

# Monsoon variability, the 2015 Marathwada drought and rainfed agriculture

Ashwini Kulkarni<sup>1,\*</sup>, Sulochana Gadgil<sup>2</sup> and Savita Patwardhan<sup>1</sup>

<sup>1</sup>Indian Institute of Tropical Meteorology, Pune 411 008, India

<sup>2</sup>Centre for Atmospheric and Oceanic Sciences, Indian Institute of Science, Bengaluru 560 012, India

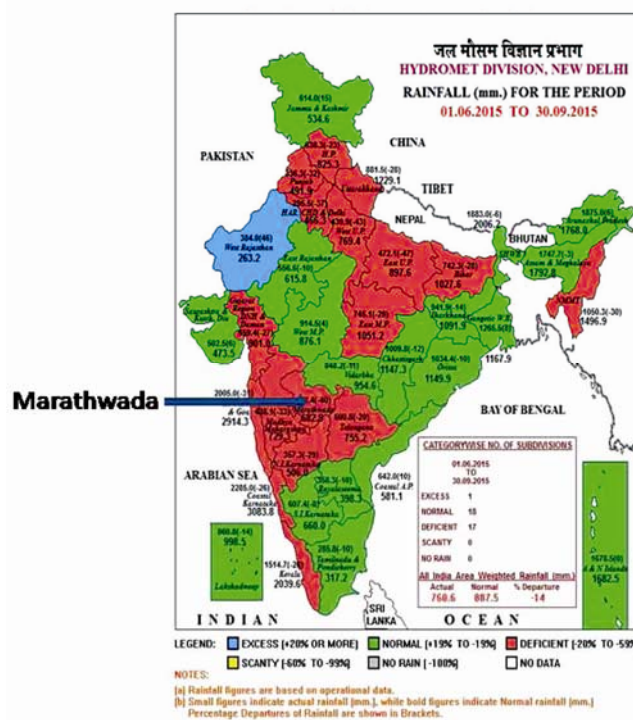
The impact of the drought of the summer monsoon of 2015 has been particularly large in the Marathwada region of Maharashtra which is now facing unprecedented water scarcity and more than one thousand farmers have committed suicide. Substantial losses in the production of important crops such as pulses have been reported in Maharashtra. Naturally, the Marathwada drought has been extensively covered in the print and electronic media. The large impact has been attributed to exceptionally large deficit in rainfall by some journalists and politicians, to two successive droughts in 2014 and 2015 by some and some have considered the drought to be a manifestation of climate change. In this article, we present an analysis of the Marathwada monsoon rainfall from 1871 onwards and show that the quantum of deficit rainfall in 2015 as well as the occurrence of two successive droughts is within the observed variability of the Marathwada rainfall and the 2015 monsoon rainfall also cannot be considered as a manifestation of climate change. Thus the large impact of 2015 is a reflection of poor management of water resources and agriculture, despite the long experience of rainfall variability. We show that the prediction by the India Meteorological Department (IMD) of a high chance of below normal rainfall or a drought on the all-India scale and the occurrence of El Niño could have been used to anticipate large deficiency in Marathwada rainfall. We suggest that the problem of lack of progress in the production of rainfed crops such as pulses has to be addressed by using the rich rainfall data sets in the country to generate information which can be used by farmers and agricultural scientists to identify strategies, which are tailored to the entire spectrum of rainfall variability experienced. Towards this end an interactive software 'RAINFO' has been developed at the Indian Institute of Tropical Meteorology (IITM), Pune to provide location-specific information derived from the IMD data, on the desired facets of rainfall variability.

**Keywords:** Marathwada drought, rainfall variability, rainfed agriculture, RAINFO.

THE Indian summer monsoon has been playing truant in the last four years with a large deficit in the rainfall in

2012 and much larger deficits in 2014 and 2015. This is not surprising in view of the well-known link of the Indian summer monsoon rainfall (ISMR) with El Niño over the Pacific Ocean<sup>1-4</sup>, because an El Niño event was developing during the summer monsoon in these three years. In fact, for each of these three monsoon seasons (June–September), El Niño had been predicted and the India meteorological Department (IMD) had predicted that ISMR would be below normal, i.e. less than the long term mean<sup>5-7</sup>, with the amplitude of the predicted deficit being the largest for 2015 and smallest for 2012. While the observed deficit in ISMR for 2012 was 7% of the long-term mean rainfall, the seasons of 2014 and 2015 turned out to be droughts (deficit > one standard deviation, which for ISMR is about 10% of the long term average) with deficits of 12% and 16% respectively.

Maharashtra was one of the states which experienced a severe rainfall deficit during the drought of 2015, ranging



**Figure 1.** Map showing the rainfall anomalies for the meteorological subdivisions for the summer monsoon of 2015 and the location of Marathwada sub-division in Maharashtra state.

\*For correspondence. (e-mail: ashwini@tropmet.res.in)

from 20% for Vidarbha to as high as 40% for the Marathwada region (Figure 1). For the 2015 *kharif* season, a massive decrease of 52% (compared to the normal) in the production of pulses in Maharashtra, with a decrease of 42% in tur dal, 71% in moong dal and 74% in urad dal was reported<sup>8</sup>. An adverse impact of deficit rainfall on pulse production is inevitable because the cultivation of pulses in India is primarily rainfed (with 16.1% of the cultivated area under irrigation for the country as a whole and only 8.7% for Maharashtra<sup>9</sup>) making the production critically dependent on the rainfall received in a given year<sup>10-12</sup>. In fact, the variability of the monsoon rainfall (ISMR) continues to have a large impact on the Indian food grain production<sup>13</sup>, because over half the area under cultivation is still rainfed<sup>9</sup>.

The impact of the drought of 2015 was particularly large for the Marathwada region. The gravity of the situation is reflected in that more than one thousand farmers of that region have committed suicides this year. There have been many discussions about the 2015 monsoon, particularly that over Marathwada, in the electronic and print media. The large impact has been attributed to the Marathwada rainfall deficit being exceptionally large in 2015, with statements like 'This is the worst drought in the history of Marathwada'<sup>14</sup>. It has also been suggested that the impact of the Marathwada drought of 2015 was particularly large because it followed the drought of 2014. Also, with the growing awareness of global warming associated with enhancement of the concentration of greenhouse gases, there is widespread concern about the impacts on various facets of climate and weather in India and the impact of the 2015 drought is believed by some to be large because 'We have not taken climate change seriously. We obviously cannot control it but we can at least make provisions to adapt to it. The global focus must now shift to climate change and our planning must be modelled accordingly, which is sadly not happening.'<sup>14</sup>

Thus it is important to determine whether, the monsoon rainfall of 2015 over Marathwada and/or the occurrence of two successive droughts, was indeed exceptional and also whether the experience of 2015 over Marathwada can be attributed to climate change. If it turns out that the quantum of deficit of the monsoon rainfall of 2015 or the occurrence of two successive droughts, is well outside the range of the variability of the rainfall observed so far, or that climate change could have played an important role in the monsoon rainfall experienced this year over Marathwada, the drought of 2015 can be considered as a one-off event and the poor management of the drought by all concerned, can be attributed to lack of experience.

