Magnetic Helicity In Emerging Active Regions: A Statistical Study

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Topics of this work

- Study magnetic helicity in emerging active regions;
- Examine the so-called ``hemisphere rule'', i.e., ARs in northern hemisphere has nagetive helicity, and in southern hemisphere positive helicity;
- Explore relationship between magnetic helicity and solar transients in ARs.

Motivation

- How an active regions builds up its helicity is still not clear;
- Hemisphere rule is weak when study the current helicity of active regions in solar cycle 22 (Pevtsov et al. 1995; Bao et al. 1998), but no systematic studies for cycles 23-24;
- Possible correlation between AR-helicity and solar transients is explored recently (e.g., LaBonte et al. 2007).

Methodology

- Select emerging active regions;
- Compute helicity flux across solar surface (photosphere in this work);
- Integrate the flux over time to estimate total helicity accumulated in the corona. The integral starts at the very beginning of AR's emergence.

Calculation of helicity flux

Helicity flux across the photosphere:

$$\left(\frac{dH}{dt}\right)_{photosphere} = 2\times\int_{photo}(\mathbf{A}_p \bullet \mathbf{B}_h)V_n ds - 2\times\int_{photo}(\mathbf{A}_p \bullet \mathbf{v}_h)B_n ds$$

B_h, B_n [obs], and V_h, V_n [obs + DAVE4VM (Schuck 2008)]

Calculation of helicity flux (cont)

- However, currently we don’t have enough vector magnetic field data that allow to carry out a statistical study. Thus we use line-of-sight field data instead, using the Demoulin & Berger’s model (2003). This model allows to estimate total helicity flux using time-series line-of-sight magnetograms only. Study shows that the helicity flux computed from this model can recover ~90% of total flux.

Demoulin & Berger's model (2003)—DB03 model

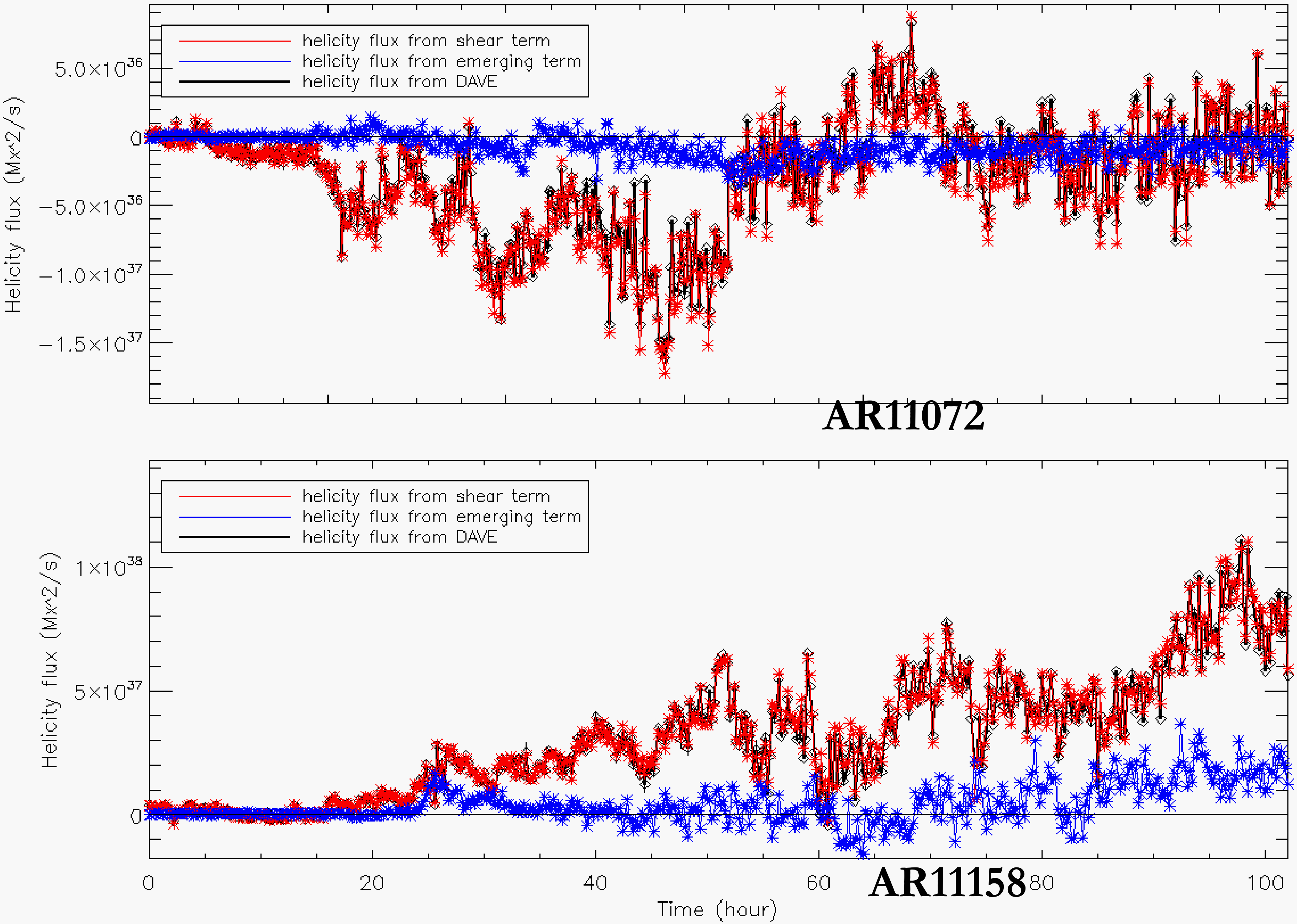
Demoulin and Berger (2003) proposed that,

