Doctoral School of Physics - Eötvös Loránd University (ELTE)

Semester 4 (Spring 2024) report by **Lisboa Nogueira Guilherme Augusto**
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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, 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 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 be 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: 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.

Summary of research work carried out in the previous three semesters: During the first semesters, the main goal was to start to understand about Solar Physics. It was also important to improve the skills in using Python programming language to perform the simulations and analyzes. The first task was to study and understand an algebraic method, an alternative to the Surface Flux Transport simulations (SFT), that can be used to forecast the amplitude of the upcoming solar cycle. The focus was to apply the data from magnetograms extracted from NSO Carrington maps to validate the model. The data was obtained from Whitbread, 2019 [1]. With the algebraic method, it was possible to introduce the Solar data and make the best choice for the two opened parameters involved in the methodology.

The next task was to evaluate different parameters of the data from the synoptic maps. We were specially interested in obtaining a correlation between the polarity separation (d) of a bipolar magnetic region (BMR) and the latitude appearance of this Active Regions (ARs).Obtaining an equation for the parameter d can be very useful. It is possible to assign an initial separation to ARs that we don't have much information about. In historical data, the information available

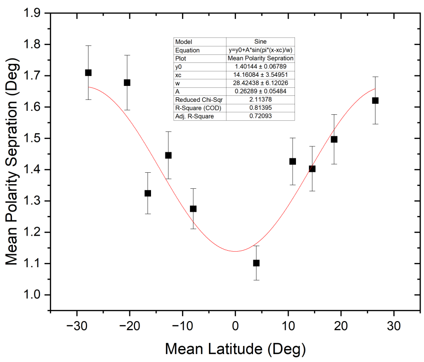
[1] "Active region dipole moments determined from NSO carrington maps."

is only the latitude and size. Unfortunately, some bias was found while performing the study and we choose to start again with a different data set.

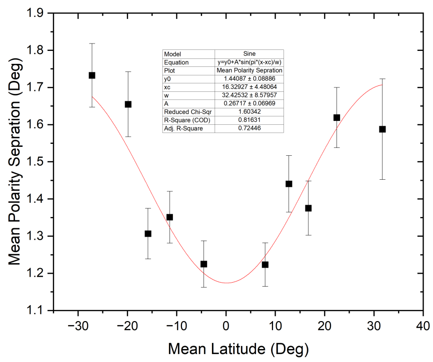
Description of research work carried out in current semester: During the fourth semester of my PhD (Spring 2024), we kept focused on studying the relationship between some parameters of the BMRs on the Sun's Photosphere. The data set we started using had great potential, as mentioned on the last report, but we found some bias on it. We migrate to a more recent data, retrieved from Wang et. all. 2023.[2] The main task was to verify if there is a relationship between the distance between the two polarities ("d") in a BMR and the latitude appearance (λ). The equation of a bipolar active region with a tilt angle α, that leads to intercycle variations on the solar cycle is given by:

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

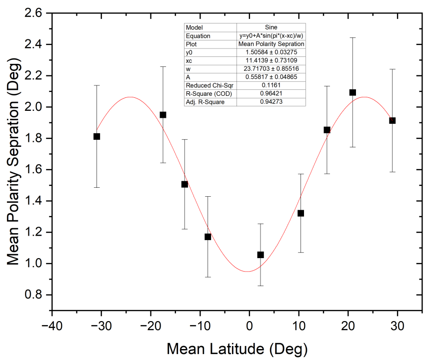
Having Eq. 1 in mind, and plotting the data, it is possible to evaluate the correlation between the parameters d and λ.



(a) All ARs



(b) Hale ARs

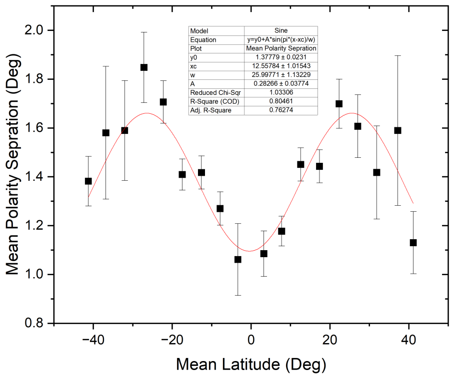


(c) Anti-Hale ARs

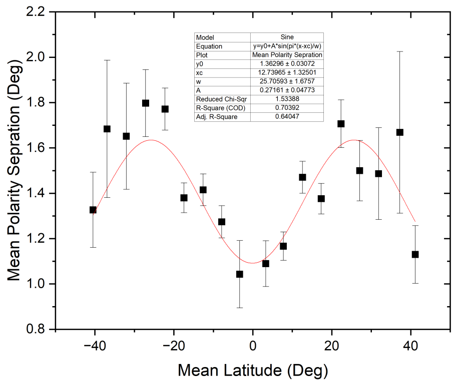
Figure 1: Mean polarity separation x mean latitude. Each bin has the same number of points

