SEA BREEZE ACTIVITY AT AN INLAND STATION KHARAGPUR (INDIA) – A CASE STUDY

(Research Note)

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Abstract. Surfaces fluxes, turbulent kinetic energy and Flux Richardson number are calculated for three typical sea breeze days characterizing three types of sea breeze onset at an inland station Kharagpur (22°21′ N, 87°19′ E), 80 km inland, one of the sites for MONTBLEX (MONsoon Trough Boundary Layer EXperiment), in India. The sea breeze onset is associated with a decrease in momentum and heat fluxes and an increase in moisture flux. The turbulent kinetic energy shows quite a significant value even in the late afternoon. The surface layer becomes nearly stable even before sunset, due to the passage of the sea breeze.

1. Introduction

An observational study made by the authors (Lohar *et al.*, 1992) shows sea breeze (SB) activity during the premonsoon months of March, April and May at Kharagpur (22°21′ N, 87°19′ E), 80 km inland from the sea coast, the Bay of Bengal (Figure 1), one of the sites of MONTBLEX (the MONsoon Trough Boundary Layer EXperiment). SB episodes at Kharagpur are a maximum in the month of April and onset takes place in the afternoon mostly around 1600 IST (Indian Standard Time). The passage of the SB front results in a change in screen-level temperature of about 2–4 °C and 10–15% in relative humidity, similar to Madras as mentioned in Atkinson (1981). So, it is quite reasonable to believe that the SB onset at Kharagpur will cause some changes in surface-layer characteristics.

An experiment was conducted to measure surface-layer characteristics for a period of 10 days starting April 1, 1991. From these 10 days, three typical days were selected as case studies, the purpose being to determine the surface-layer changes due to the onset of a SB. Another objective was to investigate whether there were any prior indications of SB activity, based on surface-layer measurements. This latter question is not well documented in the literature.

2. Large-Scale Situations

During the premonsoon period, a permanent shallow surface low pressure area exists in the interior of India (Figure 2), the effect of which is not seen on upper air charts (not shown here). This low pressure area becomes well-marked in the

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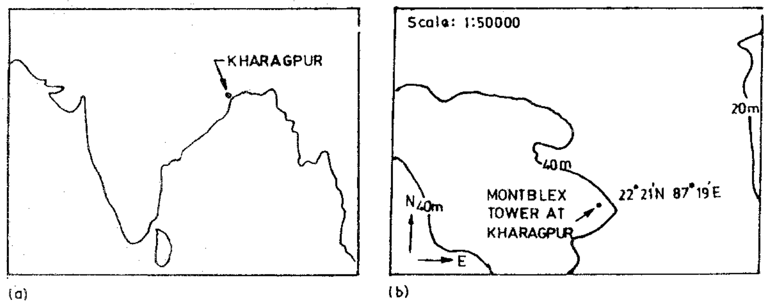

Fig. 1. Location of the study area (a) and the test region (b).

afternoon due to intense solar heating (Srinivasan *et al.*, 1973). This is accompanied by a shallow low-level southerly flow from the Bay of Bengal all along the eastern coast (Weston, 1972). Weston showed that in the month of April, this moist southerly flow along with dry northwesterlies causes a wind discontinuity in north-eastern India, known as the "Indian dry line". However, the phenomenon is not a line but rather a transition zone. Surface winds in that zone show interesting features mainly in the forenoon. Surface wind is determined by the strength of the southerlies. If the southerlies are weak, the surface wind (SSW) gradually changes to westerly or even northwesterly, depending on the strength of the interior northwesterlies. But in the afternoon, southerly winds again dominate when the heat low becomes well-marked.

The case studies considered here are representative of three situations:

Case I: Strong and clearly marked onset of a SB at Kharagpur, characterized by a change in wind direction, a rise in wind speed, fall in temperature and a striking increase in relative humidity.

Case II: Weak SB activity but with a clear onset characterized by a sharp change in wind direction but only small changes in wind speed, temperature and humidity. In such cases, SB activity does not continue for a long time.

Case III: Strong SB activity but onset indistinct, characterized by a rise in wind speed and gradual change in wind direction, temperature and relative humidity. In this case, only the wind speed indicates the onset of a SB.

Some details concerning the 3 case studies are given in Table I.

