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Comparison of JULES simulated soil moisture over Indian region

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सार – जल चक्र, मौसम और जलवायु परिवर्तन को समझने के लिए मृदा नमी की जानकारी उपयोगी है। मृदा नमी भू सतह के जल चक्र के लिए भंडार है; यह वायुमंडल की सीमा स्थिति है; यह भू सतह के ऊष्मा के विभाजन को नियंत्रित करती है, वनस्पति पर निर्भर होने की स्थिति को प्रभावित करती है और मिट्टी के ऊष्मीय गुणों को नियंत्रित करती है। मुख्य प्रश्न यह उठता है: JULES (ज्वाइंट यू के लैंड एन्वायर्नमेंट सिम्युलेटर) ने मृदा नमी की तुलना प्रेक्षणों और पुनर्विश्लेषण से कैसे की है। इस सवाल के जवाब में, 1 जून 2016 से 15 जुलाई 2016 की अवधि के लिए कुछ स्थानों में स्व स्थाने तथा AMSR2 उपग्रह प्रेक्षणों और ERA5 - भूमि रिअनलिसिस डेटा प्रेक्षणों से कानपुर, बेरमबाड़ी, जैसलमेर, नवागाम, समस्तीपुर, होशंगाबाद, बीजापुर और कल्याणी में कुल आठ स्थानों पर JULES से मृदा नमी का सत्यापन किया गया है। यह निष्कर्ष निकाला गया है कि JULES भारत में आकृति विज्ञान (मिट्टी का रंग, भौतिक संरचना, परतों पर रासायनिक और खनिज गुणों) और मृदा नमी को अच्छी तरह से वितरित किया जाता है, हालांकि कुछ क्षेत्रों में मात्रा को कम करके आंका जाता है, जबकि मॉडल अच्छी मृदा नमी के कुछ स्थानों पर अच्छे प्रेक्षण उपलब्ध कराता है। अच्छे मॉडल पूर्वानुमान के लिए आगे के अध्ययनों में अन्य मृदा प्राचलों का भी विश्लेषण किया जाना चाहिए।

ABSTRACT. Soil moisture information is useful for understanding the water cycle, weather and climate change. Soil moisture is the reservoir for the land surface hydrologic cycle; it is the boundary condition for the atmosphere; it controls the partitioning of land surface heat fluxes, affects the status of overlying vegetation and modulates the thermal properties of the soil. The key question arises: how does JULES (Joint UK Land Environment Simulator) simulated soil moisture compare with observations and reanalysis. To address this question, soil moisture from JULES has been verified at total eight places over Kanpur, Berambadi, Jaisalmer, Nawagam, Samastipur, Hoshangabad, Bijapur and Kalyani with AMSR2 Satellite observations and ERA5-Land reanalysis data and at some places with in-situ observations for the period from 1st June, 2016 to 15th July, 2016. It is concluded that JULES simulates the morphology (soil colour, physical structure, chemical and mineralogical properties of layers) and distribution of soil moistures over India well though the amounts are severely underestimated in some regions while model provide good match with observations at some places having good soil moisture. Other soil parameters should also be analysed in further studies for a good model forecast.

Key words – JULES, Soil moisture, ERA5-Land reanalysis data, AMSR2 soil moisture observations, Agro-Meteorological Stations (AMS), Soil moisture.

1. Introduction

Variations of soil moisture in response to atmospheric conditions (precipitation, radiation and evaporative demand) impact surface turbulent and radiative heat fluxes, thereby potentially feeding back on atmospheric conditions. For example, low precipitation conditions can ultimately limit soil moisture availability, leading to decreased latent and increased sensible heating at the surface. Soil moisture is one of the important components of the global energy and water balance, but only its estimates are available over the globe. Atmospheric circulation however strongly depends on the land-surface evapotranspiration from vegetation which is an important factor in the earth's climate (Shukla and Mintz, 1982). Modelling studies underscores land-surface hydrology as a crucial component of climate system (Dirmeyer and Shukla, 1993). Hence, the relationship between soil moisture and precipitation variability on daily to seasonal timescales has been emphasized by several studies (Delworth and Manabe, 1988 and references therein).

Over the last few decades, precipitation has been extensively documented. Yet, it is not feasible to derive a global soil moisture climatology from *in situ* measurements due to the high spatial variability of both precipitation and land surface properties. Soil moisture products from ECMWF have been evaluated using ground based in-situ observations from 117 stations across the world (Albergel *et al*., 2012). Remote sensing techniques, such as microwave measurements, may be used in order to obtain a better spatial coverage, but they have strong limitations and are still unable to provide reliable observations of subsurface soil moisture (Choudhury, 1993; Chakravorty *et al*., 2016). Soil moisture fields can be derived from GCM (General Circulation Model) simulations but could be unreliable due to the significant biases that are found in GCM precipitation, radiation and low-level parameters. To overcome this difficulty with GCM derived fields, a land surface model *viz*., the Joint UK Land Environment Simulator (JULES), has been used here which simulates many soil and vegetation processes.

Combined with detailed land surface modelling using JULES, this will allow testing of land surface initialization for monsoon forecasts and improved land-atmosphere coupling in weather and climate models. June-July would be a good period for comparing of soil moisture over India as June month is mainly dry for Central and North India and July is sufficiently humid. Some studies conclude positive feedback of soil moisture through evaporation (Meehl, 1994) on precipitation yet others suggest that the monsoon precipitation is not sensitive to soil moisture (Sud and Smith, 1985). In the light of such inferences for the monsoon region on soil moisture simulations with models, the present study is potentially relevant. Soil moisture verification will be done with the help of ERA5-Land reanalysis data, AMSR-2 L3 soil moisture and *in situ* soil moisture observations from Agro-Meteorological Stations available at MOSDAC (https://www.mosdac.gov.in) archive. This study thus constitutes an attempt to understand the impact of JULES simulated soil moisture as an improved input to models towards producing better predictions of the monsoons.

