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

John R. Baumgardner[1] (505-667-9102; baumgardner@lanl.gov)

Yasuko Yamagishi[2] (81-468-67-9751; yamagisi@jamstec.go.jp)

David R. Stegman[3] (510-643-5450; dstegman@seismo.berkeley.edu)

[1]Los Alamos National Laboratory, Mail Stop B216, Los Alamos, NM 87545, United States

[2]Institute for Frontier Research on Earth Evolution (IFREE), Japan Marine Science and Technology Center (JAMSTEC) , 2-15 Natsushima-Cho, Yokosuka-City 237 0061, Japan

[3]University of California, Berkeley, Department of Earth and Planetary Science, 307 McCone Hall, Berkeley, CA 94720, United States

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

Hiroaki Matsui[1] (+81-3-3712-5321; matsui@tokyo.rist.or.jp)

Li Chen[1] (+81-3-3712-5321; chen@tokyo.rist.or.jp)

Issei Fujishiro[2] (+81-3-5978-5700; fuji@is.ocha.ac.jp)

Hiroshi Okuda[3] (+81-3-5841-7426; okuda@q.t.u-tokyo.ac.jp)

[1]Research Organization for Information Science and Technology, 2-2-54, Naka-meguro, Meguro-ku, Tokyo 153-0061, Japan

[2]Graduate School of Humanities and sciences, Ochanomizu University, 2-1-1 Otsuka, Bunkyo-ku, Tokyo 112-8610, Japan

[3]Department of Quantum Engineering and System Science, University of Tokyo, 7-3-1 Hongo, Bunkyo-ku, Tokyo 113-8656, Japan

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

Malte Westerhoff[1] (malte@tgs.com)

Bill Henderson[2] (bill@tgs.com)

[1]TGS, Inc., 5330 Carroll Canyon Road Suite 201, San Diego, CA 92121, United States

[2]TGS, Inc, 5330 Carroll Canyon Road Suite 201, San Diego, CA 92121, United States

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

Geoffrey Fox (8128567977; gcf@indiana.edu)

Indiana University, Bloomington Campus UITS Pervasive Tech Labs 501 N Morton Suite 224, Bloomington, IN 47404-3744, United States

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

Gordon Erlebacher[1] ((850) 644-0186; erlebach@csit.fsu.edu)

David A. Yuen[2] ((612) 624-9801; davey@msi.umn.edu)

[1]Florida State University, 489 Dirac Science Library, Tallahassee, FL 32309-4120, United States

[2]Minnesota Supercomputer Institute, University of Minnesota, Minneapolis, MN 55415, United States

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

Richard Strelitz (505 665 7746; strelitz@lanl.gov)

CCS-1, Advanced Computing Lab, MS B287 Los Alamos National Laboratory, Los Alamos, NM 87545, United States

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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different from those from observations; they are an attempt to model the processes that control the evolution of a dynamic system. We discuss a framework that we are developing that provides effective analysis and visualization tools to the user that has the ability to evaluate development and processes over a wide range of time scales and distances. First, the data is transformed from a Cartesian grid to a (streamline, streamfront, vorticity) framework. This generalization of particles and tracers allows the user to distinguish between transport and transformation processes. Multiple variables can be viewed concurrently by brushing or selecting regions in the joint probability distribution windows. The path of a packet or particle set in space and time can also be displayed as a trajectory in the distribution space. Finally, and most specific to the essential difference between simulation data and observed data, the trajectories can be linked back to the governing equations. Nonlinearities are detectable in the visualization by relating them to innovations, instances that cannot adequately be predicted from linear perturbations of operators which can be implemented on the graphics cards for very rapid computation and analysis.

