AGU ADVANCING EARTH AND SPACE SCIENCE

AGU Advances

COMMENTARY
10.1029/2022AV000680

Key Points:

- Planned satellite earth missions today require proactive engagement with a broad user community
- The Surface Water and Ocean Topography Early Adopter program represents the start of what is possible through sustained engagement with stakeholder community
- Such early engagement is a template for other planned satellite Earth missions to maximize the return on public investments in such missions

Supporting Information:

Supporting Information may be found in the online version of this article.

Correspondence to:

F. Hossain,
fhossain@uw.edu

Citation:

Hossain, F., Das, P., Srinivasan, M., Tsontos, V., Oaida, C. M., Nickles, C., et al. (2022). Building user-readiness for satellite Earth observing missions: The case of the Surface Water and Ocean Topography (SWOT) mission. *AGU Advances*, *3*, e2022AV000680. https://doi.org/10.1029/2022AV000680

Received 15 FEB 2022
Accepted 14 SEP 2022

Peer Review The peer review history for this article is available as a PDF in the Supporting Information.

Author Contributions:

Conceptualization: Faisal Hossain
Methodology: Faisal Hossain
Supervision: Nadya Vinogradova-Shiffer
Writing – original draft: Faisal Hossain
Writing – review & editing: Faisal Hossain, Pritam Das, Margaret Srinivasan, Vardis Tsontos, Catalina M. Oaida, Cassandra Nickles, Jack McNelis, Matthew Bonnema, Nicolas Picot, Santiago Peña-Luque, Bradley Doorn,

Building User-Readiness for Satellite Earth Observing Missions: The Case of the Surface Water and Ocean Topography (SWOT) Mission

Faisal Hossain[1], Pritam Das[1], Margaret Srinivasan[2], Vardis Tsontos[2], Catalina M. Oaida[2], Cassandra Nickles[2], Jack McNelis[2], Matthew Bonnema[2], Nicolas Picot[3], Santiago Peña-Luque[3], Bradley Doorn[4], Nadya Vinogradova-Shiffer[4], Alice Andral[5], Lucile Gaultier[6], Indu Jayaluxmi[7], John Zhu[8], Nelun Fernando[8], Faizan Ul-Hasan[9], Bareerah Fatima[9], Mufeezah Ahsan[9], C. T. Dhanya[10], Susantha Jayasinghe[11], Chinaporn Meechaiya[11], Miguel Barajas[11], Vivek Balakrishnan[12], Hisham Eldardiry[13], Mohamed Elkholy[13], Ahmed Abdelrazek[13], Luciana Fenoglio[14], Mike Durand[15], Rui Wei[15], and Tamlin Pavelsky[16]

[1]University of Washington, Seattle, WA, USA, [2]NASA Jet Propulsion Laboratory, California Institute of Technology, Pasadena, CA, USA, [3]Centre National d'études Spatiales, Toulouse, France, [4]NASA Headquarter, Washington, DC, USA, [5]Collecte Localisation Satellites, Ramonville Saint Agne, France, [6]Oceandata Labs, Plouzané, France, [7]Indian Institute of Technology - Bombay, Mumbai, India, [8]Texas Water Development Board, Austin, TX, USA, [9]Pakistan Council of Research in Water Resources, Lahore, Pakistan, [10]Indian Institute of Technology - Delhi, Hauz Khas, India, [11]Asian Disaster Preparedness Center, Bangkok, Thailand, [12]Centre for Water Resources Development and Management, Kozhikode, India, [13]Alexandria University, Alexandria, Egypt, [14]University of Bonn, Bonn, Germany, [15]The Ohio State University, Columbus, OH, USA, [16]University of North Carolina, Chapel Hill, NC, USA

Abstract The goal in this commentary is to share the development of the NASA Applied Science pre-launch protocol called the Early Adopter Program (EAP) that is designed to build user-readiness of planned satellite Earth observing missions *proactively and before the launch*. Here we focus in particular on the Surface Water and Ocean Topography satellite mission EAP as an illustration of benefits of such a program of proactive and sustained user community engagement. Such a commentary will be of value to other satellite Earth observation missions that are currently in service, scheduled for launch or prioritized for development in the near future.

Plain Language Summary The commentary sheds light on the many years of preparation for a planned satellite mission for surface water (Surface Water and Ocean Topography mission) to make the data as user-ready as possible. We believe such a commentary may be of interest to other communities involved in planning, operation or use of other satellite missions.

