Effects of Climate Change on Oceans

Jamie Amelia*
Editorial office, Journal of Climatology & Weather Forecasting, United Kingdom

*Corresponding Author**
Jamie Amelia
Editorial Office, Journal of Climatology and Weather Forecasting
United Kingdom
E-mail: Climatejournal@res.com

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Abstract

Climate change refers to the long-term changes in the Earth's climate, including changes in temperature, precipitation patterns, and other weather-related phenomena, that are primarily caused by human activities, such as burning fossil fuels and deforestation. Climate change has a major impact on oceans of the world. This perspective article explains the about impacts of climate on ocean.

Keywords: Climate change • Global warming • Ocean warming

Introduction

One of the effects of climate change on oceans is an increase in sea surface temperature as well as ocean temperatures at greater depths, more frequent marine heatwaves, a reduction in pH value, a rise in sea level from ocean warming and ice sheet melting, a decline in Arctic sea ice, increased upper ocean stratification, reductions in oxygen levels, increased salinity contrasts (salty areas becoming saltier and fresher areas becoming less salty), and changes to ocean circulation, among other things. The ripple effects of all these changes disrupt marine ecosystems. The Global warming brought on by greenhouse gas emissions from human activity, such as carbon dioxide and methane, is the main factor generating these changes. Because the ocean is absorbing the majority of the excess heat in the climate system, this unavoidably results in ocean warming. The ocean employs carbon sequestration to absorb part of the additional carbon dioxide in the atmosphere, which lowers the pH of the ocean. An estimated 25% of all CO_2 emissions created by humans are absorbed by the ocean. When air temperatures rise and the ocean surface warms, there is an increase in ocean temperature stratification. The decrease in ocean layer mixing stabilises warm water at the surface while lowering circulation of cold, deep water. The ocean's capacity to absorb heat is decreased by the decreased up and down mixing, which shifts a greater proportion of future warming towards the atmosphere and land. While nutrients for fish in the higher ocean layers and the ocean's capacity to store carbon are predicted to decline, the amount of energy available for tropical cyclones and other storms is predicted to grow. The same amount of oxygen cannot be present in warmer water. As a result, the balance of gas exchange changes, reducing ocean oxygen levels while raising atmospheric oxygen levels. The oxygen concentration of the water may drop even more as a result of increased thermal stratification due to a decreased oxygen delivery from surface waters to deeper waters. The ocean's water column has already lost oxygen, and oxygen minimum zones are growing everywhere. These modifications affect marine ecosystems, which can hasten the extinction of certain species or result in population surges that shift the distribution of other species. Tourism and coastal fishing are also impacted by this. Coral reefs and other ocean ecosystems will be harmed by warming waters. Coral bleaching on these reefs is the immediate result, and because coral is sensitive to even slight temperature changes, even a small increase in temperature might have a big effect here. The productivity and distribution of organisms inside the ocean will also be impacted by ocean acidification and temperature change, endangering fisheries and disrupting marine

ecosystems. The numerous arctic animals that depend on sea ice habitat loss as a result of global warming will be severely impacted. Pressure on the climate system is increased by the interactions between several of these climate change components.

Changes due to greenhouse gases

Atmospheric Carbon Dioxide (CO_2) levels are currently (2020) more than 410 Parts Per Million (ppm) than preindustrial levels, which is close to 50% higher. These high levels and quick develop rates are unheard of in the 55 million years of the geological record. It is undeniably shown that human activity is to blame for this surplus CO_2, with the cause including emissions from fossil fuels, industry, and changes in land use and climate. Since at least the late 1950s, the hypothesis that the ocean acts as a significant sink for human CO_2 has been debated in scientific literature. Several pieces of data suggest that the oceans are responsible for absorbing around 25% of all human CO_2 emissions.

Rise in ocean temperature

It is undeniable that climate change is causing the ocean to warm, and that this warming is accelerating. In 2022, the worldwide ocean reached its highest recorded temperature. The ocean heat content in 2022 was higher than the prior maximum in 2021, which is what determines this. The Earth's energy imbalance, which is principally brought on by growing greenhouse gas concentrations, is irreversibly causing the continuous rise in ocean temperatures. The fastest warming is occurring in the upper ocean (above 700 m), although the trend is global. The Southern Ocean experiences the most ocean heat increase. While the ocean surface temperature has grown by 1.2°C from the pre-industrial period, the average temperature of the top 2000 m of the ocean rose by 0.12°C from 1960 to 2019. The pace of warming varies with depth: according to statistics from 1981 to 2019, warming occurs at a depth of 1,000 metres at a rate of over 0.4°C per century, but only at half that depth.

