Numerical Experiments on Stratosphere-Troposphere Two-Way Dynamical Coupling in the Tropics through Organizations of Moist Convective Systems

*Shigeo Yoden[1], Hai Bui[2], Takahiro Banno[1]

1. Division of Earth and Planetary Sciences, Graduate School of Science, Kyoto University, 2. Geophysical Institute, University of Bergen

Recently, we started a new international research activity on Stratospheric And Tropospheric Influences on Tropical Convective Systems (SATIO-TCS) under WCRP/SPARC. It focuses on stratosphere-troposphere (S-T) two-way dynamical coupling in the tropics, where moist convection and its large-scale organization in the troposphere could be influenced by the stratospheric variations, such as stratospheric sudden warming events, the equatorial quasi-biennial oscillation (QBO), or anthropogenic cooling trend in the lower stratosphere, as revealed by some observational studies. For example, Nishimoto and Yoden (2017) made a statistical analysis on the influence of QBO on the Madden-Julian oscillation (MJO) during boreal winter in neutral ENSO periods from 1979 to 2013, and showed that the composite OLR anomaly for a particular MJO phase over the Maritime Continent has a larger negative value and slower eastward propagation with a prolonged period of active convection in the easterly phase of QBO than in the westerly phase.

The tropical dynamics is largely different from the counterpart in the extratropics where dry quasi-geostrophic dynamics prevail. Multi-scale dynamics of moist convection and its organizations are likely to play a vital role in determining the tropospheric response to the stratospheric variations, but numerical model studies from such viewpoint are still limited. Thus, we had performed a series of numerical experiments on radiative-moist convective quasi-equilibrium states in a highly-idealized two-dimensional regional model of an S-T coupled system with explicit moist convection under a periodic lateral boundary condition without Coriolis effects, in which self-sustained oscillations dynamically analogous to the QBO were obtained (Yoden et al. 2014). Modulation of moist convective systems is associated with the QBO-like oscillation of the mean zonal wind, as alternative appearance of squall-line- or back-building-type precipitation patterns, and vertical momentum transports associated with slant-wise moist convection and convectively generated gravity waves are periodically modulated in the oscillation (Nishimoto et al. 2016). Downward influence of the QBO-like oscillation on organized moist convective systems was further investigated in a series of experiments that control the vertical shear of the mean zonal wind with a nudging term (Bui et al. 2017).

Recently, we have performed numerical experiments in a three-dimensional minimal model framework that produces a QBO-like oscillation in a radiative-moist convective quasi-equilibrium state. The computational domain is rectangular (640 km x 160 km, 5 km grid size; Bui et al., 2019), or square (100 km x 100 km, 1 km grid size), without Coriolis effects under doubly periodic boundary conditions. In these experiments, an oscillation with a period of about 300 days emerges in the stratosphere, both in the domain-averaged zonal wind and meridional wind. Synchronization of the zonal and meridional winds is characterized as an anti-clockwise rotation of a skewed spiral feature with height in the horizontal wind hodograph. The QBO-like wind oscillation penetrates into the troposphere with large reduction of oscillation amplitude, and influences tropospheric temperature anomalies and precipitation with an irregular period of about 100 days. Heavy precipitation is associated with positive temperature anomalies.

The simulation reveals three types of precipitation patterns; fast-moving back-building- and squall-line-type patterns, and isolated quasi-stationary type clusters, which is newly identified in this three-dimensional model. The zonal-height cross sections of the meridionally averaged clouds and relative humidity for this pattern show clear-sky areas with low humidity without shallow clouds, whereas shallow clouds exist over the entire domain including non-precipitating areas with high humidity for the fast-moving two patterns. Intermittent self-organization of convective systems into quasi-stationary type and transition back to the fast-moving back-building- or squall-line-type patterns are fundamental characteristics of self-aggregation in the three-dimensional model.

References

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Keywords: Stratosphere-Troposphere Dynamical Coupling, Moist Convective Systems, Tropical Meteorology

