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Sea level rise: projections and impacts for Scotland

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Summary

This report reviews the available evidence on projected sea level rise and its implications for Scotland. It focusses on projections for the 21st century:

- the strengths and weaknesses of the information used to underpin risk assessment and adaptation planning in Scotland; and
- the main sources of uncertainty.

This information is used to review adaptation options in the face of uncertainty.

Key Findings

- Sea level rise and coastal flooding are key climate change risks for Scotland.
- Scientific knowledge is advancing rapidly but projections for the 21st century are wide-ranging and have significant uncertainties, particularly regarding ice sheets in the Antarctic.
- The CCRA2 provides a comprehensive assessment, but more recent research suggests the projections that underpin it probably underestimate sea level rise.
- The new UKCP18 projections are due to be published in November 2018 and will include significantly updated sea level data.
- Initial Met Office work suggests that, for the UK, central estimates of sea level rise in UKCP18 will be around 20-30% higher than under the UKCP09 H++ (high-end) scenario.
- To extract usable data from UKCP18 for adaptation planning users will need additional software 'derived products'.

1 Identified risks

Sea level rise can increase coastal flooding and erosion, and the impacts from storm surges, posing risks to infrastructure, businesses, communities and nature (Edwards, 2017). Both the 2017 UK Climate Change Risk Assessment (CCRA2) and the Adaptation Sub-Committee's Review of Scotland's Climate Change Adaptation Programme identify sea level rise and coastal flooding as key risks for Scotland (ASC, 2016b; ASC, 2016a).

Projections of sea level rise during the 21st century are uncertain; 'generally ranging from around 25cm to around 1m (depending on greenhouse gas emissions and ranges of modelling uncertainties), with a few estimates consistent with 1.5 to 2.5m' (Edwards, 2017). The largest source of uncertainty concerns the response of the Antarctic ice sheet to climate change (ibid). Counter-intuitively, due to gravitational effects this will have a greater impact on sea level rise in the northern hemisphere and hence for Scotland (Met Office, 2016).

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These projections have implications in Scotland for flood risk management, strategic planning and sustainable coastal development, especially for low-lying coastal areas surrounding our cities (Rennie and Hansom, 2011).

The National Flood Risk Assessment identified 243 Potentially Vulnerable Areas (areas of potentially significant flood risk). Of these, 125 included some coastal flood risk and 61 have significant coastal flood risk. Areas particularly at risk include the Uists, Orkney and the inner firths of the Forth, Moray and Solway (Hansom, J., Maxwell, F., Naylor, L. & Piedra, 2017).

1.1 Evidence of sea level rise in Scotland

Observations of sea level rise are provided by the UK National Tide Gauge Network. Although Scotland has experienced long-term land uplift since the last glaciation, recent records show that rates of uplift have slowed. In a 2011 paper, Rennie and Hansom note that tidal records over the last decade indicated significant increases in relative sea level rise, compared to previous decades. Used in combination with climate projections, such as UKCP09 and UKCP18, tidal records can help to reduce the wide range of sea level projections across different scenarios. Rennie and Hansom found that 'Scotland's observed tidal record now lies close to the 95% projection of the UKCP09 High Emission Scenario' and concluded that current levels of land uplift do little to offset rising sea levels (Rennie and Hansom, 2011).

Sea level rise is the principal cause of increased flooding within Aberdeen, Millport and Stornoway tidal gauges, a pattern that is also seen at a global scale (Hansom, J., Maxwell, F., Naylor, L. & Piedra, 2017).

In 2016, global mean sea level was 20cm higher than at the start of the 20th century, and at the highest yearly average since measurements began (EEA, 2017).

1.2 Sea level rise projections

There are a number of analyses and studies looking at projected sea level rise and the related risks at various scales. The projections used are from various sources and based on a range of emissions scenarios. The main sources used for this review, the currency of the underlying data and relevance of their findings for Scotland are summarised in the table in Annex 1.

