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Sea Breeze Detection with Acoustic Radar

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A preliminary study on sea breeze fronts has been made at Visakhapatnam using a monostatic acoustic radar situated in the University campus, very near to the sea shore. During the summer of 1980 sea breeze was almost a daily phenomenon at Visakhapatnam, and was usually seen as a well marked distinct change in the character of the acoustic radar records. The increased thermal turbulence associated with the transfer of heat from the surface into the layer of marine air produced enhanced sound scattering up to the height of 150 m. The sea breeze often created an elevated layer usually in the height range 200-500 m. Acoustic backscatter records obtained in May 1980, when the sea breeze was strongest, are presented and discussed in the light of the prevailing weather conditions and previous experimental studies reported from this station.

1. Introduction

The sea breeze arises from strong local pressure gradients due to differential heating of land and sea by the sun. Naturally, the sea breeze is strongest on clear and hot summer days[1]. A front-like sea breeze occurs at coastal stations when there is a moderate to strong offshore gradient wind to form a front-like boundary over the sea, between the warm land air and cool sea air; and when the land-sea temperature difference is strong enough to overcome this gradient wind, the front crosses the coast resulting in changes in wind, temperature, humidity and pressure[2]. Several attempts have been made to describe sea breeze mathematically. Estoque[3] produced a model describing the formation of the circulation, its intensification, the movement of the whole pattern inland and its subsequent decay. Subsequently, much attention has been directed towards modelling of the sea breeze and much quantitative information concerning the development of the sea breeze has been derived from these studies[4,5].

Changes in the atmospheric stability due to land-sea breeze phenomena are important from the view point of air pollution, specially, for developed coastal urban areas like Visakhapatnam. An elevated inversion is often created with the passage of the sea breeze front, following the movement of the cool moist marine air over the land, which may fumigate and trap the pollutants. Stephens[6] has described a situation where a sea breeze caused the formation of photo-chemical oxidants and smog.

Several workers demonstrated the potentiality of the acoustic radar technique to study the sea breeze and lake breeze circulations in different parts around the globe. Using a sodar system, Aggarwal *et al.*[7] obtained very peculiar acoustic backscatter records in relation to land and sea breezes near Bombay. With the summer operation of an acoustic radar in 1974 at the University of Toronto (Canada), Bennett and List[8] detected lake breeze which developed over Toronto due to Lake Ontario. As a test of the usefulness of acoustic radar data to local forecasters, particularly, those concerned with air pollution, Edinger[9] compared the heights of the marine layer as detected by sodar to those obtained with radiosonde and light aircraft measurements, and found a good agreement between them.

During the summer of 1980, sea breeze was almost a daily phenomenon at Visakhapatnam which produced distinct changes in the character of the acoustic radar records. Records for the month of May 1980 (pre-monsoon period), when the sea breeze was strongest, have been presented and discussed in the light of the prevailing weather conditions. A crude comparison has also been attempted to correlate these results with those reported earlier by Ramanadham and Subbaramaiah[10] from this station despite the differences in the two techniques used.

2. Location of the Site and Principle of Acoustic Radar

The acoustic radar site is located in the Andhra coast. It is about 1 km away from the coast line which is oriented in the southwest-northeast direction. In the northwestern side of the sodar site is the Kailasa hill range with heights of about 300 m.

Several detailed descriptions of the principles of acoustic sounding are available in literature[11-13]. Basically, an acoustic radar (acdar or sodar) operates on a backscatter principle very much similar to that of a radar. A pulse of sound is transmitted into the atmosphere and the amount of sound scattered back is measured as a function of height. Received signals are displayed on a height-time diagram with darker areas marking the times and heights of strong acoustic backscattering. The format of these records is fairly conventional in the field of acoustic sounding. The specifications of the acoustic radar used in this study are given in Table 1.

