# Reply on RC1

**General comments**

This study makes an innovative and practically valuable contribution by providing a national-scale mangrove sub-canopy topography dataset for New Zealand. The integration of ICESat-2 and multi-source remote sensing data improves our understanding of terrain elevations beneath vegetation and their relationship with water levels in coastal environments. The reported results demonstrate high reliability and clear improvements over existing DEM products, supporting the dataset's value for coastal and ecological applications. Overall, I support publication and recommend acceptance subject to technical corrections. My comments and suggestions address the following four points:

**Reply:** We sincerely thank you for your highly positive evaluation and constructive comments on our manuscript "RFDTM: A national-scale and wall-to-wall 30 m mangrove sub-canopy topography dataset for New Zealand derived from ICESat-2, SAR and Sentinel-2". We deeply appreciate your recognition of the novelty, reliability, and practical value of our dataset. Your detailed suggestions regarding the Sentinel-2 product level and B10 band, the clear distinction of accuracy attribution, the clarification of spatial coverage and validation extent, and the expansion of potential applications are incredibly valuable. Incorporating your feedback has significantly enhanced the clarity, accuracy, and rigor of our manuscript.

Below, we provide a point-by-point response to your comments. For your convenience, our direct responses are formatted in blue text, while the specific new content incorporated into the revised manuscript is presented in blue italics.

**Comment 1:**

Section 2.2.3 describes Sentinel-2 Level-2A products, whereas B10 is included among the predictors. Since the standard Level-2A product does not contain B10, please specify the Sentinel-2 product level actually used and confirm whether B10 was obtained from Level-1C data.

**Reply 1:**

Thank you for pointing out this critical detail regarding the Sentinel-2 data product. We fully agree that clearly specifying the data level is essential for methodological reproducibility and transparency. We confirm that the B10 band (cirrus band) was indeed used in this study. Because the standard Sentinel-2 Level-2A product does not include this band, we actually utilized the Sentinel-2 Level-1C top-of-atmosphere (TOA) reflectance imagery, which natively contains B10. To eliminate any confusion for readers, we have explicitly clarified the specific product level used and the source of the B10 band in the revised manuscript, along with details on the acquisition year (2020) and spatial resolution (60 m).

**Modifications in the revised manuscript (Section 2.2.4):**

*Section 2.2.4：Sentinel-2's Multispectral Instrument (MSI) captures 13 spectral bands at native spatial resolutions of 10–60 m (Li et al., 2025). In this study, Sentinel-2 Level-1C top-of-atmosphere (TOA) reflectance imagery acquired in 2020 was used, including the cirrus band B10 at a native spatial resolution of 60 m.*

**Comment 2:**

Please clearly distinguish the centimetre-level accuracy reported by Ming et al. (2025) from the validation results of RFDTM. In Section 5.3, the sentence uses RFDTM as its subject while reporting an RMSE below 7.5 cm and $R^2$ greater than 0.89, which correspond to the cited study. Please revise the wording to attribute these values appropriately and avoid confusion with RFDTM's reported RMSE of 1.01 m.

**Reply 2:**

Thank you for your astute observation. We completely understand that when comparing different studies, clearly defining the attribution of accuracy metrics is crucial to prevent misleading the readers. In the original manuscript, the subject in the text was somewhat ambiguous, which could easily cause the centimeter-level accuracy (RMSE < 7.5 cm) of Ming et al. (2025) to be confused with the actual accuracy of our RFDTM dataset (RMSE = 1.01 m).

To resolve this, we have carefully rewritten the paragraph to explicitly attribute the centimeter-level metrics solely to Ming et al. (2025), and subsequently and separately stated the true validation results of RFDTM within the airborne LiDAR domain, thereby thoroughly eliminating any potential confusion.

**Modifications in the revised manuscript (Section 5.4):**

*Section 2.2.4： The potential advantages of RFDTM are significant and wide-ranging, making it a valuable tool for both scientific research and practical applications. One of its key strengths is its ability to produce highly accurate terrain models, even in complex environments such as mangrove-dominated coastal zones, where traditional DEMs often struggle (Yao et al., 2024). Previous research has demonstrated the potential of satellite-derived elevation data for mangrove applications. For example, Ming et al. (2025) reported an RMSE not exceeding 7.5 cm and an $R^2$ greater than 0.89 for mangrove tidal-flat elevation estimates derived from ICESat-2 and Sentinel-2 observations and evaluated against airborne LiDAR. These accuracy metrics refer specifically to their study. In the present study, RFDTM achieved an RMSE of 1.01 m, an $R^2$ of 0.99, an MAE of 0.80 m, and a bias of 0.43 m within the airborne LiDAR validation area. These results indicate its potential to provide terrain information for regional ecological monitoring, hydrological modeling, and carbon stock assessments, subject to application-specific accuracy requirements. Its 30 m spatial resolution can also support regional habitat mapping and analyses of relationships between terrain conditions and mangrove distribution.*

