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Solar flares, Ampere's Law, and the Search for Units in Scale-Free Processes

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Abstract. One of the most powerful SOC tools - the wavelet transform modulus maxima approach to calculating multifractality - is connected to one of the most powerful equations in all of physics - Ampere's law. In doing so, the multifractal spectra can be expressed in terms of current density, and how current density can then be used for the prediction of future energy release from such a system.

Keywords. Sun, Complexity, Self-Organized Criticality

My soul is spiraling in frozen fractals all around,
And one thought crystallizes like an icy blast,
I'm never going back, the past is in the past.

1. Ampere's law and the Multifractal Spectrum

Elsa, from Disney's Frozen, characterizes two fundamental aspects of scale-free processes in Nature: fractals are everywhere in space; fractals can be used to probe changes in time. Self-Organized Criticality provides a powerful set of tools to study scale-free processes. It connects spatial fractals (more generically, multifractals) to temporal evolution. The drawback is that this usually results in scale-free, unit-less, indices, which can be difficult to connect to everyday physics.

2. Results

In McAteer (2015), it is shown that calculating magnetic spatial gradients is a non-trivial issue. As gradients are non-isotropic, and occur over multiple size scales, the most appropriate way to measure gradients is to do so for every angle and every spatial size scale. We then to study how these vary over size scale, s, and show in McAteer (2015) how this connect to the current density in the plasma,

$$\partial|\mathbf{J}|/\partial s = \partial\nabla_{x,y}B_z/\partial s. \tag{2.1}$$

where J is current density, and B_z is the z component of the magnetic field. Further, by adopting a derivative of Gaussian as the mother wavelet in the analysis of the multifractal spectrum, the local holder exponent, $h(\mathbf{x0})$ is then the rate of change of the gradient of the magnetic field with size scale, i.e.,

$$h(\mathbf{x0}) = \partial\nabla_{x,y}B_z/\partial s. \tag{2.2}$$

With this approach Figure 1 show that those locations with large and persistent holder exponents are the site of the build up of current density in solar active regions.

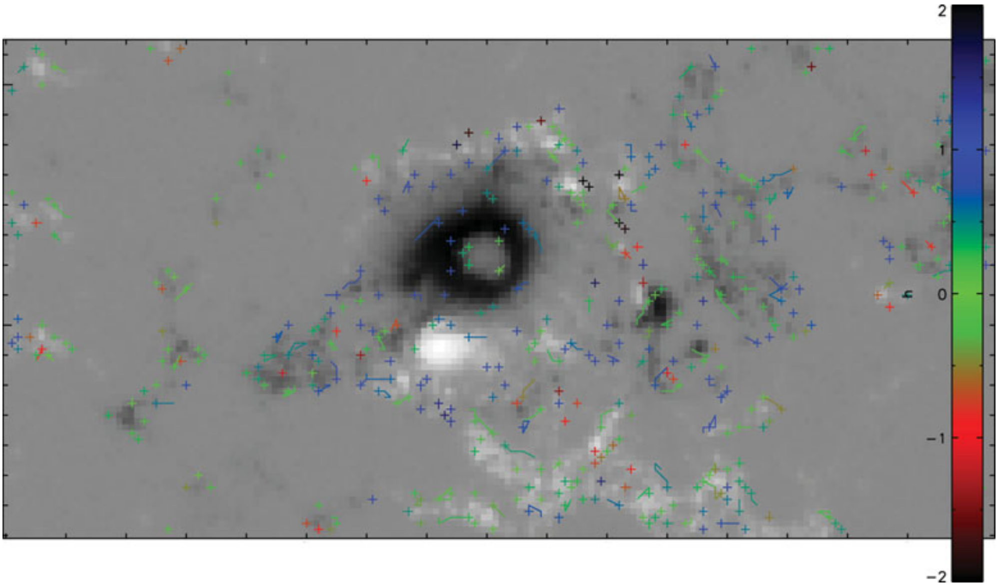

Figure 1. The magnetic field of an active region is overplotted with the holder exponent at each gradient. Negative and near-zero holder exponents occur in plage surrounding the region. Large holder exponents occur near site of the build up of current density. (from McAteer (2015)

3. Implications

Our physical understanding of the solar magnetic field structure, and hence our ability to predict solar activity, is limited by the type of data currently available, e.g., McAteer *et al.* (2015). The multifractal spectrum provides a powerful physical connection between the details of photospheric magnetic gradients of current data and the coronal magnetic structure. By decomposing Ampere's law and comparing it to the wavelet transform modulus maximum method, the scale-free Holder exponent provides a direct measure of current density across all relevant sizes. The prevalence of this current density across various scales is connected to its stability in time, and hence to the ability of the magnetic structure to store and then release energy. Hence (spatial) multifractals inform us of (future) solar activity. Such an approach can be used in any study of scale-free processes, and highlights the necessary key steps in identifying the nature of the mother wavelet to ensuring the viability of this powerful connection McAteer (2013).

Three bold predictions are now made which must be tested: (i) the multifractal spectrum of an active region will be the same regardless of the spatial resolution of data; (ii) those locations with large holder exponents will persist for longer than the lower h plague locations; and hence (iii) those structures with large current densities at large size scales will the site of future solar eruptive events.

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