To Editor:

We sincerely thank the reviewer for their valuable feedback and insightful comments. These have significantly improved the clarity, quality, and precision of our manuscript.

In response to the reviewers' comments, we have revised the manuscript and prepared a point-by-point response. For easy reference, the original comments are reproduced in blue, followed by our responses in black. All changes made to the manuscript text are highlighted in red.

This study analyzed the dynamic changes in snow cover and cropland GPP in Northeast China from 2001 to 2020. The need for such a study is well justified and the authors cite ample relevant literature, but there are many issues, including the title, data, method, and structure, need to be revised before consideration of acceptance.

Response: We sincerely thank the reviewer for their valuable feedback and insightful comments. These have significantly improved the clarity, quality, and precision of our manuscript. We made significant modifications, including: (1) removing the former results regarding paddy land, including method, figures, and context; (2) moving the former Discussion into Results and drafting a new Discussion. Below, we provide a detailed point-by-point response to each of the reviewer's comments.

My first comment is that the cropland GPP is largely influenced by human cultivation, then how can you judge the change of cropland GPP is result from snow cover change? Furthermore, the cropland is divided into dry land and paddy field. The GPP of paddy field is mostly controlled by irrigation, then how can you judge the change of paddy field GPP is result from snow cover change?

Response: We appreciate this insightful comment. Figure 1(c) shows the spatial distribution of unchanged cultivated land, including 12.63% paddy land and 87.37% dryland. Paddy land typically requires substantial irrigation water and is heavily influenced by human activities. Therefore, to more accurately examine the impact of snow cover changes, the study exclude paddy land and focus solely on dryland as a representative of cultivated land. This approach provides a clearer understanding of the mechanisms by which snow cover affects GPP on cultivated land. Furthermore, we exclude the results of paddy land throughout the manuscript.

My second comment concerns the data selection and the reliability of the analysis: the manuscript does not clearly specify whether the data used are annual data or from specific months. Moreover, the snow cover period and the crop growing season are not synchronized, so it is unclear what the "direct effect" mentioned in the paper refers to. Additionally, the study divides the area into six geographical regions for analysis; however, in some regions, croplands account for only a very small proportion. Conducting further analyses on these regions and comparing them with others raises concerns about the reliability of the results.

Response: Thank you for pointing this out. In response, we have clarified the temporal scope of the data. The data used in the analysis are annual averages, except for the snow cover data, which is specific to the snow season (typically November to March). We described the temporal resolution in Part 2.2. The snow cover day (SCD) and snow cover melt end date (SCED) are yearly data, while SWE is daily data (Line 138), and GPP is 8-day data (Line 154). The Besides, we discussed the relationship between snow cover and GPP in the new Discussion.

My third comment concerns the research rationale, logical consistency, and methodological limitations: the manuscript briefly mentions that the impact of snow cover on GPP exhibits spatial heterogeneity across different vegetation types, but it does not clearly justify why the study focuses specifically on cropland GPP as the research object. Additionally, the partial correlation analysis between snow cover and soil characteristics lacks logical connection to the exploration of the snow–GPP relationship, and there is no clear mechanistic discussion provided afterward. Furthermore, the methodology in Section 4.2 has significant limitations: it directly infers "threshold effects" and a "causal relationship" between snow cover and GPP from scatter plots and smoothed curves, which can easily lead to over-interpretation and potential misrepresentation. Since GPP variations are influenced not only by snow cover but also by other climatic factors (e.g., temperature, precipitation, and radiation), the manuscript should clarify how the effect of snow cover was isolated from other environmental influences.

Response: We have expanded the rationale for focusing specifically on cropland GPP. The reason for selecting cropland GPP as the study object is that croplands are highly sensitive to environmental changes, including those from snow cover, and represent a major portion of the agricultural area in Northeast China. We have added a more detailed explanation in the introduction (Lines 38-53), highlighting the relevance of croplands in regional GPP dynamics and the importance of understanding their response to climate factors such as snow cover.