2 Sources for sea level rise projections for Scotland

2.1 Latest evidence

The Intergovernmental Panel on Climate Change (IPCC) Fifth Assessment Report (AR5) sea level rise projections incorporate significant updates in scientific knowledge, compared to the previous AR4 report (IPCC, 2013). However, this information is not yet available at a regional scale to provide detailed projections for Scotland. This is important as local sea levels vary from the global mean due to land uplift or subsidence, gravitational effects, changes in ocean density and circulation patterns (EEA, 2017). The UKCP18 projections will provide regional detail, including updates for sea level rise and storm surge. These will be available from November 2018 and should be used to inform adaptation planning in Scotland.

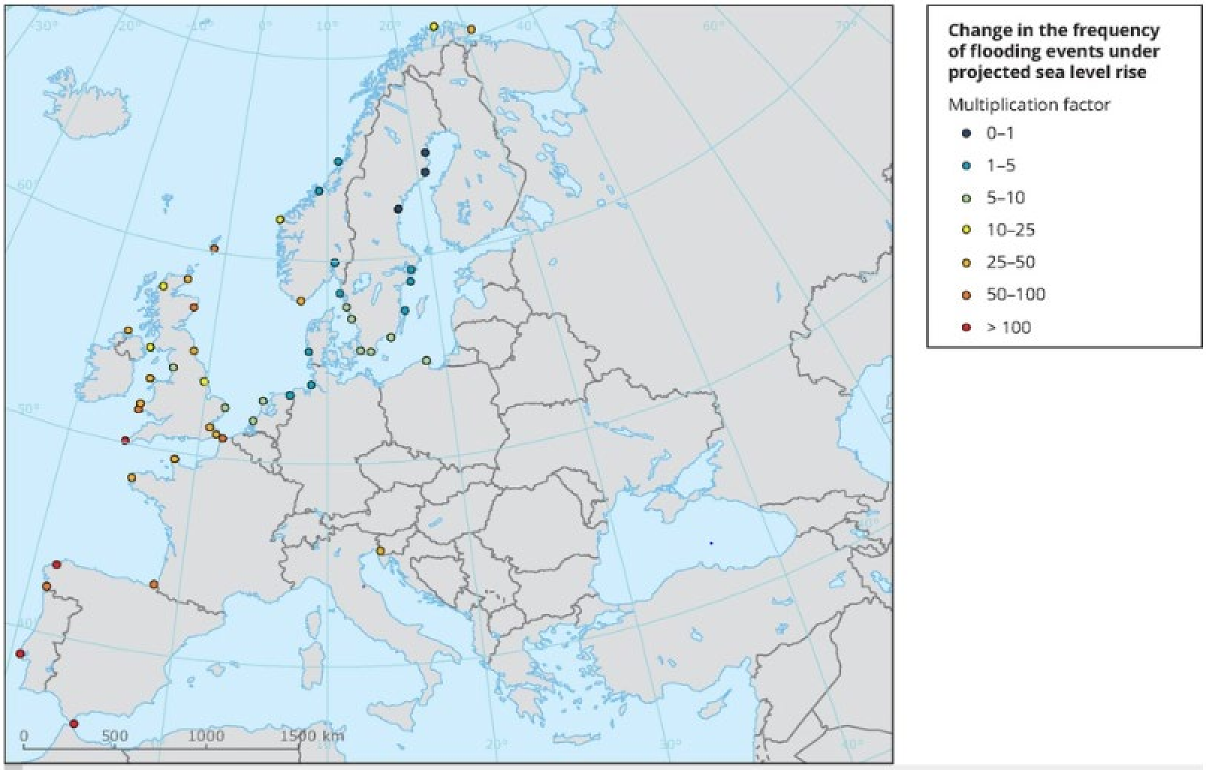
Until **UKCP18** is available, the widely used **UKCP09** sea level projections (based on AR4) remain the recommended source; however caveats apply. Underestimates of sea level rise are the most significant limitation in UKCP09, and this should be borne in mind for adaptation planning. The Met Office Hadley Centre recommends that users 'avoid using this older information and … wait for the updated UKCP18 projections to become available if possible', and where decisions have to be taken prior to the update becoming available, the updated information from AR5 should be taken into account (Met Office, 2016).

In Scotland, most agencies currently use the UKCP09 projections, and plans are in place to update these with the latest evidence when UKCP18 data becomes available. For example, while UKCP18 will not be available in time to inform the 2018 National Flood Risk Assessment, SEPA plan to begin work on analysis and interpretation of the updated projections as soon they become available, to inform future flood risk management (SEPA, 2018). However, this analysis will take some time.

