# Recurrence of galactic cosmic rays - diffusion and convection effects

Agnieszka Gil[1,2], Renata Modzelewska[1]

(1) Siedlce University, Poland; (2) Space Research Centre, Polish Academy of Sciences, Poland
gila@uph.edu.pl

ABSTRACT: Corotating interaction regions affecting galactic cosmic rays are the origin of the 27-day GCR recurrence detected by neutron monitors on the ground, and in space, by spacecraft. The GCR recurrent variation during the solar cycles 24 and 25 based on the 3-d Parker transport equation is the subject of our studies. We investigate convection and diffusion effects on the structure of this variability. We present that the most realistic description of the heliospheric GCR transport gives combination of the temporal changes of heliospheric magnetic field strength and solar wind velocity incorporated into the mathematical modeling.

http://ibex.swri.edu/
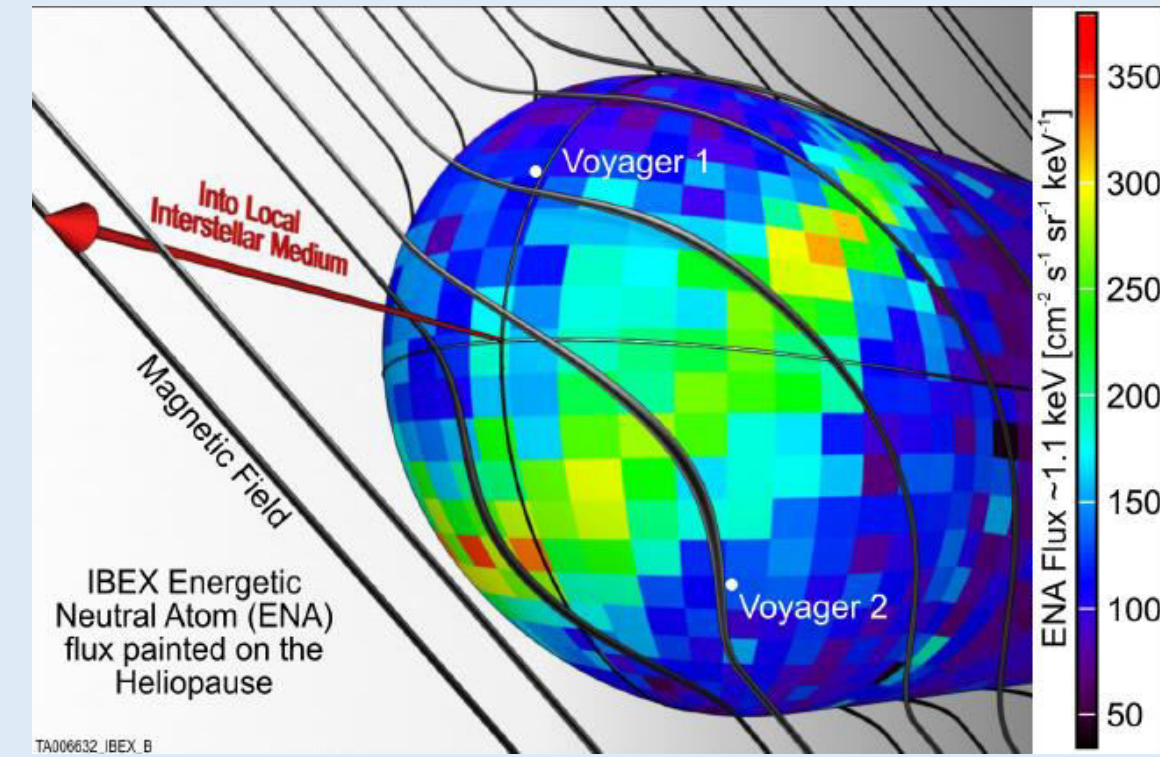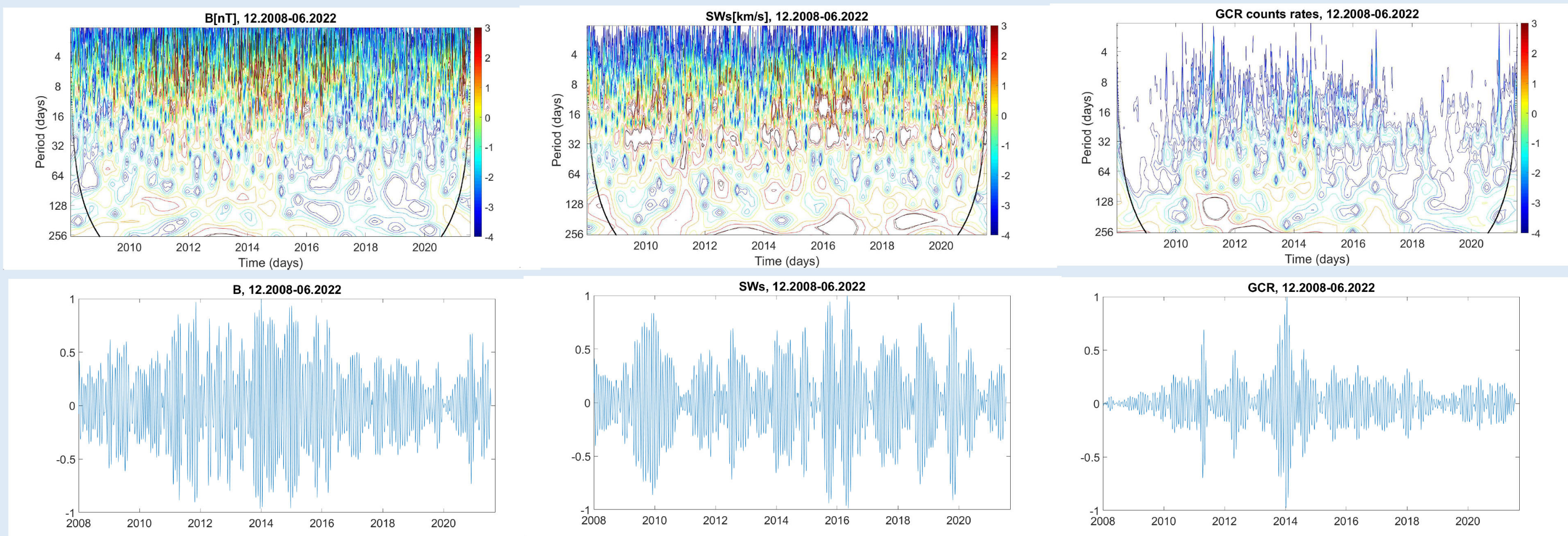
Wavelet analysis of daily data of (a) heliospheric magnetic field strength B, (b) solar wind speed, c) Oulu neutron monitor count rates, during SCs 24-25

