Fourth Semester Report

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Ph.D. Thesis title: Developing state-of-the-art Space Weather forecast tools

Summary of research carried out in previous semesters

Published work:

The most common source of large flares and coronal mass ejections (CMEs) is the magnetically complex and highly twisted active regions (ARs). Studying the evolution of magnetic helicity can help reveal and understand the processes of an AR leading to a flare and/or a CME. Korsós et al. (2020) found a relationship between the flaring activities and the unique oscillatory behaviour pattern of the emergence (EM), shearing (SH), and total (T) magnetic helicity flux (MHF) components in the photosphere.

I started my PhD research work based on Korsós et al. (2020). I further developed and expanded the research with additional ARs. I constructed the wavelet power spectrum (WPS) for all ARs then identified the local significant peaks in the WPS, with persistent homology method. Subsequently, I studied the distribution of the identified peaks with Kernel Density Estimation (KDE). Also a Kolmogorov-Smirnov test was performed to compare the peak distributions of flaring and non-flaring ARs. Also Gaussian curves were fitted to the probability density functions using the Gaussian Mixture Model.

One of my main findings is that the EM component of MHF clearly deviates from the SH and T MHFs. Next, I also determined the oscillatory harmonics for each case of MHF components. From this, we conclude that only the peaks appearing in the EM of flaring ARs are the ones that follow the properties of the harmonics well. This work was published in Soós et al. (2022).

Current work:

- I have also started developing my own sunspot search algorithm. I have i) looked for identifying the boundaries of the penumbra and the umbra in the intensity maps, ii) calculated a range of suitable parameters of identifying penumbrae and umbrae, and iii) calculated additional proxy parameters from the magnetograms to identify the intensity indices of the umbrae and penumbrae in continuum maps. I also corrected the pixels from foreshortening and limb darkening. All of this work is applicable, e.g. to verify the results of the soon-to-be-launched Sheffield Solar Catalog (SSC) (lead developer is Dr Norbert Gyenge, University of Sheffield). Furthermore, I also compared the calculated AR parameters of my own algorithm with the SSC and Debrecen Sunspot Data (HMIDD) catalogues. Especially, the position data of ARs (B, L, and LCM values). I have found that my calculated parameters are in a good agreement with their counterparts of the SSC and HMIDD catalogues. The area and magnetic field values are in a good agreement with SSC. I have also discovered few bugs in SSC what are now fixed.

- Furthermore, I started to expand a solar jet database (main developer: Dr Jiajia Liu, Queen's University Belfast) with a state-of-the-art jet detection code. My current task is to mprove the database from 6-hour resolution to 3-hour for the period 2010 – 2022. Once the higher time resolution database is completed, I will perform various statistical studies (including Kolmogorov-type power spectrum studies).

- I have also take part in the development of a cutting-edge technology, namely the new Magneto-Optical Filter (MOF) telescope at Gyula Bay Zoltan Solar Observatory (GSO), Hungary. This MOF technology kit is a crucial part of the Solar Activity Monitor NETwork (SAMNet) telescopes.

- I have also take part in the preparation of the headquarter of SAMNet, Gyula Bay Zoltan Solar Observatory, which is about to be commissioned for operation.

Description of research in current semester

Magnetic helicity flux

I have started to analyse the temporal evolution of the identified periods in Korsós et al. (2020). The aim of this study is to establish how the magnitude of the periods changes over time, to further strengthen our current prediction capabilities. For this, I made a linear fit for each significant period's 98% significance contour to be able to compile statistics for the two AR groups (i.e., flaring vs. non-flaring), see Fig. 1. I also carried out a PCA for this, but the result did not change as expected, also no error can be calculated with PCA.

