The Effect of Irrigation on Premonsoon Season Precipitation over South West Bengal, India

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ABSTRACT

The present work is on the modification of climatic variables, such as rainfall, as a result of change in land use during the premonsoon period over the southern part of West Bengal, India. Data analysis supports a decreasing tendency in rainfall during the recent years. As a possible factor behind such change, a significant increase in agricultural activity during recent years in coastal and inland regions has been stressed. The increase in soil moisture as a result of irrigation hinders the development and intensity of the sea-breeze circulation. The low-level moisture supply also decreases, which is an essential criterion for the formation of premonsoon thunderstorms, that is, northwesters. So, the increased vegetation or soil moisture is not always likely to increase rainfall activity; rather, mesoscale effects may be more important in some specific areas.

1. Introduction

Inadvertent modification of weather and climate through changes in land use has become a point of great concern among the environmental scientists throughout the world. Changes in weather and climate as a result of irrigation due to increasing agricultural activity have been studied by many researchers. Excess rainfall (Schickendanz 1976) and an increase in thunderstorm frequency (Changnon 1973) due to increased irrigated area have already been established. In a detailed study by Barnston and Schickedanz (1984), it has been shown that irrigation might be affecting the rainfall, mostly in the early part of the summer. Large-scale and mesoscale effects have also been stressed in their study.

There has been increasing attention in recent years among the people over some part of the state of West Bengal in India regarding water crises during premonsoon periods. The monsoon season sets in early June every year over the region, and rainfall activity continues until the month of September. There is very little rainfall afterward during the winter season. However, the region experiences premonsoon thunderstorms, which provide significant rainfall. For a long gap of eight months, that is, from October to May, premonsoon thunderstorms are the main source of rainfall activity over the region. Though there are many factors behind the water crisis, there is an essential need to analyze the basic input (i.e., the rainfall activity) to see whether it decreases during the premonsoon period.

Work has been carried out on the analysis of rainfall over south West Bengal for a period of 20 years at a station, Kharagpur (22.2°N, 87.3°E). An attempt has been made to find out the possible factor(s) behind any change in rainfall amount; to support this study 2D model simulations have been performed.

2. Large-scale situation

During the winter season, the large-scale flow is northerly at lower levels and westerly aloft. Northern India is frequently affected by the passage of extratropical disturbances (ETD) followed by surface lows. As a result, rainfall occurs rarely and the amount is almost insignificant. However, during the premonsoon season, that is, the transition period from winter to monsoon circulation over India, the large-scale flow becomes southerly at lower levels, while at the upper levels westerly flow remains. So the flow pattern in the premonsoon period over northern India is particularly interesting. The middle and upper troposphere is characterized by strong westerlies accompanied by a westerly jet. At lower levels there exists intense solar heating over the subcontinent. These features are associated with the large-scale circulation: ascent over the Indian landmass and decent over the surrounding seas. The general ascent over India is accompanied by a shallow inflow of moist air from the sea and the Bay of Bengal all along the eastern coast.

3. Mesoscale features

During the premonsoon period significant rainfall occurs over the region as a result of mesoscale phe-

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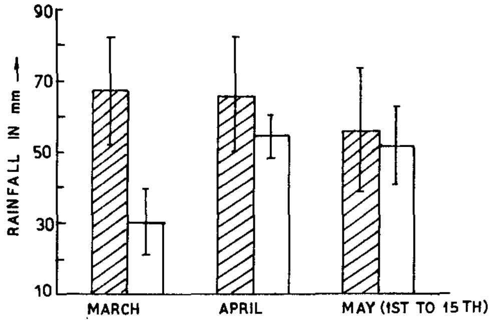

FIG. 1. Mean monthly rainfall at Kharagpur for the periods 1973–82 (hatched) and 1983–92 (open) together with their standard errors (±σ bars).

