more thin-tailed. The occurrence risk for large and very-large events using power-law frequency-size distributions is often much more conservative, with a greater chance of a large event occurring in a given period of time, compared to thinner tail distributions. One potential explanation for the frequent occurrence of power-law (fractal) frequency-size distributions among natural hazards lies in cellular-automata models, and their association with self-organized criticality and inverse cascades. The power-law behavior of the sandpile cellular-automata model has been associated by some with landslides, the forest-fire model with actual forest fires, and the slider-block model with earthquakes. A relatively simple inverse-cascade of metastable regions can explain the behavior of both models and the actual natural hazards. Metastable regions grow by coalescence and are lost in 'avalanches'. However, the losses are dominated by the largest events and have little influence on the inverse cascade of metastable region coalescence. This inverse cascade of metastable regions is self-similar and the number-area statistics are power-law. Although the theoretical explanations are still being debated, the increasing evidence for power-law statistics means that government agencies and reinsurance companies should include this much more conservative frequency-size distribution when calculating the occurrence risk of large natural hazards.

NG12A-08 1525h

Coping with climate noise: Long-range dependence and weather derivatives

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Random day-to-day changes in weather lead to random year-to-year fluctuations in monthly and seasonal means, a feature known as "climate noise". Such climate noise has direct economic impact on a wide variety of businesses. A typical example is energy vendors, whose annual revenues are closely correlated with seasonal mean temperatures. To deal with this risk, a form of insurance known as weather derivatives has been developed in recent years. We discuss a Monte Carlo approach to the pricing of weather derivatives based on stochastic modeling of daily temperature. It will be shown that this approach can only be succesful if the time-series model correctly captures the autocorrelation structure of the data even at very high lags. Evidence will be presented that observed daily temperatures exhibit long-range dependence, i.e. power-law decay of the autocorrelation. This means that classical Box-Jenkins ARMA models are unequal to the task, since their autocorrelations decay exponentially. ARFIMA, a generalisation of ARMA explicitly incorporating long-range dependence, does however prove to be suitable. We also briefly discuss the physical mechanisms which give rise to the power-law scaling found in the data.

NG12B MCC: 3005 Monday 1340h

Visualization, Analysis, and Distributed Computing in Nonlinear Geosciences II *(joint with OS, V, AE, DI)*

Presiding: **G Erlebacher,** Florida State University**; D A Yuen,** University of Minnesota

NG12B-01 1340h INVITED

Earth Sciences, GeoInformatics and Visualization and Analysis of Distributed Databases

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GeoInformatics is part of NSF's larger cyberinfrastructure initiative that broadly targets the earth sciences. GeoInformatics as a system encompasses the development and maintenance of databases, but it must also provide the mechanisms to mine, synthesize, and visualize these data in new ways, and to seamlessly use old and new numerical and statistical tools on here-to-fore inaccessible data sets. It includes high-level as well as desk-top modeling. The entire system must be accessible to the entire community - from the large research universities to the smallest college. Finally, it must provide real opportunities for wide participation - a few cannot do this for the many - it must be a community system. The overall system will include legacy as well as new data. Vast amounts of data will stream in from sensors, in particular as we establish more natural observatories. Data mining and other methodologies have to be developed and refined to allow researchers to easily, rapidly, and accurately access these data. Visualization, numerical, and statistical tools boxes have to be developed that allow the users to easily but exhaustively assess and synthesize these data as they ask a myriad of questions. Many of these questions will be new - the system will allow the researcher to ask questions they have never before thought about - that is the key for the future of our science. These tools have to be maintained and updated, and new ones developed as users ask questions in different ways, as the databases expand, and as information technology advances. Some of the computational modeling efforts will be very intensive and require significant resources; the role of the system is to connect the models with the data that they must ultimately be tested with, to insure that the models are available to the entire community, and insure that the codes are updated as necessary and archived. Thus the GeoInformatics system, indeed, the cyberinfrastructure system as a whole, starts with the mundane process of data acquisition and database construction and ends with the tools and models that will help define the next generation of science.

