Replies to the Reviewer#1

Dear Reviewer,

Thank you very much for your feedback and constructive comments. I sincerely appreciate the time and effort you devoted to reviewing my manuscript. Below are my responses to the issues you raised. In this reply, the comments of the referee are marked in black color, and the replies in blue color.

Comments 1： Lack of Novelty or Contribution
Reviewer Comment: "Similar observations of planetary waves using ST radar and meteor radar at mid-latitudes already exist. The study does not present new knowledge about the conditions for vertical planetary wave propagation."

Reply 1：

Thank you again.

We believe that the manuscript presents innovative results, as explained below:

(1) Based on our analysis, we have, for the first time, identified a reversal in the vertical propagation direction of the 16-day planetary wave phase in the ST region during the transition from autumn to winter (November–December), as shown in Figure 4(d) of the manuscript.

(2) By incorporating reanalysis data, we provide a reasonable explanation for this phenomenon. We identify that the horizontal wave mode of the 16-day planetary wave undergoes a change, resulting in a reversal of its horizontal propagation direction. This reversal subsequently leads to a change in the direction of vertical phase propagation. However, the direction of vertical group velocity remains unchanged, consistently propagating upward. This finding differs from the previously reported understanding in the literature(Jiang, Xiong, Wan, Ning, & Liu, 2005; Lu X & Zhang, 2005; Y. Luo, Manson, Meek, Thayaparan, et al., 2002; Tang & Huang, 2016), which suggested that the vertical group velocity and vertical phase velocity of the 16-day planetary wave propagate in opposite directions.

(3) Based on the significant 16-day wave observed by the ST-M radar from September to the following January, along with MERRA-2 reanalysis data, we discussed the relationship between the 16-day planetary waves in the MLT and ST regions above Langfang Station: the significant 16-day wave observed at 90–100 km during September 3–18 may have originated from meridional propagation from other latitudinal regions; the 16-day wave in the ST region during November 27–December 2 and December 6–23 may have propagated vertically into the MLT region; the significant 16-day wave observed at 80–85 km in the MLT region during December 27–January 14 may have originated from meridional propagation from other latitudes, or it may be a continuation of the upward-propagating 16-day wave from the December 6–23 period.

The above findings enhance our understanding of the 16-day planetary wave.
We have made corresponding revisions to the manuscript by adding this content to the Introduction and Conclusion sections to clearly highlight the innovative aspects of the study.

Comments 2： Poor Writing That Hampers Understanding

Reviewer Comment: "The manuscript is difficult to read due to numerous spelling errors and unusual or misleading word choices. Many statements lack clarity."

Reply 2：

We have carefully revised the entire manuscript. We used tools such as DeepL Translator and the Microsoft Word editor to check the spelling throughout the text. We also standardized the labels in the figures and revised some long sentences to improve readability.

Comments 3： Methodological Concerns and Suggestions

Reviewer Comment: The authors aim to estimate the period and vertical wavelength (hence vertical phase speed) of observed planetary waves. However, the reviewer finds the approach inefficient.

Reply 3：

Thank you!

The radar data in the manuscript were processed using the following methods:

- **Lomb–Scargle (LS) Spectral Analysis**
- **Band-pass Filtering**
- **Harmonic Fitting**

The purpose of using these methods is clearly defined. Below, we provide explanations for each method used:

The LS method was applied using a 32-day sliding time window to obtain the variation of planetary wave amplitudes with different periods at four altitudes, in order to assess the relative importance of 16-day planetary wave activity throughout the year. In fact, due to the limited amount of missing data, it is also possible to apply interpolation followed by Fourier transform as an alternative approach.

For the analysis of the spatiotemporal distribution of planetary waves and the estimation of vertical phase and vertical wavelength, we did not use the LS method. Instead, we applied **band-pass filtering** and **harmonic fitting**.

- **Band-pass filtering** was used to extract the temporal variation characteristics of the 16-day wave. This method has been widely adopted in previous studies to characterize the temporal evolution of 16-day planetary waves(Day & Mitchell, 2010; Huang et al., 2022; G. Jiang et al., 2005; G. Y. Jiang et al., 2005; Lima, Batista, Clemesha, & Takahashi, 2006; Y. Luo, Manson, Meek, Meyer, et al., 2002; Yi Luo, Manson, Meek, Meyer, & Forbes, 2000; Namboothiri, Kishore, & Igarashi, 2002; Tang & Huang, 2016; Vineeth, Pant, Kumar, Ramkumar, & Sridharan, 2009). The reason for using the same method in this study is that it provides clear and intuitive temporal variation characteristics, which facilitate comparison with results from previous studies.

