LakeLevel Tracker: A Google Earth Engine-based web application for characterizing lake water levels

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Background

Climate change and artificial water level manipulations pose a major emerging threat to the health and resilience of inland lakes. Rapid water level fluctuations brought on by climate variability and intensified by reservoir operations lead to habitat degradation in littoral zones critical for biodiversity (Carmignani and Roy 2017). Climate change is expected to intensify eutrophication in lakes and reservoirs through increased nutrient loading from stormwater runoff and stimulated biological activity from warmer temperatures (Nazari-Sharabian et al. 2018). Prolonged drought due to climate change and artificial water level drawdowns may further exacerbate these effects by concentrating nutrients and pollutants and altering nutrient dynamics, thereby increasing the risk of harmful algal blooms and hypoxia (Zohary and Ostrovsky 2011). Mitigating the ecological impacts from the cumulative instability of climate change and artificial manipulations may require enhanced regulatory constraints on operations that allow for flexible multi-year management plans focused on conservation.

Traditionally, characterizing and monitoring water levels was a challenging task due to the large spatial and temporal variability involved. In-situ measurement of lake levels via gauges and markers installed along shorelines provides accurate and precise data at specific locations but is limited in spatial coverage and consistency across different sites. Without a comprehensive, large-scale monitoring tool, it is difficult to gather consistent and reliable data, making effective management a challenge. Remote sensing approaches using satellite imagery and altimeters on satellites now offer broad spatial coverage, but these high-tech solutions have typically focused more on documenting water levels for only very large inland water bodies.

To address the above challenges, we have leveraged recent remote sensing advancements to create "LakeLevel Tracker" – an innovative web platform delivering satellite-derived lake surface water areas and levels across over 10,000 lakes in eight states (Massachusetts, Connecticut, Vermont, New Hampshire, Maine, Michigan, Wisconsin, and Minnesota) dating back to 2014. LakeLevel Tracker's remote sensing technology relies on imagery from the European Space Agency's Sentinel-1 synthetic aperture radar (SAR) satellite sensor along with Google Earth Engine (GEE) computing capabilities. SAR sensors, with their ability of self-illuminating and cloud penetration, provide more consistent observations than optical satellite sensors. Instead of requiring users to download petabytes of raw data, GEE leverages cloud servers to process imagery on demand. The web application employs advanced algorithms like Otsu for water classification, transforming complex satellite data into understandable, actionable information (Otsu 1974; Zhou et al. 2020). The application is designed with a focus on simplicity and ease of use, making advanced satellite data analysis available to all. The quick processing and visualization capabilities of GEE allow users to create a reliable, regularly updated overview of lake surface water areas and levels.

LakeLevel Tracker's user interface: Key features

The application's freely available interface guides users through a straightforward process to generate data and simple figures. Users can access the GEE web application at this link (https://tinyurl.com/musexpyw), navigate to a lake and specify a date range to generate surface water area and water level charts (Figure 1). Users can visualize changes in surface water area and water level over seasons or years and download the data for further analysis. More information on how to use this web application with step-by-step instructions can be found at this link (https://tinyurl.com/yxnernxv).

Case study: An example of winter drawdown lake

We have used LakeLevel Tracker to assess annual winter water level drawdowns in lakes and reservoirs. Winter drawdowns are a key practice used to control invasive aquatic plants, maintain reservoirs, and limit shoreline ice damage (Carmignani and Roy 2017). However, when coupled with climate variability and drought, such dramatic fluctuations strain the ecological resilience of lakes. Intensive water level fluctuations may also favor invasive species and algal blooms that decrease water clarity and overwhelm native biodiversity (Carmignani and Roy 2017). The effects of drawdowns depend on their timing, magnitude, duration, and recurrence intervals, which vary across lakes and years (Carmignani et al. 2021). Quantifying drawdown impacts has been hindered by limited monitoring capabilities and scarce historical lake-level data. Different lakes exhibit varying patterns of drawdown, influenced by factors like management strategies (He et al. 2023) and environmental conditions (Carmignani et al. 2021). The variability in the timing, magnitude, and duration of drawdowns across numerous lakes adds layers of complexity to the assessment of their ecological and socio-economic impacts.

