Dear Reviewer,

We gratefully thank you for your positive and constructive comments on our manuscript, which helped us improve the quality of the manuscript. We carefully considered and responded each suggested revision and comment, and we hope this manuscript can be further improved. We have provided a point-by-point response to the comments raised by the reviewers below, and we have indicated the revisions made in the manuscript.

This paper introduces a long-term gridded surface cloud fraction radiative kernels (GCF-CRKs) by leveraging the correlation between the TOA shortwave radiative parameters and surface radiation, combined with fused cloud fraction datasets from multiple satellite sources. Based on this kernel, the authors isolate the cloud radiative effect and corrected the downwelling surface shortwave radiation bias caused by cloud fractions. It is known that there are large uncertainties in cloud radiative effect derived from satellite observations in the Arctic region. The study used high quality cloud fractions data to quantify this effect and makes an important contribution. The manuscript is organized and well written. I recommend to accept this manuscript subject to minor but necessary revisions.

Response: We truly appreciate your time and effort in providing us with a positive review. Thank you very much for your valuable feedback on our manuscript, which has significantly improved the presentation of our manuscript. We have carefully considered all of your suggestions and have made the necessary revisions to our manuscript in accordance with your recommendations. In the following section, we summarize our responses to each comment from the reviewers. We believe that our responses have well addressed all concerns from the reviewers.

General comment:

1. There are many cloud parameters that contribute to cloud radiative effects, such as cloud optical thickness, effective radius of cloud particles, and others. This manuscript selects cloud fraction as the primary variable. Please discuss the rationale behind this choice and the feasibility of extending the study to include other variables in the future.

Response: We truly Thank you for your insightful comment. We appreciate your recognition of the importance of our study in addressing the uncertainties in cloud radiative effects in the Arctic region. In response to your suggestion, we have added a detailed discussion on the rationale behind selecting cloud fraction (CF) as the primary variable in Section 3.1 ("Cloud radiative effect and cloud radiative kernel") and have also discussed the feasibility of extending the study to include other variables in the future in Section 7 ("Conclusion").

First, CF is one of the most fundamental and easily obtainable cloud parameters, with high accuracy and spatial consistency in its measurements and retrievals. It directly determines the extent of cloud coverage and thus significantly influences the reflection, scattering, and absorption processes of downwelling surface shortwave radiation (DSSR) **(Lines 82-96, Pages 3-4; Lines 116-126, Page 4)**. Compared to other cloud parameters such as cloud optical thickness (TAU) and effective radius of cloud particles, CF datasets derived from satellite observations are more readily available and have longer temporal coverage, providing a robust basis for long-term climate studies(Liu et al., 2023). Additionally, CF is a key driver of the surface energy balance and has been widely used in previous studies to quantify cloud radiative effects.

While CF is a crucial parameter, we acknowledge that other cloud properties such as TAU and effective radius also play significant roles in modulating cloud radiative effects. In the future, we plan to extend our study to include these additional variables. The framework of our current method, which utilizes radiative kernels to isolate the radiative contributions of specific parameters, can be adapted to incorporate other cloud properties. By developing separate radiative kernels for TAU and effective radius, we can quantify their individual contributions to the cloud radiative effect. This extension will provide a more comprehensive understanding of the complex interactions between clouds and radiation in the Arctic region.

2. The validation against independent datasets and robust comparisons in high-latitude regions should be emphasized.

Response: Thank you very much for your valuable comments. We fully agree that robust validation and comparison with independent datasets are crucial for establishing the credibility of our cloud radiative effect (CRE) estimates, especially in high-latitude regions. To address your concerns, we have conducted additional analyses and provided more comprehensive validation results.

To evaluate the accuracy of our cloud radiative effect (CRE) estimates, we have conducted additional analyses and provided more robust justifications. To evaluate the fidelity of GCF-CRKs, we calculated surface shortwave CRE (2000–2014) using output from the CMIP6-AMIP (Coupled Model Intercomparison Project Phase 6, Atmospheric Model Intercomparison Project) simulations(Eyring et al., 2021). Focusing on the Community Earth System Model Version 2 (CESM2), a widely used model with detailed cloud parameterizations, we compared CRE derived from GCF-CRKs against CRE directly simulated by CESM2. The results show strong agreement, with an R^2 of 0.847, RMSE of 14.5 $W \cdot m^{-2}$, and bias of 11.19 $W \cdot m^{-2}$ **(Section 4.5,**

