Thank you very much for taking the time to review this manuscript. I have responded to each of the issues raised by the two reviewers and have revised the manuscript.

Response to Reviewer 1 Comments

Comments 1- It is recommended to supplement the Summarize section or add a dedicated Discussion section. This section should include a more in-depth analysis of the reasons why the model performs well or fails under certain conditions, a discussion of the model's limitations (for example, its performance under significant terrain variations or extreme weather conditions not represented in the dataset), and a more balanced interpretation of the results in the context of existing literature.

Response: We sincerely thank the reviewer for this important and constructive suggestion. In response to your comment, we have added a dedicated Section 4 Discussion to provide a more in-depth analysis of the reasons behind the model's performance under different conditions, its potential failure cases, and its proper positioning within the context of existing studies. In the revised Discussion, we analyze at the mechanism level why the proposed model achieves strong performance in ice type recognition, ice region segmentation, and ice thickness estimation, with particular emphasis on the roles of multi-branch feature decomposition, multi-scale attention mechanisms, and the collaborative modeling of geometric and meteorological constraints in improving both discriminative ability and physical consistency. Meanwhile, we explicitly supplement the main limitations of the current work, noting that the existing dataset does not yet cover extreme weather conditions such as strong convection and freezing rain combined with high winds, nor does it systematically represent complex terrains with significant topographical variations; therefore, the model's generalization capability under extreme meteorological and complex terrain conditions still requires further validation. In addition, the revised manuscript strengthens the comparison and connection with existing literature, providing a more balanced and objective interpretation of the results from the perspectives of background sensitivity, weak-boundary segmentation robustness, and meteorology-driven icing processes.

Specific modifications are as follows: **(Page 23-25)**

4 Discussion

4 Discussion

The dual-task learning framework, DTL-IceNet, proposed in this study demonstrates high reliability in both ice type recognition and thickness detection tasks. Its main contribution lies in the unified modeling of three types of information: type, geometry, and meteorology, which effectively enhances the comprehensive sensing ability of icing conditions on transmission lines. This fusion-based design aligns with the view emphasized in the literature that "ice physics, image features, and environmental processes must be considered in a coordinated manner" (Fan et al., 2018; Hao et al., 2023; Chen et al., 2024; Dong et al., 2022; Meng et al., 2025; Han et al., 2024), and it achieves both discriminative ability and physical consistency in typical monitoring scenarios, leading to significant improvements over existing methods.

In the ice type recognition task, the model explicitly separates the background, conductor, and icing regions through a multi-branch feature extraction structure. Studies by Fan et al. (2018). and Hao et al. (2023) have pointed out that ice recognition is highly sensitive to the environmental background, and deep networks based on a single-path feature extraction often struggle to fully capture the local texture of the conductor in complex backgrounds. The decomposition-based modeling approach of DTL-IceNet significantly enhances the distinction between different types of icing under complex lighting, fog, and noise conditions, providing stronger anti-interference ability compared to single-branch methods.

In the ice region segmentation task, MOMSA-SegNet leverages a multi-scale attention module to improve the representation capability of thin conductors and irregularly shaped icing areas. Existing research has shown that traditional edge detection or low-level feature methods exhibit poor robustness in weak boundaries, low contrast, and nighttime scenarios (Han et al., 2024; Tan & Le, 2019; Hu et al., 2018; Vasu et al., 2023; Li et al., 2016). In contrast, the multi-scale attention mechanism effectively utilizes the contextual structure surrounding the transmission line, allowing the model to maintain stable geometric contour predictions in typical scenes such as sunny, foggy, and nighttime conditions. Its accuracy advantage stems from the targeted utilization of the transmission line image structure rather than relying solely on the depth of the network or the scale of parameters.

For ice thickness estimation, the improvement in model performance is mainly attributed to the synergistic effect of geometric and meteorological constraints. The image geometric information provides the basic trend of ice volume changes, but relying solely on 2D images cannot accurately reflect the true 3D shape of the ice, leading to systematic biases during temperature, humidity, wind speed, and precipitation phases. By introducing the meteorological correction term based on environmental factors, the model performs consistent corrections on the initial thickness estimation according to the basic physical laws of ice growth and melting, effectively compensating for the inherent structural biases in the geometric estimation. Experimental results show that the thickness curves align more closely with the actual distribution across multiple phases, indicating the complementary role of geometric and meteorological information in thickness estimation.

