# CMIP5 Projected Soil Moisture Changes over South Asia

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***Abstract***

*Soil moisture is the vital component of the hydrological cycle and its variability is largely uncertain in the upcoming decades. In this paper the future projections of soil moisture changes over South Asia have been analyzed on both annual and seasonal basis from 2020-2050. The comparison of 24 CMIP5 (Coupled Model Inter comparison Project Phase 5) models with GLDAS (Global Lad Data Assimilation System) reanalysis has been done to assess their performance in simulation of soil moisture (0.1m) over the South Asian region. The BCC-CSM-1, MIROC5 were the two models that captured the soil moisture conditions well. They were selected on the basis of high correlation significant at 95 %, least RMSE and Standard Deviation. The mean of both the models were acquired to view the fidelity in the surface layer soil moisture changes in the South Asia. Under RCP's 4.5 and 8.5 BCC-CSM-1 and mean mostly showed slight to moderate decrease in soil moisture content both annually and seasonally (DJF, MAM, JJA and SON). While MIROC 5 projected slight to extreme increase in soil moisture content in the northern half of the South Asia and slight to extreme decrease over the southern and eastern parts of the South Asia annually and season-wise (DJF, MAM, JJA and SON). The MAM will be having the lowest moisture content in the region from 2020-2050. It is anticipated that if soil moisture stress projected by the two models and their mean becomes persistent in future, it may lead to the agriculture drought and generate food security threat in the South Asian region.*

**Key Words:** Soil moisture, CMIP5, General Circulation Model, RCP 4.5 and RCP8.5

## Introduction

The state of surface layer soil moisture is the prime indicator of cross-country mobility, irrigation scheduling, pest management, biomass production, and watershed modeling. It is also an important factor related to climate, floods, and drought forecasting. The erratic precipitation patterns, extensive snow/ice melting, enhancing rate of evapotranspiration and change in soil moisture and runoff are the chief components of hydrological cycle and generally associated with climate warming experienced since the last two decades. The regional variation in these hydrological components generates limitations in spatial and temporal coverage of monitoring networks (Huntington, 2006). Koster, 2004 states that surface layer soil moisture may influence the interaction between land and atmosphere. Some studies that are based upon the model generated output or soil moisture boundary conditions, point out that soil moisture has a potential contribution to climate variability and predictability (Douville, 2004; Conilet al., 2007). Climate models mostly show soil moisture variations in the first 2 m of soil due to precipitation, evaporation, and transpiration as discussed by Chen and Hu, 2004. Soil moisture is a key factor in regulating the water, energy fluxes between the land surface and atmosphere in regional and global scales. The surface soil moisture content is among the most vibrant land surface parameters both spatially and temporally. Soil moisture usually changes due to extraction through evapotranspiration and moisture conduction as well as via infiltration after rainfall or irrigation.

Soil moisture can limit vegetation growth as well as infiltration of rainfall and therefore very important for agriculture sector and flood protection. Although soil moisture plays an important position in weather, climate and ecosystems, still wide range and long-term observations of soil moisture are extremely sparse (Blyth, 1997). For most of the hydrological models soil moisture is a mandatory input. Despite the importance of soil moisture, the in situ measurement is very difficult and requires resources, both human and financial. Only limited area can be covered by in situ point observation, which cannot be the

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representative of the wide region; for example catchment area of a large river basin, because the soil moisture varies temporally and spatially (Hollinger and Isard 1994; Scipal 2005).China, Russia, Ukraine, and United States have the major in situ soil moisture networks around the globe (Jackson et al. 1999, Robock et al. 2000, Scipal 2002 and Wagner et al. 2007b). The long term temporal coverage and sampling intervals vary extremely. Therefore global soil moisture patterns are really sparse.

The South Asian region is a hub of agriculture activities. 80 % of the South Asian population lives in rural areas and rely on agriculture for their livelihood according to the World Bank. The South Asia is already annually affected by climate extremes like cyclones, torrential rains, floods and drought threatening the livelihood of poor people living in rural areas with limited adaptive capacity (Zahid and Rasul 2011). These changes in climate are expected to adversely affect the agriculture fields in near future (Zahid and Rasul 2012). The change in precipitation and runoff patterns may result into soil moisture access or deficit in agriculture lands influencing the crop growth. The increase in surface layer soil moisture will expedite the rate of evapotranspiration and will make the hydrological cycle vigorous while decrease in soil moisture for longer periods may cause the wilting of plants and leads to agriculture drought. If the soil moisture stress continues then drought conditions may prevail in that region. Biggs et al., 2008 reports that the 80 % of the global crop area encompass the rainfed crops and is responsible for 60-70 % global crop production. The soil moisture stress and events of drought causes variation in production frequently in southern India. Therefore the planning for supplemental irrigation is required.

The spatial and temporal variability of soil moisture have been studied by various authors around the world using remote sensing techniques (Engman, 1990; Singh et al., 2004; Qiong et al., 2005; Rahimzadeh et al., 2009; Aiguo Dai, 2012). Walker and Houser, 2001 states that the fully coupled general circulation models have the potential to greatly increase the accuracy of climatological and hydrological predictions due to its long term persistence and accurate initialization of surface soil moisture. The IPCC (CMIP3) 15 global climate models projected the consistent summer dryness and winter wetness in merely fraction of the northern middle and high latitudes. More than half models predict constant wetness in central Eurasia and dryness in Siberia and mid-latitude Northeast Asia. In tropics and subtropics the decrease in soil moisture is dominant. The drier soil is predicted in all the seasons over the southwest North America, Central America, the Mediterranean, Australia, and the South Africa. This decrease in soil moisture is also predicted over Amazon and western Africa in JJA and during DJF in the Asian monsoon region (Wang, 2005).

