Summary of the Third Surface Water and Ocean Topography Science Team Meeting

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Introduction and Mission Status

The third Surface Water and Ocean Topography (SWOT) Science Team Meeting was held in Montreal, Canada, June 26-28, 2018.[1] The meeting was immediately followed by the SWOT Hydrology Discharge Product Development Meeting, and Ocean Calibration/Validation Meeting, which both took place on June 29. All three meetings are summarized here; the agenda and presentations for the meetings are available at *https://swot.jpl.nasa.gov/meetings_agenda.htm?id=21*.

The meetings were planned and convened by the mission's science leads: **Tamlin Pavelsky** [University of North Carolina, Chapel Hill] and **Jean-François Cretaux** [Centre National de la Recherche Scientifique/ Laboratoire d'Études en Géophysique et Océanographie Spatiales, France] for hydrology, and **Rosemary Morrow** [Centre National d'Études Spatiales (CNES; the French space agency)] and **Lee-Lueng Fu** [NASA/ Jet Propulsion Laboratory (JPL)] for oceanography.

NASA and CNES are jointly developing and managing SWOT, with contributions from the Canadian Space Agency and the U.K. Space Agency. Now in final design and fabrication, SWOT passed its Critical Design Review (CDR)[2] earlier this year. Designs across all mission elements—systems engineering, flight, and ground systems—were brought to a state of suitable maturity for CDR, including development and testing of engineering-model hardware and software.

The majority of SWOT's flight and ground systems utilize *heritage* elements (i.e., components proven successful on previous missions). The noteworthy exceptions are the K_a-band Radar Interferometer (KaRIn)—SWOT's key technology, as illustrated in **Figure 1**—and the Science Data Processing Systems, currently in development, which implement cloud-based technologies to accommodate the large data volumes expected from KaRIn.

Development of KaRIn is steadily progressing, including development of its mast, antenna, and support structure. KaRIn's engineering models have undergone successful testing—including end-to-end radar electronics and antenna pattern analysis—and its flight modules are currently being built and tested.

In addition to KaRIn, SWOT's heritage instruments include the Altimeter, Advanced Microwave Radiometer, Global Positioning System Payload, Doppler Orbitography and Radiopositioning Integrated by Satellite (DORIS) antenna, Laser Retroreflector Array, and X-band telecommunications antenna. Flight modules for these payload components are either completed or in the final stages of construction and testing.

Science Team Overview and Major Meeting Outcomes

The SWOT Science Team is comprised of 52 investigation teams, with 22 in the U.S., 18 in France, 6 in Brazil, and 1 team in each of the following counties: Australia, Canada, Colombia, Greece, Japan, and Spain.

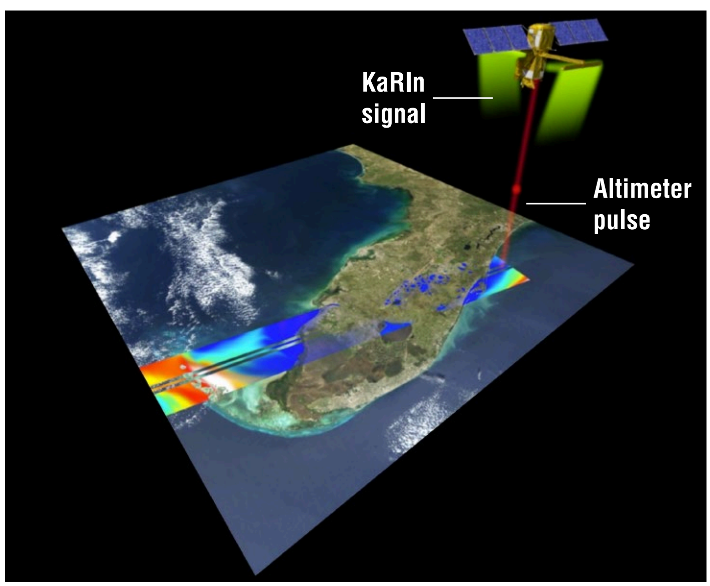

Figure 1. KaRIn's synthetic aperture radar system (SAR) will be used to determine the elevation of water surfaces on land and at sea. The white shading represents the KaRIn signal (i.e., SAR data). SAR data are shown as two relatively wide ground swaths. Between these is a narrower strip of water elevation measurements, representing data that will be collected by the nadir altimeter. The white dot in the image represents an altimeter pulse. **Image credit:** NASA/JPL

