CaMV 35S promoter and 311 bp of *SRK* gene were detected. Whereas in transgenic cauliflower, all the selected genes were amplified with the expected product size of 195 bp for *CaMV 35S* promoter, 311 bp for *SRK* gene, 219 bp for *cry1Ac* gene using cry1Ac1 primer pair and 394 bp for *cry1Ac* gene using cry1Ac 2 primer pair. As the primer for *CaMV 35S* promoter had amplified the DNA sequence in non-transgenic cauliflower, which was not desired, therefore, PCR with *CaMV 35S* promoter-specific primer was repeated twice to confirm the results; the same results were obtained. One of the reasons may be that cauliflower is a host of *Cauliflower mosaic virus* (*CaMV*), and thus due to the attack by *CaMV* on cauliflower crop, the *CaMV 35S* promoter sequence was amplified.

An ideal endogenous reference gene should not exhibit allelic variation among varieties of the same species, while it should present a consistently low copy number in the different cultivars. To investigate whether crops of the Brassicaceae family exhibit allelic variation within the amplified *SRK* sequence, simplex PCR of selected ten crops mentioned above, including five members of the Brassicaceae family was performed. The results showed that the designed primer for *SRK* gene had amplified the specific amplicon of 311 bp only in crops of the family Brassicaceae (cauliflower, broccoli, cabbage, mustard and turnip) and not in other crops, i.e. tomato, potato, brinjal, papaya and peanut, confirming its specificity to detect members of the Brassicaceae family only (Figure 2). The results indicate that there were no major sequence differences among the different crops of the family Brassicaceae in this amplified region. It has been demonstrated that the *SRK* gene is a suitable endogenous reference gene for the identification and quantification of *Bt* cauliflower and other GM crops of the family Brassicaceae. The developed MPCR assays offer a useful tool to detect and monitor *Bt* cauliflower with high efficacy and reliability to meet the regulatory requirements and solve legal disputes, if they arise.

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Surface soil moisture changes during 2007 summer monsoon season derived from AMSR-E Land3 product

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Soil moisture is an important component of the hydrological cycle. It contributes significantly to the water and energy flux from the surface of the earth, which in turn drives the atmospheric circulation. In spite of its importance, information on soil moisture is difficult to get. In India, soil moisture-measuring stations are sparse considering its dynamic nature. Remote

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sensing-based measurement of soil moisture is a better alternative to get this information over a large area. The Advanced Microwave Scanning Radiometer–Earth Observing System (AMSR-E) on-board Aqua satellite is the latest passive microwave sensor in orbit. In this study, the surface soil moisture product derived from the AMSR-E, which is available free on the web, has been used. The weekly average surface soil moisture at meteorological subdivision level for the entire country during the 2007 southwest summer monsoon season was derived. The meteorological subdivision rainfall was used to relate the soil moisture in this study. The profiles of rainfall and satellite-based surface soil moisture reveal that the soil moisture increased immediately in response to the first rainfall of the season in all the meteorological subdivisions. The amplitude of response of soil moisture decreased as the season progressed, due to interference of the growing vegetation. When the weekly surface soil moisture was regressed with the weekly rainfall, it was found that there was stronger relation during the June–July period of the monsoon and the relation became weak in the subsequent months.

Keywords: Passive microwave, rainfall, remote sensing, soil moisture.

SOIL moisture plays an important role in the hydrological cycle. It contributes significantly to the water and energy flux from the surface of the earth. The movement of water from soil into the atmosphere helps in cooling the earth's surface. The heat that is released into the atmosphere helps in driving the atmospheric circulation. It controls the proportion of rainfall that percolates into the soil, runoff and evaporation from land. Soil moisture is the major source of water for crops and hence plays a key role in the performance of the crop. Knowledge of soil moisture will help us in identifying moisture stress in the crops, which in turn helps in better assessment of agricultural drought. This is particularly more relevant in the context of the Indian summer monsoon cropping season (kharif season). The kharif season is characterized by its dependence on rainfall. The success of the crop in this season depends on the amount and distribution of rainfall both in time and space, and the resulting soil moisture. The impact of rainfall on the soil moisture depends on type of soil, topography and vegetation in the region, and also on the amount and intensity of the rainfall. The resulting soil moisture from the rainfall is the key to the success of the crop.

