Remote Detection of Harmful Algal Blooms Using Sentinel-2's MultiSpectral Instrument

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Introduction

Motivation

- Harmful algal blooms' (HABs) frequency, duration, and intensity have been increasing with the rise in human population (Burns, 2008)
- As HABs are an ecological, public health, and economic concern, it is critical to detect, monitor, and predict HABs

Objectives

- Assess the potential of high resolution satellite Sentinel-2 (S-2) to accurately detect HABs in Central Floridian lakes known to have blooms
- Determine if S-2 can produce algal biomass products that match those for Sentinel-3 (S3)
- Compare S-2's MultiSpectral Instrument (MSI) products—based on both top of atmosphere (TOA) and bottom of atmosphere (BOA) reflectance—to S-3's Ocean and Land Colour Instrument (OLCI) products

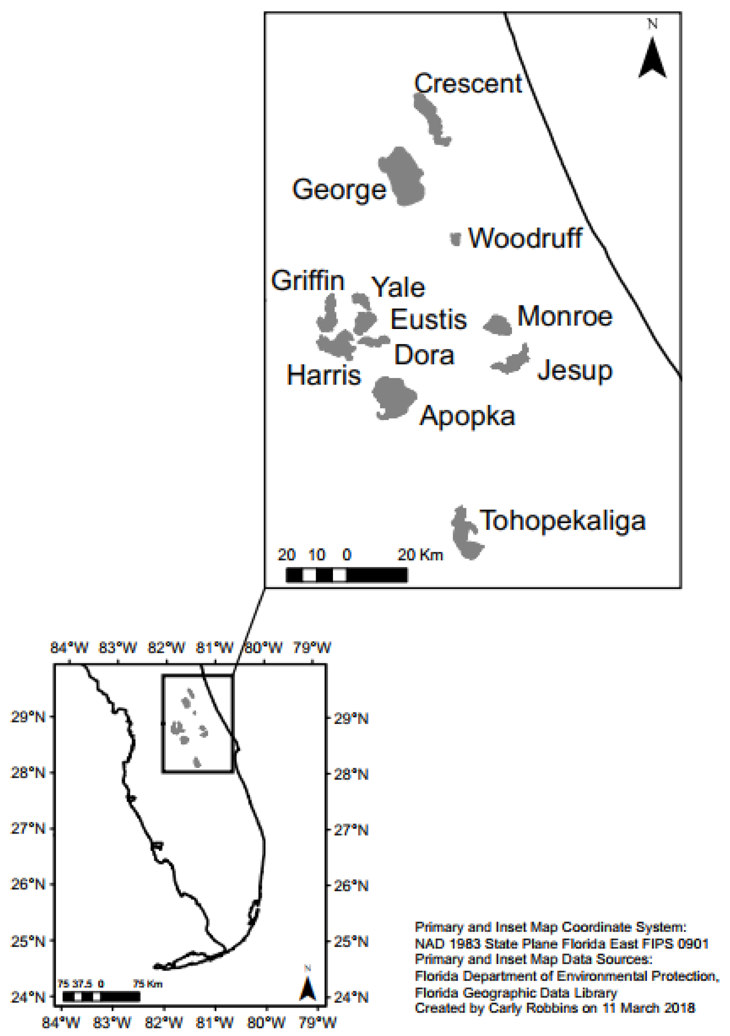

Figure 1: Map of study area

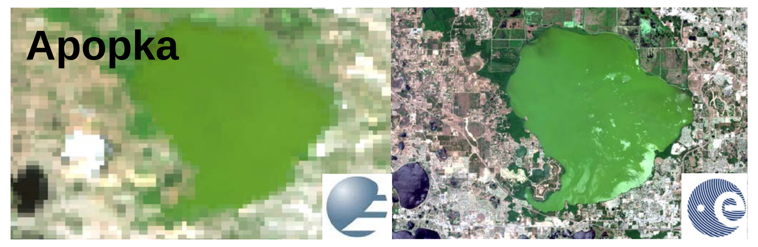

Figure 2: Comparison between spatial resolutions of S-3 and S-2
Left: OLCI (300 m)
Right: MSI (20 m)

