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# Interactive service of geoeffective phenomena

M. Sapraliev, O. Mikhalyaev, L. Kharldaev, and B. Mikhalyaev

Kalmyk State University named after B. B. Gorodovikov, Elista, 358000 Russia

**Abstract.** This work attempts to develop an online service for the specialists and amateurs interested in the problem of space weather forecasting. It is based on the scheme of the existing "Observe the Sun" service developed by the employees of the Kislovodsk Mountain Astronomical Station (KMAS) of the Central Astronomical Observatory of the Russian Academy of Sciences for rapid demonstration of current solar activity phenomena. At the first stage, we consider one of the geoeffective factors, the solar wind, for calculation of which there exist generally accepted models. The initial data are the observations of the photospheric magnetic field, regularly carried out at the KMAS. The coronal field at the source surface and the velocity field are calculated using the well-known potential field source surface (PFSS) and Wang–Sheeley–Arge (WSA) models. At the next stage, we plan to simulate the solar wind flow at a distance of up to 1 AU and evaluate its geoeffectiveness.

**Keywords:** Sun: solar wind, corona, magnetic fields

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## 1 Introduction

A promising direction in the development of solar and space weather services is the creation of various online resources designed to demonstrate active solar phenomena in real time. An example of such a domestic resource is the interactive three-dimensional synoptic map "Observe the Sun,"[1] created on the basis of observational data from the Kislovodsk Mountain Astronomical Station (KMAS) of the Central Astronomical Observatory of the Russian Academy of Sciences. There one can find, in particular, information about spots, flocculi, and prominences. Concerning the application of space weather forecasting, it is natural to create a similar map containing the information about geoeffective phenomena. This is a difficult task, since confident prediction of active phenomena such as flares and coronal mass ejections is an intractable problem to date. However, it is possible to obtaine some results such as the prediction of high-speed plasma flows. There is a developed Wang–Sheeley–Arge (WSA) method for calculating the solar wind velocity field based on the structure of the coronal magnetic field. We made an attempt to construct an interactive map using the KMAS photospheric magnetic field observations. They allow one to systematically evaluate the geoeffectiveness of high-speed solar plasma flows within the frameworks of the existing models. The KMAS has been recording coronal mass ejections using the Solar Telescope for Operative Prediction (STOP).They can serve as a basis for expanding the capabilities of the interactive map.

## 2 Magnetic field

The main input data are the distributions of the magnetic induction radial component $B_r$ in the Sun's photosphere, represented in FITS files. We download these magnetograms from the KMAS website.[2] In addition, the magnetograms from the Global Oscillation Network Group (GONG) observatories are downloaded. An example of the images obtained from these FITS files is shown in Fig. 1.

A common method for modeling magnetic fields in the solar and stellar atmospheres is the potential field source surface (PFSS) model (Altschuler & Newkirk 1969; Mackay & Yeates 1999). The PFSS equations assume that there is zero electric current in the region of interest, which leads to the equations:

$$\nabla \cdot \mathbf{B} = 0, \quad \nabla \times \mathbf{B} = 0. \tag{1}$$

The system of equations (1) is solved in a spherical shell between the surface of the star and a tunable outer radius called the "source surface." The $B_r$ boundary

