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The Sea Breeze at Visakhapatnam

R. RAMANADHAM and I. SUBBARAMAYYA

Department of Meteorology and Oceanography, Andhra University, Waltair

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ABSTRACT. The development of sea breeze and its vertical structure at Visakhapatnam are studied during the premonsoon period. A number of observed characteristics of the sea breeze are described and discussed. The winds at an inland station 10 km distant from the coast are also examined to study the variations, as the sea breeze spreads inland.

1. Introduction

The land and sea breeze phenomenon is more often and prominently observed near the coasts in tropics than in higher latitudes. It has been attributed to the pressure gradients caused by the differential heating and cooling of land and sea during day and night.

Jeffreys (1922), Schmidt (1947), Haurwitz (1947) and Defant (1951) have linearised the equations of motion based on certain assumptions and obtained solutions for the land and sea breezes. Therefrom they discussed the nature of this phenomenon. The sea breeze though perpendicular to the coast in the beginning, turns more and more parallel to the coast in course of time, due to the Coriolis force. It is shown that the maximum sea breeze occurs a few hours earlier than when the temperature difference between land and sea in the evening becomes zero. The setting of sea breeze is delayed with height due to the gradual growth of the heated atmospheric layer. Pearce (1955) has studied the land and sea breezes by numerical method and obtained certain interesting results regarding the circulation and the temperature distribution. Estoque (1961) has found by similar methods that a zone of low level convergence develops at the forward edge of the landward current in the afternoon. The cumulus development parallel to the coastline in the afternoon is suggested to be the manifestation of this convergence.

Several observational studies of the sea breeze have been made in the past. Wexler (1946) and George and collaborators (1946) have given a good summary of observations regarding the characteristics of the land and sea breezes at the ground. Fisher (1960) has studied the circulation and temperature of the sea breeze cell in the vertical at different times of the day. But his studies are based on observations of two days only. In India sea breeze studies, made by Ramdas (1932), Roy (1941), Sajnani (1956), Venkateswara Rao (1955) and Ramakrishnan and Jambunathan (1958) have been confined mostly to the frequency of occurrence and the surface characteristics based on the autorecords of Dines anemographs, thermo and hygrographs.

During the premonsoon period the atmospheric conditions in India are favourable for the development of land and sea breezes. By April, a shallow heat low forms over the country approximately following the contours of the land mass. The low disappears at higher levels and an anticyclone is situated at 2 km. At still higher levels (above 5 km) the subtropical westerlies prevail over most of the region. Under these congenial conditions land and sea breezes develop very well and offer a good scope for their study.

Fig. 1. Map of Visakhapatnam region

2. Locality and observations

The authors, with the aim of studying the sea breeze development and its vertical structure during summer at Visakhapatnam, took biweekly pilot balloon observations at two stations, one near the coast and the other at a distance of 10 km. The location of the two stations is shown in Fig. 1. The coast is oriented nearly in the southwest and northeast direction. The whole region may be described broadly as a 'V' shaped valley, with one branch in the west-east and the other in the north-south orientation. In between the two branches is the Yarada hill of thousand feet height. The outer sides of the valley are surrounded by hills of nearly the same height. The peculiar orography of the region modifies the generally expected southwesterlies in the lower levels. In the southern branch of the valley the southwesterlies would be deflected by the Yarada hill and they develop more southerly component, while in the northern branch more westerly component is developed. Hence the station A experiences a general offshore wind while station B experiences an inland wind. The region being hilly, mountain and valley winds would also develop.

The single theodolite method was followed for the estimation of winds. Pibal ascents were conducted from 6 A.M. to 6 P.M. at intervals of 2 hours. The ground wind was measured with a Casella airmeter. The observations were started in the last week of March and continued till the middle of May of the year 1962. Due to certain handicaps the observational cycles on some days could not be conducted completely. On the whole eight complete cycles near the coast and five at the inland station were successfully carried out. More frequent observations could have been taken but for several practical difficulties which could not be manoeuvered. The winds at different heights were computed from the trajectories of the balloons. The vertical time sections of both speed and direction of wind were prepared for all the cycles at the two places. Significant diurnal variation of wind occurred in the layer below 1 km a.s.l. due to land and sea breezes.

