# Referee comments - Luofeng Huang, University College London

The authors provide an interesting study on predicting Arctic sea ice condition and the associated shipping navigability. Overall I think the work is of importance under the trend of ongoing climate change, and it can provide valuable insights for relevant stakeholders such as shipbuilders and operators. Therefore, I am in favour of publishing this manuscript. However, I did find a list of issues existing in the current form, as follows:

Q1. It is rare to use the term "Northeast Passage (NEP)". The common term is "Northern Sea Route (NSR)".

*A1: Thanks for your suggestion. Northeast Passage (NEP) was replaced with Northern Sea Route (NSR) in the revised manuscript.*

Q2. Line 47-51, the authors say "Northeast Passage" is an alternative to Panama Canal and Suez Canal - this is an incorrect expression, because the Northwest Passage (NWP) is the alternative of Panama canal and the Northern Sea Route (NSR) is the alternative of Suez Canal. They should be stated separately and clearly.

*A2: Thanks for your correction. This sentence was revised as "The Northern Sea Route (NSR) extends along the northern coast of Eurasia from Iceland to the Bering Strait and shortens the transit distance by approximately 15%−50% relative to the southern routes through the Suez Canal."*

Q3. Line 51-52, "It is navigable for approximately a month and half per year for ice-strengthened ships at the end of summer (Khon et al., 2010)". Is this information outdated as reference is from more than ten years ago? Please check there is some recent reference for this, because the navigable season is probably already longer than 1.5 months nowadays.

*A3: The navigable season has extended to about 3 months for ice-strengthened ships. This sentence was revised as "It is navigable for approximately three months per year for ice-strengthened ships at the end of summer and the beginning of autumn (Yu et al., 2020)."*

*[Ref] Yu, M., Lu, P., Li, Z. Y., Li, Z. J., Wang, Q. K., Cao, X. W., Chen, X. D..: Sea ice conditions and navigability through the Northeast Passage in the past 40 years based on remote-sensing data. Int. J. Digit. Earth, 1−20, https://doi.org/10.1080/17538947.2020.1860144, 2020.*

Q4. Line 52-53, "The day at which open water (OW) ships can cross the NEP has reached 297±4 (October 24th) since 2010." It is not clear in English, please rewrite.

*A4: This sentence was rewritten as "The end of shipping season for open water (OW) vessels has reached October 24$^{th}$ since 2010 (excluding 2013)."*

*[Ref] Chen, S. Y., Cao, Y. F., Hui, F. M., and Cheng, X.: Observed spatial-temporal changes in the autumn navigability of the Arctic Northeast Route from 2010 to 2017 (in Chinese), Chinese Sci. Bull., 64, 1515–1525, https://doi.org/10.1360/N972018-01083, 2019.*

Q5. Line 54-55, "However, navigability is still affected by the ice regime around the Severnaya Zemlya Islands, the Novosibirsk Islands, and the East Siberian Sea (Chen et al., 2019)" It is unclear what does the ice regime mean? And how does the ice regime influence shipping navigability?

*A5: Thanks for your question. Ice regime mainly means ice thickness and ice concentration in Chen et al., 2019. Shipping navigability reduces with the increasing of ice thickness and concentration.*

Q6. Introduction, Page 3: I suggest the authors provide a review of the geographical and political factors on the NWP and NSR. This is because the practicality for employing the NSR is currently greater than for the NWP. As introduced by Ryan et al. [Ref], The NWP is made up of straits through the Canadian Arctic Archipelago that are both narrow and shallow. These straits are easily clogged by free floating ice, and are still insufficiently surveyed, presenting the very real risks of grounding or becoming stuck in ice; By contrast, the NSR presents a less complex situation, yet has several choke points where ships must pass through shallow straits between islands and the Russian mainland. Apart from the geographical factor, politics has also been providing increasing impetuses for adopting the NSR; for example, China has indicated its plans to establish a Polar Silk Road as part of the Belt and Road Initiative, which aims to build infrastructure and perform voyages through the NSR.

[Ref] C. Ryan, G. Thomas, D. Stagonas, Arctic Shipping Trends 2050, University College London, 2021.

