18

The Asian monsoon – agriculture and economy

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Despite structural shifts and improvements of resilience to the vagaries of the monsoon, the kernel of the Asian economy is still very intricately and critically linked to the performance of the monsoon precipitation. In this chapter, we focus on rice, which is the major food crop of the region and provides more than half the calories and protein to the teeming millions. Asia accounts for about 90% of the area and about 92% of the production of rice in the World. We consider the links of the variation of the yield, area under cultivation, and the production of rice in several countries of the Asian monsoonal region to different facets of rainfall variability. We find that there is a strong link to interannual variation of seasonal rainfall for India and a somewhat weaker link for Thailand. We then consider the variability of the Indian monsoon and its relationship with rice production over the Indian region as a whole as well as in a major rice growing state. We also attempt to assess the impact of the monsoon on the Indian economy. We find that in general, the negative impact of a deficit of rainfall is larger than the positive impact of good rainfall. We then discuss the possible strategies for using knowledge and prediction of monsoon variability to enhance agricultural production.

18.1 INTRODUCTION

Over a third of the World's population resides in the region under the sway of the Asian monsoon. Agriculture has been described as the most weather dependent of all human endeavours, and naturally the impact of the vagaries of the monsoon rainfall on food production has been of great concern. The interannual variation of the Asian monsoon rainfall has an impact on the agricultural production, particularly under rain-fed conditions. The impact is large when at the lower end of the range of variation of seasonal rainfall – crops suffer from moisture stress leading to low crop yields. Floods due to heavy rainfall events (e.g., those caused by cyclones/typhoons)

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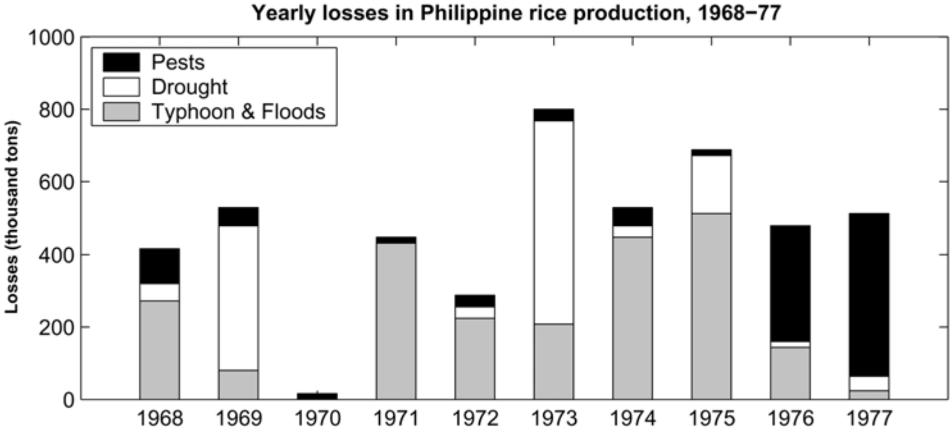


Figure 18.1. Yearly losses in Philippine rice production and their causes, 1968–1977.
After Pantastico and Cardenas (1980).

also lead to extensive crop damage. The phase of the intraseasonal variation between wet and dry spells within a season *vis-á-vis* the different phenological stages of the crop, also has an impact on the growth and yield of rain-fed crops (Gadgil *et al.*, 2002a). With similar cropping patterns over large areas (as is the case over a large part of monsoonal Asia) many pests and diseases have become endemic. In this situation whenever weather conditions are favorable (e.g., long dry spells for some insects such as leaf miner or wet spells for many fungal diseases) the population increase and incidence of the pests/diseases causes large losses (Gadgil *et al.*, 1999a, 2002a).

Pantastico and Cardenas (1980) have estimated the losses in rice yield in the Philippines due to such weather/climate related factors during 1968–1977 (Figure 18.1). The agricultural production of Bangladesh has been shown to be adversely affected by events ranging from synoptic to large scale such as floods caused by depressions and cyclones and large deficits in seasonal rainfall (Mowla, 1976). The large impact of monsoon variability over the agricultural production and hence the economy of countries such as India has been known for a very long time. In fact, the Indian economy was described as a gamble against the monsoon rains in the colonial era. A major impetus to research on the links between climate variability and agricultural production for application to the management of agriculture, particularly in the climate-sensitive areas of the tropics, came from the recommendations of the World Food Conference at Rome in 1974. Consequently, the activities of World Meteorological Organization (WMO) in the field of agrometeorology were intensified (WMO and IRRI, 1980). The recognition of the need to assess the probable impact of climate change around the mid-1970s also led to a large number of studies based on the understanding of the links between climate variability and agriculture (e.g., Takahashi and Yoshino, 1976; Mathews *et al.*, 1995). In the last decade, the major advances in the understanding of El Niño/Southern

Oscillation (ENSO) and hence in the ability to generate seasonal to interannual predictions led to a revival of interest in the atmospheric science community in application to agriculture. In view of the significant advances in the last decade in elucidating the nature of the interannual variation of the Asian monsoon (Chapter 6) and its links with ENSO (Chapter 12), the time is opportune to assess the extent to which these recent advances can contribute toward a higher productivity of the managed ecosystems.

The dominant component of the variation of agricultural production over monsoonal Asia from the 1960s or early 1970s is the enhancement in production associated with the Green Revolution. This increase in production resulted from a large increase in the yield per hectare due to the introduction of new dwarf, high-yielding, and fertilizer responsive varieties and also an increase in the area under cultivation (Abrol, 1996). The increase in the average yield over the Indian region during the Green Revolution was made possible by a substantial increase in irrigation and application of fertilizers and pesticides (Gadgil *et al.*, 1999b). Despite the large investments in irrigation, at present more than 60% of the area under cultivation is rain-fed and we do not expect the rain-fed area to decrease to levels much below 50% in the foreseeable future (Katyal, 1998). Hence the interannual variation of the Indian monsoon has continued to have an impact on agricultural production (Krishna Kumar *et al.*, 2004). The impact of the summer monsoon rainfall on the summer food grain production is particularly large (Figure 18.2). The variability of the monsoon also has an impact on irrigated crops because the quantity of water available for irrigation depends upon the monsoon rainfall. Whether our understanding of the nature of the variability of the Asian monsoon on different timescales and the enhanced ability of its prediction can contribute to the reduction of the negative impacts of monsoon variability and/or enhancement of the positive impacts on production needs to be explored.

In this chapter we consider only a few facets of the links between the Asian monsoon, agriculture, and the economy. Rather than attempting a comprehensive review (which would require an entire book) we present some results on the analysis of links of the Asian monsoon with rice production, assessment of the impact on the Indian economy, and suggest how understanding and prediction of the monsoon variability could be used for enhancing agricultural production. We focus on rice because it is the major food crop of the region and, on average, provides more than half the calories and nearly half the protein for the population. Asia accounts for about 90% of the area and about 92% of the production of rice in the World. We consider the links between the variation of yield, area under cultivation, and the production of rice in several countries of the Asian monsoonal region to different facets of rainfall variability (Section 18.2). We find that there is a strong link between the variability in rice production and interannual variation of the seasonal rainfall for India (and a somewhat weaker link for Thailand). We then consider some facets of the variability of the Indian monsoon (Section 18.3) and its relationship with the variability in rice production over the Indian region as a whole as well as in a major rice growing state of India (Section 18.4). We also attempt to assess the impact of the monsoon on the Indian economy (Section 18.5). We find that in general, the negative

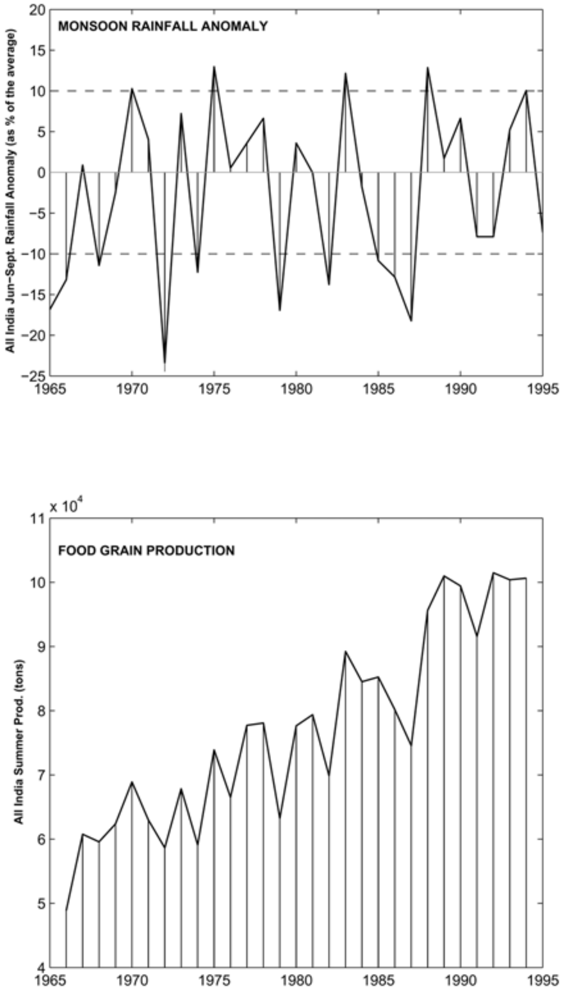


Figure 18.2. All-India summer monsoon rainfall anomalies and all-India summer foodgrain production during 1966–1994.

impact of deficit rainfall is larger than the positive impact of good rainfall. We then discuss possible strategies for using knowledge and prediction of monsoon variability for enhancing agricultural production in Section 18.6.

18.2 VARIABILITY OF RICE PRODUCTION IN ASIA AND ITS RELATION TO VARIATION IN RAINFALL

The rice production of Asia represents a very large fraction of the World's production. China, India and Indonesia are the major rice producing countries in Asia

(Figure 18.3, color section). We analyzed the variation of rice production of several countries in the region using the data from IRRI (1996) for the period 1961–1993.

18.2.1 Climatic aspects of rice production

The Asian cultivated rice (*Oryza sativa L.*) is the dominant rice of the World. Early archaeological evidences indicate that rice has come from India, China, and Thailand (Nair, 1999). Rice originated in a tropical rainy climate characterized by high temperature, high humidity, and low light intensity and abundant rainfall (Hardjawinata, 1980). Rainfall pattern is considered to be the most important limiting factor for rice production in south and south-east Asia, while temperature and radiation are more important for the higher latitude region in east Asia especially in the north-eastern and northern Japan. The total water requirement for cultivation of rice over rain-fed areas is 20 cm per month for wet season crops (Oldeman, 1980). An important feature of cultivation, which is special to rice, is transplantation, which is done after about one month of sowing (WMO and IRRI, 1980). The area under cultivation is, therefore, dependent on the rainfall in that period.

18.2.2 Observed variation of rice production: decadal-scale variation

A major component of variation in the area under rice cultivation as well as the yield per hectare (and hence the production), on the decadal scale, is the marked increase in association with the Green Revolution. However, depending on the socio-economic and political situations, there is considerable variation between the countries in the period over which the increase occurred and in the rate of increase (Figure 18.4, color section). Thus, over India, there has been an increase in the area under cultivation as well as the yield (and hence in the production) from the mid-1960s until the late 1980s; after which all three quantities seem to have reached a plateau. The variation over Thailand is similar to that over India. In Vietnam the increase in yield, area under cultivation, and production is seen only after the mid-1970s (i.e., after the end of the last war). Over Indonesia, the area under cultivation has increased steadily; the yield has increased from the mid-1960s with a more rapid increase in the early 1980s and the production has increased steadily throughout the period. Over China, the area under cultivation increased rapidly until the mid-1970s but declined thereafter; the yield has increased throughout the period (with a more rapid increase for the decade beginning in the mid-1970s) and the production has also increased throughout the period. The decadal-scale variation over the Philippines is similar to China's in that a steady increase in production is seen to be associated with a steady increase in yields although the area under cultivation declined in the early 1980s after attaining a maximum in the 1970s.

