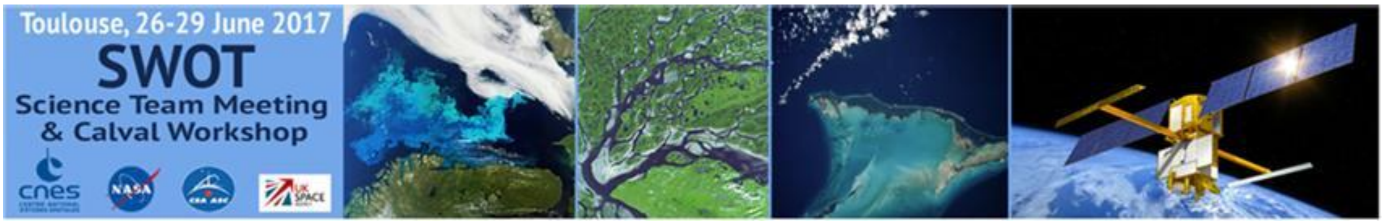

Summary Report of the 2nd SWOT Science Team Meeting 2017

June 26-28, 2017
Météo-France Conference Centre, Toulouse, France

SWOT Programme Managers:
Eric Lindstrom, NASA
Selma Cherchali, CNES

SWOT Project Scientists:
Lee-Lueng Fu, NASA Ocean Lead
Rosemary Morrow, CNES Ocean Lead
Tamlin Pavelsky, NASA Hydrology Lead
Jean-Francois Crétaux, CNES Hydrology Lead

SWOT Project Managers :
Parag Vaze, NASA
Thierry Lafon, CNES

Meeting organizing committee :
Sophie Coutin-Faye, CNES
Laurence Amen, CNES
Nicole Bellefond, CNES
Emilie Bronner, CNES
Nicolas Picot, CNES
Rosemary Morrow, LEGOS

Introduction and Meeting Objectives

The 2nd SWOT science team meeting was held in Toulouse over 3 days from 26-28 June 2017. It was followed by a 1-day workshop on 29 June 2017, dedicated to the SWOT CalVal plans, with separate sessions for the CalVal over the oceans and hydrological surfaces. The CalVal plans are to be updated for the SWOT mission's measurement review in December 2017, and in preparation for the CDR in February 2018.

All of the meeting presentations are available online on the SWOT internal website for SWOT Science Team members.

The plenary sessions discussed issues spanning all of the SWOT disciplines. One session dealt with the ongoing algorithm development, and the roadmap and schedules for the Algorithm Theoretical Basis Documents (ATBDs). These ATBDs are put together by the 2 Project teams, but need science experts to review the algorithms. In NASA/CNES language – these scientific experts are called "Subject Matter Experts" or SMEs. The nomination of these SMEs from the Science Team was discussed. Another subject concerned the SWOT data products, and the need for quick look products with a short latency (2-3 days) and slightly less accuracy for science and applications. Simulated data products are also being prepared to get users ready for the real SWOT data. This session also discussed the data access via clouds, and the new infrastructure needed for on-site extraction and analysis.

Two keynote talks were delivered. Bo Qiu presented results from a modeling study of the spatial scales of balanced motions and internal gravity waves in the ocean, showing seasonal and geographic patterns of the scales of separation between these two types of motion. Jean-Francois Cretaux presented a summary of a recent workshop on global lake science, emphasizing the importance of lakes on climate change and the challenges of observing the global water storage in lakes from SWOT.

A second plenary session addressed the need to fine-tune the high-resolution (HR) mask coverage, so that priority estuary zones are included in the coastal mask, with trades needed for non-priority zones. Another possible trade proposed is to include a demonstration Arctic sea-ice zone, in place of HR data over snow-covered northern hemisphere regions. The choice of HR data zones over the oceans during the nominal and CalVal 1-day orbit phases was also discussed.

In the final plenary session addressed the ongoing work on the SWOT "synergistic science", for coastal and estuarine studies, over sea-ice and polar ice-caps, and with advances in preparing a high-resolution mean sea-surface and geoid maps before the SWOT launch.

There was also 1.5 days of splinter session discussions for the oceans and for hydrology. The ocean splinters addressed a major challenge and opportunity for SWOT concerning the joint presence of internal waves and balanced dynamics, with similar amplitudes in SSH and similar wavelengths in the 15-200 km band. The recent progress in high-resolution modelling of these processes, and their observation in multi-satellite and in-situ data were addressed. The ocean splinters also discussed the recent progress in the observation of surface waves and roughness, their cross-swath modulation, their impact on the sea-state bias and SSH error, and their modification over surface currents.

The hydrology splinters discussed in detail the HR algorithms and data products, including the pixel cloud, raster, river and lake vectors, discharge algorithms, water detection, layover detection and a priori data sets needed. Recent progress in SWOT hydrology simulations, model integration and data assimilation efforts were also discussed.

Summary of Program & Project Status (Science leads)

SWOT Program Status :

- NASA budget is OK, Earth Science took a 1% cut – but this will not affect the altimetry missions for OSTST or SWOT.
- The CNES Board of Adminitrators confirmed the CNES entry to phase C/D/E1 on 1 July 2016.
- GRACE-FO, scheduled for launch in late 2017
- CFOSAT – French-Chinese satellite to measure wave spectrum and wind scatterometry, to be launched in fall 2018.
- TOSCA workshop, Maison des Océans , Paris, 21-22 March 2017 : SWOT presentations over the oceans, hydrology and coastal regions.
- A Mid-Term Review of the SWOT Scientific advances (Earth Observation), 6 October, 2016 Paris
- Workshop Lakes and Climate, June 1-2, Toulouse
- SWOT Applications User Workshop, April 5- 6, Washington : Engaging the User Community for Advancing Societal Applications of the Surface Water Ocean Topography (SWOT) mission

SWOT Project Status.

- Critical Design Review (CDR) is planned for February 2018
- Both JPL/NASA and CNES project teams are working hard to prepare for this. NASA has different intermediate design reviews planned : the Karin CDR (Summer 2017), the Payload CDR (Fall 2017), the spacecraft CDR (Nov 2017), and the Measurement CDR (Dec 2017). CNES has reviews for the ground control system, the science data system and the system interfaces planned over the same period.
- Launch Vehicule has been chosen – SpaceX Falcon-9
- CNES ground system – automatic verification system put in place.
- Science data system is new – JPL Keypoint in Apr 2017. CNES Preliminary Design Review (PDR) in Oct 2017. Ready to pursue the Science Data Systems (SDS) – on schedule.
- 400 kg of hydrazine just for the spacecraft re-entry
- Should quick look products be less than 1 day or 3-days ? Feasibility to be made before CDR in early 2018.
- SWOT Launch date : 16 April 2021

CalVal group status (C. Chen, N. Picot)

(see summaries of Day 4)

Application Workshop report (F. Hossain, M. Srinivasan, A. Andral)

The SWOT Application Working Group (SAWG) updated the SWOT Science and Project community on the application workshop that was organized April 5-6, 2017 in Reston, Virginia and attended by 50 participants comprising more than a dozen stakeholder agencies. The key findings from the workshop were as follows:

SWOT data availability at a latency of 2 days or less has overwhelming demand and critical societal needs, wherein a compromise between accuracy and latency appears widely acceptable.
SWOT data will be valuable for retrospective (post-event) analysis, large-scale basin or ecological management, and policy formulation.
Education and training on data products, access, and uncertainty, in multiple languages, will be necessary to maximize uptake of SWOT data for real-world applications.

