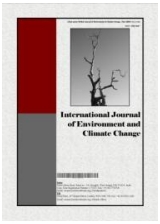

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Sensitivity of Soil Water in Community Atmosphere Model (CAM3) for Indian Summer Monsoon (ISM)

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Author's contribution

The sole author designed, analysed, interpreted and prepared the manuscript.

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ABSTRACT

The study has been attempted to investigate the relationship between the soil-water and the Indian summer monsoon (ISM) rainfall through the simulation of a global climate model named Community Atmosphere Model (CAM3). Two sets of simulation have been done during monsoon season for the years 2009 to 2012 using the pre-monsoon (May) and the previous winter season (December of previous year) state of soil-water as the model initial conditions. The control simulation and four sensitivity cases assuming 25% and 50% dryer and wetter soil-water respectively have been considered for all the aforesaid four years and for both the set of experiments. It has been observed that the impact of upper level soil-water persist for 15 to 20 days of simulation during the summer monsoon; the middle and lower layer soil state persist for a longer period of time due to its slow-varying nature with time. The daily surface temperature shows strong coupling with the upper layer of soil-water. When taken into comparison with the wet soil conditions, the dry soil state in most of the circumstances causes less rainfall. The Pearson correlation coefficient (PCC) and partial correlation technique have been implied to demonstrate the relationship between the daily soil-water columns, subsequent 30-days accumulated rainfall and past 21-days accumulated rainfall. Strong negative correlation has been reported between the soil-water and subsequent 30-days accumulated (All-India Rainfall) AIR for different simulation cases with dry soil conditions; however, the relation weakened and turned positive over some parts of the region for the simulations with wet soil conditions.

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Keywords: Indian Summer Monsoon; All-India rainfall; soil-water; correlation coefficient.

1. INTRODUCTION

The soil-water precipitation relationship (SPR) is not really straight forward due to the slow varying nature of soil-water and the presence of randomness in precipitation both spatially and temporally. The atmospheric and other land surface parameters viz. air temperature, radiation, heat fluxes, soil temperature, vegetation type, land cover and land use also largely modify the daily rainfall pattern which indeed have an impact on intra-seasonal variation. It is tough to measure the impact or variation in rainfall pattern due to any single cause viz. soil wetness separately through observational evidence only; however, the recent generation of general circulation models (GCMs) coupled with active land models can be used as a tool to quantify these relationships. Numerous studies have been attempted on SPR implying both observational and computational substantiation to achieve the purpose.

Eltahir [1], Zheng and Eltahhir [2] illustrates the role of soil-water in land-atmosphere interactions using field observations and a simple numerical model. They proposed that the upper layer soil-water in wet condition is directly associated with the boundary layer moist static energy over a relatively larger region that indeed caused more rainfall. As the soil wetness is largely driven by the past occurrence of rainfall, their proposed hypothesis implies a positive feedback mechanism between soil-water and rainfall. Salvucci et al. [3] churned out the positive feedback that SPR is affected by the high autocorrelation of precipitation and went forward to illustrate a method that partially excludes the effect of autocorrelation in computing SPR; however, on the other note, no significant influence of soil-water on the regional precipitation was traced. Recently, Wei et al. [4] explained a negative correlation in SPR using three different reanalysis products and NCAR Community Atmosphere Model (CAM). They took to the basic assumption that the soil-water of a certain day may have some influence on precipitation of subsequent days. This negative correlation is in contrast with the traditional view that soil-water has a somewhat positive impact on subsequent precipitation.

SPR is also quite region specific and strongly coupled with the climatic nature viz. wet or dryness of the region. Koster et al. [5] addressed the issue and identified the hot-spots (viz. the central Great Plains of North America, the Sahel, equatorial Africa and India) where the soil-water precipitation coupling is really very strong. These are the transition zones between wet and dry climatic regions where the boundary-layer moisture can trigger moist convection and the evaporation is quite sensitive to the soil-water [6]. Proper initialization of soil-water over these hot spots in GCM played the key role in improving the rainfall prediction skills [5]. The Indian summer monsoon (ISM) region is one of such hot spots and as a result the ISM rainfall during June-July-August-September (JJAS) is hugely affected by the pre-monsoon state of soil wetness [7]. The seasonal prediction of ISM rainfall is demanding to quantify the SPR that indeed may improve the prediction skill.

The vital objective of the present study is to examine the sensitivity of the primary atmospheric variables viz. daily minimum, maximum and average surface temperature and precipitation to the initial state of soil-water in simulating the ISM rainfall during JJAS. A detailed study has been carried out to draw the relationship between 10-layers soil-water to the subsequent days accumulated precipitation over Indian landmass during ISM. The study region is Indian landmass which has heterogeneous topography in nature. The Himalaya Foothills and Western Ghats of India are intense rainfall zone whereas the Central India received steady rainfall during summer monsoon. Almost 75% of annual rainfall over these regions are received during summer monsoon (i.e. June to Sept.). Soil water over Central India play a vital role in progress of ISM and also Active-Break cycle of rainfall. The earlier studies revealed through the simulation of GCM that the memory of soil-water lasts of the order of 200 to 300 days [8,9]. Does the state of soil-water over Indian landmass during the previous winter season have any impact on the next summer monsoon season? To address this issue, we have conducted the model simulations in one set, from June to September using the initial state of soil-water of the month of May; and another set of experiments from January to December using the soil state of the month of December of previous year. The influences of soil state during the pre-monsoon and the previous winter season over the ISM rainfall during JJAS through the two sets of experiments have been analyzed and

repeated for four different monsoon years viz. 2009, 2010, 2011 and 2012.

2. MODEL DESCRIPTION AND EXPERIMENT DESIGN

The model chosen for the purpose in this study is the NCAR fifth generation AGCM, named Community Atmosphere Model (CAM) version 3, which is the advanced version of NCAR Community climate model (CCM3) [10,11] and also the atmospheric component of the coupled climate model CCSM3. CAM3 is a state-of-art global spectral model offering a splurge of resolutions and tightly coupled with the land component named Community Land Model (CLM) taken from CCSM3 [12]. The major improvements in CAM3 include prognostic treatment of cloud water [13], longwave radiative transfer improvements, generalized cloud overlap [14], improved vertical diffusion of dry static energy [15], enhanced evaporation of convective precipitation [16], improved thermodynamic package for sea-ice and the most important is a hike in vertical levels from 18 to 26. Introduction of the fractional specification of the atmospheric grid box for land, ice and ocean in CAM3 provides far more accurate representation of flux exchanges especially from the coastal boundaries, island regions and ice edges [17]. Further, the present-day climatology of sulfate, sea-salt, carbonaceous and soil-dust aerosols have been used in CAM3 in place of a uniform background aerosol field that is used in CCM3 [18].

