PAPER 40

SEPARATION OF EXTRA TERRESTRIAL VARIATIONS IN COSMIC RAY INTENSITY AND ATMOSPHERIC EFFECTS BY DIFFERENTIAL MEASUREMENTS WITH G–M TELESCOPES

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ABSTRACT

The daily variation of cosmic ray intensity can arise partly from atmospheric and partly from non-atmospheric effects. There is at present a difference of opinion whether this latter effect is completely due to extra terrestrial causes or not.

The purpose of the present paper is to suggest a method by which the atmospheric effects could be separated from the other variations without any assumptions about the mechanism of the atmospheric influence.

Assuming that the primary particle intensity around the earth is not quite isotropic it can be shown (see Fig. 1) that, when measuring with a G–M telescope situated at P, the daily intensity variation is written:

$$I = \sum_{\nu} {}^{t}I_{\nu} . \cos \Theta . \cos \Phi . \cos (\omega t + \nu . \Psi^{*} - \nu . \Psi') + \sum_{\nu} C_{\nu} . f(\nu . \omega t), \qquad (1)$$

where the first sum represents variations due to the anisotropy and the second sum is the atmospheric component, due to the fluctuations of the atmosphere. In this expression the angles Θ and Ψ' are the positional angles of the extra terrestrial cosmic ray source, which represents the anisotropy. Ψ^{*} and Φ are the angles through which the particles have been deflected in the geomagnetic field before they are recorded by the telescope, i.e. Ψ^{*} and Φ determine the measuring direction or the asymptotic direction of a telescope, when corrected for the geomagnetic deflexion. ${}^{t}I_{\nu} . \cos \Theta . \cos \Phi$ finally, is the amplitude of the νth harmonic of the induced true cosmic ray intensity variation. The number of harmonics and their amplitudes depend on the extension of the cosmic ray source in space, but the inaccuracy of cosmic ray measurements limits our discussion to the first and second harmonics.

Suppose the daily variation in cosmic ray intensity has been measured during a long period by two telescopes, identical as far as regards geometrical dimensions. One telescope, however, is measuring in the north direction with a certain zenith angle, the other telescope in the south direction with the same zenith angle. The averaged variation for the period is then, in accordance with Eq. (1):

$$I_N = \sum_{\nu=1}^{2} {}^tI_\nu . \cos\Theta . \cos\Phi_N . \cos(\nu.\omega t + \nu\Psi_N - \nu.\Psi') + \sum_{\nu=1}^{2} C_\nu . f(\nu.\omega t),$$

$$I_S = \sum_{\nu=1}^{2} {}^tI_\nu . \cos\Theta . \cos\Phi_S . \cos(\nu.\omega t + \nu.\Psi_S - \nu.\Psi') + \sum_{\nu=1}^{2} C_\nu . f(\nu.\omega t), \quad (2)$$

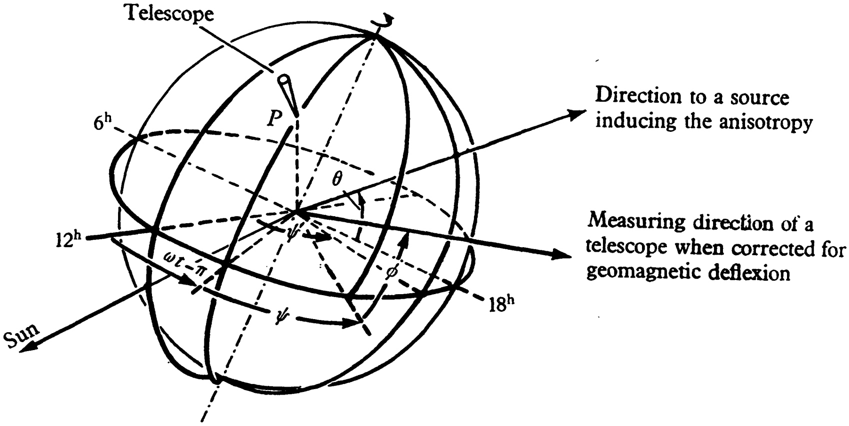

Fig. 1. Relations between the measuring direction of a telescope, direction to a source inducing an anisotropy and the position of the telescope.

