Dear community reviewer:

Thank you very much for reviewing this manuscript. We have revised and corrected the manuscript according to your suggestions, and have responded to each of your questions in detail. In this response, your questions and suggestions are marked in black, while my responses and the revised sections of the manuscript based on your suggestions are marked in blue.

Traditional bathymetric methods, such as airborne LiDAR and shipborne sonar, face significant difficulties and limitations when acquiring bathymetry data for Arctic supraglacial lakes. Using remote sensing as a non-contact method to obtain bathymetric information of Arctic supraglacial lakes is emerging as a promising approach and is gaining increasing attention. This paper combines ICESat-2 data and Sentinel-2 multispectral imagery, and applies a spectral stratification strategy to derive the bathymetry, achieving a high accuracy water depth of four representative lakes. Generally, this paper is well-written and has an easy-to-follow structure. However, there are still several points in the paper that need attention.

Major issues:

R1Q1: The paper proposes a spectral stratification method combined with the Lyzenga model, but the mechanism and rationale for combining near-infrared, red, and green bands into two layers (green and blue) are not fully explained. It is recommended to add a brief explanation to enhance the clarity of the methodology.

Major issues R1A1: Thank you very much for the comment, which makes this manuscript more rigorous. In this manuscript, the red band, near-infrared band, and green band were indeed merged, and the remote sensing images were divided into only two parts: the merged layers and the blue band layer. This part of the manuscript lacked sufficient description, and the revised paragraph is as follows:

As shown in Figure 1, the segmentation results for Lake A indicate that the segmented areas in the near-infrared and red bands are significantly smaller compared to those in the blue and green bands. This small region results in fewer ICESat-2 data points intersecting the NIR and red band segments, thereby reducing the accuracy of bathymetric model construction. To mitigate this limitation, the study employs a band-merging approach, combining the NIR, red, and green bands for analysis. While this approach may appear to overlook the differences in penetration capability among the red, near-infrared, and green bands, it actually enhances the continuity of model training by incorporating a larger amount of ICESat-2 data. Comparative analysis shows that this integrated approach yields more stable bathymetric inversion results than processing the NIR and red bands separately. In other words, Arctic supraglacial lakes (SGLs) were divided into layer of the NIR, red, and green bands and layer of blue band for bathymetry inversion, the expression was (Lyzenga 1978, 1985; Chu et al., 2023):

$$Z = a_{g0} + \sum_{i=1}^{N} a_{gi} \ln\left[L(\lambda_i) - L_\infty(\lambda_i)\right] \quad (1)$$

$$Z = a_{b0} + \sum_{i=1}^{N} a_{bi} \ln\left[L(\lambda_i) - L_\infty(\lambda_i)\right] \quad (2)$$

where Z was the predicted bathymetry result, a_{g0} and a_{gi} were the corresponding parameters of the combined segmented image layer of the NIR, red, and green bands, a_{b0} and a_{bi} were the corresponding parameters of the blue band layer, $L(\lambda_i)$ was the reflectance value of the *i-th* band, and $L(\lambda_\infty)$ was the reflectance of the deep-water zone in the *i-th* band.

