Report of the

Ocean Surface Topography Science Team Meeting

Virtual meeting

October 19-23, 2020

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Organized by CNES, NASA, NOAA, EUMETSAT and ESA

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1 Executive Summary

Due to COVID-19 restrictions, for the first time, the OSTST meeting was held as virtual event. All splinters have been organized as online forums (one per splinter), which were active all week long (19-23 October 2020) so that participants could interact regardless of their time zone. In spite of the special conditions of this OSTST meeting, participation was comparable to the usual meetings with 203 abstracts submitted, 180 and 150 participants for respectively the live opening and closing sessions and more than 700 posts from 153 users in the forums.

In addition to the usual splinters, this year marked the end of the previous science team and the beginning of a new one. For this reason, a special splinter was included: “Salient results from the 2017-2020 OSTST PIs”. The list of PIs involved can be found at: https://sealevel.jpl.nasa.gov/science/scientific-investigations . In this splinter, PIs summarized their work during the past 4 years in few slides or pages.

The opening (Monday 19) and closing (Friday 23) sessions were live and organized through Webex.

The 2020 OSTST meeting also marked the upcoming launch of Sentinel-6 Michael Freilich (Sentinel-6 MF hereafter) that successfully occurred on November 21st: http://www.esa.int/Applications/Observing_the_Earth/Copernicus/Sentinel-6

Jason-3, which was launched from Vandenberg Air Force Base on January 17, 2016, and took over as the reference mission on June 21, 2016, is fully operational with all redundant systems available. In 2020 it has completed the first year of its extended mission beyond the original 3-year prime mission, and will continue the 28-year reference series of measurements of sea level, ocean winds, and waves until Sentinel-6 MF takes over the reference orbit after it’s ~1 year period of commissioning and cross-calibration.

Sentinel-3A and -3B were launched in February of 2016, and April of 2018, respectively. Much like past missions in the reference orbit, a tandem phase with a separation of 30 seconds between the two satellites was performed to provide cross-calibration. Subsequently, Sentinel-3B was placed in a nominal orbit that is 140° out of phase with Sentinel-3A and both missions now provide sea level measurements along high inclination tracks as part of their routine operations.

CFOSAT was launched on October 29, 2018 with scatterometers to detect both wind and wave conditions. After both a validation workshop and the first science team meeting in July and September 2019, respectively, data has been publicly released as of February 2020.

At the time of the meeting, the Copernicus Sentinel-6/Jason Continuity of Service (S6/JCS) mission was progressing toward with the launch of the Sentinel-6 MF satellite on November 21th, 2020, followed by the Sentinel-6B satellite in 2025. The Sentinel-6 satellites will occupy the reference orbit through at least 2030 and will carry a new altimeter capable of Synthetic Aperture Radar (SAR) measurements as well as a radiometer with enhanced capabilities that will improve long-term stability and an additional radiometer for higher spatial resolution. Partner Agencies (EUMETSAT, ESA, NASA and NOAA with CNES providing support) are coordinating selection of a Validation Team and developing plans for the phased release of data products during the commissioning phase, which will begin after launch.

Finally, presentations on the status of other planned and existing missions were given, including SWOT, SARAL/AltiKa, for example. After discussion of these missions and other issues concerning altimetry, the OSTST adopted (among several others detailed in the full report) the following **recommendation**:

Based on subsequent input from the Jason-3 Extension of Life working group (which took place after the OSTST meeting), we recommend:

- **1 year tandem commissioning phase with Sentinel-6 Michael Freilich**
- **2 years on the Jason-2 Long Repeat Orbit (1309.5 km)**
- **4 months tandem phase with Sentinel-6 Michael Freilich (avoiding Atlantic hurricane season)**
- **1 year return to the Jason-2 Long Repeat Orbit (1309.5 km)**
- **Mission extension on the Reference orbit at +47km (disposal orbit different from Jason-2)**

2 Opening Plenary

On behalf of the Project Scientists (Josh Willis, NASA; Pascal Bonnefond, CNES; Eric Leuliette, NOAA; Remko Scharroo, EUMETSAT; Craig Donlon, ESA), Pascal Bonnefond presented the agenda and explained logistics. The session was recorded and is available at: https://meetings.aviso.altimetry.fr/fileadmin/user_upload/tx_ausyclsseminar/files/OSTST2020/OSTST%202020%20-%20OPENING%20Session%202020-10-19-17-04-32.mp4

2.1 Program and Mission Status

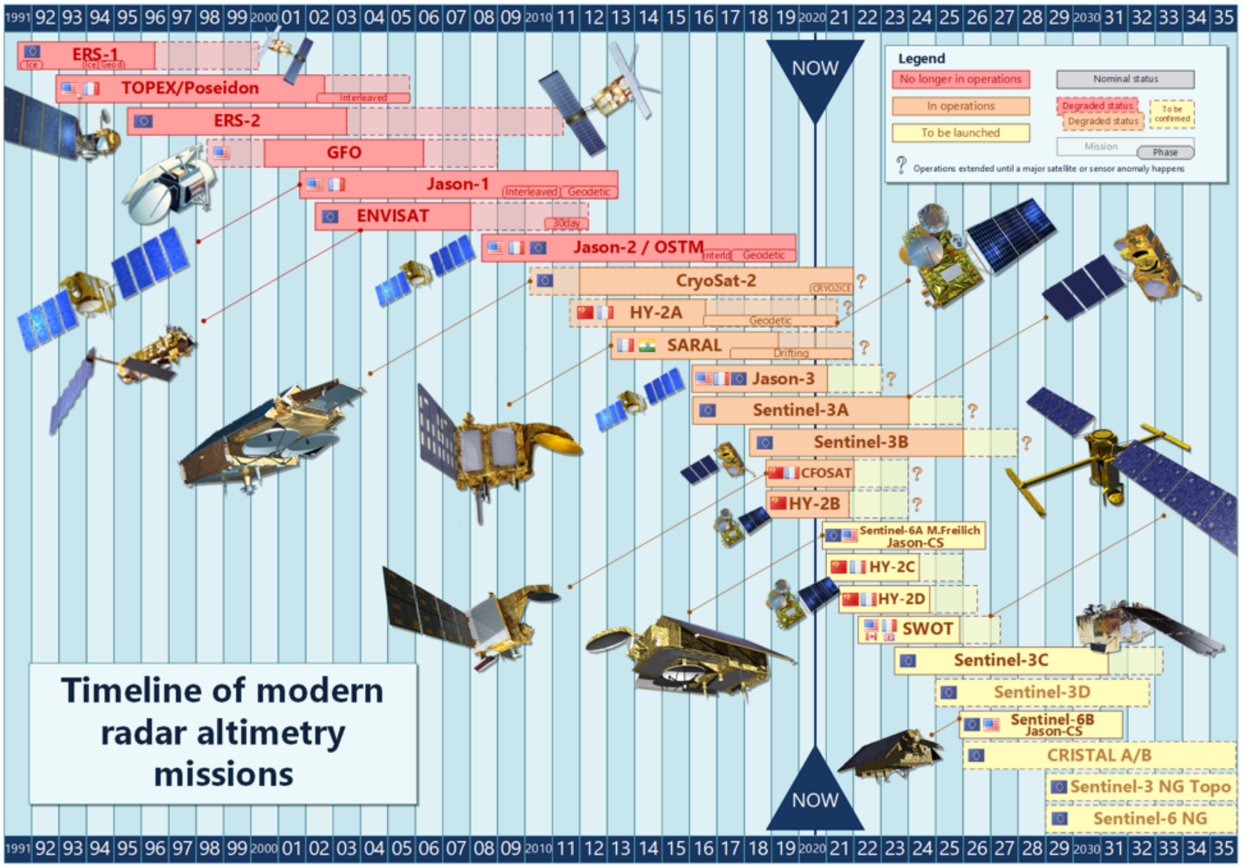


Figure 2.1-1. Altimetry mission timelines.

The program managers presented the status of altimetry and oceanographic programs at NASA (Nadya Vinogradova-Shiffer), CNES (Annick Sylvestre-Baron), EUMETSAT (Manfred Lugert), NOAA (Eric Leuliettte) and ESA (Jérôme Benveniste).

Nadya Vinogradova-Shiffer (NASA HQ) gave a summary of the NASA Ocean Program. She began by recalling the story of S6 MF travel from IABG test facility in Munich (Germany) to the launch site VAFB (California). She also thanked the space engineers at Airbus and JPL who overcame the challenge of having a successful NASA KDP-E on October 13, 2020 despite the extensive and complicated COVID-19 restrictions. Nadya also announced that proposals for selection of the next OSTST had been received by NASA, and the selected team members will begin their mandates in April 2021. She then congratulated the new SWOT Science Team selected in 2020 as well as the NASA Sea Level Change Science Team led by Ben Hamlington (JPL). Finally, she announced potential NASA/ESA partnering on upcoming mission (MC, CRISTAL, CIMR) that could follow the successful partnership for Sentinel-6.

The CNES ocean program was illustrated by Annick Sylvestre-Baron. CNES is a partner on 3 currently flying missions of interest to the OSTST: (i) The China France Oceanography SATellite (CFOSAT, launched on 10/29/2018) in collaboration with NSOAS with two main payloads

SCAT/CNSA (wind scatterometer) and SWIM/CNES (wave scatterometer), (ii) SARAL/AltiKa with ARGOS and ALtiKa payloads (launched on 02/25/2013) in collaboration with ISRO and (iii) Jason-3 (launched on 16/01/2016) which is the current reference altimetric mission in cooperation with NASA, NOAA and EUMETSAT. CNES in charge of POD and altimetry data performance expertise for the HY-2 ocean series and give a significant expertise's contribution to Copernicus Sentinel-3 & Sentinel 6 missions (altimeter measurement system performance, DORIS and POD, level L2P & L3 products). CNES is deeply involved in the development of SWOT in collaboration with NASA, CSA and UKSA (launch planned end of 2022). For all these missions, CNES gives continuing support to science studies through the OSTST and SWOT Science Team, both renewed in 2020 and 2019 respectively. Concerning the future missions, high priority missions for CNES Earth/Ocean observation are: (i) MARVEL for studying evolution of climate, Solid Earth, water mass. Earth reference system through measurements of Gravity field and SKIM to observe ocean winds and currents using a Doppler Ka-band radar in collaboration with NASA/ ESA (EE9: Not selected finally). CNES is providing a strong support to long-term altimetry and other auxiliary ocean topics: WISA (Phase 0 studies in support to the definition of Sentinel-3 Next Generation) for medium swath altimetry and hydrology, STREAM (new mission concept with heritage from SKIM - proposed at EE11 call), CRISTAL (science support) for cryosphere, sea ice, ocean and Inland water, CIMR (science support) for polar ocean (SST, SSS ...), ULID (Nanosat) and SMOS-HR for salinity. Finally, CNES is providing a Multi-mission exploitation distributed through AVISO+.

Eric Leuliette, on behalf of Chris Sisko, gave a summary of the NOAA Ocean Program. The NOAA Jason Ground System (NJGS) had a network upgrade/refresh for network connectivity and Jason data flow transition was completed using multi-mission high-speed trans-Atlantic link between Darmstadt and U.S. NOAA network (NWAVE). However due to COVID-19 impacts, the schedule and technical work was delayed and the tentative schedule for completion and operational deployment is early-to-mid 2021. NOAA also supports the OSTST with currently five PIs funded for the 2017–2020 Team (Arctic circulation, EKE, Fully-Focused SAR, Data Assimilation, and air-sea interaction) and will support the 2021-2024 OSTST in the 2020 ROSES (3–4 investigations, total ~$500K/year). NOAA is also organizing the 2nd Operational Satellite Oceanography Symposium (Darmstadt, Germany, 25–27 May 2021 with optional training on 28 May).

Jérôme Benveniste presented the ESA Programme Status. He noted that ESA currently has 15 Earth observation missions in operation, 34 under development and 7 in preparation. CryoSat-2 remains in excellent condition and mission support has been extended through the end of 2022. In 2020, the #CRYO2ICE campaign, which raised the CryoSat-2 orbit by one kilometer to achieve the "19/20 synchronization" with NASA's ICESat-2, took place seamlessly. It offers a unique (and probably unrepeatable) possibility to have coincident laser and radar altimeter data over polar areas which are key to understand climate change. The CryoSat-2 product evolutions is ongoing with Ocean Baseline D and Ice Baseline E. The overall quality of data from the Sentinel-3 constellation is excellent and it continues to meet all requirements. A rolling call for membership in the Sentinel-3 Validation Team remains open. The CRISTAL mission, an altimeter for polar ice and snow topography was discussed, as was CIMR, an imaging microwave radiometer for the polar oceans and ice caps and the Copernicus Next Generation Topography Constellation (NG-TC). The FDR4ALT (Fundamental Data Record for Altimetry) project was described. FDR4ALT aims to exploit the long-standing record of global altimetry measurements from ESA ERS-1, ERS-2 and ENVISAT heritage missions through reprocessing. Finally, CCI+ Sea Level, Sea State, Lake, and Sea Level Budget Closure were described and two events were announced: HYDROSPACE-GEOGIoWS (7-11 June 2021 (ESA-ESRIN, Frascati, Italy) and CryoSat-2 10th Anniversary Science Conference (14-17 June 2021, Taormina, Italy).

This year the EUMETSAT programmatic status was unavailable during the opening session.

On behalf of the Project Managers, Christophe Marechal (CNES) reviewed the status of the Jason-3 mission. Jason-3, which took over as the reference mission on October 14, 2016, remains fully operational with all redundant systems available, with a global Jason-3 system availability of 95.5%. All of the core payload and passengers are operating nominally, as is the ground segment. Satellite pointing, altimeter performance, DORIS, AMR and GPSP are all stable and providing data of excellent quality. Cold sky calibration maneuvers continue to provide mm-level stability for the Jason-3 AMR. The global average path delay computed from the AMR instrument is within ±1mm of the ECMWF model PD over the mission. A new DEM (V4.0) is in operation since Sept. 3rd , 2020 (91.7% usable echoes) with 7 times more hydrologic targets (Around 31,500) and usable for Sentinel 6 intercalibration. Processing of data to the GDR-F standard is available since Oct. 29th, 2020, in coherence with Sentinel-6 data products.

Nadège Quéruel (CNES) gave an update on the status of the SARAL/AltiKa Mission. The SARAL/AltiKa mission continues to perform nominally, with a global SARAL/AltiKa system availability of ~99.6% after more than 6 years on orbit, and will continue for at least one year. CNES and EUMETSAT approved SARAL mission extension until end of 2021, and there is no concern on ISRO side for extending the mission. The next extension mission to be discussed between CNES and EUMETSAT for 2022-2023. All altimeter systems are operating nominally and continue to provide high quality data and have good agreement with Jason-3, and OGDR, IGDR and GDR production continues to meet or exceed all requirements. Since July 2016, SARAL has operated in the SARAL Drifting Phase (SARAL-DP), in which the satellite's ground track and altitude have been allowed to drift. The whole mission lifetime has been reprocessed and is now available at standard F: ftp-access.aviso.altimetry.fr /geophysical-data-record/saral/.

Jean-Michel Lachiver (CNES) provided an update on CFOSAT (China France Oceanography Satellite), a wind and wave scatterometer mission to measure spectral properties of these phenomena at global scales. Launched on October 29, 2018, CFOSAT carries a Ku-band wind scatterometer called SCAT and wave scatterometer called SWIM. The global CFOSAT Satellite availability performance is 97.5% for SCAT and 98.75% for SWIM. There is a very good operational cooperation between Chinese and French teams. In July 2019, the first Cal/Val workshop for the mission was held, and in September, the first international science team meeting was convened in Nanjing, China. Data from the mission was found to be of excellent quality and in good agreement with in situ observations as well as other satellite missions. Data was released to all scientific users in February 2020, for SWIM data see https://www.aviso.altimetry.fr/en/missions/current-missions/cfosat.html, and for SCAT data see https://osdds.nsoas.org.cn/.

Pierre Féménias (ESA/ESRIN) gave an update on the status of the Sentinel-3 Mission. The Sentinel-3 mission is composed of two identical satellites flown together in the same sun-synchronous orbital plane, separated by 140°. Both satellites embark a SAR Radar Altimeter (SRAL) instrument supported by a dual frequency microwave radiometer. Sentinel-3A&B are now in routine operations with all data available to any user under the Copernicus free and open license agreement. A new S3 STM LAND/MARINE mask is operational since 9 July 2020. Pierre Féménias described the Sentinel-3 Land STM L1 & L2 Processing Baseline with major thematic IPFs evolutions that will be available by fall 2021. The Sentinel-3A and Sentinel-3B STM Inland Waters and OLTC tables have been updated respectively on 27 Aug 2020 (OLTC V6.0) and 18 Jun 2020 (OLTC V3.0) with now more than 136.000 Virtual Stations over rivers and lakes with Sentinel-3 constellation. Before implementing operationally the refurbished Envisat σ0 transponder (ESA/ESRIN), a field test campaign has been carried out (North of Rome in Italy). A significant drift has been detected on the Sentinel-3A SAR GMSL trend: about +1.7 mm/year with an uncertainty of 1.2 mm/y (95% CL) and is now understood: (i) 0.3 mm/year are due to the evolution of PTR shape in range direction (ageing of the instrument) not correctly accounted for in the MLE4 (PLRM) and SAMOSA DPM2.5 (SARM) retrackers (Note: retrackers using the real instrument PTR are able to correct for this effect, e.g.: adaptive retracker) and (ii) about 1.3 mm/year are due to the evolution of PTR shape in azimuth direction (ageing of the instrument). A recent study showed that the implementation of the range walk correction allows for correction of the range drift induced (only the SAR mode is impacted). Follow on satellites (Sentinel-3C and Sentinel-3D) are now being built as operational replacements for the A and B units: Sentinel-3C & -3D platforms have been completed and delivered to TAS, Cannes. The system level activities have started on both satellites and are progressing well. Launch dates are to be defined by the Commission, but foreseen in the range of mid 2023 – end 2024 for Sentinel-3C and end 2024 – end 2028 Sentinel-3D. A study identifying the options for a 3-satellite constellation phasing has been conducted related to the integration of Sentinel-3C in the Sentinel-3 constellation. A number of phasing options have been identified and analyzed with 4 selected as the best candidates under the following assumptions:

- Sentinel 3 orbital plane is unchanged: Altitude, Inclination and Local Time of the Descending Node being kept as they are
- Sentinel-3 Models are operated within the 27 options provided by the two (A, B) active ground tracks, with the following rationale for what concerns the mission objectives:
    - Optical: Ensuring identical acquisitions conditions for all models
    - Topography: Pursuing A duty over water and dedicated land targets after A end of life and ensuring Crete Transponder overflight by A, B and C
- Optical Mission: Enhance the optical coverage up to requirements expectations
- Topography Mission: improve the sampling of mesoscale ocean features while optimizing / reducing the inter-track minimum distance within the 4-days sub-cycle of the orbit repeat period

The Copernicus services have been asked by ESA and EUMETSAT to provide feedback on the selected options, and in the process CMEMS suggested two options which are being analyzed and will be sent out to the remaining services for comments. The feedback from the Copernicus services will be shared with the Commission, and the selected candidate(s) will be analyzed for operational constrains and cost before a selection is made.

Pierrik Vuilleumier (ESA), Manfred Lugert (EUMETSAT) and Gilles Tavernier (CNES) gave an update on the status of the upcoming Sentinel-6/Michael Freilich mission. On July 17th, the FAR/QAR Board accepted the satellite for flight. The satellite qualification status for the Falcon-9 launcher was confirmed. On September 17th, the Partner Joint Steering Group decided to proceed. The satellite arrived safely at the Payload Processing Facility in VAFB on Sep 24th. The teams are operational and the launch campaign is progressing smoothly. Sentinel-6/Michael Freilich is ready to go 10th November 2020 (Finally launched on 21th November). From EUMESAT, the system baseline is well established and under configuration control. The Overall Ground Segment (OGS) including the JPL and NOAA contribution have been deployed, qualified and validated. The plans for post-launch activities during Commissioning are well established and a joint Sentinel-6 Validation Team is nominated. An integrated in-orbit timeline for the Commissioning has been established and is shared/consolidated with the involved partners. Operations coordination and the links between the various activities (SatIOV, Cal/ Val, SysIOV) are established with the Mission Plan and the underlying processes and agreements, i.e. Operations Coordination Group and joint Anomaly Review Boards, Operations Interface Agreements. Finally, the CNES components of the Ground Segment was presented: (i) SSALTO, POD, DORIS Service, (ii) L2P/L3 Service and (iii) Mission Performance Service which includes Instruments and offline altimetry products quality monitoring.

Rosemary Morrow gave the status of the SWOT mission on behalf of both Ocean (Lee-Lueng Fu (JPL/NASA) & Rosemary Morrow (LEGOS)) and Hydrology leads (Tamlin Pavelsky (UNC) & Jean-Francois Crétaux (LEGOS)). All flight system elements are in advanced stages of Integration and testing and the THALES Platform has been completed and stored until Payload arrival. Unfortunately, key project elements are impacted by COVID-19 with probable programmatic impacts. Project teams are working hard to minimize impacts. SWOT Science Team was renewed for the 2020-2023 period with new working groups. For the ocean contribution during the fast sampling phase (1-day orbit), the SWOT Adopt-a-Crossover (AdAC) is an international consortium, CLIVAR-endorsed project for an international multi-site in-situ deployment under SWOT swaths and crossovers. Prelaunch campaigns for AdAC have been tested in Californian Current, W Mediterranean, ACC. For the hydrology contribution, by combining several global river datasets, an a priori set of SWOT reaches and nodes have been developed. These will provide the framework for SWOT river studies. The Hydrology validation will be performed over a set of selected in situ sites with a plan for joint preparatory campaigns in U.S, France, and South America in 2021 (COVID permitting). The 1st SWOT Science Team meeting with the new team was planned in June 2020 but has been cancelled due to COVID-19 restrictions. Plans are in progress to conduct business remotely, with a 2021 Science Team Meeting still possible (finally held in Feb. 2021).

2.2 Other reports and issues

On behalf of the other Project Scientists, Eric Leuliette (NOAA) presented discussion topics, at the end of the opening session, for consideration by the splinter sessions. This year, it was focused on Jason-3 Extension of Life to provide a recommendation of a plan for Jason-3 operations after the end of the Sentinel-6 MF commissioning phase from the Jason-3 EoL Working Group with input from the OSTST. The main questions to the splinters were:

1) Interleaved phase: Considering the nadir constellation from 2022 to 2026, can science and operational applications be better accomplished with a geodetic phase or an interleaved phase?
2) Second tandem calibration phase: What are the benefits of a second calibration phase for the climate record versus 6 months of additional coverage?
3) Mission extension on geodetic orbit: What are the recommended orbits and phases for a geodetic phase?

3 Splinter Sessions

The splinters were conducted In form of forums throughout the entire meeting week and extended 2 weeks after. Links to the presentations are available on the meeting website: https://meetings.aviso.altimetry.fr/programs/ostst2020-complete-program.html

The forums were grouped into the following splinters' categories:

- OSTST Opening Plenary Session [11 presentations]
- Application development for Operations [11 presentations]
- CFOSAT [6 presentations]
- Coastal Altimetry [9 presentations]
- Instrument Processing (Measurement and retracking) [11 presentations]
- Instrument Processing (Propagation, Wind Speed and Sea State Bias) [4 presentations]
- Outreach, Education & Altimetric Data Services [9 presentations]
- Precise Orbit Determination [6 presentations]
- Quantifying Errors and Uncertainties in Altimetry Data [7 presentations]
- Regional and Global CAL/VAL for Assembling a Climate Data Record [15 presentations]
- Salient results from the 2017-2020 OSTST PIs [41 presentations]
- Science Results I: Climate Data Records for Understanding the Causes of Global and Regional Sea Level Variability and Change [12 presentations]
- Science Results II: Large Scale Ocean Circulation, Variability and Change [15 presentations]
- Science Results III: Mesoscale and Sub-Mesoscale Oceanography [16 presentations]
- Science Results IV: Altimetry for Cryosphere and Hydrology [7 presentations]
- The Geoid, Mean Sea Surfaces and Mean Dynamic topography [6 presentations]
- Tides, internal tides and high-frequency processes [11 presentations]
- OSTST Closing Plenary Session [7 presentations]

3.1 Application development for Operations

Chairs: Deirdre Byrne, Gerald Dibarboure, Gregg Jacobs, Carolina Nogueira Loddo

3.1.1 Overview

This is a summary of the Application Development for Operations splinter session for the 2020 Virtual OSTST meeting. There were 11 contributions presented and discussed in the online forum. They can be divided into three types of content: presentations from Agencies about news and updates of operational Level-2 products (Scharroo et al., Donahue et al., and Lucas et al.), presentations about advanced operational products, i.e. Level-3+ (Charles et al., Philip et al., and Pujol et al.), and presentations from operational users and applications (Ricko et al., d'Addezio et al., Liu et al., Aouf et al., Beauchamp et al.). The splinter was a forum for content producers to showcase improvements and changes in their operational datasets, and a forum for users to report improvements and changes in their operational systems as well as a couple of atypical use cases.

Despite the virtual nature of the splinter, the online forum made it possible to have discussions between the authors and the audience. Three major points were highlighted.

First and foremost, the many changes in products and operational systems (e.g. new altimeters used, operational systems getting ready for upcoming missions…) are a constant reminder of the necessity to maintain a strong link between the evolving user needs and the new algorithms and models developed in other splinters. This splinter captures how robust operational systems tackle the change process with experimental products and OSSE/OSE experiments based on innovative assimilation or mapping methods.

Secondly, despite the number of altimeters in operations in 2020, the application community clearly stated that more altimeters would be desirable and used operationally. In particular, the new Chinese mission HY-2B mission exhibits an excellent performance, and it was reported as beneficial for operational models (Wave & OGCMs) if data could be produced in near real time. To that extent, the splinter recommends to investigate the technical and operational feasibility to reduce the HY-2B timeliness, ideally down to 3 - 6 hours (NRT / OGDR class).

Lastly, the case of the Extension-of-Life (EoL) of Jason-3 was discussed in the splinter forum. A vast majority of the Applications splinter community was in favor of the 'interleaved orbit' scenario as it maximizes the sampling and coverage in comparison with 'geodetic orbits'. Moreover, using the interleaved orbit would provide a continuity to past records collected since T/P was on this interleaved track (e.g. the hydrology system presented by Ricko et al.). Furthermore, the community acknowledges the benefit of a 2nd tandem phase between Sentinel-6 MF / Jason-CS and Jason-3 and the associated toll on coverage (essentially losing 4 months' worth of Jason-3 data) provided that this tandem is scheduled out of the critical season of Atlantic Hurricanes.

3.1.2 Presentations about Level-2 products

Sentinel-6 Products: What's new? (Remko Scharroo, EUMETSAT)

R.Scharroo et al. presented the product suites for Sentinel-6, which was launched a few weeks after the meeting. They recalled the dual nature of the mission and products (low-resolution dataset similar to Jason-3, and high-resolution delay-Doppler mode similar to Sentinel-3) and they gave detailed information about the product content, timeliness, format, and data access, as well as highlights about product heritage from Jason missions or GDR standard F, and novelties that are specific to S6. They also presented the Project timeline for the commissioning phase, with a tentative product dissemination in Spring 2021 for NRT/STC products, and Fall 2021 for NTC products. Lastly, Scharroo et al. gave a timely reminder of the existence of the Sentinel-6 Validation Team (https://www.s6vt.org).

Available online:

https://meetings.aviso.altimetry.fr/fileadmin/user_upload/tx_ausyclsseminar/files/Sentinel-6_Products__What_is_new_.pdf

Sentinel-6 Operational Product Baseline

Product	Latency	Format	User Data Access		
			EUMETCast	GTS	Archive
ALT Low Resolution (LRM)	NRT	BUFR	L2	L2	L2
		NetCDF	L2, L2P	–	L2, L2P
	STC	NetCDF	L2P	–	L1b, L2, L2P, L3
	NTC	NetCDF	–	–	L1b, L2, L2P, L3
ALT High Resolution (SAR)	NRT	BUFR	L2	L2	L2
		NetCDF	L2, L2P	–	L2, L2P
	STC	NetCDF	L2P	–	L1a, L1b, L2, L2P, L3
	NTC	NetCDF	–	–	L1a, L1b, L2, L2P, L3
MWR	NRT	NetCDF	–	–	L2
	STC	NetCDF	–	–	L2
	NTC	NetCDF	–	–	L2

Figure 3.1-1. Sentinel-6 operational product baseline

NOAA's Jason Products (David Donahue, NOAA)

D. Donahue et al. gave a report about the timeliness of Jason-3 near real time products (also known as Operational Geophysical Data Record, or OGDR) over the past year. They showed that excepting the two safe-hold mode events (SHM) of 2020, the OGDR product generation largely exceeds mission requirements. The goal of the Project is to go beyond these requirements and to deliver 90% of the OGDR products with 75% of its content within 3 hours of measurement time (on a weekly basis).

