

## Sea Level Rise



Global mean sea levels are projected to increase over the next century. Around the UK sea level rise will exacerbate problems of coastal flooding and erosion. This POSTnote summarizes the causes of sea level rise, and the uncertainties in and the consequences for UK climate change adaptation.

### Background

Global mean sea level has increased by approximately 20 centimetres since records began in the mid 19<sup>th</sup> century<sup>1</sup>. Sea level measurements, acquired from satellite and ground level (tide gauge) instruments, have shown that the rate of sea level rise over the last 20-30 years is greater than the 20<sup>th</sup> century average. Increasing greenhouse gas emissions may lead to increased rates of climate change (POSTnote 295) and faster rates of sea level rise.

The associated risks to the UK from rising sea level are high. Most at risk from coastal flooding and erosion are the low lying areas of eastern and southern England.

- An estimated 30% of the population of England and Wales live within 10km of the coast<sup>2</sup>.
- Similarly high proportions of agricultural land, manufacturing industry, energy supply, and transport links are found in coastal regions (POSTnote 362).
- The main finance area in the UK is on the tidal reaches of the Thames, protected by the Thames Barrier against flooding by an extreme 'storm surge' event with a "1 in a 1000 year probability of occurrence"<sup>3</sup>.
- The coastline forms an important part of the UK's cultural heritage, and has environmental significance at national and international levels.

### Overview

- Sea level rise is controlled by a range of physical processes, related to climate change.
- There are still significant uncertainties in sea level rise projections.
- Global mean sea levels are currently increasing by approximately 3mm per year.
- There are local variations in sea level rise which have important effects on the UK.
- Estimated global mean sea level rise in the next 100 years is around half a metre, although higher values cannot be excluded.
- Shoreline Management Plans, supported by Defra and the Environment Agency, provide long term plans for coastal change and risk management on the English coastline.

In total, it is estimated that there is £120 billion worth of infrastructure and resources at risk from coastal flooding and a further £10 billion at risk from coastal erosion<sup>2</sup>. With rising sea levels, the level of protection offered by current flood defences will decrease, exposing more land to potential flooding. It is therefore important to understand why sea level is rising, and at what rate, to be able to prepare effective adaptation strategies.

### Current Trends in Global Mean Sea Level

Satellite measurements show that the current rate of sea level rise is around 3mm per year. In the period 1961-2003 it has recently been estimated<sup>1</sup> that 40% of sea level rise was caused by the expansion of water as it was heated by global warming and 60% from shrinking glaciers, ice caps and ice-sheets (Box 1).

Melt of floating ice is of negligible importance to sea level rise. This is because the volume of water trapped as floating ice displaces a comparable volume of seawater. However, scientific research has shown that approximately twice as much floating ice is lost per year compared with grounded ice<sup>4</sup>. Aside from contributing to increasing sea levels, the introduction of cold water from the melt of grounded and floating ice in polar oceans may have dramatic effects on the Antarctic and Arctic environments, as well as on ocean circulation patterns (POSTnote 334). It is therefore important to understand the effects of climate change on

grounded and floating ice when modelling climate change in the Antarctic and Arctic regions.

#### Box 1. Primary Components of Sea Level Rise

Global mean sea level rise, the average rate of sea level change, is approximately 3mm per year<sup>5</sup>. The three main causes are:

##### ■ Ocean Expansion.

Water in the oceans expands with rising global temperatures, through a process referred to as thermal expansion. The reduction in the mass of land based ice directly increases the global mean sea level. Global warming of the oceans results in a sea level rise of  $1.6 \pm 0.5$ mm per year.

##### ■ Mountain Glaciers.

Due to climate change glaciers may melt faster than they gain mass through snowfall. Enough water is contained in glaciers to raise sea levels by 50cm. It is predicted that the size of mountain glaciers will decline over the next century.

##### ■ Ice-Sheets.

Mass loss of ice-sheets occurs through a net imbalance of the amount of ice melted, the amount of ice discharged into the ocean by glacial flow and the amount of ice generated by precipitation on to the ice-sheet. However, the response of sheet ice to climate change is currently poorly understood. Greenland alone is covered by enough ice to raise sea levels by over 7 metres.

### Local Variations in Sea Level

Local variations in sea level rise can have significant effects in exacerbating or mitigating the trends of global mean sea level rise. Due to the readjustment of the Earth's crust to displacement by the weight of ice-sheets during the last ice age, the south of the UK is sinking at a rate of approximately 1mm per year in comparison to global mean sea levels, whilst the north is rising at a rate of 1mm per year.

