Responses to Reviewer's Comments

2024-09-30

Dear Editor and Reviewers,

Revision of our manuscript ESSD-2024-277

Thank you for your comments and suggestions. We have made minor revisions to our paper (ESSD-2024-277 Global DEM Product Generation by Correcting ASTER GDEM Elevation with ICESat-2 Altimeter Data) according to the reviewer' suggestions (the changes have been highlighted).

Referee comments are in **bold**, and the changed text is in *italics*.

Thank you again for your valuable comments and time.

Sincerely,

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Reviewers Comments:

Q1. Can the authors numerically label the findings in the abstract, e.g., (1), (2), etc.?
Response:
Thank you for your suggestion. We have revised the related descriptions.
In the abstract,
"*…The results from the validation comparison present that the elevation accuracy of IC2-GDEM is evidently superior to that of the ASTER GDEM product. The root-mean-square error (RMSE) reduction ratio of the corrected GDEM elevation is between 16% and 82%, and the average reduction ratio is about 47%. From the analysis of the different topographies and land covers, it was also found that this error reduction is effective even in areas with high topographic relief (>15 °) and high vegetation cover (>60%)…*"
has been revised to
"""*…The results from the validation comparison present that the elevation accuracy of IC2-GDEM is evidently superior to that of the ASTER GDEM product: 1) the root-mean-square error (RMSE) reduction ratio of the corrected GDEM elevation is between 16% and 82%, and the average reduction ratio is about 47%; 2) from the analysis of the different topographies and land covers, this error reduction is effective even in areas with high topographic relief (>15 °) and high vegetation cover (>60%)…*"

Q2. L35-100: Some points within this paragraph need improvement, as follows:
First, the authors discuss the significance of refining ASTER GDEM but do not clearly explain what specific improvements or innovations this study introduces compared to previous studies.
Second, the paragraph starts by emphasizing the importance of high-quality DEMs, but the latter part seems to drift towards specific technical details about the ASTER GDEM correction method without clearly linking these details back to the broader impact or significance.
I found that the authors assumed that integrating ASTER GDEM with other DEM products will inherently lead to better outcomes but did not provide evidence or references to justify this assumption. Please revisit and address this point carefully.
I found phrases such as "high-accuracy global control point dataset" and "automatic processing scheme" are used without clear definitions or explanations of what makes them superior or innovative. This is very important for the product's validation in this work.
The significance of the study is stated multiple times (e.g., "of great significance," "beneficial supplement"), but without concrete examples or data to support these claims, the statements lack impact.
In addition, the literature review conducted on the use of remote-sensing DEMs Earth science research and scientific applications, including hydrological modeling, climate change research, natural hazard assessment, and ecosystem management was not well reviewed, suggesting accuracy of watershed delineation (10.1016/j.ejrh.2022.101282), flood risk assessment (10.3389/fenvs.2023.1304845), water resources management (10.1016/j.scitotenv.2024.174289 and 10.1007/s00382-024-07319-7), disaster preparedness (10.1109/jstars.2024.3380514), and promote human resilience for coastal communities (10.1016/j.jenvman.2024.121375).

Response:

Thank you for your detail suggestions. Maybe the descriptions in the paper are not clear and sufficient enough. We have revised the relative descriptions and added some references in the Introduction, as follows:

"In climate change research, high-quality DEMs are vital for accurate watershed delineation, disaster preparedness, promoting human resilience in coastal communities, modeling glacier dynamics, and assessing sea level rise impacts, etc., thereby improving predictive accuracy and informing mitigation strategies (Fan et al., 2022; Cook et al., 2012; Thanh-Nhan-Duc et al., 2023, 2024a, 2024b)."

Reference:

Tran, T.-N.-D., Tapas, M. R., Do, S. K., Etheridge, R., and Lakshmi, V.: Investigating the impacts of climate change on hydroclimatic extremes in the Tar-Pamlico River basin, North Carolina, J. Environ. Manage., 363, 121375, https://doi.org/10.1016/j.jenvman.2024.121375, 2024a.

Tran, T.-N.-D., Nguyen, B. Q., Vo, N. D., Le, M.-H., Nguyen, Q.-D., Lakshmi, V., and Bolten, J. D.: Quantification of global Digital Elevation Model (DEM) – A case study of the newly released NASADEM for a river basin in Central Vietnam, J. Hydrol.: Reg. Stud., 45, 101282, https://doi.org/10.1016/j.ejrh.2022.101282, 2023.

