Response to reviewer 1

We are truly grateful to you for your valuable comments and suggestions on our manuscript.

We have carefully read your suggestions and seriously revised our manuscript. Following is our response to your comments.

**Major comment:**

My major concern is that the secondary peaks may just reflect the seasonal variation of tides. It is well known that the tidal amplitude and phase of diurnal/semidiurnal migrating tides show marked seasonality due to the seasonality of background atmosphere and/or excitation sources and that these physical processes are basically linear (e.g., Hagan et al., 1999; McLandress, 2002; Zhang et al., 2006; Mukhtarov et al., 2009; Sakazaki et al., 2013 and many others). Suppose that the amplitude of diurnal tide (with the frequency of $\omega_d$) exhibits an annual variation (with the frequency of $\omega_A$). We can express this modulation formally as

$$A(1+\epsilon\cos\omega_A t)\cos\omega_d t = A\cos\omega_d t + \frac{A\epsilon}{2}(\cos(\omega_A+\omega_d)+\cos(\omega_A-\omega_d))$$

where $A$ is annual mean amplitude of diurnal tide, while $\epsilon$ is a factor of seasonal modulation. Thus, it is expected that the spectral peaks appear at these upper and lower side-band frequencies (i.e., ($\omega_c + \omega_d$) and ($\omega_c$ - $\omega_d$), respectively). So, I do not agree with the authors' view that the spectral peaks at these upper/lower side-band frequencies are the real signals of "third" wave produced by nonlinear wave-wave coupling. I would rather feel that the peaks at ($\omega_c + \omega_d$) and ($\omega_c$ - $\omega_d$) are just manifestation of seasonality of tides.

If they want to really suggest that the third waves do really exist and are caused by non-linear processes (i.e., advection terms), more analysis as well as some numerical experiments would be necessary.

As you pointed out, the tides with modulated amplitudes have their upper and lower side-band frequencies, and we fully agree with you.

1. we discuss this modulation in detail.

Firstly, we present a case analysis to further confirm the features of this modulation. A modulated DT (mDT) wind is constructed as,

$$mDT = (15 + 12\sin\omega_1 t)\sin\omega_2 t$$

where $\omega_1$ and $\omega_2$ are the frequencies of AO and DT, respectively. Figure R1 (only presented in

Response) shows the modulated DT and its Fourier spectrum. As you deduced, these are the upper and lower side-band frequencies around the tidal frequency. Besides, the tidal amplitude just equals the set mean magnitude of 15 $ms^{-1}$, and the amplitudes of the sum and difference frequency components exactly equal half (6 $ms^{-1}$) the set intensity of the annual modulation (12 $ms^{-1}$), indicating no mutual influences between their spectral magnitudes.

