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ORIGINAL RESEARCH ARTICLE

Characterization of the northern Red Sea's oceanic features with remote sensing data and outputs from a global circulation model

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Summary Sea surface temperature (SST) and surface wind (SW) are considered the most important components in air—sea interactions. This study examines the relationships between SST, SW and various oceanic variables in the northern Red Sea (NRS) during the period of 2000—2014. The current study is the first attempt to identify the SST fronts and their relationship with the dominant circulation patterns. SST fronts are mapped using the Cayula and Cornillon algorithms. The analysis is performed with available remote sensing and reanalyzed data together with 1/12° HYbrid Coordinate Ocean Model (HYCOM) outputs. Seasonal-trend decomposition procedure based on loess (STL) is applied for trend analysis, and Principal Component Analysis (PCA) is run for the atmospheric parameters. The SST, SW speed and Chlorophyll-*a* (Chl-*a*) changes show insignificant trends during the period of 2000—2014. Meridional SST fronts are more significant during the month of January, and fronts that are perpendicular to the sea's axis occur from February to May. Distinct monthly and spatial variations are present in all the examined parameters, although these variations are less pronounced for the wind direction. The SST is mainly controlled by the air

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temperature and sea level pressure. Significant correlations exist between the SST and the studied parameters (alongshore wind stress rather than the cross-shore wind stress, surface circulation, MLD, and Chl-*a*). Surface winds generally flow southeastward parallel to the Red Sea's axis explaining that alongshore wind stress is highly correlated with the studied parameters.
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1. Introduction

The Red Sea is a semi-enclosed tropical basin connected to the Indian Ocean through the Bab-al-Mandab Strait. It flows to the Mediterranean Sea through the Suez Canal. The Red Sea supports a rich and diverse ecosystem (Barale and Gade, 2013) and is a unique environment because of the lack of any permanent rivers that flow into it. The Red Sea has an overall negative water balance (i.e. the evaporation is greater than the precipitation and combined river runoff). Although the Red Sea is considered an arid climate region with negligible precipitation and runoff (Al-Horani et al., 2006), flash floods during winter, especially along the eastern coast of the Red Sea, transport terrestrial materials into the NRS. The existence of these flash floods alongside extensive sunlight, clear visibility, deep light penetration, and warm water leads to the extensive development of corals (Al-Rousan et al., 2016). The Red Sea is of special socioeconomic importance because it supports a high volume of shipping activity (Rasul and Stewart, 2015) and other economic activities, including fishing, oil exploration, and tourism. Unfortunately, limited scientific studies have been performed on the Red Sea; a large gap in knowledge exists compared to similar ecosystems (Acker et al., 2008). Thus, the Red Sea is an important area in which a further study of its dynamics would be highly beneficial (Loya et al., 2014).

This study focuses on the descriptive and statistical analysis of physical oceanic characteristics (SST, surface wind, and circulation) over the northern Red Sea (21.5°—30°N, 33.5°—40°E; Fig. 1). Moreover, the relationship between these physical characteristics and Chl-*a* is studied.

SST and SW are considered the most important components in air—sea interactions (Chu, 1989). As such, exploring these two components is the main goal to understand the various dynamics in this region, including the surface circulation, mixed layer depth, upwelling, and Chl-*a* distribution (Gai et al., 2012; Kara et al., 2003; McWilliams et al., 2005; Patzert, 1974; Sofianos and Johns, 2003; Tang et al., 2002).

1.1. Surface wind (SW)

The Red Sea's wind regime is orographically determined due to the existence of high coastal mountain ranges along its eastern and western coasts (Sofianos and Johns, 2007; Sofianos, 2003). The average wind speed generally increases northward (Patzert, 1974). These coastal mountain ranges

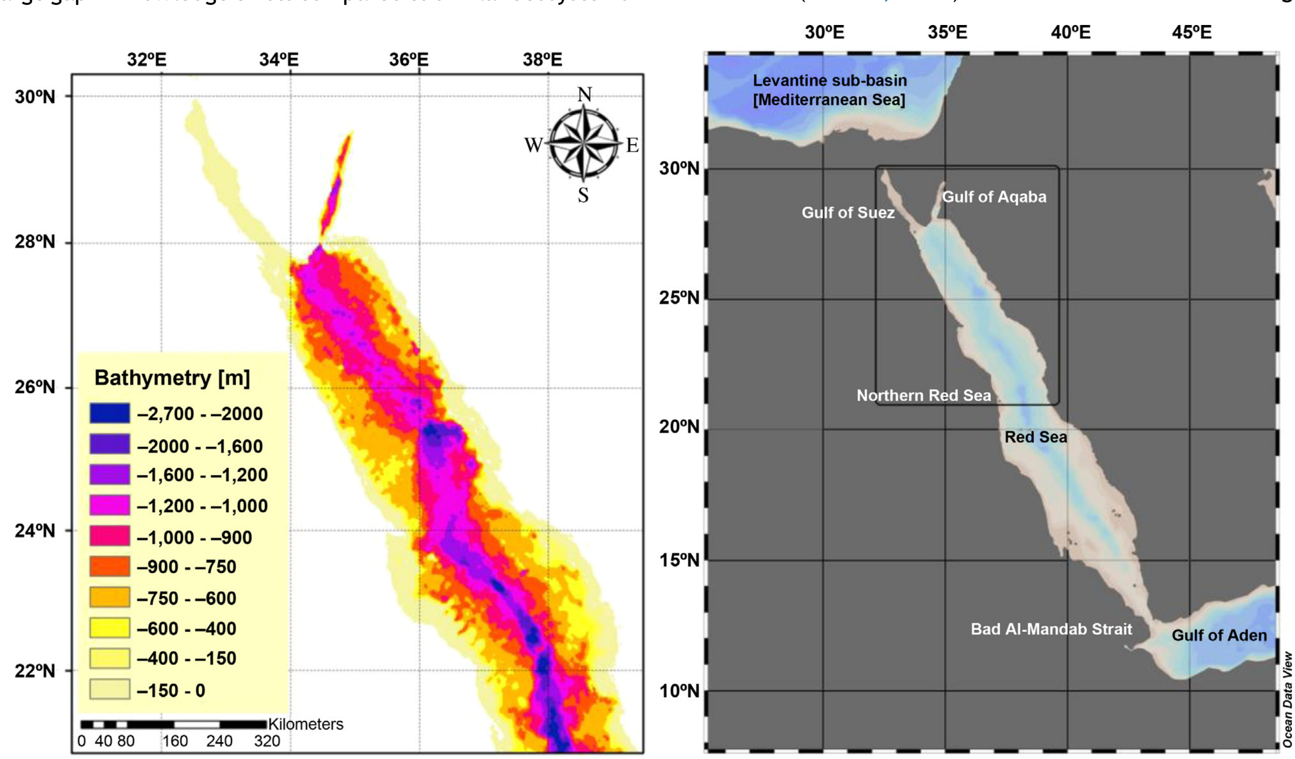

Figure 1 Left: Bathymetric chart of the northern Red Sea (data source: https://www.bodc.ac.uk/products/software_products/gebco_grid_display). Right: Red Sea map. Created from the ocean/world database (available at Arc GIS Online). The black box region represents the study area.

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