

THE ESTIMATION OF ATMOSPHERIC WATER VAPOUR CONTENT FROM AIRBORNE MEASUREMENTS OF PRESSURE, TEMPERATURE AND REFRACTIVE INDEX

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ABSTRACT

The atmospheric radio refractive index can be expressed as an empirical function of pressure, temperature and water vapour pressure. Thus an aircraft, instrumented to supply fast response readings of refractive index, temperature and pressure, can give an accurate measurement of the atmospheric water vapour content at aircraft altitudes over large areas. Two examples of aircraft measurements over Bass Strait are included to illustrate the effectiveness of this technique.

INTRODUCTION

Hitherto, studies involving the detection and movements of different air masses have been hindered by the lack of suitably accurate methods of measuring the atmospheric water vapour content over large areas. Ground based equipment gives satisfactory surface measurements and balloon-borne radiosondes can supply vertical water vapour profiles, but these measurements are hardly adequate for today's forecasters and researchers.

During a study of anomalous radio-wave propagation in the Bass Strait area of southern Australia a method of estimating the atmospheric water vapour content from aircraft measurements became evident.

The radio refractive index of the atmosphere, n , differs little from unity and is thus usually expressed in terms of refractivity, N , where

$$N = (n-1) \cdot 10^6$$

Smith and Weintraub (1953) give the following empirical relationship for refractivity,

$$N = \frac{77.6P}{T} - \frac{6e}{T} + \frac{375000e}{T^2}$$

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where P is the atmospheric pressure in mb,
T is the atmospheric temperature in $^{\circ}\text{K}$,
and e is the partial pressure of water vapour in mb

It is evident from this equation that, near the earth's surface the refractivity is mainly dependent on the water vapour content of the atmosphere. A decrease of 1 mb in the partial pressure of water vapour is equivalent to a temperature increase of 4°C in producing a refractivity decrease of 5 N-units. Thus, an aircraft instrumented to give accurate readings of pressure, temperature and refractive index could provide atmospheric water vapour content measurements over large areas.

INSTRUMENTATION

A microwave refractometer - an instrument that can accurately measure the atmospheric radio refractive index - has been constructed and calibrated in the Physics Department, RAAF Academy, University of Melbourne (Barton, 1970). The instrument is similar to those used in England by Lane (1965) and in USA by Vetter and Thompson (1962) except that a Gunn-effect oscillator is used to generate the microwave energy. The refractive index measurement is achieved by comparing the resonant frequency of an open-ended cylindrical sampling cavity with that of a similar sealed reference cavity. As these resonant frequencies are a function of the refractive index of the gas within the cavities, their difference can be converted to a measure of the refractivity of the air flowing through the sampling cavity. Both cavities were machined from an iron-nickel alloy, invar, which has a temperature coefficient of expansion of $0.7 \text{ ppm}/^{\circ}\text{C}$.

The refractometer sampling cavity was mounted 18 in (460 mm) above the cockpit of an RAAF Dakota aircraft in such a position that the air sampled was undisturbed by the aircraft's slipstream (Fig 1). Vetter (1967) has reported that with a similar refractometer the sampling cavity maintains its accuracy to better than 1 N-unit in airstreams with speeds greater than 100 kn (185 km/h). A thermistor rod from an RCA 403 MHz radiosonde was placed in a radiation shield and mounted above the sampling cavity to measure the air temperature (Fig 1). The resistance of the thermistor was monitored by incorporating it in one arm of a resistance bridge. A multi-channel ultraviolet chart recorder was used to record the measurements of time, refractivity, temperature and static pressure (height).

The refractometer was calibrated by direct measurement of those parameters which determine the radio refractive index. The refractometer time response is 30 ms but aircraft vibrations necessitated some damping of the output so that the response was increased to 300 ms. The static pressure element had a time response of 70 ms and the nominal thermistor time response was 3 s at airspeeds of 5 kn (9.3 km/h), but with the increased airspeeds this latter response was reduced to 300 ms.

The information from the chart records was transferred to data cards and analysed using an IBM 7044 computer.

COLLECTION OF DATA

On days when the anomalous propagation of radio waves occurred over Bass Strait the instrumented aircraft sampled the atmosphere between Melbourne and King Island. The normal aircraft flight pattern consisted of spiral ascents or descents at spaced intervals along the flight path. These spirals had a radius of 1 n mi (1.85 km), a rate of ascent or descent of approximately 650 ft min^{-1} (200 m/min) and an altitude range between 150 and 5000 ft (46 and 1520 m) above sea level. On transit between spirals the aircraft supplemented the spiral measurements by making frequent excursions through any layer containing large refractivity or temperature gradients. The flight path and spiral locations are shown in Fig 2.

