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High Latitude Lake and River Dynamics

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Abstract
High-latitude surface water dynamics are complex, fast, and driven by snow, ice, and permafrost. Modeling efforts that look to understanding the mechanisms, and to predicting the variability due to natural processes and climate change, often lack the basic hydraulic measurements, and the frequency of current observations are spatially and temporally poor. Satellite altimetry missions serve both the science and applied science sectors, and each mission contributes to the archive of global measurements. The ICESat-2 ATLAS laser altimeter system is recording surface elevations to ±88° latitude, monitoring surface water levels across all seasons, and with an unprecedented along-track spatial resolution. The ground-track density, particularly at high latitudes, and the simultaneous operation of 6 lasers, also offers an increase in spatial coverage compared to other profiling altimeters. This project aims to explore, create, and integrate ATLAS based measurements of lakes and rivers that are situated in the high latitude regions of North America, specifically those in the State of Alaska, and the southwest and northwest areas of the Yukon and British Columbia Provinces respectively. Here, gauge deployment is sparse. The research and applications of this project focus on Lake and River Dynamics. For lakes, the emphasis is on a wide range of types including glacial lakes prone to ice dams, a series of very small shallow lakes within an Arctic National Wildlife Refuge, and the large lakes along the Aleutian Peninsula. Required measurements are elevation variability, bathymetry or mean water depth, and the temporal/spatial knowledge of ice build-up. The laser-based measurements will input into various agency programs centered on assessing flood hazard risks and natural resources. For rivers, emphasis is on determining changes in channel morphology and assessing the complexities within large braided and meandering river reaches. The effects of the build-up of seasonal ice, and of channel erosion and scour, which are both relevant to flooding and infrastructure damage, are under study. The required measurements include high-resolution bank-to-bank and along-channel water surface gradients, elevation variability, channel width and mean water depth, and the detection and build-up of ice-cover. Utilizing ATL03, ATL13, and ATL22, system modifications are currently underway to enable lake and river measurements to be displayed at, and be accessible from, the Global Water Measurements portal (https://blueice.gsfc.nasa.gov/gwm). Technical investigations are looking at the delivery speed of the ATL data products, the quantity and quality of the laser measurements, and the ability to describe a change in surface status. Cross-validation efforts are utilizing a range of ground-based and radar altimetry datasets. The project aims at the integration of lidar-based measurements into an operational system that also contributes to longer-term climatic change detection, and which enhances agency decisions support systems.

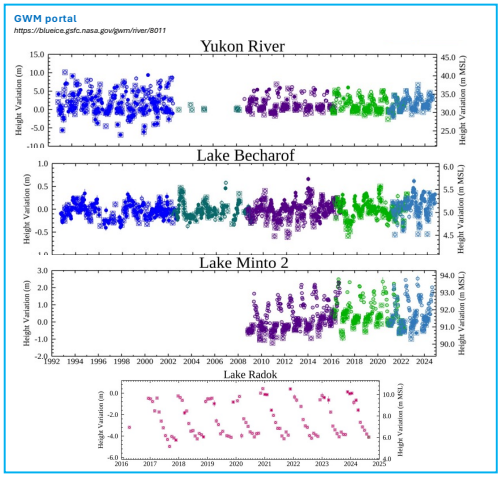
Continuity of Profiling Radar Altimeters

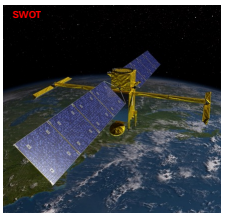
Offering multi-decadal time series of water level variations to enable the creation of Earth Data Records. These records serve science projects and applied science programs. We use multiple radar platforms to form the records and ICESat-2 ATLAS measurements for cross-validation. The Sentinel-3A/B products have just been upgraded to V3.1 to match the new ESA datasets. SWOT-nadir altimeter products are now being added at 21-day time resolution for low to mid latitude reservoirs.

