Referee comments on "Perspectives on future sea ice and navigability in the Arctic" (Chen & all – 2021) by Bjørn Åge Hjøllo, NAVTOR AS

General comments

Q0: In this study the Author give a valuable contribution to understand how global warming can influence artic navigability and open up for commercial shipping lines between Asia and Europe, based on the knowledge from the latest climate studies. Some of the discussions would benefit of a wider perspective of "navigability", e.g. by also including possible changes in met-ocean conditions in artic sea areas. However, I would recommend publishing the manuscript, as a contribution in understanding future trends in the artic shipping.

(1) The language, especially in the abstract, is basic and would benefit by a native person reading through.

(2) NEP; also commonly named North East Sea Route or Northern Sea route, especially in the shipping industry.

A0: Thanks for the positive and constructive comments. The manuscript was revised for the issues addressed by both reviewers. An English naive speaker from AJE was invited to improve the quality of writing, and the Northeast Passage (NEP) was replaced with the Northern Sea Route (NSR) in the revised manuscript. We sincerely hope our endeavor could meet your approbation.

Specific comments

Q1: Line 64 "Climate models are effective and reliable for producing present and future spatial and temporal distributions". This is a statement that should be discussed; what about uncertainties?

A1: Thanks for your suggestion. This statement is indeed in doubt for the uncertainties in climate models. Some researches showed that current climate models have some problems in hindcasting observed cryosphere trends. Therefore, this sentence was deleted in the revised manuscript, and the uncertainties have been discussed in section 5.

Q2: Line 77 "Shared socioeconomic pathways (SSPs) 2–4.5"; to reach a wider audience, a section explaining the SSPs would be beneficial, e.g.:

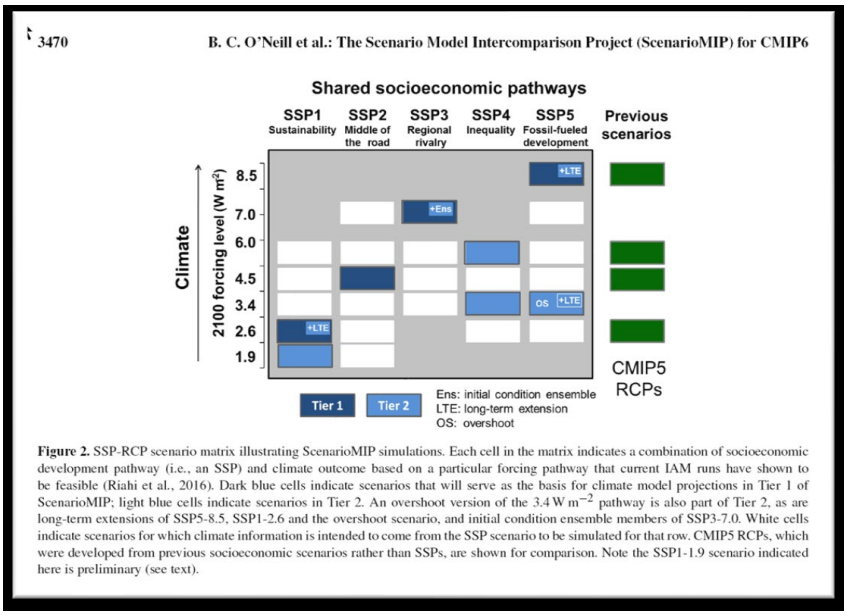

Figure 2. SSP-RCP scenario matrix illustrating ScenarioMIP simulations. Each cell in the matrix indicates a combination of socioeconomic development pathway (i.e., an SSP) and climate outcome based on a particular forcing pathway that current IAM runs have shown to be feasible (Riahi et al., 2016). Dark blue cells indicate scenarios that will serve as the basis for climate model projections in Tier 1 of ScenarioMIP; light blue cells indicate scenarios in Tier 2. An overshoot version of the 3.4 W m^{-2} pathway is also part of Tier 2, as are long-term extensions of SSP5-8.5, SSP1-2.6 and the overshoot scenario, and initial condition ensemble members of SSP3-7.0. White cells indicate scenarios for which climate information is intended to come from the SSP scenario to be simulated for that row. CMIP5 RCPs, which were developed from previous socioeconomic scenarios rather than SSPs, are shown for comparison. Note the SSP1-1.9 scenario indicated here is preliminary (see text).

A2: Thanks for your suggestion. Further explanation for the SSPs, which shown as below, was supplemented to section 2.1 Data and Model Selection.

"The new scenario framework, SSP, in CMIP6 was designed to carry out research on climate change impacts and adaptions by combining pathways of future radiative forcing and climate changes with socioeconomic developments (O'Neill et al., 2014). SSP1 indicates a sustainable development, which proceeds at a reasonably high pace. Technological change is rapid, inequalities are lessened and directed toward environmentally friendly processes. Unmitigated emissions are high in SSP3. It is due to a rapidly growing population, moderate economic growth, and slow technological change in the energy sector. SSP2 is an intermediate case between SSP1 and SSP3. SSP5 occurs in the absence of climate policies, energy demand is high and most of this demand is met with carbon-based fuels."

Q3: Line 114 "The spatial resolutions of the monthly sea ice concentration and thickness data were normalized to 1°×1° by bilinear interpolation». Why using 1°×1° resolution? A discussion related to benefit with a lower resolution would be fine, especially related to navigability ion coastal areas and straits? Could a Regional downscaling of the climate models give increased knowledge closer to the coastal areas/straits?

A3: Thanks for your question. The resolution of the models for sea ice thickness and concentration varies greatly from 10km to 250km. On the one hand, for the navigability in the Arctic, especially accessibility within the straits and near the coastal areas, higher spatial resolution would be more conductive to the route planning and decision making, while only a few of model can reach a high resolution. Regional downscaling of the climate models could give increased knowledge closer to the coastal areas/straits. On the other hand, it is generally assumed that more models

offer ensemble result and reduce the uncertainly, but it is at the expense of spatial resolution. In fact, more models may also bring errors to the result if some models are far from the truth. Therefore, 1°×1° was selected as a balance of resolution and uncertainty in this paper.

Q4: Line 236 "By mid-century, both the NEP and NWP will open for OW ships under SSP5-8.5 in September" This might be true if only ice-conditions are taken into concern, however other limitations/concerns should also be discussed, e.g.:

- Foreseen changes in extreme Met-Ocean conditions influencing navigability, e.g.
  - Very cold air outbreaks over open water forming explosive local polar lows
  - Icing on vessels
  - More fog and/or precipitation
  - Increase in extreme waves due to increased fetch caused by ice-free artic waters
- Required infrastructure to allow for a large increase in Norther Sea Route?
  - The need for supporting infrastructure in very remote areas may be a limitation (fuel, towing, general services, etc)?
  - SAR?
  - The foreseen increase in green Shipping due to IMO recommendations; could requirement for Green fuel be a limitation?

A4: Thanks for your suggestion. Yes, there are many factors influencing the navigability of passages in the Arctic, such as meteorological and hydrological conditions, facilities, geography, political restrictions, and other factors mentioned above, but it is hard to give a conclusion that takes all factors into account, especially for the forecasting with many subjective and accidental factors. Ice thickness and concentration are variables which can be predicted by the climate models in CMIP6. Therefore, the precondition passing through the paper is that all of the conclusions for the Arctic navigability only based on the ice conditions.

Technical comments (listing of purely technical corrections at the very end ("technical corrections": typing errors, etc.).

Q5: Line 218 Figure 4; mixed up units in the upper and lower figures ([m] / [%])

A5: Thanks for reminding. The units were changed in the revised Figure 4.