A New understanding from space technology for assessing the volume of lake water

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Freshwater resources are indispensable for human survival and social development, yet there is limited understanding of the variability of lake surface water at different temporal and spatial scales. Space technology offers a solution by providing wide coverage, easy data acquisition, and high spatiotemporal resolution. An integration of space data from different sources enables a more comprehensive and accurate understanding of lake water volume. This commentary explains the challenges and opportunities of satellites in monitoring global inland lakes including novel spatial information data and technologies, intelligent algorithms for multi-source data, and applications of artificial intelligence in modelling and prediction.

MONITORING LAKES FOR SUSTAINABLE USE

Due to climate change and human activities, the volume of lakes is undergoing significant changes. Regions characterized by a high abundance of lakes have encountered the challenge of shifting lake water resources in recent years.[1] Globally, climate change has resulted in alterations in precipitation patterns and an escalation in drought occurrences, thereby exerting an impact on lake water resources. The changes in water resources within basins greatly increased the uncertainty and regional variability in river and lake water cycles, resulting in the changes in volume and size of lakes. Consequently, safeguarding lake water resources and fostering their sustainable utilization emerge as pivotal factors in achieving the global Sustainable Development Goals (6).[2] The dynamic changes in lake water volume intricately intersect with the paradigm of global sustainable development. This necessitates the implementation of scientifically informed policies and management measures, bolstering monitoring and research endeavors, with the ultimate aim of ensuring the enduring provision of lake water resources, upholding ecological balance. Space technologies, on the other hand, can obtain information on the surface height and area of lakes through satellites, allowing for better monitoring and wider coverage.

ASSESSING LAKE WATER VOLUME VARIATION

In the early days, a simple estimation method that considers the type of submerged slope collected from field measurements was used to roughly estimate the volume of water in a lake. While others directly use the empirical relationship between the surface area and the capacity of a lake reservoir to estimate water storage and its variation. However, the first method requires actual or assumed values for maximum depth and surface area over the calculation period, while the second method requires actual measurements of lake volume and area to localize the empirical relationship function model. In 2023, Fang et al. proposed a 3D-lake-topography simulation method based on the assumption of topographic continuity above and below the water surface and estimated water storage.[3]

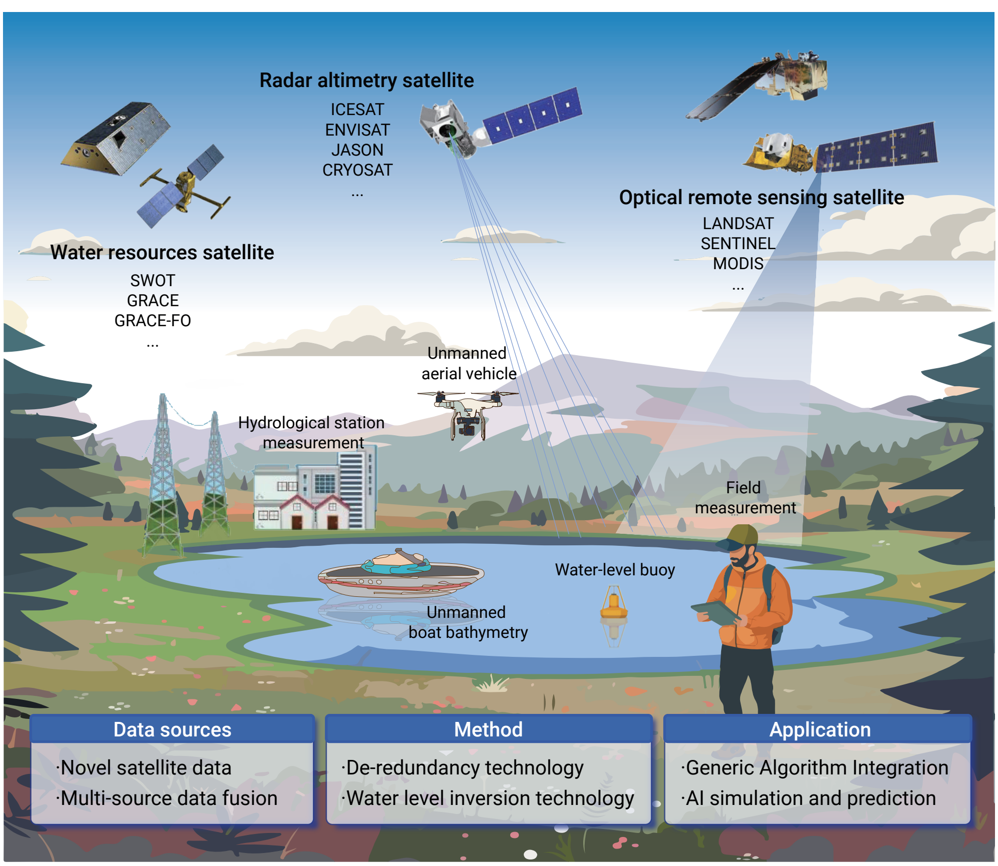

Figure 1. The opportunities and challenges of space-based technologies in assessing lake water volume.

The above research methods provide methods for estimating lake storage on a regional scale without relying on actual measurements, but they are not always robust or universal. Many scholars used optical or microwave satellite data to extract the range of lake water surface changes over different time periods. These data are combined with radar or laser altimeter data to extract the lake level over the corresponding period. [4] By assuming the changing lake water as a circular cylinder, the estimating equation for calculating the change in water storage during a certain time can be constructed.

