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,

Weifeng Hao
Chinese Antarctic Center of Surveying and Mapping
Wuhan University
Wuhan 430079, China
haowf@whu.edu.cn

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%.

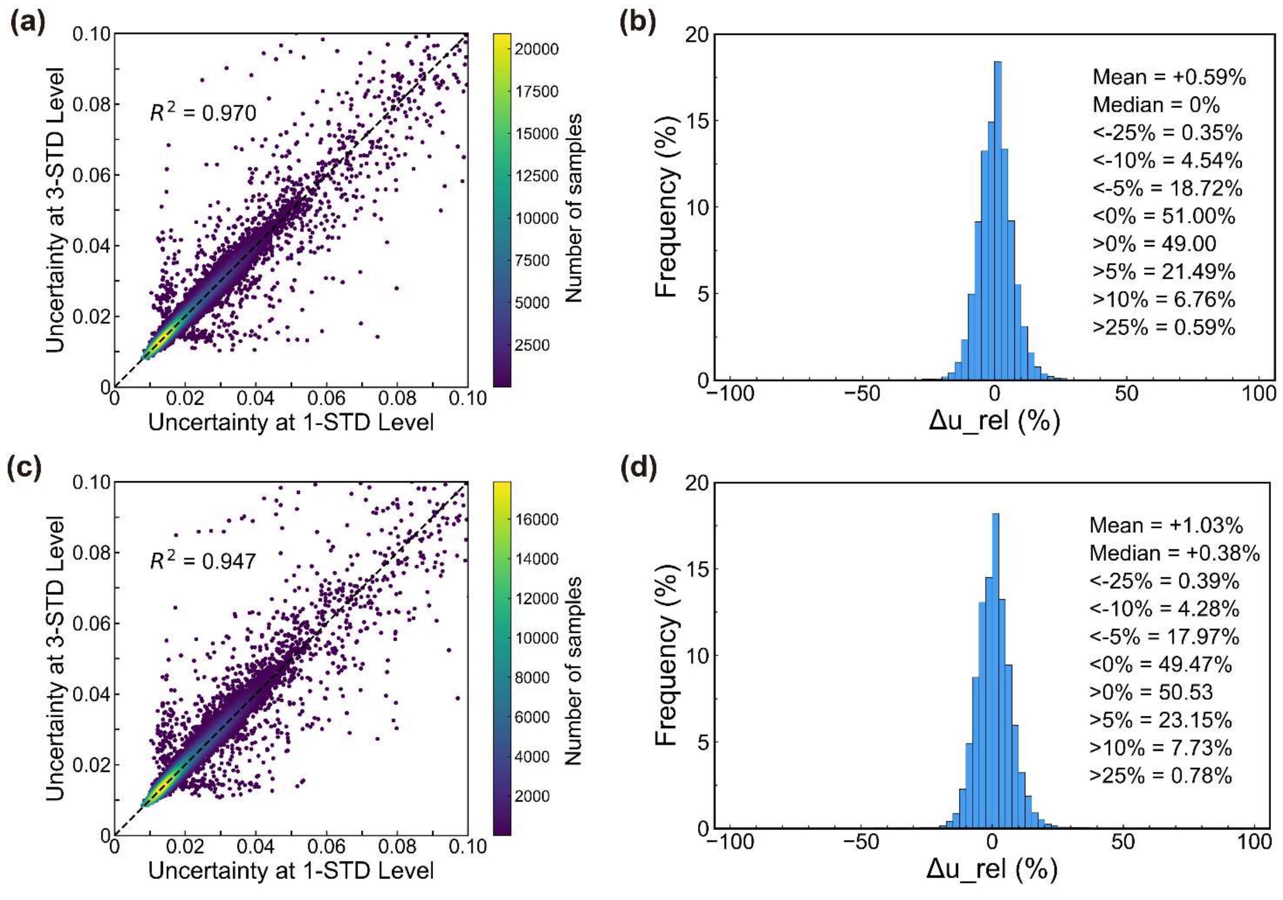


Figure 1. Comparison of model uncertainty results using input angular sampling ranges of ±σ, ±2σ, and ±3σ. (a) Scatter plot comparing model uncertainties obtained with the ±σ range versus the ±2σ range; (b) Histogram of the relative change in uncertainty (Δu_rel) between results from the ±σ range and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

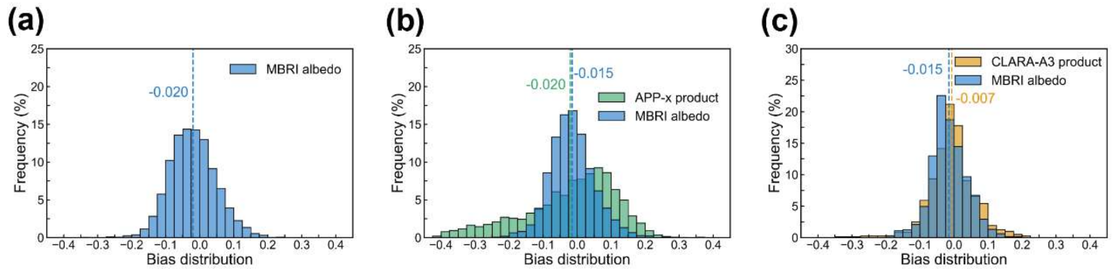
Thank you for this insightful suggestion. We have calculated the standard deviation of the bias between each product and the in situ measurements and incorporated the results into the relevant paragraph. An annotation has also been added to Figure 9. The specific changes are as follows:

