

Interactive comment on “Benefits of sea ice thickness initialization for the Arctic decadal climate prediction skill in EC-Earth3” by Tian Tian et al.

Anonymous Referee #1

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General comments:

The authors introduce a method to perform anomaly initialization of predictions with EC-Earth3. A mapping from single-category to multi-category sea ice states has been successfully developed and used, which is useful whenever data to initialize sea ice states are not given in the multi-category framework. It is common to initialize prediction systems using reanalysis products derived from different models. Performing “anomaly initialization” has proven beneficial in earlier works. Using only a subset of variables to “(anomaly-) initialize” allows to study the origin of prediction skills, here done for sea ice in the Arctic region. This discussion provides an important contribution

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to assess the contribution of particular variables, like sea ice thickness or sea ice concentration, for the prediction skill on time-scales up to decades, and has the potential to impact future decisions on initialization strategies. Due to the number of performed experiments, the material to be discussed is a lot, and the authors already confined to discuss the sea ice state and surface air temperature. It could help the improve understanding of the results and condense the information when the authors would cluster regions of similar physical properties and discuss the added/reduced skill for the different setups for these different regions. It would further improve the manuscript if the reader would be better guided through the text as done already by motivation the choices of studied variables or time-frames.

Specific major comments:

1. assessment of the results

1.1. You can better guide the reader through the script by introducing and motivating what you do in the different sections and subsections.

1.2. I suggest to restructure the assessments in Sections 3 and 4 focusing on particular regions dependent on specific physical regimes, e.g. North Atlantic section, Pacific section, Central Arctic and FYI coastal areas (as similarly done for the discussions of different regions in Sec. 4.2). Thus, one could discuss the effect of the different initializations for these regions for each experiment in a more condensed way. It would also prevent discussing some detail-regions/cases (e.g. E.Siberian Sea in I.373) while skipping others (e.g. GIN Seas for A10 in Sec.3.3.1 or skill of SIC I FREE in I.370, or I.392ff).

1.3. The authors study the benefits of keeping certain model variables unchanged while initializing the anomalies of others. I think, this is a nice and useful approach. Could you, in the discussion section, stronger indicate adjusting which anomalies lead to which skill? I.e. stronger emphasize the role of the ocean, SIC and SIT; and indicate adding of which information reduces the prediction skill where.

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2. Observed anomalies/observed state: These terms are misleading. You use fields from a reanalysis product (produced by LIM2 and NEMO3.4 with assimilated SIC, T,S, SSHA observations using 3DVar FGAT). In particular, a reanalysis-SIT, which you use as “observation”. The approach introduced as in the manuscript would not be suitable to handle observational errors and data sparsity. Using the reanalysis ORAS5 as observations, you make use of the strengths of 3DVar. Please check the manuscript and correct/clarify that phrasing. Examples are: l.45ff, l.54ff, l.114
3. Prediction systems require an initial state. Here, this has been achieved by using a EC_Earth3 spinup state where some variables have been anomaly-corrected using ORAS5 reanalysis data and a fullfield ERAI state for the atmosphere. You do not apply data assimilation. Please modify the manuscript (whenever your approach is called “assimilation” or you compare your approach with the assimilation approach) accordingly. Examples are l.72, l.202. It has not been mentioned in the introduction that and why you performed fullfield initialization in the atmosphere (as mentioned in l.178). Please add according statements.
4. Non-consistent initialization: There are systems like NorCPM, in which the model starts its prediction by using a reanalysis for initialisation that stems from performing DA in their own system, while others like the GFDL system use products from different models to initialize different model components. As model physics differ, initialization shocks are likely (see for instance the EC-Earth model-based study: <https://link.springer.com/article/10.1007/s00382-020-05560-4>), that impact the prediction skill. You should also address this when you discuss (atm) fullfield initialization and (ocean+sea ice)anomaly initialization. You already do the latter (e.g. in l.119), yet rather indirectly.
5. Variables to be discussed: The paper aims to enhance the understanding of decadal predictability of Arctic sea ice by initializing anomalies of different subsets of variables from the ocean and the sea ice state.

