Introduction of meteorological corrections into meson monitor data

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ABSTRACT

A set of regression calculations has been carried out correlating the daily average meson intensity with barometric pressure, atmospheric temperature and neutron monitor intensity. Two complete years of data from a plastic scintillator meson monitor and from a large neutron monitor, operated in a constant-temperature laboratory at Deep River, were used. An exhaustive list of atmospheric temperature parameters was investigated: ground temperature; the heights of the 100, 200, 300 and 400 mb isobaric levels; some recommended combinations of isobaric level heights and temperatures; formulations due to Dorman and to Maeda using temperatures at all the standard isobaric levels; a number of arbitrarily distorted versions of these formations including those recommended by Wada and by Lindgren. It was found that the formulations of Dorman, of Maeda, and of Wada were almost indistinguishable in terms of the available data and yielded by far the best fit among the variables. However, none of the temperature parameters tried was able to fit the day-to-day and the seasonal temperature effects equally well with a single regression coefficient. Use of the following partly empirical temperature parameter resolved the difficulty for routine correction of the Deep River data: $1.045\ T(j) + 0.215\ \bar{T}(j)$, where $T(j)$ is Maeda's temperature correction for day j and $\bar{T}(j)$ is its 31-day running average centered on day j.

1. Introduction

It was shown by DORMAN (1954), following earlier work of FEINBERG (1946), that the influence of the variability of the atmosphere upon the counting rates of cosmic ray monitors can be correctly calculated only if the temperature is known as a function of pressure throughout the atmosphere. Also, DORMAN & FEINBERG (1958) pointed out at the Guanajuato conference in 1955 that the prevalent method of introducing temperatures throughout the atmosphere, by using the calculated height of a standard isobaric level such as the 100 millibar level (DUPERIER, 1944, 1949, 1951, 1958), did not make the best use of the available temperature data. A description of DORMAN's method became generally available in 1958 when his book, *Cosmic ray variations* (1957), was translated (DORMAN, 1958). In December 1958, as chairman of an IUPAP committee, Dr. Dorman circulated *Instructions for the introduction of meteorological corrections into data of cosmic ray intensity* (DORMAN, GLOKOVA & KAMINER, 1958), a pamphlet in use in the Soviet network of stations for the continuous registration of cosmic rays. In this the necessary temperature weighting factors, for several different kinds of detector, at mountain altitudes, at sea level, and underground, were given numerically as well as by means of graphs.

For practical computation of the temperature correction at sea level, Dorman divides the mass of the atmosphere into 11 layers beginning with a layer of variable mass extending from the ground to 950 mb and ending with the layers from 150 to 75 mb and from 75 mb to 25 mb. The temperature fluctuations are obtained from the ground temperature readings and from radiosonde data which are available for the standard pressure levels 900, 800, ...100 and 50 mb. Deviations are reckoned either from the mean value for the station for a whole number of years or from a standard atmosphere. The deviation (°C) at each level is multiplied by the layer mass (mb) and also by the temperature weighting factor (% per °C per mb) for that layer for the type of detector in use and the 11 products are summed to obtain the temperature correcting factor (%). The procedure is simple, but time consuming because so many temperatures have to be transcribed.

Independently of Dorman, the influence of the variability of the atmosphere was treated theoretically by OLBERT (1953) and, for vertically incident mesons, by MAEDA & WADA (1954).

The work of Maeda & Wada was, in principle, identical with that of Dorman. Subsequently, MAEDA (1960) elaborated his calculations to include obliquely incident mesons and he also allowed for the curvature of the isobaric levels but he restricted himself to the case of detectors at sea level. The numerical weighting factors necessary for practical application of the correction were given by means of graphs for half-angle apertures of the measuring instrument up to 86°. The temperature weighting factors derived by Maeda for meson telescopes at sea level are noticeably more constant with altitude than those given by Dorman and the dependence upon the opening angle of the telescope is very small and for the most part in the opposite sense to that indicated by Dorman. The Dorman and Maeda factors, summed over the atmosphere, differ by about 12 % for a cubic telescope but by less than 3 % for a semi-cubic or wide-angle telescope, the Dorman factors being the larger in both cases.

Several attempts have been made to test the Dorman method in comparison with other methods, especially the Duperier method. In nearly all cases the procedure used has been essentially the same. The daily average counting rates M of a meson detector are fitted by the method of least squares to a regression Equation of the form,

$$\delta M = C_P \delta P + C_N \delta N + C_T \delta T \qquad (1)$$

where $C_P\delta P$ accounts for the dependence on barometric pressure P, $C_N\delta N$ for the dependence on primary itensity variations usually assumed to be proportional to the barometer-corrected counting rate N of a neutron monitor, and $C_T\delta T$ for the dependence on air temperature. The differentials indicate departures from the mean values of the sample of data being used. The definition of the temperature variable T depends upon the method being studied. It may be a derived quantity, such as the Dorman parameter or the height of a constant pressure level or it may be a simple quantity such as ground temperature. Sometimes, as in the Duperier method, two variables involving temperature are used.

BACHELET & CONFORTO (1956), in their well-known study of the Duperier, Olbert and Dorman methods, conclude that "there is no indication that for the total component a certain method is to be preferred". MATHEWS (1959), using cubic telescope data, concluded: "On fitting the intensity variations by Dorman's formula modified by the introduction of an extra factor K_D in the [temperature] term we have obtained the result ... $K_D = 0.76 \pm .03$ ... The fact that [the multiplicative factor] K_D is significantly less than unity shows that the temperature effect has been overestimated in Dorman's theoretical treatment." He also concludes that the "accuracy given by [Equation] (11) seems to be almost as good as what is obtained from the use of the modified Dorman's formula". Mathews' Equation (11) is an empirical correction formula involving the height of the 100 mb layer and the temperature of the 800 mb layer. LINDGREN & LINDHOLM (1961) concluded from their cubic telescope test of the Dorman method by multiple regression analysis, similarly using a multiplicative factor $\alpha_{73}(\equiv K_D)$, that "The value $\alpha_{73} = 0.65 \pm .10$." In other words, the temperature weighting factors given by Dorman again appeared to be too large. After further tests Lindgren & Lindholm concluded, "It has been shown that a Duperier model including three atmospheric variables leads to essentially the same atmospheric corrections of the sea-level meson intensity as a more complicated Dorman model ..." Lastly, WADA (1961) from multiple correlation analysis, using data from a standard cubic telescope, found that the Dorman temperature weighting factors should be multiplied by 0.84 [$\pm$ .12].

Wada used periods of one month for his analysis. When he tried a whole year he found that the regression analysis "does not give the correct temperature coefficient" and he thought that the analysis was "affected by seasonal changes of the meson intensity ... for the ratio of the variation of meson intensity to that of neutron intensity may not be constant as far as the primary variation is concerned." The analyses of Lindgren & Lindholm and of Mathews were similarly restricted to several short periods of one or one-and-a-half months.

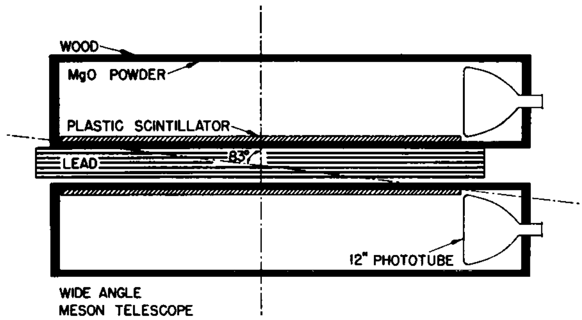

Fig. 1. Sectional diagram of the wide-angle meson telescope. The plastic scintillators are each 180 × 180 × 2.54 cm. The vertical distance from the middle of the upper scintillator to the middle of the lower is 20 cm. The absorber is 12.7 cm of lead, 1.3 cm of iron and 3 cm of wood.

The general impression obtained from reading the above-mentioned papers is that the data available for testing the various formulations of the atmospheric effects were not sufficiently accurate for the purpose. For example, in a test made by Lindgren & Lindholm, using the Dorman formulation as the temperature variable, six monthly values of the temperature regression multiplicative factor α_{7s} varied between 0.28 and 0.86. Again, in a test made by Wada, using the mean mass temperature of the atmosphere as the variable, twelve monthly values of the temperature regression coefficient varied between −0.1 and −0.4 %/°C.

