

Impact of Land-Atmosphere Interactions on the South Asian Monsoon

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Background

The South Asian summer monsoon is a seasonal change in winds and rainfall that marks the end of the dry season and the start of the rainy season over the region. It supplies nearly 80% of annual rainfall for the South Asian region (Singh, 2016).

The summer monsoon is primarily caused by a reversal of tradewinds from Northwest to Southwest, as a result of the northward migration of the East-West precipitation belt, known as the Intertropical Convergence Zone (ITCZ), from the southern to northern hemisphere during austral summer (Goswami, 2011). Low-level winds during the monsoon season are characterized by the strongest tropical westerlies at 850 hPa over the Arabian Sea, called the low-level westerly jet (LLJ), and large-scale cyclonic vorticity that spans from the Bay of Bengal (BoB) to western India, known as the monsoon trough (Goswami, 2011).

The typical onset tends to occur around June 1st. The primary indicator of the onset is a sudden, sharp and sustained increase in rainfall at the southern tip of India, accompanied by dramatic changes in some regional circulation features leading to an increase in precipitation over the monsoon region followed by sudden increase in kinetic energy (KE) over the LLJ region by a factor of 5 to 10. The high level mean KE of the LLJ is maintained by a large-scale non-adiabatic heat source from the Tibetan Plateau and deep convection over India and the BoB (Goswami, 2011).

The ITCZ begins to shift southward again around July 1st, indicating the arrival of the winter monsoon with tradewinds reversing back and the gradual retreat of summer monsoonal rains. The continent cools rapidly forming the Siberian High and the dry season is observed throughout the subcontinent by mid-October.

Weakening of Summer Monsoon

The mean monsoon has weakened since 1950 (Paul et al., 2016). It has been suggested that anthropogenic forcings including Greenhouse Gas (GHG) and aerosol emissions, as well as landuse landcover (LULC) have played a role in the observed decline in rainfall (Paul et al., 2016; Singh, 2016). GHG emissions reduce temperature contrast between land and ocean, weakening the thermally-driven monsoon circulation (Singh, 2016), and the interaction between the thermal wind-driven and moisture-driven effects determines the overall response. Landuse changes elicit a similar response by increasing surface albedo which results in near-surface cooling, weakening the monsoon.

Paul et. al. (2016) found that local changes in LULC, especially large-scale deforestation, led to a weakening of the Indian Summer Monsoon Rainfall (ISMR). There was a ~45% increase in crop cover and 30% decrease in tree fraction on the Indian subcontinent between 1950-2005 (Singh, 2016). The dominant LULC changed from woody savanna in the 1980s to crop land in 2005 (mostly irrigated) resulting in a 20% reduction of Leaf Area Index (LAI) in the core monsoon zone. The combination of deforestation and conversion to crop land led to a decrease in ET and subsequent decrease in the recycled component of precipitation (Paul et al., 2016). The decrease in ET reduces the precipitable moisture supply resulting in low Convective Available Potential Energy (CAPE), thus reducing convective precipitation. The suppression of Asian summer monsoon precipitation in the 21st century is consistent with modern monsoon dynamics (Ashfaq et al., 2009). Any perturbation in the radiative budget over the Indian subcontinent can weaken the driving pressure gradient and potentially destabilize the summer monsoon circulation (Raman, Mohanty, Reddy, Alapaty, & Madala, 1998).

Impact of Irrigation on Monsoon

Vegetation plays an important role in land-atmosphere interaction by controlling radiative and energy fluxes through albedo and roughness, transpiration through stomatal resistance, and substantial field capacity of soil with root depth and structure (YASUNARI, 2007). Atmospheric latent heating over land is also fundamentally through vegetative control of ET. A large portion of LULC on the Indian subcontinent is classified as cropland, mostly irrigated (Figure 1), and can play a major role in local and regional land-atmosphere interactions.

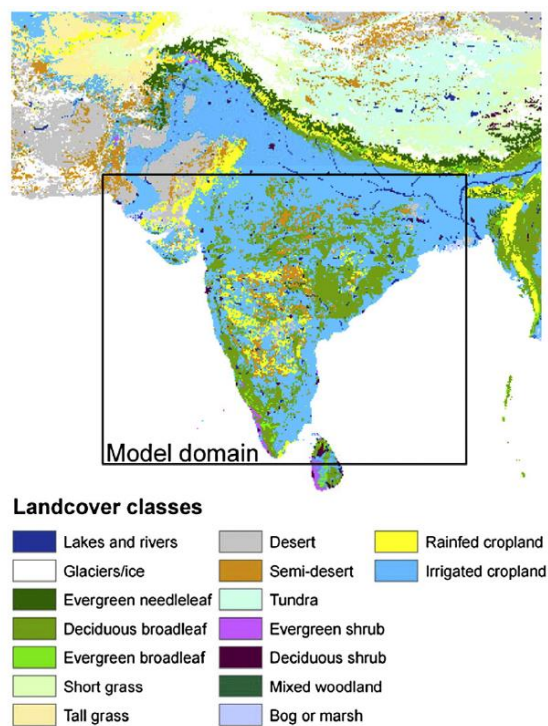


Fig. 1. Current state of land cover in India as represented by the GLC2000 land cover dataset. The model domain was constrained to peninsular India in order to reduce boundary effects due to the Himalayan Mountains.

Figure 1. Indian landcover represented by the GLC2000 land cover dataset (from Douglas et. al., 2009)

South Asia is one of the most intensely irrigated regions in the world (Saeed, Hagemann, & Jacob, 2009). The Indian subcontinent in particular has seen a rapid increase in irrigated agriculture, with gross irrigated area increasing from 23 million to 90 million hectares in the second half of the 20th century (1951-2997) alone (Douglas, Beltrán-Przekurat, Niyogi, Pielke, & Vörösmarty, 2009). A global increase in irrigated agriculture has increased global vapor flows by ~2600 km³ per year

(Gordon et al., 2005), which is more than double the estimated global consumptive irrigation water losses ($\sim 1200 \text{ km}^3$ per year) (Douglas et al., 2009).

This additional water vapor especially in dry areas affected by monsoons (i.e. India) can have an impact on convective precipitation, which can have further reaching impacts on other regions. Douglas et. al. (2009) found changes in precipitation patterns due to intensive irrigation indicating that wetter soils along the coast reduced the temperature gradient between land and sea, further weakening the sea-breeze circulation and suppressing convective precipitation, which is a major source of heavy precipitation especially in coastal areas. A decrease in convective precipitation increases atmospheric stability which is consistent with the total reduction in precipitation.

A heat low over Pakistan and Northwest India is used as an important predictor of summer monsoon rainfall, but a major portion of this area is located within the heavily irrigated Indus basin. The Indus basin is the largest contiguous irrigation network in the world and the manipulation of surface water via dams, canals, etc. modifies soil moisture. Manipulation of water at a large scale for irrigation purposes modulates the local climate in this heat low region and can affect large-scale circulation (Saeed et al., 2009).

Conclusion

Land surfaces and land-atmosphere interactions play a major role in Earth system processes and must be accounted for when studying Asian monsoonal systems. Any large-scale changes to the land surface, such as deforestation or conversion of land cover from one class to another, can have positive feedbacks on land-atmosphere interactions and can affect moisture availability and type and amount of precipitation over the region. As the world continues to grow in population and develop the land, understanding the role of land surfaces and large-scale irrigation will be essential in understanding local and regional climate patterns.

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