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Analysis of variations of muon and hadron components of cosmic rays at different phases of solar activity during the 11-year solar cycle

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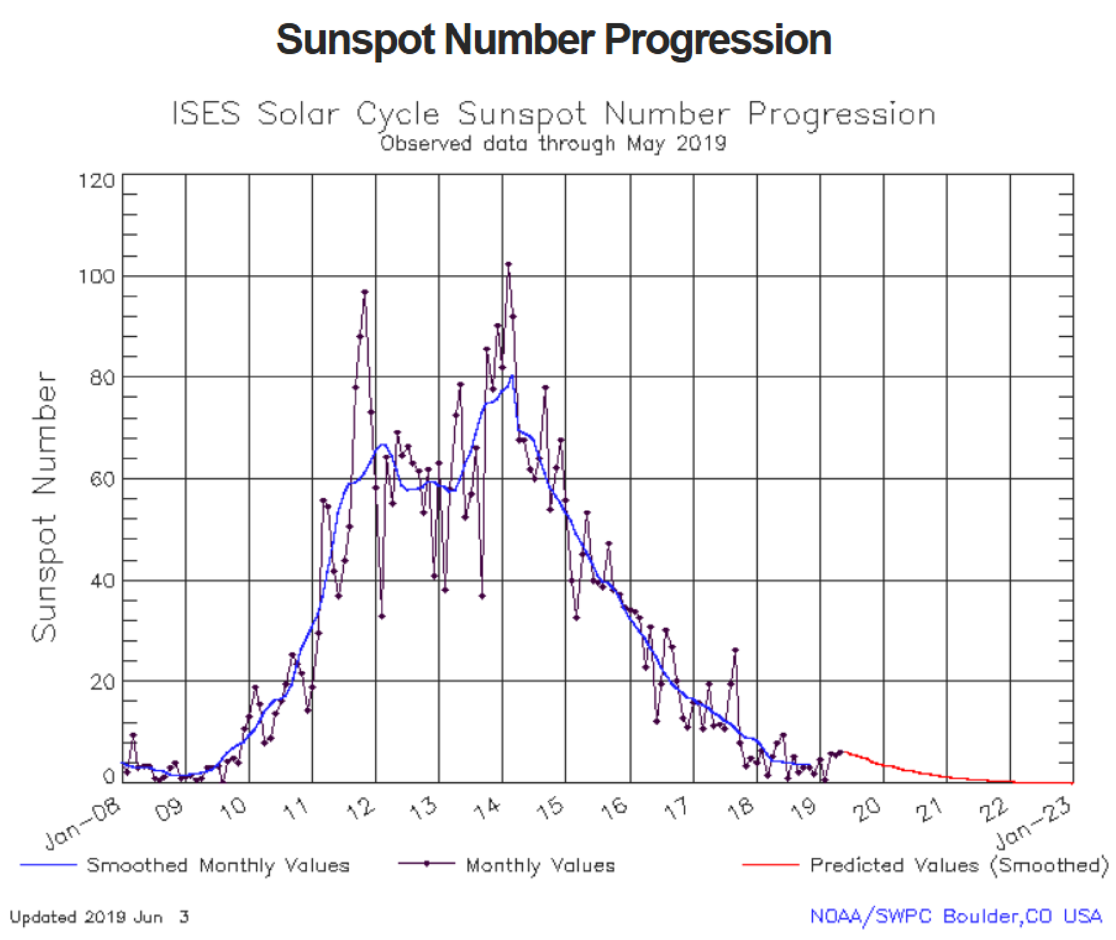
Abstract

Variations of secondary cosmic rays on the Earth's surface depend on the solar activity. The main components of secondary particles recorded by ground-based detectors are muons (from primary particles with an average energy of ~ 50 GeV) and hadrons (from primary energies of cosmic rays ~ 10 GeV). To study their variations, neutron monitors and muon detectors are used. Observations of muons and hadrons complement each other in terms of the energies of primary cosmic rays and their angular distribution. Muons save the direction of motion of primary particles, which makes it possible to obtain the spatial-angular characteristics of cosmic ray modulations in near-Earth space using a single setup - muon hodoscope.

Results of the analyses of comparison of variations of muon and hadron components of cosmic rays at different phases of solar activity in the period from 2008 to 2018 are presented. For comparison, data of neutron monitors (Moscow and Apatity stations) and the muon hodoscope URAGAN were used. The analysis of correlations of data of these detectors with changes in solar activity parameters since 2008 to 2018 was carried out.