We used the Maximum Chlorophyll Index (MCI) to identify HABs (Gower et al., 2008). MCI uses the red and "red edge" near infrared bands. This is particularly effective for lakes and estuaries, as it is less sensitive than traditional blue-green ratio algorithms to other materials in the water like dissolved and non-algal (sediment) pigments (Gilerson et al., 2010).

$$\textbf{OLCI MCI} = \rho_{BOA}(709) - \rho BOA(681) - \left[\frac{(709-681)}{(753-681)}(\rho BOA(753) - \rho_{BOA}(681))\right]$$

$$\textbf{MSI MCI} = \rho(705) - \rho(665) - \left[\frac{(705-665)}{(740-665)}(\rho(740) - \rho(665))\right]$$

where:
$\rho_{BOA}(\lambda)$ = OLCI BOA Rayleigh-corrected reflectance* (ρ_{BOA}) (dimensionless) measured at band with band center λ (wavelength) nm
$\rho(\lambda)$ = either MSI BOA Rayleigh-corrected reflectance* or MSI TOA reflectance (ρ) (dimensionless) measured at band with band center λ (wavelength) nm
*atmospherically corrected using Sen2Cor

Methods

Establish OLCI and MSI image matchups → Create polygons within lakes → Ordinary Least Squares regression → Extract zonal means by polygons → Validate using Leave-one-out-cross (LOOCV) validation and a spatial transfer of models to Utah Lake → Evaluate residuals

Residual = $y - \hat{y}$
y = observed MSI MCI value
$\hat{y}$ = predicted MSI MCI value

