NG52A-07 1520h INVITED

Creating a Distributed, Community-Modeling Environment in Support of the Working Group for the Development of Regional Earthquake Likelihood Models (RELM)

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Several recent studies have concluded that improvements in seismic hazard analysis (SHA) will require a more physics-based, system-level approach. To this end, a working group for the development of Regional Earthquake Likelihood Models (RELM; www.relm.org) has been established to develop, test, and evaluate the hazard implications of a variety of viable earthquake-forecast models. One problem faced by this working group is the lack of a computational infrastructure capable of dealing with the wide variety of models under development. Therefore, a new effort known as OpenSHA (www.OpenSHA.org) is developing an object-oriented, open-source, and web-based community-modeling environment. The goal is to enable various SHA components (including the RELM forecast models) to plug in for analysis without having to change whats being plugged into. This infrastructure will also allow the models, as well as the various data repositories upon which they depend, to be geographically distributed and run-time accessible. Building such a community-modeling environment raises several issues related to computational speed, ease of use, error prevention, and repeatability of results in an environment where the models and data are continually being updated. The Information-Technology Research collaboration of the Southern California Earthquake Center is helping us resolve some of these issues.

URL: http://www.relm.org

NG52A-08 1535h INVITED

The Solid Earth Research Virtual Observatory: A web-based system for modeling multi-scale earthquake processes

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We are building a new Problem Solving Environment for use by the seismological, crustal deformation, and tectonics communities for developing an understanding of active tectonic and earthquake processes. The top-level operational architecture of our solid earth research virtual observatory (SERVO) shows science users interacting with interface programs as well as modeling, simulation, and analysis tools. The general architecture follows the Web Services model being developed by business interests, but is applied to scientific applications and supporting software resources (such as databases). The system is divided into three tiers: a user interface layer (implemented as a browser interface), a system resource layer, and a middle control layer that maintains proxies (or brokers) to the system resources. The middle tier provides a uniform interface to the resource layer. Following the Web Services approach, we define XML interface abstractions (in WSDL) for basic services (such as File Management) and implement the interface with appropriate technologies (such as with a relational database). Communication between the services is done with an XML messaging architecture (SOAP). Our initial focus is to integrate time-dependent crustal deformation models into the system including both layered analytical and heterogeneous finite element models.

URL: http://www.servogrid.org

NG52A-09 1550h

Physics-Based Predictive Simulation Models for Earthquake Generation at Plate Boundaries

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In the last decade there has been great progress in the physics of earthquake generation; that is, the introduction of laboratory-based fault constitutive laws as a basic equation governing earthquake rupture and the quantitative description of tectonic loading driven by plate motion. Incorporating a fault constitutive law into continuum mechanics, we can develop a physics-based@simulation model for the entire earthquake generation process. For realistic simulation of earthquake generation, however, we need a very large, high-speed computer system. In Japan, fortunately, the Earth Simulator, which is a high performance, massively parallel-processing computer system with 10 TB memories and 40 TFLOPS peak speed, has been completed. The completion of the Earth Simulator and advance in numerical simulation methodology are bringing our vision within reach. In general, the earthquake generation cycle consists of tectonic loading due to relative plate motion, quasi-static rupture nucleation, dynamic rupture propagation and stop, and restoration of fault strength. The basic equations governing the entire earthquake generation cycle consists of an elastic/viscoelastic slip-response function that relates fault slip to shear stress change and a fault constitutive law that prescribes change in shear strength with fault slip and contact time. The shear stress and the shear strength are related with each other through the boundary conditions on the fault. The driving force of this system is observed relative plate motion. The system to describe the earthquake generation cycle is conceptually quite simple. The complexity in practical modelling mainly comes from complexity in structure of the real earth. Since 1998 our group have conducted the Crustal Activity Modelling Program (CAMP), which is one of the three main programs composing the Solid Earth Simulator project. The aim of CAMP is to develop a physics-based predictive simulation model for the entire earthquake generation cycles in and around Japan. The total simulation system is divided into three components: a crust-mantle structure model, a tectonic loading model and a dynamic rupture model. For a San Andreas type of plate boundaries we have already developed a standard model. In the case of convergent plate boundaries, although the basic equations governing the earthquake generation cycle are essentially the same as those in the case of transcurrent plate boundaries, the practical modelling is much more difficult, because of complexity in geometry of plate interfaces. For the present we have developed a 3-D standard structure model of plate interfaces in and around Japan, the viscoelastic slip-response functions for this structure model, and the slip- and time-dependent fault constitutive law with an inherent strength-restoration mechanism. Combining all these elements, we can construct a quasi-static tectonic loading model. For the dynamic rupture process, we have developed a simulation algorithm for rupture propagation on a 3-D curved fault surface by applying BIEM. In the last stage of CAMP the quasi-static loading model and the dynamic rupture model are connected with each other through a simulation platform on the Earth Simulator. Outputs of the simulation system are the crustal deformation, internal stress change and seismic wave radiation associated with the progress of seismic and/or aseismic slip on the plate interfaces. From comparison of these computed data and observed data, we can extract useful information to estimate the past slip history and the present stress state on the plate interfaces by using a technique of inversion analysis.

