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Copernicus Marine Service Ocean State Report, Issue 3

Chapter 1: Introduction

The fundamental role of the ocean for life and well-being on Earth is more and more recognised at the highest political level. In 2015, the United Nations (UN) Sustainable Development Goals (SDGs) of the 2030 Agenda for Sustainable Development were adopted by world leaders. The SDG 14 'Conserve and sustainably use the oceans, seas and marine resources for sustainable development' is dedicated to the oceans. The mention of the ocean in the Paris Agreement signed in 2016 marked a decisive milestone. In 2018, the UN Decade of Ocean Science for Sustainable Development (2021–2030) has been proclaimed (https://en.unesco.org/ocean-decade): The Intergovernmental Oceanographic Commission of UNESCO will gather ocean stakeholders worldwide behind a common framework to foster evidence-based policy-making. In fall 2019, the IPCC special report on ocean and cryosphere will be published, and will provide an opportunity to increase awareness and action before COP25[1] (already claimed as 'Blue COP').

This unprecedented ocean agenda is a timely one: multiple anthropogenic stressors such as climate change, over-exploitation and pollution are becoming a major threat on the marine environment and its services for human benefits and biodiversity at large. The annual Ocean State Report of the European Union's Copernicus Marine Service contributes to this unrivalled mobilisation of the global scientific community, and is one of the priority tasks given by the EU Delegation Agreement for CMEMS implementation (CMEMS 2014). Ocean observing, monitoring and forecasting are key to unravel the ocean's responses to pressures, understand and predict the evolution of the oceans and develop management actions for sustainable development, including for mitigation and adaptation to climate change.

Since its launch in 2016 with the publication of the first issue (von Schuckmann et al. 2016a), a fundamental baseline of regular science-based ocean reporting has been established. It covers the blue ocean (i.e. physical processes driven by changes in temperature, salinity and currents), the green ocean (i.e. biogeochemical processes such as fluctuations of ocean chlorophyll identifying changes at the base of the marine food chain, eutrophication processes, the uptake of carbon by the ocean, and ocean deoxygenation), and the white ocean (i.e. the rapid evolution of ice-covered polar regions). The evaluations in the Copernicus Marine Ocean State Report span local scales (e.g. extreme variability of sea level, sea surface temperature and significant wave height at the coast), the European regional seas (e.g. monitoring of key essential variables and interpretation of variations and trends), large scale (e.g. analysis of the unusual cold and fresh conditions or the Meridional Overturning Circulation in the North Atlantic), to global scale (e.g. delivering an Earth system view on the uptake of heat and carbon by the ocean). The assessments cover climate-relevant time scales (e.g. ocean deoxygenation since the 1960s), multi-decadal time scales (e.g. global mean sea level rise over the past three decades), and the evaluation of specific events taking place in the marine environment close to real time (e.g. extreme sea ice conditions in the Arctic ocean in 2016, or the polynya event in the Weddell Sea during 2017).

The scientific assessments developed in the Copernicus Marine Ocean State Report are based on a wide range of reprocessed in-situ and satellite observation data products and ocean reanalysis model products in seven ocean regions (Figure 1.1). A large fraction of these products are distributed via the Copernicus Marine Service web portal (http://marine.copernicus.eu/). In addition, products from the Copernicus Climate Change Service are used, in particular for climate-related studies such as sea level rise (i.e. a Global Climate Indicator as identified by WMO/GCOS, https://gcos.wmo.int/en/global-climate-indicators). Additional data products have been included in the Ocean State Report analyses aiming to strengthen the scope of the report, e.g. to take an Earth system perspective (i.e. the role of the ocean heat uptake in the Earth energy budget), to further investigate exchanges and processes with other components of the Earth system (e.g. air-sea exchanges), or to complement the analyses with biological data for impact studies on the marine ecosystem. All products used in each section are listed in a specific product table, which includes data source information and

