Project no. 12975

E2-C2

Extreme Events: Causes and Consequences

Specific Targeted Research or Innovation Project

FP6-2003-NEST-PATH "Tackling Complexity in Science"

Final activity report

Period covered by this report:	1st March 2008 to 31st August 2008
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Project coordinator name:	Prof. Michael Ghil
Project coordinator organisation name:	Ecole Normale Supérieure, Paris

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1 Executive Summary

1.1 Objectives

The main objective of E2–C2 was to advance the understanding of the causes and the prediction of the consequences of extreme events. To do so, we propose to improve the methodology for studying complex systems in the natural and socio-economic realm. This methodology will be used to solve several concrete, well-defined problems in the two realms.

A closely related objective was to improve the mutual knowledge of phenomena in these two realms by specialist communities in either one. It is only through a deeper knowledge of apparently unrelated phenomena that truly powerful methods can be developed for "tackling complexity in science." Specifically, a method first developed in one field needs to be tested, rigorously and critically, on a class of phenomena in a different field, in order to really gain confidence in its generality. We propose therefore to pursue close exchanges within our highly interdisciplinary team, as well as between E2-C2 and the rest of the complex systems community, in applying and testing our new methods.

The E2–C2 project was organised around six scientific work packages (WPs) that help solve real-world problems, using the concepts and tools of interactions between and feedbacks within heterogeneous systems (solid Earth, fluid envelopes, economy and society). The aim of the project was to refine several powerful theoretical methods and apply them to concrete data. The interaction between the natural and human sciences addressed in E2–C2 included applications of statistics of extremes in non-stationary cases in order to assess the impact of rare environmental events on well-defined socio-economic fields. The project used observed climate data from European databases, probabilistic and dynamic geophysical models, coupled climate simulations with state-of-the art models, and specific economic models, which were devised within this project. The study of long-time memory processes is still in its infancy in environmental sciences, and was developed further to allow us to quantify time-delayed feedbacks. The conjunction of the extreme and long-memory paradigms provided new insights into environment-society feedbacks. Thus, by adapting and improving recent statistical concepts to tackle concrete problems, the transfer of those techniques was shown to benefit both the theoretical and experimental communities.

1.2 Structure of the project

The project leader (Michael Ghil [MG], ENS) and co-leader (Pascal Yiou [PY], LSCE) organized the consortium management. The WP leaders wrote reports on their part of the project every six months. To ensure an optimal organization, two boards were created at the beginning of the project:

- The Project Executive Board (PEB), composed of WP leaders (MG, PY, Bruce D. Malamud [BDM], Stéphane Hallegatte [SH], and Alexandre Soloviev [AS]), steered the scientific policy and monitored the advancement towards the objectives of the project. The PEB wrote the scientific reports that were sent to the EC every six months.
- The Project Technical Board (PTB), with the Principal Investigators (PIs) from each partner institution, made sure that each institution was adequately involved in E2-C2 and followed the administrative protocol for the project. The PTB was responsible for budgetary matters.

A Scientific Advisory Board (SAB) with scientists of international reputation was created to evaluate the results and functioning of E2-C2. The members of the SAB were Donald Turcotte (UC Davis, USA), Jonathan Koehler (Tyndall Center, Cambridge, UK) and Martin Beniston (U. of Geneva, Switzerland). The SAB met at the Perugia (September 2006) and Paris (March 2008) meetings and assessed the quality of E2C2 research. Its reports were forwarded to the EC with the appropriate interim reports.

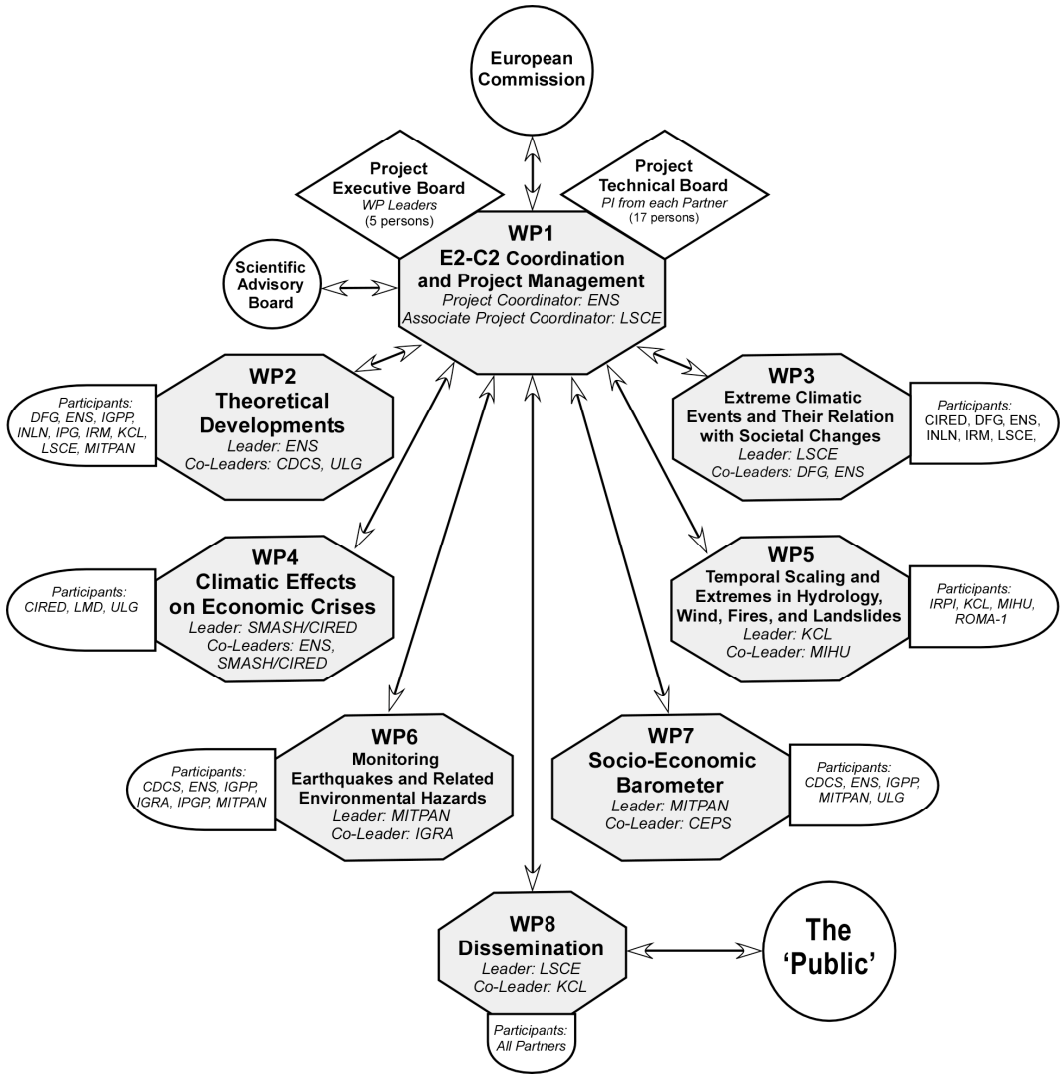

Figure 1: Management structure of E2–C2. Project management is formally conducted under WP1.

1.3 Dissemination of knowledge

Work Package 8 was lead by P. Yiou and B. D. Malamud. Its formal activity was the overall exploitation and dissemination of E2–C2. The main objective was to actively and openly inform the geosciences and socio-economic sciences communities about the objectives of E2-C2, the research we conducted, and the findings of our project. These activities, while no longer funded, are being continued, given the considerable achievements of the project and the high level of interest from different quarters.

1.3.1 Web site

A web site for E2C2 (http://e2c2.ipsl.jussieu.fr/) has been created by PY to reflect the progress of the project and to exchange information between partners.

The scientific part of the site contains:

- Key presentations by E2-C2 participants at international conferences or workshops, in particular at the EGU (April 2005, April 2006, April 2007), WP meetings (numerous), the Perugia all-hands meeting in September 2006, and the final Open Conference in Paris in March 2008.

- General audience presentations, e.g. by Alejandro Martin-Hobdey (EC) and MG;
- Papers published in the framework of the project. Around 50 papers (submitted, accepted, or published) are already listed.
- Data sets generated by members of WP2 and WP5 (*D2a.1, D5a.1*)
- Reports or papers on probability density estimates and methodologies (*D2a.1, D3.1*, *D5b.2*). WP7 reports on the detection of socio-economic crises (*D7.1*).

The site http://e2c2.ipsl.jussieu.fr/ continues to be active for the indefinite future.

1.3.2 Conferences

A summer school on "Extreme Events: Nonlinear Dynamics and Time Series Analysis" was organized and co-sponsored by GIACS and ENS. This summer school, organized by MG, Fabio d'Andrea, PY and Philippe Naveau [PN], was held in Comorova, Romania, in September 2007. The goal of the summer school was to provide a "hands on" experience of modern statistical techniques to PhD students and young researchers in the geosciences or human sciences (since E2-C2 topics intersect both fields). The presentations of the school can be found on the E2-C2 web site.

An EGU session ("Extreme Events: Causes and Consequences"), co-sponsored by the *Natural Hazards* and *Nonlinear Processes* divisions of the EGU (European Geosciences Union), was and continues to be organised every year at the EGU General Assembly by BDM, Stéphane Vannitsem and PY. This session is open and offers opportunities to discuss E2-C2 results with colleagues outside the project. The first three sessions (in 2005, 2006 and 2007) had respectively 4.5 hours and 3 hours of oral presentations, in addition to a large 'poster' session associated with it each year, suggesting the overall success of the topic. This session was renewed in 2008.

An open conference was organised in Paris in March 2008 to present new results obtained in E2C2. The conference invited high profile scientists from outside the project to give keynote lectures. The programme and presentations of the meeting can be found at http://e2c2.ipsl.jussieu.fr/. The Scientific Advisory Board (SAB) was present and the EC Officer of the project was invited.

1.3.3 Publications

The project has produced **over 120 publications** in international, refereed journals during the past 42 months. The SAB commented most favourably on this number being quite high for a STREP with such limited funding. Many more conference proceeding papers and other reports were also published.

The complete citations for many of these publications are available on the project web site. Further collaborations between the institutes that participated in the project continue, so that the publication rate of researchers active in this area should be durably enhanced.

A special issue of *Nonlinear Processes in Geophysics*, edited by BDM, Henning Rust and PY, was produced in 2008. Papers in this special issue were subject to the journal's rigorous review. Contributions outside of the project were welcome. We aimed at providing a general overview of the methodological developments provided by the project, along with particularly interesting applications. As of the date of this report day, 14 papers have been published or accepted in this special issue.

