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Investigation of the local anisotropy of cosmic ray muon flux during coronal mass ejections in 2007 – 2018

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Abstract

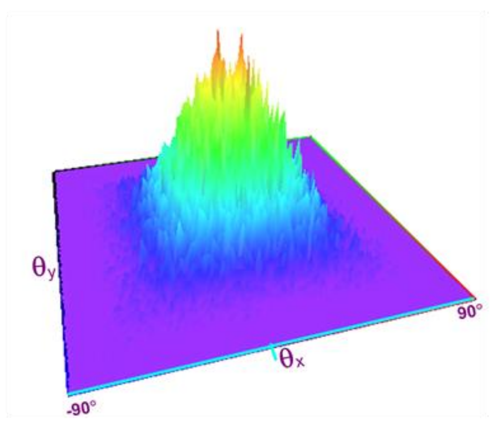
Coronal mass ejections are among the most powerful disturbances of the interplanetary space. They can influence the state of the near-Earth space, including magnetosphere of the Earth. In addition, such disturbances modulate the flux of cosmic ray and penetrate both the heliosphere and the Earth's magnetosphere. If the coronal ejection moves to our planet, it can lead to a magnetic storm and have negative consequences. In order to find an early alert of such events, it is necessary to investigate the flux of particles arriving to Earth and providing information about events in the heliosphere. The results of investigation of the anisotropy of the cosmic ray muon flux are presented. This flux was registered by the muon hodoscope URAGAN in the period from 2007 to 2018. It covers practically the entire 24th solar cycle. The influence of various coronal mass ejections at the muon flux registered in hodoscopic mode at different phases of solar activity is described.

Equipment and experimental data

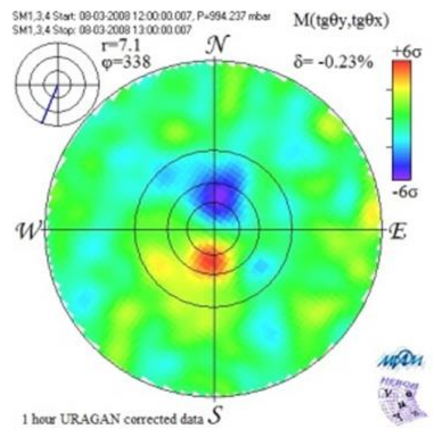
Muon hodoscope (MH) URAGAN is a large-aperture coordinate-tracking detector capable to detect muons in a wide range of zenith angles (0-80°). It is used to study characteristics of spatial-angular variations of muon flux. Hodoscope consists of four supermodels (SMs) with a total area of ~ 46 m^2 and has high spatial (~ 1 cm) and angular (~ 1°) accuracies. SM consists of eight layers of streamer tubes equipped with a two-coordinate system of external readout strips. Each registered muon with its reconstructed arrival direction is recorded in a two-dimensional angular matrix which represents an image of the upper hemisphere in the flux of muons with an 1-minute exposure.

To describe the angular distribution of the muon flux, a vector of local anisotropy (***A***) is used. This vector is a sum of unit vectors having directions of reconstructed tracks of individual muons normalized by their number. The local anisotropy vector indicates the average arrival direction of muons which is close to vertical. As a characteristic of deviation from the mean direction, the length of the horizontal projection r_h of the relative anisotropy vector is used. It describes the difference between the current value of the vector and the average anisotropy vector calculated over a long period of time. The r_h-vector magnitude is expressed in units of standard deviation.

