A FRONTAL SURFACE OFF THE NORTH QUEENSLAND COAST

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ABSTRACT

A description is given of a front formed in the southeast trades off the north Queensland coast and along which there is often a line of raining clouds. The frontal surface is nearly vertical and at least 500 m deep. It forms at a distance from the land which increases as the incoming air becomes more southerly and it has been observed at up to 100 km from the coast. It is of considerable horizontal extent and is not associated with reefs or sea surface temperature changes.

INTRODUCTION

During the course of a series of measurements of the eddy fluxes of heat and vapour seawards of Cairns (16.51°S, 145.43°E) in June to July 1966 abrupt changes in wet and dry bulb temperature were noticed as the observing aircraft headed seawards before commencing the measurement program. An investigation of radiative properties of the atmosphere was carried out in the same area in July to August 1970; changes were observed in temperature and humidity similar to those found in the previous expedition. The characteristics of the frontal surface revealed by these measurements are summarized below.

(1) Potential temperature changes often in excess of 1°K occur in a horizontal distance sometimes little more than 1 km.

(2) There is an accompanying change in mixing ratio in excess of 1 g kg^{-1}.

(3) The temperature increases and the mixing ratio decreases through the front from the landwards to the seawards side.

(4) These temperature changes are separate from those at the landbreeze-seabreeze front which occurs closer to the coast.

(5) The front is roughly parallel to the coast at a position which changes little over a period in excess of 3 hr.

(6) It is of considerable horizontal extent.

(7) The distance from the coast at which it appears increases as the mean wind turns towards the south.

(8) It is not associated with reefs or sea surface temperature changes.

(9) The wind turns cyclonically at the front as the air moves in from the sea.

(10) The frontal surface is surprisingly close to the vertical and extends to heights in excess of 500 m.

The observations from which these deductions were made are described below. It should be emphasized that the observations, particularly those in 1966, were incidental to a separate measurement program, and much more work would be necessary to fully document the characteristics of the front and deduce its origin.

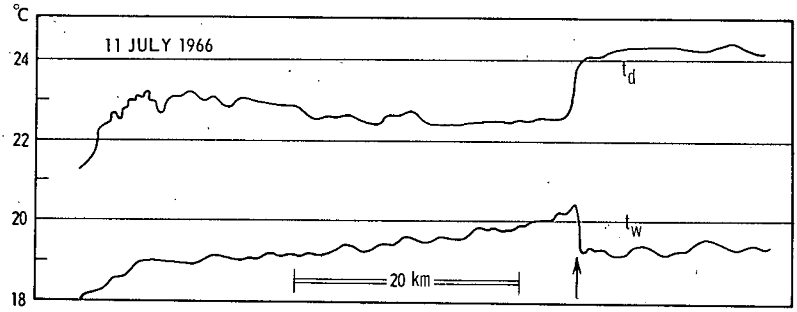
EQUIPMENT AND OBSERVING PROCEDURE

The observations were made from an instrumented aircraft. In the 1966 series of observations the basic purpose was to measure the fine structure of temperature, humidity and air motion, and papers describing these results have already appeared (Warner, 1971, 1972). In addition to the fine structure recorder a sequential printing unit recorded dry and wet bulb temperatures every 6 s and static and pitot-static pressures every 12 s throughout each flight. The response time of the temperature sensors was less than 10 s and their accuracy 0.05°C. The static and pitot-static pressures were used to deduce potential temperatures and to correct for adiabatic compression and heating of the air in the instrument housing. Information from an air mileage unit and a compass were combined in an instrument to enable an air plot to be maintained throughout each flight. The same equipment was used to obtain wind speed and direction by repeated passages over a fixed ground point such as an island or reef. In the 1970 series of observations the fine structure recorder was not installed; in its place net radiation and sea surface temperature were recorded. The slow-speed printing recorder and air plotting equipment were still installed and in use.

In 1966 the measurements of the front were restricted to a single height, 90 m, as the aircraft headed seawards towards the area selected for the main observing program or returned. Further, the heading on which the aircraft set out or returned usually gave little information on the horizontal extent of the front that was observed. In 1970 measurements were made over a wide range of heights from 30 to 550 m and soundings were made on either side of the front as the aircraft spiralled down from 1 km or more. In addition, the flights covered a much greater horizontal range of the frontal surface than those in the previous operation.

