New Trans-Arctic shipping routes navigable by midcentury

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AUTHOR SUMMARY

Record lows in observed Arctic sea ice extent, together with climate model predictions of even greater ice declines in the future, have fueled speculations about new trans-Arctic shipping routes linking the Pacific and Atlantic oceans. However, little is known about how the projected geophysical changes in sea ice will impact the viability of ship navigation through the region. To address this question, we applied numerical transportation analysis (1) to individual and ensemble-averaged datasets of projected sea ice thickness and concentration from seven respected general circulation models. This method allowed for an evaluation of peak-season (September) Arctic shipping potential for early- (2006–2015) and mid-21st century (2040–2059) and their comparison with past decades (1979–2005).

The general circulation models were selected for their abilities to reproduce the observed total extent and volume of sea ice and/or realistic representations of ice interannual variability and radiation physics. To control for seasonal changes, our analysis was restricted to the peak Arctic navigation month of September, when open water reaches its maximum annual extent. For September of each year of study, the optimal navigation route—narrowly defined as the fastest available navigation course avoiding sea ice thick and/or concentrated enough to block the passage of a particular vessel—was identified for hypothetical ships seeking to traverse the Arctic Ocean between the North Atlantic (Rotterdam, The Netherlands and St. John's, Newfoundland) and the Bering Strait. These optimal navigation routes were computed for two different climate change scenarios representing medium-low [a +4.5 W/m^2 increase in radiative forcing, known as the representative concentration pathway (RCP) 4.5 scenario] and high (a +8.5 W/m^2 increase, known as the RCP 8.5 scenario) increases in greenhouse warming, respectively. Optimal routes were determined for two vessel types: Polar Class 6 (PC6) ships with moderate ice-breaking capability, and common open-water (OW) ships (2). Route simulations for the time periods of 1979–2005 and 2006–2015 accurately mimic the historical pattern of highly restricted shipping activity in the Arctic, with PC6 and OW vessels transits confined to the Northern Sea Route along the Russian coast. However, by midcentury (2040–2059), the region's overall navigation potential increases substantially (Fig. P1), with three conclusions broadly apparent across both climate scenarios as follows.

First, the ability of OW vessels to complete September trans-Arctic voyages along the Northern Sea Route (NSR) increases in both frequency and geographical range, with a number of optimal routes shifting northward away from the Russian coast (Fig. P1, blue lines). During the historical baseline period (1979–2005), sea ice limited the probability of a technically feasible September OW passage through the NSR to just ~40% in any given year, rising to 71% for RCP 4.5 and 61% for RCP 8.5 by 2006–2015 and 94% for RCP 4.5 and 98% for RCP 8.5 by 2040–2059. Thus, although numerous economic and other factors unrelated to climate also limit the viability of Arctic marine shipping (3), from a purely geophysical sea ice perspective, the ability of common OW ships to traverse the NSR and the eastern Arctic Ocean will increase.

Second, unprecedented new optimal navigation routes for PC6 vessels will emerge through the central Arctic Ocean and Northwest Passage (NWP) by 2040–2059 (Fig. P1, red lines). This dramatic northward shift of optimal PC6 routes well away from the NSR (which dominates optimal PC6 traffic today) to the North Pole (for transits to/from Europe) and the NWP (for transits to/from eastern North America) is apparent regardless of whether a medium-low or high climate-forcing scenario is assumed. The emergence of a robust PC6 corridor directly over the North Pole, for example (Fig. P1), indicates that, in either scenario, sea