Table 1—Acoustic Radar Specifications

Frequency of operation	1600 Hz
Output power	
Electrical	100 W
Acoustical	10 W
Pulse duration	100 m sec
Pulse interval	18 sec
Operational range	1000 m
Transmit-receive antenna	Paraboloid reflector surrounded by acoustic cuff

3. Detection of Sea Breeze Circulation

Repeated occurrences of sea breeze during the summer of 1980 at Visakhapatnam produced a recognizable pattern of events in the acoustic radar records. Some of the records obtained in May 1980 are shown in Figs. 1 and 2. There were two primary characteristics of the acoustic radar record that indicated the presence of sea breeze. (i) There was a regime of convective plumes produced by moderate to strong surface heating prior to the arrival of the sea breeze front[8]. The convective plumes were characterized by short (2-10 min) bursts of strong scattering extending over a considerable vertical range, usually 200-500 m. The plumes were intermittent, usually, with little or no scattering occurring between them. With the passage of the sea breeze front the intermittent thermal plumes were replaced by an intensified low level signal that was fairly uniform in time. (ii) The second characteristic was a limited vertical extent and temporal coherence of the echo region. This type of record is indicative of a stable region limiting the vertical development of turbulent scattering region. The probable explanation for this is that the intensified low level scattering was associated with the strong vertical heat transfer from the surface into the layer of

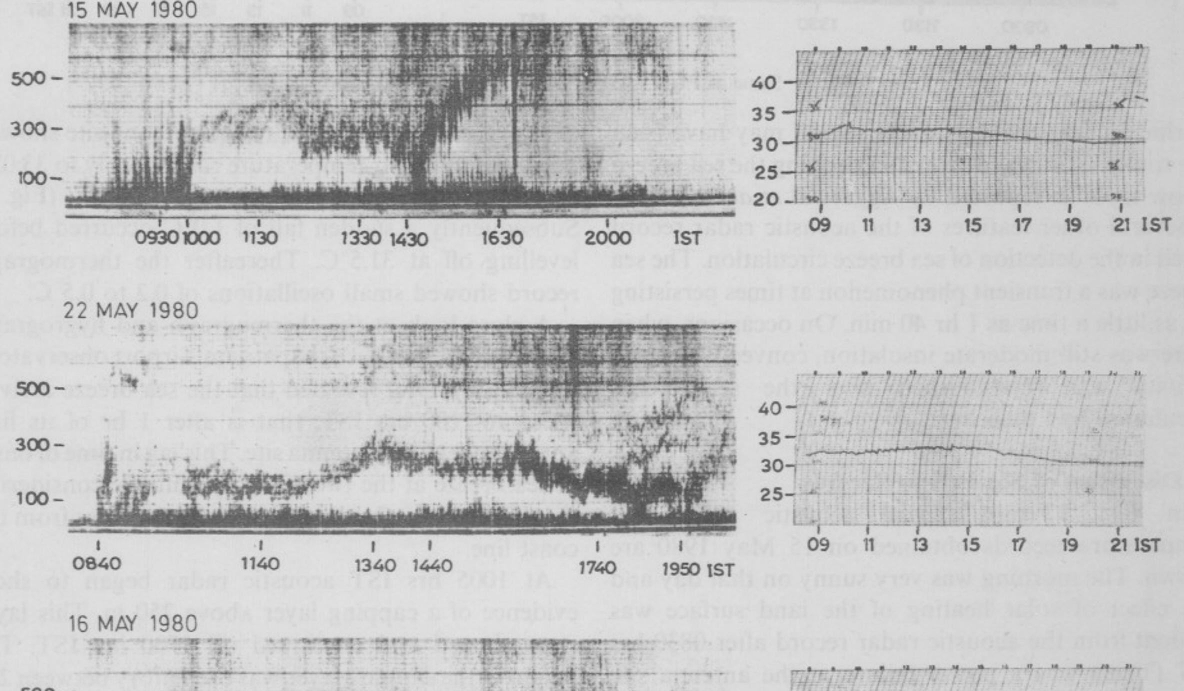

Fig. 1—Acoustic radar records for 15, 22 and 16 May 1980 showing three examples of sea breeze related returns [The horizontal scale is the local time of the day (hrs IST) while the vertical scale gives the heights (m) of scattering features. Also shown (right side) are the surface temperature (°C) records from the antenna site for the corresponding days.]

