are all good candidates for detailed validation across many scales.

Because of their inherently wide-area coverage and reasonable spatial and temporal sampling, remote sensing observations from space are seen as an attractive source of validation data for Earth system models. Upward-looking ground-based devices can also be used for atmospheric process modeling. However, remotely-detected radiances are not natural model output. Either a “forward” radiative transfer stage should follow the dynamical computation, or geophysical parameters need to be retrieved or “reconstructed” from the radiances. Generally speaking, neither task is simple enough to be considered error-free.

There is a wide variety of techniques for characterizing space-time variability to choose from in a multi-scale validation exercise: Fourier- and wavelet-spectra, auto-correlation analysis, structure-functions (a.k.a. semi-variograms), fractal dimensions, multifractal statistics, etc. At the larger scales we may require a one-to-one deterministic correspondence between models and observations; at smaller scales, a weaker statistical correspondence is likely to be sufficient.

With this general validation framework in mind, we consider the remote-sensing data needs for cloud-model validation. Even before the systematic model-data comparisons are performed, we need to examine the integrity of the remote-sensing data as a validation benchmark. In other words, the remote-sensing products need to be themselves validated, again scale-by-scale, in the sense used by NASA’s Earth Observation System (EOS) program: error-bars with respect to ground-truth or otherwise reliable in-situ measurements are assigned, and hopefully their magnitude explained. To be useful for cloud-model validation, we require the remote sensing data, at a minimum, to be free of bias in their 1-point statistics at the observation (pixel) scale and in their 2-point correlations at all observable scales.

Fourier-, wavelet- and multifractal singularity spectra are used, in combination with 3D and 1D (pixel-by-pixel) radiative transfer, to uncover systematic differences between *inherent* (in-situ) and *apparent* (remotely observed) cloud structure according to visible/near-IR satellite imagery as well as time-height transects from ground-based milli-meter radar. All of these biases are such that if not thoroughly investigated –hence removed, or at least identified– they can lead to a spurious validation of dynamical cloud models in one respect or another.

URL: http://nis-www.lanl.gov/~adavis

NG11A-05 0930h INVITED

A statistical approach to merge output from dynamic models with ground observations

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In this research we consider a purely stochastic model to represent rainfall variability in time and space. The model is based on truncating and transforming a multivariate Gaussian variable.

We use the truncated normal model to combine the information given by ground observations with predictions produced by a purely deterministic regional climate model (RCM). RCM models use initial and boundary conditions from different sources and models to produce their predictions, but they do not use ground observations, so they can be seen as prior information on the rainfall of a given area. Furthermore, the output of RCM models relates to averages over fairly large grid cells. So we have observations from two sources at different spatial scales.

Our model allows for the updating of samples of the RCM model output conditioning on the observed point observations. The posterior distribution of the model parameters is explored using a Markov Chain Monte Carlo method that consists on a series of Metropolis Hastings steps for a chosen arrangement of the parameters in blocks. We considered a set of data from an area in Nebraska where monthly rainfall is available at 39 stations as well as predictions from an RCM over 28 50km by 50km grid cells.

NG11A-06 0945h INVITED

Evaluation of Point Process Models for Earthquakes

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A point process consists of events (e.g. earthquakes) occurring at random points in time. It is specified by a conditional intensity $\lambda(t \mid H_t)$ such that

$$\Pr(\text{event } \in (t, t + dt) \mid H_t) \approx \lambda(t \mid H_t)dt.$$

The history H_t incorporates times, usually magnitudes, and possibly locations, of previous events. In general, λ is parameterized, for example the stress release process has

$$\lambda(t \mid H_t) = \alpha + \nu \left(\rho t - \sum_{t_i < t} 10^{0.75 m_i} \right),$$

where earthquakes of magnitude m_i occur at times $t_1, t_2, \ldots \in T$, where T is the observed time interval. Model parameters can be estimated by maximizing the log-likelihood

$$\log L = \sum_i \lambda(t_i) - \int_T \lambda(t)dt.$$

Probability forecasts of hazard can then be produced by repeated simulation. The history can also include non-catalog information, provided an auxiliary model is available to predict such information forward.

Due to the complexity of the seismogenesis process, most mathematical models can only be, at best, a rather crude approximation. By considering a number of simple models, each constructed from a few characteristics, it is possible to decide whether these particular characteristics are present in the observed data. The accumulation of observed characteristics are then suggestive of a more comprehensive model.

