

Engaging the User Community for Advancing Societal Applications of the Surface Water Ocean Topography (SWOT) mission

2nd SWOT Application User Workshop

April 5-6, 2017

United States Geological Survey HQ, Reston, Virginia

WORKSHOP REPORT

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Summary

During April 5-6, 2017, a workshop was organized at the United States Geological Survey (USGS) headquarters (HQ) in Reston (Virginia) on the application potential of the planned Surface Water and Ocean Topography (SWOT) mission. SWOT is a research satellite mission jointly developed by NASA, the French space agency (CNES), with participation from the Canadian and UK space agencies to serve both the hydrology and oceanography communities. The workshop was organized by the SWOT Application Working Group (SAWG) leads comprising Margaret Srinivasan (NASA JPL), Alice Andral (CNES), Craig Peterson (NASA Stennis), Ed Beighley (Northeastern University) and Faisal Hossain (University of Washington) with support provided by French Space Agency (CNES) SWOT Program Manager Selma Cherchali and NASA Applied Sciences SWOT Applications and Water Resources program manager Bradley Doorn. This is the second such application workshop organized by SAWG to explore how best to maximize the user-readiness of the SWOT data after launch in 2021. Thus, the workshop was appropriately titled “*2nd SWOT Application User Workshop: Engaging the User Community for Advancing Societal Applications of the Surface Water Ocean Topography (SWOT) mission.*” More than fifty participants attended the workshop over the period of two days with many attending remotely as time permitted. These participants represented various stakeholder agencies from the public and private sector that deal with water issues such as U.S. Army Corps of Engineers (USACE), US Bureau of Reclamation (USBR), USGS, US Naval Research Laboratory (NRL), Radiance Technologies Inc., Mercator, Environmental Systems Research Institute (ESRI), World Wildlife Fund for US (WWFUS), SERVIR, Indian Institute of Technology (IIT), Collecte Localisation Satellites (CLS) and FM Global. Several participants from the NASA and CNES SWOT Mission HQ and SWOT Science Team (ST) were also present to foster an engagement with the application community and address their questions. Thirty-six presentations were delivered over five sessions in two days. The workshop culminated in a discussion session leading to a consensus-building agenda to advance SWOT’s application potential. This agenda was developed through questionnaires provided to participants, organizing the survey responses into actionable items and finally voting to accept the final draft as a guidance document to follow in future. While the agenda developed is quite comprehensive, the three key take home messages extracted from this workshop are:

- i) 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.
- ii) While the availability of SWOT data in near real-time (NRT) will spur the most innovative societal applications and significantly improve many current operational applications, SWOT data regardless of latency will remain valuable for retrospective (post-event) analysis, large-scale basin or ecological management and policy formulation.
- iii) The SWOT mission needs to coordinate activities that will engage with application community to provide simulated data products, education and training on data, uncertainty, access for various levels of expertise among users and in multiple languages and formats.

INTRODUCTION

MOTIVATION FOR THE WORKSHOP

Scheduled for launch in 2021, the Surface Water and Ocean Topography (SWOT) mission will be truly a unique, pathfinder mission that will provide high frequency maps of the surface elevations of water bodies (lakes/reservoirs, rivers, estuaries, oceans, sea and land ice) globally and at higher spatial resolution than is available with current technologies. The availability of high frequency and high-resolution maps of elevations for surface water bodies and oceans now presents the applications community with unique opportunities to solve numerous societally relevant challenges around the globe. These may include such diverse and far ranging issues as fisheries management, flood inundation mapping/risk mitigation/forecasting, wild life conservation, global data assimilation for improving forecast of ocean tides and weather, reservoir management, climate change impacts and adaptation, and river discharge estimation, just to name a few.

Although SWOT is a research mission and not scheduled for launch for another four years, work by SWOT Application Group (SAWG) to build strong engagement with the applications community is in full force. This workshop was planned to allow us to understand how we, as a community, can move forward to underscore the profound societal relevance of the SWOT mission. In an online survey of users carried out by SAWG in early 2016 (before the workshop), the community's need for SWOT data for various societal applications was overwhelming. Fifty percent or more of those surveyed indicated the need to have SWOT data within seven days or less of the satellite overpass with many indicating their unique preference for much shorter latencies, data format, structure and access.

AIMS AND KEY WORKSHOP QUESTIONS

The workshop aimed to build on the information learned in the survey, and to seek answers to specific and important questions that can provide actionable guidance for maximizing SWOT's societal impact. Key questions include;

- *What are the specific applications that stakeholder agencies/users need to carry out on water issues that can benefit from high frequency mapping of water elevations?*
- *What are specific latency requirement of such data for an agency's application?*
- *How compelling in terms of beneficial impact (economics, quality of life improved) is the availability of SWOT data products in near real-time?*
- *Is there a specific latency of SWOT data products that can capture most, if not all, of critical societal applications around the world?*
- *What does each stakeholder agency see as potential roadblocks to sustainable and organic uptake of SWOT data in their agency environment?*
- *What type of support would they like the SWOT mission to provide in terms of training and incubation of potential application ideas?*

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Although the workshop addressed various issues related to application, the availability of near real-time (NRT), or short time-critical (STC), SWOT data was given particular emphasis as a topic to seek perspectives on from the application and science communities. It should be mentioned that clear consensus was achieved on the importance of NRT data for advancing SWOT’s societal relevance (see “Workshop Findings”).

GOALS OF THE WORKSHOP

The workshop had two key goals, as follows:

Goal 1: Document the feedback and interaction for SWOT along the following themes:

1. Priority societal applications by each stakeholder agency where SWOT data is required or may significantly improve applications.
2. Specific support stakeholder agencies would like to have in terms of data access, usage, and training to allow sustainable uptake of SWOT data for societal applications.
3. Prioritization of action items during 2017-2021 for SAWG and SWOT mission that would help further the engagement with potential stakeholder agencies.

Goal 2: Document the above feedback into wide-audience forums for the application community.

MAKE UP OF WORKSHOP PARTICIPANTS

Table below provides a distribution of participants according to their parent organization.

Participating Agency/Institution	Name	Participating Agency/Institution	Name
NASA HQ	Bradley Doorn	NASA HQ	Eric Lindstrom
USBR	Subhrendu Gangopadhyay	CNES	Selma Cherchali
USGS	John Fulton	CNES	Nicolas Picot
USGS	David Bjerklie	CERFACS	Sophie Ricci
USGS	John Jones	LEGOS	Adrien Paris
USGS	Robert Mason	University of Rouen	Benoit Laignel
USACE	Jeff Arnold	JPL	Cedric David
USACE	Chris Frans	University of Massachusetts	Colin Gleason
Remote Sensing Solutions Inc.	Guy Schumann	Northeastern University	Ed Beighley
University of Maryland-ESSIC	Charon Birkett	University of Washington	Faisal Hossain
FM Global	Yasir Kaheil	UNC Chapel Hill	Tamlin Pavelsky
IIT Kharagpur India	Abhijit Mukherjee	JPL	Lee-Lueng Fu
IIT Bombay India	Subimal Ghosh	NASA ARSET Program	Amita Mehta
World Wildlife Fund for US	Jorge Escurra	JPL	Diane Evans
SERVIR NASA-USAID	Eric Anderson	SAWG Lead/JPL	Margaret Srinivasan

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Participating Agency/Institution	Name	Participating Agency/Institution	Name
Naval Research Lab (NRL)	Li Li	SAWG Lead/SSC	Craig Peterson
NRL	Gregg Jacobs	SAWG Lead/CNES	Alice Andral
Radiance Technologies Inc.	Eric Trehubenko	JPL	Jessica Hausman
NGA	Anthony (Tony) Nguy-Robertson	JPL	Amini Rashied
NRL	Cheryl Ann Blain	JPL	Phil Callahan
CLS	Fabien Lefèvre	JPL	Shailen Desai
ESRI	Sudhir Shrestha	JPL	Annette deCharon
Mercator Ocean	Pierre-Yves Le Traon	Colorado University	Toby Minnear
US Navy	Mark Middlebusher	IRD	Marielle Gosset
ESRI	Charles Tripp Corbett	Meteo-France	Patrick Le Moigne



Figure 1. Group picture of participants at the 2nd SWOT Application User Workshop in USGS HQ in Reston, VA, taken on April 5, 2017.

During the planning stages of the workshop between December 2016 and April 2017, the organizers from SAWG had communicated to the participants a draft agenda with the above goals and motivation. In

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addition, the following was also articulated to encourage stakeholder participants to be proactively involved in furthering the application agenda of the SWOT mission:

“How can you contribute to the SWOT mission and positively impact societal applications?”