NG61A-07 1010h INVITED

Visualization of large particle systems

Steffen Abe[1,2] (61-7-3365-4853; steffen@quakes.uq.edu.au)

Place David[2] (dplace@bigpond.net.au)

Peter Mora[1,2] (61-7-3365-2128; mora@quakes.uq.edu.au)

[1]Australan Computational Earth Systems Simulator (ACESS), The University of Queensland, Brisbane, QLD 4072, Australia

[2]Queensland University Advanced Centre for Earthquake Studies (QUAKES), The University of Queensland, Brisbane, QLD 4072, Australia

Particle based simulation models such as the lattice solid model (LSM) and discrete element models (DEM) have been shown to provide valuable tools for the numerical investigation of a variety of nonlinear dynamic processes such as fault and gouge dynamics, rock fracture and granular flow. Advances in computational resources in recent years have enabled the simulation of more realistic, in particular three-dimensional models. However, the resulting increase in the number of particles contained in those model has also made the visualization of the models and the extraction of important features a more challenging task. For the lattice solid model, a variety of techniques have been implemented, both for interactive and non-interactive visualization. For the interactive visualization of large models techniques to reduce the total amount of data and to extract the data of interest have been implemented such as the mapping of the particle data to a lower resolution grid and the selection and display of arbitrary slices or regions of the model. For non-interactive visualization the model data can be exported either directly to external rendering software or in a file format suitable for use with standard visualization tools.

NG61A-08 1045h

An Advanced Visualization System For Planetary Dynamo Simulations

Moritz Heimpel[1] (780-492-3519; mheimpel@phys.ualberta.ca)

Pierre Boulanger[2] (pierreb@cs.ualberta.ca)

Curtis Badke[1] (cbadke@phys.ualberta.ca)

Farook Al-Shamali[1] (shamali@Phys.UAlberta.CA)

Jonathan Aurnou[3] (jona@dtm.ciw.edu)

[1]Department of Physics, Institute for Geophysical Research, University of Alberta, Edmonton, AB t6g-2j1

[2]Department of Computing Sciences, University of Alberta, Edmonton, AB t6g-2e8

[3]Department of Earth and Space Sciences, University of California, Los Angeles, Los Angeles, CA 90095-1567

A major problem for modern four dimensional computational simulations is that they generate large volumes of data at a much faster rate than can be effectively processed using standard storage and visualization techniques. We are in the process of building an advanced system for interactive, real-time visualization of the output from computational planetary dynamo simulations. The dynamo code is a modified version of *Magic2* (J. Wicht, Phys. Earth Planet. Int., in press, 2002). Time-scaling of typical dynamo simulations is such that it is presently feasible to observe the motion of convection and magnetic variations in the real time numerical output, similar to a laboratory experiment. The visualization system is designed to run relatively independently of the dynamo code. In particular, the system architecture allows three-dimensional rendering of scalar and vector fields to occur independently of the data production process. Thus data production delays do not cause delays in manipulation of the visual representation, such as object rotation and data queries. In fact, for truly immersive applications the display refresh rate should be on the order of 10 Hz minimum. The main components of the system are 1) the simulation program; 2) the solution server; 3) the solution formatter; and 4) the visualization program. Here the simulation program is the dynamo code. The solution server controls which data from the simulation will be processed, thus helping to solve the problem of large data volume. The solution formatter converts simulation output for further processing by the visualization program. The subsystems 1), 2) and 3), are run on a large multiprocessor shared memory parallel (SMP) machine whereas subsystem 4) may be run on a remote PC or workstation. The data transfer from the SMP machine to the PC is facilitated by data compression and a high speed link of 1 gigabits per second. This system architecture will allow us to visualize key diagnostics in the dynamo simulations in real time, which will greatly facilitate output computational efficiency and understanding of run results. The relative independence of the visualization system from the simulation code makes it amenable for future application to different computational dynamics simulation codes.

NG61A-09 1100h

Robust Hidden Markov Models for Geophysical Data Analysis

Robert A Granat (1-818-393-5353; granat@aig.jpl.nasa.gov)

Jet Proplsion Laboratory, M/S 126-347 4800 Oak Grove Dr., Pasadena, CA 91109

We employed robust hidden Markov models (HMMs) to perform statistical analysis of seismic events and crustal deformation. These models allowed us to classify different kinds of events or modes of deformation, and furthermore gave us a statistical basis for understanding relationships between different classes.

A hidden Markov model is a statistical model for ordered data (typically in time). The observed data is assumed to have been generated by an unobservable statistical process of a particular form. This process is such that each observation is coincident with the system being in a particular discrete state. Furthermore, the next state is dependent on the current state; in other words, it is a first order Markov process. The model is completely described by a set of model parameters: the initial state probabilities, the first order Markov chain state-to-state transition probabilities, and the probabilities of observable outputs associated with each state.