Cultivated land is a critical natural resource for ensuring food security, ecological stability, and economic sustainability. Under the pressure of intensifying soil erosion and climate change, understanding the trends in gross primary productivity (GPP) variation of cultivated land and its associated environmental response mechanisms has become imperative for sustainable development and enhanced cropland conservation. GPP represents vegetation's photosynthetic carbon fixation capacity per unit time and serves as a key metric of carbon assimilation through photosynthesis (Beer et al., 2010; Sjöström et al., 2013). Cropland ecosystems play a pivotal role in terrestrial carbon cycling (Wang et al., 2022), where GPP directly governs crop growth dynamics, carbon sequestration potential, and agricultural productivity variations, making it an essential indicator of agroecosystem productivity (Wagle et al., 2015). As a key component of terrestrial ecosystems, snow cover significantly affects the carbon cycle by altering ecosystem functioning. In recent decades, amid global warming, significant changes in snow cover have been observed (Mudryk et al., 2020; Pulliainen et al., 2020), which subsequently influence vegetation dynamics and GPP through altered environmental conditions (Meredith et al., 2019). (Lines 38-53)

We adjust the structure of results and discussion of this manuscript greatly, as shown below. Secondly, we add a discussion on snow cover, soil, and GPP, and remove former Part 4.2.

4.2. Linkages of snow, soil, and GPP

The spatial patterns of SWE, SCD, and SCED reveal a clear north–south and east–west organization of snow regimes over cultivated land. Areas with deeper snowpacks and longer snow duration are concentrated at higher latitudes and elevations, while low-lying southern and coastal croplands experience shallower and shorter-lasting snow. Against this backdrop, our correlation analyses show that snow metrics affect GPP primarily by altering soil hydrothermal conditions, consistent with the notion that vegetation responds to hydrothermal states rather than snow itself (Liu et al., 2023).

In cold, energy-limited subregions, thicker and more persistent snow tends to enhance GPP by moderating winter and early-spring stress. Increased SWE and longer SCD insulate the soil, maintaining higher near-surface temperatures and reducing freeze–thaw damage, which promotes higher early-season GPP through improved root activity and reduced winter mortality (Mudryk et al., 2020; Liu et al., 2023). In these areas, our PLS-SEM results indicate that the dominant pathway from snow to GPP is temperature-driven: SWE and SCD warm the soil profile, advance favorable thermal conditions for crop emergence, and indirectly raise GPP by shortening the period of severe cold stress.

By contrast, in relatively warm but moisture-limited croplands, SWE emerges as the primary control on interannual GPP variability. Here, snow acts as a critical seasonal water reservoir. Higher SWE increases spring soil moisture, which alleviates early-season water stress and supports more vigorous canopy development, consistent with prior work highlighting the role of snow-derived water for spring soil moisture and subsequent crop performance in Northeast China (Li et al., 2022; Wang et al., 2024). In these zones, the structural paths in the PLS-SEM are dominated by SWE, soil moisture, and GPP, underscoring a moisture-mediated mechanism akin to the broader link between water availability and global GPP.

Reference:

Mudryk, L. R. et al. (2020). Historical Northern Hemisphere snow cover trends and projected changes in the CMIP6 multi-model ensemble. The Cryosphere, 14(7), 2495–2514

Liu, H., Xiao, P., Zhang, X., Chen, S., Wang, Y.,Wang, W. 2023. Winter snow cover influences growing-season vegetation productivity non-uniformly in the Northern Hemisphere. Communications Earth & Environment, 4, 487.

Wang, Y. et al., 2024. Unraveling the effects of snow cover change on vegetation productivity: Insights from underlying surface types. Ecosphere, 15(5): e4855.

Li, Y. et al., 2022. Responses of spring soil moisture of different land use types to snow cover in Northeast China under climate change background. Journal of Hydrology, 608: 127610.