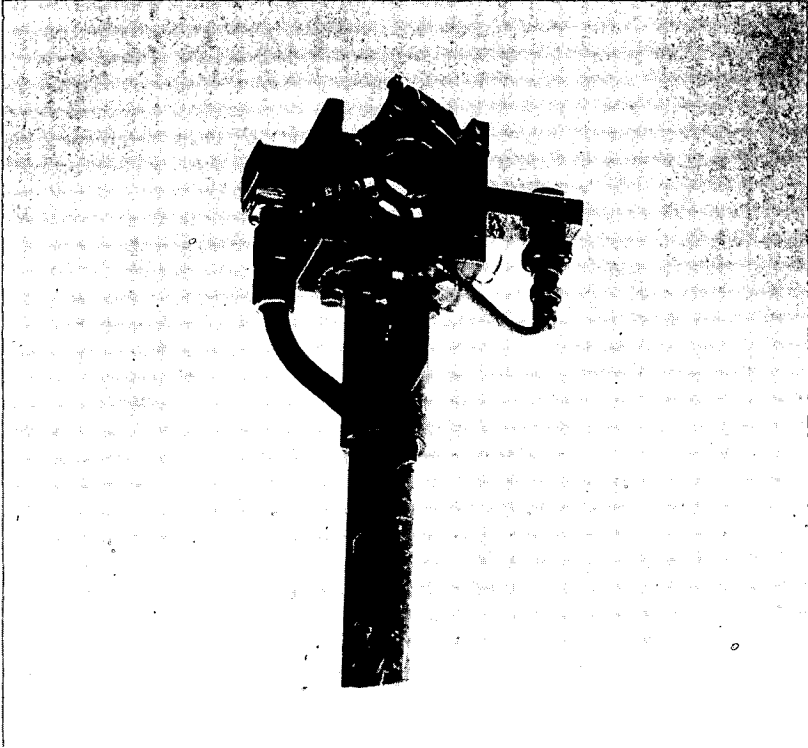


Fig 1 The refractometer sampling cavity mounted on the aircraft fuselage. The thermistor rod and shield are visible on top of the cavity.

(Photo by courtesy of RAAF).

EXAMPLES OF THE TECHNIQUE

The results from two sorties between Melbourne and King Island are presented and discussed to illustrate how this technique provides an accurate estimate of water vapour content and how it can be used to identify different air masses and their movements. The two sorties were flown at the following times.

Sortie 1	18 February 1971	0838 - 1307 EST
Sortie 2	2 April 1971	0940 - 1300 EST

Sortie 1

During this sortie the weather over the southeast of Australia was dominated by a high pressure system in the South Tasman Sea. The radiosonde balloon flight launched from Laverton, Victoria at 0900 hr detected an isothermal layer between 5000 and 6500 ft (1520 and 1980 m). The air below the layer had a relative humidity of 42% while that above was much drier at 24%. Radar tracking of the balloon showed that the area was under the influence of a northerly wind of 20 kn (37 km/h) from the surface to 4500 ft (1370m) with easterly winds above this level.