Comparison of diurnal variations in the counting rate of detectors with changes in the parameters of solar wind, interplanetary magnetic field, sunspot numbers and geomagnetic idexes

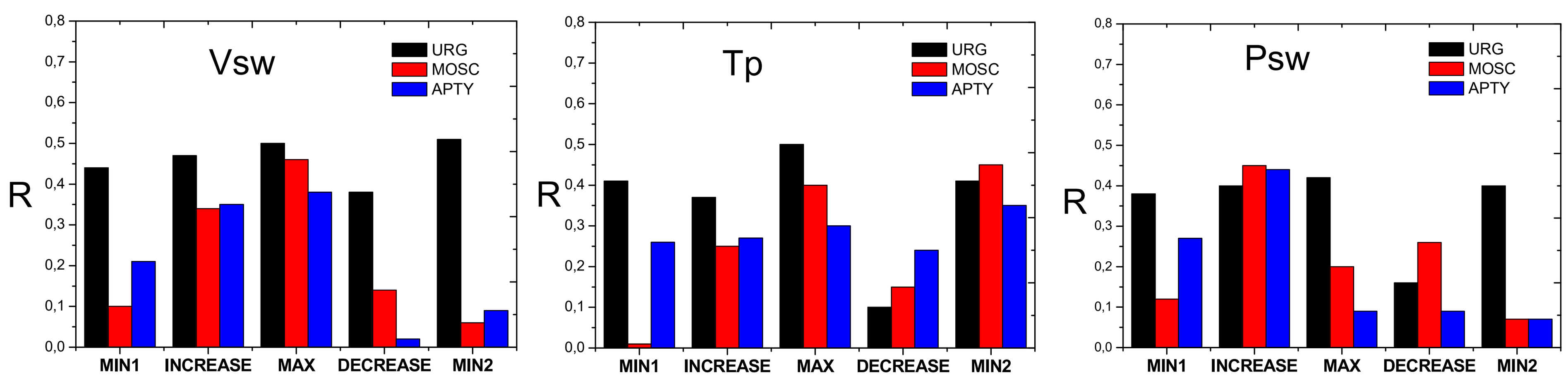


The study was based on a comparison of monthly averaged standard deviations of the counting rate of detectors

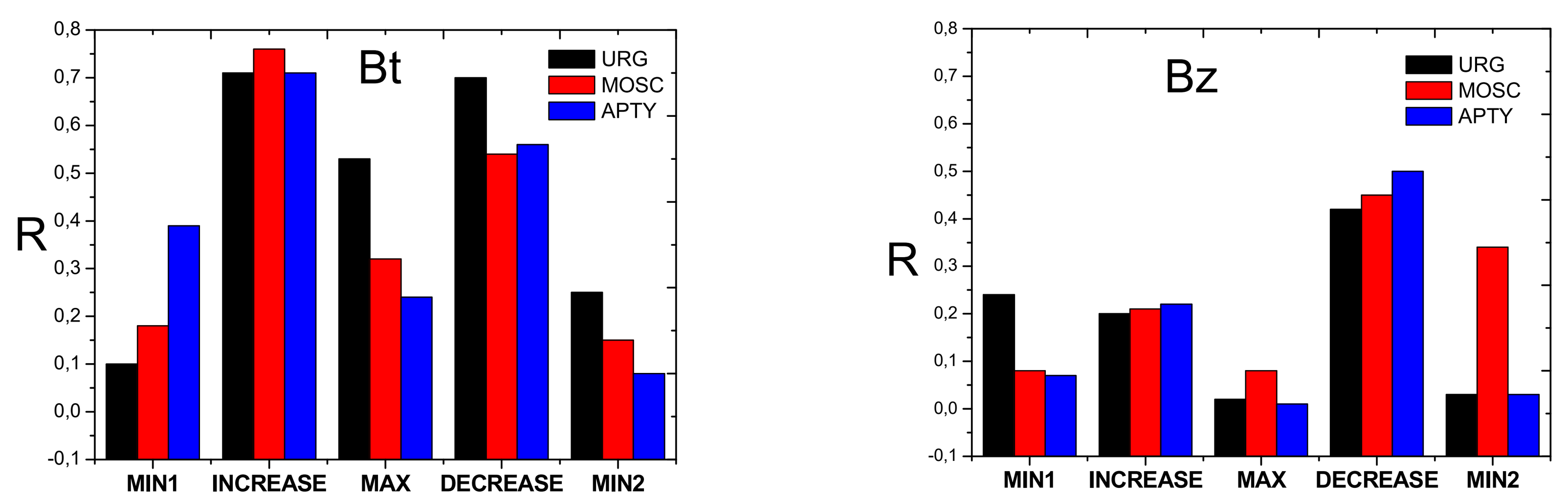
$$\sigma I_{24} = \sqrt{\left(\frac{\sum_{i=1}^{24} I_i^2}{n} - \left(\frac{\sum_{i=1}^{24} I_i}{n}\right)^2\right)\frac{n}{n-1}}$$

where I_i - the detector counting rate, i - the number of hours in the day, n - the number of available hourly data in the days.

