SHORTER CONTRIBUTION

Atmospheric Effects on Cosmic Radiation, Air-mass Absorption and Meson Decay

By F. LINDHOLM, Swedish Meteorological and Hydrological Institute

(Manuscript received 17 Oktober, 1949)

Abstract

The percentage variations of twenty-four hour means of C. R. in Stockholm (magn. lat 58°) amount to ± 5 % of the mean value over a quiet period of two months' duration. The two atmospheric effects, the mass absorption due to ionisation and the meson decay, contribute ± 4 %. The residual variations, in excess of statistical fluctuations of 0.1 %, depend upon other factors, such as geomagnetic activity and solar influences.

The true absorption coefficient for zenith radiation (β) is calculated to have a value of $1.27 \cdot 10^{-3}$ cm²/g and the rate of decay (β') is found to be about 0.060 pr km. The meson producing layer is attributed to the 200 mb surface, the highest level reached by the daily radiosonde ascents in Stockholm.

The most reliable decay value is obtained by considerations of the thermal structure of air-mass changes in travelling deep depressions.

Introduction

I am indebted to Dr Malmfors for copies of the continued counter records from Stockholm (MALMFORS 1949) which have been used in the investigations discussed in this paper. The first objective, of an analysis of the intensity values Z, N and S of C. R., was to deduce the true absorption and decay coefficients of particles from the three central directions with the mean zenith distances $\vartheta = 0°$, 35° N and 35° S.

The change dN in the number of particles penetrating from a direction deviating $\vartheta°$ from the zenith depends upon ionisation and decay and can be expressed by

$$dH = -N\beta dB \sec\vartheta - N\beta' dH \sec\vartheta$$

where dB in mm Hg is the change in the air-mass over the station and dH the height-changes in m of the meson producing layer in the lower stratosphere β representing the true absorption coefficient and β' the mean rate of decay. $\beta' = \frac{1}{L}$, L the mean range of the meson before disintegration.

With the mean values $\overline{N}$, $\overline{B}$ and $\overline{H}$ for the whole period in question we have

$$N - \overline{N} = -\overline{N}\beta(B - \overline{B})\sec\vartheta - \overline{N}\beta'(H - \overline{H'})\sec\vartheta$$

The daily mean-values of the airmass, the barometric pressure, were taken from the hourly values of the Meteorological station at Stockholm-Bromma airport.

Tre results of counter-soundings to upper levels (PFOTZER 1936) show the meson producing layer to be at a pressure of about 100 mb. Unfortunately the daily aerological and wind soundings at Stockholm generally do not reach higher than the 200 millibar surface. These soundings, which have been employed in the present investigation, are made twice daily at 5^h and 15^h GMT. The geopotentials of the 200 millibar surface are taken from these soundings and the corresponding height values have been given in geometric metres.

The analysis of the daily means has given the following regression coefficients μ and μ' in the formula

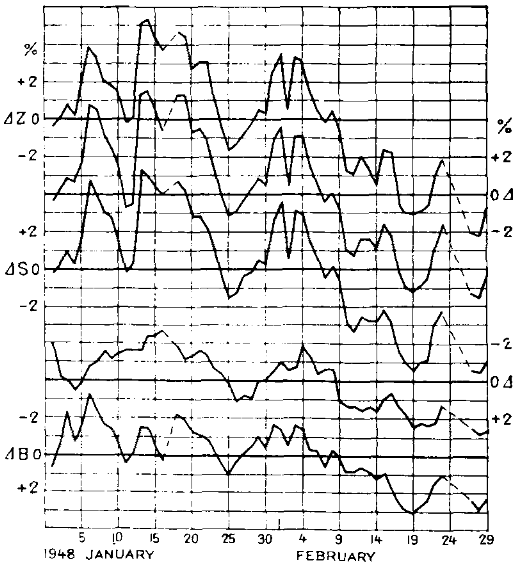

Fig. 1. Observed percentage variations of the daily means of Z, N och S intensities, the barometrique pressure at the ground and the height of the 200 mb surface.