1. Introduction

Of the many ways Earth observations can be measured, collected, and archived, the vantage from space using satellite remote sensing offers the most synoptic, regular option at scale with seamless global spatial coverage and temporal continuity. In the field of Earth science, satellite remote sensing has contributed to numerous disciplines with the launch and continuation of Earth-observing satellites dedicated to routinely monitoring the pulse of our planet. For example, improvement in our ability to model and analyze physical processes can now be clearly attributed to satellite remote sensing applications in hydrologic science (Durand et al., 2021; Lettenmaier et al., 2015; Peters-Lidard et al., 2018), atmospheric sciences (North et al., 2015), numerical weather prediction (Bauer et al., 2015) and ocean science (Fu & Cazenave, 2000; Martin, 2014), just to name a few. Such advances continue to proliferate and enable more multidisciplinary scientific research.

According to the Union of Concerned Scientists, there have been about 1,000 satellites launched for Earth observation or Earth science out of more than 7,000 launched in total to date (UCS, 2021). The year 2021 witnessed a near-30% increase in the number of satellites launched compared to 2020 (UN Office for Outer Space Affairs, 2021). Despite the increasingly common use of satellites to understand the Earth, each satellite mission experiences its own evolution. For example, the Landsat mission today (in 2022) stands as the longest, continuously recording mission with 50 years of Earth surface data. The Landsat Advisory Group of the National Geospatial Advisory Committee (NGAC) reported that the top applications of Landsat imagery produced savings

Alice Andral, Lucile Gaultier, Indu Jayaluxmi, John Zhu, Nelun Fernando, Faizan Ul-Hasan, Bareerah Fatima, Mufeezah Ahsan, C. T. Dhanya, Susantha Jayasinghe, Chinaporn Meechaiya, Miguel Barajas, Vivek Balakrishnan, Hisham Eldardiry, Mohamed Elkholy, Ahmed Abdelrazek, Luciana Fenoglio, Mike Durand, Rui Wei, Tamlin Pavelsky

of approximately half a billion dollars each year for federal and state governments, non-governmental organizations (NGO), and the private sector (Lauer et al., 1997; NGAC, 2014). In a recent review of satellite nadir altimeter missions, more than a dozen successful societal application use cases were identified spanning a wide range of topics such as sea-level rise monitoring, iceberg detection, potential fishing zone identification, reservoir monitoring, marine wildlife conservation and offshore wind farm design (Eldardiry et al., 2022).

While the primary mission of many space agencies is to provide the necessary Earth observations to advance scientific understanding of the Earth and how it is responding to human and natural drivers of change, an implicit need is also to understand how best to promote the use of satellite mission data products and information for application activities that directly benefit society and the world at large. In this commentary, we share our collective experience in building user-preparedness for a planned mission called the Surface Water and Ocean Topography (SWOT) mission that is scheduled for launch in late 2022. Building on a long heritage of engagement with stakeholders (some of whom are co-authors of this manuscript) via the NASA Applied Science Program (ASP) and French Space Agency (Centre National d'études Spatiales—CNES), we share a summary of where the potential user community stands today for maximizing the value of SWOT data. In particular, our goal in this commentary is to share the development of the pre-launch ASP protocol called the Early Adopter Program (EAP) that is designed to build user-readiness of planned missions *proactively and before the launch of the mission* (Brown & Escobar, 2019). SWOT is a satellite mission that will produce very unique global data on water over land and ocean that is qualitatively different from what the community has. The development of early engagement protocols and necessary training materials via the EAP was therefore recognized as essential to get the broader community ready for such a novel and vital mission for surface water. Our hope is that such a commentary will be of value to other satellite Earth-observing missions that are currently in service, scheduled for launch or prioritized for development in the near future according to the 2018 National Academies on Science, Engineering and Medicine Decadal Survey for NASA (NASEM, 2018).

2. The Uniqueness of the SWOT Mission

The SWOT mission (Andreadis & Schumann, 2014; Biancamaria et al., 2016; Durand et al., 2010; Fu et al., 2009) is jointly developed by NASA and CNES with contributions from the Canadian and UK space agencies. It is designed to provide, for the first time, spatially extensive, high resolution measurements of water elevation for the hydrology and oceanography communities (Morrow et al., 2019). Even though the sampling frequency of SWOT is latitude-dependent (lowest at equator, highest over poles), a large fraction of the Earth's ungauged surface will benefit from multiple SWOT observations in a 21 day repeat cycle (Figure 1). By virtue of its stated scientific goals, SWOT satellite data is expected to have beneficial societal impact in various sectors that involve water, including but not limited to, disaster management, reservoir operations, water management, flood management, ecosystem services planning, wetlands monitoring, hydropower and navigation, fisheries (freshwater and marine), coastal protection, and marine shipping. Readers interested in knowing more about the application potential of the SWOT mission are referred to the SWOT website at http://swot.jpl.nasa.gov or at http://www.aviso.altimetry.fr/swot.