$\mathbf{u} = \mathbf{v}_h - \mathrm{v}_z \mathbf{B}_h / B_z$,

where, $\mathbf{u}$ is the horizontal velocity derived by tracking the photospheric footpoints of flux tubes. In this way, helicity flux across the photosphere can be re-written as,

$$\left(\frac{dH}{dt}\right)_{photosphere} = 2 \times \int_{photosphere} \left(\left(\mathbf{A}_p \bullet \mathbf{B}_h \right) \mathrm{v}_z - \left(\mathbf{A}_p \bullet \mathbf{v}_h \right) B_z \right) ds = -2 \times \int_{photosphere} \left(\mathbf{A}_p \bullet \mathbf{u} \right) B_z ds.$$

Using DAVE (Schuck 2006)→u


helicity flux from shear term
helicity flux from emerging term
helicity flux from DAVE
Helicity flux (Mx^2/s)
5.0×10^36
0
−5.0×10^36
−1.0×10^37
−1.5×10^37
AR11072
helicity flux from shear term
helicity flux from emerging term
helicity flux from DAVE
Helicity flux (Mx^2/s)
1×10^38
5×10^37
0
0
20
40
60
80
100
Time (hour)
AR11158

Results (18 Emerging ARs)

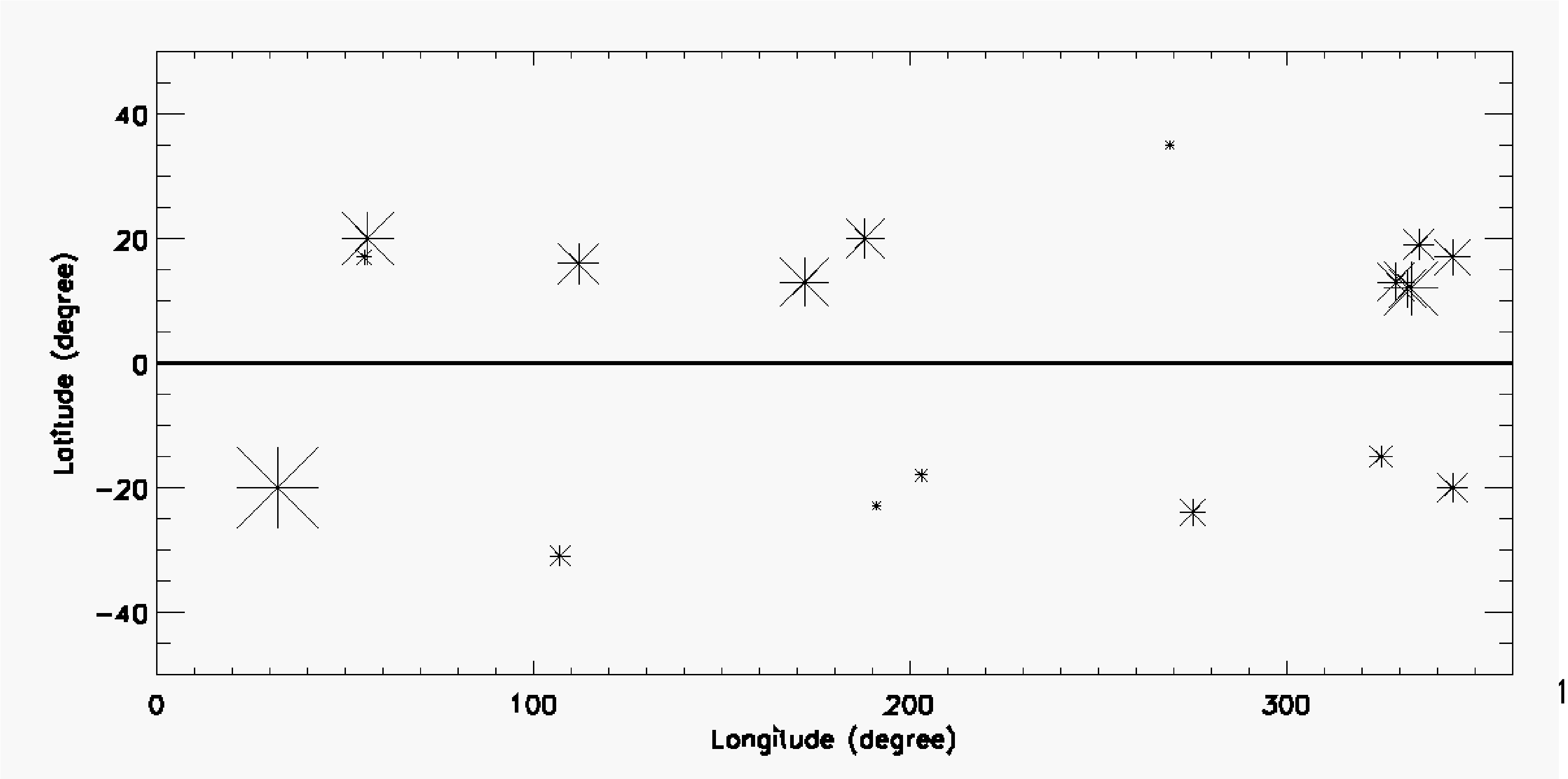
AR	Period	Location	Unsigned flux	Total helicity	remarks
	Start-stop	Lat, lon	Mx	Mx^2	
11072	2010.05.20-2010.05.26	-15, 325	7.00e21	-1.10e42	No flares
11112	2010.10.14-2010.10.18	-18,203	5.50e21	3.10e40	No flares
11117	2010.10.23-2010.10.27	20,56	1.50e22	1.60e42	C flares