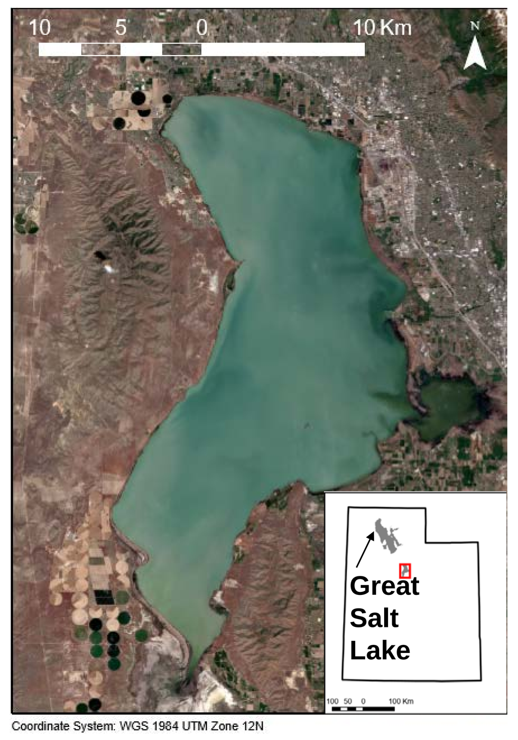

Figure 3: Utah Lake

Results

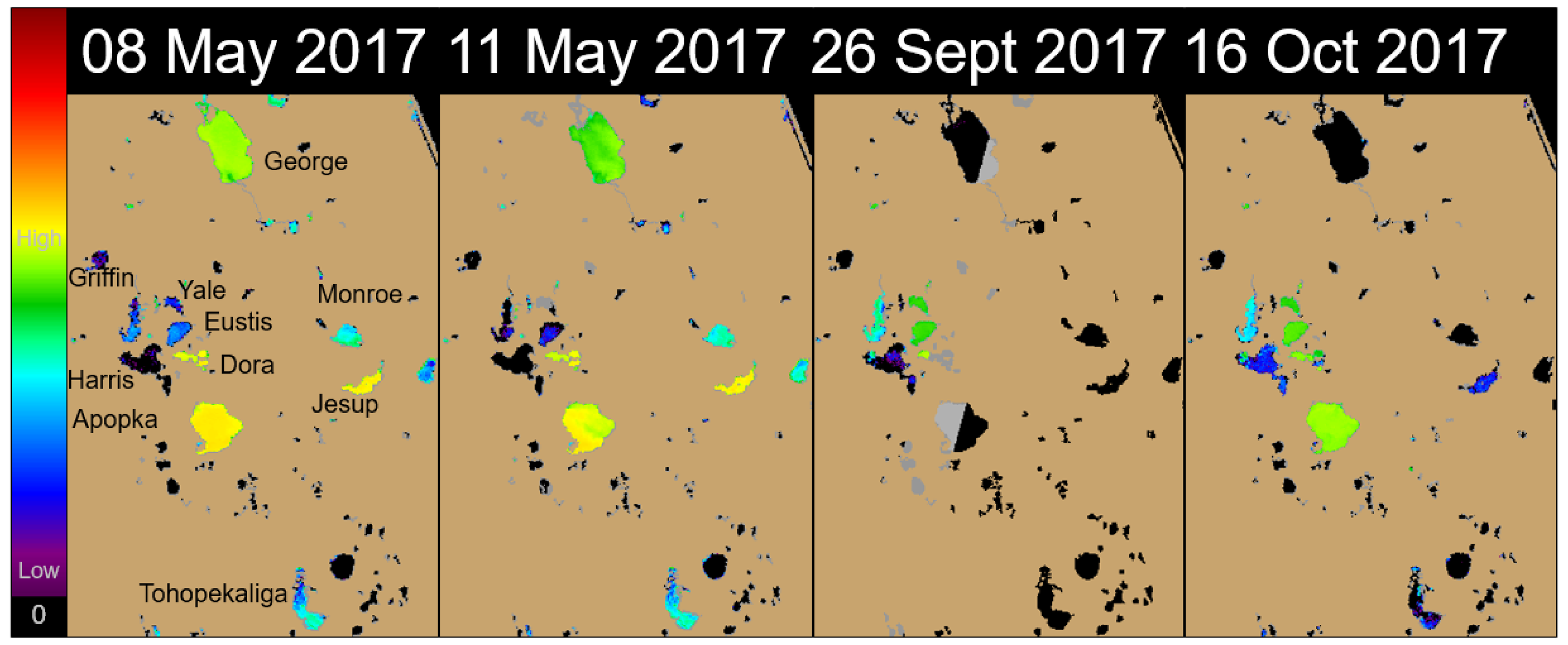

Figure 4: MCI imagery
Warmer colors indicate higher levels of chlorophyll, which are associated with higher concentrations of cyanobacteria. Cooler colors indicate lower levels of chlorophyll, which are associated with lower concentrations of cyanobacteria. Gray represents clouds. Black represents areas unlikely to have significant levels of chlorophyll.

