

# OZONE VARIATION IN THE STRATOSPHERE AT ASPENDALE, VICTORIA

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## ABSTRACT

An investigation is made of the relation between the vertically integrated ozone content of the atmosphere as measured by a Dobson spectrophotometer and ozone-sonde measurements at Aspendale, Victoria. The correlation coefficients between the partial ozone content, total ozone, and other parameters are examined. It is found that, at Aspendale, most of the short term variation in total ozone occurs below 50 mb, whilst correlations established between ozone, temperature and poleward wind throw some additional light on previous discussions of the general circulation utilising ozone data.

## INTRODUCTION

The study of ozone data has always played an important part in investigations of the mass transfer within the stratosphere and through the tropopause. Total ozone readings (as obtained by a Dobson spectrophotometer) have been taken daily from numerous stations over a considerable number of years. Measurement of the vertical ozone distribution has, until recently, been taken for only isolated periods of time. The measurements were usually made using the Umkehr method, which as many authors have pointed out, has severe limitations. Recently a number of advances have been made. Particularly promising is the North American ozone-sonde network, and developments in satellite sensing, which may in the future add considerably to our knowledge of the dynamics of the ozone-layer. It will no longer be necessary to assume, as did Newell (1963), that the ozone at particular levels is proportional to the total ozone.

A particularly notable feature discovered by early experimenters was the so-called Normand-Reed effect. Normand (1951) obtained positive correlations between total ozone and tropopause pressure and temperatures between 200 and 70 mb, and negative correlations for tropopause height surface pressure and 1000 - 300 mb geopotential thickness. Reed (1950), and Normand (1953) explained such effects in terms of vertical motion and advection.

## THE OBSERVATIONAL DATA

The ozone-sonde observations which serve as a basis for this paper were made at the CSIRO Division of Atmospheric Physics at Aspendale, Victoria, Australia ( $38.0^{\circ}\text{S}$ ,  $145.1^{\circ}\text{E}$ ) under the direction of Dr. A.B. Pittock, using Mast-Brewer electrochemical ozone-sondes (Pittock, 1968). The observations have been carried out once or twice a week since June 1965. The present study is based on the first four years of data. In addition to the basic observations, upper wind and temperature data were also utilised, and obtained from Laverton, about 25 mi (40 km) northwest of Aspendale.

### TIME VARIATIONS IN OZONE DISTRIBUTION

#### (a) Seasonal and year to year variations

Mean ozone profiles showing values of both ozone partial pressure ( $\mu\text{mb}$ ) and mixing ratio (ppm) for each season through the four year period of observations are given in Fig 1.

In Fig 2 the variation of ozone partial pressure at particular levels through the four year period is shown by a series of seasonal means together with the standard deviation; whilst in Fig 3, twelve-month running means are shown for particular levels through the complete period. Both Fig 2 and 3 show that in this four-year period of record, a year to year variation is particularly marked at 50 mb, the level where Angel and Korshover (1964) found the greatest quasi-biennial temperature oscillation.

#### (b) Short and long term correlations

The standard deviation values of seasonal ozone partial pressure (Fig 2), indicate the day to day variations, and demonstrate that these are greatest in the lowest levels considered. A study by Pittock (1968), which included all tropospheric data, suggests that the maximum day to day variation occurs near the tropopause.

Short term correlations can be calculated from values obtained over three-monthly periods, because a period of this length filters out much of the seasonal variation. Furthermore if this is done for a number of levels, those with the strongest correlation indicate the levels at which dynamical processes play the most important part as a transport mechanism. Such levels become even more evident if instead of correlating partial ozone content (expressed either in ppm or mixing ratio), the correlation is made between *fractional* ozone content, *ie* the fraction of the total ozone in the layer appropriate to the level, and the total ozone, because positive correlations are then found at levels where most of the variation is occurring, but negative correlations are found elsewhere.

The first study to adopt this type of approach was that of Mateer and Godson (1960) for two Canadian stations. They found that below 12 km (approximately 200 mb) and above 24 km (approximately 30 mb) there was a negative correlation between the fractional content of ozone and the total ozone in the atmosphere. Most of the increase in the total ozone was found to occur in the 12 to 24 km layer, the correlation coefficient between the total ozone and fractional ozone in this layer being 0.86. The correlation coefficient for the same layer between the total ozone and actual ozone concentration within this layer was 0.97. The observations of Mateer and Godson were taken over a relatively short period (three months) and should therefore not be greatly influenced by seasonal

