Magnetic Winding as an indicator of flux emergence and flare activity

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Introduction

The winding is a measure of the entanglement of magnetic field lines and is closely related to the well known magnetic helicity, while the second is weighted by the magnetic flux, the first is not. The winding is therefore a direct measure of the topology of a magnetic field configuration.

While the helicity is widely used to characterize observed magnetic fields in active regions (AR) and to construct predictive metrics for flare/CME activity, the winding has been applied only to MHD simulations only.

Here we directly use observational AR data to show that the winding is able to provide useful information that may help us predict within ≈ 20-30 hours of advance whether an AR will produce flares with significant intensity and quantity.

Magnetic Helicity: $$\mathcal{H}(\Omega) = \int_{\Omega} \mathbf{A}.\mathbf{B}d\mathbf{x}^3$$

Change in relative helicity:

$$\frac{d\mathcal{H}_R}{dt} = -\frac{1}{2\pi}\int_{\partial\Omega}\int_{\partial\Omega'} \frac{(\mathbf{x}-\mathbf{x}')\times(\mathbf{u}(\mathbf{x})-\mathbf{u}(\mathbf{x}'))}{||(\mathbf{x}-\mathbf{x}')||^2} B_n(\mathbf{x})\mathbf{B_n}(\mathbf{x}')\mathbf{d}\sigma(\mathbf{x}')\mathbf{d}\sigma(\mathbf{x})$$

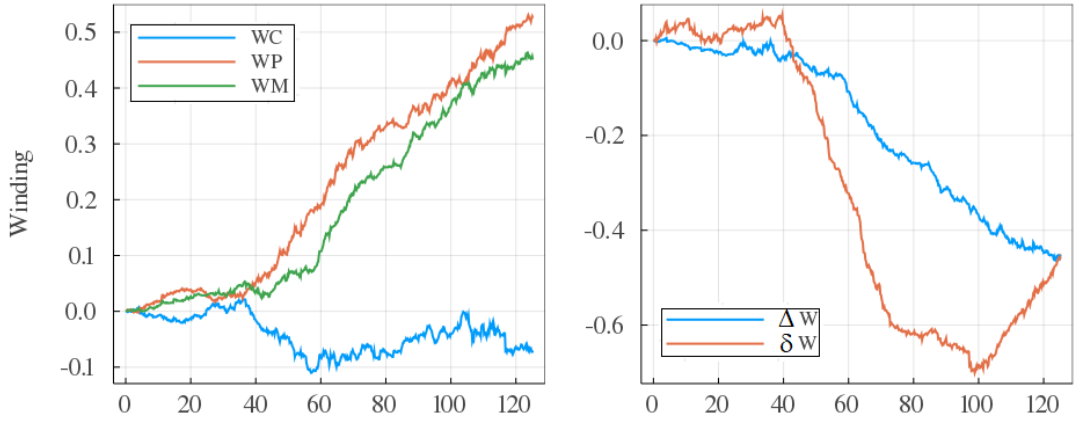
Change in magnetic winding:

$$\frac{d\mathcal{W}}{dt} = -\frac{1}{2\pi}\int_{\partial\Omega}\int_{\partial\Omega'} \frac{(\mathbf{x}-\mathbf{x}')\times(\mathbf{u}(\mathbf{x})-\mathbf{u}(\mathbf{x}'))}{||(\mathbf{x}-\mathbf{x}')||^2} d\sigma(\mathbf{x}')\mathbf{d}\sigma(\mathbf{x})$$

Data and methodology

We used vector magnetic field data from the Helioseismic and Magnetic Imager (HMI) with 12 minute cadence. From the magnetic field data we obtain the velocity fields by using the DAVE4VM method (Schuck, 2006). We calculated the evolution of the magnetic helicity and winding for two poor flaring ARs (AR NOAA 11318 and 12219 and two with strong flaring activity:

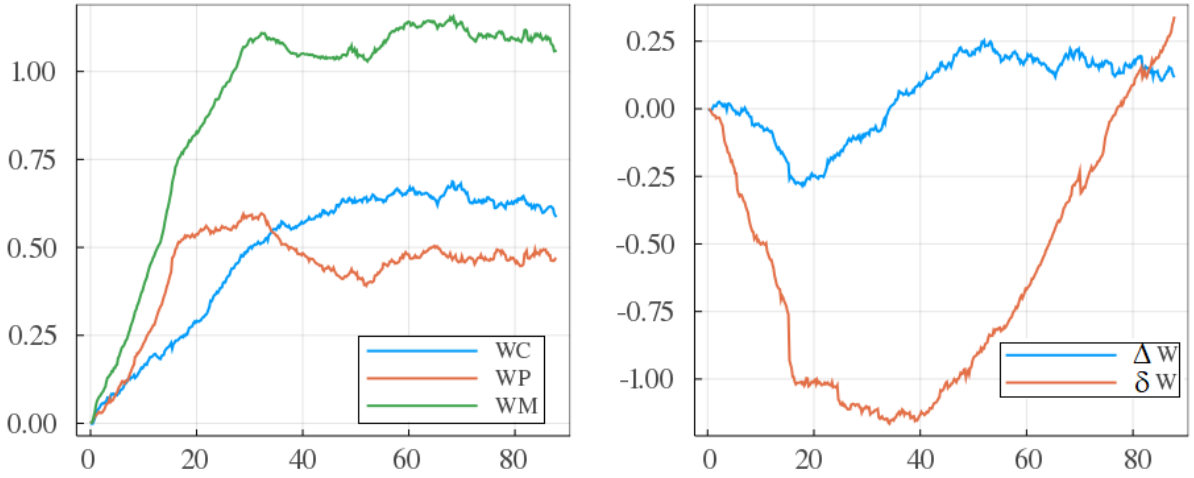
Results (AR 12119)