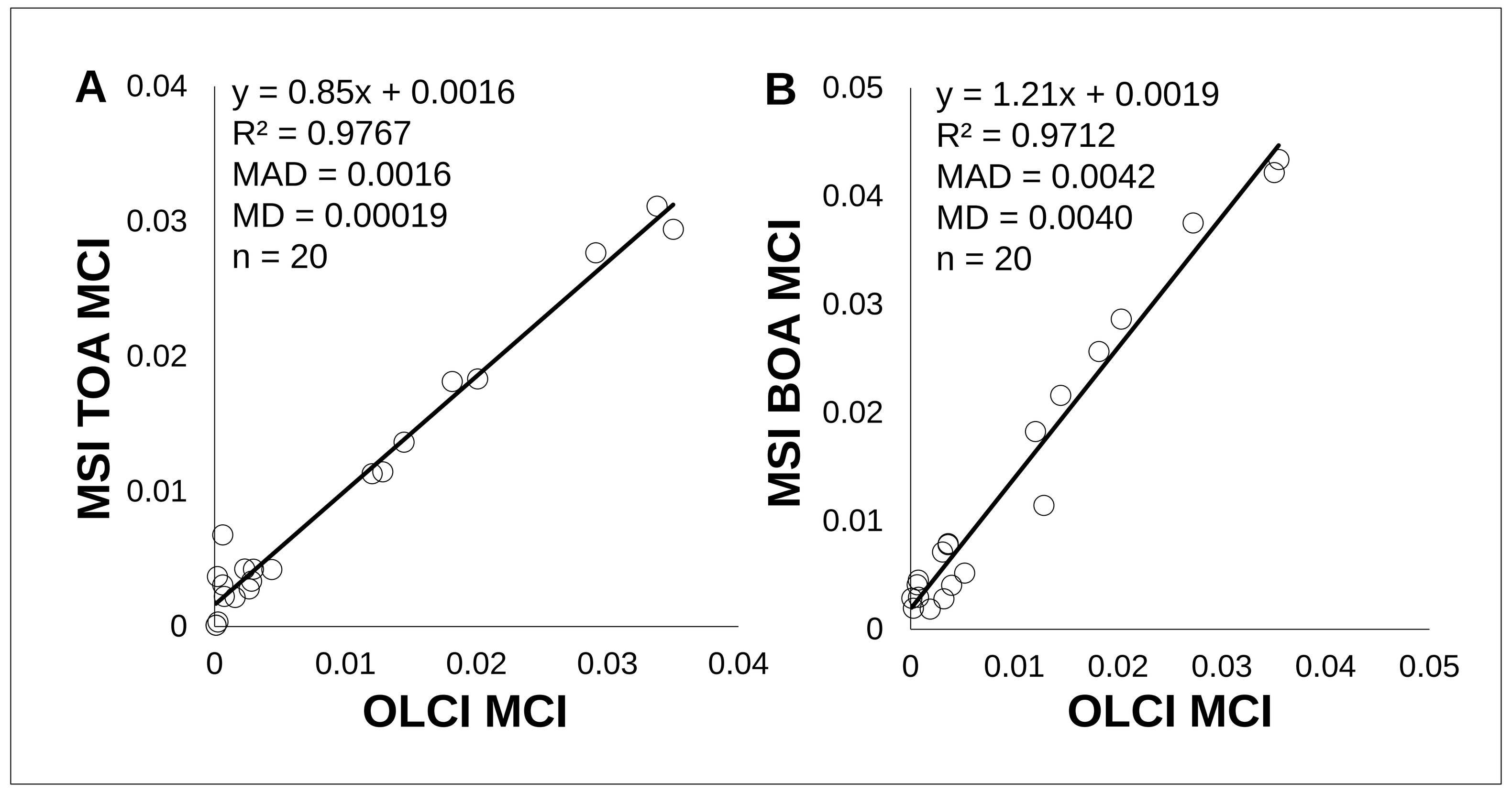

Figure 5: Comparisons between OLCI and MSI derived MCI
The solid black line represents the Ordinary Least Squares best fit regression line. The dashed black line represents the 1:1 line.

OLCI MCI and MSI MCI are linearly related. Figure 5A's smaller MAD indicated better model performance.

