10th Surface Water Ocean Topography (SWOT) Applications Meeting Final Report

7–8 December 2023, California Institute of Technology, Pasadena, CA

Prepared by

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1 EXECUTIVE SUMMARY

The 10th SWOT Applications meeting was organized to highlight the work and project status of the SWOT Early Adopters (EAs) and to assess future objectives and methods in anticipation of future SWOT data reprocessing and releases within 2024.

The meeting took place 7–8 December at the California Institute of Technology Keck Institute for Space Studies (KISS) and online with over 100 in-person and virtual participants from across the globe and over many time zones. Meeting participants followed the more than 30 talks related to planned and current operational and applied uses of SWOT data, the current state of the data products and access to the data, and a variety of other projects that may/will include SWOT in their application, as well as several auxiliary projects funded from NASA Earth Action. The discussion periods provided further insights into the gaps and challenges of incorporating SWOT data into operational and decision-support frameworks. Feedback from these discussions will be exceptionally useful to the SWOT Project and Applications Teams. Table 2 (Day 1 agenda) and Table 3 (Day 2 agenda) list the meeting topics and participants.

The work and contributions of the EAs are at the core of the SWOT Applications program. The willingness of the EA cohort to share early-stage progress and plans is highly valuable to the SWOT Applications effort, to the SWOT Project, the SWOT Programs at NASA, and the French space agency, Centre National d'Etudes Spatiales (CNES). Illustrating and supporting the use of SWOT observations by the applied science community gives a view into the breadth and depth of value that the SWOT mission is expected to provide to the operational and private-sector user communities in addition to the primary research objectives of the mission.

A further important goal of the workshop was to better understand the use of SWOT in models and modeling systems. In particular, how will SWOT support and improve models as inputs, used in conjunction with other Earth observations, or assimilated in larger contexts? With the early release of beta pre-validated (BPV) SWOT data to the SWOT Science Team and to SWOT Applications EAs, we reached out to our community of users who are using or expect to use SWOT data in local or community-wide modeling efforts or modeling systems with a pre-meeting survey to answer these questions. Information and results from this survey are discussed in Section 4.

As we get closer to operational availability of a validated version of the data, the advances by the EA projects will be increasingly interesting to a growing audience. We endeavor to provide an early assessment of the value of SWOT to our user community through this meeting and related activities.

Outcomes from this meeting included insights into the direction and variety of operational use of SWOT data products, and the needs and desires of the applications user communities. Through examples and shared experiences during the meeting, we have learned that SWOT data products have already been successfully incorporated into some EA applications, with indications of more broad use potential. Known limitations of SWOT data with respect to data latency and mission length (with implications of future data availability) are addressed. As the EA community works to integrate SWOT data into their models and operational systems, the SWOT Applications team will continue working with and supporting these activities. Collaborations with the data centers and the project and science communities will be a future focus of the work of the SWOT Applications team as well. The demonstrated use and value of SWOT data in operational systems will benefit all EAs and future applied science user communities. Documenting and sharing this work will provide the SWOT Project with valuable information about how the data is being used and will thus allow for optimizations and improvements.

2 INTRODUCTION

2.1 BACKGROUND

The SWOT mission, developed jointly by NASA and CNES, with contributions from the Canadian and U.K. space agencies, was launched 16 December 2023 from California.

The NASA Applied Sciences Program (now called NASA Earth Action), the SWOT Project, the CNES SWOT Downstream Program, the SWOT Applications Working Group (SAWG), and members of the SWOT science community have coordinated efforts in support of the SWOT Applications Program since 2012. The SWOT EA Program was initiated in 2018 and comprises a growing community working to incorporate SWOT data into the operational and applied science activities of their organizations. The SWOT Applications Program Plan (http://tinyurl.com/SWOTApplicationsPlan2014) was developed and finalized in 2014. The SWOT Early Adopter Program Guide (http://tinyurl.com/SWOTEAGuide2018) was written in 2015 and updated in 2018. These two documents have guided the SAWG interactions with applied science and operational agency user communities through the development and engagement of the current SWOT EA cohort of 40 individuals and organizations (see https://swot.jpl.nasa.gov/applications/early-adopters/).

The SWOT satellite implements cutting-edge interferometric radar technology, along with traditional nadir altimeter and positioning instruments. The data from this mission will continue and expand upon the more than 32-year time series of the surface height measurements of oceans and large water bodies. SWOT data products are designed to provide unprecedented high spatial frequency measurements of global surface water extent and elevation as well as other key derived parameters, such as river discharge.

The SWOT Applications and EA Programs endeavor to align with the general goals of respective NASA and CNES elements to discover and demonstrate innovative uses and practical benefits of Earth science data, scientific knowledge, and technology for societal benefit. Specifically, the SWOT Applications programmatic thrusts align directly with the goals to:

- Promote applications research,
- Facilitate development of accessible data products for applications users,
- Identify and engage a broader community of users beyond traditional science researchers to maximize the societal benefit of remote sensing Earth science data, and
- Encourage and enable the applications community to contribute to Earth-observing satellite design and mission planning in the long term.

At the time of the 10th SWOT Applications Meeting, the SWOT EA cohort included 40 individuals and organizations (Table 1). These EAs represent a wide variety of surface hydrology and oceanography domains and organizations, including both domestic U.S. and international private-sector companies, academia, nonprofits, operational agencies, state and national government organizations, and research communities.

The efforts of the SAWG to build strong engagement with the applications community began in 2015. This 2023 workshop was the latest in an annual series organized by the SAWG that are intended to both support the SWOT EA community in developing and advancing their proposed activities and demonstrate potential real-world benefits of the use of SWOT data products through their work. Cooperation between SWOT Applications and Program and Project leadership (Figure 1), and the support of NASA, CNES, JPL, and members of the SWOT Science Team, are key components contributing to the success of the SWOT Applications efforts.

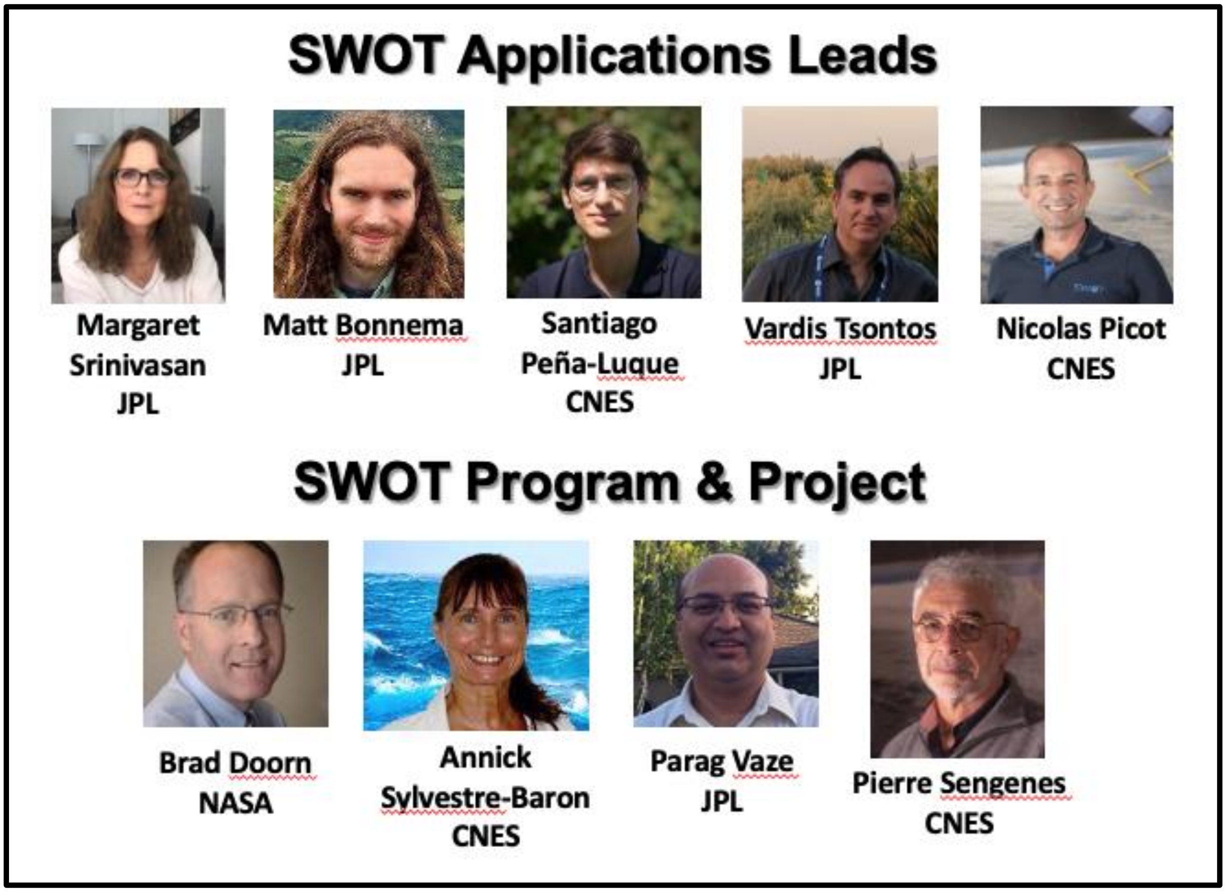

Figure 1. SWOT Applications, Project, and Institutional leadership

SWOT KaRIn Low Rate (LR) Ocean Products from the calibration phase became available to users in September 2023. In November 2023, EAs, along with the science community, were provided access to BPV KaRIn data products (JPL, 2023). The release included limited spatial and temporal samples of KaRIn high-rate (HR) data over land collected during the one-day repeat Calibration/Validation orbit phase in mid-2023.[1] The purpose of the release was to familiarize users with science data products from in-flight KaRIn data. Subsequent to this meeting, SWOT science data products became publicly available on March 6, 2024, as described in the release notes for the Version C KaRIn Science data products and the Nadir Altimeter and Radiometer Geophysical Data Records (JPL, 2024).