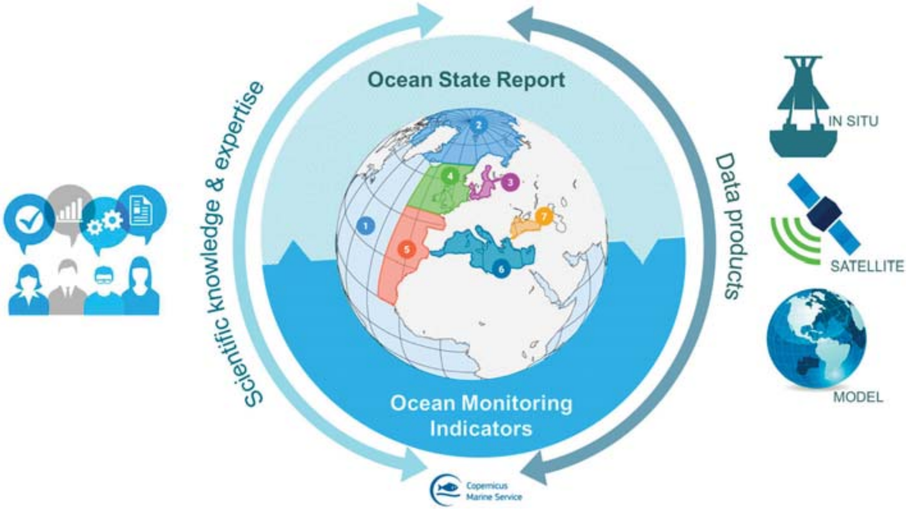

Figure 1.1. Schematic overview on the Copernicus Marine Ocean State Report and Ocean Monitoring Indicator activities, which are both linked to each other, and cover seven principal regions. The interplay of scientific knowledge and expertise, as well as the data products (*in situ*, satellite, model) from Copernicus services and other sources is the key ingredient for the Copernicus Marine scientific evaluation and reporting. See text for more details. Regions include: 1 – Global Ocean; 2 – Arctic Ocean from 62°N to the North Pole; 3 – Baltic Sea, including Kattegat at 57.5°N from 10.5°E to 12.0°E; 4 – European North West Shelf Sea, which includes part of the North East Atlantic Ocean from 48°N to 62°N and from 20°W to 13°E. The border with the Baltic Sea is situated in the Kattegat Strait at 57.5°N from 10.5°E to 12.0°E; 5 – Iberia-Biscay-Ireland Regional Seas, which includes part of the North East Atlantic Ocean from 26°N to 48°N and 20°W to the coast. The border with the Mediterranean Sea is situated in the Gibraltar Strait at 5.61°W; 6 – Mediterranean Sea until the Gibraltar Strait at 5.61°W and the Dardanelles Strait; 7 – Black Sea until the Bosporus Strait.

documentations (product manuals, quality assessment documents, and scientific publications).

The major objective of the Copernicus Marine Ocean State Report activity is to provide scientifically assessed added-value information, for a wide range of topical domains in the marine environment and at different space and time scales. Expert collaboration is indispensable to achieve this goal. Since the launch of this activity, more than 150 European scientific experts from more than 25 European institutions have joined forces to develop the Copernicus Marine Ocean State Report and the number of new collaborators is steadily increasing with the evolution of the reporting activity. This activity is a breeding ground for new and innovative science activities across multidisciplinary expertise (e.g. joint analysis on physical and biogeochemical topics), space scales (e.g. between different European basins), and time scales (e.g. interplay of climate change and natural variability).

The Ocean State Report content is designated to a specific audience, including scientists, expert stakeholders and European and International environmental agencies and organisations (e.g. EEA, WMO, IPCC, …). In order to enlarge the audience, two supplement tools have been established by the Copernicus Marine Service. The first tool is the preparation of a summary for each issue of the Ocean State Report in collaboration with communication and graphical experts, highlighting and synthetising key outcomes of the scientific publication. This summary is aiming to reach out to policy and decision-makers, as well as to increase general public awareness about the status of, and changes in, the marine environment. These documents are freely available at the Copernicus Marine web portal (http://marine.copernicus.eu/science-learning/ocean-state-report/).

The second tool includes the dissemination of numerical values, quality and background documentation and figures of key variables used to track the vital health signs of the ocean and changes in line with climate change and natural variability. All elements (data, documentation, figures) are regularly updated, and build the Copernicus Marine Ocean Monitoring Indicator framework (http://marine.copernicus.eu/science-learning/ocean-monitoring-indicators/). For example, close-to-real-time knowledge of how much heat is stored in the ocean, the pH of the ocean, how fast sea level is rising and sea ice is melting, is essential to understanding the current state and changes in the ocean and climate. This information is critical for assessing and confronting ocean and climate changes associated with global warming and they can be used by scientists, decision-makers, environmental agencies, economy, the general public, and in measuring our responses to environmental directives. The Ocean Monitoring Indicators were developed through a long process of scientific analysis and validation, with the consensus of scientific experts after review as part of the Ocean State Report. The online publication of an Ocean Monitoring Indicator generally requires that the scientific rationale, validation and interpretation went through the Ocean State Report peer review.

