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Key Points:
- There is a reduction of the precipitation dry bias over Ganga basin in Indian monsoon simulations using a coupled land-atmosphere regional model
- Reduction of bias comes from improvement in local recycling and atmospheric moisture transport from the Western and Upper Indian Ocean
- Better land surface process representation in climate models is necessary to capture the monsoon rainfall over the Ganga basin

Supporting Information:
- Supporting Information S1

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Coupled Land-Atmosphere Regional Model Reduces Dry Bias in Indian Summer Monsoon Rainfall Simulated by CFSv2

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Abstract Global climate models including the Climate Forecast System version 2, the operational model used for prediction of Indian summer monsoon rainfall by the India Meteorological Department, has dry precipitation bias, mostly over densely populated Ganga basin. This restricts the use of model output in hydrological simulations/forecasts. We use regional atmospheric Weather Research and Forecasting model coupled with land surface models, driven by the boundary conditions from Climate Forecast System version 2. We find significant reduction in the dry bias of Indian summer monsoon rainfall with regional land-atmosphere model and this attributes to (a) improved moisture transport from Western and Upper Indian Ocean to Ganga Basin and (b) improved precipitation recycling over the Ganga basin. We find that the smoothened topography in the global model allows advection of cold dry subtropical air into the Indian monsoon region, contributing to the cold temperature and dry precipitation bias. These results have important implications for monsoon simulations in developing operational hydroclimatic prediction system in India.

Plain Language Summary The operational monsoon prediction model for India, Climate Forecast System version 2, has significant dry bias in precipitation over the Ganga basin, and this restricts the use of model output for hydrologic prediction. We attribute such bias to the lack of representation of land surface processes and characteristics in the model. We show that an improved representation of land characteristics in a regional coupled atmospheric-land model improves not only the land-atmosphere interactions but also the moisture contributions from distant oceanic sources. This finally results into improved simulations of monsoon.

1. Introduction

Seasonal scale prediction of the Indian summer monsoon rainfall (ISMR) is necessary for planning and management of water resources and agricultural activities of the 1.7 billion population of South Asia. Variations in monsoon rainfall have a large impact on food production and gross domestic product (Gadgil & Gadgil, 2006), and accurate hydrological forecasts are the need of the hour. India Meteorological Department (IMD) issues long range (June–September, JJAS) forecasts of ISMR using statistical models based on linear and projection pursuit regressions (Rajeevan et al., 2007; Wang et al., 2015). The forecasts are supplemented by dynamical model outputs from the operational seasonal prediction model, Climate Forecast System version 2 (CFSv2), adopted for monsoon prediction over India (Pokhrel et al., 2013; Ramu et al., 2016).

Dynamical simulations of the monsoon system remain a challenge due to limitations in understanding and model representation of the land-atmosphere-ocean feedbacks that modulate the monsoon rainfall and its variability (Goswami, 2005; Koster et al., 2004). Coupled ocean-atmosphere simulations have shown an increase in model skill compared to their atmosphere only counterparts (Krishna Kumar et al., 2005; Wang et al., 2005), but further improvements in forecasts and its uncertainty are necessary for seasonal and subseasonal hydrological applications (Yuan et al., 2011). In the case of Indian monsoon, a persistence of dry rainfall bias over Central India is seen in coupled dynamical simulations using CFSv2 (Goswami et al., 2014; Saha, Pokhrel, et al., 2014). This dry bias is not unique to CFSv2 and is also reported in the Coupled Model Intercomparison Project phase 5 (CMIP5) general circulation models (Sperber et al., 2013). This is a major hindrance for using dynamical models for Indian monsoon simulations. The twentieth century simulations of the CMIP5 models are also unable to capture the decreasing trend of Indian summer monsoon rainfall (ISMR) seen in observations (Saha, Ghosh, et al., 2014; Turner & Annamalai, 2012). Studies indicate that errors in sea surface temperature alone cannot account for the ISM biases in current coupled general circulation models and missing process representations associated with aerosols (Bollasina et al., 2011) or land surface processes (Niyogi et al., 2010; Paul et al., 2016) might contribute to some of the model biases.