The meeting was organized around four primary foci for achieving the workshop goals. These were:

1. NASA and CNES overview and SWOT Project status and update,
2. NASA and CNES data product and data center updates,
3. SWOT EA project updates, and in particular, those beginning to use the SWOT nadir and BPV KaRIn data, and
4. Auxiliary SWOT-relevant projects from NASA Applied Sciences (Earth Action), and other organizations doing interrelated work.

Brief summaries of each of these topical areas, along with synopses of specific presentations, follow. Information products from the meeting will be available on the SWOT website's meeting page (https://swot.jpl.nasa.gov/events/62/10th-swot-applications-meeting).

[1] The CalVal orbit was a period after launch when the SWOT orbit was configured for a three month, one-day repeat phase that targeted fewer areas of the globe, but more frequently, for purposes of calibration and validation.

2.2 MEETING OBJECTIVES AND GOALS

With the November 2023 release of SWOT data to the SWOT Science Team, SWOT Applications EAs, and other user groups, this workshop focused on the achievements of the SWOT EAs, with an emphasis on their project status and what their needs were in incorporating SWOT data (pre-validated or fully validated) into their systems. SWOT systems and data engineers outlined and demonstrated data access, tools, and products as well as processes for ingestion of these data into operational systems.

The time has arrived when we may now begin the process of demonstrating the very high potential and actual value of the international partner space agencies' considerable investments in satellite systems for Earth observations in general, and for SWOT specifically, and the societal benefits that will result. We will continue to deepen the meaningful engagement we have built with the SWOT EA community by supporting the use of SWOT data in their operations and systems, and in supporting applied research in the relevant hydrology and oceanography areas that SWOT can now provide.

With SWOT EA user readiness at its peak, this meeting was an opportunity for EAs to share their projects with our community—the SWOT Science Team and Project—and to look ahead to using SWOT in their decision-making capacities. How will SWOT improve their analysis workflows? What questions can SWOT help them to answer? What support do they need to achieve the outcomes they seek, and how can we—the mission—be a resource?

The support of the CNES and NASA SWOT Projects has been a key component of the successes so far of the SWOT EA community. As we move through the next months and year, our community is transitioning from "early adoption" to simply "adoption" of SWOT as a valuable resource in their system management toolbox. This meeting was an opportunity to begin demonstrating the utility of SWOT data, identify what needs remain in the transition to full data product utilization, and engage even more applied and operational users who can benefit from SWOT. This will require continued support and collaboration with the mission and data systems organizations at NASA and CNES.

Over two days, the workshop focused on the following objectives:

1. Hear from SWOT EAs who shared status on their SWOT-related application projects with fellow EAs, the SWOT Project, and the Science Team.
2. Share status of EAs and modelers working primarily with BPV SWOT data.
3. Illustrate the range of uses, particularly in modeling, and the value of pre-/post-SWOT activities.
4. Identify concerns and remaining needs of EAs as their projects enter the final phase of development after the calibration/validation (CalVal) period and into the Science Phase of the mission.
5. Identify and explore how this data can be integrated with existing groundwater and ocean models.
6. Identify gaps and community concerns.
7. Document the activities and outcomes of the meeting to the broader Earth science community and identify strategies in the near term to maximize access to the data and information products from SWOT.
8. Demonstrate the high potential and expected value of SWOT mission data for societal benefit.

General formational goals for SWOT EA workshops and meetings are to:

- Provide an opportunity for EAs to share their projects and progress,
- Facilitate peer-to-peer collaborative learning,

- Provide hands-on training on cloud computing platforms to process, analyze, and make decisions using large amounts of satellite data in the cloud,
- Familiarize EAs with SWOT-like data on water elevations,
- Identify concerns and needs of EAs to promote success of their projects,
- Document activities and outcomes of the workshop for the broader Earth applied science community and maximize societal relevance of the SWOT mission and its future data products.

Following successful virtual SWOT EA “hackathons” in 2020 (Hossain et al., 2020), 2021 (Srinivasan et al., 2021), and 2022 (Hossain et al., 2022), the SAWG Leads held this first post-launch meeting after the BPV data products became available. The timing of the BPV data release in November 2023 gave EAs only enough time to begin looking at the data and assessing their approach to incorporating the data into their systems and models. The 2023 SWOT Applications meeting was, therefore, an opportunity to meet with SWOT Project team members, the Applications Team, and fellow EAs in person and virtually to share first impressions, preliminary data interactions, and project status.

All KaRIn data is currently being reprocessed with the best available algorithms and calibrations to generate “pre-validated” science data products. These pre-validated products were released in early March 2024. Fully validated KaRIn products are expected to be released in mid-2024 following validation and science team meetings. The public release of SWOT nadir altimeter products began in June 2023.

The agenda (Table 2 and Table 3) was designed to provide substantive review of all topical areas relevant to the current state of work efforts of the EAs and related projects, and to review and share the status of NASA and CNES data product and data center activities. This meeting was also an opportunity to invite other applied science Principal Investigators (PIs) with work projects including, related to, or relevant to SWOT to share that work with the SWOT Applications community.

The meeting began with an overview of the meeting goals and objectives, followed by welcoming messages from NASA and CNES programmatic Leads, **Brad Doorn** (NASA) and **Annick Sylvestre-Baron** (CNES), and from the SWOT Project Managers, **Parag Vaze** (JPL) and **Pierre Sengenes** (CNES). Participation from these high levels of agency and project management reflects the importance of the SWOT Applications Program and engagement activities at these organizational levels.

The introductory remarks were followed by a series of talks designed to provide a broad and thorough summary of SWOT Project data activities and centers, including status overviews for the CNES hydroweb and AVISO platforms by **Lionel Zawadzki** and **Cyril Germineaud** (CNES) and NASA’s Physical Oceanography Distributed Active Archive (PO.DAAC) data management and distribution centers by **Catalina Taglialatela** and **Cassandra Nickles** (JPL). We also heard from the SWOT Science Data System Leads, **Shailen Desai** (JPL) and **Nicolas Picot** (CNES). These talks included overviews of their activities to bring SWOT data to the research and applied science communities, including updates on cloud access to data. The first morning session closed with two highly relevant and illuminating talks—the first on SWOT KaRIn performance and CalVal activities (**Jinbo Wang**, JPL) and the second detailing many critical and important proclivities of KaRIn data products by **Curtis Chen** (JPL),which will prove very valuable to EAs and other users as they use and interpret data results. Project summaries by fifteen SWOT EA organizations, along with eight SWOT-related auxiliary projects followed, with key discussions throughout.

Section 3 of this report provides an overview of the SWOT Early Adopter program and information and status of the current cohort of SWOT EAs. Section 4 contains summaries of the contributions made from participating EAs, presentations from other SWOT-relevant projects, and presentations by the SWOT Science Data System and data distribution organizations outlining the data systems and products available to the EAs. A key focus of this meeting was to investigate and understand how SWOT data will be used in and improve models and modeling systems. Section 5 summarizes a pre-meeting survey and discussions during the meeting on the topic of SWOT in models. The remainder of the report summarizes key discussions about use of the data, SWOT in models, and a look to the future.

3 SWOT EARLY ADOPTERS

3.1 PROGRAM

NASA and CNES have developed a focused and robust program to actively recruit and engage individuals and organizations to promote applied science objectives as well as address societal needs and practical and operational applications of the data. This broad community of users, identified as the SWOT EAs, are focused on decision support and operational activities related to water resources management for energy, agriculture, infrastructure, and disasters, including in coastal and open ocean realms. To date, 40 SWOT EAs (Table 1) have joined from five continents and twelve countries across Asia, Europe, Africa, and the Americas (Figure 2). Still others have expressed interest in joining.

The EA program is a nonfunded activity (for NASA and CNES) with the primary goals of the program, initiated in 2018, to:

1. Expand communities of SWOT users who work in areas of tangible and potential applications that would benefit from the use of SWOT data and information products,
2. Facilitate feedback on SWOT data products pre-launch, and
3. Accelerate the use and integration of SWOT products into applications post-launch by providing specific support to EAs who committed to engaging in pre-launch applied research.