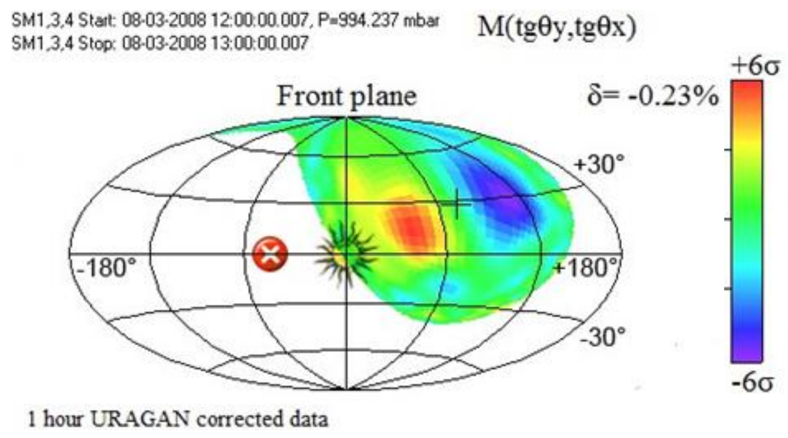
Data matrix



Muonograph

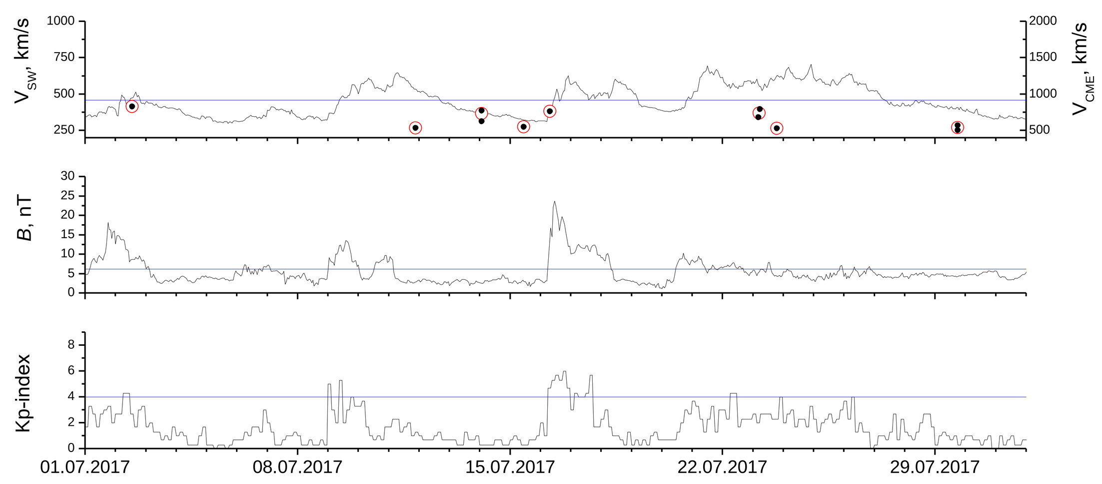


Muonograph in GSE-system