The projections of soil moisture for the South Asia with respect to the agriculture sector can be very helpful for the decision makers and all the stakeholders. Therefore considering the importance of soil moisture projections the present study has been designed. The main aim of this paper is to illustrate near future projections of surface layer soil moisture under RCP 4.5 and RCP 8.5 for the South Asia from 2020-2050. The 24 CMIP5 AOGCM's (Atmosphere-Ocean General Circulation Models) were compared and then performance wise top two models were selected and their mean (ensemble) was taken to generate the less uncertain future projections for the South Asian region.

## Data and Methodology

### Reanalysis Data

The monthly data of soil moisture (10cm) has been obtained from data archives of Global Land Data Assimilation System (GLDAS) for the period 1979-2005 ftp://hydro1.sci.gsfc.nasa.gov/ data/s4pa/GLDAS/GLDAS_NOAH10_M.020/. The resolution of GLDAS data is 1° × 1°. This reanalysis data is used for the comparison of GCMs data sets (Rodell et al., 2004). The GLDAS data show more fidelity when compared with Pakistan Meteorological Department data sets.

### CMIP5 Models Data

The monthly data of moisture content of soil layer (moisture in upper portion of soil column) that compute the mass of water in all phases in the upper 0.1 meters (0-10 cm) of soil for the 24 GCMs of

CMIP5 database has been used in the study for the period 1979-2005. The information of all the models used in the study has been summarized in Table 1. Firstly the CMIP5 models data were downloaded from http://cmip-pcmdi.llnl.gov/cmip5/ for the historical runs and then for RCP 4.5, RCP 8.5 to generate future projections. The relam for all the data was Land and first ensemble r1i1p1 was chosen for the study.

Taylor et al. (2012) reports that about 1/3rd of the models have atmospheric resolution of approximately 1.5° latitude or less. This higher resolution will be helpful in examining regional hydro climate variables over the globe, although still coarser than would be desirable in regions of complex topography and coastlines. RCP8.5 and RCP4.5 represent the core concentration pathways used for the CMIP5 project (Taylor et al. 2012). These experiments represent high concentration and moderate mitigation pathways in which radiative forcing due to anthropogenic factors reaches 8.5 $Wm^{-2}$ and 4.5 $Wm^{-2}$ by 2100, respectively. Meinshausen et al. 2011states that radiative forcing continues to grow beyond 2100 in RCP 8.5, whereas in RCP4.5 stabilization at 4.5 $Wm^{-2}$ occurs around 2050 and remains fixed. In terms of the time evolution and value of globally-averaged radiative forcing at 2100, these pathways most closely resemble the A1B and A2 scenarios for CMIP3 used in the IPCC Assessment Report 4 (IPCC 2007).

## Methodology

The domain of the study is South Asian region (5-50 °N and 45-100 °E) as shown in Figure 1. The aim of selecting this domain is to compare the CMIP5 GCMs which have the best ability to represent the surface soil moisture for the South Asia region. The soil moisture data of all the GCMs was firstly regridded at 2° x 2° for acquiring the homogeneity of the resolution and comparison among both the data sets (models and reanalysis). The biases have been calculated using the historical climate data (1979-2005). The annual bias analysis has been performed to check the variability in surface layer soil moisture over the South Asian region. The scatter plots have been drawn to find out the spatial pattern correlation between the models and reanalysis datasets. The standard deviation and root mean square error (RMSE) have also been calculated for all the models. The best three models (FGOALS-G2, BCC-CSM-1 and MIROC5) were then selected on the basis of their performance in simulating the upper layer soil moisture for the South Asian region. Unfortunately, FGOALS-G2 RCPs datasets were not available. Hence, the future projections were then generated for RCP4.5 and RCP8.5 by BCC-CSM-1, MIROC5 and their mean in order to investigate the annual and seasonal soil moisture changes in the near future 2020-2050. In order to explain and summarize the results with more clarity the percentage changes in soil moisture have been divided into six parts i-slight increase (<6 %) ii-Slight decrease (<-6 %), iii-moderate increase (<12 %) iv-moderate decrease (<-12 %) and v-extreme increase (>12 %) vi-extreme decrease (>-12 %) on the basis of results obtained from the analysis. The Climate Data Operator (CDO) was used to perform annual and seasonal analysis. The regridding of data to 2° x 2° was also done by the CDO. The Grid Analysis and Display System (GrADS) have

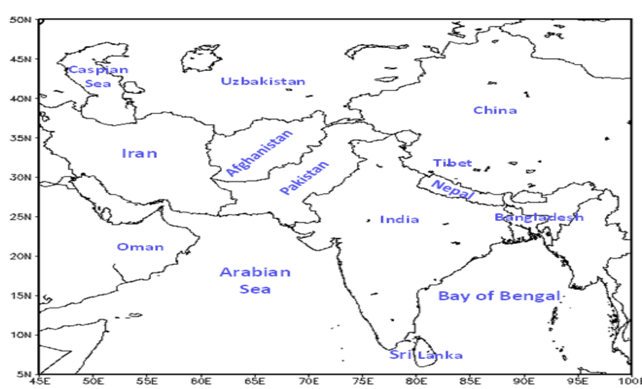


**Figure 1:** The Study Domain (5°N- 50°N - 45°E-100°E)

been used as a visualization tool for the outputs display. The statistical methods (correlation, standard deviation and root mean square error) and significance test (t-test) have been applied in R-Software version 3.02.

