Reply to Reviewer 2- tc-2021-282 Asadi et al. 2021 - Probabilistic Gridded Seasonal Sea Ice Presence Forecasting using Sequence to Sequence Learning

We sincerely thank the reviewer for the thorough review and excellent comments. Reviewer comments are shown in black, our response are shown in blue.

The authors present a fascinating application of machine learning techniques to better predict ice presence/absence within Hudson Bay, using ERA5 data as an input. The results show promise in helping plan shipping operations around the ice-free season, however, the clarity of these results is lost in lengthy wording. It is recommended that the authors read through the document for grammatical errors and places where the wording of sentences can be made more succinct. This article can become much more impactful and easier to read with more ‘straight to the point' sentences.

Thank you for this comment. We agree and will revise the wording throughout the manuscript to make the manuscript more readable.

General comments:

- Ensure you are consistent using ‘freeze-up’ with a hyphen throughout the document, and choose either ‘breakup’ or ‘break up’ to use throughout the document

Thank you. This has been corrected.

- I am aware that it is difficult to phrase sentences when discussing the number of lead days and the two models, however, I found most sentences discussing these topics hard to read. For example, line 149:

‘For example, the top row of Fig 1b shows the accuracy of forecasts launched in January using Basic model for forecast lead days of 1 to 90. E.g., the first top-left box in this figure (Fig 1(b)) corresponds to the average accuracy after 1 day forecast for all forecasts launched between January 1 and January 31, ending in January 2 to April 1 and the second box corresponds to average accuracy of forecasts launched between January 1 and January 31 ending in January 3 to April 2.’

I think it would be easier if you use articles when you are referencing lead days or models. For example: ‘the Basic model’ or ‘a 1 day forecast’. This would make your sentences flow better while reading them, which would communicate your results more efficiently.

We agree the wording can be improved and will take this into account by doing a thorough revision.

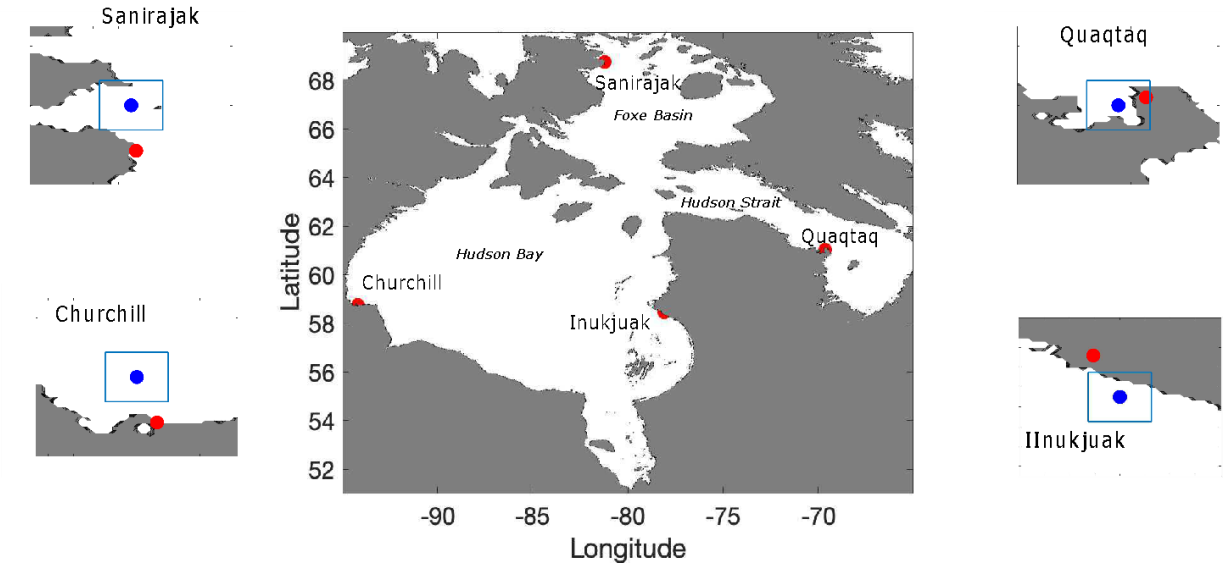
- The results section has some statements that are more suited towards the discussion section, however I see your discussion and conclusion section are combined. I'm unsure if the section headers are pre-determined by the journal, but if they are not I would suggest making section 6 'Results and Discussion', and section 7 'Conclusion'. This would allow you to discuss your results more in depth as you present them, as I feel like some of your results could be discussed more in depth.