In spite of its importance, it is difficult to get the soil moisture information over a large area. The available ground soil moisture information is non-spatial in nature, with sparse spatial network. In India, only 55 soil moisture measuring stations are present under the Agricultural Meteorology Division of India Meteorological Department (IMD; www.imdagrimet.org). Since soil moisture is highly variable, it is ideal if one could get these data from a space platform. Several studies during the past three decades have proved that passive microwave remote sensing is capable of discerning soil moisture variations. The passive microwave region of the electromagnetic spectrum responds to changes in the dielectric property of the soil, which in turn varies with the moisture content of the soil. Although passive microwave measurements have lower spatial resolution, they are less affected by aerosols and clouds. Passive microwave remote sensing has been effectively used[1] to measure soil moisture since late 1970s. Studies were carried out to derive empirical relations between the actual observed values and satellite-derived soil moisture value[2–4]. Gohil[5] has developed an empirical model for retrieval of soil moisture using 6.6 GHz frequency of Oceansat-1 MSMR sensor. Singh *et al.*[6] have used this model to assess the spatial and temporal variability of soil moisture over India. Passive microwave sensors like the Special Sensor Microwave Imager (SSM/I) and the Advanced Microwave Scanning Radiometer–Earth Observing System (AMSR-E) measure the brightness temperature of the soil, which is fundamentally related to the dielectric property of the soil[10]. AMSR-E instrument on-board the NASA EOS Aqua satellite provides global passive microwave measurements of terrestrial, oceanic and atmospheric variables for the investigation of water and energy cycles. The soil moisture product derived from the AMSR-E sensor is available from EOS gateway website. In this study, the surface soil moisture product of AMSR-E has been used to derive the surface soil moisture of the 36 meteorological (met) subdivisions of India during the 2007 southwest summer monsoon season (June–September). The main objective of this study is to investigate the surface soil moisture changes before and after the onset of monsoon at meteorological subdivision level. It is also envisaged to find the strength of relation between rainfall and soil moisture throughout the season and to determine which part of the season has a stronger relation.

India, with 329 million hectares of the geographical area, presents a large number of complex agro-climatic conditions. IMD has divided the country into 36 meteorological subdivisions. This study considers all the meteorological subdivisions of the Indian mainland, except Andaman and Nicobar Islands and Lakshdeep Islands. The actual weekly rainfall during the 2007 southwest monsoon, for each subdivision was downloaded from the IMD official website (www.imd.gov.in) and used in the analysis.

The AMSR-E gridded Level-3 land surface product (AE_Land3) has been used in this study. The product is available in the Earth Observation System Data Gateway (EOS Gateway) webpage (http://delenn.gsfc.nasa.gov/~imswww/pub/imswelcome/). This product includes daily measurements of surface soil moisture of the top few centimetres of soil and vegetation/roughness water content interpretive information, as well as brightness tempera-

