Comment 1:

The method relies heavily on the use of Sentinel-2 percentile composites to serve as machine learning covariates that reflectance tidal variability. However, due to persistent tidal biases associated with sun-synchronous sensors, satellites like Sentinel-2 rarely observes the same tidal conditions at different locations along the coastline (see Figure 8 in Bishop-Taylor et al. 2018 https://www.sciencedirect.com/science/article/pii/S0272771418308783, and Figure 7, Fitton et al. 2021 https://www.sciencedirect.com/science/article/pii/S2352938521000355). These biases mean that, for example, an 80th percentile composite in one location may observe high tide conditions, while the same 80th percentile composite in another location

may only observe mid-tide. How does your approach handle these tide biases, and how do they affect the large-scale consistency of your results? There is currently a single sentence touching on tide variation issues in the manuscript ("First, regional variations in tidal regimes can alter the spectral-elevation relationship, affecting intertidal height retrieval") but I feel it needs to be elaborated on given the importance of these biases for large-scale coastal remote sensing analysis.

Response 1:

We highly appreciate your insightful comment regarding the persistent tidal biases associated with sun-synchronous sensors. You have pointed out a fundamental and critical issue in large-scale coastal remote sensing, as comprehensively demonstrated in your work (Bishop-Taylor et al., 2018) and Fitton et al. (2021). We fully agree that if a sun-synchronous satellite repeatedly observes the same restricted phase of the tidal cycle, the physical meaning of the percentile composites will vary geographically, severely undermining large-scale consistency.

To rigorously address your concern and verify whether this tidal aliasing compromises our modeling in New Zealand, we conducted a systematic quantitative analysis using continuously measured tidal data. We downloaded the 1-minute interval sea-level records from 2018 to 2023 for 12 permanent tide gauge stations across New Zealand (provided by Land Information New Zealand, LINZ, http://sealevel-data.linz.govt.nz/tidegauge). For each station, we extracted the sea level at the exact Sentinel-2 overpass times and compared its statistical distribution

with the natural, continuous full-tidal distribution.

The results strongly confirm that within the specific geographic and tidal context of New Zealand, the Sentinel-2 tidal bias is exceptionally minimal. As shown in Fig. 1 (using the Auckland and Napier station as an example) and summarized in Table 1, the 20th, 50th, and 80th percentiles derived solely from Sentinel-2 overpass moments are almost identical to the true tidal percentiles derived from the full 5-year continuous records.
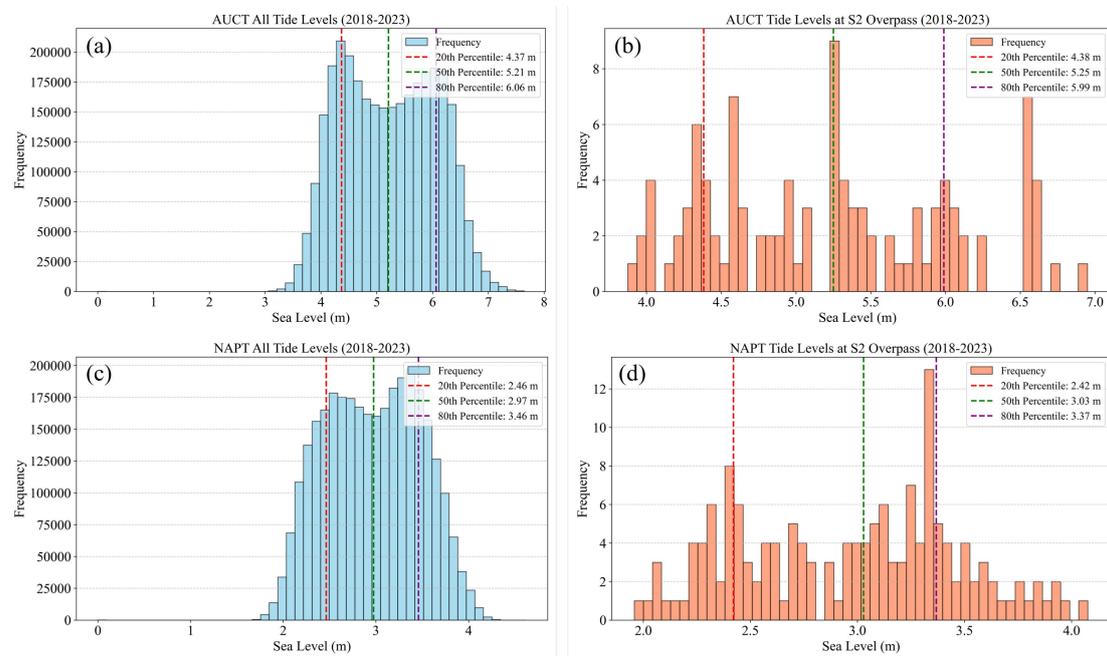
Fig. 1. Frequency histograms of tidal levels comparing continuous full-tidal records and Sentinel-2 (S2) overpass moments. Panels (a) and (b) represent the total observed tide level frequency histogram and the S2 observed tide level frequency histogram for the AUCT (Auckland) tide gauge station, respectively. Similarly, panels (c) and (d) display the total observed tide level frequency histogram and the S2 observed tide level frequency histogram for the NAPT (Napier) tide gauge station. The dashed

vertical lines indicate the 20th, 50th, and 80th percentiles.

