Climate Extremes

Pascal Yiou

游柏光

LSCE, IPSL

SOFIE

SINO-FRENCH INSTITUTE FOR EARTH SYSTEM SCIENCE

PEKING UNIVERSITY CEA VERSAILLES ST QUENTIN UNIVERSITY

LSCE

PEKING UNIVERSITY 1898

Extreme Events

- Society and some eco-systems are more sensitive to a few extreme events than slow climate variations
- Extreme phenomena are by essence rare, and require an ad hoc methodology

Definitions

- Mathematics & statistics
  - Annual maximum, peak over thresholds, rare values…
- Physics
  - Typology of events: heatwaves, cold spells, storms, droughts…
- Society & impacts
  - Losses, damages…
  - ☛Risk & vulnerability

Examples

Cold, hot, wet, dry…

Challenges

- Scientific questions
  - Are (climate) extreme events like normal events, but just more intense? (see S.F. Fitzgerald, *The Great Gatsby*)
  - Are they more intense,
  - Do they occur more often?

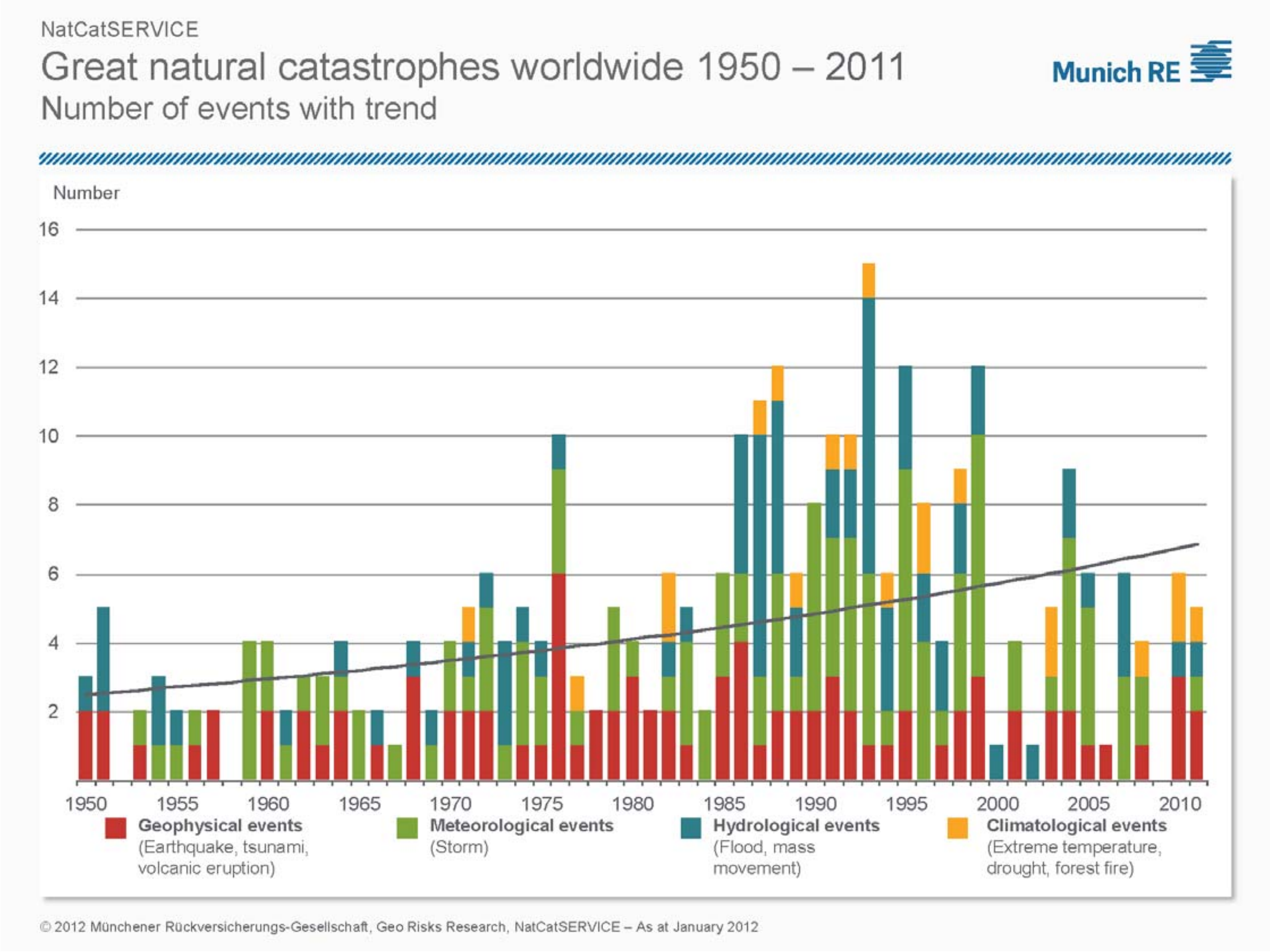
Special Extremes

- *Black swans*
  - Events that were never observed before, and become conspicuous
- *Perfect storms*
  - Combination of two or more events without serious consequences, when taken individually, but with a devastating sum
  - E.g., Tohoku earthquake, tsunami and Fukushima plant failure (March 2011)

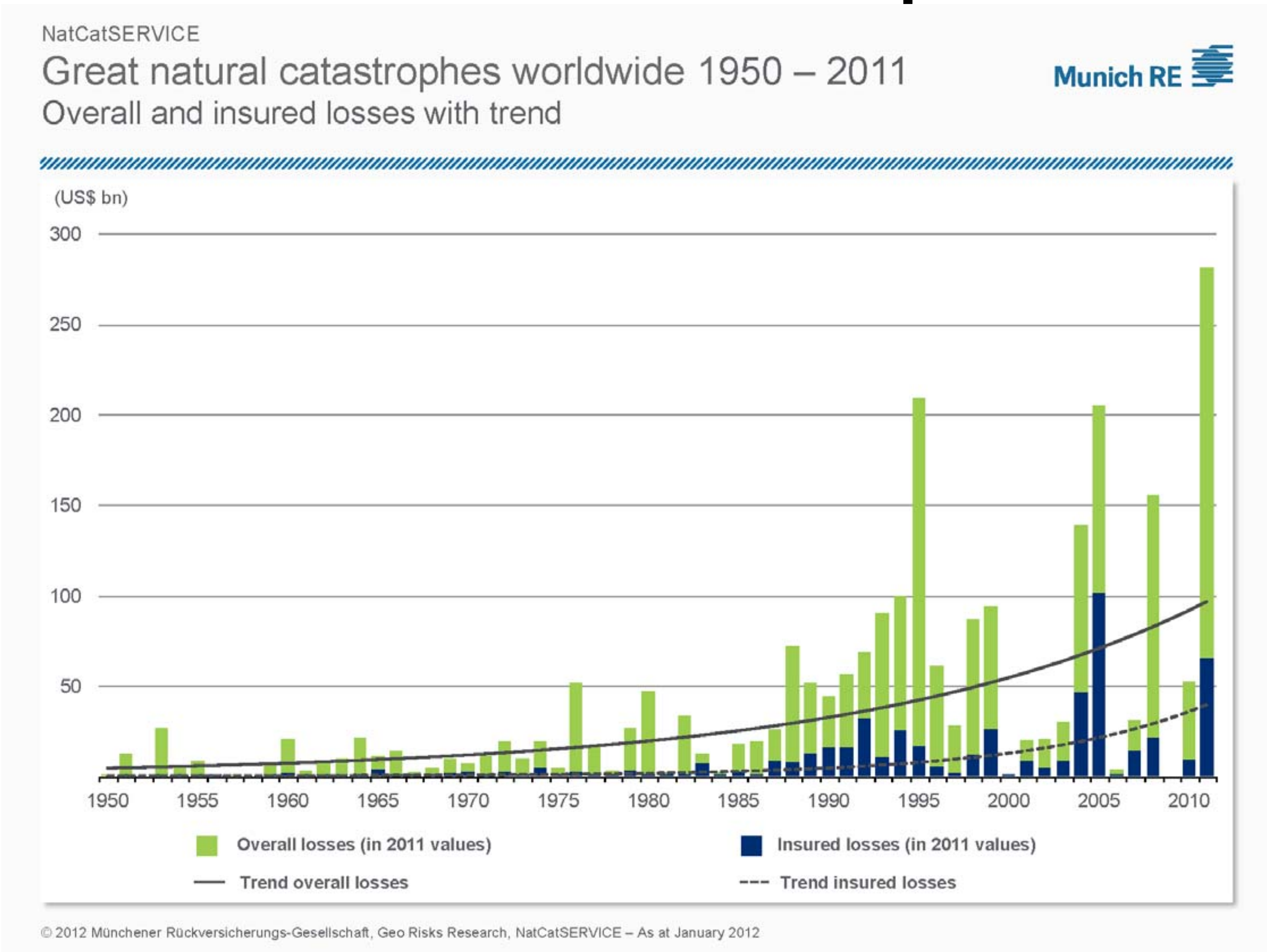
What is risk?