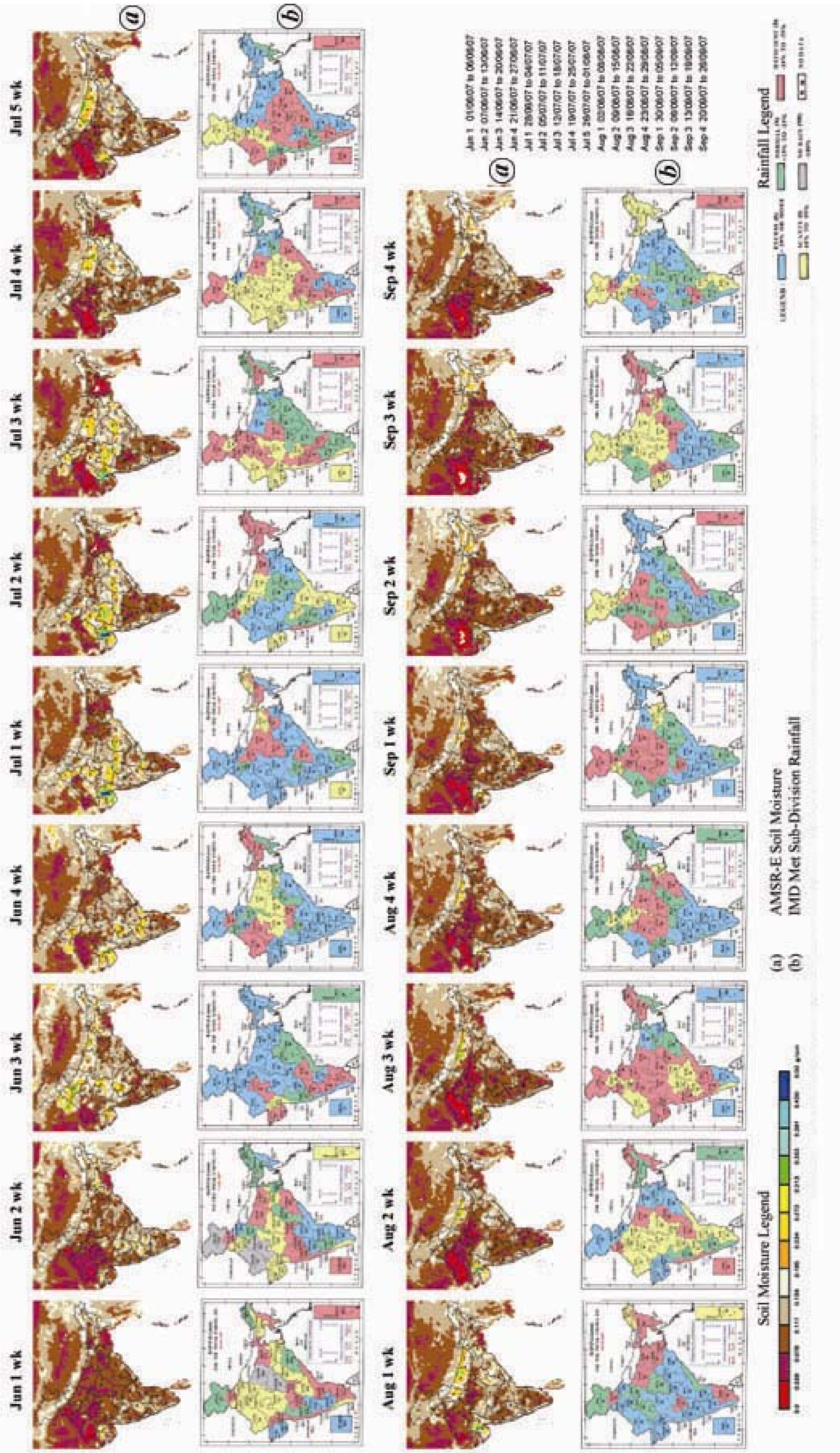


Figure 1. AMSR-E Land3 product surface soil moisture and meteorological subdivision rainfall during the 2007 monsoon season.

tures and quality-control variables[11,12]. The ancillary data include time, geo-location and quality assessment. This product offers coverage of the global land surface, excluding snow-covered and densely vegetated areas. It is provided in global cylindrical equal area projection at a nominal grid spacing of 25 × 25 km (true at 30°N and S), with 1383 columns and 586 rows.

The daily AE_Land3 product was imported through appropriate software along with its geo-location information from HDF format to IMG format. The IMG files were multiplied with the scales factor to convert the digital number to surface soil moisture values. The range of soil moisture measured was 0–0.5 g/cm^3, with an estimated accuracy of 0.06 g/cm^3. The quality control flags were used to remove the unwanted pixels[13]. The daily surface soil moisture was maximum value composited for each IMD standard week starting from the week of 1 June. The weekly spatial mean surface soil moisture of each subdivision was extracted and used for analysis. Figure 1 gives the AMSR-E Land3 product-derived surface soil moisture of India along with meteorological subdivision rainfall during the 2007 southwest monsoon season.

Figures 2 and 3 show the actual rainfall profiles of the meteorological subdivision and the corresponding average soil moisture derived from the AMSR-E surface soil moisture product from the first week of June to the last week of September 2007. It was observed from the profiles that, the soil moisture changed in synchrony with the increase or decrease in rainfall in most of the subdivisions, confirming the results of Oza *et al.*[10].

During the first week of June (1–6) there was excess rainfall in the three subdivisions of North interior Karnataka, South interior Karnataka, and Saurashtra–Kutch and Diu. In all these three subdivisions the soil moisture was high at around 0.14 g/cm^3 during this week, when in most of the other subdivisions soil moisture value was around