3. Results and discussion

The beginning and the later development of the sea breeze could be very clearly noticed by the backing and strengthening of the wind in the forenoon. As a typical example, Fig. 2 is presented which shows the variation of

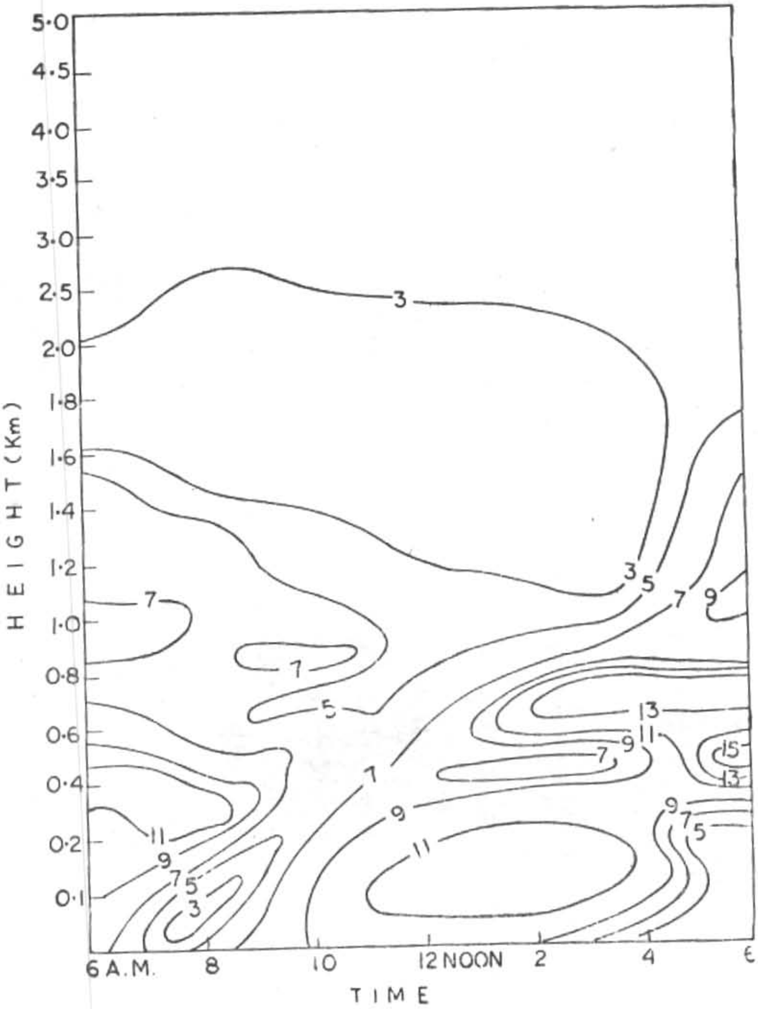

Fig. 2(a). Wind speeds on 9 April 1962 at station A

speed (in knots) and direction (in degrees) at different heights during day time. The winds in the upper levels are very weak. In the lower levels they weaken after sunrise, reach a minimum and then rapidly strengthen before noon. This strengthening is also associated with backing and starts earlier at the ground (about 8–30 A.M.) and late at higher levels. The sea breeze attains a maximum at noon time but its depth increases till evening. Gradual veering takes place in the afternoon.

The time of onset of sea breeze, its strength, thickness, the amount of forenoon backing etc are found to vary from day to day. These variations are due to a number of factors like the synoptic situations with the associated wind and clouding, the previous rains, etc. The present interest is not the study of those factors but the general characteristics