Bandpass filtered daily data of (a) heliospheric magnetic field strength B, (b) solar wind speed, c) Oulu neutron monitor count rates, during SCs 24-25, with 27±5 days being the boundaries of this band. On the vertical axes is the bandpass filter

Transport equation

Parker, 1965

$$\nabla_i \left(\kappa_{ij} \nabla_j f \right) - \nabla_i \left(U_i f \right) + \frac{1}{3R^2} \frac{\partial \left(f R^3 \right)}{\partial R} \left(\nabla_i U_i \right) = \frac{\partial f}{\partial t}$$

$$\psi = arctg \frac{-B_\varphi}{B_r} = arctg \frac{\Omega r \sin\theta}{U}$$

$$\delta = arctg \frac{B_\theta}{B_r}$$

$$\alpha = \frac{\kappa_\perp}{\kappa_\parallel} \qquad \alpha_1 = \frac{\kappa_d}{\kappa_\parallel}$$

Diffusion tensor

$$\kappa_{ij} = \begin{pmatrix} \kappa_{11} & \kappa_{12} & \kappa_{13} \\ \kappa_{21} & \kappa_{22} & \kappa_{23} \\ \kappa_{31} & \kappa_{32} & \kappa_{33} \end{pmatrix}$$

$$\kappa_{21} = \kappa_\parallel \left[\sin\delta \cos\delta \cos^2\psi (1-\alpha) + \alpha_1 \sin\psi \right]$$
$$\kappa_{22} = \kappa_\parallel \left[\sin^2\delta \cos^2\psi + \alpha \left(\sin^2\delta \sin^2\psi + \cos^2\delta \right) \right]$$
$$\kappa_{23} = \kappa_\parallel \left[\sin\delta \sin\psi \cos\psi (\alpha-1) + \alpha_1 \cos\delta \cos\psi \right]$$

$$\kappa_{11} = \kappa_\parallel \left[\cos^2\delta \cos^2\psi + \alpha \left(\cos^2\delta \sin^2\psi + \sin^2\delta \right) \right]$$
$$\kappa_{12} = \kappa_\parallel \left[\sin\delta \cos\delta \cos^2\psi (1-\alpha) - \alpha_1 \sin\psi \right]$$
$$\kappa_{13} = \kappa_\parallel \left[\sin\psi \cos\delta \cos\psi (\alpha-1) - \alpha_1 \sin\delta \cos\psi \right]$$