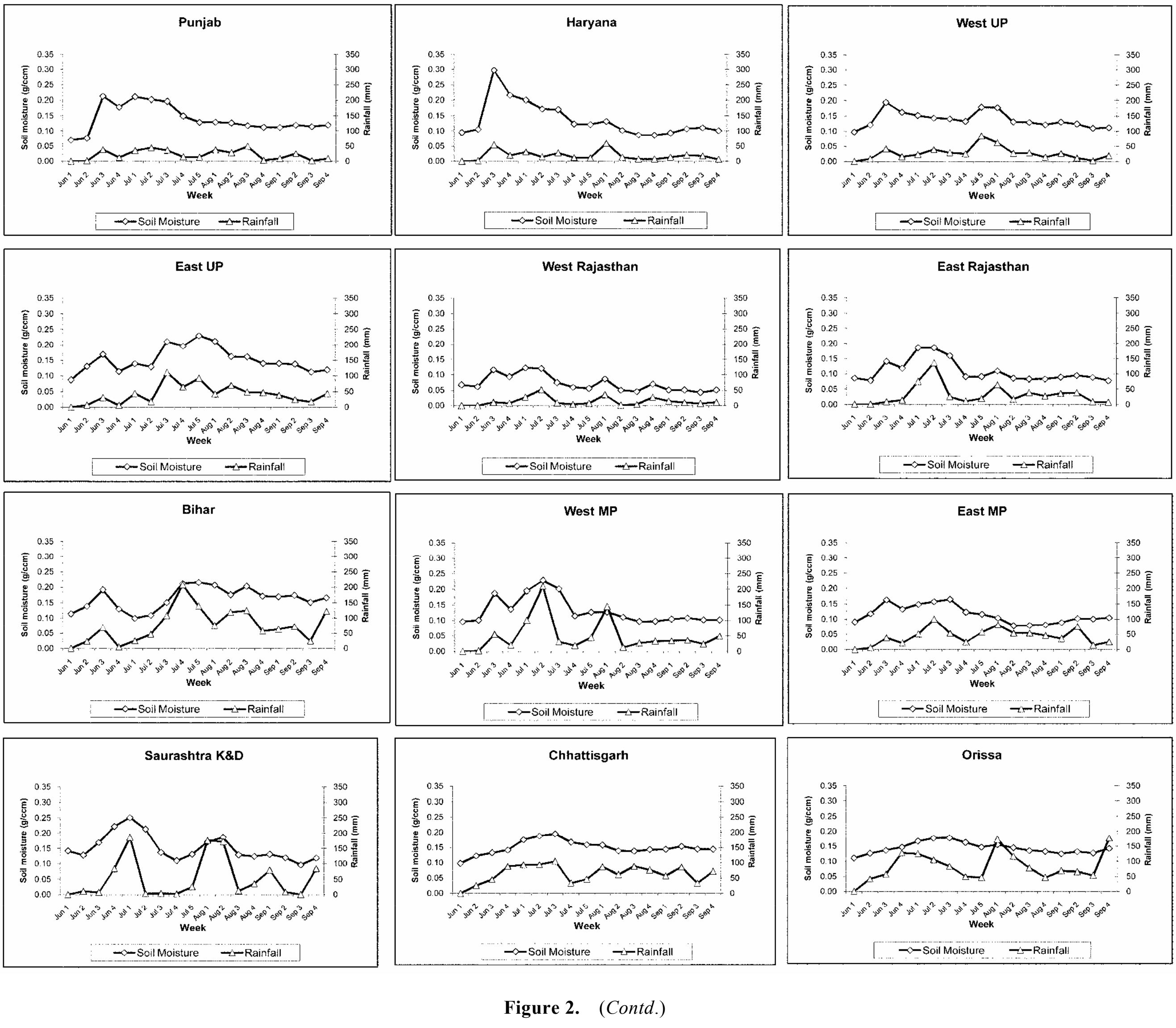