3. Data and Instrumentation

A 30 m high mast was installed at Kharagpur in 1988 as part of the MONTBLEX programme. The site enjoys an uninterrupted fetch of 500 m towards the south (Bandyopadhyay *et al.*, 1991), the direction of the SB. As the region is flat with fairly open terrain, the influences of topography and ground obstacles are expected to be small. The mast was equipped with slow response sensors to measure wind

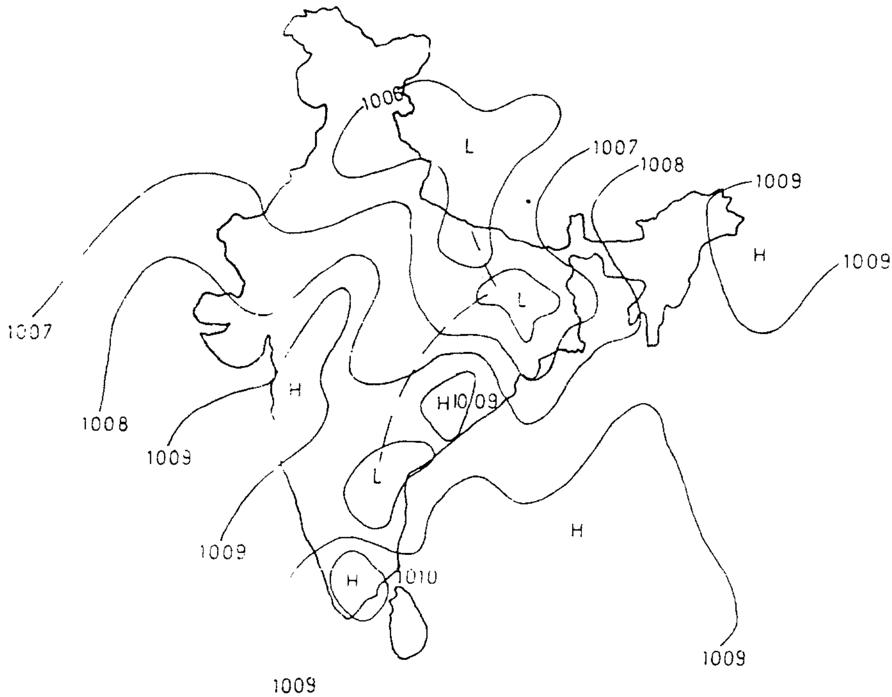

Fig. 2. 00 GMT surface pressure chart on the 8th of April 1991 showing the shallow heat low over Bihar and the adjoining area.

TABLE I

Some details concerning the three case studies

	Date	Sky condition	Time of SB onset in IST	Characteristics
Case I	8th April 1991	Fair	1500	Strong SB with sharp onset
Case II	7th April 1991	Cloudy in the morning becoming fair towards afternoon	1630	Weak SB: sharp wind shift but no other changes
Case III	6th April 1991	Partly cloudy with high cloud	1530	Strong SB but onset indistinct

speed, wind direction, temperature and relative humidity at six levels: 1, 2, 4, 8, 15 and 30 m, using cup anemometers, wind vanes, temperature-measuring thermistors and humidity-measuring humicaps. In addition, a fast-response sonic anemometer was operated at 8 m.

Ten-minute data samples were collected from the sonic anemometer at specific

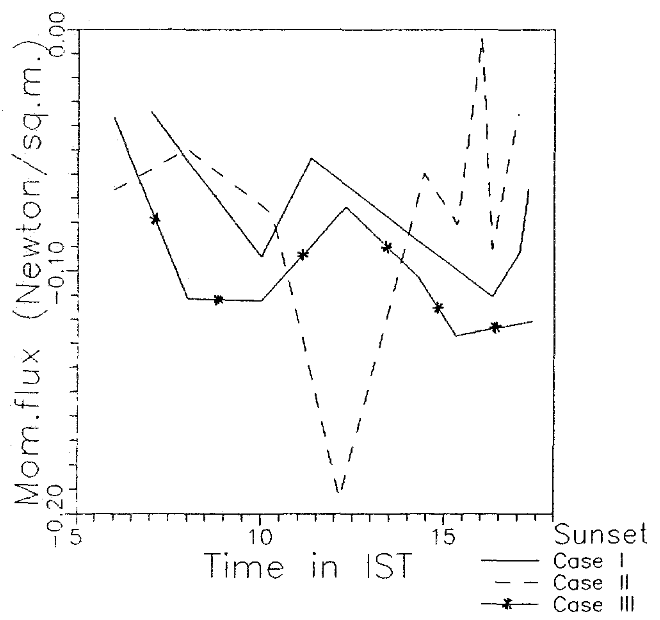

Fig. 3. Diurnal variation of momentum flux for three typical cases.