nomena, that is, thunderstorm activity. There are mainly two types of thunderstorms: (i) deep convection resulting from the dryline, which forms where the moist low-level southerlies meet arid westerlies causing severe thunderstorms (Weston 1972) and (ii) convection initiated at the sea-breeze (SB) front, causing thunderstorms (Lohar 1993). The former is known locally as "Norwesters" as they appear to come from a northwesterly direction; the latter is well known as SB-generated thunderstorms as occur in many other places. Observational study (A. Patra, personal communication) shows that the Kharagpur station registers about 38.5% of the thunder squalls from the south, which may be due to SB, and 56% from the northwest direction, which are due to norwesters. The remaining 5.5% are from other directions. Apart from the thunderstorm activity, cyclonic activity is rare, occurring only eight times in the past 20 years. However, most of them occur in the second half of the month of May.

4. Data analysis

Analysis of rainfall data for a period of 20 years (1973–92) at Kharagpur has been made, considering the years 1973–82 as the first phase and the next 10 years (1983–92) as the second. It may be mentioned that the heavy rainfall due to cyclonic storms has been removed from the present analysis. It is seen that in the month of March, rainfall becomes just half of that in the second phase (Fig. 1). The decreasing tendency has also been noticed for the months of April and 1–15 May, though it becomes gradually less toward May. Standard errors of the mean monthly rainfall have been calculated in order to check the statistical significance of the result and they are plotted over the mean (Fig. 1). It is seen that the result is quite significant in March and to some extent in April.

A possible explanation among the various possibilities, regarding such climatic change may be given in terms of the change in land use due to increasing agricultural activity over the region. As a result of such activity, soil moisture content over the region increases, which in turn decreases the intensity of the SB circulation. Agricultural activity for the summer paddy crops is going on mostly over the southeastern part of the area of interest (Fig. 2) where soil remains wet for more than 6 months in a year. Total land covered by summer crops has been shown (Fig. 3) for the past 20 years over the southeastern sector of the area of interest. Records show that significant agricultural activity of summer paddy crops started in the 1970s. Due to the growing need for food grains, the activity increases year to year. On average, in recent years it has become more than double compared with what it was in the 1970s. Presently, agricultural activity covers nearly 20% of the total geographical area. Cultivation starts mostly in late De-

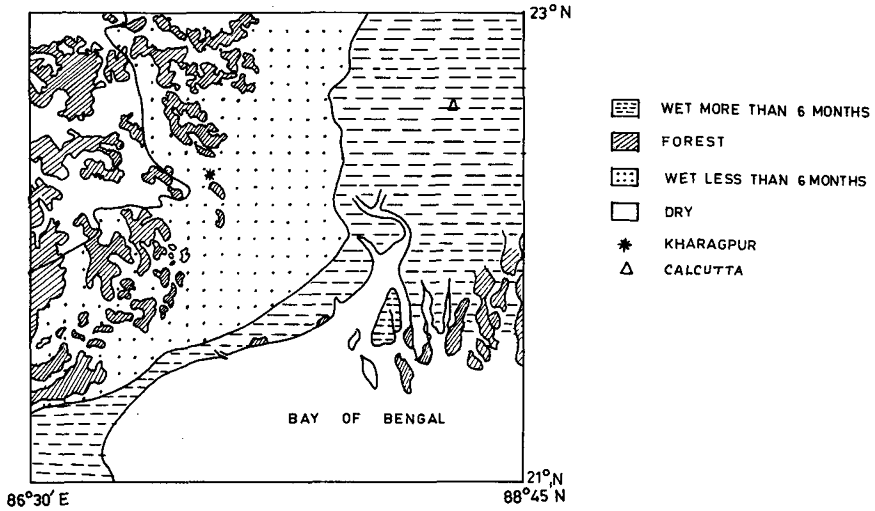

FIG. 2. Geographical location of the area of interest.