*A6: The review, as shown below, for geographical and political factors on the NWP and NSR was made in the revised manuscript.*

*"Geographical and political factors also pose some challenges to the navigability of passages and choice of routes (Ryan et al., 2020). The straits along the NWP are at times narrow and shallow, which are easily clogged by free floating ice. NSR is greater than NWP in terms of geography, while it still has several choke points where ships must pass through shallow straits between islands and the Russian mainland (Streng et al., 2013). Apart from the geographical factor, the various organizations and groups formed between the surround-Arctic nations, as well as the disputes and agreements, give impetuses for adopting the NSR. Russia has committed several large infrastructure projects to support the NSR, such as Yamal-Nenets railway and emergency rescue centers (Serova, N. A. and Serova, V. A, 2019). China, which is characterized as a near-Arctic state, also outlined the plans to build a Polar Silk Road by building infrastructure and conducting trial voyages (Tillman et al., 2019)."*

Q7. Introduction Page 4: I suggest the authors provide a table of Ice Class versus Operating Ice Thickness for ships. In the current manuscript, I feel the authors suddenly bring out the concept of Polar Class (PC) from Line 68 – this does not fit for a general audience if no background information is given.

*A7: Thanks for your suggestion. The table of vessel class versus operating ice thickness was provided in the revised manuscript.*

*Table 1 Vessel classes versus operating ice thickness*

| Vessel class | Maximum allowable ice type | Ice thickness (cm) |
|---|---|---|
| *Polar class 3* | *Second year* | *No limit* |
| *Polar class 6* | *Medium first-year* | *70–120* |
| *Ordinary merchant* | *Open water/Grey* | *10–15* |

Q8. End of Introduction: the authors should clearly state the novelty and contribution of this work, in comparison with previous studies, e.g. V. Khon, I. Mokhov, M. Latif, V. Semenov, and W. Park, "Perspectives of northern sea route and northwest passage in the twenty-first century," Climatic Change, vol. 100, no. 3-4, pp. 757–768, 2010.

*A8: Thank you. Compared with previous studies such as Khon et al., 2010, one novelty of this work is that the latest multi-model results from CMIP6 were used to evaluate the future changes of sea ice, and the other is that the filtration for multi-models to reduce the*

*uncertainties. Both of them were stated in the revised Introduction.*

Q9. Line 223-224: "The number of vessels passing through the Arctic is increasing year by year, but OW ships usually need the guidance of icebreakers, which increases transportation costs." I believe this is not a correct statement, because open water vessels only need icebreakers when encountering unnavigable consolidated ice.

*A9: Thanks for you correction. This sentence was deleted.*

Q10. Line 225: "The opening of Arctic passages for OW ships is profitable for ocean shipping companies" Some references to support this statement?

*A10: This sentence was revised as "The opening of Arctic passages is profitable for ocean shipping companies (Chang et al., 2015)".*

*Chang, K. Y., He, S. S., Chou, C. C., Kao, S. L., Chiou, A. S.: Route planning and cost analysis for travelling through the Arctic Northeast Passage using public 3D GIS. Int. J. Geogr. Inf. Sci., 29, 7–8, 1375–1393, https://doi.org/10.1080/13658816.2015.1030672, 2015.*

Q11. Line 230-232: "Fortunately, the crucial straits, such as the Shokalskiy Strait, Vilkitskty Strait, Sannikov Strait, and Dmitrii Laptev Strait, will be accessible for OW ships." I suggest the authors remove the word "fortunately", because it is not academic writing and many readers may feel uncomfortable if you say the global-warming effect is fortunate.

*A11: Thank you. The word "fortunately" was removed in the revised manuscript.*

Q12. Section 3.3. The authors need to provide a more comprehensive description of ice conditions, such as level ice, pack ice, pancake ice, ice channels. These ice conditions are very different for different types of ships' navigabilities and should be clarified. Some brief discussion of ship interactions with different ice types is required here, for which, I suggest the authors check more references. If different ice conditions are all assumed the same in your model, you should say more about the assumption and the associated limitation.

*A12: Thanks for your suggestion. Ice conditions considered in this study were ice thickness and ice concentration, in which the function of ice thickness was regarded as a value according to the corresponding interval in formula (2-3). It is hard to distinguish different types of*

*ice, such as level ice, pack ice, and pancake ice in our calculation and Figure (6), but their different navigability for two types of ships has already been quantified based on the ice thickness and ice concentration. So ice conditions still have different functions in ATAM.*

Q13. Results: seems only PC6 ships are studied in this work? What is the authors' opinion about other polar ships?