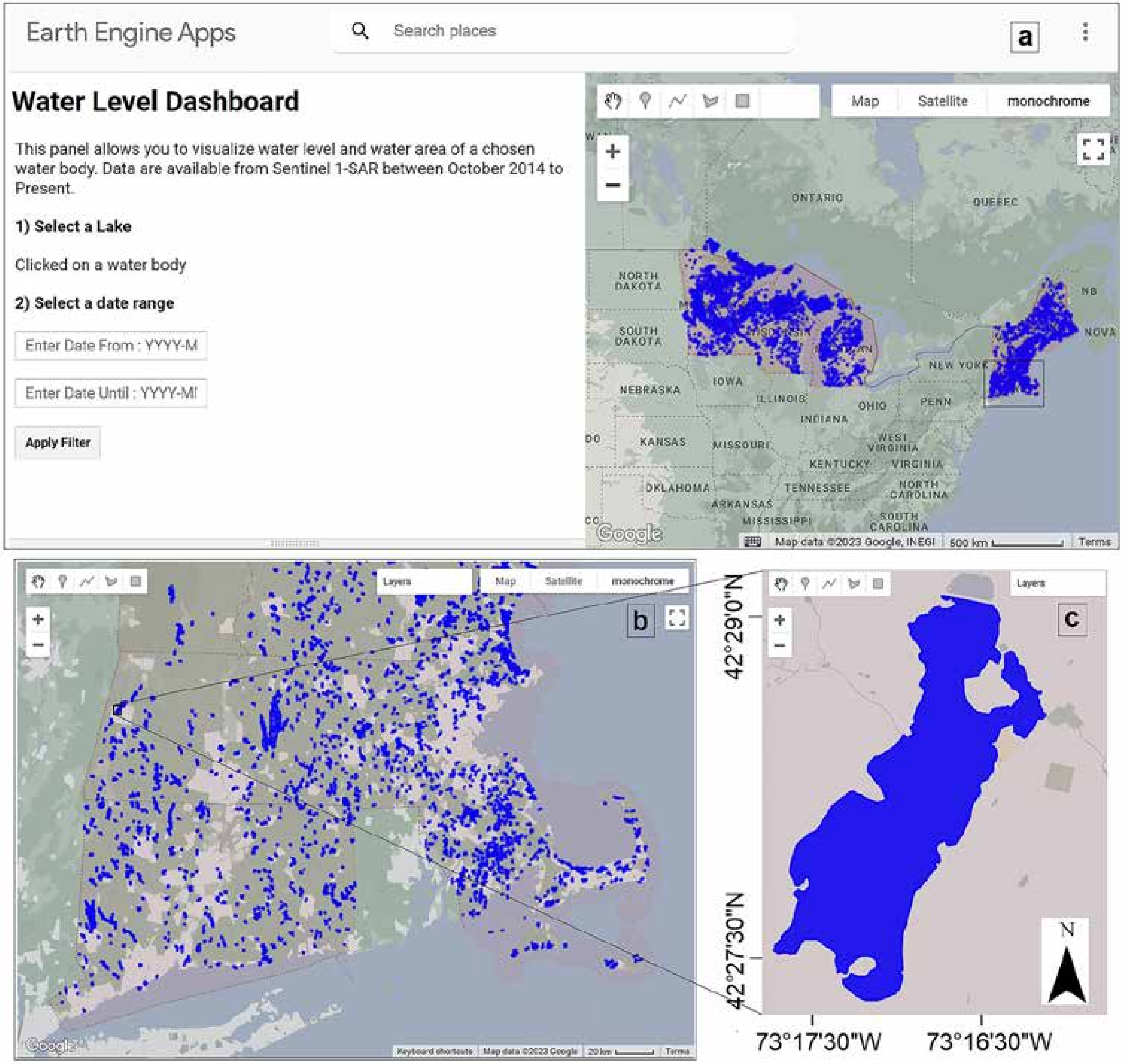

Figure 1. LakeLevel Tracker user interface which includes shapefiles for lakes in eight states (Minnesota, Wisconsin, Michigan, Massachusetts, Vermont, Maine, Connecticut, New Hampshire). (a) Various input parameters that users need to provide. (b) Expanded view of statewide lakes within the lower part of Vermont, Massachusetts, and Connecticut .(c) A zoomed-in view of Lake Onota, Figure 2.

