In this revised version, three major improvements are introduced:

(1) The relationship between the 2015/16 El Niño and the 2016 QBO disruption is reviewed, with emphasis on how the El Niño event triggered the QBO disruption and how both phenomena jointly influenced the DW1 heating sources, particularly water vapor.

(2) The (1,1) mode of the DW1 is extracted and analyzed, and its amplitude and phase responses to the event are presented in Sections 3.1 and 3.2.

(3) The discussion of mechanisms is expanded. Section 4 is reorganized into three subsections addressing tidal heating, tidal propagation, and tidal–gravity wave interaction. The result of (1, 1) mode water vapor heating is given in Section 4.1. The role of ozone heating is discussed in Section 4.1. The contribution of zonal wind latitudinal shear and gravity wave drag are also discussed in 4.2 and 4.3, respectively.

Major Comments:

1. The authors attribute all of the variability in the DW1 in 2016 and 2020 to be related to the QBO disruptions that occurred during this time period. They thus neglect other possible sources of variability. This is especially pertinent for the 2016 time period, when there was a strong ENSO, which has also been shown to influence the DW1 in previous studies. Given that the DW1 anomalies are significantly stronger in the 2016 case compared to the 2020 case, there could be additional contribution from the ENSO event during 2016. The DW1 anomalies in 2016 may thus not be solely due to the QBO disruption. The authors should consider the potential role of other sources of variability in the DW1 and how these may influence the results.

Response 1: Thanks for the valuable comments. In the current version of the article, we report an increase in radiative heating of water vapor and ozone, then link it to the amplification of DW1. We lack an analysis of the reasons for the increasing in water vapor or ozone.

The 2016 QBO disruption has been confirmed to have a close causal relationship with the 2015/16 extreme El Niño event (Newman et al., 2016; Osprey et al., 2016; Barton and Mccormack, 2017; Coy et al., 2017). The 2015/16 El Niño substantially weakened the subtropical easterly jet, allowing enhanced Rossby wave propagation from the extratropics into the deep tropics near 40 hPa (Barton and Mccormack, 2017). These amplified Rossby waves subsequently broke and deposited momentum near the QBO westerly core, rather than at the climatological zero-wind line, causing a pronounced deceleration. The deceleration gave rise to a persistence of westerlies at 40–15 hPa, preventing the expected transition to easterlies and ultimately leading to the QBO disruption (Newman et al., 2016; Osprey et al., 2016; Coy et al., 2017; Barton and Mccormack, 2017; Kang et al., 2022; Wang et al., 2023). The QBO disruption was accompanied by a marked strengthening of the Brewer–Dobson residual circulation, thereby intensifying tropical upwelling. This upwelling contributed to an upward displacement of westerlies in the tropical lower stratosphere (Coy et al., 2017), modifying the transport and distribution of trace gases such as water vapor. The persistent westerlies also created conducive background conditions for the vertical propagation of DW1. Nevertheless, not all strong El Niño events trigger QBO disruptions. In the 2015/16 case, the QBO westerly wind core was weaker and Rossby wave activity stronger than in other extreme events, such as the 1998 El Niño (Barton and Mccormack, 2017).

For the role of modulating heating source of DW1, after reviewing, we found it a compound effect of 2016 QBO disruption and 2015/16 El Nino event.

In the troposphere, during the 2015/2016 El Nino (Johnston et al., 2022), fractional moisture anomalies are small in the tropical lower troposphere (~2%–3% ONI^{-1}) and increase with height into the middle troposphere. In the upper troposphere and lower stratosphere (UTLS), the positive signal becomes much stronger (up to 10% ONI^{-1}). So, the role of 2015/2016 El Nino contribute most in increasing of the water vapor concentration in UTLS.