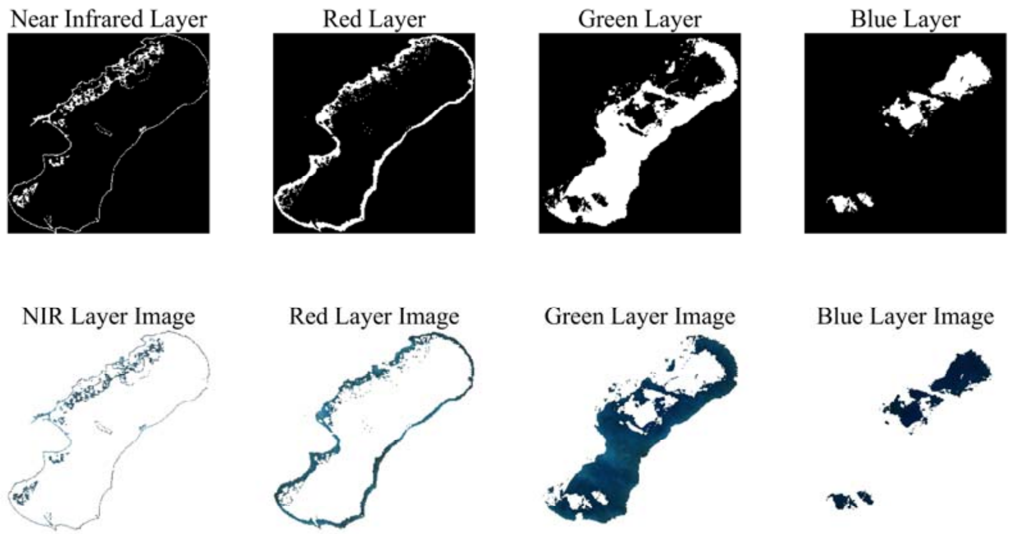


Figure 1. Binarized segmentation and spectral stratification of the Lake A

References

[1] Chu, S., Cheng, L., Cheng, J., Zhang, X., and Liu, J.: Shallow water bathymetry using remote sensing based on spectral stratification, Haiyang Xuebao, 45, 125-137, http://doi.org/0253-4193(2023)01-0125-13, 2023.

[2] Lyzenga, D. R.: Passive remote sensing techniques for mapping water depth and bottom features, Applied optics, 17, 379-383, http://doi.org/10.1364/ao.17.000379, 1978.

[3] Lyzenga, D. R.: Shallow-water bathymetry using combined lidar and passive multispectral scanner data, International journal of remote sensing, 6, 115-125, http://doi.org/10.1080/01431168508948428, 1985.

R1Q2: There is a time difference of two to four months between Sentinel-2 images and ArcticDEM validation data. Although the paper mentions that lakebed materials are relatively stable, it is suggested to strengthen the explanation and explicitly acknowledge the potential uncertainty this brings.

Major issues R1A2: We sincerely appreciate the reviewer's careful reading and valuable comment. Although the lakebed in the study area is mainly composed of bedrock and is unlikely to undergo significant changes over a short period, minor variations are inevitable. Therefore, deviations between ICESat-2-derived bathymetry and ArcticDEM are indeed unavoidable. However, the overall consistency between the two datasets is strong, as also demonstrated in the experiment by Melling et al. (2024). The discrepancies fall entirely within an acceptable range and do not undermine the validity of ArcticDEM as a high-quality validation dataset. Due to the limited temporal resolution of ArcticDEM, it is difficult to conduct comparative experiments to assess the impact of different acquisition dates on the validation results. We have clarified this limitation in the revised manuscript, which is provided in the following paragraph. We also aim to address it through experimental improvements in future work.

Additionally, there was a temporal discrepancy of two to four months between the ArcticDEM data and the ICESat-2 data in this study. This time difference inevitably introduces some error between the ArcticDEM data and the ICESat-2 data used for modeling. However, the sediment in the lakes of the experimental area primarily consists of bedrock, a type of material that remains stable and does not undergo significant changes over a short period, Melling et al. (2024) also demonstrated through their experiments that ICESat-2 and ArcticDEM data collected several months apart show a high degree of consistency. Therefore, under appropriate conditions, it is feasible to use ArcticDEM as validation data in this study (Melling et al., 2024)

References

[1] Melling, L., Leeson, A., McMillan, M., Maddalena, J., Bowling, J., Glen, E., Sandberg Sørensen, L., Winstrup, M., and Lørup Arildsen, R.: Evaluation of satellite methods for estimating supraglacial lake depth in southwest Greenland, The Cryosphere, 18, 543-558, http://doi.org/10.5194/tc-18-543-2024, 2024.

R1Q3: The implementation details of NDWI are missing: the Methods section mentions using NDWI for water-land separation but does not specify the exact Sentinel-2 band numbers (e.g., B3 for Green and B8 for NIR), which may affect the reproducibility.

