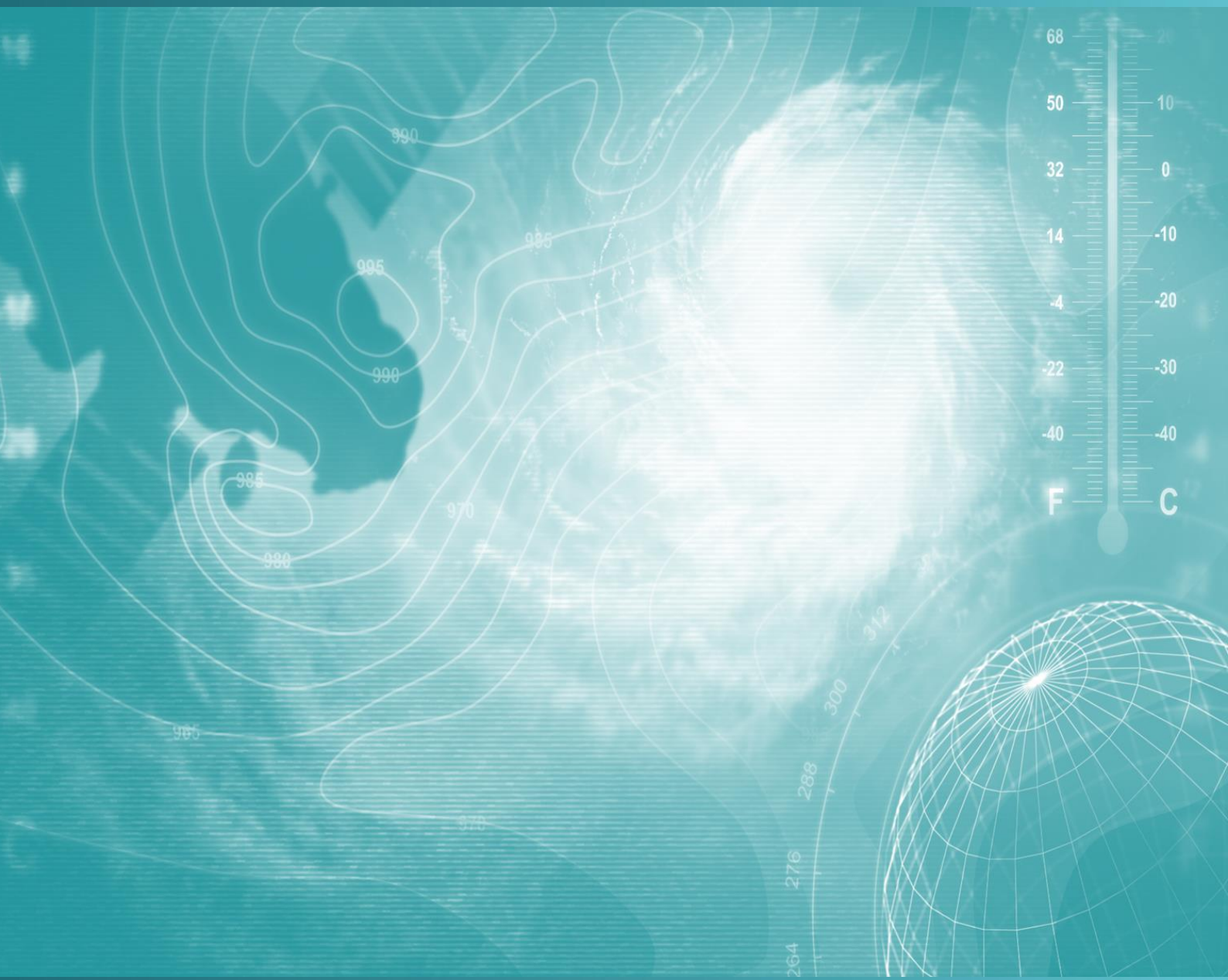
Office for Nuclear Regulation

Research Briefing

Office for Nuclear Regulation Expert Panel on Natural Hazards: sub-panel on meteorological and coastal flood hazards



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Research Briefing

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Contents

Purpose of the Research Briefings

The purpose of the Research Briefings is to highlight recently published research that the Office for Nuclear Regulation (ONR) may consider when developing its Technical Assessment Guide (TAG) on External Hazards[1] and the supporting annexes on Meteorological Hazards and Coastal Flood Hazards.

The Research Briefings are produced by our Expert Panel on Natural Hazards, specifically members of the Sub-Panel on Meteorological and Coastal Flood Hazards[2]. The Research Briefings identify research relevant to meteorological and coastal flood hazards, including climate change[3].

