# Strong long-period tropospheric and stratospheric rhythm in the Southern Hemisphere

THE recent EOLE satellite-balloon atmospheric sensing experiment conducted in the Southern Hemisphere between August 1971 and July 1972, provided large quantities of upper tropospheric data in a hitherto near-dataless region. Besides measurements of ambient temperature and pressure reported directly from the balloon to the satellite, the experiment allowed the calculation of series of highly accurate Lagrangian velocities by the positioning of the balloon between successive satellite orbits. The experiment and data are described in detail by Morel and Bandeen[1].

To obtain a Eulerian data set, the Lagrangian data required transformation. As no general analytical transformation exists[2], the Eulerian information was obtained by computing daily averages of all the measured Lagrangian quantities in each area of 10° latitude by 20° longitude. The resulting average was assumed to be the representative Eulerian daily average of that quantity. The rationale and justifiction of this method is given elsewhere (ref. 3 and P.J.W., D. G. Curtin and Y. Mintz, to be published).

Tropospheric rhythms: The many attemps to find a distinct atmospheric periodicity on a global or hemispheric scale have met with little success. Most notable are the efforts of Willett[4] and Namias[5] in the Northern Hemisphere and recently by Taljaard[6] in the Southern Hemisphere. All studies defined some index which was more or less sensitive to the change of state of the atmosphere. Although large variations in the various indices did occur, no dominant rhythm was identified[6]

Another common feature of these studies was the use of land based Eulerian sensors which, on account of their geographical grouping, may not have been suitable for the calculation of a representative hemispheric index. To overcome this problem, the Eulerian data inferred from the dense EOLE data set was used to define a zonal index sensitive to the transition of the atmosphere from perturbed to a zonal state. Such an index ($R$) is defined as the ratio of the kinetic energy of the mean flow ($K_Z$) and the zonal average of the perturbation or eddy kinetic energy ($K_E$), that is,

$$R = K_E/K_Z = \frac{1}{2\cos\phi}\int_0^{2\pi} (\bar{V} - [\bar{V}])^2\, d\lambda/([\bar{V}]^2/2)$$

where

$$[\bar{V}] = \frac{1}{\cos\phi}\int_0^{2\pi} \bar{V}\, d\lambda.$$

Here $\lambda$ represents longitude, $\phi$ latitude and $\overline{V}$ the distribution of the daily mean Eulerian velocity inferred from the EOLE data.

Time sections of R are shown in Fig. 1 for three 10° latitude bands between 30° and 60°S. Large amplitude variations may be seen with an apparent period of some 20 d, especially in the higher latitudes. These represent regular changes from highly perturbed states (large $R$) to highly zonal states (small $R$). Superimposed upon this trend are variations of higher frequency and smaller amplitude indicating similar but short lived variations.

The times series spectral analyses of $R(t)$, shown in Fig. 2, tend to support these observations. In the 50°–60°S latitude spectra for $R$, a strong isolated peak suggests a strong rhythm centered near 20 d in the high latitudes, a feature which is also reflected in the $K_E$ spectra. As illustrated by the 40°–50° spectra of $R$, the peak is somewhat weaker and further diminishes into the subtropics. Spectra of the zonally averaged pressure (lower diagram) indicates a weaker periodicity near 20 d, whereas the zonally averaged temperature field does not exhibit relatively as large a variation. This is common to the temperature field at all latitudes.

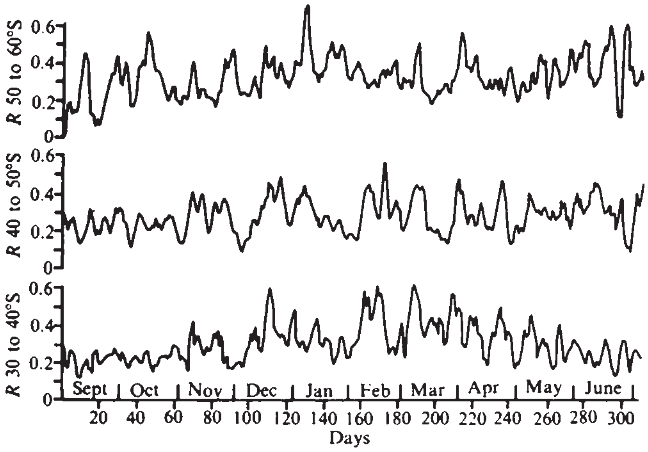


Fig. 1 Variation with time of the index $R$ over the EOLE period for the three latitude bands indicated.

