Original Manuscript ID: essd-2025-79

Original Article Title: Daily 1 km seamless Antarctic sea ice albedo product from 2012 to 2021 based on VIIRS data

Reply to Reviewer's Comments

2025-7-20

Dear Editors and Reviewers,

Revision of our manuscript essd-2025-79.

Thank you for your constructive comments. We have made revision to the manuscript according to the reviewers' comments.

We are uploading (a) our point-by-point response to the comments (below), (b) an updated manuscript with the modifications highlighted in yellow.

The reviewer's comments are in **bold**, and the modified text is in *italics*.

Thank you again for your valuable comments and time.

Sincerely,

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Reviewer #1

Comment #1:

Line 50: Also mention the recent product Niehaus et al. (2024). Melt pond fractions on Arctic summer sea ice retrieved from Sentinel-3 satellite data with a constrained physical forward model. The Cryosphere, 18, 933–956. doi:10.5194/tc-18-933-2024

Author response:

Thank you for your suggestion. We agree that the work by Niehaus et al. (2024) is significant, as their proposed MPD2 algorithm represents a substantial advancement in the retrieval of melt pond fraction and albedo under large-scale observations. We have added a citation to Niehaus et al. (2024) on line 53 of the revised manuscript: "*Numerous studies utilize satellite data to calculate the sea ice albedo in the Arctic region and have published several products (Cheng et al., 2023; Key et al., 2001; Liang et al., 2013; Lindsay and Rothrock, 1994; Niehaus et al., 2024; Qu et al., 2016; Riihelä et al., 2013; Stroeve et al., 2005)*".

We believe this addition provides readers with important context regarding more advanced developments in the field. In our future research, we will also reference the methodologies presented in this work.

Comment #2:

Line 63: Wording: "have strong forward-scattering effects of direction reflectance" == > "have strong directional effects of forward scattering".

Author response:

Thank you for your suggestion. On line 63 of the original manuscript, we have replaced the "*have strong forward-scattering effects of direction reflectance*" with "*have strong directional effects of forward scattering*" (revised manuscript, line 67).

Comment #3:

Line 73: "muti- band" == > "multi-band".

Author response:

Thank you for your suggestion. On line 73 of the original manuscript, we have corrected "*muti-band*" to "*multi-band*" (revised manuscript, line 77).

Comment #4:

Line 80: "The rest of this paper" == > "This paper".

Author response:

Thank you for your suggestion. On line 80 of the original manuscript, we have replaced "*The rest of this paper is organized as follows*" with "*This paper is organized as follows*" (revised manuscript, line 84).

Comment #5:

Line 114: Correct reference is Spreen et al., 2009: Spreen, G., L. Kaleschke, and G. Heygster (2008), Sea ice remote sensing using AMSR-E 89-GHz channels, J. Geophys. Res., 113, C02S03, doi:10.1029/2005JC003384.

Author response:

Thank you for your suggestion. On line 114 of the original manuscript, we have corrected the citation "*(Melsheimer, 2019)*" to "*(Spreen et al., 2008)*" (revised manuscript, line 122).

Comment #6:

Line 305: Only give meaningful number of digits, assumed 2 or 3.

Author response:

Thank you for your suggestion. We acknowledge the reviewer's concern regarding significant digits. Values have been rounded to 3 significant digits with citation of the original source. This preserves traceability to the original source while complying with established numerical reporting standards.

On line 305 of the original manuscript, we have replaced the "*and* β_i *are empirical coefficients with values of -0.0491243, 1.06756, 0.0217075, and 0.0179505 respectively*" with "β_i $(i=1,2,3,4)$ *are empirical coefficients with values of -0.0491, 1.07, 0.0217, and 0.0180 respectively, derived from Key et al. (2001) and rounded to 3 significant digits according to empirical coefficient conventions.*" (revised manuscript, line 318).

Comment #7:

Line 320: Could'nt this way STD take large values?