The same general conclusion results from appraisal of the values found for the correlation coefficient R (defined by Equation 7 below). With regard to this quantity Mathews (1959) says, "The only criterion that can validly be used (within the framework of the multiple correlation method) in judging the relative merits of different formulae is the magnitude of the multiple correlation coefficient R which gives a measure of the combined effectiveness of all the terms of any formula." For two periods of about one and one-half months each Mathews (1959) found $R = 0.976$ for the Dorman formula and a mean value 0.975 for his own method (see 5.4 below). For six periods of one month each Lindgren & Lindholm (1961) found a mean value $R = 0.972$ for the Dorman method and 0.982 for the Duperier (1949) method. For four periods of one month each Wada (1961) found a mean value $R = 0.926$ for the Dorman method and 0.891 for the ordinary Duperier (1944) method. In fact no author has found it possible to distinguish between rival methods on the basis of the values of the multiple correlation coefficient.

In this work, in testing the Dorman formula for twenty-four periods of one month each, the arithmetical mean of the 24 values of R was 0.992. This is comparatively close to the value 1.000 which would represent perfect fit of the data. For the ordinary Duperier (1944) method the corresponding value of R was only 0.970. Indeed, in our case, the multiple correlation coefficient always appeared to be a sensitive index of the validity of the various procedures and values exceeding 0.9975 were ultimately reached.

The cosmic ray and pressure data were obtained in a temperature-controlled laboratory at Deep River, Ontario, during the years 1962, 1963 and 1964 which were years of comparatively low solar activity. The temperature data were the routine radiosonde observations of the Meteorological Branch of the Canadian Department of Transport. The good quality of the meteorological data is possibly a principal reason why this work has yielded more definitive results than the earlier studies.

2. Equipment

The meson telescope is shown diagrammatically in Fig. 1. It used two horizontal slabs of plastic scintillator (manufactured in Winnipeg, Canada, by Nuclear Enterprises Ltd.) each 180 × 180 × 2.54 cm, separated by an absorber of 12.7 cm of lead, 1.3 cm of iron and 3 cm of wood. The vertical distance from the middle of the lower plastic slab to the middle of the upper slab was 20 cm, so that the half-angle aperture

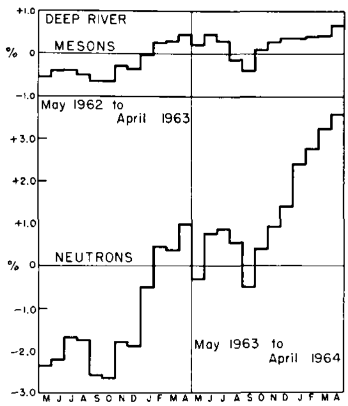

FIG. 2. The pressure-corrected monthly totals of the Deep River neutron monitor expressed as percentage deviations from the mean for the period May 1962 to April 1964. Also shown are the pressure and temperature corrected monthly totals of the Deep River wide-angle meson telescope.

exceeded 83°. Each plastic scintillator was enclosed in a plywood box lined with a layer of dry magnesium-oxide powder about $\frac{1}{4}$ inch thick, supported behind methylmethacrylate (Plexiglas) sheets $\frac{1}{16}$ inch thick. Each box was viewed by a single, 12 inch diameter photomultiplier (EMI-9545B) conveniently mounted through one side. The slope of the coincidence counting rate plateau of the meson telescope was 0.28 % per percent of simultaneous change of the voltages on both phototubes. The attainment of this exceptionally small dependence of coincidence counting rate upon pulse size in a large wide-angle telescope is to be attributed to the use of unusually thin plastic slabs with consequent reduction of the relative number of particles intersecting the edges of the slabs.

The neutron monitor need not be described in detail. It was made of lead and paraffin-wax and contained 24 large boron-trifluoride proportional counters. The thickness of the paraffin reflector was 13 cm. Monthly graphs showing the hourly totals of this monitor have been published (STELJES, 1962–64). The counting rate of the neutron monitor was about 0.6×10^6 per hour and that of the meson monitor about 1.3×10^6 per hour.

The barometer was a mercury-in-glass instrument providing on demand a digital output to 0.1 mb.

The counting totals of the meson telescope and the neutron monitor, and the reading of the barometer were automatically recorded on punched paper tape every five minutes. The tape was processed to provide hourly cards containing the average of the barometer readings, the counting total of the neutron monitor corrected for barometer, and the uncorrected counting total of the meson telescope. For the work described below, the hourly cards were processed to obtain daily cards containing the 24 hour averages of the hourly values in Universal Time.

Ground temperatures at Deep River, needed for one of the tests described below, were read at hourly intervals from a chart record produced by a thermometer in a Stevenson screen mounted above the roof of the laboratory and the UT daily averages computed.

The least-squares-fit multiple-correlation analyses were carried out using a high speed computer.

3. Observational data

The daily totals of the meson telescope and the neutron monitor are continuous from May 1, 1962 until April 30, 1964. During this time one recording failure of five hours' duration and one of one hour's duration occurred due to interruption of commercial power. Hourly totals were interpolated for those occasions before deriving the daily totals.

In the case of the neutron monitor no correction for instrumental drift was needed. Also, the effect of snow on the laboratory roof was minimized by use of an aluminum roof which was too steep (60°) to permit the retention of a layer of snow more than about one inch thick. In the case of the meson telescope there was some instrumental drift which was determined from time to time by measuring the counting rate versus phototube voltage plateaux of the two detectors. The rate of drift between calibrations was assumed to be uniform and was corrected for. Drift was relatively faster in the first year and during that year amounted to an apparent increase in counting rate of 0.6 %.

As shown in Fig. 2, the barometer-corrected monthly average counting rate of the neutron monitor increased by about 7 % between May 1962 and April 1964. This variation of counting rate is attributable to the well-known 11 year cycle in the modulation of galactic cosmic radiation within the solar system (the intensity

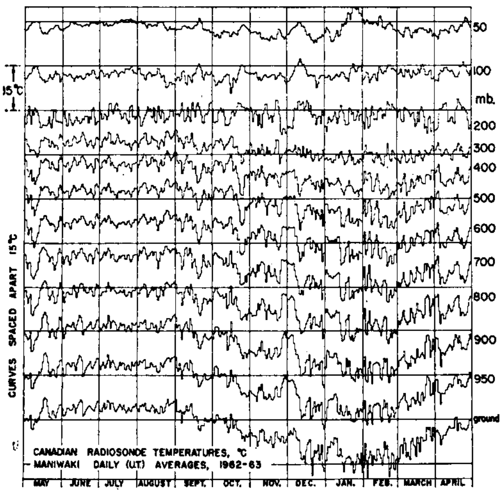

FIG. 3. Radiosonde daily average temperatures for the period May 1962 to April 1963 plotted from the Monthly Bulletin of the Meteorological Branch of the Canadian Department of Transport. The curves have been spaced apart by 15°C to avoid overlapping.

passed through a minimum in 1958–59 and will probably reach a maximum in 1965). Superimposed upon the 11 year variation throughout the whole period were the quasiperiodic 27 day variations not seen in Fig. 2 but visible in Fig. 9. These are slow decreases seldom exceeding 2 %, lasting for several days, and usually associated with recurring magnetic storms. There were also some Forbush decreases in September and October 1963. Apart from these, the whole two-year period may be characterized as quiet.

All the above mentioned variations may be assumed also to occur in the meson telescope data but in smaller degree because of the higher average energy of the primary cosmic rays detected by the meson telescope. Thus it is known that a Forbush decrease in a meson telescope at high latitude, expressed as percentage of the normal counting rate, is usually slightly less than half as large as in a neutron monitor. However it is not known if the same factor applies for the 27 day and the 11 year variations. In fact there is evidence (SIMPSON, 1964) that throughout 1963 and 1964, at Huancayo where the neutron monitor is affected only by primary cosmic rays of rigidity greater than ~ 13 GV, the 11 year increase may have ceased. This implies that the 11 year increase of the meson telescope at Deep River may also have ceased, or may have been very small. The upper curve of Fig. 2 indicates that the 11 year increase of the meson monthly averages was indeed very small. The correction procedure for atmospheric temperature to be described later in this paper was used to obtain this latter curve.

