Indian Journal of Radio & Space Physics
Vol. 14, October 1985, pp. 136-142

Simultaneous Study of Sea Breeze with Two Monostatic Acoustic Sounders

A RAGHU KUMAR, M PURNACHANDRA RAO, J S R MURTHY & A S MOHANA RAO
Department of Physics, Andhra University, Visakhapatnam 530003
and
C POORNACHANDRA RAO
Cyclone Warning Centre, India Meteorological Department, Visakhapatnam 530003

Received 7 January 1985; *revised received* 29 *May* 1985

Sea breeze at Visakhapatnam is influenced by the unique combination of topographic, meteorological and oceanographic features. To characterize the main features of sea breeze as it penetrates inland, two monostatic acoustic sounders have been operated simultaneously in May 1983, one at the University site about 1 km away from the coastline and other at the airport meteorological observatory about 11 km west inland. From the sounder records of the two sites and the supporting meteorological data it has been observed that the sea breeze at the two locations differs considerably in respect of its onset, duration, depth and thermal turbulence distribution. This marked variability is attributed to the peculiar orography of the locale.

1 Introduction

The sea breeze circulation is one of the most prominent mesoscale features in coastal areas. The circulation is derived by the transfer of heat energy from the land surface and its eventual transformation into the kinetic energy of air motion. The closed circulation begins near the shoreline and expands both landward and seaward with time. The landward penetration is largely influenced by the coastline shape[1], terrain[2,3], sea surface temperatures[4] and prevailing general winds[2]. The sea breeze as it penetrates inland affects the climatology and meteorology of coastal zone. A more important factor is the effect on diffusion of airborne affluents particularly in a complex orographic industrial region like Visakhapatnam[5].

In the past, acoustic sounder studies at the University site in Visakhapatnam have revealed that sea breeze has unique characteristics like longevity, height variability and oscillatory behaviour[6,7]. The continuous documentation of the changes in the thermal structure and characteristics of sea breeze as it penetrates inland could be made by simultaneous operation of acoustic sounders at different points of interest. To this end, two monostatic sounders have been operated in May 1983 at the University site and airport observatory to characterize the main features of sea breeze at a mountainous upwelling region.

2 Experimental Technique and Site

Acoustic sounder (SODAR) provides an informative continuous cross-section of the thermal structure of lower atmosphere[8,9,10]. It transmits a brief burst of sound upward, collects the echoes which return from small scale temperature fluctuations and displays the heights of these echoing regions on a facsimile chart. Such small scale temperature fluctuations are often generated by turbulence in non-neutral regions because the induced vertical motion can carry away a parcel of air to surroundings of different temperature. When the temperature lapse rate is adiabatic, such vertical motion cannot set up temperature differences. Acoustic backscattering is dependent not only on the presence of stably or unstably stratified layers in the atmosphere but also on the presence of turbulent fluctuations at a scale equal to $\lambda/2$.

The specifications of the two sounder systems are given in Table 1. The University sounder developed at the University laboratories has a permanent antenna assembly. The parabolic dish antenna used for the sounder system at airport observatory was placed in a ditch 6 ft deep. The tapered ditch has an opening

Table 1—Specifications of the Two Systems

Parameter	University sounder	Airport observatory sounder
Frequency	2000 Hz	1600 Hz
Transmitter power	40 W	100 W
Transmit duration	100 ms	100 ms
Pulse repetition period	1 per 8 sec	1 per 18 sec
Receiver bandwidth	80 Hz	40 Hz
Antenna diameter	4 ft	6 ft
Range	500 m	1000 m
Recorder	Facsimile (wet paper)	Facsimile (dry paper)