SWOT/KaRIN - Swath Radar Altimeter

Focusing on high-latitude rivers, open lakes and glacial lakes with KaRIn. The team is testing: 1) SWOT-KaRIn capabilities to measure water level and extent of lakes and reservoirs to formulate hypsometry curves, and 2) whether SWOT-KaRIn can assist ICESat-2 elevation validation exercises. We will also endeavor to provide multi-platform measurements over the Yukon Flats region to aid SWOT field campaign efforts. The SWOT profiling altimeter measurements are already being employed for lake monitoring at the GWM data product portal.

Figure 1: Below are GWM water level products at 10-day or 27-day resolution for a reach on the Yukon River, Lakes Becharof and Minto in Alaska, and meltwater lake Radok, Antarctica. The USGS have adopted several virtual altimeter stations on river reaches within Alaska to supplement meagre gauge measurements. The National Parks Service and Fish and Wildlife agencies are keen to record variations in elevation, depth and surface status for a variety of open lakes in Alaska for flooding, ecosystem and tourism applications.





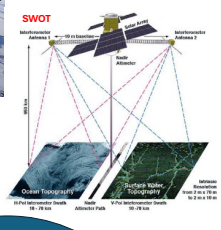
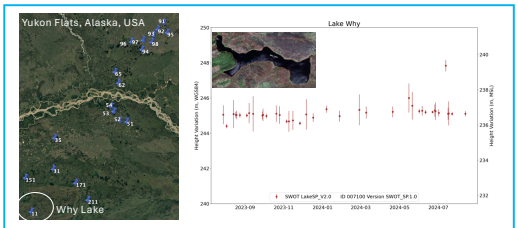
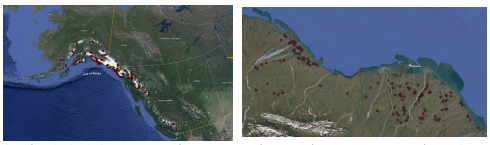


Figure 2: First results from the SWOT-KaRIn instrument. Focusing on the small lakes on the Yukon Flats in Alaska (a specific SWOT field campaign region) and other high latitude open and glacially dammed lakes.



Using the SWOT-KaRIn Level2 Lake Single Pass dataset which provides a single average height measurement within the lake on a specific date. A preliminary time series of elevation change for Lake Why on the Yukon Flats (No. 11 below left). These lakes, which are frozen for many months of the year, will experience <1m variability. The team are working on quality flags and the use of KaRIn raster products to enable a more detailed cross-comparison between the SWOT swath and ICESat-2 profiling observations.

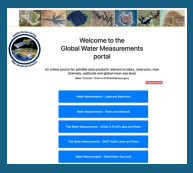


Combined SWOT/ICESat-2 lake targets include many glacial and glacially dammed lakes (left) in the USA and Canada, and small open lakes on the North Slope (coastal low-lying plains) of Alaska. The former are being observed for climate and flood considerations, the latter are being studied for fish and wildfowl habitat and conservation efforts. Required hydraulic parameters are elevation, slope, depth, and surface status change.

ICESat-2 – Contribution of Laser Altimeters

With exceptionally high along-track resolution, the ATLAS instrument can offer surface elevation and slope capability over very small lakes and reaches. With high-latitude targets in mind, the team is testing minimum target sizes, the ability to capture surface height during ice-on winters, and any capability that defines transitions from water to ice. A number of stakeholders in Alaska are collaborators on this project with interests in flooding, ecosystems, tourism and the effects of regional climate change. The ATLAS is also currently assisting the GWM/G-REALM programs by acting as a cross-validation source for the radar altimeter measurements.

Operational and Archive elevation, slope, extent, width, depth, bathymetry and storage products with a suite of Status Indicators
https://blueice.gsfc.nasa.gov/gwm



FOCUS on High Quality Earth Data Records

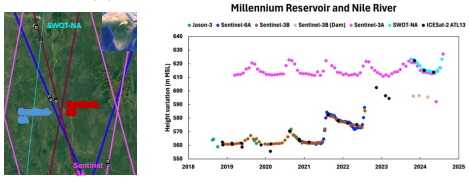
ICESat-2 – Lake and River Dynamics

Before dynamics can be studied the quantity and quality of the ATLAS measurements must be assessed, and the GWM portal modified to accept new laser based elevation, slope, and depth estimates in formats suitable for the project agency end users. River reach and lake study sites have been identified and the ATL13 dataset is the primary dataset. Matching ATL13 lake/reach polygons and identifying the correct ATL13 ID number is proving tricky in complex terrains where multiple water bodies exist. For some targets data quantity is also low or absent and the team will look to ATL06 and ATL03 in the next phase. The ability to record seasonal or spatial variability is being noted.

