In this revised version, several improvements are introduced:

(1) The logic of the Discussion section has been organized. A summary paragraph is added to give the logic of mechanism analysis. The subtitle is changed to be more detailed. Then, the transitional sentences between each section are added.

(2) The grammar of the entire manuscript has been checked and corrected.

(3) A comparison between disruption events and QBOW is supplemented, including the Abstract, Result section, and Summary section.

(4) The relationship between QBO and gravity wave drag has been supplemented.

(5) Possible reasons for differences in wavelength statistics compared to previous studies is discussed.

(6) The discussion of tidal dissipation using amplitude ratio method is added.

(7) The connection between water vapor radiative heating variations and the joint modulation by ENSO and QBO disruption has been strengthened.

Response to Reviewer 1:

We would like to express our sincere appreciation to the reviewers for their comprehensive assessment and insightful comments, which have been so helpful in enhancing the substance of our work.

Comment 1: The discussion section has become somewhat disorganized, making it difficult to discern the central arguments of the paper. I recommend that the authors reorganize the narrative, clarify the focus, and streamline the discussion and conclusion based on the updated results.

Response 1: Thanks for the helpful comments. In discussion section, our aim is to study how the QBO disruptions and 2015/16 extreme El Nino modulate the DW1 by several mechanisms from the lower atmosphere to upper atmosphere. Therefore, the discussion part is organized as tidal heating (troposphere and stratosphere), tidal propagation (from stratosphere to mesosphere) and tide-gravity wave interaction (significantly in mesosphere and lower thermosphere, as shown in Figure 11). However, these subtitles are so broad that they obscure what we want to express. Consequently, at the beginning of the Section 4, a summary paragraph is added to give the logic of mechanism analysis. Furthermore, the subtitle will be changed to be more detailed. Then, the transitional sentences between each section are added.

Comment 2: Additionally, while I am not a native English speaker, I strongly recommend that the manuscript be proofread by a native speaker. Some sentences are structurally awkward or grammatically incorrect.

Response 2: Thanks for the helpful comments. We have carefully reviewed our manuscript and corrected faults.

Comment 3: The title refers to "Migrating diurnal tide anomalies," but it is unclear what is meant by "anomalies." Based on the results, the DW1 tide appears comparable to that during a typical QBOW phase, which raises doubts about whether "anomaly" is the appropriate term. Moreover, the manuscript discusses differences from QBOE but provides minimal comparison with QBOW. The authors should clarify: Whether the 2016 and 2020 events are similar to a typical QBOW period, and if so, explain why they resemble QBOW conditions.

If these events are instead unique and distinct from QBOW, the manuscript should discuss in detail how they differ.

In short, the key points of the paper are not clearly conveyed.

Response 3: Thanks for the helpful comments. The comment that the reviewer give is reasonable. In our studies, the comparison with QBOW and QBOE are both presented. However, in the previous version of the manuscript, we mainly present the differences between events and QBOEs in Abstract and Summary. That's because, as the previous response (round 1) mentioned, if there are no events, the QBO should evolve into QBOE. That's why we focus on the comparison between QBOE and event in the previous version of the manuscript. However, as the reviewers pointed out, the differences of DW1 between events and both QBOW and QBOE should be clearly presented.

The differences are summarized as follows. In term of the amplitude difference:

(1) In MLT region, during the 2016 event, the amplitude at equator is smaller than that during QBOW about 10.2% and larger than that during QBOE about 20.5%. In subtropical latitude (30°N/S), the amplitude is larger than that during QBOW about 4.6% and larger than that during QBOE about 14.4%. During the 2020 event, the amplitude in the equatorial MLT is smaller than that during QBOW about 21.1% and larger than that during QBOE about 6.0%. In subtropical latitude (30°N/S), the amplitude in the equatorial MLT is smaller than that during QBOW about 21.1% and larger than that during QBOE about 6.0%.

(2) In the upper stratosphere, during the 2016 event, the amplitude of DW1 (1, 1) mode is smaller than that during QBOW about 10.9% and larger than that during QBOE about 21.1%. During the 2020 event, the amplitude of DW1 (1, 1) mode is smaller than that during QBOW about 12.5% and larger than that during QBOE about 17.0%

In term of the mechanism difference:

(3) During the 2016 event, the water vapor radiative heating is enhanced by 8.3% relative to QBOE and 10.9% relative to QBOW due to the compound effect of QBO disruption event and 2015/16 El Nino event.

(4) Comparing the tide-gravity wave interaction during different QBO phases and QBO disruption, the GW forcing during 2016 event is stronger than that during the QBOW and QBOE.

These summary of difference have been supplemented in Abstract and Summary.

