

SYNOPTIC OZONE OBSERVATIONS DURING THE PASSAGE OF A CYCLONE VORTEX

A. B. Pittock

C. S. I. R. O., Division of Meteorological Physics,
Aspendale, Victoria

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ABSTRACT

Data from a synoptic network of ozone sounding stations have been used to derive a picture of the processes involved in the passage overhead of a weak cyclonic vortex. An order of magnitude estimate of the rate of transfer of stratospheric air into the troposphere in this particular case is presented and discussed.

INTRODUCTION

In October 1966, a synoptic network of ozone sounding stations was operated in southeastern Australia in cooperation with the Commonwealth Bureau of Meteorology and the Weapons Research Establishment. This coincided with the Laverton "Serial Sounding Experiment" (Bureau of Meteorology, 1968) during which rawin soundings were made every three hours from Laverton (37.9°S , 144.8°E).

The ozone network, consisting of Aspendale (38.0°S , 145.1°E), Adelaide (34.9°S , 138.6°E), Mount Gambier (37.8°S , 140.7°E), and Hobart (42.9°S , 147.3°E), operated from 10 to 14 October. During this period a trough, associated with a short wave which weakened as it moved over Victoria, passed over the network.

The observational material is presented and discussed in relation to stratospheric-tropospheric exchange.

OBSERVATIONS

Mast-Brewer model 730-6 ozone sondes were used as described in Pittock (1968). A Dobson spectrophotometer at Aspendale enabled individual sounding correction factors to be computed at this station. For the other stations the mean correction factor found for the Aspendale soundings, viz. 1.11_3 (± 0.05 standard deviation), was applied. In all cases a pressure-dependent pump rate correction was made in accordance with the mean curve obtained by Komhyr and Harris (1965).

Soundings were made at all four stations at 0500GMT and 1700GMT on 10 October; 1700GMT on 11, 12 and 13 October; and 0500GMT on 14 October. Additional soundings were made at Aspendale at 0500GMT on 11, 12 and 13 October, but the 1700GMT soundings on 11 and 12 October reached only 310 and 120 mb, respectively.

Temperature and wind data at Adelaide, Mount Gambier and Hobart were obtained from the ozone-sounding flights, in addition to wind soundings daily at 0500, 1100, and 2300GMT. At Aspendale temperature data from the ozone-sounding flights supplemented the three-hourly temperature and wind data from Laverton, some 45 km northwest of Aspendale.

The absolute accuracy of the ozone data at stations not having Dobson spectrophotometers is about ± 10 per cent, although the relative accuracy, or shape, of individual soundings is much better.

RESULTS

Surface and 300 mb analyses are shown in Fig. 1 together with a map of the total amount of ozone in the 200 - 300 mb layer at 2300GMT on 12 October.

Space cross-sections, approximately in the northwest-southeast and west-east vertical planes at 1700GMT on 12 October, for ozone partial pressure and potential temperature, are given in Fig. 2.

Time cross-sections of potential temperature and ozone mixing ratio over Mount Gambier are shown in Fig. 3, and the corresponding zonal and meridional winds in Fig. 4.

Unfortunately the ozone time cross-section had to be interpolated over the 24-hour gap from 1700 GMT on 12 October to 1700 GMT on 13 October. The reality of the secondary ozone maximum at about the 500 mb level in the troposphere at 1700GMT on 13 October and 0500GMT on 14 October is beyond question. The continuity of this tropospheric maximum with the secondary maximum in the lower stratosphere at 1700GMT on 12 October is not quite so obvious and requires careful justification.

Consider the details of the critical three ozone mixing ratio profiles, shown in Fig. 5, in conjunction with the potential temperature cross-section in Fig. 3.

Firstly, in order to explain away either of the tropospheric maxima, at 1700GMT on 13 October and 0500GMT on 14 October, would require a 25 - 30 per cent relative error in the response of the same ozone sensors over a height interval of about $1\frac{1}{2}$ km. This is not reasonable, and thus the tropospheric maxima are real.

Secondly, the uncertainty of ± 10 per cent in the absolute values can readily explain the lower secondary peak value at 1700GMT on 13 October relative to that twelve hours later.