Radiosonde data for Maniwaki, 120 km east of Deep River, were taken from the Monthly Bulletin of the Meteorological Branch of the Canadian Department of Transport. The Maniwaki station used the audio-modulated electronic radiosonde of the United States Weather Bureau with an unshielded thermistor to which no radiation corrections were applied. Ascents were made at the standard world times of observation, 0000 UT and 1200 UT. At Maniwaki these times are 1900 and 0700 local standard time. For our purpose the average daily temperature t_i for the ith level was computed using,

$$t_i = \tfrac{1}{4}t_{i(0000)} + \tfrac{1}{2}t_{i(1200)} + \tfrac{1}{4}t_{i(2400)}. \qquad (2)$$

It was occasionally necessary at the highest levels to make interpolations for missing radiosonde data. The temperature variations are exhibited graphically in Fig. 3 and 4 where the curves showing the daily average values at the successive millibar levels have been spaced apart by 15°C to avoid overlapping. It is easy to

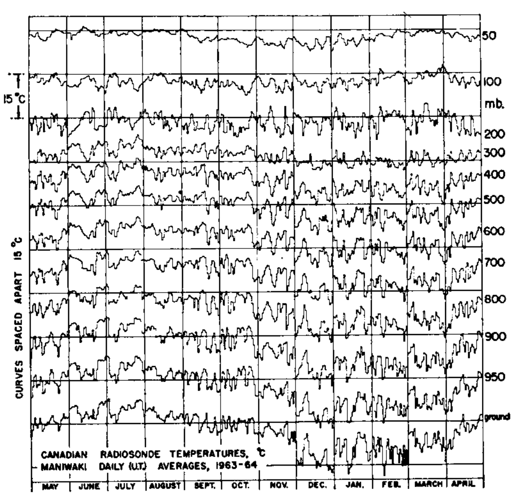

FIG. 4. Radiosonde daily average temperatures for the period May 1963 to April 1964 plotted from the Monthly Bulletin of the Meteorological Branch of the Canadian Department of Transport. The curves have been spaced apart by 15°C to avoid overlapping.

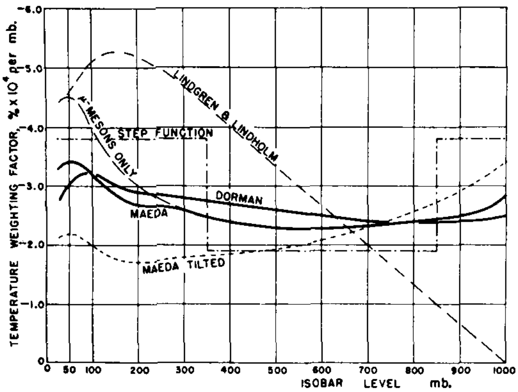

FIG. 5. Six different proposed sets of atmospheric temperature weighting factors. The seventh tested was the mean mass temperature which would appear as a horizontal straight line.

recognize the stratosphere beginning above 200 mb in mid-summer and from beneath 300 mb in mid-winter. The annual temperature cycle, strong near the ground, does not persist at and above the 200 mb level. The day-to-day weather fluctuations of temperature have a tendency to occur in the opposite sense above the 300 mb level.

4. Examination of the Dorman method

4.1. USE OF THE ATMOSPHERIC TEMPERATURE WEIGHTING FACTORS

We shall first describe the testing of the Dorman atmospheric temperature weighting factors. Referring to Equation (1), let

$$T = \sum_{1}^{11} D_i \, \Delta p_i \, t_i, \tag{3}$$

where t_i is defined by Equation (2), D_i is the Dorman temperature weighting factor for the ith layer, and Δp_i represents the mass of the ith layer. In Equation (1) δT is the deviation of T from its mean value for the period under study. Then C_T becomes a multiplicative factor which permits variation of the temperature effect without alteration of its dependence upon height. If the absolute values of D_i given by Dorman are correct, C_T will equal unity.

The temperature weighting factors read from Dorman's graph (Fig. 5) for a semicubic meson telescope at sea level are given in Table 1. The layer 'mass' Δp_i is 50 mb at the 50 millibar level, 75 mb at the 100, and then 100 mb at each lower level except for the layer of variable mass adjacent to the ground for which

$$\Delta p_i = P - 950. \tag{4}$$

The multiple regression analysis was carried out in terms of the differences from the yearly means for the year 1962–63 and the year 1963–64. These calculations were called 'cumulative'. The analysis was also carried out in terms of the differences between one day and the next and these calculations were called 'daily differences'. The values of the regression coefficients are given in Table 2. The estimates of error of the regression coefficients were computed according to ROSE (1953, Equation 30).

As a simple criterion of the relative overall goodness of fit to a given set of n values of the meson daily counting rates, the root mean square deviation Δ_M of the fitted value from the measured value may be used. Thus,

$$\Delta_M = \sqrt{\sum_{k=1}^{n} [\delta M(k) - \delta M_{\mathrm{FIT}}(k)]^2 / n} \tag{5}$$

TABLE 1. *Seven sets of temperature weighting factors.*

Set	Name	Temperature weighting factor, % × 10⁵ per mb										
		1000	900	800	700	600	500	400	300	200	100	50
A	Dorman, semi-cubic	−25	−24	−24	−24	−25	−26	−27	−28	−29	−32	−30
B	Maeda, 86°	−28	−25	−24	−23	−23	−23	−24	−26	−27	−32	−34
C	Wada, mean mass	−24	−24	−24	−24	−24	−24	−24	−24	−24	−24	−24
D	Lindgren & Lindholm	0	−7	−13	−20	−27	−33	−40	−47	−52	−51	−46
E	Maeda, tilted	−34	−29	−26	−23	−21	−19	−18	−18	−17	−20	−22
F	Maeda, μ-decay	−28	−25	−24	−23	−23	−23	−24	−26	−30	−40	−44
G	Step function	−38	−38	−19	−19	−19	−19	−19	−38	−38	−38	−38

TABLE 2. *Regression coefficients calculated, according to Equation (1), for the Dorman temperature weighting factors for a semi-cubic meson telescope, set A of Table 1.*

Year	C_P, % per mb	C_N	C_T	σ_M, %	Δ_M, %	R
CUMULATIVE CALCULATION						
May 1962 to Apr. 1963	$-.1634 \pm .0015$	$.300 \pm .009$	$1.181 \pm .009$	2.349	.208	.9961
May 1963 to Apr. 1964	$-.1619 \pm .0019$	$.240 \pm .010$	$1.135 \pm .011$	2.273	.280	.9924
DAILY DIFFERENCES CALCULATION						
May 1962 to Apr. 1963	$-.1592 \pm .0014$	$.394 \pm .026$	$.964 \pm .023$	1.027	.156	.9883
May 1963 to Apr. 1964	$-.1546 \pm .0012$	$.369 \pm .014$	$.969 \pm .020$	1.098	.148	.9909

where the fitted value

$$\delta M_{\mathrm{FIT}}(k) = C_P \delta P(k) + C_N \delta N(k) + C_T \delta T(k). \quad (6)$$

In comparing the goodness of fit for different sets of values the root mean square dispersion σ_M of each set of values must be taken into account. Following DORMAN (1958, Equation 9.24) we use the correlation coefficient

$$R = \sqrt{1 - \left(\frac{\Delta_M}{\sigma_M}\right)^2}, \quad (7)$$

where $$\sigma_M = \sqrt{\sum_{k=1}^{n} [\delta M(k)]^2 / n}. \quad (8)$$

The values of σ_M, Δ_M, and R are given in Table 2 (σ_M will not be repeated in subsequent tables).

