Abstract

India lies on the edge of the Asian summer monsoon domain and receives almost 80% of its annual rainfall during June to September (referred as Indian summer monsoon rainfall: ISMR). The dominant forcing behind inter-annual variations of ISMR, the sea surface temperature (SST), explains only 50% of the total variance of the Indian summer monsoon. In this thesis, we analyses the effect of land-atmosphere coupling on the Indian monsoon and its characteristics, like the seasonal cycle, the onset of monsoon, mean seasonal precipitation, and intra-seasonal variability. Using decade-long simulations of a general circulation model (GCM), we show that land-atmosphere interactions over India as well as over its surroundings play the central role during the onset phase of monsoon and thus modulates the seasonal cycle of monsoon. The GCM, in its default configuration, simulates an early onset and excess precipitation (about double of that observed) over the Gangetic Plains (GP) in June. We find that excessive moisture advection and its convergence over GP are the main reasons for this June precipitation bias, whereas local evaporation contributes minimally. Moreover, the model has large positive surface soil moisture bias over India throughout the year and negative bias over the arid-semiarid regions to the north-west of India during the pre-monsoon months. From multiple sensitivity experiments, it is discerned that the remote dry soil moisture bias in the model over the western Asia region intensifies the tropospheric low-level wind circulation causing excessive moisture advection toward the Indian region, followed by moisture convergence over GP, which results in heavy June precipitation. The remote influence is particularly strong during the onset phase of monsoon but weakens once the monsoon is established over the Indian region. Local soil moisture over GP makes a diminutive contribution to precipitation bias in June but is crucial in determining the trade-off between local evaporation and moisture advection into GP in the later phase of monsoon. Through a consolidated experiment, in which surface soil moisture bias is corrected in the model by nudging towards observed values over the Gangetic Plains and western Asia simultaneously, we showed an improvement in the model simulation of the Indian monsoon and its seasonal cycle.

In the second part of the study, the remote influence from western Asia on the onset phase of the Indian monsoon is examined by using 68-years of observational data of precipitation and meteorological variables. It is found that a negative surface pressure anomaly over western Asia acts as a precursor to an early onset over central India, a region which is a fair representation of

core monsoon zone. A lower than normal surface pressure over western Asia strengthens the equator-to-pole surface pressure (and geopotential) gradient, resulting in stronger zonal winds over the Arabian Sea, bringing in more moisture toward the Indian monsoon region. This increases the moist static energy in the lower layer, which consequently decreases atmospheric stability, causing early monsoon onset. The phenomenon is not restricted to the surface only, signatures of early onset can be seen in mid-troposphere and upper-level circulations as well, which show correlation with surface pressure anomalies over western Asia. May surface pressure over western Asia is strongly influenced by surface heating over arid regions of western central Asia, and sea surface temperature anomalies over the central-north Pacific Ocean and Nino 3.4 region. Thus, may surface pressure over western Asia acts as an integrated indicator and shows the highest correlation to onset date over central India (0:53). In addition, we found that the relationship between western Asia surface pressure and onset date shows variability at decadal time scale, specifically related to change in sign of the Pacific Decadal Oscillations (PDO). After the late 1970s, when a change in the PDO phase from negative to positive has been reported, the relationship between surface pressure and onset date has weakened, whereas an increased correlation between surface temperature over western Asia and the onset over central India is noticed.

In the third part of the study, anthropogenic effects of intensification of irrigation over the Gangetic Plains are analyzed, as irrigational activities add a huge amount of moisture to top layer of soil and thus can alter land-surface properties. The effects of irrigation on the mean and intra-seasonal variability of the Indian monsoon are analyzed using the general circulation model and a high-resolution soil moisture dataset. We find that winter-time irrigation increases monsoonal precipitation over the Indian region through large-scale circulation changes, which are analogous to a positive phase in the North Atlantic Oscillation (NAO) during winters. The effects of positive phase of NAO persist from winters to pre-monsoon months through the changes in surface characteristics over Eurasia and western Asia, which makes the pre-monsoon conditions suitable for a subsequent good monsoon over India. Reduction in the intensity of low-frequency oscillations is also noted with winter-time irrigation. However, when irrigation is done throughout the year, that is during both winter and summer seasons, a localized decrease, significant at 95%, in June-September precipitation over the Gangetic Plains is noted, in addition to a decreased variability in the low-frequency oscillations. In specific, these changes show a remarkable similarity to the long-term trends in observed rainfall spatial patterns and low-frequency variability over India. Summertime irrigation alone does not cause significant changes in mean rainfall or low-frequency variability during monsoon. A decreasing trend in rainfall in the last few decades over the Indo-Gangetic Plains of northern India as seen from ground-based observations, along with swiftly perishing groundwater resources, pose a serious threat to water sufficiency and agricultural productivity of the region. Our results suggest that the water crisis could exacerbate, with irrigation having a negative effect on the monsoonal climate over the Gangetic Plains.