Dynamical characteristics of mesoscale disturbances around Asian monsoon anticyclone and its influence on Stratosphere-Troposphere exchange

*Arata Amemiya[1], Kaoru Sato[1]

1.Graduate School of Earth and Planetary Science, Tokyo University

Recent studies on the stratosphere-troposphere exchange of tracers have focused on the importance of the Asian monsoon anticyclone (hereafter 'AMA'), which is planetary-scale, thermally driven circulation dominating the upper troposphere and lower stratosphere (UTLS) over South and Southeast Asia (Randel et al., 2010). On 360-380K isentropic surfaces, in most cases, the AMA is surrounded by a boundary between the tropospheric air inside and the stratospheric air outside. Isentropic mixing between inside and outside the AMA is suppressed by the strong anticyclonic circulation, which corresponds to the maximum in PV gradient acting as a mixing barrier (Ploeger et al., 2015). On the other hand, the AMA itself has a large intra-seasonal variability including synoptic-scale disturbances and vortex-shedding due to instability (Popovic and Plumb, 2001), which are probably essential processes that lead to irreversible mixing. In this study, we explore dynamical characteristics of synoptic-scale disturbances around the AMA, focusing on a vertical flow.

We used ERA-Interim reanalysis data for June-September, 2011-2015 with the horizontal resolution 1.5^{o}x1.5^{o}. Because of possible large differences in the UTLS region among reanalysis data sets, we also performed the same analyses using JRA55 and MERRA to confirm the results.

First, the intermittent nature of the occurrence of a large PV air in 5-20^{o}N on the southern flank of the AMA is confirmed. The air with large stratospheric PV is formed as an occasional cutoff of mid-latitude stratospheric air and is advected from the northeastern part of the AMA ('in-mixing'). The positive anomalies of PV averaged over 0-20^{o}N on 370K decay gradually during westward migration, suggesting that in-mixing is essentially irreversible. Thus, we next focus on individual events of PV disturbances and associated meridional circulation, which is likely important for the irreversible diabatic mixing.

On 150 hPa level, it seems that most high PV anomalies appear with a downward flow. This feature can be understood as a low-latitude version of a well-known tropopause descent around a westerly jet, which is seen also on the northern flank of the AMA. Similar results are obtained from different reanalysis data.

Next, this characteristic vertical flow pattern is examined from a perspective of the balanced jet dynamics. Even in the low latitude UTLS region, the horizontal flow roughly satisfies the geostrophic balance because it is dominated by easterly jet. This means that the meridional circulation on a plane perpendicular to the geostrophic wind can be diagnosed using the Sawyer-Eliassen equation, which is based on a balanced-jet approximation (Hoskins, 1975).

$$N^2 \partial^2\psi/\partial y^2 + 2S^2 \partial^2\psi/\partial y \partial z + Fs^2(\partial^2\psi/\partial z^2 - \psi/4H^2) = Q_y$$

Note that Q_y is regarded as the forcing by the balanced flow. A previous study on the tropopause folding around the cold-front jet (Uccelini et al., 1985) successfully reproduced a spatial pattern of the meridional flow using this equation. On the northern flank of the AMA, a similar pattern of Q_y is observed around the meandering jet, which is characterized as a vertical dipole across the jet exit region. However, on the southern flank, Q_y is not always consistent with the vertical flow pattern. Instead, we found that it can be explained as moist symmetric instability. Figure 1 shows snapshots of PV, vertical flow, equivalent potential temperature and absolute angular momentum. Isopleths of the latter two quantities are inclined southward closely each other around 15^{o}-25^{o}N, 125-250hPa. This implies the existence of oblique instability forming a vertical flow pattern observed near the tropopause.

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