The cross spectra between the two component energies of $R(t)$ indicate an extreme peak near 20 d. An important feature is that, in the 50° to 60° band, $K_E$ and $K_Z$ are almost exactly out of phase (−176°) and have a coherence of 0.825 in the 18 to 23 d band, surpassing the 99.9% confidence limit at this spectral band width. (Coherence between the various values of $R$ for the different latitudes each

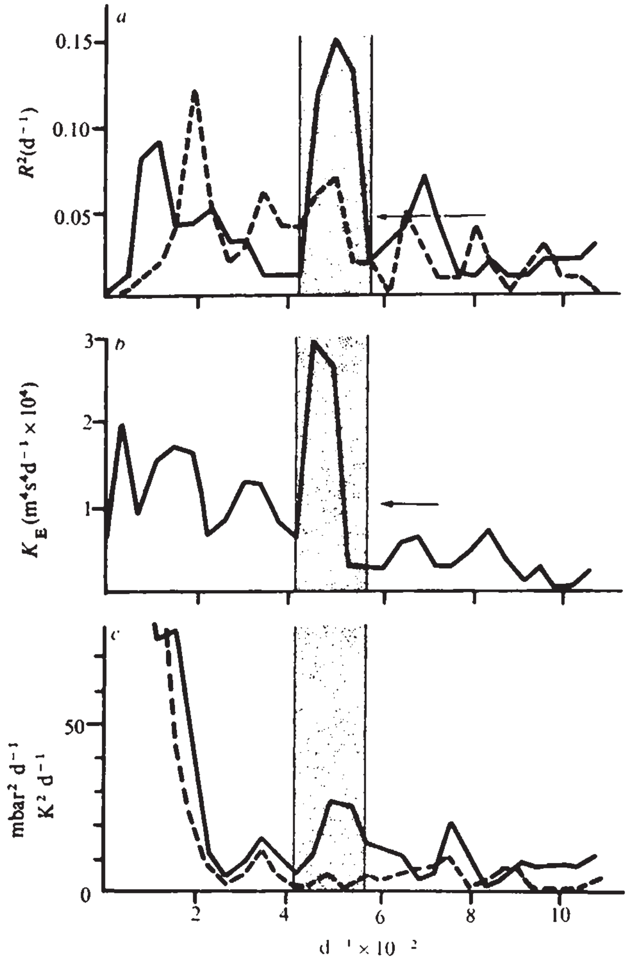


Fig. 2 Variance spectra. $a$: ——, $R$ for 50° to 60° S; – – – –, $R$ for 40° to 50°S. $b$: $K_E$ for 50° to 60°S. $c$: ——, $P$; – – – –, $T$. Both for 50° to 60°S. Arrows denote 90% confidence level, shaded region the 18 to 23 d band.

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surpasses the 99% level in this frequency band.) Such phase and coherence strongly suggests that the quasi-20-d rhythm in $R$ may be accounted for by the conversion of kinetic energy between that of the eddies and that of the mean flow, such that the cycle consists of waves growing at the expense of the mean flow and then the reverse conversion.

Spectral analysis in space and time indicates that much of the power of the 20-d rhythm is in the ultra-large scale waves. For example, in the 50° to 60° band, the kinetic energy in longitudinal wave numbers 1 and 2 is an order of magnitude greater in the 18 to 23 d period interval than for any other wavenumber. The momentum flux also shows a 20-d rhythm, which, together with the above, suggests that this variability in $R$ is a manifestation of a slow period and very large scale barotropic energy conversion between $K_E$ and $K_Z$ which is similar in character to the barotropic energy conversion described by Lorenz[7]. But this process is generally thought to be restricted to a much smaller scale (~1,000 km) and higher frequency motions (~4 to 5 d) and is considered to be of secondary importance in the energetics of the general circulation.

In contrast, we suggest that the precominant process in upper-troposphere of high latitudes over the time scale of weeks is the barotropic exchange of energy between the ultra-long waves and the zonal flow.

(ii) Stratospheric rhythms: Initial attempts have been made to determine to what extent the stratosphere is effected by the large scale, long period tropospheric oscillations suggested above. Due to the scarcity of conventional data and the consequent inability to construct a zonal index for the stratosphere, total ozone data from the few scattered Southern Hemisphere stations were analysed.