Although DTL-IceNet demonstrates robustness under typical monitoring conditions, its applicability is still limited by the data coverage and experimental conditions. The data used in this study were primarily collected in typical meteorological scenarios and have not yet covered extreme weather conditions such as severe convection or freezing rain coupled with strong winds. Under such conditions, the signal-to-noise ratio of images and the rate of ice morphology change may exceed the training distribution, and the model's robustness needs further validation. Moreover, the current experimental data do not systematically reflect complex spatial environments with significant topographic variations. Existing studies have shown that terrain, especially in valley wind fields, significantly impacts icing distribution, so the model's performance in complex terrain scenarios remains uncertain.

Comments 2- The manuscript presents two distinct results: (1) MOMSA-SegNet achieves the highest segmentation mIoU, and (2) the overall framework reports a thickness MAPE of 11.82%. To clarify the relationship between these two findings, additional controlled experiments would be helpful. In particular, demonstrating that, under the same test set and using the same thickness estimation procedure, the proposed segmentation model yields a consistently lower thickness estimation error compared with the other segmentation models discussed in the paper would provide more direct evidence of its contribution. Without such comparisons, the extent to which the segmentation module influences the final estimation accuracy remains uncertain.

Response: We sincerely thank the reviewer for this targeted and insightful comment. In response to your concern that the independent presentation of segmentation accuracy and final thickness accuracy is insufficient to directly demonstrate the actual contribution of the front-end segmentation module to thickness estimation, we have added a new Section 3.5.2, entitled "Effect of Different Segmentation Models on Ice Thickness Detection," and included Table 5 in the revised manuscript. This new experiment systematically compares the impacts of UNet++, SegNet, DySample, and the proposed MOMSA-SegNet on thickness estimation accuracy under the same observation-site dataset and identical ice-type recognition and meteorological correction processes. The results indicate that, under fully consistent thickness calculation and meteorological correction procedures, better segmentation performance leads to lower MAPE and MSE for both the initial and optimized thickness estimates, and MOMSA-SegNet achieves the lowest errors in both cases. Moreover, even after introducing meteorological correction, the error differences among different segmentation models remain evident, indicating that geometric structural biases caused by segmentation errors cannot be completely eliminated by meteorological correction alone. These findings directly verify, under a unified experimental framework and dataset, the substantial influence of the segmentation module on the final thickness estimation accuracy and clearly demonstrate the fundamental and irreplaceable role of segmentation quality in thickness estimation. We sincerely appreciate your professional guidance and valuable suggestions, which have significantly strengthened the rigor and completeness of this work.

Specific modifications are as follows: **(Page 21-22)**

3.5.2 Effect of Different Segmentation Models on Ice Thickness Detection

3.5.2 Effect of Different Segmentation Models on Ice Thickness Detection

To quantitatively evaluate the impact of the segmentation module on the accuracy of final ice thickness estimation, this study, under the premise of maintaining consistency in the ice type recognition and thickness optimization calculation processes, uses UNet++, SegNet, DySample, and MOMSA-SegNet as the frontend segmentation models. The thickness estimation experiments were conducted on the same observation field test dataset. The ice type recognition module and thickness optimization calculation module were kept unchanged, and only the ice segmentation submodule was replaced with different typical methods. The initial thickness and optimized thickness errors were then computed on the corresponding observation field thickness test data. This approach allows a direct comparison of the effects of different segmentation models on geometric scale calculation and error propagation within a unified framework, providing a clearer insight into the structural relationship between segmentation quality and thickness detection accuracy. The experimental results are shown in Table 5.

