論文の内容の要旨

A study on the background sea surface temperature field and moist processes contributing to the realization of the Madden-Julian Oscillation

(マッデン・ジュリアン振動の発生に寄与する海面水温背景場と湿潤過程の研究)

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The Madden-Julian Oscillation (MJO) is prominent intraseasonal variability in the tropics which is now widely accepted to be an eastward proceeding envelope of convective activity coupled with circulation. However essential factors for the realization of the MJO and what modulates their properties are still controversial. This study hypothesizes that for an MJO-like large-scale atmospheric circulation to develop and to persist on an intraseasonal timescale, a background state longer than the intraseasonal timescale should provide long-standing conditions that support the development of MJO convection. Based on this hypothesis, I investigated for an environment favorable for the development of the MJO and analyzed how MJO properties are affected by the differences in the environment that they develop in.

An environment supporting MJO development was investigated by classifying MJO-like atmospheric patterns as MJO and regionally confined convective (RCC) events. Comparison of MJO and RCC events showed that even when preceded by a major convective suppression event, convective events did not develop into an MJO when the large-scale buildup of moist static energy (MSE) was inhibited. The difference in the MSE accumulation between MJO and RCC was related to the contrasting low-frequency basic state

sea surface temperature (SST) pattern; the MJO and RCC events were associated with anomalously warm and cold low-frequency SSTs prevailing over the western to central Pacific respectively. Differences in the SST anomaly field were absent from the intraseasonal frequency range of 20-60 days. The basic state SST pattern associated with the MJO was characterized by a positive zonal SST gradient from the Indian Ocean (IO) to the western Pacific (WP), which provided a long-standing condition that allowed for sufficient buildup of MSE across the IO to the WP via large-scale low-level convergence over intraseasonal and longer timescales. The results suggested the importance of such basic state SST, with a long-lasting positive zonal SST gradient, for enhancing convection over a longer than intraseasonal timescale to realize a complete MJO lifecycle.

Subsequently, how MJO propagation speed is affected by the background SST was investigated through constructing a tracking method of MJO propagation and comparing the background states that MJO occurred in by their propagation speed. Analysis on the fastest and the slowest 10 MJO events revealed differences in the moist processes that occurred during each of the MJO groups. MSE budget analysis showed that long-lasting deep convection develops across the IO region to the WP region for the slow MJO with preceding build-up of MSE from horizontal advection, and positive feedback to convection from latent and radiative heating terms. On the other hand, for the fast MJO, deep convection developed only for about 10 days, and occurrence of moist processes supporting convection appeared to be confined to the IO. The differences in the accompanied moist processes in slow and fast MJO were associated with different oceanic states that they occurred in; the slower events were associated with a condition of low-frequency SST distribution with a positive zonal gradient from the IO to WP. Low-frequency SST associated with fast MJO were much the same across IO to WP. Significant differences in the SST pattern were not recognized in the intraseasonal timescale of 20-60 days. Furthermore, the extension of the analysis of propagation speed to rest of the events revealed that the relationship between zonal SST gradient and propagation speed was not a tendency restricted to the fastest and the slowest group but is an overall relationship that is displayed by all of the events. Taking note that the presence of zonal SST gradient in low-frequency range has the potential to enhance large-scale zonal circulation, the component of the zonal wind associated with the background circulation was also analyzed. The analysis showed that there is a tendency for MJO to propagate slower when the background large-scale zonal circulation was stronger, implying that slower MJOs is embedded in enhanced large-scale zonal circulation.

Following this analysis, the reproducibility of such relationship of MJO properties with the background fields in a model simulation was investigated using climate simulation data from an Atmospheric Model Intercomparison Protocol (AMIP) type run with the Nonhydrostatic Icosahedral Atmospheric Model (NICAM). It was found that the simulated MJO events tended to be slower than reality and were biased in the season of their occurrence to late boreal winter. The causes for the systematic slow bias and decrease in the number of boreal summer MJO were related to the difference in monsoonal circulation in the NICAM-AMIP run. Although it appeared that the strength of the background circulation related to MJO propagation speed was being modulated by different reasons than in reality, MJO in NICAM-AMIP still also showed the relationship between its propagation speed and the SST gradient and circulation indices that supported results from real-world MJO.

In summary, this study identified characteristics of the MJO that distinguishes them from other tentative convective activities in the differences in the MSE build-up processes. Such differences were related to the low-frequency SST pattern in which, MJO was associated with a positive zonal SST gradient from IO to the WP. Investigation of how such SST pattern affects the MJO properties showed that MJO propagation speed becomes slower as the zonal SST gradient increases in both observation and NICAM-AMIP simulation. The results of this study indicated the importance of the influence of the low-frequency SST on the MJO and implied that MJO exists as part of the large-scale circulation driven by the low-frequency zonal SST pattern.