Application of the model to data involves optimizing these model parameters with respect to some function of the observations, typically the likelihood of the observations given the model. Our work focused on the fact that this objective function typically has a number of local maxima that is exponential in the model size (the number of states). This means that not only is it very difficult to discover the global maximum, but also that results can vary widely between applications of the model. For some domains, such as speech processing, sufficient a priori information about the system is available such that this problem can be avoided. However, for general scientific analysis, such a priori information is often not available, especially in cases where the HMM is being used as an exploratory tool for scientific understanding. Such was the case for the geophysical data sets used in this work.

Our approach involves analytical location of sub-optimal local maxima; once the locations of these maxima have been found, then we can employ a modified optimization procedure designed to avoid these sub-optimal points in the parameter space. The end result is a robust technique for estimating the optimal parameters of an HMM and thereby the statistical properties of the data.

Initial experiments involved application of this technique to two particular geophysical data sets of general interest. The first is a catalog of seismic events in the Southern California region. Each earthquake was treated as an observation in six dimensions: latitude, longitude, depth, magnitude, time since the previous event, and time until the next event. Our preliminary investigations using HMMs yielded some very promising results, including models identifying classes of earthquakes such as aftershock sequences and earthquake swarms. Our HMM analysis of the second data set, consisting of GPS measurements collected by the SCIGN network, yielded equally promising models that clearly identified certain modes of crustal deformation caused by earthquakes and ground water pumping, among others. In both cases, our robust technique allowed us to generate high quality models of the data that were consistent across many experiments.

NG61A-10 1115h

Three-Dimensional GIS for the storage, analysis, and visualization of large complex models

Witkowski S Marc[1] (505-665-8332; witk@lanl.gov)

Gordon S Keating[1] (505-667-5902; gkea@lanl.gov)

Thomas L Riggs[1] (505-667-1735; tlriggs@lanl.gov)

Paul M Rich[1] (505-667-1850; pmr@lanl.gov)

[1]GISLab, Los Alamos National Laboratory, Mailstop D452, EES, Los Alamos, NM 87545, United States

Large, complex numerical models are typically composed of many different input data sources and produce results that are in a variety of data formats not easily integrated into a single visualization environment. Results from geologic models, groundwater models, digital elevation models (DEMs), and microclimate models are examples of such model data. Through the use of a three-dimensional geographic information system (3DGIS), all model (both model inputs and outputs), field and experimental data can be effectively integrated on one platform. We employ a 3DGIS comprised of a Raid storage device, an Oracle database, a spatial database engine (SDE), GIS software, and custom GIS tools for three-dimensional (3D) analysis. We create tables within the Oracle database that can be assembled to store model components, including information about nodes, elements, and calculations at a given time step. This allows for efficient query of the model within the 3DGIS visualization environment. Effective database storage with access via SDE, and coupled with spatial analysis tools, provide key capabilities for addressing complex problems. Because our 3DGIS is enterprise capable (connected through a series of high-speed networks and accessible concurrently) many users can access and share the same data. By integrating the latest GIS technologies with 3D numerical modeling techniques, we provide effective means to analyze, store, and visualize model results.

URL: http://gislab.lanl.gov

NG61A-11 1130h

Identification of 3-D Mantle Plumes and the Relative Contributions of the Surface Heat Flow by Wavelet Thresholding

David A. Yuen[1] (612 6249801; davey@krissy.geo.umn.edu)

Gordon Erlebacher[2] (850 644 0186; erlebach@csit.fsu.edu)

Fabien J.W. Dubuffet[1] (612 6246730; celinda00@msn.com)

Oleg V. Vasilyev[3] (303 492 4717; oleg.vasilyev@colorado.edu)

[1]University of Minnesota, Dept. of Geology and Geophysics, Minnesota Supercomputing Institute, Minneapolis, MN 55455-0219, United States

[2]Schol of Computational Science and Information Tech., Florida State University, Tallahassee, FL 32306-4120, United States

[3]Dept. of Mech. Engineering, University of Colorado, Boulder, CO 80309, United States