As the SWOT mission moves through mission development, you can engage your communities of practice, communicate SWOT data products, communicate science advances, identify, highlight and work with applications of high potential and become or identify initial Early Adopters to further develop the SWOT Early Adopter Program. The SWOT Early Adopter program is a mechanism where you can stay engaged with the SWOT mission and co-design societally relevant applications for your agency’s needs. You can also help identify opportunities and needs for additional SWOT user workshops and Tutorial Workshops and Short Courses on SWOT data. You can articulate your application’s priority requirements for SWOT data and data delivery so the SWOT mission can enable meaningful and high impact applications for your agency.”

All participants representing various stakeholder agencies were also provided with a template for their presentation and were encouraged to follow it loosely. This template provided further background on the planned SWOT mission, its science requirements/objectives and key topics that each presenter should present to align their talk along workshop objectives. The whole idea was to help participants attend the workshop with a basic awareness and understanding of what SWOT mission can or cannot do as a sensor and thus contribute deeply to the workshop goals through presentations and discussion.

WORKSHOP AGENDA

DAY 1 (8.30AM-5.30PM) – April 5, 2017

Presentations are available at

<https://www.dropbox.com/sh/bxg00uxseckhebo/AABbzZwqpL7FaIzndRLoiX8Ya?dl=0> *These presentations may not be reposted on a public site without the explicit permission of the primary author*

8.30AM-9.30AM

Greetings: *Why are we gathered here today?* – Faisal Hossain/Margaret/Ed/Craig/Alice (10 min)

Welcome Message from NASA Applied Sciences Program – Bradley Doorn (5 min)

Welcome Message from CNES and NASA on SWOT project - The potential of the SWOT mission for applications: a unique opportunity – Selma Cherchali and Eric Lindstrom (15 min)

Welcome Message from SWOT Science Team– Tamlin Pavelsky and Nicolas Picot (10 min)

Welcome Message from SWOT Mission Project and SWOT 101 – Lee-Lueng Fu, JPL (25 min)

9.35 AM- 11.20AM

Societal Applications of Relevance to the SWOT Mission (1 hour 40 mins)

Hydrology (Overland) Applications (50 minutes)

1. Charon Birkett, University of Maryland (10 min) - *Monitoring of Lakes, Reservoirs and Wetlands for Water resources, Agriculture, and Fisheries*
2. Marielle Gosset, IRD (10 min) - *SWOT / GPM and flood forecasting – Towards a pilot site for the satellite based monitoring of Niger River floods in Niamey*
3. Adrien Paris, LEGOS (10 min)- *Near real-time discharge estimates from satellite altimetry in the tropical basins*

Q &A: 10 minutes

Oceanography (Ocean) Applications (40 minutes)

4. Gregg Jacobs, NRL (10 min) – *Exploiting the SWOT Mission for Scientific Needs*
5. Fabien Lefevre, CLS (10 min)- *Ocean applications (fisheries, offshore) and SWOT Perspectives*
6. Benoit Laignel, University of Rouen (10 min) - *issues and applications of SWOT in the coastal and estuarine environments* (presented by Alice Andral)
7. Li Li, NRL (10 min) - *How SWOT could be used to Improve the U.S. Navy's Sea Ice Forecasting Capabilities?*

11.20 AM- 11.45 AM Coffee Break and Q&A

11.45AM-1.00PM Emerging Applications in the context of the SWOT mission (1 hour 10 minutes)

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1. Colin Gleason, University of Massachusetts (10 min) - *SWOT and River Discharge: What we do, don't, and need to know* (Remote presentation)
2. Pierre-Yves Letraon, Mercator (10 min)- *Expected impact of SWOT in Mercator Ocean analysis and forecasting systems*
3. Faisal Hossain, University of Washington (10 min) -*Residence Time and Flow Alteration of River Basins by Dams: Developing a SWOT-based System for the Mekong*
4. Guy Schumann, Remote Sensing Solutions (10 min) -*SWOT potential to assist Flood Inundation Mapping and Modeling at the Global Scale*
5. Cedric David, UC Irvine (10 min) -*Preparing for the integration of SWOT measurements into global terrestrial hydrologic models* (Remote presentation)
6. Sophie Ricci, Cerfacs (10 min)- *SWOT Assimilation Combining SWOT data and Numerical models with Data Assimilation methods for a better Simulation and Forecast of Water level and Discharge*
7. Patrick Le Moigne, CNRM (10 min)- *Preparing Strategies to optimally use SWOT measurements in order to Improve the Global Hydrological Cycle including lakes and reservoirs*
8. Ed Beighley, Northeastern University (10 min)- *Characterizing Regulated Reservoirs Dynamics in Regional to Global-scale Hydrologic Models*

1.00PM -2.00PM –LUNCH

2.00PM-4.00PM – Stakeholder Agency/User Perspective in the Context of SWOT's Application Readiness

15 Min presentations for each agency + 2 mins Q&A per talk (17 mins)

1. United States Geological Survey (Robert Mason) – *SWOT Mission and the USGS* (15 min)
2. United States Bureau of Reclamation (Subhrendu Gangopadhyay) – *USBR Operations in the context of the SWOT Mission* (15 min) (remote presentation)
3. US Army Corps of Engineers (Jeff Arnold) – *The Climate Preparedness and Resilience programs of USACE for Water Resources Infrastructure* (15 min)
4. US Army Corps of Engineers (Chris Frans) – *Potential applications of SWOT to support USACE missions* (15 min)
5. MERCATOR OCEAN (Pierre-Yves Letraon) - *Use of SWOT data for the Copernicus Marine Environment Monitoring Service and its applications* (15 min)
6. CLS (Fabien Lefevre) - *Water Resources Management and the Use of Satellites* (15 min)
7. Radiance Technologies, Inc. (Eric Trehubenko) - *Satellite Altimetry - U.S. Navy Operational Use* (15 min)

4.00PM – 4.15 PM Coffee Break

4.15PM-5.30PM DISCUSSION: User Feedback on applications, needs, latency, roadblocks, impact (of SWOT data)

DAY 2 (8.30AM-5.30PM) APRIL 6, 2017

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8.30AM-8.45AM

Overview of First Day activities and accomplishment; any issue left over from yesterday (15 mins)
Faisal/Ed/Margaret/Craig/Alice

8.45AM -10.45PM – Stakeholder Agency/User Perspective in the Context of SWOT’s Application Readiness (Contd. from Day 1 afternoon session)

Stakeholder agency perspective (15 min each+ 2 min Q and A)

1. FM Global (Yasir Kaheil) -*The Global Flood Hazard Model and its Application in SWOT-era* (15 min)
2. Indian Institute of Technology (Subimal Ghosh) -*Understanding Water Cycle and Hydrologic Forecasting in Data Scarce Indian River basins* (Remote Presentation) (15 min)
3. Indian Institute of Technology (Abhijit Mukherjee) *Sensing of Flood Discharges and low Flows for Indian rivers: a Collaborative exercise with SWOT data* (15 min)
4. National Geospatial-Intelligence Agency (Anthony Nguy-Robertson) – *NGA Water Security Applications* (Remote Presentation) (15 min)
5. Worldwide Fund for US (Jorge Escurra) – *Use of Satellite Information for the Development of Report Cards* (15 min)
6. SERVIR (Eric Anderson)- *Capacity Building for SWOT in the Developing World* (15 min)
7. GEOGLOWS (Bradley Doorn and Selma Cherchali) – *Overview of GEOGLOWS Program and Implications for the SWOT Mission* (15 min)

10.45AM-11.15AM Discussion on GEOGLOWS and Coffee Break

11.15AM – 12.30PM - DISCUSSION User Feedback on applications, needs, latency, roadblocks, impact (of SWOT data) [*Participants from Stakeholder agencies were asked to fill out a questionnaire form*]

12.30-1.30PM LUNCH

1.30-5.30PM DISCUSSION AND DOCUMENTING PARTICIPANT FEEDBACK

Compilation of survey results from workshop participants (both in-person and remote presenters)

WORKSHOP GOAL ONE (1.30-2.30PM)

Specific societal applications by each stakeholder where SWOT data is required or may significantly improve applications; its compelling societal impact as a function of availability and latency.

WORKSHOP GOAL TWO (2.30-3.30 PM)

Specific support stakeholder agencies would like to see in terms of data access, usage, and training to allow sustainable uptake of SWOT data for societal applications.

