Observations of atmospheric waves generated by cyclone centres in the Bay of Bengal using microbarographs at Delhi, Hyderabad and Calcutta are presented. There appears to be a cause-and-effect relationship between infrasonic pressure variations and microseisms generated during a cyclone. The possibility of using a suitably deployed system for cyclone detection and monitoring is discussed.

1 Introduction
Storm-type microseisms in association with depressions/cyclonic storms (period, 2-5 s) both in the Bay of Bengal and the Arabian sea, which invariably reached a peak amplitude at the time of the storms crossing the coast, have been reported. Several storm detecting radars have been installed along the coast by the India Meteorological Department as a part of its storm warning system. The range of these radars, however, is limited to 400 km. With a microbarograph, it is possible to detect depressions/cyclonic storms when they are beyond the range of radars.

Infrasonic waves associated with severe convective storms have been detected at ground level by microbarographs and dopplometers. Identical microbarographs of condenser microphone type, sensitive in the frequency range 0.001-2 Hz, have been in operation at Delhi, Hyderabad and Calcutta, for several years. Depressions and cyclones formed in the Bay of Bengal during 1985 and 1986 have been studied with the help of microbarograph records from these stations with a view to identifying precursors of depressions/cyclones when they are still out at sea.

2 Observations
Continuous records of infrasonic pressure variations were taken at Hyderabad, Calcutta and Delhi, during 1985-86. These records have been scrutinized along with the details of cyclonic storms supplied by the India Meteorological Department (IMD), New Delhi. Fig. 1 (a and b) shows the tracks of the cyclonic storms during 1985 and 1986. It will be of interest to discuss the microbarograph signatures at Delhi, Hyderabad and Calcutta for the cyclonic storms of 9-12, 13-17 Oct. 1985 and depressions of Aug. and Sep. 1986.

It has been found that at the coastal station of Calcutta and the inland station of Hyderabad, characteristic precursors in the form of rapid oscillations (period, \( \approx 5 \) s) superimposed on longer period oscillations were observed 1-3 days before the cyclone crossed the coast, depending on its severity. These rapid oscillations reached a peak amplitude at the coastal station synchronizing with the cyclone crossing the coast, similar to cyclone-generated microseismic activity from the sea (Fig. 2).

Scrutiny of the data reveals the following:
(a) For a cyclonic storm starting as a depression on 9 Oct. 1985 near the Andaman and Nicobar Islands in the Bay of Bengal, both Hyderabad and Calcutta records showed similar patterns with a time lag of 1 hr at Hyderabad. To investigate the origin of the disturbances observed at Hyderabad and Calcutta, power spectral analysis of the two records was carried out.

This depression concentrated into a cyclonic storm on 10 Oct. and crossed the coast early morning on 11 Oct. and lay as a depression on land between Hyderabad and Calcutta, it being nearer to Hyderabad. Fig. 3 shows similar infrasonic waves from this depression at both the places on 11 Oct. 1985, its commencement being earlier by 5 min at Hyderabad due to its proximity to this place.
Fig. 1(a)—Tracks of cyclonic storms during 1985 (courtesy: IMD, New Delhi)

Fig. 1(b)—Tracks of cyclonic storms during 1986 (courtesy: IMD, New Delhi)
(b) For the depression which formed on 13 Oct. 1985 north of Andaman Island in the Bay of Bengal, similar infrasonic waves were observed on 14 Oct. 1985 at Calcutta and Hyderabad. Fig. 4 shows a portion of these waves at these two places; this depression commenced earlier by 40 min at Calcutta due to its proximity to this place. The power spectrum analysis shows that short period oscillations are predominant when the depression becomes intense. This is similar to our observations with a dopplerometer\(^5\).

The cyclonic storm on 15 Oct. 1985, when it was still in the Bay of Bengal but close to Calcutta, generated similar infrasonic waves superimposed by rapid oscillations (period, \(\approx 5\) s). However, the wave at Calcutta occurred over a period of 15 min, whereas the same wave was observed over a period of 30 min at Hyderabad (Fig. 5). This again can be ascribed to the close vicinity of the storm to Calcutta, where the entire wave pattern was recorded much earlier than that at Hyderabad.

(c) For the deep depression formed in the Bay of Bengal during Aug. 1986 (which was responsible for very heavy rainfall leading to unprecedented floods in Andhra Pradesh then), rapid infrasonic oscillations (wind type) with periods of 30 s and below were observed at Hyderabad (Fig. 6); rapid infrasonic oscillations (wind type) are generally observed in association with strong and gusty winds locally on land (30-
depressions are those for late evening hours only. An examination of the Delhi records shows that this station, being an inland station far away from the coast, does not respond to these cyclonic effects.

Another interesting point we have observed is that cyclones which cross the east coast south of Ongole do not produce any significant signatures on the infrasonic pressure variations at Calcutta, irrespective of their severity. This is in agreement with the results obtained with a dopplometer\(^5\). But these cyclones do produce a characteristic effect at Hyderabad.

3 Conclusion

There appears to be a cause-and-effect relationship between the rapid pressure fluctuations and microseisms generated when the cyclone is still out in the sea. Microbarographs could provide convenient ground-based equipment for monitoring the development, intensification and movement of cyclones in the Bay of Bengal. From a number of stations (both coastal and inland) with their known locations and from the relative time differences, it should be possible to locate the storm centre. The propagation speed of infrasonic waves is of the order of 500 m/s (Ref. 6). These preliminary results will have to be followed up with detailed network studies of the kind suggested in this paper.

Acknowledgement

The authors are thankful to the India Meteorological Department, New Delhi, for providing the cyclone charts for 1985 and 1986. They are also thankful to Dr S K Chatterjee of the Institute of Radio Physics and Electronics, Calcutta, for maintaining the microbarograph at Calcutta. The help rendered by Mr Kanwaljit Singh of the Computer Section, NPL, is also acknowledged.

References