planes have been correlated to the fractures observed by diagraphy in the injection well. One of the major fractures observed in this well experienced a slip of 4.3 cm during the injection. We selected the multiplets spatially correlated with the plane of this fracture, and estimated the source parameters of every event in each multiplet. The distance between them is much smaller than their size (as deduced from their corner frequency), showing that each multiplet consists of a repeating slip on the same asperity. The cumulative slip obtained for each multiplet is of the same order as the one observed in the well on the selected fracture. The calculations shows a clear relation in time between the increase of the pore pressure and the cumulative slip of the seismic fractures. There is also a decrease of the seismicity rate with time. We interpret these observations as resulting from the occurence of a mostly aseismic slip on a major fracture (size 100 m), forcing small asperities (size 10 m) to rupture repeatedly for accommodating this creep event, generating the multiplets, and decelerating with time, as pore pressure reaches an equilibrium. The resulting Omori law has therefore little to do with fault patches accelerating their slip towards rupture, such as in Dieterich's models, but would be linked to the contrary to some decelerating aseismic slip on destabilized, creeping faults. We suggest that such a model may apply, at least in part, for sequences of aftershocks from natural earthquakes.

NG41C-0080 0830h POSTER

Simulation of the Burridge-Knopoff Model with Long-Range Interactions

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We simulate the Burridge-Knopoff model in one dimension for various interaction ranges. The computed size distribution of the events shows that the scaling range of the nearest-neighbor model is poorly defined. For longer range interactions, our results suggest that the existence of two scaling regions, corresponding to different types of events. The scaling regions become better defined as the interaction range increases.

NG41C-0081 0830h POSTER

Search for Direct Empirical Spatial Correlation Signatures of the Critical Earthquake Model and a New Mechanism for Long-Range Interactions

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We propose a new test of the critical earthquake model based on the hypothesis that precursory earthquakes are "actors" that create fluctuations in the stress field which exhibit an increasing correlation length as the critical large event becomes imminent. Our approach constitutes an attempt to build a more physically-based time-dependent indicator (cumulative scalar stress function), in the spirit of but, improving on the cumulative Benioff strain used in previous works documenting the phenomenon of accelerating seismicity. Using a simplified scalar space and time-dependent visco-elastic Green function of a two-layers model of the Earth lithosphere, we compute spatio-temporal pseudo-stress fluctuations induced by a series of events before four of the largest recent shocks in Southern California. Through an appropriate spatial wavelet transform, we then estimate the contribution of each event in the series to the correlation properties of the simplified scalar stress field around the location of the mainshock at different scales. This allows us to define a cumulative scalar stress function which shows neither an acceleration of stress storage at the epicenter of the mainshock nor an increase of the spatial stress-stress correlation length with time, in contradiction with those deduced previously from the cumulative Benioff strain. The earthquakes we studied are thus either simple "witnesses" of a large scale tectonic organization, or are simply unrelated, and/or the Green function describing interactions between earthquakes has a significantly longer range than predicted for standard visco-elastic media used here. We then propose a simple mechanism for these long-range interactions, based on seeing the Earth crust as crisscrossed by faults and cracks filled with fluid at close to lithostatic pressures. We develop a model in which its elastic modulii are different in net tension versus compression. In 2D, for a given strike-slip earthquake source, such nonlinear elasticity is observed to (i) rotate, widen or narrow the different lobes of stress transfer, (ii) to modify the $1/r^2$ 2D-decay of elastic Green functions into the generalized power law $1/r^\gamma$ where γ varies with increasing tension-compression asymmetry and depends on the azimuth, and can reach values significantly lower than 1. Using reasonable estimates, this implies an enhancement of the range of interaction between earthquakes by a factor up to 5-10. This may explain certain long-range earthquake triggering and hydrological anomalies in wells and suggest to revisit the standard stress tranfer calculations which use linear elasticity.

NG41C-0082 0830h POSTER

Critical Threshold for Spontaneous Failure: Macro- and Micro- Behavior of Granite Loaded to Failure

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The ultimate strength, time-dependence creep and associated microstructure of granite samples are examined as an attempt to characterize the critical parameters of brittle rock failure. We loaded triaxially 27 cylinders of the medium grain-size Mount Scott granite (western Oklahoma) under dry, room temperature conditions. Thirteen of the samples were loaded under confining pressure ranging from 0 to 50 MPa, and the group of 14 samples was loaded under confining pressure of 41MPa, for which the ultimate strength is Us = 586+-16 MPa. The 14 samples were loaded up to preselected differential stress (NDS) that ranges from 0.54 Us to 1.05 Us, and were then held under constant stroke for periods as long as six hours. The failure could be reasonably well predicted by two macroscopic parameters. One is the maximum differential stress: the eleven samples loaded under NSD $\leq$ 0.95 did not fail during the six hours of hold period, whereas the three samples loaded by NDS>0.95 failed spontaneously after a few seconds to an hour of hold time. The high Weibull parameter (m=13-22) of strength distribution of a heterogeneous rock is in agreement with this observation. The second parameter is the "crack volumetric strain" (CVS) that increases monotonously for NDS$\leq$0.95, but at NDS>0.95 it reaches a critical value of 0.001 beyond which it is poorly constrained (with CVS approaching 0.005). We mapped the microfractures in thin-sections prepared from 5 deformed samples that cover the full loading range: 0.00, 0.57, 0.88, 0.96 of the rock strength and failure. The microstructural thin-section maps provided quantitative damage intensity (approaching 0.2) and fractal dimensions of the microfractures length distribution (1.5 for unloaded sample and 2.2-2.4 for loaded samples); these maps however, provide no critical failure indicator. Which of the examined parameters could be used to determine a critical failure state in an active fault-zone? We believe that the "crack volumetric strain" is the most promising one as in the experiments it displays critical behavior and in the field it could be detected by velocity decrease of guided waves.

