Funded by
the European Union

PART OF THE
EU MISSIONS
RESTORE OUR OCEAN & WATERS

COPERNICUS OCEAN STATE REPORT

SUMMARY

ISSUE 8 PUBLISHED IN 2024

PROGRAMME OF
THE EUROPEAN UNION

Copernicus
Europe's eyes on Earth

Copernicus
Marine Service

Implemented by
MERCATOR OCEAN
INTERNATIONAL

SECTIONS

LEGEND

Blue Ocean
The physical state of the ocean

Green Ocean
The biological and biogeo-chemical state of the ocean

White Ocean
The lifecycle of sea ice within the polar regions

WHAT IS...?
Provides definitions

IMPACTS
Highlights the impacts of ocean change and extremes on the ocean, ecosystems and society

OSR 8
Link to the relevant section in the complete OSR 8 (digital only)

EXPLORE THE

COMPLETE REPORT

THIS DOCUMENT IS INTERACTIVE!

The **toolbar above** was developed to help you navigate the summary. The left and right arrows cycle through the pages and sections. Throughout the document, blue → buttons link to supplementary information from the Mercator Ocean International website, and OSR 8 buttons link to the relevant section in the complete OSR 8.

ABOUT THE **OCEAN STATE REPORT**

The Copernicus Ocean State Report (OSR) is an annual publication of the Copernicus Marine Service, which is implemented by Mercator Ocean International. The report provides state-of-the-art scientific knowledge about the current conditions, natural variations, and ongoing changes in the European regional seas and the global ocean. It is meant to act as a reference for the scientific community, national and international bodies, decision-makers, blue economy actors, and the general public.

Using model data and satellite and in situ measurements, this integrated description of the ocean state feeds into a four-dimensional view (latitude, longitude, depth, and time) of the **Blue, Green, and White Ocean** (see Legend). The Ocean State Report draws on the expert analysis of more than 120 scientific experts from research institutions across Europe and around the world. Scientific integrity is assured through a process of independent peer review in collaboration with the State of the Planet journal from Copernicus Publications.

The Ocean State Report is a contributing initiative to the **EU Mission: Restore Our Ocean and Waters.** This mission aims to protect and revitalise the ocean by 2030, by supporting innovation, research, blue investments and citizen action across EU seas and river basins.

ABOUT THIS **SUMMARY**

This summary of the 8th issue of the annual Ocean State Report highlights the current state, variations, and ongoing changes in the ocean in Europe and around the world. It explores the ocean as a living, dynamic entity, one experiencing a range of extremes, and which has strong interactions with both Earth's climate and our society.

Section 1 focuses on chapter 1 of the OSR 8 — The State of the Ocean — which is dedicated to detailing variations and trends in key characteristics of the ocean, including the Ocean Monitoring indicators. It also shows the global picture of extreme and notable ocean events across 2022 and 2023. **Section 2** focuses on the complex interplay between the ocean and the other components of Earth's climate system, and dives into key oceanographic processes. **Section 3** showcases some of the innovations and technologies which directly benefit society — innovations and technologies supporting humans and improving our relationship with the ocean.

Together, the information in this summary demonstrates how accurate and timely information is key to monitoring, understanding, and adapting to a changing ocean.

* In this summary, an "anomaly" is defined as the difference of a measurement when compared to the long-term average, representing the mean state.

THE REPORT AT A GLANCE

The ocean is a dynamic and complex system, which changes constantly through natural variations — and due to unprecedented impacts from human overexploitation, pollution and climate change. This section provides the key takeaways from the OSR 8, showcasing some of the ways the ocean is transforming.

Unprecedented Marine Heatwaves

Strong and extreme marine heatwaves have grown in frequency, duration, intensity and geographical spread over the past four decades.

22 % of the global ocean surface experienced at least one severe to extreme marine heatwave event in 2023

Marine Heatwaves in Europe/Northeast Atlantic and Adjacent Seas

In the northeast Atlantic Ocean and nearby seas, marine heatwaves grew stronger, more frequent, larger and longer over the past few decades. Areas of this region suffering marine heatwaves in any given year grew from around 20 % to over 90 % between 1982 and 2023.

Sea Ice

2023 saw the lowest sea ice on record in the world's polar regions. The Arctic region lost 4 % of sea ice per decade during the period 1979-2023, followed by an increase in surface water temperature in the region. Meanwhile, the Antarctic region reached the lowest ever sea ice value since the beginning of satellite observations.

↓ 4 % mean annual sea ice lost in the Arctic per decade since 1979

Deep Marine Heatwaves

A marine heatwave in the Mediterranean Sea reached up to 1,500 m below the surface. While heatwaves were more frequent at the surface, temperatures rose further and for longer beyond 150 m.

Rising Ocean Heat Content

A new method to measure Earth's energy budget shows a significant positive trend of 0.75 $W\ m^{2}$ over the period 1993-2022, indicating continued warming of the ocean.

Unexpected Bloom

An extreme phytoplankton bloom was detected southeast of Crete in 2022, caused by a strong and unusual cold spell across the eastern Mediterranean Sea. The event led to a 35 % rise in annual primary productivity in the area, which may have impacted marine life across food chains.

↑ 35 % rise in annual primary productivity

Record-Breaking Wave Events

The tallest 5 % of global ocean waves have grown much higher in recent years. A violent storm that struck Melilla, Spain in April 2022 broke several records at once, with towering, enduring waves sweeping over the port and disrupting maritime operations.

Key Ocean Innovations

New tools and technologies are helping to monitor the ocean and support our society. This includes safeguarding marine life to bolster aquaculture, state-of-the-art wave analysis which could improve coastal protection, and a pioneering technique to power heat pumps with thermal energy from the ocean.

THE STATE OF THE OCEAN

The OSR 8 has introduced a new **Chapter 1 "The State of the Ocean"**, which provides an overview of the current state of the global ocean and the North Atlantic and adjacent seas, including key **Ocean Monitoring Indicators** (OMIs).

OSR 8

Tracking these vital signs helps us monitor long-term changes, understand what has already happened and consider the future of the ocean under a changing climate.

The Copernicus Marine Service has also launched an **Ocean Climate Portal**, with graphs, trends and maps of ocean health across the Blue, Green and White Ocean.

OCEAN CLIMATE PORTAL

1. Arctic Ocean
2. Mediterranean Sea
3. Baltic Sea
4. North West Shelf Seas
5. Iberia-Biscay-Irish Seas
6. Black Sea
7. Northeast Atlantic and Adjacent Seas (including European Regional Seas)

WHAT IS...?