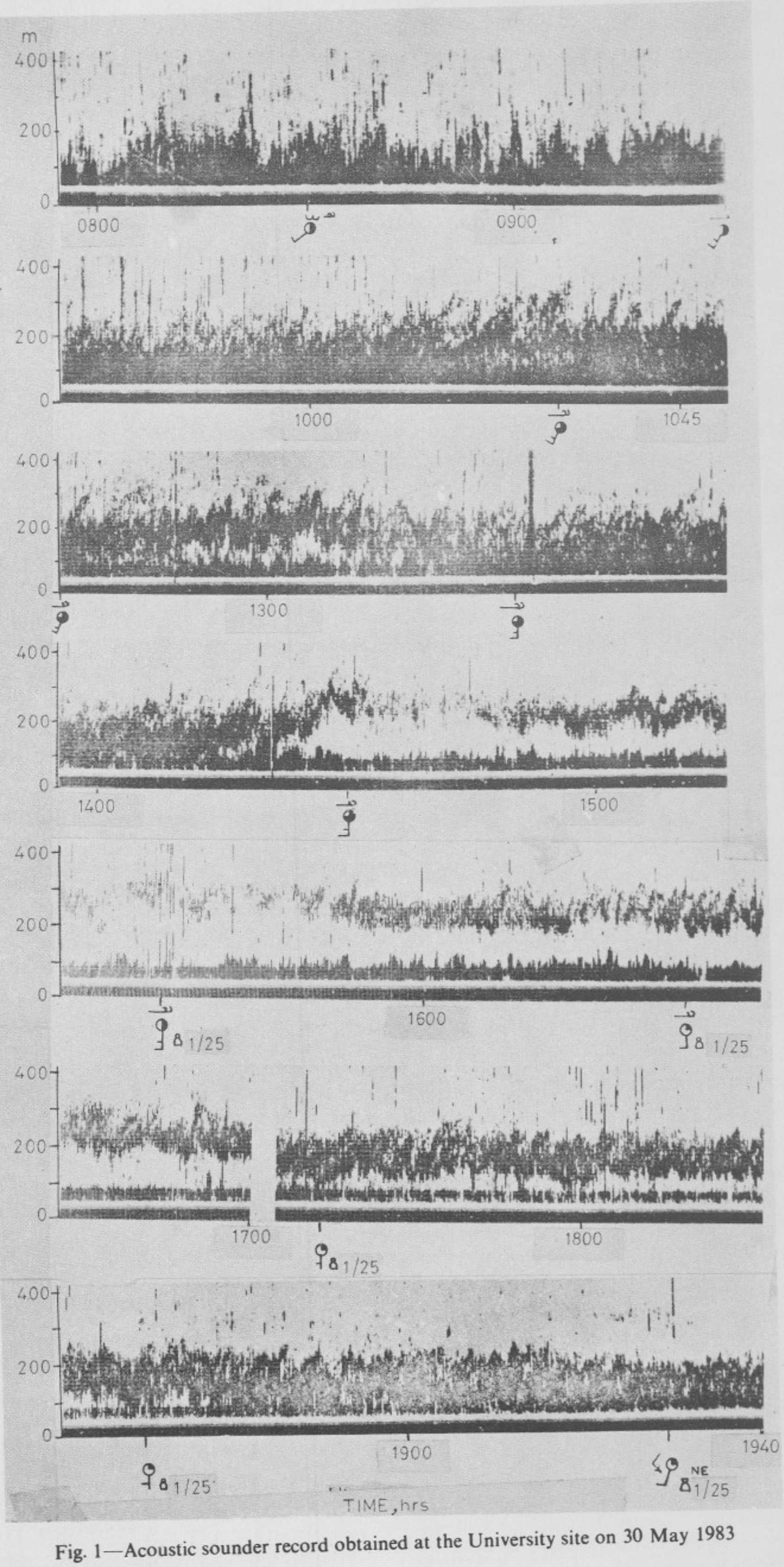

Fig. 1—Acoustic sounder record obtained at the University site on 30 May 1983

aperture of about 10 ft and a bottom diameter of 8 ft. The soft earth of the bottom and walls serves as acoustic absorbing cuff. It is surrounded by 12 planks of dimensions 90 × 60 cm arranged in the shape of dodecahedron to decrease the wind noise and general background surface interference. Each plank is lined with 3 mm thick tarfelt and 5 cm thick mineral wool blanket.

