Response to Reviewer #1's Comments:

Ruixue Li et al. (Author)

We are very grateful for the Reviewer #1' detailed comments and suggestions, which help us improve this paper significantly. Based on the comments and suggestions from reviewer, we reorganize the abstract, introduction, datasets and methods, results and conclusion sections to highlight the innovations, key points of this study and improve coherence between sections. In addition, we add some interpretations and delete some superfluous information in each section in order to make the manuscript clearer.

Important revision includes:

(1) Section 1, Introduction, is rewritten to enhance clarity regarding the significance and innovations of the manuscript. Superfluous information is removed, and specifically, we highlight the reasons for studying the changes in reflected solar radiation (RSR) at finer spatiotemporal scales and the importance of assessing the applicability of different radiation datasets with longer record in hemispheric symmetry studies. More details are described in Line 65-138. The abstract is also further reorganized to summarize the main findings of this paper.

(2) In Section 2, Datasets and Methodology, we update the CERES data to the latest version (CERES-EBAF 4.2) and correct some bugs in the data processing, and revise the corresponding descriptions.

(3) We agree the reviewer's comments. In Section 3.1, we acknowledge that there is a little bit overlap between Fig. 1 and previous studies. However, the focus of this section is on analyzing changes in RSR and its components at the latitude and monthly scales. We have reorganized Section 3.1 and added an expanded discussion on hemispheric RSR trends, highlighting the contributions of finer spatiotemporal scales to these trends. Additionally, we have analyzed the changes in the contribution rates of different components to the RSR.

(4) The content discussing the contribution of different factors to latitudinal zones in extreme years (Section 3.2) is removed. The adjustment allows us to maintain a more focused and streamlined discussion, centering on the primary objectives and findings of the study.

(5) We substantially expand the original Section 3.3 (now revised as Section 3.2) to systematically quantify the performance of four radiation datasets in reproducing hemispheric differences and symmetry

of RSR observed by CERES at hemispheric and finer temporal-spatial scales. This expansion ensures a smoother and tighter connection with Section 3.1.

(6) In the Section 4, Discussion and Summary, we revise the main conclusions of this study and delete some superfluous information.

(7) In each section, we also add some interpretations about the comments from reviewers.

Please see our point-by-point reply to comments. All revisions are shown in revised manuscript by using track changes.

General responses:

1. The authors cite large amounts of published studies on hemispherical albedo symmetry. The authors analyze southern and northern hemispheres' surface and atmosphere contributions. However, the result of the zonal analysis is mainly that higher land albedo in the northern hemisphere present in the mid-latitude is compensated by clouds over southern ocean, which was pointed out in earlier studies (e.g. Stephens et al. 2015). Hemispherical albedo trends were analyzed by Datseries and Stevens (2021). Therefore, most of their results are reproduction of the results of earlier studies. Among three main results discussed in the discussion and summary session, only 3), which is the result of the comparison of different products, might be new. But the result is not essential in understanding the hemispherical albedo symmetry. In addition, as far as I know, AVHRR and ISCCP data products were not used in analyzing hemispherical albedo symmetry in earlier studies. Therefore, the motivation of the comparison is not clear. New knowledge added by this study is not significant enough to worth publication. However, because the extensive coverage of earlier studies, there might be a path forward. Because of the good coverage of earlier studies on this subject, I suggest converting this manuscript to a review paper.

   Response: We agree with the reviewer and are very appreciated for reviewer providing such helpful comments and suggestions. Indeed, our research results exhibit consistency and similarity with previous studies. In fact, the aim of this study is to interpret the characteristics of variations in hemispheric planetary albedo at finer temporal and spatial scales, thereby providing support for the investigation of hemispheric symmetry mechanisms. Additionally, we aim to systematically evaluate the applicability of existing long-term radiation data in hemispheric symmetry studies. We acknowledge the reviewers' concern regarding the lack of emphasis on the manuscript's highlights, potentially causing confusion about its novelty. Following the suggestion from reviewer, therefore, we reorganize the manuscript, remove redundant content, and focus on addressing two key issues: (1) the characteristics of hemispheric reflected solar radiation variations at different latitudes and months, and (2) the ability of four datasets to accurately reproduce hemispheric differences and symmetry of reflected solar radiation observed by CERES.