The WMO Global Climate Indicators

The World Meteorological Organization (WMO) Global Climate Indicators are a set of parametres that provide key information for the most relevant domains of climate change.

Temperature and Energy | Ocean and Water | Cryosphere

GLOBAL CLIMATE OBSERVING SYSTEM

GREEN OCEAN

OCEAN ACIDIFICATION

Ocean and Water

UNITS: pH units/decade **TIME:** 1985–2022

*A decrease in pH denotes an increase in ocean acidification.

Global Ocean	Northeast Atlantic and Adjacent Seas
↓ -0.017 ±0.002 pH units/decade	↓ -0.017 ±0.01 pH units/decade

KEY FIGURES

There has been a **30% increase in acidity** since 1985.

CONTRIBUTIONS TO EUROSTAT

WHITE OCEAN

ANNUAL SEA ICE EXTENT

Cryosphere

UNITS: million km²/ decade **TIME:** 1979–2023

NORTHERN HEMISPHERE

Arctic Observations

↓ -0.50 ±0.02 10^6 km²/decade

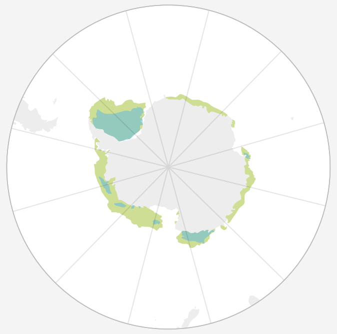
September 1993–2023 | September 2023

SOUTHERN HEMISPHERE

Antarctic Observations

— -0.03 * ±0.06 10^6 km²/decade

* The observed trend is not statistically significant



February 1993–2024 | February 2024

KEY FIGURES

Arctic: Since 1979, **a loss of nearly 2.2 million km²** of sea ice was observed. If this area represented a country, it would be the 11th **largest country in the world.**

Baltic: The Baltic Sea had a moderate winter of 2022/23, with 15% total sea ice coverage.

Antarctic: In 2023, Antarctica's sea ice hit record lows not seen since satellite observations began in 1979. The maximum extent was 16.8 million km², **1.9 million km²** less than the 1993-2010 average and corresponding to a loss **three times** the size of France.

BLUE OCEAN

SEA LEVEL

Ocean and Water

UNITS: mm/year **TIME:** 1999-2023

Global Ocean	Northeast Atlantic and Adjacent Seas
↑ 3.4 ±0.3 mm/year	↑ 3.2 ±0.8 mm/year

North West Shelf	Iberian-Biscay-Ireland	Baltic Sea	Black Sea	Mediterranean Sea
↑ 3.2 ±0.8 mm/year	↑ 4.0 ±0.8 mm/year	↑ 4.1 ±0.8 mm/year	↑ 1.0 ±0.8 mm/year	↑ 2.5 ±0.8 mm/year

KEY FIGURES OSR 8

The North Atlantic Ocean has expanded its size almost continuously since 2002, due to the loss of mass from land ice melt, thermal expansion, and land water storage.

SEA SURFACE TEMPERATURE

Ocean and Water

UNITS: °C/decade **TIME:** 1982-2023

Global Ocean	Northeast Atlantic and Adjacent Seas
↑ 0.13 ±0.01 °C/decade	↑ 0.25 ±0.03 °C/decade

North West Shelf	Iberian-Biscay-Ireland	Baltic Sea	Black Sea	Mediterranean Sea
↑ 0.22 ±0.02 °C/decade	↑ 0.24 ±0.02 °C/decade	↑ 0.38 ±0.04 °C/decade	↑ 0.65 ±0.02 °C/decade	↑ 0.41 ±0.01 °C/decade

KEY FIGURES

Global sea surface is warming differently. **75%** of the ocean surface in the northern hemisphere is warming **faster** than the global average, and **35%** in the southern hemisphere.

OCEAN HEAT CONTENT

Ocean and Water

UNITS: watts/m² **TIME:** 1960-2023

	0–300 m	0–700 m	0–2000 m
Global Ocean	↑ 0.27 ±0.03 watts/m²	↑ 0.41 ±0.09 watts/m²	↑ 0.59 ±0.11 watts/m²
Northeast Atlantic and Adjacent Seas	↑ 0.39 ±0.02 watts/m²	↑ 0.55 ±0.07 watts/m²	↑ 0.72 ±0.08 watts/m²

KEY FIGURES

Since 1960, the global ocean (down to 2000 metres) has absorbed on average **1.5 million TWh** of heat each year, nearly **9x the world's energy** consumption in 2023.

THE STATE OF THE OCEAN

EXTREME PHYTOPLANKTON BLOOM OSR 8

Time: 2022 **Location:** Southeast Mediterranean Sea

A pronounced and unusual cold spell southeast of Crete in 2022 caused an extreme phytoplankton bloom, likely through increased mixing of deep and shallow waters and higher nutrient concentrations at the surface. The phytoplankton bloom was 50 % more intense, started a month later than would be expected in this region, and lasted between 3-4 weeks.

IMPACTS

- 35 % higher annual oceanic primary production — the process by which phytoplankton convert inorganic carbon into organic matter through photosynthesis — compared to the long-term average in the area
- A boost in marine life across food chains might have occurred in the eastern Mediterranean Sea, which would need to be further addressed in detail

STORM MELLILA OSR 8

Time: April 2022
Location: Southwest Mediterranean Sea

In April 2022, a violent storm brought record-breaking waves and winds to the port of Melilla, in Spain. A combination of strong winds and high sea level pressure gradient induced waves that stretched over 7 metres and lasted more than nine seconds. This, in turn, drove waves within the harbour to a record-breaking 1.41 m, disturbing maritime operations. Simulations indicate that similar extreme waves are likely to happen in the region in 25 years time, significantly sooner than previous analysis suggested.

IMPACTS

- Disrupted port operations due to extreme waves and harsh weather conditions
- Damage to coastal infrastructure like the seawall tip, marina pontoons and several boats
- Climate-driven extreme coastal hazards impose heavy socio-economic tolls, due to port downtime and interrupted transport and trade

OCEAN EXTREMES

MARINE HEATWAVES OSR 8

In 2023, 22 % percent of the global ocean surface experienced at least one severe to extreme marine heatwave event.