It should be noted that UKCP18 outputs will be in a 'raw' format, requiring an add-on 'derived product' to translate the output into usable data for decision makers.

Dynamic Coast, Scotland's National Coastal Change Assessment, *provides an analysis of historic coastal change and aims to inform strategic planning (Hansom, J.D., Fitton, J.M., and Rennie, 2017). The existing maps of coastal change and future projections do not account for climate change scenarios. The potential climate change implications on erosion are being considered in ongoing research and results are anticipated by March 2020 (Monfries, 2018).*

The EEA's **Indicator Assessment** *considers the changing frequency of flooding events under projected sea level rise (EEA, 2017). While a rise in sea level of 10cm will generally increase the frequency of flooding by a factor of three, this factor varies widely and is over 100 in some places. Figure 1, reproduced from the indicator, shows this factor for several locations in Scotland and Europe, for the AR5 RCP4.5 scenario. The multiplication factor is particularly high for North-east Scotland and the Shetland Isles.*



Note: This map shows the estimated multiplication factor, by which the frequency of flooding events of a given height changes between 2010 and 2100 due to projected regional sea relative level rise under the RCP4.5 scenario. Values larger than 1 indicate an increase in flooding frequency

Figure 1. Change in the frequency of flooding events under projected sea level rise (Source: EEA, 2017).

2.2 What has changed?

The **Met Office** summarise the main areas in which the science of sea level change has evolved between AR4 (UKCP09) and AR5 (UKCP18):

- 'greater confidence in projections of global mean sea level owing to improved understanding of the components of sea level'
- 'better agreement between process-based model and observations'
- 'ice sheet dynamical changes have been included in process-based projections of global and regional sea level change'

The most important of these changes is the incorporation of ice sheet dynamics, which substantially increases projected sea level rise for the 21st century (Met Office, 2016). Taking regional effects into account, initial Met Office work indicated that for the UK, central estimates of sea level change for UKCP18 will be some 20-30% larger than those for the highest emissions scenario in UKCP09, H++ (ibid).

2.2.1 Making local estimates

An **SNH report** on climate change-driven sea level rise and storm surge impacts in the Firth of Clyde provides estimates in a Scottish context (Hansom, J., Maxwell, F., Naylor, L. & Piedra, 2017). This study used UKCP09 data, i.e. AR4 projections translated into small scale geographical areas. The high-end 'H++' scenario, provided in AR4 to compensate for known limitations in scientific understanding of the behaviour of ice sheets under climate change, was used in the Clyde study. However, the study also took account of the new AR5 projections, noting a derived 'best estimate' correction to apply to its findings. The AR5 projections do not provide data at a regional scale, so the correction is a general one, at global scale. It results in an increase in projected sea level rise of approximately 60%, compared to the UKCP09 projections[1]. A more detailed description of the methodology used is described in Annex 2.

2.2.2 Uncertainty and knowledge gaps

The main sources of uncertainty and knowledge gaps summarised here are described in detail in a report for the UK Government Office for Science (Edwards, 2017) and in a Met Office report into updates since UKCP09 (Met Office, 2016).

2.2.3 Ice sheet sensitivity: Antarctic

Uncertainty in ice sheet sensitivity to climate change mainly concerns Antarctica rather than Greenland. Since the publication of AR5 in 2013, new evidence has emerged suggesting that part of the West Antarctic ice sheet may be collapsing. Projections for such a collapse vary widely and should be interpreted carefully. However, these projections potentially increase sea level rise to above the AR5 'likely ranges'[2]. The extreme end of this range estimates global sea level rise of around 2.50m (Edwards, 2017). The Met Office highlight the rapidly evolving scientific knowledge relating to the extreme H++ scenarios as new information on ice sheets becomes available (Met Office, 2016). In their 2017 **Indicator Assessment** of sea level, the European Environment Agency (EEA) discuss the recent research on high-end scenarios for Antarctic and Greenland ice sheet melting, which they describe as 'controversial' and 'speculative' but nevertheless important considerations when planning long term coastal risk management, especially in densely populated areas (EEA, 2017).