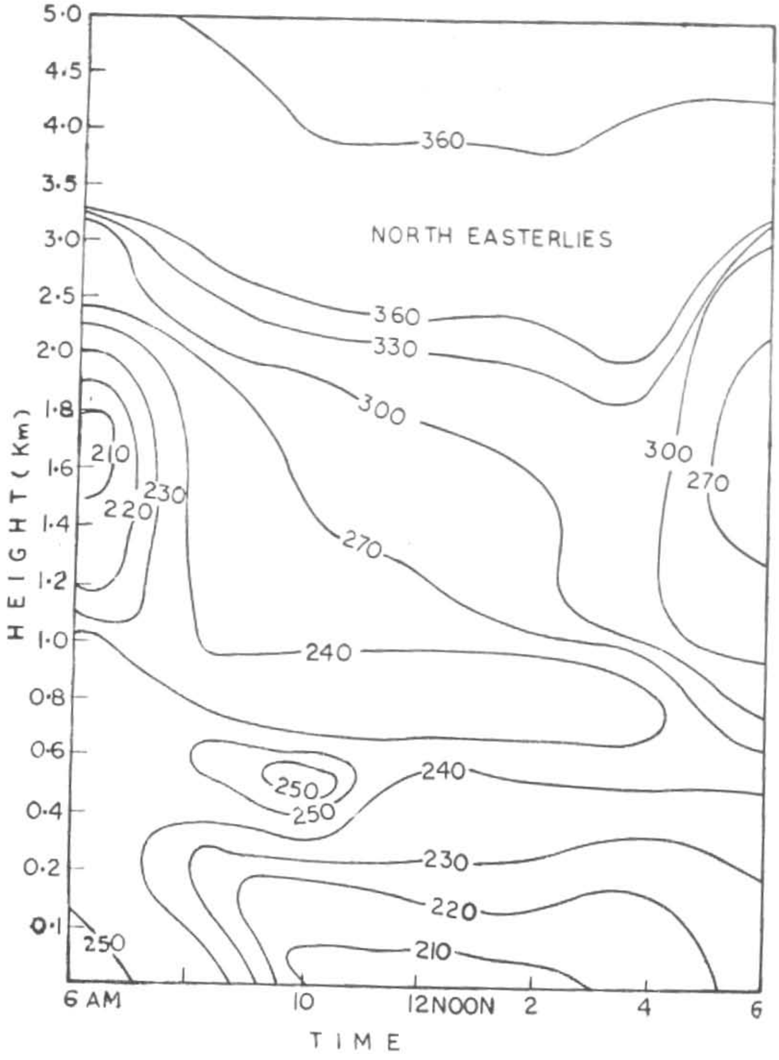

Fig. 2 (b). Wind directions on 9 April 1962 at station A

of the sea breeze development and its vertical structure. As such the wind components parallel and normal to the coast at different heights and times of the day were evaluated for all the cycles. The averages of the wind components for different levels for each hour of ascent were obtained and the mean vertical time sections of both the components at the two stations were prepared (Figs. 3 and 4). During the period of observations (27 March to 15 May) the pressure gradient near the coast intensifies. Nevertheless, the isobars run nearly parallel to the coast line, as such the above changes in the synoptic situations do not introduce serious limitations in the present investigation.

Fig. 3 (a) shows the variation of the component normal to the coast at different levels at station A. In the morning hours, throughout the depth of the atmosphere considered, there is land breeze. This gradually weakens and becomes zero by about

8-15 A.M. at the ground. Thenceforth sea breeze developes rather rapidly which reaches to a maximum of 5 knots (on certain days it is 7 to 8 knots) at about 12-30 P.M. and then slowly weakens. The transition from land to sea breeze is delayed with height. The sea breeze maximum at higher levels also occurs some time after the surface maximum. At 0·2 km elevation maximum sea breeze is noticed at 2-30 P.M. Above 0·8 km there is land to sea wind throughout the day. This is partly associated with the upper anticyclone. It is evident from continuity considerations that there would be return currents at higher levels corresponding to the surface land and sea breezes. These return currents could not be seen clearly in the present case unlike the lower land and sea breezes. But, the early morning weak offshore wind between 0·6 and 2 km and the stronger wind in the evening may be the manifestations of the return currents. It can be seen that the return currents are not strong but extend over a thick atmospheric layer.

The wind component parallel to the coast (Fig. 3b) above 1 km is fairly constant throughout the day at any level. It decreases with height and reverses above 1·6 km. This is due to the thermal wind blowing parallel to the coast but opposite to the surface wind. The reversal at 1·6 km indicates that the warm low is confined to the lower 1·6 km depth. There is strong wind (8 knots) between 0·2 and 0·6 km in the early morning which decreases to about 5 knots by 8-00 A.M. and again intensifies in the afternoon. At still lower levels the parallel component is about 5 knots in the forenoon and intensifies in the afternoon. This intensification is due to the effect of the Coriolis force on the sea breeze (Haurwitz 1947).