Table 5. Comparison of ice thickness detection performance driven by different segmentation models

Modules	Initial ice thickness MAPE(%)	Optimized ice thickness MAPE(%)	Initial ice thickness MSE	Optimized ice thickness MSE
UNet++	69.53	14.58	80.93	2.26
SegNet	65.38	13.71	76.09	2.12
DySample	57.45	12.05	66.86	1.87
MOMSA-SegNet(Ours)	**56.36**	**11.82**	**65.60**	**1.83**

As seen in Table 5, under the same ice type recognition and meteorological correction processes, the performance of ice thickness detection shows a consistent trend with different segmentation models as frontend submodules. The better the segmentation performance, the lower the initial and optimized thickness errors. When MOMSA-SegNet, the segmentation model proposed in this paper, is used, both the MAPE and MSE of the initial thickness are the lowest. After replacing it with UNet++, SegNet, or DySample, both errors increase to varying degrees. This indicates that the segmentation stage directly affects the accuracy of the ice contour and area depiction, which in turn influences the downstream geometric parameter estimation. Segmentation errors accumulate and amplify in the calculation of equivalent ice thickness.

A further comparison of the initial and optimized thickness metrics reveals that after the introduction of meteorological correction, the MAPE and MSE for all models significantly decrease, showing that the environmental-driven correction terms can effectively compensate for the system errors caused by the 2D perspective and geometric simplifications. However, the relative differences between the models still remain even after optimization. Even with meteorological correction, the thickness estimation based on MOMSA-SegNet maintains the lowest MAPE and MSE, while segmentation models with weaker performance still exhibit higher optimization errors. This suggests that the meteorological correction mainly targets global system biases related to environmental processes, and cannot fully counteract the structural errors in the ice region contour and scale caused by segmentation. Thus, it can be concluded that segmentation quality determines the geometric baseline for thickness estimation, while meteorological correction fine-tunes this baseline, forming a hierarchical complementary relationship.

In conclusion, under the condition of complete consistency in the thickness estimation algorithm and test dataset, simply replacing the segmentation module results in a monotonous or nearly monotonous decrease in thickness errors with the improvement of segmentation model performance. This result confirms the substantial contribution of MOMSA-SegNet in ice thickness detection from a data-driven perspective. Its higher segmentation accuracy not only reflects in pixel-level metrics but also significantly reduces the initial errors in downstream thickness estimation, maintaining its advantage even after meteorological correction and effectively transmitting the improved segmentation performance to the final physical quantity estimation results.

Comments 3- Regarding environmental conditions, although the segmentation component includes descriptions of performance under different weather scenarios, the influence of these varying conditions on the final thickness estimation results is not examined. Expanding the Discussion section to include an evaluation of thickness estimation performance across different weather conditions would help provide a more complete understanding of the method’s behavior.

Response: We sincerely thank the reviewer for the constructive suggestions regarding the related work. In response to your comment, we have added a specific analysis in Section 4 Discussion on the potential influence of different meteorological conditions on thickness estimation. We clearly state that, due to the practical limitations of the observation site, the current thickness validation experiments only include real thickness calibration data under daytime clear-sky conditions, and thus a direct quantitative comparison of thickness errors under multiple weather conditions is not yet available. On this basis, combined with the segmentation results and the physical mechanism of icing formation, we systematically analyze at the mechanism level two main pathways through which weather factors may affect thickness estimation: on the one hand, imaging degradations such as heavy fog and low illumination weaken the clarity of the ice–conductor boundaries, thereby influencing the geometrically derived initial thickness through segmentation errors; on the other hand, meteorological variables such as temperature, humidity, and wind speed strongly drive the growth and ablation of icing and introduce systematic corrections to thickness estimation through the meteorological correction module. We also objectively point out that under severe imaging degradation, meteorological correction cannot completely offset the amplification of geometric errors, and therefore the thickness estimation accuracy under real complex weather conditions still requires further investigation. Once again, we sincerely appreciate the reviewer’s valuable comments, which have played an important role in improving the completeness and rigor of this work.

