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Remote Sensing of Water Quality in Lake Toba (Indonesia)

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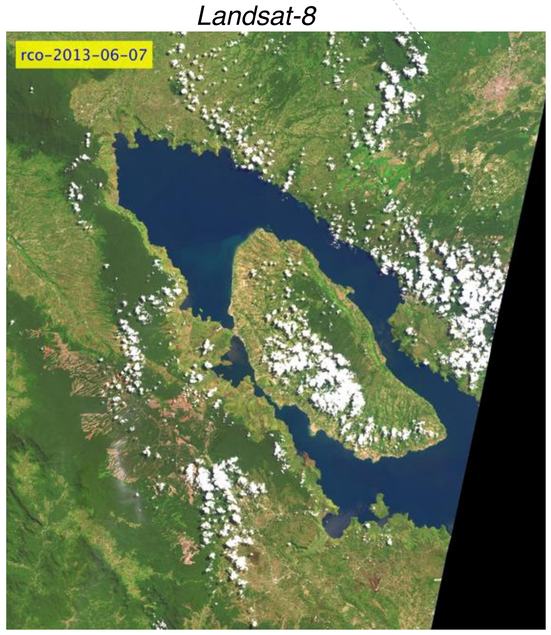
Introduction: Lake Toba on the island of Sumatra is the largest volcano-tectonic lake in the world. The location of a massive super-eruption approximately 75,000 years ago, this caldera is presently home to over a half-million inhabitants and has broader economic significance for the region. Since the 1990s the lake has suffered from a continual decline in water quality, which threatens the long term value and sustainability of the ecosystem-services provided by the lake. In the context of technical assistance efforts to the Government of Indonesia to strengthen capabilities for water quality monitoring, an assessment of available remote sensing platforms for monitoring water quality of Lake Toba was made. A survey of earth observation imagery, including Sentinel-2A, Landsat-8 MERIS, Sentinel-3A and Himawari-8 was conducted to generate synoptic visualizations of water-quality and land-use, and also to construct time series of turbidity and chlorophyll at the lake surface and evaluate feasibility of water-quality monitoring using satellite remote sensing. In this region frequent atmospheric cloud cover limits the availability of water-quality retrievals and 'fusion' of multiple sensors is needed in order to bridge the gaps in available information and obtain adequate temporal and spatial coverage.

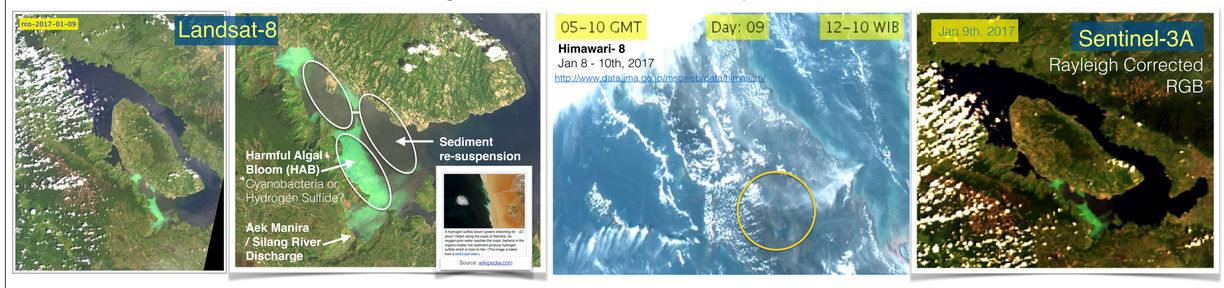
Landsat-8 and Sentinel-2A high resolution multi-spectral sensors showing water-quality spatial dynamics along with atmospheric clouds prevalent in the region of interest