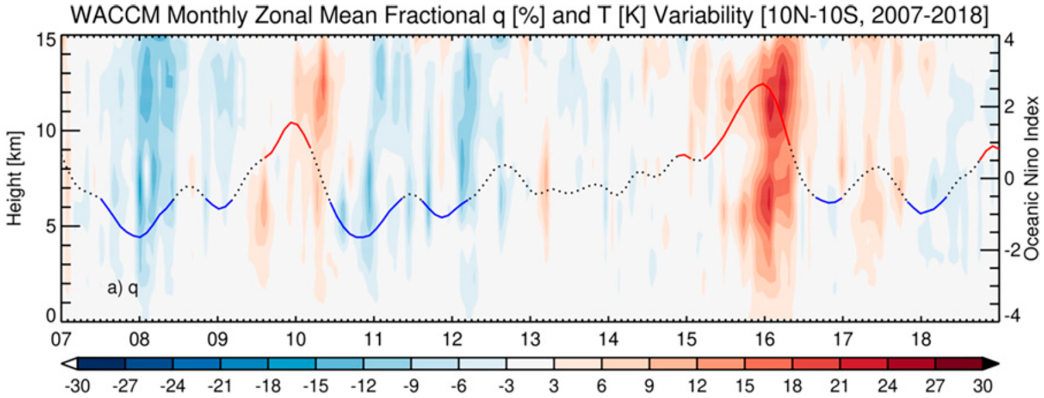
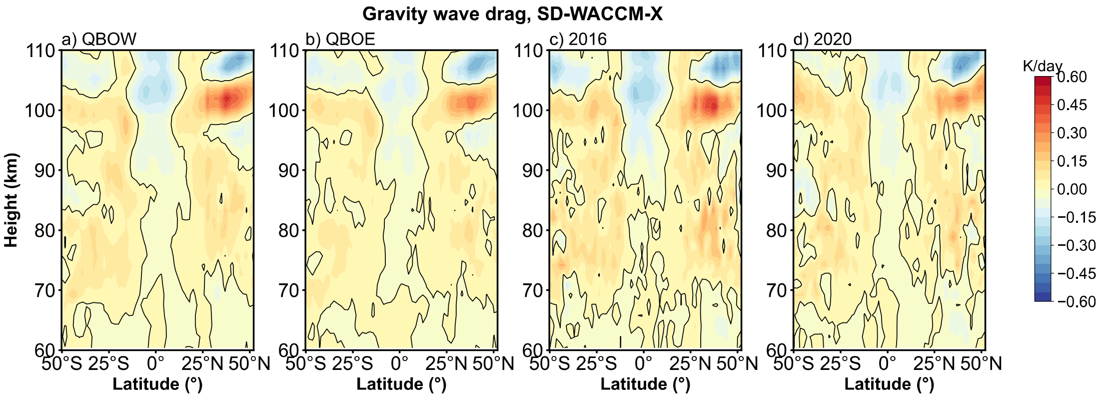


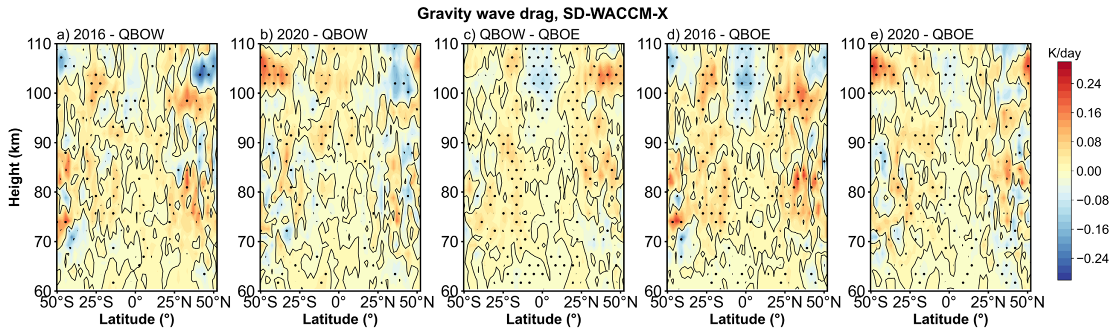
Fig 1. Time–height cross sections of WACCM monthly zonal mean fractional specific humidity (%) from 2007 to 2018 within 10°N–10°S. (Johnston et al., 2022)

The occurrence of 2016 QBO disruption introduces a shear transition from westerly to easterly near 40 hPa, which strengthens tropical upwelling and lowers cold-point temperatures. This dynamical response injects H_2O-poor air into the lower stratosphere, partially offsetting the El Niño–driven moistening. (Diallo et al., 2018). The water vapor concentrations are still above the climatological seasonal cycle under the modulation of these two phenomena.
How the El Niño event triggered the QBO disruption is supplemented in line 48-61 (manuscript).
How both phenomena jointly influenced the DW1 heating sources, particularly water vapor is supplemented in line 369-375 (manuscript).

2. The authors focus on analysis of heating rates to explain the reason for the anomalous DW1 amplitudes during the 2016 and 2020 QBO disruptions. However, previous studies, such as Mayr and Mengel (2005, doi:10.1029/2004JD005055) and Wang et al. (2024, dot:10.5194/acp-24-13299-2024), illustrate the potential importance of tide-gravity wave interactions in the DW1 variability due to the QBO. The manuscript provides no details about the possible influence of tide-gravity wave interactions on the DW1 anomalies during the 2016 and 2020 QBO disruptions. Given these previous studies, the possible impact of tide-gravity wave interactions should also be considered.
Response 2: Thanks for the valuable comments. We miss the effect of tide-gravity wave. In line 83 – 85, we cite some papers to draw out the role of the gravity wave. In discussion part, the analysis of gravity wave (GW) is supplemented. Please see Section 4.3.



