DISCREPANCIES IN ARCTIC-BOREAL LAKE AREA TRENDS DRIVEN BY SENSITIVITY TO DRY CONDITIONS

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INTRODUCTION

Multidecadal trends in northern lake areas are highly uncertain, with different studies often reporting directionally opposite trends over the same region. Much of the uncertainty in the net direction of decadal trends in lake area is likely due to limitations inherent to the data sources and analytical methods used to characterize lake water dynamics. Here, we seek to understand the causes of between-study differences in multidecadal lake area trends by examining the sources of differences between lake area estimates and short-term lake area trends derived from one Sentinel-2-based and two Landsat-based surface water products across five northern study regions.

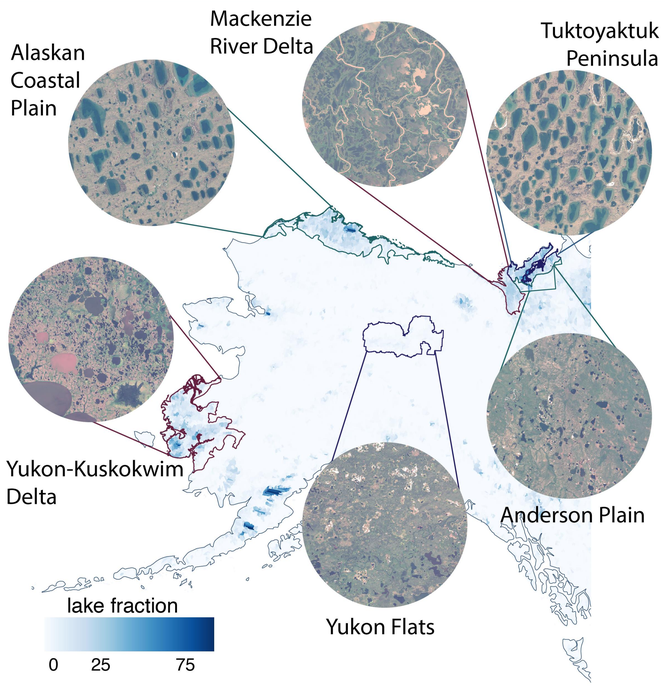

Figure 1: Location of study regions. True color images are from Sentinel-2 taken in July. The radius of each circle is ~ 10 km.

METHODS

We created a database of high resolution (10 m) lake polygons in six study regions (Fig. 1). We then evaluated annual maximum surface water area within each of these lake polygons estimated using three products, two products derived from Landsat (**GSWO**: Pekel et al., 2016; **GLAD**: Pickens et al., 2020) and one derived from Sentinel-2 (Levenson et al., 2025). Lakes without data from all products in all years of data overlap (2016-2021) were excluded from analysis. We compared the difference between lake area estimated with products at the individual lake level and aggregated at the regional level as well as the short-term regional lake area trends (2016-2021).

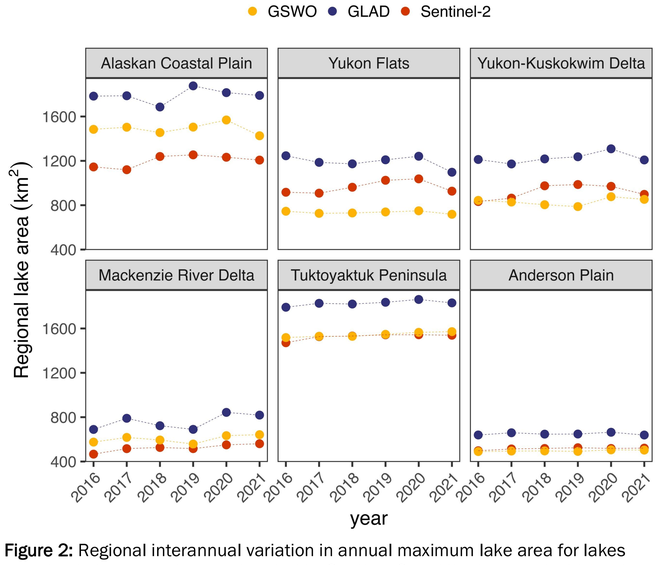

Figure 2: Regional interannual variation in annual maximum lake area for lakes included in the analysis, as estimated by Sentinel-2 and the two Landsat-based products.