Available online:

https://meetings.aviso.altimetry.fr/fileadmin/user_upload/tx_ausyclsseminar/files/Jason-3_Near-Real_Time_Products_Latency_over_Past_Year_2020_OSTST_Meeting.pdf

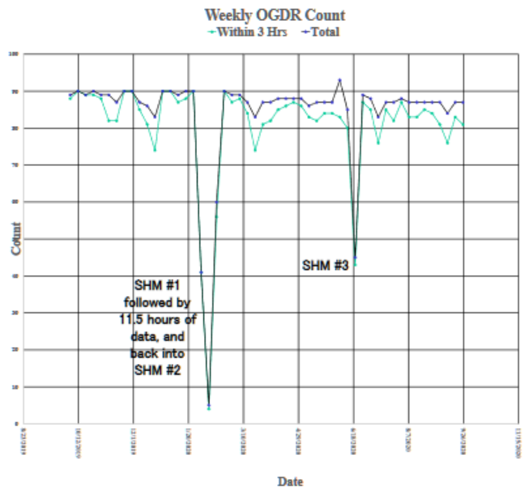


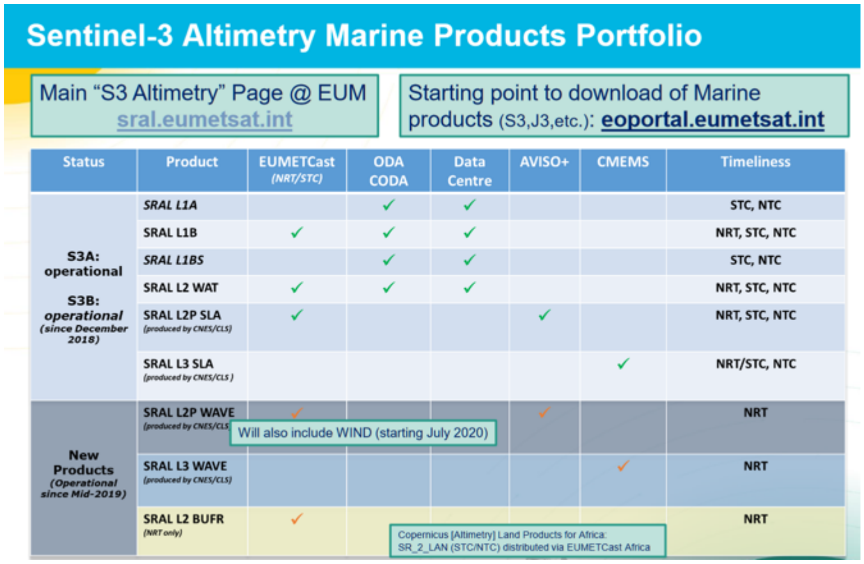
Figure 3.1-2. Timeliness of Jason-3 near real time products

Operational marine topography products from Copernicus Sentinel-3 missions (Bruno Lucas, EUMETSAT)

B. Lucas et al. gave a detailed view of the Sentinel-3 Marine Centre Status, processing and product portfolio. As observed by S3 users, both satellite units (A & B) and their payload are performing nominally or better (e.g. timeliness requirement met more than 98.5% of the time). Lucas et al. recalled that a major reprocessing was completed by EUMETSAT in January 2020 (with more than 10+ upgrades in product baseline 2.61). They also presented the new product baseline (namely PB 2.68 marine) that was deployed in July 2020. They illustrated the benefits of the new products with Cal/Val metrics and comparisons with Jason-3. Lastly, they provided a tentative schedule for future evolutions of the S3 product baseline in the next 2 years.

Available online:

https://meetings.aviso.altimetry.fr/fileadmin/user_upload/tx_ausyclsseminar/files/Sentinel-3_Marine_Centre_-_Status__OSTST2020_.pdf



Sentinel-3 Altimetry Marine Products Portfolio

Main "S3 Altimetry" Page @ EUM sral.eumetsat.int

Starting point to download of Marine products (S3,J3,etc.): eoportal.eumetsat.int

Status	Product	EUMETCast (NRT/STC)	ODA CODA	Data Centre	AVISO+	CMEMS	Timeliness
S3A: operational S3B: operational (since December 2018)	SRAL L1A		✓	✓			STC, NTC
	SRAL L1B	✓	✓	✓			NRT, STC, NTC
	SRAL L1BS		✓	✓			STC, NTC
	SRAL L2 WAT	✓	✓	✓			NRT, STC, NTC
	SRAL L2P SLA (produced by CNES/CLS)	✓			✓		NRT, STC, NTC
	SRAL L3 SLA (produced by CNES/CLS)					✓	NRT/STC, NTC
New Products (Operational since Mid-2019)	SRAL L2P WAVE (produced by CNES/CLS)	✓			✓		NRT
	SRAL L3 WAVE (produced by CNES/CLS)					✓	NRT
	SRAL L2 BUFR (NRT only)	✓					NRT

Figure 3.1-3. Sentinel-3 Marine Centre Status, processing and product portfolio

3.1.3 Presentations about Level-3+ products

CMEMS WAVE-TAC, Recent upgrades and enrichment of the satellite constellation for near-real-time ocean waves characterization (Elodie Charles, CLS)

E. Charles et al. presented in detail the portfolio of advanced (L3+) products of the Wave Thematic Assembly Center (Wave-TAC) of the Copernicus Marine Environment Monitoring Service (CMEMS). They gave an overview of the satellites processed by their system (all altimeter missions, CFOSAT, and Sentinel-1A and -1B SAR imagers) as well as the list of wave products CMEMS generates in collaboration with EUMETSAT, ESA and CNES: along-track SWH spectra and derived parameters. Charles et al. also reported the recent upgrades of their system with the addition of CFOSAT and HY-2B in 2020, and the evolution of their processing (e.g. new mapping process for their L4 product) and product line (e.g. new Level-4 swell product, new sets of parameters now observed by the SWIM instrument of CFOSAT).

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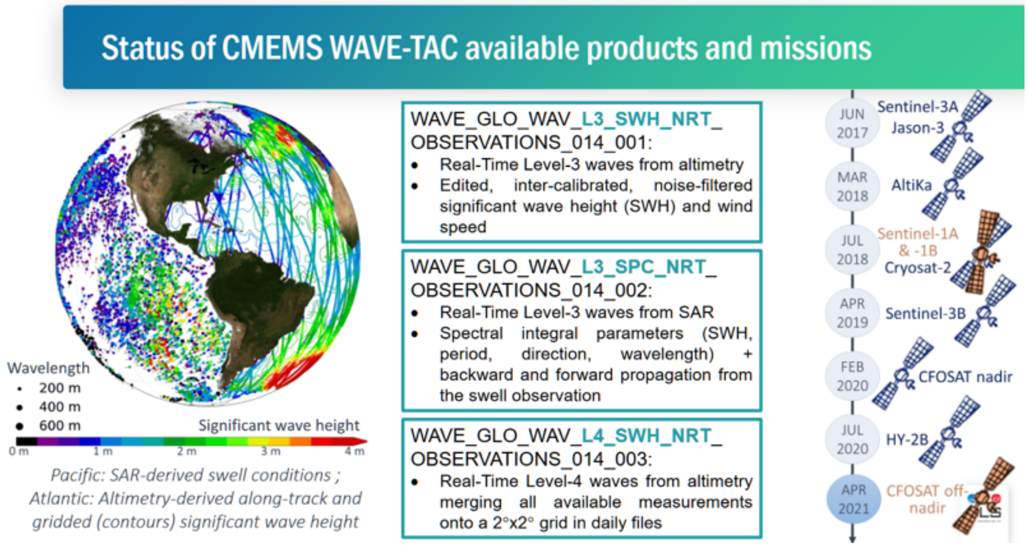

Figure 3.1-4. Portfolio of advanced (L3+) products of the Wave Thematic Assembly Center (Wave-TAC) of the Copernicus Marine Environment Monitoring Service (CMEMS)

HY-2B in DUACS: feedback on performances and contribution to multi-mission products (Alexandre Philip, CLS)

A. Philip et al. reported the successful integration of the HaiYang-2B mission in the so-called DUACS system (also known as CMEMS SL-TAC or AVISO maps). HY-2B was commissioned by NSOAS in late 2019, and is now routinely processed by CNES and CMEMS with IGDR / STC timeliness. Data availability is reported as nominal (90% or better) and the quality of the Chinese L2 altimeter product is shown to be very good. A. Philip et al. explain that HY-2B now represents more than 14% of the overall altimetric constellation content in the Level-4 (multi-mission gridded map). They also presented the positive impact in the assimilation of the CMEMS OGCM (misfit RMS of HY-2B is on par with Copernicus altimeters). Lastly, they presented the good quality of the significant wave height after a cross-calibration on Jason-3 as a reference mission and in-situ data (also mentioned by L. Aouf et al.). More importantly, the most limiting factor they find for operational applications is the timeliness of the Chinese Level-2 product (IGDR-class): it is essentially a showstopper of operational wave applications, and the lack of NRT data artificially decreases the contribution of HY-2B in the L4 topography mapping by a significant fraction.

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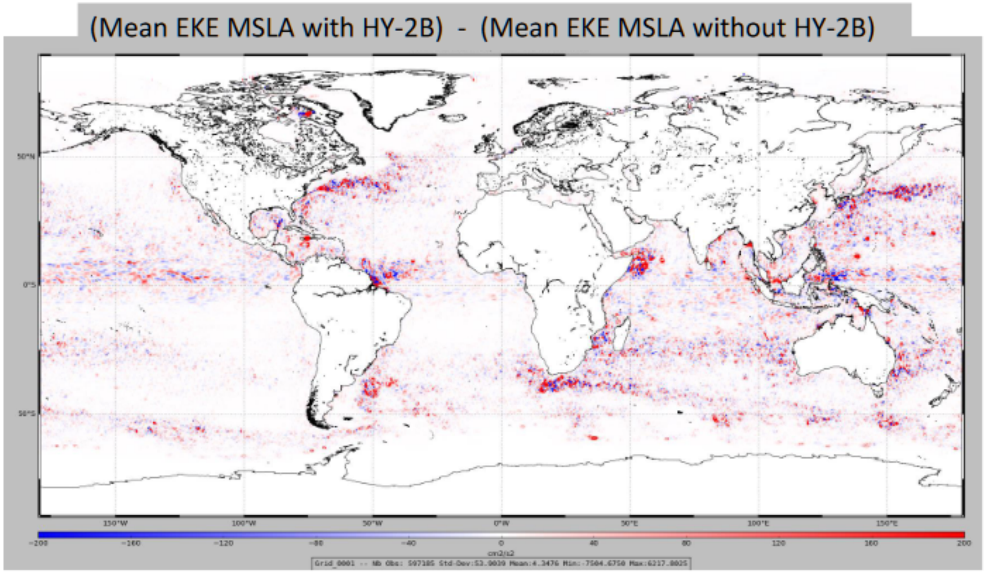

Figure 3.1-5. Positive impact in the assimilation of HY-2B in the CMEMS OGCM. The increase of energy, visible in regions of high mesoscale variability is expected when using additional missions and indicates a positive impact of HY2B on the maps quality

Toward Higher Resolution Level-3 altimeter products (Marie-Isabelle Pujol, CLS)

M-I. Pujol et al. presented the second version of the high-resolution experimental Level-3 product (along-track sea-level anomaly) developed by CLS for CNES and CMEMS. This product is designed to resolve smaller mesoscale features (35 to 50 km) which are usually hidden by instrumental noise (the limit is 50 to 70 km in traditional products). To do this, Pujol et al. leverage new experimental processing (e.g. adaptive retracker, LR-RMC processing of Sentinel-3, high-frequency adjustment, new hybrid mean profile) that enhance the signal-to-noise ratio of the smaller scales. Moreover, they used a posting of 5 Hz or 1 km in order to retain the small scale content and the coastal coverage that are absent in the classical 1 Hz posting. Pujol et al. presented comparisons with independent data that illustrate and quantify the strengths of their experimental products. They also reported positive user feedback: an operational high-resolution model assimilation of CMEMS was able to reduce the forecast error by up to 20 % with this product.

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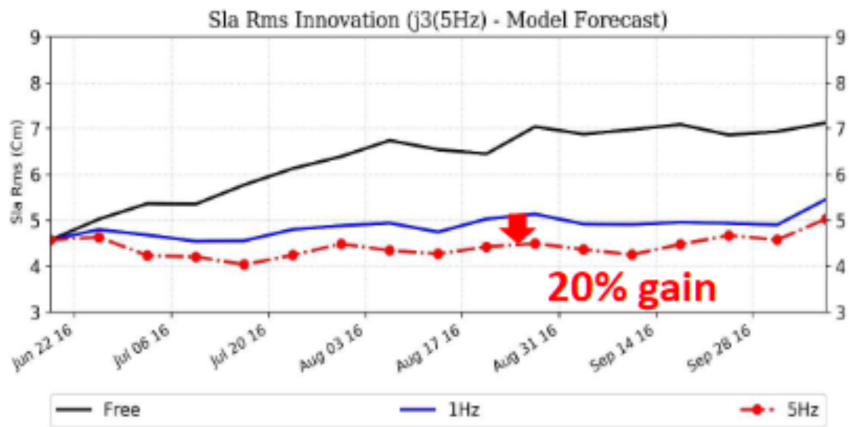

Figure 3.1-6. SLA innovation temporal evolution (difference between observation and model forecast) for model free run (black) and model assimilated with 1Hz (blue) or 5Hz (red) altimeter measurement

3.1.4 Presentations from users and operational systems

Global Water Monitor (Martina Ricko, NASA/GSFC)

M. Ricko et al. presented the recent changes in NASA's Global Water Monitor which is designed for operational monitoring of lake, wetland and river water levels for natural hazards and regional security. Their system uses altimetry from operational missions (Jason-class and Sentinel-3) as well as technology demonstrators such as CRYOSAT-2, ICESat and other missions to deliver operational services and bulletins about inland water every 1 to 3 days. Ricko et al. presented their processing sequence for topography, and their multi-sensor approach for water extent. They gave an overview of the interactive distribution portal. Lastly they reported recent improvements from CRYOSAT-2 and ICESat-2 and the expected benefits with Sentinel-6 MF.

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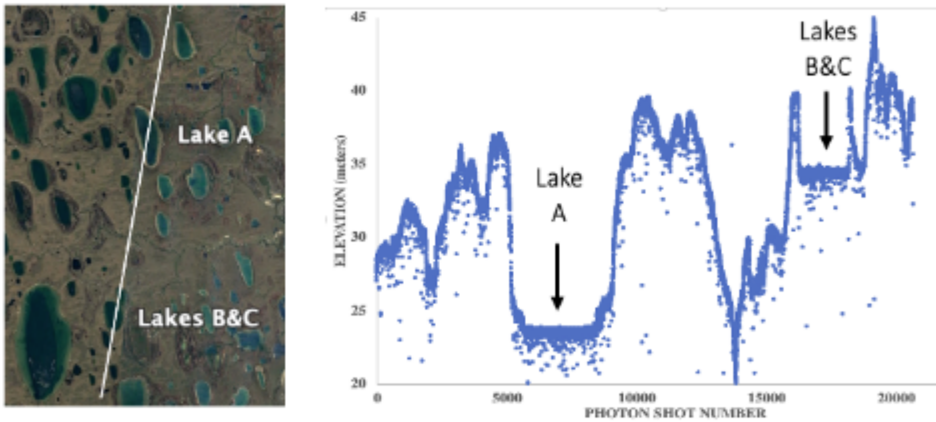

Figure 3.1-7. On-board DEM enhancement. Laser altimeters are capable of acquiring very small water bodies. Such data will be utilized to enhance the Sen-6A/MF onboard DEM. Example shown is from ICESat-2 (11/17/2018, white ground track location). With an along-track spacing of 0.7m the surfaces of three small lakes on the Alaskan North Slope (0.5 to 1.5km overpass width) are captured. This region is an important fish habitat and the ability to acquire elevation measurements is of particular interest to USGS and NOAA

ALPS-2 SWOT Data Processing (Joseph D'Addezio, NRL)

J. d'Addezio et al. gave an update of the ALPS-2 system of the Naval Research Laboratory and the data processing they are developing for the upcoming SWOT mission. An important challenge when assimilating SWOT data is to handle the large-magnitude and spatially correlated errors of the swath data. D'Addezio et al. used the SWOT simulator to get a proxy of the swath measurement errors, estimated their bidimensional autocovariance, and derived a filtering process. Results indicate the method provides a reasonable estimate of the correlated error sources and can be used to filter the SWOT data. A further objective is to mitigate the correlated errors in an upcoming Observing System Simulation Experiment (OSSE).

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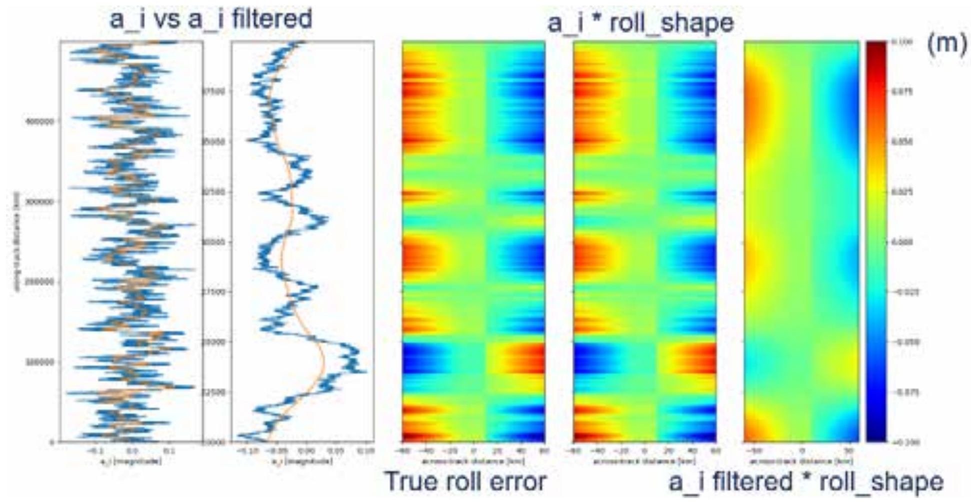

Figure 3.1-8. ALPS-2 system of the Naval Research Laboratory

Comparisons of Altimetry and Model Products with High-Frequency Radar Observed Radial (Yonggang Liu, U.Florida)

Y. Liu et al. performed comparisons between altimetry-derived geostrophic velocities with coastal HF radar in the Straits of Florida. They presented the dense HF radar coverage around Florida with 10 sites equipped, or awaiting permits. They focused their analysis in the Straits of Florida where a Jason-3 track is well oriented to compare radial radar velocities with cross-track geostrophic velocities. Liu et al. report a 10 to 20 cm/s RMS difference with substantially more energy captured by the HF radar. They also compared the radial velocities with gridded products from altimetry (namely CMEMS Level-4 maps, formerly known as AVISO maps) and HYCOM model analyses (with altimetry data assimilation). Although all radial velocities qualitatively agree, Liu et al. found substantially less agreement with gridded altimetry products (RMS difference of 34 cm/s, bias up to 20 cm/s), and HYCOM analyses (40 cm/s) than with along-track measurements.

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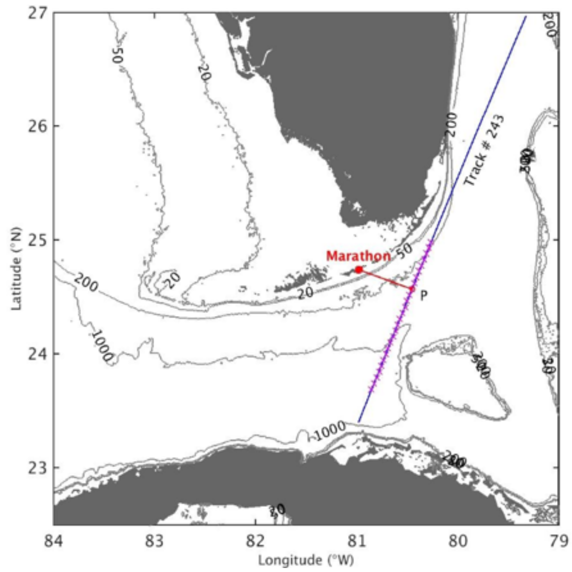

Figure 3.1-9. Locations of the HFR site origin (Marathon) and Jason-3 altimeter satellite ground track # 243. The magenta crosses along the track indicate the locations of the geostrophic velocity estimates

On the assessment of HY-2B in the wave model MFWAM (Lotfi Aouf, Meteo France)

L. Aouf et al. presented their results on the first assimilation of the HY-2B wave data in the Météo France wave model (MFWAM). They performed an Observing System Experiment (OSE) with twin configurations with a control run and a configuration assimilating HY-2B data. Independent data from other altimeters were used to quantify the improvement. Despite the presence of a significant bias in HY2B waves (also reported by other papers in this splinter), Aouf et al. found a significant reduction of the scatter index when HY-2B is assimilated. To correct for the bias in SWH, they used a Deep Learning calibration process developed by Wang et al. (2020), as it yields significant bias reductions, particularly in the Southern Ocean. This calibration had a very positive impact on the assimilation outcome, essentially doubling the gain from adding HY-2B to the system. L. Aouf et al. reported that their operational wave model is ready to assimilate this altimeter mission, and would like to. Unfortunately, there is no NRT/OGDR products for HY-2B, so the Chinese altimeter is currently used only for validation or offline reprocessing.

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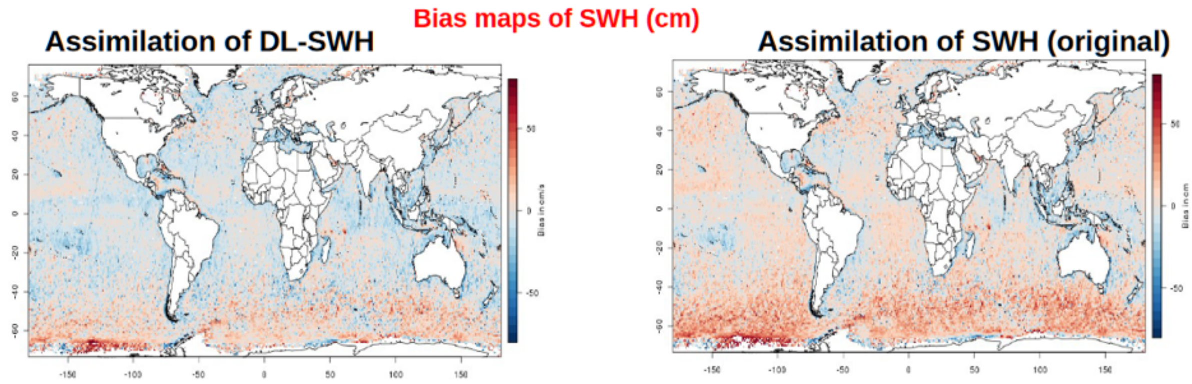

Figure 3.1-10. Good reduction of the bias in particular in the Southern ocean by using the Deep Learning calibration process (left) developed by Wang et al. (2020)

Variational Deep Learning-based interpolations of along-track Nadir and wide-swath SWOT altimetry observations (Maxime Beauchamp, IMT Atlantique)

M. Beauchamp gave an overview of the innovative interpolation method they developed for nadir altimetry and SWOT. They developed and compared multiple data-driven methods (DINEOF, Analog data assimilation, and convolutional neural networks) to reconstruct NEMO / NATL60 model simulation snapshots in a 10° box of the Gulf Stream region in a classical OSSE framework. They also compared the performance of their AI interpolators with the operational software used in CMEMS and AVISO. Beauchamp et al. report that the Gibbs energy-related neural network (GENN) performed extremely well in these simulations with a reduction of the error RMS of the reconstructed Level-4 map of up to 40% with respective to a classical objective analyses interpolator, in particular for scales from 50 to 150 km. This deep learning strategy is also promising because the neural network learned only from simulated observations (along-track or swath), i.e. with no information about the control run snapshots to be reconstructed.

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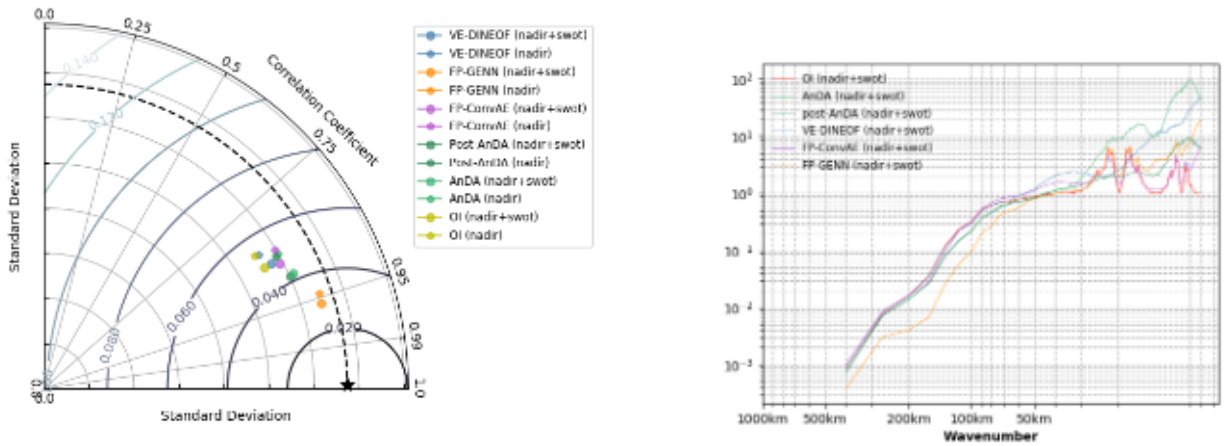


(a) *Taylor diagram* **(b)** *Signal-to-noise ratio*

Figure 3.1-11. Taylor diagram and signal-to-noise ratio computed on the 80-days non-continuous validation period for a joint assimilation/learning with wide-swath SWOT data

3.2 CFOSAT

Chairs: Danièle Hauser, Lotfi Aouf, Doug Vandemark

The CFOSAT session was held for its second year in the OSTST meeting and provided latest reports on OSTST-relevant altimeter and ocean wave spectral data and analyses from the recently-launched CFOSAT mission (China French Oceanographic Satellite). CFOSAT operates with two core ocean radar systems, the first combines a nadir and near-nadir incidence scanning Ku-Band radar instrument (SWIM) and the second is a scanning ocean wind scatterometer. Six new studies and project updates were presented during this session and the forum allowed for, and captured, a significant amount of useful back and forth discussion related to their findings. Overall, it is apparent that the CFOSAT SWIM instrument, the main focus of these talks, is functioning very well, and that substantial progress has been to improve both the SWIM ocean surface wave data products and their application.

E. Le Merle et al., Directional and frequency spread of surface ocean waves from CFOSAT/SWIM measurements 8 replies

This study explored the all-new global CFOSAT capability to map the directional and frequency spread within measured 2D ocean wave spectra. These statistical measures can help to better identify changes in gravity wave steepness, regions with high wave/current interaction, potential rogue wave generation sites, and deficiencies in physical parameterizations in global wave models. Relationships between sea state, peak spectral wavelength and the spread parameters were investigated, and in many respects, compare reasonably well with the MFWAM wave model output. One highlight was a first global map of the Benjamin-Feir Index, a proxy for extreme instability in the wavefield - with possible application to rogue wave detection or warning (Figure 3.2-1).