SWOT EA Project Leads identify a region within their working programs where SWOT data have the potential to provide measurable to substantial improvements in their knowledge base for operations. Information about the SWOT EA Program, as well as project summaries for the EA organizations can be accessed at https://swot.jpl.nasa.gov/applications/early-adopters/.

3.2 SWOT EARLY ADOPTER ORGANIZATIONS

The individuals and organizations that make up the current SWOT EA cohort began in early 2018 with 10 EAs joining in the first year. Since that time more organizations have found benefit in the annual meeting focused on training, including three EA Hackathons (Hossain et al., 2020; Srinivasan et al., 2021; Hossain et al., 2022); cross-EA collaborations; and interactions with the SAWG and SWOT Applications Leads. Table 1 lists the SWOT EA organizations as of December 2023.

	Country	Organization
1	Egypt	Alexandria University
2	Brazil	ANA Brazil (Brazil National Water Agency)
3	Argentina	Argentina Research Centers for the Study of Pampas Lagoons and Large Rivers
4	Thailand	Asian Disaster Preparedness Center (ADPC)/SERVIR-Mekong
5	France	BRL Ingénierie (BRLi)
6	India	Centre for Water Resources Development and Management (CWRDM)

	Country	Organization
7	U.S.	Cleveland Water Alliance
8	France	Collecte Localisation Satellite (CLS)
9	France	Compagnie Nationale du Rhône (CNR)
10	U.S.	Consortium of Universities for the Advancement of Hydrologic Science, Inc. (CUAHSI)
11	Canada	Environment and Climate Change Canada (ECCC)
12	U.S.	ESRI
13	U.S.	FM Global
14	Brazil	FUNCEME—Water Resources Board, State of Ceara, Brazil
15	U.S.	Geometric Data Analytics, Inc.
16	France	ICUBE SERTIT
17	India	Indian Institute of Technology (IIT) Bombay
18	India	IIT Delhi
19	France	IRD (South American community)
20	U.K.	JBA Consulting
21	France	Magellium
22	France	Mercator Ocean
23	U.S.	NASA Short-term Prediction Research and Transition (SPoRT) Center, Univ. Ala.
24	U.S.	National Park Service
25	U.S.	National Oceanic and Atmospheric Administration (NOAA) / Cooperative Institute for Research in Environmental Sciences (CIRES) University of Colorado Boulder
26	U.S.	Northeastern University
27	U.S.	Ohio State University
28	Pakistan	Pakistan Council of Research in Water Resources (PCRWR)
29	U.S.	Pacific Northwest National Laboratory (PNNL) U.S. Department of Energy (DOE)
30	Brazil	SBG (Geological Survey of Brazil) & IRD
31	U.S.	Sofar Ocean
32	U.S.	Stantec Consulting Services Inc. (Stantec)
33	U.S.	Texas Water Development Board (TWDB)
34	Germany	University of Bonn and Helmholz-Zentrum Geesthacht
35	U.S.	University of Montana
36	U.S.	U.S. Air Force Weather's Land Information System (LIS), Offutt AFB, Nebraska
37	U.S.	U.S. Navy—Naval Research Laboratory (NRL)
38	U.S.	U.S. Geological Survey (USGS)
39	France	vorteX.io
40	Sweden	Water in Sight

Table 1. SWOT EAs span five continents and twelve countries, representing forty organizations.

Figure 2 indicates the current geographic distribution of SWOT EAs. The current forty SWOT EA organizations span five continents and twelve countries with new EAs pending that would further expand the reach of SWOT Applications.

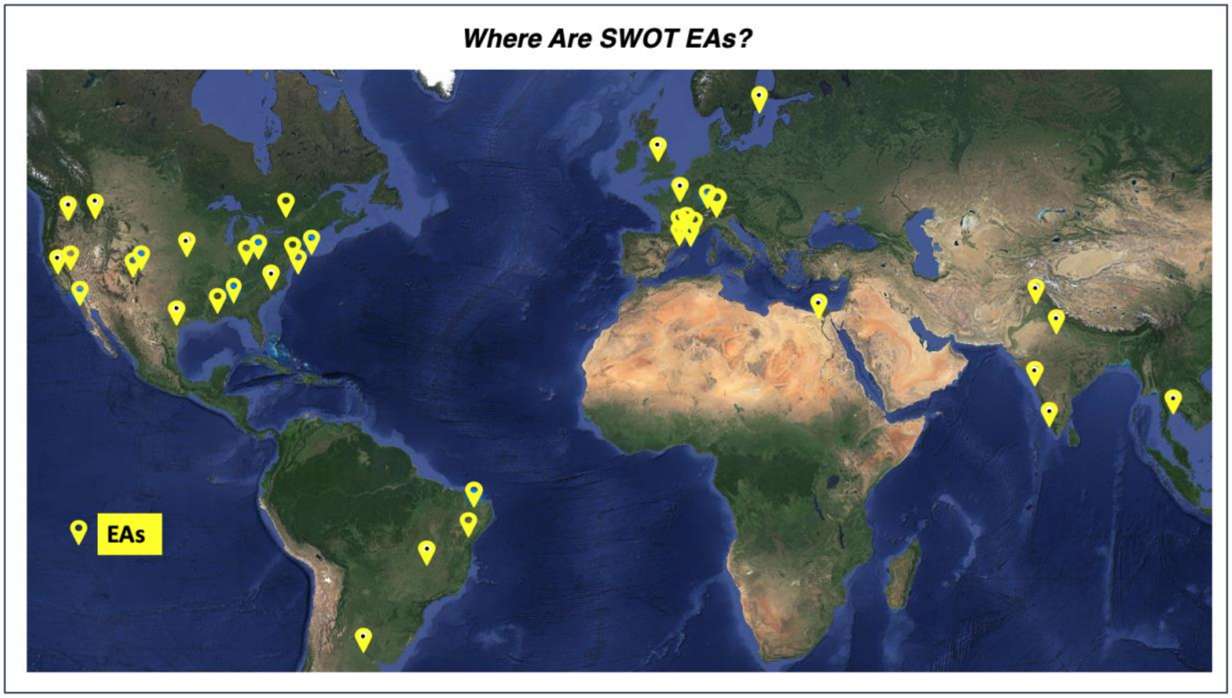

Figure 2. Forty SWOT EA teams span the globe with a wide range of operational and applied science project topics. Visit https://swot.jpl.nasa.gov/applications/early-adopters/ for information about all SWOT EA projects.

4 10th SWOT APPLICATIONS MEETING

Prior to this meeting, experience with using simulated and proxy data made publicly available by the mission since early 2018 ranged from minimal to extensive among the EA organizations. With the more recent availability of the BPV data, some EAs were able to begin incorporating this actual, albeit limited, data into their models and data systems. For example, one EA, Sofar Ocean, in fact also began incorporating SWOT nadir altimeter data into their operational system by late Summer 2023.

4.1 AGENDA

Meeting attendance was open to all SWOT EAs who were ready and willing to share their project status. In addition, other groups doing SWOT applied science–relevant work were invited to hear the EA stories and share their own projects. Each of the two meeting days included a mix of EA presentations, auxiliary project presentations, and talks from the SWOT data centers. Due to the broad global distribution of the speakers, the grouping of presentations by topics was superseded by the presenters' time zone. Table 2 shows the agenda for Day 1 of the meeting and Table 3 shows the agenda for Day 2.

DAY 1, 7 December 2023		
Category	**Topic**	**Speakers and Organizations**
REGISTRATION AND COFFEE		
Meeting Overview and Project Status	Meeting Welcome and Objectives	**SWOT Applications Leads: Srinivasan, Bonnema, Tsontos (JPL); Peña-Luque, Picot (CNES)**
	NASA and CNES Remarks	**Brad Doorn (NASA); Annick Sylvestre-Baron, Yannice Faugere (CNES)**
	Project Status	**Parag Vaze (JPL); Christophe Maréchal, N. Picot (CNES)**
Data Systems and Products	Introduction to Platforms: hydroweb and AVISO	**Lionel Zawadzki, Cyril Germineaud (CNES)**
	PO.DAAC—NASA—Data System Overview	**Catalina Taglialatela, Cassandra Nickles (JPL)**
	SWOT Data Management and Products Status	**Shailen Desai (JPL)**
	SWOT KaRIn Performance/CalVal	**Jinbo Wang (JPL)**
	Features of KaRIn Data that Users Should Be Aware Of	**Curtis Chen (JPL)**
SWOT EARLY ADOPTER UPDATES		
SWOT Early Adopter Project Updates	The SWOT CalVal over the Amazon: Preparing the Science and Applications	**Daniel Moriera (SGB)**
	Using SWOT Data to Improve FM Global's Worldwide Flood Hazard Model	**Alain Dib (FM Global)**
	USGS SWOT Remote Gauging of Streamflow	**Robert Dudley (USGS)**
	Operational Assimilation of Satellite and In Situ Wave Observations	**Isabel Houghton (Sofar Ocean)**
	FIRST Evaluation of SWOT KaRIn Beta Pre-Validated Data at Coasts and Rivers	**Luciana Fenoglio (Univ. Bonn)**
SYNERGISTIC PROJECTS & SWOT - I		
Synergistic Projects	G-REALM—Reservoir Database	**Charon Birkett (NASA)**
	NASA ASP WR PI—Tracking Fresh Water from Space for Congo River Water Resources Management and Water Related Decision-Making	**Chandana Gangodagamage, PI (NASA)**
SWOT Early Adopter Project Updates	NASA ASP WR PI—Decision Support for Alaska Ungauged Basins	**Bidhya Yadav (University of Ohio)**
	Integrating SWOT Data Products into Applications	**Ed Beighley (Northeastern University)**
Synergistic Projects	WWAO	**Stephanie Granger (JPL)**
OCEAN MODELS		
SWOT Early Adopter Project Updates	SWOT Ocean Forecasts	**Gregg Jacobs (U.S. Navy NRL)**
Synergistic Projects	SWOT ECCO	**Dimitris Menemenlis, Babette Tchonang, Matt Archer (JPL)**
DISCUSSION		
Data Centers	PO.DAAC Data Tutorials	**Cassandra Nickles, Catalina Taglialatela (JPL)**
LEGEND:	Early Adopters	