11123	2010.11.10-2010.11.13	-23,191	4.00e21	7.64e41	C flares
11124	2010.11.11-2010.11.16	13,172	1.37e22	-4.79e41	No flares
11126	2010.11.14-2010.11.19	-31,107	6.58e21	-3.06e41	NO flares
11130	2010.11.28-2010.12.02	13,329	1.04e22	-1.86e42	C flares
11141	2010.12.30-2011.01.03	35,269	4.91e21	-2.73e41	C flares
11149	2011.01.21-2011.01.23	17, 344	9.96e21	1.86e42	C flares
11150	2011.01.29-2011.02.02	-20,334	8.22e21	5.67e41	No flares
11158	2011.02.12-2011.02.17	-20,32	3.10e22	1.05e43	X, M, C flares
11160	2011.02.17-2011.02.22	19,335	8.59e21	1.85e41	C flares
11161	2011.02.15-2011.02.22	12,333	1.58e22	5.61e42	C flares
11175	2011.03.18-2011.03.21	12,332	1.03e22	7.64e41	No Flares
11184	2011.04.02-2011.04.07	16,112	1.11e22	5.12e42	No flares
11199	2011.04.25-2011.04.29	20,188	1.06e22	2.60e41	No flares
11214	2011.05.13-2011.05.19	-24,275	7.65e21	3.42e41	No flares
11242	2011.08.28-2011.07.01	17,55	5.66e21	5.75e41	No flares

Results (18 Emerging ARs)

- 7 ARs in southern hemisphere, 11 ARs in northern hemisphere;
- 5 ARs have negative helicity, 13 ARs have positive helicity;
- 8 ARs obey the hemisphere rule (44%); 10 ARs are opposite to the rule (56%);
- 71% ARs in southern hemisphere obey the hemisphere rule; 27% ARs in northern hemisphere are opposite to the rule.