Specific modifications are as follows: **(Page 24-25)**

4 Discussion

While the segmentation experiments presented in this study systematically show performance differences under various imaging conditions such as sunny days, fog, and nighttime, the thickness validation experiments were limited by the actual conditions of the observation field, which only included real thickness calibration data from sunny scenarios and could not directly quantify thickness estimation accuracy under various weather conditions. To address this logical gap, we will further analyze the potential impact of weather factors on thickness estimation. Mechanistically, weather changes affect thickness results mainly through two paths. First, imaging degradation such as fog and low light reduces the clarity of the ice and conductor boundaries, causing segmentation masks to deviate in geometric details and directly affecting the preliminary thickness calculation based on area and contour inference. Second, meteorological variables such as temperature, humidity, and wind speed determine the growth and melting rates of the ice, strongly driving the temporal evolution of thickness. The meteorological correction module of DTL-IceNet can provide systematic corrections based on this driving pattern, but it cannot completely compensate for geometric deviations caused by severe imaging degradation. Therefore, under real fog or nighttime conditions, the initial thickness errors may increase, while the optimized thickness is expected to show more stable but still limited corrections.

Comments 4- The manuscript claims to propose a comprehensive “dual-view” solution. While the approach of collecting real thickness data in controlled field experiments is understandable and commendable, the current experimental setup does not sufficiently validate the core contribution of the method, and instead highlights certain limitations. Specifically, the final performance evaluation is conducted on a restricted, single-view version of the system. This creates a substantial mismatch between the claimed capabilities and the empirical validation. We note that the authors provide “site conditions” as a rationale for this choice. However, this results in the core claim of the method—that leveraging multi-view structures from a single image enhances information capture—remaining unverified in thickness estimation experiments. By effectively omitting the higher-error components during validation, a critical question arises: does the reported thickness accuracy truly reflect the capability of the complete main-view and side-view system, or does it primarily represent performance in a simplified main-view scenario, which conveniently avoids the error propagation associated with the less accurate side-view segmentation?

Response: We sincerely thank the reviewer for the valuable comments and suggestions regarding the proposed “dual-view” framework. We fully understand and agree with the core concern you raised. Due to the fact that the current experimental conditions only provide real data from the main-view camera, and no true side-view data are available at present, the icing cross-section is assumed to be circular in our simulations; therefore, the side-view thickness is set equal to the main-view thickness for the purpose of calculation. In response to your comment, we have added a dedicated discussion in Section 4 to explicitly clarify and reflect on the experimental validation boundary of the dual-view scheme. We clearly state that, constrained by the observation-site layout and transmission line installation conditions, the current thickness validation experiments do not yet include transmission lines with real side-view imaging, and the thickness estimation therefore relies on a simplified geometry dominated by the main-view assumption. As a consequence, the reported thickness accuracy primarily reflects the performance under a single-view scenario rather than the theoretical upper bound of the complete dual-view structure. We also objectively point out that the error propagation effect introduced by side-view segmentation has not yet been quantitatively evaluated, which constitutes an important limitation of the current engineering validation. Nevertheless, the existing results still verify the feasibility and effectiveness of the proposed geometry–meteorology fusion framework through the main-view pathway and provide a solid foundation for further validation of the dual-view structure in more complex scenarios. We have accordingly identified the complete experimental validation of the dual-view scheme as a major direction for future work and plan to construct a real multi-view acquisition platform to systematically evaluate the performance gain of multi-view geometric constraints and the associated error propagation mechanisms in thickness estimation.

Specific modifications are as follows: **(Page 25)**

4 Discussion

The dual-perspective approach proposed in this study is one of the key innovations of the overall framework. Through joint segmentation of the main and side perspectives, the major and minor axes of the ice-covered cross-section can be theoretically estimated, improving the certainty of geometric parameters. However, it is important to note that the thickness validation experiment in this paper was limited by site constraints and did not actually deploy transmission lines for real side-perspective imaging. Thickness detection relied on a simplified geometric assumption primarily based on the main perspective. This experimental condition means that the final obtained thickness accuracy mainly reflects the performance under the simplified single-perspective system rather than the upper limit of a complete dual-perspective structure. Therefore, while the current results prove the feasibility and potential value of the proposed framework, they do not fully validate the information gain of the dual-perspective structure in real multi-conductor scenarios. This also suggests that the side-perspective segmentation error's impact on thickness calculation has not been fully quantified. Future work will focus on building an experimental platform that truly reflects the dual-perspective structure to systematically evaluate error propagation mechanisms and further optimize geometric fusion methods.

