Doctoral School of Physics - Eötvös Loránd University (ELTE)

Semester 3 (Fall 2023/2024) report by **Lisboa Nogueira Guilherme Augusto**
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PhD Program: Astronomy and Space Physics.
Supervisor(s): Petrovay Kristóf
Ph.D. Thesis title: Modelling periodic and quasiperiodic variations in solar activity.

Introduction: In recent years solar activity has undergone a remarkable change, switching to a quieter state as compared to the period of strong activity ("Modern Maximum") in the second half of the 20th century. The realization of the importance of solar activity variations as the single most important natural external driver of terrestrial climate change, has led to renewed attention on understanding the solar dynamo and forecasting cycle-to-cycle variations. In contrast to more traditional studies of the solar dynamo where emphasis was on understanding the root of the basic 11-year periodicity, with attention on the detailed spatial structure of the models but often in a linear approach, the focus on cycle-to-cycle variation implies that nonlinearities and/or stochastic variations in the models must be given special attention. Therefore, our approach will be to consider spatially truncated models of a lower dimensionality and focusing on a deeper understanding of temporal variation. The objective is to carry out a detailed analysis of the relative importance of nonlinear deterministic feedback mechanisms and stochastic fluctuations in determining intercycle variations of solar activity. The results of this analysis are expected to yield constraints on solar dynamo models and help improving forecasts of solar activity. The analysis will imply two kinds of spatially truncated models of the solar dynamo: 1) Theoretical modeling: a combination of axisymmetric mean field dynamo models (in 2D and truncated to 1D as in the updated Leighton model) and surface flux transport simulations (in 1D and 2D) will be considered, and a detailed comparative analysis of various models and their chosen parameter profiles (e.g.meridional circulation profile) will performed. In such models, the effect of various nonlinearity mechanisms and types of stochastic forcing can be readily tested, covering a large domain in parameter space. 2) Data assimilation from observations (during the secondment to USFD, 8M): here the source term in the surface flux transport simulations will be partly or fully fed in from actual observations, allowing the reproduction of actual variations of solar activity in specific solar cycles, including forecasts for Cycle 25.

Description of research work carried out in current semester: During the third semester of my PhD (Fall 2023), We kept on getting familiarized with the research topic. During this semester, we wanted to study the relationship between some parameters of Bipolar Magnetic Regions (BMRs) on the Sun. The data set we were using had great potential to be explored. The main task was to verify the relationship between the magnetic flux, the initial dipole moment, and the latitude of the BMRs. We wanted to find the distance between the two polarities of the bipolar AR. Our first attempt was to obtain the polarity separation d by using the relation between the initial dipole moment and the flux ($\delta D_i/\Phi$). The equation of a bipolar active region with a tilt angle α, that leads to intercycle variations on the solar cycle is given by:

$$\delta D_i = \frac{3}{4\pi R^2}\Phi d \sin\alpha \cos\lambda, \tag{1}$$

Which can be rewritten as:

$$\frac{\delta D_i}{\Phi} = \frac{3}{4\pi R^2} d \sin\alpha \cos\lambda, \tag{2}$$

The tilt angle α is proportional to the latitude, which gives us:

$$\frac{\delta D_i}{\Phi} = \frac{3}{4\pi R^2} d \sin(2\lambda), \quad (3)$$

Figure 1 shows the dependence of the sine of the latitude (sin λ) on the mean value of the initial dipole ($D1$) divided by the flux (Φ) x $sign(n)$, where n is the cycle number. the $sign(n)$ is +1 for odd cycles and -1 for even cycles.

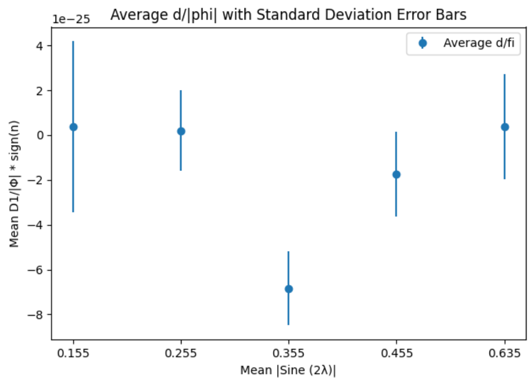

Figure 1: Dependence of the mean sine of the latitude (λ) on the mean value of the initial dipole ($D1$) divided by the flux (Φ) *sign(n)

The second task performed was to use the relation between the initial dipole moment and the cos(λ) ($\delta D_i / \cos\lambda$) to obtain the polarity separation d . From equation 1, a BMR at the time of emergence, can be rewritten as:

$$\frac{\delta D_i}{cos\lambda} = \frac{3}{4\pi R^2} \Phi \, d \sin\alpha, \quad (4)$$

Figure 2 shows the latitude dependence on the initial axial dipole ($D1$) divided by the cosine of the latitude ($\cos\lambda$) of an BMR. The values of D_1 for the even cycles were multiplied by -1 to account for the flip of the magnetic field.