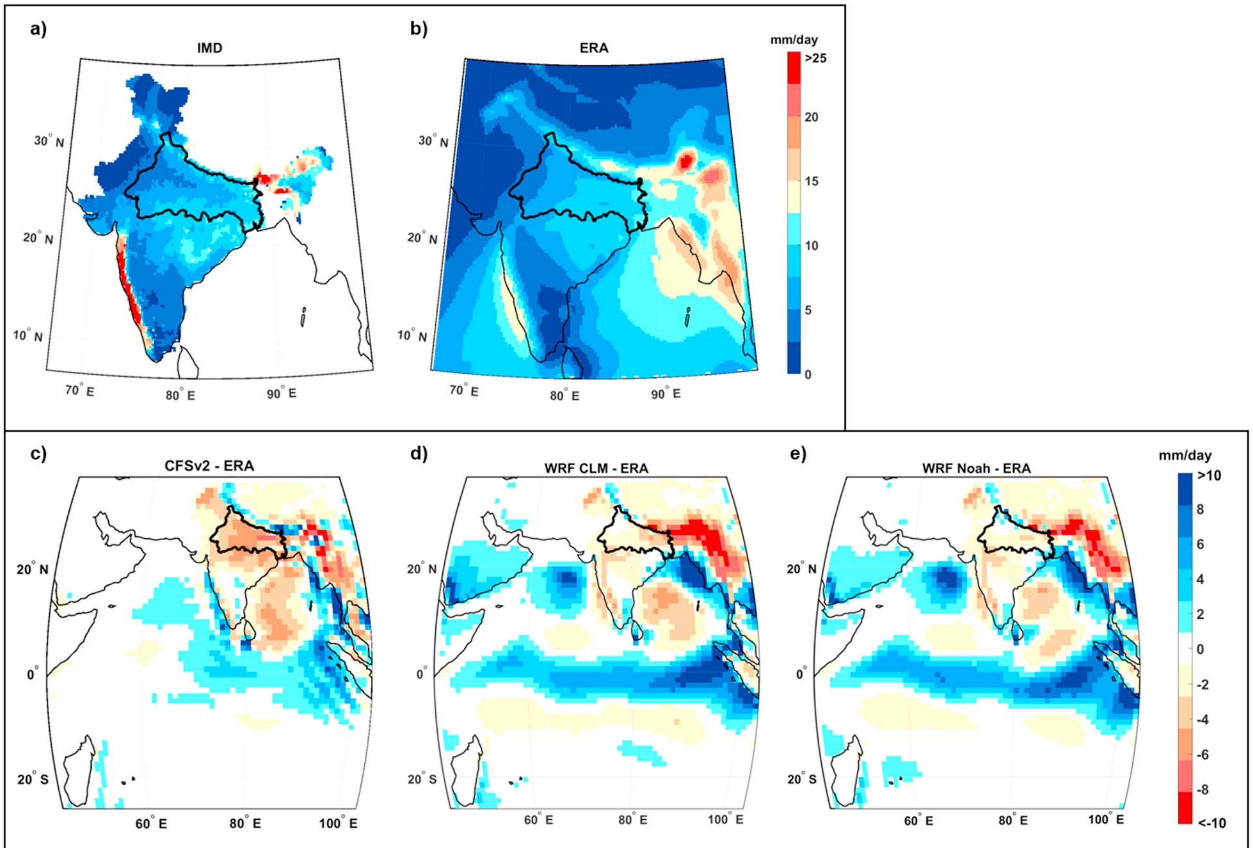
Recent years have seen concentrated efforts on the evaluation of CFSv2 for Indian monsoon simulations and diagnosis of the model biases. Despite improvements of monsoon intraseasonal variations, cross equatorial and low-level flow, and changes in the spatial pattern of sea surface temperature biases in the model, the dry bias over Central India have been persistent in both the previous and current versions of CFS (Saha, Moorthi, et al., 2014; Saha, Pokhrel, et al., 2014). The local Hadley circulation and low-level convergence over the Indian landmass simulated by CFSv2 show errors, and the representation of subgrid-scale processes is thought to be behind them (Goswami et al., 2014). It is reported that the northward extend of Intertropical Convergence Zone is not accurately represented by the model and may be related to the dry bias over the Indian subcontinent (Narapusetty et al., 2016; Pokhrel et al., 2013). Investigation of the impact of subgrid-scale processes in ISM simulations using CFSv2 have focused on convective parameterization schemes, with some success (Goswami et al., 2015, 2017). However, the role of land surface process representation in the dry bias simulated by CFSv2 over the Indian subcontinent have not been explored. Such an investigation is necessary given the emerging understanding of the importance of land surface processes in the monsoon dynamics (Koster et al., 2004; Pathak et al., 2017, 2014), especially in the northward migration of the rainband over the Indian landmass (Bollasina & Ming, 2013).

Dynamical regional model simulations that improve upon the CFSv2 dry rainfall bias in over central India is of particular relevance to hydrological applications. Hydrological modeling typically involves statistical bias correction of hydrometeorological variables obtained from dynamical models (Acharya et al., 2013; Shah et al., 2017). However, the technique of bias correction cannot rectify incorrect representation of physical and dynamical processes in climate models. In some cases, the use of bias correction is reported to affect the spatiotemporal consistency of the variables and hide rather than reduce the uncertainty in climate model outputs (Ehret et al., 2012; Haerter et al., 2011). The intraseasonal and interannual variability of ISMR is modulated by variations in atmospheric moisture supply from terrestrial and oceanic sources of moisture (Pathak et al., 2017). Hence, the bias is also expected to have similar variations reflected from moisture sources that make them nonstationary. Statistical bias corrections assume stationary bias (Chen et al., 2011), and hence, such a method may degrade the quality of monsoon prediction. Thus, the possibility of using physically consistent dynamical regional model simulations for seasonal hydrological prediction is of interest.