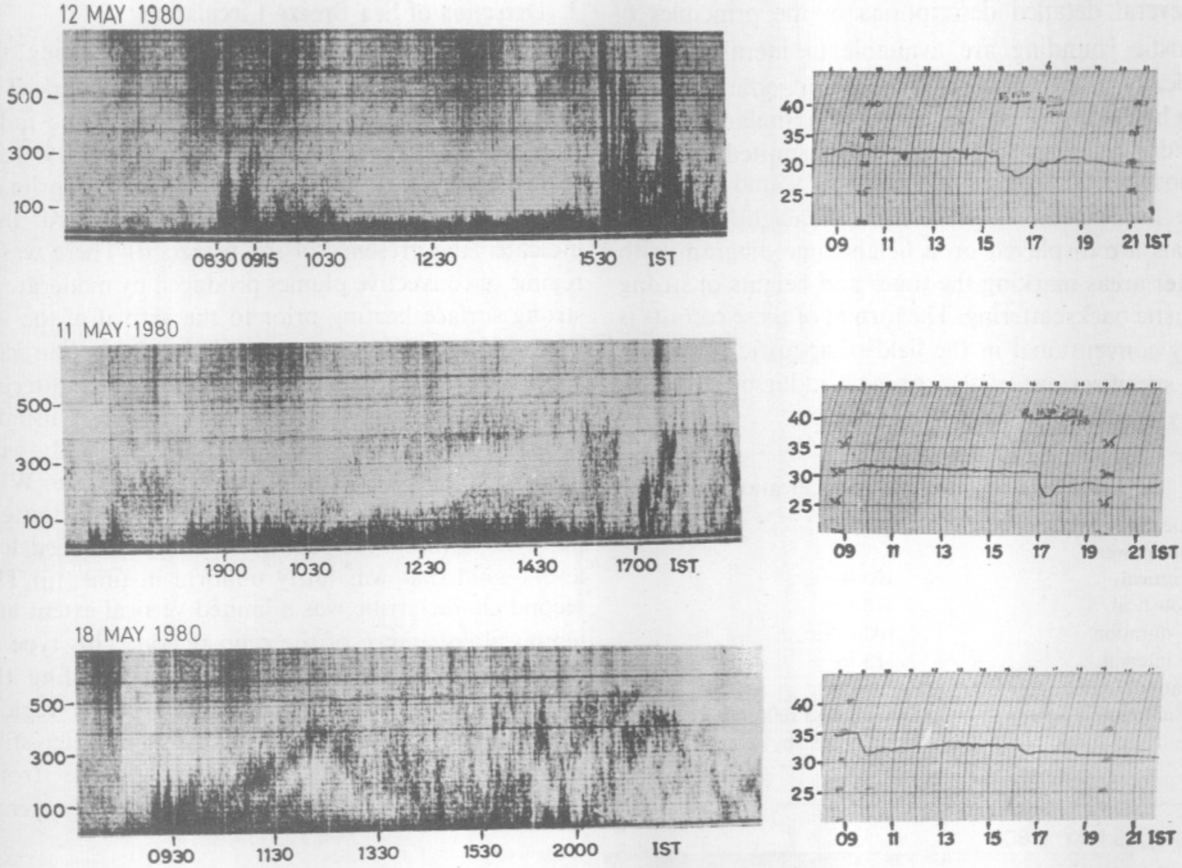

Fig. 2—Same as Fig. 1 except for 12, 11 and 18 May 1980

marine air and that the stable region may have been due to the subsidence inversion capping the sea breeze inflow layer as reported by Aggarwal *et al.*[7]

Several other features of the acoustic radar record aided in the detection of sea breeze circulation. The sea breeze was a transient phenomenon at times persisting for as little a time as 1 hr 40 min. On occasions, when there was still moderate insolation, convective plume activity was reestablished after the sea breeze circulation had died out.

