



# The interaction of ice and law in Arctic marine accessibility

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Sea ice levies an impost on maritime navigability in the Arctic, but ice cover diminution due to anthropogenic climate change is generating expectations for improved accessibility in coming decades. Projections of sea ice cover retreating preferentially from the eastern Arctic suggest key provisions of international law of the sea will require revision. Specifically, protections against marine pollution in ice-covered seas enshrined in Article 234 of the United Nations Convention on the Law of the Sea have been used in recent decades to extend jurisdictional competence over the Northern Sea Route only loosely associated with environmental outcomes. Projections show that plausible open water routes through international waters may be accessible by midcentury under all but the most aggressive of emissions control scenarios. While inter- and intraannual variability places the economic viability of these routes in question for some time, the inevitability of a seasonally ice-free Arctic will be attended by a reduction of regulatory friction and a recalibration of associated legal frameworks.

Arctic | sea ice | law of the sea | climate change | marine navigation

Of the world's oceans, the critical trends and alternative futures wrought by climate change are most intensely captured in the Arctic. Historically, human activities on the Arctic Ocean were focused on fish, seals, whales, and bear. The new "Race to the North" is for exploitation of hydrocarbon and mineral wealth, strategic advantage, tourism opportunities, and cargo transport. Navigability is the critical condition that enables all of these activities, and a key component of Arctic navigability is sea ice cover. The temporal and geographic distribution of navigability is a critical determinant of the evolving applications of international maritime law.

With ice cover in retreat, Arctic routes for destination shipping present a plausible alternative to the Suez Canal. Whether by the Northern Sea Route, the Northwest Passage, or the Transpolar Route, Arctic routes are 30 to 50% shorter than the Suez or Panama Canals (1), with transit time reduced by 14 to 20 d assuming the same sailing speed (2). The slower sailing speeds typically adopted in the Arctic could reduce this advantage, but worldwide "slow steaming" is a candidate short-term strategy identified by the International Maritime Organization to achieve greenhouse gas emissions reductions (3). In this context, emissions reductions for viable Arctic routes are around 24% (4). Furthermore, Arctic routes are not subject to the kinds of single-vessel blockages recently exposed by the stranding of the *Ever Given* container ship in 2021. This 6-d incident was estimated by shipping journal *Lloyd's List* to have cost around \$400 million per hour. However, Arctic shipping is not as active as might be expected. The Arctic remains risky because of high spatial and temporal variability, limited satellite navigation coverage and ice forecasting capacity, challenges for emergency management, and inexperienced crews. The Arctic remains expensive due to the cost and limited size of vessels permitted under the Polar Code, as well as regulatory requirements that include ice-breaker escort on the Russian-controlled Northern Sea Route.

Russia accounts for more than 24,000 km of Arctic Ocean coastline, and under anthropogenic climate change sea ice has retreated most rapidly from its coasts (5). This has enabled the expansion of the Russian Arctic presence. Since 2000, satellites have detected new infrastructure covering hundreds of square kilometers associated with oil and gas, mining, fishing, and military activities (6). Russian law describes the Northern Sea Route as the "historically established national transport communication route." (7) Significantly, Russia employs straight baselines such that segments of the route lie within internal waters. The official Russian view appears to have evolved to characterize the entire Northern Sea Route as internal waters (8).

In contrast to the Antarctic and its single-treaty regime, the constitutive process of the Arctic comprises multiple transnational legal instruments and institutions (9). The prevailing legal regime is the customary and codified law of the sea which balances "the special exclusive demands of coastal states, and other special claimants, and the general inclusive demands of all states in the world arena" (10). The widely applicable codified

