SWOT Science Team meeting, June 13-16, 2016, Pasadena

The presentations delivered in the SWOT ST meeting in Pasadena can be found at the following link:

http://swot.jpl.nasa.gov/meetings/swotscienceteammeeting2016/

The following provides a summary of the main points discussed during the 4-day meeting.

1) Mission Overview and Description

Program Status
Eric Lindstrom gave an overview of the different SWOT proposals accepted from US and French/International groups. An annual report is requested. He asked that each SWOT Project should provide a short few page report & one powerpoint slide with a key result & citation (suitable for communication).

Programmatic Issues in 2016-2017:
1) Understanding AirSWOT issues : Report to NASA HQ in February 2017
2) Design and planning of science submesoscale dynamics process study & internal waves in 2022-23 (analogue to SPURS)

CNES entry to phase C/D/E1 should be confirmed on July 7 2016 (Paris). (*It is now confirmed*)

Project Status
Parag Vaze presented an overview of Project accomplishments since the last meeting of the Science Definition Team. These include :
- Consolidated 2-beam radiometer
- Enhanced data downlink (additional ground stations) confirmed.
- Enhanced reliability program in response to SMAP failure.
- Descoped Karin Nadir Channel.

The project has entered Phase C - the final design and fabrication phase – with a baseline to build engineering models to flight models for hardware & software.
- Focus on algorithm baselines for the on-board Processor
- Algorithm development requires Algorithm Thoeretical Basis Documents (ATBDs) and prototype code
- Need to refine the science data products
- A detailed CalVal plan is being developed, and needs to be consolidated
- Work needed on Data distribution & applications

2) Oceanography

Onboard Processor-
E. Peral presented the status on the Onboard Processor (OBP).
Following the discussion in the SDT meeting in Toulouse in June 2015, the output of the OBP available globally over all surfaces, accepted by the Project is :
9 complex interferograms and SAR images at 500m x 500 m pixels & 250 m posting.

3 additional products were still under consideration, for wave mitigation, editing and synergestic science

- power image at 250m2 resolution, 250 m posting for the central beam – removing anomalous points & synergestic science
- Doppler centroid image for each swath – extract ocean velocities to improve wave corrections
- HR cross-track interferograms for wave spectra

ATBD JPL D-79130 contains test cases for wave effects, etc.

Parag Vaze reported that the ATBD for these 3 additional OBP products should be finalized and ready for approval by July 15. Any proposals for changes must be received by the Project for review before June 30.

Ocean Simulator

Clement Ubelmann presented the recent results for the ocean science simulator – a light portable tool to simulate the SWOT L2 data over the oceans, with realistic sampling and errors/noise. This tool relies on spectral error budget specifications – it is different from the high-level instrument simulator. Two orbits are provided, for the fast-sampling (1-day) calibration orbit, and the nominal (22-day) science orbit.
Open source, download online:
https://swot.jpl.nasa.gov/science/

AirSWOT

Ernesto Rodriguez reported that the wave motion effects were the cause for the AirSWOT SSH spectral hump at wavelengths from a few hundred m to a few km.
Waves coming in the perpendicular (cross-track) direction are well imaged; when their direction is slightly offset – their image becomes distorted. Wave bunching in the alongtrack direction leads to spectral distortion, and contributes to the spectral hump in AirSWOT at the wavelengths of the dominant waves..

Simulation studies have shown that the theory is able to explain the observations for three wave conditions: SWH ~0, 3.5 m, and 2 m. The SWOT OBP doesn't have this problem because it forms spatially averaged inteferograms. Simulations of the SWOT OBP processing have indicated that the signal power-weighted average of the phase in forming the interferograms was able to reduce the wave motion effects well below the SWOT error budget. For SWOT, these effects should be much smaller than the surfboard effect.