[1] The first SWOT Science Team Meeting took place June 13-15, 2016, in Pasadena, CA and was summarized in the September–October 2016 issue of *The Earth Observer* [**Volume 28**, **Issue 5**, pp. 18-23—*https://eospso.gsfc.nasa.gov/sites/default/files/eo_pdfs/Sept-October%202016%20color%20508.pdf#page=18*]. The second SWOT STM took place June 26-28, 2017, in Toulouse, France and was summarized in the September–October 2017 issue of *The Earth Observer* [**Volume 29**, **Issue 5**, pp. 26-29—*https://eospso.gsfc.nasa.gov/sites/default/files/eo_pdfs/Sept_Oct_%202017_color.pdf#page=26*].

[2] A Critical Design review is a crucial step in development for a NASA Mission or Program. For details, see *NASA Procedural Requirements*, **7120.5D**, p. 30.

There are 25 oceanography teams, 21 hydrology teams, and 6 synergistic science teams (e.g., coastal and estuarine studies, applications, sea ice, and marine geophysics). In addition to discussing investigation teams' findings, this meeting was marked by major outcomes that will benefit the oceanography, hydrology, and synergistic sciences communities. Two of these major outcomes are summarized here.

Reduction of Latency of KaRIn Data Products

One important discussion that took place during the meeting was the SWOT Project's evaluation of reducing the latency of some KaRIn data products to less than three days. This activity was primarily in response to the needs of SWOT applications and operational users. Over the past year, the Project assessed the potential impact of adding short-latency products in terms of science algorithms, data processing workflow, and expected performance. The Project has concluded that it would able to generate routine, short-latency science products while still meeting mission requirements.[3]

Reprocessing of SWOT Data

Another significant outcome of the meeting was related to reprocessing of SWOT data. Science Team members have advocated for annual reprocessing of SWOT data, as opposed to the baseline plan of one full and one partial processing pass during the duration of the prime mission (three years). The rationale behind this request is a desire to leverage the expected evolution of science data algorithms as in-flight data become available, along with the evolution of hydrology information over time (e.g., updates to a database of global river locations and characteristics over the life of the mission—an example of one such database is described later in Figure 5). The SWOT Project concluded that annual reprocessing would be a valuable enhancement and that the products (routine and reprocessed) would be distributed by JPL and CNES.

Key Updates in Oceanography and Hydrology

During the 2018 SWOT Science Team Meeting, approximately half of the time was spent on oceanography- and hydrology-related Splinter Sessions. The objectives of these sessions are summarized in **Table 1**.

In the oceanography sessions, much of the discussion centered on potentially SWOT-relevant observations of sea surface height (SSH) at fine scales—between 10 and 100 km (6.2 and 62 mi). At these spatial resolutions, SWOT will reveal two-dimensional ocean variability as never before seen, providing deeper insight into ocean mixing caused by fine-scale fronts and eddies, including their strong impact on vertical transport between the upper ocean and deeper layers. Deciphering such small-scale exchanges is key to understanding the ocean's role in climate change.

To assess the small spatial scales that SWOT will resolve, investigators are examining the *wavenumber spectrum*[4] of SSH from past satellite altimeters and other instruments. For example, **Figure 2** shows a wavenumber spectrum based on Jason-2 SSH anomaly data. At wavelengths longer than 100 km (~62 mi), the spectrum shows power density increasing with wavelength. At wavelengths shorter than 100 km, the leveling off of the spectrum indicates the dominance of the measurement errors of Jason altimeters.

[3] The current best estimate of the hydrology height errors for the higher latency products is 5.7 cm (2.2 in) over 1-km^2 (0.39-mi^2) areas (as opposed to 5.4 cm (2.1 in) for the nominal 45-day latency products); no change in hydrology slope error; and negligible impact on sea surface height spectrum requirements.

[4] Wavenumber is the spatial frequency of a wave. Whereas temporal frequency can be thought as the number of waves per unit time, wavenumber is the number of waves per unit distance.