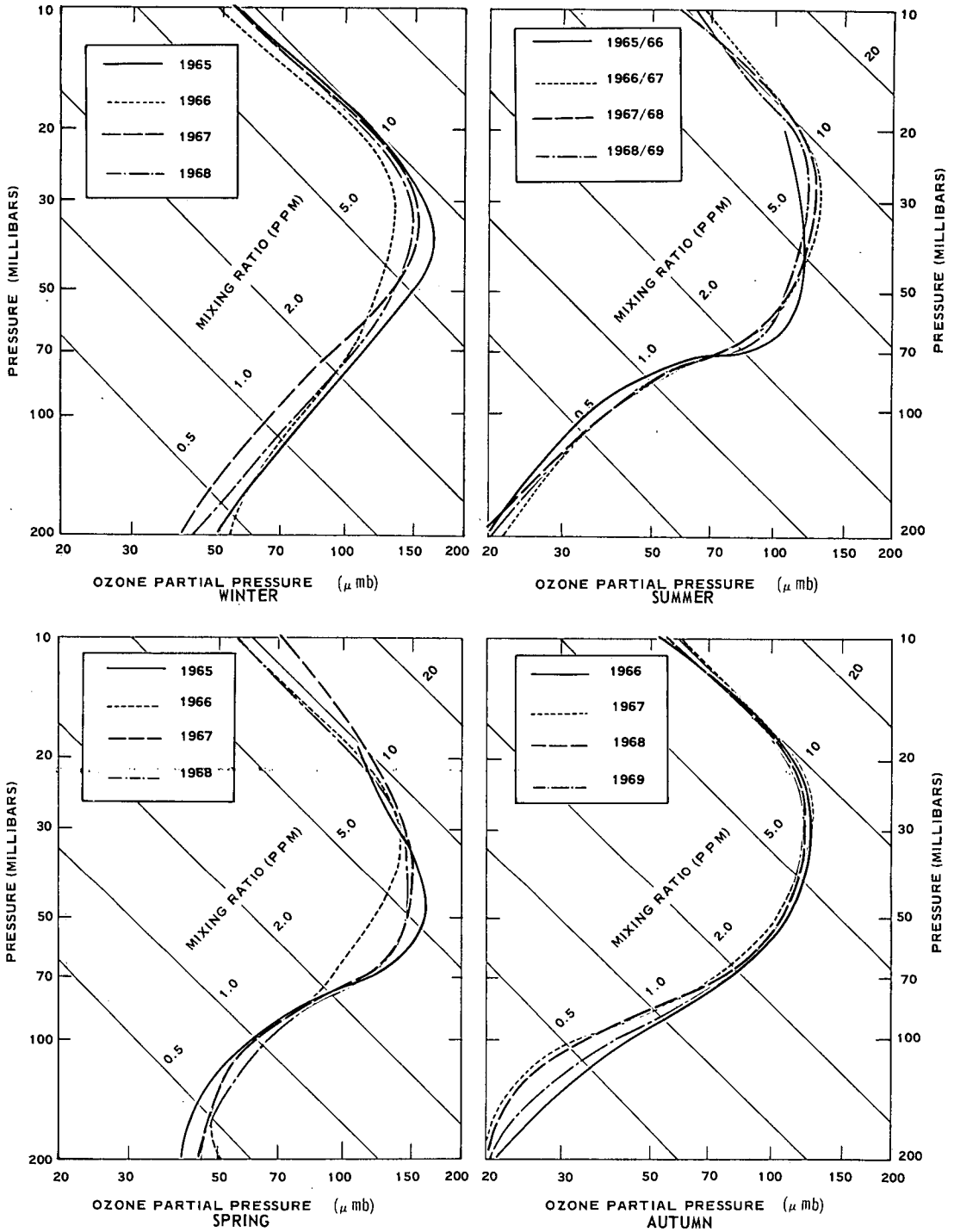
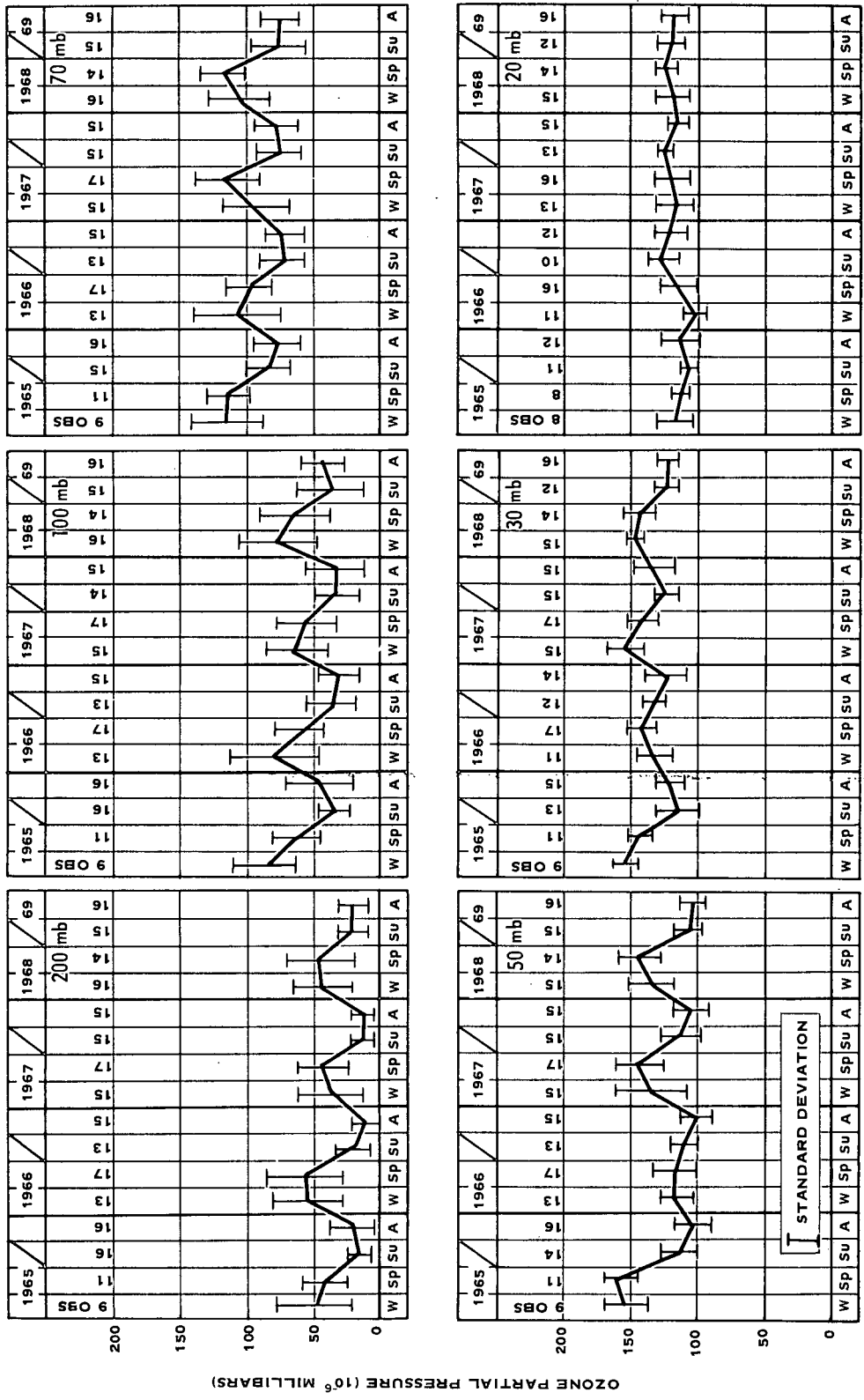


Fig 1 Seasonal means of the ozone partial pressure at Aspendale.



SEASONS (WINTER 1965 TO AUTUMN 1969)

Fig. 2 Means and standard deviations of the ozone partial pressure at seasonal intervals.