- The fraction of the global ocean surface that experienced a marine heatwave event **increased from 50 % in 1982 to 80 % in 2023.**
- The regional extension of strong marine heatwave events and the yearly average maximum duration of marine heatwave events have **doubled** since 2008 from about 20 % to 40 % in recent years, and from 20 days to 40 days, respectively, while they were relatively stable before the mid-2000s.

IMPACTS

Potential impacts of marine heatwaves include:

- Decreased marine biodiversity: migration of species, mass die-off events, invasive species, and degradation of ecosystems
- Threatened food security and loss of livelihood: ecosystem damage, combined with biodiversity loss; leads to less fish catch
- Ocean stratification: in some regions of the global ocean and in some seasons, MHWs reduce the capacity of ocean layers to mix and therefore hamper the distribution of nutrients

WAVE EXTREMES OSR 8

The tallest 5 % of waves have reached new heights in recent years.

- In the Southern Hemisphere, **both large and extreme waves have increased in height** between 2002-2020.
- In the North Atlantic, 'significant wave heights' **increased** above the circle of latitude 45 degrees north of the equator, and **decreased** below this line.

IMPACTS

Potential impacts of wave extremes include:

- Increased probability of flooding and aggravated coastal erosion, which leads to population displacement, property damage, and loss of critical services
- Modified ocean circulation, and changes to the distribution of momentum from air to sea across the ocean surface
- Altered interactions between the atmosphere and the ocean, and impacts on the extent and thickness of sea ice

A DEEPER LOOK INTO EUROPE'S MARINE HEATWAVES IN 2022

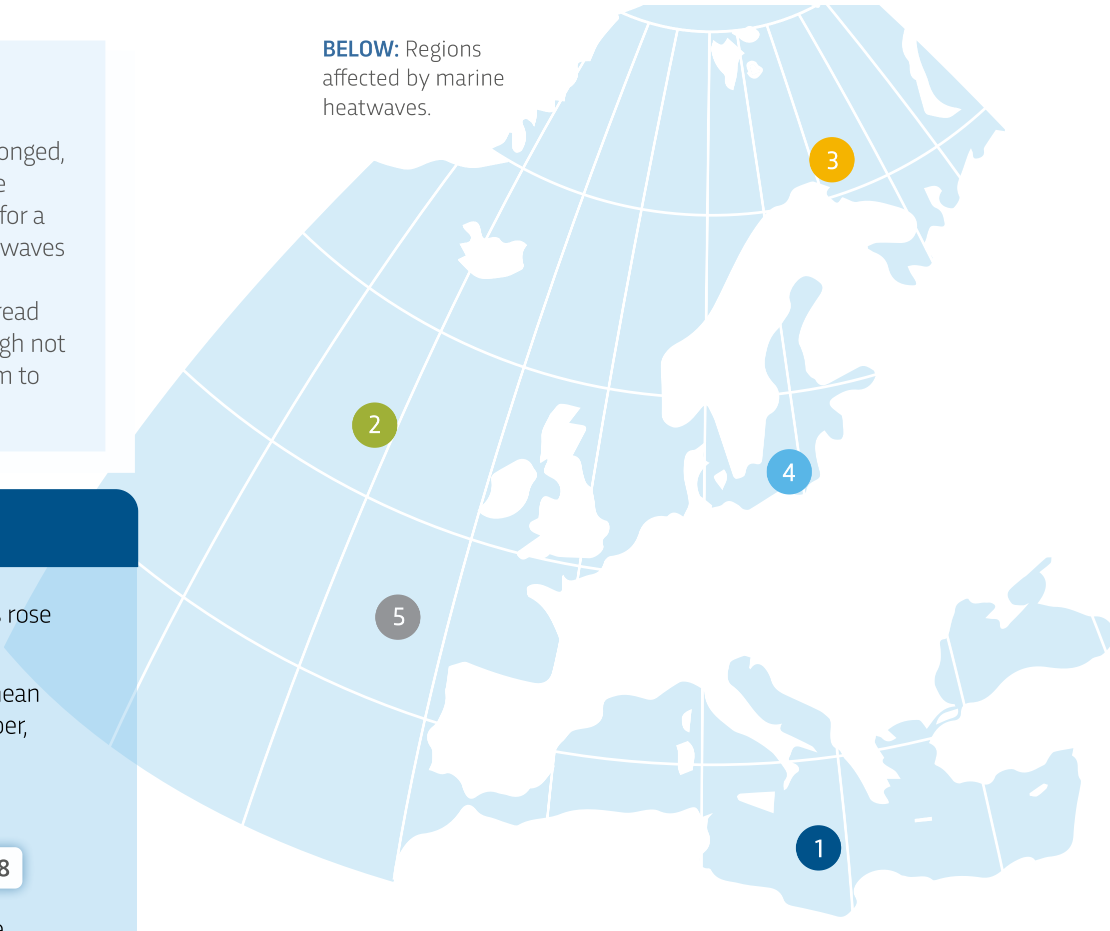
Over the past few decades, marine heatwaves in the northeast Atlantic and adjacent seas grew in strength, occurred more often, stretched further and lasted longer. In this section, we will dive deeper into the status of marine heatwaves in different European regions.

WHAT IS...?

MARINE HEATWAVE

Marine heatwaves (MHWs) are temporary, prolonged, and anomalously warm water events, which are defined by unusually high ocean temperatures for a minimum of five consecutive days. Marine heatwaves are assigned a category from I (moderate) to IV (extreme) based on their intensity. They can spread from the surface to deep waters and even though not all are harmful, MHWs can bring significant harm to marine life and human livelihoods.

BELOW: Regions affected by marine heatwaves.



1. MEDITERRANEAN SEA — OSR 8

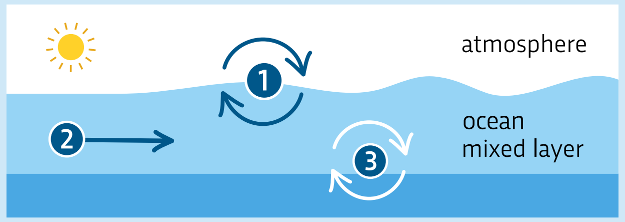
RECORD: In August 2022, record-breaking temperatures of 29.2°C hit the coastal waters in the Balearic Islands — the warmest regional sea surface temperature in forty years.

