

1 Reviewer 2

Review of “Relevance of warm air intrusions for Arctic satellite sea ice climatologies” by Rostosky and Spreen. <https://doi.org/10.5194/tc-2023-69>

- 5 The authors introduce a method to detect and categorize Warm Air Intrusion from atmosphere reanalysis temperature data. They apply the method over four decades and document a (slight) increase in the occurrence and severity of WAIs. They also document that four widely used sea-ice concentration datasets derived from passive microwave data respond differently to WAIs. All datasets are affected by the most severe WAIs ($T2m > -2C$), but three out of four are already significantly affected by less severe WAIs ($-10C < T2m < -5C$). The study is of interest for users of sea-ice data records, and can be interesting for
10 developers of sea-ice concentration retrieval algorithms. It can be published after some revisions.

We thank the reviewer for their positive and helpful comments. We believe that, thanks to these reviews, the manuscript has improved a lot. Please find below our responses to the individual comments.

15 GENERAL COMMENTS:

- Kern et al. (2019) concluded that the NSIDC CDR (v3) was high-biased at 100% SIC, while the OSISAF CDR (v2) was low-biased at 100% SIC. This is very well in line with your results. For a SIC CDR to appear un-affected by WAIs, a strategy is to overestimate the SICs (by selecting tiepoints that return $> 100\%$ SICs) and apply the 100% SIC threshold. You see this with your Figure A.6. At present, algorithm calibration is mentioned in passing with only 2 sentences (257-261) in your manuscript,
20 although it is possibly a key element of what you observe. By referring to Kern et al. (2019), using your knowledge of how SIC algorithms work and especially the impact of tie-point selection, and moving your Figure A.6 to the main body of the manuscript, I invite you to significantly expand on these aspects in the Discussions.

- We thank the reviewer for this valuable comment. We added a paragraph to the discussion section and moved figure A6 to
25 the main document as suggested by the reviewer. For example, we added*

*"The NSIDC CDR is computed from the NASA-Team and Bootstrap algorithms. The CDR sea ice concentration is based on the sub algorithm with the higher sea ice concentration, which, in case of strong warm air intrusions, is the bootstrap algorithm (since the NASA-Team shows a strong underestimation of sea ice concentration during warm air intrusions). In the NSIDC CDR, an updated bootstrap algorithm with dynamic (daily adapted) tie points for open ocean and full sea ice cover is used
30 (Comiso et al., 2017). By using dynamic tie points the impact of changing snow and surface conditions are mitigated and thus the impact of warm air intrusions on the derived sea ice concentration is reduced.*

- While the NSIDC CDR generally performs best during warming events, we note that an overestimation of sea ice concentration can be a result of the method applied in this algorithm. Especially in areas like the Greenland Sea, frequent polynyas and large leads open after strong storm events. These are not captured by the NSIDC CDR, while in the OSI SAF CDR or the ASI
35 algorithm using its natural resolution (6.25 km²), these events are clearly visible (see Figure 9). Kern et al., (2019) performed an inter-comparison of several sea ice concentration products and found that the NSIDC CDR systematically overestimates sea ice concentration by around 3% when the ice concentration is close to 100%. This overestimation is not visible in the final product since the NSIDC CDR is truncated at 100% ice concentration. Therefore, in the case of strong warm air intrusions, the NSIDC CDR sea ice concentration can remain close to 100% even though the (non-truncated) average ice concentration
40 would drop by a few % (e.g., from 103% to 99%)."*

- From your text, it looks like you are using the OSI SAF SIC CDR v2 (OSI-450 and OSI-430-b). If this is the case, I strongly encourage you to update your study to use the SIC CDR v3 (OSI-450-a and OSI-430-a). The v2 CDR is deprecated, the v3 CDR was released in October 2022. Part of the update from v2 to v3 was exactly to reduce the low bias observed in v2 at high
45 SICs. Using the v3 SIC CDR should not be too cumbersome, as it has the same file format and map projection as v2. This would ensure that your manuscript stays relevant for the latest version of the SIC CDRs. If you are already using the v3 CDR, all is good, but you should make it clear in the text (see specific comments below).

50 *We thank the reviewer for pointing this out. When the study was initialized, OSI-450 was the latest version. In the revised version, we will our analysis with the latest OSI SAF CDR (OSI-450-a). While some numbers changed, the outcome of the study remains the same. In fact, we don't find any improvements using the OSI-450-a product.*

55 If SIC algorithm developers want to improve their SIC CDRs, they will need to study in details how the Tbs change with WAIs on many WAI cases, across satellite missions, etc... Even if imperfect, your WAI detection method could be a key asset to get these studies started. I thus invite you to: 1) publish the maps of your WAI detection (e.g. daily maps with integer values recording if there was a WAI, and what category it was) and 2) publish the software for the WAI detection on a software repository. This will ensure not only transparency and reproducibility of your research, but also help future developments of SIC algorithms to improve on the situations you report.