18.2.3 Interannual variation of the rice yield and cultivated area

Over and above these decadal-scale changes, there are changes on the interannual scale for the area under rice cultivation and/or the yield per hectare and hence the rice production for several countries. It is seen from Figure 18.3 that the interannual variation of the Indian rice production is large and the major dips in the Asian production (e.g., 1965, 1979, and 1987) coincide with those in the Indian production. On the other hand, the amplitude of interannual variation in rice production over China and Indonesia is rather small.

The frequency distributions of the change in yield from one year to the next (expressed as a percentage of the yield of the previous year) for several countries are shown in Figure 18.5 (color section). For each of these countries, the mode corresponds to an increase of up to 5% in the yield per year, which is a manifestation of the Green Revolution. In Indonesia, the yield can increase by more than 20% in a year, but it seldom decreases. The frequency distribution for rice yield in countries such as India and Sri Lanka is more symmetric, with long tails on both sides implying a large magnitude in the decrease/increase in yield in some years.

In the period considered here (viz. 1961–1993), the length of the runs of years with a continuing increase or decrease in the Indian rice yields is rather short (Table 18.1). For a majority of the years, an increase (decrease) in one year is followed by a decrease (increase) in the subsequent year. It is seen from Table 18.1 that the runs in the variation of the rice yield of Thailand are also short. For rice yields of China, the runs are longer with all the runs of three years or longer being characterized by increasing yield. For Indonesian rice yield, there are even longer runs with increasing yields and only one run of one year with a decreasing yield. Clearly the longer timescale variation associated with the Green Revolution dominates the rice variation over Indonesia and to somewhat less extent over China. There is a significant component of interannual variation in the rice yields of countries such as India and Thailand.

The frequency distribution of the year-to-year changes in the area under rice cultivation in different countries is shown in Figure 18.6, (color section). Over countries such as India and Thailand, there are large fluctuations of the areas under cultivation. While the fluctuations in area are well correlated with those in

Table 18.1. Lengths of runs of years with a continuing increase/decrease in rice yields.

	Runs with increasing yield					Runs with decreasing yield		
Country	1 yr	2 yrs	3 yrs	4 yrs	>4 yrs	1 yr	2 yrs	3 yrs
India	8	3	–	–		8	–	–
Thailand	6	3	–	–		6	2	–
China	3	3	1	1	1	4	1	–
Indonesia	1	1	1	1	1	1	–	–

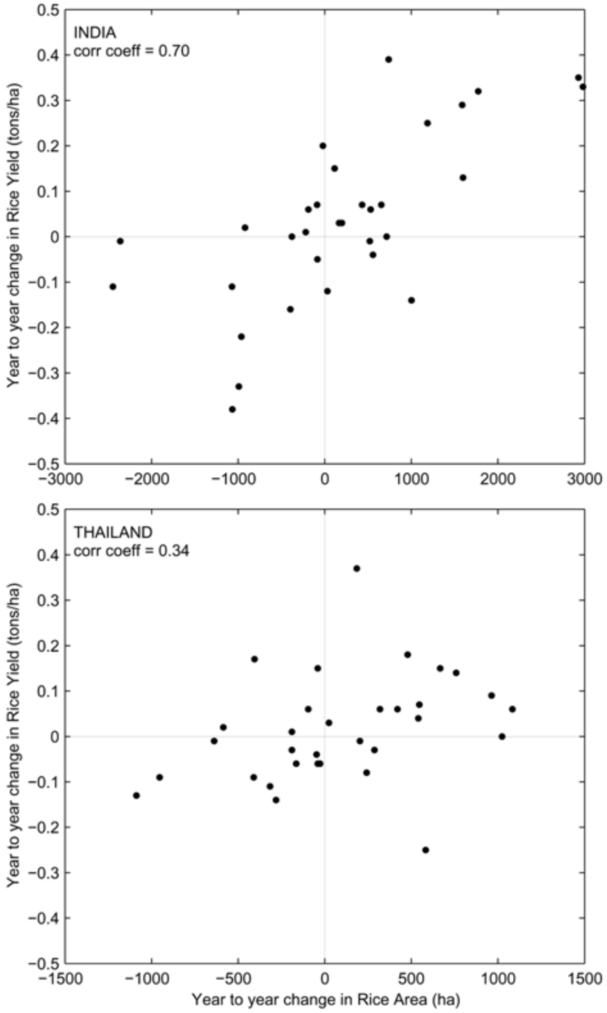


Figure 18.7. Change in yield from one year to the next vs. change in area from one year to the next for India and Thailand.

yield for India, the correlation between area and yield changes for Thailand is not as high (Figure 18.7); for Bangladesh, the correlation is in fact close to zero. It is interesting to note that there are large variations on the interannual scale in the area under cultivation, but not in yield, in Indonesia.

18.2.4 Relation between variation of rice production and variation of rainfall

In order to analyze the relationship between the interannual variation of the yield/production with rainfall, the trends on the longer timescales in the time series (such

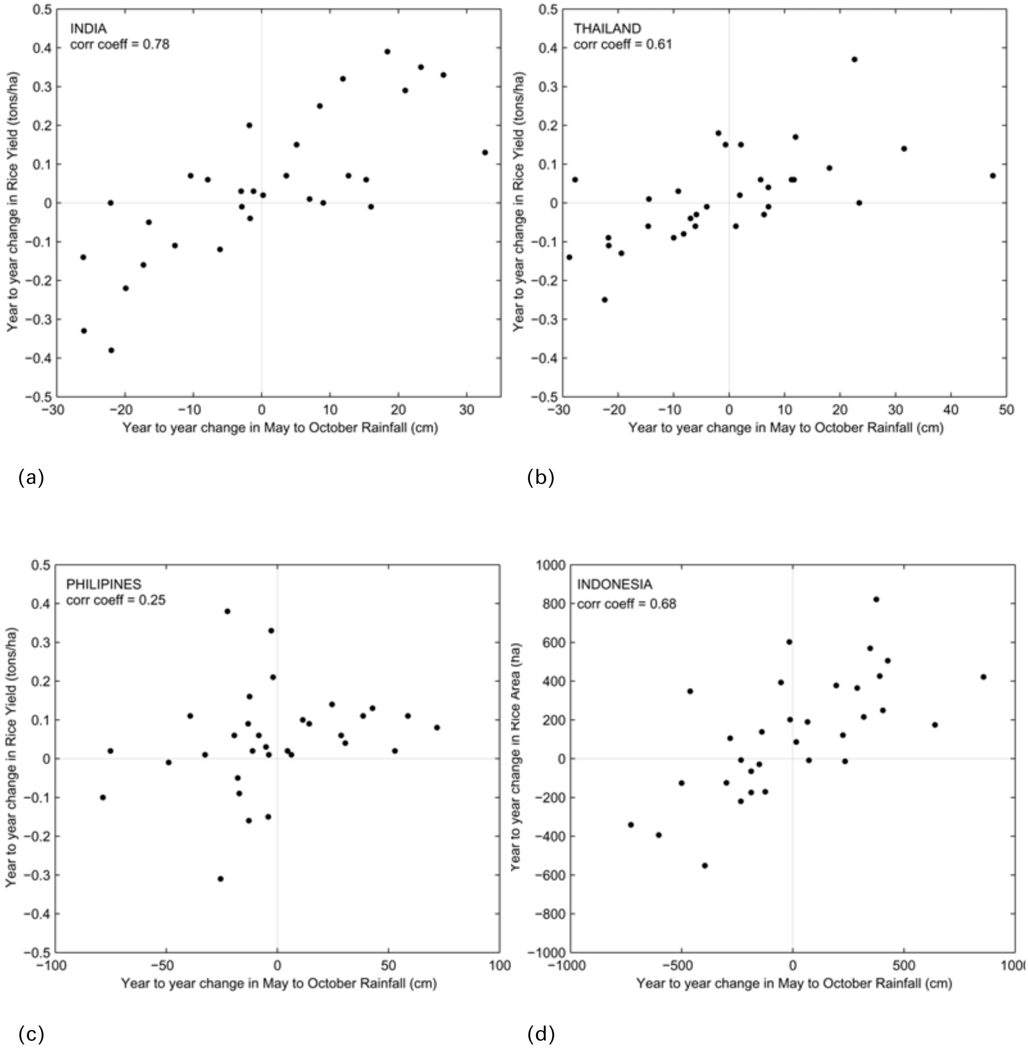


Figure 18.8. (a) Relationship between year-to-year changes in rice yield and those in May–October rainfall over India. (b), (c), and (d) – same as (a) but for Thailand, the Philippines, and Indonesia, respectively.

as those associated with the Green Revolution) have to be removed. A simple way of focusing on the shorter timescales is by considering the year-to-year difference in yield/production and their relation to the year-to-year difference in the seasonal rainfall (Krishna Kumar *et al.*, 2004). We expect the interannual variation in the yield to be related to that of the total seasonal rainfall and distribution within the season. However, the variation in the area under cultivation is related to the rainfall received in the early part of the season, up to the time of transplantation. We consider here the relationship for India, Bangladesh, Sri Lanka, Myanmar, Thailand, Vietnam, and Indonesia using a countrywide means of monthly rainfall data for the period 1961–1993. These data have been prepared from the gridded monthly precipitation data sets of the Climatic Research Unit (CRU), University of East Anglia, UK (New *et al.*, 2002) by taking the arithmetic means of all the land grid points within the respective countries.

For most of the countries considered here, the rainfall occurs primarily during May–October, and we consider the relationship of the yield to the rainfall during that season. The exceptions are Indonesia, over which the rainfall is less during June–September than in other months, and Sri Lanka, where most of the rainfall occurs during October–December. The year-to-year change in rice yield is highly correlated with the year-to-year change in the seasonal rainfall for India and Thailand (Figure 18.8(a,b)). The relationship of the rice yields of the Philippines to rainfall is rather complex (Figure 18.8(c)). It is seen that an increase up to 0.2 tons per hectare occurs irrespective of the change in seasonal rainfall in a majority of years. The decrease of the seasonal rainfall in the other years is associated with a decrease in yield in 6 out of 10 years and an increase beyond 0.2 tons per hectare in 4 out of 10 years. It appears that deficit rainfall could have a positive impact (perhaps because of absence of floods or suppression of some pests and diseases) whereas there is hardly any impact for the positive rainfall anomaly. We find that there is no discernable relationship between the year-to-year changes in rice yields over Vietnam, Bangladesh, and Myanmar and the change in seasonal rainfall.

In the period considered, while the Indonesian rainfall has fluctuated from year to year, the Indonesian yields have decreased only on one occasion and the year-to-year change in Indonesian rice yield is poorly correlated with that of the seasonal as well as the annual rainfall. Thus, despite the presence of the biennial component in the interannual variation of rainfall over the Asian monsoonal region (Chapter 6), there is hardly any variation on this timescale in the rice yield/production of some of the countries such as Indonesia. The rice season in Indonesia for the first crop begins during the dry period of May–October (Tanaka, 1976). There is no relationship between the rice yields and rainfall because the Indonesian rainfall is seldom less than the required amount (about 20 cm per month from transplanting to maturity stages) for good growth and yield of rice crops (Gadgil *et al.*, 1999c). However, there is considerable variation in the area under rice cultivation in Indonesia with large decreases in the El Niño years of 1972, 1982, and 1991. This suppression in the area under cultivation could be because the Indonesian rainfall during May–October (i.e., the season in which transplantation occurs), is tightly coupled to ENSO with a deficit during El Niño (Hendon, 2003). In fact, the year-to-year variation in the area under rice cultivation in Indonesia is highly correlated with that of the May–October rainfall (Figure 18.8(d)).