Content

The papers included in the Research Briefings are selected by our Expert Panel on Natural Hazards on a sampling basis. As experts in their respective fields, the Expert Panel are best placed to identify and highlight to us changes in scientific understanding, research trends including shifts in the scientific consensus, and new areas of research.

There are an extensive number of books, scientific journals, research papers and notes published each year relating to meteorological and coastal flood hazards. To provide an insight into the evolution of scientific consensus and understanding the Research Briefings will focus on research that meets the criteria described on the ONR website.

The Research Briefings will only sample some of the available research and are intended to be supplemented by the Expert Panel highlighting other relevant research to us, for example, via the Expert Panel meetings[4]. The papers identified by the Expert Panel will be based on themes and words defined on the ONR website.

ONR's Position

The Research Briefings provide us with insight into recent scientific advances in relation to meteorological and coastal flooding hazards, and climate change. Each research item included in a Research Briefing will not by itself constitute relevant good practice. Rather, the Research Briefings will highlight any trends or significant changes in scientific understanding in relation to these hazards. This information will ultimately inform our regulatory guidance in relation to meteorological and coastal flooding hazards.

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1 NS-TAST-GD-013 available via the ONR website: http://www.onr.org.uk/operational/tech_asst_guides/ns-tast-gd-013.htm

2 Details of ONR's Expert Panel on Natural Hazards are available via the ONR website: http://www.onr.org.uk/external-panels/natural-hazards-panel.htm

3 Further information available via the ONR website: https://www.onr.org.uk/climate-change/index.htm

4 Minutes of the Expert Panel meetings are published to the ONR website: http://www.onr.org.uk/external-panels/natural-hazards-panel.htm

Research Item 1

Delicate seafloor landforms reveal past Antarctic grounding-line retreat of kilometers per year

Dowdeswell, J.A., Batchelor, C.L., Montelli, A., Ottesen, D., Christie, F.D.W., Dowdeswell, E.K. and Evans, J., 2020. Delicate seafloor landforms reveal past Antarctic grounding-line retreat of kilometers per year. Science, 368(6494), pp.1020-1024.

Key words: Sea-level rise, Ice-sheets, Antarctic ice-sheet.

Summary

Sea-floor sedimentary deposits in Antarctica reflect changes in the position of where land ice interacts with the sea floor (grounding line). Analysis of these deposits has enabled researchers to reconstruct the retreat rate of the grounding line and therefore the ice sheet. The authors argue that the retreat rate was up to 40-50m per day over short periods during deglaciation, and extrapolate this to 10-18km per year. This is an order of magnitude greater than current retreat rates measured from the fastest retreating outlet glaciers in Antarctica, and suggests ice loss from such outlet glaciers is highly dynamic.

Context

Current estimates of future sea-level rise are challenged by incomplete information on the ways in which large ice sheets are likely to respond to climate change. Some researchers argue that climate model projections of sea-level rise underestimate the rate and eventual magnitude of rise. Several recent papers have suggested that the ice sheets are more dynamic than current observations or modelling has allowed, and argue multi-metre, sea-level rise is possible by the end of this century. This paper supports this conclusion.

Expert Panel View: The work supports current scientific consensus

Further commentary from the ONR and the Expert Panel on Natural Hazards

This work supports the scientific consensus that the West Antarctic ice-sheet is more dynamic than Eastern Antarctica, and likely to be more responsive to climate change[5]. Rapid retreat of the ice sheet could increase the projected rate of global sea-level rise. Further work is needed to understand if such rapid retreat occurs simultaneously across the ice sheet or is a result of regional variations in driving variables. Consideration of a credible maximum scenario to inform a managed adaptive approach to sea-level rise is considered to be an appropriate response from ONR and licensees. An example of the credible maximum scenario is the current H++ scenarios based on UKCP09 for sea-level rise and storm surge. It is already expected that these scenarios will be updated for UKCP18[6].

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5 See UKCP18 Marine Report: https://www.metoffice.gov.uk/binaries/content/assets/metofficegovuk/pdf/research/ukcp/ukcp18-marine-report-updated.pdf

6 There is currently an ongoing research project on High Impact Scenarios and Storylines. More details are available on the UK Climate Resilience Programme website: https://www.ukclimateresilience.org/projects/high-impact-scenarios-and-storylines/

Research Item 2

Causes of higher climate sensitivity in CMIP6 models

Zelinka, M.D., Myers, T.A., McCoy, D.T., Po-Chedley, S., Caldwell, P.M., Ceppi, P., Klein, S.A. and Taylor, K.E., 2020. Causes of higher climate sensitivity in CMIP6 models. Geophysical Research Letters, 47(1), p.e2019GL085782.

