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Axial dipole moments of solar active regions in cycles 21-24

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Axial dipole moment

- The axial dipole moment of an active region can be defined as

$$D = \frac{3}{4\pi} \int B_r(\theta, \phi) cos(\theta) d\Omega$$

- According to Hale’s and Joy’s laws the latitude and longitude ordering of the positive and negative polarity parts of active regions should remain the same in each solar cycle
- If all active regions follow Hale’s and Joy’s laws, their axial dipole moments have the same sign in each cycle (normal-sign moments)
- Violations of these laws can cause the sign of the axial dipole moment to be opposite to the expected sign (opposite-sign moments)
- The normal and opposite signs change from one cycle to the next, in accordance with the reversal of the polarity of the solar magnetic field
- We identified active regions from NSO/SOLIS and HMI synoptic maps of the photospheric magnetic field between 1975 and 2019 and computed their axial dipole moments

Axial dipole moments of ARs

The majority of the axial dipole moments have the expected sign but smaller numbers of opposite-sign moments continuously emerge. A few very strong opposite-sign moments can be seen.

The northern hemisphere activates first and opposite sign moments emerge on average later than the normal-sign moments. The only execption is cycle 24, where the average emergence time is almost identical for both signs.

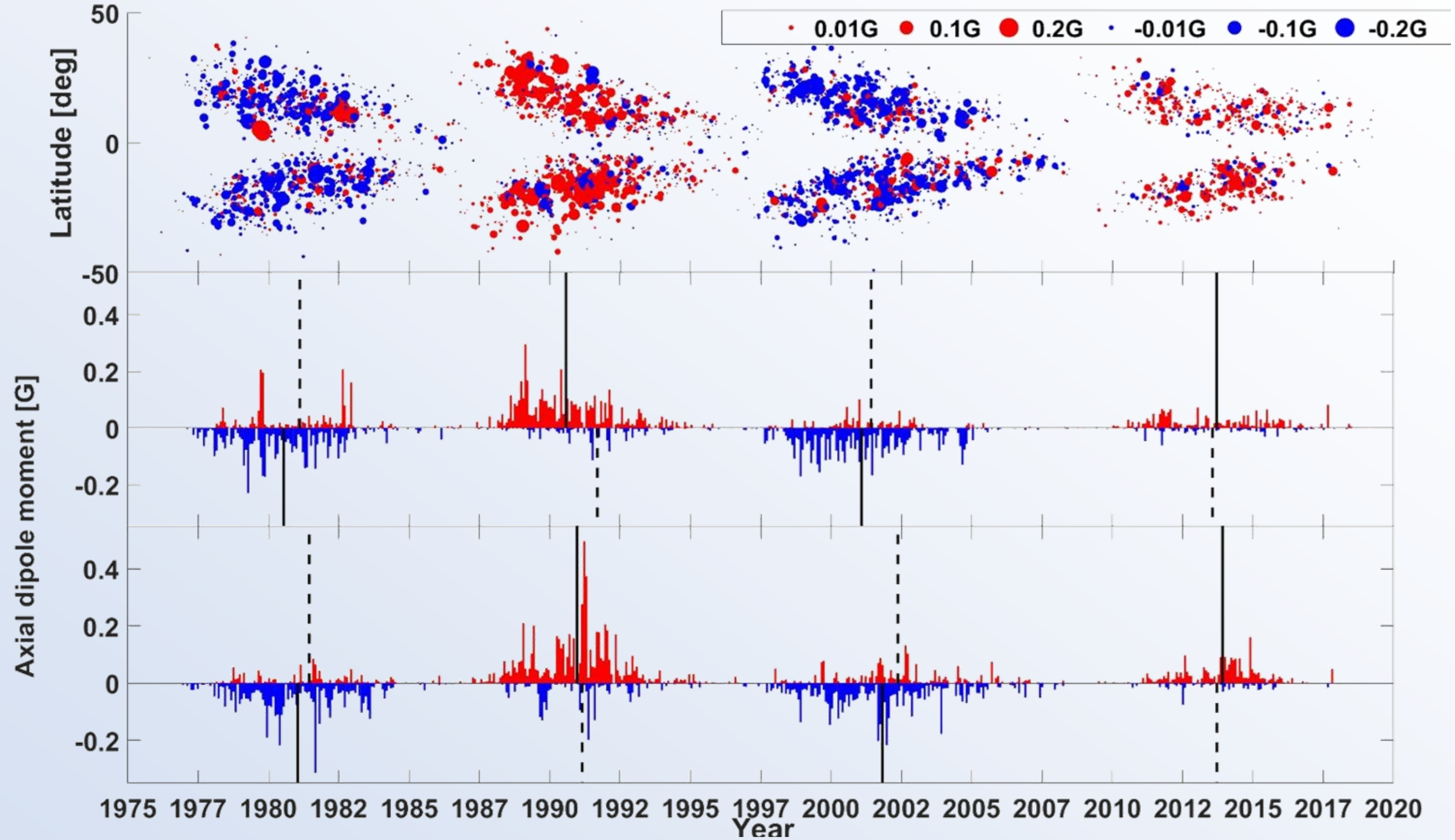

Figure 1. Top panel: Axial dipole moments of active regions. Dot size represents the absolute value and red and blue colors positive and negative signs.
Middle panel: Total axial dipole moment during each rotation in the northern hemisphere. Sums of positive and negative moments are shown separately with red and blue bars. Solid and dashed vertical lines show the mean emergence time of normal and opposite-sign moment, respectively.
Bottom panel: Same as middle panel, but for the southern hemisphere.

Dipole moment histograms

The relative number of active regions with small normal-sign axial dipole moments is very similar in all wings of cycles 21-23, as indicated by the similar values in the first few bins in the normal (right) side. However, cycle 24 shows a significantly higher number of active regions with a small normal-sign axial dipole moment. This indicates a very low number of active regions with large axial dipole moments, which was also seen in Figure 1.

The relative number of small opposite-sign axial dipole moments is fairly similar in all wings. Cycle 24 does not differ from the other cycles in this respect.

