Towards time-continuous long-term monitoring of global lakes and reservoirs: a novel algorithm for improving temporal frequency of lake area time series

Fangfang Yao[1], Jida Wang[1], Chao Wang[2], and Jean-François Crétaux[3]

[1]Kansas State University
[2]University of Puerto Rico
[3]Centre National d'Études Spatiales (CNES)

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Abstract

Improved monitoring of inundation area variations in lakes and reservoirs is crucial for assessing surface water resources in a growing population and a changing climate. Although long-record optical satellites, such as Landsat missions, provide sub-monthly observations at fairly fine spatial resolution, cloud contamination often poses a major challenge for producing temporally continuous time series. We here proposed a novel method to improve the temporal frequency of usable Landsat observations for mapping lakes and reservoirs, by effectively recovering inundation areas from contaminated images. This method automated three primary steps on the cloud-based platform Google Earth Engine. It first leveraged multiple spectral indices to optimize water mapping from archival Landsat images acquired since 1992. Errors induced by minor contaminations were next corrected by the topology of isobaths extracted from nearly cloud-free images. The isobaths were then used to recover water areas under major contaminations through an efficient vector-based interpolation. We validated this method on 428 lakes/reservoirs worldwide that range from ˜2 km2 to ˜82,000 km2 with time-variable levels measured by satellite altimeters. The recovered water areas show a relative root-mean-squared error of 2.2%, and the errors for over 95% of the lakes/reservoirs below 6.0%. The produced area time series, combining those from cloud-free images and recovered from contaminated images, exhibit strong correlations with altimetry levels (Spearman's rho mostly ˜0.8 or larger) and extended the hypsometric (area-level) ranges revealed by cloud-free images alone. The combined time series also improved the monthly coverage by an average of 43%, resulting in a bi-monthly water area record during the satellite altimetry era thus far (1992–2018). Given such performance and a generic nature of this method, we foresee its potential applications to assisting water area recovery for other optical and SAR sensors (e.g., Sentinel-2 and SWOT), and to estimating lake/reservoir storage variations in conjunction with altimetry sensors.

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Fangfang Yao [1], Jida Wang [1], Chao Wang [2], Jean-François Crétaux [3]

Contact: fyao@ksu.edu; jidawang@ksu.edu

[1] Kansas State University [2] University of North Carolina at Chapel Hill [3] Centre National d'Études Spatiales (CNES)

F. Yao, J. Wang, C. Wang, and J.-F. Crétaux. Constructing long-term high-frequency time series of global lake and reservoir areas using Landsat imagery. Remote Sensing of Environment, 232 (2019): 111210, doi:10.1016/j.rse.2019.111210.

Objectives

Improved monitoring of inundation extent variations in lakes and reservoirs is crucial for assessing surface water resources in a growing population and a changing climate. Although long-record optical satellites, such as Landsat missions, provide sub-monthly observations at fairly fine spatial resolution, cloud contamination often poses a major challenge for producing temporally continuous time series.