The present study is mainly to identify the role of initial state of soil-water in simulating the ISM rainfall. The pre-monsoon (May month) as well as the previous winter season (December month) state of soil-water have been used to initialize the model states to identify the memory of soil-water in the Indian climatic system and its impact on the ISM rainfall simulation. The model simulations have been carried out in T85 (~ 1.4°×1.4°) resolution, 26 vertical levels in the atmosphere and 10 soil layers below the land surface. The initial conditions for CAM utilizes the wind, temperature, humidity profiles and the land surface conditions taken from NCEP-GFS analysis with 0.5°×0.5° resolution, interpolated into the model resolution. Optimum interpolated sea surface temperature (OI-SST) and sea-ice concentrations at 1°×1° resolution taken from NOAA have been used as the boundary conditions for all the model simulations. Initially, the model simulated rainfall has been calibrated and validated through long-term simulation of ISM and different case studies have been done to evaluate the model capability to estimate the ISM rainfall in hind-cast as well as forecast modes [19,20].

In this study, two sets of experiments have been conducted. First, 'ISM Phase' includes comparison of five cases each of four months of simulation viz. JJAS started with the initial state of soil-water perturbations imposed on 31 May of each year from 2009 to 2012. As the model spin-up to reach a reasonable state before the sensitivity tests starts, a control simulation was integrated from 01 May to 31 May of each year. Considering the model state of 31 May as the initial condition, a control and four sensitivity simulations were conducted from 01 June to 30 September of each year, applying the perturbations of the soil-water to 25% drier and wetter and 50% drier and wetter relative to the initial soil state of control simulation. The second set of experiment named 'Annual Phase' comprises of another five cases similar to that of first, but integrated from 01 January to 31 December for the years 2009 to 2012. These experiments started with the initial soil state of 31 December of previous years. The model spin-up has been carried out from 01 December to 31 December. All other initial and boundary conditions have been kept identical for all five cases in both the set of experiments. The schematic diagram of the experiments performed has been given in Fig. 1. The five cases for each set have been referred as 'Normal' (the control simulation), 'DrySoil' (25% drier than normal), 'VeryDry' (50% drier than normal), 'WetSoil' (25% wetter than normal) and 'VeryWet' (50% wetter than normal) in the following sections. All the analysis carried out during the study has been restricted over the Indian landmass region only.

3. RESULTS AND DISCUSSION

3.1 Soil Water

The soil-water representation in the land model CLM has 10 unequal layers from surface up to 3.44 m deep into the soil. The thickness of the soil layer is increased exponentially with depth started from 1.75 cm at the top layer to 114 cm at the deep bottom layer. The upper layers of soil-water are highly interactive with the atmosphere through the processes like evaporation, precipitation etc; however, the water in the deep layers has the slow-varying nature mainly

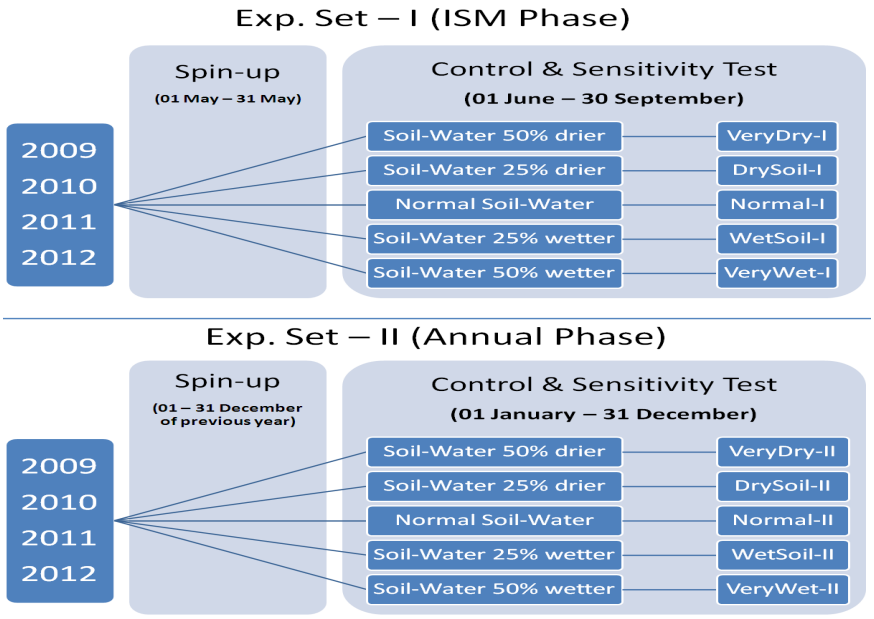

Fig. 1. Schematic diagram of the experiments planned

interacting with atmosphere through the transpiration process [21]. The time series of soil-water in 10 layers have been analyzed for each five cases and for the experiments 'ISM Phase' as well as 'Annual Phase' averaged over the Indian landmass region. Fig. 2 and Fig. 3 show the evolution of daily soil-water at different layers viz. upper (at 0.01 m), middle (at 0.62 m) and lower (at 2.87 m), and also the accumulated water column of soil depth up to 3.44 m simulated by 'ISM-Phase' and 'Annual-Phase' experiments respectively. All the time series have four parts (separated by the black vertical lines) corresponding to the four different monsoon-years viz. 2009, 2010, 2011 and 2012 respectively. Notably, simulations not being continuous in time frame, these parts of the time series are independent to each other. The upper layer of soil-water at 0.01 m depth from surface is highly interactive with atmospheric precipitation. The memory of soil-water due to the change in the initial state of land conditions of different sensitivity cases for each year got departed within 15 to 20 days of model simulations; noticeably, the memory persists for more than 20 days for the year 2012 whereas it vanishes in less than 12 days for the year 2011. This can be seen in Fig. 2 for all five cases.