*A13: Thanks for your question. The navigability of PC6 ships and OW ships was focused in this study. They also attached a lot of attention in previous researches, such as Smith and Stephenson, 2013 and Melia et al., 2017. Besides, PC3 was concerned in some work. In our opinion, the study for OW ships is more important to shipping industry. This study showed that the Arctic would be accessible to PC6 ships in September in the next 10 years. Certainly, PC3 ships would be navigable.*

*[Ref] Smith, L. C., and Stephenson, S. R.: New Trans-Arctic shipping routes navig able by midcentury, P. Nati. Acad. Sci. USA, 110, E1191–E1195, https://doi.org/10. 1073/pnas.1214212110, 2013.*

*Melia, N., Haines, K., Hawkins, E., and Day, J. J.: Towards seasonal Arctic shipp ing route predictions. Environ. Res. Lett., 12, 084005, https://doi.org/10.1088/1748-9326/aa7a60, 2017.*

Comment1: I can understand that it is hard to clearly distinguish ice conditions in your climate model, so you consider them as ice thickness and ice concentration. However, different ice conditions do make a big difference to ship navigability. For example, for the same ice thickness * ice concentration (e.g. t * C = 0.3), pack ice (say t = 0.6 m thick and C = 50%) have a high degree of freedom that level ice (say t = 0.3 m and C = 100%) doesn't have. Thus, ships are easier to navigate in broken ice floes. I think you should at least mention this limitation and say it can be a future direction. I suggest you look into this paper to get insights into the ship interaction with unconsolidated ice floes: Huang, L., Tuhkuri, J., Igrec, B., Li, M., Stagonas, D., Toffoli, A., Cardiff, P. and Thomas, G., 2020. Ship resistance when operating in floating ice floes: a combined CFD&DEM approach. Marine Structures, 74, 102817.

R1: *Thanks for your detailed annotation and constructive suggestion. Indeed, it is better to distinguish sea ice types at first, and then use sea ice thickness and concentration as indicators. ATAM is hard to do that now. This limitation was mentioned in the revised*

*manuscript. We have read the recommended literature and got a lot of inspiration. We also read another paper: Huang, L. F., Li, M. H., Romu, T., Dolatshah, A., Thomas, G.: Simulation of a ship operating in an open-water ice channel. Ships Offshore Struc. Both of them were cited in the revised manuscript.*

Comment2: as you said, lower ice-class vessels are increasingly important for the current research. Although your work addresses PC6 ships, I still suggest you give a brief/rough prediction (or comment) based on your research, regarding how many days are navigable for PC3 and open-water vessels, which will very valuable information. Maybe you could also say that you intend to do a detailed future study for PC3 and open-water vessels, or recommend other scholars to look into it.

R2: *Thanks for your suggestion. This paper used monthly sea ice data. The navigable days can be calculated by daily scale sea ice data. However, there are few models provided it, and this will increase the uncertainty of the outcome. We will try to do that in the future study.*

# 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.:

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B. C. O'Neill et al.: The Scenario Model Intercomparison Project (ScenarioMIP) for CMIP6

**Shared socioeconomic pathways**

**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.*

# Referee comments on 'Perspectives on future sea ice and navigability in the Arctic' by Jean-Francois Lemieux.

In this paper, the authors use CMIP6 simulations to assess the navigability in the Arctic until the end of the 21st century. I think the topic of this manuscript is very interesting and timely. Although the manuscript has the potential to be a nice scientific contribution, I find that it requires a lot of work and substantial revisions. The authors need to clarify many aspects of their methodology. Moreover, I find that the figures require a lot of work; there are typos, captions are incomplete and readability is difficult due to the font size. Finally, I really think the english should be improved. This manuscript could be considered for publication in The Cryopshere once the authors have addressed the following comments.

*A: Thanks for the constructive comments. The methodology and figures were revised for the issues addressed in your comments. An English naive speaker from AJE was invited to improve the quality of writing. We sincerely hope our endeavor could meet your approbation.*

## Major comments

Q1: Section 2.1: the authors need to better explain how they selected a subset of CMIP6 models for their study.

*A1.1: The selection of CMIP6 models was explained as below in the revised manuscript.*

   *"This study selected models by comparing the historical trend of Arctic sea ice extent in simulation with remote sensing observation during 1979–2012. The observation data comes from Sea Ice Index in the National Snow & Ice Data Center. The selected models are those the correlation coefficient between original simulation and observation greater than 0.8 (0.7 for March). Five-point moving averages of simulations were made in Figure 1."*

-For a given model, did you use all the members or just the ensemble mean? What do we see in Figure 1?

