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Cycle-dependent and cycle-independent surface tracers of solar magnetic activity

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Abstract. We consider several tracers of magnetic activity that separate cycle-dependent contributions to the background solar magnetic field from those that are independent of the cycle. The main message is that background fields include two relative separate populations. The background fields with a strength up to 100 Mx cm^{-2} are very poorly correlated with the sunspot numbers and vary little with the phase of the cycle. In contrast, stronger magnetic fields demonstrate pronounced cyclic behaviour. Small-scale solar magnetic fields demonstrate features of fractal intermittent behaviour, which requires quantification. We investigate how the observational estimate of the solar magnetic flux density B depends on resolution D in order to obtain the scaling $\ln B_D = -k \ln D + a$ in a reasonably wide range. The quantity k demonstrates cyclic variations typical of a solar activity cycle. k depends on the magnetic flux density, i.e. the ratio of the magnetic flux to the area over which the flux is calculated, at a given instant. The quantity a demonstrates some cyclic variation, but it is much weaker than in the case of k. The scaling is typical of fractal structures. The results obtained trace small-scale action in the solar convective zone and its coexistence with the conventional large-scale solar dynamo based on differential rotation and mirror-asymmetric convection. Here we discuss the message for solar dynamo studies hidden in the above results.

Keywords. solar activity, solar dynamo, solar magnetic field

1. Introduction

Solar magnetic field underlying the famous 11-year solar activity cycle is generated by solar dynamo driven by differential rotation and mirror-asymmetric convection. This dynamo, known as the large-scale one, produces large-scale magnetic field **B** as well as small-scale one **b**. Both **B** and **b** are expected to demonstrate 11-year cyclic behaviour. The point is that one more type of dynamo, so-called small-scale or turbulent dynamo, can act in the solar interior to produce cycle-independent small-scale magnetic field. The question is to what extent we can separate contributions of both type of dynamos, i.e. cycle-dependent and cycle-independent components in surface small-scale solar magnetic field.

2. Fractal properties of solar magnetic field as tracers for cyclic behaviour of small-scale field

The problem to be resolved addressing small-scale magnetic field behaviour is that smallest structures of surface solar small-scale magnetic fields cannot be resolved even by modern observations. A possible approach here is to separate small-scale magnetic fields according to its strength measured as magnetic flux per a resolved area. In the framework of this approach we demonstrate (Obridko *et al.* 2017) that the background fields with a strength up to 100 Mx cm^{-2} are very poorly correlated with the sunspot numbers and vary little with the phase of the cycle. In contrast, stronger magnetic fields demonstrate pronounced cyclic behaviour.

We identify this distinction as that one between small-scale magnetic field generated by small-scale and large-scale solar dynamo correspondingly.

Another approach is to use concepts of fractal geometry to quantify intermittent magnetograms where very weak as well as very strong magnetic fields are present (Shibalova *et al.* 2017). For this purpose we emulate magnetograms with lower resolution D rather the actual one smoothing a given magnetogram with a kernel with a size D. We investigate how the observational estimate of the solar magnetic flux density B_D at a magnetogram smoothed up to resolution D depends on D in order to obtain the fractal scaling $\ln B_D = -k \ln D + a$ in a reasonably wide range. The quantity k demonstrates cyclic variations typical of a solar activity cycle. k depends on the magnetic flux density, i.e. the ratio of the magnetic flux to the area over which the flux is calculated at a given instant. The quantity a demonstrates some cyclic variation, but it is much weaker than in the case of k.

Our interpretation of the result obtained is that we see again a coexistence of cycle-dependent and cycle-independent small-scale magnetic field components.

3. Conclusion and Discussion

We conclude that surface solar small-scale magnetic field contains cycle-dependent and cycle-independent components. The first one can be identified as a result of a large-scale dynamo action while the second one appears to be a result of a more or less independent small-scale dynamo.

We note however that this separation is far from perfect and perhaps it is more adequate to say that the above two kinds of solar dynamo are in practice quite interacting and have to be considered as two theoretical extrema of a joint process.

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