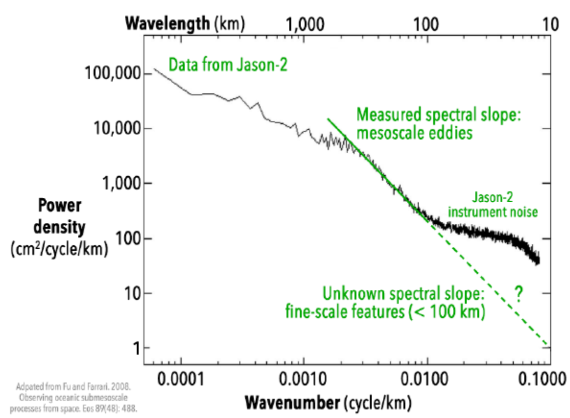

Figure 2. Spectrum of sea surface height anomaly data from the Jason-2 altimeter, sampled along a long satellite pass from the Bering Sea to Drake Passage in the Southern Ocean. At shorter wavelengths [less than 100 km (62 mi)], these data are dominated by instrument noise. The solid line represents the spectral slope associated with mesoscale eddies sampled during this altimeter pass; the dashed line projects the spectrum into ranges that Jason-2 cannot obtain—but that SWOT will. **Image credit:** Fu and Farrari

Table 1. Science topics of Oceanography and Hydrology Splinter Sessions.

Oceanography Session Topics	Hydrology Session Topics
Sea surface height (SSH) and currents at fine scales [less than 100 km (62 mi)]	Coordination of SWOT calibration/validation activities among international partners
High-resolution ocean general circulation models	*A priori* datasets and algorithms
Reconstruction of SSH and upper-ocean circulation	Hydrology data products (i.e., pixel cloud, river and lake data products, raster data products)
Representing tides and internal tides in models	Hydrological and hydrodynamical models
Ocean calibration/validation and *in situ* validation experiments	Data assimilation studies and cycle average (i.e., multiple swath) products