Legend: W-winding, Wp/Wm/Wc-potential/mixed and current components, δW=|Wc|-|Wm|

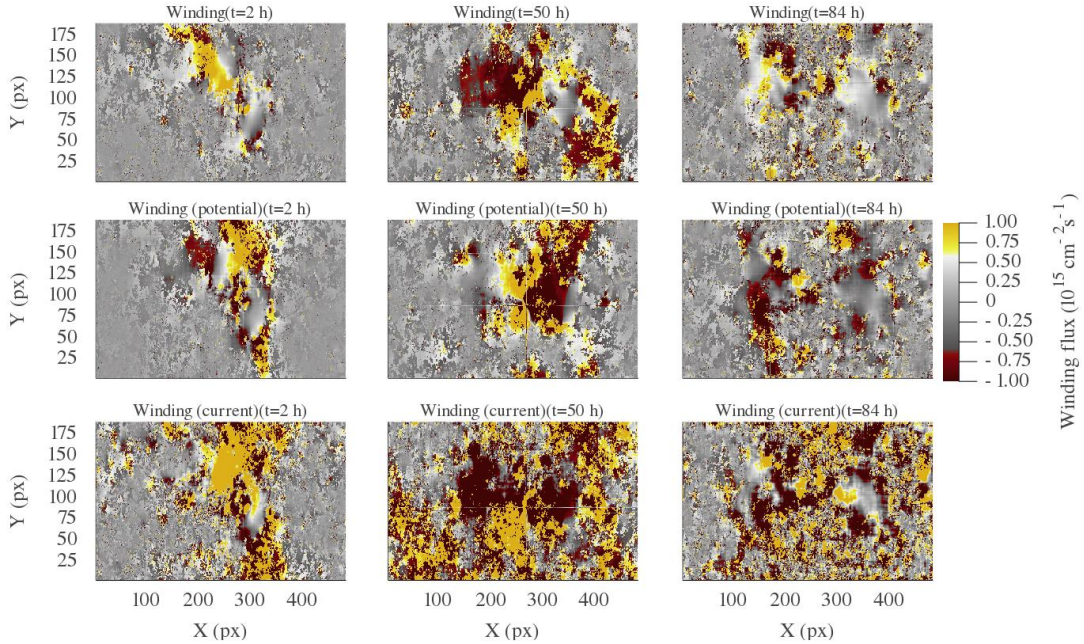
AR 11138

Helicity/winding accumulation

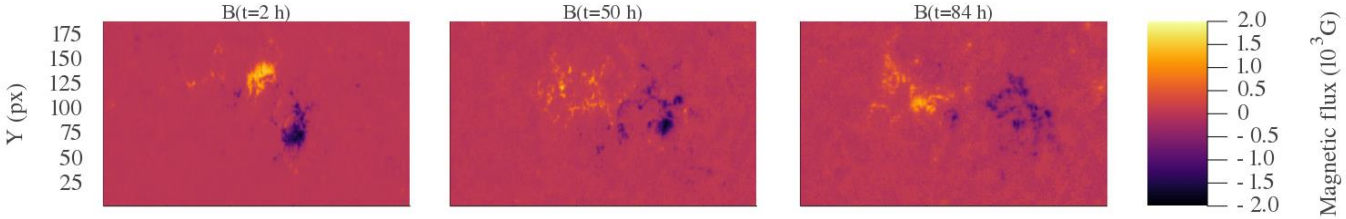


Wp/Wm/Wc-potential/mixed and current components, ΔW=|Wc|-|Wm|

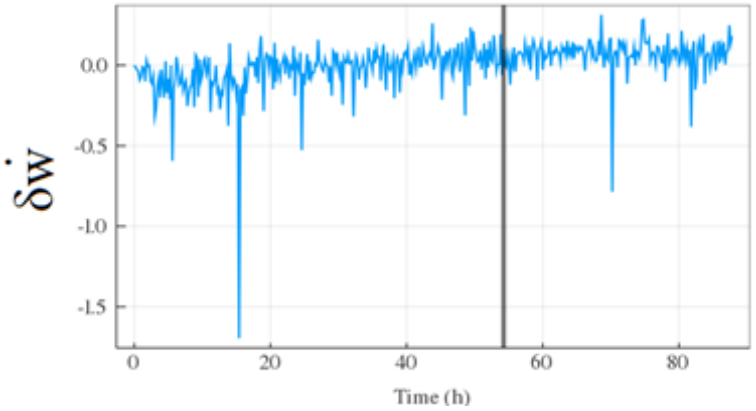
Winding density distribution



Magnetic flux density



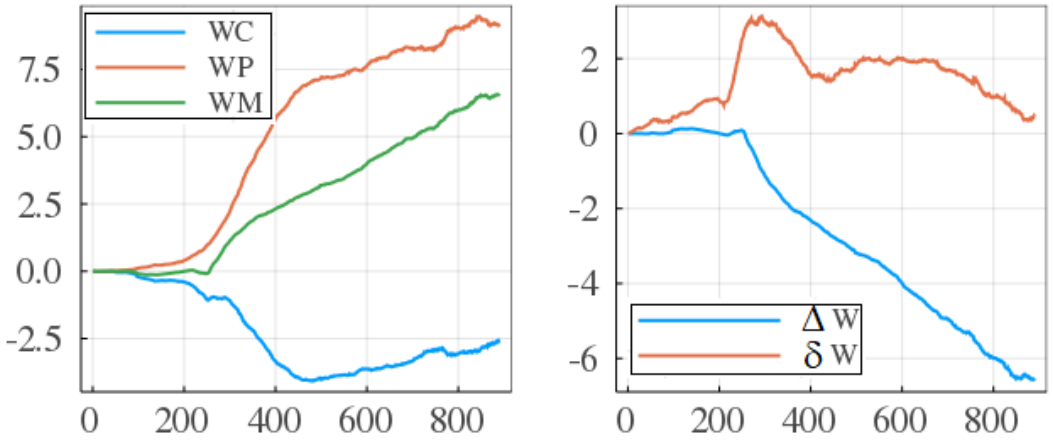
Winding input:



The only C-class flare marked in grey

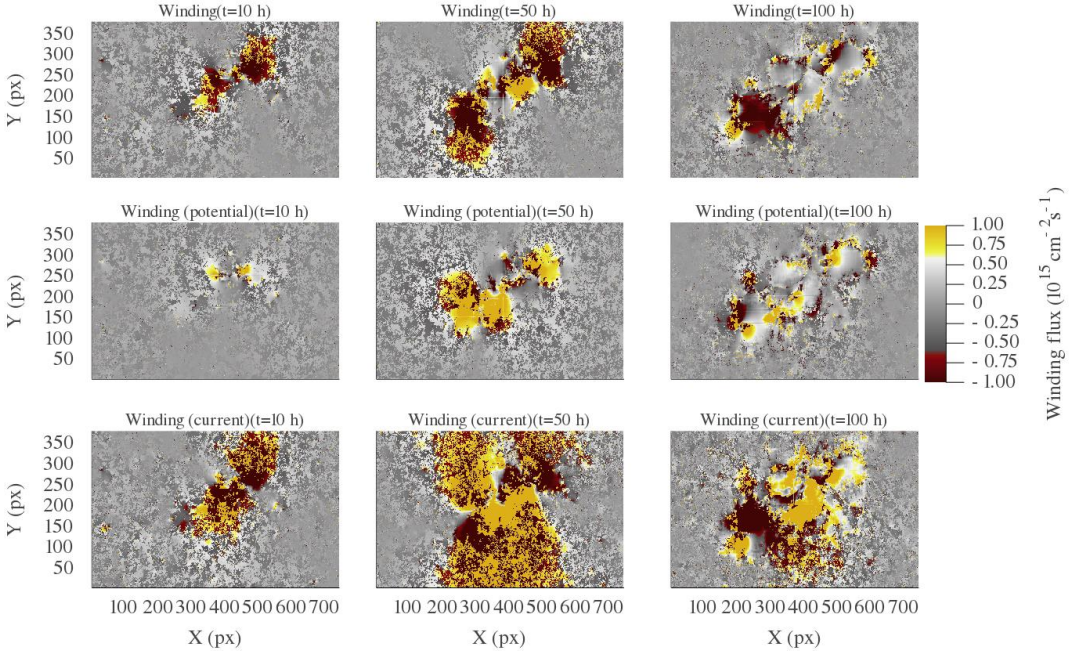
AR 11158

Helicity/winding accumulation

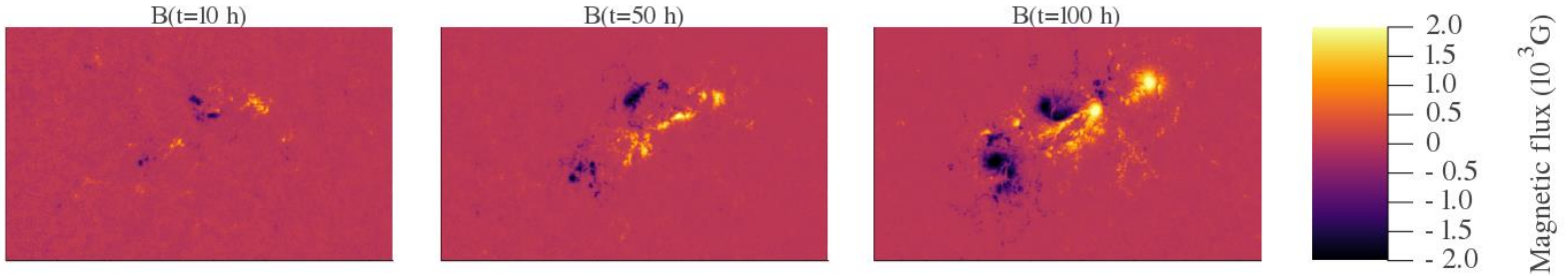


Legend: Wp/Wm/Wc-potential/mixed and current components, ΔW=|Wc|-|Wm|