Finally, the crucial evidence linking the two observed tropospheric maxima with the secondary maximum in the lower stratosphere at 1700GMT on 12 October, is that the hyper-baroclinic zone evident in Fig. 3 clearly descends from the tropopause at 1700GMT on 12 October to at least the 500 mb level in the next 24 hours. This is accompanied, for instance, by the quite marked descent of the 314 K potential temperature surface from 328 mb to 532 mb.

Such descent is accompanied by mixing and dilution of the intruding ozone-rich air of stratospheric origin. Thus the secondary ozone maximum decreased from 0.47 ppm at 1700GMT on 12 October to 0.043 ppm 24 hours later;

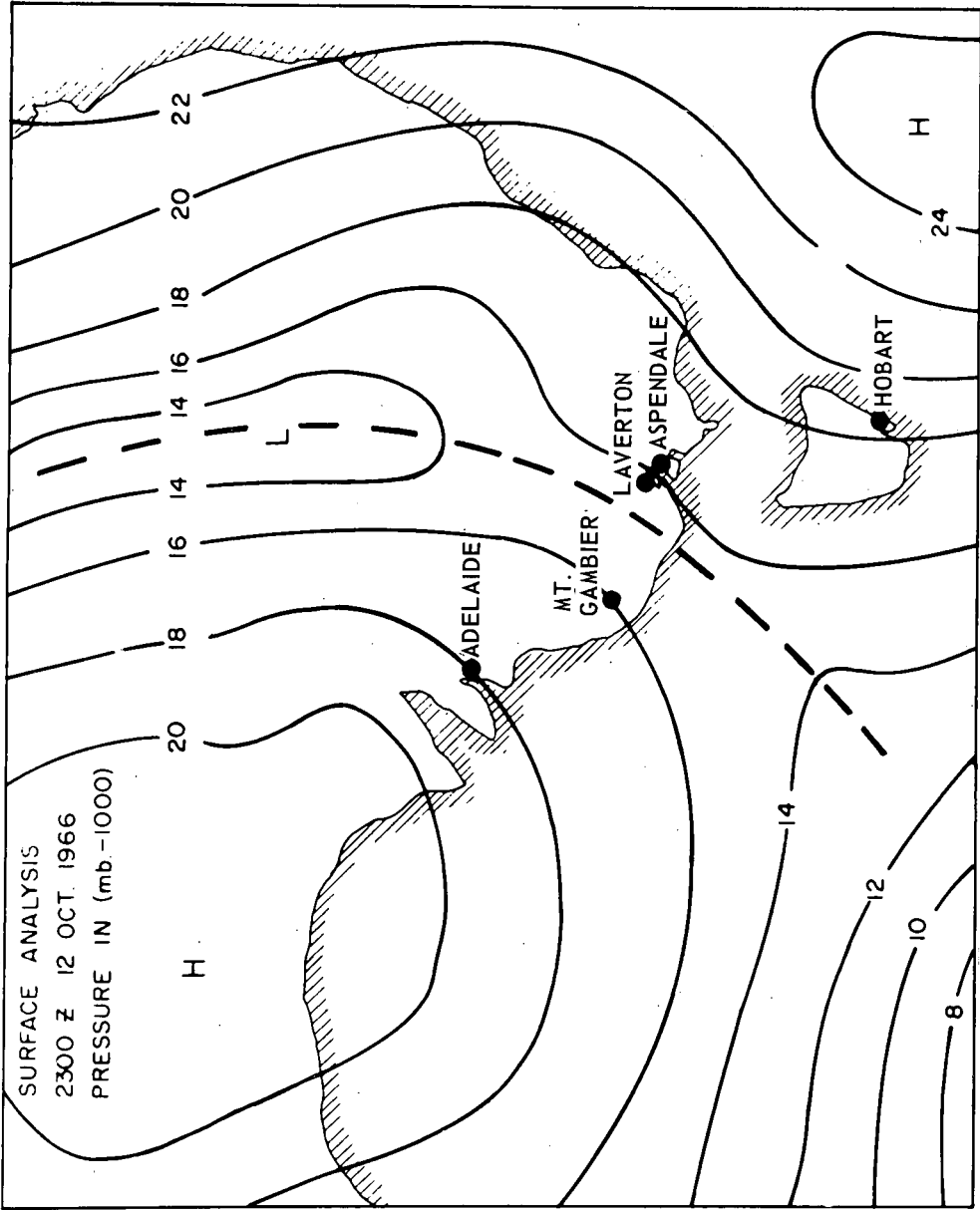


Fig. 1(a) Surface analysis for southeastern Australia 2300 GMT on 12 October 1966.

