Lincoln Park, Chicago, IL, on the shores of Lake Michigan.

Monitoring the World's Lakes:

Progress from Citizen Science and Remote Sensing

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A sneak-peak at NASA's Lake Observations by Citizen Scientists and Satellites (LOCSS) project to help measure changes in lake water levels

Although lakes are important for our water supply, the ecosystem services they provide, and their role in local and regional water cycles, there is still a lot we don't know about them. Water storage is not measured in most lakes in the United States and around the world, which makes it difficult to manage these important natural resources. NASA has funded a new initiative, the Lake Observations by Citizen Scientists and Satellites (LOCSS) project (http://locss.org), that extracts lake area from satellite data and works with citizen scientists to collect lake water level data. Together, these measurements allow us to measure change in volume. These data can help us address science and management questions now, and they will be used in the future to help validate a lake-focused satellite mission that NASA will launch in 2021.

Worldwide, there are something like six million lakes larger than one hectare, but almost none of them are regularly monitored.[1] As a result, we know surprisingly little about them. Simple questions about the quantity of water they store, how that varies in time, and the quality of the water in them are answered mostly by inference. This lack of information is unfortunate because lakes are such useful sentinels of the water cycle. As integrators of all hydrologic processes in their catchments, knowing how lakes vary can help us understand the nature of hydrologic and ecological processes more generally. These processes are well-monitored in some parts of economically developed countries but are poorly measured globally.

Accordingly, scientists and engineers are looking to two solutions at opposite ends of the technological spectrum. Satellites can be used to remotely infer variations in lake water quantity, but the algorithms used to extract information from satellite data can be complex and sometimes unreliable. Meanwhile, collaboration with citizen scientists offers local observations and knowledge, but without the potential for fully global coverage. Combining these two approaches offers the exciting prospect of global satellite measurements validated against widespread local observations made by citizen scientists.

This combined approach is particularly promising in the context of the upcoming Surface Water and Ocean Topography (SWOT) Satellite Mission (http://swot.jpl.nasa.gov), a joint project of NASA and CNES, the French space agency. SWOT, a Ka-band interferometric radar satellite specifically designed to simultaneously measure variations in inundation extent and water level in lakes, rivers, and oceans worldwide, is scheduled to launch in September, 2021.[2] By observing lake height and inundation extent simultaneously, SWOT will allow measurement of variations in storage volume for lakes as small as 250 m x 250 m worldwide (with a goal of one hectare).

The novel SWOT measurements require considerable on-the-ground validation before they are likely to be trusted by end users. While water level in some lakes and most large

reservoirs is professionally monitored, this is largely not true for smaller lakes. To address this limitation and develop a robust validation network for SWOT, NASA has initiated the LOCSS project. The project involves installing staff gauges in lakes (see Figure 1), often in partnership with local management agencies, and asking citizen scientists to send in measurements of lake height via text message, web page, data sheet, or other methods.

The LOCSS project, funded by the NASA Citizen Science for Earth Systems Program, began in 2017 with a prototype phase focused on 12 North Carolina lakes. Since that time, the project has expanded to 62 lakes in Washington, Illinois, and Massachusetts in the United States, as well as France and Bangladesh, with plans for more lakes in new locales in the coming two years. Almost 1,000 (993) citizen scientists have submitted over 4,000 total measurements of lake height see Figure 2). Scientists have assessed the accuracy of these measurements against comparable measurements from several hundred automated pressure transducers and found a mean absolute error of 1.1 cm, only slightly higher than the 0.8 cm uncertainty associated with the transducer measurements.

Figure 1. A LOCSS gauge in Walupt Lake, WA.

Figure 2. Key summary metrics regarding data collected for by the LOCSS project by citizen scientists.

LOCSS is certainly not the first project to work with citizen scientists to measure variations in lake height. For example, there are excellent programs in Minnesota and Wisconsin, the latter of which was developed in collaboration with the CrowdHydrology project.[3] However, we believe that LOCSS is the first such project to focus specifically on links with satellite missions. At present, researchers are combining measurements of lake height by citizen scientists with measurements of lake area from the Landsat 8 satellite to calculate variations in lake volume. Landsat 8 has an orbit repeat time of 16 days, and regular reminders are sent out to newsletter subscribers to measure heights on overpass days. Measurements are received within +/-1 day of a satellite overpass more than 70% of the time.

This success suggests to us that, after the SWOT launch, we will likely be able to count on regular measurements by citizen scientists in many of our validation lakes. This reliability will be particularly important during a three month phase at the beginning of the SWOT mission, the so-called fast sampling phase, when we will observe only a small fraction of the Earth on a daily basis (see Figure 3). During the bulk of the mission, SWOT will observe each lake, on average, approximately every 11 days. During the fast sampling phase, we hope to work with citizen scientists to collect as many measurements as possible. These measurements will be used to evaluate SWOT's accuracy and assess its suitability for science and engineering objectives.

Even before SWOT's launch, LOCSS is achieving a range of goals in science, monitoring, and community engagement. Most of the more than 60 lakes had no prior monitoring, and because all of the data is available in real time on the LOCSS website, managers and other stakeholders can use the data for any purpose they choose. Many have been enthusiastic collaborators.

For example, Dan Grigas of the DuPage County Forest Preserve District, one of our collaborators in Illinois, wrote: "We chose to work with the LOCSS team because it is important for us to try to widen our understanding of how our environments change over time. This includes how changes in climate patterns in both the near-term and long-term can affect freshwater ecology. This program also allows for and relies on citizen scientists to participate, which strengthens the relationships among government agencies, the people they serve, and the environments that we all treasure."

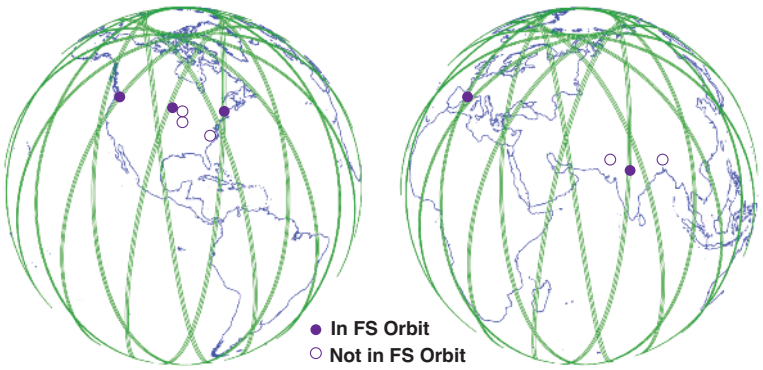

Figure 3. Map of current focus locations for the LOCSS project overlaid on the areas to be covered daily during the SWOT fast sampling phase (in green).

Scientists are also using data from the LOCSS project to better understand the primary drivers of lake water levels and water storage variations—are they primarily driven by regional climate, local physiography (e.g., bedrock geology), or human management? In Bangladesh, for example, LOCSS data have revealed contrasting water level dynamics for the seasonally inundated water bodies (locally known as haors) as a function of size. The smaller ones (e.g., the 3.7-km^2 Dekhar haor) seem to be experiencing withdrawals for neighboring water applications. Meanwhile, the larger haors (e.g., the 63-km^2 Korchar haor) maintain steady water levels as the monsoon rain arrives, suggesting that the larger water bodies are most likely being maintained for aquaculture. This type of information, not previously available to managers, allows for improved understanding and management of water resources. Ultimately, everyone's goal—researchers, lake managers, citizen scientists—is to better understand our lakes here in the United States and around the world. **em**

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