OCEANS AND THE LAW OF THE SEA: REPORT OF THE SECRETARY-GENERAL PART I (2017)

The effects of climate change on oceans

Contribution by WMO

Executive summary (400 words)

During 2011-2016 global ocean temperatures were at unprecedented levels. Globally averaged sea-surface temperatures for 2015 were the highest on record for a calendar year, with 2014 in second place. Sea-surface temperatures for the period were above average in most of the world, although they were below average in parts of the Southern Ocean and the eastern South Pacific.

Global sea levels continued to rise over the period 2011–2016. The level of interannual variability in global sea level over the period was high by the standards of the satellite era. There was a further marked rise in early 2015 as an El Niño developed, with sea levels about 10 mm above trend through the second half of 2015. These departures from trend were larger than anything observed between 1993 and 2009, including during the very strong 1997/1998 El Niño. The trend over the full satellite record from 1993 to present of approximately 3 mm per year is larger than the average 1900–2010 trend (based on tide gauges) of 1.7 mm per year.

A number of studies have concluded that the contribution of continental ice sheets, particularly Greenland and west Antarctica, to sea-level rise is accelerating. Cryosat-2 data show that the contribution of Greenland ice-sheet melting to global sea-level rise in the period 2011–2013, which includes the extreme melt year of 2012, was approximately 1.0 mm per year. This was well in excess of the 0.6 mm per year reported in the IPCC Fifth Assessment report for the period 2002–2011.

Since the industrial revolution about 375 billion tonnes of carbon have been emitted by humans to the atmosphere as CO_2. The main sinks for CO_2 emissions from fossil fuel combustion are the oceans and terrestrial biosphere. Latest analysis results show that globally averaged surface CO_2 reached new highs in 2015 at 400.0±0.1 ppm, that is, 144% of pre-industrial (before 1750) levels. The increase of CO_2 from 2014 to 2015 was larger than that observed from 2013 to 2014 and that averaged over the past 10 years. The El Niño event in 2015 contributed to the increased growth rate through complex two-way interactions between climate change and the carbon cycle.

Today, the growing impacts of climate change are making ocean observations, research and services more critical than ever before. Recognizing the importance of the effects of climate change on oceans, national weather agencies and researchers within the WMO community continue to regularly monitor the ocean, model how it affects the atmosphere and deliver marine services to support coastal management and safety at sea. These activities are detailed below.

Key interactions between oceans and climate change (drivers)

Introduction The ocean's tight linkage with the atmosphere makes understanding its behaviour vital for forecasting weather and climate conditions. The ocean absorbs most of the solar energy reaching the Earth; because the Equator receives much more solar energy than do the Poles, enormous horizontal and vertical ocean currents form and circulate this heat around the planet. Some of these currents carry heat for thousands of kilometres before releasing much of it back into the atmosphere.

Another key interaction is that, because the ocean warms and cools more slowly than the atmosphere, coastal weather tends to be more moderate than continental weather, with fewer hot and cold extremes. Evaporation from the ocean, especially in the tropics, creates most rain clouds, influencing the location of wet and dry zones on land.

Over 90 per cent of the extra heat trapped by humanity's carbon emissions is stored in the ocean – only about 2.3 per cent warms the atmosphere, while the rest melts snow and ice and warms the land. As a result, the atmosphere is warming less quickly than it otherwise would. This should not lull us into inaction, however, as ocean warming only delays the full impact of climate change. Much of the ocean's newly absorbed heat will flow out into the atmosphere over the coming centuries.

In addition to influencing the geography of the planet's climate zones, the ocean causes the climate to vary over periods of weeks to decades through regular oscillations. Examples are the El Niño-Southern Oscillation in the tropical Pacific, the Indian Ocean Dipole and the North Atlantic Oscillation. Oscillations are caused when changing patterns of sea-surface temperature, atmospheric pressure and wind interact to produce climatic periods that are warmer or cooler, or wetter or drier, than normal.