Identifying plume-like structures in an utomatic manner in 3-D mantle convection is a challenging technical problem. A successful method can help immensely in shedding light on the relative contributions from various sources to the surface heat budget and also to understand the dynamics of plumes interacting with each other and with the background flow. We have developed a technique based on wavelets for detecting the coherent structures of plumes in 3-D convection. The wavelets used are second-generation discrete bi-orthonormal wavelets which, in contrast to first-generation wavelets, can be constructed in a spatial domain. Collocation wavelets set up a one-to-one correspondence between the points in physical space and the set of wavelet coefficients. Proper identification of the wavelet basis functions that cover the features of interest, both in scale and position, will automatically yield a reduced representation of these coherent features associated with plumes. We have employed simple thresholding technique to identify plumes in mantle convection problems. We have constructed a user interface to Amira, a visualization software, to allow a user to construct I_p, the set of grid points in physical space, corresponding to the set of wavelet coefficients with absolute value greater than a given threshold value, ϵ. By plotting these set of points as cubes, we can localize the plume structures. We have demonstrated the feasibility by reconstructing the plumes for different threshold values. We find that we can identify the plumes by keeping around 1% of the full set of wavelet coefficients. From identifying the locations of the plumes, we can also calculate the fraction of surface heat flow due to the cylindrical plumes, as compared to the surrounding network of downwellings and the bulk interior. We

have investigated this for a range of Rayleigh numbers from 10^6 to 10^9. We have found that wavelets can provide a useful tool for extracting coherent features in mantle convection and can be applied to other types of problems in geophysics, such as geodynamo simulations and earthquake deformation.

NG61A-12 1145h

A LARGE-SCALE SPECTRAL PARALLEL IMPLEMENTATION OF 2-D POISSON EQUATION WITH APPLICATIONS TO MESOSCALE CRYSTAL SURFACES

Alain P. Vincent[1] (514 369 5264; vincent@cerca.umontreal.ca)

David A. Yuen[2] (612 6249801; davey@krissy.geo.umn.edu)

Xavier Thibert-Plante[1] (514 369 5274; thibert@cerca.umontreal.ca)

[1]Dept Physique, Univ. Montreal, Montreal, QC H3C 3J7, Canada

[2]Dept. of Geology and Geophysics and Minnesota Supercomputing Center, 310 Pillsbury Dr. SE Univ. Minnesota, Minneapolis, MN 55455-0219, United States

The Poisson equation is a partial differential equation with a universal applicability embracing gravity , porous flow, materials science, and biochemical surfaces.Thus far most Poisson equations have been restricted to a relatively low resolution on the order of a thousand grid points along each direction. The imaging of nano to meso features on lattices requires very high resolution. An example is given by the surface potential of inorganic crystals. Surface topography can be mapped out by using atomic force microscopy (AFM), Kelvin probe microscopy and related solid-state techniques. A strong correlation between the surface topography and surface potential can be found. THe Si(111) 7x7 is a very complex crystal. Defects have been observed with AFM on surface maps of 60 nm by 60 nm . Starting from a given charged distribution field, however complex, we can compute surface potential with such a map. Counting 8x8 points as a minimum resolution for each atom would then entail an order of between 100,000 and one million grid points along one direction for the characteristic mesoscale areas scanned by AFM. We demonstrate that we can , with an easy-to-program algorithm, reach a spatial resolution of 20,000 x 20,000 points for computing the electric potential on a 2-D periodic lattice. We have employed a spectral Fourier technique and parallelized Fourier transforms on 32 Silicon Graphics processors. The speed is about a few minutes for the largest grid. An out-of-core version of this code is needed to handle the extremely large grids involving one million points along each direction. This method can be extended easily to 3-D.

NG62A MCC: Hall C Saturday 1330h

Earthquake Fault Models: Current Practice and Future Challenges Posters *(joint with G, S, T)*

Presiding: **K F Tiampo,** University of Colorado**; M Glasscoe,** University of California, Davis

NG62A-0923 1330h POSTER

Quasi-static and quasi-dynamic modeling of earthquake failure at intermediate scales

Gert Zoeller[1] (49-331-977-1175; gert@agnld.uni-potsdam.de)

Matthias Holschneider[2] (49-331-977-1663; hols@math.uni-potsdam.de)

Yehuda Ben-Zion[3] (1-213-740-6734; benzion@terra.usc.edu)

[1]Institute of Physics and Institute of Mathematics, University of Potsdam, POB 601553, Potsdam 14415, Germany

