Demonstrating Fresh and Coastal Water Products from PACE/OCI Proxy Observations

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Introduction

Cyanobacteria Harmful Algal Blooms (cyanoHABs) create toxins that harm local wildlife and public health, thereby impacting the local economy through reduced recreation and tourism. Satellite products can complement *in situ* measurement to provide consistent observations at representative spatial and temporal scales for water quality managers to perform risk assessments of cyanoHABs and issue advisories. Satellite-derivable biogeochemical parameters (BPs), such as the pigments chlorophyll *a* (chl*a*) and phycocyanin (PC), total suspended sediment (TSS) and colored dissolved organic matter at 440 nm (CDOM), can serve as proxies for aquatic plant biomass, potentially harmful algae, and nutrient availability. Inherent optical properties (IOPs) such as phytoplankton absorption (a_{ph}), non-algal absorption (a_{nap}), and CDOM absorption (a_{cdom}) enable phytoplankton community composition analysis as well as DOM and NAP source and composition estimation. In our work[1], we train and validate mixture density networks (MDNs) to fully leverage the available hyperspectral data to improve the simultaneous estimation of biogeochemical variables and IOPs from global inland and coastal waters. We validate our models with atmospherically corrected (via SeaDAS or ACOLITE) hyper- and multispectral satellite imagery, from the Hyperspectral Imager for the Coastal Ocean (HICO), the PRecursore IperSpettrale della Missione Applicativa (PRISMA), and the Ocean and Land Colour Instrument (OLCI). Efficacy of our algorithms on these missions serve as proxies for the upcoming Plankton, Aerosol, Cloud, ocean Ecosystm (PACE) mission.

Global *In situ* BPs & IOPs of Coastal & Inland Waters

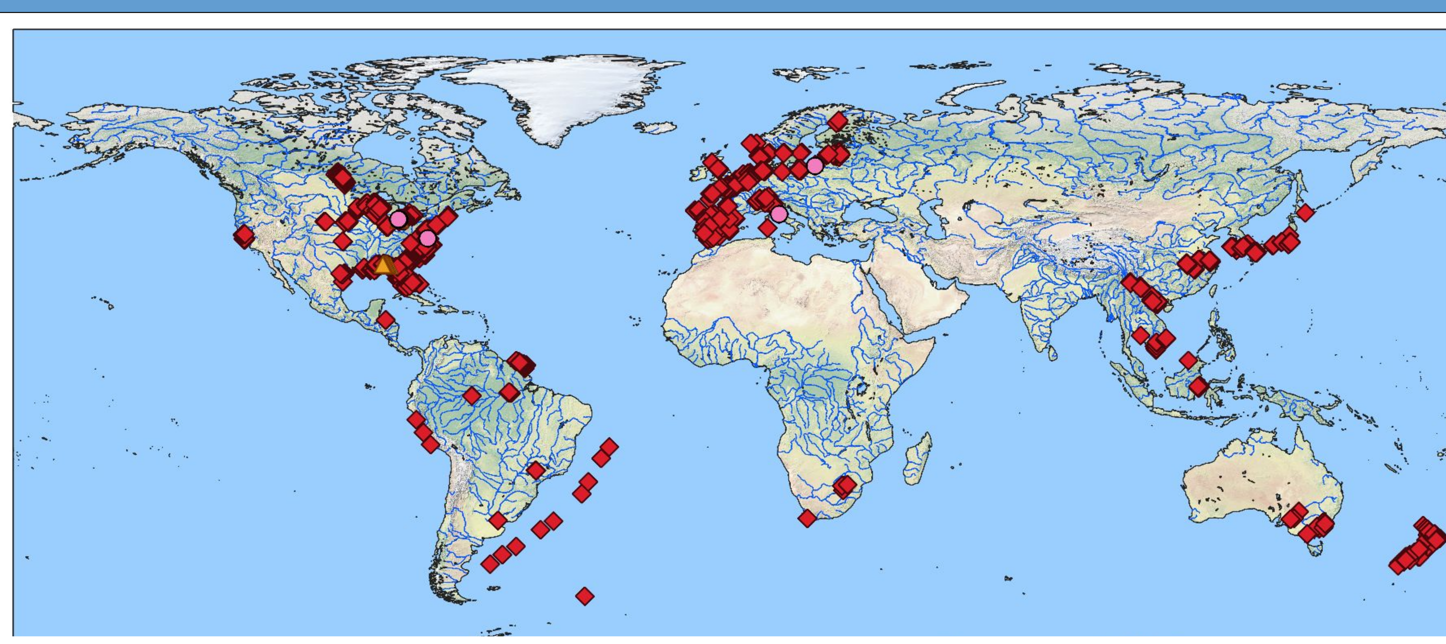


Fig. 1: Globally distributed *in situ* measured biogeochemical parameters and IOPS with associated hyperspectral R_{rs} (an augmented version of the GLORIA dataset[2]). Red diamonds show in situ R_{rs} and measurements (N=8,237), pink circles show *in situ* measurements and satellite R_{rs}, Orange triangles show R_{rs} and co-aligned satellite R_{rs}.