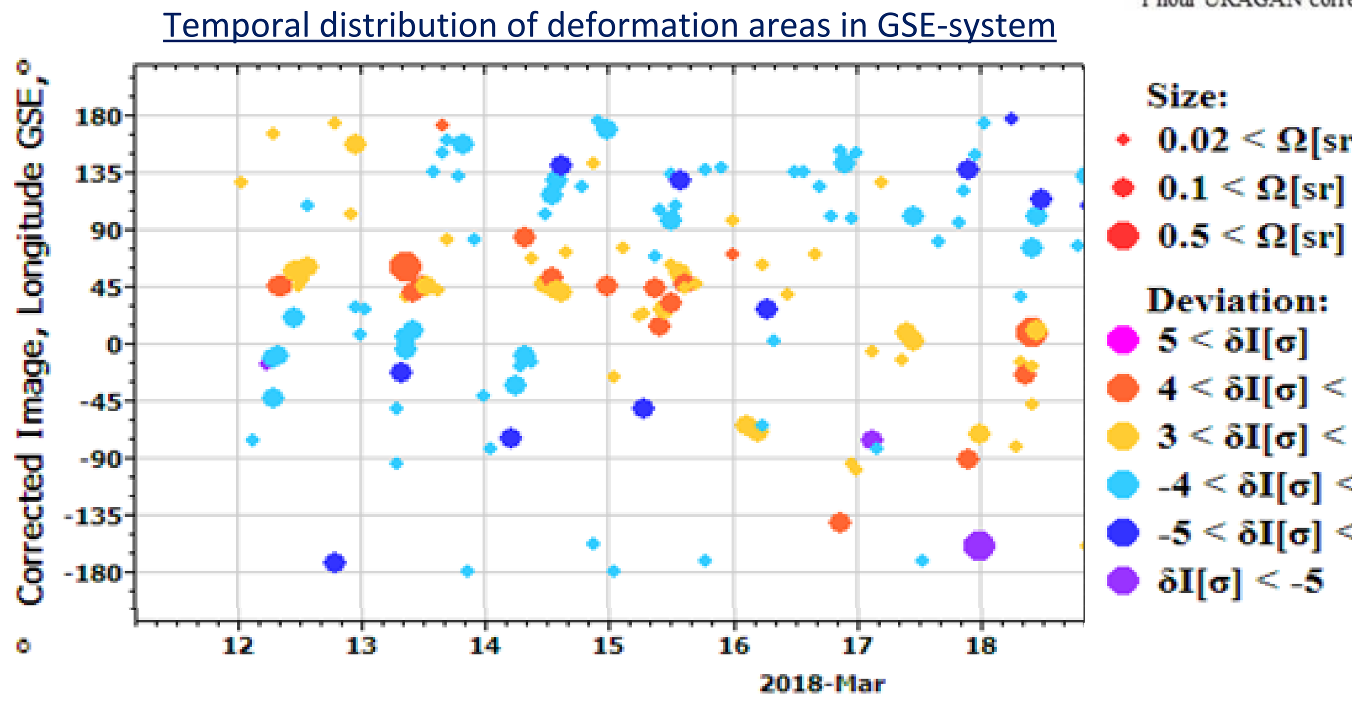


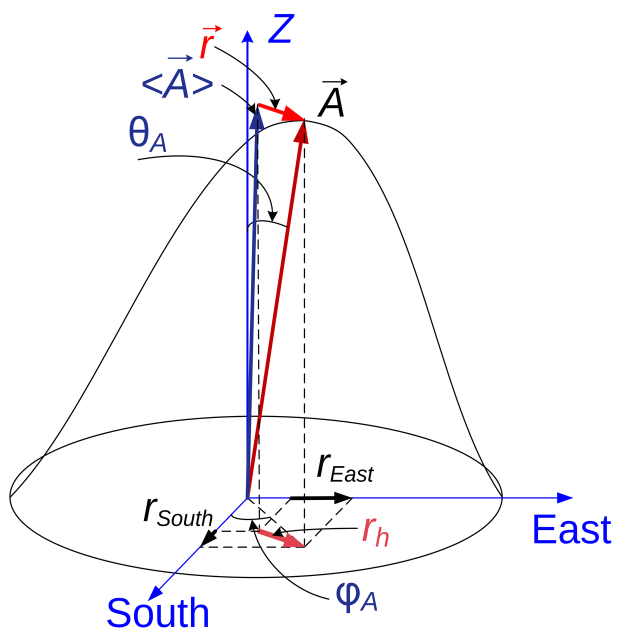
$$\vec{r} = \vec{A} - \langle \vec{A} \rangle$$