We anticipate SWOT will play a pioneering role in building the world's space-based observational network for surface water similar to the Global Precipitation Measurement (GPM) mission with its constellation of precipitation sensors (Skofronick-Jackson et al., 2017). Current literature indicates that SWOT data will be able to increase knowledge of surface water fluxes, detect ocean features significantly better than current technologies (Fu et al., 2009), improve global water budget calculations in conjunction with other models and satellite observations (see e.g., Allen & Pavelsky, 2018; Andreadis et al., 2007; Durand et al., 2016, 2021; Garambois & Monnier, 2015; Lee et al., 2010; Lin et al., 2019) and estimate unobserved hydraulic parameters (see e.g., Brêda et al., 2019; Emery et al., 2020). SWOT data will also be a pathfinder to discover the human footprint in surface water storage variability associated with the development of water resources (Biswas et al., 2021; Bonnema & Hossain, 2019; Wongchuig-Correa et al., 2020) and bring benefits for the oceanographic community and marine applications (Eldardiry et al., 2022). A brief summary of the scientific measurement requirements of the SWOT mission can be found in Table 1 of Fernandez et al. (2017).

While the SWOT mission has all the ingredients to become an enduring mission for scientific discovery and societal applications due to its open-access and unique capability to observe water surface topography, a key challenge is the structure and format of its data products that are probably unfamiliar to many water scientists,

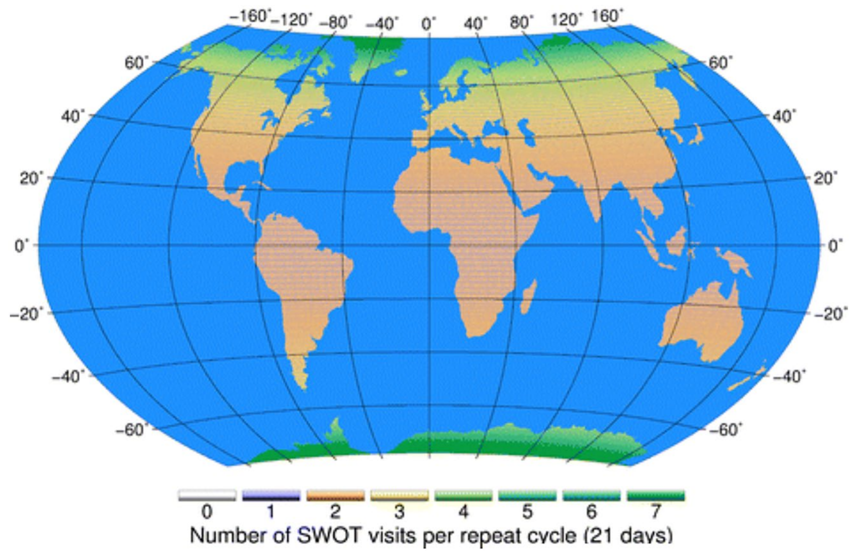

Figure 1. The sampling frequency of the Surface Water and Ocean Topography mission (based on Biancamaria et al. [2016]).

practitioners and decision-makers. Using Synthetic Aperture Radar (SAR) interferometry, SWOT will provide data on water surface elevations in the form of point clouds, that will then be packaged into other more widely used geospatial formats such as feature polygons and raster data (Altenau et al., 2021; Grippa et al., 2019; see also—https://podaac.jpl.nasa.gov/SWOT?tab=datasets). However, there remains a sizable community of water scientists and practitioners who are more accustomed to point-based data from in-situ gauges which have a longer heritage and record of availability compared to remotely sensed data. For them, such spatially distributed formats may present some initial challenges for uptake. This is particularly relevant for hydrology applications while the challenge for ocean applications may be more on the use of the image information from SWOT.

This data format challenge is, however, not insurmountable, as a promising precedent already exists for SWOT and is further mitigated by the adoption of Earth science and Open Geospatial Consortium (OGC) data interoperability standards for SWOT mission data. The history of SAR data usage in general has remained confined to users with high literacy in data science. Recently, this challenge was mitigated for proliferating forest biomass applications by creating the *SAR Handbook* by NASA SERVIR program through a range of SAR workshops for stakeholders (NASA SERVIR, 2019). The handbook, which is open-access, builds on a comprehensive overview of the SAR remote sensing theory to provide detailed step-by-step tutorials on various application areas, such as forest stand height estimation, forest biomass monitoring and deforestation mapping, to name a few. This handbook also walks the reader through ways to access data. Such an example of a SAR handbook can now be emulated for SWOT.