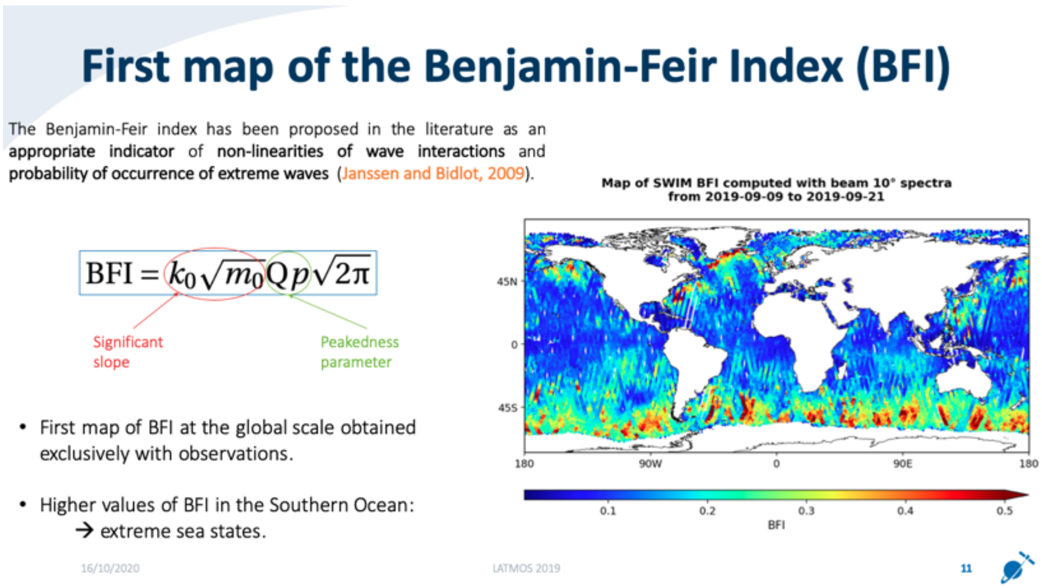


Figure 3.2-1. First global map of the Benjamin-Feir Index, a proxy for extreme instability in the wavefield - with possible application to rogue wave detection or warning

J. Wang et al., Acquisition of the Significant Wave Height from CFOSAT SWIM Spectra through a Deep Neural Network and its Impact on Wave Model Assimilation 11

This study evaluated several new approaches to use machine learning algorithms to improve the accuracy of the SWH estimates that are derived at the location of each 2D wave spectral estimate made by the SWIM instrument - their so-called "box". As noted in the Tourain talk, SWIM seeks to provide unbiased SWH estimates via their MTF, but small empirical corrections may still be needed. This study showed that by using the SWH and sigma0 from the nadir-altimeter, plus ocean wave data from each box they can improve on the overall SWH estimate for each box. This was termed the nadir-box or nadir+box deep neural net (DNN) solution. They then went on to perform an MFWAM data assimilation experiment using these new nadir-box SWH SWIM measurements. Clear improvements were observed at global scale as shown in this example (Figure 3.2-2).

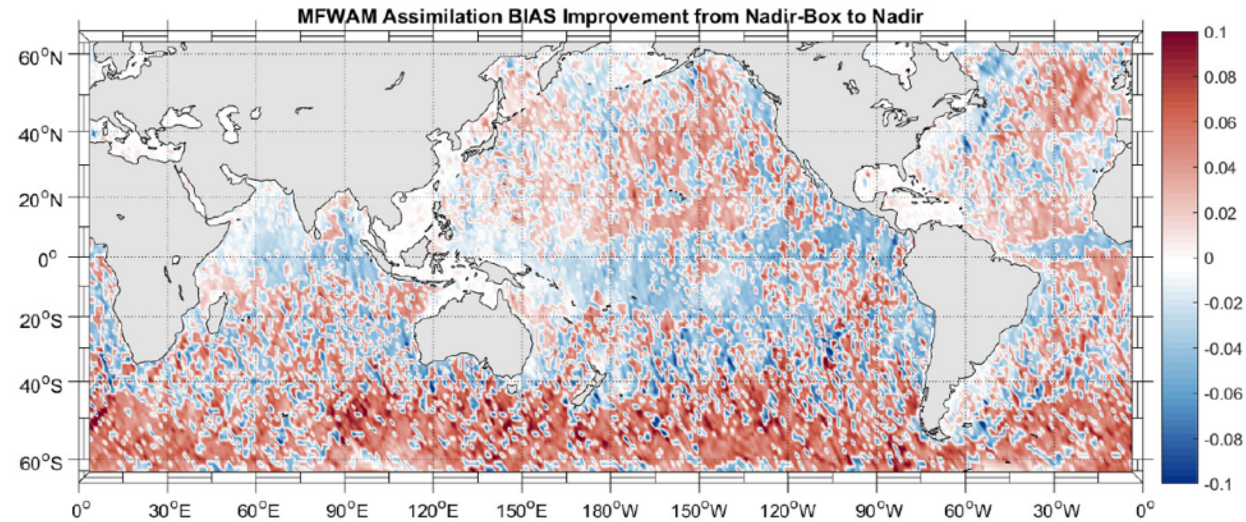


Figure 3.2-2. improvements observed at global scale from nadir-box solution in MFWAM data assimilation

C. Tourain et al., CFOSAT: SWIM Products latest evolutions and improvements

This update talk on CFOSAT ocean wave measurements and products provided an overview of significant effort and progress that has been made by the CFOSAT team since the 2019 OSTST Chicago meeting. As predicted, the team has been able to provide a viable empirical, but objective, correction approach to fix the large ocean wave spectral observing gap that was apparent +/- 15 deg. of the along-track directions due to limited Doppler bandwidth/speckle noise issue. Newly available SWIM data are significantly improved using the latitude and sea state dependent along-track speckle mitigation approach that was presented. An example shown here illustrates the strong change in derived 2D ocean wave spectra in the along-track direction with the latest version product clearly being improved (Figure 3.2-3). A second key activity and improvement was addressed where the fundamental SWIM modulation transfer function needed to transform the baseline radar measurements to directional wave slope and wave height spectra has moved to its third option - termed MTF3, which is based on a normalization of significant wave height from nadir SWH. Data produced with this latest show clear improvement in the reported comparisons to global reference data.

Figure 3.2-3. The strong change in derived 2D ocean wave spectra in the along-track direction with the latest version product clearly being improved

L. Aouf et al., Towards an improvement of wave forecasting in the Southern Ocean : Thanks to directional wave observations from CFOSAT

The application of CFOSAT 2-D wave spectra data into ocean wave models via data assimilation is a much-awaited step towards improved forecasts. Aouf and co-authors presented on a numerical experiment of such a data assimilation - performing twin experiments using the MFWAM model and assimilation of SWIM SWH and/or wave spectral partition (e.g. sea and swell mode direction and length) data for the month of May 2019. Their study focused on Southern Ocean waves and the changes seen there between the 4 model runs that were produced. The metric for skill was in agreement with satellite altimeter SWH data. The assimilation of SWIM partition wavenumber components significantly reduced the SWH bias under wind-wave generation in unlimited fetch conditions. The study also revealed that the assimilation of directional wave observations from SWIM led to a better energy transfer from short to long waves during the growth phase in comparison with data assimilation of SWH only (Figure 3.2-4). Overall, the results suggest some clear gains will be made in both model data assimilation and in model modifications as more SWIM data are applied.

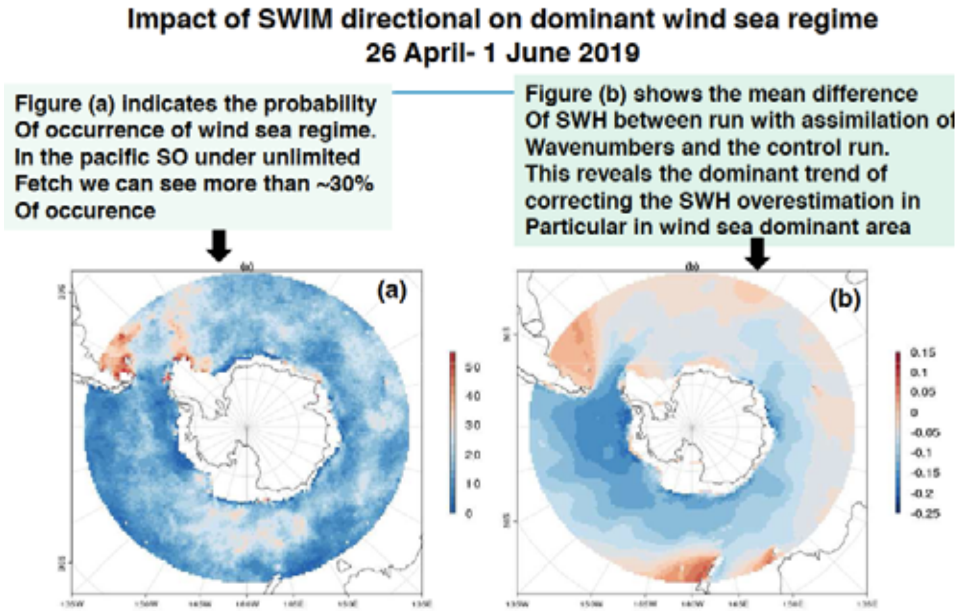


Figure 3.2-4. Impact of SWIM directional on dominant wind sea regime.

S. Bhowmick and M. Seemanth, Analysis of Wind and Waves from SWIM on-board CFOSAT: A gen-next altimeter

This comprehensive study in the Bay of Bengal looked at both the validation of SWH data from the nadir- and wave-modes of the SWIM instrument as well as the benefit of data assimilation into Wavewatch III wave model forecasts for their region (Figure 3.2-5). Their work used Jason-3 altimeter and waverider buoy data SWH for validation. Their results are consistent with others, showing highly accurate nadir-altimeter SWH measurements and slightly less-accurate wave-mode off nadir SWIM SWH - and that the nearer-nadir SWH data have lower accuracy. Their data assimilation experiments in May 2020 suggest an encouraging 8-12% improvement in model forecast skill compared to using Jason-3 alone, particularly for the Cyclone phase data of 16-20 May 2020.

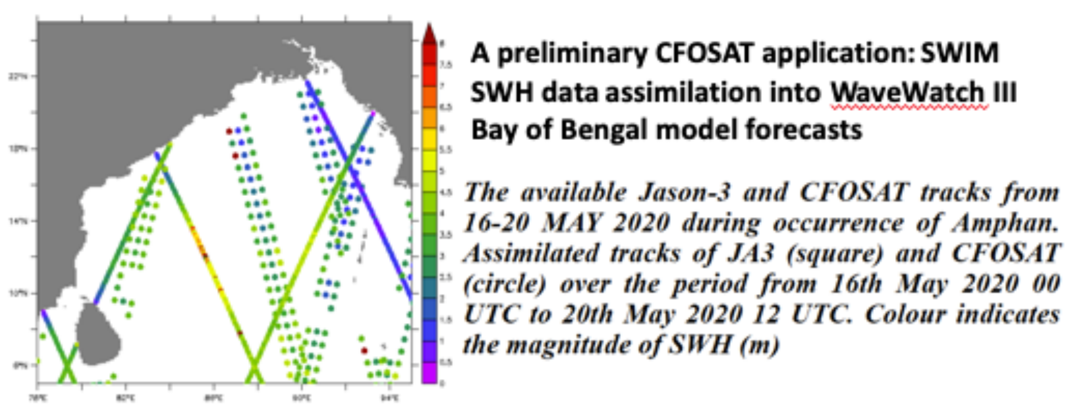


Figure 3.2-5. SWIM SWH data assimilation into WaveWatch III Bay of Bengal model forecasts.

H. Li et al., Up-to-downwave asymmetry of CFOSAT SWIM fluctuation spectrum for the direction ambiguity removal

This study investigates the potential to use SWIM's 360 degree azimuth scan data to help resolve the 180 deg. uncertainty in the direction of wave propagation. The assumption is that there may be subtle but measurable differences in the SWIM radar modulation signatures when looking down the wave versus when the radar faces the wave direction of travel. The study shows evidence that this is true and that the down-wave modulation intensity can be markedly lower than for the up-wave looks. They then developed an approach to compute a down/up ratio for each SWIM wave spectral peak and to use this measure to predict the direction of wave propagation. Their preliminary results show promising agreement with global wave model data and appear to work similarly for the 6, 8 and 10 deg. SWIM data products (Figure 3.2-6).

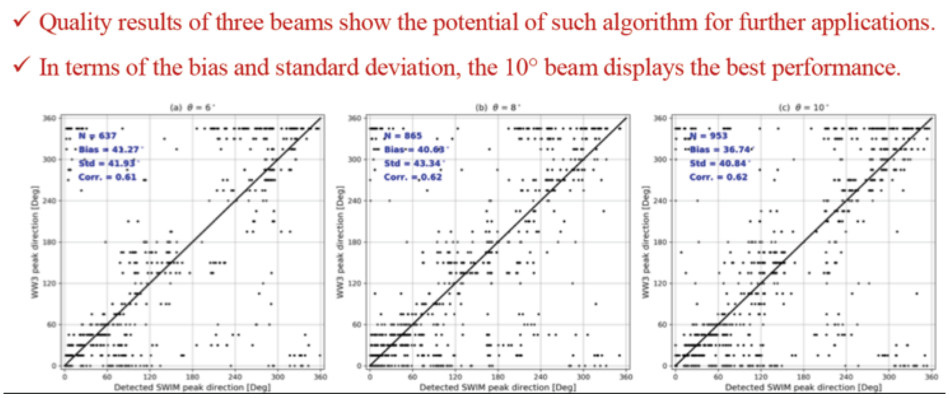


Figure 3.2-6. Promising agreement with global wave model data.

3.3 Coastal Altimetry

Chairs: Mathilde Cancet and Ted Strub

A majority of the nine presentations in the Coastal Altimetry session use a variety of altimeter products to resolve geophysical signals such as tides, non-tidal tide gauge variability, coastal jets, and Coastal Trapped Waves. Other (and some of the previous) studies test competing SAR algorithms or compare SAR to LRM performance in coastal areas. There is a general confirmation that SAR and SARin along-track data yield better retrievals of along-track heights and cross-track geostrophic velocities than LRM or PLRM data, as expected.

Comparing SAR algorithms, **Fenoglio et al.** find that the SAR-SAM+/++ and RDSAR/STAR algorithms work best, retrieving data as close as 3 km from the coast. Using these very near-shore data, their analysis of sea level rise from the short SAR records are consistent with results from the much longer LRM records. **Sanchez-Roman et al.** compare tide gauge (TG) data to nearly coincident Jason-3 and Sentinel-3 along-track data from a wide geographical area (from Scandinavia to the Mediterranean Sea, Figure 3.3-1), finding better agreement between the Sentinel and TG data than between the Jason and TG data. The reasons for the geographic differences between TG and altimeter SLA measurements remain to be determined. One of these reasons may be the accuracy of the ocean tide correction applied to the altimetry data as the largest differences are observed in regions of large tidal range.

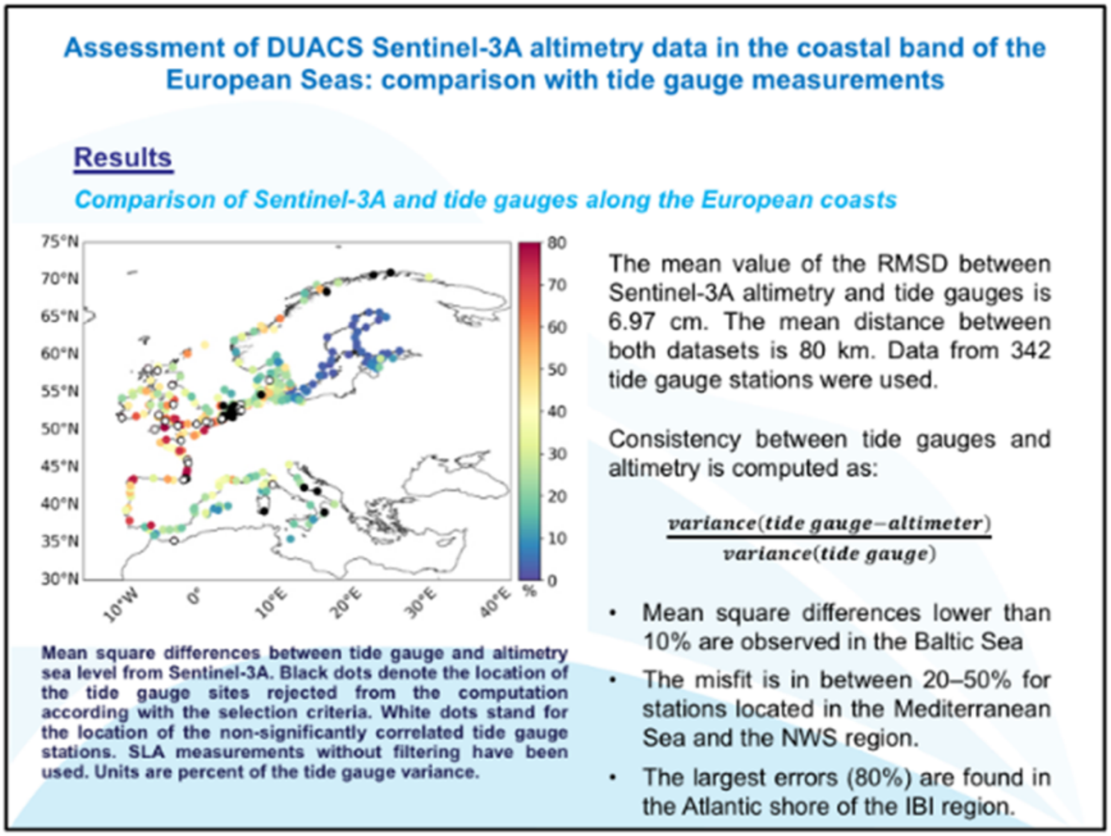


Figure 3.3-1. From Sanchez-Roman et al., showing the RMSD between Sentinel-3A altimetry and tide gauges at a wide variety of stations.

Likewise, **Chupin et al.** closely examine waveforms from tracks passing near land in the Noumea Lagoon and find less distortion of the waveforms due to nearby land for Sentinel than for Jason data.

Moving to more applied studies of coastal currents, both **Lago et al.** and **Le Hénaff et al.** employ Jason data over the Patagonia shelf and slope to look at the alongshore vertically integrated transports. **Lago et al.** first determine that gridded SLA velocities are better correlated with *in situ* velocities than along-track velocities, and so analyze the gridded velocity data. The two studies find the flow over the shelf at different locations to be approximately barotropic. **Le Hénaff et al.** find the upper slope flow (over the 400 m isobath) also to be approximately barotropic, while the lower slope at the 3600 m isobath has a substantial baroclinic component. Thus, in estimating vertically integrated transports, surface currents over the shelf and upper slope can be integrated (assumed constant) to the bottom but a regression needs to be applied to estimate the baroclinic component offshore of some isobath. **Lago et al.** also use EOF analysis to define an 'interannual' component of the shelf transport time series and find it to be correlated with the Southern Annular Mode (SAM) of climate variability. They state that this connection is accomplished through the correlation of the SAM time series and the alongshore wind stress over the Patagonia shelf. Relatively narrow (50 km) coastal surface jets/currents are also examined by **Feng et al.** over the Scotian shelf and within the Gulf of Maine, using along-track Sentinel data in three modes: Fully Focused SAR (FFSAR), Unfocused SAR (UFSAR) and pseudo-LRM (PLRM) (Figure 3.3-2). All three are used to calculate cross-track geostrophic velocities. The result is that FFSAR data are better than UFSAR data and both are better than the PLRM data in defining the jets. The jet is less clearly defined in the PLRM-derived velocities, which also displace the jet slightly offshore.

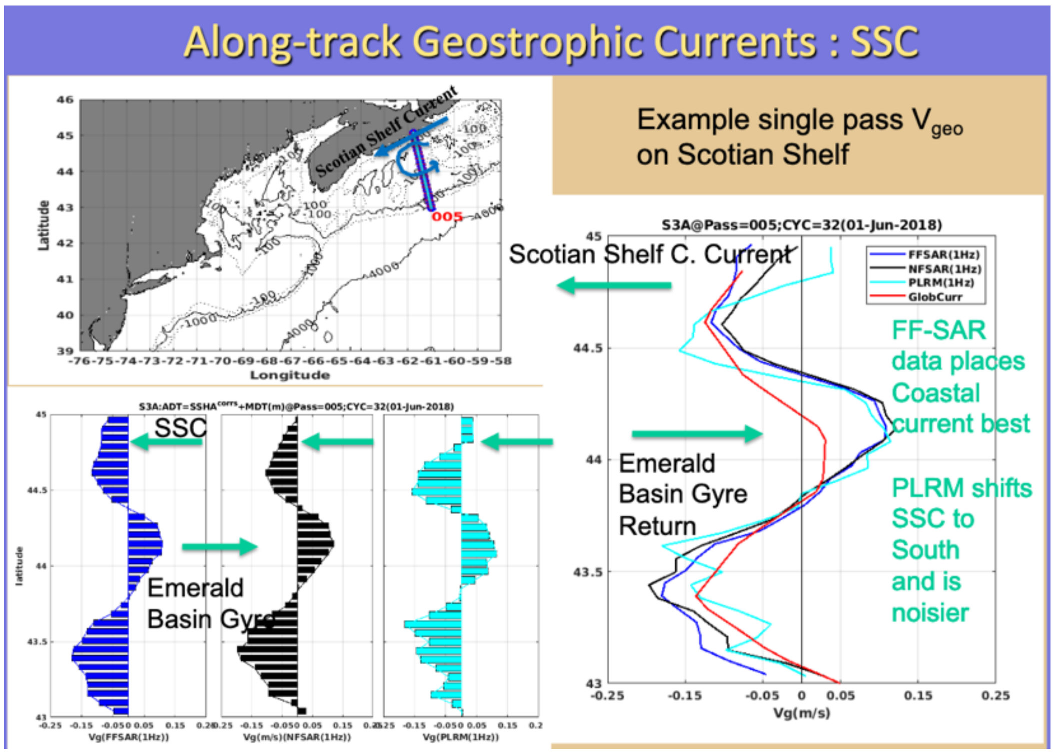


Figure 3.3-2. From Feng et al. et al., showing three retrievals of velocity from S-3.

The last three studies consider other signals near the coast or inland. To detect coastal height signals associated with Coastal Trapped Waves (CTW, an illusive target for altimetric studies), **Strub et al.** determine the timing of relaxations of upwelling-favorable wind forcing off central California, which trigger CTWs. They use that timing to synchronize composites of the TG and altimeter data, using nearshore along-track Jason SLA, retrieved with both ALES and standard RADS LRM methods. Composites of TG data, synchronized with the wind events, reduce the noise and detect the CTW signals at locations north of the wind forcing. Similar composites of the Jason data, averaged over 10-30 km from the coast, approximately reproduces TG data in resolving the development of Coastal Trapped Wave signals. ALES data retrieves more data, from more events, and thus reduces the considerable noise better than the RADS data. The along-track altimeter data also provide a rough view of the offshore structure associated with the coastal signals. **Tranchant et al.** identify driving processes and quantify improvements made in high-resolution tide modelling using two hydrodynamic models (SCHISM and TUGO-m) around the Kerguelen Island altimetry calibration site by comparing to FES2014 global model and repeated 'towed-sheet GPS' instrument surface height measurements. Competing models are used to remove the tidal signal from the towed sheet height measurements, separated by 3 days. The idea is that the signal that remains after removing the tides is mostly the stationary MSS, so the tide model that reduces the difference between the repeated profiles (made along and in-between altimeter tracks) will be the better model. Using the two higher resolution tide models reduces the residuals between the repeated GPS measurements. Finally, moving farther inland, **Cotton et al.** describe the ESA "Hydrocoastal" Project – a two-year program that began in February 2020, with the goal of connecting the coastal ocean and estuaries to inland rivers and lakes. They are using Sentinel 3A/3B and Cryosat-2 SAR data on selected targets from around the globe. The project intends to produce a global product (water heights) by August 2021, finishing their assessment by March 2022. They will also evaluate methods of producing river discharge estimates.

3.4 Instrument Processing: Measurements and Retracking

Chairs: Phil Callahan, Jean-Damien Desjonqueres, Alejandro Egido, Cristina Martin-Puig and Walter H.F. Smith [Unable to participate: Francois Boy and Robert Cullen]

The Instrument Processing Measurements and Retracking Splinter (IPM) had 11 presentations. Development of methods for SAR processing continued. Much of the work covered developments in support of Sentinel-6.

<u>The main conclusions were</u>:

- As SAR processing is better understood, approximations need to be eliminated to provide the highest quality data. The effects of approximations in SAR processing are at the millimeter level and could approach the millimeter per year level.
- The inclusion of the full PTR in processing is important for securing the GMSL record.

<u>Recommendations</u>:

- The effects of approximations in SAR processing that may cause differences at the millimeter level or approaching the millimeter per year should be fully evaluated. Computational methods and resources to allow full processing of all data should be investigated.
- The GDR-F format should be applied to all missions. The data should include important processing and auxiliary information.

<u>Session summary</u>

Impact of Range Walk Processing in the Sentinel-3A Sea Level Trend

J. Aublanc (CLS) et al. discussed a drift of Sentinel-3A global sea level measurements from the SAR mode of approximately 2 mm/yr with respect to other altimeters. Pseudo-Low Resolution Mode (PLRM) processing shows a smaller trend. About 0.3 mm/yr of the drift was explained by the instability of the Point Target Response (PTR), affecting both SAR and PLRM. They noted that the current SAR mode processing chain in the Sentinel-3 ground segment makes some approximations to save complexity and computation time. In particular, the Doppler processing applied at level-1 does not compensate accurately for the range variation during the burst acquisition: the so-called range walk correction shown in Figure 3.4-1. Initially considered negligible, the range walk correction was found recently to be of some interest.

They analyzed the impact of the range walk correction in Sentinel-3 sea surface height and wave estimates from July 2016 to July 2018. They demonstrated that the main part of the current GMSL drift observed with Sentinel-3 in SAR mode will be removed once range walk is applied. The range walk correction also removes an SWH bias of approximately 5 cm and a 2 mm "drift" in this effect. The range walk and PTR change corrections are projected to bring both SAR and PLRM GMSL trends to about 3.6 mm/yr.

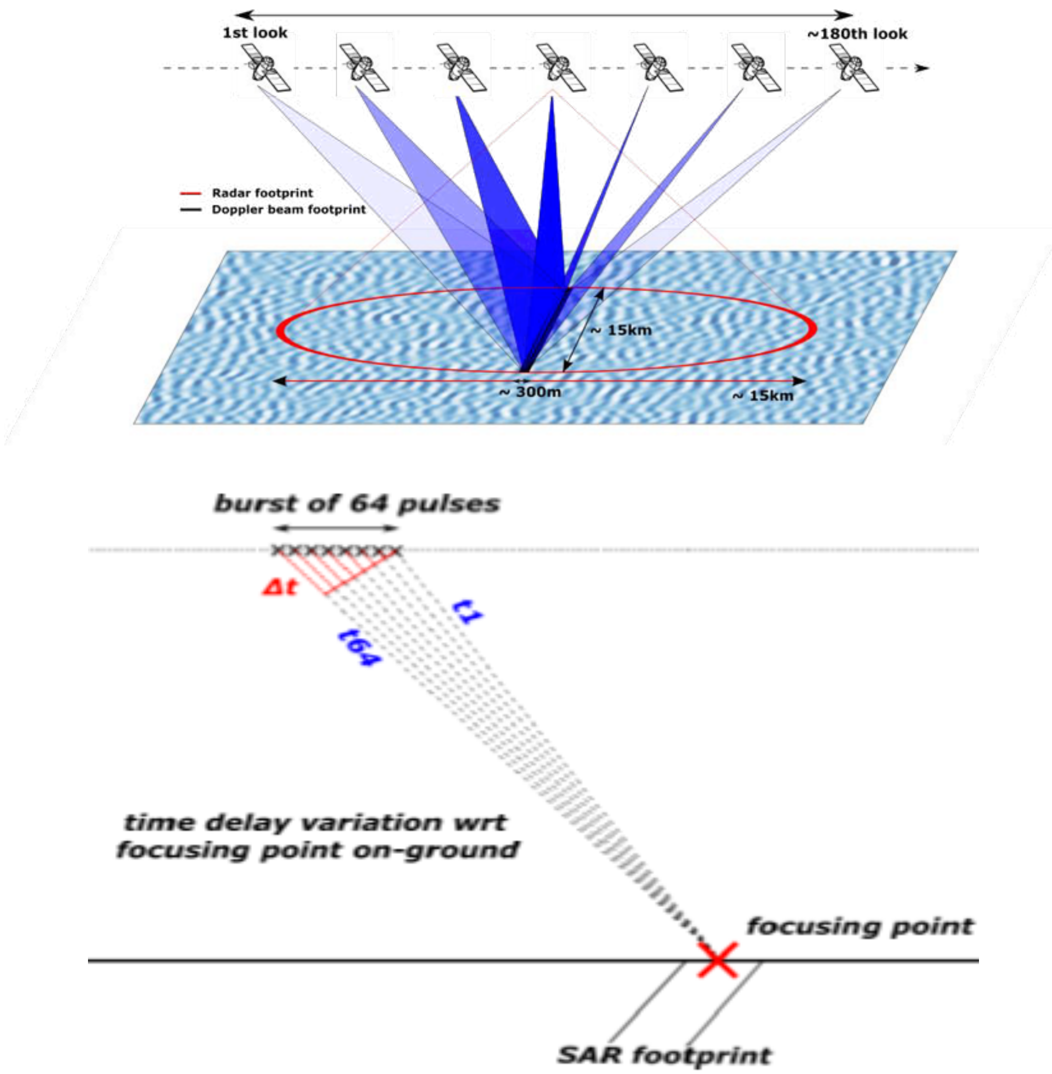


Figure 3.4-1. Different looks and ranges to a single azimuth cell on the surface. Each look needs to be corrected for range before Doppler compression to get the measurement for the cell.

