Evaluating Atmospheric Correction Algorithms for Accurate Water Quality Detection in Lakes Using Landsat: A Comparative Study

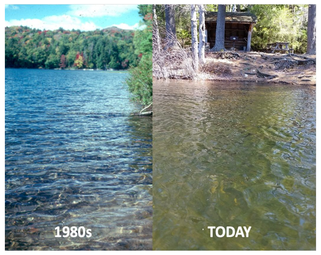
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Research Objective

This study aims to enhance water quality monitoring of lakes using remote sensing, addressing the following objectives:

- Utilize Landsat to monitor lake water quality parameters (WQPs) such as chlorophyll-a and colored dissolved organic matter (CDOM).
- Emphasize the need for tailored atmospheric correction methods for specific water bodies to enhance remote sensing-based water quality assessments.
- Overcome limitations of remote sensing, including spatial resolution and cloud coverage, to improve the accuracy of atmospheric correction models for complex waters.
- Identify the most effective atmospheric correction algorithms for estimating CDOM/DOC by comparing their performance and accuracy.

These objectives aim to improve the efficiency and accuracy of remote sensing for managing and conserving inland water bodies.



Bear Pond

Study Region

Adirondack Park (Upstate NY)

- Protected Wilderness Area: One of the largest protected wilderness areas in the US, safeguarded by the Clean Air Act to control anthropogenic impacts on lake health.
- Historical Acidification: Previously experienced lake acidification; the Adirondack Lake Survey (ALS) collected extensive field data on water chemistry, fish populations, and more, revealing significant lake recovery.
- Ongoing Concerns: Algal blooms, rising lake temperatures, and other threats to lake ecosystems persist in the region.

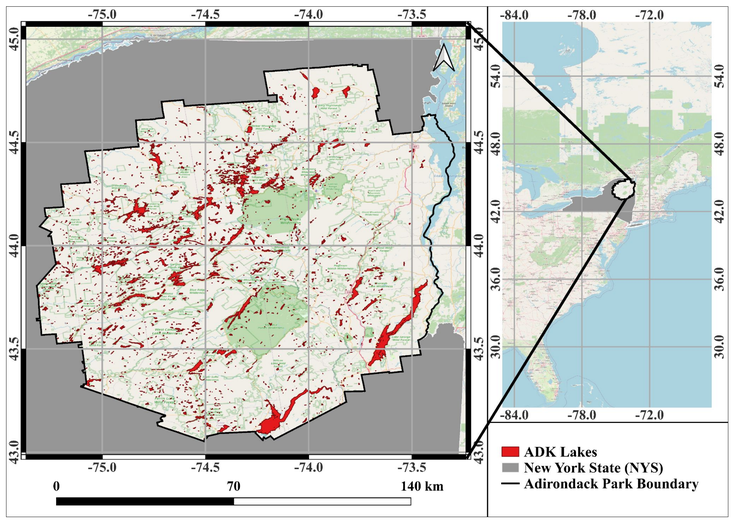


Figure 1. *Map of Adirondack Park and sampled ADK lakes.*

Datasets

Satellite series used:

- **LANDSAT-5**
  - 30m pixel resolution
  - 16-day temporal resolution
  - 1984 - 2013

In-situ Data:

- ADK ⟶ 1469 Lakes
- AEAP ⟶ 28 Lakes
- NY CSLAP ⟶ 51
- NY LCI ⟶ 86
- **ALTM ⟶ 54**

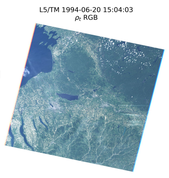


Figure 2. *Single ACOLITE processed RGB image for path 015 and row 030.*

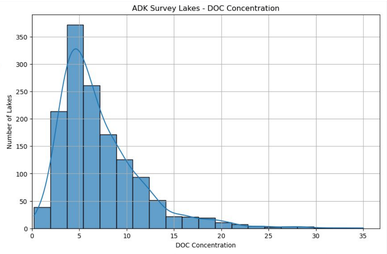


Figure 3. *Histogram of DOC concentration of ADK sampled lakes*

Methodology

- Data Collection:
  - Satellite Data: 15 Landsat 5 images were utilized.
- Atmospheric Correction:
  - USGS Level 2 Collection: Landsat Ecosystem Disturbance Adaptive Processing System (LEDAPS).