The question then arises as to how adequately a given model describes the data, particularly relative to competing models. The Akaike Information Criterion (AIC), by penalizing overfitting, can be used to eliminate parameters unless the resulting model provides a significant improvement in fit. Examination of the residual point process(es), which basically transform the data using the fitted model, can identify systematic deficiencies in the model. Repeated simulation and refitting can be used to assess goodness of fit, and hence verify the fitted model. Standard errors and thus, in principle, prediction intervals can also be derived. The performance of the model in probabilistic forecasting is bounded above by the point process entropy, which can be estimated by simulation if it cannot be calculated directly.

NG11B MCC: 121 Monday 1015h

Recent Advances in Nonlinear Geophysics II: Natural Hazards/Nonlinear Physical Processes *(joint with S, MR)*

Presiding: **S Tebbens,** University of South Florida**; S Burroughs,** University of Tampa**; K McCall,** University of Nevada, Reno**; R Guyer,** Los Alamos National Laboratory

NG11B-01 1015h INVITED

Model Verification and Other Oxymorons of Real-World Forecasting

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Models of physical systems can never be verified; at best our models can be shown to be consistent with observations. For dynamic systems this implies that the model can shadow the the phenomena of interest (ideally the data) to within the observational uncertainty for some (initially unknown) initial condition. When shadowing trajectories exist, operational questions of model tuning, adaptive observations and the selection of initial conditions can be approached by looking for indistinguishable states of the model given the observations (see Judd and Smith, Physica D, 151, 125–141, 2001 and references thereof).

All models are imperfect; for nonlinear systems this implies a time scale on which they cannot shadow for any empirically reasonable definition of observational uncertainty. At these time scales, there is no ”uncertainty in the initial condition” as there is no ”initial condition” of the model which is consistent with the physical system. With a focus on weather forecasting and climate modelling, this talk considers how to best proceed given that all models are wrong. How should we interpret the output of models which have not yet been falsified? And more relevantly, how can we best use forecasts models which have?

URL: http://www.maths.ox.ac.uk/~lenny

NG11B-02 1030h INVITED

Dynamics of Shoreline Position

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Change in the position of a shoreline over time results from the interaction of a large number of processes, which appear to produce a random pattern of change. Complexity analysis has been applied to a twenty-year record of mean high water shoreline positions surveyed approximately biweekly along four transects at Duck, NC. A Lomb Periodogram permits spectral analysis of the unevenly spaced data. The spectral analysis reveals that the signal is a 1/f noise with b, the scaling exponent, equal to one. Properties of 1/f noises are power-scaling, long-range persistence, and slight non-stationarity. Power-scaling signals exhibit spectral density that increase with wavelength, and contain no characteristic wavelength. Long-range persistence of a signal measures the temporal correlation among values of like magnitude relative to the mean. Non-stationarity of a signal measures the drift of the mean over time. Runs (successive movement in the same direction) for both erosion and accretion range from 1 to 7 consecutive surveys lasting from weeks to months and conform to a Gaussian distribution. The magnitudes of lateral excursions of shoreline position conforms to a Gaussian distribution with a mean of zero and a standard deviation of 3 meters. The size distribution of both runs and lateral excursions show a balance between erosion and accretion.

The distributions derived from the field data were used to create a synthetic signal that is statistically identical to the shoreline position time series. In contrast to the field time series, the synthetic signal is uniformly spaced (daily) and is run for 100 years. The synthetic signal exhibits erosional and accretionary runs and excursions at all scales and drifts within a narrow envelope of plus or minus 30 meters.

The size distributions of both runs and excursions in shoreline position indicate that they result from a Poissonian process, i.e. random, with no memory, analogous to a fair coin toss. But, the persistence measure, b=1, indicates that the position of the runs and excursions is not random in time. Thus, similar shoreline positions tend to cluster in time, so that a particular shoreline position is more likely to be followed by a similar position, rather than randomly distributed in time. The analysis indicates that the physical processes operating at this beach are self-organizing over a broad range of time scales, resulting in a stable shoreline position in the face of a high rate of sea level rise (calculated to be 5 cm/decade at this site).

NG11B-03 1045h INVITED

Self-Organized Evolution of Sandy Coastline Shapes: Connections with Shoreline Erosion Problems

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Landward movement of the shoreline severely impacts property owners and communities where structures and infrastructure are built near the coast. While sea level rise will increase the average rate of coastal erosion, even a slight gradient in wave-driven alongshore sediment flux will locally overwhelm that effect, causing either shoreline accretion or enhanced erosion.