**Table 1:** List of 24 CMIP5 Models used in the study.

| Sr. No | Modelling Center | Model | Resolution (Lat × Lon°) |
|---|---|---|---|
| 1. | Beijing Climate Center, China Meteorological Administrtion, China | bcc-csm1-1 model | 2.8 × 2.8 |
| 2. | Canadian centre for climate Modelling & Analysis , Canada | CanESM2 | 2.8 × 2.8 |
| 3. | National Centre for Meteorological Research, France | CNRM-CMS | 1.4 × 1.4 |
| 4. | Canadian centre for climate Modelling & Analysis , Canada | CanCM4 | 2.8 × 2.8 |
| 5. | National  Center for atmospheric Research, USA | CCSM4 | 1.25 × 0.94 |
| 6. | Met Office Hadley Centre, UK | HadCM3 | 3.75 × 2.5 |
| 7. | Met Office Hadley Centre, UK CC(Chemistry Coupled) | HadGEM2-CC | 1.875 × 1.25 |
| 8. | Met Office Hadley Centre, UK | HadGEM2-ES | 1.875 × 1.25 |
| 9. | Institute for Numerical Mathematics, Russia | INM-CM4 | 2 × 1.5 |
| 10. | Institut Pierre Simon Laplace, France | IPSL-CM5A-LR | 3.75 × 1.8 |
| 11. | Institut Pierre Simon Laplace, France | IPSL-CM5A-MR | 2.5 × 1.25 |
| 12. | Institut Pierre Simon Laplace, France | IPSL-CM5B-LR | 3.75 ×1.894 |
| 13. | LASG, Institute of Atmospheric Physics, Chinese Academy of Sciences | LASG-FGOALS-G2 | 2.8 × 1.6 |
| 14. | LASG, Institute of Atmospheric Physics, Chinese Academy of Sciences | LASG-FGOALS-S2 | 2.8 × 1.6 |
| 15. | Commonwealth Scientific and Industrial Research Organization in collaboration with the Queensland Climate Change Centre of Excellence | CISRO-MK3-6.0 | 1.8 × 1.8 |
| 16. | Japan Agency for Marine-Earth Science and Technology, Atmosphere and Ocean Research Institute(The University of Tokyo), and National Institute for Environmental Studies | MIROC-ESM | 2.8 × 2.8 |
| 17. | Japan Agency for Marine-Earth Science and Technology, Atmosphere and Ocean Research Institute(The University of Tokyo), and National Institute for Environmental Studies | MIROC-ESM-CHEM | 2.8 × 2.8 |
| 18. | Atmosphere and Ocean Research Institute (The University of Tokyo), National Institute for Environmental Studies, and Japan Agency for Marine-Earth Science and Technology, Japan | MIROC4H | 0.56 × 0.56 |
| 19. | Atmosphere and Ocean Research Institute (The University of Tokyo), National Institute for Environmental Studies, and Japan Agency for Marine-Earth Science and Technology, Japan | MIROC5 | 1.4 × 1.4 |
| 20. | Meteorological Research Institute, Japan | MRI-CGCM3 | 1.1 × 1.1 |
| 21. | Norwegian Climate Center, Norway | NorESM1-M | 2.5 × 1.9 |
| 22. | Norwegian Climate Center, Norway | NorESM1-ME | 2.5 × 1.9 |
| 23. | NASA Goddard Institute for Space Studies | GISS-E2-H | 2.5 × 2.5 |
| 24. | NASA Goddard Institute for Space Studies | GISS-E2-R | 2.5 × 2.5 |

## Results and Discussion

### Annual Comparison of CMIP5 Models

The comparison of all 24 CMIP5 Models listed in Table 1 have been done considering upper layer soil moisture of 0.1m depth. The biases have been calculated by comparing it with the GLDAS soil moisture data on annual basis. The regridding for both the data sets have been done at 2°x 2° degree resolution and then biases have been plotted as shown in Figure 2.

The annual comparison between reanalysis (GLDAS) and models data showed that the simulation of the soil moisture content by all the 24 GCMs is diverse over the South Asian region. All the countries (Pakistan, Iran, Afghanistan, Bangladesh, Sri Lanka, India, Nepal and Tibet) within the South Asia have their own spatial pattern. The models were showing high biases for one area and lowest biases for another area. For example the BCC-CSM1, CanESM2, CNRM-CM5, FGOALS-G2, HadCM3, HadGEM2-ES, HadGEM2-CC, IPSL-CM5A-LR, IPSL-CMA-MR, IPSL-CM5B-LR, CSIRO-Mk3-6-0, CanCM4, CCSM4, MRI-CGCM3, GISS-E2-H and GISS-E2-R were underestimating the soil moisture conditions indicating deficit in soil moisture over the most parts of the South Asia. While