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*"

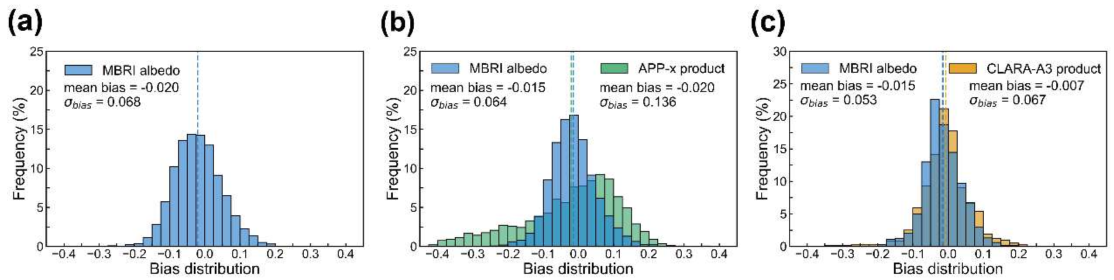
has been rewritten as

"*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 (* σ_{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).

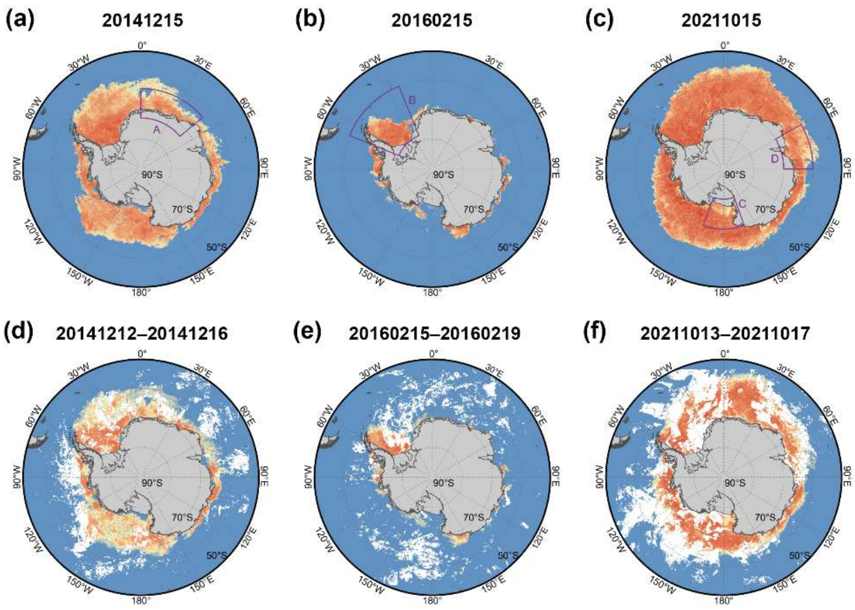
Comment #18:

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:

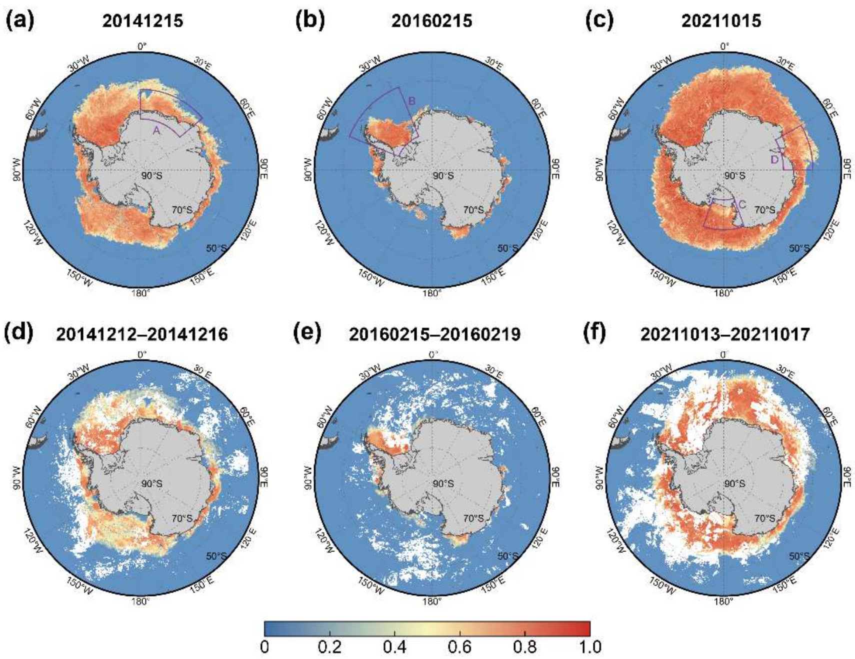
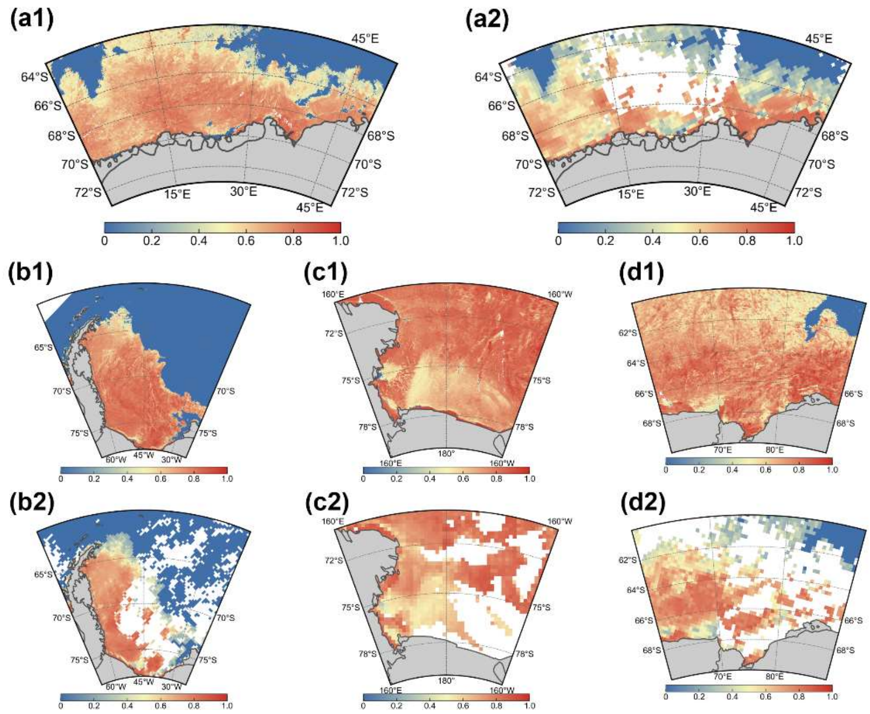
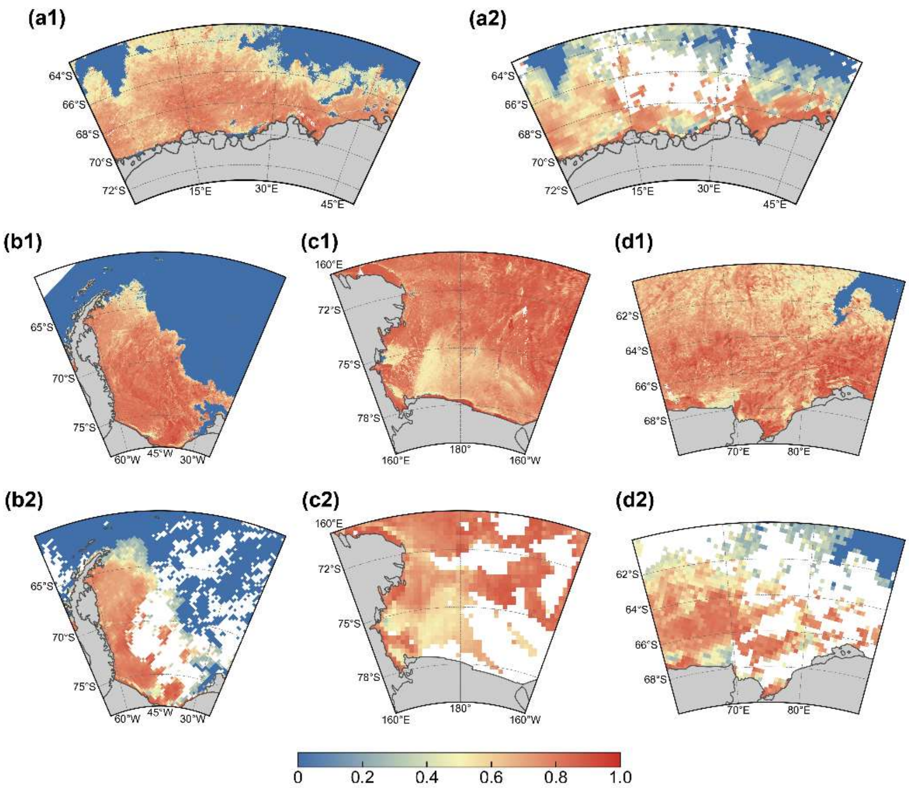


Figure 13 of the original manuscript:



has been replaced with:



Reviewer #2

Comment #1:

This study uses the Multiband Reflectance Iteration (MBRI) algorithm to report sea ice albedo data in the Antarctic region. The accuracy was verified by comparing it with some observations and other products. The description and figures are clear and adequate. However, the structure of the manuscript could be improved. For example, many parts of the Result section are mixture of method and result. Some titles were not suitable.

Author response:

We sincerely appreciate your time and valuable feedback on our manuscript. We are grateful for your constructive comments regarding the manuscript structure. Each of your comments has been carefully considered, and we have made detailed revision accordingly.

Comment #2:

1 Introduction: L36-37, This sentence is ambiguous.

Author response:

Thank you for your suggestion. We agree that the original sentence ("*Snow and ice have the highest albedo of all surface types*") did contain ambiguity. To address this, we have revised both the sentence and the paragraph it is in to improve logical flow and ensure a more accurate expression.

(1) On lines 35-38 of the original manuscript, "*Antarctic sea ice plays an important role in the context of climate change, and its physical parameters are crucial factors for precise climate simulations (Brandt et al., 2005). Snow and ice have the highest albedo of all surface types (Xiong et al., 2002). Changes in the properties and coverage of sea ice, and weather events such as snowfall or sea ice melting, can result in significant changes of the sea ice albedo (Laine, 2008)*"

has been rewritten as

"*Antarctic sea ice plays a crucial role in climate change, with its albedo serving as a key parameter regulating the radiation energy budget of the earth-atmosphere system (Brandt et al., 2005; Xiong et al., 2002). The high albedo of sea ice is sensitive to environmental disturbances. Variations* *in sea ice properties, surface snow cover, and weather events can lead to significant fluctuations in its surface albedo (Laine, 2008).*" (revised manuscript, lines 35-38).