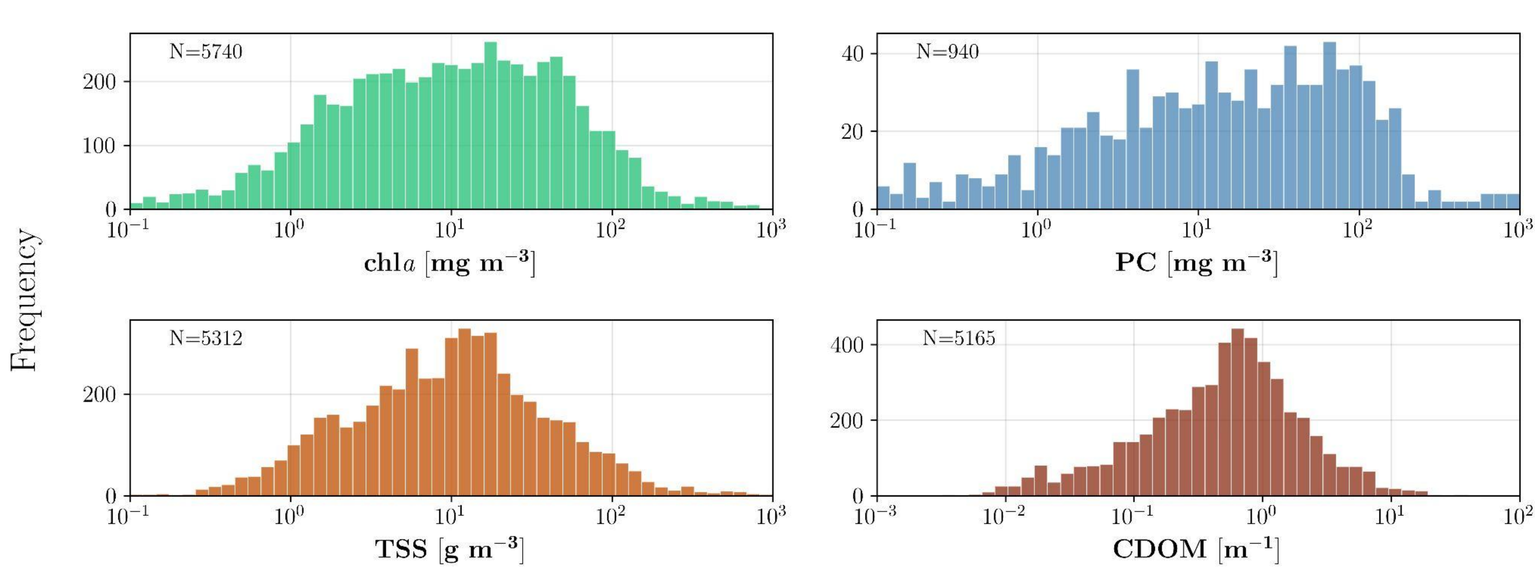


Fig. 2: Histograms of chl*a*, PC, TSS, and CDOM, with number of samples in the top left. The median values for chla, PC, TSS, and CDOM are: 10.5 mg/m³, 15.09 mg/m³, 10.4 g/m³, and 0.55 m⁻¹, respectively.

