ENGAGING THE USER COMMUNITY FOR ADVANCING SOCIETAL APPLICATIONS OF THE SURFACE WATER OCEAN TOPOGRAPHY MISSION

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Scheduled for launch in 2021, the Surface Water and Ocean Topography (SWOT) mission will be a truly unique mission that will provide high-temporal-frequency maps of surface water extents and elevation variations of global water bodies (lakes/reservoirs, rivers, estuaries, oceans, and sea ice) at higher spatial resolution than is available with current technologies (Biancamaria et al. 2016; Alsdorf et al. 2007). The primary instrument on SWOT is based on a Ka-band radar interferometer (KaRIN), which uses radar interferometery technology. The satellite will fly two radar antennas at either end of a 10-m (33 ft) mast, allowing it to measure the elevation of the surface along a 120-km (75 mi)-wide swath below. The availability of high-frequency and high-resolution maps of elevations and extents for surface water bodies and oceans will present unique opportunities to address numerous societally relevant challenges around the globe (Srinivasan et al. 2015). These opportunities may include such diverse and far-ranging applications as fisheries management, flood inundation mapping/risk mitigation/forecasting, wildlife conservation, global data assimilation for improving forecast of ocean tides and weather, reservoir management, climate change impacts and adaptation, and river discharge estimation, among others.

Although SWOT is a research mission and not scheduled for launch for another 4 years, there is a need to build engagement within the application community now and to explore how best to

SECOND SWOT APPLICATION USER WORKSHOP: ENGAGING THE USER COMMUNITY FOR ADVANCING SOCIETAL APPLICATIONS OF THE SURFACE WATER OCEAN TOPOGRAPHY MISSION

What: A workshop was organized to explore how best to maximize the user readiness of data from the Surface Water and Ocean Topography (SWOT) mission after its planned launch in 2021.
When: 5–6 April 2017
Where: U.S. Geological Survey Headquarters, Reston, Virginia

advance the societal relevance and benefits of the SWOT mission from concept to reality. The SWOT Applications Working Group organized a workshop on 5–6 April 2017 at the U.S. Geological Survey (USGS) headquarters in Reston, Virginia. The goal of the workshop was to understand and communicate how the applications community can use SWOT data to address problems of profound societal relevance.

Key workshop questions. The questions that the workshop was developed to answer were as follows:

- What are the specific surface water–related applications that users and stakeholder agencies administer that can benefit from high-frequency mapping of water elevations?
- What are the specific latency requirements of data products and information for an agency or user's application?
- Is there a specific latency of SWOT data products that can capture many, if not most, of the critical societal applications around the world?
- What does each stakeholder agency see as potential roadblocks to sustainable and organic uptake of SWOT data in its agency environment?
- What type of support would user organizations benefit from in terms of training and incubation of potential application ideas?

Although the workshop addressed various issues related to applications, the availability of SWOT data in near–real time (NRT)—within hours after acquisition—and short time critical (STC)—within 2 days of acquisition—was given particular emphasis as a topic in order to seek perspectives from the application and science communities.

Makeup of workshop participants. The workshop participants spanned numerous stakeholder agencies and organizations that frequently address water-related issues for decision-making. These entities represent a substantial cross section of the SWOT applications community. They included the U.S. Army Corps of Engineers (USACE), the U.S. Bureau of Reclamation (USBR), USGS, the Environmental Systems Research Institute (ESRI), the World Wildlife Fund (WWF), the U.S. Navy (USN), the Naval Research Laboratory (NRL), Mercator Ocean (France), Collecte Localisation Satellites (CLS), Indian Water Management Agencies represented by the Indian Institutes of Technology (IIT), the National Geospatial-Intelligence Agency (NGA), FM Global, and Météo-France. In addition, many scientists and program managers involved with the SWOT mission planning and scientific investigations also attended on-site or remotely to present information to stakeholder agency participants on the key features of the SWOT mission, and how it is intended to perform for matters related to water.