The sea coast at Visakhapatnam is roughly oriented in the southwest-northeast direction with Bay of Bengal in the east. The University site is roughly 1 km away from the coastline whereas the airport observatory is situated 11 km west inland. Continuous records of temperature and relative humidity are available at the former site and that of wind is also available at the latter site. The Kailasa range of hill with an average height of 300 m runs east-west, jutting into sea in the north. A group of hills stands on the fringe of the tidal swamp in the west. The Yarada hill having an average height of 150 m lies in the south, 7 km away from the northern hill range.

3 Results and Discussion

3.1 Case I: 30 May 1983

Shown in Fig. 1 is the acoustic sounder record obtained at the University site on 30 May 1983 from 0800 to 1940 hrs. The temperature and relative humidity (RH) traces of the same day have been shown in Fig. 2. There were two power failures at the University site from 1050 till 1230 hrs and from 1700 till 1725 hrs. The convective plume activity was interrupted by the onset of sea breeze at about 0915 hrs. A shallow layer of cool moist air advected as a result of southsouthwesterly and later southerly winds. The sea breeze appeared on the sounder record as a surface based echo layer that represented the advected inversion[11]. Concurrently, both the temperature and RH had been curtailed. After 15 min, temperature dropped by 1.5°C and RH was found to increase.

The modification of marine air from below due to surface heating was evidently seen during the periods 1020 to 1030 hrs and 1235 to 1315 hrs. The acoustic sounder began to show the development of internal boundary layer[12] in the form of intensified low level plume-like structure which is vertically contiguous. The modification of marine air within the internal boundary layer requires the vertical transfer of heat and will result in the generation of thermal turbulence. The elevated layer that caps the continguous structure evidently coincides with the mixing zone between the inflowing marine air and outgoing land air aloft[8]. The near constancy in both the depth and scattering strength was probably indicative of steady dynamic force behind the marine air. The decay of the circulation was well marked by the approach of elevated layer to the ground. The cassation was probably due to a thunderstorm developed in the northeast of the city. Lightning was reported from 1400 till 1600 hrs.

The sea breeze pattern at the airport area is completely different from that at the University site. The sounder record obtained on the same day at the airport area is shown in Fig. 3 along with the temperature, RH and wind records. The wind was variable around southwest, and the temperature and RH attained the values of 39.5°C and 48%, respectively, at 1130 hrs. The temperature and RH were fastened at these extreme values of the day for about 15 min from 1130 hrs. During this period, the sea

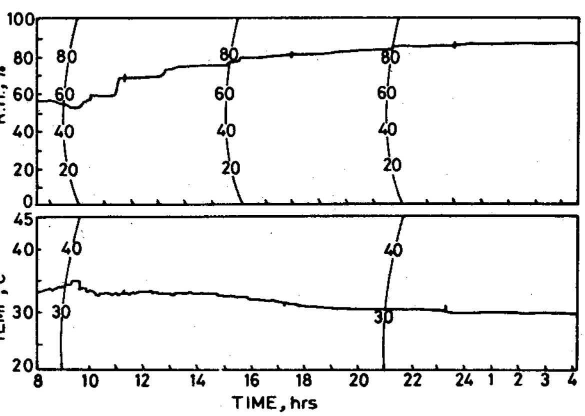

Fig. 2—Hygrograph and thermograph traces obtained at the University site on 30 May 1983