NG52A-10 1605h

A Proposed Physical Model of Strain Accumulation in the San Francisco Bay Region

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Strain accumulation in tectonically active regions is dependent on several factors, including background tectonic loading, steady-state dislocation processes such as creep, and transient deformation. In the San Francisco Bay (SFB) region, the most uncertain of these processes is transient deformation, which arises primarily in association with large historic earthquakes. As such it depends upon the history of faulting and the rheology of the crust and mantle, which together determine the pattern of longer-term (decade-scale) post-seismic response to earthquakes. We utilize a set of 99 GPS velocity vectors in the SFB region in order to characterize the strain field and construct a physical model of its present deformation. We first perform an inversion for the continuous velocity gradient field from the discrete GPS velocity field, from which both tensor strain and rotation may be extracted. We then fit this strain field to a model of time-dependent deformation within a 135 km-wide, arcuate shear zone bounded by strong Pacific plate and Sierra Nevada block lithosphere to the SW and NE, respectively. Driving forces are purely lateral, consisting of shear zone deformation imposed by the relative motions between the thick Pacific plate and Sierra Nevada block lithospheres. Assuming depth-dependent viscoelastic structure within the shear zone, we account for the effects of steady creep on faults and viscoelastic relaxation following the 1906 San Francisco and 1989 Loma Prieta earthquakes, subject to constant velocity boundary conditions on the edges of the shear zone: 38 mm/yr fault-parallel motion and variable fault-perpendicular motion. Fault creep is realized by evaluating dislocations on the creeping portions of faults in the fluid limit of the viscoelastic model. The present strain pattern is well-described as a nearly uniform shear strain oriented approximately N35°W (140 nanostrain/yr) plus a more heterogeneous N55°E uniaxial compression averaging 20 nanostrain/yr across the shear zone. A grid search based on fitting the observed strain pattern yields a mantle viscosity of 1.2×10^{19} Pa s and a fault-perpendicular convergence rate of $\sim$ 3 mm/yr. Most of this convergence appears to be accommodated in a zone much narrower than the Pacific-Sierra Nevada plate boundary zone.

NG52B MCC: 103 Friday 1630h

The Lorenz Lecture Series: Donald Turcotte

Presiding: **J Rundle,** University of Colorado**; S Tebbens,** University of South Florida

NG52B-01 1635h INVITED

Self-Organized Complexity in Geophysics

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It is easy to give examples of self-organized complexity in geophysics, examples include fluid turbulence, earthquakes, drainage networks, and many others. It is much more difficult to define what is and what is not self-organized complexity. Two common characteristics are: (1) fractal behavior and (2) chaotic behavior. Two simple models that have been introduced in statistical physics typify self-organized complexity: (1) diffusion limited aggregation (DLA) and (2) site percolation. DLA is a random branching network that exhibits Horton-Strahler and Tokunaga branching statistics. So do stream networks. Site percolation is equivalent to randomly planting trees on a grid. The condition when a cluster of trees has grown to span the grid is a critical point. If matches are also randomly dropped on the grid to burn the tree clusters the system is said to exhibit self-organized criticality. This behavior can be explained in terms of the self-similar coalescence of tree clusters. This behavior is also applicable to actual forest fires, earthquakes, landslides, and possibly floods.