ADT Plenary Session (S. Desai, N. Picot)

The JPL and CNES project Algorithm Development Team (ADT) presented the baseline plans for the SWOT low-resolution (LR) and high-resolution (HR) science data products, and the algorithms used to generate those products. Prototype LR and HR science data products are to be provided to the science team by mid-2018 for their evaluation and input. The plan for the generation and review of Algorithm Theoretical Basic Documents was also provided, with a first version expected to be available to the science team by the end of 2018. The data distribution centers at JPL and CNES also provided their current approach for distribution of the SWOT science data products.

The science team (S. Gille et al) presented a recommendation to remove the requirement to provide sea surface height slope in the SWOT science data products. The LR science data product includes the provision of sea surface heights at the original 250 m posting and 500 m resolution from combining the 9-beam measurements from the KaRIn instrument. Users will then have the capability to investigate their own methods to generate sea surface height slope from these measurements.

High-rate Data coverage session (C. Pottier/R. Fjortoff, P. Callahan)

Current status and project recommendation for the HR pre-summing factor (C. Chen)

- Better not to change the presume factor in-flight (tests during CalVal not feasible)

Current status and way forward for nominal science phase HR mask, including coverage of coastal-estuarine sites (N. Tchintcharadze, C. Pottier, B. Laignel)

- HR cover = 22.28%, 21 passes/day, 212 min/day.

- Seg 1-3 sec ~591, 18min. Seg 3-10 sec, 1hr 32min. || Short interruption <~3 sec.
- LR mode: everywhere; HR mode: only when the nadir is over a mask => the mask DOESN'T represent the true HR coverage
- Current version of the mask: Y. Chao, S. Biancamaria et al. 2013-2014; major basins + 3km around coastlines – big lakes / deserts, …
- Current mask needs to be optimized: many short segments (< 3s), many short interruptions among long segments, some areas need to be covered
- Seasonal mask needed ?
- New working group: CNES lead (N. Tchintcharadze + C. Pottier) + JPL (D. Esteban)

Status of HR data coverage during Fast sampling phase, calibration OBP (C. Chen, T.Pavelsky, R. Morrow)

- Cal/Val Hydro Objectives: Tier 1, 2 cal/val sites; Arctic environments (seasonality); long river overpasses, dense lakes
- Cal/Val Ocean Objectives: Cal/val sites; crossovers; "selected sites" (edges, reefs, etc.)

Seasonal HR coverage – trade for Northern hemisphere sea-ice and snow-covered land? (T. Pavelsky, JF Cretaux, R. Kwok)

- Sea ice leads CDF ~80-90% for 50-75m.
- Collect ~220k km2 in Beaufort Sea in Dec-Feb; remove high Canadian islands. – After 1 full yr to see what is there.
- TP: Uncertainty on phenomenology, so keep Andes, other likely problematic areas for first yr.

Priorities for potential sites for the four (?) HR ocean/coastal/sea-ice 120 km2 zones (can change zones seasonally) in nominal phase (R. Morrow, S. Gille, N. Steunou)

- Objectives: waves, cal/val sites, in situ campaigns, sea ice (freeboard, volume), reefs, coastal/estuary sites
- US west coast areas studied by gliders, airborne
- Drake Passage – instrumented lines
- Proposed areas for 3 mission years

Discussion

Ocean Splinter session summaries

Advances in SWOT Ocean Simulator (C. Ubelmann)

This session was a great opportunity to discuss the recent updates of the scientific Ocean simulator as well as proposing new functionalities for the future.
- E. Zaron proposed a new module to account for internal tides in the simulated SWOT data. This module may be used when the reference SSH scene does not already contain internal tides. The user will be able to add the internal tide effects on SWOT SSH, potentially strong on fine scales in low-energetic regions. Module is available for the next release.
- L. Gaultier and C. Ubelmann presented the recent updates of the simulator, including more accurate random noise generator and new functionalities to simulate a constellation of nadir satellites. Outputs format has changed (to meet new conventions). It is now compatible with Python 3. Update September 2017: the simulated timing bias will be independent both side of the swath (following D. Esteban-Fernandez discussion during the meeting). Low impact expected.

Tides, Internal Tides, Internal Waves (*R. Ray, B. Arbic, F. Lyard, T. Farrar*)

The presentations were focused on analysing the internal tides, and their stationarity.

L. Carrere presented an intercomparison of different internal tide models. The R. Ray internal tide model did a slightly better job in comparison to altimetry & thermistor data, but new models are being developed and further testing is in progress. Eventually one or more of these models will be included as an additional correction in future alongtrack altimetry products. There was wide variability amongst the empircal internal tide models, especially away from strong internal tide generation sites. Internal tide variability in dynamical models such as HYCOM is just beginning to be explored.

R. Ray : discussed internal tide non-stationarity. For the ratio of non-stationary to total variance – tropics 20°N-20°S is mostly incoherent, as shown by a recent paper by Zaron. Z Zhao (GRL, 2016) showed cases of variability along internal tide beams that could be related to Argo heat content, and stratification changes. There is considerable interannual variability : Peak mode-1 wavelengths vs Nino-3 index show ENSO-related upper ocean heating and internal tide amplitudes. Ray showed maps of M2 theoretical wavelengths from WOA stratification data – little changes in seasonal M2 wavelengths, except in tropical Pacific and Indian Oceans, where modal wavelength changes of < 8 km appear to be confirmed by altimetry.

J. Shriver and M. Buijsman : 0.04° HYCOM global model with tides should be hosted at Univ Michigan soon. Internal tide incoherence is strong at the equator, consistent with altimetry-based results from Zaron (2017, JGR-O). Buijsman et al. JGR-O, 2017 uses simple wave trace model to examine two mechanisms of internal tide variability; changing stratification as well as Doppler shifting from mesoscale currents. On monthly time scales, equatorial jets and TIWs introduce strong variations in incoherence. Stratification is also important on annual time scale.

S. Kelly presented results from his simplified and efficient numerical modeling approach. BT modes are set using TPXO. His approach uses a simple shallow water model and investigates using altimetric maps of mode-1 energy to constrain the parameterizations of dissipative & incoherent processes, somewhat similar to the approach of Ansong et al. (2015).

E. Zaron explored using the Ray-Zaron (JPO, 2016) internal tide model to correct *in situ* measurements for tidal variability. This work has now been published as "Using an altimeter-derived internal tide model to remove tides from in situ data," Geophys. Res. Lett., 42, 4241-4245.

Discussion. Seasonally varying internal tides could be mapped in place of the mean tides. Incoherent tides appear to be mainly due to mesoscale eddies and varying stratification.

We need to have a better in-situ data set – from data mining of ADCP, XBTs, gliders etc, and also a global internal tide data set ? Arbic's group can provide a historical dataset of some thousands of historical time-series measurements, while Gille's group is working on collecting and archiving ADCP data, and several investigators are looking into PIES data.

Bathymetry - Need to work on a global bathymetry data set at HR for internal tides.