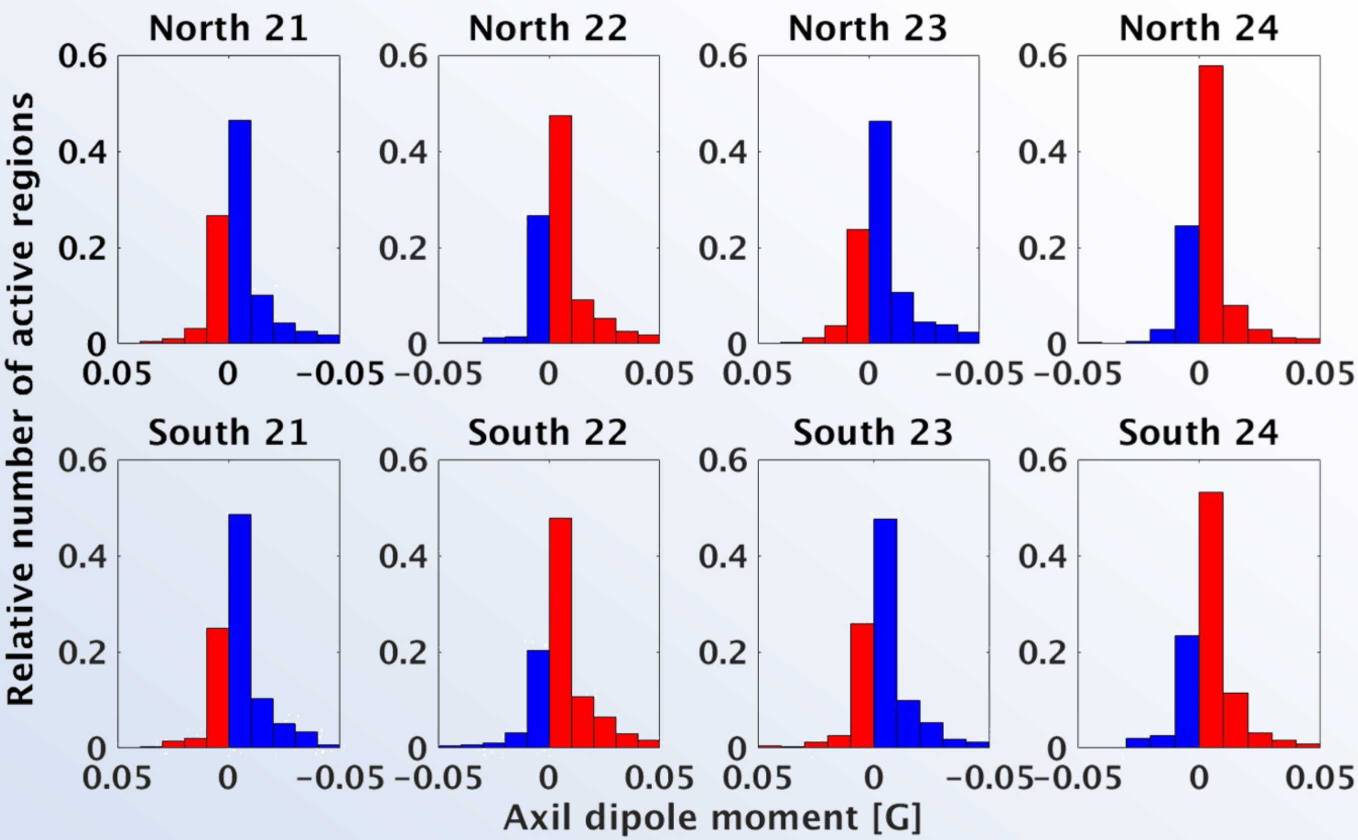

Figure 2. Histograms of axial dipole moments of active regions for the northern and southern wings of cycles 21-24. The values of each wing have been normalized by dividing with the total number of active regions in the wing. Bin size is 0.01G. The horizontal axes of cycles 21 and 23 have been reversed so that the normal sign of the cycle is always on the right.

Normal and opposite distributions

Figure 3 shows the difference in the distributions of normal- and opposite-sign axial dipole moments. The opposite-sign moments are on average smaller, as indicated by the narrower distribution. Active regions with large opposite-sign axial dipole moments exist but are rare.