- Hazard
  - Climate or geophysical event, terrorism…
- Exposition
  - Goods, economic activity, health, biodiversity…

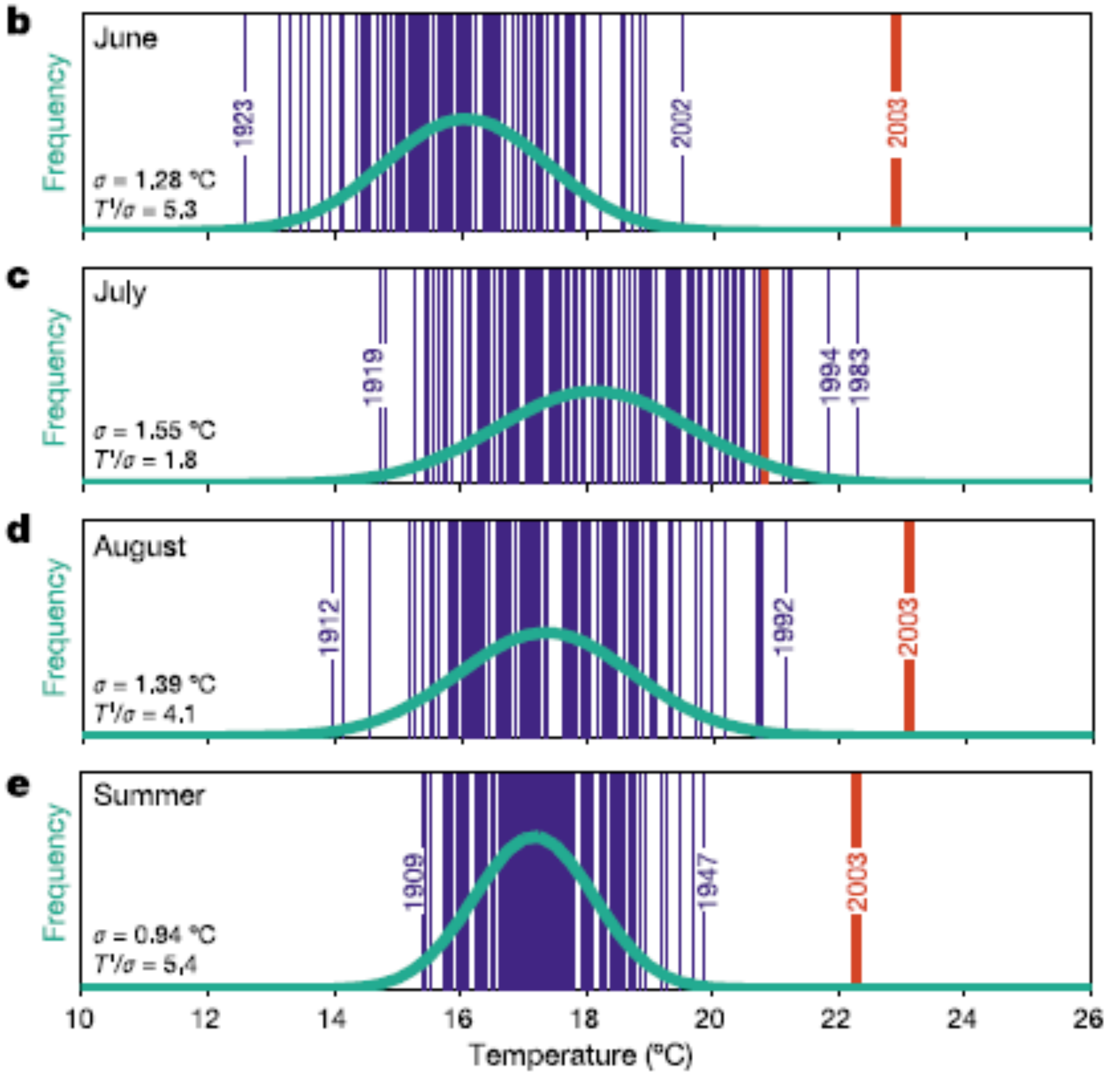
Natural Catastrophes



Cost of catastrophes