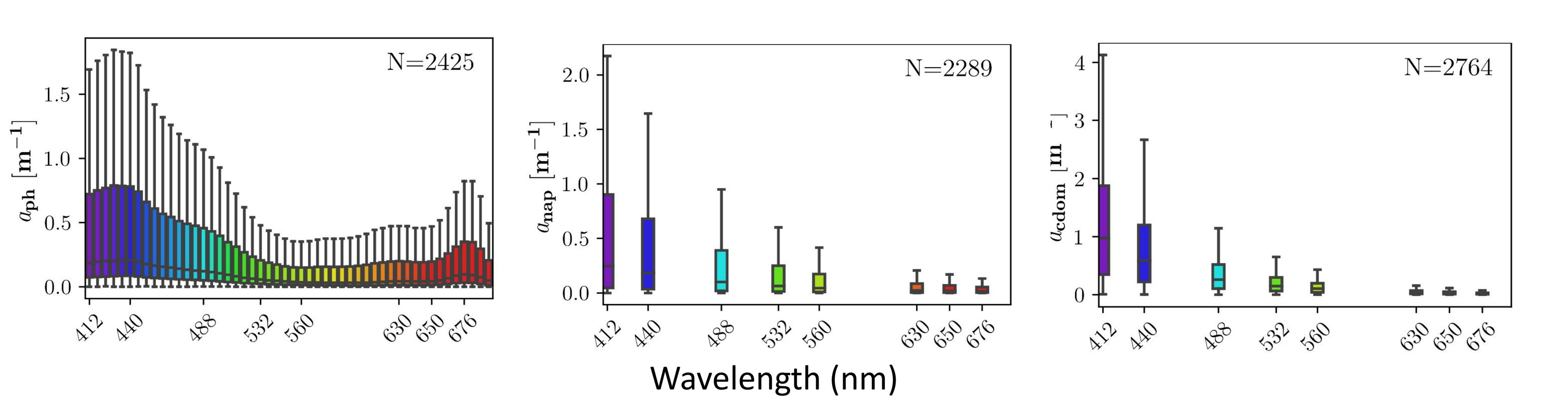


Fig. 3: Box and whisker plots of a_{ph}, a_{nap}, and a_{cdom}, with number of samples for each IOP in the top right. a_{nap} and a_{cdom} are only displayed at select wavelengths, to reduce MDN model complexity.

Mixture Density Network (MDN) Architecture

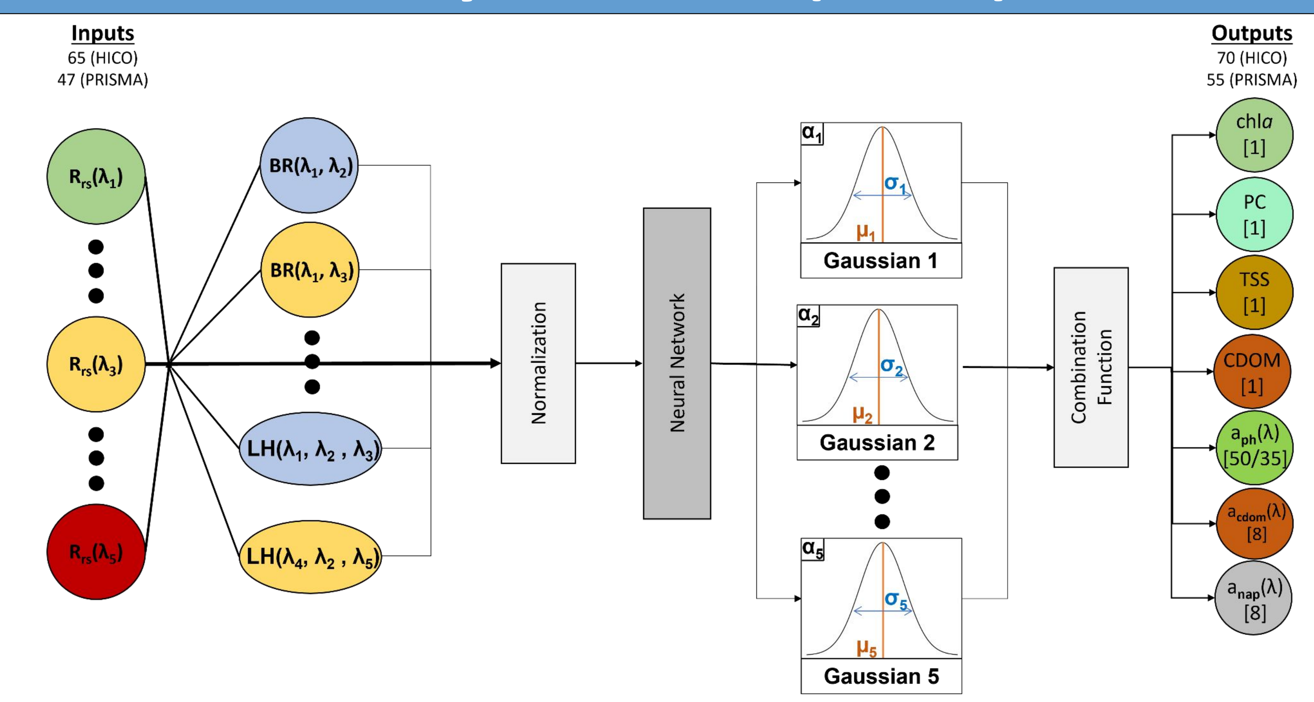


Fig. 4: Simultaneous MDN's architecture. R_{rs} in the 409-724 nm range are input to the MDN. Select band ratios (BRs) and line heights (LHs)s are calculated and added to the input of a standard neural network. The output layer estimates the mean (μ_n), standard deviation (σ_n), and probability (α_n) of 5 gaussians representing each parameter. The final parameter estimate is chosen using a combination function (median), to select the highest likelihood (instead of the most probable) estimate.