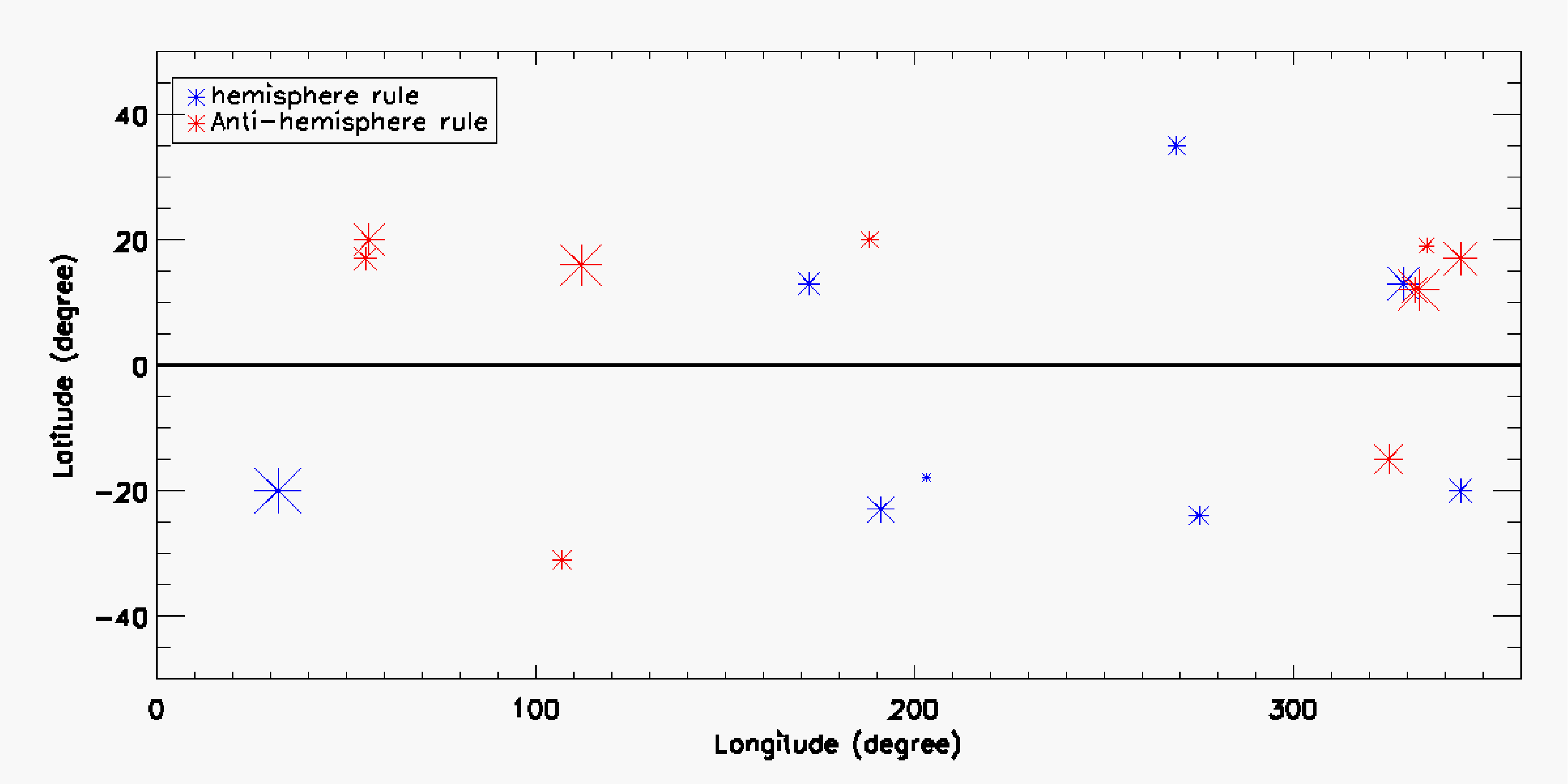
Distribution of Emerging ARs

- Size of symbol is proportional to unsigned flux of the AR.