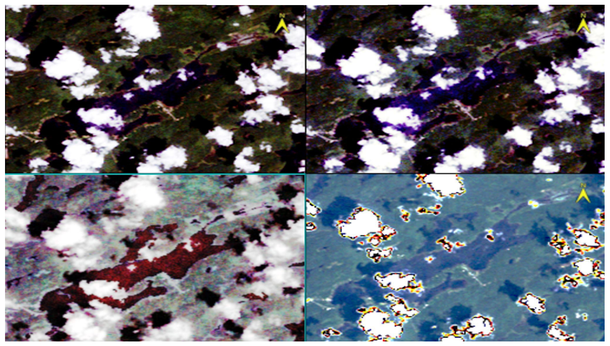
$$\rho^{TOA} = \rho_{atm} + \frac{T_d T_u \rho^s}{1 - s_{atm}\rho^s}$$

  - FLAASH: Fast Line-of-sight Atmospheric Analysis of Spectral Hypercubes.

$$L = \left(\frac{A\rho}{1-\rho_e S}\right) + \left(\frac{B\rho_e}{1-\rho_e S}\right) + L_a$$

  - ACOLITE: Atmospheric Correction for OLI 'Lite'.
    - Utilizes the "dark spectrum fitting" (DSF) approach for inland water applications.

$$\frac{\rho_t}{T_g} = \rho_{path} + \frac{\rho_s \cdot T_d T_u}{1 - \rho_s \cdot S},$$


Figure 4. *Comparison of USGS Level 2 LEDAPS, ACOLITE, and FLAASH corrected image vs. Level 1 raw image for 07/12/2008. Top left is Level 1, top right is LEDAPS, bottom left is ACOLITE, and bottom right is FLAASH.*

- Comparative Analysis:
  - Performance differences among the atmospheric correction algorithms were evaluated based on the accuracy of CDOM/DOC estimations using B4/B1 band ratio.
  - Cluster Analysis: Lakes were classified into low, medium, and high mean depth clusters.

Results

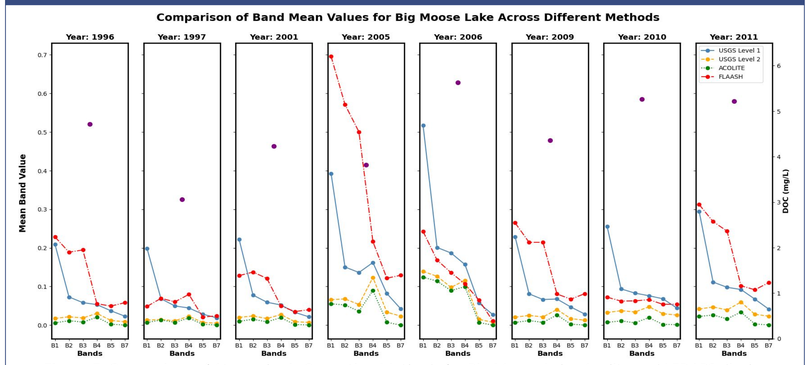


Figure 5. *Comparison of Atmospheric Correction Methods for Big Moose Lake. Acolite and LEDAPS display similar trends, while FLAASH shows more variability over time.*

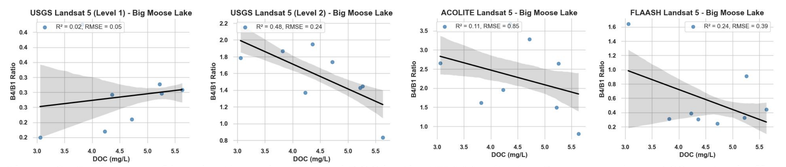


Figure 6. *Evaluation of band ratio and measured DOC by the LTM Monitoring Program using a 100-meter buffer around Big Moose Lake sample location. Acolite exhibits the lowest R^2 value at 0.11, while LEDAPS shows the highest with an R^2 of 0.48.*