2. JULES model description

NCMRWF adapted Unified Model from UK Met Office with acronym NCUM (Rajagopal *et al*., 2012) for medium range weather forecast. This is a grid point model with ~17 km horizontal resolution in mid latitude regions and has 70 vertical levels to represent the depth of the atmosphere. Model initial conditions have been created by 4D variational data assimilation procedure. JULES originated from the Met Office Surface Exchange Scheme (MOSES; Cox *et al*., 1999; Essery *et al*., 2003), the land surface model developed at the UK Met Office for applications ranging from operational weather forecasting to earth system modelling. Detailed scientific formulation of JULES on its energy and water fluxes are provided by Best *et al*. (2011) and the carbon and vegetation dynamics part is documented by Clark *et al*. (2011). It is a tiled land surface model with sub-grid heterogeneity and computes surface temperatures and fluxes separately for each surface type in a grid-box. It can represent a grid box with nine major LU/LC types (surface type fractions) namely broad leaf trees, needle leaf trees, temperate grass, tropical grass, shrubs, urban, inland water, bare soil and land ice. JULES exchanges surface fluxes (latent heat flux, sensible heat flux and CO_2, etc.) and momentum to the atmospheric model at each time step. At the same time atmospheric component of Unified Model forces the evolution of JULES 2D land surface model by precipitation, surface short-wave and long-wave radiation, surface wind speed, pressure and moisture.

JULES has four vertical levels for soil moisture and soil temperature prediction. These soil layers are of thicknesses 0.1, 0.25, 0.65 and 2.0 m, giving a total soil depth of 3 m. Here the verification is for the uppermost layer. The other parameters are taken from archived data: thus, land use and land cover data are specified from IGBP (International Geosphere - Biosphere Programme) data (Loveland and Belward, 1997); soil data from HWSD (Harmonized World Soil Database) (Nachtergaele *et al*., 2008) and Albedo data from WHS (Henderson-Sellers & Wilson, 1983). Soil data from HWSD (Harmonized World Soil Database) considers selected soil parameters (organic carbon, pH, water storage capacity, soil depth, carbon exchange capacity of the soil and the clay fraction, total exchangeable nutrients, lime and gypsum contents, sodium exchange percentage, salinity, texture class and granulometry).

3. Objective of the study

The objective of this study is to assess the accuracy of soil moisture forecasts by JULES model during monsoon period by evaluating with regard to corresponding analyzed fields of ERA5-land reanalysis data, Satellite derived soil moisture (AMSR2-L3) and ground-based observations from Agro-Meteorological Stations. Over the Indian region, there are 8 locations (Kanpur, Berambadi, Nawagam, Jaisalmer, Bijapur, Hoshangabad, Kalyani and Samastipur) where soil moisture derived from JULES model has been verified. These places have been chosen based on different kinds of soil and availability of observations.

The study period has been taken from 1st June, 2016 to 15th July, 2016. Kanpur, Berambadi, Jaisalmer, Nawagam, Hoshangabad, Samastipur, Bijapur and Kalyani have been chosen within the study region (8-37° N, 68-97° E) in Indian monsoon region. Initial conditions are prepared from NCUM SURF analysis (Fig. 1).

Biases and correlation coefficient will be computed to analyse the model reliability. Bias gives the information about how much expected value differ from the true value.

Bias = Forecast – Observation

Correlation coefficient is computed between model values and with each different kind of observation separately.

$$\text{Corr} = \frac{\sum_{i=1}^{n}\left(x_i - \bar{x}\right)\left(y_i - \bar{y}\right)}{\sqrt{\sum_{i=1}^{n}\left(x_i - \bar{x}\right)^2 \sum_{i=1}^{n}\left(y_i - \bar{y}\right)^2}}$$

Correlation coefficient values range between -1.0 to 1.0. A correlation of -1.0 shows a perfect negative correlation, while a correlation of 1.0 shows a perfect positive correlation. A correlation of 0.0 shows no linear relationship between the movement of the two variables.

4. Datasets

ERA5-Land is a reanalysis dataset with a consistent view of the evolution of land variables over several decades at an enhanced resolution compared to ERA5 (Henderson-Sellers *et al*., 2008; Hersbach *et al*., 2020). It is globally gridded dataset with 0.1° × 0.1° horizontal resolution (~9 km resolution) available on hourly basis. Its temporal coverage is from January 1981 to present. It is now extensively used for evaluating model simulations at various resolutions.

Advanced Microwave Scanning Radiometer 2 (AMSR2) on board the Global Change Observation Mission First Water "SHIZUKU" (GCOM-W1) of Japan Aerospace Exploration Agency (JAXA), provide the first opportunity to retrieve the standard satellite soil moisture product with global coverage and long duration period (Njoku *et al*., 2003; Koike *et al*., 2004; Fujii *et al*., 2009). The AMSR2 sensor provides passive microwave measurements at seven bands, ranging from 6.93 to 89.0 GHz at HH-VV polarization, with daily ascending (1:30 P.M. equatorial local crossing time) and descending (1:30 A.M. equatorial local crossing time) overpasses. The AMSR2 L3 soil moisture product at 6.93 GHz with a grid resolution of 0.25° is evaluated in this study. Parinussa *et al*., 2017 found that passive microwave observations in the AMSR2 C-band frequency (6.9 GHz) have an advantage over the AMSR2 X-band frequency (10.7 GHz) over moderate to densely vegetated regions. AMSR2/GCOM-W1 surface soil moisture (LPRM) L3 1 day 10 km × 10 km descending Vg001 is a Level 3 (gridded) data set. Its land surface parameters, surface soil moisture, land surface (skin) temperature and vegetation water content, are derived from passive microwave remote sensing data from the Advanced Microwave Scanning Radiometer 2 (AMSR2), using the Land Parameter Retrieval Model (LPRM). There are two files per day, one ascending (daytime) and one descending (nighttime), archived as two different products.