High-resolution ocean general circulation models (*P. Klein, B. Arbic, …*)

The session on "High-resolution ocean general circulation models" allowed presentations of the first results and the future perspectives of the modeling efforts undertaken by the SWOT community. All numerical simulations have a resolution of at least 2-4 km and therefore resolve a large part of submesoscales. Many simulations include internal tides and display a significant impact of internal gravity waves on SSH, a major issue for SWOT. The presentations detail these efforts. They concern:

HYCOM / MITgcm comparisons: UM/NRL/USM, B. Arbic 1/25° and 1/48°, Global with tides

MITgcm: JPL, D. Menemenlis, 1/48° Global with tides

HYCOM: FSU, E. Chassignet 1/50° North Atlantic, no tides, will include them in the near future (2017/18)

NEMO: LGGE J. Le Sommer. 1/60° North Atlantic no tides, will include them in the near future (2017/18)

MITgcm: MIT, J. Callies North Atlantic with tides (1/24° -> 1/48°). Will consider other regions in the near future.

ROMS: UCLA J. Molemaker. J. McWilliams, 1/100°, North Atlantic.

MITgcm: CI/NYU, R. Abernathey/S. Smith, Southern Ocean, 1/133°, will include tides in the near future.

ROMS: UCLA J. McWilliams/R. Barkan, 1/400° with tides, CCS

MITgcm: JPL, D. Menemenlis/H. Torres 1/400° with tides, CCS, 2 week-integration.

Reconstruction of the upper ocean 2D & 3D circulation (*C. Ubelmann, B. Qiu, S. Gille, …*)

The reconstruction of upper ocean circulation session showcased work in progress to develop methods to map SWOT data, both through formal data assimilation and through strategies building on objective interpolation.

- Sarah Gille (Scripps Institution of Oceanography, UC San Diego) presented work by Jörn Callies (MIT/Caltech)using the MITgcm to simulate high wavenumber variability, with and without tidal forcing, and work under development (at SIO) to incorporate tides (via TPXO) as well as waves (using WaveWatch III) into an assimilating version of the MITgcm, using 4Dvar.
- Emmanuel Cosme (U. Grenoble) discussed the implementation of image reconstruction techniques to recover high-wavenumber features in noisy fields
- Aurélien Ponte (IFREMER) and Jinbo Wang (JPL) both gave talks that discussed disentangling unbalanced and balanced motions in SWOT data. Aurélien focused on a strategy that can use both SST and SSH data. Jinbo explored a PV inversion taking into account surface and interior contributions to sea surface height, as well as internal waves, again considering possibilities for using both SST and SSH.
- Elisabeth Rémy (Mercator Ocean) discussed a SWOT assimilation study carried out at Mercator, using an OSSE approach to replicate results from a 1/36° "truth" simulation, in this case using a 1/12° reference model and working with daily averages to avoid contributions form tides. Future work will address internal waves and use a higher-resolution 3-km model.
- Clément Ubelmann (CLS) reviewed a dynamical interpolation method that has been implemented for the Gulf Stream and the Mediterranean. By incorporating some dynamics into the interpolation, he reported achieving better eddy structure.

Ocean Phenomenology : roughness & surface waves (*F. Ardhuin, B. Chapron, F. Soulat, C. Chen, …*)

The revised error budget presented by D. Esteban-Fernandez now includes motion errors, mainly from surface waves. These include the Doppler shift from target motion effects, mainly from the vertical wave velocities, the surfboard effect and alongtrack shifts from waves giving spectral distortion (wave bunching). The main effect of wave bunching is when waves are aligned alongtrack. These errors have now been included in the budget – the main error is from the surfboard effect. A request was made to JPL to provide seasonally-averaged global maps of the rms SSH amplitude of these wave motion effects.

This is confirmed by calculations by P. Dubois, who nevertheless pointed out potential issues in the far range part of the swath, where Hs estimates from the signal coherence are less accurate. Small-scale variations of SWH are dominated by effects of currents (Ardhuin et al. JGR 2017). In regions of strong currents (e.g. Gulf Stream), this can produce an error of 1 cm2/(cycle/km) at 50 km wavelength for SWH=2 m. Brachet et al. have looked at different averaging strategies for SWH estimation (one single value for whole swath or averaging over 10 by 10 km boxes or 5 by 60 km).

B. Villas-Boas has discussed the climatology of waves offshore of California showing an interesting range of values around SWH=2m, changing with seasons, making it an interesting site for CAL/VAL.

In order to handle parts of the ocean that are not in the SWH=2m specification, Dubois et al. have proposed to introduce a quality flag on SWH or refine the estimation of SWH or SSB based on the sigma0 and the Doppler centroid.

Current effects on waves are also expected to be the dominant source of variability of the Doppler centroid and mean square slopes, which have stronger gradients than the SWH.

Maps of sigma0 over the ocean provide a unique opportunity to estimate current gradients at small scales, with a direct measurement of the current divergence (Rascle et al. GRL 2017). Data from AirSWOT acquisitions during the 2016 LASER experiment over the Gulf of Mexico has been used to validate theoretical expressions of Doppler centroid for incidence angles 5 to 20° (Nouguier et al., submitted), and confirmed the link between Doppler centroids and orbital velocities.

Observations of SSH, currents at small mesoscales : Part 1 : in-situ observations (*T. Farrar, K. Drushka, S. Gille, R. Morrow, …*)

Discussion of in situ observations focused on new analyses of high-frequency and high-wavenumber observations that provide information about the signals that SWOT will reveal at 10-100 km scales.

- Tom Farrar (WHOI) discussed frequency spectra from the SPURS moored site, and used a modal decomposition to estimate wavenumber spectra of internal waves. He compared results with equivalent spectra from the 1/48° version of the MITgcm (llc4320).
- Kyla Drushka and Luc Rainville (UW/APL) discussed the assessment of internal tide variability in glider data from the Luzon Strait, showing that the glider and the llc4320 model produced similar results.
- Sarah Gille (SIO, UCSD) discussed efforts to distinguish balanced (geostrophic) and unbalanced (e.g. associated with internal waves) motions in wavenumber spectra inferred from Acoustic Doppler Current Profiler (ADCP) data from the California Current region and she discussed efforts to expand the availability of long-transect, quality controlled ADCP data from other regions of the global ocean.
- Uwe Send (SIO, UCSD) showed mooring-based measurements from the California Current, from the North Atlantic, and from the Solomon Sea. To infer long-term transport observations, he found best results by using sea surface height or gravity data to obtain reference level information.

Observations of SSH, currents at small mesoscales : Part 2 : multi-satellite observations (*T. Farrar, K. Drushka, S. Gille, R. Morrow, … *)

Discussion of high-wavenumber variability in satellite observations included consideration of new sensors and new strategies for assessing existing observations.

- Ernesto Rodriguez (JPL) showed results from the DopplerScatt air-borne instrument, which showed measurements of surface wind and currents.
- Bertrand Chapron and Nicolas Rascle (IFREMER) examined the link between surface roughness and surface currents, using sunglitter and divergence or convergence of surface roughness.
- Marie-Hélène Rio (CLS, currently working at ESRIN) discussed the joint use of SSH and SST data to improve estimates of surface currents.
- Oscar Vergara (LEGOS) showed wavenumber spectra inferred from altimeter data, comparing SARAL/AltiKa and Sentinel 3. His results suggest that SARAL has lower noise in the 15-100 km band.