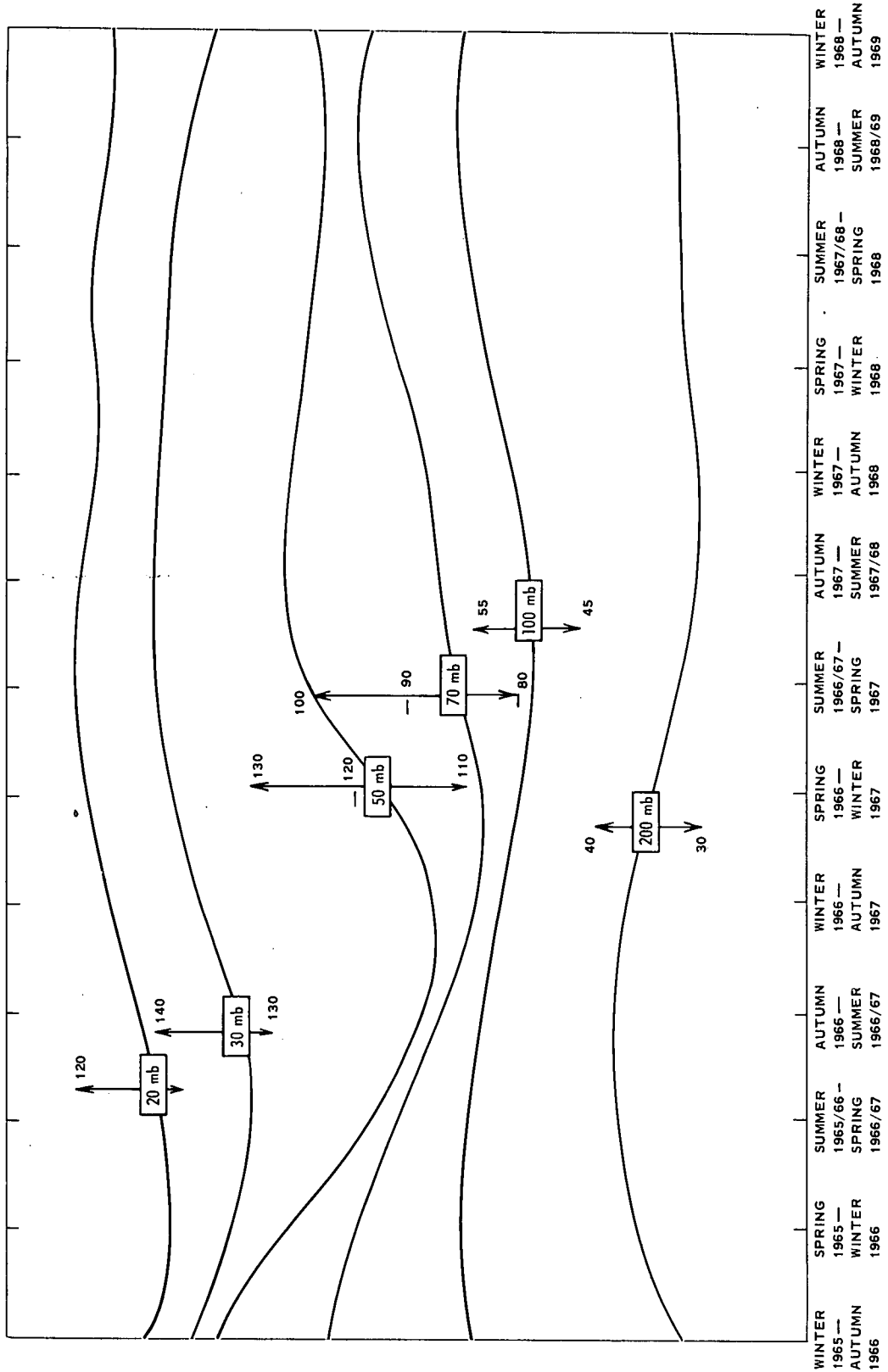


Fig 3 Twelve months running means of ozone partial pressure ( $\mu$  mb).

variations. This possibly explains a discrepancy between their results and those of other authors, although the results were not expressed in exactly the same form.

A problem arises when a period of three months is chosen for short term calculations and the number of available observations is low, for there is then considerable uncertainty in the computed correlation coefficients. However another method can be adopted.

The distribution of the correlation coefficients is highly skew but, as shown by Fisher (1921), the transformation  $Z = \frac{1}{2} \ln \frac{1+r}{1-r}$  is approximately normal with standard deviation  $1/\sqrt{n-3}$ ,  $r$  being the correlation coefficient, and  $n$  the number of observations used in its derivation. A  $\chi^2$  test can be applied to determine whether the differences obtained for individual three-monthly periods are significant. If this is not the case an effective short term correlation coefficient can be obtained by combining the results according to the formula

$$\bar{Z} = \frac{\sum (n_i - 3) Z_i}{\sum (n_i - 3)}$$

with variance  $1/\sum (n_i - 3)$

Here  $n_i$  is the number of observations used for the  $i^{\text{th}}$  estimate of  $Z$ .

This was the method employed in the present analysis. Fig 4a presents the long term correlation coefficient (over four years) and  $Z$  transform of the correlation coefficient between ozone partial pressure at standard levels and total ozone, together with the best estimate of the short term values as calculated above. Standard errors are shown by the bars. At 50 mb and 20 mb a  $\chi^2$  test did suggest that the difference in short term values over the year was significant, but at other levels the type of variation was that which could be expected for a normal distribution and the limited number of observations. Comparing the short-term and long-term calculations, it can be inferred that between 70 and 30 mb the short-term correlation between the total ozone within the layer differs substantially from that calculated over a long term.

The correlation between fractional ozone content and total ozone is shown in Fig 4b. The greatest difference between the long and short term correlations is found at the 50 mb level, and it can also be seen that for short term correlations, the transition between correlation and anti-correlation occurs at about 50 mb (21 km), but closer to 40 mb (25 km) for the long term correlations. Although not expressed in exactly the same form, the results agree approximately with those of Bojkov (1967) at Arosa (using Umkehr data).

## TEMPERATURE CORRELATIONS AND THE REED-NORMAND EFFECT

Examination of the ozone profiles shown in Fig 1 indicates that because the mixing ratio will be conserved in an adiabatic process, sinking motion will be associated with an increase in ozone partial pressure for levels below 20 mb. This motion, associated with an increase in temperature, may therefore explain, at least partially, any observed correlation between ozone and temperature occurring in lower levels. It would not be a sufficient explanation, however, for correlations which may occur at levels where the vertical gradient

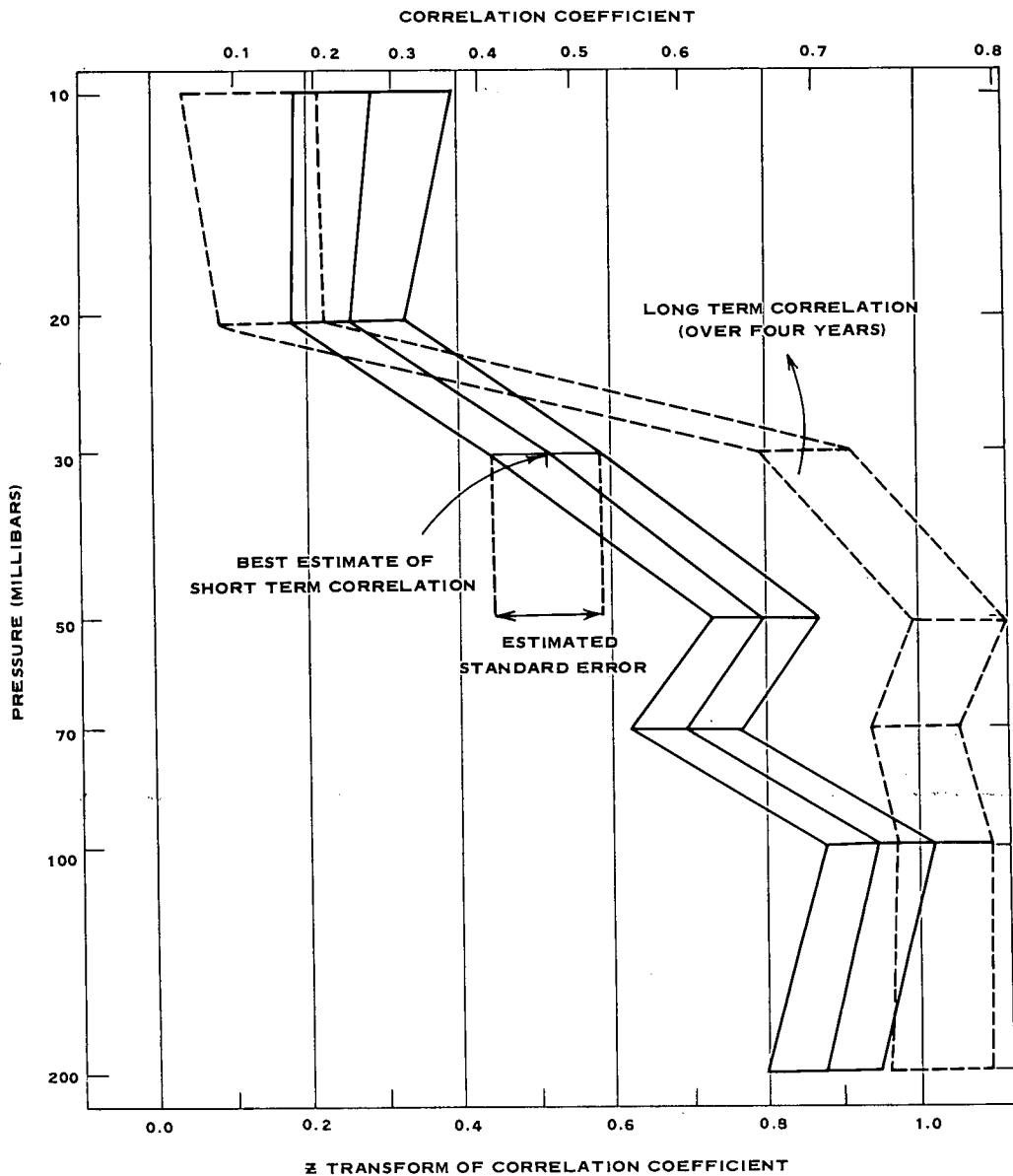


Fig 4 (a) Short term and long term correlations between ozone partial pressure at standard levels and total ozone.

