and avalanche transport are examples of two transport mechanisms that frequently coexist. Understanding the dynamical interaction between these varied mechanisms is important if we are to understand both the proposed robustness of the SOC paradigm and the real behavior of the physical systems being modeled.

Diffusion, or diffusion like processes, are common in many physical systems. For example, in addition to the dominant "discrete" earthquakes, other mechanisms are available to relax tectonic stress such as plastic deformation and creep. While in solar flare or accretion disk dynamics, diffusion and/or convection of energy or mass can provide alternative transport mechanisms whose role is often ignored.

We show that neglecting the diffusion processes, or other similar transport mechanisms, can lead to a reduction of the range of dynamics found in the SOC like models and therefore a narrowing of the relevance of these models for physical systems. We show how diffusion can strongly modify the SOC dynamics while remaining a very subdominant transport mechanism. A dynamical transition takes place in the system as the relative importance of diffusive transport increases beyond a critical threshold. The role of the avalanche-like transport events characteristic of the self-similar SOC state is then abruptly taken over by quasi-periodic constant-size edge-triggered events. As a result, the system loses its "Self Organized Critical" properties. We show that the required diffusion for this to happen is remarkably small. These results while suggesting a reduction of the robustness of the SOC paradigm broaden the dynamics available though such simple models. The possible implications for relevant systems such as earthquake dynamics will be discussed.

**NG21A-0933 0830h POSTER**

### Modeling flow and sedimention of slurries

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Many natural processes involve flows of sediments at high particle concentrations. The equations describing such two-phase flows are highly nonlinear. We will give an overview of the performance of a continuum constitutive model of suspensions of particles in liquid for low Reynolds number flows. The diffusive flux model (Leighton and Acrivos, J. Fluid Mech., 1987, and Phillips et al., Phys. Fluids A, 1992) is implemented in a general purpose finite element computational program. This constitutive description couples a Newtonian stress/shear-rate relationship (where the local viscosity of the suspension is dependent on the local volume fraction of solids) with a shear-induced migration model of the suspended particles. The momentum transport, continuity, and diffusive flux equations are solved simultaneously. The formulation is fully three-dimensional and can be run on a parallel computer platform. Recent work introducing a flow-aligned tensor correction to this model has had success in representing the anisotropic force that is seen in curvilinear flows. Gravity effects are added in an approach similar to that of Zhang and Acrivos (Int. J. Multiphase Flow, 1994). The model results are compared with laboratory data obtained with Nuclear Magnetic Resonance (NMR) of evolving particle concentration profiles in complex flows, as well as in batch sedimentation. Interesting secondary flows appear both in the experiment and model. Overall, good agreement is found between the experiments and the simulations.

This work was supported by the United States Department of Energy under Contract DE-AC04-94AL85000. Sandia is a multiprogram laboratory operated by Sandia Corporation, a Lockheed Martin Company, for the United States Department of Energy. The authors would like to acknowledge support for this work by the U.S. Department of Energy, Division of Engineering and Geosciences, Office of Basic Energy Sciences.

**NG21A-0934 0830h POSTER**

### Direct Simulation of 2D Fluid-Particle Sedimentation : Velocity Fluctuations and Diffusion.

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Motivated by the study of environmental fluids with massive particle sedimentation, we have used direct numerical simulations to study massive particles falling in a viscous fluid with periodic boundaries in a two-dimensional geometry. We computed different cases involving different particle concentration ranging from 0.02 to 0.4, and three different regimes characterized by the particulate Reynolds number and the Stokes number.

The mean settling velocity verify the Zaki-Richardson law, and is similar to published experimental results. The probability distribution function for the particulate horizontal fluctuating velocity is found to be almost gaussian while it is rather an exponential in the vertical direction showing an intermitent behavior.

The velocity variance exhibits a maximum for an intermediate concentration which increases with Reynolds number. The variances scale like the product of concentration with the mean settling velocity.

The anisotropy based on the ratio of the vertical over horizontal particle velocity fluctuations decreases with the particulate Reynolds number. However, this is not observed at concentrations higher than 0.4 where the interactions between particles predominates over gravity.

A statistical particle diffusivity can be defined as the product of the mean free path by the mean fluctuation velocity. However, it is also proportional to the anisotropy in the vertical direction and it is the reverse in the horizontal. Furteher ongoing extensions will be discussed, especially an analysis of the fluid structures induce by the non-local hydrodynamic interactions between the settling particules.

