# Nonlinear Geophysics

## NG11A CC: 516 B Monday 0830h

### Scaling and Fractals in the Earth, Atmosphere, and Hydrosphere: Resolution Dependence and Nonlinear Variability I

*Presiding:* **H Gaonach,** GEOTOP, Iniversite du Quebec a Montreal**; Q Cheng,** York University

**NG11A-01 0830h INVITED**

### Multifractal Modeling and the Pareto Distribution

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The high-value tails of the sizes of mineral deposits and oil pools often can be modeled as Pareto distributions plotting as straight lines on log-log paper. However, except in their high-value tails, the central parts of the frequency distributions for these resources tend to satisfy the lognormal model with clearly developed peak and zero frequency density at the origin. Some types of multifractal cascade models result in approximately lognormal distributions but with tails controlled by the hyperbolic law. Depending on type of multifractal model used, the high-value Pareto tail is either weaker or stronger than the lognormal outward extension from the central, approximately lognormal, distribution. The multifractal cascade model corresponding to the model of De Wijs for geochemical data results in an approximately hyperbolic tail that is weaker than the lognormal extension. Hyperbolic tails stronger than lognormal can be generated if the highest concentration values are controlled by enrichment processes that are stronger than those controlling the lognormal background. For example, case history studies will be reviewed for large gold and hydrocarbon deposits.

**NG11A-02 0845h**

### Multifractal Predictability

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The “chaos revolution” clearly emphasized that strong nonlinearity generates sensitive dependence to initial conditions and drastic predictability limits. This was achieved with the help of apparently simple caricatures of complex systems leading nevertheless to non-trivial behaviors. This was widely popularised as the 'butterfly effect', i.e. the existence of an exponential error growth and therefore of a characteristic predictability time. This became considered as the universal law of predictability limits, in spite of observed discrepancies. Spatially extended systems, like turbulent dynamics of the atmosphere and the oceans or the rain field, are extremely variable over a wide range of scales. These systems do not yield characteristic times of predictability: a limited uncertainty on initial and/or boundary conditions on a given range of time and space scales rapidly grows across the scales and yields scaling (i.e. power-law) decays of the predictability. Secondly, the predictability decay is highly inhomogeneous: intermittency plays a fundamental role and the loss of information occurs by intermittent puffs. As a consequence, predictability limits are much more complex than those foreseen with homogeneous theories: instead of a unique exponent relating time and space scales, an infinite hierarchy of power-law exponents is required to characterize the predictability decay from average to extreme events. Nevertheless, contrary to those of simple chaotic systems, these scaling predictability decay laws are not only asymptotic, but they are meaningful over the whole range from short to long term. We give an explicit expression of these laws, to which our current effective prediction skills should be compared. In this respect, we confirm the necessity to proceed to stochastic sub-grid modeling rather than deterministic ones, as well as the possibility to directly proceed to stochastic forecasts.

URL: http://www.enpc.fr/cereve/~schertze

**NG11A-03 0900h**

### Detecting Lévy and fractal Gaussian Intermittencies in Geophysical Phenomena

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Time series from complex phenomena are characterized by complicated memory and/or distribution patterns. We discuss models of different statistics and explore the relationship between the statistical properties of time series and observed patterns in various phenomena. In particular, we discuss the difference between Lévy-walk intermittent noise and fractal Gaussian intermittent noise. We show that two complementary scaling analysis techniques (Diffusion Standard Deviation Analysis and Diffusion Entropy Analysis), when used together, can distinguish between the two kinds of intermittent statistics. Finally, we apply these methodologies to geophysical phenomena: (a) the stochastic coupling of solar flare intermittency with the total solar irradiance and global temperature anomalies can be modeled [1]; (b) the earthquake occurrences in California are modeled by a long-range correlated Generalized Poisson model [2]. [1] N. Scafetta and B.J. West, Solar Flare Intermittency and the Earth's Temperature Anomalies, Physical Review Letters 90, 248701-1 (2003). [2] N. Scafetta and B.J. West, Multi-Scaling Comparative Analysis of Time Series and a Discussion on “Earthquake Conversations” in California, accepted by Physical Review Letter

