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A PRELIMINARY REPORT OF WORK ON ASPECTS OF THE LOWER STRATOSPHERE*

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ABSTRACT

Some examples of recent analyses of Australian high level winds are presented which show the recently discovered Southern Hemisphere sub-tropical zonal wind fluctuation in relation to the well-known tropical oscillation. It is suggested that a difference between Northern and Southern Hemispheres favours a terrestrial cause of the 'quasi-26 month' phenomena.

The theory relating a vertical exchange coefficient for momentum to large-scale horizontal eddies and the zonal wind oscillation in the tropics is outlined. Preliminary results suggest very low values for the vertical exchange coefficient immediately above the tropopause, $K = 3 \times 10^3$ cm^2 sec^{-1}, but increasing to about 10^4 cm^2 sec^{-1} at 25 Km.

1. INTRODUCTION

The validity of a concept such as the large scale vertical exchange coefficient can be gauged only by its effectiveness when used to make further deductions which can later be verified. The concept of a large-scale vertical eddy viscosity was used in a recent study of the momentum balance of the lower stratosphere in the vicinity of the Equator (Tucker, 1964) which demonstrated the importance of the vertical and horizontal eddy fluxes of momentum. It was shown that, on the climatological scale, horizontal advection can be neglected in this region and that vertical advection is effectively balanced by the convergence of the vertical eddy flux, the convergence of the horizontal eddy flux and the local rate of change of zonal momentum.

The vertical eddy flux in this analysis was represented by the product of the vertical wind shear and a climatological vertical exchange coefficient for momentum. This enabled the deduction that the convergence of momentum due to the horizontal eddy flux must change sign during the zonal wind cycle; it was inferred to have a sinusoidal form of the same period as the zonal wind oscillation, but with an important phase difference. This form was confirmed from observations at a small number of low latitude stations observing winds at these high levels, but only a very approximate value of $10\pi/13$ was obtained for the phase difference. A later analysis (Tucker, 1965a) suggested that $\pi/2$ might be a better value.

More recently Wallace and Newell (1965) have provided further evidence of the fluctuation in large-scale horizontal eddy fluxes in the lower stratosphere. From a large number of stations in the Northern Hemisphere the authors conclude that a quasi 26-month oscillation exists over a wide range of latitudes but that, unlike the zonal wind oscillation, the phase is almost simultaneous at all latitudes and levels. They also conclude that the oscillation of $\frac{\partial}{\partial y}\overline{v'u'}$ is of proper size and phase to account for the zonal wind changes.

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Further studies of these phonomena are obviously required, particularly since the variation in $\overline{v'u'}$ is difficult to detect, and the variation in $\frac{\partial}{\partial y}\overline{v'u'}$ even more so. The south-western part of the North Pacific Ocean and Australia are areas in which a fairly close network of stations observing high-level winds exists from north to south across the tropical zone. Accordingly this problem is being attacked along three lines - first, by making a detailed analysis of high level winds in this area; second, by investigating the theoretical relation between the vertical eddy viscosity and the sinusoidal form used to represent the convergence of zonal momentum due to large-scale horizontal eddies; third, by investigating the structure of synoptic systems occurring in the tropical troposphere and lower stratosphere. Some preliminary results from the first two of these studies are presented here.

2. SOUTHERN HEMISPHERE WIND DATA ANALYSES

Some studies of high level winds in the Southern Hemisphere, mainly over Australia, have been published (Rofe, 1963; Sparrow and Unthank, 1964). These confirm the existence of the approximately 26-month zonal wind oscillation in tropical areas, but also indicate an unexpected reappearance of a similar oscillation south of 35^{o}S.

A more detailed consideration of the observations on which these results were based showed that observational and data reduction methods suitable for obtaining synoptic data are not acceptable for this type of detailed analysis. A thorough examination of each individual ascent was made and more refined computational techniques were used to minimise the inherent errors in the observing system. Preliminary results for several Australian stations are given in Figs. 1 and 2; most observations extend up to December 1965. New Zealand data were kindly provided by the Director, New Zealand Meteorological Service. Only the usual 12-monthly running means using data at 70,000 ft are presented here. More sophisticated treatments involving harmonic and spectrum analyses are nearly complete and will be published soon.