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## NG21B MCC: Hall C Tuesday 0830h

### Damage Rheology and Physics of Earthquakes Posters *(joint with S, T, MR)*

***Presiding:*** **Y Ben-Zion,** University of Southern California**; D L Turcotte,** Cornell University

**NG21B-0935 0830h POSTER**

### Off-Plane Secondary Faulting and Damage Induced by a Dynamic Slip-Pulse

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The analysis of the stress field near the tip of a semi-infinite dynamic mode II rupture (Poliakov et al., *JGR*, in press, 2002; http://esag.harvard.edu/dmowska/PDR.pdf), with slip-weakening failure, is extended to the case of a dynamic slip pulse of finite length. Slip-weakening occurs over distance $R$ at the tip, and slip itself takes place over a region of total length $L$ before locking occurs at the trailing edge. The slipping configuration moves in steady state at constant velocity $v_r$. The important parameters are the scaled stress drop $(\sigma^o_{yx} - \tau_r)/(\tau_p - \tau_r)$ and rupture velocity $v_r/c_s$, the pre-stress ratio $\sigma^o_{xx}/\sigma^o_{yy}$, residual to peak strength ratio $\tau_r/\tau_p$, and peak friction coefficient on the fault plane $f_p = \tau_p/(-\sigma^o_{yy})$ where $\sigma^o_{ij}$ is the initial stress state, $\tau_p$ and $\tau_r$ are the peak strength to initiate slip and residual strength at large slip, and $v_r$ and $c_s$ are the rupture and shear velocity. $R^*_o = (3\pi/4)\mu G/(\tau_p - \tau_r)^2$ is the slip weakening zone size in the low rupture velocity, low stress drop limit, where $G$ is the fracture energy and $\mu$ the rigidity. The scaled actual zone size $R/R^*_o$ depends on $v_r/c_s$ and, weakly, on $(\sigma^o_{yx} - \tau_r)/(\tau_p - \tau_r)$. The Poliakov et al. (2002) solution is the asymptotic limit of the current model when $L/R^*_o \rightarrow \infty$ and $\sigma^o_{yx} \rightarrow \tau^+_r$. The major difference between the slip pulse analyzed here and their solution is that the size of the region which supports Coulomb failure reaches a maximum value for the slip-pulse on the order of $R^*_o$ when $v_r > 0.9c_s$. For $G \approx 0.5$ to 5 MJ/m$^2$, secondary faulting should extend to distances on the order of $R^*_o \approx$ 4-40 m from the principal slip surface if $\tau_p - \tau_r = 100$ MPa, but 25 times larger if if $\tau_p - \tau_r = 20$ MPa. The damage model formulated by Ashby and Sammis (*Pure Appl. Geophys.*, 1990) is used to estimate the lateral extent of gouge formation in the slip-pulse stress field. By modeling the nucleation, growth and interaction of individual microfractures, this damage mechanics allows us to estimate the contribution of gouge formation to the fracture energy and the seismic radiation field. Seismic radiation is calculated by integrating the moment tensors of individual growing cracks over space and time in the evolving damage zone following the methodology in Johnson and Sammis (*Pure Appl. Geophys.*, 2001).

**NG21B-0936 0830h POSTER**

### Effects of Pre-Stress State and Rupture Velocity on Dynamic Fault Branching

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We consider a mode II rupture which propagates along a planar main fault and encounters an intersection with a branching fault that makes an angle with the main fault. Within a formulation that allows the failure path to be dynamically self-chosen, we study the following questions: Does the rupture start along the branch? Does it continue? Which side is most favored for branching, the extensional or compressional? Does rupture continue on the main fault too? What path is finally self-chosen? Failure in the modeling is described by a slip-weakening law for which the peak and residual strength, and strength at any particular amount of slip, is proportional to normal stress. We use the elastodynamic boundary integral equation method to allow simulations of rupture along the branched fault system.