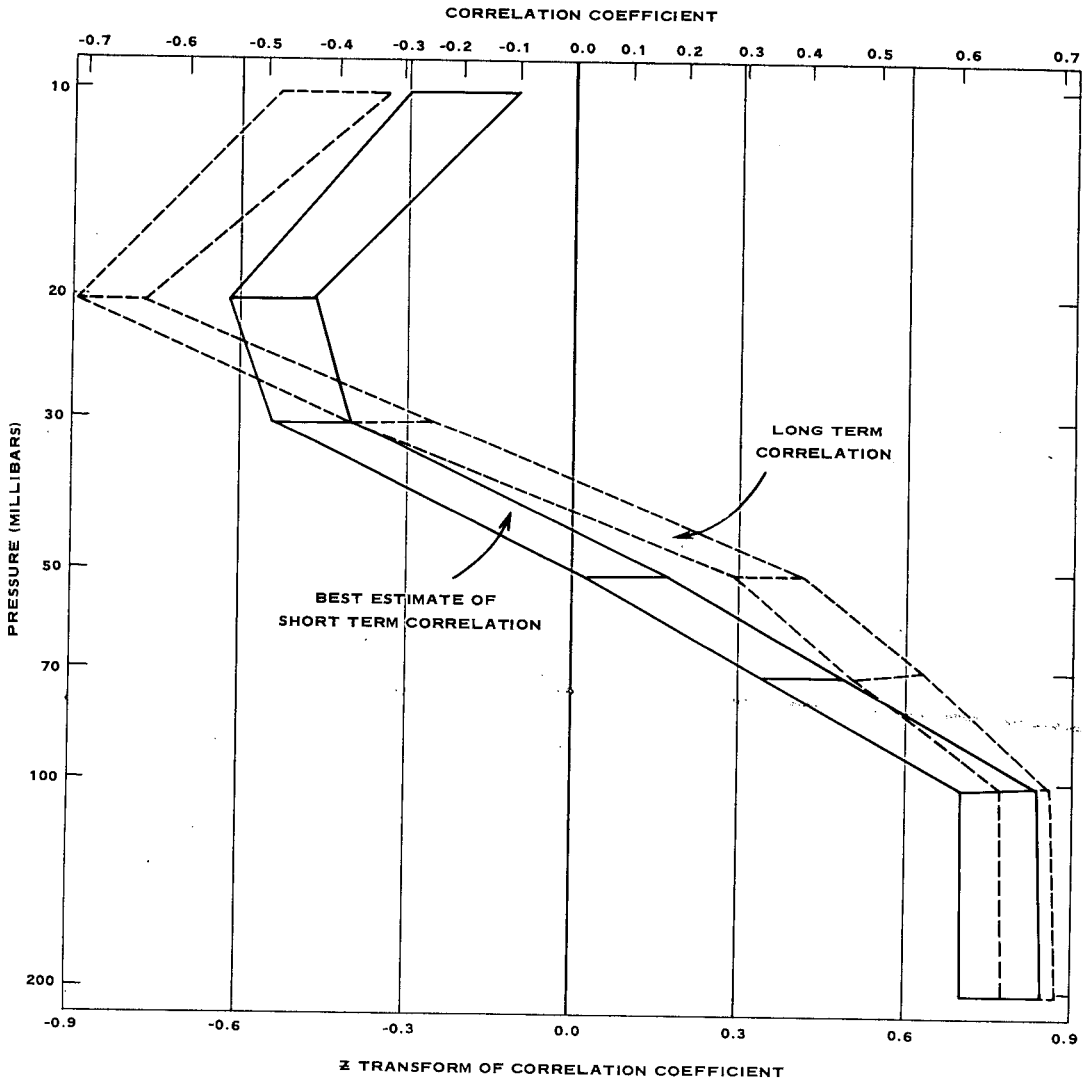


Fig 4 (b) Short term and long term correlations between fractional ozone contents at standard levels and total ozone.



of mixing ratio is small. For such a result to occur it would be necessary for a transport mechanism combining vertical motion and horizontal advection, in agreement with Dobson *et al* (1927) and the computer model of Hunt and Manabe (1968).

Fig 5a shows the variation with pressure of the correlation coefficient (and Z transform) of total ozone and temperature for Aspendale. The results are in accord with Normand, the correlation gradually decreasing with altitude above the 70 mb level to near zero at 20 mb, indicating that the vertical motion or advection at this level has very little correlation with that at lower levels.

Fig 5b gives the correlation coefficients between ozone partial pressure and temperature at different levels. The curve follows Fig 5a approximately, the main differences being that a significantly higher correlation is present at 200 mb and 20 mb, while at levels in between the coefficients are lower.

Fig 5c shows the long term correlation between ozone partial pressure and temperature taken over a four-yearly period. A long term variation is evident at 50 mb where there is a marked departure from the short term correlation. This shows how seasonal and probably quasi-biennial variations distort the correlation coefficients when calculated for extended periods.

## POLEWARD EDDY TRANSFER OF OZONE

By calculating the theoretical state of photochemical equilibrium of the atmosphere and comparing this with the actual ozone distribution, Dobson (1956) found that the observed distribution could be largely accounted for by a hypothesis advanced by Brewer (1949) to explain observations of low water vapour content in the lower stratosphere. This hypothesis assumed a net downward vertical motion in high latitudes, and a net upward motion near the equator. Such a mechanism is necessary to explain the maximum observed ozone at temperate latitudes. By photochemical arguments alone the maximum production of ozone should be near the equator. Neglecting eddy transport, a qualitative agreement was obtained by Murgatroyd and Singleton (1961). They calculated the mean meridional and vertical motions in the stratosphere and mesosphere necessary to transport the heat from the radiational sources and sinks. A feature of their model is a marked downward vertical motion in the stratosphere for high latitudes, commencing at late winter to early spring, the time of maximum ozone concentration.

The high correlation between total ozone and the amount in the 12-24 km layer, obtained by Mateer and Godson, together with similar results in India for the 18-27 km layer by Ramanathan (1956), prompted Newell (1963) to estimate the ozone transfer in the lower stratosphere, taking the total ozone to be proportional to the ozone at levels of 50 and 100 mb as a first approximation.

