THE ROYAL SOCIETY

Ocean, cryosphere and climate change
Opportunities and challenges for the UK

Introduction

The Intergovernmental Panel on Climate Change (IPCC) special report on the *Ocean and Cryosphere in a Changing Climate* summarises observed and projected effects of climate change in the ocean and for the frozen parts of the Earth – including sea ice, permafrost, mountain glaciers and ice sheets. Vigorous and flexible adaptation measures can help reduce the impact of these changes, but they must be applied in parallel with the emissions reductions needed to meet the goals of the Paris Agreement. This briefing provides an overview of the key findings of the IPCC report and their implications for the UK. It identifies possible UK policy responses that would improve outcomes, both in the UK and globally.

The global perspective

How ocean, ice and climate change are connected

The ocean plays a major role in regulating the Earth's temperature and carbon budget. It has absorbed about 25% of the carbon dioxide generated by fossil fuel burning and other human activity and has slowed warming by also absorbing heat.

Global warming causes melting of ice on land such as glaciers, and ice sheets in Antarctica and Greenland, adding water to the ocean, and thus raising sea level. The warming that has affected the atmosphere is also slowly penetrating the whole ocean, which causes the ocean to expand, adding to sea level rise.

By reflecting sunlight, ice and snow have a cooling effect on the climate. Removing the ice to leave darker land or ocean reduces this cooling and so amplifies climate change. Thawing permafrost releases significant amounts of greenhouse gases, causing further warming.

The ocean and cryosphere support ecosystems and the human population, both of which will be affected by impacts of climate change. As well as the many communities who depend on the sea for resources such as food, around 680 million people live less than 10 metres above sea level and many of them are therefore vulnerable to sea level rise. A similar number live in high mountain regions where changes in snow and ice cover affect their water supply.

Where we are and where we are going

Ocean

The ocean has warmed throughout its depth and is continuing to do so at an increasing rate. At the surface, marine heatwaves have doubled in frequency and become more intense. By absorbing carbon dioxide, the ocean has also become more acidic.

Marine ecosystems have been affected by warming and increased acidity, as well as by reduced oxygen content and changes in sea ice, which floats over the polar oceans. All these trends are predicted to continue, causing polar habitats to shrink and warm water species to move into previously temperate waters. Almost all warm-water coral reefs will suffer significant losses and local extinction, even under a low-emissions scenario.

Changes in ocean fish stocks and their distribution are likely to lead to significant changes in fisheries and challenges to

their governance, posing risks to nutrition in some regions. Under a high emission scenario[1], there is also a risk that some marine organisms will no longer be able to build their shells because of acidification.

Ocean circulation transports large amounts of heat to the North Atlantic, warming the UK and Europe. Under the expected pattern of increasing temperatures, the circulation system known as the Atlantic Meridional Overturning Circulation (AMOC) will weaken and the impacts of this, for example on European climate and ecosystems, are hard to predict. The AMOC is very unlikely to stop completely before 2100, but this cannot be ruled out on longer timescales should greenhouse emissions remain high.

Sea level

Sea level has risen between 12 and 21 cm on a global average since 1902, as a result of ocean warming and expansion, as well as melting of land ice, with an increasing contribution from the Greenland and Antarctic Ice Sheets in recent years.

Sea level is expected to rise by 29 to 59 cm by 2100, compared to the 1986 – 2005 period, under a low emissions scenario, and by 61 to 110 cm under a high emissions scenario. It is expected to continue rising for many further centuries beyond 2100 under all emission scenarios even if the climate is stabilised.

By 2300, sea level rise is projected to reach 0.6 to 1.07 m under a low emissions scenario. Under a high emission scenario, sea level is projected to rise between 2.3 to 5.4 m, increasing at a rate of several centimetres per year in the 22nd century (more than ten times the present rate). The broad ranges for these numbers represent remaining uncertainty in major contributory processes, such as those affecting the stability of the Greenland and Antarctic Ice Sheets.

In most locations globally, the highest sea levels, those occurring during storm surges and cyclones, which have historically occurred once per century, will be reached annually by 2100.

The risks from sea level rise to populations and infrastructure means that communities in low lying coastal areas, including island atolls, will probably be forced to re-locate under higher sea level rise projections.