[1] Note: As this is a general correction at global scale, it is likely to be less accurate than the Met Office estimate of 20-30% increase in sea level rise, which takes regional effects into consideration.
[2] under the highest emissions scenario, the 'likely ranges' indicate a global mean sea level increase of up to 0.98m (Met Office, 2016)

2.2.4 Other gaps

Other gaps identified in the literature by Edwards (Edwards, 2017) include storms, coastal processes, infrastructure exposure and vulnerability, 'correlated risks' (e.g. combined river and coastal flooding, infrastructure interdependencies), indirect and hard-to-measure losses, and a lack of 'uncertainty quantification' (statistical quantification of uncertainties; e.g. for comparing contribution of different types of uncertainty). There is a strong emphasis in the literature on the increased risk due to socio-economic factors, with the contribution of development in coastal areas to increasing exposure and vulnerability (Vousdoukas *et al.*, 2018).

2.2.5 Summary: Sea level rise projections for the 21st century

- Global estimates are generally in the range 25cm – 1m (with a few of 1.5-2.5m)
- AR5 projections plus the possible collapse of the West Antarctic ice sheet; range up to 2.5m
- The Met Office estimate that UKCP18 projections will be 20-30% higher than the UKCP09 H++ scenario

3 Sources used for adaptation guidance

3.1 CCRA2

The CCRA2 (and recommendations from the ASC based thereon) used analysis provided by Sayers et al, based on UKCP09 projections (Sayers *et al.*, 2015). The UKCP09 projections are underpinned by data from the IPCC AR4, based on the SRES A1B scenario.

More recent evidence including AR5 indicates that the SRES (Special Report on Emissions Scenarios) systematically underestimate sea level rise and the associated risks. The SRES scenarios have been replaced by a new set of scenarios, the Representative Concentration Pathways (RCPs), used in AR5.

Adaptation action responding to risks identified in CCRA2 may therefore be insufficient in light of the updated projections. For example, the Firth of Clyde study considered adjusted UKCP09 projections to account for the AR5 knowledge, resulting in a guideline 60% increase in projected sea level rise (Hansom, J., Maxwell, F., Naylor, L. & Piedra, 2017).

While the projections used in the CCRA2 are fairly comprehensive, Edwards highlights additional factors that may increase the overall risk for the UK. These include socio-economic factors; population increase, demographic changes and impacts on health, impacts on ICT infrastructure, and on natural capital. There may also be compensating factors such as higher levels of flood protection (Edwards, 2017).

3.2 Dealing with changes in projections (or progression) of sea level rise

Planning adaptation action involves making decisions under uncertainty. Taking an adaptive management or iterative approach allows plans to be drawn up and action to start. Available options in an iterative plan can be reviewed at staged decision points. For example, if a change in the speed of progression of sea level rise is detected or projected, measures can be scaled up or down accordingly. The Thames Estuary 2100 plan is frequently cited as an exemplar of a flexible, iterative plan (Edwards, 2017). Scotland already has examples of policy designed to accommodate this type of approach, for example Shoreline Management Plans can be reviewed by local authorities at any time. This flexibility enables responsiveness to changing risk scenarios and situations (ASC, 2016b).

3.3 IPCC AR5

The contribution of Working Group II to the AR5 recognises how climate change risks evolve over time, and builds from existing experience (IPCC, 2014). An iterative risk management approach is recommended for decision-making, particularly under conditions of ongoing uncertainties and long timeframes, influenced by multiple climate and non-climate related factors. The report notes that 'Assessment of the widest possible range of potential impacts, including low-probability outcomes with large consequences, is central to understanding the benefits and trade-offs of alternative risk management actions. The complexity of adaptation actions across scales and contexts means that monitoring and learning are important components of effective adaptation.' (ibid).

The key elements captured in this approach are the ability to make decisions and take action using the best available information (accepting that knowledge and circumstances are constantly evolving), while the process of taking action (and monitoring its impacts) will in turn lead to better informed future actions, 'learning by doing'.

