Search for heliospheric disturbances and Forbush decreases in time series of matrix data of the URAGAN hodoscope using decision rules for sequences of confidence intervals

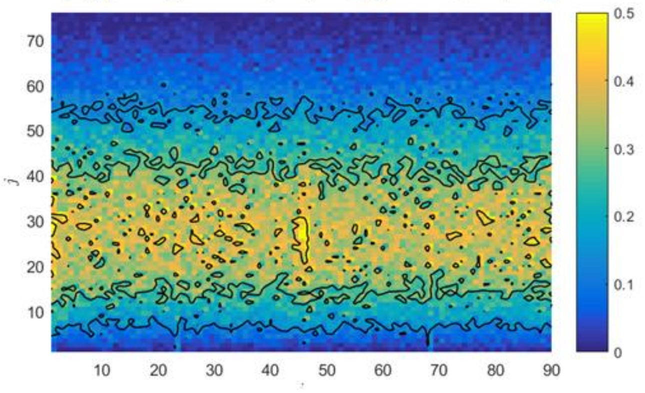
R.V. Sidorov[1], M.N. Dobrovolsky[1], V.G. Getmanov[1,3], V.E. Chinkin[1], N.V. Osetrova[2], E.I. Yakovleva[2], I.I. Yashin[1,3]

[1] Geophysical Center RAS, Russia
[2] National Research Nuclear University MEPhI, Russia
[3] Schmidt Institute of Physics of the Earth RAS, Russia
e-mail: v.chinkin@gcras.ru

Statement of the Problem

Initial experimental matrix data

$\boldsymbol{Y(i,j,kT), i = 1,\dots,N_1, j = 1,\dots,N_2}$



Input **muon flux intensity distribution functions** (MFIDF)

$$\boldsymbol{Y_0(i,j,kT)}$$

matrix linked to observation matrix using **hardware function** (HF)

$$\boldsymbol{A(i,j)} \Rightarrow ?$$

And **local anisotropy** (LA) function

$$\boldsymbol{\mu(i,j,Tk)} \Rightarrow ?$$

Set of LA

$$\Psi_a: (i,j) \in \Psi_a \subset \Psi_0 \qquad \Psi_a \Leftrightarrow \boldsymbol{\mu(i,j,Tk)}$$

As result

$$\boldsymbol{Y(i,j,kT) = A(i,j,kT)Y_0(i,j,kT)\mu(i,j,Tk)}$$

LA search method

The basis of the method is the rules for confidence intervals

$$\lambda^\circ = \lambda^\circ(i,j) = (1/k_f)\sum_{k=1}^{k_f} Y(i,j,Tk), k=1,\dots,k_f$$

Confidence level δ_γ confidence set $h_{mn} \le \lambda^\circ \le h_{mx}$

Reference and current confidence sets $h_{e,mn,mx} = \{\pm\delta_\gamma / 2\sqrt{k_f} + \sqrt{\lambda_e^\circ + \delta_\gamma^2 / 4k_f}\}^2, h_{n,mn}, h_{n,mx}$

Abnormality parameter $a_n = a(h_{e,mn}, h_{e,mx} h_{n,mn}, h_{n,mx})$ threshold a_0 making decisions $a_n \ge a_0$

Indicator matrix (IM): If $a_n(i,j) \ge a_0(i,j)$ then $I_n(i,j) = 1$ else $I_n(i,j) = 0$

IM Spatio-temporal filtering $I_n(i,j) \Rightarrow I_{n,\Phi1}(p,q) \Rightarrow I_{\Phi2}(p,q)$

Model test

$$S_{n,a} = \sum_{i,j\in\Psi_a} I_n(i,j) \qquad S_{n0} = \sum_{i,j\in(\Psi_0-\Psi_a)} I_n(i,j)$$

$$S_{En0} = \sum_{i,j\in(\Psi_0-\Psi_a)} e(i,j) \qquad S_{En,a} = \sum_{i,j\in\Psi_a} e(i,j)$$

$$d_{n,a} = S_{n,a} / S_{En,a} \quad d_{n,0} = S_{n,0} / S_{En,0}$$

Recognition rate

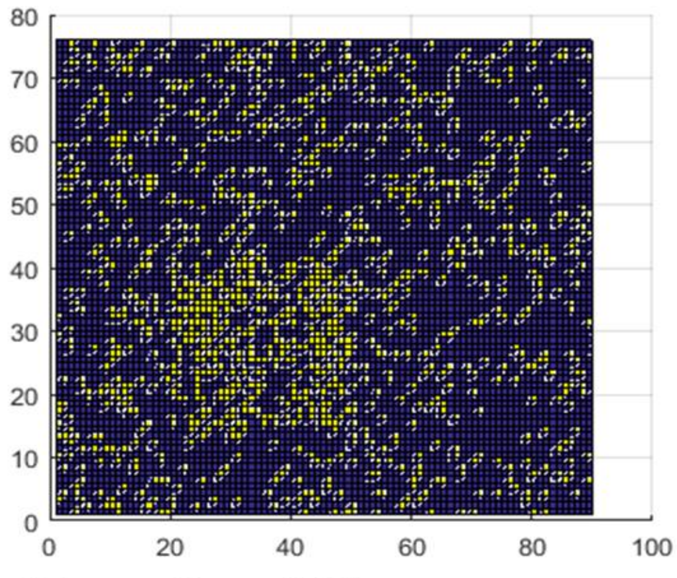
$$\boldsymbol{\varepsilon_{n,a,0} = d_{n,a}/d_{n,0}}$$

