MODERN ASTRONOMY: FROM THE EARLY UNIVERSE TO EXOPLANETS AND BLACK HOLES

The features of the north-south asymmetry of the magnetic flux in active regions with different magnetic morphology in solar cycles 23 and 24

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Abstract. We use the CrAO catalog of the magneto-morphological classes (MMC) of active regions (ARs) to study the hemispheric distribution of the number and magnetic fluxes of ARs that appeared on the disk from May 1996 to December 2021. 3047 ARs were distributed between classes of the regular (bipolar groups that obey empiric rules for sunspots) and irregular (all the rest, except for unipolar sunspots) ARs. The analysis of the results showed that all the trends are more pronounced in the flux data. For the irregular ARs, the strongest peaks in time profiles are observed in the second maximum of the cycle in the S-hemisphere. ARs of both MMC types demonstrate noticeable N-S asymmetry. The most abrupt changes are shown by the irregular ARs fluxes. For the compiled quadrupolar-like component of the flux, the evidence of oscillations with a period of about 15 years is found for all studied ARs and for the irregular groups. For the regular ARs, cross-correlation of ARs fluxes in different hemispheres in adjacent cycles showed no features. For the irregular groups, a high correspondence in flux dynamics in the N-hemisphere of cycle 23 and in the S-hemisphere of cycle 24 is found.

Keywords: Sun: activity, magnetic fields, sunspots

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1 Introduction

Active regions (ARs) on the surface of the Sun bear imprint of the processes hidden under the photospheric level. Occurrence of ARs with atypical magnetic configuration allows us to reveal signs of complex non-linear processes in the convection zone that interfere in the global dynamo action (Abramenko et al. 2018, 2023). The hemispheric distribution of such ARs also demonstrates significant features (Zhukova et al. 2023).

According to the magneto-morphological classification (MMC) of ARs proposed earlier by CrAO (Abramenko et al. 2018; Abramenko 2021), 3047 ARs that appeared on the disc from May 1996 to December 2021, excluding unipolar spots, were distributed between the regular groups (bipolar ARs obeying empirical rules for sunspot groups) and irregular ARs (all the rest). The catalog MMC ARs CrAO[1] was used to continue the study of the North-South asymmetry of ARs with different magnetic morphology.

2 Results

Cyclic variations of ARs number and fluxes are shown in Fig. 1.

Flux time profiles are more expressive than those for the number of ARs (Fig. 1). Such a tendency was also noticed in Zhukova et al. (2024). A typical time lag between the activity in different hemispheres is found for both the regular and irregular ARs. The pattern for different MMC type ARs is not the same. For the irregular ARs, the distinct peaks observed in the second maximum may be due to the manifestation of the turbulent dynamo action (Abramenko et al. 2023).

The North-South (N-S) asymmetry is found for ARs of both MMC types. However, for the irregular ARs, it is more pronounced (especially, for ARs fluxes). The predominance of the irregular ARs in one of the hemispheres might be due to the more noticeable turbulence manifestation in the hemisphere where the magnetic field is weakened due to the interaction of the dipolar and quadrupolar components of the global field.

Synoptic maps of the magnetic field are suitable for the harmonic analysis (see, e.g., Obridko et al. (2021)). However, such data are not available for the regular and irregular ARs to date. For this reason, despite the limitations of the approach, we compiled a proxy for the dipolar and quadrupolar components of the magnetic flux using the simplest axisymmetric approximation (Hazra & Nandy 2019). Following Kitchatinov (2022), we used F_{N} and F_{S} (the part of the flux observed in the N- and S- hemispheres, respectively) to express the quadrupolar-like and dipolar-like