- The temperature extreme reached over 3°C higher than the average for the past few decades, with abnormal warming felt mainly in the western Mediterranean Sea.
- In the Mallorca Channel, ocean temperatures rose to over 32°C during the summer.
- In 2022, marine heatwaves in the Mediterranean Sea arrived early and ran through to December, threatening marine life and society.

HOW DO MHWs FORM & DECLINE? — OSR 8

A study exploring marine heatwaves between 1993 and 2022 in the Mediterranean Sea found that oceanic processes have an important role in raising sea surface temperatures during the onset and decline of marine heatwaves. **Heat advection**, where heat travels horizontally with moving water, explained most of the upper ocean temperature anomalies during marine heatwave events. **Air-sea fluxes** — heat exchanges between the atmosphere and ocean — were less critical to increasing the severity of the episodes, but did contribute to the development of marine heatwaves—particularly in warmer months and during heatwave onset.

DRIVERS OF MARINE HEATWAVES

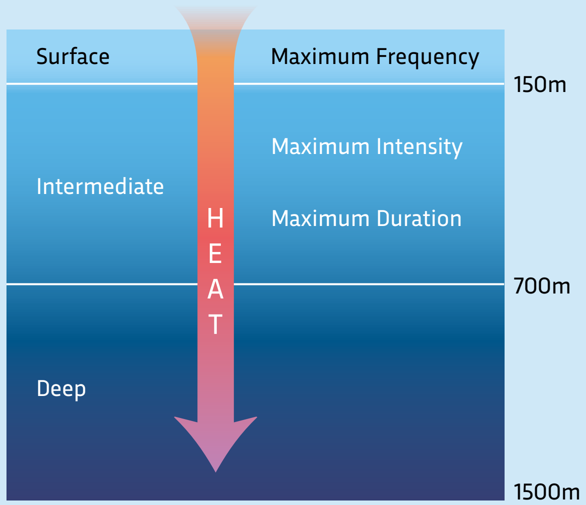


1. **Air-sea fluxes:** Exchanges between the atmosphere and the surface layer of the ocean.
2. **Heat advection:** Horizontal transport of heat in moving water, through currents.
3. **Vertical mixing:** Vertical movement of heat in both directions, which occurs as a result of density gradients caused by temperature and salinity.

HOW DEEP DO THEY GO? — OSR 8

OSR 8 findings suggest marine heatwaves in the Mediterranean Sea in 2022 reached depths of up to 1,500 m below the surface. Although the frequency of marine heatwaves was found to be higher at the surface, temperatures rose **further** and **for longer** beyond 150 m below the surface. In waters between 150-700 m depth, temperatures remained elevated at similar levels both during and after the heatwave. The findings support the notion that the impacts of marine heatwaves stretch far beyond the surface layer.

MARINE HEATWAVE DEPTH



2. NORTHWEST EUROPEAN SHELF — OSR 8

More frequent and longer-lasting marine heatwaves are striking the Northwest European Shelf, including during winter.

- Their effects are particularly pronounced in coastal areas, including the English Channel, which experienced marine heatwaves between two to four days per year.
- In the North Sea, the intensity of marine heatwaves is decreasing, possibly due to large-scale climate patterns.

DO MARINE HEATWAVES AFFECT OCEAN STRATIFICATION?

Marine heatwaves are thought to increase ocean stratification, a natural separation of waters with different densities. An analysis of temperature and salinity data in OSR 8 revealed that marine heatwaves are increasing in frequency and duration in this region, especially in coastal areas. The study recommended that further research is needed to improve our knowledge of the complex interplay between marine heatwaves, salinity and the **vertical mixing** of waters. This information is critical to inform regionally-important industries such as fisheries, and can help with conservation efforts and ecosystem management.

3. BARENTS SEA — OSR 8

The bottom of the north-eastern Barents Sea appears to have entered a state of a permanent marine heatwave, compared to a baseline between 1961 and 1990.

- Marine heatwave events in the region are more frequent at the surface, but last longer on the ocean floor. This transition threatens several commercially-important fish stocks, and a diverse ecosystem of mammals, birds and bottom-dwelling organisms.
- Marine heatwaves could become more frequent and severe in this complex region, which would affect the seasonally ice-covered part of the Arctic.

4. BALTIC SEA — OSR 8

Nearly two-thirds of the Baltic Sea suffered marine heatwaves in 2022.

- The third-warmest sea surface temperatures since 1997 were reached during summer and autumn months in 2022.
- Two major marine heatwaves spread over two regions of the sea, with temperatures reaching as high as 9.6 °C above normal in the Gulf of Bothnia.
- There is an increase in marine heatwave frequency in the Baltic Sea, one of the fastest-warming marine ecosystems on the planet. Increasing temperatures can impact phytoplankton production, with knock-on effects across food chains and blue industries in the region.

5. IBERIAN-BISCAY-IRELAND — OSR 8

RECORD: In 2022, heatwaves in the IBI region lasted 145 days on average, with temperatures reaching 6°C higher than normal.

- In 2022, nearly all marine heatwaves on the Iberian Peninsula were more intense than those seen during the longest such event there in 1997.
- The number of heatwaves increased at higher latitudes.
- Marine heatwaves during the cold season reached deeper waters than on record, extending down to 200 metres.

OCEAN-CLIMATE INTERACTIONS

The ocean is a fundamental part of the Earth's climate system, and influences global weather systems through its interactions with the atmosphere. Understanding the oceanic processes that drive this complex and dynamic interchange will help us better predict and adapt to the impacts of climate change. In this section, we expand on some of these processes, and highlight the ocean as a sentinel for global warming.

THE OCEAN: OUR SENTINEL FOR GLOBAL WARMING

OCEAN WARMING IS INCREASING

OSR 8

The pace of ocean warming has almost doubled since 2005. Global ocean warming started to rise from around 1960 onwards, with a long-term rate of 0.58 watts per square metre (W/m²). Over the past two decades the rate has about doubled to 1.05 W/m², a steady increase seen in data from various sources. The rise in ocean heat content appears to be happening in all regions of the globe, although at different intensities. In the top 2000 metres of the ocean, the strongest long-term heating effects have been found in the North Atlantic, South Atlantic and Southern Ocean.

RIGHT: Various estimates show the global ocean has been warming since around 1960 onwards, while the rate of warming has doubled in the past two decades from 2005. Ocean warming is the result of the human-driven Earth energy imbalance, and warming of the deep ocean is irreversible for hundreds to thousands of years.

