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Power spectra of the Sun's large-scale magnetic field during solar cycles 23 and 24

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Abstract. The magnetic power spectrum analysis provides an effective way to understand the observed distribution of the photospheric magnetic fields and their interaction with plasma motions. We aim to investigate the power spectra using spherical harmonic decomposition of SOHO/MDI and SDO/HMI synoptic magnetograms for cycles 23 and 24. We find that the calibration factor between MDI and HMI power spectral density is spatial scale-dependent. The magnetic power spectra show two peaks at the AR scale (l≈30) and supergranular scale (l≈120). The power law indices between these show a good anti-correlation with the amplitude of magnetic activity.

Keywords. Sun: magnetic fields, Sun: activity, Sun: photosphere

1. Introduction

People usually utilize Fourier decomposition of local magnetograms to derive the magnetic power spectrum and further investigate the properties of the photospheric magnetic fields, especially the small-scale field. However, the long-term evolution of the large-scale magnetic field is rarely analyzed based on the power spectrum. Also, there are questions of what is the proper calibration factor to adopt when doing comparative studies of HMI and MDI, e.g., Liu et al. (2012). So this work aims to get new calibration method and analyze the power spectrum across two solar cycles.

2. Methods

Prior to the analysis, we pre-processed the synoptic magnetograms. Then the spherical harmonic decomposition were conducted on these data to obtain the spherical harmonic coefficients, which are used to calculate the power spectra based on Parseval's theorem.

3. Results

We found that the calibration function between MDI and HMI power spectral density (B^2_{MDI}/B^2_{HMI}) is $-0.0021 * l + 1.91$ rather than 1.42^2 (Fig. 1). After the spatial scale-dependent calibration, MDI and HMI show roughly the same power spectrum distributions in the range from $l = 5$ to $l = 200$ and a distinct peak at about $l \approx 120$.

Significant power is found at two spatial scales, i.e., about $l = 30$ (146 Mm AR size) and $l = 120$ (36 Mm supergranular size), when analyzing the total magnetic field and non-axisymmetric component. No such features are instead observed in the spectra of the axysimmetric component of the field, which shows a continuous decrease (Fig. 2). The power-law indices (k) for the spatial range of $l = 30$ and $l = 120$ show a good anti-correlation with the amplitude of magnetic activity. The function between them is

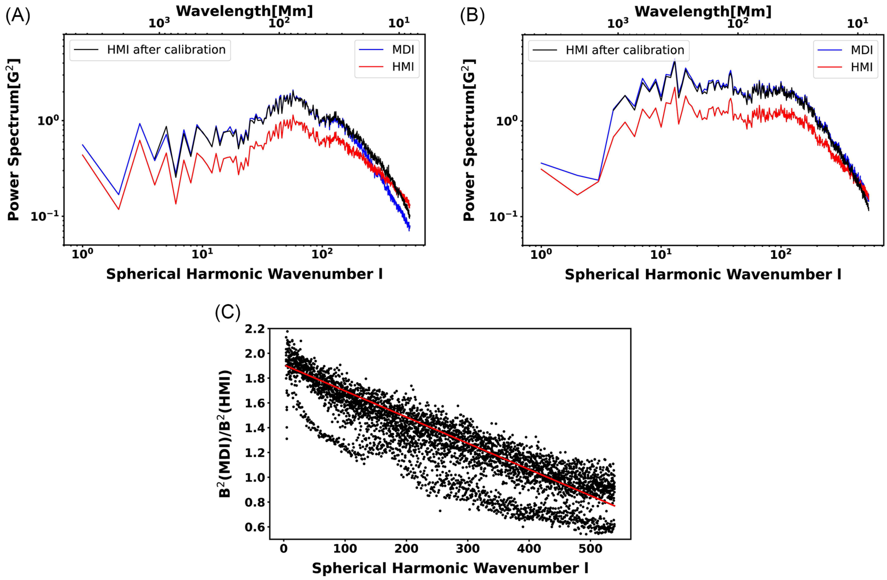

Figure 1. Comparison and calibration of the magnetic power spectra obtained by MDI and HMI maps. CRs 2097 (panel A) and 2100 (panel B) are taken as examples to illustrate the power spectra of the HMI map (red), MDI map (blue), and HMI map calibrated (black) using the red line in Panel (C). Panel (C): spatial scale dependence of the calibration factor between MDI and HMI power spectral density. Black dots and red lines are the observations and the linear fit to the data, respectively.

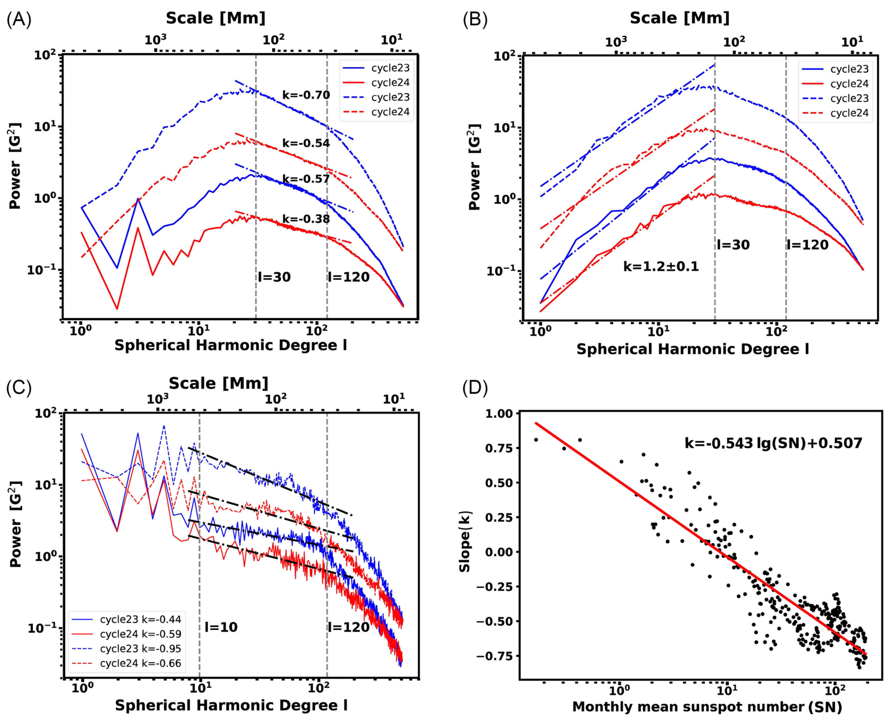

Figure 2. Magnetic power spectra for total magnetic field (panel A), for non-axisymmetric field (m≠0, panel B), and for axisymmetric field (m=0, panel C) of cycles 23 and 24. Red (blue) curves: cycle 24 (23); dotted (solid) curves: active (quieter) phase of a cycle. Panel D: Power-law indices k shown in panel A of the power spectra as a function of the sunspot number.

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$k = -0.53lg(SN) + 0.51$. For the non-axisymmetric field, the spectrum for the scales larger than ARs' size shows a constant power index, that is 1.2.

4. Conclusions

The magnetic power spectra over broad spatial scales from about 22 Mm to the global scale for cycles 23 and 24 are derived and analyzed. We obtained a new calibration function between MDI and HMI maps. The power spectra reflect the characteristics related to solar activity and solar structures such as supergranlues.

Acknowledgements

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Supplementary material

To view supplementary material for this article, please visit https://doi.org/10.1017/S1743921323000510.

Reference

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