Fig. 1 shows the usual oscillation at 70,000 ft in the tropics and indicates quite clearly that it is superimposed upon a general easterly flow.

In Fig. 2, the extreme curves of Fig. 1 have been retained and in addition three sub-tropical latitude stations included. The fluctuations appear remarkably consistent at all three stations and are about 3 months in advance of the tropical oscillation. Northern Hemisphere data do not appear to show this sub-tropical phenomenon. If these fluctuations are concomitant with the tropical oscillation and a clear difference between Northern and Southern Hemisphere has been established, then this appears to be quite strong evidence in favour of Newell's (1964) suggestion that the best place to seek a source for this periodicity is in the lower atmosphere. The troposphere responds readily to hemispheric differences in land/sea distribution and, if hemispheric differences also occur in stratospheric phenomena, it seems reasonable to suppose that terrestrial influences may be responsible.

3. THE RELATION BETWEEN $\mu(z)$ AND $\frac{\partial}{\partial y}\overline{v'u'}$

It has been shown previously (Tucker 1964) that the momentum balance in the lower equatorial stratosphere can be represented by the equation.

$$\rho w \left(\frac{\partial u}{\partial z} + 2\omega\right) = \frac{\partial}{\partial z}\left(\mu \frac{\partial u}{\partial z}\right) - \rho \frac{\partial}{\partial y}\overline{v'u'} - \rho \frac{\partial u}{\partial t} \qquad \ldots(1)$$

where u, v, w represent the average values along a circle of latitude of the wind components in the x (northward), y (eastward) and z (upward) directions; $\overline{v'u'}$ denotes the covariance between northward and eastward wind components and thus represents the northward eddy flux of zonal momentum; ρ represents density; t, time; and μ the vertical dynamic eddy viscosity. The term on the left hand side of equation 1 can be regarded as representing vertical advection, and the terms on the right hand side as the effects of vertical eddy fluxes, horizontal eddy fluxes and the local rate of change of momentum respectively.