MDN Testing on *in situ* data: 50/50 Training/Testing Split

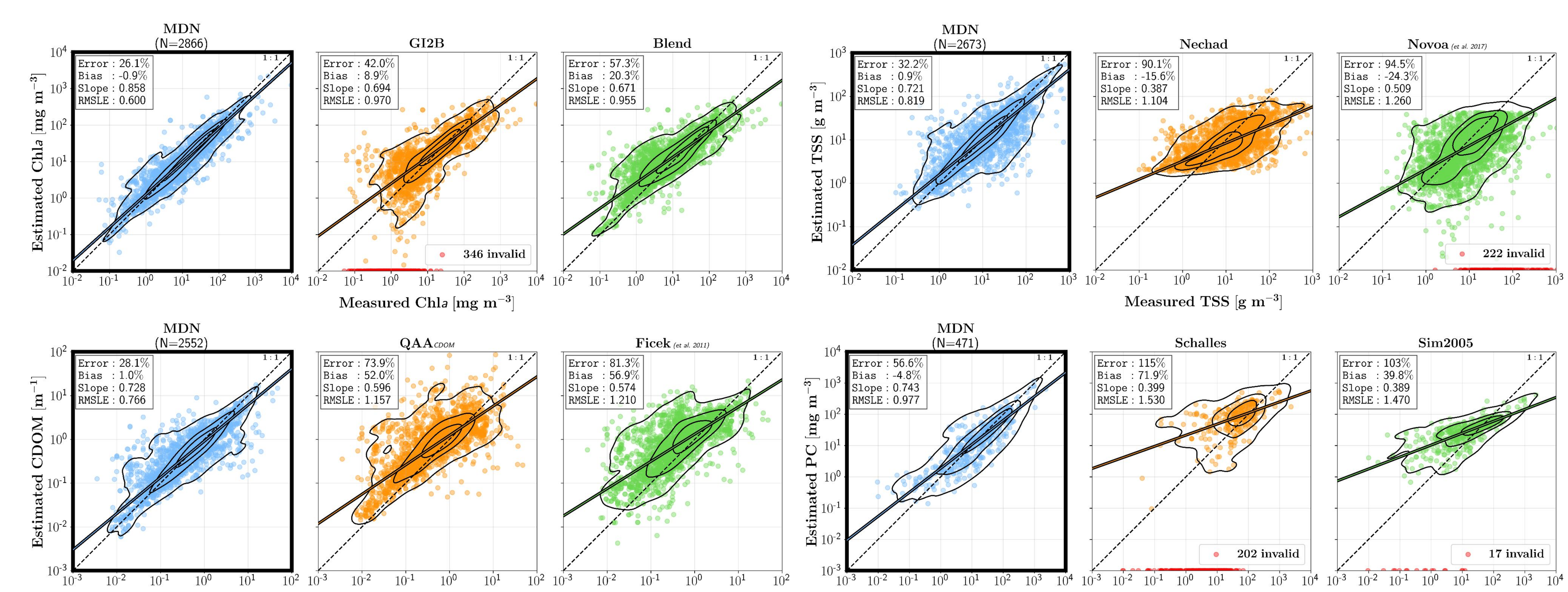


Fig. 5: Estimated vs. measured BPs from the testing half of the *in situ* dataset.