*A1.2: The ensemble means were used in this paper. Figure 1 shows the variation of sea ice extent in observation and five-point moving averages of simulations during 1979–2012.*

-I don't understand why the authors base their selection on the correlation coefficients and not on the trends of the sea ice extent. Is the correlation calculated in detrended time series or on the original ones? I guess on the original ones, the correlation in fact measures the quality of the trend. Please clarify. Note that another way to select a subset of models would be to follow the approach of Notz and SIMIP community GRL 2020.

*A1.3: Notz and SIMIP community, 2020 selected a subset of models for estimating a best guess of the future evolution of the Arctic sea-ice cover with strict approach if the ensemble spread of model includes the observational record, considering observational*

*uncertainty. It has great revelation for our future work. Previous studies to the Arctic navigability directly used the average of multi-model. In this paper, a simple selection was made to filter out the models with large deviation. Correlation coefficient is a statistical variable to indicate the relationship of the trends between the simulation and observation. It was calculated on the original ones and clarified in the revised manuscript as "The selected models are those the correlation coefficient between original simulation and observation greater than 0.8".*

-In Figure 1, there is more variability in the observations than in the CMIP6 time series. Is it because the averaging window (5 points) is not applied to the observations? Please clarify.

*A1.4: We want to show the actual changes of sea ice extent during 197-2012. So the averaging window is not applied to the observations in Figure 1. The caption was revised as "The observations and five-point moving average of sea ice extent in March and September during 1979–2012".*

-For many analyses and figures (e.g. figure 6) it is not clear if the authors use the multi-model ensemble mean? Please clarify.

*A1.5: Thanks for your reminding. It was clarified as "Variables in figures and tables were from the ensemble means of selected models" in the revised manuscript.*

Q2: Section 2.2: the authors need to clarify equations (1), (2) and (3).

-what are the ice types in equation (1)? Do you get these from the CMIP6 simulations? I would be surprised. I guess you get concentration and thickness. Related to this, please make sure you use the thickness (h) and not the mean thickness in a grid cell or in other words the volume (h*concentration).

*A2.1: Thanks for your question and reminding. Ice types do not represent the named types of sea ice, such as pack ice and first-year ice in Equation (1). They are ice within a range of thicknesses corresponding to IMs in equation (2). This sentence was revised as "a, b, and n, are ice within a range of thicknesses corresponding to IMs in equation (2)." in case of confusion. We are sure the thickness is not h*concentration.*

-once you find an IM (e.g. equation (2)), how do you calculate IN in equation (1)? Is it the same IM for all the ice types? This needs to be clarified.

*A2.2: As explained in A2.1, IM is same for ice within corresponding range of thickness.*

-what do you show in Figure 6? Is it IN? Why is it called Arctic navigability then? Also explain how you define navigable area. Is it where IN is greater than 0?. Please clarify.

*A2.3: The caption of Figure 6 was revised as "INs for OW ships under SSP5-8.5 in September".*
*The navigable area was clarified as "It is the percentage of grids where INs are greater*
*0." In the revised manuscript.*

Q3: The figures need to be improved. Here are some comments related to that.

-all the figure captions need to be reworked. At the moment, they don't provide enough details.

*A3.1: Thanks for your suggestion. All of figure captions were reworked as follows.*

*Figure. 1. The observations and five-point moving averages of sea ice extent in*
*March and September during 1979–2012.*

*Figure. 2. Sea ice extent under multiple scenarios and observation trends in March and*
*September*

*Figure. 3. Linear trends and probability distributions (PD) of Arctic sea ice extent (SIE)*
*in March and September*

*Figure. 4. Linear trends of sea ice thickness and concentration under SSP5-85 in September*

