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DECIPHERING WATER QUALITY AND ALGAL DYNAMICS IN CLEAR LAKE THROUGH HYPERSPECTRAL ANALYSIS USING EMIT DATA

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ABSTRACT

This study evaluates the potential application of hyperspectral Earth Surface Mineral Dust Source Investigation (EMIT) remote sensing for monitoring harmful algal blooms (HABs) and water quality in Clear Lake, California. The research focuses on correlating the chlorophyll-a (Chl-a) concentrations with EMIT spectral signatures, using waterbody-wide statistical analysis of Chl-a and EMIT data sampling at various lake locations. Results demonstrate distinct spectral signatures associated with varying Chl-a levels, highlighting the potential of hyperspectral imaging in differentiating algae levels and assessing water quality variables. It also indicates the EMIT's utility in filling data gaps and offering high-resolution monitoring. This study underscores the need for further research in hyperspectral imaging for aquatic ecosystems, especially under challenging atmospheric conditions, enhancing our understanding of water quality dynamics.

Index Terms— Hyperspectral Imaging, EMIT, Chlorophyll-a, Clear Lake, Harmful Algal Bloom

1. INTRODUCTION

Harmful algal blooms significantly impact inland water quality. Brooks et al. [1] identified harmful algal blooms as a major threat to inland water quality, especially during summer with overabundance of nutrients (eutrophication). Liao et al. [2] demonstrated that storm events can trigger these blooms, with water temperature and nutrient levels being crucial factors. These blooms degrade water quality, alter plankton composition, and diminish biodiversity [3]. Wasmund [4] noted the role of nutrient influx in fostering algal blooms, with eutrophication as a primary contributor. Collectively, these studies highlight the urgency of addressing eutrophication and its effects on water quality.

Remote sensing has become a key tool for monitoring harmful algal blooms [5], underscoring its value in detecting and predicting blooms, such as cyanobacterial blooms in the Baltic Sea [6]. In particular, the effectiveness of satellite ocean color sensors and aerial remote sensing have been approved in monitoring and predicting these blooms [7], [8], with satellite-based Chl-a concentration as a common indicator. Li [9] examined and modelled historical chlorophyll-a surge and corresponding Net Primary Productivity in the Red Sea using remote sensing data such as Moderate Resolution Imaging Spectroradiometer (MODIS), and studied factors regulating the blooms such as eddy circulation, dust deposition and nutrient dynamics in the Red Sea [9]–[11]. Fazli and Sima [12] used MODIS data to analyze harmful algal blooms in the Strait of Hormuz, focusing on early detection and environmental influences for effective management of these events.

Recently, hyperspectral remote sensing is becoming more promising with distinct advantages in water quality monitoring. It provides timely, high-resolution data on various water constituents, including algae, chlorophyll-a, and turbidity [13]. It effectively estimates water quality variables like phosphorus, nitrogen, and dissolved organic matter and excels in differentiating algae types [14]. Recent applications of hyperspectral sensors like PRISMA and DESIS have shown promise in retrieving water quality parameters across diverse aquatic ecosystems [15]. As a novel hyperspectral remote sensing data source, the recently launched Earth Surface Mineral Dust Source Investigation (EMIT) instrument (https://earth.jpl.nasa.gov/emit/), aim to measure surface mineralogy in the Earth's arid dust source regions with hyperspectral information. Mounted on the International Space Station (ISS), EMIT employs imaging spectroscopy to analyze sunlit areas between 52° N and 52° S latitudes. However, its potential usability in monitoring water quality is unknown. This study presents the first assessment of EMIT's utility in water quality monitoring and exploring its potential for inland water quality analysis.

2. METHODOLOGY

2.1 Study Area:

Clear Lake, or Lypoyomi in Pomo, located in Lake County, California, is the state's largest natural freshwater lake, spanning 68 square miles (180 km²). It holds the distinction of being North America's oldest lake, with a 0.5 million-year history in a region dating back over 2.5 million years [16]. Characterized by its shallow depth and warm temperatures, Clear Lake is naturally eutrophic, a condition exacerbated by increased nutrient levels, particularly phosphorus from fertilizer runoff. Historical records since the late 19th century note its propensity for cloudy discolorations due to cyanobacteria (blue-green algae) blooms, which occur from spring to fall and are associated with both short and long-term health impacts [17]. Therefore, it is critical to know the impact of the blooms on its water quality and thus selected as study area.

