The First Global Integrated Marine Assessment

World Ocean Assessment 2016

Excerpts for climate change and atmospheric GHG pollution

Peter Carter

Climate change and atmospheric GHG pollution In depth Page 28 in the UN Assessment

J. Urgency of addressing threats to the ocean

The greatest threat to the ocean comes from a failure to deal quickly with the manifold problems that have been described above. Many parts of the ocean have been seriously degraded. If the problems are not addressed, there is a major risk that they will combine to produce a destructive cycle of degradation in which the ocean can no longer provide many of the benefits that humans currently enjoy from it.

Excerpts from Table 1. Pressures and Impacts of Human Activities …
on the Marine Environment (relevant to atmospheric GHG pollution total effects)

1. Acidification of the ocean (arising from increased CO2 emissions)

Reduction of reproductive success, recruitment, growth and survival of some species, especially those with (calcareous) exoskeletons (shells etc). Reduced resilience of coral reefs to other stresses. Second-order loss of habitat for other species if coral reefs degrade.

2. Changes in sea temperature

Increased sea-surface temperature will probably increase stratification and thus affect nutrient cycling, with effects on productivity. Changes in species distribution and productivities, bottom up ecosystem productivity and community structure. Coral bleaching. Reduction of sea-ice cover in Arctic and Antarctic will impair species dependent on that habitat. Adverse changes in weather patterns, including increased storms in higher latitudes.

3. Changes in the salinity of seawater (arising from climate change)

Changes to the thermohaline circulation of the ocean, in some places leading to increased up-welling of nutrients (see also Item 14). Increased likelihood of stratification of seawater, with consequent adverse effects on primary production that supports fish and seabirds. Changes in currents may alter the way that ocean moves heat around the planet, with widespread consequences

4. Creation of underwater noise (arising from shipping, offshore prospecting, offshore renewable energy installations and tourism and recreation)

Disturbance of fish, macro-invertebrates, and marine mammals. Mortality due to noise rare but disruption of behaviour may have consequences for life history activities including feeding, migration, recruitment and social behavior.

6. Increased direct mortality of marine animal populations, including those not directly targeted (arising particularly from fisheries, including recreational fisheries)

Decline in populations if the mortality is unsustainable. Alterations in population structures towards ones composed of smaller and younger individuals, with broader impacts on productivity. Potential alterations to ecosystem balance through differential effects on species. Unsustainable mortality rates imply declines of living marine resources, with implications of decreasing food security

7. Increased disturbance of fauna and flora, arising from increased numbers of people in the coastal zone, and increased amounts of shipping

8. Increased ultra-violet radiation (arising from reductions in ozone layer

Possible adverse effects on primary production and on fish larvae. Effects on titanium dioxide nanoparticles, creating biocides affecting phytoplankton, and thus potentially the food web.

10. Input of hydrocarbons (from land-based sources, offshore installations, pipelines and shipping)

Killing of benthic biota, fish, marine mammals and reptiles and sea birds. Adverse effects on their later reproductive success.

11. Input of nutrients, both airborne and water-borne (arising from land-based activities, shipping, solid waste disposal).

Coastal eutrophication, leading to dead zones, hypoxic zones and algal blooms (including toxic algal blooms). Shifts of ecosystem regimes. Consequent loss of benthic diversity and adverse effects on fish and shellfish stocks and on seabirds and marine mammals and reptiles. Algal smothering of coral reefs

17.Physical alteration of seabed habitats (arising from bottom-fishing, aquaculture, dredging for shipping, ports, submarine cables and pipelines, offshore hydrocarbon industries and mining, coastal defences, land reclamation, solid waste disposal and tourism and recreation)

Direct mortality by physical impacts or smothering. Reduction in three-dimensional habitat structure can reduce biodiversity and productivity. Disturbance of sediments can reduce water quality and/or release contaminants, also impacting biotic communities and populations

19. Sea-level rise (arising from climate change).

Changes in coastal habitats. Contaminants from frequent coastal flooding are likely to add to toxics and nutrient pollution. Loss of costal ecosystems such as sea grasses due to increase in turbulence.