2 Project Objectives

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3 Work Package Progress of the Fourth Period

3.1 WP2: Theoretical Developments

3.1.1 Overview (WP2)

WP2 played a key role in the project, by developing new theoretical concepts, while interacting with all other scientific work packages in applying these concepts. As such, WP2 was led by the project coordinator, M. Ghil, and encompassed two complementary activities: WP2a emphasised the analysis of time series, and its co-leader was M. Ausloos (ULG, Liège); WP2b stressed modelling of nonlinear and complex phenomena, as well as their extreme events, and its co-leader was J. Kurths (CDCS, Potsdam).

3.1.2 Progress Report (WP2a)

One of the major reasons for requesting the 6-month no-cost extension for March–August 2008 was the organization of the "Extreme Events: Causes and Consequences" (E2-C2) Open Conference that took place on 26–28th March 2008, at the Ecole Normale Supérieure (ENS), in its Salle Dussane, normally reserved for major events at the ENS. The Open Conference was a considerable success, bringing together major outside speakers from ETH Zurich, the Max-Planck-Institute for the Physics of Complex Systems (MPIPKS) in Dresden, and the private sector, as well as a large group of E2C2 participants from the various WPs. WP2 played a lead role in both the organization of the Open Conference and the discussions during and after the formal sessions.

As a result of these and other interactions, an important joint area of study developed between the ENS, CDCS, DFG and SMASH-CIRED in studying synchronization in climatic and in macro-economic time series. The ideas of the CDCS group on synchronization have been modified by M. Ghil and collaborators, and applied to climate signals from the North Atlantic and the Middle East. This work involved a collaborative effort between the ENS and INLN groups, Y. Feliks, from the Israel Institute of Biological Research (IIBR), and A.W. Robertson from the International Research Institute for Climate and Society (IRI).

Under separate, complementary funding from the French CNRS, Andreas Groth has obtained, in collaboration with P. Dumas and S. Hallegatte from CIRED and M. Ghil from the ENS, interesting results on synchronization in macro-economic time series, which helped extract stylized facts of a canonical business cycle from U.S. National Bureau of Economic Research (NBER) data. Similar studies are being carried out in collaboration with a Ph.D. student from DFG in Torino, Gianna Vivaldo, and additional researchers in the Economics Faculty of the University of Torino, on gross domestic product (GDP) data sets for Italy, Germany, The Netherlands and the United Kingdom.

Work at CDCS continued in developing and exploring methods to describe periodic cycles and their change for meteorological variables. This included a study of the seasonal cycle of extreme precipitation in the UK, prepared in collaboration with the Climatic Research Unit (CRU) in Norwich (Maraun et al., 2008). For almost 700 stations the extreme precipitation was described using a non-stationary generalized extreme value distribution with location and shape parameter parametrised by using sinusoidal functions. The main results from this study are accurate estimations of return levels with a monthly resolution for an extensive spatial coverage of the UK. A similar study for European temperatures is currently prepared as a master's thesis at the University of Potsdam.

Also at CDCS, Rust et al. (2008) focussed on the problem of estimating a long-range dependence parameter (such as the Hurst exponent) in inhomogeneous temperature time series (i.e., including jumps). Accurate estimation of this parameter is important for the determination of uncertainty intervals for basically any kind of statistics that is derived from the series. The main result of this work is that a proper homogenisation procedure is required for reliable estimation of

the long-range dependence parameter. Homogenisation and estimation of the long-range dependence parameter was applied to a set of temperature time series from France, thus confirming the theoretical results.

Work at ULG continued on applying Bak-Sneppen models and Tsallis statistics to various time series. In particular, speculative bubbles were studied in financial data and high-frequency modes of the El Niño/Southern Oscillation phenomenon were analysed by using daily values of Southern Oscillation Index data.

3.1.3 Progress Report (WP2b)

In the area of modelling non-linear and complex dynamics, Barbara Coluzzi, a post-doc hired in October 2005 at the ENS, continued her research under independent funding from the Région Ile-de-France, since E2C2 support expired. In collaboration with M. Ghil and G. Weisbuch she made substantial progress on the study of "partial" Boolean delay equations (BDEs). BDEs are semi-discrete dynamical models with Boolean-valued variables that evolve in continuous time. Previous work of M. Ghil and collaborators had shown that even small systems of BDEs could exhibit very complex behaviour. During the last 6 months of the E2C2 project, we have made considerable advances on studying large systems of BDEs, in which each site of a one-dimensional, linear array carries a Boolean variable, coupled to its immediate neighbours. The previously studied, small systems of BDEs are thus analogous to ordinary differential equations (ODEs), while these larger systems are analogous to partial differential equations (PDEs); hence the short-hand designation of "partial BDEs" or P-BDEs.

A review of BDE work was published in *Physica D*, a leading nonlinear journal (Ghil, Zaliapin & Coluzzi, 2008). The latter paper also reviews the connections between BDEs and other discrete and semi-discrete dynamical systems, such as cellular automata and stochastic Boolean networks. These results are currently being applied to the study of micro-economic, client–supplier networks, with a very large number of nodes. In this context, the ENS collaboration with CIRED is again of great interest, with P. Dumas and S. Hallegatte providing crucial input.

The ENS–IGPP collaboration with Ilya Zaliapin concentrated on the parameter sensitivity of the distribution of extremes in a relatively simple climate model of the El Niño – Southern Oscillation (ENSO). In collaboration with E. Foufoula-Gheorghiu, they attacked problems arising from the distribution of extremes in river networks.

Work at IRM continued on studying the distribution of extrema in iterated maps. It has been shown that deterministic dynamics leaves a clear-cut signature on the statistical properties of the return time of extreme events, giving rise to properties that are not accounted for by the classical statistical approach. Analytical expressions were derived, compared to those of classical statistical theory and applied to generic examples of dynamical systems giving rise to quasi-periodic, strongly chaotic and intermittent chaotic behaviors.

The extreme value statistics of systems possessing a two-hump probability density of the relevant variable, in which the left peak is more pronounced than the right one, has been studied. It was shown that systems of this type display a non-trivial transient behavior in the form of anomalous fluctuations around the mean, for certain (finite) ranges of observational time windows. The results were illustrated on independent identically distributed random variables, systems possessing two locally stable states and subjected to additive white noise, and dynamical systems in the regime of deterministic chaos.

The MITPAN-IGPP collaboration produced a theoretical analysis of the earthquake prediction problem in space-time. An explicit structure of the optimal strategy and its relation to the generalized error diagram has been found. This study is an extension of the theoretical results for prediction in time alone. The possibility and simplicity of this extension is due to the choice of the class of cost functions. The generalized error diagram allows one to suggest a natural measure of prediction efficiency at the research stage. The quality of earthquake prediction is usually characterized by a two-dimensional diagram n vs. τ, where n is the rate of failures-to-predict and τ

is a characteristic of the space-time interval covered by alarms. Unlike the pure-time prediction case, the quantity τ is not defined uniquely in the more general situation. A theoretical analysis of the properties of the (n, τ) diagram has been made on the basis of this study.

Let $x(s)$ be a Gaussian self-similar random process of index H in d dimensions. The problem of log-asymptotics for probability p_T that $x(s)$, with $x(0) = 0$, does not exceed a fixed level in a star-shaped expanding domain G as $T >> 1$ has been considered. The problem of the existence of the limit $a = \lim(-\log p_T)/(\log T)^b$, $T >> 1$, for the Fractional Brownian Sheet $x(s)$, $d = 2$, $G = [0,1]$x$[0,1]$ has been solved and the value of a has been estimated for the integrated Fractional Brownian Motion in the case when $d = 1$ and $G = [0,1]$.

3.1.4 Tasks (WP2)

3.1.4.1 Time series analysis (WP2a)

Task 2a.1. *Develop a set of time series to test the skill of analysis and prediction methods.* This task is shared with WP5 and has extensively been reported upon in section 3.4.2.3 below.
Task 2a.2. *Develop a library of existing methods for PDF and spectral estimation*. Work on this task has consisted in further development of the SSA-MTM Toolkit maintained by the IGPP, at http://www.atmos.ucla.edu/tcd/ssa/, and linked to the E2C2 web site.
Task 2a.3. *Develop new methods for estimation and prediction*. Several methods, including those based on fractional integrated autoregressive moving average models (FARIMA) and on random dynamical system (RDS) theory, have been developed and tested.

3.1.4.2 Modelling (WP2b)

Task 2b.1. *Systems with delays*. Considerable progress has been made in the study of Boolean delay equations (BDEs) and their application to novel areas, including river networks and regional economic networks.
Task 2b.2. *Multivariate synchronization analysis*. The novel approach of multi-channel singular spectrum analysis (M-SSA) has been applied to this problem and is proving remarkably successful.
Task 2b.3. *Noise-induced effects*. Such effects have been studied extensively within the framework of RDS theory. Several ways in which these effects may interfere with nonlinear deterministic dynamics are under investigation.
Task 2b.4. *Dynamics in networks with complex topology*. In the study of micro-economic, client–supplier networks, several topological types are under study. These involve both one- and two-way interactions, as well as hierarchical structures.

3.1.5 Deliverables (WP2)

D2a.1 *(Month 12):* The set of time series from different applications and exhibiting important commonalities as well as interesting differences was updated at the end of month 36. Delivered as described in items *D5a.1* and *D5a.2* below.
D2a.2 *(Month 36):* "A report providing the results of the comparison of the different PDF estimation methods (updated month 36) and, if necessary, the new algorithms, developed during the project." In this case, the single report was replaced by a set of papers published in the refereed literature, as a result of the ENS–IGPP collaboration and involving additional researchers, mainly from Columbia University in New York City and UC Irvine. The latter collaborations were supported under separate and complementary funding. The papers are available, in preprint form, at the IGPP web site http://www.atmos.ucla.edu/tcd/MG/mg_stat.html and are linked to the E2C2 web site.
D2b.1 *(Month 36):* A preliminary review of the published papers based on WP2b appears in two review papers (Ghil, Chekroun, & Simonnet, 2008; and Ghil, Zaliapin, & Coluzzi, 2008), both in the prestigious non-linear journal *Physica D.* A more definitive review paper is planned as the introduction of the Special Issue of *Nonlin. Processes Geophys*. (Ghil, Yiou, *et al*., 2008).

3.1.6 Publications (WP2)

3.1.6.1 Refereed publications

Ghil, M., M. D. Chekroun, and E. Simonnet, 2008: Climate dynamics and fluid mechanics: Natural variability and related uncertainties, *Physica D*, **237**, 2111–2126, doi:10.1016/j.physd.2008.03.036.

