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Sensitivity studies on the air flow characteristics in Kharagpur using a meso-scale model

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सार–दक्षिण-पश्चिमी बंगाल, विशेषकर स्थल केन्द्र खड़गपुर (22° 21′ उ०, 87° 19′ पू०) में समुद्र-समीर के परिसंचरणों के अध्ययन के लिए एक त्रि-अक्षीय हाइड्रोस्टेटिक मॉडल का उपयोग किया गया है। मानसून-पूर्व अवधि के दौरान, दक्षिण-पश्चिमी बंगाल में इन परिसंचरणों पर आंशिक ऊष्मन के महत्व की पुष्टि करने के उद्देश्य से कुछ सुग्राहिता प्रयोग किये गये हैं। ज्ञात हुआ कि स्थल और समुद्री सतहों के बीच आंशिक ऊष्मन की दर के कारण, समुद्र-समीर स्थल केन्द्र खड़गपुर तक तथा माध्यम अनुप्रवण–पवन और आगे तक प्रवेश कर सकता है। मॉडल के परिणामों की तुलना करने के लिये खड़गपुर के धरातलीय और उसके निकट कलाइकुंडा केन्द्र के पवन सूचक गुब्बारा आंकड़ों का प्रयोग किया गया। समुद्र-समीर के आरम्भ के वायुतापमान और आर्द्रता में परिवर्तन मॉडल के परिणामों के साथ काफी हद तक मेल खाते हैं। जबकि मॉडल समुद्र-समीर के परिसंचरण को अत्यानुमानित करते हैं और प्रात: देर से चलने वाली समुद्र-समीर के परिवर्तन की भविष्यवाणी कर पाने में सक्षम नहीं है।

ABSTRACT. A three-dimensional hydrostatic model has been employed for the study of sea breeze circulations over south West Bengal with special reference to an inland station Kharagpur (22° 21′ N, 87° 19′E). A series of sensitivity experiments have been performed to stress the importance of differential heating on circulation over south West Bengal during pre-monsoon period. It is found that due to differential heating rate between land and sea surfaces, sea breezes can penetrate to the inland station Kharagpur and beyond even in case of moderate gradient wind. Surface observations at Kharagpur and pilot balloon observation at nearby station Kalaikunda are used to compare the model results. The onset of sea breezes, variation of the air temperature and humidity are in fairly good agreement whereas it over estimates the depth of the circulation and cannot predict the variation of the late morning hours surface wind.

Key words—Sea breeze, Thunderstorm, Pre-monsoon, Topography.

1. Introduction

During the pre-monsoon period, southerly wind, *i.e.*, from the sea, the Bay of Bengal, at the lower level over Gangetic West Bengal received special importance because it plays a significant role in the formation of thunderstorm activity, *i.e.*, "Norwesters" over this region (Koteswaram and Srinivasan 1958). Srinivasan *et. al.* (1973) pointed out in their climatological study that a shallow heat low develops over interior of the country, *i.e.*, east Madhya Pradesh and adjoining area of Bihar, which becomes prominent towards the afternoon due to strong insolation and sea breeze (SB) effect is well marked over Gangetic West Bengal. In fact, large scale synoptic situation has been stressed for these southerly winds in their study. Lohar *et al.* (1992) also reported SB activity at an inland station Kharagpur over this region, which is about 80 km far from the sea, the Bay of Bengal. However, the study was based on observations for a particular station only. A study through model, therefore, called for to have a comprehensive idea regarding this activity over this region, particularly when there is a typical Bengal coastline and there is no meso-network of observation stations. In India till today, no numerical modelling study on SB activity has been undertaken except Kar and Ramanathan (1987, 1991). They studied SB activity over Andaman island while studying meso-scale circulations over the island. However, Dixit and Nicholson (1964) applied the model of Estoque (1961) to verify the observational results on SB activity over Bombay, but it was rather sketchy.