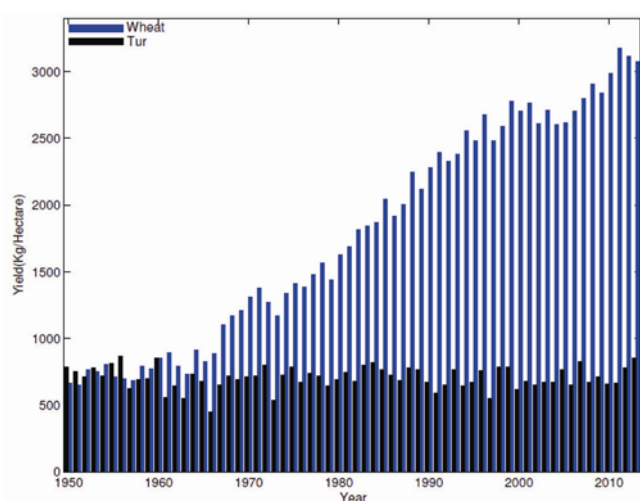
In this article, we present an analysis of the year-to-year variation of the rainfall for the period 1871–2015 over Marathwada to assess whether the monsoon of 2015 over Marathwada was exceptional or a manifestation of climate change. This analysis indicates that neither the

rainfall deficit of the Marathwada monsoon of 2015 nor the occurrence of two successive years of drought can be considered as an exceptional behaviour of the weather gods. In fact, a much larger deficit (54%) in the monsoon rainfall over Marathwada occurred in the drought of 1972 which succeeded the Marathwada drought of 1971. We also consider the climate change component, i.e. the observed long period trends for the monsoon rainfall over the country as a whole as well as over Marathwada and other meteorological subdivisions and show that the drought of 2015 cannot be considered as a manifestation of anthropogenic climate change.

Why then, despite the long experience of monsoon variability, and despite the recommendations given by scientists such as the crops/varieties to be cultivated, has the management of the 2015 drought, by the administrators and politicians in charge of policy decisions and implementation, been so poor? The current strategies of agriculture and water management which led to an unacceptably large adverse impact on farmers, are obviously inappropriate, and better strategies have to be identified and implemented. In fact, the water scarcity in the Marathwada region in the aftermath of the drought of 2015 is far more severe than that associated with the more severe deficit rainfall in 1972, which also succeeded a drought in the previous year. In 1972, food and fodder was the predominant concern, not water and there were no suicides by farmers<sup>15</sup>. This time around, major concerns are water and fodder<sup>14</sup>. Even the impact of the much milder drought of 2012 was much larger than that of 1972 (ref. 16), even though in the 40 years since 1972, Maharashtra had built a large number of big dams, ostensibly to help these drought-prone areas and there has been a marked increase in groundwater use facilities. The large impact of the relatively mild drought of 2012 and the larger impact of the drought of 2015 have been attributed to an increase in the area under sugarcane in Maharashtra from 1.67 lakh ha in 1970–71, to 10.22 lakh ha in 2011–12 (Maharashtra Economic Survey 2012–13) and 10.48 lakh ha in 2014–15 (ref. 8) and increase in water intensive activities such as running of sugar mills and beer factories in the drought-prone districts<sup>16</sup>. While the area under pulses in the *kharif* season of 2015 decreased by 19% and production by 52%, the area under sugarcane was over 100% of the normal in 2014–15 as well as 2015–16 and the production was 9% above normal in 2014–15 and only 13% below normal in 2015–16 (ref. 8). This is an implication of the priority given to sugarcane relative to other crops such as pulses in the current policy of irrigation water allocation. Clearly, the changes over the last four decades in the strategies of agriculture as well as water resource management including, use of flow irrigation water<sup>17</sup>, exploitation of ground water and allocation to cultivation of sugarcane, water intensive activities, etc. have to be examined and sustainable strategies consistent with the natural variability of the rainfall

have to be identified and adopted. However, here we restrict the discussion to only agricultural strategies.

One of the major impacts of the 2015 drought for consumers has been the high prices of pulses and particularly of tur dal (pigeonpea) which reached an all-time high of Rs 200 per kilo. The price rise of pulses in the last few years is considered to be a reflection of the demand–supply gap due to simultaneous occurrence of low stock levels, less domestic production and, to some extent, speculative activity in the commodity futures market<sup>11</sup>. India is the largest producer and consumer of pulses in the world, yet the yield is almost the lowest in the world (higher than only of Niger) and less than half of that of Canada, US and Russia<sup>12</sup>. Over the years, the demand–supply gap for pulses has continuously increased because the growth rate of the population is much higher than that of pulse production<sup>12</sup>. In fact, whereas a phenomenal increase in the Indian food-grain production was achieved during the green revolution associated with a rapid increase in yields due to the adoption of new dwarf, high-yielding and fertilizer-responsive varieties (of rice and wheat, in particular), and a substantial increase in fertilizer application, irrigation and pesticide application, there has been hardly any increase in the production of rainfed crops such as pulses in the country since the fifties<sup>18,19</sup>. The sharp contrast between the observed variation of the yields of tur and wheat since the fifties is clearly brought out in Figure 2. ‘Due to stagnant production of pulses over several decades, the net per capita availability has come down from about 60 g/day/person in 1951 to about 31 g/day/person (Indian Council of Medical Research recommends 65 g/day/capita) in 2005’ (ref. 11). Sharma and Jodha<sup>10</sup> have pointed out that ‘At present, a very large fraction of the area under pulses is confined to unirrigated areas, and in future the bulk of pulse production will continue to come from unirrigated areas. Therefore,



**Figure 2.** Variation during 1950–2014 of all-India yields of wheat and tur (based on data from ref. 9).

any plan for increasing pulse production in the country should be based on a long-term approach for improved productivity of these crops under rainfed farming conditions’. Pulses have long been considered as a poor man’s source of protein<sup>11</sup>. Thus, for ensuring nutritional security, it is important to consider whether the knowledge of rainfall variability on different spatio-temporal scales and the increasing ability to predict the variability can be used to identify strategies for enhancement of the production of important rainfed foodgrains such as pulses.

In this article, analysis of the year-to-year variation of the rainfall for the period 1871–2015 over Marathwada to assess whether the monsoon of 2015 over Marathwada was exceptional. This year, it had been predicted that the El Niño would develop over the Pacific during the summer monsoon and that there was a high probability of deficit rainfall/ drought over the country. We examine whether we could have made an educated guess and anticipated a deficit in rainfall over Marathwada and perhaps a drought, on the basis of these predictions. We consider next whether 2015 monsoon can be considered to be a manifestation of climate change by examining the observed climate change component, i.e. long period trends for the monsoon rainfall over the country as a whole as well as over Marathwada and other meteorological subdivisions vis-à-vis the observed variability of the monsoon on year-to-year and decadal time scales. We then discuss the way forward involving the use of knowledge and prediction of rainfall variability for enhancement of rainfed agricultural production.

## Data

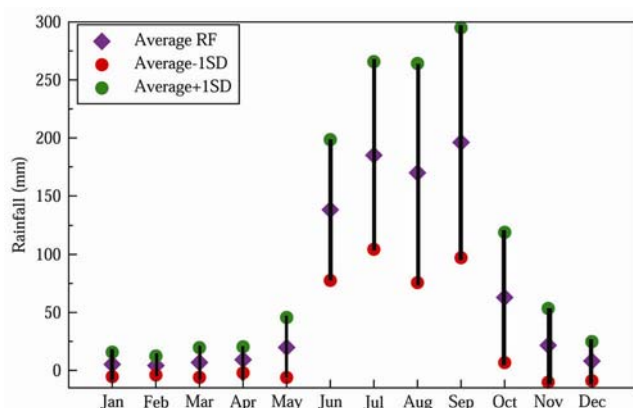
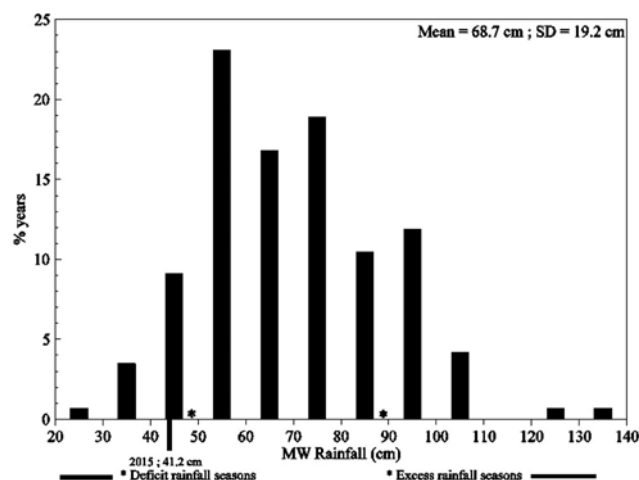
Monthly rainfall data for Marathwada sub-division for the period 1871–2013 have been taken from the website of the Indian Institute of Tropical Meteorology, Pune, [www.tropmet.res.in/](http://www.tropmet.res.in/). The data have been updated to 2015 using the data from the website of the India Meteorological Department, New Delhi, [www.imd.gov.in/](http://www.imd.gov.in/). We use as index of the phases of the El Niño and the Southern Oscillation (ENSO), the sea surface temperature of the equatorial central Pacific (the Niño 3.4 region: 170°–120°W, 5°S–5°N). The monthly data for Niño 3.4 SST have been taken from [http://www.esrl.noaa.gov/psd/gcos\\_wgsp/Timeseries/Data/nino34.long.data](http://www.esrl.noaa.gov/psd/gcos_wgsp/Timeseries/Data/nino34.long.data).