Here we use a regional climate model, the Weather Research and Forecasting model (WRF) coupled to two land surface models, Community Land Model (CLM) and Noah land surface model (Noah), driven by CFSv2 boundary conditions (Halder et al., 2015; Maharana & Dimri, 2016; Pattnayak et al., 2017; Singh et al., 2007; Srinivas et al., 2013, 2015; Unnikrishnan et al., 2017). We aim to understand the impact of land surface processes in the dry bias over Central India, specifically over the Ganga basin region. Our results are consistent with the hypothesis that the representation of land surface affects the low-level atmospheric circulation and land-atmospheric coupling and plays a substantial role in the CFSv2 dry bias over the Ganga basin. The analyses presented here emphasizes the importance of land surface processes in local precipitation recycling as well as the regional circulation that transports moisture from remote sources over the Ganga basin.

2. Models and Methods

CFSv2 is the latest version of the climate forecast system developed by the National Centre of Environmental Prediction (NCEP). CFSv2 uses NCEP Global Forecast System model as the atmospheric component coupled to Modular Ocean Model version 4 from the Geophysical Fluid Dynamics Laboratory (Griffies et al., 2004). The land surface is represented by the Noah land surface model (Ek et al., 2003). CFSv2 data used here consist of coupled CFSv2 free run outputs (T126 resolution) from simulations initialized on 1 December 2009, after discarding the initial 20 years of simulations. The analyses are performed using 35 years of CFSv2 free run outputs. Regional model outputs are from WRFv3.8.1 (Miguez-Macho et al., 2004; Skamarock et al., 2008; von Storch et al., 2000) coupled to two land surface models (Long et al., 2014; Mishra et al., 2017), viz, CLM (WRF-CLM) (Swenson et al., 2012) and Noah (WRF-Noah), forced with initial and boundary conditions from the CFSv2 free run. The regional model domain covers the Indian monsoon region (supporting information



	c) CFSv2 - ERA	d) WRF CLM - ERA	e) WRF Noah - ERA
Mean Error	-4.82 mm/day (-68%)	-1.81 mm/day (-25%)	-0.93 mm/day (-13%)
RMSE	9.84 mm/day	4.08 mm/day	2.30 mm/day

Figure 1. Biases in model simulations of mean seasonal (June–September, JJAS) rainfall. (a, b) JJAS rainfall climatology (mm/d) from India Meteorological Department (IMD) data and ERA-Interim reanalysis data. (c–e) Biases in mean JJAS rainfall (mm/d) from Climate Forecast System version 2 (CFSv2), Weather Research and Forecasting model (WRF)-Community Land Model (CLM), and WRF Noah. Ganga basin is marked on the map. The error statistics are for seasonal rainfall over the Ganga basin. RMSE = root-mean-square error.

Figure S1a), and simulations are performed from May to October of each year at a resolution of 36 km. Indian monsoon simulations are known to be sensitive to the representation of cloud physics in the climate models (Devanand et al., 2017; Mukhopadhyay et al., 2010). We use the Kain-Fritsch cumulus scheme to represent convection, and WRF single-moment class 5 scheme to represent cloud microphysics as the combination has been found to work well for seasonal scale WRF simulations over the Ganga basin region (Devanand et al., 2017). Further details of the models and simulations are provided in the supporting information.

The observed data used consists of gridded precipitation at 0.25° resolution from IMD for years 1981–2015. The variables precipitation, evaporation, winds, temperature, and humidity from European Centre for Medium-Range Weather Forecasts ERA-Interim (ERA) reanalysis product (Dee et al., 2011) for years 1981–2015 are also used for the analysis. We also use additional data sets (Adler et al., 2003; Dorigo et al., 2017; Gruber et al., 2017; Liu et al., 2012; Rodell et al., 2004; Rohde et al., 2013; Willmott & Robeson, 1995; Yatagai et al., 2012) to validate the biases in the model simulations (supporting information S4). In order to understand the atmospheric moisture supply from terrestrial and oceanic regions in the model simulations, we use a dynamic recycling model (DRM) (Dominguez et al., 2006; Martinez & Dominguez, 2014; Pathak et al., 2017). DRM uses a Lagrangian approach to track the atmospheric moisture in an air column backward in time. The model is based on mass conservation and quantifies the relative contributions from different source regions to the atmospheric moisture over a given sink region. The model equations are given in the supporting information. The source sink regions used for DRM are adopted from Pathak et al. (2017) and shown in supporting information Figure S1b.

3. Results

The 35 year mean climatological monsoon (JJAS) rainfall pattern from ERA matches the observed gridded rainfall data from IMD (Figures 1a and 1b) (Sebastian et al., 2016). CFSv2 exhibits a dry bias in monsoon rainfall over the Ganga basin region (−4.82 mm/d, −68%) (Figure 1c), consistent with previous studies using CFSv2 for ISM (Goswami et al., 2014; Saha, Pokhrel, et al., 2014). Meanwhile, the climatological monsoon rainfall from the WRF simulations (WRF-CLM and WRF-Noah) forced with CFSv2 boundary conditions show reduction of dry bias (mean bias of −1.37 mm/d, −19%) over the Ganga basin (Figures 1c–1e and supporting information Figure S2).