3.3.0PM-3.45PM Coffee Break: 15 minutes

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WORKSHOP GOAL THREE (4.45PM-5.30PM)

Prioritization of action items during 2017-2018-2021 by SWOT Application Working Group that would help further the engagement with potential stakeholder agencies (e.g. hold specific training workshop, tutorials, webinars, co-design solutions etc.)

5.30PM – Workshop Adjourned

WORKSHOP DELIBERATIONS

WELCOME SESSION

The workshop kicked off with SAWG leads presenting a welcome presentation titled “*Why are We Gathered Here Today?*” SAWG lead (Faisal Hossain) emphasized the key objectives and goals of the workshop (see page 3) and that SWOT was the satellite mission of interest. The presentation stressed that the meeting was tailored for building engagement with application community and the hope was that the engagement would only grow after the workshop was adjourned. The welcome session was then followed by messages from Bradley Doorn (Program Manager of NASA Applied Sciences Water Resources Program), Eric Lindstrom (Program Manager of Physical Oceanography and SWOT Science Program), Selma Cherchali (Program Manager of CNES), Tamlin Pavelsky (SWOT Science Hydrology Team Lead-US), Nicolas Picot (SWOT Algorithm Development Team lead-France). At the end, Dr. Lee-Lueng Fu (SWOT Science Team lead) presented an overview of the SWOT Mission Project for the audience (titled ‘SWOT 101’).

The key unifying message coming out of the welcome session was clear. SWOT is a pathfinder research mission designed to enable unique scientific investigations overland, estuaries and oceans for all things related to water on the earth’s surface. Because of the unique capability of SWOT to observe water extent and height simultaneously, the application potential was deemed equally unique and far-reaching. Selma Cherchali of CNES stated that SWOT would be an ambitious and challenging mission leading scientific innovation. She stressed that SWOT could have economic and social impact through development of new applications. She went on to lay out the French Investment Program and the firm commitment the French Government has made on realizing the application potential of SWOT mission. A SWOT preparatory program has already been outlined by CNES to help SWOT data users develop their own routine processes, support research laboratories, improve existing applications, create new services for coastal/estuarine regions and create new environmental services through an open data policy. In summary, Selma Cherchali stressed that a total and integrated system was required for SWOT for the hydrologic community “*based on the heritage of Ocean Community...and strengthen the ocean capabilities.*” Eric Lindstrom added information related to budget and programmatic elements of the SWOT mission from the NASA HQ perspective. He summed up by saying that the mission development was progressing smoothly and per schedule for a launch in 2021 A.D.

Tamlin Pavelsky with Nicolas Picot welcomed the participants with an overview of the makeup of Science Team leads and the coordination that currently exists with the SWOT Mission Program at JPL. Tamlin articulated the following fundamental questions for the participants from the application community to ponder on during the 2 days of the workshop:

What capabilities do SWOT data products need to have in order to serve my applications?

How will SWOT data product formats affect my ability to use those products?

How will the latency of SWOT data affect their usability for my applications?

How can I contribute to SWOT in ways that might result in improved data products? (for example, datasets for cal/val or algorithm testing)

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Lastly, Lee-Lueng Fu (SWOT Science Team lead) provided a comprehensive overview of the scientific and observational aspect of the SWOT mission as part of his welcome address. He broke down this overview into hydrology and ocean sciences and demonstrated the expected scientific benefits of SWOT's unique capability in the context of what is currently available from space platforms.



Left panel -Dr Lee-Lueng Fu from the SWOT Mission at JPL giving his welcome address with a SWOT 101 introduction; Right panel – the participants on Day 1 morning.

SOCIETAL APPLICATIONS OF RELEVANCE TO THE SWOT MISSION

The next session had five presenters planned. However, in the interest of time, two of the presenters (Faisal Hossain and Ed Beighley) presented their talks at a latter session before lunch. Charon Birkett presented the heritage of monitoring of lakes, reservoirs and wetlands for water resources, agriculture and fisheries management (known also as the G-REALM project). She provided examples of stakeholder requirements such as the need for real-time or near real-time (NRT) data access (hours to days delay) with at least one recorded water level per month at 10cm root mean-squared error (RMSE) accuracy. She stressed the need for data continuity across multiple altimetry missions and the need to be prepared for SWOT and upcoming water height measurement missions for enhanced reservoir applications. One of the participants (Rashied Amini of JPL) made the note that it would be worth exploring the return of investment in terms of societal impact for operational systems maintained by various institutions.

Marielle Gosset of IRD presented a potential application idea of combining the Global Precipitation Measurement (GPM) mission with SWOT to address flood forecasting applications in the Niger river basin. Given the transboundary issues, the frequent water excess (flooding) or shortage (droughts) and the unavailability of in-situ data faced by the riparian nations with high population, Marielle articulated a vision for an integrated system for monitoring of water resources from space for the Niger inhabitants. The hydrology topics of this session ended with the presentation by Adrien Paris (of IRD and LEGOS) who presented on the state of the art on NRT discharge estimation using altimetry. Because of the advancements made on discharge estimation using the classic Manning's equation and altimeter measurements, SWOT is likely to be a natural extension of this work through the availability of water heights from wide swath altimetry.

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Gregg Jacobs, head of Ocean Dynamics and Prediction Branch of NRL, delivered a talk titled, “*Exploiting the SWOT mission for Scientific Needs.*” Using the Gulf of Mexico as an example, he first showed what is currently being measured for oceans and how that enables scientific understanding of important phenomenon such as eddies, currents. While significant capability has already been built, current measurements remain inadequate for resolution of important features of the ocean of critical societal importance. Gregg argued that SWOT would be a game changer in this regard for the following key reasons:

- i) SWOT is a new instrument with a high potential to observe new physics in coordination with existing measurements.
- ii) SWOT will improve field campaigns and cal/val of models at sites where a particular ocean phenomenon is occurring.
- iii) SWOT data will help improve forecasts systems with further constraining of initial states.

Gregg likened SWOT to a new microscope in the sky watching water on planet earth. He opined that calling it just a wide-swath altimetry mission was an understatement. With such game changing observational capability, SWOT is likely to impact emergency response for events like Fukushima, Deep Water Horizon, Haiti Earthquake; improve commercial activities such as offshore drilling and sustainable fisheries management and strengthen environmental management of harmful algal blooms and hypoxia. Gregg demonstrated clear improvements in accuracy and feature delineation with the assimilation of SWOT data in near real time. In closing, he argued that the application community has to get prepared with knowledge about SWOT mission and example datasets; there needs to be wider access to SWOT Simulator and a better communication of the uncertainty. Finally, availability of SWOT data in NRT is critical for the mission to be identified as game changing.

Fabien Lefevre of CLS overviewed the ocean applications (e.g. fisheries and offshore) that are likely to be enabled during the SWOT era. He presented the worldwide reach of CLS in the fields of sustainable fisheries management, energy and mining, space and ground applications and environmental monitoring. It was noteworthy for participants to observe that CLS already has a well-resourced and comprehensive data and information infrastructure in place where data from 130 satellites stream in daily for routine applications among 5 different processing centers (in France, USA, Italy and Spain). In particular, SWOT appears highly 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.

Benoit Laignel, whose presentation was delivered by Alice Andral of CNES, provided a thorough overview of issues and applications of SWOT in coastal and estuarine environments. His presentation provided clear examples of the multi-scale utility of SWOT data (at port/harbor scale to city/regional scale) for a variety of hazards that built environment along the coast is exposed to.

Li Li of NRL discussed how SWOT’s observational capability could potentially improve current sea ice forecasting operations by the US Navy especially along the Marginal Ice Zone (MIZ). This is particularly important for shipping and various maritime/naval operations in the Arctic cap in the context of global

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warming. He stated that although ICESat-2 appears very promising in providing accurate sea ice forecast, it would have significant sampling gaps that could be filled with SWOT measurements. Li Li suggested the following: a) ice thickness/freeboard as a data product, b) coupling SWOT data in US Navy models for sea ice; c) development of better physics in sea ice models using the SWOT simulator and d) availability of SWOT data in NRT.



Leftmost panel – Robert Mason from USGS presenting the USGS perspective of SWOT mission; Middle panel – Gregg Jacobs from US Naval Research Laboratory presenting SWOT’s application potential for ocean applications; Rightmost panel – Jeffrey Arnold of US Army Corps of Engineers presenting USACE’s program on climate change adaptation.

During the coffee break and question and answer session, participants from stakeholder agencies had several questions based on the applied science oriented presentations in the preceding hydrology and ocean sessions. Highlights of this question and answer session are integrated in the section “Discussion of Day 1” on page 19.