In Fig 6a and b various parameters are graphed relating to the poleward eddy transfer of ozone. Dotted lines represent the covariance of ozone partial pressure and the poleward (NS) wind component at the specified pressure level (units  $10^{-6}$  mb kt), and the full lines represent the covariance between this wind and total ozone ( $\mu$  STP kt). The corresponding correlation coefficients and Z transforms are shown in the lower portion of the diagrams, with the probable

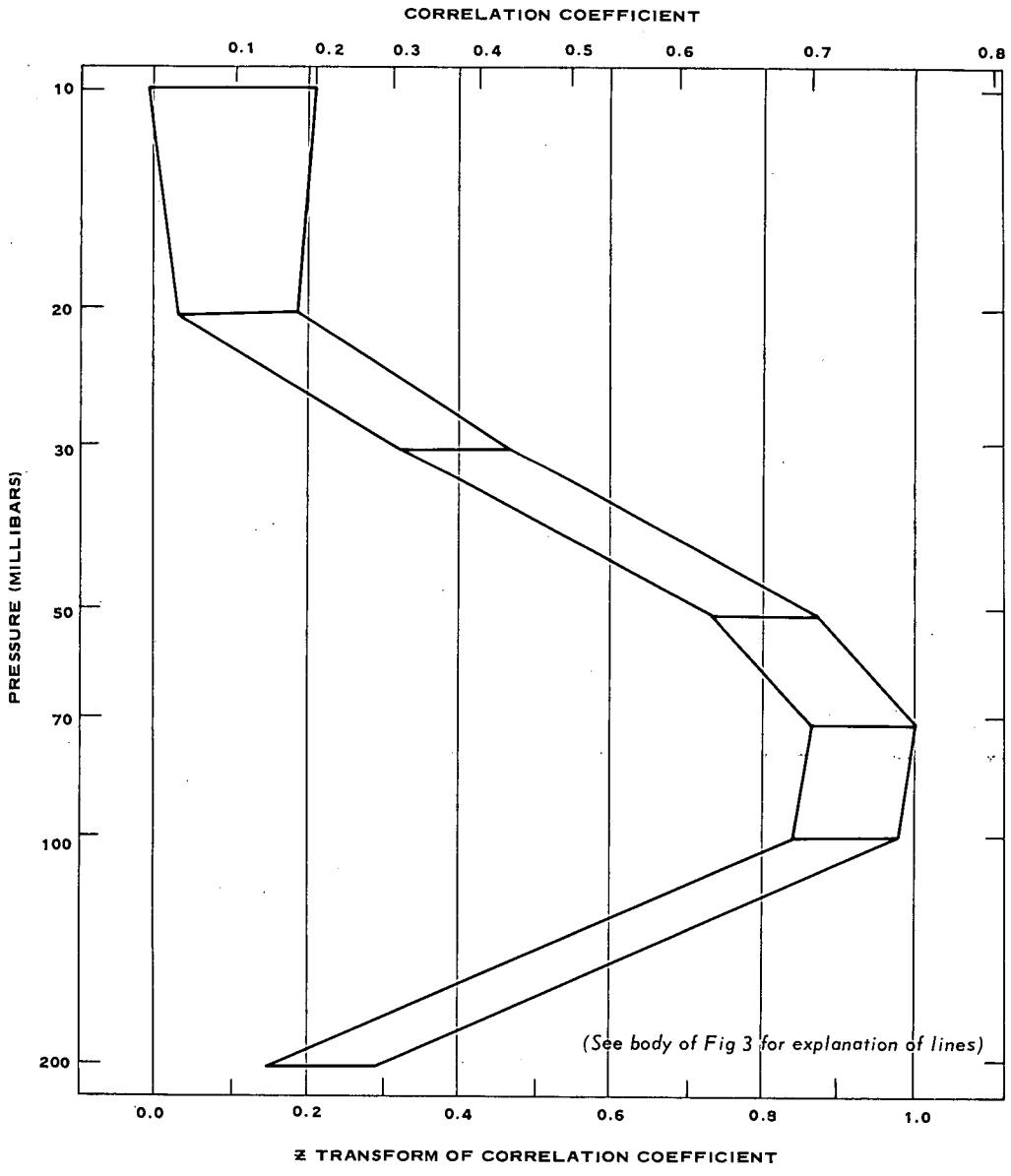


Fig 5 (a) Correlation of total ozone and temperature (short term).

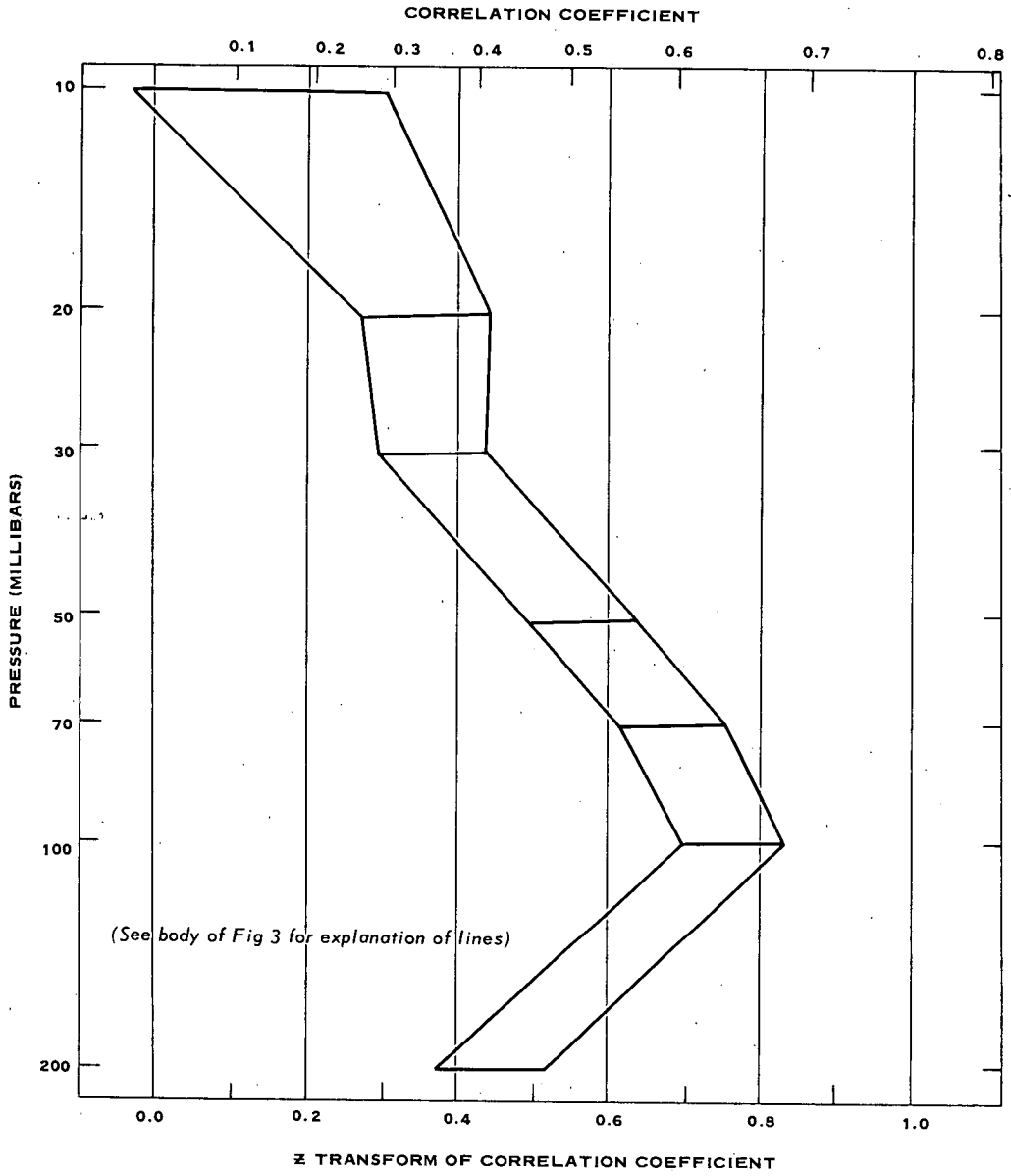


Fig 5 (b) Correlation between ozone partial pressure and temperature (short term).

