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Monitoring Harmful Algal Bloom (HAB) Development with PACE and TEMPO

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NASA PACE OCI



NASA's PACE (Plankton, Aerosol, Cloud, ocean Ecosystem) [1] satellite's mission is to observe ocean color, aerosols, and clouds, extending and improving current missions. The Ocean Color Instrument (OCI) is an ultraviolet to visible hyperspectral radiometer, with a resolution of 1.2 km.

- Launch: 8 Feb 2024
- Sun-synchronous, polar orbit
- Instruments
  - Ocean Color Instrument (hyperspectral UV to near IR)
  - Spectro-Polarimeter for Planetary Exploration (SPExone)
    - multi-angle infrared polarimeter (aerosols)
  - Hyper-Angular Rainbow Polarimeter #2 (HARP2)
    - wide-angle visible/IR imaging polarimeter (clouds/aerosols)

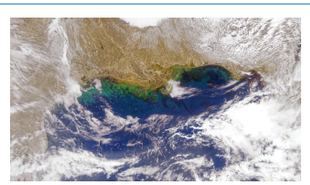
Among the many ocean, atmosphere, and land data products [to be] produced by PACE, OCI will produce 22 ocean-related data products. This project uses the chlorophyll-a concentration (OC_BGC), providing a proxy for near-surface algal biomass, ecosystem health, and eutrophication.

Harmful Algal Blooms

Harmful Algal Blooms (HABs) are blooms of high concentrations of algae, plankton or seaweed leading to levels of toxins harmful to marine life and human health, possibly including surface scum or foam, red tide, and/or oxygen depletion. Eutrophication occurs when excessive nutrients lead to algae and plankton growth. Subsequent decomposition of plant matter produces large amounts of CO_2, acidifying the water. In freshwater, HABs are usually from cyanobacteria. Different species thrive in different conditions.

Factors affecting HAB formation and evolution

- Agricultural runoff (phosphorus, nitrogen)
- Iron deposition (e.g. from Saharan dust)
- Smoke deposition
- High SST is favorable but not necessary.
- Coastal upwelling
- Winds or currents can cause mixing, decreasing algae concentration.



True color image of Louisiana coast, where HABs, fed by outflow from the Mississppi River, often lead to oxygen depletion. This image was taken by the Ocean Color Instrument (OCI) sensor aboard the PACE satellite on March 6, 2024. Source: PACE mission gallery.

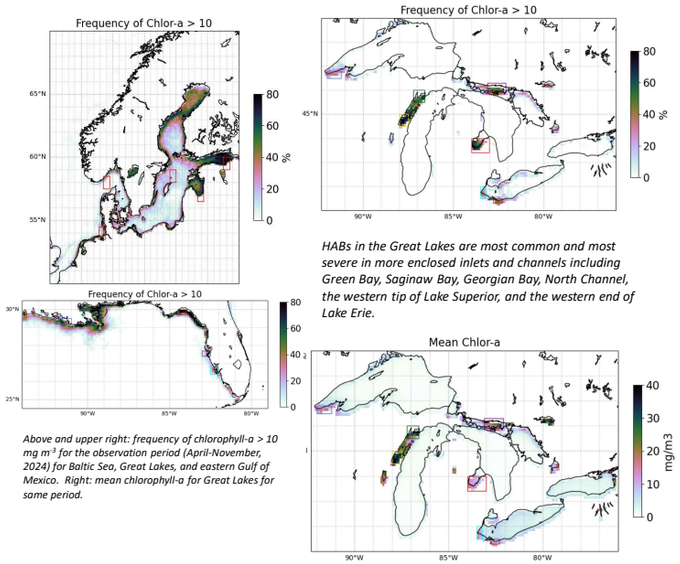
Goals

- Document HAB development and evolution using PACE OCI.
- Investigate the influence of sea surface temperature, aerosol deposition, streamflow, and other factors on HABs using satellite and *in situ* data.