Author response:

Thank you for your question. In the original manuscript, we used the Monte Carlo method to simulate how uncertainty of the input parameters affects the retrieved albedo results. For the average angular data, we employed the standard deviation (STD) as its uncertainty (σ). We fully understand the reviewer's concern: that the initially set ±σ range might not sufficiently cover all possible input variations. To enhance the reliability of our analysis, we have rerun the Monte Carlo simulations following the suggestion. In this update, we additionally used sampling ranges of ±2σ and ±3σ for the input angle parameter. We then compared the output results from the original approach and the new approaches.

Because the original dataset had too many pixels, performing a complete recalculation was extremely time-consuming. Therefore, we sampled based on the proportion of valid pixels per season, selecting a total of 50,000 samples for computation. The angles of each pixel were sampled within the ranges ±σ, ±2σ, and ±3σ, and Monte Carlo simulations were performed separately. The results are shown in the Fig. 1. Specifically:

Fig. 1a presents a scatter plot comparing the simulated uncertainty results obtained using the ±σ (1-STD) range (u1) and ±2σ (2-STD) range (u2). The result exhibits a strong correlation between the results from these two sampling ranges ($R^2 = 0.970$). Fig. 1b shows a histogram of the relative change in uncertainty (Δu_rel), defined as (u2 - u1) / u1 × 100%. Key observations include:

- The distribution is approximately normal, with its peak centered around 0%.
- Additionally, the probability density drops rapidly to < 1% when |Δu_rel| > 25%.
- Overall, approximately 89% of samples show |Δu_rel| < 10%, and 60% show |Δu_rel| < 5%.

Comparisons between the 1-STD (u1) and 3-STD (u3) simulations yielded similar results (Fig. 1c and 1d):

- The correlation remains strong ($R^2 = 0.947$).
- The distribution of Δu_rel was also approximately normal.
- Other statistical indicators show only minimal differences: approximately 88% of samples have |Δu_rel| < 10% and about 59% of samples have |Δu_rel| < 5%.