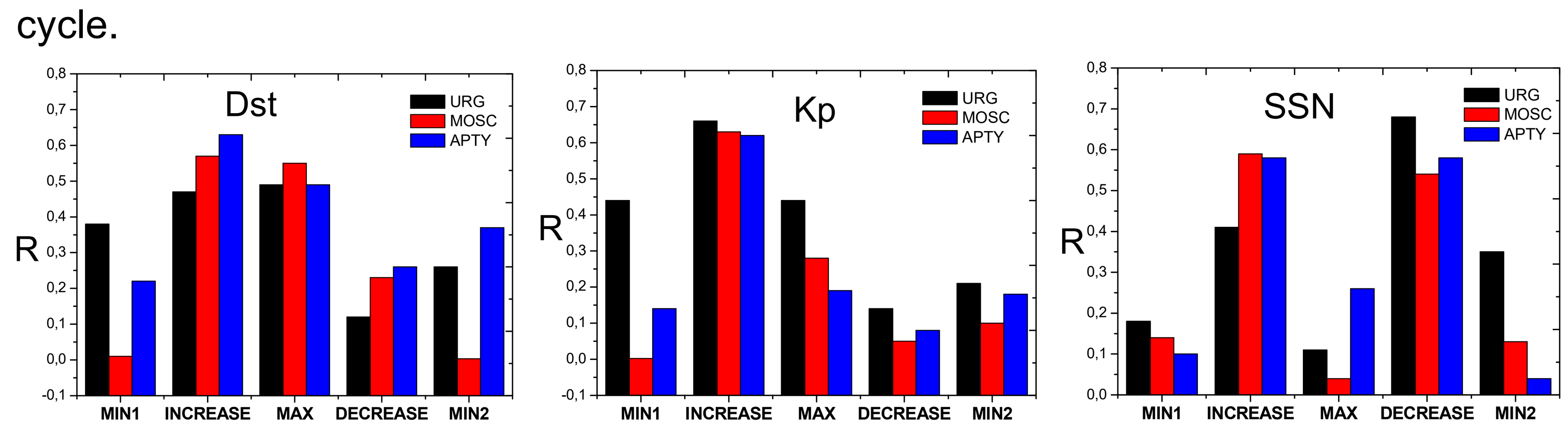
Histograms of correlation coefficients between MH URAGAN, NM Moscow and NM Apatity data and solar wind parameters at different phases of the solar cycle.



Histograms of correlation coefficients between MH URAGAN, NM Moscow and NM Apatity data and interplanetary magnetic field parameters at different phases of the solar cycle.