Time and Frequency Domain Numerical SAR Retracking for Sentinel-6: First results prior to S6PP (Processing Prototype) implementation

S. Dinardo et al. discussed the development of the Sentinel-6 Processing Prototype (S6PP). Sentinel-6 has several features that need to be accounted for in processing: onboard range migration, open burst operation, Doppler ambiguities, and pulse-to-pulse correlation. S6PP is a multi-chain (LRM, LR-RMC, UF-SAR, FF-SAR) processor in which the novel algorithms developed in the CNES/CLS R&D activities are implemented. In particular, they described the unfocused SAR (UF-SAR) chain of the S6PP which is complementary to what to the standard processing. The UF-SAR chain for L1b implements a standard Delay-Doppler processing complemented by the Range Walk Correction application (above and Scagliola et al. 2019) and by an exact beam-steering and a beam formation by DFT (Discrete Fourier transform) or CZT (Chirp Zeta transform) for reducing CPU time. For L2, in order to be less prone to errors in range coming from range PTR shape distortions during the mission, a real-PTR based numerical SAR retracking is proposed in the frequency-domain and in the time-domain, both having as minimization problem solver the Levenberg–Marquardt algorithm.

First results outlining the impact of the range walk for Sentinel-6, the impact of the Beam sub-sampling (S. Figerou et al., OSTST-2020), and good consistency between the results from SAR numerical retracking (time domain) versus the S6 GPP data results were shown.

Jason-CS Level 2 Processing Development from GPP (Ground Processor Prototype) to PDAP

S. Figerou et al. described the global validation strategy to assess both the protype and the operational processing chains They focused on new algorithms or adaptations from existing ones: range compression, retracker fitting, and Doppler beam sampling.

The main differences between the Level-2 Ground Processor Prototype (GPP) and the level-2 Payload Data Acquisition and Processing (PDAP) are:

- Both consider negative wave height, but where PDAP limits negative wave height to a positive sigma composite (effective pulse width), the GPP derives the SWH without constraint on sigma composites. Unconstrained sigma composite leads to an increase the noise on small waves. Thus, the GPP version for commissioning will only consider positive sigma composite (as PDAP).

- In the GPP, range compression is computed directly on the range, while PDAP applies the compression on SSH. It was shown that SSH compression takes into account second and greater orders of the altitude variability, where range compression only covers linear variability of the altitude. The difference can be up to +/-4 mm.

- Different numerical libraries are used, but showed minimal effect.

The assessment of performance was done using a simulation of 1500 radar cycles with different parameters (SWH, attitude, surface slope, altitude rate). Analysis was also done on a pass of “reconditioned” Sentinel-3 data. These data verified that requirements are met by the GPP.

Combining Fully Focused and Swath Processing for Glacier Applications

Garcia-Mondejar et al. gave an overview of the Copernicus polaRIce and Snow Topography Altimeter (CRISTAL) mission. It will use open burst high pulse repetition frequency (PRF) transmission making the received echoes suitable for fully-focused (FF-)SAR processing on the ground increasing performance in terms of the speckle reduction and along-track resolution. In closed burst mode (like CryoSat-2), replicas induced by the non-uniform sampling of the Doppler spectrum are mixed with the main echo and, in most cases, cannot be filtered out. It will also have interferometric capability like CryoSat-2. Both features will allow the monitoring of elevation of areas with complex topography such as over ice sheet margins, ice caps and mountain glaciers.

Capability of Jason-2 Sub-waveform Retrackers for Significant Wave Height in the Calm Semi-enclosed Celebes Sea

K. Ichikawa et al. discussed the capability to measure SWH in the presence of relatively smooth surfaces (slicks, calm water, or near land) with sub-waveform (or “leading edge”) retrackers. They examined 20 Hz Jason-2 measurements in the calm Celebes Sea region They particularly considered a new retracker that uses along-track information about the waveform as suggested in Figure 3.4-2. The new retracker uses samples up to the black line rather than the white line used in original ALES.

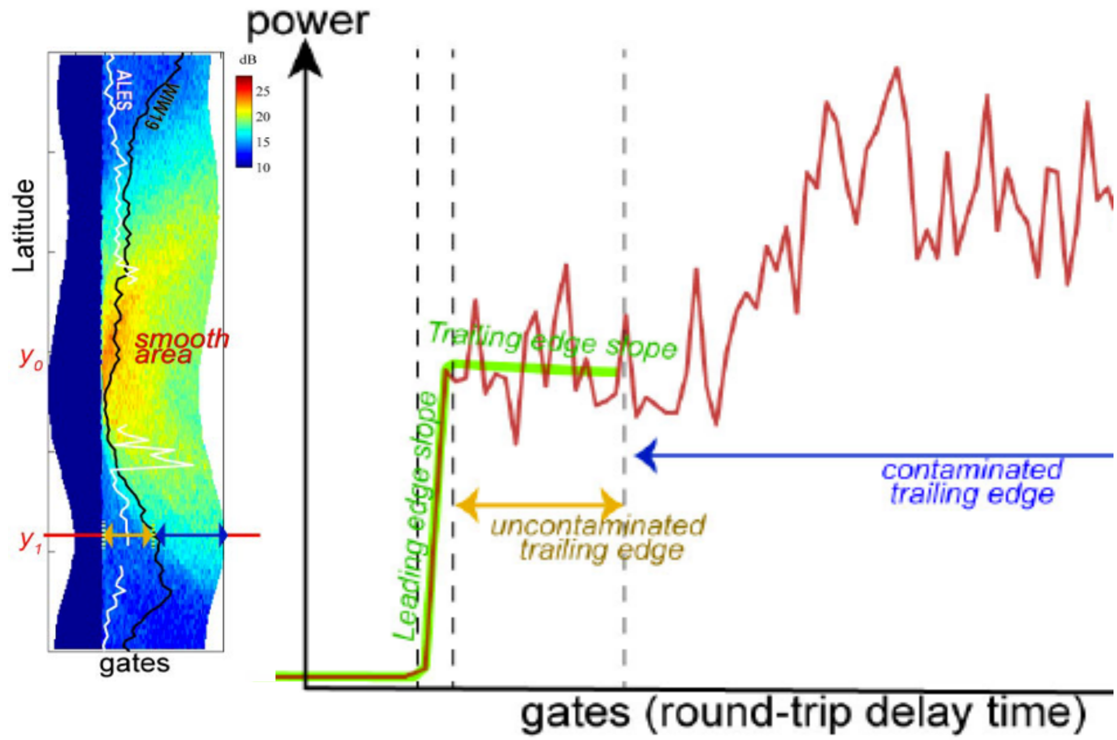


Figure 3.4-2. A "radargram" showing (left) signal amplitude as a function of range gate for a hypothetical along-track sequence and (right) an individual waveform indicating the selection of uncontaminated "leading edge" of the total waveform.

Distances from contamination sources and Jason-2 observation points can be determined using sequentially assembled adjacent waveforms (radargram) as shown in Figure 3.4-2. The figure is included to remind readers of the basis of leading-edge trackers that have been discussed extensively over the years and were discussed in the last presentation by M. Wenzl et al. regarding altimetry over the Great Salt Lake.

Ichikawa et al. found that when no contamination sources are present within a Jason-2 footprint, sub-waveform retrackers are in excellent agreement with the SGDR MLE4 retracker that uses full-length waveforms, except that the ALES retracker has a positive bias in a calm sea state (SWH < 1m), which is not unusual in the Celebes Sea. Meanwhile, when contamination sources exist within 4.5 km from Jason-2 observation points, SGDR occasionally estimates unrealistically large SWH values, although they could be partly eliminated by sigma0 filters. The retracked data were also compared with WAVEWATCH III model and showed fairly good agreement.

Homogenizing Metocean Data from Sentinel-3

Quartly discussed differences in SWH and sigma0 estimates between PLRM and SAR modes for the Sentinel-3A data from the January 2020 reprocessing. The shape of altimeter waveforms generated by LRM and SAR processing differ considerably, necessitating the use of different retracking algorithms to extract the geophysical parameters of interest. The PLRM estimates of wave height are roughly equivalent to those obtained by Jason-3, whereas those derived from SAR processing are higher and increasingly more so at large wave heights. Differences in sigma0 are found to show some dependence on parameters such as sigma0 or SWH themselves. However, it should be noted that latitude, range rate, and SWH, are all quite correlated and anti-correlated with sigma0 (lower for high wind speed, SWH, latitude). The disparity in the sigma0 estimates is also significantly affected by high-frequency variability due to fading noise on each individual waveform and can consequently be corrected for using adjustments from intra-1 Hz analysis.

S6 Validation Activities Addressing Instrumental Calibration, Processing Evolution, and Product Validation by isardSAT

M. Roca-Aparici, P. Garcia, et al. discussed validation activities to be undertaken in support of Sentinel-6 (Michael Freilich) by isardSAT. The work will include:

- Instrumental calibration and validation activities for altimeter and radiometer
- Altimeter Level 1 and Level 2 product validation and calibration
- Detailed investigation and evolution of altimetric Level 1 and Level 2 processing algorithms

The work will use natural targets, calibration point targets, and internal calibration data. Open ocean, coastal, and hydrology areas will be considered. Cross -calibration with Sentinel-3A and 3B will be done. A unique feature is calibration of both sigma0 and radiometer brightness temperatures using salt flats.

A Transponder Calibration Tool Based on Fully Focused SAR: Results for CryoSat from 10 years of Operation

M. Scagliola discussed calibration of fully-focused SAR (FF-SAR) from CryoSat with a transponder. The process needs as input the FBR or L1A product for the acquisition over the transponder and auxiliary information about the transponder characterization as well as atmospheric corrections. The FF-SAR processing uses time domain back projection (Ref 1). The calibration estimates:

- Datation bias (along-track phase ramp) ~ -14 +/-8 microsec
- Range bias (expected vs estimated range) SAR = 24.5 +/-14.8 mm; SARIN = 30.0 +/-15.4 mm
- FFSAR point target response characterization (comparison to theoretical)

All the CryoSat acquisitions in SAR and SARIN mode over the Svalbard and Crete CDN1 transponders were processed starting from Baseline-D FBR products. The long-term analysis of the transponder calibration parameters verified the quality of the CryoSat Baseline-D FBR products and the stable performance of the SIRAL instrument from the beginning of the mission. PTR characterization showed excellent comparison.

[1] A. Egido and W. H. F. Smith, "Fully Focused SAR Altimetry: Theory and Applications," in IEEE Transactions on Geoscience and Remote Sensing, vol. 55, no. 1, pp. 392-406, Jan. 2017, doi: 10.1109/TGRS.2016.2607122.

Benefits of the Adaptive Retracker for Improving Jason-3 GMSL Estimates

Thibaut et al. discussed work done for the Jason-3 GDR-F reprocessing campaign. The adaptive retracker, which has been presented at previous at OSTSTs, was implemented together with other improvements to the geophysical corrections. The outputs of the adaptive solution will be provided in the GDR-F products in addition to the historical MLE-4 solution. The key feature of the adaptive retracker is that it uses the real current PTR numerically thus natively accounting for PTR drifts/changes. It was noted that the lookup tables related to PTR shape for MLE-4 were computed only once at the beginning of the mission, but the drift of the PTR peak (internal path delay) is updated daily. Changes in PTR characteristics – total power, internal path delay, main lobe width, difference of first side lobe widths – for several missions were shown. Range changes are at the millimeter level. Jason-3 characteristics are similar to other missions. The key changes of total power affecting sigma0 and internal path delay are routinely corrected by calibration monitoring.

An in-depth analysis of the differences between the MLE4 and the Adaptive solutions was performed with particular attention paid to the instrumental drifts directly impacting the GMSL estimation. The adaptive algorithm showed differences with the MLE4 solution: bias of 7 mm, jumps of up to 0.5 mm at instrument resets, and a long term drift of ~0.2 mm/yr. These differences show that inclusion of the full PTR in processing is important for securing the GMSL record.

Impact of the Ocean Waves on the Delay/Doppler Altimeters: Analysis Using Real Sentinel-3 Data

N. Tran et al. evaluated some the expected effects from waves on delay-Doppler altimeters using Sentinel-3 data processed with the CNES prototype (S3PP). Parameters from three wave models (mainly ERA-5) were used in the analysis. The work expanded on results presented at the OSTST in 2019. They found generally good agreement between the predictions and observations. In particular, there is no bias in range estimates.

Doppler altimeters, which use the satellite motion to improve the measurement resolution, assume that the surface is stationary. If the surface motion is not negligible, the processing assumptions are no longer valid, and the final performance may be impacted. The largest effects are expected on SWH measurements and range noise. Large positive biases between the S3A SAR mode SWH estimates and the low-resolution mode data may be explained by the waves’ orbital velocities that affect the Doppler signal. This phenomenon is not linked to swell and is independent of the wave propagation direction. Swell with high wavelengths propagating in the same direction as the satellite causes a significant increase in noise on the range and SWH estimates. Fortunately, the effects do not grow strongly with SWH above 3 m; effects are somewhat different (and less) for SWH < 2 m. Effects on range are somewhat stronger and more variable and need to be further investigated.

Since wave direction is available from the models, those effects were also investigated. Several measures of wave period were also used. There are fairly clear effects suggesting nonlinear mechanisms, but additional analysis is need.

Investigating SAR Altimetry over the Great Salt Lake – Comparing SAMOSA+/++ and ALES+ SAR

M. Wenzl et al. investigated two Sentinel-3 tracks over the Great Salt Lake with an eye to using altimetry over inland waters (Figure 3.4-3). They used the ESA G-POD/SARvatore online and on-demand processing service for the exploitation of CryoSat-2 and Sentinel-3 data (https://gpod.eo.esa.int/services/SENTINEL3_SAR/) and obtained results from the SAMOSA+ and SAMOSA++ retrackers tailored for inland water. In addition, the new ALES+ SAR processer for Sentinel-3A/B, developed within the current ESA Baltic+ SEAL project (http://balticseal.eu/), was used. The ALES+ SAR retracker (sub-waveform/leading edge as also discussed by Ichikawa), tailored to coastal regions but not specifically designed for the inland water, was applied to the official S3 processed data as well. It should be noted that ALES+ uses a simplified Brown-Hayne waveform model which is not entirely appropriate for SAR waveforms. Empirical retracker outputs, available in the official 20-Hz Sentinel-3 LAN products, were also considered. The water flag in GPOD/SARvatore was used to identify the water areas. There was significant off-line discussion about the use of empirical vs physical retracking approaches. The development of a physical model for highly variable coastal or inland water areas would likely be a major undertaking.

Figure 3.4-3. Great Salt Lake study area. Two gauges are shown with yellow pins.

Filtering (Pulse Peakiness, Misfit, ALES+ SAR quality flag) for likely corrupted waveforms was applied. The data were then compared based on distance to two gauge stations. Results depended more on specific conditions of the track to shore geometry rather than distance. SAMOSA+ generally performed better. Filtering improved the agreement in some cases, but in many cases did not provide much improvement.

3.5 Instrument Processing: Propagation, Wind Speed and Sea State Bias

Chairs: Shannon Brown, Estelle Obligis, Marie-Laure Fréry

The instrument processing corrections splinter focused 1/ RFI, 2/ Improvement in WTC retrieval algorithms, 3/ new SSB model for TOPEX and 4/ Sentinel-6 AMR-C status.

1/ RFI impact (particularly important in the framework of the future deployment of the 5G network) is a serious concern that could impact the ability of future altimeter missions to provide accurate wet tropospheric path delay corrections. A new method has been presented enabling the detection of low amplitude interference and potential flagging of contaminated data (Figure 3.5-1). The method is based on the TB spectrum, showing a different behavior in the presence of RFI, with additional energy where we would expect only white noise.

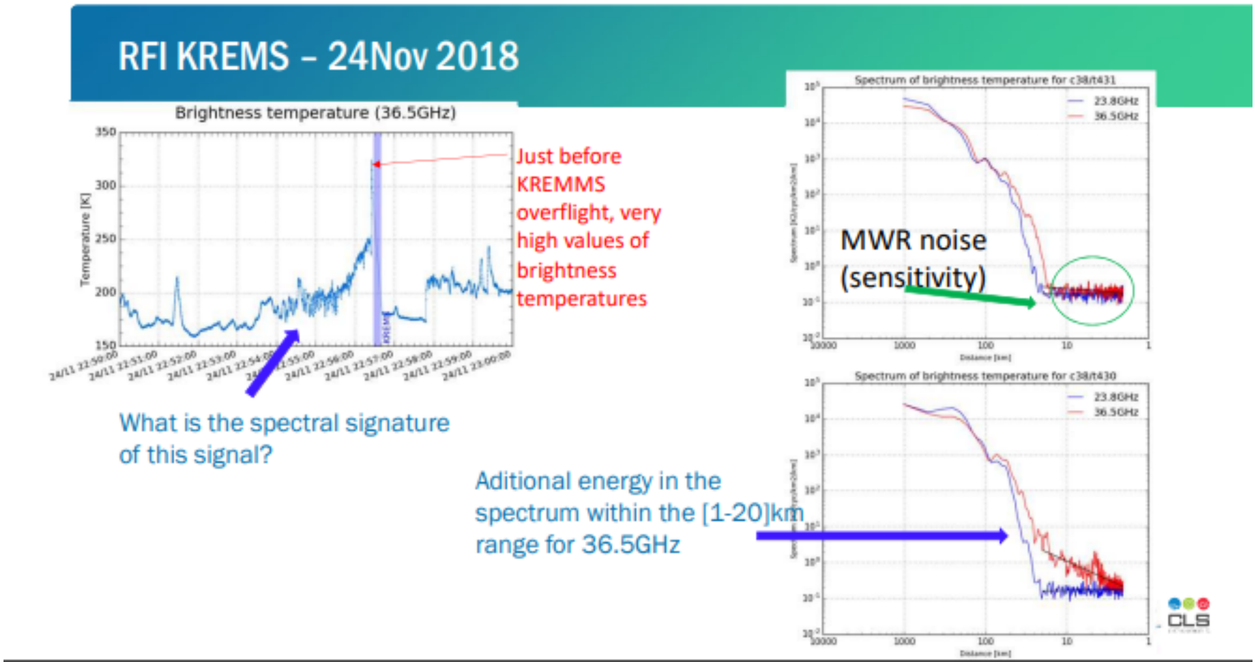


Figure 3.5-1. Impact of RFI on TB spectrum

2/ The community still work on the improvement of Wet Tropospheric Correction retrieval algorithms. Performances of different algorithms, using different inputs on top of the brightness temperatures measured by the Sentinel-3 Microwave Radiometer, have been compared (Figure 3.5-2). It is confirmed that SST brings useful information to retrieve WTC and once the short time-scales are included, the fifth input (γ800) becomes redundant and unnecessary. A new algorithm is proposed that decreases the RMS values of WTC differences by about 1 mm globally, and up to 3mm in coastal areas.

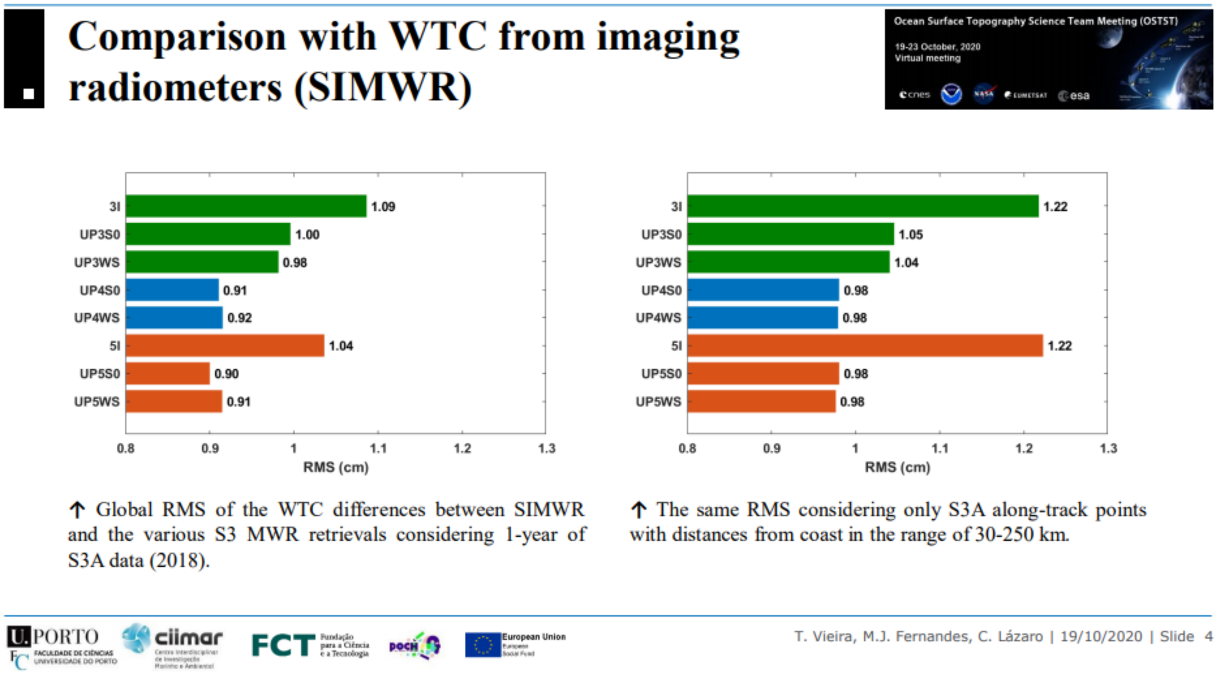


Figure 3.5-2. Performances of different WTC retrieval algorithms compared.

3/ A new method called LSQI was presented to retrieve TOPEX sea state bias. It was developed as a simple and efficient approach to nonparametric SSB modeling, that also allows for a direct means to generate an SSB error budget. The joint measurements provided as the observables to the model consist of both crossover and collinear difference measurements. The measurement combination utilizes the high temporal resolution of the crossover measurements, along with the high spatial resolution of the collinear measurements. The LSQI model performance is similar to the one provided on the Jason-2 GDR-D products (Figure 3.5-3).

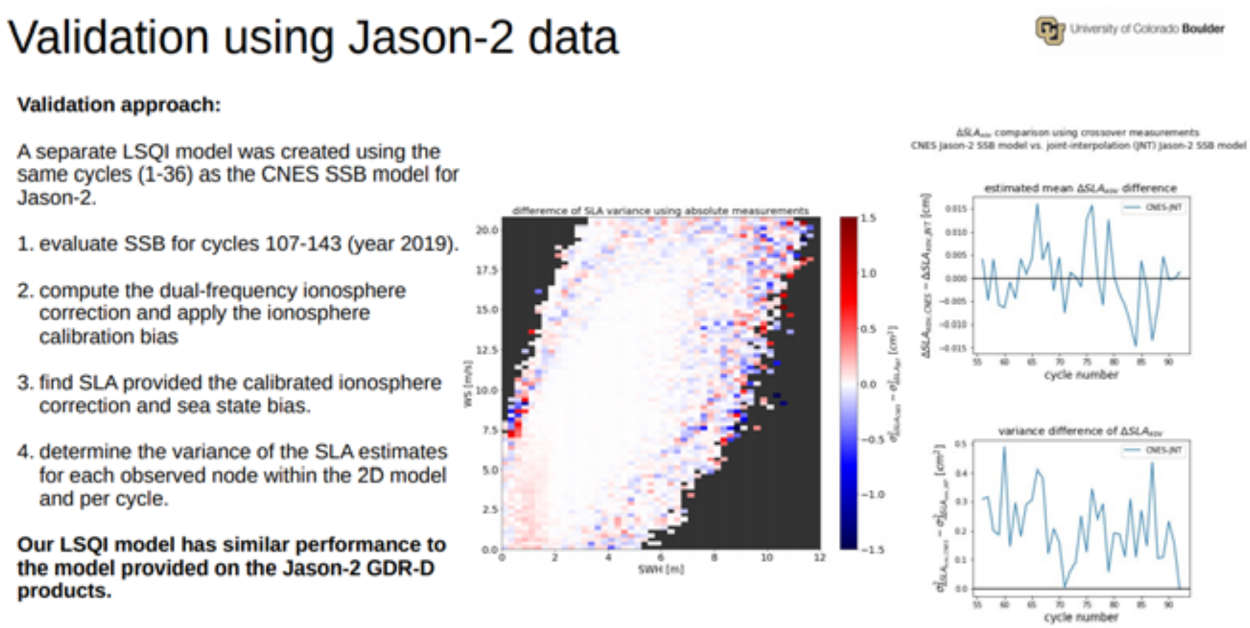


Figure 3.5-3. Performance of the new LSQI model for TOPEX SSB.

4/ One month before launch, a status on Sentinel-6 AMR-C Instrument was provided (Figure 3.5-4). For AMR-C, there is specific requirement to measure path delay with absolute stability of 1mm/year (was only a goal for Jason-3). This drives the addition of a on-board Supplemental Calibration System (SCS). Also a High Resolution Microwave Radiometer (HRMR) is added as a technical demonstration with three high-frequency (90, 130, and 168 GHz) channels to provide higher resolution path delay correction in coastal regions where heritage AMR measurements are degraded by land contamination. In conclusion, AMR-C is expected to reduce the wet path delay component of the GMSL trend uncertainty to a negligible level and HRMR will demonstrate new capability for increasing the accuracy of PD up to the coast line.