Algorithm Development Team (ADT) Ocean Priorities

- <u>Measurement phenomenology</u> – effects of waves, swell, mixed surfaces (ocean-ice, ocean-reefs / sandbanks, coastal ocean-land)
- <u>Defining expert products and product grids</u>
- <u>Developing robustness algorithms</u> in ground processing (and using OBP additional products) - for editing/separating anomalous points, wave effects, mixed surfaces.
- No specific products are currently planned for <u>synergistic science</u> : sea-ice, continental ice sheets, ocean bathy/gravity
- <u>Proportion of HR mask over ocean</u> – current plan is for a 3km band around all coasts (measured from the nadir intersection with the coast). No more than 4 ocean/ice patches of 120 km x 120 km can be added to the current HR mask. HR mask can be changed seasonally (4 times/yr).

Ocean CalVal-

Results of comparison of simultaneous AirSWOT and MASS Lidar observations during the Carthe experiment were presented (Ernesto Rodriguez and Ken Melville). MASS Lidar showed reasonable comparisons to Altika overflight data except at wavelengths shorter than the Altika resolution, ~ 40 km. AirSWOT comparisons were not as good.

Actions were requested to make more comprehensive comparisons of MASS lidar and AirSWOT observations to the Carthe drifter observations, which had been analyzed to produce SSH estimates. Both AirSWOT and Mass lidar must be tested for meeting the calval requirements.

In-situ calval options were extensively discussed in the calval workshop. A white paper will be initiated to address the various approaches to ocean calval: Airborne observations, in-situ observations, internal consistency analysis of the 1-day repeat data, MSS reference analysis, etc.

A modeling framework was proposed by Jinbo Wang and Lee Fu to evaluate various in-situ observing systems for tradeoff of performance vs affordability.

C. Ubelmann and G. Dibarboure showed that spectral separation between range-dependent or spatially coherent instrument errors and geophysical signals was possible through an along-track cross-spectral analysis of the 1-day repeat data.

Ocean Data Products

The OBP will download 9 beam interferograms + power images + additional products with a resolution of 500 m and 250 m posting. Some issues are currently under discussion:

1) An intermediate 9-beam "expert" product has been proposed at the same resolution, but instead of dealing with interferometric phase and amplitude, it will be converted into height, with SWH, wind, SSB estimates. A justification of this intermediate product is available, and will be distributed to ST members. The usefulness of this product for science and applications needs further discussion/recommendation.
2) After a weighted beam combination, two Level 2 products are planned over the ocean – one on a native grid which moves with the swath, the other on an earth-fixed grid. The definition of the earth-fixed grid needs discussion/recommendations.
3) The low-rate (LR) data from the OBP are global, but the data processing and parameters are tuned for ocean surfaces. What is needed for coastal and estuarine areas, including the regions with both HR (high-rate) & LR data? What is required for ocean-ice studies, and for the HR patches over oceans/ice?

To help the analysis, a representative 1-pass sample of the L2A product on the swath-oriented grid will be available to the ST this summer.

Working Groups

Ocean surface waves

SWOT sea state bias (SSB) is introduced by wave effects, with more power returned from horizontal facets. The SSB is often estimated as 1-3% of significant wave height (SWH). For SWOT, SWH is estimated from the inversion of the volume correlation and the SSB is estimated as a swath-averaged value set at 1% of SWH. AltiKa shows SSB being~3% SWH. Recent results from Fabrice Ardhuin, Bertrand Chapron show that SWH varies

spatially across the swath, and small-scale gradients in SWH & SSB are induced by surface currents. These can introduce SSH biases up to 100 km wavelength. Biases are not just a function of SWH, and proxies of the SSB 2D field may be derived from higher-resolution radar cross-sections and Doppler centroids (proposed as additional OBP algorithms). More work is needed to understand these effects, using coupled wave-ocean circulation models, observations of current gradients obtained from satellite sun glitter, wave observations from drfting wave buoys, and Lidar and AirSWOT data.
A new working group is proposed, dedicated to the impact of ocean waves for SWOT.

