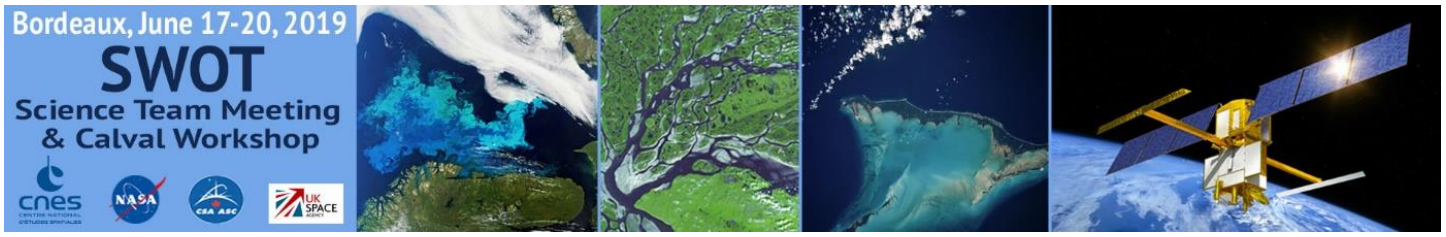

Report from the 4th SWOT Science Team Meeting

University of Bordeaux, Talence, 18-20 June 2019

Report compiled by the SWOT Science Leads :
Ocean : Rosemary Morrow (LEGOS/OMP, FR), Lee-Lueng Fu (JPL/NASA, USA)
Hydro : Jean-Francois Crétaux (LEGOS/CNES, FR), Tamlin Pavelsky (UNC, USA)

Agenda / contents

Monday 17 June 2019 :

Ocean Calval Workshop

Morning : Toward designing the post-launch Californian CalVal site

C. Chen & N. Picot introduced the session by providing a brief overview of the Airborne lidar , GPS, and in-situ experiments that have been recently tested in Californian Current region and elsewhere.

- There was a brief review of a previous presentation in Montreal by G. Dibarboure, that a global statistical approach based on the alignment of SWOT Karin/J-CS or SWOT Karin-S3A-B tracks having time differences of less than 1h could validate wavelengths SWOT-Karin wavelengths down to 50-70 km,
- Lidar campaigns have been run of the US coasts in 2019 (report later in the morning). Lidar flights are not planned during the Pre-launch campaign over the SWOT crossover location – plans to be discussed in meeting
- French lidar flights in the Mediterranean Sea have been postponed twice due to weather conditions, some flights were made over the Gironde Estuary
- SKIM in-situ campaigns have been performed near Brest in spring 2019, observing surface currents, tidal currents and SWH variability. There is a potential synergy with the CFOSAT CalVal site in 2020 in the Bay of Biscay, with information on surface wind-waves of interest for SWOT
- DUACS R&D 2018 reprocessing has been performed on alongtrack conventional Jason, Ka-band Saral and SAR Sentinel-3 data. When applying retracking/editing to reduce the surface wave effects, SARAL has a lower global SSH noise floor than S3. The reprocessed S3 SAR – LR-RMC has better white-coloured noise & small-scale errors. Encouraging for the validation of smaller scales with SWOT.

SWH – M. Raynal

The current baseline for the SWOT SWH estimation is to have 1 average SWH observation in the centre of each swath – yet there are smaller-scale gradients in SWH that could be estimated. A backup for SWOT could be based on SWOT nadir values – the spatial scales of SWH are analyzed here.

The study was based on using Jason-1 Geodetic phase / Jason-2 matchups with less than 1-day differences as proxy to give a global description of how the SWH will vary in the SWOT swath, and to characterise the observed sea state & SSH

- In the worst cases (far range swath, worst geographical areas), wave height will vary significantly (~1 m) in the SWOT swath.
- Transformed into SSH error, through the sea-state bias (SSB) computation, the SSB allocation error is found to be under estimated for wavelength between 300 and 50 km.
- Even in regions where the SWH variability is high, the error signal remains low with respect to SSH signal amplitude.

=> SWOT will have at least 1 nadir & 2 near swath SWH observations – extrapolation of SWH over 30 km in far swath should have low SSB errors

Q. R. Ray … Why not just analyse the alongtrack SWH data everywhere ?

In-situ Ocean CalVal Objectives (L-L. Fu. J. Wang)

The following are key points of the presentation:

- A fundamental challenge of SWOT is insufficient temporal sampling.
- Oceanographic validation and understanding will require thoughtfully designed in-situ observing systems.
- The twice-per-day sampling at crossovers during the fast sampling phase will provide the best opportunities for oceanographic validation.
- SWOT Project will deploy an in-situ observing system at the California calval site.
- A prelaunch campaign will be conducted in September 2019 at the California site to collect data for the design of the post-launch observing system, addressing the following objectives:

    - Test the closure of determining SSH with GPS buoy, CTD mooring, and BPR.
    - Test the sampling of the scales of SSH variability not resolved by conventional altimeters such as Sentinel 3A (S3A).
    - Evaluate the vertical scale of the upper ocean circulation that can be determined by SSH at the SWOT scales for different frequency bands.
    - Evaluate the roles of bottom pressure in SWOT SSH signals.
    - Assess the information content of the in-situ observations:
    - Continuation of the S3A wavenumber spectrum to the SWOT regime
    - Evaluate the reconstruction of the upper ocean circulation
    - Provide information for the design of the post-launch in-situ observing system.

- Data assimilative modeling is important for the ocean calval efforts.

Recent in-situ observations in the Californian Current region : Y. Chao

A review was provided on the 2017/2018 Monterey Pilot experiment. Seagliders were included as past of the CalTech KISS experiment in the Californian Current region.

Deployment & recovery cruises performed for gliders, GPS buoy and bottom pressure recorders (BPRs). Pb GPS mooring – data not being recorded properly. Intermediate Recovery cruise needed, but GPS giving a very good comparison to mooring dynamic height

Dec 2019 Pre-launch campaign– Instrumentation to be deployed under a S3 track within the SWOT Californian 1-day xover region, with 3 moorings

Geodetic objective : measure absolute SSH from a GPS mooring & colocated BPR

Oceanographic objective : understand the vertical structure leading to this SSH obervation … two options will be tested :

1. T/S at depths from full-depth CTD mooring – as a benchmark.
2. T/S profiles : from a GPS & wirewalker, prawler, glider

Deployment cruise is planned during the period 3-8 Sept 2019 on R/V Sproul – SIO (chief scientist: Uwe Send). Moorings to remain in water for 90 days (planned duration of the 1-day science validation phase) : recovery cruise planned on 3-8 Dec.

Pre-launch campaign in Dec 2019:

1. Mooring 2 : GPS & CTD mooring – for SSH & T/S at depth (delayed mode)

2. Mooring 1 : GPS-Prawler mooring – SSH & T/S profiles (PMEL/JPL)
3. Mooring 3 : Wirewalker – CTD mooring – T/S profiles & T/S at depth (SIO)
4. 2x BPS (SIO) separated by 30 km
5. glider hybrid – with propellor – vertical station keeping (Rutgers)

Data distribution : Each institute makes data available : then RSS/UCLA : Mirrored data

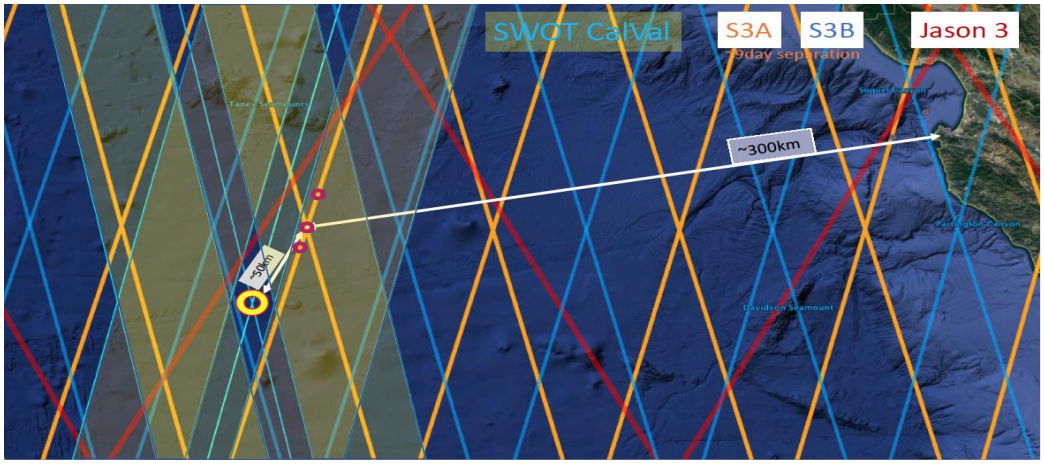

Figure : Pre-Launch Ocean In Situ Field Experiment 90-days during September - December 2019

GPS mooring : B. Haines, J. Wang, LL Fu

Temporal smoothing over 1h in GPS moorings seems efficient to reduce the temporal variability due to the waves. Using this noise reduction at the Daisy Bank GPS mooring – the GPS error is 0.1 cm2 at SWH = 3.3m

A Pair of GPS buoys was also deployed with 1.5 km separation along a Jason track

SSH-difference from these moorings confirms that the high-frequency GPS error is mainly due to waves

Conclusion : the GPS noise at 4 mm meets the SWOT requirements for SWH less than 4 m, after hourly averaging.