- **Harmonic fitting** (see Equation (1) in the manuscript) was applied to estimate the vertical phase slope and the zonal background wind of the 16-day planetary wave. The zonal wind was further used to evaluate the vertical propagation conditions of the 16-day wave and to analyze the relationship between wave activity in the ST and MLT regions.

(1) A 32-day sliding window was used to perform harmonic fitting of the 16-day planetary wave, yielding the amplitude and phase at different altitudes.
(2) The altitude range with relatively large 16-day wave amplitudes was identified, and the positions of wave peaks at different heights were extracted. A linear fit of the form $\varphi(z) = mz + \varphi_0$ (where z is altitude and φ_0 is the initial phase) was then applied to obtain the vertical phase slope.
(3) The sign of vertical phase slope was used to determine the direction of the apparent vertical phase speed of the planetary wave ($m > 0$ indicates upward propagation, while $m < 0$ indicates downward propagation), and the vertical wavelength was calculated using $\lambda = 2\pi/m$.

Comments 3.1： Step 1: This step is valid and reasonable. However, the computation of the error of daily mean winds and wind variances should be included. These can be used to establish significance levels in the Lomb-Scargle (LS) analysis.

Reply 3.1：

Adopted.

We calculated the errors of the daily mean wind speed and wind variance and added information on the confidence level in the LS analysis section and updated Figure 3 in the manuscript, where the white dashed lines represent the 90% confidence level.

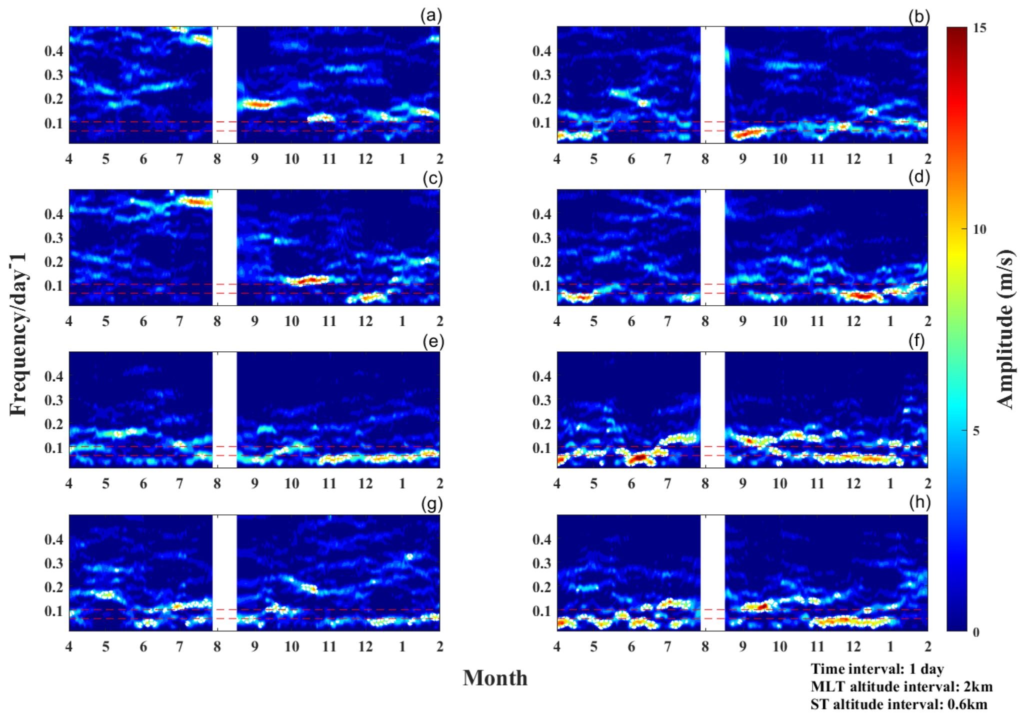

Figure 3: LS spectral analysis results of horizontal wind perturbations at different altitudes over Langfang from March 2023 to February 2024: (a)(c)(e)(g) are the results of the LS spectrum analysis of the meridional wind disturbance at 96 km, 84 km, 13.8 km, and 7.2 km,

respectively; (b)(d)(f)(h) are the results of the LS spectrum analysis of the zonal wind disturbance at 96 km, 84 km, 13.8 km, and 7.2 km, respectively. (The red dashed lines from top to bottom correspond to the frequencies of 10-day and 16-day planetary waves. The white dotted line represents 90% confidence level.)