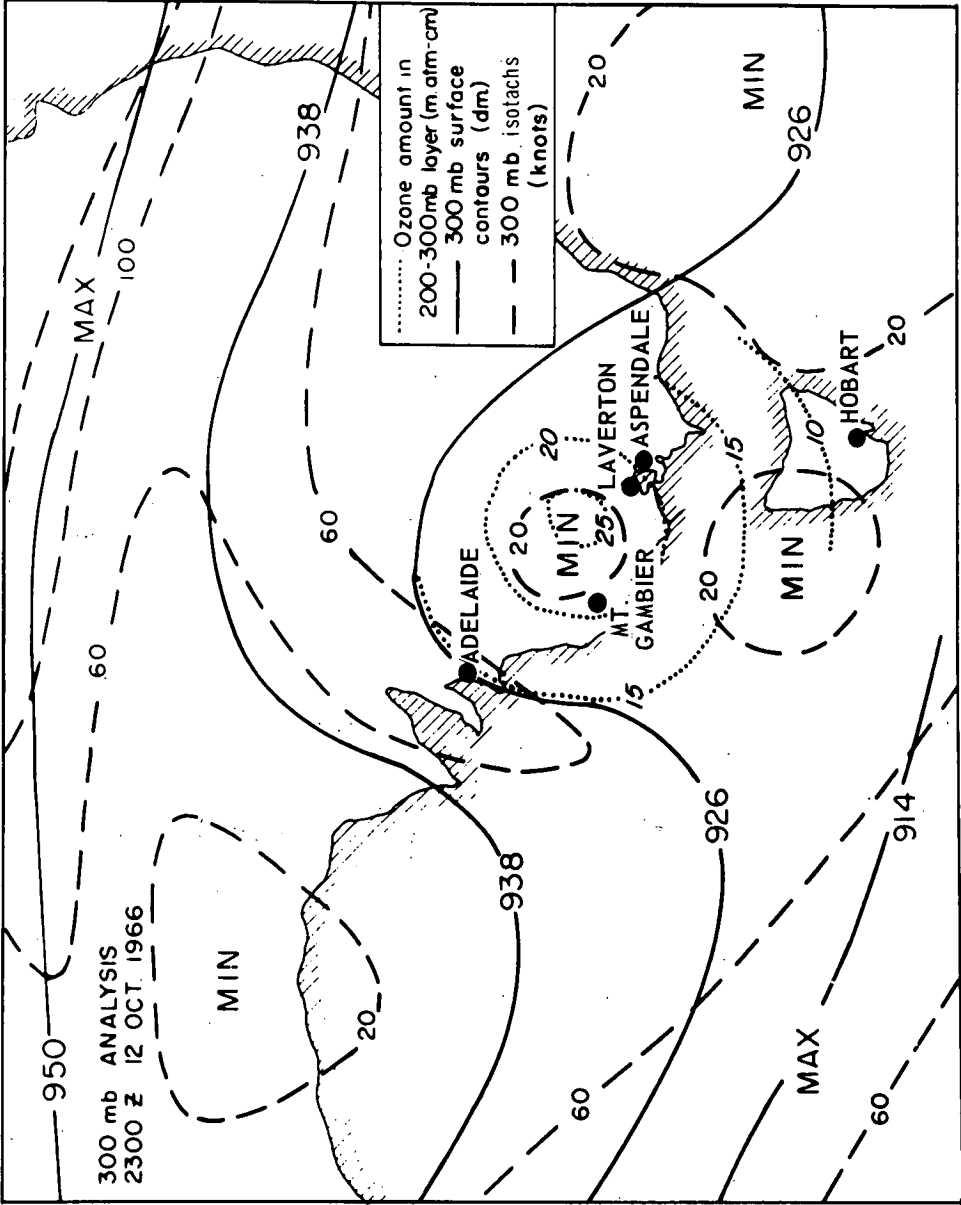


Fig. 1(b) 300 mb analysis for southeastern Australia 2300 GMT on 12 October 1966.
The integrated amount of ozone in the 200-300 mb layer is shown in m. atm. -cm.

