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Discussion

Kane, R.P.: (1) Why do you get different total pressure coefficients for different seasons? Could this be due to differences of temperature *vs* altitude patterns for different seasons?

(2) In your zenith angle dependence of barometric coefficient, there is no reference to azimuth. Will the coefficients be the same for say, the East and West directions for the same zenith angle?

Wada, M.: (1) I think the seasonal variation is caused merely by variations due to some unknown effects. We may find different mode of seasonal variation for different year.

(2) Of course there is certain difference, but I have not calculated yet.

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II-4-34. Atmospheric Effects on the Sea Level C.R. Intensity

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An experimental study of the atmospheric modulation of the meson intensity could be based on essentially two types of regression equations. The first type assumes that most of the mesons, reaching the surface of the earth, are produced in a layer close to the 150 mb level. As a rule three atmospheric parameters are used : (1) the ground pressure, (2) the height of some isobar level close to the assumed production level, (3) the temperature at that height[1)2)]. The second type takes into consideration the meson production from the top of the atmosphere down to the ground. Thus a large number of parameters are necessary, usually seven or eight. One is the ground pressure, the others are the mean temperatures of the six or seven layers into which the atmosphere has to be divided[3)].

Now the meson intensity recorded at the surface of the earth is a function not only of the atmospheric conditions but also, and fortunately, of the primary intensity fluctuations. The latter type of variations has to be eliminated in a study of the modulation effects due to the atmosphere. Various methods have been suggested: one method is the use of the pressure corrected neutron intensity recorded at the same station as the mesons, another method utilizes meson data from a station which can be regarded as a nearby station from a geomagnetic point of view but which must be sufficiently far away to display a different atmospheric behaviour.

Both methods have been used to obtain the results presented in this paper. No discrepancies are found between the two sets of results. The C. R. data were recorded at Murchison Bay and Uppsala in the years 1957-1959 with standard equipment for both mesons and neutrons. All the calculations have been based on daily means.

In Fig. 1 temperature coefficients referring to the standard cubical telescope are plotted as a function of atmospheric depth. The full curve is a reproduction of Dorman's theoretical curve[3]. The broken curve is drawn to fit the points calculated here. As

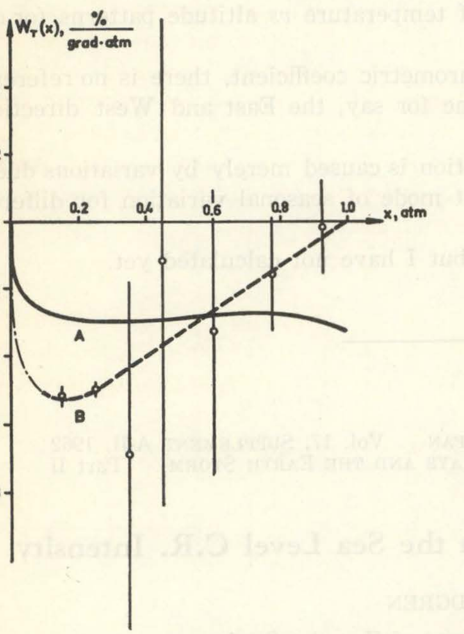

Fig. 1. Temperature coefficients for the standard cubical telescope plotted as a function of atmospheric depth. Full curve: according to Dorman[3]. Broken curve: drawn to fit the points calculated in this paper.

could be expected from an analysis of this kind most of the experimental points are characterized by a large degree of uncertainty. Accordingly no significance could be attached to the shape of the broken curve in the lower atmosphere. However, the small errors of the two points representing the uppermost layers of the atmosphere are believed to reflect a strong correlation between the variations in the heights of these layers and the variations in the meson intensity recorded at ground. Thus one reasonable interpretation of the results seems to be that the upper layers of the atmosphere play a dominant role in the modulation process.

This conclusion justifies an examination of a simpler picture of the atmospheric effects, *i.e.* a regression equation of the first type mentioned in the introduction. To this end the coefficients have been determined in a regression equation of the Duperier type with the 100 mb level chosen as reference level. The results obtained are displayed in Fig. 2 (C). Here are also shown the results from two earlier determinations by Trumpy

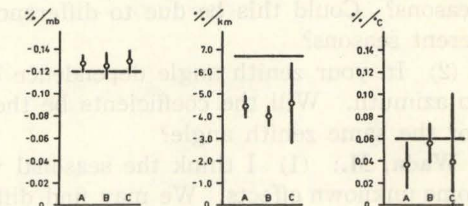

Fig. 2. Pressure, height and temperature coefficients determined for a 100 mb Duperier equation by A: Trumpy and Trefall[4], B: Dawton and Elliot[5], C: Lindgren and Lindholm[6]. Horizontal lines: calculated theoretically by Trefall[2].

and Trefall (A)[4] and Dawton and Elliot (B)[5] made for recorders of approximately the same geometry. The agreement between the three sets of points is good. The larger errors in the present determination are probably to be attributed to the high solar activity during the recording period. The three horizontal lines represent the theoretical values by Trefall[2]. There is a significant difference between theory and experiment as to the magnitude of the decay of coefficient.

