Современная наука и инновации.
2023. № 4 (44). С. 56-63.
Modern Science and Innovations.
2023; 4 (44):56-63.

ТЕХНИЧЕСКИЕ НАУКИ / TECHNICAL SCIENCE

ИНФОРМАТИКА, ВЫЧИСЛИТЕЛЬНАЯ ТЕХНИКА И УПРАВЛЕНИЕ / INFORMATICS, COMPUTER ENGINEERING AND MANAGEMENT

Научная статья / Original article

УДК 533.9.01/ 533.9-116/ 533.951
https://doi.org/10.37493/2307-910X.2023.4.6

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Проект Sun Gazers

Project Sun Gazers

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Аннотация. *Актуальной задачей современной солнечной физики является прогноз геоэффективных явлений, к которым относят быстрый солнечный ветер, вспышки и выбросы корональной плазмы, вызывающие возмущения геомагнитного поля в околоземном космическом пространстве. Некоторые из этих возмущений хорошо известны как магнитные бури. Целью проекта Sun Gazers является создание базы данных, трехмерная визуализация и прогноз описанных выше событий. Данная база позволит сопоставлять начальные и граничные условия для МГД-моделирования. Визуализация необходима для наглядного сравнения и анализа событий указанной базы данных.*

Ключевые слова: геоэффективные явления, корональные дыры, линии коронального магнитного поля, 3D-визуализация

Для цитирования: *Михаляев О. Н., Сапралиев М. Е., Манкаева Г. А., Велегурин Т. В., Харлдаев Л. Н. Проект Sun Gazers // Современная наука и инновации. 2023. № 4 (44). С. 56-63.* https://doi.org/10.37493/2307-910X.2023.4.6

Финансирование: *результаты лабораторных исследований получены в ходе выполнения гранта Министерства науки и высшего образования Российской Федерации № 075-03-2023-121/3 «Разработка новых наблюдательных и теоретических подходов в прогнозе космической погоды по данным наземных наблюдений».*

Abstract. *An actual task of modern solar physics is the prediction of geoeffective phenomena, which include the fast solar wind, flares, and coronal plasma ejections that cause perturbations of the geomagnetic field in near-Earth space. Some of these disturbances are well known as magnetic storms. The goal of the Sun Gazers project is to create a database, three-dimensional visualization and forecast of the events described above. This database will allow us to match initial and boundary conditions for MHD-modeling. Visualization is necessary for visual comparison and analysis of the events of the above database.*

Keywords: geoeffective phenomena, coronal holes, coronal magnetic field lines, 3D visualization

For citation: *Mikhalyaev ON, Sapraliev ME, Mankaeva GA, Velegurin TV, Kharldaev LN. Project Sun Gazers. Modern Science and Innovations. 2023;4(44):56-63. (In Russ.).* *https://doi.org/10.37493/2307-910X.2023.4.6*

Funding: *the results of laboratory studies were obtained during the implementation of the grant of the Ministry of Science and Higher Education of the Russian Federation No. 075-03-2023-121/3 "Development of new observational and theoretical approaches in space weather forecasting based on ground-based observations".*

Introduction. In modern realities, work activities are often reflected on the website, which gives every Internet user free access to research results. Space agencies and various organizations specializing in space weather forecasting are no exception and also have their own websites. For example, the Kislovodsk project "Observe the Sun" [1] implemented 3D interactive visualization of various solar events, including coronal holes. However, their model lacks the coronal magnetic field lines taken into account in the MHD simulation. Most of the remaining publications are primarily 2D images of the Sun. At the same time, a remarkable map of the magnetic field on the photosphere with images of coronal magnetic field lines and contours of coronal holes is available on the website of the Kislovodsk State Autonomous Station [2]. Demonstrations of coronal holes have been implemented on many sites, for example, on the site of the Lockheed Martin Solar and Astrophysical Laboratory [3]. Visualization of coronal magnetic field lines is available on the website of the GONG (Global Oscillation Network Group) project [4].