60 *Before the final publication, we plan to publish the code and some working examples on github. Publishing daily maps of detected WAIs would result in a huge dataset. In addition, since the impact of WAIs is lasting for several days to weeks, we believe that such maps would be of limited use. Instead we suggest to add a text file containing monthly statistic of the detected WAIs. In connection with the algorithm, SIC algorithm developers can chose interesting years/events from that text file and apply the detection algorithm for the specific events.*

65 SPECIFIC COMMENTS:

70 Title: Your study is only about Sea Ice Concentration (not Drift, Type, etc...). Also, "Climatologies" often refers to the average (or median, etc...) over long time periods (WMO definition). The data you are studying are often referred to as "Climate Data Records", or "timeseries". Please modify the title to reflect the above.

*We will change the title to
"Relevance of warm air intrusions for Arctic satellite sea ice concentration time series"*

75 Abstract :

- "during warm air intrusions". This does not convey that the SIC is impacted after as well (when when Temps are back to nominal).
- The last sentence could be made shorter and more impactful.

80 *We will change the text to
"...during (and up to 10 days after) warm air intrusions..."
we will change the last sentence to*

"With a further increase of temperature, such warm air intrusions will occur more frequent and earlier in the season. The influence of these warm air intrusions on sea ice climate data records will therefore become more important in future."

85 L23 : You could have cited the recent Kern et al (2019, 2020, 2022) papers. Especially Kern et all 2020 look specifically at summer conditions.

We thank the reviewer for pointing to these relevant publications and will add them in the introduction section

90 L25-26 : Here would be a good place to remind the readers that WAIs have different phases, and that the effects on the microwave emissions might perdure several days after the WAI is finished (in terms of higher temperature).

*That is a good point. We will add
"Of importance is that the impact of snow warming, snow metamorphism and snow surface changes due to melt-refreeze events*

95 *can be visible in the microwave signal for several days and up to weeks after the event (Rückert et al. 2023, e.g.,)"*

L29 : surface ice glazing was the main hypothesis of Rückert et al. (2023) but formulate your sentence as a certainty. You could revise. Also it might be interesting to note that the two case studies in Rückert et al. (2023) were along the MOSAIC drift.

100 *We will revise this sentence to:*

" Rückert et al. (2023) investigated the impact of such a warm air intrusion along the MOSAIC campaign in the central Arctic in April 2020 and found a strong drop in retrieved ice concentration caused by the formation of a large-scale glazed ice layer on top of the snow."

105 L33-34 : please specify which versions of the CDRs you are using. Also you should spell out these acronyms.

We will add the versions used (Version 4 of the NSIDC CRD and version 3 of the OSI SAF CDR) and spelled out the acronyms

110 L38 : “the following” — “as follows”. Possibly rework these sentences. For example you state here that chapter two will briefly discuss the physics of microwave emissions, but the title of the section is about SIC algorithms, which is not exactly the same thing. Also, I think these are called “Sections” and not “Chapter”.

We will change the sentence to

115 *"The article is organized as follows. In section two, the passive microwave sea ice concentration algorithms and auxiliary data used in this study are introduced."*

L45 “quantities” — “surfaces”

Changed

120

L53 You could rework the transition from your first to second paragraph. For example open the 2" with “However, the emissivity of the snow/ice system depends on many parameters”. And maybe introduce the WAIs later in the 2" paragraph, when the other parameters have been discussed.

125 *We will rework this paragraph as suggested by the reviewer*

130 *"In general, the emissivity of sea ice depends on the physical quantities of the ice and snow as well as on the microwave frequency. In Spreen et al. (2008), Figure 1, the typical emissivity of different surface types (first-year ice, multiyear ice and open ocean) are shown in dependence of typical microwave frequencies used by satellites and most of the common sea ice concentration retrievals. However, the emissivity of the snow/ice system depends on many parameters. The main drivers are snow/ice temperature, ice type and the snow microstructure. Ice layers within or ice crusts at top of the snowpack can influence sea ice concentration retrievals that use polarization differences or ratios (due to their strong impact on horizontal polarization, Comiso et al. (1997); Mätzler et al. (1984)). At frequencies higher than 19 GHz, also parameters like snow grain size and shape become important influences for, e.g, retrievals that use gradient ratios of two different frequencies. Several studies have shown that strong weather events like warm air intrusions, introducing snow metamorphism, melt-refreeze events or liquid water formation in the snow modify the above mentioned parameters and consequently influence the emissivity of the snow/ice system (Liu and Curry, 2003; Rückert et al., 2023; Stroeve et al., 2022; Tonboe et al., 2003, e.g.,). Therefore, warm air intrusions can introduce false changes in the retrieved sea ice concentration (Tonboe et al., 2003, e.g.,)."*

135

L73, L81, L85, L93, L97, etc... check the numbering of your headings. Should it be “2.1”, “2.2”, etc...

140

We will correct the numbering

L74 From the URL it seems you are using NSIDC SIC CDR v4. Please check and write it in the text.

145 *Added*

L81 OSI SAF is preferred to OSI-SAF (throughout the text and figures).