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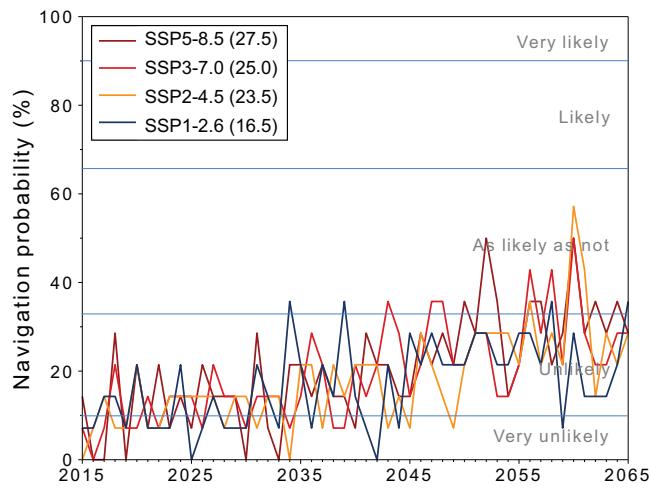
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instrument is the United Nations Convention on the Law of the Sea of 1982, supplemented by the international code of safety for ships operating in polar waters, or “Polar Code,” the International Convention for the Safety of Life at Sea, and the International Convention for the Prevention of Pollution from Ships. The five Arctic littoral states have affirmed their commitment to the Convention on the Law of the Sea through the Ilulissat Declaration. This legal framework is now unstable owing to climate change. We project that key Convention on the Law of the Sea provisions pertaining to baselines, ice-covered waters, navigation, and straits will be acutely affected by climate change. Here we focus on navigation.

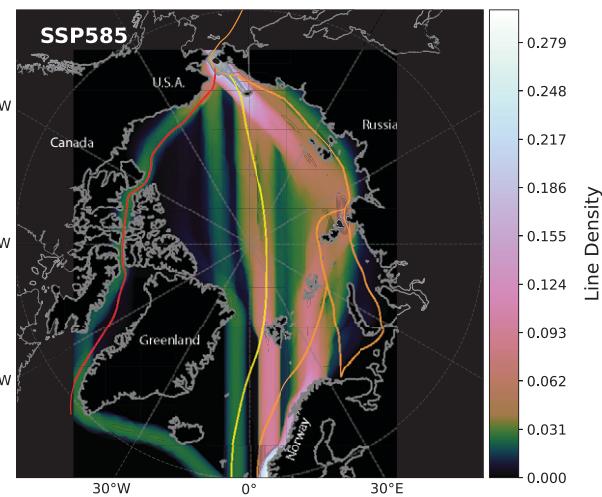
## Results

Projections for transit routes are constructed using scenarios (11) that span the range from very high emissions to policies that constrain average warming below around 1.5 °C. All realizations demonstrate substantial interannual variability, and the projected navigable season varies widely from one model to another: Some models project no navigability by 2065, while others suggest a reliable season now. The ensemble of realizations indicates that the start of the shipping season trends earlier at almost 3 d per decade in all of the emissions scenarios considered here. There is significant extension in the close of the shipping season of 4 d per decade for the medium- and high-emissions scenarios.

Using these data, we assess the likelihood of a viable open-water shipping season that avoids Russian territorial waters (Fig. 1). These routes require transits through the Bering Strait but would not require icebreaker transport or, indeed, Polar Class ice-strengthened vessels. Consistent with the earlier retreat of sea ice from the Russian Arctic, the projections suggest that the likelihood of viable open-water shipping outside Russian regulatory reach will increase over time. The likelihood of these routes increases faster in the high-emissions scenarios, as expected. However, interannual variability, and thus uncertainty, remains high in all scenarios to midcentury. Further, it is unlikely that access in the lowest-emissions scenario will be realized with any reliability by midcentury.



**Fig. 1.** Projections from 14 CMIP models across four scenarios of the probability of Arctic navigability for 32 d (including shoulder periods) outside Russian territorial waters over the period 2015 to 2065. Numbers in parentheses show the increase in probability over five decades with 99% confidence. The level of confidence for this assessment corresponds to the Intergovernmental Panel on Climate Change convention, that is, very likely expressed as 90 to 100% probability, likely 66 to 100%, as likely as not 33 to 66%, unlikely 0 to 33%, and very unlikely 0 to 10%.



**Fig. 2.** Spatial distribution of open-water navigable routes over the period 2015 to 2065 for the SSP5-8.5 scenario, expressed as a frequency of route detection per unit time. Also shown are indicated eastern and western Northern Sea Routes (orange); Northwest Passage (red); and the Transpolar Route (yellow.) The routing model indicates the potential for a regime shift toward both the Northwest Passage and the Transpolar Route.

