Space-time variability of equatorial Kelvin waves and intraseasonal oscillations around the tropical tropopause

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Recently some research efforts have been focusing on the tropical tropopause layer (TTL) where dynamical and chemical properties of the atmosphere gradually change from tropospheric to stratospheric features [1]. They have been conducted mostly from the view point of stratosphere-troposphere exchange (STE), since the TTL is the primary exchange region of mass and chemical species between the troposphere and the stratosphere. In particular for water vapor, temperature variation in the TTL is one of the most important factors to control the dehydration mechanism of air entering the lower stratosphere from the upper troposphere. The Kelvin wave and the intraseasonal oscillation (ISO) are dominant variations around the tropical tropopause. In spite of their importance in variations around the TTL, seasonal and longitudinal characteristics of the Kelvin wave and the ISO have not been clearly documented yet. Using the European Centre for Medium-Range Weather Forecasts (ECMWF) 40-year reanalysis data for the period September 1957 through August 2002, seasonal and longitudinal variations of the Kelvin waves and ISOs in temperature and zonal wind around the tropical tropopause are investigated. The outgoing longwave radiation (OLR) data for the proxy of deep convections are also examined because of their possible influence on the dynamical fields in the TTL.

The space-time spectral analysis was first performed for the temperature and zonal wind fields around the tropical tropopause, and two dominant spectral regions in the eastward propagating domain are found: one for Kelvin waves with zonal wavenumbers from 1 to 10, periods from 4 to 23 days and equivalent depths from 8 to 240 m and the other for ISOs with wavenumbers from 1 to 10 and periods 23 to 92 days. To investigate space-time variability of Kelvin waves and ISOs we reconstructed the grid data for the two spectral windows through the Fourier forward and inverse transforms, and calculated the square amplitude at each grid point. We mostly focused on the zonal wind field, because the vertical structure in zonal wind is less variable than that in temperature; consequently the results for zonal wind seem to be unaffected by the seasonality around the tropical tropopause particularly seen in the temperature field. Kelvin wave activities in zonal wind are vigorous during two seasons, one in January to March and the other in June to August around the upper troposphere up to 100 hPa. In contrast, there is a clear difference in the maximum longitude (Figure 1); at 100 hPa it is located in the eastern hemisphere from the Indian Ocean to the western Pacific, but at 150 hPa and below it is located in the western hemisphere from the eastern Pacific to the South America. To further investigate a relation to deep convection as a source of these disturbances we calculated activities in the OLR data for the Kelvin wave spectral window. Then we found that the activities in OLR do not correspond to those in zonal wind, suggesting that the Kelvin wave activity in zonal wind may not necessarily depend on convection.

As to the change in the maximum altitude of Kelvin wave activities in the upper troposphere we refer to the climatological background zonal wind which is easterly in the eastern hemisphere and westerly in the western hemisphere. Kelvin waves in the westerly region possibly suffer damping when the background zonal wind is getting close to the zonal phase speed. In such a condition the group velocity slows down, and the zonal wind amplitude is increasing. On the contrary in the eastern hemisphere, the amplitude of Kelvin waves propagating vertically in the easterly can increase, because of sudden increase in the Brunt-Väisälä frequency N [2]. Another point to note at 100 hPa is that the maximum Kelvin wave activity is large in the westward of the maximum easterly wind. It would be due to distortion or dissipation of Kelvin waves propagating into the active convective region which is located around the maximum easterly.

The ISO activities in zonal wind at 100 hPa are seen in the western Pacific during northern winter, which are somewhat larger than those of the Kelvin waves. For this spectral window the ISO activities in zonal wind and OLR are related with each other, indicating that the eastward moving disturbance with the ISO timescale is somehow coupled with the organized convective system such as the Madden-Julian oscillation (MJO).

The lifecycle of Kelvin waves is further investigated in relation to background wind and convective activity. To pick up Kelvin wave events we set the threshold as the easterly component with -1σ at each height (e.g., -2.79 m s^{-1} at 100 hPa). The total number of extracted Kelvin waves is over 3000 for 45 years. The Kelvin wave amplitudes do not show large difference in longitude, but Kelvin wave events can be seen in a specific region at each height, which is closely related to Figure 1: at 100 hPa the waves mostly appear around 15°W - 60°E and disappear around 15°E - 120°E; at 200 hPa they appear around 150°E - 90°W and 75°W - 0 °, and disappear 180° - 45°W and 60°W - 45°E, respectively.

From the composite analysis the Kelvin waves appearing around 165°E - 125°W at 200 hPa seem to be generated by latent heat energy released from deep convection over the Indian Ocean and the western Pacific (Figure 2-A). These waves propagate eastward through the westerly wind and decrease their amplitudes. After that, weak signals still continue to propagate with acceleration over the South American Continent. At 100 hPa the Kelvin waves appearing around 15°W - 60°E seem to be generated in the convective region over the South American Continent, and the signals propagate eastward and get into another convective region which is located over the African continent or the Indian Ocean and western Pacific Ocean (Figure 2-B). To the west of the South American Continent, the signals could be traced upstream: some waves found at 200 hPa could propagate up to the 100 hPa-level (Figure 2-A'). The OLR and easterly wind anomalies propagate eastward in phase around the appearance region: the convectively coupled Kelvin waves are included in these waves found at 100 hPa over the Indian Ocean and the western Pacific (Figure 2-C).

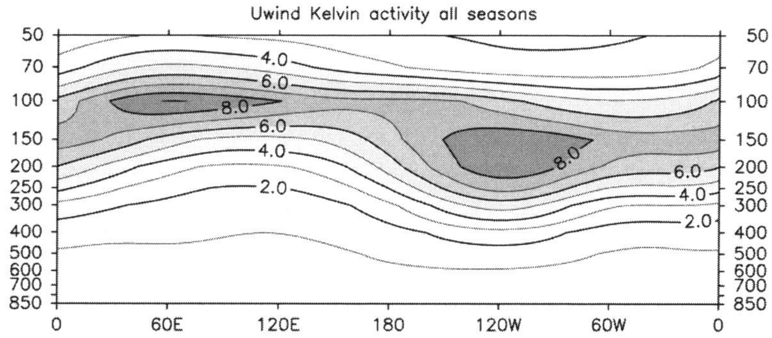

Figure 1: Longitude-height section of the annual mean Kelvin wave activities of zonal wind. A contour interval is 1.0 $m^2 s^{-2}$, and shading begins above 4.0 $m^2 s^{-2}$.

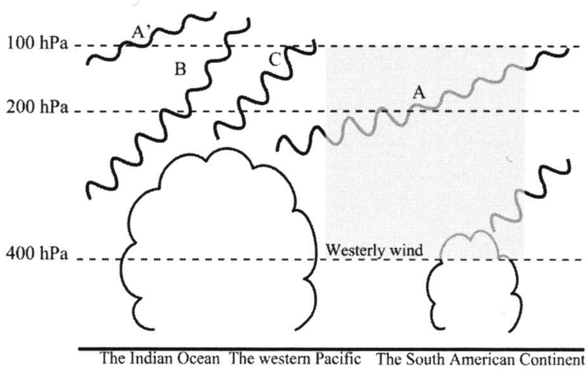

Figure 2: Schematic longitude-height diagram illustrating the source and passing through regions of Kelvin wave. Wavy lines represent Kelvin waves. Shading represents the westerly region. Letters of A (A'), B and C are described in the text.

REFERENCES

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[2] Shiotani, M., and T. Horinouchi (1993), *J. Meteorol. Soc., Jpn.*, *71*, 175- 182.