- Throughout the document, you abbreviate some month names and use the full name for others. You should pick one method and stick to it throughout (i.e. always abbreviate or always use the full word).

These have been fixed using the full word except for the figures, which still have the abbreviations.

- There is a comment in the specific comments regarding this, but you should include some discussion regarding the resolution of your results, and how this may impact the use of your results for port-specific operations. I am a little wary of how the land mask may impact how 'close' the pixel you use to represent the port is to the actual port in question. A figure representing this may add some clarity.

We have put together a map of the port locations, including one requested at Sanirajak (formerly known as Hall Beach). The map of the study region is shown below with the port locations shown in red. The Insets show the port location (red) and the nearest point on the model grid (blue) that is outside of the land boundary (where landmask from ERA5 is less than 0.6), in addition to a bounding box that approximates a grid cell. The model grid point near Quaqtaq is located (correctly) in the water region because the landmask from ERA5 has a low value in that region due to the low elevation.



Specific comments:

Line 3 – You may be limited on word count in your abstract, but I think it would be helpful if you stated the type of data you are feeding into your ML system to derive these predictions.

Modified

Line 3 – recommend changing to “Given the recent observations of the declining trend”

Modified.

Line 6 – recommend changing to ‘within a 7-day time period’, unless you define why a 7-day time period is ‘valid’ in the manuscript?

Modified.

Line 8 – The introductory sentence needs a little bit of work. I would recommend removing ‘northern communities’ as you do not speak of them in the rest of the introduction. Maybe focus more on the topic of shipping and why ice forecasting is vital for shipping operations in this introductory sentence. OR add in reference to communities, and why they rely on ice.

Thank you. We have changed to “Sea ice presence is an important variable for shipping operators in the Arctic and surrounding seas as it poses a significant hazard to their operations. For ships with little or no ice-breaking capability, the timing of freeze-up and break-up defines the period over which shipping operations can be carried out. For ships with some ice-breaking capability, the predicted ice cover along a proposed shipping route provides information on transit time and is also required for accurate weather forecasts in ice-covered regions.”

Line 12 – Could you expand on what you mean by ‘Typical approaches are usually statistical or dynamical in nature.’? Maybe add a reference to examples of these? I see that you go more in depth in the next paragraph into dynamical forecasts, but what about statistical like you mentioned earlier?

We have added the following text to the introduction: Typical approaches are usually statistical or dynamical in nature. Statistical models have included multiple linear regression (Drobot et al., 2006), or Bayesian linear regression (Hovarth et al., 2020), whereas by dynamical approaches we are referring to those that use a forecast model solving the prognostic equations governing evolution of the ice cover (Askenov et. al., 2017, Sigmond et al. 2016). An excellent overview is given in Guemas et al. (2014).

Line 15 – I would recommend splitting this up into two sentences, breaking it up at one of the commas Modified.

Line 16 – remove ‘the summer of’ before 2008, as you have already indicated that this study was in the spring and summer Modified.

Line 18 – I am not too sure what you mean by ‘skill’. Do you mean the forecasts ability to predict ice? There may be a better way to word this to avoid ambiguity. We agree “skill” was not specific enough.

We have changed this to “A comparison between pan-Arctic and regional forecast skill was carried out by (Bushuk et al. 2017), where skill was assessed using the anomaly correlation coefficient (ACC) between sea ice extent derived by applying a threshold to an ensemble-mean sea ice concentration and sea ice concentration from passive microwave data, and detrending both. It was shown that the ACC of seasonal forecasts in specific regions was dependent on the region and forecast month.”

Line 20 – It might be nice to list some environmental controlling factors in brackets, like: (i.e. wind speed and direction, tides)

Line 24 – Recommend to change to ‘Both of these approaches determine…’ Modified

Line 28 – Change to ‘composed of sea ice concentration data…’Modified

Line 30 – Remove ‘good’ Modified

Line 30 – Would help the reader if you included where the mean September sea ice extents from 2017 came from (ice charts? Passive microwave data?)

Changed to “Their predictions were in agreement with the mean September sea ice extent from 2017 where the sea ice extent is the total area in a given region that has at least 15\% of ice cover, according to passive microwave data.”

Line 43 – ‘calibrated probability of ice’: presence or concentration?

Line 64 – Need to define ‘SST’ Modified

Line 65 – Doesn’t ERA5 have a 31km resolution? I would state this plainly so the reader knows what resolution your results are.

This information had been added to the manuscript (lines 52, 92 and 146)

Line 74 – Would recommend shuffling around this sentence: ‘Shipping traffic is also generated by mining, fishing, tourism and research activities, being mostly confined to the ice-free and shoulder season’.