EMERGING APPLICATIONS IN THE CONTEXT OF SWOT MISSION

The last session before lunch on Day 1 was dedicated for scientific research based findings for SWOT that have relevance for innovative applications. These were presentations primarily by the SWOT Science Team for the 2016-2020 timeframe to help the application community appreciate some of the innovative applications that are likely to be feasible after launch.

This session started with Colin Gleason of University of Massachusetts presenting about discharge algorithms tailored for SWOT observations. He focused particularly on the value of having algorithms for discharge that work purely on the basis of SWOT data given the lack of in-situ data and transboundary hurdles in the developing world. Faisal Hossain of University of Washington laid out the concept of ‘compound eye’ with the near-simultaneous use of sensor data from five different satellites to characterize reservoir behavior in the Mekong river basin. Using a combination of visible imagery for reservoir area extent, altimeter for height, precipitation data for hydrologic modeling of reservoir inflow, he presented how one could derive the reservoir rule curve without any in-situ data. The concept was presented in the context of the SWOT mission that is expected to further enhance such comprehensive monitoring of reservoir operations through the simultaneous availability of reservoir extent and height. Pierre Yves Le Traon of Mercator Ocean discussed the expected impact of SWOT mission for ocean analysis and forecasting systems. Compared to three nadir altimeters (i.e., present situation), a future system involving SWOT + three nadir altimeters was found to reduce five-day sea level forecast errors by about 30% and

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sea level analysis errors by about 45%. A clear take home message from this simulation exercise is that the availability of SWOT data in NRT (latency < two days) is essential to make the SWOT mission impactful for most ocean applications.

Sophie Ricci of CERFACS (France) presented a work titled “*Combining SWOT data and numerical models with Data Assimilation methods for better simulation and forecast of water level and discharge.*” Using data assimilation technique, she demonstrated the wide potential of SWOT data for recreating the most accurate hydrodynamic analysis of rivers and their floodplains for societal applications such as land zoning, flood risk management, insurance, urban planning etc. Guy Schumann of Remote Sensing Solutions overviewed SWOT’s potential for flood inundation mapping and modeling at the global scale. He stated that without the availability of data at latency shorter than twelve hours, SWOT will not be able to positively impact the management of disaster or its response given what is already available from space platforms. However, he noted that a longer latency data can drive the calibration and validation of a flood inundation mapping model at the global scale. In addition, several types of slow response flooding that typically occur in seasonal precipitation climates (such as South Asia) are believed to benefit from SWOT data at latencies longer than 5 days. There is currently an effort underway with Google and the Dartmouth Flood Observatory (i.e., University of Colorado, Boulder) to make preparations for SWOT mission.

Patrick LeMoigne of Meteo-France discussed strategies for optimal usage of SWOT data for the full hydrological and management assessment. He laid out procedures for data assimilation as well as development of appropriate modules for various stores of the water cycle (lakes, rivers, reservoirs). Finally, Cedric David of JPL showed specific simulation work on address the same thing. The specific questions of his presentation were:

What is the added value of including SWOT terrestrial measurements into global hydro models for enhancing our understanding of the terrestrial water cycle and the climate system?

Are current global hydrologic models ready to ingest expected SWOT data?

What SWOT variable(s) or SWOT-derived product(s) offer the best promise for integration and for data assimilation?

To address these critical questions for SWOT mission, the multi-team research consortium led by Cedric is taking a global view spanning numerous large river basins, simulated SWOT data and data assimilation techniques.

STAKEHOLDER AGENCY PERSPECTIVE OF THE SWOT’S APPLICATION POTENTIAL

Day 1 Afternoon

Once a wide-ranging overview of SWOT and its current and emerging application potential were presented by members from the science and applied science community, it was time for the application/stakeholder community to provide their perspectives on the SWOT mission. This was completed over two sessions, with the first one held after lunch on Day 1 and the second one held the morning after. The goal of these two sessions was to give the application community a strong voice in this process of how to make SWOT as user-ready as possible and to build the desired engagement after the

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workshop. The stakeholder agency participants loosely followed the template given to them so that their presentations were aligned to workshop goals as closely as possible.

This session started with Robert Mason of USGS presenting the USGS perspective on SWOT. He started with the overview of the agency and its role as the gatekeeper of measurements and records related to all things surface water. He placed particular emphasis on streamflow records that are essential to driving the mission of many large agencies such as USACE, USBR, NWS and EPA. Gaps were highlighted in current USGS network in terms of streams that are currently ‘missed’ by in-situ monitoring. Robert Mason provided clear topics on how SWOT could add value and synergy to current efforts of USGS as follows:

- a) Extension of SWOT network of discharge estimates (and vice versa for USGS) using current ‘transfer’ methods adopted by USGS; application hydraulic routing hydrologic modeling with SWOT data calibrated against USGS data at strategic locations (such as weirs and notches)
- b) 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
- c) Dynamic mapping of river, lake and wetland surface water extent and height

USGS believes that the above SWOT-driven synergy with USGS will directly support local, regional, and national scale flood mapping, fluvial transport, water-quality and ecological studies. It will also enhance gaging data and networks, filling gaps between gaging stations. A particularly unique point that was noted for SWOT’s application relevance is the USGS ability and protocol to rapidly deploy water level gauges/sensors during an impending landfall from a hurricane. Such an ability of USGS and the unique datasets that are generated from it can directly help improve SWOT data-based storm surge model (calibration/validation, physics improvement or even data assimilation). The critical importance of NRT data from SWOT was clear once again from this USGS presentation. In summary, Robert Mason stressed that the USGS and NASA need to partner development of tools and datasets for dynamic mapping of surface-water extent, river slopes, and hydraulic roughness that will be mutually beneficial and add to the greater good of society.

In the next talk, Subhrendu Gangopadhyay of USBR provided an overview of the agency and what it does as its mission to its stakeholders through the operation of 337 large reservoirs. With the current programs by USBR on basin scale planning, research and development, he articulated the following topics of direct relevance where SWOT could be potentially useful:

- a) Improved prediction of reservoir evaporation
- b) Expansion of streamflow gauges (including ungauged locations) and reservoir elevation information
- c) Improved modeling and prediction of snowmelt runoff via SWOT data-constrained models
- d) Data and information to support reservoir operations and long-term water supply planning

Subhrendu made the following support needs from the SWOT community for building engagement and making SWOT user-ready for the USBR mission:

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- a) Calibration and expansion of reservoir operations models to improve model accuracy related to managed releases, reservoir evaporation, predicted reservoir inflow, storage fluctuations, and reservoir system management (i.e. managed impacts across a river basin)
- b) Collaboration on information systems development to improve reservoir evaporation estimates that is interoperable with existing reservoir/basin models
- c) Coupling SWOT terrestrial surface water storage and river discharge information to link groundwater-surface water interactions to determine groundwater baseflow
- d) Assistance to determine the general format and availability of SWOT data into shorter term reservoir operations models and longer-term basin planning models

As a suggestion Subhrendu noted that a Water Operations Working Group comprising large operational water management agencies of the world and holding workshops on SWOT data, tutorials would be very timely for the SWOT Mission to consider.

Jeff Arnold presented the USACE perspective on how SWOT data can help USACE adapt to climate change. This was followed by Chris Frans (also from USACE), who presented on the potential applications of SWOT to support USACE missions. Chris first provided an overview of USACE activities of relevance to SWOT mission. The mission statement of USACE clearly indicates the important role SWOT data could play in building engagement:

“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.”

Because of USACE’s focus also on disasters (such as flood inundation), the value of NRT data from SWOT is very clear to the Army. SWOT data will have direct value in calibration/validation of flood mapping tools (such as the widely used HEC-River Analysis Software developed by USACE), coastal engineering and reservoir sedimentation estimation. These applications are not latency sensitive. For supporting real time operations of the USACE, a latency of less than 4-5 days would be useful in large basins such as the Columbia for improving currently adopted monitoring systems. Chris Frans also articulated the various and flexible data formats for SWOT data that would be acceptable for USACE operations. He stressed that for building deep engagement with USACE, it is important to partner with the following USACE institutions by SWOT Science Team:

- a) Hydrologic Engineering Center (HEC – developers of HEC RAS)
- b) Engineering Research and Development Center (ERDC)
- c) Institute of Water Resources

In summary, USACE noted that there exists high potential to use SWOT data for:

- i) Model refinement (such as HEC RAS and coastal inundation models)
- ii) Coastal design
- iii) Post-event inundation analyses

Although latency is a limitation for real or near real-time USACE applications that currently rely on a tele-connected network of observed data, SWOT data would bring tremendous utility if it is available in

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NRT (< 1 day). It was also noted that for USACE's overseas applications in data limited situations, latencies of a few days may be useful.