Discussion : the 1h temporal averaging of the GPS data is assumed to be equivalent to SWOT spatial averaging over 7.5 km to reduce the noise at wavelengths < 15 km (SWOT Spectral requirements calculation). But this equivalence between 1h temporal and 7.5 km spatial averaging has not been demonstrated.

Moorings - U Send.

The Wirewalker mooring concept was shown. This includes a Wirewalker profiling over the upper 500 m & 7 microcats measuring T/S at optimized depths below. Sampling error is < 0.3 cm. This type of hybrid mooring can generate full ocean profil data < +- 8 minutes in temporal resolution – with a full profile from the wirewalker every hour

For the SWOT CalVal campaign in 2022, there is a proposition for 12 hybrid moorings each separated by 7.5 km. In the 4-5 km depth, the mooring watch circle may move by +/- 4 km

Lidar flights - L. Lenain

- Modular Aerial Sensing System (MASS) integration onto the NASA JSC G-V ("NASA5")
  Faster, longer range aircraft – NASA Gulfstream-V - could also add AXBTS, ACTDs

15h duraton, up to 500 knots, 15000 ft altitude limit for the non-pressurised MASS installation

Prelaunch experiment overview :

1. Terrestrial flights over El Paso & Central Valley dunes 17-19 Oct 2016 – Lidar SSH variations below SWOT noise level
2. Sentinel 3 underflight along Gulf Stream #364 pass on September 29 2018.

- Spatially collocated measurements, 1-2hr apart due to weather (late take-off)
- MASS lidar derived ssha was corrected for tides using the same models used for S3 products (recomputed by CNES for aircraft trajectory) and using S3 MSL model.
- First look at the SSHA and SWH data is promising.

3. MASS-SWOT pre-launch Californian xover Mission could be done in early April 2019.

- Up & crosswind/waves repeated reciprocal legs – Two flights
- Sentinel 3A overflights (March 29 2019) – one flight
- Grid pattern, reciprocal legs – Two flights - 5x5 grid passes with 20 km spacing & 80 km length

Discussion Points

- should we move the position of the in-situ pre-launch array to be in the centre of tracks

- should the BPGs be separated by 30-50 km to detect deep BT motions < 120 km in wavelength ?

=> An independent review team will meet this summer to review the Pre-launch in-situ campaign plan.

Afternoon Session : dedicated to other ocean in-situ campaigns

SWOT Science Campaign workshop Nov 2018 – main points – T. Farrar.

Workshop Recommandations

1) Support the adopt a crossover effort
2) Organise additional measurements in the California Current region to complement SWOT & S-MODE – possible to resolve the 4D ocean variability
3) Separate dedicated SWOT field campaign 1-2 years after the SWOT launch

- Launch uncertainty makes it difficult to plan field campaigns with ships, etc, to co-incide with the Fast-Sampling phase science validation period.
- Difficulty also in keeping drifting observations in small 50km wide swaths … better to have the fine-scale science campaign during the nominal phase
- For 2) Better to rely on sustained measurements in Calif Current in case narrow sampling window shifts back in time. A small number of PI-driven proposals could be funded through US agencies.
- For 3) a multi-national campaign- could address questions about the meso-submesoscale circulation and balanced-unbalanced interactions. Possibly in the Gulf Stream Latmix region. Strong gradient signal here in mesoscale end submesoscales – depending on distance from the GS.

Overview of some sub-mesoscale initiatives of interest for SWOT

1) S-MODE – T. Farrar

Campaign in the Californian Current designed to measure the 3D structure of the submesoscale circulation, and the relation between surface velocity and that below the surface boundary layer. Estimate vertical heat transfers w'T'. 5-year $30M, start June 1 2019

Observations :

- 3 aircraft – Dopplerscat & SST ; Prism hyperspectral ocean color, MASS lidar
- In situ observations ; drifters with GPS ; wavegliders & saildrones, gliders, lagrangian floats (Saildrones – autonomous sailboats with meteo obs of wind stress & surface fluxes ; and upper ocean surface processes)

April 2020 – 2 week pilot campaign; April 2021 – 1-month campaign

Sept 2021 – 1 month campaign (could be aligned with SWOT fast sampling phase)

2) CALYPSO – A. Pascual

Series of in-situ campaigns with new technology in the W Med – strong meandering currents & front. Deep subduction

Campaigns held in July 2017 ; may/june 2018, March 2019. Experiment planned for 2020/2021

Includes multiscale modelling & Lagrangian coherent structure detection. Moorings with T/S and 7 instruments over upper 500 m. Important to have other tracers than T/S – eg chlorophyll ?

Length scales of 20 km – need 10 km grid observations. Time scales of 6-days

Drifter scales < 10 km, were very energetic 2f, but with shallow cells.

Adopt a crossover – d'Ovidio

The CLIVAR Adopt-a-crossover group will provide a global intercomparison of fine-scale ocean processes over a 3-month period in early 2022. The group has the opportunity to share analysis techniques and in-situ sampling strategies for the different dynamical regions, in different hemispheres/seasons. Both physical and biological themes can be addressed.

The Adopt-a-crossover inititaive has been supported by two OceanObs papers (one general one on SWOT by Morrow et al 2019 ; one dedicated to the Adopt-a-crossover initiative by d'Ovidio et al., 2019). There was also an EOS publication on this in 2019. The in-situ consortium for the fast-sampling phase now has a CLIVAR endorsement

The risk of a last-minute launch delay was discussed – regional deployments would then have to rely on conventional altimetry & other satellite products (shame for SWOT)

A provisional steering group for Adopt-a-crossover is in place. A formal CLIVAR steering group should be established with non-SWOT members and from different continents by the end of the year.

Satellite packages for adopt a crossover in-situ campaigns

The CNES will support satellite data packages available before, during and after the cruises within the official adopt a crossover sites working within the CLIVAR group.

Alongtrack SSH data will be available from different missions with retracking to reduce wave noise errors. Products would include SLA, ADT, currents, formal mapping error, FSLE, eddy tracking – from global & regional altimetric data sets. Probably Merged ADT & drifter products, or SST data for improved MDT or currents, ocean color & SAR images. Possibility of CFOSAT SWH, and optical images from S2 & Pleaides

AUSWOT – C. Watson, B. Legresy

Bass Strait CalVal site. The long term Bass Strait CalVal sites for both Jason-3 & S3A are within one swath of the SWOT Fast sampling phase orbit.

Bass Strait is a shallow sea with different surface conditions from the Californian site, with 1-2m waves & strong tides, and small submesoscales. The site is instrumented with C-PIES & 6 GNSS/INS buoys. Buoys separated by 50 m. Std de 8.5 to 10 mm.

The site will continue to be supported by the Australian IMOS for SWOT activities in 2021-2024. Additional support is needed if the Bass Strait mooring array is to be extended to cover both swaths with 12 GNSS buoys (GNSS buoys : Low cost US$30K per buoy). Is this needed ?

Other Australian sites under discussion for the Fast Sampling or nominal phase :

https://auswot.org

The fast-sampling orbit passes over 2 national reference moorings, with T/S & GPS – Yongala – on the Great Barrier Reef in Queensland, & over the Southern Ocean Time Series station near 50°S. Possibility to put other instrumentation on these 2 sites.