The regional model maintains consistency with the large-scale circulation from the forcing data and exhibit biases in large-scale temperature and winds similar to those from CFSv2 (supporting information Figure S3). This indicates that local scale changes in the regional model are behind the reduction of dry bias in the WRF simulated rainfall over Ganga basin. The lack of improvement in the large scale circulation simulated by WRF is not surprising, as regional models do not fix large scale errors in global model simulations (Chan & Misra, 2011; Mishra et al., 2014; Singh et al., 2016) and generally add value through better representation of local scale processes (De Sales & Xue, 2013; Yoon et al., 2012). Locally, over the north Indian landmass, the low-level temperature and winds show reduced biases. The JJAS mean surface soil moisture and latent heat fluxes over northern India are underestimated by CFSv2 (mean bias of -0.12 m^3/m^3 (−41%) and -57 W/m^2 (−57%)), and improved through the WRF simulations (mean bias of -0.06 m^3/m^3 (−20%) and -3 W/m^2 (−3%)) (supporting information Figures S4 and S5). This improved simulation of land surface states lends weight to the possibility that a better representation of land-atmospheric coupling in the regional model is behind the improved precipitation in the regional simulations. Northern India is reported to be one of the hot spots of land-atmospheric coupling (Koster et al., 2004). Recycled precipitation over a region is defined as the precipitation that results from evaporated moisture from the same region. The evaporation over the Ganga basin and Northeast India is responsible for a substantial portion (as high as 25% in some regions) of the monsoon rainfall through local recycling (Pathak et al., 2014).

To gain a process-based understanding of the improvement in regional model simulated precipitation over the Ganga basin, we use DRM. The average moisture contributions from the major land and oceanic regions to the monsoon (JJAS) rainfall as simulated in ERA-Interim reanalysis, and its biases in CFSv2 and WRF are shown in Figure 2. Comparison of the model simulations with reanalysis shows that CFSv2 underestimates the recycled precipitation (bias of −0.91 mm/d (−81%)) over the Ganga basin. WRF-CLM (bias of −0.16 mm/d (−14%)) and WRF-Noah (bias of 0.18 mm/d (16%)) shows substantial improvement over CFSv2 in recycled precipitation over the basin (Figures 2a–2d). The monsoon rainfall over the Ganga basin generated by evaporation from adjacent north Indian land masses are also underestimated in CFSv2 (−0.74 mm/d (−76%)) and show improvements in the regional simulations (−0.15 to 0.02 mm/d (−16% to 2%)) (Figures 2e–2h and supporting information Figure S6). This reveals that a better representation of land surface and land atmospheric coupling is partly responsible for the improved monsoon rainfall over the Ganga basin in the regional model simulations. The atmosphere-land component of NCEP CFS, the Global Forecast System model, is reported to exhibit a weaker land-atmosphere coupling strength in a few global studies (Guo et al., 2006; Zhang et al., 2011), supporting this finding.

The DRM analysis reveals that a rainfall of 2.7 mm/d (37% of monsoon rainfall over Ganga basin) in ERA-Interim reanalysis comes from adjacent oceanic regions. CFSv2 shows a mean bias of −1.52 mm/d (−57%) in the moisture contributed by oceanic regions and the bias is reduced to −0.43 mm/d (−16%) in the WRF simulations. Largest improvements come from improved representation of the contribution of moisture from Western Indian Ocean (WIO) over the north Indian landmass. CFSv2 underestimates the WIO moisture contribution to rainfall over the Ganga basin by −0.92 mm/d (−59%), while the regional model simulations show an underestimation of −0.25 mm/d (−16%) (Figures 2i–2l and supporting information Table S1). The moisture contribution from Upper Indian Ocean (UIO) is also underestimated in CFSv2 (bias of −0.24 mm/d, −44%) and show improvements in the regional simulations (bias of 0.06 mm/d, 12%). Thus, apart from improved