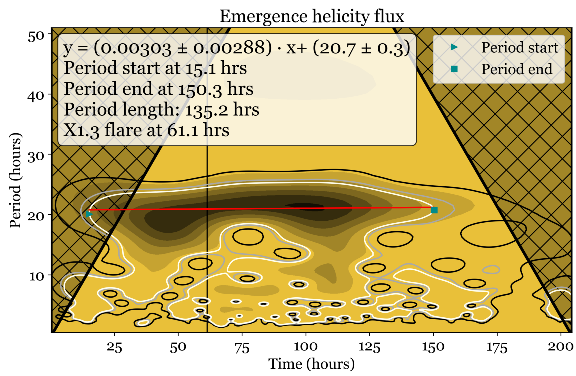
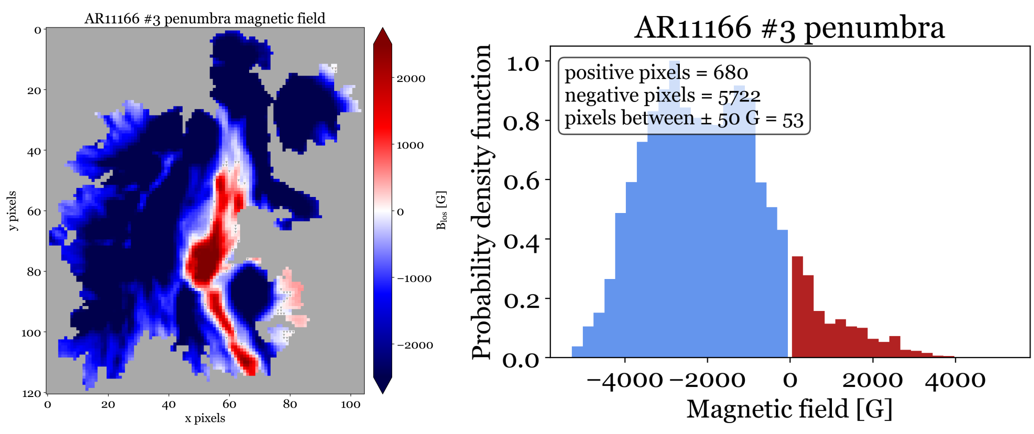


Figure 1: Linear fit on the 98% significance contour level with errors for the Magnetic Helicity Flux Emergence component of AR11430.

After my successful ESPOS seminar presentation that was broadcasted across Europe, we were contacted by Dr. Aneta Wisniewska (Leibniz-Institut, Potsdam) about a new collaboration opportunity. Our aim is to study the short-scale periods (∼few minutes) and the longer (∼20 hrs) periods in 3D before flare eruptions.

Sheffield Solar Catalogue



(a) B_{los} values of the δ-spot

(b) Histogram of the δ-spot

Figure 2: An example of showing the magnetic field and pixel distribution of the same δ-spot in AR11166.

I further expanded the capabilities of SSC. I developed the fully automated visualization techniques for the numerical data of SSC (see Fig. 2). In Fig. 2a, the B_{los} values below the bitmaps of each penumbra identified by the SSC are shown. These images are similarly elegant for each penumbra (colorbar, markersize, etc.) via our fully automated code. The gray small triangles in the figure indicate the pixels where the magnetic field is between -50 and +50 G, which are called the polarity inversion lines (PILs). These PILs are very important features to identify the δ-spots, which are often the hosts of solar flares. Fig. 2b shows the distribution of pixels belonging to the same penumbra.

For the statistical study, I have selected 8 non-flaring and 10 flaring ARs that contained at least one δ-spot. First, I determined the largest spatial extent of the entire AR for each case. These times became the reference times for that AR. Then, for the flaring ARs, I picked the δ-spot that produced the X-class flare(s). For non-flaring ARs, I selected the largest or most complex δ-spot. After that, I calculated my own parameter (called as soft-δ parameter) for each δ-spot. Namely, when the AR is on the northern half of the Sun, I divided the number of positive pixels by the number of negative pixels . If the AR is on the southern side of the Sun, I did the other way around. I calculated this parameter 12/9/6/3-hour prior the reference time and at 3 hours after the reference time. Then, I normalized the soft-δ parameters. Next, I looked for the distribution of these soft-δ parameters with KDE, see Fig. 3.