Pierre Yves Le Traon presented the use of SWOT data for the Copernicus Marine Service for societal applications. This information service coordinated by Mercator Ocean is already a very comprehensive system with more than nine thousand users and routinely ingests numerous satellites. It was very clear from this presentation that several ocean applications will benefit from the advent of SWOT data. The key contribution from SWOT will likely be to constrain models at small scales (<100-200 km) through data assimilation. These scales are currently not well-constrained by conventional altimeters. It was speculated that such improvement would likely result in improved marine safety, pollution monitoring, ship routing, newer offshore industry, coastal applications and biogeochemical/biology applications. To realistically achieve such an impact, the following three key requirements were outlined for the SWOT mission:

- i) A capability for near real-time processing of SWOT data (< 2 days). A need to define/refine required products and data latency requirements (trade-offs to be analyzed).
- ii) Consistency with other altimeter missions (such as Sentinels, Jason series) with cross platform calibration applied in near real time.
- iii) Assimilation of SWOT data in very high-resolution models and assessment of the added value of SWOT and data latency.

In conclusion, Pierre-Yves summarized that there are likely to be a wide range of ocean applications that will benefit from SWOT data and that these applications will be best served in conjunction with nadir altimeter missions. For a successful integration of SWOT data in Copernicus Marine Service to demonstrate wide range of ocean applications, the availability of data in near real-time will be essential.

Fabien Lefevre of CLS presented "*Satellite-based water resources management in the context of the SWOT mission.*" He overviewed a comprehensive vision for an architecture involving data streaming, modeling, dissemination, and capacity building for catering to various water management applications. This architecture will rely on Earth-Observation and, then, on space technology, complementary of in situ data and numerical modeling. Indeed, the use of satellite data is tremendous at the size of a basin-scale where water resource management must support a wide range of downstream applications (water distribution, irrigation, hydroelectricity, navigation, fisheries, ecosystem services, urban development). Satellite technologies provide more reliable and more comprehensive information to monitor our environment (zonal visibility, long-term monitoring, historical data, real-time monitoring). The use of SWOT will refine/ deliver new hydrological parameters for a better understand of water resources. Thus, dedicated applications will be improved, or even developed, in the field of water information databases, transboundary context, impact of climate change, natural hazards, water pollution, multiple water use, governance.

Eric Trehubenko of Radiance Technologies, Inc. overviewed the operations of Commander, Naval Meteorology and Oceanography Command (CNMOC) in the context of satellite altimetry missions and

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SWOT mission. CNMOC supports Navy operations globally, providing analyses and forecasts of the physical environment at global and regional scales. The current suite of nadir altimeter satellites already enables the derivation of products such as Sea-surface height (SSH) anomalies, wind/wave products, and various products that support warfighting applications. However, studies have shown that while minimum capability for the US Navy is achieved with two satellites, improved results are obtained with a minimum of four satellites, allowing for the analysis and prediction of smaller scale ocean features (< 10km scale). In summary, it was therefore very clear that SWOT data, should it be available in NRT, would improve models and products used by the US Navy, informing decision making and enhancing fleet safety.

Discussion of Day 1

As the first day drew to a close, Faisal Hossain led the discussion to recapitulate the issues raised and discussed by stakeholder agency participants. The discussion was led keeping in mind that the workshop aimed to define as outcomes the following:

- 1) The roadblocks to sustainable use of SWOT data in end user environment after launch
- 2) Needs from the application community to make SWOT as user-ready as possible
- 3) SWOT data latency

Starting backwards (item#3 above), it became abundantly clear to all participants that SWOT would need to provide its data at lowest latency possible to be game changing and innovative in realizing unique societal applications. While there exists a wide range of acceptable latency and the fact that SWOT data at high latency would retain value in many sectors (such as model calibration/validation, reservoir planning in large basins, analysis of river hydrodynamics for zoning/insurance/built-environment), all participants agreed that a latency of < 2 days at some reasonable coarseness in quality would be acceptable. Additional resources would be required to address the NRT data availability. Participants from the SWOT Mission team stated that there are several intrinsic factors that compound the availability of NRT data. For example, a SWOT overpass, even if its data was available instantaneously, would provide partial coverage of regional domain of interest. Many from the SWOT Mission opined that low latency data was technologically feasible. While several stakeholder participants indicated a wide range of latency (from 45 days to 3 days) as being acceptable for their needs, many noted that quick look product with even partial coverage with degraded accuracy (such as for large lakes) would be very useful. Faisal Hossain argued forcefully that the application community must voice strong and clear demand for NRT data rather than being equivocal. He stated that it is important to push the envelope on latency as much as possible in order to spur innovations that would be unique to the SWOT mission. Quoting Steve Jobs of Apple Inc. (*“People do not know what they want until they have seen it”*), Faisal opined that the availability of NRT data from the SWOT mission was critical to innovating societal applications that the community has not thought of yet. A suggestion was made that a sub-working group be formed spanning ocean and hydrology to explore the issues of complexities involving latency and provide a roadmap to the mission. Later, a decision was taken to have one of the SAWG Application Leads (Margaret Srinivasan) lead this sub-working group (see “Workshop Findings”).

For needs (item #2 above), the need to organize tutorials and more training workshops on the SWOT mission to help users understand the mission, physics, data products and uncertainty was a clear favorite.

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Many cited the need for student programs for internships/fellowships that would allow the next generation of end users and trainer workforce for the application community to become more proactively immersed in the SWOT data production/science environment. Many highlighted the need to communicate clearly the uncertainty associated with SWOT data and how that translated to risk in making decisions in the stakeholder agency environment. On the topic of roadblocks (item #1 above), timely access to and guidance on SWOT simulator, establishment of cal/val sites (for SWOT data) and user-friendliness of data hosting portals were cited as key.

Day 2 Morning

The first talk of the second day of the workshop was by Jorge Escurra who presented a perspective on the value of SWOT for ecosystem services and wildlife protection for the US Wildlife Fund. He stated that SWOT data could potentially help in developing the ecological (bio-diversity) report cards for each basin. Water storage capacity is a key aspect in the preparation of basin report cards on wildlife where SWOT data products can help fill this need. In addition, having better knowledge about dynamics of the scales of oceans currents from SWOT data is likely to improve the understanding of migration of marine species.

Subimal Ghosh from IIT Bombay presented on the application of SWOT data for water management in India. Despite the long-standing need and existing in-situ measurement infrastructure, irrigation water management and flood forecasting were two areas where SWOT is likely to be most beneficial to Indian stakeholders. More specifically Subimal outlined the following applications of SWOT data towards improving water management in India:

- i) Calibration and Validation of Models that are routinely used in water management decision support systems.
- ii) Real-time initial condition of streamflow (NRT SWOT data)
- iii) Conjunctive use of ground and surface water
- iv) Vertical profiles of potential density to understand surface and sub-surface ocean dynamics for coastal applications.

It was noted that perhaps the most highly coveted data product from SWOT for India would be streamflow at low latency (near real-time) that is sampled at <weekly frequency at the same location. The specific support requested from the SWOT community was: a) continuous data download and access so that the real-time systems in Indian can access the data; b) validation of SWOT data with respect to available observed data. Topic b) may be appropriate for further discussion in the larger context of the SWOT cal/val working group that has established several sites around the world for validation of SWOT data. Subimal concluded with the need for an online training program on SWOT mission that would build further engagement with the stakeholder community of India.

The next speaker, Abhijit Mukherjee, also from IIT (Kharagpur), discussed the potential SWOT applications for Indian water systems. In addition to the application topics raised by the previous speaker (Subimal Ghosh), the issue of surface water-groundwater interaction for more integrated groundwater and agricultural management was highlighted as a potential SWOT application. SWOT data on surface water storage could also help improve predictions of future surface and groundwater inventory for India. The needs by Indian stakeholders from the SWOT community were similar to the previous speaker.

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Availability of SWOT data in NRT was considered essential for the mission to play a direct role in improving current flood forecasting systems in India.

Anthony Nguy-Robertson of National Geospatial-Intelligence Agency (NGA) presented on international water security and the potential role SWOT could play. A particular aspect that he stressed was that of reservoir monitoring using satellites and how that could help flood or water management downstream. Because NGA's focus is also on policy makers rather than instantaneous decision making, maintaining long-term records of global water stocks (such as reservoirs) and understanding the uncertainty associated with remote sensing data are considered more important than latency. According to Anthony, SWOT will be potentially relevant to NGA mission for building long-term water budgets and for quantification of uncertainty in remote or denied locations.