(2) On lines 40-42 of the original manuscript, "*This feedback mechanism makes the albedo of Antarctic sea ice a crucial factor in polar environmental evolution and global climate modeling (Riihelä et al., 2021)*"

has been rewritten as

"*This positive feedback amplifies even minor albedo changes, potentially triggering significant fluctuations in surface energy balance across polar regions.*" (revised manuscript, lines 41-42).

(3) At the end of the first paragraph of the Section 1 of the original manuscript, added "*Consequently, accurate estimation of Antarctic sea ice albedo and its dynamic changes is essential for improving climate model accuracy and advancing global climate change research.*" (revised manuscript, lines 45-47).

Comment #3:

1 Introduction: L59, Blank Line.

Author response:

Thank you for your suggestion. We confirm that a blank line was missing before the sentence starting on line 59 in the original manuscript. We have inserted the required blank line between the preceding table and the new paragraph (now beginning on line 63 of the revised manuscript).

Comment #4:

2 Data: L85-88, I recommend rewriting this paragraph. Currently, it may be difficult for most readers to understand how these data described in 2.1 were used. Alternatively, move the data section after the methods section.

Author response:

We sincerely thank the reviewer for this constructive suggestion. To enhance clarity and explicitly link each input dataset to its application in the MBRI albedo product generation process, we have revised the paragraph (line 85-88 of the original manuscript) in Section 2 (Data).

The paragraph of the original manuscript, "*In the proposed MBRI albedo product generation process, multiple remote sensing satellite products and reanalysis product are used as input data. In addition, the MBRI albedo product was comprehensively assessed based on in situ measurements collected from several Antarctic automatic weather stations (AWSs), alongside existing products APP-x and CLARA Edition 3 (CLARA-A3).*".

has been rewritten as

"*The generation of the MBRI albedo product utilized multiple satellite and reanalysis products. The data sources employed for clear-sky pixel albedo retrieval include: the VIIRS/NPP Surface Reflectance Daily L2G Global 1 km and 500 m SIN Grid (VNP09GA) product; the European Centre for Medium-Range Weather Forecasts (ECMWF) Reanalysis v.5 (ERA5) wind products; and the Global Ocean Colour (GlobColour) chlorophyll concentration product. Sea ice albedo under cloudy-sky was reconstructed based on the Pathfinder Atmospheres–Extended (PATMOS-x) cloud optical depth dataset. Sea ice pixels were identified using the Advanced Microwave Scanning Radiometer 2 (AMSR2) and Special Sensor Microwave Imager/Sounder (SSMIS) sea ice concentration (SIC) datasets. In addition, the MBRI albedo product were comprehensively assessed based on seven ground sites from the Baseline Surface Radiation Network (BSRN), the Institute for Marine and Atmospheric Research Utrecht (IMAU), and Alfred Wegener Institute (AWI) networks. Furthermore, the MBRI albedo product was compared with the APP-x and CLARA Edition 3 (CLARA-A3)-A3 products.*".

In Section 2 (Data), other modifications were also made to certain expressions to enhance readability:

(1) The original title of Section 2.1 "*2.1 Input data*" has been replaced with "*2.1 Satellite and reanalysis data*".

(2) On line 121 of the original manuscript, we have replaced the "*The information on the input data sets used is summarized in Table 2.*" with "*Table 2 summarizes the information of satellite and reanalysis products used to generate MBRI albedo product in this study.*" (revised manuscript, line 128).

(3) The original title of Table 2 "*Table 2. Basic information of input datasets in the study*" has been replaced with "*Table 2. Basic information of satellite and reanalysis products used to generate MBRI albedo product*".

In addition, following their definition in the revised paragraph, the full terms have been replaced by their abbreviations throughout the subsequent paragraphs.

Comment #5:

2 Data: Sections 2.2 and 2.3 can be combined into one section entitled 'Comparative data'. Then, 2.2.1 Existing Antarctic sea ice albedo products. 2.2.2 In situ measurements. This may be clearer.

Author response:

Thank you for your suggestion to improve the clarity of the data presentation. We have merged the content of the original Sections 2.2 and 2.3 into a new single section titled "*2.2 Comparative data*", with the following subsections:

- *2.2.1 Existing Antarctic sea ice albedo products*
- *2.2.2 In situ measurements*

We believe this revised structure has enhanced the organization and readability of this part of the manuscript.

Comment #6:

4 Result: L310-325, This paragraph is not the result. It should be moved to the 'Method' section. Also, L336-340 is not a result, but rather an introduction.

Author response:

Thank you for this insightful suggestion. The paragraph describing uncertainty quantification methodology has been moved to Section 3 (Methodology) as a new subsection 3.5. Additionally, the content was revised to enhance logical coherence. Now the uncertainty results analysis in Section 4.1 focuses on quantitative findings.

Furthermore, regarding the content on lines 336-340 of the original manuscript, we agree that it was redundant for results presentation and have made corresponding deletions and modifications.

Key modifications include:

(1) The first paragraph of Section 4.1.1 of the original manuscript (lines 310-325) has been moved to Section 3 as a new subsection 3.5, titled "*3.5 Estimation of Sea Ice Albedo Uncertainty*". (revised manuscript, lines 323-359)

(2) On lines 312-314 of the original manuscript, "*The production process of the MBRI albedo product can be broadly divided into clear-sky albedo retrieval and cloudy-sky albedo reconstruction. In the retrieval process, the model used in this study is complex, involving processes such as derivation and integration, making it difficult to derive the Gaussian error propagation formula.*"

has been rewritten as

"*As previously mentioned, the MBRI albedo production involves two main steps: broadband clear-sky albedo retrieval and cloudy-sky albedo reconstruction. This study separately quantifies uncertainty propagation in both processes.*

For the clear-sky albedo retrieval, the complex model employed here involves mathematical operations such as derivation and integration, making it difficult to derive the Gaussian error propagation formula." (revised manuscript, lines 324-328).