Line 84 – ‘In Seq2Seq learning, which has successful applications in machine translation’ Modified

Line 87 – Recommend to spell out ‘two’ Modified

Line 88 – suggest removing ‘part’ Modified

Line 92 – In line 54 you use the double wavy equal sign, but here you use a single wavy line. I would recommend picking one and keeping it consistent throughout. Modified

Line 94 – Recommend to change to: ‘The encoder section of the Basic model takes the last three days of environmental conditions as an input’ Modified

Line 97 – Remove ‘so as’ Modified

Line 99 – May be better to spell out ‘LSTM’ in full form Modified

Line 101 – Recommend rewording the last sentence for clarity: ‘The output to the encoder is a single raster with the same height and width as the input, but a higher number of channels to represent the fully encoded system state.’ Modified

Line 115 – Remove ‘so as’ (try and write sentences as simply as possible, i.e. with as little unnecessary words) Modified

Line 128 – Just verify that your quotation is facing the correct way before ‘April’ Modified

Line 137 – How did you determine what learning rater and momentum to use? We used the default Keras stochastic gradient descent (SGD) optimizer parameters (learning rate = 1e-2, momentum = 0.9). We also used a learning rate decay of 1e-4 and L2 regularization of 0.0003 with clipnorm=True. These parameters were determined as part of an initial hyperparameter search carried out at the beginning of the study when the compatibility of the data and the model architecture are investigated.

Line 142 – Suggest to remove ‘coming’, or replace with ‘derived’ Modified

Line 151 – I would recommend changing the formats of your dates here: ‘forecasts launched between 1-31 January, ending in 2 January to 1 April, and the second box corresponds to average accuracy of forecasts launched between 1 – 31 January, ending in 3 January to 2 April. Changed to “forecasts launched between January 1 to 31, ending in January 2 to April 1, and the second box corresponds to average accuracy of forecasts launched between January 1 to 31 ending in January 3 to April 2.”

Line 154 – This sentence needs a lot of work: suggest removing ‘very’ and changing ‘on January’ to ‘of January’. As well, are you indicating that the accuracy is close to 100% for

both January and the span of January – March (this is not clear)? It would be helpful if you stated the actual accuracies.

Thank you. The accuracies are close to 100% for lead days from the beginning of January to the end of March. We will revise the text to include this.

Line 155 – This sentence struggles with the same structural problems as the first, I would recommend rewording to something like: 'In contrast, for forecasts at the beginning of the open water season (June and July), the climate normal struggles to accurately capture the ice cover for lead times of 1 to 50 days likely due to inter-annual variability and the impact of climate change'. You might also want to indicate what climate change has to do with this (i.e. 'lengthening of the open water period due to climate change')

Line 165 – This sentence also needs to be reworded, I have underlined grammatical errors: 'Using additional climate variables for the input of the Augmented model is showing its impact here where in the periods that Basic model is worse than climate normal (Fig 1d), the Augmented model has better accuracy and is closer accuracy to climate normal.

We will use clearer wording in the revised manuscript.'

Line 169 – Double check if it should be 'the climate normal' or 'climate normal' Checked

Line 179 – Spell out 'April' fully, as you have spelled out every other month Modified

Line 202 – 'Observations' should not be capitalized Modified

Figure 4 – Include units for Latitude and Longitude, and capitalize the words in your legend Modified

Figure 5 – Units for lat and long Modified

Line 212 – 'Figure 5 and 6 show the overall…' Modified

Line 215 – 'The freeze-up accuracy maps at Fig 5 show that except the Basic model's prediction at 30 lead day (Fig 6b), other maps are showing similar patterns of accuracy.' This sentence needs reworking – would recommend flipping the sentence, so you are presenting the positive results first, then adding on the Basic model's prediction after. Modified

Line 221 – 'compared' instead of 'comparing' Modified

Line 222 – Capitalize 'fig 6a' Modified

Figure 6 - Units for lat and long Modified

Line 227 – I would recommend changing all of your dates to the format: '1 Oct to 31 Jan'. This is a more standard way of presenting dates and is more simplistic. We have revised the dates.

Line 233 – 'Compared' instead of 'comparing' Modified

Line 234 – Change to 'its accuracy over the breakup season…' Modified

Line 235 – Since you discuss the break up at three sample ports, and present the results in Figures 8 and 9, I think it would be important to include a map of these three locations, indicating which pixels you use to extract this data. I am curious how the land mask affects the data, i.e. how close are the pixels you are using to the actual port? Since you are using 31km ERA5 data, I would suspect that the pixel you chose to represent each port is actually a distance away from the actual dock. In the end, I guess I am a little wary of how applicable your results are to local communities, as they are likely more impacted by ice break up on a smaller scale along the coast (for hunting and travel), whereas shipping operations are more concerned of the large scale ice break up along shipping corridors. Some discussion of how the scale of your results impacts how they are used by different groups may help address this.