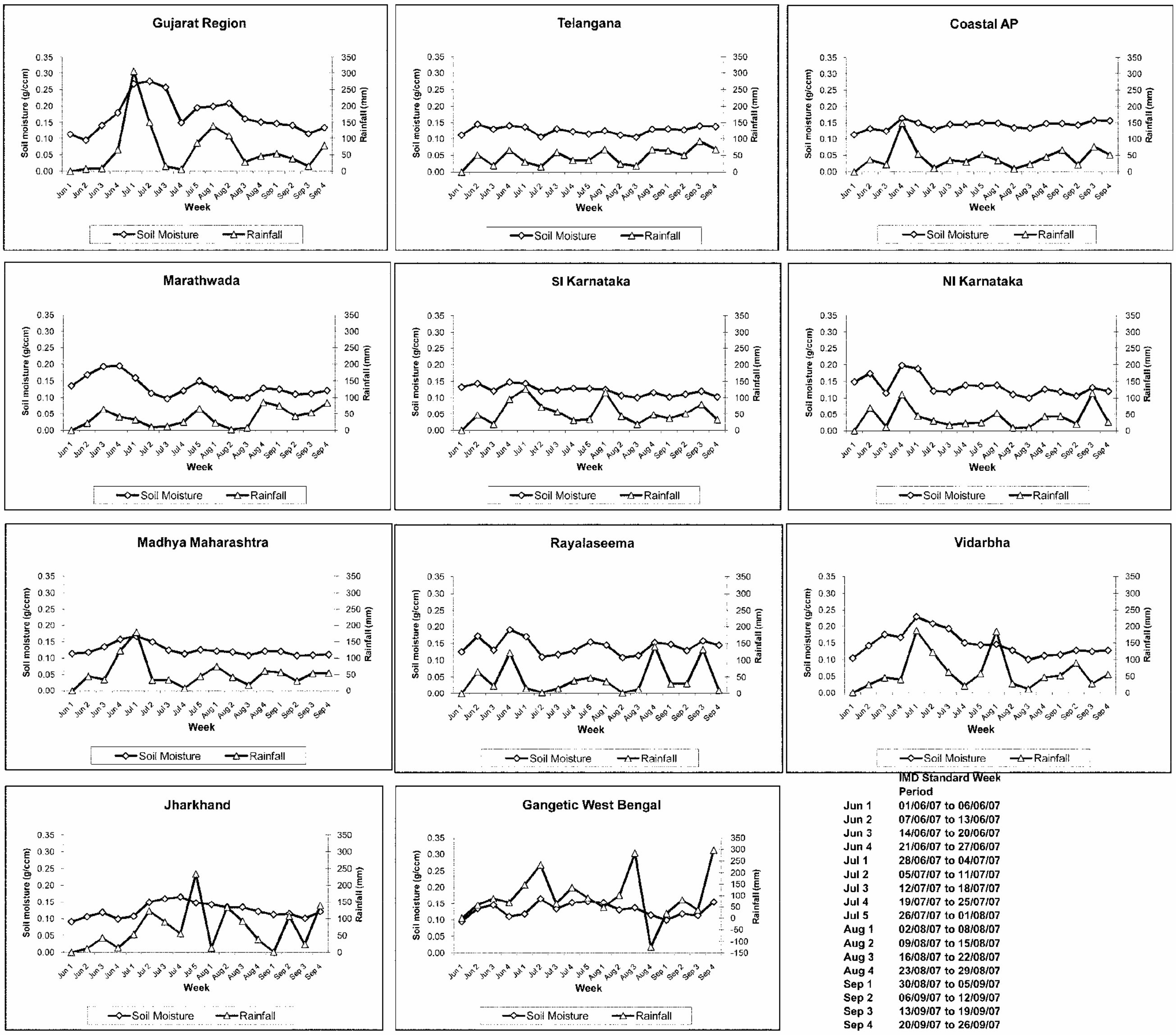