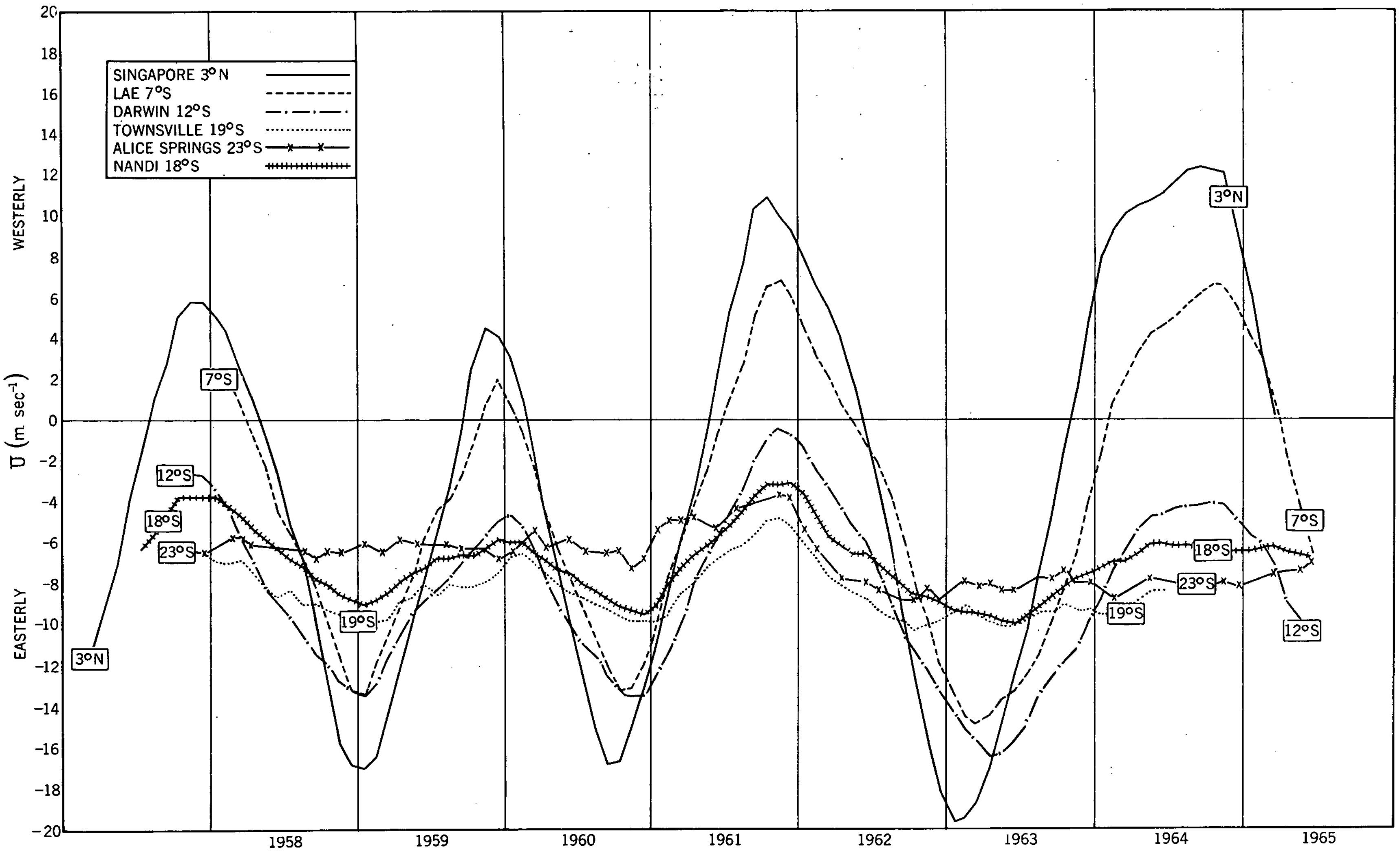

Fig. 1. Twelve-monthly running means of $\overline{U}$ (m. sec^{-1}) at 70,000 feet.