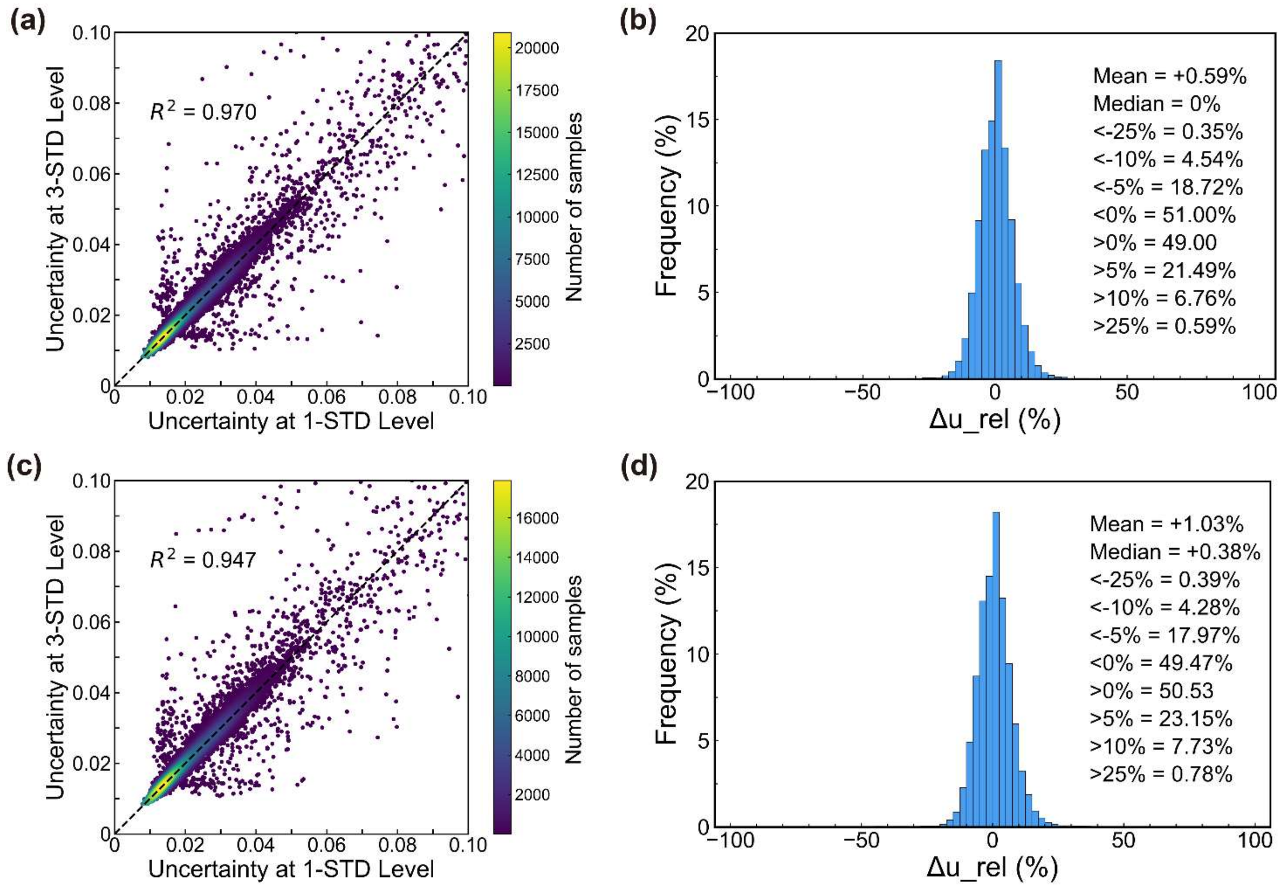


Figure 1. Comparison of model uncertainty results using input angular sampling ranges of ±σ, ±2σ, and ±3σ. (a) Scatter plot comparing model uncertainties obtained with the ±σ range versus the ±2σ range; (b) Histogram of the relative change in uncertainty (Δu_rel) between results from the ±σ range and the ±2σ range; (c) Scatter plot comparing model uncertainties obtained with the ±σ range versus the ±3σ range; (d) Histogram of the Δu_rel between results from the ±σ range and the ±3σ range.

Overall, the results from the new approaches closely align with those from the original scheme. The findings presented in Fig. 1 indicate that during the course of this study, the model output uncertainty is not particularly sensitive to variations in the input angular data across the tested range (from ±σ to ±3σ). This demonstrates that our initial analysis results possess reasonable robustness.

Comment #8:

Table 4: Explain STD also here for easier reading.

Author response:

Thank you for your valuable suggestion. We have defined the meaning of STD in Table 4. The original title of Table 4 "*Uncertainties of input parameters*" has been replaced with "*Uncertainties of input parameters. STD is the standard deviation of each input angle*".

Comment #9:

Table 4: This line uses larger font than the others.

Author response:

Thank you for your suggestion. We have adjusted the font size in Table 4 to match the other lines.

Comment #10:

Line 348: Which fraction of observations does each of the ranges comprise?

Author response:

Thank you for raising this important point regarding the representativeness of the selected SZA ranges. We agree it's crucial to understand the coverage within these ranges. We calculated the proportion of data within each chosen SZA range:

- Range 1 (55–65°) comprises approximately 28.3% of the total observations.
- Range 2 (75–85°) comprises approximately 47.55% of the total observations.

Together, these two ranges cover 75.85% of the total observations. These percentages show that both ranges include a significant portion of the data. This high coverage in these key ranges suggests our follow-up analysis should have sufficient data for statistically representative results.

On line 348 of the original manuscript, we have replaced the "*two SZA ranges were selected for further analysis: range 1 (55–65°), where uncertainty is relatively higher, and range 2 (75–85°), where the SZA is more concentrated*" with "*two SZA ranges were selected for further analysis: range 1 (55–65°), where uncertainty is relatively higher (representing ~28.3% of samples), and range 2 (75–85°), where the SZA is more concentrated (representing ~47.6% of samples)*" (revised manuscript, line 383).