4. Discussion of Sea Breeze Records

In Fig. 1 (top) typical acoustic radar and temperature records obtained on 15 May 1980 are shown. The morning was very sunny on that day and the effect of solar heating of the land surface was evident from the acoustic radar record after 0830 hrs IST (There was a power failure at the antenna site between 0600 and 0830 hrs IST.) as the height of the plumes started to increase. With the arrival of the sea breeze front at 1000 hrs IST the plume activity was abruptly quenched and scattering below 100 m was intensified and became persistent. The sloping echo region to a height of 300 m at 1000 hrs IST corresponds to the frontal surface of the sea breeze circulation[14]. The thermograph (1.37 m above ground level and 65.74 m above msl) located close to the antenna site showed that the surface air temperature rose sharply to 33.0°C prior to the onset of the sea breeze (Fig. 1). Subsequently a sudden fall of 1.0°C occurred before levelling off at 31.5°C. Thereafter the thermograph record showed small oscillations of 0.2 to 0.5°C.

A close look at the thermograph and hygrograph records (Fig. 3) of Visakhapatnam Airport observatory for 15 May 1980 revealed that the sea breeze arrived there at 1100 hrs IST, that is after 1 hr of its first appearance at the antenna site. This lag in time of onset of sea breeze at the two sites is justifiable considering the difference in the distances of the two sites from the coast line.

At 1005 hrs IST acoustic radar began to show evidence of a capping layer above 250 m. This layer strengthened and continued till 1700 hrs IST. The height of the capping layer was oscillatory between 200 and 350 m till 1330 hrs IST. Thereafter this layer had slowly descended to ground level at 1430 hrs IST and stayed there for 15 minutes and ascended quickly after 1445 hrs IST to a height of 500 m. During this 15-min period, the small oscillations in the temperature record close to the antenna site ceased and reappeared only after 1500 hrs IST and continued till 1700 hrs IST. But the hygrogram and thermogram of Visakhapatnam

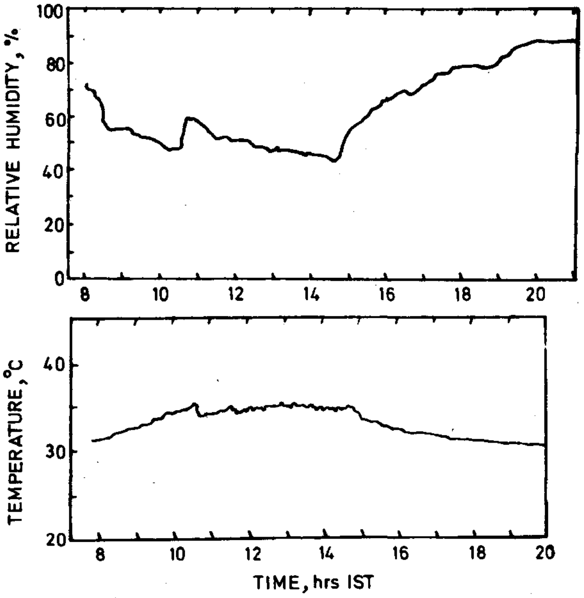

Fig. 3—Hygrograph and thermograph records of Visakhapatnam airport observatory on 15 May 1980

Airport observatory showed a sharp rise of 14% in relative humidity and a slight drop in surface air temperature at 1510 hrs IST. The surface wind turned more southerly from south-southwest with no appreciable change in the speed. From this it is inferred that a fresh surge of sea breeze had arrived at the two stations with a time difference of 40 min appearing first at the antenna site, as it is very close to the coast line. This fresh surge did not cause any surface air temperature change at the antenna site possibly because a shallow layer of sea breeze was persisting due to the nearness of the antenna site to the coast, whereas, it was completely absent at the airport observatory just before the occurrence of the fresh surge. However, to confirm these interpretations, collection of more meteorological data to higher levels is required.