Major issues R1A3: Thank you very much for the suggestion, which makes this manuscript clearer. Indeed, the manuscript does not specify the correspondence between different wavelength ranges and the Sentinel-2 band numbers. Generally, the green band corresponds to Band 3 of Sentinel-2, and the near-infrared band corresponds to Band 8. We have clarified in the revised manuscript as below:

The water column was extracted from multispectral imagery using water-land separation methods, i.e., the Normalized Difference Water Index (NDWI) (Eq. (3)) and threshold-based grayscale segmentation (McFeeters, 1996)

$$NDWI = \frac{Green - NIR}{Green + NIR} \tag{3}$$

where *Green* represents the reflectance at the green band (corresponding to Band 3 of Sentinel-2), and *NIR* represents the reflectance at the near-infrared band (corresponding to Band 8 of Sentinel-2). Since the multispectral imagery obtained contained partially unmelted ice cover on the acquisition date, a mask was applied to the ice cover on the lake to ensure the accuracy of the study during the water column extraction process.

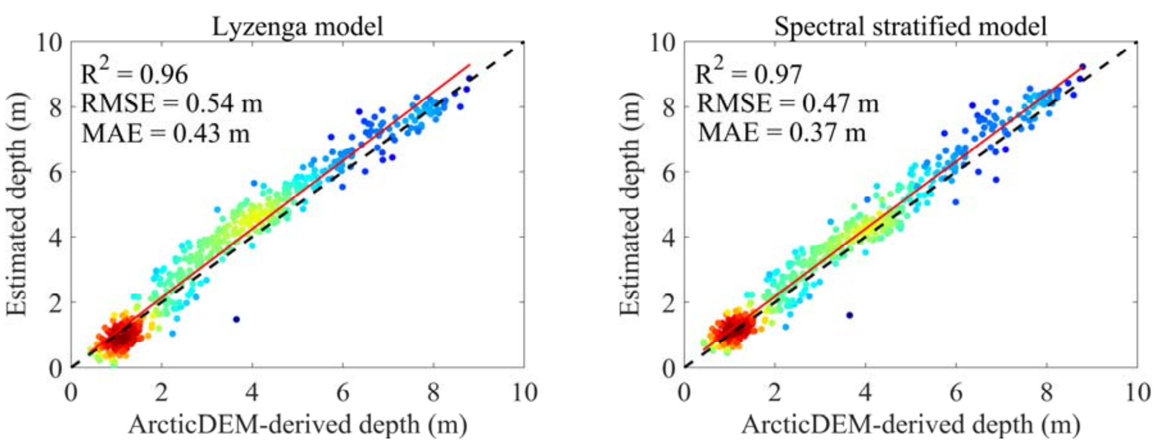
References

[1] McFeeters, S. K.: The use of the Normalized Difference Water Index (NDWI) in the delineation of open water features, International journal of remote sensing, 17, 1425-1432, http://doi.org/10.1080/01431169608948714, 1996.