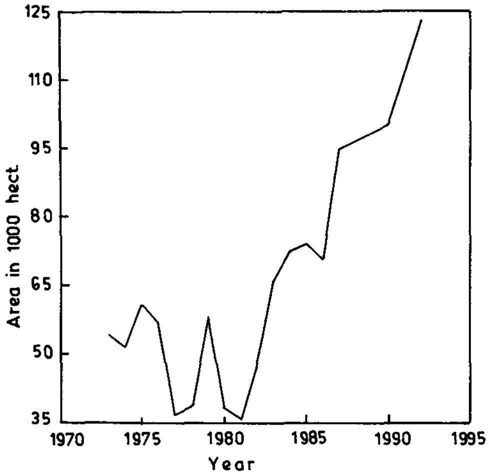

FIG. 3. Total area covered by summer paddy crops over the southeastern sector of the domain.

cember or early January, and harvesting takes place mostly in late March or early April. Incidentally, it may be mentioned here that normal crops are grown during the summer monsoon season and harvested just before winter. Thus, two cycles of crops are harvested per year in this region. So, the impact of the irrigation required for summer paddy crops is likely to be more pronounced in the month of March as compared with April and May. An indirect validation of the premonsoon precipitation through model simulations has been performed in the next section.

5. Model simulations

Mathematical models are the tools by which evaluation of the specific impact of the changes of surface forcing on climate can be made, though these are only approximations of the real world conditions. However, model results may be helpful to validate trends. A modeling system, which has been validated for a wide range of thermally forced atmospheric systems, has been used for the present purpose. The details of the model equations, solution techniques, and parameterizations, namely, boundary layer, radiation, soil and vegetation, are described elsewhere (Pielke 1974; McCumber and Pielke 1981; etc.).

TABLE 1. Input parameters used in the model simulations.

Surface pressure	1006.3 mb
Surface specific humidity	0.0180 g g^{-1}
Mean latitude	22.5°N
Surface synoptic wind	calm
Sea surface temperature	299 K
Roughness length over land	4 cm
von Kármán constant	0.35
Initial depth of the PBL	310 m
Time step	60 sec
Initial $\frac{\delta\theta}{\delta Z}$	4 K/km

TABLE 2. Soil parameters used in the model simulations.

Soil type	Sandy loam
Soil porosity	0.410 cm cm^{-3}
Saturation moisture potential	−9.0 cm
Saturation hydraulic conductivity	0.01563 cm s^{-1}
Dry volumetric heat capacity	0.336 J cm^{-3} $°C^{-1}$
Permanent wilting moisture content	0.075 cm cm^{-3}

The idealized potential temperature and specific humidity profiles used to initialize the model are based on morning radiosondes taken at Calcutta (the only radiosonde station for the region). Various other parameters (Table 1) and soil characteristics (Table 2) have been collected so as to represent the situation over the area of interest. Two-dimensional simulations have been performed on a 45 × 16 grid with a constant horizontal grid spacing of 9 km, while the vertical grid spacing is variable with high resolution near the ground. The model top has been fixed at a height of 6 km.

Simulations have been carried out with uniform soil wetness over the land surface (case I) and with a sharp horizontal gradient in soil moisture content (case II) in order to study the effect of nonhomogeneity in soil moisture content on the SB circulation.

Case I: This is a dry SB simulation where the land surface is considered to be bare with constant soil wetness (0.07). The simulation has been performed to compare with the results from the case II simulation.

As time progresses, the land surface heats up more rapidly than the sea surface and as a result, a closed solenoidal circulation develops at the discontinuity. At about 1600 h IST (Indian Standard Time), the SB penetrates to 50 km inland with a depth of the circulation about 2 km (Fig. 4). At this time,

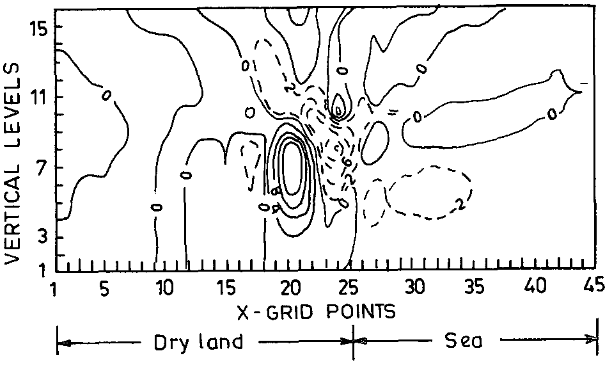

FIG. 4. Vertical cross section of the vertical velocity for case I simulation at about 1600 h IST.

maximum vertical velocity is seen to be about 19 cm s^{-1}.