Weather forecasters combine ocean observations and knowledge of how ocean–atmosphere interactions shape long-term weather and climate patterns with atmospheric observations of daily temperature, wind, precipitation and other variables. Together, these data become key inputs for weather and climate models. The WMO community therefore has a major stake in supporting ocean observations, research and services.

Studying the ocean is also essential for gaining a better understanding of human-induced climate change. The World Climate Research Programme (WCRP) coordinates efforts to understand fundamental questions about the ocean and climate and how their interaction leads to extreme events.

WMO coordinates efforts to study how the ocean and the atmosphere exchange gases and aerosols. In collaboration with other organizations, such as the Food and Agriculture Organization of the United Nations (FAO), WMO is also supporting observations that are needed for a better understanding of how climate change is affecting marine productivity and fisheries.

Ocean warming and sea level rise According to WMO's report *The global climate in 2011-2015*[1], during 2011-2015 global ocean temperatures were at unprecedented levels. Globally averaged sea-surface temperatures for 2015 were the highest on record for a calendar year, with 2014 in second place. Sea-surface temperatures for the period were above average in most of the world, although they were below average in parts of the Southern Ocean and the eastern South Pacific. Areas where 2011–2015 was the warmest five-year period on record include most of the South Indian Ocean, the Southern Ocean south of Australia, the central and eastern North Pacific, the western equatorial Pacific, most of the western half of the North Atlantic north of the tropics, parts of the subtropical western South Atlantic, and the Mediterranean Sea.

[1] See: https://public.wmo.int/en/resources/library/global-climate-2011%E2%80%932015

Two notable ocean temperature anomalies developed from late 2013 onward: a large area of very warm water in the eastern North Pacific, with sea-surface temperatures more than 2 °C above average in places, and a persistent pool of below-normal sea-surface temperatures in the eastern North Atlantic between the British Isles and the southern tip of Greenland.

As the oceans warm, they expand, resulting in both global and regional sea-level rise. Increased ocean heat content accounts for about 40% of the observed global sea-level increase over the past 60 years and is expected to make a similar contribution to future sea-level rise. The warming of ocean waters adjacent to the ice sheets can also affect the flow of ice into the ocean, which is another key component of sea-level rise. In 2015, global ocean heat content reached record levels through both the upper 700 m and 2 000 m of the oceans.

Global sea levels continued to rise over the period 2011–2015. The level of interannual variability in global sea level over the period was high by the standards of the satellite era. The period began with global sea level about 10 mm below the long-term trend value in early 2011, due to the strong La Niña at that time, and resultant high rainfall over some land areas resulting in above-normal water storage on land (especially in Australia). Sea levels quickly rebounded as the La Niña ended and had returned to trend or above by mid-2012. There was a further marked rise in early 2015 as an El Niño developed, with sea levels about 10 mm above trend through the second half of 2015. Both the 2010–2011 and 2015 departures from trend were larger than anything observed between 1993 and 2009, including during the very strong 1997/1998 El Niño. The trend over the full satellite record from 1993 to present of approximately 3 mm per year is larger than the average 1900–2010 trend (based on tide gauges) of 1.7 mm per year.

A number of studies have concluded that the contribution of continental ice sheets, particularly Greenland and west Antarctica, to sea-level rise is accelerating. Cryosat-2 data show that the contribution of Greenland ice-sheet melting to global sea-level rise in the period 2011–2013, which includes the extreme melt year of 2012, was approximately 1.0 mm per year. This was well in excess of the 0.6 mm per year reported in the IPCC Fifth Assessment report for the period 2002–2011.

There have been strong regional differences in rates of sea-level rise in the Pacific Ocean over the period 1993–2015, largely associated with the El Niño/Southern Oscillation (ENSO),11 and the predominance of El Niño events in the 1990s and La Niña events between 2007 and 2012. The world's fastest rates of sea-level rise over this period have been in the western Pacific, more than 10 mm per year in places, whereas in parts of the eastern Pacific there has been little change in sea level over the period 1993–2015. Sea-level rise has been more consistent in the Atlantic and Indian Oceans, with most parts of both oceans showing rates similar to the global average.

