Helicity Injections in Regions of Various Magnetic Fluxes

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In this study, we investigate the amount of magnetic helicity injection (hereafter, helicity flux) among active region of various sizes (having different magnetic fluxes). We analyzed 78 active regions (more than 600 magnetograms), using the vector magnetograms obtained with the Solar Flare Telescope of NAOJ and SOHO/MDI magnetograms with the method proposed by Kusano et al. (2002). Ten active regions are tracked for several days, while other regions are studied based on single-day observation. The time cadence of data is 96 minutes. The magnetic flux of these regions ranges from 2.e+12 Wb to 4.e+14 Wb, and the absolute values of the helicity flux are from 1.e+17 Wb^2/s to 2.e+22 Wb^2/s.

From a scatter plot of magnetic flux and helicity flux, we found that the helicity flux has an upper limit for a given value of the magnetic flux, and the upper limit is nearly proportional to the magnetic flux. We can interpret these results with the model of helicity injection due to helical turbulence (Sigma-Effect; Longcope et al. 1998).

1. Helictiy Injection

Magnetic Helicity Injection (Berger 1999)

$$H_M = \int \vec{A}\cdot\vec{B}\,dV$$

Magnetic Helicity
Berger & Field (1984)

$$\dot{H}_M = 2\int[(\vec{A}_p\cdot\vec{B}_t)V_n - (\vec{A}_p\cdot\vec{V}_t)B_n]\,dS$$

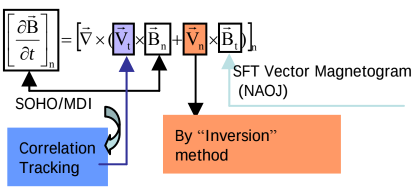
Emerging term — Shearing term

*t : tangential component
*n : normal component.

$\vec{A}_p$: Vector Potential of the current-free field.

Here we need the three-dimensional velocity and magnetic components to get the magnetic helicity injection. It is difficult to get normal velocity components. Here we used the method proposed by Kusano et al.(2002)

Induction Equation Method (Kusano et al. 2002)



In this method, normal velocity components are got from the induction equation. Other components are got from (vector) magnetogram.

Normalized Helicity Injection (Yamamoto et al. 2005)

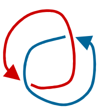
Because the magnetic helicity (H_M) is proportional to the magnetic flux (**Φ**) squared, it is not appropriate to compare the magnetic helicity among regions having different magnetic flux. Here we introduce the 'normalized' helicity (= twice linking number, Yamamoto et al. 2005), which is divided by the magnetic flux squared.

$$H_M = \int \vec{B}\cdot\vec{A}\,dV \;\Rightarrow\; H_M = 2L\Phi_1\Phi_2$$

Gauss's Linking Number : L

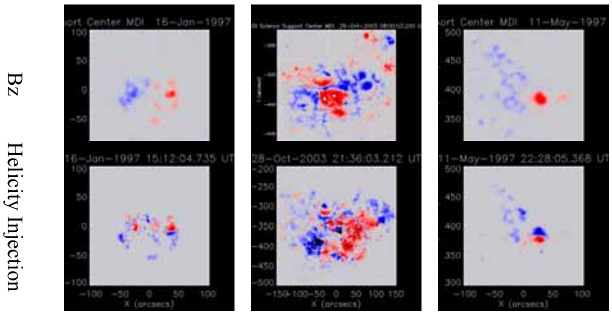
Flux Lope 1 : $\Phi = \Phi_1$

2 : $\Phi = \Phi_2$



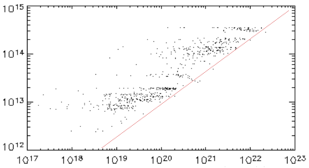
$$\frac{dH_M}{dt}(Wb^2/sec) \;\rightarrow\; \frac{dH}{dt}(/sec)$$

2. Data

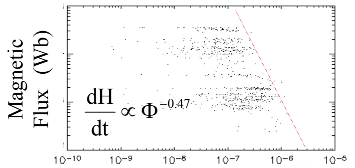


Upper row figures show the longitudinal magnetic field strength taken with MDI/SoHO. Lower row show the helicity injection map. All data points is over 600.

3. Results



Net Magnetic helicity rate (Wb^2/s)



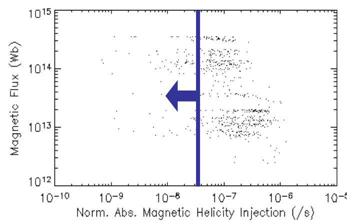
Net Normalized helicity rate (/s)

Above figure show scattered plots of the net magnetic/normalized helicity injection rate, which is integrated over each active region.In the right side of the plots, there may be the maximum value limit. In the left side of the plots, some points show small injection rate.

=> What physical process make this trend ?

4. Candidate Process

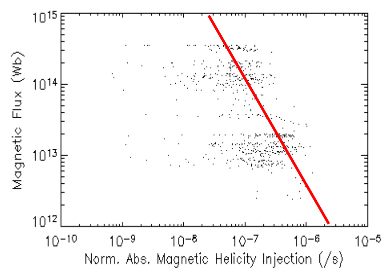
4-1. Differential Rotation



DeVore (2000): In his study, a magnetic bipolar is under the photosphere. He estimated the magnetic helictiy injection rate due to the differential motion analytically and numerically. He do not lead a dependence on the magnetic flux.

As a result, estimated magnetic helicity injection rate due to the differential motion is less than the observed values by one order.

4-2. Turbulence (Sigma-effect)



As a result of Longcope et al. (1998), twist (= force free alpha) is proportional to the magnetic flux.

$$\alpha \propto \Phi^{-0.7}$$

With magnetic flux tube model and proper velocity of line of sight (~2km, Inversion method of Kusano), we got the normalized helicity injection rate.

$$\frac{dH}{dt} = \alpha v_z/2\pi \propto \Phi^{-0.7}$$

With above proportional relation, red line on the plot show the dependence of the helicity injection on the magnetic flux.

5. Summary

@ the helicity flux has an upper limit for a given value of the magnetic flux, and the upper limit is nearly proportional to the magnetic flux.

@ We compare our results with those of the previous papers.
- Differential Rotation: One order smaller.
- Turbulence : Promising order and power of the magnetic flux.

@ We hope the Solar-B/SOT will give us the excellent quality magnetogram data to investigate the helicity.