**NG11A-04 0915h INVITED**

### On Why Fractals Everywhere

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Fractal is a ubiquitous phenomenon. It can be classified as deterministic or stochastic. Deterministic fractals have been commonly generated by iterative function systems (e.g., Cantor set, Sierpinski carpet and Koch snowflake) or recurrence relation (e.g., Lyapunov fractal). Stochastic fractals involve random processes and they have been used to describe some highly irregular real-world phenomena (e.g., clouds and turbulence). Stochastic fractals have been investigated with local models (e.g., Diffusion Limited Aggregation, and Percolation), as well as non-local models (e.g., Dielectric Breakdown Model and Self Organization). The objective of this study is to construct a universal non-local model to provide a plausible explanation of the origination of fractal characteristic in a wide variety of natural phenomena, without taking into account the underlying microscopic physics on a detailed level. The natural phenomena under consideration include turbulence, river networks, soil hydrology, lightning, avalanches, earthquakes, volcanic activities and distribution of leaves, updrafts/downdrafts, rain areas, clouds, interstellar clouds, sunspots or galaxies.

**NG11A-05 0930h**

### Third Generation Multifractal Models and Geophysics

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Geophysical fields typically display extreme variability over huge ranges of scale. The simplest assumption about the corresponding dynamical mechanism is that it respects a scaling symmetry; the process is multifractal. In such processes, the variability is produced by the scale by scale repetition of a cascade-like mechanism. This is the phenomenological basis of the cascade models. In some cases, notably for cloud radiances and for the topography, the isotropic horizontal statistics can be shown to be multiscaling from planetary scales down kilometers or less to within 1-2% per octave in scale. The first generation multifractal models were the discrete (in scale) models introduced in the turbulence literature in the 1960's and 1970's. While these were useful in advancing research into scaling and intermittency, they had ugly (and unrealistic) construction lines, artifacts of the fact that that their scaling was only exactly valid for integer powers of integer scale ratios. The second generation models were introduced in the 1980's: these were continuous in scale (their generators were infinitely divisible processes), in the 1990's they were rendered anisotropic and causal (for space-time modeling). Since they were based on the exponentiation of fractionally integrated Levy noises, they are very sensitive to problems of numerical stability; this is particulary true of the strongly anisotropic models of geophysical interest. Such strong anisotropy is needed for example in modeling stratification in flows and rock strata as well as filamentary and rotating structures such as those commonly observed in clouds, or highly elongated structures such as mountain ranges. In this talk, we describe a series of technical improvements which promise to make multifractal models a standard element in the geophysicists' toolbox.

**NG11A-06 0945h INVITED**

### Self-stabilized Fractality of Sea-coasts Through Damped Erosion

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Coastline morphology is of current interest in geophysical research and coastline erosion has important economic consequences. At the same time, although the geometry of seacoasts is often used as an introductory archetype of fractal morphology in nature there has been no explanation about which physical mechanism could justify that empirical observation. The present work propose a minimal, but robust, model of evolution of rocky coasts towards fractality. The model describes how a stationary fractal geometry arises spontaneously from the mutual self-stabilization of a rocky coast morphology and sea eroding power. If, on one hand, erosion generally increases the geometrical irregularity of the coast, on the other hand this increase creates a stronger damping of the sea and a consequent diminution of its eroding power. The increased damping argument relies on the studies of fractal acoustical cavities, which have shown that viscous damping is augmented on a longer, irregular, surface. A minimal two-dimensional model of erosion is introduced which leads to the through a complex dynamics of the earth-sea interface, to the appearance of a stationary fractal seacoast with dimension close to 4/3. Fractal geometry plays here the role of a morphological attractor directly related to percolation geometry. The model reproduces at least qualitatively some of the features of real coasts using only simple ingredients: the randomness of the lithology and the decrease of the erosion power of the sea. B. Sapoval, Fractals (Aditech, Paris, 1989). B. Sapoval, O. Haeberlé, and S.Russ, J. Acoust. Soc. Am., 2014 (1997). B. Hébert B., B. Sapoval, and S.Russ , J. Acoust. Soc. Am., 1567 (1999).



## NG12A CC: 516 B Monday 1030h

### Nonlinear Phenomena in Fluid Dynamics With Implications for Climate I

*Presiding:* **M Stastna,** University of Toronto**; F Poulin,** Scripps Institution of Oceanography