Recent analysis shows that because of the nonlinear relationship between alongshore sediment flux and the angle between deep water wave crests and local shoreline orientation, in some wave climates a straight coastline is unstable (Ashton et al., Nature, 2001). When deep-water waves approach from angles greater than the one that maximizes alongshore flux, in concave-seaward shoreline segments sediment flux will diverge, causing erosion. Similarly, convex regions such as the crests of perturbations on an otherwise straight shoreline will experience accretion; perturbations will grow. When waves approach from smaller angles, the sign of the relationship between shoreline curvature and shoreline change is reversed, but any deviation from a perfectly straight coastline will still result in alongshore-inhomogeneous shoreline change.

A numerical model designed to explore the long-term effects of this instability operating over a spatially extended alongshore domain has shown that as perturbations grow to finite amplitude and interact with each other, large-scale coastline structures can emerge. The character of the local and non-local interactions, and the resulting emergent structures, depends on the wave climate. The 100-km scale capes and cuspate forelands that form much of the coast of the Carolinas, USA, provides one possible natural example. Our modeling suggests that on such a shoreline, continued interactions between large-scale structures will cause continued large-scale change in coastline shape. Consequently, some coastline segments will tend to experience accentuated erosion. Communities established in these areas face discouraging future prospects. Attempts can be made to arrest the shoreline retreat on large scales-for example through large beach nourishment projects or policies that allow pervasive hard stabilization (e.g. seawall, jetties) along a coastline segment. However, even if such attempts are successful for a significant period of time, the pinning in place of some parts of an otherwise dynamic system will change the large-scale evolution of the coastline, altering the future erosion/accretion experienced at other, perhaps distant, locations.

Simple properties of alongshore sediment transport could also be relevant to alongshore-inhomogeneous shoreline change (including erosion 'hot spots') on shorter time scales and smaller spatial scales. We are comparing predictions arising from the modeling, and from analysis of alongshore transport as a function of shoreline orientation, to recent observations of shoreline change ranging across spatial scales from 100s of meters to 10s of kilometers, and time scales from days to decades (List and Farris, Coastal Sediments,1999; Tebbens et al., PNAS, 2002). Considering that many other processes and factors can also influence shoreline change, initial results show a surprising degree of correlation between observations and predictions.

NG11B-04 1100h INVITED

Ergodicity in Natural Fault Systems

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Attempts to understand the physics of earthquakes over the past decade generally have focused on applying methods and theories developed based upon phase transitions, materials science, and percolation theory to a variety of numerical simulations of extended fault networks. This recent work suggests that the fault system can be interpreted as mean-field threshold systems in metastable equilibrium (Rundle et al., 1995; Klein et al., 1997; Ferguson et al., 1999), and that these results strongly support the view that seismic activity is highly correlated across many space and time scales within large volumes of the earth's crust (Rundle et al., 2000; Tiampo et al., 2002). In these systems, the time averaged elastic energy of the system fluctuates around a constant value for some period of time and are punctuated by major events that reorder the system before it settles into another metastable energy well. One way to measure the stability of such a system is to check a quantity called the Thirumalai-Mountain (TM) energy metric (Thirumalai & Mountain, 1993; Klein et al., 1996). In particular, using this metric and other physical measures, we show that the California fault system is ergodic in space and time for the period in question, punctuated by the occurrence of large earthquakes, and that, for individual events in the system, there are correlated regions that are a subset of the larger fault network.

NG11B-05 1115h INVITED

The role of fluids in nonlinear hysteretic rocks

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In this paper we describe the role of fluids in the mechanical behaviour of non-linear elastic hysteretic materials. Experiments show that the nonlinear quasi-static and dynamic material behaviour primarily changes in the range of low saturation, where high fluid-solid interaction forces are present. Using the Priesach-Mayergoyz space (P-M space) model, we show that micro- to mesoscopic hysteretic entities, that cause the non-linear response, are activated with increasing saturation. The description introduces different macroscopic interaction pressures for the reversible and hysteretic elements and provides quantitative agreement with experiment This allows us to delineate populations of mechanical elements, where moisture induced activation is most pronounced and to correlate the observations in perspective of the material composition.

NG11B-06 1130h INVITED

Thermal–Stochastic Properties of Hysteretic Elastic System

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Recent experiments of dynamical stress–stain measurements draw attention to the presence of broad time scales in the elastic response of rocks and other systems. These experiments are complementary to some quasi–static experiments, where applying a constant force, one observes a logarithmic recovery in time. This phenomena has been termed *slow dynamics*, one of the most intriguing nonlinear phenomena of these materials.