Tran, T. N. D., Do, S. K., Nguyen, B. Q., Tran, V. N., Grodzka-Łukaszewska, M., Sinicyn, G., and Lakshmi, V.: Investigating the Future Flood and Drought Shifts in the Transboundary Srepok River Basin Using CMIP6 Projections, IEEE J. Sel. Top. Appl. Earth Obs. Remote Sens., 17, 7516-7529, 10.1109/JSTARS.2024.3380514, 2024b.

"*Furthermore, some studies (Pham et al., 2018; Yamazaki et al., 2017; Crippen et al., 2016; Franks et al., 2020; Okolie and Smit, 2022) have also reported that diversified choices and complementary use strategies for GDEMs are still favored by many scholars and users. For instance, the data sources for the void filling of the Copernicus GLO-30 DEM consist of other DEMs, including the ASTER GDEM, SRTM DEMs, and several national DEMs (Del Rosario González-Moradas et al., 2023). Thus, obtaining more accurate ASTER GDEM elevation products is a great significance for advancing the research of the GDEM diversified choices and complementary use strategies.*"

"Researchers can use the enhanced ASTER GDEM in conjunction with other DEM products to cross-validate qualities, fill data gaps, and conduct multi-scale analyses (Del Rosario González-Moradas et al., 2023). This complementary use of multiple DEMs can lead to more reliable and comprehensive scientific discoveries, thereby improving the overall quality and reliability of geoscience research (Del Rosario González-Moradas et al., 2023; Ao et al., 2024). However, the previous studies have hardly focused on integrating ASTER GDEM and satellite laser altimeter data to generate and release a new enhanced ASTER GDEM product at a global scale."

"*In this study, based on these models, we further optimized and designed an automatic processing scheme for correcting ASTER GDEM elevation. This scheme does no required human intervention during the processing and is suitable for large-scale data processing.*"

"*Meanwhile, a high-accuracy global elevation control point dataset (elevation RMSE: 0.5-3 m within different topographies) (Li, et al., 2022; Xie, et al., 2021) and multiple local DEMs (LDEMs) with a high resolution and accuracy were used to validate the accuracy of the original and refined ASTER GDEM, including comparison of the elevation accuracy in areas with different geolocations, topographic relief, and vegetation cover. The related validation results at global scale will provide a beneficial supplement for the accuracy qualification of the latest ASTER GDEM with different geolocations, altitudes, topography, vegetation cover, etc.*"

Q3. The study specifically excludes polar regions from the correction process due to challenges like high variability in ice sheets and flow rates. This exclusion limits the global applicability of the IC2-GDEM product and leaves a coverage gap, particularly for researchers focused on polar studies.

Response:

Thank you for your suggestions. Compared with other areas, ICESat-2 laser altimeter observations are denser in polar areas, making this data particularly suitable for generating polar DEMs. Previous studies have refined ICESat/ICESat-2 altimeter data to produce and release polar DEM products. Moreover, ASTER GDEM does not fully cover polar areas, and correcting elevations in these regions is challenging due to the high variability in ice sheets and flow rates. For the researchers focused on polar studies, they can directly use the polar DEM production mainly sourced from ICESat-2 laser altimeter data. Maybe the descriptions in the paper are not clear and sufficient enough. We have revised some descriptions.

"*Given the particularity of polar areas, namely the high variability of ice sheets and ice flow rates, and the dense observations of satellite altimeter data, etc., only the parts of the product within the land areas between 83 °N and 60 °S (except for polar areas) were corrected.*"

has been revised to

"*Compared with other areas, ICESat-2 laser altimeter observations are denser in polar areas, making this data particularly suitable for generating polar DEMs. Previous studies have refined ICESat/ICESat-2 altimeter data to produce and release polar DEM products. Moreover, ASTER GDEM does not fully cover polar areas, and correcting elevations in these regions is challenging due to the high variability in ice sheets and flow rates. Therefore, only the parts of the product within the land areas between 83 °N and 60 °S (except for polar areas) were corrected.*"

Q4. The potential for temporal inconsistencies between the ASTER GDEM data and the more recent ICESat-2 data is not fully discussed. In dynamic landscapes, such as areas experiencing rapid coastal erosion or land use changes, these temporal discrepancies could lead to inaccuracies in the corrected DEM, which the authors did not quantify or address adequately. Please revisit and provide reasonable discussions to address this point.