My fourth suggestion is to revise the use of English language and grammar, while it is largely satisfactory overall, there are multiple linguistic issues throughout the whole manuscript that need to be revised, preferably by someone with a solid knowledge of English grammar. E.g., in line 35, “play are pivotal role” should be “play a pivotal role”.

Response: We thank the reviewer for highlighting the need for language improvement. We have thoroughly revised the entire manuscript to correct grammatical errors, including the one specifically mentioned (line 45). The language has been polished to enhance clarity and readability. We believe the manuscript now meets the required linguistic standards. We have carefully checked the manuscript using grammar-checking tools and had it reviewed by colleagues proficient in academic English.

Cropland ecosystems play a pivotal role in terrestrial carbon cycling (Wang et al., 2022), where GPP directly governs crop growth dynamics, carbon sequestration potential, and agricultural productivity variations, making it an essential indicator of agroecosystem productivity (Wagle et al., 2015). (line 45)

Furthermore, there are a few important and minor comments/mistakes that are listed below and should be considered.

Please make consistent expression of the “cultivated land” in the title and the “cropland” in the main text.

Response: We have revised the manuscript to ensure consistency in terminology. The term " cultivated land " is now used throughout the manuscript, including in the title.

Abstract: What are “HY2001” and “HY2020”?

Response: We have clarified that "HY" refers to the hydrological year, which runs from September to August. This clarification has been added to the abstract.

Hydrological year is defined as the duration from September to August (Lines 137-138).

Abstract: The results just show some increase and decrease numbers of snow and GPP, how can you say “these findings elucidate the critical role of snow cover in modulating cropland GPP variations”?

Response: We appreciate this comment. We have revised the abstract to better reflect the conclusions drawn from the data. We now emphasize that while the results show variations in snow cover and GPP.

These findings suggest a significant correlation between snow cover changes and cropland GPP variations, providing insights into the potential role of snow cover in modulating GPP dynamics. (Lines 33-35).

There are both “HY2000” and “HY2001” mentioned in the manuscript, which is inconsistent throughout the text.

Response: We have corrected this inconsistency by standardizing the use of “HY2001” throughout the manuscript.

Line 37 and 108, the citation style is wrong.

Response: Thank you for the careful suggestion. We have corrected the citation style on Lines 37 and 108 to conform to the journal’s guidelines, as seen in Line 48 and 153.

making it an essential indicator of agroecosystem productivity (Wagle et al., 2015). (Line 48)

The MOD17A2H version 6 GPP data product (2001 to 2020) was adopted (Running et al., 2021). (Line 153)

Line 512: There is a spelling error in "...The red and blue arrows represent..."; the word "blue" is incorrect.

Response: We have corrected the spelling error. The correct term is now "blue" (Line 474). The red and blue arrows represent the positive and negative influences.

Line 205: Missing space before the citation in "...signal (Ruffin and King, 1999)."

Response: The former "Part 2.3.4 Savitzky-Golay filter" has been removed.

Line 469: There is a missing space between the parentheses and the letters in "(c)SCED".

Response: The former "Part 4.2 The thresholds of snow cover-GPP correlation" has been removed.

Line 145: The description "SM and temperature data" is ambiguous; please keep the terminology consistent throughout the manuscript.

Response: Thank you for careful checking. We have checked the whole manuscript and corrected it.

This comprehensive dataset includes the 0-10 cm soil moisture and soil temperature used in this study. (Line 186)

Figure 1, the dry land and paddy field should be expressed in the map because the influence of snow cover on them is different.

Figure 1(b) presents the land use data for 2020; however, the analysis in the manuscript only considers croplands with unchanged land use types. It is recommended to display the actual land use data of the analyzed croplands in the figure.

Response: Thank you for these two suggestions for Figure 1. We added the distribution of paddy and dry land in Figure 1(c), as well as the distribution of unchanged cultivated land used in the paper. The new version of Figure 1 is presented as follows.