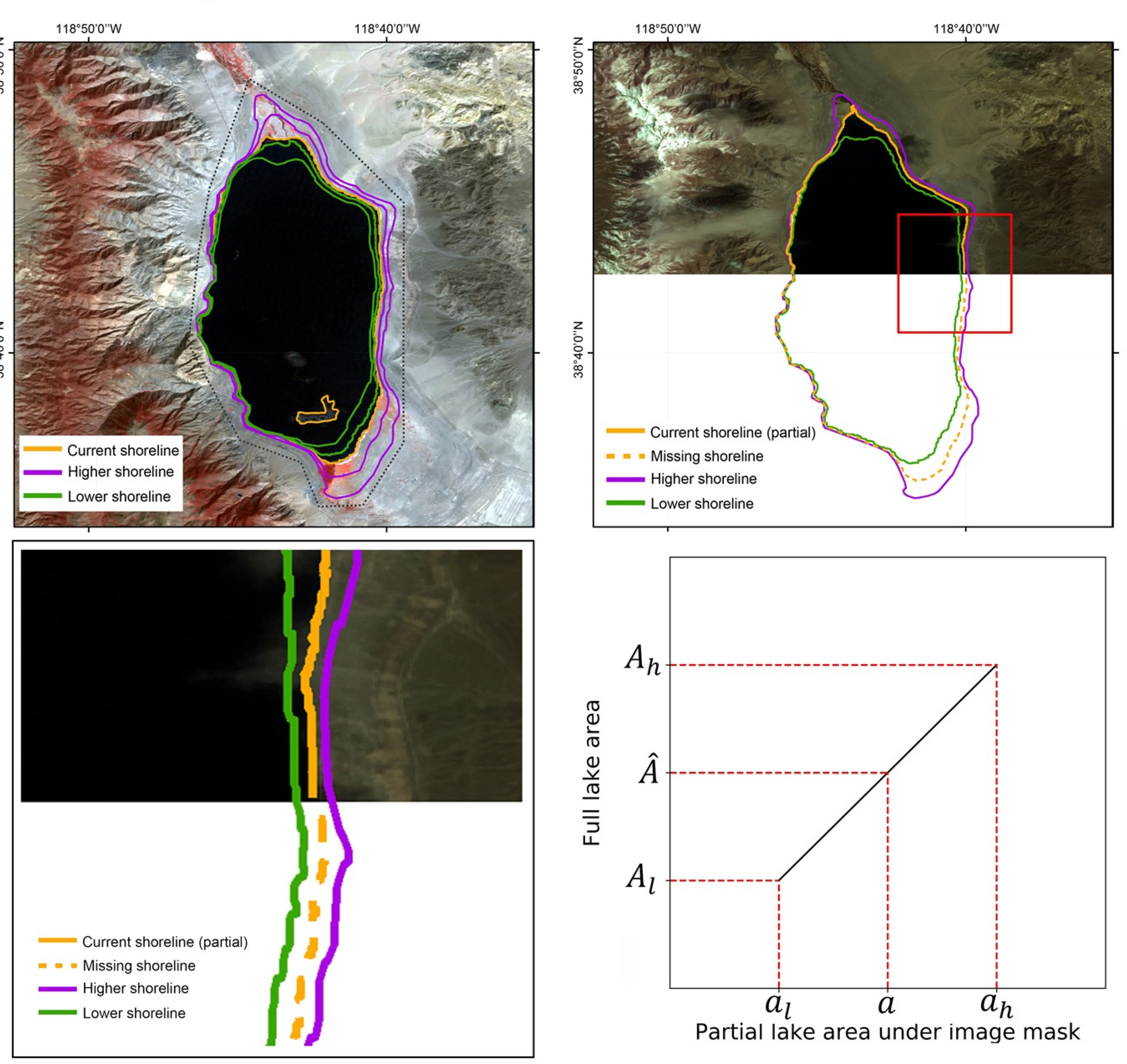
Our objectives

- To improve the temporal frequency and accuracy of long-term water mapping using Landsat imagery
- To produce an up-to-date high-resolution record of global lake/reservoir area time series (**GLATS; https://lakewatch.users.earthengine.app/view/glats**)

Methods

This method automates three steps to recover water areas from contaminated images on a cloud-based platform Google Earth Engine

- Step 1: Leveraging multiple indices to optimize water mapping
- Step 2: Correcting errors from minor contaminations by isobaths extracted from cloud-free images
- Step 3: Recovering water areas under major contaminations through a vector-based interpolation