A. Impacts of climate change and related changes in the atmosphere Changes

Major features of the ocean are changing significantly as a result of climate change and related changes in the atmosphere. The work of the Intergovernmental Panel on Climate Change has been used, where climate is concerned, as the basis of the present assessment

Sea-surface temperature

The Intergovernmental Panel on Climate Change has reaffirmed in its fifth report its conclusion that global sea-surface temperatures have increased since the late nineteenth century. Upper-ocean temperature (and hence its heat content) varies over multiple time scales, including seasonal, inter-annual (for example, those associated with the El Niño-Southern Oscillation), decadal and centennial periods. Depth-averaged ocean-temperature trends from 1971 to 2010 are positive (that is, they show warming) over most of the globe. The warming is more prominent in the northern hemisphere, especially in the North Atlantic. Zonally averaged upper-ocean temperature trends show warming at nearly all latitudes and depths. However, the greater volume of the ocean in the southern hemisphere increases the contribution of its warming to the global heat content. The ocean's large mass and high heat capacity enable it to store huge amounts of energy, more than 1,000 times than that found in the atmosphere for an equivalent increase in temperature. The earth is absorbing more heat than it is emitting back into space, and nearly all that excess heat is entering the ocean and being stored there. The ocean has absorbed about 93 per cent of the combined extra heat stored by warmed air, sea, land, and melted ice between 1971 and 2010. During the past three decades, approximately 70 per cent of the world's coastline has experienced significant increases in sea-surface temperature. This has been accompanied by an increase in the yearly number of extremely hot days along 38 per cent of the world's coastline. Warming has also been occurring at a significantly earlier date in the year along approximately 36 per cent of the world's temperate coastal areas (between 30° and 60° latitude in both hemispheres). That warming is resulting in an increasingly poleward distribution of many marine species.

Sea-level rise

It is very likely that extreme sea-level maxima have already increased globally since the 1970s, mainly as a result of global mean sea-level rise. That rise is due in part to anthropogenic warming, causing ocean thermal expansion and the melting of glaciers and of the polar continental ice sheets. Globally averaged sea level has thus risen by 3.2 mm a year for the past two decades, of which about a third is derived from thermal expansion. Some of the remainder is due to fluxes of freshwater from the continents, which have increased as a result of the melting of continental glaciers and ice sheets. Finally, regional and local sea-level changes are also influenced by natural factors, such as regional variability in winds and ocean currents, vertical movements of the land, isostatic adjustment of the levels of land in response to changes in physical pressures on it and coastal erosion, combined with human perturbations by change in land use and coastal development. As a result, sea levels will rise more than the global mean in some regions, and will actually fall in others. A 4°C warming by 2100 (which is predicted in the high-end emissions scenario in the report of the Intergovernmental Panel on Climate

Change) would lead, by the end of that period, to a median sea-level rise of nearly 1 metre above the 1980 to 1999 levels.

Ocean acidification

Rising concentrations of carbon dioxide in the atmosphere are resulting in increased uptake of that gas by the ocean. There is no doubt that the ocean is absorbing more and more of it: about 26 per cent of the increasing emissions of anthropogenic carbon dioxide is absorbed by the ocean, where it reacts with seawater to form carbonic acid. The resulting acidification of the ocean is occurring at different rates around the seas, but is generally decreasing the levels of calcium carbonate dissolved in seawater, thus lowering the availability of carbonate ions, which are needed for the formation by marine species of shells and skeletons. In some areas, this could affect species that are important for capture fisheries.

Salinity

Alongside broad-scale ocean warming, shifts in ocean salinity (salt content) have also occurred. The variations in the salinity of the ocean around the world result from differences in the balance between freshwater inflows (from rivers and glacier and icecap melt), rainfall and evaporation, all of which are affected by climate change. The shifts in salinity, which are calculated from a sparse historical observing system, suggest that at the surface, high-salinity subtropical ocean regions and the entire Atlantic basin have become more saline, while low-salinity regions, such as the western Pacific Warm Pool, and high-latitude regions have become even less saline. Since variations in salinity are one of the drivers of ocean currents, those changes can have an effect on the circulation of seawater and on stratification, as well as having a direct effect on the lives of plants and animals by changing their environment.

Stratification

Differences in salinity and temperature among different bodies of seawater result in stratification, in which the seawater forms layers, with limited exchanges between them. Increases in the degree of stratification have been noted around the world, particularly in the North Pacific and, more generally, north of 40ºS. Increased stratification brings with it a decrease in vertical mixing in the ocean water column. This decreased mixing, in turn, reduces oxygen content and the extent to which the ocean is able to absorb heat and carbon dioxide, because less water from the lower layers is brought up to the surface, where such absorption takes place. Reductions in vertical mixing also impact the amount of nutrients brought up from lower levels into the zone that sunlight penetrates, with consequent reductions in ecosystem productivity.