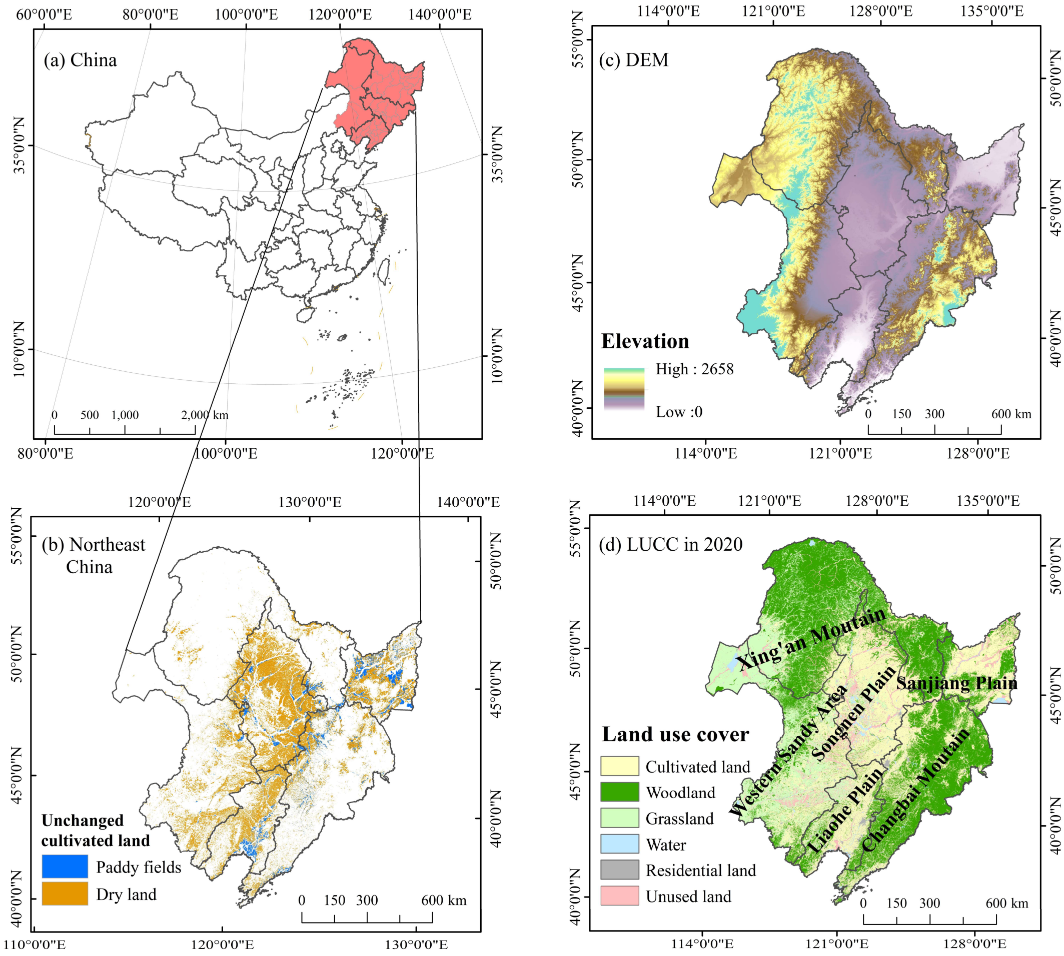

Figure 1 The overview of the study area: (a) China; (b) cultivated land in Northeast China; (c) digital elevation model (DEM) provided by SRTM; (d) land use cover provided by LUCC.

In Figures 2, 3, and 4, when presenting the variations of snow-related factors across different cropland types, it is recommended to provide the proportion of areas with significant changes.

Response: We appreciate this suggestion. We supplement the percentage of areas with significant changes in Figures 2 to 4.