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- 5.1. The relevance of the atmosphere in the Arctic region (regarding aspects of predictability and/or necessity for skillfull predictions) should be addressed, in particular the need to study TAS. Suitable places in the text may be the introduction or Section 2.3.
- 5.2. A discussion on the atmosphere is lacking in the discussion section. If there is no particular need to study TAS (for instance as feedback from altered ocean/sea ice state and potentially back to the ocean/sea ice state in the Arctic region), it may be an idea to skip the discussion on TAS.
- 5.3. It should be addressed, why the skill in the upper ocean state in the Arctic region is not discussed, though the authors could use the ORAS5 reanalysis product (as is done for SIT) and TAS is studied. Insights might be gained for instance on the degradation in SIT in the Atlantic water inflow region for AI2 (e.g. also by studying the bias of SST or T in the upper ocean in Fig.2, which I suggest to add). One argument could be that TAS is a reflection of SST and in addition provides information on how the skill changed over land dependent on the initialization scheme.
- 5.4. Table1 (l.103): Snow thickness anomaly is also initialized in AI2. The role of snow cover for prediction should be discussed in the introduction. As well leave a note why you do not assess the skill for SNT, or if you did, provide a brief summary of the results, e.g. in the discussion.

Specific minor comments:

6. choice of title: The authors primarily discuss the added benefit from sea ice initialization for decadal prediction skill in the Arctic. Discussions on the improvement of AI2 over AI1 are of rather subordinated relevance. Line 71f hints towards a more suitable adaptation of the title: “benefits of sea ice initialization”.
7. l.110ff: could you add a statement about the sea ice state in ORAS5? Does it compare well against observations?

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8. L.143: Could you explain why A^{ctrl} has only one dimension (i.e. one value per time)?
9. L. 153: "Different from weight [...], Fig.1 plots the $h_l^{\text{ctrl}} - A^{\text{ctrl}}$ histogram": Eq. (2) is not a plotted histogram. Please, rephrase how equation 2 is linked to Fig.1.
10. L.159: If V^{ice} is not "ice volume per unit area" with unit m (compare l.18), then area should be taken into account. Otherwise, $[A^{\text{ice}}]$ should be [0,1] and not [%] (l.154). Compare also with Fig.3.
11. l.159/l.161: Could you clarify more in detail how you constructed h_l^{ice} ? The thickness classes are defined by lower and upper bounds of each thickness bins. Do you reduce these bins to its mean value dependent on the value of A^{ice} ? I.e. for a given value A^{ice} , are h_l^{ice} the exact mean values taken from Fig.1 dependent on in which bin A^{ice} falls?
12. On pages 6f you explained how you constructed fullfield multicategory A^{ice} , V^{ice} and SIT^{ice} fields. Could you make it clearer in l.125 that you start already with the initialized (i.e. corrected) A^{ice} , along the line: "To derive anomaly-corrected A^{ice} values we add the anomalies of ORAS5 ice concentrations to the climatology of A^{FREE} and then split this corrected field into different thickness categories"? It is unclear to me, how you anomaly-initialize SIT. Could you add a sentence in l.161?
13. L.405, Fig 9: could you explain the degradation found in TAS over Barents and Kara Seas by added SIT initialization?
14. L.406ff (last paragraph) I do not see that clear improvement as the authors see between lead years 6-9 and 2-5 in the North Atlantic. (S5 and S7) There are mostly dipole patterns of improvement /degradation in each graph and discussed region. I would skip that part and the graphs. I do not see added information of looking into these periods for the paper.
15. L.434: Using RMSESS as explanation for moderate skill in AI2 is an unfortunate

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choice as RMSESS is a relative skill score.

16. Assessment of the results. Could you provide some more explanation or correct, respectively?
- 16.1. l.244: you indicate that the reason for the biases in the sea ice state are linked to MYI region, which seems to contradict with the results of Fig.S2. It appear to be linked to O-A heat exchange resulting in too little ice in summer, too fast freezing in autumn and too thick ice in winter.
- 16.2. L.295: high skill in FREE seems to be an indication that the external forcing determines the skill in contrast to internal variability. Could you add an indication for that?
- 16.3. In Fig.3 it would be beneficial to also plot FREE to identify the differences between FREE and REF. You use FREE-SIC and FREE-SIT in AI0, while for AI1 REF-SIC and in AI2 additionally REF-SIT, resulting in presumably different anomalies.
- 16.4. L.321: SIT discussion: You derive the anomalies for ocean and sea ice from the same product, that has been constructed via 3D-Var FGAT. The initial anomalies of ocean and SIT in AI2 should not be "counteracting". I am wondering if AI0/FREE has negative skill score in that region. Might the degradation be linked to model biases (see also Fig S2) that are kept unchanged by the initialization, and O-A heat exchange?
- 16.5. Discussion on Fig.7 (l.349ff): It appears that different measures are used to judge "similar performance" or "improved performance", e.g. compare ACC(SIV) ("much difference") vs, ACC(TAS) ("hardly any differences").
- 16.6. l.392ff: The center graph in Fig.9 indicates a change in SIT which might also be seen for SIC in AI0/FREE. Changes in the Arctic basin SIT are regulated by the ocean circulation such as the Beaufort Gyre and the Transpolar drift (Davis et al. (2014)). Here, it looks like the Beaufort Gyre has been impacted by ocean anomaly initialization, which might explain as well the degradation found in Fig 8 left lower two graphs.

