Diurnal Variation of Monsoon Precipitation and Water Cycle in a Global Content: A Challenge to Climate Models

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Abstract

As indicated by the global distribution of seasonal mean values and variance, northern summer (JJA) rainfall occurs largely over the Asian monsoon western tropical Pacific region. The water vapor budget of the hemisphere (60ºE-120ºW) covering this region (which is designated as the Asian monsoon hemisphere) was used to illustrate the contribution of the Asian monsoon to the global hydrological cycle. Climatologically, the Asian monsoon hemisphere contributes 50% more than the extra-Asian monsoon hemisphere (120ºW-60ºE) to global precipitation. Therefore, part of this excessive rainfall in the Asian monsoon hemisphere is supported by water vapor diverged out of the extra-Asian monsoon hemisphere and converged toward the former hemisphere. Based on this hemispheric water vapor budget, it is clear that the Asian monsoon hemisphere is a sink region of water vapor and the extra-Asian monsoon is a source region. Water vapor budgets of both hemispheres exhibit diurnal variations. Although amplitude of diurnal variation mode is an order of magnitude smaller than that of precipitation itself, an out-of-phase, east-west seesaw of precipitation and water vapor flux exchange is observed between the two hemispheres. Variations of global precipitation follow those of the Asian monsoon hemisphere because it contributes more to global precipitation than the extra-Asian monsoon hemisphere. Nevertheless, roles played by the two hemispheres in the global hydrological cycle are not changed by the diurnal variation mode.

Because the Earth rotates in an eastward direction, the immediate atmospheric response to the wavenumber-1, east-west differential solar heating/cooling at the surface is the westward propagation of the global divergent circulation. Diurnal seesaw variations in hydrological variables of the hemispheric water vapor budgets between the Asian monsoon and the extra-Asian monsoon hemisphere are caused by this westward propagation of the global divergent circulation diurnal mode. The tropical atmosphere is conditionally unstable, while the troposphere in the middle to high latitudes is climatologically stable. Thus, the atmospheric response to the surface solar heating in triggering convection/rainfall is faster in the tropics than in the middle to high latitudes. On the other hand, the heat capacity contrast between east-west land and ocean, and between land (mountain range) and air enables the land to be warmed up by the solar heating faster than water and air. A collaboration of these two differential responses to the surface solar heating forms a clockwise rotation in the diurnal variation of continental-scale rainfall.

Performance of three global climate models (NCAR CCSM, GSFC GEOS, JMA MRI) in simulating diurnal variations of the global precipitation and water-vapor budget are validated against observational analyses. The most serious bias of model simulations are in phases of the westward propagation and the continental-scale clockwise rotation of rainfall and potential function of water vapor flux.