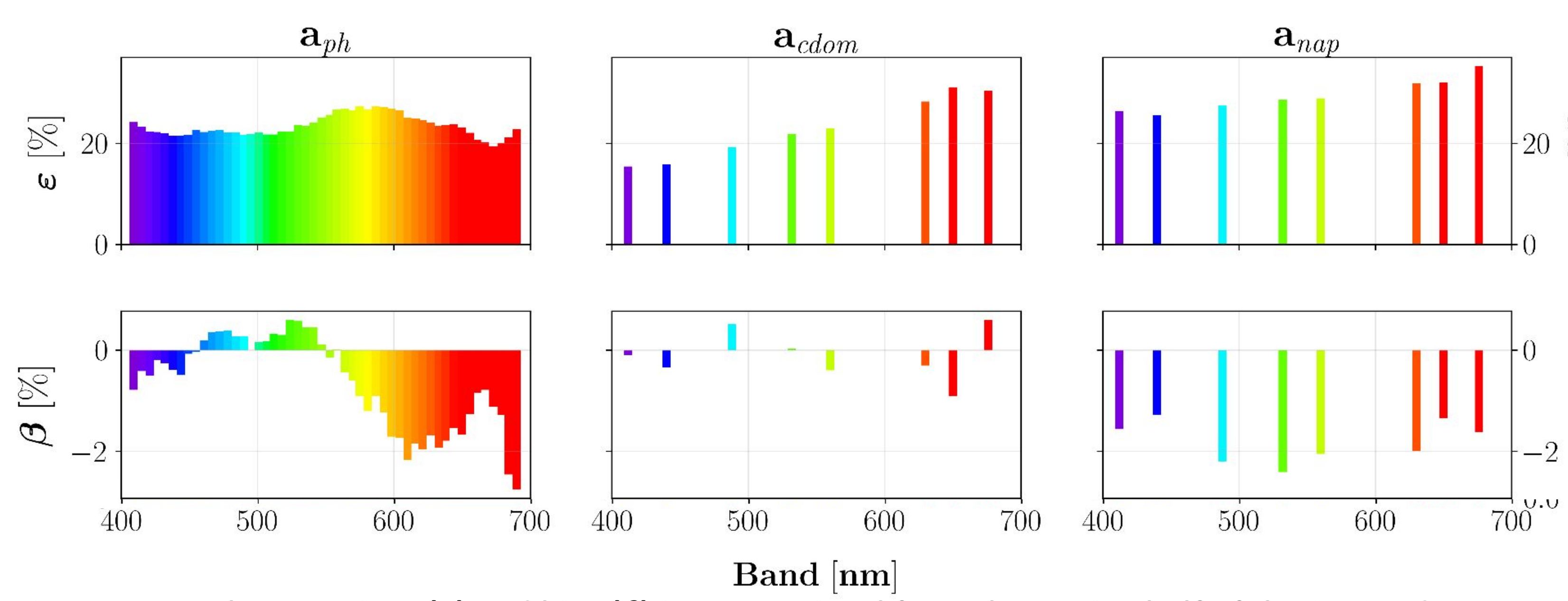


Fig. 6: Spectral uncertainty (ε) and bias (β) in IOP retrieval from the testing half of the *in situ* dataset.

Product Maps of the Curonian Lagoon (PRISMA)

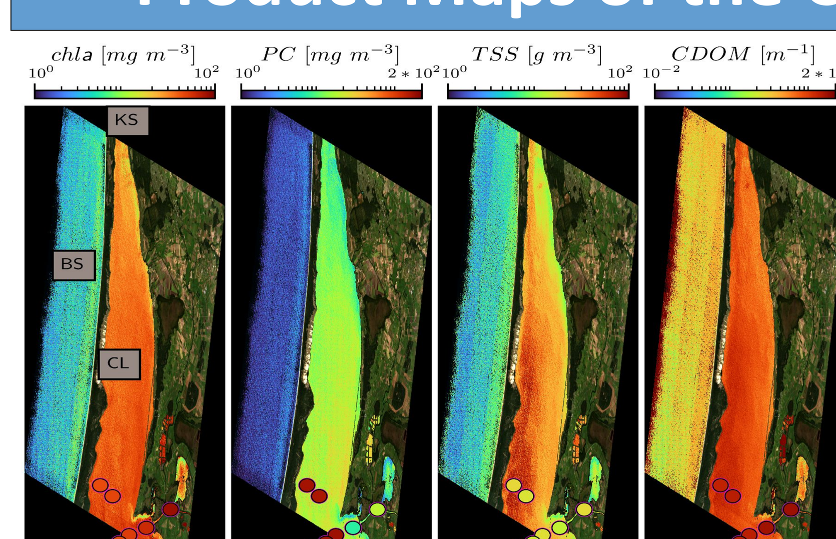


Fig. 7: Product maps of retrieved BPs from the Curonian Lagoon on 09/20/23 (PRISMA).