Another challenge for new Earth science data user communities is that of data informatics and access given the high volume of data that the SWOT mission will produce. Data services implemented within cloud computing environments, which no longer require local download and storage of data while offering scalable computing resources, will be the norm for archiving, accessing, analyzing and using SWOT data. SWOT data will be archived by NASA and made accessible via the new Earthdata Cloud. Data from missions such as Sentinel-6 Michael Freilich are already being hosted in repositories where users require some competency in cloud computing (Hausman et al., 2019) or where access to emerging cloud-based data archives is completely transparent to users. However, many among the scientific and end-user community lack such cloud computing literacy, which could inadvertently result in building a stratified, non-inclusive user community and thus defeat one of the objectives of open science movement towards equity and inclusivity. This essential need is a key reason why user-readiness for planned missions such as SWOT needs to be built in a more proactive manner using programs such as the NASA ASP EAP in coordination with CNES application initiatives. Efforts are already under way with the data distribution arm of space agencies (such as the Physical Oceanography Distributed Active Archive Center [PO.DAAC] of NASA, and Hydroweb-Next by CNES for SWOT) to bridge the skill and understanding

Figure 2. The map of current Surface Water and Ocean Topography Early Adopters. Refer to http://swot.jpl.nasa.gov/applications or http://depts.washington.edu/saswe/swot for details.

gap of satellite data users (Hossain, Bonnema, et al., 2020; Hossain, Elmer, et al., 2020; Hossain et al., 2017), and in the case of NASA PO.DAAC, to also build data user literacy for accessing and interacting with data in the new cloud-based paradigm. The scientific community also needs to keep up with advances in data informatics in order to continue its vital role in brokering science-based application data from innovative missions, such as SWOT, for the practitioner community.

3. The SWOT Early Adopter Program

As mentioned earlier, SWOT has had an EA Program (EAP) since 2018 (Hossain, Elmer, et al., 2020; Hossain et al., 2017). In the vision of the EAP, each selected EA (i.e., a potential stakeholder) proposes an activity for the use of planned satellite data using either proxy datasets or simulated data that mimics the anticipated mission during the post-launch phase. EAs are defined as those groups and individuals who will have a potential or clearly defined need for data from the planned mission, and who are planning to apply their own resources to demonstrate the utility of planned satellite mission data for their application, system, or model. Experience from satellite missions such as Soil Moisture Active and Passive (SMAP) indicates that the sooner this pre-launch engagement begins and is sustained, the better the outcomes for use of mission data in areas beyond the declared goals of scientific requirements and data generation (Escobar et al., 2016).

In the case of SWOT, proactive outreach and engagement were carried out in a systematic manner. First, the key features of the SWOT mission and its potential societal value were promoted extensively across a wide range of audience forums, and at various practitioner and science meetings that are usually frequented by non-SWOT science community. Second, potential early adopters were identified and then "encouraged" to explore the SWOT mission and the EAP. Third, based on existing networking relationship maintained by the core leadership of SWOT applications, these potential early adopters were asked to join the EAP after tangible examples were shown on how their involvement could be "win-win" for both the mission and the stakeholder groups. Often times, this outreach and engagement relied heavily on pre-existing institutional relationships and trust between stakeholder agencies and SWOT application scientists. This outreach process is often long, with consistent engagement required through activities such as development of community articles and hands-on workshops to avoid stalling and to maintain fresh and lively interactions between the mission and the evolving needs of stakeholder groups. The need for constant engagement is key as the SWOT EAP is an unfunded program and interest from stakeholder agencies can quickly wane during long periods of inactivity.

In the initial cohort of the SWOT EAP in 2018, 11 Early Adopters (EA) were selected from various hydrology and oceanography domains around the world (Figure 2 provides a general idea of the current geographic distribution). These were: Asian Disaster Preparedness Center (ADPC)/SERVIR-Mekong; NASA Short-term Prediction Research and Transition (SPoRT) Center; Pakistan Council of Research in Water Resources (PCRWR); Indian Institute of Technology (IIT Bombay); University of Bonn (UBonn); Consortium of Universities for the Advancement of Hydrologic Science, Inc. (CUAHSI); FM Global; Collecte Localisation Satellites (CLS); Compagnie Nationale du Rhône (CNR); BRL Ingénierie (BRLi) and Mercator Ocean. In preparation for the first EAP engagement activity that took the form of a workshop (20–21 May 2019), organizers from the SWOT Application Working Group (SAWG) worked proactively with many EAs to explain the purpose of the program and its specific expectations. EAs were mentored beginning in 2018 and were encouraged to think carefully about the core issues of using SWOT data in advance of the 2019 EAP workshop. Each EA was requested to imagine desired future press releases or newspaper headlines that their EA project might enable with the use of SWOT data. The resulting press release titles or headlines were aspirational. Their realization is dependent on numerous conditions beyond the control of the EA or the SWOT mission. Nevertheless, the articulation of an eventual press release title as an end-goal summarizing the success of each EA project was deemed a useful exercise to define the ultimate goal of the SWOT EAP. The reader is referred to Hossain, Elmer, et al. (2020) or the webpage at http://depts.washington.edu/saswe/swot for more information on these press release titles. Of the many recommendations that emerged from the first EAP workshop in 2019, the key one we wish to highlight here is as follows (Hossain, Elmer, et al., 2020):

> "Close and more frequent mentoring support for EAs is needed as EA projects mature and EAs begin facing new challenges with data structure and processing. EAs will continue to require guidance, pointers on data access, and with queries on data structure/handling. Effective support of EAs will set a good precedent to maximize the user readiness of SWOT data after launch."