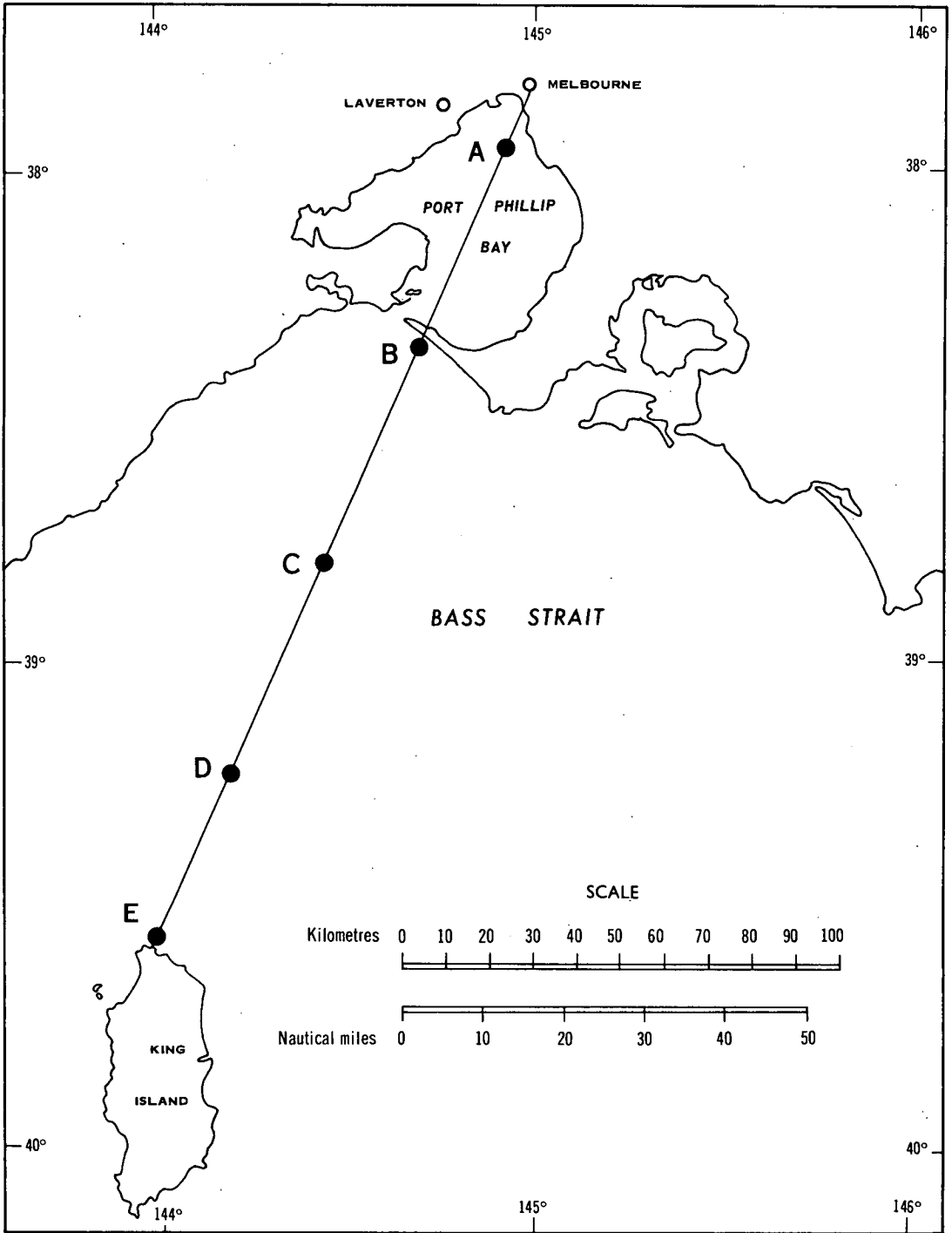


Fig 2 The aircraft flight path with spiral locations A, B, C, D and E.

From the aircraft results of this sortie profiles of refractivity, temperature and water vapour content were obtained and isopleth diagrams of temperature and water vapour pressure constructed. The set of profiles obtained near the mainland coast on the return journey of this sortie is shown in Fig 3. Two temperature inversions were detected and both were associated with a strong lapse rate of refractivity and water vapour content. The isopleth diagrams for both the outward and return journeys are presented in Fig 4 and 5. Both isotherm diagrams indicate a surface temperature inversion which involved a dense sea fog over the southern half of the flight path. While the aircraft was flying in this sea fog the refractometer sampling cavity became contaminated with small water droplets resulting in unrealistically high values of refractivity and leading to values of water vapour content that were well in excess of saturation. Once clear of the sea fog the sampling cavity was quickly cleared by the flushing action of the 100 kn (185 km/h) airstream. The anomalous radio propagation evident during this sortie was due to this temperature inversion (Barton, 1972). The isopleth diagrams also indicated a large dry air mass above 2500 ft (760 m) over the southern half of the flight path. The return journey diagrams show that this air mass was much drier than on the outward journey and suggests some east-west transport at these altitudes. Relatively moist warm air from the mainland transported by the northerly winds was flowing under this dry air mass and, as the moist air came in contact with the sea, a fog developed. Petterssen (1969) reports that advection fogs are frequent over the sea since the conductive capacity of water is very high and the air adjusts its temperature to that of the water surface. In the time between the outward and return journeys the boundary between the elevated dry air mass and the moister continental air, and the boundary of the sea fog had both moved 20 mi (32 km) south.

