the past several years we have proposed an alternative paradigm which we call the Self Organized Spinodal(SOS) Hypothesis. This is based on the fact that faults and fault systems have stress Greens functions that have a very long range. Such systems are known to be well approximated by meanfield. These systems have a spinodal critical point that marks the boundary betwee metastable and unstable states. Such spinodal points act in many ways like critical points, i.e. they generate scaling, however they also give rise to other phenomena such as nucleation which play a role in the earthquake cycle. The SOS picture then naturally generates an earthquake cycle and provides a physical basis for the forcasting algorithm developed by our group. In this presentation I will explain the SOS hypothesis and describe how it generates scaling as well as how it can be used as a basis for statistical forcasting.

### NG32A-05 1440h INVITED

## Long Range Earthquake Interaction in Iceland

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It has been observed that earthquakes can be triggered by similarly sized events at large distances. The phenomenon has recently been shown to be statistically significant at a range up to several source dimensions in global earthquake data. The most appropriate explanation of the phenomenon seems to be criticality of the Earths crust as e.g. changes in static and dynamic stresses would otherwise be too small to trigger remote events. I present results for a regional (as opposed to global) study of seismicity in Iceland which is based on a high quality reprocessed catalogue. Results include the time-dependent determination of the maximum range of interaction and the correlation length and also address the question whether small events can trigger larger ones. Pitfalls such as data accuracy and geometry as well as boundary effects are thoroughly discussed. A comparison with surrogate data helps to assess the statistical significance of the results.

### NG32A-06 1455h INVITED

## Proximity to Criticality: Statistical Mechanics, Numerical Models and Natural Earthquake Data

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Complex driven threshold systems often produce statistical fluctuations that are very similar to those of equilibrium systems, with Boltzmann fluctuations in energy that can be used formally to define an entropy S and a 'temperature term' T. In this spirit we develop a mean field formulation for the frequency-magnitude distribution of earthquakes. Based on the results of numerical models for earthquakes as a complex system (averaged over several cycles), we assume a positive correlation between the distribution of potential strain energy U in the internal system and the radiated seismic energy E. The model predicts a functional relationship between S and <lnE> that can be used to answer the question: 'How close is the system to the critical point?'. We examine this question for temporal and spatial ensembles using CMT data. The answer for the temporal ensemble (annual data) is that the fluctuations represented by the earthquakes are indistinguishable from self-organised criticality, with a linear relationship between S and <logE>, but no correlation between S and <E>. Similarly <lnE> and <E> are not strongly correlated because <lnE> is determined most by intermediate-sized events on the Gutenberg-Richter trend, and <E> is dominated by the largest events. However, the spatial ensemble (with regions as defined in the Flinn-Engdahl scheme) show a systematic curvature in the plot of S v <lnE> consistent with an intermittently (but still near-critical) critical point system.

### NG32A-07 1510h

## Phase-locking in Coupled Non-linear Relaxation Oscillators: an Explanation for Observed Temporal and Spatial Correlation and Anti-correlation of Large Earthquakes

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There is mounting paleoseismological evidence that large earthquakes on a given fault network tend to occur in temporal clusters. Examples include the southern San Andreas system in the Imperial Valley (Rockwell et al., in prep, 2003), the Eastern California Shear Zone (Rockwell et al., BSSA, 2000), the Garlock system (Dawson et al, in prep., 2003) and the Los Angeles area (Dolan et al., in prep., 2003). This last study has also found evidence that clusters within the Los Angeles area tend to be anti-correlated with similar clusters in the Eastern California shear zone and on the Garlock fault. This clustering behavior is expected if large earthquakes behave as coupled non-linear relaxation oscillators. As a simplest case, we consider two identical faults which are loaded at constant strain rate and which fail at a prescribed stress threshold. Each thus produces the saw-tooth stress strain curve characteristic of a relaxation oscillator. The faults are non-linear oscillators because we assume the stress-strain curve is non-linear, having the negative curvature typical of laboratory experiments and regional damage mechanics models (Ben-Zion and Lyakhovsky, 2002). The two faults are coupled by symmetric stress transfer, in that we assume each fault either increases or decrease the Coulomb stress on the other by an equal amount. We find that events on the two faults phase-lock either in phase if the Coulomb stress transfer is positive or 180 degrees out of phase if the transfer is negative. This phase-lock is driven by the non-linear stress-strain relation. When a fault is close to failure, the increment of stress transfer causes a larger increment in strain. Since time is linked to strain through the assumption of constant strain rate loading, the time shift of the impending event is larger the nearer a fault is to failure. For a positive stress transfer, this shortens the interval and leads to in-phase locking. For a negative stress transfer, the interval is lengthened and the system evolves to a 180 degree out of phase lock. Preliminary models of simple faults controlled by rate- and state-dependent friction have found that non-linearity introduced by friction has a similar effect.