Here, an attempt has been made for the numerical study of SB activity over south West Bengal. The work which has been reported in this present paper is a series of sensitivity experiments with a three dimensional version of University of Virginia meso-scale model. The results of model calculations have been compared with the observational data available at or near Kharagpur.

2. Sea breeze arrival at Kharagpur

During the pre-monsoon months of March, April and May SB activity is quite prominent in the afternoon (Lohar *et al.* 1992). Activity is very clear from the surface chart recording itself and characterised by a sharp change in wind direction (Fig. 2), temperature and relative humidity. This is of general occurrence during that period. However, in such cases, large scale wind changes with time and becomes westnortherly/northwesterly from an initial onshore southsouth-

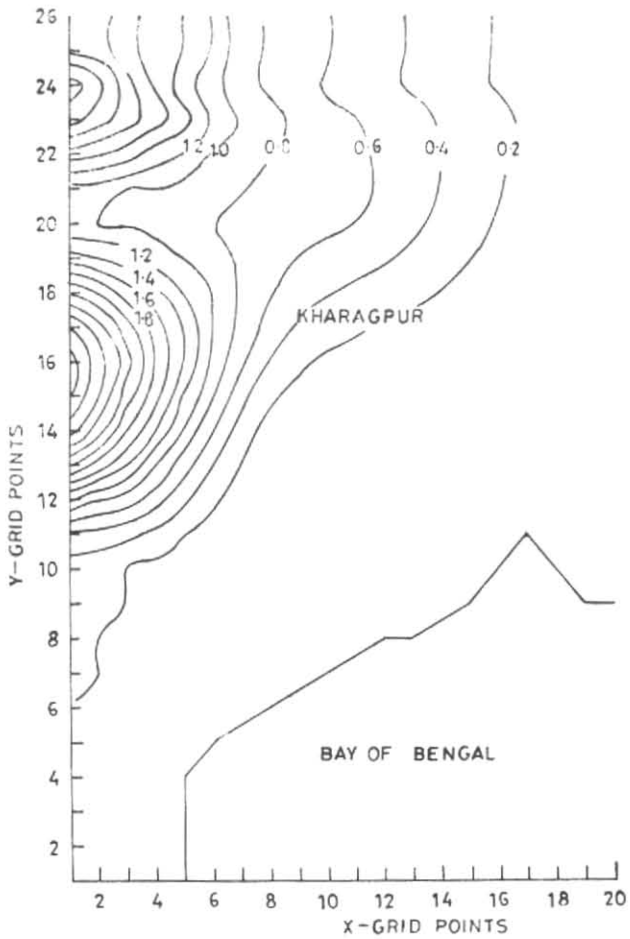


Fig. 1. Figure shows the model domain and topography of the study area. Top graphic height is in 100 of metres

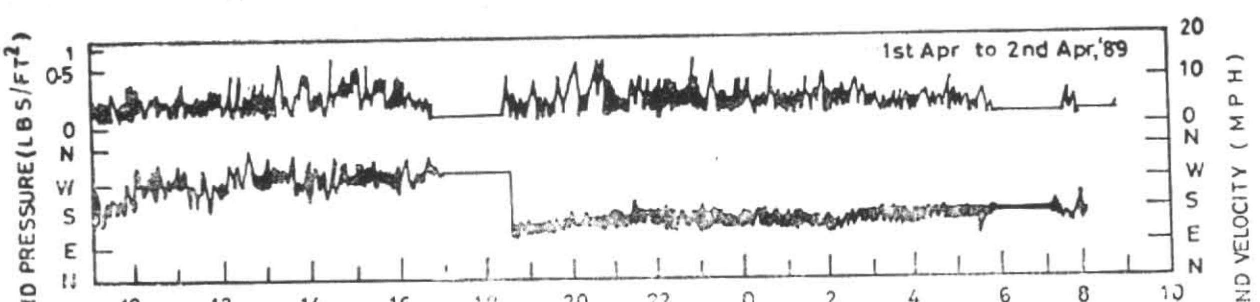


Fig. 2. Anemograph recording for wind speed and direction at Kharagpur on a particular day (adopted from Lohar *et al.* 1992)

westerly. Since the wind at Kharagpur becomes gradient offshore wind just before onset time, a calm condition exists for some time as shown in the Fig. 2. It may be mentioned here that in many occasions the flow continues throughout the night. However, it is not yet verified whether it has got the similar characteristics as was observed in Australia (Clarke 1983). In case of large-scale wind, which does not change with time it is difficult to make out the onset of SB activity because of the onshore flow and thereby gradual change in meteorological parameters.