Ocean heat content

The ocean's temperature changes depending on where you are. At the poles, temperatures are lower while those towards the equator are greater. Hence, variations in the total heat content of the ocean best represent ocean warming. Heat consumption has risen between 1993 and 2017 as compared to 1969-1993. Ocean Heat Content (OHC) is a word used in climatology and oceanography to represent the energy that the ocean absorbs and stores. Almost 90% of the extra thermal energy produced by global warming on Earth between 1971 and 2018 is attributed to the increase in OHC. Most likely, growing greenhouse gas emissions caused by anthropogenic forcing were the primary factor in this OHC rise:1228 Around one-third of the additional energy has reached depths below 700 metres by 2020. More than 90% of the additional heat brought on by increased greenhouse gas concentrations is absorbed by the ocean. As a result, "ocean warming" is the main cause of "global warming". As a result, sea level rise and ocean heat content are the "most important markers of climate change." Ocean waters easily absorb solar energy and have a far higher heat capacity than gases in the atmosphere. As a result, the ocean's top few metres hold more thermal energy than the whole atmosphere of the planet. Research stations and boats have collected data on global sea surface temperatures and temperatures at higher depths since before 1960. A growing network of about 4000 Argo robotic floats has also been measuring temperature anomalies, or the shift in OHC, since the year 2000.

Since at least 1990, the OHC has been rising steadily or quickly. From 2003 and 2018, the upper 2000 m net rate of change was +0.580.08 W/m^2 (or annual mean energy gain of 9.3 zettajoules).

Reducing ocean pH value

Ocean acidification is the lowering of the ocean's pH. The average pH of the ocean's surface decreased from about 8.25 to 8.14 between 1751 and 2021. Ocean acidification is mostly caused by carbon dioxide emissions from human activity, with atmospheric Carbon Dioxide (CO_2) levels above 410 ppm (in 2020). The oceans take up CO_2 from the atmosphere. As a result, Carbonic Acid (H_2CO_3) is produced, and this causes it to split into bicarbonate ions (HCO_3) and Hydrogen ions (H^+). Free Hydrogen ions (H^+) increase acidity by lowering the pH of the ocean (this does not mean that seawater is acidic yet; it is still alkaline, with a pH higher than 8. The oceans' hydrogen ion concentration increased by over 30% as the pH changed from 8.25 to 8.14 (the pH scale is logarithmic, so a change of one in pH unit is equivalent to a tenfold change in hydrogen ion concentration). Ocean depth and location affect sea-surface pH and carbonate saturation states. More CO_2 may be absorbed by oceans in higher latitudes and colder temperatures. The pH and carbonate saturation levels in these locations may decrease as a result of increased acidity. Ocean currents and upwelling zones, proximity to big continental rivers, sea ice coverage, and atmospheric interaction with nitrogen and sulphur from fossil fuel burning and agriculture are other elements that affect the atmosphere-ocean CO_2 exchange and therefore local ocean acidification.

Observed effects on the physical environment

Sea level rise: Global sea levels have increased at an average pace of 1 mm/yr-2 mm/yr since 1900 (the global average sea level was about 15 cm-25 cm higher in 2018 compared to 1900). Sea levels climbed by around 4 mm year between 2006 and 2018; this represents an acceleration of the pace of sea level rise. In the upcoming decades and beyond, coastal flooding will affect many coastal communities. Coastal flooding can be made worse by local subsidence, which may be natural but can also be exacerbated by human activity. By 2050, hundreds of millions of people would be at risk from coastal flooding, primarily in Southeast Asia.

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Changing ocean currents: Ocean currents are brought on by differences in temperature brought on by sunlight and air temperatures at various latitudes, as well as by dominant winds and the varied salt and freshwater densities. At or around the equator, warm air rises. Then, it cools down once more as it flows near the poles. Toward the poles, cool air falls, but as it flows towards the equator, it warms and rises once more. A mid-latitude cell is driven by these Hadley cells, which are large-scale wind patterns, with similar effects in both hemispheres. Surface currents are pushed to higher latitudes where the air is cooler by wind patterns connected to these circulation cells. The ocean currents work to move water across the sea by being driven by this sinking, the upwelling that takes place at lower latitudes, as well as the driving force of the winds on surface water. Changes take place when global warming is taken into account, especially in regions where deep water is generated. More and more fresh water is discharged into the high latitude areas where deep water occurs as the seas warm and glaciers and polar ice caps melt, reducing the density of the surface water. The effect is that the water lowers more gradually than it typically would. According to current measurements, climate models, and paleoclimate reconstructions, the Atlantic Meridional Overturning Circulation (AMOC) has diminished since the pre-industrial period (the AMOC is part of a global thermohaline circulation). The AMOC is expected to deteriorate significantly during the remainder of the 21st century, according to the most recent climate change estimates for 2021. The North Atlantic is particularly sensitive to the effects of a weakening of this size, which might have a large effect on the climate worldwide. Areas warmed by the North Atlantic Drift, including Scandinavia and Britain, would be affected by this.