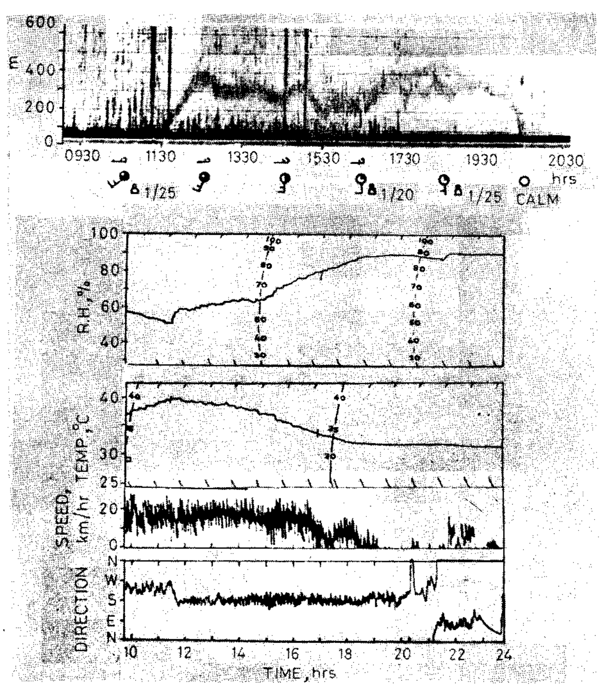

Fig. 3—Acoustic sounder record along with surface autographic charts obtained at airport observatory on 30 May 1983

breeze was trying itself to dominate the prevailing wind flow which can be seen from the wind record. The winds at the observatory showed a gradual movement from westerly to southerly direction from 1130 hrs. The winds were strong reaching 25 kmph and there were considerable fluctuations in direction during the change. The winds became more southerly from 1145 hrs, indicating the well established sea breeze circulation. Associated with this change, temperature dropped by nearly 1°C. The advected marine air was wetter than the prevailing flow, resulting in an increase of RH by 8% within the first 15 min after the onset of the sea breeze. The development of layer of echoes in the lower atmosphere at about 1130 hrs on the facsimile record indicated the onset of sea breeze. The near fastening of temperature and RH for a period of about 15 min at the onset of sea breeze was observed at both the places.

By 1145 hrs the sounder record showed an elevated layer rising from the base of the chart. The layer originates from the zone of enhanced static stability within which turbulent temperature fluctuations are generated by mechanical mixing induced by wind shear. As the sea breeze moves inland, the internal boundary layer of modified turbulent air grows vertically in the lower portions of the marine air. The low level scattering regions found at the base of the chart were intermittent unlike the contiguous vertical echoes observed at the University site. The strong scattering was indicative of strong thermal turbulence produced by convective plumes which rose out of the shallow surface layer, existing at the base of the internal boundary layer[13]. The near surface heating is distributed upward by turbulent mixing and modifies the advected stable stratification. The ground-based layer which persisted for more than 5 hr on the facsimile record located at University site was not seen on the sounder record obtained at the airport area. The advected marine air might already be modified at lower levels before it could reach the airport area while passing over a long fetch of heated land surface.

The elevated layer of mixing zone rose to a height of above 300 m at 1230 hrs and thereafter remained steady at a height of 260 m. By 1730 hrs, when the convective activity disappeared on the chart, the elevated layer underwent a change, splitting and becoming more complex, but the main layer of stability descended to the ground at 2030 hrs. This marked the cessation of sea breeze that was also disclosed by the wind record—the wind became calm and later easterly. No thunderstorm activity was reported at the airport area.

The vertical thermal structure of the sea breeze observed at the two stations is different from each other. No relation was found between the depth of sea breeze at the two stations, but the depth of the marine air and low level echoing region observed at the University site were less than those observed respectively at the airport area. The onset of sea breeze at the two stations was not abrupt, in the sense that the sea breeze was struggling to overcome the prevailing general flow at the two stations for about 15 min. The earlier cessation of sea breeze at University site was because of cold outflow from the thunderstorm from northeast which had not affected the conditions at the airport area.

