Self-Organized Criticality and Turbulence

Coordinator: Markus Aschwanden

2nd ISSI Team Meeting - 2013 Sept 16-20 - Hallerstr. 6, 3012 Bern, Switzerland

Program :

Time	Monday Sept 16	Tuesday Sept 17	Wednesday Sept 18	Thursday Sept 19	Friday Sept 20
0830-0930		Watkins	Aschwanden	Pruessner	Morales
0900-0930	Welcome and Introduction				
0930-1030	Georgoulis	Nishizuka	Hergarten (1000-1100)	Crosby [2]	Discussion 4 (Publication)
Coffee break					
1100-1200	Milovanov	Jensen		Chapman	Conclusions
Lunch break			Excursion		Adjourn
1330-1430	Dimitropoulou	Strugarek		Discussion 1 (Hergarten)	
1430-1530	Crosby [1]	Uritsky (1500-1600)		Discussion 2 (Crosby)	
Coffee break					
1600-1700	McAteer	Sanchez		Discussion 3 (Aschwanden)	
1700-1730	ISSI Apero				

MONDAY

Welcome and Introduction

Markus Aschwanden (LMSAL)

Introduction, overview, and scope of meeting.

Supporting Evidence for the Action of Self-Organized Criticality in Turbulent, Multiscale Solar Active Regions

Manolis K. Georgoulis (RCAAM of the Academy of Athens)

Following a more general account of the concept of Self-Organized Criticality (SOC) in solar magnetism, delivered during the first ISSI Workshop on SOC and Turbulence, we now report on a more detailed analysis presenting evidence that magnetic fields of eruptive solar active regions may, in fact, be in a SOC state. Key concepts include irreversibility in active-region evolution, meaning that at least one major eruption follows after a certain "point of no return", and marginal stability, that gradually but naturally results from irreversibility. A physical, system-specific description of the fulfillment of these SOC prerequisites is attempted, while at the same time the magnetic structures of active regions, including our particular example, show clear multiscale behavior and turbulent power spectra. Discussion cultivates with a numerical test that shows how a valid force-free equilibrium of the three-dimensional coronal magnetic field of an active region can be reproduced while the region is demonstrably in a SOC state. If eruptive active regions are indeed in some form of a SOC state, then open questions continue to involve the validity of SOC in (otherwise multiscale and turbulent) non-eruptive active regions, the quite Sun, and the entire Sun as a whole, including the outstanding, strongly debated physical connection between turbulence and SOC. Once again, our overarching goal is to stimulate critical discussion and constructive debate on the validity of SOC in solar magnetic structures.

A mixed SOC-turbulence model for nonlocal transport and space-fractional Fokker-Planck equation

Alexander Milovanov (ENEA) and Jens Juul Rasmussen

The phenomena of nonlocal transport in magnetically confined plasma are theoretically analyzed. A hybrid model is proposed, which brings together the notion of inverse energy cascade, typical of drift-wave- and two-dimensional fluid turbulence, and the ideas of avalanching behavior, associable with self-organized critical (SOC) behavior. Using statistical arguments, it is shown that an amplification mechanism is needed to introduce nonlocality into dynamics. We obtain a consistent derivation of nonlocal Fokker-Planck equation with space-fractional derivatives from a stochastic Markovian process with the transition probabilities defined in reciprocal space.

Are Eruptive Solar Active Regions in a Self-Organized Criticality state?

Michaila Dimitropoulou (University of Athens)

The long-standing debate on whether magnetic fields of eruptive solar active regions (AR) are indeed in a in Self-Organized Criticality (SOC) state triggers a new methodology of investigation that fully exploits recent SOC flare simulation models. This methodology relies on externally forcing an extrapolated coronal magnetic configuration above an observed AR photospheric magnetogram to reach the SOC state. This state is reached by means of randomly perturbing the system by small magnetic-field increments and then letting it relax via avalanche-like events and conservative magnetic-field redistribution rules. The diagnostics used to identify that the system has reached the SOC state include the stabilization of the critical physical quantity (in our case, the Laplacian of the magnetic field), and a well-defined mean number of avalanches produced over a specified number of iterations. Preliminary results show that this SOC configuration can fully revert to the initial extrapolated state, by iterative magnetic-field interpolation. The interpolation mechanism now serves as the external driver of the system while instabilities are treated using the same conservative redistribution rules. Using the same SOC-state diagnostics, we find that the system reverts to its original state without exiting the SOC state. We consider this as direct evidence that the coronal magnetic fields of eruptive solar active regions may, in fact, be in a SOC state. We discuss possible implications of this finding, pending appropriate further study.