## Variability of the rainfall over the Marathwada region

For identification of the strategies which are appropriate for the rainfall variability of the region, detailed information on the climatological probability of droughts, excess rainfall seasons, the frequency distributions of the rainfall as well as information on the assured rainfall at a given level of probability (say 90%) is required on seasonal,

**Table 1.** Various measures of variation of monthly and seasonal rainfall (cm) over Marathwada during summer monsoon season

Month	Mean	SD	Minimum	Maximum	Minimum assured rainfall at 75%	Minimum assured rainfall at 90%
June	13.8	6.0	1.8	31.6	8.9	6.8
July	18.4	8.1	2.3	51.8	12.4	8.5
August	17.0	9.4	2.3	49.3	11.7	7.4
September	19.6	9.9	2.9	48.8	1.7	0.5
JJAS	68.7	19.2	24.3	130.1	54.6	47.6

**Figure 3.** Mean monthly rainfall and the range given by mean-standard deviation and mean + standard deviation.**Figure 4.** Frequency distribution of the June–September rainfall for Marathwada.

monthly and even smaller timescales<sup>20,21</sup>. It should be noted that while rainfall variability plays a critical role in rainfed agricultural production, for assessing the actual impact of rainfall variability on agricultural yields, it is necessary to consider the impact of rainfall variability on the soil moisture which depends on the type of soil. We present the basic information on rainfall variability for the case of Marathwada rainfall in this section. The monthly mean rainfall over Marathwada and its typical range of variation (i.e. one standard deviation around the

mean), are shown in Figure 3. As most of the annual rainfall (83%) is received during June to September, i.e. the summer monsoon season, we first consider the variation of the summer monsoon rainfall over Marathwada.

### Variation of the seasonal rainfall

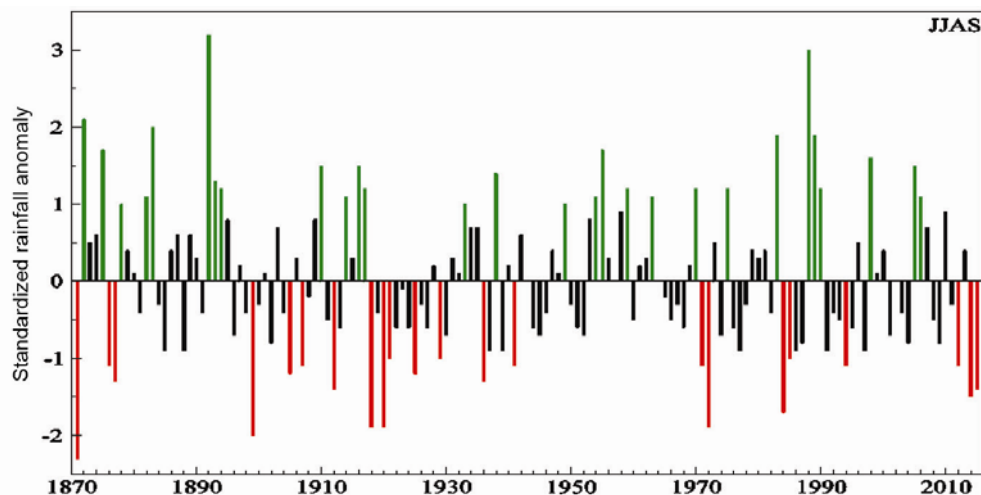
The average June–September rainfall of the Marathwada region is 68.71 cm and its standard deviation is rather large, being 27% of the average rainfall (Table 1). The frequency distribution of the seasonal rainfall (Figure 4) is skewed with a long tail towards high rainfall. It is seen that the chance of seasonal rainfall being as low as in 2015 is small. However, the seasonal rainfall was lower in six years in the period 1871–2015 (i.e. about 4% chance) and hence rainfall being as low as in 2015 is not unprecedented. The minimum assured rainfall at 90% and 75% are indicated in Table 1.

We define a drought as a monsoon season with the anomaly (difference between the rainfall and its long-term mean) of the summer monsoon rainfall, normalized by its standard deviation less than  $-1$ . An excess rainfall season is defined as one with the normalized anomaly  $>1.0$ . The other categories, i.e. below normal, normal and above normal are defined on the basis of the normalized anomaly being between  $-0.5$  and  $-1.0$ ,  $-0.5$  and  $0.5$  and  $0.5$  and  $1.0$  respectively. The interannual variation of the normalized anomaly of the summer monsoon rainfall over Marathwada, is shown in Figure 5 for 1871–2015 in which droughts and excess monsoon seasons are indicated with distinct colours. It is seen that the frequency of droughts exhibits a large variation on the decadal scale. It is interesting that the epoch of 1940–1970 did not have any droughts over Marathwada and during 1999–2011 although there were several years of below normal rainfall, there were no droughts.

Table 2 gives the number of years in which the seasonal rainfall was in each of the categories. Marathwada is a drought-prone region<sup>22,23</sup> and during the 145 years, there have been 22 droughts implying a probability of occurrence of 15%. Thus the chance of a drought in this drought-prone area is close to 1 in 6 to 7 years. In fact, in the period considered, there have been five episodes of two consecutive droughts, viz. 1876–77, 1920–21, 1971–72, 1984–85, 2014–15. It is clear that neither the severity of the drought of 2015 nor the occurrence of two

**Table 2.** Number of years for various categories for Marathwada monthly and seasonal rainfall

Months/category	Marathwada standardized rainfall anomaly					Total
	<= -1	-1 to -0.5	-0.5 to +0.5	+0.5 to +1	>= +1	
June	26	21	51	16	31	145
July	22	25	60	18	20	145
August	23	25	64	6	27	145
September	29	19	55	16	26	145
JJAS	22	27	55	13	28	145