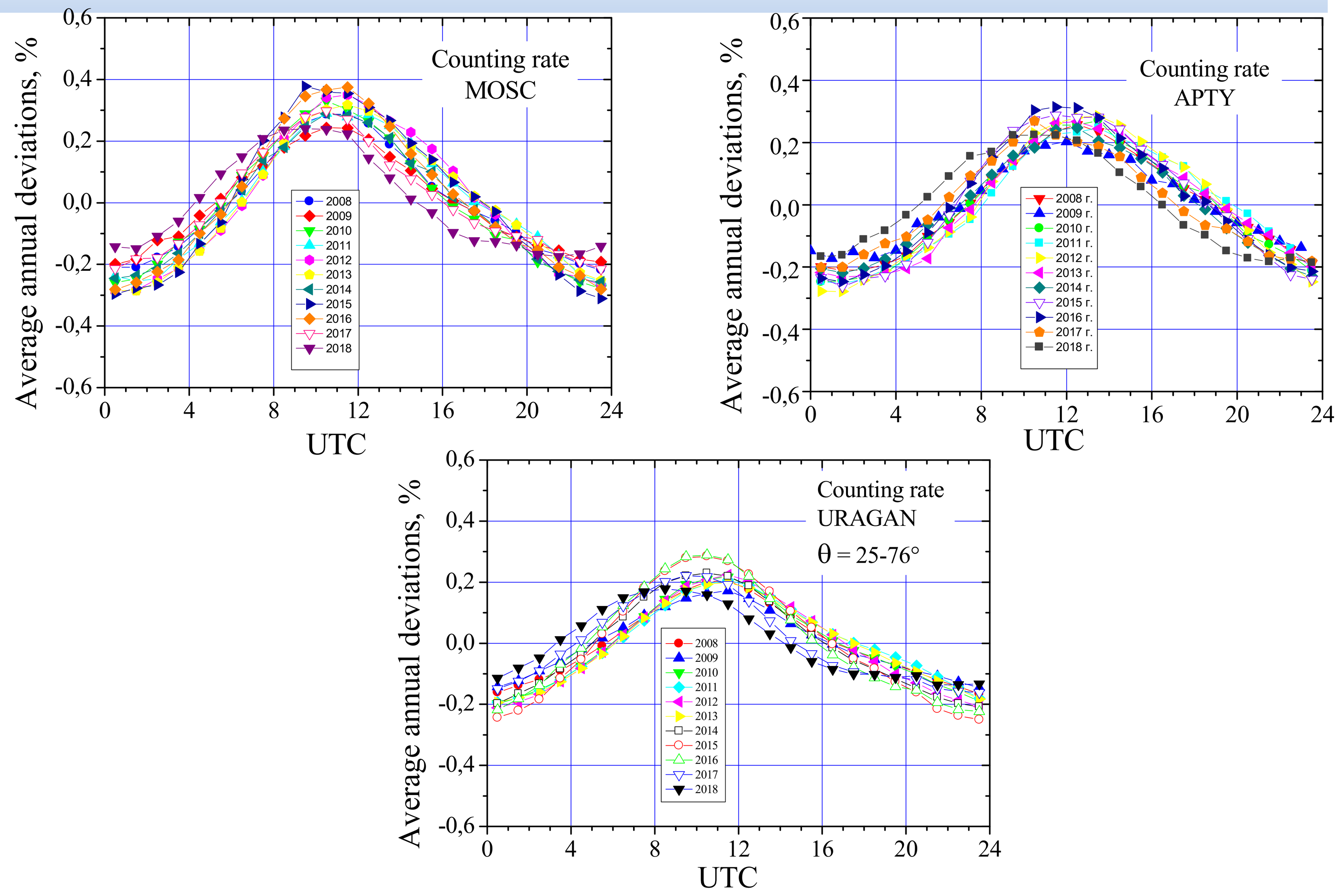


Histograms of correlation coefficients between MH URAGAN, NM Moscow and NM Apatity data and sunspot number, geomagnetic indexes at different phases of the solar cycle.