Here we give a brief discussion. The latitude-height distribution of gravity wave drag on DW1 in different QBO phases are shown above. We could see that above 105 km GW tend to damp the DW1 amplitude at nearly all latitude. Below ~105 km, the gravity wave tends to damp the DW1 amplitude at equator and strengthen the DW1 amplitude at subtropical. There are differences in the amplitude of gravity wave drag between different QBO phases. We give the drag amplitude differences between different QBO phases. The dots represent the region over 95% statistical significance.



As shown in Figure c, during the QBO westerly phases (QBOW), the damping at equator and strengthening at subtropical is stronger than QBO easterly phases (QBOE). When comparing the 2016 QBO disruption and QBO easterly phases (Figure d), the pattern is similar to the QBO westerly minus QBO easterly. While comparing the 2020 QBO disruption and QBO easterly phases (Figure e), the difference is weaker compared to 2016-QBOE.

3. The ozone heating rates are derived from TIMED/SABER observations. Only a brief statement (lines 99-100) is included for the calculation of the ozone heating rates. Additional details and appropriate references should be included for the calculation of the ozone heating rates.

Response 3: Thanks for the valuable comments. We apply the Strobel/Zhu model (Strobel, 1978; Zhu, 1994) to calculate the heating rate of Hartley band, Huggins band and Chappuis band. The calculation details will be supplemented in Appendix B and section 2.6.

4. The description of the SD-WACCM-X model in Section 2.2 needs to be revised as it is not completely correct. The manuscript states that WACCM-X consists of two parts, WACCM and the TIE-GCM. This is incorrect as WACCM-X is a single model that extends WACCM into the upper thermosphere and includes additional ionosphere and thermosphere processes. These additional processes are largely based on the TIE-GCM,

but it is incorrect to state that the entire upper atmosphere of WACCM-X is the TIE-GCM as there are some differences between the two models.

Response 4: Thanks for the valuable comments. The current manuscript's description of SD-WACCM-X as "consisting of two parts, WACCM and the TIE-GCM" is indeed imprecise. WACCM-X is a single, self-consistent whole-atmosphere model that extends WACCM from the surface to the upper thermosphere/ionosphere (~500–700 km). While many of the thermosphere–ionosphere physics modules (e.g., electrodynamo, O^+ transport, electron/ion energetics) were adapted from the NCAR TIE-GCM, they have been re-implemented within the WACCM-X dynamical core and coupled to WACCM's lower and middle atmosphere through a dedicated interface layer. Consequently, WACCM-X is not simply WACCM plus TIE-GCM; rather, it is a unified model in which the upper-atmosphere processes are integrated into the WACCM framework, with some differences in numerical methods, boundary conditions, and physical parameterizations. We will revise Section 2.2 to make this point explicit. Please see line 131-137 (manuscript).

5. The data availability section should include the availability of the SD-WACCM-X output.

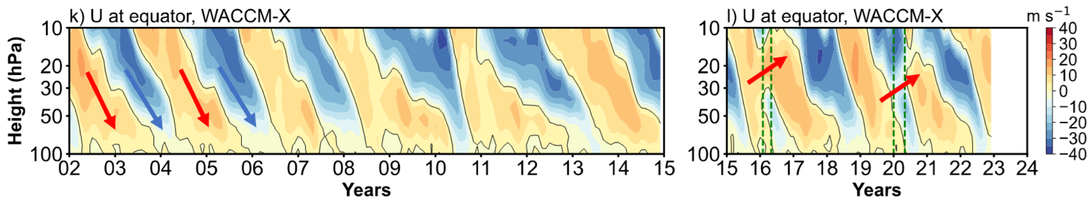
Response 5: We have given it in data availability part.

Minor Comments:

1. Line 15: "in mesosphere and" should be "in the mesosphere and"

Response 1: We have revised.

2. Lines 47-48: This sentence should be revised as it is unclear what is meant by "upward westerly wind" and "upward easterly wind".



Response 2: Thanks for the valuable comments. The normal QBO phases manifests as alternating downward-propagating westerly and easterly winds (red arrow and blue arrow). During the period of disruption event, unique westerly wind occurs and then propagate upward. We want to distinguish between normal downward-propagating and unique upward-propagating, but our sentences are too simple and obscure the meaning.

3. Line 64: "SOBO disruption" should be "QBO disruption"

Response 3: We have revised.

4. Line 90: "sun-synchronal" should be "sun-synchronous"

Response 4: We have revised.