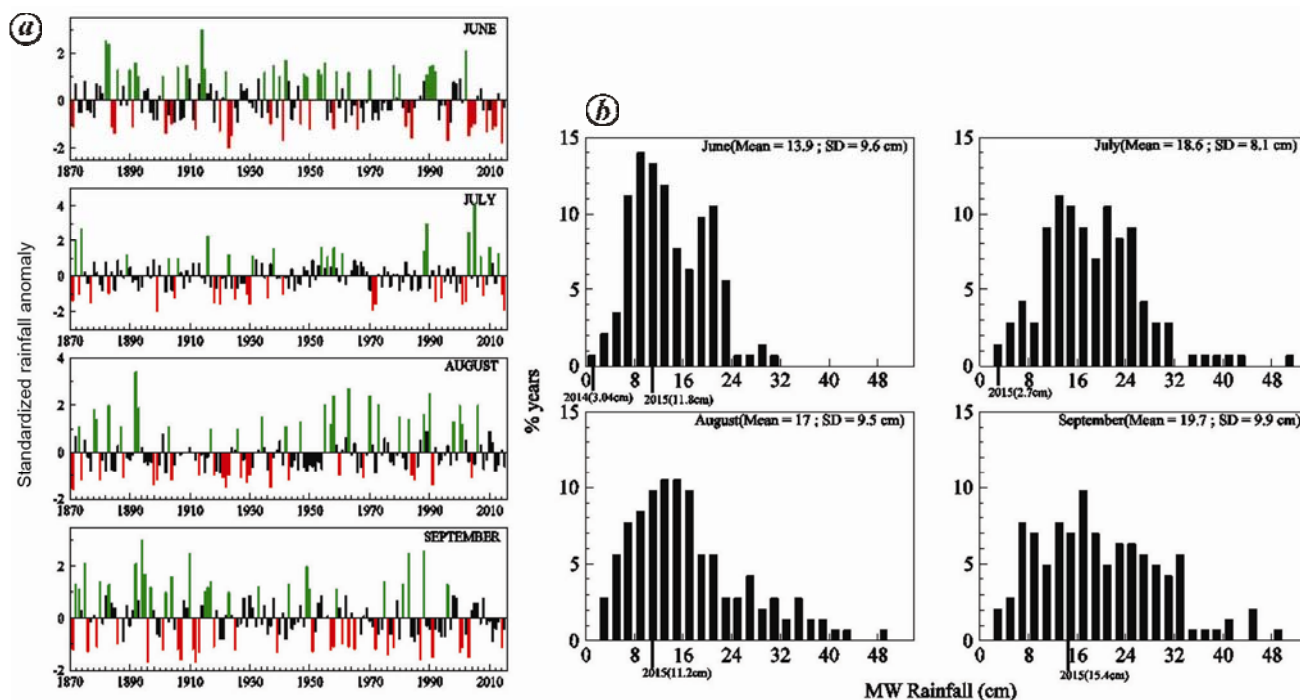
**Figure 5.** Variation during 1871–2015 of the anomaly of the summer monsoon rainfall over Marathwada, normalized by the standard deviation. Years with magnitude of normalized anomaly greater than 1 are marked red for droughts, i.e. for negative anomalies and green for excess rainfall seasons, for positive anomalies.

droughts in consecutive years is unprecedented. In fact, in the drought of 1972 which followed that of 1971, the rainfall deficit over Marathwada was much larger.

*Variation of the monthly rainfall during the summer monsoon season*

Information on the variability of monthly rainfall is important for water management. The variation of Marathwada rainfall on the monthly scale is rather large (Table 1, Figure 3) and that at individual locations in Marathwada is even larger, with that of June rainfall being more than 100% at many locations and the rainfall in other months varying between 50% and 100% (ref. 24). The interannual variation of the rainfall over Marathwada in each of the four months of the summer monsoon season is shown in Figure 6 a. The variation of July and August rainfall is interesting, in that there have been periods of several years in which no droughts occurred. The frequency distributions for the monthly rainfall are shown in Figure 6 b. It is seen that during the monsoon season of 2015, the monthly rainfall is exceptionally low only in July 2015. The minimum assured rainfall at 90% and 75% are indicated in Table 1.

The frequency distributions for the different months are rather different (Figure 6 b). The distribution is rather flat in September with almost equal probability of rainfall over 6–34 cm range. It is seen that during the monsoon season of 2015, the monthly rainfall is exceptionally low only in July 2015 with only two years in the 145 years considered, with lower July rainfall (Figure 5). There was a marked difference between the June rainfall of the summer monsoon seasons of 2014 and 2015 which were both droughts. While in June 2014, very little rainfall was received (Figure 6 b), the rainfall was close to the average in June 2015. However, the satisfactory June rainfall in 2015 did not turn out to be a boon. Although it led to record *kharif* crop sowing, almost all of this was lost in face of extended dry spell that lasted nearly all of July and continued in early August<sup>25</sup>. The dismal July rains in the region led to a dilemma for the farmers: Should they undertake second cropping for *kharif* in the expectation of rain, or keep fields fallow for *rabi* plantation? Some efforts were made to make seeds available to the farmers for a second sowing. By this time, a high likelihood of below normal rainfall or a drought on all-India scale was already predicted by IMD and the El Niño was already strong. Had they been informed of a high chance of a



**Figure 6.** *a*, Standardized monthly rainfall anomaly time series for the monsoon months June, July, August and September based on 1871–2015; years with large monthly deficits and excess shown as red and green respectively. *b*, Frequency distribution of the monthly rainfall for Marathwada.

drought over Marathwada in this situation (as shown in the next section), the funds and efforts involved in the second sowing could have been saved.

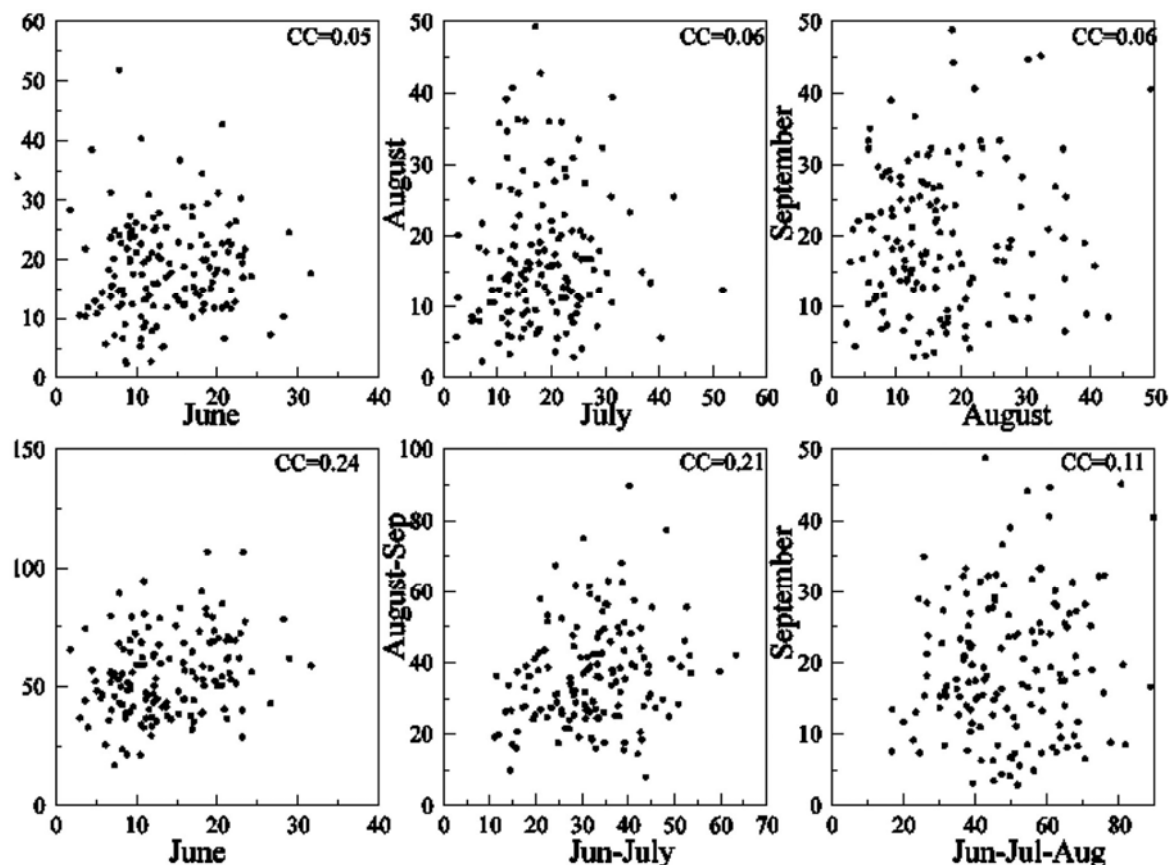
It would also be useful if, after the season has begun, it is possible to use the information on how the monsoon has fared up to that point for suggesting the likely rainfall in the succeeding month or the rest of the season. Figure 7 shows the scatter plots of the rainfall in a given month versus that in the succeeding month or in the rest of the season. It is seen that the scatter is very large for each case and the rainfall in any month or remaining months of the season is poorly correlated with that in the previous month/months. Hence the rainfall over Marathwada has no memory on monthly scale to allow an educated guess about the rainfall in one month or the remaining part of the season on the basis of the rainfall in the previous month or earlier part of the season.