MULTISOURCE SATELLITE SENSORS FOR EFFECTIVE LAKE WATER MONITORING

The monitoring of lake water areas lays the foundation for the study of lake water conditions. The spatial resolution of the optical sensors is one of the main factors to be considered in remote sensing monitoring studies of surface water. Coarse resolution remote sensors are less accurate but usually have high temporal resolution and wide coverage. Landsat, as a medium- and high-resolution optical satellite, has improved its spatial resolution from 80 m to 30 m, a level of resolution that is well suited for fine monitoring of long-term changes in surface water at large scales. Sentinel-2 can provide high-quality multispectral imagery with spatial resolution from 10 to 60 m. However, high spatial resolution sensors have small scene coverage; the other is the presence of shadows on the images. In addition, high resolution data acquisition methods are generally charged, which limits its application in scientific research.

NASA launched the laser altimetry satellite ICESat (the Ice, Clouds, and Land Elevation Satellite) in 2003. ICESat has a high spatial resolution, with a sub-satellite footprint of 70 m and a vertical accuracy of 3 cm. However, a single altimetry satellite has the shortcomings of covering a small number of lakes and having a short service life. In recent years, several advanced algorithms have been developed to estimate the dynamics of lakes, some of which can drive the creation of global lake datasets. However, the number and timing of lakes or reservoirs included in these datasets are limited and do not allow us to achieve fine-scale monitoring of a single lake. Space informatics techniques combining optical remote sensing and satellite altimetry remain an effective means of monitoring changes in lake dynamics. Studies have used multi-source space information technology tools to focus on regional lake clusters and other inland lakes, many of which are brackish lakes located on the plateau. There is an urgent need to carry out long-time series space informatics monitoring studies of lake water reserves to reveal their dynamic patterns, especially freshwater lakes that are directly related to human production and life.

HOW CAN SATELLITE TECHNOLOGIES CONTRIBUTE TO FUTURE GLOBAL CHANGE IN LAKE WATER MONITORING?

Many studies have been conducted to derive global and regional lake surface water levels using the Advanced Topographic Laser Altimeter System (ATLAS) on board NASA's recently launched ICESat-2. The effective along-track resolution has been improved to about 70 centimeters along the satellite's ground track. The total variability of surface water storage can be quantified by combining ICESat-2 observations with global surface water extent datasets. Researchers not only successfully used GRACE satellite data for terrestrial water storage variability studies but also started to develop applications for mega-lake water storage variability studies by using this data source in conjunction with optical space informatics, satellite altimeters and hydrological models. In addition, the French National Centre for Space Studies (CNES), together with NASA, recently launched the new Surface Water and Ocean Topography (SWOT) satellite, which employs radar interferometry to provide high-resolution data on the heights of water bodies. By measuring changes in the height of the water surface, it is also possible to infer the flow velocity of the water body. This information will help scientists better understand the dynamics of surface water resources and thus improve the prediction and management of global lake water resources.[5]

The availability of modern hyperspectral and high-resolution remote sensing data has led to advances in data analysis techniques, and artificial intelligence (AI) and machine learning algorithms will be crucial for future global lake water estimation. Utilizing a combination of multi-source satellite optical and radar remote sensing imagery, automated classification algorithms were developed to discern water bodies. This process was executed through iterative refinement and implementation of machine learning methodologies. Integration of site-specific observations, complemented by data from diverse radar and laser altimetry satellites, enabled the reconstruction of extensive time-series data pertaining to lake water levels. The proposed integrated technological framework is slated for transition to remote sensing cloud platforms such as GEE (Google Earth Engine), thereby laying the groundwork for the creation of operational products geared towards assessing lake water conditions on either a national or global scale.

Hydrological remote sensing, as a depth and breadth of the expanding field, also faces many problems, including inversion algorithm universality, differences of multi-source remote sensing data, and the reliability of long time series remote sensing trend inversion (Figure 1). What's more, some extraction methods are still affected by mixed pixels, shadows, spectral features of similar features, and the index algorithms used for extraction are gradually optimized and developed to address these problems. Moreover, most studies relied on 1 to 2 types of altimetry data to analyze lakes intersecting specific portions of satellite orbits. Constrained by the orbital spacing of altimetry satellites and their limited service life, these endeavors faced challenges in encompassing a comprehensive range of lakes and establishing an extended historical sequence of their water levels. However, with the development of altimetry technology and the maturity of data processing algorithms, multi-source altimetry data has become the focus of lake water level extraction. In the future, there is still a need to design lake waveform re-tracking algorithms for multi-source radar altimeters that take into account the waveform characteristics of frozen lakes and contaminated echoes, which will serve for more accurate lake water level extraction. To effectively tackle the contemporary opportunities and challenges inherent in leveraging spatial informatics for water resource monitoring in global lakes, fostering interdisciplinary collaboration is imperative. Leveraging the collective expertise and technological prowess across remote sensing technology, geoscientific knowledge, computer science, and allied disciplines is essential for perpetuating the advancement and refinement of remote sensing technology tailored for global lake water resource monitoring.

CONCLUDING REMARKS

In summary, this commentary points out that future developments in multi-source spatial informatics for monitoring lake water resource changes will include a wider range of data sources, enhanced data analysis capabilities, interdisciplinary collaboration, and advances in real-time monitoring and intelligent decision support. Furthermore, proposed future directions warrant exploration, constituting a pivotal stride towards an enhanced comprehension of processes governing lake water resource changes and sustainability. Prospective global collaboration and data sharing are envisioned to fortify the understanding and management of lake water resources, fostering their sustainable utilization and protection.

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DECLARATION OF INTERESTS

The authors declare no competing interests.