Key words: Climate Models, Coupled Model Intercomparison Project Phase 6 (CMIP6), Climate sensitivity, Equilibrium climate sensitivity.

Summary

The authors use the latest climate models from the Coupled Model Intercomparison Project Phase 6 (CMIP6) suite to estimate future climate sensitivity. This reflects the temperature response to doubling of atmospheric carbon dioxide (CO_2) above pre-industrial levels. It differs from equilibrium climate sensitivity (ECS) estimates because it allows radiative response at the top of the atmosphere to change rapidly. The authors show that the temperature response to CO_2 doubling is in the range 1.8-5.6K[7], a larger upper limit compared to previous projections that suggested warming would be in the range 1.5-4.5K.

Context

For over 100 years there have been attempts to constrain the expected temperature rise if atmospheric CO_2 doubled over pre-industrial levels. This is called the ECS, which is the standard metric for sensitivity assessments, and represents the global mean-surface temperature after reaching 550 parts per million of CO_2 in the atmosphere. The temperature sensitivity of the atmosphere to CO_2 emissions drives government and international emissions policy. Since 1979 there has been a consensus that ECS averages around 3°C. The latest climate model projections in CMIP6 appear to show a higher sensitivity (more in line with assessments developed from the palaeoclimate record).

Expert Panel View: This work challenges the current scientific understanding

Further commentary from the ONR and the Expert Panel on Natural Hazards

If climate sensitivity is higher than previously predicted then global temperature rise may also be more onerous than expected. The CMIP6 project is beginning to report and ONR and the Expert Panel will monitor the research published from this project to inform the development of regulatory guidance such as updates to ONR's TAG on External Hazards (TAG 13) and supporting Annexes.

[7] K is the symbol for Kelvin, which is the base unit of temperature in the International System of Units (SI)

Research Item 3

On the extraordinary winter flood episode over the North Atlantic Basin in 1936

Ballesteros-Cánovas, J.A., Stoffel, M., Benito, G., Rohrer, M., Barriopedro, D., García-Herrera, R., Beniston, M. and Brönnimann, S., 2019. On the extraordinary winter flood episode over the North Atlantic Basin in 1936. Annals of the New York Academy of Sciences, 1436, pp.206-216.

Key words: River flooding, Atmosphere-ocean modes.

Summary

The authors collected discharge data from all major rivers draining to the North Atlantic Basin to identify links between winter floods over the last century and the main atmosphere-ocean modes[8]. Discharge data were combined with historical flood records and flood reconstructions based on tree-ring data. The authors have identified clear links between atmosphere-ocean coupled modes and large flood events; specific atmosphere-ocean modes[9] lead to an increased probability of flooding over the North Atlantic Basin.

The authors also identified the likely drivers[10] of the extreme winter 1935-36 floods in Western Europe (amongst the most extreme of the past 120 years). The specific combination of atmosphere-ocean modes linked with these floods is extremely rare for the data period, and could aid prediction of future extreme flooding. The authors conclude that the effects of the atmosphere-ocean modes need to be considered in combination rather than individually.

Context

A recurrent theme in analysing the magnitude and frequency of extreme floods is that the length of instrumental data sets is usually insufficient to capture flood variability. Climate models have been used to distinguish between the causes of flood variability. Several papers suggest that recent large floods (e.g. the Millennium Floods of northern England) would have been unlikely to have occurred without human activity and related climate change (e.g. Pall et al., 2011[11]). However, the past flood record suggests that extreme floods have occurred when human activity was insignificant. This means flooding may be inherently more variable than allowed for in climate models.

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8 Namely the: Atlantic Meridional Oscillation (AMO), Arctic Oscillation (AO), Pacific Decadal Oscillation (PDO) and North Atlantic Oscillation (NAO)

9 Both positive AMO phases and negative AO/NAO phases were associated with enhanced flood probability

10 A combination of extremely positive AMO/PDO and negative AO/NAO modes.

11 Pall, P., Aina, T., Stone, D.A., Stott, P.A., Nozawa, T., Hilberts, A.G.J., Lohmann, D. and Allen, M.R., 2011. Anthropogenic greenhouse gas contribution to flood risk in England and Wales in autumn 2000. Nature, 470, pp 382-385.

