Dear Referee #1,

We really appreciate your precious time spent on carefully reviewing our paper titled "*Retrieval of the precipitable water vapor from shipborne multi-GNSS measurements in tropical cyclone-prone regions of the Northwest Pacific during the summer season in 2021*". We revised our manuscript by considering your comments and reviews as much as possible. In this way, we believe, the quality of our manuscript improved significantly.

In the following pages, **your comments are shown in black** while our replies are colored in blue, and *corrections and new explanations are shown in italic and red*.

Sincerely yours,

D.-H. Sohn, B.-K. Choi, J. Hong, Y. Park, H. Jang, B.-I. Lee, and J.-K. Chung

[Responses to Referee #1 - comments] ---------------

[Comment 0] Dear authors, Thank you for revising the manuscript. While my comments on the GNSS are taking into account another round of revision is needed to clarify remaining issues.

Response: We really appreciate your precious time spent carefully reviewing our manuscript and your comments.

[Comment 1] It's debatable whether ground-based techniques can provide sufficient global coverage (L.43). However, I recommend the associated statements as the focus of this paper is on one specific receiver and does not address global coverage.

Response: We thank you for your comment. We agree that ground-based techniques face inherent limitations regarding global coverage. In the case of GNSS observations, a significant number of stations are installed on land, and almost none are at sea. As the reviewer noted, the primary focus of this study is entirely on evaluating the specific receiver, rather than addressing global coverage. Following your feedback, we have reviewed the associated statements and added the relevant details in the manuscript as follows:

(L.87) ~ ~ from low Earth orbit and geostationary satellites. *While this work is limited to analyzing PWV estimated along the track of a single vessel, it aims to demonstrate the practical usefulness and stability of PWV measurements obtained from a shipborne GNSS receiver over the ocean.* ~ ~

(L.404) ~ ~ atmospheric modeling (Saunders, 2021). *Although this work estimated the amount of water vapor using a single specific receiver,* as the number of vessels equipped with GNSS receivers capable of recording raw observation data ~ ~

[Comment 2] You used the GFZ MGEX series (https://doi.org/10.5880/GFZ.1.1.2016.003) rather than the GFZ rapid products (https://doi.org/10.5880/GFZ.1.1.2020.003). Please use the appropriate description and refer the products via their DOI.

Response: We thank you for this insightful comment. As the reviewer suggested, we have modified the sentences as shown in the box below. An additional reference has also been included in the revised manuscript.

(L.116) ~ ~ The German research centre for geosciences (GFZ) ~~rapid products are~~ *multi-GNSS experiment (MGEX) series is* employed to estimate precise ship positioning and tropospheric zenith total delay (ZTD) *(Deng et al., 2016)*. These products include precise orbits and clock corrections for GPS, GLONASS, ~ ~

(L.135) **Table 1.** Models and methods for multi-GNSS kinematic PPP processing.

Item	Models and Methods
Satellite orbit and clock	GFZ ~~rapid products~~ *MGEX series*
Earth rotation parameters	GFZ ~~rapid products~~ *MGEX series*

(L.469) ~ *Deng, Z., Fritsche, M., Nischan, T., and Bradke, M.: Multi-GNSS Ultra Rapid Orbit-, Clock- & EOP-Product Series. GFZ Data Services. doi:10.5880/GFZ.1.1.2016.003, 2016.* ~ ~

[Comment 3] While both reviewers commented intensively on the GNSS processing the revised description is not sufficient. The authors claim to estimate coordinates and ZTD every 5 min (L.120) with 30s observation. If true, this would cause high correlation in the vertical and significant smoothing. Therefore, the derived results are questionable. PVW plotted in Fig. 2 indicate a more realistic ZTD sampling interval.

Response: Thank you for the critical comment. We apologize for the lack of clarity in our previous description of the methodology. To clarify, although the shipborne GNSS receiver collected data every 30 seconds, the actual PPP processing was performed on observation data resampled to 5-minute intervals. Because the observation interval perfectly matches the parameters (coordinates and ZTD) estimation at a 5-minute interval, the mathematical smoothing and vertical correlation issues are avoided. We have revised the manuscript to explicitly state that the 30-second observation data were resampled to 5 minutes for parameter derivation, as shown in the box below. And in the case of Figure 2c, we only plotted data points at 1-hour steps for better visual clarity.