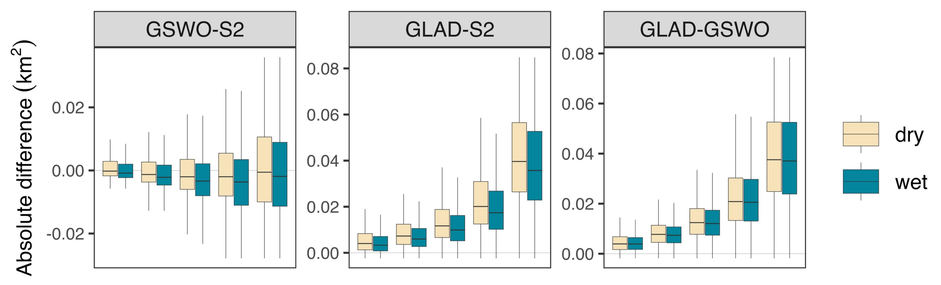

Figure 3: Absolute difference between lake area estimated by Landsat products and the Sentinel-2 product. Wet (dry) years were determined separately for each region and are the three years with the greatest (least) regional lake area as measured by Sentinel-2. Lakes size bins, which contain equal numbers of lakes, are: [0,0.006], [0.006, 0.013], [0.013, 0.028], [0.028, 0.076], [0.076, 30.235] km2 and are based on lake size determined by the Sentinel-2 product.

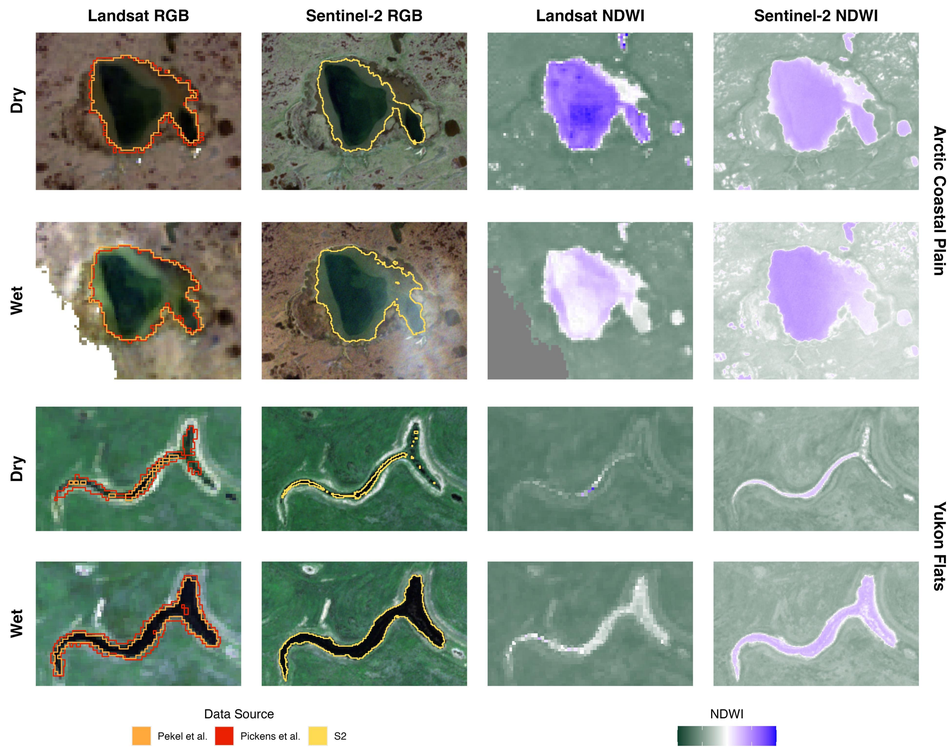

Figure 4: Example lakes from the Alaskan Coastal Plain (top) and Yukon Flats (bottom) showing how Landsat and Sentinel-2 surface water classifications vary between wet and dry years. The colored lines in the left two columns are lake polygons derived from our weekly Sentinel-2 and the monthly GSWO and GLAD surface water products. The left two columns are true color images; the right two columns are the Normalized Difference Water Index (NDWI), where positive values indicate the presence of open water and negative values represent non-water features.

RESULTS

BETWEEN-PRODUCT DIFFERENCES IN LAKE AREA ESTIMATES

- GSWO estimated 0.99 ± 3.8 % more lake area than Sentinel-2, but this varied considerably by region, with the GSWO underestimating lake area in three regions and overestimating lake area in the other three regions (Fig 2)
- GLAD overestimated lake area by 27.5 ± 3.4 % relative to Sentinel-2 and 26.5 ± 1.1 % relative to GSWO (Fig 2).

BETWEEN-PRODUCT DIFFERENCES IN LAKE AREA IN DRY AND WET YEARS

- Between-product differences in lake area were higher in dry years vs. wet years ($p < 0.001$ for all comparisons) (Fig. 3)
- In wet years, all products were generally in agreement on the location of lake perimeters, but in dry years, there was considerably more variability between products (Fig. 4).

INTERANNUAL VARIABILITY IN LAKE AREA

- The two Landsat-based products tended to measure less interannual variability in lake area compared with our Sentinel-2 based product (Fig 2.) Across the entire study domain, the coefficient of variation was 1.8, 2.2, and 3.8 according to the GSWO, GLAD, and Sentinel-2 products, respectively.

