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Analyzing Magnetic Network and its Variations over Solar Cycles 23, 24 and 25 Based on Magnetic Power Spectra

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Abstract. The magnetic network is a typical magnetic structure of the quiet Sun. Investigating its cycle dependence is crucial for understanding its evolution. We aim to identify and analyze the spatial scales of the magnetic network within magnetic power spectra derived from high-resolution Solar and Heliospheric Observatory (SOHO)/Michelson Doppler Imager (MDI) and Solar Dynamics Observatory (SDO)/ Helioseismic and Magnetic Imager (HMI) synoptic magnetograms. The data sets cover the entirety of solar cycles 23, 24, and part of cycle 25. We find that the identified magnetic network sizes identified range from 26 Mm to 41 Mm. There seems to be no obvious dependence on the solar cycle, and the sizes are distributed uniformly within the identification range.

Keywords. Magnetic Network Size, Solar Cycle Dependence

1. Introduction

The solar surface outside of active regions is mainly covered by the quiet sun. The magnetic network contributes most of the flux in the quiet sun (Gosic 2015). The network field is typically associated with supergranulation. This is due to the interaction between magnetic fields and convection flow fields (Rincon and Rieutord 2018). Additionally, the investigation of the magnetic network is important because it is also crucial to understand the origin of the magnetic field and its contribution to the solar atmosphere (Bellot Rubio and Orozco Suárez 2019). However, there is still a debate about the variation of the network.

Previous works investigating the chromospheric network and supergranulation produce divergent results. While Hagenaar et al. (1997) suggest no dependence on network sizes, most other studies propose that the size should be either anti-correlated or correlated to the magnetic activity (Rincon and Rieutord 2018). For instance, Singh and Bappu (1981) find that network sizes tend to be smaller during the solar maximum with respect to the chromosphere network. Muenzer et al. (1989) report that the network sizes should increase with the solar activity. Previous disparities may be due to various identification and analysis methods for different proxies Berrilli et al. (1999). Therefore, it is necessary to investigate the size variation of the network directly from magnetograms.

The power spectrum is a useful tool for investigating characteristic structures in the images. Therefore, in this study, we aim to derive magnetic power spectra from MDI and HMI synoptic maps. We then identify the network based on the power spectra and provide insights into the cycle dependence of network sizes.

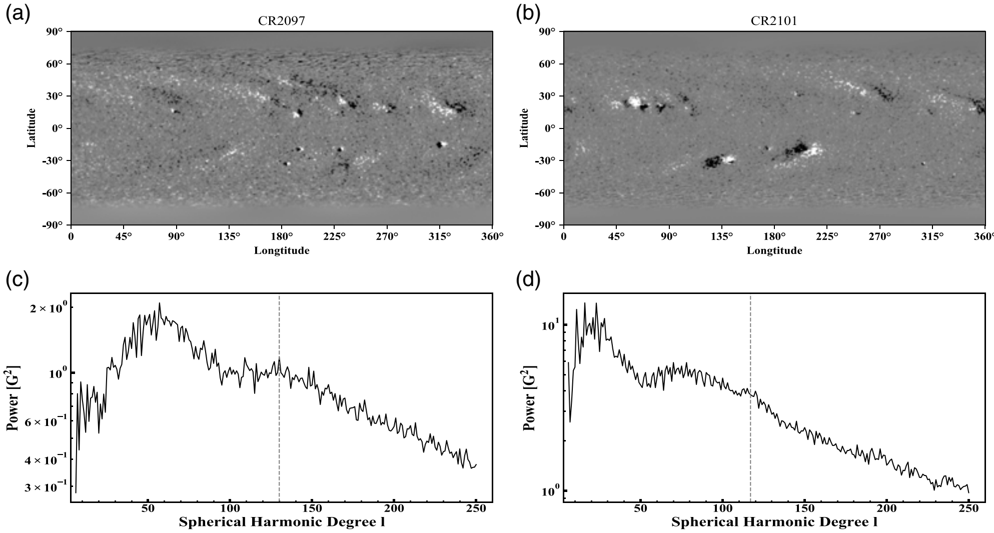

Figure 1. Example of network identification results. (a) & (b) are synoptic magnetograms for CR 2097 and CR 2101, respectively. (c) & (d) are corresponding magnetic power spectra for (a) and (b). The identified network is highlighted by the vertical dashed lines. Image adapted with permission from Luo et al. (2023), copyright by the American Astronomical Society.

2. Methods

For this study, we analyze continuous radial HMI and MDI synoptic magnetograms covering solar cycles 23, 24, and part of cycle 25. The data sets begin in Carrington Rotation (CR) 1911 (1996 July) and end in CR 2265 (2022 December). We perform the spherical harmonic decomposition to obtain the magnetic power spectra, after preprocessing the HMI and MDI synoptic magnetograms. Then we calibrate HMI power spectra based on the methods proposed by Luo et al. (2023) to ensure consistent and homogeneous data for the following analysis.

The magnetic power spectra show network features as peaks or knees, depending on the relative strength relationship between active region power and network power. We improve the morphology methods used in Luo et al. (2023) for the peak and knee, respectively. All of the data processing is done in Python. We successfully identified the network in the power spectra of 254 CRs, for a total of 355 CRs.

3. Results

Figure 1 displays two examples of network identification. The top panel shows two synoptic maps during the overlapping period for HMI and MDI. The bottom panel displays magnetic power spectra derived by spherical harmonic composition. In both power spectra, the small peaks in $l = 130$ for (c) and $l = 117$ for (d) are considered as the representation of the magnetic network. Their actual sizes are 33.7 Mm and 37.4 Mm, respectively.