Distribution of helicity in ARs

- Size of symbol is proportional to the total helicity in an AR.



Distribution of current helicity for cycle 22.

Pevtsov et al. (1995) for studying distribution of current helicity in ARs.

1. Using IVM vector data from 1988 to 1994. In total 69 ARs are studied;
2. Compute linear force-free alpha by minimizing the difference between linear-force-free field and observed field (transverse component);
3. 76% ARs in northern hemisphere obey hemisphere rule, 69% ARs in southern hemisphere obey the hemisphere rule.

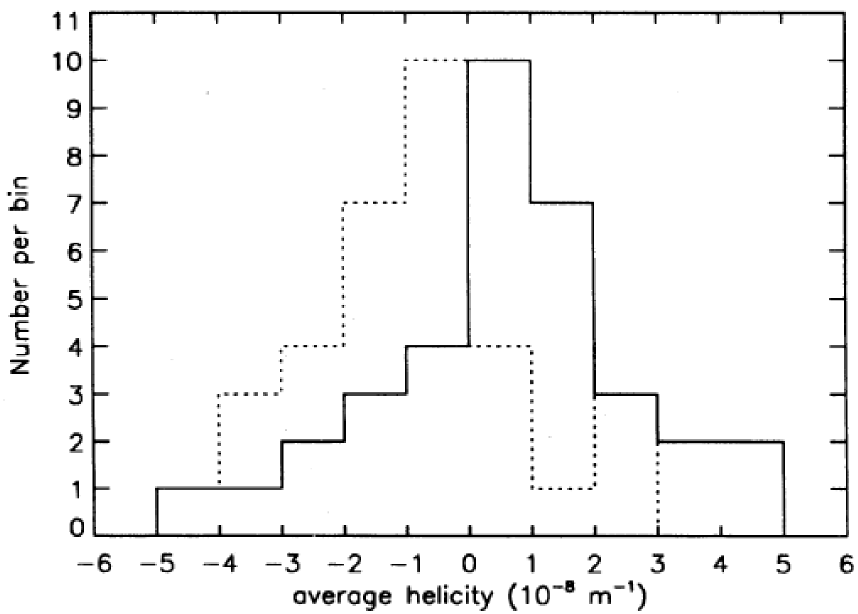
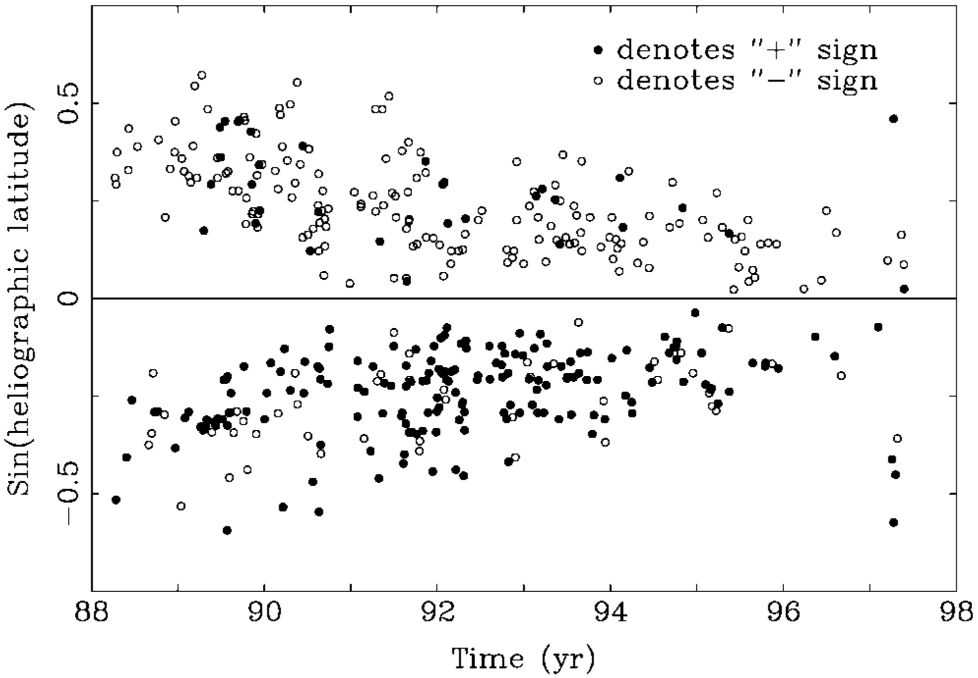


FIG. 2.—Histogram of average magnetic helicity of 33 active regions of northern (*dashed line*) hemisphere and 36 active regions of southern (*solid line*) hemispheres.