where Ψ_N and Φ_N (which represent the geomagnetic deflexion for particles recorded by the *north* pointing telescope) are not equal to Ψ_S and Φ_S depending on the difference in aximuth angles for the two recording telescopes. As the telescopes measure particles, which have passed or come from atmospheric layers not more than about 30 km apart, it seems legitimate to assume, that the atmospheric components are the same for the two telescopes. Thus taking the difference between I_N and I_S the atmospheric components cancel and we get a difference function, which represents only the extra terrestrial variations:

$$I_N - I_S = \sum_{\nu=1}^{2} {}^tI_\nu . \cos\Theta$$

$$\times [\cos\Phi_N . \cos(\nu.\omega t + \nu.\Psi_N - \nu\Psi') - \cos\Phi_S . \cos(\omega t + \Psi_S - \Psi')]. \quad (3)$$

This fact has been pointed out by several authors. Elliot has also pointed out, that the difference function could be used for calculating the true intensity variations.

When comparing this theoretically derived function with experimental results, given in the form of a Fourier series,

$$I_N - I_S = \sum_{\nu=1}^{2} (a_\nu . \cos \nu . \omega t + b_\nu . \sin \nu . \omega t), \tag{4}$$

it can be shown that

$$a_\nu = {}^t\bar{I}_\nu . f_a(\Psi', p); \qquad b_\nu = {}^t\bar{I}_\nu . f_b(\Psi', p), \tag{5}$$

where ${}^t\bar{I}_\nu$ means the amplitude of the true variation, when the measuring direction of a telescope outside the geomagnetic field is parallel to the earth's equatorial plane. Consequently ${}^t\bar{I}_\nu$ is a measure of the strength of the cosmic ray source, inducing the anisotropy and gives its position, measured in the equatorial plane, as mentioned before. The functions f_a and f_b are due to the geomagnetic deflexion, p is the primary particle momentum.

It is now possible to calculate ${}^t\bar{I}_\nu$ and Ψ' for different momenta and then also calculate the true variation, that would be recorded by the two telescopes after correction for the atmospheric effects.

The valuable data from Manchester, where north and south pointing telescopes have been measuring during several years are used for these calculations. Fig. 2 gives the result for the year 1948 assuming 20 GeV/c as the average momentum of the effective primary spectrum.

I_N and I_S are the actually measured variations without any corrections. $(I_N - I_S)$ is the difference, which represents a variation that is not caused by atmospheric fluctuation. ${}^t\bar{I}_N$ and ${}^t\bar{I}_S$ are the calculated true variations, corrected for the atmospheric component and C is the atmospheric component. First and second harmonics are given.

It is of interest to compare different years and to find the dependence of the momentum. This is done in Fig. 3, where the phase and amplitude of the true intensity variation as well as the atmospheric component have been plotted for momenta between 14–32 GeV/c.

The following points may be noted:

(1) The direction to the source depends very little on the chosen momentum while the intensity shows a strong dependence. The phase changes from year to year, which has been pointed out by Elliot and Thambyahpillai [1] and Sarabhai and Kane [2]. The phase of the second harmonic of the true variation is approximately constant during the period considered.

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(2) The second harmonic of the atmospheric component derived in this way has a constant phase during all the years as should be expected. The first harmonic has approximately the same phase during all the years, if we choose 20 GeV/c as the average momentum (except perhaps for the year 1951).

(3) A value around 20 GeV/c seems to be adequate because for this value the second harmonic of the atmospheric component is opposite in phase with the pressure. Assuming as a first approximation that the second harmonic of the atmospheric component is only pressure dependent, which

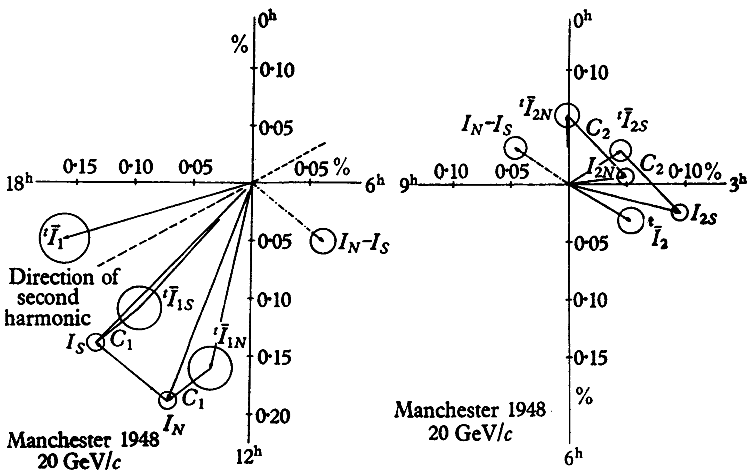

Fig. 2. First and second harmonics of measured and calculated intensity variations. I_N, I_S = Measured intensity variations. ${}^t\bar{I}$ = The true intensity variation, corrected for geomagnetic deflexion. C = The atmospheric component.