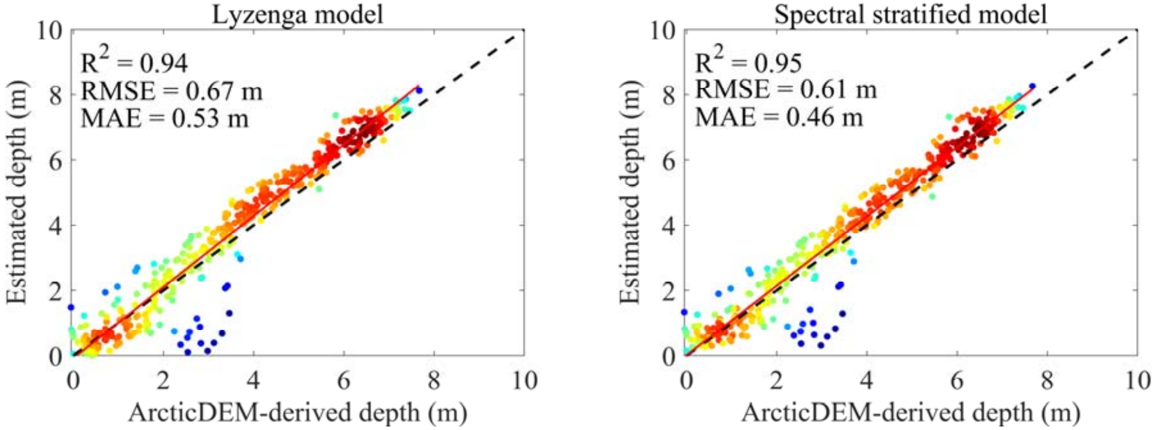
R1Q4: The validation focuses on RMSE and MAE, but lacks a more detailed visualization of residual distribution (e.g., error scatter or residual histograms). It is suggested to add one simple figure or a few lines of text to further illustrate the validation quality.

Major issues R1A4: Thank you very much for your insightful comments, which make this manuscript more rigorous. We have revised the manuscript to include a more comprehensive explanation in this part, the revised paragraph is as follows:

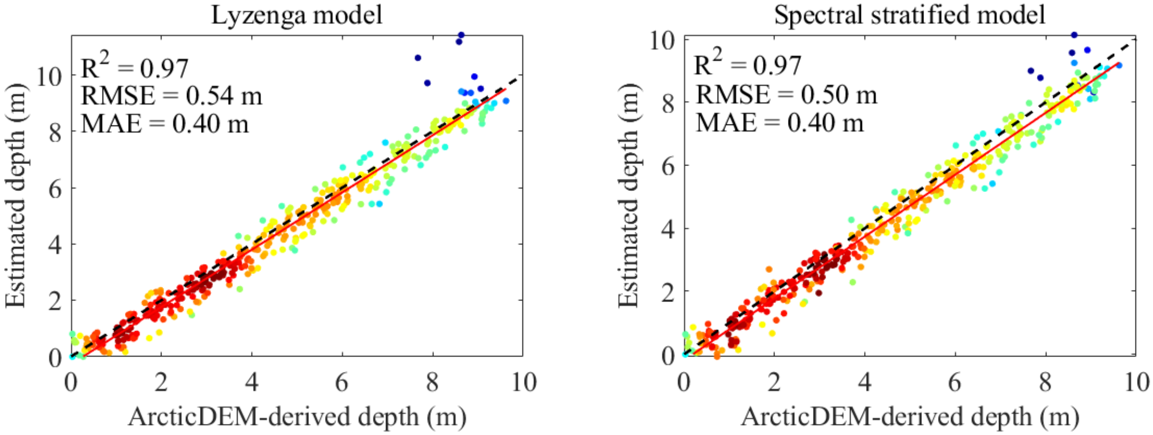
To quantitatively and visually demonstrate the performance of the method, the validation results of the SDB using the traditional Lyzenga model and the spectrally stratified Lyzenga model are presented in Figure 2.



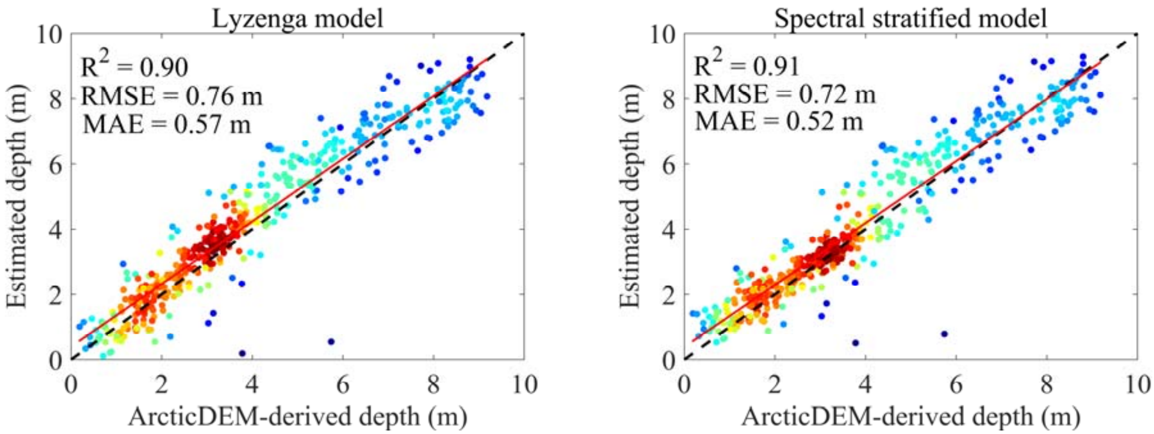
(a)