Ghil, M., I. Zaliapin, and B. Coluzzi, 2008: Boolean delay equations: A simple way of looking at complex systems, *Physica D,* **237**, 2967–2986, doi:10.1016/j.physd.2008.07.006.

Maraun, D., H. W. Rust, and T. J. Osborn, 2008: The annual cycle of heavy precipitation across the UK: a model based on extreme value statistics. *Int. J. Climatol.*, accepted.

Molchan, G., and V. Keilis-Borok, Earthquake prediction: probabilistic aspect. *Geophys. J. Int*., 2008, 173(3): 1012–1017.

Molchan, G., 2008: Unilateral small deviation of processes related to the fractional Brownian motion. *Stoch. Proc. & Applications*, in press.

Nicolis, S. C., and C. Nicolis, 2008: Extreme events in bimodal systems, Phys. Rev. E, **78**(036222), doi: 10.1103/PhysRevE.78.036222.

Petroni, F., and G. Rotundo, 2008: Effectiveness of measures of performance during speculative bubbles. *Physica A*, **387**, 3942–2948.

Petroni, F., and M. Ausloos, 2008: High frequency modes in El Niño Southern Oscillation Index data analysis. *Physica A*, **387**, 5246–5254.

Rust, H. W., O. Mestre, and V. K. C. Venema, 2008: Fewer jumps, less memory: Homogenized temperature records and long memory. *J. Geophys. Res.*, **113** (D19110), doi:10.1029/2008JD009919.

3.1.6.2 Submitted or in preparation

Coluzzi, B., M. Ghil, S. Hallegatte, and G. Weisbuch, 2008: Boolean delay equations with random delays: An application to economic networks, in preparation.

Feliks, Y., M. Ghil, and Andy W. Robertson, 2008: Oscillatory climate modes in the Eastern Mediterranean: Synchronization with the NAO and Southern Oscillation, in preparation.

Ghil, M., P. Yiou, P. Naveau *et al*., 2008: Extreme events: Dynamics, statistics and prediction, *Nonlin. Processes Geophys*., in preparation.

Groth, A., M. Ghil, S. Hallegatte, and P. Dumas, 2008: The average business cycle in U.S. macroeconomic data and its stylized facts, in preparation.

Molchan, G., 2008: Space-time earthquake prediction: the error diagrams, *Pure Appl. Geophys*., submitted.

3.1.7 Conference and workshop talks

The 3-day E2C2 Open Conference in March 2008 was a major opportunity for exchange of information between project members and WPs, as well as between the E2C2 project as a whole and outside specialists and users of extreme-event information from the academic world and the private sector. A lasting repository of the results presented at this Open Conference, at the EGU Special Sessions 2005, 2006, 2007 and 2008, and at many other venues is the Special Issue of *Nonlinear Processes in Geophysics* dedicated to "Extreme Events: Nonlinear Dynamics and Time Series Analysis." Twelve papers have already been published electronically, and several more have been accepted or are under revision. A lead paper for the issue, reviewing "Extreme events: Dynamics, statistics and prediction" is in advanced stages of preparation.

M. Ghil gave talks based on the E2C2 project as a whole or on WP2 activities at many independent venues, including a Harvard Climate Seminar and an Annual Meeting of the American Physical Society in New Orleans in March 2008; five talks in five distinct State Key Laboratories in four cities in China in April-May 2008; one talk in the Mathematics Department of University

College, London, in May 2008; three lectures at the International Summer School on "Interaction and co-evolution of climate and biosphere" that he co-organized in the Val d'Aosta, Italy, in June 2008; a keynote lecture at the International Symposium on "Topical Problems of Nonlinear Wave Physics" on the Volga River, which he co-organized in July 2008; and a keynote lecture to the Executive Committee of the International Union of Geodesy and Geophysics (IUGG) in Karlsruhe, Germany, in August 2008. All other lead scientists in WP2, including M. Ausloos, V. Keilis-Borok, J. Kurths, P. Naveau, and P. Yiou, gave a substantial number of invited and other talks, while the junior researchers also presented their work in posters and oral presentations at professional society meetings, symposia and workshops.

3.2 WP3: Extreme Climatic Events and Their Relation with Societal Changes

3.2.1 Overview (WP3)

WP3 is co-led by P. Naveau (LSCE), M. Ghil (ENS) and C. Taricco (DFG). The methodological developments in WP3 focus on Extreme Value Theory (EVT). EVT attempts to describe the tails of random variable probability distributions, i.e., their extremes or rare occurrences. Roughly speaking, when a sequence of independent and identically distributed (IID) variables exceeds a large threshold (i.e. becomes extreme), its probability distribution follows a Generalised Pareto Distribution (GPD) that depends on a scale parameters σ and a shape parameter ξ. The shape parameter determines the "thickness" or "weight" of the tail. The rate of extreme events follows a Poisson distribution. The crux in this statistical theory is to estimate reliably the parameters of the GPD and Poisson laws.

Standard EVT is well defined in the case of univariate, stationary processes. Climate changes over the past decades, however, are intrinsically nonstationary and multivariate; hence the theory needs to be modified. Dealing with the spatial variations of extremes is a "hard" problem, with no general theoretical solutions. Our approach was to base spatial GPD estimates on the *variogram* concept, which has been the cornerstone of Geostatistics. Applications of the methodological developments were carried out on various climatological datasets (temperature, precipitation, river flows) over and around the North Atlantic basin.

The WP3 experimental work performed at the Dipartimento di Fisica Generale (DFG) in Torino concerns the study of possible effects of volcanic activity on climate, based on eruptions of the Campanian area (near Naples, Italy) as recorded in coastal cores, taken from the Gallipoli Terrace (Ionian Sea) and accurately dated using tephroanalysis and radiometric methods. Pyroxene number density peaks were recognized as good markers of eruptions in Campania and the pyroxenes series covering the last two millennia was measured in the shallow-water GT89-3 core. The data so obtained are treated with advanced time series analysis methods, and the intense volcanic eruptions were modelled with tools developed in the methodological part of WP3.

3.2.2 Progress (WP3)

New theoretical models have been developed to better represent the distributions of extreme events in time and space. More precisely, algorithms for analyzing spatial extremes have been proposed, implemented and tested on simulations and real data sets, thus satisfying *Deliverable 3.1*; see Cooley et al. (2007), Dielbolt et al. (2008), Furrer and Naveau (2007), and Naveau and Poncet (2007). These novel procedures were based on the statistical paradigms of Generalized Extreme Value (GEV) theory and Generalized Pareto Distributions (GPD). In addition, a downscaling technique for extremes has been studied, in order to understand the relation between grid cells and individual stations; see Vrac et al. (2007) and Samaleh et al. (2008). We also focussed on the statistical modeling of the impact of major eruptions on extremes on past and future forcing climate scenarios (Batista et al., 2008; Naveau and Ammann, 2005).

During the E2-C2 project, the DFG-Torino group has carefully checked the correspondence between peaks in the series and historically documented eruptions and a spectral analysis of this record, using classical and advanced methods, including Singular Spectrum Analysis and Wavelet transform have been performed, in compliance with *Deliverable 3.6*; see Taricco et al. (2008). This study was aimed at identifying possible regularities, which might also facilitate prediction of future volcanic activity. Furthermore, the DFG-Torino group have spectrally analyzed the stable isotope series ($\delta^{18}O$ and $\delta^{13}C$), measured in the past by our group in the foraminifera of the same cores. In particular, the $\delta^{18}O$ analysis has shown centennial and decadal spectral components at high statistical significance levels. This series provides a continuous and homogeneous baseline of natural climate variability over the last two millennia; see *Deliverable 3.5*.

By taking advantage of the probabilistic tools developed by the LSCE team (see Cooley et al., 2006), the Belgian IRM team led by C. Nicolis has analyzed the spatial dependences among precipitation maxima over Belgium, thus satisfying *Deliverable 3.2*; see Vannitsem and Naveau (2007).

3.2.2.1 Tasks (WP3)

Concerning the four tasks defined in WP3, we detail below the progress during this project.

Task 3.1. *Methodology developments*. Many interesting directions have been taken to develop new mathematical, physical and statistical methods for analyzing extreme events. For example, Vanistem (2006, Tellus) studied the statistical properties of the temperature maxima in an intermediate-order, quasi-geostrophic model. Cooley et al. (2006) proposed a Bayesian Spatial model in order to compute Extreme Precipitation Return Levels. Dielbolt et al. (2008) developed a novel statistical procedure to estimate Return Level Bounds for Extreme Values. Concerning the difficult problem of assessing the statistical dependence among extremes in space, Naveau et al. (2007) and Cooley et al (2006) proposed and studied different estimators specially tailored for maxima. Concerning the properties of the classical EVT estimators used in hydrology, Furrer and Naveau (2006) derived the statistical properties of probability-weighted moments. From a more geological point of view, Cooley et al. (2006) built a Bayesian Hierarchical Extreme Value Model to better date moraine advances in Bolivia. To present the recent advances in extreme value theory to the climate community, Naveau et al. (2005) wrote a review article on the Statistical Analysis of Climate Extremes. With respect to rainfall analysis, Vrac and Naveau (2007) derived a stochastic downscaling of extreme precipitation and dry events. Overall, this series of publications indicates that Task 3.1 has generated a wide variety of research topics dealing with extreme value theory.

Task 3.2. *Extreme events in numerical simulations*. Christian Scholzel joined the LSCE lab as a post-doc in order to analyze the numerical simulations that have been generated by the IPSL coupled atmospheric GCM. As already mentioned in Task 3.1, Vanitsem (2006, Tellus) carefully looked at the extremes events simulated in an intermediate order quasi-geostrophic model. Overall, after constituting the GCM database, the second step of analyzing the extremes in IPSL coupled atmospheric GCM outputs has been implemented.

Task 3.3. *Extremes of observed precipitation in Belgium*. The IRM lab in Belgium has studied this long time series of precipitation; see also *Deliverable 3.2*. Following the theoretical work developed in Task 3.1, novel algorithms have been applied to various Belgian time series; see *Deliverable 3.2*, Vannitsem and Naveau (2007).