A European Black Swan in 2003

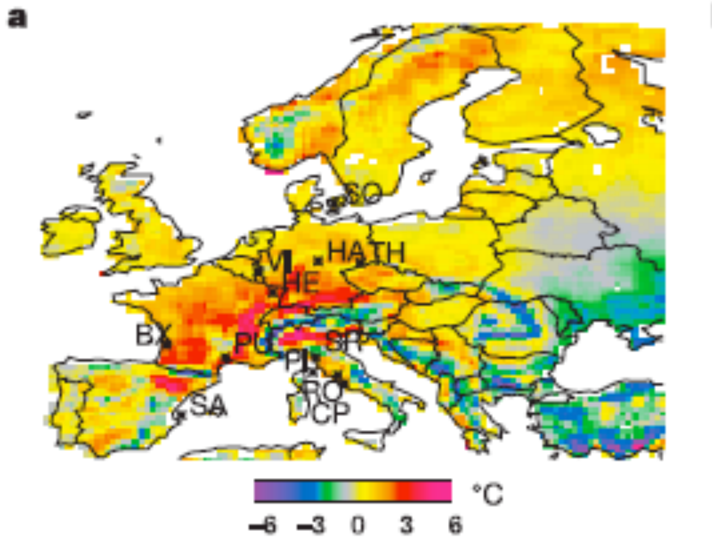


(Schär et al., Nature, 2004)

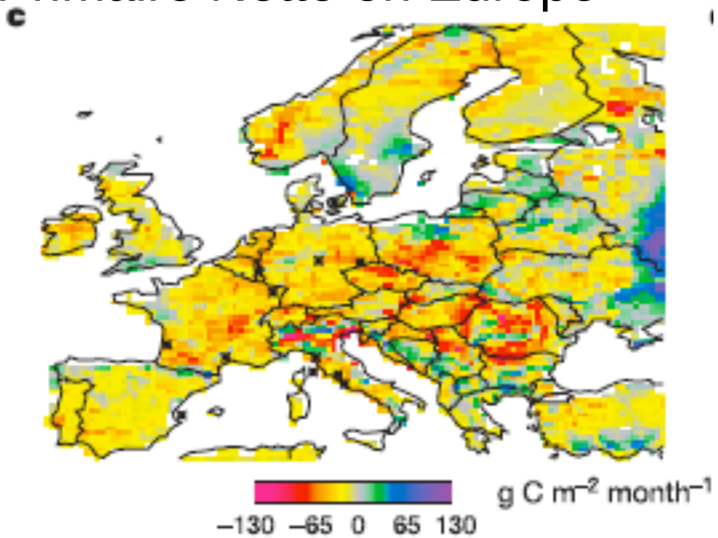
Impacts of 2003 Heatwave

- Impacts on ecosystems (observation & modeling)