RESULTS

Tracings of two typical recordings of wet and dry bulb temperatures as the aircraft headed seawards from the coast at a height of 90 m are shown in Fig 1. These were taken at approximately 0900 hr and the cooler land breeze was still apparent near the coast; its effects had disappeared well before the occurrence of the sudden temperature changes arrowed in the figure.



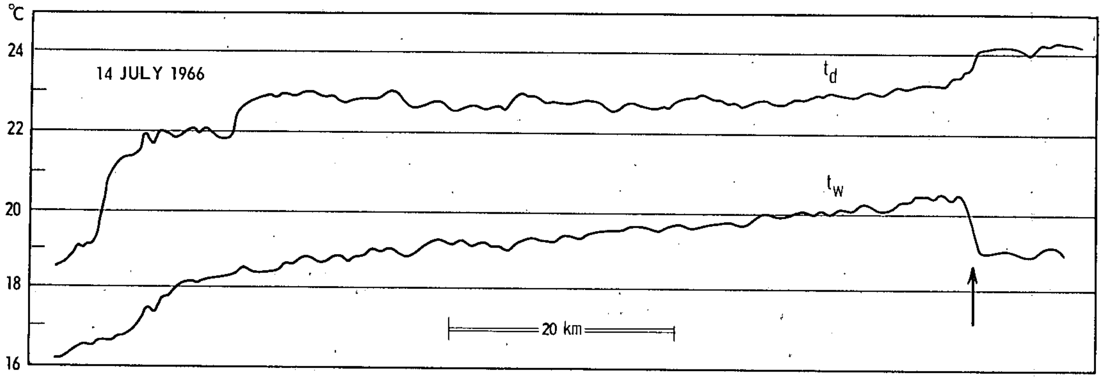


Fig 1 Tracings from dry and wet bulb temperature records as the aircraft headed seawards. In both cases the record commenced a few kilometres seawards of the coastline.

An example of a particularly sharp transition zone is shown in Fig 2. Here potential temperature and mixing ratio are given; they were computed as a matter of routine from all the recordings though normally only at 12 s intervals *ie*, approximately 750 m intervals for our flight speed of 65 m s^{-1}).

In Fig 3 the positions at which the front was observed on the out and return flights on two days are shown. Both flights were at a height of 90 m. Fig 4 shows a flight path on which the position of the front was determined over a distance of about 150 km parallel to the coastline. There is no indication that it did not continue for much greater distances to both north and south of the area studied. Apart from the positions at which soundings were made the aircraft remained at a height of 90 m above the surface, heading seawards and generally northeast till it passed through the front and then heading roughly northwest back towards the land till the front was again passed and then repeating the whole procedure.

The distance from the coast at which the front was observed is plotted against mean wind direction in Fig 5. The mean wind is that over the time interval from when the aircraft left Green Island heading seawards till its return to the island usually some 3 hr later. Since the aircraft spent a varying fraction of this interval in air seawards of the front, where the wind was more easterly than on the landwards side, the position of the front against the author's estimate of wind direction on the seawards side of the front is given in Fig 6. This wind direction was obtained by having the pilot turn the aircraft in stages till it was heading directly into the path of oncoming white caps. Experience indicates that this procedure produces a result consistent to within a few degrees in heading,