Lyzenga model
R2 = 0.94
RMSE = 0.67 m
MAE = 0.53 m
Estimated depth (m)
ArcticDEM-derived depth (m)
Spectral stratified model
R2 = 0.95
RMSE = 0.61 m
MAE = 0.46 m
Estimated depth (m)
ArcticDEM-derived depth (m)

(b)


Lyzenga model
R2 = 0.97
RMSE = 0.54 m
MAE = 0.40 m
Estimated depth (m)
ArcticDEM-derived depth (m)
Spectral stratified model
R2 = 0.97
RMSE = 0.50 m
MAE = 0.40 m
Estimated depth (m)
ArcticDEM-derived depth (m)

(c)


Lyzenga model
R2 = 0.90
RMSE = 0.76 m
MAE = 0.57 m
Estimated depth (m)
ArcticDEM-derived depth (m)
Spectral stratified model
R2 = 0.91
RMSE = 0.72 m
MAE = 0.52 m
Estimated depth (m)
ArcticDEM-derived depth (m)

(d)

Figure 2. Comparison of bathymetric inversion results using the Lyzenga model and spectral stratified Lyzenga model for four lakes. (a) Lake A bathymetry validation. (b) Lake B bathymetry validation. (c) Lake C bathymetry validation. (d) Lake D bathymetry validation. The point represents the ArcticDEM validation points, the black dashed line indicates the 1:1 line, and the red solid line represents the data fitting line.

To visually demonstrate the improvement in the bathymetric inversion accuracy achieved by the spectral stratification method, we selected Lake A as a case study to compare the traditional Lyzenga model with the spectral stratified Lyzenga model. Based on the bathymetric inversion results shown in Figure 3, the study examines the differences in depth inversion results between the two methods. In areas where relatively obvious discrepancies are observed, ArcticDEM data is used for accuracy validation, as illustrated in Figure 4.