Anomalie de Température en 2003



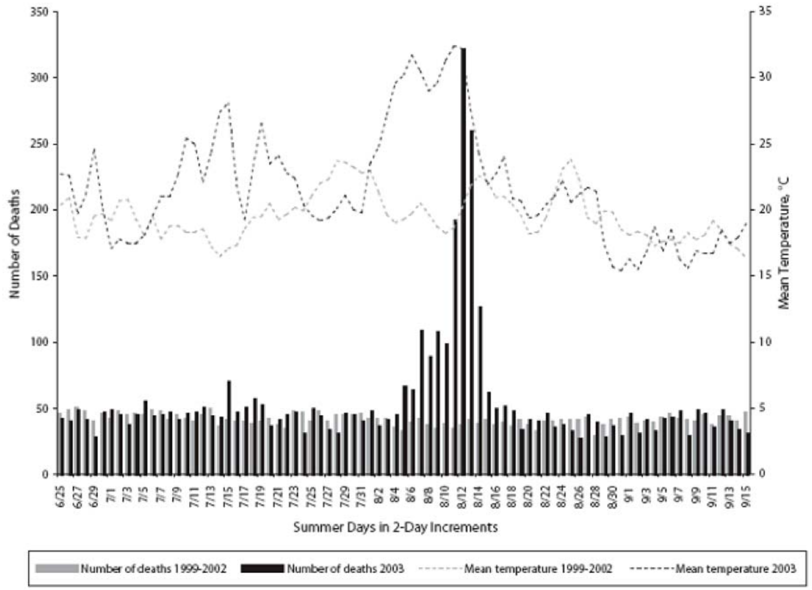
Anomalie de Productivité Primaire Nette en Europe



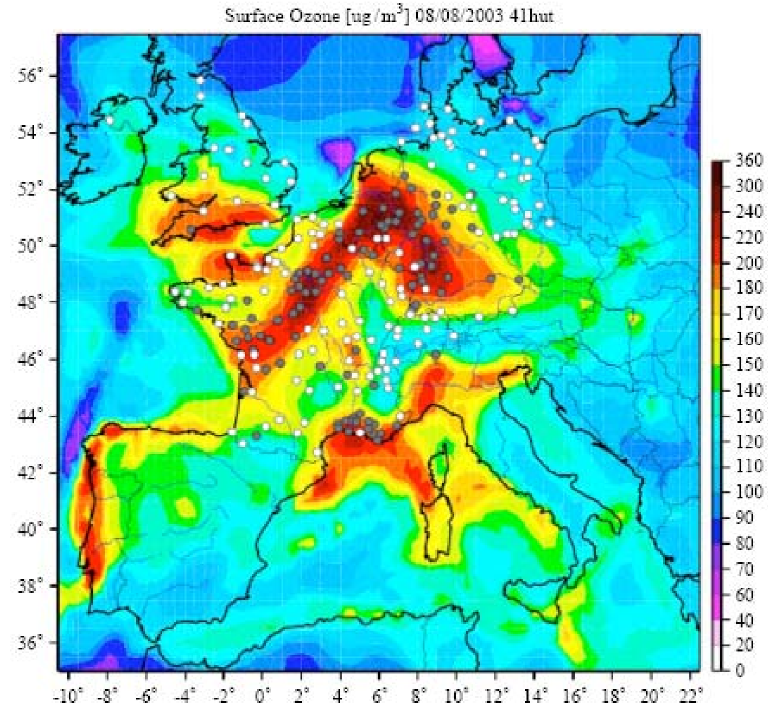
Forest net primary production is stopped

Ciais et al., Nature, 2005

Impacts of 2003 Heatwave



Excess mortality in France
Vandentorren et al., 2004



Large-scale photochemical pollution
Vautard et al 2005

- Drought: agricultural losses, eco-systems
- Reduced river flows, and high water temperatures
- Fires : pollution, carbon