Specific Responses:

1. Line 69-70 The location of ITCZ shifting with season is known before 2007.

   Response: Thanks for your comment! Indeed, as early as 1993, Waliser and Gautier (1993) systematically investigated seasonal variations in the intensity and location of the ITCZ. Hu et al. (2007) further noted that the seasonal shift in the global average ITCZ is not smooth, but jumps from the winter hemisphere to the summer hemisphere. The relevant reference is added in the revised manuscript: "For example, the Intertropical Convergence Zone (ITCZ) plays an important role in regulating cloudiness in the 10°S-10°N region, with its location and intensity varying seasonally (Waliser and Gautier, 1993; Hu et al., 2007)."

   Please see the Line: 69-71.

2. Line 70-71 There are many places that sentences are either awkward or do not make sense. In addition to this sentence, the sentence on line 84-85, line 290 "contribution rate", line 294 "molecular part of Eq. (14), line 360 (10a)-1 awkward units, for example.

   Response: We very thank reviewer for providing detailed comments and suggestions. We have carefully reviewed the manuscript and made the necessary revisions to address the issues you raised. Specifically, we have rephrased these sentences in the revised manuscript.

   Please see the Line: 73-76, 96-98, 296, 299-301, 357.

3. Line 80 the authors used "oblique pressure activity" several places in the manuscript. I think what they mean is mid-latitude baroclinic low pressure systems or synoptic systems, but I am not sure.

   Response: We are sorry to confuse the reviewer by the term "oblique pressure activity". It includes the mid-latitude baroclinic synoptic systems. For clarity, we correct the term and statement in the revised manuscript: "In addition, recent studies have emphasized the impact of the distinct land-sea distribution between hemispheres, which leads to enhanced baroclinic activities at mid-latitudes in the SH, resulting in an increase in baroclinic synoptic systems (Hadas et al., 2023)."

Please see the Line: 82-85.

4. Line 88-90. If the authors are telling that aerosols increase deep convective clouds, could you cite papers?

   Response: Thanks for your comments. Both model simulations (Wang et al., 2014) and satellite observations (Zhang et al., 2007) have pointed out that aerosols, as cloud condensation nuclei, act on the microphysics and dynamics of deep convective clouds, altering the cloud structure, elevating the cloud top heights, and inducing the development of deep convective clouds. The relevant references are added in the revised manuscript: "This, in turn, increases the amount of deep convective clouds due to the indirect effects of aerosols (Zhang et al., 2007; Wang et al., 2014). The increased deep convective clouds can strengthen the storm track in the Pacific Ocean and increase the contribution of the cloud component (Wang et al., 2014)."

   Please see the Line: 101-103.

5. Line 97-98. I do not think that available data limit studying hemispherical albedo symmetry. The authors might mean studying how the symmetry changes with time?

   Response: We are sorry that our expression has caused confusion to the reviewer. Yes, it means the available data limit the study of hemispherical albedo symmetry changes with time. In the revised manuscript, we correct the inappropriate statements: "However, the CERES observational record is relatively limited (2000-present), we cannot determine how hemispheric symmetry changes over time." (See the Line: 117-118).

6. Line 139 Why do the authors mention filtered radiance here?

   Response: We are sorry to mislead the reviewer. Filtered radiation is mentioned here to explain the process of generating monthly regional TOA radiative fluxes from the original CERES measurements. We correct the inappropriate statements in the revised manuscript: "The radiance received by the CERES instrument is first converted from digital counts to calibrated "filtered" radiances. This is then converted to unfiltered radiances to correct for imperfections in the spectral response of the instrument (Loeb et al., 2001), and then transformed into TOA instantaneous radiative fluxes using an empirical angular distribution model (Su et al., 2015). Instantaneous fluxes are converted to daily-averaged fluxes using sun-angle dependent diurnal albedo models (Loeb et al., 2018)."