Our results show that dynamic stresses around the rupturing fault tip, which increase with rupture velocity at locations off the main fault plane, relative to those on it, could initiate rupture on a branching fault. As suggested by prior work [Poliakov, Dmowska and Rice, 2002, http://esag.harvard.edu/dmowska/PDR.pdf], whether a branching rupture, once begun, can be continued to a larger scale depends on principal stress directions in the pre-stress state and on rupture velocity. The most favored side for rupture transferring on a branching fault switches from the extensional side to the compressive side as we consider progressively shallower angles of the direction of maximum pre-compression with the main fault. Simultaneous rupturing on both faults is usually difficult for a narrow branching angle due to strong stress interaction between faults, which discourages rupture continuation on the other side. However, it can be activated by enhanced dynamic stressing when the rupture velocity is very near the limiting velocity (Rayleigh wave velocity for mode II). It can also be activated when the branching angle is wide because of decreasing stress interaction between faults. Natural examples seem consistent with the simulations we present.

**NG21B-0937 0830h POSTER**

### Aftershocks and Damage Mechanics

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All earthquakes are followed by an aftershock sequence. A universal feature of aftershock sequences is that they decay in time according to Omori's law, a power-law decay. In this paper we consider the applicability of damage mechanics to earthquake aftershocks. The damage variable introduced in damage mechanics quantifies the deviation of a brittle solid from linear elasticity. We draw an analogy between the metastable behavior of a stressed brittle solid and the metastable behavior of a superheated liquid. The nucleation of microcracks is analogous to the nucleation of bubbles in the superheated liquid. In this paper we have applied damage mechanics to four problems. The first is the instantaneous application of a constant stress to a brittle solid. We verify the results by applying them to studies of the rupture of chipboard and fiberglass panels. We then obtain a solution for the evolution of damage after the instantaneous application of a constant strain. We show that the subsequent stress relaxation can reproduce Omori's law. We also obtain solutions for application of constant rates of stress and strain. A fundamental question is the cause of the decay in the occurrence of damage and aftershocks. It is argued that the aftershocks themselves cause random fluctuations similar to the thermal fluctuations associated with phase changes.

## NG21B-0938 0830h POSTER

### Seismicity Patterns in a Lithospheric Model Consisting of a Seismogenic Crust Governed by Damage Rheology Over a Viscoelastic Substrate

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We discuss different dynamic regimes of seismicity patterns in a regional lithospheric model consisting of a seismogenic upper crust governed by damage rheology over a viscoelastic substrate. The employed damage rheology (Lyakhovsky et al., JGR, 1997) is based on nonlinear continuum-mechanics and thermodynamics of irreversible damage evolution. Theoretical details on the damage model and its experimental verification with lab data are covered in a companion presentation by Lyakhovsky and Ben-Zion. The large scale parameters of the regional lithospheric model (dimensions, background elastic properties, viscosity values) are constrained by seismological and geodetic data associated with the San Andreas fault. The evolving damage in the seismogenic layer simulates the creation and healing of fault systems as a function of the deformation history and associated seismicity patterns.

For cases with constant-stress remote loading, analytical and numerical parameter space studies (Ben-Zion et al., EPSL, 1999; Lyakhovsky et al., JGR, 2001) indicate that the types of generated fault structures and earthquake statistics are governed by the ratio R1 of time scale for material healing ($\tau_H$) to time scale for loading ($\tau_L$). Relatively low ratios of R1 lead to the development of highly disordered fault zones, frequency-size statistics of earthquakes compatible with the Gutenberg-Richter distribution, temporal clustering of intermediate and large events, and accelerated seismic release before large earthquakes. Relatively high ratios of R1 lead to the development of geometrically regular fault zones, frequency-size statistics compatible with the characteristic earthquake distribution, and quasi-periodic temporal occurrence of large events without accelerated seismic release. Intermediate cases of R1 produce a "mode-switching" response in which the fault zone structures and seismicity patterns alternate, over long time intervals compared to large earthquake cycle, between the forgoing two modes of behavior.

For cases with constant-velocity remote loading, the model produces aftershock sequences after large events that depend on the ratio R2 of time scale for material degradation ($\tau_D$) to Maxwell relaxation time ($\tau_M$). For a simplified 1D case, we obtain analytical solution for damage evolution during the relaxation process following large events. The analytical expression has exponential and error functions but it can be approximated for a range of R2 values by a simple power law. Three-dimensional numerical simulations with R2 $\approx$ 0.1-0.25, representing highly brittle cases with high viscosity and $\tau_M$, produce clear aftershock sequences that can be fitted well by Omori-type power law $\Delta n/\Delta t \sim (c{+}t)^{-p}$ with exponent values $p \approx$ 1.1-1.2. Simulations with R2 $>$ 0.35, representing cases with lower viscosity and $\tau_M$, produce diffused aftershock sequences that can be fitted by a power law decay with $p < 1$.

