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Nonlinear Processes in Geophysics

Preface

“Extreme Events: Nonlinear Dynamics and Time Series Analysis”

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1 Introduction

This Special Issue reports on recent work related to extreme events. It focuses on research related to the European-Commission–supported project “Extreme Events: Causes and Consequences” (E2C2). E2C2 investigated various methodologies for the study of extreme events and their applications to several areas of the geosciences in which such events occur. The strength of the project – which included 17 partners in nine countries – was to bring together a number of usually disparate communities, from statistics, climate science, geophysics, economy and sociology. The results of the E2C2 project already include over 100 papers published in a number of journals in different fields. This Special Issue collects in a unified setting 13 representative research papers related to extreme-event research, complemented by an overall review paper, with the purpose of highlighting the project’s combined impact on the field.

In March 2005, when this 3.5-yr project started, events like the storms Lothar and Martin in 1999, the European 2003 heat wave, the Sumatra 2004 earthquake or the 2005 cyclone Katrina were all fresh in the minds of the over 70 researchers participating in E2C2. Such events represented not only climatic or geophysical extremes, but they had huge and durable consequences on large populations because: in each case, one or more geophysical events impacted structural weaknesses in the societies found in their path.

To paraphrase F. Scott Fitzgerald in “The Great Gatsby,” the E2C2 project investigated whether – or to what extent – extreme events are “like you and me, only bigger”. In this case, one can provide a mathematical definition for the extreme of a real variable, and then rely on Extreme Value Theory (EVT) from classical statistics. But things become increasingly complex, or even intractable, when several variables interact with each other, long-term memory (LTM) effects play a role, or simply if the conditions for the applicability of the EVT are not satisfied.

A major gap in mutual understanding between statisticians and geoscientists arises from the fact that the definition of extreme events is often conditioned on an event’s impact, be it on health, the economy, infrastructures or ecosystems. Hence, high-impact geophysical events may be called *extremes* by some researchers, although a physically quite similar event occurring in a different place or under different conditions would not have the same impact and thus would not qualify as an extreme in the public’s mind.

A synthesis of the advances in the modeling, understanding and prediction of extreme events appears in the comprehensive review paper by Ghil et al. (2011), which heads this special issue. Following this paper, 13 research papers deal with both methodological issues and applications. The applications covered by this diverse range of papers include eight papers on climatic extremes, one on volcanic eruptions, three on earthquakes, and one on geomagnetic activity. We summarize here the main contributions of each of these research papers, first considering extremes in the climate system, and then extremes that occur in the solid Earth.

2 Climatic extremes: precipitation, temperature, pressure and humidity

Vannitsem and Naveau (2007) determine the spatial dependencies among precipitation maxima over Belgium. The pairwise dependences are estimated by a variogram of order one, also called madogram, which is specially tailored to capture EVT bivariate structures. The analysis of Belgium these precipitation maxima indicates that the degree of dependence

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amongst them varies greatly according to three factors: the distance between two stations, the season (summer or winter) and the duration over which precipitation is accumulated (hours, days or months).

Vrac et al. (2007) model pairwise dependencies in precipitation intensities. They propose a new statistical bivariate model that takes advantages of the recent advances in multivariate EVT. This model can be viewed as an extension of an inhomogeneous univariate mixture. The model's two strong points are its capacity to account for the entire range of precipitation and the absence of an arbitrarily fixed large threshold to define exceedances. The performance and flexibility of this new model are illustrated on simulated and real precipitation data.

Bernacchia and Naveau (2008) propose a new method to detect spatial patterns from a multivariate cumulant function. This method takes high-order moments of the distribution into consideration, rather than just second-order moments, as in principal component analysis. Three families of multivariate random vectors, for which explicit analytical formulae are obtained, and the results are evaluated numerically to illustrate this approach. In addition, this method corresponds to selecting the directions along which projected data display the largest spread over the marginal probability density tails. Bernacchia et al. (2008) applied this multivariate cumulant method to detect patterns of spatial variability in the El Niño-Southern Oscillation (ENSO), using observations of temperature and sea level pressure from the Tropical Pacific.