Task 3.4. Sources of variability and volcano/climate connections. Concerning the impact of large volcanic eruptions on future climate, Batista et al. (2008) proposed a statistical volcanic forcing-scenario generator for climate simulations. With respect to the past, Taricco et al. (2008) provided a 2200-year long isotopic record to better assess the climate variability in the central Mediterranean. In addition, Taricco and her co-workers took advantage of an automatic volcanic pulse extraction developed in Task 3.1 to study a record of the Vesuvius activity in the last 2 millennia. G. Cini et al. (2005, Adv. Space Res.) were able to study the imprint of solar centennial cycles in the past 2 millennia from an Isotopic record in a marine shallow-water core. C. Taricco

and S. Alessio (2005, Mem. S.A. It) focused on Decadal and centennial cycles revealed in two climate isotopic records.

3.2.2.2 Deliverables (WP3)

D3.3 *(Month 24):* Dataset of fields of climate model simulations, with various forcings on a daily timescale, with a zoom over Europe. Three data sets of model simulations were achieved (preindustrial control, present and a future scenario) with different types of land use. Those data sets are still under investigation.
D3.4 *(Month 36):* Report on computation of the parameters of extremes, return values and associated confidence intervals for the simulations, and re-analysis datasets; assessment of the sensitivity of these parameters to the forcing factors and determination of the potential areas whose extreme return levels are most significantly affected. This deliverable is included in publications (e.g., six articles in the *Nonlin. Proc. Geophys*. Special issue).
D3.5 *(Month 24):* A new data set of experimental measurements that will allow to extend the number density series of the pyroxenes covering the period 79 AD (eruption of Pompeii)–1979 AD. This result is delivered in two publications (including an article in the *Nonlin. Proc. Geophys*. Special Issue).
D3.6 *(Month 36):* Report on spectral analyses of the volcanic time series and comparison with climatic records measured in the same cores. This result is delivered in one publication in the *Nonlin. Proc. Geophys*. Special Issue.

3.2.3 Publications (WP3)

C. Taricco, S. Alessio and G. Vivaldo, Sequence of eruptive events in the Vesuvio area recorded in shallow-water Ionian Sea sediments, Nonlin. Processes Geophys., 15, 25, 2008.

Bernacchia A, Naveau P (2008) Detecting spatial patterns with the cumulant function - Part 1: The theory. Nonlinear Processes in Geophysics 15:159-167

Bernacchia A, Naveau P, Vrac M, Yiou P (2008) Detecting spatial patterns with the cumulant function - Part 2: An application to El Nino. Nonlinear Processes in Geophysics 15:169-177

Cooley D, Nychka D, Naveau P (2007) Bayesian spatial modeling of extreme precipitation return levels. J. Amer. Stat. Assoc. 102:824-840

Dielbolt J., Guillou A., Naveau, P. and Ribereau P. (2008). Improving Probability-Weighted Moment Methods for the Generalized Extreme Value Distribution, Rev. Stat., in press.

Furrer R. and Naveau P. (2006). Statistical Properties of Probability Weighted Moments, Statistics and Probability Letters, in press.

Naveau P. and P. Poncet (2007). State-space models for precipitation maxima. Journal de la Socíete Francaise de Statistique et Revue de Statistique Appliqúee, vol. 148, pp 107–120.

Nogaj M, Parey S, Dacunha-Castelle D (2007) Non-stationary extreme models and a climatic application. Nonlin. Proc. Geophys. 14:305-316

Rabatel, A., V. Jomelli, B. Francou and P. Naveau. A chronology of the Little Ice Age in the tropical Andes of Bolivia (16S) based on moraine dating by lichenometry: implications for climate reconstruction. Quaternary Research, in press.

Vrac M, Naveau P (2007) Stochastic downscaling of precipitation: From dry events to heavy rainfalls. Water Resour. Res. 43, doi:10.1029/2006WR005308.

Yiou P, Goubanova K, Li Z, Nogaj M (2008) Weather regime dependence of extreme value statistics for summer temperature and precipitation. Nonlin. Proc. Geophys., 15, 365-378, 2008

3.2.4 Submitted papers (WP3)

Samaleh T., P. Drobinsky, M. Vrac and P. Naveau (2007). Statistical downscaling of near-surface wind fields over complex terrain in Southern France, in review.

C. Taricco, M. Ghil, S.M. Bernasconi and G. Vivaldo (2008). Two millennia of climate variability in the Central Mediterranean, Clim. Past, in review.

3.3 WP4: Climate Effects and Economic Crises

3.3.1 Overview (WP4)

So far, only long-term, balanced-growth models have been used in the assessment of economic damages due to climate change. In these models, climate change impacts on society are represented only through continuous and regular changes in mean productivity. As a consequence, climate change only results, in these models, in a slight reduction of the long-term economic growth, which is more than largely compensated by the productivity rise due to technical change.

The influence of climate upon the economy is, however, likely to involve mainly short-term, out-of-equilibrium processes. But since long-term growth models and general equilibrium models are based on a static representation of the exchanges, any disequilibrium is supposed (i) to be transient; (ii) to last only a short period of time with respect to the model's time step; and (iii) to have negligible impacts on the steady state of the model. Of course, extreme events may be responsible for lasting damages that are significant at the macro-economic scale. To study such a possibility, these three hypotheses can no longer be valid. Rapid-change phenomena are captured so far only by short-term econometric models, which are used for short-term economic forecasts. Conversely, though, these econometric models are unable to simulate long-term trajectories.

As a consequence, the objectives of this WP were:

1. To develop new models that are capable of simulating both long-term trajectories, over more than one century, and to capture, albeit approximately, short-term disequilibria.
2. To validate such models on extreme-event data.
3. To assess the consequences of possible changes in the extreme event distribution, due to climate change.

3.3.2 Progress (WP4)

As outlined in the project's Description of Work, we developed a macro-economic framework (NEDyM) that is able to capture both long-term growth and short-term disequilibrium. Two complementary aspects of this activity were: (i) the analysis of the potential role of extreme events in climate change damage assessment; and (ii) the analysis of the endogenous behaviour of the model, and of its ability to reproduce observed business cycles.

(i) On the first topic, Hallegatte and M. Ghil's (2008) paper has now appeared in Ecological Economics; it discusses the difference in disaster consequences, depending on the pre-existing economic situation. This paper highlights the fact that modelling the ability of the economy to carry out the reconstruction is important. Hallegatte (2008a) examined this macro-economic result further by investigating the reconstruction phase with an Input-Output model, and compared this model's results with observations from Hurricane Katrina's landfall on New Orleans. Hallegatte (member of the E2C2 project) and partners from Risk Management Solutions (RMS) took an even closer look at the role of the construction sector during the reconstruction period after the 2004 and 2005 hurricane seasons in Florida. Finally, the results from these works have been integrated in a book chapter (Hallegatte, 2008c); this chapter proposes a methodological roadmap to assess climate change damages through extreme events, and represents the *Deliverable D4.3*.

(ii) On the second topic, methodological developments have been pursued to implement an extended Kalman filter in our modelling environment. The aim is to be able to calibrate our macroeconomic model using historical data. To do so, a prerequisite is to create synthetic business cycles, in which exogenous shocks (e.g., oil shocks) are removed. Andreas Groth, a post-doc supported under independent and complementary funding, M. Ghil and S. Hallegatte, have carried out this work, leading to an article that will soon be submitted to the Journal of Business and Economic Statistics. The synthetic business cycle is now used to calibrate the NEDyM model using an extended Kalman filter, with interesting preliminary results.

3.3.3 Deliverables (WP4)

D4.2 *(Month 24):* A detailed study presenting: (i) the model responses to a series of stylized shocks; (ii) an assessment of the model ability to reproduce historical data; and (iii) the model response to the current extreme event distribution. Delivered via papers Hallegatte (2008a,b), Hallegatte and Ghil (2008), and Hallegatte *et al*. (2008).

D4.3 *(Month 36):* A final report presenting: the changes due to climate change in the extreme event module calibration; the consequences of these changes on the macroeconomic behaviour of the model; the consequences of this work on the assessment of the economic damages of climate change; and, in the light of the previous results, some proposals for future research in the field of integrated assessment of climate change. Delivered by Hallegatte (2008c).

3.3.4 Publications (WP4)

Hallegatte, S., 2008a: An adaptive regional input-output model and its application to the assessment of the economic cost of Katrina, Risk Analysis 28(3), doi: 10.1111/j.1539-6924.2008.01046.

Hallegatte, S., 2008b: Can natural disasters have positive consequences? Investigating the role of embodied technical change, Ecological Economics, accepted.

Hallegatte, S., 2008c, A Roadmap to Assess the Economic Cost of Climate Change with an Application to Hurricanes in the United States, in "Climate Change and Hurricanes", J. Elsner and T. Jagger (Eds.), in press; see *also Deliverable D4.3*.

Hallegatte, S., and M. Ghil, 2008: Natural disasters impacting a macroeconomic model with endogenous dynamics, Ecological Economics, **68**, 582–592, doi:10.1016/j.ecolecon.2008.05.022 .

Hallegatte, S., A. Boissonnade, M.-E. Schlumberger, and R. Muir-Wood, 2008: Demand surge and worker migrations in disaster aftermaths: Application to Florida in 2004 and 2005, *Journal of Regional Science*, submitted.

3.3.5 Conference and workshop talks

S. Hallegatte, 7 Avril 2008, Soft vs. Hard Adaptation to Climate Change, OECD Workshop on Climate Change Adaptation, Paris, invited.

S. Hallegatte, August 26, 2008, Adapting to climate change and disaster risk management, International Disaster Risk Conference, Davos.

S. Hallegatte, August 26, 2008, A Roadmap to Assess the Economic Cost of Climate Change with an Application to Hurricanes in the United States, Poster, International Disaster Risk Conference, Davos; this poster received the IDRC Poster Award.

3.4 WP5: Temporal Scaling and Extremes

3.4.1 Overview (WP5)

WP5 had five partners (ENS, IRPI, KCL, MIHU, and ROMA-1) and 14 researchers working on the project objectives, three of them on fixed-term contracts. This work package examined temporal persistence and extremes in hydrology, wind, landslides, and wildfire time series, and corresponding risk and other implications. WP 5 was divided into two parts, with WP5a (KCL/IRPI) concentrating on landslides, wildfires, and wind, and WP5b (MIHU/ROMA-1) on hydrology. The co-leaders were B. Malamud (KCL), for WP5a, and K. Fraedrich (MIHU), for WP5b.