Please see the Line: 160-165.

7. Section 2.2.1 is largely the reproduction of earlier study.

   Response: Thanks for your comments. In section 2.2.1, we have adopted the planetary albedo decomposition method proposed by Stephens et al. (2015) and therefore most of the formulas are derived from previous research. We retained this section for the purpose of enhancing clarity and providing a comprehensive understanding for the readers. This decision allows readers to understand the method more effectively within the context of our study.

8. Equation (12) Weighting by clear and cloud fraction is missing in the equation.

   Response: Thanks for your comments. The cloud contribution $F^{\uparrow}_{\mathrm{cloud}}$ in Equation (12) is the difference between the all-sky atmospheric contribution $F^{\uparrow}_{\mathrm{atm}}$ and the clear-sky atmospheric contribution $F^{\uparrow}_{\mathrm{atm,clear}}$ (see equation (13)). Its definition is similar to the shortwave radiative effect of clouds, and thus not need to be weighted by clear and cloud fractions.

9. Equation (14) area weighted mean is probably sufficient instead of introducing the equation.

   Response: Thanks for your suggestion. In the revised manuscript, we replaced the regional weighted average method with the geodetic weighting method as recommended by the CERES website. This updated approach takes the Earth's oblate spheroid shape into account. Consequently, we have maintained these formulas and adjusted their introduction accordingly. The following is the revised text:

   "In calculating regional averages radiative flux, the study employs a geodesic weighting method consistent with the official CERES product. This method assumes Earth's oblate spheroid shape and takes into account the annual cycle of the Earth's declination angle and the sun-Earth distance (details about the method can be found in the website:

"https://ceres.larc.nasa.gov/documents/GZWdata/zone_weights.f"). The regional averaged TOA RSR F_k is spatially aggregated using the following calculation formula:

$$F_k = \frac{\sum_{i=1}^{N_k} W_{ki} \cdot \mathrm{F}_{ki}}{\sum_{i=1}^{N_k} W_{ki}} \tag{14}$$

Here, N_k is the number of grid samples in region k, and F_{ki} is the RSR flux corresponding to grid i in the region k. Moreover, W_{ki} is the geodetic zonal weight for the grid i, which can be obtained from "https://ceres.larc.nasa.gov/documents/GZWdata/zone_weights_lou.txt". Regional averages for other variables are calculated according to the similar weighting equation."

Please see Line 283-293 for more details.

10. Equation (20). Generally, we do not put variables with different units in an equation. Correlation coefficient is a non-dimensional number while mean and RMS have units.

Response: We very thank reviewer for providing detailed comments and suggestions. in the revised manuscript, the metrics (CC, AE, RMSE) are normalized to non-dimensional metrics (NCC, NAE, NRMSE), which are between 0 and 1, using the normalization formula following Chen et al. (2024) as:

$$NS_a = \frac{S_a - \min(S)}{\max(S) - \min(S)} \tag{20}$$

Where S indicates the metric (CC, AE, and RMSE). Here, a=0, 1, …, m, "0" indicates the observed data, and m is the total number of model data used for comparison. Please note that Eq. (20) is a newly added equation in revised manuscript, and the Eq. (20) in the original manuscript is now renumbered as Eq. (21). After correcting this statistical error, we redraw the Fig. 5 in Section 3.2 in the revised manuscript (see the Fig. R1). The Fig. R1 (same as the Fig. 5a in the revised manuscript) indicates that the performance of ERA5 is better than the ISCCP in reproducing CERES observed hemispheric difference (NH-SH) of total RSR compared with our previous results. Please see Line 333-338 and 616-636 for more details.