2.2 Datasets:

Satellite data from 2016 to the present were sourced from the OLCI instruments on the Copernicus Sentinel-3 missions, provided by EUMETSAT, with additional level-3 product processed by NOAA's National Ocean Service. The Chl-a product, based on the RE10 algorithm [18] with 300 by 300-meter spatial resolution, which uses a red-edge band (665nm) to near-infrared (NIR) ratio is used to estimate Chl-a concentration as a biomass proxy. Concentrations range from 0.05 to 134.6 ug/L in micrograms per liter. However, it is noted that the satellite data do not differentiate potential toxin-producing cyanobacteria genera or measure water toxins.

The EMIT Level 2A Estimated Surface Reflectance and Uncertainty and Masks (EMITL2ARFL) Version 1 data product offers surface reflectance data in a spatially raw, non-orthocorrected format. Each EMITL2ARFL granule comprises three NetCDF4 files at a 60-meter resolution: Reflectance (EMIT_L2A_RFL), Reflectance Uncertainty (EMIT_L2A_RFLUNCERT), and Reflectance Mask (EMIT_L2A_MASK). The Reflectance file contains 285 bands' surface reflectance maps, spanning 381-2493 nanometers at ~7.5 nm spectral resolution.

Fig. 2. EMIT RGB Imagery for 13-Aug-2022, 15-Apr-2023, 26-Jul-2023 of the Clear Lake CA

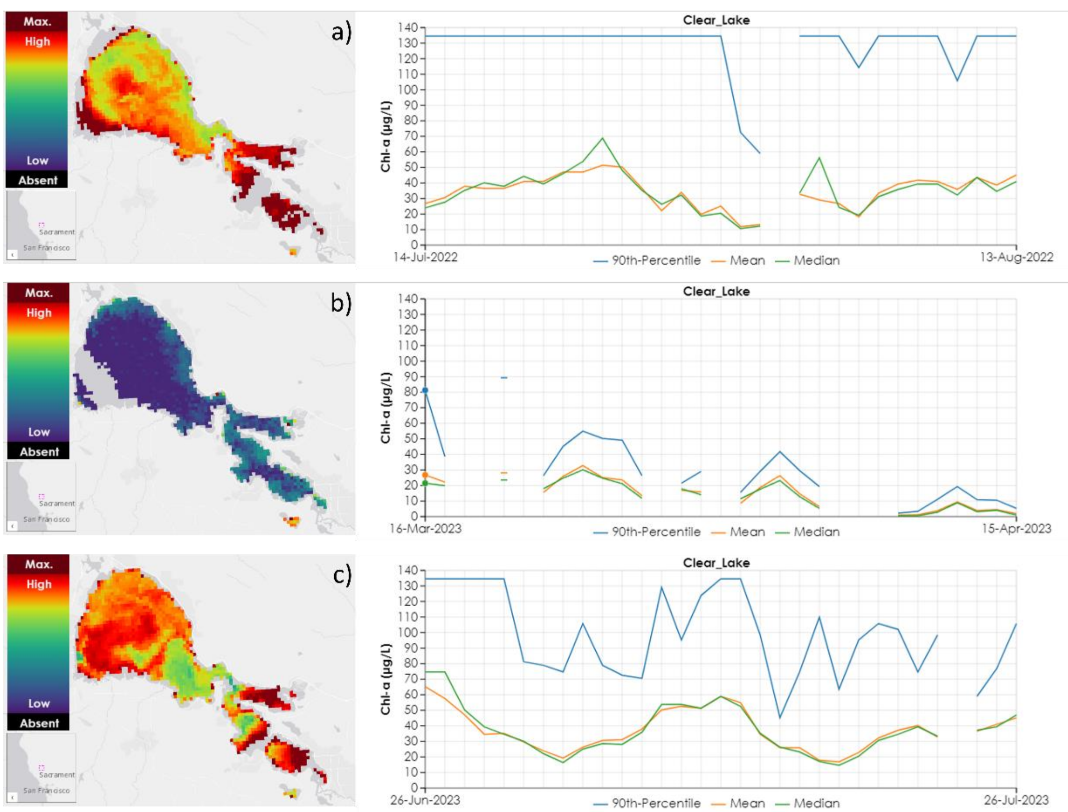

Fig. 1. The Chl-a map for the selected dates and the 30-day time series of daily maximum Chl-a concentration

2.3 Methods:

We extract the waterbody-wide mean, median, and 90th percentile statistics from all valid pixels in each composite for detailed waterbody analysis for the Lake using HAB Satellite Analysis Tool (https://fhab.sfei.org). Next, we sampled Chl-a data at specific lake locations, focusing on both Upper and Lower regions of the Lake on three EMIT-available dates with low cloud coverage, namely, 13-Aug-2022, 15-Apr-2023 and 26-Jul-2023 (Fig. 1). The sampling sites, along with Chl-a concentrations, were used to depict hyperspectral reflectance curves for EMIT bands ranging from 381nm to 1250nm.