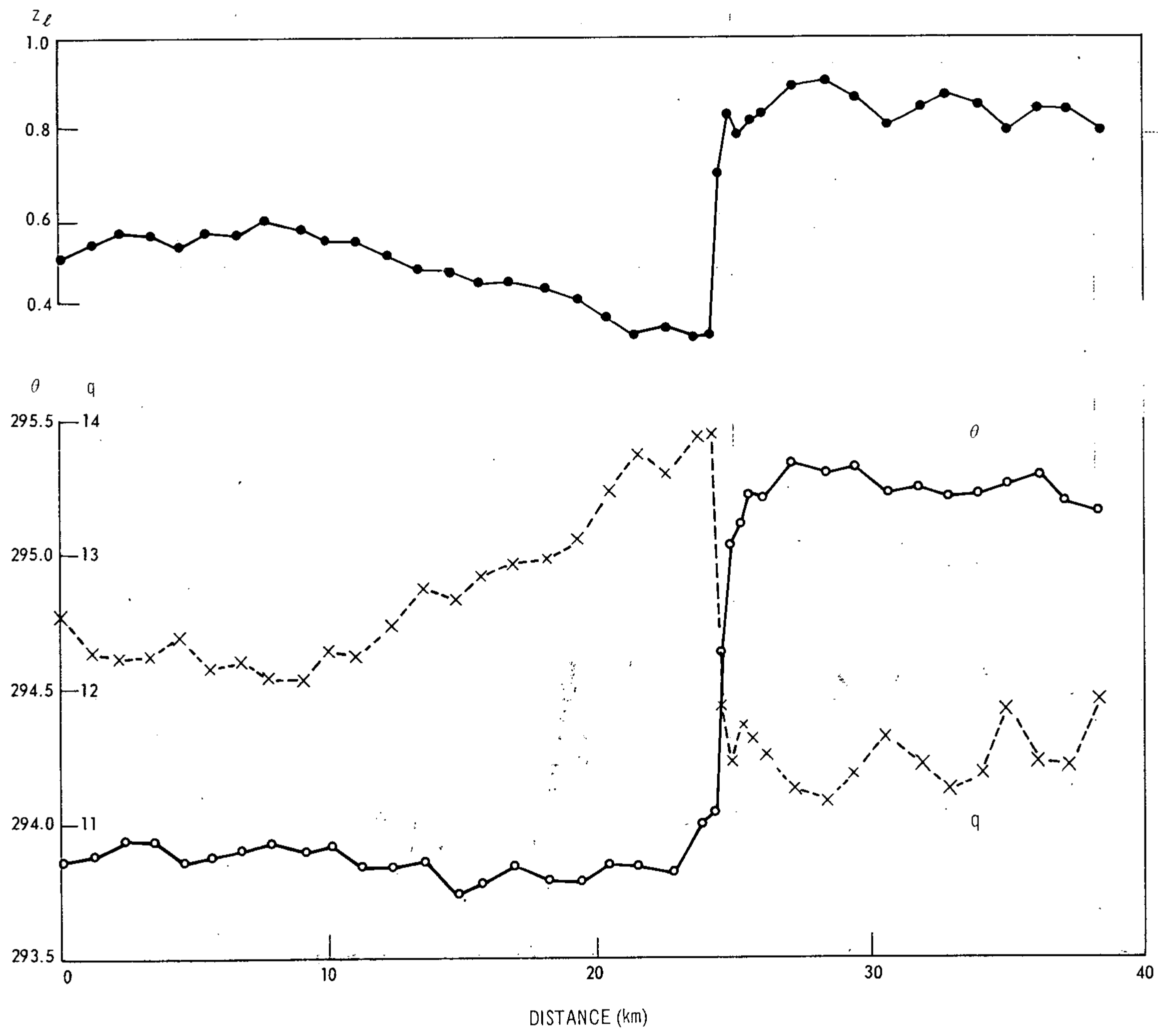


Fig 2 Potential temperature θ (K), mixing ratio q (g kg^{-1}), and lifting condensation level z_ℓ(km) as a function of distance. The starting point of the record is some kilometres seawards of the coastline.

provided the wind speed exceeds 4 to 5 m s^{-1} and white caps are readily visible; this was the case for all days of observation in 1966. In both Fig 5 and 6 it is clear that there is a strong correlation between wind direction and the distance of the front from the coast, with the distance increasing as the wind becomes more southerly.

Results of simultaneous measurements of sea surface temperature and air temperature with the aircraft at a height of 90 m are shown in Fig 7. Neither in these three cases nor in any of the other measurements was there any evidence that the sudden air temperature change was associated with a change in sea surface temperature. The example given for the 31 July flight is particularly interesting in this regard because the aircraft passed over a reef where the water was shallow and warmer than the nearby deep water; this sea surface anomaly produced a corresponding change in air temperature - displaced downwind as would be expected; however, the later, more marked air temperature change appeared over a region in which the sea surface temperature was nearly constant.

As was remarked earlier, during the 1970 expedition the front was investigated at a number of heights. An example is shown in Fig 8 where the front was encountered at heights of 30, 90, 250, 400 and 550 m. The positions plotted here are ground positions obtained from the air position by correcting for the observed wind and adjusting where necessary by reference to distance measuring equipment in the aircraft which gave the distance to Cairns. It is clear from this example that the front is nearly vertical, with a minimum slope of 60°. Also shown in Fig 8 are estimated winds at positions on either side of the front at which soundings were made.