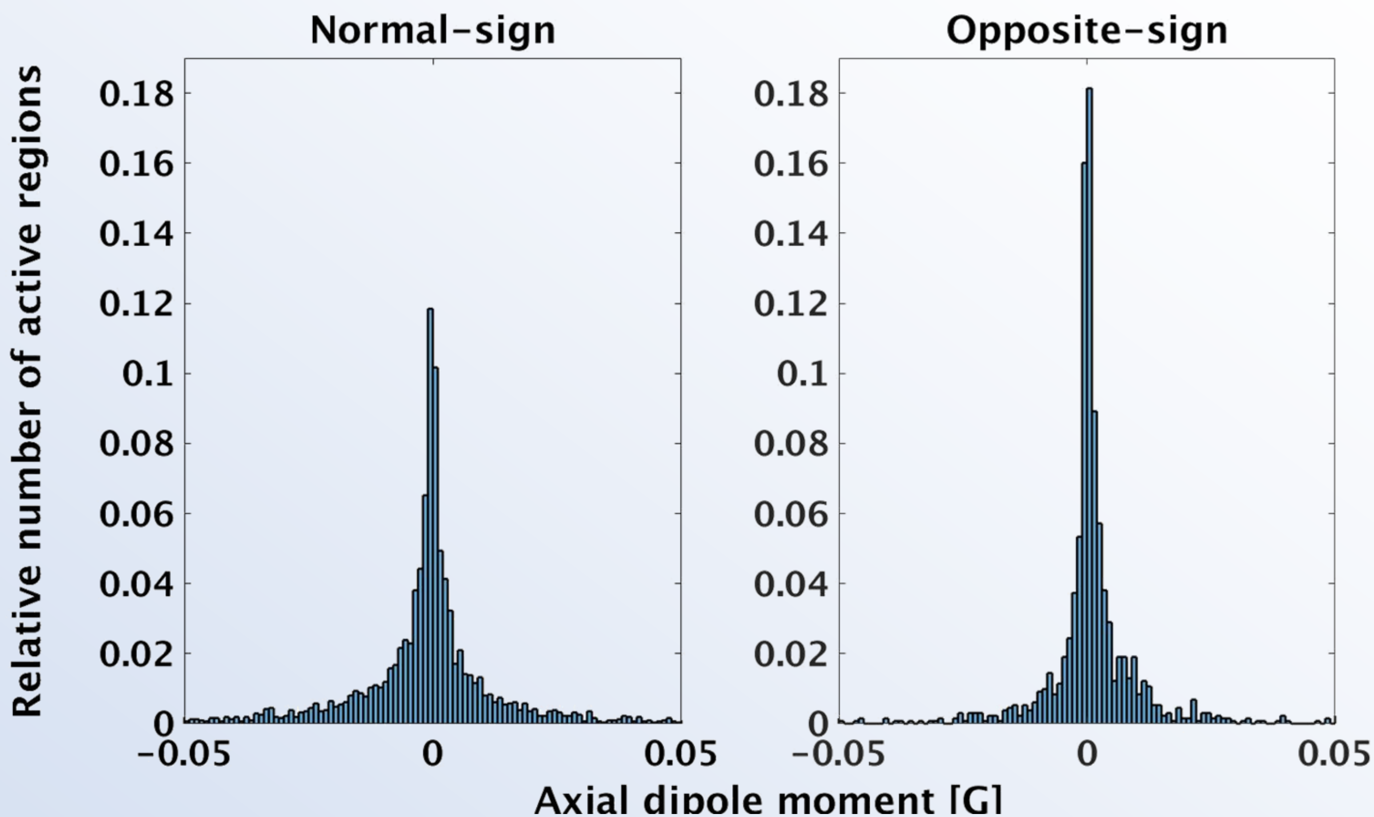

Figure 3. Histograms of axial dipole moments for all active regions of cycles 21-24. The values have been normalized by dividing with the total number of normal- and opposite-sign active regions, respectively.

Dipole moment vs. total flux

For active regions with a small total flux the distribution of axial dipole moments is a similar cone in all wings. Normal- and opposite sign moments emerge in roughly the 2:1 ratio shown in Figure 2.

At high total fluxes the wings differ sigificantly. Note for example the almost complete lack of large active regions and axial dipole moments in cycle 24.

While there are limits to the axial dipole moment an active region with a certain amount of flux can obtain, the moments are fairly randomly distributed within these limits.