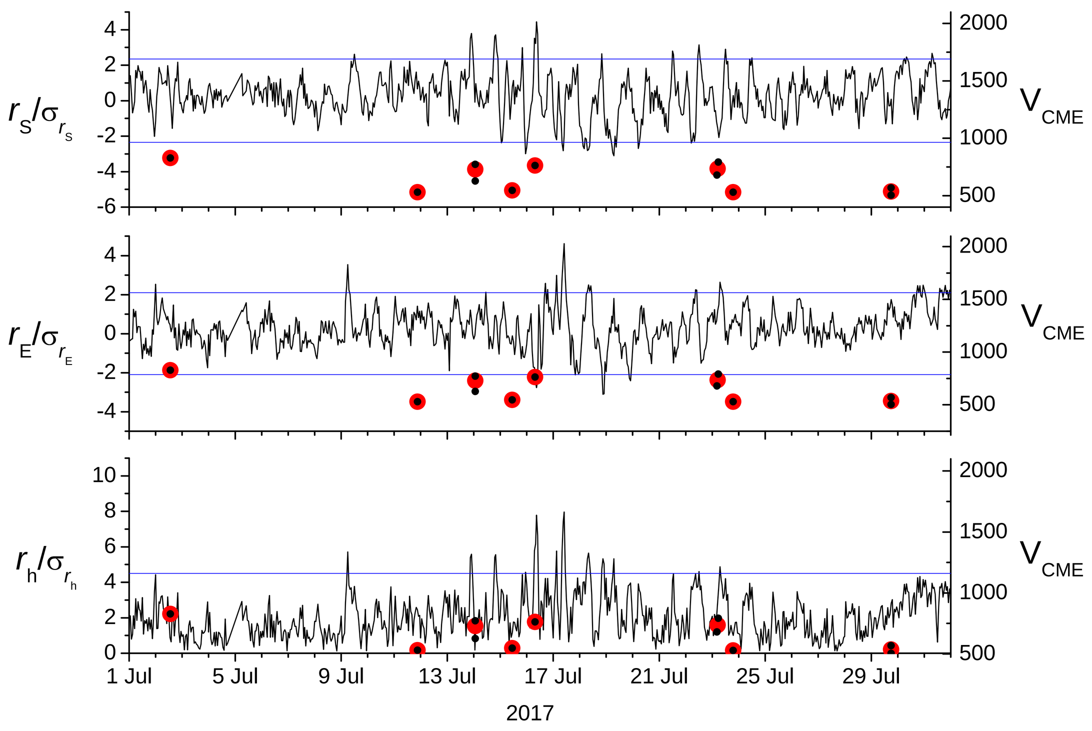
$$r_h = \sqrt{r_s^2 + r_e^2}$$



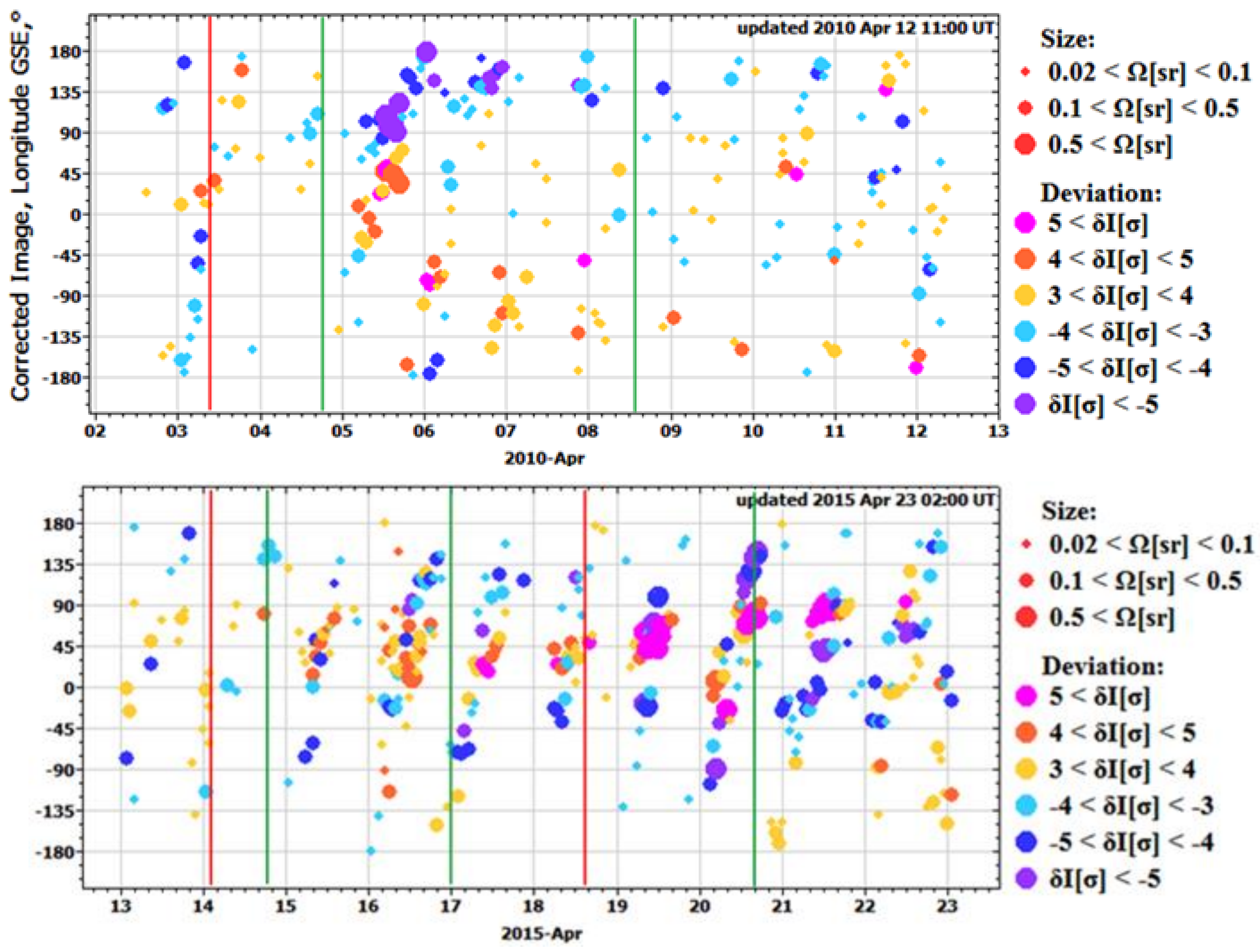
Temporal distribution of deformation areas in GSE-system