General Discussion : (R. Morrow, L.-L. Fu)

- A lot of new and exciting work is ongoing with the HR modelling including high-frequency tides and the internal gravity wave field (IGWs). An important question still concerns the observability of these small-scale processes in SSH, which have different spectral peaks compared to the energy spectra. In the preparation for the SWOT CalVal, the difference between the total SSH seen by SWOT and the dynamic height observed from in-situ density data also needs to be explored with realistic models.
- Validating these models at fine scale and high-frequency is also required. The comparison of glider observations to the simulations of the MITgcm in the Luzon Strait conducted by the UW group has shown very encouraging results, suggesting that the state-of-the-art ocean general circulation models are having reasonable skills in describing the spatial and temporal variability at the SWOT scales. Having a global network of deep ocean current meter moorings would be ideal – in the same way that the global tide gauge network was used for global large-scale altimetric SSH validation. Observations at depth are also required to validate the models' deep layers (eg SSH vs upper ocean dynamic height)
- Interesting techniques are being explored to separate the internal waves/tides from in-situ data (gliders, ADCPs). This raises the perspective of data mining, and analyzing the past repeat in-situ lines to separate the fine-scale balanced or internal wave/tide structures. Sharing of analysis tools and techniques should be encouraged between SWOT ST members. Even creating an analysed data base to help validate the HR models
- By 2021, internal tide models may help us correct the coherent amplitude and phase, however the incoherent tides and IGW spectra will remain. Techniques to separate these internal tides/IGWs based on their different signatures in SSH and SST were also discussed. Image processing techniques to separate a wave pattern from a turbulent pattern could also be explored?
- An interesting point is the relation between surface divergent current fields and surface roughness – so the SWOT 250m surface roughness images may be useful for identifying divergence/convergence regions along fronts.

Hydrology Splinter session summaries

Data Products (M. Durand, C. Pottier)

The session addressed key points about the SWOT data products, which are summarized below. Note that this is not a full description of the data products. Please contact the session chairs to receive the current data product descriptions.

Hydrologic data products consist of 4 main products: the pixel cloud, vector data products specific to rivers and lakes, and a raster product. The last 3 are derived from the pixel cloud.

The pixel cloud product is a pass-based product, and is composed of an unstructured list of geolocated pixels (lat/lon/height). These pixels are water pixels and some land-classified pixels (around the water bodies + always-included zones). For each pixel, there are many variables in addition to the geolocation information: radar image pixel indices, interferogram data, geophysical corrections, etc. The pixel cloud consists of 2 NetCDF files with 1D arrays: a "main" file, organized into swath side tiles and ~60km along-track, and a "sensor" file, giving sensor position and attitude. The information is given with 2 levels of smoothing: the "rare" layer is no longer geolocated, but is available for expert users. The "medium" layer with the minimal smoothing needed before geolocation; this is the basis of most downstream processing. The "well-done" layer, providing more smoothed heights and locations, is now in a separate product.

River and lake products are pass-based and cycle-based products. Pass-based products cover both swaths over a pole-to-pole pass and a continent. Cycle-based products are stored by major basins.

The pass-based river product consists of 2 files:

- A line shapefile: each object corresponds to a reach defined in the river a-priori database; the line corresponds to the river centerline as defined in the a-priori database.
- A point shapefile: the points correspond to node, defined at 200m intervals along the centerline. Pixels of the pixel cloud are mapped to the closest node.

Data elements will be comprehensive, including corrections, uncertainties, geoid elevations, etc.

The reach boundaries definition is on-going work and is currently based on SWOT swath edges, tributaries, dams with the goal of later incorporating hydraulic and geomorphologic indices in determining reach boundaries.

The cycle-based river product is a reach line shapefile. The baseline method for its computation is a simple average of observations within each cycle. Error characteristics of this method are being quantified, and more complex options for its calculation are being assessed.

An example dataset is available for download on the Sacramento River: go.osu.edu/swotbeta

Both pass-based and cycle-based lake products are polygon shapefile; each object is a lake or reservoir observed by SWOT; the polygon delineates lake and inner islands boundaries.

Only lakes in the a priori database will be processed in cycle-based products. The extent for polygons will be the maximum extent during the cycle.

The object of the raster product is to provide SWOT height and inundation extent data resampled on a uniform grid. There should be a systematic and an on-demand production.
For systematic production, the tile size is ~120km x ~120km (4 pixel cloud tiles). The grid should be fixed, with 2 resolutions: 100m and 250m.

For on-demand data production, area and resolution can be specified by the user. The data distribution centers are assessing the computational demands of this ability.

The last hydrology product is the flooplain DEM. It will be produced at the end of SWOT mission, from the pixel cloud improved geolocation, using the so-called "bathtub ring method".

Hydrology cal/val (T. Minear, S. Calmant)

The Hydrology Cal/Val Study Plan is relatively well established, with a network of selected Cal/Val sites, identified methods, and standard validation methods in development. There are a few remaining uncertainties about the accuracy of specific methods and assumptions for Cal/Val at certain sites but these are planned to be addressed in upcoming pre-launch experiments.

- Minear gave an overview of the draft SWOT Cal/Val Study Plan. Included was a description of the Hydrology Cal/Val sites, which have been grouped into Rivers, Lakes, Wetlands, and Tidal / Estuarine areas. There are two 'Tiers' of Cal/Val sites: The Tier 1 sites, known as 'gold standard' sites, are the most-intensively studied Cal/Val sites where most aspects of Cal/Val can be performed, whereas Tier 2 sites are essentially upgrades of existing gage infrastructure (e.g. USGS stage gages), which are more numerous. Tier 1 site selection is mostly final and is in the SWOT Cal/Val Study Plan, with one major change: the substitution of the Sagavanirktok River, Alaska, for the Red River, Canada (both large Arctic rivers). Tier 2 sites have not yet been chosen but selection criteria are being developed. Standardized methods for calibration and validation activities at Tier 1 and Tier 2 Cal/Val sites are in development and expected to be finished in late 2017.
  Identified pre-launch Cal/Val studies for the US include:
  - Effect of wind setup on lake water surface topography (this year)
  - Spatial variation in river water surface elevations (2018)
  - Standards and methods for Tier 1 and Tier 2 sites (this year)
  - Developing international partnerships (continuing)
  - Vegetation phenomenology (2018+)
  - AirSWOT proxies (2017+)

- Calmant discussed international Cal/Val partnerships. The two approaches for the international partnerships are to have joint data collections with host countries during the 1-day fast sample phase, and to have access to host country data during both the fast and science phases. The planned South American SWOT meeting in spring 2017 was cancelled due to funding issues but is hoped to be reinitiated in early 2018. France also is planning for additional collaborations in Africa and Asia. WMO has been approached about SWOT and has been receptive to additional collaborations, particularly through Hydrolare. A major hurdle will be the preparation and signing of Official Agreements between various countries.
- Moreira discussed ongoing efforts in Brazil to utilize remote sensing capabilities for monitoring inland hydrology and the reciprocal interests of SWOT Cal/Val needs and the needs of Brazil. Brazil has started work setting up SWOT Cal/Val sites, primarily under the 1-day fast sampling orbit. These Cal/Val sites consist of a mix of Tier 1 and Tier 2 sites, as well as very long profile GNSS surveys from moving boats (>10,000 km). One nice result from using long profile surveys from a moving boat compared to in-situ gages is that averaging slope between gages greatly oversimplifies slope dynamics.

