Quasi-Biennial Cycles in Cosmic Ray Intensity

KAICHI MAEDA

Goddard Space Flight Center, Greenbelt, Md.

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Since its discovery in the tropical stratospheric wind system by Reed[1] in 1960 and independently by Veryard and Ebdon (1961), many features of the biennial variation or the so-called 26-month oscillation of the earth's atmosphere have been revealed in the past few years (Reed 1962, 1963, 1964, 1965[2]; Reed and Rogers, 1962; Staley, 1963; Veryard and Ebdon, 1963; Belmont and Dartt, 1964; Dartt and Belmont, 1964; Newell, 1964a,b; Kriester, 1964; Sparrow and Unthank, 1964; Westcott, 1964).

The intent of this short note is to point out that atmospheric variations may also appear in certain cosmic ray data, and to show one preliminary result obtained by power spectrum analysis of cosmic ray data.

Cosmic ray intensities observed at the earth's surface are continuously modulated not only by astrophysical variations in outer space (particularly magnetic field variations) but also by atmospheric variations. Due to the decay processes of unstable components such as pions and muons produced by incoming primary cosmic ray particles in the upper atmosphere, cosmic ray intensities at the ground change with variations of barometric pressure and atmospheric temperature (Jánossy, 1950; Dauvillier, 1954; Heisenberg, 1953; Dorman, 1957). Therefore, the cosmic ray muon data—which are more commonly called cosmic ray meson data or the hard component intensities—measured at the ground and corrected for barometric effect are very good indicators of continuous atmospheric temperature variations, provided that information about the geomagnetic variations is available. For this reason we can expect that variations occurring in the upper atmosphere should also be found in the pressure-corrected cosmic ray muon data.

The variation of cosmic ray intensity at the ground due to atmospheric temperature variations is an accumulated effect of the differential contribution from each layer in the atmosphere, which are not only functions of the altitude of each layer in the atmosphere but also of the cut-off energy of the observed cosmic rays. The latter depends on the geomagnetic and geographic location of the observing station and on the parameters of the measuring instrument, such as shield thickness and type of cosmic ray detector. These relations are well known both experimentally and theoretically, and can be expressed by the simple formula,

$$\frac{\delta I}{I_0}=\int_0^{x_0}\gamma(E_0,x)\delta T(x)dx,$$

$$\cong\sum_{i=0}^{n}\gamma(E_0,x_i)\delta T(x_i)\Delta x_i,$$

where I_0, δI are the mean and the deviation of cosmic ray intensity at the atmospheric depth x_0 due to the temperature variation δT at the depth x in dx.

$\gamma(E_0,x)$ is called the partial temperature coefficient, which indicates the relative variation of cosmic ray muon intensity with cut-off energy E_0 at the depth x_0, due to a 1C increase in the layer δx at x. Details of these coefficients as functions of E_0 and x, as well as comparisons with the experimental data have been discussed by many workers (Maeda and Wada, 1954; Trefall 1955a, b; Wada and Kudo, 1956; Dorman, 1957; French and Chasson, 1959; Mathews, 1959; Wada 1961; Carmichael *et al.*, 1963, 1965[3]).

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[1] Reed, R. J., 1960: The circulation of the stratosphere. Paper presented at the 40th Anniversary meeting of the Amer. Meteor. Soc.

[2] Reed, R. J., 1965: The present status of the 26-month oscillation. Paper presented at the 45th Annual Meeting of the Amer. Meteor. Soc.

[3] Carmichael, H., M. Bercovitch and J. F. Steljes, 1965: Introduction of meteorological corrections into meson monitor data. Paper presented at the Ninth Intern. Conf. on Cosmic Rays, London.