3. RESULTS AND DISCUSSION

Fig. 2 displays the Chl-a levels on the previously selected dates and their preceding 30-day time series. Notably, 13-Aug-2022 (Fig. 2a) and 26-Jul-2023 (Fig. 2c) exhibit elevated Chl-a levels across the lake, particularly in the lower lake area, where concentrations approach maximum levels, such as in coastal regions. Concurrently, the time series for these dates indicate an overall lake-wide increase in Chl-a levels, nearing 40 ug/L. Conversely, 15-Apr-2023 presents uniformly low Chl-a levels throughout the lake. However, data gaps were observed in certain lake regions, specifically south of the Lower Lake on 13-Aug-2022 and west of the Upper Lake on 15-Apr-2023 due to the resolution limit of Sentinel-3 OLCI instrument.

Fig. 3 illustrates the spectral reflectance at sampling sites in the Upper and Lower Lake for the same dates, with Chl-a levels indicated by color. It is evident that high Chl-a concentrations correlate with distinct spectral signatures. Specifically, high Chl-a levels are associated with increased reflectance in the green (~550nm) and near-infrared (NIR) (~700nm) bands, and reduced values in the red-edge band (~665nm). Interestingly, maximum Chl-a points also show heightened reflectance at shorter wavelengths (400nm-500nm) and bands above 750nm, with notable values at 650nm. We conjecture it is due to impact of the atmospheric conditions. Our findings align with previous research [19], suggesting the utility of bands below 443 nm, like the 412 nm band in most ocean color sensors, under certain conditions for