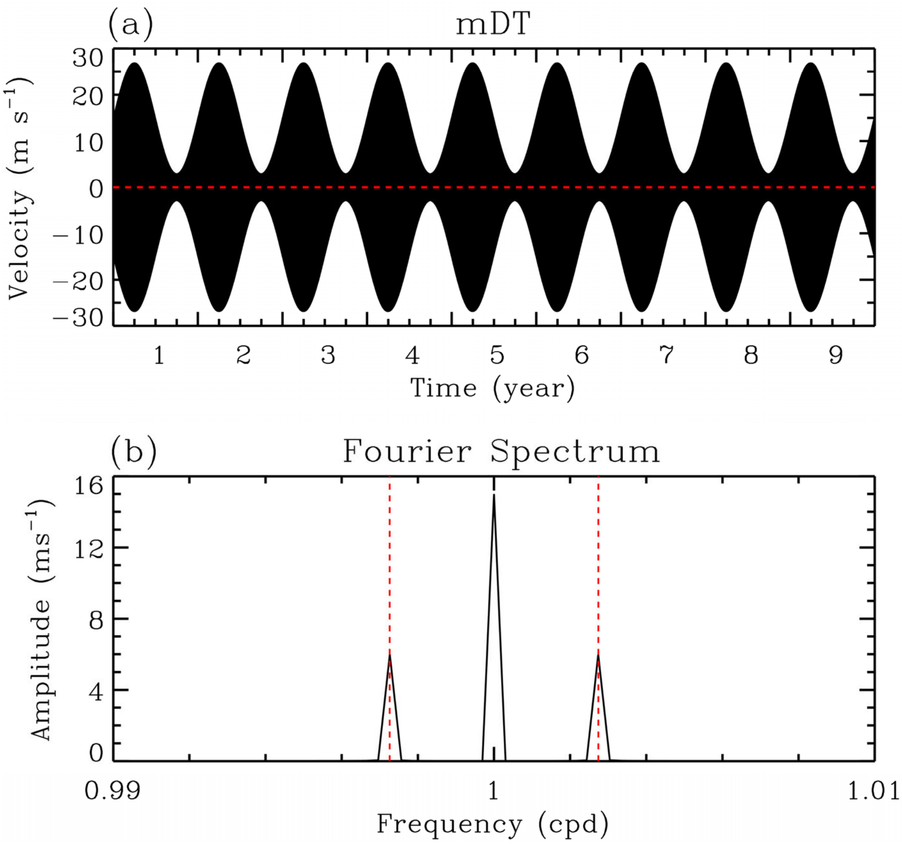


**Figure R1.** (a) Diurnal tidal wind with annual modulation and (b) its Fourier spectrum. The dashed vertical lines are at the sum and difference frequencies between DT and AO.

And then, we extract the DT and SDT from the 9-year zonal and meridional winds from meteor radar observations at Wuhan by fitting. A 3-day sliding window with a 1-day increasement is used, and the fitting is performed when the available data is larger than 70% in a window length. Figure R2 shows the fitted amplitudes of DT and SDT. On the average, the DT is stronger than the SDT, which is consistent with the spectral results in our manuscript. And then, if the fitted-amplitude numbers at an altitude can reach 70% in the 9 years, we make a Lomb-Scargle spectrum analysis on these fitted amplitudes of DT and SDT, which is presented in Figure R3.