Table 2. Agenda for day one of the 10th SWOT Applications Meeting, a hybrid event held at the California Institute of Technology in Pasadena, California, and online.

DAY 2, 8 December 2023		
Category	**Topic**	**Speakers and Organizations**
REGISTRATION AND COFFEE		
SWOT Early Adopter Project Updates	SWOT Data for Indian Hydrology: Preliminary Results and Ongoing Works	**Indu Jayaluxmi (India Institute of Technology)**
	Impact of SWOT for Global Ocean Prediction	**Pierre Yves Le Traon (Mercator Ocean International)**
Data Centers	Produits L3&L4 Ocean	**Yannice Faugere (CNES)**
	AVISO and hydroweb.next	**Lionel Zawadzki, Cyril Germineaud (CNES)**
SWOT Early Adopter Project Updates	Exploring New In Situ Observations and SWOT Integration in Malawi	**Guy Schumann (Water in Sight)**
	Utilization of SWOT Data for Water Resources Management for Lakes and Large Rivers in Argentina	**Paula Torre Zaffaroni (Argentina Research Centers for the Study of Pampas Lagoons and Large Rivers)**
SYNERGISTIC PROJECTS & SWOT - II		
Synergistic Projects	GEWEX and SWOT	**Peter van Oevelen (GEWEX)**
	OPERA	**Matt Bonnema (JPL)**
	NASA ASP WR PI—Multi-Platform WS Observations to Support USACE	**Renato Frasson (JPL)**
HYDROLOGY MODELS		
	VIC Model for Floods	**Bareerah Fatima (PCRWR)**
	NASA LIS	**Jerry Wegiel (NASA)**
Synergistic Projects	SWOT Modeling Water Surface Topography	**Cedric David (JPL)**
	Mapping Brazilian Rivers and Water Bodies Using SWOT Satellite: Challenges and Opportunities	**Alexandre Araujo, Alexandre Amorim Teixeira (ANA Brazil)**
DISCUSSION: GAPS AND CHALLENGES IN USING/INTEGRATING SWOT DATA		
CLOSING REMARKS AND ANNOUNCEMENTS		
LEGEND:	Early Adopters	

Table 3. Agenda for day two of the 10th SWOT Applications Meeting, a hybrid event held at the California Institute of Technology in Pasadena, California, and online.

4.2 SWOT EA PROJECT SUMMARIES

The following summaries and updates of EA projects presented during this meeting follow the order of the meeting agenda (Table 2 and Table 3). Summaries of data system–related presentations and summaries of other SWOT-relevant projects funded by NASA Water Resources (under NASA Earth Action) can be found in sections 4.3 and 4.4, respectively.

These talks provided an indication of the range and depth of the extensive work accomplished by the SWOT EA community to date. Anticipation is high among the group for the next pre-validated data release, which is expected to encompass the mission's full global extent. These examples showing how SWOT data will be an important tool in managing surface water resources and in forecasting ocean and coastal conditions via operational systems are part of an ongoing story this user community will continue to share over the coming years (Srinivasan et al., 2023). These stories also provide an opportunity for this community to provide feedback to the SWOT Project and science community on potential needs and challenges users will face as SWOT science data products are released for general availability.

4.2.1 Brazil Geological Society (SBG), Daniel Moriera—The SWOT CalVal over the Amazon, Preparing the Science and Applications

Given the limited gauge network over the Amazon, a major South American transboundary basin, SBG are expecting SWOT to provide valuable information on floods and extreme events in the basin. SBG are maintaining CalVal sites for comparison and have conducted campaigns that include river profile surveys and gauge networks. Intercomparisons have been conducted at the

Curuai Lake CalVal site (May 2023), the Negro River site providing Global Navigation Satellite System (GNSS, and the Icana gauge station elevation time series with very good results. In addition, SBG maintains a weekly water level report for the Amazon Basin, which includes anomaly reports and warnings. A web application leverages satellite altimetry data from the Sentinel missions and Jason 3 (https://hydrologyfromspace.org/hfs-app/). Current levels relative to historical ranges can be observed. SBG will produce discharge datasets using altimetry and will evaluate geoid models over the Amazon. The benefits of SWOT in this system include unprecedented spatial coverage, additional temporal coverage, and information on water storage processes over floodplains where otherwise data is lacking.

4.2.2 FM Global, Alain Dib—Using SWOT Data to Improve FM Global's Worldwide Flood Hazard Model

FM Global is a commercial/industrial property insurance company, leveraging engineering and research-based approaches to deliver solutions for its clients. These solutions help clients manage their risk from hazards and ensure their operational resilience. FM Global produces a worldwide flood map identifying regions that are vulnerable to moderate to high flooding on a global scale using hydrologic and hydraulic modeling. SWOT will aid in model calibration, especially in ungauged regions. Sparse coverage over some key basins is a limiting factor, but data from similar catchments can be used as proxy. Two experiments were conducted using SWOT synthetic data to run hydrologic model calibrations:

- The Ohio River basin simulation used 21 stream gauges over 6 years. A hydrologic model was run for 31 years to estimate 100- and 500-year discharges using different calibrations (SWOT synthetic data vs. stream gauge data). Using SWOT, comparable 100- and 500-year values resulted.
- SWOT will provide an opportunity to calibrate FM Global's worldwide hydrologic model, especially in ungauged regions. A longer mission life (more than 3 years nominal mission length) from SWOT would be more beneficial for such applications.

4.2.3 USGS, Robert Dudley—Satellite River Gauging (SatRSG) and SWOT

The primary focus of this project from the USGS is currently to increase gauge coverage in Alaska given the remote locations and safety and cost issues. This project will integrate SWOT with in situ data to derive discharge and flow velocity, and will calibrate against in situ observations. Examples included the Tanana and Yukon Rivers in Alaska with a comparison of ground-gauged vs. satellite-based discharge. In cooperation with PO.DAAC, the group is integrating SWOT in SatRSQ measurements to develop a USGS dashboard (Water Information from Space (WISP)). This dashboard makes use of the PO.DAAC Hydrochron API, which allows for querying and access to time series of SWOT hydrology products. A demonstration video of the USGS WISP dashboard incorporates the SWOT a priori River Database (SWORD; swot.jpl.nasa.gov/documents/4031/), showing data access and download of SWOT time series as well as USGS ground-gauged data and enabling comparison with collocated ground-gauged time series. The dashboard indicates SWOT orbital ground tracks and will eventually include the SWOT lake database. The dashboard and API are nearing completion and, although currently for internal USGS use only, may eventually be publicly available later in 2024. The dashboard focuses on U.S. regions but is being considered for global coverage.

4.2.4 Sofar Ocean, Isabel Houghton—Operational Assimilation of Satellite and In Situ Wave Observations

Sofar Ocean runs 10-day, data-assimilating marine weather forecasts that inform their downstream ship route optimization and navigational safety platform, Wayfinder. Data sources include significant wave height estimates from both the Sofar spotter buoy network and estimates derived from nadir altimeters on the Sentinel 6 Michael Freilich, Jason-3, and Saral satellites. These observations are incorporated into their data-assimilating forecasts based on the NOAA

WaveWatch III model with demonstrated improvement of forecast skill of their system with the addition of the altimeter data. Preliminary work with SWOT significant wave height data from the onboard nadir altimeter indicates that SWOT wave data is less noisy than that of the predecessor altimeters and its use, therefore, improves the skill of their model. Including SWOT data in models reduces forecast error. Sofar expects SWOT to improve their observation numbers by 50%–100% in a given 24-hour period. Additionally, Sofar has an Earth system model in development (waves, circulation, atmosphere) to which they plan to add KaRIn observations.