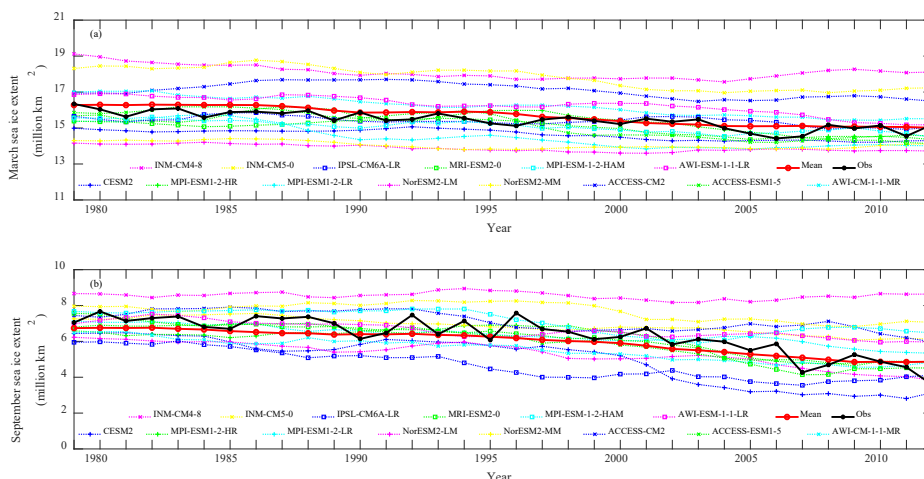
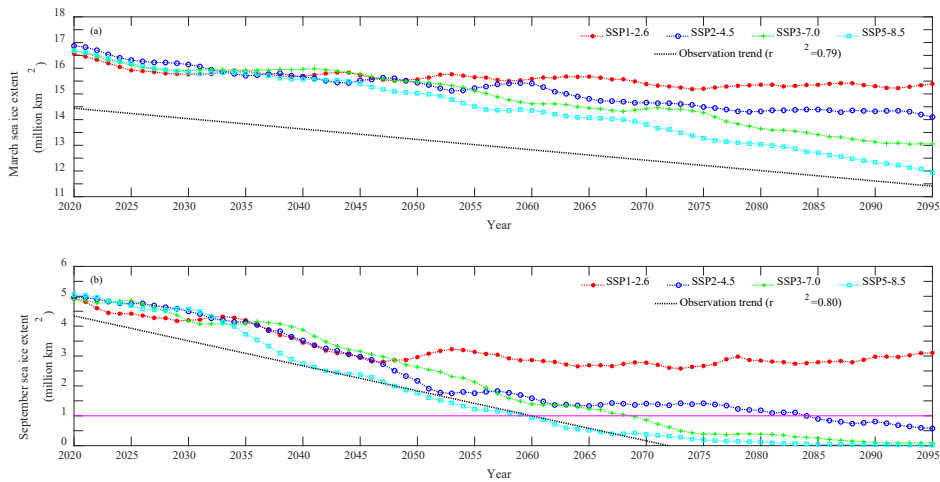
*Figure. 5. The changes in sea ice volume and age under SSP5-85*

*Figure. 6. INs for OW ships under SSP5-8.5 in September*

*Figure. 7. Total navigable areas for OW ships and PC6 ships under SSP2-4.5 and SSP5-8.5*

*Figure. 8. Navigable areas for OW ships and PC6 ships under SSP2-4.5 and SSP5-8.5 within*
*different latitudes*

-use units and labels that are commonly used. Example, in figures 1 and 2, the units on the y axis
should be M km2 and the label should be September sea ice extent (not remaing ice in
September...with the typo in remaining).

*A3.2: Thanks for your suggestion. Figures 1 and 2 were revised as bellow.*

-increase the font size for the text. It is often very difficult to look at these figures.

*A3.3: The font size was increased in some Figures. The resolution of Figure was reduced when it was inserted into paper. The original Figures (600 dpi) will be submitted to journal.*

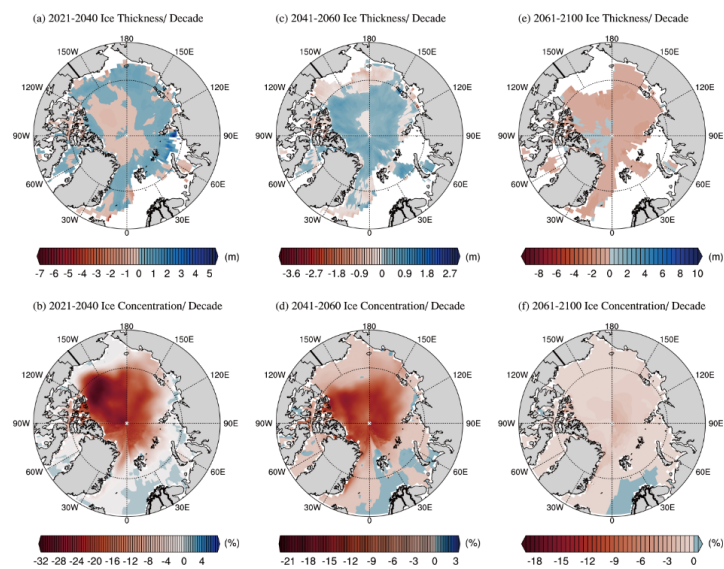
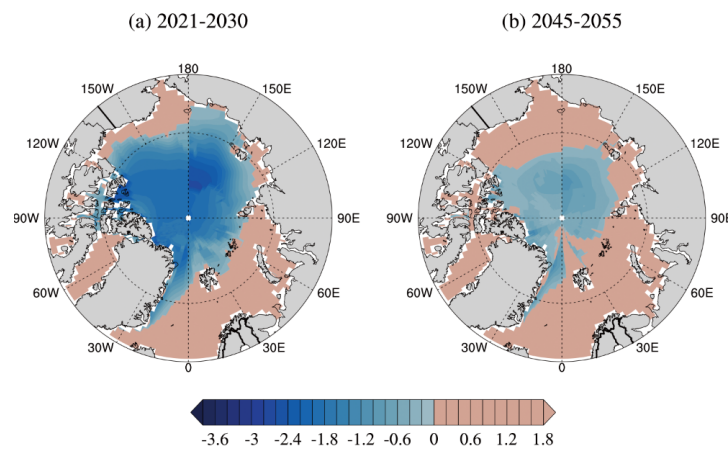
-figure 3: wouldn't it be better to use a histogram instead?