4. Where Do SWOT Early Adopters Stand Today?

Since the first SWOT EAP workshop in 2018, there have been regular training workshops and hackathons organized for early adopters with continuous engagement year round. Today the SWOT EA program boasts of 25 organizations from public, private, national, regional and international stakeholder entities (Figure 2). The hackathons and workshops have helped SWOT EAs improve technical literacy on the SWOT mission, learn more about SWOT's data structure and explore how exactly SWOT data can add value or solve a previously unsolved societal challenge. This engagement process has led to many EAs making cross-connections with other EAs to facilitate greater collaboration in newer areas of application (see e.g., Nair et al., 2021, 2022 on water surface mapping and citizen science). It has also contributed to the development of educational content and open-source tools for analysis (Soman & Indu, 2022). Finally, EAs are currently preparing to develop the software and hardware infrastructure necessary within their organization to leverage anticipated SWOT data in their operations or decision making environment (Hossain, Bonnema, et al., 2020; Hossain, Elmer, et al., 2020; Hossain et al., 2022). Here it should be noted that the data distribution arm of space agencies, such as NASA PO.DAAC and Hydroweb-Next by CNES, provides data infrastructure required for processing, archiving and distribution. The EAs are responsible for any further complementary downstream capabilities needed for the specific user communities they serve. The societal challenges addressed by the EAs now cover diverse topics such as flood and reservoir management, fisheries and marine science, transboundary water resources, state-wide water supply, wetlands monitoring, marine navigation and coastal studies. The EAs span the continents of North America, Africa, South America, Europe and Asia (Figure 2).

The SWOT EAP has so far convened five workshops that include three virtual training hackathons. These workshops have led to the development of open-source EA-specific tools for SWOT data with more than a dozen peer-reviewed publications showcasing the expected impact of SWOT data on the EA's baseline operations (Hossain et al., 2022). With support from the SWOT science community, the SWOT EAP has been able to build a growing archive of freely available multimedia tutorials, education materials and self-help resources for any user interested in exploring SWOT applications. This archive of resources continues to expand because of the communal spirit of the EA program where fellow Early Adopters and the scientific community help each other to overcome their respective project hurdles in a "hack" manner (Hossain, Bonnema, et al., 2020; Hossain et al., 2022). The SWOT EA program has also been able to grow consistently because of the continuous support from the partnering space agency of France (CNES), NASA and their respective agency data archives of record for the SWOT mission. In other words, the SWOT EAP has been able to increase the user-readiness of SWOT data in anticipation of mission launch for the broader application community. This pro-active and sustained engagement approach is the hallmark of the EAP seeking to maximize the return in public investments of global satellite missions. Detailed information on the SWOT mission on application-related activities and SWOT Early Adopter projects can be found at http://swot.jpl.nasa.gov/applications. For a more comprehensive overview of SWOT application activities and EA projects, the reader is referred to http://depts.washington.edu/saswe/swot.

To help the reader understand how each SWOT EA has evolved during the tenure of the EAP, we have summarized SWOT EA journeys comprising specific societal need, anticipated SWOT-based solution and tangible EA success stories at http://depts.washington.edu/saswe/swot (click on "Early Adopter Success Stories"). We encourage readers to explore each Early Adopter journey and success stories to develop an understanding of the tangible benefit that proactive and sustained engagement can bring for a planned satellite mission.

5. Conclusion

We are aware that the current stage of building user-readiness via the SWOT EAP and the anticipated scientific breakthroughs and societal applications during the initial years after launch may not be a sufficient guarantee for SWOT mission continuity demanded by end users. There are many other factors beyond the control of the scientific community for each satellite Earth mission.

However, we are maximizing our chances for mission success through the Early Adopter program, inspired by age old adage—"*By failing to prepare you are preparing to fail*." Planned Earth-observing satellite missions today require proactive and sustained engagement with a broad user community that spans the spectrum of scientific research and practitioner end-user needs if the mission is to hit the ground running when data becomes publicly available. Doing so will also allow us to realize the full potential of SWOT observations in the longer-term. SWOT is a pathfinder mission, not officially an operational one—no other satellite has ever collected similar data globally on water. The sooner the community exploits and demonstrates the societal impact of such novel data, the better position the community will be to argue for future mission continuity beyond its nominal life span. Hence, the EA program can play a major role in describing and quantifying the societal benefits of new pathfinder missions such as SWOT to various governing bodies that decide the fate of future missions.