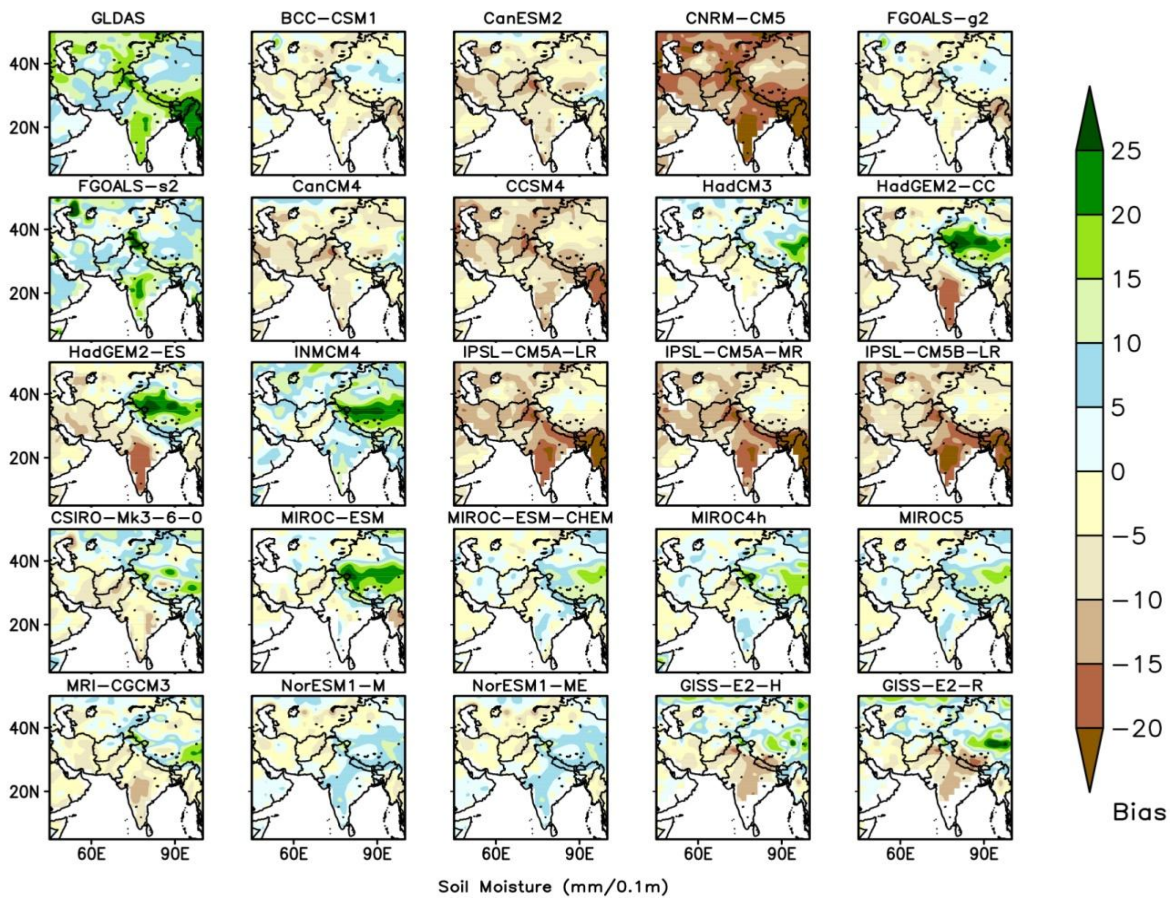


**Figure 2:** Annual mean of surface layer soil moisture of reanalysis dataset (GLDAS) and different GCM 1975-2009.

the MIROC4H, MIROC5, MIROC-ESM-CHEM, MIROC-ESM, NorESM1-M and NorESM1-ME were overestimating in few regions and underestimating in other regions of the South Asia. The INMCM4 and FGOALS-S2 were the only models showing lowest bias for the soil moisture. None of the 24 models have shown homogeneity in estimating and simulating the soil moisture. The model, which seems good for one country seems to be bad for another. The results were not clear so it was not an easy task to conclude through this annual bias analysis that which model is good for the South Asian region.

### Statistical Methods

The bias analysis of models revealed uneven bias distribution throughout the region. Therefore statistical methods were applied on all the 24 models for the selection of approximately accurate top three GCMs for the South Asian region. The correlation, standard deviation and root mean square error have been used for further evaluation of all the models. The scatter plots have been drawn to calculate the pattern correlation between the reanalysis and 24 models on annual basis. Out of 24 models, most of the models have shown very strong positive correlation ≥ 0.7 except FGOALS-S2, IPSL-CM5A-LR, IPSL-CM5A-MR, IPSL-CM5B-LR, CSIRO-Mk3-6-0 and MIROC-ESM which has shown correlation ≤ 0.6 at 95 % confidence level which is statistically significant (Figure 3).

The statistical significance has been plaid by applying t-test. Then models were also compared through standard deviation and root mean square error. The low standard deviation values indicate that the models data point will be very close to mean but large standard deviation values indicate that the data points are spread over a large range of values. Figure 4 shows that the standard deviation is the lowest for the two models (MIROC 5 and MIROC4H) among all indicating the better performance of the mentioned models for the South Asia. Both models have shown statistically significant correlation of >0.75 as well at 95 % confidence level.