times of the day at a sampling rate of 8.42 samples/sec. The quality of the sonic data sets was checked and edited as follows. Very high values, evidently erroneous, observed near the end of each data set were removed; the number removed in each data set was quite small (around 50). Then the data samples which deviated by more than 2σ were replaced by the mean values for the series. Finally, the 8 m level fluxes, viz., momentum flux, heat flux and moisture flux, were calculated using the eddy correlation technique. Turbulent kinetic energy and flux Richardson number were also calculated for those typical days.

4. Results

Figures 3, 4 and 5 show that cases I and III are rather similar whereas case II follows a different trend. The momentum flux (Figure 3) in Case II increases abruptly around 1200 IST, the heat flux (Figure 4) decreases by about 50 W/m^2 and the moisture flux (Figure 5) decreases by about 70 kg/m/sec, all at about the same time. These changes may be due to a strong northwesterly wind which persisted for about an hour.

After the SB onset, there is a general tendency for decreasing momentum and heat fluxes and an increasing tendency for moisture flux, which indicate a steady flow of cool moist marine air after the passage of the SB over Kharagpur. It is perhaps worth noting here that the heat flux becomes close to zero (case II) for

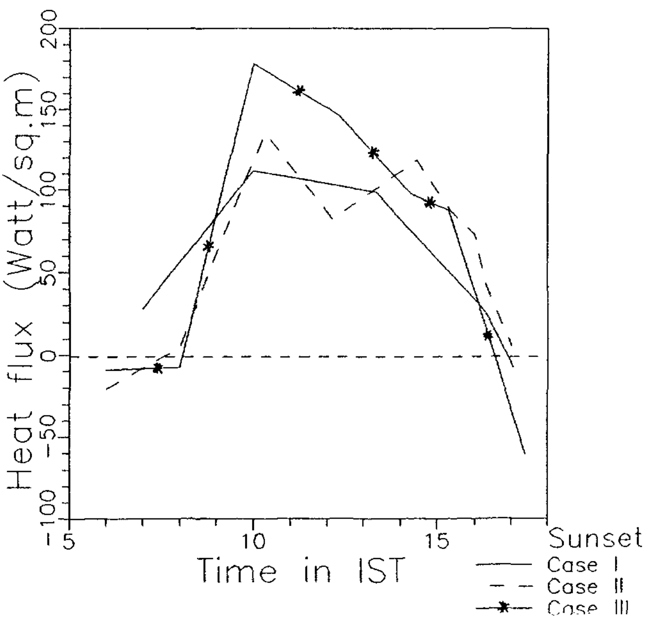

Fig. 4. Same as Figure 3 but for heat flux.

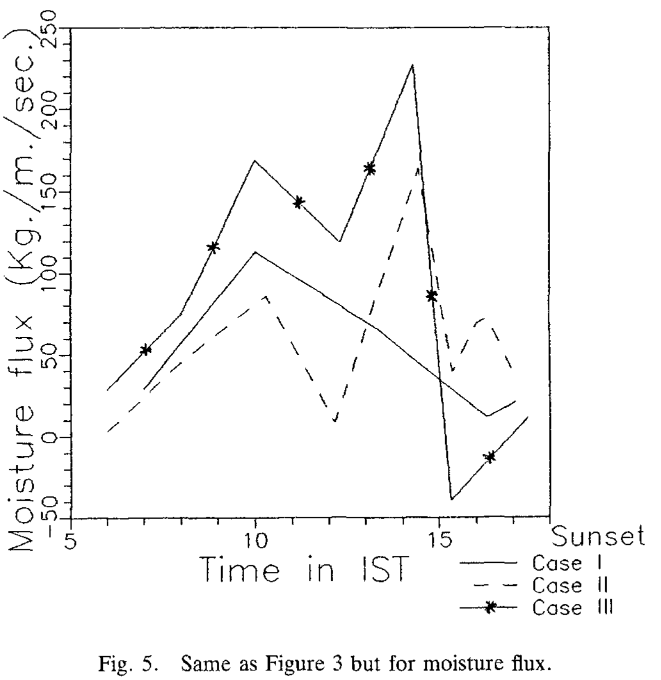

Fig. 5. Same as Figure 3 but for moisture flux.