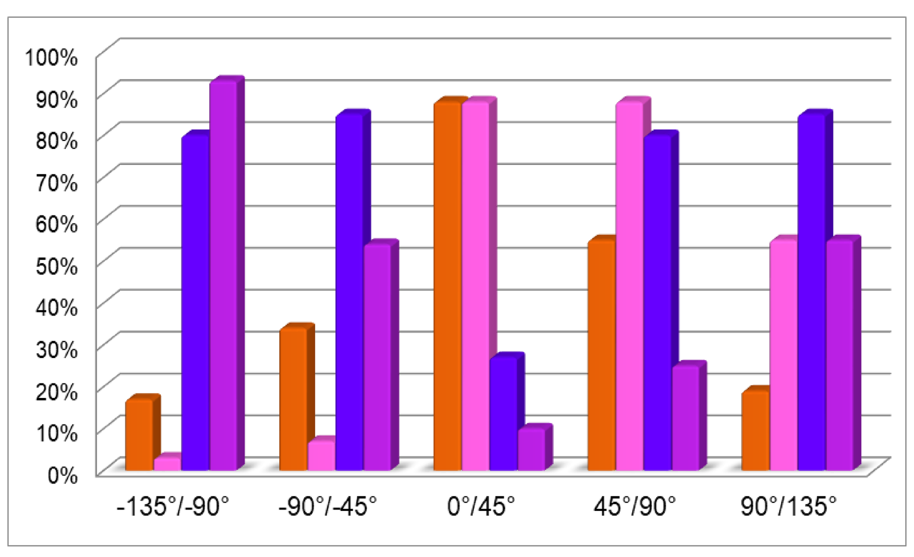


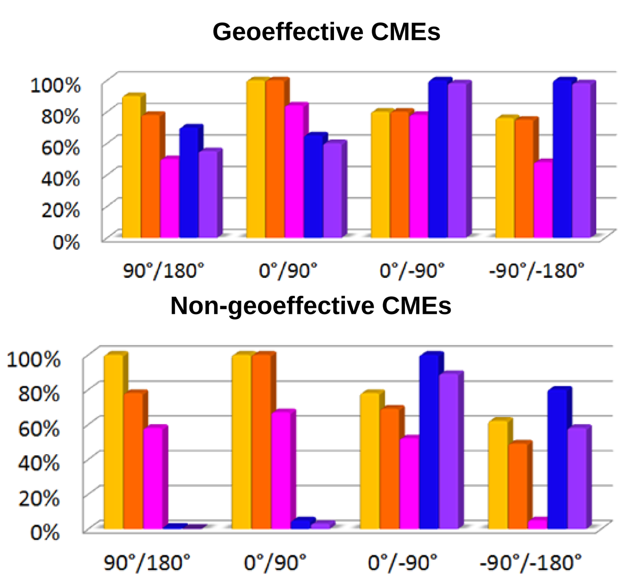