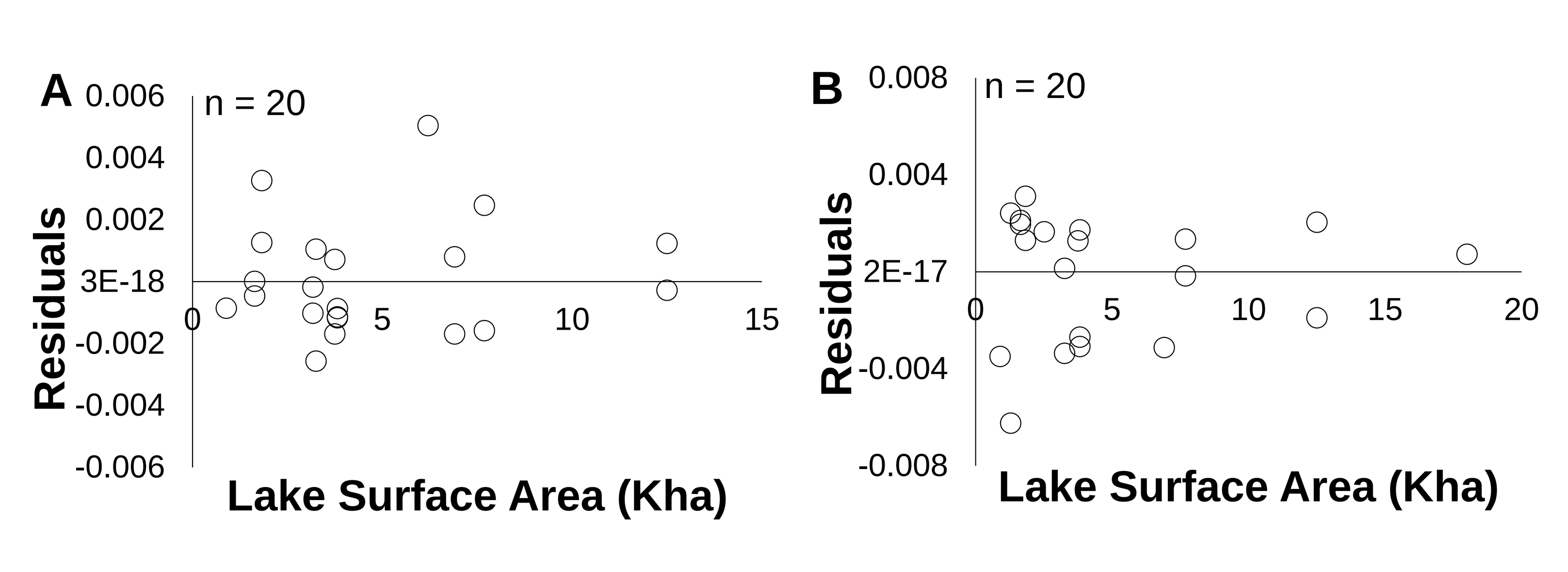

Figure 6: Comparison of residuals calculated after LOOCV and lake surface area (kilohectares)
Left: Residuals based on MSI MCI TOA
Right: Residuals based on MSI MCI BOA

Residuals show an even distribution and no evidence of a pattern. Therefore, the linear model is appropriate for the data.