NG12B-02 1400h INVITED

NaradaBrokering as Middleware Fabric for Grid-based Remote Visualization Services

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Remote Visualization Services (RVS) have tended to rely on approaches based on the client server paradigm. The simplicity in these approaches is offset by problems such as single-point-of-failures, scaling and availability. Furthermore, as the complexity, scale and scope of the services hosted on this paradigm increase, this approach becomes increasingly unsuitable. We propose a scheme based on top of a distributed brokering infrastructure, NaradaBrokering, which comprises a distributed network of broker nodes. These broker nodes are organized in a cluster-based architecture that can scale to very large sizes. The broker network is resilient to broker failures and efficiently routes interactions to entities that expressed an interest in them. In our approach to RVS, services advertise their capabilities to the broker network, which manages these service advertisements. Among the services considered within our system are those that perform graphic transformations, mediate access to specialized datasets and finally those that manage the execution of specified tasks. There could be multiple instances of each of these services and the system ensures that load for a given service is distributed efficiently over these service instances. Among the features provided in our approach are efficient discovery of services and asynchronous interactions between services and service requestors (which could themselves be other services). Entities need not be online during the execution of the service request. The system also ensures that entities can be notified about task executions, partial results and failures that might have taken place during service execution. The system also facilitates specification of task overrides, distribution of execution results to alternate devices (which were not used to originally request service execution) and to multiple users. These RVS services could of course be either OGSA (Open Grid Services Architecture) based Grid services or traditional Web services. The brokering infrastructure will manage the service advertisements and the invocation of these services. This scheme ensures that the fundamental Grid computing concept is met - provide computing capabilities of those that are willing to provide it to those that seek the same.
[1] The NaradaBrokering Project: http://www.naradabrokering.org

NG12B-03 1420h INVITED

Visualization Techniques in Laboratory Experiments: Resolving the Mechanics of Mixing in Complex flows

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Many geological phenomena such as the emplacement of lava flows, the cooling and solidification of magma chambers, and the thermal evolutions of the core and mantle of the Earth involve mixing processes operating in a large range of dynamical regimes and acting over a wide range of time and length scales. Whereas turbulent stirring can play a role, say, in magma mixing processes that lead to volcanic eruptions, the compositional evolution of planetary mantles is largely due to three-dimensional (3D) unsteady laminar flow. Moreover, all such flows can involve fluids with strongly contrasting viscosities and densities. Inherent difficulties with simulating such flows numerically under appropriate conditions makes analog experiments essential to their understanding, the results of which may be incorporated into parameterized numerical models. In this talk I review some invasive and noninvasive laboratory approaches to visualizing and quantifying both the time-evolution and end result of mixing processes in complex convective flows. A particular experimental challenge is the precise resolution of 3D time-dependent overturning motions leading to mixing. Accordingly, I discuss some 2D and 3D particle image velocimetry (PIV) and particle tracking velocimetry (PTV) techniques for flow visualization that have been developed and applied to extract detailed information about the mechanics of mixing in a number of situations.

NG12B-04 1440h INVITED

The international Solid Earth Virtual Research Observatory (iSERVO) institute seed project

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Numerical simulation models that capture the essential physics and dynamics of the solid earth system provide a critical means to probe the earth's complex system behaviour. The APEC Cooperation for Earthquake Simulation (ACES) was established to develop simulation models for the complete physics of earthquakes and related processes, to foster collaboration between complementary national programs, and to foster development of research infrastructure. Research by ACES participants is summarised in 3 special issues of PAGEOPH (2000, 2002, and in press). Solid earth simulator programs linked via ACES include a new 5 year program to establish a national facility in Australia (Australian Computational Earth Systems Simulator MNRF), USA programs being developed by NASA JPL in collaboration with science centers, and Japan's new Centre of Excellence in predictability of the evolution and variation of the multi-scale earth system. Plans are now commencing to establish the framework for an international institute for computational earth system simulation to maximise benefits of these international efforts. The institute will make extensive use of the World Wide Web, computational Grid technologies, and multi-tiered information architectures to allow simulation models and data to be manipulated by symbolic means in a way not previously possible. A

seed iSERVO project is underway to illustrate the approach. It involves development of web based services and portals to enable different numerical simulation models contributed by Australia, Japan and USA to be run using several "standard" crustal fault system models (strike-slip, intraplate, and subduction). The iSERVO Grid is being constructed from Web services enhanced to be consistent with Grid Forum standards. The system uses distributed computing including high performance computers and distributed heterogeneous databases using OGSA interfaces. These are accessed with portals exploiting the new portlet standards. The iSERVO project aims to lead to an international virtual laboratory for solid earth systems simulation that builds on complementary efforts worldwide, and hence, to provide a basis to foster breakthrough advances in grand challenge science questions such as that of earthquake forecastability.