3.4 Firth of Clyde report

*The Firth of Clyde SNH report p*rovides an example of using available knowledge to compile a report that can be used in long-term planning for adaptation, including local development planning, flood risk management, and regional marine planning. Although detailed projections for Scotland were not available, the authors were able to use the latest evidence available, from IPCC AR5, to adjust older data to give the best available estimate at that time (Hansom, J., Maxwell, F., Naylor, L. & Piedra, 2017). In future, UKCP18 will translate the AR5 projections to small scale geographic areas. However, similar corrections could be applied in future as new knowledge becomes available; e.g. as discussed above, new evidence suggests the AR5 sea level rise projections may be exceeded.

3.5 EEA Indicator Assessment

With regard to coastal flooding, the EEA recognise that while adaptation can significantly reduce potential impacts, costs can be high. It is therefore important to consider individual locations. For locations that are projected to experience a large increase in frequency of flooding, more robust adaptation measures should be considered, including higher defences or managed retreat (EEA, 2017).

4 Bibliography

ASC (2016a) *Scottish Climate Change Adaptation Programme : An independent assessment for the Scottish Parliament*. London. Available at: https://www.theccc.org.uk/publication/scottish-climate-change-adaptation-programme-an-independent-assessment-for-the-scottish-parliament/.

ASC (2016b) *UK Climate Change Risk Assessment 2017: Evidence Report. Summary for Scotland, Adaptation Sub-Committee of the Committee on Climate Change*. London. Available at: https://documents.theccc.org.uk/wp-content/uploads/2016/07/UK-CCRA-2017-Scotland-National-Summary.pdf.

Edwards, T. (2017) *Future of the Sea: Current and Future Impacts of Sea Level Rise on the UK. Foresight-Future of the Sea Evidence Review*. London. Available at: https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/663885/Future_of_the_sea_-_sea_level_rise.pdf.

EEA (2017) *Global and European sea level. Indicator Assessment*. Copenhagen. Available at: https://www.eea.europa.eu/data-and-maps/indicators/sea-level-rise-5/assessment .

Hansom, J., Maxwell, F., Naylor, L. & Piedra, M. (2017) *Impacts of sea-level rise and storm surges due to climate change in the Firth of Clyde. Scottish Natural Heritage Commissioned Report No. 891*. Available at: https://www.nature.scot/snh-commissioned-report-891-impacts-sea-level-rise-and-storm-surges-due-climate-change-firth-clyde.

Hansom, J.D., Fitton, J.M., and Rennie, A. F. (2017) *Dynamic Coast -National Coastal Change Assessment: Summary*. Available at: http://www.dynamiccoast.com/files/reports/NCCA - Summary - 3 page.pdf (Accessed: 29 September 2017).

IPCC (2013) *Climate Change 2013: The Physical Science Basis. Contribution of Working Group I to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change*. Cambridge University Press, Cambridge, UK and New York, NY, USA. Available at: https://ipcc.ch/report/ar5/wg1/.

IPCC (2014) *Summary for Policymakers. In: Climate Change 2014: Impacts, Adaptation and Vulnerability. Part A: Global and Sectoral Aspects. Contribution of Working Group II to the 5th Assessment Report of the Intergovernmental Panel on Climate Change*. Cambridge University Press, Cambridge, UK and New York, NY, USA. Available at: http://www.ipcc.ch/report/ar5/.

Met Office (2016) *Is UKCP09 still an appropriate tool for adaptation planning ?* Exeter. Available at: http://ukclimateprojections.metoffice.gov.uk/media.jsp?mediaid=88736&filetype=pdf.

Monfries, R. (2018) *Climate risks and policy gaps. Unpublished CXC report.*

Rennie, A. F. and Hansom, J. D. (2011) 'Sea level trend reversal: Land uplift outpaced by sea level rise on Scotland's coast', *Geomorphology*. Elsevier, 125(1), pp. 193–202. doi: 10.1016/J.GEOMORPH.2010.09.015.

Sayers, P. B., Horritt, M., Penning-Rowsell, E. C. and McKenzie, A. (2015) *Climate Change Risk Assessment 2017. Projections of future flood risk in the UK. Project A.* doi: 10.13140/RG.2.1.1176.8563.

SEPA (2018) 'Flood Risk Management in Scotland. 2018 consultation on Potentially Vulnerable Areas. FAQs', pp. 1–4. Available at: https://www.sepa.org.uk/media/352559/2018-consultation-on-pvas-faqs.pdf.

