International Journal of Multidisciplinary Research and Publications
ISSN (Online): 2581-6187

Atmospheric and Oceanic Drivers of Chlorophyll-a Variability in the Arabian Sea: A Review

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Abstract—*The Arabian Sea, one of the most biologically productive regions in the global ocean, exhibits substantial spatiotemporal variability in chlorophyll-a (Chl-a) concentrations due to complex interactions between oceanic and atmospheric processes. This review synthesizes recent research on the relationships between sea surface temperature (SST), atmospheric factors (including aerosols, pressure systems, and monsoon winds), and Chl-a dynamics, focusing on studies from the past five years. Key mechanisms include monsoon-driven upwelling, aerosol-mediated nutrient input, and high-pressure-induced stratification. By integrating remote sensing, in situ data, and model simulations, this paper outlines the current understanding and identifies gaps for future research.*

Keywords— *Arabian Sea, Chlorophyll-a, SST, aerosols, monsoon, phytoplankton, Indian Ocean Dipole, remote sensing.*

I. Introduction

The Arabian Sea plays a critical role in regional and global biogeochemical cycles due to its high productivity and monsoon-driven dynamics. Chlorophyll-a concentration serves as a proxy for phytoplankton biomass and a key indicator of ocean productivity. Understanding the environmental drivers of Chl-a variability is crucial for predicting ecosystem responses to climate change and anthropogenic pressures.

Sea Surface Temperature (SST) and Chlorophyll-a Dynamics

Several studies have highlighted the inverse relationship between SST and Chl-a in the Arabian Sea. Warmer SSTs typically suppress vertical mixing and nutrient entrainment, leading to lower Chl-a concentrations. Conversely, cooler SSTs, often associated with upwelling, promote phytoplankton blooms. A 2024 study by Yang et al. reconstructed monthly Chl-a patterns over two decades, showing clear SST-Chl-a correlations aligned with monsoonal cycles.

Atmospheric Influences: Monsoons, Aerosols, and Pressure Systems

Atmospheric processes strongly modulate marine productivity in the region:

- Monsoon Winds: The southwest monsoon induces coastal upwelling, enhancing nutrient supply and boosting Chl-a concentrations. Seasonal variability in wind strength and direction directly affects bloom magnitude.
- Aerosols and Dust: Sun et al. (2023) found a strong correlation between dust aerosols and Chl-a concentrations, particularly along the coasts of Oman and Somalia. Iron and other micronutrients necessary for the development of phytoplankton are provided by dust.
- High-pressure Systems: A study in *Scientific Reports* (2023) found that winter high-pressure systems suppress convective mixing and enhance water column stratification, resulting in enhanced Chl-a accumulation due to favorable light and nutrient retention conditions.

Large-scale Climatic Oscillations and Phytoplankton Structure

Climatic phenomena like the Indian Ocean Dipole (IOD) significantly influence Chl-a variability and phytoplankton composition. Remote sensing studies indicate shifts in bloom timing and size class distributions during positive and negative IOD phases, with implications for fisheries and carbon cycling.

Regional Case Studies and Bathymetric Effects

In the Gulf of Oman and UAE coastal waters, bathymetry influences SST-Chl-a relationships. Shallower regions exhibit rapid temperature changes that can trigger short-term blooms. MODIS data analysis (2003–2019) confirms these patterns, reinforcing the need for region-specific monitoring.

Methodologies and Data Integration

Most reviewed studies utilized satellite observations (MODIS, SeaWiFS), ocean reanalysis products (ERA5), and empirical orthogonal function (EOF) or principal component analysis (PCA) to identify dominant modes of variability. DINEOF was particularly effective in gap-filling chlorophyll data series.

Future Directions and Research Gaps

Despite advances, challenges remain in distinguishing causality versus correlation in Chl-a dynamics. Future work should:

- Improve high-resolution coupled ocean-atmosphere models
- Incorporate in situ biological data (e.g., nutrient concentrations, phytoplankton taxonomy)
- Assess anthropogenic impacts (e.g., shipping, eutrophication)

II. Conclusion

This review underscores the multifaceted influences on chlorophyll-a variability in the Arabian Sea. SST, monsoon winds, aerosols, and climatic oscillations collectively shape the productivity landscape. A combination of satellite and model data offers valuable insights, but integrated multidisciplinary approaches are essential for forecasting ecosystem responses in a warming world.

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