### Relation of seasonal rainfall over Marathwada with ISMR and El Niño

While forecasts of the Indian summer monsoon rainfall (ISMR) region can be generated with dynamical models of the atmosphere–ocean system, it is not possible to generate such forecasts of the seasonal rainfall of a region as small as Marathwada, because the spatial and temporal scales are inexorably linked. We, therefore attempt to assess whether anything more than the climatological information about the likelihood of the different categories

of the rainfall over Marathwada (Table 2) such as below normal, droughts, etc. can be learnt from the forecasts made for ISMR. The seasonal rainfall over Marathwada is highly correlated with ISMR, with the relationship explaining 36% of the variation of Marathwada rainfall. We take ISMR to be normal if the anomaly (normalized by the standard deviation) is between  $-0.5$  and  $+0.5$  standard deviation, and to be below normal or a drought if the magnitude of the anomaly is  $< -0.5$ . Analogously, ISMR is taken to be above normal or excess rainfall season if the normalized anomaly is  $> 0.5$ . The frequency distribution of the categories of droughts, below normal, normal as well as above normal and excess rainfall of Marathwada for three categories of ISMR, i.e. (i) below normal or drought, (ii) normal and (iii) above normal or excess rainfall are shown in Figure 8 *a*.

It is seen that when ISMR is below normal or a drought, the likelihood of a drought over Marathwada is doubled, relative to the climatological likelihood when all years are considered and that of below normal is also substantially increased. At the same time, there is no chance of excess rainfall over Marathwada and almost no chance of above normal rainfall. On the other hand, when ISMR is above normal or in excess, the chance of Marathwada rainfall in the categories of above normal rainfall or excess rainfall is double that when all the years are considered. For 2015 the IMD had predicted in June that there was a 93% chance of below normal rainfall or a drought for the monsoon over the country as a whole. Hence we should have expected a high chance of below



**Figure 7.** Scatter plots of standardized rainfall anomalies of consecutive months in the summer monsoon season and for rainfall of part of the season versus the remaining part of the season, for Marathwada.

normal rainfall or drought for Marathwada as well and planned for facing the deficit in rainfall.

An El Niño, which is a strong warm phase of ENSO, had also been predicted for 2015. The seasonal rainfall over Marathwada is also well correlated with Niño 3.4 SST with the relationship with Niño 3.4 SST, explaining 25% of the variation of Marathwada rainfall. The frequency distribution of the categories of droughts, below normal, normal as well as above normal and excess rainfall of Marathwada are shown for three categories of the anomaly of Niño 3.4 SST, viz. warm events with SST anomaly  $>0.5^{\circ}\text{C}$  (i.e. weak El Niño or El Niño), cold events with the SST anomaly  $<-0.5^{\circ}\text{C}$  and neutral events with SST anomaly between  $-0.5$  and  $+0.5$ , in Figure 8b. It is seen that the chance of Marathwada rainfall being in the below normal or drought categories is almost doubled for warm events, relative to the chance when all the events are considered. At the same time, the chance of above normal or excess Marathwada rainfall is reduced to less than half of that when all the years are considered. On the other hand for cold events, the chance of Marathwada rainfall being in the above normal or excess rainfall categories is almost doubled, relative to the chance when all the events are considered. Thus, since an El Niño (a

very warm event) had been predicted for the 2015 monsoon season (incidentally also for the 2014 season) a large deficit in Marathwada should have been expected in each of these years.

### Climate change component of monsoon variability

An important question to address is whether the 2015 experience of the summer monsoon over the country as a whole or over Marathwada can be considered as a manifestation of the impact of global warming associated with enhancement of the concentration of greenhouse gases in the atmosphere, i.e. anthropogenic climate change. The variation of the anomaly of the global mean surface temperature during 1870–2015 is shown in Figure 9. It is seen that over the scale of about a century there has been a substantive increase in the global mean surface temperature. We expect the climate change component of global warming to be manifested as a change over time-scales of about a century. The variation of the anomalies of ISMR and the summer monsoon rainfall over Marathwada along with the global mean temperature anomalies

during 1871–2015 are shown in Figure 9. It is seen that the variation of ISMR and Marathwada monsoon rainfall is dominated by interannual variation and there is hardly any change in the mean rainfall over the last 145 years. Guhathakurta and Rajeevan<sup>26</sup> have shown that there is no statistically significant trend in the mean ISMR, i.e. the summer monsoon rainfall over the country as a whole during the period 1901–2003. They have also shown that the monsoon rainfall over Marathwada region has no decreasing trend; rather it shows an increasing trend at the minuscule rate of 0.026 cm per year (which is not statistically significant). Note that the standard deviation of the year-to-year variation of seasonal rainfall is 19.2 cm, suggesting that the long-term trend will not be perceived in the presence of such large interannual variation.

Although we have focused on Marathwada rainfall in this article, given the recent propensity to attribute every noteworthy weather/climate event including variation of the monsoon rainfall to anthropogenic climate change, particularly in the media, we briefly discuss next the long

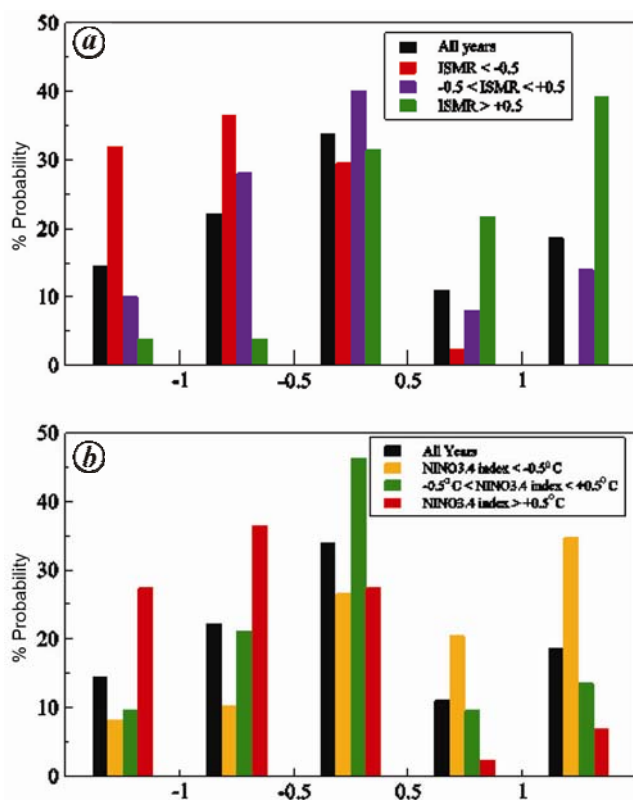
period trends of the monsoon rainfall over all the meteorological subdivisions of the country. It has been shown that for the summer monsoon rainfall over most of the 36 subdivisions, the trends are not statistically significant<sup>26</sup>. Significant decreasing trends are observed for three meteorological subdivisions of which the largest trend is for Chattisgarh. The monsoon rainfall over Chattisgarh decreases at the rate of 15.7 cm for 100 years which is about 1% of the standard deviation of the year-to-year variation and 0.1% of the mean rainfall. The largest increasing trend is for the rainfall over Konkan and Goa of 29.7 cm over 100 years, which is about 7% of the standard deviation and 1% of the mean. Thus while for ISMR there is no long period trend, for the meteorological subdivisions also, the magnitude of the year-to-year fluctuations is so much larger than the trend, that the trend, even if significant, will not be perceived.