The gravitational pull of ice-sheets is large enough to significantly distort sea level around the globe. As the large ice-sheets pull water towards them, sea levels around them rise whilst sea levels at the other side of the planet decrease. If the ice-sheets shrink then this effect will be reduced. It is predicted that for every 1 metre of global sea level rise caused by mass loss from the Antarctic ice-sheet, the UK will suffer a rise of 1.1 metres. Conversely, the local amount of sea level rise around the UK caused by mass loss from the Greenland ice-sheet will be less than the global average.

Other regional effects include distortions to the global mean sea level by atmospheric and ocean circulations. For example it is estimated that shutdown of critical temperature and salinity driven ocean currents could cause a sea level change of up to half a metre in the Northern Atlantic.

### Future Changes in Global Mean Sea Level

The Fourth Assessment Report of the Intergovernmental Panel on Climate Change (IPCC) provides detailed projections of future sea level rise<sup>6</sup>. It provides a summary of prior published academic findings, and is not a source of new academic research itself. The climate and sea level rise projections it contains are based on a series of future emission scenarios<sup>7</sup>.

IPCC predictions of future sea level change are based on the physical climate models (Box 2). In the Fourth Assessment Report a change of 18-59cm in global mean sea levels was predicted for the period 1990 to 2095. It is important to note that these projections excluded possible rapid changes in the net rate of discharge from ice-sheets, as there was a lack of scientific understanding of the relevant processes. It is therefore plausible that sea level rise projections in the Fifth Assessment Report of the Intergovernmental Panel on Climate Change, due in 2013, will be higher.

However, even if greenhouse gas emissions are stabilised in the next few decades, sea level rise will continue over the next millennia<sup>8</sup>, until the ice-sheets have stabilised in the Earth's new climate.

#### Box 2. Modelling Sea Level Rise

Two major methods are used to project future climate change and sea level rise.

##### Physical Models

- Physical models of sea level rise attempt to describe the physical processes relating to sea level rise. These models are based on fundamental physical laws to describe how Earth systems such as global temperature and mass of ice-sheets change with variations in the amount of greenhouse gas emissions.
- The merit of these models is that they are based on well understood physics. However, the models that are produced are complex and hard to interpret. Further, the models are incomplete as it is not known how to describe all of the physical causes of sea level rise.

##### Empirical Models

- Empirical models of sea level rise attempt to relate previous changes in the Earth's climate to changes in global mean sea level. This relation is used to make a projection of how sea level will change, based on recent trends and predictions of future climates.
- Often some physics are included to place physical limits on the models. These are referred to as semi-empirical models. The merit of such models is that they capture observed behaviour during periods of past sea level rise, so appear to reproduce past changes well. However, there is no guarantee that past changes are indicative of the future

### Uncertainty in Sea Level Rise Projections

A cause of uncertainty in projections of sea level rise is the amount of climate change due to variation in future greenhouse gas emissions. While the total amount of global greenhouse gas emission will define the future global temperatures and sea levels, the rate of greenhouse gas emissions will determine rate of sea level rise around the UK and the rest of the world.

Due to uncertainty in the physical models used to make projections of climate change in the Fourth Assessment Report, the Intergovernmental Panel on Climate Change specifies a model-based range of sea level rise, for each individual emission scenario. The range in the sea level projections arises from the range of possible future greenhouse gas emission scenarios and uncertainties in the models used.

The exclusion of possible rapid changes in the net rate of discharge from ice-sheets is another source of uncertainty in the projections made in the Fourth Assessment Report. Current research, such as the EU “Ice2sea” programme led by the British Antarctic Survey<sup>9</sup> (Box 3), is studying the effect of climate change on ice-sheets, ice caps and mountain glaciers and the potential impacts this will have on sea level rise.

#### Box 3. Ice2sea

##### The response of ice-sheets to climate change

Ice2sea is a research project studying the response of ice-sheets to climate change, funded by the European Union Framework 7 Programme<sup>9</sup>. The project covers 4 years (2009-2013) with a schedule designed to provide input to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change in 2013. Ice2sea has twin goals of improving the science behind sea level predictions, and making projections of future sea level rise over the next 200 years.

Ice2sea aims to improve the modelling of the dynamical imbalance of the mass of ice-sheets, and any changes in this caused by future climate change. The processes contributing to the change in mass of ice-sheets primarily include mass gain through precipitation onto the surface, and mass loss either through discharge of ice into the ocean via outlet glaciers or surface melt.

To inform coastal defence initiatives such as Thames Estuary 2100<sup>3</sup> and the Dutch Delta Commission<sup>10</sup>, ice2sea is making projections for sea level rise for the next 200 years. Such long term projections have been requested in order to assist future-proofing of coastal regions against sea level rise for the foreseeable future.