We are now in a position to correct the meson daily rates for atmospheric pressure and temperature using values of the regression coefficients C_P and C_T selected on the basis of Table 2. However, large discrepancies are apparent between the different calculations in Table 2. The values of C_N for the cumulative calculation are about 30 % less than the values for the daily differences calculation. This discrepancy does not matter as regards the process of correcting the mesons because the coefficient C_N is not used in this process. The discrepancy does indicate that the meson-neutron ratio for long-term changes of rate is less than for day-to-day changes to the detriment of the regression analysis. The values of C_T for the cumulative calculation are about 19 % larger than the values for the daily differences calculation. This is an

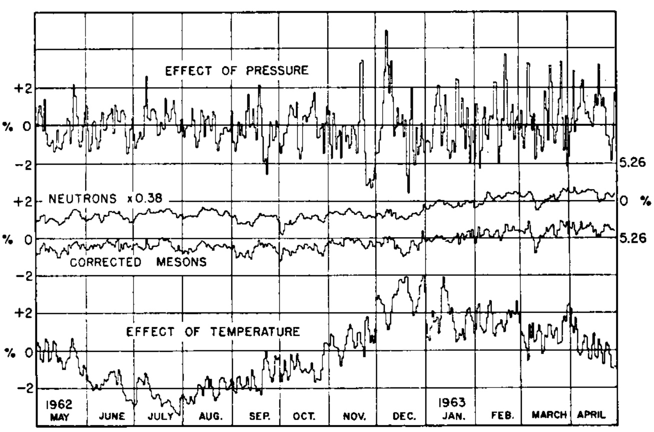

FIG. 6. The uppermost curve shows the corrections made on account of pressure to the daily meson telescope counting rates. The lowermost curve shows the corrections made on account of atmospheric temperature to the daily meson telescope counting rates. Both these curves also contain the deviations of the fit of the regression analysis but the presence of these deviations may be neglected. Also shown on the same scale are the fully-corrected meson daily totals and, for comparison on a scale adjusted by the factor 0.38, the neutron monitor pressure corrected daily totals.

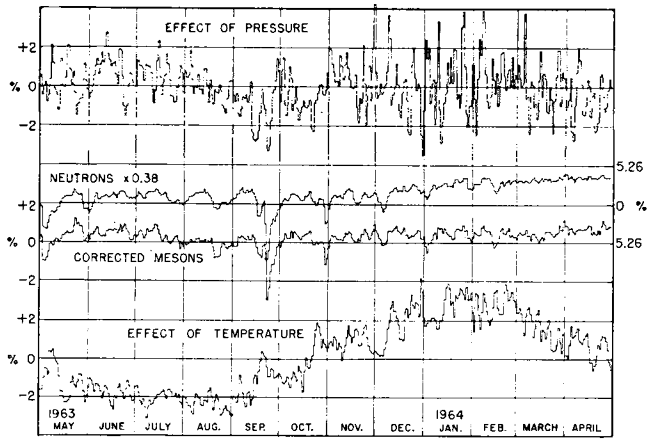

FIG. 7. The uppermost curve shows the corrections made on account of pressure to the daily meson telescope counting rates. The lowermost curve shows the corrections made on account of atmospheric temperature to the daily meson telescope counting rates. Both these curves also contain the deviations of the fit of the regression analysis but the presence of these deviations may be neglected. Also shown on the same scale are the fully-corrected meson daily totals and, for comparison on a scale adjusted by the factor 0.38, the neutron monitor pressure-corrected daily totals.

unexpected and serious discrepancy which directly affects the correction process. The four values of C_P differ by less than 6 % so they present no serious problem as regards choice of an unique value. In the next section the temperature weighting factors will be varied in every possible way and the effect upon the C_T discrepancy examined.

To facilitate the discussion it is desirable at this point to exhibit graphs separately illustrating the effects of the fluctuations of atmospheric temperature and pressure on the meson daily rates. These graphs are given in Figs. 6 and 7 for the years May 1962 to April 1963 and May 1963 to April 1964, respectively. The fully corrected meson daily rates are also shown. However, rather than use relatively imperfect corrections based on the coefficients of Table 2, we have anticipated the final correction procedure and used it for Figs. 6 and 7. The fully corrected meson graphs may be compared with the adjacent neutron graphs plotted on a scale (× 0.38) which equalizes primary variations.

4.2. Variations of the Dorman factors

4.2.1. *Maeda*

A set of numerical temperature weighting factors for the same eleven isobaric levels as used by Dorman was read from the curve given by MAEDA (1960) for a meson telescope of half-angle aperture 86°. Maeda's curve is shown in Fig. 5 and the factors are given in Table 1. Using exactly the same procedure as was used with the Dorman factors, the regression coefficients of Equation (1) were calculated and they are given in Table 3, set B. For convenience, set A of Table 3 has been copied from Table 2. The Dorman and the Maeda sets of temperature weighting factors appear to be practically indistinguishable apart from differences of a few percent in the values found for C_T. But C_T is a parameter introduced only to adjust the absolute values of the various sets of temperature weighting factors and so is unlikely to be the same for all sets.

4.2.2. *Wada*

It was suggested by WADA (1961) that the Dorman and Maeda temperature weighting factors were so nearly constant with altitude that the mean mass temperature might conveniently be used instead. This corresponds to a set of eleven equal factors as indicated in Table 1, set C. The result of using these factors is given in Table 3, set C. The regression coefficients and the correlation coefficients differ only slightly from those found with the Dorman and Maeda weighting factors and in the case of the daily difference method the goodness of fit is actually improved slightly.

We believe that for general use at sea level

TABLE 3. *Regression coefficients calculated, according to Equation 1, for each of the seven different sets of temperature weighting factors given in Table 1.*

Set	Name	C_P, % per mb	C_N	C_T	Δ_M, %	R
CUMULATIVE CALCULATION						
Year May 1962 to April 1963						
A	Dorman, semi-cubic	$-.1634 \pm .0015$	$.300 \pm .010$	$1.181 \pm .009$	.208	.9961
B	Maeda, 86° half angle	$-.1638 \pm .0014$	$.303 \pm .010$	$1.229 \pm .009$	.200	.9964
C	Wada, mean mass temp. -	$-.1610 \pm .0016$	$.305 \pm .011$	$1.230 \pm .010$	.226	.9953
D	Lindgren & Lindholm	$-.1741 \pm .0024$	$.285 \pm .016$	$1.421 \pm .017$	.331	.9900
E	Maeda, tilted	$-.1593 \pm .0017$	$.318 \pm .011$	$1.220 \pm .010$	.240	.9948
F	Maeda, μ-decay only	$-.1658 \pm .0014$	$.304 \pm .009$	$1.238 \pm .008$	.190	.9967
G	Step function	$-.1705 \pm .0014$	$.295 \pm .010$	$1.185 \pm .008$	.199	.9964
Year May 1963 to April 1964						
A	Dorman, semi-cubic	$-.1619 \pm .0019$	$.240 \pm .010$	$1.135 \pm .011$	.280	.9924
B	Maeda, 86° half angle	$-.1622 \pm .0019$	$.243 \pm .010$	1.176 ± 0.11	.278	.9925
C	Wada, mean mass temp.	$-.1603 \pm .0020$	$.238 \pm .011$	$1.189 \pm .012$	.295	.9916
D	Lindgren & Lindholm	$-.1686 \pm .0024$	$.259 \pm .013$	$1.321 \pm .016$	.351	.9880
E	Maeda, tilted	$-.1592 \pm .0022$	$.242 \pm .012$	$1.184 \pm .013$	.319	.9901
F	Maeda, μ-decay only	$-.1636 \pm .0019$	$.248 \pm .010$	$1.175 \pm .011$	.270	.9929
G	Step function	$-.1663 \pm .0021$	$.248 \pm .011$	$1.118 \pm .012$	.299	.9913
DAILY DIFFERENCES CALCULATION						
Year May 1962 to April 1963						
A	Dorman, semi-cubic	$-.1592 \pm .0014$	$.394 \pm .026$	$.964 \pm .023$	.156	.9883
B	Maeda, 86° half angle	$-.1601 \pm .0014$	$.397 \pm .027$	$1.017 \pm .024$	.158	.9881
C	Wada, mean mass temp.	$-.1576 \pm .0013$	$.388 \pm .025$	$.974 \pm .022$	149	.9894
D	Lindgren & Lindholm	$-.1530 \pm .0025$	$.542 \pm .045$	$.958 \pm .051$	.273	.9640
E	Maeda, tilted	$-.1573 \pm .0013$	$.393 \pm .025$	$.951 \pm .021$	.149	.9895
F	Meada, μ-decay only	$-.1617 \pm .0016$	$.406 \pm .028$	$1.056 \pm .027$	.168	.9865
G	Step function	$-.1658 \pm .0020$	$.449 \pm .034$	$1.048 \pm .034$	.201	.9805
Year May 1963 to April 1964						
A	Dorman, semi-cubic	$-.1546 \pm .0012$	$.369 \pm .014$	$.969 \pm .020$	.148	.9909
B	Maeda, 86° half angle	$-.1554 \pm .0012$	$.370 \pm .014$	$1.020 \pm .021$	.149	.9908
C	Wada, mean mass temp.	$-.1530 \pm .0011$	$.366 \pm .013$	$.976 \pm .019$	141	.9917
D	Lindgren & Lindholm	$-.1512 \pm .0023$	$.426 \pm .025$	$1.053 \pm .050$	.271	.9690
E	Maeda, tilted	$-.1527 \pm .0011$	$.366 \pm .013$	$.949 \pm .018$	.139	.9919
F	Maeda, μ-decay only	$-.1570 \pm .0013$	$.375 \pm .015$	$1.063 \pm .024$	.158	.9896
G	Step function	$-.1609 \pm .0018$	$.397 \pm .019$	$1.042 \pm .031$	.199	.9834