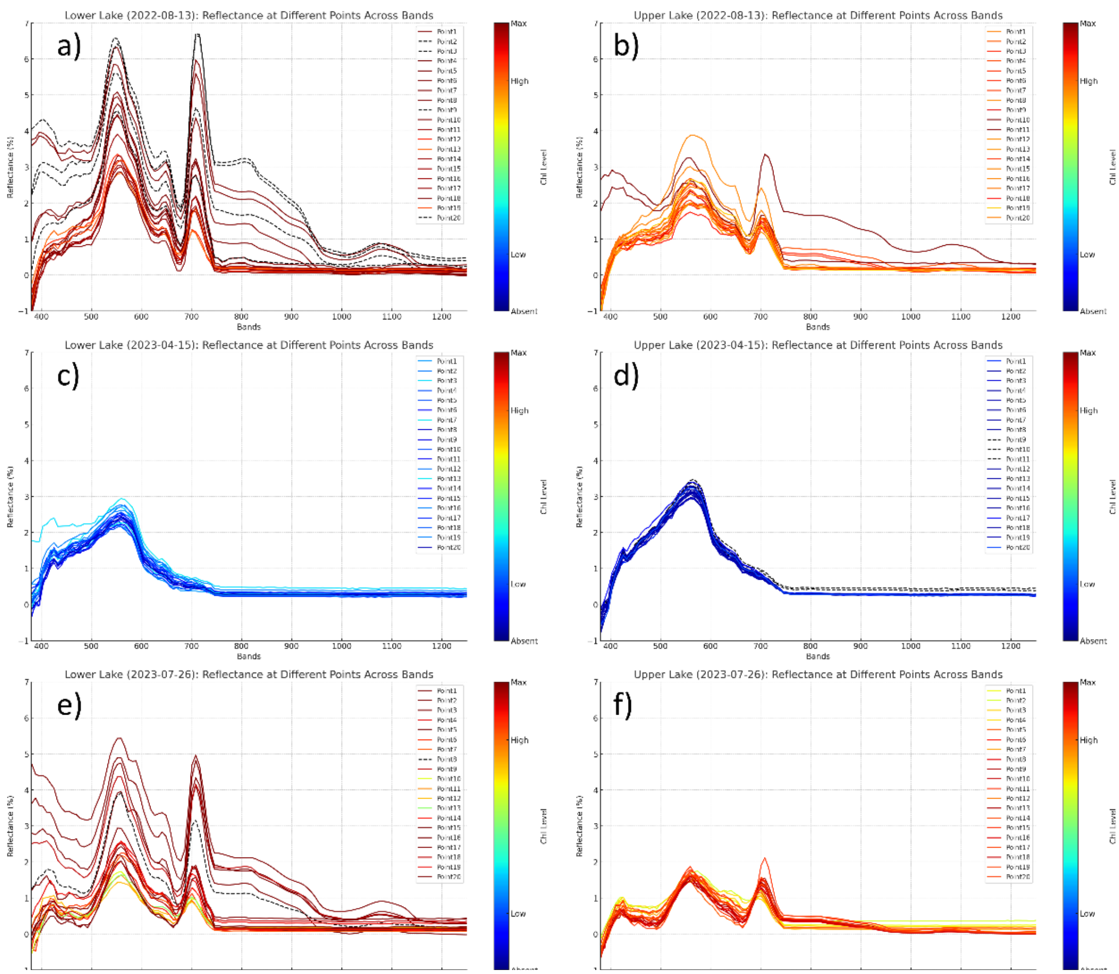

Fig.3. Spectral reflectance curves of the samples in the upper and lower Lake for the selected dates, with the color bar showing the Chl-a level for the sampling locations.

chlorophyll detection. These spectral features could inform the development of hyperspectral-based Chl-a algorithms, such as the emerging OCx algorithms for future more advanced hyperspectral sensors like the Plankton, Aerosol, Cloud, ocean Ecosystem sensor (PACE, see details in NASA https://pace.oceansciences.org/home.htm).

Moreover, spectral curves were observed at sites lacking OLCI Chl-a data (indicated by dashed lines), showing the potential of EMIT data in filling these gaps. Our preliminary observations suggest EMIT's satisfactory reflectance response to Chl-a blooms, suggesting potential solutions such as empirical algorithms or machine learning models for high-resolution monitoring using EMIT data across a broader range of lakes. Further research is encouraged to explore water quality monitoring under non-ideal atmospheric conditions, such as dusty environments. Additionally, evaluating signal-to-noise ratios (SNR) is crucial for assessing EMIT's efficacy in water quality monitoring, necessitating detailed performance reports and specific metrics like SNR.

4. CONCLUSION

Our research showcases the integration of EMIT hyperspectral data with satellite observations to monitor and understand water quality dynamics in Clear Lake. We have successfully identified specific spectral patterns associated with varying Chl-a levels, highlighting the utility of hyperspectral imaging in detecting and analyzing harmful algae blooms. The study underscores EMIT's potential capability in providing detailed insights into water quality, which is crucial for environmental management and ecological research. This work suggests future efforts of developing applications of hyperspectral imaging in aquatic ecosystems and supports the advancement of remote sensing techniques in environmental monitoring.

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6. REFERENCES

[1] B. W. Brooks *et al.*, "In some places, in some cases, and at some times, harmful algal blooms are the greatest threat to inland water quality," *Environ. Toxicol. Chem.*, vol. 36, no. 5, pp. 1125–1127, May 2017, doi: 10.1002/etc.3801.

[2] A. Liao, D. Han, X. Song, and S. Yang, "Impacts of storm events on chlorophyll-a variations and controlling factors for algal bloom in a river receiving reclaimed water," *J. Environ. Manage.*, vol. 297, p. 113376, Nov. 2021, doi: 10.1016/j.jenvman.2021.113376.

[3] C. A. Amorim and A. D. N. Moura, "Ecological impacts of freshwater algal blooms on water quality, plankton biodiversity, structure, and ecosystem functioning," *Sci. Total Environ.*, vol. 758, p. 143605, Mar. 2021, doi: 10.1016/j.scitotenv.2020.143605.

[4] N. Wasmund, "Harmful Algal Blooms in Coastal Waters of the South-Eastern Baltic Sea," in *Baltic Coastal Ecosystems*, G. Schernewski and U. Schiewer, Eds., Berlin, Heidelberg: Springer Berlin Heidelberg, 2002, pp. 93–116. doi: 10.1007/978-3-662-04769-9_8.