Cryosphere

Warming in recent decades has resulted in ice mass loss from mountain glaciers worldwide. Warming has been amplified in the Arctic where it has led to a reduction in June snow cover of over 50% since 1967 and a thinning and reduction in the area of Arctic sea ice to an extent likely not experienced in at least 1,000 years. These effects have caused:

- Changes in the distribution and seasonal activities of species and ecosystems on land in polar regions and high mountain areas;
- Higher risks for food and water security in many high mountain areas and in the Arctic;
- Disruption of traditional hunting and fisheries activities by indigenous people in the Arctic; and
- Increased access for shipping and commercial development in the Arctic due to the reduction in sea ice.

If impacts intensify in the future, especially under high emissions scenarios, there are concerns about:

- The effect on water resources in mountain areas as many glaciers will disappear completely;
- Landslides, infrastructure damage and release of greenhouse gases in polar and high mountain areas, due to thawing of permafrost; and
- Cultural, aesthetic and economic impacts of a changing Arctic.

What can be done to reduce the impacts?

The best way to avoid the most serious impacts is to implement rapid and large reductions of emissions across all sectors. Ice sheet losses and sea-level rise will continue even if and when emissions reach net-zero and the temperature stabilises, but the size and rate of the change will be much smaller under low emissions scenarios. Limiting the duration of any warm period would reduce likely impacts.

Since further changes to oceans and the cryosphere are inevitable, communities will still need to take action to adapt to ocean and cryosphere change. Many of those most vulnerable to change are in low income nations with a low capacity to respond.

1. In this briefing, the low emissions scenario (referred to as RCP2.6 by the IPCC) represents a low greenhouse gas emission, high mitigation future, that in simulations used by the IPCC gives a two in three chance of limiting global warming to below 2°C by 2100. The high emissions scenario (RCP8.5) is based on the absence of policies to combat climate change, leading to continued and sustained growth in atmospheric greenhouse gas concentrations.

The UK's role – risks, opportunities and priorities

How do the IPCC findings affect the UK?

In the UK, with no glaciers or permafrost areas, the direct impacts projected by this IPCC report will occur in the form of sea-level rise and ocean ecosystem changes. They will primarily affect coastal areas and marine resources, including fisheries, and will have economic, societal and environmental impacts.

In the next few decades, there will be negative effects on some fisheries and aquaculture and positive effects on others around the UK. The impacts are likely to become worse as temperatures rise further. Warm water species are expected to become more common at the expense of existing stocks. For example, squid, cuttlefish and octopus populations are expanding around the UK in response to warming, while a reduction in numbers of juvenile cod is thought to be a result of climate change. Farmed species are likely to become exposed to a wider range of pathogens.

Human health could be at risk for those consuming seafood due to increased prevalence of pathogens such as vibrio (a bacterium that can cause foodborne infection), and harmful algal blooms leading to shellfish poisoning events.

Multiple stressor impacts of climate change (warming, acidification, deoxygenation, extreme weather) are increasing in UK waters and need to be monitored as they could have fundamental and disruptive impacts on the structure and functioning of ecosystems. The implications are still highly uncertain and therefore policies that are flexible and robust against future change are needed.

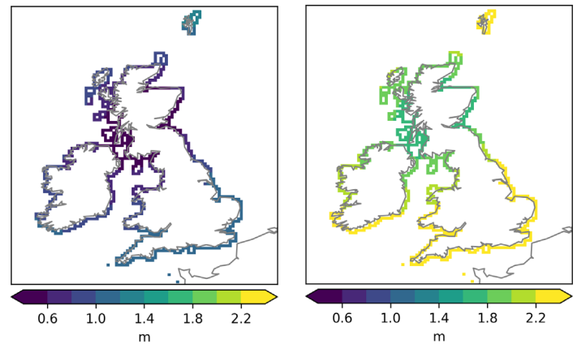
Sea levels around the UK have been rising compared to the global average, with somewhat higher increases in the south than the north because of concurrent rises and falls in the land surface (see figure). Sea levels are expected to continue to rise for several centuries even after the temperature stabilises, as ice sheets continue to retreat and warmth spreads through the ocean.

Rising sea levels will make the most damaging coastal floods more frequent, as well as increasing rates of coastal erosion. Homes, infrastructure and assets, including power plants, roads, railways, agricultural land, and ports will be subject to increased flood risk.