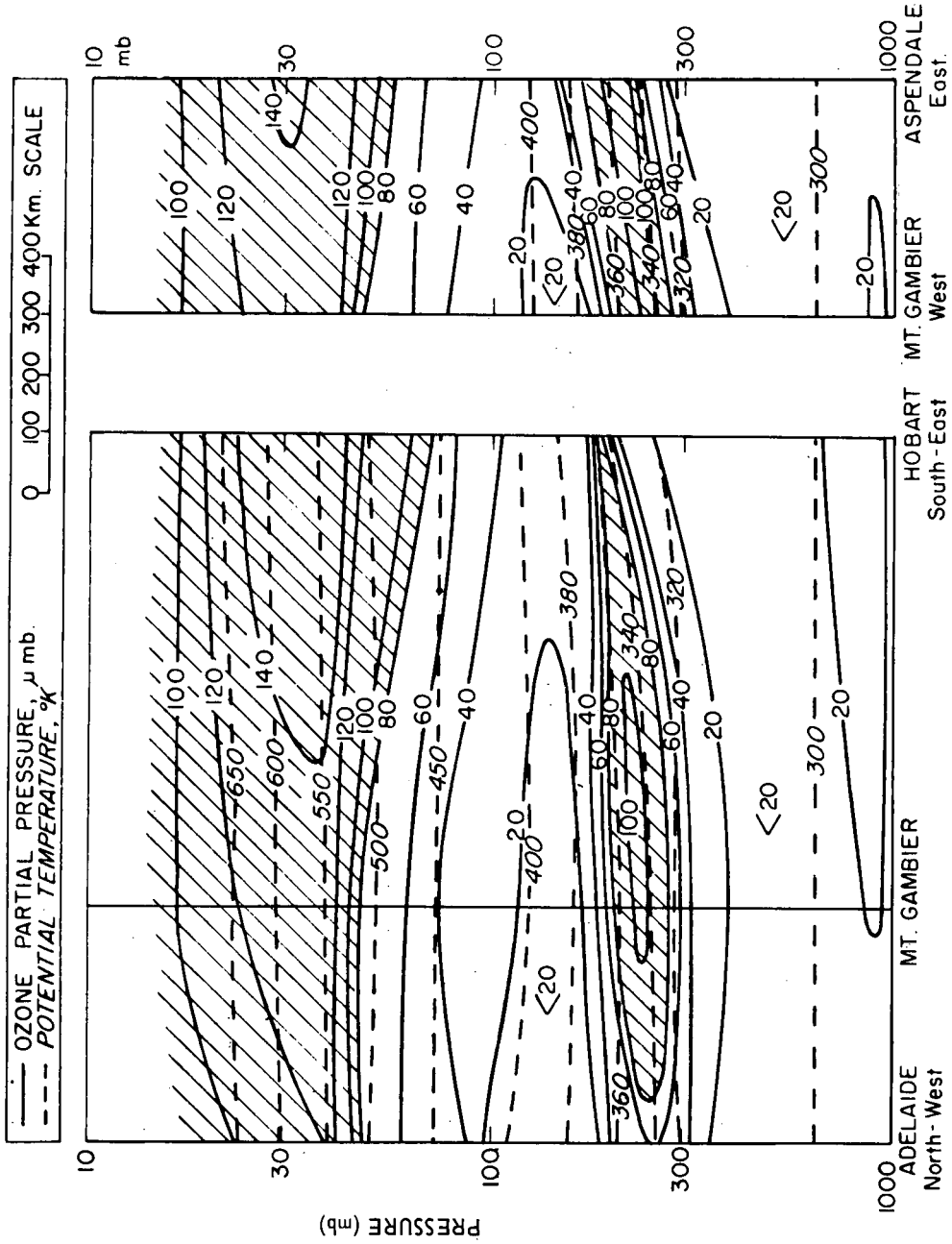


Fig. 2 Space cross-sections in the northwest to southeast and west to east vertical planes through Mount Gambier at 1700 GMT on 12 October 1966. Ozone partial pressures in μ mb and potential temperatures in $^{\circ}$ K are indicated