Discharge Algorithms (M. Durand, P.-A. Garambois, C. Gleason)

Outline of the session:

- Recent advances in discharge estimation. C. Gleason. 15 minutes.
- Discharge estimation from surface observables and ancillary data. P. Garambois, Jerome Monnier, and Kevin Larnier 30 minutes.
- Discussion. 5 minutes.

The session started with a pan-DAWG (discharge algorithm working group) summary of the work we have been doing to date. C Gleason (UMass Amherst) reviewed the role of the DAWG and then presented slides sent in by various members of the DAWG. These slides revealed that DAWG members have been improving their individual discharge algorithms, developing new datasets for testing algorithms (including using the instrument simulator and AirSWOT), and that the term McFLI (mass conserved flow law inversion, the basis for most SWOT discharge algorithms) has entered into the scientific lexicon following an EOS piece from the DAWG.

PA Garambois (ICUBE-INSA Strasbourg), J Monnier (IMT-INSA Toulouse), and Kevin Larnier (IMT-ICUBE-IMFT-CS) then presented an in-depth look at the inverse problem of estimating discharge from space, noting past DAWG developments and anticipated future developments/needs. These presenters emphasized the physics of the problem and its spatio-temporal observability and then noted that ancillary data makes a huge difference in our ability to estimate flow: even one depth measurement, for example, dramatically improves discharge estimation accuracy. The talk firmly posed the problem at hand.

Due to time constraints (the session had started late and we wanted to give the full time to the next session), a short presentation by M Durand was not given, entitled "Expected

Advances in River Science from SWOT Discharge”. Slides available upon request (durand.8@osu.edu). Discussion included approximately 2-3 questions were lodged, and these were mostly technical and focused on different inversion challenges.

In summary, the session presented a good overview of the work done by the DAWG to date and introduced some new ideas. Time was short, so discussion about future directions happened largely offline after this session.

Water detection (R. Fjortoft, B. Williams)

The status on water detection algorithm development was given. Several methods have been prototyped, and a baseline method (maximum a posterior classification with Markov random field regularization) has been integrated with the science simulator. Other methods and a fusion scheme will be integrated progressively. ATBDs and first deliveries of operational software are scheduled for 2018.

The occurrence map of Pekel et al. is foreseen as the main reference water mask for water detection and other HR processing steps. However, to compensate known weaknesses and omissions, ADT proposes to also use other data sources such as GIEMS-D3 (presented by P. Aires in the following session), in particular to define inclusion zones that are always kept in the PIXC product (i.e. even if not detected by the automated water detection). Rather than combining the different masks into a unique reference mask, it was recommended to keep them apart and combine them in software for greater flexibility. The possibility of likewise defining exclusion zones that are never included in the PIXC was also presented, but ST recommended to be very careful in precluding water detection.

A method to flag missed detection due to dark water (no signal at very low wind speed) based on Pekel occurrence was presented, and successful sample results shown.

The way water detection performance is assessed w.r.t. science requirements was presented to the ST, and will be used for Measurement review 2 scheduled in December. Large scale simulations based on lidar DEMs for 100+ sites in the US and several European sites have been prepared and will be used to assess performance for water detection, layover prediction and phase unwrapping.

A Priori lake & river datasets (T. Pavelsky, C. Pottier, Y. Sheng)

Outline of the session:

- Comparison of Three A Priori Inundation Datasets at Global Scale (F. Aires)
- Choices for A Priori Lake Datasets (C. Pottier)
- Circa-2000 and Circa-2015 Global Lake Databases (Y. Sheng)
- Progress and Remaining Tasks for A Priori River Database (T. Pavelsky)
- A Priori Layover Analysis (C. Chen)
- SWOT Global Layover Modeling and Lake Observability from SWOT (Y. Sheng)
- A Priori Geoid Dataset (JF Cretaux)

The session reported the recent progress on a-priori dataset development for SWOT hydrology. Global water mask products have become increasingly available in the past year. After comparing three major products (i.e., G3WBM, GSWO and GIEMS-D3), Aires suggested the radar-based GIEMS-D3 product be used to complement the GSWO product in generating probability water masks for SWOT, especially in vegetation and cloud contaminated areas. Sheng introduced two high-resolution systematic global lake datasets (i.e., Circa-2000 and Circa-2015) that could be potentially used as a priori lake databases in the SWOT mission. Pottier presented a validation on French portion of two global lake databases (i.e., SWBD and Circa-2000) using the very detailed BD Carthage dataset extracted from open street map. Further assessments are planned to conduct on the Circa-2015 lake database. Pavelsky and Durand reported the progress and improvements of their global river database (GRWL) describing both river centerline nodes and reach segments. The remaining tasks include a performance assessment in complex flow environments, an analysis of SWOT river reach-observability due to layover, and an effort to complete the dataset beyond 60^{o}N. Chen presented a parameterized layover model under development to quantify layover-induced height errors for both rivers and lakes, and the performance of the model will be evaluated in the forthcoming ADT meetings. Sheng provided a geometric layover model to map global layover distributions using digital elevation models, and reported that ~70% of global lakes are well observed with one 21-day SWOT cycle. A Geoid a priori dataset is necessary for the geoid correction of individual SWOT passes over large lakes. Using 22 large lakes across the globe, Cretaux compared three major geoid models: GGM02C, EGM2008 and EIGEN_6C, and found that EIGEN-6C and EGM2008 correction can reach an accuracy from a few centimeters to 20-30 cm in worst cases.

SWOT & Global Models (*C. David, A. Boone*)

Sylvain Biancamaria presented his work on a Fast simulation of SWOT hydrology observations, a significant step forward global hydrological preparedness for the mission.
The SWOT Science Team (ST) Working Group (WG) on "Continental-scale hydrologic/hydraulic ('hydro') model inter-comparison" (RivMIP), led by Cedric David, reported on the group effort over the past year. The experiment focuses on Mississippi River Basin study. Our group is currently formed of 36 participants at varying levels of involvement, some of which are already running their hydrologic or hydraulic models on the Mississippi River Basin. The team has fostered international collaboration with participation from researchers spanning the United States, Brazil, France, and Japan. The web page for RivMIP (http://rapid-hub.org/inter-comparison.html) includes the agenda, presentations and summary of all monthly teleconferences. A scientific manuscript is currently in preparation.
Colby Fisher presented global simulations and river discharge using the routing scheme of VIC and initial data assimilation results of virtual SWOT observations. Results suggest that in addition to the influence of latitude on spatio-temporal frequency of observations, the orientation and shape of river basins has an impact on the quality of data-assimilated discharge.
Dai Yamazaki presented global simulations of river stage and discharge using CaMa-FLOOD and proposed two data assimilation experiments. The first experiment consisted in corrupted runoff forcing (25% Gaussian noise uncorrelated in space nor in time) and the second experiment was similar to the above with the addition of corrupted model parameters. Initial results indicate that data assimilation has a strong potential to improve global discharge estimates from SWOT measurements.