Sortie 2

At the time of this sortie the synoptic weather chart showed a high pressure system centred 500 mi (800 km) southeast of Melbourne and a cold front 900 mi (1450 km) southwest of Bass Strait. The 0900 hr radiosonde launched from Laverton, Victoria detected temperature inversions of 0.7°C and 2.5°C at 2200 and 5200 ft (670 and 1580 m) respectively. There was a large lapse rate of water vapour content at the upper inversion but no significant change across the lower. A 10 kn (18 km/h) northerly wind was present between the surface and 2000 ft (610 m) but above this level the winds backed to 8 kn (15 km/h) southwesterly at 4000 ft (1220 m).

Isopleth diagrams of temperature and water vapour pressure were again drawn from the aircraft measurements and are shown in Fig 6 and 7. Both the outward and inward diagrams show the existence of a front over the northern coast of King Island. During the outward journey the atmosphere between the surface and 5000 ft (1520 m) was quite moist with a relative humidity between 60 and 100%. However, on the return journey this situation had changed markedly. The air sampled was much drier than previously and a subsidence inversion with an associated dry air mass above was evident near 5000 ft (1520 m) at the northern end of the flight path. The appearance of the drier atmosphere between the surface and 4000 ft (1220 m) over the centre of the flight path can only be explained by east-west movement of the moister atmosphere and its replacement by relatively dry air. (There was no visual record of clouds or precipitation.)

CONCLUSIONS

The two examples cited illustrate how the aircraft measurement of refractivity, temperature and pressure could give an accurate measurement of atmospheric water vapour content over large areas and thus enable different air masses and their movements to be identified. The relatively high cost of aircraft hire and maintenance and the time factor involved in the collection of the raw data detract from this technique for use on a synoptic scale, nevertheless the prospect of accurately identifying the boundaries of different air masses and noting their movement and interaction should be attractive to research workers involved in these studies.