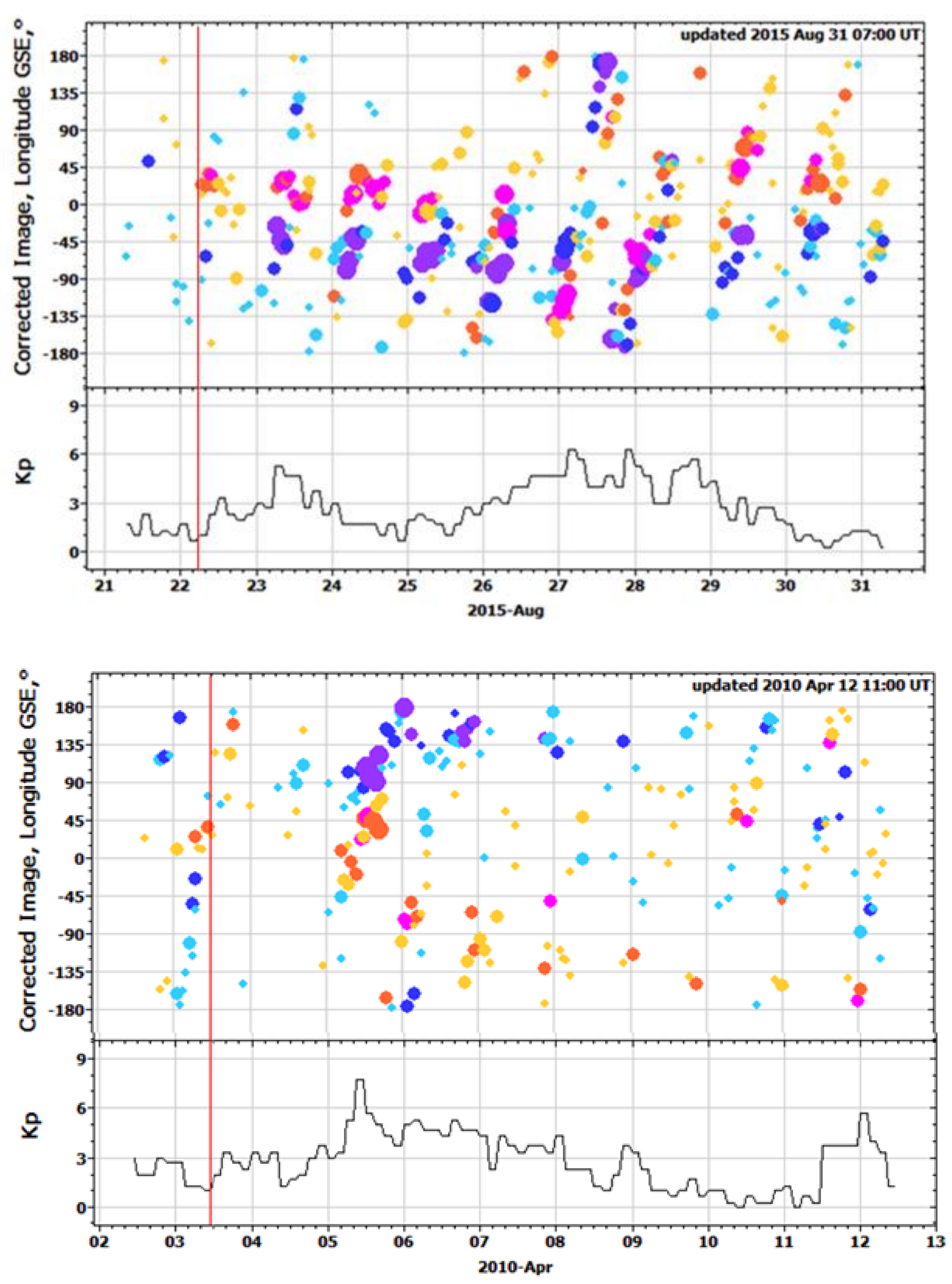
Analysis of cosmic ray muon flux anisotropy