3.2 Case II: 29 May 1983

The facsimile records obtained on 29 May 1983 at the University site along with surface autographic charts collected at the same area have been reproduced in Fig. 4. A trough of low pressure was persisting over north coastal Andhra Pradesh from 0530 till 1430 hrs with the trough line passing through Visakhapatnam. The trough showed a movement inland subsequently. The lowest pressure prevailing over Visakhapatnam prevented the onset of sea breeze till about 1440 hrs at the University site. Associated with the local onset of sea breeze, a temperature drop of 2.5°C was noticed. The trend of RH was reversed to increase by 34% in a time period of 2½ hr following the passage of marine air. The sounder record indicated that intermittent convective plumes were replaced by a stable ground based layer which persisted for about half an hour.

The sudden rise of echoes up to an altitude of 350 m was seen at the onset. This scattering region may perhaps be related to the zone of convergence and updrafts that are assocaited with the sea breeze front[14]. Shortly after 1500 hrs the stable region was modified into low level convective plume-like activity. Evidence of strong thermal turbulence at the surface lasted until about 1930 hrs without any capping layer. An interesting feature that appears in this record, though by no means unique to this observation, is the persistence of plume-like activity even after the sunset. It is probably because of the fact that the intruded marine air was cooler than the land surface[15,16].

The sounder record along with surface autographic records collected at the airport area is shown in Fig. 5. The winds in the noon hours were strong reaching 30 kmph, whose direction was variable between southwest and west. The sea breeze came from south at about 1730 hrs. The late onset of sea breeze was characterized by sharp wind shift with significant changes in the temperature and RH (temperature dropped by 1°C and RH increased by 4%). This time lag was relatively higher which might be the result of prevailing trough of low pressure that showed a slow movement inland. The stable ground-based layer which replaced the intermittent convective plumes was