The assumption of a main production level close to the 150 mb level offers a reason to study a regression equation where the reference level is situated even lower, at the 200 mb level. From such a study the following coefficients were obtained: (1) -0.12%/mb, (2) -4.8%/km, (3) -0.05%/°C. The negative value of the temperature coefficient is not unexpected as the reference level is lower than the main production level.

The pressure coefficient obtained together with the temperature coefficients plotted in Fig. 1 is -0.16%/mb which value is considerably larger than the pressure coefficients obtained for the regression equations of the Duperier type (-0.12%/mb). The difference is probable due to the fact that in a regression equation of the Dorman type the pressure coefficient must account for not only intensity changes due to absorption but also changes due to decay.

Now the three sets of coefficients obtained here have been utilized to correct daily as well as monthly meson intensities. An example of the latter kind of correction is shown in Fig. 3. Each curve represents the corrections, expressed in percent, which should be added to the recorded meson intensity to eliminate the atmospheric effects that are indicated at the curve. The temperature corrections in the third column were calculated by means of the broken curve in Fig. 1. The corrections based on this curve are larger than those proposed by Dorman down to about 600 mb. Below that level they are smaller.

It is somewhat surprising that the curves giving the total corrections seem to be copies of one and the same curve. In fact the deviation are only of the order of 0.01 percent. Similar results, although not shown here, were obtained in the correction of daily meson intensities[6].

The information about the atmospheric conditions that can be obtained from only two soundings a day is not sufficient to justify an elaborate correction procedure, especially as the data from the upper atmosphere include radiation errors which according to many meteorologists can be considerable. The advantages that could be reached by the use of large number of atmospheric parameters are counteracted by the disadvantages caused by the uncertainty in the included parameters. Thus it seems justified and reasonable to use the simpler type of regression equation proposed by Duperier, at least for high latitude stations.

Pressure coefficients have been calculated for some Swedish, Canadian and Australian neutron monitor stations by means of the formula

$$ln\ (N_1/N_2)=C+\alpha(\delta P_1-\delta P_2)$$

N is the recorded neutron intensity, δP the deviation of the actual ground pressure from the normal value. The subscripts 1

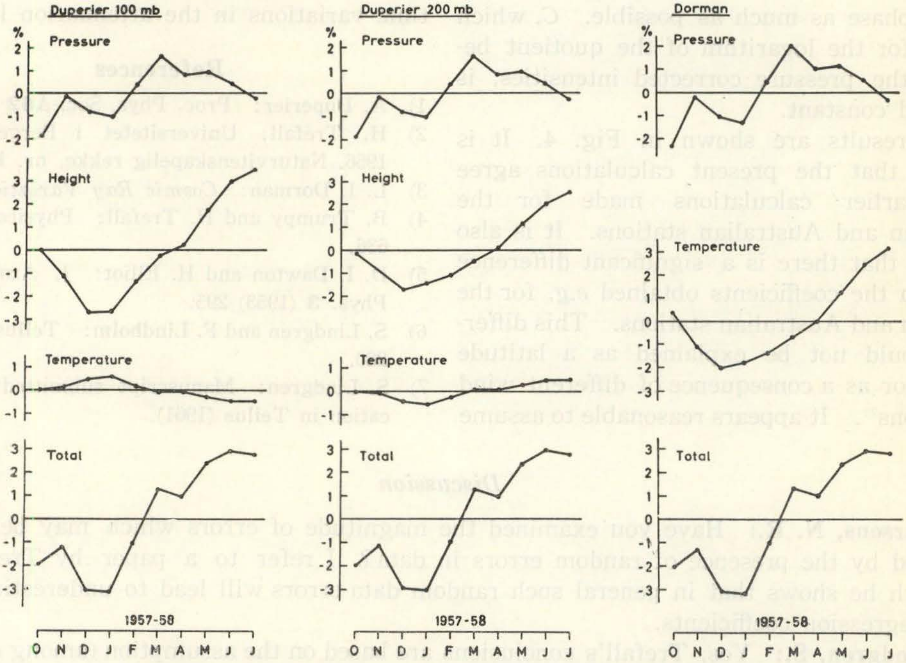

Fig. 3. Corrections to be applied to the Murchison Bay meson data October 1957–July 1958 to account for the atmospheric effects. Notice the close agreement between the three curves giving the total corrections.