A general rule is that a scientific topic already addressed in one of the issues of the Ocean State Report should not be repeated in upcoming new issues. However, in order to maintain a comprehensive review on the variations and changes in the blue, green and white ocean as part of the Ocean State Report, the Ocean Monitoring Indicator framework is indispensable. From the third issue of the Ocean State Report onwards, two synthesis figures based on the Ocean Monitoring Indicator information, as well as on scientific evaluations in the corresponding issue will be included in Chapter 1 (i.e. the introduction). One figure will summarise the long-term changes reported over the past decades (Figure 1.2), and the second figure is dedicated to deliver an overview of the anomalies close to real time for the European regional seas and the global ocean (Figure 1.3).

What else is new in the third issue of the Copernicus Marine Ocean State Report? Beside the new strategy for Chapter 1 as described above, a large number of new topics have been gathered in this new issue. In Chapter 2 – which addresses the state, variability and change in the marine environment – topics such as sea wind, coastal and regional current systems, phytoplankton blooms, hydrographic pressure on cod stocks and extreme variability have been analysed. Chapter 3 discusses selected case studies that analyse specific aspects of the ocean change that are of scientific and more general interest. For example, this issue proposes a marine atlas for the Pacific Ocean Island states, which responds directly to Fiji's requests at the 2017 United Nation Oceans for SDG 14, life below water and the 2017 COP23 for SDG13, climate action. A review on the use of ocean data in European fishery management is developed in this issue as well. Other specific studies include for example a joint analysis between Copernicus Marine and Marine Protected Areas (e.g. t-mednet.org) to analyse the impact of thermal stress on marine biodiversity, and reported environmental changes and their impact on aquaculture. Chapter 4 reports on specific events during the year 2017, including for example the Weddell Sea polynya, marine heat waves and the 2017 coastal El Niño.

1.1. Trends over the past decades

Continuous reporting of trends contribute to the understanding of observed changes in the marine environment around the world, and improves knowledge of the likely responses to climate change affecting social, environmental and economic systems, i.e. the three pillars of sustainable development. As also reported in the second issue of the Ocean State Report, the results of the third issue show ocean surface and subsurface warming, rising total and thermosteric sea level and a decrease in global sea ice extent over the past 25 years (Figure 1.2). Ocean deoxygenation is shown to take place over the past decades. Decreasing and increasing regional trends since the year 2007 are reported for chlorophyll-a. These changes can be observed not only at global scale, but also in the seven European regional seas. The following changes are highlighted:

- The ocean surface continues to warm, and sea surface temperature trends for the European regional seas range from 0.03 to 0.07°C year^{-1} at 0.002–0.005°C year^{-1} uncertainty ranges. Sea surface temperature trends have also been evaluated as part of the Copernicus Marine Atlas for Pacific Islands (Section 3.1), as sea surface temperature is a much-needed variable for assessing coral reef health and bleaching, as well as for tropical cyclone forecasting. While the ocean surface is warming in the Western and Central Pacific Islands areas, we note a strong variability over various time scales, such as for example the El Niño Southern Oscillation.
- The subsurface ocean continues to warm (von Schuckmann et al. 2016b, 2018). Global ocean heat content of the upper 700 m increases currently at a rate of 0.9 ± 0.1 Wm^{-2} as obtained over the period 1993–2017 (Figure 1.2). Over the shorter time window 2005–2017 during which Argo provides the best available coverage of the global ocean observing system (e.g. Riser et al. 2016), this rate of change is smaller (0.6 ± 0.1 Wm^{-2}), and needs correction for short-term climate variability (Cazenave et al. 2014). Increasing the integration depth to 2000 m yields a rate of change of ocean heat content of 1.2 ± 0.1 Wm^{-2} due to the excess heat sequestered into the deeper layers of the oceans (e.g. Meehl et al. 2011; Abraham et al. 2013). By adding a contribution of 0.1 Wm^{-2} for the deep ocean below 2000 m depth (Purkey and Johnson 2010; Desbruyères et al. 2016), we obtain an estimate of the Earth energy imbalance of 0.5–0.7 ± 0.1 Wm^{-2} based on the CMEMS reporting (1993–2017, 0–700 m: 0.7 Wm^{-2}; 2005–2017, 0–700 m: 0.5 Wm^{-2}; 0–2000 m: 0.7 Wm^{-2}, taking into account that the heat content is related to the ocean surface only i.e. multiplied by 0.7). At regional scales, subsurface ocean warming in the upper 700 m depth increases at rates close to the global value in the Mediterranean Sea and the Central Pacific Islands area, and doubles for the Western Pacific Islands area (Figure 1.2).