Other possibilities being discussed with the Australian collegues are in the Leeuwin Current extension region on the SW coast of Australia, where there are active coastal trapped waves. Or on the Aust NW shelf region where there are energetic internal waves

A recent research cruise was undertaken in the ACC south of Australia to study mesoscale to submesoscale dynamics in Oct-Nov 2018. Its a region of low internal tides, clean mesoscale-submesoscale cascades

The campaign used Triaxus towed profiler … 2 km resolution at the surface, profiles down to 300 m – giving 1 to 10 cm SSH structure at the surface.

An Australian-US consortium is discussing a Cruise proposal submission for early August 2019, for a SWOT cruise planned in early 2022. An alternative is for a SWOT ACC cruise during the nominal phase in late 2022.

Other potential SWOT fast-sampling phase sites and observational techniques and applications were presented :

- W Mediterranean CalVal updates - (A. Doglioli)
- New Caledonia site, with equal mix of mesoscale and internal tide SSH signals (L. Gourdeau, F. Marin)
- Internal tides interacting with the slope current off the Amazon, with an international AMAZONMIX campaign planned in Sept 2020 (A. Koch-Larrouy)
- Observations of (sub)mesoscale bio-physical variability (K. Drushka, P. Gaube)

Discussion Points :

- Both the Fast-sampling phase Adopt a crossover effort and the Californian science extension of the CalVal mooring array must be organised within 1 year.

⇨ Discussion with the current Adopt a crossover in-situ group will be organised in Sept/Oct 2019 by F. D'Ovidio. A videoconference will be held with current adopters, and a transition from the provisional steering committee. The policy for in-situ data availability and sharing is to be decided.

⇨ The ocean community expressed a willingness to have an extension of the fast-sampling phase by a few months (to June 2022), which would allow more secure planning of CalVal activities in case of a few month launch delay, and also provide observations during the spring bloom. To be discussed with the Hydrology community and the Project

- For the SWOT science field campaign during the nominal phase … need to start organizing this over the 2019/2020 period for a campaign planned in late 2022 or 2023

⇨ T. Farrar will work with E. Lindstrom to set the agenda to plan this post-launch campaign.

⇨ Q. is the Gulf Stream the best site for the Science campaign ? Further downstream may be better for mesoscale – internal tide interactions, and more fully developed turbulence. International partners are also desired – so other sites may be explored.

⇨ PACE ocean colour mission will be launched in 2022 … would it be good for the SWOT science campaign to address both physical and biological themes?

SWOT Hydrology Data Products Workshop Summary

Tamlin Pavesky

On the Monday prior to the 2019 SWOT Science Team Meeting, SWOT hydrology science team members and key project members met to discuss the current status and future plans for SWOT high-resolution data products. The overall meeting objectives were to describe the SWOT level 2 hydrology data products, explore choices the algorithm team is making regarding the products, getting Science Team feedback on these decisions, and, where possible, introducing the science team members to example data products.

The day started with presentations from members of the SWOT project, including Curtis Chen, Brent Williams, and Roger Fjortoft on the lowest-level products of interest to the hydrology community. Discussion started with a presentation of the overall HR data flow, along with a summary of how the SWOT data products will be broken up into granules and the data storage formats planned (primarily netCDF, with shapefiles for the vector products). The single-look complex imagery (a L1 product) was presented briefly, although it was agreed that most hydrologists would be unlikely to work with this expert-level product. As a result, much more time was spent discussing the pixel cloud (a L2 product), which many Science Team hydrologists will work with. The pixel cloud will represent all SWOT-visible water areas within the high-rate mask, along with an adjacent buffer area. A good deal of the discussion focused on the classification of water pixels vs. land pixels.

The second portion of the day's meetings focused on SWOT river products. Elizabeth Altenau gave an update on development of the SWOT a priori river dataset (SWORD), which will serve as the foundational layer for creation and distribution of the SWOT river vector products. SWORD is being developed based on a combination of the MERIT Hydro DEM-based river product, the Global River Widths from Landsat (GRWL) product, and several other, more specific global datasets. It will ultimately contain predefined river reaches and nodes for all SWOT-observable rivers. Mark Hagemann showed a web-based tool that he has developed for users to explore a set of example SWOT river products. Mark walked the room through this tool, available at https://swot-riv-viz.shinyapps.io/riverproducts/, which allows users to examine river reaches and nodes visually. Finally, Mike Durand gave a presentation on some of the challenges in creating high-quality river products, showing some cases involving braided rivers, migrating channels, and river-lake interfaces, all of which will prove problematic for the river vector products. In these areas, users should probably focus on using the raster data product.

In the afternoon, discussion focused on lake data products for the first session. Claire Pottier and Yongwei Sheng gave presentations on the SWOT a priori lake database, which is well along its development trajectory. It is largely developed for Europe, and the French team leading the development is awaiting delivery of the rest of the world's lake boundaries from Yongei Sheng to complete the database. Claire Pottier's second presentation summarized the planned single-pass lake product, which will include polygons and related attributes for all SWOT-observable lakes in shapefile format. Drafts of all related algorithms are more or less complete, and the product description document is under review. The hope is to release example data products and the PDD soon.

The final session of the meeting focused on three additional topics: the raster data product, data quality flags, and the floodplain DEM product. Tamlin Pavelsky provided an update on the raster product, which will be provided natively at 100 m and 250 m spatial resolution in UTM coordinates (although PO.DAAC is planning a tool to allow arbitrary characteristics, within bounds). Example data products have been created over the Sacramento and Severn rivers and will be released with the PDD later in 2019. A panel discussion with Cedric David, Larry Smith, and Sylvain Biancamaria focused on needs for data quality flags. The overall conclusion was that both data quality flags indicating good/bad data and data quality metrics allowing users to assess this on their own should

be provided whenever possible. Finally, Damien Desroches gave a presentation on the floodplain DEM product, which will largely be developed based on his work associated with pixel assignment to water/nonwatery classes.

Tuesday 18 June 2019 :

Morning : Plenary session, Project and Science overviews

This was the final Science Team meeting for the current 2016-2019 Science Team, and it was held in an old monastery on the grounds of Bordeaux University. The main objectives of this meeting were :

- To update/discuss with the science team on recent progress from the Project in the instrument development and testing, on data products
- For the science team to discuss ongoing issues for the SWOT observations and their inclusion with models via data assimilation, and with other data sets for the hydrology, oceanography and coastal/estuarine themes
- As the final meeting with this Science Team – present a short review of the past 3 years achievements by the Science Team hydrologists and oceanographers in the preparation for SWOT, and the key work underway. A coastal and estuarine review was given on Thursday
- The Science team is actively involved in Algorithm Development leading up to the launch, subject matter experts are working on analyzing some of the Product Description Documents and the Algorithm Theoretical Basis Documents are in preparation – updates were given during the science team meeting.

Program overview (Eric Lindstrom, Selma Cherchali)

Eric Lindstrom (NASA) and Selma Cherchail (CNES) gave an overview of the SWOT Program status. A NASA/ CNES Joint Steering Group meeting was held on April 18th 2019, to review the SWOT project status which has progressed well in support of the 2021 launch. The JSG also supported the goal of shortening the SWOT data latency from 45 days to <3 days, as well as introducing additional opportunities to generate reprocessed science data products for greater science return. The board endorsed the change in the baseline plan for the science data processing workshare between NASA and CNES, needed to implement these changes.

The current science Team is funded until spring 2020 (US) and to the end of 2019 (Fr). A new SWOT Science Team will be formed next year, to accompany the mission during its pre-launch, launch, calibration/validation phase and the early science mission, with a task duration from April 2020 to April 2024 (4 years). A call was issued on June 14th for TOSCA proposals, covering French, European and international proposals. The SWOT TOSCA call will have a deadline for 31 Oct 2019, and will be funded at a level of 1ME/yr for French oceanographers and hydrologists. European and international partners need to find their own national funding. For US participants, a new SWOT Science Team call will be issued as an amendment to ROSES 2019, circa July-August 2019. The due date for ROSES proposals is TBD (Nov 2019?) with a funding level at 3M$ for oceanographers and hydrologists. Post-launch, an expansion of the science team is likely and would be in the ROSES & TOSCA calls of 2022.

It has been decided that core SWOT CalVal activities for infrastructure and data collection will be managed by the SWOT Project – field campaigns and data processing needed to meet the basic mission requirements will be organised by the Project. There will be no specific ROSES or TOSCA SWOT CalVal field campaign or CalVal data analysis calls. SWOT Science Team members 2020-2024 may still be engaged in measurement validation as part of their science projects.

