Magnetic winding as an indicator of eruptive activity in the Sun

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One of the most important problems in solar physics is to differentiate the magnetic field configurations in active regions (ARs) that will lead to flaring events and coronal mass ejections (CMEs) from those that will not. A significant number of teams have developed methods aiming to predict AR flaring and CME activity based on magnetogram data (see Guennou et al. 2017; Leka et al. 2019a, 2019b). A recent collaborative effort to cross-compare forecasting methods published a number of papers discussing the means for comparing and testing the efficacy of some of the established predictive tools currently available (Leka et al. 2019a, 2019b; Park et al. 2020). A particular (and significant) subset of these methods relevant to our work is termed "Magnetic/Modern Quantification" and involves the calculation of scalar measurements or proxies for the free magnetic energy of the system (which implies the existence of magnetic helicity Berger (1993). Alternative methods also use machine-learning techniques or regression-based methods to assess the importance of multiple parameters across historical data. The results detailed in Leka et al. (2019a, 2019b) indicate that the methods (across all classes) do show intelligence (in a statistical sense) but that they are still not consistently reliable.

Magnetic helicity is a fundamental quantity of magnetohydrodynamics (MHD). It is a conserved quantity in ideal MHD, and even in the limit of small or vanishing dissipation (Berger & Field 1984). Magnetic helicity has a topological interpretation in terms of the average linking number of the magnetic field lines weighted by the field strength (Arnold & Khesin 1999; Berger & Field 1984). The use of magnetic helicity as a diagnostic tool in the analysis of solar ARs has led to significant progress in the understanding of the structural evolution of the magnetic field in ARs (e.g., Pariat et al. 2006; Pariat et al. 2005).

Here we present the analysis of *magnetic winding* as a diagnostic tool in the characterization of the developing magnetic field topology in AR. Magnetic winding is a renormalization of magnetic helicity that removes the magnetic flux weighting, thus leaving a direct measure of field-line topology (Prior & MacTaggart 2020; MacTaggart et al. 2021). As such, magnetic winding is more sensitive to topological changes in the magnetic field configurations than the helicity. We present the application of magnetic winding to vector magnetogram data from active regions and analyze their evolution in terms of their magnetic flux, magnetic helicity, and winding (Raphaldini et al. 2022). We show, by decomposing the magnetic field into potential and nonpotential/current-carrying components, that highly complex (strong winding) current-carrying fields are associated with eruptive events, while fields with winding dominated by the potential component have minimal flaring activity.

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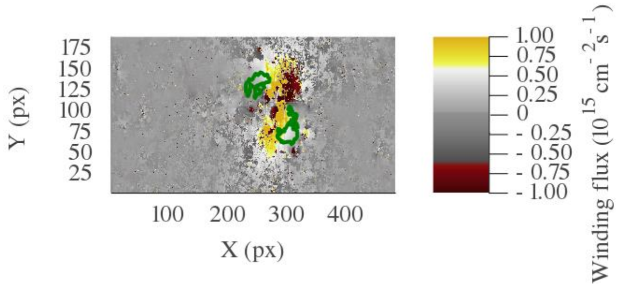

Figure: Winding flux density for AR 11318 showing a dominance of the magnetic field complexity in between sunpot’s footpoints (green)