The SWOT Early Adopter program represents the start of what is possible through sustained and continuous engagement with the stakeholder community through training, workshops, hackathons and collaborative learning in tandem with mission planning and development. As it continues to grow and evolve, we hope this model of early engagement will serve as a template for other planned satellite Earth missions to maximize the scientific and societal return on public investments in the Earth-observing enterprise.

Conflict of Interest

The authors declare no conflicts of interest relevant to this study.

Data Availability Statement

No data was used in this manuscript.

Acknowledgments
All authors are grateful for the continuous support and engagement received from all corners spanning space agencies (NASA and CNES), programs (NASA Applied Sciences) and stakeholder agencies (early adopters) over the last decade to build user readiness for SWOT data.

References

Allen, G. H., & Pavelsky, T. M. (2018). Global extent of rivers and streams. *Science*, *361*(6402), 585–588. https://doi.org/10.1126/science.aat0636

Altenau, E. H., Pavelsky, T. M., Durand, M., Yang, X., Frasson, R. P. D. M., & Bendezu, L. (2021). The Surface Water and Ocean Topography (SWOT) Mission River Database (SWORD): A global river network for satellite data products. *Water Resources Research*, *57*(7), e2021WR030054. https://doi.org/10.1029/2021WR030054

Andreadis, K. M., Clark, E. A., Lettenmaier, D. P., & Alsdorf, D. E. (2007). Prospects for river discharge and depth estimation through assimilation of swath-altimetry into a raster-based hydrodynamics model. *Geophysical Research Letters*, *34*(10), 1–5. https://doi.org/10.1029/2007GL029721

Andreadis, K. M., & Schumann, G. J. P. (2014). Estimating the impact of satellite observations on the predictability of large-scale hydraulic models. *Advances in Water Resources*, *73*, 44–54. https://doi.org/10.1016/j.advwatres.2014.06.006

Bauer, P., Thorpe, A., & Brunet, G. (2015). The quiet revolution of numerical weather prediction. *Nature*, *525*(7567), 47–55. https://doi.org/10.1038/nature14956

Biancamaria, S., Lettenmaier, D. P., & Pavelsky, T. M. (2016). The SWOT mission and its capabilities for land hydrology. In A. Cazenave, N. Champollion, J. Benveniste, & J. Chen (Eds.), *Remote Sensing and Water Resources*, *Space Sciences Series of ISSI* (Vol. 55). Springer.

Biswas, N., Hossain, F., Bonnema, M., Lee, H., & Chishtie, F. (2021). Towards a global reservoir assessment tool for predicting hydrologic impacts and operating patterns of existing and planned reservoirs. *Environmental Modeling and Software*, *140*, 105043. https://doi.org/10.1016/j.envsoft.2021.105043

Bonnema, M., & Hossain, F. (2019). Assessing the potential of the Surface Water and Ocean Topography mission for reservoir monitoring in the Mekong River Basin. *Water Resources Research*, *55*(1), 444–461. https://doi.org/10.1029/2018WR023743

Brêda, J. P. L. F., Paiva, R. C. D., Bravo, J. M., Passaia, O. A., & Moreira, D. M. (2019). Assimilation of satellite altimetry data for effective river bathymetry. *Water Resources Research*, *55*(9), 7441–7463. https://doi.org/10.1029/2018WR024010

Brown, M. E., & Escobar, V. M. (2019). NASA's Early Adopter program links satellite data to decision making. *Remote Sensing*, *11*(4), 406. https://doi.org/10.3390/rs11040406

Durand, M., Barros, A., Dozier, J., Adler, R., Cooley, S., Entekhabi, D., et al. (2021). Achieving breakthroughs in global hydrologic science by unlocking the power of multisensor, multidisciplinary Earth observations. *AGU Advances*, *2*(4), e2021AV000455. https://doi.org/10.1029/2021AV000455

Durand, M., Fu, L., Lettenmaier, D. P., Alsdorf, D. E., Rodriguez, E., & Esteban-Fernandez, D. (2010). The Surface Water and Ocean Topography mission: Observing terrestrial surface water and oceanic submesoscale eddies. *Proceedings of the IEEE*, *98*(5), 766–779. https://doi.org/10.1109/JPROC.2010.2043031

Durand, M., Gleason, C. J., Garambois, P. A., Bjerklie, D., Smith, L. C., Roux, H., et al. (2016). An intercomparison of remote sensing river discharge estimation algorithms from measurements of river height, width, and slope. *Water Resources Research*, *52*(6), 4527–4549. https://doi.org/10.1002/2015WR018434