Comments 5- On the other hand, achieving strong final results does not, by itself, validate the correctness or effectiveness of the front-end image segmentation plus area ratio approach. It primarily demonstrates the strength of the back-end correction module. Only with supplementary ablation experiments can it be convincingly shown that meteorological data and image information are complementary and both necessary, thereby substantiating the true value of the fusion framework.

Response: We sincerely appreciate the reviewer's careful and insightful comments. We fully agree with your concern that strong final thickness estimation results alone are insufficient to validate the effectiveness of the front-end image segmentation and area-ratio-based geometric modeling, nor are they adequate to demonstrate the complementarity and necessity of meteorological and image information within the fusion framework. In response to this important comment, we have added a new Section 3.5.3, entitled "Ablation Experiment on Multi-Source Input Data," in the revised manuscript. Under strictly consistent settings of dataset, thickness calibration, and evaluation metrics, we systematically constructed and compared three thickness estimation modes: an image-only mode based solely on geometric information, a meteo-only mode relying exclusively on meteorological variables, and the proposed fusion mode (DTL-IceNet) integrating both image and meteorological information. The experimental results show that neither the image-only nor the meteo-only mode can achieve high-accuracy thickness estimation, whereas the fusion mode significantly outperforms both single-modality configurations in terms of MAPE, PCC, and MSE. These results directly verify the clear complementarity between image geometric information and meteorological process information in icing thickness estimation and confirm that both are indispensable sources of information. Moreover, this ablation study quantitatively distinguishes the independent contributions of the front-end geometric pathway and the back-end meteorological correction pathway within the overall framework, thereby avoiding the misleading conclusion that the final performance is dominated solely by the back-end correction module.

Specific modifications are as follows: **(Page 22-23)**

3.5.3 Ablation Experiment on Multi-Source Input Data

3.5.3 Ablation Experiment on Multi-Source Input Data

To systematically assess the independent contributions and complementary relationship between image geometric information and meteorological factors in ice thickness estimation, this study conducted an ablation experiment based on the observation field thickness test data. Under the premise of maintaining consistent datasets, thickness calibration methods, and evaluation metrics, three different information configurations were constructed. The first configuration retained only the thickness estimation derived from the segmentation results and area ratio geometric relationship, aiming to measure the independent capability of the image geometric path; the second configuration relied solely on meteorological features such as temperature, humidity, wind speed, and precipitation to directly fit ice thickness using a regression model, evaluating the prediction potential of environmental driving factors without image data; the third configuration introduced the meteorological correction term based on geometric thickness, which is the complete fusion mode of DTL-IceNet proposed in this paper, used to test the practical benefits of the synergistic effects between the two information sources. The comparison results of the three configurations are shown in Table 6.

Table 6. Comparison of ablation experimental results based on source input data

Model Configuration	Image geometry	meteorological elements	MAPE(%)	PCC	MSE
Image-only	Yes	No	58.51	0.96	69.70
Meteo-only	No	Yes	39.88	0.90	30.26
DTL-IceNet(Ours)	**Yes**	**Yes**	**13.16**	**0.98**	**2.54**

As seen in Table 6, the three input configurations exhibit clear hierarchical differences in thickness estimation accuracy, reflecting the complementary nature of image geometry and meteorological factors in terms of information structure. In the Image-only mode, the PCC reaches 0.96, indicating that the geometric thickness derived from the segmentation results and area ratio relationship can well capture the trend of ice variation over time. However, due to the scale uncertainty introduced by single-view imaging, the amplification effect of segmentation errors on area estimation, and the simplification of cross-sectional morphology, the magnitude deviation is still significant, with MAPE reaching 58.51% and MSE reaching 69.70, which reflects the inherent limitations of the geometric path in the absence of environmental process constraints. In the Meteo-only mode, the thickness estimation, relying on the phase changes of meteorological conditions, partially captures the growth and melting rhythm of the ice layer, so the PCC remains at a reasonable level of 0.90. However, due to the lack of spatial volume information, this mode struggles to differentiate between absolute thickness differences, exhibiting characteristics of large magnitude errors and significant fluctuations. These results indicate that meteorological factors alone cannot provide precise thickness information, especially in scenarios with small-scale changes and significant spatial heterogeneity.