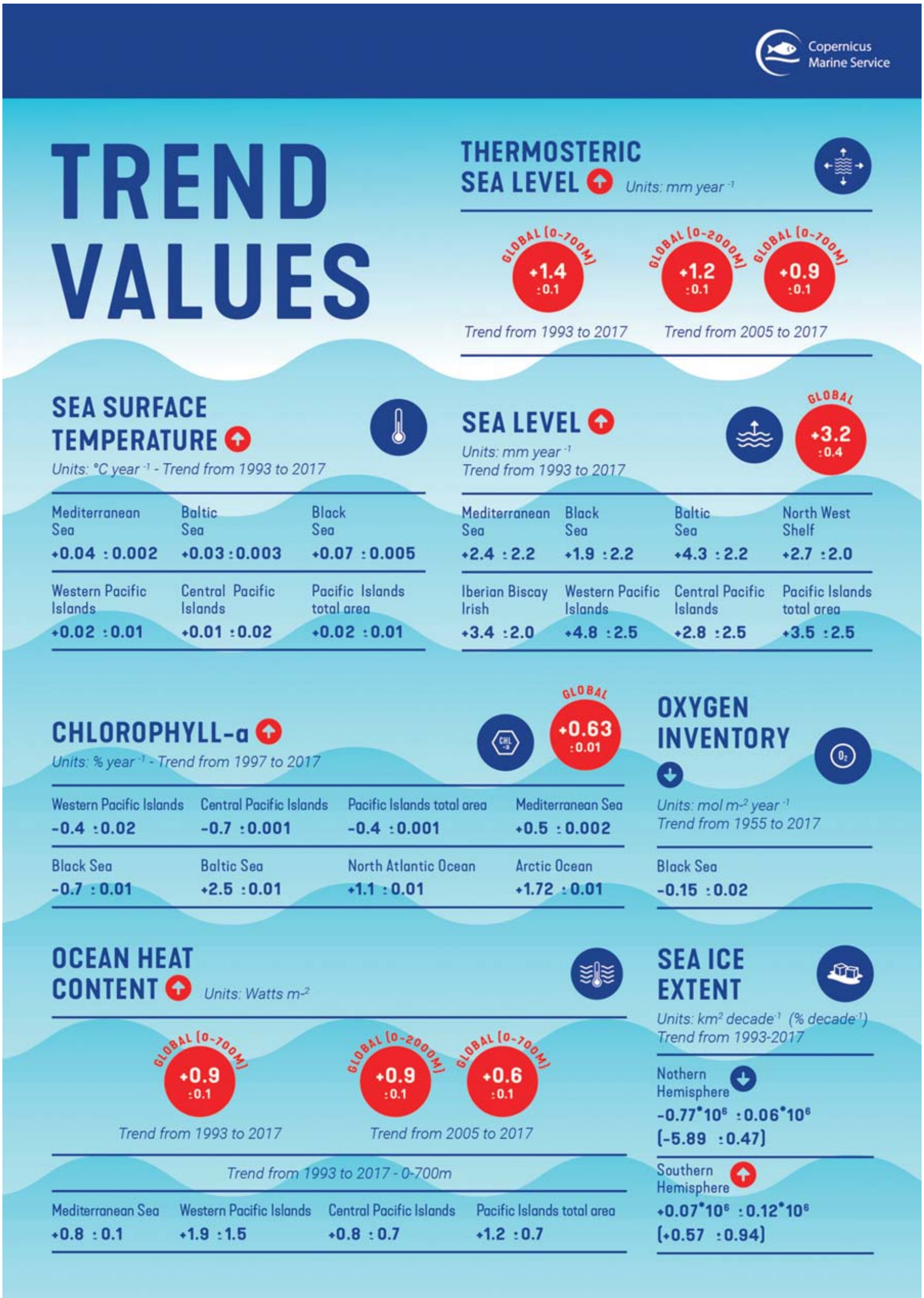

Figure 1.2. Overview on trend values reported in the third issue of the CMEMS Ocean State Report, and in the CMEMS Ocean Monitoring Indicator framework (http://marine.copernicus.eu/science-learning/ocean-monitoring-indicators/). Upward arrow indicates increasing trends, downward arrow decreasing trends. Time intervals for trend evaluation are indicated for each parameter, respectively.