Internal gravity waves

Modeling and observational evidence has suggested that the SSH signatures of internal gravity waves might be comparable to those of low-frequency motions in certain regions and seasons. A priority was identified to collect available moored and towed data for assessing the relative importance of internal gravity waves and geostrophic motions in various oceanic regions and seasons and for testing the performance of the various models to be used to guide CalVal planning and post-launch analysis strategy.

Tides

A tide working group was established to develop global coastal models, internal tide models, as well as strategies for handling incoherent internal tides.
Strategies are needed for testing and comparing models – assessing their accuracy with independent (non-assimilated) altimeter data (eg geodetic missions, CR2), or independent in-situ tide gauge data or PIES. Specific in-situ campaigns may be needed for characterizing internal tides.
A research question is to better understand the interaction between the internal tide and the ocean mesoscale circulation.
There is a need to seamlessly integrate the best local models for coastal & shallow seas with the global models before launch. Tidal models for estuaries will remain as research studies.

Ocean Modeling

A working group was formed to address the utility of high-resolution ocean models for mission development and science planning. A priority task was to establish a data base to test the performance of the various high-resolution ocean models that are candidates for mission analysis, including calval design.

Reconstruction of 3-dimensional ocean circulation

Different techniques were discussed concerning the reconstruction of the upper ocean circulation from SWOT SSH data. Clement Ubelmann showed that standard 2D objective mapping retains scales > 80 km, whereas dynamical interpolation can access smaller scales in regional studies. Bo Qiu demonstrated the reconstruction using eSQG with realistic SWOT simulations. Dudley Chelton showed the challenges of estimating geostrophic velocity and vorticity from SWOT, given the SWOT sampling and estimated errors. Jim McWilliams showed that at smaller wavelengths (smaller than 30 km), the cyclostrophic correction to geostrophic balance matters and at small wavelengths, the divergent component of velocity is comparable to the rotational component of velocity, but these points can be addressed using balanced equations. The problem of separating the internal waves from geostrophic mostions remains an issue at small scales.

3) Hydrology

High-rate Land Mask
Sylvain Biancamaria gave a presentation about the current state of the SWOT high-rate land mask, which determines which areas will be covered by high-resolution SWOT data and, conversely, which areas will only be covered by low-resolution data. The presentation summarized the steps used to construct the HR mask, which focus on identifying regions containing rivers, lakes, and wetlands potentially observable by SWOT and ensuring that they will be covered. This process was first completed using an automated system and then modified based on input from the science team. The HR mask covers 83% of SWOT-observed continental surfaces and does not include some deserts and very large lakes. The HR mask also includes the opportunity to download data for four 120 km x 120 km patches over the ocean, which can be used to improve understanding of SWOT ocean phenomenology. The current HR Mask is available at:
hNp://west.rssoffice.com/SWOT/hrmask.jsp

Hydrology Simulator
There were two presentations on the SWOT hydrology simulator at the meeting: on Monday, Brent Williams gave a talk introducing the overall structure of the hydrology simulator, which is modular in nature. The primary modules currently available produce (a) radar interferograms and a geolocated/classified pixel cloud, (b) river vector products (RiverObs), and (c) information on vegetation impacts (still awaiting validation from AirSWOT). There are currently no modules available for lake vector products or raster products. The simulator is currently being used by the ADT to develop and refine algorithms and data products and is available to science team members. Brent presented preliminary results from the Sacramento River, showing the outputs of the simulator, including the pixel cloud and vector products. There is also a large-scale hydrology simulator under development at CNES/LEGOS, which will allow quick and easy development of a SWOT-like pixel cloud. This simulator is designed to produce SWOT=like data for hydrology analysis but not to mimic actual SWOT data processing steps.

The second presentation on the hydrology simulator, also by Brent Williams, was given on Wednesday in the hydrology breakout. He discussed the details of how the simulator is actually obtained and run. A new version of the simulator will be out a few months after the ST meeting, with an improved user interface and enhanced functionality.