Distribution of current helicity in cycle 22

$$H_c = \boldsymbol{B} \cdot (\nabla \times \boldsymbol{B}).$$

$$h_c = \mu_0 B_z J_z,$$

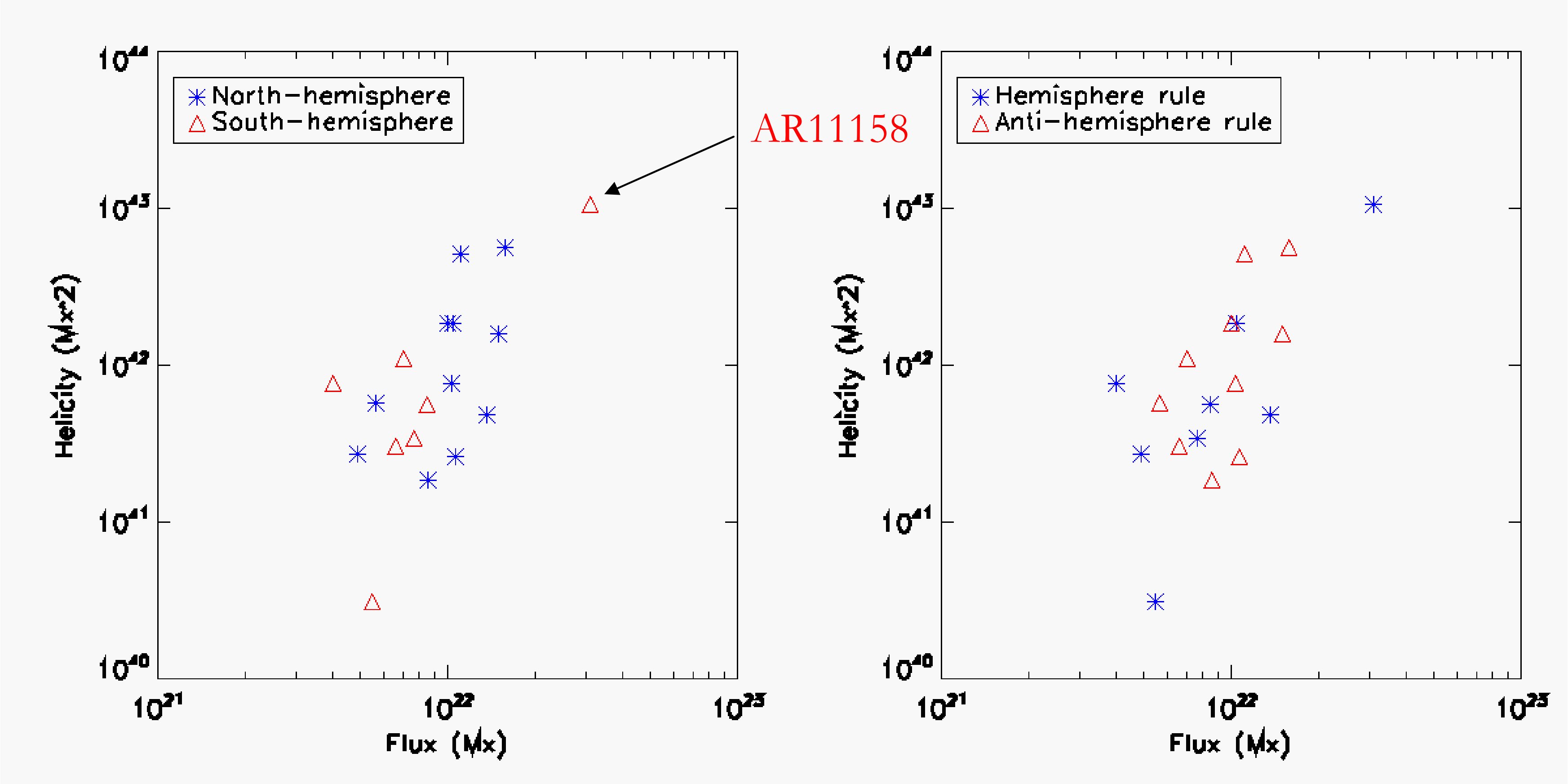


Bao & Zhang (1998)

1. Data from Huairou from 1988-1998;
2. In total 422 ARs are used for this study;
3. 84% ARs in north hemisphere obey hemisphere rule; 81% ARs in south hemishpere obey the rule.