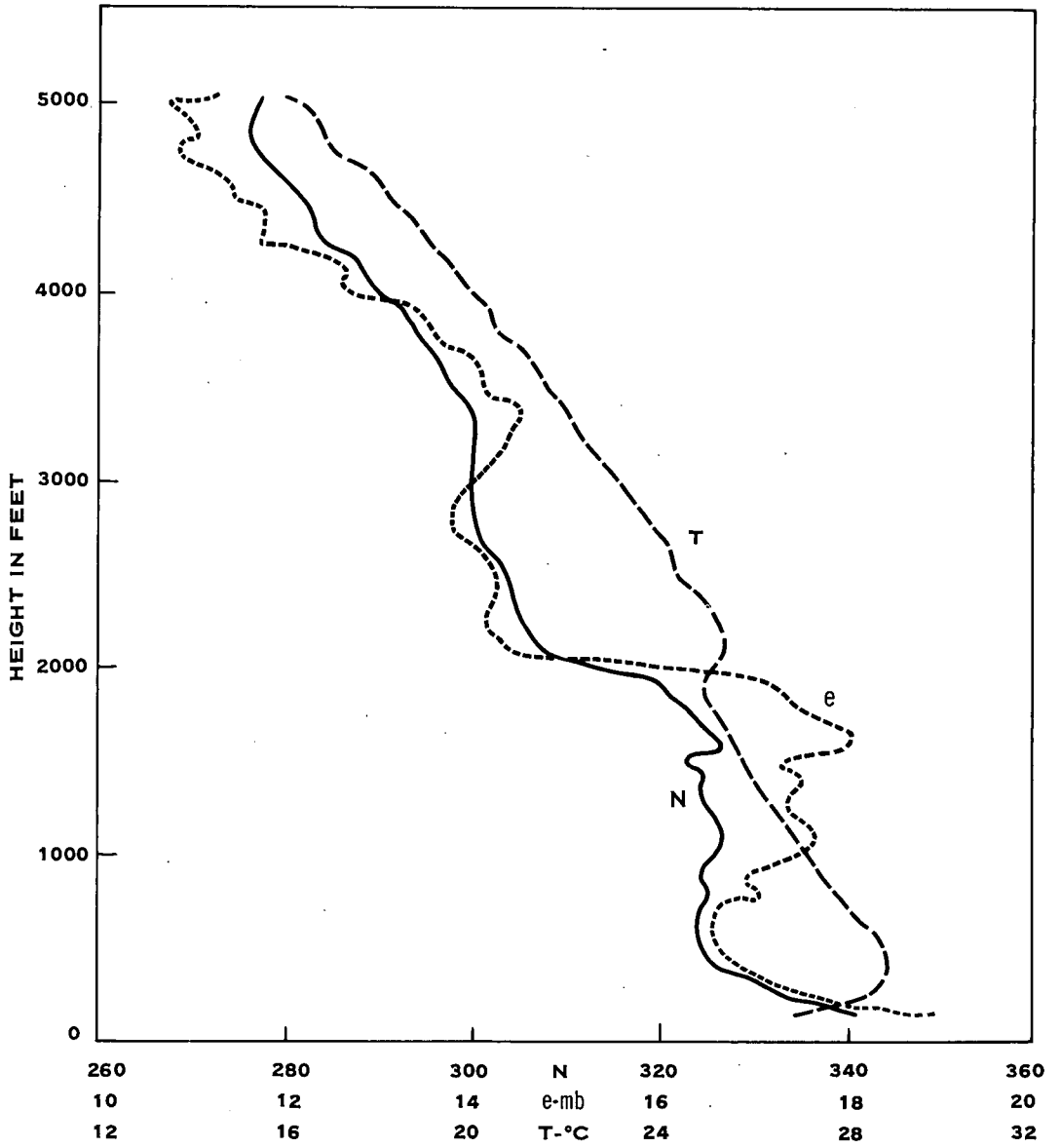


Fig 3 A typical set of profiles of refractivity, temperature and water vapour partial pressure for 18 February 1971.

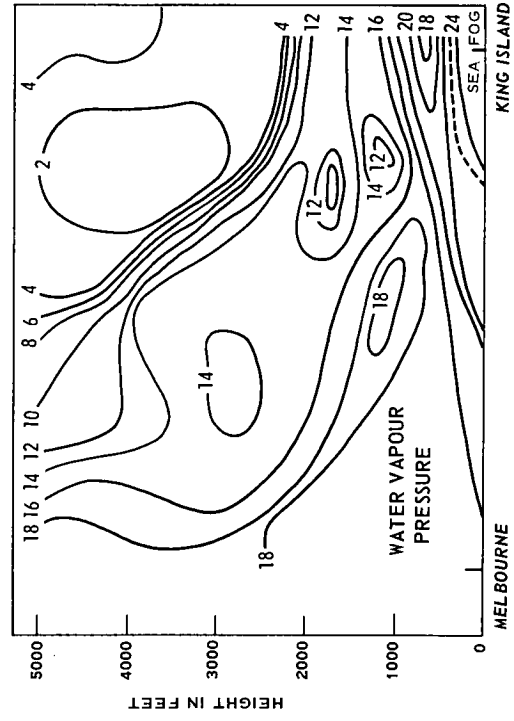
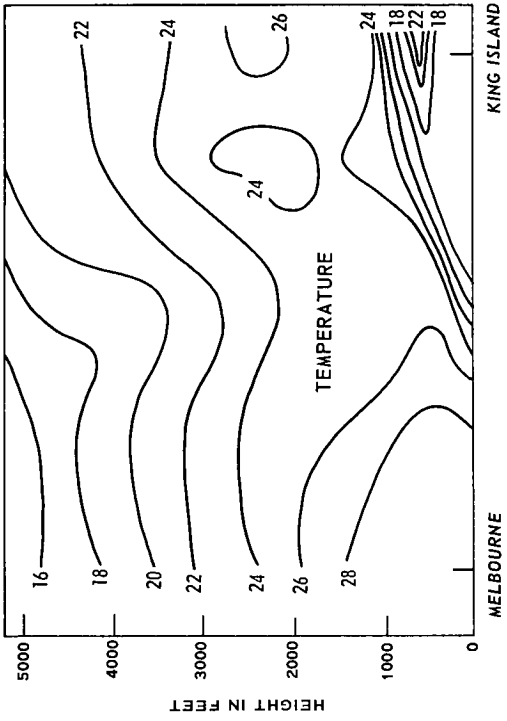


Fig 5 Sortie 1, inward journey. Top: temperature ($^{\circ}\text{C}$). Bottom: partial pressure of water vapour (mb).