Results

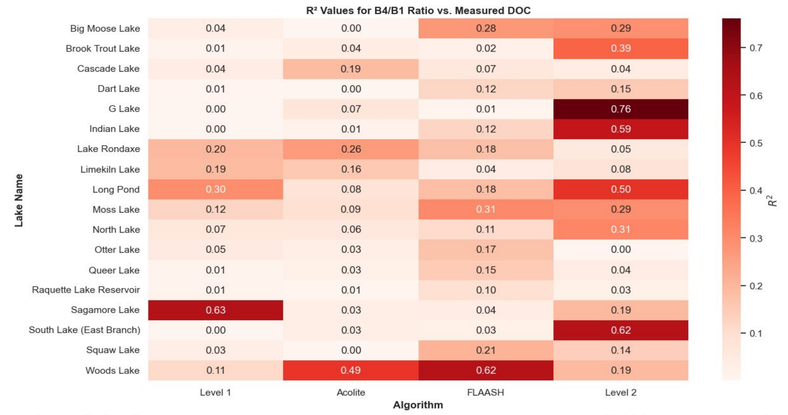


Figure 7. *The R^2 values across different algorithms show contrasting trends, with LEDAPS exhibiting large R^2 values, while other algorithms display very low values. Data points are derived using centroid coordinates.*

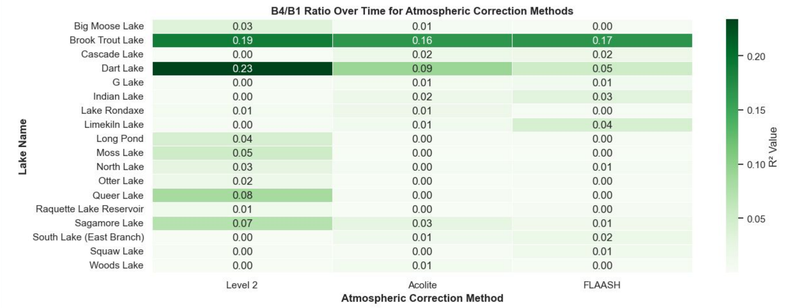


Figure 8. *The R^2 values across different lakes and algorithms indicate a generally weak correlation between the B4/B1 band ratio and time.*

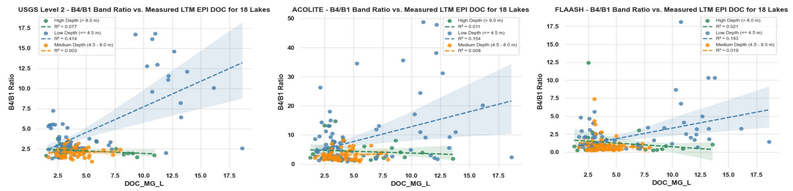


Figure 9. *Lakes with medium mean depth show low in-situ DOC concentrations, low B4/B1 band ratios, and overall weak R^2 values. Low depth lakes exhibit more variable behavior but demonstrate the strongest correlations between the band ratio and in-situ data. High depth lakes generally have low B4/B1 band ratio values.*

Discussion

- To investigate long-term trends in water quality, it is essential to apply a consistent, water-specific algorithm across Landsat 5 data. This ensures compatibility and accuracy, particularly when analyzing changes in water transparency, biomass, and sediment over time.
- The comparison of the models for 18 selected lakes within the tile shows that LEDAPS algorithm applied on USGS Collection-2 performs better than FLAASH and has an offset compared to Acolite.
- Despite the accuracy of the LEDAPS algorithm, there are notable exceptions that exist. In some cases, Acolite and FLAASH demonstrate stronger correlations than LEDAPS in certain lakes, highlighting the variability in algorithm performance across different environments.

Conclusion

- The LEDAPS algorithm reveals consistent superiority over FLAASH and Acolite in overall accuracy for atmospheric correction.
- Future efforts will involve:
  - Utilizing Landsat 8 data to compare and validate the atmospheric correction results obtained from Landsat 5.
  - Developing a machine learning model to predict lake water quality parameters (WQPs) across the broader Adirondack region.

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Acknowledgements

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