[1] https://sun.crao.ru/databases/catalog-mmc-ars

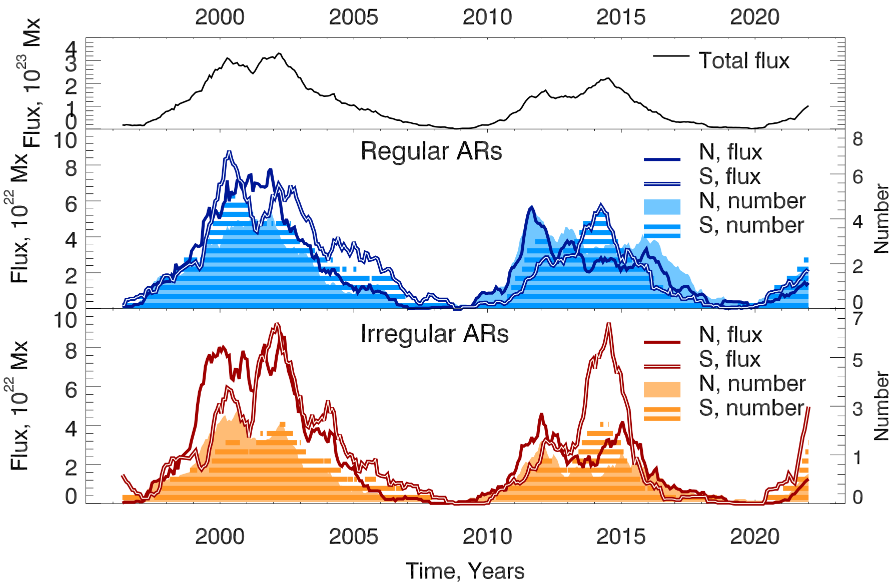

Fig. 1. Cyclic variations of ARs. Total magnetic flux (top panel); the number (fill) and fluxes (lines) of the regular (middle panel) and irregular (bottom panel) ARs in different hemispheres.

components as

$$F_{\mathbf{QL}} = \frac{(F_N + F_S)}{2} \quad \text{and} \quad F_{\mathbf{DL}} = \frac{(F_N - F_S)}{2}, \tag{1}$$

respectively.

To explore this two proxies we applied for them the auto-correlation function technique using the following equation

$$C(n\delta t) = \frac{1}{N-n} \sum_{i=1}^{N-n} F(t_i) F(t_{i+n}), \tag{2}$$

where $F(t)$ is the magnetic flux (in Maxwell), δt is the time increment, N is the total number of data points, n is the time lag.

For all types of ARs, for the dipolar-like component, the periodicity of about 12 years with anti-correlation of about minus one is observed (Fig. 2), which implies a whole cycle of about 22–24 years. For all ARs and for the irregular groups, for the quadrupolar-like component, oscillations with a period of about 15 years are found.

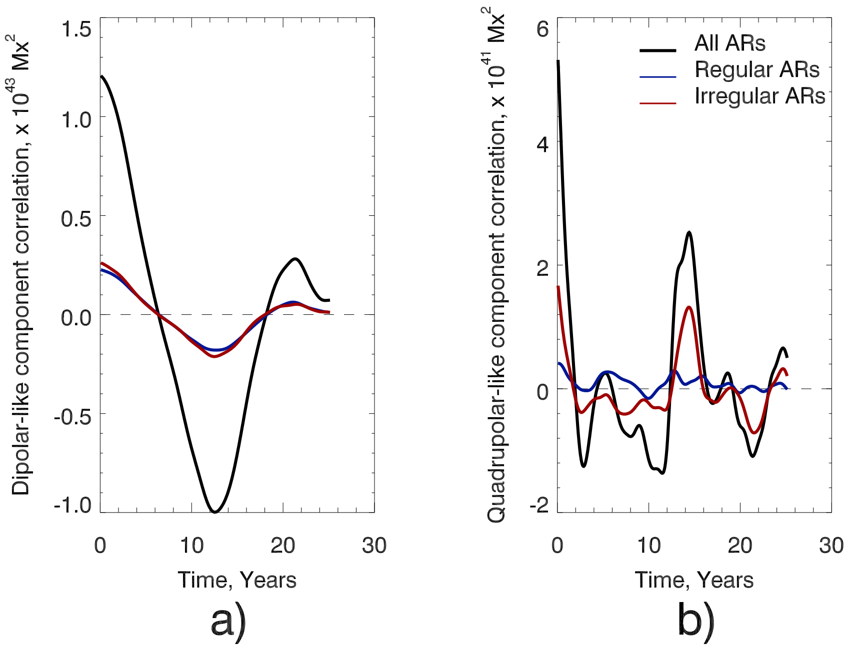

Fig. 2. Autocorrelation for the dipolar-like (a) and quadrupolar-like (b) parts of the flux.

For the regular ARs, evidence of the quadrupolar-like component oscillations are not observed.

A superposition of the dipolar and quadrupolar components implies some specific asymmetry for adjacent cycles (Sokoloff & Nesme-Ribes 1994). The activity in the N-hemisphere in the cycle n and in the S-hemisphere in the cycle $(n+1)$ is supposed to be similar. And this is also true for the S-hemisphere in the cycle n and the N-hemisphere in the cycle $(n+1)$.