4.2.5 University of Bonn, Luciana Fenoglio—FIRST Evaluation of SWOT KaRIn Beta Pre-Validated Data at Coasts and Rivers

The University of Bonn has two projects in their SWOT EA work. The Baltic region project is intended to assess the quality of SWOT data, including both KaRIn and nadir altimetry data, by constructing a time series and comparing its accuracy against in situ (GNSS) and model data. Study areas are estuaries, lakes, and rivers, including several locations along the Rhine River, Lake Geneva, and the Elbe Estuary. First results are promising, and future plans will include comparisons with Sentinel 3, Sentinel 6, and future SWOT data releases.

4.2.6 Ohio State University, Bidhyananda Yadav—SWTO Visualization Dashboard to Improve Decision Support for Alaska Ungauged Basins

This project leverages SWOT measurement to enhance decision-making processes for currently ungauged basins in Alaska. The project has two focus areas: development of SWOT visualization dashboard (SWOTviz); and to using SWOT for monitoring of rivers and glacially dammed lakes. The SWOTviz dashboard will provide an easy way to access, download and visualize the key SWOT variables such as water surface elevation, width, slope, discharge, and quality flags. The prototype developed by the team is currently being developed into a full-fledged global app by CUASHI. This app will serve as a valuable tool for both experts and non-experts of SWOT, addressing a requirement of our stakeholders to have an easy way to access SWOT data. The project's focus on Alaska river discharge of centered around using SWOT data to improve discharge computation in the monitoring of ungauged rivers. Coincident with SWOT overpasses, the team will conduct targeted field measurements to generate a gage-constrained discharge product, effectively improving the quality of discharge derived from SWOT data.

4.2.7 Northeastern University, Ed Beighley—Integrating SWOT Data Products into Applications

This project includes several activities designed to assess various calibration activities using SWOT BPV data and models. The North Carolina study includes development of a near-real-time flood mapping system using the National Weather Service National Water Model and Height Above Nearest Drainage (HAND) mapping method. They are calculating HAND using Federal Emergency Management Agency (FEMA) 100-year flood maps but will transition to using SWOT WSE for calibration. This study is funded by the NASA Water Resources program and will assess the capability of SWOT to represent target rivers (SWORD) as well as smaller rivers. This work is based on SWOT simulated data. A second study, Terrestrial and Carbon Export to Ocean utilizing SWOT, uses gauge data to estimate discharge and link to remotely sensed carbon to estimate fluxes. It also uses a simulated SWOT time series with uncertainties added to show that carbon flux is largely driven by hydrology. A third study explores SWOT KaRIn pixel cloud products compared to gauge data and found this method shows promise for seeing rivers smaller than SWORD rivers.

4.2.8 U.S. NRL, Gregg Jacobs—SWOT Ocean Forecasts

NRL is determining best practices in assimilating SWOT KaRIn SSH data into ocean forecast models by first characterizing the along-track errors in the BPV data and determine necessary corrections. A daily interpolation of nadir altimeter data is computed and then sampled at SWOT crossover locations. They are finding good agreement between their corrected SWOT estimates and interpolated SSH from nadir altimeters. Ocean forecast experiments based on California SWOT crossover CalVal sites were conducted. Initial work has identified new methods to improve their model's predictive skill in forecasting smaller features previously unresolved by the existing nadir altimeter constellation, and therefore not represented in their forecasts. NRL has had success in assimilating KaRIn data with resolution scales down to 5 km along the swath.

4.2.9 IIT, Indu Jayaluxmi—SWOT Data for Indian Hydrology: Preliminary Results and Ongoing Works

IIT have developed a web dashboard visualization tool to assess the impact of satellite WSE assimilation from Jason 2, Jason 3, and Sentinel 6 for flood hydrographic model improvement over India. Their work involves post-launch evaluation of SWOT pixel cloud data, making comparisons with other data sources. In addition, they are looking at flood discharge estimation on Indian rivers using SWOT, including collaborations with SWOT EA University of Bonn (Luciana Fenoglio) near the coasts. Challenges for their work include data gaps, for example, for the upcoming monsoon season beginning in the region in June.

4.2.10 Mercator Ocean International (MOi), Pierre Yves Le Traon—Impact of SWOT for Global Ocean Prediction

The Copernicus Marine Service is a long-term European Union capability for ocean monitoring and forecasting. Cooperative work between the French CLS and MOi is being carried out with CNES. This work will prepare for the assimilation of SWOT data into MOi and Copernicus Marine Service. The primary contribution of SWOT is in constraining small scales in models. Very positive preliminary results are seen using CNES Level-3 (L3) products as part of a demonstration project. A SWOT demonstration model project for MOi global forecasts is planned for spring 2024. SWOT KaRIn data will be integrated into the operational Copernicus Marine Service operational forecast portfolio in 2025.

4.2.11 Water in Sight, Guy Schumann—Exploring New In Situ Observations and SWOT Integration in Malawi

Malawi is the first test case for Water in Sight for establishing a database with a government-funded citizen science crowdsourcing project to report in situ gauge data via cellphones, as river level observations in the country are currently manually collected. The data is integrated in a cloud platform from which data can be accessed. This method can be used for SWOT CalVal, and SWOT can also provide validation for in situ data. The simple but useful data platform and integration system was shown. SWOT data will be integrated when it becomes available in early 2024 and will be assimilated into 2D flood models on the lower Zambezi River. Issues of latency and gaps/challenges in assessing and optimizing hydrologic networks and in situ data will need to be addressed. To accomplish this, Water in Sight suggests co-designed joint explorations, engagement activities, and technology alignment. The CNES hydroweb tool may be very useful for this, but interoperability challenges will have to be overcome. Two-way collaborations with PO.DAAC and hydroweb and data APIs can support advancement of this tool.

4.2.12 Argentine Water Resource Centers, Ricardo Szupiany and Paula Torre Zaffaroni—Utilization of SWOT Data for Water Resources Management for Lakes and Large Rivers in Argentina

The SWOT one-day CalVal orbit contained one crossover point in South America, and that point was in a location in Argentina with numerous lakes and the anabranching Parana River. The Parana is the 9th largest river by discharge globally and has important economic value for the region. The proposed work for this project was 1) evaluate discharge estimated from SWOT, 2) evaluate and develop additional river properties needed to improve discharge estimates, and 3) use SWOT to better understand river system dynamics. Field work to support these objectives was carried out from March to June 2023. SWOT EA project work evaluated SWOT products for lake and lagoon assessments with the goals of developing methods to estimate surface water level gradients, identifying fast- and slow-responding lakes, and providing improved tools for water management. Emphasis in 2024 will be to work on SWOT CalVal and comparisons.

4.2.13 PCRWR, Bareerah Fatima—VIC Model for Floods

Fresh water resources in Pakistan from precipitation/surface water and groundwater are not well accounted for or controlled with respect to flooding hazards, soil moisture variations, and other scenarios related to climate change (referencing the UN Sustainable Development Goal 6.6.1, “Changes in the extent of water-related ecosystems over time”). SWOT can support assessments of “hill-torrent” flood potential for the purpose of installing flood early warning stations. PCRWR is very interested in utilizing SWOT data, tools, and capabilities, and needs support from the EA community and science team, perhaps in the form of joint work and collaboration.

4.2.14 NASA U.S. Air Force Weather LIS, Jerry Wegiel

The Global Hydrology Intelligence (GHI) system (rebranding of LIS) is a comprehensive framework for hydrologic analysis, forecasting, and projections across scales. LIS was initially a software framework for simulating land/hydrology processes by integrating various models and assimilating Earth observation data for global hydrology modeling. The Air Force Weather Service is used by multiple agencies with high impact for operational use. Widely used products are daily, 10-km scale, and near-real-time. GHI forecast subsystems encompass all aspects of water security and address significant hydro-intelligence gaps identified by the defense and national security communities. GHI will transform the way the U.S. government conducts hydro-related business going forward. The U.S. Department of State is a key stakeholder, including for climate adaptation. Integration of SWOT Level-2 (L2) products operationally into the LIS Hydrological Modeling and Analysis Platform (HyMAP) model is expected to provide for a global hydrological model data analysis system and improve extreme hydrological event monitoring, reduce forecasting uncertainty, and support water security conflicts. To do this, LIS needs quality-controlled, operational, low-latency L2 data for routine assimilation. This is the emphasis of this SWOT EA project and is an opportunity to demonstrate SWOT value at an operational center.

4.2.15 National Water and Sanitation Agency (ANA) of Brazil, Alexandre de Amorim Teixeira and Alexandre Abdalla Araujo—Mapping Brazilian Rivers and Water Bodies Using SWOT Satellite: Challenges and Opportunities

ANA hydrography datasets and water maps have extended the SWORD river reaches significantly in Brazil (over 400,000 reaches compared to 20,000 reaches) as demonstrated in an overlay of the two databases. The ANA EA project objective is to evaluate SWOT to support water resource management in Brazil. ANA is working in collaboration with University Brasilia to integrate available gauge information on rivers and reservoirs to fulfill their mandate to determine and report on water availability in the country. A sophisticated “Hexagonal Hierarchical Geospatial” indexing system was discussed that will support hydrological and hydrodynamical modeling and cross-validation. They are considering which SWOT data product (pixel cloud or raster) will best serve their needs and are very interested in gaining from shared experiences on best practices from this community.