3.4.2 Progress (WP5)

Over months 37–42 of WP5a, we finished working on and submitted two substantial papers, both intended for the 'practicing' earth scientist (vs. the theoretician):

(i) In the first of these papers, "Analysis of Time Series of Historical Landslides in the Emilia-Romagna Region, Northern Italy" (Rossi *et al.*, 2008), the co-authors from IRPI (Mauro Rossi, Fausto Guzzetti, and Silvia Peruccacci) took the lead, while those from KCL were Annette Witt and Bruce Malamud. In this paper, we described in detail a catalogue of 2255 historical landslides, based on historical archives and chronicles during the period 1951–2002, for three provinces in the Emilia-Romagna Region of northern Italy and studied their statistical properties. We found that the probability density of landslide intensities in the time series are power-law distributed over at least two orders of magnitude, with an exponent of about –2.0. Although our data set is a proxy for land sliding built from newspaper reports, it provides the first tentative evidence that the frequency-size of triggered landslide events over time (not just the landslides in a given triggered event), just like earthquakes, scales as a power-law or other heavy-tailed distributions. If confirmed, this result could have important implications for risk assessment and erosion modelling in a given area. In a second, complementary analysis of this data set, we found that, for short antecedent rainfall periods, the minimum amount of rainfall necessary to trigger landslides varies considerably with the intensity of the land sliding. For long antecedent periods, though, the magnitude is largely independent of the cumulative amount of rainfall, and the largest values of landslide intensity are always preceded by abundant rainfall. In addition, the analysis of the rainfall trend suggests that the trigger of landslides in the study area is related to seasonal rainfall.

(ii) In the second paper, "Temporal Correlation and Clustering of Landslides (Witt *et al.*, 2008), the KCL co-authors took the lead. In this paper, we (a) investigated whether triggered landslide events are themselves temporally correlated or clustered, using the historical landslide time series from Rossi *et al.* (2008; see above), and (b) use this dataset as a typical example of how to explore temporal correlations in unequally spaced landslide data that have a heavy-tailed size distribution; both of these attributes are commonly found in 'natural-world' data sets. We investigated the correlations in time of the unequally spaced landslide intensities, by using Lomb power-spectral analysis, with an equivalent comparison to uncorrelated data. We then explored the clustering of landslide occurrences with intensities over a given threshold, by using three methods to compare the clustering in this data set to the one in uncorrelated time series: (i) statistical distribution of landslide inter-event occurrence times; (ii) statistical measures of the correlation of these inter-event occurrence times; and (iii) Fano factor analysis. We concentrated on statistically testing the hypothesis that the data are uncorrelated or unclustered and came to the conclusion that, for a number of analyses, this hypothesis cannot be rejected for the landslide time series examined. In addition, we provided a systematic overview of methods to examine clustering in unequally spaced, heavy-tailed time series.

3.4.3 Tasks (WP5)

The major tasks over months 36–42 have been as follows:

Task 5a.1. *Construct synthetic time series (fractional noises).* This was a continuation of work begun during months 1–36, and has now been completed as described in the last section, *Progress for WP5a* (parts 'A' and 'B') with updates for the data and report put on the E2-C2 web site in month 37.

Task 5a.2*. Evaluate temporal scaling & extremes in 'actual' natural hazards.* This is a continuation of research begun during months 1–36, where we have now examined temporal scaling and extremes in landslides, wildfires and wind, as described in the last section, *Progress for WP5a* (parts 'C', 'E', 'F'). The results are included in the next task in terms of publications (in addition to four publications already published as described in the E2C2 report for month 18).

Task 5a.3. *Use of synthetic time in natural hazard assessment.* Synthetic and 'actual' natural hazards data sets have been used, and are the basis for two papers that are in progress (as described in the last section, *Progress for WP5a*, parts 'C' and 'E'). In addition, a related project was begun to

create a deterministic and stochastic computer programme for landslide statistics, the first phase has finished and a report produced (see *Progress for WP5a*, parts 'D').

Task 5b.1. *Analyse long-time memory of the hydrological cycle.* Research for this task was finished during months 1–18.

Task 5b.2. *Create general methodologies for practical forecasts in extremely variable and long-time correlated events.* Research for this task was continued (with some papers already published during months 1–36), and is described, along with three new papers published, under *Progress for WP5b* in the last section.

3.4.1 Deliverables (WP5)

D5a.1 and D5a.2 were originally due month 18 (and delivered) with an update month 36, all other deliverables below were due month 36. D5a.1 and D5a.2 were delivered month 37 (during the six month extension), and D5a.3 at month 42. D5b.3 and D5b.4 were both delivered by month 36.

- ***D5a.1 & D5a.2****: DATASET of synthetic time series data and REPORT describing construction of synthetic time series ensembles.* Status: *D5a.1* and *D5a.2* were first delivered at month 18, with a significant revision and report delivered at month 37. The noises themselves and reports are available on the E2–C2 web site.
- ***D5a.3****: REPORT describing use of synthetic time series ensembles in natural-hazard assessment.* Status: Two papers based on *D5a.3* research have been submitted: Rossi *et al.* (2008) and Witt *et al.* (2008) to *Earth Surface Processes and Landforms*.
- ***D5b.3 & D5b.4***: REPORT on comparison of models for long time memory and REPORT on feasibility of forecast models for long time memory time series. Status: D5b.3 and D5b.4 were combined into a single report, posted on the E2–C2 web site, and accepted for publication as Blender *et al.* (2008).

3.4.2 Publications (WP5)

Blender, R., Fraedrich, K and Sienz, F (2008) Extreme event return times in long-term memory processes near 1*/f, Nonlin. Processes Geophys*. **15:** 557-565.

3.4.3 Submitted Papers (WP5)

Pereira, M., Trigo, R., Malamud, B.D., Alves, P. (in prep, version 14, 2008) Frequency-size distribution of wildfires in Portugal. To be submitted to: *International Journal of Wildland Fire*.

Rossi M., Witt A., Guzzetti F., Malamud B.D., Peruccacci S. Analysis of historical landslides in the Emilia-Romagna region, Northern Italy. *Earth Surface Processes & Landform*, submitted.

Witt A., Malamud B.D., Rossi M., Guzzetti F., Peruccacci S. Temporal Correlation and Clustering of Landslides. *Earth Surface Processes & Landform*, submitted.

3.4.4 Workpackage Meetings (WP5)

- WP5a Meeting in Perugia to work on research and paper, 7–25/3/08
- At 'E2C2 all-hands public meeting', included general WP5a meeting, Paris, 26-28/3/08.
- Malamud and Witt (both WP5a) met in Paris, to work on paper, 29–31/3/08.

3.4.5 Conferences and Other Presentations (WP5)

Blender, R. and Fraedrich, K. (2008): *Climate variability scaling on decadal to millennial time scales in observations and simulations*, EGU 2008 General Assembly, Vienna, Austria, 14-18 April 2008.

Fraedrich, K. and Blender, R. (2008): *Scaling of weather and climate fluctuations: on CAPE and river discharges*, EGU 2008 General Assembly, Vienna, Austria, 14-18 April 2008.

Guzzetti F. (2008) *Forecasting landslide hazard and risk*. Geophysical Research Abstracts, Vol. 10, 03227, 2008, SRef-ID: 1607-7962/gra/EGU2008-A-12036, Vienna, 13-18 April 2008.

Malamud BD (2008) Wildfire Statistics: Implications for Ecology, Risk and Government Agency Reporting: *5th EGU General Assembly*, Vienna, Austria, 13–18 April 2008, *Geophysical Research Abstracts*, v. 10, 11879, 2008, SRef-ID: 1607-7962/gra/EGU2008-A-11879.

Peruccacci S., Rossi M., Guzzetti F. & Stark C.P. (2008) *Logistic modelling of landslide rainfall thresholds*. Geophysical Research Abstracts, Vol. 10, 12200, 2008, SRef-ID: 1607-7962/gra/EGU2008-A-08721, Vienna, 13-18 April 2008.

Rossi M., Peruccacci S., Witt A., Malamud B.D. & Guzzetti F. (2008) *Characteristics of an historical landslide catalogue for the Emilia-Romagna Region, Northern Italy: frequency-size, temporal clustering and triggering factors*. Geophysical Research Abstracts, Vol. 10, 12200, 2008, SRef-ID: 1607-7962/gra/EGU2008-A-07210, Vienna, 13-18 April 2008.

Rossi M., Wainwright J., Guzzetti F. & Malamud B.D. (2008) *Simulating landslide frequency-magnitude relationships.* Geophysical Research Abstracts, Vol. 10, 12200, 2008, SRef-ID: 1607-7962/gra/EGU2008-A-08721, Vienna, 13-18 April 2008.

Rossi, M.; Guzzetti, F.; Peruccacci, S.; Reichenbach, P.; Cardinali, M.; Ardizzone, F. (2008) *A statistical modelling tool in R for the evaluation of landslide susceptibility*. Geophysical Research Abstracts, Vol. 10, EGU2008-A-07176, 2008, SRef-ID: 1607-7962/gra/EGU2008-A-07176, Vienna, 13-18 April 2008.

Sienz, F., Fraedrich, K., Blender, B. (2008): *Extreme event return times in long-term memory processes near 1/f*, EGU 2008 General Assembly, Vienna, Austria, 14-18 April 2008.

3.5 WP6: Monitoring Earthquakes and Related Environmental Hazards

3.5.1 Overview (WP6)

WP6 is co-lead by A. Soloviev (MITPAN) and D. Zugravescu (IGRA). The main goals of this WP include (i) improvement of existing intermediate- and short-term earthquake prediction algorithms and their adaptation to deep earthquakes of the Vrancea region (Carpathian Mountains, Romania); (ii) use of state-of-the-art measurement methods to observe ongoing earthquakes; and (iii) gaining deeper insight and confidence in earthquake prediction. The following activities were conducted to reach the WP6 objectives. New methods to model macroscopic phenomena, such as earthquakes and reversals of Earth's magnetic field, were developed to obtain new insights into crustal dynamics that will lead to more accurate and reliable earthquake prediction, as well as to strengthen the connections between complex system science and the geosciences in general. We concentrate on cellular automata that include long-range, as well as nearest-neighbour interactions. The models are based on scaling organization of fracture tectonics (SOFT) and mimic the continuum-mechanics solutions, while retaining the inherently discrete approach of statistical physics. It is assumed that this approach will offer the opportunity to use rate-and-state friction laws in our conceptual modelling.