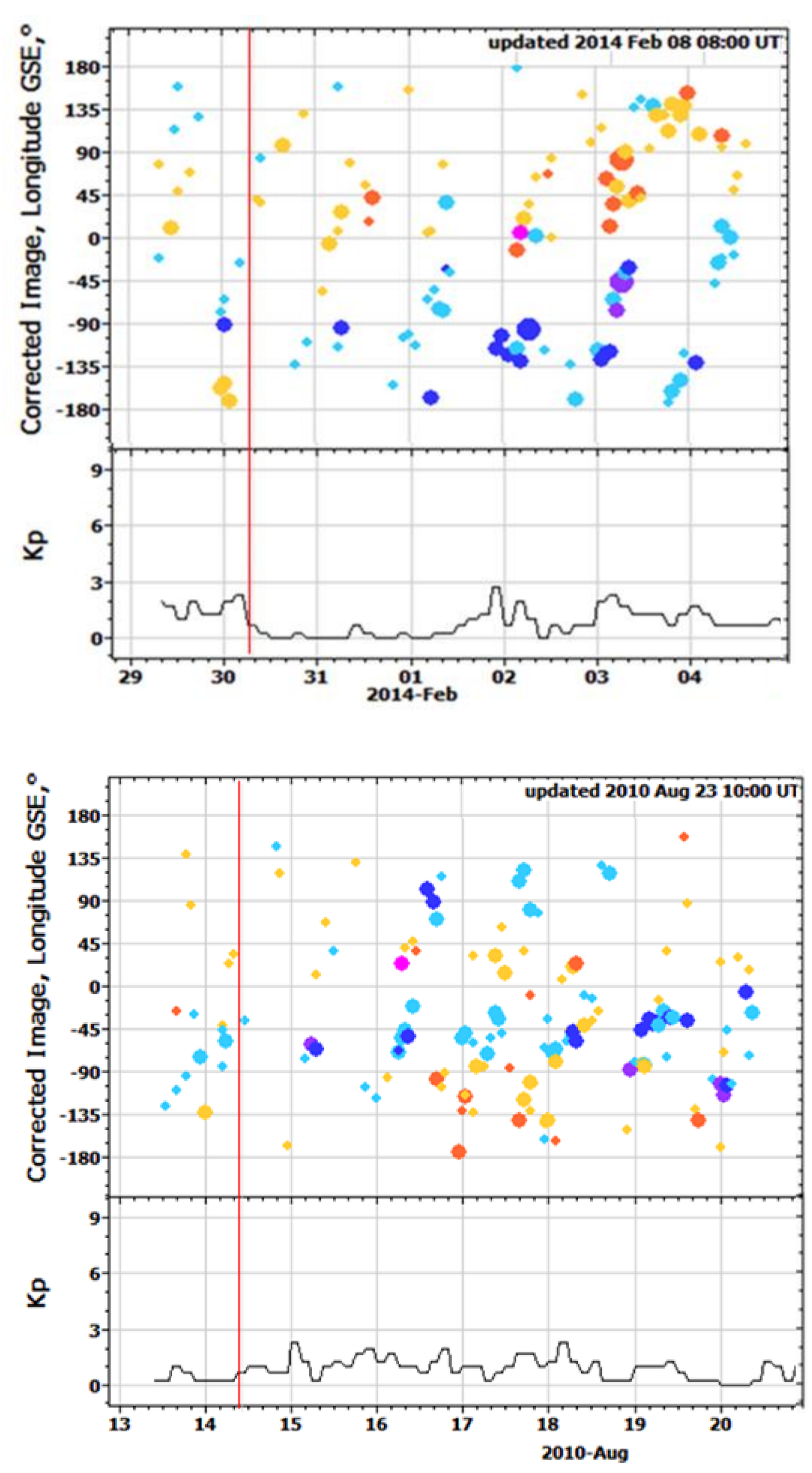




Response of MH to geoeffective CME during periods of high (top) and low (Bottom) solar activity



Response of MH to non-geoeffective CME during periods of high (top) and low (bottom) solar activity



Conclusion

294 coronal mass ejections occurred in the period from 2009 to 2018 were analyzed. The list of events was provided by the database of the Pushkov Institute of Terrestrial Magnetism, ionosphere and radio wave propagation (IZMIRAN). 178 (61% ± 3%) coronal ejections are classified as geoeffective and 116 (39% ± 3%) as non-geoeffective ones.

For the considered geoeffective events, the increase of the cosmic ray flux occurs mainly at the longitudes from 0° to 135°, as well as at the longitudes from 0° to -45°. The flux reduction occurs at longitudes from -45° to -180° and at longitudes from 135° to 180°. For geoeffective CMEs, the increase of the flux by 5σ is observed within 3-5 days after the ejection at the longitudes from 0° to 135°. The most frequent increase of the flux by values of 3-4σ occurs at the same longitude. Flux decrease by -5σ occurs at Longitudes from 0° to -180° and from 135° to 180°.

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