Yiou et al. (2008) determine the dependence of extreme value statistics for summer temperature and precipitation in France on North Atlantic weather regimes. Their approach is based on a conditioning of EVT parameters on indices obtained from a classification of atmospheric synoptic variables.

Ghil et al. (2008) analyze parametric instability in a delay differential model of ENSO variability, and the distribution of extremes in it. The model reproduces the complex resonance pattern sometimes called "Devil's bleachers" that characterizes other ENSO models, such as nonlinear, coupled systems of partial differential equations. Some of the features of this behavior have been documented in general circulation models, as well as in observations.

Blender et al. (2008) study the distribution of return times of extreme events, as well as their correlations. They used both simulated and observed time series with the LTM property and an $1/f$ power spectrum. The observational data are time series of tropical temperature and mixing ratio (specific humidity) from TOGA COARE with 1 min resolution and an approximate $1/f$ power spectrum, while the simulated time series is very long and is produced by a fractionally differenced process.

Schölzel and Friederichs (2008) provide an overview of copulas for application in meteorology and climate research. They examine the advantages and disadvantages of this approach compared to alternative ones, like mixture models, summarize the current problem of goodness-of-fit tests for copulas, and discuss the connection with multivariate extremes. An application to station data shows the simplicity and the capabilities of this approach, as well as its limitations. Serinaldi (2009) comments on this work by providing additional information on the properties of copulas.

3 Geophysical extremes: volcanoes, earthquakes and geomagnetic variability

Taricco et al. (2008) investigate a sequence of eruptive events in the Vesuvio area recorded in shallow-water Ionian Sea sediments. They use an automatic extraction of pulse-like signals and advanced spectral analysis methods (Ghil et al., 2002) to reveal that the volcanic pulses are superimposed on a millennial trend and a 400-yr oscillation.

Abaimov et al. (2007) provide insight on the recurrence and inter-occurrence behavior of self-organized complex phenomena, with a focus on a slider-block model. They investigate how the statistical properties of system-wide events depend on the stiffness of the model, and hence how they contribute to characterize the slider-block model.

Soloviev (2008) presents a methodology to describe the transformation of the frequency-magnitude relation prior to very large earthquakes in a model of block structure dynamics. He generates a very long synthetic catalogue of earthquakes from such a model to study this change of the Gutenberg-Richter distribution as a possible precursory pattern for extreme seismic events.

Narteau et al. (2008) investigate the loading rate in Southern California and the change in stress induced by a transient slip event across the San Andreas fault (SAF) system in Central California, using a model of static fatigue. They show that this rate of change is proportional to the deficit of slip rate along the SAF. This new relationship between geodetic and seismological data is in good agreement with predictions from a band-limited power law model. In such a model, the evolution of the duration of a linear aftershock decay rate over short time results from variations in the load of the brittle upper crust.

Anh et al. (2007) analyze global geomagnetic variability. They use the orthogonal field components from global INTERMAGNET magnetometer stations via a multifractal version of detrended fluctuation analysis to determine whether there are clear and consistent regional patterns in the behavior of the fluctuations.

4 Summary and conclusions

The 13 research papers plus the review paper discussed above use a variety of mathematical and statistical techniques that were brought to bear on our understanding of extreme events, both climatic and geophysical. The papers in this special issue are in addition to the hundred or more papers by the

E2C2 team across disciplinary journals. However, E2C2 was completed in August 2008 and much research remains to be done. Since then, other extreme events have struck the planet: the 2009 storm Klaus in Europe, the 2010 storm Xynthia in France, and the 2011 Tōhoku earthquake in Japan. The latter event and its consequences included a combination of factors – a major earthquake and tsunami, as well as a nuclear power plant in a region not designed to withstand these events – that exacerbated its effects to yield the totally unexpected consequences we witnessed. Current mathematical techniques and physical understanding to cope with such an emergent risk are still in their infancy.

As a conclusion, understanding and hence predicting extreme events might be possible in some cases. There are, at least, tools to estimate their probability distributions. But such conclusions only hold for *known* extremes, in particular the ones of the "Great Gatsby" type. One still cannot evaluate what was *never* observed, as was the combination of events in Japan in 2011, unless a drastic rethinking of methodologies is planned and executed. This leaves a lot of room for further developments of *extremology*, the science of extreme events and their consequences.

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