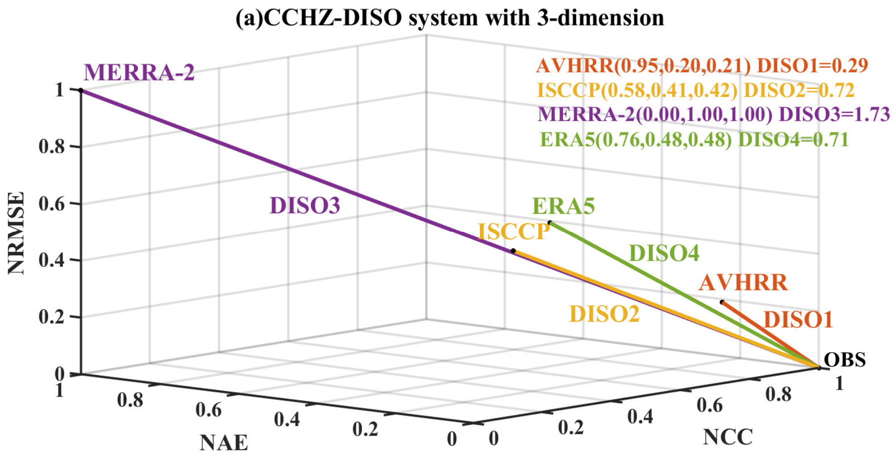

Figure R1 (same as the Fig. 5a in the revised manuscript): CCHZ-DISO system with 3-dimension for hemispheric difference of annual-average total RSR between NH and SH. The coordinate axis consists of three statistical indicators, normalized correlation coefficient (NCC) for x-axis, normalized absolute error (NAE) for y-axis, and normalized root mean square error (NRMSE) for z-axis. OBS indicates observations, here referred to as CERES EBAF.

11. Figures are generally too small to see the details.

    Response: Thanks for your comments. We have enlarged the text in all figures in the revised manuscript.

Reference:

Chen, F., Wang, D., Zhang, Y., Zhou, Y., and Chen, C.: Intercomparisons and Evaluations of Satellite-Derived Arctic Sea Ice Thickness Products, Remote Sensing, 16, 508, https://doi.org/10.3390/rs16030508, 2024.

Hadas, O., Datseris, G., Blanco, J., Bony, S., Caballero, R., Stevens, B., and Kaspi, Y.: The role of baroclinic activity in controlling Earth's albedo in the present and future climates, Proceedings of the National Academy of Sciences, 120, e2208778120, https://doi.org/10.1073/pnas.2208778120, 2023.

Hu, Y., Li, D., and Liu, J.: Abrupt seasonal variation of the ITCZ and the Hadley circulation, Geophysical research letters, 34, https://doi.org/10.1029/2007GL030950, 2007, 2007.

Loeb, N. G., Priestley, K. J., Kratz, D. P., Geier, E. B., Green, R. N., Wielicki, B. A., Hinton, P. O. R., and Nolan, S. K.: Determination of unfiltered radiances from the Clouds and the Earth's Radiant Energy System instrument, Journal of Applied Meteorology, 40, 822-835, https://doi.org/10.1175/1520-0450(2001)040<0822:DOURFT>2.0.CO;2, 2001.

Loeb, N. G., Doelling, D. R., Wang, H., Su, W., Nguyen, C., Corbett, J. G., Liang, L., Mitrescu, C., Rose, F. G., and Kato, S.: Clouds and the earth's radiant energy system (CERES) energy balanced and filled (EBAF) top-of-atmosphere (TOA) edition-4.0 data product, Journal of Climate, 31, 895-918, https://doi.org/10.1175/JCLI-D-17-0208.1, 2018.

Stephens, G. L., O'Brien, D., Webster, P. J., Pilewski, P., Kato, S., and Li, J.-l.: The albedo of Earth, Reviews of Geophysics, 53, 141-163, https://doi.org/10.1002/2014rg000449, 2015.

Su, W., Corbett, J., Eitzen, Z., and Liang, L.: Next-generation angular distribution models for top-of-atmosphere radiative flux calculation from CERES instruments: Methodology, Atmospheric Measurement Techniques, 8, 611-632, https://doi.org/10.5194/amt-8-611-2015, 2015.

Waliser, D. E. and Gautier, C.: A satellite-derived climatology of the ITCZ, Journal of climate, 6, 2162-2174, https://doi.org/10.1175/1520-0442(1993)006<2162:ASDCOT>2.0.CO;2, 1993.