As we advance towards the deeper layers, the memory of initial soil-state persists for longer periods of time; the middle layer (7th layer, at 0.62 m depth) and the lower layer (10th layer, at 2.87 m depth) shown in the second and third rows of Fig. 2 exhibit very slow movements of evolution of soil-water with time. The time series of 'DrySoil' and 'VeryDry' (magenta and red line respectively) have a high tendency to refill the soil-water in the middle layers compared to the experiment cases viz. 'WetSoil' and 'VeryWet' (cyan and green line respectively) in which the soil-water level is close to its saturation level for a longer period of time. Further, the total water column up to 3.44 m depth below the land surface is persistent in nature throughout the simulation period.

The initial state of the top layers of soil-water in 'Annual Phase' of experiment do not show any significant impact during JJAS as the initialization of soil state has been done during the previous winter season; on the contrary, the changes in middle and deep layers of soil-water persist up to the mid monsoon season and end of the year respectively for the different sensitivity cases as shown in Fig. 3. Thus the wet or dry soil state through the winter season plays a significant role in the next summer monsoon as well. Further, the total water column in 3.44 m deep soil (last row of Fig. 3) exhibits important variations for the different sensitivity cases. The 'DrySoil' and 'VeryDry' (magenta and red line respectively) soil states try to re-fill the water column to some extent during JJAS but it needs several monsoon years to match-up the normal level of soil-water.

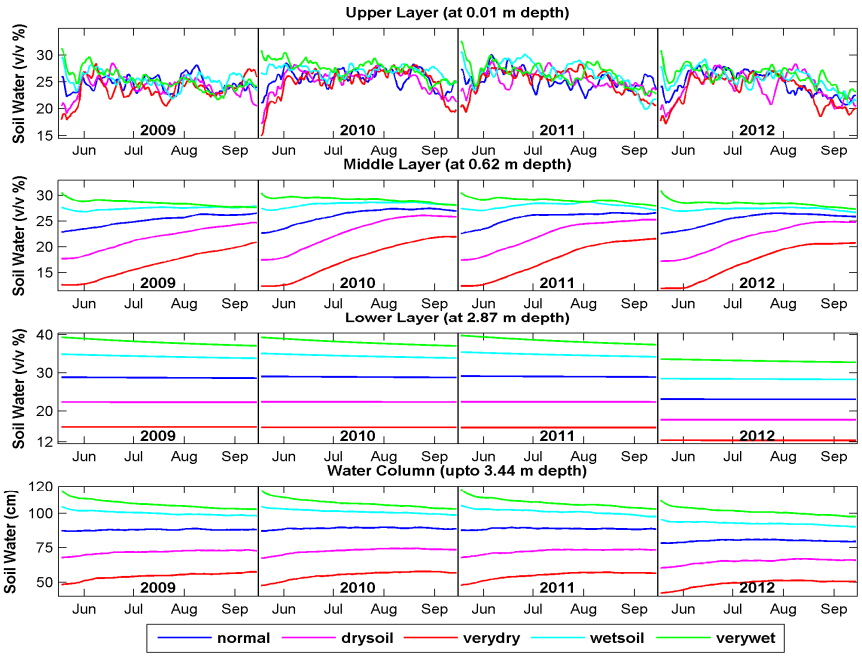

Fig. 2. Daily variation of domain averaged soil-water at different layers viz. upper, middle and lower layers (row-wise from the top) and the accumulated water column in soil depth up to 3.44 m (last row) simulated by exp. set – I (ISM Phase)

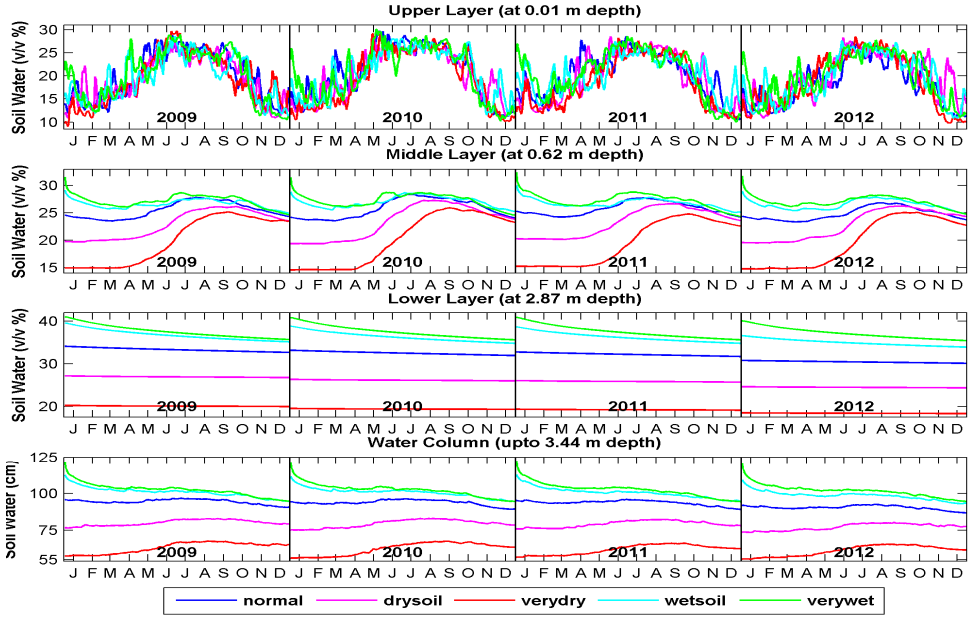

Fig. 3. Same as Fig. 2 but simulated by exp. set – II (annual phase)

3.2 Surface Temperature

The upper level soil-water can impact directly on the surface temperature. In the case of 'WetSoil' and 'VeryWet', the land surface absorbs more radiation to evaporate more water available in the soil into the atmosphere resulting in less albedo and sensible heat flux but increase in

latent heat flux. These indeed will drop down the sensible daily surface temperature. On the other hand, when the soil is dry viz. 'DrySoil' and 'VeryDry' cases, the land surface will radiate more sensible heat and uses less latent heat for the evaporation process as the availability of the soil-water is less compared to the normal soil. This will lead to the rise in instantaneous surface temperature. Fig. 4 shows the time series of the domain averaged daily surface temperature simulated by the five different cases of the ISM Phase experiment. The impact of different initial state of soil-water forcing (the five cases) can be witnessed in all the four years of the time series. Noticeably, the average and maximum surface temperature showed in top and middle rows of Fig. 4 exhibits similar behavior as the surface soil-water in all four years of simulation. The longest impact of more than 20 days can be seen for the year 2012 but peter out very fast within 12 days for 2011; however, the daily minimum surface temperature shows less sensitivity towards the differences in initial state of soil-water.