## NG21B-0939 0830h POSTER

### Fault Branching and Rupture Directivity

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Can the rupture directivity of past earthquakes be inferred from fault geometry? Nakata et al. [*J. Geogr.*, 1998] propose to relate the observed surface branching of fault systems with directivity. Their work assumes that all branches are through acute angles in the direction of rupture propagation. However, in some observed cases rupture paths seem to branch through highly obtuse angles, as if to propagate "backwards".

Field examples of that are as follows: (1) Landers 1992. When crossing from the Johnson Valley to the Homestead Valley (HV) fault via the Kickapoo (Kp) fault, the rupture from Kp progressed not just forward onto the northern stretch of the HV fault, but also backwards, i.e., SSE along the HV [Sowers et al., 1994, Spotila and Sieh, 1995, Zachariasen and Sieh, 1995, Rockwell et al., 2000]. Measurements of surface slip along that backward branch, a prominent feature of 4 km length, show right-lateral slip, decreasing towards the SSE. (2) At a similar crossing from the HV to the Emerson (Em) fault, the rupture progressed backwards along different SSE splays of the Em fault [Zachariasen and Sieh, 1995]. (3). In crossing from the Em to Camp Rock (CR) fault, again, rupture went SSE on the CR fault. (4). Hector Mine 1999. The rupture originated on a buried fault without surface trace [Li et al., 2002; Hauksson et al., 2002] and progressed bilaterally south and north. In the south it met the Lavic Lake (LL) fault and progressed south on it, but also progressed backward, i.e. NNW, along the northern stretch of the LL fault. The angle between the buried fault and the northern LL fault is around −160°, and that NNW stretch extends around 15 km.

The field examples with highly obtuse branch angles suggest that there may be no simple correlation between fault geometry and rupture directivity. We propose that an important distinction is whether those obtuse branches actually involved a rupture path which directly turned through the obtuse angle (while continuing also on the main fault), or rather involved arrest by a barrier on the original fault and jumping [Harris and Day, *JGR*, 1993] to a neighboring fault on which rupture propagated bilaterally to form what appears as a backward-branched structure.

Our studies [Poliakov et al., *JGR* in press, 2002; Kame et al, *EOS*, 2002] of stress fields around a dynamically moving mode II crack tip show a clear tendency to branch from the straight path at high rupture speeds, but the stress fields never allow the rupture path to directly turn through highly obtuse angles, and hence that mechanism is unlikely. In contrast, study of fault maps in the vicinity of the Kp to HV fault transition [Sowers et al., 1994], discussed as case (1) above, strongly suggest that the large-angle branching occurred as a jump, which we propose as the likely general mechanism.

Implications for the Nakata et al. [1998] aim of inferring rupture directivity from branch geometry is that this will be possible only when rather detailed characterization (by surface geology, seismic relocation, trapped waves) of fault connectivity can be carried out in the vicinity of the branching junction, to ascertain whether direct turning of the rupture path through an angle, or jumping and then propagating bilaterally, were involved in prior events. They have opposite implications for how we would associate past directivity with a (nominally) branched fault geometry.

## NG21B-0940 0830h POSTER

### The Energy Dissipation of Propagating Cracks in Solnhofen Limestone

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Crack propagation events are initiated in Solnhofen limestone under impact loading conditions. The Fracture energy respectively the fracture toughness and the velocity of propagating cracks are measured by means of an optimized strain gauge measuring technique. Cracks are accelerated to velocities in the range of 1500 m/s. The measured crack propagation energies/crack propagation toughnesses are significantly higher than the crack initiation energy/crack initiation toughness. Control measurements on the basis of a global energy approach by means of Charpy pendulum impact tests verify the found behaviour. The results explain characteristic peculiarities of the crack propagation behaviour of brittle fracture in rock.