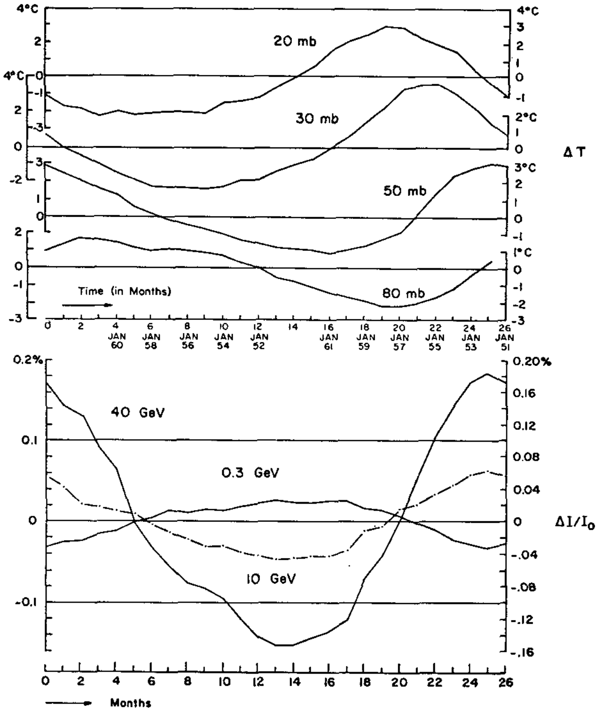

FIG. 1. 26-month variations of stratospheric temperatures in tropical regions and corresponding variations of cosmic ray intensities. The upper curves are variations of stratospheric temperature difference on a 26-month scale between an equatorial station (Canton Island, 3S) and five subtropical stations (Reed, 1965[2]). The lower curves are calculated variations of the relative intensities of cosmic ray muons by making use of the data shown by upper curves for cut-off energies of 0.3, 10, and 40 GeV.

In the upper portion of Fig. 1, the 26-month oscillations of atmospheric temperature at various pressure altitudes for the periods of years from 1951 to 1961 in the equatorial region reported by Reed (1965[2]) are reproduced. The corresponding variations of cosmic ray muon intensities can be calculated by using these data and the above mentioned formula, and are shown in the lower portion of Fig. 1 for different cut-off energies, i.e., $E_0=0.3$, 10, and 40 GeV, where values of $\gamma(E_0,x)$ are taken from previous calculations (Maeda, 1960).

As can be seen from these curves, the phase relation between the 26-month oscillation in upper atmospheric temperature and that of cosmic ray intensity at the ground is not simple, with the phases being reversed at low ($E_0<0.5$ Gev) and at high energies ($E_0\gg1$ Gev). This results from the different temperature effects at low energies (negative) and at high energies (positive). The former correspond to the usual hard component data such as those observed by an ion-chamber or by the so-called cubical meson telescope, while the latter correspond to underground cosmic ray intensities.

At any rate, if continuous measurements of cosmic ray intensity had been made at the geographic equator for more than one decade, the 26-month variation with amplitude of the order of 0.03% or the maximum deviation of the order of 0.1% could be detected even by ion-chamber data. If the underground cosmic ray measurements had been made continuously for more than several years near the geographic equator, the 26-month variation with amplitude of more than 0.2% (which is the order of magnitude observed in the diurnal variation of cosmic ray intensity) could also be found in these data with anti-phase to those of low energies.

Since no cosmic ray data corresponding to the curves shown in Fig. 1 are presently available,[4] detection of the biennial or 26-month variations in cosmic ray intensities by means of a simple statistical method is not feasible. However, the so-called Type C ion chamber, which is shielded with a 12 cm Pb-equivalent absorber, has been operated at Huancayo, Peru (12S geographic, 3350 m MSL) since June 1936. Therefore, a power spectrum analysis has been made using the monthly average data from this station for the 23-yr period from 1937 to 1959. Since the identical ion chamber has been operated at Cheltenham, Md. (39N, near sea level), a similar analysis has also been applied to these data for the same period. These results are shown in Fig. 2, where un-normalized power spectra (the Lebesque power integrals of monthly mean values of ion-chamber data) are plotted against the frequency h. The periods τ, in months, are also marked on the horizontal scale under the corresponding values of h. The computer program used in the present calculation (IBM 7094) is the same as the one applied to spectral analysis of traveling pressure waves in the atmosphere (Maeda and Young, 1964), which is based on the formula used by oceanographers (Pierson and Marks, 1952). The dashed line in Fig. 2 represents the monthly mean value from Huancayo, which includes not only geomagnetically disturbed data but also the effect of drift on the recording systems. The heavy solid line is obtained by choosing "five quiet days" in each month and the data are then corrected for the drift using the formula given by Forbush (1958).

The thin solid line is obtained from the monthly average data from Cheltenham,[5] which included geomagnetic disturbed days. It is obvious from this figure that the well-known annual variation of cosmic ray intensity, which strictly speaking should be called the seasonal variation because of its "anti-phase" relationship between the two hemispheres, does not exist in the tropical region. Rather broad bands, however, with periods from 16 to 60 months exist. Also, it is interesting to note that there are small peaks at 16-, 24-, and

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[4] Except the following two stations: Lae, New Guinea (7S geographic), and Makerere in Kampala, East Africa (0.33N geographic) both near sea level. The analysis of the pressure-correction muon data of these stations are in process and the results will be published by Suda (1967).