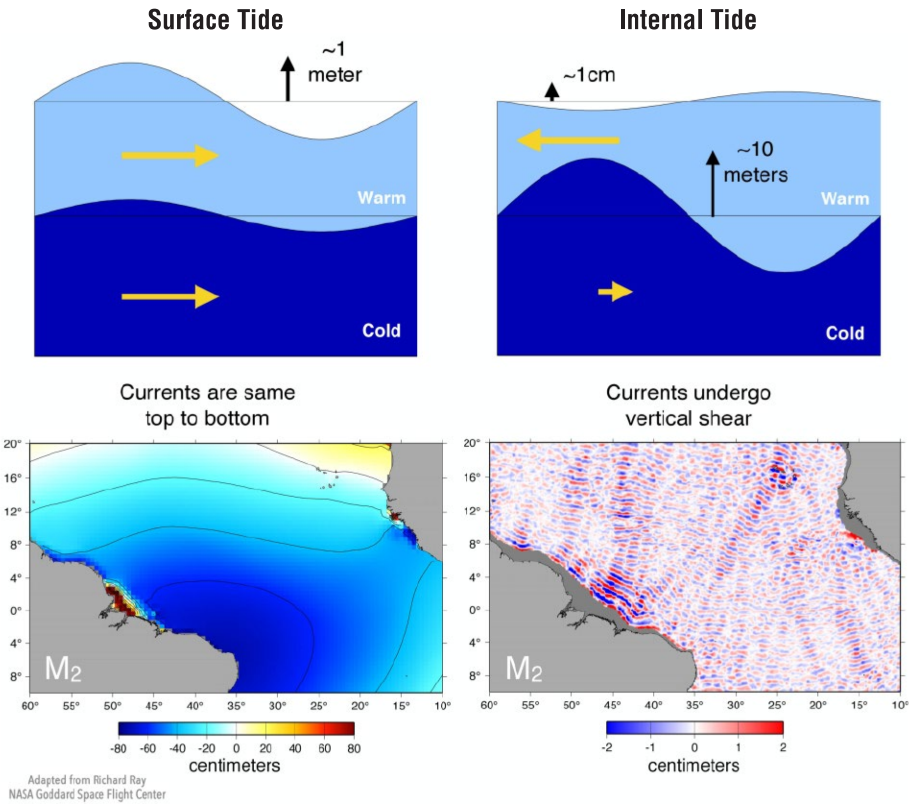

Figure 3. *Upper panels*: Cross-sectional depiction of surface tides [*left*] and internal tides [*right*]. Surface tides change sea level about 1 m (3.3 ft) in the open ocean. They have been modeled well using altimetry data. Internal tides are complicated by vertical shear in the ocean; they change sea level a few centimeters in the open ocean. It is anticipated that SWOT will be able to observe SSH caused by internal tides. *Lower panels*: Snapshot views showing associated SSH impacts of one tidal constituent (M_2) in the Atlantic Ocean (South America is at lower left; Africa is at upper right). **Image credit:** NASA's Goddard Space Flight Center

The finer scale SSH data to be obtained by SWOT will also include some high-frequency signals that present both an opportunity and challenge for oceanographers. The decades-long record of SSH from ocean altimeters (e.g., TOPEX/Poseidon and the Jason series) has been combined with computer models that can reliably predict surface tides with high accuracy, particularly between the latitudes covered by these missions (66° N to 66° S). However, as opposed to surface tides that alter SSH on the order of 1 m (3.3 ft) in the open ocean, internal tides create complicated fine-scale signatures while affecting SSH by only a few centimeters—see **Figure 3**. The SWOT orbit was chosen to mitigate some internal tide issues; nonetheless, many members of the Science Team are using high-resolution, high-frequency ocean general-circulation models and other methodologies to develop approaches to deal with internal tides and other high-frequency motions in SWOT SSH data.

For hydrologists, a key update delivered during the meeting concerned a comprehensive verbal report[5] on a study carried out by JPL on possible *layover* impacts on SWOT data, an item of potential concern. Layover in SAR data occurs when topographic variations cause multiple radar pulse echoes from different parts of a target surface to arrive simultaneously at a receiver, thus becoming indistinguishable from one another—see **Figure 4**. Layover is largely determined by viewing geometry and cannot be feasibly mitigated by changes in instrument hardware or algorithm design. Moreover, assessing layover impact on continental-to-global scales through direct simulation is not possible because of a lack of high-fidelity digital elevation models (DEMs). Instead, using available DEMs, scientists and engineers from JPL developed and validated a conceptual model for predicting layover errors in SWOT data as a function of topographic variability. Members of the Science

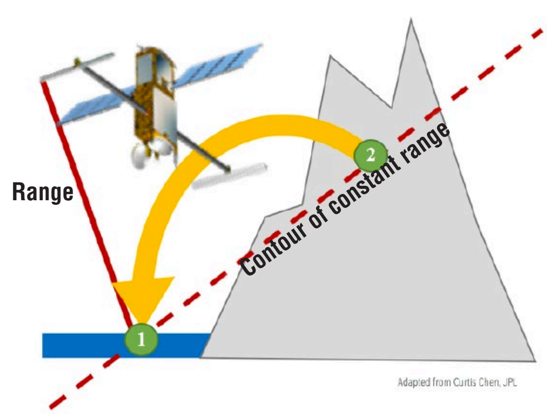

Figure 4. *Depiction of KaRIn layover issue.* (1) Desired radar echo from water surface (intersection of solid and dashed lines near arrowhead) could arrive simultaneously with (2) undesired echo from high topography (intersection of the dashed contour line of constant range and end of the curved arrow). In this case, the desired and undesired echoes would be indistinguishable from one another. The arrow indicates how data from position (2) can appear to be "laid over" data from position (1). **Image credit:** NASA/Jet Propulsion Laboratory

[5] To view slides from this report, visit *https://spark.adobe.com/page/RoNb1GpyhcBsJ*.

Team then implemented this model globally. Key findings from the study showed that:

- Layover will cause primarily random errors (i.e., biases will be small);
- magnitude of errors due to layover will be significant at times but rarely dominating (since, in SWOT data, land is usually much darker than water);
- layover errors will vary geographically (i.e., from site to site); and
- overall, layover effects will be widespread but with relatively low magnitude.