Comments 3.2： Step 2: This step is unnecessary.

Reply 3.2：

The main purpose of detrending is to remove background trends in the data (such as seasonal increases or decreases), in order to better analyze the underlying fluctuations. Therefore, we have decided to retain this step.

Comments 3.3： Step 3:

- The choice of Lomb-Scargle spectral analysis is appropriate given the unevenly sampled data. This method provides spectral amplitudes and phases as functions of both frequency and time/altitude thanks to the usage of a sliding window.
- However, a proper significance analysis, based on measurement uncertainties and daily wind variances, is essential to identifying significant peaks in the LS periodogram.

Reply 3.3：

That's correct. We only performed phase analysis when the 16-day planetary wave exhibited significant amplitude.

We added confidence level information to the LS results by performing LS analysis at each altitude and extracting the 16-day wave components. This allowed us to obtain the amplitude and phase as functions of height and time. A 90% confidence level was applied, and Figures 5 and 6 in the manuscript have been updated and supplemented accordingly.

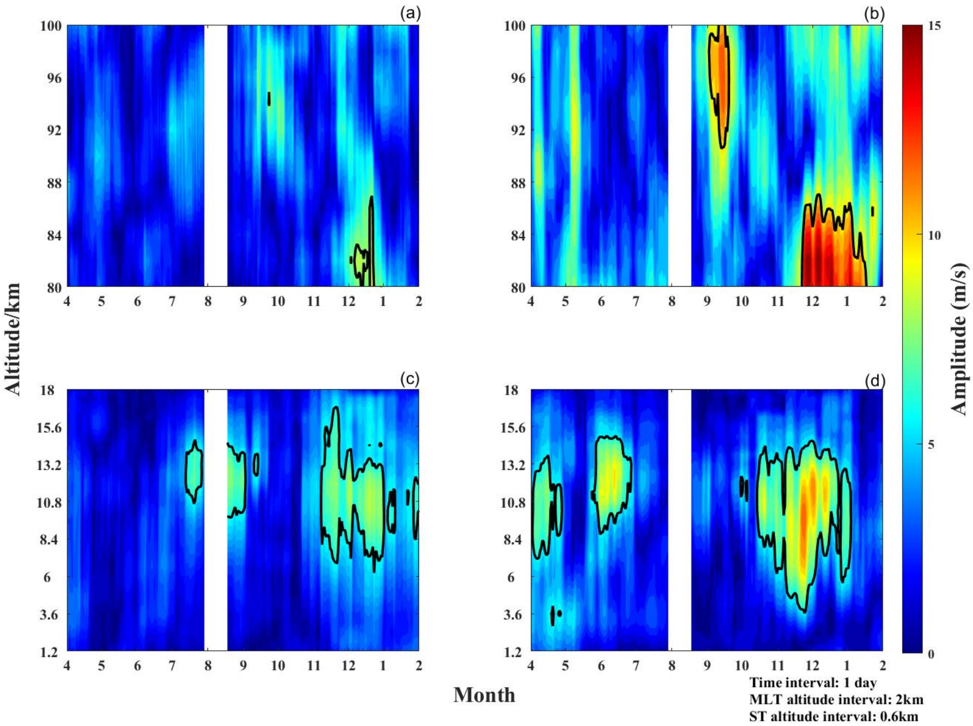

Figure. 5 Amplitudes of 16-day waves with 90% confidence level versus height and time: (a)(c) results of LS processing of daily-mean meridional wind perturbations; (b)(d) results of LS processing of daily-mean zonal wind perturbations (the blank area indicates the time period when the data coverage is less than 50%, and the black solid line represents 90% confidence level)