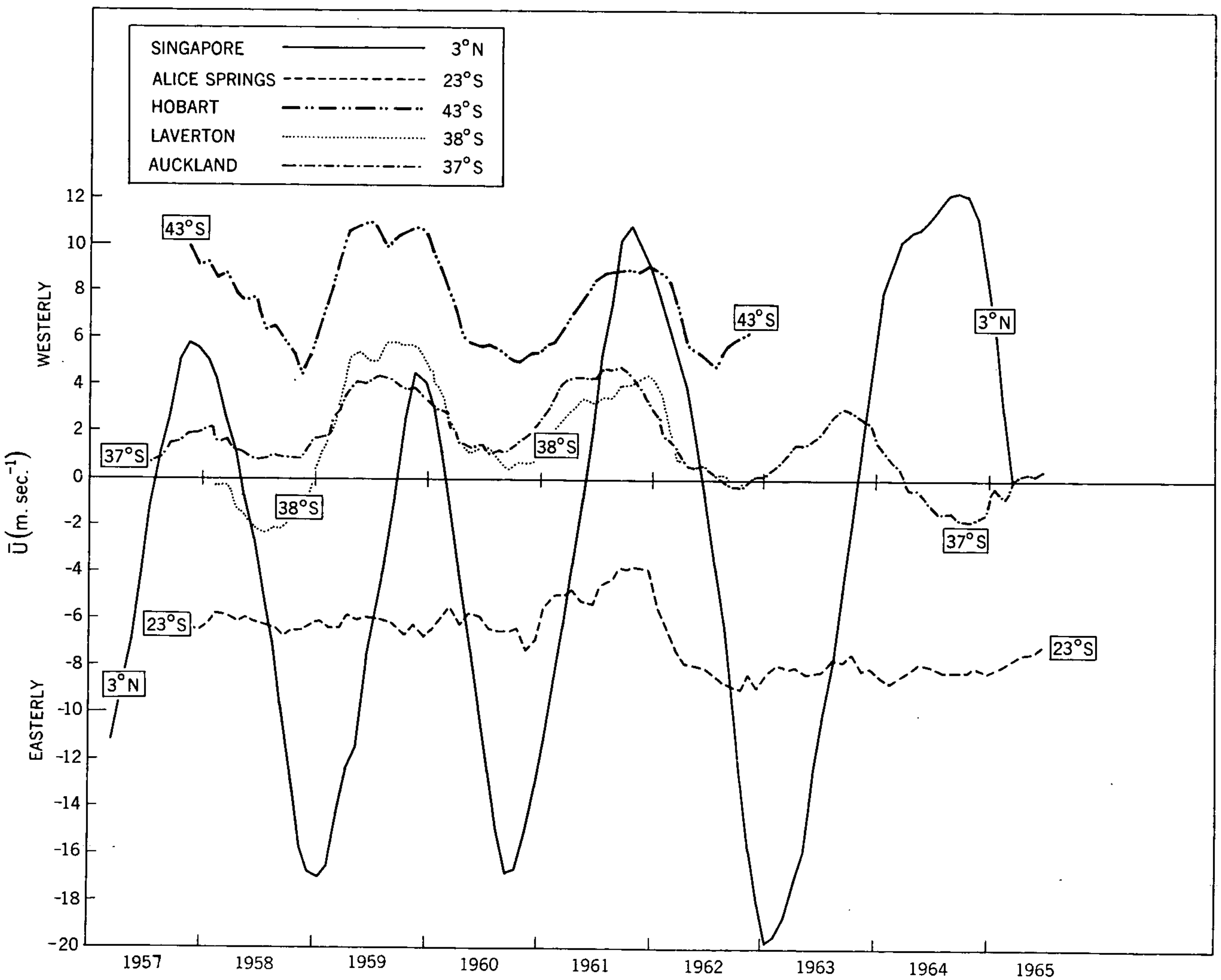

Fig. 2 Twelve-monthly running means of $\overline{U}$ (m. sec^{-1}) at 70,000 feet.

The zonal wind is given by

$$u = U + \mathcal{U} \qquad \ldots(2)$$

where U (z) is that component of the zonal flow which is invariant in time; $\mathcal{U} = A \sin \Psi$, and $\Psi = \frac{\pi}{13}\left(\frac{z^*}{c} + t^*\right)$. $\mathcal{U}$ (z,t) represents the 26-month zonal wind oscillation, A(z) being the amplitude, c the downward rate of propagation (assumed to be 1.2 km per month), and z^* and t^* are the height and time above and beyond some reference time and level.

The effect of large scale horizontal eddies is given by

$$\frac{\partial}{\partial y}\overline{v'u'} = B + C \sin(\Psi + \phi) \qquad \ldots(3)$$

Here the convergence of horizontal eddy flux is assumed to have a sinusoidal form (Tucker 1965) in which B, C and ϕ are functions of height only. C is the amplitude of this oscillation and ϕ is the phase difference between it and the zonal wind oscillation.

It can be seen from equation (1) that when $\frac{\partial u}{\partial z} + 2\omega = 0$, i.e. close to a maximum or minimum in the vertical profile u(z), the contribution of vertical advection is zero; therefore the right hand side of equation (1) is also zero. Whence

$$\frac{1}{\rho}\frac{\partial}{\partial z}\left(\mu\frac{\partial u}{\partial z}\right) = \frac{\partial}{\partial y}\overline{v'u'} + \frac{\partial u}{\partial t} \qquad \ldots(4)$$

at $$\Psi_{1,2} = 2 \arctan \frac{-\frac{\partial A}{\partial z} \pm \left(\left(\frac{\partial A}{\partial z}\right)^2 - \left(\frac{\partial U}{\partial z} + 2\omega\right)^2 + \left(\frac{A\pi}{13c}\right)^2\right)^{\frac{1}{2}}}{\frac{\partial U}{\partial z} + 2\omega - \frac{A\pi}{13c}}$$

The following argument applies only when Ψ_1 and Ψ_2 are real.

Applying equation (4) at Ψ_1 and Ψ_2, subtracting and rearranging we can obtain

$$\mu + \alpha\frac{\partial \mu}{\partial z} + \beta = 0 \qquad \ldots(5)$$

where $$\alpha = \frac{\frac{A\pi}{13c}(\cos\Psi_1 - \cos\Psi_2) + \frac{\partial A}{\partial z}(\sin\Psi_1 - \sin\Psi_2)}{\frac{2\pi}{13c}\frac{\partial A}{\partial z}(\cos\Psi_1 - \cos\Psi_2) + \left(\frac{\partial^2 A}{\partial z^2} - A\left(\frac{\pi}{13c}\right)^2\right)(\sin\Psi_1 - \sin\Psi_2)}$$

and $$\beta = -\rho\frac{\frac{A\pi}{13}(\cos\Psi_1 - \cos\Psi_2) + C(\sin(\Psi_1 + \phi) - \sin(\Psi_2 + \phi))}{\frac{2\pi}{13c}\frac{\partial A}{\partial z}(\cos\Psi_1 - \cos\Psi_2) + \left(\frac{\partial^2 A}{\partial z^2} - A\left(\frac{\pi}{13c}\right)^2\right)(\sin\Psi_1 - \sin\Psi_2)}$$