stations the Maeda curve should be recommended because it has been calculated in the greatest detail but in so far as the present cosmic ray observations and radiosonde data are concerned the mean mass temperature appears to be equally satisfactory. Note, however, that the discrepancy between the cumulative and the daily difference values of C_T has increased from 21 % and 15 % for the Maeda set of factors to 26 % for 1962–63 and 22 % for 1963–64 for the mean mass temperature.

4.2.3. *Lindgren & Lindholm*

A temperature weighting curve which increased the weights for the atmospheric layers above 500 mb with respect to the layers near the ground was recommended by LINDGREN & LINDHOLM (1961). Their curve is shown in Fig. 5 and a set of eleven factors read from their curve is given in Table 1. The results of using these factors are given in Table 3, set D. It is apparent that the fits obtained with this set of factors are not good and it is noted also that the discrepancy between the cumulative and the daily difference values of C_T has been increased to 48 % for 1962–63 and 25 % for 1963–64.

4.2.4. *Maeda tilted*

It is of interest to slope the temperature weighting curve in the other direction so as to increase the weights of the atmospheric layers near the ground with respect to the layers above the 500 mb level. The curve used for this trial is labelled 'Maeda tilted' in Fig. 5 and the factors used are given in Table 1. The fit for the daily difference is as good as any hitherto obtained and for the cumulative calculation is only slightly less good. However, the C_T discrepancy is increased from 21 % and 15 % for the Maeda set of factors to 28 % and 25 % for this set.

4.2.5. *Maeda, μ-decay only*

It appears that the magnitude of the discrepancy between the cumulative and the day-to-day values of C_T is affected by altering the dependence of the temperature weighting factors upon altitude. To investigate this further, the Maeda curve for μ-meson decay only was now used, omitting the so-called positive temperature effect which arises from π-meson decay. The purpose of this expedient was to enhance the effect of the reversals of the day-to-day fluctuations that take place (see Figs. 3 and 4) above the 300 mb level. The curve is shown in Fig. 5 and the set of factors used is given in Table 1. The results are given in Table 3, set F. The fit for the cumulative calculation is as good as any yet obtained, for the daily differences is only slightly less good, and the discrepancies between the cumulative and the daily difference values of C_T have now been reduced from 21 % and 15 % for the Maeda set of factors to 17 % and 11 % for this set.

4.2.6. *Step function*

It is desirable to demonstrate quantitatively how the temperature fluctuations at various altitude levels contribute on the average to the day-to-day meson intensity changes on the one hand and to the summer-winter meson intensity changes on the other.

At each altitude level, i, the day-to-day temperature difference $t_i(j+1) - t_i(j)$, where j is the day number, was averaged over a complete year (1962).

$$\overline{\Delta t_i} = \sum_{j=1}^{365} \pm \left| t_i(j+1) - t_i(j) \right| / 365 \tag{9}$$

in each case taking the positive sign if the effect of the temperature change was in the same direction (and negative if opposite) as the overall atmospheric effect given by $T(j+1) - T(j)$, where $T(j)$ is the Dorman correction factor for the jth day defined by equation (3). Similarly, the manner in which the summer-winter temperature differences at various altitude levels contribute was obtained by taking at each level the differences between the monthly average temperatures for the months July 1962 and February 1963 and using the same rule to determine the sign of the difference.

The day-to-day temperature change distribution is shown by the solid curve in Fig. 7 and the seasonal change by the dashed curve. The day-to-day temperature contributions show a very much stronger reversal above the tropopause than do the seasonal contributions and also the day-to-day contributions are relatively somewhat smaller than the seasonal contributions near the ground. Hence it would appear to be possible to reconcile the discrepancy between the predicted day-to-day and seasonal atmospheric temperature effects on the meson intensity by adjusting the weighting factors so as to increase the contributions of the levels near the ground and also of those above the tropopause at the expense of the contribution from the layers between. The arbitrarily chosen set of factors illustrated in Fig. 5, curve F (see also Table 1) attempts this and results in the calculated regression coefficients given in Table 5, set F. The multiple regression coefficients, R, are essentially equal to those given in Tables 2 and 3 for the cumulative calculations but appreciably less good for the daily difference calculations. The discrepancies between the cumulative and the daily difference values of C_T are now reduced to 13 % for 1962–63 and 7 % for 1963–64.

The significance of the improvement obtained by such a violent distortion of the calculated Dorman–Maeda dependence of the temperature weighting factors on altitude is not understood and we do not consider it advisable to recommend the use of such a curve in practice. A more satisfactory solution of the practical difficulty will be described in the next section.

4.3. Method recommended for practical use

The empirical modification of the Dorman–Maeda method which we have found to be necessary for fully correcting the Deep River meson telescope data will now be introduced. We note that it has not been found possible to fit a common set of calculated atmospheric temperature weighting factors to both the day-to-day and the seasonal meson telescope fluctuations. When the relative variation of the weighting factors with altitude is kept constant the absolute values needed for the seasonal effect have to be some 20 % larger than for the day-to-day changes. It is therefore necessary to supply as an auxiliary temperature variable a term from which the day-to-day variations have been removed leaving only the seasonal variation. It is convenient to use the 31 day running average of T as the auxiliary variable. The regression equation becomes,

$$\delta M = C_P\delta P + C_N\delta N + C_T\delta T + C_{\bar T}\delta \bar T, \quad (10)$$

where $\bar T$ is the running average. It may be objected that instead of the original term $C_T\delta T$ in (10) we should have used $C_T(\delta T - \delta \bar T)$ so as to confine the seasonal effect to one term on the right-hand side but an alteration of this kind has no influence upon the goodness of fit because

$$C_T(\delta T - \delta\bar T) + C'_{\bar T}\delta\bar T \equiv C_T\delta T + (C_T - C'_{\bar T})\delta\bar T.$$

The values of the regression coefficients and of Δ_M and R were calculated using the Maeda temperature weighting factors and the fit was much improved for the first year, May 1962 to April 1963, but only slightly for the second year. The results of this intermediate calculation need not be given here.

As regards the regression coefficient C_N, a 30 % discrepancy between the cumulative and the daily difference calculations using Equation (1) has already been noted. Examination of the corrected meson and neutron graphs of Fig. 2 indicates that this discrepancy may have arisen because of the relatively small long term (11 year) rate of increase of the meson counting rate. Hence in this case also it will be advantageous to supply an auxiliary variable from

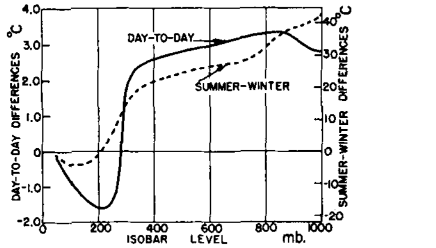

Fig. 8. Comparison of the influence of day-to-day changes of temperature at different isobaric levels, on the sea level meson intensity, with the effect of summer-winter changes. For details please refer to the text.

which the day-to-day variations have been removed leaving only the long term variation. It is convenient to use the 31 day running average of N as the auxiliary variable. The regression equation becomes,

$$\delta M = C_P\delta P + C_N\delta N + C_{\bar N}\delta\bar N + C_T\delta T + C_{\bar T}\delta\bar T, \quad (11)$$

where $\bar N$ is the neutron running average.

The values of the regression coefficients and of Δ_M and R were calculated for each of the seven sets of temperature weighting factors given in Table 1. The results are given in Table 4.