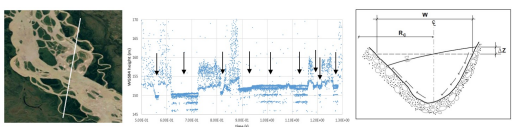
Figure 3: Below example shows water level products derived from multiple radar altimeters and the ICESat-2 lidar altimeter for the Millennium Reservoir and a reach on the Nile River in Africa.

ICESat-2/ATLAS to help cross-validate radar elevations

ATL13 contains along-track surface heights (orthometric wrt WGS 84 ellipsoid) of inland water bodies, including lakes, reservoirs, rivers, bays, and estuaries for the Oct 2018-period. The OpenAltimetry tool is useful for quick look ATLAS-derived elevations though for validation purposes the ICESat-2 ground track can be far from the location of interest. For example, in the case of the Millennium Reservoir, the dam in the north has S3B and SWOT ground tracks (Fig.4 left-top), and in the south there are S6A and S3B tracks (Fig.4 left-bottom). Differences in track location can result in a significant height differences when comparing measurements from multiple platforms.



ICESat-2/ATLAS for Hydraulic Parameters



(Left) ATLAS surface acquisitions across a braided reach of the Yukon River, Alaska, 35km upstream of the Fort Yukon gauge site are successful. The ability to detect each channel is demonstrated but cross-checks are required to investigate the apparent sub-surfaces (ATL03 from 09/10/2020 beam 1L). (Right) ATLAS is being used to determine the bank-to-bank surface slope, also called "superelevation", in meandering channel bends. This is an important hydraulic parameter when considering estimations of streamflow and changes due to erosion and scour.

Acknowledgements

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i) NASA ROSES NNH22ZDA001N-ICESAT2
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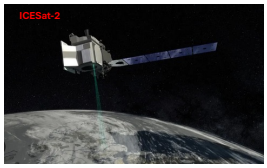
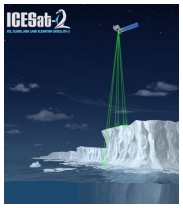
iii) NASA ROSES NNH20ZDA001N-OSTST





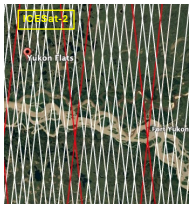
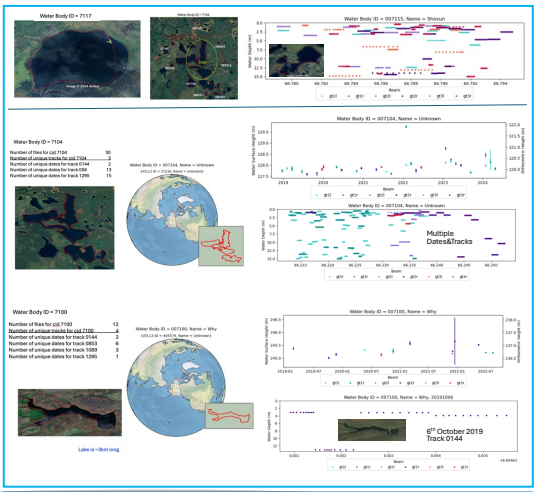


Figure 4: Preliminary ICESat-2 products based on ATL13 and 2019-2024. Checking polygon shapes, identifying correct lake in complex terrain, look at quantity of data for series of height variability , and checking the "depth" parameter.



Conclusions:
- ICESat-2- further work required on most elements, especially data quality flags
- Sentinels - OLTC DEM great but some failures, ICESat-2 DEM may help at High Latitudes
- SWOT/KaRIn – further work required to explore the Singla Pass and Raster products
- Multi-platform, multi-instrument approach essential for combining instrument advantages and for cross-validation checks.

Recommendations: Continuity of laser and radar profiling AND swath instruments required for science projects and the applied science programs.

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