Over India, the year-to-year change in the area under cultivation is correlated with the change in yield. This is because in most of the extreme years (with the amplitude of the summer monsoon rainfall anomaly being more than 10% of the mean) the anomalies are coherent within the monsoon season. There are a few exceptions such as the drought of 1987 in which the impact on the area was much larger since the rainfall in June was highly deficient.

Thus, of the countries considered here, the relationship between rice yields, area, and production with seasonal rainfall is strongest for India, followed by Thailand.

Next we summarize what is known about the variability of some facets of the monsoon rainfall over the Indian region and then consider in detail the case of rice cultivation in the state of Andhra Pradesh in southern India, a major rice growing state, to illustrate the impact of the different facets of the monsoon on cultivation in irrigated areas.

18.3 SOME FACETS OF THE MONSOON VARIABILITY OVER THE INDIAN REGION

Rainfall has the most extensive and perhaps the longest data set available for analysis among all the meteorological parameters over India. A great deal is known about the space–time variation of rainfall (Pant and Rupa Kumar, 1997, and references therein). The focus of most of the studies has been the rainfall in the summer monsoon (June–September) season during which a large part of the country receives over 80% of the annual rainfall. The variation of the spatial average of the seasonal rainfall over the Indian region, widely known as the 'all-India' summer monsoon rainfall (ISMR), during 1871–2004 is depicted in Figure 18.9 (color section). The Indian summer monsoon is very stable in the longer term (Pant and Rupa Kumar, 1997), and is a dependable source of water for the region. The most prominent feature of the variation of ISMR is interannual variability, with the standard deviation being 10% of the long-term mean of ISMR. Annual countrywide mean ISMR anomalies beyond ±10% are associated with severe droughts and floods over extensive areas in the country. While the monsoon rainfall displays a very complex spatio–temporal variability, extreme situations have remarkable spatial coherence (Pant and Rupa Kumar, 1997) and demonstrate the existence of large-scale anomalies in the monsoon circulation. Hence, ISMR is considered to be a robust index for subcontinental-scale monsoon variability. The all-India production of foodgrain is highly correlated with ISMR (Parthasarathy *et al.*, 1988, 1992a). We find that the correlation of the year-to-year change in all-India rice yield is slightly better correlated with that of ISMR than with May–October rainfall shown in Figure 18.8(a).

The frequency of years with large deficits/excesses shows significant variation on the decadal scale. Figure 18.10 shows the 31-year moving averages of ISMR anomalies and also the variations in the standard deviations of the corresponding 31-year periods. The standard deviations are expressed as percentage departures from the overall standard deviation for the data period, to indicate decadal-scale decreases and increases in the variability. The moving average clearly shows two multidecadal periods of deficient (1900s to 1930s and late 1960s to present day) and

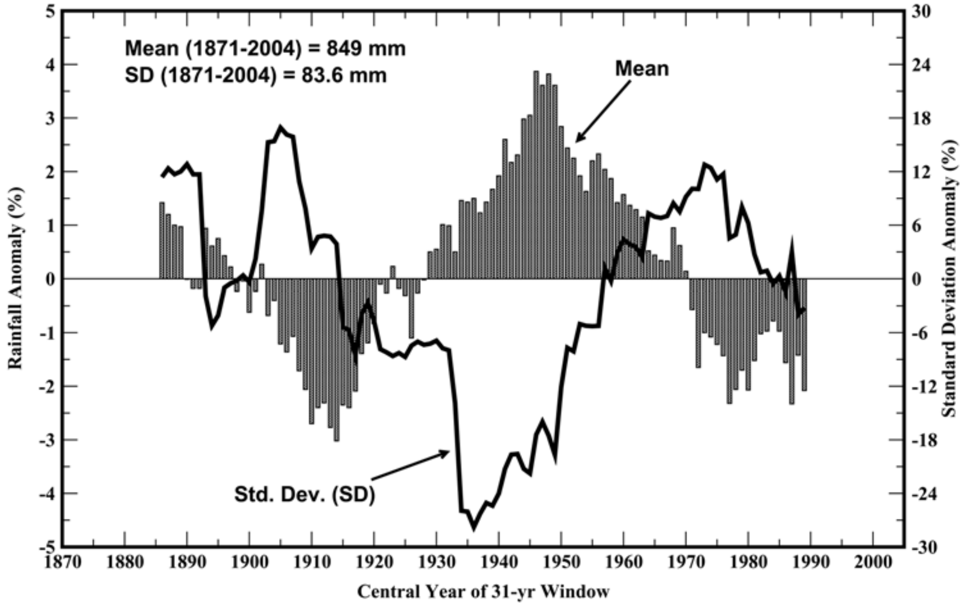


Figure 18.10. 31-year running means and standard deviations of all-India summer monsoon rainfall using the data period 1871–2004.

excess (1870s to 1900s and 1930s to early 1960s) monsoon rainfall, which is manifested in the actual data as frequent occurrences of droughts and floods. Interestingly, the variability in rainfall (see the standard deviation curve in Figure 18.10) increases during the dry epochs and decreases during the wet epochs.

The Green Revolution with phenomenal increase in agricultural production over India occurred in the last dry epoch during a high variability of the monsoon rainfall. As seen in the earlier section, droughts (defined as seasons with a larger than 10% deficit in ISMR) have continued to have a large impact throughout this period.

18.3.1 Extremes of seasonal rainfall: droughts and floods

A major advance in our understanding of the year-to-year variation of the monsoon rainfall occurred in the 1980s, with the discovery of a strong link with ENSO, the dominant signal of interannual variation of the coupled atmosphere–ocean system over the tropical Pacific. It was shown that there is an increased propensity of droughts during El Niño or the warm phase of this oscillation and of excess rainfall during the opposite phase (i.e., La Niña) (Sikka, 1980;

Table 18.2. El Niño/La Niña association with ISMR anomalies during 1871–2004 (number of years, category wise).

Number of years with...	Deficient monsoon	Normal monsoon (Negative)	Normal monsoon (Positive)	Excess monsoon	**Total**
El Niño	11	11	4	0	**26**
La Niña	0	1	9	8	**18**
Other	13	24	42	11	**90**
Total	**24**	**36**	**55**	**19**	**134**

Note: A year is classified as deficient, normal (negative), normal (positive), or excess monsoon year, when the ISMR is below −10%, between −10% and zero, between zero and +10%, or above +10%, respectively.

Pant and Parthasarathy, 1981; Rasmusson and Carpenter, 1983). Consistent with the nature of the links with ENSO, the La Niña event of 1988 was associated with a large excess in the ISMR, and the El Niño events of 1982 and 1987 were droughts. However, for 14 consecutive years beginning with 1988, there were no droughts despite the occurrence of El Niño. Further, during the strongest El Niño event of the century in 1997, the ISMR was even slightly higher than the long-term mean (Figure 18.9, color section) and Krishna Kumar *et al.* (1999b) suggested that the relationship between the Indian monsoon and ENSO had weakened in recent decades. Although a weak El Niño was known to be developing in 2002, none of the predictions for 2002 suggested a large deficit in the Indian monsoon rainfall. The experience of 1997 and 2002 suggests that we do not as yet understand adequately the response of the monsoon to El Niño. It should also be noted that droughts do occur in the absence of El Niño (e.g., 1979 in Figure 18.9). In fact, of the 24 droughts that occurred during 1871–2004, only 11 were associated with El Niño (Table 18.2, updated from Rupa Kumar *et al.* (2002)).

Gadgil *et al.* (2003, 2004) have suggested that the deficient and excess rainfall monsoon seasons are linked not only to ENSO, but also to events over the equatorial Indian Ocean involving an enhancement of deep convection over the western part with suppression over the eastern part of the equatorial Indian Ocean and vice versa. The oscillation between these two states, which is reflected in the pressure gradients and the wind along the equator, is termed as the Equatorial Indian Ocean Oscillation (EQUINOO). Gadgil *et al.* (2004) showed that every season with excess rainfall/drought during 1958–2003 can be ‘explained’ in terms of a favorable/unfavorable phase of either this oscillation or the ENSO or both. There is a strong relationship between large (of magnitudes larger than 10% of the mean) deficits/excesses of ISMR and a composite index based on indices of ENSO and EQUINOO (Figure 18.11).

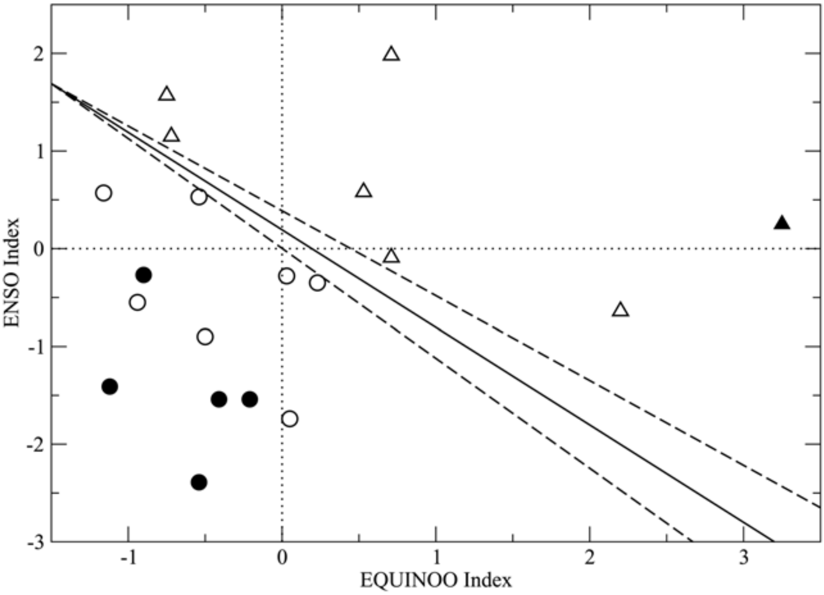


Figure 18.11. Extreme ISMR anomaly represented in the phase plane of the EQUINOO index and the ENSO index. Filled (open) circles represent the ISMR anomaly above (below) +(−) 1.5 s.d. and open (filled) triangles represent the ISMR anomaly between +(−)1 and +(−) 1.5 s.d.

18.3.2 Subseasonal patterns of monsoon anomalies

The months of July and August are generally the most active months of the summer monsoon season, contributing 60% of the monsoon rainfall. On an all-India scale, there is no significant correlation (Table 18.3) between the monthly rainfall within the season, mainly because synoptic situations of smaller timescales dominate the rainfall variability on a monthly scale. These synoptic situations are basically generated and developed independently, though broadly embedded in the monsoon circulation. Thus, the seasonal total rainfall cannot indicate the monthly distribution of rainfall. However, the highly significant correlations between the monthly rainfall and the seasonal total (Table 18.3) indicate that all the months substantially contribute to the variations in the seasonal rainfall.

To examine the monthly rainfall variations in extreme seasonal rainfall situations, the departures from the normal of monthly rainfall for deficient and excess years can be considered. There are several years in which the monthly rainfall anomalies are opposite to the seasonal anomalies (Table 18.4). In general, these subseasonal patterns indicate that the excessiveness or deficiency of the monsoon

Table 18.3. Correlations between monthly and seasonal ISMR.

Month	July	August	September	**Monsoon**
June	−0.05	−0.05	−0.07	**0.36****
July		0.11	0.23*	**0.57*****
August			0.26**	**0.61*****
September				**0.65*****

*Significant at 5% level.
**Significant at 1% level.
***Significant at 0.1% level.

Table 18.4. Subseasonal patterns of extreme ISMR anomalies (% departures from normal). From Pant and Rupa Kumar (1997).