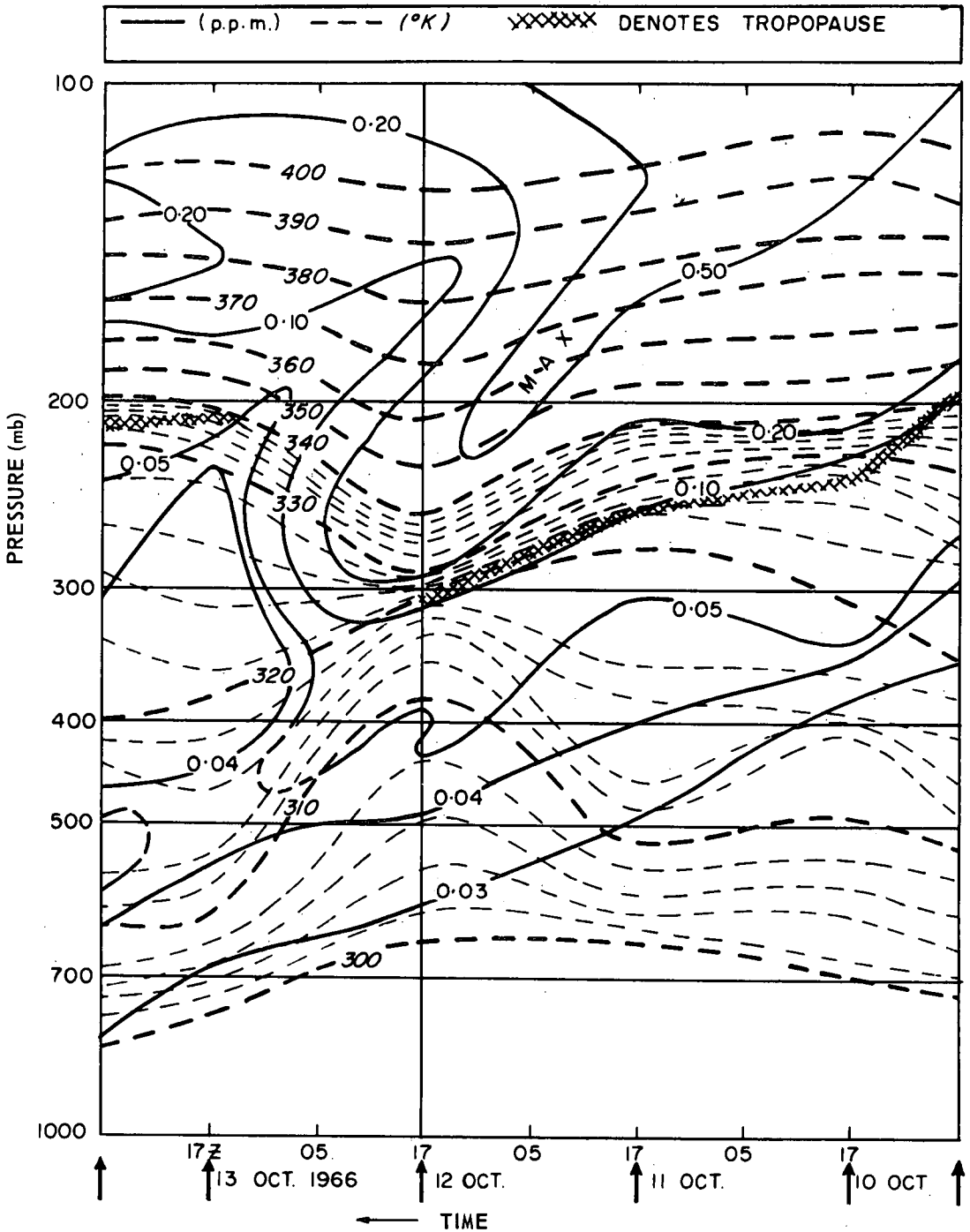


Fig. 3 Time cross-section at Mount Gambier of ozone number mixing ratio in ppm, and potential temperature in °K. Conventional tropopause indicated by cross-hatching. Times of ozone and temperature soundings are indicated by arrows.