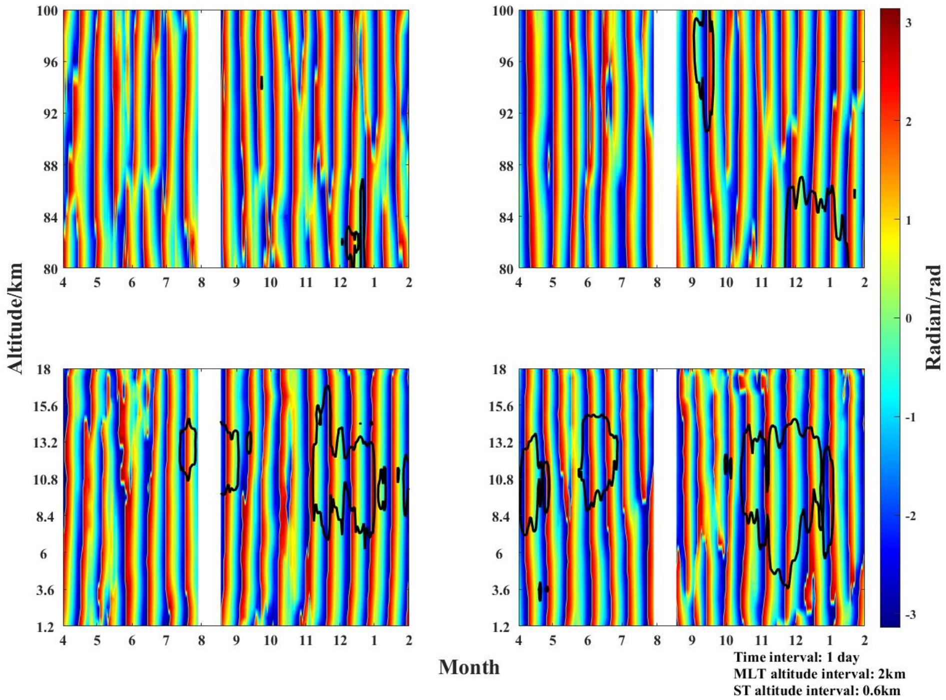

Figure.6 16-day planetary wave phases versus height and time: (a)(c) results of LS processing of daily-mean meridional wind perturbations; (b)(d) results of LS processing of daily-mean zonal wind perturbations (the blank areas indicate time periods with less than 50% data coverage, and the solid black lines indicate areas with 90% confidence amplitudes).

Comments 3.4： Band-pass Filtering Concern:

- The reviewer questions the use of a band-pass filter, which requires a Fast Fourier Transform (FFT) and thus necessitates regular gridding of the data.
- Why is interpolation applied at this stage when it was carefully avoided earlier?

Reply 3.4：

- Band-pass filtering is a commonly used method for observing the temporal characteristics of planetary waves. It allows for a straightforward visualization of amplitude magnitude and phase trends. To facilitate comparison with previous studies that also used band-pass filtering, we applied the same method. The results from this method were used solely to observe the activity characteristics of the 16-day planetary wave; the subsequent amplitude and phase calculations were performed using harmonic fitting.

- Since the amount of missing data was minimal, we first applied interpolation to obtain complete time series before performing band-pass filtering. This has little impact on the results. Using the FFT method, we derived the amplitude and phase and reconstructed the 16-day planetary wave time series. As shown in the figure below, the reconstruction results are compared with those from the band-pass filtering (Figure 4 in the manuscript), and they exhibit very similar amplitude distributions and phase trends.