IPCC →

OCEAN WARMING HAS MAJOR IMPACTS

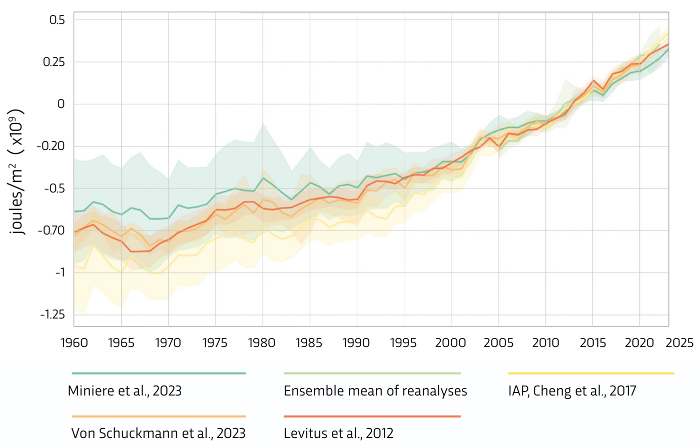
Increasing ocean temperatures impact every element of the ocean – from its physics to biogeochemical processes and marine life. Yet the effects extend far wider through the climate system, as the ocean helps to regulate the flows of water, heat and carbon around the planet.

BELOW: Infographic adapted from Cheng, L., von Schuckmann, K., Abraham, J.P. et al. Past and future ocean warming. *Nat Rev Earth Environ* (2022). doi.org/gq3b4v

WHAT IS...?

OCEAN HEAT CONTENT

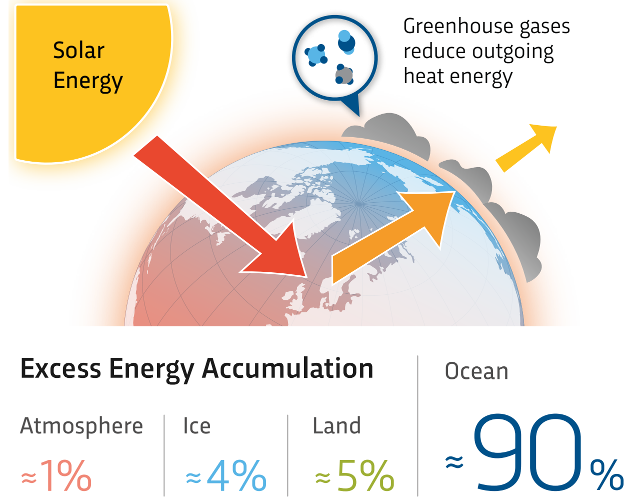
Ocean heat content measures the amount of heat that is stored in the ocean from the surface to its deeper layers. The ocean has the largest capacity for heat storage than any other component of the Earth's climate system: it absorbs nearly 90 % of the extra heat from anthropogenic activities trapped in the climate system. With continuing greenhouse gas emissions, the amount of heat stored in the ocean has increased over recent decades, and is expected to increase further this century, leading to a broad range of widespread impacts. Global ocean heat content — measured as energy, watts per square metres (W/m²) or joules (J)— is used as an indicator of how much heat is entering and staying in the Earth's system.



EARTH'S ENERGY IS OUT OF BALANCE

Earth's energy imbalance grew by 0.29 watts per square metre per decade between 1993-2002.

The Earth has an energy budget, which is essentially the balance between incoming heat from the Sun and that which is released through the atmosphere into space. When this balance shifts — as it currently is due to anthropogenic greenhouse gas emissions — more heat gets trapped within the Earth system. This warms the atmosphere, the continents and the ocean (a huge heat reservoir), which can push many species to extinction, cause dramatic fluctuations in the climate system, and increase extreme weather events. It also melts ice, which contributes to sea level rise, warms the temperature of the planet further — and also pushes the energy balance further off kilter.



ABOVE: The Earth is out of energy balance, as anthropogenic greenhouse gas emissions are trapping excess heat and preventing it from being released into space. This is causing a build-up of heat in the Earth's climate system, most of which is absorbed by the ocean.

NEW METHOD TO MEASURE THE EARTH ENERGY IMBALANCE

OSR 8

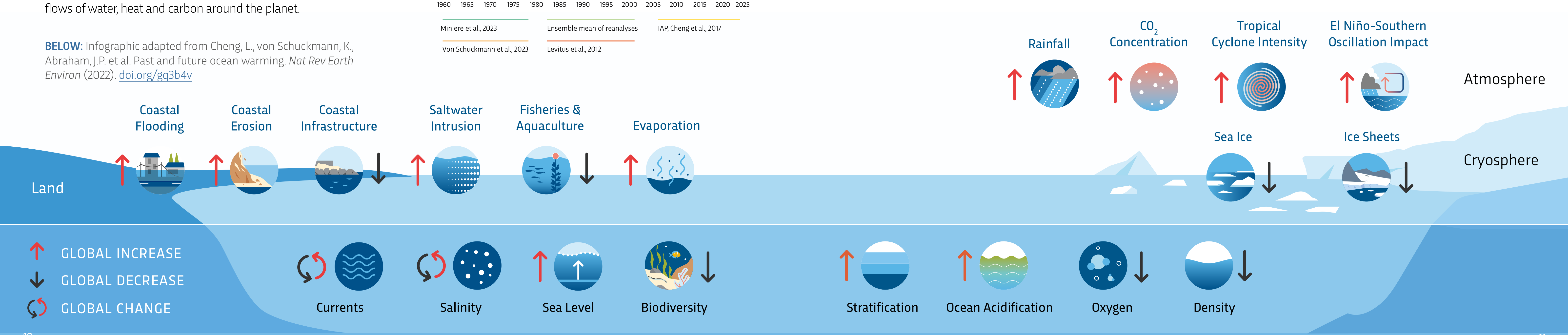
Measuring changes in the Earth's energy budget is tricky, as variations are very small. The OSR 8 introduces an extended estimate from 1993 to 2022, based on changes in the expansion of the ocean using satellite measurements of gravity and surface height (space geodesy). This approach gives an accurate, broad and long-term estimate of changes in the amount of heat stored in the ocean — a major component of Earth's energy budget — which can be used to find the overall energy imbalance. This trend matched those found in other estimates, which suggest the rate of ocean warming has increased compared to the long term.