Case II: In this case, the first 15 grid points are considered to be dry (with soil wetness 0.07), and the next 10 grid points are considered to be relatively wet (with soil wetness 0.30). A weak SB circulation develops at about 1200 h IST. However, the inland breeze (IB) circulation, as a result of sharp horizontal gradient in soil moisture content, becomes more prominent at that time (Fig. 5). Since the land adjacent to the sea is wet, the temperature gradient between the land and the sea is not enough to produce a strong SB circulation. Later on, at about 1600 h, the IB circulation becomes the only circulation where the maximum vertical velocity is seen to be only 14 cm s^{-1} (Fig. 6).

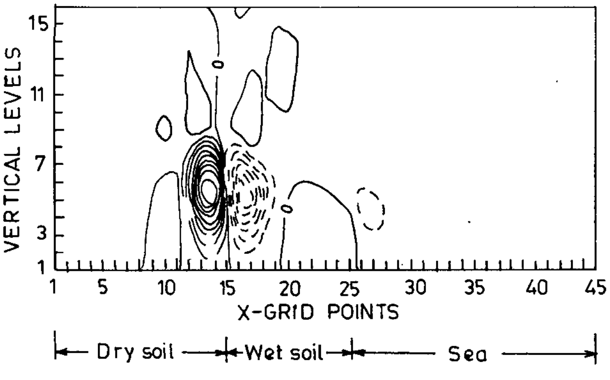

FIG. 5. Same as in Fig. 4 except for case II simulation at about 1200 h IST.

6. Discussions and conclusions

Vegetation (summer paddy crops) needing adequate irrigation increases the soil moisture. It also increases atmospheric moisture content through increased evapotranspiration, which enhances convective activity as noted by several researchers. However, over south West Bengal, large-scale or mesoscale effects may be more important. The southerly flow (from the Bay of Bengal) as a result of large-scale circulations is enhanced by the SB activity. The decreased intensity of the SB activity due to irrigated area near the sea reduces the supply of low-level moisture as is indicated in the case II simulation. This has a twofold effect. First, the inland moisture supply, which is an essential criterion for the formation of thunderstorm activity, decreases. Second, the low-level SB convergence also decreases. The result is, therefore, less possibility for the formation of different types of thunderstorms. Thus, the overall decrease in thunderstorm frequency may lead to less rainfall over the region during the premonsoon period. So, an irrigated area does not always enhance the rainfall amount everywhere, especially when mesoscale effects are more important. The two-dimensional simulations presented here do not provide the sufficient support for the effect observed, and a detailed study with more realistic three-dimensional simulations is required to establish the fact firmly.

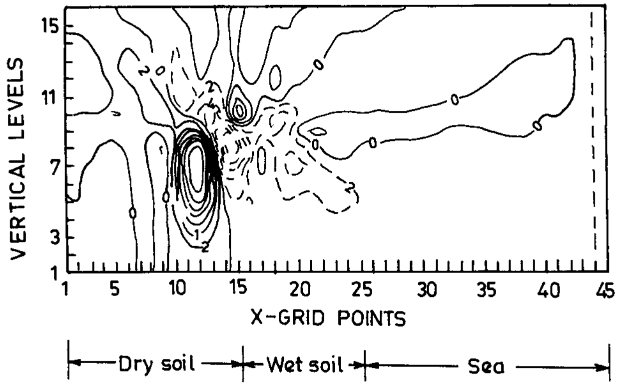

FIG. 6. Same as in Fig. 5 except at 1600 h IST.

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