(L.123) ~ ~ BeiDou (B1/B2). ~~*The observation sampling interval is set to 30 s. Furthermore, the precise position and tropospheric ZTD values are estimated every 5 minutes.*~~ *Although the shipborne GNSS observation sampling interval was 30 s, the data were resampled to 5-minute intervals for the kinematic PPP processing. Accordingly, the precise coordinates and tropospheric ZTD values were estimated every 5 minutes.* ~ ~ (L.168) ~ ~ Figure 2c presents the PWV time series for two days. *The data points were displayed only in 1-hour intervals for better visual clarity.* The shipborne PWV from ~ ~

[Comment 4] In addition, table 1 mentions a "gradient component" without specifying the associated interval. As you manuscript relies on GNSS processing, this part should be very clear.

Response: Thank you for your comment. Clarifying the gradient estimation strategy is indeed critical. The associated interval for the gradient component is every 5 minutes. We have added the corresponding sentences in the revised manuscript as follows:

(L.125) ~ ~ *ZTD values were estimated every 5 minutes. Tropospheric horizontal gradients are also estimated at 5-minute intervals to compensate for atmospheric azimuthal asymmetry. These parameters are estimated as random walk processes.* ~ ~

[Comment 5] The comparison between kinematic coordinates and tide gauge is acknowledged but the numerical comparison is missing. The 1.1-1.4 m differences include the full tidal signal, while the authors might provide the RMS of the epoch-wise differences.

Response: Thank you for your valuable feedback. As the reviewer suggested, we have added the corresponding sentences as shown in the box below. These refined descriptions will be incorporated into the revised manuscript.

(L.163) ~ ~ variation in height of the vessel's GNSS and tide gauge due to the sea level change over two days. *Based on the 2-day time-series data, the GNSS height exhibits a mean of 48.8 m with a variation range of 1.4 m, whereas the tidal height averages 0.96 m with a range of 1.1 m.* The range of height variation for both measurements is 1.1–1.4 meters. The change patterns are also similar. *To evaluate the performance of PPP, the same epoch data sets are processed in an epoch-wise difference. After applying demean to both datasets, the RMS of the epoch-wise differences was calculated at 0.138 m.* This allows us to validate the performance of PPP. ~ ~

We hope the revised manuscript will better meet the requirements of your journal for publication. I really appreciate your comments, which improved the quality of our manuscript tremendously.

Sincerely yours,

Dong-Hyo Sohn, Ph.D.

Space Science Division, Korea Astronomy and Space Science Institute

776, Daedeokdae-ro, Yuseong-gu, Daejeon 34055, Republic of Korea

Tel: +82-42-869-5921, Fax: +82-42-865-3358, E-mail: dhsohn@kasi.re.kr

Dear Referee #2,

We really appreciate your precious time spent on carefully reviewing our paper titled "*Retrieval of the precipitable water vapor from shipborne multi-GNSS measurements in tropical cyclone-prone regions of the Northwest Pacific during the summer season in 2021*". We revised our manuscript by considering your comments and reviews as much as possible. In this way, we believe, the quality of our manuscript improved significantly.

In the following pages, **your comments are shown in black** while our replies are colored in blue, and *corrections and new explanations are shown in italic and red*.

Sincerely yours,

D.-H. Sohn, B.-K. Choi, J. Hong, Y. Park, H. Jang, B.-I. Lee, and J.-K. Chung

[Responses to Referee #2 - comments] ---------------

[Comment 0] I thank the authors for their responses and for the modifications made to the manuscript, which in my opinion has improved in quality. However, regarding these responses and corrections, I still have some comments:

Response: We really appreciate your precious time spent carefully reviewing our manuscript and your comments.

[Comment 1] (L.114) Why are rapid products used instead of final products, which are normally the most precise? There does not appear to be any time constraint on obtaining the solutions.

Response: We thank you for the insightful comment. We made a mistake in describing this part. In this study, we used the German Research Center for Geosciences (GFZ) MGEX series. As you know, the GFZ MGEX series provides ultra-rapid multi-GNSS orbits, clock, and EOP products for GPS, GLONASS, Galileo, and Beidou (https://doi.org/10.5880/GFZ.1.1.2016.003). For the GFZ rapid product series, GFZ provides ultra-rapid, rapid, and final solutions for GPS, GLONASS, and Galileo, excluding BeiDou and QZSS (https://doi.org/10.5880/GFZ.1.1.2020.003). To ensure the availability of multi-GNSS data processing, we utilized the GFZ MGEX series.

(L.116) ~ ~ using kinematic PPP mode. The German research centre for geosciences (GFZ) ~~*rapid products are*~~ *multi-GNSS experiment (MGEX) series is* employed to estimate precise ship positioning and tropospheric zenith total delay (ZTD) *(Deng et al., 2016)*. These products include precise orbits and clock corrections for GPS, GLONASS, ~ ~

(L.135) **Table 1.** Models and methods for multi-GNSS kinematic PPP processing.