As an example, by 2100, sea level near London could rise between 29 and 115 cm depending on whether global emissions will be greatly reduced or not. Significant expenditure is already foreseen to enhance existing infrastructure such as the Thames Barrier that protects the Thames estuary from flood risk, and additional protection will be needed if it becomes apparent that sea level is following a path towards the higher values.

FIGURE 1

The pattern of sea level rise around the UK in 2300 associated with the central estimate under low (left) and high (right) emissions scenarios.



Source: Figure adapted from the UKCP18 Marine report, Met Office Hadley Centre

Beyond the UK itself, the UK Overseas Territories include small island states, some of which are particularly exposed to sea level change or reliant on fisheries. Other vulnerable countries include many Commonwealth nations with which the UK has close ties.

Under high emissions scenarios, many regions across the globe will suffer economic, environmental, health and trade impacts, which are likely to be felt even in nations that have themselves successfully adapted. In some cases, loss of land or livelihood could lead to conflict and migration, with important implications for the UK.

UK policy options to limit and adapt to climate change

The UK has set in law the goal of reaching net-zero emissions of greenhouse gases by 2050. This challenging commitment, if met and adopted by others worldwide, would greatly reduce the impacts on the cryosphere and oceans, including those affecting the UK.

The UK can play a substantial role in influencing other nations to commit to and reduce their emissions in a similar manner.

Even if warming is limited to a global average of well below 2°C, there will remain substantial impacts and a continuation of sea level rise. This needs to be faced

and action taken to adapt to a wide range of possible outcomes, with the flexibility to respond to scenarios up to a 4˚C rise if commitments are not met.

For UK impacts, the Committee on Climate Change has concluded that the current approach to sea level rise and coastal adaptation is unsustainable in the face of climate change and the near-certainty that adaptation to at least 1 metre of sea level rise will be needed sooner or later, perhaps before 2100. Appropriate actions vary by location but include:

- Decisions, based on technical, economic and social grounds, defining those coastal areas that can be protected against erosion and flood; those where new development should be restricted; and those where relocation and managed retreat cannot be avoided;
- Protection and restoration of coastal environments such as saltmarshes, mudflats, shingle beaches, sand dunes and sea cliffs, that can all provide natural long-term protection against waves and storm surges; and
- Greater protection for vulnerable infrastructure that cannot be relocated, such as coastal power plants and their cooling systems, and offshore wind installations.

Some impacts are hard to predict including regional changes in acidification and oxygenation, and their effects on marine ecosystems. Greater monitoring will allow decision making on issues such as sustainable fish quotas or marine protected areas to be based on the actual changes that are found to occur.

What the UK can do at international level

It is in the UK's interest to ensure that other nations not only set ambitious targets for emissions reductions, but also adapt to inevitable changes without damaging economic and social stability. Through trade, research and aid, the UK can assist mitigation and adaptation in countries with less capacity through:

- Technology transfer and financial aid to help reduce emissions;
- Research and aid spending to support adaptation such as sea level defences, early warning of storm surges, and forecasting of water resources as glaciers retreat. Instruments such as the Newton Fund and the Global Challenges Research Fund (GCRF) can be directed to support the development of adaptation activities for this purpose;
- Providing help to devise policies and responses to sea level rise, particularly in countries where some areas may become uninhabitable;
- Offering expertise and support to ensure sustainable management of fisheries, seafood and aquaculture in regions most strongly affected by changing sea temperatures, acidification and deoxygenation; and
- Including consideration of climate (or ocean) impact in new international and commercial agreements.

PRIORITY ACTIONS

Priority actions to minimise the negative impacts of climate change on the ocean and the cryosphere and prepare for unavoidable change include:

- **Achieving net-zero emissions by 2050**, nationally and globally, will greatly reduce all effects of climate change, including those on the ocean and cryosphere;
- **Adaptation planning** for significant sea level rise and frequent storm surges;
- **Establishing flexible adaptation policies** to allow for various climate change scenarios;
- **Supporting mitigation and adaptation** around the world through trade, research and aid;
- **Coordinating between all government departments** to enable effective action as climate change cuts across many areas of policy.

WORKING GROUP MEMBERS

Melanie Austen, Jonathan Gregory FRS, Corinne Le Quéré FRS, John Shepherd FRS, Eric Wolff FRS (Chair)