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Impacts of Sea Ice Change on Scottish Climate

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Summary

A number of recent climate trends for Northern Europe may be linked to Arctic sea ice loss. Similarly, projected changes in climate may be enhanced or tempered by Arctic sea ice loss. The literature at present is inconclusive regarding these relationships, and scientists are working to understand any causal relationships that exist between sea ice loss and four observed or projected changes:-

(a) Colder winters (limited supporting evidence for near-term change only)

(b) Wetter summers (a small effect compared to internal variability)

(c) More persistent weather extremes (mechanisms uncertain)

(d) Colder upper ocean temperatures (likely, but contribution from sea ice is undetermined)

The impacts are uncertain for a number of reasons. Firstly, large internal variability is present in the climate system, causing natural fluctuations. This means that the observational record of around 40 years may not show longer-term natural cycles, even if it were perfectly accurate. Secondly, poor understanding of physical processes and imperfect modelling limits confidence in climate model representation. Thirdly, unpicking the various inter-connected processes to establish causation is difficult. Lastly, some of the possible impacts compete and may also be obscured by the overall global warming trend. More research is required to reach robust conclusions about impacts of sea ice decline.

Impacts are discussed individually below. Scientific terms are suffixed with an asterisk and defined in a glossary.

The Current State of Arctic Sea Ice

The US National Snow and Ice Data Centre (NSIDC) publish an interactive chart of the current Arctic sea ice extent. This shows this year's sea ice extent (2015; blue line), 2012, when a record low extent was observed (green dashed line) and the 1981--2010 average and range (black line and grey shading respectively). Other years can be selected interactively. These plots show that although recent years (2013--2015) have had greater extents than 2012 they still represent very little sea ice relative to earlier decades.

Proposed Impacts of Arctic Sea Ice Decline

Colder Winters

Recent change: Since 1990, despite the overall global warming trend, winters in North Western Europe have cooled[1] and the number of days below freezing in mid-latitudes has increased[2].

Proposed mechanisms: (i) Reduction of sea ice cover exposes the ocean surface, leading to increased atmospheric water content and therefore increased Siberian snow cover, resulting in colder ground temperatures. These trigger a large area of higher-than-normal pressure which results in changes in the upper atmosphere*[1]. (ii) A decrease in sea ice in the Barents/Kara Seas directly creates an area of high pressure in the atmosphere above the Arctic Ocean due to the increase in surface temperature[3].

Both (i) and (ii) warm and weaken the polar vortex*. This in turn can affect the atmospheric circulation at the surface, resulting in patterns which represent negative Arctic Oscillation (AO)* and North Atlantic Oscillation (NAO)* pressure indices[2]. These are associated with wind anomalies which bring cold Arctic air over Europe and Asia, resulting in cold winters.

Evidence: The proposed mechanism relies on a long series of relationships, not all of which are well understood, and which may be acting in opposite directions. However, a correlation between reduced sea ice and increased Siberian snow cover [mechanism (i)] is confirmed by several climate modelling studies[4,5]. Modelling experiments find recent sea ice change in the Barents/Kara Seas to be a powerful driver of atmospheric response[3,6] [mechanism (ii)], although only a quarter of cold winter months are found to coincide with Barents/Kara sea ice decline in simulations of the recent past[7].

Reduced sea ice cover has been associated with negative AO/NAO in many simulations corresponding to recent years, but the reaction of the atmosphere in these simulations differs both in location and in timing [6,8,9]. Furthermore, the response is small and can be masked by atmospheric internal variability, with some simulations even showing an opposite response[9]. Analysis of observations over the past three decades link snow cover differences to Arctic sea ice changes, and find a negative AO-like response to low autumn sea ice, but again the exact response of the atmosphere differs between studies [10].

Future projections: Model projections over the next century show that low sea ice extent continues to create an atmospheric response with some similarities to a negative NAO[5] and may even have a more dominant role in the occurrence of cold winters[7]. However, models also show that winter cold extremes are not likely to increase over the 21st century[11], and some show a clear reduction[7]. Any tendency for Arctic sea ice loss to favour colder European winters is projected to be negated by the global warming trend by the end of the 21st century.

Wetter Summers

Recent change: Relative to the 1981 to 2010 average, the six summers from 2007 to 2012 were unusually wet in Northern Europe, a sequence unprecedented in the last three decades[12].

Proposed mechanism: It is well-established that wetter summers in Northern Europe (including Scotland) occur when the jet stream* is displaced southwards of its normal position, thus passing over Northern Europe[13,14] . It has been suggested that this could be partially caused by reduced sea ice causing changes in the Arctic atmosphere, with impacts seen at other latitudes (due to planetary wave* transport)[12].

Evidence: The association between reduced sea ice and wetter summers in Northern Europe is supported by observational evidence[15]. A large number of simulations in a climate model show that low ice shifts the jet stream southwards and results in a statistically significant increase in summer precipitation in Northern Europe[12]. However, the response is smaller than year-to-year natural variability. Other influences, such as Atlantic and equatorial Pacific sea surface temperatures, play a large role in the rainfall trend and could easily negate the impact of sea ice decline[12].

Future projections: Arctic sea ice loss is found to significantly affect the atmosphere only in winter at the end of the 21st century,[5] suggesting future impacts on European summer weather are limited.