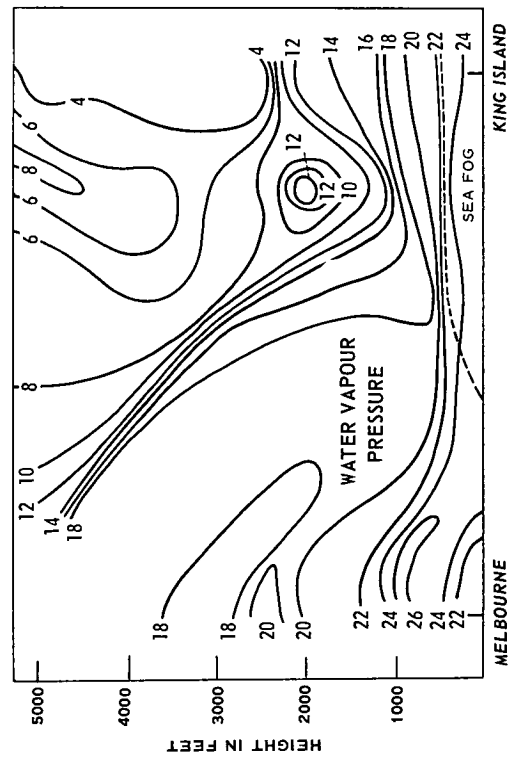
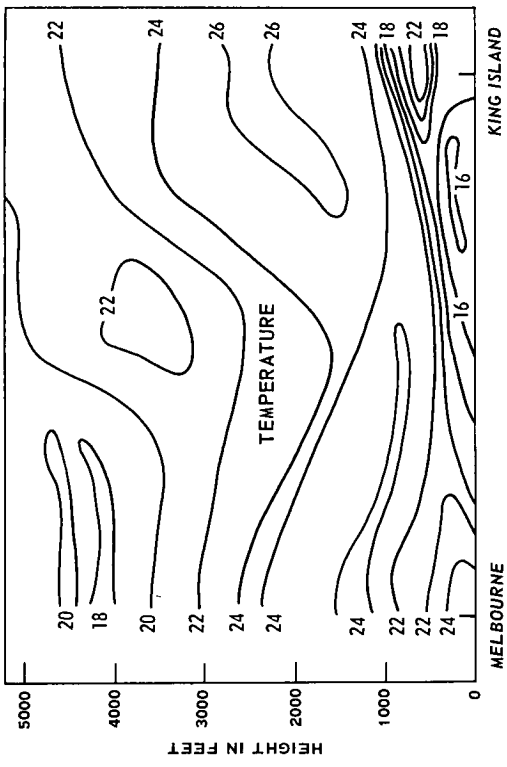


Fig 4 Sortie 1, outward journey. Top: temperature ($^{\circ}\text{C}$). Bottom: partial pressure of water vapour (mb).

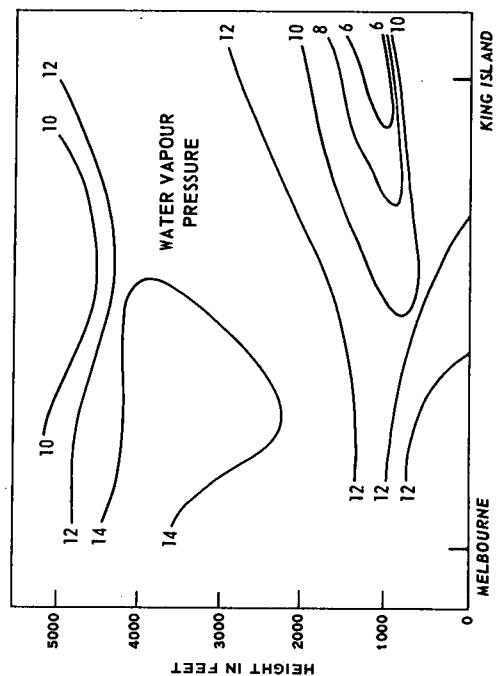
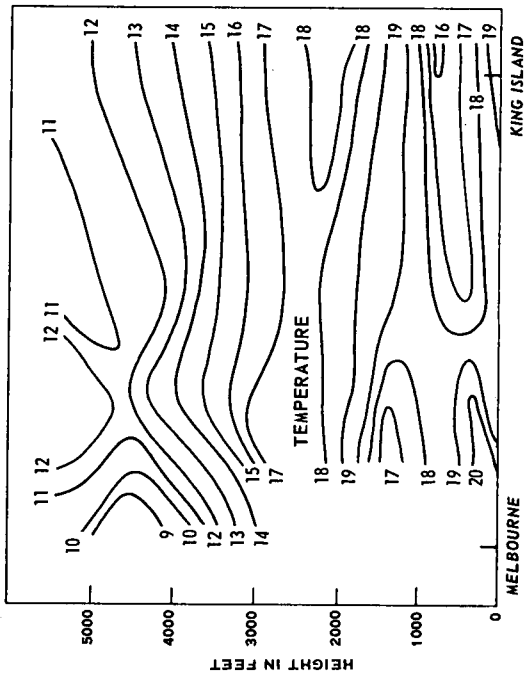


