of the proposed deployment. In principle these will be accommodated within the constraint of re-allocating the calibration polygons. The established PI polygons will not be modified without the explicit agreement of the relevant PI. The OSTST cannot propose changes that would impact the primary ice mission. However, within those constraints, there is some capacity for flexibility in deployments. Interested OSTST scientists should send a proposed polygon and a justification to Prof. Wingham, who will consider it in consultation with the mission team. Allocation of resources is complex since it has to consider the location of polygons with respect to the visibility of the ground station used for downlink. The team will have to analyze which requests can be met and how and when is best to meet them.

The discussion that followed this introduction generated many interesting comments. A few key ideas are summarized here:

- CryoSat-2 tracks run near-parallel to Envisat tracks over long distances in some areas. These would be good opportunities for validation of CryoSat-2 results by comparison with Envisat.
- The Coastal Altimetry community has spent a few years learning how to exploit the many kinds of ocean instruments in coastal areas to validate altimetry. This effort could be leveraged to validate CryoSat-2 data.
- It is an interesting research question whether CryoSat-2 SAR mode data could be sensitive to the direction of the swell. Coastal direction-sensitive wave buoys exist. Dierdre Byrne will look into the availability of this data.
- It is also another interesting research question whether the SARIn mode can detect the cross-track slope associated with energetic currents and eddies. A SARIn deployment in such an area would be of interest.
- It was also noted that areas of low energy could be used for calibration and validation of the basic measurements.

7.8 Science Results from Satellite Altimetry

Chairs: Hans Bonekamp, Pascal Bonnefond, Lee-Lueng Fu, Rosemary Morrow, John Lillibridge, Josh Willis

In addition to a large poster session with many excellent contributions, three oral splinter sessions were dedicated to the presentation of science results from satellite altimetry. They were organized around the following themes: Mean Sea Level, Fine-scale Circulation and Large-scale Circulation. All talks and posters can be downloaded from the Meeting Website:
http://www.aviso.oceanobs.com/en/courses/sci-teams/ostst-2011/index.html

7.8.1 Mean Sea Level

In the first oral science splinter session, global and regional sea level changes over the altimeter record were addressed. These included regional patterns of sea level change observed in the 17-year altimeter record, which seem to be dominated by natural, decadal variability. In addition, changes in the contribution to global sea level from change in land storage were discussed, as well as the contributions to sea level change due to deep warming and the possibility of detecting any acceleration in the rate of global sea level rise during the altimeter period. Finally, one presentation addressed the impact of internal tides on sea level variability and another showed evidence of a large-scale, 90-day signal sea level in the Indian Ocean.

Oral Presentations:

- Spatial Trend Patterns in Sea Level from Altimetry, Past Sea Level Reconstructions and CMIP3 Coupled Climate Models *Benoit Meyssignac* (LEGOS)
- Land waters contribution to sea level during *ENSO* events (altimetry era) *Anny Cazenave (LEGOS-CNES)*
- Can a Combination of Altimetry, *Argo*, and GRACE Detect Deep Ocean Warming? *Don Chambers* (College of Marine Science)
- Why has an acceleration of sea level rise not been observed during the altimeter era? *R. Steven Nerem* (University of Colorado)

- Comparison of Internal Tides in a High Resolution Global Ocean Circulation Model with Altimetric Estimates *Jay Shriver* (Naval Research Laboratory)
- Indian Ocean near 90-day resonance: its structure as resolved by the merged multi-satellitel sea level and dynamics *Weiqing Han* (University of Colorado)

7.8.2 Fine-scale Circulation

The second oral science splinter contained talks on ocean circulation at the smallest spatial scales. These included talks on filament structures in the ocean as well as the spectra at high frequency and wavenumber. In addition, estimates of ocean circulation at the mesoscale and larger made using observations only were also presented, along with observations of the sub-mesoscale ocean circulation from ship-board observations and coastal radar. Finally, estimates of global surface currents based on satellite altimetry were shown to be in good agreement with other observations and carry important information about the El Niño Southern Oscillation.

