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Estimates of the likelihood of Arctic shipping routes opening up in the 21st centuary using an IPCC class model

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Abstract

The increasing likelihood of the Arctic becoming ice free in summer raises important questions regarding the likely timing of Arctic navigation routes becoming available. This note discusses estimates of the opening of the Northern Sea Route based on output from the HadGEM1 climate model under A1-B scenarios. Our results suggest that by 2030 the Northern Sea Route may be open up to 40 days per year. We have not made estimates of the opening of the North-West Passage because we do not believe that the current class of climate models are able to sufficiently represent processes of landfast ice in the Archipelago.

1. Introduction

Routing ships travelling between Europe, the United States and Asia via the Arctic rather than via either the Suez or Panama canal would reduce journeys by thousands of nautical miles which translates to reductions in costs for a container ship by as much as 20% and even greater for ships which sail via the Southern Ocean as they are too large to pass through the canals (Borgerson, 2008) with commensurate reductions in CO_2 emissions. However, to route a ship through the Arctic would require that the ocean was 'nearly' ice free. Due to anthropogenic climate change, the possibility of ice-free summers in the Arctic is likely over the next few decades (Wang and Overland, 2009) and for strategic planning it is therefore a good idea to consider the possibility of Arctic ship routing. Strategic planning is required for Arctic ports and ship building (to incorporate designs which can cope with encountering ice floes). It is therefore timely to be able to provide some guidance to planners on when the Arctic is most likely to be navigable.

To forecast possible sea ice conditions in the Arctic fifteen years or more from now, the most obvious tool to use is output from a climate model forced by scenarios of future forcing such as described in the Fourth Assessment Report by the Intergovernmental Panel on Climate Change (IPCC, 2007). Khon et al. (2010) have made a first attempt at such an assessment using a selection of IPCC models based on their ability to model the present ice season length for the Arctic routes. Here we will use the HadGEM1 climate model (Johns et al., 2006). However, Stroeve et al. (2007) demonstrates that the IPCC models cover a range of future evolutions of Arctic sea ice. Wang and Overland (2009) select a subset of the IPCC models based on their ability to model the seasonal cycle of Arctic ice extent (the subset of six models includes HadGEM1) and suggest that the Arctic will be seasonally ice free by the mid 2030s. However, even the better models can demonstrate a range in their prediction of Arctic sea ice (figure 1).

We have chosen HadGEM1 as the basis for our estimates as the representation of sea ice in HadGEM1 (McLaren et al., 2006) is one of the more sophisticated sea ice models in the IPCC AR4 due to the realistic sea ice dynamics and the inclusion of a distribution of ice thickness. However, even such a state of the art model still has limitations which we will discuss in section 2.

2. Navigation routes

There are two major navigation routes through the Arctic (figure 2); the North-West passage which passes through the Canadian Archipelago and the Northern Sea Route which passes along the Russian coast to the Arctic. The resolution of the ocean and sea ice grid in HadGEM1 is 1º x 1º and the land mask from HadGEM1 for the Arctic is shown in figure 2(b). This demonstrates that while it may be valid to discuss the navigation of the Northern Sea Route, the poor representation of the North-West passage would lead to serious questions

about the validity of such an approach. Indeed with this resolution, resolving bathymetry and coastal currents which are believed to be important for determining cover of landfast ice in the Canadian Archipelago would not be represented. For this reason, although Khon et al. (2010) looked at the North-West passage, we do not believe that the IPCC class of models can be used in this way and therefore we only use the model to investigate the likelihood of the Northern Sea Route being open to shipping.