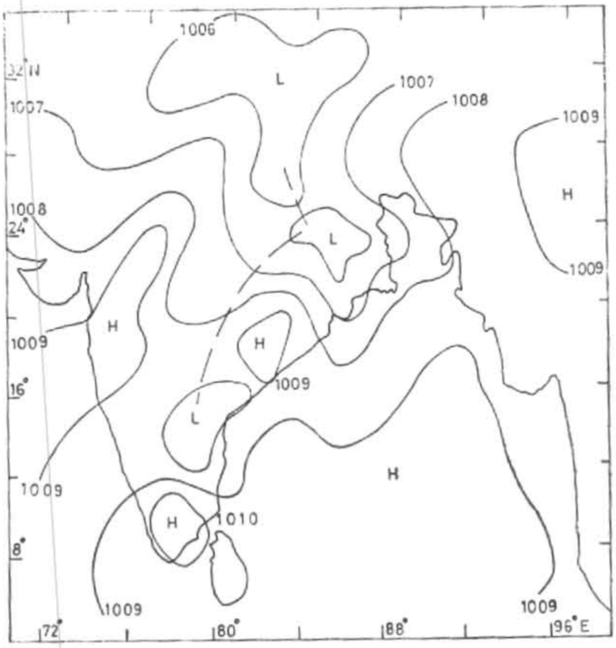


Fig. 3. Surface synoptic chart at 0000 UTC for the simulation day

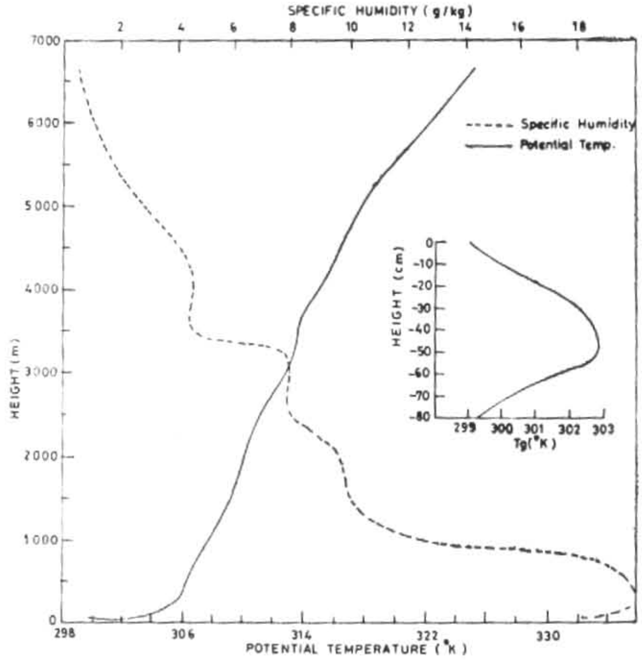


Fig. 4. Initial vertical profile of potential temperature (solid), specific humidity (dashed), and soil temperature. Potential temperature and specific humidity profiles are derived from the morning radiosonde ascent taken at Calcutta (Dum Dum) on 8 April 1991

3. Surface synoptic description for the simulated day

During the pre-monsoon period the eastern region of the country is affected by a shallow heat low developed over north east Madhya Pradesh/Bihar and consequently many sunny days are characterised by a weak southerly flow (Srinivasan *et al.* 1973). As shown in the Fig. 3, surface synoptic chart at 0000 UTC for the simulation day shows a low over Bihar with the centre near Hazaribag, *i.e.*, northwest of Kharagpur. A high is also there over northeast Andhra Pradesh, *i.e.*, southwest of Kharagpur. As time progresses, the trough line flattens and appears as if that high moves northward and in the evening chart (not shown here) it reaches north Madhya Pradesh and surface wind at Kharagpur changes gradually to westwestnortherly from southsouthwesterly till the onset of SB after which it becomes southeasterly.