Drought years						Flood years					
Year	June	July	August	September	JJAS	Year	June	July	August	September	JJAS
1873	−31	−3	−12	−3	−11	1874	39	12	−5	20	14
1877	−12	−43	−35	−13	−29	1878	−20	7	39	25	14
1899	20	−32	−41	−40	−26	1892	−3	15	26	24	16
1901	−29	−20	7	−27	−16	1893	48	−7	−5	32	12
1904	10	−10	−19	−26	−12	1894	33	14	−1	18	14
1911	18	−44	−14	5	−14	1916	23	−6	19	19	12
1918	11	−48	−10	−39	−24	1917	31	−11	14	57	18
1920	−12	6	−33	−29	−16	1933	24	−6	27	20	14
1928	−6	3	−19	−23	−10	1942	7	18	16	6	13
1941	1	−20	−14	−20	−14	1947	−25	6	21	37	11
1951	−5	−7	−15	−29	−13	1956	28	24	4	5	15
1965	−32	−3	−22	−18	−17	1959	−4	17	2	25	10
1966	2	−15	−19	−20	−14	1961	15	15	11	42	20
1968	−17	5	−20	−22	−11	1970	30	−19	23	21	10
1972	−25	−33	−11	−25	−23	1975	10	6	9	33	13
1974	−35	0	−7	−19	−12	1983	−15	0	21	47	12
1979	−12	−18	−18	−18	−17	1988	4	17	14	20	16
1982	−20	−21	10	−29	−14	1994	32	15	9	−18	10
1987	−29	−25	0	−19	−19						
2002	+5	−51	−16	−7	−19						
2004	0	−17	−5	−29	−13						

rainfall is more frequently realized in the later half of the season (Rupa Kumar *et al.*, 1992).

18.3.3 Dry spells – breaks in the monsoon

Though the mid-monsoon months July and August contribute most of the seasonal monsoon rainfall, the rainfall distribution is not spatio-temporally uniform over the subcontinent even in these two months. There are significant variations on the intraseasonal scale between wet spells and dry spells. In some years during the 'breaks' in the monsoon the rainfall over the Indian monsoon zone is interrupted for several days in July–August (Gadgil and Joseph, 2003, and references therein). The phenomenon of break monsoon has been of interest because prolonged intense breaks often occur during droughts. For example, a prolonged break situation in the peak monsoon month of July in 2002 (Figure 18.12) resulted not only in a record deficit for the month of July, but also caused a seasonal-scale drought over the whole country.

18.3.4 Seasonal transitions: onset and retreat

The seasonal transition from the pre-monsoon to monsoon is so sudden (Figure 18.13(a)) that it is often termed as the 'burst' of the monsoon over the Indian subcontinent. The south-west monsoon over the Indian peninsula first arrives over the south Indian state of Kerala, while almost simultaneously the Bay of Bengal branch reaches west Bengal and the hills of the Assam region in the north-east of India. Kerala is widely known as the *gateway* of the Indian summer monsoon and its onset over the south Kerala coast is one of the most important meteorological events in the region that the public in general as well as the Indian meteorological community in particular eagerly look forward to every year. This event, with remarkable punctuality around the first week of June, heralds the rainy season for the region, ending the days of parching heat and bringing in much needed water for agricultural, industrial, and domestic use. This date also serves as an indicator of the timely or otherwise commencement of monsoon rains over the other parts of the subcontinent, which is very important for the start of agricultural operations for the main cropping season of the year known as *kharif*. The onset, advance, and withdrawal of the monsoon are particularly critical to the rain-fed agriculture during the *kharif* season.

Although the four-month period June through September is termed as the Indian summer monsoon season in a general large-scale sense, the actual rainy period differs widely over different parts of the subcontinent. Sustained increase in the rainfall and cessation of rainfall activity have been traditionally used to demarcate the beginning (or onset) and end (or withdrawal) of the monsoon circulation. The calendar dates of these seasonal demarcations also have considerable interannual variability, of the order of 1–2 weeks. The onset of the monsoon brings with it a dramatic change in the weather situation, associated with a conspicuous cloud cluster over a large area near the western part of the southern tip of the Indian peninsula. It gradually proceeds northwards and by the middle of July the whole of the Indian subcontinent comes under the grip of monsoon. However, the northward progress of the monsoon is not a smooth affair and takes place in surges, interspersed by periods of weakening or stagnation of monsoon activity. The retreat of the monsoon begins in the western parts of the north-west

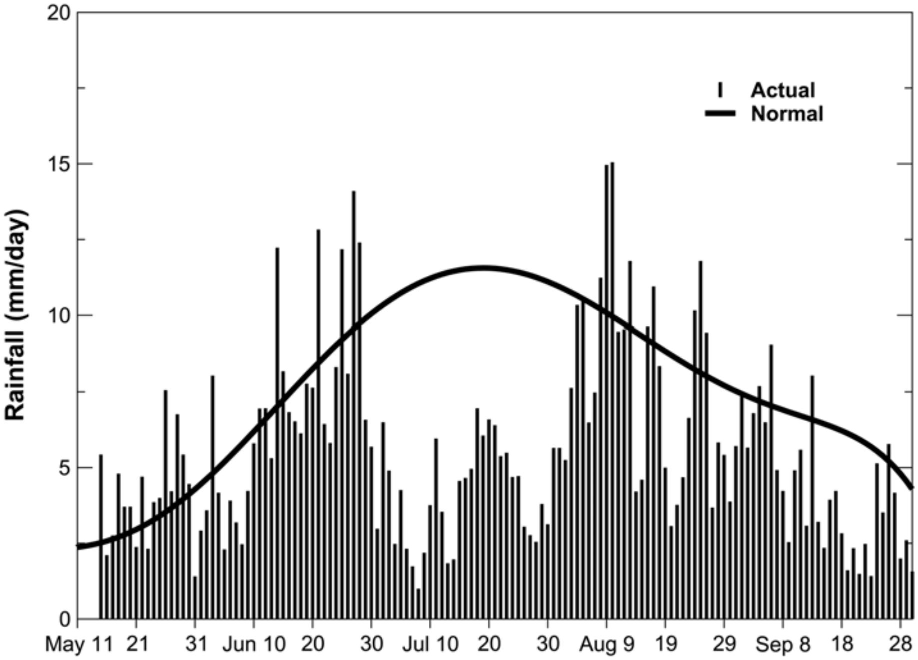


Figure 18.12. Daily variation of all-India summer monsoon rainfall during the recent drought year of 2002.
Source: Monsoon On Line (http://tropmet.res.in/~kolli/mol).

Indian state of Rajasthan in early September. Thus, the effective duration of the south-west monsoon rains over this area is only about $1\frac{1}{2}$ months. The southward retreat of the monsoon rains continues rapidly until about the middle of October, by which time it withdraws completely from the northern half of the Indian peninsula.

Ananthakrishnan and Soman (1988, 1989) have prepared long-term series of onset dates for south and north Kerala. They reported that the mean date of onset for south Kerala is 30 May, with a standard deviation of 8.5 days, while the mean onset date for north Kerala is 1 June, with a standard deviation of 8.4 days. The frequency distribution of the onset dates over south Kerala during the 100-year period 1891–1990 is shown in Figure 18.13(b). The onset of the monsoon over Kerala, although it may appear to be of local character, is generally considered to be a pointer for the advance of the monsoon over the entire Indian subcontinent. The time series of the onset dates of the south-west monsoon suggests considerable interannual variability. During the past century, there had been extremes in the dates of onset of the monsoon over Kerala which were as much as three weeks away from the normal.

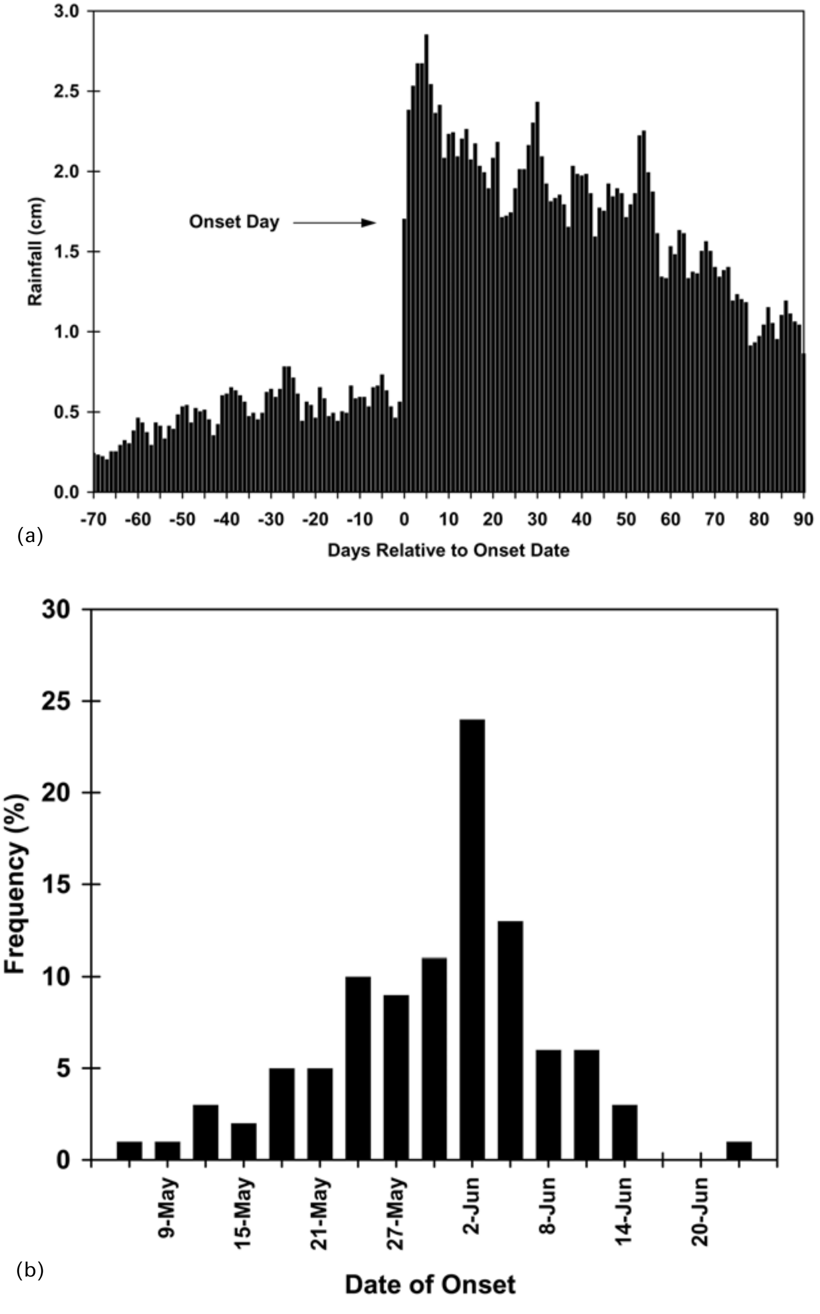


Figure 18.13. (a) Superposed-epoch composites of daily rainfall variation relative to the summer monsoon onset over south Kerala. (b) The frequency distribution of the onset dates of the south-west monsoon over south Kerala in three-day intervals for the period 1891–1990.

18.4 ROLE OF THE MONSOON IN RICE CULTIVATION IN THE STATE OF ANDHRA PRADESH IN INDIA

In India, rice is cultivated in the *Kharif* and *Rabi* seasons. *Kharif* rice is sown in July–August and harvested between October–January. The rice grown during the *Rabi* season is planted in winter (November–December) and is harvested in March–May. The rainfall during the summer monsoon determines to a large extent the availability of water for irrigation during the dry season. Hence, monsoon variability also has an impact on production of *Rabi* rice as the Indian rivers are mostly fed by the monsoon rainfall, with only a partial contribution from snowmelt in the northern regions.

