Contributors, Titles and Abstracts of proposed Theme Issue

Chris Ferro[1], Peter Cox[1], Tim Jupp[1], Hugo Lambert[1], Chris Huntingford[2]: Model Resolution versus Ensemble Size: Optimizing the Trade-off for Finite Computing Resources

[1]Mathematics Research Institute, University of Exeter, [2]Centre for Ecology and Hydrology, Wallingford

Climate modelling is generally considered to be limited by computing resources. Model biases are typically reduced by increasing spatial resolution or improving the parametrization of non adiabatic processes – both of which tend to increase the computational cost per model. Policymakers, businesses and members of the public also need to know the changing risk of tipping points and other extreme events. This requires ensembles of climate models spanning the key sources of uncertainty in initial conditions and internal model parameters.

Thus there is a tension between increasing computational cost per climate model and the feasible size of ensembles. Finite model resolution implies some biases, while finite ensemble size implies some sampling error. This paper provides a simple relationship for the total uncertainty in a predicted climate variable as a function of ensemble size and computational cost per model. For given total computational resources, we show that there exists an optimal trade-off between ensemble size and model cost that minimises the overall uncertainty.

Axel Kleidon: How does the Earth system generate and maintain thermodynamic disequilibrium and what does it imply for the future of the planet?

Max-Planck-Institute for Biogeochemistry

More than forty years ago, James Lovelock noted that the chemical composition of the Earth's atmosphere far from thermodynamic equilibrium is an unambiguous sign for the presence of widespread life on the planet. Here I show how this rather fundamental perspective on what represents a habitable environment can be quantified using non-equilibrium thermodynamics. Generating thermodynamic disequilibrium in a thermodynamic variable requires the extraction of power from another thermodynamic gradient, and the second law of thermodynamics imposes fundamental limits on how much power can maximally be extracted. When applying this to complex Earth system processes, where several irreversible processes compete to deplete the same gradients, it is easily shown that the maximum thermodynamic efficiency is much less than the classic Carnot limit. When this approach is used to quantify how much free energy is generated by various Earth system processes to generate chemical disequilibrium, it is easily shown that surface life generates orders of magnitude more chemical free energy than any abiotic surface process, therefore being the primary driving force for shaping the geochemical environment at the planetary scale. When applied to present-day global change, this perspective implies that evaluating the impacts of change on power generation by Earth system processes is far more relevant than changes in temperature or radiative forcing. After all, it is the basic, human need for free energy to drive their metabolism and industrial activities that closely relates to many of the key issues related to global change and this need is most likely going to increase substantially in the future. The central question for addressing future global change is then how human free energy demands can increase sustainably in the future without negatively impacting the functioning of the Earth system. I illustrate the implications of this thermodynamic perspective by discussing the forms of renewable energy and planetary engineering that would enhance overall free energy generation and thereby empower the future of the planet.

Tim E. Jupp[1], Rachel Lowe[1], Caio A. S. Coelho[2], David B. Stephenson[1]: On the interpretation, verification and calibration of ternary probabilistic forecasts

[1]University of Exeter, Exeter, Devon EX4 4QF, UK, [2]Centro de Previsao de Tempo e Estudos Climaticos, Instituto Nacional de Pesquisas Espaciais, Cachoeira Paulista, 12630-000, SP, Brazil

We describe a geometrical interpretation of ternary probabilistic forecasts in which forecasts and observations are regarded as points inside a simplex (that is, a triangle). A continuous colour palette is defined on this simplex in which colour saturation increases with information gain relative to the climatology. In contrast to current methods, forecast maps created with this colour scheme convey all of the information present in the forecast.

The geometrical interpretation is then extended to include verification under quadratic scoring rules (of which the Brier Score and the Ranked Probability Score are well-known examples). Each scoring rule defines an associated simplex in which the square roots of the score, the reliability, the uncertainty and the resolution all have natural interpretations as root-mean-square distances.

This leads to our proposal for a Ternary Reliability Diagram in which verification data can be interpreted visually. Finally, we derive a procedure for calibrating ternary forecasts by calculating a best linear calibration matrix T with which to transform the raw forecasts.

We illustrate these ideas both with data that are inherently ternary (the outcome of football matches predicted by betting odds) and with data that are continuous (precipitation predicted by climate models at lead times ranging from sub--yearly to centennial).

Codes implementing these ideas have been produced using the statistical software package R and are available from the authors.