NG41D MCC: 3010 Thursday 1020h

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

(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

NG41D-01 1020h INVITED

Effects of Space-Time Multifractality of Rainfall on Hydrologic Regionalization

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The effect of a space-time multifractal structure of rainfall fields on runoff scaling in nested basins is being analyzed in this work. The scaling relationship between runoff and watershed area is reevaluated as a consequence. The temporal filtering effect of the watershed on the temporal singularity structure of rainfall is also evaluated. Conclusions are drawn concerning the regional transposition of hydrologic statistics and regularities.

NG41D-02 1035h

Multifractals and plankton

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The scaling relationships (m-km) of plankton distributions from transects collected in-situ using CTD and Optical Plankton Counter have been analysed using the double-trace moment multifractal analysis. The scaling behavior has indicated distinct ranges. As expected with turbulence, passive scaling behaviour is seen for the temperature spectra down to the smallest scales. Zooplankton spectra have a scaling discontinuity below which they are no longer "prisoners of turbulence". Fluorescence (phytoplankton) indicated consistent multiple "breaks in scaling" with large-scale and a small-scale turbulence-growth dominated regime but an intermediate rougher region. Zooplankton modify the scaling relationships of the phytoplankton through grazing at these scales.

NG41D-03 1050h INVITED

Low Rain-Rates, Spurious Scale Breaks and a new Depth Based Analysis Technique

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The non-linear variability of rainfall is present over a broad range of time and space scales; in addition, at a given scale it involves a huge dynamic range. Both of these characteristics challenge traditional measuring techniques; they require explicit modeling of the rain and the response of measurement devices - including tipping-bucket and siphon type rain gauges. Since they generically produce extreme variability over wide scale ranges, multifractal models of rain are the natural

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choice. The generic multifractal process is a multiplicative cascade. From the point of view of multifractals, there is an enormous difference between low but finite rain rates and exactly zero rates. This leads to a fundamental modeling question: is a single rain process adequate to model rain (perhaps with a very low rate cut-off to zero) or does one require separate processes for determining where and when it rains and another for the rates in the raining regions? In more mathematical terms, is the support of the rain process a fractal subset of space-time? On the other hand, the low and zero rain rates are particularly difficult to measure; for example, a tipping-bucket type rain gauge does not have a fixed temporal resolution, but rather a fixed depth resolution so that at the low rain rate limit, the temporal resolution becomes infinite. We show that this problem leads to spurious breaks in the scaling at scales which can be of the order of an hour even though the depth resolution can be very small (0.1 mm). In order to overcome these problems an alternative is explored, which analyses the rain as a function of total rain-depth rather than time. This method is particularly suitable for tipping-bucket rain data, because it uses the raw data rather than reconstructed time-series. By comparing results from two climatological regions we show that whereas the statistics from reconstructed series are very different, those with the new depth based series are almost identical (since they are insensitive to the low/zero rain rate problem). In addition, it eliminates the scale breaks so that rain is clearly seen to be scaling from the smallest resolvable scales to the synoptic maximum (roughly 2 weeks).

NG41E MCC: 3010 Thursday 1120h

Funding Agency Perspectives on Nonlinear Approaches in Data Analysis and Simulations: Public Forum

Presiding: **D L Turcotte,** University of California, Davis**; C C Barton,** U.S. Geological Survey

NG41E-01 1125h

Funding Agency Perspectives on Nonlinear Approaches in Data Analysis and Simulations: Public Forum

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This session will be a panel discussion.

NG51A MCC: Level 2 Friday 0830h

Scaling in Our Fluid Earth: Chaos and Multifractals in the Atmosphere, Oceans, Hydrology, and Climate III Posters *(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

NG51A-0822 0830h POSTER

Study of the Space-Time Variability of the Precipitations in the semi Arid Tropics Areas like African Sahel