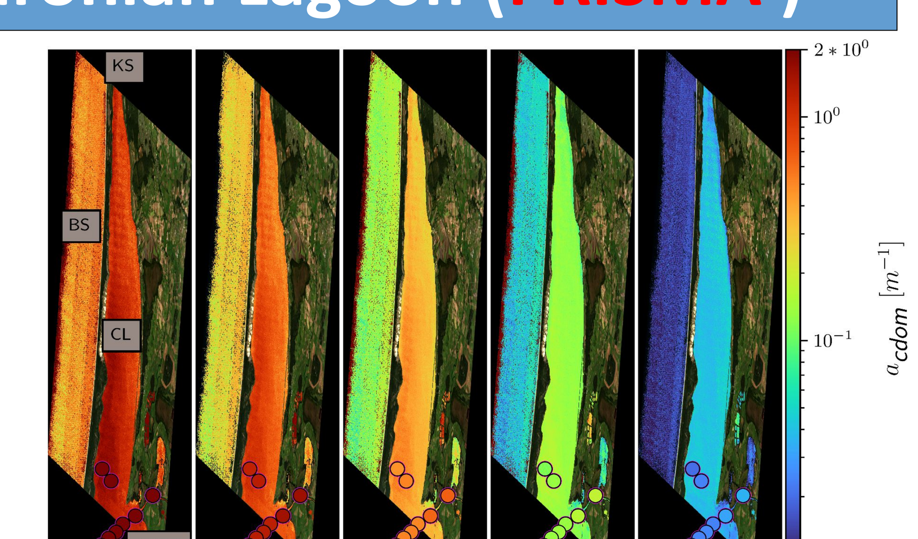


Fig. 8: Retrieved spectral CDOM from the Curonian Lagoon on 09/20/23 (PRISMA).

Product Maps of Lake Erie (HICO)

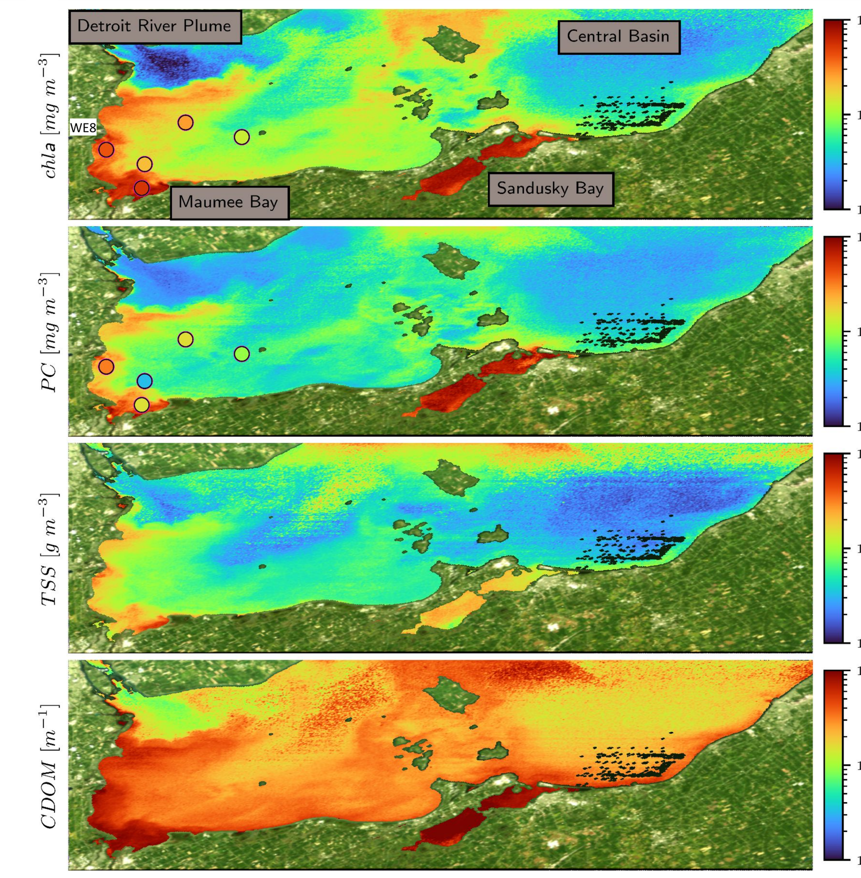


Fig. 9: Estimated BPs from ACOLITE-corrected HICO imagery (09/08/2014).