is generally accepted, we can even calculate the pressure coefficient. Thus, as an average value for the first three years we get:

$$-(4 \pm 1)\%/\text{cm Hg}.$$

We must remember that the average value of the momentum, inducing the variation, is not necessarily the same when measuring with different azimuth angles, even if the zenith angles are the same. Also the geomagnetic latitude is important. This depends on the geomagnetic deflexion, but for the north and south pointing telescopes at high latitudes it has been found, that as a first approach the same momentum can be used in the two directions.

The atmospheric effect should be expected to be constant over all the years. The result of the analysis shows that this is the case. The residual

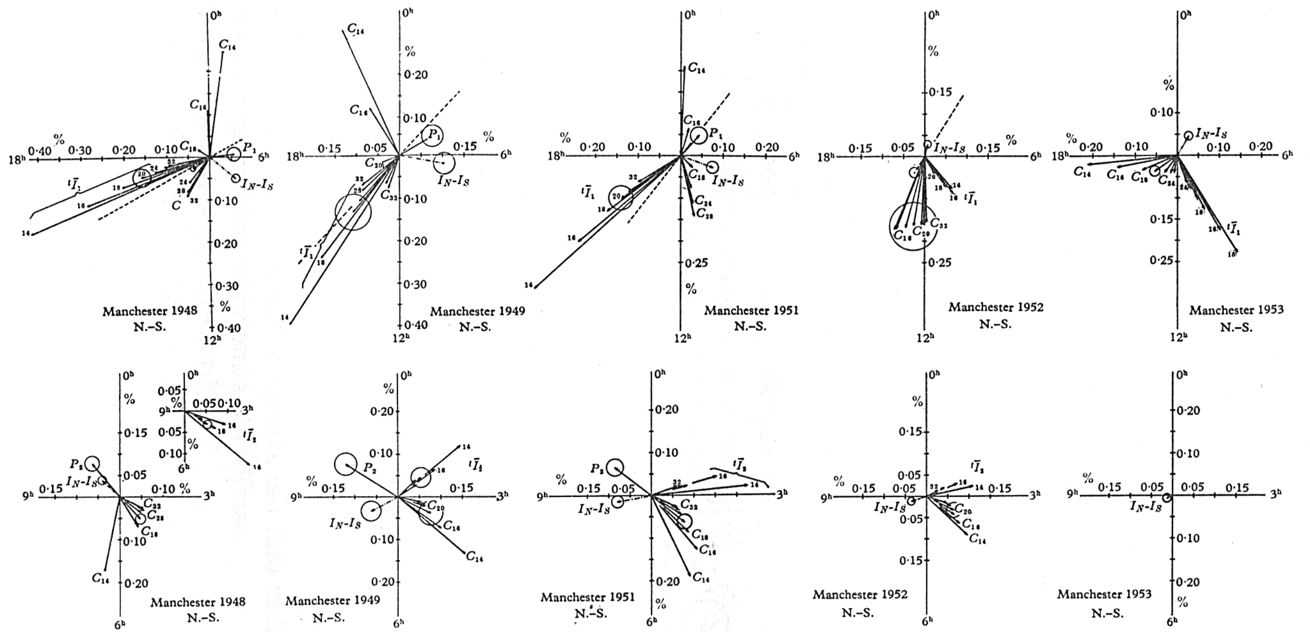

Fig. 3. $I_N - I_S$ = Difference between the measured intensity variations of the north and south pointing telescopes. ${}^{t}\bar{I}$ = the true intensity variation, corrected for geomagnetic deflexion. C_{14}–C_{32} = The atmospheric components assuming different average momenta from 14–32 GeV/c. P = Pressure. Dashed line in the 24-hr dial is the direction of the second harmonic of the true intensity variation corrected for geomagnetic deflexion.

variation, which changes from year to year is completely free of atmospheric effects. This residual variation is most likely interpreted as being due to an extra terrestrial anisotropy, but the possibility that the variation is caused by some local changes within the geomagnetic field is not ruled out by this differential method.

REFERENCES

[1] Elliot, H. and Thambyahpillai, T. *Nature, Lond.* **171**, 918, 1953.
[2] Sarabhai, V. and Kane, R. P. *Phys. Rev.* **90**, 204, 1953.