Wang, Y., Wang, M., Zhang, R., Ghan, S. J., Lin, Y., Hu, J., Pan, B., Levy, M., Jiang, J. H., and Molina, M. J.: Assessing the effects of anthropogenic aerosols on Pacific storm track using a multiscale global climate model, Proceedings of the National Academy of Sciences, 111, 6894-6899, https://doi.org/10.1073/pnas.1403364111, 2014.

Zhang, R., Li, G., Fan, J., Wu, D. L., and Molina, M. J.: Intensification of Pacific storm track linked to Asian pollution, Proceedings of the National Academy of Sciences, 104, 5295-5299, https://doi.org/10.1073/pnas.0700618104, 2007.

Response to Reviewer #2's Comments:

Ruixue Li et al. (Author)

We are very grateful for the Reviewer #2' constructive comments and suggestions, which help us improve this paper significantly. Based on the comments from reviewers, we reorganize the abstract, introduction, datasets and methods, results and conclusion sections, and add some interpretations in each section in order to enhance the manuscript's continuity and depth of analysis. In addition, some superfluous information in each section is deleted. Based on the comments and suggestions, we also correct inappropriate or unclear descriptions in the manuscript.

Important revision includes:

(1) Section 1, Introduction, is rewritten to enhance clarity regarding the significance and innovations of the manuscript. Superfluous information is removed, and specifically, we highlight the reasons for studying the changes in reflected solar radiation (RSR) at finer spatiotemporal scales and the importance of assessing the applicability of different radiation datasets with longer record in hemispheric symmetry studies. More details are described in Line 65-138. The abstract is also further reorganized to summarize the main findings of this paper.

(2) In Section 2, Datasets and Methodology, we update the CERES data to the latest version (CERES-EBAF 4.2) and correct some bugs in the data processing, and revise the corresponding descriptions.

(3) We agree the reviewer's comments. In Section 3.1, we acknowledge that there is a little bit overlap between Fig. 1 and previous studies. However, the focus of this section is on analyzing changes in RSR and its components at the latitude and monthly scales. We have reorganized Section 3.1 and added an expanded discussion on hemispheric RSR trends, highlighting the contributions of finer spatiotemporal scales to these trends. Additionally, we have analyzed the changes in the contribution rates of different components to the RSR.

(4) The content discussing the contribution of different factors to latitudinal zones in extreme years (Section 3.2) is removed. The adjustment allows us to maintain a more focused and streamlined discussion, centering on the primary objectives and findings of the study.

(5) We substantially expand the original Section 3.3 (now revised as Section 3.2) to systematically quantify the performance of four radiation datasets in reproducing hemispheric differences and symmetry

of RSR observed by CERES at hemispheric and finer temporal-spatial scales. This expansion ensures a smoother and tighter connection with Section 3.1.

(6) In the Section 4, Discussion and Summary, we revise the main conclusions of this study and delete some superfluous information.

(7) In each section, we also add some interpretations about the comments from reviewers

Please see our point-by-point reply to comments. All revisions are shown in revised manuscript by using track changes.

General responses:

1. In Section 3.3, rather than simply comparing with CERES for the asymmetry issue in modeled PA, the analysis should be integrated more cohesively with key findings from previous sections. This integration is essential for establishing a stronger motivation and relevance for the comparison. For instance, it would be valuable to assess whether the model data captures the interannual anomaly of the contribution rate of different components to total reflected radiation, thus linking the analysis with earlier sections and enhancing the manuscript's continuity and depth of analysis.

   Response: We very thank reviewer for providing detailed and constructive comments and suggestions. Based on the comments and suggestions from two Reviewers, in the revised manuscript, we delete the Section 3.2 and substantially expanded the original Section 3.3 (now revised as Section 3.2) to systematically quantify the performance of four radiation datasets in reproducing hemispheric differences and symmetry of reflected solar radiation observed by CERES at hemispheric and finer temporal-spatial scales. Please see Section 3.2.

2. Simulated Snow uncertainty has been suggested to introduce substantial bias of surface albedo among reanalysis data, especially at mid and high latitudes [1]. Are there any influences for the TOA asymmetry issue in simulations?