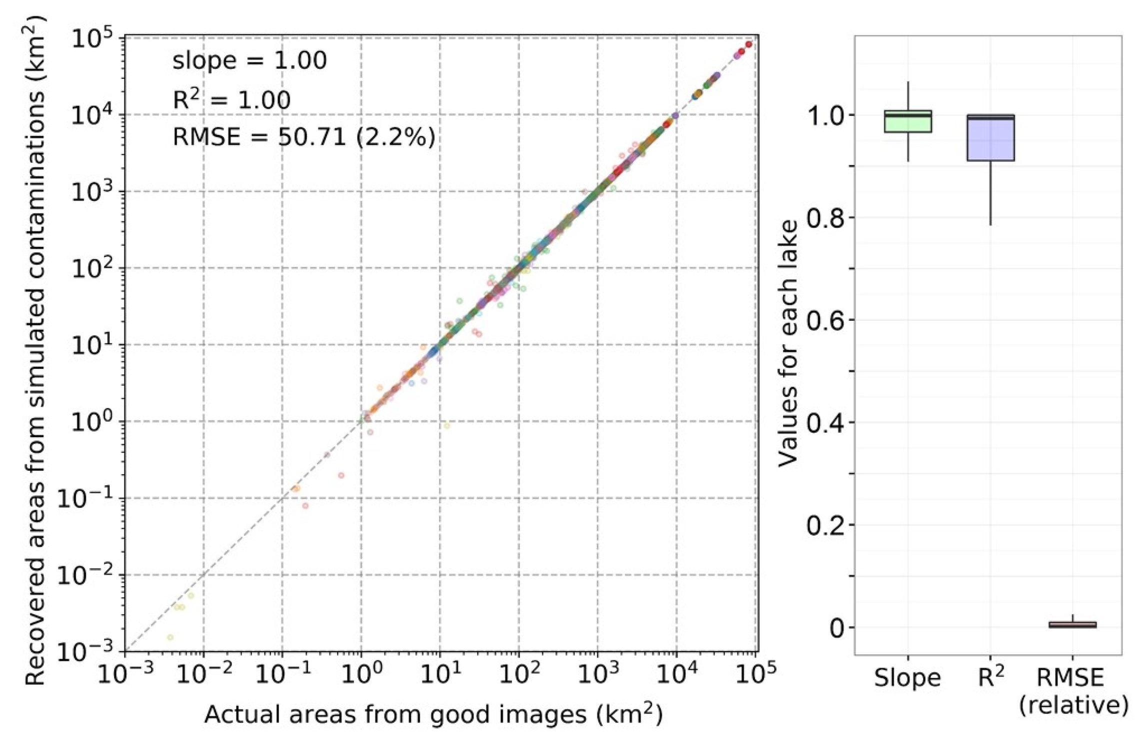
Validations

1) Complete areas mapped from good images were used to assess the recovered areas from simulated partial observations in the same images.

2) Comparison with altimetry water levels in terms of area-level (A-L) correlations. Altimetry levels were acquired from Hydroweb, DAHITI, and USDA G-REALM.

Results: Validations on 400+ lakes/reservoirs

Validation of recovered areas from simulated contaminations on good images

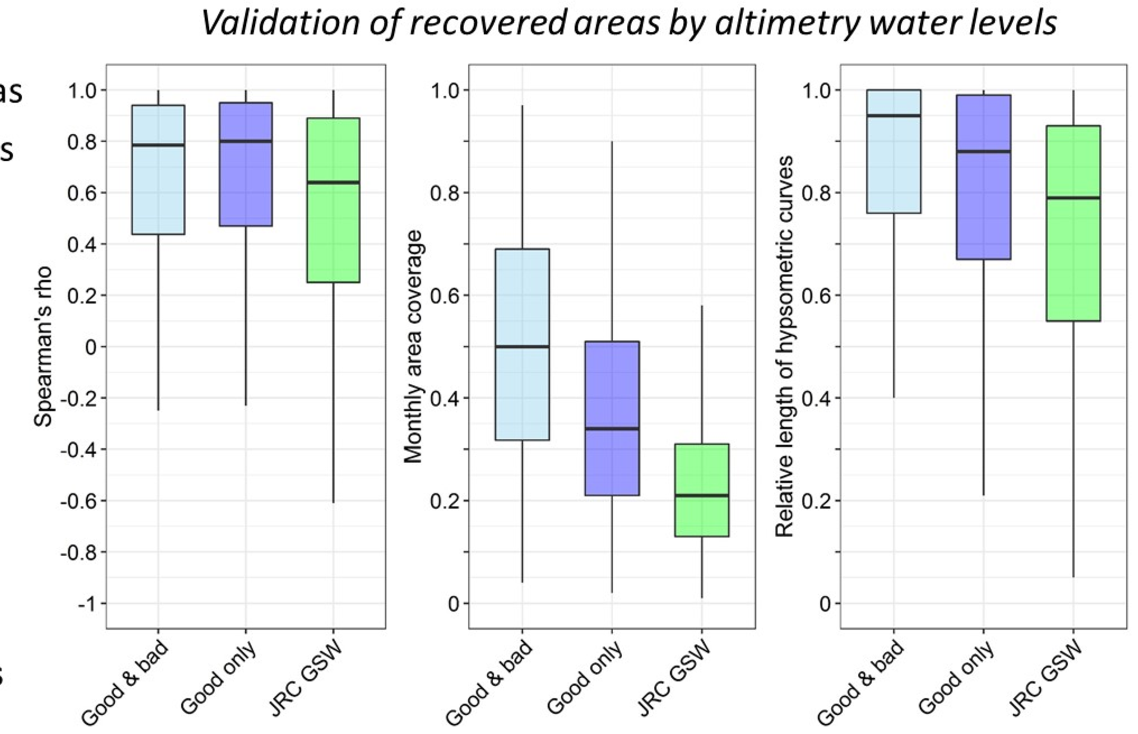


- **Overall, recovered areas have a bias of only 2.2%**
- More than 95% of the studied lakes/reservoirs have biases below 6.0%
- The variation in recovered areas agrees well with that in the actual areas in terms of both the slope and R^2 of the linear regression (validation).