According to WMO's *Provisional statement on the status of the global climate in 2016*[2], such trend continued in 2016. Temperatures were above normal over most ocean areas. This contributed to significant coral bleaching and disruption of marine ecosystems in some tropical waters, including the Great Barrier Reef off the east coast of Australia, and Pacific island countries such as Fiji and Kiribati. Coral mortality of up to 50% was reported in parts of the Great Barrier Reef.

[2] See: https://ane4bf-datap1.s3-eu-west-1.amazonaws.com/wmocms/s3fs-public/2016_WMO_Statement_on_the_Status_of_the_Global_Climate-14-11-16-ver2.pdf?ZmIaubFZknHEGDBpyxTBpTcrNotiDpDo

The most prominent area of below-normal sea surface temperatures was the Southern Ocean south of 45° South (especially around the Drake Passage between South America and Antarctica, where temperatures were more than 1°C below normal in places).

Global sea levels rose about 15 millimetres between November 2014 and February 2016 as a result of El Niño, well above the post-1993 trend of 3 to 3.5 mm per year, with the early 2016 values reaching new record highs. Since February, sea levels have remained fairly stable.

Carbon dioxide flux Since the industrial revolution about 375 billion tonnes of carbon have been emitted by humans to the atmosphere as CO_2. The main sinks for CO2 emissions from fossil fuel combustion are the oceans and terrestrial biosphere. Despite the increasing emissions from fossil fuel energy, ocean and land biosphere still take up about half of the anthropogenic emissions. There is however potential that these sinks might become saturated, which will increase the fraction of emitted CO_2 that stays in the atmosphere and thus may accelerate the CO_2 atmospheric growth rate.

The latest analysis results published in WMO *Greenhouse Gas Bulletin* No. 12[3], based on the observations of the Global Atmosphere Watch (GAW), show that globally averaged surface CO_2 calculated from the GAW ground-based network reached new highs in 2015 at 400.0±0.1 ppm. This value constitutes 144% of pre-industrial (before 1750) levels. The increase of CO_2 from 2014 to 2015 was larger than that observed from 2013 to 2014 and that averaged over the past 10 years. The El Niño event in 2015 contributed to the increased growth rate through complex two-way interactions between climate change and the carbon cycle.

CO_2 concentrations recorded at GAW stations in the northern hemisphere (Mauna Loa Observatory) and southern hemisphere (Cape Grim and Casey Stations) reached the 400ppm mark in 2015 and 2016, respectively. This jump in CO_2 was probably driven by increased emissions from fossil fuels as well as the impact of the recent El Niño, which reduced the capacity of plant life and other terrestrial systems to absorb CO_2.[4]

The last ten years of research have provided a sound basis on which to begin to understand the magnitude and diversity of effects ocean acidification may have on the ocean, its ecosystems and all those who depend on ocean resources for health, wealth, sustenance and wellbeing.

The *WMO Greenhouse Gas Bulletin* No. 10[5] published in 2014 includes a section on ocean acidification and trends in ocean pCO_2 for over a period of two decades. The section was jointly produced by the International Ocean Carbon Coordination Project of the Intergovernmental Oceanographic Commission (IOC) of UNESCO, the Scientific Committee on Oceanic Research, and the Ocean Acidification International Coordination Centre of the International Atomic Energy Agency with support from WMO. The ocean's acidity increase is already measurable because oceans uptake is equivalent to 4 kg CO_2 per day per person. The rate of acidification is limited by the presence of carbonate ion (CO_3^{2-}), which binds up most of the newly formed H+, forming bicarbonate. Yet that buffering reaction consumes CO_3^{2-}, reducing the chemical capacity of the near-surface ocean to take up more CO_2. Currently that capacity is only 70% of what it was at the beginning of the industrial era, and it

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3 See: http://library.wmo.int/opac/doc_num.php?explnum_id=3084

4 See WMO's Press Release (18 May 2016) "CO2 breaches milestone, drives warming" (http://public.wmo.int/en/media/news/southern-hemisphere-breaches-co2-milestone).