Fig 6 Sortie 2, outward journey. Top: temperature (°C).
Bottom: partial pressure of water vapour (mb).

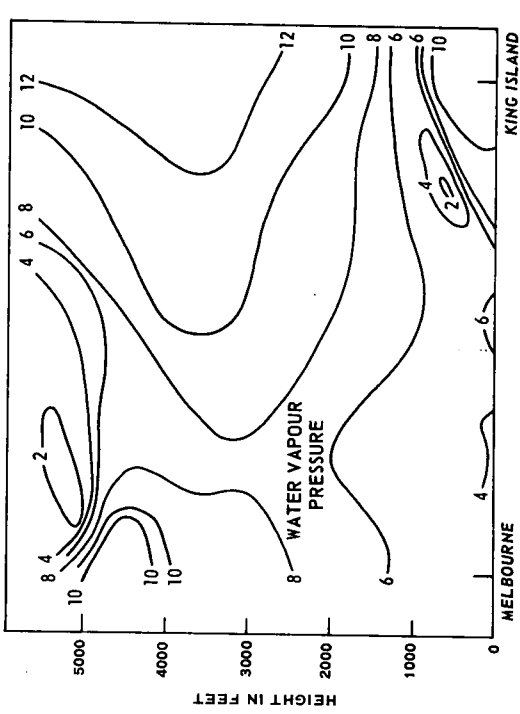
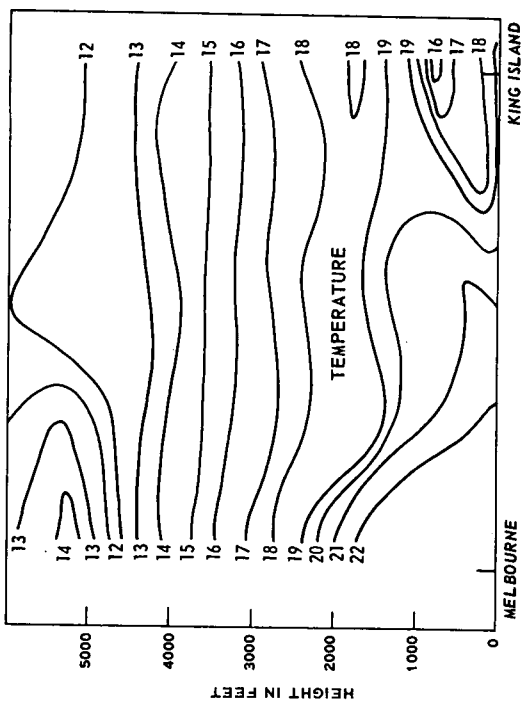


Fig 7 Sortie 2, inward journey. Top: temperature (°C).
Bottom: partial pressure of water vapour (mb).

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REFERENCES

- Barton, I.J. 1970. Construction and calibration of a microwave refractometer, *RAAF Academy Research Report No 58*, University of Melbourne, Australia.
- Barton, I.J. Unpublished. Anomalous Radio Propagation in the Troposphere, Ph.D. Thesis, University of Melbourne, 1972.
- Lane, J.A. 1965. Some investigations of the structure of elevated layers in the troposphere, *J.Atmos.Terr.Phys.*, 27, 969-978.
- Petterssen, S. 1969. *Introduction to Meteorology*, McGraw-Hill Book Co. Inc.
- Smith, E.K. and Weintraub, S. 1953. The constants in the equation for atmospheric refractive index at radio frequencies, *Proc. I.R.E.*, 41, 1035-1037.
- Vetter, M.J. 1967. Private communication
- Vetter, M.J. and Thompson Jnr. M.C. 1962. An absolute microwave refractometer, *Rev.Sci.Instr.*, 33, 656-660.