Another important outcome for hydrology was the participation of AirSWOT—an aircraft-mounted interferometer meant to simulate SWOT—in NASA's Arctic-Boreal Vulnerability Experiment (ABoVE)[6] campaign. This calibration/validation effort was conducted during summer 2017, with AirSWOT collecting data over 28,000 km (17,400 mi) of flight lines in the U.S. and Canada. These data included observations of over 40,000 Landsat-observable water bodies, providing valuable scientific insights into anticipated SWOT capabilities and error characteristics.

Good progress is being made toward global-coverage river and lake *a priori* datasets, which are needed to facilitate analysis of raw SWOT data. The datasets are expected to be finalized in about two years. Results from the current database of large rivers, Global River Widths from Landsat (GRWL), were recently published in *Science*—see **Figure 5** for an example of GRWL output. Co-authored by SWOT Hydrology Lead **Tamlin Pavelsky**, the study determined that global river and stream surface area is about 45% greater than indicated by previous studies. These findings may change our understanding of the importance of streams and rivers in exchanging greenhouse gases with the atmosphere.

Next Steps

In anticipation of launch in 2021, the third SWOT Science Team Meeting demonstrated a high degree of coordination and interaction among the investigation teams and with SWOT Mission staff members across the participating countries. Many activities over the next year will focus on calibration/validation efforts, including ocean field campaigns located at targeted SWOT orbit cross-over locations. In parallel, efforts to assess relevant global oceanographic and hydrodynamic computer models, simulate (and then assimilate) SWOT observations, refine data-processing algorithms (e.g., lake-storage change, ice flagging) and products, and engage potential SWOT data users will continue in earnest.

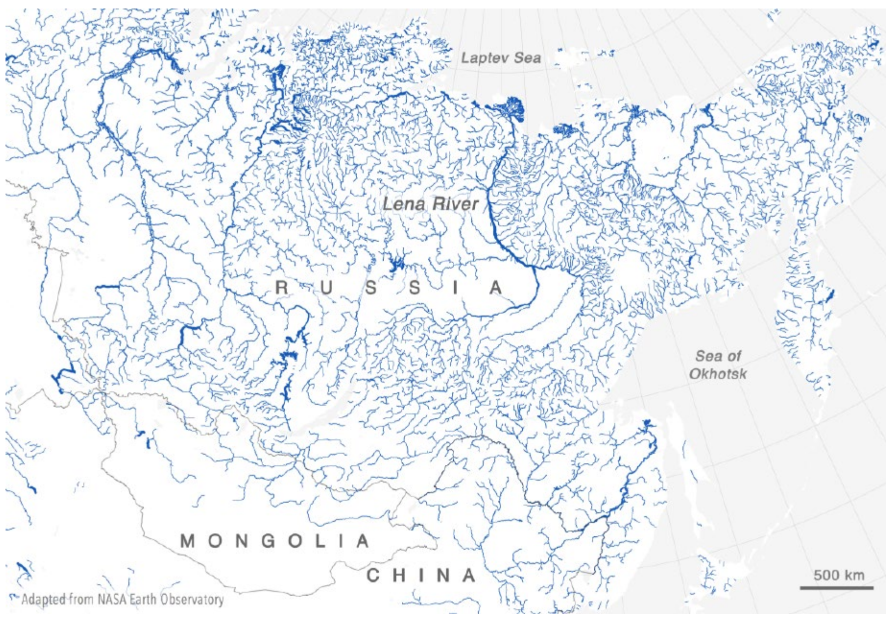

Figure 5. GRWL database plot for northeastern Asia. In this image, the width of a river—for example the Lena River in Russia—is depicted by the width of the line. Most of the area of a river network is comprised of smaller tributaries that feed the main stem. **Image credit:** NASA's Earth Observatory

[6]ABoVE is a NASA Terrestrial Ecology Program field campaign in Alaska and Western Canada. ABoVE is a large-scale study of environmental change and its implications for social-ecological systems. To read about the most recent ABoVE Science Team meeting, see the May–June 2018 issue of *The Earth Observer* [**Volume 30, Issue 3**, pp, 28-30—*https://eospso.gsfc.nasa.gov/sites/default/files/eo_pdfs/May-June%202018%20color%20508.pdf#page=28*]. To learn more about ABoVE, visit *https://above.nasa.gov*.

The next SWOT Science Team Meeting will likely be held in Europe during the last two weeks of June 2019. ■