   Response: Thanks for your comments. Surface snow cover significantly affects surface albedo, especially at middle and high latitudes. In the process of calculating reflected solar radiation, surface parameters, including snow products, are introduced into the radiative transfer model, which may introduce bias. The inaccuracy in snow cover products can introduce some bias in the top-of-atmosphere radiative fluxes and potentially influence hemispheric differences of reflected solar radiation to some extent. The relevant reference and discussion are added in the revised manuscript：“Moreover, MERRA-2 significantly underestimates surface components in Antarctica during melting season (November to January), which could be due to biases in the input snow products that introduce significant uncertainties in surface albedo (Jia et al., 2022).”

Please see the Line: 755-757.

3. Line 546: despite including various driving factors (e.g., NDVI, snow cover) for anomaly attribution, their corresponding radiative forcings differ significantly. Consequently, even if two factors exhibit similar anomaly magnitudes in a given year, the importance of NDVI may not be comparable to snow cover changes, rendering the anomaly analysis less meaningful. Therefore, I recommend converting the anomaly analysis to a corresponding radiative forcing analysis to better capture the relative importance of different factors in driving changes in radiative forcing over time.

Response: We very thank reviewer for providing detailed comments and suggestions. We agree with the reviewer. Indeed, even if two factors exhibit similar magnitudes of anomalies in a given year, their relative importance may not be comparable. As stated in original manuscript: “the radiation contributions from different latitudinal zones exhibit varying sensitivities to changes in different factors, resulting in different magnitudes of response." Therefore, in previous analyses, the relative anomalies of factors serve merely as a reference for identifying and analyzing anomaly events. Based on the comments and suggestions from two Reviewers, we reorganize the manuscript and only focus on two key issues: (1) analyze the characteristics of the variations in hemispheric reflected solar radiation at a latitude- and month-based perspective; and (2) systematically quantify the performance of four radiation datasets in reproducing hemispheric differences and symmetry of reflected solar radiation observed by CERES. In the revised manuscript, we reorganize the section of results in order to make the manuscript clearer. Thus, the content discussing the contribution of different factors to latitudinal zones in extreme years (Section 3.2) is already removed and some ambiguous descriptions are also corrected in the revised manuscript.

4. The difference of r in Eqs. 4 and 5: r in Eq.4 represents blue-sky reflectance, where the solar beam reflects from the surface, whereas the r in eq5 is black-sky reflectance and the incoming radiation is from space. Does this difference in physics have any impact, particularly at high latitudes where the SZA is large?

Response: We very thank reviewer for providing detailed comments and suggestions. We fully understand the reviewer's concerns and apologize for any confusion caused by our unclear expression. Black-sky albedo is the intrinsic albedo of the surface when atmospheric diffuse is ignored. Blue sky albedo is the actual surface albedo. However, r in Eq. 4 and Eq. 5 represents atmospheric intrinsic reflectivity, which is independent of the surface albedo. We correct the inappropriate statements in the revised manuscript: "Here, r and t represent atmospheric intrinsic reflectivity (that is, PA purely contributed by the atmosphere) and atmospheric transmittance, respectively."

Please see the Line: 260-261.

Specific Responses:

1. Suggest introducing parameters with 0 in Eq. 20

Response: Thanks for your suggestions. We have added the introduction for parameters with 0 in Eq. 21 (same as the Eq. 20 in the original manuscript) in the revised manuscript:

$$DISO_i^{xj} = \sqrt{(CC_i - CC_0)^2 + (NAE_i - NAE_0)^2 + (NRMSE_i - NRMSE_0)^2} \quad (21)$$

Where i and xj represent the ith model and jth variable. The subscript "0" in Eq. 21 represents statistical parameters of variable xj from observation data (here refers to CERES EBAF).

Please see Line: 340-341.

2. Figure 2a: I suggest changing the color bar because the conventional association of 'blue & red' typically implies negative and positive directions, whereas the result here is uni-directional.