The goodness of fit, as indicated by the values of Δ_M and R, has been considerably improved over that of Table 3, particularly for the year May 1962 to April 1963. In fact it is now necessary to give R to five decimal places to show differences between the Dorman, Maeda, and Wada values. These three calculations are now practically indistinguishable and clearly superior to each of the other four. The only large difference between the regression coefficients for the two years is in the value of C_N which is more than twice as big for the second year.

For correcting the Deep River wide-angle mesons from May 1962 to April 1964, using the Maeda temperature weighting factors (Table 1, set B) the following average values of the coefficients were adopted: $C_P = -0.1593$ % per mb, $C_T = 1.045$, $C_{\bar T} = 0.215$. The meson telescope counting rate, corrected with these coefficients and expressed as percent of the two year mean, is shown in Figs. 6 and 7 and in Fig. 2.

It is instructive to exhibit the deviations of the fit of the regression analysis visually by carrying out a "correction" for the neutron rates and plotting the remainders. The coefficients adopted for this were $C_N = 0.335$ and

TABLE 4. *Regression coefficients calculated, according to Equation (11), for each of the seven different sets of temperature weighting factors given in Table 1.*

Set	C_P, % per mb	C_N	$C_{\bar{N}}$	C_T	$C_{\bar{T}}$	Δ_M, %	R
31-DAY RUNNING AVERAGES CALCULATION							
Year May 1962 to April 1963							
A	$-.1591\pm.0012$	$.338\pm.016$	$-.072\pm.019$	$.976\pm.015$	$.260\pm.017$	.164	.99755
B	$-.1598\pm.0012$	$.340\pm.016$	$-.067\pm.019$	$1.035\pm.016$	$.242\pm.018$	.165	.99751
C	$-.1566\pm.0012$	$.340\pm.016$	$-.078\pm.019$	$.982\pm.015$	$.319\pm.017$	.164	.99755
D	$-.1671\pm.0024$	$.327\pm.030$	$-.070\pm.035$	$1.160\pm.038$	$.315\pm.041$	.309	.99131
E	$-.1550\pm.0013$	$.354\pm.018$	$-.079\pm.020$	$.969\pm.016$	$.325\pm.019$	.178	.99712
F	$-.1624\pm.0013$	$.340\pm.017$	$-.058\pm.020$	$1.089\pm.018$	$.183\pm.020$	.173	.99727
G	$-.1683\pm.0015$	$.334\pm.020$	$-.055\pm.022$	$1.110\pm.021$	$.091\pm.023$	.195	.99652
Year May 1963 to April 1964							
A	$-.1581\pm.0018$	$.330\pm.014$	$-.172\pm.019$	$1.003\pm.023$	$.201\pm.026$	.245	.99415
B	$-.1588\pm.0018$	$.330\pm.014$	$-.166\pm.019$	$1.055\pm.024$	$.186\pm.028$	.248	.99403
C	$-.1557\pm.0018$	$.333\pm.014$	$-.186\pm.020$	$1.013\pm.023$	$.266\pm.027$	.250	.99396
D	$-.1663\pm.0025$	$.328\pm.019$	$-.126\pm.026$	$1.242\pm.042$	$.125\pm.046$	.340	.98878
E	$-.1541\pm.0019$	$.338\pm.015$	$-.192\pm.021$	$.984\pm.024$	$.299\pm.029$	.269	.99297
F	$-.1614\pm.0018$	$.327\pm.014$	$-.147\pm.019$	$1.105\pm.025$	$.177\pm.029$	.250	.99394
G	$-.1648\pm.0021$	$.333\pm.016$	$-.154\pm.022$	$1.083\pm.028$	$.076\pm.032$	.280	.99237

$C_{\bar{N}} = -0.117$. The result is shown in Fig. 9 for the two-year period May 1962 to April 1964 in comparison with the corrected meson graph and with the neutron graph scaled by the factor, $\times 0.38$. The deviations of the fit for the more rapid variations seem to be about the same in each of the two years. The deviations of the fit for the slow variations are larger throughout the second year and this must be the cause of the lower correlation coefficient found for that year.

Inasmuch as the neutron monitor rates, the short-term meson monitor rates, and the pressure data are highly reliable, the cause of the deviations of fit for the more rapid variations must reside in the radiosonde data and also in the fact that the radiosonde observations are relatively infrequent. A change of temperature of 1°C throughout the atmosphere will produce (Table 1) an alteration of 0.25 % in the meson rate. Hence the observed deviation of the fit,

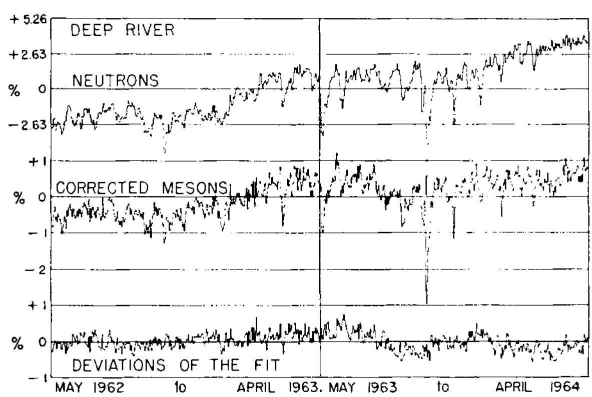

FIG. 9. Meson telescope daily rates, fully corrected for atmospheric pressure and temperature throughout the two-year period from May 1962 to April 1964 compared with the corresponding pressure corrected neutron monitor daily rates scaled by the factor 0.38. For the lowest curve the corrected mesons have been further "corrected" using the neutron monitor readings and their 31-day running average with the coefficients given in the text. Thus the lowest curve closely represents the deviations of the fit of the regression analysis.

0.16 % of the meson rate, represents a root mean square error in the radiosonde daily averages (Equation 2) of 0.4°C throughout the atmosphere. The error due to distance from the radiosonde station was examined (see next section) and found to be relatively small.

4.4. Effect of distance from the radiosonde station

When a graph of the Dorman temperature weighting factor T, calculated according to Equation (2) from the Maniwaki data, was compared with a graph of the Deep River meson telescope counting rate corrected for barometer only, a time lag of the temperature effects between the two stations of about 4 hours was observed. It is well known that in our geographical region the weather tends to travel from west to east. Hence most weather changes will affect Maniwaki, which is 120 km to the east, some hours later than Deep River. To test this in greater detail, sets of daily average temperatures were computed from the Maniwaki data by modifying Equation (2) to give the averages appropriateto 1400 UT, 1600 UT, 1800 UT ... 2400 UT. Then the regression analysis was carried out for each successive month for each of the sets of averages and the values of Δ_M were plotted against the amount of time displacement as shown in Fig. 10. The vertical scale is % and the minimum value of Δ_M is indicated on each curve. The Dorman temperature weighting factors, Table 1, were used.

Most of the curves of Fig. 10 show a well-defined minimum indicating best fit of the data at one particular time delay of the radiosonde information. Sometimes, as in November 1962, the delay is only 1 hour; sometimes, as in July 1962, the delay is 7 hours; sometimes, as in June 1962, the effect of imposed delay is weak; sometimes, as in December 1962, the effect is strong. It may be concluded that the introduction of an average time delay of about 3 hours would have been beneficial for the regression analyses reported in the present work, but it is easily shown that the improvement of fit obtained would have been very small indeed. The detection of this effect by the regression analysis is of interest and the effect should be taken into account whenever meteorological corrections based upon radiosonde data from a distant station are being computed, especially at times of violent weather change.

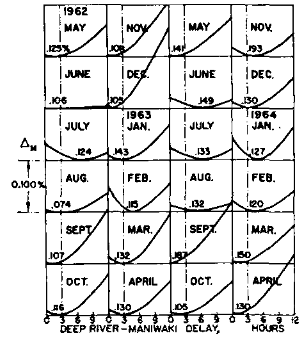

Fig. 10. The effect of the eastward march of the "weather" from Deep River to the radiosonde station at Maniwaki at a distance of 120 km. The minimum values of Δ_M, the root mean square deviations of the fit, are written on the curves.