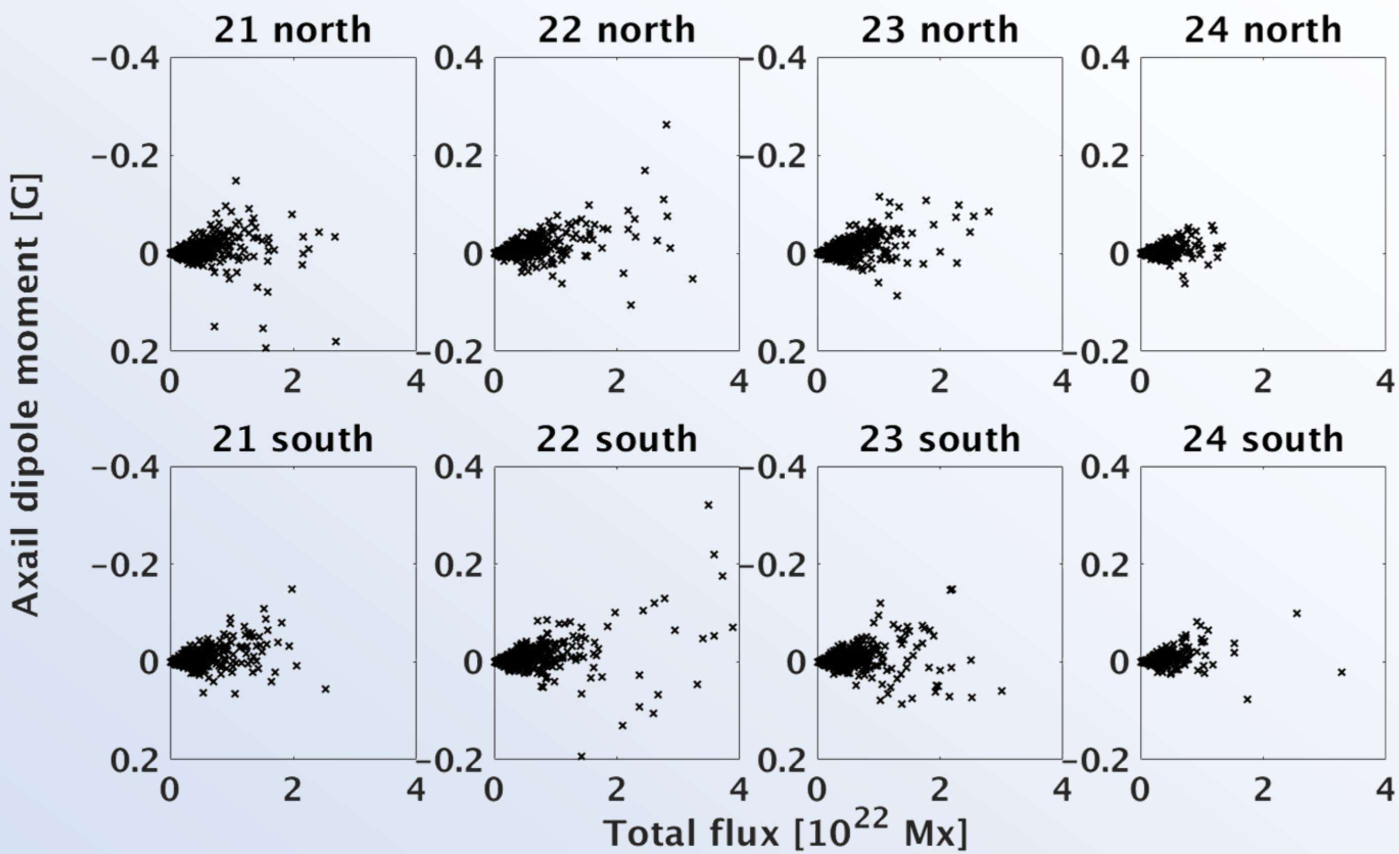

Figure 4. Axial dipole moment of active regions as a function of total flux for northern and southern wings of cycles 21-24.

Conclusions

- Active regions with opposite-sign axial dipole moments continuously emerge
- Most of the opposite-sign moments are small, but large moments occasionally appear, and can potentially affect the evolution of the cycle
- The emergence of small active regions with small axial dipole moments tends to be similar in all cycles and wings
- Cycle 24 differs from cycles 21-23 in many ways. Active regions with large total fluxes and axial dipole moments are missing almost completely.

For more information see our paper on the subject:

Virtanen, I.O.I., I.I. Virtanen, A.A. Pevtsov, and K. Mursula, Reconstructing solar magnetic fields from historical observations. VI. Axial dipole moments of solar active regions in cycles 21–24, Astron. Astrophys., 632, A39, 2019

https://www.aanda.org/articles/aa/full_html/2019/12/aa36134-19/aa36134-19.html