Long-term Helicity Evolution in AR 8100

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Introduction

Magnetic helicity measures the twist and writhe of the magnetic field and builds up in the corona through various mechanisms including the emergence of previously twisted field, and via photospheric shearing motions on already emerged field. Magnetic helicity is a well preserved quantity with an ideal MHD diffusion timescale of 10^5 years (Berger, 1984, Geophys. Astrophs. Fluid Dynamics). Even under resistive conditions in the corona, helicity does not decay but is redistributed within the coronal volume. Rust (1994, Geophys. Res.Lett) and Low (1996, Sol.Phys.) suggested that coronal mass ejections (CMEs) are a method by which the corona is able to expel helicity which would otherwise endlessly accumulate.

Research now needs to quantify the helicity ejected via CMEs and also to identify the main helicity source. This work follows active region (AR) 8100 during 5 solar rotations Nov. 1997 to Feb. 1998 and assumes the linear force-free field condition to compute:

A. The relative magnetic helicity content of the coronal field

B. The magnetic helicity injected by photospheric differential rotation

C. The magnetic helicity ejected via CMEs

Magnetic Helicity Overview

Magnetic helicity is defined by the volume integral: $H=\int_V \mathbf{A}\cdot\mathbf{B}\,dV$ (where **A** is the vector potential and **B** is the magnetic field)

It is **physically meaningful** only when B is fully contained inside the volume V. In a more general approach Berger & Field (1984, J. Fluid mech.) have shown that one can define a **relative magnetic helicity** by subtracting the helicity of a reference field which has the same distribution of B_n on the surface, S.

$$H_r=\int_V \mathbf{A}\cdot\mathbf{B}\,dV-\int_V \mathbf{A_0}\cdot\mathbf{B_0}\,dV$$

Helicity builds up in the corona via the emergence of twisted flux and photospheric shearing motions.The change of relative helicity is given by Berger & Field (1984) to be:

$$\frac{dH_r}{dt}=-2\int_S \left[(\mathbf{A}_0\cdot\mathbf{v})\mathbf{B}-(\mathbf{A}_0\cdot\mathbf{B})\mathbf{v}\right]\mathbf{dS} \quad (1)$$

Injection by photospheric motions

Injection by helicity flux across boundary

A. Relative magnetic helicity in the corona

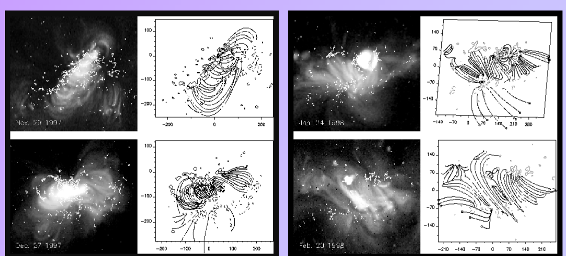


Fig. 1. Yohkoh Soft X-ray Telescope (SXT) images at central meridian passage for rotations 2-5 with corresponding linear force-free field extrapolations.

• The coronal helicity is computed under the linear (constant α) force-free assumption ($\vec{\nabla}\times\vec{B}=\alpha\vec{B}$), from magnetic field models using MDI magnetograms as the boundary condition. An iterative process is used, adjusting the value of α until the best **global** fit to the SXT images is achieved. The relative helicity is then found by following the method of Berger (1985, ApJS, 59, 433) which gives:

$$H_r=2\alpha\sum_{n_x=1}^{N_x}\sum_{n_y=1}^{N_y}\frac{\left|\tilde{B}^2_{n_x,n_y}\right|}{l(k_x^2+k_y^2)}$$

where $\tilde{B}_{n_x,n_y}$ are the Fourier amplitudes of the harmonics (n_x,n_y), $N_x=N_y=256$, $l=\sqrt{k_x^2+k_y^2-\alpha^2}$, $k_x=2\pi n_x/L$, $k_y=2\pi n_y/L$, and L is the horizontal size of the computational box.

• **The relative helicity has been computed for each central meridian passage of the AR using a linearised expression in α, and is detailed in columns 2 and 3 of the Results Table.**

• Initially, AR 8100 has negative helicity which is against the hemispheric trend (Pevtsov et al., 1995).

B. Magnetic helicity injected by differential rotation

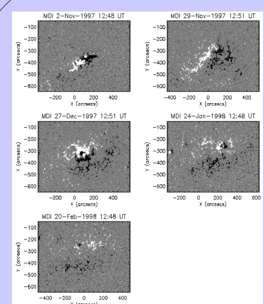


Fig. 2. MDI/SoHO line of sight magnetograms at each central meridian passage

The photospheric polarities rotate one around the other through more than 150 degree as is seen in the line of sight MDI/SoHO data (Fig. 2). Each image is taken at central meridian passage (CMP). This rotation indicates that the flux tube has been deformed as a result of vortices deep within the Sun (López Fuentes et al, 2000, Astrophys. J.).