Eldardiry, H., Hossain, F., Srinivasan, M., & Tsontos, V. (2022). Success stories of satellite radar altimeter applications. *Bulletin of the American Meteorological Society*, *103*(1), E33–E53. https://doi.org/10.1175/bams-d-21-0065.1

Emery, C. M., Biancamaria, S., Boone, A., Ricci, S., Rochoux, M. C., Pedinotti, V., & David, C. H. (2020). Assimilation of wide-swath altimetry water elevation anomalies to correct large-scale river routing model parameters. *Hydrology and Earth System Sciences*, *24*(5), 2207–2233. https://doi.org/10.5194/hess-24-2207-2020

Escobar, V. M., Arias, S. D., Moran, M. S., Nearing, G., Entekhabi, D., Njoku, E., et al. (2016). Overview of the SMAP Applications and the SMAP Early Adopters program - NASA's first mission-directed outreach effort. In *Paper presented at 2016 IEEE International Geoscience and Remote Sensing Symposium (IGARSS)* (Vol. 2016, pp. 5225–5228). IEEE. https://doi.org/10.1109/IGARSS.2016.7730361

Fernandez, D. E., Fu, L.-L., Pollard, B., Vaze, P., Abelson, R., & Steunou, N. (2017). SWOT mission performance and error budget. Revision A, JPL D-79084. Retrieved from https://swot.jpl.nasa.gov/system/documents/files/2178_2178_SWOT_D-79084_v10Y_FINAL_REVA__06082017.pdf

Fu, L.-L., Alsdorf, D., Rodríguez, E., Morrow, R., Mognard, N., Lambin, J., et al. (2009). The SWOT (Surface Water and Ocean Topography) mission: Spaceborne radar interferometry for oceanographic and hydrological applications. In J. Hall, D. E. Harrison, & D. Stammer (Eds.), *Proceedings of OceanObs'09: Sustained Ocean Observations and Information for Society, Venice, Italy, 21–25 September 2009* (Vol. 2). ESA Publication WPP-306. https://doi.org/10.5270/OceanObs09.cwp.33

Fu, L.-L., & Cazenave, A. (Eds.). (2000). *Satellite Altimetry and Earth Sciences: A Handbook of Techniques and Applications* (p. 463). Academic Press.

Garambois, P. A., & Monnier, J. (2015). Inference of effective river properties from remotely sensed observations of water surface. *Advances in Water Resources*, *79*, 103–120. https://doi.org/10.1016/j.advwatres.2015.02.007

Grippa, M., Rouzies, C., Biancamaria, S., Blumstein, D., Cretaux, J.-F., Gal, E., et al. (2019). Potential of SWOT for monitoring water volumes in Sahelian ponds and lakes. *IEEE Journal of Selected Topics in Applied Earth Observations and Remote Sensing*, *12*(7), 2541–2549. https://doi.org/10.1109/JSTARS.2019.2901434

Hausman, J., Moroni, D., Gangl, M., Zlotnicki, V., Vazquez-Cuervo, J., Armstrong, E. M., et al. (2019). The evolution of the PO.DAAC: Seasat to SWOT. *Advances in Space Research*, *68*(2), 1187–1193. https://doi.org/10.1016/j.asr.2019.11.030

Hossain, F., Bonnema, M., Srinivasan, M., Beighley, E., Andral, A., Doorn, B., et al. (2020). The Early Adopter program for the Surface Water and Ocean Topography Satellite mission: Lessons learned in building user engagement during the pre-launch era. *Bulletin of the American Meteorological Society*, *101*(3), E259–E264. https://doi.org/10.1175/BAMS-D-19-0235.1

Hossain, F., Elmer, N., Srinivasan, M., & Andral, A. (2020). Accelerating applications for planned NASA satellite missions: A new paradigm of virtual hackathons during pandemic and Post-Pandemic era. *Bulletin of the American Meteorological Society*, *101*(9), E1544–E1554. https://doi.org/10.1175/BAMS-D-20-0167.1

Hossain, F., Srinivasan, M., Peterson, C., Andral, A., Beighley, E., Anderson, E., et al. (2017). Engaging the user community for advancing societal applications of the Surface Water and Ocean Topography (SWOT) mission. *Bulletin of the American Meteorological Society*, *98*(11), ES285–ES290. https://doi.org/10.1175/BAMS-D-17-0161.1

Hossain, F., Srinivasan, M., Picot, N., Pena-Luque, S., & Doorn, B. (2022). Engaging potential users of the planned Surface Water and Ocean Topography (SWOT) mission in the year of launch. *Bulletin of the American Meteorological Society*, *103*(8), E1861–E1865. https://doi.org/10.1175/BAMS-D-22-0107.1

Lauer, D. T., Morain, S. A., & Salomonso, V. V. (1997). The Landsat program: Its origins, evolution, and impacts. *Photogrammetric Engineering & Remote Sensing*, *63*(7), 831–838.

