SOWER (Soundings of Ozone and Water in the Equatorial Region):

Ozone variations associated with Kelvin Waves in the Tropical Tropopause Layer

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1. Introduction

Trace gases entering the stratosphere from the troposphere usually path through the tropical tropopause layer (TTL). In this region it is known that equatorial waves can largely perturb the tropopause structure; one big perturbation is due to Kelvin waves. Recently, *Flannaghan and Fueglistaler* (2011)[1] put a focus on turbulent mixing by shear-flow instability in connection with Kelvin waves. However, their discussion is based on the reanalysis dataset with a rather coarse vertical resolution (~1.5 km). Here, we explore the ozonesonde archive with a high vertical resolution (~0.2 km) which is provided by SHADOZ project (as describe in Section 2) in terms of dynamical structure of Kelvin waves seen near the TTL. Because photochemical life time of ozone in the TTL is about a few months, so that this can be used for tracer of atmospheric motion. *Fujiwara et al.* (1998, 2003)[2,3] and *Koishi and Shiotani* (2011)[4] have already suggested the importance of turbulent mixing, although their interpretation is based on a few observation results. To overcome the limitation of spatial and temporal coverage of ozone-sondes, composite analysis is applied. This enables us to describe the behavior of ozone associated with Kelvin waves. Furthermore, to avoid the influence from vertical advection accompanied by the waves, we investigate the ozone variation in the isentropic coordinate.

2. Data

We analyzed ozonesonde profiles between 10 degrees bands from the equator of 10 observation stations; they are provided by SHADOZ (Southern Hemisphere ADditional OZonesondes). About 3000 vertical profiles of ozone and temperature are interpolated to 0.2 km vertical bins. To categorize the phase of Kelvin waves, we used temperature (T) and zonal wind (U) data at 100 hPa level from the ERA-Interim dataset provided by the ECMWF for the period 1998 to 2009.

3. Method

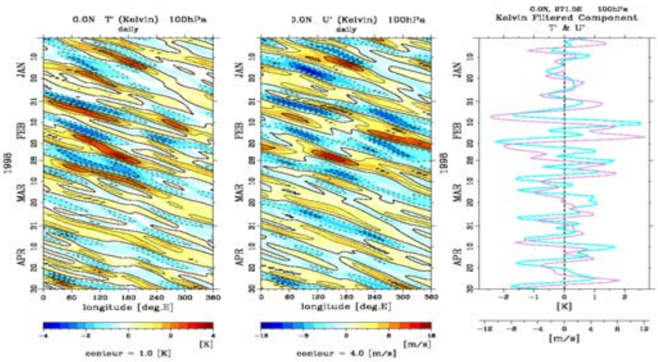


Figure 1: Longitude time sections of (left) 100 hPa temperature anomaly, (middle) 100 hPa zonal wind anomaly, and (right) their time series at 271.5 degrees east calculated by Kelvin wave filtered component of ERA-Interim.

To capture Kelvin wave signal, the filter is applied by the eastward traveling component of zonal wave numbers 1-10 and period from 4-23 days in the spectral-frequency domain (same as *Suzuki and Shiotani* (2008)[5]). Longitude-time sections of filtered 100 hPa temperature anomaly (T') and zonal wind anomaly (U') are shown in the left and the middle panels of Figure 1. The time series of T' and U' at 271.5 deg. E are shown in the right panel of Figure 1. We can see T' (light blue line) leads U' (pink line) by about a quarter cycle at fixed location. Then we use these time series at 10 locations, which is corresponding to sounding sites provided by SHADOZ, for calculating wave properties.

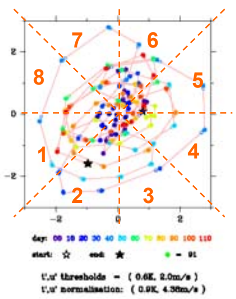


Figure 2: Normalized T'-U' diagram.

Figure 2 is an example of the normalized T'-U' diagram. The trajectory using the time series of Figure 1 rotates anticlockwise in the T'-U' plane, indicating the signal of eastward traveling waves in this location and period. Because it is theoretically expected that T' is in quadrature with U', we can identify the phase of Kelvin waves from this diagram. After we put the phases into 8 categories, we made composite analyses for ozone and temperature profiles in terms of the phase evolution of Kelvin wave.