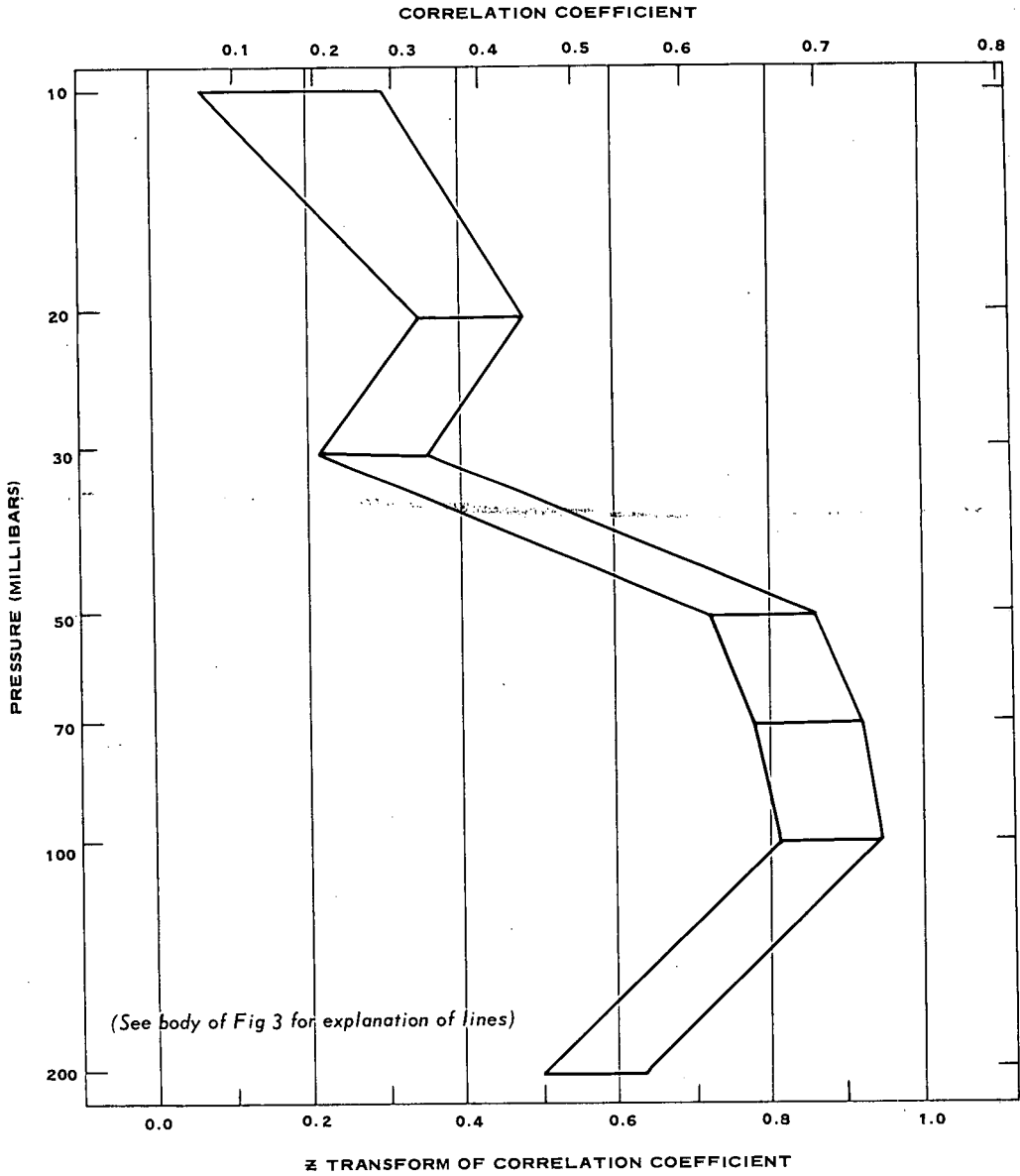


Fig 5 (c) Long term correlation between ozone partial pressure and temperature.