Lee, H., Durand, M., Jung, H. C., Alsdorf, D., Shum, C. K., & Sheng, Y. (2010). Characterization of surface water storage changes in Arctic lakes using simulated SWOT measurements. *International Journal of Remote Sensing*, *31*(14), 3931–3953. https://doi.org/10.1080/01431161.2010.483494

Lettenmaier, D. P., Alsdorf, D., Dozier, J., Huffman, G. J., Pan, M., & Wood, E. F. (2015). Inroads of remote sensing into hydrologic science during the WRR era. *Water Resources Research*, *51*(9), 7309–7342. https://doi.org/10.1002/2015WR017616

Lin, P., Pan, M., Beck, H. E., Yang, Y., Yamazaki, D., Frasson, R., et al. (2019). Global reconstruction of naturalized river flows at 2.94 million reaches. *Water Resources Research*, *55*(8), 6499–6516. https://doi.org/10.1029/2019WR025287

Martin, S. (2014). *An introduction to ocean remote sensing*. Cambridge University Press. https://doi.org/10.1017/CBO9781139094368

Morrow, R., Fu, L.-L., D'Ovidio, F., & Farrar, J. T. (2019). Scientists invited to collaborate in satellite mission's debut. *Eos, Transactions American Geophysical Union*, *100*. https://doi.org/10.1029/2019EO110423

Nair, A., Kaushlendra, V., Karmakar, S., Ghose, S., & Indu, J. (2022). Exploring the potential of SWOT mission for reservoir monitoring in Mahanadi basin. *Advances in Space Research*, *69*(3), 1481–1493. https://doi.org/10.1016/j.asr.2021.11.019

Nair, A., Kumar, N., Jayaluxmi, I., & Vivek, B. (2021). Monitoring lake levels from space: Preliminary analysis with SWOT. *Frontiers in Water*, *3*, 717852. https://doi.org/10.3389/frwa.2021.717852

NASA SERVIR. (2019). In A. Flores, K. Herndon, R. Thapa, E. Cherrington, & NASA (Eds.), *SAR Handbook: Comprehensive Methodologies for Forest Monitoring and Biomass Estimation*. Retrieved from https://gis1.servirglobal.net/TrainingMaterials/SAR/SARHB_FullRes.pdf

10.1029/2022AV000680

National Academies of Sciences, Engineering, and Medicine. (2018). *Thriving on our changing planet: A decadal strategy for Earth observation from space*. The National Academies Press. https://doi.org/10.17226/24938

National Geospatial Advisory Committee. (2014). Landsat Advisory Group1. The value proposition for Landsat applications – 2014 Update. Retrieved from https://www.fgdc.gov/ngac/meetings/december-2014/ngac-landsat-economic-value-paper-2014-update.pdf

North, G. R., Pyle, J., & Zhang, F. (2015). *Encyclopedia of atmospheric sciences* (2nd ed.). Elsevier Sciences.

Peters-Lidard, C. D., Hossain, F., Leung, L. R., McDowell, N., Rodell, M., Tapiador, F. J., et al. (2018). 100 years of progress in hydrology. *Meteorological Monographs*, *59*, 25.1–25.51. https://doi.org/10.1175/amsmonographs-d-18-0019.1

Skofronick-Jackson, G., Petersen, W. A., Berg, W., Kidd, C., Stocker, E. F., Kirschbaum, D. B., et al. (2017). The Global Precipitation Measurement (GPM) mission for science and society. *Bulletin of the American Meteorological Society*, *98*(8), 1679–1695. https://doi.org/10.1175/bams-d-15-00306.1

Soman, M., & Indu, J. (2022). Sentinel-1 based Inland water dynamics Mapping System (SIMS). *Environmental Modelling & Software*, *149*, 105305. https://doi.org/10.1016/j.envsoft.2022.105305

Union of Concerned Scientists. (2021). UCS Satellite Database. Retrieved from https://www.ucsusa.org/resources/satellite-database

United Nations Office for Outer Space Affairs. (2021). Outer Space Objects Index. Retrieved from https://www.unoosa.org/oosa/osoindex/index.jspx?lf_id=

Wongchuig-Correa, S., Cauduro Dias de Paiva, R., Biancamaria, S., & Collischonn, W. (2020). Assimilation of future SWOT-based river elevations, surface extent observations and discharge estimations into uncertain global hydrological models. *Journal of Hydrology*, *590*, 125473. https://doi.org/10.1016/j.jhydrol.2020.125473