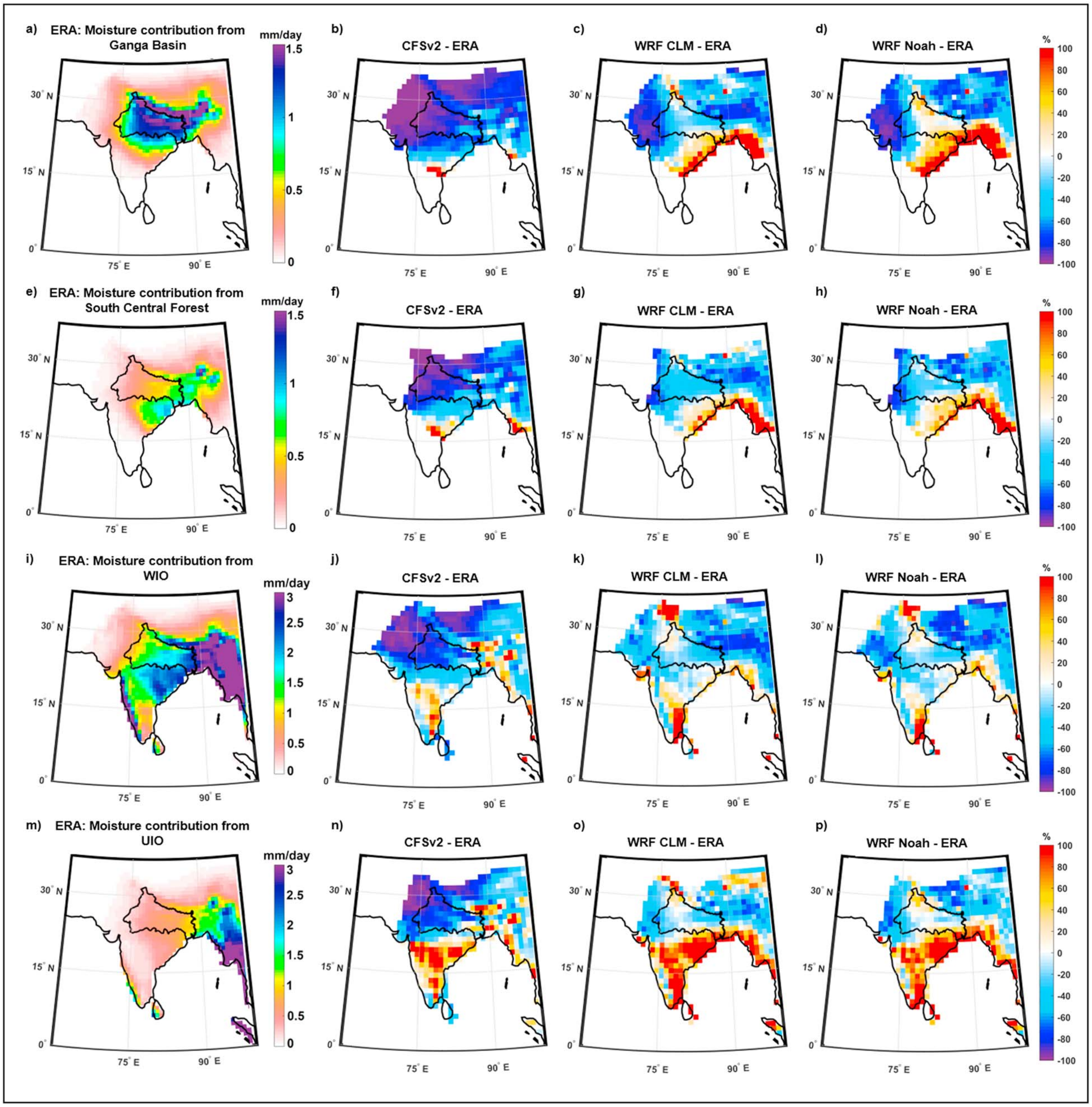


Figure 2. Mean seasonal (June–September) rainfall (in mm/d) that originated from major land and ocean regions in ERA-Interim reanalysis and its biases (in %) in the model simulations. Mean seasonal moisture contribution from (a–d) Ganga basin, (e–h) South Central Forest, (i–l) WIO, and (m–p) UIO. Ganga basin is marked on the map. CFSv2 = Climate Forecast System version 2; WRF = Weather Research and Forecasting model; CLM = Community Land Model.

representation of land surface conditions and recycled precipitation, the moisture contributions from remote sources are also better represented in the regional model simulations.

We present the comparison of 35 year monsoon climatology of Ganga basin rainfall from ERA and the model simulations in Figure 3. The reduction of precipitation dry bias in WRF stemming from improved representation of land and oceanic sources of moisture are equally important throughout the season. The dramatic increase in precipitation during monsoon onset, due to moisture transport from oceanic regions are especially well represented in the regional simulations (Figures 3c and 3d). This raises the question whether the root cause of the precipitation dry bias in CFSv2 is the underestimation of moisture contribution from remote sources during the initial phase of the monsoon. This underestimation could result in low recharge