The CNES mentioned two other satellite campaigns of interest for SWOT. CFOSAT, and French-Chinese satellite will make global observations of wind/waves over the oceans using scatterometry techniques. CFOSAT was launched on 29 October 2018, its commissioning phase is ongoing, and data will be available in Fall 2019. Quicklook wave data from the SWIM instrument is already available.

The SKIM mission (surface currents and waves) is a candidate mission for the ESA's Earth Explorer 9 series, final selection will be decided in a user meeting in July.

Project status (Parag Vaze, Thierry Lafon)

All elements of the SWOT mission are maturing towards the 2021 launch. The Karin Instrument integration and testing is the critical element, and this is well underway. The antenna and deployable (folded) mast is being assembled, integrated and tested. The design also contains an antenna alignment mechanism for correcting for on-orbit alignment errors in the azimuth direction. The SpaceX Falcon-9 launch vehicle development and long lead production are well underway.

The CNES provided KaRIn Radio Frequency Unit (RFU) has been developed. A capacitor parts failure risk was recently detected, the capacitor has been replaced and is under final testing, with a pre-shipment review planned in mid-July. This adds a delay on the planned delivery to JPL, but the joint (NASA-CNES) projects are working to evaluate and optimize the global schedule towards mainting the launch readiness date. This won't be confirmed before Fall 2019. DORIS testing is well underway and nearing completion for delivery to JPL. The nadir altimeter's point target response (PTR) is slightly out of specification. Modifications are underway to correct this and the Poseidon 3C altimeter should be completed in Oct 2019 and prepared for delivery to JPL.

As mentioned in the program status, the joint JPL/CNES project team has made a detailed performance and engineering study to see if the existing system can be modified to shorten the latency of standard data products from 45 to 3 days. Measurement performance after 3 days was found to be similar to 45 days. PO.DAAC and CNES mission center development is ramping up to archive and distribute these products and engage with the user community, including the Early Adopters.

CNES and their prime contractor (Thales) are progressing on the satellite bus development. The Flight software and other key inputs are progressing well for the bus to start Assembly, Integration, and Test (AIT) in the fall and to be completed by late spring 2020. The bus will then await the delivery of the complete payload module from JPL planned for late 2020. Other work to prepare for the future launch is ongoing such as debris avoidance & maneuvering, especially during deployment.

A final point addressed the 24 GHz spectrum auction for 5G telecommunications applications and its potential impacts on the AMR-S wet tropo correction (23.6 to 24.0 GHz). This could impact the AMR on SWOT, but also most other current radiometer missions and likely future altimeter missions using this wavelength band. Simulation and analysis are underway at JPL to further investigate the effects. In some situations, the Model path delay could give 1-2 cm error. An onboard filter could attenuate this additional noise at this frequency, but it likely won't eradicate it completely. Various implementations are being proposed for which various scenarios will be evaluated. Notionally user devices (phones) along with the towers may cause interference particularly along heavily populated coastal cities.

Potential Mitigations :

- Modify AMR hardware to add an RFI filtering spectrometer to 24 GHz; This is not practical for SWOT as the AMR is already complete and delivered.
- Develop ground software detection/flagging 2-frequencies, UPorto GPD+ algorithms

This is a general problem for many Earth Observation missions, and a progressive study approach is planned with the next results of the studies will be discussed more at the next OSTST meeting.

SWOT applications Working Group overview

A. Andral, M. Srinivasan, E. Beighley, F. Hossain

The status of the Early Adopter program was given with 40+ people representing 12 agencies from the US/Canada, Europe and Asia (India, Thailand, Pakistan). An early Adopter workshop and training session with SWOT data was organized in May 2019 in Paris, with 26 participants and 24 Webex attendees. Cloud computing and Google earth Engine tutorials were organized, as well as simulator tutorials using the CNES SWOT Hydrology Toolbox. Over the oceans, data visualization and extraction using multiple data sources is also in development through the PANGEO frameworks, and the CNES computing facilities and seascope https://seascope.oceandatalab.com/.

The Workshope recommendations were :

1. **Make available SWOT hydrology simulated datasets** that represent realistic performance characteristics over land and follows the SWOT data product definition.

2. **Make available additional online resources for tutorials** on a) cloud computing; b) explanation of SWOT mission, function and its data type; c) existing tools and datasets relevant to SWOT for the EA projects.

3**. Organize hackathons for SWOT EA projects** to solve specific hurdles and build tangible solutions.

4. **Arrange for more immersive learning/training experiences** for EAs for rapid prototyping of solutions identified as a need.

In 2019-2020, the Applications working group will continue activities to support and train the early Adopters, and propose to organise one hackathon/year for EAs to solve specific problems, and build an application. Key resources for early Adopters are on the SWOT website

SWOT Ocean and Hydro Splinters – Key Results 2016-2019

The second half of the morning session was dedicated to an overview of the main SWOT splinter sessions, presenting the key results from the last few years of this SWOT Science Team, and the key remaining challenges. The presentations are online :

Ocean Splinter key results :

- Ocean HR modelling for SWOT - Klein, Arbic, Le Sommer;
- Ocean observations for SWOT - K. Drushka
- Ocean Tides and HF motions - E. Zaron;
- 2D/3D reconstruction of SSH and currents - E. Cosme;

Hydro splinter key results talks :

- Lakes sciences and progress - J-F Cretaux, Y. Sheng
- Discharge algorithm and science -DAWG Team
- SWOT and Hydrologic Modeling - E. Beighley, P. Lemoigne
- Cal/val on lakes, rivers and estuaries -Minear, Calmant, Pavelsky

Afternoon : Hydrology and Oceanography Splinter sessions :

14h-15h30 SWOT Lake Algorithms, Science & Processes

Convenors : Yongwei Sheng, Tamlin Pavelsky, Jean-Francois Crétaux

Lake changes across the Earth are rather complicated. Decadal lake area changes have been examined at the global scale using circa-2000 and circa-2015 Landsat images, and a large number of

lake change hotspots have been identified and would be crucial areas for the SWOT mission to study lake storage change. Lake storage change is the most important lake product of the SWOT mission. A set of comprehensive lake storage change algorithms has been developed for the mission and being validated. SWOT data would be very useful to monitor the dynamic and poorly known water bodies in the Sahel. SWOT-like data were found to be well suited to retrieve the water level seasonal cycle and to estimate water volume variability in Sahelian lakes. Moreover, SWOT will provide fundamental data to estimate surface water exchanges during the dry season and to provide a proxy for runoff in ungauged watersheds. These data together with water quality information that can be derived from the current generation of high resolution optical remote sensing sensors will allow an integrated vision of the dynamics of waterbodies in this area. A major new acquisition of AirSWOT data was collected across Alaska and western Canada in 2017 as part of the NASA Arctic-Boreal Vulnerability Experiment (ABoVE). Both Ka-band InSAR data mapping water surface elevation (WSE), and high-resolution color-infrared camera images revealing inundation extent were obtained. Both datasets are now freely available to the SWOT community at Oak Ridge National Laboratory (ORNL) and provide a valuable empirical dataset for testing water classification algorithms and hydrological science using SWOT-like measurements.

16h-17:30 Discharge Algorithms & Science

Convenors : Mike Durand, Pierre Olivier Malaterre, and Colin Gleason.

This session covered three general topics: First Pierre Andre Garambois highlighted a new scientific paradigm: “hydraulic visibility”, or HV. Garambois was the inventor of this paradigm, and it relates to a very important topic as related to SWOT, namely how measurements at a SWOT overpass can be used to reconstruct river processes before and after the overpass. Algorithms to perform this reconstruction are readily available (interpolation, data assimilation, etc.). The contribution of HV is to set rule-of-thumb thresholds on the upper limit of such capabilities. HV is an important contribution to the science of remote sensing of rivers.

The second topic was an update on the results of Pepsi Challenge version 2, and was presented by Kevin Larnier, Renato Frasson, and Hind Oubanas. While results are still preliminary, there are three emerging findings. First, we found that discharge can be estimated from SWOT alone, with acceptable accuracy, even when algorithms are run truly blind. This is different than what was concluded in a previous round of testing. Second, we found that neither measurement uncertainty nor temporal frequency governed the final discharge accuracy. This was encouraging, as this was the first systematic study to test those aspects. Third, we found that prior discharge estimates play an important role in governing accuracy. This led naturally to the discussion of how we should best employ ancillary datasets such as in situ discharge measurements in SWOT discharge data products, which was next on the agenda.