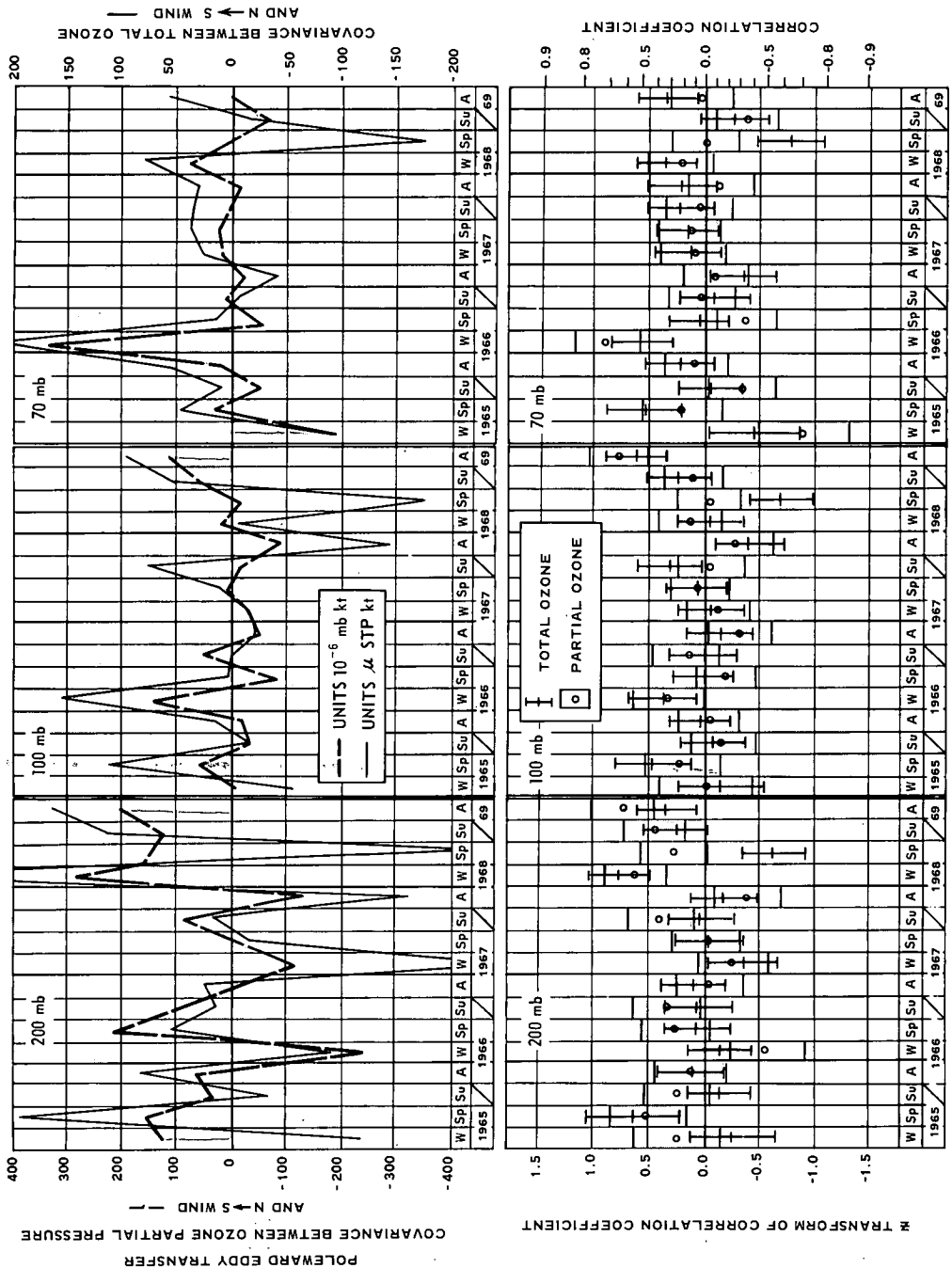


Fig 6 (a) Various parameters relating to the poleward eddy transfer of ozone for levels 200, 100 and 70 millibars.

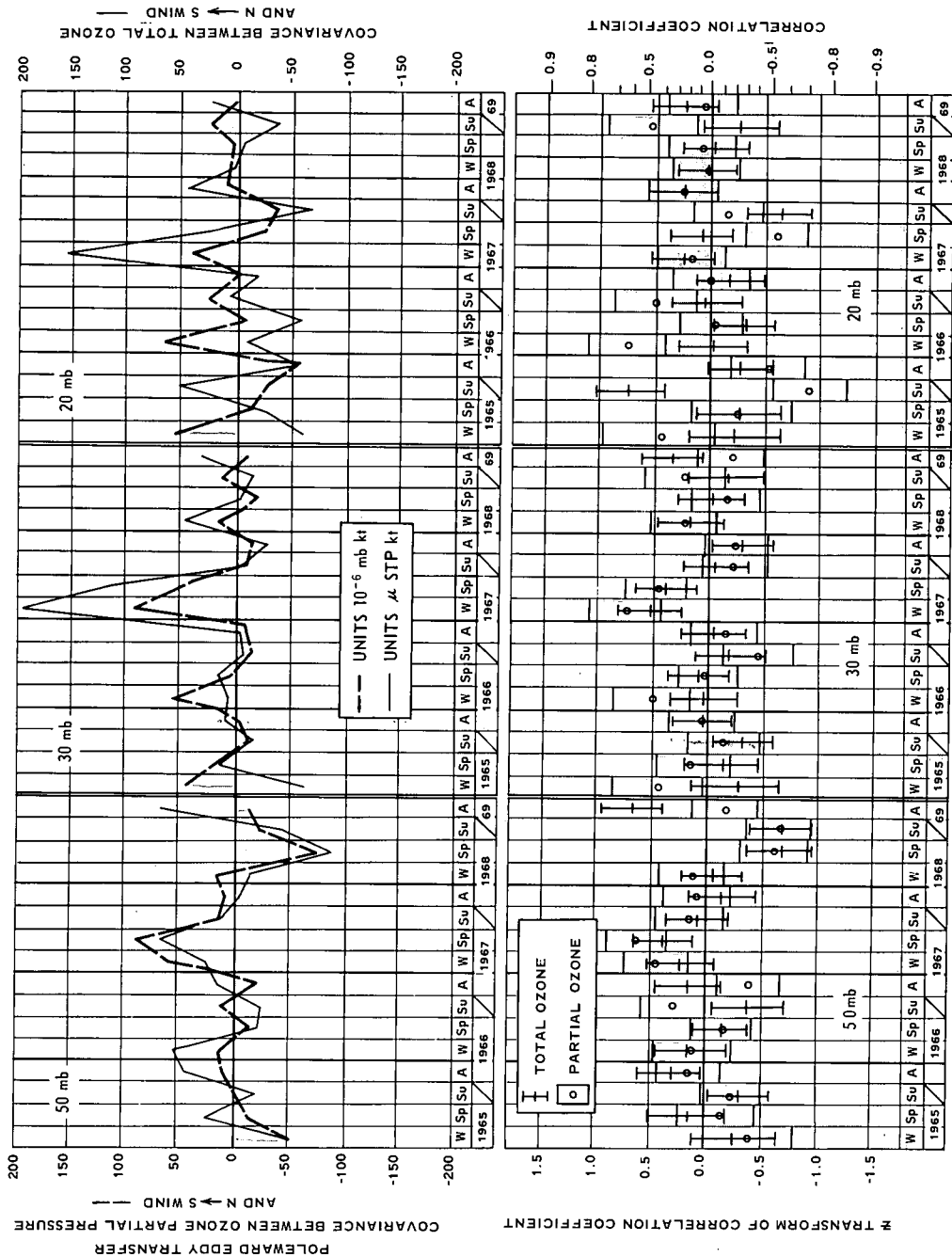


Fig 6 (b) Various parameters relating to the poleward eddy transfer of ozone for levels 50, 30 and 20 millibars.

standard errors indicated. The scale used for the covariance between ozone partial pressure and NS wind in Fig 6a is half that of Fig 6b. The calculated eddy transports between ozone and NS wind were based only on data from those days when ozone-sonde flights were made. It is for this reason that slight variations exist between the present calculations and those of Pittcock (1968), based on the first two years of observations.

A comparison between the two covariances will give some indication of the accuracy which may be expected from the approximation of Newell (1963). The graphs do indicate a reasonable correspondence for levels below 20 mb. There is some evidence for seasonal periodicities, chiefly in upper levels, and at levels up to 50 mb there is some evidence for year to year variations.

The analysis of variations in ozone distribution, shown in Fig 4 is also relevant for appraising Newell's model. The proportion of variation in local ozone content not accountable through regression is given by  $\sqrt{1-r^2}$  where  $r$  is the correlation coefficient, determined by the analysis above. It can thus be seen that Newell's calculations should have their greater validity at the 100 mb level, and this conjecture is borne out by the calculations of Hering (1965) for the North American ozone-sonde network. However, Fig 6 suggests that even in upper levels, Newell's approximation still has some validity.

The results of Feely and Spar (1960) relating to tungsten data together with the studies of Newell indicated a meridional circulation between 1/5 and 1/10 of that of Murgatroyd and Singleton (1961), with the largest transport by eddies. Prabhakara (1963), in his model, used a circulation 1/5 that of Murgatroyd and Singleton assuming standard coefficients for eddy diffusion. This gave a reasonable ozone distribution, with a maximum in late winter when the downward vertical motion is at a maximum according to Murgatroyd and Singleton's data. Prabhakara assumed a non-linear tensor diffusion coefficient which always transports ozone from regions of high concentration to low concentration. It has been shown however (Murgatroyd, 1965) that in many cases for the lower stratosphere the transfer is actually countergradient. This can be explained by assuming an axis of preferred mixing which slopes slightly downward from equator to pole. Assuming a poleward motion associated with a downward motion, the tensor nature of the diffusion coefficient will result in a counter gradient flow. This may be forced by an energy source in the troposphere.

The estimates of the poleward eddy transfer for Aspendale, although limited by the number of observations used, do indicate that, for some cases, there is a net poleward transfer (therefore counter gradient) below 20 mb, agreeing with the computer model of Hunt (1969) for similar latitudes to Aspendale. The net poleward transfer is more apparent for the winter and spring seasons, in agreement with Newell (1963) and Hering (1966).