The vertical time sections at the second station, though complicated, show certain interesting features. The perpendicular component (Fig. 4a) at higher levels is always directed towards the sea and it increases after 8-00 A.M. In the surface layers there is inland component throughout the day. It is very weak in the early morning, intensifies by noon and slowly weakens after 4-00 P.M. Between 0·1 and 0·8 km there is weak seaward component in the early morning which reverses in the forenoon itself; the reversal being delayed with height. The persistence of the landward component throughout the day in the lower levels may be due to the southerly wind produced by the deflection of the general westerly wind in the valley. Some time after sunrise the sea breeze reinforces the landward component of the general wind and hence it strengthens. (Particularly in the lowest 50 metres, there is very strong wind from south which appears both in the normal and parallel components. This strong wind is not due to the sea breeze. A detailed account of that is given at a later stage).

The depths of the sea breeze at the two stations seem to be nearly the same while its strength at the coastal station is more. It is rather difficult to compare the beginning of the sea breeze at both the places because of several complications at the inland station. Firstly, the general wind itself has a landward component, secondly, the valley wind modifies the beginning of the sea breeze. Also, it should be noted that the difference of times of onset does not indicate the time of travel of the sea breeze from station A to B. The sea breeze at the second station comes mostly from the southern branch of the valley.

The parallel component (Fig. 4b) shows variation similar to that at the first station in the upper layers. A very significant point to be noted is the strong wind in the surface 50 metres. This wind starts some time between 8-00 and 9-00 A.M. and remains fairly steady till evening. Its very shallow depth suggests that it may be due to the valley wind. The hills on the western side being predominant and their eastern slopes facing the rising sun, produce more and early valley wind than the other hills. Up-slope winds develop on the eastern sides of the hills due to the strong heating by the summer sun and the air from the two branches of the valley is drained to feed the up-slope winds.

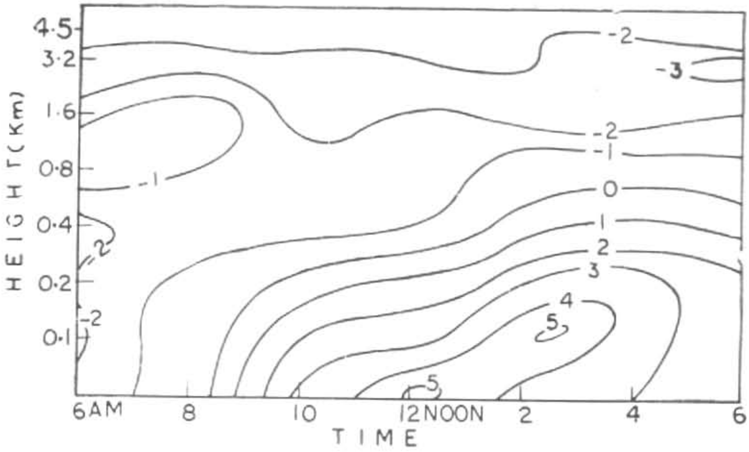

Fig. 3(a). Mean perpendicular component at station A

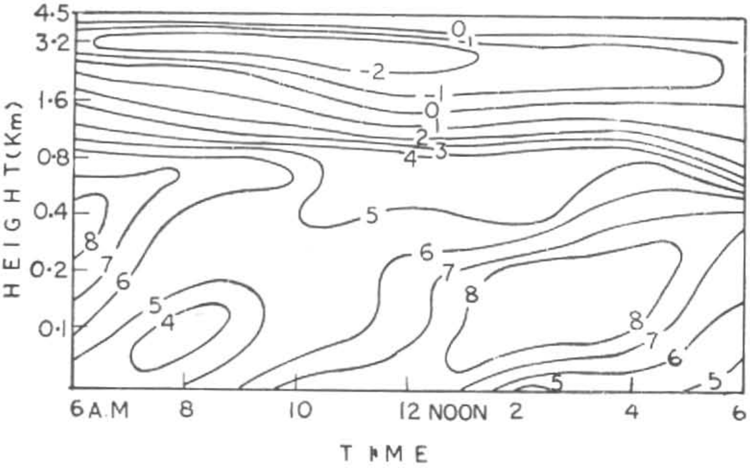

Fig. 3(b). Mean tangential component at station B

As a result southerly wind blows in the north-south oriented branch and easterly wind blows in the west-east branch. The station B being situated in the former branch near the hills, strong southerly wind is experienced at the surface, which appears both in the normal and parallel components. The intense upward motion over the western hills is further indicated by the huge cumulus development over those hills in the afternoon during the premonsoon period while over the other hills clouds are practically absent. (The intensive convention over Narava hills generally results in thunderstorms and most of the rainfall in this region is caused by them).