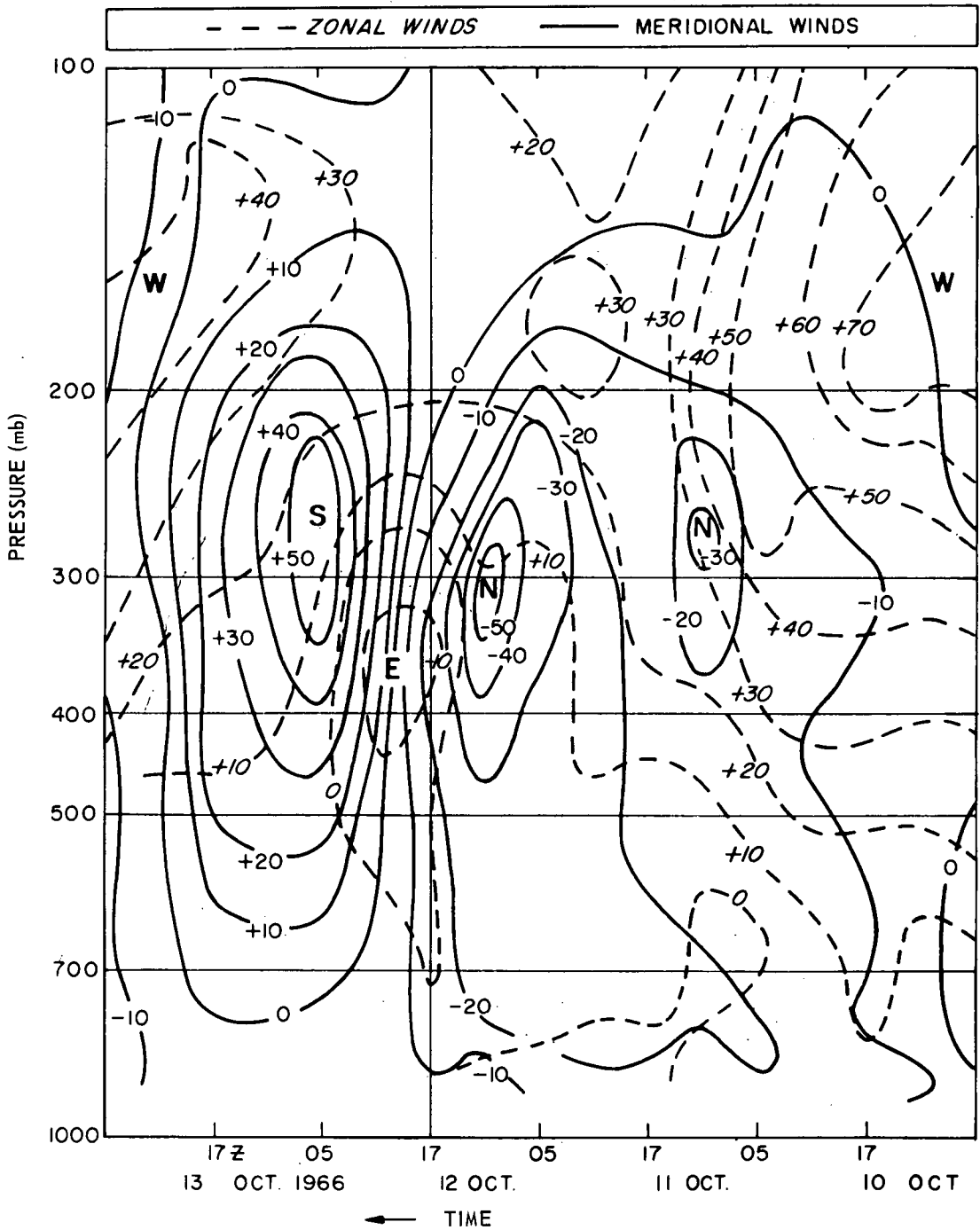


Fig. 4 Time cross-section of zonal and meridional wind components in knots, at Mount Gambier, corresponding to the cross-section given in Fig. 3