A joint discussion was held here and after the following session, and some emphasis was placed on the necessity of community work to further justify the need of global data assimilation efforts for SWOT hydrology as such endeavors, and the related Level 4 data products, are not included in the mission requirements.

SWOT Data Assimilation (*K. Andreadis, S. Ricci*)

A number of ongoing studies on the assimilation of SWOT observations were presented during the session. Most have used synthetic observations generated over river basins that ranged in size. The study areas included the Garonne, Sacramento and Po rivers as well as continental-scale rivers such as the Upper Mississippi and the Amazon. Results showed the both Kalman Filtering and variational methods were able to reconstruct water surface elevation profiles as well as estimate river discharge relatively successfully. The positive impacts of using localization within the assimilation algorithms were shown in capturing features such as pools. A technique using a surrogate model in order to reduce the computational cost of forward modeling showed promise, and should be tested further as a viable alternative to the traditional data assimilation approaches. Apart from estimating water surface elevation and discharge, data assimilation techniques were shown to also being able to retrieve parameters such as river channel bathymetry.
The need for data assimilation in the context of generating the cycle-average SWOT data products has been initially evaluated by assessing the impact of using a simple arithmetic mean to calculate the cycle-average discharge globally. Although mean errors were on the order 20-40%, maximum errors reached 90-100% for the majority of rivers. As expected, errors were lower for higher latitudes where the number of observations per orbit cycle is higher.

SWOT Simulations & Tools (J.-F. Cretaux, E. Rodriguez)

The goal of this session was to review tools being developed by the project and science teams to use the SWOT hydrology products at various levels to derive higher level products or conduct performance analysis of the algorithms in development by the Algorithm Development Team (ADT).

New SWOT Lake Simulator (J.-F. Crétaux, LEGOS/CNES, Q. Lagrelle, L. Fruteau, C. Pottier):

One of the science goals of the SWOT mission is to study lake storage variability, but SWOT does not measure storage change directly. Rather, it measures lake extent and elevation at different times, and provides no bathymetric information. In this talk, an approach to computing storage change based on a pyramidal volume approximation was presented. To assess the performance of this approximation, several lake volume simulators of different complexity have been developed, including: a) simple analytic simulators; b) polygon simulators using idealized bathymetry and dynamics that include dynamic lake mergers and splits; c) a detailed simulator including real bathymetry for selected regions (e.g., the Aral Sea or Lake Poopo). The talk presented sample storage change calculations for dynamic lake mergers and splits and emphasized the importance of a dynamic *a priori* lake database that is updated at yearly intervals for the successful calculation of lake storage change dynamics. Finally, the talk gave a long term vision of the end-to-end processing, including the use of multi-year data to not only generate storage change, but, by the end of the mission, generate lake hypsometry and "useful" (i.e., observed) bathymetry by the end of the mission, including a final calibrated reprocessing.

Updates to Lake Processing (C. Pottier, CNES, SWOT Project Team):

Claire Pottier, on behalf of the project team, presented a detailed overview of the baseline processing of lake data. The processing steps include gathering pixel cloud data into connected components, separating lakes, averaging and vectorizing and linking with the *a priori* lake database. Data products are generated both at the single-pass level (only products associated with lakes in specific observation tiles) and multi-pass levels (products associated with specific lakes). Work is currently ongoing to develop prototype code following SDS documentation, and to incorporate the code into the current end-to-end simulator scheme starting from the HR simulator. It is expected that the relevant ATBDs (version 1) will be completed by mid-2018, and a prototype implementation by the end of 2018.

Updates to RiverObs (E. Rodríguez, JPL):

The low-level data product for rivers is a set of point measurements that are geolocated, but contain no topology information (e.g., organization into rivers and river networks). RiverObs is a tool initially developed by E. Rodríguez whose aim is to take the point measurements in the pixel cloud and provide topology information by associating points with river reaches, associate additional information beyond the point cloud (e.g., in situ information), and generate higher level products such as reach slopes, widths, mean water elevation and instantaneous discharge. Since its original development, RiverObs has been adopted by the ADT as a baseline for generating higher-level SWOT data products and the interface of RiverObs has been modified to work with the current SWOT high-resolution Level 2 data simulator. In this talk, the principles and change history of RiverObs were reviewed and the future of RiverObs development was discussed. This future consisted in:

1. Release of a beta version of RiverObs to selected members of the CNES and JPL projects as well as members of the science team for testing and validation. (**Completed)**
2. Open source release of RiverObs so that members of the scientific community, including the SWOT science and algorithm teams, could contribute in a unified way. (**Completed.** RiverObs is now publicly available on github: https://github.com/SWOTAlgorithms/RiverObs
3. Discussions about future evolutions of RiverObs capabilities beyond support of the SWOT ADT effort (ongoing).

Synergestic Sciences session summaries:

Coastal/estuarine group (*B. Laignel, M. Simard*)

The coastal and estuarine session has been focused on (1) Estuarine and coastal tide and Aliasing, (2) Hydrodynamic modeling and SWOT simulation, (3) Multi-aircraft airborne and field campaign in the wetlands.

The SWOT aliasing with the tide in the estuarine and coastal environments is studied in 16 sites/areas selected in different tide contexts (macro, meso & microtidal), diverse morphologies (estuary, delta, bay, coast with sandy beaches or cliffs, shelf) and different climates (temperate, Mediterranean, tropical, arctic…) (SWOT COTEST project; coord: B. Laignel). The results show: a best reproduction of the main variability modes of the water level by the simulated SWOT data in the coastal and estuarine zones located in the microtidal context than macrotidal context, a decrease of the wavelet coherence from upstream estuary (87-90) to downstream (50-82), with a best reproduction in upstream estuary similar to the river (hydrological cycle, seasonal variability, flood periods) and a more heterogeneous and difficult reproduction in the downstream estuary according to the tide and river context; an exaggeration of the 2-4 months variability mode in the coasts and downstream estuaries (mainly in macrotidal contexts) linked to the aliasing between the SWOT revisit and different components of the tide; the possibility to observe the energy of some storm surges in microtidal context.

On other hand, a new method called Constrained Harmonic Analysis (ConHA) has been developed to help assess the potential contribution of SWOT observations for mapping tides in estuaries and coastal environments (works of P. Matte, N. Bernier, J.M. Fiset, V. Fortin, Y. Secretan). By using a combination of in-situ and simulated SWOT data, spatially varying constituent amplitudes and phases are retrieved by constrained minimization, with bounds defined based on information at nearby estuarine stations. The method is both robust to the data frequency of acquisition (i.e. no tidal aliasing) and to the record length (i.e. no limit on the number of constituents); it is also independent of river geometry (i.e. no spatial function needed). The method was applied to the St. Lawrence estuarine transition zone, a very complex region where tidal ranges reach their highest level (~7m) and where significant 2D variability in water levels is observed. Results show that the spatial coherence is maintained throughout the domain. With respect to the SWOT orbits, an accuracy <10% is obtained during Cal/Val, while a stable accuracy <8% is achieved after 1 yr of science mission. However, results show some sensitivity to initial launch time. Applications of ConHA can be foreseen in any coastal areas where tides are spatially coherent as well as in remote areas, with limited field efforts.