Similar behavior in surface temperature has been observed for the Annual Phase of experiment as well during the month of January for all the respective years; however, no significant impact of initial soil state of previous winter season on surface temperature has been identified during the monsoon period of JJAS (Fig. not shown). The daily surface temperature is highly sensitive to the past 20-days upper layer soil state that nullified the effects of long-term bottom layers of soil state on the daily surface temperature.

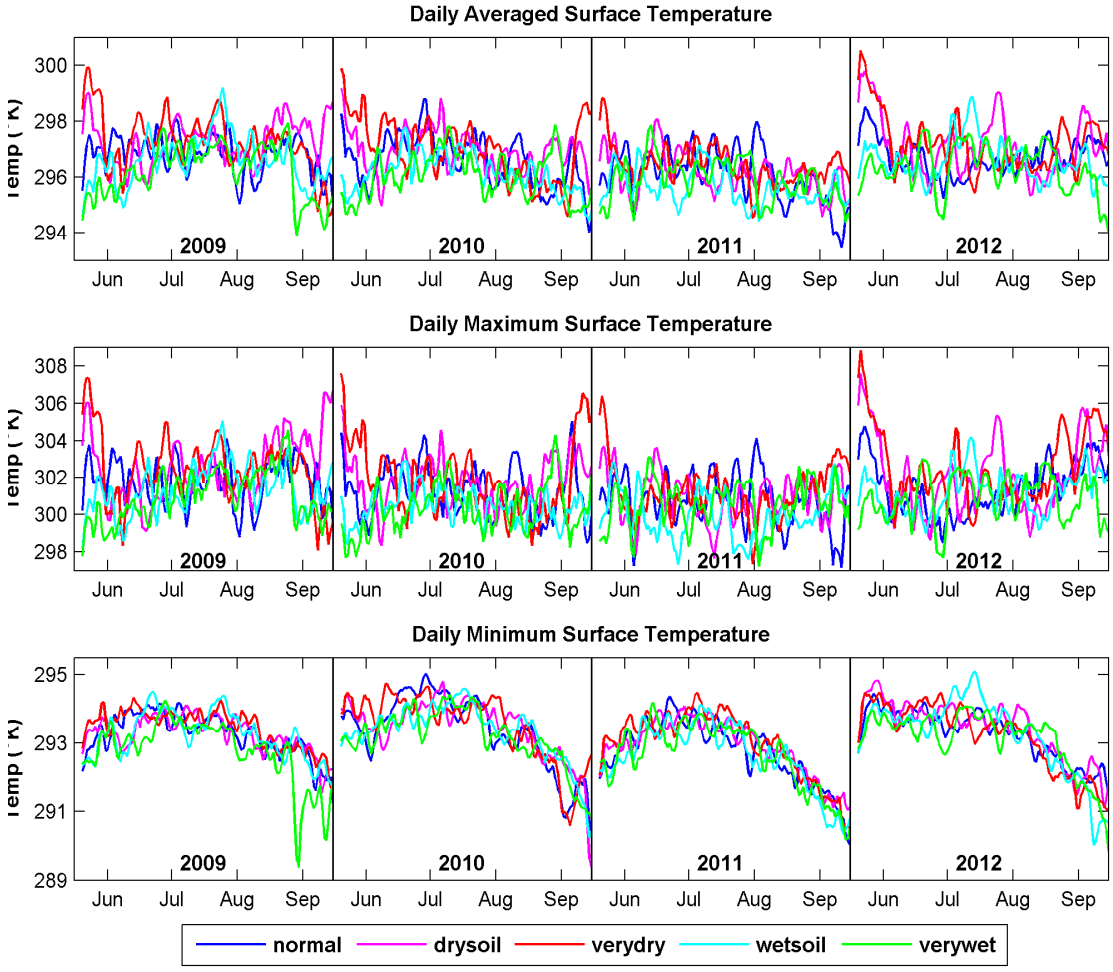

Fig. 4. Daily variation of domain averaged surface temperature simulated by exp. set – I (ISM phase); daily mean (top row), daily maximum (middle row) and minimum (bottom row)

3.3 Heat Fluxes

Soil-water has a direct impact on the net surface radiation and its re-distribution into sensible and latent heat flux. These heat fluxes further control the height of the atmospheric boundary layer and water vapor flux within it [22]. The surface radiation has to be balanced by the sensible, latent and soil heat fluxes that largely modify the lower atmospheric temperature, soil temperature and moist static energy in the atmospheric boundary layer. The redistribution of surface radiative energy into the sensible and latent heat fluxes largely depend on the soil-water available at surface and sub-surface layers [22,1,23]. The impact of soil-water is stronger than that of soil heat content as the later has small memory compare to the soil-water and thus the contribution of soil-water is more significant to the long-term disturbances in the land-atmosphere system [8].

The monthly averaged heat fluxes for the control simulation and different sensitivity cases over the Indian region have been plotted in Fig. 5. The upper panel shows the net longwave flux at surface, the middle and lower panel show the latent and sensible heat flux at surface respectively. Clear impact of the sensitivity cases due to the water availability in the soil can be seen for each year of simulation. The dry soil conditions mostly show the high longwave flux and sensible heat flux but low latent heat flux as compared to the control simulation for each monsoon year. On the other hand, the wet soil cases tend to have high latent heat flux but low longwave and sensible heat flux as compared to the control simulation (Fig. 5). Due to the high rainfall occurred during the peak monsoon month viz. July and August, the availability of soil-water in the upper layers increases that resulted into anonymous simulation of heat fluxes during these months of different years of monsoon. However, the impact of soil-water over the heat fluxes can also be seen at the end of monsoon i.e. the month of September for the years 2010, 2009 and 2012. Further, the net longwave and the sensible heat fluxes are positively correlated in contrast to that the latent and sensible heat fluxes are negatively correlated for different sensitivity cases and for different monsoon years of simulation.