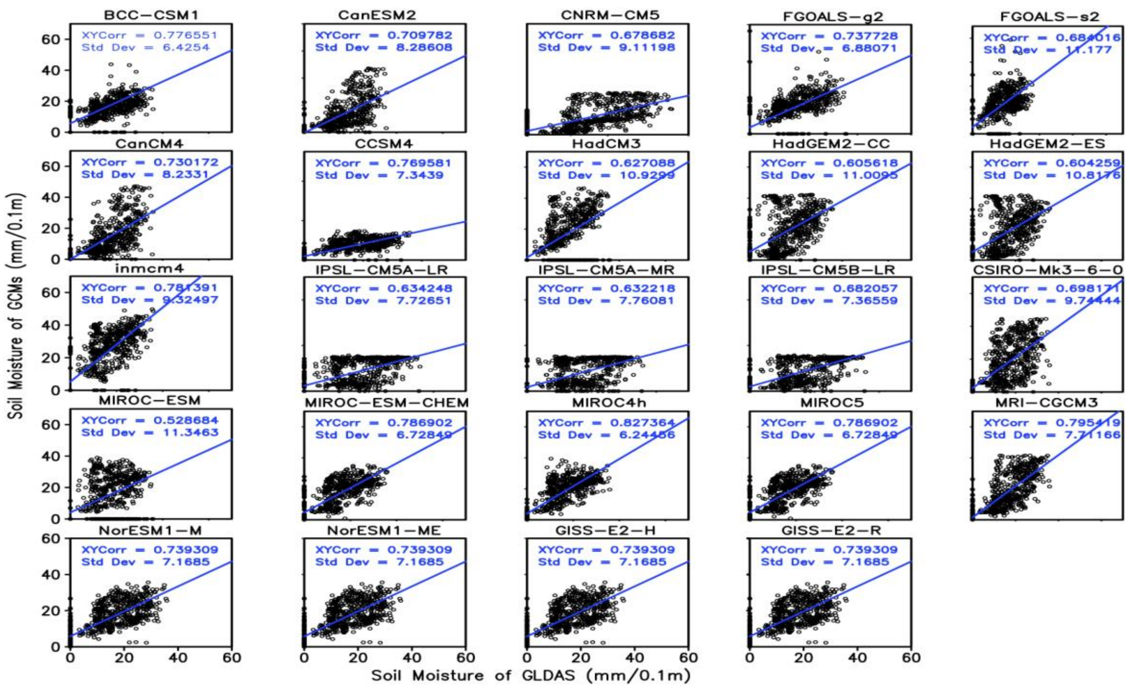


**Figure 3:** Correlation between different GCMs and reanalysis (GLDAS) on annual basis from 1979-2005.

The Root Mean Square Error (RMSE) is a frequently used measure of the difference between values predicted by a model and the values actually observed from the environment that is being modelled. RMSE is considered to be the best statistical approach to compare the individual model performance to that of reanalysis data sets. It is preferred to distinguish model performance during evaluation and

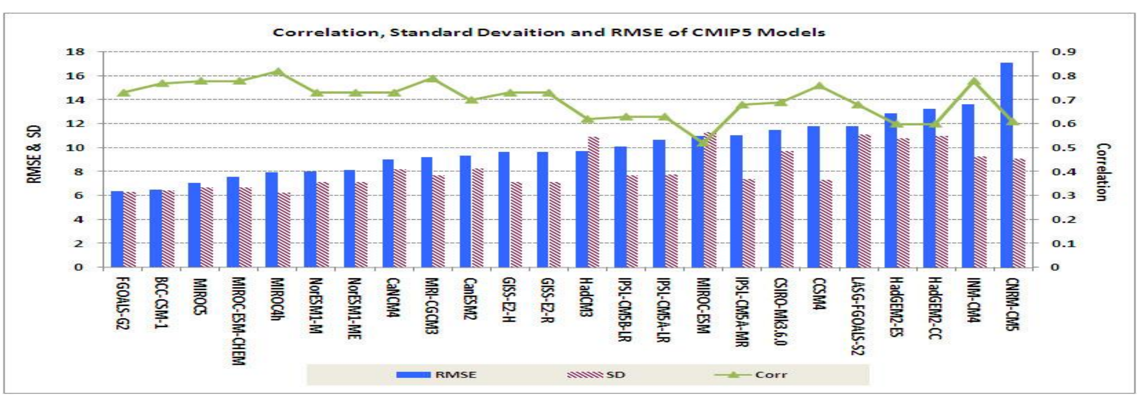


**Figure 4:** Correlation, Standard Deviation and Root Mean Square Error of CMIP5 models with reanalysis data on annual basis (1979-2005).

validation period. RMSE values usually ranges from 0 to 1. The lowest the value of RMSE the greater the performance of that model is expected. The RMSE has been calculated in the study using R-software to analyze the performance of all the models. The FCOALS-G2, BCC-CSM-1, MIROC 5 showed the lowest RMSE during the study. Figure 4 shows the result of statistical methods applied on data sets. The top three models were selected on the basis of statistical techniques (correlation, standard deviation and RMSE) i- FGOALS-G2 ii-BCC-CSM-1 and iii- MIROC 5. The projections of BCC-CSM-1 and MIROC5 were slightly different from each other therefore the mean of both the models were taken to compensate the errors and to have a clear picture about the variability of soil moisture over the South Asia.