Comment #11:

Figure 5: Any comment on the increased uncertainty in the RAA directions 65° and 245°, most pronounced in Fig. 5(b), but also visible in (a)?

Author response:

Thank you for this valuable suggestion. Regarding Figure 5, we have revised the presentation of albedo retrieval uncertainty variations with angle bins. The description now includes the increased uncertainty observed at RAA values of 65° and 245°. These modifications provide a more accurate expression.

On line 351 of the original manuscript, "*In SZA range 1 (Fig. 5a), most angular bins exhibit uncertainties less than 0.02, with slightly higher uncertainty in the backward direction (RAA near 0°). The largest uncertainty, exceeding 0.1, is observed at larger VZAs in the backward directions. Similarly, in SZA range 2 (Fig. 5b), most angular bins maintain uncertainties below 0.02, with the largest values again appearing at higher VZAs in the backward directions. Additionally, a few larger uncertainties occur at higher VZAs across other RAA directions.*"

has been rewritten as

"*In SZA range 1 (Fig. 5a), uncertainty remains below 0.02 for most angular bins. For VZA less than 40°, uncertainty shows a slight increase across almost all RAA directions but generally stays below 0.03. However, when VZA exceeds 40°, uncertainty increases significantly (exceeding 0.1) in the backward scattering direction (RAA = 0°±30°). In SZA range 2 (Fig. 5b), uncertainty similarly remains mostly below 0.02, with significant increases again in the backward scattering direction for VZA greater than 40°. Additionally, isolated instances of higher uncertainty appear in other RAA directions, which indicates the need for an optimization algorithm specifically designed for large SZA.*

And such optimization is necessary because satellite observations typically are less reliable under large SZA conditions due to low solar radiation or obscure of clouds. Furthermore, a slight increase in uncertainty is observed around RAA = 65° and 245, although it remains within acceptable limits.” (revised manuscript, line 387)

Comment #12:

Line 425: “Compared to” == > “Among”.

Author response:

Thank you for your suggestion. On line 425 of the original manuscript, we have replaced “*Compared to the Atka Bay AWSs, the MBRI albedo product also shows the best accuracy (Fig. 7g-i)*” with “*Among the Atka Bay AWSs, the MBRI albedo product also shows the best accuracy (Fig. 7g-i)*” (revised manuscript, line 434).

Comment #13:

Line 448: Give sigma value

Author response:

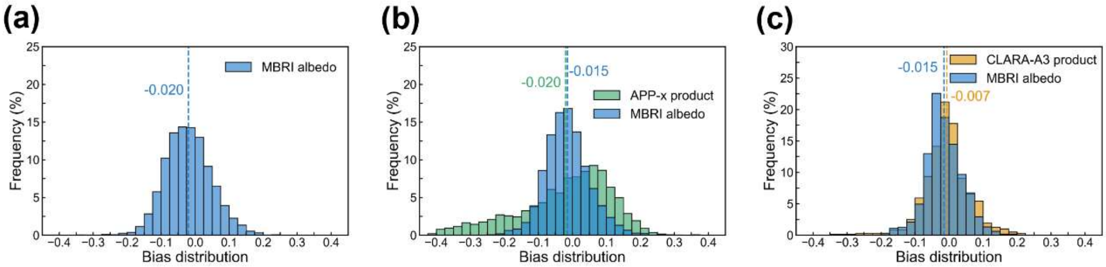
Thank you for this insightful suggestion. We have calculated the standard deviation of the bias between each product and the in situ measurements and incorporated the results into the relevant paragraph. An annotation has also been added to Figure 9. The specific changes are as follows:

On line 448 of the original manuscript, “*The bias distributions for the MBRI albedo product and CLARA-A3 product are similar, clustering around zero, indicating that both products have small differences and high stability. In contrast, the bias distribution for the APP-x product is more scattered, with larger errors*”