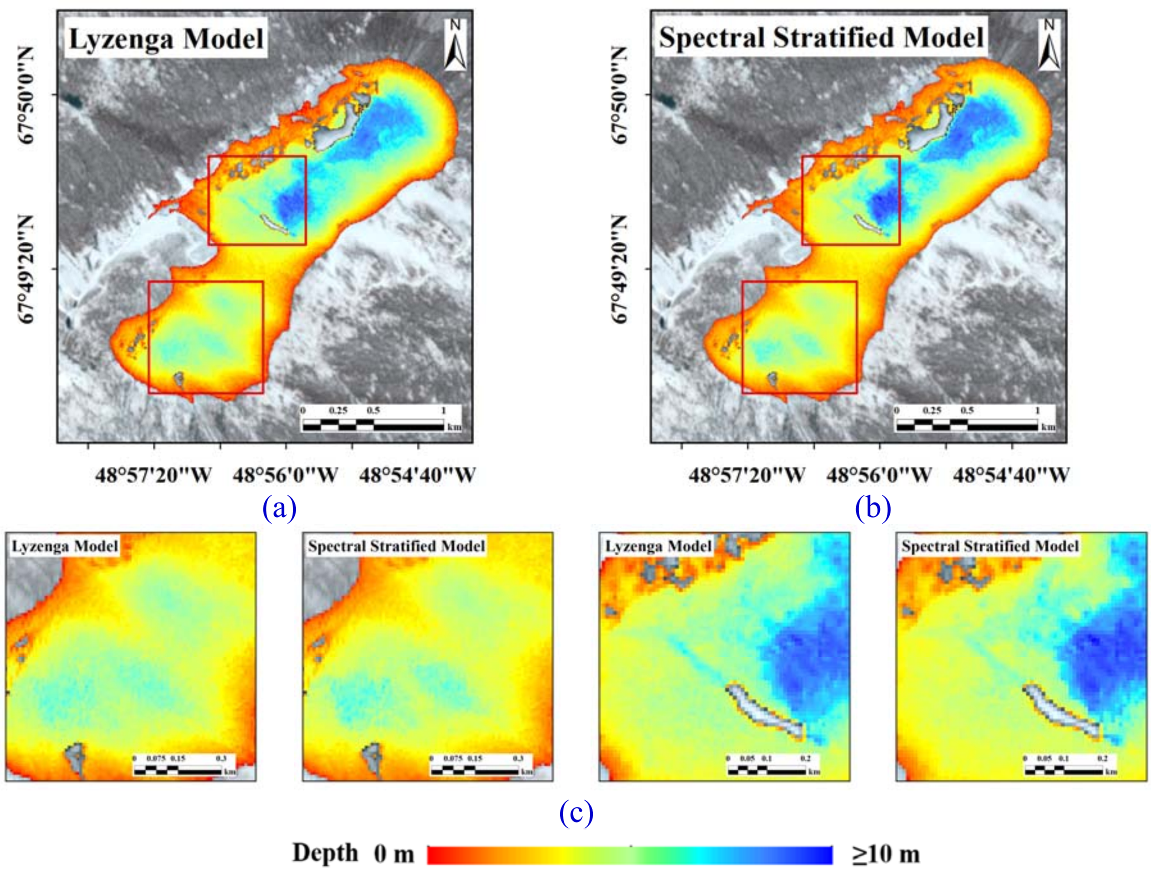


Figure 3. Comparison of the bathymetric maps using the Lyzenga model and the spectral stratified model with Lake A. (a) The depth inversion results derived from the Lyzenga model. (b) The depth inversion results are derived from the spectral stratified model. The red box highlights areas with relatively notable differences in depth inversion between the two models. (c) A detailed view of the water area within the red box.

A qualitative analysis of the bathymetric inversion results for Lake A indicates that the discrepancies between the Lyzenga model and the spectral stratified model are primarily concentrated in the 2-6 m range, with more pronounced differences at the transitions between different spectral layers.