WORKSHOP DELIBERATIONS. Workshop organizers articulated the key objectives and goals of the workshop. SWOT project scientists then articulated the science objectives of the mission to provide

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DOI:10.1175/BAMS-D-17-0161.1

In final form 14 June 2017
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a context for the potential applications that are likely to be enabled by SWOT. The key unifying message from the welcome session was that SWOT is designed to enable unique scientific investigations over land, estuaries, and ocean. Representatives from the various stakeholder agencies provided their perspectives on the SWOT mission and how it is likely to be useful in their respective agency's missions. Each agency participant articulated key issues related to hurdles or roadblocks for sustainable uptake of SWOT data, support needs from the SWOT mission, and the specific applications of interest that SWOT data could drive. In the next section, we summarize a sample of stakeholder agency perspectives provided by the respective participants. These perspectives are a collection of thoughts and opinions by individuals, and with the exception of the USGS contributions, they are not necessarily the official agency positions on the SWOT mission.

A sample of stakeholder perspectives on the SWOT's application potential. U.S. Geological Survey. The official mission of the USGS is to "serve the Nation by providing reliable scientific information to describe and understand the Earth; minimize loss of life and property from natural disasters; manage water, biological, energy, and mineral resources; and enhance and protect our quality of life." SWOT may add value and synergy to current efforts of USGS in the following areas:

1) extension of the USGS stream gauge network via SWOT observations (and vice versa) using statistical "transfer" and blending methods; application of hydraulic routing and hydrologic modeling with SWOT data calibrated against USGS stream gauges and water-level monitoring locations; such data compilation could play a significant role in new USGS efforts toward "planning and implementing the next-generation integrated water observing system" through partnerships and increased USGS investments in remote sensing as described in the USGS strategic science directions plan for water (objective 1, strategic action 1; Evenson et al. 2012);
2) dynamic mapping of reach-scale river hydraulic characteristics—extensive mapping of channel pattern, water surface slope, water surface height, river flow resistance characteristics, and water surface extent;
3) dynamic mapping of river, lake, and wetland surface water extent and height; and
4) dynamic mapping of water extent and height in estuaries and along coastlines.

USGS participants stated that the SWOT-driven synergy with USGS will directly support large-scale, large-river flood mapping, fluvial transport, water quality, and ecological studies, particularly for international and remotely located streams, as found in U.S. regions like Alaska; support for many regional and most local needs will require increased resolution, generally finer than 100 m in stream width and, more likely, less than 50 m. In summary, USGS called for partnership with National Aeronautics and Space Administration (NASA) and others in the development of tools and datasets for dynamic mapping of surface water extent, river slopes, and hydraulic roughness at higher resolution than may be envisioned by many as adequate for the SWOT mission. Nonetheless, pursuit of such capabilities will be mutually beneficial and add to the greater good of society.

U.S. Bureau of Reclamation. The official mission of the USBR is to "manage, develop, and protect water and related resources in an environmentally and economically sound manner in the interest of the American public" (http://www.usbr.gov). Topics of direct relevance where SWOT may be useful for USBR mission are as follows:

1) improved prediction of reservoir evaporation;
2) expansion of streamflow gauges (including ungauged locations) and reservoir elevation information;
3) improved modeling and prediction of snowmelt runoff; and
4) data and information to support reservoir operations and long-term water supply planning.

USBR participant suggested the need for a Water Operations Working Group and holding workshops on SWOT data tutorials would be very timely for the SWOT mission to consider.

U.S. Army Corps of Engineers. The mission of USACE is to deliver "vital public and military engineering services; partnering in peace and war to strengthen our Nation's security, energize the economy and reduce risks from disasters" (http://www.usace.army.mil). SWOT data are expected to have direct value in calibration/validation of flood mapping tools [such as the widely used Hydrologic Engineering Center (HEC) River Analysis System (RAS) developed by USACE], coastal engineering, and reservoir sedimentation estimation. A USACE participant stated that it is important to partner with the following USACE

institutions by SWOT Science Team members in order to advance SWOT's application potential:

1) Hydrologic Engineering Center (developers of HEC RAS);
2) Engineer Research and Development Center (ERDC); and
3) Institute for Water Resources (IWR).