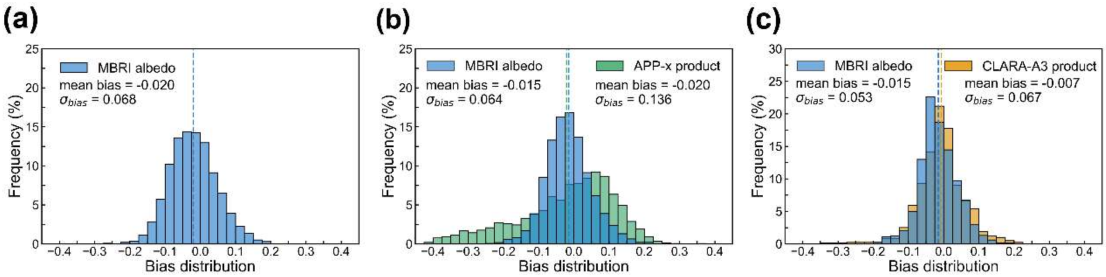
has been rewritten as

“*The bias distributions for the MBRI albedo and CLARA-A3 product are similar, with values clustering around zero ($\sigma_{bias} < 0.07$). In contrast, the bias distribution for the APP-x product is more scattered ($\sigma_{bias} = 0.136$), with larger errors.*” (revised manuscript, line 457).

Figure 9 of the original manuscript:



has been replaced with:



Comment #14:

Line 450: "did not participate in" == > "was excluded from".

Author response:

Thank you for your suggestion. On line 450 of the original manuscript, we have replaced "*it did not participate in the following comparison*" with "*it was excluded from the following comparison*" (revised manuscript, line 460).

Comment #15:

Line 472: Insert something like 'Figures 10 (b) to (d) present more examples confirming these findings.' In order to give reason for showing them.

Author response:

Thank you for this valuable suggestion. To support the conclusion that "the MBRI product better reflects the rapid changes in sea ice albedo", we have revised the relevant section. The revisions primarily involve a more detailed description of the results presented in Figure 10, while also modifying some descriptions to improve the logical flow of this part.

The last two paragraphs of Section 4.2 of the original manuscript (lines 456-473), "*Additionally, several albedo time series were randomly selected for comparison, as shown in Fig. 10. It is evident that the MBRI albedo product shows continuous temporal variation, demonstrating the effectiveness of albedo reconstruction under cloudy-sky condition. Taking the BSRN SYO station as an example (Fig. 10a), the observed sea ice albedo varies between 0.6 and 0.95 during this period. Between days 20 and 40, the albedo increases and then decreases, while between days 70 and 100, two peaks are observed. The daily MBRI albedo time series effectively captures these changes and is consistent with the in situ measurement time series. In contrast, the CLARA-A3 product, with a 5-day resolution, is less effective at capturing the rapid changes in sea ice albedo and lacks temporal continuity.*

Overall, the MBRI albedo product proposed in this study demonstrates satisfactory accuracy. The accuracy of the APP-x albedo product is slightly lower, and its RMSE is basically consistent with the validation results of Key et al. (2016). Although the CLARA-A3 product also provides acceptable accuracy, its relatively coarse spatiotemporal resolution and cloud gaps make it less effective than the MBRI product in capturing detailed changes in sea ice. Therefore, it can be concluded that the performance of the MBRI albedo product is superior."

has been rewritten as

"*Additionally, Figure 10 presents a representative selection of albedo time series for comparison. Results indicate that after cloudy-sky albedo reconstruction, the MBRI product achieves improved continuity and completeness in the albedo time series across different stations compared to CLARA-A3. The CLARA-A3 product, however, exhibits temporal gaps – notably after day 60 (Fig. 10a and 10b), before day 275 (Fig. 10c), and at specific points such as day 41 at BSRN SYO (Fig. 10a) and day 287 at Atka AWS2 2012 (Fig. 10d). Owing to its higher temporal resolution, the MBRI product also aligns more closely with rapid changes in the in situ albedo time series. Examples include: (a) BSRN station (Fig. 10a and 10b): MBRI and in situ time series remain highly synchronized throughout the selected period. Around days 90-96 at SYO, the in situ albedo peaks (~0.93), while the MBRI albedo concurrently rises to approximately 0.96; both decline sharply after day 96. Peak timing and pattern are also consistent at GVN. (b) IMAU AWS17 station (Fig. 10c): Both time series oscillate initially. Between days 300-340, they synchronously rise slightly, then decrease, and rise again after day 340. (c) Atka AWS2 2012 station, the two time series exhibit coordinated fluctuations across the observation period, particularly during periods of significant albedo change (e.g., after day 330).*