NG61A MCC: Hall C-TH Saturday 0830h

Visual Computing in Nonlinear Geophysical Phenomena I *(joint with G, GP, OS)*

Presiding: **D A Yuen,** University of Minnesota; **G Erlebacher,** Florida State University; **B J Travis,** Los Alamos National Laboratory

NG61A-01 0830h INVITED

Efficient Visual Data Exploration in High-Resolution Global Dynamical Models of the Earth's Mantle

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The Earth Simulator now makes practical global dynamical models of the Earth's mantle and lithosphere at a spatial resolution of 15 km using about 700,000,000 computational cells. Our approach to visual exploration of such large 4D datasets includes concurrent parallel image rendering using a set of pre-specified formats to generate several simultaneous movies while the model calculation itself is being performed. These movies can be played and replayed as they are being created during the course of the model calculation. The input data file specifying the movie formats also can be modified during the course of a run. We exploit the multigrid hierarchy inherent in our numerical method for data compression as appropriate. We find that multiple movies at different spatial resolutions, some providing a global overview and others focusing on fine details at full resolution but in a restricted portion of the computational domain, are of great assistance in obtaining a rapid grasp of the important aspects of a given model run. Generating the graphics simultaneous with performing the numerical calculation also eliminates the onerous steps of storing and post-processing large numbers of huge data files. The quantity of data associated with even 100 movie files is minuscule compared with that contained in the large number of global data files associated with a typical high-resolution 4D calculation.

NG61A-02 0850h INVITED

Visualization Strategy on the Earth Simulator for Large-Scale Unstructured Data Sets of GeoFEM

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We have been developing visualization tools for large-scale unstructured data sets in GeoFEM. GeoFEM is a parallel Finite Element Method (FEM) platform for simulations of various solid Earth phenomena such as the plate tectonics or the geodynamo processes, and intended to perform on the Earth Simulator, which is the fastest supercomputer in the world today. We intend the simulations with over 10^7 elements on the Earth Simulator (ES), which is the fastest vector-parallel supercomputer today. Visualization and data management are large issues for our project because of lack of interactivity of the ES and of difficulty of huge data access on the ES. We design to perform the simulation and visualization sequentially. To perform the visualization system with simulations, the visualization programs optimized with three level optimization; that is, vectorization for each processor, and OpenMP parallelization for each processor node, and MPI communication among processor nodes with domain decomposition. However, because we cannot obtain the whole domain data in this processes, we have to design methods and parameters of the visualization when the simulation is started. Because the visualization tools can be performed independently, we can choose several processes of the visualization and combine several processes of the visualizations and data analysis. We have developed Parallel Surface Rendering (PSR), Parallel Volume Rendering (PVR), and the hybrid rendering of both methods in GeoFEM.

NG61A-03 0910h

Scientific Visualization Made Easy for the Scientist

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amira is an application program used in creating 3D visualizations and geometric models of 3D image data sets from various application areas, e.g. medicine, biology, biochemistry, chemistry, physics, and engineering. It has demonstrated significant adoption in the market place since becoming commercially available in 2000. The rapid adoption has expanded the features being requested by the user base and broadened the scope of the amira product offering.

The amira product offering includes amira Standard, amiraDev, used to extend the product capabilities by users, amiraMol, used for molecular visualization, amiraDeconv, used to improve quality of image data, and amiraVR, used in immersive VR environments.

amira allows the user to construct a visualization tailored to his or her needs without requiring any programming knowledge. It also allows 3D objects to be represented as grids suitable for numerical simulations, notably as triangular surfaces and volumetric tetrahedral grids. The amira application also provides methods to generate such grids from voxel data representing an image volume, and it includes a general-purpose interactive 3D viewer. amiraDev provides an application-programming interface (API) that allows the user to add new components by C++ programming.

