学 位 論 文 内 容 の 要 旨

Dissertation Abstract

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学 位 論 文 題 名

Title of dissertation

Responses of the East Asian summer monsoon to mid-latitude forcings: effects of Indian summer monsoon heating and Tibetan Plateau land surface processes

（中緯度の強制に対する東アジア夏季モンスーンの応答： インド夏季モンスーンの対流加熱とチベット高原の陸面過程の効果）

The East Asian summer monsoon (EASM) stands out as a significant component within the Asian summer monsoon system. It is characterized as a northeastward extension of a rainband, leading to spatiotemporally persistent rainfall affecting East China, the Korean Peninsula, and Japan in summer. As a subtropical hybrid-type monsoon, large scale circulation of EASM is marked by multiple meridional circulation cells extending from tropical to mid-latitude regions. This feature distinguishes the EASM from the classical-type monsoon (e.g., the South Asian monsoon) with a single meridional cell confined to the tropics, which is largely determined by the land-sea thermal contrast. This feature allows the EASM to interact with various influences of remote factors originating from tropical, mid-latitude, and even polar regions. The complex influencing factors of EASM make its forecast continues to present as a challenging issue, even with increasing attention being paid to extreme weather events such as droughts and floods. For instance, during the abnormal EASM in 2020, operational forecasts started one month ahead are unsatisfactory in predicting its intensity, being 3 to 4 times lower than the observed values. Therefore, it is still motivated to further explore and expand our understanding of the EASM, as the effectiveness of mitigation strategies is strongly influenced by the accuracy of operational forecasts. To achieve this, two mid-latitude forcings and their potential interaction with EASM are presented in this dissertation, which are less understood previously.

The circumglobal teleconnection (CGT) is one of the forcings considered, which is recognized as the dominant summer circulation pattern as a wave train across the Eurasian continent, originating in Western Europe, moving to the northern Indian subcontinent, and reaching East Asia. The evidence from previous studies showed that Indian summer monsoon (ISM) is the primary trigger of the CGT wave train at interannual time scale, the consequent influence of CGT wave train acts as a bridge between the ISM and the EASM. This process, if effective and robust, has the potential to increase the predictability of the EASM. Nonetheless, the monthly and seasonal mean of summer precipitation in the ISM and EASM do not exhibit a long-term coherence during the past few decades; instead, their relationship is non-stationary. This non-stationary might primarily lie on that the monthly to seasonal mean precipitation hinder the signal of the ISM–EASM connection, and therefore this dissertation aims to investigate it at a subseasonal time scale in early summer (June).

The subseasonal lead–lag composite analysis relative to the abnormal ISM heating suggests a possible synchronization between ISM and EASM, namely an EASM rain band appears and grows rapidly after the anomalous ISM heating. The upper-level circulation pattern denotes a potential interaction between CGT wave train and ISM behind this synchronization. The diabatic heating released from ISM precipitation perturbs the air near the westerly jet stream, triggering a Rossby wave trapped within it. This Rossby wave travels along the westerly jet stream to the East Asian sector, with the wave phase orthogonal to the CGT wave train initially, and gradually reverts to CGT pattern in the following days. These features are seen in observation, 100-member ensemble climate model simulation output, as well as a simplified model simulation with

imposed ISM heating. Furthermore, the prevailing poleward flow in the East Asian troposphere due to the ISM-induced Rossby wave leads to enhanced mid-tropospheric warm advection and substantial lower-tropospheric moisture transport to the EASM, contributing to the formation of the rain band. Further analysis suggests that ISM heating may act as a trigger or reinforcer of the EASM rain band, contingent on structure of the westerly jet stream. These findings highlight the importance of accurately predicting the ISM to help improve the prediction of EASM.

The investigation on another mid-latitude forcing relates to the interannual variation of soil enthalpy over the Tibetan Plateau (TP), which reflects thermal conditions at the land surface, including soil temperature and soil moisture. In recent years, the study of land surface processes in the climate system has grown in popularity due to advances in modelling capabilities, improved observations, and a better understanding of the role of land in climate variability. In particular, previous findings have emphasized the critical effect of accurate representation of land characteristics for improved seasonal forecasting. Here, singular value decomposition (SVD) is used to identify a delayed influence of TP land surface processes on EASM. Through homogenous regression, the first SVD mode (36.87 %) highlights the ISM–EASM connection, while the second SVD mode (32.13 %) shows a coupling of the May cold TP with a June horizontal wet-dry-wet East Asian precipitation pattern. The observations from in situ meteorological stations based on second SVD mode suggest that the TP soil enthalpy has the ability to retain the sign of the heat capacity in response to the anomalous atmospheric temperature, which potentially be one of the mechanisms involved in the delayed impact. Soil memory appears to be particularly significant in the central western TP, which accompanies the initiation zone of a Rossby wave pattern propagating along the westerly jet stream. The Rossby wave affects the upper-level circulation pattern in East Asia, potentially modulating the EASM precipitation. The climate model simulations also show that the central western TP has a more pronounced soil memory effect compared to other regions within the TP. These results illustrate the possibility of the delayed influence of anomalous TP soil conditions on the EASM, which provides value-added insights for improving seasonal forecast initialization strategies.

In summary, this dissertation explored two mid-latitude forcings and their potential impacts on the EASM activity: the subseasonal ISM heating and the interannual TP land surface processes. The current study at subseasonal timescale revealed that the ISM–CGT interaction serves as a bridge between the ISM and EASM in early summer, and it contributes to rain band formation over EASM region. Therefore, the results suggest the subseasonal ISM heating could be one of the optimal predictors of the EASM onset and intensity, as well as the associated drought and floods event for East Asian countries. Furthermore, the research proposed the delayed impact of TP soil enthalpy on EASM, which is found to exert a significant soil memory effect particularly in the central western TP. This effect includes the storage of the heat anomalies given from the atmosphere, and it can further interact with the atmosphere in the subsequent month. The results indicate the importance of accurately representing TP soil processes for initializing seasonal forecasting. Overall, this dissertation suggests the improved representations of ISM precipitation and TP soil processes are essential for EASM prediction capabilities. The incorporation of these processes contributes to better mitigation strategies for the socio-economic of East Asian countries under the complex EASM variability. The future works should focus their interactions with the processes arisen from lower atmosphere (e.g., air-sea interaction) and the optimal way to represent them in the numerical simulations.