Increasing stratification: Since they can affect productivity and oxygen levels, stratification variations within the ocean are crucial. The division of water into strata according to a particular quantity is referred to as stratification. There is layered stratification in every ocean basin. The stratified layers prevent the water from mixing, which can affect how heat, carbon, oxygen, and other nutrients are exchanged. Since 1970, the upper ocean has become more stratified as a result of both global warming and regional salinity variations. Evaporation in tropical seas, which results in greater salinity and density levels, is the cause of the salinity fluctuations. Water's salinity and temperature both affect its density. As a result, the ocean's huge basins' water column is stratified, with less dense water at the top and heavier water at depth. The Atlantic Meridional Overturning Circulation, which affects the weather and temperature across the world, is not the sole result of this stratification. Moreover, it is significant because stratification regulates the movement of nutrients from deep water to the top. This is related to the compensatory downward water flow that transports oxygen from the atmosphere and surface waters into the deep ocean and helps fuel ocean production. Low oxygen levels naturally result from the breakdown of organic material that sinks from primary production in the ocean's mid deep waters, which mix slowly with surface waters. Yet, warming has the consequence of reducing how much oxygen dissolves in surface waters. Also, when stratification increases, these mid-depth waters become increasingly more isolated, both of which contribute to reduced oxygen levels (see also oxygen depletion section). The open ocean is already losing oxygen, and climate change is anticipated to accelerate this trend, resulting in a several percent drop in global oxygen levels.

Reduced oxygen levels: The majority of bigger creatures and plants depend on the oxygen concentration of the ocean to survive, and it also has a long-term function in regulating atmospheric oxygen, which is essential for terrestrial life. Ocean oxygen is affected by climate change. The mid-depth open ocean waters and the coastal waters are the two regions of concern for ocean oxygen levels. The first area of concern is to the open ocean's mid-depth waters, which have a low saturation level of oxygen by nature. This is due to the fact that these regions, known as oxygen minimum zones, are cut off from the atmosphere by sluggish ocean circulation, cutting off these waters from the atmosphere (and thus oxygen) for decades, while sinking organic matter from surface waters is broken down, using up the oxygen that is currently available. Throughout the course of 50 years since the 1960s, it is believed that ocean oxygen concentrations have decreased 2% overall. Because of the way the water circulates, these low oxygen zones are often more prominent in the Pacific Ocean. Almost all marine species are stressed by low oxygen levels. Regions with very low oxygen levels have substantially less wildlife. Climate change is expected to cause these low oxygen zones to grow in the future, which poses a major threat to the marine species that now exists there.

Modifications to the Earth's wind and weather systems

Increased tropical storm and monsoon intensities, as well as weather extremes with some regions becoming wetter and others drier, will result from climate change and the warming of the ocean that it causes, undermining the present agricultural systems. Wave heights are expected to rise in some places as a result of shifting wind patterns. This may put marine infrastructure and seamen at risk.

Intensifying tropical cyclones

The typical tornado travels 5 miles on the ground (8.0 km). Tornadoes, on the other hand, are capable of much shorter and much longer damage paths: one tornado was reported to have a damage path only 7 feet (2.1 m) long, while the Tri-State Tornado, which affected parts of Missouri, Illinois, and Indiana on March 18, 1925, was on the ground continuously for 219 miles (352 km). Usually tornadoes with path lengths of 100 miles (160 km) or more are made up of a family of tornadoes that developed in fast succession; however, there is no strong evidence that this occurred in the case of the Tri-State Tornado.