### NG32A-08 1525h

## Which Works Best, ETAS or SAM?

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In recent years a number of models have been proposed that describe evolutionary seismicity as an interplay between aftershocks and Coulomb stress interactions. The Epidemic-Type Aftershock Sequence (ETAS) model has in particular been proposed as a possible explanation for the widely observed phenomenon of accelerating moment release before large earthquakes. This model is based on the idea that large earthquakes are the end result of a period of self-organization in the background stress field (i.e. smaller earthquakes). In contrast to this concept is the Stress Accumulation Model, (SAM) which treats the evolution of seismicity before a large earthquake as the result of loading of the main fault primarily by creep on an extension of the fault at depth. While both of these models predict accelerating seismicity before the mainshock, they make different predictions of the spatial distribution of this activity. We demonstrate that the predictions of the Stress Accumulation model are more consistent with observed seismicity than the predictions of the ETAS model.

# NG32B MCC: 3001-3003 Wednesday 1600h

## Lorenz Lecture

***Presiding:*** **S F Tebbens,** University of South Florida

### NG32B-01 1605h INVITED

## Wonders of Planet Earth: Complexity and Order in Earth Systems

Rafael L. Bras (617-253-2117; rlbras@mit.edu)

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Much of the climate, weather and landscape of the earth is mediated by the ever present water. This talk explores the non-linearities of hydrologic processes which commonly lead to chaotic-like behavior yet beautifully organized systems. Land-atmosphere interactions are discussed first. The dynamic impact on the atmosphere and climate of land surface conditions like soil moisture and vegetation are illustrated. The ideas of multiple equilibria in vegetation and soil moisture, and of maximum evaporation at all times, are discussed. Self organization in landscape forms are the next topic. Organization in geometry and in surface texture of the river basin is achieved jointly and is the result of highly nonlinear phenomena.

# NG41A MCC: 3010 Thursday 0800h

## Scaling in Our Fluid Earth: Chaos and Multifractals in the Atmosphere, Oceans, Hydrology, and Climate I

*(joint with A, B, GP, H, OS, PP, SA, AE, C, GC)*

***Presiding:*** **S Lovejoy,** McGill University**; D Schertzer,** Laboratoire de Modélisation en Mécanique, Université Pierre et Marie Curie

### NG41A-01 0800h

## Deriving Spatiotemporal Fractal And Wavelet Models In Terms Of The Generalized Random Field Theory

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A powerful unified framework is suggested in terms of generalized spatiotemporal random fields (GS/TRF), which can derive well-known models as its special cases, including fractal, wavelet and heterogeneous random field models. It is worth-noticing that the development of the GS/TRF theory precedes that of its special cases above. A G-S/TRF is typically defined in terms of a functional involving a so-called test function belonging to a space D. The choice of D is made on the basis of the physics of the atmospheric situation and the goals of the analysis. Very rich classes of moments across space and time are derived by means of the corresponding GS/TRF functionals. By properly selecting the test functions, space-time heterogeneous models are generated, termed GS/TRF-n/m, where n and m are the corresponding spatial and temporal orders of heterogeneity, respectively. Well-known fractal random fields are readily obtained from the GS/TRF-n/m which, in addition, can lead to new and richer fractal representations in space-time. By assuming test functions having properties useful in the study of important field characteristics (multiscale features, singularities caused by physical laws, sharp variations etc.), continuous space-time wavelets are derived which have a wide range of earth science and image processing applications.

### NG41A-02 0815h

## Multifractals and Chaos, Predictability and Prediction Skills in Geophysics

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The question of prediction - from short to very long term - and its intrinsic limits is a fundamental question in Geophysics; it cross-cuts traditional discipline boundaries. The chaos revolution emphasized the fact that nonlinearity is at the core of this question. This was widely popularized as the 'butterfly effect' with the help of the celebrated Lorenz model, which was introduced as a highly simplliefied mathematical model