We have included a map of the port locations, indicating the locations of the pixels used to extract the data. As the reviewer has pointed out these locations are a distance from the actual port. For this reason, and also because i) atmospheric conditions represented from ERA5 would be different from those at the actual port locations ii) we do not have a complete description of sea ice conditions that can represent the complexity of port conditions, our model output is expected to be more representative of offshore conditions, which is important for route planning. We will revise the manuscript wording to reflect this.

Line 237 – Capitalize 'figures' Modified

Line 242 – Would recommend moving the figure reference to the end of the sentence, and putting it in brackets OR starting the sentence with 'In figure 8, 30 lead day predictions for freeze-up are more…' Modified

Line 242 – Any idea why this is? I am curious why the predictions varied at the different town ports and would think a discussion of this would add to your paper. We agree the predictions for the various ports is interesting. It should be noted that the range of dates covered in the x-axis (Observed dates) varies between the ports. For freeze-up, the narrowest range is for Churchill (approximately 1 month), whereas Quataq and Inukjuak both have a wider range (approximately 6 weeks). We will look into this by comparing the variability (over the years) of sea ice break-up and freeze-up dates at the various locations

with the variability (over the years) of the input data. The sea ice break-up and freeze-up used in the comparison is from the observations (ERA5, based initially on passive microwave data) and may have outliers not captured by our train-test procedure. We are also planning to compare the predictions at the various ports with data from regional ice charts provided by the Canadian Ice Service. The regional charts are weekly analyses of ice cover (concentration and stage of development of the ice) that are based on manual interpretation of synthetic aperture radar (SAR) imagery in addition to other sources, such as passive microwave and visible imagery and ship reports. A similar comparison has been done in Gignac et al. (2019).

Line 252 – If you have space in your word count, I would recommend listing the 8 variables used in the Basic model, and the other variables added to the Augmented. This would help refresh the reader's memory as to how these two models vary. Good idea. Thank you

Figures 8 and 9 – If possible, the font size should be increased, particularly for your axis labels. This might take some reorganizing of your figure boxes – maybe you could rotate the 'model' and 'day' labels on the far left of your figures? Modified

Askenov Y., Popova E.E., Yool, A., Nurser, A.J., Williams, T.D., Bertino, L. and Bergh, J. (2017), On the future navigability of Arctic sea routes: High-resolution projections of the Arctic Ocean and sea ice, Marine Policy, 75, 300-317.

Bushuk, M., Msadek, R. Winton, M. Vecchi, G. A., Gudgel, R., Rosati, A. and Yang, X., (2017), "Skillful regional prediction of Arctic sea ice on seasonal time scales", Geophysical Research Letters, 44, doi: 10.1002/2017GL073155.

Dirkson, A., Merryfield, W.J., and Monahan, A.H., (2019) "Calibrated probabilistic forecasts of Arctic sea ice concentration", Journal of Climate, 32, 1251-1271.

Dirkson, A., et al. (2021) "Development and Calibration of Seasonal Probabilistic Forecasts of Ice-free Dates and Freeze-up Dates." Weather and Forecasting 36.1: 301-324.

Drobot, S.D., Maslanik, J.A., and Fowler, C., (2006) "A long-range forecast of Arctic summer sea-ice minimum extent", Geophysical Research Letter, 33, L10501, doi:10.1029/2006GL026216.

Gignac, C., Bernier, M., & Chokmani, K. (2019). IcePAC–a probabilistic tool to study sea ice spatio-temporal dynamics: application to the Hudson Bay area. The Cryosphere, 13(2), 451-468.

Guemas et. al., (2014), "A review on Arctic sea ice predictability and prediction on seasonal-to-decadal time scales", Quarterly Journal of the Royal Meteorological Society, doi:10.1002/qj.2401.

Horvath, S. et al., (2020) “A Bayesian logistic regression for probabilistic forecasts of the minimum September Arctic sea ice cover”, Earth and Space Science, 7, doi:10.1029/2020EA001176.

Sigmond, M., Reader, M.C., Flato, G.M., Merryfield, W.J. and Tivy, A. (2016) “Skillful seasonal forecasts of Arctic sea ice retreat and advance dates in a dynamical forecast system”, Geophysical Research Letters, 43, 12,457-12,465, doi:10.1002/2016GL071396.