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ABSTRACTS (PH D THESIS)

Variability in the temperature structure around the tropical tropopause and its relationship with convective activity

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Temperature around the tropical tropopause is one of the most important factors controlling the aridity of air in the stratosphere. Low temperatures generally occur to the east of tropical active convection around the equator and to the west in the subtropics, forming a horseshoe-shaped structure. This structure resembles a stationary wave response known as the Matsuno-Gill pattern, which is induced by the heating generated by the convective activities. This study investigates the variability of the horseshoe-shaped temperature structure and its relationship with the convective activities by using contemporary reanalysis and outgoing longwave radiation (OLR) data.

In the first part of this study, an index representing a zonally asymmetric temperature structure in the tropical tropopause has been established, and then its variability associated with convective activity has been investigated using ERA-40 and NOAA/OLR data. Particularly during the northern and southern summers, low temperatures persist over the tropics and extend north-west and south-west. These low temperatures form a horseshoe-shaped structure that resembles the Matsuno-Gill pattern, which consists of the Rossby response in the western part and the Kelvin response in the eastern part. Regarding the horseshoe-shaped structure, two preliminary indices were defined. As a representative of the Rossby response, an index HSI-R($x;\ t$) was calculated from a curvature of the 100-hPa temperature along the meridional circle at the equator; as a representative of the Kelvin response, an additional index HSI-K($x;\ t$) was calculated from a zonal gradient of the 100 hPa temperature along the equator. The two indices were then combined into one index HSI-1 as a result of the EOF analysis using HIS-R and HSI-K values. The index HSI-1 projected a positive linear relation between HSI-R and HSI-K; hence, its negative value should suggest clear existence of the horseshoe-shaped temperature structure.

The negative value of HSI-1 is frequently observed in the Eastern Hemisphere, and its seasonal cycle is closely related to convective activities in and adjacent to the monsoon areas, including the Southern Asian monsoon (SoAM) and the North Pacific monsoon (NPM) domains during the northern summer and the Australian monsoon (AUM) domain during the southern summer. Convective activities in the SoAM and NPM domains may induce two horseshoe-shaped structures individually, and a superposition of the two structures can produce a longitudinally elongated horseshoe-shaped structure during the northern summer. The El Niño-Southern Oscillation (ENSO) cycle is shown to greatly affect variations in HSI-1 values and convective activities, particularly during the southern summer. As discussed in previous studies, low temperatures form the horseshoe-shaped structure over the equator in the western Pacific during the southern summer for the non-El Niño years, while low temperatures shift eastward and becomes more zonally elongated and meridionally narrow for the El Niño years. The longitudinal phase difference between the OLR and HSI-1 minima in the El Niño years is larger than that observed in the non- El Niño years.

During the northern summer, the interannual variability in HSI-1 in the NPM domain is affected by the ENSO cycle in the previous winter, which is consistent with a previous study on convective activities in the NPM area. In the SoAM domain, interannual variation in HSI-1 values is not significantly related to convective activities in the monsoon domain. It was detected that the HSI-1 value in the SoAM domain is mainly controlled by the isolated high temperatures observed around 60°E over the equator during July-August, which are surrounded by the horseshoe-shaped structure. The interannual variation in the HSI-1 values is related to the ENSO cycle. The variation in the high temperature may be related to an anticyclone in the upper troposphere over the Tibetan Plateau. However, further discussion is necessary on the detailed mechanism of formation and variability of the isolated high temperatures.

To summarize the first part of this study, it has been clearly revealed the seasonal and interannual variability of the temperature structure around the tropical tropopause and its relationship with convective activities over the monsoon regions with respect to the horseshoe-shaped temperature structure. Relations to shorter time scale oscillations such as intraseasonal oscillation, traveling Kelvin waves and active/break cycles in the Asian monsoon circulation are interesting topics for further investigation. Moreover, numerical experiments are required to validate the use of the index representing the horseshoe-shaped temperature field with respect to convective activities.