The availability of the listed solar data in the public domain allowed us to implement our project. Data on coronal holes, namely the coordinates in the HGS (Heliographic Stonyhurst) system of boundary points and lifetimes are downloaded from the HEK database (Heliophysics Events knowledgebase). The initial data for the coronal magnetic field lines are synoptic maps of the magnetic field of the Kislovodsk GAS.

Materials and research methods. Sun Project Data Gazers for constructing coronal hole boundaries are downloaded from HEK, processed by the Spatial algorithm Possibilistic Clustering Algorithm (SPoCA) [6] based on AIA / SDO (Solar) images Dynamics Observatory) 193Å. Coronal magnetic field lines using the potential field source surface model (PFSS) are calculated on the server of the Solar Physics laboratory using the PFSS software package [7].

The Spatial Probabilistic Clustering Algorithm (SPoCA), used to automatically detect coronal holes, segments EUV images of the Sun into regions, here called "classes", corresponding to active regions (AR), coronal holes (CH) and quiet sun (QS). SPoCA uses a multi-channel, unsupervised, spatially constrained fuzzy clustering procedure in which classes are defined by minimizing intra-class variance. An example of using the SPoCA algorithm is shown in Fig. 1.

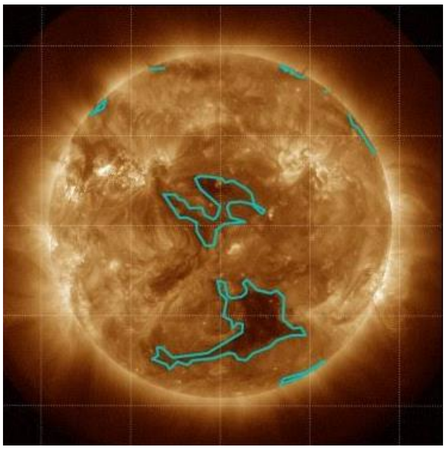

Figure 1 – Coronal holes highlighted by the SPoCA algorithm. The image of the Sun in EUV (extreme ultraviolet radiation) was used. The picture was taken on 05/4.23 AIA/SDO at 193 Å.

To construct coronal magnetic field lines, the Potential Field Source Surface (PFSS) model is used, which provides a simple and efficient model. To reflect the field structure in the model, we can assume that electric currents in the corona do not have a significant effect on the global field structure. The PFSS model was originally developed by Schatten, Wilcox and Ness (1969) [8] and Altshuler and Newkirk (1969) [9] and further developed by Hoeksema (1984) [10] and Wang and Shiley (1992) [11]. The PFSS model provides a reasonable estimate of the coronal field structure, since most of the time the coronal field is in a state without Maxwellian stresses. There is twisting and shearing in active regions, and the solar wind produces inertial forces on the streamers, but ignoring these effects does not fatally undermine the model, and in practice the PFSS model compares well with MHD models (Neugebauer et al. 1998 [12], Riley et al. 2006 [13]). An example of coronal magnetic field lines can be observed in Figure 2.

Lower bound data for the PFSS models are provided by synoptic magnetograms (Fig. 3). Full-disk photospheric magnetograms from the solar telescope for operational forecasts (telescope-magnetograph of the Kislovodsk GAS STOP 3) are used to compile maps of the magnetic field over the entire surface of the Sun. These maps are used as lower bound data for the PFSS model. The PFSS model includes at its upper boundary the surface of the electric current source, where the field lines are forced to be radial. This models the effect on the field of the outgoing solar wind. Altshuler and Newkirk (1969), based on photographs of the 1966 eclipse, deduced that the surface radius of the source was approximately 2.5 solar radii. Hoeksema (1984) compared the observed interplanetary mean field (IMF) with predictions based on PFSS models for various intervals of the 21st solar cycle, and found similar optimal values for the source surface radius, 2.5 +/- 0.25 solar radii. Lee et al. (2011) [14] and Arden et al. (2014) [15], based on IMF comparisons, argue that the radius of the source surface "breathes", so its height should be lower during solar minima than during time of maximums.