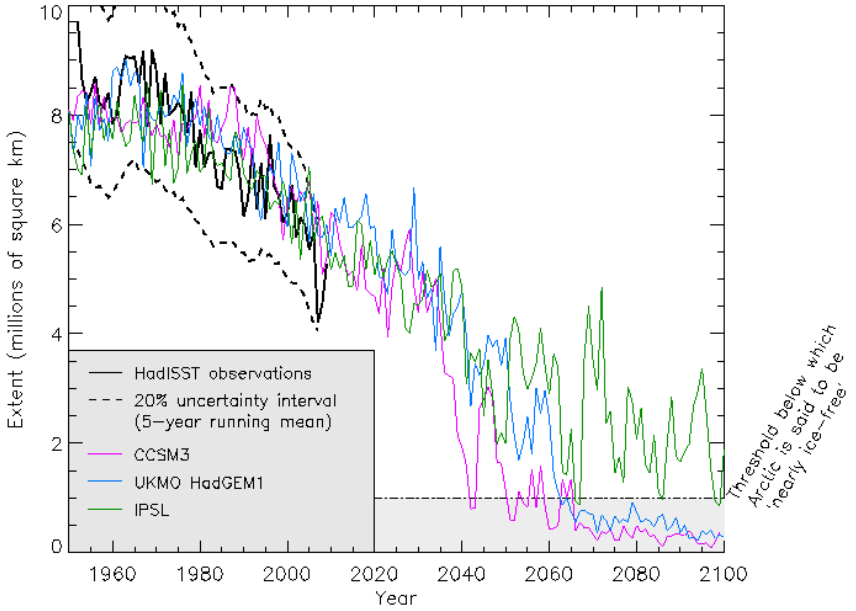

Figure 1: Sea ice extent in HadISST (Rayner et al, 2003) and IPCC model projections from HadGEM1, CCSM3 and IPSL.

3. Calculating navigability of Northern Sea Route

This analysis utilises monthly sea ice concentration data from an A1-B scenario of HadGEM1. The Northern Sea Route is defined as the region to the right of the red line shown in figure 2. For the purposes of this analysis, we define three levels of minimum ice concentration; 5%, 10% and 15%. Each grid cell in the Northern Sea Route region is analysed by examining whether sea ice concentration falls below the designated minimum concentration level. The Northern Sea Route region is then analysed to see if a continuous pathway exists through the region with sea ice concentration below the designated minimum value. If such a path exists, the Northern Sea Route is said to be 'navigable' for that particular month and year. The number of months for which the Northern Sea Route is projected to be navigable under a maximum ice concentration of 5% is shown in figure 3.

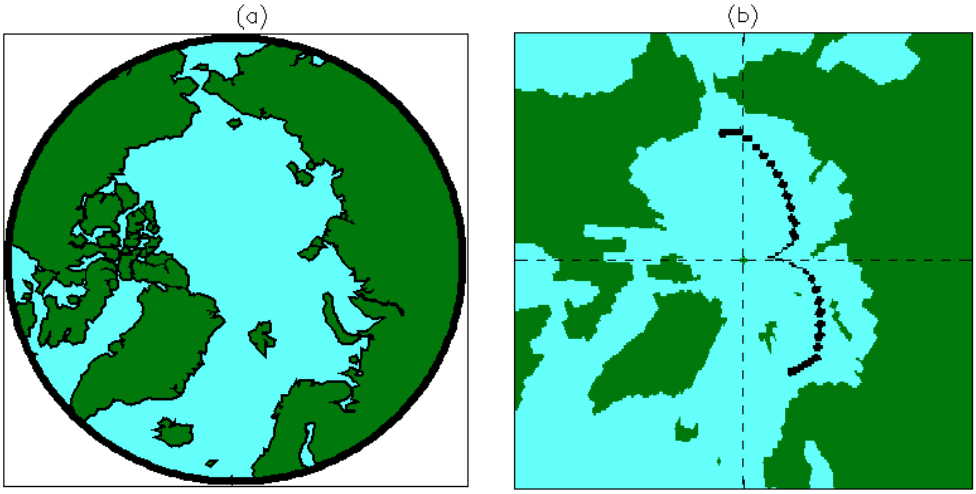

Figure 2: (a) A map of the Arctic. (b) The Arctic in the HadGEM1 grid. The Northern Sea Route is defined for this analysis as the area to the right of the black line in (b).

In order to use the monthly data to estimate the number of days for which the Passage would be ice-free, a cubic was fitted to the monthly data with the additional observational constraint that the Northern Sea Route was never navigable between 1990 and 2000. The RMS difference between the monthly data and the cubic was calculated, and Figure 3 shows the cubic fit, +/- the RMS difference. This method has the advantage of removing the year-on-year variability, for which we have low confidence, and making the trend clearer. Table 1 shows the mean and standard deviation of the duration of ice-free conditions in each decade of the 21st century under three definitions of 'ice-free', with critical concentration set to 5%, 10% and 15% respectively. This demonstrates that by 2030 we might expect up to 40 navigable days through the Northern Sea Route. This is broadly consistent with the results of Khon et al. (2010).