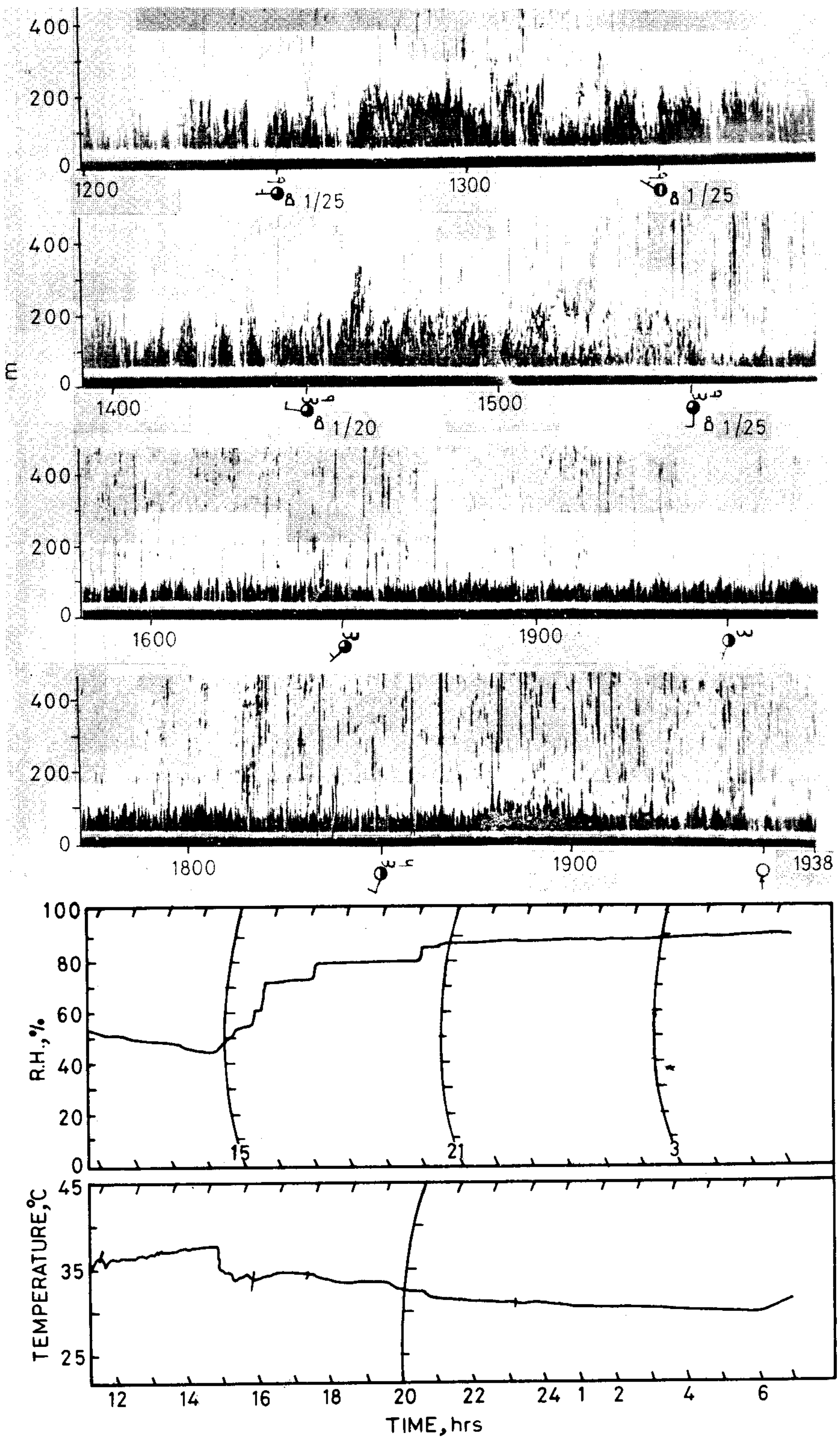

Fig. 4—Acoustic sounder record along with hygrograph and thermograph traces obtained at the University site on 29 May 1983

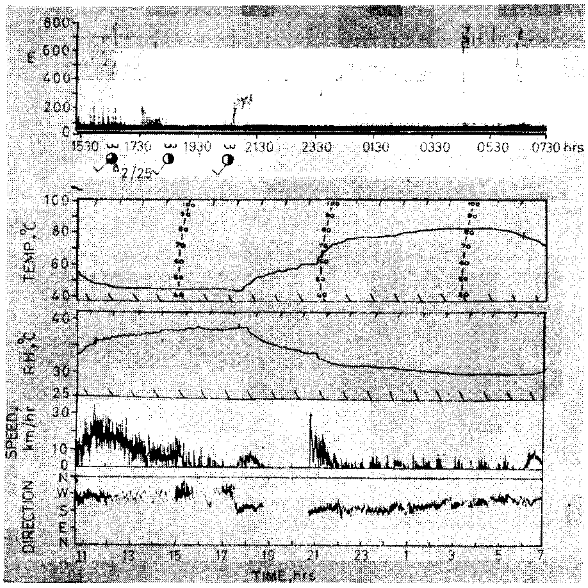

Fig. 5—Acoustic sounder record along with surface autographic charts obtained at airport observatory on 29 May 1983

prevalent until 1850 hrs. The termination of sea breeze flow was also depicted by the wind record which became calm at 1850 hrs.

Soon after 2040 hrs there was a sudden change in all the surface meteorological parameters as well as in the sounder record. The wind speed abruptly rose to 36 kmph from calm conditions as the direction became south. Accompanying this gust, there was a temperature drop of 1°C and a rise in RH by 5%. The layered appearance of the echoes at this time was noticed on the facsimile record (Fig. 5). From these simultaneous changes it is inferred that a fresh surge of sea breeze has arrived from southerly direction at 2040 hrs. Such delay in the onset of sea breeze to the extent of occurring after sunset had been reported at the other places also[17,18].

After the initial period of gustiness (about half an hour) the wind decreased to a lower value, while the layer of echoes quickly ascended to a height of 300 m deepening the echo-free region. The cooling surface and greater mechanical turbulent mixing associated with sea breeze might have established a neutral adiabatic lapse rate from the ground to the base of the subsidence inversion. The layer of wind shear subsequently became steady at 400 m and was not discernible after 0500 hrs. The surface wind became almost parallel towards the termination of sea breeze.