The third topic was a discussion of how to use a priori data such as in situ discharge measurements. This generated some debate; some in the community felt that no in situ discharge should ever be used to constrain the SWOT discharge products. Others felt it was imperative to use in situ data. The emerging consensus, to be fleshed out and reaffirmed, is to have separate products that use and do not use in situ data, to satisfy the various elements of the community, and to support the widest range of hydrologic science applications of the data. This decision highlights the need to coordinate with the cal/val team to ensure discharge validation follows best practices.

14h-15h30 : High-resolution ocean general circulation models

Convenors : Patrice.Klein, Brian Arbic, Julien Le Sommer

- B. Arbic presented **a comparison of resolved internal tides and gravity waves in several global models versus observations**, highlighting the different skills of existing hi-res models depending on their detailed formulation.
- A. Nelson presented results showing **how increased model resolution affect the simulated internal wave spectrum**
- S. Gille discussed results from **regional modelling activities in the Californian current**, showing how **resolved internal wave field is sensitive to the boundary forcing** from the open ocean, and how this challenges regional modellong strategies.
- L. Brodeau / J. Le Sommer presented their **new North Atlantic model experiments** and discussed energy exchanges at scales <100km, **highlighting how internal waves affect energy cascades towards dissipation scales**
- S. Smith presented results on **vertical transport due to ocean fine scales** from two studies focusing respectively on tracer subduction and nutrient fluxes toward the surface, highlighting how solutions vary with model resolution
- P. Klein presented results from LLC4320 simulations showing **how balanced submesoscale motions are driving deeper vertical exchanges of heat and buoyanc**y in the open ocean.

16h - 17h30 : Ocean fine-scale observation : In-situ & Multi-satellite studies

Convenors : Aurelien Ponte, Ananda Pascual

- To accompany the SWOT SSH observations, there is a need for integrated multi-platform experiments (e.g., satellite, ship, gliders, drifters, floats, aircraft):
    - With both Eulerian & Lagrangian strategies
    - Making direct measurements of vertical velocities
    - With an interdisciplinary approach for understanding fine-scale processes, notably biochemistry
- Biogeochemical efforts should include:
    - Deep biological sampling (e.g., at the deep chlorophyll maximum)
    - Improving knowledge of higher levels of the trophic web (e.g. grazers)
- Efforts are already underway in the Western Mediterranean, where contrasting water masses give rise to interesting fine-scale activity for both physics and biology.
    - Could there be an international coordination in this region (2022)? Funding could be sorted at national and/or European levels.
- Several experimental studies have focused on internal gravity waves in order to:
    - estimate the continuum of the internal gravity wavefield directionality from moorings
    - Sarah Gille showed a Helmholtz decomposition analysis applied to shipboard Acoustic Doppler Current Profiler (ADCP) measurements in order to identify the transition length scale from balanced to unbalanced motion. The transition scale was consistently estimated to be 70-80 km in three domains in the eastern Pacific (the California Current, Chereskin et al 2019), the tropical Pacific north of 15N, and the tropical Pacific south of 5S. This contrasts with Qiu et al's (2018) estimates from high-resolution model output, which show greater spatial variability.

- Promising airborne surface velocity measurements from DopplerScatt have led to maps of vorticity and divergence
- Lia Siegelman presented observational work combining conventional satellite altimetry data and high-resolution *in situ* measurements collected by an instrumented elephant seal in the ACC. Results highlight the existence of intense submesoscale fronts below the ocean surface mixed layer. These fronts are associated to strong vertical velocities reaching 100 m/day and driving a mean vertical heat flux of 100 W/m^2 that is directed upward. A good correlation is found between FSLE derived from altimetry data and buoyancy gradients at depth, opening new perspectives to infer vertical velocities in the ocean interior by combining e-sqg methods (Qiu et al. 2016) with the omega equation.

17h30 Poster session

Many of the posters can be viewed on the AVISO website at :
https://www.aviso.altimetry.fr/fr/coin-utilisateur/equipes-scientifiques/swot-science-team/swot-science-team-meeting-2019-bordeaux-france/swot-science-team-meeting-2019-bordeaux-france-posters.html

Wednesday 19 June 2019

Morning : Plenary session, Products and Science data algorithms

Chairs : Nicolas Picot, Shailen Desai

D. Fernandez and N. Steunou provide an update on the current best estimates (CBEs) of the SWOT KaRIN error budget based upon analyses to date. The SWOT requirements on the short wavelength (< 1000 km) measurements of sea surface height are expected to be met with approximately 35% worst-case margin. For the long wavelengths (> 1000 km) the CBE is near the required value. The requirements for hydrology height and slope are expected to be met with approximately 46 and 37% margin, respectively.

The SWOT project has committed to a new baseline for routine (forward processing) and reprocessing of science data products. The new baseline consists of a goal to generate forward processed science data products with a latency of less than 3 days, and a reprocessing plan of approximately once per year, depending on the evolution of the algorithms. The short latencies will be achieved by generating products with preliminary inputs for the orbit ephemeris, crossover calibration, radiometer calibration, model for the dynamic atmosphere correction, Earth pole location, and climatology (vs. optical-based) ice flag. The reprocessing opportunities will then use precise inputs to generated products. Analyses presented at the 2018 science team meeting demonstrated that the preliminary inputs are expected to have negligible impact on the sea surface height spectrum, no change to the hydrology slope error, and reduce the hydrology height error margin to 43% (from 46% using precise inputs and CBE metrics).

A high-level summary of the current status of the development of various documents that are intended for users of the SWOT science data products was presented by S. Desai and N. Picot. These documents include a User Handbook, the Product Description Documents (PDDs), and the Algorithm Theoretical Basis Documents (ATBDs). A summary of these documents is provided in the table below.

User Handbook	• Aimed towards all users • Provides general context of SWOT mission and measurement system that apply to all products.
Product Description Documents (PDDs)	• Aimed towards general users, especially those that might find ATBD to contain too much technical detail. • Intended to capture as wide of an audience as possible. • Provides high-level qualitative descriptions of parameters within each product.
Algorithm Theoretical Basis Documents (ATBDs)	• Aimed towards more-expert users interested in technical details of how reported variables are computed. • Contain mathematical and physical basis of algorithms users to generate products.

A separate PDD and ATBD is being written for each of the SWOT science data products. The SWOT KaRIn PDDs and ATBDs are subject to review by Subject Matter Experts from the SWOT Science Team. The SWOT nadir altimeter PDDs and ATBDs have strong heritage from the Jason missions and were comprehensively reviewed by the Ocean Surface Topography Science Team during the Jason-1 mission development. The SWOT nadir altimeter products and algorithms will use the best available Jason and Sentinel-6 standards.

Review of the first version of the PDDs by the Science Team's Subject Matter Experts started in early 2019 and is expected to continue through the end of 2019. When this review is completed the PDDs

will become publicly available along with sample data products. A similar review of the ATBDs is expected to begin by the end of 2019 and is targeted for completion by the middle of 2020, at which time they will also become publicly available. Members of the JPL and CNES Algorithm Development Team (B. Styles, N. Steunou, B. Williams, D. Desroches, J. Turk, C. Pottier, C. Chen, T. Pavelsky) also presented the current status of the SWOT KaRIn Level 2 science data products, as they are expected to be defined in the initial release of the PDDs. The most notable change with respect to the 2018 Science Team Meeting is that the Level 2 ocean science data product will consist of four files, instead of seven, per half-orbit revolution. These consist of three files that provide measurements of sea surface height, significant wave height, sigma0, and wind speed on a 2 km geographically-fixed grid, and one file with sea surface height and sigma0 on a 250 m (500 m resolution) native center-beam grid.

The data distribution centers for the SWOT science data products presented their status and plans, including value-added products and services. S. Vannan et al. presented that status of the NASA's Physical Oceanography Distributed Active Archive Center (PODAAC). F. Gouillon and G. Dibarboure presented the status of the CNES THEIA/Hydro and AVISO/ocean data distribution centers. Both described approaches for handling the high data volume expected from SWOT. These included traditional approaches for explicitly downloading data to a user's computer, or for users to process at the data center locations (e.g., cloud computing services).