The experimental data needed for selecting and testing the most suitable prediction algorithms and models were obtained by means of IGRA's network of permanent measuring stations. This permanent network is supplemented by deploying its high-quality mobile equipment to "ambush" an earthquake of sufficiently high magnitude, given an alert provided by the theoretical work. In fact, the Vrancea region constitutes a natural laboratory, situated entirely on the Romanian territory, which is practically without equal all over the world in terms of opportunities to monitor earthquakes, landslides and the hydrographical system's stability. The following actions were considered in order to successfully install a rapid-response monitoring system for this natural laboratory: (i) the optimisation of the specific sensor array structure, for each type of surveyed natural hazard, to emphasize the short-term precursory parameters related to the accumulation and release of the stress in the Vrancea geodynamic active zone; (ii) identification, using recent regional and global studies and the sensors' characteristics, of the selected area for deployment of the arrays;

(iii) adaptation of the monitoring and special field-campaign arrays to the specific conditions in the area of interest, to allow for real-time warning and alert; (iv) optimisation of early warning systems on a regional, national and continental scale; and (v) implementation of an internet interface to disseminate all recorded data to organisations in charge of civil protection.

3.5.2 Progress (WP6)

The regular update of the real-time prediction experiment in the Vrancea region has been performed (as of July 2008). According to it, the region remains in a window of increased probability for M7.0+, M6.5+, and M6.0+ earthquakes. These alerts are expected to expire in the middle of 2011 for M7.0+ and M6.5+, and by the end of 2012 for M6.0+ events.

Applications of the RTP (Reverse Tracing of Precursors) algorithm have been continued to predict large earthquakes in Vrancea ($M \geq 6.0$, informal test) and in five seismically active regions worldwide (formal test). No alarms were detected in Vrancea, and no large earthquake occurred there. Only two predictions were issued during the period within the formal RTP test, both in approximately the same area, but for different target magnitudes. No large earthquakes occurred in the five regions under consideration.

Strain accumulation rates, stress regimes and aftershock decay rates were studied. A strong correlation of the *C*-value of the Modified Omori law with the focal mechanisms of the main shocks has been found. The *C*-value is found the largest for normal faulting, the smallest (~5 times smaller), for thrusts, and intermediate for strike-slip.

3.5.3 Tasks (WP6)

We detail below the tasks achieved for WP6 over the entire duration of the project.

Task 6.1. *Provide as complete a dataset as possible on seismic and related activity in the Vrancea region, including estimates of accuracy, when available*. A data set on seismic activity in the Vrancea (Romania) region has been compiled using several available sources. Vrancea is a geographical region between the Eastern and Southern Carpathian Mountains. The region is characterized by a rather high level of seismic activity, mainly at intermediate depths, up to 200 km. These intermediate-depth earthquakes occur in a square (45°–46°N, 26°–27°E). The shallow earthquakes are dispersed over a much broader territory. As the first step, a comparative analysis of earthquake catalogues available for the Vrancea region was performed, with the aim of compiling a more definitive data set, as complete and homogeneous as possible. This data set is intended to be used for the prediction of strong and possibly moderate earthquakes in the region. Two catalogues have been studied: (1) the Global Hypocenter Data Base catalogue of NEIC and (2) the local Vrancea seismic catalogue. The data set contains the earthquake catalogue for the Vrancea region that covers the period 1900–2005. Since 1962 the catalogue is complete for magnitudes $M \geq 3.0$ and since 1980 it is complete for $M \geq 2.5$. This data set is continued by the RomPlus earthquake catalogue that is compiled at the National Institute of Earth Physics (Magurele, Romania). Starting from April 2006, IGRA provides monthly update of this catalogue.

Task 6.2. *Train the intermediate-term prediction algorithm M8 on the Vrancea earthquake catalogue and determine whether its length and resolution permit useful alerts. Continue development of the more recent short-term prediction algorithm and adapt it to the Vrancea seismic activity. Continue development of the more recent short-term prediction algorithm and adapt it to the Vrancea seismic activity*. The retrospective simulation of seismic monitoring by means of the M8 algorithm indicates the applicability of the method for earthquake prediction purposes in the Vrancea region: with the best data available, the methodology allows to identify (albeit retrospectively) three out of the last four strong (magnitude 6 or larger, $M \geq 6.0$) earthquakes that occurred in the region. The RomPlus earthquake catalogue seems preferable for real time monitoring of seismic activity aimed at prediction of strong and major earthquakes in the Vrancea region. Finalizing the comparative analysis of earthquake catalogues of intermediate-depth seismic activity resulted in the conclusion that these data can be used for monitoring the Times of Increased

Probability (TIP) of strong (magnitude 6.0–6.9) and major (magnitude 7.0–7.9) earthquakes in the region by means of the M8 algorithm or a suitable modification thereof. Real-time prediction experiments by means of the M8 algorithm have been launched in the region. Moreover, TIP of strong earthquakes has been declared for the five-year period starting from July 2006. The parameters of the earthquake prediction algorithm RTP have been adapted to the region and retrospective tests have been made to apply this algorithm to Vrancea for prediction of earthquakes with $M \geq 6.0$. An informal test of this prediction algorithm in Vrancea for target earthquakes with $M \geq 6.0$ was performed by using seismic data provided on a monthly basis. A test of the RTP algorithm in five seismically active regions of the world was conducted as well and has given several successful predictions that were made and documented in advance. These predictions include the Simushir, Kuril Islands, earthquakes of 15 November 2006, with $M_w = 8.3$, and of 13 January 2007, with $M_w = 8.2$, as well as the Andreanof Islands, Aleutians, earthquake of 19 December 2007, with $M_w = 7.2$.

Task 6.3. *Develop the BDE version of the SOFT model, taking into account specific features of the Vrancea seismic context; including rate-and-state law and analysis of results with respect to testing prediction algorithms*. Strain accumulation rates inferred from aftershocks have been studied on the basis of the simplified SOFT model. The Limited Power Law (LPL) model of the aftershock decay derived from the SOFT model has been studied. The model suggests that the delay of the power-law decay of aftershocks depends on the heterogeneity of the stress field: this delay is shorter for the larger stresses. This delay has been estimated for considered stacked aftershock sequences from moderate main shocks in some volume (for example, a system of faults, different time intervals). A decrease of this delay in the central part of San Andreas fault system during the period 1985 to 1995 and a fast increase in 1995 may be explained by a strong increase of the slip rate along San Andreas in 1995 found by several authors by means of different methods. A strong correlation of this delay with the focal mechanism (rake angle) of the main shocks has been found. Temporal properties of seismicity in Vrancea have been studied in order to estimate the hazard rate distribution of the largest seismic events. The average return period of the largest events has been estimated on the basis of Generalized Extreme Value techniques. Then, scaling properties of recurrence times between earthquakes have been studied in appropriate spatial volumes. It has been found that the seismicity is temporary clustered, and the distribution of recurrence times is significantly different from a Poisson process even for times largely exceeding corresponding periods of foreshock and aftershock activity. Modelling such a clustering by gamma distribution of recurrence times gives possibility to estimate hazard rates now depending on the time elapsed from the last large earthquake. Methods to unveil relations between structural fault parameters and the degree of temporal clustering of large earthquakes (quasi-periodic versus random occurrence) have been developed by means of numerical simulations. The analysis of the recurrence time distribution of large events from long numerical simulation has been started. Several analytical functions (e.g. Weibul distribution, lognormal distribution, Brownian passage time distribution) are compared with respect their relevance for seismicity. The problem of uncertainties and lacking observational data is addressed by using Bayesian analysis with the purpose to improve seismic hazard assessment by combining extensive numerical simulations with the available observational data. A new model of blocks-and-faults dynamics has been developed for the Vrancea region. The model reflects more details of the region than the model worked out early. The possibility to develop intermediate-term prediction algorithms on the basis of the model is studied. A hierarchical model of rupture incorporating healing and faulting has been developed. The seismicity obtained in the model demonstrates the main characteristics of the observed seismicity: Gutenberg-Richter law for the frequency-magnitude relationship, Omori law for the aftershock decay rate, clustering of major events, swarms of earthquakes, seismicity of creeping segment and seismic noise. A new multiscale cellular-automaton model of rupture has been designed to reproduce structural patterns observed in the formation and evolution of a population of strike-slip faults.

Task 6.4. *Develop the plans for deployment of field-campaign monitoring arrays, according to alerts provided under Task 6.2. Carry out real (if alert is sounded) or practice deployment (if*

not). Analyse results of the field measurements and relate them to improved prediction. Optimisation of the specific sensor structure for each type of natural risk monitored (earthquakes and landslides) has been made: time stability and frequency response have been studied for two types of electric sensors (Pb-PbCl2 and Cu-CuSO4, both having solution of kaolin gel, very stabile in time); time stability and frequency response have been studied for magnetic sensors of the induction coil type (for two frequency ranges: 0.5 kHz–24 kHz (HF) and 10.4 Hz–1 kHz (LF)) and for the fluxgate magnetic sensors (with 3 axes), frequency range: 3kH-DC. Specific pattern recognition of the test sites for continuous monitoring of the short-term precursory phenomena of the tectonic activity (earthquakes, active faults and landslides associated) has been made. The adequate equipment has been installed in two relevant geodynamic test sites (Surlari Observatory for short term precursory parameters and Provita de Sus landslide test site). Continuous monitoring of geophysical fields in order to reveal the short-term precursory phenomena of the tectonic activity (earthquakes, active faults and landslides associated) has been launched. Assessment of the electromagnetic parameters related to both the earthquakes characteristic of the seismic-active Vrancea zone and the landslides associated to the active faults, has been carried out by emphasizing: (i) daily mean distribution of the Bzn parameter related to the Vrancea intermediate depth earthquakes; (ii) resistivities ($\rho\perp$ and $\rho_{||}$), skew, strike and anisotropy distributions associated to the landslide activity in the Provita de Sus test site. It has been found that several days before an earthquake occurrence, the daily mean variation of the Bzn parameter has an anomalous behaviour marked by a significant increase in respect with its standard deviation, as a result of the electrical conductivity changes that may be associated with the dehydration-induced faulting processes and fluid mitigation through cracks and faulting system developed inside the seismogenic volume (slab) Vrancea and its neighbouring zones. As regards landslide activity, the results highlight the possibility of merging electromagnetic parameters with tomographic images and with low frequency electric signals occurred prior the stress to reach a critical value. Subsequently, in the Provita de Sus locality, after implementing a complex monitoring system, it was possible to provide near real-time early-warning against the risk arising from landslide triggered by the earthquakes that occurred in the Vrancea zone.

Task 6.5. *Combine results from Tasks 6.1-to-6.4 to develop improved prediction algorithms for the Vrancea region, by month 36*. Within the framework of the real-time prediction experiment in the Vrancea region, the intermediate-term earthquake prediction algorithm M8 has been launched as expected. Real-time updates through January 2007 did confirm the preliminary results that were presented at the E2-C2 "All hands" Meeting in Perugia (September 2006). The region, in fact, has entered a time of increased probability (TIP) of magnitude 6.5+ or 7.0+ event(s) in the middle of 2006 and will be in this state at least as long as 2011. This prediction has not yet been supported by short-term predictions described in *Task 6.4* and a pertinent earthquake has not occurred so far.