Keywords: Fracture energy, fracture toughness, crack propagation, crack velocity, rock

## NG21B-0941 0830h POSTER

### Dynamic Rupture Simulation of Bending Faults With a Finite Difference Approach

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Many questions about physical parameters governing the rupture propagation of earthquakes seem to find their answers within realistic dynamic considerations. Sophisticated constitutive relations based in laboratory experiments have lead to a better understanding of rupture evolution from its very beginning to its arrest. On the other hand, large amount of field observations as well as recent numerical simulations have also demonstrated the importance, in rupture growing, of considering more reasonable geological settings (e.g., bending and step-over fault geometries; heterogeneous surrounding media).

So far, despite the development of powerful numerical tools, there still exist some numerical considerations that overstep their possibilities. Authors have solved the dynamic problem by applying the boundary integral equations method (BIEM) in order to explore the influence of fault geometry. This can be possible because of the fact that only the rupture path must be discretized, reducing the impact of numerical discretization. However, the BIEM needs the analytical solution of Green functions that can only be computed for a homogeneous space. Up to date, no interaction with heterogeneous structures can be taken in to account. In contrast, finite difference (FD) approaches have been widely used. In this case, due to the specific discretization of the elastodynamic equations through the entire domain, and the azimuthal anisotropy intrinsic to differential operators, only planar faults have been considered and numerical artefacts have to be carefully checked.

In this work, we have used a recently proposed four-order staggered grid finite difference scheme to model in-plane (mode II) dynamic shear fracturing propagation with any pre-established geometry. In contrast with the classical 2-D staggered grid elementary cell in which all the elastic fields are defined in different positions (except the normal stresses), the stencil used here consider the velocity and stress fields separately in only two staggered grids. This permit an efficient treatment of boundary conditions to impose the shear stress drop in the nodes where the stresses are located. On the other hand, the stencil allows the four order Cartesian differential operators being decoupled into two different 45 degrees rotated operators. This procedure reduces numerical anisotropy along preferred directions and provides stable solutions for any fault orientation. Numerical solutions of dynamical fracture still exhibit large oscillations coming from local discretization effects and integration procedures. These perturbations can strongly alter the rupture front velocity and the average slip rate behind the crack tip. We controlled this phenomenon by applying a smoothing Laplacian operator to velocity equations. Such a mathematical tool, provided that suitable input parameters are supplied, helps to vanish these oscillations. Specifying a fault thickness in simulations yields similar results as we scale down numerical parameters, if the same fault geometry is kept.

A simple definition of the fault is done placing it in the middle of the grid without using any adhoc numerical ghost plane often used in FD approaches. The fault is a sum of source points taken as close as possible to the hypothetical fault line. Simulations of irregular fault geometry (e.g., bending faults) are possible using the superposition technique. Spontaneous and velocity fixed rupture propagation will be presented with abrupt stress drop, as well as with time- and slip- weakening constitutive laws. Analysis of arbitrarily heterogeneous media surrounding the fault region in the dynamics of seismic sources evolution is possible.

## NG21B-0942 0830h POSTER

### Near Surface Damage Caused by the Strong Ground Motion of the M6.9 Loma Prieta and M5.4 Chittenden Earthquakes

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We use a catalog of 57 repeating earthquake sequences to study the damage to near-surface materials, manifest as changes in seismic wave velocity, caused by strong ground motion. We believe that near surface damage (cracking) is the most likely cause for velocity reductions that we observe immediately following both the M6.9 Loma Prieta and M5.4 Chittenden earthquakes. The strong ground motion during both of these events was strong enough to open cracks near the Earth's surface, the presence of which reduces seismic velocities. The velocity reductions heal with time, following Loma Prieta and Chittenden in a manner similar to the "slow dynamic" healing behavior observed in laboratory studies [TenCate, et al., 2000]. Since the damage left by Loma Prieta had not completely healed by the time Chittenden occurred, it is probable that the local rocks were more susceptible to further damage, allowing the much weaker motions of the Chittenden Earthquake to cause damage comparable in magnitude as that of the Loma Prieta Earthquake.

We have identified the above conditions by studying repeating earthquakes (multiplets) on the San Andreas Fault. Using a moving window cross correlation technique to identify changes in the nearly identical waveforms of a repeating earthquake sequence, we can observe late-arriving phases, after both the Loma Prieta and Chittenden earthquakes. We attribute these delays to near surface velocity reductions localized to a damage zone close to the Loma Prieta rupture zone.