Comment 4: Additionally, the abstract attributes the tidal enhancement during the 2016 disruption to zonal wind shear and gravity wave drag. While the shear is clearly related to the QBO, it is unclear whether gravity wave drag is also linked to the QBO. It may be more related to the SAO or gravity wave source activity. Please expand on the relationship between QBO and gravity wave drag.

Response 4: Thanks for the helpful comments. This question has been discussed in Wang et al., (2024). QBO-dependent zonal wind shear and associated zero-wind lines filter the upward-propagating gravity waves that can reach the mesosphere, making the gravity wave drag exhibit QBO-like feature. In the tropical region of mesosphere, because of the strong interaction between the GWs and the semi-annual oscillation (SAO) in zonal wind, the GWs in mesosphere exhibit a weak QBO signature. QBO-related variations in GWs primarily exists in the mid-latitude mesosphere.

Wang, J., Li, N., Yi, W., Xue, X., Reid, I. M., Wu, J., Ye, H., Li, J., Ding, Z., Chen, J., Li, G., Tian, Y., Chang, B., Wu, J., and Zhao, L.: The impact of quasi-biennial oscillation (QBO) disruptions on diurnal tides over the low- and mid-latitude mesosphere and lower thermosphere (MLT) region observed by a meteor radar chain, Atmos. Chem. Phys., 24, 13299-13315, 10.5194/acp-24-13299-2024, 2024.

This part could be seen in Line 554-558 (in marked-up manuscript) or Line 525-530 (in all-accepted manuscript).

Comment 5: According to my understanding, westerly winds increase DW1 tidal vertical wavelengths, leading to amplified tidal amplitudes (Forbes and Vincent, 1989; Kogure and Liu, 2021). This is inconsistent with the findings presented in this manuscript. I recommend computing theoretical vertical wavelengths at the equator using Equation (14) from Forbes and Vincent (1989). It is important to note that vertical wavelengths in the mesosphere are influenced not by the QBO but by winds in the mesosphere. If the authors intend to discuss vertical wavelength and dissipation processes in the mesosphere, they should include wind profiles from that region.

Response 5: Thanks for the helpful comment. The statistical results derived from the method used in this study were compared with those obtained from the approach proposed by Kogure and Liu (2021, hereafter KL21). The comparison reveals that, in the lower stratosphere of the SABER data, the standard deviation of the wavelengths estimated by the KL21 method is sufficiently large to obscure distinctions between different QBO phases. For instance, as shown in Table 2, the mean wavelength difference between QBOW and QBOE in the lower stratosphere (~18–32 km) is only 0.62 km, whereas the corresponding standard deviation reaches approximately 3 km. After careful consideration, we decided to preserve our results.

According to the theoretical framework proposed by Forbes and Vincent (1989) and Kogure and Liu (2021), zonal winds modify the intrinsic frequency of tides through Doppler shifting, thereby altering their vertical wavelengths. Specifically, westerly winds lead to longer DW1 vertical wavelengths, whereas easterly winds result in shorter ones. However, the result of wavelengths shown in Table 1 differs from that reported in previous studies. This discrepancy can be attributed to differences in methodology. In this study, the vertical wavelengths are determined from the phase difference between adjacent peaks (+π). In the stratosphere, one of these peaks typically occurs in the lower stratosphere (~18 km) and the other in the upper stratosphere (~40 km). Consequently, the estimated wavelengths encompass the combined influences of both the QBO and SAO, producing a mixed result that deviates from earlier findings. The advantage of our method is that it only requires two points to calculate the wavelength. The result is as following:

Table 1. Wavelengths statistic using peak difference method

Data	SD-WACCM-X			SABER		
altitude	~15 km – ~ 40 km	~40 km – ~ 75 km	~75 km – ~105 km	~15 km – ~ 40 km	~40 km – ~ 75 km	~75 km – ~105 km

Westerly	22.97/1.49	34.47/1.79	25.10/1.84	21.81/1.44	33.12/1.78	21.29/1.04
Easterly	22.51/1.73	34.42/2.15	25.60/2.20	24.46/1.99	30.84/2.35	20.56/1.30
2016	22.56/1/33	33.26/1.58	25.58/2.03	21.48/2.31	33.32/2.10	21.28/0.85
2020	22.71/1.87	33.80/2.68	26.27/2.41	21.08/1.77	34.24/1.46	20.39/1.35

In our result, the standard deviation does not obscure wavelength differences during different QBO phases.