**Annual Future Projections (2020-2050) under RCP 4.5 and RCP 8.5**

The surface layer soil moisture of historical run (1979-2005) has been used to calculate the percentage change in the surface layer soil moisture under RCP 4.5 for the period 2020-2050 over the South Asia. The BCC-CSM-1 showed slight to moderate decrease in surface layer soil moisture in western (Iran and Afghanistan) and North-Western parts (Uzbekistan and western China) of the region. While Pakistan, India, Tibet and Nepal have shown slight increase in soil moisture. MIROC5 has also indicated the slight to moderate decrease in the soil moisture over southern and central Pakistan, central India, central Iran, most of the areas of Afghanistan and south of Burma while slight to moderate increase in extreme northern parts of Pakistan and Tibet area. Mean of both the models showed slight decrease in soil moisture over central and southern Pakistan, central India, Afghanistan, Bangladesh and Iran while slight increase in Northern Pakistan and Tibet. The moderate decrease in soil moisture has been observed over northern parts of Afghanistan and few areas of Iran and Oman as shown in Figure 5(a).

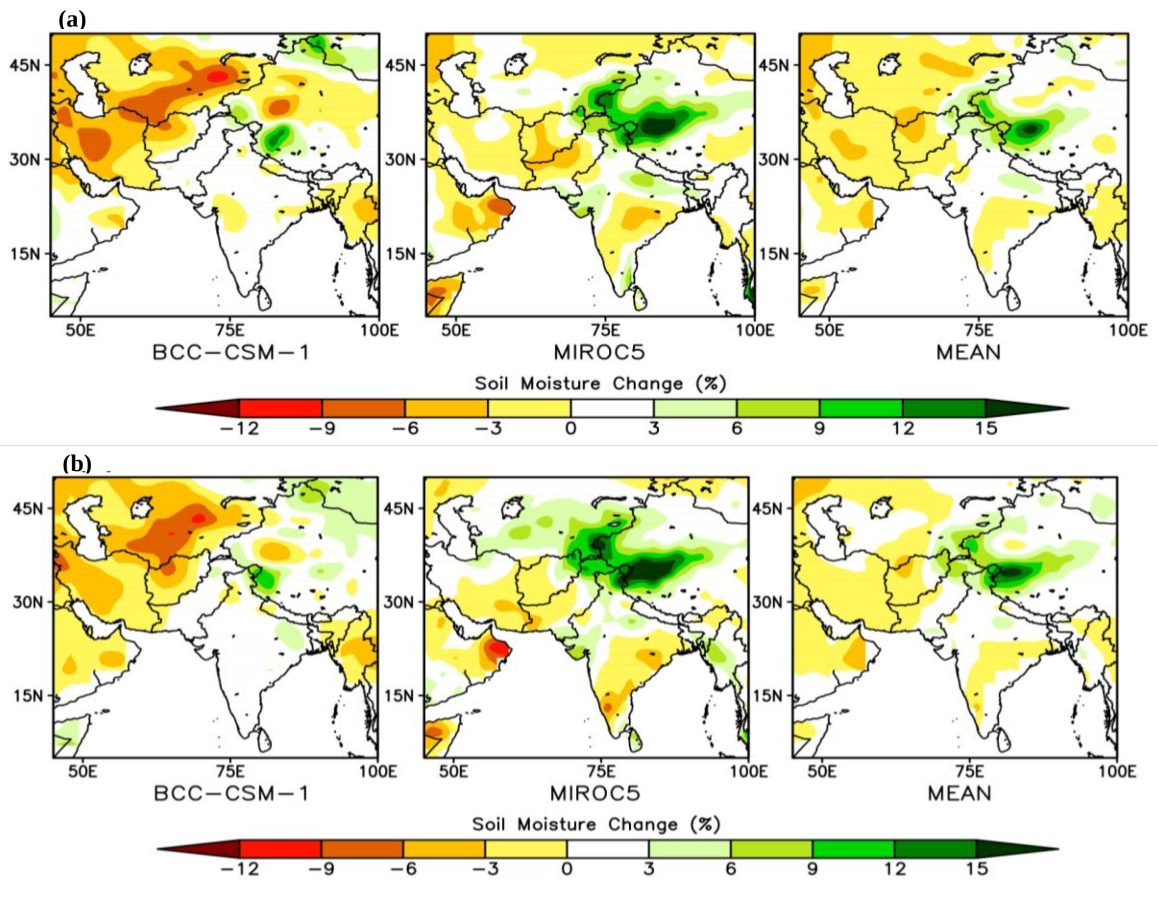


**Figure 5:** Future projections of surface layer soil moisture under **(a)** RCP 4.5 **(b)** RCP 8.5 from 2020-2050.

The future projections for percentage change in surface layer soil moisture have been drawn under RCP 8.5 for the period 2020-2050 over the South Asia as shown in Figure 5(b). The BCC-CSM-1 showed the northward (Iran to Uzbekistan) shift of moderate decrease in soil moisture over the western parts of the South Asia. The slight decrease in soil moisture also shifted eastward from Afghanistan and Iran gripping the south western border and north eastern parts of Pakistan. However slight increase in soil moisture over most of Pakistan, India and western China is quite obvious.MIROC5 has indicated the area with slight decrease in soil moisture has extended over the south western Pakistan, south eastern India, eastern Iran, south of Afghanistan and Bangladesh while slight to extreme increase in soil moisture have been noticed in the northern areas of Pakistan, Tibet, Uzbekistan, Burma, eastern Pakistan and western India. Mean has shown slight decrease in soil moisture in almost various parts of every country lie within the South Asia. While the increase in soil moisture has been projected over the north-eastern and south eastern parts of Pakistan, north and south-western India, central China, north-west of Afghanistan, Iran and Tibet. In nutshell, the decrease in soil moisture in near future is quite evident annually over the South Asia.