4. Model

The model used in this study is a version of the numerical meso-scale model described by Pielke (1974) and his colleagues. The model is three dimensional, hydrostatic and consists of the equations of motion, continuity, thermodynamic and moisture equation. It also includes a diagnostic equation of pressure, radiation parameterization and boundary layer parameterization.

(*i*) *Domain*

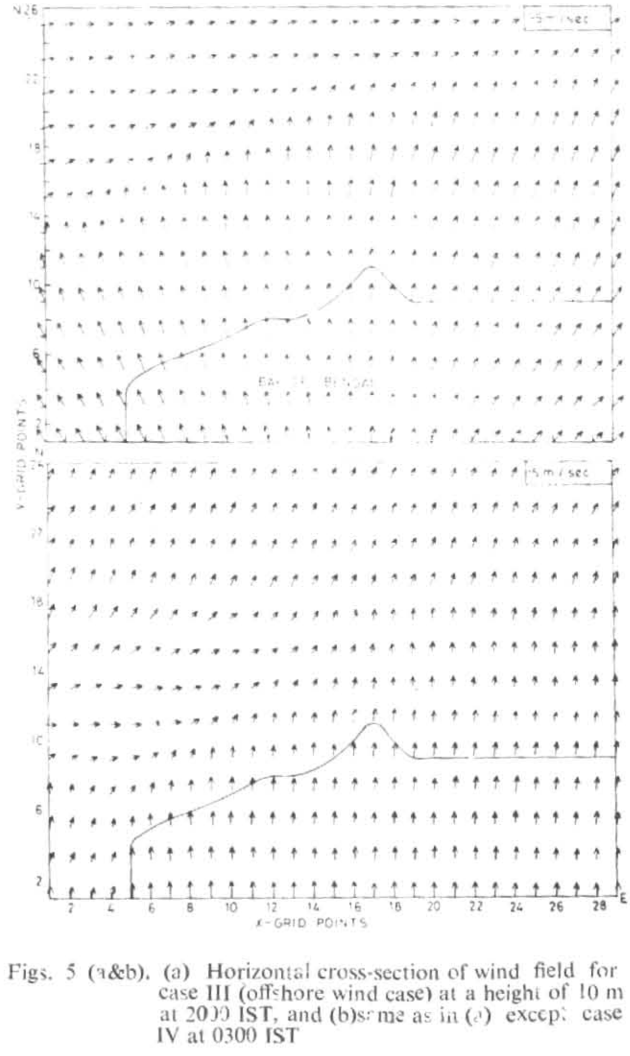
Fig. 1 shows the model domain, over which simulations have been performed on a $29 \times 26 \times 16$ grid with a constant horizontal grid spacing of 9 km. However, simulation with topography has been performed on a $38 \times 35 \times 16$ grid with the same horizontal spacing except at the outermost grid points in the horizontal where it expands linearly (only the inner 9 km grid are represented in the subsequent figures). In the vertical grid spacing is variable with high resolution near the ground. The bases of the vertical levels are as, 2, 10, 30, 50, 100, 200, 500, 1000, 1500, 2000, 2500, 3000, 3500, 4000, 5000 and 6000 m. In the soil, there are 16 levels with constant spacing of 5 cm. As shown in the Fig. 1 the location of the place Kharagpur is of more concern in this study and is in between 17th ($IY=17$) and 18th ($IY=18$) grid-point in the y-direction.