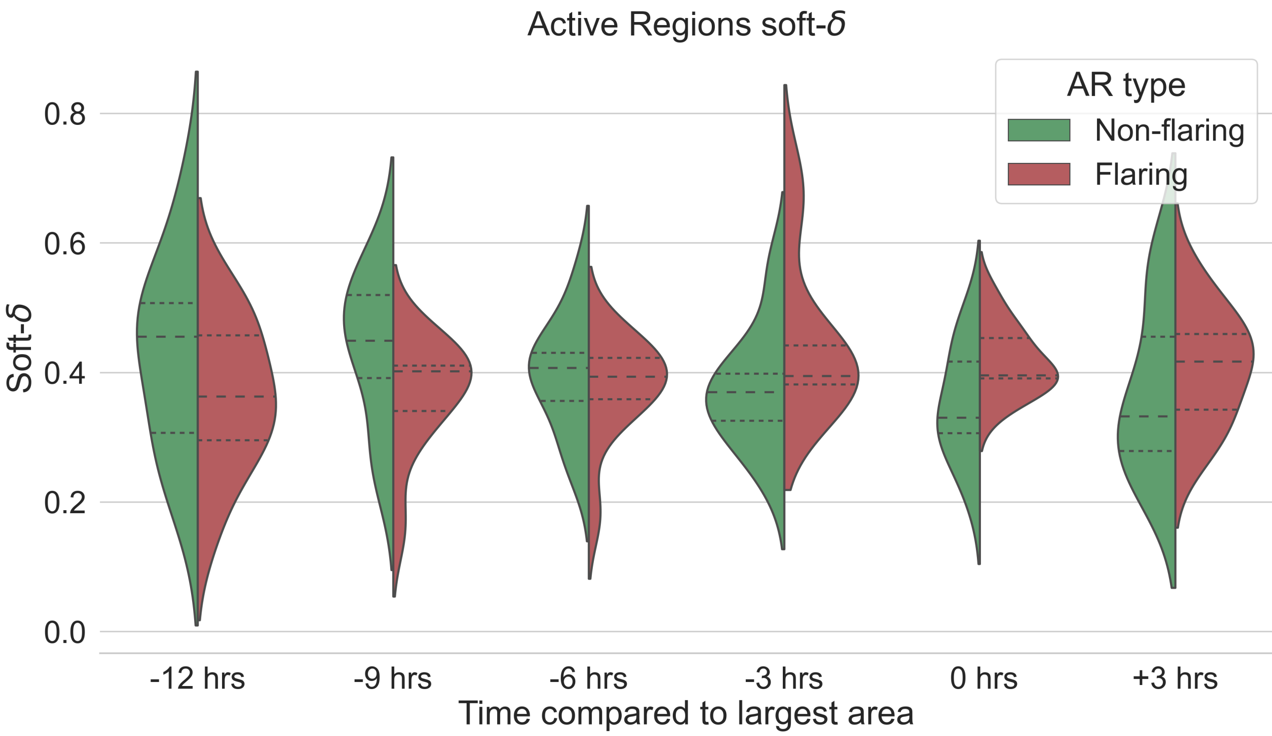


Figure 3: Violin plot of studied flaring and non-flaring ARs soft-δ parameter.

Outliers in the distribution of flaring ARs at 9/6/3-hour before the reference time are due to SSC morphsnakes. Like, where and how much the SSC drew the contour line on that penumbra. Because X-class flares occurred predominantly before the largest spatial extent of the ARs, this cannot be used for prediction in this form. Now, the goal is to obtain the same figure, only the reference times are the on-set times of the flares. In addition, it may be worth considering additional times before the reference time.

Solar Jets

Automated jet detection for full SDO area (2010-2022) is now completed. The very laborious manual check is now in progress.

Magneto-Optical Filter

The GSO was equipped with a solar telescope and a MOF (Fig. 4). The ceremonial handover took recently place. The first light images were taken. Now, various background applications, interfaces are still being developed before the GSO can be officially launched.

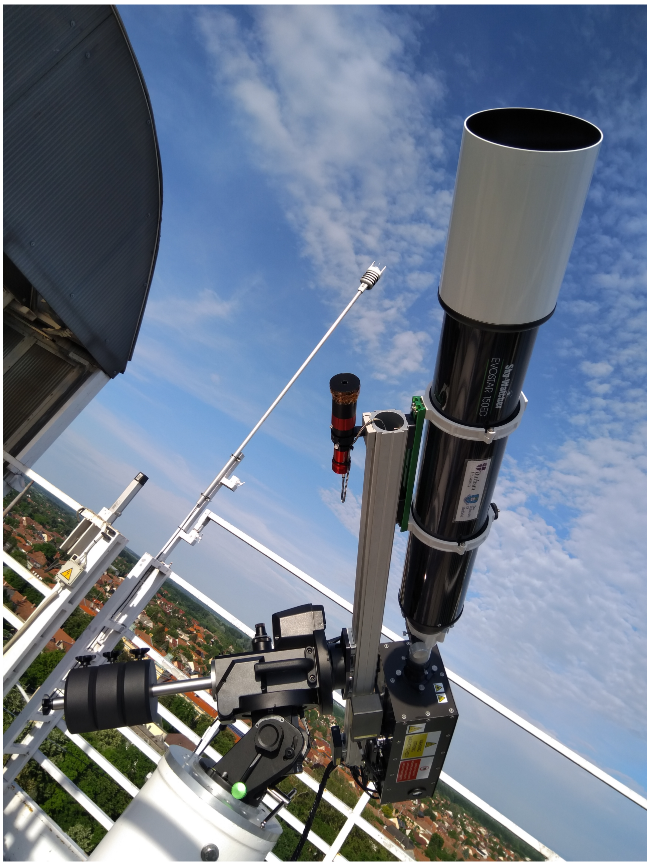


Figure 4: Complete GSO telescope with MOF.

The other MOF will be build in Hungary. All the necessary main parts of the MOF had already been acquisitioned. After reviewing the blueprints and selecting the construction site, assembly can be begin.