To highlight the critical role of the summer monsoon variability in rice cultivation, we consider here rice production over the smaller spatial scales of the states of India. A large fraction of the area under rice in the state of west Bengal (which contributes by over 15% to the Indian production) is rain-fed, and large anomalies of the summer monsoon rainfall over the region have a large impact on the yield, area, as well as production (Gadgil *et al.*, 1999a). On the other hand, a large fraction of the area under rice in Andhra Pradesh (Figure 18.14) is irrigated. Andhra Pradesh is a surplus rice growing state in India, which produces about 13% of the country's rice output with 9% of total rice area. Rice is the dominant staple food for about 70 million people in the state and a major source of livelihood for nearly 70% of rural households. Rice production and yields have nearly doubled with only a marginal expansion of cropped area since the introduction of modern rice varieties in the late 1960s (Janaiah, 2003). About 95% of the rice area in Andhra Pradesh under modern varieties is irrigated. However, this dramatic increase in rice production due to the use of modern varieties has almost plateaued during the last decade, once again bringing to the fore the weather (and consequently water) related stresses on rice production.

18.4.1 The impact of local and remote anomalies in seasonal rainfall

The interannual variation of the total kharif rice production in Andhra Pradesh and the seasonal rainfall (MJJASO) over three meteorological subdivisions of Andhra Pradesh, namely Coastal Andhra Pradesh, Telangana, and Rayalaseema (Figure 18.14) is shown in Figure 18.15 (color section). Of these, rice production is mainly concentrated over coastal Andhra Pradesh. In order to remove the technological trend from the production time series, a backward differencing filter is used (Stephenson *et al.*, 2001), where the value for each year is expressed as the difference from the previous year. Similar differencing is also applied on the rainfall time series, to make them consistent with each other. All the correlation analyzes presented in this section are based on the difference filtered time series. All the major anomalies in the series closely agree with each other (Figure 18.15), highlighting the spatial coherence of season-scale rainfall anomalies over Andhra Pradesh and also their significant impact on the total rice production in the state. Figure 18.16 (color

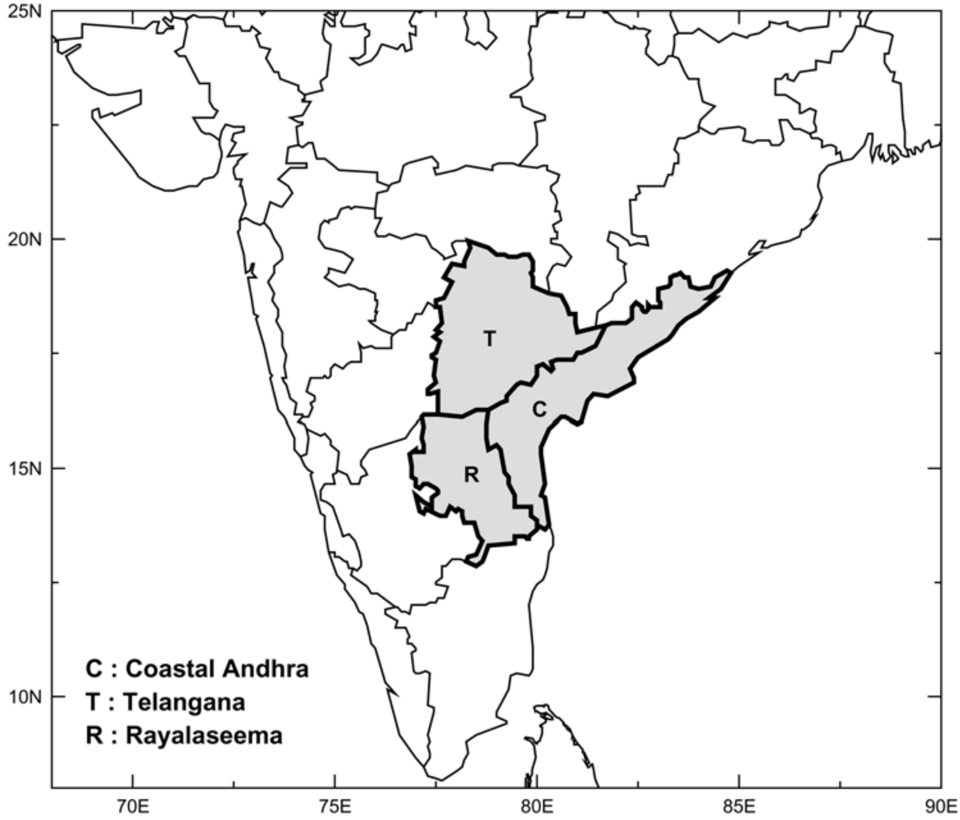


Figure 18.14. Andhra Pradesh state (shaded area) of India and its meteorological subdivisions.

section) presents the correlation between the monthly/seasonal rainfall over the three subdivisions of Andhra Pradesh with different rice production parameters (viz., area, production and yield of the kharif as well as the rabi crop). While almost all the rice parameters show significant correlation with the seasonal total rainfall, there are interesting differences on the monthly scale. The rainfall in the months of June, July, and August over both coastal Andhra Pradesh and Telangana is significantly correlated with the area as well as production of kharif rice, but not rabi rice. Rainfall in July and August over Rayalaseema significantly influences the kharif production in the state. Rainfall in the month of September appears to be more crucial for the rabi crop. Thus, the monsoon rainfall has a complementary influence on the kharif and rabi crops. In general, it can be seen that the correlations are the highest in the case of area and production of rice. However, the variations in yield per unit area do not seem to be sensitive to rainfall variability. This is possibly because unviable cropping situations due to rainfall anomalies are abandoned. As already noted, the water required for rice cultivation also depends on the monsoon rainfall in catchment areas upstream in the western parts of the peninsula. Keeping this in view, we have examined the spatial patterns of correlations between the seasonal total rainfall and different rice parameters (Figure 18.17). For the kharif as well as rabi rice crops in Andhra Pradesh, the monsoon rainfall within the state as well as that over western Maharashtra and Karnataka is critical. As already seen, the rainfall has a limited impact on the yields. However, within the season, the kharif rice crop seems to be more dependent on local rainfall during the early part of the growing season, while in September the rainfall over the western peninsula is more favorable (Figure 18.18(a)). Interestingly, for the rabi crop, September rainfall over a large part of the peninsula stands out as the most important parameter affecting production (Figure 18.18(b)).

18.4.2 Impact of the timing of the onset of the monsoon

Rice cultivation involves transplantation of seedlings about one month after sowing. The seedlings are initially grown in nursery beds during the later part of the pre-monsoon season, with water from bore wells or by other methods of lifting water from the substantially reduced water available in the local canals/lakes. These nurseries are planned in such a way that the seedlings will be of transplantable age by the time the onset spells of the monsoon commence. Thus, even this operation is closely tied with the normal onset of the monsoon over the respective areas, which is typically in the later half of June. The transplantation activity is taken up during the onset phase, so that the cloudy and moist conditions help the young seedlings to establish. If the onset is delayed, transplantation cannot be taken up even if water for irrigation is available, as the high temperatures and intense solar radiation causes the seedlings to wilt. Consequently, the seedlings in nursery beds grow beyond the optimal age for transplantation, making the nursery beds unviable. Some farmers raise nursery beds with staggered dates to account for possible anomalies in the onset date, but such practices cannot be taken up on a large scale. Further, it is also essential that the rice fields have enough water available in the rivers for irrigation in the transplantation phase. Most of the rivers in Andhra Pradesh are dried up during the pre-monsoon season, and the release of water from the hydrological reservoirs initially helps to provide water at the time of transplantation. However, a weak onset spell in the upstream areas causes delays in the release of water, either delaying the transplantation or sometimes even causing a total abandonment of the activity. Thus, the onset phase not only over the state, but also over the western parts of the peninsula where the rivers fed by the summer monsoon originate, has a crucial impact on the initial phase of rice cultivation. For example, due to the late onset of the monsoon in 2003 which followed a severe drought in 2002, there was a substantial delay in the release of water for irrigation leading to large-scale abandonment of transplantation in the main rice-growing