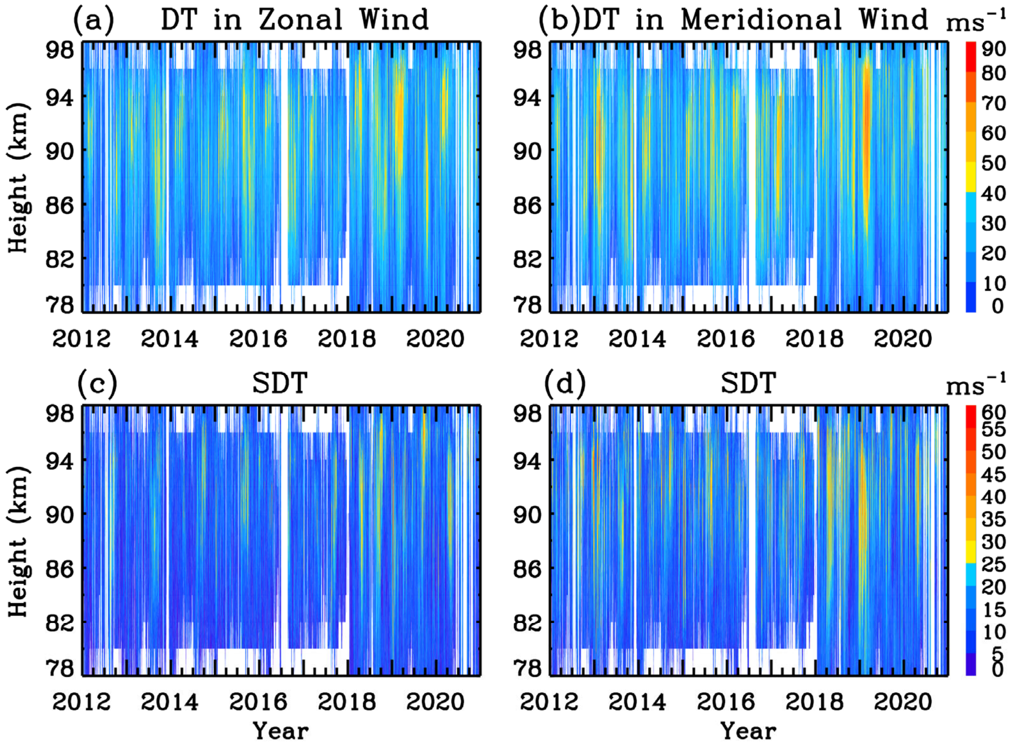


**Figure R2.** Fitted amplitudes of (a, b) DT and (c, d) SDT in (left column) zonal and (right column) meridional winds from meteor radar observations at Wuhan for 9 years.

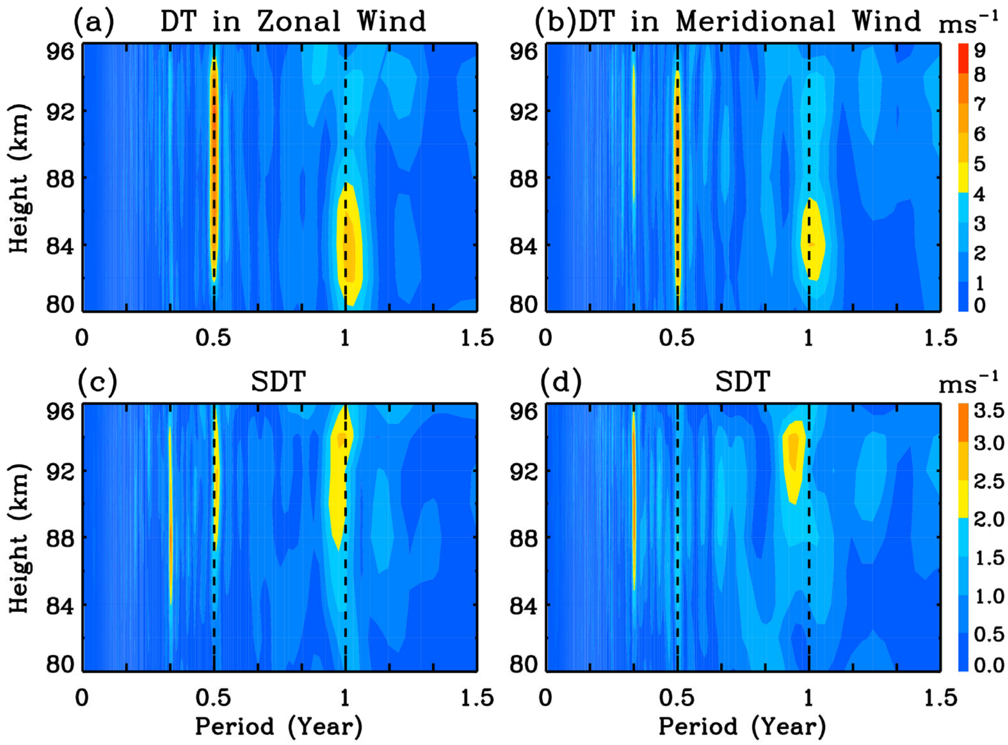


**Figure R3.** Lomb-Scargle spectra of fitted amplitudes of (a, b) DT and (c, d) SDT in (left column) zonal and (right column) meridional winds from meteor radar observations at Wuhan for 9 years. The dashed vertical lines denote the periods of SAO and AO, respectively. The amplitude data at 78 and 98 km are less than 70%.