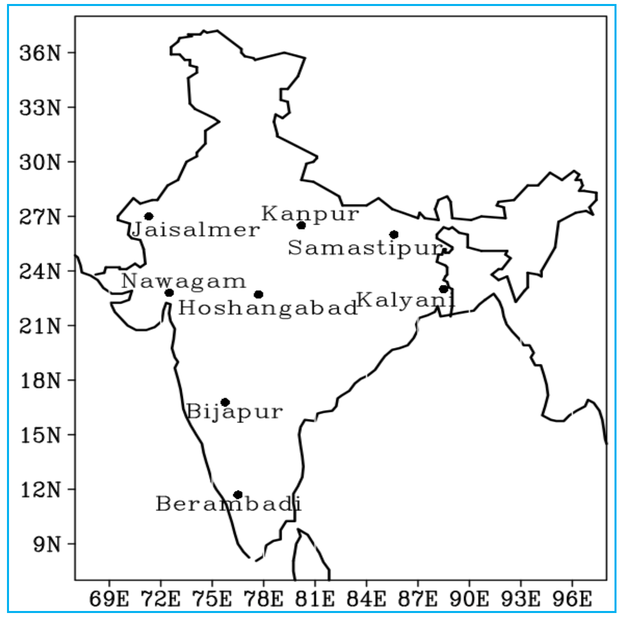

Fig. 1. Study region

Ground based observations have been taken from MOSDAC (Meteorological & Oceanographic Satellite Data Archival Centre; https://www.mosdac.gov.in/), a data archival of Space application Centre, ISRO. There are total 24 Agro-Meteorological Stations (AMS) available all over India, where *in situ* soil moisture observations are being recorded. Based on the availability of observations and their location, the eight places have been chosen for this study.

5. Results and discussion

Simulated volumetric soil moisture fields (level 1) from JULES have been compared to ECMWF ERA5-Land reanalysis data for June, 2016 and 1-15 July, 2016 separately. As shown in Fig. 2, JULES is able to capture the main features of level-1 soil moisture for the month of June, albeit low values over Indian region in comparison with ERA5-Land data. However, high values of soil moisture in some parts of Jammu and Kashmir region, West Coast and in North-Eastern states of India may be noted. While June is representative of a hot period in Central India during which the Southwest monsoon has already covered Southern Peninsular region and Northeast region. An important finding from Fig. 2 is that though the JULES simulated soil moisture amounts