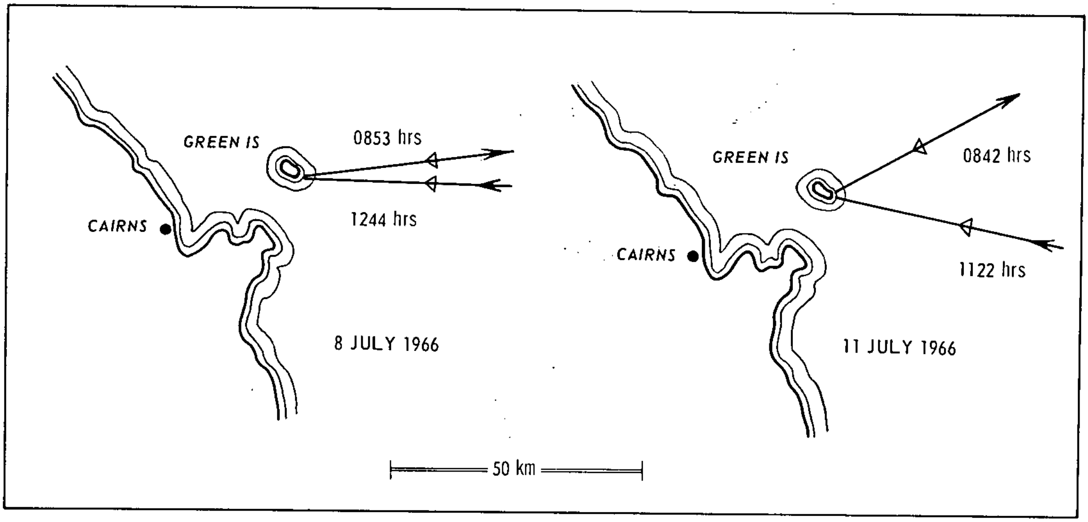


Fig 3 The triangles mark the position at which the front was encountered at the specified times on out and return flights on two days.