[5] The ion-chamber was moved from Cheltenham, Md., to Fredericksburg, Va., in October 1956. The difference between these two locations, which is only of the order of 100 km, is not significant in the present analysis.

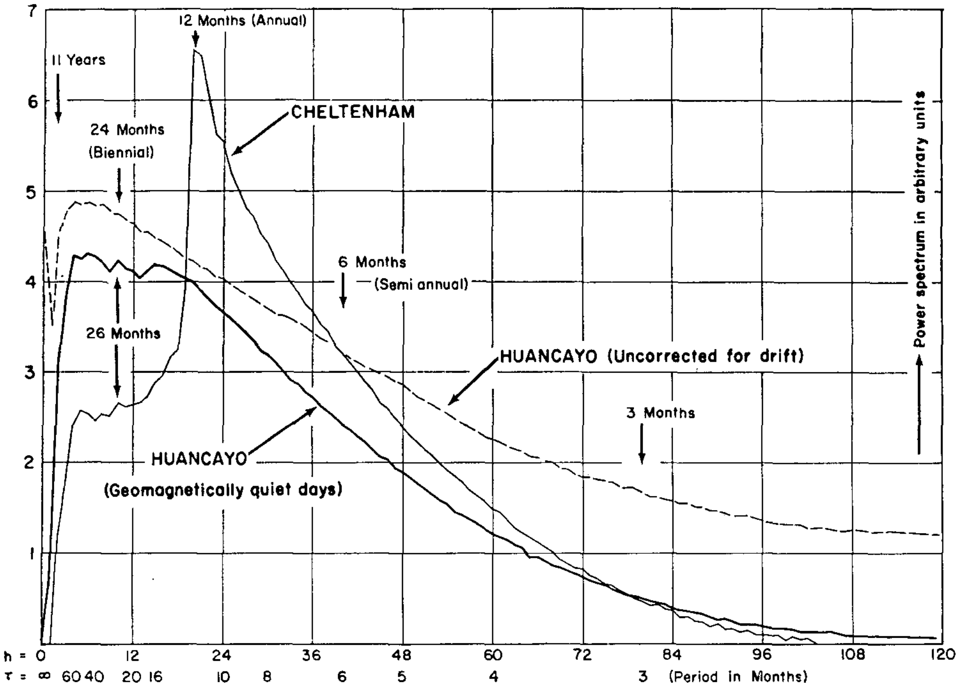

FIG. 2. Un-normalized power spectra (the Lebesque power integrals) of monthly mean ion-chamber data for the period 1937–1959 for Cheltenham (39N, geographic, near sea level), including geomagnetic disturbed days, and Huancayo (12S, geographic, 3350 m), where the dashed line is not corrected for the drift (see text) and geomagnetic disturbances, while the heavy line is based on the monthly means of "five quiet days" and is corrected for drift. The vertical scales for these three curves are the same. The horizontal scales are frequency h ($240\times\text{month}^{-1}$) and period τ in months.

40-month periods in the geomagnetically quiet data of Huancayo and similar peaks in the 24 and 48 month periods in Cheltenham data, although further accumulations of data are necessary to establish the significance of these peaks.

As indicated by recent aerological observations, the quasi-biennial variations are persistent even at high latitudes, especially in the Southern Hemisphere, including the Antarctic (Funk and Garnham, 1962; Landsberg, 1962; Landsberg *et al.*, 1963; Angell and Korshover, 1964; Sparrow and Unthank, 1964; Reed, 1965[2]). Since high energy cosmic-ray data, particularly those measured underground, should be available several places in the world, quasi-biennial cycles in cosmic ray phenomena seem to be a worthwhile subject for further investigation.

Finally, it should be mentioned that the sources of cosmic ray variations are terrestrial as well as extraterrestrial, and that the latter can be obtained from cosmic ray neutron data corrected for barometric variations because the temperature effect on cosmic ray neutron intensity has been known as negligible [Dorman (1957), for example]. Thus, investigations of world-wide cosmic ray data, especially comparisons of muons and neutron data (both corrected for barometric effect) may provide additional data on these mysterious oscillations in the earth's atmosphere which have been discussed recently in several different fields (Shapiro and Ward, 1962; Stacey and Westcott, 1962; Hope, 1963; Westcott, 1964; Newell, 1964a, b; Lindzen, 1964; Reed, 1965[2]). More detailed analyses on this subject are reported elsewhere (Maeda and Suda, 1965).

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