*A3.4: Thanks for your suggestion, but histogram cannot cover all the information shown in Figure 3.*

-there are lines or features emanating from the North Pole in many figures (e.g. figures 4 and 6). Is it the interpolation that is used? I am sure the authors can do better than this.

*A3.5: Yes, it was resulted by interpolation. The lines in Figure 4 and Figure 6 were eliminated.*

(a) 2021-2030      (b) 2045-2055

-3.6  -3  -2.4  -1.8  -1.2  -0.6  0  0.6  1.2  1.8

**Q4:** lines 250-255 and lines 306-310: the authors show an abnormal decrease in the navigable area at high latitudes in September. They mention it but argue that this is difficult to explain. As the navigability depends on the concentration and thickness, I think they can explain it if they investigate it a bit further.

*A4:Firstly, we checked all of data and programs, and did not find any error in calculation. According to Figure 8, this abnormal point results from the decrease within 85°N–90°N. It directly attributes to the increase of sea ice thickness transiting from lower than 120cm to be equal or greater than 120cm. However, further reasons on physical mechanisms are hard for us to explore. We can only use multi-model data released by CMIP6, and respect the abnormal result from calculations and show it to the public and researchers, but cannot conduct tests for it. We sincerely hope the development teams of models could give an explanation for this.*

## Minor comments

**Q1:** lines 42-44: the authors describe a mix of two physical mechanisms in the same sentence. Sea ice reflects a significant fraction of the solar radiation because it has a high albedo. It also reduces the heat transfer between the ocean and the atmosphere as it acts as an insulator.

*A1: Thank you. This sentence was revised by divided into two parts as you mentioned above.*

**Q2:** line 103 (and at other places): replace 'excellent models' by 'selected models'.

*A2: Replaced.*

**Q3:** usually the discussion comes before the conclusions. Given the fact that the discussion is really short, I would combine it with the conclusions and name the section: Discussion and concluding remarks.

*A3: Two of sections was combined and named as Discussion and concluding remarks in the revised manuscript.*

# Referee comments on "Perspectives on future sea ice and navigability in the Arctic" (Chen & all – 2021) by Hajime Yamaguchi

Comment: This is an interesting analysis, but I question the huge scale difference between model computations and ship navigation. The ensemble mean is expected to improve the overall prediction accuracy but substantially smoothen the spatial resolution. In my experience, ship navigation simulation could not be well made without careful interpolation and sea ice data modification. Do you have any correlation data between model results and real ship navigability? If you have done such processing in your work, please clarify it. Even if you have not done it, I think you should comment on the uncertainty of your assessment.I also agree with the other reviewers' comments on the web and I think the authors reply properly. Thus I will not repeat the same comments here.

*A: Thanks for your review and constructive comments. Indeed, there are considerable difference between model computations and real ship navigation for the uncertainties of model simulations and the influences of other complicating factors in terms of hydrology, meteorology, facilities, geography, political restrictions, but this research might still has some implications for the navigation in the future. Ship navigation may be well made under model certainty and high resolution, but the ensemble mean reduces uncertainty at the expense of resolution. Therefore, the possible navigable time rather than specific shipping routes planning was mainly investigated in this research. We did not do correlation between model results and historical ship navigability because the real ship navigability is influenced by many other subjective and objective factors in addition to the sea ice thickness and concentration which just taken into account in this paper. The uncertainty was discussed in the revised manuscript.*