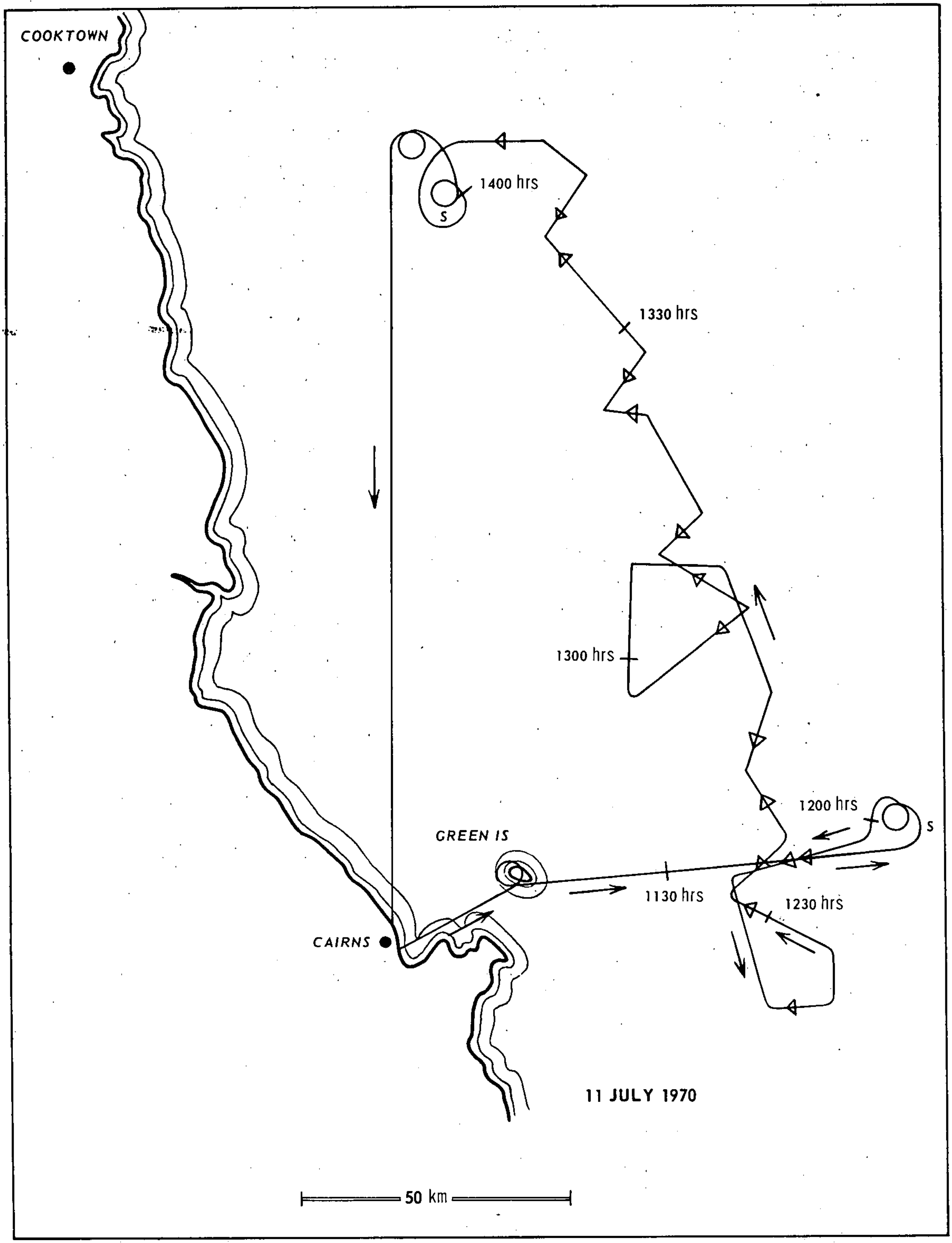


Fig 4 The position of the front is marked by triangles on the flight path indicated.

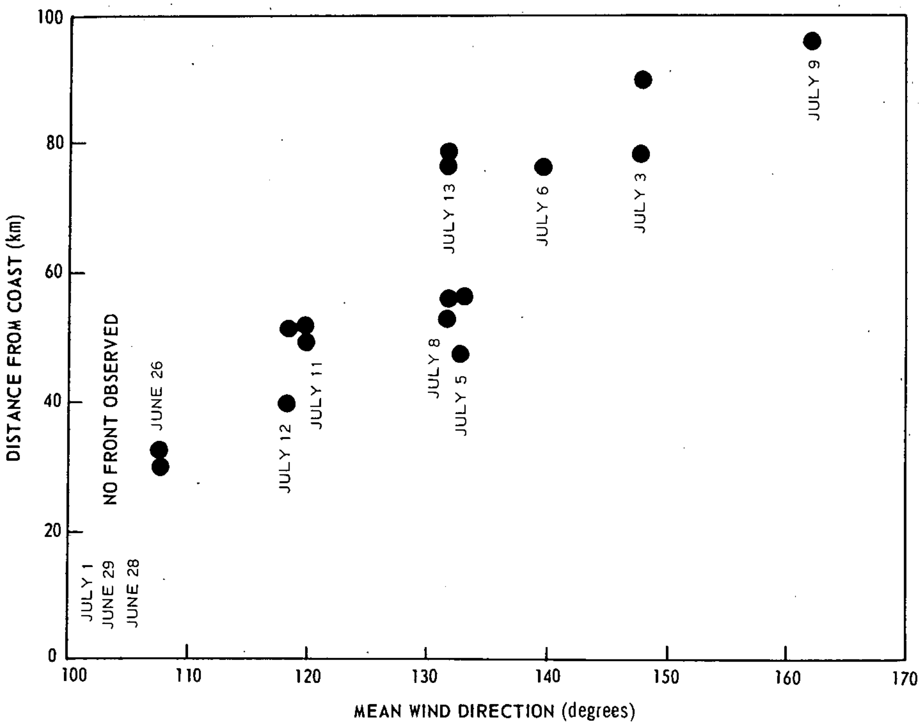


Fig 5 The distance from the coast at which the front was encountered as a function of mean wind direction during the 1966 expedition. The wind direction was between 100° and 105° on the days on which the front was not observed.

