論文の内容の要旨

Cross-scale Interaction in the Realization Processes of the Madden–Julian Oscillation

(マッデン・ジュリアン振動の顕在化過程における

スケール間相互作用に関する研究)

氏　名　　髙 須 賀　大 輔

The Madden–Julian oscillation (MJO) is characterized by slow eastward propagation of organized convective envelopes coupled with a planetary-scale zonal overturning circulation over the Indo-Pacific warm pool. Since the MJO is the most dominant intraseasonal variability in the tropics and globally affects various meteorological and climatological phenomena, there have been dedicated efforts to reveal physical processes of the MJO and improve its predictability. While previous studies have primarily focused on MJO-scale dynamical and thermodynamical variations to propose the mechanisms of MJO initiation and propagation, there are also some evidences which implicate the importance of synoptic-scale and interannual variabilities to MJO dynamics. However, our knowledge of such cross-scale processes in MJO realization is piecemeal compared to MJO-scale process-oriented understanding. The aim of this study is to clarify the detailed mechanisms which explain MJO convective initiation and subsequent propagation based on the multi-scale framework involving active roles of synoptic-scale equatorial waves and the mutual relationship between the intraseasonal and interannual variability.

In Chapter 2, mainly from observational data analyses of an MJO event initiated in December 2017 during the field campaign of the Years of the Maritime Continent Project, it is found that

dynamical variations associated with mixed Rossby–gravity waves (MRGs) are directly responsible for MJO convective initiation and propagation in the Indian Ocean (IO). The in-situ intensive observation and reanalysis data have captured westward-propagating MRG-related meridional wind signals in the mid-troposphere over the IO during the MJO-suppressed phase. Before MJO convection is activated, tight MRG–convection coupling is enhanced in accordance with zonal wave contraction due to weak mid-tropospheric convergence in the western IO. Basin-scale midlevel moisture resurgence caused by MRG shallow circulations is also observed. These processes stimulate the MRG wave packet formation in the lower-troposphere and successive triggering of MJO convection via MRG dynamics, with the eastward MRG group velocity corresponding to MJO propagation. This MRG-driving mechanism is also confirmed to a certain degree in other two MJO events initiated in October and November 2011, although it is not so evident in the October event.

In Chapter 3, the robustness and inevitability of the MJO–MRG relationship is explored by statistical analyses of 47 MJO events realized in the IO during December–March in 1982–2012. On average, MJO convection is initiated in the southwestern IO (SWIO), where strong MRG–convection coupling is statistically found. Further classification suggests that initiation of 26 of 47 MJO cases is related to more enhanced MRG activities than any other convectively coupled equatorial waves. MJO initiation for MRG-enhanced cases is characterized as convective triggering by low-level MRG circulations which develop via active downward energy dispersion related to upper-tropospheric baroclinic conversion, consistent with Chapter 2. This is supported by the modulation of MRG structure associated with upper-level background zonal convergence, and plentiful moisture advected into the western IO. In addition to this MRG-induced convection in the SWIO, mid-tropospheric pre-moistening in the IO due to MRG shallow circulations and MJO convective propagation driven by low-level MRG winds are also recognized as in Chapter 2. The comparison between the MRG-enhanced events and all others suggests that intraseasonal cross-equatorial circulations during the MJO-suppressed phase in the IO, which is possibly originated from the equatorial asymmetry of background convective activities, may be the source of MRGs. Whether the MRG-related processes are effective or not may depend on the strength in this asymmetry modulated by the low-frequency variability and seasonal march.

Chapter 4 focuses on the diversity of MJO initiation regions associated with the intraseasonal and interannual variability to understand favorable environments for MJO initiation comprehensively. MJOs initiated in the IO (IO-MJO), Maritime Continent (MC-MJO), and

western Pacific (WP-MJO) are targeted. Both observations and a series of 15-yr perpetual-boreal-winter experiments using an atmospheric GCM reveal the following two points: (i) horizontal moisture advection mainly by equatorial intraseasonal circulations is commonly important before MJO initiation in every region, and (ii) the variety of MJO source basins is partly generated by the change of where advective moistening is more likely to work due to the modulation of background circulations forced by interannual SST variability. For IO-MJO cases as the canonical MJO, because climatological ascent in the MC–WP can support intraseasonal convective organization there, resultant convective suppression around the western MC can lead to moisture advection to the IO via intraseasonal low-level easterly anomalies. MC-MJO cases are more favored under the eastern-Pacific (EP) El Niño-like condition, because SST-induced background suppressed convection in the eastern MC can cause the eastward shift of the intraseasonal circulation and convective pattern seen in IO-MJO cases and result in efficient moistening and subsequent development of convection around the western MC. WP-MJO cases tend to occur under the central-Pacific (CP) Niño-like state and dipole SST structure in the southern IO. This is owing to selective moistening in the WP associated with westward intrusion of enhanced disturbances as a result of background convective enhancement in the WP–CP and suppression in the southeastern IO and EP.

Taken together, my results suggest that potential roles of interannual, intraseasonal, and synoptic-scale variations in the mechanics of the MJO are to affect the existence of equatorial intraseasonal zonal circulations related to the MJO, to provide a necessary environment for MJO realization through allowance of sufficient moistening, and to directly trigger MJO convection and assist moisture transport in a favorable environment for the MJO, respectively. This study has emphasized that considering the hierarchical relationship ranging from synoptic-scale variations to interannual variabilities is important to the precise and comprehensive understanding of MJO realization.