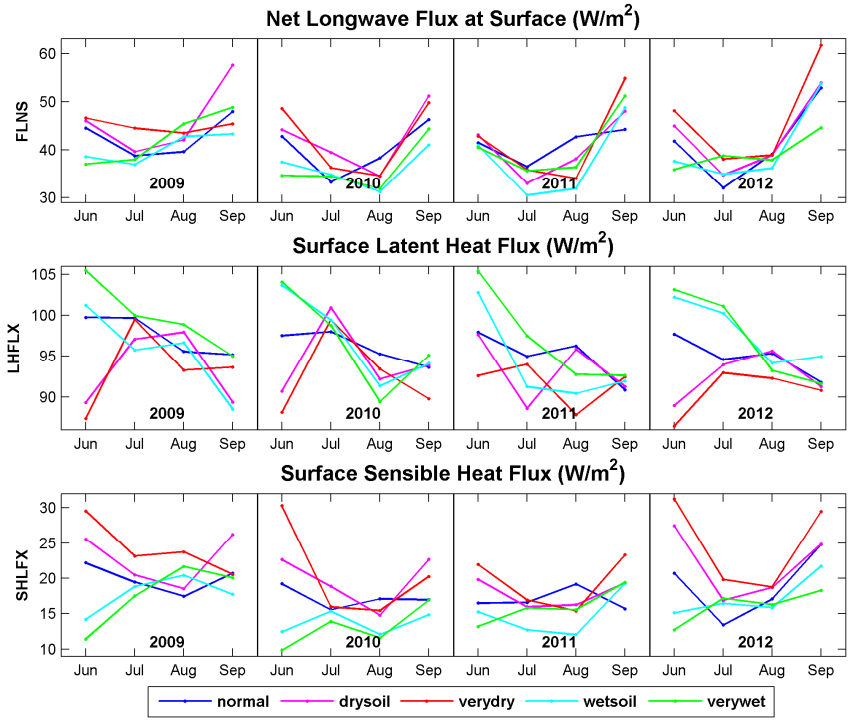

Fig. 5. Monthly variation of domain averaged heat fluxes for different sensitivity cases simulated by exp. set – I (ISM phase); net longwave flux at surface (top row), latent heat flux at surface (middle row) and sensible heat flux at surface (bottom row)

3.4 ISM Rainfall

The summer monsoon rainfall has not been driven by only the regional land surface conditions but also by a handful of local and global phenomena that leads to an uncertainty in intra-seasonal and inter-annual variability [24,25]. These uncertainties make it difficult to predict the ISM rainfall using any GCM [26]. Due to many other causal factors that affect the ISM rainfall, it is not possible to measure the significant impact of the different state of soil-water on the All-India rainfall (AIR) directly on daily basis. The AIR is commonly defined as the area-weighted average of rainfall over a certain time frame over Indian landmass. It this study, AIR has been computed on daily basis averaged over Indian landmass. Here we consider the basic hypothesis that the vertical column of soil-water of a certain day may have influence on the accumulated AIR of subsequent days [4]. Noticeably, this assumption also implies to the fact that the accumulated AIR of the past few days significantly modifies the current soil state. Here, the SPR has been investigated on the basis of this assumption.

The subsequent 30-days accumulated AIR has been computed on daily basis for all five different cases of the ISM Phase experiment. The running 30-days accumulated AIR during JJAS has been shown in Fig. 6 along with the differences of accumulated AIR for the four sensitivity cases of the simulation experiment from the control simulation. Significant variations in accumulated AIR can be seen between the different sensitivity cases and between the monsoon years as well. The dry soil conditions viz. DrySoil and VeryDry (magenta and red line respectively) cases mostly simulate less rainfall compared to the wet soil conditions viz. WetSoil and VeryWet (cyan and green line respectively) in major times during the monsoon for all the years; however, as an exceptional case, the accumulated AIR from dry-soils shows higher peaks during July-August for the simulation year 2011. This has also been exhibited in the difference plot of accumulated AIR from the control simulation showed in bottom row of Fig. 6.

Similar analysis has been carried out for the Annual Phase experiment; however, the domain averaged 30-days accumulated AIR for the different sensitivity simulations does not show any significant trend with respect to the control simulation (figure not shown).

3.5 Soil-water and AIR Relationship

The SPR on short time scale is mainly dominated by the upper layers of soil-water. Strong positive correlation has been reported by several studies through observational evidence as well as model simulations [1,2,27]. On the other hand, soil-water in the deeper layers plays the key role on the long term relationship with precipitation [4]. The present section will deal with the SPR in terms of the spatial and temporal Pearson correlation coefficient (PCC). PCC is primarily viewed as the ratio of the sample covariance of the two variables to the product of their standard deviations and defined as $r_{xy} = \frac{\sum_i (x_i - \bar{x})(y_i - \bar{y})}{\sqrt{\sum_i (x_i - \bar{x})^2 \sum_i (y_i - \bar{y})^2}}$ Statistical significance of the correlation coefficient has been determined by a 2-tailed *t*-test. To test the significance level say 90%, we assume that the statistic $t = r\sqrt{\frac{n-2}{1-r^2}}$ follows the student t-distribution with $(n-2)$ degrees of freedom where r is the PCC and n is the sample size [28].