The terrain of the modelling domain is also shown in the Fig. 1 where data were collected from the toposheets with a resolution of 3 km which were later averaged to 9 km. East sector of the domain may be considered as flat (height less than 20 m) whereas west sector is relatively high, having two peaks leading to a maximum height of 300 m. In fact, this portion is the extended part of the Chhota Nagpur plateau.

(*ii*) *Input data*

The idealized potential temperature and specific humidity profiles used to initialize the model were based on morning radiosonde ascent taken at Calcutta (Dum Dum) on 8 April 1991. The profiles including soil temperature are shown in Fig. 4.

Soil characteristics used are based on soil measurements taken at Kharagpur, although soil type and soil condition are not same throughout the domain. Soil type is sandy loam with field capacity 25.2%. During summer,



Figs. 5 (a&b). (a) Horizontal cross-section of wind field for case III (offshore wind case) at a height of 10 m at 2000 IST, and (b) same as in (a) except case IV at 0300 IST

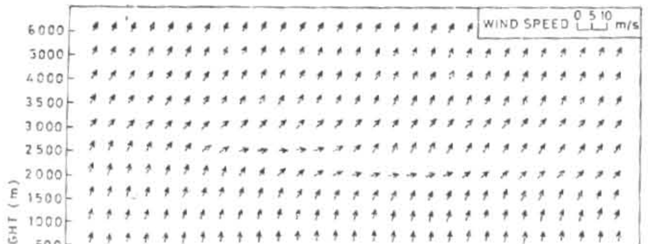


Fig. 6. Predicted vertical cross-section ($IY=17$) of wind field for case II at 1600 IST

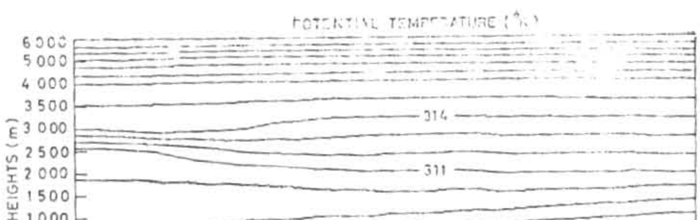


Fig. 7. Same as in Fig. 6 except for potential temperature

it becomes very dry but because of the precipitation over Kharagpur on 7 April 1991, moisture content was slightly high (7.27%).

Average sea surface temperature for the enclosed sea surface area on 8 April 1991 is taken from NOAA satellite SST measurement. The input parameters are given below :

Mean latitude	22.5°N
Surface pressure	1006.3 mb
Surface specific humidity	0.0181 gm/kg
Surface synoptic wind	3.5 m/sec,210°SSW
Sea surface temperature	301.5°K
Albedo	0.15
Roughness length	4 cm
von Karmann constant	0.35
Soil conductivity	0.004 cm^2/sec*
Soil specific heat	0.23 cal/gm/°K*
Soil density	1.48 gm/cm^3*
Soil wetness	0.07
Initial depth of PBL	310 m
Time step	60 sec

**Ref* : Ghildyal and Tripathi (1971)

5. Results

In order to study the SB activity in this region a series of sensitivity experiments have been performed as follows :

Case I : Without land-sea contrast for flat terrain in case of onshore flow.

Case II : Same as case I but with land-sea contrast.

Case III : Same as case II but for gradient offshore flow.

Case IV : Same as case II but with topography.

Case I , case II and case III are considered to emphasize the importance of land-sea contrast whereas case IV is a more realistic case.

Case I —This is a basic case with no land-sea contrast (the full domain is considered as land surface) and without topography. The model has been initialized with the above mentioned data and run for 15 hrs. It is found that throughout the time of simulation wind is southsouthwesterly, since the initializing wind itself is southsouthwesterly. Both wind speed and direction do not change much. Vertical cross-section (IY=17) of the wind field (not shown here), shows southsouthwesterly wind only till the model top at a height of 6 km. Vertical cross-section (IY=17) of potential temperature (not shown here), shows no change along the horizontal direction.