In contrast, DTL-IceNet uses geometric thickness as a spatial scale constraint and employs meteorological features to fit the systemic offset driven by environmental factors, significantly suppressing errors in both trend and magnitude. The fusion mode's MAPE decreases significantly to 13.16%, MSE reduces to 2.54, and PCC increases to 0.98. This demonstrates that the structured information provided by the geometric path and the phased features captured by the meteorological path are highly complementary in mechanism, with the former determining the spatial baseline for estimation and the latter correcting the deviations caused by changes in meteorological conditions. As the ice formation process involves both geometric morphological evolution and meteorological-driven characteristics, both types of information are indispensable. Therefore, a single modality struggles to achieve high accuracy in thickness prediction, while the fusion mode can fully leverage the advantages of both types of information, reflecting a dual enhancement in robustness and physical consistency.

Comments 6- Minor comments:

Line 141 and Fig9 “glaz”->”glaze”; Table 1 Consider rephrase the table title; Fig13 Consider rephrase the figure title.

Response: We sincerely thank the reviewer for the careful and detailed review of our manuscript. In response to the issues you pointed out, we have made the following revisions: all occurrences of “glaz” in the manuscript have been consistently corrected to “glaze”; the title of Table 1 has been revised to “Comparison of icing type recognition performance of various recognition models”; and the title of Figure 13 has been refined with a detailed description for each subfigure. In addition, we have carefully reviewed the entire manuscript and corrected other minor issues accordingly. For brevity, these detailed modifications are not listed one by one in this response.

Specific modifications are as follows:

Table 1 **(Page 17)**

Table 1. Comparison of icing type recognition performance of various recognition models

Modules	Accuracy(%)	W-Prec(%)	W-Recall(%)	W-F1	M-Prec(%)	M-Recall(%)	M-F1
EfficientNet-V2	86.87	87.65	86.87	86.57	84.71	84.41	82.57
MobileNet-V3	90.93	90.86	90.93	89.67	87.13	85.55	84.42
ResNeXt	93.02	93.83	93.02	92.80	90.10	90.69	90.05
MobileOne	93.41	94.26	93.41	93.21	91.21	90.71	89.27
ResSepNet(Ours)	**95.23**	**96.44**	**95.23**	**94.84**	**92.84**	**91.84**	**90.84**

Figure 13 **(Page 18)**

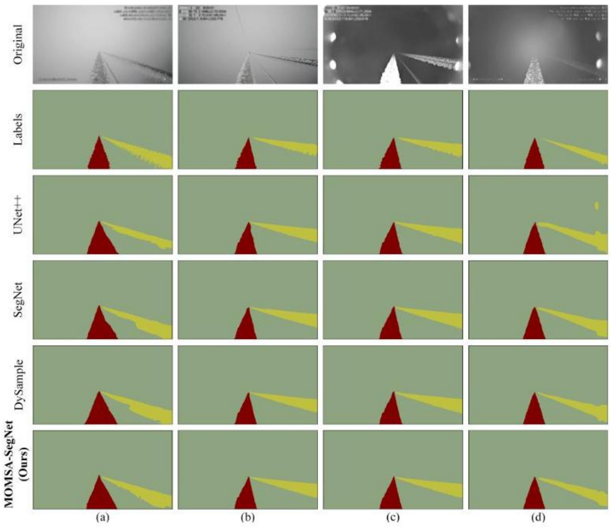

Figure 13. Comparison of segmentation performance across different models. (a) Segmentation result under daytime conditions (first image), (b) Segmentation result under daytime conditions (second image), (c) Segmentation result under nighttime conditions (first image), and (d) Segmentation result under nighttime conditions (second image).