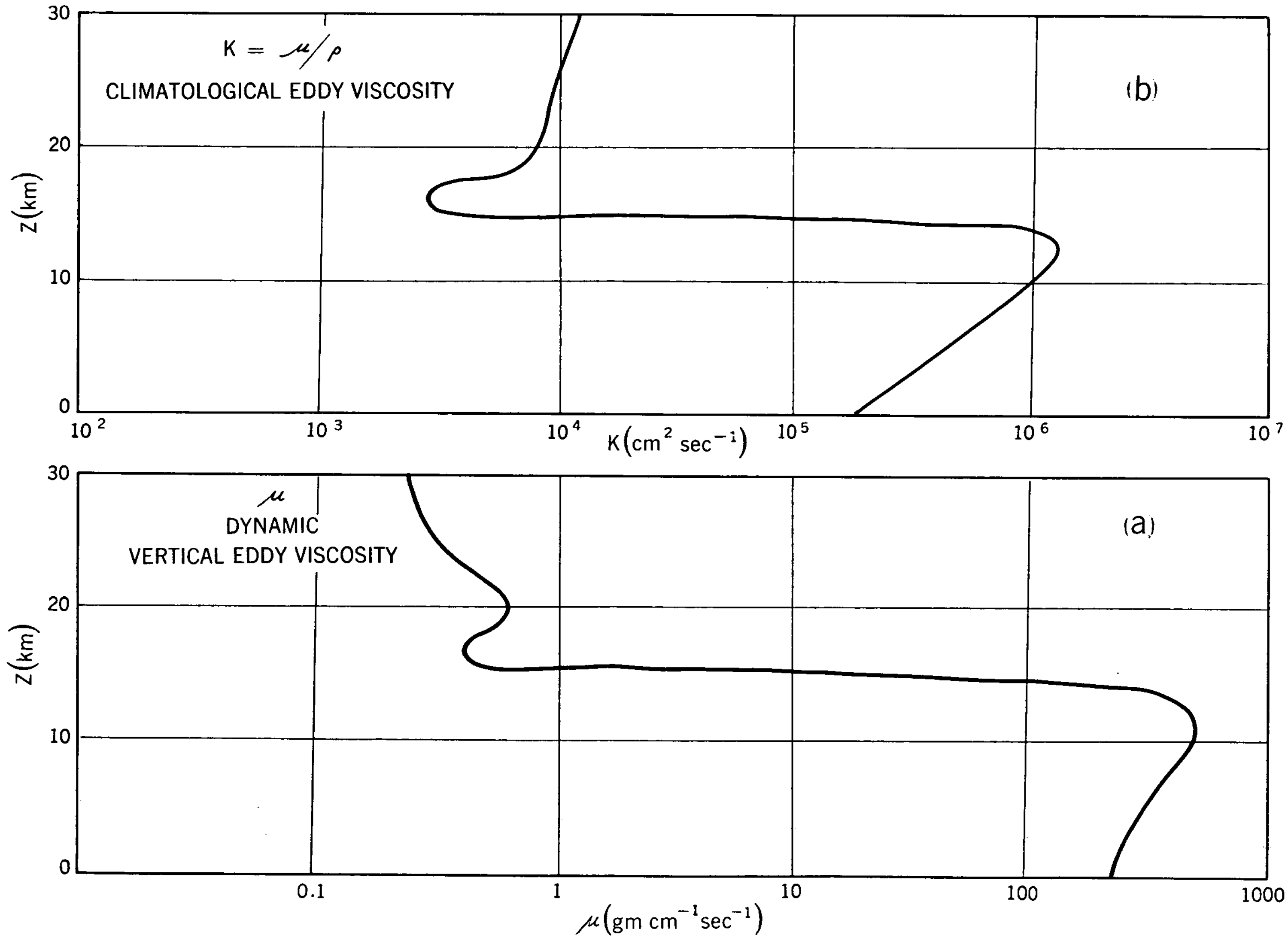

Fig. 3 Vertical profiles of vertical exchange coefficient for zonal momentum.