**Seasonal Future Projections (2020-2050) under RCP 4.5 and RCP 8.5**

The seasonal analysis has also been done over the South Asian region to describe the future uncertainty in soil moisture variability for the period 2020-2050 under rcp 4.5 and rcp 8.5. Four seasons have been selected i- DJF (December-January-February) ii-MAM (March-April- May), iii-JJA (June- July-August), iv-SON (September-October-November) for the analysis.

**RCP 4.5**

The BCC-CSM-1 projected the slight to extreme decrease in soil moisture over most of the South Asia during DJF, MAM, JJA and SON under RCP 4.5. The slight to decrease in soil moisture was seen over almost entire Pakistan and central India, central Iran, central Afghanistan north-eastern parts of India and north-western areas of China in DJF. The MAM showed slight decrease in soil moisture over central India, some parts of Iran, Afghanistan, Bangladesh, Nepal, and Pakistan. JJA illustrated the slight stress in soil moisture over most parts of the South Asia except over the monsoon zones of India and Pakistan where abundant soil moisture was evident. The SON showed slight to moderate increase in soil moisture conditions over India, Nepal and Pakistan and slight to moderate decrease in soil moisture in western parts and northern regions of the South Asia (Figure 6).

The MIROC5 has also shown seasonal variation in soil moisture under RCP 4.5. The slight to moderate decrease in soil moisture have been analyzed during DJF, JJA and SON in different regions of the South Asia. While in MAM moderate to extreme decrease in soil moisture has been examined over the south eastern Pakistan, south eastern India and Oman. The quite obvious slight to extreme increase in soil moisture can also be seen within the South Asia in each season. The MIROC5 showed that the regions (northern Pakistan, south western China and western India) with increase in soil moisture are almost same in all season only the extent and intensity varied. The slight increase in soil moisture has been observed in northern Pakistan and western India however a small patch of extreme increase in soil moisture has also been projected in the south western China during DJF. The extent of the small patch of extreme rise in soil moisture over south western China enhances over the same regions during MAM, JJA and SON. The sharp rise in extreme soil moisture among all the season has been noticed during JJA.

The mean of BCC-CSM-1 and MIROC5 showed the slight to moderate decrease in almost all the countries lying within the South Asia during DJF, JJA and SON except MAM, where moderate to moderate drop in soil moisture is visible over the south western parts of Pakistan. The slight increase in soil moisture has also been viewed over northern areas of the South Asia during DJF, MAM and JJA. However, in SON the slight increase can be seen over whole Pakistan, south western China, western India, eastern Afghanistan and southern Iran.