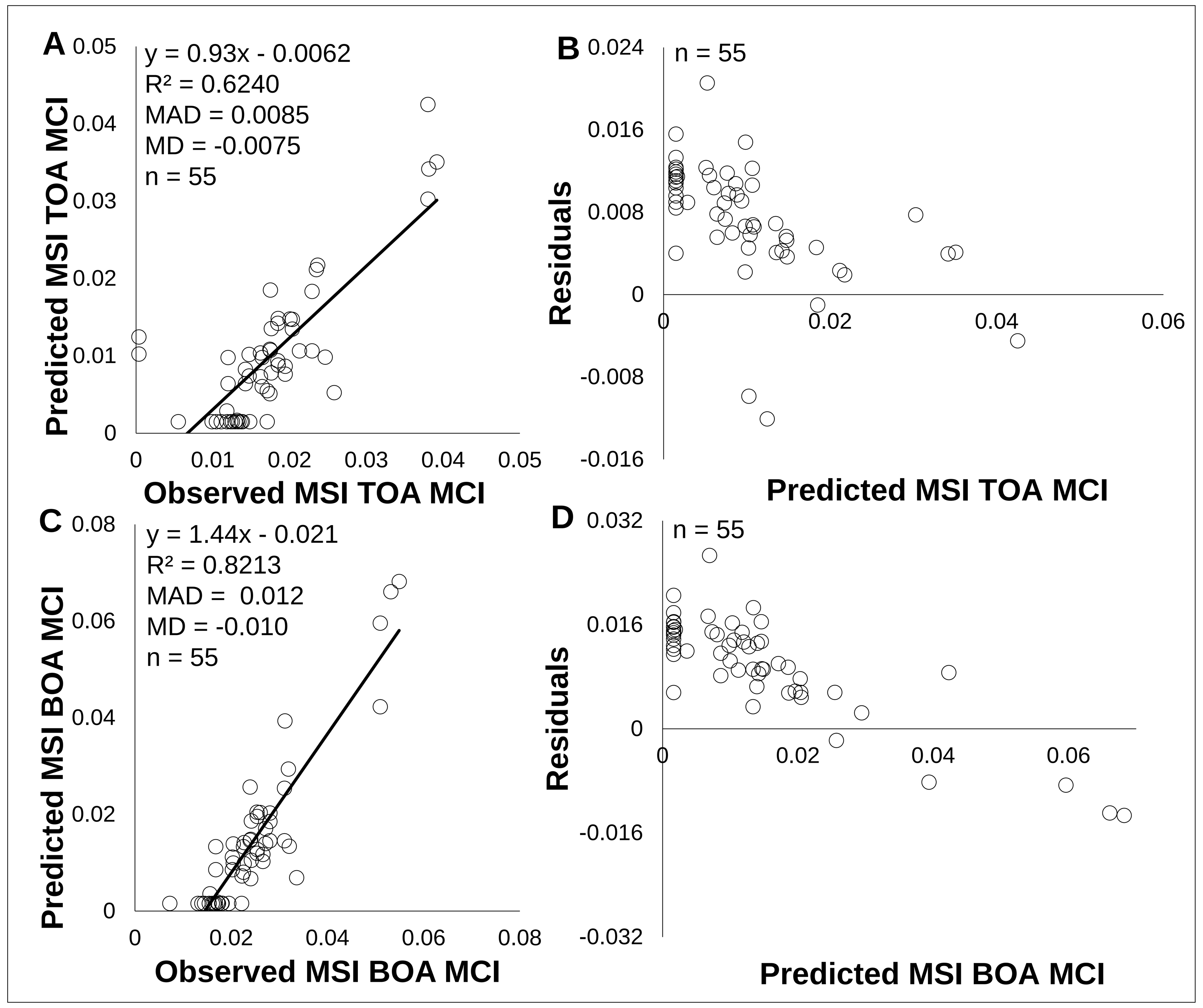

Figure 7: Spatial transfer of MCI models to Utah Lake
Left: Comparisons between observed and predicted MSI MCI
Right: Associated residual plots

Residuals are mostly positive and not distributed evenly, so the models are not transferable.

Conclusion

- MSI can be used as a high resolution proxy for OLCI to estimate chlorophyll (Figure 5)
- MSI MCI is linearly related to OLCI MCI (Figure 5)
- LOOCV residual plots indicate that a linear model is appropriate for the Florida data (Figure 6)
- No clear relationship between size of residuals and area of lake (Figure 6)
- MCI based on uncorrected MSI data provide MCI estimations from OLCI closer to real MSI values than MCI based on BOA Rayleigh corrected data (Figures 7A and 7C)
- Sen2Cor method is not appropriate for inland lakes (Figures 7A and 7C)
- Spatial partitioning results indicate that models trained with Florida data are not transferable to Utah Lake (Figures 7B and 7D)
- Recalibration is needed if the model is applied for different study areas due to unique environmental conditions such as water temperature and nutrient levels
- Future work consists of conducting a band-by-band comparison between OLCI and MSI and field data validation

References

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Acknowledgments

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