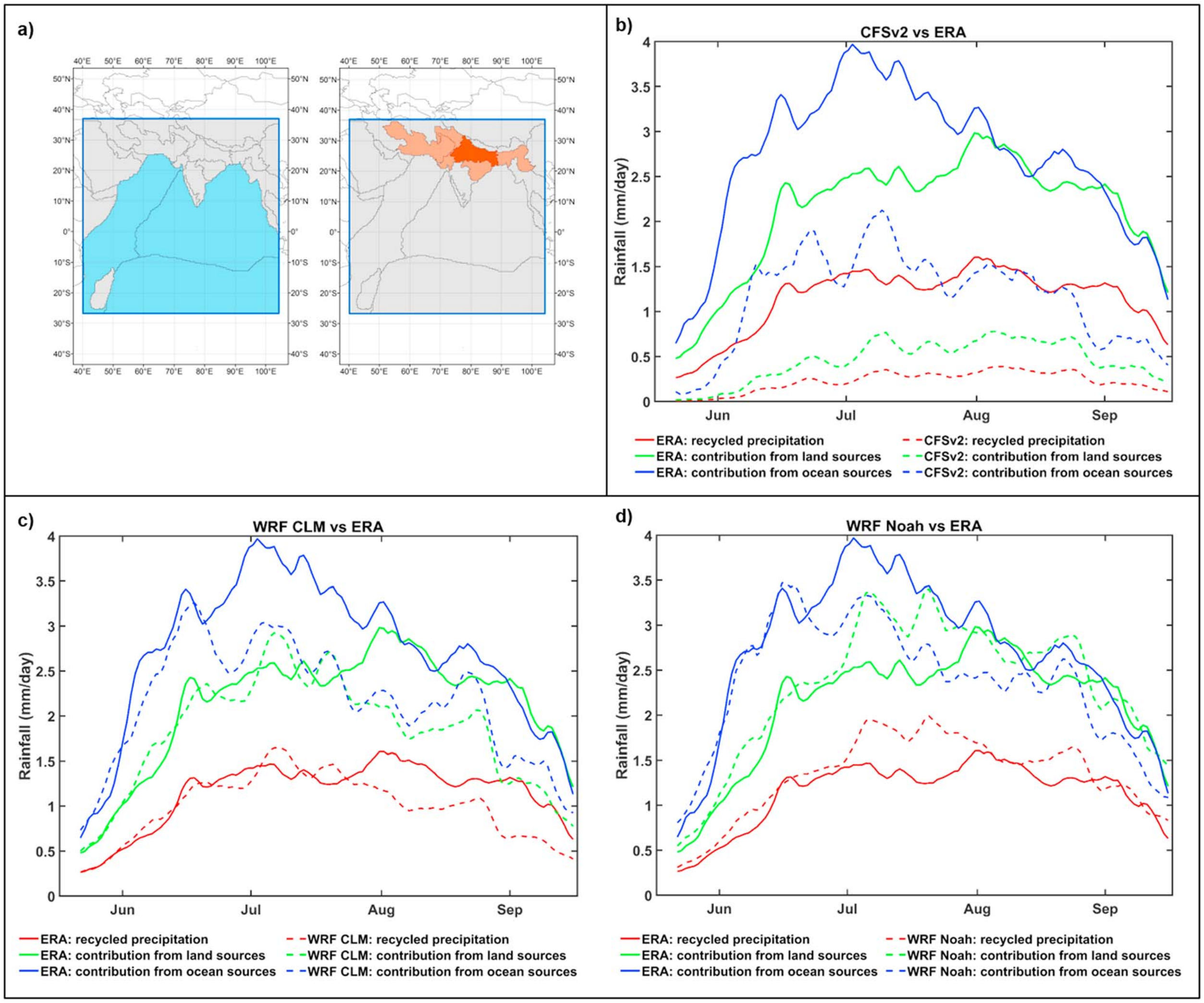


Figure 3. Climatology of seasonal (June–September, JJAS) rainfall over Ganga basin differentiated by contributions from oceanic regions (blue), major land regions (green), and recycling (red). (a) Oceanic (blue) and land (orange) regions. (b) Comparison of climatological JJAS rainfall from Climate Forecast System version 2 (CFSv2) (dotted) and ERA-Interim reanalysis data (solid). (c) Comparison of climatological JJAS rainfall from Weather Research and Forecasting model (WRF) Community Land Model (CLM) using CFSv2 boundary conditions (dotted) and ERA-Interim reanalysis data (solid). (d) Comparison of climatological JJAS rainfall from WRF Noah using CFSv2 boundary conditions (dotted) and ERA Interim reanalysis data (solid).

of soil moisture, reduced ET, and subsequently low feedback and recycled precipitation. We examine the precipitation (*P*)-evaporation (*E*)-recycled precipitation (RP) relationship over the Ganga basin in order to understand whether CFSv2 captures the observed proportions. Comparison of the ratios from ERA, CFSv2, and WRF reveals that CFSv2 underestimates the mean JJAS recycled precipitation by evaporation ratios (RP/*E*) (supporting information Table S3). Thus, even if an improvement in rainfall from remote sources over the Ganga basin can be achieved in CFSv2, it might not necessarily result in improved soil moisture-precipitation feedbacks and recycling.

Thus, the DRM analysis reveals that the reduction of precipitation dry bias in the WRF simulations come from improved representation of precipitation recycling over the Ganga basin (additional 0.92 mm/d, 13% of monsoon rainfall) and improved moisture transport from adjacent land (additional 0.67 mm/d, 9% of monsoon rainfall) and oceanic regions (additional 1.09 mm/d, 15% of monsoon rainfall), especially WIO. We investigate the regional atmospheric processes behind the improved transport of moisture to Ganga basin in the regional simulations. The regional simulations show improvements in the horizontal winds and vertical motion over the Indian landmass. The 850 hPa winds over Northern India show reduced biases in the regional