We observe a similar phenomenon in the cross correlation coefficient (CCC) data. Immediately following the Loma Prieta and Chittenden Earthquakes, the CCC drops sharply and heals in time in a manner similar to the healing of the velocity reductions. This is not surprising because the changes in CCC reductions should scale linearly with the magnitude of the velocity perturbation. The drops in CCC don't always parallel velocity changes; however, they can also measure more general changes in waveform character. A combination of the two measurements not only allows us to identify parts of the seismogram where an arrival disappears or a new one appears, but it also allows us to further constrain the nature of the variation.

TenCate, J.N., D.E. Smith, and R. Guyer, Universal Slow Dynamics in Granular Solids, Physical Review Letters, 85, 1020-1023, 2000.

### NG21B-0943 0830h POSTER

### Dynamic parameters estimation of the 1999 Chi-Chi, Taiwan, Earthquake

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We estimated the dynamic parameters of the 1999 Chi-Chi earthquake from a dynamic finite-difference code that calculate a north-south dipping fault in a herterogenous medium with a free surface and use the kinematic inverted slip solutions as constraints. The stress time history over the thrust fault plane show stress continuous to drop through the entire duration of slip at the region with slip greater than 12 m. The regions surround large slips show significant restrengthening of the fault during the rupture. Large strength of up to 10-15 MPa is found at the bottom of hinge-axis, the axis where the fault bending to the northeast. The derived slip-weakening curves for the subfaults with large slips yield a large Dc of up to 10m. Considering the trade-off between Dc and strength, the Dc could be reduced to the value of 3 m, which is still much larger than the value from laboratory experiment. The determination of Dc value might be limited by the resolution on the numerical calculation. This large Dc is suspicious, but might be also physically implicit. The maximum fracture energy over the fault plane is up to 108 J/m2. The estimated dynamic parameters will be further discussed with laboratory experiments to understand the stability and instability of fault slip.

### NG21B-0944 0830h POSTER

### Generic Quasi-static Nucleation With Slip Dependent Friction

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The stable quasi-static nucleation of slip has been the focus of various experimental studies in the past. In the framework of non linear slip dependent friction laws, mechanical models were proposed to explain this phase of nucleation and its transition to the dynamic unstable regime. To account for details of experimental observations and seismological scalings between the size of the nucleation zone and the size of the whole earthquake, those models relied on the presence of specific heterogeneities of constitutive properties and ad hoc assumptions about their geometry. We raise the question of the need of such assumptions and an underlying question about the interaction between structural heterogeneities and the non-linear behavior of faults.

We show that most of the physics of the quasi-static nucleation and stability in a heterogeneous fault described by non-linear slip dependent friction, with strengthening and weakening phases, can be understood, qualitatively and quantitatively, by studying a special aspect of an ideal case: the bifurcations to localized slip in a homogenenous, perfect, fault. In fact, a range of loading conditions lead a homogeneous fault to continuously evolve from uniform slidding to a stable a non uniform slipping state. We analytically characterize those conditions as well as the behavior and stability in a vicinity of the bifurcation point by a perturbative analysis.

Depending on the load coupling of the fault, the nucleation can be characterized by a localization process preceeding the unstability. The localization phase is followed by a crack-like growth with classical fracture mechanics scalings. This post-bifurcation regime is solved by numerical means, showing the progressive localisation of slip inside a shrinking nucleation zone, as seen in rate-and-state models.

We then assess the robustness of these results to the presence of different kinds of heterogeneities. We show that the essential characteristics are preserved and that the spectrum of sensitivity introduces a characteristic screening length. This length can be related to the bifurcations of the ideal case first studied. Interestingly enough, the quasi-static nucleation appears as a cascade from long to short wavelengths, a feature not present in a recent analysis of the linear slip weakening nucleation length. As a result, at the onset of instability the state of the fault can be heterogeneous but not by structural reasons.