Figure 2. (*Contd.*)

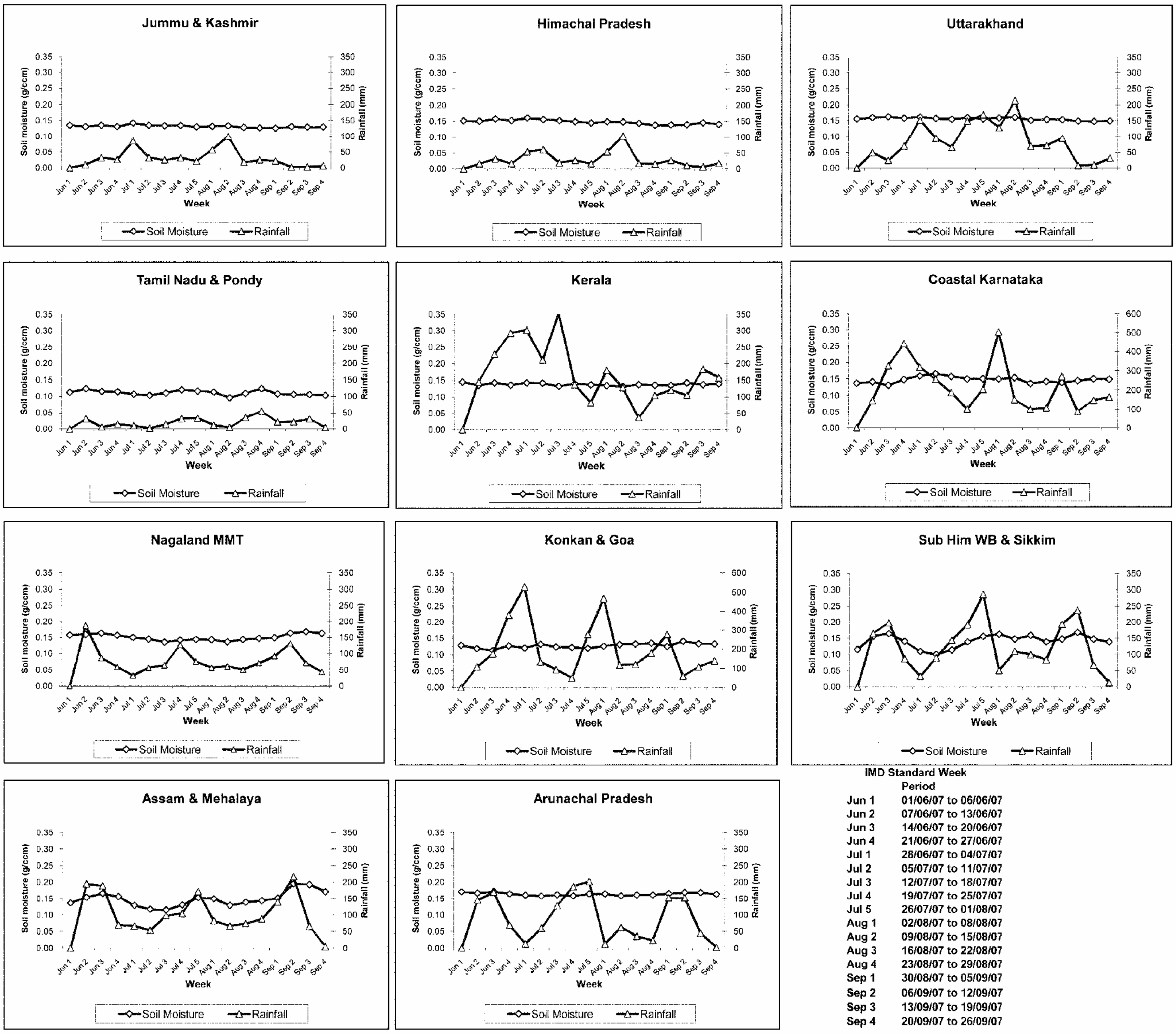


	IMD Standard Week Period
Jun 1	01/06/07 to 06/06/07
Jun 2	07/06/07 to 13/06/07
Jun 3	14/06/07 to 20/06/07
Jun 4	21/06/07 to 27/06/07
Jul 1	28/06/07 to 04/07/07
Jul 2	05/07/07 to 11/07/07
Jul 3	12/07/07 to 18/07/07
Jul 4	19/07/07 to 25/07/07
Jul 5	26/07/07 to 01/08/07
Aug 1	02/08/07 to 08/08/07
Aug 2	09/08/07 to 15/08/07
Aug 3	16/08/07 to 22/08/07
Aug 4	23/08/07 to 29/08/07
Sep 1	30/08/07 to 05/09/07
Sep 2	06/09/07 to 12/09/07
Sep 3	13/09/07 to 19/09/07
Sep 4	20/09/07 to 26/09/07

Figure 2. Weekly soil moisture and rainfall profiles of meteorological subdivisions with large kharif area during the 2007 summer monsoon.

$0.11\ g/cm^3$. In the second week of June (7–13) there was normal to excess rainfall in the subdivisions of Tamil Nadu (TN) and Puducherry, North interior Karnataka, South interior Karnataka, all the three subdivisions of Andhra Pradesh, Chhattisgarh, West Bengal, Uttarakhand, West Uttar Pradesh (UP) and the entire Northeast. Figures 1 and 2 show that in all these subdivisions the soil moisture increased during this week and in other subdivisions soil moisture remained the same or decreased. During the third week of June (14–20) the entire country received normal to excess rainfall, except TN and Puducherry, North interior Karnataka, South interior Karnataka, Telagana, Saurashtra – Kutch and Diu, Gujarat Region and East Rajasthan. Here again, except the deficient rainfall subdivisions, all the other subdivisions showed increase in soil moisture. There was a decrease in soil moisture values in the deficient rainfall subdivisions during this period. These observations clearly indicate the sensitivity of the AMSR-E soil moisture to the onset of monsoon.