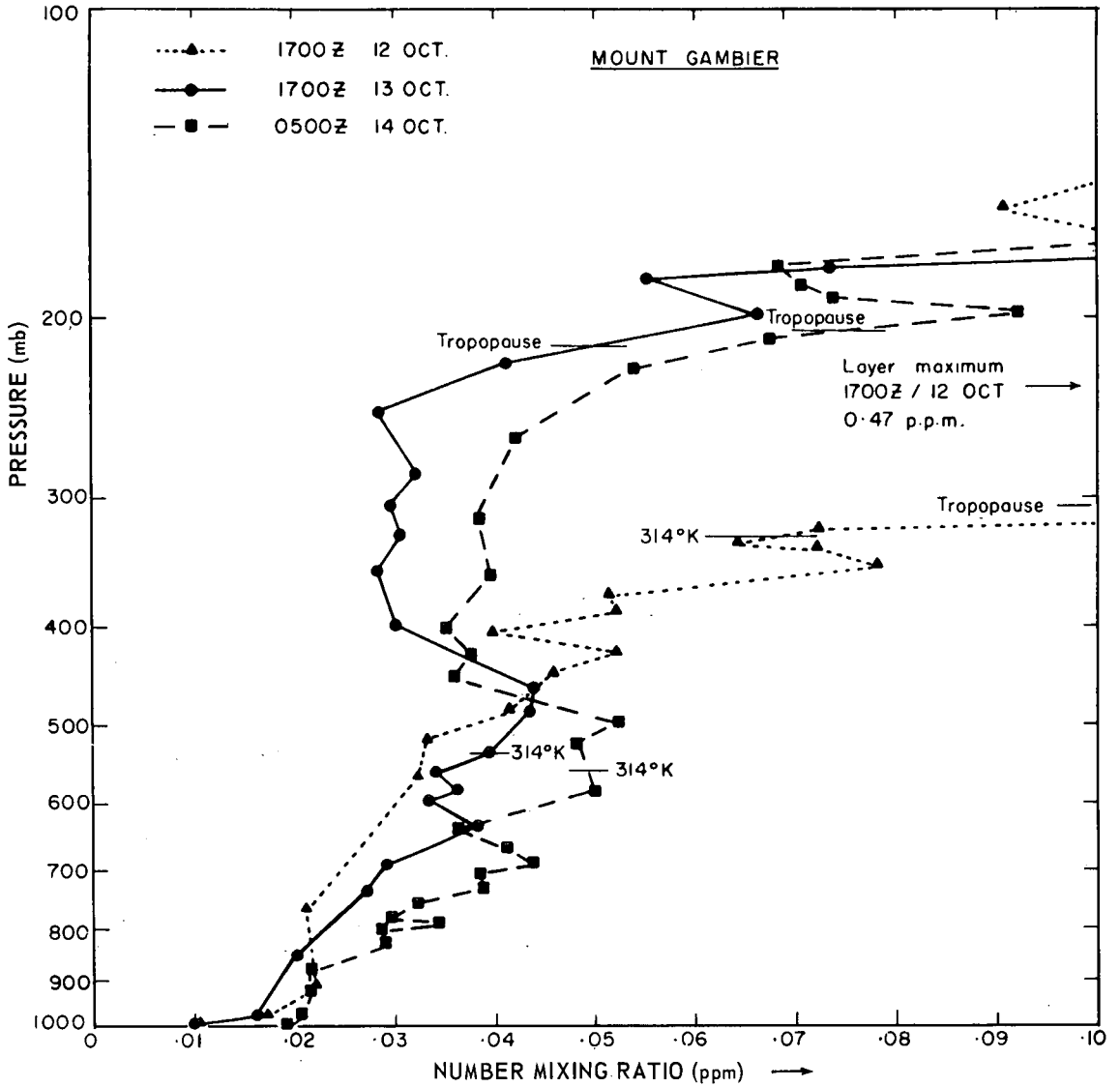


Fig. 5 Vertical profiles of ozone number mixing ratio in ppm at Mount Gambier. Corresponding conventional tropopause levels, and the height of the 314°K potential temperature surface, are indicated.

a dilution by a factor of ten or more. The corresponding potential temperature at the secondary ozone maximum decreased from 345°K to about 315°K . Given a similar dilution of the stratospheric air by a factor of ten or more this requires only an acceptably small change in temperature due to diabatic processes.

Further mixing in the following 12 hours would not be expected to substantially alter either the ozone mixing ratio or potential temperature since the intruded air is already well mixed with tropospheric air.

DISCUSSION

A secondary ozone maximum in the lower stratosphere is indicated by Fig 1 to 5, associated with the central area of a cyclonic vortex embedded in the mean westerly air stream at the 300 mb level.

This ozone maximum propagates downwards in time relative to a stationary observer. In space this corresponds to a secondary maximum along a laminar surface sloping downwards from east to west from the main ozone maximum down into the troposphere through the centre of the cyclonic vortex. It passes down under the weak 300 mb jet stream from the cyclonic to the anticyclonic side to the rear of the trough, ie. under the entrance region of the jet. This is broadly consistent with Reiter (1963), Danielsen (1968), and Pittcock (1969).