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## NG21C MCC: Hall C Tuesday 0830h

## Wave-Wave Coupling at Interfaces: From Ground Roll to Morning Glory Phenomena Posters *(joint with A, S, T)*

***Presiding:*** **C Lomnitz,** National University of Mexico /UNAM**; W Stephenson,** Institute of Geological and Nuclear Sciences

### NG21C-0945 0830h POSTER

### The Non-Linear Morning-Glory Wave of Southern California

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A pulse-like disturbance traveling across the Los Angeles basin was observed on Oct 12, 2001 with seismographs of the TriNET network. This wave had a period of about 1000 s, and a propagation speed of about 10 m/s, much slower than seismic waves. The seismograph data was compared with barograph data and a good correlation was found, so the wave was determined to be atmospheric in origin. It had an amplitude of about 1 mbar, but it was not known what process could produce such a wave. Since the initial finding, we inspected all the TriNET barograph and seismograph data for a period of two and a half years (from Jan 2000 to July 2002), and found 5 more events with similar characteristics. Another event occurred in 1988. Each of the events has an amplitude between 0.8 and 1.3 mbar, a period between 700 and 1400 s, and a propagation speed between 5 and 25 m/s. Analysis of these data has led us to the conclusion that the wave is a solitary wave (a non-linear internal gravity wave) similar to the spectacular morning glory wave observed in Australia. We present data here that supports the hypothesis that this morning-glory wave of Southern California is caused by an excitation of the stable inversion layer by some atmospheric condition or seismic disturbance as it enters the LA basin. In particular, we believe it may be coupled to stormy weather, winds such as the Santa Ana Winds, and large teleseismic events. Furthermore, the morning-glory wave could contribute to the excitation of the background free oscillations of the Earth reported recently. Additionally, because of its large amplitude, it could have important implications for aviation safety, as was suggested earlier for the morning-glory waves in Australia.

### NG21C-0946 0830h POSTER

### Infrared sounds coupled with the Earth's free oscillations

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Recent observations of Earth's free oscillations show that they are continuously excited at nano gal level. The most probable mechanism of such oscillations is that these oscillations are excited by turbulence motions in the atmosphere. To confirm the mechanism, a survey of atmospheric disturbances is necessary. If atmospheric turbulence can excite the free oscillations, the same mechanism can also excite continuous atmospheric infrared sounds. Detection of the sound waves can be another test for the mechanism that our atmosphere can really excite the global oscillations. Thus, Fukao et al. (2002) recently installed an array of high resolution barometers to search continuously excited atmospheric oscillations. To evaluate the observational feasibility, here we discuss the excitation of sounds by atmospheric turbulence.

The sound waves considered here are trapped between the Earth's surface and the mesopause. For the infrared sounds the mesopause behaves a lid. The frequency of the waves is about 3.7 mHz which is just inverse of propagation time of traveling sounds nearly vertically in the region, and $Q$ of the waves is low (about 100) since the lid is not perfect. The excitation mechanism of sounds by turbulence is well known as Lighthill mechanism, which shows that efficiency ($E$) of sound generation is $2n + 1$-th power of ratio of fluid velocity to sound velocity. The input energy per unit mass per unit time ($I$) is evaluated from solar radiation energy absorbed in the lower atmosphere. Thus sound energy per unit mass is equated to $I \times E$ multiplied by fraction of solid angle for vertical radiation of sounds, the period of sounds and the squared root of $Q$. From this equation, the pressure intensity of sound waves are about $1 \times 10^{-3}$ Pa for n=2 (quadrupole radiation) as a whole. For each singlet mode, this corresponds to $1 \times 10^{-7}$ Pa.

On the other hand, from the amplitudes of the continuously excited Earth's free oscillation mode (${}_0S_{29}$) that is coupled with atmospheric sounds, we can evaluate amplitudes of the coupled infrared sounds. The evaluated value is consistent with the above value. Thus we conclude that infrared sounds in the mHz band can be excited by turbulence in the lowest atmosphere as same as the Earth's free oscillations can be.

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### Hamiltonian formalism and the Garrett-Munk spectrum of internal waves in the ocean

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Wave turbulence formalism for long internal waves in a stratified fluid is developed, based on a natural Hamiltonian description. A kinetic equation appropriate for the description of spectral energy transfer is derived, and its self-similar stationary solution corresponding to a direct cascade of energy toward the short scales is found. This solution is very close to the high wavenumber limit of the Garrett-Munk spectrum of long internal waves in the ocean. In fact, a small modification of the Garrett-Munk formalism includes a spectrum consistent with the one predicted by wave turbulence.

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