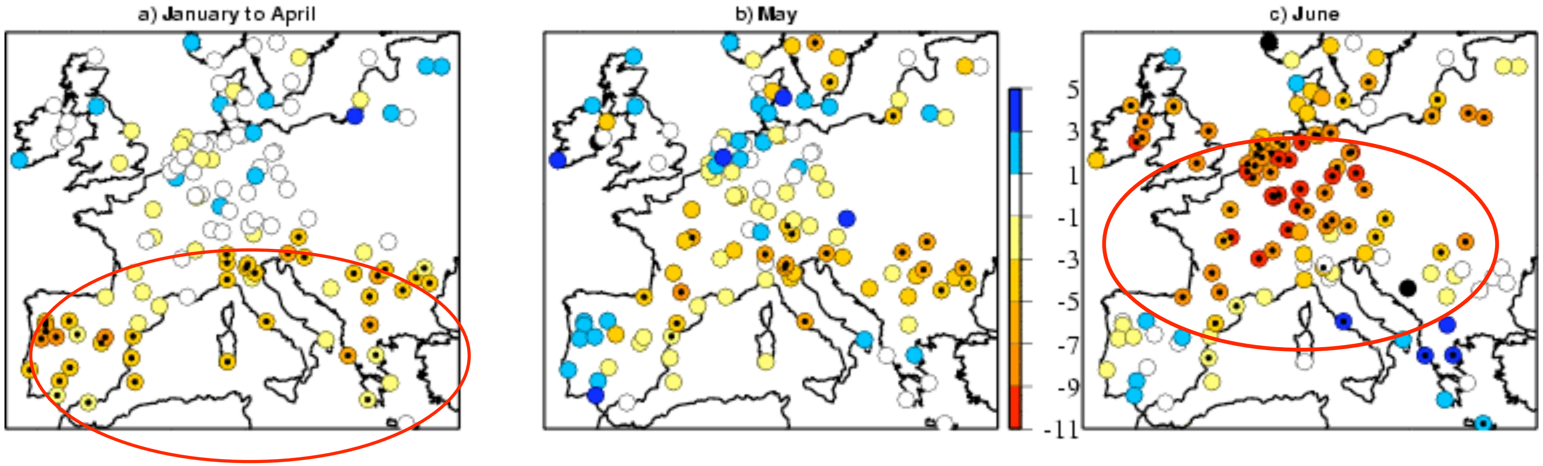
Heatwaves

- Mechanisms of genesis
  – Soil moisture
  – Atmospheric circulation (weather types)