Next, by comparing Figure R3 with Figures 2-5 in our manuscript, we can note that some results in our manuscript are distinguished from the features of modulation mechanism as follows,

(1) at 90-94 km, the annual modulation of the SDT amplitudes in both the zonal and meridional winds has actually a period slightly less than a year. For instance, in the meridional wind at 90-94 km, the actual period of the annual modulation is 346 days in the Lomb-Scargle spectrum. Figure R4 presents the Lomb-Scargle spectrum of the SDT in the meridional wind at 94 km for 9 years. We mark the sum and difference frequencies between the SDT and the AO (1/365 d) with red dashed lines and between the SDT and the actual annual modulation (1/346 d) with blue dashed lines.

Although the two difference (sum) frequencies are joined together without being separated from each other, their spectral peak is at the difference (sum) frequency of the SDT and the AO rather than at the difference (sum) frequency of the SDT and the modulation (1/346 d). The spectral magnitude at the SDT and AO difference frequency is about 11.6 $ms^{-1}$, whereas, the approximately annual-modulated magnitude of the SDT amplitude is only 2.68 $ms^{-1}$.

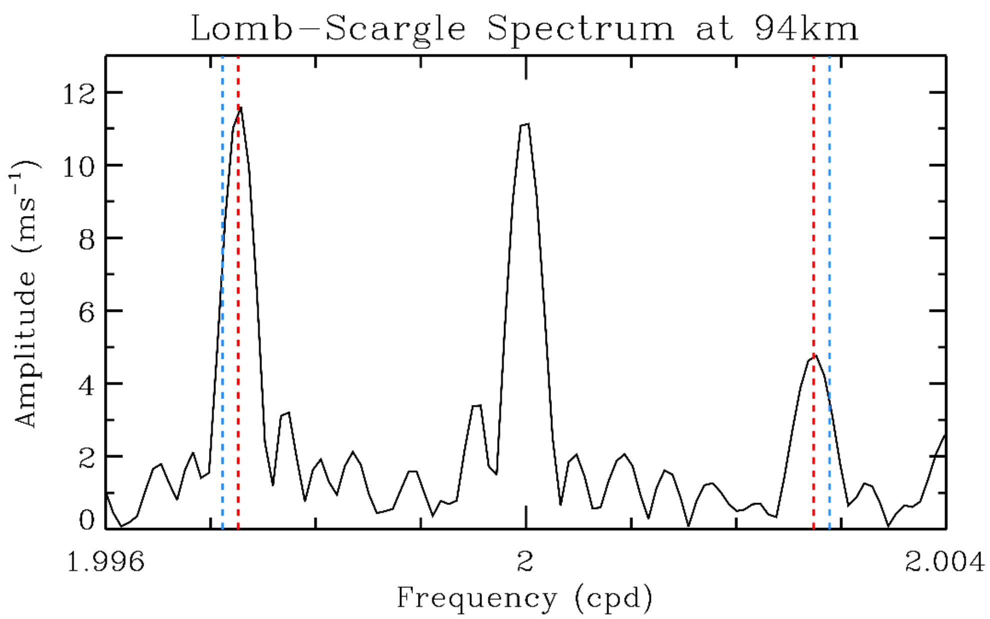


**Figure R4.** Lomb-Scargle spectra of SDT and its upper and lower side-band frequencies in the meridional wind at 94 km for 9 years. The two red vertical lines are marked at the sum and difference frequencies between the SDT and the AO, and the two blue vertical lines are marked at the sum and difference frequencies between the SDT and the modulation (1/346 d), respectively.