4. Results in the height coordinate

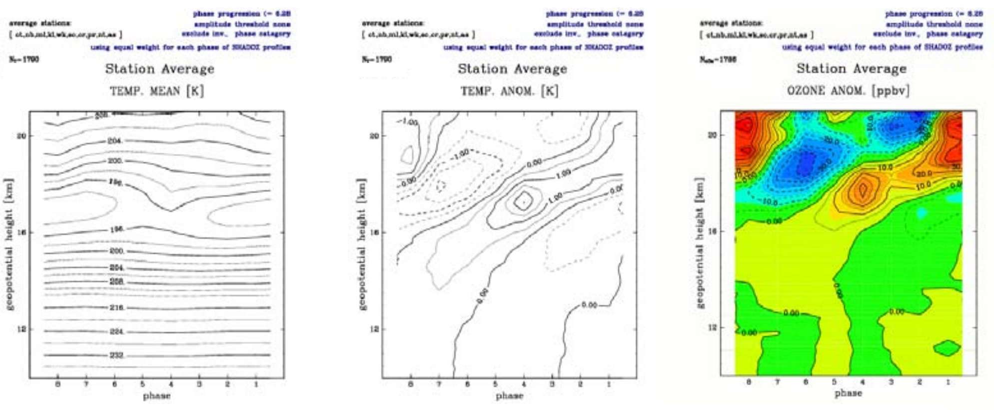


Figure 3: Phase-height sections of (left) temperature, (middle) temperature anomaly, and (right) ozone anomaly. Negative values are indicated by dashed lines.

Figure 3 is the phase-height cross sections using composite profiles of temperature and ozone. In these cross sections or, in other words, the longitude-height cross sections for eastward traveling Kelvin waves, the composite temperature profiles show clear warm and cold anomalies in relation to the Kelvin wave in the height coordinate. The phase line of temperature anomalies tilts eastward, indicating the downward phase propagation of the Kelvin wave structure. For the ozone composite, deviations from the height average also indicate the downward phase propagation. This in-phase relationship between temperature and ozone is probably due to vertical advection. Because the undulation of isentropic surfaces associated with Kelvin waves should not be negligible, we further described the ozone variations in the isentropic coordinate.

5. Results in the isentropic coordinate

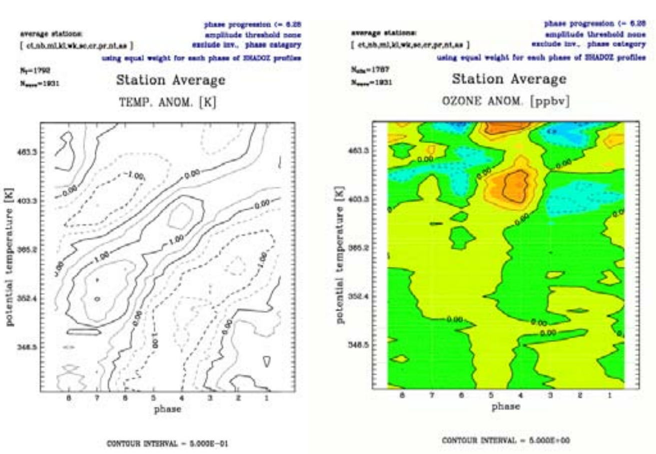
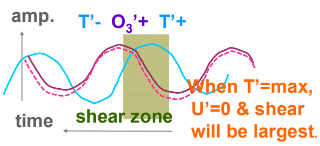


Figure 4: Phase-isentrope sections of (left) temperature anomaly and (right) ozone anomaly. Negative values are indicated by dashed lines.



In the isentropic coordinate as seen in Figure 4, the temperature anomalies still show the phase progression associated with Kelvin waves. As for the ozone anomalies, however, the phase progression almost disappears, but the enhancement of ozone can be seen in the warm phase around 420 K level. Focusing on the positive ozone anomalies around 420 K level, the enhancement of ozone corresponds to the transition from positive to negative temperature anomalies. This suggests that the turbulent mixing may occur in the shear zone particularly for the warm anomaly.

6. Conclusion

We investigated the observed variation of ozone around the TTL in relation to large-scale waves. These results provide the consistent picture between diffusion process and ozone enhancement in connection to Kelvin waves. There may be a large shear zone near the maximum of temperature. Further research is required to focus on the structure of temperature and wind associated with waves.

References

1. ***Flannaghan, T. and S. Fueglistaler*** **(2011),** ***GRL***, **38, doi:10.1029/2008GL033641.**
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3. ***Fujiwara, M., et al.*** **(2003),** ***GRL***, **30, doi:10.1029/2002Gl016278.**
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