R.S. Plant: Convective cloud parameterization away from the quasi-equilibrium, large N, non-interacting limits

University of Reading

The representation of deep convective clouds presents some notoriously stubborn problems for climate modelling, familiar examples including equatorial waves, the Madden-Julian oscillation, the meridional distribution of tropical rainfall and the diurnal cycle. The starting point for very many of the convective parameterizations in current use is a system which describes the interaction of convective plumes with their environment. Typically there are some strong, simplifying assumptions made when implementing this system as a parameterization: the homogeneous environment, the existence of very many plumes, the absence of interactions between the plumes, the use of a single, effective "bulk" plume rather than a spectrum of plume types, the separation of timescales between the convection and a slowly-varying large-scale forcing. These assumptions are contestable at best, and dubious at worst. This article will discuss to what extent they are actually necessary, and their implications. As examples, accounting for finite cloud number leads in a very natural way to important stochastic effects while a consideration of the approach to equilibrium can constrain the equilibrium reached. Finally, a system of convective clouds is proposed away from the limits of a quasi-equilibrium of very many non-interacting plumes.

M. M. Joshi, R. S. Smith and P. D. Williams: Stochastic perturbations to the ocean mixed layer in a coupled climate model

University of Reading

Stochastic representations of unresolved processes have improved weather forecasts and seasonal predictions, but remain relatively untested in long-term climate simulations. Here, we implement a stochastic representation of vertical mixing in the ocean of FAMOUS, a fast coupled atmosphere-ocean general circulation model. We compare three runs: a control run; a run in which the vertical diffusion coefficient in the ocean mixed layer is perturbed by multiplicative noise with a prescribed decorrelation timescale but no spatial correlations; and the same, but with depth-coherent noise. We comment on the changes achieved to the mean state, as well as the variability in the ocean. In particular, a more realistic ENSO emerges in the stochastically-perturbed run.

Mikhail A. Semenov: Delivering local-scale climate scenarios for impact assessments

Rothamsted Research, Harpenden, Herts, AL5 2JQ UK

Process-based impact models used in assessments impacts of climate change depend often on daily weather as one of their main inputs. The direct use of output from global climate models (GCMs) could be problematic, because of the coarse spatial resolution of GCMs and large uncertainty in their output at a daily scale, particularly for precipitation. Output from GCM requires application of various downscaling techniques. This paper reviews one of these techniques which are based on a stochastic weather generator. A weather generator (WG) is a model which, after calibration of site parameters with observed weather, is capable of simulating synthetic time-series of daily weather that are statistically similar to observed weather. By altering the parameters of the WG using changes in climate predicted from GCM, it is possible to generate synthetic daily weather for the future. The paper describes recent developments, including multi-site WGs and the use of multi-model ensembles (MME) of climate predictions from global or regional climate models. Multi-model ensembles emphasize the uncertainty in climate predictions resulting from structural differences in the global climate models as well as uncertainty due to variations in initial conditions or model parameterisations. A dataset of daily local-scale (25-km grid) climate scenarios for impact assessments, ELPIS, recently developed for Europe is described. A case-study of impact of climate change on wheat is given which predicts that heat stress, not drought, will increase vulnerability of wheat in Europe.

Christian Franzke: On Self-Similarity, Long-Range Dependence and Paradigmatic Models for Natural Time Series

British Arctic Survey

Long-range dependence, self-similarity and non-Gaussianity are ubiquitous in many natural systems like ecosystems, biological systems and climate. These commonly observed properties in complex systems act to make them simultaneously potentially more predictable and yet subject to longer-lived fluctuations. These properties also impact the occurrence and re-occurrence of extremes. Here we review long-range dependent and self-similar processes and their interrelationship. We also discuss various paradigmatic models for natural time series like fractional Gaussian noise, Levy noise, Fractional Autoregressive Integrated Moving Average and Linear Fractional Stable Motion and critically re-evaluate popular estimators of self-similarity and long-range dependence for their utility and robustness. We also discuss how important properties of the climate system like annual cycles, trends and multiplicative noise impact estimators of long-range dependence and self-similarity.

Frank Kwasniok: Dynamics of glacial millennial-scale climate variability: multiple equilibria versus relaxation oscillations

University of Exeter

Simple nonlinear stochastic models of glacial millennial-scale climate variability (the so called Dansgaard-Oeschger events) are derived from ice-core records. Two types of conceptual models are considered: (i) stochastically driven motion in a multistable potential and (ii) a relaxation oscillator with state-dependent damping. The parameters of the models are estimated from ice-core data using a nonlinear Kalman filter. A likelihood function and an information criterion as well as statistics from long-term integrations of the models are used to assess the degree of fit of the models to the data. The relaxation oscillator paradigm appears to be better supported by the data than the multiple equilibria paradigm.

