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Effect of Solar Modulation on the Low Energy Sea Level Muon Spectrum near the Geomagnetic Equator

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Abstract

A study is made of the influence of long-term solar modulation on the low energy sea level muon spectrum near the geomagnetic equator. Recent experimental data are compared with theoretical results calculated from the phenomenological model of Allkofer and Dau. It is suggested that the observed enhancement in the muon intensity is mainly due to a shift in the solar potential.

Generally a change in the Zurich sunspot number causes a variation in the solar wind velocity which modulates the low energy spectrum of cosmic ray particles in the Earth's atmosphere. The solar modulation is a consequence of cosmic ray transport through the interplanetary medium. Allkofer and Dau (1970) have made calculations of the influence of long-term solar modulation on the secondary nucleon and muon spectra at different depths in the atmosphere. Previously reported measurements of muon spectra have often been normalized to the Rossi point, which is the differential intensity for a muon momentum of 1 GeV/c at sea level. The Rossi intensity is found to change by around 4–7% due to solar activity. A review of the influence of long-term solar modulation on 1 GeV/c muon intensity at sea level has been made earlier (Bhattacharyya 1974*a*).

Recently O'Brien (1974) has concluded that the influence of solar activity is important below a muon energy of 10 GeV, at a 10% level of significance. He found that the sea level muon intensity was depressed from 32% to 8% over an energy interval of 0·1–10 GeV, and that the absolute spectra below 10 GeV were time-dependent. He studied the differences between muon spectra (measured by the Kiel Group at different periods) on the basis of a theoretical phenomenological model dependent on the solar modulation. This model was based on a transport code.

In this note we use the phenomenological model of Allkofer and Dau (1970) for low latitudes to study the enhancement of the sea level muon intensity near the geomagnetic equator due to solar modulation. The predictions are compared with the results of recent observations (Bhattacharyya 1974*b*; 1976).

The adopted differential primary proton spectrum fitted to the model of Allkofer and Dau (1970) for solar minimum and solar maximum follows the form

$$N(E)\,\mathrm{d}E = 1\cdot 9(E+C_2)^{-2\cdot 7}\,\mathrm{d}E,$$

where

$$C_2 = 1\cdot 8 \qquad \text{at solar minimum,}$$
$$= 3 \qquad \text{at solar maximum,}$$

and E (GeV) is the kinetic energy per nucleon. The primary spectrum for $C_2 = 1 \cdot 8$ is in approximate agreement with the recent survey of Ramaty *et al.* (1973) for proton energies up to 5 GeV. From the proton spectra for the two different C_2 values, the corresponding sea level muon spectra can be calculated using the collision model and the nuclear physical parameters given by Allkofer and Dau (1969).

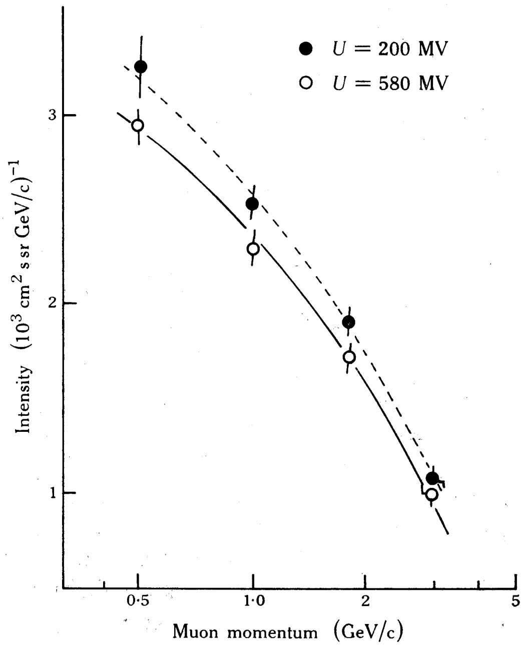

Fig. 1. Sea level muon spectra near the geomagnetic equator at solar maximum ($U = 580$ MV) and at solar minimum ($U = 200$ MV). The experimental data are from Bhattacharyya (1974*b*, 1976). The full curve is a best fit to the solar maximum data, while the dashed curve is the calculated enhancement of the muon spectrum at solar minimum from the model of Allkofer and Dau (1970). It is clear that the corrected spectrum is in accord with the measured data.

The solar potentials U over the periods January 1969 and March 1973 have been calculated from the theory of Ehmert (1960), using the Deep River neutron monitor data reported by Steljes (1970) and the Kiel data reported by Binder (1973). The calculated values of U are 200 and 580 MV for March 1973 and January 1969 respectively. The expected enhancement of the sea level muon intensity due to this change in U can then be estimated from the phenomenological model of Allkofer and Dau (1970).

The values obtained from recent range-spectrograph measurements (Bhattacharyya 1974*b*, 1976) for the vertical sea level muon intensities near the geomagnetic equator in the spectral range $0 \cdot 5$–3 GeV/c are plotted in Fig. 1 for solar potentials U of 580 MV (near solar maximum) and 200 MV (near solar minimum). The full curve in the figure shows the best fit to the data near solar maximum. This curve was corrected for a solar potential of 200 MV according to the model of Allkofer and Dau (1970), and the result is shown by the dashed curve. It is evident from Fig. 1 that the corrected spectrum is in accord with the measured data. We can thus conclude that the observed enhancement of the sea level muon spectrum near the geomagnetic equator over the period considered can be explained by the shift in the solar potential U from 580 to 200 MV.

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