4.5. Discussion of the C_T discrepancy

It was noted in the regression analyses according to Equation (1) that the values found for the coefficient C_T were always larger for the cumulative calculations (over a period of one year) than for the method using day-to-day differences. The magnitude of the discrepancy was different for different sets of temperature weighting factors but could be eliminated only by an unreasonably large distortion of the theoretical factors. It is not known whether or not the radiosonde measurements can possibly contain sufficient systematic error in the day-to-day temperature fluctuations or in the seasonal variation to account for the discrepancy. It maybe of significance that it is for the seasonal variation that the theoretical temperature coefficient is in error.

In order to find if the temperature weighting factors are indeed independent of the summer-winter difference of height of the atmosphere, as is assumed in the Dorman method, the pressure and the neutron coefficients were fixed as follows and the meson data were corrected accordingly: $C_P = -0.1593$, $C_N = 0.335$, $C_{\bar{N}} = -0.117$. Then the value of C_T, using the Maeda set of factors, was determined for each of the 24 separate months from May 1962 to April 1964. The result is plotted in Fig. 11. There is no evidence of a seasonal fluctuation in the monthly values of C_T.

The neutron monitor rate, seen in Fig. 2, increased relatively rapidly in January and February 1963 and again between October and April 1964–65, these two occasions being about

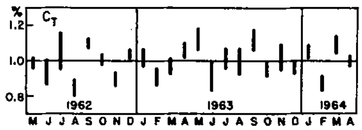

FIG. 11. The result of calculating C_T for the Maeda set of temperature weighting factors, by months, after fixing C_P, C_N and $C_{\bar{N}}$ at the values given by the regression analysis according to Equation (11). There is no evidence of a seasonal dependence.

one year apart. This suggested that the regression analyses might be in error because of chance correlation of these fluctuations with the annual temperature wave. However it is apparent that this neutron pseudo periodicity is of insufficient amplitude and of hardly the correct phase to have caused the observed discrepancy. The annual temperature effect of the mesons, as can be seen from Figs. 6 and 7, has an amplitude of about 3 %. The day-to-day temperature coefficient leaves about one-fifth (0.6 %) of this uncorrected. If this is due to the presence of a compensating annual effect of neutron intensity, this must have an amplitude $1/C_N \times 0.6\ \% \approx 2\ \%$. The periodicity exhibited in the neutron intensity curve in Fig. 2 is clearly not to be blamed.

The neutron intensity is known to contain a small atmospheric temperature effect which so far has been neglected. This effect, for which DORMAN *et al.* (1958) have calculated the appropriate temperature weighting factors, is closely correlated with the meson temperature effect and about one-fifth as large. The regression analysis according to Equation 11 was repeated, this time using the temperature corrected neutron intensity. The effect of removing the temperature variation from the neutron intensity was to increase C_T by approximately 5 % (0.976 ± 0.015 in the first line of Table 4 became 1.028 ± 0.015). The seasonal discrepancy in C_T however, remained unaffected.

5. Examination of earlier methods

It is of interest now to make use of the data already tested above to study and assess the various early methods that have been recommended for correcting meson rates for atmospheric effects.

5.1. CORRECTION FOR PRESSURE ONLY

The coefficients obtained when the regression analysis was carried out with no atmospheric temperature term according to the relation

$$\delta M = C_P \delta P + C_N \delta N \tag{12}$$

are given in Table 5. To minimize the harmful effect of the annual temperature wave the full two-year period from May 1962 to April 1964 was used for this analysis.

The correlation coefficient R for the cumulative calculation is very poor because of the scatter introduced by the annual temperature wave. Nevertheless, the presssure coefficient obtained agrees with that given by the daily differences calculation. The coefficient found, ~ 0.125 % per mb, is small, presumably because the atmospheric pressure at Deep River is correlated with the atmospheric temperature. TREFALL (1955) asserted that the pressure coefficient determined in this manner was the "total barometer coefficient" on the basis of the assumption that "the atmospheric temperature distribution is independent of the sea level pressure". This is evidently not true at Deep River.

5.2. USE OF GROUND TEMPERATURES

In the absence of radiosonde data, ground temperatures can be tried. The degree of success obtained will depend upon how much the ground temperature at the station is affected by local conditions. With ground temperature there is one advantage, that continuous readings are available. The regression coefficients calculated, according to Equation (1), using Deep River

TABLE 5. *Regression coefficients calculated, according to Equation 12, for the 2 year period, May 1962 to April 1964.*

Calculation	C_P, % per mb	C_N	σ_M, %	Δ_M, %	R
Cumulative	$-.1293 \pm .0082$	$.537 \pm .032$	2.321	1.704	.6787
Daily differences	$-.1221 \pm .0020$	$.585 \pm .032$	1.063	.401	.9261

TABLE 6. *Regression coefficients calculated, according to Equation 1 using Deep River ground temperatures.*

Year	C_P, % per mb	C_N	C_T, % per °C	Δ_M, %	R
CUMULATIVE CALCULATION					
May 1962 to Apr. 1963	$-.1518 \pm .0034$	$.488 \pm .002$	$-.143 \pm .002$	.468	.9791
May 1963 to Apr. 1964	$-.1518 \pm .0034$	$.307 \pm .018$	$-.141 \pm .003$	.498	.9770
DAILY DIFFERENCES CALCULATION					
May 1962 to Apr. 1963	$-.1400 \pm .0024$	$.642 \pm .048$	$-.073 \pm .005$	.301	.9561
May 1963 to Apr. 1964	$-.1361 \pm .0023$	$.425 \pm .029$	$-.075 \pm .005$	.308	.9598

ground temperatures are given in Table 6. C_T is about 100 % larger for the cumulative calculation than it is for the calculation using daily differences. This indicates that the day-to-day ground temperature changes are much larger than the annual changes with respect to the atmosphere as a whole. The fit of the regression analysis is very much improved over that obtained with no temperature term but it is easily surpassed by even the poorest-fitting set of Table 3.

5.3. HEIGHTS OF ISOBARIC LEVELS

Use of the height of the 100 mb level to represent the effect of atmospheric temperature was introduced by DUPERIER (1944). WADA (1951) proposed instead the use of isobaric height measured from the 1000 mb isobaric level. The purpose of Wada's proposal was to make the temperature term used in the regression analysis independent of pressure.

Both forms of temperature parameter were tested by regression analysis according to Equation (1) for the millibar levels H_{100}, H_{200}, H_{300} and H_{400}. The results are given in Table 7 for the period May 1962 to April 1963 for the cumulative calculation and also for the daily differences calculation.

The goodness of fit was not affected by substituting $H-H_{1000}$ for H; only the value of the pressure coefficient C_P was altered by this change. The larger value obtained with $H-H_{1000}$ is the "total" barometer coefficient of TREFALL (1955) which is also the coefficient found by the Dorman method (WADA, 1960).

The cumulative calculations indicated that H_{100}, as was found by DUPERIER (1944), gave the best result, closely followed by H_{200}. The daily differences calculations, however, pointed to H_{300} and H_{400} as the best parameters. The C_T discrepancy between the cumulative and the daily difference calculations was present and was quite large; it was smallest for H_{100} where it amounted to 24 %.

The daily differences fit for H_{300} ($\Delta_M = 0.140$) was better than was found for any of the sets of Table 1, and this raised the question whether the height of an isobaric level, with the help of the 31 day running average, might be used in practice instead of the more laborious Dorman method. The analysis was therefore repeated, using the 31 day running averages, in accordance with Equation (11). The results are given in Table 7. A comparison with Table 2 shows that the use of the height of any single isobaric level is not nearly as good as the Dorman method.

5.4. COMBINATIONS OF HEIGHTS AND TEMPERATURES

In a later paper DUPERIER (1949) reported that the inclusion of a term representing the mean temperature of the air layer between 200 and 100 mb in the regression equation improved the fit. The new regression coefficient was positive and it was interpreted to arise from the decay probability of the π-meson. DORMAN (1957) has described in detail how the choice of the height of the 100 mb level was initially incorrect and led to subsequent errors of interpretation.

The use of the height of the 100 mb level in conjunction with the temperature at the 800 mb level was recommended by Mathews (1959).

In Table 8, using the period May 1962 to April 1963, we give, for H_{100} and T_{100}, and for H_{100} and T_{800}, the regression coefficients and the values of Δ_M and R.