Overall, the MBRI albedo product proposed in this study demonstrates satisfactory accuracy.

The accuracy of the APP-x albedo product is slightly lower, and its RMSE is basically consistent with the validation results of Key et al. (2016). Although the CLARA-A3 product also provides acceptable accuracy, it is less effective than the MBRI product in capturing detailed changes in sea ice, as previously described, due to its relatively coarse temporal resolution and cloud gaps." (revised manuscript, last two paragraphs of Section 4.3, lines 467-488)

Comment #16:

Line 500: Meaning unclear. Take out?

Author response:

Thank you for your suggestion. We agree that this sentence is not clear. It has been removed, as the subsequent paragraph provides more detailed spatial comparisons.

Comment #17:

Line 501: "It can be found that" == > It is redundant.

Author response:

Thank you for your suggestion. We have revised the sentence to remove redundant phrasing and enhance its coherence and clarity.

On line 501 of the original manuscript, "*It can be found that the albedo in the marginal ice zone and along the coastline is generally lower than in stable pack ice areas. Then, the maps of both products were zoomed in for a detailed comparison in four regions.*" has been changed to "*On a broad scale, both products show lower albedo in the marginal ice zone and along the coastline than in stable pack ice areas. To enable a more detailed comparison, the maps of both products were zoomed in on four regions.*" (revised manuscript, line 516).

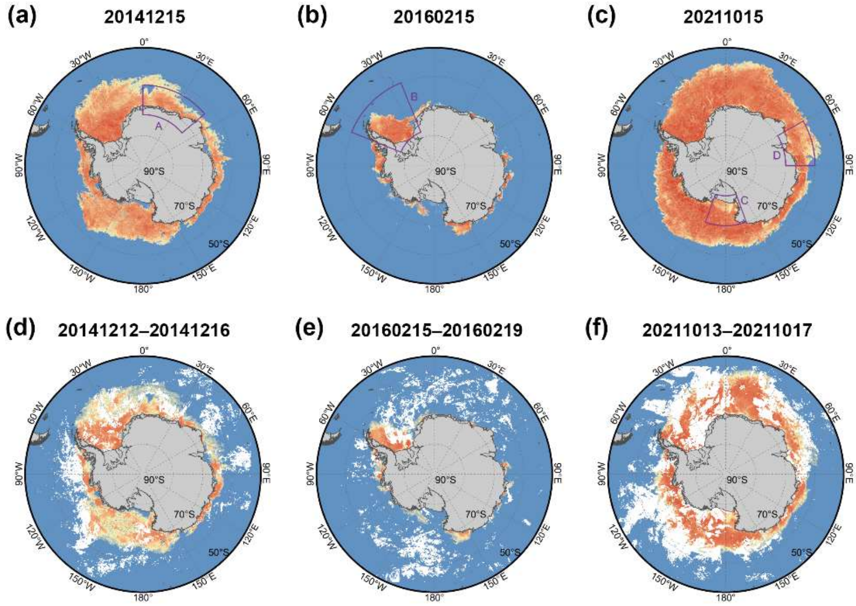
Comment #18:

Figure 12: Add 'For color scale see Fig. 13.'

Author response:

Thank you for your suggestion. We have added the color bar into Figure 12 as recommended. In addition, we have replaced the individual color bars in each subplot of Figure 13 with a single, shared color bar, making the figure clearer.