It can be observed from Figure 2 that subdivisions which had a major proportion of the area under kharif crops, like Punjab, Haryana, West and East UP, East Rajasthan, Bihar, West and East Madhya Pradesh (MP), Jharkhand, Gangetic West Bengal (WB), Gujarat region, Saurashtra region, Chhattisgarh, Orissa, Madhya Maharashtra, Vidarbha, Marathwada, Telangana, coastal Andhra Pradesh, North and South interior Karnataka, and Rayalaseema had surface soil moisture level at around $0.11\ g/cm^3$ in the first week of June 2007. The surface soil



IMD Standard Week

	Period
Jun 1	01/06/07 to 06/06/07
Jun 2	07/06/07 to 13/06/07
Jun 3	14/06/07 to 20/06/07
Jun 4	21/06/07 to 27/06/07
Jul 1	28/06/07 to 04/07/07
Jul 2	05/07/07 to 11/07/07
Jul 3	12/07/07 to 18/07/07
Jul 4	19/07/07 to 25/07/07
Jul 5	26/07/07 to 01/08/07
Aug 1	02/08/07 to 08/08/07
Aug 2	09/08/07 to 15/08/07
Aug 3	16/08/07 to 22/08/07
Aug 4	23/08/07 to 29/08/07
Sep 1	30/08/07 to 05/09/07
Sep 2	06/09/07 to 12/09/07
Sep 3	13/09/07 to 19/09/07
Sep 4	20/09/07 to 26/09/07

Figure 3. Weekly soil moisture and rainfall profiles of meteorological subdivisions with less kharif area during the 2007 summer monsoon.

moisture peaked between the third week of June and the third week of July depending on the substantial rain that each subdivision received during this period. The soil moisture subsequently started to decrease and continued till the end of the season. There was a small increase in soil moisture in the subdivisions which received rainfall during August, but the increase in soil moisture did not exceed the June–July peak. Though the weekly rainfall during August in many subdivisions was more than that in June–July, the increase in soil moisture was not substantial. This is because, as the season progressed the vegetation covered the soil. The vegetation canopy over the soil attenuates the emission of the soil and adds to the total radiative flux with its own emission[14]. Attenuation from vegetation increases the retrieval error in soil moisture[15]. As the vegetation cover increases, the retrieval error for soil moisture increases and becomes unreliable at higher biomass region[9]. This was the reason for the amplitude of increase in soil moisture being much less compared to the amplitude of rainfall in August than in June–July. At the same time the surface soil moisture responded to the August rainfall in subdivisions such as West and East Rajasthan, Gujarat and Saurashtra and Marathwada regions, where the density of vegetation is low.

From Figure 3, the subdivisions adjoining the Himalayas and the Western Ghats had higher soil moisture from the start of the season, compared to other subdivisions. These meteorological subdivisions were Jammu & Kashmir, Himachal Pradesh, Uttarakhand, Sub-Himalayan West Bengal and Sikkim, Assam and Meghalaya, Arunachal

Table 1. Regression coefficients of the weekly rainfall related with soil moisture during the 2007 monsoon

Meteorological subdivision	June–July	July–August	August–September	Entire season
Jammu & Kashmir	0.86	0.36	0.38	0.38
Himachal Pradesh	0.53	0.17	0.37	0.16
Punjab	0.79	0.49	0.58	0.56
Uttarakhand	0.30	0.65	0.90	0.76
Haryana C&D	0.84	0.78	0.26	0.76
West Uttar Pradesh	0.38	0.81	0.92	0.56
West Rajasthan	0.53	0.69	0.87	0.41
Arunachal Pradesh	0.13	0.00	0.12	0.10
East Uttar Pradesh	0.85	0.51	0.52	0.61
East Rajasthan	0.60	0.55	0.59	0.46
Sub-Himalayan West Bengal and Sikkim	0.51	0.07	0.22	0.17
Assam and Meghalaya	0.48	0.28	0.06	0.11
Bihar	0.65	0.56	0.38	0.51
Nagaland MMT	0.09	0.07	0.11	0.08
West Madhya Pradesh	0.59	0.41	0.42	0.41
East Madhya Pradesh	0.27	0.06	0.01	0.01
Jharkhand	0.32	0.05	0.27	0.21
Gangetic West Bengal	0.23	0.00	0.24	0.25
Gujarat region	0.74	0.74	0.65	0.72
Saurashtra K&D	0.81	0.76	0.79	0.53
Chhattisgarh	0.48	0.13	0.00	0.29
Orissa	0.24	0.07	0.42	0.13
Madhya Maharashtra	0.90	0.90	0.31	0.74
Vidarbha	0.80	0.76	0.26	0.54
Marathawada	0.44	0.40	0.44	0.09
Konkan and Goa	0.00	0.14	0.51	0.09
Telangana	0.40	0.46	0.88	0.46
Coastal Andhra Pradesh	0.70	0.79	0.69	0.62
North interior Karnataka	0.74	0.44	0.53	0.69
Rayalaseema	0.61	0.25	0.42	0.41
South interior Karnataka	0.36	0.40	0.39	0.32
Tamil Nadu and Puducherry	0.68	0.69	0.62	0.44
Kerala	0.02	0.01	0.01	0.00
Coastal Karnataka	0.01	0.13	0.05	0.01