The wavelength is then calculated using the KL21 method. The method is as follows. The tidal vertical wavenumbers are firstly derived from the (1,1) mode tidal phase with the least-square method in a range of 2 scale heights (~14 km) by 0.2 scale height steps. The vertical wavenumbers were then averaged in three regions: the QBO zonal wind height range (18–32 km), Stratospheric Semi-Annual Oscillation zonal wind height range (32 – 60 km), and Mesosphere and lower thermosphere Semi-Annual Oscillation zonal wind height range (60 – 100 km). Then the wavelengths are calculated by $2\pi/wavenumber$. The result is as following:

Table 2. Wavelengths statistic using KL21 method

Data	SD-WACCM-X			SABER		
altitude	~18 km – ~ 32 km	~32 km – ~ 60 km	~60 km – ~100 km	~18 km – ~ 32 km	~32 km – ~ 60 km	~60 km – ~100 km
Westerly	22.36/1.09	26.57/1.16	25.37/1.35	24.59/2.81	25.48/1.57	21.10/0.44
Easterly	22.01/1.27	26.57/1.33	25.54/1.39	23.97/3.23	23.91/2.48	20.52/0.53
2016	21.96/0.77	26.23/0.97	25.48/1.43	24.49/2.55	24.71/1.16	20.93/0.23
2020	21.98/1.10	26.93/1.22	25.82/1.38	26.74/3.78	23.28/1.58	20.26/0.46

This result is consistent with previous studies. However, the standard deviation shown in SABER observations is so large in stratosphere that the wavelengths difference between different QBO phases is negligible to the standard deviation. There's no doubt that KL21 method is very suitable for analyzing the regional wavelengths, especially in model simulation results. However, considering the SABER observations, we retain our results.

Furthermore, in section 3.2, we tent to present the wavelengths feature during the QBO disruptions and their difference to the normal. We plan to discuss the dissipation process using the ratio method provided by the reviewer, which will locate at Section 4.2.

Possible reasons for differences in wavelength statistics compared to previous studies could be seen in Line 363-370 (in marked-up manuscript) or Line 358-365 (in all-accepted manuscript).

Comment 6: I recommend using the ratio of DW1 tidal amplitudes, rather than the absolute difference, to account for the decrease in atmospheric density with altitude. Here's why the ratio method is advantageous: For example, comparing 2016 to QBOE using the ratio 2016/QBOE: If the ratio is larger than 1 from the lower stratosphere to the mesosphere-lower thermosphere (MLT), this suggests stronger tidal source activity in 2016 than in QBOE.

If the ratio is almost 1 in the lower stratosphere but decreases in the middle stratosphere, this implies enhanced tidal dissipation in the middle stratosphere, possibly linked to QBO.

If the ratio is almost 1 below the middle stratosphere but decreases in the upper stratosphere, the change may not be due to QBO but rather to SAO effects.

Simply say, the amplitude ratio changes, suggsting tidal dissipation varies at the altitude. This framework originates from Forbes and Vincent (1989), which I strongly encourage the authors to review carefully.

Currently, Liu et al. (2025) do not clearly identify the altitudes at which tidal dissipation increases or decreases. If the ratio does not vary in QBO-sensitive altitude ranges, it would suggest that QBO has limited influence on tidal variation.

Response 6: Thanks for the helpful comments. We believe the reviewer refers to Figure 4 in section 3.1 of manuscript. In that figure, we would like to analyze how the DW1 (1, 1) amplitude vary during the QBO disruption event and its difference to the normal QBO phases. It will be kept in that section. The amplitude ratio will be discussed in section 4.2 (about tidal propagation). The analysis of the method is given following.

As in Forbes and Vincent (1989), the amplitude growth equation is:

$$\frac{A(z)}{A(70)} = \exp\left\{\int_{70}^{z}\left[-k_i + \frac{1}{2H}\right]dz\right\} \qquad (1)$$

where A is the amplitude, H is the local scale height and k_i is the imaginary part of the complex vertical wavenumber that governs damping of the amplitude profile.

When applying ratio of equation (1) like 2016 divided by QBOE, the equation become：

$$\frac{A_{2016}(z)}{A_{QBOE}(z)} = \exp\left\{\int_{70}^{z} -\left(k_{i,2016}(z) - k_{i,QBOE}(z)\right) dz\right\} \qquad (3)$$

The scale height term is removed, leaving the dissipation term. Thus, the amplitude ratio changes may reflect tidal dissipation variations at the altitude.