Response: We very thank reviewer for providing detailed comments and suggestions. We have modified the inappropriate color bar of figures in the revised manuscript. Additionally, based on the comments and suggestions from two Reviewers, we reorganize the Section 3.1 to only focus on analyzing the characteristics of the variations in hemispheric reflected solar radiation at a latitude- and month-based perspective, rather than on the contribution of different latitudinal zones to hemispheric total reflected radiation at TOA. As a result, we replace the related content regarding the "contribution of different latitudinal zones to hemispheric total reflected radiation at TOA from 2001 to 2021 and the corresponding components (Figure 2a-d in the original manuscript)" with "reflected solar radiation of different latitudinal zones at TOA from 2001 to 2021 and the corresponding components (Figure 3a-d in the revised manuscript, please see the Figure R2)". Although the variables shown here are different, they essentially reflect the same information.

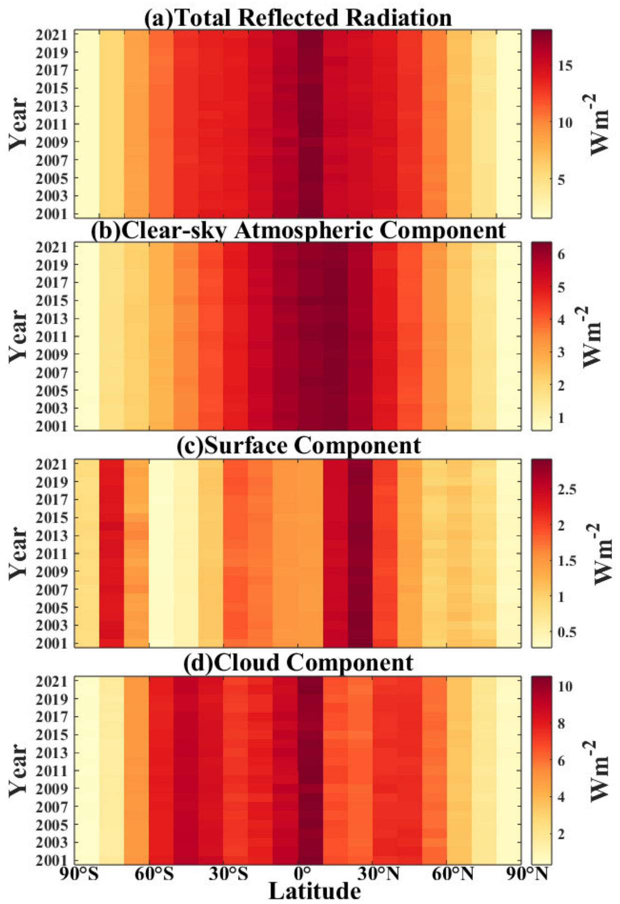

Figure R2 (same as the Fig. 3a-d in the revised manuscript): Annual averages from 2001 to 2021 of (a)total reflected solar radiation flux and its (b) clear-sky atmospheric component, (c) surface component, and (d) cloud component at different latitudinal zones.

3. Line 437: The dominant component in the NH?

Response: It is corrected in the revised manuscript: "The higher RSR from the 0°-40° latitude zones in the NH stems from the higher cloud component from the equator to 10° and the combined effect of clear-sky atmospheric and surface components in the 10°-40°."

Please see the Line: 469-471.

4. Line 438: 0°-70°? Why does it have some overlaps with the following ones?

   Response: Thanks for your comments. We correct the inappropriate statements in the revised manuscript: "The higher RSR from the 0°-40° latitude zones in the NH stems from the higher cloud component from the equator to 10° and the combined effect of clear-sky atmospheric and surface components in the 10°-40°."

   Please see the Line: 469-471.

5. The figures should be enlarged.

   Response: Thanks for your comments. We have enlarged the text in all figures in the revised manuscript.

Reference:

Jia, A., Wang, D., Liang, S., Peng, J., and Yu, Y.: Global daily actual and snow-free blue-sky land surface albedo climatology from 20-year MODIS products, Journal of Geophysical Research: Atmospheres, 127, e2021JD035987, https://doi.org/10.1029/2021JD035987, 2022.