(3) On lines 336-340 of the original manuscript, "*In addition, the anisotropy of the sea ice surface means that satellite-observed surface radiation is not only related to the direction of solar incidence, but also to the direction of observation. As shown in Eq. (2), the BRDF is a function of the solar/view geometries. Qu et al. (2016) pointed out that the accuracy of sea ice albedo retrieval varies significantly with different solar/view geometries, with errors exceeding 0.3 in cases based on the Lambertian assumption. To analyze the relationship between uncertainty and solar/view geometries, we sampled the retrieval uncertainty results for all pixels across the four seasons based on the angle distribution proportions (sample size = 50,000).*".

has been rewritten as

"*Due to the anisotropy of sea ice surfaces, clear-sky albedo retrieval exhibits significant sensitivity to solar/view geometries. To assess the relationship between retrieval uncertainty and these angular conditions, we sampled the retrieval uncertainty results for all pixels across the four seasons based on the angle distribution proportions (sample size = 50,000).*" (revised manuscript, lines 374-375).

Comment #7:

4 Result: L371-385, This part is also the method.

Author response:

Thank you for your suggestion. The part describing cloudy-sky albedo uncertainty quantification methodology has been moved to the new Section 3.5. The content was also revised to enhance logical coherence:

(1) On lines 371-373 of the original manuscript, "*As described in Section 3.4, the cloudy-sky albedo is reconstructed based on the albedo of adjacent clear-sky pixels. Therefore, the cloudy-sky albedo uncertainty originates from the propagation of clear-sky albedo uncertainty (retrieval uncertainty) through the reconstruction process.*"

has been rewritten as

"*The reconstructed cloudy-sky albedo uncertainty primarily stems from the propagation of clear-sky albedo retrieval uncertainty, interpolation errors, and errors in cloud radiative forcing adjustment.*" (revised manuscript, lines 343-344).

(2) Lines 386-387 of the original manuscript, "*To estimate σ_{hyp}, we randomly masked some clear-sky pixels (over 400,000) and then reconstructed their albedo using interpolation and smoothing following Eq. (18) and Eq. (19).*"

has been moved to Section 3.5 and rewritten as

"*To estimate σ_{hyp}, we randomly masked some clear-sky pixels (over 400,000) and then reconstructed their albedo using interpolation and smoothing following Eq. (18) and Eq. (19). Then, the cloudy-sky albedo uncertainty was calculated using Eq. (21) and Eq. (22).*" (revised manuscript, lines 357-359).

Comment #8:

4 Result: L400-411, This part is the preliminary processing of the measured data, not the results.

Author response:

Thank you for your suggestion. We fully agree with your point that the preliminary processing of raw measured data belongs to the data preparation stage and is more appropriately described in the "Data" section to ensure the clarity of presentation of the results.

The first paragraph of Section 4.2 of the original manuscript (lines 400-403) described the error sources for albedo product. As this information represents common knowledge within the field and is not directly relevant to the validation results analysis, we have deleted this paragraph in the revised manuscript.

The second paragraph of Section 4.2 of the original manuscript (lines 404-411) has been moved to the end of Section 2.2.2, "In situ measurements", to describe the preprocessing of the in situ measurement datasets.

Comment #9:

4 Result: L439-473, This section should be given a separate title because it is not about validation with in situ measurements.

Author response:

Thank you for your suggestion sincerely. We have restructured Section 4.2 based on the suggestion to enhance organizational clarity.

The sixth paragraph of the Section 4.2 of the original manuscript (lines 439-450) comprised two components: (a) a summary analysis comparing the MBRI product against in situ measurements (lines 439-444); (b) distribution characteristics of bias between the three remote sensing products and in situ measurements (lines 444-450).

(1) We maintain that component (a) remains integral to validation with in situ measurements. Hence, this summary analysis has been retained in the revised Section 4.2 titled "Validation with in situ measurements", which now exclusively focuses on accuracy assessment;

(2) Component (b) has been separated into an independent paragraph. It has been merged with the original seventh paragraph of the Section 4.2 to form a new Section 4.3 (revised manuscript, lines 455-488), titled "*Bias characteristics analysis and representative time series comparison*". This section analyzes error distribution patterns and time series comparison between remote sensing products with in situ data.