Pradesh, Nagaland–Manipur–Mizoram–Tripura, Konkan and Goa, coastal Karnataka, TN and Puducherry and Kerala. These subdivisions had major portion of their area under dense vegetation like the forests and plantations on the mountainous topography. They showed less variation in soil moisture and maintained constant moisture level throughout the season. Since rabi is the major cropping season in TN and Puducherry, the soil moisture during kharif shows less variation. Similarly, majority of Jammu & Kashmir is waste land; it also exhibited constant soil moisture value throughout the season. Konkan and Goa, coastal Karnataka and Kerala are regions with narrow land mass along the coast. The anomalous soil moisture values in subdivisions were also due to the boundary pixel effect along the ocean. Singh *et al.*[6] have mentioned that the higher soil moisture found near the ocean in coastal areas was due to the contamination by ocean signature, which is difficult to avoid at coarser spatial resolution data.

Table 1 shows the regression coefficients of the weekly meteorological subdivision rainfall related with weekly average meteorological subdivision surface soil moisture for June–July, July–August and August–September and for the entire season. It was found that in majority of the subdivisions, the strength of the relation was stronger during June–July. This is obvious from Figure 2, which shows substantial increase in soil moisture for the rainfall received during the first two months of the season. The relation in the subsequent months was significantly lower in all these subdivisions. The subdivisions of Uttarkhand, West UP, West Rajasthan, Orissa, Konkan and Goa, and Telangana had stronger relation during August–September 2007. These subdivisions do not show much variation in soil moisture throughout the season. However, stronger relation of weekly rainfall with soil moisture during August–September needs to be investigated. In subdivisions with high rainfall such as coastal Karnataka and South interior Karnataka, the strength of the relationship was uniform throughout the season.

The strength of relation was weak throughout the season in the subdivisions of Arunachal Pradesh, East MP, Nagaland–Manipur–Mizoram–Tripura, Gangetic WB, Coastal Karnataka and Kerala. It is a known fact that these subdivisions had a major share of land under forest and permanent vegetation. In the high density vegetation region, the retrieved soil moisture is unreliable due to interference radiation by the vegetation[9]. Further, the effects of the topography and snow cover were not explicitly modelled in the soil moisture retrieval algorithm[9] and hence the poor relation.

The analysis indicates that the AE_Land3 soil moisture product was able to identify the onset of monsoon by showing an increase in soil moisture instantaneously. Secondly, its relation with the seasonal rainfall was maximum during the first two months of the season. The first two months of the kharif season are the period of crop germination and establishment. During these stages if the crop suffers moisture stress, it will lead to crop mortality or reduction in quantity and quality of the yield. Further, in the early stage of the crop, the root system will be shallow and the surface soil moisture derived from AE_Land3 product will help in identifying the regions suffering from moisture stress. AE_Land3 soil moisture product helps in monitoring the surface soil moisture during this period. Though the resolution of the AE_Land3 product is 56 km^2 resampled and provided at 625 km^2, it is a much better option to the coarse-resolution ground network.

Soil moisture is important to monitor the performance of the kharif crop in a region during the summer monsoon. In this study, the AE_Land3 product was used to derive soil moisture at meteorological subdivision level. The meteorological subdivision rainfall and the soil moisture were plotted for the 2007 monsoon season. The profiles clearly showed that the soil moisture increased with the onset of monsoon during June and July. After August, the response was subdued as the vegetation covered the soil. The response was also poor in the subdivisions which had large area under permanent vegetation and hilly terrain. When the meteorological subdivision rainfall was regressed with the soil moisture during June–July, July–August, August–September and for the entire season, the relationship was stronger in the June–July. The relationships in the latter months were weak because of the increased vegetative cover over the soil, which induces error in the retrieval of soil moisture. However, stronger relation of weekly rainfall with soil moisture during August–September in some subdivisions needs to be investigated. The response of the AE_Land3 product for the onset of monsoon and its stronger relation with rainfall during the first two months of the cropping season show that there is potential in using this product in monitoring the moisture stress during initial months of the cropping season. Though encouraging results have been obtained, this study was done using a single-year data. Further studies using multi-year data have to be carried out to check the consistency of these observations.

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