Spatial and temporal variability of marine heatwave in the Baltic Sea

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Marine heatwaves (MHWs) are recognized as one of the most prominent extreme events in our oceans. Characterized by prolonged periods of exceptionally high ocean temperatures, their frequency and intensity have been increasing in recent decades due to climate change. Moreover, marine heatwaves are not limited to any specific part of the world's oceans and have been observed across different temporal and spatial scales. The Baltic Sea, as a high-latitude basin, is also subject to extreme climatic events, emphasizing the importance of focused research to understand and investigate MHWs in such regions. Our study aims at systematically detecting MHW events recorded in recent decades. Utilizing available datasets, the main goal of this study is to analyze the spatial and temporal variability of MHWs in the Baltic Sea. To achieve this goal, high-resolution reprocessed satellite SST data from 1989-2020 (spanning 32 years) were obtained from the Copernicus Marine Service. MHWs are defined relative to the baseline period, which should represent the climatic neutral state of the region. In this study's preprocessing phase, we aimed to identify a neutral period of maximum possible duration (at least 10 years) during which the average absolute values of the Atlantic Multi-decadal Oscillation (AMO) and the North Atlantic Oscillation (NAO) indices are the lowest (zero or close to zero). Given the total data span of 32 years, our evaluation determined that the twelve-year period from 1992 to 2002 (11 years) is the most suitable for determining the baseline period to define the daily SST thresholds at each specific spatial point within the data grid. For the spatial analysis, the characteristics of the intensity of the events and the number of days of their establishment were examined. The comparison of intensity maps and the number of event days showed that in general, the Baltic Sea average intensity of past MHW events reaches 2.5 C. The intensity spatial distribution shows little changes in most areas of the Baltic Sea. At the same time, the number of MHW event days decreases gradually from north to south, and the most frequent areas containing MHWs are the coastal waters of Poland and Germany. Also, it was shown that the intensity of the detected MHWs is associated with an increasing trend but with a different spatial distribution in the Baltic Sea, so that this trend in the eastern and southern parts of the Baltic Sea is around 0.2 to 0.25 C /decade, and in the Gulf of Finland reaches its maximum of about 0.3 C/decade. For the temporal analysis, we assessed the intra-annual variability and monthly climatology of MHW intensity, the number of MHW days, and the area affected by MHWs. We define an index that captures the combined effect of mean intensity, the number of days, and the affected area of MHWs. This index results from multiplying the average intensity of MHWs by the normalized number of MHW days, and then by the normalized event area. Using this index, we identified 2020 as the year with the most severe MHW in the last 32 years. This was followed by 2014, 2015, and 2006. Notably, the index displays an increasing trend of 0.02 C/decade on average for the Baltic Sea. Monthly

climatology indicates that MHW occurrences are aligned with a seasonal cycle, peaking in July and again in December. The latter suggests the importance of MHWs in the Baltic Sea in winter. Examining the influence of ice coverage on the detection and behaviors of MHWs revealed differences specifically in the northern and eastern part compared to the rest of the Baltic Sea. Removing ice covered grid cells from the analysis decreased MHW index in these areas.