TABLE 7. *Regression coefficients calculated using the heights of isobaric levels, for the year May 1962 to April 1963.*

Isobaric levels	C_P, % per mb	C_N	$C_{\bar{N}}$	C_T, % per km	$C_{\bar{T}}$	Δ_M, %	R
CUMULATIVE CALCULATION							
Using height above ground							
H_{100}	$-.1333 \pm .0024$	$.259 \pm .016$		$-6.43 \pm .08$		.334	.9898
H_{200}	$-.1144 \pm .0025$	$.279 \pm .018$		$-5.69 \pm .07$		.363	.9880
H_{300}	$-.0989 \pm .0031$	$.346 \pm .021$		$-5.77 \pm .09$		.438	.9825
H_{400}	$-.0885 \pm .0031$	$.356 \pm .021$		$-6.93 \pm .11$		.445	.9819
Using height above H_{1000} isobaric level							
$H_{100}-H_{1000}$	$-.1809 \pm .0027$	$.279 \pm .018$		$-6.35 \pm .08$		.367	.9877
$H_{200}-H_{1000}$	$-.1571 \pm .0026$	$.290 \pm .018$		$-5.67 \pm .07$		.367	.9877
$H_{300}-H_{1000}$	$-.1425 \pm .0031$	$.354 \pm .020$		$-5.78 \pm .09$		.430	.9831
$H_{400}-H_{1000}$	$-.1409 \pm .0031$	$.364 \pm .020$		$-6.96 \pm .11$		.431	.9830
DAILY DIFFERENCES CALCULATION							
Using height above ground							
H_{100}	$-.1276 \pm .0020$	$.572 \pm .044$		$-5.19 \pm .27$		.269	.9651
H_{200}	$-.1235 \pm .0012$	$.431 \pm .028$		$-3.88 \pm .10$		.170	.9863
H_{300}	$-.1189 \pm .0010$	$.392 \pm .023$		$-3.50 \pm .07$		.140	.9907
H_{400}	$-.1144 \pm .0010$	$.397 \pm .024$		$-4.05 \pm .09$		.143	.9902
Using height above H_{1000} isobaric level							
$H_{100}-H_{1000}$	$-.1592 \pm .0034$	$.631 \pm .050$		$-4.42 \pm .31$		.309	.9538
$H_{200}-H_{1000}$	$-.1523 \pm .0016$	$.446 \pm .032$		$-3.96 \pm .12$		.191	.9825
$H_{300}-H_{1000}$	$-.1456 \pm .0012$	$.390 \pm .025$		$-3.70 \pm .08$		.147	.9896
$H_{400}-H_{1000}$	$-.1457 \pm .0012$	$.389 \pm .024$		$-4.40 \pm .09$		.145	.9899
31-DAY RUNNING AVERAGES CALCULATION							
Using height above ground							
H_{100}	$-.1340 \pm .0023$	$.308 \pm .032$	$.235 \pm .019$	$-5.67 \pm .19$	$-6.58 \pm .08$	.323	.9905
H_{200}	$-.1227 \pm .0016$	$.311 \pm .022$	$.174 \pm .013$	$-3.99 \pm .09$	$-6.40 \pm .06$	.223	.9955
H_{300}	$-.1142 \pm .0017$	$.343 \pm .023$	$.197 \pm .014$	$-3.76 \pm .08$	$-6.89 \pm .06$	.231	.9951
H_{400}	$-.1071 \pm .0018$	$.348 \pm .024$	$.204 \pm .015$	$-4.51 \pm .10$	$-8.30 \pm .08$	.247	.9945
Using height above H_{1000} isobaric level							
$H_{100}-H_{1000}$	$-.1781 \pm .0029$	$.322 \pm .034$	$.256 \pm .020$	$-5.66 \pm .21$	$-6.50 \pm .09$	.348	.9890
$H_{200}-H_{1000}$	$-.1545 \pm .0016$	$.317 \pm .022$	$.204 \pm .013$	$-4.04 \pm .09$	$-6.31 \pm .05$	.223	.9955
$H_{300}-H_{1000}$	$-.1442 \pm .0015$	$.348 \pm .021$	$.232 \pm .012$	$-3.83 \pm .08$	$-6.79 \pm .06$	.214	.9958
$H_{400}-H_{1000}$	$-.1432 \pm .0016$	$.353 \pm .021$	$.246 \pm .013$	$-4.62 \pm .10$	$-8.16 \pm .07$	.223	.9955

TABLE 8. *Regression coefficients, calculated according to Duperier using height of a high isobaric level (H_{100}) temperature near that level (T_{100}) and according to Mathews using height of a high isobaric level (H_{100}) and temperature near a low isobaric level (T_{800}), for the year May 1962 to April 1963.*

Author and method	C_P, %/mb	C_N	C_H, %/km	C_T, %/°C	Δ_M, %	R
CUMULATIVE CALCULATION						
Duperier H_{100}, T_{100}	$-.1305 \pm .0023$	$.247 \pm .016$	$-6.31 \pm .07$	$0.35 \pm .005$	.317	.9908
Mathews H_{100}, T_{800}	$-.1385 \pm .0018$	$.276 \pm .012$	$-4.40 \pm .13$	$-0.60 \pm .003$	.249	.9944
DAILY DIFFERENCES CALCULATION						
Duperier H_{100}, T_{100}	$-.1255 \pm .0017$	$.493 \pm .039$	$-3.47 \pm .26$	$.081 \pm .007$	.238	.9728
Mathews H_{100}, T_{800}	$-.141 \pm .002$	$.419 \pm .031$	$-2.18 \pm .22$	$-.071 \pm .003$	.186	.9834

The temperature coefficient of Duperier, $C_{T_{100}}$ is indeed positive both for the cumulative and the daily differences calculations at the 100 mb level. The fit of the Duperier method is, however, surprisingly poor. Comparison with Table 7 indicates that the fit was almost as good with no additional temperature term.

The temperature coefficient of Mathews, $C_{T_{800}}$, makes a substantial improvement to the fit, both for the cumulative calculation and for the daily differences calculation. However the goodness of fit is surpassed by all but one of the sets of temperature weighting factors of Table 3 in the cumulative calculation and by all but two in the daily differences calculation.

It seems evident that the regression analysis in both the Duperier and the Mathews case is merely using the extra temperature term to change the temperature weights implicit in the height of a millibar level (varying inversely as the pressure; DORMAN, 1958, Fig. 42) into a form corresponding more closely to the Dorman–Maeda–Wada curve (independent of pressure).

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ВВЕДЕНИЕ МЕТЕРЕОЛОГИЧЕСКИХ ПОПРАВОК В ДАННЫЕ МЕЗОННОГО МОНИТЕРА

Были выполнены ряд регресивных вычислений для корреляции средней интенсивности мезонов с барометрическим давлением, атмосферной температурой и интенсивностью нейтронов, измеренной монитором.

Для этого были использованы данные за два года, полученные с мезонного (plastic scintillator) и большого нейтронного мониторов работавших при постоянной температуре в лаборатории в Deep River. Был исследован исчерпывающий список температурных атмосферных параметров: температура поверхности, высоты следующих изобарических уровней: 100, 200, 300 и 400 mb некоторые рекомендованные комбинации температур и высот изобарических уровней; полученные Dorman и Maeda формулы с использованием температур на всех стандартных изобарических уровнях, произвольно искаженные варианты этих формул, включая те, которые были рекомендованы Wada и Lindgren. Установлено, что формулы Dorman, Maeda и Wada почти неразличимы при имеющихся данных и дают гораздо лучшее совпадение для этих величин.

Однако, не один из рассматриваемых температурных параметров не мог совпадать одинаково хорошо с ежедневными и сезонными изменениями температуры при одном и том же регресивном коэффициенте. Использование следующих частично эмпирических температурных параметров позволило вести постоянную поправку для данных, полученных в Deep River. Это — 1,045 $T(j)$ + 0,215 $\bar{T}(j)$, где $T(j)$ температурная поправка Maeda для j дня, $\bar{T}(j)$ — среднее этой поправки взятой за период $(j-15)$–$(j+15)$ дней.

CORRIGENDUM

Tellus volume 18, number 1 in Yoshiaki Toba's paper "On the giant sea-salt particles in the atmosphere. III. An estimate of the production and distribution over the world ocean", the text to figure 2 on page 136 should be the text to figure 3 on page 137 and vice-versa.