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16.7. L.423: Can you link the skill in Barents Sea to reemergence of SST and longtime benefit from ocean initialization?

16.8. L.424: Is the added skill in the Barents Sea due to ice initialization due to SIC initialization or added SIT initialization?

16.9. Fig 10: Do you have an explanation why there is this strong degradation in the Hudson Sea and the Baffin Bay?

Technical corrections:

- L.2: "sea ice volume, being a product of sea ice area/concentration (SIC) and thickness (SIT)": remove "area"
- L.6: "regional benefits"
- L.79: "this paper is structured as following s"
- L.79: "the" ensemble-experiment"al" design (potentially also remove "ensemble" as you do not address the topic of ensembles in the introduction.)
- L.82: I suggest to replace "benefits of [...] at decadal scales [...] regional mean" by "benefits of [...] at decadal scales in/for different Arctic regions"
- L.87: remove "configures".
- Check use of articles, e.g. in l.87f, l.233, l.224 ("A TAS index")
- L.91. Use of adverb: "linearly reduced"
- L.94 : remove "embedded"
- l.104ff: "This approach[...] Since ORAS4 [...] EC-EARTH2.3": I suggest to shorten these two sentences to "This approach has already been applied to initialize EC-Earth2.3 decadal predictions contributing to CMIP5."
- L.117: "Horizontally, "

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- L.124: thickness for of snow. . .
- L.140 replace "l=1-L" by "l=1,...,L" or "l ∈ {1,...,L}"
- l.151: Please shift the definition of \hat{h}_{ice_l} before equation (4-5), and introduce these two equations. Currently they are not connected with the surrounding text.
- L.155: replace "suggesting" by "and" as the two parts of the sentences address two different observations from Fig.1.
- L. 169: "an one-day spin."
- L.159: Could you shift eq.4 and 5 up to where these are introduced (l.152)?
- L.166. Introduce abbreviation IC (initial condition).
- Fig.1 shows \hat{h}_{ice} -A^{ice} histogram, conflicting with the superscript "ctrl" in l.153.
- l.153: Fig.1 does not depict a histogram, but mean ice thickness values for different SIC ranges.
- l.192: introduce SSP2-4.5
- l.202: This is not a sentence. Check after comma.
- L.204: Consider replacing "thanks to" by "using, as also with a short assimilation window one might end up in a low quality reanalysis product.
- L.210: reference of "it" is unclear
- l.246: "initial anomalies from REF": Better call it along the line "differences between anomalies of FREE and of REF". For instance, in AI2 these initial "anomalies" should be zero.
- L.291 : Could you precise that you refer to ACC(SIC) as for instance the statement is not correct for ACC(SIT).
- L.293: replace "east of the Kara Sea" by "Kara Sea" according to the definition in Fig

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S2.

- L.387: (Fig 9., center, left), l.392: “Comparing the center and the lower panels”
- L.4 in caption of Fig 3: “Backwards extensions. . .”
- L.352: remove “in summary”. I suggest to shift this and the following sentence to l.351, where you discuss SIV. Similarly, shift the then following sentences on SIE performance where you discuss SIE performance (l.350).
- Caption Fig 4, L.4: “lines plot”
- L.376f: I would suggest to phrase that the improvements in TAS follow those of improved sea ice state in FYI regions and expand over land as well.
- L.381ff: Could you add names of variable and experiment you are discussing?
- l.397: Please add a Figure reference from section 3.3.1 you are referring to.
- L. 412: “from sections 3.3 and 4.1”
- L.415: check sentence “but its impact can. . .”
- L.430: Could you name the initialization you are discussing (all/AI1/AI2)?
- Fig.6 -0.5 is missing in the colorbar and last sentence in the caption: correct “The regions discard SIT initialization”
- Caption of Fig 10.: “RMSE in AI2 and FREE are equal”: add “AI0, respectively”.

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