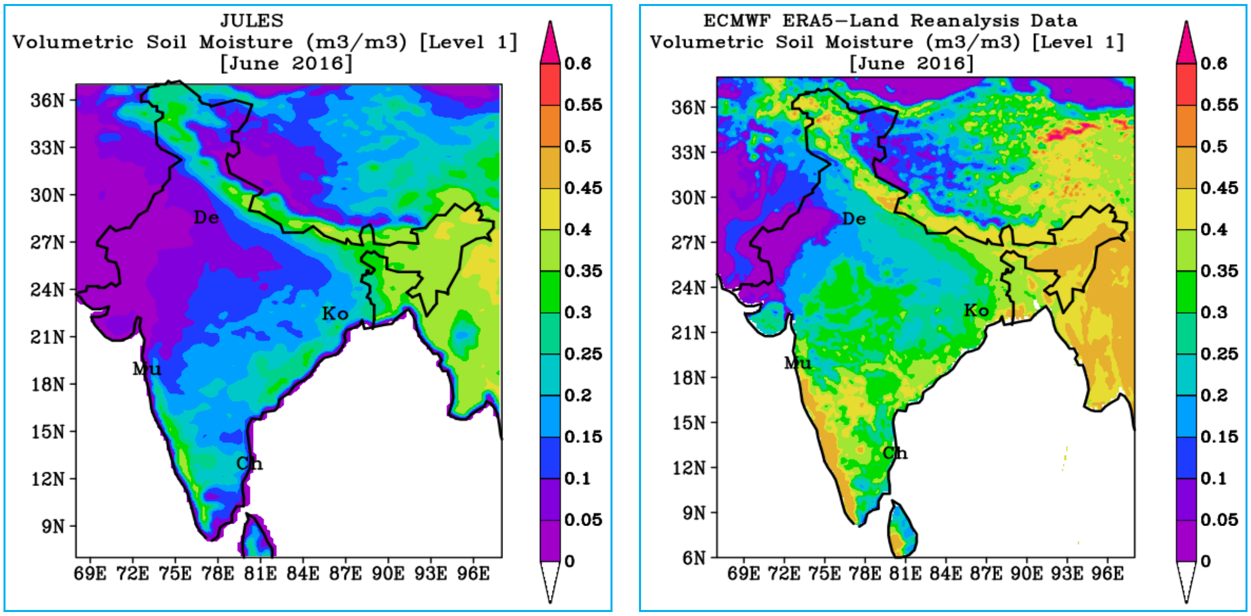

Fig. 2. Comparison of volumetric soil moisture (m^3/m^3) for June 2016

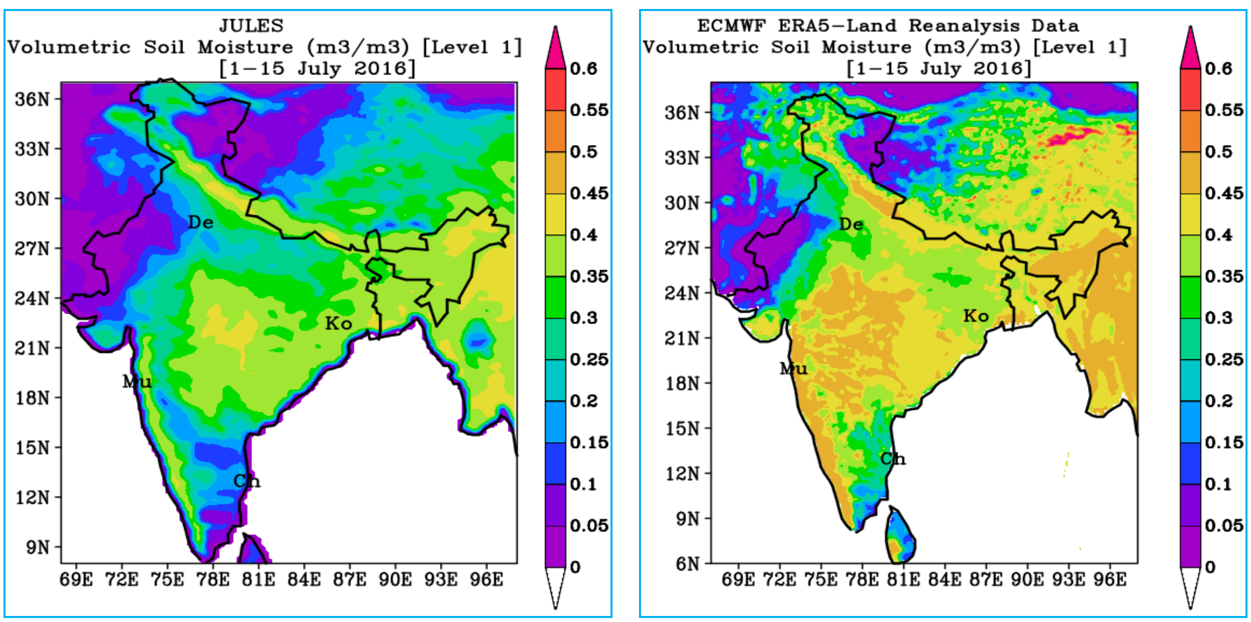

Fig. 3. Comparison of volumetric soil moisture (m^3/m^3) for 1-15 July, 2016

are relatively lower, its distribution is in good agreement with the ERA5-land soil moisture pattern.

During the fortnight 1 - 15 July, 2016, Again JULES showed lower magnitudes of soil moisture over India in comparison with ERA5-land data (Fig. 3). However, larger differences in soil moisture amounts may be noted over Central India, West coast, Uttarakhand and North-Eastern states, where monsoon have reached by this time, which indicates the bias of rainfall forecast from NCUM model. Rainfall values have been taken from NCUM model in JULES.

Biases too have been analysed for the June and July months separately for 2016 and displayed in Fig. 4. As expected, negative biases in soil moisture dominate the June-July month, except some parts of Jammu & Kashmir, Himachal Pradesh, Gujrat and Rajasthan.

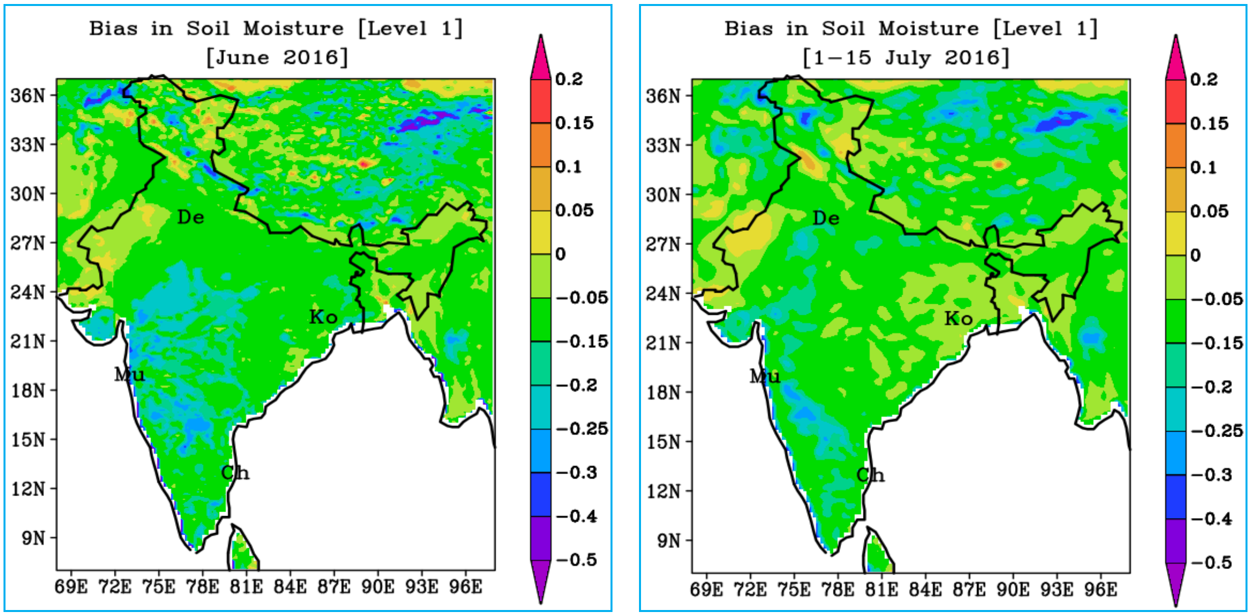

Fig. 4. Bias in soil moisture from ERA5-Land reanalysis data

Besides the study of soil moisture magnitudes and the biases in it over India, further verification has been carried out by examining the time series, biases and correlation coefficients of volumetric soil moisture at eight representative locations, *viz*., Kanpur, Nawagam, Jaisalmer, Samastipur, Hoshangabad, Kalyani, Bijapur and Berambadi (Fig. 1 shows their location on the map) from JULES, ERA5-land data, AMSR2 satellite observations and with some available *in situ* observations.