5 See: http://www.wmo.int/pages/prog/arep/gaw/ghg/documents/GHG_Bulletin_10_Nov2014_EN.pdf

may well be reduced to only 20% by the end of the 21st century. The current rate of ocean acidification appears unprecedented at least over the last 300 million years based on proxy-data from paleo archives. In the future, acidification will continue to accelerate at least until mid-century based on projections from Earth system models. Acidification rates are slightly affected by climate change . Warming enhances the increase in H+ while reducing the decrease in CO_3^{2-}, but those effects amount to less than 10% of the changes due to increasing CO_2. Yet freshening, e.g., from enhanced ice melt in the Arctic, can accelerate acidification rates by much more.

Action undertaken to address the effects of climate change on the oceans and to foster climate resilient sustainable development of oceans and seas

Science, data collection and awareness raising

Observation Because the ocean is a global commons, strong international coordination is needed to ensure regular and sustained observation.

WMO hosts and co-sponsors the Global Climate Observing System (GCOS) which sets requirements for the observations of the Atmosphere, Land and Oceans required to track changes and variability in the climate system. In 2016 a new GCOS Implementation Plan was welcomed by the UNFCCC, who encouraged parties to work towards its implementation.

To deliver the ocean component, GCOS works closely with the Global Ocean Observing System (GOOS) which coordinates observations of physics, chemistry and biology required to deliver requirements for climate, services and ocean health through an integrated observing system of satellites, ships, moored and autonomous platforms. GOOS is also co-sponsored by WMO and led by the Intergovernmental Oceanographic Commission of the United Nations Educational, Scientific and Cultural Organization (IOC/UNESCO).

Technological advances in telecommunications, autonomous platforms and new sensors are revolutionizing our ability to systematically monitor the ocean and thus understand its role in weather and climate. In the past decade the International Argo Array of profiling floats has enabled us to systematically monitor the global subsurface oceans for the first time. The next revolutions will be as new technologies enable us to systematically observe the deep ocean, ice covered oceans, and new chemical and biological variables to enable us to track issues such as ocean acidification. WMO collaborates with the maritime industry to ensure continuous weather and ocean observations from Voluntary Observing Ships and ocean-based observing platforms.

With improved monitoring of the ocean and atmosphere and enhanced scientific understanding, scientists can increasingly identify and predict these oscillations – and thus the climate and weather. WMO Regional Climate Centres and Regional Climate Outlook Forums use this knowledge to produce consensus seasonal climate forecasts.

Maritime safety (WMO) collaborates with the International Maritime Organization (IMO) to provide standardized information, forecasts and warnings to ensure the safety of life and property at sea. This increasingly includes disseminating maritime safety information for the Arctic, where melting sea ice is boosting marine traffic. WMO works to improve search and rescue operations and emergency responses to environmental hazards such as oil and chemical spills and radionuclide fallout. It also supports the efforts of national weather agencies to deliver forecasts and warnings to protect coastal and inland communities from hazards such as ocean-generate storms and related storm surges, coastal flooding and high winds. Developing multi-hazard early warning systems for addressing coastal inundation is now a high priority.

Extreme weather The enormous amount of energy captured by the ocean creates the world's most powerful and destructive storms, known variously as cyclones, typhoons and hurricanes. The enormous amount of energy captured by the ocean creates the world's most powerful and destructive storms, known variously as cyclones, typhoons and hurricanes. WMO's tropical cyclone Regional Specialized Meteorological Centres and Tropical Cyclone Warning Centres facilitate international collaboration and the sharing of best practices (they also decide on the names of each year's storms to improve coordination and the clarity of warnings).

