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# Magnetic Helicity as a Predictor of the Solar Cycle

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**Abstract.** It is known that the poloidal field is at its maximum during solar minima, and that the behaviour during this time acts as a strong predictor of the strength of the following solar cycle. This relationship relies on the action of differential rotation (the Omega effect) on the poloidal field, which generates the toroidal flux observed in sunspots and active regions. We measure the helicity flux into both the northern and southern hemispheres using a model that takes account of the omega effect, which we find offers a strong quantification of the above relationship. We find that said helicity flux offers a strong prediction of solar activity up to 5 years in advance of the next solar cycle.

**Keywords.** Sun: Activity, Sun: Magnetic Fields, Magnetic Fields

## 1. Overview

Solar activity and its associated phenomena and drivers are known to have wide ranging effects on the heliosphere, and (for example) how cosmic rays pass through said regions, a process described in (for example) Ferreira & Potgieter (2004). There have been many attempts to make predictions of the solar activity cycle, which itself tends to be quantified by either sunspot/active region number or area. Prediction methodologies can be split into three subsets: extrapolation methods, precursor methods and model-based predictions, see Munoz-Jaramillo, Balmaceda & Deluca (2013). There have been many attempts to refine predictions of the solar cycle. One notable example is the work of Choudhuri, Chatterjee & Jiang (2007), which uses a mean field dynamo model. In this paper, they give a prediction of the strength of cycle 24.

Magnetic helicity has even recently been used as a proxy for solar eruptions, see Pariat *et al.* (2016), although this is admittedly restricted to singular events, rather than over the whole solar body. Considering only helicity flow across a boundary, Berger & Ruzmaikin (2000) gives the rate of change of helicity with respect to time as,

$$\frac{dH_{\mathcal{V}}}{dt} = 2\oint_{\mathcal{V}} (\mathbf{A}_P \cdot \mathbf{v}) B_n \, d^2x - 2\oint (\mathbf{A}_P \cdot \mathbf{B}) v_n \, d^2x, \tag{1.1}$$

where $B_n$ is the component of the magnetic field normal to the sun's surface, $\mathbf{A}_P$ is the potential field and $\mathbf{v}$ is the plasma surface velocity. The expressions for $B_r$ and $\mathbf{A}_P$ are expanded using a spherical harmonic model (see Berger & Ruzmaikin (2000)). The time variability of the model comes from the spherical harmonic co-efficients, which we use to calculate helicity flux from 1976 onwards.

Our estimations for helicity generation is based upon differential rotation alone (the $\Omega$ effect) - the zonal velocity of the solar body decreases as we move away from the equatorial slice towards the polar regions. The velocity field $\mathbf{v}$ is an analytical expression, which can be also be found in Berger & Ruzmaikin (2000). We therefore consider only the first integral of equation (1.1).



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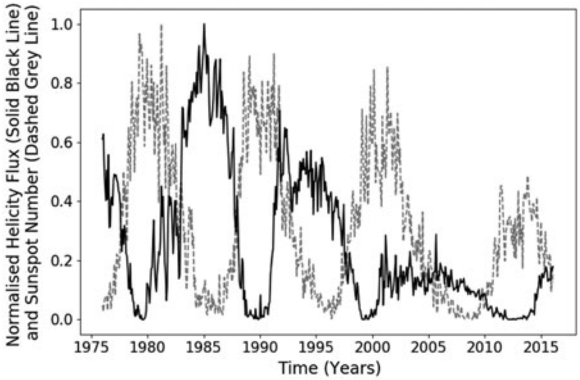


**Figure 1.** Normalised Helicity Flux (solid line) plotted against Normalised Sunspot Number (dashed line) for the period of 1976 to 2017