The relationship between soil-water and the AIR shows unique characteristics in terms of PCC. The investigation consists of the three different time-series viz. daily soil-water column of up to 3.44 m depth divided into 10 unequal soil layers (referred as soil-water), accumulated AIR of subsequent η number of days, η varies from 2 to 30 (referred as next η-days AIR) and accumulated AIR of previous 21 days including the current day (referred as past 21-days AIR); noticeably, all the time-series are slow varying red noise process provided the accumulated AIR is computed for large number of days [29,30]. The reason to choose these time-series is the hypothesis as mentioned in the previous section that says the present day's soil-water is sensitive to the previous-days (typically 21 days) rainfall and also significantly modifies the upcoming-days (typically 30 days) rainfall. The PCC between the time-series have been computed for each monsoon year separately. All the time-series have been normalized before computing PCC. Further, a partial correlation technique [31,32] has been used to compute the partial relationship between the soil-water and next 30-days AIR that excluding the influence arising by the past 21-days AIR on next 30-days AIR. The partial correlation has been defined as

$$r_{xz,\,y} = \frac{r_{xz} - r_{xy}\,r_{yz}}{\sqrt{1 - r_{xy}^2}\,\sqrt{1 - r_{yz}^2}}$$

Here, r_{xy}, r_{yz} and r_{zx} are the PCC between soil-water & past 21-days AIR, past 21-days AIR & next 30-days AIR and soil-water & next 30-days AIR respectively. The statistical significance of the partial correlation coefficient has been determined by the 2-tailed *t*-test.

The PCCs between the soil-water and next 30-days AIR have been computed for each year and for different sensitivity cases of the ISM Phase experiment, shown in Fig. 7. The soil-water is negatively correlated with next 30-days AIR in the case of *Normal* soil condition (middle column of Fig. 7) mostly over the central, western and northern parts of India. The east part of India and southern peninsula are either largely affected by the insignificant PCCs or showing non-negative correlations by the *Normal* cases for different years of simulation. The negative PCCs become stronger for the dry soil conditions viz. DrySoil and VeryDry (first, second columns of Fig. 7) all over the country but it becomes weakened or turn out to be positively correlated over some regions of Indian landmass for the wet soil conditions viz. WetSoil and VeryWet (last two columns of Fig. 7). Noticeably, as an exceptional case, a small region over the central and western landmass of southern India show strong positive correlations for the cases of dry soil conditions but on the contrary exhibits equally strong negative correlations for wet soil conditions along with positive PCC in the control simulations for different monsoon years. Further, the simulations of wet soil conditions viz. WetSoil and VeryWet produced large area affected by insignificant correlations along the stretches over the central and southern parts of India.

The present day soil-water and past 21-days AIR are strongly (positive) correlated for *Normal*, *DrySoil* and *VeryDry* simulation cases; however, the relationship become weakened and produced large regions with insignificant PCCs for the *WetSoil* case. Importantly, the *VeryWet* soil condition case shows negative coupling between the soil-water and past 21-days AIR mostly over the central and north India all the years of simulation. This is reflected in Fig. 8 for different sensitivity cases and years of the *ISM Phase* experiment. Further, the past 21-days AIR is negatively correlated with next 30-days AIR over Indian landmass for all the sensitivity cases and control simulations for different monsoon years (Fig. not shown). The all-India average PCCs for past 21-days AIR and next 30-days AIR range from –0.11 to –0.37 for the different simulation cases and years of the ISM Phase experiment.

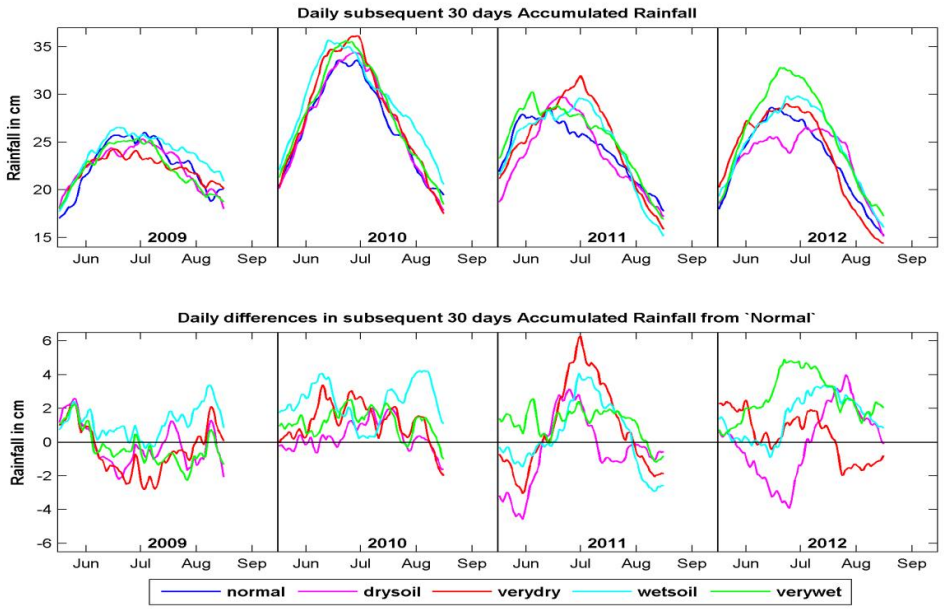

Fig. 6. Variation of domain averaged daily subsequent 30-days accumulated AIR (top row) simulated by exp. set – I (ISM phase) and differences of the accumulated AIR for different sensitivity cases from the control simulation (bottom row)

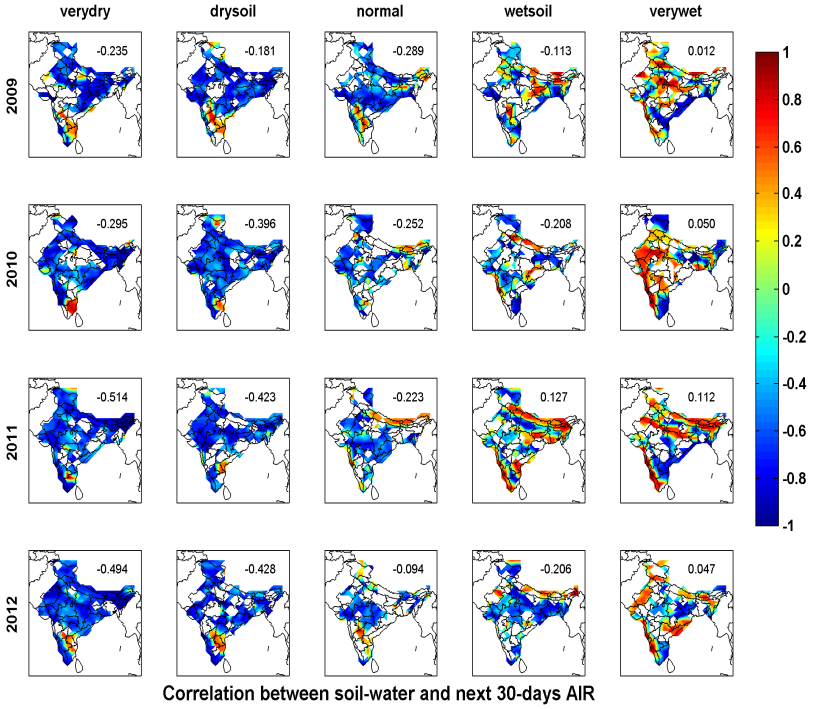

Fig. 7. Pearson correlation coefficient of soil-water and next 30-days AIR during JJAS over Indian landmass derived at each grid cell along the temporal direction for the control and different sensitivity cases of ISM phase experiment conducted for the years 2009 to 2012