We selected Lake Onota in Pittsfield, Massachusetts (Figure 2) as an example to demonstrate LakeLevel Tracker's utility for observing interannual drawdown patterns. By simply navigating to Lake Onota within the web application, providing a date range from January 2016 to November 2023, and clicking "apply filter," water area and water level time series were produced within minutes (Figure 3a-b). Hovering over points in these time series charts displays exact values for a given date. Typically, Lake Onota's surface water area and water level drop start in November, reach their lowest level in December, and recover by spring. Exporting these time series as Comma Separated Values (CSV) files allows derivation of drawdown timing, magnitude, duration, and percentage lake exposure. Clicking on water area points renders associated maps, clearly highlighting exposed regions in contrast to water (Figure 3c). The drawdown magnitude also fluctuates annually as observed by minimal reductions in water area and water level in 2022 and 2023 compared to the other years (Figure 3).

Features and benefits

LakeLevel Tracker has several features that may be used for various applications (Table 1). Academics can

Figure 2. An example of winter lake drawdown showing exposed shorelines of Lake Onota in Massachusetts, United States during the drawdown phase (Photo: Jason Carmignani; Date: December 01, 2017).

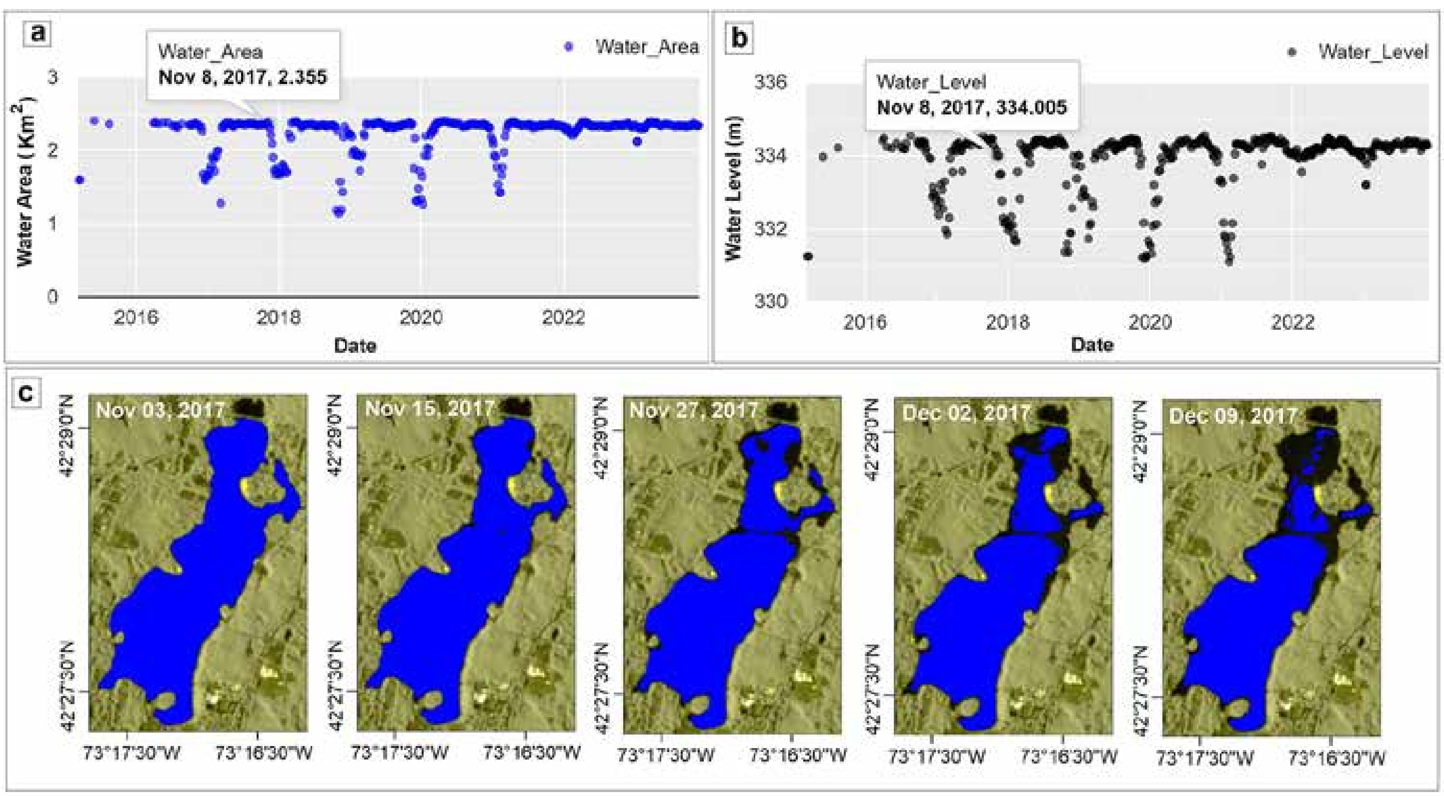

Figure 3. LakeLevel Tracker web application produced time-series data for (a) water area, and (b) water level in Lake Onota (Massachusetts, United States). Example water area maps (c) highlight Lake Onota's exposed area (dark regions) during winter drawdown phase.