Yasir Kaheil of FM Global, a global insurance company, presented a talk titled "*Global Flood Hazard Model.*" As a commercial and industrial property insurer, FM Global collaborates with academia and risk reduction community. On the topic of flooding, the key attributes of SWOT relevance for insurance is inundation extent and elevation. This is an area where SWOT data is likely to be useful. While latency is not a showstopper for the insurance industry, it was indicated that high frequency sampling by SWOT in flood vulnerable regions can be used for decision making and client recommendation by FM Global. Such high frequency data would help calibrate flood inundation models. Yasir stressed that guidance and training on understanding uncertainty of SWOT data is important along with data format and collaboration opportunities for improvement of hydrodynamic models.

The next speaker, Eric Anderson, presented NASA's SERVIR program in collaboration with USAID. SERVIR is a capacity building and application enabling program for NASA earth observations at international regions faced with various resource and livelihood challenges. While SERVIR engages in building applications in various sectors (Food, ecosystem, agriculture, energy), SWOT is believed to be most useful in the water management and water hazard sector. Because of the pre-existing operational application of nadir altimetry by Bangladesh Government's flood agency (enabled by SERVIR) and the recent scaling up of altimetry data availability for reservoir and virtual stream gauging by SERVIR, SWOT is ideally poised to bring further benefit to many countries in flood forecasting and reservoir management. For needs, the SERVIR program articulated the following from the SWOT mission:

- i) Education on layman understanding of geodesy and satellite altimetry basics
- ii) Determining water bodies meet that would provide skillful SWOT data
- iii) Understanding the circumstances SWOT data will and will not improve decision support for various applications, especially flood forecasts

A most valuable aspect of Eric's presentation was the range of advice there was to offer to the SWOT mission (that the workshop organizers had solicited) to be successful in building engagement with application community. These were:

- *Do listen. Understand unique decision-making environments inside of an agency and how the agency interacts with other agencies / communities outside (information flow mapping).*
- *Do train applications users through co-development of science applications and not only through training workshops.*

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- *Do pay attention to ARSET's Remote Sensing Training: Methods and Best Practices (<https://arset.gsfc.nasa.gov/all/webinars/best-practices-2016>).*
- *Don't expect to reach a lot of decision making users with expensive software. What can we do with completely free-and-open solutions?*
- *Do find a few champions. This requires trust and relationship building over a long period of time.*
- *Do find people to tell your story (Don't just tell it yourself).*

Speaking of telling stories, Eric was asked if he would be willing to help SAWG leads leverage the vast outreach of SERVIR to stakeholder communities for conducting user SWOT-related surveys. The answer was affirmative and SAWG hopes to conduct another survey to raise awareness of SWOT mission around the world via SERVIR and to understand the user perspectives.

Amita Mehta of NASA Capacity Building Program's ARSET (Applied Remote Sensing Education and Training) provided an introduction to the ARSET program. The workshop organizers considered this an important topic for stakeholder agency participants given the extensive call outs made during the workshop for the need for tutorials and education workshops for those who are not familiar with SWOT. After overviewing the mission and operations of ARSET, Amita provided specific examples of remote sensing training that is available for various levels of users (beginners, intermediate and advanced). She stressed the importance of having real-world case studies with the data used for training as that often engaged well with trainer users.

The last presentation before lunch was on the GEO program for water (GEOGLOWS) by NASA Water Resources Program Manager Bradley Doorn and CNES Program Manager Selma Cherchali. Due to the focus of GEOGLOWS on basin risk reduction, addressing water security and estimating key water cycle variables, SWOT data needs to be a critical part of the GEOGLOWS effort. Selma stressed that there is clearly a need to integrate the various datasets and missions (such as from SWOT) in the context of a more integrated effort that provides information such as basin risk reduction, or essential water variables. Because there exist ample documentation and literature on the GEOGLOWS program, a detailed overview of the presentation will not be repeated here.

The last presentation of the day before the discussion session began was by Rashied Amini of JPL, who presented the NASA Disasters Program in the context of SWOT mission. It was clear that SWOT data, whether it is available in real-time or not, would have value in calibrating disaster/flooding models. In addition, NRT SWOT data, if available would be tremendous for furthering disaster management in making real time decisions during disaster response. Rashied outlined a range of needs or issues for the SWOT community to consider for advancing application in disaster management. In particular, Rashied suggested that it would be appropriate to learn from lessons learned by the NISAR remote sensing mission. He stressed that because SAR imagery is already available within 24-36 hours, SWOT's value in operational (nowcast) disaster management can be game changing only if the latency is similar or shorter.

SURVEY OF PARTICIPANTS TO FACILITATE DISCUSSION

To facilitate a healthy discussion among workshop participants, the workshop goals and outcomes were reminded to all before lunch. The key issues identified during the previous day were highlighted by Faisal Hossain. Next, all participants (include remote participants) were provided a 3-question questionnaire (see

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Appendix 1) to complete. This mapped directly to the workshop goals of documenting a) support needs b) latency and c) SWOT-enabled applications.

A total of 24 responses were received that were then organized thematically and according to the three key workshop goals during the lunch session. The organization of the responses were then shared with all to facilitate a discussion to a) correct any misrepresentation; b) address any glaring omission and c) further organize the responses into actionable items for the SAWG during the post workshop phase. The next section titled “Workshop Findings” provides a summary of the responses received and delineates the action items for the SWOT community as workshop outcomes.

WORKSHOP FINDINGS

STAKEHOLDER INPUT ON APPLICATIONS ENABLED BY SWOT

The 24 survey responses received from participants on the topic of applications that the SWOT mission and its data would enable or improve revealed an overwhelming clustering of ideas around specific themes. These themes are: a) Disaster Response and Management; b) Water Resources Management; c) Ocean and Estuarine Applications. We provide below a synopsis of the perspectives shared by participants on each of these themes. The detailed responses provided by each participant are available in Appendix 2.

Disaster Response and Management

Capsule Summary of Participant Perspectives: *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 post-event analysis).*

Water Resources Management

Capsule Summary of Participant Perspectives: *Reservoir level and water storage measurements are a key product 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 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

Capsule Summary of Participant Perspective: *SWOT data will be useful for marine safety, transport, and pollution management. This is particularly important in coastal environments and at river/coastal interfaces. Sea ice forecast models are also a potential user, as are ocean acoustics and derived bathymetry.*

STAKEHOLDER INPUT ON SWOT DATA LATENCY AND FORMAT

Capsule Summary of Participant Perspectives: *There is certainly tremendous demand and interest in an NRT/STC (STC: short-time critical) product, with latencies desired between <1 and 5 days. A latency of < 2 days was most popular. It should be noted that there are many applications that are not latency-critical. A wide range of data formats appeared acceptable given the versatility of today's data processing tools. NETCDF, GeoTIFF, vector and gridded raster formats are more popular.*

NEEDS OF APPLICATION STAKEHOLDER COMMUNITY FROM SWOT MISSION

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Capsule Summary of Participant Input: *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 ‘fits’ in their scheme of business. Such education and training should be aimed at users ranging from relatively non-expert to high-expertise background. In addition, multiple languages (beyond English) should to be considered for reaching out to application communities worldwide. Such effort should have close coordination with SWOT Science Team/PIs/Project and NASA ARSET program could play an important role. Accessing locations of SWOT-observable features would be very useful.*

ACTIONABLE WORKSHOP OUTPUTS & RECOMMENDATIONS

Based on the capsule summary and detailed responses that were shared with all at the workshop during the discussion session of Day 2 afternoon, participants then discussed ways to consolidate the feedback and condense the input into a more manageable set of outputs. The idea behind this consolidation was to remove ‘noise’ and repetitive issues and to create a clean and simpler set of priorities that would be easier to act on during the post-workshop phase. This discussion was facilitated by Faisal Hossain with a goal of reaching wide consensus. Once a consolidated and condensed draft was created on the three workshop outcomes, a motion was put forward (by Ed Beighley) that was seconded (by Tamlin Pavelsky). Upon no participant wishing for any further discussion, a vote was conducted. A vote of 24 (approving the draft below) to 0 (disapproving the draft below) was recorded. Consequently, this vote approved the following actionable output from the workshop for the SAWG and SWOT community for the post-workshop phase. The workshop was then adjourned at 5.24pm (Eastern Time) on April 7, 2017.

