The Effect of Climate Change on Marine Productivity in the Northwest African Coastal Upwelling Zone

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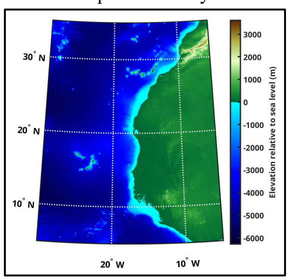
Introduction

- Coastal upwelling zones are small regions where deep, cooler, nutrient-rich waters rise to the surface, supporting 20% of the world's fish catch and playing a significant role in food security and fishing industries.
  - The uplifted nutrients fuel the growth of phytoplankton (primary producers).
- Phytoplankton productivity is often measured in chlorophyll-α concentration levels on the ocean surface, which can be observed via spectroradiometer satellites.
- The Northwest African coastal upwelling zone, with continuous upwelling north of 21°N and seasonal variation to the south of 19°N, is influenced by trade and monsoon winds. Northeast trade winds, which blow southwest and are dominant in winter, drive upwelling by pushing surface waters offshore. Southwest monsoon winds, which blow inward and are dominant in summer, often weaken the strength and direction of trade winds.
- Long-term effects of climate change on marine productivity in the Northwest African coastal upwelling zone are relatively underexplored. This project aims to investigate this via satellite observations. It is predicted that rising temperatures and shifting winds may increase or decrease productivity, varying in different parts of the system from changes in local alongshore winds.

A map of the study region. The coastal upwelling zone exists in the ocean regions along the coast from around 12°N to 35°N.

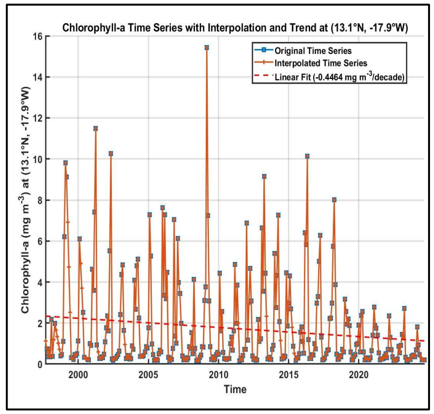


Methods

- The dataset, taken from the Copernicus Marine Service, is called "Global Ocean Colour (Copernicus-GlobColour), Bio-Geo-Chemical, L4 (monthly and interpolated) from Satellite Observations (1997-ongoing)."
  - It includes observations from spectroradiometer satellites, the most important being MODIS-A, MODIS-T, VIIRS-SNPP, and JPPS1, with spatial resolution = 4 × 4 km.
  - The data spans from Sep 1st, 1997, to Sep 1st, 2024, latitude 5.208°N to 34.9792°N, and longitude 27.9792°W to 5.208°W. It contains regions in the eastern Atlantic Ocean off the coast of West Africa, including the coastal upwelling zone.
  - The data measures the concentration of chlorophyll-α levels (milligram/meter cubed).
- Literature review was used for insights into what drives coastal upwelling, the seasonal variation of upwelling, and the estimated long-term chlorophyll trend.
- The coding application, MATLAB, was used for data analysis using plots and maps.
  - Linear interpolation was utilized to estimate unavailable values in the original dataset due to atmospheric factors like clouds.

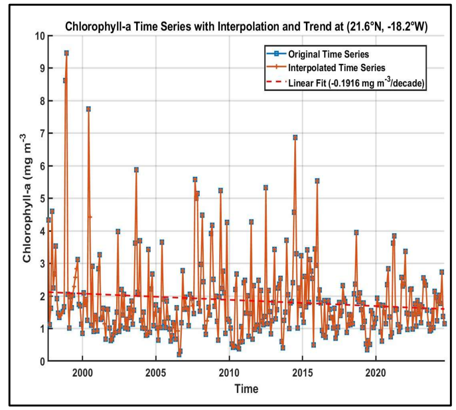
Resources

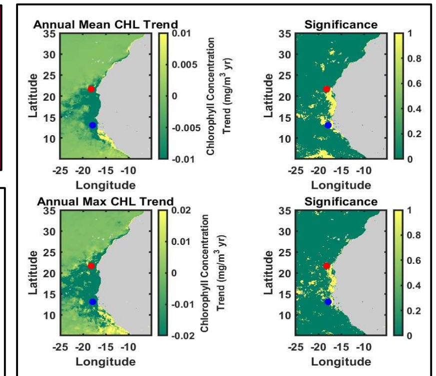
Results



An interpolated time series representing the chlorophyll concentration at a coordinate in the seasonal (southern) upwelling zone over time. It includes the interpolated data's line of best fit, representing the trend of chlorophyll concentration.

An interpolated time series representing the chlorophyll concentration at a coordinate in the permanent (northern) upwelling zone over time. It includes the interpolated data's line of best fit, representing the trend of chlorophyll concentration.





Spatial trends of annual mean and maximum chlorophyll concentrations and their statistical significance. Left maps show yearly change (slope) in chlorophyll concentration at each location—positive (increase) or negative (decrease). Right maps are binary. 1 (yellow) indicates statistical significance, and 0 (dark green), means insignificance (random fluctuations).

Discussion

- Time series of monthly surface chlorophyll concentrations were analyzed at a specific point in both the permanent and seasonal upwelling region of the Northwest African coastal upwelling zone.
  - In the seasonal zone, chlorophyll shows a clear seasonal cycle, with typical peaks from winter to spring when trade winds are strongest. Weakening trade winds and strengthening monsoon winds in the summer disrupt coastal upwelling. Seasonal peaks here often surpass those of the permanent upwelling zone, highlighting the intense seasonal cycle of productivity in this area.
  - In the permanent upwelling zone, the seasonal cycle here is weak, and somewhat higher surface chlorophyll concentrations (> 1 mg/m^3) are maintained throughout the year. The graph shows less short-term variability, consistent with permanent upwelling.
- Both regions illustrate a statistically significant decline in surface chlorophyll (as illustrated by the negative slope of the trend line in both time series plots).
  - The more significant decrease in chlorophyll in the seasonal zone (0.4464 mg m^-3/decade) than in the permanent zone (0.1916 mg m^-3/decade) may be related to strengthening monsoon winds and weakening trade winds. This long-term pattern of wind variations was also observed by Ibrahim and Sun in 2022. The more significant impact of monsoon winds on the seasonal upwelling system suggests that a potentially larger decline in primary productivity has occurred here.
  - Spatial surface chlorophyll trends reflect this pattern. The decline in concentrations is weaker and restricted to a narrow coastal band along the northern region (permanent upwelling system). In contrast, this decline is more intense and extends further offshore in the southern region (seasonal upwelling system).
- The noticeable drop in peaks in recent years suggests an intense long-term decrease in primary productivity throughout this region.
  - This threatens the marine food web, including commercially important fisheries. As one of the world's major upwelling systems, ongoing reductions in productivity raise concerns for global food security.
- In addition to the long-term variations in surface wind patterns, other conditions potentially influence productivity levels. Variations in surface wind and greater surface heat input can raise the sea surface temperature (SST). Rising SSTs increase ocean stratification, limiting the vertical mixing needed to bring nutrient-rich deep water to the surface and lowering productivity.
- While satellite data provide valuable surface-level insights, they cannot capture all subsurface variations of productivity, and further research is needed to fully understand the long-term ecological impacts of these changes. Additionally, the limited time span of this observational data is not entirely sufficient to isolate the long-term trend from multi-decadal variations.