**Comment 3:**

Please clarify the spatial coverage of RFDTM and the extent of the airborne LiDAR validation. Section 2.1 mentions a mangrove area of approximately 2–9 km² within the selected regions, while Section 2.2.6 specifically describes the Northland LiDAR dataset. Please explain how these areas relate to the national-scale product and ensure that the abstract's description of validation coverage is consistent with the actual extent evaluated.

**Reply 3:**

Thank you for your careful review and for highlighting the need to clarify the spatial scales. We agree that it is highly necessary to distinguish between the spatial coverage of the generated dataset and the spatial extent of the validation. While the RFDTM product is designed at a national scale (covering all mapped mangroves in New Zealand), the airborne LiDAR reference data available for this study period was limited to the Northland region (New Zealand's mangroves are exclusively located in the northern North Island). Therefore, our accuracy assessment was restricted to the overlapping areas. To avoid any misunderstanding regarding the validation extent, we have thoroughly revised the relevant sections to explain this relationship and ensured that the descriptions in the abstract and conclusion strictly align with the actual physical domain evaluated.

**Modifications in the revised manuscript (Section 2.2.7 and Section 7):**

*Section 2.2.7 ： 2.2.7 Airborne LiDAR DEM data*

*To validate the derived terrain parameters, high-resolution airborne LiDAR elevation data were obtained from the open data service of Land Information New Zealand. The Northland LiDAR 1 m DEM dataset was used as reference terrain data, and the datasets acquired between December 2018 and February 2020 were selected for analysis. New Zealand's mangroves are confined to the northern part of the North Island, with no naturally occurring mangroves on the South Island. RFDTM covers the mapped mangrove extent nationwide. However, owing to the limited spatial coverage of airborne LiDAR reference data available for the study period, accuracy assessment was restricted to overlapping mangrove areas in Northland, representing a subset of the national mangrove extent. The DEM was derived from airborne laser scanning observations collected using the Leica TerrainMapper-LN system, with an average point density of ~4 points $m^{-2}$ and a reported vertical accuracy of approximately 0.2 m. Elevations referenced to NZVD2016 were converted to EGM2008 to ensure consistency with ICESat-2 observations. The data are available at https://data.linz.govt.nz/data/.*

*Section 7： Conclusion*

*To address the persistent lack of accurate and spatially continuous sub-canopy terrain information in mangrove ecosystems, this study produced RFDTM, the first national-scale 30*

*m mangrove sub-canopy topography dataset for New Zealand generated entirely from publicly available satellite observations. By integrating ICESat-2-derived ground elevations with SAR, optical, and ancillary satellite-derived features, RFDTM provides spatially continuous terrain estimates across New Zealand's mapped mangrove extent. Owing to the limited spatial coverage of airborne LiDAR reference data available for the study period, accuracy assessment was restricted to overlapping mangrove areas in Northland. Within this validation domain, RFDTM achieved an $R^2$ of 0.99, an RMSE of 1.01 m, an MAE of 0.80 m, and a bias of 0.43 m. These results support the potential of the proposed framework for national-scale mangrove terrain mapping.*

**Comment 4:**

I suggest expanding the discussion of the dataset's potential applications, with a few concrete examples such as coastal inundation modelling, mangrove habitat assessment, restoration planning, and blue-carbon research. Briefly explaining how sub-canopy topography could support these applications would help readers better appreciate the practical value of RFDTM and encourage its wider use.

**Reply 4:**

Thank you for this highly forward-looking and constructive suggestion. We completely agree that detailing specific application scenarios will greatly enhance readers' appreciation of RFDTM's practical value. To address this, we have significantly expanded the Discussion section by incorporating recent literature and providing concrete examples of how sub-canopy topography supports coastal inundation modeling, habitat assessment, ecological restoration planning, and blue-carbon research. We further elaborated on how integrating these high-precision terrain data with local hydrological observations can meet application-specific accuracy requirements, thereby providing clear guidance for the broader adoption and practical utilization of the dataset.