T. Pavelsky et al. provided an update on the high resolution (HR) data acquisition mask. This mask defines the portions of the SWOT ground track for which HR data will be downloaded given the available downlink capacity. Most HR data is collected over continents to support the hydrology science data products. A summary of the evolution of the HR mask since its first version in 2015 was provided. The changes facilitate download of HR data over sea ice and addressed various issues in the original HR mask including missing coverage (e.g., coastal areas, islands, previously missed lakes), and coverage over uninteresting areas (e.g., deserts and/or other areas with no rivers or lakes). The most recent version of the HR mask is available for download by the science team (e.g., in KML format at https://www.aviso.altimetry.fr/fileadmin/documents/missions/Swot/swot_science_hr_2.0s_4.0s_June2019-v3_perPass.kml). The science team was invited to suggest any additional minor changes to this mask by August 1, 2019.

Afternoon : Hydrology and Oceanography Splinter sessions :

14h-15:30 HR Data Access & Online Facilities

Chairs : C. David, R. Fjortoft

While the archiving and distribution of remotely-sensed ocean observations from satellites has benefitted from over two decades of experience with nadir altimetry missions, the advent of the "high rate" (*i.e.* high spatial resolution) measurements of rivers, reservoirs, lakes, and wetlands that are expected from the SWOT mission poses new challenges for data centers as it does for data users. The primary goal of this splinter session was therefore to foster dialogue between the community of hydrologists from the SWOT Science Team and representatives of the two data centers tasked with the management of SWOT data products. These data centers are the Theia Data and Services Centre (hereafter Theia) on the French side and the Physical Oceanography Distributed Active Archive Center (PO.DAAC) on the U.S side. The splinter session was organized such that the two data centers were given 30 minutes each for presentations of their current activities and a 30-minute discussion with the audience followed.

Flavien Gouillon represented Theia and discussed ongoing plans to build on the success of HydroWeb (http://hydroweb.theia-land.fr/) to develop a new data sharing platform called Hydroweb-NG, a component of the HYSOPE II system. A demonstration on how to "Bring Your Processing to the Data" was also shown. Michael Gangl represented PO.DAAC and discussed how SWOT data archiving and distribution (https://podaac.jpl.nasa.gov/swot) fits within the larger NASA transition to the Amazon Web Services. A detailed road map was also provided to discuss prioritization of activities including the interoperability with existing standard tools, platforms, and programming interfaces.

An initial discussion with SWOT Science Team hydrologists helped reassure that data downloads (including some data transformations) from NASA's Amazon cloud to local computers will remain free of charge, which had otherwise been conveyed as a potential concern. Hydrologists also expressed a strong interest in the facilitation of methodologies allowing ad-hoc data processing in proximity of SWOT data and in the testing of these options in advance of SWOT data availability. Such eased access to large data volume allowed by processing within cloud platforms was acknowledged as a new research paradigm necessitating further thought on the cost model for research activities. An alternative approach based on High Performance Computing (HPC) and large disk archives is proposed by CNES and offers both data proximity and access to HPC at no cost for a number of users that remains to be determined. Potential scalability issues could be addressed by extending processing to the cloud when large processing requests are made. High enthusiasm was furthermore expressed by the audience for the importance of developing Application Programming Interfaces (APIs) for 1) data download, 2) spatial and temporal sub-setting, and 3) reformatting, re-gridding and reprojection. No specific standard of API was recommended by SWOT ST hydrologists, although the importance of standards was recognized, and hydrologists are therefore looking to data centers for recommendations on best practices. Potential interfaces with popular Geographic Information Systems (GIS) such as QGIS and ArcGIS were seen as valuable although of lower priority than API development and eased cloud/HPC access. Note that this feedback was provided solely by SWOT ST hydrologists and therefore may not be fully representative of the broader SWOT hydrology user community that is expected to include other academic researchers as well as water management agencies.

16h-17:30 SWOT Data Assimilation and Hydrologic Modeling

Chairs : Patrick LeMoigne and Ed Beighley

The data assimilation and modeling hydro splinter focused on understanding discharge uncertainty, simulated river discharge performance from global scale hydrologic models, advances in lake models and their integration into Earth System Models, and applications for SWOT derived discharges. The following captures the key contributions, discussions, opportunities and remaining challenges.

A novel method was presented for quantifying river discharge uncertainty by characterizing and propagating uncertainty from runoff sources and routing processes. The approach was used to improve river discharge estimates based on the assimilation of synthetic SWOT discharges. Although a specific example was presented, the approach is applicable to other models/methods. Next, a global scale hydrologic model was shown to be capable of providing "reasonable" a priori river discharges along SWOT observable rivers. Although results are reasonable, performance varies regionally with arid/semi-arid regions being the most challenging. Note, that the presented discharge results were from a model calibrated using in-situ streamflow data. Discussions focused on how best to use simulated discharges from models calibrated with in-situ streamflow vs. models calibrated using only remotely sensed data for a priori discharges used as input to (or for assessment of) SWOT discharge algorithms. Given the global variation in available in-situ streamflow data, further discussion is needed. Several presentations highlighted advances in lake modeling and integration into ESMs. The need for coupled modeling systems was highlighted, with lake models leveraging

water surface elevations and extents from remote sensing. Although progress has been made, there is still a lot of work remaining to implement a global scale coupled modeling systems. Focusing on SWOT derived river discharge, several presentations suggested that baseflows will be well represented by SWOT time series leading to advances groundwater understanding and modeling capabilities. Lastly, a coupled system using SWOT-like discharges derived from LandSat river widths and a discharge algorithm (i.e., remotely sensed river discharges) and a priori river discharges from a global scale hydrologic model was presented. The coupled system was shown to generate "better" & "network-wide" discharge estimates. This system provides a framework for SWOT-like discharges using only remote sensing. In this case, the hydrologic model was calibrated using in-situ discharges.

In summary, the discussions focused on opportunities for advancing global scale modeling capabilities. Specific opportunities included: increasing data assimilation of river water surface elevations from satellite altimetry (e.g., ENVISAT, JASON, SWOT) in river routing models, increasing the resolution of global scale hydrologic models, characterizing runoff characteristic (i.e., regional runoff and lateral inputs to SWOT rivers), integrating dams/reservoirs/lakes into ESMs, and building coupled systems that integrated SWOT and ESMs derived rivers discharges. Although the integration of lake models into ESMs has been discussed for years and progress has been made, a lot of work remains, especially in terms of required input data and process parameters (i.e., lake bathymetry, energy budget parameters, groundwater in/out parameters). In addition, two issues were discussed throughout the splinter: (i) quantifying and propagating discharge uncertainties, and (ii) the use of models calibrated with in-situ streamflow vs. models calibrated using only remotely sensed data. Further discuss/research is needed on how best to quantify discharge uncertainties and use simulated discharges from models calibrated with & without in-situ observations in the development and assessment of SWOT discharges.

14h-15h30 Tides, internal tides, internal gravity waves, DAC

Convenors : Richard Ray, Brian Arbic, Florent Lyard

Barotropic tides

--High-latitude barotropic tides are constantly improving due to Cryosat2 in particular; global tide correction models will soon reflect this

--Coastal tide modeling is in constant need of better bathymetric datasets.

Internal tides

--Collecting as much in-situ validation data as possible for internal tides

--Moorings, drifters, PIES, ADCP data, etc.

--Stationary internal tides: Carrère et al. demonstrates substantial skill in several empirical tide models and even some skill in a hydrodynamical model

-- Nonstationary internal tides: Suggest non-stationary internal tide prediction as a "grand challenge" for regional and global models—can it be done?