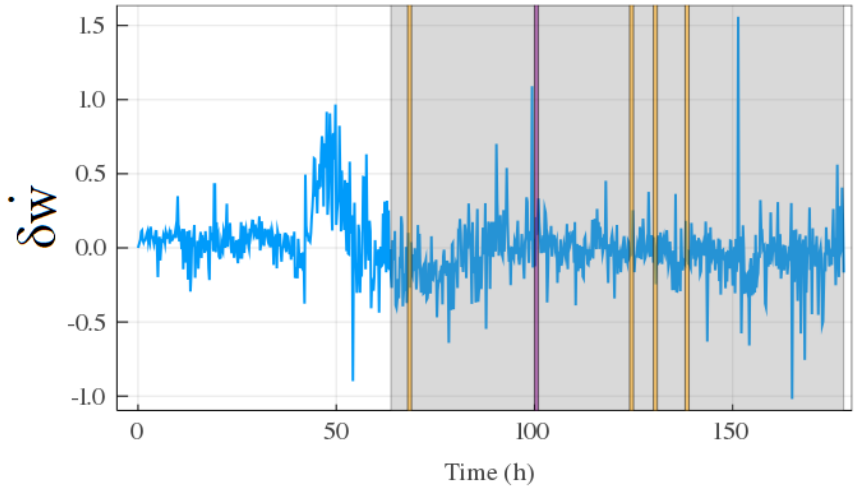
Winding density distribution



Magnetic flux density



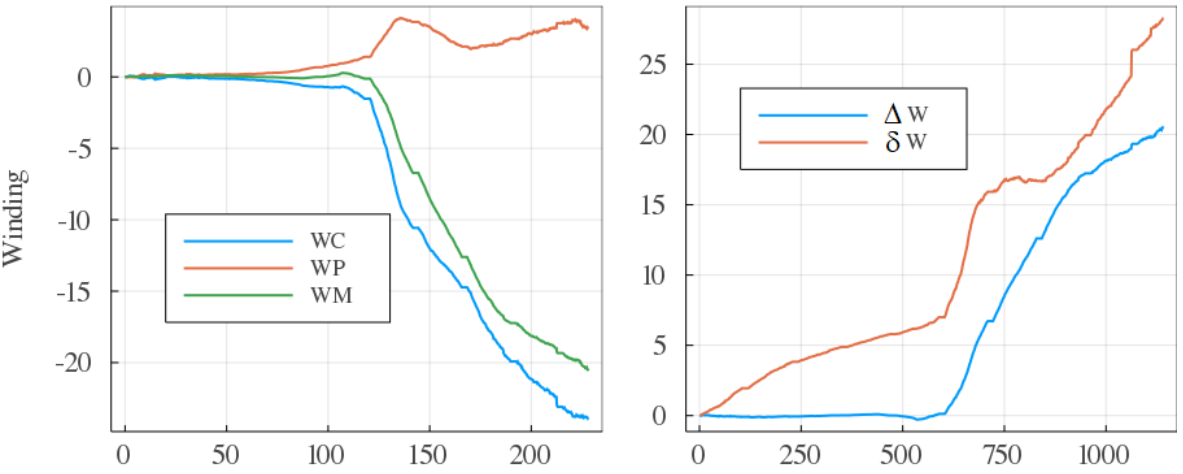
Winding input



A large input of winding is seen before the activity starts (grey), M-class flare (yellow), X-class flare (purple)