Case II — In this case the actual land-sea contrast has been made in the domain. But the complex patches of land areas in the Sundarban area are not considered, rather a straight land-sea boundary is taken for the modelling purpose. Initialization data and other input parameters are same as in the case I. The model has been run for 24 hrs starting from 0500 IST. Since initial surface wind was southsouthwesterly, southsouthwesterly wind continues for some time and then gradually it becomes southeasterly. Unlike case I, vertical cross-section (IY=17) of the wind field (Fig. 6) shows a change at about 1600 IST at a height of about 2000 m, which may be due to the counter flow. So onset of SB activity at Kharagpur as found out by seeing the counter flow is at about 1600 IST.

Vertical cross-section (IY=17) of potential temperature at the time of onset (Fig. 7) shows a horizontal variation in the lower levels unlike case I. Potential temperature at different places along the horizontal is different unlike case I.

Case III — In this case initializing wind is taken as 3·5 m/sec, 300 deg northwesterly. This case has been considered to find out whether in case of gradient offshore wind SB sets on far off the coast at Kharagpur. As time progresses, SB front moves more inland and northwesterly wind is replaced by southerly wind. At about 2000 IST it reaches Kharagpur [Fig. 5(a)], *i.e.*, the onset at Kharagpur is delayed by 4 hrs compared to case II.

Case IV—There is no significant changes in flow pattern observed in the east sector of the domain whereas in the west sector a slight change is noticed. Quantitatively, at Kharagpur wind speed increases by about 0.5m/sec at the time of onset, whereas maximum wind at night at about 1900 IST decreases by about 0.6 m/sec compared to flat terrain case. Maximum temperature is also less by about 1° K.

It is also noticed that throughout the night flow continues. But it becomes more and more southeasterly at Kharagpur till the mid-night and then again gradually becomes southwesterly in the morning. Even in some part of the west sector flow becomes westerly [Fig. 5(b)]. However, it may be mentioned here that in this case wind at Kharagpur becomes more southeasterly unlike case II in the morning.

Vertical velocity field (Fig. 8) shows two peaks centred over the two peaks as mentioned earlier while explaining the topography of the study area. It may be mentioned here that the overall vertical velocity is very less.

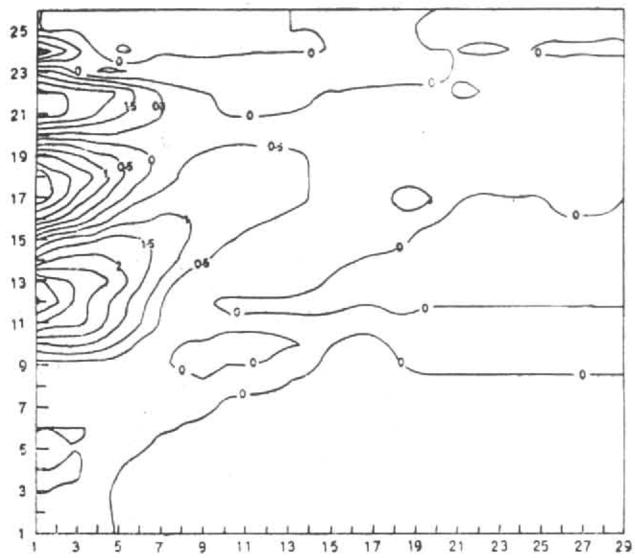


Fig. 8. Horizontal cross-section of vertical velocity field for case IV at 10 m level at the time of onset at Kharagpur. Contour interval is 0.5 cm/sec