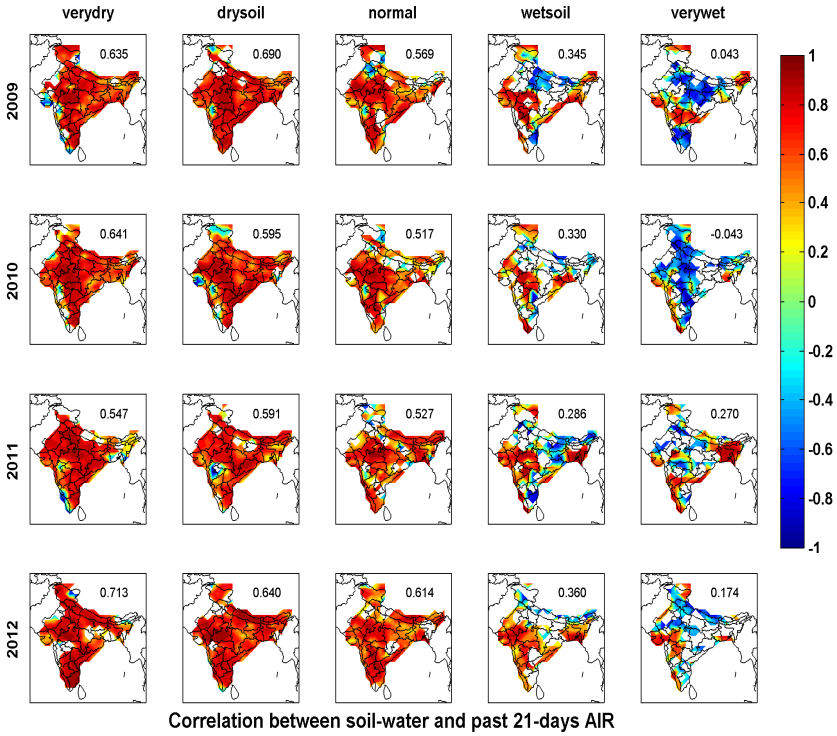

Fig. 8. Same as Fig. 7 but for the correlation of soil-water and past 21-days AIR

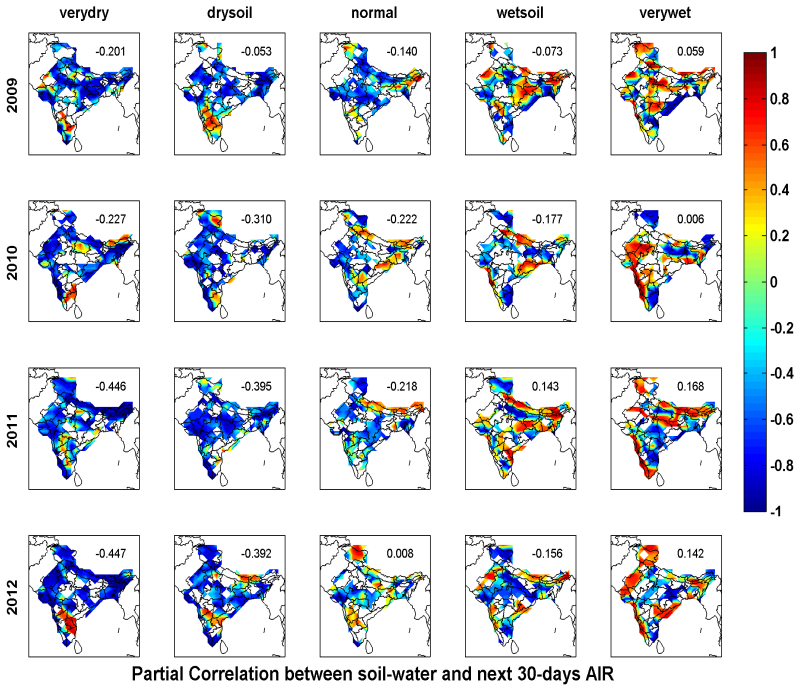

Fig. 9. Partial correlation coefficient of soil-water and next 30-days AIR excluding the effect of past 21-days AIR during JJAS over Indian landmass derived at each grid cell along the temporal direction for the control and different sensitivity cases of ISM phase experiment conducted for the years 2009 to 2012