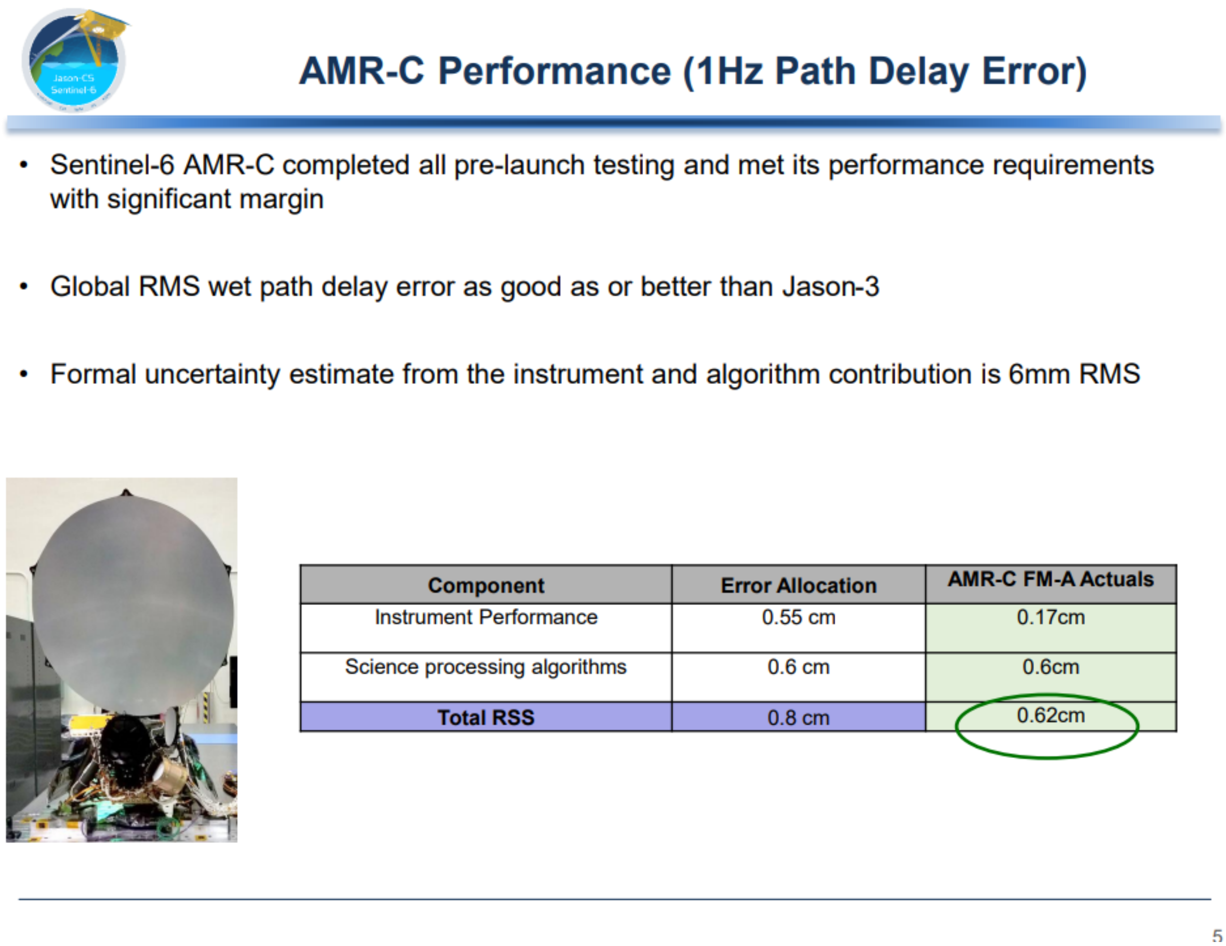


Figure 3.5-4. Error budget for Sentinel-6 WTC.

3.6 Outreach, Education & Altimetric Data Services

Chairs: Jessica Hausman, Vinca Rosmorduc and Margaret Srinivasan

3.6.1 Session presentations:

- The BRAT and GUT Couple: Broadview Radar Altimetry and GOCE User Toolboxes, Jérôme Benveniste
- The ALES+ SAR Service for Cryosat-2 and Sentinel-3 at ESA GPOD, Marco Restano
- SAR and SARin Altimetry Processing on Demand for Cryosat-2 and Sentinel-3 at ESA G-POD, Marco Restano
- Outreaching hydrology from space & SWOT (updates), Vinca Rosmorduc
- Argonautica, altimetry from kindergarten to engineering school, Danielle de Staerke
- Altimetry Applications Program Status, Margaret Srinivasan

- The Aresys FF-SAR Service for Cryosat-2 at ESA GPOD, Marco Restano
- Increasing satellite oceanography literacy and research in West Africa-the role of data availability, Ebenezer Nyadjro
- Waves of Change: Ocean Surface Topography Updates from PO.DAAC, Jack McNelis

3.6.2 2019-2020 Highlights

The ideas proposed last year around virtual meetings were in part tried this year, even though it was not with the goal of lowering our carbon footprint.

The session had a rather small share of submissions from outreach and education as well as from data services compared to previous years. One possible reason may be a smaller number of outreach, training or education 'in person' events this year due to the pandemic. On the data services side, due to the incoming launch of Jason-CS Sentinel-6 Michael Freilich. globally, no new activity arose this year.

The fact that there are few 'debatable' topics in outreach or data services probably contributed to the small number of exchanges on the forum.

The demo format was not implemented online this year, due, in part, to reduced planning timeline. In any future virtual meeting, this could be achieved through a link to webinar(s) or screencast tutorials.

3.6.3 Data services

Data Services provide a method and process for exchanging information and linking projects and users for greater benefit from the wide variety of altimetry-derived available datasets.

Updates of data services were shared from NASA PO.DAAC.

ESA presented on the existing tools, Grid Processing On Demand (GPOD), GOCE User Toolbox (GUT) and the Broadview Radar Altimetry Toolbox (BRAT), and also showed two new waveform processers (available through GPOD).

3.6.4 Outreach

An update of the SWOT efforts on Aviso was proposed, as well as altimetry applications features on JPL web site.

Outreach and communication for Jason-CS/Sentinel-6 Michael Freilich launch was not covered in the session, even though a very active campaign is ongoing from ESA, EUMETSAT and NASA, especially on social media.

3.6.5 Education

In Argonautica, an “ArgoHydro” data portal is available using for now existing satellite data (water levels from Hydroweb) with the idea of integrating other types of data in the future, including of course ultimately, SWOT data. A new “DIY” buoy is now available to use in the “ArgoTechno” projects, where the students are building their own buoy. The aim was to propose a more buoyantly robust system which would be less susceptible to sinking than the shells previously used.
The Argonautica project has registered nearly 600 classes total for the 2020-2021 period.

3.6.6 Training

How and where to retrieve data, how to read at the most basic level, and how to process data seem to be important topics that are not always broached in formal curricula. Development of such training events seems interesting both for the users and for the Projects.

A number of training events were organized this year, most switching from completely or partially in person, to fully virtual. Among them:

- The training in Ghana was conducted by Ebenezer Nyadjro
- D. Cotton answered a question about outreach they are planning in the Hydrocoastal project by mentioning a future online tutorial for user training on their output data.
- Eumetsat and CMEMS are continuing their training sessions online, with some altimetry included in some of them.
- The SWOT Hackathon aimed at training “early adopter” users for use of SWOT data after launch in 2022.

Most reported trainings seem to be either in Europe, the EU or by US OSTST members working in developing countries. Training events in the US were not reported on in the outreach and data services session.

3.6.7 Discussion

Questions were asked on feedbacks / user statistics, plans for the future in particular for trainings, or possible outputs of some data services.

No discussion on Jason-3 end-of-life activities occurred.

3.6.8 Recommendations

- Virtual meeting

The forum format was not that successful for the outreach and data service session. A ‘discussion’ space, or questions asked instead of an abstract might be more interesting for the outreach and data services session than questions on formal “presentations” only.

We, therefore, recommend that for future virtual OSTST meetings, registrants and/or chairpersons be able to post questions for everybody, in advance or not, to feed discussion when the usual presentations do not lead to many questions.

Pre-registering for a session could be useful to organize a time for a virtual meeting, other than just the authors who submitted, as well.

- Future meeting topics

No new activity arose this year. Part or most of outreach events planned in person were cancelled, but a number of online initiatives developed, and feedbacks from those would definitely be interesting. We should explicitly mention that aspect in the next call for proposals.

A presentation on feedback from the Jason-CS/Sentinel-6 efforts, and especially the social media aspect of it, would also be interesting in a future meeting.

- Developing exchanges on outreach and training

A workshop format on the training material or on outreach 'good practices' is of interest to propose within the OSTST time frame, but would need to be prepared with very concrete questions, material to exchange, etc. And possibly an output required from attendees – e.g. present their own technical presentation in short (~three minutes) blocks for an audience to be defined, draw lots on OSTST abstracts and try to outreach or explain the one selected to (e.g.) graduate trainees… etc.

- Note: Recommendations from last year largely still apply (in bold some addition):

We recommend that the demo format is kept as part of the program, with announced hours/topics for improved access and attendance if done in person. **Recorded webinars/screencasts could be proposed online**; and projected on a screen during the meeting (optimally, the demo screen should be situated in the very middle of the poster area, and/or close to the coffee to make it more accessible to the ST community during the meeting).

We plan to continue inviting personnel from local informal science venues such as museums and science centers to present at the OSTST.

To advance coastal, hydrology, cryosphere, and ocean altimetry, the outreach team propose that tutorials on coastal altimetry, hydrology and cryosphere tools/data products are developed to further use **and reported/mentioned/listed somewhere, as well as calls for those.**

3.6.9 New Planned Efforts

The focus of the outreach team for the coming years will be on climate and hydrology education, public outreach, as well as on applications outreach for all of the current and especially the upcoming ocean altimetry missions—Jason-CS/Sentinel-6 and SWOT. The anticipated elements of this focus (not withstanding new opportunities) will include:

- SWOT education & public outreach
- SWOT Applications focus on Early Adopters and other applied science users
- Jason-CS/Sentinel-6 Michael Freilich
- Training events
- A Eumetsat training session could be organized between the Ocean from Space and the OSTST meetings in 2021.

3.7 Precise Orbit Determination

Chairs: Sean Bruinsma, Alexandre Couhert and Frank Lemoine

3.7.1 Status of OSTST satellite POD

The Centre National d'Etudes Spatiales (CNES) gave a status of the performances of the POE-F (DORIS+GPS reduced-dynamic) orbits of the current altimeter missions Jason-3, Sentinel-3A/B and HY-2A. The POE-F performance is satisfactory on all missions, with excellent statistics for the independent SLR measurements as shown in Figure 3.7-1.

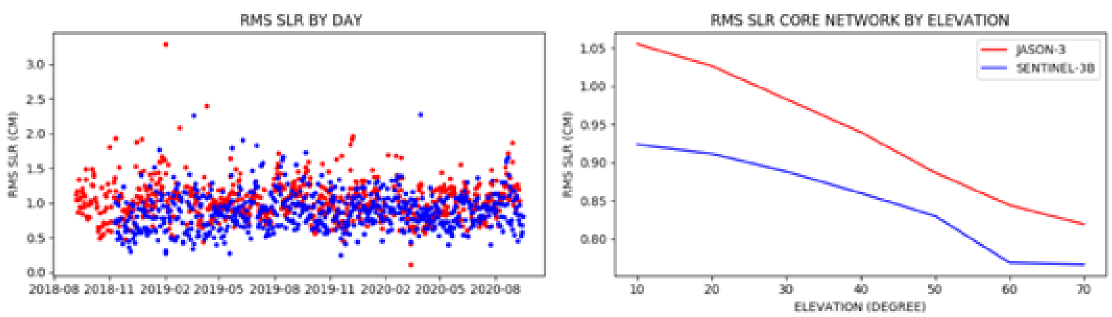


Figure 3.7-1. The RMS of the SLR residuals on Jason-3 and Sentinel-3B, per day (left frame) and as a function of elevation (right frame).

Presently, preparations are ongoing for the new altimeter missions Sentinel-6 MF and HY-2C.

Goddard Space Flight Center (GSFC) presented their recently updated orbits based on updated standards and a complete reprocessing: GSFC std2006 (DORIS+SLR dynamic). The importance of employing the most accurate gravity models including time variability (TVG) was shown, and notably having this information before 2002, i.e. the GRACE era. Biweekly 5x5 SLR+DORIS 17 satellite TVG solutions (tvg0075) were computed to ensure a consistent background model over the entire T/P and Jason period from 1992-2020. The satellite data used in the construction of tvg0075 is shown in Figure 3.7-2.

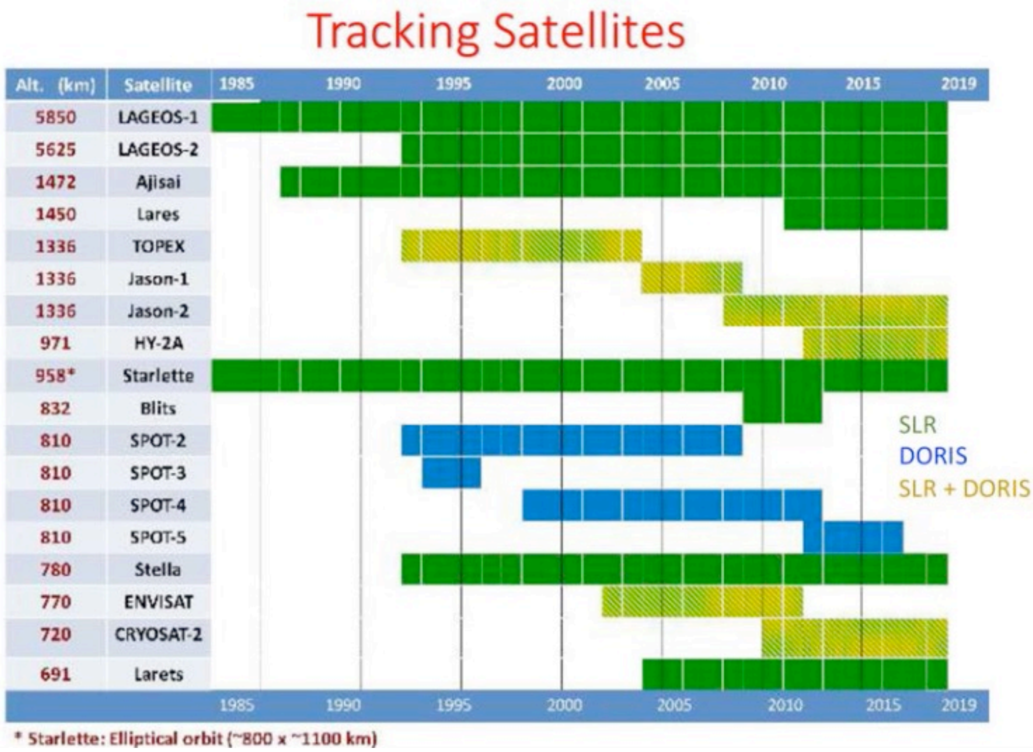


Figure 3.7-2. The contribution of the satellites used in tvg0075.

Comparisons to independent orbits (CNES/POE-F, JPL/Reduced-dynamic orbits) show RMS radial orbit agreement of 5-7 mm for Jason-3 for the new std2006 orbits, compared to 7-9 mm radial RMS agreement for the previous version std1504_dpod2014 of orbits, as shown in Figure 3.7-3 for the comparison with POE-F. Similar comparisons on SSH differences also demonstrated the higher accuracy of std2006.

The std2006 orbits will be made available through the NASA GSFC NCCS data portal.

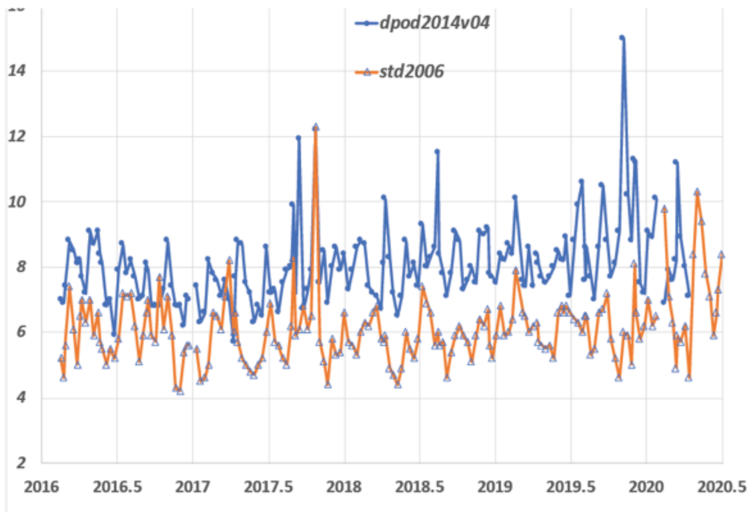


Figure 3.7-3. The RMS of the Jason-3 radial orbit differences between std2006 and the previous version std1504_dpod2014, and CNES POE-F.

Jet Propulsion Laboratory (JPL) presented results on the investigation of the use of high rate GPS tracking data for Jason-3 precise orbit determination. Since the receiver provides the data at 10 sec cadence, the heritage approach of using 5-minute sampling could be tested against using a higher data rate. In this study, a data rate of 30-seconds using 3 data weights were tested, with or without elevation-dependency.

Comparisons with independent SLR data showed similar performance of all GPS-only solutions, and the RMS of orbit overlap differences also.

The higher data rate of 30-seconds does not lead to noticeable improvement in Jason-3 GPS-based orbits, but future work will consider down-weighting PC data to account for higher data noise at higher cadence.

3.7.2 Status of complementary mission POD

The non-reference missions, with lower altitudes and higher inclinations than the OSTST satellites, also contribute to the altimeter constellation and enhance the global coverage.

PosiTim presented evolutions in Sentinel-3 orbit determination for the Copernicus POD Service, which is in charge for the POD of Sentinel-1, -2, -3. For Sentinel-3 NTC POD, the background models were updated in April 2020, and notably more recent and more accurate gravity models (TVG, ocean and atmosphere tides) are presently employed. Also, new orbit parameterizations were tested and a solution (F+) with 21 more parameters than estimated in CPOD OPER compares very well now with the combined orbit of the Quality Working Group (QWG). This is shown if Figure 3.7-4. In any case, the target accuracy of 2 cm radial for Sentinel-3A/B is easily reached.

The switch to the new orbit parameterization can be made after approval by the Copernicus POD QWG.

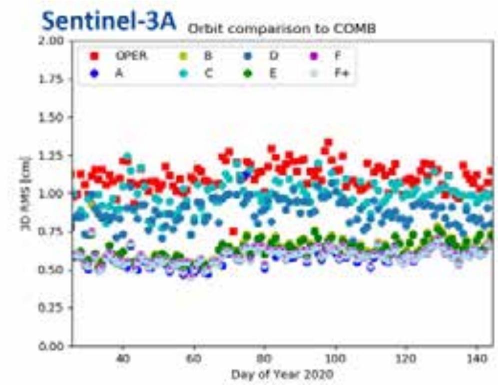


Figure 3.7-4. The 3D RMS difference of the tested orbit parameterizations and the operational orbit (red) compared with the QWG combined orbit.

CNES presented a study on using GPS-derived clock corrections to model the USO of the DORIS measurements, both on board and on ground. On Sentinel-3A and B, the DORIS and GPS receivers are connected to the same USO, while certain GNSS REGINA (**RE**seau **G**NSS pour l'**I**GS et la **Na**vigation – global GNSS station network operated by CNES and IGN) stations and DORIS beacons are similarly connected on ground.

The effect of 1) estimating df/f parameters on station/dynamic parameters, 2) the precision of the modelling of the DORIS phase measurements with the GPS-derived corrections, and 3) substitution of DORIS by GPS-inferred df/f corrections were assessed.

The conclusions are as follows:

1. It has a considerable impact on the observation of the along-track errors: the change of the ground clock correction has the most significant effect (up to few centimeters, see Figure 3.7-5);

2. GPS- and DORIS-derived clock corrections have the same performance, the former leading to better performance at high elevations;

3. It partly explains the along-track errors of the DORIS-only orbit, and it can correct for these errors locally.

Increasing the number of collocated DORIS/REGINA stations is expected to lead to a much larger improvement of the along-track errors.

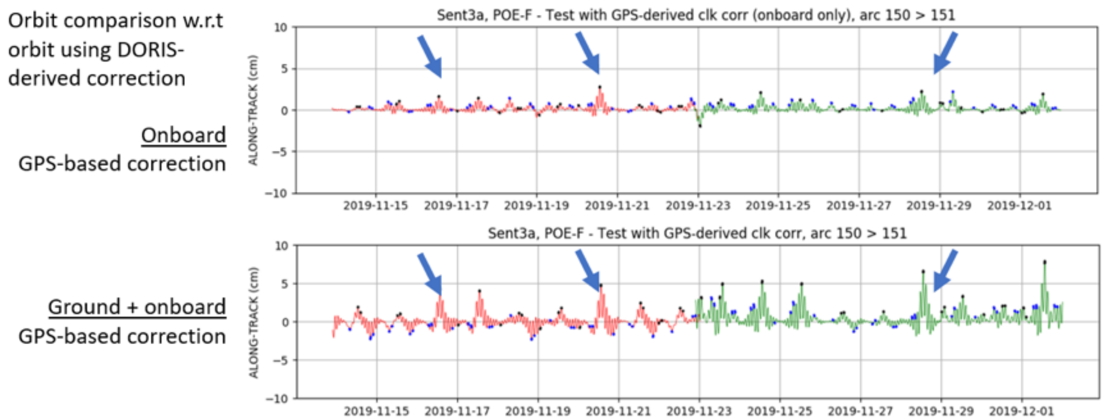


Figure 3.7-5. Orbit differences when using on-board and on-ground GPS clock corrections.

3.7.3 Tz geocenter signals in Jason-3

A new approach, based on using data specifically around flip events, to better monitor residual normal perturbations and estimate geocenter motion along the South-North axis (Tz) was presented by CNES. It allows to delineate radiation errors and thermal effects from Tz geocenter motion. By taking the miscentering thus estimated into account and using GPS integer ambiguity fixing, the annual Tz geocenter amplitude is much reduced, as can be seen in Figure 3.7-6. Unfortunately, this new approach, based on the observation of normal perturbations, cannot be used with GPS float ambiguities and DORIS data, because the observability of these measurements in the cross-track direction is not strong enough. Complementary analyses will be performed with SLR data and also to explain the lower annual Tz geocenter amplitude obtained with this new approach.

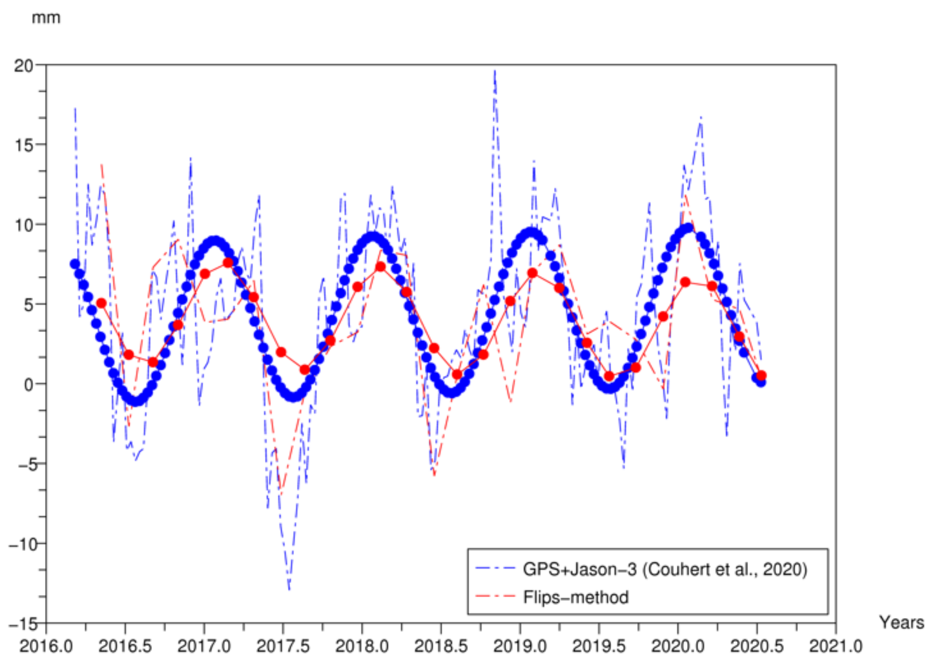


Figure 3.7-6. The estimated Tz with Jason-3, and the fitted annual signal (solid symbols)

In view of the results of this and previous studies, the OSTST POD group has recommended to maintain the yaw flips for the Sentinel-6/Jason-CS mission.

3.8 Quantifying Errors and Uncertainties in Altimetry Data

Chairman: Michael Ablain, Remko Scharroo and Joel Dorandeu

3.8.1 Overview

Objectives of this session are to strengthen the link between altimetry experts and applications regarding errors in the altimetry system. This covers information exchange in both directions: the exports informing the end-users about new insights about errors in altimetry, and the end-users providing their needs and requirements in terms of errors but also in terms of error formulation.

The splinter was composed into 7 presentations, each of them tackling the error topic with a different approach:

- **Error formalism and method:**
    - Benefit of a second calibration phase to estimate the relative global and regional mean sea level drifts between Jason-3 and Sentinel-6a (**Michaël Ablain, Magellium**)

- What sea-level drifts can be detected at global and regional scales by comparing recent altimetry missions together: S3A, Jason-3 and Saral-Altika? (**Rémi Jugier, Magellium**)

- Implicitly localized MCMC sampler to cope with nonlocal/nonlinear data constraints in large-size inverse problems (**Emmanuel Cosme, IGE**)

- **Error detection and characterization:**

  - Revised uncertainties of the Global Mean Sea Level biases between the Topex & Jasons reference missions (**Adrien Guerrou, CLS**)

  - Long-Term Assessment of Sentinel-3 NRT Wind and Wave Data (**Saleh Abdallah, ECMWF**)

- **Error reduction:**

  - Regional changes in Ka-band SSH related to influence of SST and mean wave period on altimeter backscatter coefficient (**Ngan Tran, CLS**)

  - Lessons learned from Sentinel SARM missions in preparation of Jason-CS – Progress made (**Emeline Cadier, CLS**)

3.8.2 Recommendations

The main recommendations of the session have been listed hereafter:

Recommendation#1: A second tandem phase between Jason-3 and Sentinel-6a should be envisaged in order to be able in the future to verify the sea-level stability requirements (C3S) at global and regional scales, which cannot be achieved with the current calibration tools.

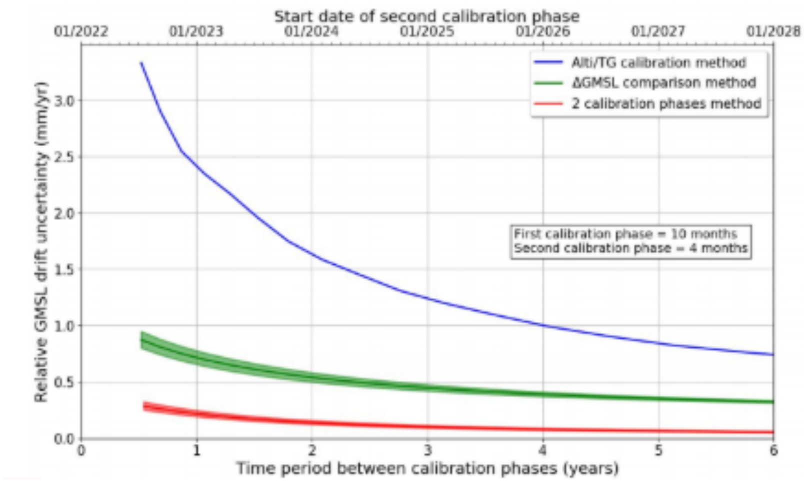


Figure 3.8-1. Evolution of the relative GMSL drift uncertainties with the time period between the two calibration phases between Jason-3 and S6A for the different calibration methods - The duration of the second calibration phase was arbitrarily set at 4 months and present significant improved results. Details are available in Ablain et al., 2020, https://www.essoar.org/doi/10.1002/essoar.10502856.2.

Recommendation#2: Continue to improve the estimation of sea-level uncertainties by proposing innovative mathematical formulations and refined uncertainty calculations (e.g. a new estimate of the uncertainty of the GMSL bias), which is of major interest for climate change studies.

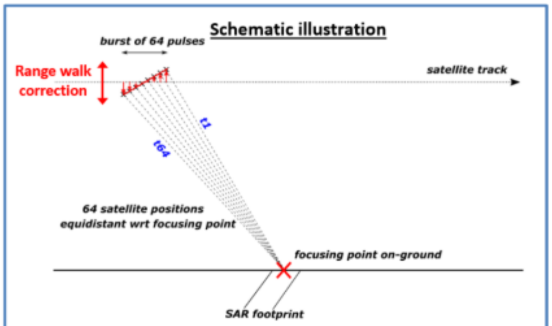
@ 1-sigma	TOPEX-A/B Jason-1	Jason-1 Jason-2	Jason-2 Jason-3
GMSL bias uncertainties [mm]	0.8 *[0.65/0.97]**	0.40 *[0.25/055]**	0.37 *[0.2/0.5]**

Figure 3.8-2. New estimation of the inter-mission GMSL bias uncertainties of the four reference missions: 0.8 mm for TOPEX-B/Jason-1 ; 0.4 mm for Jason-1/Jason-2 and Jason-2/Jason-3 (Guerou et al., in prep.)

Recommendation#3: Continue to learn on altimetry errors and make progress on altimetry measurements (e.g. Sentinel-3a measurements, new SSB correction based on wind speed taking into account SST) in order to reduce the sea-level error budget at all scales.