16h15-17h30 Techniques for separating dynamics and noise in SWOT SSH images

Convenors : Julien Le Sommer & Emmanuel Cosme

- Several oceanographic applications will require separating internal waves and balanced motions from SWOT SSH data
- Many groups in SWOT ST are working on this topic and developing approaches for this separation

- During the ocean splinter 4, we have discussed how to better leverage hi-res model data for preparing and comparing separation techniques
- The presentations have reviewed existing frameworks (A. Ponte), presented image separation techniques (J.F. Giovannelli) and discussed the potential of deep learning for this task (R. Fablet)
- Discussions have identified the need for coordinating the definition of commonly defined cases for developing and comparing separation methods and for engaging a wider community outside SWOT-ST on this problem

- A subgroup of interested SWOT-ST members (~12p) interested in formulated these problems has been identified

Thursday 20 June 2019

Morning : Hydrology and Oceanography Splinter sessions :

9h-10h30 Hydrology Cal/Val I

In this session, we heard from the US and French projects about their Cal/Val plans, updates to the plans, and plans for pre-launch Cal/Val activities. We also heard about progress on the US Tier 2 Cal/Val site selection and methods for upgrading those sites to be comparable to SWOT measurements. In addition, Cal/Val plans for the French and US lake sites were presented. Other highlights of the session included:

- **US project perspectives on Cal/Val (C. Chen)**
  - Cal/Val objectives: 1.) Estimate calibration parameters for ground processing based on flight data; 2.) Validate error budget – is the system performing as expected?; 3.) Validate measurements and data products compared to Science Requirements
  - Cal/Val is split between instruments, not between Ocean and Hydrology. As such, some calibration and validation will be shared. E.g. crossovers will be used for both Ocean and Hydrology calibration.
  - Next steps: Need to prioritize Cal/Val activities, discuss technical feasibility / risks / benefits, update Cal/Val plans correspondingly.
- **French / CNES CalVal perspectives and approach (N. Picot)**
  - CalVal based on: In-situ measurements, existing networks, and satellite constellations (Sentinel 3A and 3B, etc)
  - Sentinel based nadir altimetry planned for ~20k inland sites that can be used for Cal/Val. Also FF-SAR is being assessed and is expected to provide much higher resolution water surface elevations.
  - Sentinel and SWOT overlaps can be quite close in time and space enabling high-precision Cal/Val of SWOT measurements.
- **Overview of Inland Hydrology Cal/Val (J.T. Minear)**
  - Provided a broad overview of Inland Hydrology Cal/Val, including justification for site selection based on Science Requirements.
  - Includes an updated timeline of pre- and post-launch US activities.
- **SWOT Tier 2 Cal/Val sites (J.T. Minear)**
  - Tier 2 site selection criteria for ~75 updated gages across the US (some but not all should be under the 1-day fast-repeat orbit):
    1. SWOT KaRIN visible greater than 90% of the time (50m+ width)
    2. Avoid or flag tidal sites or sites with multiple channels
    3. Sites represent spread across the SWOT swath (left and right, 10-60 km from centerline)
    4. Temporally filter chosen sites using hydraulic geometry from field measurements (e.g. above or below SWOT width threshold)
  - Tier 2 proposed methods: update stage recorder with a high-quality GNSS measurement relative to the ellipsoid, determine or estimate water surface elevation distribution near the gage
    - For GNSS measurements:
      1. Static GNSS base receiver (1 hr recommended PPP solution),

2. Determine elevation difference from base to gage datum or water surface elevation using survey equipment or kinematic GNSS receiver
3. Kinematic GNSS receiver: 15+ min minimum, one pass in middle of river, PPP+PPK solution

- A conceptual model was presented for assessing SWOT measurements and point ground WSE measurements using the expected spread of errors.
  - In particular, we do not have a good idea what the real-world distribution of water surface elevations are near a streamgage.
- Next steps: Determine expected distribution of water surface elevations within two channel widths of USGS gage transducers, confirm Tier 2 methods.

- **US lakes Cal/Val (J.T. Minear)**
  - Three main US Tier 1 lake sites: Lake Tahoe (large), Sierra alpine lakes (small lakes, high elevation), Prairie Potholes (small lakes, low elevation)
  - No US lake Cal/Val sites currently are under the 1-day fast repeat
    - Under discussion: Shifting Prairie Potholes site east under the 1-day fast repeat orbit
  - Presented results from 2017 Prairie Potholes AirSWOT and wind experiment
    - Methods: 9 lakes, 24 pressure transducers, 3 weather stations, GNSS surveys, drone surveys, AirSWOT overpass (1 day only).
    - AirSWOT mostly produced dark water over the lakes (low wind period)
    - Only ~2 cm variation in water surface elevation during low wind velocity periods (<10m/s).
    - Winds over 10m/s created up to 10 cm variations in water surface elevations across the lake, even greater if including waves.
    - Drift of ~1 cm / month was observed in the pressure transducers. Possibly due to settling of the mounts (1 m rebar buried 2/3 depth in substrate), biological fouling of the transducers, or wave / biological plant affecting the mounts.

11h-12:30 Hydrology Cal/Val II

In this session, we heard about advances in French Cal/Val river studies, citizen science efforts to measure lakes in the US and France, and the 2020 Connecticut River field and AirSWOT campaign.

- **SWOT Cal/Val on Rivers (S. Calmant)**
  - Many gages are not as well surveyed as claimed. This is particularly true for gages in developing nations but it even includes many gages in developed nations (see Pascal's presentation).
  - Reach slope from leveled gages often is not comparable to GNSS-measured longitudinal slope. Slope is also particularly sensitive to gage leveling errors.
  - Interesting question: Should we compare SWOT slope with any gages?
  - International collaborations:
    - Hydroweb: ~2k operational global sites at present; expected to increase to ~20-30k sites by end of 2020.

        - ScaHyLab: International collaboration focused on SWOT / altimetry validation, many international collaborators, common tools and models, long term effort
    - Interesting site in India under the 1-day fast repeat orbit: Mahanadi Basin. India is interested in joining.
- **LOCSS – Citizen Science for Lake Validation (T.M. Pavelsky)**
    - Exciting project involving stage gages recorded by citizen scientists via text through mobile phone. Citizen scientists can go to the main website to check on the lakes.
    - Website: www.locss.org
    - Citizen science visual observations validated pressure transducer measurements - errors are close to the pressure transducer limit. 1.1 cm for CS measurements, 0.8 cm for pressure transducer limit.
    - Piloted in North Carolina lakes, now expanded to Washington state, Massachusetts, Illinois, and Bangladesh. Expanding to other states and countries soon, including France.
- **Connecticut River Field and AirSWOT Campaign, 2020 (C. Gleason)**
    - Field campaign in spring or summer of 2020 on the Connecticut River, USA.
    - Objectives:
        - Study tidal effects (lower Connecticut River)
        - Attempt long reach AirSWOT Cal/Val (400+ km of river)
        - Investigate effects of locks, dams, cities
        - Test AirSWOT vs aerial lidar for water surface elevation measurements, possibly other methods (drone, etc).
    - Site: The Connecticut River includes two SWOT Tier 1 sites (River and Tidal). Many universities and research labs nearby. Many dams and small cities (effects of 'Radiant Rooftops').
    - Methods:
        - 5-6 days of AirSWOT flights, pressure transducer arrays, GNSS long profiles
        - Several teams: upper sites, middle sites, tidal reach.
    - Anyone interested is welcome to join. Contact Colin Gleason at Univ. of Massachusetts, Amherst for info.

9h-10h Specifying and removing measurement errors & corrections

Convenors : Clement Ubelmann & Ed Zaron

The session consisted of 4 talks connected with characterizing the expected errors of the SWOT mission. The first talk (Samelson and Chelton) presented the SWOT spectral white noise floor requirement, i.e., the KarIn noise, as it will appear when sampled on grids with different spatial resolution. The purpose of this is to inform the SWOT user community of the noise characteristics at the resolution of the data which shall be provided, rather than at the assumed spatial Nyquist wavenumber, 1/15cpkm, specified in the Science Requirements Document. The second talk (Gauthier and Ubelmann) described recent updates to the SWOT simulator, including implementation of a model for SWH-dependent KarIn noise, the amplitude of which varies across the swath. The third talk (Sandwell) discussed the importance of consistently smoothing and correcting the conventional nadir altimetry to efficiently blend it with the SWOT data for MSS estimation. This talk also discussed how correlated error between SSH and SWH currently limits the smallest spatial scales resolvable with nadir altimetry. Finally, the last talk (Villas Boas and Lenain) discussed

expectations for small-scale SWH variability in SWOT data, suggesting important variations at the cross-swath scale, that should be highly correlated with current structures (and therefore SSH).

There was discussion of the unknown impact of future developments connected with 5G cell phone networks. Nations are presently allocating 5G radio frequencies near the spectral window used by the microwave radiometer. Depending on how the technology is implemented and deployed, the radio frequency contamination may lead to increased noise in the frequency bands used for the wet-troposphere correction.

Two comments were made regarding future studies with the SWOT simulator: (1) it was suggested to add a simulated field of radar power and its noise (related to volumetric decorrelation), since this would facilitate studies seeking to exploit the correlated signals and noise amongst SWOT images, and (2) it was suggested to evaluate the roll error crossover corrections using simulated SSH data which contain an internal tide signal.

10h-12h30 2D/3D reconstruction of SSH and currents

Conveners: Sarah Gille, Bo Qiu, Pierre-Yves Le Traon, Emmanuel Cosme

The session 2D/3D reconstruction of SSH and currents gathered seven 15-minute presentations and a 15-minute discussion. The speakers highlighted a large variety of problems and methods, particularly for the SSH mapping problem. They also showcased the potential of machine learning methods to support SWOT-based reconstructions of the ocean circulation. Significant advances are also underway for three-dimensional assimilation of SWOT data and sea surface height reconstruction from SWOT. All of these developments should be further encouraged.