Vousdoukas, M. I., Mentaschi, L., Voukouvalas, E., Bianchi, A., Dottori, F. and Feyen, L. (2018) 'Climatic and socioeconomic controls of future coastal flood risk in Europe', *Nature Climate Change*. Springer US, 8(September). doi: 10.1038/s41558-018-0260-4.

5 Annex 1: Main Sources summarised

Report	Data source	Analysis/currency	Scale	Relevant findings
SCOTLAND/UK				
UK CCRA2; ASC assessment of SCCAP1	UKCP09, based on IPCC AR4 (used CMIP3), and analysis by Sayers et al.	Now thought to systematically underestimate sea level rise; superseded by IPCC AR5.	UKCP09 enables analysis at regional level	Underestimates future sea level rise; therefore adaptation actions informed by this source may be insufficient in light of new knowledge.
SNH Firth of Clyde study	UKCP09, applies an adjustment to account for the gap between AR4 and AR5.	Appears to be best currently available estimate at a Scottish regional scale, with an allowance to account for updated AR5 projections.	Regional level within Scotland, but correction is estimated from global-scale projection.	Good estimate at regional level in Scotland, until UKCP18 is available.
NFRA 2018	SEPA hazard maps	Based on UKCP09 analysis; and 2080, high emissions scenario (as described in Flood Risk Management Strategies).	Expected sea level rise varies around the coastline; taken into account through a future coastal scenario and a consideration of expected changes in coastal locations.	SEPA will take UKCP18 projections into account as soon as available; however significant analysis and interpretation will be required (SEPA, 2018).
UK Government Office for Science	Covers all main sources including CCRA2 and IPCC AR5	Includes IPCC AR5 and more recent studies; generally reflects current state of evidence.	UK level.	Up-to-date analysis for the UK. Includes adaptation response options.

Met Office	Science updates since UKCP09; primarily IPCC AR5.	Generally reflects current state of evidence.	UK level.	Up-to-date analysis for the UK.
GLOBAL				
C40 Cities report	CMIP5 (Coupled Model Intercomparison Project) ensemble of climate models. The CMIP5 models underpin the latest AR5 data, superseding UKCP09 based projections.	Current. Uses a high-end RCP8.5 scenario[3].	Not clear to what extent regional variation is accounted for.	Specific Scotland data not included. The 4 cities in Scotland large enough for consideration in the report are all projected to experience at least 0.5m of SLR by the 2050s under RCP8.5 (relative to a 2000-2004 baseline).
IPCC AR5	CMIP5 ensemble of climate models.	Current.	Global. UKCP18 will provide the means to extract usable regional level data for Scotland.	Significant change (increase) in sea level rise projections compared to AR4. Recent research suggests that Antarctic ice sheet collapse may result in increased levels of sea level rise, than those projected by AR5.
EEA Indicator Assessment	Covers all main sources including IPCC AR5	Current. Details projections using the range of AR5 scenarios: RCP2.6; RCP4.5; RCP6.0; RCP8.5.	Europe, including specific Scottish locations.	Up-to-date analysis including projected change in frequency of flooding events at Scottish locations, based on AR5 RCP4.5

[33] RCP8.5 a business-as-usual emissions scenario, with projected global temperature rises of well over 2°C this century (*EC April 2017 – cite*)

6 Annex 2. Methodology used by SNH Firth of Clyde project

This project used UKCP09 projections. There is currently no data for the Firth of Clyde derived from the more up-to-date AR5. A comparison between AR4 and AR5 data was attempted. Most of the RCP scenarios are not directly comparable between AR4 and AR5; however there is one scenario common to both: A1B, which is a medium emissions scenario. Comparing central estimates of global sea level rise under A1B using AR4 and AR5, it was found that AR5 increased sea level rise by 60% compared to AR4 projections[4]. This appears to be the best estimate that has been used for Scotland to date, and the best available until UKCP18 is launched in November 2018. As UKCP18 is based on AR5 outcomes, it will provide the means to translate this into small scale geographical areas (i.e. usable climate data for planners and decision-makers.

Annex 1A of the SNH Report details the data sources and methodology for sea level rise figures.