#### Low Probability, High Impact Sea Level Rise

Recently published semi-empirical models have predicted much higher sea level rise than suggested in the Fourth Assessment Report<sup>11</sup>, with change in global mean sea levels in the next century exceeding 1 metre or more if greenhouse gas emissions continue to escalate.

Although the upper end of such projections are “highly uncertain and very unlikely”<sup>12</sup>, they are useful in providing upper limits in coastal adaptation plans, where current physical models of future sea level rise do not provide a complete picture. Furthermore any sea level rise of a sizeable proportion of these projections would still have dramatic effects on UK coastlines. Semi-empirical models such as the High++ scenario presented in the UK Climate Projection Report 2009<sup>12</sup> (Box 4) are already being considered in various Shoreline Management Plans around the UK.

#### “Tipping Point” Events

It is postulated<sup>13</sup> that human activities have the potential to alter climate conditions significantly, by pushing Earth systems, such as ice-sheets, past “tipping points”. Estimates place a threshold for partial deglaciation of the Greenland ice-sheet within a global mean temperature rise in the range 1.9-4.6°C<sup>13</sup>. Any significant change in the total mass of the major ice-sheets would cause sea level rise of the order of metres and have a dramatic impact on coastal communities and habitats across the world. While it is thought that the

Greenland and Western Antarctic ice-sheets may be vulnerable to collapse, satellite measurements and models suggest that the size of the Eastern Antarctic ice-sheet is relatively stable.

However, any significant change in the mass of the ice-sheets would be gradual, with adjustment occurring over many centuries. Further scientific research has suggested that even if atmospheric greenhouse gas concentrations could be reduced to preindustrial levels, mass loss from ice-sheets might only be partially reversible.

#### Box 4. High++ Scenario

The High++ scenario is a low probability, high impact projection for sea level rise around the UK, carried out by the UK Climate Projection Report 2009<sup>12</sup>. The High++ scenario has been used to consider the worst case outcomes of sea level rise over the next century. It was designed for use in contingency planning in coastal management. The Thames Estuary 2100 project (Box 5) currently uses the High++ scenario as a limit to the range of sea level rise considered.

Records of sea level and climate, inferred from deep ocean sediments, ice cores and corals, relating to the last interglacial period, 125,000 years are thought to correspond approximately to current climate conditions. The High++ sea level rise projection is based on such proxy records of past climates and estimates of maximum glacial flow rate.

The High++ scenario is distinct from IPCC reports of future climates and sea level rise which are based on physical modelling (Box 2). The High++ scenario derives an upper bound of sea level rise around the UK of 1.9 metres in the next century. This model describes a much greater sea level rise than in projections presented in the IPCC Fourth Assessment Report, which has an upper bound of 0.6 metre.

#### Adaptation to Sea Level Rise in the UK

Rising sea level results in higher storm surges, which will exacerbate the risk of coastal flooding and erosion. To prepare for changing sea level, adaptive approaches to coastal flood and erosion risk management are being studied. Further, coastal management is undergoing direction and policy change away from hard defences to more sustainable approaches (POSTnote 342). The key objectives of current policy on coastal change are:

- to ensure policy is based on up to date science
- to evaluate the risk of new developments in coastal region,
- to ensure any necessary coastal development provides substantial social and economic benefits
- to ensure the long term “sustainability” of the coastline<sup>14</sup>.

#### Shoreline Management Plans

Due to the length and variety of the English coastline, no single approach is suitable to adapting to all coastal changes, through sea level rise or otherwise. Non-statutory, Shoreline Management Plans were introduced in the mid 1990s to provide a strategy for long term coastal adaptation on a local scale.

While the first generation Shoreline Management Plans were aimed at raising public awareness of changing coastlines and at using and evaluating new and alternative methods of coastal flood and erosion risk management, they did not directly consider sea level rise. Current second generation Shoreline Management Plans have started to incorporate projections of sea level rise into long term plans for coastal defences, as predictions of greater sea level rise due to climate change have recently been made<sup>15</sup>. The Thames Estuary 2100 project (Box 5), has outlined timelines specifying how tidal defences will need to be improved, using the High++ scenario to specify worst case sea level rise.

#### Box 5. The Thames Estuary 2100 Project

Thames Estuary 2100 is an Environment Agency-led flood risk management project set up to protect London and the tidal reaches of the Thames<sup>3</sup>. The project called for an adaptive plan able to protect against a 1.9 metre rise in sea level predicted in the High++ scenario (Box 3), as well changes in the frequency and severity of North Sea storm surges and water drainage from the Thames and its tributaries.