Datasets Used

- PACE OCI Level 2Chlorphyll-a product (OC_BGC)
- Aerosol Optical Depth from Terra/Aqua MODIS (MAIAC), NOAA-20 VIIRS (Deep Blue and Dark Target)
- Sea Surface Temperature composites from NASA SPoRT [2]
- USGS streamflow gages (discharge, dissolved oxygen, and others)

HAB Likelihood Maps

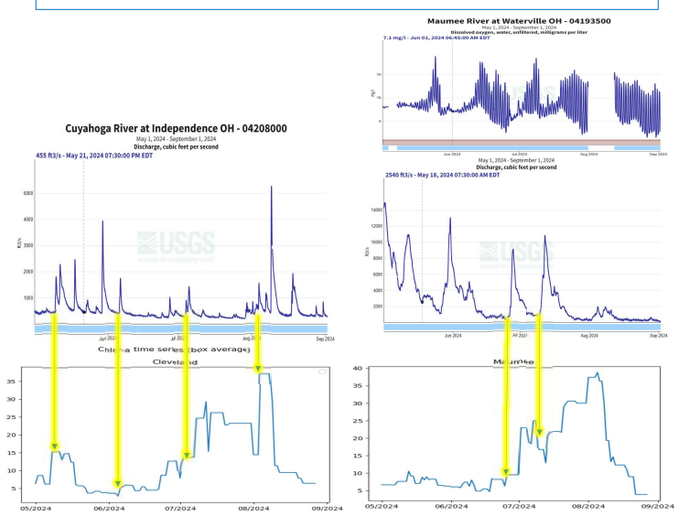


Above and upper right: frequency of chlorophyll-a > 10 mg m^{-3} for the observation period (April-November, 2024) for Baltic Sea, Great Lakes, and eastern Gulf of Mexico. Right: mean chlorophyll-a for Great Lakes for same period.

HABs in the Great Lakes are most common and most severe in more enclosed inlets and channels including Green Bay, Saginaw Bay, Georgian Bay, North Channel, the western tip of Lake Superior, and the western end of Lake Erie.

Influence of Streamflow

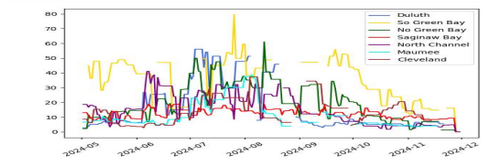
HABs can be triggered by agricultural runoff, usually from phosphorus and/or nitrogen in fertilizer [3]. This example (left) shows several chlorophyll-a increases near Cleveland coincident with large streamflow rates in the Cuyahoga River.
At right, high streamflow on the Maumee River precedes two increases in western Lake Erie chlorophyll-a. High dissolved oxygen at the river stream gage indicates that algae growth may have started in the river.



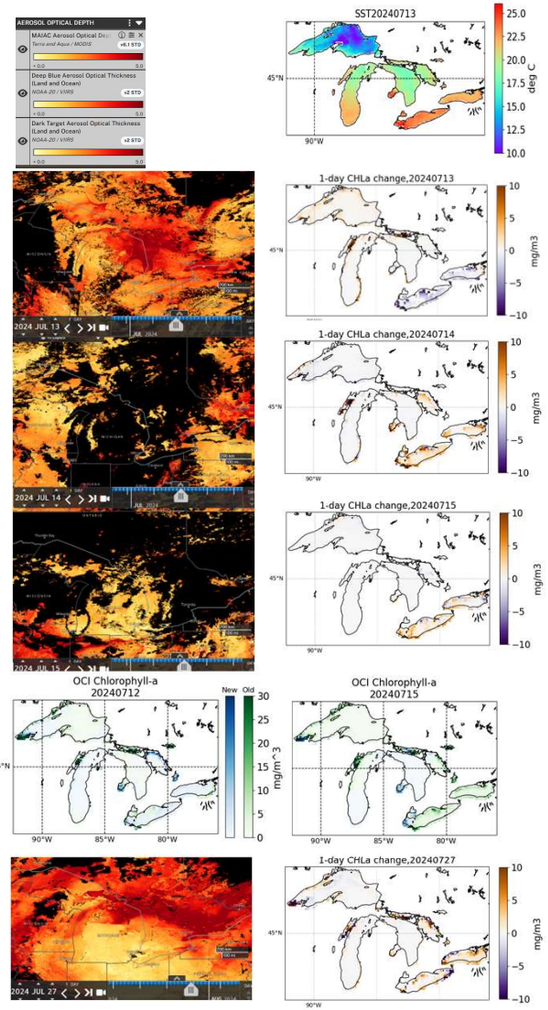
Streamflow (with dissolved oxygen) in lake tributaries and chlorophyll concentration in Lake Erie near outflow. Top (right): Stream gage dissolved oxygen. Middle: Streamflow. Bottom: Chlorophyll-a in Lake Erie near river inlet from PACE OCI. Chlorophyll changes may be delayed one or more days due to overpass gaps or cloud cover.