Oral Presentations:

- Predicting unobserved ocean filaments from altimeters *Gregg Jacobs* (Naval Research Laboratory)
- Statistical Parameters of the Geostrophic Ocean Flow Field, Estimated from the *Jason*-1-TOPEX/*Poseidon* Tandem Mission *Martin Scharffenberg* (University of Hambourg)
- *SSH* wavenumber spectrum in the North Pacific
  Animation: surface oceanic vorticity *Patrice Klein* (IFREMER)
- Monitoring the ocean from observations *Marie-Helene RIO* (*CLS*)
- Characterization of oceanic mesoscale and submesoscale energy *Sung Yong Kim* (MPL Scripps Institution of Oceanography)
- Surface Currents as an Early *ENSO* Index *Kathleen Dohan* (Earth and Space Research Seattle)

7.8.3 Large-scale Circulation

The third oral science splinter dealt primarily with large-scale changes in ocean circulation. Talks included presentations that considered closure of the heat budget on interannual time scales over a large region in the North Atlantic. In addition, an effort to explain drivers of regional sea level change using data assimilation techniques was presented, as well as an assessment of decadal predictability of the Kurishio Extension. Decadal predictability of regional sea level patterns was also investigated using coupled climate model runs and historical reconstructions of regional sea level changes. Regional sea level trends and their causes in the Indian Ocean were also discussed. Finally, observations of bottom pressure were used to provide new insight and validation of altimeter derived tides.

Oral Presentations:

- Estimates of Heat and Mass Budgets in the Atlantic Ocean *Kathryn Kelly* (University of Washington)
- Dynamics and thermodynamics of interannual sea level variability *Rui Ponte* (Atmospheric and Environmental Research)
- Use of Satellite Altimeter Data for Decadal Predictions of the Kuroshio Extension Dynamic State *Bo Qiu* (University of Hawaii)
- Reliability estimates of decadal sea-level trend hindcasts: a case of predictions with uncertain verification data *Philippe Rogel* (CERFACS)

- Low-frequency sea level variability in the southern Indian Ocean *Ming Feng* (*CSIRO* Marine and Atmospheric Research)
- A new "ground truth" ocean-tides dataset based on bottom pressure measurements *Richard Ray* (NASA/*GSFC*)

8. Summaries and Recommendations

The closing session was chaired by P. Bonnefond, R. Morrow, J. Lillibridge, and J. Willis. In addition to the presentation of summaries by the splinter session chairs, Phil Callahan discussed TOPEX Reprocessing and Nicolas Picot discussed Jason-2 GDR-D standards. Finally, a number of recommendations were discussed by the OSTST and adopted.

8.1 TOPEX Reprocessing

Phil Callahan gave an overview of TOPEX reprocessing. There were two main points:

1. TOPEX data from the 2009 retracking version are now available in netCDF from PODAAC (http://podaac.jpl.nasa.gov/dataaccess ➔ PODAAC_Labs (second bar);
2. A Climate Data Records (CDR) project from NOAA is just beginning to retrack the data again to correct problems with the 2009 retracking and update the product to the standards applicable in 2013-14.

The netCDF data currently available on PODAAC have been enabled by a NASA ACCESS grant. The netCDF data structure is very similar to the Jason-2 data and includes CF-compliant metadata. The data are available from a tool that can update orbits and tides by simple installation of new parameter files. The current data have been updated to GSFC orbits from 2010 and to the GOT 4.7 tide model. The data have corrected TMR, but not the newer coastal processing. At the 2009 OSTST problems were noted with the retracking deviating significantly from the original GDRs for Alt-A, and the Sea State Bias (SSB) was significantly different from Jason.

The NOAA CDR project is a three-year effort to deliver updated climate quality TOPEX data to NOAA and PODAAC by the summer of 2014. The work will include:

- Develop and apply systematic PTR fitting and retracking
- Assess and correct the 59 day variation in the data
- Apply the newest versions of orbits, tide model(s) (1 or 2), mean sea surface, and atmospheric corrections
- Apply reprocessed radiometer data
- Fit the newly processed data to estimate the SSB for each altimeter.

