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# SOME ASPECTS ON ATMOSPHERIC EFFECTS OF THE COSMIC RAY $\mu$-MESON INTENSITY

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## Abstract

The $\mu$-meson intensity of cosmic radiation has been registered with the cubical meson telescope at the Department of Physics, University of Oulu, during the year 1965. The Duperier model has been applied to the registered data using a linear multiple correlation and regression analysis. The partial pressure coefficient $\alpha$, the height coefficient $\beta$, the positive temperature coefficient $\gamma$, and the total correlation coefficient $R$, of the applied model were calculated for every month of the year. There was not a very good success in trying to get better correlation coefficients using neutron monitor data to eliminate primary variations.

## *Introduction*

Cosmic ray variations have been intensively studied during the past three decades. Together with the ionization chamber the most important detector is the meson telescope, because it has already been in operation for a long period. During the year 1963 a meson telescope was built at the University of Oulu. Tanskanen [1] has analysed the data from the year 1964; in this paper his work is continued. The main purpose is to study atmospheric effects on $\mu$-meson intensity to get a right method for the study of primary cosmic ray variations in the future.

*Theory*

Collisions between primary cosmic ray particles and atmospheric atoms produce $\mu$-mesons in primary and secondary interactions. $\pi$-mesons constitute the most important source of $\mu$-mesons. The former have a short life-time and decay as follows [2]:

$$\pi^{\pm} \rightarrow \mu^{\pm} + \nu \tag{1}$$

The production of $\pi$-mesons is independent on the state of the atmosphere, because primary particles are stable. But there are many atmospheric effects on unstable $\mu$-mesons and so the largest $\mu$-meson variations have their origin in the atmosphere. The intensity registered on the ground varies when the number of $\pi$-mesons captured by atomic nuclei or when the number of $\mu$-mesons decaying before registeration varies [3].

The number of $\mu$-mesons on the ground decreases in the following cases:

1) $\mu$-mesons have not energy enough to be registered because of increasing ionization losses [4].

2) The energy-depending life-time is not long enough because of increasing energy losses. These two effects can be explained by the pressure at the altitude of the registering instrument [4].

3) The life-time runs out too early because of the increasing path to the detector. When the average production level of $\mu$-mesons (100—200 mb) goes up, the probability of the decay of $\mu$-mesons increases. This is explained by the height variations of the pressure levels of 100 — 200 mb.

4) The life-time runs out too early when a rearrangement of the atmosphere is going on, *e.g.* the lower parts of the atmosphere are warming and the upper ones are cooling. To explain these variations we need the temperature distribution along the path of $\mu$-mesons.

5) The probability of the absorption of $\pi$-mesons increases, when the temperature in the production level is lowering.

According to the above remarks, the $\mu$-meson variations can be explained by the ground pressure, the height and temperature of the production level. DUPERIER has presented a linear regression equation for the intensity registered on the ground [5].

$$I = \text{const.} + a \cdot B + b \cdot H + c \cdot T \,. \tag{2}$$

The equation for relative variations is then

$$\frac{\Delta I}{I} = \alpha \cdot \Delta B + \beta \cdot \Delta H + \gamma \cdot \Delta T \, , \qquad (3)$$

where $\alpha$ is the partial pressure coefficient (%/mb), $\beta$ the height coefficient (%/km) and $\gamma$ the positive temperature coefficient (%/°C). $B$ is the ground pressure and $H$ and $T$ are the height and the temperature of the reference level.

The equations 2 and 3 are available during the quiet sun, when primary intensity variations are small. During the active sun it is possible to take into account primary variations using pressure corrected neutron monitor intensity $N$ , as one parameter. LINDGREN and LINDHOLM [6, 2] have used instead of the equation 3 the equation

$$\frac{\Delta I}{I} = \alpha \cdot \Delta B + \beta \cdot \Delta H + \gamma \cdot \Delta T + \delta \cdot \Delta N \, , \qquad (4)$$

Here the term $\delta \cdot \Delta N$ describes the effect of primary variations on the $\mu$-meson intensity on the ground.

### *Treatment of data and results*

We have applied a linear multiple correlation and regression analysis to the data registered at Oulu during the year 1965. Calculations have been carried out on the electronic computer of type Elliot 803 at the Computer Centre of University of Oulu. We have used as reference levels the pressure levels of 400, 300, 200, 150 and 100 mb. The aerological data are from Sodankylä and Luonnetjärvi. The following periods have been studied:

12.1.—17.1.
18.1.—16.2.
18.2.—25.2.
7.3.—23.2.
2.4.— 9.4.
17.4.—26 4.
8.5.—14.5.
29.5.—13.6.
21.6.— 2.7.
7.7.—16.7.
29.7.— 9.8.
22.8.— 5.9.
8. 9.—30. 9.
1.10.—20.10.
27.10.— 9.11.
26.11.—13.12.
23.12.—31.12.

Thus there was at least one period for each month. During selected periods the telescope operated well and there were no Forbush-effects nor great geomagnetic disturbances.

In Fig. 1 the calculated values of the coefficients $\alpha$ , $\beta$ and $\gamma$ and the total correlation coefficient $R$ , are presented for every month. There are for comparison also the corresponding values from the year

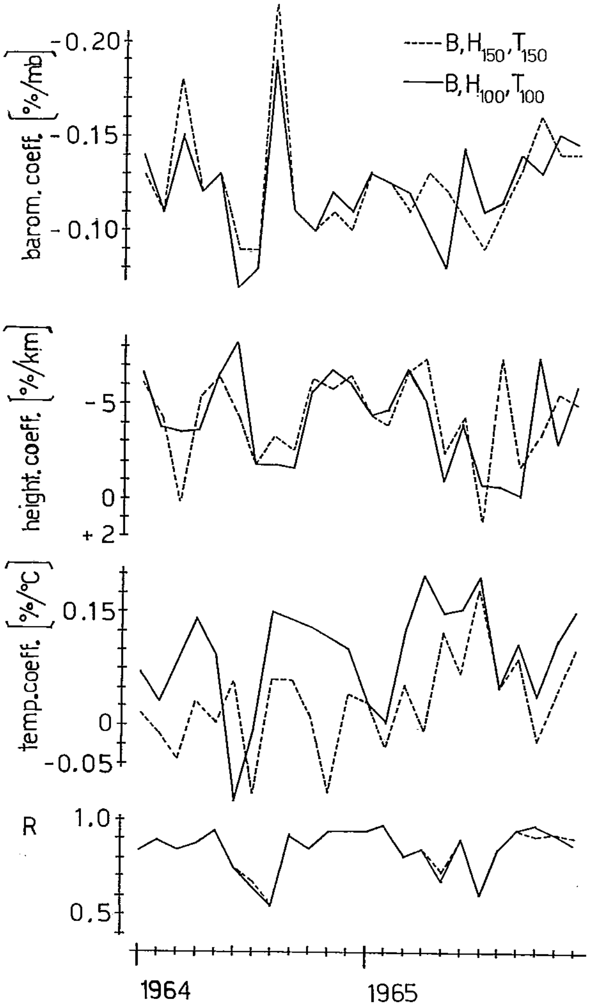

Fig. 1. The variations of the partial barometric coefficient, height coefficient, temperature coefficient and total correlation coefficient at reference levels 100 and 150 mb according to Sodankylä aerological data at Oulu during the years 1964 and 1965.

1964 calculated by TANSKANEN [1]. In the figure only the pressure levels of 100 and 150 mb are used, because they descripe best the production level of $\mu$-mesons [7, 3]. According to the results of correlation analysis the smallest residual deviations and the largest t-numbers have been found with these reference levels. It is possible that the large variations in the results are partly caused by the fact that the aerological data get only twice a day and originate too far from Oulu (Sodankylä 260 km and Luonnetjärvi 300 km). It should be necessary to make at least four soundings per a day from the registeration place to avoid statistical errors [2, 8]. The total correlation coefficient is smallest in summer. Tanskanen [1] explains this effect as follows. In summer the meteorological parameters are too strongly correlated with each other. Then the assumption that atmospheric parameters are independent variables does not hold, and the correlation analysis loses its meaning. The partial pressure coefficient varies most strongly in summer. On the other hand it has been nearly constant in 1964, but in 1965 there is an evident change. In the beginning of the year 1965 $\alpha$ has been —0,12 %/mb and at the end of the year —0,13 %/mb. It is interesting to see wheather $\alpha$ will vary during the period of the sun's activity in the same manner as the pressure coefficient of neutron monitor [9]. The temperature coefficient depends greatly on the pressure of the reference level. It seems to be greater for the 100 mb level than for the 150 mb level. It has been found also by Lindgren and Lindholm [6, 2] that $\gamma$ decreases with increasing pressure level. The height coefficient has its minimum in summer. It is difficult, however, to find any exact periodicity in the variations of coefficients because the period studied at Oulu is yet too short.

The following means for coefficients in the years 1964 and 1965 have been found at Oulu.

| | 1964 | 1965 |
|---|---|---|
| $\alpha$ 100 mb | $-0{,}12 \pm 0{,}02$ %/mb | $-0{,}13 \pm 0{,}02$%/mb |
| $\alpha$ 150 mb | $-0{,}12 \pm 0{,}02$ %/mb | $-0{,}13 \pm 0{,}02$%/mb |
| $\beta$ 100 mb | $-4{,}66 \pm 0{,}58$ %/km | $-3{,}71 \pm 0{,}50$%/km |
| $\beta$ 150 mb | $-4{,}40 \pm 0{,}52$ %/km | $-3{,}69 \pm 0{,}54$%/km |
| $\gamma$ 100 mb | $+0{,}06 \pm 0{,}01$ %/°C | $+0{,}07 \pm 0{,}02$%/°C |
| $\gamma$ 150 mb | $+0{,}02 \pm 0{,}006$%/°C | $+0{,}05 \pm 0{,}02$%/°C |

95% of the calculated values of coefficients are inside error limits. The mean values are in a fairly good agreement with both theoretical and empirical values to be found in the literature [2, 3].

We tried in several periods also equation 4. We had a little success, but not as good as Lindgren and Lindholm [6] by using the same equation. The improvement of the total correlation coefficients was usually less than one per cent while Lindgren and Lindholm [6] had usually much more improvement. In coefficients $\alpha$ , $\beta$ and $\gamma$ we had not any changes in using equations 3 or 4. The coefficient $\delta$ has usually the value $+2 \cdot 10^{-5}\%$ per the change of one count in the neutron intensity, and the average neutron intensity is about $3{,}6 \cdot 10^5$ counts per one hour. Its significance is very small. However during the period 7.7.—16.7. the change of $R$ was from 0,62 to 0,88 and correspondingly $\delta$ was $+1{,}2 \cdot 10^{-4}\%$ per count. So we can find that the change of $R$ and $\delta$ have correlated positively, which fact is very natural.

The small increase of $R$ can perhaps be explained as follows. The studies of LINDGREN and LINDHOLM [6] are from the years 1957 and 1958, when the mean energy of cosmic radiation had its maximum because of the sun modulation [10]. At that time the neutron monitor and the meson telescope had nearly the same energy regions. But during the quiet sun period the cosmic radiation is softer and on the other hand a neutron monitor is more sensitive to variations of the low energy cosmic radiation than a meson telescope. In 1964—65 the common energy region of these detectors has been relatively smaller and a neutron monitor describes less correctly primary variations registered by a meson telescope.

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