Application Priorities for the SWOT Mission

Disaster Response and Management

- NRT flood mapping/forecasting
- NRT coastal storm surge and circulation
- Water quality/pollution Management
- Flood hazard map development
- Post-disaster assessments

Water Resources Management

- NRT/non-NRT Reservoirs and Lake (addressing food and water security)
- NRT Agriculture (irrigation management)
- Hydrologic and hydraulic analysis for planning and engineering
- River navigation and hydropower management

Ocean/Estuarine/large lakes

- NRT Operational ocean forecasting
- NRT Land-sea interface (freshwater inputs into the ocean/ estuaries, coastal ocean forecasting);

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- NRT sea-ice (thickness) forecasting

Needs from the Application community for SWOT Mission to consider

- Latency (ranging from <1 to 5 days) with < 2days being the most desired
- NETCDF, GeoTIFF, raster/vector data. Tools for format conversion, spatial/temporal subsetting, selection of parameters and export user data); leverage the CUAHSI WaterML format.
- Data Portal/Dissemination/Hosting/Training/Sample SWOT-like data (in multiple languages)

Tasks ahead for SAWG and SWOT Community (2017-2021)

- Explore synergies with NISAR mission
- Explore re-organizing applications working groups into inland, estuary, ocean, water systems (and a sub-group based on latency needs)
- Obtain a list of all relevant end users for land-sea interface and operational ocean forecasting applications (from Pierre-Yves LeTraon, Mercator and Copernicus)
- Develop a timeline from hours to 45 days with horizontal boxes showing the time component that makes the application feasible.
- Explore a working group to quantify the benefits for NRT data (*Margaret Srinivasan agreed to lead it with Gregg Jacobs willing to help; Brad Doorn will recruit a member for hydrology*). Using existing application workshop reports, real-world examples and data from past surveys, this working group will prepare a report on the value and need for NRT data. (*goal in September 2017 to make a decision at mission level*)
- Make a recommendation to the SWOT Science Team that NRT data products are needed and should be available immediately following the cal/val phase.
- Prepare a task order (scope: 1 page) for Bradley Doorn for comprehensive assessment of impact of latency on applications (2017+)
- Explore how to best provide data uncertainty to users
- For longer-term planning and engagement with users (post-launch), carry out additional survey of users (e.g. use the SERVIR network of stakeholder groups) to comprehensively gauge the NRT data needs around the world.
- Develop required tutorials, training, outreach (*training and outreach will take many forms based on level of users*; explore available resources to host training, e.g., COMET/MetEd – ARSET; different languages when possible).
- Provide early adopters with case studies/simulated “SWOT” like data (Starting point: Collect all datasets, simulator output from SWOT Science Team, Pepsi-DA datasets that are available) (Contact: Sophie Ricci and Science Team PIs using SWOT Simulator)
- Explore developing a hyperwall for SWOT (develop content; resources are available to help with the graphics)
- Work with SERVIR for user-surveys on needs, education/outreach (Contact: Eric Anderson)

APPENDIX 1 – Questionnaire Survey for Workshop Participants

QUESTION ONE. What is the specific application you would like to consider for a potential SWOT Application and why? Describe it briefly (with the motivation).

QUESTION TWO. What are the specific features of SWOT data you would like to see for the application(s) listed above? Please highlight or quantify a) Latency and accuracy ('accuracy requested by Shailen Desai), b) data format, c) data size, d) miscellaneous

QUESTION THREE. What are the specific types of support you would like to have from SWOT Application Working Group to consider for the application(s) outlined above? Your support requested could be in the form of tutorials, 1-1 training sessions, co-design support, early adopter program etc.

[Based on these inputs, the SAWG will coordinate with participants later to continue the engagement]

Remote participants may continue to email their responses to FHOSSAIN@uw.edu

APPENDIX 2

SWOT Applications Workshop Survey Summary (unedited)

Question 1 - APPLICATIONS

Below are specific comments from participants;

Disaster

Summary: SWOT can potentially help with flood mapping/modeling. Real-time flood mapping requires NRT products. Development of better flood models does not have latency requirements. Coastal flooding/storm surge is also a fruitful application to pursue.

1. NRT Flood mapping.
2. Storm surge and its effects on the coastal and estuarine environment: Water elevation data are key to characterizing storm surge intensity; water extent data are key to the extent of the surge. The simultaneity of the two observations makes SWOT unique to enhance the understanding and forecast of the dynamics of surge and its interaction with the environment: floods, upstream intrusion of salty water into wetlands and river basins, effects on ecosystems.
3. Disaster Management (floods and others) - *[Will SWOT be able to sense stream (river) height?] We work with global end-users who have very little or no access to water data.*
4. Riverine flood forecasting, especially in poorly gauged basins (e.g. the Niger). Motivation: Upstream data on streamflow are not shared, and people need to know when and where they may be in harm's way, with enough lead time to react.
5. Coastal hazards and threats to agro-ecosystems due to sea level rise, salinization, storm surge, subsidence. Motivations: Huge proportion of population lives along coast. Sea level rise, subsidence, and storm surge are coupled and are driven by different natural and anthropogenic factors.
6. NGA - Reservoir modeling, flood modeling, and water budgets. These are problems we routinely address for policy makers, warfighters, intelligence professionals, and first responders.
7. Applications I am most interested in are the use of SWOT data to capture inundation and river/inland flooding events as well as estimating river discharge.
8. Flood hazard model development. SWOT will help with water level, inundation extent, discharge in areas where there are data gaps in observations of flood data. Typically, datasets are point records helping little for process calibration and validation.
9. Disasters uses for these products or what can be derived from them. For example, develop maps which can be sent to organizations responding to disasters.

Water resources Management

Summary: Reservoir level and water storage measurements are a key product for water security/resources. Using SWOT to develop better global river models will help with understanding water resources. NRT products potentially useful.

1. Reservoir level monitoring and general water availability for irrigation purposes and water resources management. Motivation: water security in the face of increasing population and increasing water demand. Making better decisions about extracting surface vs. ground water
2. For SWOT applications in developed nation, we have not talked much about small lakes and wetlands. What about an application of whole-watershed surface-water storage estimates? I would think this would be helpful for downstream larger reservoir operations as we presently do not measure the majority of natural lakes and water bodies. Would it be possible to link these products to discharge at gaged sites?
3. Reanalysis of river hydrodynamics at small to global scale with numerical models and SWOT data assimilation for water resource management and flood risk assessment.
4. Near real-time (as much as possible) use of SWOT data for model correction
5. Reservoir/Lake Storage/Level monitoring for agriculture, fisheries, water resources with multiple stakeholders.
6. Real or near-real time distributed inundation area and depth. Interest in developing tools to supplement current methods used in decision making in regions that already have observation networks.

Ocean Applications/Estuarine Applications:

Summary: SWOT data will be useful for marine safety, transport, and pollution. This is particularly true in coastal environments and at river/coastal interfaces. Sea ice forecast models are also a potential user, as are ocean acoustics and derived bathymetry.

1. Ocean applications that are now served by Mercator Ocean and Copernicus Marine Service operational oceanography services. Main applications that will benefit most from SWOT high resolution ocean observations: marine safety, maritime transport, marine pollution monitoring and coastal applications.
2. I am developing a coupled hydrologic-coastal ocean modeling forecast capability for the US Navy. We are interested in bringing an accurate representation of freshwater volume and distribution to into the coastal ocean. There is also a possibility for assimilating the inland surface water extent into either hydrology and/or coastal ocean models. Our interest lies in largely ungauged areas of the world so mapping the freshwater resources for hydrology model application and/or estimating freshwater discharge to the coastal ocean are paramount.
3. Assimilation SWOT data into the sea ice forecast model have a great potential to improve the Navy's forecasting capability, especially in the marginal ice zone. SWOT's high resolution and accuracy can potential offer a unique sea ice data set that meets Navy's needs
4. Global Ocean Sea Surface Height which will be used for inputs into global ocean circulation models that provides ocean circulation and acoustic predictions.
5. Ocean analysis/forecasting at scales <15km
6. Can be applied to a number of defense areas: high seas WRGS, ocean acoustics, ice analysis, safety of navigation, derived bathymetry measurements

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Data Portal/Dissemination/Hosting/Training:

Summary: See individual comments.