Fig. 2 shows the alternative routes that are generated for the highest-emissions scenario (SSP5-8.5). A viable route passing from Norwegian waters to the central Arctic just north of Svalbard is frequently available, and an even more westerly route through Danish waters emerges midcentury. This second route is significantly further west than the currently identified Transpolar Route. A significant open-water season for the Northwest Passage also becomes viable.

## Discussion

The Convention on the Law of the Sea provision that will be most affected by climate change is Article 234, which allocates coastal states broad prescriptive and enforcement jurisdiction in ice-covered areas for “the prevention, reduction and control of marine pollution from vessels.” Some Arctic littoral states, notably Canada and Russia, assert broad claims under Article 234. During the 1990s the Russian Federation, invoking Article 234, adopted regulations applicable to the entire Northern Sea Route. These now include mandatory insurance, navigation rules including authorization procedures, the requirement to carry a state pilot, and mandatory ice-breaker pilotage be paid for in accordance with a published schedule of charges. They apply to all vessels, purportedly including warships and government vessels, which under the international law of the sea are accorded immunity and thus should fall beyond the scope of Article 234 (12). Indeed, Article 234 itself calls out the requirement for “due regard” for navigation.

The key question for climate change projections flows from the Article 234 provision that ice cover persist “for most of the year.” Changing ice phenology suggests that fewer states will be able to rely on Article 234 over less marine space. At present interannual variability of ice remains high (13), raising questions pertaining to the scope of Article 234. What extent of ice coverage over what period is required for application of this provision?

Flexibility and realism will be required for recalibrating the international law of the sea in the face of the geographic and temporal distribution of ice retreat. Alternative routes generate increased shipping choice and reduced economic friction, but

substantial financial risk remains in the face of low ice predictability (14). Nevertheless, sea traffic will be able to traverse the Russian Exclusive Economic Zone seaward of coastal islands and thus be subject to fewer navigational servitudes. Pursuant to the Convention on the Law of the Sea, the Exclusive Economic Zone navigational encumbrances are minimal. As a result, disagreements over the legal status of the Northern Sea Route as a strait used for international navigation will be moot, and our projections suggest the gradual termination of Article 234. This requires attention by governments, shipping owners, and lawyers based on available science. The consequences for Arctic shipping and global maritime trade will be profound.

## Materials and Methods

Projected sea ice and associated route accessibility were calculated from four Tier 1 scenarios (SSP5-8.5, SSP3-7.0, SSP2-4.5, and SSP1-2.6) (11) using ensemble members from each of 14 models as part of the Coupled Model Intercomparison Project phase 6 (CMIP6) (15). The daily ice concentration and thickness from each realization is extracted for use in the marine accessibility model. Our approach (13) builds upon the Polar Operational Limit Assessment Risk Indexing

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System (POLARIS) (16). Within the POLARIS framework, the viability of passage is quantified by the Risk Index Outcome (RIO):

$$RIO = \sum_{i=1}^n C_i RIV_i$$

where  $C_i$  is the ice concentration and  $RIV_i$  is the risk index value (RIV) of a particular ice category and vessel class. For the results shown here, we assume open water vessels to simulate alternative routes that do not require icebreaker escort. A positive RIO indicates acceptable risk and a corresponding travel speed to safely navigate the given ice regime. The resulting travel speeds are used to identify the optimal least-cost route using Dijkstra's algorithm. The optimal route and its travel time are only recorded when a transit can be realized from Rotterdam to a destination at the Bering Strait. Routes can be generated that conform to any of the Northern Sea Route, the Northwest Passage, and the Central Arctic Route. For each model realization a navigable season is flagged if at least 32 continuous days of viable routes are available.

**Data Availability.** CMIP6 climate scenarios are freely available for download from [esgf-node.llnl.gov/search/cmip6/](https://esgf-node.llnl.gov/search/cmip6/). The algorithms described here are available from ref. 13. The resulting route shapefiles are available from Zenodo (<https://zenodo.org/record/6539994#.Yokql1TMJPY>). All other study data are included in the article.

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