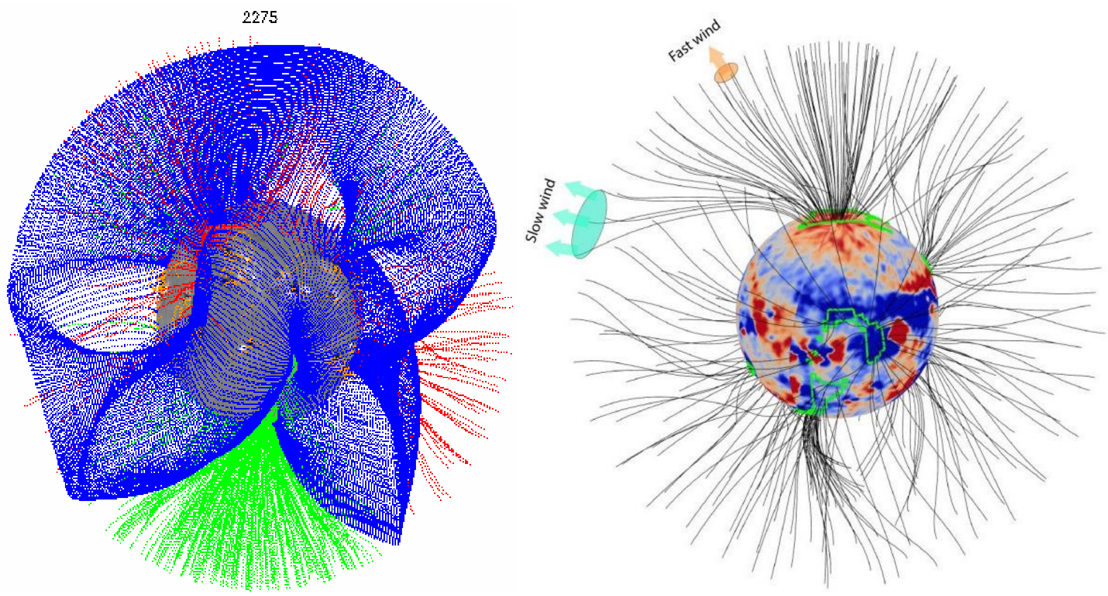

Figure 2 – **Coronal magnetic field lines generated using the PFSS model. On the left is a 2D image of the GONG project, on the right is an example**
Source: compiled by the authors based on data [16]

The described model is implemented in the pfsspy algorithm, which runs on the laboratory server according to a schedule. And when a new synoptic map of the magnetic field is discovered, the coordinates of the points that form the lines of the coronal magnetic field are calculated.

The Sun Gazers project we created is a database of geoeffective data, including coronal holes and coronal magnetic field lines, and an interactive three-dimensional model of the sun, published on the laboratory's website.

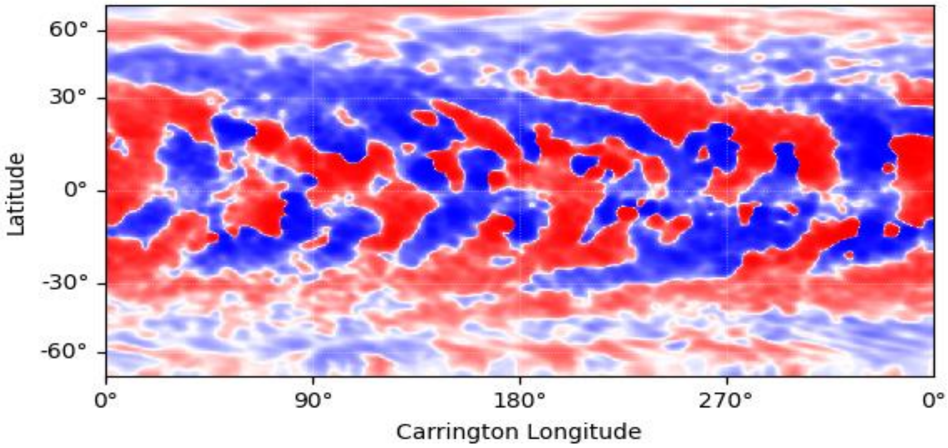

Figure 3 – **Synoptic magnetogram. Carrington rotation 2276. Enlarged contrast method leveling histograms**

The PostgreSQL DBMS version 12.15 contains 3 tables:

○ event — describes events in the sun, contains the following fields: id (bigint) – event identifier; type (varchar) - type, at this stage there are two - “Coronal Hole” and “PFSS Magnetic Line” [coronal magnetic field lines]; start_time (timestamptz) – start time of the event; end_time (timestamptz) – end time of the event; spec_id (varchar) – unique identifier, set only for coronal holes – SPoCA frame specific id.