The directly relevant parts of the original manuscript (incomplete), “*This study summarizes the validation results between the MBRI albedo product and in situ measurements from all stations, as shown in Fig. 8. Overall, the MBRI albedo product exhibits a good agreement with the ground truth values (R = 0.60), with an RMSE of 0.071 and a bias of -0.02. The slight underestimation of the MBRI albedo may be due to the broader spatial coverage of satellite observations compared to AWS. When sea ice further from the AWS begins to melt, AWS sensors only capture the albedo of ice and snow, while satellite pixels represent a mixture of snow/ice, melt ponds, and open water, leading to an underestimation of the albedo (Stroeve et al., 2005). Fig. 9 shows the distribution histogram of the bias (estimated albedo minus in situ measurements). Although the average bias for all three products is relatively small, their distributions differ. 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. Additionally, all these products show a slight negative bias trend. Given the relatively poor accuracy of APP-x product, it did not participate in the following comparison.*

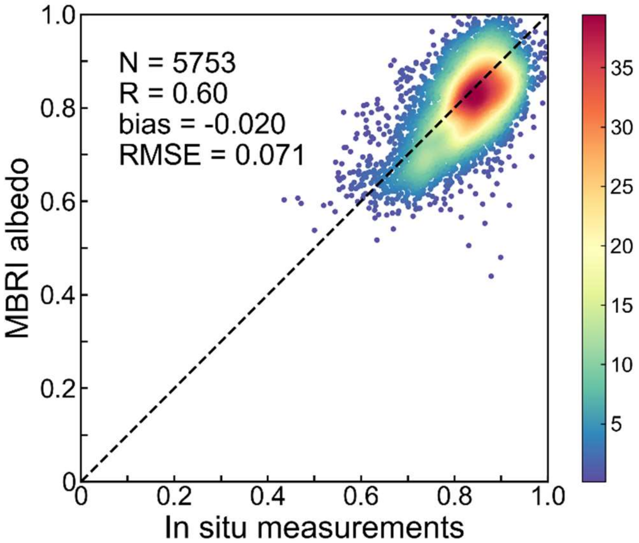


Figure 8. Probability density scatter plot of the MBRI albedo product compared to all in situ measurements.

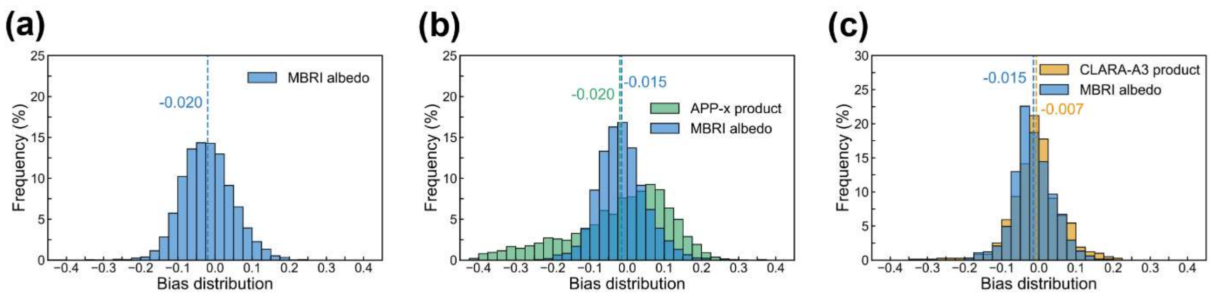


Figure 9. Bias distribution histograms of three albedo products compared to in situ measurements.

Blue represents the MBRI albedo product, green represents the APP-x product, and yellow represents the CLARA-A3 product."

has been replaced with

"*This section summarizes the validation results between the MBRI albedo product and in situ measurements from all stations, as shown in Fig. 8. Overall, the MBRI albedo product exhibits a good agreement with the ground truth values (R = 0.60), with an RMSE of 0.071 and a bias of -0.02. The slight underestimation of the MBRI albedo may be due to the broader spatial coverage of satellite observations compared to AWS. When sea ice further from the AWS begins to melt, AWS sensors only capture the albedo of ice and snow, while satellite pixels represent a mixture of snow/ice, melt ponds, and open water, leading to an underestimation of the albedo (Stroeve et al., 2005).*

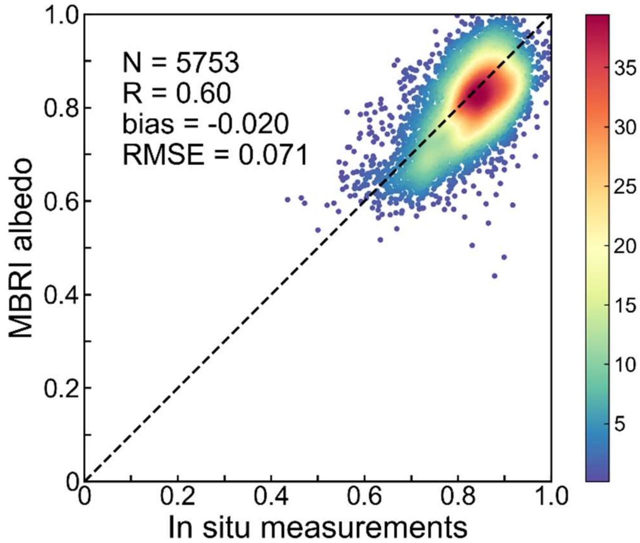


Figure 8. Probability density scatter plot of the MBRI albedo product compared to all in situ measurements.

4.3 Bias characteristics analysis and representative time series comparison

Fig. 9 shows the distribution histogram of the bias (estimated albedo minus in situ measurements). Although the average bias for all three products is relatively small, their distributions differ. 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. Additionally, all these products show a slight negative bias trend. Given the relatively poor accuracy of APP-x product, it was excluded from the following comparison.