We note that climate change in rainfall could be manifested as a change in the mean seasonal rainfall and/or a change in the frequency of extreme events such as droughts. The variation of the anomaly of ISMR (Figure 9) clearly shows that there is also no increasing or decreasing trend in the frequency of droughts/excess rainfall seasons over this long period. However, the frequency of droughts has changed over the decadal scale with epochs of less frequent droughts interspersed with more frequent droughts. The frequency of droughts over Marathwada also varies on the decadal scale and there is no prominent long-term trend in the frequency of droughts over Marathwada (Figure 5).

Thus the monsoon rainfall variability over Marathwada and the 2015 event cannot be considered as a manifestation of climate change. Clearly what was experienced in 2015 is a facet of the rainfall variability observed over a period of 145 years and we should have been prepared for such an event. It is clear that it is necessary to address the problem of adapting to climate variability for which plenty of information is already available as illustrated earlier for the case of Marathwada.

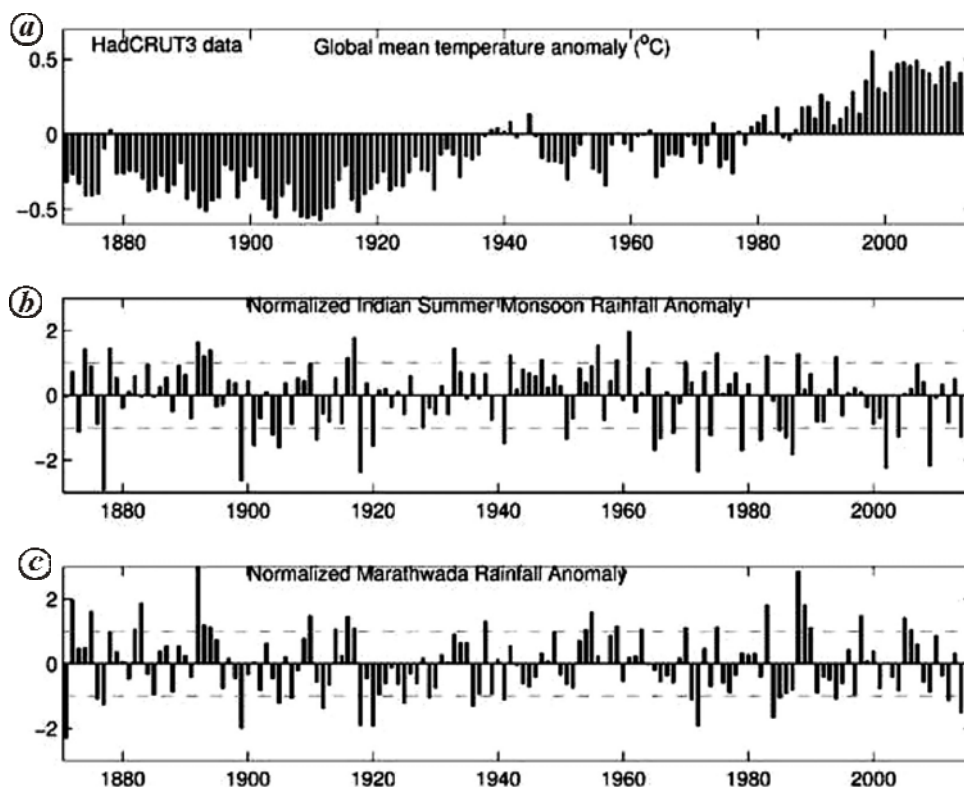
### Adapting to rainfall variability – way forward

We have seen that the large adverse impact of the drought of 2015 (which is even more adverse than the impact of the more severe drought of 1972) can neither be attributed to unusual behaviour of the weather gods nor to climate change but rather to adopting strategies for agriculture and water resource management which have proved inappropriate for the rainfall variability experienced by the region. Of great concern is the identification of appropriate strategies for rainfed agriculture (which is particularly sensitive to the variation in rainfall received), since there is a growing realization that further gains in productivity of crops and livestock will have to emanate from the rainfed regions<sup>27</sup>. Further, it has been estimated



**Figure 8.** *a*, The probability of marathwada seasonal rainfall in the five categories, viz. deficit (normalized anomaly < -1.0), below normal (-1.0 < normalized anomaly < -0.5), normal (-0.5 < normalized anomaly < +0.5), above normal (+0.5 < normalized anomaly < 1.0), excess (normalized anomaly >1.0) for three categories of ISMR, viz. drought or below normal, i.e. normalized anomaly < -0.5, normal (-0.5 < normalized anomaly < +0.5) and above normal or excess (normalized anomaly >+0.5), for the period 1871–2015. *b*, same as Figure 8*a*, but for Niño 3.4 anomaly categories warm (anomaly > 0.5°C), normal (0.5°C > anomaly > -0.5°C) and cold (anomaly < -0.5°C).





**Figure 9.** Variation of the global average surface temperature (a), normalized ISMR anomaly (b) and normalized anomaly (c) of summer monsoon rainfall over Marathwada.

that even if the full irrigation potential of the country is realized, 50% of the net sown area will continue to remain rainfed. Hence, it will be necessary to increase the productivity levels of the major rainfed crops such as pulses to meet the ever-increasing demand of protein<sup>28</sup>. However, unlike over the irrigated regions, the developments of agricultural science and meteorology have not led to an overall increase in rainfed production and the increasingly adverse impacts of droughts such as the one in 2015 cannot be compensated for by much better production in other years. The challenge is, therefore, achieving a sustained increase in rainfed production.

With the rich data sets available at IMD, a great deal of information about variability of ISMR exists and a lot of information for sub-regions of the country can be derived, as illustrated for Marathwada rainfall in this article. The skill of predictions is rapidly increasing as witnessed this year in prediction of the summer monsoon rainfall over the country as a whole. Over the last three decades there has been a rapid development of crop models which are capable of simulating the response of rainfed crops to variation in rainfall. However, it appears that these advances in agricultural science and the available knowledge of rainfall variability and reasonable prediction skill on the all-India scale have not led to better management of rainfed agriculture and hence improving the lot of the farmers.

A critical question to address is, therefore, whether the knowledge of monsoon variability (and reliable predictions if available) can be used to enhance production of rainfed crops such as pulses. Whether such knowledge is useful naturally depends on the impact of the monsoon variability on the agricultural production. A quantitative assessment of the impact of ISMR on the Indian foodgrain production has shown that over 57% of the year-to-year variation in food grain production is explained by the impact of the year-to-year variation in ISMR<sup>13</sup>. This sensitivity of the total food grain production to the rainfall arises because, although the area under rainfed cultivation has decreased over the years from around 82% in 1950, it is still slightly over 50% (ref. 9) and the adverse impact of large deficits in ISMR has remained large throughout<sup>13</sup>. It turns out that the response of the production of food grains to the variation of ISMR is highly nonlinear, with the benefits of a normal or good monsoon in terms of enhancement in production in years not being comparable to the losses for monsoon deficits of similar magnitude<sup>13</sup>. Furthermore, since the eighties, this asymmetry in the response to monsoon variation, with the magnitude of the impact of deficit rainfall on food-grain production being larger than that for surplus rainfall, has become even larger than in the previous three decades<sup>13</sup>. Clearly, for overall increase in rainfed production, it is necessary to harness strategies which lead to

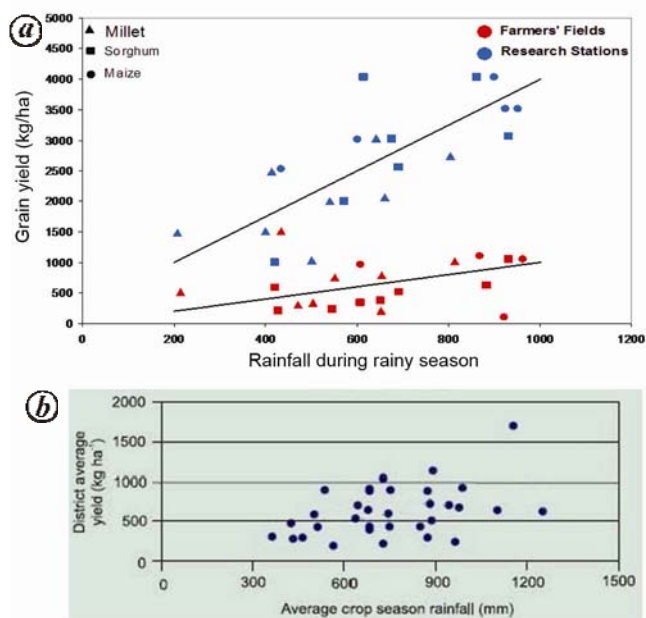
enhancement of production in years of normal or good monsoon.