- 1) Any that would involve tool development or storage considerations outside of typical data access and distribution. This way we can plan our system to be robust enough to support a variety of communities. But I would really be interested in what applications that can use the Level 1 Single Look Complexes (SLC) since that's a monstrous data volume. Also, estuary applications, where ocean and hydro data might need to be blended, maybe outflow and tidal mixing.
- 2) We have users at every range of the latency spectrum, meaning they would like to see low-latency disaster products, as well as the current planned 45-day timeline. Given that the current plan is 45 days, it would help us to best present this to folks in a realistic context with applications that can make use of the data at that timeline.
- 3) Many of our GIS users do not know what satellites are up, or what could be good to combine with SWOT data for a more accurate picture. As Brad alluded to, multi-satellite aggregate products could get them started with current data, and then enhanced with SWOT data when it comes online to get them use to it.
- 4) One of the earlier comments was some type of model to understand correlations between other satellite readings and phenomenon to potentially predict what SWOT is going to show when the data is done processing.
- 5) As the gentleman from India noted, many of our international customers have trouble finding open data, as that is not the culture of those governments. Many of these users, as well as QGIS and open-source users, have low bandwidth connections. Consequently, an application that could allow them to select and download vector-data locally may be helpful instead of the full NETCDFs. ESRI has free and open source tools for this on our GitHub site I can share to help with something like this.
- 6) Data format, data access tool or procedure (spatial/temporal sub-setting), continuity with TOPEX-Jason (1, 2,3)-Sentinel would be useful to form long time series
- 7) I really like NETCDF, but I'm also for multiple data formats. Having vector files with XML or JSON file associated with them that contains the metadata is fine for the L2 river and lake data. NETCDF is self-describing so it contains a lot of useful information for ingestion that tools can use later on. If the shapefiles have associated metadata in XML then similar services can be provided as NETCDF, outside of GIS applications; We'll make it work; I would really like to know what setbacks the community has so that we can try to prevent as much of it as we can, either through tool development or how the data are accessed.
- 8) ESRI has a specific definition of how we observe the CF Convention standard when it comes to our software reading NETCDF data. Many other NASA missions are producing NETCDF data in line with this, making ingestion of their data very straightforward for our users. If SWOT can produce their NETCDF's metadata in a similar way, this will reduce the barrier to entry for GIS users. ESRI or NASA would of course be able to build special transformations or connectors if not, but every extra step presents a barrier to entry for users.
- 9) ESRI is working with 52N out of Europe on an SOS connector. If through GEOGLOWS SWOT is considering some type of SOS push, it would be good to check compatibility with 52N's SOS connector.

10) Tutorials on handling SWOT data--volume; products; formats.

Question 2 Specific Features of SWOT Data desired (latency, accuracy, data format, data size, misc.)

Summary: There is a lot of interest in an NRT/STC product, with latencies desired between <1 and 5 days, with 2 days showing up a lot. There are some applications that are not latency-challenged. Data formats are flexible, but NETCDF and GeoTIFF are popular.

Below are some specific comments;

1. We need SWOT sea ice thickness, but can work with freeboard or elevation data as well if necessary. We hope the data will be in high-resolution mode in the marginal ice zone, the latency would be 24-48 hours, with an accuracy of about 5 cm or less. The data should be in swath and NETCDF format.
2. Latency / Accuracy: STC latency 2- 5 days/ accuracy best available; NRT < ~ 12 hours or best available/ accuracy best available; Data Format: NETCDF; Data Size: smallest available
3. SWOT Nadir IGDR and OGDR datasets - Latency / Accuracy: IGDR latency ~2 days / accuracy similar to Jason Missions; OGDR latency ~ < 12 hours / accuracy similar to Jason Missions; Data Format: NETCDF; Data Size : smallest available
4. 1-3 day latency for operational Coastal Circulation and river discharge models and Ocean circulation modeling
5. high resolution: ~250 m in the open ocean, ~50 m in the near shore and estuaries; latency – less than 2 days; data format – no specific requirement
6. Lowest latency possible, on the order of hours. Would be nice to have different timing and quality of products (like IMERG early, late, and final/research). It is acceptable to have lower accuracy on early products.
7. For most purposes frequency of observations at weekly to monthly scales is sufficient. The only exception is for disaster response in which we do have the need for real-time or near real-time data.
8. We utilize altimeter and surface area expressions slightly differently. ASCII/CSV text formats are useful for altimeter data. However, this, along with surface area extents, could also be presented in raster-format. We work in a variety of formats: GeoTIFF, HDF, NETCDF, GRB. However, it does seem that NETCDF is becoming more common between different user communities (e.g. meteorological, remote sensing). Data size is generally not a big concern.
9. Latency as short as possible - 2 days would be great; Accuracy: absolute value does not matter too much if information on variability since last SWOT overpass is reliable. A specific study on the impact of uncertainty (and the structure of error) on applications is needed to answer this question; any standard format such as NETCDF ok
10. Latency should be less than 2 days and possibly 1 day.
11. We would not like to wait until we have full global coverage of the SWOT data to implement its use but the latency is a particular concern. I believe the accuracy is more than adequate for our purposes
12. Strong need for SWOT error estimation/accuracy quantification.

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13. No strong pressure for reanalysis but DA community very interested in demonstrating the potentiality of short latency.
14. Data Format: NETCDF, HDF5, TIFF
15. Latency Optimally <1 day if possible; else what is most feasible
16. A) SSIta products for ocean modeling (ID mesoscale ocean features). for defense applications + disaster relief (e.g. Tsunamis, hurricanes, tropical cyclone) B) Arctic ice C) river discharge identification
17. Latency requirements: Latency is not relevant for Inundated area products used for flood risk analysis. Latency < 1 day for real or near-real time distributed inundation area and depth. Latency hours to weeks (variable depending on stakeholders) for lake products
18. Ability to request downlink prioritization and new acquisitions (will not ask to change orbit or point).
19. Would like better coordination with project, not only working group! Would work to help define data plan, (?conops?), other.
20. Accuracy needs: 10 cm rms
21. For Lakes, monthly temporal resolution is sufficient.
22. Need to work on data continuity (e.g. an immediate follow-on mission)

Question 3 – NEEDS

Summary: Definitely need tutorials and example datasets, and they need to be aimed at a range of different users, from relatively non-expert to high-expertise groups (language needs to be considered). Close coordination with SWOT Science Team/PIs/Project would be very useful. Locations of SWOT-observable features would be very useful.

Below are some specific comments.

1. Direct support from science team member can help us to better understand and use the data products.
2. Set up a Latency working groups in investigation reasonable data latency solutions for Near Real-time data products.
3. For KaRIn NRT and STC Products: Evaluate the use of cross-over corrections to mitigate systematic roll errors; Evaluate lower accuracy orbit solutions; Evaluate predicted geophysical corrections ; Evaluate path delay error: Evaluate what resources are required to make these products.
4. Close communication with PIs developing products about data retrieval procedure, accuracy, validation. Limitations of SWOT data (and also about reservoir size, temporal sampling sensed by SWOT).
5. Examples of SWOT data usage for hydrology (case studies).
6. outreach to the agencies responsible to storm surge forecast and coastal and estuarine management with offering of informational/training sessions in phase with the mission development.
7. Having a global list (and map) of freshwater bodies that meet the width/size criteria for SWOT (and all other existing altimetry data) would let applications community know where

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- they are on solid technical ground in interpreting altimeter data. This knowledge product may need to be disaggregated to be application specific.
8. Creating free and open tools with necessary documentation on how to access and use these data are very helpful. We recognize that it can be challenging to provide tech support on this, but it's always appreciated. SERVIR network may be way to build a cadre of applications users who can address regular tech issues on such tools.
 9. Support for web data sources would be helpful. As NGA's customers are not scientists, I do see some potential synergy with others participants in developing communication/training tools to help common end users.
 10. Conceptual tutorials to drive interest within agency (directed at technical policy level, research entities). Detailed/technical tutorials for a smaller audience of technical users.
 11. We definitely will need trainings and tutorials. A user workshop would be good, short tutorials at the NASA booth at big conferences (AGU, AMS, etc.).
 12. Developing the workflow of here's what this data can show you, what do you need to know, and what answer do you want to get will take longer. Consequently, sample 'use cases' of here's how an insurance company would use this, here's how a water management district would use this, here's how an emergency manager would use this, will help to connect with users.
 13. Training also but language issues to be considered – other languages (French, Spanish).
 14. End-to-end simulator of NRT processing.
 15. I'd be interested in on-line training in accessing and understanding what the data is and is not, its uncertainty, etc. I especially like the idea of using a SWOT data simulator to begin working with SWOT-like data to see how it can be best integrated into the coupled hydrology-coastal ocean modeling system.
 16. I would think that an early adopter program would be most useful, with online video tutorials possibly being popular. An ARSET class, and perhaps 1:1 training sessions also would be helpful.
 17. Tutorials, synthetic proxy data products for early adopters with examples of reading/plotting data/post processing.
 18. Earlier adopter working group could consolidate latency (NRT) issue(s) and bring forward to NASA/CNES to drive design and NRT delivery of a 'quicklook' product
 19. Flood hazard model validation study co-design & data support.
 20. Standard documentation of low level data is sufficient.