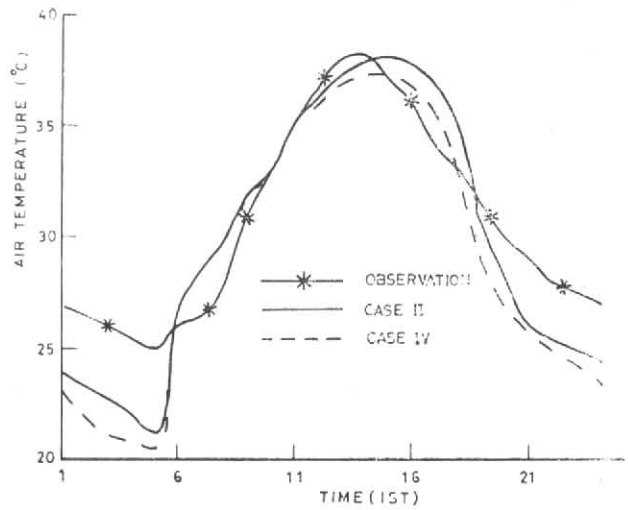


Fig. 9. Comparison of predicted diurnal variation of air temperature at 2 m level for case II and case IV with the observations at Kharagpur

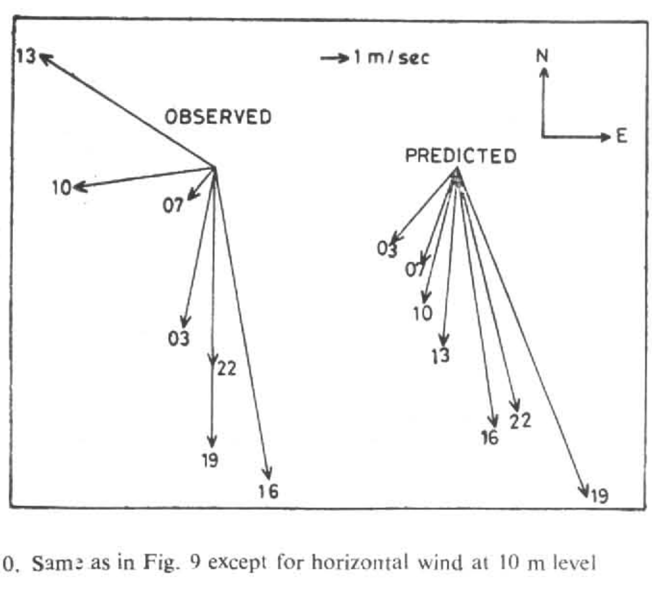


Fig. 10. Same as in Fig. 9 except for horizontal wind at 10 m level

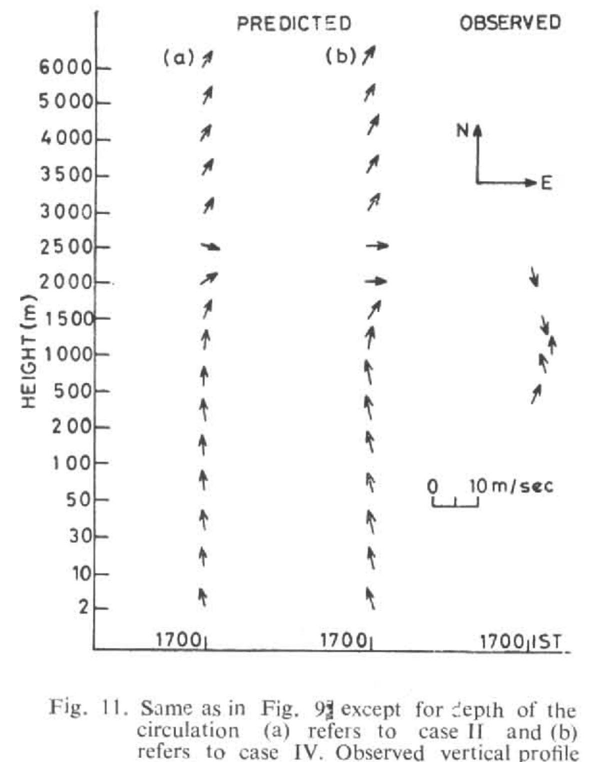


Fig. 11. Same as in Fig. 9 except for depth of the circulation (a) refers to case II and (b) refers to case IV. Observed vertical profile is derived from the pilot balloon observation taken at nearby station Kalaikunda

6. Comparison of results with the observations

The model predicted air temperature (Fig. 9) and relative humidity at a height of 2 m for case II and case IV are compared with the observation at Kharagpur. The horizontal wind in case IV is also compared (Fig. 10) with the observations. The predicted depth of the circulation for case II and case IV are shown in the Fig. 11 alongwith the pilot balloon observation.