○ polyline — defines a set of points of a specific event (a polygon describing the outer boundary for coronal holes, and an array defining one line from a set of coronal magnetic field lines), contains the fields: id (bigint) – polyline identifier; event_id (bigint) – event identifier; start_time (timestamptz) – start time for a given set of points; end_time (timestamptz) – end time for a given set of points; polarity (boolean) – polarity of magnetic lines: true in the positive case, false in the opposite case, for coronal holes the value is always NULL.

○ point — determines the position of a point in spherical coordinates in the HGS (HeliographicStonyhurst) system, contains the fields: id (bigint) – point identifier, phi (double precision) in the range [-90, 360], theta (double precision) – in the range [- 90, 90], r (double precision) - measured in solar radii in the range [1.0, 2.5], polyline_id (bigint) - polyline identifier.

A schematic representation of the geoeffective data base can be seen in Figure 4.

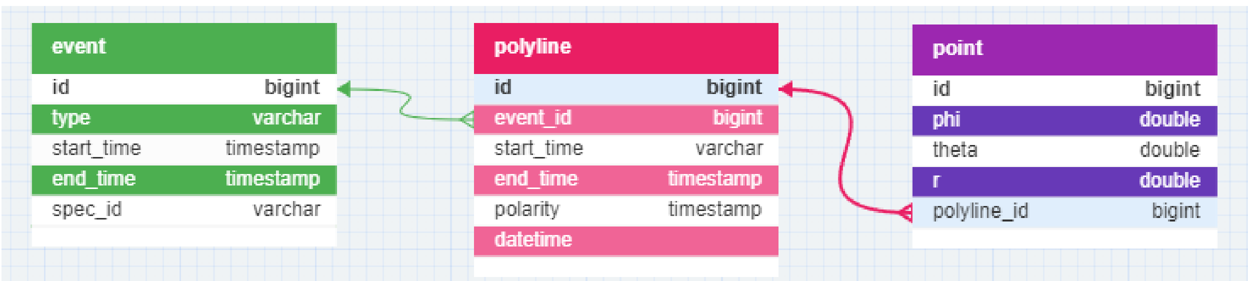

Figure 4 – **Tables in the Sun Gazers database**

Free access to the database is available via an access point (api) with the following address: sw.kalmsu.ru:8000/ api / v 1/ [type]/[year]/[month]/[day]. Parameters in parentheses, among them type can take the following values: CH - coronal holes, PML - coronal magnetic field lines; the remaining values are the desired date in the year/month/day format. The response is provided in JSON format. The main functionality of the web server can be described by three functions: issuing data from the database using dynamic queries, entering data on coronal holes, calculating and entering data on coronal magnetic field lines. Queries are filtered by event type and date.

Research results and their discussion. A database of coronal holes and coronal magnetic field lines was created, and an interactive three-dimensional model was published on the laboratory’s website [5]. The database of coronal holes and coronal magnetic field lines allows you to filter data on request; an interactive three-dimensional model is published on the laboratory’s website.