Ocean circulation

The intensified study of the ocean as part of the study of climate change has led to a much clearer understanding of the mechanisms of ocean circulation and its annual and decadal variations. As a result of changes in the heating of different parts of the ocean, patterns of variation in heat distribution across the ocean (such as the El Niño-Southern Oscillation) are also changing. Those changes in patterns result in significant changes in weather patterns on land. Water masses are also moving differently in areas over continental shelves, with consequent effects on the distribution of species. There is evidence that the global circulation through the open ocean may also be changing, which might lead, over time, to reductions in the transfer of heat from the equatorial regions to the poles and into the ocean depths.

Storms and other extreme weather events

Increasing seawater temperatures provide more energy for storms that develop at sea. The scientific consensus is that this will lead to fewer but more intense tropical cyclones globally. Evidence exists that the observed expansion of the tropics since approximately 1979 is accompanied by a pronounced poleward migration of the latitude at which the maximum intensities of storms occur. This will certainly affect coastal areas that have not been exposed previously to the dangers caused by tropical cyclones.

Ultraviolet radiation and the ozone layer

The ultraviolet (UV) radiation emitted by the sun in the UV-B range (280-315 nanometres wavelength) has a wide range of potentially harmful effects, including the inhibition of primary production by phytoplankton and cyanobacteria, changes in the structure and function of plankton communities and alterations of the nitrogen cycle. The ozone layer in the Earth's stratosphere blocks most UV-B from reaching the ocean's surface. Consequently, stratospheric ozone depletion since the 1970s has been a concern. International action (under the Montreal Protocol on Substances that Deplete the Ozone Layer) 29 to address that depletion has been taken, and the situation appears to have stabilized, although with some variation from year to year. Given those developments and the variations in the water depths to which UV-B penetrates, a consensus on the magnitude of the ozone-depletion effect on net primary production and nutrient cycling has yet to be reached. There is, however, a potential effect of ultraviolet on nanoparticles.30

Physical, chemical, and ecological characteristics

2.3 Pollution

The deep sea was once considered as being too remote from the point sources of industrial pollution for pollution to be a significant issue. However, key contaminants of © 2016 United Nations 10 concern, including mercury and many halogenated hydrocarbons (e.g., DDT, PCBs, and many other pesticides, herbicides, and industrial chemicals) are volatile and enter the ocean predominantly through the atmosphere. These are discussed in Chapter 20. As noted there, concentrations of persistent organic pollutants in deep-sea-dwelling fish may be an order of magnitude higher than in surface-dwelling fish, and the deep sea has been described as one of the ultimate global sinks for such contaminants. Butyl tin, an antifoulant that causes imposex in mollusks, is reported in elevated concentrations in deep-sea organisms, particularly in the vicinity of shipping lanes (Takahashi et al., 1997), and microplastics are now widely reported in deep-sea sediments (van Cauwenberghe et al., 2013).

2.4 Climate change, including acidification and deoxygenation

Predicted shoaling in the depth of calcium carbonate saturation horizons will expose large areas of seamount, ridge, plateau and slope habitat to undersaturated waters (Guinotte et al., 2006). Recent reviews and meta-analyses of the impacts of ocean acidification summarize the present understanding of its effects on cold-water corals (e.g. Wicks and Roberts, 2012), although to date no experimental studies have focused on seamount species. Studies have highlighted the ability of live cold-water corals to maintain calcification at reduced pH (Maier et al., 2009; Form and Riebesell 2012) but synergistic effects with increasing temperature and longer-term effects on resource allocation and reproduction remain unknown. It is becoming clear that deep-water ecosystems may experience more natural variability in carbonate chemistry than was previously supposed (Findlay et al., 2013; Findlay et al., 2014) and that calcareous species can persist even in under-saturated conditions on Tasmanian seamounts (Thresher et al., 2011). However, undersaturated waters will be corrosive to dead coral skeletons that provide structural habitat for many other species, a factor potentially explaining the limited scleractinian coral reef framework on the Hebrides Terrace Seamount (Henry et al., 2014). Increased carbon dioxide and reduced pH may also directly affect marine organisms' physiology, growth, and behaviour (Wicks and Roberts, 2012). It is thus necessary to understand their ecosystem-level impacts, such as the effects of acidification on bioerosion of deep-water corals (Wisshak et al., 2012).