Initial work is underway on developing PTR fitting methods and investigating the 59 day variations in the data that were discussed at the 2010 OSTST.

8.2 Jason-2 GDR-D Standards

The standard and plans for the Jason-2 GDR-D were discussed both in the Instrument Processing Splinter and the plenary by Nicolas Picot. First, the main points of GDR-C, which were recommended last year, were reviewed. Jason-2 GDR-C includes (N. Picot, p 3):

- New Jason-2 AMR processing (coastal area + new flags) and updates to work around the 34 GHz VFC anomaly
- Use of a null mispointing value in input of the C band retracking algorithm
- Use of LTM information filtered over 10 days
- New tide model: GOT00.2 → GOT 4.7
- Pole tide anomaly correction
- Long period non equilibrium tide anomaly correction
- SSHA on OGDRs computed when meteo grid are extrapolated
- NRT orbit quality flag in OGDR products
- Update of the altimeter characterisation file and impacts
- Ice Flag in SSHA products
- New parameters in SGDR products (including all MLE3 derived parameters).

Since reprocessing to GDR-C has not begun, it was proposed to make some additional improvements (N. Picot, p 6):

- Absolute bias correction: The origin of the 20 cm absolute bias has also been found by Desjonquères et al., and is due to an inconsistent definition of the antenna reference point for both satellites. With this additional correction, the absolute sea surface height bias for both the Jason-1 and Jason-2 missions is statistically indistinguishable from zero.
- Datation bias correction (a datation bias of about 250 microsec is observed on current Jason-1&2 products and will be corrected in Jason-2 GDR-D products)
- Use of GOT 4.8 version instead of GOT 4.7
- New atmospheric correction algorithm provided by JPL
- Include MLE3 key parameters in both GDRs and SGDRs datasets, following what has been implemented for MLE4 (there is an unusual feature in the MLE3 sigma0 near 12 dB)
- New altimeter instrumental corrections tables (LUT) have been generated and delivered.
- Compute more precisely the relative sigma0 bias between Jason-1 and Jason-2 to compute the wind table and rain flag tables
- Account for the POE GDR_D orbits
- Assess the slight dependency between Jason-1 and Jason-2 SLA for low winds/waves states

Jason-2 cycles 1-8 were processed in mid-September for an assessment of the new product by the OSTM partners. New SSB tables were computed based on preliminary data for inclusion. After some additional checks and corrections, it is recommended that production of GDR-D for Jason-2 start in early 2012 with the Jason-1/2 tandem phase to more carefully estimate the Jason-1/2 bias. GDR-D will not be produced for Jason-1 at this time, but the derived corrections will be widely publicized.

After discussion, it was recommended by the OSTST that **an intermediate (and simple solution) should be studied by both CNES and JPL to allow users to generate a Jason-1 product that is in line with Jason-2 GDR-D standards.**

8.3 Recommendations

The Jason-3 Project's proposal to perform a periodic pitch maneuver in order to calibration the Jason-3 radiometer against a cold sky target was considered in the splinter sessions and by the OSTST at large. After discussion, **the OSTST adopted the following recommendation:**

The Jason3 Project should proceed with plans to perform a maneuver during flight in order to periodically calibrate Jason-3 radiometer. In addition, the Jason-2 Project should study the feasibility of performing a similar calibration maneuver on Jason-2.

In addition to the dedicated splinter on Advanced Altimetry Methods, considerable attention was given to new data from CryoSat-2 over the oceans in splinter sessions such as Instrument Processing. These interactions were considered to be mutually beneficial to both the OSTST and the CryoSat-2 Project. In light of this, and of the recommendation adopted by the OSTST at the 2010 Meeting in Lisbon concerning availability of CryoSat-2 data, **the OSTST further recommended that ESA and the CryoSat-2 Project make all efforts to:**

3. **Allow distribution of currently generated value-added science products made on a free and open basis.**
4. **Provide a global seamless product over the ocean (LRM & SAR regions) as soon as possible.**