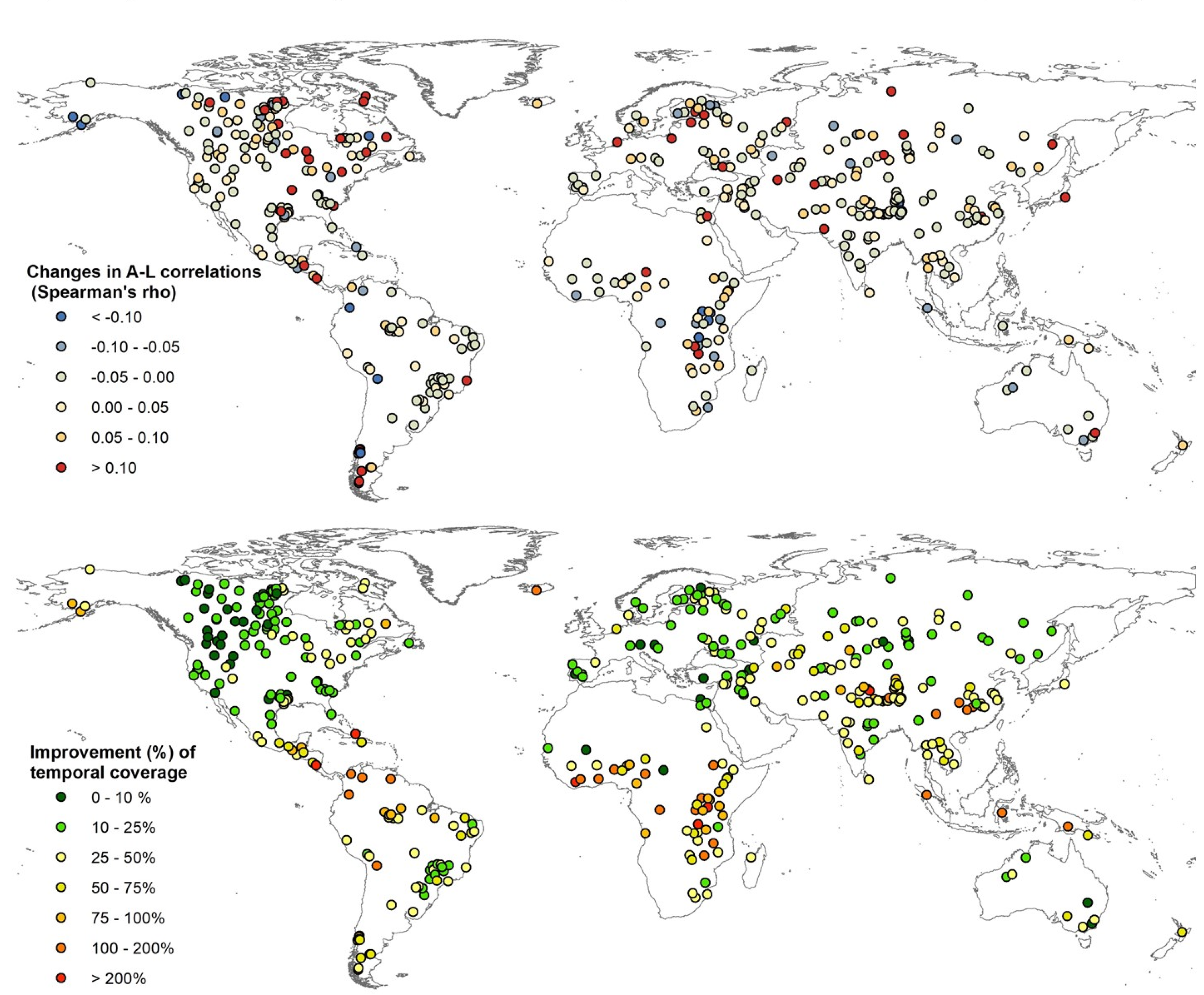
Validation of recovered areas by altimetry water levels