4.3 DATA SYSTEMS AND PRODUCTS FOR EARLY ADOPTERS

In the early days of the SWOT EA Program, science and EA project teams were limited to using similar or proxy datasets (for example, Jason 2 and Jason 3 satellite data and in situ data), which were missing important structural components of actual future SWOT data products.

In 2021, the SWOT Project and Science Team made simulated datasets available for select hydrologic and oceanographic regions. These datasets shared many characteristics (with respect to file format, content, volume, etc.) with future SWOT data products and were intended to familiarize users with the format and content of the expected SWOT science data products, including their formats, metadata, and data contents so as to begin preparations enabling the incorporation of SWOT into their systems.

At this meeting, teams from both the NASA and CNES mission data system and data repositories shared timely and valuable information and updates with the EA community. The following talks provided the key information and insight into what users can expect from SWOT products. The order of talks follows the presentation order indicated in Table 2 and Table 3.

4.3.1 Hydroweb and AVISO Introduction to SWOT Data Access— Lionel Zawadzki (CNES) and Cyril Germineaud (CNES)

The SWOT data distribution system for CNES is through the AVISO (https://www.aviso.altimetry.fr/en/home.html) and hydroweb.next (https://hydroweb.next.theia-land.fr) data portals. The AVISO portal is focused on ocean and coastal user communities with a wide range of ocean, sea ice, and winds products. BPV data is currently available and will be updated with public release of validated and operational data. Hydroweb.next hosts both ocean and hydrology data (currently pre-validated and then publicly released when available) for all users. Systems supporting data access include data acquisition and production, data repositories (which lead to distribution services), and ultimately cloud data access via thematic portals. Their data offerings will be updated as new data is processed.

4.3.2 PO.DAAC-NASA Data System Overview—Catalina Taglialatela (JPL) and Cassandra Nickles (JPL)

Both HR and low-rate (LR) SWOT data from NASA are available through PO.DAAC. PO.DAAC will provide centralized access to SWOT data (as well as many other NASA Earth observations) from dedicated portals through which data from missions PO.DAAC is responsible for can be searched and accessed either on premises or via in-cloud Amazon Web Service (AWS), or through the NASA EarthData portal. Access includes free download and in-cloud direct data access. In addition to overview information about SWOT, a PO.DAAC data demonstration closed the first day of the workshop. The PO.DAAC Cookbook: SWOT Chapter resources and tutorials were demonstrated, as were the new Hydrocron SWOT time series API for generating time series over water features identified in SWORD and SWODLR, a SWOT on-demand L2 raster generator tool. Further information about the data and resources available can be found at https://podaac.jpl.nasa.gov/SWOT?sections=data.

4.3.3 SWOT Data Management and Products Status/Plans—Shailen Desai (NASA)

A complex and sophisticated processing data flow developed jointly by NASA and CNES illustrates the interrelated nature of the entire measurement system. A cascading dependence begins with the need for highly accurate upstream orbit and attitude products to produce accurate radiometer products. Nadir altimeter products depend on upstream orbit, attitude, and radiometer products, and KaRIn products depend on all of those for optimal accuracy. Plans are in place to release pre-validated KaRIn products in early 2024. Product description documents and algorithm theoretical basis documents (ATBD) are all publicly available.

4.3.4 Evaluating SWOT's Capability in Observing Small Scale (<100 km) Sea Surface Height—Jinbo Wang (NASA)

The SWOT ocean calibration and validation campaign has produced critical verifications of SWOT retrieved ocean sea surface heights (SSH). This discussion was based on the question of whether SWOT measurements at scales smaller than 100 km represent ocean physics. A significant history of development in the potential of the SWOT measurement system to answer this question began in 2016 with observation system simulation experiments (OSSEs). These were followed by several field campaigns between 2017 and 2020, and a post-launch CalVal campaign. The conclusion is that KaRIn meets the science requirements of accurate measurements at scales below 100 km.

4.3.5 Features of KaRIn Data that Users Should Be Aware Of—Curtis Chen (JPL)

Because of the complex nature of the novel KaRIn measurement, it is extremely important for users to understand all aspects of the data to ensure robust interpretation of the results. The SWOT science data system team has attempted to reduce the complexities of the measurement for users as much as possible, but many items that may not be immediately intuitive remain. Knowledge of measurement details may be especially important in trying to interpret the pre-validated data products. This talk addressed practical aspects of interpreting KaRIn data products, including answers to frequently asked questions and tips to avoid misinterpretation and confusion in using the data. The proclivities of cross-track correlations, quality flags, uncertainty estimates, and crossover calibration corrections are just a few of the many other features of the data that will benefit expert and new users alike. Slides and a recording of the talk are available at https://swot.jpl.nasa.gov/internal_resources/738/.

4.3.6 Products L3&L4 Ocean CNES—Yannice Faugere (CNES)

For operational and applied user communities, higher-level products provide for higher-level applications, such as mapping and data assimilation. CNES has a formal plan for L3 products through the science team project Developing an Effective assimilation of SWOT data in Mercator Ocean Systems-II (DESMOS II) with PI and SWOT EA for Mercator Ocean Pierre-Yves Le Traon. This product has value-added elements, including multi-mission calibration, noise mitigation, and images that blend KaRIn and nadir instruments. Version 1.0 of an L3 product is expected in early 2024 based on reprocessed L2 data. A preliminary assessment of Level-4 (L4) products was conducted using one-day CalVal orbit measurements with promising results. Tests on 21-day data are forthcoming. An L4 “data challenge” is underway in order to gain community feedback and for comparison of mapping and validation methods in select regions of the ocean. See https://ocean-data-challenges.github.io.

4.3.7 AVISO and hydroweb.next—Lionel Zawadzki (CNES) and Cyril Germineaud (CNES)

Data center elements closed with a demonstrations of the AVISO and hydroweb.next portal for accessing SWOT data, CNES Cloud Support for project hosting, and the CNES JupyterLab Interface.

4.4 COMPLEMENTARY PROJECTS

A number of other projects and programs represented at this meeting are funded variously by NASA Earth Action Water Resources, other NASA programs, the World Meteorological Organization’s (WMO’s) Global Energy and Water Exchange (GEWEX) program, or other programs. These projects include elements that are focused on, including, or relevant to SWOT Applications. The PI, director, or lead for the projects listed below generously shared their time to contribute to the success of this meeting. The order of talks follows the presentation order indicated in Table 2 and Table 3.

4.4.1 G-REALM: Reservoir Database—Charon Birkett, PI (NASA)

The Global REservoir and LAke Monitoring (G-REALM) portal sponsored by the U.S. Department of Agriculture (USDA) and NASA hosts a 30-plus-year time series of nadir altimeter data from the NASA/CNES reference missions for this measurement (Topex/Poseidon; Jason 1, 2, and 3; Sentinel 6) as well as the European Remote Sensing (ERS), Satellite with ARgos and ALtiKa (SARAL), Sentinel 3, and other satellite observations. A second portal, Global Water Measurements (GWM), is focused on lakes and reservoirs, rivers, and wetland water levels to derive surface extents and storage change. SWOT will be integrated into both G-REALM and

GWM to integrate nadir (USDA-supported) and KaRIn (will require NASA support) to improve global coverage of smaller lakes and surface extents.

4.4.2 NASA Applied Science Program (ASP) Water Resources (WR) PI: Tracking Fresh Water from Space for Congo River Water Resources Management and Water Related Decision-Making—Chandana Gangodagamage, PI (NASA)

This project is a collaboration between NASA Goddard Space Flight Center (GSFC), University of Maryland, USGS, Congo Basin Water Resources, and the University of Kinshasa. The geographic scope includes a large swath of central Africa encompassed by the Congo Basin. Using a number of NASA and European Space Agency (ESA) data, products, and tools, including the reference altimetry missions and SWOT, the project objective is to partner with a broad community engaged in research and management of this region and to support the Congo Basin Water Resource and Modeling Tool for key decision-making in the basin.

4.4.3 WWAO Overview and Example Projects and Needs SWOT Potential—Stephanie Granger (JPL)

The Western Water Applications Office (WWAO) is a NASA Earth Action program established in 2016 with a mission to directly benefit water management in the western U.S. by getting NASA data, technology, and tools into the hands of western water managers. The WWAO Team completes "needs assessments" for basins, which is a challenging management activity because over 100 agencies are involved in water management in the western U.S. Several needs and future projects identified could benefit from SWOT data, such as extreme event predictions and impacts, timely streamflow predictions at a sub-basin level, wet/dry indicators from streamflow monitoring, and flood plain mapping.