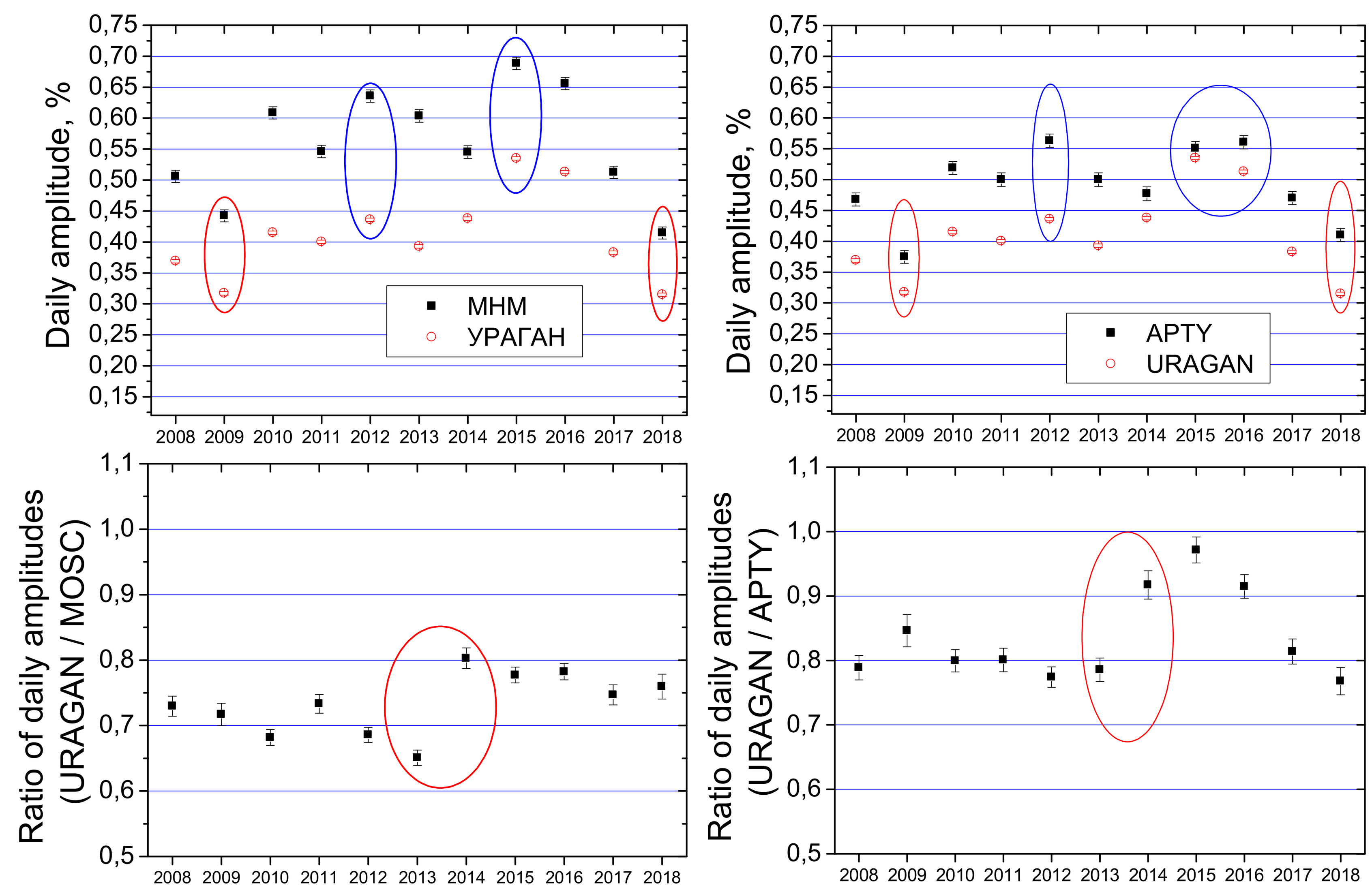
The analysis showed that the values of the correlation coefficients between the daily mean-square deviations of the counting rate of the detectors, averaged over months, increase with growth of solar activity. This is explained by the fact that the part of the primary cosmic rays, which contribute to the counting rate of MH URAGAN, is expected by a stronger influence of the interplanetary magnetic field (IMF fluctuations), as well as various processes associated with the growth of solar activity.

Average annual daily deviations of the detectors counting rate



The character of the changes in the counting rate of neutron monitors during the day is visually less distinct in years than for MH URAGAN. In periods corresponding to the minimum of solar activity (2008–2009 and 2018), the behavior of the diurnal variation is comparable, similarly during periods of maximum (2013–2015). Thus, the both types of detectors are equally sensitive to changes in solar activity, despite the higher particle energies recorded by MH URAGAN.

Daily amplitude and ratio of daily amplitudes of the detectors counting rate



In general, over the considered period, the ratio of daily ranges of the average annual deviations of the counting rate of the detectors is in the range of 65-80% (for MH URAGAN and NM Moscow) and 76-97% (for MH URAGAN and NM Apatity). However, the zone in circles in the period from 2013 to 2014 attracts attention, a sharp jump is most likely due to the change of the magnetic poles of the Sun that occurred during this time period.

Conclusion

A correlation analysis of variations in the muon hodoscope URAGAN and neutron monitors counting rate showed that the highest values of the correlation coefficients were observed when considering the entire period, during the increase phase and decrease phase of the solar cycle in all detectors.

The values of the correlation coefficients between these detectors and the all parameters in the phases of the solar cycle minimum are significantly higher in the muon hodoscope URAGAN than in neutron monitors. An analysis of the average annual diurnal deviations of the detectors counting rate showed that the pattern of behavior of the daily variation is comparable and remains similar throughout the period under consideration. However, it will be possible to confirm this only if the statistics are extended for another eleven-year period of solar activity.

When analyzing the long-term variations in the counting rate of the detectors, the interrelation of the daily span of the average annual deviations of the counting rate of muon hodoscope URAGAN, neutron monitors Moscow and Apatity with the phases of the solar cycle was revealed.

The study of secondary cosmic rays variations in the muon flux and in the hadron flux using the daily standard deviation of data gives similar results and can be effective in studying the dynamic processes of the Sun-Earth system in regions of different energies.

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