5.1. *Kanpur (26.51, 80.22)*

Kanpur is an urban location in Uttar Pradesh, grassland type land characteristics with alluvial soil. Alluvial kind of soil is porous with equal proportion of and and clay nature. Porosity and texture provide good drainage and other conditions favourable for agriculture. Kanpur is hot and dry in June month; southwest monsoon reaches there during July. An inspection of the time series as depicted in Fig. 5(a), shows that at Kanpur, JULES simulated soil moisture follows the pattern of ERA5-L and dataset trend but relatively underestimated. AMSR2 observations are also higher than the model simulated soil moisture in the month of June, but a bit closer during July.

The bias at Kanpur with ERA5-land data is –0.13 and with AMSR2 is –0.12 (Table 1). Furthermore, the correlation coefficient of JULES with ERA5-land is quite good (0.92) as compared to AMSR2 (0.77). Satellite observations (AMSR2) are missing for most of the days, that could be the reason for low correlation coefficient.

5.2. *Berambadi (11.76, 76.56)*

Berambadi is in Karnataka state and comes under semi-arid climate zone, mostly covered with natural vegetation. Here, the soil types are black, red and rocky/weathered kind of [Fig. 5(b)].

Here also JULES simulated soil moisture is under-estimated in comparison with ERA5-land and AMSR2 observations. AMSR2 observations are more than ERA5-Land reanalysis dataset and missing in between too. The average bias during June-July with ERA5-Land data is -0.15 and with AMSR2 -0.3, while the correlation coefficient with ERA5-land is quite less (0.538) than the Kanpur and AMSR2 observations, it is lesser (0.508).

5.3. *Nawagam (22.80, 72.57)*

Nawagam is a town in Gujarat, covered in semi dense forest. Types of soil in this area is clay type, slightly saline. Land is generally irrigated agriculture type. JULES simulated soil moisture is underestimated from ERA5-Land values, AMSR2 observations and *in situ* observations too. *In situ* observations from Agrometeorological stations are available for 21 days only (1st June - 21st June, 2016). JULES is in tune with *in situ* observations and ERA5-Land except the AMSR2. JULES and ERA5-Land follow the same trend for June-July 2016 but there is a difference in values.

The soil moisture during June is quite low at Nawagam, In the June end, soil moisture starts to pick up. JULES model follows the pattern of observed datasets. The magnitude of AMSR2 observations look closer to