Response:

Thank you for your suggestions. There is a potential for temporal inconsistencies between the ASTER GDEM data and the more recent ICESat-2 data, which may lead to inaccuracies in the corrected DEM in dynamic landscapes. To this end, we selected multiple areas located near the coast in the validation areas for evaluating the performance of DEM elevation correction, including the coast of the Netherlands, the coast of Australia, the islands of New Zealand, the west coast of the United States and the island of Hawaii, etc. From the results, it can be found that the corrected DEM elevations still have an obvious accuracy improvement. Maybe the descriptions in the paper are not clear and sufficient enough. We have added some descriptions.

In the section 4.4,
"…Moreover, the temporal differences between the ICESat-2 data survey and ASTER GDEM collection may lead to elevation inconsistencies, especially in extremely dynamic landscapes (e.g., coastal erosion areas). To this end, for the validation areas, we selected multiple areas located near the coast for further evaluating the performance of DEM elevation correction in this kind of landscape, including the coast of the Netherlands, the coast of Australia, the islands of New Zealand, the west coast of the United States and the island of Hawaii, etc., as shown in Figure 2. From the validation results (as shown in Figure 8), it can be found that the corrected DEM elevations still have an obvious accuracy improvement. The main reason for this phenomenon is that the discrepancy caused by the change between the collection times of the two data sets is generally lower than the error in the ASTER GDEM elevation (about 10 m)"
has been added.

Q5. The authors acknowledged that the density of ICESat-2 observations varies significantly with latitude, but it does not thoroughly investigate how this variation impacts the accuracy of the DEM corrections. In low-latitude regions, where ICESat-2 data are sparser, the correction results might be less reliable, a factor that needs more detailed examination.

Response:

Thank you for your suggestions. The data density of the ICESat-2 laser altimeter data varies greatly in different latitude regions, and the data density of the ICESat-2 laser altimeter data in the low-latitude regions is generally less than that in the high-latitude regions. From the corrected results, as shown in Fig. 7, we found that there is no significant difference in the DEM elevation correction errors between low-latitude and high-latitude areas. There are two main reasons causing this phenomenon. First, the DEM elevation correction model has a good generalization within different spatial distributions (Li et al., 2023). Second, in the generation of the GDEM elevation deviation, extracting the seed points (sourced from ICESat-2 laser altimeter data) of the model has been designed multiple strategies. These strategies ensure to obtain the even distribution of the seed points for further weakening the impact of the differences of density of the ICESat-2 laser altimeter data. Maybe the descriptions in the paper are not clear and sufficient enough. We have revised and added some descriptions.

After "*Similar to the analysis results in Figure 6, in the different latitude regions, it is also apparent that the systematic error and standard deviation after ASTER GDEM elevation correction are significantly reduced, compared with the original ASTER GDEM elevation, as displayed in Figure 7. Notably, the data density of the ICESat-2 laser altimeter data varies greatly in different latitude regions,* *and the data density of the ICESat-2 laser altimeter data in the low-latitude regions is generally less than that in the high-latitude regions (Neuenschwander and Pitts, 2019; Markus et al., 2017). However, the errors of the ASTER GDEM elevation corrections in low-latitude regions (especially near the equator) are no larger than those in other latitude regions, which indicates that the correction results are less affected by the difference in the data density of the ICESat-2 laser altimeter data.*"

"*There are two main reasons for the observed phenomenon in DEM elevation correction. First, the DEM elevation correction model generalizes well across various spatial distributions (Li et al., 2023). Second, multiple strategies have been designed for extracting seed points from ICESat-2 laser altimeter data during the generation of GDEM elevation deviation. These strategies ensure an even distribution of seed points, thereby mitigating the impact of varying densities in the ICESat-2 laser altimeter data.*"

has been added.

Q6. The authors briefly mention the challenges posed by dynamic landscapes, where changes between the times of data collection could lead to inconsistencies. However, it does not provide a detailed analysis or propose methods to mitigate these issues, which is crucial for applications in rapidly changing environments.

In general, please separate the Discussion from the Conclusion section and provide a more in-depth discussion based on qualitative results.

Q7. Please include a section on limitations and future work.

Response:

Thank you for your suggestions. There are two strategies for weakening the impact of this kind of inconsistency. First, using repeated observations from the ICESat-2 satellite to analyze the areas with the elevation potential changes can qualify the application potential of IC2-GDEM within the dynamic landscapes. Second, integrating IC2-GDEM with other elevation data (closer to the ASTER GDEM data collection time) can reduce deviations in the analysis results within the dynamic landscapes. Maybe the descriptions in the paper are not clear and sufficient enough. We have separated a section on limitations and future work, and added some more in-depath discussions in this section.