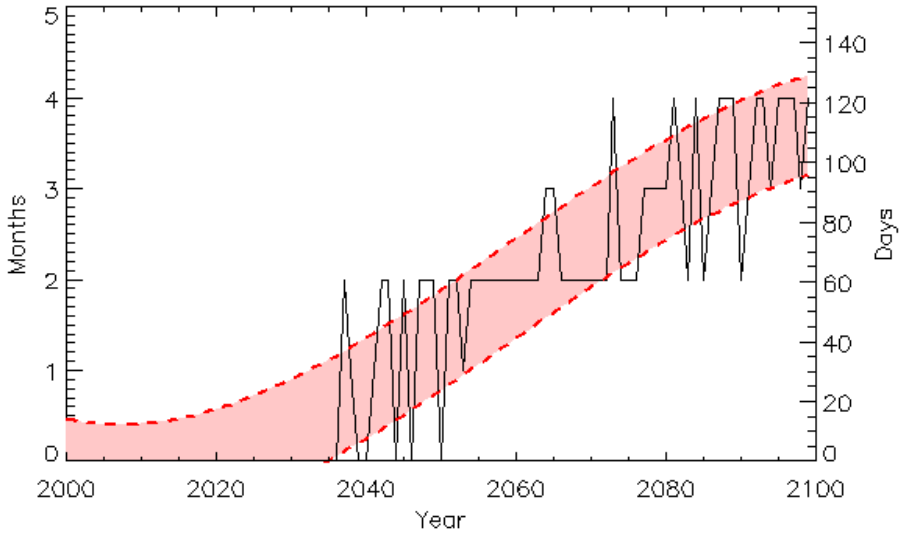

Figure 3: Projected duration of navigability of Northern Sea Route according to method HadGEM1 A1-B scenario in months (black) with approximate number of days (pink) assuming a maximum ice concentration of 5%.

	Duration of ice-free period (mean +/- standard deviation)		
Decade	**Cutoff = 5%**	**Cutoff = 10%**	**Cutoff = 15%**
2000-09	0.0 +/- 0.0	0.0 +/- 0.0	4.6 +/- 1.5
2010-19	0.0 +/- 0.0	2.1 +/- 1.8	11.8 +/- 2.7
2020-29	4.9 +/- 2.8	11.0 +/- 3.3	22.9 +/- 3.7
2030-39	16.6 +/- 3.9	24.3 +/- 4.4	37.1 +/- 4.4
2040-49	31.5 +/- 4.6	40.9 +/- 5.1	53.5 +/- 5.0
2050-59	48.3 +/- 5.0	59.5 +/- 5.5	71.3 +/- 5.2
2060-69	65.7 +/- 5.0	79.0 +/- 5.6	89.7 +/- 5.3
2070-79	82.3 +/- 4.6	98.2 +/- 5.3	107.9 +/- 5.1
2080-89	97.0 +/- 3.8	115.8 +/- 4.7	125.0 +/- 4.7
2090-99	108.5 +/- 2.7	130.7 +/- 3.8	140.3 +/- 4.0

Table 1: Projected duration (in days) of 'ice-free' conditions in the Northern Sea Route for decades of the 21st century according to HadGEM1, according to three criteria of ice concentration.

4. Summary and discussion

In summary, this note demonstrates that we can use model output from the current class of IPCC models to make estimates of the opening of the Northern Sea Route. The HadGEM1 climate model under A1-B scenario forcing suggests that by the 2030's the Northern Sea Route may be open for navigation up to 40 days per year. However, this is crucially

dependent on the ice concentration which a ship can cope with; Khon et al. (2010) assume that light ice-class ships can navigate through 15% ice concentration yet if 5% ice concentration was the threshold the number of navigation days would be significantly reduced. We have not made estimates of the navigability of the Northwest Passage because we do not believe that the current class of climate models can adequately represent the sea ice processes in the narrow passages of the Canadian Archipelago sufficiently to estimate navigation seasons. In order to make such estimates a regional high resolution model would be required.

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