## CORRELATION OF OZONE AND SURFACE PRESSURE

Dobson *et al* (1927) showed that maximum ozone concentrations existed just to the west of surface lows. Such a result was also obtained from the numerical model of Hunt and Manabe (1968). It was found that the lower stratospheric troughs lay to the west of the surface lows and areas of maximum ozone concentrations. This would mean that low mean sea level pressure should be associated with high ozone. Fig 7, showing the effective correlation coefficients

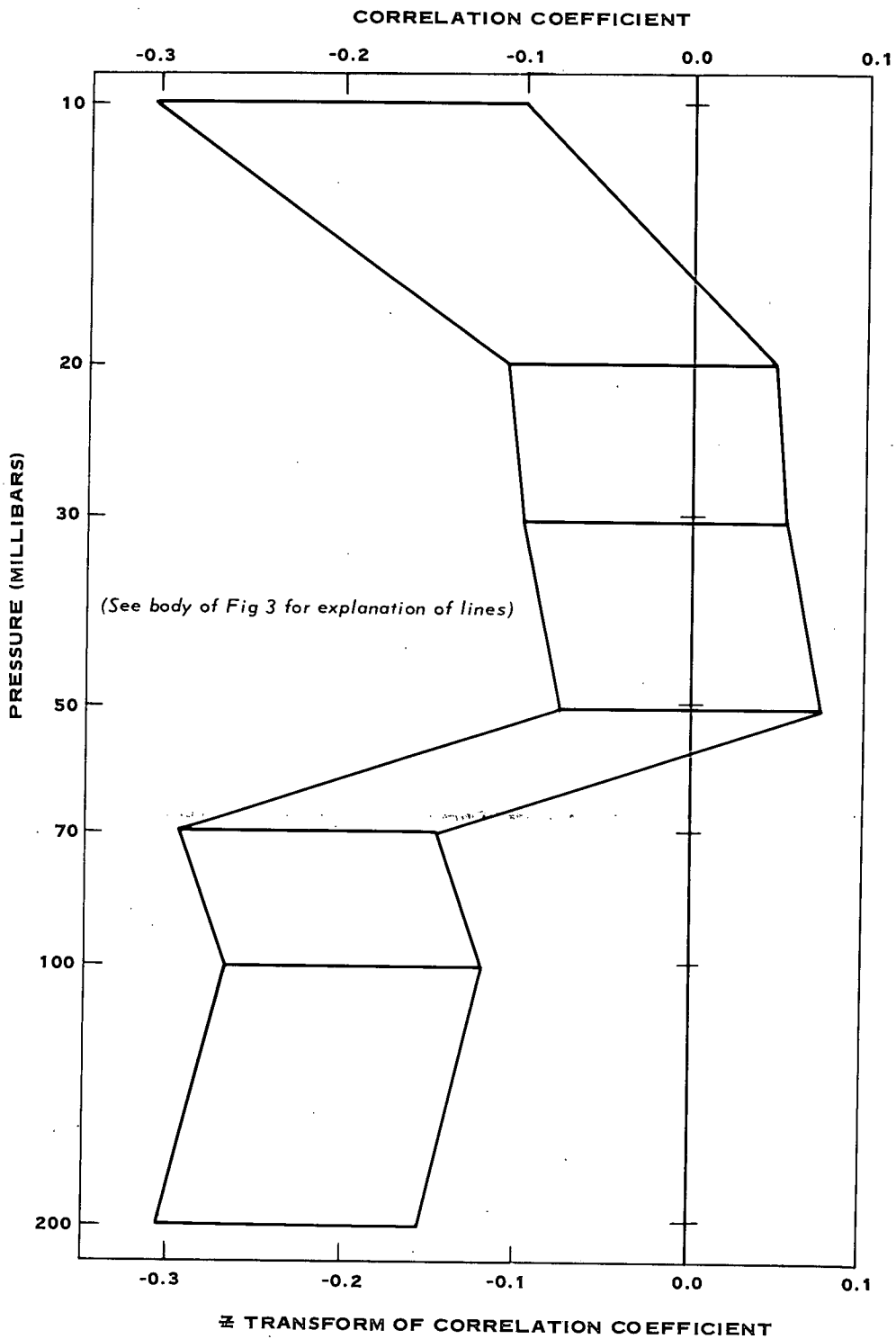


Fig 7 Correlation coefficients between ozone partial pressure and mean sea level pressure.



between ozone partial pressure at particular levels and mean sea level pressure, reveals that a negative relation exists below 50 mb but very little correspondence exists above this level. The greatest negative correlation is at 200 mb, the lowest level which was considered in this particular study and that closest to the tropopause. This is the level where the correlation between ozone partial pressure and temperature is substantially higher than that between total ozone and temperature, and possibly reflects an interchange process between troposphere and stratosphere such as reported by Pittock (1971) and Danielsen (1968).

## CONCLUSIONS

This examination of stratospheric ozone observations obtained at seven standard pressure levels 200, 100, 70, 50, 30, 20 and 10 mb, together with total ozone amount, at Aspendale (Victoria), shows that

- (1) the greatest day to day variation of ozone partial pressure in the 200-20 mb layer, during a season, occurs at the lower levels *ie*, from 200 to 50 mb
- (2) over this four-year period of record, the greatest year to year variation in ozone partial pressure in the 200-20 mb layer occurs at the 50 mb level
- (3) when seasonal correlation coefficients are calculated between ozone partial pressure and total ozone, using both short term and long term values, significant differences are found at and above the 70 mb level, but not below 70 mb
- (4) when seasonal correlation coefficients are calculated between the fractional content and total ozone, they decrease rapidly above 100 mb, becoming negative at about 50 mb (21 km) for short term correlation, and at about 40 mb (25 km) for long term correlation
- (5) a marked increase with height in the correlation coefficient between total ozone and short term temperature occurs from 200 to 100 mb reaching a maximum (exceeding 0.7) at the 70 mb level then decreasing to very low values (near 0.1) at 20 mb. This suggests that vertical motion at the 20 mb level is not highly correlated with that at the 100 mb level
- (6) the correlation between ozone partial pressure and temperature is more consistently positive for all levels considered, giving a smaller spread in coefficients than that for the correlation between total ozone and temperature. Although in lower levels such correlation can be explained, at least partially, by vertical motion it is not sufficient in itself to explain the positive correlation observed in upper levels.
- (7) higher coefficients are obtained when the correlations between ozone partial pressure and temperature are calculated for a long period. This result may be attributed to seasonal and year to year effects

- (8) at pressure levels between 200 mb and 20 mb reasonable correspondence is found between the covariances of poleward (NS) wind component and ozone partial pressure, and the same wind component and total ozone content
- (9) negative, but small, correlation is found between ozone partial pressure and MSL pressure at 200, 100 and 70 mb, whilst at 50, 30 and 20 mb values decrease almost to zero.

The results in (8) above taken with (3) and (4) suggest that, for Aspendale, the greatest validity is obtained near 100 mb for the approximation that eddy transports of ozone are proportional to the corresponding covariances between total ozone and wind. At levels above 100 mb the approximation still shows some validity. It is consistent, by (6), that such inferred eddy transports of ozone may account, at least partially, for the observed correlations between ozone and temperature in upper levels at Aspendale.

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