The plan has developed different flood management options for different reaches of the Thames. The plans include adaption to different future climate scenarios on short (2010-2035), medium (2035-2070) and long (2070-2100) timescales. These have been evaluated to find the most effective and cost beneficial solution. From this process, thresholds have been determined specifying when decisions need to be made to adequately prepare in time for future sea level and climate changes. The plan also provides detailed recommendations should the most extreme projections be realised.

The final plan has been subject to public approval and consultation with key stakeholders. The plan will receive periodic review, approximately every 5 years, including incorporating the latest developments in sea level rise projections provided by the Met Office.

#### Current UK Policy

It is estimated that given current costs of building or maintaining coastal defences, there will be some locations where defences can no longer be sustained by government funding due to changes along the coastline and rising sea levels. To help reduce this risk, means for encouraging and developing local funding to contribute to future flood and coastal defence are being studied<sup>16</sup>. Under current existing policy, in areas where it is no longer feasible to maintain or build coastal defences, Defra will seek to support communities in the process of adapting to the physical and social implications of coastal change. Defra has also committed to a £6,000 coastal erosion assistance grant for homeowners who are at risk of losing their property to coastal erosion. This contributes to costs of demolishing the property and some basic moving costs<sup>17</sup>.

The threat of loss of property and cultural heritage due to coastal change and from coastal defences that are determined to be unfeasible has resulted in friction between government policy and local communities. In places where the perceived threat to property and community vitality is high, community action groups have formed to seek policy

change or compensation for loss. The National Voice for Coastal Communities Forum acts as a single point of contact for these groups, and liaises between them and Defra, the Environment Agency and Natural England<sup>18</sup>.

#### International Coastal Adaptation Approaches

The Environment Agency is responsible for creating a national flood and coastal risk management strategy, under the Flood and Water Management Act, 2010. To maintain state-of-the-art coastal management planning, the Environment Agency commissioned a review of best international approaches on coastal adaptation<sup>19</sup>, taken by the USA, France, the Netherlands and Australia. In summary the key findings of international adaptation strategies were:

- **USA:** range of coastal adaptation approaches, no universal long term planning strategy
- **France:** statutory but non mandatory relocation assistance for properties in areas of risk assessed to be worthy of intervention
- **Netherlands:** due to the proportion of land at risk from sea level rise, a national strategy has been developed for coastal adaptation. The government will not provide protection for new development in high risk areas.
- **Australia:** 'voluntary purchase' process for properties in high risk areas based on amenity and access requirements.

In comparison, the UK does not have a current policy of compensating those at risk of losing their properties. Adaptation to coastal change in the UK is being generated through local authority and community-led "pathfinder" programmes. The Environment Agency and Defra provide expertise and some funding for local government to develop Shoreline Management Plans appropriate for their given stretch of coastline.

#### Endnotes

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- <sup>2</sup> de la Vega-Leinert & Nicholls, Potential Implications of Sea Level Rise in the UK, *J. Coastal Research*, 2008
- <sup>3</sup> <http://www.environment-agency.gov.uk/homeandleisure/floods/38353.aspx>
- <sup>4</sup> Shepherd et al, Recent loss of floating ice and the consequent sea level contribution, *Geophysical Research Letters* 2010
- <sup>5</sup> Milne, et al, Identifying the causes of sea-level change, *Nature Geoscience*, 2009
- <sup>6</sup> Summary for Policymakers, *Fourth Assessment Report* IPCC
- <sup>7</sup> Special Report: Emissions Scenarios, *Third Assessment Report* IPCC
- <sup>8</sup> Mean Sea level and sea level extremes, *2010 Annual Report Card*, MCCIP
- <sup>9</sup> <http://www.ice2sea.eu/info.html>
- <sup>10</sup> <http://www.deltacommissie.com/en/advies>
- <sup>11</sup> Rahmstorf, A new view on sea level rise, *Nature* 2010
- <sup>12</sup> <http://ukclimateprojections.defra.gov.uk/>
- <sup>13</sup> Ridley et al, Thresholds for irreversible decline of the Greenland ice-sheet, *Climate Dynamics*, 2009
- <sup>14</sup> *Planning Policy Statement 25 Supplement: Development and coastal change*, Department of Communities and Local Government, 2010
- <sup>15</sup> <http://www.environment-agency.gov.uk/research/planning/104939.aspx>
- <sup>16</sup> *Adapting to Coastal Change: developing a policy framework*, Defra 2010
- <sup>17</sup> *Investing for the Future, flood risk and coastal management in England*, Environment Agency 2009
- <sup>18</sup> <http://www.coastnet.org.uk/coastalchange>
- <sup>19</sup> *Coastal Adaptation Project: review of best international practice*, Environment Agency 2008