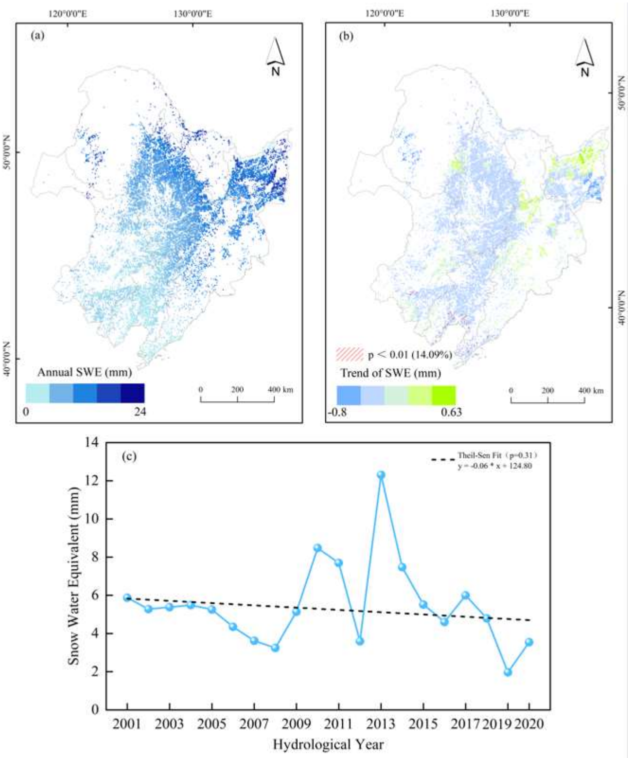

Figure 2 The spatial and temporal changes of SWE in Northeast China from HY2001 to HY2020: (a) spatial distribution of mean SWE; (b) changing trend of SWE, the green areas represent positive impacts, while the blue areas indicate negative impacts; and the shaded regions denote pixels that were significant at the $p < 0.1$ level; (c) annual changes of SWE.

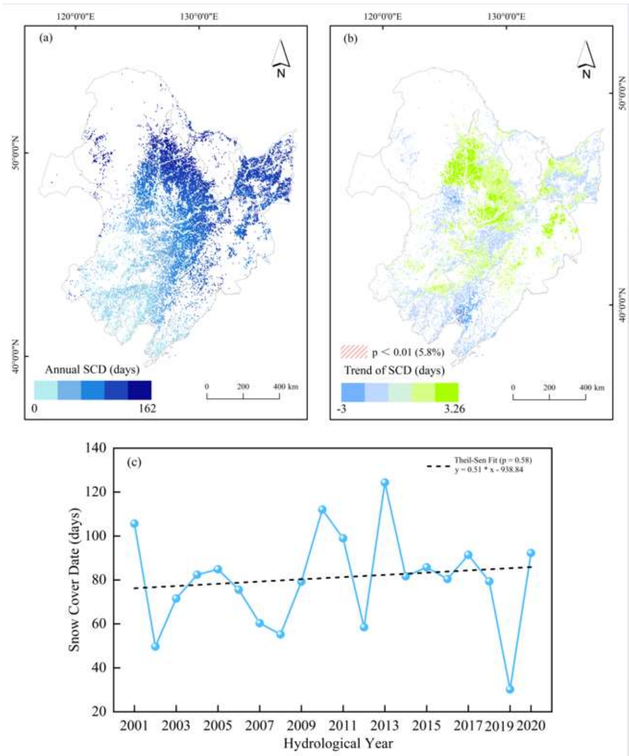

Figure 3 The spatial and temporal changes of SCD in Northeast China from HY2001 to HY2020: (a) spatial distribution of mean SCD; (b) changing trend of SCD, the green areas represent positive impacts, while the blue areas indicate negative impacts; and the shaded regions denote pixels that were significant at the $p < 0.1$ level; (c) annual changes of SCD.