3.5.4 Deliverables (WP6)

1. ***D6.2*** *(Month 36): A final report, analysing the field measurement results, providing an improved prediction algorithm for the Vrancea region, and describing the general scientific outcome of the WP*. This report has been prepared and is available upon request.

3.5.5 Publications (WP6)

Narteau, C., P. Shebalin, and M. Holschneider, Loading rates in California inferred from aftershocks. *Nonlin. Processes Geophys*., **15**(2): 245–263.

Soloviev, A. Transformation of frequency-magnitude relation prior to large events in the model of block structure dynamics. *Nonlin. Processes Geophys*., 2008, **15**(1): 209–220.

3.5.6 Submitted papers (WP6)

Narteau, C., P. Shebalin, S. Byrdina, and D. Schorlemmer, Common dependency on stress for the

two fundamental laws of observational seismology, *Nature*, submitted.

3.5.7 Meetings

A scientific session entitled "The Planet Earth" has been held on July 22, 2008 within the framework of the Euroscience Open Forum 2008 in Barcelona (Barcelona, Spain, July 18–22, 2008). The session was co-organized and chaired by Vladimir Kossobokov (MITPAN). It highlighted the importance of the Earth Sciences in Europe and elsewhere in a multi-disciplinary setting on the occasion of the International Year of Planet Earth (IYPE), International Polar Year (IPY), International Heliophysical Year (IHY), and Electronic Geophysical Year (eGY). Welcome addresses were given by Professors Enric Banda (President, Euroscience), Eduardo de Mulder (Executive Director, IPY), and Alik Ismail-Zadeh (Secretary General, IUGG), and exciting talks by Professors Russell Hemley (Director of Geophysical Laboratory, Carnegie Institution of Washington, USA), Volker Mosbrugger (Senckenberg Forschungsinstitut und Naturmuseum, Frankfurt, Germany), and Gerald Haug (ETH Zürich, Switzerland). These addresses and talks brought the audience to the centre of the Earth, then to the climatic environment of the Cenozoic, and on to Maya civilization, eventually leading into a general discussion of extreme events and the environment, their causes and consequences for the mankind. V. Kossobokov moderated the discussion, publicizing the E2C2 project and bringing the audience to the conclusion that geoscientists must act today to increase and disseminate knowledge on extreme events and to implement state-of-the-art measures to warn in advance and facilitate protecting society from natural catastrophes and humanitarian tragedies.

3.5.8 Presentations

Kossobokov, V. Testing earthquake forecast/prediction methods: Real-time forecasts of tomorrow' earthquakes in California. Geophysical Research Abstracts, Volume 10, 2008. Abstracts of the Contributions of the EGU General Assembly 2008, Vienna, Austria, 13-18 April 2008 (CD-ROM): EGU2008-A-07826.

Kossobokov, V., L. Romashkova, and A. Nekrasova, Targeting the next mega-earthquake. Geophysical Research Abstracts, Volume 10, 2008. Abstracts of the Contributions of the EGU General Assembly 2008, Vienna, Austria, 13-18 April 2008 (CD-ROM): EGU2008-A-07303.

Molchan, G., and V. Keilis-Borok, Earthquake prediction: Probobalistic aspect. 2008 SSA Annual Meeting, 16-18 April 2008, Santa Fe, New Mexico, USA. Seismological Research Letters, 2008, 79, 2: 359.

Molchan, G., and V. Keilis-Borok, Earthquake prediction: Probabilistic aspect. Collaboratory for the Study of Earthquake Predictability (CSEP) Global Working Group Meeting 21 April 2008 at USC, http://us.cseptesting.org/WGGMeeting21042008.

Molchan, G.M. Space-time earthquake prediction: the error diagrams. In European Seismological Commission. XXXI General Assembly. Oral & Poster Abstracts. Creta Maris Conference Center, Hersonissos, Crete island, Greece, 7-12 September, 2008. Institute of Geodynamics – National Observatory of Athens, 2008: 183.

Narteau, C., P. Shebalin, S. Byrdina, and D. Schorlemmer, The onset of the aftershock decay rate across different stress regimes. Geophysical Research Abstracts, Volume 10, 2008. Abstracts of the Contributions of the EGU General Assembly 2008, Vienna, Austria, 13-18 April 2008 (CD-ROM): EGU2008-A-05624.

Romashkova, L. Algorithm M8S, real-time testing in Italy. Collaboratory for the Study of Earthquake Predictability (CSEP) Global Working Group Meeting 21 April 2008 at USC, http://us.cseptesting.org/WGGMeeting21042008.

Romashkova, L.L., and V.G. Kossobokov, Expanding the on-going test of earthquake prediction algorithm M8S in Italy and over European-Mediterranean region. In European

Seismological Commission. XXXI General Assembly. Oral & Poster Abstracts. Creta Maris Conference Center, Hersonissos, Crete island, Greece, 7-12 September, 2008. Institute of Geodynamics – National Observatory of Athens, 2008: 51-52.

Shebalin, P.N., and V.I. Keilis-Borok, First 5 years of the experiment in predicting future earthquakes by reverse tracing of precursors (rtp): Results and lessons. 2008 SSA Annual Meeting, 16-18 April 2008, Santa Fe, New Mexico, USA. Seismological Research Letters, 2008, 79, 2: 333.

Shebalin, P. Earthquake prediction algorithms using pattern-recognition methods (invited). Collaboratory for the Study of Earthquake Predictability (CSEP) Global Working Group Meeting 21 April 2008 at USC, http://us.cseptesting.org/WGGMeeting21042008.

Stanica, D., and D.A. Stanica, An improved geodynamic model for the seismic active Vrancea zone, Romania. Geophysical Research Abstracts, Volume 10, 2008. Abstracts of the Contributions of the EGU General Assembly 2008, Vienna, Austria, 13-18 April 2008 (CD-ROM): EGU2008-A-02358.

Stanica, D., D.A. Stanica, N. Vladimirescu, and M. Popescu, Ground-based monitoring technique used to emphasize the precursory electromagnetic marks associated to the Vrancea's intermediate depth earthquakes (Romania). Geophysical Research Abstracts, Volume 10, 2008. Abstracts of the Contributions of the EGU General Assembly 2008, Vienna, Austria, 13-18 April 2008 (CD-ROM): EGU2008-A-02138.

Stanica, D., M. Stanica and C. Diacopolos, Real-time electromagnetic monitoring system for landslides assessment due to the seismic activity. Geophysical Research Abstracts, Volume 10, 2008. Abstracts of the Contributions of the EGU General Assembly 2008, Vienna, Austria, 13-18 April 2008 (CD-ROM): EGU2008-A-03537.

3.6 WP7: Socio-Economic Barometer

3.6.1 Overview (WP7)

WP7 was co-lead by A. Soloviev (MITPAN) and G. Schaber (CEPS), but the latter had to withdraw from the project for health reasons.

WP7 took steps to develop a "socio-economic barometer", with a methodology and relevant algorithms and software for forecasting crises (or stable development) in socio-economic systems. The work under WP7 was carried out by (i) integration of relevant databases; (ii) expertise in socio-economic processes targeted for prediction; and (iii) expertise in modelling and analysis of complex systems. The barometer can be explained as follows: (i) the forecast is based on the analysis of relevant socio-economic indicators, which are the algorithm's *input*; (ii) the *output* of the algorithm is a forecast – whether a crisis is or is not approaching, where the forecasts include probabilities of false alarms and failures to predict; (iii) different algorithms will be needed for prediction of different crisis types, but for a given crisis type a self-adaptive algorithm and relevant software are developed that can be applied without adaptation in different settings; (iv) the barometer complements existing methods of forecasting, but is much more specific, indicating narrower time intervals where a crisis should be expected.

A set of premonitory patterns of socio-economic indicators was determined. Their behaviour was analysed to determine *the order* in which different premonitory patterns appear and to reconstruct *scenarios* of crisis development. A new generation of forecasting algorithms was designed. The algorithms were tested by exhaustive sets of numerical experiments and by real-time, advance prediction. Results of the tests were summarised to estimate the forecast skill.

The methodology used by WP7 included the analysis of complex socio-economic systems by pattern recognition methods and computer modelling. Our approach is holistic, from the whole to the details, combining macro- and micro-indicators. Specific methods include: (i) pattern

recognition methodology developed for the study of rare phenomena of highly complex origin; (ii) statistical and morphological analysis of time series; (iii) modelling of precursors to critical phenomena in complex systems; and (iv) statistical testing of the results. The main result was a set of algorithms and relevant software that can be used for issuing forecasts of yes-or-no type, i.e. at each moment they indicate whether a crisis under consideration should or should not be expected within the subsequent τ months, τ being the "duration of alarm".

3.6.2 Progress (WP7)

A new algorithm for prediction of extreme events in complex socio-economic systems has been applied to prediction of terrorism surges; a key ingredient is identification of the level of "background activity". The data on terrorism were taken from the web site (www.mitp.org) of the Memorial Institute for the Prevention of Terrorism. Monthly series of total number of deaths and injuries (NDI) as a result of terrorist attacks were analyzed for France, Israel, Pakistan, Spain and Turkey. Months when NDI is greater than a certain threshold were considered as extreme events and prediction targets. The retrospective analysis of the terrorism data shows that this approach could be applied to prediction of extreme terrorist events.

The statistical dynamics of religions and adherents has been studied. It was found that empirical laws could be deduced and related to preferential attachment processes, like on an evolving network; two different algorithmic models reproducing the data equally well have been proposed. A population growth-and-death equation was shown to be a plausible model of evolution dynamics in a continuous-time framework.

3.6.2.1 Tasks

We detail below the tasks achieved in the last 6 months for WP7.

Task 7.1. *Preliminary data analysis*. The main problems that arise in data processing are: (i) what kind of change in the examined time series should be treated as non-random; and (ii) what kind of change (events) could one try to forecast. Several approaches to developing formal procedure(s) to distinguish random *vs.* non-random features and time-frequency domains in the time series under examination have been analysed. Differences between the regime of strong and ordinary events was studied by using the distribution law (for the case of discrete events) and the spectral approach (in the case of regular data series). Methods of morphological analysis of time series were applied for the formal determination of specific patterns connected with extreme events, beyond methods that based only on expert decision. For example, the periods of increase in crime activity and the fuzzy extremes in crime statistics series were formally identified by this way.