Table 1. The recorded values corresponding to the three percentiles (20th, 50th, and 80th) of the total continuous observations and the S2 overpass times across 12 representative tide gauge stations in New Zealand (2018–2023). This table also lists the geographic coordinates (longitude and latitude) where each station is located. The 12 analyzed stations are: AUCT (Auckland), CHIT (Chatham Islands), CPIT (Castlepoint), GBIT (Great Barrier Island), GIST (Gisborne), KAIT (Kaikoura), LOTT (Lottin Point), NAPT (Napier), OTAT (Port Chalmers), PUYT (Puysegur Point), TAUT (Tauranga), and WLGT (Wellington).

Station	Continuous tidal record (m)			Sentinel-2 overpass (m)			Lon (°)	Lat (°)
	20p	50p	80p	20p	50p	80p		
AUCT	4.37	5.21	6.06	4.38	5.25	5.99	174.79	-36.83
CHIT	2.22	2.57	2.96	2.21	2.50	2.82	-176.37	-44.02
CPIT	2.51	3.55	4.34	2.45	3.65	4.30	176.23	-40.90
GBIT	5.20	5.78	6.44	5.14	5.73	6.31	175.49	-36.19
GIST	3.41	3.88	4.37	3.50	3.83	4.31	178.02	-38.68
KAIT	1.49	2.00	2.54	1.40	1.89	2.49	173.70	-42.41
LOTT	2.99	3.54	4.06	3.02	3.59	4.12	178.16	-37.55
NAPT	2.46	2.97	3.46	2.42	3.03	3.37	176.92	-39.48
OTAT	3.83	4.39	5.00	3.83	4.29	4.78	170.63	-45.81
PUYT	5.78	6.37	6.96	5.79	6.29	6.78	166.59	-46.08

TAUT	4.37	4.94	5.47	4.41	4.98	5.49	176.18	-37.64
WLGT	2.52	2.88	3.29	2.53	2.86	3.21	174.78	-41.28

This remarkable consistency is primarily attributed to New Zealand's tidal regime, which is overwhelmingly dominated by the semi-diurnal lunar tide (M2) with a cycle of approximately 12.4 hours. Because the timing of high tide shifts by about 50 minutes each day, Sentinel-2's fixed ~22:00 UTC overpass naturally drifts through all phases of the tidal cycle over our 5-year observation window. Consequently, the satellite has successfully "sampled" the complete tidal range, ensuring that our 20th and 80th percentile spectral composites genuinely represent the physically wet (inundated) and dry (exposed) states across the national coastline.

Furthermore, to handle any minor residual regional tidal variations, our XGBoost model incorporates spatial and geometric features, including absolute geographic coordinates (X, Y) and relative distance metrics. As demonstrated by our SHAP analysis, this allows the machine learning framework to implicitly adapt to distinct regional spectral-elevation mappings and enforce a realistic topographic structure, rather than applying a rigid universal rule.

We recognize, however, exactly as you rightly pointed out, that this approach faces critical challenges when transferred to regions dominated by diurnal tides (where a fixed overpass time may repeatedly capture the same restricted tidal phase). In such environments, tidal aliasing would severely distort the physical representation of the

percentiles. We deeply appreciate your comment, which prompted us to explicitly define the environmental scope and limitations of our methodology.

We have significantly expanded the discussion on this tidal bias issue in Section 5.3 (Potential for global application and challenges). The revised text is as follows:

First, regional variations in tidal regimes can profoundly alter the spectral-elevation relationship, affecting intertidal height retrieval. Specifically, the persistent tidal biases associated with sun-synchronous sensors pose a major challenge for large-scale coastal remote sensing (Bishop-Taylor et al., 2018; Fitton et al., 2021). Our framework benefits from New Zealand's predominantly semi-diurnal tidal regime (M2 cycle of ~12.4 hours). Over the 5-year observation window, Sentinel-2's fixed overpass time naturally samples the complete range of tidal phases, ensuring that our multi-percentile composites genuinely reflect full tidal exposure dynamics. However, applying this statistical percentile approach to regions dominated by diurnal tides (where a fixed overpass time may repeatedly capture the same tidal phase, leading to severe tidal aliasing) will result in percentiles lacking consistent physical meaning. To mitigate this at a global scale, the temporal compositing strategy must be explicitly coupled with regional hydrodynamic models to strictly filter imagery based on absolute tidal stages rather than relying solely on observation percentiles. Additionally, implementing a regionalized modeling approach can further alleviate these spatial inconsistencies. By clustering coastal segments based on distinct tidal characteristics—such as tidal range, phase, and geomorphic type—independent, localized machine learning models can be trained to accurately capture the specific

spectral-elevation relationships unique to each tidal zone.