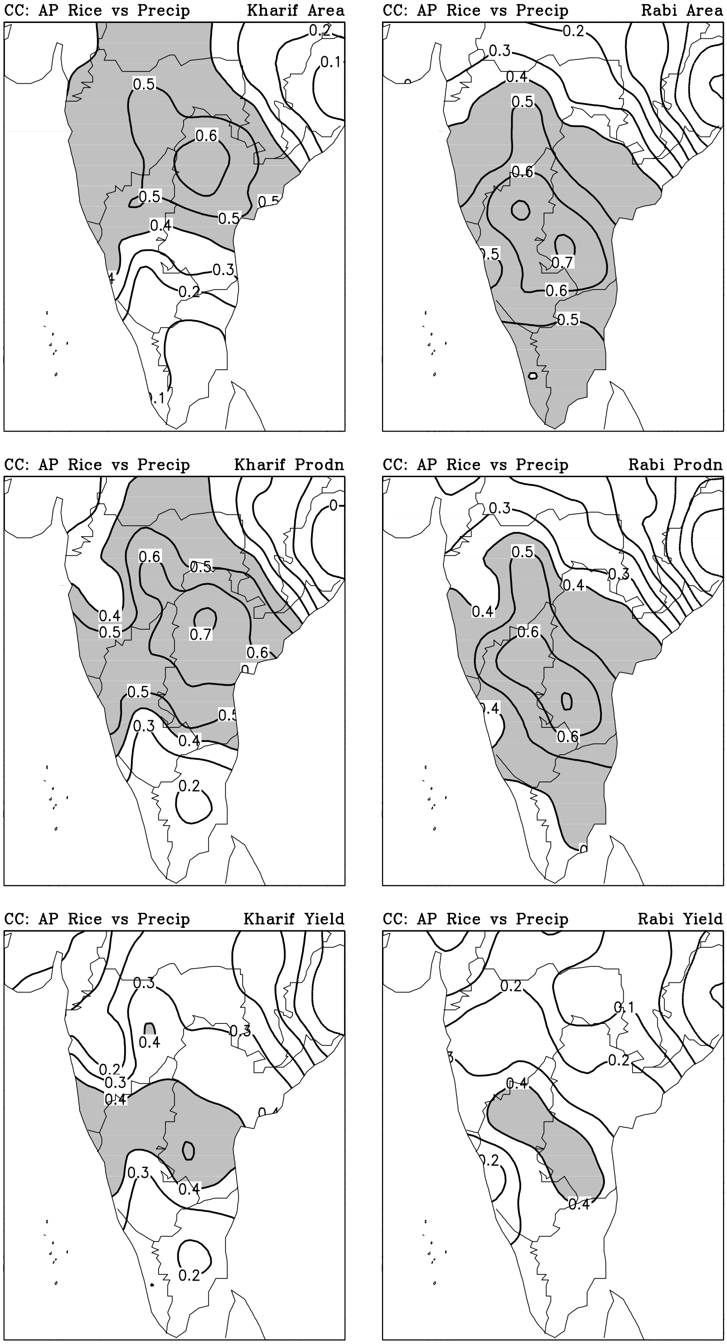
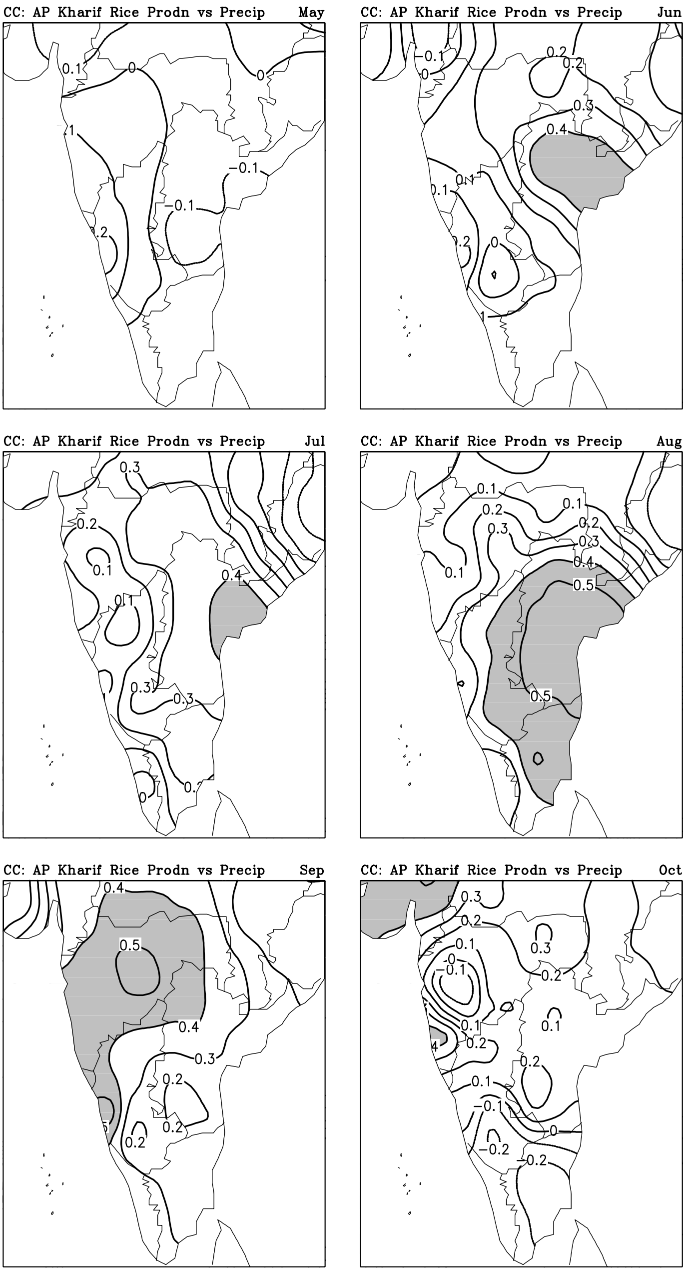
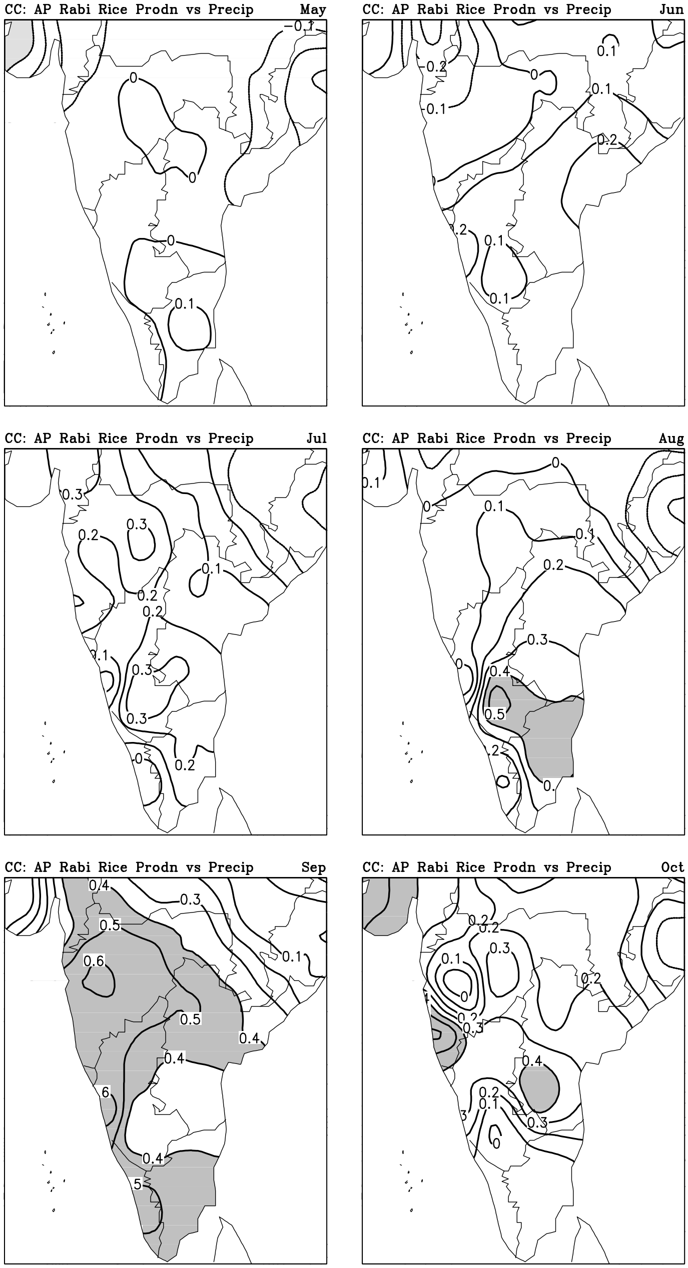


Figure 18.17. Spatial patterns of correlation between various rice production parameters over Andhra Pradesh and seasonal (MJJASO) rainfall over the peninsular of India.



(a)

Figure 18.18. (a) Spatial patterns of correlation between kharif rice production in Andhra Pradesh and monthly rainfall during the monsoon season over the Indian peninsula. (b) Same as (a) but for rabi rice.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(b)

districts of Andhra Pradesh. Thus, monsoon variability has a significant influence on the area under the rice crop as well as production. Once the transplanted rice crop is established and enters a vegetative growth phase, the crop can withstand dry spells within the monsoon season. However, irrigation is still essential as the crop is grown under inundated conditions. Indeed, a few dry spells with bright sunshine may even help the crop to grow better and ward off pests and diseases which thrive under cloudy and humid conditions. Thus, intraseasonal variability may not be so crucial for irrigated crops, provided there is enough storage of water.

18.5 IMPACT OF THE MONSOON ON THE GROSS DOMESTIC PRODUCT – THE INDIAN CASE

It is well known that monsoon variability has a large impact on agricultural production in India. Since in the first half of the twentieth century, the contribution of the agricultural sector to the gross domestic product (GDP) was over 50%, the impact of monsoon variability on the economy was substantial. After freedom from colonial rule in 1947, there has been a rapid growth of other sectors and the share of the agricultural sector of the GDP has declined to about 22% (in 2000). However, the agricultural sector continues to be very important, since the livelihood of 70% of the working population is linked to agricultural activities and hence the Indian economy. Here we present an assessment of the impact of the monsoon on the agricultural component of the Indian GDP as well as the total Indian GDP (Gadgil and Gadgil, 2004).

The agricultural component of the GDP (GDP agriculture) has grown at an increasing rate with time (Figure 18.19). The rate of decrease in the contribution of the agricultural sector to GDP was rapid in the two decades following independence; smaller from the mid-1960s because of the Green Revolution but picked up again since 1980 with the commencement of liberalization of the economy (Figure 18.20). The Indian GDP has grown exponentially in the last five decades at a rate of about 3.8% before 1980 and 5.1% thereafter (Figure 18.21). We expect part of the fluctuations around the smoothly varying components of GDP agriculture and GDP (Figures 18.19 and 18.21) on the interannual scale to arise from the fluctuations in the monsoon.

The variation of the departure from the smoothly varying component (normalized by the actual value) with the anomalies of the ISMR is shown in Figure 18.22. It is seen that, for all the years characterized by the ISMR deficit of more than 10% (i.e., droughts), there is a negative departure of the GDP as well as GDP agriculture. Furthermore, for years with a deficit in the ISMR of over 5%, the magnitude of the dips in GDP agriculture and GDP increases with the magnitude of the ISMR anomalies, suggesting that deficits of ISMR have a large impact on the GDP

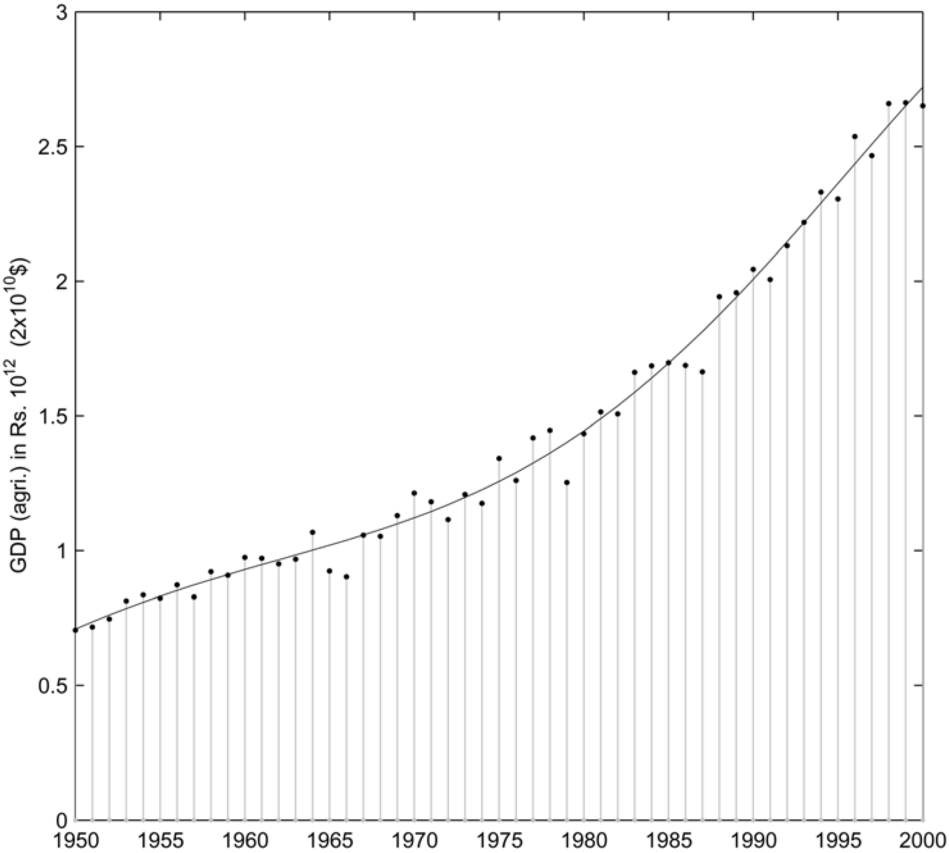

Figure 18.19. Variation of the agricultural component of the Indian GDP (observed and fitted).

agriculture as well as GDP. All the years for which rainfall is very good (the ISMR is in an excess by well over 10%) are characterized by positive departures of GDP agriculture as well as GDP. However, the magnitude of these departures does not appear to depend on the magnitude on the ISMR anomalies. When the monsoon rainfall is not as high, but still well above average (ISMR anomaly being positive between 5 and 10%), the values of the departure of the GDP and GDP agriculture are highly scattered. All but one such year are characterized by positive departures of GDP agriculture. However, the impact of above average monsoon rainfall on GDP agriculture does not seem to be commensurate with the magnitude of the rainfall anomaly; rather it seems to follow a law of diminishing returns. The relationship of