**NG12A-01 1030h INVITED**

### The Nonlinear Dynamics of Antarctic Intermediate Water Formation

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Recently, there has been considerable interest in the properties and formation of the oceans' intermediate waters. These waters are a complex and essential part of the role the ocean plays in modulating and driving climate change. The Antarctic Intermediate Water (AAIW) is the largest body of intermediate water. AAIW forms in the Southern Ocean in the region of the worlds strongest current, the Antarctica Circumpolar Current (ACC). However the exact details

of how AAIW forms and what role the ACC plays remains a puzzle. The difficulty in examining the formation of AAIW is the many nonlinear process involved at different scales. It's fairly clear that the dynamics of the ACC are important. But this is far from trivial since eddy fluxes play a critical role in balancing the forcing of strong westerly winds that drive the ACC. The eddy fluxes transfer momentum downwards through form drag to depth where it can be diffused by mountain drag. An inherently nonlinear process involving baroclinic instability and large bottom topography. In this presentation, we examine the formation of AAIW which is a secondary effect to the ACC's nonlinear balance. Its formation is thought to be driven by air-sea surface fluxes of both heat and salt which produce cold and fresh waters to the south of the ACC. These waters move northward and then sink to form AAIW. Using some idealized models and theory, we examine many of the details in this process: the role of the turbulent mixed layer, the response of the interior flow to the surface forcing, the role of topography in inducing mixing and the role of convection.

### NG12A-02 1045h INVITED

## MESOSCALE MOTIONS IN THE UPPER OCEAN

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Mesoscale eddy transports of large-scale momentum and material tracers exert a profound influence on the oceanic general circulation, and on the exchange of heat, freshwater, and anthropogenic tracers between the ocean and the atmosphere. In present climate models, the ocean horizontal grid resolution is O(100) km or larger. At this resolution, the mesoscale dynamics are sub-grid scale and their effects must be parameterized. The mesoscale parameterizations used in ocean general circulation models (GCMs) typically represent the adiabatic release of potential energy by baroclinic instability in the interior, as suggested by Gent and McWilliams (1990). However, as the surface is approached, eddy fluxes develop a diabatic component, because density is maintained vertically homogeneous by strong mixing, while motions are constrained to be horizontal near the boundary. In this study we discuss the dynamical consequences of the transition to diabatic horizontal eddy fluxes in the upper ocean, and we propose closure schemes to account for this transition.

URL: http://mit.edu/raffaele/www/

### NG12A-03 1100h

## Numerical Simulations of Vortical and Wave Motion in Stably Stratified Turbulence

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Observations of the atmospheric mesoscale and oceanic submesoscale, where stable density stratification is strong but rotation is weak, have a certain universality: energy spectra, for instance, are often found to be relatively independent of location and season. Different theories have been proposed to account for these observations; however, the underlying physics remain controversial. This issue has implications for climate research, as the effects of these intermediate scales on the large-scale flow must be parameterized in GCMs. An important feature of these flows is that they can be decomposed into a potential vorticity-carrying (vortical) component and an internal wave component. In this talk, we examine some of the characteristics of these two modes of motion. Numerical simulations of an idealized stratified fluid are presented, in which large-scale vortical and wave motion are forced separately for a wide range of stratifications. In the vortical case, stratification leads to vertical decoupling and flat energy spectra in the vertical wavenumber $k_z$. The decoupling is shown to break down at a vertical scale of $U/N$, where $U$ is the RMS velocity and $N$ is the Brunt-Väisälä frequency; wave energy is generated by nonlinear interactions at this scale. We contrast these findings with wave-forced simulations, and discuss the relation of our numerical results with various asymptotic theories of wave and vortical mode dynamics.

### NG12A-04 1115h

## Low-Latitude Balanced Dynamics in Analyses and GCM Output

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A dynamical balance is derived, which is applicable in the equatorial middle atmosphere whenever zonal lengthscales significantly exceed meridional lengthscales. Although the traditional geostrophic relation formally breaks down at the equator, its meridional derivative remains valid, and is the natural balance that arises from the assumption of lengthscale separation. Anisotropy in the spatial scales as well as residuals associated with this balance relation are investigated in the context of output from the Canadian Middle Atmosphere Model and forecast analyses from the Met Office and the Canadian Meteorological Centre. In particular, it is shown that the residuals decrease with the zonal wavenumber, and that dynamical fields produced by the numerical model are more balanced than analyzed fields. Currently, forecast analyses exhibit more error in wind velocities in the tropics than at mid-latitudes. Consistent application of a balance relation in assimilation schemes should prove useful in improving future analyses.