Models $A_M(i,j)\; Y_M(i,j,Tk)\; Y_{0M}(i,j,Tk)$

$$i_{a1} \le i \le i_{a2} \;\; j_{a1} \le j \le j_{a2} \;\; I_n(i,j)$$

Forbush decrease model $\mu(i,j,Tk) = 1 - \delta\mu$

$$i_{a1} \le i \le i_{a2} \quad j_{a1} \le j \le j_{a2} \quad I_n(i,j)$$



2D image of the model MI

$\delta\mu = 0.06 \quad \varepsilon_{1,a0}(\delta\mu) = 1.69$

Experimental test

Spatio-temporal filtering of MI

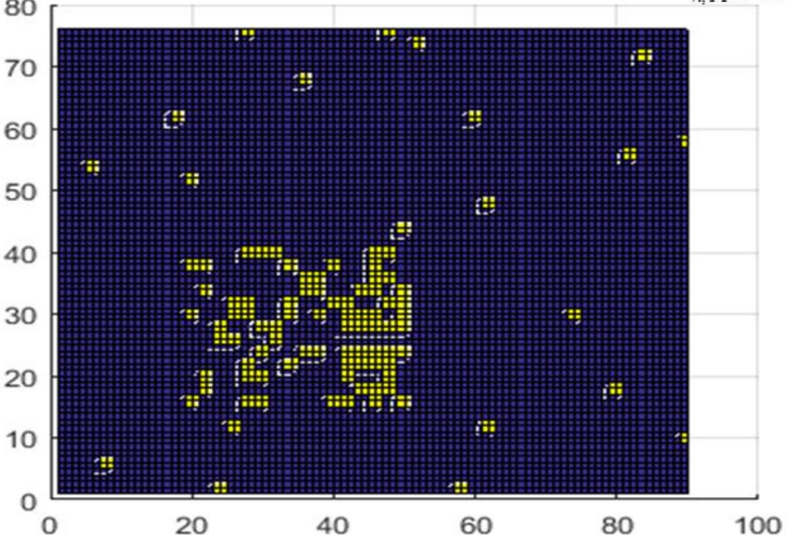
$$1 + (p-1)\Delta N_1 \le i \le p\Delta N_1 \;\; p = 1,..,\overline{p}$$

$$1 + (q-1)\Delta N_2 \le j \le q\Delta N_2 \; q = 1,..,\overline{q} \quad n=1$$

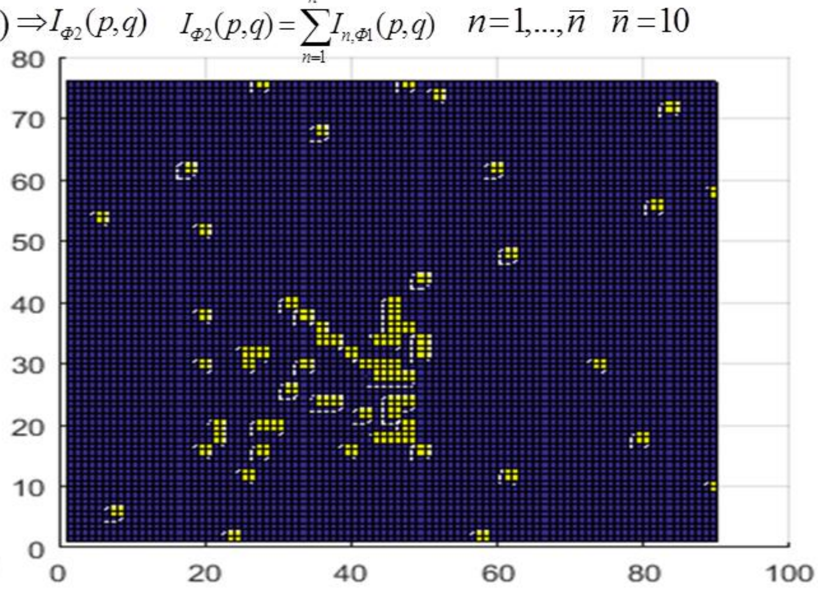
$$I_n(i,j) \Rightarrow I_{n,\Phi1}(p,q)$$

$$\Delta N_1 = \Delta N_2 = 2 \;\; \overline{p} = 45, \overline{q} = 38$$

$$I_{n,\Phi1}(p,q) \Rightarrow I_{\Phi2}(p,q) \quad I_{\Phi2}(p,q) = \sum_{n=1}^{\overline{n}} I_{n,\Phi1}(p,q) \quad n = 1,\dots,\overline{n} \;\; \overline{n} = 10$$



2D image of experimental IM $\delta\mu = 0.05 \; \varepsilon_{1,a0}(\delta\mu) = 25.62$



2D image of experimental IM $\delta\mu = 0.04 \quad \varepsilon_{1,a0}(\delta\mu) = 14.76$