（雛型）博士学位論文内容の要旨

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学位論文題名	Climatological study on precipitation characteristics over the Indian monsoon region and their interactions with land surface features: Insights from convection permitting climate simulations （インドモンスーン域における降水特性とその地表面特性との相互作用に関する気候学的研究：対流解像気候シミュレーションからの知見）
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【論文の内容の要旨】

The India summer monsoon precipitation exhibits different scales of variabilities, for example, diurnal, intra-seasonal, and inter-annual variability. Among these variabilities, the fundamental mode of tropical climate variability is the diurnal cycle of convection. Concerning to summer monsoon, the diurnal cycle of convection is an essential triggering process that develops and organizes the precipitation systems and contribute to the spatial and temporal distribution of monsoon precipitation.

These features of the diurnal convection and precipitation system development are not well represented in the global and regional climate models over different monsoon regions. Such uncertainty in the diurnal convection representation questions the fundamental reliability of the simulated physical process in climate models. These questions have encouraged to explore for the reasons behind the unpredictability of Indian monsoon diurnal convection in climate models, which is not much focused in the past.

Current research is based on the observations and modelling techniques to diagnose the observed diurnal cycle in the tropical monsoon convection and to

understand the importance of its representation in the climate models. After simulating the diurnal cycle convincingly in the regional climate model, we utilize the opportunity to explore the sensitivity of diurnal precipitation characteristics to the land surface conditions over heterogeneous surfaces of India.

This research begins with the observational understanding of the diurnal cycle of convection in terms of precipitation and its characteristics during summer monsoon by utilizing satellite observations 21-year (1998-2018) climatology (TRMM-3B42 V7). The diurnal cycle in climatology shows peak precipitation during the afternoon/evening over land and early-morning over the Bay of Bengal. These climatological diurnal patterns show some exceptions near-certain topographic features and coastal regions. For example, overland mid-night/early-morning diurnal precipitation peak is noted near the transition's region of Ganges Plains and the Himalayan foothills, near the central-east and south-east coast of India. These mid-night/early-morning diurnal peaks are associated with the propagating convective systems.

Afterward, the observed diurnal cycle feature during the Indian monsoon is investigated in the global and regional climate models. The evaluation reveals uncertainty in the representation of diurnal characteristics, for example, noon precipitation peak and high frequency of precipitation events, unlike observations. This error in diurnal precipitation representation is mainly associated with the model horizontal resolution and cumulus parameterization. Even so, the high-resolution regional climate models could not capture the diurnal cycle of precipitation. Instead, cumulus parameterizations in the different climate models have simulated varying diurnal cycle spatial patterns that challenge to look for the impact of different cumulus schemes.

This challenge to understand the sensitivity of the diurnal cycle of precipitation to the different cumulus parameterization is explored over Indian monsoon precipitation with a suite of 30 regional climate experiments. These sensitivity experiments expose the uncertainty in the present generation cumulus parameterizations that simulate diurnal characteristics with the high frequency of precipitation events over each grid and poorly represent the organization of the precipitation systems, unlike observations. These fundamental problems in the cumulus parameterizations arise due to consideration of closure assumptions and trigger functions that promotes linear growth of diurnal convection. In fact, the diurnal growth is explicitly non-linear. This leads to a foundation to simulate regional climate model explicitly without cumulus parameterization to avoid those assumptions.

To understand the impact of with/without cumulus parameterization on the diurnal convection, a suite of season-long 18 regional climate experiments are conducted at different model horizontal resolutions. These experiments establish that the diurnal precipitation characteristics of the Indian summer monsoon are more dependent on diurnal convection explicit representation and convincingly simulates diurnal cycle close to observation by without cumulus parameterization experiments. A clear difference in the simulated precipitation systems is evidenced when convection is explicitly represented, for example, high intensity localized, and organized precipitation systems are simulated by high resolution without cumulus parameterization (convection-permitting) experiments rather than with cumulus parametrization. Convincing the reproducibility of diurnal precipitation systems is attributed to the better diurnal simulation of simulated monsoon low-level circulation and its convergence.

The successful simulation of the diurnal cycle by high resolution convection-permitting experiments promotes some opportunity to explore the sensitivity of diurnal precipitation characteristics to the surface heterogeneities like topographic features and land surface conditions over India. Land surface heterogeneity influences the heat flux calculation by altering roughness length that, in turn, controls the convection initiation. This understanding of heterogeneous surface features may change in the soil moisture limited regimes. For example, dry and wet surface limited regimes impact on the diurnal precipitation characteristics is explored in a suite of 30 experiments. These experiments demonstrate that the wet surfaces favour low-intensity and high frequency of precipitation events during noon/afternoon than dry surfaces. Further analysis shows that wet surfaces show a scale-dependent and Brown ocean effect. For instance, short-duration precipitation events increase at noon and maintain their state for long-duration until night by consuming moist energy from the evaporating wet surface.

The results presented in this research concerning Indian summer monsoon diurnal convection suggests that 1) convection-permitting simulations has the convincing reliability in representing the convection, and 2) Land surface features and conditions are essential forcing's that need to be adequately represented to simulate diurnal convection accurately. These two aspects contribute to better monsoon convection simulation.