Another record is obtained on 22 May 1980, a sea breeze day. This record clearly shows that the depth of the sea breeze circulation at Visakhapatnam was quite variable. The depth of the sea breeze circulation attained its maximum value at around 1340 hrs IST. At an interval of 1 hr 10 min (from 1230 to 1340 hrs IST) it increased by 120 m. From 1340 hrs IST the depth of the sea breeze started decreasing and continued so till 1810 hrs IST.

Fig. 2 (top) shows a very peculiar record obtained on 12 May 1980. Prior to the arrival of the sea breeze front, thermal plumes were observed on the record extending to a height of 350 m. The sea breeze circulation engulfed the antenna site at 0915 hrs IST and the intermittent thermal plumes were abruptly quenched and the scattering below 100 m was intensified. No elevated layer was observed on the record. This may be due to the lack of appreciable temperature contrast between the land air overlying the sea breeze air and the sea breeze itself[15]. The vertical currents associated with the surface convergence on account of sea level trough of low pressures at 0830 hrs IST over north coastal Andhra Pradesh and adjoining Orissa might have been responsible for the suppression of inversion on top of the sea breeze. It may be mentioned that a thundershower occurred in Visakhapatnam in the afternoon on account of this trough of low pressure.

5. Sea Breeze and Associated Surface Air Temperature Characterisitcs

Despite the variability of the structure, of sea breeze at Visakhapatnam, characteristic features such as increased low level scattering and capping layer by a stable region allowed the sea breeze to be detected. The characteristics of the sea breeze detected by the acoustic radar on 27 occasions in May 1980 and the associated surface air temperature characteristics (Fig. 4) are discussed below.

Out of 31 days in May 1980 sea breeze was observed on 27 days and only 16 of these caused an elevated layer giving the vertical extent of the sea breeze, while the remaining 11 sea breezes intensified the low level scattering to a maximum of 200 m and did not show any elevated capping layer. An examination of the weather data of these 11 days revealed that on 6 days thundershowers occurred at Visakhapatnam while on the remaining 5 days cloudy conditions prevailed. On all these days surface/upper air troughs affecting Visakhapatnam area were present.

The maximum height of the sea breeze during the observational period was nearly 500 m (15 May 1980 at 1630 hrs IST, Fig. 1) and the average onset time at the antenna site was 0945 hrs IST. The onset of sea breeze at Visakhapatnam was always delayed with height as shown by the acoustic radar records. For example on 16 May 1980 (Fig. 1 bottom) the sea breeze first appeared at 1020 hrs IST at ground level, but reached maximum height of 300 m only after 1500 hrs IST. A study on sea breeze at Visakhapatnam (unpublished) by one of the authors (C P R) using thermograph and hygrograph records of the observatory located close to the sodar site for the year 1977, showed that the average onset time of sea breeze at Visakhapatnam in May 1977 was 0937 hrs IST. This is in close correspondence with sodar determined onset times considering year-to-year variability of weather. Earlier, Ramanadham and Subbaramaiah[10] reported that the maximum height of the sea breeze at Visakhapatnam was 600 m.