4.4.4 Evaluation of a 4DVAR Assimilation System in the California Current at the SWOT Calibration/Validation Site—Babette Tchonang (JPL), Dimitris Menemenlis (JPL), Matt Archer (JPL)

The study evaluates the feasibility of applying the Massachusetts Institute of Technology general circulation model—Estimating the Circulation and Climate of the Ocean 4-Dimensional Variational (MITgcm-ECCO 4DVAR) data assimilation framework to a submesoscale resolving model (grid resolution of 1 km). This regional model implementation is in preparation for future studies to understand and eventually assimilate novel SSH measurements from the SWOT satellite. The model domain is centered at the SWOT CalVal site, located 300 km offshore of Monterey Bay, California. The project focuses on reconstructing the ocean variability at this site by assimilating hydrographic observations from a linear array of three moorings between September and December 2019. Two model solutions are analyzed: 1) a first-guess, or non-assimilating forward run and 2) an optimized data assimilation run, which assimilates the in situ observations. Both runs are nested within the global 1/12° Hybrid Coordinate Ocean Model (HYCOM) / Navy Coupled Ocean Data Assimilation (NCODA) analysis. The performance of this system is evaluated by comparing the two model solutions against assimilated and withheld in situ observations. This study indicates for the first time that the MITgcm-ECCO 4DVAR framework can be successfully applied to the reconstruction of submesoscale ocean variability via nesting a high-resolution regional domain into a large-scale global outer domain. This data assimilation system is now being used by Scripps Institution of Oceanography to support SWOT post-launch activities. Other contributors to this work include Ganesh Gopalakrishnan, Bruce Cornuelle, and Matthew R. Mazloff from Scripps Institution of Oceanography, and Jinbo Wang and Lee-Lueng Fu from JPL.

4.4.5 GEWEX and SWOT—Peter van Oevelen (GEWEX)

The goal of GEWEX is to facilitate international research collaboration at a programmatic level to advance biogeophysical climate and weather research with a focus on water and energy. As

SWOT will observe surface water, there may be opportunities to support prediction of the Earth's water cycle in contexts relevant to GEWEX goals. Goals that may be supported by SWOT measurements include determining the rate of change in reservoirs (land surface and atmospheric) and spatial characteristics and predictability of change through model evaluation. Understanding and quantifying how exchanges between water, energy, and carbon are determined by large-scale circulation of the ocean and atmosphere can influence our ability to predict these changes across scales. SWOT certainly can help assess and quantify water flux exchange processes.

4.4.6 OPERA—Matt Bonnema (JPL)

The Observational Products for End-Users from Remote Sensing Analysis (OPERA) project produces a suite of surface water extent products, Dynamic Surface Water extent (DSWx), based on a variety of optical and radar sensors. These are higher-level data products built on existing satellite data and are freely available from NASA. The water extent observations provided by these products are complementary to SWOT in several ways. While DSWx only gives two dimensions of surface water measurements (spatial extent) and SWOT gives three (spatial extent and elevation), DSWx has a much higher revisit time (~1–2 days on average) compared to SWOT's 10 days on average. There is potential for DSWx to fill in temporal gaps between SWOT observations, and there is potential to cross-compare DSWx and SWOT when observations are concurrent. Ultimately, DSWx is a valuable source of global water information that can be used to interpret and enhance SWOT's capabilities.

4.4.7 NASA ASP WR PI: Multi-Platform Water Surface Observations to Support U.S. Army Corps of Engineers (USACE)—Renato Frasson (JPL)

National to global water availability stressors can be a source of social unrest. The USACE supports the National Geospatial-Intelligence Agency (NGA) using water storage and lake/reservoir flux information primarily from NASA's MODerate resolution Imaging Spectroradiometer (MODIS) satellite. Higher spatial resolution SWOT (specifically, river widths) and NASA-ISRO Synthetic Aperture Radar (NISAR) observations are planned to be incorporated into the OPERA platform in the third year of this project for water surface extent determination. An example in the Indus River demonstrated that optical data has resolution challenges. Adding multisensory technologies can improve the knowledge base for drought response, cascading threats to water supplies, and infrastructure assessment.

4.4.8 SWOT Modeling Water Surface Topography—Cedric David (JPL)

Urgent environmental and societal challenges exist and are growing in global river system science. Some of these include increased flooding, threatened water security and transboundary issues, endangered river biodiversity, and changing deltas. SWOT can support improvement in state-of-the-art hydrologic modeling, such as the U.S. National Water Model, by advancing knowledge of surface water dynamics. Model advancements can be realized in areas such as uncertainty quantification, data assimilation, and bias correction, and particularly in a condition of decreasing numbers of in situ observation systems. The future of river modeling will improve the ability to understand and effectively manage this critical and threatened resource.

5 SWOT IN MODELS

5.1 SURVEY

This meeting was an opportunity to share early experiences with the data and to look ahead in the near term and to future integrations of SWOT into operational and decision-support workflows. We are particularly interested in understanding more about the use of SWOT in models and model systems. Few applications can be accomplished through direct use of SWOT observations. Instead, it is expected that SWOT data will be integrated into models of some kind (e.g., ocean circulation, hydrologic, hydrodynamic, decision support). Understanding the processes employed by EAs to integrate SWOT data and the associated challenges is critical for maximizing SWOT's societal impact and provides a clear analytical path for assessing the value of SWOT's observations.

With the early release of SWOT BPV data to the SWOT Science Team and to SWOT Applications EAs, we reached out to our user community who are using or expect to use SWOT data in a local or community-wide model or modeling system with a pre-meeting survey. We solicited feedback and perspectives on needs, expectations, and readiness for use of SWOT data in their models. Table 4 shows the survey questions.

	SWOT Model Survey Questions
1	What is your organization, group, or model?
2	Are you using or planning to use SWOT in a modeling system?
3	How mature are your plans to use SWOT? For example, are you integrating SWOT data already? Or are you planning to use it in the future?
4	What is the context of the SWOT measurement in your model—where in the model is it anticipated to be? Plugged in where (i.e., is it a forcing? A constant? Are you doing data assimilation?)
5	What is your thematic area?
6	How applicable is SWOT data for your thematic area? Please elaborate.
7	Are there any major constraints/issues to adoption of SWOT for your use (i.e., ease of access, ease of use, data format, data resolution/accuracy/quality, spatio-temporal sampling)?
8	What data are you currently using and how are they incorporated into the model (e.g., data assimilation?)
9	Will SWOT replace existing data assets (that may be a lower res), or are you building new capabilities with SWOT? Are you swapping for modeled data?
10	How are models being adapted to the new data? Is there synergistic use of multivariate data from different missions, platforms, formats (e.g., in situ, remote sensing, data assimilation, models)?
11	How do you expect SWOT to improve your model? Quantitatively or qualitatively?
12	Is there anything else you would like to share?

Table 4. Survey questions distributed prior to the 10th SWOT Applications Meeting to assess information about the expected use of SWOT data in models and model systems.

5.2 FEEDBACK

Feedback within the model survey and in meeting discussion periods contained thematic consistencies related to data availability, data latency, and long-term outlook for continued measurements from SWOT and wide-swath radar observations. Although the sample was not representative of the thematic mix of EAs (weighted towards oceanography), responses revealed several broad expectations by EAs and possible opportunities for further support of applied user communities by the SWOT Project and SWOT Applications Program. Some key findings provided relevant information on opportunities and possible challenges of integrating SWOT in model systems:

- Responding organization types included a mix from U.S. federal agencies, universities, NASA centers, and private companies.
- Thematic areas were represented across the spectrum of rivers, lakes, oceans, and coastal regimes.

- Over 85% of respondents intend to use SWOT in their modeling systems, indicating that our sample was heavily represented by groups already familiar with and sophisticated in modeling methodologies.
- Some constraints on adoption of SWOT data were reported.

Figure 3 indicates that some EA respondents plan to use SWOT in model systems, within a broad spread of application domains. The expectation is that the data will be generally useful for integration and use in their systems and will be used in conjunction with other and existing datasets and systems.