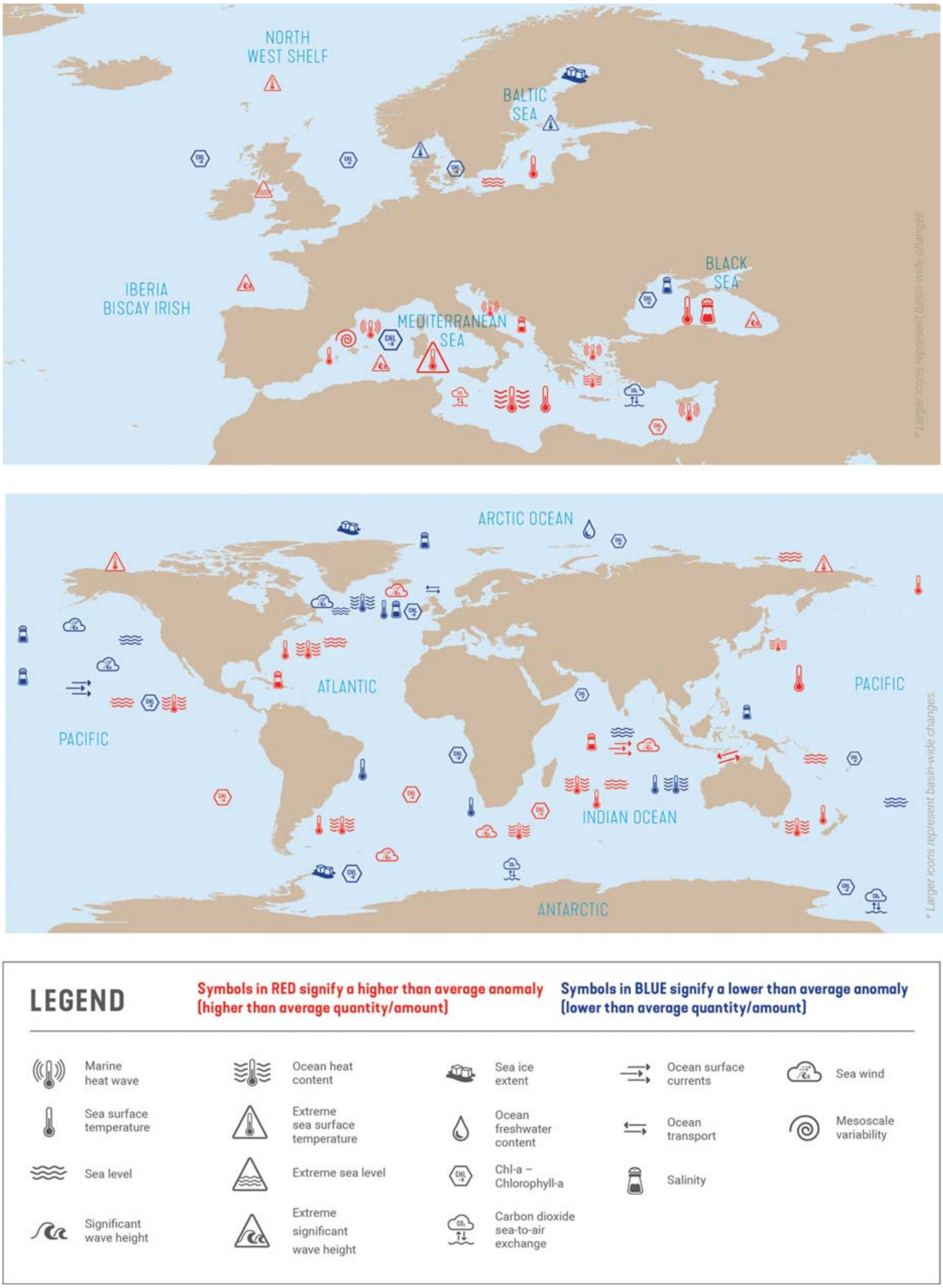

Figure 1.3. Anomalies and extreme events during the year 2017 as reported in the third issue of the CMEMS Ocean State Report and from the Copernicus Marine Ocean Monitoring Indicator framework (see text for more details) for the global ocean (upper panel), and the European regional seas (lower panel). A legend for all icons is included. Red coloured icons signify higher-than-average anomalies and extremes, and blue coloured icon show lower-than-average values.