$$\kappa_{31} = \kappa_\parallel \left[\cos\delta \sin\psi \cos\psi (\alpha-1) + \alpha_1 \sin\delta \cos\psi \right]$$
$$\kappa_{32} = \kappa_\parallel \left[\sin\delta \sin\psi \cos\psi (\alpha-1) - \alpha_1 \cos\delta \cos\psi \right]$$
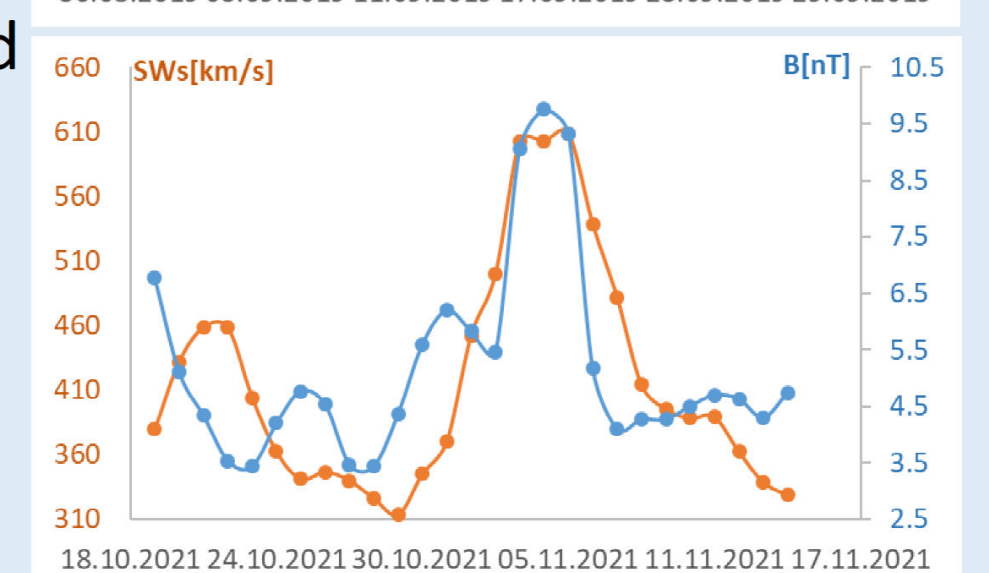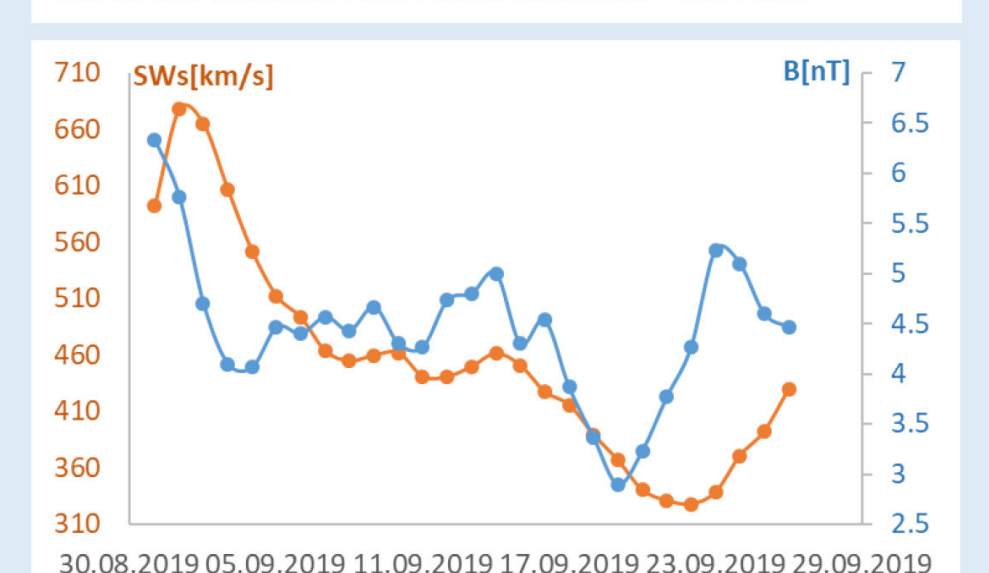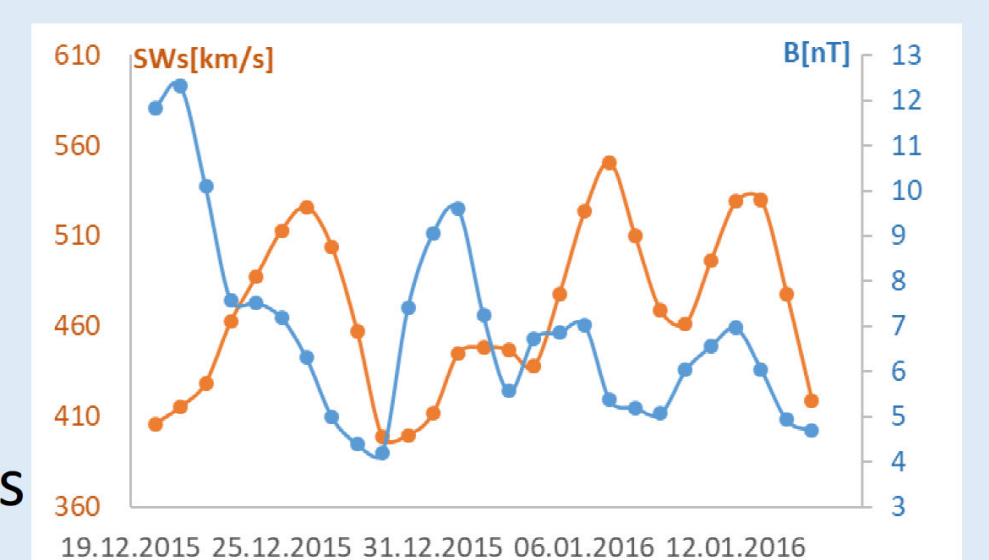$$\kappa_{33} = \kappa_\parallel \left[\sin^2\psi + \alpha \cos^2\psi \right]$$