More Persistent Weather Extremes

Recent change: The last fifteen years have seen 'an exceptional number of unprecedented extreme weather events,' such as heatwaves, prolonged heavy rainfall and drought[16] in Europe.

Proposed mechanism: Extremes can be caused when weather systems are persistent, remaining in the same place for several weeks. High-latitude warming, which can be linked to sea ice decline, has been proposed to cause (i) a reduction in west-east winds due to a reduced temperature difference between the poles and the equator, and (ii) an increase in planetary wave* amplitude, as there are more air pressure changes in the warmer polar regions than in mid-latitudes[17]. These result in slower circulation systems, a slower and more meandering jet stream, and therefore increased persistence of mid-latitude weather[17].

Evidence: This conclusion is based on analysis of observed pressure fields[17]. (i) is supported by other work which also found a reduction in west-east winds associated with sea ice loss in the 2000s[18]. However mechanism (ii) has been shown to be dependent on the methodology and metrics chosen, in particular how the waves are described[19, 20]. Furthermore, some decreased weather system blocking* in high-latitudes has been identified in observations over the last half-century[21], which would in fact reduce weather persistency. More investigation is required before any robust conclusions can be drawn about the proposed link between more persistent weather and Arctic changes. However, an alternative mechanism suggests that, as the Arctic warms, there might be less (or weaker) cold extremes. This is because very cold weather is often associated with winds from the North or North-East; as the Arctic warms, these winds also warm, leading to weather which is less cold.[22,23]

Future projections: Due to uncertainty in the mechanism and disagreement over classification methods, the future likelihood has not been assessed.

Colder Upper Ocean Temperatures

Recent change: The Atlantic meridional overturning circulation (AMOC)* has slowed down over the last decade,[24] reducing northward ocean heat transport. A particularly strong reduction in 2009/10 is thought to have reduced mid-latitude temperatures and contributed to the negative NAO with cold winter conditions [25].

Proposed mechanism: When sea ice forms, it pushes out salt, which sinks and drives the AMOC. Arctic sea ice melt releases freshwater and reduced ice formation reduces salt expulsion into the Arctic Ocean.[26] This, together with increased local precipitation as more ocean is exposed to the atmosphere,[27] causes an outflow of fresh water and slows down the AMOC [27], reducing sea surface temperature in the North Atlantic.

Evidence: The reduction in salinity of the Arctic as a result of increased precipitation, river runoff and reduced ice formation is observed in model simulations over the 20th and 21st centuries[28, 26, 27]. The freshening is consistent with observations[29]. Discharge from the Greenland ice sheet as it melts is also thought to have made a significant contribution to the slowdown in the AMOC [30]. On the other hand, surface heat changes, rather than freshwater, may play a larger role[31].

Future projections: All state-of-the-art models project a reduction in the AMOC over the 21st century,[31] cooling the upper levels of the North Atlantic ocean. Some studies conclude that sea ice decline contributes substantially to this, through increased Arctic precipitation[27] and liquid freshwater export[26]. However, results rely on models which may not incorporate important local ice processes[32hg] and the exact contribution of sea ice to the AMOC reduction is uncertain.

* Glossary

North Atlantic Oscillation (NAO): The NAO is a recurring pattern of pressure fluctuations between permanent areas of high pressure over the Azores and of low pressure over Iceland. A positive NAO (large pressure difference) leads to increased winds and therefore cool summers and mild, wet winters in Europe. A negative NAO with reduced westerly (west-east) winds results in cold dry winters in Northern Europe.[33]

Arctic Oscillation (AO): The AO is another pressure index which quantifies the difference between pressure anomalies in the Arctic and at a region around 37-45°N. A positive AO (large positive pressure difference) means low pressure around the Arctic, with a strong westerly mid-latitude jet stream that confines cold air to the high latitudes. A negative AO allows cold Arctic air to move into lower latitudes, resulting in an increase in mid-latitude storminess [34kijhyj].

Upper atmosphere: This refers here to the **stratosphere,** the region of very dry air above about 10 km in height. The atmosphere below about 10 km is the **troposphere**.

Polar vortex: Polar vortices are large (up to 1000km diameter), cold air masses centred around areas of low pressure, which are located in the upper atmosphere above the North and South Poles. They are strongest during winter and rotate in the same direction as the Earth and so are associated with strong west-to-east winds in the upper atmosphere.

Jet Stream: Jet streams are bands of fast-moving air around 10-15 km above the Earth's surface. The Northern Hemisphere polar jet stream passes above the UK and plays a large role in Scottish weather. It generally flows from west to east, with some north-south variations. The flow is strongest when the temperature difference between the poles and tropics is strongest.

Planetary waves: Also known as Rossby waves, planetary waves are giant, high-altitude meanders in the atmosphere which transport energy around the Earth.

Blocking: Blocks or blocking highs are near-stationary areas of high pressure, which block other, faster-moving pressure systems from moving into the region.

Atlantic meridional overturning circulation (AMOC): The AMOC is a large-scale Atlantic ocean current which transports heat energy to high latitudes and thus warms the North Atlantic region. It is driven by density differences. Cold water sinks to the bottom of the ocean near the poles and travels southward in the deep ocean, while warmer water moves northwards near the surface to replace it. The density of water also depends on its salt content, with saline water being denser.

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