**Modifications in the revised manuscript (Section 5.4):**

*Section 5.4：The potential advantages of RFDTM are significant and wide-ranging, making it a valuable tool for both scientific research and practical applications. One of its key strengths is its ability to produce highly accurate terrain models, even in complex environments such as mangrove-dominated coastal zones, where traditional DEMs often struggle (Yao et al., 2024). Previous research has demonstrated the potential of satellite-derived elevation data for mangrove applications. For example, Ming et al. (2025) reported an RMSE not exceeding 7.5 cm and an $R^2$ greater than 0.89 for mangrove tidal-flat elevation estimates derived from ICESat-2 and Sentinel-2 observations and evaluated against airborne LiDAR. These accuracy metrics refer specifically to their study. In the present study, RFDTM achieved an RMSE of 1.01 m, an $R^2$ of 0.99, an MAE of 0.80 m, and a bias of 0.43 m within the airborne LiDAR validation area. These results indicate its potential to provide terrain information for regional ecological monitoring, hydrological modeling, and carbon stock assessments, subject to application-specific accuracy requirements. Its 30 m spatial resolution can also support regional habitat mapping and analyses of relationships between terrain conditions and mangrove distribution.*

*Specifically, mangrove sub-canopy topography can support several practical applications. For coastal inundation modeling, terrain elevations can be combined with tidal observations, storm-surge scenarios, and surrounding topographic and bathymetric data to assess potential inundation extent and depth. Incorporating these data into hydrodynamic models can further support analyses of inundation frequency and duration under different sea-level scenarios, helping assess mangrove vulnerability (Xie et al., 2022). For habitat assessment, integrating elevation, vegetation maps, tidal observations, and salinity information can help characterize environmental gradients and habitat suitability. For ecological restoration planning, comparing elevations between degraded sites and nearby reference forests can support preliminary site screening and guide field investigations of tidal connectivity. Such assessments should incorporate local hydrological observations because elevation alone may not fully characterize inundation conditions (Van Loon et al., 2016).*

*For blue carbon research, elevation can serve as an environmental covariate for examining spatial variation in mangrove biomass and soil carbon stocks. Combined with field measurements, vegetation structure, and sediment properties, it may support sampling*

*stratification and spatial carbon assessments, building on approaches linking tidal elevation to biomass development and carbon accumulation (Lovelock et al., 2022). Given the dataset's 30 m spatial resolution and the approximately 1 m RMSE observed within the validation domain, these applications should focus on regional assessments and preliminary planning, with elevation uncertainty evaluated against application-specific requirements.*

*In addition, RFDTM's integration of multi-source remote sensing data, including ICESat-2 LiDAR, SAR, and Sentinel-2 imagery, enhances its adaptability and robustness. This fusion of data sources allows RFDTM to capture fine-scale terrain variations, even in densely vegetated or flooded areas where other DEMs may fail to provide accurate representations (Yao et al., 2024). The versatility of RFDTM makes it particularly useful for assessing the impacts of climate change and human activities on coastal ecosystems, as well as for supporting disaster management efforts, especially in regions that are difficult to access or monitor through traditional methods.*

*Furthermore, RFDTM's transferability across different regions and its ability to maintain consistent performance across diverse topographic conditions underscore its potential for global-scale applications. It is not only a powerful tool for mangrove terrain mapping but also an essential resource for ecosystem conservation, land-use planning, and environmental policy-making (Ming et al., 2025). By offering a reliable and comprehensive approach to terrain estimation, RFDTM provides valuable insights into the dynamics of mangrove and coastal ecosystems, supporting sustainable management and protection efforts on both regional and global scales.*

References:

Lovelock, C. E. et al., 2022. Modeled approaches to estimating blue carbon accumulation with mangrove restoration to support a blue carbon accounting method for Australia. Limnology and Oceanography 67(S2), S50–S60. https://doi.org/10.1002/lno.12014

Van Loon, A. F. et al., 2016. Hydrological classification, a practical tool for mangrove restoration. PLoS ONE 11(3), e0150302. https://doi.org/10.1371/journal.pone.0150302

Xie, D. et al., 2022. Implications of coastal conditions and sea-level rise on mangrove

vulnerability: A bio-morphodynamic modeling study. Journal of Geophysical Research: Earth Surface 127(3), e2021JF006301. https://doi.org/10.1029/2021JF006301

Thank you so much for all comments to this manuscript, which significantly improve this manuscript. In the revised manuscript, all revised contents are highlighted in blue font. Please see the revised details in the manuscript. If some issues still need to be addressed in the revised manuscript, please give us an opportunity to revise and improve it again.

Best regards.