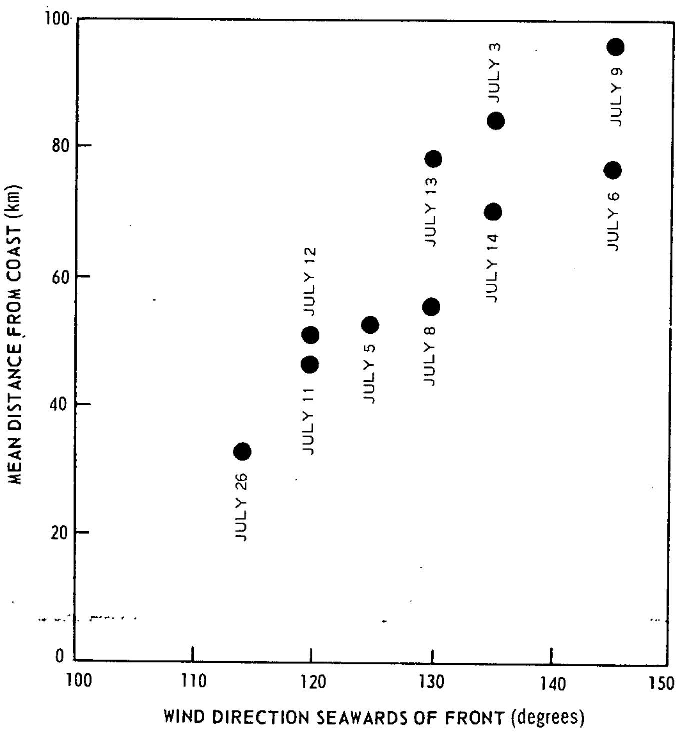


Fig 6 The distance from the coast at which the front was encountered as a function of wind direction on the seawards side of the front.