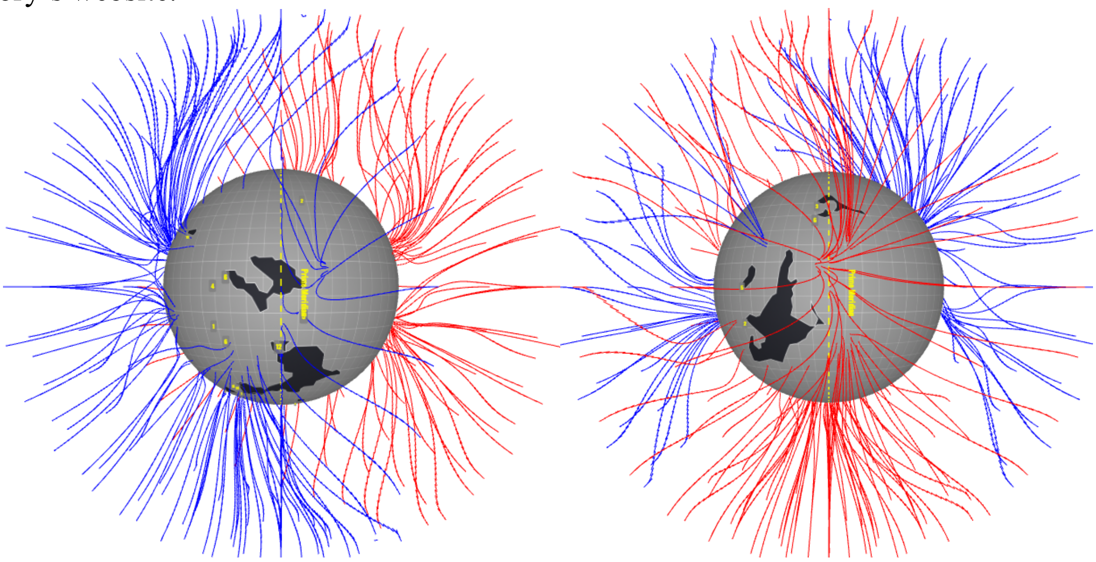

Figure 5 – **Coronal holes identified by the SPoCA algorithm and coronal magnetic field lines. Image by Sun Gazers**

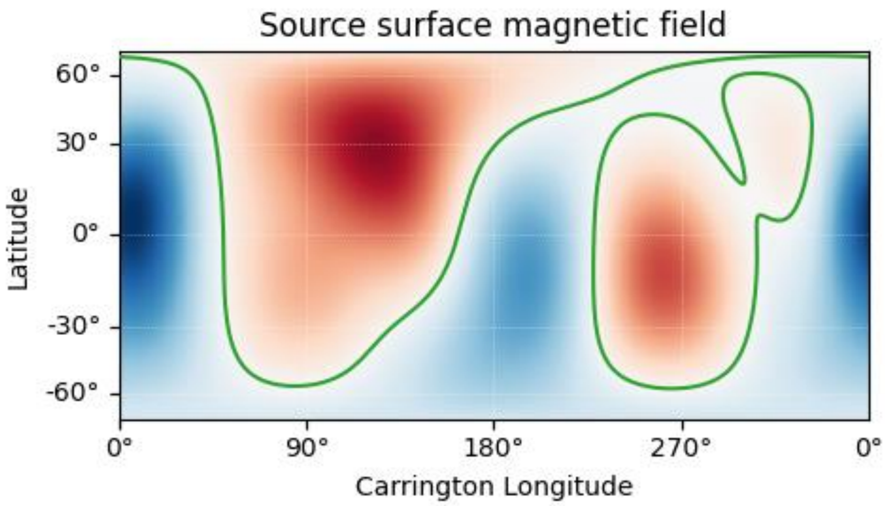

Figure 6 – **Magnetogram of the source surface. Curington Rotation 2276. Image by Sun Gazers**

The data stored in the database makes it possible to calculate the characteristics of the solar wind and coronal mass ejection to set initial conditions in MHD modeling with further prediction of the impact on the earth (K-Index).

Conclusion. At the first stage of the project, part of the data concerning coronal holes was implemented. At the next stage, it is planned to create a database of eruptive prominences obtained using the solar patrol telescope of the Kislovodsk State Autonomous Station.

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Вклад авторов: все авторы внесли равный вклад в подготовку публикации.
Конфликт интересов: авторы заявляют об отсутствии конфликта интересов.

Contribution of the authors: the authors contributed equally to this article.
Conflict of interest: the authors declare no conflicts of interests.

Статья поступила в редакцию: 01.10.2023;
одобрена после рецензирования: 03.11.2023;
принята к публикации: 11.12.2023.

The article was submitted: 01.10.2023;
approved after reviewing: 03.11.2023;
accepted for publication: 11.12.2023.