- 0.3 mm/year are due to the evolution of PTR shape in range direction (ageing of the instrument) not correctly accounted for in the MLE4 (PLRM) and SAMOSA DPM2.5 (SARM) retrackers *(JC.Poisson / S.Dinardo OSTST 2019).* Retrackers using the **real instrument PTR** allow to correct this effect (eg: adaptive retracker, see P. Thibaut et al. presentation in instrument processing session)

- About 1.3 mm/year are due to the evolution of PTR shape in azimuth direction (ageing of the instrument). A recent study **(see J. Aublanc et al. presentation in instrument processing session)** showed that the implementation of the **range walk correction** (Scagliola et al., 2019) allows to correct the range drift induced. Only the SARM is impacted.



***Objective of the range walk correction :** to compensate the range variation during the burst acquisition wrt focusing point.*

Figure 3.8-3. One of the main achievement this year at OSTST, 2020 is the understanding of the significant drift detected on the S3A GMLS trend last year (Ablain at al., 2019): about +1.3 mm/yr. See Cadier's talk (this splienter) and Aublan's talk (Instrumental splinter).

3.8.3 Error splinter needs

The splinter encourages:

- **Need for systematic (and rigorous) uncertainty estimations, need for agreed formalism**
  - Standard uncertainty formulation: drifts, calibration/Validation results, climate signals
  - Input for applications: a) Assimilation into ocean models, b) Climate studies: MSL close out budget, c) Some gaps to fill: variance/covariance matrix of Orbit Errors and MWR WTC for, e.g. local MSL trend estimates
- **Improving the involvement of user community (e.g. from assimilative systems) in OSTST in order to better understand their needs in terms of data quality and uncertainty requirement**
  - Open question: forum should we target? Ocean, Hydro, Climate, etc. communities
  - How to make then contribute, then report (feedback) in OSTST

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

Chairs: Pascal Bonnefond, Shailen Desai, Luisella Giulicchi, Bruce Haines, Eric Leuliette, and Nicolas Picot

3.9.1 Introduction

Determining the random and systematic errors in the fundamental instrument observations and in the Level-2 geophysical data products is a continuing process that involves participation of both the project teams and the OSTST investigators. The principal objectives of joint verification are to:

- Assess the performance of the measurement system, including the altimeter and orbit-determination subsystems;
- Improve ground and on-board processing;
- Enable a seamless and accurate connection between the current (OSTM/Jason-2 and Jason-3) and legacy (TOPEX/Poseidon and Jason-1) time series, but also prepare the connection between Jason-3 and Sentinel-6/Michael Freilich
- Enable the development of Level 3 and Level 4 products by an accurate analysis of any regional bias between the reference mission and the other flying altimeters (currently SARAL/AltiKa, Sentinel-3A & B, CryoSat-2, HY-2).

To succeed in these objectives, the general approach is to pool the talents and resources of the project and science teams. Engaging the science team in the continuous CALVAL effort has been one of the hallmarks of success for the TOPEX/Poseidon and Jason altimeter programs. The CNES and NASA research announcements have consistently emphasized CALVAL, recognizing that the science investigators conducting research in some of the most demanding applications (e.g., mean sea level) are often positioned to offer the most innovative CALVAL solutions.

During the first 6 months of each new mission (12 months for Sentinel-6/Michael Freilich), an intensive verification effort is conducted by all members of the Verification Team in order to verify the integrity of the system—and to perform adjustments where necessary—before starting the routine GDR production. However, the verification effort continues afterwards on a routine and permanent basis. These ongoing efforts are essential for understanding and minimizing regionally correlated errors, and for ensuring the integrity of the long-term climate record at the 1-mm/yr level.

CALVAL activities are conducted based on dedicated in-situ observations, statistics, cross comparisons between models, different algorithms and external satellite data. The studies go well beyond validation of the overarching error budget underlying the mission requirements. They focus in particular on the temporal and geographically correlated characteristics of the errors. Reduction of this class of errors is critical, since they are conspicuously damaging to estimates of ocean circulation and sea level. CALVAL activities also encompass issues related to data return, such as data editing and flagging. We also encourage CALVAL presentations on specialized topics, such as the characterization of SSH in Arctic Ocean sea ice leads, and the examination of the impacts of SWH, swell, and roughness on SSH data quality.

Because of the usual large number of contributions, the CALVAL splinter is separated into two parts:

- Local CALVAL (focusing on bias estimates from in-situ measurements) and
- Global CALVAL (focusing on relative SSH biases between different missions, the assessments of correction terms and error budget).

This year's Cal/Val sessions consisted of 15 virtual presentation (7 in-situ, and 8 global). Presentations spanned calibration and/or validation results with in-situ or global methods from numerous missions ranging from TOPEX/Poseidon, Jason-2 and -3, Sentinel-3A and 3B, HY-2B, SARAL/AltiKa, and CryoSat-2.

Results from in-situ calibration sites

The latest (2020) results from the dedicated in-situ calibration sites (absolute SSH biases) are summarized in Table 3.9-1 and **Erreur ! Source du renvoi introuvable.**. The results continue to show good overall consistency among legacy and current missions, but particularly for Jason-2 and -3. Four years into the mission, the Jason-3 SSH bias estimates are stabilizing, and the overall results are in keeping with prior-year (2019) results. There are some minor changes due to the accumulation of additional overflights, and also to the evolution of in-situ models (e.g., land motion) and techniques. The Jason-3 SSH bias estimates from the four primary sites are all slightly negative (SSH too low) and tightly clustered in the range of –4 to –12 mm (σ = 3 mm). Analysis continues to support that all Jason-3 data products (OGDR, IGDR and GDR) are of very good quality, and show small differences with Jason-2 during the verification phase. Jason-3 SSH, however, remains slightly lower (by 2 cm on average) than comparable values from Jason-2. Detailed analysis shows that this relative SSH bias is due mainly to the Ku-band range, but probably also to the C-band range. Together, they lead to smaller (by < 1 cm) ionosphere delays for Jason-3.

As was noted in the 2019 report, the Jason-1 (GDR-E) results depict a persistent and puzzling discrepancy. Results from three sites (Bass Strait, Corsica and Gavdos) are clustered tightly together, yielding positive SSH bias estimates in the range of 4–5 cm. Observations from Harvest, on the other hand, yield a significantly lower bias (<1 cm), consistent with the comparable Harvest result for Jason-2 (GDR-D). Work is underway to better understand the allocation of errors contributing to this discrepancy.

Absolute SSH bias estimates for all reference (Jason-class) missions, including the original TOPEX/POSEIDON mission, are in the range of –1 to +4 cm. The specific sources of larger (decimeter-level) biases that have plagued historical versions of the data products have been gradually identified and removed, a decades-long process that has been informed by careful and continuous monitoring from the dedicated (absolute) calibration sites, using disparate measuring technologies (tide gauges, moorings and transponders). The focus has now turned to smaller (1–3 cm) discrepancies that are attributable to systematic, site-specific in-situ errors and geographically correlated patterns in the altimeter measurement system errors but also non-homogeneous standards for the different products. Reprocessing of the Jason series to

GDR-F processing standards is underway. A consistent processing standard should better reconcile the results from different sites and/or better expose site-specific in-situ errors and geographically correlated patterns. We also note that a major update to the TOPEX data product to the same (GDR-F) processing standard is imminent. While preliminary results were shown at this meeting, the evaluation of this reprocessed product will be a significant focus of the coming year (see Talpe et al. presentation).

Regional calibration techniques are routinely employed at the dedicated sites to monitor altimetric missions that are not flying on the reference (10-d repeat) ground track. The latest results for Sentinel-3A indicate that SSH observations remain very stable, and that the overall bias is statistically indistinguishable from zero. Results from the newer Sentinel 3B mission (April 2018 launch) are stabilizing with additional overflights. These results suggest SSH data from this new (3B) mission are well aligned with comparable values from its predecessor (3A) mission (cf. Table 4.9-1).

Mission	Bass Strait	Harvest	Corsica	Gavdos	Average
TOPEX-A	+8 ± 2	–3 ± 2	+25 ± 8		+10 (σ = 14)
TOPEX-B	+19 ± 3	–3 ± 4	+24 ± 4		+13 (σ = 14)
Jason-1 GDR-E	+46 ± 2	+6 ± 2	+43 ± 3	+41	+34 (σ = 19)
Jason-2 GDR-D	+19 ± 2	+5 ± 2	+16 ± 2	+5	+11 (σ = 17)
Jason-3 GDR-D	–7 ± 2	–12 ± 3	–7 ± 3	–4 ± 4	-8 (σ = 3)
Sentinel 3A	+24 ± 2		+17 ± 4	-8 ± 5	+11 (σ = 17)
Sentinel-3B	+50 ± 3		+20 ± 8	+3 ± 7	+24 (σ = 24)

Table 3.9-1. Absolute SSH bias values (in mm) for different missions and from the different calibration sites (using in-situ SSH measurements).

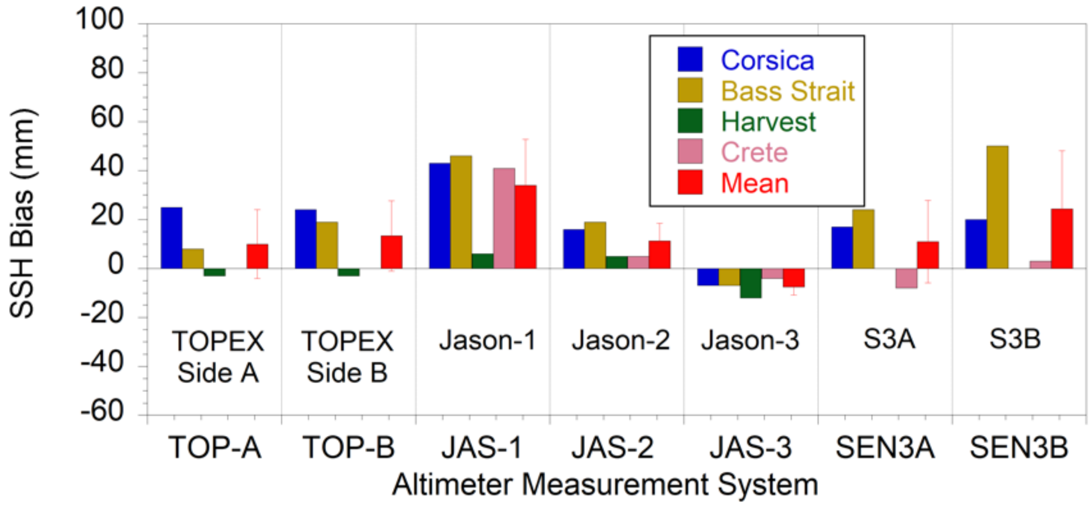


Figure 3.9-1. Absolute SSH bias values (in mm) for different missions and from the different calibration sites (using in situ SSH measurements).

Esselborn et al. also presented regional results through an assessment of Jason-3 and Sentinel-3A precision at six tide gauge stations in the German Bight (SE North Sea). The precision of Jason-3 (02/2016-12/2019) and Sentinel-3A (04/2016-12/2019) altimetry is assessed at 6 collocated tide gauge stations in the German Bight (tide gauge stations are georeferenced by GPS, with data every minute). The results showed an excellent correlation at all stations ($\geqslant$ 0.997) and RMS error of 2.9-3.0 cm for Jason-3 at the open ocean (coast) and 3.1-6.1 cm for Sentinel-3A.

The transponder technique is showing increasing promise in contributing to the understanding of the overall measurement system, and offers a unique perspective on the fundamental behavior of the altimeter in isolation from sea-state effects. The permanent transponder installed in Crete at a crossover point of the Jason and Sentinel-3 ground tracks continues to provide absolute calibration results focused on the altimeter range component of the measurement systems. Mertikas et al. reported range biases of +5 mm for both Jason-3 and Sentinel-3A and -3 mm for Sentinel-3B (We note that the range bias is by definition opposite in sign to the SSH bias). The interest of transponder technology is also highlighted by Garcia-Mondejar et al. for monitoring and calibrating backscatter (σ_0) from a radar altimeter. Before operationally implementing the refurbished Envisat σ_0 transponder (ESA/ESRIN), a field test campaign with 6 acquisitions of Sentinel-3A and 3B was performed at a provisional location (north of Rome, Italy). The final operational site will be selected at a later stage once the transponder commissioning is successful. Results were successfully obtained for both Delay Doppler and Fully Focused methods, and show good consistency. In another presentation, Garcia-Mondejar et al. showed results of CryoSat-2 range, datation and interferometer calibration with a transponder installed at the KSAT Svalbard station (SvalSAT). Results show consistency between the different types of data used (Stack data and Level 1B). The observed residual range bias is ~3.5 cm. A trend of 0.1 mm/year is observed in the range results over Svalbard after compensating for vertical land motion as measured by a GPS ground station.

Highlighted at this year's session was the maturing role of new technologies, especially GNSS (GPS) buoy systems, in supporting the altimeter calibration initiatives. Watson et al. updated results from repeated buoy leveling sessions in the Bass Strait, but also described developments with the Current, Waves Pressure Inverted Echo Sounder (CWPIES). In shallow (Bass Strait) water, CWPIES is yielding results comparable to those from surface GPS, while providing additional variables of interest. Two key areas of improvement for GNSS processing have been identified by Zhou et al.: (i) Impact of antenna orientation with robust treatment of inertial (INS) data (one to several centimeters) and (ii) Impact of tether tension (current and wind stress) on buoyancy position (~5 mm reduction in standard deviation). Haines et al. showed the comprehensive results from the successful 2018–19 tandem GPS buoy campaign near the Harvest Platform. Absolute SSH bias results were competitive with those from the platform, and results from differential (between buoys) SSH corroborated those from prior Bass Strait tests, except over a wider range of sea states. Results from the buoy campaigns at Bass Strait, Corsica and Harvest have particular implications for verification of high-resolution (swath) measurements from the future SWOT mission. The GPS buoys can be used not only for SSH calibration, but also for monitoring SWH and wet path delay (e.g., to compare with retrievals from spaceborne radiometers). Haines et al. also presented the planned developments for the Santa Catalina Island Cal/Val Site and the New dual frequency transponder under fabrication/test and schedule for installation in December 2020 on Catalina Island.

3.9.2 Global validation studies

Jason-2 and Jason-3 products continue to demonstrate nominal performance (Desjonquères et al.), though Jason-2 reached its end-of-life in October 2019. The Jason-3 mission has been collecting sea level measurements along the reference 10-day repeat ground-track since February 2016. Altimeter parameters (SWH, sig0, etc.) and the sea level anomaly curve correspond to expectations in spite of maneuvers and safe hold events. The geographic distribution of sea surface height anomaly (SSHA) crossovers for the Jason-3 mission contains cm-level geographically-correlated patterns. Averages of SSHA crossover differences indicate that the Jason-3 orbit standard change greatly attenuated a periodic hemispheric signal: 120 days signal at crossovers is reduced and its phase is changed (see Bignalet-Cazalet et al. presentation). Jason-2 data presented good agreement with Jason-3 and high quality until the very end of the mission. The next product standard (GDR-F) for Jason-3 shows improvements when compared to the current (GDR-D) standard (Figure 3.9-2).

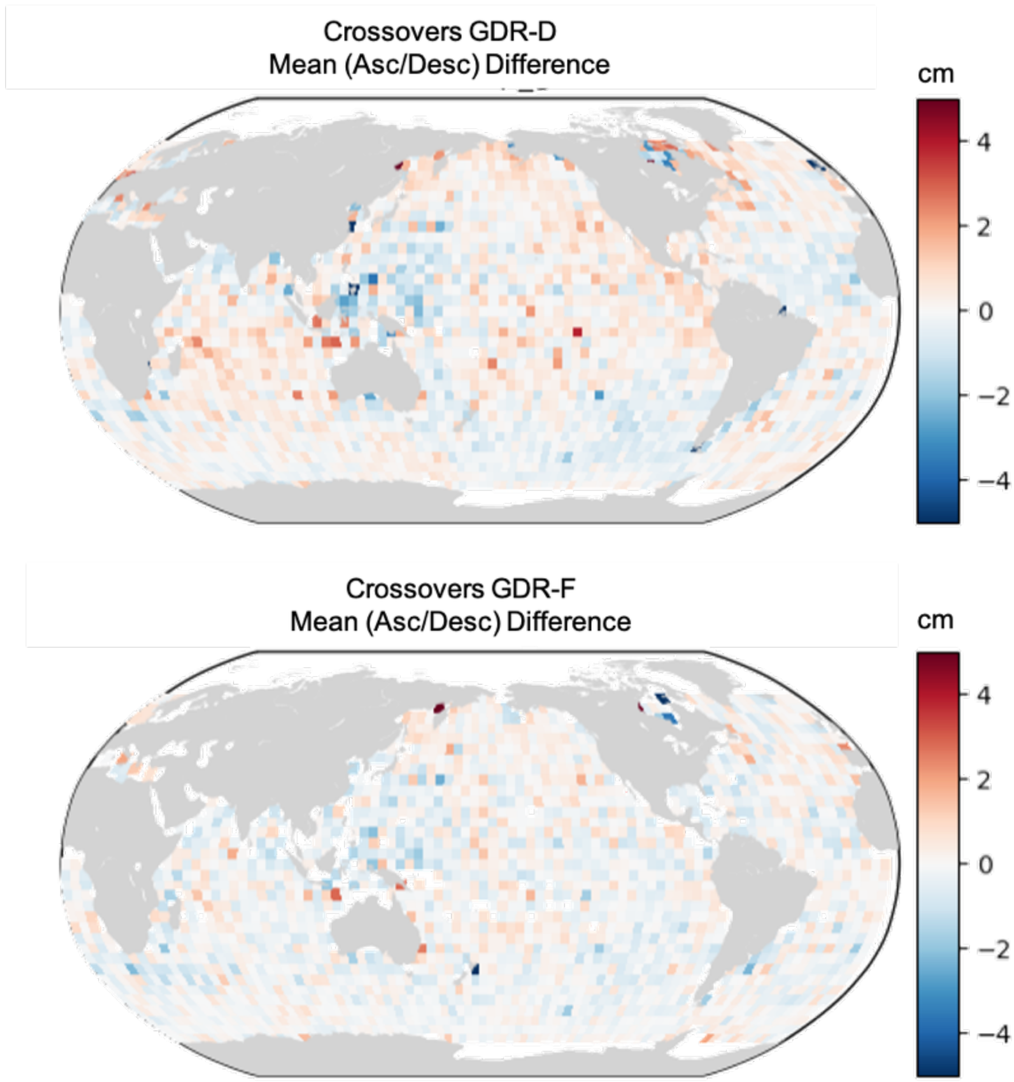


Figure 3.9-2. Geographical patterns are reduced for Jason-3 *GDR-F (bottom) crossovers compared to GDR-D (up) (*Desjonquères *et al).*

A reprocessing of the TOPEX/Poseidon data record by NASA/JPL and CNES is now underway, with reprocessed products expected to be available in 2021. Detailed results from this reprocessing show very promising results (Talpe et al.). Well-known systematic errors in the TOPEX measurements have been significantly reduced through the use of numerical retracking methods that explicitly also account for features of the instrument itself. In addition, the application of modern GDR-F geophysical standards and orbit determination solutions enables significant improvement (see Figure 3.9-3).

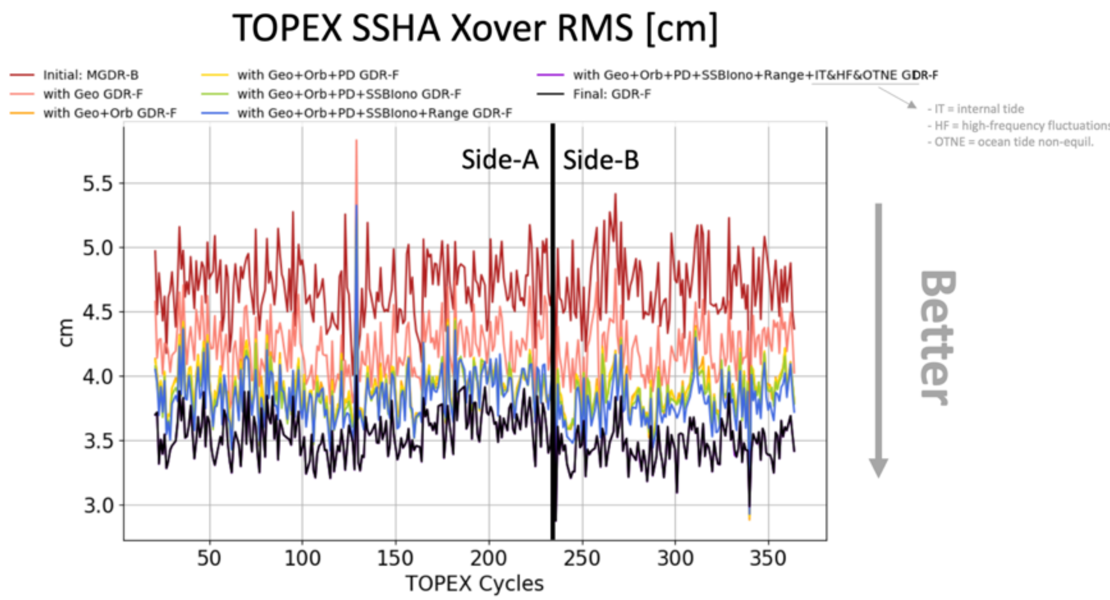


Figure 3.9-3. Application of modern GDR-F standards for geophysical models and new orbit determination solutions from GSFC, together with new TOPEX retracked solutions, dramatically improves the SSHA crossovers (Talpe et al.).

Bignalet-Cazalet et al. presented the Jason-3 GDR-F standard which is ready to be applied in operational production. The global SLA variance is significantly reduced from GDR-D to GDR-F, primarily due to new MSS and along-track ionospheric correction filtering. There is a global bias of -0.19 cm from GDR-D MLE4 SLA to GDR-F MLE4 SLA. Regional biases can reach several centimeters mainly due to MSS evolution. When using data editing recommendations in the user handbook, GDR-F SLA MLE4 data have more rejected measurements than GDR-D data, due to edge effects of the ionospheric correction filtering near ice. The performance of GDR-F is better than GDR-D when using consistently valid measurements: (i) variance of SSH difference at crossovers is reduced by -4.6 cm^2 and (ii) standard deviation of along-track SLA is reduced from 11.05cm to 10.33cm (see Figure 3.9-4).

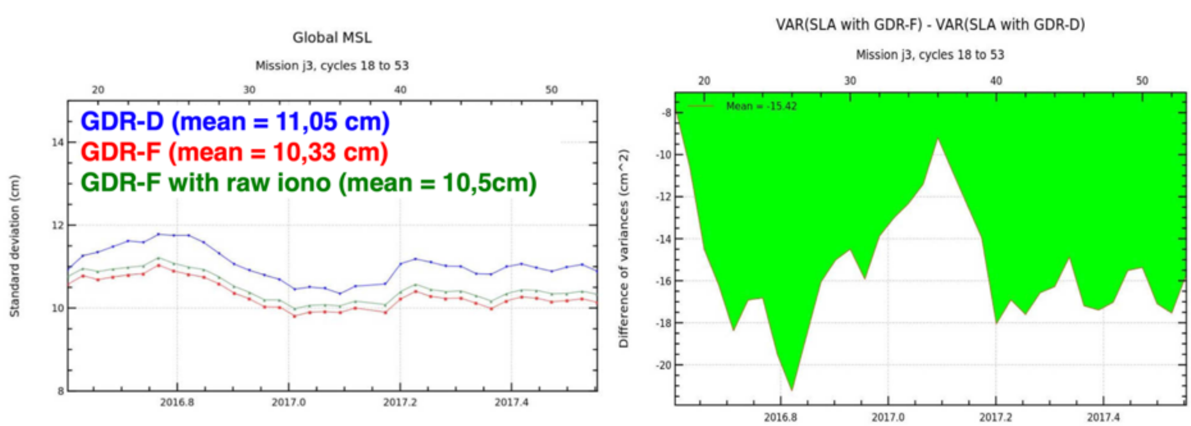


Figure 3.9-4. Global SLA variance is significantly reduced from GDR-D to GDR-F (Bignalet-Cazalet et al.).

Lievin et al. presented the reprocessing of sea Level L2P products for 28 years of altimetry missions aimed at providing a unified and up-to-date data set for all altimetry missions. In the frame of the SALP (Service d'Altimétrie et de Localisation Précise) project supported by CNES (Centre National d'Etudes Spatiales) and of the Sentinel-3 Marine Altimetry L2P-L3 Service (operated under an EUMETSAT contract in the frame of the Copernicus Programme funded by the European Union), L2P data are available to users for all the altimeter missions. The last Level 2P 2018 reprocessing also benefited from the ESA Sea Level CCI project. The Level 2P products are easy to use (netcdf format) homogenous along-track mono-mission products, providing as much as possible the same updated corrections and models for the altimeter missions, in order to facilitate inter-mission comparisons. Global and regional sea-level biases are corrected versus a reference mission. The data sets are regularly updated to use the best available Level 2 reprocessing and corrections (geophysical and instrumental) (Figure 3.9-5). Reprocessed Level 2P products are the inputs for two Copernicus Services (CMEMS and C3S) for their own reprocessing (L3 and L4 products) for assimilation experiments and climate monitoring. The whole altimetry Level 2P time-series was reprocessed during 2020 and available in netcdf 4 format. The reprocessed Level 2P products were based upon recently reprocessed Level 2 data for several missions: ENVISAT V3.0, Sentinel-3 A & Sentinel-3 B Baseline Collection 004, SARAL GDR-F, Cryosat Ocean Baseline C (Jason-3 GDR-F was not available for the Level 2P reprocessing). The Level 2P data and handbook are available on the AVISO+ website:

https://www.aviso.altimetry.fr/en/data/products/sea-surface-height- products/global/along-track-sea-level-anomalies-l2p.html.

Reprocessing L2 | no update = 2018 | New for 2020

Update	Poseidon	Topex	Jason 1	Jason 2	Jason 3	ERS-1	ERS-2	ENVISAT	SARAL	Sentinel 3A	Sentinel 3B	Geosat FO	Cryosat 2	HY 2A
ORBIT	GSFC STD18		POE-E	POE-F		Reaper		POE-E	POE-F	POE-F		GSFC	POE-F	POE-D
IONOSPHERIC	DORIS	SLOOP		SLOOP (SSB C)	SLOOP	NIC09	GIM	Filtre L2 / GIM	GIM	Filtre L2		GIM		
SEA STATE BIAS	BM4	Non parametric [N. Tran 2010]	2D [N. Tran 2015]	2D J2 [N. Tran 2012]		BM3 [Gaspar Ogor 1994]	Non parametric [Mert 2005]	2D [N. Tran 2017]	2D [N. Tran 2018]	2D J2 [N. Tran 2012]		Non parametric [N. Tran & S. Labroue 2010]	2D [N. Tran 2018] Baseline C	Non Parametric [N. Tran 2012 Vent S. Labroue]
WET TROPOSPHERE	GPD+ [Fernandes et al. 2015]		JMR (GDRE) radiometer	AMR radiometer		GPD+ [Fernandes et al. 2015]		MWR radiometer reprocessed	Neuronal Network (5 entries) V4	MWR 3 radiometer		Radiometer and ECMWF	GPD+	ECMWF
DRY TROPOSPHERE	ERA5 (1-hour) model based													
DYNAMICAL ATMOSPHERIC CORRECTION	TUGO model forced with ERA 5 model				MOG2D HR forced with ECMWF	TUGO model forced with ERA 5 model			TUGO ERA 5 + MOG2D HR	MOG2D HR forced with ECMWF		TUGO forced with ERA5	TUGO ERA 5 + MOG2D HR	
OCEAN TIDE	FES 2014 B													
INTERNAL TIDE	ZARON 2019 (HRETv8.1 tidal frequencies: M2, K1, S2, O1)													
POLE TIDE	DESAI et al.2015 ; Mean Pole Location 2017													
SOLID TIDE	Elastic response													
MEAN SEA SURFACE	Composite (SCRIPPS,CNES/CLS15,DTU15)													

Figure 3.9-5. Standards evolutions for the L2P products

Naeije et al. presented the long-term analysis and validation of the CryoSat-2 Level 2 Geophysical Ocean Product (GOP). This is achieved by assessing the quality, consistency and stability of Level 2 GOP parameters through comparisons to concurrent in situ data from tide gauges and transponders, relevant numerical ocean and meteorological models, and other concurrent altimeter data sets. An example is given for Sea Level Anomaly during cycle 34 in Figure 3.9-6.