Expert Panel View: The work supports current scientific consensus

Further commentary from the ONR and the Expert Panel on Natural Hazards

This study can aid prediction of extreme future flood events in western Europe. ONR expects monitoring to be provided to meet the expectations of a number of licence conditions. Monitoring is expected to provide warning of the occurrence of external hazards events that could exceed a specified level. Although such extreme floods are, by definition, rare, there is concern that such events might become more common in future as climate change continues. In addition to including the effects of climate change over the lifetime of a facility in the design basis event definition, ONR's Safety Assessment Principles (SAPs) expect licensees to demonstrate plant resilience against beyond design basis events including flooding. Following the Fukushima Daiichi incident, existing nuclear sites participated in the EU stress tests[12] to demonstrate resilience against extreme events, whilst new nuclear build has implemented new measures based on the lessons learned from the Fukushima incident. For example, this includes the addition of passive cooling systems for response to beyond design basis events, which can maintain fundamental safety functions.

[12] Details available on the ONR website: https://www.onr.org.uk/fukushima/european-council-stress-tests.htm

Research Item 4

Land ice melting and sea level rise

Edwards, T.L., Nowicki, S., Marzeion, B., Hock, R., Goelzer, H., Seroussi, H., Jourdain, N.C., Slater, D.A., Turner, F.E., Smith, C.J. and McKenna, C.M., 2021. Projected land ice contributions to twenty-first-century sea level rise. Nature, 593(7857), pp.74-82.

Key words: Sea-level rise, Ice Sheets; Antarctic Ice Sheet; Greenland Ice Sheet.

Summary

Researchers used Shared Socioeconomic Pathways (SSPs) from the Intergovernmental Panel on Climate Change (IPCC) 6th Assessment Report to assess future sea-level rise in response to melting of the world's glaciers and ice sheets. The authors show that the land-ice contribution to sea-level rise by 2100 would decrease if global warming is limited to 1.5°C above pre-industrial levels (e.g. the median figure decreases from 25cm to 13cm).

The authors also produce some 'risk averse' projections based on high impact, but plausible, assumptions of sea-level change. These projections use models most sensitive to basal melting in Antarctica, but did not include a marine ice-cliff instability component, which could increase sea-level rise by tens of centimetres if shown to be a valid mechanism. Despite this omission, the 'risk averse' projections indicate Antarctic ice loss could be five times higher than the 'standard' projections. Under the 'risk averse' projections and current policy agreements, the median land-ice sea level contribution increases to 42cm (5–95% range 25 to 67cm). The authors conclude there remains considerable uncertainty in sea-level rise, which needs to be accounted for in adaptation planning.

Context

Projections of sea-level change expected from the melting of land ice have been based on the Ice Sheet Model Intercomparison Project (ISMIP6) and the Glacier Model Intercomparison Project (GlacierMIP) that use older climate projections, models and processes. This paper uses a different approach, employing a simpler assessment of sea-level rise using land-ice melt as a function of global mean surface air temperature, Greenland marine calving, and Antarctica ice-shelf basal melting and collapse.

Expert Panel View: The work supports current scientific consensus

Further commentary from the ONR and the Expert Panel on Natural Hazards

This paper produces possible sea-level changes for different scenarios. There is uncertainty with the rate and height of sea-level rise that varies depending on the modelling assumptions. ONR's guidance expects a managed adaptive approach[13] to be used to manage the uncertainty related with sea-level rise and climate change. This approach is

[13] Further details on the ONR website: https://www.onr.org.uk/climate-change/faqs.htm

detailed in the ONR and the Environment Agency Joint Advice Note[14]. The managed adaptive approach aims to build flexibility into options selected and decisions made today, so they can be adjusted in response to what happens in future, ensuring that sites remain safe. The managed adaptive approach is appropriate, given current climate change uncertainty and the timescales for the development of the effects on sea level and meteorological events. A managed adaptive approach expects evaluation of a credible maximum scenario that should consider the latest scientific understanding of future sea-level projections. It is also important that trigger points are clearly defined, so that once reached, the planned measures can be implemented to reduce risks associated with sea-level rise and flooding.

[14] The ONR and EA joint advice note “Principles for Flood and Coastal Erosion Risk Management”. Available on the ONR website: https://www.onr.org.uk/documents/2017/principles-for-flood-and-coastal-erosion-risk-management.pdf

Research Item 5

Marine Ice Cliff Instability

Bassis, J.N., Berg, B., Crawford, A.J. and Benn, D.I., 2021. Transition to marine ice cliff instability controlled by ice thickness gradients and velocity. Science, 372(6548), pp.1342-1344. And Commentary by: Golledge, N.R. and Lowry, D.P., 2021. Is the marine ice cliff hypothesis collapsing? Science, 372(6548), pp.1266-1267.