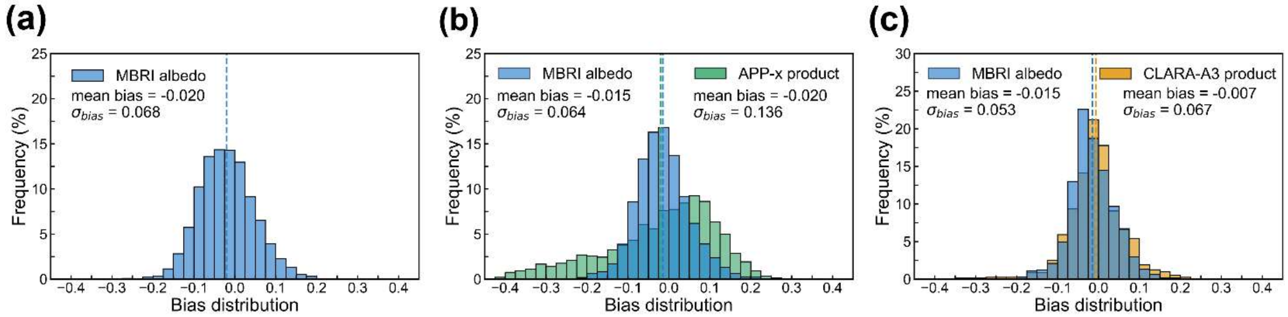


Figure 9. Bias distribution histograms of three albedo products compared to in situ measurements. Blue represents the MBRI albedo product, green represents the APP-x product, and yellow represents the CLARA-A3 product. The dashed line represents the average bias. σ_{bias} ***represents the standard deviation of the bias distribution.***”

Comment #10:

4 Result: L439, This study -> This section

Author response:

Thank you for your suggestion. On line 439 of the original manuscript, we have replaced “*This study*” with “*This section*” (revised manuscript, line 447).

Comment #11:

4 Result: Section 4.3, The title I suggest is “Temporal and spatial difference with other products”.

Author response:

Thank you for this valuable suggestion. We agree that the original title “*4.3 Temporal and spatial analysis*” did not sufficiently highlight the comparative focus of this section. We have revised the title to explicitly state the comparison with CLARA-A3, as this section solely analyzes differences relative to this specific product. The new title is “*4.4 Temporal and spatial difference analysis with the CLARA-A3 product*” (revised manuscript, Section 4.4).

Comment #12:

4 Result: L475, I don't think this section is "To explore the potential use of albedo in studies of Antarctic sea ice changes". I recommend paying more attention to the comparison (just like L496-520). The use of present data can be conducted in future works.

Author response:

Thank you for your insightful suggestion. We agree that the original statement did not reflect this section's focus on comparing the temporal performance of the MBRI and CLARA-A3 products. Therefore, we have revised both this statement and the concluding sentence to ensure objectivity and precision.

On line 475 of the original manuscript, we have replaced "*To explore the potential use of albedo in studies of Antarctic sea ice changes*" with "*To assess the applicability of the MBRI albedo product for Antarctic sea ice monitoring, we conducted temporal and spatial comparisons with the CLARA-A3 product.*" (revised manuscript, line 490).

On line 487 of the original manuscript, we have replaced "*These results demonstrate that the MBRI albedo product can be applied to the study of Antarctic environmental change to some extent.*" with "*These results indicate that the MBRI albedo product performs well in capturing Antarctic sea ice temporal variability signals.*" (revised manuscript, line 503).

Comment #13:

5 Discussion: This section looks like a summary of the results. I didn't see any discussion beyond the results. I recommend adding a discussion about the advantages and disadvantages of the current product and how these affect the accuracy (spatial or temporal). You could also discuss which situations are more suitable for using the present product due to its advantages.

Author response:

We sincerely thank the reviewer for the insightful suggestion. We fully agree that the Discussion section should extend beyond summarizing results to objectively evaluate the product's advantages, limitations, and applicability. As suggested, we have comprehensively revised the Discussion section to address these points. The restructured section now includes:

(1) Advantages of MBRI albedo products and their origins: spatiotemporal resolution

improvement, improved accuracy and spatial completeness.

(2) Limitations and future optimization: high uncertainty in large VZA backscatter geometries, low albedo areas, and cloudy-sky albedo reconstruction.

(3) Product applicability and usage suggestions.

The rewritten discussion is as follows:

“*The MBRI Antarctic sea ice albedo product offers improvements in spatial and temporal resolution compared to existing datasets, while maintaining high accuracy. This advantage stems primarily the use of a physically-based BRDF model that explicitly accounts for the anisotropy of sea ice surfaces, particularly its strong forward-scattering property. This represents a substantial advancement over models relying on the Lambertian assumption, leading to more accurate sea ice albedo calculations. Validation results (Fig. 7) confirm the MBRI product's superior accuracy compared to existing products. Notably, the CLARA-A3 product correct anisotropy by averaging observations from different angles over multiple days. However, this angular sampling is insufficient, potentially causing underestimation of sea ice albedo (Ding et al., 2022; Qu et al., 2016). The MBRI algorithm leverages multi-band reflectance data from VIIRS, enabling BRDF inversion from single date/angle observations. This avoids the need for temporal compositing, thereby improving temporal resolution. As shown in the time series comparisons (Fig. 10), the daily resolution of the MBRI product effectively captures rapid sea ice changes. Additionally, the 1 km spatial resolution of VIIRS enhances the product’s ability to reflect the fine-scale spatial features of sea ice albedo (Fig. 13).*

Another advantage is enhanced spatial completeness. We analyzed the MBRI product and in situ measurements under both clear-sky and cloudy-sky conditions to investigate cloud impacts on sea ice albedo. Figure 14 and Table 5 quantify the differences between these conditions. The results show that average albedo under cloudy-sky is significantly higher (by approximately 0.035-0.064, $p<0.001$) than under clear-sky for both the in situ measurements and the MBRI product, consistent with earlier finding (Key et al., 2001). This indicates that the influence of cloud forcing effects on sea ice albedo cannot be ignored. Furthermore, missing data from either low-albedo marginal ice zones or high-albedo stable pack ice areas can bias regional averages. The stronger correlation between the MBRI albedo anomaly series and SIC anomaly series (Figure 11) supports this conclusion. Therefore, we consider cloudy-sky albedo reconstruction is necessary for accurately assessing long-term climate change.