URL: http://www.atmosp.physics.utoronto.ca/people/matt/atmos-res.html

### NG12A-05 1130h

## The Spatial and Temporal Structure of ENSO Nonlinearity

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The spatial structure of asymmetries in sea surface temperature (SST) and surface air temperature (SAT) between average El Niño and La Niña events is considered. It is demonstrated that in historical SST and SAT reconstructions, the anomaly spatial pattern that changes sign between El Niño and La Niña events (the "linear" signal) strongly resembles that of principal component analysis (PCA) mode 1, while that which does not change sign (the "nonlinear" signal) resembles the pattern of PCA mode 2. The linear and nonlinear patterns also strongly resemble the standard deviation and skewness fields, respectively. Furthermore, temporal subsampling of long (130-year) SST reconstructions suggests that the magnitude of the nonlinear signal and its similarity to PCA mode 2 are functions of the strength of ENSO, as measured by the standard deviation of the PCA mode 1 time series. Finally, it is found that of several coupled general circulation models (GCMs) considered, the spatial and temporal structure of the El Niño/La Niña asymmetry is captured only by the GFDL R30 model, despite large biases in its covariance structure.

### NG12A-06 1145h INVITED

## An Oscillating Jet in the Cape Cod Bay

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During the spring months, the Cape Cod Bay is a roaming ground for the North Atlantic right whale, perhaps the most endangered whale species in the world. The whales are observed to travel along the topographic steps that run parallel to the shore, eating plankton patches that form in the coastal water. In this region, off the coast of Provincetown, there is an oscillatory current with the same period as that of the ambient tides. The location of the current and its periodicity suggest that the topography and tides play fundamental roles in generating the jet. This current, depending on its velocity profile, may become unstable and generate vortices. It is likely that the local surface convergences and divergences in the tidal flows and vortices are related to the aggregation of the copepods (Calanus Finmarchicus), which are the right whale's primary food source. Understanding the dynamics of this jet is essential to predicting the spatial and temporal patterns of the codepods, which will in turn help us understand the likely locations and feeding history of the whales. In this talk we discuss results of the first phase of this study, that of the oscillatory jet in the Cape Cod Bay. This jet is rather complicated since it involves complex topography and coastlines, bottom and lateral friction, stratification and numerous other effects. Rather than study this system in fine detail, we investigate an idealized model that captures the essential features. In the context of this model, we first compute possible profiles for the oscillating jet. We then solve the linear stability problem to determine how the growth rates depend on the various parameters. Finally, and most importantly, we study the nonlinear problem to observe the time evolution of the instability process along with its equilibration. This provides some insight into how the instabilities are related to fluid transport across the shelf.

# NG21A CC: 516 D Tuesday 0830h

## Scaling and Fractals in the Earth, Atmosphere, and Hydrosphere: Resolution Dependence and Nonlinear Variability II

*Presiding:* **D Schertzer,** Ecole Nationale des Ponts et Chausses**; B Sapoval,** Ecole Polytechnique

### NG21A-01 0830h

## How Hawaiian lava flow Textures Rhyme with Anisotropic Scaling

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Textural morphology of subsurface lava flows is an expression of the intense stress applied at the surface during an eruption over a large range of scales. Pahoehoe and A'a Hawaiian textures are typical examples illustrating different conditions of volcanic eruption styles. However a particular and prominent aspect of these different textures is the ubiquity of scaling properties, implying a scaling symmetry over a wide range of scales. While the existence of a scaling and multiscaling may reveal the continuity of a dynamic process over these scales it is also important to consider these properties in a more general context where the (scale by scale) differential anisotropy is taken into account. Indeed, a qualitative well known difference between the two Hawaiian texture types is the differentially oriented structures present in the Pahoehoe lavas as for example in the ropy type Pahoehoe. In such cases, generalized scale invariance (GSI) could provide new powerful insights for describing highly variable anisotropic phenomena. We will discuss this question through Pahoehoe and A'a textures acquired in Hawaii studying images spanning the range of millimeters to meters. In particular we may combine isotropic and anisotropic results to compare structures revealing stratification, rotation or both from more isotropic growing texture flows.

### NG21A-02 0845h INVITED

## Multifractal PMP Estimates in the Eastern US - Spatial Variability and Temporal Stability

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Multifractal analysis provides a framework to estimate physically meaningful estimates of the magnitude of extreme precipitation events, and to determine the risk associated with events of known magnitude. Specifically, the multifractal behavior of rainfall at daily (327 gauges) and monthly (1400 gauges) timescales, as well 6 - hourly fluxes of precipitable water from NCEP-NCAR Reanalysis was characterized. This study showed that multifractal estimates of the return periods of conventional PMP estimates (< 100,000 years) differ substantially from the desired values ( about 1,000,000 years) in engineering design. Evaluation of this result for small dams in the Northern Appalachians implies that the reliability of existing structures is substantially lower (up to 100 per cent) than the assumed design standard. A detailed analysis of the