Inclusion of the recovered areas

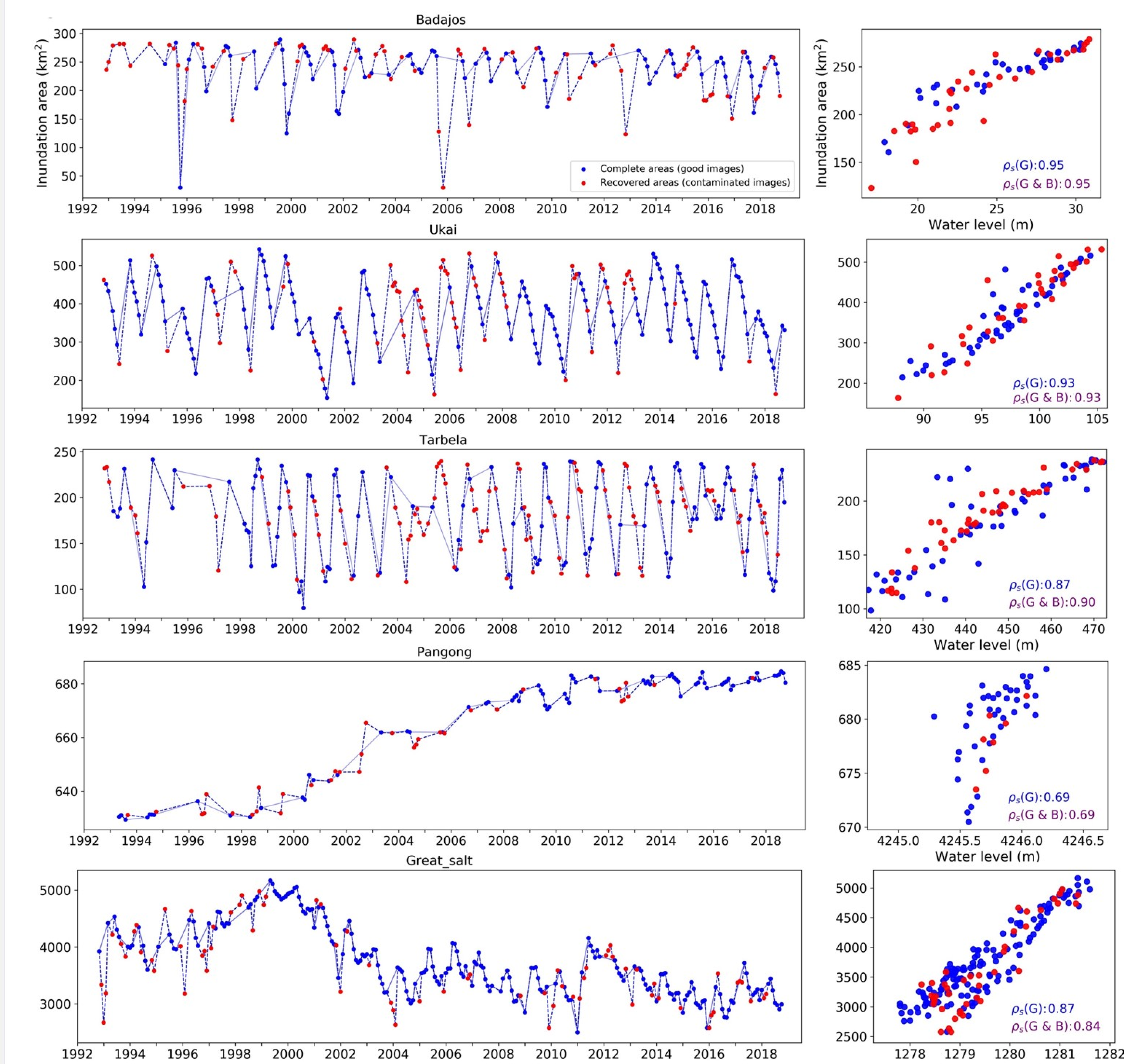
- Maintained high correlations with altimetry levels
- Improved the temporal resolutions by an average of 43%
- Increased the ranges of the hypsometric curves (area-level relationships)
- **Potentially benefit lake volume change estimations**



Impacts of recovered areas from contaminated images on A-L correlations and temporal coverage



Results: Applications on challenging scenarios



This method was tested to be robust under various challenging scenarios, including fluvial lakes in humid basins with frequent cloud contaminations, reservoirs with complex shape geometries, water bodies in deep valleys with terrain shadows, high-altitude lakes with snow/ice covers, and saline lakes with high mineral concentrations.

Conclusions

- This method could accurately estimate lakes and reservoir water areas from contaminated Landsat imagery with a mean relative error of 2.2%.
- The combined water area time series from both good and contaminated images show strong correlations with altimetry water levels, with Spearman's rho greater than 0.8 for most lakes/reservoirs.
- The combined area time series increased the monthly coverage using good images alone by an average of 43%, achieving a bi-monthly frequency for open surface water mapping.
- **This method has a potential to i) assisting water area recovery for other optical and SAR sensors (e.g., Sentinel-2 and SWOT), and ii) estimating lake/reservoir storage variations in conjunction with altimetry sensors.**

Data Availability

Our produced global lake/reservoir area time series (**GLATS**) will be available on the website https://lakewatch.users.earthengine.app/view/glats or upon reasonable request.