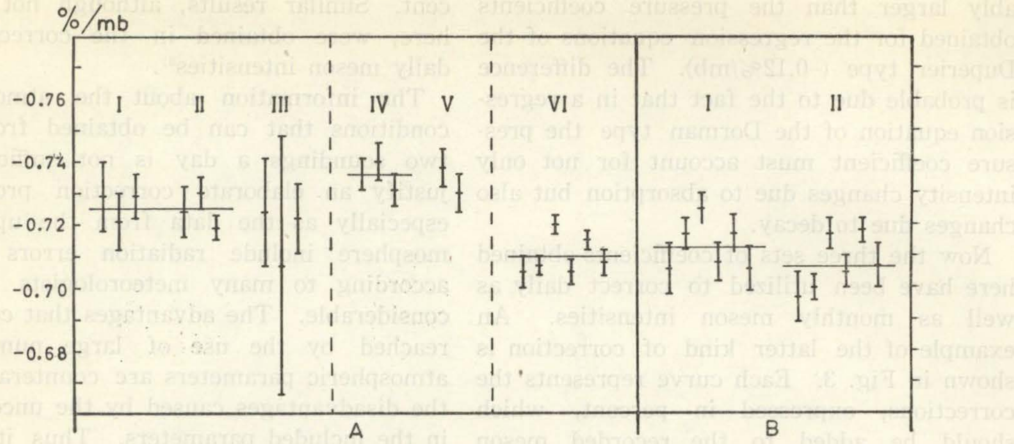

Fig. 4. Pressure coefficients determined for neutron monitor stations

A I Resolute—Churchill
II Churchill—Ottawa
III Ottawa (Mathews 1958)
IV Mawson—Mt. Wellington
V Mawson and Mt. Wellington (McCracken and Johns 1959)
VI Murchison Bay—Uppsala

B I Murchison Bay
II Uppsala.

and 2 refer to two stations which must have about the same altitude and geomagnetic latitude. Moreover the stations must be chosen so that the pressure variations are out of phase as much as possible. C, which stands for the logarithm of the quotient between the pressure corrected intensities, is assumed constant.

The results are shown in Fig. 4. It is evident that the present calculations agree with earlier calculations made for the Canadian and Australian stations. It is also evident that there is a significant difference between the coefficients obtained *e.g.* for the Swedish and Australian stations. This difference could not be explained as a latitude effect nor as a consequence of different wind conditions[7]. It appears reasonable to assume that it is due to small dissimilarities between the equipments used to record the station pressure and the neutron intensity. Attention should be paid to this fact in studies of time variations in the attenuation length.

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Discussion

Parsons, N. R.: Have you examined the magnitude of errors which may be introduced by the presence of random errors in data? I refer to a paper by Trefall in which he shows that in general such random data errors will lead to underestimation of regression coefficients.

Lindgren, S.: Yes, Trefall's conclusions are based on the assumption (among others) that the sample considered has a very large number of members. My results did not agree with Trefall's predictions. This might be due to the fact that the samples examined were too small (about 25 members in each).

Wada, M.: In order to examine what is the best function for correcting the temperature effect, we must use data of several stations in different latitudes. Thereby we can treat the case of largely deviated temperature distribution.

Sarabhai, V. A.: I would like to make the following comments on the question of correcting the muon intensity for atmospheric effects.

(1) Everyone will recognize that the vertical distribution of density is most important. Dorman's method of considering many isobaric levels is therefore very approximate. It may be that at individual places and for certain types of weather changes, the variations at two or more isobaric levels are well correlated. In this case a simple method can of course be used.

(2) For the temperature effect to correct the daily variation, we (Rao and Sarabhai, Proc. Roy. Soc. of London, in print) have suggested a method which we believe is fairly satisfactory. This is based on experimental and theoretical studies by meteorologists on the attenuation with elevation of the daily variation of temperature in the atmosphere. It uses terms in Dorman's formula up to 2 km.

(3) There is need for theoretical and experimental studies for intensity recorded in inclined directions. However, for the experimental method, I believe that the one suggested by Forbush (eliminating cosmic-ray storms) is better than making a partial correlation analysis in the manner suggested by Duperier.

Ehmert, A.: At the Moscow meeting I gave a paper with a correction formula found empirically for Weissenau using the equivalency of corrected meson and neutron intensity differing only in the percent amount. This formula functioned extremely well for the time until now and it is transformable into the formula written on by Wada using an integral over the distribution of temperature over pressure. Using these data better at hand from charts of topography of the atmosphere used by the German Weather Service, we prefered to introduce the functions of the heights of pressure levels instead of temperatures. The coefficients calculated by Dorman are by 20% too high for Weissenau and that seems to be even the experience of Wada. The π-meson decay effect introduced by Dorman in his calculation has not its equivalent invert empirical correction and it seems to us that by this part the seasonal effects are introduced into the records corrected by Dorman method.