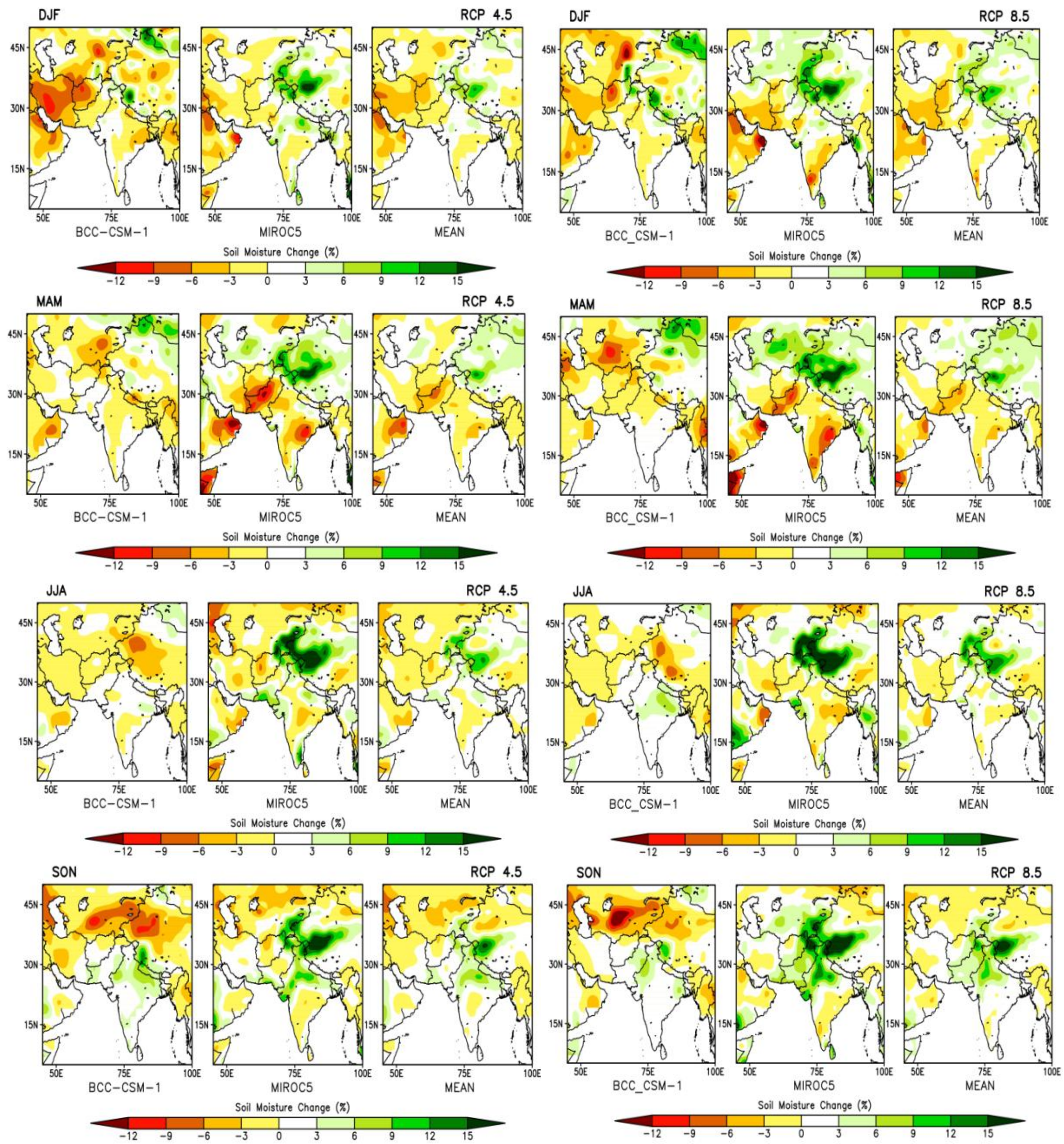


**Figure 6:** Future projections of surface layer soil moisture under RCP 4.5 and RCP 8.5 for different seasons from 2020-2050.

## RCP 8.5

The RCP 8.5 projections illustrated that those areas which were showing the slight decrease in the soil moisture according to RCP 4.5 have converted in to the areas with moderate to extreme decrease. The scope of areas depicting the extreme fall or extreme rise in soil moisture has been extended under RCP 8.5 as shown in Figure 6. The BCC-CSM-1 projected slight to moderate decrease over Iran, Bangladesh and Afghanistan during DJF, MAM, and JJA. However, slight increase in soil moisture was observed in SON. The Pakistan India and Nepal showed slight decrease in soil moisture during DJF and MAM while surplus soil moisture conditions during JJA and SON. The MAM showed westward shift (from India towards Pakistan) of decrease in soil moisture capturing the entire Pakistan and Afghanistan under RCP8.5

The MIROC5 also illustrated the moderate deficit in soil moisture over south eastern Iran, south western Pakistan and southern India during DJF, MAM and JJA. The SON depicts the decrease over central Iran only under RCP 8.5. The slight to extreme increase in soil moisture has been seen in all seasons over China, northern Pakistan, Uzbekistan, Tajikistan, some parts of Pakistan and India. The surplus amount of soil moisture has been noticed during JJA and SON most probably due to the monsoon precipitation (William et al., 2012).The mean of both the AOGCMs (BCC-CSM-1 and MIROC5) has shown slight to moderate increase in soil moisture over western China, northern Pakistan, northern Afghanistan and eastern India during DJF, JJA and SON. The MAM has depicted that slight increase in soil moisture is in extreme north of Pakistan and south west of China. The slight to moderate decrease in soil moisture can be seen over different parts of Iran, Pakistan, India, Bangladesh and Afghanistan during MAM under RCP 8.5

## Conclusion

RCP 4.5 scenario results concluded that BCC-CSM-1 and models mean have shown slight to moderate decrease in soil moisture in almost all the regions of South Asia annually as well as seasonally. While the MIRCO 5 showed slight to extreme increase in surface layer soil moisture content in some northern parts and slight decrease in southern parts of the South Asia throughout the year and in all seasons (DJF, MAM, JJA and SON). RCP 8.5 scenario concluded that annually the BCC-CSM-1 and models mean projected slight to moderate decrease but seasonally slight to extreme decrease in soil moisture has been experienced in all the seasons (DJF, MAM, JJA and SON) over most of the South Asia. However, slight increase in soil moisture has been noticed in DJF, JJA and SON) over central Pakistan, south western China and western India. The slight stress in soil moisture seems to be stretched over some areas of Pakistan, India, Iran, Afghanistan and Bangladesh and slight to extreme increase in soil moisture has been noticed in northern areas of Pakistan, western China, northern Afghanistan and eastern India under RCP 8.5 annually and seasonally (DJF, MAM and JJA). Whereas the SON season of MIROC 5 showed slight to extreme increase in soil moisture over most of the regions lies in the center of South Asia and slight to moderate decrease in the rest of the few regions. The selected models and their ensemble mean clearly projected the evident dryness of lands in the South Asian region particularly in MAM. The overall pattern of percentage soil moisture anomalies between RCP 4.5 and 8.5 seems similar with only slight variation in geographical location indicating slight and gradual decrease in soil moisture within the region. Therefore it has been planned that these two selected models will further be downscaled by the Regional Climate Models and more detail research will be carried out to study the impacts of this soil moisture deficit over the South Asia focusing Pakistan to plan adaptation strategies for the agriculture lands under the changing climate.

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