SHORT-TERM LAKE AREA TRENDS

- Short-term lake area trends estimated by Sentinel-2 were stronger than those estimated by Landsat across all regions ($p < 0.05$ for both GSWO and GLAD) (Fig. 6).
- There was no significant difference between trends estimated with GLAD and GSWO ($p > 0.1$) (Fig 6).
- Between-product differences in short-term trends were related to sensitivity to ground wetness conditions ($p < 0.001$) (Fig. 6).
- Dryness sensitivity, which refers to the degree to which the between-product difference in regional lake area is higher in dry years (Fig. 5), explains 51% of the variance in the between-product differences in trends (Fig. 6).

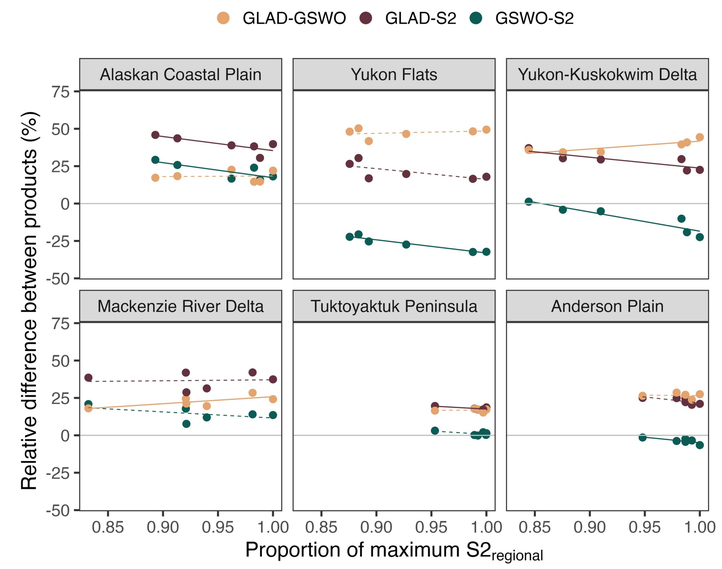

Figure 5: Relative difference between estimates of maximum lake area each year plotted by the proportion of Sentinel-2-estimated maximum regional lake area. The dryness sensitivity is the slope of the best fit line. Statistically significant relationships ($p < 0.1$) are identified with solid lines; dotted lines indicate non-significant ($p > 0.1$) slopes.

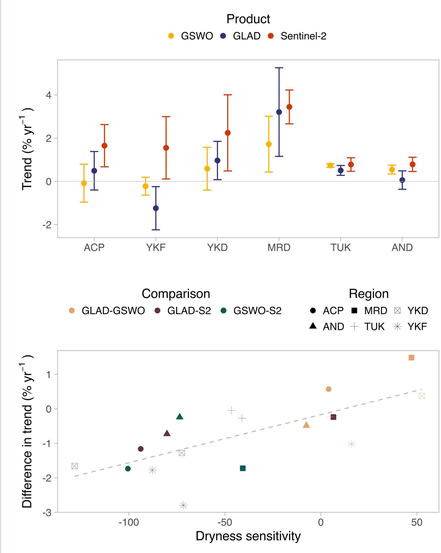

Figure 6: Lake area trends measured across regions with Sentinel-2 and Landsat products (top) and effect of dryness sensitivity to the absolute differences in trend estimates (bottom). Short-term trends were estimated by calculating the linear relationship between regional lake area and year and converted to percent by dividing by the regional lake area in the first year (2016). Dryness sensitivity refers to the degree to which the between-product difference in regional lake area is higher in dry years than in wet years (see Fig. 5). Dashed grey line on the left plot is the best fit linear relationship between variables.

CONCLUSIONS

- Directional differences in lake area trends between surface water occurrence products over the same region is due, at least in part, to differences in how the products classify water in dry conditions.
- Between-product differences in surface water classification mostly arise in mixed and ambiguous pixels, which are typically found along lake margins where the majority of lake area change occurs. These mixed and ambiguous pixels likely represent extremely shallow, muddy environments or areas with inundated vegetation such as floating mats, emergent vegetation, or fens.
- Resolving differences in between-product estimates of long-term trends in lake area will require methods that reduce uncertainty in shallow water and that can distinguish inundated vegetation from land and water.

REFERENCES

- Pekel, J.F., Cottam, A., Gorelick, N., Belward, A.S., 2016. High-resolution mapping of global surface water and its long-term changes. Nature 540, 418–422. https://doi.org/10.1038/nature20584
- Pickens, A.H., Hansen, M.C., Hancher, M., Stehman, S.V., Tyukavina, A., Potapov, P., Marroquin, B., Sherani, Z., 2020. Mapping and sampling to characterize global inland water dynamics from 1999 to 2018 with full Landsat time-series. Remote Sensing of Environment 243, 111792. https://doi.org/10.1016/j.rse.2020.111792
- Levenson, E.S., Cooley, S., Mullen, A., 2025a. ABoVE: Alaska Lake and Pond Occurrence. https://doi.org/10.3334/ORNLDAAC/2399

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