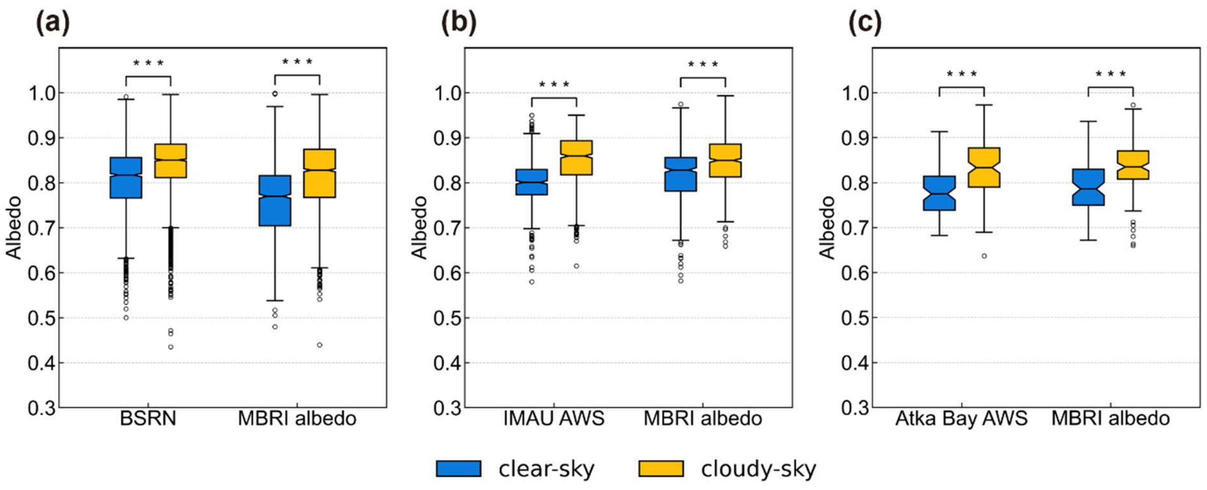


Figure 14. Boxplots of the in situ measurements and MBRI albedo under cloudy-sky and clear-sky conditions. *** indicates that the difference between clear-sky albedo and cloudy-sky albedo is significant with a p-value less than 0.001.

Table 5. Mean values of in situ measurements and the corresponding MBRI mean albedo at different stations, along with the differences under clear-sky and cloudy-sky conditions. *** indicates that the difference is significant with a p-value less than 0.001.

	BSRN SYO	MBRI Albedo	BSRN GVN	MBRI Albedo
Clear-sky mean	0.786	0.720	0.831	0.807
Cloudy-sky mean	0.802	0.784	0.875	0.853
Difference	0.016***	0.064***	0.044***	0.046***
	IMAU AWS5	MBRI Albedo	IMAU AWS17	MBRI Albedo
Clear-sky mean	0.811	0.848	0.794	0.799
Cloudy-sky mean	0.862	0.883	0.848	0.840
Difference	0.051***	0.035***	0.054***	0.041***
	Atka Bay AWS2 2012	MBRI Albedo	Atka Bay AWS 2013	MBRI Albedo
Clear-sky mean	0.750	0.778	0.800	0.807
Cloudy-sky mean	0.797	0.817	0.850	0.854
Difference	0.047***	0.039***	0.050***	0.047***

Despite its advantages, the MBRI product has limitations that can affect spatial and temporal accuracy in specific situations. First, retrieval uncertainty rises significantly (exceeding 0.1) for observations with high VZA in the backward-scatter direction. This issue may arise because the ART model used for the sea ice BRDF, while accurately describing forward-scattering, exhibits higher sensitivity to parameter variations in the backward direction. Although such scenarios are relatively rare, they can introduce inaccuracies in regional albedo analysis. The algorithm's performance at *large SZA also requires improvement, as satellite observations under this condition become relatively unreliable. Second, Fig. 3 shows increased uncertainty in low albedo regions like the marginal ice zone and during spring melt. This likely occurs because increased open water and melt ponds in these areas challenge assumptions within the TCOWA model. For instance, sea ice restricts open water movement, altering the relationship between windspeed and wave, and chlorophyll concentrations differ in polar waters compared to open ocean areas. Future work should focus on optimizing these radiative transfer models to enhance their versatility. Finally, cloudy-sky albedo reconstruction relies on spatiotemporal interpolation, introducing higher uncertainty (~0.065). During rapid melt events or extreme weather, these reconstructed values may not fully capture the true, fast-changing albedo. Future research could explore machine learning-based approaches for gap filling to improve reconstruction accuracy.*

Given these advantages and limitations, the MBRI product is well suited for studies requiring high spatial resolution and daily temporal scale, including short-term sea ice radiation budget estimation, analysis of regional sea ice albedo changes and feedback assessment, and coupling with regional climate models. For multi-decadal climate trend assessments, the CLARA-A3 albedo product might offer a more consistent long-term baseline. Additionally, during periods of persistent cloud cover, users are advised to use the MBRI product in conjunction with its uncertainty dataset or, where possible, supplement it with ground measurements.”.