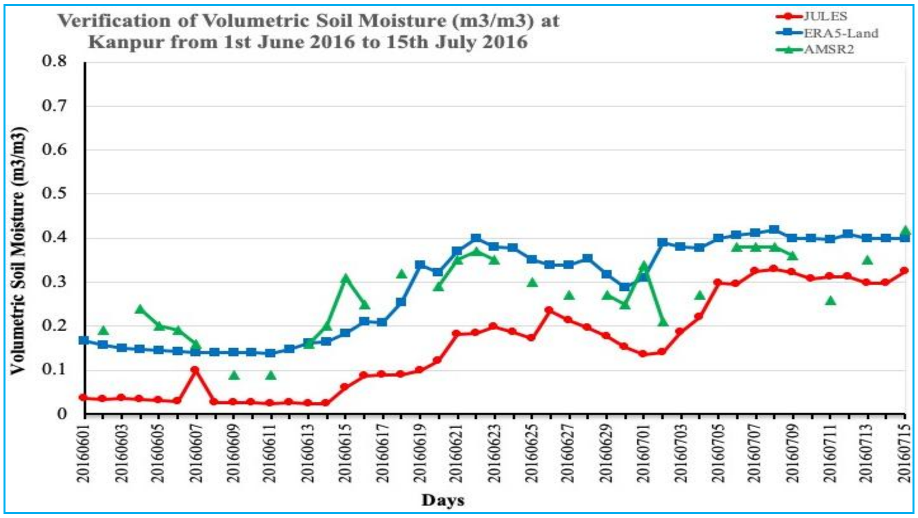

Fig. 5(a). Volumetric soil moisture for 1st June - 15th July, 2016 at Kanpur

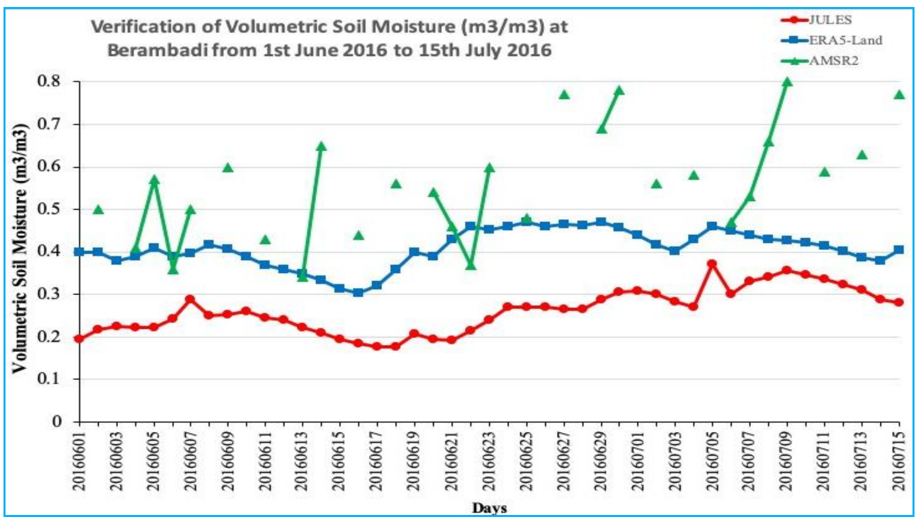

Fig. 5(b). Volumetric soil moisture for 1st June - 15th July, 2016 at Berambadi

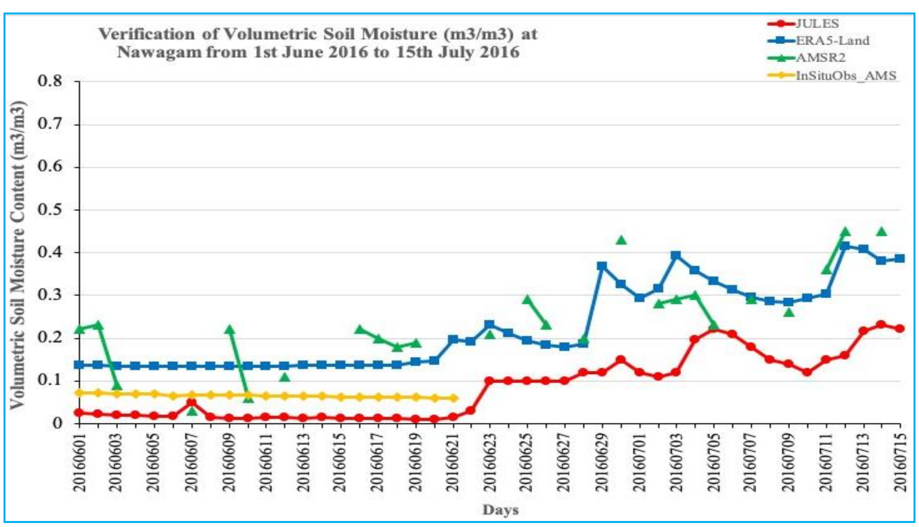

Fig. 5 (c). Volumetric soil moisture for 1st June - 15th July, 2016 at Nawagam

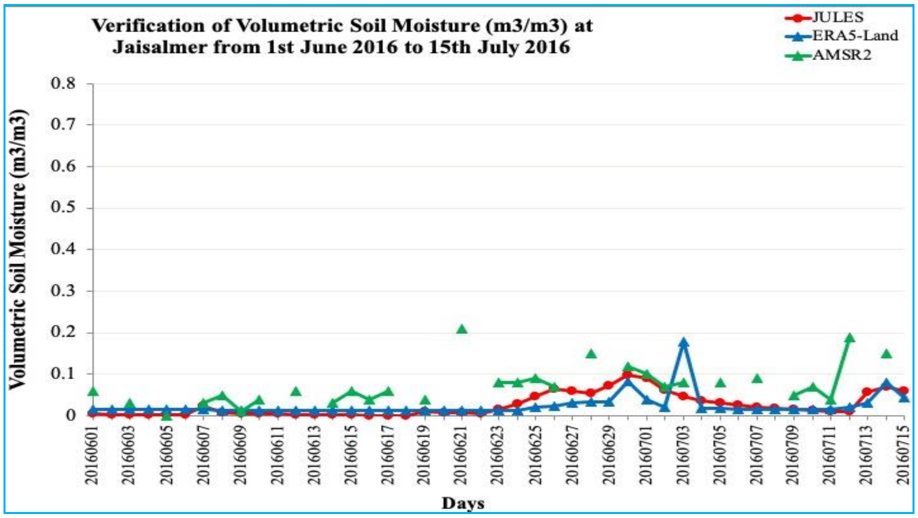

Fig. 5(d). Volumetric soil moisture for 1st June - 15th July, 2016 at Jaisalmer

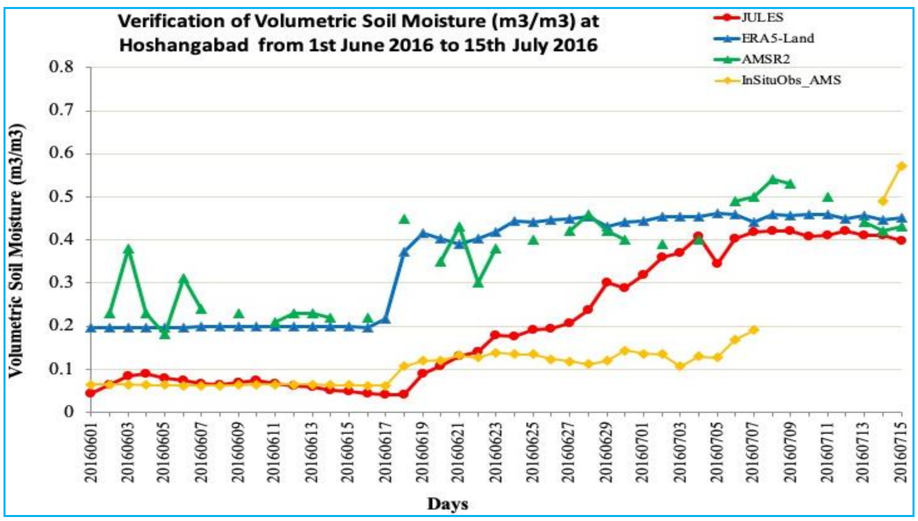

Fig. 5(e). Volumetric soil moisture for 1st June - 15th July, 2016 at Hoshangabad