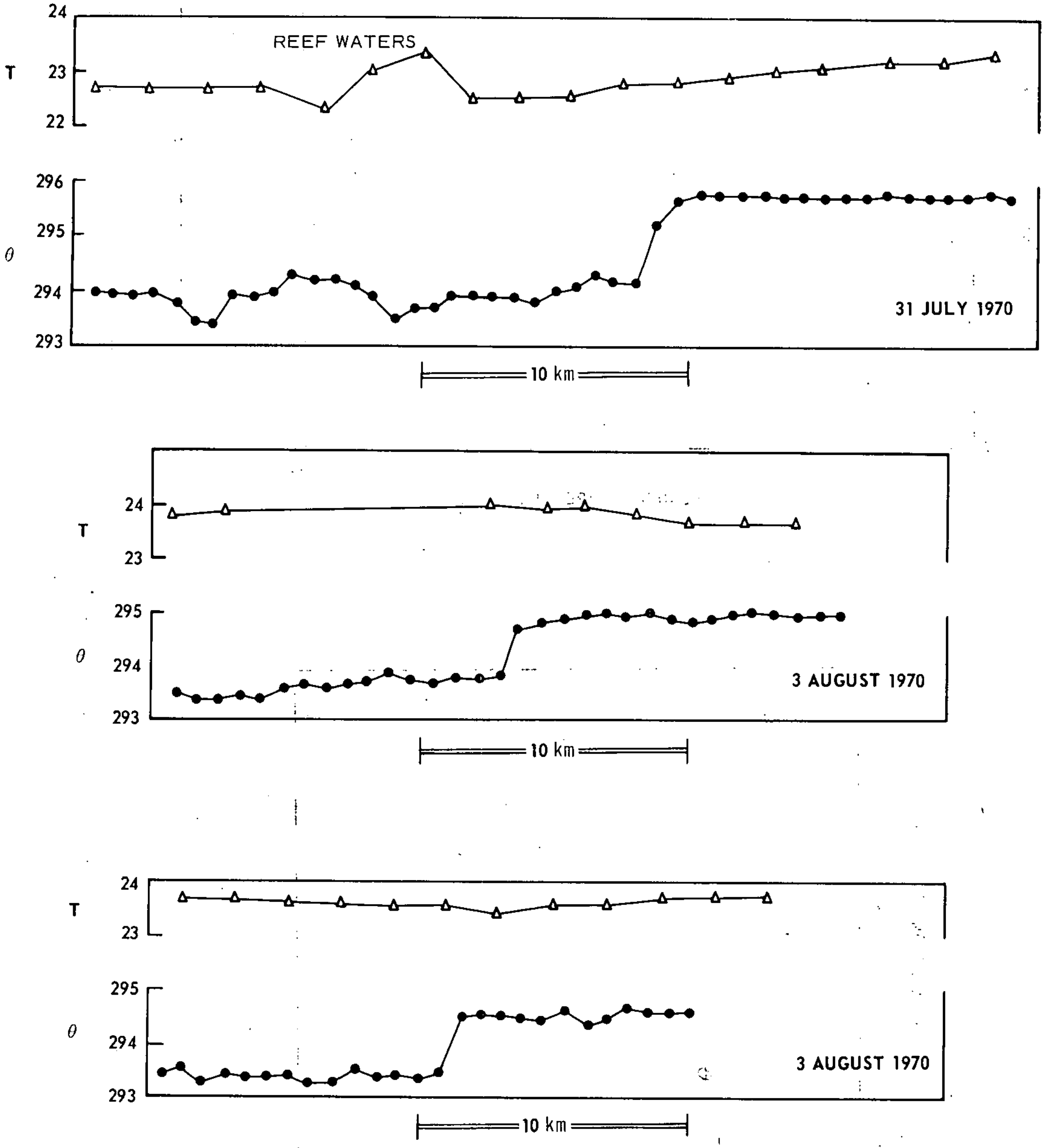


Fig 7 Simultaneous measurements of sea surface temperature T and potential temperature θ of the air at a height of 90m on three flights.

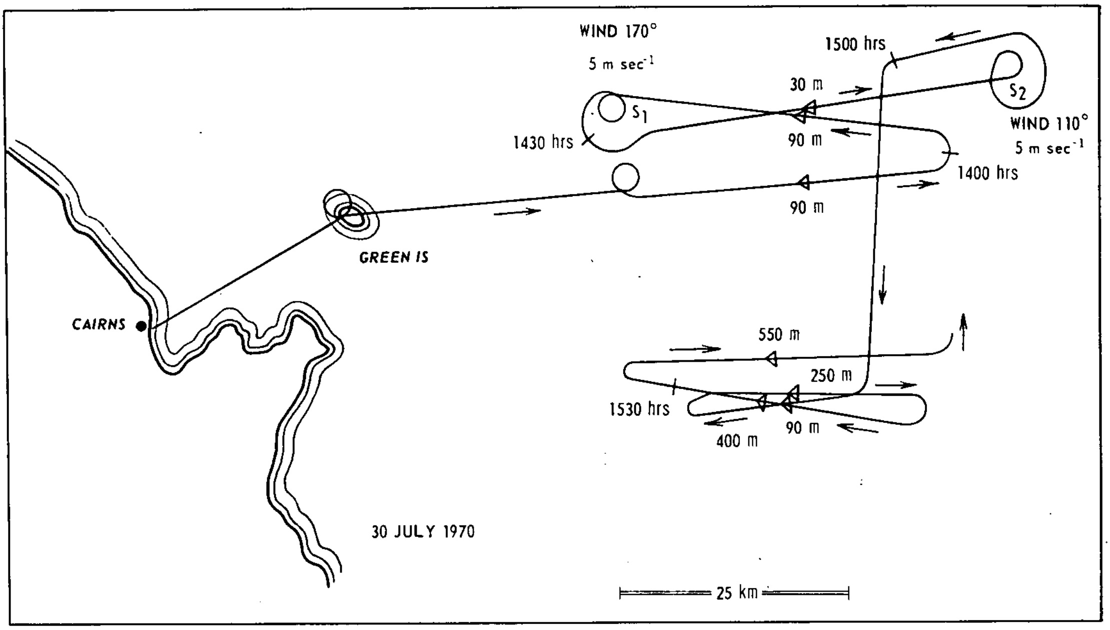


Fig 8 The position of the front at different heights on July 30 1970.

The potential temperature and mixing ratio obtained from these soundings are plotted as a function of height in Fig 9. There are differences in the soundings right up to the maximum height of 1 km at which measurements were made but the major difference is in the lower 500 m. Unfortunately no soundings were made immediately adjacent to and on either side of the front on this day nor on any of the other days on which flights were made. It is clear, however, that the front is at least 500 m deep.

DISCUSSION AND CONCLUSIONS

The front that has been described has a number of peculiarities. It seems likely that it results from a slowing and turning of the trade wind air as it strikes the land mass, but it is surprising that this should be effective up to 100 km from the coast. While the land immediately inland from the coast is hilly - rising in places to heights in excess of 1000 m - there is no continuous steeply rising ridge.

As seen in Fig 2, the lifting condensation level is at its lowest point at the front. This results in a bank of low clouds concentrated at the front which often produce heavy rain showers. The weather radar at Cairns often indicates a line of showers out at sea, and it is likely that they coincide with the front. An attempt was made during the 1970 expedition to use the radar to observe the front, but this was unsuccessful because of the use of unsuitable elevation angles and receiver gain settings. Further studies with the radar would appear desirable, as would further direct observations.

