論 文 の 内 容 の 要 旨

Self-sustained interannual variability of the Australian summer monsoon system and its remote influence on East Asia

（夏季オーストラリアモンスーン系の自己維持的な年々変動とその東アジアへの遠隔影響）

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Sea surface temperature (SST) variability in the tropics, such as El Niño-Southern Oscillation (ENSO), changes convective activity and thereby influences the extratropical atmosphere through exciting quasi-stationary Rossby waves. Due to its slow evolution compared to the intrinsic time scale of the large-scale atmospheric motion, it provides seasonal predictability to not only the tropics but also extratropical regions under its (remote) influence. Many studies have shown that the interannual variability of cumulus convective activity around the Maritime Continent exerts significant impacts on the wintertime East Asian climate. However, it is known that the convection variability in that region is hardly maintained by local SST anomalies in boreal winter, although it is partly influenced by the remote SST variability such as ENSO. Under the lack of the SST forcing onto the atmosphere, a significant fraction of the interannual variability in seasonal-mean convective activity may be generated through coupling with the atmospheric circulation variability without any local and remote forcing by SST anomalies.

Since the center of strong convection around the Maritime Continent in boreal winter (austral summer) is located in northern Australia (NAUS) associated with the Australian summer monsoon (AUSM), the origin of SST-unforced convection variability may be anomalous AUSM activity. Many studies have examined the interannual variability of AUSM from the viewpoint of the relationship with SST variability. They found that the influence of tropical SST anomalies on NAUS rainfall becomes weaker after the AUSM onsets, resulting in a decrease in prediction skill for the monsoonal rainfall. Nevertheless, the fundamental properties and mechanisms of the internal variability of AUSM have not been clarified yet.

In the present study, we elucidate the fundamental properties and maintenance mechanisms of the interannual variability in seasonal-mean strength of the AUSM. We decompose the tropical convection variability in the monsoon season into SST-forced and SST-unforced components based on the observational data and outputs from atmospheric general circulation models. The decomposition demonstrates that the SST-unforced convection variability dominates over NAUS, as a manifestation of the internal AUSM variability. We also confirm that this AUSM rainfall variability is not directly produced by modulated activity of the Madden-Julian Oscillation or tropical cyclones, although summertime NAUS rainfall undergoes significant intraseasonal variability.

We investigate how the anomalous convective activity over NAUS is maintained associated with the strengthening of the AUSM, through a linear decomposition analysis for latent heat flux anomalies and moist static energy (MSE) budget analysis. The intensified low-level monsoonal circulation in stronger AUSM years enhances surface evaporation over the tropical southeastern Indian Ocean (SEIO) through the strengthening of surface wind speed. This effect is found to be twice as large as the countering effect by the slightly lowered SST, and the resultant net enhancement of moisture supply into NAUS can sustain the anomalous AUSM convection. This positive feedback loop for the self-sustained AUSM variability is named the “wind-evaporation-convection (WEC)” feedback. Our results from the MSE budget analysis reveal that anomalous moisture evaporated from the tropical SEIO is advected into NAUS and consumed by the enhanced convective activity, supporting the notion that the wind-induced enhancement of evaporation is essential for sustaining the anomalous AUSM activity. The WEC feedback owes its effectiveness to the climatological westerlies associated with the AUSM system, prevailing only in the austral summer monsoon season.

For the WEC feedback mechanism to operate effectively, the negative SST anomalies over the tropical SEIO associated with the stronger AUSM must be weak enough to prevent evaporation from being reduced. In fact, both the seasonal deepening of the ocean mixed layer and wind-induced anomalous subsurface downwelling act to suppress SST anomalies. The intensified monsoon westerlies under the stronger AUSM modulate the subsurface vertical motion and associated entrainment at the mixed-layer bottom in the tropical SEIO, thereby acting to damp the negative SST anomalies. This damping effect on SST anomalies induced by ocean dynamics is quantitatively verified through the mixed-layer heat budget analysis based on a long-term simulation with a high-resolution ocean general circulation model.

In addition to the WEC feedback under the effect of dynamical air-sea interaction, we also point out a potential role of atmosphere-land interactions over the Australian continent between terrestrial evaporation and soil moisture anomalies, through which the rainfall anomaly in the inland areas can be maintained from January into February. We therefore hypothesize that the AUSM variability is essentially a locally self-sustained air-sea/land coupled variability within the monsoon system.

The present study shows that the interannual variability of AUSM not only affects the local weather conditions in Australia but also exerts significant remote impacts on wintertime East Asia. Although the center of anomalous convective activity is located in the Southern Hemisphere, we find a distinct quasi-stationary Rossby wave train with the northeastward wave-activity propagation from the Maritime Continent and a meridional dipole pattern of geopotential height anomalies over the midlatitude western North Pacific, which is similar to the West Pacific (WP) pattern. At the southern center of action of the dipolar anomaly pattern to the east of Japan, almost 25% of the interannual variance of wintertime 500hPa geopotential height is linked to the AUSM variability. The cyclonic (anticyclonic) anomaly to the east of Japan associated with the strong (weak) AUSM intensifies (weakens) the East Asian winter monsoon, resulting in colder (milder) winter in East Asia. This suggests that the interannual variability of AUSM unlikely forced by SST anomalies can limit the seasonal predictability in wintertime East Asia.

Possible dynamical mechanisms for the cross-equatorial teleconnection are proposed on the basis of the observations and numerical experiments with a linear baroclinic model. The anomalous divergent winds in the upper troposphere forced by the enhanced convection over NAUS cross the equator and reach the Asian subtropical jet, inducing the Rossby wave sources along the jet due to the anomalous divergent wind across the strong gradient of absolute vorticity and associated upper-level convergence near the jet axis. The quasi-stationary Rossby wave train with northeastward wave-activity propagation from the subtropics excites dipolar height anomalies similar to the positive WP pattern through energy conversion from the background state. The positive WP-like pattern thus formed acts to intensify the East Asian winter monsoon and thus generate significant cold anomalies in East Asia.