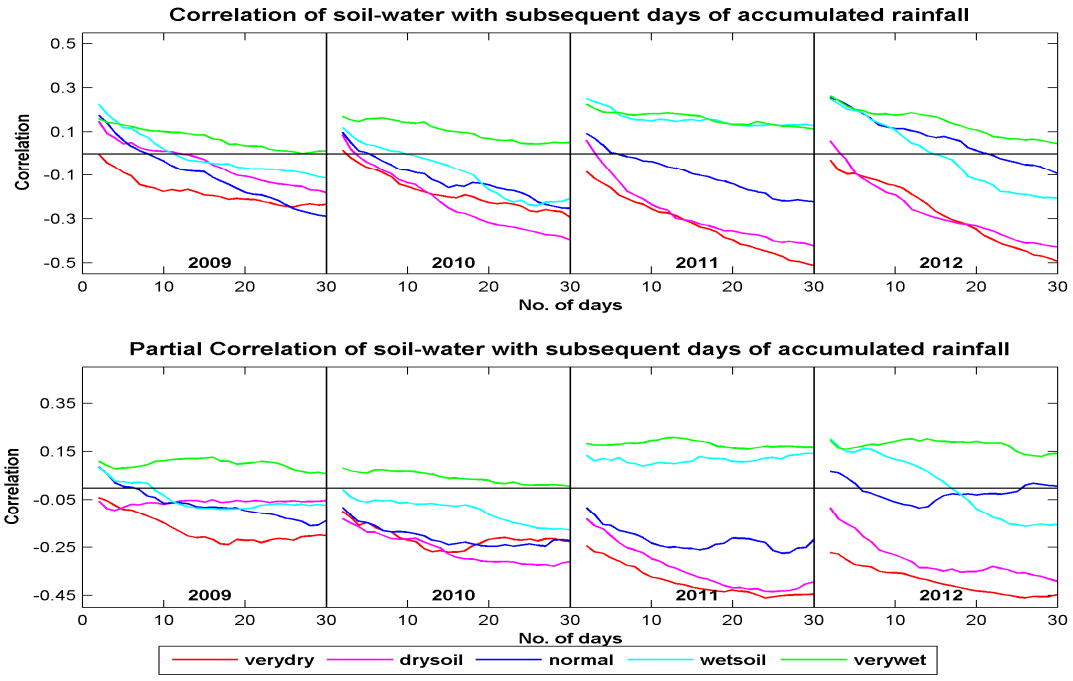

Fig. 10. Evolution of Pearson correlation coefficient (top) and partial correlation (bottom) for different number of days of accumulated AIR viz. 2 to 30 days between the soil-water and next n-days AIR excluding the impact of past 21-days AIR

Overall, it has been found that the next 30-days AIR during JJAS over the Indian landmass is negatively correlated with the present day soil-water and past 21-days AIR in the temporal direction for the different simulation cases for all the years; however, the relationship between soil-water and next 30-days AIR is dominated by positive PCCs in case of wet soil conditions but no such trend has been noticed in the relationship between next 30-days AIR and past 21-days AIR. All these three time-series are partially dependent on each other and thus partially correlated to positive or negative ways. At this juncture of the study, it is important to quantify the impact of soil-water over the next 30-days AIR by excluding the effects of the past 21-days AIR. This will ensure the role of soil-water in the negative coupling with next 30-days AIR during the monsoon time period. The partial correlation coefficients between soil-water and next 30-days AIR by excluding the effect of past 21-days AIR have been derived as discussed earlier in this subsection and plotted in Fig. 9. A similar behavior in spatial distribution of the partial correlations have been noticed as seen in the case of PCCs discussed in Fig. 7 for all the sensitivity cases; however, a number of regions over Indian landmass have emerged as strongly coupled zone between soil-water and next 30-days AIR (Fig. 9). North-west region of India, western peninsula and the foothills of Himalaya are showing negative (partial) correlations for the dry soil conditions but turns out to be positive in case of wet soil. Further, some portion of north-east region exhibit negative partial correlation for all the sensitivity cases and years of the ISM Phase experiment.

An exercise has been done during the study by altering the number of accumulated days from 30 to 40 or 20 for the next η-days AIR and from 21 to 31 or 11 for the past η-days AIR; however, the exercise shows comparable results for all such cases. Importantly, the evolution of correlation coefficients has been analyzed for different number of days of accumulated AIR viz. 2 to 30 days considered to compute the next η-days AIR time-series. Significant changes in the PCCs have been identified and presented in Fig. 10 in which the upper panel shows the evolution of all-India averaged PCCs between soil-water and next η-days AIR as the number of accumulation days (η) for computing AIR increased from 2 to 30. On the other hand, the lower panel shows the same as upper but for the partial correlation between the soil-water and next η-days AIR excluding the effect of past 21-days AIR. Initially, almost all the sensitivity cases and for all years produces positive PCC for 2 to 10 days of accumulated AIR; however, the PCCs become negative and the coupling between the time-series become stronger with increased number of days (top row of Fig. 10). Further, the simulations with dry soil viz. *DrySoil* and *VeryDry* show high negative PCCs compared to the *Normal*, *WetSoil* and *VeryWet* cases. Similar observations can be made for the partial correlations (bottom row of Fig. 10) as well; however, slope of the correlation curves along the number of days are low compared to that of PCCs.

4. CONCLUSION

The study is focused on the relationship between soil-water and precipitation in the simulation of ISM using a GCM. The atmospheric model CAM has been used for the study. Simulation of ISM rainfall with different sensitivity cases assuming 25% and 50% drier and wetter of soil-water over Indian landmass during pre-monsoon time and previous winter season has been analyzed for June through September. The impact of upper layer soil-water in different sensitivity cases last only for 12 to 20 days for different simulation years; however, the middle and lower layers show stronger impact during the monsoon season. The total water column over soil exhibits very slow movement of soil-water with time.

The upper layer soil-water has direct impact on the daily surface temperature; increase in soil-water leads to less sensible heat and the low availability in soil-water causes high surface temperature. Further, the impact of soil-water on the surface temperature can only be seen during the first 20 days of model simulations. The ISM rainfall, on the other hand, does not show any direct impact of soil-water due to the strong influence of several local and global phenomena that significantly modify monsoon rainfall. The total water column over soil has measurable impact on the subsequent 30-days rainfall over Indian landmass. It has been shown through the different sensitivity simulations that the dry-soil conditions mostly simulate less rainfall compared to the wet-soil in the 30-days time scale.

Further, the PCC and partial correlation have been analyzed for the three different time-series viz. daily soil-water column, next subsequent 30-days accumulated AIR and past 21-days accumulated AIR. Strong negative coupling has been identified between soil-water and next 30-

days AIR over Indian landmass for normal and dry-soil conditions; however, the negative coupling becomes weak and turned into positively correlated over some regions for the sensitivity simulations considering the wet-soil conditions. Strong negative partial correlation has been reported for the dry-soil condition cases viz. 'DrySoil' and 'VeryDry' compared to the 'Normal', 'WetSoil' and 'VeryWet' cases. North-west region of India, Western Peninsula and the foothills of Himalaya has been identified as the strongly coupled zone between soil-water and next 30-days AIR due to the negative (partial) correlations reported for the dry soil conditions but turns out to be positive in case of wet soil.

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COMPETING INTERESTS

Author has declared that no competing interests exist.

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