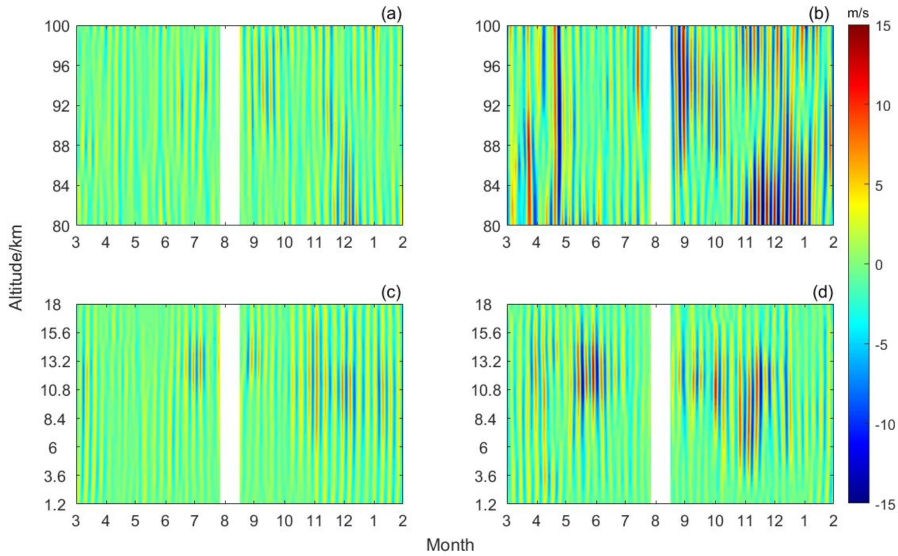

Figure. a Results of the reconstructed time series of the 16-day planetary wave

Comments 3.5: Final Step (Harmonic Fitting & Wave Reconstruction):

- Harmonic fitting could be done without prior filtering since it is already a part of the LS algorithm.
- To determine the uncertainty of vertical wavelengths a Monte Carlo approach should be used in the linear fit of phase lines.
- This is crucial because small errors in phase line slopes can lead to incorrect conclusions about vertical propagation direction.

Reply 3.5:

Adopted.

The fitting error is critical for determining the direction of vertical propagation. Based on the filtered data, we applied harmonic fitting to determine the vertical phase variation of the 16-day planetary wave. We have supplemented the analysis with fitting uncertainties and provided confidence intervals for the phase slope and vertical wavelength to demonstrate the reliability of this conclusion.

The results for the MLT and ST regions are presented in Tables 3 and 4, respectively.

Table.3 Dates, altitude ranges and calculations of significant 16-day wave in the MLT

Date	Altitude (km)	Slope (km/rad)	Wavelength (km)
9.3~9.18	90~100	-16.37 ± 2.43 95% CI: [-21.41, -13.40]	102.84 ± 15.25 95% CI: [84.21, 134.53]
11.22~12.23	80~85	19.36 ± 10.89 95% CI: [13.34, 32.00]	121.62 ± 59.99 95% CI: [86.52, 203.54]
12.24~1.14	80~85	14.28 ± 1.08 95% CI: [13.11, 15.57]	89.75 ± 4.31 95% CI: [82.38, 97.82]

Table.4 Dates, altitude ranges and calculations of significant 16-day wave in the ST

Date	Altitude (km)	Slope (km/rad)	Wavelength (km)
10.12~11.5	8.4~12.6	15.00 ± 2.28 95% CI: [12.17, 21.26])	94.23 ± 14.34 95%CI: [76.44, 133.59]
11.7~12.2	6~12	13.50 ± 1.27 95% CI: [11.61, 16.35]	84.80 ± 7.97 95%CI: [72.97, 102.74]
12.6~12.23	9.6~13.2	-9.61 ± 1.33 95% CI: [-11.35, -7.76]	60.37 ± 8.36 95% CI: [48.78, 71.34]
12.24~1.3	6~12	-5.52 ± 0.42 95% CI: [-6.65, -4.91]	34.70 ± 2.65 95% CI: [30.86, 41.76]

The above provides clarification, explanation, and additional details regarding the methods and approach used in the original manuscript.

For the data used in this study, planetary wave information can be obtained using the LS, FFT, or harmonic fitting methods. We applied all three approaches to calculate the amplitude and phase of the planetary waves and found that the results are largely consistent across methods, as shown in the figure below.