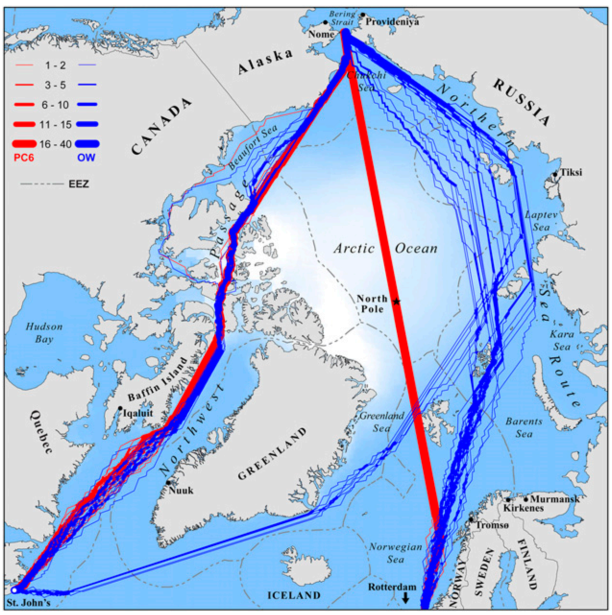

Fig. P1. Optimal September navigation routes for hypothetical ships seeking to cross the Arctic Ocean between the North Atlantic (Rotterdam, The Netherlands and St. John's, Newfoundland) and Pacific (Bering Strait) during the consecutive years of 2040–2059 as driven by ensemble-averaged general circulation models' projections of sea ice concentration and thickness assuming a medium-low (+4.5 W/m^2) increase in climate forcing. Red lines indicate fastest available trans-Arctic routes for Polar Class 6 (PC6) ships; blue lines indicate fastest available routes for common open-water (OW) ships. Where overlap occurs, line weights indicate the number of successful transits using the same route. Dashed lines reflect currently existing (200 nautical mile) national Exclusive Economic Zone boundaries; white backdrop indicates period-averaged sea ice concentration.

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ice will become sufficiently thin and/or diffuse enough to surpass a critical technical threshold—and the shortest possible great circle route will thus become feasible—for ships with moderate ice-breaking capability.

Third, the NWP, arguably the most historically famed of potential shipping routes through the Arctic, has the lowest historical and current navigation potential but will become substantially more accessible by 2040–2059. Under no simulations (past, present, or future) do ice conditions in the NWP attract transits to/from Europe for either PC6 or OW vessels. For transits to/from eastern North America, however, the NWP becomes optimal 100% of the time for PC6 vessels by midcentury (in either climate-forcing scenario); for OW vessels, it will often be more efficacious than the NSR. During the 1979–2005 historical baseline period, sea ice limited the probability of a technically feasible OW passage through the NWP to just ∼15% in any given year, increasing slightly to 17%/27% by 2006–2015 (for RCPs 4.5 and 8.5, respectively) and 53%/60% by 2040–2059. Put simply, by midcentury, September sea ice conditions in the NWP will have changed sufficiently such that trans-Arctic shipping to/from North America will often be able to capitalize on the ∼30% geographic distance savings that this route offers over the NSR.

Although Arctic shipping potential is limited by diverse factors, including economics, infrastructure, safety, and others (3), our findings have important implications for trade, environmental risk, and evolving strategic and governance policies for the region. The prospect of OW ships (which comprise the vast majority of the global fleet) entering the Arctic Ocean in late summer, and even its remote central basin by moderately ice-strengthened vessels (like those used today in the Baltic), heighten the urgency for a comprehensive International Maritime Organization (IMO) regulatory framework to ensure adequate environmental protections, vessel safety standards, and search-and-rescue capability in this unique and challenging polar ecosystem (4). Many of the new "Supra-Polar" routes identified here deviate outside of the standard 200 nautical-mile Exclusive Economic Zone of the Russian Federation, thus enhancing potential appeal of the international high seas and Norwegian, Greenlandic, Canadian, and US coastal waters for transits relative to the NSR (the Russian Federation currently charges escort fees for international vessels seeking to traverse the NSR). Finally, two chronic, long-standing debates over the status of international shipping through the NWP (now claimed as a domestic waterway by Canada but international straits by the US and other countries) and US ratification of the United Nations Convention on the Law of the Sea (5) may warrant renewed attention, in light of its nascent navigability and the broader circumpolar changes projected here.

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