Insight into the poor response of rainfed agriculture to increasing rainfall can be obtained from a series of studies at the International Crop Research Institute for the Semi-Arid Tropics beginning with that of Sivakumar *et al.*<sup>29</sup>. They showed that while the yields of several rainfed crops on the farmers' fields increase rather slowly with increasing growing season rainfall, the yields at agricultural stations (of the same crops also under rainfed conditions) increase more rapidly with increasing rainfall. Since the yields at the agricultural stations are comparable to the farmers' yields when the rainfall is low, the yield gap, i.e. the gap between yields achievable with existing technology at agricultural stations and yield of the farmers' fields, is small; the rapid increase of the yield at the agricultural stations with increasing rainfall leads to a large yield gaps for years with normal or good rainfall (Figure 10 *a*). Bhatia *et al.*<sup>27</sup> comprehensive study of yield gaps for different crops including pigeonpea (the price of which reached an all-time high after the monsoon of 2015), shows that the situation is similar to that shown in Figure 10 *a*. While the district average yield hardly increases with the rainfall in the growing season (Figure 10 *b*), the potential yield simulated with models and the yield achieved at agricultural stations increase more rapidly<sup>27</sup>. In fact, they have shown that for Maharashtra, the mean achievable yield is 136% of the obtained yield and for Parbhani, in Marathwada the mean achievable yield is well over twice the obtained yield. Hence it should be

possible to enhance the yields in normal or good monsoon years by adopting available technology.

Why is the technology not adopted by the farmers? After all, the green revolution was achieved by farmers implementing the recommendations of the agricultural scientists about cultivation of high-yielding varieties, application of fertilizers, pesticides, etc. It should be noted that the major difference between rainfed cultivation and cultivation over irrigated areas is that while for irrigated areas (over which substantial enhancement of production occurred during the green revolution) the yields are assured, in the rainfed crop yields, there are large fluctuations from year to year in response to the interannual variation of rainfall, which leads to the farmers facing special resource constraints. Thus, for each recommendation for rainfed cultivation (e.g. regarding the application of fertilizers and pesticides), before a decision in favour of the recommended practice can be made, the farmers have to assess the expected benefit in terms of enhancement of yields/profits in the face of rainfall variability of the specific region, vis-à-vis the additional cost involved in implementing the recommendation. Swaminathan<sup>30</sup> has identified the major reasons for the lack of progress in production of rainfed crops. In his words, 'The research farms programmes have mostly been scientist oriented and not farmer or user centered. These were perceived, planned, implemented, supervised and evaluated by scientists. The transfer of results followed a top down approach. In this "take it or leave it approach", the farmer was at best a passive participant. Scientific findings which became the so-called "technologies" were born from small plots and short-term research and were invariably not associated with critical cost-benefit studies.'

There are many cases of the farmers involved in rainfed cultivation not implementing the given recommendations for one or more of the reasons pointed out by Swaminathan<sup>30</sup>. For example, for pulses, it has been found that the farmers prefer to cultivate old varieties on commercial scale as they like their performance and profile<sup>12</sup>. Farmers in the Anantapur region, cultivating a new variety of groundnut, introduced in the seventies, found that they got higher yields when they had to sow late, well outside the sowing window recommended by agricultural scientists<sup>31</sup>. Almost none of the farmers involved in rainfed cultivation invests at the recommended level in fertilizers and pesticides, because such inputs enhance yields only when the rainfall is normal or good, and in the absence of information on the chance of low rainfall, the farmers do not consider such an investment cost-effective. This leads to particularly poorer yields on farmers' fields in comparison with the yields at agricultural stations in years with normal or good monsoon rainfall, leading to an increase in the yield gap as seen in Figure 10 *a*. Over the years as soil fertility has declined, pest and disease incidence has increased and



**Figure 10.** *a*, Relationship between the rainfall during rainy season and yield of maize, sorghum, millet at 15 dryland locations in India (after Sivakumar *et al.*<sup>29</sup>); *b*, Variation of district yield of pigeonpea with growing season rainfall (after Bhatia *et al.*<sup>27</sup>).

chemical inputs, whose prices have been continually increasing, have become more and more essential to realize a good yield. Hence the yield gap in normal and good monsoons (and hence the asymmetry in response to the monsoon) has increased since the 1980s.

We note that the chance of occurrence of very large deficits, i.e. droughts, even in a drought-prone region such as Marathwada is 15%. Thus the strategy adopted by the farmers, i.e. inadequate level of investments in fertilizers and pesticides, while appropriate for years with large deficits in the growing season rainfall, leads to their not reaping benefits of a normal or good monsoon and is, therefore, inappropriate for most of the years. This implies that production could be increased in over 80% of the years by having a strategy of application of fertilizers and pesticides which is appropriate for the entire spectrum of variability experienced in the region. Clearly, an important input for deriving the appropriate strategies for application of fertilizers and pesticides for specific crops for specific regions is the probability of different categories of the growing season rainfall and particularly of that rainfall being above the threshold for which there would be enhancement in yields with such applications. Farmers are also often interested in the chance of wet spells in specific periods for operations such as harvesting. The appropriate choice of sowing window, for many crops is associated with a minimum chance of dry spells in the critical pod-filling stage<sup>31,32</sup>.

In order to cater to such information needs, at the Indian Institute of Tropical Meteorology, Pune we have developed an interactive software 'RAINFO' which utilizes the rainfall data for long periods from IMD and generates information which could be readily used, for a specific location (or any one of the meteorological subdivisions of the country, or all-India average), for a given period (such as a month, June–September season or the growing season for a particular crop, etc.). For the location/region specified by the user (such as Aurangabad or Marathwada subdivision), for the period of interest (such as June–September or the growing season), besides the standard statistical attributes such as the mean rainfall and the standard deviation, information on the probability of occurrence of rainfall in different ranges, can be obtained from the website, <http://www.tropmet.res.in/~lip/climvar/rainfall.php>. In addition, for several locations for which daily data for sufficiently long periods are at present available with us, the probabilities of wet and dry spells of different duration within the specified period (such as a week, or a two-week period corresponding to a solar *nakshatra* used by farmers, or a month) can be obtained. An example in which RAINFO could be used to identify an appropriate strategy is the level of investment in fertilizers. With RAINFO, for a specific crop and a specific region, the probability of the growing season rainfall being in different ranges and, in particular, being above the threshold for which fertilizers can improve the

yield can be made available. Depending on the costs involved, it may turn out to be profitable to invest in an appropriate fraction of the recommended level in fertilizers, or on an appropriate fraction of the cultivated area (determined by the chance of having the growing season rainfall above the threshold) every year so that substantial enhancement of yields in a majority of years will offset the lack of benefit in the few years in which the rainfall is below the threshold. To cater to requests for the seasonal rainfall probabilities for a specific region for a specific year such as one in which an El Niño is predicted, the climatological probabilities as well as those associated with warm events over the Pacific can be supplied.