URL: http://www.quakes.uq.edu.au/ACES

NG12B-05 1500h INVITED

Computing and Visualizing the Complex Dynamics of Earthquake Fault Systems: Towards Ensemble Earthquake Forecasting

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We consider the problem of the complex dynamics of earthquake fault systems, and whether numerical simulations can be used to define an ensemble forecasting technology similar to that used in weather and climate research. To effectively carry out such a program, we need 1) a topological realistic model to simulate the fault system; 2) data sets to constrain the model parameters through a systematic program of data assimilation; 3) a computational technology making use of modern paradigms of high performance and parallel computing systems; and 4) software to visualize and analyze the results. In particular, we focus attention of a new version of our code Virtual California (version 2001) in which we model all of the major strike slip faults extending throughout California, from the Mexico-California border to the Mendocino Triple Junction. We use the historic data set of earthquakes larger than magnitude M > 6 to define the frictional properties of all 654 fault segments (degrees of freedom) in the model. Previous versions of Virtual California had used only 215 fault segments to model the strike slip faults in southern California. To compute the dynamics and the associated surface deformation, we use message passing as implemented in the MPICH standard distribution on a small Beowulf cluster consisting of 10 cpus. We are also planning to run the code on significantly larger machines so that we can begin to examine much finer spatial scales of resolution, and to assess scaling properties of the code. We present results of simulations both as static images and as mpeg movies, so that the dynamical aspects of the computation can be assessed by the viewer. We also compute a variety of statistics from the simulations, including magnitude-frequency relations, and compare these with data from real fault systems.

URL: http://cse.ucdavis.edu/~rundle/

NG12B-06 1520h

Wavelet and Statistical Thresholding of convection plumes in High-Rayleigh number flows

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We present some novel approaches to the problem of analyzing the characteristic properties of temperature plumes in high Rayleigh number (Ra) convection flows. The datasets are computed at $Ra = 10^6$ to 10^9. As Ra increases, the characteristic width of the upwelling and downwelling patterns decreases as $Ra^{-1/2}$ and occupy a increasing small fraction of the volume. In the presence of ever increasing data set sizes, it is necessary to develop compression algorithms that are consistent with the physics of the flow (which is localized within these plumes).

We describe two approaches for plume identification. The first technique uses second generation wavelets combined with thresholding to only retain 1-5 percent of the dominant wavelet coefficients. The particular wavelets used permit a one to one identification between each wavelet and a point in physical space. By displaying those points corresponding to wavelets whose coefficients are above a user-specified threshold, the structure of the plumes becomes clear.

There is also a need to study the morphology of the plumes, including their surface, volume and other characteristics. We explore a computational approach that constructs probability density distributions (pdf/histogram) of variables integrated over the isosurface of temperature as a function of temperature. The novel approach lies in performing this computation using one pass through the data. By choosing appropriately the values integrated, one derives information on the distribution of functional values, gradients, and curvature. Maxima and inflection points become characteristic properties of the flow. We study their variation as a function of Ra. This technique is also applied to automatic color map selection; we illustrate the results on our datasets.