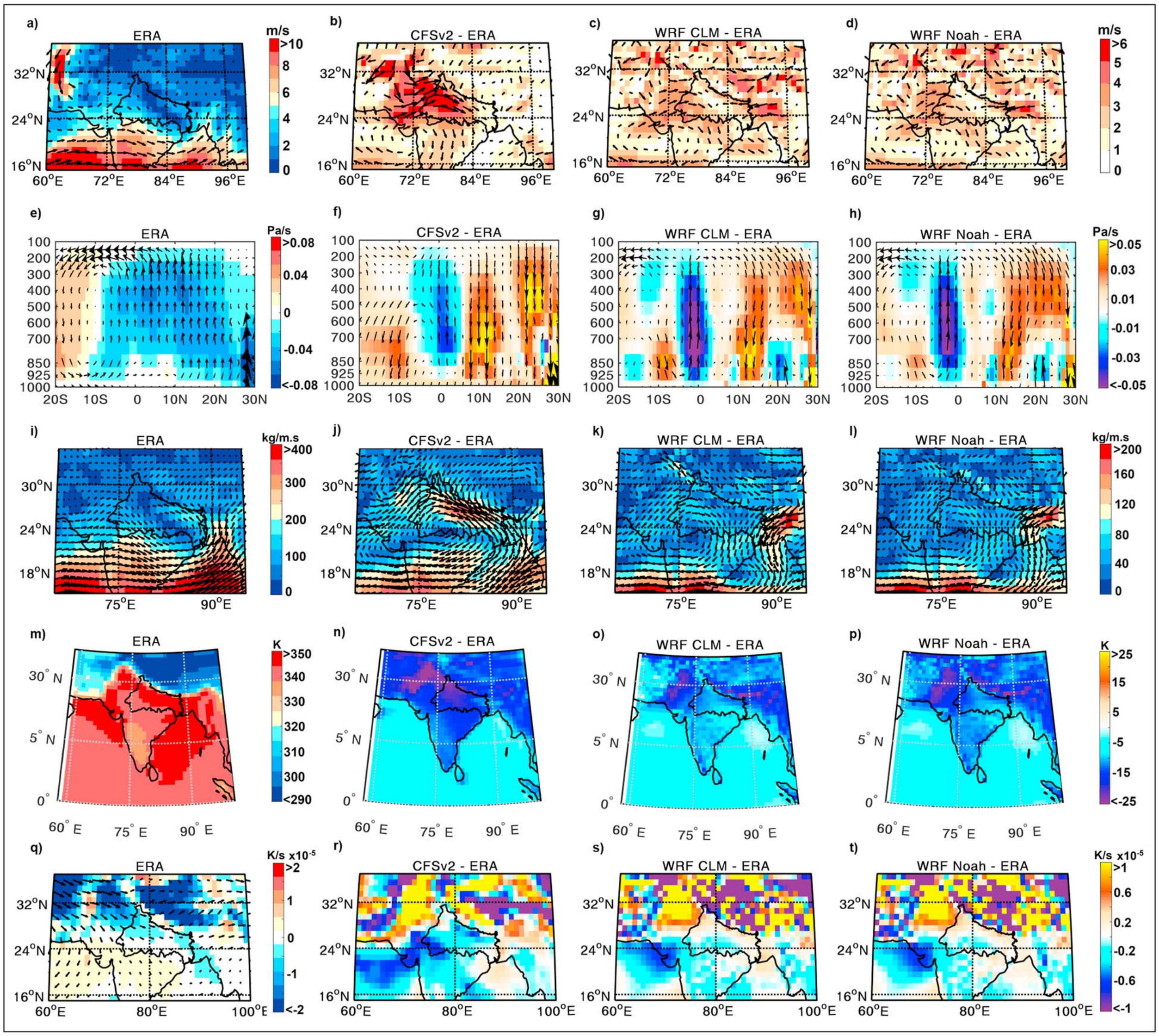


Figure 4. Climatology of regional circulation from ERA-Interim reanalysis data and its biases in Climate Forecast System version 2 (CFSv2), Weather Research and Forecasting model (WRF) Community Land Model (CLM), and WRF Noah using CFSv2 boundary conditions. (a–d) Seasonal (June–September, JJAS) mean 850 hPa wind (in m/s). (e–h) Latitude-pressure section of seasonal (JJAS) mean local Hadley circulation averaged over 70–90°E. The shading denotes vertical velocity in Pa/s (positive values denote downward velocity and negative values upward velocity). (i–l) Seasonal (JJAS) mean vertically integrated moisture flux (in kg/m s). (m–p) Seasonal (JJAS) mean surface moist static energy (in K). (q–t) Temperature advection (in K/s) and wind on the 500 hPa pressure surface. Ganga basin is marked on the map.

simulations (Figures 4a–4d). CFSv2 is reported to show biases in moisture convergence over the monsoon region and a weaker ascending motion over the Indian landmass around 20°N (Goswami et al., 2014). This is visible in our simulations as well. The weaker ascending branch of the Hadley circulation in the CFSv2 free run simulations is strengthened in the regional model, especially in WRF-Noah in the lower troposphere (Figures 4e–4h). However, the biases in ascending motion over the equator in CFSv2 is strengthened in the regional model, consistent with the enhanced precipitation biases seen there. The regional simulations also show improvements in the moisture transport over northern Indian landmass. The WRF simulations capture the observed pattern of vertically integrated moisture transport over the Ganga basin better (Figures 4i–4l). Thus, we find the monsoon dynamics over the north Indian landmass to be better represented in the regional simulations, leading to improved regional precipitation.