[2]"Toward a Live Homogeneous Database of Solar Active Regions Based on SOHO/MDI and SDO/HMI Synoptic Magnetograms. I. Automatic Detection and Calibration"

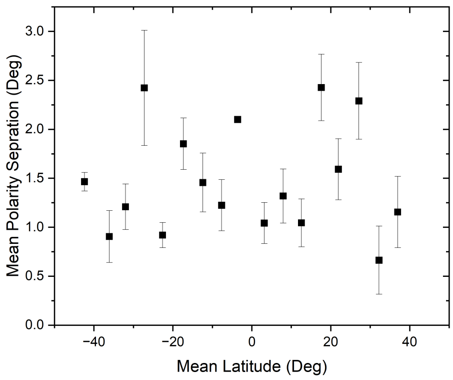
Fig. 1 shows the values of the mean polarity separation (degrees) plotted against the latitude appearance of the BMR. The data have a total of 2950 points with 2741 (92.9%) being classified as Hale ARs and 209 (7.1%) as Anti-Hale ARs. Here, the data was separated into bins containing the same number of points. Each plot was fitted with a sinusoidal function and the parameters can be seen in the plot. The next step is to use the chi-squared information from the plot to perform the chi-squared test.



(a) All ARs



(b) Hale ARs



(c) Anti-Hale ARs

Figure 2: Mean polarity separation x mean latitude. Each bin has the same latitude interval

Figure 2 presents a similar result obtained before. The parameters for the sinusoidal fit can be seen in the plot. This analysis was performed by choosing the bins to have the same latitude interval. It is possible to see that for this particular choice of bin, the anti-Hale ARs (c) did not present a correlation between the polarity separation and the latitude.

Another characteristic that we wanted to check was the dependence on the magnetic flux (Φ). To do so, since the polarity separation scales with the square root of the magnetic flux, a plot with the polarity separation divided by the $\sqrt{\Phi}$ versus the latitude. The plot is presented in the figure below.

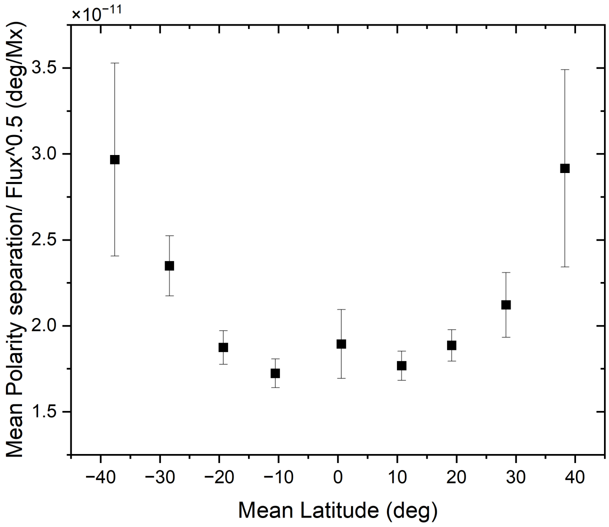


Figure 3: Polarity separation divided by the $\sqrt{\Phi}$ versus the latitude for the Hale ARs

It is possible to see a clear correlation in the plot. The next step involves changing the power of the flux, other than the square root of it. We will also check the results if we create bins for the magnetic flux.

From February (2024) until November (2024), I will be based in Sheffield to fulfill the requirement for the joint PhD in the University of Sheffield. Since all required credits were already taken, it is time to focus on the research. After the complex examination, it will be possible to start writing the first paper with the results obtained so far.

Publications: The first publication will be written after the complex examination. The results will be discussed with the group that developed the algorithm to extract the data.

Studies in current semester: No studies on this semester.

Other studies during the PhD:

- SWATNet School 2: "Sun-Earth Interactions."
- SWATNet Workshop 3: "Solar Activity and Space Weather: Physics Behind the Process."
- SWATNet Workshop 5: "Mini-Master of Business Administration (Mini MBA)."
- SWATNet School 3: "Space Weather and our Technology-Based Society."
- SWATNet Workshop 6: "Entrepreneurship in Space Physics"
- SOLARNET Summer School: "Solar atmospheric dynamics – From waves to instabilities and jets"
- One month training at the Gyula Bay Zoltan Solar Observatory (GSO) in Gyula, Hungary.
- SWATNet Workshop 7 "Careers: Academic versus non-academic opportunities."

Conference participation during the doctoral studies: I couldn't attend to any conference yet, but for this year, the plan is to participate in the European Space Weather Week, the European Sol Physics Meeting, and the Space Climate 9 Symposium.