ACCELERATED OCEAN WARMING → ACCELERATED GLOBAL WARMING

According to a new study, the warming of the world ocean has accelerated at a relatively consistent pace since 1960, which has led to the observed and substantial increase in ocean warming. This long-term acceleration aligns qualitatively with a rise in CO_2 concentrations and a decline in aerosol concentration.

The ocean takes up most of the extra heat from human activities. If we know the ocean is warming at an accelerated pace, this tells us the same is happening for the entire Earth system.

LEARN MORE →



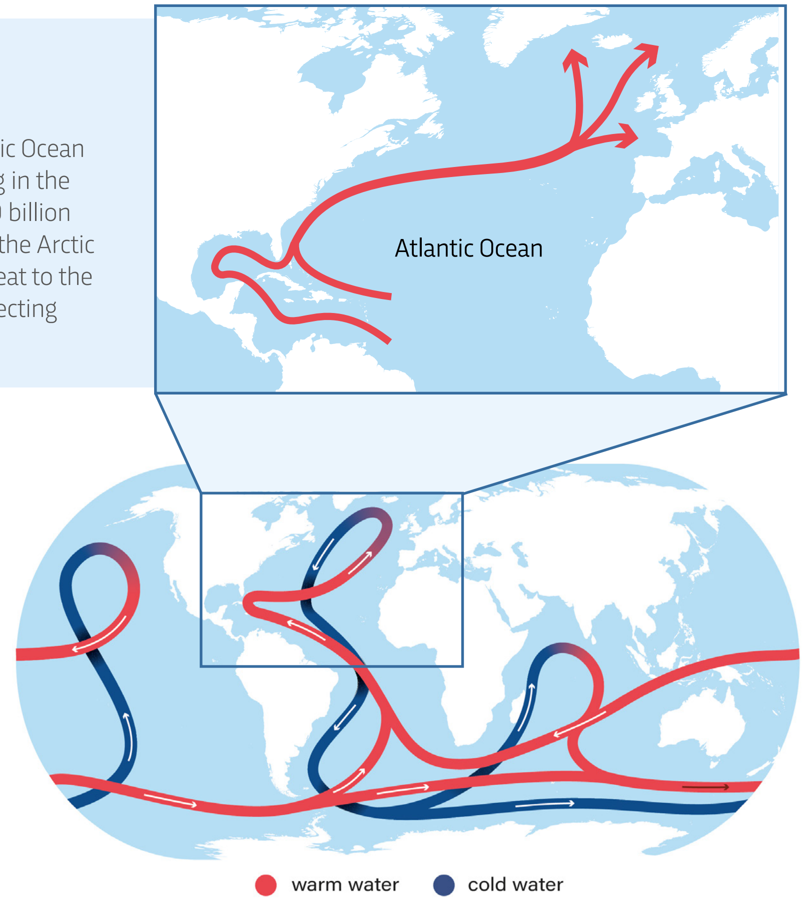
OCEAN-CLIMATE INTERACTIONS

OCEAN CIRCULATION: IS IT CHANGING?

WHAT IS...?

THE GULF STREAM

The Gulf Stream is the largest current in the North Atlantic Ocean and part of the North Atlantic current system. Originating in the Gulf of Mexico and flowing northward, it carries about 30 billion kilograms of water per second to the North Atlantic and the Arctic regions. Due to its location, the Gulf Stream distributes heat to the coasts in the North Atlantic and to the atmosphere – affecting climate and weather patterns in Europe.



TOP: The North Atlantic Current system, which includes the Gulf stream and forms part of the AMOC.

ABOVE: The AMOC is the Atlantic part of the Meridional Overturning Circulation (MOC), a system of major ocean currents that transfers heat and nutrients around the planet, with profound impacts on the climate and biodiversity.

THE GULF STREAM AND THE AMOC

The Gulf Stream is a part of two major circulation patterns - the Atlantic Meridional Overturning Circulation (AMOC) and the North Atlantic Subtropical Gyre.

The Gulf Stream supplies warm surface water northwards, and is one of several currents that make up the AMOC. Once that water reaches the north pole, it cools down, sinks, and is carried southwards. This cycle of warm, surface water streaming northwards and cool deep water streaming southwards forms the AMOC, a system with strong effects on the regional climate.

DOES THE GULF STREAM VARY? WILL IT SHUT DOWN?

OSR 8 | IPCC

A study in the Ocean State Report 8 analyses changes in the pathway of the Gulf Stream over the past few decades. These observed variations are thought to be triggered by the North Atlantic Oscillation, a series of pressure gradients in the northern hemisphere.

Research cited by the Intergovernmental Panel on Climate Change (IPCC) suggests that the AMOC is expected to slow as the climate warms over the next few centuries.

Yet even if the AMOC stopped entirely, the Gulf Stream would slow but continue flowing northwards, as the portion pushed by winds would still remain.

WHAT ABOUT THE AMOC?

OSR 8

The Atlantic Meridional Overturning Circulation showed no significant fall in strength during the 20th century. According to the latest IPCC assessment, the AMOC is projected to weaken over the 21st century under all emissions scenarios. Melting sea ice around Greenland will freshen ocean waters, changing their density and affecting water flow, while precipitation is projected to rise over northern seas as they warm. It is still possible that at some point in the future, the AMOC will suddenly collapse, which would likely have strong impacts on global water circulation and weather patterns. Published literature around the AMOC remains controversial, as it is hard to quantify how much anthropogenic warming is impacting the AMOC.