[5] D. Durand, L. H. Pettersson, O. M. Johannessen, E. Svendsen, H. Søiland, and M. Skogen, "Satellite observation and model prediction of toxic algae bloom," in *Elsevier Oceanography Series*, vol. 66, Elsevier, 2002, pp. 505–515. doi: 10.1016/S0422-9894(02)80057-5.

[6] M. Hansson, "The Baltic Algae Watch System - a remote sensing application for monitoring cyanobacterial blooms in the Baltic Sea," *J. Appl. Remote Sens.*, vol. 1, no. 1, p. 011507, Dec. 2007, doi: 10.1117/1.2834769.

[7] K. Kubiak, J. Kotlarz, P. Czapski, and A. Mazur, "Monitoring Cyanobacteria Bloomsin Freshwater Lakes using RemoteSensing Methods," *Pol. J. Environ. Stud.*, vol. 25, no. 1, pp. 27–35, Jan. 2016, doi: 10.15244/pjoes/60175.

[8] R. P. Stumpf, "Applications of Satellite Ocean Color Sensors for Monitoring and Predicting Harmful Algal Blooms," *Hum. Ecol. Risk Assess. Int. J.*, vol. 7, no. 5, pp. 1363–1368, Sep. 2001, doi: 10.1080/20018091095050.

[9] W. Li, H. El-Askary, K. ManiKandan, M. Qurban, M. Garay, and O. Kalashnikova, "Synergistic Use of Remote Sensing and Modeling to Assess an Anomalously High Chlorophyll-a Event during Summer 2015 in the South Central Red Sea," *Remote Sens.*, vol. 9, no. 8, p. 778, Jul. 2017, doi: 10.3390/rs9080778.

[10] W. Li *et al.*, "An Assessment of Atmospheric and Meteorological Factors Regulating Red Sea Phytoplankton Growth," *Remote Sens.*, vol. 10, no. 5, p. 673, Apr. 2018, doi: 10.3390/rs10050673.

[11] W. Li, S. P. Tiwari, K. P. ManiKandan, and H. El-Askary, "Ocean Color Modeling in the Central Red Sea Using Oceanographical Observation and Simulated Parameters," in *IGARSS 2020 - 2020 IEEE International Geoscience and Remote Sensing Symposium*, Waikoloa, HI, USA: IEEE, Sep. 2020, pp. 5620–5623. doi: 10.1109/IGARSS39084.2020.9323304.

[12] S. Fazli and S. Sima, "Detection of harmful algal blooms in the Strait of Hormuz using satellite data".

[13] Y. Zur, O. Braun, D. Stavitsky, and A. Blasberger, “A potential hyperspectral remote sensing imager for water quality measurements,” presented at the International Symposium on Remote Sensing, H. Fujisada, J. B. Lurie, M. L. Aten, and K. Weber, Eds., Crete, Greece, Apr. 2003, p. 709. doi: 10.1117/12.462910.
[14] M. Mbuh, “Use of Hyperspectral Remote Sensing to Estimate Water Quality,” in *Processing and Analysis of Hyperspectral Data*, J. Chen, Y. Song, and H. Li, Eds., IntechOpen, 2020. doi: 10.5772/intechopen.89222.
[15] M. Bresciani *et al.*, “Application of New Hyperspectral Sensors in the Remote Sensing of Aquatic Ecosystem Health: Exploiting PRISMA and DESIS for Four Italian Lakes,” *Resources*, vol. 11, no. 2, p. 8, Jan. 2022, doi: 10.3390/resources11020008.
[16] D. Rapport, W. L. Lasley, D. Rolston, N. O. Nielsen, C. O. Qualset, and A. B. Damania, *Managing for healthy ecosystems*. 2002, p. 1510.
[17] “Harmful cyanobacteria blooms and their toxins”.
[18] T. T. Wynne *et al.*, “Evaluating the Efficacy of Five Chlorophyll-a Algorithms in Chesapeake Bay (USA) for Operational Monitoring and Assessment,” *J. Mar. Sci. Eng.*, vol. 10, no. 8, p. 1104, Aug. 2022, doi: 10.3390/jmse10081104.
[19] J. E. O’Reilly and P. J. Werdell, “Chlorophyll algorithms for ocean color sensors - OC4, OC5 & OC6,” *Remote Sens. Environ.*, vol. 229, pp. 32–47, Aug. 2019, doi: 10.1016/j.rse.2019.04.021.