Figure 12 of the original manuscript:



has been replaced with:

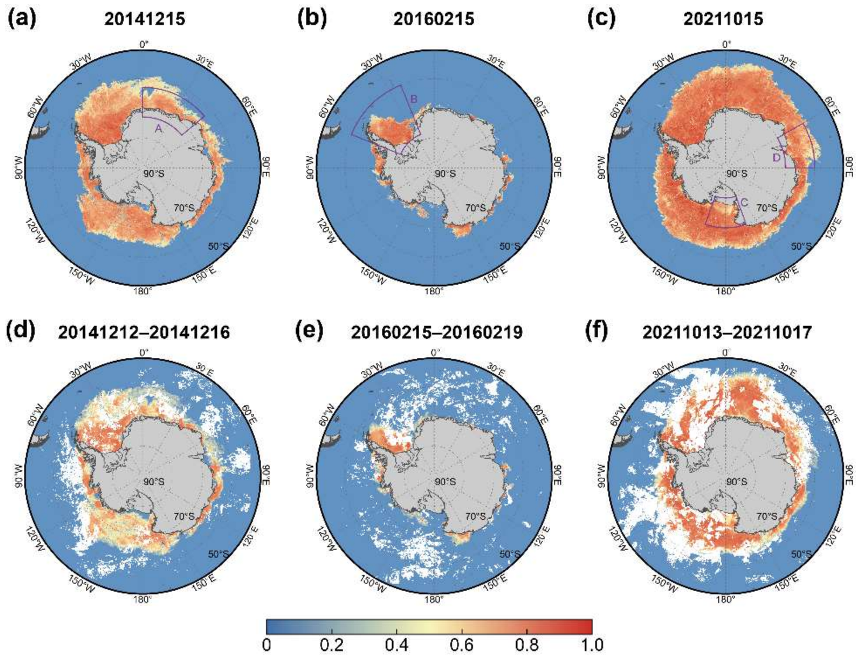
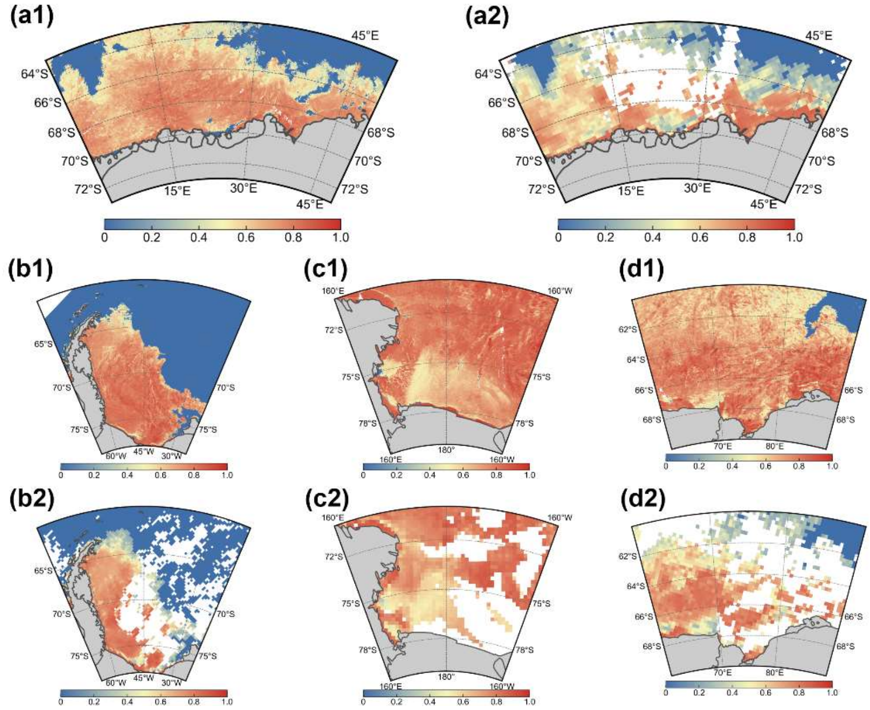


Figure 13 of the original manuscript:



has been replaced with: