SPATIAL HETEROGENITY OF COSMIC RADIATION MEASURED AT EARTH'S SURFACE

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Abstract: *This paper offers an analysis of spatial distribution of cosmic radiation detected near the Earth's surface, and more specifically its seasonal variations. We found that the latter is confined by the geographic latitude and vary in anti-phase with ozone in the lower stratosphere. The paper provides and hypothetical explanation for such a relation between ozone and neutron monitors' counting rates.*

ПРОСТРАНСТВЕНА НЕЕДНОРОДНОСТ НА КОСМИЧНАТА РАДИАЦИЯ ИЗМЕРВАНА НА ЗЕМНАТА ПОВЪРХНОСТ

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Ключови думи: *сезонна изменчивост в показанията на неутронните монитори, дължинен дрейф на захванатата радиация в нехомогенното геомагнитното поле*

Резюме: *Изследвани са пространствените нееднородности в сезонната вариация на космичните лъчи, измервани на земната повърхност. Установено е наличие на връзка с озона в ниската стратосфера. Предложен е механизъм за обяснението на тази свързаност между показанията на неутронните монитори и озона.*

Introduction

Cosmic rays entering Earth's atmosphere collide with atmospheric molecules, producing secondary ions and electrons, as well as different products of nuclear reactions. Some of these secondaries are highly penetrating and are able to reach the ground surface and to be detected by the sea-level neutron monitors. The efficiency of the ion-molecular and nuclear reactions depends on the atmospheric characteristics such as density, temperature, humidity, etc. Thus for more than 70 years scientists have noticed the existing relation between the neutron monitors' counting rates and the lower stratospheric temperature and pressure [1–4].

This paper investigates the seasonal variability of the near surface cosmic radiation measured by 33 neutron monitors, spread over the world. The found latitudinal dependence – related to the lower stratospheric ozone density – has been interpreted as an O_3 modulation of two processes: 1.) nuclear absorption of *π-mesons* (produced by the interaction of cosmic rays with the atmospheric nuclei, and 2.) natural decay of *π-mesons* to muons, easily propagating to, and beneath the Earth's surface.

Data and methods of analysis

The temporal and spatial variability of galactic CR's neutron component, during 2009, has been analysed in 33 neutron monitors, with freely available data at NMDB portal:

http://www01.nmdb.eu or at IZMIRAN data server: http://cr0.izmiran.ru/common/links.htm. The data used are pressure and efficiency corrected.

The 2009 year has been chosen, because of the encountered minimum in the 24-th solar cycle. This means that the neutron monitors' (NMs) data are less affected by the solar induced geomagnetic activity, being weaker in periods of less active Sun. On the other hand, the intensity of arriving galactic cosmic rays is higher, because less of particles arriving at the heliospheric boundary are reflected back to space by the slower, uncompressed solar wind. Consequently, the effects of the geomagnetic irregularities, as well as the meteorological effects, could be easily detected in a period of a quiet Sun.

Analysis of the temporal variation has been done after extraction of the annual mean from each time record. The calculated difference is normalised by the annual mean, which allows a comparison of individual seasonal variability between different NMs.

Grided data for a lower stratospheric temperature and ozone at 70 hPa has been taken from the ERA-Interim reanalysis http://apps.ecmwf.int/datasets/data/interim-full-daily/levtype=sfc/.

Spatial distribution of the NM's seasonal variations

The study of seasonal variation of all examined neutron monitors shows that they vary quite a lot between the individual monitors. More detailed analysis reveals that the shape of the seasonal variability is mostly confined to the geographic latitude. This implies that the seasonal variations of neutron monitors are more probably related to meteorological, instead to geomagnetic effects. Here it is worthy to remain that the data used are already corrected for the surface pressure variability, what means that some other atmospheric effect should influence the NMs' measurements.

Meanwhile, in the middle of 20th century, some authors found out the dependence of NMs' seasonal variations on the temperature and pressure between 50 and 100 hPa [1–3]. This is the altitude of the maximum of π-mesons production in the lower atmosphere by the primary CR [5], so Duperier [2] attributed this relation to the following competing processes: 1.) *π-mesons*' decay into *muons* and 2.) nuclear capture of *π-mesons* (known also as *pions*) through interaction with other nuclei.

Our comparative analysis of the NMs' counts and temperature at 70 hPa shows that the suggested relation is generally not well traceable, especially at Northern Hemispheric high latitudes (see Fig.1). Comparison between zonally averaged ozone and temperature at 70 hPa shows in addition that at latitudes where the ozone controls the temperature (i.e. in latitudinal rage: 40^0–10^0N and 30^0–40^0S, as well as over the Southern Hemisphere polar region) the seasonal variations of temperature at 70 hPa and the near surface cosmic radiation covariate with opposite phases. At other latitudes there is not any systematic relation between temperature and NMs counting rates.

Taking into account the strong radiative power of ozone – adsorbing the incoming solar radiation and controlling in such a way the local temperature balance – the uncoupled seasonal variations of ozone and temperature at middle and high northern latitudes could be puzzling for someone. It should be remind, however, that O_3 density at these latitudes is strongly influenced by energetic particles [6-7] and to some extent by stratospheric dynamics. The less importance of the latter factor is well seen in the Southern Hemisphere polar latitudes, where the ozone and temperature are fairly well coupled. This asymmetry should be related to the hemispherically asymmetrical distribution of the lower stratospheric O_3, determined by the spatially heterogeneous geomagnetic field [8].

The comparison of NMs' seasonal variations with those of O_3 at 70 hPa shows, on the other hand, a well pronounced anti-correlation (see Fig. 2). This result suggests that the lower stratospheric influence on the NMs' measurements goes not through the temperature of the *pions'* production layer, but more likely through its chemical composition (particularly through the amount of the heavier O_3 molecules). In this relation, recent studies show that under certain conditions the ion-molecular reactions, activated in the Regener-Pfotzer maximum of ionisation, could produce ozone in the lower stratosphere [6-7]. Besides the lower energy electrons, the other critical condition – necessary for the activation of the O_3 producing cycle – is a *dry* atmosphere. The latter requirement is usually fulfilled in the winter lower stratosphere – at middle and high latitudes.

The analysis of Fig. 2 shows a well pronounced winter reduction of NMs' counting rates (in both hemispheres), when the ozone density at 70 hPa is raised. The coincidence of the region of π-*mesons* nuclear absorption, or its decay to *muons,* with the ozone layer is noticed also in [9]. Such a coincidence motivated us to assume that the increased concentration of heavier O_3 molecules favours the nuclear capture of *pions* [10], reducing in such a way the additional source of highly penetrating *muons* (registered by the ground-based neutron monitors).

Despite the great complexity of pion absorption (i.e. its' dependence on the pions' charge and energy, variety of mechanisms of absorption, influence of the nuclear environment, etc.), it is well documented that the *pions'* absorption cross-section increases with the rice of the target's mass number [10]. It is worth to remind that the *pion* absorption on a single nucleon is strongly suppressed [11], but in the stratosphere all atmospheric constituents have quite a lot of nucleons (protons and neutrons) in their nuclei. Among them the ozone's molecule is the heaviest one with a mass number of 48 au. Near the delta resonant energy of 165 MeV, its absorption cross-section is almost half of the total reaction cross-section corresponding to its mass number [10]. The cross-sections of the lighter atmospheric molecules (i.e. N_2, O_2, H_2O) are substantially smaller and consequently the probability for *pion* absorption by them is much less.

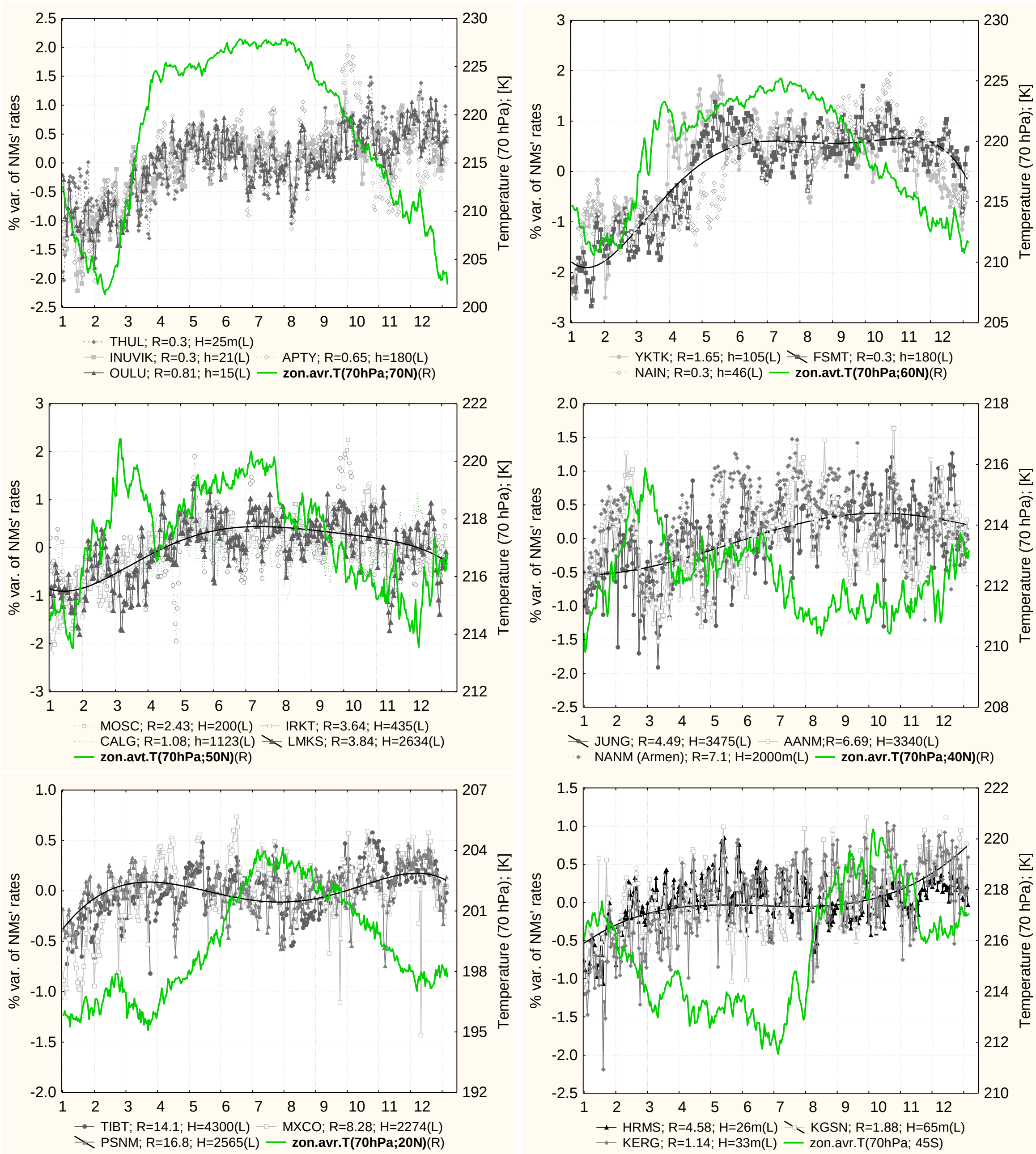

Fig. 1. Seasonal variation of NMs' counting rates (different grey-black symbols) and temperature at 70 hPa (green contour) shown for different geographic latitudes

Besides *pions'* disappearance, the nuclear capture of *pions* is followed by the appearance of secondary products, including *pions* (neutral or charged). For atmospheric molecules the *pion* production is relatively weak [12], but not negligible. Appearance of the triple oxygen (i.e. O_3) molecule in the denser lower stratosphere – at middle and high latitudes – could be a possible reason for the *pions* and *muons* maxima obtained close to the peak ozone density [5]. Unfortunately, to the best of our knowledge experimental measurement of the *pion* absorption/production from the interaction with ozone's nucleus does not exist. Based on theoretical consideration, we, however, hypothesise that seasonal variations of ozone density could modulate the *pions* absorption in the atmosphere and consequently the amount of *muons* detected on the ground surface. For example, the enhanced ozone density in winter season will reduced the amount of *muons,* due to the *pions'* absorption prior to their natural decay to *muons*. Oppositely, the reduced O_3 density in summer should increase the life time of *pions*, enhancing the probability for their decay to *muons* – an effect which should be accompanied by an increase of NMs' counting rates [9].

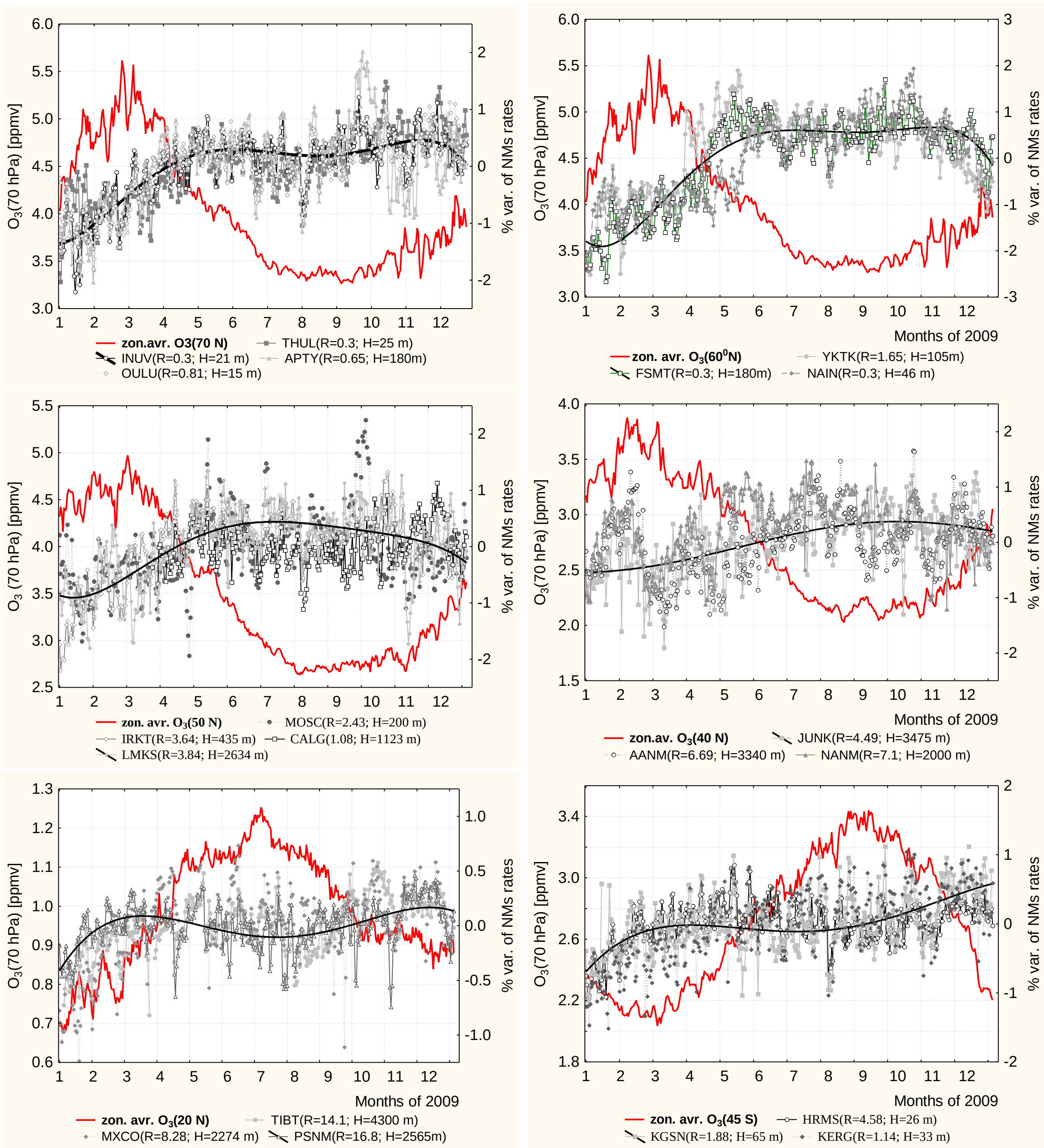

Fig. 2. Seasonal variation of NMs' counting rates (different grey-black symbols) and ozone mixing ration at 70 hPa (red contour) shown for different geographic latitudes

Analysis of the amplitude of O_3 effect on the NMs' seasonal variations shows that the maximal seasonal variations are observed at 60^0N latitude and gradually decreases poleward and equatorward (see Table 1). The gradual weakening of ozone influence on the near surface cosmic radiation could be attributed to the higher elevation of ozone layer at tropical and subtropical latitudes. For example, the ozone peak is situated near 70 hPa in latitude range 70–50^0N. However, at 30^0N latitude it is placed already at 30 hPa [6].

In the Southern Hemisphere the number of CR detectors is much less, but the calculated amplitude of seasonal variation at 45^0S is equal to that found at 40^0N and 50^0N (i.e. 1.5 %). The higher amplitude of the atmospheric influence on the NMs' rates at the surface of the Ice Cube in Antarctica (i.e. equal to 5%), which is reported in [9] – obviously should be attributed to the higher elevation of the detector – placed at 2835m above the sea level.

Table 1. Average amplitude in [%] of NMs' seasonal variability, Related to the lower stratospheric O_3 variations

Latitude	70^0N	60^0N	50^0N	40^0N	20^0N	45^0S
Ampl.[%]	2.3	2.75	1.5	1.5	1	1.5

Conclusion

Analysis of the CRs' seasonal variability reveals a great variety of patterns – generally confined to geographic latitudes. Comparative investigation of atmospheric ozone at 70 hPa, and NMs' counting rates, reveals that they covariate fairly well – with an opposite phases. This result implies that previously suggested connection between lower stratospheric temperature and NMs' counting rates are more likely due to the variations of the lower stratospheric composition, and particularly – to the O_3 density. The latter possibly affects the decay of π-*mesons* to *muons*, which easily rich the ground level. For example, an enhancement of the heavier ozone molecules' density increases the probability for nuclear capture of π-*mesons*, reducing in such a way the production of *muons*. Oppositely, reduced O_3 density increases the life time of π-*mesons*, raising the probability for their decay to *muons*. As a result an increase of the counting rates of ground-based NMs should be detected.

These results suggest that the amplitude of the ground level enhancement of CR intensity, registered by the ground based NMs [i.e. 13–17], is not uniformly distributed over the globe. Having in mind the CR influence on the some meteorological parameters [18] it becomes clear that a re-assessment of the factors affecting the production of CR secondaries in the lower atmosphere, similar to that presented in [19] is necessary.

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