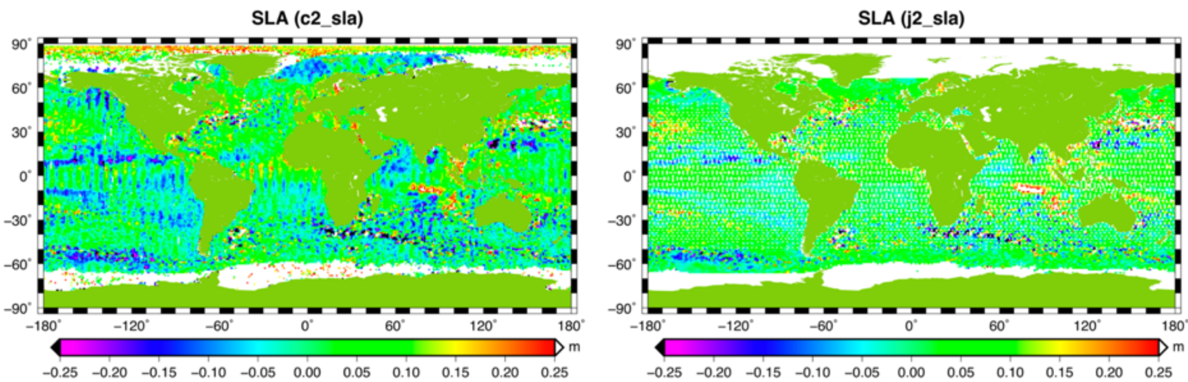


Figure 3.9-6. Example 1 Hz sea level anomalies from the GOP Baseline C level-2 P2P product (left, cycle 34), compared with those from Jason-2 (right, cycles 159-162). (Naeije et al.).

Martin-Puig et al. presented the Sentinel-6 Michael Freilich calibration and validation implementation plan defined by the five Agencies: ESA, NASA/JPL, NOAA, CNES and EUMETSAT. This presentation included a high-level overview of the main planned activities of the agencies and their implementation during the commissioning phase. This included the plans for the mode mask that will be used to evaluate the relative performances of the Range Migration Compensation (RMC) data versus raw SAR data over regions of geophysical nature (ocean slope and wave state, for example) in order to establish if RMC can be used everywhere for primary and secondary topography mission objectives, the modes of acquisition, as well as information of the key milestones and events.

3.10 Science I: Climate data records for understanding the causes of global and regional sea level variability and change

Chairs: Ben Hamlington and Benoit Meyssignac

There were 12 presentations in this sessions from which emerged the following main conclusions:

1) The forced sea level response to anthropogenic emissions seems to emerge at the regional level from the noise caused by the internal variability of the climate system. However when we remove the GMSL signal from this regional signal then the forced signal (in trend and acceleration) has a very low amplitude which is at the limit or even below the instrumental uncertainties and the chaotic uncertainty evaluated by other studies. On a large scale, recent results show that if we could correctly assess the covariance of the instrumental errors then we could hope for an averaging of the errors or a compensation of the errors like what we see at global scale and the forced signal would be perhaps above the instrumental noise.

2) The reprocessing of the coastal data gives observations close to the coast (<10km) which are in general consistent in trend with the observations in the open ocean or observations from the tide gauges. The general increasing consistency of tide gauge measurement with altimetric observations makes it possible to envisage new techniques for filtering vertical movement in tide gauge records and regional systematic errors in altimetry by comparing altimetric coastal observations with tide gauge records

3) The sea level observations combined with the spatial gravimetry observations of GRACE and GRACE-FO allow to constrain the estimates of ocean warming and the planet's energy imbalance. This makes it possible to constrain the flows of the global water / energy balance of the planet and to verify through this approach the consistency of the sea level observations with the different atmospheric water/energy flux data sets. This should open the way for the development of global fluxes estimates that are more coherent with each other and therefore more relevant for the analysis of climate change and ocean circulation.

4) At the regional level, the improvement of the precision of the altimetric data, GRACE / GRACE-FO and in-situ henceforth make it possible to make regional assessments of the sea level and its contributions. This allows the analysis of ocean circulation and its causes regionally such as in the South Atlantic or in the Straits of Florida

From these conclusions several elements emerge for recommendation:

i) the need for a second tandem phase to explore with an unprecedented level of precision the regional and global signature of the instrumental uncertainties. This should feed the research elements 1), 2) and 3) mentioned above.

ii) propose an estimate of regional sea level errors which takes into account the spatial covariance of errors this should feed elements 1) 3) and 4)

ii) FDR4alt reprocessing should be used to improve regional sea level measurements in the past. A problem in these reprocessing is the only partial consideration of the blurring effect (ERS missions).

3.11 Science II: Large Scale Ocean Circulation Variability and Change: summary of session

Chairs: LuAnne Thompson and Thierry Penduff

The 2020 OSTST Science II virtual session had 15 presentations. These presentations focused on the evolution of ocean circulation and ocean climate in locations that covered the globe. Regional studies were presented on western and eastern boundaries, the tropics, the Arctic, and the Southern Ocean. The space scales investigated in these studies ranged from global to mesoscale, and most took advantage of the full length of the altimetry record. Some overall themes and highlights are given below.

1. Nine of the 15 presentations concerned joint analyses of SSH observations and model outputs or oceanic reanalyses (in particular GLORYS12), often complemented by other datasets such as SST, CTD, Argo profiles, tide gauges, current meters, atmospheric reanalyses, etc. This session confirmed the strong synergy between observations and simulations (Artana 1&2, Aubone, Han, Matano, Park, Song, Thiam, Webb).

2. Five studies highlighted important connections between the open and coastal oceans via water mass transformations or wave propagation, with connections to inter-basin exchanges or extreme events along coastlines (Han, Matano, Sane, Song, Strub)

3. The use of the available 28-year high precision altimetric record for the monitoring of the integrated transport of ocean currents is now mature and reveals rich and interesting signals, especially in the Southern Hemisphere (Artana 1&2, Park)

4. Two studies showed the importance of air-sea coupling and internal ocean variability for the interpretation of large scale SSH/SST signals in the equatorial and mid latitude North Pacific (Qiu, Webb)

5. New Arctic sea level products and gravimetry-based estimates of inter basin water exchanges were also presented, opening new perspectives in the use of satellite data for science and climate monitoring (Prandi, Garcia-Garcia).

The presentations and discussions in the forums lead to the following recommendations:

1. Foster common activities between the Ocean SWOT ST and OSTST group as soon as possible to include SWOT nadir and 2D data into the existing multi-altimeter dataset.

2. Bring together the groups that are studying large-scale, mesoscale and sub-mesoscale oceanography from altimetry (and other datasets).

3. Consolidate the connections between open ocean, coastal ocean, and ice-covered mapped sea level products.

4. Increase the usage of SLA in climate studies by fostering closer ties with the climate modeling community.

5. Encourage usage of cutting-edge machine learning technology with the goal of integrating in situ observations with SLA data to improve our understanding and predictability of climate

3.12 Science III: Mesoscale and sub-mesoscale oceanography

Chairs: Lee-Lueng Fu, Rosemary Morrow, Clement Ubelmann and Jinbo Wang

This session included an interesting range of presentations based on mesoscale processes, and the smaller mesoscale to sub-mesoscale range of dynamics. The 16 presentations were mainly concerned with how fine-scale ocean dynamics are observed in along-track altimetry or mapped altimetry products, and how altimetry may be combined with other satellite and in-situ data, or numerical models, to investigate physical and biophysical processes at these scales. Most studies concentrated on today's altimetry missions, although many studies paved the way for future fine-scale SSH observations with SWOT.

Different studies used the finer resolution from **along-track altimetric data** to investigate the energy cascade of balanced motions in the ocean, and the spatial scales where internal gravity waves start to dominate the SSH signals, both in global analyses (Vergara et al.) and in the eastern tropical Pacific (Soares et al.). The signature of along-track Sentinel-3 properties (SSH, SWH, sigma-0) varying across strong fronts and eddies detected from gridded products was also explored (Morrow et al.).

Today's altimetry maps were also shown to underestimate the propagation of large-scale rapid Rossby waves in the North Pacific (Farrar et al.), due to the temporal decorrelation scales used in DUACS maps. Improvements to the altimetry mapping techniques were proposed. A comparison of the tsunami warning array of DART moorings with mapped altimetric SSHA showed they were complementary – altimetry representing the low-frequency (>14d) and the DART array capturing the larger-scale high-frequency (7-14d) signals and the local very high frequencies (< 7d) (Mungov et al.). An eddy-tracking technique that uses Eulerian estimates of the non-linearity of ocean eddies was presented (Samelson et al.) with a strong influence on the fluid trapped within the eddy, and on lagrangian transports.

Several regional studies used a combination of numerical simulations and altimetry products and considered the evolution of Loop Current rings (Andrade-Canto et al.), velocity variability in the Malvinas Current (Paniagua et al.), the surface characteristics of rapid sub-inertial waves on the Patagonian shelf (Poli et al.), and cross-shelf exchanges in the SW Atlantic (Combes and Matano). Advection by mesoscale dynamics in the Malvinas confluence region was also shown to be critical for the recruitment fluctuations of Argentine squid (Torres et al.). A study using near real-time lagrangian stirring based on Lyupunov exponents was able to predict short-term front displacements, with impacts for tracking pollution dispersion (Fifani et al.). These studies present the utility of altimetry in regional ocean applications, which are anticipated be enhanced by the upcoming SWOT mission.

A number of studies also used simulations to assess how **SWOT data will observe the finer scale dynamics**, in comparison to in-situ moorings' reconstruction of SSH in the Californian Current region (Wang et al.), in the Bay of Bengal (Chaudhary et al.) and within data assimilation schemes (Archer et al.; d'Addezio et al.).

Overall, this session was rich in new results, with interesting new applications, and recommendations for future DUACS altimeter mapping and for using along-track and SWOT altimetry in future high-resolution assimilation schemes.

Presentations

1. Vergara et al. Global spectral characteristics from 1Hz along-track altimetry
2. Soares et al. : Transition from balanced to unbalanced dynamics in the eastern tropical Pacific from in situ, numerical simulation and altimetry data
3. Morrow et al.: Detection of open ocean fronts and eddies with Sentenel-3 data
4. Farrar et al.: Long-distance radiation of Rossby waves from the equatorial current system
5. Mungov and Zhang: Comparison of SSH anomalies derived from open-ocean bottom pressure measurements (from NOAA DART® systems) with multi-satellite merged altimeter missions and coastal tide gauge records.
6. Samelson et al.: Eulerian Statistics for Fluid Trapping and Transport by SSH-Tracked Eddies: Preliminary Results
7. Andrade-Canto et al.: Genesis, evolution, and apocalypse of Loop Current rings
8. Paniagua et al.: Malvinas Current at 44.7ºS: First assessment of velocity temporal variability from in situ data
9. Poli et al. Anatomy of subinertial waves along the Patagonian shelf break in a 1/12° global operational model.
10. Combes and Matano: Circulation and Cross-Shelf Exchanges in the Northern shelf of the Southwest Atlantic
11. Torres et al. Dynamics of the Confluence of Malvinas and Brazil currents, and a Southern Patagonian spawning ground, explain recruitment fluctuations of the main stock of *Illex Argentinus*
12. Fifani et al.: A method for predicting the displacement of Lagrangian fronts from near-real time altimetry
13. Wang et al.: Measuring SSH at sub-centimeter level using in-situ platforms in preparation for the SWOT post-launch SSH Calibration and Validation
14. Chaudhary et al.: Nadir altimetry Vis-à-Vis swath altimetry: A study in the context of SWOT mission for the Bay of Bengal
15. Archer et al.: An assessment of the data assimilation (DA) system developed for the SWOT satellite mission
16. Joseph M. D'Addezio et al.: Multi-Scale Assimilation of Simulated SWOT observations

3.13 Science Results IV: Altimetry for Cryosphere and Hydrology

Chairs: Charon Birkett, Jérôme Bouffard, Jean-Francois Crétaux and Sinead Farrell

3.13.1 Hydrology

A multi-agency presentation outlined recent progress on the Hydrology Targets database that is being used to construct the on-board DEM (Open Loop Tracking Command, or OLTC) for Sentinel-6 Michael Freilich, Sentinel-3A,-3B, and Jason-3. Using new sources and revised methods together with quality control, over 30,000 (Jason/Sentinel-6) and 74,000 (Sentinel-3) lake and river targets are now included in the 2020 on-board DEM. This is a significant increase over the 2017/2018 DEM versions. Sentinel-3 targets are now also defined above 60^{o}N, but not over Greenland to ensure successful mapping of the Greenland ice sheet change. While the ultimate goal is to provide a DEM value everywhere, to maximize the acquisition of water targets, for Sentinel-3A,-3B only 800 DEM 'segments' per orbit are possible. It has been estimated that the current OLTC DEM contains ~10-12 % of erroneous measurements and data users are encouraged to report errors. The quality of the Open vs. Close Loop surface acquisitions was assessed in detail for the Sentinel-3A and -3B tandem phase and it was clearly demonstrated that Open Loop mode provided more valid water elevation measurements.

The HydroCoastal project was also highlighted at the meeting. A new enterprise funded by ESA, it's aim is to maximize exploitation of SAR and SARin altimeter measurements in the coastal zone and over inland waters for both science and applied science programs. Focus is on CryoSat-2 (SAR, SARin) and Sentinel-3 (SAR) with new processing algorithms under development. The ultimate goal is to generate optimized and global L2 surface elevations. Additionally, water level time series (L3) will be produced at virtual stations for lakes and rivers, and river discharge (L4) will be produced for select rivers. Tests are currently being conducted using 18 study regions.

The OSTST hydrology projects are looking towards the next generation of GDR-F data standard and to improvements in waveform retracking. Investigations into SAR data continue over inland water targets with emphasis on testing the various retracking algorithms. A case study of the Great Salt Lake USA revealed that SAMOSA+ had a slight advantage over ALES+ SAR, but overall, both performed very well. The ALES+ SAR sub-waveform retracker, designed for coastal oceans, is thus noted to have good additional potential for inland water.

Fully-Focussed SAR altimeter processing, also a multi-agency effort, could be a major step forwards in the improvement of along-track spatial resolution, a requirement that ultimately enables the acquisition of much small lakes and river reaches (Figure 3.13-1). This innovative technique offers a spatial resolution of ten to tens of meters, and discussions on how to overcome its limitations, and how best to perform this data processing for the delay-Doppler radar altimeters, are ongoing. Ultimately this higher resolution Range output needs to be offered to the OSTST and to end users in general.

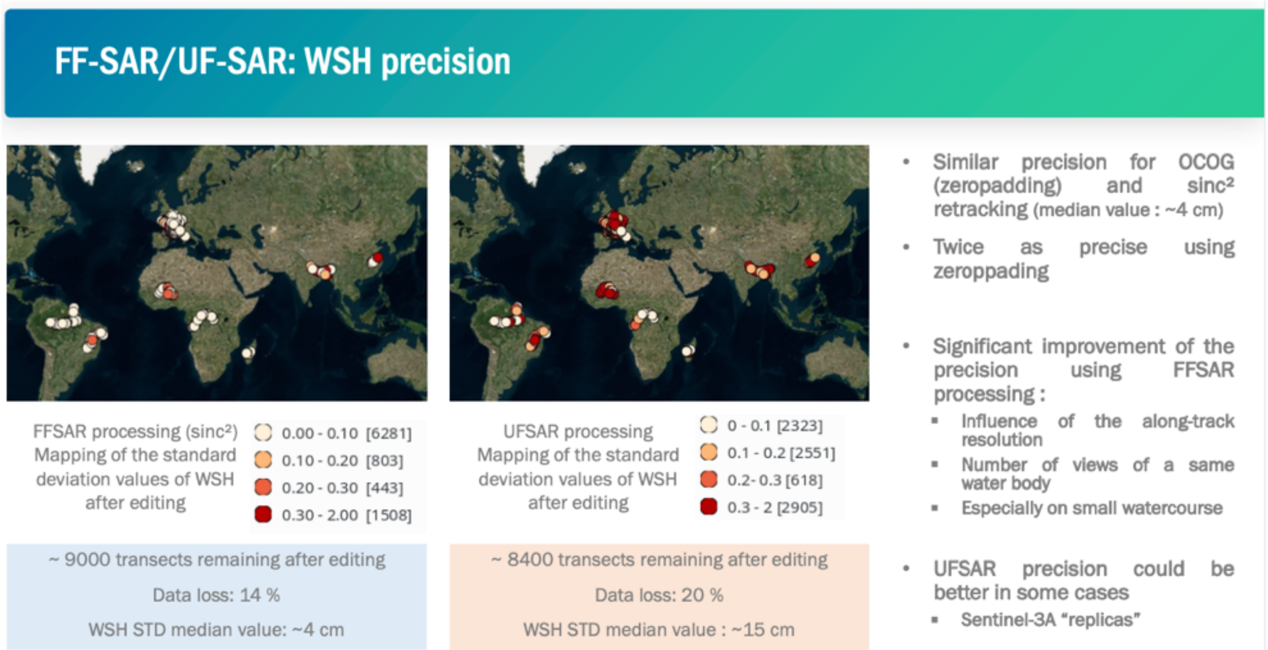


Figure 3.13-1. Comparison of FF-SAR and UF-SAR over ~700 study regions regarding water surface height (WSH). FF-SAR shows a greater potential for improved along-track resolution and precision, but a greater sampling of UF-SAR (e.g., 80Hz) would do likewise. In both cases this enables a greater acquisition of small lakes and narrow reaches. Unlike Sentinel-3, Sentinel-6 data will not suffer from 'water body replicas' (figure courtesy of Maxine Vayre).

3.13.2 Cryosphere

The two presentations related to the cryosphere provided a status update of activities, data products and science results from ESA's CryoSat-2 and NASA's ICESat-2 missions. Both presentations also highlighted new science opportunities offered by the #CRYO2ICE campaign (Figure 3.13-2). Indeed, ESA recently (August 2020) changed the orbit of CryoSat-2 to periodically align with ICESat-2, providing for the first-time spatially coincident radar and laser altimeter measurements over the same ice, at short time separations. This will allow scientists to characterize snow depth from space on both sea ice and land, improving the accuracy of both the sea ice thickness and ice-sheet elevation change time series, while also offering novel opportunities for advancing our understanding of surface currents in the polar oceans.

In its 10 years of operations, CryoSat-2 has achieved its mission objectives over the cryosphere and has triggered new scientific questions. Several projects are currently conducted by ESA in order to measure snow depth from space on both sea ice and land, improving the accuracy of sea ice thickness measurements and ice-sheet elevation time series. The CryoSat-2 data product portfolio is also continuously evolving, with current (EOLIS) and future CryoSat-2 thematic products (so called "Cryo-TEMPO"), which will include fully traceable uncertainty parameters and aims to maximize the mission for new operational and science applications over multiple surfaces (Polar Ocean, Inland Water, Coastal Ocean, Sea Ice and Land Ice). The first two years of sea ice retrievals from ICESat-2 demonstrate its capability to track the evolution of the ice cover throughout the year, and detailed satellite altimeter measurements of the summer melt season have been obtained for the first time. ICESat-2 sea ice freeboard and thickness results are fully consistent with the complementary results from CryoSat-2. ICESat-2 mission data products are now publicly available from the National Snow and Ice Data Center (NSIDC).

CryoSat-2 and ICESat-2 deliver high-resolution topography measurements of the cryosphere which are providing scientific results that are vital in the preparation and design of future polar altimetry missions such as the Copernicus polaR Ice and Snow Topography Altimeter Mission (CRISTAL). The CRISTAL mission is currently in Phase B2 of development and the contract for the mission was recently signed (September 2020). CRISTAL will carry a dual-band radar altimeter with the goal of measuring variability in sea ice and land ice thickness, thus extending the CryoSat-2 and ICESat-2 time series. CRISTAL is planned for launch in 2027. There exists however a significant concern that a 2027, or later, launch timeframe may result in a gap in observational capabilities of the polar regions due to the expected lifetimes of the two current altimeters (CryoSat-2 and ICESat-2).

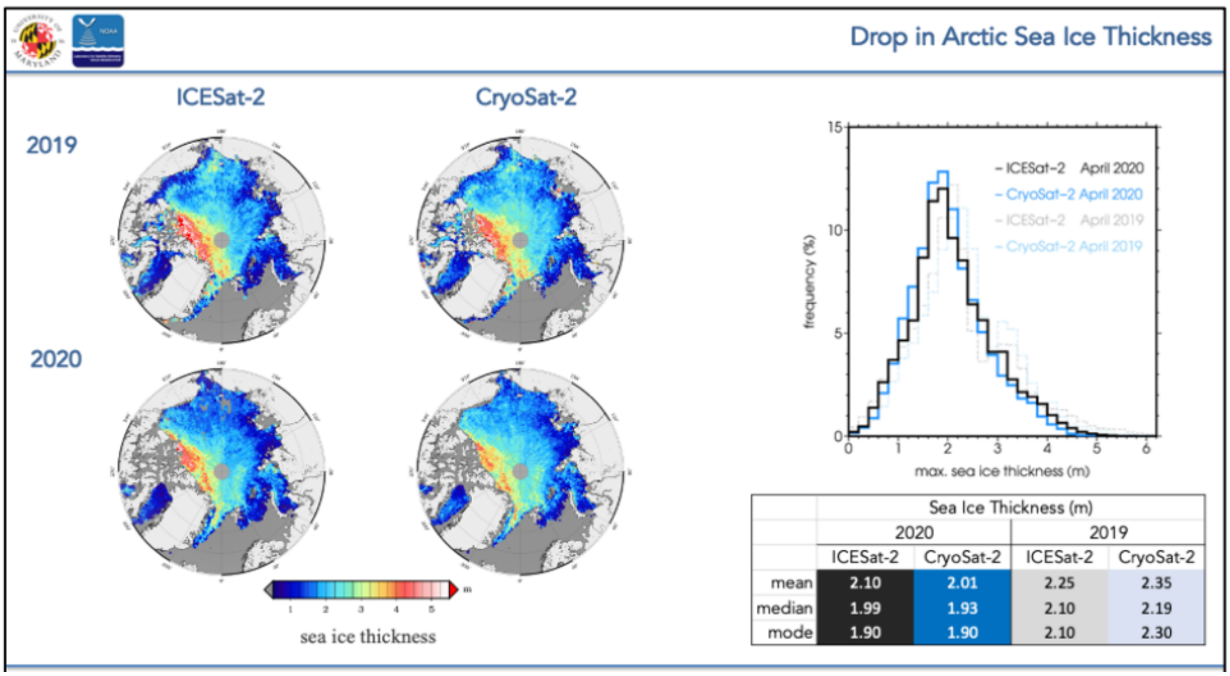


Figure 3.13-2. Arctic sea ice reaches its maximum thickness in April. A comparison of sea ice thickness between the laser altimeter of ICESat-2 and the radar altimeter of CryoSat-2 shows that in certain regions, the central Arctic and Canada Basin, ice thickness was thinner in April 2020 than in April 2019 (Figure courtesy of Sinead Farrell).

3.14 The Geoid, Mean Sea Surfaces and Mean Dynamic topography

Chairs: Ole B. Andersen and Yannice Faugere

A total of six presentations have been submitted in the session this year, two on gravity fields, two on MSS and two on MDT. We highlight the main messages and recommendations to OSTST 2020 science keynote questions (bold):

Andersen et al.: Using Jason-2 Geodetic Mission to explorer possible EoL scenarios for Jason-3 for High Resolution Gravity Field Modelling

- Improvement of gravity field quality thanks to Jason-1 GM & Jason-2 LRO
- Observed a clear negative impact of Safehold on marine gravity ad urge to recover the larger of these.
- **Recommendation 1: strongly recommend to reuse the Jason-2 LRO orbit with Jason-3 to densify (bisect) the geodetic grid in a regular way as opposed to a new GM orbit where the grids will not be aligned**
- **Recommendation 2: strongly recommend to rewind the GM to recover mission tracks**

Zhang et al.: Comparison and evaluation of high-resolution gravity recovery via sea surface heights or sea surface slopes

- Comparison of 2 gravity field approaches using independent in situ data: SSH (used by DTU, CLS) vs SSS (used by SIO):
- Low differences in open ocean
- Sea Surface Slope degraded in coastal regions, when the orientation of topography (e.g. Trench) is parallel to the orientations of altimeter ground tracks, & more vulnerable to the energetic western boundary currents

Abulaitijiang et al: Status of Mean Sea Surface preparation for SWOT

- Description of the existing MSS strategies (data, method, assessment) for the various approached by DTU/SIO/CLS
- DTU/SIO starts from an existing grid for large scales (respectively DTU15 and CLS15) and focuses on recovering residuals to these.
- Importance of altimetry processing for small scales retrieval: 2-pass retracking and along track filtering (SIO & DTU)
- **Recommendation: Importance of cross comparison and collaboration to insure the best MSS possible for SWOT. A combination of multiple MSS fields could also be considered.**

Yu et al: Assessment of ICESat-2 for the Recovery of Ocean Topography

- Analysis of the interest of IceSAt-2 for MSS/gravity field improvement

- Pollution of topography at small scales in open ocean due to *"signals in 3-20km wavelength come from aliasing from short-wavelength surface waves"*

Mulet et al.: New regional Mean Dynamic Topography of Mediterranean and Black Seas from altimetry, gravity and in-situ data

- Regional MDT developed over Black Sea and Med Sea as part of CMEMS (additional in situ and regional tuning)

- Better performances compared to existing models (compared to drifters and T/S profiles)

Vargas et al.: Geostropic Currents in the Southern Ocean: ACC and Drake Passage Volume Transport

- satellite data / MDT are consistent with in-situ /Argo ocean observations enabling the possibility of new studies in oceanography at global scales

3.15 Tides, internal tides and high-frequency processes

Chairs: Loren Carrere, Florent Lyard and Richard Ray

This year, the session counted 9 presentations on barotropic tides and internal tides, one presentation on a new tidal analysis tool and one presentation concerning the new DAC-ERA5 correction.

Barotropic tides:

- EOT20: An updated global empirical ocean tide model derived from multi-mission satellite altimetry - First validation results (Hart-Davis et al.)

- A new global ocean barotropic tide model: FES2022 (Carrere et al.)

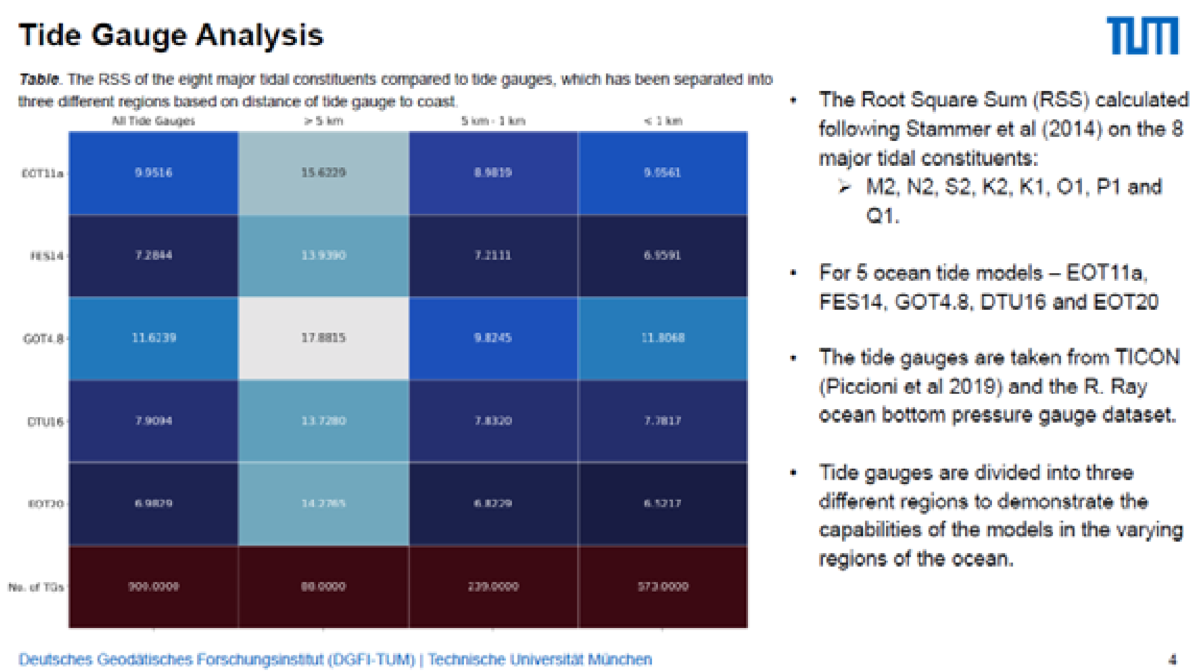
- Bathymetry improvement and high-resolution tidal modelling around Australia (Sahuc et al.)