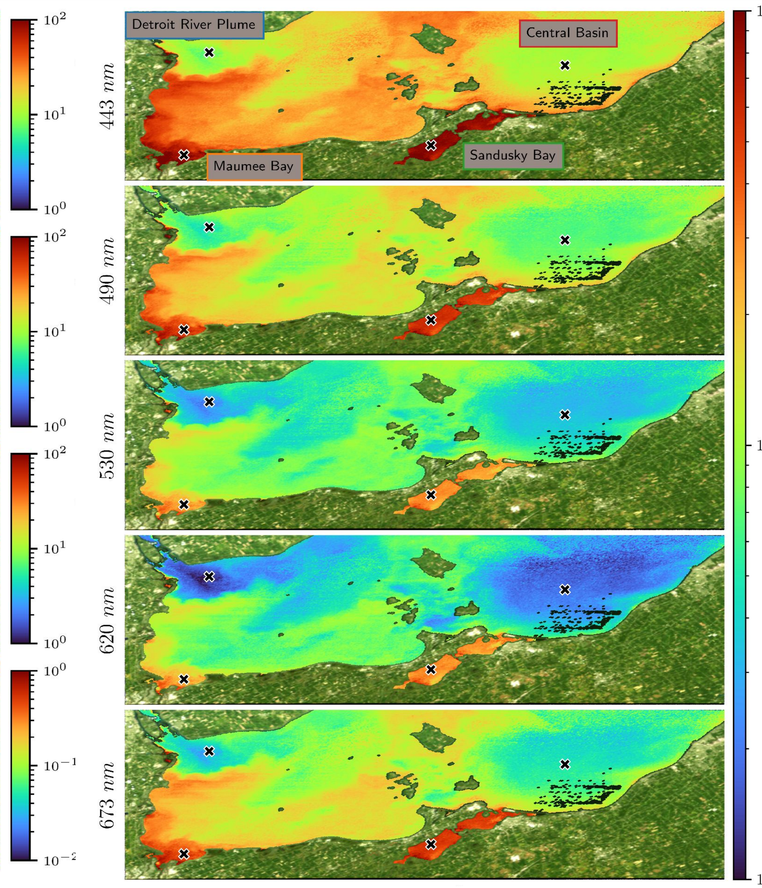


Fig. 10: Estimated a_{ph} from ACOLITE-corrected HICO imagery (09/08/2014).

Validation in Lake Erie & Chesapeake Bay (OLCI)

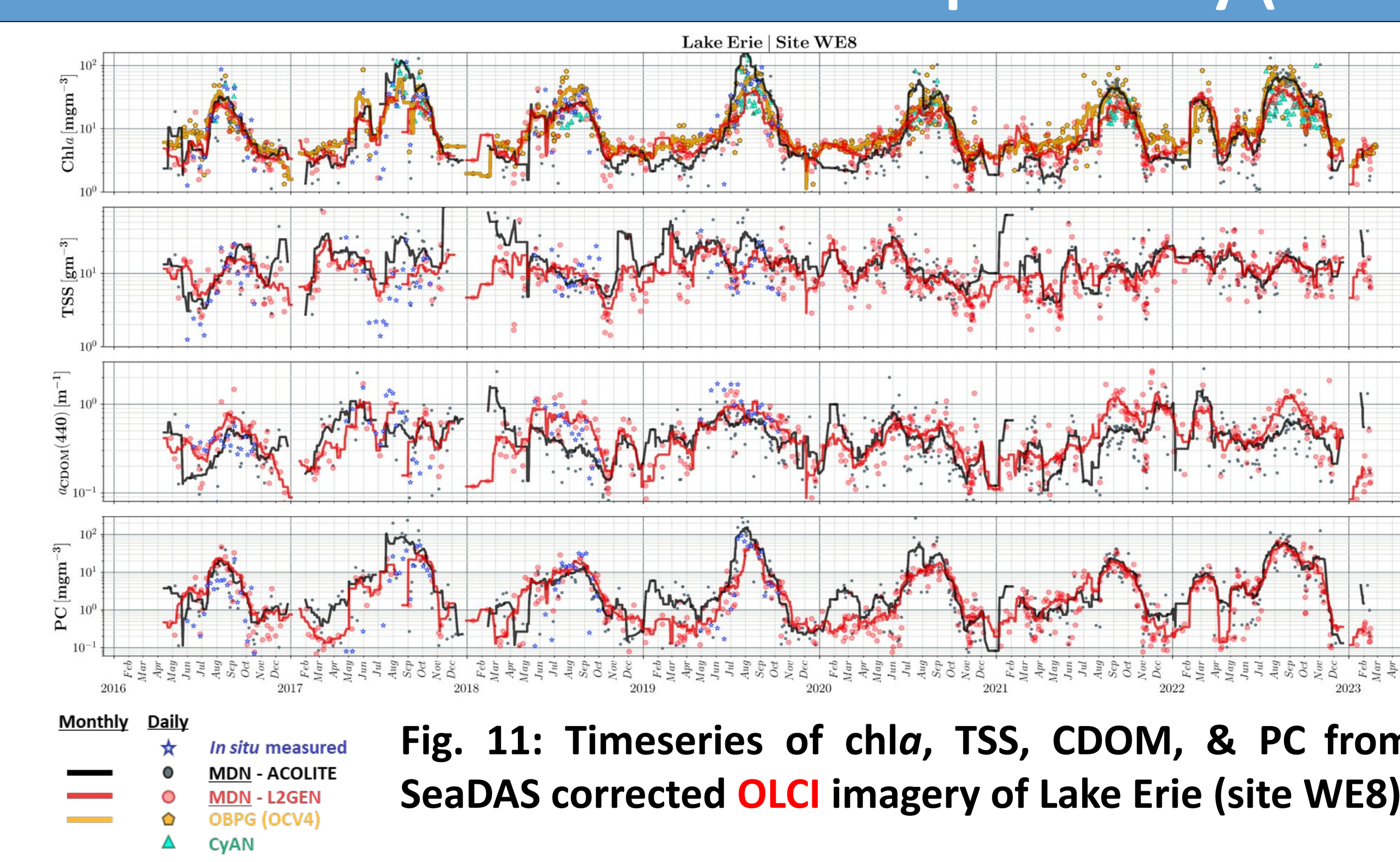
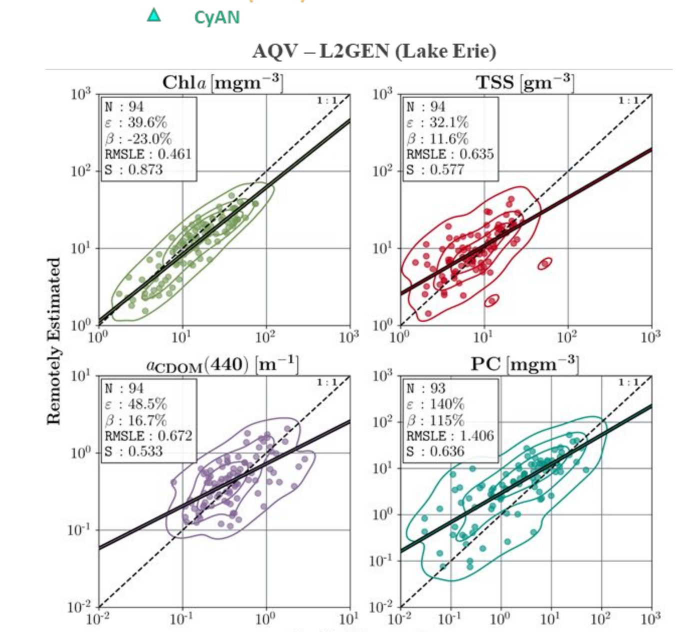