Another issue widely discussed in association with the severe water scarcity in the aftermath of the 2015 Marathwada drought, is the impact of the large increase in the area for cultivation of sugarcane since the seventies in this drought-prone region. It has also been pointed out that recommendations of some varieties of pulses and of the sowing window for the variety of groundnut cultivated in the Anathapur region are not accepted by farmers. Assessing the performance of different crops/varieties or of the variation in the sowing date or seed rate, etc. by experiments at agricultural stations will take an inordinately long time to adequately sample the rainfall variability experienced over different regions. However, now this can be achieved by running crop models with the observed variation in rainfall over long periods. With this approach and active collaboration among farmers, atmospheric scientists and agricultural scientists, it will thus become possible to identify the optimum cropping pattern, implementable strategies for the sowing window or the seed rate, etc. as well as for intercropping by using crop models in conjunction to enhance yield and hence profit<sup>31–33</sup>. We hope that in not too distant a future, appropriate implementable strategies, tailored to the entire spectrum of rainfall variability, leading to maximum gains in normal and good monsoon seasons, while minimizing the adverse impact of droughts, can be identified and adopted to meet the challenge of increasing rainfed agricultural production.

1. Sikka, D. R., Some aspects of the large scale fluctuations of summer monsoon rainfall over India in relation to fluctuations in the planetary and regional scale circulation parameters. *Proc. Indian Acad. Sci. (Earth Planet. Sci.)*, 1980, **89**, 179–195.
2. Pant, G. B. and Parthasarathy, B., Some aspects of an association between the southern oscillation and Indian summer monsoon. *Arch. Meteorol. Geophys. Bioklimatol.*, 1981, **1329**, 245–252.
3. Glantz, M. H., Katz, R. W. and Nicholls, N. (eds), *Teleconnections Linking Worldwide Climate Anomalies*, Cambridge University Press, 1991, p. 535.
4. Kripalani, R. H. and Kulkarni, A., Climatic impact of El Niño and La Nina on Indian monsoon: a new perspective. *Weather*, 1997, **52**, 39–46.
5. Long Range Forecast Update for 2014 Southwest Monsoon Rainfall, 9 June 2014, Earth System Science Organization (ESSO), Ministry of Earth Sciences, India Meteorological Department.

6. ENSO: Recent Evolution, Current Status and Predictions, Update prepared by Climate Prediction Center/NCEP, 26 May 2015.
7. Long Range Forecast Update for 2015 Southwest Monsoon Rainfall, Earth System Science Organization, Ministry of Earth Sciences, India Meteorological Department, 2 June 2015.
8. *Memoires on Drought*, Govt of Maharashtra, November 2015.
9. *Agricultural Statistics at a Glance*, Ministry of Agriculture, Government of India, 2014.
10. Sharma, D. and Jodha, N. S., Pulses production in semi-arid regions of India: constraints and opportunities. *Econ. Polit. Weekly*, 1982, **17**(52), A135–A137 + A139–A148.
11. Reddy, A. A., Pulses production technology: status and way forward review of agriculture. *Econ. Polit. Weekly*, 2009, **xliv**(52), 73–80.
12. Singh, R. P., Status paper on pulses. Government of India, Ministry of Agriculture, Directorate of Pulses Development, Bhopal, 2009.
13. Gadgil, S. and Siddhartha Gadgil, The Indian monsoon, GDP and agriculture. *Econ. Polit. Weekly*, 2006, **XLI**(47), 4887–4895.
14. Deulgaonkar, A., This is the worst drought in the history of Marathwada. *DNA*, 1 October 2015.
15. Brahme, S., *1972 Drought in Maharashtra*, Gokhale Institute of Politics and economics, Orient Longman, 1976, p. 78.
16. Dandekar, P. and Thakkar, H., How is 2012–13 Maharashtra drought worse than the one in 1972?, South Asia Network on Dams, Rivers & People, 2013.
17. Rath, N., Economic use of flow irrigation water – a comparatively neglected subject in Indian Agriculture policy.
18. Abrol, I. P., India's agriculture scenario. In *Climate Variability and Agriculture* (eds Abrol, Y. P., Gadgil, S. and Pant, G. B.), Narosa Publishing House, London, 1996, pp. 19–25.
19. Gadgil, S., Abrol, Y. P. and Seshagiri Rao, P. R., On growth and fluctuation of Indian foodgrain production. *Curr. Sci.*, 1999, **76**(4), 548–556.
20. Virmani, S. M., Climatic approach to transfer of farming systems technology in the semi-arid tropics, 1979; pdf.usaid.gov/pdf\_docs/PNAAR934.pdf
21. Swindale, L. D., Virmani, S. M. and Sivakumar, M. V. K., Climatic variability and crop yields in the semi-arid tropics, *Food-Climate Interactions*, Springer, 1981.
22. Gore, P. G., Thakur, P. and Hatwar, H. R., Mapping of drought area over India. NCC research report No 12, India Meteorological Department, Pune, 2010, p. 25.
23. Pai, D. S., Lata, S., Guhathakurta, P. and Hatwar, H. R., District-wise drought climatology of southwest monsoon season over India based on standardised precipitation index (SPI), NCC Research report No. 2/2010, India Meteorological Department, Pune, 2010, p. 26.
24. Rajmane, K. D., Rainfall pattern, its variability and frequency in the Marathwada region of India. *J. Maharashtra Agric. Univ.*, 1988, 329–331.
25. Dandekar, P., Drought and Marathwada: an oft repeated tragedy. South Asia Network on Dams, Rivers and People, 2015.
26. Guhathakurta, P. and Rajeevan, M., Trends in rainfall pattern over India. *Int. J. Climatol.*, 2008, **28**, 1453–1469.
27. Bhatia, V. S., Singh, P., Wani, S. P., Kesava Rao, A. V. R. and Bhatia, K. S., Yield gap analysis of soybean, groundnut, pigeonpea and chickpea in India using simulation modeling. Global theme on agroecosystems report #31, ICRISAT, Patancheru, India.
28. Katyal, J. C., Ramachandran, K., Narayana Reddy, M. and Rama Rao, C. A., In *Regional Land Cover Changes, Sustainable Agriculture and their Interaction with Global Change (with Focus on Asian counties)*, Proceedings of International Workshop held in Chennai, India, organized by COASTED-ICSU-UNESCO/IBN, 16–19 December 1996, pp. 16–34.
29. Sivakumar, M. V. K., Singh, P. and Williams, J. H., Agroclimatic aspects in planning for improved productivity of Alfisols. In Alfisols in the Semi-Arid Tropics: A Consultants' Workshop, 1–3 December 1983, ICRISAT Centre, India, 1983, pp. 15–30.
30. Swaminathan, M. S., Climate and sustainable food security, *Bull. India Meteor. Soc.*, 1998, **28**, 3–10.
31. Rao, K. N., Gadgil, S., Seshagiri Rao, P. R. and Savithri, K., Tailoring strategies to rainfall variability – I: the choice of the sowing window. *Curr. Sci.*, 2000, **78**, 1216–1230.
32. Gadgil, S., Seshagiri Rao, P. R. and Narahari Rao, K., Use of climate information for farm-level decision making: Rainfed groundnut in Southern India. *Agric. Syst.*, 2002, **74**, 431–457.
33. Rao, P. R. S. *et al.*, Exploring cropping options with crop models: a case study of pigeonpea versus peanut in rainfed tracts of semi-arid southern India. In *New Directions for a Diverse Planet*, Proceedings of the International Crop Science Congress, Brisbane, Australia, 26 September–1 October 2004.

ACKNOWLEDGEMENTS. It is a pleasure to acknowledge illuminating discussions with Professors Nilakanth Rath, Madhav Gadgil and Seshagiri Rao. A.K. and S.P. are grateful to Dr R. Krishnan, Director, IITM for providing all the facilities to carry out this work.

Received 9 June 2016; revised accepted 15 September 2016

doi: 10.18520/cs/v111/i7/1182-1193