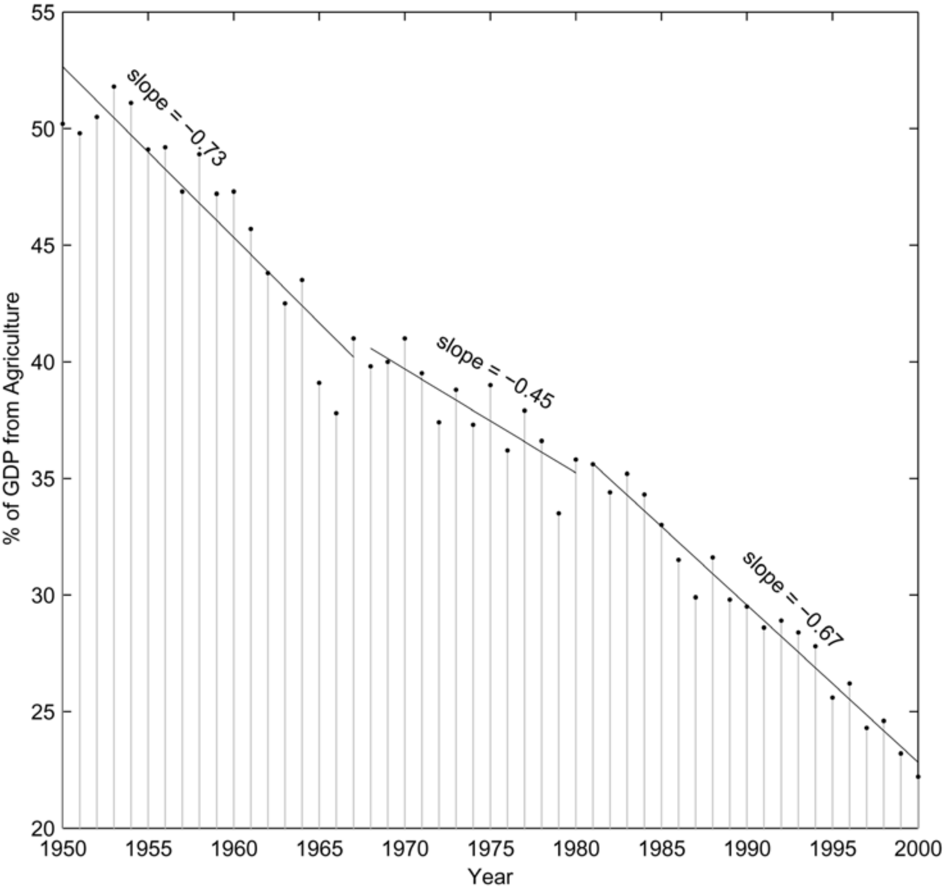

Figure 18.20. Variation of the percentage contribution of agriculture to the Indian GDP.

departures of GDP to positive rainfall anomalies in this range (5 to 10%) is more complex with more than half the years being characterized by negative departures.

Thus, for both GDP agriculture and GDP, there appears to be a large adverse impact of deficit monsoon rainfall, which increases with an increase in the magnitude of the deficit. However, when the rainfall is above average, the magnitudes of the GDP-agriculture as well as GDP departures are weakly related to that of the rainfall anomaly and the GDP-agriculture/GDP anomalies for such years are positive only for positive rainfall anomalies over 10 percent. Clearly, it has not been possible to reap as much benefit from good rainfall years in terms of enhanced agricultural production as the loss incurred in production in poor rainfall years.

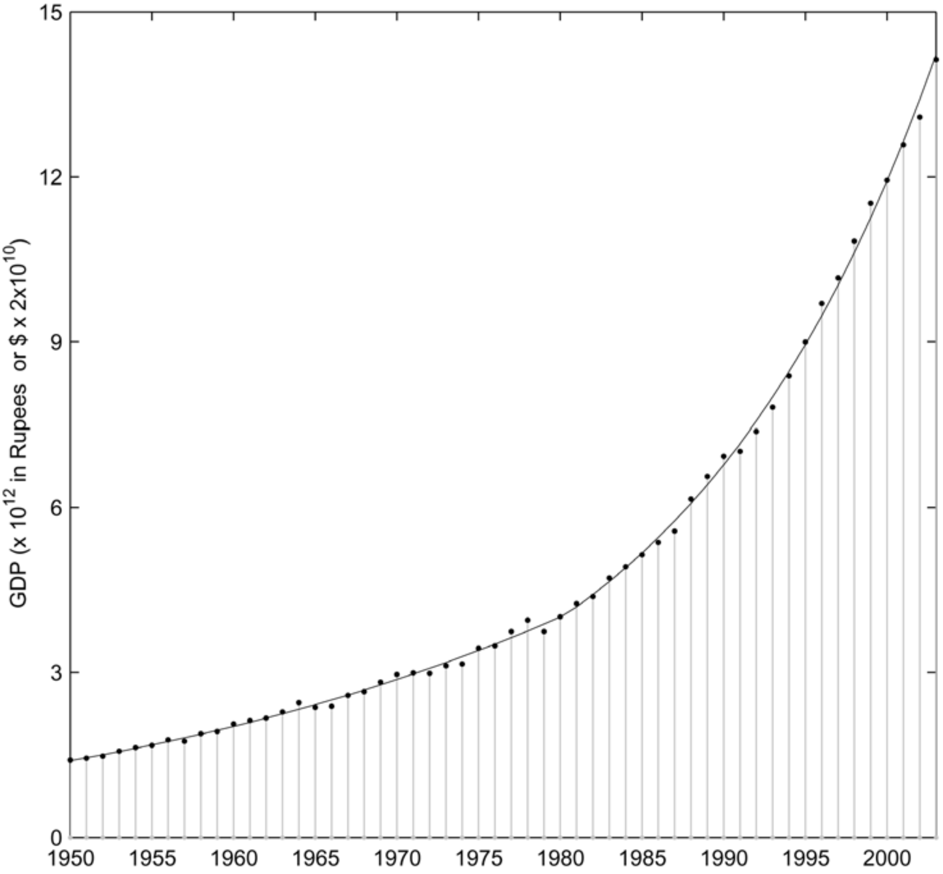

Figure 18.21. Variation of the Indian GDP (observed and fitted).

18.6 DISCUSSION ON THE USE OF METEOROLOGICAL INFORMATION AND PREDICTIONS FOR ENHANCEMENT OF AGRICULTURAL PRODUCTION IN A VARIABLE CLIMATE

We have seen that various facets of rainfall variability such as the interannual variation of the seasonal rainfall can have an impact on agricultural production and the economy. Such analyses can help in quantitative assessments of the impacts. In addition, we also need to derive the implications of the prediction of an event such as El Niño for the rainfall anomalies and hence the anomalies in agricultural production of the different regions, to provide advance information to enable mitigatory strategies. Also, if the aim is to use meteorological information or

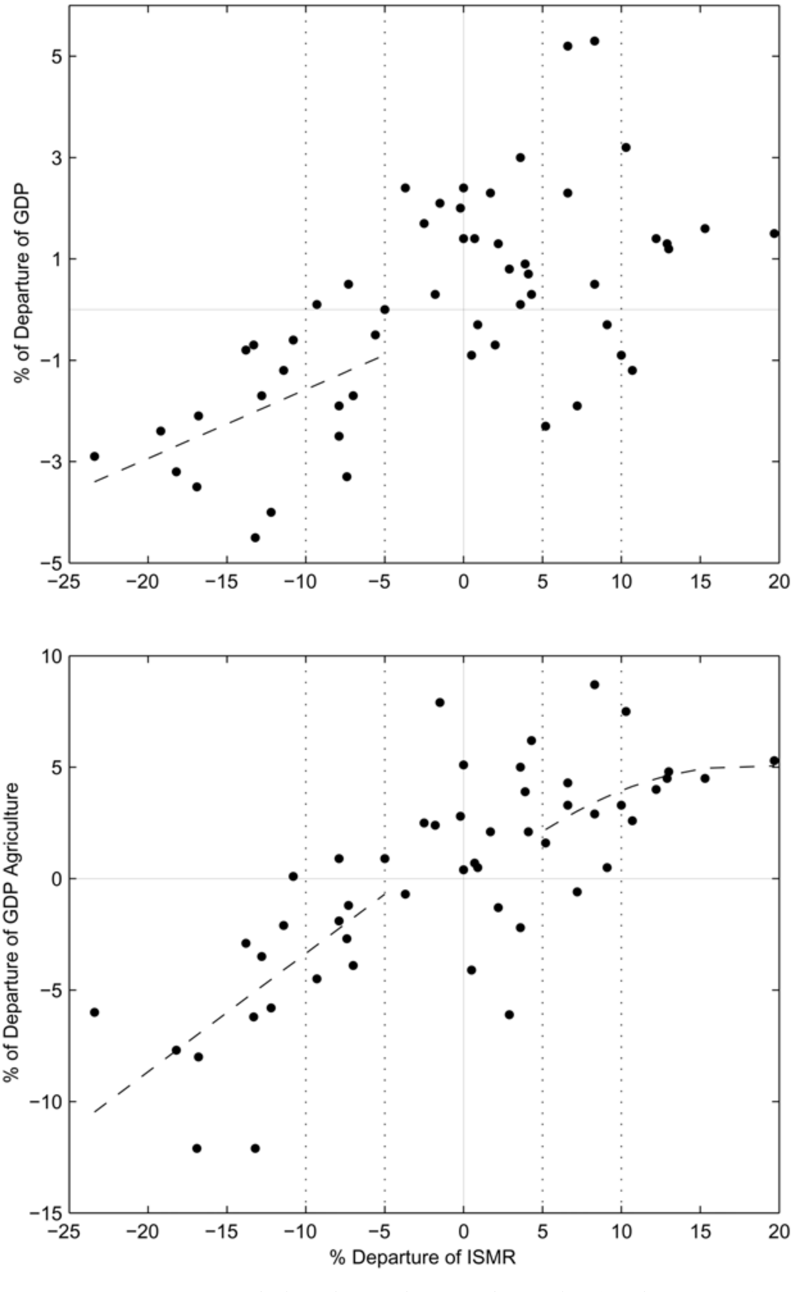

Figure 18.22. (*top*) Departure of the observed GDP from the fitted GDP (Figure 18.21) normalized by the fitted GDP vs. the ISMR anomalies normalized by the average ISMR for each year. (*bottom*) Departure of the observed GDP–agriculture from the fitted GDP–agriculture (Figure 18.21) normalized by the fitted GDP–agriculture vs. the ISMR anomalies normalized by the average ISMR for each year.

predictions for the enhancement of agricultural productivity, it is necessary to generate predictions that can directly impact farm level decisions.

18.6.1 Use of ENSO predictions

We have seen that the area under rice cultivation in Indonesia is highly correlated with the May–October rainfall which in turn depends on ENSO. However, the impact of different El Niños on crop yields of the region appear to differ considerably, as shown for the Australian wheat yield by Potgieter *et al.* (2004). The rainfall anomaly patterns for June–September for the two recent El Niño events of 1997 and 2002 are shown in Figure 18.23 (color section). The marked difference between the two seasons suggests that it may be important to predict/assess the phase of EQUINOO as well as ENSO for assessing the impact on rainfall and hence crop yields for the Asian region.

18.6.2 The Indian case

We have seen that the agricultural production of the country as a whole does not increase with ISMR when the rainfall is well above average. Some insight into the quantum of enhancement of agricultural production achieved in the years with good rainfall *vis-á-vis* that achievable with the current level of agricultural science and technology, is provided by Sivakumar *et al.* (1983), who compared the yields of several rainfed crops on the farmers' fields with the yields at 15 dry-land stations over semiarid parts of India (Figure 18.24). The major difference in the farming practices at the agricultural stations relative to those on the farmers' fields is in the application of fertilizers and pesticides. It is seen that the yield at the agricultural stations increases more rapidly with rainfall in the growing season. This is probably because when rainfall is not a limiting factor, the yields are limited by the degree to which the nutritional requirements are met. The yield gap (i.e., the difference between these yields) increases with good rainfall years because the farmers do not make the necessary additional investments in fertilizers and pesticides on their rain-fed land. It is clear that this is not because of a lack of know-how, since the farmers do make these additional investments for irrigated patches with assured yields. This is because the cost–benefit ratio for such applications is favorable only in the years in which the level of rainfall and yields are reasonably good. If meteorologists could provide reliable forecasts of seasonal rainfall on the scale of agroclimatic zones, it would be possible to influence these farm-level decisions and enhance production within the years with good rainfall.