Landsat-8

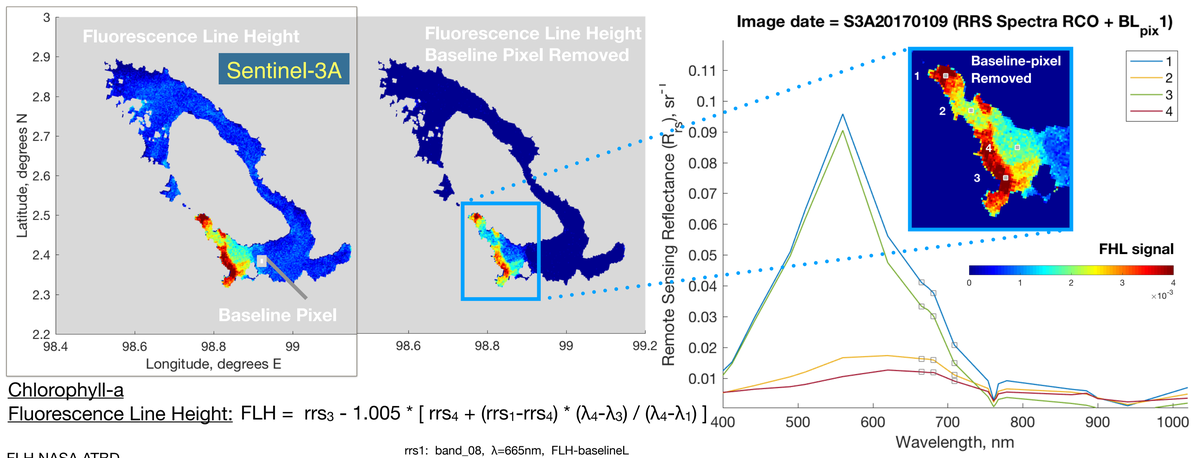


Sentinel-2A

Lake Toba Harmful Algal Bloom (HAB), January 9th, 2018



A water-quality event on January 9th 2017 in the SE of part of Lake Toba (Baktiraja region) is observed in remote sensing imagery from multiple satellite platforms including Landsat-8, Sentinel-3A and Himaware-8. The reported in-situ water-quality reached severe hypoxic conditions and resulted in significant loss of local aquaculture. Although the clohrophyll-a levels appear slightly elevated, reaching 10mg/m^3 to 30 mg/m^3 locally, satellite imagery also shows evidence of benthic sediment re-suspension, likely driven by cold-water discharge from the Aek Silang watershed following a period of significant rainfall. This evidence supports a hypothesis that re-suspension of the benthic-microbial mat could also be contributing to vertical mixing of Hydrogen-sulfide (H_2S) or H_2S metabolizing micro-organisms , additionally impacting the water-quality. Work is ongoing to design operational approaches for water quality monitoring in Lake Toba using remote sensing imagery and to increase the availability of in situ measurements.

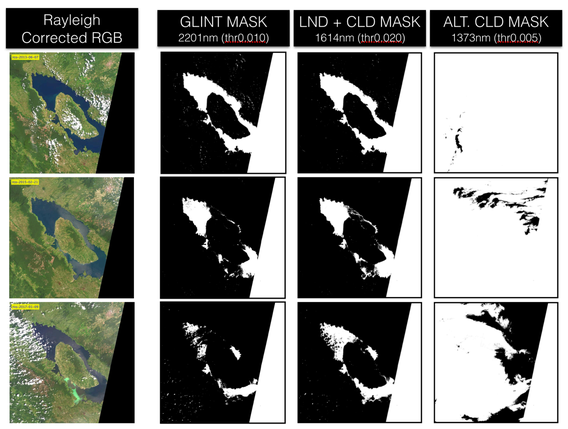


Chlorophyll-a
Fluorescence Line Height: FLH = $rrs_3 - 1.005 * [rrs_4 + (rrs_1 - rrs_4) * (\lambda_4 - \lambda_3) / (\lambda_4 - \lambda_1)]$

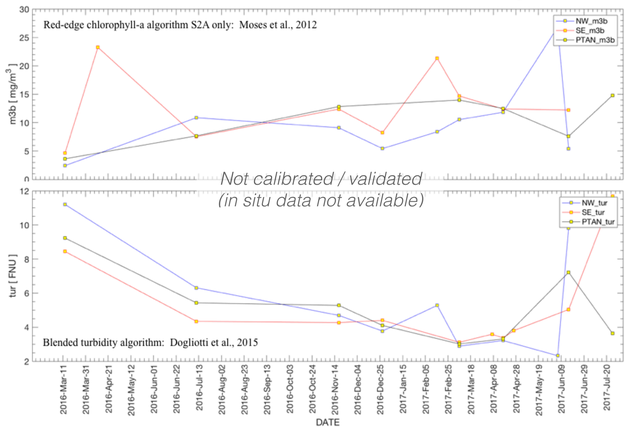
FLH NASA ATBD
https://modis.gsfc.nasa.gov/data/atbd/atbd_mod22.pdf

rrs1: band_08, λ=665nm, FLH-baselineL
rrs3: band_10, λ=681nm, FLH-peak
rrs4: band_11, λ=709nm, FLH-baselineR

NIR / SWIR masking used to improve remote sensing retrievals limited by frequent atmospheric cloud cover