Literature indicates that land surface processes influence the regional monsoon circulation over India (Ashfaq et al., 2017; Bollasina & Ming, 2013). The May insolation "perpetual" experiments conducted by Bollasina and Ming (2013) show that monsoon-like circulation is able to evolve driven only by internal land-atmosphere processes mediated by soil hydrology. Thus, the better representation of land surface in the regional model could be responsible for the improvement in regional monsoon circulation seen here. Another possible aspect of the regional simulations that may contribute to the improved monsoon circulation is the higher resolution and improved representation of topography. The 2 m air temperature (T2m) simulated by CFSv2 shows a cold bias over land and the strongest biases are in May, prior to the onset of the monsoon (supporting information Figure S8). The mean bias in T2m during May, over the monsoon land regions (0°–37°N, 60°–100°E) in CFSv2 amounts to −3.8 K, which is reduced to −2.3 K in the regional simulations. Such an anomalous cooling of South Asian landmass and Arabian Sea have also been reported in some CMIP5 models as well. Previous studies have attributed this bias to inadequately resolved western Himalayan orography in the global simulations. The smoothened topography allows advection of cold and dry subtropical air into the North Indian monsoon trough region, inhibiting the setup of continental convection and monsoon circulation (Boos & Hurley, 2013; Chakraborty et al., 2006). The biases in surface moist static energy and surface level winds observed by Boos and Hurley (2013) in the colder CMIP5 models are similar to the biases in CFSv2 and are improved in the WRF simulations (Figures 4m–4p). Figures 4q–4t shows the mean temperature advection at a pressure level of 500 hPa and its biases in the global and regional simulations. CFSv2 shows a cold air advection over northern India which is reduced in the regional simulations.

Here we point out to two factors that contributes to the improvement of regional monsoon circulation and Ganga basin precipitation in the WRF simulations (1) improved representation of the land surface and land-atmosphere coupling and (2) higher resolution and improved representation of topography. In order to understand the relative importance of the two, we perform two additional regional simulations (supporting information S5)—an uncoupled WRF-CLM simulation (Agrawal & Chakraborty, 2016) and a coarser resolution WRF-CLM simulation. The coupled WRF-CLM simulation at 36 km resolution shows a precipitation bias of −1.81 mm/d (−25%) over the Ganga basin. The dry uncoupled WRF-CLM simulation at the same resolution shows an enhanced precipitation bias of −5.22 mm/d (−73%) over the Ganga basin while the 90 km resolution coupled simulation shows a bias of −2.47 mm/d (−35%) (supporting information Figure S10). This indicates that the dominant reason behind the reduction of dry bias over the Ganga basin in the regional model is the better representation of land surface and land atmosphere coupling.

For seasonal predictions, capturing the interannual variability of monsoon rainfall is extremely important. CFSv2 is reported to underestimate interannual variability of global precipitation (Yuan et al., 2011). A preliminary analysis of the free run simulations used here do not reveal significant increase in the interannual variability of Ganga basin rainfall from regional simulations. This is because the interannual variability of moisture contribution from oceanic regions is underestimated in both CFSv2 and the regional simulations (supporting information Figure S11). Thus, the added Indian monsoon prediction skill that can be achieved through regional modeling using CFSv2 hindcasts is yet to be examined and is a potential area of future work.

4. Conclusions

We find a reduction in the climatological monsoon precipitation dry bias over Ganga basin in the operational seasonal prediction model CFSv2, through regional modeling using WRF. Analysis of model simulations using DRM reveals that the improved rainfall in the regional model comes from moisture contributions from both land and oceanic regions. The better representation of land surface and precipitation recycling over the Ganga basin is partly responsible for the reduction of dry bias. Additionally, the regional simulations capture the transport of moisture from oceanic regions (largest improvements in WIO and UIO moisture contribution) to Ganga basin better, especially during the onset phase of the monsoon. The improvement in regional circulation in the WRF simulations that results in realistic moisture transport is due to a better representation of western Himalayan orography and land surface conditions over Northern India. The smoothened topography in the global model allows advection of the cold dry air from the subtropics into the Indian monsoon region, contributing to the cold temperature and dry precipitation bias. The key implication is that a better orographic and land-atmosphere representation is necessary to capture the pattern of monsoon rainfall over northern India. This is relevant for hydrological predictions of Indian monsoon, over the Ganga basin region. Bias correction approaches used on climate data for hydrological modeling do not account for flaws in the representation of physical processes in climate models. Hence, the typically used statistical bias correction approaches may not be ideal for CFSv2 simulations used for hydrological predictions over the Ganga basin region.

The absence of irrigation representation is a limitation of the regional simulations shown here. While literature has not reached a consensus on the effect of irrigation on the South Asian Monsoon (Niyogi et al., 2010; Saeed et al., 2009; Shukla et al., 2014; Tuinenburg et al., 2014), irrigation is thought to have an impact on the regional circulation and monsoon variability. The realistic representation of irrigation and understanding its effects on the monsoon are of prime importance and is a future scope of this work. Another limitation of this work is the use of regional simulations at 36 km resolution. The use of higher-resolution simulations to understand the effect on topography and land surface representations is required and is another potential area of future work.

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