The frequency distribution of onset time (Fig. 4) of the sea breeze at the antenna site showed that all the fronts arrived before noon with a maximum

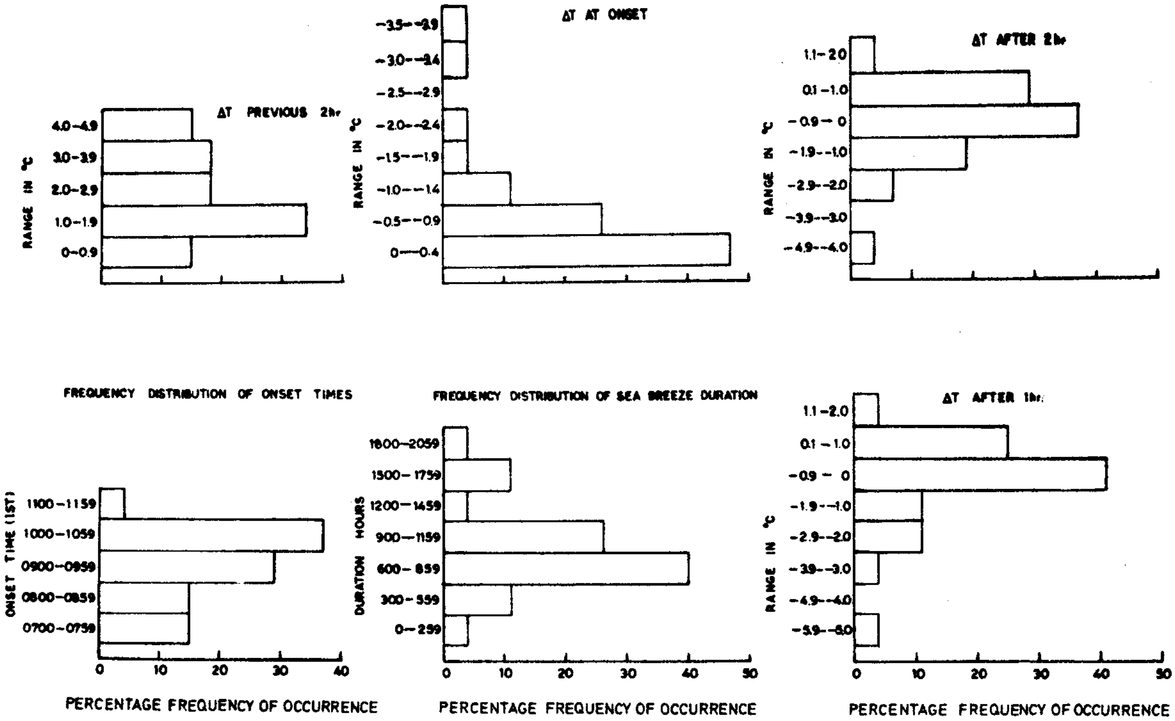

Fig. 4—Plots showing the characteristics of the sea breezes detected by acoustic radar on 27 occasions in May 1980 and associated surface temperature characteristics

occurrence between 1000 and 1059 hrs IST. The duration of sea breeze was within the range of 6 to 8.59 hrs on maximum number of days.

Frequency distribution of surface air temperature change (ΔT) in 2-hr interval preceding the onset of sea breeze showed that the temperature was always found to be increasing. This warming trend was reversed by the onset of sea breeze.

Frequency distribution of temperature change at onset showed that the temperature was always decreasing with a sharp maximum in the range 0 to -0.4°C. On occasions the surface air temperature decreased by as much as 3-4°C with the onset of sea breeze.

The distribution of temperature change in the first hour (ΔT after 1 hr) and first two hours (ΔT after 2 hr) following the onset of the sea breeze has a wide range with several cases of temperature increases. Both of them showed weak maxima in the range -0.9 to 0°C. However, the majority of temperature changes were negative indicating that the inflowing marine air was controlling the rate of rise in surface air temperature over land.

6. Conclusion

The acoustic radar proved to be very useful for the detection and study of the sea breeze circulation over Visakhapatnam. In particular, the acoustic radar was able to show the following.

(i) The arrival of the sea breeze front and, frequently, the decay of the sea breeze circulation.

(ii) The effectiveness of the sea breeze in quenching the convective plumes.

(iii) The development of the stable capping layer which often accompanied the sea breeze.

(iv) The considerable variability in structure, depth and intensity (as inferred from the height of the low level scattering region) of the sea breeze.

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