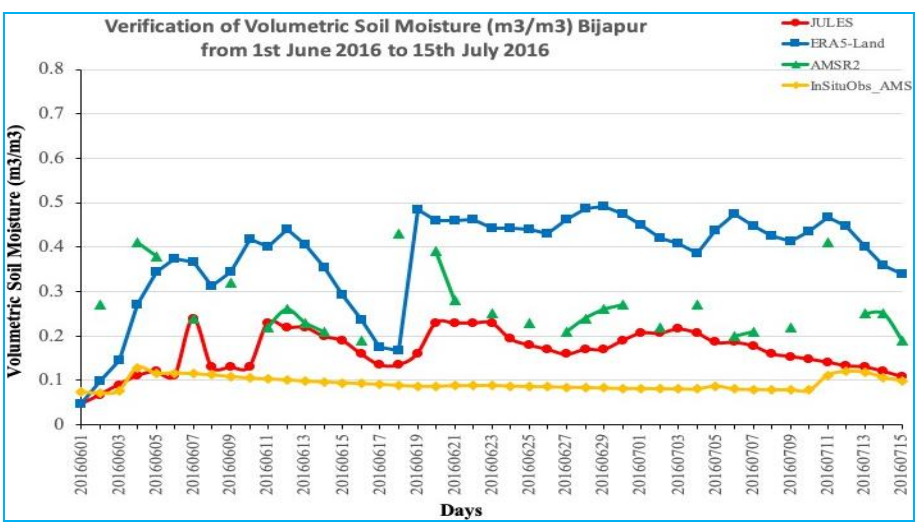

Fig. 5 (f). Volumetric soil moisture for 1st June - 15th July, 2016 at Bijapur

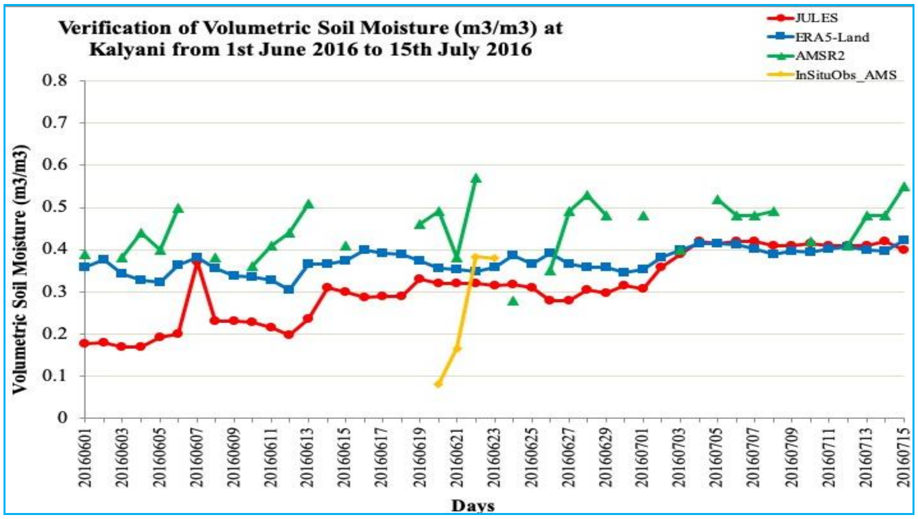

Fig. 5(g). Volumetric soil moisture for 1st June - 15th July, 2016 at Kalyani

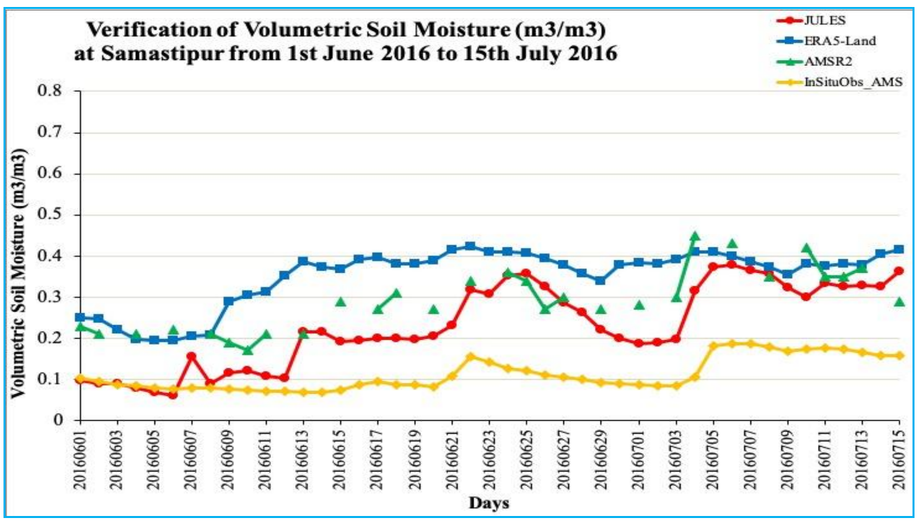

Fig. 5(h). Volumetric soil moisture for 1st June - 15th July, 2016 at Samastipur

TABLE 1

Correlations and biases at different locations over India (Biases are shown in brackets)

	ERA5-Land	AMSR2	*In situ* Observation
Kanpur (26.51, 80.22)	0.917 (-0.133)	0.774 (-0.118)	NA
Berambadi (11.76, 76.56)	0.538 (-0.147)	0.508 (-0.298)	NA
Nawagam (22.8, 72.57)	0.9 (-0.138)	0.7 (-0.149)	0.5 (-0.049)
Jaisalmer (26.99, 71.34)	0.52 (0.0018)	0.4 (-1.48)	NA
Hoshangabad (22.69, 77.74)	0.82 (-0.14)	0.80 (-0.15)	0.64 (0.052)
Bijapur (16.78, 75.75)	0.64(-0.213)	-0.26 (-0.099)	-0.14 (0.072)
Kalyani (23.06, 88.54)	0.78 9-0.061)	0.33 (-0.14)	-0.55 (0.06) *only 4 observation
Samastipur (26.0, 85.67)	0.78 (-0.12)	0.82 (-0.06)	0.82 (0.117)

ERA5-Land dataset, therefore the bias with AMSR2 observations is -0.15 and with ERA5-Land data is -0.14 and with the available *in situ* observations (1-21st June) is -0.05. The correlation coefficients are as follows 0.50, 0.70 and 0.90 for *in situ*, AMSR2 and ERA5-Land data respectively. Absence of AMSR2 and ground-based observations for some days give the low correlation coefficients [Fig. 5(c)].