Comparison shows fairly good agreement in case of air temperature and relative humidity, specially during day time. However, prediction does not show the onset so clearly as observed. In case of wind, model cannot predict the variation of wind direction in the day time till onset. The time of onset at Kharagpur is delayed by one hour in flat terrain case whereas it coincides in case IV (with topography). In case of depth of the circulation, however, it overestimates slightly.

7. Discussion and conclusions

The onset of SB is detected through the counter flow here because of the initial onshore flow. As shown in the Fig. 6, wind speed suddenly decreases to a small value and direction also changes at a height of about 2 km. Although wind direction does not change by about 180 degree at this time, which gradually changes with time, this may be due to the counter flow of SB circulation. It is also seen (Fig. 6) that around the 17th grid-point in the horizontal and at 2 km height, counter flow restricts itself within a small strip of about 40 km. So, the onset takes place first for this region, which may be due to the typical curvature of Bengal coast, *i.e.*, the extended watermass at the Head Bay. Counter flow is also seen at the same time at greater distance from the coast at higher height of 2.5 km. The potential temperature distribution as shown in the Fig. 7, also shows the impact of SB unlike case I, *i.e.*, cool air from the sea, the Bay of Bengal changes the potential temperature distribution pattern.

The effect of topography on SB circulation over south West Bengal is studied through case IV simulation. There is no significant changes in the east sector whereas the west sector is relatively influenced by topography. The increased wind speed after onset during the day time indicates strengthening the circulation which agrees with Kar and Ramanathan (1991). This is also similar to Mahrer and Pielke (1977), where the upslope wind integrates with the SB flow and becomes strengthened. But the decreased wind speed in the night might be due to downslope wind which opposes the SB flow. And less vertical velocity may be due to initial onshore flow which does not allow to be intensified (Estoque 1962) and also agrees with the numerical study made by Bechtold *et al.* (1991). The flow pattern as discussed above in case IV, may be due to almost flat terrain in the east sector (Fig. 1). The morning southsouthwesterly wind at Kharagpur as noticed in the prediction (case IV), which occurs most of the days during that period in not seen in the case II, again may be due to elevated terrain in the west sector of the domain. The time of onset is earlier by 1 hr in case IV compared to flat terrain case and exactly matches with the observation. This also may be due to topography which strengthened the flow.

Diurnal variation of air temperature and relative humidity at 2 m height fairly agrees with the observations. In case of wind, prediction is poor in the late morning. The variation of wind before onset which may be due to the changing synoptic situation of the simulated day is not predicted because the model cannot take care of that. Moreover, during the night wind at Kharagpur becomes more southeasterly unlike observation. This may be due to the enclosed sea portion considered in the domain. However, further study with changing sea surface area is required to confirm it. In case of vertical extent the prediction is slightly overestimating.

Model simulations support the SB activity at an inland station Kharagpur over south West Bengal due to differential heating rate between land and sea surfaces, even in case of moderate gradient offshore wind. So even without the favourable large scale synoptic situation which is responsible for the southerly flow (Srinivasan *et al.* 1973), meso-scale pressure gradient is enough to produce such a circulation. However, unlike coastal places, SB activity at Kharagpur becomes complicated because of the changing synoptic wind with time.

The soil condition and type are very much different throughout the domain. Moreover, agricultural activity (summer paddy crops) in the coastal as well as inland places over southeast/east of Kharagpur is quite significant during that period. Summer paddy crops require irrigation which in turn increases the soil moisture also. This will modify the radiation budget a lot over that region and the flow pattern specifically over east sector will get changed considerably. The inclusion of variable surface conditions is required to have a better understanding so far as flow pattern over south West Bengal is concerned.

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