(2) at 80-88 km, the annual-modulated magnitudes of the SDT amplitudes in both the zonal and meridional winds are very weak with the values smaller than 2 $ms^{-1}$, nevertheless, the new components at the sum and difference frequencies between the SDT and the AO have the magnitudes of 2-3 $ms^{-1}$, especially, their sum frequency component in the meridional increases from 3 $ms^{-1}$ at 78 km to 8 $ms^{-1}$ at 88 km, shown in Figure 5(b) in the manuscript;

    Similarly, in the meridional wind, the semiannual-modulated magnitude of the SDT amplitudes at 80-96 km is less than 2 $ms^{-1}$, however, the difference frequency component of SDT and SAO increases from 2 $ms^{-1}$ at 78 km to 6.5 $ms^{-1}$ at 96 km, shown in Figure 5(d) in the manuscript;

    Again, in both the zonal and meridional winds at 88-96 km, the annual-modulated intensities of the DT amplitudes are smaller than 4 $ms^{-1}$, but the difference frequency component has the amplitudes of 9-12 $ms^{-1}$ in the zonal wind and 15-18 $ms^{-1}$ in the meridional wind, and the sum frequency component has the magnitudes of 4-8 $ms^{-1}$ in the zonal wind and 7-11 $ms^{-1}$ in the meridional wind, as shown in Figure 4(a, b) from the manuscript.

(3) the amplitudes of the new components can be far stronger than not only the semiannual- and annual-modulated magnitudes of the DT and SDT amplitudes, but also the amplitudes of the DT and SDT themselves, as shown in Figures 4(b) and 5(b) from the manuscript.

Therefore, the comparison above demonstrates that the sum and difference spectral components should mainly be generated from the nonlinear effect rather than the modulation effect.

2. The nonlinear mechanism is described.

As you know very well, the nonlinear interaction originates from the advection terms in the dynamic equations. Based on the theory, modeling and observation, the nonlinear resonant interactions among planetary waves and tides have extensively been investigated, and the nonlinear resonant and nonresonant excitations of gravity waves were also widely studied. According to the same physical mechanism, the resonant interaction between the global-scale atmospheric tides and AO/SAO can be accepted.

Numerical investigation demonstrated clearly that in the resonant and even nonresonant interactions between gravity waves, final energy of the newly generated wave may exceed energy of the primary wave owing to intense energy exchange in the interaction (Huang et al., GRL, 2009; JASTP, 2011). Hence, since the annual- and semiannual-modulated magnitudes in the tidal amplitudes are generally weak, the interaction can provide an explanation for the strong new components, including their amplitude larger than tidal amplitude in our manuscript.

In essence, the atmospheric DT and AO originate from the rotation and revolution movement of the earth. The cycle absorption of powerful radiation causes the stable periods of DT and AO, and relatively, the modulation period of tidal amplitudes may have a small variability in some years due to the changes in water vapor, ozone, circulation and atmospheric temperature and motion conditions. In this case, the DT/SDT, AO/SAO and their sum and difference spectral peaks are exactly located at frequencies where they should be, as shown in our manuscript.

In our manuscript, we show the occurrence of the DT/SDT and AO/SAO interactions in the atmosphere. Nevertheless, there are many unclear aspects in the nonlinear interaction, such as energy exchange intensity and efficiency, why sometimes a stronger sum spectral component but sometimes a stronger difference spectral component, etc. Since these new components are the atmospheric nonlinear response to the earth's rotation and revolution, we hope that more scientists will pay attention to the phenomenon.

3. According to your suggestion, we add the corresponding description in the revision.

"Similar to the interaction of waves in the atmosphere, the interaction between the tides and AO/SAO comes from the nonlinear advection terms in the dynamic equations. Differential absorption of powerful solar radiation is the basic driver of atmospheric motion, and the rotation and revolution movement of the Earth leads to the diurnal and annual variabilities in the atmosphere. In this case, the diurnal and annual periods are stable in the atmosphere, and then the new components are exactly located at their sum and difference frequencies. When considering the seasonality of the tidal amplitudes, this means that there are also their sum and difference spectral components in the spectrum analysis. The investigation (not presented) indicates that the annual and semiannual modulations in the tidal amplitudes are weak, and the modulation can deviate from the period of a year or half a year due possibly to the changes in water vapor, ozone and atmospheric temperature and motion conditions. Hence, these new components originate mainly from the nonlinear dynamic response in the atmosphere to the rotation and revolution movement of the Earth."