NG12C MCC: 2010 Monday 1600h

From Microscale to Macroscale: Models for Material Damage Mechanics and Earth System Dynamics and Their Relation to Seismicity and Earthquakes I *(joint with S, T, AE, GC, MR)*

Presiding: **J B Rundle,** University of California, Davis**; R Shcherbakov,** University of California, Davis**; D L Turcotte,** University of California, Davis

NG12C-01 1600h

A Damage Mechanics Model for the Continuum Rheology of the Upper Continental Crust

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Deformation of the lithosphere is clearly complex. Ideally, the lithospheric plates are rigid and displacements are restricted to plate-boundary faults. But it is clear that broad zones of deformation occur within the lithosphere, particularly the continental lithosphere. Although this deformation may be primarily restricted to faults in the upper continental crust, it may still be appropriate to treat this deformation using a continuum approach. A standard engineering approach to brittle deformation of a solid is to use damage mechanics. There is also a close association between damage mechanics and the behavior of fiber bundles. We derive a continuum model for deformation assuming that broken fibers in a fiber bundle are instantaneously replaced by new, unstressed fibers. The result of our analysis is a non-Newtonian viscous rheology. We show that the same result can be obtained using damage mechanics directly. Using Omori's law for the decay of aftershocks, we conclude that the power-law exponent in the non-Newtonian rheology is in the range 5 to 15. With this strong nonlinear viscous rheology, the behavior of the deforming upper crust approaches that of a perfectly plastic material.

NG12C-02 1615h INVITED

A generalized law for aftershock rates in a damage rheology model

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Aftershocks are the response of a damaged rock surrounding large earthquake ruptures to the stress perturbations produced by the large events. Lyakhovsky et al. [JGR, 1997] developed a damage rheology model that provides a quantitative treatment for macroscopic effects of evolving distributed cracking with local density represented by a state variable a. The equation for damage evolution, based on the balance equations of energy and entropy and generalization of linear elasticity, accounts for both degradation and healing as a function of the existing strain tensor and material properties that may be constrained by lab data (rate coefficients and ratio of strain invariants separating states of degradation and healing). Analyses of stress-strain and acoustic emission laboratory data during deformation leading to brittle failure indicate further [Liu et al., AGU, F01; Hamiel et al., this meeting] that the fit between model predictions and observations improves if we also incorporate gradual accumulation of a non-reversible deformation with a rate proportional to the rate of damage increase. For analysis of aftershocks, we consider the relaxation process of a material following the application of a strain step associated with the occurrence of a mainshock. The coupled differential equations governing the damage evolution and stress relaxation can be written in non-dimensional form by scaling the elastic stress to its initial value and the time to characteristic time of damage evolution td. With this, the system behavior is controlled by a single non-dimensional ratio R = td/tM representing the ratio between the damage time scale to the Maxwell relaxation time tM. For very small R there is no relaxation and the response consists of constant rate of damage increase until failure. For very large R there is rapid relaxation without significant change to the level of damage. For intermediate cases the equations are strongly coupled and nonlinear. The analytical solution for the damage evolution contains error functions and is richer than a simple power law relation. However, the results associated with the analytical expression can be fitted well for various values of R with a power law similar to the modified Omori law for aftershocks. This also holds for 3D numerical simulations of aftershock sequences with our damage rheology model. Initial results based on 3D simulations indicate that high values of R corresponding to low viscosity material produce diffuse (swarm-like) aftershock sequences, while low values of R corresponding to more brittle material produce clear (Omori-like) aftershock sequences.

NG12C-03 1630h

Damage Mechanics: Connecting the Microscale and Macroscale in Material Deformation

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Material damage occurs when microscopic processes of dislocation dynamics and microcrack formation are produced in association with strain and fracture mechanisms operating on the macroscopic scale. Here we discuss the physics of self-organization and damage at the "microscopic" scale. We begin by writing a free energy functional that connects the microscale with the macroscale processes. Since damage represents a modification of a brittle elastic system, we expect to find that the interactions produce the mean field dynamics characteristic of elastic systems. Sudden transitions in the state of these systems can be understood in the context of first order phase transitions, where the influence of the classical limit of stability, or spinodal, is felt. The appearance of a mean field spinodal leads to a general coarse-grained equation, which expresses the balance between rate of stress supplied, and rate of stress dissipated in the processes leading to surface damage. We can use ideas from thermodynamics and kinetics of phase transitions to develop the form of standard equations for material damage, giving clear physical meaning to all terms and variables. Ultimately, the self-organizing dynamics arise from the appearance of an energy landscape in these systems, which in turn arises from the strong correlations and mean field nature of the physics. We demonstrate that these ideas lead to