- Study of height and tidal currents from in-situ data, models and satellite altimetry over the Argentine Continental Shelf (Garcia Santacruz et al.): only abstract was available for this presentation.

New EOT20 global ocean tide model will be available in 2021, it uses the new tidal correction from FES2014 and new ALES retracker data, and shows some improvement comparing to FES2014 (cf Figure 3.15-1).

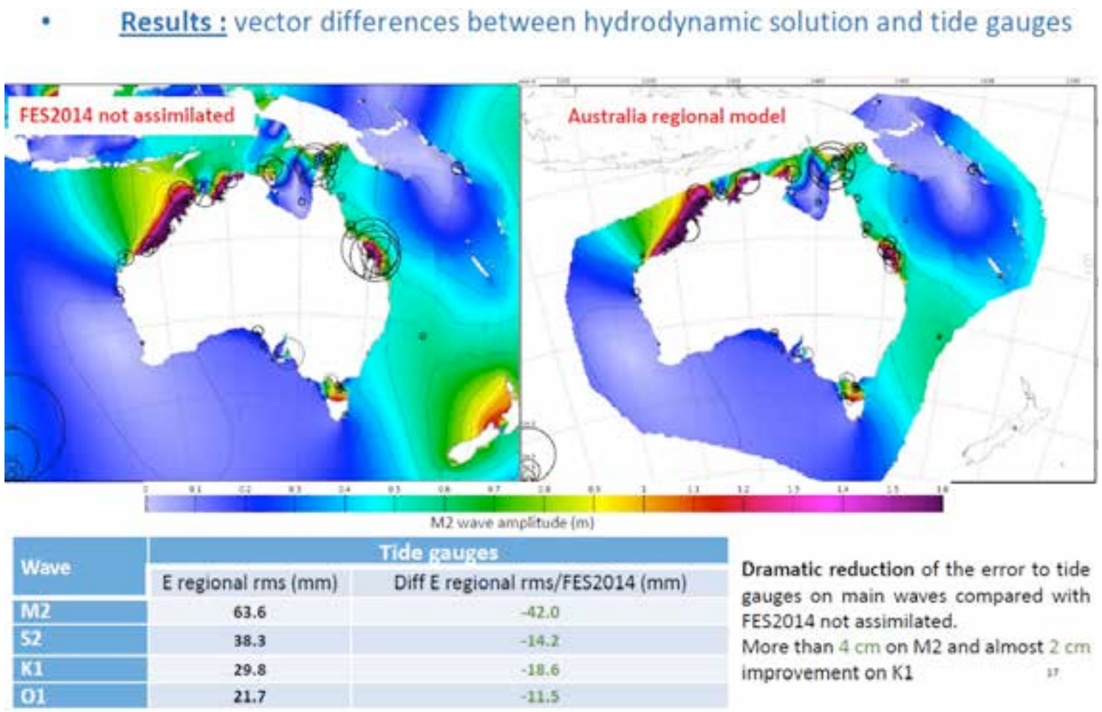
The production of the new global ocean barotropic tide FES (Finite Element Solution) has started this year; the objective is to produce a preliminary new global ocean atlas FES2022 by the end of 2021.

A new regional high-resolution barotropic tide atlas has been produced on the Australia area, showing strong improvement comparing to FES2014 global solution (cf Figure 3.15-2). But many questions about the quality of the bathymetry field remain, particularly around the Bass-Strait region.



	All Tide Gauges	> 5 km	5 km - 1 km	< 1 km
EOT11a	9.9516	15.6229	8.9819	9.9561
FES14	7.2844	13.9390	7.2111	6.9591
GOT4.8	11.6239	17.8815	9.8245	11.8068
DTU16	7.9094	13.7280	7.8320	7.7817
EOT20	6.9829	14.2765	6.8229	6.5217
No. of TGs	909.0000	88.0000	239.0000	572.0000

Figure 3.15-1. RSS of 8 major tidal constituents of 5 global ocean tide model compared to tide gauges (Hart-Davis et al)



Wave	Tide gauges	
	E regional rms (mm)	Diff E regional rms/FES2014 (mm)
M2	63.6	-42.0
S2	38.3	-14.2
K1	29.8	-18.6
O1	21.7	-11.5

Figure 3.15-2. validation results of the regional barotropic tide solution around Australia (Sahuc et al).

Internal tides:

- High-frequency surface kinetic energy in global high-resolution models (Brasch et al.)
- Improved internal wave spectral continuum in a regional ocean model (Nelson et al.)
- Simultaneous estimation of ocean mesoscale and internal tides: evaluation of the internal tide solution (Ubelmann et al.)
- Energetics of the baroclinic tide from the HRET model (Zaron et al.)
- Seasonality of M2 internal tides observed by satellite altimetry (Zhao et al.)

A new global seasonal IT (Internal Tide) model has been produced and tested by Zhao et al.: results indicate that the seasonal model is less efficient than the multi-year model (cf Figure 3.15-3). More developments and tests are likely needed to better understand the seasonality of IT.

A new global solution for coherent IT is also proposed by C. Ubelmann using an innovative method. Validation results show some improvement compared to the Zaron IT model (2019) depending on the locations (cf Figure 3.15-4).

Energetic considerations about IT fluxes and dissipation can help understanding the IT models results as demonstrated by Zaron et al (cf Figure 3.15-5).

Some interesting results using OGCM simulations with tides have been presented, indicating the importance of both the horizontal and vertical resolution. Using a global drifters dataset shows the interest to discriminate differences between models. Some new development and tests are still needed to provide accurate tides/baroclinic tides estimations with OGCM.

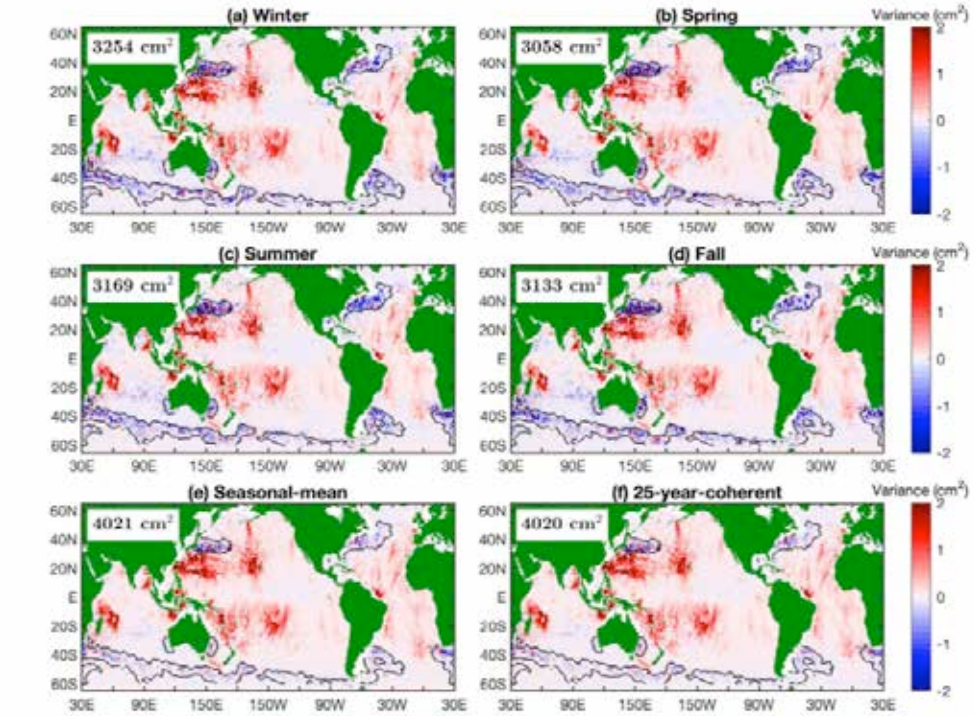


Figure 3.15-3. Validation of seasonal IT model from Zhao et al: variance reduction with CryoSat-2 data.

Cycles 96-124

M2

SSH Crossovers

Modèles comparés	Global	Tahiti	Hawaii	Madagascar	Gulf of Guinea	Luzon	NATL	NPAC
MIOST – ZERO	- 1.26cm²	- 2.19cm²	- 1.93cm²	- 2.20cm²	-	- 4.26cm²	- 0.24cm²	- 0.60cm²
%	- 2.40%	- 9.07%	- 7.13%	- 3.86%	-	- 5.00%	- 0.91%	- 2.74%
MIOST – ZARON_2019	- 0.16cm²	- 0.43cm²	- 0.16cm²	0.04cm²	-	- 1.12cm²	- 0.10cm²	- 0.02cm²
%	- 0.39%	- 1.92%	- 0.63%	0.07%	-	- 1.42%	- 0.38%	- 0.09%

K1

SSH Crossovers

Modèles comparés	Global	Tahiti	Hawaii	Madagascar	Gulf of Guinea	Luzon	NATL	NPAC
MIOST – ZERO	- 0.46cm²	- 0.29cm²	- 0.08cm²	- 0.16cm²	-	- 1.04cm²	0.00cm²	- 0.03cm²
%	- 0.88%	- 1.20%	- 0.30%	- 0.28%	-	- 1.22%	0.02%	- 0.14%
MIOST – ZARON_2019	- 0.02cm²	0.01cm²	- 0.04cm²	- 0.13cm²	-	0.52cm²	0.15cm²	- 0.07cm²
%	- 0.05%	0.04%	- 0.13%	- 0.23%	-	0.67%	0.93%	- 0.35%

Figure 3.15-4. Validation diagnostic of the new IT model from Ubelmann et al: variance reduction for independent C2 crossovers database.

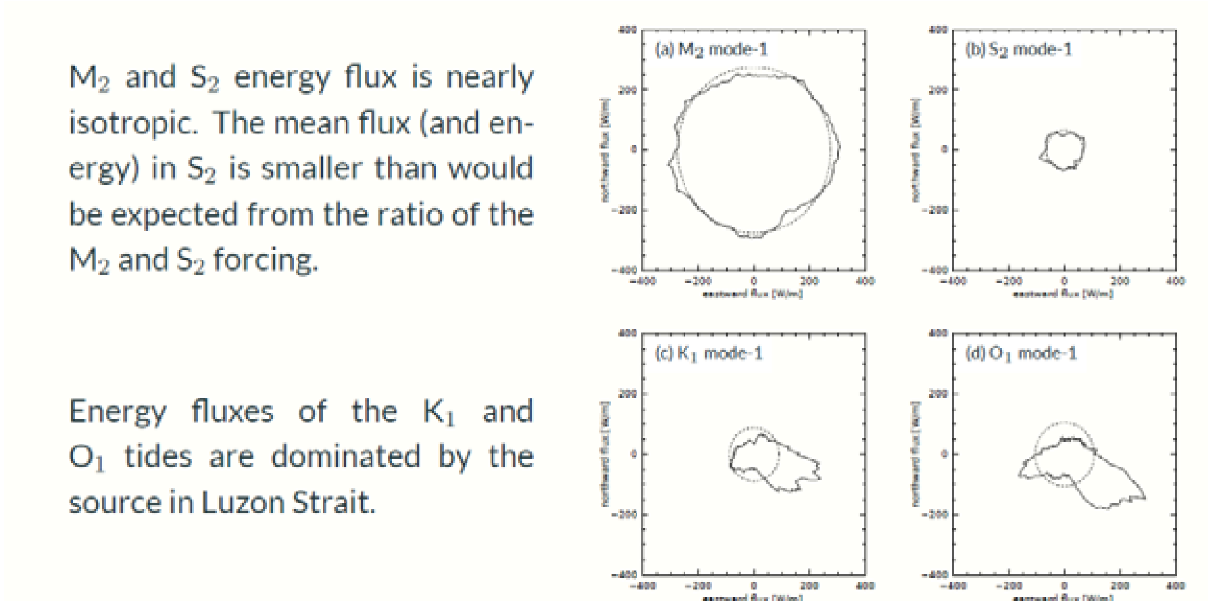


Figure 3.15-5. Directional distribution of the energy flux for HRET model (Zaron et al)

<u>Tidal analysis tool:</u>

- The development of a novel tidal analysis package and its application to surface currents (Kachelein et al.)

A new tidal analysis package is proposed to address non-stationarity variability and structured noise. It is applied on HFR datasets to extract the non-stationary energy.

<u>DAC:</u>

- Using ERA5 meteorological reanalysis to improve the Dynamic Atmospheric Correction for altimetry (Carrere et al.)

A new global dataset DAC-ERA5 has been produced and validated showing a strong improvement compared both to DAC-ERA-Interim and the operational DAC. Improvement is significant on the entire altimetric period (cf Figure 3.15-6). The new dataset will be used for the production the new DUACS DT-2021 product and for FES2022.

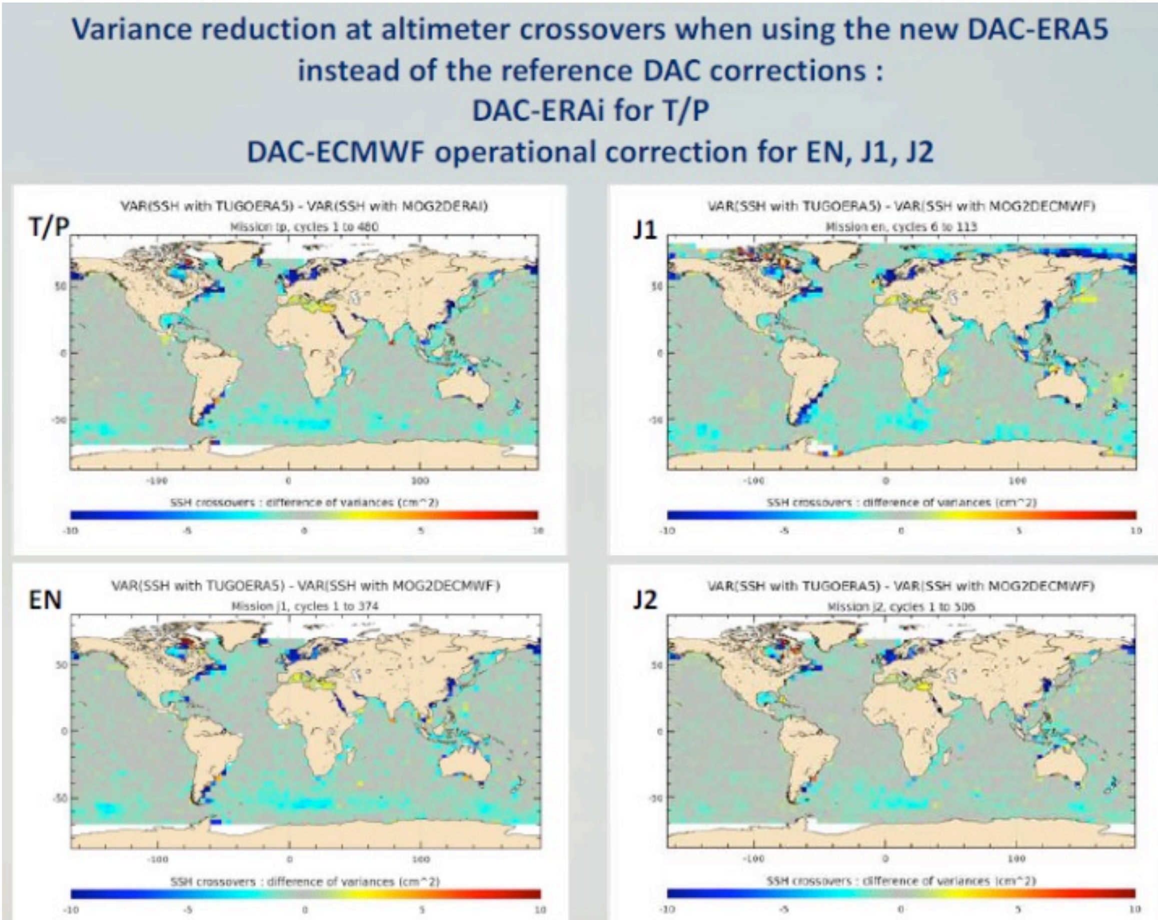


Figure 3.15-6. Validation results of DAC-ERA5 with altimetry (Carrere et al)

The recommendations of the session are:

Concerning interleaved phase, the recommendation is to use the interleaved orbit as long as possible for tides (RMS error of harmonic constants decreases as $\mathbf{1}/\sqrt{\boldsymbol{N}}$).

Concerning the mission extension on a geodetic orbit, it is not known at the moment if a geodetic orbit could improve the tide models between the repetitive tracks. A specific analysis for each geodetic orbit envisioned could be done to get some answers, trying to consider also the trade-off between spatial resolution and accuracy.

4 Closing Plenary

The closing plenary took place on Friday. This year splinter session summaries were not provided, and instead a discussion took place at the end of the session.

4.1 Science keynotes

The science keynotes session held during the first part *of* the closing session on Fri, Oct 23 2020.

Anny Cazenave (LEGOS/ISSI) presented a keynote on "Sea level change from global to local: role of observations" related to the Science I splinter (Climate data records for understanding the causes of global and regional sea level variability and change). **Abstract:** "To understand the complex functioning of the climate system and its evolution under the effect of natural and anthropogenic forcings, as well as the impacts of climate change on natural systems and human societies, major international organizations and space agencies in many countries have recommended or set up, for about three decades, a wide variety of observation systems for climatic parameters, at global, regional and local scales. The GCOS (Global Climate Observing System) has defined dozens of essential climate variables (ECVs) that must be observed very precisely over the long term, from space or the ground, to better understand the processes involved and their interactions, and validate models simulating future evolutions. Sea level from global to global scale is one of them. Closure of the sea level budget at global and regional scales is also part of the GCOS goals. For studies based on the global mean and regional sea level budget, we need sustained sea level observations from satellite altimetry with quasi global coverage. This means continuity of the high-precision altimetry record beyond the Sentinel-6 Michael Freilich mission, reprocessing of past missions and coverage the Arctic Ocean; For the steric component, it is crucial to maintain Core Argo and implement Deep Argo, perform regular subsurface temperature and salinity measurements in marginal seas, high latitudes, boundary currents, and shallow areas and shelf regions; perform systematic calibration of Argo data using independent observing systems; For the mass component, we also need sustained measurements of ocean mass changes, of ice sheet and glaciers mass balances, and of land water storage changes from GRACE-type missions with improved performances. Sustained monitoring of land ice bodies using other remote sensing systems (InSAR, radar and optical imagery, standard radar as well as SAR/SARIN, and laser altimetry) and modeling are also requested; Improvement of global hydrological models is also a major goal to estimate the land water component. This requires more accurate global digital elevation models as well as remote-sensing-based stream flow estimates. In addition to observational requirements, we also recommend continuing modeling efforts for terms not yet easily accessible by observations; e.g., GIA and fingerprints of present-day land ice melt. Another major challenge concerns coastal sea level. SAR technology and dedicated reprocessing of classical altimetry missions now allows to estimate sea level changes in the world coastal zones, with sometimes significant departure from open ocean changes. Unfortunately, coastal data (e.g., in situ temperature and salinity, coastal currents, river discharge, bathymetry, shoreline position, etc.) needed to quantify small-scale coastal processes that superimpose to the global and regional factors, are very sparse or inexistent in most of the world coastal zones. A specific effort is crucially needed to implement coastal observation networks, especially along vulnerable shorelines, that combine a variety of sensors from space and ground (including GNSS collocated tide gauges) to improve knowledge of forcing factors on coastal sea level and associated impacts. Development of very-high resolution hydrodynamical models covering coastal zones is also highly recommended."

LuAnne Thompson (University of Washington, United States) presented a keynote on "Provinces of air-sea interaction" related to the Science II splinter (Large Scale Ocean Circulation Variability and Change). **Abstract:** "Using analysis of the temporal relationship between sea surface temperature (SST), sea level anomaly (SLA), and turbulent flux of heat (Q), we investigate the relative role of the atmosphere and ocean in controlling air-sea interaction in the North Atlantic Ocean on monthly to interannual time scales. Here, we use SLA as a proxy for upper ocean heat content. We introduce a modification of a stochastic air-sea interaction model of air-sea interaction created by Frankignoul et al (1998) to frame the analysis. We add a low frequency noise forcing term that represents ocean heat transport convergence anomalies. The stochastic model demonstrates that the symmetry around zero lag depends on the relative strength of atmospheric and oceanic forcing with a more symmetric lagged correlation indicating that ocean processes dominate, while a deeper mixed layer gives more persistence. To identify the spatial provinces of air-sea interaction and the dominant processes that control air-sea interaction in each region using surface observations alone, we employ k-means clustering of lagged correlations of SST(SLA) with Q. We specify three clusters and interpret the lagged correlations by the results of the stochastic model. We find clear demarcation of regions with differing controls on air-sea interaction, one where ocean heat transport convergence anomalies dominate the control of air-sea fluxes (Gulf Stream and Recirculation Gyres), another where the atmosphere drives and then damps SST(SLA) anomalies (the Subtropical Interior), and a region where the atmosphere drives SST(SLA) anomalies that are not damped locally (Subpolar Gyre). We perform the analysis on both monthly and interannual time scales and find more robust features at interannual time scales, with SLA providing more detailed spatial demarcation than does SST. These results provide direct evidence for the potential of the use of SLA in air-sea interaction studies."

Bo Qiu (University of Hawaii, United States) presented a keynote on "Balanced upper ocean variability in the 15-150 km wavelength range" related to the Science III: splinter (Mesoscale and sub-mesoscale oceanography). **Abstract:** "The globally-gridded AVISO SSH product of 1993-present based on multiple altimeter missions has become the backbone for advancing our understanding of the nature and variability of the ocean circulation/sea level on spatial scales > 150-200 km. Availability of recently-reprocessed along-track nadir altimeter data, along with the forth-coming wide-swath SWOT data, provides us now an opportunity to explore the upper ocean processes in the wavelength range of 15-150km. This presentation will review recent progress regarding the balanced dynamic processes in this smaller-mesoscale-to-submesoscale range, the validity of geostrophy, the eddy kinetic energy pathways, and the contributions to vertical heat/materials transport."

Maxime Vayre (CLS, France) presented a keynote on "Water level monitoring over continental areas from fully focused SAR altimeter processing" related to the Science IV splinter (Altimetry for Cryosphere and Hydrology). **Abstract:** "The access to fresh water becomes increasingly difficult for many local populations. This natural and incompressible need for living beings leads to economic and geopolitical stakes. The knowledge of inland water resources represents a major challenge to anticipate floods hazards, assess inland waterways sailing conditions and estimate freshwater stocks or rivers discharge. At the same time, public in situ data are decreasing and heavy modifications of the water cycle are expected due to the current global warming and intensive deforestation. It is against this background that the use of altimetry data to monitor surface water levels over continental areas has been considered by altimetry experts since the beginning of the spatial altimetry in the 1990s. Inland water observation has never been the main objective of altimetry mission. However, consistent water surface height measurements have been provided from these satellites especially using SAR-mode altimeters. SAR-mode altimetry is currently used on-board operational missions such as Cryosat-2, Sentinel-3A and Sentinel-3B. It brings significative improvements when comparing with conventional altimetry over ocean but also inland waters areas. Based on the scientific community feedbacks, a greater use of SAR-mode altimeter is foreseen in the future (as for the upcoming Sentinel-3C/D and the Sentinel-6 missions of the Copernicus programme). In the operational ground segments, the current SAR-mode processing is based on the so-called unfocused SAR altimeter (UFSAR) processing. It performs the coherent summation of pulses over a limited number of successive pulses (64-pulses bursts of a few milliseconds in length). The possibility to realize coherent pulses summations has been recently [Egido and Smith, 2017] extended to the whole illumination time of the surface (from few milliseconds to more than 2 seconds). It allows the increase of the along-track resolution from 300 m (UFSAR) to the theoretical limit of approximately 0.5 m (FFSAR). Improving the effective number of looks, the capability for obtaining consistent measurements over reflective surfaces of small size is thus enhanced. As part of ESA and CNES project a so-called SMAP open-source software (FFSAR Standalone Multi-mission Altimetry Processor) has been developed. The purpose of this talk is to assess the FFSAR processing performances over more than 700 water bodies (French rivers, the Amazon, the Congo, the Niger …) within a 1-year period (April 2019 – April 2020) using Sentinel-3A measurements acquired in Open-Loop mode. The benefits from a user perspective will be addressed in terms of measurements precision, timeseries stability and ability to track water bodies of small sizes. The advantage related to the improved along-track resolution to select consistent measurements will be shown. Metrics will be presented to understand the main differences when comparing with the UFSAR. “Replicas” issues of Sentinel-3A and their implications for the FFSAR processing will be also discussed.”

At the end of the science keynotes, François Bignalet-Cazalet (CNES) discussed the current GDR status for altimetry missions. He recalled that we have currently 8 flying altimeters, with a quite homogenous processing baseline (thanks to coordination between all agencies) and of overall very good data quality: 28 years of past data (since TOPEX-ERS1) to continue improving data quality. He also noted that Sentinel-6-MF is using GDR-F standard and SWOT nadir will use the same baseline and product format. The Jason-3 processing of data to the GDR-F standard is available since Oct. 29th, 2020, in coherence with Sentinel-6 data products. The whole SARAL/AltiKa mission lifetime has been reprocessed and is now available at standard F: ftp-access.aviso.altimetry.fr /geophysical-data-record/saral/. A reprocessing of the TOPEX data record by NASA/JPL and CNES is now underway, with reprocessing products expected to be available by early 2021 and Poseidon-1 GDR-F products is in progress. Jason-2 GDR-F reprocessing campaign shall be engaged just after Jason-3 one, and finished end 2021. Then, if possible, we will prepare the Jason-1 reprocessing to GDR-F standard.

4.2 Recommendations and Appreciations

OSTST Recommendations:

- Based on subsequent input from the Jason-3 Extension of Life group (which took place after the OSTST meeting), we recommend:
  - 1 year tandem commissioning phase with Sentinel-6 Michael Freilich
  - 2 years on the Jason-2 Long Repeat Orbit (1309.5 km)
  - 4 months tandem phase with Sentinel-6 Michael Freilich (avoiding Atlantic hurricane season)
  - 1 year return to the Jason-2 Long Repeat Orbit (1309.5 km)
  - Mission extension on the Reference orbit at +47km (disposal orbit different from Jason-2)
- We recommend further joint-Agency study of the potential for using Jason-3 as an Altimetric Reference Transfer Standard (ARTS), as proposed by ESA to further homogenize discrepancies between Sentinel-3A/B and Sentinel-6 through crossover optimization to provide a consistent data set extending into the Arctic Ocean - a key area of Global Climate Change
- We recommend that given the high quality of currently available Slow Time Critical Data, an effort be made to produce and distribute Near Real Time data from HY-2B.
- We recommend that the Sentinel-6 MF Project consider performing yaw flip maneuvers during the commissioning phase that last approximately 4 days and occur during minimum beta angles in order to improve accuracy of orbit determination, by gauging the movement of the satellite CoM and potential antenna phase center biases.
- We recommend that in light of the high value of its data the SARAL/AltiKa mission should be extended beyond 2021.

OSTST Appreciations:

- for the successful release of GDR-F for SARAL/AltiKa and continuing effort to implement a consistent GDR-F standard across the missions.
- to the agencies for maintaining the launch schedule under the challenging conditions during the global pandemic for Sentinel-6 Michael Freilich, which is critical to maintaining the climate data record.
- to the agencies for continuing to improve and develop the next generation of satellites with extended capabilities compared to conventional altimetry (e.g., SKIM, SWOT, CRISTAL, Copernicus Next Generation, COMPIRA, HY-2).
- to the agencies for the delivery of high quality ocean altimeter data from HY-2B.

Finally, the 2021 OSTST meeting will be held, Oct 18-22 in Venice, Italy.