Helicity versus magnetic flux

- A linear fit to data yields:
  Helicity = 2.17e41 + 0.044 * Flux^2



LaBonte et al (2007)

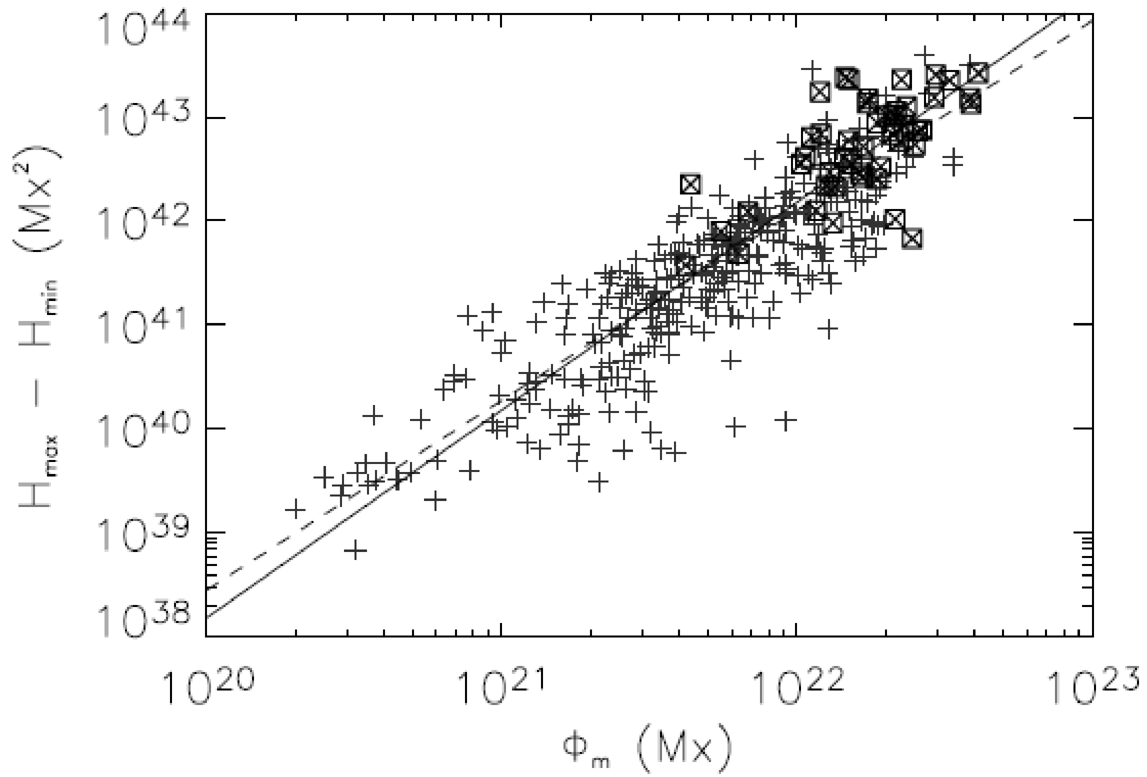


FIG. 8.—Integrated helicity flux as a function of total AR magnetic flux. The best-fit line (*dashed line*) is very close to the solid line, which would result if the integrated helicity flux were proportional to Φ_m^2 during the sampling interval. Most X-flare regions had an integrated helicity flux that exceeded the typical helicity content of CMEs, 2×10^{42} Mx^2.

Summary

- We study 18 emerging active regions in early phase of solar cycle 24. It is found that (1) 72% active regions have positive helicity; (2) 56% ARs are against the hemisphere rule; (3) ratio of |helicity| versus Flux^2 is about 0.044, if fit to the data from all 18 ARs.