5.4. *Jaisalmer (26.99, 71.34)*

Jaisalmer is located in Rajasthan in arid desert region in extreme temperature conditions. Jaisalmer region has aeolian sand, having natural sewan grass at few places. Being in arid desert region, the soil moisture amounts are very low at Jaisalmer. End of June and start of July, there is a small peak in soil moisture, which is captured by the model too.

JULES model is having positive bias (0.0018) with ERA5-land data at Jaisalmer and negative bias (-1.482) with AMSR2 observations. Correlation coefficients are very poor with ERA5-land data is ~0.52 and with AMSR2 observations is 0.4 [Fig. 5(d)].

5.5. *Hoshangabad (22.69, 77.74)*

Hoshangabad is a city in Madhya Pradesh; having hot and dry weather except the southwest monsoon season. Hoshangabad is having black soil, sandy clay loam type. Soil moisture trend is well captured by model but there is consistent underestimation. When there is increase in soil moisture then, model try to catch at the observed values. Upto 18th June, 2016, soil moisture is almost stagnant very low, after that it picks up. *In situ* observations are lower than JULES model forecasted values. ERA5-Land datasets values match with AMSR2 observations at Hoshangabad. Model shows good correlation with both the datasets (ERA5-Land and AMSR2) except the *in situ* observations.

At Hoshangabad, JULES model is having almost same negative bias with ERA5-land data and AMSR2 observations, -0.14 and -0.15 respectively and positive bias (0.052) with *in situ* observation. Therefore, the correlation coefficient is also similar 0.82 and 0.80 for ERA5-Land and AMSR2 observations, while with *in situ* observations, it is 0.64 [Fig. 5(e)].

5.6. *Bijapur (16.78, 75.75)*

Bijapur has a semi-arid climate, generally dry. There are two types of soil. First one is “deep black soil” and second one is “red soil”. *In situ* observations are quite low at Bijapur, almost stagnant for most of the time. ERA5-Land data values are higher than the AMSR2 observations. JULES simulated soil moisture seems to be closer with AMSR2 observations. That’s why bias with AMSR2 observation is quite low (-0.099) and the bias with ERA5-land data is -0.21 and with *in situ* Observations is 0.07.Correlation coefficient with ERA5-land data is 0.64, because the reanalysis values are quite high. AMSR2 time series is closer to model time series but do not follow the pattern at most of places and missing observations too gives negative correlation (-0.26). *In situ* observations also have negative correlation coefficient (-0.14) because model differ from there pattern [Fig. 5(f)].

5.7. *Kalyani (23.06, 88.54)*

Kalyani is in Indo-Gangetic plains and the soil is predominantly alluvial in origin. At Kalyani the JULES model is showing soil moisture values closely matching with observations. JULES values are underestimated in comparison to AMSR2 observations.

At Kalyani, JULES is having negative bias with ERA5-land data (-0.06) and with AMSR2 observations (-0.14) and positive bias with only 4 available *in situ* observations (0.06).Positive correlation with ERA5-land (0.78) and very poor correlation coefficient (0.33) with AMSR2 observations and negative correlation with very few *in situ* observations (-0.55). JULES model and ERA5-Land data values have a lag in June but during July both are seem to be very much matching [Fig. 5(g)].

5.8. *Samastipur (26.00, 85.67)*

Samastipur is having semi-arid to sub-tropical climate located in middle Gangetic plain. Soil is light to clay in texture, good for irrigated agriculture use. JULES model is having good match with *in situ* observations, ERA5-Land dataset and with AMSR2 observations too.

In situ observations are present for the whole study period at Samastipur. ERA5-Land dataset and *in situ* observations are having almost opposite biases, *i.e.*, -0.12 and +0.12. Bias with ERA5-land is -0.12, while with *in situ* observations 0.12 and -0.06 with AMSR2 observations. The correlation coefficient is 0.78 with ERA5-Land and 0.82 with AMSR2 observations and with *in situ* observations 0.82 [Fig. 5(h)].

6. Conclusions

Offline simulation of JULES land surface scheme (2D) forced with NCMRWF UM analysis is compared with ERA5-Land reanalysis dataset, AMSR2 L3 observations and Agro-Meteorological Stations observations. This a first study for JULES simulated soil moisture for the Indian monsoon region that compares soil moisture fields and time series to assess the application of JULES and the need for further improvements. In this sense the study has fulfilled its objective of showing that JULES simulates the morphology and distribution of soil moistures over India well though the amounts are severely underestimated in some regions depending on the month. The results also show that with ERA5-Land dataset, at Kanpur, Nawagam and Hoshangabad, the correlations are good (~92%), (~90%) and (~82%) while at some places it is poor, *e.g*., Berambadi (~54%), Jaisalmer (~52%) (Table 1). JULES show good correlations with AMSR2 observations at Samastipur (~82%) and Hoshangabad (~80%), while with ground-based observations Samastipur shows good correlation. To sum up, JULES 2D simulations of volumetric soil moisture mostly shows good correlation at places where soil holds good amount of moisture in comparison with very dry places. Climate and type of soil, both plays a vital role in this. Further studies should be done to analyse the other soil features from JULES simulations for a robust forecast.

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