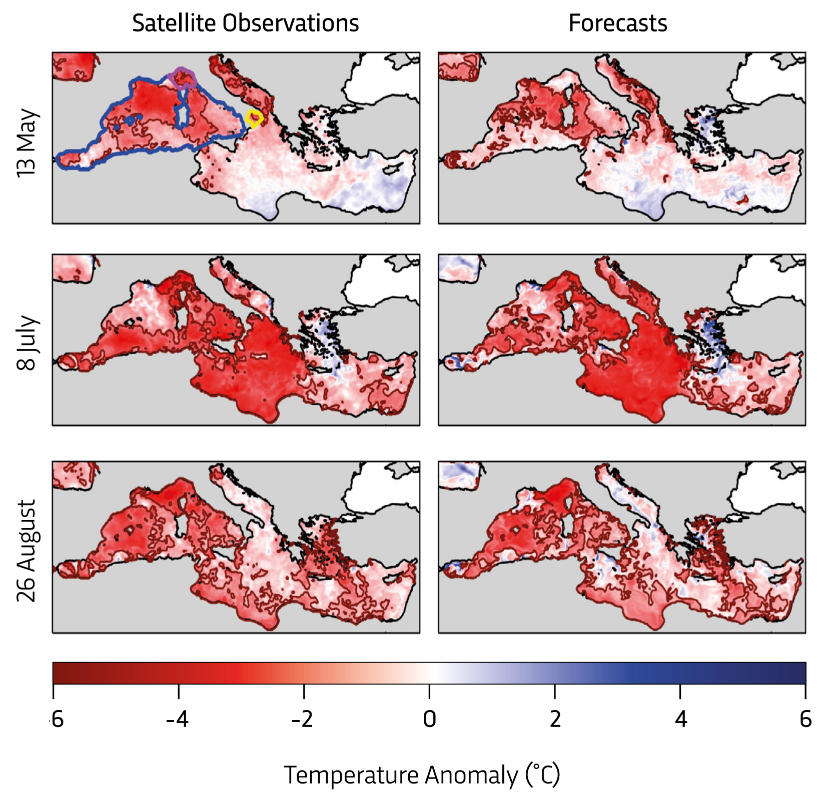
OCEAN & SOCIETY: INNOVATIONS

As we better understand climate change, we are developing new methods to monitor it, adapt to it, and even fight it. This section provides a snapshot of some of the new tools developed in OSR 8, which can help us draw more sustainably from the resources the ocean provides and protect our society over the long term.

IN SUPPORT OF FISHING AND AQUACULTURE

The ocean provides a range of direct and indirect benefits to society, from the regulation of climate, to food, energy and medicine. These resources - such as fisheries and aquaculture - depend on healthy ecosystems, including sustainable harvesting practices. Degradation of the ocean through overexploitation, pollution and climate change leads to biodiversity loss, weakened ecosystems, and fewer provisions from the sea.

Preserving the ocean comes from first understanding it. This includes extreme events such as those explored in the OSR 8. This will not only protect the biodiversity the ocean harbours, but the millions of lives and livelihoods of coastal populations that depend directly on it to survive.



ABOVE: Marine heatwaves across the Mediterranean Sea in 2022. The left column shows reprocessed satellite images, the right shows forecasts four days in advance. The darker the red, the higher the water temperature above expected levels.

UNDERSTANDING WAVE STATISTICS: A CASE STUDY

OSR 8

Wave conditions in the Baltic Sea vary between and within seasons, information that could help fish farm operations. Using the Copernicus Marine Service's wave hindcast for the region, a study in the OSR 8 found that between 1993 and 2021, the highest waves arrive in late autumn or early winter. The research found 7 m wave events can last up to 15 hours—though these happen less than once per year. However, even waves just 1 m high can disrupt fish farming, and the number of such waves can potentially double during the growth season if farms are moved further from the shore.

PREDICTING MARINE HEATWAVES: A SUCCESS STORY

OSR 8

In an OSR 8 study, the Copernicus Marine Service's state-of-the-art Mediterranean Forecasting System detected a record-breaking marine heatwave ten days prior to its arrival in the summer of 2022. The short-term forecast also precisely anticipated the heatwave's evolution in intensity and duration, from its onset to its eventual decline.

Early warnings of extreme events like marine heatwaves allow marine industries such as aquaculture and fishing to make contingency plans, and conservation scientists to monitor damage and recovery in marine ecosystems.

OCEAN & SOCIETY: INNOVATIONS

OSR 8

USING SEAWATER HEAT FOR RENEWABLE ENERGY

A CASE STUDY FROM TALLINN BAY

Thermal energy from seawater could be used to power renewable energy installations, an analysis in the Baltic Sea has shown. As reported in the OSR 8, researchers investigated the potential to use seawater for heat extraction in Tallinn Bay — a promising target due to the relatively short distances down to ocean layers that do not freeze during winter.

In some parts of the world, ocean surface layers can get too cold and freeze, preventing their use for thermal energy. Pumping warmer seawater from below could support next-generation energy systems — such as large-scale heat pumps — throughout the winter. Conditions for extractable seawater heat in Tallinn were found to be poor down to 20 m, yet became more frequent at lower depths, with a significant increase from 30-50 m below the surface.

ABOVE: Research in the OSR 8 suggests Estonia's Tallinn Bay is a promising place to extract heat from seawater during the winter. In some parts of the world, frozen deeper water prevents thermal energy extraction, but conditions in the bay improved beyond 20 m. The heat could support next-generation energy systems such as large-scale heat pumps.

OSR 8

ANALYSIS OF EXTREME WAVE EVENTS COULD IMPROVE COASTAL INFRASTRUCTURE PROTECTION

After a violent storm hit the harbour of Melilla in April 2022, researchers investigated trends in wave heights and atmospheric configurations over a 30-year period. The results published in OSR 8 revealed an increasing intensity of extreme events between 1993-2022, and the likelihood of a similar storm returning dropped from 53 to 25 years.

Wave analysis can be used to identify dangerous weather events, which can cause widespread destruction, especially in semi-enclosed basins like the Mediterranean Sea or exposed sectors like harbour systems. These findings can improve the design of port facilities, and create multi-hazard early warning systems and mitigation plans around harbours, boosting the resilience of coastal communities.

RIGHT: OSR 8 wave analysis from a storm in Melilla could be used to improve coastal infrastructure, supporting local society and maritime trade.

ABOUT US

Implemented by MERCATOR OCEAN INTERNATIONAL

ABOUT MERCATOR OCEAN INTERNATIONAL

Mercator Ocean International was selected by the European Commission to implement the Copernicus Marine Service in 2014. Based in France, Mercator Ocean International (MOi) is a non-profit organisation in the process of becoming an intergovernmental organisation dedicated to ocean prediction and digital ocean systems. MOi provides ocean intelligence, data, and expertise that covers the global ocean and plays a leading role in the development of the European Digital Twin Ocean. Its scientific experts design, develop, operate, and maintain state-of-the-art numerical modelling systems that describe and analyse the past, present, and near-future state of the ocean in 4D (reanalyses, hindcasts, near-real-time data, and forecasts).

MERCATOR OCEAN WEBSITE

Copernicus Europe's eyes on Earth

ABOUT THE COPERNICUS MARINE SERVICE

The **Copernicus Marine Service** is dedicated to ocean monitoring and forecasting. It is implemented by Mercator Ocean International, a global ocean analysis and forecasting centre, and funded by the European Commission (EC). It is one of the six services that comprise Copernicus, the European Union's Earth Observation Programme. The agreement was established in 2014 for Copernicus 1 and renewed in 2021 for Copernicus 2.