amira supports many import formats including a 'raw' format allowing immediate access to your native uniform data sets. amira uses the power and speed of the OpenGL and Open Inventor graphics libraries and 3D graphics accelerators to allow you to access over 145 modules, enabling you to process, probe, analyze and visualize your data. The amiraMol extension adds powerful tools for molecular visualization to the existing amira platform. amiraMol contains support for standard molecular file formats, tools for visualization and analysis of static molecules as well as molecular trajectories (time series).

amiraDeconv adds tools for the deconvolution of 3D microscopic images. Deconvolution is the process of increasing image quality and resolution by computationally compensating artifacts of the recording process. amiraDeconv supports 3D wide field microscopy as well as 3D confocal microscopy. It offers both non-blind and blind image deconvolution algorithms. Non-blind deconvolution uses an individual measured point spread function, while non-blind algorithms work on the basis of only a few recording parameters (like numerical aperture or zoom factor).

amiraVR is a specialized and extended version of the amira visualization system which is dedicated for use in immersive installations, such as large-screen stereoscopic projections, CAVE or Holobench systems. Among others, it supports multi-threaded multi-pipe rendering, head-tracking, advanced 3D interaction concepts, and 3D menus allowing interaction with any amira object in the same way as on the desktop. With its unique set of features, amiraVR represents both a VR (Virtual Reality) ready application for scientific and medical visualization in immersive environments, and a development platform that allows building VR applications.

NG61A-04 0925h INVITED

Incorporating Web services into Earth Science Computational Environments

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Grid technology promises to greatly enhance the analysis of data and their integration into all Earth Science fields. To prepare for this, one should "package" applications as Web Services using standards develop by the computer industry and W3C consortium. We report on some early experience with several earthquake simulation programs.

URL: http://www.servogrid.org

NG61A-05 0940h INVITED

Web-based visualization services for the Geosciences

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The size of geophysical datasets keeps increasing without apparent end in sight, collaboration between researchers of disciplines is on the rise, and their primary institutions are often geographically dispersed. As a consequence it is very important to develop tools that ease collaborative efforts. Our aim is to provide services that allow researchers with access to a web browser to perform data analysis and visualization tasks from anywhere at anytime. We present several web services related to visualization, meant to be eventually integrated into the portal work developed by Geoffrey Fox. We describe herein a remote visualization tool, a video creation tool, and a data querying tool, all accessible from the World Wide Web.

We have chosen the package Amira to display our geophysical datasets. A new web-based interface to Amira that allows users to execute existing scripts, create their own scripts interactively, and retrieve images generated by Amira on the server. generated by Amira running on the server This tool allows the user to explore complex datasets without access to high-powered visualization tools. Animations of large-scale geophysical datasets (e.g., mantle convection, earthquake simulation data) are created from a large number of static images combined into an appropriate movie format. We describe a Linux-based video creation tool that allows the user to roam directories, view images, and view/create animations from most web browsers. Visualization programs often run on servers and are not available to clients. We have implemented a tool to video stream the output of OpenGL programs running on a Linux server to a variety of Linux clients, including PDA's across wireless networks. Finally, we describe a Java applet aimed at querying large-scale geophysical datasets. Large datasets reside on the server, and cross sections are downloaded to a client PC or PDA. The applet provides a series of analysis tools to compute histograms over localized spatial regions, selectable by the user. Additional features such as zooming, magic lens, dataset comparison, are available to enrich the visual experience.

NG61A-06 0955h

New Tools for Visual Analysis of Multivariate Data from Large Scale Climate Simulations

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The POP ocean model is used to compute global velocity, temperature, salinity, and surface conditions at .1o resolution and 40 irregularly spaced depths, resulting in data sets 80 Gb in size for 200 time steps. This is too large for most screens and most programs; POPTEX, a visualization application developed at LANL uses low level graphics primitives to accelerate animation to a sufficiently high frame rate. Todays graphics cards employ increasingly powerful processors that rival if not exceed the capabilities of the CPU, although the instruction sets and data paths are highly optimized for graphics processors. However, there is now enough power and flexibility to migrate many algorithms to the card level, increasing the speed sufficiently to reach interactive levels even for the larger data sets. The data from the simulations are markedly

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