[2]Institute of Mathematics, University of Potsdam, POB 601553, Potsdam 14415, Germany

[3]Department of Earth Sciences, University of Southern California, Los Angeles, CA 90089-0740, United States

We present a model for earthquake failure at intermediate scales (space: 100 m - 100 km, time: 100 m/v_{shear}- 1000's of years). The model consists of a segmented strike–slip fault embedded in a 3-D elastic solid as in the framework of Ben-Zion and Rice (J. Geophys. Res. 98, 1993). The model dynamics is governed by realistic boundary conditions consisting of constant velocity motion of the regions around the fault, static/kinetic friction laws with possible gradual healing, and stress transfer based on the solution of Chinnery (Bull. Seism. Soc. Am. 53, 1963) for static dislocations in an elastic half space. As a new ingredient, we approximate the dynamic rupture on a continuous time scale using a finite stress propagation velocity (quasi–dynamic model) instead of instantaneous stress transfer (quasi–static model). We compare the quasi–dynamic model with the quasi–static version and its mean field approximation, and discuss the conditions for the occurrence of frequency-size statistics of the Gutenberg–Richter type, the characteristic earthquake type, and the possibility of a spontaneous mode switching from one distribution to the other. We also introduce time-dependent log (t) healing and show that the results can be interpreted in the context of the phase diagram framework of Dahmen et al. (Phys. Rev. E 58, 1998). To have a flexible computational environment, we have implemented the model in a modular C++ class library.

NG62A-0924 1330h POSTER

Instability of a Periodic System of Faults

Michel Campillo[1] ((33) 4 76 82 80 36; campillo@obs.ujf-grenoble.fr)

Ioan Ionescu[2] (ionescu@univ-savoie.fr)

Cristian Dascalu[3] (cristiandascalu@hotmail.com)

[1]LGIT, Universite Joseph Fourier, BP 53X, Grenoble 38041, France

[2]Laboratoire de Mathmatiques, Universit de Savoie, Le Bourget du lac 73376, France

[3]L3S, Universite Joseph Fourier, BP 53X, Grenoble 38041, France

To investigate the effect of heterogeneity of resistance on a fault, we present an analysis of the behaviour of a canonical model, namely a periodic system of coplanar faults which can slip under a slip weakening friction law. The friction on the sliding patches is characterized by a weakening rate α. We present a stability analysis based on the decomposition of the solution on a set of eigenfunctions of increasing periodicities which are multiple of the natural period of the system. We discuss the structure of the discrete spectrum of the static solution. For a given geometry, we show that it exists a transition value α_0 of weakening rate defining two distinct regimes. When α is smaller than α_0, the system is stable while when α is larger than α_0, unstable modes with exponential growth are present. This stability limit can be regarded as a non-local criterion of sliding. A somehow surprising result is the fact that a system with infinite extension can exhibit a stable behaviour. Specifically, we show that even a fault with weakening almost everywhere can be stable. An infinite homogeneous fault, on the contrary, is always unstable as soon as weakening is assumed. To understand this apparent paradox, we refer to the concept of the effective friction law that describes the large scale behaviour of the fault system, and more precisely here to the effective weakening rate. The results presented here indicate that the effective friction law of a periodic fault system with weakening on the sliding parts can be either a weakening or strengthening law depending on the geometry of the surface of sliding.

NG62A-0925 1330h POSTER

On boundary-element models of elastic fault interaction

Thorsten W Becker[1] (thwbecker@post.harvard.edu)

Bertram Schott[2] (bertram.schott@ctr.at)

[1]SIO, IGPP, IGPP-0225, U.C. San Diego, 9500 Gilman Drive, La Jolla, CA 92093, United States

[2]Smart Automation & Simulation, CTR Carinthian Tech Research AG, Europastrasse 4/1, Villach/St.Magdalen A-9524, Austria