ADT Hydrology Priorities
Roger Fjortoft presented an end-to-end summary of the SWOT hydrology data processing chain on Monday of the ST meeting. On Wednesday, Ernesto Rodriguez and Nicolas Picot discussed the key priorities for hydrology in developing the algorithms required by this data processing chain. These include:

- Layover characterization and flagging: development of more robust layover flagging was a key emphasis of the recent SWOT PDR.
- A priori database generation: SWOT water classification and vector data processing depend on prior databases of rivers and lakes, which must be fully developed. River datasets are currently under final development and testing. Lake a priori datasets for SWOT are less well established, and a group including scientists at LEGOS, UCLA, UNC, and SERTIT have agreed to jointly test available datasets.
- River and lake product prototyping: river and lake product description documents have been developed, and the next step is to produce prototype products.

- Further development of discharge algorithms: current discharge algorithms exist, but they must be improved and fully tested/validated (meeting on this in October).
- Multitemporal data processing challenges: SWOT hydrology data processing will likely rely on the use of multitemporal data from SWOT, and possibly other sources. How this will be carried out remains to be defined (meeting on this in September).
- Measurement phenomenology over rivers, lakes, and wetlands: there is a need to further improve understanding of SWOT phenomenology over inland waters.
- Development of additional simulations over inland waters: we have only a handful of completed simulations over actual rivers, and almost none over lakes. We need to substantially increase the number and size of simulations available to the ADT and ST.
- Improved understanding of geoid variations on SWOT data products and algorithms: over large water bodies, in particular, errors in current representations of the geoid may result in erroneous estimates of lake height (and storage) variations and river slope (and discharge). We need to develop a plan to address these sources of error prior to SWOT launch.

Hydrology Data Products

SWOT hydrology data products can be divided into three groups: the pixel cloud product, vector products, and raster products (including the floodplain DEM). Roger Fjortoft and Phil Callahan gave a presentation on the current state of these products on Monday of the meeting. All hydrology data products will be created from the KaRIn high-rate single look complex (SLC) data, which will be available on request. The pixel cloud, which will be produced from the SLC, will be geolocated and classified with several different amounts of averaging. Vector and raster products will be produced from the pixel cloud. Many of the key issues going forward mimic the ADT considerations detailed above, including:

- Water Detection robustness (dark water, flooded vegetation…)
- Layover (vegetated/non-vegetated impact estimation, impact flagging, correction…)
- Phase unwrapping (robustness, dependency on DEM accuracy…)
- Use of priors and multi-temporal data; dynamic update of priors
- Generation of hydrology products: lake vectors, cycle averages, raster, discharge algorithms, storage change, floodplain DEMs

Hydrology Cal/Val

On Monday, Ernesto Rodriguez gave an overview of SWOT hydrology calibration and validation (cal/val) status on behalf of the cal/val team. A draft cal/val plan has been collaboratively developed over the last two years and is in final review by the project. Calibration of hydrology products will largely take place using data collected over the ocean, especially at crossovers, in order to reduce roll error. As such, in this area there is considerable cross-over interest between the two disciplinary portions of the mission. Additional calibration will occur using corner reflectors installed at crossover sites on land, and possibly using well-monitored lakes. Validation will take place at a range of sites that are divided into two categories: tier-1 sites, which the project will instrument and which will be intensively monitored, and tier-2 sites, which will leverage existing instruments (e.g. USGS stream gauges) with minimal investment from the project. Key goals going forward include developing robust coordination among partners in France, the U.S., Canada, and beyond; instrument and characterize tier-1 sites prior to launch; and finalize the methods and tools that will be used to robustly validate SWOT measurements.

AirSWOT for Hydrology
One of the key tools available for both SWOT hydrology cal/val and to characterize phenomenology is AirSWOT, the airborne SWOT analogue. Tamlin Pavelsky presented preliminary results over the Tanana River, Mississippi River Delta, and Sacramento River demonstrating that AirSWOT measurements appear to match *in situ* measurements of river height and slope. However, this work remains preliminary and additional analysis is required to characterize AirSWOT errors and to improve and standardize AirSWOT processing. Plans for future campaigns were also discussed, including those designated in the cal/val plan and a possible campaign (TBC) to study the impacts of layover from vegetation in the Mississippi Delta region.

