Soil Moisture Feedback over Wet vs. Arid Regions of India

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Rationale

Understanding the spatial and temporal variability of soil moisture is essential for monitoring the water and energy balances in the land-atmosphere interaction. Also, the slowly evolving nature of soil moisture can act as an additional source of predictability for tropical precipitation (Charney Shukla, 1981). The present study aims to analyze how the mean and variability of soil moisture over contrasting regions in India can lead to differences in rainfall variability through an indirect effect affecting regional prediction skills in the monsoon mission (MM) model(Rao et al., 2019)). The study uses soil moisture analysis data (Nayak et al., 2018), which was developed under the MM project.



Figure 1: Seasonal mean (June to September) (a) and standard deviation (b) of soil moisture (m^3/m^3) computed using reanalysis. (c) and (d) are the same as (a) and (b) but computed for MM model simulations. (e) Subdivisional map of seasonal Prediction skill of rainfall in MM model.

Results and Discussion

The observed seasonal mean (Fig.1(a)) soil moisture is high over the central, east coast, northeast India, and southern India (except some parts of Tamil Nadu), whereas the mean is comparatively less over northwest India (specifically Rajasthan). The larger (smaller) values of soil moisture over central (northwest) India are associated with the larger (smaller) contribution of monsoon rainfall. On the other hand, the soil moisture variability (Fig.1(b)) over the east and northeast of India is significantly less than that of the northwest and southern India. The model-simulated mean and variability of soil moisture (Fig.1(c, d)) is significantly underestimated throughout the Indian landmass. The underestimation of the mean is more significant over the eastern coast and central India. On the other hand, soil moisture variability is underestimated majorly in north-west India. The underestimation of the mean and variability of soil moisture can result in errors in the feedback processes associated with precipitation or convection and hamper the model's prediction capability. For example, Fig.1(e) shows the seasonal prediction skills at different subdivisions in India. The prediction skill is calculated as the anomaly correlation coefficient between the observed (IMD) and MM model (details in Rao et al., 2019) simulated rainfall. A contrasting skill between dry and wet regions in India can be clearly noted from this figure. The eastern and central parts of India have significantly less skill than the north-western parts, where the skill (0.4) is as high as the prediction skill for all of India's average rainfall (0.5 for this model version). Therefore, we hypothesize that soil moisture and rainfall feedback over these regions play an important role in the differential prediction skill over dry (north-west) and wet (east-central) regions in India.

Eltahir (1998) proposed a mechanism where soil moisture can modulate rainfall variability by changing the boundary layer characteristics and atmospheric stability. Therefore, in Fig. 2, we investigate how these feedback processes differ in observation and model over east-central India and northwest India at an intra-seasonal time scale. An ISO index is defined as the standardized filtered (30–60-day Lanczos bandpass filter) soil moisture anomalies averaged over the regions mentioned above. Active (break) cycles are defined as days when the ISO index is greater (less) than +1(-1). From Fig. 2, during the active phase, the lowered SHF and increased LHF result in a decreased Bowen ratio (ratio of SHF to LHF). Also, due to high moisture, surface albedo decreases, and therefore, the active phase is accompanied by increased net surface radiation and reduced Bowen ratio. Combinedly, they weaken the mixing in the boundary layer. Therefore, the planetary boundary layer (PBL) growth rate is reduced during the active phase of soil moisture. The reduction in the depth of PBL height causes a reduction in entrainment of air with low moist static energy (MSE) from above the PBL. Also, the increase in surface fluxes can cause entrainment of air with high MSE into the PBL from below. Both processes result in an increased MSE in the PBL. An increase in MSE in the



Figure 2: Intra-seasonal variability of soil moisture (m^3/m^3) against (a) SHF (W/m^2) , (b) LHF $(W/m^2$, (c) PBL (m), (e) MSE (W/m^2) and (e) rainfall (mm/day) during active cycle. The y axis on the left-hand side represents the range for intra-seasonal soil moisture whereas, the right-hand y axis represents the variability in other parameters. Lag-0 indicates the peak of monsoon active phase. The blue and red line in each subplot represents the variability in soil moisture and individual parameters respectively. (f)-(j) same as (a)-(e), but for north-west India. (k)-(t) are same as (a)-(j) but for MMCFS model.

PBL increases instability and an increase in convective activity in the atmosphere. Therefore, both the frequency and magnitude of convection can be enhanced due to the increase in soil moisture and associated feedback. The observed intra-seasonal variability in soil moisture is higher over north-west India than over east-central India. However, the observed variability in turbulent fluxes over north-west India is smaller than that of east-central India. Therefore, the observed response of surface fluxes to the intra-seasonal soil moisture is weaker over north-west India. However, the amplitude of PBL height, MSE, and rainfall variability during the active spell is larger, even if the turbulent fluxes are smaller over north-west India.

To see how well these feedback are represented over east-central and north-west India in MMCFS, a similar analysis is carried out in Fig.2(k-t). The model could reproduce the phase relationship between the soil moisture and turbulent fluxes (SHF, LHF), PBL height, MSE, and rainfall during the active phase over both regions. However, the intra-seasonal variability in soil moisture, MSE, and precipitation is underestimated in the model. On the other hand, the variability in turbulent fluxes, specifically the LHF during the active spell, is significantly overestimated in the model simulations. Therefore, the feedback between the turbulent fluxes and MSE in the PBL is weaker in model and hence the rainfall variability during the active phase is also weaker in the model. Hence, difference in mean and variability of soil moisture along with weaker idirect feedbacks affects the model's regional prediction skills significantly.

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