The hydrodynamic modeling is carried out on the Seine and Gironde estuaries and the Red river and Mississippi delta and on the French coasts of the Channel and Atlantic ocean and in the Canadian coastal oceans. The main objective is to study the physical processes (wave, tide, storm surge, river flood…) in the continuum of the different environments: River-estuary-mouth-shelf continuum, Shoreline-nearshore-shelf continuum, Wetland-estuary channels continuum, Wetland-shoreline continuum…

In the Seine and Gironde estuaries, twelve different hydrodynamic contexts were calculated by the T-UGOm model according to tide and discharges (Neap/Spring tide, High/Low tide, High/Medium/Low discharges) (SWOT COTEST project). The results show that the water levels are spatialy, highly variable in different hydrodynamic conditions and in specific hydrodynamic condition. This shows the importance of the high spatial resolution of SWOT to understand and modeling these energy transitions. T-UGOm outputs were used as input data in the HR SWOT simulator in the Seine estuary. After application of geolocated correction method, all of SWOT measurement points are in the channel and HR simulator shows a good restitution of the spatial variability of water level along the estuary from the downstream to upstream (length: 160 km). After a geolocation correction and a filtering process, averages of SWOT measurements are performed for each section of 1 km and these averages were compared with T-UGOm values: the results show low differences between 0,3 cm and 20 cm, except for one case where the difference is 2m due to layover effect.

Modeling of the water level, wave, wind and currents is carried out on the French coasts of the Channel with the DELFT 3D and SWAN models (SWOT COTEST project). The modeling is performed under different hydrodynamic conditions, including the propagation of the Xaber storm, which is particularly important for the Normandy coast (Dec/5/2013). This work shows it possible to visualize the spatial variability of the water levels and currents, and particularly in the zones where the energy is concentrated (= hazard zones). In addition, these numerical simulations were carried out on the basis of two meshes with resolutions of 500 m and 250 m in order to optimize the sampling of the hydrodynamic variables and the various coastal processes. The results show that 80% of small scale variability is captured by a resolution of 250 m and that only 20% can be captured by a resolution of 500 km.

On the Bay of Biscay shelf, modeling results show that baroclinic instabilities are developing at the edges of river plumes (Loire and Gironde), and explain a great part of the submesoscale frontal activity observed in the area (COCTO project; coord: N. Ayoub, P. de Mey). The Gironde plume impact on small-scale processes on the shelf is investigated, by calculating in particular a stratification index, and comparing with relative vorticity and SSH fields. A T-UGOm configuration is under development to model the upstream part of the Garonne and Dordogne rivers (joining in the Gironde). The Red River Delta and Southern China Sea are another area of study in this project, where detailed work has been done on the bathymetry and coastline.

A coastal circulation model off eastern Newfoundland has been developed, based on the Finite Volume Community Ocean Model (FVCOM) (SWOT simulation in the Canadian coastal oceans project; coord : G. Han). The model results are evaluated against coastal tide-gauge data and moored currents data. The SWOT ocean simulator is used to generate simulated SWOT data from the ocean model results. Various errors are considered in generating simulated SWOT data. After the spatial filtering of simulated SWOT data within each swath, the time-space optimal interpolation is able to reasonably recover the model inshore Labrador Current, the dominant coastal current in the study region.

The session also included discussions on the validation process and lessons learned during two multi-aircraft airborne and field campaigns carried out in the Mississippi Delta. Given the need for procedures and standard for cal/val in coastal wetlands, a set of recommendations were introduced based on these campaigns which included airborne (UAVSAR, AVIRIS-NG, ASO Lidar and AirSWOT), spaceborne (Landsat 8, Sentinel-1, RadarSat-2) and a series of *in Situ* (river discharge, sediment and carbon concentrations, vegetation species and above ground biomass, river bathymetry and wetland elevation. These campaigns, coordinated by M. Simard, were specifically designed to understand SWOT measurements in coastal wetlands project. It was demonstrated the measurements could serve initialization of hydrodynamic models which is in turn used for time interpolation of in situ and airborne measurements. The simulated SWOT measurements in the wetlands allow to better understand the hydrodynamic in the wetlands and its impact on the vegetation, and particulary the water exchanges between the wetlands and the channels in the delta, and between the wetlands and the sea along the coast. The resulting calibrated hydrology model and a SWOT simulator in coastal wetland environments, will soon enable the generation of scenarios in various hydrologic conditions and phenological stages over part of the Mississippi delta. The session also highlighted the need to compile a global coastal wetlands map with attributes (e.g. herbaceous, scrubs, trees, expected growth stage as a function of time, etc.) necessary to design appropriate processing algorithms to generate science products.

Advances over the Cryosphere, Snow & Sea-Ice (*R. Kwok, J. Monnier*)

Sea-Ice (R. Kwok)

- Preliminary results from simulations (using a SWOT simulator) suggest that it is feasible to extract sea surface height and freeboard information from high-rate SWOT data.

- Arctic Ocean coverage for demonstration of SWOT utility over the ice-covered ocean during the second and third years of the mission was discussed in a different session.

- The acquisition of sea ice in high-rate data collection mode early on in the mission (during the fast sampling, 1-day repeat phase), if opportunity permits, was suggested.

Marine Geoid & bathymetry advances (*D. Sandwell*)

A high-resolution Mean Sea Surface (MSS) will be needed for the mission's CalVal phase and early science phase, before a new SWOT MSS can be created. The session described recent work to use the CLS MSS model to constrain the large scales (> 30 km wavelength) and the SIO slope profiles obtained from alongtrack altimeter data to constrain the smaller scales. Biharmonic splines in tension are used to combine height and slope data with specified uncertainties. The slope correction will be needed for SWOT but also for estimating the mean dynamic topography (MDT) for all missions, using the new GOCE geoid models.

Executive Meeting Summary (Science Leads)

The science leads highlighted the excellent work being done by the different teams to understand the future SWOT signals and errors over different surfaces (terrestrial surface waters, oceans, coastal regions, ice). Particularly noteworthy are the joint efforts between many teams to tackle the main problems, with significant advances since the first ST meeting last year.

The science leads congratulated the Project teams for their excellent work on preparing the instrument and platform, and for their progress on providing data distribution at short latency.

A recommendation was made to remove the ocean sea surface slope calculation from the SWOT requirements and high-level data, since it will be calculated on ground by individual users differently (see ADT summary).

For the ocean session, this meeting concentrated on the ongoing work to separate high-frequency internal tides and internal gravity waves from the internal ocean dynamics. This fundamental problem is advancing well, with the ST groups working on this from HR modelling, in-situ data and alongtrack altimetry.

Ocean CalVal Workshop report (C. Chen, N. Picot)

The meeting objectives, adapted from the slides for introduction talk, are below as major bullets. Subbullets give the meeting outcome(s) for each of these objectives.