The nocturnal sea breeze had controlled the minimum temperature of the day. The day marked the lowest minimum temperature of all the days in the May excluding those which have nocturnal rainfall. It indicates that sea breeze can hamper the minimum temperature if its onset is delayed while its influence on the maximum temperature is well known.

The sea breeze at the University site was seen as low level convection while at the airport area it was observed as a stable ground-based layer. The revival of sea breeze at the latter area was delegated by an elevated layer while its presence at the University area had not been monitored, because sounder was not in operation.

3.3 General Comments

The two case studies revealed a marked variability in the thermal structure and characteristics of sea breeze at both the sites. A similar behaviour was observed on the remaining days of simultaneous observation. The sea breeze differed considerably in the onset time, duration, vertical extent and in the thermal turbulence structure.

Fig. 6 shows the relation between the onset times of sea breeze at both the sites on 16 days in May. It is observed that sea breeze sets later at the airport area than at the University site. The average time lag is 96 min and this may be attributed to difference in the distances of the two sites from the coastline. It should be noted here that this time lag does not indicate the time of travel of marine air from the University site to the airport area since the origins of sea breeze at the two sites are not the same. Sea breeze at the University site is expected to develop near the land jutting into the sea. But sea breeze at the airport area comes mostly from the passage way between the Yarada hill and the group of hills standing in the west[19]. The presence of

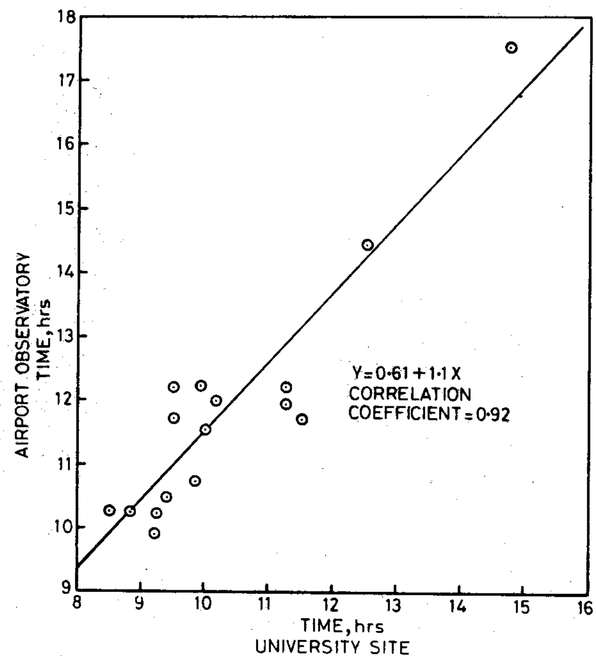

Fig. 6—Relation between the onset timings of sea breeze at the University site and airport observatory

sea breeze at airport area (inland site) even after its abrupt cessation at University site owing to thunderstorm outflow from northeast on 30 May 1983 confirms the aforesaid contention. The average temperature drop associated with sea breeze at the University site is about 1°C, whereas it is nearly 0.5°C at the airport area. It is clear that the marine air that penetrates inland is heated up by the warmer land surface before reaching the airport area but may have been cooler than the ambient air. The average rise of RH is more at the airport area (2.5%) than at the University site (1%).

The variability in the vertical extent of sea breeze at the two sites may partly be due to prevailing wind conditions[20]. The peculiar orography of this region modifies the generally expected southwesterlies in the lower levels. The southwesterlies would be deflected by Yarada hill resulting in more southerly component at airport area, while more westerly component of the prevailing wind develops at the University site[21]. In addition, the region being hilly, mountain and valley winds would also develop and modify the sea breeze circulation. The rapid modification of marine air and wider zone of low-level echoes reveal more turbulence within the sea breeze at the airport area. The sea breeze at the airport has a long fetch of land (8 to 17 km) with hilly regions to cross before reaching the sounder sites, whereas sea breeze at the University site has a small fetch of land (1 to 3 km) with small residential buildings. The differences in the lengths of fetch (amount of heating) and in roughness (mechanical friction) along the two fetches should be considered for comparing the sea breeze thermal turbulence distribution. For example, an increase in roughness decreases the intensity of sea breeze, but increases turbulence and vice versa. The increased turbulence at the airport area is thus understood to be due to increased travel distance and roughness.