$$N - \overline{N} = -\mu\,(B - \overline{B}) - \mu'\,(H - \overline{H}'):$$

$Z - 25\,423 = -44.05(B - 757.3) - 1.629(H - 11\,340)$

$N - 16\,263 = -29.94(B - 757.3) - 0.920(H - 11\,340)$

$S - 15\,645 = -28.45(B - 757.3) - 0.998(H - 11\,340)$

As shown in fig. 1 the observed variations of the daily means of Z, N and S amount to about $\pm$ 5 % of the means for the whole period. However they are reduced to $\pm$ 1 % by considering both mass absorption and decay (the thick curves in fig. 2). The thin curves in fig. 2 represent the percentage deviation after reduction to a constant pressure of 757.3 mm Hg. Other factors are responsible for residual changes larger than the statistical fluctuations of about 0.1 % of the mean intensity. Though not yet fully elucidated the influence of magnetic activity and of solar influences on the primary radiation seem to be of particular importance.

1. *Barometric coefficient.* We obtain the true absorption coefficient β from the barometric regression coefficient μ by means of the equation

$$\mu = \overline{N}\beta \sec\vartheta$$

With the above values of μ the absorption coefficients β_{0° and β_{35° for zenithal and for an incidence of 35° are

$\beta_{0^\circ} = 1.73$ % per cm Hg or 1.27×10^{-3} cm²/g

$\beta_{35^\circ} = 1.50$ % » » » » 1.10×10^{-3} cm²/g

This result is in accordance with our knowledge of the C. R., for with a greater angle of incidence the weaker component of the C. R. is absorbed by the greater air-mass in the oblique direction.

As at sea level the hard meson-component is about 75 % of the total zenithal radiation and as the N or S intensities are found to be in about the same relation to the Z intensity, we may suppose that the oblique radiation N or S is about equivalent with the hard meson-component of the zenithal radiation. The absorption coefficient of this meson-component must then be of the order of 1.10×10^{-3} cm²/g.

The calculated values of β are lower than the BE-value LINDHOLM (1944) deduced without accounting for the disintegrating process, as H is also a function of B according to the hypsometrical formula.

2. *Decay coefficient.* From the regression coefficient μ' we deduce the rate of decay

for Z $\beta'_{0^\circ} = 6.5$ % per km and

» $N + S$ $\beta'_{35^\circ} = 4.9$ % » km.

Considerations of the thermal structure of travelling cyclones, causing different slopes of the isobaric surfaces at upper and lower levels, suggest a method for determination of the rate of decay independently of the barometric effect. During the period investigated there were two deep depressions passing

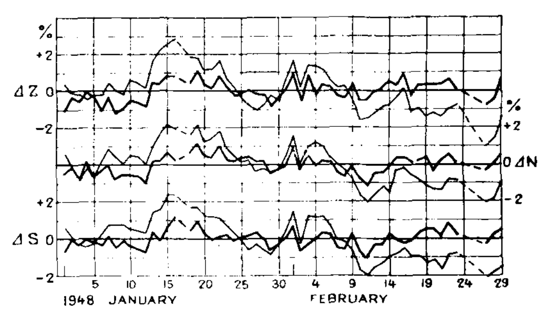

Fig. 2. Percentage variations of daily means of Z, N and S. Thin curves represent variations after reduction to the mean pressure (757.3 mm Hg). Thick curves represent variations after reduction both to mean pressure and mean height of the 200 mb. surface.

over Scandinavia, one during the days 5—7 January 1948 with a pressure minimum at Stockholm of 730.6 mm Hg at 16^h on the 6th and another one during the days 12—14 January with a minimum of 735.5 mm Hg between 0—3^h on the 14th.

Fig. 3 shows the average pressure variation at the ground and furthermore the variation of the height of the 200 mb surface and of the Z and $N + S$ values during the passages of the two depressions. The pressure and height values are taken at three hour intervals before and after the occurance of the pressure minimum at the ground. The values of Z and $N + S$ are the sum of the number of coincidenses at the same time interval on the two occasions. The points indicate the values of Z and $N + S$ reduced to a mean pressure of 737,5 mm Hg.

The corresponding observed mean values of H (200 mb) in meters at a mean pressure of 737.5 mm Hg before and after the passage of the depression and the sum of Z and $N + S$ at the two events are given in Table 1.

Table 1. Mean values of Z, N + S and height of the 200 mb surface for constant pressure at the ground during depression passages.

Hour from barometer minimum passage	Mean pressures at the station	Height of 200 mb surface meter	Z	μ'_{0°	$N + S$	μ'_{35°
12½ before	737.5	11,247	53,000		66,460	
12½ after	737.5	11,124	53,400	— 3.25	66,820	— 2.93

From the value of μ' the rates of decay are calculated

$$\beta'_z = 0.0061\ \%\ \text{pr meter or } 6.1\ \%\ \text{pr km}$$
$$\beta'_{N+S} = 0.0036\ \%\ \text{»} \quad \text{»} \quad \text{»}\ 3.6\ \%\ \text{»} \quad \text{»}$$

If a great number of cyclone passages are treated in this manner the determination of β' can be made with great accuracy without knowing the barometric effect.

In fig. 4 the values of Z and $N + S$ reduced to 737.5 are represented as functions of H and $H \cdot \sec 35^\circ$ resp. The correlation coefficient between Z and $N + S$ reduced to constant pressure and H^{200} mb is $\mu = -0.92$. By means of the least square method we obtain:

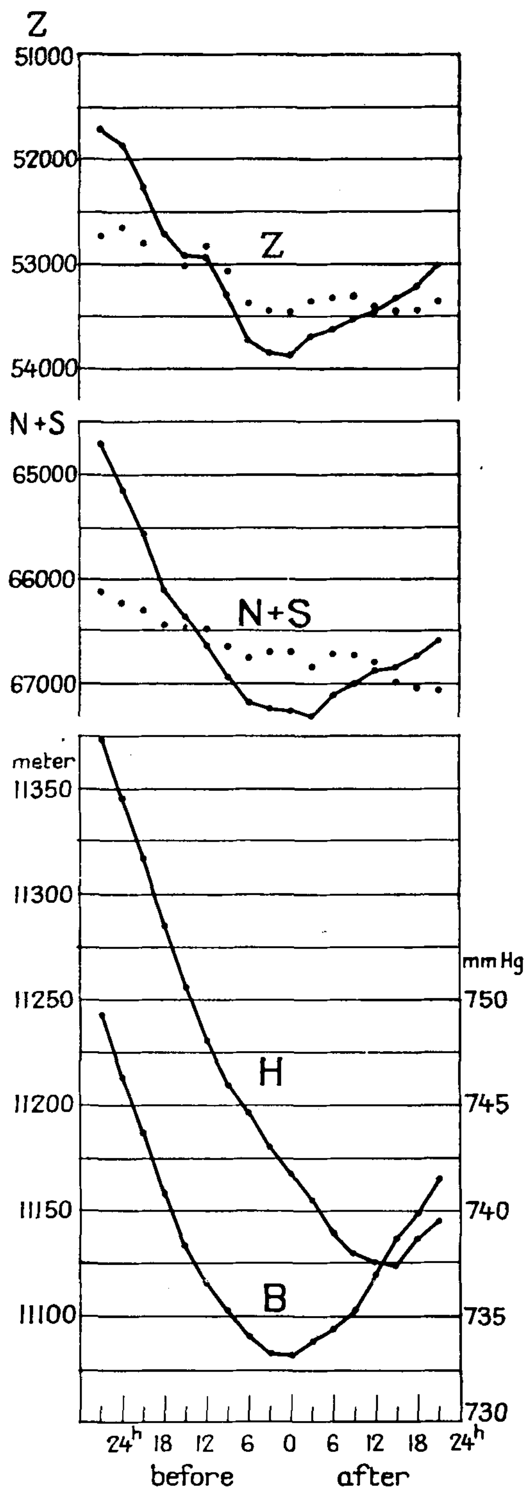

Fig. 3. Average variations of B, H, Z and $H + S$ during passages of two deep depression. (The points indicate values of Z and $N + S$ reduced to a mean pressure of 737.5 mm Hg.)

5—906620

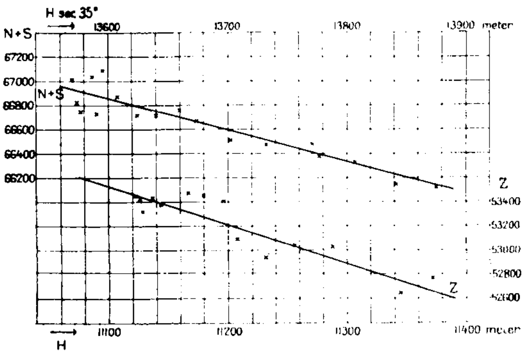

Fig. 4. Relation between Z and $H_{200\ \text{mb}}$ and between $N+S$ and $H_{200\ \text{mb}} \cdot \sec\vartheta$.

$$\mu'_z = 3.17 \pm 0.35 \text{ and } \beta'_0 = 6.0\,\% \text{ per km}$$
$$\mu'_{N+S} = 2.60 \pm 0.28 \quad » \quad \beta'_{35} = 3.2\,\% \quad » \quad »$$

The high correlation between the intensity reduced to constant pressure and the height of the 200 mb surface support the assumption that the variations in height of the 200 mb surface differ only insignificantly from those of the meson producing layer assumed to be at about 100 mb.

SCHERHAG'S (1948) northern hemisphere charts of the mean absolute topography of the upper troposphere and the lower stratosphere, drawn by means of soundings 1941—44, show but little change from the 225 to the 96 mb surface of the difference between the extreme values equator (max) — pole. Expressed in geodynamic decameters (gdm) this variation is found to have the following values:

	Level	Equator	Pole	Difference
Jan.	225 mb	1,136 gdm	980 gdm	156 gdm
	96 »	1,648 »	1,492 »	156 »
July	225 »	1,164 »	1,068 »	96 »
	96 »	1,688 »	1,624 »	64 »

It is interesting to note that, if we take the corresponding height values for the 300 mb level, we find a very little change in the calculated value namely $\beta' = 5.92\,\%$ per km.

KOLHÖRSTER and MATTHEW (1939) found $\beta'_0 = 1.13 \times 10^{-3}$ cm²/g by recording double coincidences at Potsdam, and compensating for the variation of atmospheric pressure with a variable wood screen. This value corresponds to $\beta'_0 = 6.6\,\%$ per km and is quite close to that given above.

From a two months record in London in 1943 DUPERIER (1944) found, from threefold coincidences, a lower value $\beta'_0 = 5.4\,\%$ per km at a mean pressure of 756.7 mm. This value was deduced by means of height values of the 100 mb surface over southern England. The barometric coefficent, however, was found to be 2.28 % pr cm Hg so that the sum of the two coefficients is the same in both cases.

It is interesting to find how well the height of the 200 mb surface can be determined by records of the cosmic radiation. With the decay formula given above the height values have been calculated from the intensity values of Z reduced for pressure variations. The mean error $\varepsilon(H) = \pm\sqrt{\frac{\Delta^2}{n-1}}$ of the individual height values is found to be ± 32 m i.e. 3 pro mille or not far from the accuracy of the actual soundings. This result was obtained by averages from the two passing cyclones.

For the whole material we find $\varepsilon(H) = \pm 96$ m or 8 pro mille.

3. *Temperature coefficient.* The temperature coefficient is obtained from

$$\alpha = \frac{dz}{dH} \cdot \frac{dH}{dT_m} = -\beta' \frac{dH}{dT_m}$$

If we define the mean temperatur T_m of the air column between $\overline{B}$ and the 200 mb surface by the hypsometric formula

$$H_{200\ mb} = 0.0674 \cdot T_m \log \frac{B_0}{200} \text{ km}$$

we find, for $B_0 = 1010$ mb, $\left(\frac{dH}{dT_m}\right) = 0.0474$ and with $\beta' = 0.06$ per km we have $\alpha = -0.06 \times 0.0474 = -0.0028$ pr °C or $\alpha = -0.28\,\%$ pr °C. We obtain for the air column between $\overline{B}$ and 100 mb $\left(\frac{dH}{dT_m}\right) = 0.00677$ and assuming the same value $\beta' = 0.06$ pr km

$$\alpha = -0.00406 \text{ or } -0.41\,\% \text{ per °C.}$$

DUPERIER (1944) has found the value of $\alpha = -0.35\,\%$ per °C. Other methods for calculation of the temperature effect have given values of α between — 0.30 and — 0.40 pr °C.

4. *Meson-decay and latitude effect of cosmic radiation.* The mean slope equator — pole of the isobaric surfaces in the upper troposphere and lower stratosphere, and also of the layer where mesons are

generated, must have some bearing on the interpretation of the latitude effect of C. R., which is found by CLAY (1932), HOERLIN (1933) and in the extensive observations of A. H. COMPTON (1933). From the fact that a latitude effect — an increase of the intensity of 12 per cent of the radiation —, is found, when going from the equatorial region to 55 °N geomag. latitude, it is concluded by these authors that this part of the radiation consists of corpuscles deviated by the earth's magnetic field before entering the earth's atmosphere.

In table 2 the meridional changes of the topography of the 96 mb surface are given in dyn decameter (gdm) as taken from SCHERHAGS mean chart for January and July. The great seasonal variation of the slope of the 96 mb surface with maximum in the wintermonths and minimum in summer is evident from this table.

The decay causes a variation with latitude of the mean intensity of C. R. as is shown in column 3 and 5 of table 2 for January and July respectively.

It is thus evident that in the winter months the decay effect contributes with about one third in the latitude effect, up to 55° latitude. Still farther north the meson decay must cause further increase of the average intensity amounting to 10 % in the polar region.

Table 2. Average absolute topography of the 96 mb surface over the northern hemisphere according to SCHERHAG (1948)

Lat.	January		July	
	Mean Geop. gdm.	Mean Rel. Int. C.R. Z	Mean Geop. gdm.	Mean Rel. Int. C.R. Z
90° N	1,496	1.097	1,632	1.017
80	1,504	1.088	1,636	1.015
70	1,540	1.058	1,640	1.012
60	1,564	1.049	1,644	1.010
50	1,580	1.040	1,652	1.005
40	1,596	1.033	1,670	0.994
30	1,610	1.027	1,682	0.987
20	1,624	1.013	1,676	0.990
10	1,640	1.005	1,664	0.998
0	1,648	1.00	1,660	1.00

REFERENCES

CLAY, J., BERLAGE, H. P., 1932: Variation der Ultrastrahlung mit der geographischem Breite und dem Erdmagnetismus. *Naturwiss.* **20**, 687.

COMPTON, A. A., 1933: A geographical study of Cosmic Rays. *Phys. Rev.* **43**, 387.

DUPERIER, A., 1944: A new Cosmic-Ray Recorder and the Air-Absorption and Decay of Particles. *Terr. Magn. and Atmosph. Electr.* **49**, 1.

HESS, V. F. and BENEDETTO, F. A., 1938: Mesotron Variation with Upper Air Temperatures. *Phys. Rev.* **60**, 610.

HOERLIN, H., 1933: Latitude Effect of Cosmic Radiation. *Naturwiss.* **32**, 61.

KOLHÖRSTER, W., and MATTHEWS, I., 1939: Nachweis der Mesotronen der Höhenstrahlung durch Luftdruckkompensation. *Phys. Z. S.* **40**, 142.

LINDHOLM, F., 1944: Der Barometereffekt der kosmischen Strahlung. *Arkiv f. Mat., Astr. och Fys.* **30 A**, 13.

MALMFORS, K. G., 1949: Recordings of Cosmic Radiation. *Tellus* **1**, 2.

PFOTZGER, G., 1936: Dreifachkoinzidensen der Ultrastralung aus vertikaler Richtung in der Stratosphäre. *Z. S. Phys.* **102**, 38.

SCHERHAG, R., 1948: Methoden der Wetteranalyse und Wetterprognose. Mittlere absolute Topographie der 225 mb und 96 mb Flächen über die Nordhalbkugel. Abb. 26, 27.