Mercator Ocean (France). Mercator Ocean is an entity that is engaged in providing ocean/marine services to various stakeholders. The foremost direct impact of SWOT is likely to be in improved constraint of ocean models at about 20-km scale as opposed to the current state of the art afforded by altimeters at scales of hundreds of kilometers. Such improvement would likely result in improved marine safety, pollution monitoring, ship routing, offshore operations and activities, coastal applications, and biogeochemical/biology applications. To realistically achieve such an impact, the following three key requirements were outlined for the SWOT mission:

1) a capability for near-real-time processing of SWOT data (<2 days) along with a need to define/refine required products and data latency requirements (trade-offs to be analyzed);
2) consistency with other altimeter missions (such as the European Space Agency's Sentinel series, the U.S.–European Jason series, and CryoSat) with cross-platform calibration applied in near–real time; and
3) assimilation of SWOT data in very high-resolution models and assessment of the added value of SWOT and data latency.

Collecte Localisation Satellites (France). CLS, a subsidiary of Centre National d'Études Spatiales (CNES; French Space Agency), ARDIAN (AXA private equity), and IFREMER (French Research Institute for the Exploitation of the Ocean), is a pioneer provider of monitoring and surveillance solutions for Earth since 1986. CLS has worldwide reach in the fields of sustainable fisheries management, energy and mining, space and ground applications, and environmental monitoring. It has a comprehensive data and information infrastructure in place where data from 130 satellites stream in daily for routine applications among five different processing centers (in France, the United States, Italy, and Spain). SWOT is therefore likely to be relevant in advancing offshore oil/gas exploration and sustainable fisheries management. The data from SWOT can potentially drive decision tools for fishing entities to optimize fishing activity, while a more accurate understanding of front and eddies could help maintain the safety of offshore infrastructure. New applications using future SWOT data flows are envisioned within CLS mainly for environmental monitoring.

U.S. Navy. The USN operates globally and is supported by ocean forecasting at global and regional scales. The unprecedented SWOT resolution and coverage in both space and time could enable the USN to predict fine ocean and sea ice features that are unresolvable or unavailable in its existing models. It was therefore very clear that SWOT data, made available in NRT, would improve models and products used by the USN, informing decision-making and enhancing fleet safety. Furthermore, the estimate of freshwater entering the coastal ocean is of particular relevance at all scales of naval ocean forecasting. SWOT-derived estimates of river discharge and land-margin water storage will inform hydrologic overland flow and routing models that bring freshwater into the ocean models at various scales.

Indian Institutes of Technology (India). The interests of Indian water management stakeholders were represented by members of the India Institutes of Technology. The following applications of SWOT data toward improving water management in India were outlined:

1) provision of real-time streamflow measures;
2) conjunctive use of ground and surface water;
3) characterizing profiles of water density to understand surface and subsurface ocean dynamics for coastal applications;
4) integration of surface water–groundwater modeling for improved groundwater and agricultural management; and
5) supporting surface water storage prediction to improve predictions of future surface and groundwater inventory for India.

U.S. National Geospatial-Intelligence Agency. Because of the focus on global water and food security, SWOT would have direct relevance to the NGA's mission on reservoir monitoring and how that could help flood, water, and agricultural management downstream. SWOT will be relevant to the NGA mission for building long-term water budgets and for quantification of uncertainty in remote or ungauged locations.

FM Global. As a commercial and industrial property insurer, FM Global collaborates with academia

and the risk reduction community. On the topic of flooding, the key attributes and relevance of SWOT data and information products for the insurance industry are inundation extent and water elevation. In addition, high-frequency data from SWOT could help calibrate flood inundation models.

World Wildlife Fund. As a nongovernmental organization, the WWF works to challenge the threats to nature and to ensure a sustainable future for both people and nature. SWOT is an innovative response that could potentially help the WWF to more accurately quantify floodplain and other inland water habitat extent as well as water availability in the rivers of the world at high frequency, especially in places where data scarcity is a constraint. Potential applications include informing environmental flow determinations in ungauged rivers and monitoring the status of habitat extent or other water-related indicators.