[1] https://observethesun.com
[2] https://solarstation.ru

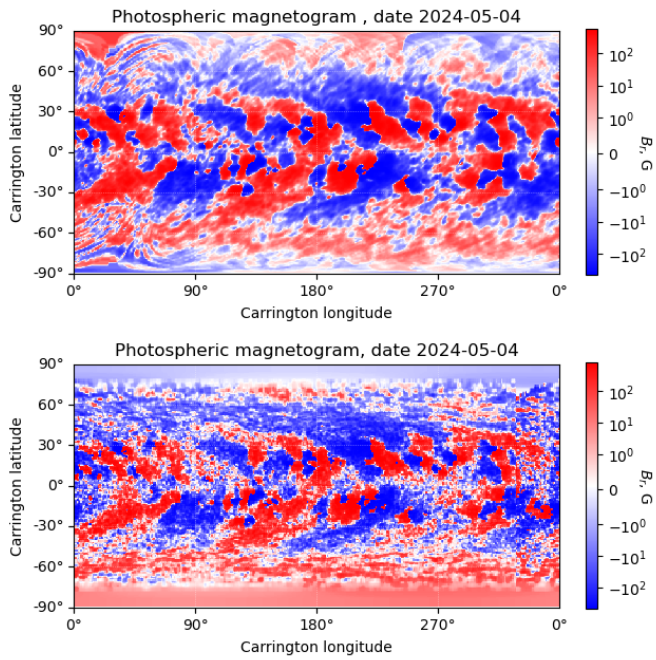


**Fig. 1.** The STOP (top) and GONG (bottom) distributions of $B_r$ in the photosphere on 04.05.2024.

conditions are set at the inner boundary, and the condition of a purely radial magnetic field is superimposed at the source surface, which mimics the effect of fleeing stellar wind. The `pfsspy`[3] software is a well-documented library with tested functionality for performing the PFSS extrapolation. We computed the PFSS model and obtained the source surface layer. An example of the resulting image is shown in Fig. 2.

Wang & Sheeley (1990) introduced the parameter $f_s$ characterizing the divergence of the force lines. The magnetic fields at the source surface ($B_\mathrm{S}$) and at the photospheric surface ($B_\mathrm{P}$) are used in the calculation of this parameter. Arge & Pizzo (2000) obtained a correlation coefficient of 0.39 between the wind speed and the divergence parameter $f_s$. These calculations has formed the basis of the widely used and cited WSA method (Arge & Pizzo 2000; Argeet al. 2004).

Belovet al. (2006) used the following velocity model:

$$V_\mathrm{SW}(t) = (393.2 \pm 7.6) + (192.9 \pm 40.0)\, W_S + (3.94 \pm 0.35)\, |B_\mathrm{S}| - (0.019 \pm 0.004)\, |B_\mathrm{P}|, \quad (2)$$

where

$$W_\mathrm{S} = 6.25\, (B_\mathrm{S}/B_\mathrm{P})^2. \quad (3)$$

[3] https://github.com/dstansby/pfsspy/tree/main

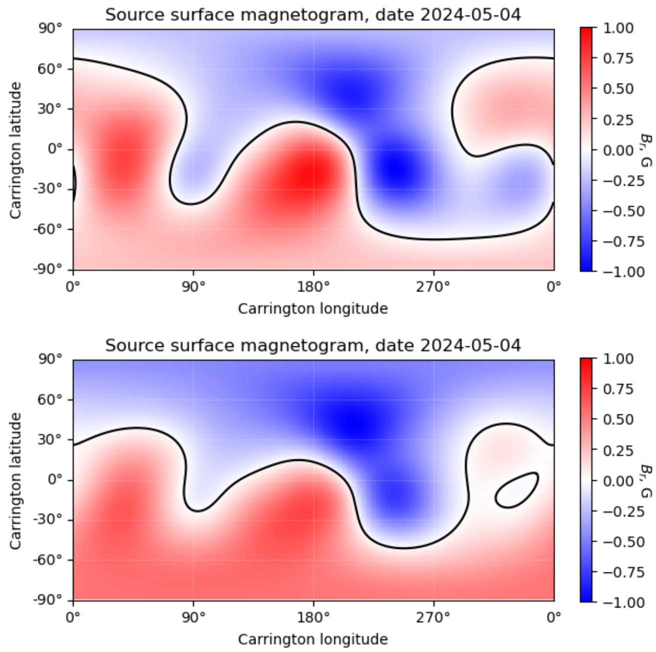


**Fig. 2.** The STOP (top) and GONG (bottom) distributions of $B_r$ on the source surface on 04.05.2024.

Using this model, we obtained images of the solar wind speed distribution on the source surface. An example of the constructed image is shown in Fig. 3.

## 3 Interactive three-dimensional map

A three-dimensional model of the coronal magnetic field is implemented on the laboratory website. Using the `pfsspy` module, magnetic field streamlines are constructed. The seeds for line tracing are formed with a sufficiently small step, which allows us to achieve a resolution of $30'$. At the ends of the open magnetic lines lying on the photosphere, we form a set of points. This set is divided by the DBSCAN[4] algorithm into separate clusters which correspond to coronal holes. We find the parameters of the coronal holes such as area, magnetic flux, mean and maximum magnetic induction. In addition, the median is calculated from the set of cluster points to determine the center of the coronal hole. Its coordinates together with the date forms a unique identifier: the Solar Object Locator (SOL). Figure 4 demonstrates a resulting coronal hole. Similar visualization can be seen in Berezin & Tlatov (2022). The interactivity