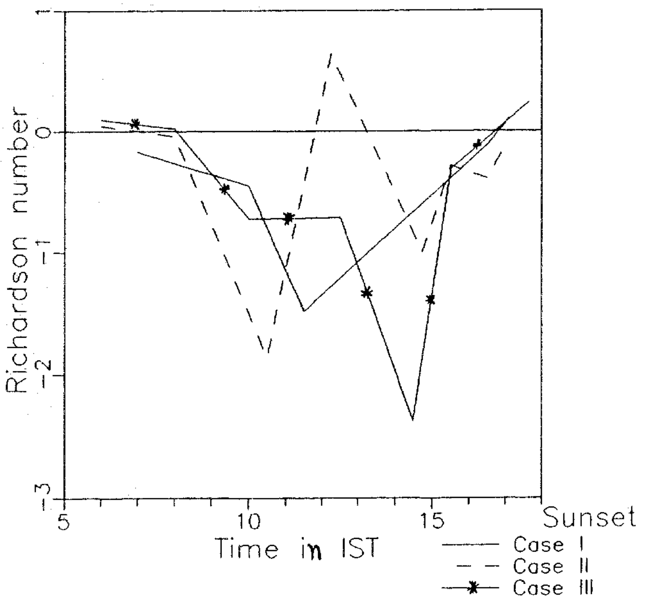

Fig. 6. Same as Figure 3 but for Richardson number.

the weak SB case and even negative (cases I and III) for strong SB cases before sunset. This might be due to the passage of the SB, which alters the vertical profile drastically up to the top of the circulation. Since the circulation is about 1 km in thickness at Kharagpur, the effect may be seen in the mixed layer also, which needs to be studied observationally. This is also reflected in Figure 6, where flux Richardson number is less negative (case II) and even positive in cases I and III.

Turbulence kinetic energy as shown in Figure 7 does not follow the expected diurnal variation for a clear undisturbed sunny day at an inland station. In particular, a sharp fall in TKE around 1200 noon fall in TKE is not noticed in the strong SB cases (Cases I and III). This is perhaps due to the mechanical production of turbulence because of the strong wind after the SB onset. It is safe to assume that although thermal production of turbulence decreases sharply in the afternoon, mechanical production of turbulence will continue.

5. Discussions and Conclusions

Like other coastal and inland stations, the initial wind field plays an important role in determining SB activity at Kharagpur. Three types of SB activity have been identified in three case studies: see Table I. The strongest SB activity occurred in Case I when there was a moderate offshore wind (Bechtold *et al.*, 1991).

The study further reveals that after a SB onset, the surface layer became nearly

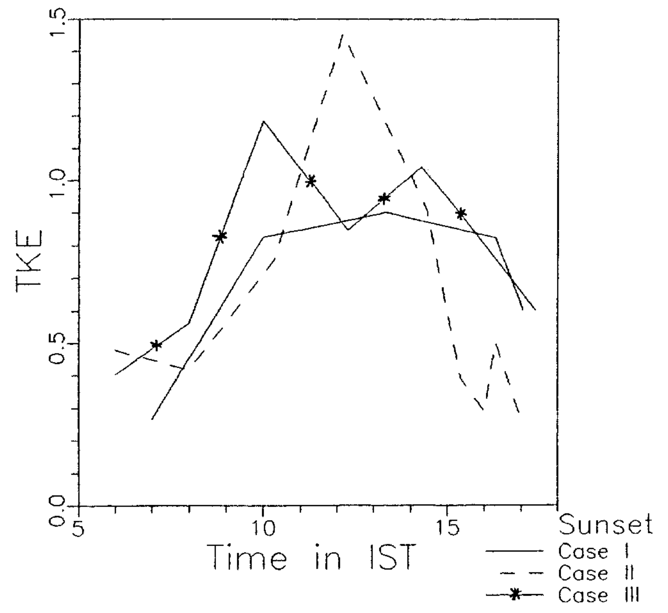

Fig. 7. Same as Figure 3 but for turbulent kinetic energy.

stable even before sunset due to cool advected marine air following passage of the SB front. The turbulent kinetic energy did not show its usual diurnal variation on sunny days at inland locations but remained high in the late afternoon. This may be due to the mechanical production of TKE after the onset of the SB.

Further detailed investigations are needed to establish firmly the signatures distinguishing the three types of SB onset and also the changes in surface-layer characteristics due to passage of an SB front.

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