Publications during the doctoral studies

- Sz. Soós, M. B. Korsós, H. Morgan, and R. Erdélyi. On the differences in the periodic behavior of magnetic helicity flux in flaring active regions with and without x-class events. *The Astrophysical Journal*, 925(2):129, feb 2022. doi: 10.3847/1538-4357/ac4094. URL https://doi.org/10.3847/1538-4357/ac4094.

Awards during the doctoral studies

- KDP-2021 application granted for 31 months (400.000 HUF/month + part time job at AstroTech Kft. + other significant benefits): Developing state-of-the-art Space Weather forecast tools.
- Financial support granted from the Doctoral School of Physics (811.500 HUF) for AZ-EQ6GT mount.
- Financial support granted from the Doctoral School of Physics (559.900 HUF) for ZWO ASI 1600MM Pro camera.
- National Astronomy Meeting 2021 fee waiver granted.

Professional Standing

- From 2022, I am the representative of the Hungarian Solar Physics Foundation (HSPF) on the Board of the European Association for Solar Telescopes (EAST).
- From 2022, I am the Hungarian contact person for European Solar Physics Online Seminars (ESPOS).
- As a continuation of (Soós et al., 2022) work, I am partly involved in the supervision of two BSc students' thesis. On one hand, the task is to mathematically derive the standing MHF waves as pre-cursors of solar eruptions in ARs using MHD equations. On the other hand, we further investigate the MHF relation to Coronal Mass Ejections.

Studies in current semester

- SWATNet Summer School: Managing a Research Project (15-16 March, 2022)
- Python in Heliophysics Community (PyHC) Summer School (30 May - 3 June, 2022)

Conference participations during the doctoral studies

- European Solar Physics Online Seminars, from 10 September 2020, Thursday on each second week.
- UK Solar Online Seminar Series, from 17 September 2020, once a month on Thursdays.
- ESPOS (Online, March 3, 2022), with ***seminar presentation***: On the Differences in the Periodic Behavior of Magnetic Helicity Flux in Flaring Active Regions
- Planetariums and Demonstration Observatory Workshop (Pécs, November 21-22, 2021)
- Solar Physics and Space Plasma Research Centre Seminar (Online, October 29, 2021), with ***seminar presentation***: On the differences in the periodic behaviour of magnetic helicity flux in flaring active regions with and without X-class events
- XVIIth Hvar Astrophysical Colloquium (Online, September 22, 2021), with ***presentation***: On the differences in the periodic behaviour of magnetic helicity flux in flaring active regions with and without X-class events
- 16th European Solar Physics Meeting (Online, September 9, 2021), with ***presentation***: Different periodic behaviours of magnetic helicity flux in flaring and non-flaring AR cases

- National Astronomy Meeting 2021 (Online, July 22, 2021), with ***presentation***: Different periodic behaviours of magnetic helicity flux in flaring and non-flaring AR cases
- SolFER Spring 2021 (May 24-26, 2021)
- RAS SDM, MHD oscillations and waves (May 14, 2021) with ***poster***: On the oscillatory behaviour of magnetic helicity in flaring and non-flaring solar active regions (Link to poster!)
- 27th Open Young Scientists' Conference on Astronomy and Space Physics (April 26-30, 2021)
- SDO 2021 Science Workshop (March 11 & 25, April 8 & 15, 2021)
- Cool Stars 20.5 (March 2-4, 2021)
- European Space Weather Symposium 2020 (November 2-6, 2020)
- UKSP Specialist Discussion Day (July 30-31, 2020)

Professional activities in current semester

- Participation in various outreach presentations in Gyula.

Teaching in current semester

- Csillagászati észlelési gyakorlatok 1 (cg1c4eg1), 2 hours a week during semester time.
- Csillagászati észlelési gyakorlatok 3 (cg1c4eg3), holding only the observational lessons with telescopes during semester time.

References

M. B. Korsós, P. Romano, H. Morgan, Y. Ye, R. Erdélyi, and F. Zuccarello. Differences in Periodic Magnetic Helicity Injection Behavior between Flaring and Non-flaring Active Regions: Case Study. *The Astrophysical Journal, Letters*, 897(2):L23, July 2020. doi: 10.3847/2041-8213/ab9d7a.

Sz. Soós, M. B. Korsós, H. Morgan, and R. Erdélyi. On the differences in the periodic behavior of magnetic helicity flux in flaring active regions with and without x-class events. *The Astrophysical Journal*, 925(2):129, feb 2022. doi: 10.3847/1538-4357/ac4094. URL https://doi.org/10.3847/1538-4357/ac4094.