[4] https://scikit-learn.org/stable/modules/generated/sklearn.cluster.DBSCAN.html

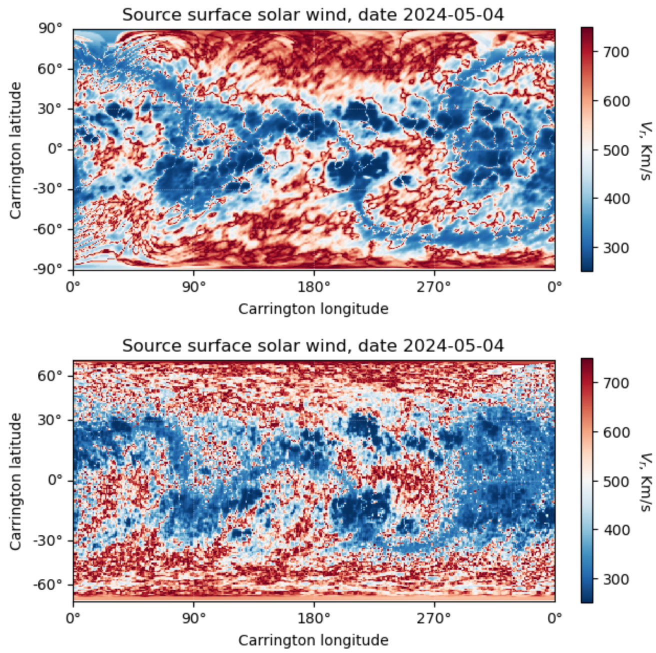


**Fig. 3.** The STOP (top) and GONG (bottom) distributions of $V_r$ on the source surface on 04.05.2024.

of the model provides the possibility to change the viewing angle by mouse click and drag and the image size by scrolling the mouse wheel. A calendar is implemented on top, where one can select a desired date. The "hide details" button removes the coronal hole legend, leaving only the unique identifier.

## 4 Discussion

At this moment, we reconstruct the magnetic field of the solar corona in the potential approximation, assuming that the field on the photosphere is directed along the radius. Of course, a magnetic field with a horizontal component, as well as a nonpotential magnetic field, may give a more accurate picture. We can move to such an approach as soon as satisfactory theoretical models are available. The same is true for the velocity field at the source surface, for the calculation of which different approaches are possible. Considering the coronal hole parameters such as the total magnetic flux or the mean and maximum magnetic induction, we believe that they may be relevant for the development of new promising models of the velocity field.

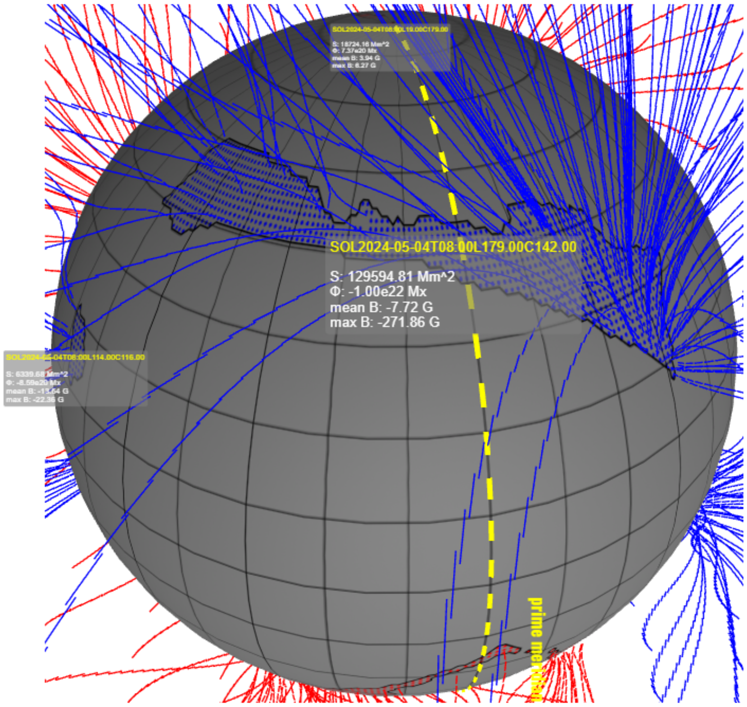


**Fig. 4.** A coronal hole image on 04.05.2024.

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