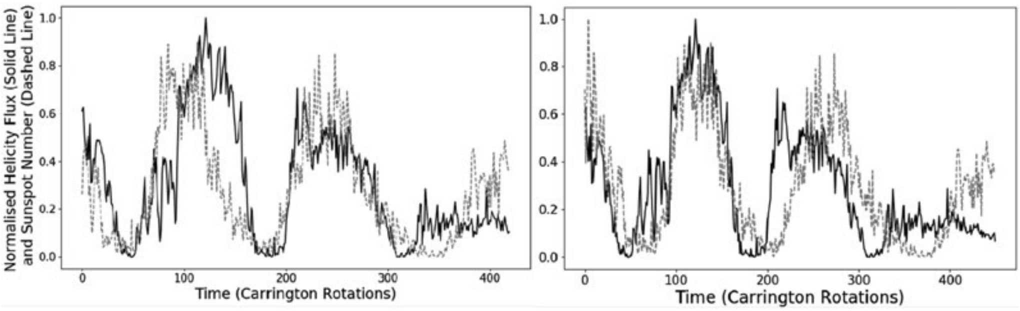


**Figure 2.** Normalised Helicity Flux (solid lines) plotted against Normalised Sunspot Number (dashed lines) with Helicity shifted forwards by 6.75 years (left) and 5.6 years (right)

Helicity flow for the solar body is modelled as shown in the aforementioned paper, with positive helicity flowing from the northern corona, through the northern and southern hemispheres (in that order) and out into the southern corona.

Sunspot number has frequently been used as a solar activity proxy, indicating regions of increased magnetic activity. Sunspots will often appear in pairs, of opposing polarity.

## 2. Data and Analysis

In Figure 1 we see Normalised helicity flux through the northern hemisphere plotted against monthly sunspot number over a period of $\sim 1976-2017$. Both data sets are averaged over a Carrington Rotation (27.28 days) - see Acknowledgements for data sources. During this period we observe three complete helicity cycles, and nearly four complete sunspot number cycles. Disregarding incomplete cycles, and the first sunspot cycle, we see clear similarities between each helicity cycle and the sunspot cycle that follows. We see the sunspot peaks decreasing approximately in line with the trend of the helicity flow peaks, with some phase shift (which is estimated below).

In Figure 2 we attempt to optimise the phase shift of the two underlying cyclic behaviours. On the left panel we have plotted we have an $\sim 6.75$ year phase shift on the left, whilst on the right we have an $\sim 5.6$ year phase shift. Both have their strong and weak points. For the former, we see a good correlation of foot points, and excellent correlation for the second pair of peaks. The first pair of peaks is less well aligned (in the region between the footpoints). This is could be due to the sudden drop observed in the helicity

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flux around the year 1990, which is not reflected in the sunspot relation. The 5.6 year phase shift gives a stronger correlation for the first pair of peaks, although the footpoints are no longer as well aligned. In the right panel, the second pair of peaks is less well aligned between the footpoints.

The maximisation of the correlation of the first pair of peaks offered a Pearson Correlation Co-efficient of $\mathbf{r = 0.79}$. Similarly, the second pair of peaks offered $\mathbf{r = 0.89}$, both of which indicate strong positive correlation. The longer lag time between the second pair of peaks could be due to a number of factors, the most obvious of which is the amplitude of the cycles.

| **Cycle** | **Integrated Helicity Flow** | **Integrated Sunspot Number** | **Ratio** |
|---|---|---|---|
| 1 | 59.50 CR | 48.90 CR | 74% |
| 2 | 42.39 CR | 46.79 CR | 90.6% |
| 3 | 17.5 CR | 22.79 CR | 76.8% |

To take account of the differences in structure, particularly notable for the third pair of peaks, we attempt a different form of data analysis. We note that whilst the third helicity flux cycle is quite long, its sunspot twin is shorter, but taller. We thus reduce these cycles to singular data points by integration.

These values are dimensionless quantifications of the area under the respective curves. The normalisation is performed with respect to the largest curve of each respective data set. The results of this are shown in the table above.

## 3. Conclusions

We have provided strong indication of a relationship between the solar cycles of helicity flux and the corresponding sunspot number cycle. Our analysis indicates that there is a phase shift between the two mechanisms of approximately $5 - 7$ years. We aim to collect more data to further verify our hypothesis, and make direct comparisons with the predictive capability of the polar field alone (given the presence of $B_n$ in our flux equation).

## 4. Acknowledgements

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