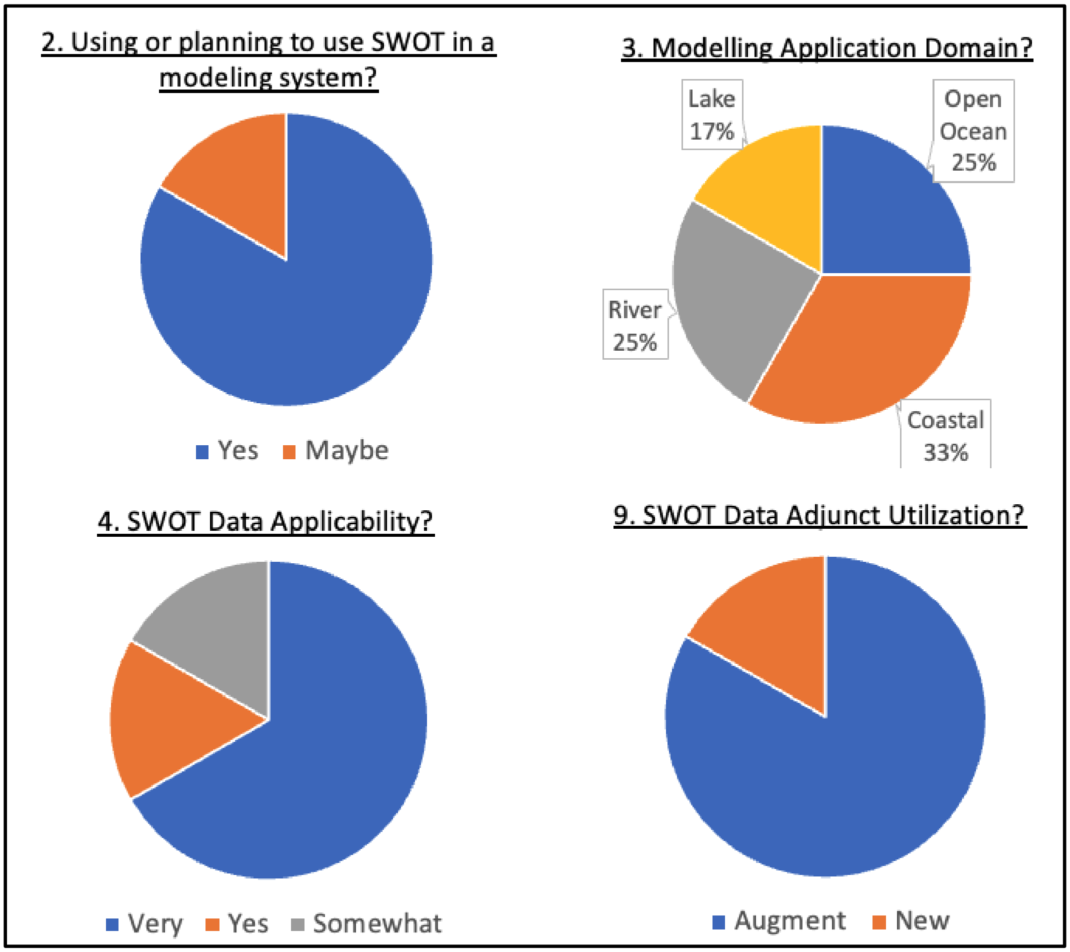

Figure 3. Responses from questions 2, 3, 4, and 9 of the SWOT Applications model survey.

Select feedback and inputs from model survey questions in Table 4 not illustrated in Figure 3 are given in Table 5.

Select Survey Questions	Collated Survey Answers
5. Mode of SWOT data usage?	• Independent data for comparison to model data assimilation analysis • Ocean model & forecast system data assimilation • Flood model data assimilation
6. Integration effort maturity/readiness?	• “Aspirational” as time permits • Preparations to support SWOT data/format ingestion • Preliminary effort using simulated datasets

Select Survey Questions	Collated Survey Answers
	• Initial demonstration capability by Q2-2024 with Validated SWOT data
7. Constraints to uptake in modeling applications?	• No constraints • Data Latency • Ease of Access • Data format (specialist oriented) • Funding • Computing resources • Need for reconciliation in terms of datum with other altimeter satellites
8. Currently assimilated data types?	• All relevant nadir altimetry • Supporting SST, SSS • In-situ (various types)
10. Expected utility/value-added?	• Improve model resolution and improve data assimilation techniques to better constrain the smaller scales • Better constraint for the ocean mesoscales and better thin sea ice estimates • Improve accuracy of simulated hydrological processes that will directly impact the certainty of hydrological forecasts • Reduction of errors in ocean analyses/ forecasts

Table 5. Select questions and answers from SWOT Applications pre-meeting survey on model and modeling systems.

5.3 OUTCOMES

Although the SWOT nadir altimeter data products are being operationally produced and distributed through the data centers, we understand that it is still very early days for assessing the brand-new data products from the novel KaRIn instrument. On the order of a full year of data will be necessary to make a more comprehensive assessment of value, ease of use, and degree to which SWOT data will impact operations and decision-making.

Throughout the workshop, EAs shared their experiences and specific needs in regard to early use of SWOT data in their modeling frameworks. Overall impressions were positive; “Everyone is excited about SWOT within African Governments,” said Guy Schumann of Water in Sight. However, it was also acknowledged that actual use of SWOT beta product data was limited. Exceptions to this illustrated at the meeting included the U.S. NRL, which has already successfully integrated the SWOT beta product into its ocean models and demonstrated improvement over the model without SWOT data (refer to section 4.2.8) and demonstration by the USGS of great progress toward integrating SWOT into its new streamflow data portal (see section 4.2.3). Similarly, Sofar Ocean (see section 4.2.4) has already incorporated SWOT nadir altimeter data (significant wave height) into its operational ocean state assessments, and the Copernicus Marine Service, as described by EA Mercator Ocean (see section 4.2.10), has found very positive preliminary results in using CNES L3 products in constraining small scales in ocean models in a demonstration project.

Despite these early signs of success and overall positive response to the early data testing, both NRL and USGS expressed need for lower-latency products. Gregg Jacobs of the NRL reported that “people need regular near real time data for ocean applications of forecasting. Analysis of existing data is very valuable, and the data enables great progress. End users also want to know that the advancements lead to information for daily decisions. The daily decisions need low latency data.” In the coming year, it is expected that the impact of SWOT data with lower 21-day science orbital repeat frequency and latency on various applications will be understood further. Ultimately, the most important feedback from early users of SWOT is yet to come. The EA community showed great enthusiasm for SWOT data, and EAs are eagerly awaiting the next release of data. Capturing this feedback and providing technical support for EA projects as they navigate the full release of SWOT data was identified as a top priority.

6 FUTURE PLANS

6.1 SUMMARY

The 2023 SWOT Applications meeting was a successful and timely engagement opportunity, further strengthening the connection between the SWOT Project, the SWOT science community, the SAWG, and the user community. Many EAs demonstrated early ingest of the preliminary release of KaRIn data, with some having already started using the nadir altimeter data in their operational processes. As more data, including pre-validated and validated science products, become regularly available, we will continue to engage with, support, and communicate with the EA community.

Going forward, we will focus on strengthening the connections between the science community and the SWOT EAs. Feedback from the EA community to the science data system team and the science community on experiences, data interactions, challenges, and data issues can improve the data products for all.

Interaction and collaboration between EAs and the data centers is well established. PO.DAAC and hydroweb/AVISO regularly participate in Applications meetings, workshops, hackathons, and telecons. We will continue to foster this connection with the data centers and provide them with valuable feedback on data access experiences from the Applications community.

Past SWOT Applications meetings and support of EAs was focused on introducing and familiarizing the community with mission capabilities as well as expected data products and management. Our forward focus will be for the SWOT Applications team to work together with EAs, other applied science users, data centers, and the project and science communities to advance the use of SWOT in the multitude of operational systems that will incorporate SWOT data.

We recognize a continued need for training with pre-validated and validated SWOT data for our existing and new EAs. Continued cooperation and collaboration with the data centers to provide training on accessing and manipulating data from and within the cloud will continue to provide high value to current and future EAs. Continued guidance and engagement from the SAWG, the SWOT Project, and SWOT Science Team members for troubleshooting problems will remain valuable benefits.

6.2 ACTION ITEMS FOR FUTURE SWOT APPLICATION ACTIVITIES (2024–2025)

The following are foci for future SWOT Applications activities that were identified based on feedback from EAs and in the discussion sessions of the meeting:

1. Communicate value of SWOT for rivers, estuaries, ocean, and coastal topics at community meetings and conferences.
2. Work to identify key models and modeling communities that are and can use SWOT in support of decision makers and operational agencies.
3. Communicate value of SWOT for water inundation modeling and detection and promote the knowledge from and about these communities.
4. Work with NASA and CNES data distribution centers on training in cloud data access and the variety of data formats (raster, vector, pixel cloud) to assess needs

and preferred formats for topics and provide EA feedback to improve data products and platform services.

5. Communicate the multitude of applications examples using SWOT data from our community to broad audiences in order to engage increasing numbers of users for both applied research and operational activities.
6. Work with EAs to overcome technical hurdles, help complete their projects, and generate high-impact success stories.
7. Continue to expand the extent of SWOT EAs and applied science users to build recognition of SWOT among practitioners and enable community-driven solutions to challenges pertaining to the use of SWOT data.

Documenting this journey of early and focused use of SWOT data will benefit the entire EA and future applied science user communities and will provide the SWOT Project with important insights into how the data is being used, allowing for optimizations and improvements. Peer-reviewed publications are one way to share the work and interests of the EA community. We encourage all to share any peer-reviewed publications that involve SWOT EA projects. These can then be shared on the SWOT Publications portals page of the SWOT website.

6.3 CONTINUING COMMUNICATIONS

Quarterly telecons for the SWOT EA Program are opportunities to share progress, ask questions, get help, express interest or concerns, and interact with other SWOT EAs. We encourage all EAs to participate in these. We distribute a periodic SWOT Applications Newsletter, and we invite the EA community to contribute to this. We plan to continue annual SWOT Applications meetings (in the form of meetings, workshops, or hackathons, as appropriate).

7 APPENDICES

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