In the second part of this study, space-time variations of the tropical convective activity and temperature around the tropical tropopause has been investigated associated with the intraseasonal oscillation (ISO), such as the Madden-Julian Oscillation (MJO), by using NOAA/OLR and ERA-Interim data. In the case study of the 1984/85 southern summer, which is during the weak (normal) ENSO period, various types of the convective propagation features associated with the ISO are observed in the unfiltered OLR field. These convective activities accompany low temperatures to their east in the tropics and to their west in the subtropics around the tropical tropopause. These low temperatures form a horseshoe-shaped structure, which resembles the Matsuno-Gill pattern. The 72 ISO events that occur during the southern summer from January 1979 to December 2011 were first selected with respect to the time series at the reference point (102.5°E) where variations of the band-pass-filtered OLR averaged over 5°N-15°S are largest. Cluster analysis was then performed with Ward's method by using the locus of the unfiltered OLR minima in the ISO events, and the propagation features were categorized into five clusters, which consist of 20, 20, 18, 12, and 2 events.

Most of the events in Clusters 1 and 2 occur during the La Niña and El Niño periods, respectively, and those in Clusters 3 and 4 during the weak ENSO periods. In association with the ISO, the convective activities observed in the unfiltered OLR field in Clusters 1 and 3 have a relatively slow speed (<2 m/s) and propagate to 120°E and 135°E, respectively. The faster (~ 4 m/s) convective activities in Clusters 2 and 4 propagate into the central Pacific. The composite SST field reveals the following facts about the convective propagation. During the weak ENSO periods (Clusters 3 and 4), the propagation speed is slow when the SSTs over the western Pacific are relatively low. During the El Niño periods (Cluster 2), as the eastern edge of the warm pool extends over the date line, so does the active convection. To investigate space-time variability in the horseshoe-shaped temperature structure associated with the ISO, the horseshoe-shaped structure index (HSI-1) was used; the index was defined in the first part of this study. The composite HSI-1 fields have similar features to those of OLR, located about 10°-20° degrees west of the active convective area. Both the ISO life cycle and event-to-event variation in the HSI-1 values are significantly correlated with those in the unfiltered OLR values. Those results imply that the convective heating associated with the ISO induces the horseshoe-shaped temperature structure around the tropical tropopause.

Low temperatures at 100 hPa change accordingly with the HSI-1 minima at least in the ISO life cycle. Furthermore, the strength and location of the temperature minima at 100 hPa are different among the ISO clusters. These results could suggest that the different types of the ISO would be different impacts on the troposphere-stratosphere exchange such as the dehydration process depending on their types, considering the previous studies which investigated the possible influence of the ISO and horseshoe-shaped structure on the troposphere-stratosphere exchange process in the TTL. Diagnostic interpretation of reanalysis data and model simulations revealed that much of the upwelling in the TTL is forced by the dissipation of tropical waves such as the Rossby waves. Therefore, the upwelling in the TTL may occur over the horseshoe-shaped temperature structure associated with the ISO.

In the second part of this study it has been clearly revealed the intraseasonal variability in the convective activities and temperatures around the tropical tropopause during the southern summer by employing cluster analysis according to the propagation features of the convective centers. A better understanding of lower troposphere conditions that would induce variations in the propagation features of the convective activities is needed.

Throughout this study it is clearly confirmed that the horseshoe-shaped temperature structure around the tropical tropopause is induced by the heating generated by the convective activities. These results could improve the understanding on the TTL dynamics and, consequently, the troposphere-stratosphere exchange process. The methodologies developed in this study are expected to contribute to future tropical studies. The horseshoe-shaped structure index should become a powerful diagnostic tool for investigating the temperature distribution in the tropical tropopause. As the future work, it would be interesting to compare the tropical tropopause temperatures derived from some reanalysis data sets and climate models by using the horseshoeshaped structure index. The method to categorize the ISOs should be a very helpful to study convectively coupled tropical dynamics. Relationship to the intraseasonal oscillation during the northern summer is an interesting topic for further investigation.