4 Conclusion

On the basis of the simultaneous observations it can be concluded that there is a marked variability in the onset, duration, depth and stability stratification of sea breeze at the University site and the airport observatory. This significant variation is a result of topographic and land heating effects on sea breeze. Influences of complex topography could not be distinguished from the ideal sea breeze phenomenon due to lack of more detailed meteorological data. A more comprehensive observational programme that includes a mesoscale network of self-recording instruments will be essential to critically examine several features noted in this paper.

Acknowledgement

The opportunity for this work was provided by Prof. B Ramachandra Rao, MP. Thanks are due to Dr S P Singal, National Physical Laboratory, New Delhi, for helpful discussions and Mr K Raja Kumar for the technical assistance in the installation of acoustic sounder at airport observatory. This work was supported by the University Grants Commission, New Delhi.

References

1 Barbato J P, *Bull Am Meteorol Soc (USA)*, **59** (1978) 1420.
2 Wexler R, *Bull Am Meteorol Soc (USA)*, **27** (1946) 272.
3 Brittain O W, *Meteorol Mag (GB)*, **107** (1978) 88.
4 Clancy R M, Thompson J D, Hurlburt H E & Lee J D, *Mon Weath Rev (USA)*, **107** (1979) 1476.
5 Vittal Murthy K P R, Sarma K S & Rao B S, *J Inst Environ Eng (India)*, **63** (1983) 117.
6 Purnachandra Rao M, Raghu Kumar A, Murthy J S R & Poornachandra Rao C, *Indian J Radio & Space Phys*, **10** (1981) 176.
7 Purnachandra Rao M, Raghu Kumar A, Murthy J S R, Rao A S M & Poornachandra Rao C, *Indian J Radio & Space Phys*, **11** (1982) 199.
8 McAllister L G, Pollard J R, Mahoney A R & Shaw P J R, *Proc IEEE (USA)*, **57** (1969) 579.
9 Cronenwett W T, Walker G B & Inman R L, *J Appl Meteorol (USA)*, **11** (1972) 1351.
10 Parry H D, Sanders M J & Jensen H P, *J Appl Meteorol (USA)*, **14** (1975) 67.
11 Rizzo K R, *Special rep.* 28, *Centre for Great Lake Studies, University of Wisconsin, Milwaukee, USA*, 1975.
12 Munn R E, *Land and sea breezes*, *Chap.* 19, in *Descriptive micrometeorology*, *Advances in Geophysics*, *Suppl.* 1 (Academic Press, New York and London), 1966.
13 Venkatram A, *Atmos Environ (GB)*, **11** (1977) 479.
14 Lyons W A, *J Appl Meteorol (USA)*, **11** (1972) 1259.
15 Russell P B & Uthe E E, *Atmos Environ (GB)*, **12** (1978) 1061.
16 Aggarwal S K, Singal S P, Kapoor R K & Adiga B B, *Boundary Layer Meteorol (Netherlands)*, **18** (1980) 361.
17 Natarajan K K, *Indian J Meteorol & Geophys*, **15** (1964) 431.
18 Narayan V & Murthy G K, *Indian J Meteorol & Geophys*, **20** (1969) 401.
19 Purnachandra Rao M, *Acoustic sounding of sea breeze at Visakhapatnam*, Ph.D. thesis, Andhra University, Waltair, 1981.
20 Frizzola J A & Fisher E L, *J Appl Meteorol (USA)*, **2** (1963) 722.
21 Ramanadham R & Subbaramayya I, *Indian J Meteorol Hydrol & Geophys*, **16** (1965) 241.