[Alania 1978; 2002]

Similar form is presented by Burger et al. (2008), but with an angle defined as:

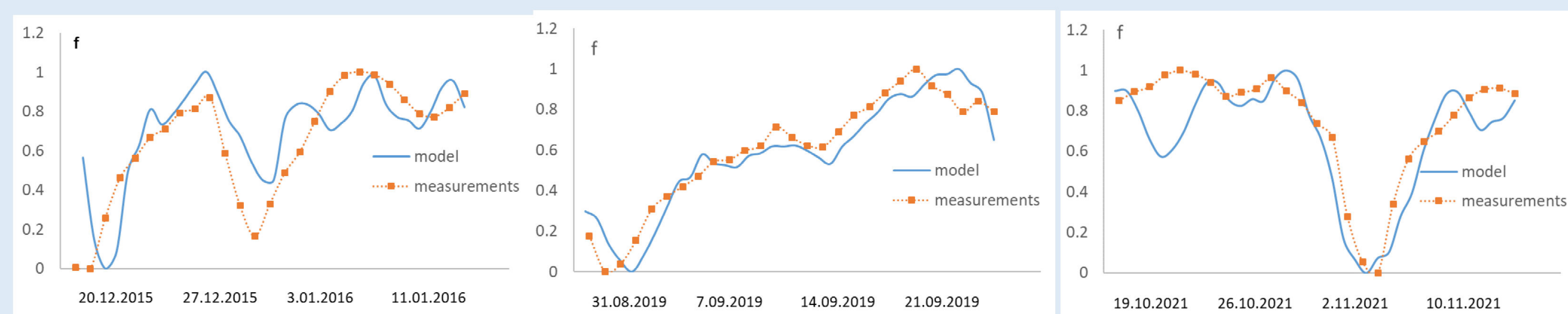$$\psi = arctg \frac{-B_\varphi}{\sqrt{B_r^2 + B_\theta^2}}$$

In situ measurements as an input for the GCR modeling during solar rotations: a) 20.12.2015-15.01.2016 (only B included in the modeling), b) 31.08-26.09.2019 (only SWs included in the modeling), c) 19.10-14.11.2021 (both, B and SWs included in the modeling)

Modelling Results

Summary:

Comparison of the experimental data (the GCR counts by Oulu neutron monitor, orange) with modeling results (relative density of the GCR particles, solid blue line) with taken into account heliolongitudinal asymmetry of: a) HMF strength during 20.12.2015-15.01.2016, b) SW velocity during 31.08-26.09.2019, c) both, during 19.10-14.11.2021

A stable 27-day recurrence of the galactic cosmic rays appeared regularly due to long-leaving coronal holes creating corotating interaction regions in the Earth vicinity during the solar cycles 24-25. Solutions of the Parker's transport equation show that the heliolongitudinal asymmetry of the solar wind velocity and HMF have to be taken into account.