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One of the difficulty of decision making in the matter of climate in semi arid tropics areas like African Sahel, is to manage the high time space variability of the atmospheric fields. For example, the high time space variability of the rain fields (intermittency) is explained by the multiplicity of time space scales which involves. A multifractal approach of the field is assumed. Some aspects of the study are related to : o Down scaling adaptations of the outputs of global climate models to regional and local scales; o Prediction of extremes events : floods, droughts or "dry spells"... Studies are developed by the African Centre for Meteorological Application for Development (ACMAD) This Centre, located in Niamey, Niger, acts as an African institution for weather and climate. Its long term goals are to : - reduce the dryness effects or any other catastrophe related to the climatic conditions such as the tropical cyclone, the floods and the storms; - to develop methodologies and techniques for weather and climate application at the national and sub-regional level; The basic activities to realize this objectives are: - the collection and analysis of hydrometeorological data; - the dissemination of climatic information for the early alarm in the fields related to the agriculture or the management of resources in water and energy; - the dissemination in due time of useful information on the weather and climate; - the connected of the variability and of the climatic change, and such as their impact upon the economy, - the development of strategies of appropriate responses to the impact of the desertification, floods, tropical cyclones,

URL: http://www.acmad.ne

NG51A-0823 0830h POSTER

Multifractal Large particle limit in rain: implications for radar rain measurements

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Raindrop size and position data - from eighteen scenes of a = 8 m**3 region each containing 5,000 to 15,000 rain drops - obtained for 5 different storms in the HYDROP (HYdrometeor Detection and Ranging using stereO-Photography) experiment - was systematically statistically analyzed in spheres ranging from 10 cm to 2m in diameter. In four of the five storms, we found convincing evidence for the convergence to a multifractal scaling large N limit; the observed scaling exponents were quite close to those reported in the rain literature at much larger scales. By randomizing the positions of the drops, we could compare directly the true fluctuation statistics with those of the classical theory; the latter were significantly smaller. By carefully considering the meteorological conditions, in particular the turbulence intensity and the drop size distributions, we could explain the observed variations in the inner scale. In the multifractal large N limit, the drop size distribution is of secondary importance, it is the drop number, liquid water content, and other densities which tend to universal multifractal scaling limits. These results are related to the often invoked log-normal behavior of rain, but with important differences. We also show that if the densities are multifractal with the same universal multifractal index a, that we recover power law relations between their statistics, for example mean(R)=a*Mean(Z)**b (c.f. the usual deterministic relations R=a*Z**b where R, Z are random variables).

NG51A-0824 0830h POSTER

Multifractal downscaling of a GCM rainfield

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In order to get a more efficient production management of reservoirs, it would be helpful to apply long-term meteorological forecasts to hydrological models. Unfortunately, the explicit scales of present GCM's are quite larger (e.g. 243kmx243kmx32 days) than those of hydrological models (e.g. 1 kmx1kmx1day). Therefore it is indispensable to proceed to a downscaling of the output of the former in order to obtain an input for the latter. In this paper, we present a multifractal downscaling procedure. The site of the study is the area of Doubs river, with the help of a dense local hydrological network, but in order to get a larger spatial scale ratio we extend our multifractal analysis to France, with the help of Météo-France PRECIP data base. We first argue that it is indispensable to consider a multifractal downscaling procedure in order to respect the scaling properties of the hydro-meteorological fields. We performed time, scale and time-space multifractal analysis of the available data and evaluate the corresponding universal exponents, as well as the anisotropy/dynamical exponent of the time-space generalized scale. We show that these exponents are quite robust. We compare our analysis to similar works, but restricted to the use of Log-Poison cascade and space-time isotropy. We show both theoretically and empirically that these restrictions are untenable, in particular with respect to the extremes. We also show simulations should be done with the help of continuous (in scale) and causal cascade models, not with ad-hoc time-space cascades, and present the corresponding numerical simulations. of space-time downscaling of (meso-scale) GCM data down to (micro-scale) hydrological scales. We greatly acknowledge the financial support from Electricité de France, as well as Météo-France for providing access to its PRECIP data base.

URL: http://www.multifractal.jussieu.fr

NG51A-0825 0830h INVITED POSTER

Potential of Multifractals for Water Resources Planners

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The natural variability of water resources and the augmenting demand for water leads mankind to strongly interfere with the hydrologic cycle in attempts too ensure that water will be available in adequate quantity and quality, with a proper distribution in space and time. So, engineers will be often concerned with ambitious plans of flood control. Runoff predictions, such as the estimates of peak flows that are associated with a particular exceedence probability, form the basis for the design of most civil engineering works. Since river runoff phenomena reflect many complex interactions at different scales between diverse basin factors as well as meteorological and climatic fluctuations, that strongly modify the precipitation input, the prediction of a maximum expected water flow remain a rather unsolved issue. Indeed, as hydrologists often observed it, the probabilistic distribution of runoff is skew; however its mathematical form is far from being known, in particular its tails. As a consequence, the insufficient spillway capacity remains worldwide the second commonest cause of dam failure (after the foundation failure). Present communication demonstrates how the multifractal framework overcomes some present difficulties in the flood predictions within space and time domains. Moreover, our multifractal results reflect crucial changes in river regimes after dam construction, that may have drastic consequences for the spillway capacity. To consolidate our results, we use few millions of flow measurements at very different hydrological locations all over the World. The time-scale of the data ranges from a day to several centuries.

URL: http://www.multifractal.jussieu.fr