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Wissenschaftliche Zusammenfassung der kumulativen Dissertationsschrift

Basic physical mechanisms for monsoon failure in past and future climate

In this work, I first present simulations with a coupled climate model of intermediate complexity, CLIMBER-3 α , that project monsoon rainfall around the world to increase quasi-linearly with global warming in the coming centuries. While this is generally consistent with many other studies, the atmospheric component of CLIMBER-3 α is based on a simplified statistical-dynamical approach, and may not sufficiently represent all processes that are relevant for the response of monsoon circulations to rapid and intense climate change. Therefore, this study attempts to identify those physical mechanisms that are of first-order importance for large-scale monsoon dynamics and their response to external changes.

I perform a scaling analysis of the heat and moisture budgets of the Earth's major monsoon systems, based on reanalysis data and theoretical considerations. I find that, during the monsoon season, a self-amplifying feedback involving the advection and release of latent heat is essential for sustaining monsoon rainfall after the surface land-sea thermal contrast has ceased. I frame this moisture-advection feedback in a minimal conceptual model and show that it leads to a threshold behaviour with respect to changes in the system's energy budget. In particular, when either net radiation over land or specific humidity over the adjacent ocean region fall short of a critical value, no conventional monsoon circulation can exist. I thus define a domain of existence for continental monsoon rainfall, and estimate the threshold values within the restrictions of the conceptual model. I demonstrate the applicability of this concept to abrupt and persistent monsoon shifts observed in paleoclimatic records.

To understand monsoon failure occurring on shorter timescales and within the domain of existence, I develop a minimal theory of intraseasonal monsoon dynamics. Supported by observations and by results from a comprehensive global climate model, the core assumption of this theory is that the positive moisture-advection feedback and its interaction with the smaller-scale eddy field render the circulation inherently unstable. I apply this theory to an ensemble of millennial climate simulations and show that both multi-decadal variability and projected future trends in Indian summer monsoon (ISM) rainfall can be reproduced with a simple stochastic model of the inherent instability, modulated by ambient climate conditions only during the onset period. A projected increase in ISM failure in response to a global warming scenario can thus be readily explained by a shift in central Pacific mean spring-time climate that persistently alters the initial conditions for internal ISM dynamics. I thereby propose a novel perspective on monsoon variability as the result of internal instabilities modulated by pre-seasonal ambient climate conditions.

In summary, the results in this thesis offer a simplified framework for the investigation of both long-term (permanent) and short-term (seasonal) monsoon failure, including the basic physical mechanisms that lead to a non-linear response of the monsoon system to external changes.

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