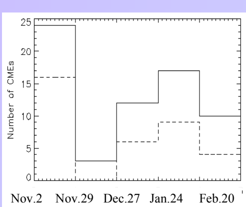
• To find the injection of helicity by differential rotation we use the first term on the right hand side of Eq.(1) which involves only shearing motions on the surface boundary. Berger (1984,1988) give an expression for the change of relative helicity due to shearing motions that depends only on observable quantities B_n and **v.** We can find the injection of relative helicity by using the B_n distribution as given by MDI data, and subjecting it to the differential rotation shear profile from the classic expression (Komm et al., 1993, Sol.Phys.). **Results are shown in column 4 of the Results Table, and give upper and lower bounds for the injected helicity**.

• Shearing motions other than differential rotation are only evident during the first rotation and inject negligible helicity (Green et al., 2002, Sol. Phys.).

• During rotations 2 to 5 the coronal helicity was positive and differential rotation served to deplete the coronal helicity as it injected negative helicity, but the CME activity continued.

• The rotation of the polarities produces a change in magnitude and even sign of the helicity injected by differential rotation (column 4 of Results Table).

C. The ejected magnetic helicity



The dashed line shows the observed CME number using lower coronal signatures to associate LASCO CMEs to the AR. The solid line shows the estimated CME number accounting for instrument data gaps and times when the active region passes behind the limb of the Sun.

• We assume a one to one correspondence between a CME and a magnetic cloud. Data from observations of 18 magnetic clouds (MCs) have been well fit with a force-free model (Lepping et al., 1990. J. Geophys. Res.) where average values of radius and magnetic field are: $R=2.1\times10^7$ cm, $B_0=2\times10^{-4}$ G. Démoulin et al. (2002, A&A) give the helicity content of a MC under the linear force-free assumption to be: $\frac{dH_r}{dz}\approx 0.70B_0^2R^3$

• Observations thus far have not revealed the lengths of MCs. Using a length of **0.5 AU** (as did DeVore, 2000, Astrophys. J.) the helicity content is **2×10^{42} Mx^2**. However, the MC may remain attached to the Sun giving it a length of at least **2 AU** and a helicity content of **8×10^{42} Mx^2**. Further work remains to be done to make these values more accurate.

• **Results for the helicity contained in the MCs are given in column 7 of the Results Table with upper and lower bounds given by the 2 flux rope lengths**. No quantity is given for the first rotation as the coronal helicity is changing sign during this time and we cannot tell which helicity sign the MCs carry away.

• Differential rotation cannot inject a sufficient amount of helicity into this rotating active region to account for the helicity shed by CME activity, commensurate with the results of Démoulin et al. (2002, A&A).

•The helicity source is likely to lie in the inherent twist of the AR flux tube deep within the Sun, created in the tachocline, and not in surface shear motions.

• The flux tube forming AR 8100 must either continue to emerge during the 5 rotations bringing with it the twist from the lower portions, or provide an upward propagation of twist (via torsional Alfven waves?) into the corona to supply a source of helicity for the continued CME activity.

CMP Date (1997/8)	H_{corona}	ΔH_{corona}	$\Delta H_{diff. rot.}$	N_{LASCO_cme}	N_{CME}	$H_{mag.cloud}$
Nov. 2	-11					
		33.5	[1.4,5.1]	16	24.1	?
Nov. 29	22.5					
		-2.9	[5.1,-4.6]	0	2.5	[5,20]
Dec. 27	19.6					
		-11.2	[-4.6,-2.8]	6	11.7	[23.4,93.6]
Jan. 24	8.4					
		-3.3	[-2.8,-1.6]	9	16.8	[33.6,134.4]
Feb. 20	5.1		-1.6	4	3.1	[6.2,24.8]

Results Table (Units for the table are 10^{42} Mx^2)

Future work with STEREO

• **In situ measurements are normally taken at only one point along the length of the magnetic cloud. We must assume that the model which has been fitted to this in situ data, and which we use to compute the magnetic helicity in the MC, applies to the full extent of the flux rope. Also, since the true length and structure of the magnetic cloud is not known we must assume values for several parameters to compute the magnetic helicity content.**

• **STEREO will allow us to determine the 3-D structure of the magnetic cloud for the first time. This will enable us to better understand its spatial extent resulting in a more accurate volume over which we can integrate the helicity.**

• **Lower coronal signatures of CMEs have already provided a way to study the source regions of these ejections. A more accurate knowledge of the helicity content of magnetic clouds will enable us to better relate the cloud to its source region and help us understand the cause of the CME.**