Key words: Sea-level rise, Antarctic ice sheet.

Summary

Recent work suggests that the ice sheet margins might respond quickly to ocean warming, leading to collapse of ice cliffs and rapid retreat of the ice sheet. This Marine Ice Cliff Instability (MICI) hypothesis suggests that a sea-level rise of around 1m from Antarctica alone might be expected by 2100. Understanding of how ice cliffs collapse and under what conditions is lacking. This paper shows that the critical height required for collapse depends on how rapidly a marine ice cliff becomes exposed by break up of ice shelves. Resistive forces at the front of the marine ice cliff (such as those produced by icebergs and ice left behind during calving events) can slow or prevent the retreat of ice cliffs. The authors also suggest that ice cliffs might be stable if the speed of ice flow or sub-ice bed slope are within certain limits.

Context

The West Antarctic ice sheet is projected to contribute most to future sea-level rise in the next century and there have been recent concerns that the ice sheet could respond rapidly to future warming. This risk is one of the leading contributions to uncertainties in projections of sea-level rise. MICI has been proposed as a mechanism that could produce rapid ice sheet recession and sea-level rise. However, analysing these processes has previously relied on semi-empirical methods. This paper has developed a physical model of ice-cliff stability that suggests they may be less vulnerable to warming than previously suggested.

Expert Panel View: This work challenges the current scientific understanding

Further commentary from the ONR and the Expert Panel on Natural Hazards

Improved understanding of ice-cliff processes is required to develop robust projections of ice-sheet stability and future sea-level rise. This work challenges the current understanding by indicating ice cliffs might be less vulnerable to warming than previously suggested, thereby so potentially reducing the contribution of sea-level rise from West Antarctica. As described for the previous paper, one way to address the significant uncertainty surrounding climate change in the future is by adopting the managed adaptive approach.

Research Item 6

Atmospheric rivers

Payne, A.E., Demory, M.E., Leung, L.R., Ramos, A.M., Shields, C.A., Rutz, J.J., Siler, N., Villarini, G., Hall, A. and Ralph, F.M., 2020. Responses and impacts of atmospheric rivers to climate change. Nature Reviews Earth & Environment, 1(3), pp.143-157.

Key words: Atmospheric Rivers, Extreme Rainfall, River Flooding.

Summary

Atmospheric rivers (ARs) extend thousands of kilometres in length and hundreds of kilometres in width. They transport moisture in the bottom three kilometres of the atmosphere. ARs are estimated to comprise up to 90% of poleward moisture transport, with total transport in a North Pacific AR several times the discharge of the Amazon River. In Western Europe, ARs are estimated to provide 20-30% of annual precipitation, this is often spatially and temporally concentrated resulting in extreme rainfall events and associated flooding.

Context

Improvements in global climate models (GCMs) have resulted in a better understanding of AR location, intensity and frequency of occurrence compared with previous climate model projections. New ‘weather resolving’ GCMs allow examination of high-impact events in the context of climate variability and change. This will provide useful information on the impact of ARs on water resources and prediction of flooding events. In the UK, ARs are the dominant contributor to winter precipitation extremes and floods. For example, in a study of nine different river basins, 40–80% of flood events were associated with persistent ARs.

Expert Panel View: The work supports current scientific consensus

Further commentary from the ONR and the Expert Panel on Natural Hazards

This work supports the consensus that ARs are a possible source of extreme rainfall and associated flooding. ONR’s TAG on External Hazards[15] has considered the potential for extreme hydrological events associated with ARs. Topography plays a significant role in mediating the impact of large-scale weather systems that affect the British Isles including ARs. ONR’s SAPs expects licensees to take account of local physical aspects and consider extreme hydrological phenomena including accounting for the reasonably foreseeable effects of climate change on relevant hazards over the lifetime of the facility. Licensees are also expected to demonstrate the resilience of their facility against beyond design basis events including flooding.

[15] NS-TAST-GD-013 Annex 2 on Meteorological Hazards has considered advice from the associated expert panel paper in relation to atmospheric rivers and their significance on UK climate and hazard occurrence. The TAG-013 suite of documents is available on the ONR website: https://www.onr.org.uk/operational/tech_asst_guides/ns-tast-gd-013.htm

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Any enquiries related to this document should be sent to contact@onr.gov.uk
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