To analyze the flux dynamics in different hemispheres in adjacent cycles for ARs of each MMC type, we used a cross-correlation function expressed as

$$C_{NS}(n\delta t) = \begin{cases} \frac{1}{N-|n|} \sum_{i=1}^{N-|n|} F_N(t_{i+|n|}) F_S(t_i), & n < 0 \\ \frac{1}{N-n} \sum_{i=1}^{N-n} F_N(t_i) F_S(t_{i+n}), & n \geq 0 \end{cases} . \quad (3)$$

For the regular ARs, the correlation pattern is found as typical (the main central peak and slightly lower approximately the same side peaks, Fig. 3). However, the irregular ARs demonstrate unusual pattern with a high right-side peak and low left-side peak. It means, on the one hand, a high correspondence in the dynamics of the magnetic flux in the N-hemisphere (cycle 23) and in the S-hemisphere (cycle 24) and, on the other hand, a low correspondence in the flux dinamics in the S-hemisphere (cycle 23) and the N-hemisphere (cycle 24).

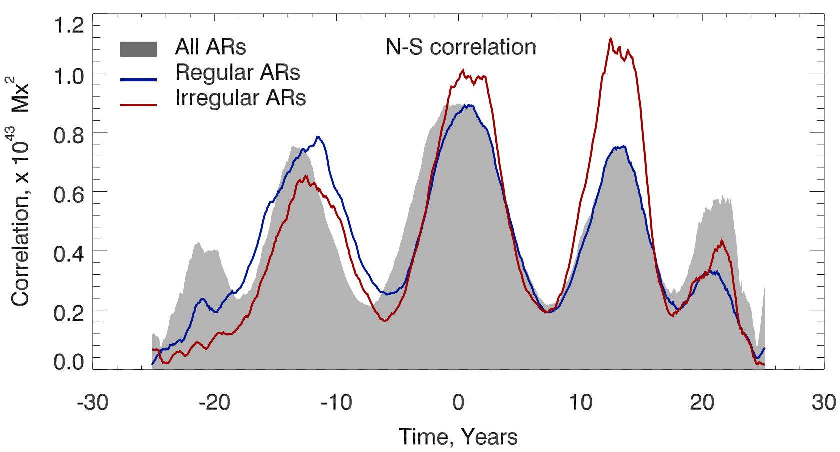

Fig. 3. Cross-correlation for ARs fluxes in different hemispheres.

3 Summary

The results of the study can be summarized as follows.

1. The peaks in the cycle maxima are more pronounced in the flux data than that in the number data. The strongest fluxes of the irregular ARs are observed in the second maximum of the cycle in the S-hemishpere.
2. The ARs of both MMC types demonstrate noticeable N-S asymmetry. The form of time profiles for the ARs of different MMC types is not the same. The most abrupt changes are shown by the irregular ARs fluxes.
3. For the compiled dipolar-like component of the magnetic flux, the periodicity of about 12 years is found for all types of ARs. For the quadrupolar-like component, the evidence of oscillations with a period of about 15 years is observed. This tendency is expressed only for all studied ARs and for the irregular groups.
4. The results of the cross-correlation analysis show a standard pattern of fluxes for the regular ARs (high central peak, weaker lateral peaks). For the irregular ARs,

an inequality of side peaks might imply a high correspondence in the dynamics of the magnetic flux in the N-hemisphere of cycle 23 and in the S-hemisphere of cycle 24 and, on contrary, a low correspondence in the flux dynamics in the S-hemisphere of cycle 23 and in the N-hemisphere of cycle 24.

5. The above findings also allow us to conclude that, despite the name, irregular ARs are not a random phenomenon, but an integral part of the cycle and may be of interest for the development of a dynamo model in modern times.

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References

Abramenko V., Zhukova A., Kutsenko A., 2018, Geomagnetism and Aeronomy, 58, 8, p. 1159
Abramenko V., Suleymanova R., Zhukova A., 2023, Monthly Notices of the Royal Astronomical Society, 518, 3, p. 4746
Abramenko V., 2021, Monthly Notices of the Royal Astronomical Society, 507, 3, p. 3698
Hazra S. and Nandy D., 2019, Monthly Notices of the Royal Astronomical Society, 489, 3, p. 4329
Kitchatinov L., 2022, Geomagnetism and Aeronomy, 62, 7, p. 817
Obridko V., Pipin V., Sokoloff D., et al., 2021, Monthly Notices of the Royal Astronomical Society, 504, 4, p. 4990
Sokoloff D. and Nesme-Ribes E., 1994, Astronomy & Astrophysics, 288, p. 293
Zhukova A., Sokoloff D., Abramenko V., et al., 2023, Advances in Space Research, 71, 4, p. 1984
Zhukova A., Abramenko V., Suleymanova R., 2024, Geomagnetism and Aeronomy, in print