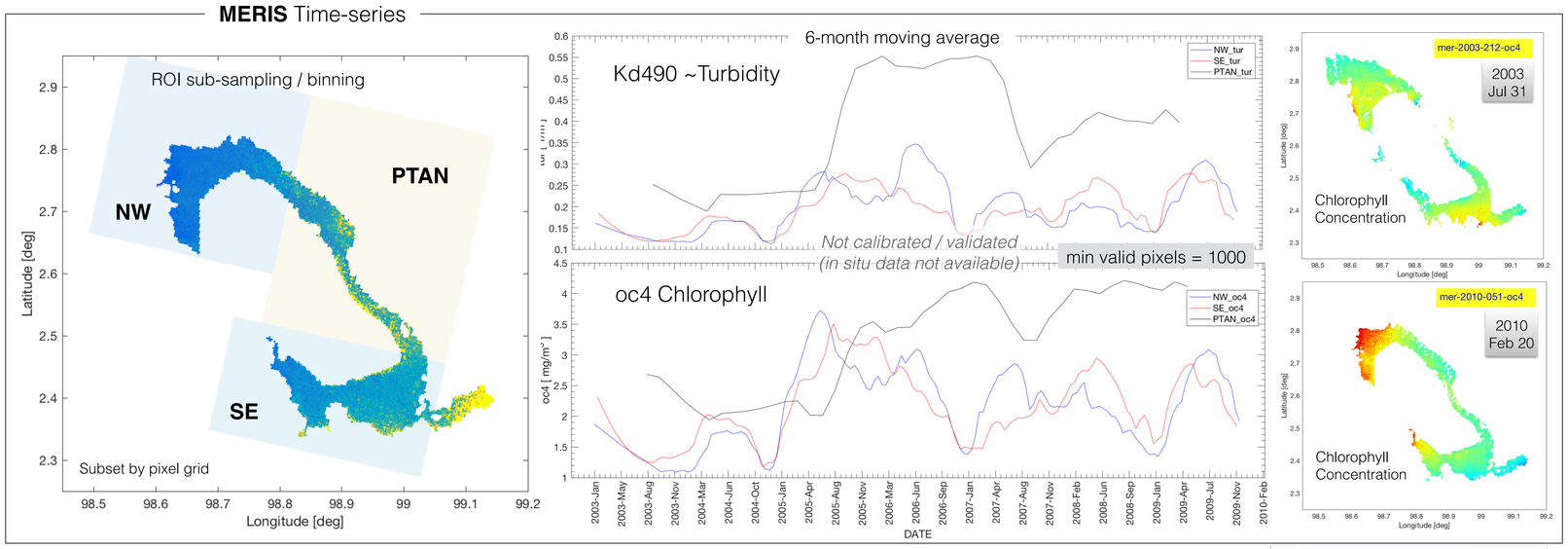
Sentinel-2A time-series data with NIR / SWIR RRC-derived masking



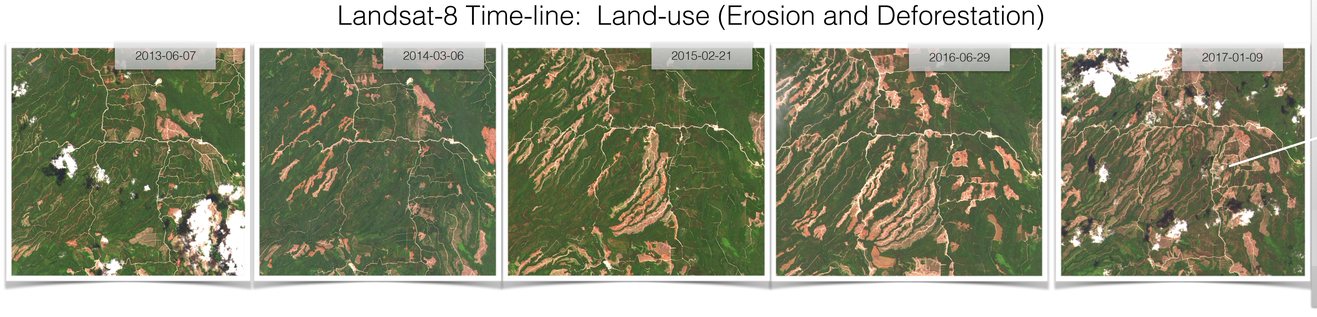
Discussion: Evidence of lake eutrophication and land-use changes are apparent from analysis of the near-term high-resolution Landsat-8 and Sentinel-2A imagery as well as the long-term MERIS earth observation record. Lake Toba's water quality is driven by complex mixing of nutrients, oxygen, and solar radiation, as well as geo-thermal activity. Due to limited vertical mixing and significant mean depth of the lake, the benthic zone is suspected to be anoxic and nutrient rich thereby enhancing the periodic occurrence of harmful algal blooms (HAB), such as the January 9th 2017 event captured in the visible spectrum using multiple sensors (and chlorophyll fluorescence in Sentinel 3A spectra).

Although meteorological conditions limit availability of satellite remote sensing observations here, the use of atmospheric pixel masking and multiple sensing platforms (including the newest satellites, Sentinel-2B and Sentinel-3B), provide the capability for operational monitoring of the water quality in Lake Toba. Combined with in-situ monitoring, remote sensing can be used to quantify seasonal dynamics or longer-term water-quality changes, as seen for example in the 6-month moving average MERIS time-series. These types of insights can help guide prioritized improvement in water-quality as well as land-use management.

MERIS Time-series



Landsat-8 Time-line: Land-use (Erosion and Deforestation)



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