Figure 13b). This demonstrates that our kernel-based approach effectively isolates cloud fraction-driven radiative effects, capturing ~85% of the variance in model-simulated CRE. We further validated GCF-CRKs against the CERES-EBAF Ed4.2 dataset (2000–2014), achieving even higher consistency: $R^2 = 0.9009$, RMSE = 9.762 $W \cdot m^{-2}$, and bias = 1.8916 $W \cdot m^{-2}$ (**Figure 13a**). This further supports the accuracy and reliability of GCF-CRKs. This manuscript also compared the GCF-CRKs based CRE with those from CERES-EBAF in spatial distribution, our method captures the spatiotemporal variability of CRE more accurately (**Section 4.5, Figure 12**). We believe that these additional analyses strengthen the credibility and applicability of our methodology. We will continue to refine our validation procedures and incorporate additional datasets in future work to further enhance the accuracy and reliability of our CRE estimates.

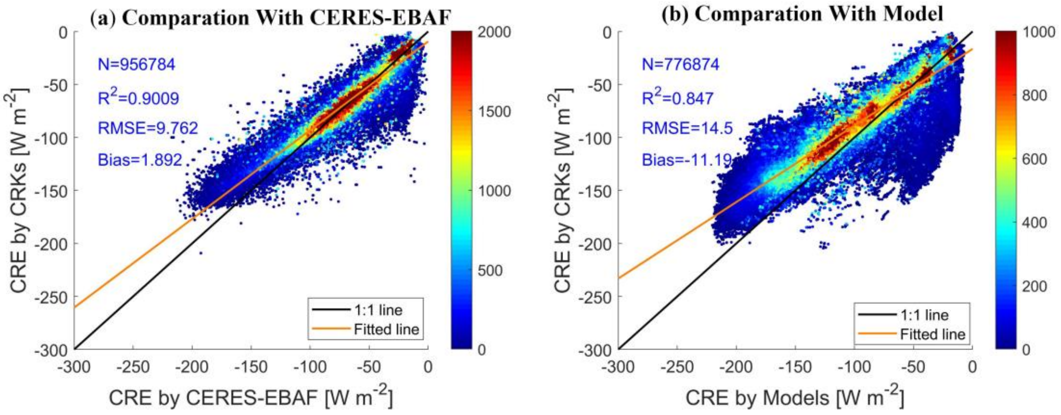

Figure 13. Comparison of cloud radiative effect (CRE) estimated by GCF-CRKs with observed and model-estimated CRE.

3. Enhance the discussion section of the paper by integrating current hot topics in climate change, such as the Arctic amplification effect. Elaborate on the potential contributions of this study's findings to understanding global climate feedback mechanisms and polar climate change.

Response: Thank you for your suggestion. In response, we have enhanced the Introduction section and the Discussion section of our paper by integrating current hot topics in climate change, particularly focusing on the Arctic amplification effect. We have elaborated on the potential contributions of our study's findings to understanding global climate feedback mechanisms and polar climate change. We expand the Introduction section to include a detailed discussion of cloud radiative forcing and its impacts on Arctic amplification and the global radiation balance **(Lines 61–180, Pages 3–4)**, thereby providing additional context for the background of this study. Additionally, we incorporate a detailed subsection in the Discussion section titled "Potential Contributions of GCF-CRKs to Understanding Climate Feedback

Mechanisms" **(Lines 961–1041, Pages 36–38)**. Our study reveals that the cooling effect of clouds on Arctic surface shortwave radiation is more complex and exhibits greater spatiotemporal variability than previously recognized. Specifically, we find that the cloud-induced cooling effect is particularly pronounced over Greenland, where the radiative cooling deviation caused by clouds reaches approximately 4 Wm^{-2}. This suggests that clouds play a more significant role in regulating surface energy balance in the Arctic, potentially offsetting some of the warming effects caused by sea ice loss. The Arctic amplification effect, characterized by a warming rate that is 2 to 4 times the global average, is primarily driven by the complex interplay between sea ice loss, surface albedo feedback, and cloud radiative dynamics. Our findings indicate that the cooling effect of clouds on Arctic surface shortwave radiation has been overestimated in previous studies. This implies that the actual rate of Arctic warming could be faster than previously predicted, which has important implications for understanding polar amplification and its effects on global climate patterns.

These revisions aim to provide a clearer and more complete picture of the significance of our work within the context of current climate research. In the future, we will involve integrating cloud vertical structure, microphysics, and optical thickness into our methodology. This will enable us to address more complex scientific questions and improve the usability of our dataset in broader climate modeling and research contexts.

Thank you again for your valuable feedback. We believe that these enhancements significantly strengthen the relevance and impact of our work.

References:

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