Toward consensus on an application agenda for the SWOT mission. As the workshop drew to a close, a discussion was held to summarize the issues raised and discussed by stakeholder agency participants. This discussion was centered on the workshop goals to clarify the following challenges of making SWOT data and information products widely available to stakeholders:

1) roadblocks to sustainable use of SWOT data in the end-user environment;
2) needs from the application community to make SWOT as user ready as possible; and
3) SWOT data latency.

All participants were provided a three-question survey (aligned to the three issues above) before the final discussion period of the workshop. The next section provides a summary of the responses.

WORKSHOP FINDINGS. The survey responses received from participants on the topic of applications that the SWOT mission would enable or improve revealed a clear clustering of ideas around specific themes. These themes were 1) disaster response and management, 2) water resources management, and 3) ocean and estuarine applications. A synopsis of the perspectives shared by participants on each of these themes is outlined below.

Stakeholder input on applications enabled by the SWOT mission. Disaster response and management. SWOT can potentially help with flood mapping/modeling. Real-time flood mapping would require NRT products, although development of better flood inundation and hydrodynamic models does not have latency requirements. Coastal flooding/storm surge is also a fruitful application to pursue given the value that SWOT's wide-swath altimetry measurement could add to existing applications (both in NRT and postevent analysis).

Water resources management. Reservoir level and water storage measurements are key products for water security/resources that SWOT data would enable and therefore must be pursued. Using SWOT to develop better global river models will also help with understanding of water resources. While many aspects of water management at seasonal or annual planning scales are not NRT critical, availability of NRT products will certainly open new vistas of innovative water management for many large stakeholder agencies.

Ocean applications/estuarine applications. SWOT data will be useful for marine safety, transport, and pollution management. SWOT's capabilities will be particularly important in coastal environments and at river-coastal interfaces. SWOT data can both force and constrain navy coastal ocean forecast models. Sea ice forecast models are also a potential application of SWOT, as are ocean acoustics and derived bathymetry.

Stakeholder input on SWOT data latency and format. There is tremendous demand and interest in an NRT/STC product, with latencies desired between less than 1 and 5 days. Data latency of less than 2 days was the most commonly requested product. It should be noted that there are many applications that are not latency critical. A wide range of data formats appeared to be acceptable given the versatility of today's data processing tools. NetCDF, Georeferenced Tagged Image File Format (GeoTIFF), and vector and gridded raster formats were more popular.

Needs of application stakeholder community from the SWOT mission. Education and outreach workshops are very important. Tutorials involving example datasets and real-world case studies are needed for the application community to understand how SWOT data can be used in actual practice by stakeholders. Such education and training should be aimed at users with backgrounds ranging from relatively nonexpert to expert. In addition, multiple languages (beyond English) should to be considered for reaching out to application communities worldwide. Such effort

should have close coordination with the SWOT Science Team/Principal Investigators (PIs) project, and the NASA Applied Remote Sensing Training (ARSET) program could play an important role. Accessing locations of SWOT-observable features would be very useful.

CONCLUSIONS. The three key take-home messages extracted from this workshop are as follows:

1) SWOT data availability at a latency of less than 2 days has overwhelming demand and critical societal need, wherein a compromise between accuracy and latency appears widely acceptable.
2) While the availability of NRT SWOT data will spur the most innovative societal applications and significantly improve many current operational applications, SWOT data, regardless of latency, will remain valuable for retrospective (postevent) analysis, model calibration and development, large-scale basin or ecological management, and policy formulation.
3) The SWOT mission needs to engage with its application community now to provide education and training on data products, uncertainty, access for various levels of expertise among users (layman, beginners, and advanced), and in multiple languages and formats (in person, online, and multimedia tutorials).

More information on the SWOT mission is available online (see https://swot.jpl.nasa.gov/ or https://swot.cnes.fr/en/SWOT/index.htm). SWOT is a planned satellite mission at this time, and the information contained in this paper should therefore be used for planning and discussion purposes only.

ACKNOWLEDGMENTS. Margaret Srinivasan, Lee-Lueng Fu, Jessica Hausman, Shailen Desai, Phil Calahan, Rashied Amini, and Cédric H. David are supported by the Jet Propulsion Laboratory, California Institute of Technology, under a contract with the U.S. National Aeronautics and Space Administration.

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