VARIABILITY AND RESPONSE OF SURFACE CHLOROPHYLL TO THE MARINE HEATWAVE IN THE SOUTHERN NORTH SEA

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Abstract
This study investigates the variability and response of surface chlorophyll (CHL) concentrations in the southern North Sea to marine heatwaves (MHWs) over 26 years (1998-2023). The analysis uses daily high-resolution cloud-free SST and CHL data obtained from CMEMS. The SST showed a significant positive temporal trend, while the CHL concentration showed a non-significant trend. Spatially, the CHL trend map showed high variability, with significant negative trends along the French coast and in certain regions west of the Dogger Bank and significant positive trends along the east coast of the United Kingdom, the Belgian and Dutch coasts, and the German Bight. The analysis of MHW and low chlorophyll (LCHL) events showed an increasing trend in the total number of MHW and LCHL days as well as compound MHW-LCHL days over the study period.

Keywords: Chlorophyll-A, North Atlantic, Temperature

Introduction
The SNS is a highly productive region characterized by dynamic physical and biological processes [1]. In recent years, the SNS has experienced the effects of marine heatwaves (MHWs) [2], which are prolonged periods of unusually warm SST [3]. These MHWs can have profound impacts on the marine environment, including alterations in CHL concentrations [4,5]. The CHL is a key indicator of the productivity of marine ecosystems. It serves as a proxy for phytoplankton biomass, which forms the base of the marine food web and plays a crucial role in global carbon cycling. However, the response of CHL to environmental changes, such as MHWs, can significantly impact ecosystem dynamics [5]. The aim of this study is to investigate the variability and trend of CHL concentrations in the SNS and their response to MHWs over the last 26 years (1998-2023).

Methods
To identify MHW metrics and their compound MHW-LCHL events, we follow [5,6], who defined the MHW (LCHL) as days when the SST (CHL) anomalies are above (below) their 90th (10th) percentile threshold for that time of year. For more details on the compound MHW and LCHL events, the reader is referred to [5]. Here we have used the daily high-resolution cloud-free SST and CHL concentrations at the surface downloaded from the CMEMS. Both data sets are available from 1998 to 2023 with a horizontal resolution of 2 km for SST and 1 km for CHL. The CHL data were re-mapped by cubic spatial interpolation to obtain the same resolution as the SST (i.e. 2 km).

Results
Fig1 shows the temporal evaluation of the SST and CHL concentration anomalies (SSTA, CCA) in the SNS during the period from 1998 to 2023. The highest SSTA was found in 2007, 2014, 2016, and 2022, while the highest CCA was observed in the spring of 2001 and 2003. Although there is no strong significant correlation between SSTA and CCA over the whole study period, there is a coincidence between the extremely positive SSTA and extremely negative CCA in some years during the study period (see the pink line in Fig.1). Excessive heat in these years can lead to thermal stress, which affects the growth, photosynthesis, and overall productivity of phytoplankton. Consequently, this can lead to a decrease in CHL concentrations. The SST showed a significant temporal trend of 0.28 °C/decade, while the CHL concentration showed a non-significant trend of 0.09 (mg/m^3)/decade (Fig. 1). The analysis of the seasonal chlorophyll cycle (not shown) usually peaks in April and May and describes the phytoplankton spring bloom in the SNS.

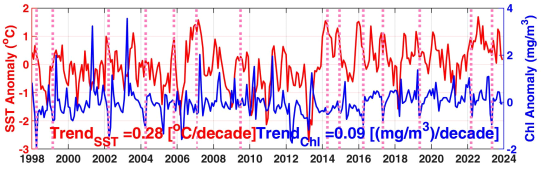

Fig. 1. Time series of SST anomaly and CHL concentration anomaly averaged in the southern North Sea. The pink lines show the coincidence of low CHL with high SST.

The CCA trend map shows high spatial variability, ranging from significant negative trends to positive trends (Fig. 2). The negative CCA trend is found along the French coast, in the Wadden Sea, and in the deep part west of the Dogger Bank. The strongest significant positive CCA trends are found along the east coast of the United Kingdom, in the central part of the study area, along the Belgian and Dutch coasts, and in the German Bight. The regions where higher CCA trends were recorded coincided with lower SSTA trends (see Fig. 4 in [2]), which is influenced by the inflow of freshwater. The spatial correlations revealed a non-significant relationship between CCA and SSTA for most of the study area. However, significant positive correlations ($p<0.05$) are found in the same regions that show positive CCA trends (i.e. along the Belgian and Dutch coasts and in the German Bight), while a patch of negative correlation is observed in the deep regions around the Dogger Bank.

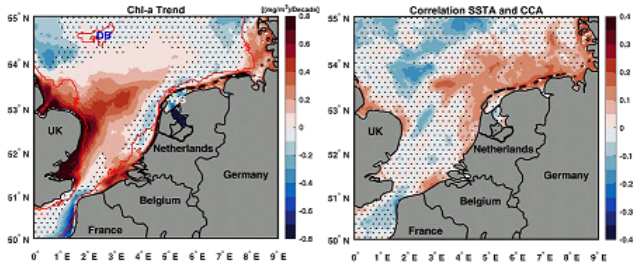

Fig. 2. Trend map of chlorophyll-a concentration anomaly (mg/m3)/decade and its correlation with sea surface temperature anomaly. The abbreviations stand for the Dogger Bank (DB) and the Wadden Sea (WS).

To investigate the temporal development of MHW and LCHL events or composite MHW-LCHL events, we calculate regional annual mean values of the total days in the entire study area from 1998 to 2023 (not shown). The highest total number of MHW days and MHW frequency were recorded in 2007, 2014, 2016, and 2022. The highest mean MHW-LCHL days were also recorded in the same years. The overall trend of MHW and LCHL days was 8.31 and 2.84 days/decade, respectively. The mean MHW-LCHL days also show an upward trend of around 0.87 days/decade over the entire study period.

Conclusions: This study highlights the complex relationship between MHWs and surface chlorophyll concentrations in the SNS, providing valuable insights into the dynamics of this productive marine region.

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