Georgy Manucharyan and Anirban Sinha presented innovative and exploratory applications of machine learning techniques to reconstruct SSH and surface currents. Both of them implemented deep neural networks. They showed promising results and emphasized the need for further developments in order to make such techniques applicable to future SWOT data.

Matt Archer and Florian Le Guillou proposed new methods to reconstruct 2D maps of SSH from SWOT, achieving spatial resolutions higher than what nadir altimetry allows. Matt has implemented a static 2DVar method, and Florian showed an innovative back-and-forth nudging method that estimates SSH fields from time-distributed SWOT data.

Sammy Metref presented a method to reduce the spatially correlated noise from a SWOT data swath. The method involves or can be incorporated into a data assimilation scheme.

Bo Qiu discussed the skill of the eSQG method to reconstruct vorticity and vertical velocity in 3 dimensions, stressing the fact that the limitation of the method primarily comes from the 2D mapping of SSH.

Mounir Benkiran discussed the skill of the Mercator global prediction system for the horizontal and vertical reconstructions of the ocean circulation from nadir and SWOT altimetry, and for the prediction of the ocean circulation.

Patrick Heimbach discussed the introduction of SWOT into the 4DVar data assimilation system of ECCO consortium, emphasizing the developments needed to account for SWOT: high resolution modelling, balance issues, multiscale approaches and length of assimilation window.

Discussion focused on strategies for coordinating an intercomparison of mapping and assimilation methods. There is consensus that an intercomparison effort could be initiated after the next SWOT science team has been formally selected. In the coming year, investigators interested in SWOT mapping and assimilation problems could discuss strategies for setting up such an intercomparison. Different mapping and assimilation methods optimize different processes, and each of the methods under development will likely have applications for which it performs particularly well. An intercomparison exercise could for example consider strategies for mapping both sea surface height and also full three-dimensional fields (possibly including non-stationary internal tides) and could consider a range of different regions including the California Current, a western boundary current, a coastal domain, with a range of different evaluation metrics, including existing mapped altimeter products and in situ observations.

Afternoon : Plenary session

14-16h Coastal and estuarine processes

Convenors : B. Laignel, M. Simard, N. Ayoub

The coastal and estuarine session focused on hydrodynamic and SWOT simulations, and assimilation of SWOT data in coastal and estuarine regions. The session also emphasized ongoing and planned efforts for critical pre- and post-launch Cal/Val experiments specific to these dynamic environments.

Deltas and estuaries are very dynamic regions driven by hydrological, atmospheric and oceanographic processes (e.g. offshore currents, winds, waves, tides, storm surges, river discharge) that vary at short and seasonal timescales. The SWOT Coastal and Estuarine Group (CEG) has developed algorithms to reproduce the spatial and temporal variability of the hydrodynamics in a wide range of coastal settings (e.g. macro, meso and microtidal, and estuary, delta, shoreline with beaches or cliffs, shelf) along the river-estuary-nearshore-shelf continuum. Research results were presented in several sites including the St-Lawrence River, the Seine and Gironde estuaries, the Red River, the Wax Lake delta (a part of the Mississippi delta), the French Channel and Bay of Biscay and along the Newfoundland coasts.

Hydrodynamic modelling in the Wax Lake Delta (WLD), based on Delft3D and Xbeach, demonstrated the significant role of tides, discharge, winds and waves, and highlight the need to consider spatial variations of roughness values with morphology and wetland structure. We also modeled a year of the Seine estuary using the T-UGOm model with 12 different hydrodynamic contexts, based to the tide and discharge. The WLD and Seine hydrological simulations were used to generate SWOT HR simulations in the spatially complex regions, which were subsequently analyzed to estimate spatial patterns in water surface elevation and slope. New superpixel spatial averaging methods showed SWOT can surpass its accuracy requirements in theses environments. These SWOT simulations also highlighted the significant impact of layover in estuarine settings and new methods to mitigate these effects were presented. Numerical simulations with T-UGOm and Symphonie, and in situ observations in the 2018 Gironde Estuary have highlighted the strong asymmetry of the tidal signal, the non-stationarity resulting from river-tide interactions and small scale variability. To address the impact of high frequency processes on SWOT measurements, a new method called Constrained Harmonic Analysis (ConHA) was developed and applied in the St. Lawrence estuarine transition zone. The analysis showed the use of ConHA with SWOT long-time series (~1 year) preserves spatial coherence throughout the model domain. To study SWOT's ability to resolve ocean currents across the coastal shelf, a numerical circulation model was implemented over the shelf and slope of the Bay of Biscay and Gulf of Tonkin, showing the relative contribution of geostrophic currents to vary spatially (shelf vs slope) and seasonally. Simulated SWOT observations exhibit low signal to noise ratio with large variability across the swath and between neighboring passes. Ensemble modelling in

the Bay of Biscay is used to explore the errors in a coastal model due to uncertainties at the open-boundary (downscaling of errors from a parent model) and due to local wind. Further away from the coast, along the coastlines of NewFoundland, simulated SWOT data was assimilated to improve the knowledge of submesoscale processes. This particular coastal application of SWOT aims to improve tide correction, understand wave-current interactions in the Gulf Stream front zone, and the results show reasonable recovery of the model inshore Labrador Current, the dominant coastal current in the study region.

We reported on our 2018 coastal workshop to advance SWOT application in deltas and estuaries. The CEG generated the new Coastal HR mask which ensures SWOT will cover all critical deltas and estuaries worldwide. The CEG also identified 55 global coastal sites of interest representing a wide range of geophysical and climatic environments. The list contains 21 sites covered by SWOT's 1-day cal/val phase and 34 sites potentially useful for the nominal phase cal/val (11 in USA, 4 in Canada, 5 in France, 10 in Europe (without the 5 sites in France), 5 in South America, 7 in Africa, 13 in Asia). The Coastal group finally selected 7 cal/val sites for the 1-day orbit (i.e. St Lawrence estuary, the Gabon estuary, Guayas estuary, Connecticut river, East Normandy Coast, Columbia river and Maroni estuary). We also proposed 6 additional sites, and 8 cal/val sites covered only with SWOT's 21 day-orbit.

To prepare the Cal/Val post-launch, currently, we have 6 sites for the Cal/Val pre-launch, where several campaigns are already done: the Mississippi delta, the Seine estuary, the Gironde estuary, the eastern part of the Normandy coast from the Bay of Mt St Michel to the Raz Blanchard, the Maroni estuary and the St Lawrence estuary. The session described results from complex Cal/Val experiments in estuaries/deltas and nearshore areas including the Gironde 2018 campaign with GPS carpets and the series of multi-sensor Delta-X airborne + in-situ experiments in the Mississippi River delta (2015, 2016, 2020). These experiments provided an extensive list of to-dos and not-to-dos that will help the planning of that campaign, ensuring the success of both the pre-launch and post-launch campaigns.

Finally, a panel discussion at the end of the session on capabilities of SWOT in coastal environments and estuaries underlined the following elements:

Need to better understand the potential and limitation SWOT observation along the coast to fully take advantage of the SWOT societal applications;

Need to define the HR and LR products for estuaries and coasts (nearshore and shelf specifically) and include requirements, if any, on tidal correction in HR product;

Need to improve SWOT HR and LR simulators on the nearshore, shoreline and intertidal zone to simulate the complex hydrodynamics by integrating the different roughnesses & the layover phenomenon encountered in these environments;

Assess pre- and post-launch cal/val priorities and design campaign, noting the coastal group strongly recommends international participation in a pre-launch campaign with AirSWOT and in situ measurements in the St-Lawrence estuary in the summer 2020.

Need to assess the SWOT retrieval algorithms for a) tidal signals and discharge in estuaries and b) water fluxes and connectivity in coastal wetlands and intertidal zones?

16h – 16h30 Meeting Summary

The Science leads provided a brief summary of the different splinter session discussions, which has been expanded here in this written report.

Finally, it was Eric Lindstrom's last SWOT Science team meeting, and the Science Leads and all of the Science Team sent him thanks for shepherding us through these last 10 years of SWOT's preparation. We hope he can continue guiding our ocean CalVal activities, and we wish him "Bon Vent" – fair winds for his future endeavors.