Changed

150

L82 From the URL it seems you are using OSI SAF SIC CDR (OSI-450) and ICDR (OSI-430-b) v2. Check and write it in the text.

155 *We thank the reviewer from pointing this out. When the study was performed, OSI-450 was the latest version. In the revised manuscript, we will use OSI-450-b*

L82 The OSI SAF processing chain also uses ERAS NWP fields and corrects the Tbs for the atmospheric effects. This could be noted as one could have assumed that this would help in the early phases of the WAI.

160 *This is an interesting point. We believe that one major outcome of this study is that not only atmospheric, but also surface effects introduced by WAIs can strongly impact sea ice concentration algorithms. We will add "OSI-SAF includes ERA5 reanalysis data for correcting the effect of atmospheric effects on the brightness temperatures."*

L87 I thought ASI was the name of an algorithm. Could you write "ASI SICs from AMSR-E and AMSR2", e.g. ?

165

Done

L97 Since your only auxiliary data is ERA5, you can rename your section.

170 *Changed*

L98 I think ERA5 (not ERA-5) is the accepted acronyms.

Changed

175

L100 For the ERAS bias, please add some more citations rather than the etc, e.g. Wang et al. 2019, Batrak and Müller (2019).

We thank the reviewer for the additional reference and will add them to this section

180 L119 the definition of the three categories is not entirely clear. L118 you define T threshold with $> -10C$, $> -5C$, and $> -2C$. Thus, a category 2 ($> 5C$) is automatically also a category 1 (since $> 10C$). But later (L133) you use the thresholds as brackets ($-10C > T > -5C$). Please clarify in the text and review your figure captions and headings of Table 2.

185 *We agree that the categories were not defined clearly. We will change the text to "We defined the following categories for the temperature thresholds: category 1: $-10^{\circ}C < T \leq -5^{\circ}C$, category 2: $-5^{\circ}C < T \leq -2^{\circ}C$, and category 3: $> -2^{\circ}C$ (in the following, for simplicity we will refer to category 1 as $T > -10^{\circ}C$ and to category 2 as $T > -5^{\circ}C$)."*

190 Fig 1 and Fig 2 : Please use the same y-range for the top row graphs. Currently Fig 1 uses (84-100) while Fig. 2 uses (86-100)

We now use the same y-range

195 Table 2: In Fig 1, Fig 2, and Table 2 you introduce the concept of “All Categories” but this is not explained in the text. Is it the collection of all Cat1, Cat2, and Cat3 events? But it is then not obvious why the number of “All categories” events in Table 2 is not the sum of the three other Categories.

200 *All categories refers to all the areas where the temperature crossed -10°C . It is not necessarily the sum of the individual sub-categories since the effective are reduction is calculated and optimized for all sub-categories and thus the sum of them is expected to be larger than the "all categories" class. We added an explanation to the text*
200 *"All categories refers to all the areas where the temperature crossed -10°C . It is not necessarily the sum of the individual sub-categories since the effective are reduction is calculated and optimized for every individual category."*

Table 2: specify the units of the area and area loss.

205 *We added the units to the table header*

L180: Rather than performance of the algorithm, you could refer to the impact of the WAIs on the algorithms.

Changed

210 Fig 4 : Fix NSIDC (not NSICD) and OSI SAF (not OSI-SAF).

Corrected

215 Fig3 and Fig 5 : re-use the same colors as Fig 1 and Fig 2 (for the data sources)

We will now use consistent colors for all figures

Fig 4: use the same colors as Fig 1 and Fig 2 (Categories)

220 *We will now use consistent colors for all figures*

Fig 4: add text for the time periods covered in the panels.

225 *We v now use consistent colors for all figures*

L206: From what I understand, you have two observations: 1) the number / area / category of WAIs detected by your method increases throughout the 40 years, and 2) their impact on the SIC products increases. You might want to reformulate this paragraph to make this distinction.

230 *We will rework this paragraph to*

235 *"The results presented in the Figures 6 to 8 show that the strength and frequency of the warm air intrusions increased in the last 20 years, especially during April. Compared to the earlier years between 1980 and 1990, the average area of category 3 warm air intrusions increased from $58 \cdot 10^4 \text{ km}$ to $71 \cdot 10^4 \text{ km}$ in the period from 2010 to 2020. Additionally, the average length of these waves increased from 6 to 8 days (not shown). All of these changes contribute to an increased impact of category 3 warm air intrusions on the sea ice concentration in recent years."*

L218 : The sentence starting with “Through...” seems broken. Please rework.

240 we will rework this paragraph to

"ERA5 2 m air temperature has a known a positive bias over Arctic sea ice (??). Because of this bias, some warm air intrusions might not be captured by the algorithm, even though, in reality, the temperature crossed the defined thresholds. Also, miss-classification could be a result of the temperature bias (e.g., an area which is classified as $> -10^{\circ}\text{C}$ might belong to the $> -5^{\circ}\text{C}$ class in reality)."

245

L237 : The sentence would work equally well without "sophisticated".

We will remove "sophisticated"