Dear editor,

We sincerely appreciate your time and efforts in handling our manuscript. We have carefully considered all the comments and revised the manuscript accordingly. Our point-by-point responses are provided below:

Response:

1) First, I recommend the authors to edit the manuscript by using professional proofreading service before resubmitting the revision.

Response: Thank you for your constructive suggestion. We have thoroughly revised the manuscript with the assistance of a native English speaker (from Australia) with experience in academic writing. We kindly ask you to assess whether the current language quality meets the standards for publication, and we are happy to make further improvements if necessary.

2) L76: Reword to "numerical weather model (NWM)".

Response: Revised as suggested.

3) L77: Reword to "Global Pressure and Temperature (GPT)".

Response: Revised as suggested.

4) L79: Following sentences are too vague. "In such empirical models, spatiotemporal variations of the atmospheric parameters are modelled, and then the atmospheric parameters can be predicted directly. Incorporating advanced height correction model is an effective method to improve the modeling accuracy of atmospheric parameters or the tropospheric delays (Huang et al., 2023; Jiang et al., 2024; Li et al., 2018; Sun et al., 2023). However, while easy to use, these models have limited accuracy due to rapid variation of the troposphere (Wang et al., 2017; Xia et al., 2023), as these models can only capture the mean status of the annual, semi-annual and diurnal variations of the parameters."

Here do you intend the following contents?

"For instance, some studies improved the prediction of the atmospheric parameters by incorporating an advanced height correction in these empirical models (e.g., Li et al., 2018; Huang et al., 2023; Sun et al., 2023; and Jiang et al., 2024). Nevertheless, their results are still insufficient in accuracy of WHAT (Temperature? Pressure? Moisture? Boundary-layer height? Or other variables?) due to coarse spatiotemporal resolution for modelling those rapid variations in the troposphere (Wang et al., 2018; Xia et al., 2023)."

Authors should revise the sentences with brief and precise description.

Response:

We appreciate for this constructive comment. This paragraph has been revised to enhance the readability, which now reads:

These models operate independently of external meteorological inputs and empirically estimate atmospheric parameters (such as atmospheric pressure, water vaper pressure, temperature, etc.) based solely on a given location and time. The UNB3m model uses lookup tables that provide the mean and annual amplitude of meteorological variables at mean sea level, facilitating tropospheric delay computation through standardized vertical reduction models. Boehm et al. (2007) introduced the first version of the GPT model, which represents global atmospheric pressure and temperature using spherical harmonics. Its successor, GPT2 (Lagler et al., 2013) advanced the GPT series by implementing a global 5°×5° grid and characterizing atmospheric pressure, temperature, temperature lapse rate, and water vapor pressure by accounting for their mean, annual, and semi-annual harmonics. The GPT2w model (Böhm et al., 2015) refined this framework by incorporating additional parameters and increasing the resolution to 1°×1°. The GPT3 (Landskron and Böhm, 2018) integrated an empirical gradient model while maintaining the other meteorological parameters consistent with GPT2w. Both the UNB3m and GPT model series furnish meteorological parameters at a single reference level (either mean sea level or Earth's surface), necessitating their vertical propagation to the desired elevation. To enhance the accuracy of tropospheric delay modelling, recent studies have introduced more advanced modelling techniques that better describe the height-dependent variability of atmospheric parameters (Huang et al., 2023; Jiang et al., 2024; Li et al., 2018; Sun et al., 2023). Nevertheless, while these empirical models can predict atmospheric parameters with reasonable accuracy, they are fundamentally limited to capturing long-term average variations, primarily annual and semi-annual cycles. As a result, their predictive accuracy is inherently constrained by the atmosphere's continuous and often abrupt variability, particularly for rapidly fluctuating parameters such as air temperature and water vapor pressure (Wang et al., 2017; Xia et al., 2023)

Please let us know if further revision or clarification is needed.

5) L129-133: Authors should provide key references.

Response: Thank you for the suggestion. We have added two relevant references to support Equation (4). Regarding the criterion that each station must have at least 500 profiles during the experimental period, this was defined to ensure data reliability and consistency. Including stations with too few profiles could introduce biases and reduce the robustness of the statistical evaluation.

6) Table 1: Authors wrote the "Table 1 lists … found from Schemes 1 and 2" in L251, but

Table 1 provides information on only difference among VMFs and no information on schemes. Authors should provide all necessary information in Table 1 and describe the results in the manuscript.

Response: We appreciate the reviewer's careful reading and acknowledge the confusion caused by our previous wording. The description of "Schemes 1, 2, 3" in the manuscript refers to the experimental setups introduced at the beginning of Section 4:

4 Results and discussion

To compare the accuracies of the standard and alternative vertical reduction models for reducing the ground surface ZHD and ZWD from the grid reference height to GNSS station heights, the following three schemes were tested using ZHD and ZWD data obtained from grid-wise VMF1/VMF3 products.

1) Scheme 1: for the officially recommended reduction methods, which utilizes fixed empirical decay parameters, corresponding to Eq. (9) for ZHD and Eq. (10) for ZWD.

2) Scheme 2: for the temperature-dependent pressure decay model (Eq. (11)) and the exponential ZWD decay model (Eq. (12)). The required atmospheric variables, including temperature (T_0), temperature lapse rate (β), and water vapor decay coefficient (λ), are predicted by the GPT2w model.

3) Scheme 3: for the new vertical reduction model developed in this research, i.e., Eq. (15) for ZHD and Eq. (18) for ZWD.

7) L252: Do not describe explanation of Fig. 4 without specifying the figure.

Response: Thank you for pointing this out. We have revised the paragraph to explicitly refer to Figure 4 at the beginning of the explanation, thereby improving the clarity and structure of the discussion.

8) L252: IQQE IGS station is first appearance here. Authors should provide basic information on this station and reason why this station was selected for reference data.

Response:

Thank you for this constructive suggestion. We have revised the manuscript to introduce the IQQE station with appropriate context.

We selected the IQQE IGS station as a key example to demonstrate the significant impact of height differences between a GNSS station and its neighboring VMF (Vienna Mapping Function) grid points on the interpolation accuracy of tropospheric delay. IQQE (IGS) station is located in Iquique, Chile, lies to the west of the Andes Mountains, thus this station exhibits substantial differences in height compared to its surrounding closest VMF1/VMF3 grid points: the maximum height differences reach 1562 m for VMF1, 4632 m for VMF3 (5°×5°), and 2750 m for VMF3 (1°×1°). These significant height disparities create challenging conditions where the traditional method (referred to as Scheme 1 in our study) tend to produce large biases. By showcasing IQQE, we effectively illustrate how our novel method maintains robust performance even in such complex topographical environments. This highlights the superior accuracy of our approach in mitigating errors caused by height variations.