We consider the relationship of the variation of crop performance with the variation of rainfall in the growing season for two cases: (i) rice in Andhra Pradesh and (ii) rain-fed peanut for the Anantapur district of the Rayalaseema subdivision of Andhra Pradesh. The variation of rice production with the variation of rainfall during May–October for the three subdivisions of Andhra Pradesh is shown in Figure 18.25. It is seen that when the rainfall is very much below average (a deficit of over 250 mm) the production also tends to be below

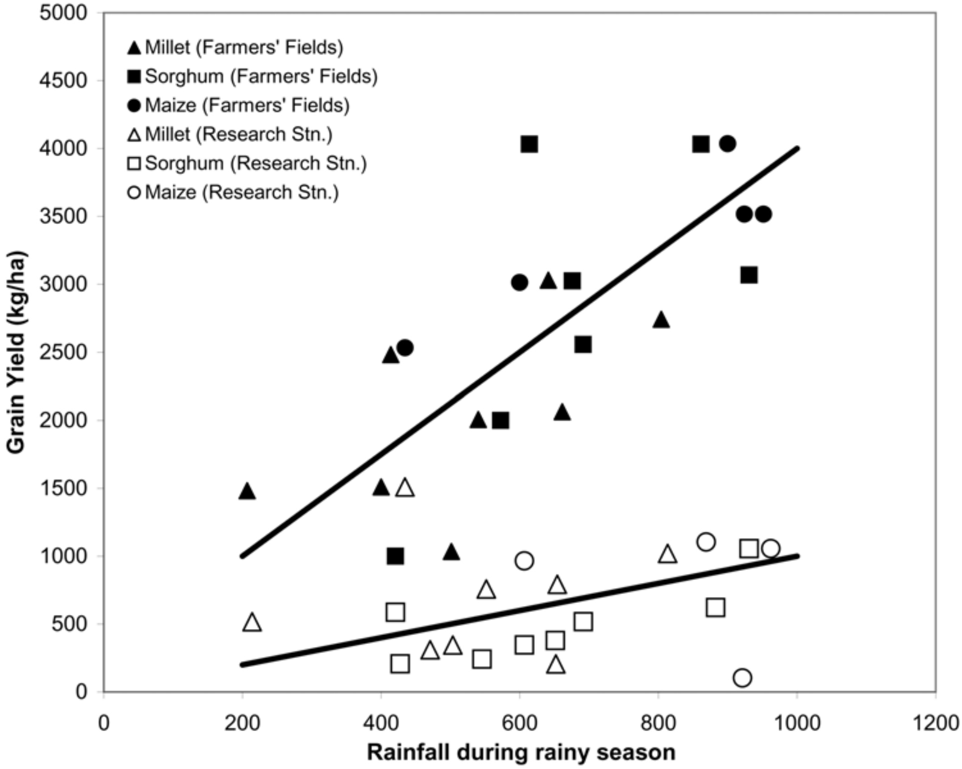

Figure 18.24. Relationship between rainfall during the rainy season and yield of maize, sorghum, and millet at 15 dryland locations in India.
After Sivakumar *et al.* (1983).

average; whereas when the rainfall is well above the average (an anomaly over 250 mm), the anomaly in production is almost always positive. Between these two limits there is a large spread. The variation during 1911–2000 of the peanut yield simulated by the PNUTGRO model (Boote *et al.*, 1987), which has been validated for the region (Singh *et al.*, 1994) and that of the observed district yield during 1975–2000, with rainfall during July–December at Anantapur station is shown in Figure 18.26. It is seen from Figure 18.26 that for every year in which the seasonal rainfall is above the threshold of 50 cm at Anantapur the model yield is above 700 kg per hectare. However, when the rainfall is less than 30 cm the chance of yield above this level is small. These two examples suggest that prediction of seasonal rainfall relative to the relevant thresholds for specific cropping systems would be of considerable use in farm-level decisions regarding application of fertilizers, pesticides, etc.

The impact of intraseasonal variation (i.e., the occurrence of dry spells on the crop yields) can also be high when they occur at critical stages of the crop (Rao *et al.*, 1999; Gadgil, 2003). This is illustrated in Figure 18.27 in which the daily rainfall at

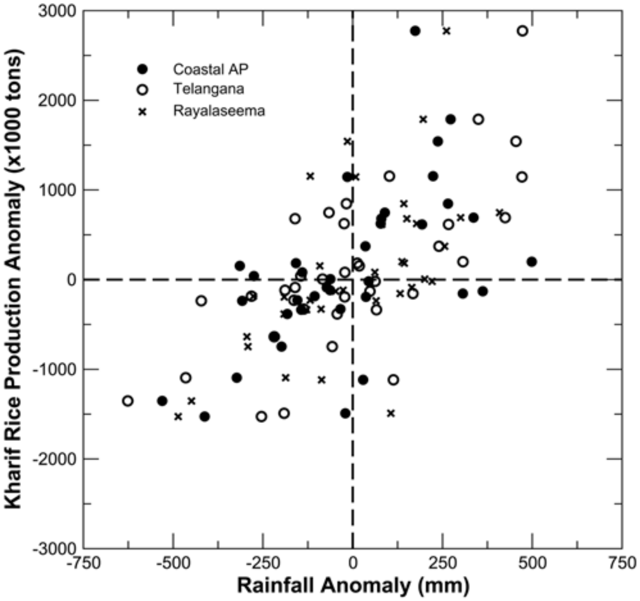

Figure 18.25. Variation of rice production anomalies with the variation of rainfall anomalies during May–October for the three subdivisions of Andhra Pradesh.

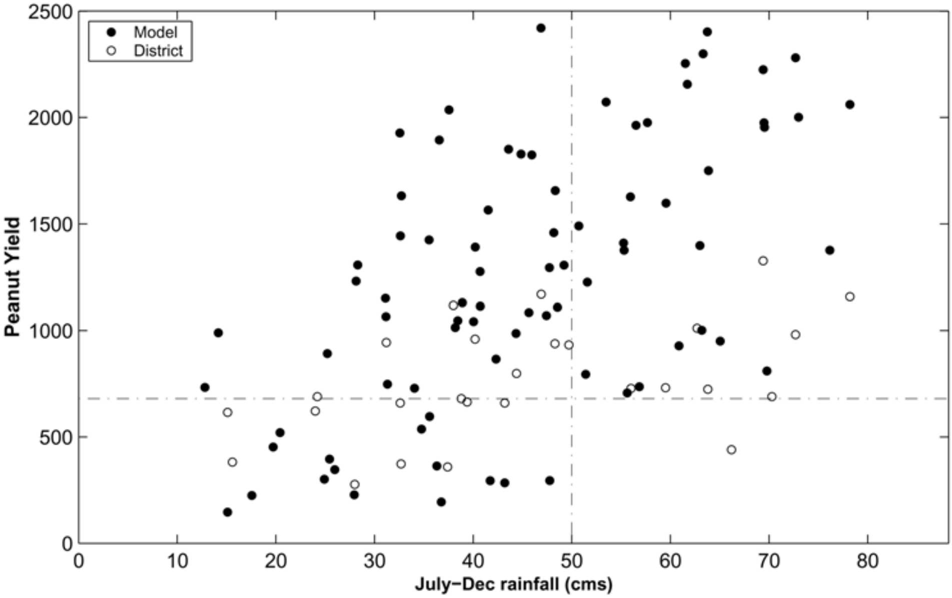

Figure 18.26. Simulated (PNUTGRO, 1911–2000; solid circles) and observed (1975–1998; open circles) peanut yield vs. July–December rainfall for the Anantapur district of Andhra Pradesh.

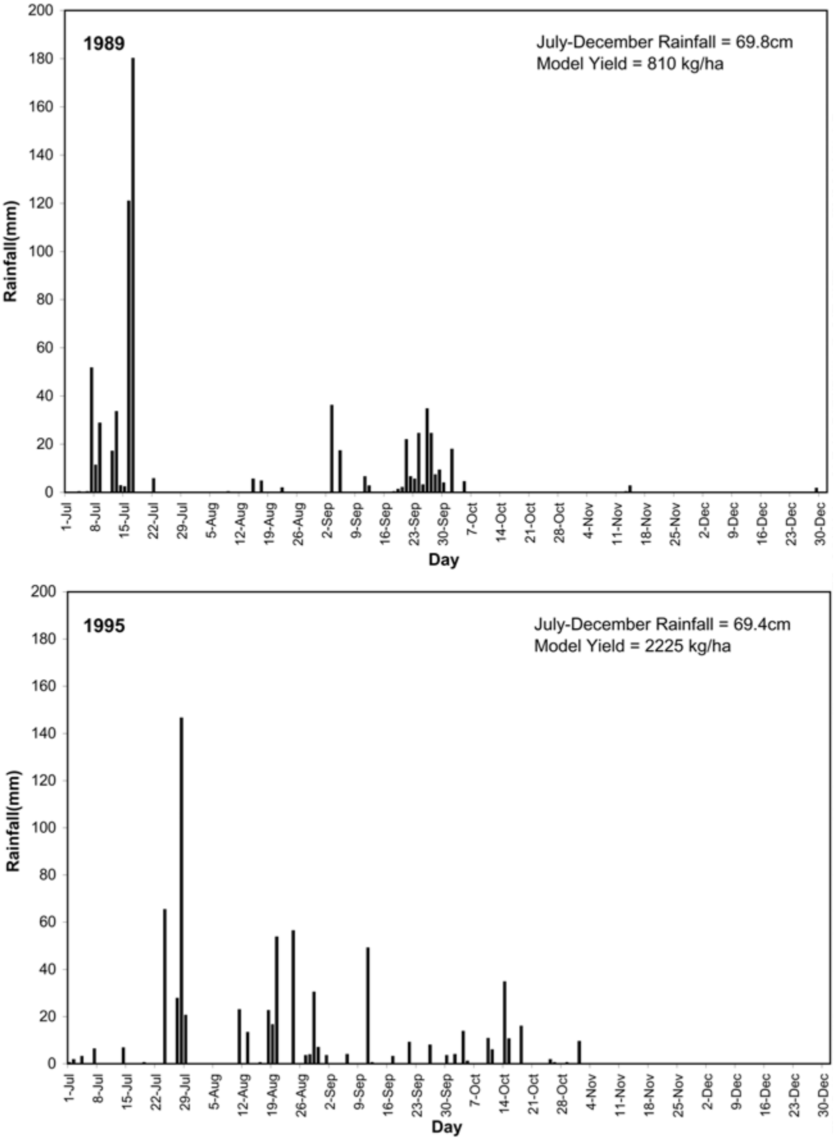

Figure 18.27. Daily rainfall at Anantapur during July to December in 1989 and 1995. Note that although the seasonal total rainfall is almost the same, the simulated yields are very different.

Anantapur for July–December 1989 and 1995 is shown. Although the total rainfall in the season is almost identical, the simulated yield for the latter year is more than twice that in the former year, which had a long dry spell in July–August. It appears unlikely that the detailed distribution of the rainfall in a season (i.e., the occurrence of such spells), can be predicted in the beginning of the season. However, available information on climate variability can be used to choose the planting dates which imply a low probability of occurrence of such dry spells in the critical stages of the plant (Gadgil *et al.*, 2003).

A judicial use of information and prediction of important events should help in reducing adverse impacts and lead to better strategies of exploiting favorable conditions for enhancement of agricultural production.

18.7 ACKNOWLEDGEMENTS

The authors are grateful to Dr. G. B. Pant, Director, Indian Institute of Tropical Meteorology, for his keen interest in this field and the encouragement of this collaborative work. Much of the basic meteorological data used in the study has been provided by the India Meteorological Department. The authors are also thankful to Dr. Mark New for supplying the CRU gridded precipitation data and to IRRI for the data on rice crops. The authors have greatly benefited from many interesting discussions with Dr. K. Krishna Kumar of IITM. The authors place on record their deep appreciation of the excellent editorial review support provided by Dr. Bin Wang and the anonymous reviewers.