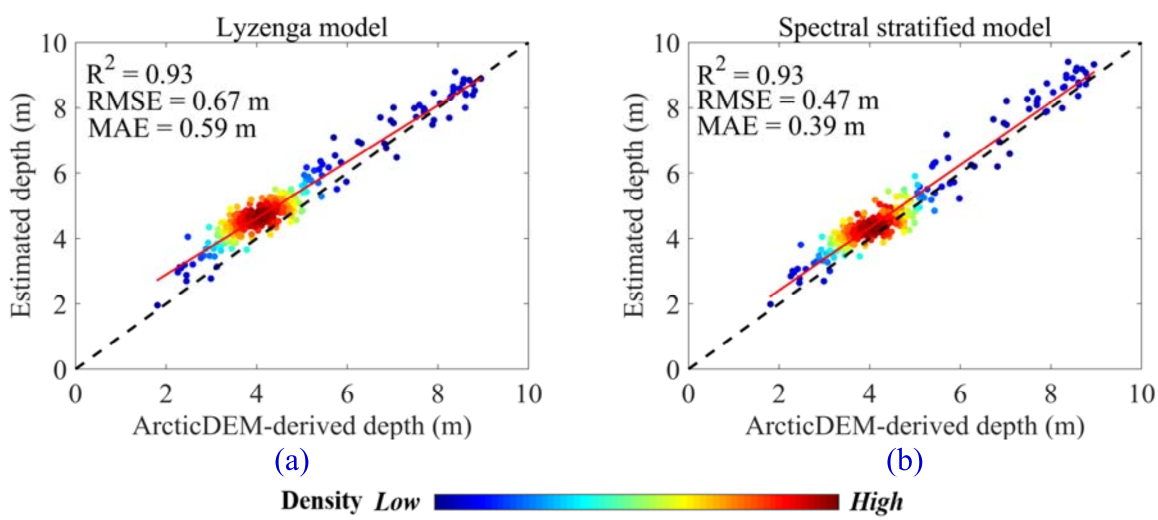


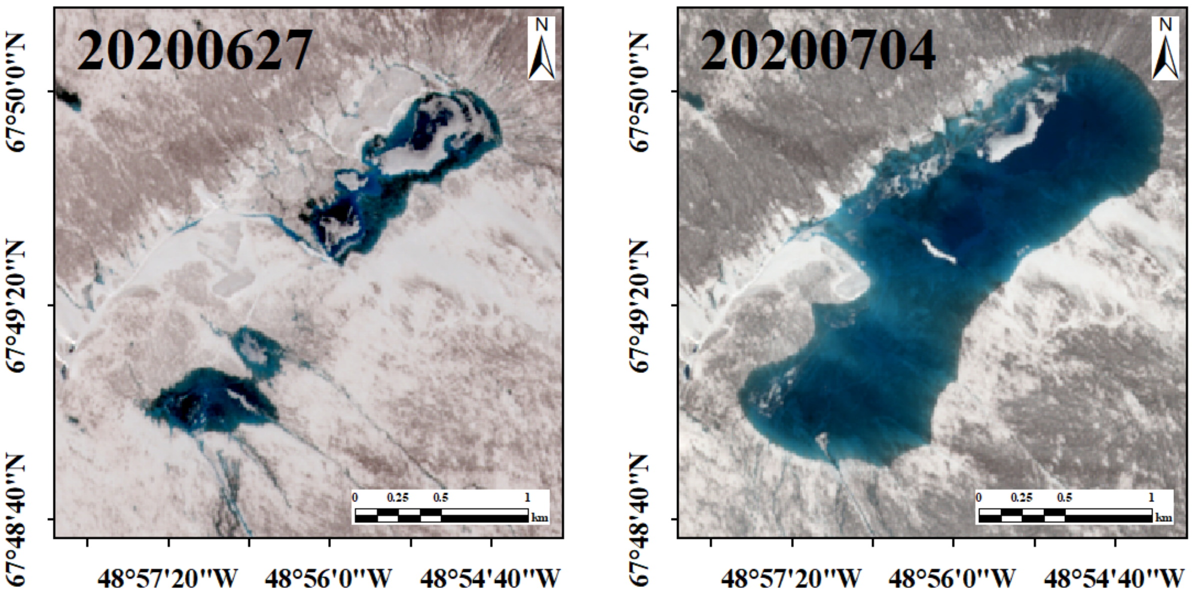
Figure 4. Comparison of accuracy using the ArcticDEM data with the Lyzenga model and the spectral stratified Lyzenga model of Lake A. (a) The Lyzenga model. (b) The spectral stratified model. The black dashed line indicates the 1:1 line, and the red solid line represents the data fitting line.