The effect of horizontal advection and wind shear on the descending core of the secondary ozone maximum, which at 1700GMT on 12 October was nearly stationary over Mount Gambier, must have been to carry the core away from Mount Gambier approximately to the north (Fig 4). Thus the ozone concentration in the tropospheric maximum observed over Mount Gambier was undoubtedly less than that along the trajectory of the core of subsiding air. Unfortunately, neither the ozone-sonde network nor the conventional rawin-sonde network is adequate to allow a detailed trajectory analysis.

From Fig 4 we can see that zero horizontal wind speed occurred over Mount Gambier at about the 270 mb level at about 1920GMT on 12 October. From the slope of the tongue of ozone-rich air at this point on Fig 3 we can arrive at an estimate of the vertical velocity near the core of the vortex of about -6 cm s^{-1} .

Using the three-hourly observations at Laverton, computed balanced-adiabatic vertical velocities in the vicinity of the tongue of ozone-rich air were found to be about -4 cm s^{-1} .

(G. B. Tucker, personal communication).

An order of magnitude estimate of the flow rate of air from stratosphere to troposphere may be made from the cross-sectional area of the tongue of ozone-rich air in the lowest part of the stratosphere, and its motion relative to the moving vortex and tropopause configuration.

The air in the core of the vortex is approximately stationary in the horizontal (Fig 4), although descending, whilst from the series of synoptic analyses provided by the Commonwealth Bureau of Meteorology it is evident that the vortex itself has a mean horizontal displacement speed of about 9.6 m s^{-1} towards a direction slightly north of east in the 24 hours from 2300GMT on 11 October. From various horizontal and vertical cross-sections (of which Fig 1(b) and 2 are examples only) the tongue was estimated to have a cross section of about 2 km in the vertical by 300 km in the horizontal direction at right angles to the direction of displacement of the vortex.

On this basis some $6 \text{ by } 10^9 \text{ m}^3 \text{ s}^{-1}$ (at 250 mb pressure) or $1.8 \times 10^{17} \text{ g day}^{-1}$ of stratospheric air was being left behind by the moving vortex and thus passed through the "tropopause gap" into the troposphere. This corresponds to about $1.2 \text{ by } 10^6 \text{ g s}^{-1}$ or $1.5 \text{ by } 10^{28} \text{ mol s}^{-1}$ of ozone. These figures represent upper limits since they assume that all the air in the tongue of ozone-rich air passed through the tropopause gap. This could well be in error by a factor of possibly two or three, but as is stressed above, only an order of magnitude of the exchange rate is being estimated.

Obviously the present estimated exchange rate, associated with a single rather weak cut-off low, is not representative of the qualitatively similar exchange associated with long-wave troughs and cyclonic vortices in general. Many of these will be more vigorous, not only transferring air at a greater rate, but also with a higher ozone mixing ratio.

Danielsen (1959) determined by isentropic analysis a transport of $2.7 \text{ by } 10^{17} \text{ g day}^{-1}$ through the tropopause in association with a major trough system. In another case study Reiter and Mahlman (1965) found an outflow from the stratosphere of $3 \text{ by } 10^{17} \text{ g day}^{-1}$, an estimate which was later modified to $5.3 \text{ by } 10^{17} \text{ g day}^{-1}$ with a nearly balancing inflow elsewhere (Reiter, Glasser and Mahlman, 1969). Danielsen *et al* (1970) have found mesoscale structure in a similar folded tropopause situation.

These results are broadly consistent with the present order of magnitude estimate, and together they suggest that such exchange processes associated with discrete synoptic disturbances may well account for a major part of the total exchange of air between stratosphere and troposphere.

For example, taking the global stratospheric mass to be about 10^{21} g , the mean stratospheric residence time to be about 1.5 years, and a representative rate of transfer through the tropopause by a single synoptic disturbance to be about $2 \text{ by } 10^{17} \text{ g day}^{-1}$, then each such disturbance accounts for about one-tenth of the total global rate of exchange through the troposphere.

CONCLUSION

Data from a synoptic network of ozone sounding stations over southeastern Australia have been used to derive a picture of the processes involved in the passage overhead of a weakening cyclonic vortex and its associated weak jet.

A trailing tongue of ozone-rich stratospheric air was found to descend from about the 100 mb level through the centre of the vortex at the level of the "tropopause break" and to pass into the troposphere under the entrance region of the jet.

From an order of magnitude estimate of the rate of transfer of stratospheric air into the troposphere, and similar estimates by other workers, it is inferred that such discrete events may well account for a major part of the total global transfer of air from stratosphere to troposphere.

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