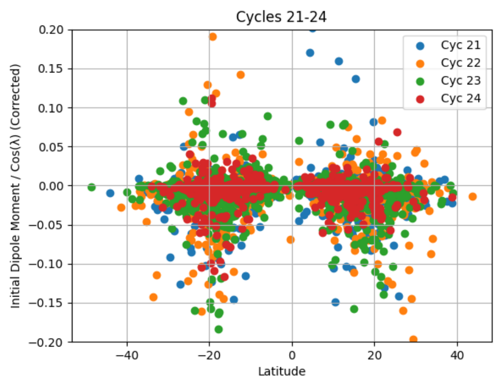

Figure 2: Latitude dependence on the Initial dipole moment divided by Cos (latitude) for cycles 21-24

Another task was to find a dependence of the mean value of the initial dipole moment divided by the cosine on the latitude of the BMRs. This dependence may be also dependent on the Flux. To verify this, the data was separated in Flux ranges. The separation was arbitrary and the idea was to keep the same number of points for each range. It was separated into 3 ranges, based on the order of power on the magnetic flux. Figures 3 to 5 shows the latitude dependence on the mean value of the initial dipole moment divided by the cosine of the latitude for a given flux range. In these figures, the latitude was separated in intervals of 9^0 each, with the first interval is between 0 and 9^0 and the last between 36.1^0 and 45^0.

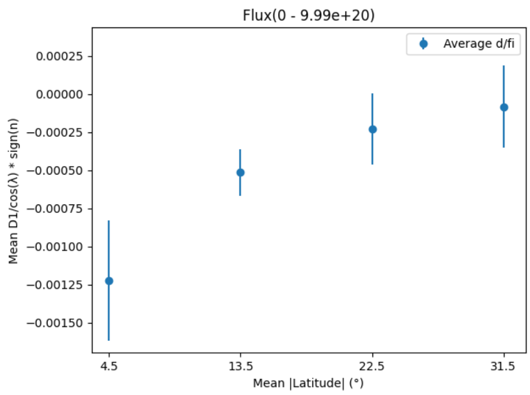

Figure 3: Latitude dependence on the mean value of the initial dipole moment divided by the cosine on the latitude for a flux ranging from 0 - 9.9 e+20

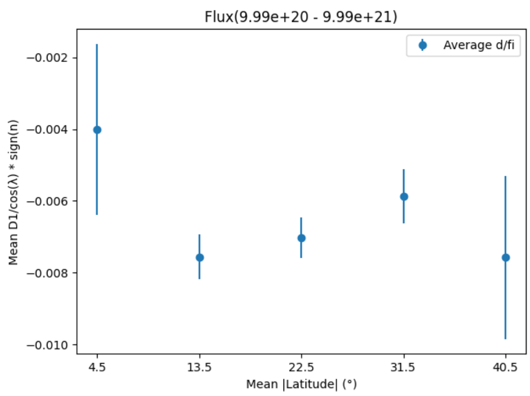

Figure 4: Latitude dependence on the mean value of the initial dipole moment divided by the cosine on the latitude for a flux ranging from 9.99 e+20 - 9.99 e+21

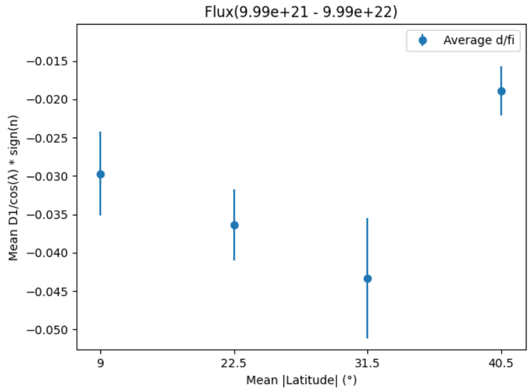

Figure 5: Latitude dependence on the mean value of the initial dipole moment divided by the cosine of the latitude for a flux ranging from 9.99 e+21 - 9.99 e+22

For the joint PhD with the University of Sheffield, I had to go through an assessment to check how was the first year of the PhD. A report was produced and I had to make a presentation. The board was composed by 2 professors from Sheffield and one from ELTE. The result of the evaluation was positive, and they agreed that I was able to continue the research.

Publications: No publications on this semester.
Studies in current semester:
Subjects
- Radio astronomy I (FIZ/5/009)
- Chapters from modern celestial mechanics (FIZ/5/053)

Other courses
- One month training at the Gyula Bay Zoltan Solar Observatory (GSO) in Gyula, Hungary.

Conferences in current semester: No conference attended this semester.