Task 7.2. *Reconstructing scenarios of crisis development*. A model similar with a Brownian motion process but with an additional component that simulates a long, randomly "switching in" memory has been used to capture the main features of certain dynamical systems found in social dynamics and to examine the effectiveness of methods used for the investigation of such systems. This model is rather natural and simple, and the time series it produces resemble, visually and in their power spectra, those of typical social systems, including those of crime statistics. The method of *morphologic analysis* has been developed for distinguishing the cases of quasi-equilibrium behaviour of the system under consideration and the time intervals of highly non-equilibrium behaviour. This method was used to recognise intervals of activation in both synthetic and natural time series. Application to the synthetic series shows its effectiveness in recognition of time intervals of activity increase; application to crime statistics and heavy social-incident statistics has been carried out and preliminary results are encouraging.

Task 7.3. *Development of forecasting algorithms*. The problem of predicting the end of an American economic recession by the analysis of macro-economic indicators within the recession period has been considered. The goal is to identify by an analysis of macroeconomic indicators a robust prediction algorithm of the "yes or no" variety indicating at any moment in time whether the recession end should be expected or not within the subsequent months. A specific "premonitory"

pattern of six macroeconomic indicators that may predict algorithmically the recession end has been found for six economic recessions in the U.S. between 1960 and 2000. The ends of all six recessions under consideration are preceded within 5 months by this pattern that appears at no other time. The end of the last recession, which occurred in 2001, has been retrospectively predicted based on data preceding its occurrence.

Critical deceleration has been used as a precursor of strong change in the behaviour of a dynamical system. It has been applied and verified in the case of long synthetic time series. The method has then been applied to observed data: the seismic regime in California, time variation of share prices (General Motors, Microsoft, and General Electric), and number of crimes in several urban centres. Preliminary results confirm the effectiveness of this approach. A simple model of fore-crisis behaviour has been built, and an indicator of approaching fore-crisis situation has been formulated. Long time series obtained in geophysical monitoring (geomagnetic observations) were used to examine the usefulness of this approach to prediction of change in the system's behaviour.

Patterns of "background activity" have been studied for complex socio-economic systems. The analysis of this background activity shows an analogy with background seismicity. It has been found that an increase in this activity can be used for prediction of extreme events in the U.S. economy and in megacities (e.g., Los Angeles). New algorithms for prediction of extreme events have been designed on the basis of sets of premonitory indicators associated with increasing background activity in a complex system before an extreme event, and the relevant software has been developed. The algorithms have been tested and found useful in real-time, advance prediction.

Crime dynamics has been studied on the basis of weekly crime statistics for Yaroslavl (Russia). An algorithm for predicting sharp surges of homicides (SSH) has been suggested. For the retrospective data, the algorithm predicts about 70% of SSHs within an alarm time of 30% of total time under study and gave only 4% of false alarms. The mean alarm time is about 3 weeks.

Task 7.4. *Summarizing results of the tests of the forecasting algorithms*. Our algorithm for predicting a specific phenomenon in the dynamics of unemployment – episodes of a sharp increase in the unemployment rate, called "Fast Acceleration of Unemployment" (FAU) — was applied for advance prediction of FAUs in the U.S. It is based on trend analysis of monthly series of three macroeconomic indicators: industrial production, long-term interest rate on 10-year government bonds, and short-term interest rate on 3-month bills. The values of the trends are considered on the lowest level of resolution, distinguishing only the values above and below a certain threshold. The algorithm declares an FAU alarm after a month when all three trends are large. In 1999 an experiment in prediction in advance for the U.S. was launched. The first prediction for early 2000 has been correct. The final period of alarm was May 2006–April 2007. The prediction has been confirmed by the FAU that occurred in December 2006.

Task 7.5. *Forecasting the change of the "regime" of crises*. The changing of magnitude distribution (scaling law) as an extreme event approaches seeme to be a universal feature present in natural as well as socio-economic complex systems. This has been found for distributions associated with scale invariance (e.g., Gutenberg-Richter law in seismology), as well as for nearly exponential distributions. These findings have a potentially two-fold application: fundamental understanding of complex systems and disaster preparedness. They are relevant to seismicity, economical recessions, unemployment, crime waves, industry performance, elections etc.

3.6.2.2 Deliverables (WP7)

All deliverables for WP7 were ready by month 36.

3.6.3 Conferences

Kossobokov, V., and A. Soloviev, Forecast/prediction of extreme events: Fundamentals and prerequisites of verification. Geophysical Research Abstracts, Volume 10, 2008. Abstracts of the Contributions of the EGU General Assembly 2008, Vienna, Austria, 13–18 April 2008 (CD-ROM): EGU2008-A-07031.

4. Consortium Management

This management was the object of Work Package 1. The project leader (Michael Ghil [MG], ENS) and co-leader (Pascal Yiou [PY], LSCE) organized the consortium management. The WP leaders wrote reports on their part of the project every six months. To ensure an optimal organization, two boards were created at the beginning of the project:

- The Project Executive Board (PEB), composed of WP leaders (MG, PY, Bruce D. Malamud [BDM], Stéphane Hallegatte [SH], and Alexandre Soloviev [AS]), steered the scientific policy and monitored the advancement towards the objectives of the project. The PEB wrote the scientific reports that were sent to the EC every six months.
- The Project Technical Board (PTB), with the Principal Investigators (PIs) from each partner institution, made sure that each institution was adequately involved in E2-C2 and followed the administrative protocol for the project. The PTB was responsible for budgetary matters.

The administrative staff at the ENS (led by Ms. Chantal Kamarudin) assisted the PTB in coordinating the financial and legal aspects of the contract. ENS had the key responsibility for the administrative and financial management of the project:

- To prepare the contracts and collect the administrative information from the E2-C2 institutions.
- To collect informally budget forms every 12 months to ensure that the project runs normally.
- To assist the E2-C2 institutions in filling out the audit forms and prepare the periodic reports to the EC.

The PEB has interacted frequently — formally as well as informally — in person, over the phone and by E-mail, as necessary. The project leaders and the PEB organized four general WP meetings:

- A kick-off meeting was organized in Vienna (EGU General Assembly, April 2005) and defined the role of each participant.
- The PEB met in Paris (January 2006) to check on the progress of all work packages. The PEB encouraged exchanges between the E2C2 institutions, and across WPs. Various meetings with members from two or more WPs have been held throughout the project.
- An "all hands" meeting was held in Perugia (September 2006) to present the progress of all WPs at mid-project and ensure that the deliverables were in time all along the project duration.
- An Open Conference was held in Paris in March 2008, to finalize and distribute project results with the participating institutions and the community at large.

A Scientific Advisory Board (SAB) with scientists of international reputation was created to evaluate the results and functioning of E2-C2. The members of the SAB were Donald Turcotte (UC Davis, USA), Jonathan Koehler (Tyndall Center, Cambridge, UK) and Martin Beniston (U. of Geneva, Switzerland). The SAB met at the Perugia (September 2006) and Paris (March 2008) meetings and assessed the quality of E2C2 research. Its reports were forwarded to the EC with the appropriate interim reports.

One of the E2C2 project members (G. Weisbuch, ENS) is a member of the GIACS Coordinating Action. Attendance in GIACS meetings by E2-C2 members was encouraged.

4 Appendix A: Dissemination of knowledge

Work Package 8 was lead by P. Yiou and B. D. Malamud. Its formal activity is the overall exploitation and dissemination of E2–C2 results. The main objective was to actively and openly inform the geosciences and socio-economic sciences communities about the objectives of E2-C2, the research we conducted, and the findings of our project.

4.1 Overview Table

Planned/actual dates	*Type*	*Type of audience*	*Countries addressed*	*Size of audience*	*Partner responsible/involved*
June 2005	Press release (press)	General public	France		ENS
2005	Conference	General public	India		All
April 2005, 2006, 2007, 2008	Conference organization	Research	Austria	50+	KCL, LSCE
2007	Summer school	Research, Higher Education	Romania	50+	ENS, LSCE
2005, 2006	Conference presentation	Research	Europe		All
2008	Open conference	Research, Higher education	Europe	50+	ENS, LSCE
2005	Project web site	Research	Europe		LSCE
	Publications (50+)	Research	All		All

4.2 Web site

A web site for E2-C2 was created by Dr. Christian Schölzel (postdoc at LSCE, and designer of the web site of the Bonn University Department of Meteorology) to reflect the progress of the project and to exchange information between partners.

The scientific part of the site contains:

- Key presentations by E2-C2 participants at international conferences or workshops, in particular at the EGU, WP meetings, the Perugia and Paris meetings.
- General audience presentations, e.g. by Alejandro Martin-Hobdey (EU) and MG;
- Papers published in the framework of the project. Around 50 papers (submitted, accepted, or published) are listed and linked.
- Data sets generated by members of WP2 and WP5 (*D2a.1, D5a.1*)
- Reports or papers on probability density estimates and methodologies (*D2a.1, D3.1*, *D5b.2*). WP7 reports on the detection of socio-economic crises (*D7.1*).
- Pointers to relevant web sites, including institutions and data centres.

The administrative part of the web site contains:

- Official documents for E2-C2 participants,
- Recommendations for a smooth project administration.

The web site continues to be maintained and updated, given the interest of various communities for the project results.

4.3 Conferences

An EGU session ("Extreme Events: Causes and Consequences"), co-sponsored by the Natural Hazards and Nonlinear Processes sections of the EGU, is organised each year at the EGU General Assembly by BDM, S. Vannitsem and PY. This session is open and offers opportunities to discuss E2-C2 results with colleagues outside the project. This session took place in 2005, 2006, 2007 and 2008.

An open conference was organised in Paris (March 2008) by ENS to present new results obtained in E2C2. The conference was co-sponsored by the ENS foundation, the Club of Rome and EGU. The programme of the meeting and the talks delivered can be found at http://e2c2.ipsl.jussieu.fr/. The Scientific Advisory Board (SAB) was present and the EC Officer of the project was invited. Around 50 people attended the meeting, including colleagues outside of the project, and members of private companies. The SAB convened to write its report on the project advancement

4.4 Presentations

E2-C2 scientists regularly attended international conferences. The EGU and AGU are important conferences for meeting and disseminating key results of the project. Those presentations are available on the E2-C2 web site (http://e2c2.ipsl.jussieu.fr/).

4.5 Publications

The project has produced **over 120 publications** in international, refereed journals during the past 42 months. The SAB commented most favourably on this number being quite high for a STREP with such limited funding. Many more conference proceeding papers and other reports were also published.

The complete citations for many of these publications are available on the project web site. Further collaborations between the institutes that participated in the project continue, so that the publication rate of researchers active in this area should be durably enhanced.