"4.4 Limitations and Future Work

From the above analysis, while the IC2-GDEM demonstrates significant improvements in elevation accuracy, its quality of elevation correction is notably limited in the areas with steep slopes or high vegetation cover index. For research or applications with high-quality elevation requirements, this limitation can be quantified and identified through topographic relief calculations or in combination with vegetation cover data. Moreover, the temporal differences between the ICESat-2 data survey and ASTER GDEM collection may lead to elevation inconsistencies, especially in extremely dynamic landscapes (e.g., coastal erosion areas). To this end, for the validation areas, we selected multiple areas located near the coast for further evaluating the performance of DEM elevation correction in this kind of landscape, including the coast of the Netherlands, the coast of Australia, the islands of New Zealand, the west coast of the United States and the island of Hawaii, etc., as shown in figure 2. Validation results (Figure 8) show that the corrected DEM elevations still exhibit significant accuracy improvements. This phenomenon is because the temporal discrepancy between the datasets is generally smaller than the ASTER GDEM elevation error (about 10 m). To further mitigate these inconsistencies, two main strategies are proposed. First, using repeated ICESat-2 observations to analyze areas with potential elevation changes can assess the application potential of IC2-GDEM in dynamic landscapes.

Second, integrating IC2-GDEM with other elevation data collected closer to the ASTER GDEM collection time can reduce analysis deviations in dynamic landscapes. In future work, we will identify areas with elevation changes using the above strategies and integrate other GDEMs to further enhance IC2-GDEM elevation quality in dynamic landscapes." has been added.

Q8. In the conclusion, please highlight the main findings with a brief description (suggest highlighting qualitative results), but please keep them short, direct, and concise. The current form is lengthy and difficult to follow.

Response:

Thank you for your suggestions. We have revised the conclusion.

"In this study, we introduce a new open-source dataset, named IC2-GDEM. IC2-GDEM is generated by directly refining the ASTER GDEM elevation with ICESat-2 altimeter data, as well as FROM-GLC10 data and GFCC30TC data. This strategy leverages existing datasets and enhances them with additional data and it is cost-effective for improving elevation accuracy, which is particularly beneficial for applications in developing regions where resources to obtain high-accuracy DEMs may be limited.

The elevation quality of IC2-GDEM has been evaluated at a global scale and in multiple local regions by using other laser/LiDAR data from satellite or airborne platforms. From the evaluation results for the different geolocations at a global scale, it was found that the correction results are less affected by the difference in the data density of the ICESat-2 laser altimeter data. ICESat-2 observations at higher-latitude areas are denser than those at lower-latitude areas. However, the errors of the IC2-GDEM elevation in low-latitude regions are no larger than the errors in high-latitude regions. From the evaluation results for the different topographies, the ASTER GDEM after elevation correction shows an obvious improvement of elevation quality for the different topographies, even in the mountainous areas with higher slopes. A similar conclusion was also found from the evaluation of the different land covers. These analysis results show that the IC2-GDEM presents a superior elevation quality at a global scale.

IC2-GDEM is expected to promote seamless integration with the historical datasets of ASTER GDEM, which is essential for longitudinal studies of long-term environmental changes, land use dynamics, and climate impacts. As a dataset for exploring the quality improvement of GDEM sourced from optical imaging, IC2-GDEM can serve as a new complementary data source for other GDEMs, such as SRTM, and Copernicus DEM. Researchers can combine IC2-GDEM with other DEMs to cross-validate qualities, fill data gaps, and conduct multi-scale analyses for earth science studies such as Flood risk, climate change, etc. with more reliable and comprehensive scientific discoveries."

has been revised to

"*In this study, we introduce a new open-source dataset, named IC2-GDEM. IC2-GDEM is generated by directly refining the ASTER GDEM elevation with ICESat-2 altimeter data, as well as FROM-GLC10 data and GFCC30TC data. This strategy provides a cost-effective way to improve elevation accuracy, especially beneficial for developing regions with limited resources for high-accuracy DEMs. After validating at a global scale, IC2-GDEM presents a superior elevation quality and application potentials: 1) be less affected by the difference in the data density of the ICESat-2 laser altimeter data; 2) an obvious improvement of elevation quality for the different topographies, even in the mountainous areas with higher slopes; 3) a clear improvement in elevation quality was observed across various land covers, including areas with dense vegetation cover; 4) be expected to promote seamless integration with the historical datasets of ASTER GDEM for studying longitudinal studies of long-term environmental changes, land use dynamics, and climate impacts; 5) as a new complementary data* *source for other GDEMs, such as SRTM, and Copernicus DEM to cross-validate qualities, fill data gaps and conduct multi-scale analyses.*"