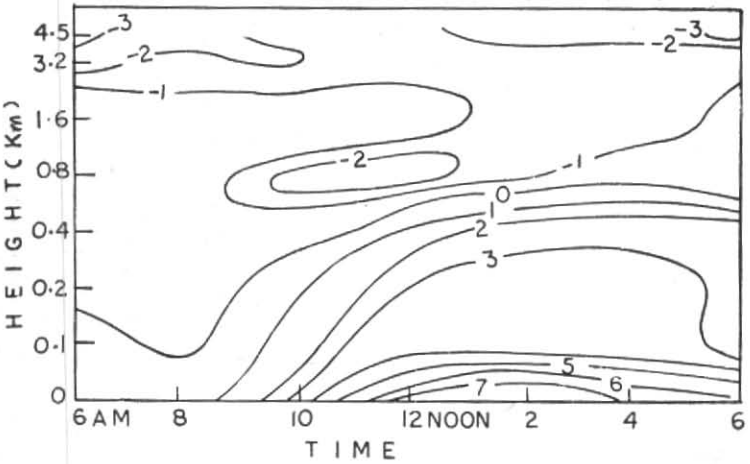

Fig. 4 (a). Mean perpendicular component at station A

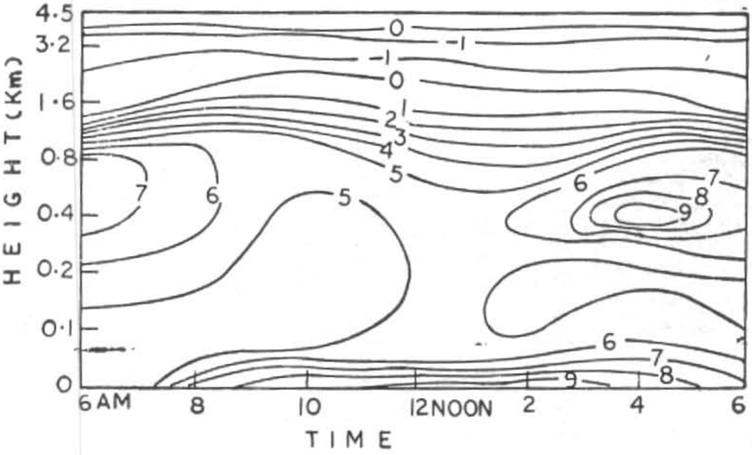

Fig. 4 (b). Mean tangential component at station B

At a height of about half a kilometre the parallel component is found to be strong both in the morning and evening and relatively weak during the period of active heating at the ground. Similar variation is noticed at the coastal station also. This typical change occurred on all the days of observation. It may be considered that the cyclonic circulation round the low over the country has maximum intensity at a height of half a kilometre which is retarded by friction at lower levels and weakened by thermal wind at higher levels. During the period of intense heating the isobaric surfaces at different levels over land are pushed up more, due to the greater heating than on the surrounding ocean. This weakens the low in the upper parts and the parallel component becomes less strong due to super-gradient wind. As the air flows out and the accelerated heating ceases, the low regains the original intensity in the afternoon. The weakening of the tangential component between 8-00 A.M. and 2-00 P.M. may thus be due to the process of adjustment of the atmosphere to changes produced during the heating of air. It should be noted that this phenomenon is connected with the oscillation of the large scale pressure system and the consequent super and subgradient winds.

4. Summary

The sea breeze sets in at about 8-30 A.M. at the ground during the premonsoon period. It is delayed at higher levels. The onset is associated with backing of wind. Maximum sea breeze occurs at 12-30 P.M. at the ground. Veering of the wind is noticed in the afternoon which is due to the effect of Coriolis force. The depth of the sea breeze increases till evening to a maximum of about 0·6 km. The return flow is very weak but extends over a much thicker layer of 2 km depth.

The sea breeze farther inland at a distance of 10 km is also very significant but is greatly modified because of the mountaneous terrain.

The wind component parallel to the coast also showed variation during the course of the day and is explained on the basis of the physical and dynamical processes that occur as a consequence of the heating.

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