Influence of Aerosols

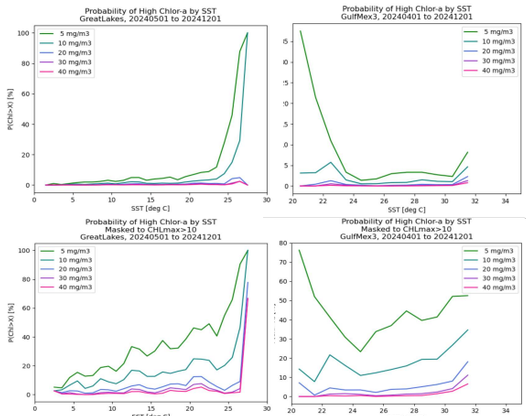
During the summer of 2024, the Great Lakes were impacted by smoke from Canadian wildfires, including severe episodes from July 10-15 and July 20-August 4. These often coincided with increases in chlorophyll-a in certain areas, suggesting that nutrient deposition from smoke may have led to increases in phytoplankton, as observed by [4] and others.



Chlorophyll-a concentrations for selected areas in the Great Lakes.

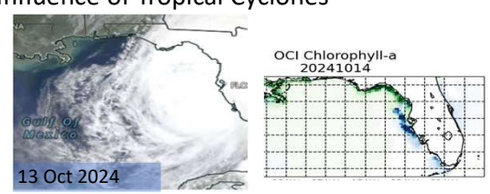


Influence of SSTs



Probability of elevated chlorophyll-a as a function of SST, for Great Lakes and eastern Gulf of Mexico regions for the observation period (May [April] to November, 2024). In the lower row, these are masked to areas with max chlorophyll-a >10 for the observation period. The Great Lakes show a strong dependence on SST.

Influence of Tropical Cyclones



Following the passage of Hurricane Milton (seen on 9 Oct 2024, left), an unusual offshore chlorophyll-a maximum formed off the Florida coast on 10 Oct 2024 (right). Previous research, e.g. [5] has shown that tropical cyclones can stir up sediments, leading to algal blooms.

References

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[2] Berndt, E. B., K. K. Fuell, S. S. Harkema, and G. J. Jedlovec (2024): NASA SPoRT's Sea Surface Temperature Composite Product: Status and Applications. *14th Conf. on Transition of Research to Operations, AMS 104th Annual Meeting,* Amer. Meteorol. Soc., Baltimore, MD. 15B.4.

[3] Jankowiak, J., Hattenrath-Lehmann, T., Kramer, B. J., Ladds, M., & Gobler, C. J. (2019). Deciphering the effects of nitrogen, phosphorus, and temperature on cyanobacterial bloom intensification, diversity, and toxicity in western Lake Erie. *Limnology and Oceanography*, *64*(3), 1347–1370. https://doi.org/10.1002/LNO.11120

[4] Olson, N. E., Boaggio, K. L., Rice, R. B., Foley, K. M., & LeDuc, S. D. (2023). Wildfires in the western United States are mobilizing PM2.5-associated nutrients and may be contributing to downwind cyanobacteria blooms. *Environmental Science: Processes & Impacts*, *25*(6), 1049–1066. https://doi.org/10.1039/D3EM00042G

[5] Hampel, J. J., McCarthy, M. J., Reed, M. H., & Newell, S. E. (2019). Short Term Effects of Hurricane Irma and Cyanobacterial Blooms on Ammonium Cycling Along a Freshwater–Estuarine Continuum in South Florida. *Frontiers in Marine Science*, *6*, 453242. https://doi.org/10.3389/FMARS.2019.00640/BIBTEX

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