According to Figure 2, R^2 is relatively high, all of which could reach 0.9 or above, proving that the Lyzenga model is rational for application in these Arctic SGLs. Specifically, the RMSE of the bathymetry inversion for Lake A decreased from 0.54 m to 0.47 m, and the MAE decreased from 0.43 m to 0.37 m, with reductions of 13.0% and 14.0%, respectively. For Lake B, the RMSE and MAE of the spectral stratified bathymetry inversion accuracy values were 0.61 m and 0.46 m, respectively, with decreases of 9.0% and 13.2%. In the case of Lake C, the RMSE was reduced to 0.50 m, with reductions of 7.4%. For Lake D, the RMSE reduced to 0.72 m and MAE reduced to 0.52 m, which the RMSE decreased by 5.3% and MAE decreased by 8.8%. Validation results for the red box region of Lake A indicate that the spectral stratified method achieves higher accuracy than the traditional Lyzenga model too, with the RMSE reduced from 0.67 m to 0.47 m, a decrease of 29.9%, and the MAE reduced from 0.59 m to 0.39 m, a decrease of 33.9%, as shown in Figure 4. The validation results shown in Figures 2 and 4 indicate that the spectrally stratified bathymetry depth inversion model achieves higher accuracy across different depth ranges by taking into account the varying penetration capabilities of electromagnetic waves at different wavelengths. Taking Lake A as an example, and based on validation with ArcticDEM, the scatter plots clearly demonstrate that the spectrally stratified model outperforms the traditional Lyzenga model in terms of accuracy across various water depths. For the points with significant absolute errors in the validation results, this may be related to anomalies in pixel reflectance values caused by errors during the radiometric correction of the multispectral imagery data. The validation results further demonstrate the effectiveness of the spectral stratification method in improving bathymetric inversion accuracy. In summary, the experimental results demonstrate that the proposed spectral stratified model can comparatively improve the bathymetric accuracy for Arctic SGLs by the SDB method.

R1Q5: In the Discussion section, although the challenges and limitations are mentioned, the dynamic changes of supraglacial lakes are described relatively generally. It is suggested to slightly expand the discussion on how data acquisition timing affects inversion accuracy.

Major issues R1A5: We appreciate your suggestion, as it is a crucial point in the manuscript. The morphological changes of supraglacial lakes in Arctic regions occur rapidly, and training datasets from different dates can significantly affect the SDB results. This differs from the SDB methods that are widely used for ocean bathymetry. According to your valuable comment, we have modified the Discussion section, as follows:

The dynamic nature of Arctic SGLs, which undergo significant morphological changes over short periods, as shown in Figure 5, where the lake's morphology changed markedly within just 7 days, this poses a challenge for combining ICESat-2 and Sentinel-2 data in bathymetric inversion. Accurate results require close temporal synchronization of these datasets, which imposes higher demands on data acquisition and availability.



(a) (b)

Figure 5. Comparison of the morphology of Lake A on different dates: (a) Sentinel-2 image on June 27, 2020; (b) Sentinel-2 image on July 4, 2020.

Minor issues:

R1Q6: Minor grammatical and typographical errors exist in the manuscript. For example, “Figure. 1” should be “Figure 1” without a period

Minor issues R1A6: Thank you very much for this comment, which makes this manuscript more rigorous. We have revised the entire manuscript to correct similar instances.

R1Q7: In Section 3.1.2, the font of the section number "3.1.2" should be standardized to Times New Roman.

Minor issues R1A7: Thank you very much for this comment, which makes this manuscript more rigorous. We have thoroughly checked the entire manuscript to ensure that no such detail issues remain.

R1Q8: In line 283, results such as 9.46 $10^6 m^3$ should have a space between the number and the unit.

Minor issues R1A8: Thank you for your comment, which enhances the rigor of this manuscript. We have thoroughly revised the entire manuscript to address similar instances.

R1Q9: The date format in Table 1 should be clearly indicated as dd/mm/yyyy to avoid ambiguity.

Minor issues R1A9: Thank you very much for your suggestion, which makes this manuscript clearer. We have made corrections to the manuscript to ensure rigor and clarity before its publication.

R1Q10: The terms "spectral stratified model" and "spectral stratification model" in the text should be unified into a single expression.

Minor issues R1A10: Thank you very much for this comment, which makes this manuscript more rigorous. We have unified the usage of the “spectral stratified model” throughout the manuscript.

In this manuscript, the sections that need improvement have been highlighted in blue. Your comments and have greatly contributed to enhancing the quality of this manuscript. Thank you once again for taking the time to review it.

Best regards.