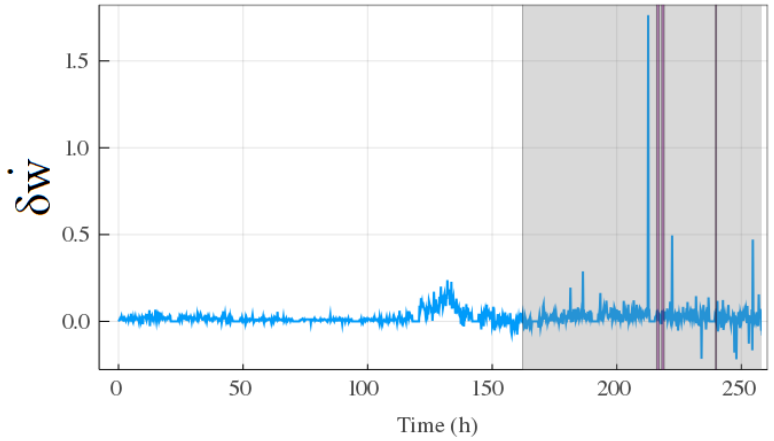
AR 12673

Helicity/winding accumulation

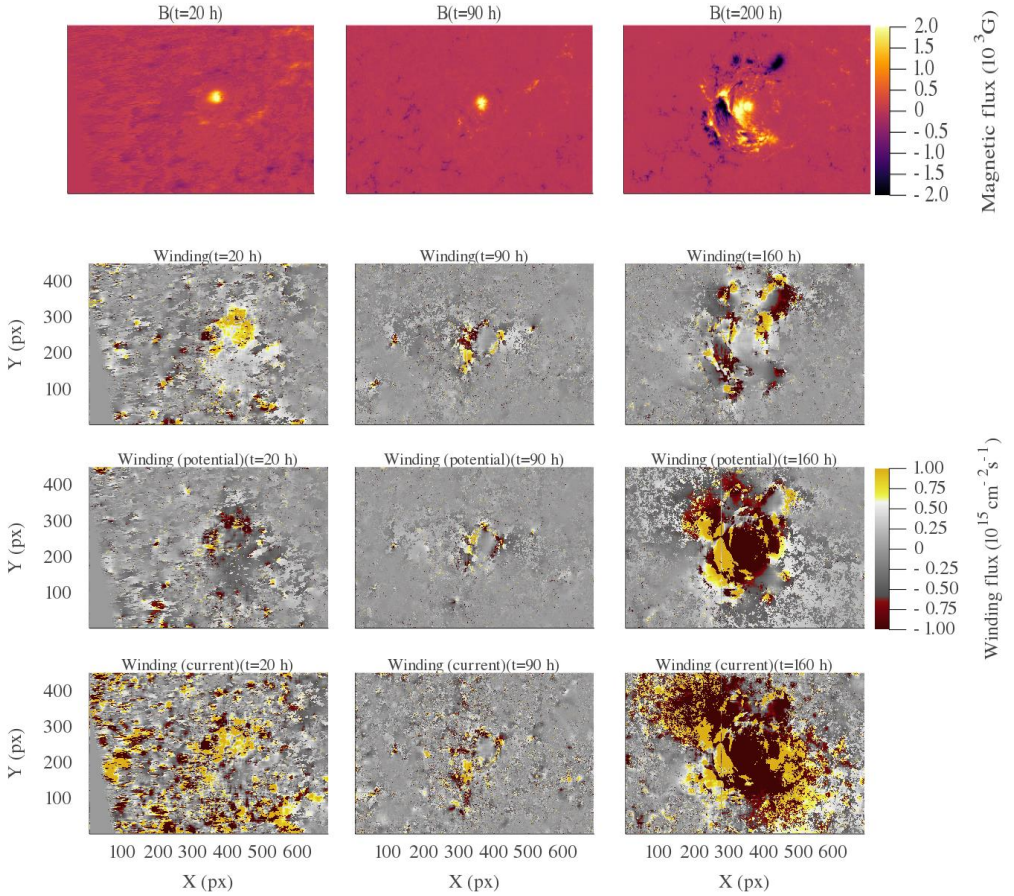


Legend: Wp/Wm/Wc-potential/mixed and current components, δW=|Wc|-|Wm|

Winding input:



A large input of winding is seen before the activity starts (grey), M-class flare (yellow), X-class flare (purple)



Magnetic flux density

Winding density distribution

Conclusions

The winding provides information that may help predict whether an AR will produce significant flaring activity, consisting of a dominance of the current carrying part of the winding over the potential one, 23-30 hours before the activity starts.

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