Impacts on aquatic life

The structure of the ocean's biomass community will change as a result of climate change, in addition to the ocean's overall production. As a result, it is generally predicted that species would migrate towards the poles. During the 1950s, several species have already travelled hundreds of kilometres. Also, the timing of phytoplankton blooms is already changing and migrating earlier in the season, especially in polar regions. With the continued growth of climate change, these patterns are expected to become more pronounced. In the polar areas, where species with highly specialised survival strategies would need to adjust to significant changes in habitat and food availability, there are additional potentially significant implications of climate change on seabirds, fish, and mammals. Sea ice also frequently plays a significant part in the life cycle of these organisms. Providing polar bears with hunting grounds and haul-out locations, for instance, in the Arctic. Although the effects of climate change to date vary by location, sea bird and penguin populations in the Antarctic are also thought to be particularly susceptible to it.

Impacts on oceanic calcifying organisms: Notwithstanding the complexity of the biological effects of the changes in calcification brought on by ocean acidification, it seems likely that many calcifying organisms will suffer as a result. Ocean acidification makes it more challenging for organisms that build shells to get carbonate ions, which are necessary for the development of their rigid exoskeletal shells. Oceanic calcifying creatures include coccolithophores, corals, foraminifera, echinoderms, crabs, and molluscs and are found at all levels of the food chain, from autotrophs to heterotrophs. Ultimately, increases in ocean acidification and other ocean biogeochemical processes will affect all marine ecosystems on Earth. In order to sustain calcification, certain organisms may be forced to reallocate resources away from productive endpoints. For instance, it is known that energy trade-offs brought on by pH imbalances cause the oyster Magallana gigas to undergo metabolic modifications as well as changed calcification rates.

Impacts on coral reefs: While some marine species that can move about can migrate in response to climate change, others, like corals, find this to be far more challenging. An underwater environment known as a coral reef is characterised by corals that construct reefs. Coral polyp colonies are bound together by calcium carbonate to build reefs. Coral reefs are significant biodiverse hotspots and essential to millions of people who depend on them for food, coastal protection, and tourism in many areas. Warm water corals have obviously declined over the past 30 years to 50 years, losing 50% of their population. This reduction is attributed to a number of challenges, including ocean warming, ocean acidification, pollution, and physical harm from activities like fishing. This pressure is anticipated to increase.

Impact on fisheries: Ocean productivity affects how much fish can be caught sustainably. The maximum fish harvest allowed in nations' exclusive economic zones will drop as ocean productivity declines. By the end of the century, many forecasts anticipate that this catch will have decreased globally by 5% to 25%. The food security of the local population is threatened by expected higher decreases in some places, such as the South.

Pacific, within this average worldwide drop. Marine aquatic ecosystems are impacted by increasing ocean temperatures, ocean acidity, and ocean oxygenation, while freshwater ecosystems are impacted by changes in water temperature, water flow, and fish habitat loss. Fisheries are impacted by climate change in many different ways. The setting of each fishery affects these impacts differently. Fish distribution patterns and the productivity of marine and freshwater species are changing as a result of climate change. The availability and commerce of fish products are predicted to undergo major changes as a result of climate change. The geopolitical and economic repercussions will be substantial, particularly for the nations that rely on this industry the most. The South Pacific and other tropical areas should see the largest drops in maximum catch potential.

Impacts on marine animals: There are some very immediate implications for marine animals, particularly those in the Arctic, including as habitat loss, temperature stress, and exposure to extreme weather. Some consequences are more subtle, such modifications in host-pathogen linkages, adjustments in body composition as a result of predator-prey interactions, adjustments in toxin and CO_2 exposure, and increased human interactions. Considering the significant potential effects of ocean warming on marine animals, it is still unclear how vulnerable they are globally to climate change. Oceans are where marine animals have evolved to dwell, yet their natural environment is changing due to climate change. Some species could go extinct if they can't adapt quickly enough. Given the significant observed and anticipated reduction in Arctic sea ice, it was widely believed that Arctic marine animals were the most vulnerable to climate change. The species that are most susceptible to climate change are found in the North Pacific Ocean, Greenland Sea, and Barents Sea, according to studies. In addition to being a hotspot for sensitivity to global warming, the North Pacific has already been recognised as a hotspot for anthropogenic risks to marine mammals. As marine creatures often experience more steady temperatures than terrestrial species do, they are probably more susceptible to temperature changes than their terrestrial counterparts. Hence, when endangered species migrate in search of a better environment, ocean warming will result in the movement of additional species. Species that are on the margin of their ranges may vanish from local areas or have their ranges limited globally if sea temperatures continue to increase. Some animals may also migrate to colder waters. The food supplies that are accessible to marine mammals will change when the abundance of particular species changes, which will subsequently cause biogeographic alterations in marine mammals.

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