Thus if A (z), ρ (z), C (z), U (z) and ϕ are specified, then commencing with a given value of μ_o at any one level we can obtain the vertical profile of μ (z). Also, the effect of various modifications to the specified profiles can be investigated. The profiles A (z) and ρ (z) are well known, and at present observations in the West Pacific Australian region are being analysed to obtain C (z), U (z), and ϕ.

Preliminary results are given in Figure 3 which depicts the vertical profiles of μ and K ($=\mu/\rho$) based on values of C obtained from one pair of stations over the Atlantic (San Juan and Ascension Island). The tropospheric part of the curve is drawn from considerations of vertical stability (Tucker, 1964). It can be seen that very low values of μ ($\sim$0.3 gm cm^{-1} sec^{-1}) occur in the vicinity of the tropopause; these correspond to values of K($=\mu/\rho$) of about 3×10^3 cm^2 sec^{-1}. In the first few kilometres of the stratosphere μ appears to increase sharply to a maximum at about 20 km of about twice its value at the tropopause; above this it decreases slowly with increasing height.

In the lowest layers of the stratosphere the atmosphere is always assumed to be very stable, nevertheless the very low values deduced for the vertical exchange coefficient are somewhat surprising. The extreme stability of these regions is indicated by the prolonged existence of very thin dust layers at these levels which appear to retain their identity for long periods and over wide areas. Dr. E.K. Bigg (C.S.I.R.O. Division of Radio Physics, Sydney) has used aircraft photographs to calculate thicknesses of less than 100 m for some of these stable dust layers at about 18 Km.

The maximum at about 20 km is an intriguing result which has stimulated an investigation of the variation with height of the horizontal scale of synoptic disturbances in the lower stratosphere. No results are yet available.

4. CONCLUSION

If, in the large scale, the vertical eddy flux of zonal momentum is proportional to the vertical shear of zonal wind then it has been shown that an oscillation in the effects of large scale horizontal eddies is necessary for balance. From this it is interesting to postulate that the dynamical controls on the zonal wind fluctuations operate through the eddy mixing processes and a broad overall vertical advection rather than through meridional circulations which fluctuate in a regular way throughout the cycle. The changes in temperature necessary to ensure that the flow is geostrophic (Reed, 1962) may be brought about by superimposed meridional circulation variations; this is effectively what Reed (1964) has done - and obtained the corresponding velocities. In some ways these meridional circulation variations can be considered as a side product, due to variations in the structure of systems in the lower stratosphere (Tucker, 1965b) and not necessarily directly related to a causal mechanism. In this context one may note that Reed's (1964) velocities are appreciably smaller than Tucker's (1964). However, in view of the difficulty of resolving the effects of large scale horizontal eddies from inaccuracies inherent in current high level wind observations, further time and painstaking analyses are required before the above theory can be confirmed or rejected.

REFERENCES

Newell, R.E.	1964	"A note on the 26-month oscillation". J. Atmos. Sci., 21, p. 320.
Reed, R.J.	1962	"Evidence of geostrophic motion in the equatorial stratosphere". Quart. J.R. Met. Soc., 88, p. 324.
	1964	"A tentative model of the 26-month oscillation in tropical latitudes". Quart. J.R. Met. Soc., 90, p. 441.

Rofe, B.	1963	"Australian sounding rocket experiments". Technical Note SAD 127, Department of Supply, Salisbury, Australia.
Sparrow, J.G. and Unthank, E.L.	1964	"Biennial stratospheric oscillations in the Southern Hemisphere". J. Atmos. Sci., 21, p. 592.
Tucker, G.B.	1964	"Zonal winds over the Equator". Quart. J.R. Met. Soc., 90, p. 405.
	1965a	"The divergence of horizontal eddy flux of momentum in the lower equatorial stratosphere". Quart. J.R. Met. Soc., 91, p. 356;
	1965b	"Comments on 'An evaluation of certain forms of momentum transfer in the 26-month oscillation'". Correspondence, Mon. Weather Rev., 93, p. 704.
Wallace, J.M. and Newell, R.E.	1965	"Eddy fluxes and the biennial oscillation in the stratosphere". Report No. 14, M.I.T. Department of Meteorology.