Atmosphere-ocean exchange of chemicals and marine geoengineering Through its Global Atmosphere Watch (GAW) network of observing stations, WMO is a long-term sponsor of the Joint Group of Experts on the Scientific Aspects of Marine Environmental Protection (GESAMP) Working Group on The Atmospheric Input of Chemicals to the Ocean (WG 38). WG38 studies the atmospheric-ocean exchange of chemicals and the impact on ocean biogeochemistry. In 2017, WG 38 is embarking on an investigation of the impact of ocean acidification on fluxes of non-CO_2 climate-active species. A workshop to gather the relevant international scientific experts and initiate this activity will be held in Norwich, UK from 27 Feb to 2 March, 2017. WMO/GAW is also a sponsor of a new GESAMP Working Group (WG 41) on marine geoengineering under the lead of IMO with support also from IOC/UNESCO and co-chaired by independent experts. The WG was tasked with carrying out an assessment of a wide range of marine geoengineering approaches for their potential environmental and socio/economic impacts on the marine environment (and the atmosphere where appropriate) as well as their potential scientific practicality and efficacy for climate mitigation purposes. The final peer-reviewed report, to be completed by January 2018, is intended to assist the Parties of the London Convention and London Protocol to determine which marine geoengineering activities might be listed in Annex 4 of the Protocol and consequently regulated.

Polar activities Recognizing the growing need for better weather and sea ice forecasts, more reliable climate predictions and, ultimately, better services for those who live and work in polar regions and beyond, the 68th Executive Council of WMO adopted a decision on the implementation of the Year of Polar Prediction[6]. The implementation of the Year of Polar Prediction, a flagship initiative of the Polar Prediction Project, relies on special observing periods lasting as long as several weeks when researchers enhance their observation activities with additional ocean buoys, at weather stations, on research vessels and on aircraft missions simultaneously. This information will enter the global prediction system in order to improve the delivery of weather/climate services in the polar regions. Core activities of the Year of Polar Prediction take place from mid-2017 to mid-2019, in order to cover two entire field seasons in both the Arctic and Antarctic. The Year of Polar Prediction will also boost education activities and engagement of people using polar forecasting products. Better polar predictions - especially of weather and sea ice conditions – will be an absolutely essential pre-condition for future safety in economic development caused by an expected increase in maritime transport in polar regions.

The World Climate Research Programme (WCRP) and the Prince Albert II of Monaco Foundation (FPA2), together with other major sponsors such as WMO, are jointly promoting a Polar Challenge with a Prize money award of 500,000 Swiss francs to the first team to

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[6] Decision 53 (EC-68), 2016.

complete a 2000km continuous mission under the sea-ice with an autonomous underwater vehicle in the Arctic or Antarctic. The start of the competition was formally announced at the Arctic Science Summit Week in March 2016. This challenge aims to promote innovation towards a cost-effective, scalable and sustainable monitoring system for the polar oceans.

Capacity-building, partnership and financing

Coastal inundation The Coastal Inundation Forecasting Demonstration Project (CIFDP) is a multi-hazard warning system that promotes an integrated approach in the enhancement and delivery of early warnings, no matter what the causes for coastal inundations are, in line with the concept of impact-based forecasting and the UN Sendai Framework for Disaster Risk Reduction (DRR). The CIFDP is currently underway in four sub-projects (Bangladesh, Dominican Republic, Fiji and Indonesia), three of which are in urban coastal settings. Substantial progress to date has been made in each of these CIFDP sub-projects since 2013 and expected completion by 2017-2018. The development of the CIFDP as a more sustainable platform for the strengthening of national multi-hazard early warning systems to address flooding in coastal areas is currently being considered.

Small islands States and territories Rising sea levels can damage freshwater supplies and worsen storms and coastal inundation. Better projections of how storm patterns will change, polar ice sheets melt and regional sea levels rise is vital for the improved safety of life and property at sea and for coastal zone management. WMO has launched a dedicated programme on Small Island Developing States and Member Island Territories[7] to help small, vulnerable islands to use weather, marine and climate services. This will contribute to the implementation of Sustainable Development Goal 14 – Conserve and Sustainably Use Oceans, Seas and Marine Resources for Sustainable Development.

7 Resolution 54 (Cg-17), 2015.