Fig. 11: Timeseries of chl*a*, TSS, CDOM, & PC from SeaDAS corrected OLCI imagery of Lake Erie (site WE8).



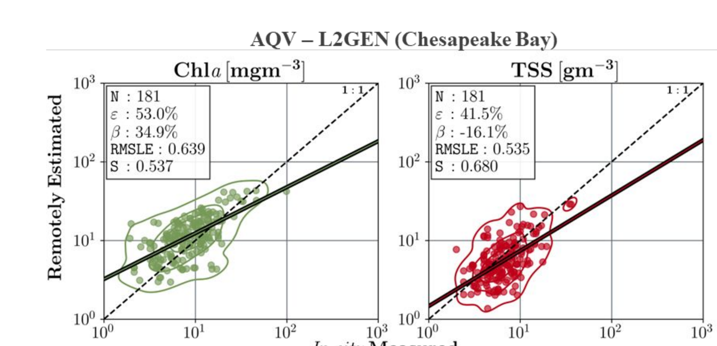


Fig. 12: Product matchups, from SeaDAS-corrected OLCI imagery, from Lake Erie (left, +/- 4 hrs) and the Chesapeake Bay (top, +/- 0.5 hrs).

Conclusions

1. Expected ranges of *in situ* uncertainties
   - ~30% for Chla/TSS/acdom(440), 60% for PC, 20-40% a_{ph}, a_d, & a_g
2. Product maps consistent with literature understanding & *in situ* measurements despite atmospheric correction uncertainties
   - a_{ph} is the most sensitive to uncertainties
3. Model rapidly redeployable to hyper- or multispectral sensors
   - Similar architecture model, with the addition of particulate backscatter retrieval, will be pushed to PACE SDS
   - Code will be available at: https://github.com/STREAM-RS/STREAM-RS

References

[1]O'Shea, R., Pahlevan, N., Smith, B., Boss, E., Gurlin, D., Alikas, K., Kersit, K., Kudela, R., Binding, C., & Vaičiūtė, D. **A Hyperspectral Inversion Framework for Estimating Absorbing Inherent Optical Properties and Biogeochemical Parameters in Inland and Coastal Waters**. *Under revision in Remote Sensing of Environment.*

2. Lehmann, M.K., et al. **GLORIA - A globally representative hyperspectral in situ dataset for optical sensing of water quality.** *Scientific Data.* https://doi.org/10.1038/s41597-023-01973-y.