SOC behavior: How important is the state of the dataset?

Norma Crosby (BISA, Belgium)

Phenomena that display "avalanche" behavior display in most instances power-law behavior. Each type of phenomenon is observed to have a range of powerlaw slope values. The difference in value is also observed on measured parameters of the same type of "avalanche" suggesting that the slope may be detector dependent. Here it is investigated how sensitive the slope value is in regard to the dataset being used (how "clean" is the dataset?). For this purpose a study is presented where solar energetic particle data is considered.

The search for units: a gradient distribution route to multifractality in solar magnetic fields

James McAteer (New Mexicao State University)

(Skype presentation) – Abstract: (TBD)

TUESDAY

SOC and turbulence in astrophysical plasmas: Some ways forward

Nick Watkins (MPIPKS, Dresden)

Our last meeting played a very useful role in showing that SOC was quite tightly defined by its creators, and in mathematical physics, and that its status both observationally and theoretically remains controversial in that community, even 25 years on [Pruessner, Self-Organised Criticality: Theory, Models and Characterisation, CUP, 2012].

We also found, however, that considerable observational evidence existed in space physics and elsewhere for the various properties which inspired the SOC idea [Aschwanden book, his ISSI talk, and others]. In addition, several speakers reminded us of the fertile role ideas drawn from SOC had played in plasma transport. In this talk I will offer some thoughts on how these two points can be reconciled, and how SOC-inspired ideas can continue to play a useful role in space physics.

I will also talk about the other types of physical process that have been studied as models for heavy tails and long-range dependence, some having roots in the pioneering work of Mandelbrot.

Fractal structure and SOC of a current sheet of a solar flare via dynamic magnetic reconnection

Naoto Nishizuka (National Astronomical Observatory of Japan (NAOJ)

Two new papers related to fractal and turbulence/SOC. In the next team meeting, I would like to introduce a turbulent/fractal current sheet in a solar flare with 3D MHD simulation and preliminary results of my analysis of fractal structure and SOC of a current sheet via time-dependent dynamic magnetic reconnection.

References: http://www.kwasan.kyoto-u.ac.jp/∼nisizuka/nishida2013apjl.pdf http://www.kwasan.kyoto-u.ac.jp/∼nisizuka/nisizuka2013prl.pdf

Self-Organised (near to) Criticality

Henrik Jeldtoft Jensen (Dept. Mathematics and Complexity & Networks Group, Imperial College London)

We revisit the evidence that some of the traditional models of Self-Organised Criticality in fact doesnt seem to be self tuning to a critical point and suggest that the coupling between dynamics and control parameter may tend to move the system to the vicinity of a critical state but will prevent the system from reaching exact criticality. Numerical studies of variations of the Drossel-Schwable forest fire model is compared to corresponding statistics in percolation and we relate this to recent analysis of brain activity by Chialvos group and to analysis of rain by Peters and co-workers.

Predictive capabilities of avalanche models for solar flares

Antoine Strugarek (Université de Montreal, Canada)

It was recently proposed [Blanger et al. 2007] that cellular-automaton based self-organized critical avalanche models could be used to forecast real solar flares using modern data assimilation techniques. Though, the inherent random ingredients included in such models can severely affect their predictive capabilities, which were not characterized by previous studies. We use different variations of the standard Lu and Hamilton model and systematically characterize their predictive capabilities for large avalanches in term of (i) time at which the avalanche will take place and (ii) energy released by the avalanche. We study two classes of models: one where we bias the random forcing of the model, and the other where we use a determinist forcing and introduce a random process in the redistribution rule. We demonstrate that the latter class of model possess very good predictive capabilities, while the former one barely exceeds statistical expectations obtained from waiting-time distributions analysis.

Stochastic Coupling of Solar Photosphere and Corona

Vadim Uritsky (NASA Goddard Space Flight Center), J. Davila, L. Ofman, and A.Coyner

The observed solar activity is believed to be driven by the dissipation of non-potential magnetic energy injected into the corona by dynamic processes in the photosphere. In this talk, we present an ensemble-based approach for testing the photosphere-corona coupling in a quiet solar region as represented by intermittent activity in Solar and Heliospheric Observatory Michelson Doppler Imager and Solar TErrestrial RElations Observatory Extreme Ultraviolet Imager image sets (Uritsky et al., ApJ 2013). We show that the dynamics of the two solar regions is described by the same occurrence probability distributions of energy release events but significantly different geometric properties. We also present waiting time statistics for the studied quiet solar region consistent with paradigmatic self-organized critical models. Our analysis suggests that multiscale intermittent dissipation in the corona at spatial scales ¿3 Mm is controlled by turbulent photospheric convection, with complex topology of the photospheric network making this coupling essentially nonlocal and non-deterministic.