- Objective 1: Describe status of how well different Cal/Val approaches can meet the needs/objectives of ocean Cal/Val at scales from 15-100 km as described in the slides for the introduction talk.
    - Airborne lidar has much potential for Cal/Val. It has the advantage that it directly measures sea surface height (SSH) as will be measured by SWOT. However, another ocean experiment must be completed successfully before it can be considered fully ready for Cal/Val.
        - The lidar instrument noise at high frequencies is below the SWOT height error spectrum requirement as demonstrated by the Algodones data.
        - Lidar performance over the ocean still needs to be fully validated. Because of the lack of truth data at the scales and accuracies required, however, this can only be achieved through examinations of lidar self consistency over time and/or comparisons to existing nadir altimeter data. In order to avoid temporal variability near the coast, the lidar must be moved to an aircraft with longer endurance and higher speed. The temporal and spatial decorrelation of the ocean between the times of aircraft overflights and SWOT overflights should be assessed more fully with modeling.
        - A question was raised about the slope behavior of the lidar SSH spectrum at 10-100 km scales. A measurement artifact (e.g., aircraft position/attitude error) cannot be ruled out, but there are plausible mechanisms (e.g., imperfect MSS) that might explain the observed behavior.
        - Besides its potential for validating the SWOT error spectrum requirements, the lidar offers other Cal/Val benefits including cross-track height assessments, directional wave spectra, and SST.
        - While multiple organiziations (NASA, NOAA, NRL) have suitable fast, long-endurance aircraft (e.g., P-3 or C-130), aircraft availability is generally a logistical constraint for the lidar that must be addressed.
        - The lidar can support any of the proposed Cal/Val sites, although the costs would be lower for sites closer to the aircraft base of operations. Preliminary assessments suggest that weather is not a major factor.
    - Data from in situ approaches would offer the best linkage between the SWOT measurements and the science that underpins the SWOT requirements. The in-situ data approach with high-frequency observations allows us to observe and understand the ocean dynamical processes contributing to the SSH spectra in the 15-100 km wavelength band at the main Calval site. This "signal content" is complementary to the total SSH measured by Lidar, or by the Global CalVal activities comparing SWOT to other nadir altimeters, which include the sum of the ocean dynamical signal and other variations (MSS, waves, ...). Multiple in situ approaches (moorings, gliders, PIES, UCTD) have

been considered and offer relative advantages and disadvantages as described in Jinbo's slides.

  - Hydrographic approaches are the gold standard for measuring dynamic height. Being able to measure dynamic height at a SWOT Cal/Val site would allow the SWOT measurements to be tied to existing oceanographic data, literature, etc. Hydrographic measurements of dynamic height could also serve as important inputs for data assimilation in numerical ocean models.
  - Simulations suggest that an along-track array of 20 gliders sampling to 500 m depth would give an error spectrum for dynamic height measurements (measured dynamic height vs. truth) that is on par with the SSH error spectrum defined in the SWOT L2 requirements.
  - Preliminary results from the Monterey pilot experiment show good agreement between the glider and the mooring and show that the glider is able to achieve the expected stationkeeping ability.
  - A question was raised about whether sampling only the upper 500 m of the ocean with CTDs was sufficient, although the simulation above did capture this effect. PIES would help validate the performance of gliders doing dives to only 500 m depth.
  - A question was raised about whether gliders could realistically be borrowed or rented for a glider-based SWOT Cal/Val campaign.
  - Costs of in situ approaches (except for PIES) were not discussed at this meeting.
  - An array of moorings with real-time data transfer capabilities would satisfy hydrographic objectives for Cal/Val, but it has been deemed too expensive and dropped from consideration.
- GPS approaches are being investigated and will definitely have some place in Cal/Val (especially for hydrology). However, due to cost uncertainty, they are not currently being proposed as a standalone approach for validating the SWOT error spectrum requirement. The GPS buoys are a good candidate for Cal/Val if mooring deployment costs can be reduced or offset by external contributions.
- Comparison of SWOT data to known MSS slopes near seamounts may offer a means of additional validation.
- Planning for science campaigns that may be tied to SWOT Cal/Val activities should begin so that these activities can complement each other. These are not being pursued for direct validation of the SWOT error spectrum requirement, however.
- Experiments in the Mediterranean may also be folded into SWOT Cal/Val activities and could provide useful validation data. This work is not being pursued to directly validate the SWOT error spectrum requirement, however.
- Global statistical Cal/Val approaches provide a powerful, reliable means of validating many aspects of the SWOT error budget and products.
  - Global statistical Cal/Val can likely validate the SWOT along-track spectral requirement at wavelengths as short as 50-70 km. Validation of wavelengths as long as 150 km by local means (in situ and/or lidar) would still be preferred, but global statistical approaches could

validate wavelengths longer than 70 km if local means cannot practically extend to such wavelengths.
    - Global statistical Cal/Val approaches are already in the baseline plan

- Objective 2: Decide on next steps for how to converge on concrete baseline plan for ocean Cal/Val: Needed analyses/experiments, timeline of activities, etc. [including definition of Cal/Val site(s)]
  - Lidar team (to be coordinated by Curtis):
    - Engage modeling community (POC: Jinbo/Lee) to assess temporal/spatial decorrelation issues in order to mitigate the associated risks.
    - Continue to refine assessments of P-3 aircraft availability and cost.
    - Continue assessment of Algodones GPS data to mitigate risk of long-wavelength positioning errors.
    - Articulate risks with impacts and mitigation plans associated with the proposed approach.
  - in situ team (to be coordinated by Lee):
    - Complete execution of Monterey experiment and associated data analysis.
    - Define proposal for inclusion in baseline plan, including cost estimate. The proposal might include additional pre-launch activities to mitigate risks [e.g., pre-launch ocean experiment(s)], but should still provide a plan for eventual SWOT Cal/Val work (and associated cost) that assumes the successful completion of pre-launch activities.
    - Address question of whether full-depth measurement is needed and incorporate any needed risk mitigation activities into the proposal.
    - Consider whether GPS buoys are beneficial as part an integrated in situ Cal/Val approach and incorporate them into the in situ proposal if desired.
    - Articulate risks with impacts and mitigation plans associated with the proposed approach. These might include risks associated with full-depth vs. 500 m sampling, whether gliders can be borrowed or rented, etc.
    - Initiate assimilation study that includes the different Cal/Val data sources that may be available.
  - GPS team (to be coordinated by Bruce):
    - Assess Monterey data in coordination with in situ team.
    - Develop cost model for GPS buoys with parameter inputs such that in situ team can estimate costs of different use cases.
  - Follow-on science campaign team (to be coordinated by Tom):
    - Coordinate inputs from science community and consider holding a workshop to refine the strawman concept presented. The points of contact will be Tom, Rosemary, and Lee.
  - Mediterranean team (to be coordinated by Francesco):
    - Continue to plan activities that could be synergistic with SWOT Cal/Val.
  - Global statistical Cal/Val team (to be coordinated by Nicolas):

        - Continue to prepare for SWOT Cal/Val
    - Decision (All teams): The Azores Cal/Val site will be dropped from consideration. Planning activities going forward for the lidar and in situ teams should assume that the California site is the primary joint Cal/Val site, though activities at other sites may still be evaluated for specific standalone purposes if desired.

Other notes:

- The meeting participants reaffirmed the overall Cal/Val objectives documented in the presentation material for the introductory talk, which was copied from the introduction to the November 2016 ocean Cal/Val meeting in Paris.