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Satellite orbit and clock	GFZ ~~*rapid products*~~ *MGEX series*
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(L.469) ~ *Deng, Z., Fritsche, M., Nischan, T., and Bradke, M.: Multi-GNSS Ultra Rapid Orbit-, Clock- & EOP-Product Series. GFZ Data Services. doi:10.5880/GFZ.1.1.2016.003, 2016.* ~ ~

[Comment 2] (L.114 and L.122) You state twice that you use the "Precise satellite orbit and clock products" from GFZ. Please correct this redundancy.

Response: Thank you for your comment. As the reviewer's suggestion, the sentence in line 122 has been revised to improve clarity and address the redundancy, as shown in the box below.

(L.127) ~ ~ *are estimated as random walk processes.* ~~*Precise satellite orbit and clock products, and Earth rotation parameters are obtained from the GFZ analysis center.*~~ *To maintain consistency in the processing strategy, Earth rotation parameters were derived from GFZ products.* Both satellite and receiver antenna ~ ~

[Comment 3] (L.134) One point in the methodology raises some concern. You use GPT2 to compute the ZHD and the Tm required for converting ZWD into IWV. It seems to me that the GPT2 climatology may be insufficient to retrieve accurate IWV values, particularly when meteorological conditions deviate from the climatological mean, as might be expected here in a cyclonic situation. In this approach, the GPT2 pressure is used to compute the ZHD; if this pressure differs by about 10 hPa from the actual value, this could lead to a bias on the order of ~3 kg m^{-2} in IWV. If the study remains as it is, the potential error introduced by using GPT2 rather than an actual pressure measurement should be discussed, and the reported biases should be interpreted in light of the uncertainty associated with GPT2.

Response: We thank the reviewer for pointing this out. We completely agree with the reviewer's suggestion regarding the limitations of using the GPT2 model in cyclonic conditions. The GPT2 model has been widely adopted and conventionally used in GNSS PPP data processing to provide empirical tropospheric parameters. In our previous experiences, integrating in-situ meteorological data often led to diminished positioning performance, potentially due to sensor inconsistencies or local site effects in the harsh marine environment. The stable kinematic positioning is a fundamental prerequisite for reliable shipborne GNSS applications. Although GPT2 is an empirical model, we determined that GPT2 is more suitable for this PPP processing as it ensures stable and continuous corrections.

However, we have revised the Discussion section to address your constructive feedback. We have described the potential PWV errors introduced by relying on the GPT2 model rather than actual pressure measurements, particularly under cyclonic conditions, as shown in the box below.

(L.375) ~ ~ as shown in the final part of the time series in the Fig. 8. *In our PPP processing strategy, we utilized the GPT2 model rather than in-situ measurements to ensure continuous and stable kinematic positioning by avoiding potential sensor anomalies. However, it should be noted that relying on the meteorological model can introduce biases in the estimated PWV. This is particularly relevant during cyclonic events, where significant pressure anomalies could result in a PWV bias.* ~ ~

[Comment 4] Finally, what are the reasons for using GPT2 instead of GPT3? (I assumed that GPT2, as indicated in Table 1, is used rather than GPT; however, Section 2.3 mentions GPT. Is this an error?)

Response: Thank you for your careful review. The reason we did not adopt GPT3 is that our current PPP processing software does not yet fully support the integration of the latest GPT3 model. Therefore, GPT2 was consistently applied to ensure stable data processing. Also, we confirm that the use of 'GPT' described in Section 2.3 is a typo. It should be 'GPT2', and have corrected this error in the revised manuscript, as presented in the box below.

(L.146) ~ ~ (Elgered et al., 1991). Surface pressure Ps is estimated by interpolating climatological grid coefficients of the ~~*GPT*~~ *GPT2* model according to the vessel's location and applying harmonic functions to account for seasonal variability. ZWD ~ ~ (L.151) ~ ~ relationship, Tm=70.2+0.72 Ts, with surface temperature Ts (Bevis et al., 1994). The Ts is obtained from the ~~*GPT*~~ *GPT2* model at the vessel's specified position. ~ ~

We hope the revised manuscript will better meet the requirements of your journal for publication. I really appreciate your comments, which improved the quality of our manuscript tremendously.

Sincerely yours,

Dong-Hyo Sohn, Ph.D.

Space Science Division, Korea Astronomy and Space Science Institute

776, Daedeokdae-ro, Yuseong-gu, Daejeon 34055, Republic of Korea

Tel: +82-42-869-5921, Fax: +82-42-865-3358, E-mail: dhsohn@kasi.re.kr