Reference: Uritsky,V.M., Davila, J.M., Ofman, L. and Coyner, A.J. 2013, ApJ 769, 62.

WEDNESDAY

Multi-Wavelength Observations of the Spatio-Temporal Evolution of Solar Flares with AIA/SDO: Universal Scaling Laws and Hydrodynamic Scaling Laws

Markus J. Aschwanden (Lockheed Martin Solar and Astrophysics Laboratory)

We present a statistical solar flare study of 155 GOES M and X-class flares observed with AIA/SDO. We find near-identical size distributions of geometric (lengths L, flare areas A, volumes V, fractal dimension D2), temporal (flare durations T), and spatio-temporal parameters (diffusion coefficient κ, spreading exponent beta, and maximum expansion velocities v_{max}) in different wavelengths, which are consistent with the universal predictions of the fractal-diffusive avalanche model of a slowly-driven self-organized criticality (FD-SOC) system, i.e., $N(L) \propto L^{-3}$, $N(A) \propto A^{-2}$, $N(V) \propto V^{-5/3}$, $N(T) \propto T^{-2}$, $D_2 = 3/2$, for a Euclidean dimension d=3. We find also a new correlation $\kappa \propto L^{0.94 \pm 0.01}$ and the 3-parameter scaling law $L \propto \kappa T^{0.1}$, which is more consistent with the logistic-growth model than with classical diffusion. The findings suggest long-range correlation lengths in the FD-SOC system that operate in the vicinity of a critical state, which could be used for predictions of individual extreme events.

We analyze also the statistics of physical parameters that are specific to the hydrodynamics of the high-temperature flare plasma, such as the peak emission measure EM_p, the peak temperature T_p, the electron density n_p, and the thermal energy E_{th} We find that these parameters obey the Rosner-Tucker-Vaiana (RTV) scaling law $T_p^2 \propto n_p L$ and $H \propto T^{7/2} L^{-2}$ during the peak time t_p of the flare density n_p, when energy balance between the heating rate H and the conductive and radiative loss rates is achieved for a short instant, and thus enables the applicability of the RTV scaling law. The application of the RTV scaling law predicts powerlaw distributions for all physical parameters, which we demonstrate with numerical Monte-Carlo simulations as well as with analytical calculations. A consequence of the RTV law is also that we can retrieve the size distribution of heating rates, for which we find $N(H) \propto H^{-1.8}$, which is consistent with the magnetic flux distribution $N(\Phi) \propto \Phi^{-1.85}$. The fractal-diffusive self-organized criticality model in conjunction with the RTV scaling law reproduces the observed powerlaw distributions and their slopes for all geometrical and physical parameters and can be used to predict the size distributions for other flare datasets, instruments, and detection algorithms.

References: Aschwanden, Zhang, and Liu, 2013, Astrophys. J. 775, 23.
Aschwanden and Shimizu, 2013, Astrophys. J. (in press)

Branching processes and SOC

Stefan Hergarten (Univ. Freiburg)

A self-organized critical branching process based on a local interaction rule is presented. In accordance with the self-organized branching process model introduced by Zapperi, Lauritsen, and Stanley, its event-size distribution follows a power law with scaling exponent =(3)/(2), but the new model does not require a global variable to self-organize to a critical point. The self-organized critical behavior of the model seems to be extremely robust. The model may be seen as a new paradigm for progressive mechanical failure (e.g., earthquakes or landslides) or other avalanching phenomena, and perhaps even for self-organized criticality in general.

Reference: Hergarten,S. (2012), Branching with Local Probability as a Paradigm of Self-Organized Criticality, Phys. Rev. Lett. 209, 14

THURSDAY

Identifying Self-Organised Criticality in nature (a guide by the confused)

Gunnar Pruessner (Imperial College London)

One reason why Self-Organised Criticality (SOC) is so difficult to define is that it has never been clear whether it refers to the (perceived) phenomenon, to the (supposed) cause for it or something in between. Over the years, some features of SOC models have become commonly accepted as generic, such as slow drive (time scale separation), interaction, thresholds and thus intermittency. If one takes the term "Self-Organised Criticality" seriously then we are concerned with criticality brought about by the system tuning itself to a critical point, i.e. without the need of explicit, external tuning of a control parameter. I want to argue that a good definition of SOC makes use of both points of view. Once well-defined, I will ask what makes a good observable in the hunt for SOC?