The goal of this work is to establish a model that provides an explanation of these experimental results and to provide a means to describe the time evolution to equilibrium. In particular in this paper the effects of the temperature on these systems in terms of slow dynamics are studied numerically and analytically and the elastic response in a fluctuating thermal environment are reproduced.

A new phenomenological model termed the *DMG* (Dynamical McCall Guyer model) describes most of the nonlinear features seen in dynamical experiments, but not the slow dynamics. In the model a rock is represented as a chain of N particles (rigid units) connected by hysteretic elastic elements (bond system) that describe the mesoscopic nonlinear elastic properties. Two quantities are used used in the model, the displacement $u_i(t)$, describing the displacement for the $i-th$ particle and $\eta_i(t; u_i, u_{i+1}, u_{i-1})$ the state variable associated with $i-th$ elastic units describing the nonlinear behavior of the system. We propose a generalization of the DMG where a fluctuating thermal environment has been included in the system. The time evolution of the system has been studied to analyze how the system reaches equilibrium and to show how the slow dynamics can be described in terms of thermal properties. Numerical results agree well with experimental results.

NG11B-07 1145h INVITED

Low temperature elastic behavior of rocks

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The resonant frequencies of a material sample are directly related to the elastic constants characterizing the sample. Thus, by studying trends in resonant frequencies as a function of temperature, the elastic behavior of the sample may be inferred, and changes in the physical properties of the material may be tracked (for example, phase changes). Historically, tracking the resonant frequencies of a crystalline sample as a function of temperature is one of the most sensitive methods for identifying phase changes in the sample. We are using Resonant Ultrasound Spectroscopy (RUS) to track the resonant frequencies of rock samples at low temperatures. Our initial measurements showed unexpected behavior in a millimeter-sized sample of Berea sandstone in the temperature range from 77 K to 300 K [Ulrich and Darling, 2001], including hysteresis in the temperature dependence of the resonant frequencies, and softening rather than hardening as the temperature decreases. A second experimental apparatus has been developed to make RUS measurements on samples up to 2 cm by 3 cm by 8 cm in size, and over the temperature range 77 K 400 K. RUS measurements using the new experimental system have been made on several rock samples, as well as several standards, and will be described in this talk. In general, the rock samples exhibit anomalous elastic behavior, consistent with the initial measurements on much smaller samples. Similar elastic phenomena, with similar activation energies, are seen in these rocks in room temperature measurements of resonant frequency versus strain [Tencate and Shankland, 1996]. Thus, low temperature measurements could provide insight into the mechanisms for the nonlinear elastic behavior of rocks and other materials.

Ulrich T.J., Darling T.W., *Observation of anomalous elastic behavior in rock at low temperatures.* Geophys. Res. Let., Vol. 28, No. 11, pgs. 2293-2296, June 1, 2001.

Tencate J.A., Shankland, T.J., *Slow dynamics in the nonlinear response of Berea sandstone.* Geophys. Res. Let., Vol. 23, pgs. 3019-3022, 1996.

NG12A MCC: Hall C Monday 1330h

Visual Computing in Nonlinear Geophysical Phenomena II Posters

(joint with G, GP, OS)

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

NG12A-1016 1330h POSTER

Visualization of P-T Paths Derived From Numerical Thermomechanical Experiments: new Insights Into Geodynamic Problems

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The pressure (P)-temperature (T)-time (t) path of a rock is a direct record of its movement within the Earth's interior. Thus P-T-t paths are powerful tools for understanding geodynamic processes, and in the last 25 years many P-T-t paths have been worked out for rocks of the crust and upper mantle. Although one-dimensional modelling of P-T-t paths during regional metamorphism (e.g., [1]) has allowed many important features of the P-T-t evolution of metamorphic rocks to be explained, and the necessary further progress can be achieved with 2D and 3D numerical approaches (e.g., [2-5]), the majority of numerical studies on geodynamic processes at present do not specifically address the details of P-T-t trajectories. Thus, the huge amount of empirical data available on the P-T-t evolution of crustal and mantle rocks is at present not adequately used to check and interactively optimize numerical models of geodynamic processes. This is especially true in those geodynamic settings where rocks must evolve contrasting P-T-t trajectories within the same rock complex (e.g., [3-4]). We suggest that there is a general major problem in visualizing the results of numerical geodynamic modelling in terms of the P-T-t evolution of the rocks involved. We have developed a user-friendly dynamic visualisation and animation technique to allow direct interactive comparison between P-T-t paths and numerical experiments of