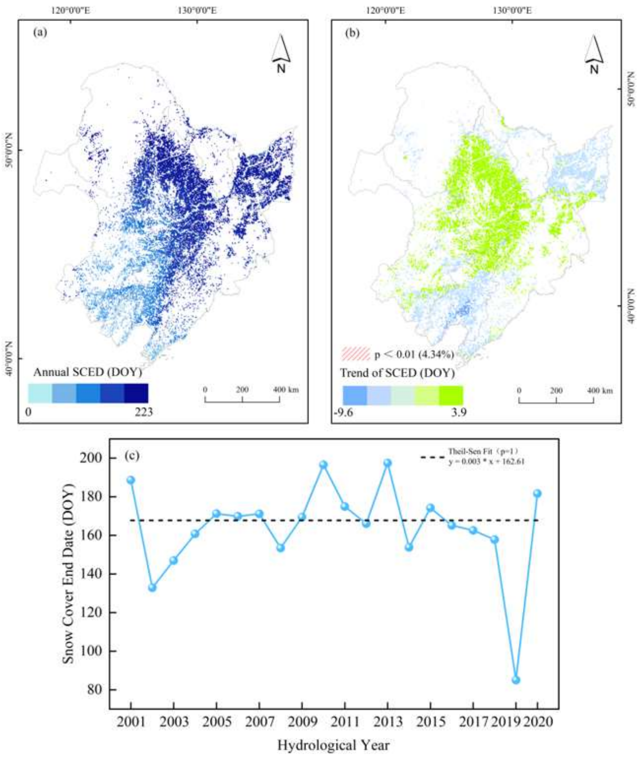

Figure 4 The spatial and temporal changes of SCED in Northeast China from HY2001 to HY2020: (a) spatial distribution of mean SCED; (b) changing trend of SCED, the green areas represent positive impacts, while the blue areas indicate negative impacts; and the shaded regions denote pixels that were significant at the $p < 0.1$ level; (c) annual changes of SCED.

In Figure 9 and similar figures, the Y-axis label is "Area," then the unit should not be in percentage (%).

Response: We removed the context about paddy land, as well as this sub-figure.

Figure 13: A space is missing before the units in the figure title.

Response: We removed the context about paddy land, as well as this sub-figure.

“snow cover-GPP correlation” in the section title may cause ambiguity, and it is recommended to replace “snow cover” with a single word to avoid potential confusion.

Response: We have improved the titles as “3.3 The influence of Snow Cover on GPP” (Line 370).

The conclusion section is too long to capture the main findings of the study.

Response: We have shortened the conclusion section to focus on the key findings and implications of the study. The revised conclusion now succinctly summarizes the main contributions of the research, as shown below (Line 581-606).

This study used multi-source remote sensing data to clarify how snow cover dynamics regulate cultivated land GPP in Northeast China from HY2001 to HY2020. By jointly analyzing SWE, SCD, SCED, and GPP, we revealed pronounced regional heterogeneity in snow cover–crop interactions: snow cover reductions in the Liaohe Plain and Western Sand Area contrasted with prolonged snow duration and delayed melt in the Songnen and Sanjiang Plains, where GPP increased most strongly.

By controlling for temperature, precipitation, and radiation, we isolated the intrinsic snow–GPP relationships for different cropping systems. SCD was identified as the dominant snow metric for dryland GPP, whereas SCED exerted stronger control on paddy GPP. Ridge regression further showed that SWE primarily regulates GPP in the Western Sand Area and Liaohe Plain, while SCD dominates in the Songnen and Sanjiang Plains, and SCED is most important in the Changbai Mountain and Khingan regions. Threshold analysis quantified optimal snow conditions for maximum GPP enhancement, identifying characteristic SWE, SCD and SCED ranges beyond which positive effects weaken or reverse.

Finally, the PLS-SEM framework quantified both the direct effects of snow cover indicators on GPP and their indirect effects via soil moisture and temperature, elucidating the snow–soil–vegetation coupling mechanism in cold-region agroecosystems. Collectively, these findings provide a process-based basis for optimizing regional agricultural management and developing climate change adaptation strategies in the cultivated lands of Northeast China.

Future work should integrate field experiments and higher-resolution data on crop types and management practices to disentangle these complex interactions and validate the proposed mechanisms at a finer scale.