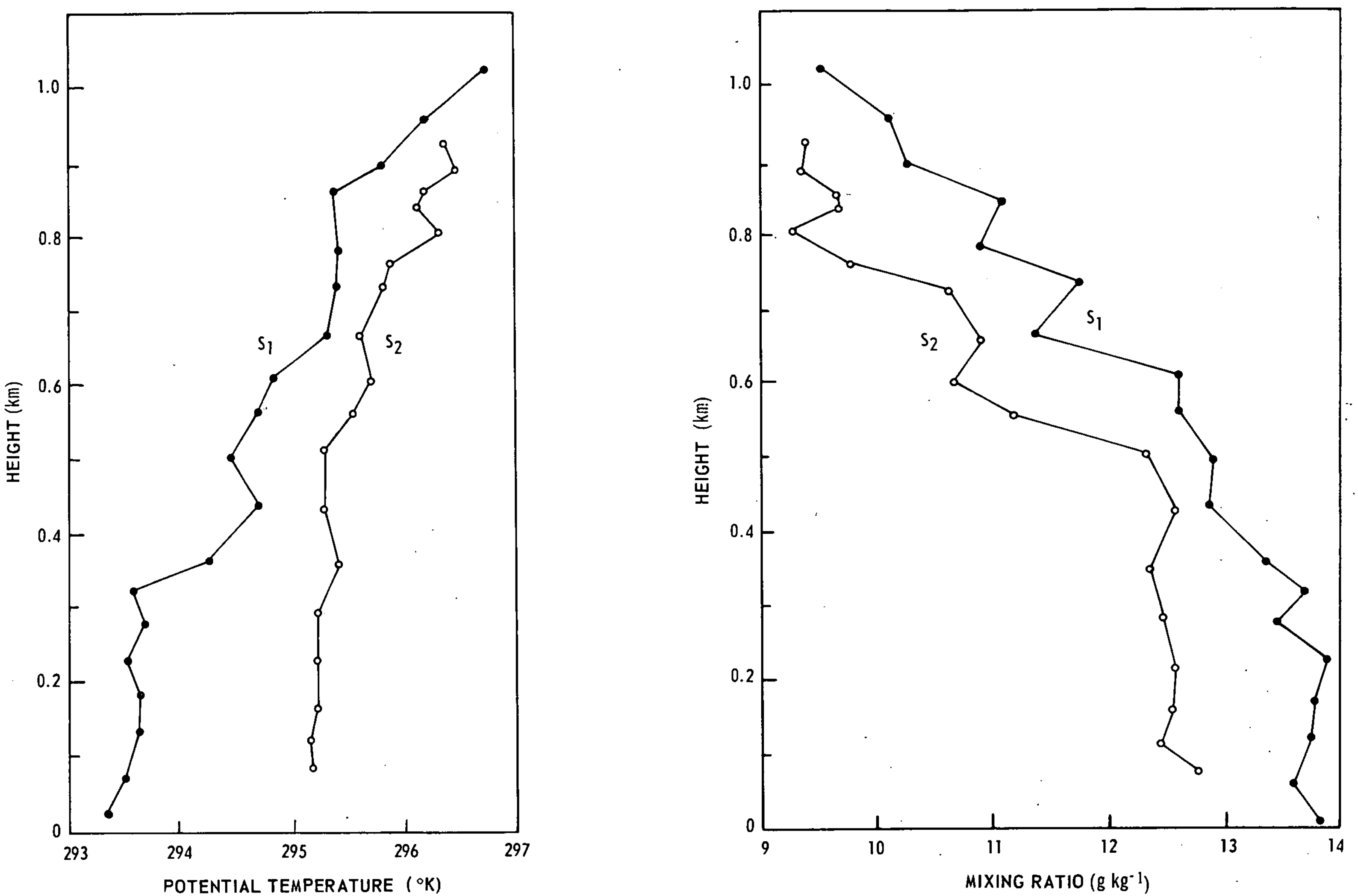


Fig 9 Soundings on either side of the front on July 30 at the positions marked in figure 8.

ACKNOWLEDGMENTS

The sea surface temperatures were measured by C.M.R. Platt, who kindly provided the data used in Fig.7. The temperature observations and other measurements in 1970 were made by H.E. Miller and A. Tapp. Most of the processing of the data from both expeditions was done by Mrs. C. Fraser.

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