Global climate models predict that oxygen concentrations will decline in the deep ocean due to decreased ventilation (a warmer ocean will be a more stratified ocean) and decreased oxygen solubility at warmer temperatures (Sarmiento et al., 1998; Matear and Hirst, 2003; Shaffer et al., 2009). Over the past 20 years, oxygen concentrations have declined in regions around the North Pacific Ocean and the tropical Indian, Atlantic and Pacific Oceans which have pronounced OMZs, with concomitant horizontal and vertical expansion of these OMZs (Whitney et al. 2007, Bograd et al., 2008; Stramma et al., 2008; Keeling et al., 2010). Benthic communities are dramatically affected where OMZs impinge on seamounts, ridges or continental margins, with greatly reduced biomass and biodiversity (Wishner et al., 1990; Levin 2003; Stramma et al., 2010). Deoxygenation may also affect deepwater benthic organisms indirectly through habitat oss and declining food availability. Midwater fishes, the primary food of many deepwater squid and fish species, including orange roughy, declined ~60 per cent during recent periods of low-oxygen availability in the California Current (Koslow et al., 2011). Palaeoceanographic studies have pointed to the significance of perturbations in oxygen concentration in controlling deep coral occurrence in the Eastern Mediterranean (Fink et al. 2012) and on seamounts (Thiagarajan et al., 2013). Most major marine mass extinction events in the geological past are associated with anoxia and acidification (Harnik et al., 2012)

Chapter 5. Sea-Air Interactions

Climate change in depth page 28

Introduction

From the physical point of view, the interaction between these two turbulent fluids, the ocean and the atmosphere, is a complex, highly nonlinear process, fundamental to the motions of both. The winds blowing over the surface of the ocean transfer momentum and mechanical energy to the water, generating waves and currents. The ocean in turn gives off energy as heat, by the emission of electromagnetic radiation, by conduction, and, in latent form, by evaporation. The heat flux from the ocean provides one of the main energy sources for atmospheric motions. This source of energy for the atmosphere is affected by the turbulence at the air/sea interface, and by the spatial distribution of the centres of high and low energy transfer affected by the ocean currents. This coupling takes place through processes that fundamentally occur at small scales. The strength of this coupling depends on airsea differences in several factors and therefore has geographic and temporal scales over a broad range. At these small scales on the sea-surface interface itself, waves, winds, water temperature and salinity, bubbles, spray and variations in the amount of solar radiation that reaches the ocean surface, and other factors, affect the transfer of properties and energy. In the long term, the convergence and divergence of oceanic heat transport provide sources and sinks of heat for the atmosphere and partly shape the mean climate of the earth. Analyzing whether these processes are changing due to anthropogenic influences and the potential impact of these changes is the subject of this chapter. Following guidance from the Ad Hoc Working Group of the Whole, much of the information presented here is based on or derives from the very thorough analysis conducted by the Intergovernmental Panel on Climate Change (IPCC) for its recent Fifth Assessment Report (AR5). The atmosphere and the ocean form a coupled system, exchanging at the air-sea interface gases, water (and water vapour), particles, momentum and energy. These exchanges affect the biology, the chemistry and the physics of the ocean and influence its biogeochemical processes, weather and climate (exchanges affecting the water cycle are addressed in Chapter 4). From a biogeochemical point of view, gas and chemical exchanges between the oceans and the atmosphere are important to life processes. Half of the Global Net Primary Production of the world is by phytoplankton and other marine plants, uptaking CO2 and releasing oxygen (Field et al., 1998; Falkowski and Raven, 1997). Phytoplankton is therefore also responsible for half of the annual production of oxygen by plants and, through the generation of organic matter, is at the basis of most marine food webs in the ocean. Oxygen production by plants is a critical ecosystem service that keeps atmospheric oxygen from otherwise declining. However, in many regions of the ocean, phytoplankton growth is limited by a deficit of iron in seawater. Most of the iron alleviating this limitation reaches the ocean through wind-borne dust from the deserts of the world.

Gas and chemical exchanges between the atmosphere and ocean are also important to climate change processes. For example, marine phytoplankton produces dimethyl sulphide (DMS), the most abundant biological sulphur compound emitted to the atmosphere (Kiene et al., 1996). DMS is oxidized in the marine atmosphere to form various sulphur-containing compounds, including sulphuric acid, which influence the formation of clouds. Through this interaction with cloud formation, the massive production of atmospheric DMS over the ocean may have an impact on the earth's climate. The absorption of CO_2 from the atmosphere at the sea surface is responsible for the fundamental role of the ocean as a carbon sink (see section 3 below).