Table 1. Summary of LakeLevel Tracker's (https://tinyurl.com/musexpyw) key features and associated descriptions or the value of these applications

Key Features/Applications	*Description*
Individual lake monitoring	LakeLevel Tracker's design is intuitive, allowing users to easily monitor water levels approximately every six days.
Temporal trends	Users can access historical and current data, allowing for comprehensive analysis of lake surface water area and level fluctuations
Statewide monitoring	The web application offers a broad-scale monitoring capability, crucial for statewide analysis and decision-making
Insights into ecological variability	By providing data on inter-lake and intra-lake variability, the web application aids in understanding broader ecological patterns and trends

incorporate real-time data into their research and teaching, offering students hands-on experience with the technology. For example, they can guide students through real-world case studies linking lake levels to climate change and analyzing local lake trends. This tool can also help state agencies and lake managers with informed decision-making, enabling them to respond more effectively to the challenges of lake management. Consultants can use this tool to offer important insights into drawdown parameters, informing both short-term and long-term strategies. The data generated from LakeLevel Tracker can also help modelers to incorporate drawdown scenarios into forecasts on climate change effects including extreme flood risks or drought. In essence, this tool democratizes access to advanced satellite data, empowering a wide range of users to make informed, data-driven decisions.

Limitations

While this innovative LakeLevel Tracker web application signifies an advancement in remote data usability, users should be aware of some limitations in accuracy, scope, and logistics. In terms of accuracy, the application cannot capture flooding events that surpass the maximum surface water area of the lake, which is used to define static boundaries; however, a buffer could be applied around the lake to capture high water levels. Potential errors may also arise from ice cover, high wind, or heavy wave action affecting lake surface roughness and consequently backscatter signal received by satellite sensors. In particular, winter ice formation can be mistaken for loss of water area; thus, additional information such as ice-on and ice-off dates may be needed to differentiate winter drawdown from ice cover. In terms of scope, the application only works for lakes >0.3 km^2 surface area, and satellite data are only available from October 2014 onward, captured every 6 to 12 days. While the current web application is focused on the Upper Midwest and Northeast U.S., there is potential to include lakes from other regions by uploading the shapefiles of lakes. Logistically, users may experience computation time errors for very large lakes; using a smaller time period solves this issue. Finally, the web application allows extracting data for only one lake at a time. For multiple lake data extraction, users may access the code from our GitLab repository (https://gitlab.com/gee_codes/winter-drawdown).

Conclusions

We developed an interactive web application that makes use of satellite data and cloud computing to visualize lake drawdown patterns, offering state agencies and other stakeholders a user-friendly resource to inform water policies and conservation efforts. LakeLevel Tracker's unique remote sensing approach expands knowledge of water level variability over large regions unavailable from traditional gauges alone. Observing water level timing, magnitude, frequency, and duration for thousands of lakes simultaneously has not been feasible across large regions until now. By providing easy access to satellite-derived data, the application has the potential to empower diverse stakeholders to make informed decisions based on reliable and up-to-date information, supporting progress toward more effective and inclusive environmental management practices. Partnership across academia, government agencies, and conservation groups may further advance LakeLevel Tracker features and capabilities based on inputs gained through collaborative efforts in the future. For example, integration of meteorological data such as precipitation and temperature alongside water level in LakeLevel Tracker could be helpful to understand the interplay between water levels and weather patterns, providing deeper insights into lake management. As we look to the future and continue to face the challenges posed by climate change and environmental degradation, web applications like this could help in balancing the needs of human activities with the preservation of natural ecosystems, guiding decisions and actions to ensure the health and sustainability of these vital ecosystems.

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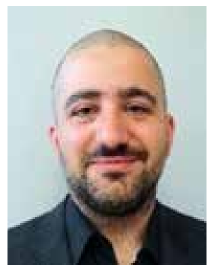

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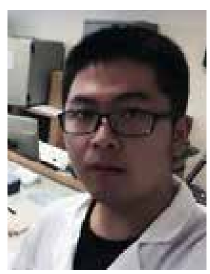

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