References

Bishop-Taylor, R., Sagar, S., Lymburner, L., and Beaman, R. J.: Between the tides: Modelling the elevation of Australia's exposed intertidal zone at continental scale, Estuarine Coastal Shelf Sci., 223, 115-128, https://doi.org/10.1016/j.ecss.2019.03.006, 2019.

Fitton, J. M., Rennie, A. F., Hansom, J. D., and Muir, F. M. E.: Remotely sensed mapping of the intertidal zone: A Sentinel-2 and Google Earth Engine methodology, Remote Sens. Appl.: Soc. Environ., 22, 100499, https://doi.org/10.1016/j.rsase.2021.100499, 2021.

Comment 2:

The paper focuses primarily on open coast beach environments, which is a valuable niche for intertidal elevation modelling that has not seen as much research attention as more sheltered, tide dominated systems. However, I feel it would be valuable to also include either include an example of model performance across more extensive tidal flat environments, or include some discussion points about how/why these intertidal environments were excluded from the study.

Response 2：

Thank you for this insightful suggestion. You have accurately captured the specific

geomorphological niche of our study. We intentionally bounded our study domain to open sandy beaches (using the OpenStreetMap sandy beach polygons) and excluded extensive muddy tidal flats and estuarine systems.

This exclusion was driven by several physical and methodological considerations. Firstly, sandy beaches and muddy tidal flats exhibit fundamentally different spectral-elevation relationships. Extensive tidal flats typically possess much gentler gradients, distinct sediment properties (mud/silt vs. sand), and much higher moisture retention capacities due to more frequent and prolonged inundation. Training a single global model encompassing both environments without explicit geomorphological classification would dilute the model's accuracy and introduce cross-domain prediction errors.

Secondly, extending this topographic inversion method to extensive tidal flat environments is highly feasible, but it requires further methodological refinement. Because tidal flats are wetter and often characterized by complex creek networks or transient biological cover (e.g., algal mats), accurate retrieval in these areas necessitates the introduction of additional spectral features. For instance, incorporating water and vegetation indices (such as the multi-percentile statistics of MNDWI and NDVI) is crucial for capturing the complex moisture dynamics. Furthermore, a regionalized modeling approach based on coastal typologies would be required to achieve high accuracy.

We fully agree that discussing this boundary is valuable for readers. We have added a

dedicated paragraph in the Discussion section (Section 5.3) explaining the rationale for excluding extensive tidal flats and highlighting the distinct geomorphological and feature engineering considerations required for modeling those environments.

We have added the following paragraph to Section 5.3 (Potential for global application and challenges) to explicitly define our study boundary and discuss tidal flats:

Furthermore, it is important to note that the current framework is specifically optimized for and applied to open sandy beach environments, intentionally excluding extensive muddy tidal flats and estuarine systems. This boundary was established because sandy beaches and muddy tidal flats exhibit fundamentally different spectral-elevation relationships. Tidal flats typically possess much gentler gradients, distinct sediment properties (mud/silt), and higher moisture retention capacities due to more frequent and prolonged inundation. Consequently, applying this beach-focused model directly to tidal flats could introduce cross-domain prediction errors. Extending this topographic inversion method to extensive tidal flat environments is highly feasible but requires specific methodological refinements. Because tidal flats are significantly wetter, accurate retrieval would necessitate the introduction of additional feature variables, such as multi-percentile statistics of the Modified Normalized Difference Water Index (MNDWI) and Normalized Difference Vegetation Index (NDVI), to better capture complex moisture and biological dynamics. Additionally, implementing a regionalized modeling framework based on coastal geomorphological classification would be essential to accurately map these distinct

intertidal environments.

Comment 3:

The data package includes only data for the "NoData" voids in the DeltaDTM dataset. Are there plans to also provide a combined DeltaDTM + NZ-BeachTopo30 data as a single seamless topobathy DEM? Or is the expectation that downstream users will combine these datasets themselves?

Response 3:

Thank you for carefully reviewing our data repository. We apologize for any confusion caused by our initial description on Zenodo. To clarify, the dataset currently provided in the data package is already the combined, seamless DEM (i.e., the original valid DeltaDTM backshore data completely mosaicked with our newly predicted intertidal topography). Downstream users do not need to perform any further integration themselves.

We realize that our previous Zenodo description stating "The model specifically targets and fills the 'NoData' voids in the DeltaDTM dataset" may have inadvertently implied that only the newly predicted pixels were included in the downloaded file. We highly appreciate you pointing this out.

To prevent any future misunderstandings, we have updated the Zenodo repository description to make it explicitly clear that the downloadable file (NZ-BeachTopo30)

is the fully integrated, mosaicked beach topography DEM. Additionally, we have slightly refined the text in the "Data availability" (Section 6) of the revised manuscript to emphasize that the published dataset is a complete, mosaicked product.

Modifications in the revised manuscript (Section 6):

The final seamless beach topography dataset, NZ-BeachTopo30 (a fully integrated mosaicked product combining the DeltaDTM baseline and our newly predicted intertidal elevations), is available on Zenodo via the digital object identifier (DOI): https://doi.org/10.5281/zenodo.17785546 (Wang, 2025).