- Global sea level continues to rise at a rate of 3.2 ± 0.4 mm year^{-1} (Figure 1.2). As the ocean warms, its volume expands (thermosteric effect), which is a major cause of global mean sea level rise. The upper ocean (0–700 m) thermosteric sea level has been rising since 1993 at a rate of 1.4 ± 0.1 mm year^{-1}. Sea level rises also in all European regional seas at rates that even exceed the global mean rate (e.g. the Baltic Sea). Sea level has been also included in the Copernicus Marine Atlas for the Pacific Islands areas as it is a key ocean variable to better inform climate adaptation and coastal planning. Sea level in these areas is rising as well and a strong rate of 4.8 ± 2.5 mm year^{-1} can be noticed in the western part (Chapter 3).
- Since 1993, there has been a sea ice extent loss of nearly 770,000 km^2 decade^{-1} in the northern hemisphere, and a sea ice extent gain of 80,000 km^2 decade^{-1} in the southern hemisphere (Figure 1.2).
- Chlorophyll-a, the main photosynthetic pigment contained in all phytoplankton, has shown increasing and decreasing trends over the past 19 years (1998–2017). At global scale, chlorophyll-a has been increasing by 0.6 ± 0.01% year^{-1} (Figure 1.2). Increasing trends are also reported in the Mediterranean Sea, Baltic Sea, North Atlantic and Arctic Ocean. Decreasing trends occur in the Black Sea, as well as in the areas of the Pacific Islands. However, given that the chlorophyll-a time series from remote sensing used here is only 19 years long characterised by large signals of decadal variability, the time series are too short to disentangle the effect of interannual variability and longer-term climate change.
- There is an ongoing deoxygenation trend reported in the Black Sea, with a decrease at a rate of −0.16 ± 0.02 mol m^{-2} year^{-1} (Figure 1.2).

1.2. Anomalies and extreme events

Anomalies and extreme events observed in 2017 are summarised in Figure 1.3. The results have been drawn from the third issue of the CMEMS OSR, as well as from the CMEMS OMIs. Chapters 2, 3 and 4 contain reported anomalous changes in the marine environment during the year 2017. Some specific events have been highlighted and described in Chapter 4. The anomalous changes are summarised in Figure 1.3, which include:

- The northern parts of the European regional seas (e.g. the Baltic Sea, the North West Shelf Sea) have been characterised by lower-than-average sea ice extent and chlorophyll-a values respectively during 2017. Moreover, extreme cold temperature conditions have been reported in these areas, together with higher-than-average ocean temperature and sea level in the Baltic Sea.
- The southern parts of the European regional seas have undergone significant changes during the year 2017: the Mediterranean Sea has been impacted by strong heat wave events during boreal summer in the eastern and western basins (Section 4.4), several events of extreme variability in the western basin, and higher-than-average ocean surface and subsurface water temperature. Chlorophyll-a values have been larger than previous years. Air-to-sea carbon fluxes show higher-than-average values in this area. Higher-than-average significant wave height, surface water temperature and salinity have been reported in the Black Sea.
- The Arctic Ocean has experienced lower-than-average sea ice extent and ocean freshwater content during the year 2017. In addition, extreme sea surface temperature anomalies of values up to +6°C have been reported, for example in the East Siberian Sea and the Beaufort Sea (Section 2.6).
- In the Antarctic region, a large hole in the winter sea ice cover (polynya) appeared in the Weddell Sea and stayed open for almost three months (Section 4.1). This was the first occurrence of such an event since 1976. Additionally, the Antarctic ocean area has showed lower-than-average air-to-sea carbon flux. Chlorophyll-a concentration was below its average value.
- At global scale, surface and subsurface temperature and sea level are particularly high in several areas such as the southwestern Indian Ocean, eastern tropical Pacific, subtropical and southwestern Atlantic and southeast of Australia. Anomalous cold and fresh conditions together with low sea level have prevailed in the subpolar North Atlantic, the western tropical and north Pacific, and in the northeastern Indian Ocean. Higher-than-average chlorophyll-a is reported in the southeastern Pacific and in the Indian Ocean south of Madagascar, while chlorophyll-a was anomalously low in the northwestern Indian Ocean, and in the eastern tropical Atlantic and Pacific. The tropical Pacific was in neutral El Niño Southern Oscillation conditions in 2017. However, coastal El Niño conditions have been reported along the coast of Peru and Ecuador at the beginning of the year.

Note

1. *25th meeting of the Conference of the Parties to the United Nations Framework Convention on Climate Change.*

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