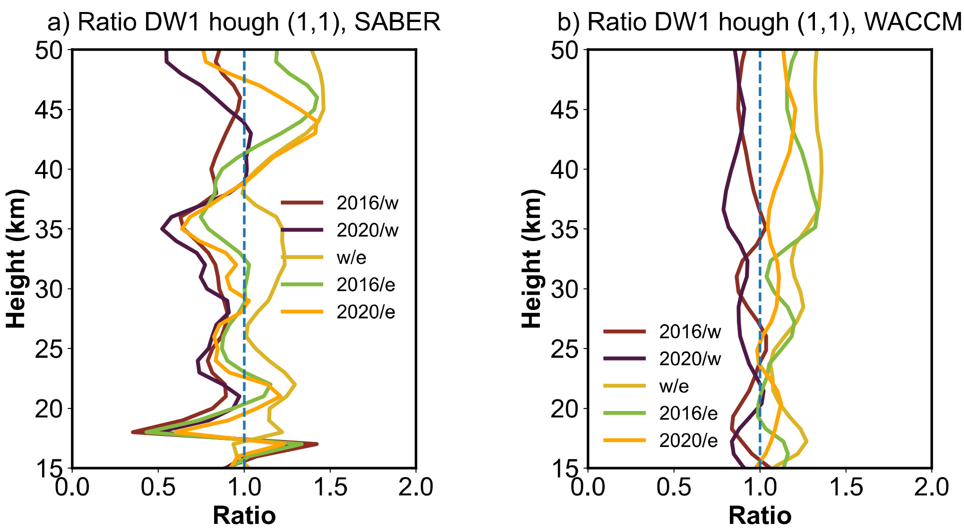

Figure 1. the vertical profile of DW1 (1, 1) mode amplitude ratio derived from 2016/westerly (dark

red), 2020/westerly (dark purple), westerly/easterly (yellow), 2016/easterly (green), and 2020/easterly (orange). The dashed blue lines represent the ratio of 1.

Figure 1 presents the ratio results derived from SABER observations and SD-WACCM-X simulations. In the SABER data (Figure 1a), during the 2016 event, two distinct peaks appear in the lower stratosphere near 22 km and 30 km when comparing the disruption events with the QBOE phase (green lines), possibly indicating relatively less dissipation during the 2016 QBO disruptions. During the 2020 event, the lower peak (~22 km) is close to that during 2016 event, while the upper peak (~30 km) is relative weak to the 2016 event. This may suggest a relatively large dissipation at those heights. The SD-WACCM-X simulations reproduce a similar pattern, although the peak altitudes differ slightly. All simulated ratios remain above 1, which may indicate stronger tidal source activity from the SD-WACCM-X perspective. Overall, these results suggest that during QBO disruptions, zonal wind may result in relative less dissipation processes, thereby affecting DW1 amplitudes.

The discussion of dissipation could be seen in Line 505-525 (in marked-up manuscript) or Line 482-502 (in all-accepted manuscript).

Response to Reviewer 2:

We would like to express our sincere appreciation to the reviewers for their comprehensive assessment and insightful comments, which have been so helpful in enhancing the substance of our work.

1. The authors have included discussion of the 2015/2016 El Nino in relation to the 2016 QBO disruption, though they primarily discuss how the ENSO played a role in causing the QBO disruption. An important additional point is that a substantial fraction of the increased water vapor heating during the 2016 QBO disruption is likely to be due to the El Nino event that occurred during this time. This should be explicitly mentioned in both the abstract and conclusions as well as the discussion (lines 482-489).
Response 1: Thanks for the helpful comments. This suggestion is particularly valuable because the water vapor radiative heating during the 2016 QBO disruption event was strongly modulated by both the disruption itself and the 2015/16 extreme El Niño event. We have added this point to the Abstract, Discussion, and Summary. In particular, in the Discussion section, the paragraph describing how the ENSO and QBO disruption modulate water vapor concentration has been moved above the paragraph on water vapor heating rate, allowing a clearer connection between variations in water vapor concentration and the corresponding heating rate.
The supplement in Discussion could be seen in Line 454-466 (in marked-up manuscript) or Line 433-445 (in all-accepted manuscript).

2. The manuscript contains a number of grammatical and spelling mistakes that need to

be corrected. Below are some example. The authors should carefully edit the manuscript to address grammatical issues.

Response 2: Thanks for the helpful comments. We really appreciated the reviewer for carefully reviewing out manuscripts. We have carefully checked our manuscript and corrected faults.

Line 69: “in south hemisphere” should be “in southern hemisphere” Done

Line 85: “have been proposed could be considered” should be “have been proposed” Done

Line 115: “tidal-gravity wave during” should be “tidal-gravity wave interactions during” Done

Line 340: “Hence, the phase of (1,1) mode is focused.” should be “Hence, we focus on the phase of the (1,1) mode” Done

Line 343: “We apply the method following” should be “We apply the following method” Done

Line 343: “devotion” should be “deviation” Done

Line 345 (and elsewhere): “confidential interval” should be “confidence interval” Done

Lines 390-391: “QBOW about 2 km” should be “QBOW by about 2 km) Done

Line 513: “thick in stratosphere” should be “thick in the stratosphere” Done

Line 516: “tides compare to QBOE” should be “tides compared to QBOE” Done

Line 556: “at subtropical” should be “at subtropical latitudes” Done