Earth's outer electron radiation belt and its dynamic behavior

Norma Crosby (BISA, Belgium)

Frequency distributions have been performed on several outer electron radiation belt datasets. The powerlaw slope value is investigated as a function of solar cycle. Specifically, the influence of solar events on the outer electron radiation belt is studied; How does the slope value change before, during and after the event? Does this place constraints on the ongoing physics?

Plasma turbulence, and other kinds of scaling-what we can learn from large scale kinetic simulations and observations within our heliosphere

Sandra Chapman (University of Warwick, UK)

Abstract: TBD

Discussion I: Real-world data beyond event-size distributions and temporal correlations

Discussion Leader: Stefan Hergarten

I remember that we tried to find some consensus on what kind of temporal correlations should be included in a definition of SOC. But when we consider models for real-world phenomena, we should think about further properties to give insight into the models in order to find out whether they capture the phenomenon appropriately or not. I remember that one of the young colleagues presented an approach where measurable properties were incorporated into the model last year. I could give some kind of starter for the discussion using my model for rockfalls which can be directly applied to a given topography.

Discussion 2: SOC behavior: short-term to long-term

Discussion Leader: Norma Crosby

- SOC behavior: short-term (e.g. solar flares, earthquakes) to long-term (e.g. Saturn's ring).
- Is it the same behavior that one is observing but on different time-scales?
- Does SOC reach a "saturation limit"?

Discussion 3: A physicist's view of SOC models

Discussion Leader: Markus Aschwanden

Nonlinear energy dissipation processes can be characterized by (powerlaw-like) scaling laws between physical variables (A,B,C,...) Assuming the fundamental scale-free probability conjecture, a statistical probability distribution of spatial scales can be predicted within the scale-free inertial range, $N(L) \propto L^{-D}$ (with D the Euclidean dimension of the system), from which the statistical distributions of all physical variables follow N(A)dA, N(B)dB, N(C)dC,..., which are powerlaw-like distributions themselves in the ideal case, but can exhibit significant deviations due to imcomplete sampling and related truncation effects. Using the observed statistical distributions and correlations of physical variables, we can then "back-engineer" the underlying scaling laws that govern the SOC processes. How does that relate to the original SOC concept in terms of sandpile avalanches and cellular automata? Can SOC size distributions of spatial scales (L, A, V) and time scales (T) just be considered as manifestations of basic geometric scaling laws ($A \propto L^2$, $V \propto L^3$) and simplified approximations of transport processes $T \propto L^\beta$ in systems with complex next-neighbor interactions?

FRIDAY

Multifractal analysis of simulated solar flares

Laura Morales (Universite de Montreal, Canada)

Fractal and multifractal analysis had been proposed as a way to treat complex systems exhibiting fluctuations on a wide range of time scales. Self organized criticality (SOC) is the mechanism to lie underneath this scale free or multiscale behavior. In the last couple of decades multifractal studies had been applied successfully to a variety of natural phenomena such as: precipitation, ozone levels, wind speed, seismic events, climate dynamics, solar flares and active regions. Multifractal scaling properties were mainly explored by means of the structure function and the singularity spectra. Several methods have been used to calculate the multifractal spectrum (most of them applying wavelets formalism). In recent literature McAteer and collaborators (McAteer et al. ApJ 662:691-700, 2007) have suggested that "a direct comparison between multifractal spectra of observed solar flares with SOC models may provide a direct comparison with the underlying physics of the nonlinear phenomena that dissipates energy in solar flares". We intend a first approach in this sense by applying the Haar wavelet to a new generation of SOC model for solar flares that we have recently produced (Morales and Charbonneau, ApJ. 682 (1), 654). This system produced avalanches of reconnection events characterized by scale-free size distributions that compared favorably with the corresponding size distribution of solar flares, as inferred observationally thus, making it a suitable starting point.

Reference: McAteer, Young, Ireland, and Gallagher (2007), Astrophys. J. 662, 691-700.

Morales and Charbonneau (2008) Astrophys. J. 682, 654.

Discussion 4: Discussion on Publications

Moderator: Aschwanden

Should we start to write a comprehensive overview article on "Self-Organized Criticality and Turbulence: A review and discussion of current trends"? Let us discuss this project, writing assignments of authors, the choice of journal for publication, and deadlines.

Conclusions: All

What new aspects did we learn during this ISSI meeting? What goals did we accomplish, and what new collaborations do we start?

Adjourn