The identified results for all CRs and their relationship with time are shown in Figure 2. The typical magnetic network sizes typically range from $l = 106$ ($\approx$26 Mm) to $l = 169$ ($\approx$41 Mm). During any phase of the solar cycle, a wide range of network sizes can be identified. The distribution of network sizes is also homogeneous over time, suggesting that the network can emerge randomly in the same size range during both solar maximum and minimum. Furthermore, this may imply that some intrinsic properties of the network

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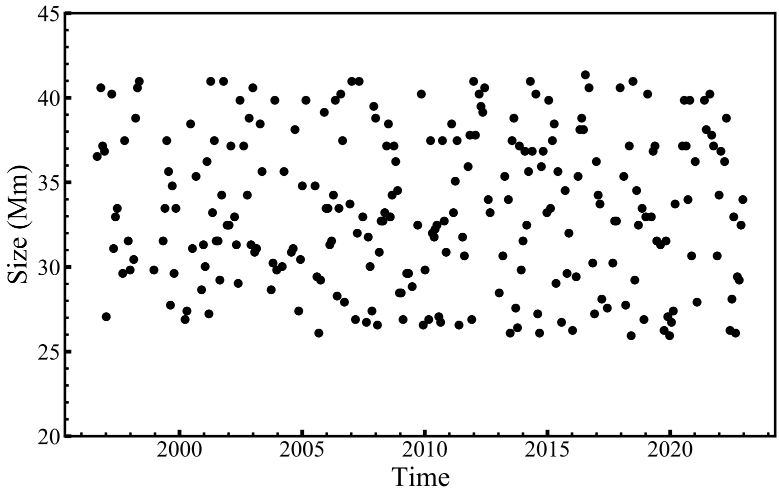

Figure 2. The network sizes identified by magnetic power spectra during 23rd, 24th and part of 25th solar cycles. Image reproduced with permission from Luo et al. (2024).

are unchanged for different solar cycles. Importantly, there is no significant temporal variation in the range and distribution of identified network sizes. This may suggest that magnetic network sizes are not dependent on cycles.

Our results are similar to those of Hagenaar et al. (1997), who focus on the chromosphere network. They propose no correlation between network sizes and local magnetic strength. Similarly, Hagenaar et al. (2003) study the temporal variation of network fields with different flux. They find that the network with fluxes $\leq 20 \times 10^{18}$ is independent of the solar cycle, while the network with more flux varies with solar activity. The study explains two different relationships based on the origin of the network. They suggest that the weaker network is contributed by ephemeral regions and active regions, showing cycle independence. As the network flux increases, the dominant role of decaying active regions is enhanced, causing the dependence on solar cycles. This may imply that the network we identified is related to both ephemeral regions and decaying active regions.

Figure 3 shows the statistical results of the identified network sizes. The histogram indicates that the counts of different network sizes do not change significantly. Additionally, the mean network size is 33.4 Mm ($l = 131$), and the standard deviation is 4.43 Mm. These values are similar to the characteristic parameters of uniform distribution in the same size range. The skewness and kurtosis are 0.058 and 1.87, respectively, which are close to the values for the uniform distribution (0 and 1.8). All of the above statistical parameters indicate that the identified network sizes are close to the uniform distribution in our identification range. This is different from the previous work about supergranulation sizes, which usually give an unimodal distribution like Simon and Leighton (1964). The difference in results may be due to various analysis methods and subjects, and further investigation is needed to resolve this.

Our identification results may contain possible misidentification due to similar scale structures, such as ephemeral regions. This misidentification contributes to the uncertain range of identified network sizes. It is possible that a weak cycle dependence of network sizes exists but is masked by the uncertain range. Therefore, our identification results may not show the possible weak cycle dependence.

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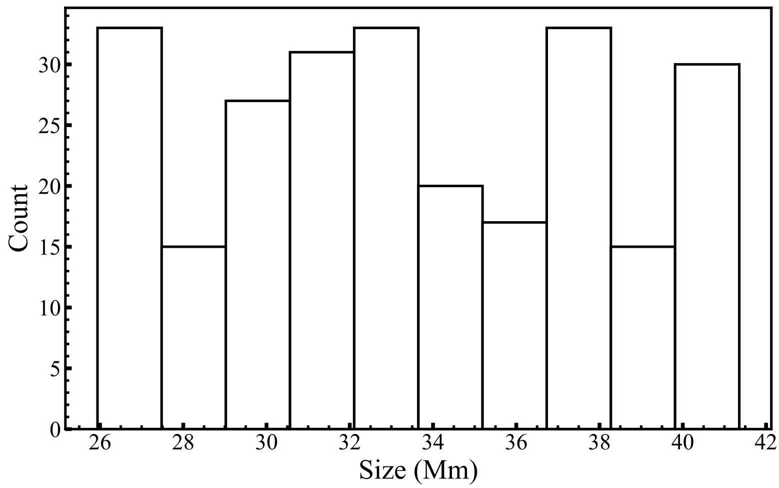

Figure 3. The histogram of identified network sizes. Image reproduced with permission from Luo et al. (2024).

4. Conclusions

In this study, we successfully identify magnetic network features in magnetic power spectra using morphology identification methods. The identified network sizes range from 26 Mm to 41 Mm. The statistical analysis of typical network sizes indicates that the size of the magnetic network is close to the uniform distribution and does not depend significantly on the solar cycle. Additionally, we can speculate that the supergranulation size may also have a weak cycle dependence according to the relationship between supergranulation and the magnetic network (Rincon and Rieutord 2018).

The magnetic network is an important source of the variation in the total solar irradiance (TSI). However, it is not well-studied in previous models (Solanki et al. 2013). Our results may provide a new constraint for the investigation of the TSI model.

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