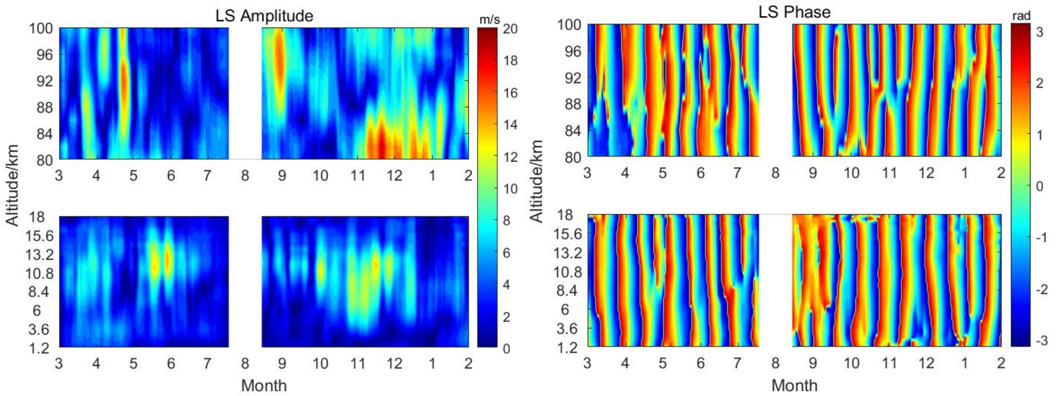

Figure. b LS results of the zonal wind amplitude and phase

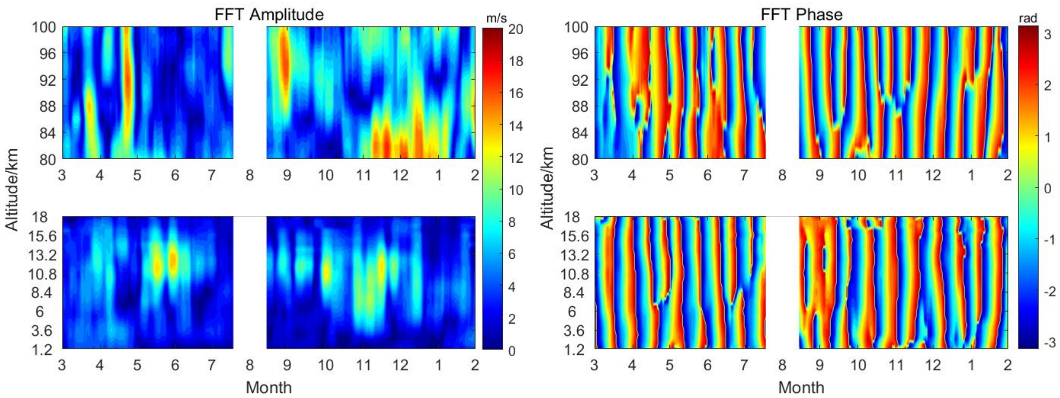

Figure. c FFT results of the zonal wind amplitude and phase

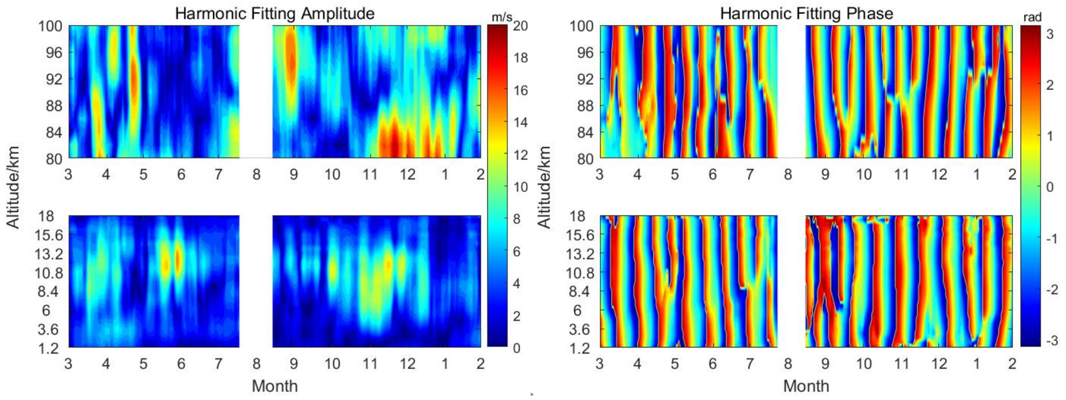

Figure. d Harmonic fitting results of the zonal wind amplitude and phase

As the manuscript involved multiple methods, we acknowledge that the use of different approaches—despite yielding consistent results—may cause confusion for readers regarding the methodology. To address this, we have standardized the analysis by using the LS method to obtain the amplitude, phase, and vertical wavelength of the 16-day planetary wave, and we have also added confidence level information.

Once again, we sincerely thank you for your valuable comments.

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