Figure 3 shows the time series spectral analyses of the total ozone for the three stations, Argentine Island (65°S), MacQuarie Island (55°S) and Brisbane (28°S) chosen for the initial study on the basis of data availability and latitudinal spread. The only data modification was the removal of the dominating annual trend before the spectral analysis.

The common feature of all three spectra is the existence of power, to varying degrees, in the 18 to 23 d period band. This is especially evident at Argentine Island and MacQuarie Island, and surprisingly for a station so far equatorward, at Brisbane. Cross spectra between these ozone stations show strong coherence during the EOLE period in the 18 to 23 d band. The coherence between $R$ and the stratospheric ozone is slightly weaker but this may be because we are seeking cross-spectra between point observations (the ozone) and hemispheric quantities ($R$).

The results presented here are not conclusive, but there seems to be a strong suggestion of a preferred and dominating physical mechanism existing over the period of weeks in the high latitudes of the upper troposphere of the Southern Hemisphere. This large scale and long period oscillation seems to be tied to the barotropic interchange of energy between the perturbations and the mean flow and possesses vertical propagation properties such that it may provide an important energy source for the stratosphere over this time scale.

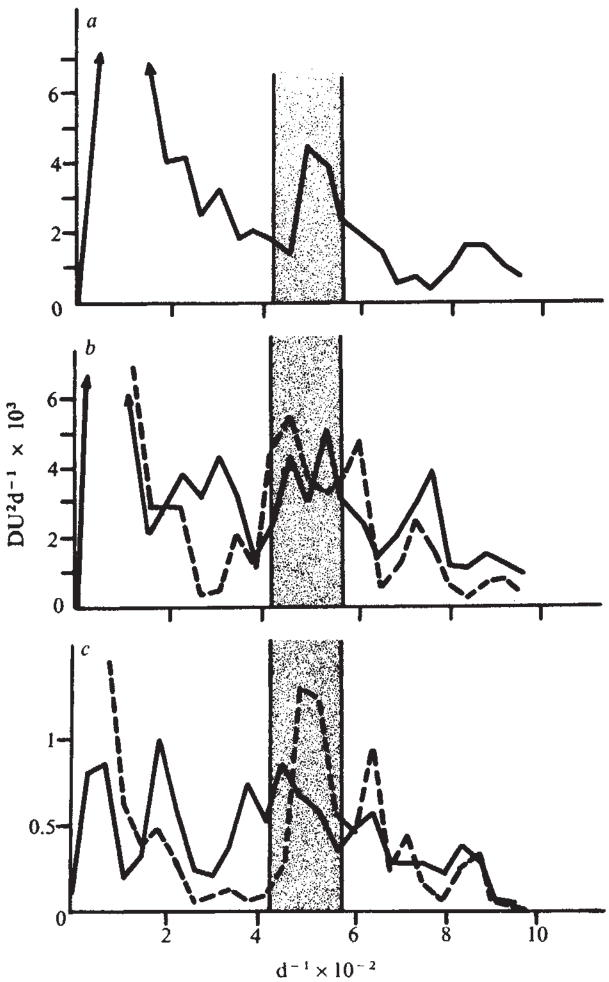


FIG. 3 Variance spectra of total ozone. *a*: Argentine Island (65°S), 1962–64. *b*: Macquarie Island (55°S), 1971–72. *c*: Brisbane (28°S), 1971–72. Dashed lines denote data from EOLE period. 1 DU is equivalent to $10^{-3}$ cm NTP.

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Received October 24, 1973; revised January 2, 1974.

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## Dispersion of ionospheric waves

THE phase speed dispersion of travelling ionospheric disturbances (TIDs) has been measured using data from a three-dimensional array of c.w. Doppler sounders[1]. Horizontal and vertical trace speeds of phase surfaces were measured as a function of wave period by performing cross-spectral analysis of the array signals. Although the measured dispersion varied considerably depending on the coherence of the wave activity across the array, the average horizontal trace speed was approximately proportional to $T^{-1/2}$, where $T$ is the period. From a very limited set of measurements, vertical trace speed was tentatively determined as proportional to $T^{-1}$. Additional measurements of highly coherent waves now indicate that the vertical dispersion is even stronger than $T^{-1}$ at the short periods (12-25 min.).

Based on the reliably determined horizontal dispersion and a large diurnal variation of speed, I suggested[1] an

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