Peter Ashwin, Sebastian Wieczorek, Renato Vitolo and Peter Cox: Tipping points in open systems: bifurcation, noise-induced and rate-dependent examples in the climate system

University of Exeter

Climate tipping points associated with bifurcations (B-tipping) and/or noise (N-tipping) are recognized dynamical mechanisms that may potentially lead to sudden climate change. However, tipping points need not be associated with either bifurcation or noise - we show there may be rate-dependent tipping (R-tipping) points, where a sufficiently rapid change to an input or parameter of a system may cause the system to "tip" or move away from a branch of attractors. This may be an irreversible (permanent) or a reversible (transient) change. We discuss various examples in the climate system - including examples with R-tipping suggesting that there may be dangerous rates of global warming even when no bifurcations are present in the system.

Michel Crucifix et al: Stochastic dynamical systems for ice ages : a review

University of Louvain (Belgium)

The present contribution focuses on the slow climate variations over the Pleistocene, and more specifically on the phenomenon of ice ages. There is ample evidence that the slow variations in Earth orbital elements and obliquity influence climate at these time scales, but there is no definitive model of ice age dynamics. Understanding ice ages may be understood as a problem of calibration and selection of stochastic dynamical systems. To this end, we outline a strategy to construct plausible dynamical systems by reference to a number of proposals in the literature over the last 30 years. We emphasize the notion of 'climatic potential' and introduce stochastic parameterisations as a way to account for non-explicitly resolved processes, such a Dansgaard-Oeshger events. Finally, we define a set of critical tests for model selection.

T. M. Lenton[1] and V. N. Livina[1], V. Dakos[2], E.N. van Nes[2], M. Scheffer[2]: Detection and early warning of climate tipping points

[1]School of Environmental Sciences, University of East Anglia, Norwich NR4 7TJ, UK, [2]Aquatic Ecology and Water Quality Management, Wageningen University, The Netherlands

A suite of 'tipping elements' in the climate system have been identified that may pass a tipping point under human-induced climate change. Recent climate changes add to the collective concern that these pose a significant risk to societies. Here we address how tipping points can be detected, and whether any useful early warnings can be provided before a tipping point is reached. We classify tipping points into those that involve approaching (and/or passing) a bifurcation point, those that are purely noise-induced (with no change in the underlying potential), and those that depend on rate of forcing. For these classes of transitions we apply recent methods that are being developed for tipping point detection and early warning. We also test these methods to pick up known historical climate anomalies. Finally, we review the different methods, and recent critiques, in an effort to identify robust approaches which are generic and could equally apply to tipping points in other dynamical systems.Detection and early warning of climate tipping points.

Claudie Beaulieu: Change point detection in presence of autocorrelation using the informational approach

Princeton University

A change point in a time series can be viewed as a time point at which the parameters of a statistical distribution or a statistical model change. Change points methods have been developed and applied in a wide variety of fields to detect artificial or natural discontinuities and regime shifts (e.g. economy, social sciences and climate). Most change point methods have been developed to detect a specific type of shift: shift in the mean, shift in the variance, shift in both the mean and variance or a shift in the parameters of a regression model. A major drawback with change point methods is that they make the hypothesis that the residuals are independent. This can be a problem for climate applications, since the presence of positive autocorrelation is a common feature in climate time series (especially at monthly or shorter time scale). If not taken into account, it can lead to the detection of false shifts. In the climate literature, a few studies have started to take into account a first order autoregressive model in change point detection. However, this is not appropriate if the autocorrelation structure is different than a first-order autoregressive model. In this study, a general and simple approach to take into account any type of autocorrelation that is present in the residuals of the change point model is presented. It consists in using Schwarz Information Criterion for change point detection, which allows identifying the most likely position for a shift, discriminating between several types of shifts and integrating the autocorrelation model. The usefulness of this approach is demonstrated through applications for change point detection in atmospheric time series.

JMT Thompson[1,2], Jan Sieber[3]: Quantifying noise-induced early escape near tipping points

[1]DAMTP Cambridge, [2]University of Aberdeen, [3]University of Portsmouth

A typical feature of dynamical systems near dangerous bifurcations with slowly drifting system parameters and noise is that the jump (escape) from the current attractor may occur early or delayed, depending on the balance between drift speed and noise and the properties of the noise. We determine the probability distribution of escape over time for the fold normal form subject to Gaussian white noise of constant amplitude depending on drift speed and noise amplitude. We also perform a systematic study on the accuracy of extracted normal form parameters from time series to demonstrate how early escape affects the early-warning signals and the prediction of tipping.