Global Hydrologic Modeling
Among the key activities of the science team is development of methods to leverage SWOT data in global hydrologic models. A collaborative proposal on Tuesday morning set the stage for these efforts. One of the key efforts, led by Cedric David at JPL, will be an intercomparison of SWOT integration into at least five different hydrologic/hydrodynamic models over four large river basins. This will serve as a means of testing the best ways of integrating SWOT into models and, conversely, the best models to use with SWOT. This effort includes collaborators from the U.S., France, Canada, Japan, and Brazil. Further global modeling plans include efforts to assimilate SWOT data into global models led by Aaron Boone and work to combine SWOT observations of lakes with global model output to better simulate variations in global lake water storage.

River Discharge
Colin Gleason presented the latest results from the Discharge Algorithm Working Group (DAWG), which included a collaborative publication in *Water Resources Research* showing the results from the so-called Pepsi Challenge, which involved the application of five different discharge algorithms to hydrodynamic model output for 19 rivers. Results suggest both the promise of the algorithms (for nearly all rivers, at least one algorithm did a good job) and also the challenges (each algorithm failed in some cases). Going forward, priorities include integration of existing algorithms into one new, optimized algorithm, integration with available in situ and remote sensing data to constrain algorithm output, and development of additional test cases beyond those currently available.

Hydrologic Data Assimilation
In addition, there is considerable interest in developing discharge products based on assimilation of SWOT data into hydrodynamic models. The model output would have the advantage of being constrained by SWOT while also being temporally and spatially continuous. Several science team groups are working on this challenge, including those of Sylvain Biancamaria, Eric Wood, and Kostas Andreadis). The potential of SWOT data assimilation has been demonstrated in several cases going as far back as 2007, but developing methods for data assimilation over large spatial scales remains a challenge. The science team members working in this area are planning to develop an intercomparison project analogous to the Pepsi Challenge described above, in which several different models will assimilate SWOT-like data over the same rivers. The results will then be compared to each other and to truth datasets.

Applications
Margaret Srinivasan presented results of the ongoing SWOT Applications Working Group. These efforts include conducting a user survey on needs and interests of potential

applications partners and development of an early adopters program. Efforts to engage these early adopters are starting with the cases of a few applied science adopters who are affiliated with the science team.

4) Synergistic sciences

Coastal and estuarine studies -
The SWOT HR simulator combined with estuarine/coastal models has shown that SWOT should be able to reproduce the hydrodynamics in the coastal zones in a macrotidal context. Work is needed in other environments with different tidal conditions and in different climatic, morphological & sedimentological contexts. There are difficulties to address the continuum from regional seas to shelves, nearshore dynamics and estuaries.
The combination of HR data and the ocean 250m data in the 3-km coastal band needs to be explored, and the definition of coastal/estuarine products and parameters.

Cryospheric studies-
Sea-ice and continental ice science will need adapted simulators – need scenes with leads, etc for plugging into the ocean and HR simulators.
HR data may be needed in test cases at crossover points over sea-ice or continental ice.
Trades may be needed with the 4 open ocean patches, or the seasonal HR mask.

5) SWOT Science Team Future Activities

Meetings and communications

- 2016 Fall AGU SWOT sessions
- Working group communications (email, webex, etc)
- ADT/CalVal meetings
- 2016 OSTST meeting in end of October
- Next SWOT ST meeting will take place next June in France

Working group/Project interactions

- Tide model
- Mean sea surface model and Geoid
- Discharge algorithm

Mission Science Investigation Plan

- Team posters will be the first version
- A 3-5 page summary of each team will be requested in the near future as the basis of the formal plan as an update of the Mission Science Description Document dated back to 2012