We present the freely available, modular, and UNIX command-line based boundary-element program *interact*. It is yet another implementation of Crouch and Starfield's (1983) 2-D and Okada's (1992) half-space solutions for constant slip on planar fault segments in an elastic medium. Using unconstrained or non-negative, standard-package matrix routines, the code can solve for slip distributions on faults given stress boundary conditions, or vice versa, both in a local or global reference frame. Based on examples of complex fault geometries from structural geology, we discuss the effects of different stress boundary conditions on the predicted slip distributions of interacting fault systems. Such one-step calculations can be useful to estimate the moment-release efficiency of alternative fault geometries, and so to evaluate the likelihood which system may be realized in nature. A further application of the program is the simulation of cyclic fault rupture based on simple static-kinetic friction laws. We comment on two issues: First, that of the appropriate rupture algorithm. Cellular models of seismicity often employ an exhaustive rupture scheme: fault cells fail if some critical stress is reached, then cells slip once-only by a given amount, and subsequently the redistributed stress is used to check for triggered activations on other cells. We show that this procedure can lead to artificial complexity in seismicity if time-to-failure is not calculated carefully because of numerical noise. Second, we address the question if foreshocks can be viewed as direct expressions of a simple statistical distribution of frictional strength on individual faults. Repetitive failure models based on a random distribution of frictional coefficients initially show irregular seismicity. By repeatedly selecting weaker patches, the fault then evolves into a quasi-periodic cycle. Each time, the pre-mainshock events build up the cumulative moment release in a non-linear fashion. These temporal seismicity patterns roughly resemble the accelerated moment-release features which are sometimes observed in nature.

NG62A-0926 1330h POSTER

Two-Dimensional Stick-Slip: How the Seismic Activity Depends on the Direction of Tectonic Plates Motion

Vladimir B. Ryabov (+81-138-34-6129; riabov@fun.ac.jp)

Future University Hakodate, 116-2 Kamedanakano-cho,Hakodate-shi, Hokkaido, Hakodate 041-8655, Japan

We consider a two-dimensional slider-block model subject to the rate and state dependent friction. The block interacts with a slowly moving substrate through static and dynamic friction coefficients defined separately in the stick and slip phases of motion. The rebound strain is described by a tensor, which in the simplest case can be reduced to two stiffness coefficients in mutually orthogonal directions. The model is capable of reproducing complicated oscillatory patterns of stick-slip motion, starting from simple periodic oscillations to quasiperiodic, chaotic, and intermittent behavior. In contrast to the Dieterich and Ruina description of friction where the complexity is produced by the intrinsic dynamics of the hidden state variables, the complex behavior in this model appears due to the interaction of two spatial degrees of freedom defined by the fault geometry.

It has been found out that the oscillatory patterns shown by the model can be roughly attributed to two big classes of creep and strong motions, and the system can demonstrate sudden transitions between the oscillations of different classes, either periodically or in an irregular intermittent manner. This behavior looks similar to the temporal distribution of seismic events in some areas, where long time intervals of creep motion are interrupted by large events. On the other hand, the model can be used for the study of those regions where only creep behavior or only strong motions are observed.

In this presentation, we focus on the dependence of the model behavior on the geometry of fault structure it can simulate. The transitions between the two classes of behavior are analyzed in detail, depending on the direction of motion of the substrate. This setting corresponds to the analysis of dynamics of a fault segment with respect to the angle between the fault surface and velocity vector of the tectonic plates constituting the fault. We show that even small changes in the angle value can switch the dynamics shown by the fault segment from creep to stick-slip motion of high amplitude. This result can be used for interpreting the observations where geographically close fault segments demonstrate qualitatively different dynamics, i.e. some part of the fault produces only creep motion while the adjacent parts generate big events.

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Slip-Weakening Distance in Dynamic Rupture of Inslab Normal-Faulting Earthquakes

Takeshi Mikumo[1] (52-55-5622-4127; mikumo@ollin.igeofcu.unam.mx)

Yuji Yagi[2] (81-298-64-6755; yagi@kenken.go.jp)

[1]Instituto de Geofisica, UNAM, Ciudad Universitaria, Del. Coyoacan, Mexico, D.F 04510, Mexico

[2]International Institute of Seismology and Earthquake Engineering, Building Research Institute, Tachihara 1, Tsukuba, Iba 305-0802, Japan

It is now one of the important issues in rupture dynamics to estimate the critical slip-weakening distance at which the shear stress drops to the final level during natural earthquakes. In this study, we estimate the slip-weakening distance on inslab earthquake faults in a subduction zone, by applying a recent approach proposed by Mikumo et al. (2002). This approach is to find the a relation between the breakdown time of shear