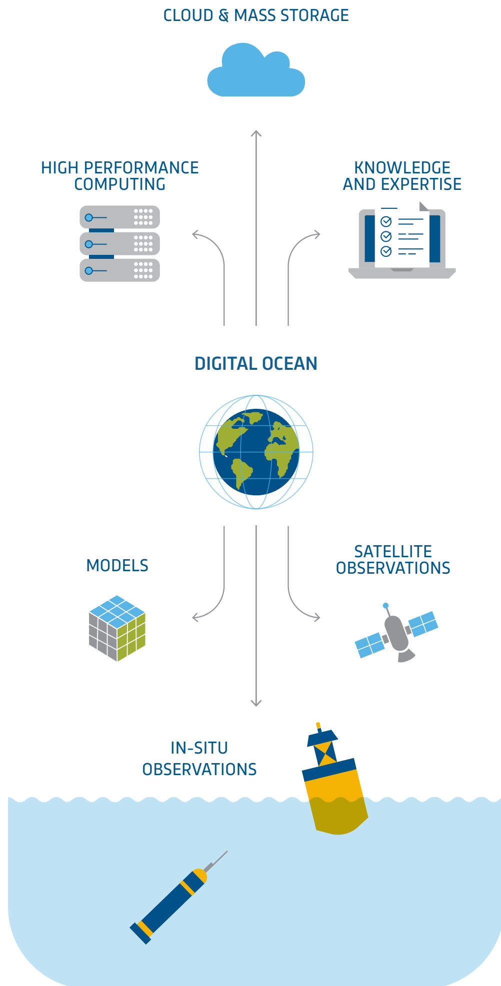
The Copernicus Marine Service provides regular and systematic reference information on the state of the physical and biogeochemical ocean at the global and European regional scales. It provides key inputs that support major EU and international policies and initiatives and can contribute to combating pollution, marine protection, maritime safety and routing, the sustainable use of ocean resources, developing marine energy resources, blue growth, climate monitoring, weather forecasting, and more. It also aims to increase awareness among the general public by providing European and global citizens with information about ocean-related issues.

COPERNICUS MARINE SERVICE

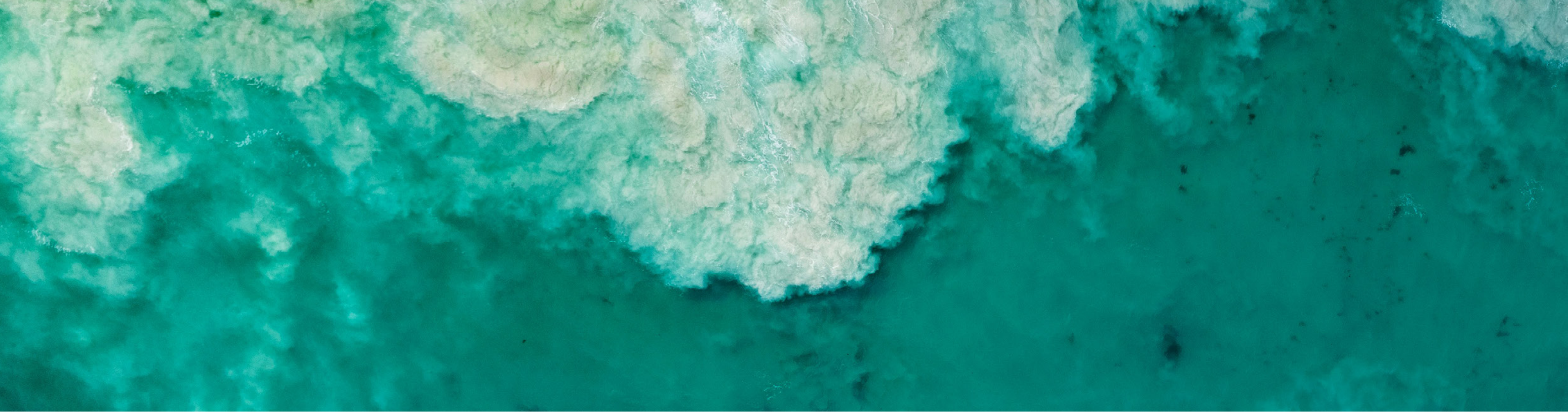
PART OF THE EU MISSIONS RESTORE OUR OCEAN & WATERS

Funded by the European Union

EU Missions are the European Commission's greatest challenges to be achieved by 2030. The **Restore Our Ocean and Waters** mission aims to protect and restore marine and aquatic ecosystems through research and innovation, citizen engagement and blue investments. The Ocean State Report of the Copernicus Marine Service is now part of this mission, by contributing to the dissemination of science-based knowledge on the state of the ocean.



ABOVE: The Copernicus Marine Service uses satellite observations, in situ platforms, and models to create a digital representation of the ocean. Scientific knowledge and expertise feed into these models to help describe and forecast the state and variability of the global ocean and the European regional seas and to provide a foundation for the development of marine protection and sustainable ocean stewardship.



PROGRAMME OF THE EUROPEAN UNION

Join the Copernicus Marine Service Community

- MERCATOR OCEAN INTERNATIONAL WEB PORTAL →
- COPERNICUS MARINE SERVICE WEB PORTAL →
- COPERNICUS MARINE HELP CENTRE →
- FULL OCEAN STATE REPORT 8 →

For Copernicus Ocean State Report Inquiries:

kvonschuckmann@mercator-ocean.fr
lmoreiramendez@mercator-ocean.fr

For Communication Inquiries:

gratianne.quade@mercator-ocean.fr

Copernicus Marine Service

Mercator Ocean International

Citation of Full Report

Disclaimer

This document was produced with funding from the European Union. The views and opinions expressed are, however, those of the author(s) only and the European Commission cannot be held responsible for any use which may be made of the information contained therein.

Acknowledgements

Special appreciation to the entire author and editorial team of the 8th instalment of the Copernicus Marine Service Ocean State Report for their dedication and expertise. And a sincere thank you to the reviewers of this summary.

The Copernicus Ocean State Report is published in the journal *State of the Planet*, Copernicus Publications.

Summary design and production: Design & Data - www.designdata.de

Cover photo by Rod Long on Unsplash.