European summer heatwave anomalies

Soil moisture – temperature positive feedback

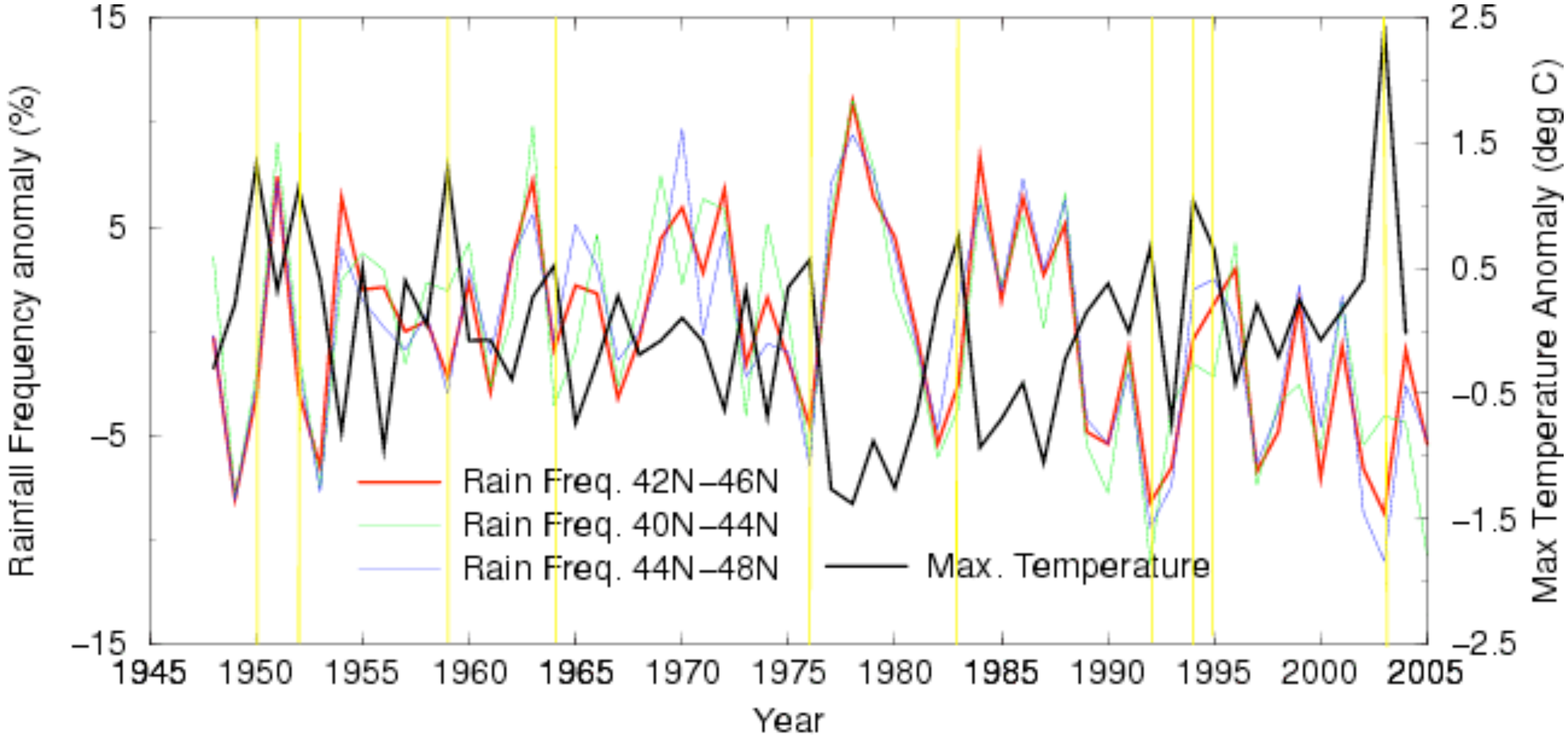
Precipitation frequency anomalies



It is necessary to have a drought in the south of Europe to trigger a heat wave

Vautard et al., Geophys. Res. Lett., 2007

Predicting Summer T with Spring Precipitation

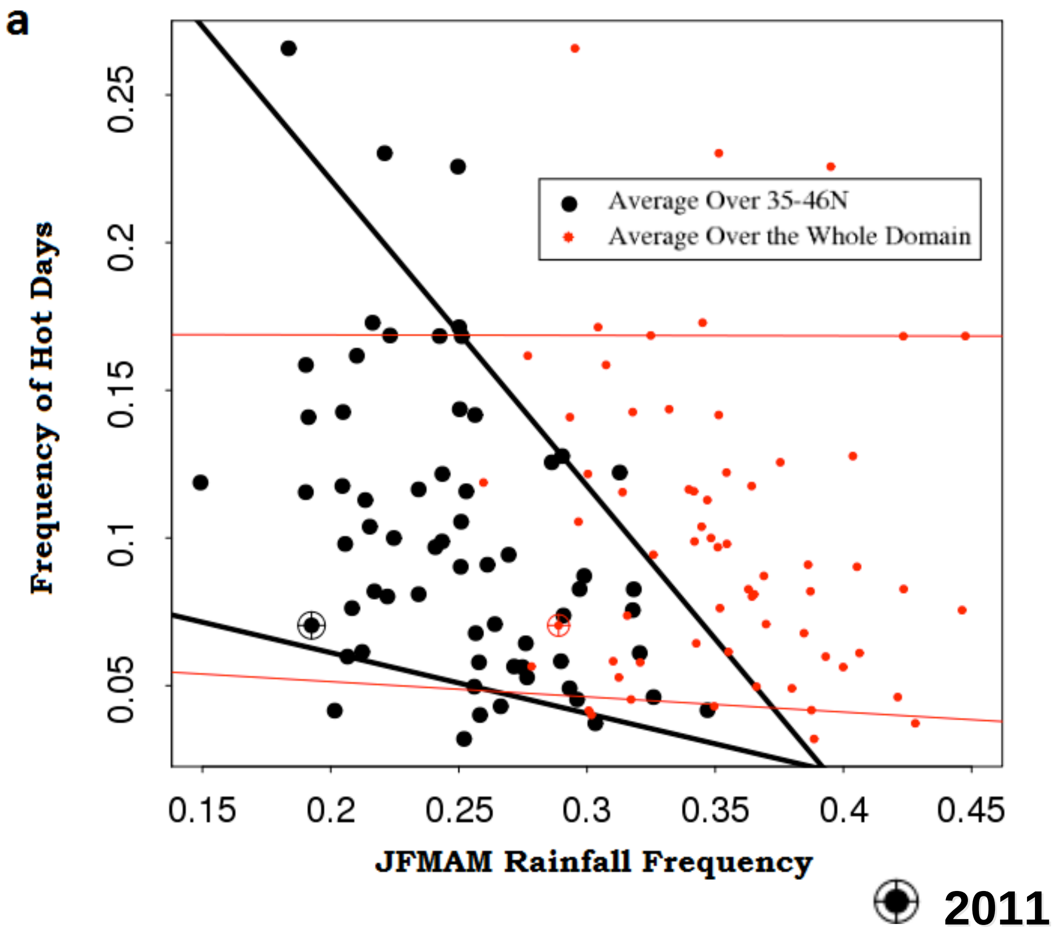


R=-0.7

Vautard et al., Geophys. Res. Lett., 2007

Southern signal for hot day frequency

a



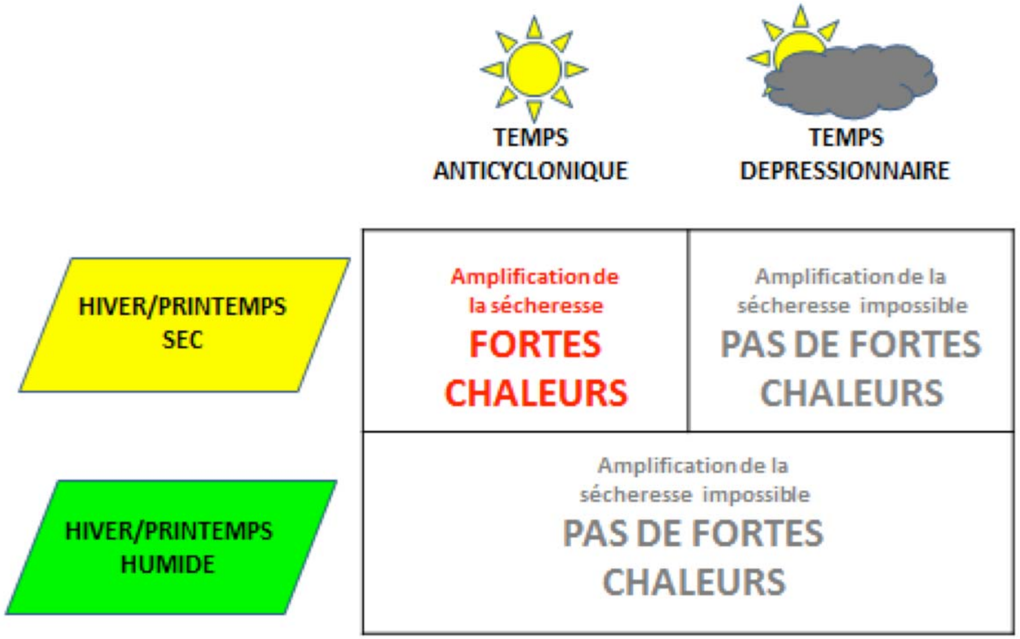
- **Quantile regression**
- **Predictive information in Southern Europe**
- High (resp. weak) previsibility with humid (resp. dry) initial conditions

(Quesada et al., Nature CC, 2012)

Heatwaves and atmospheric circulation

Soil damping effect

- Wet soils, solar energy → evaporation with increasing $T°_{sol}$
- Dry soils, solar energy → ↗ surface heating **possible amplification into summer heatwave**



Motivation for Extreme Value Theory

- Need to estimate return periods that are longer than the observations:
  - E.g., centenal floods from 50 years of
- How to compute return levels/periods that are longer than the observation period?

Some Limit Theorems

Basic Limit Theorems

- General hypotheses
  - $X_1, \ldots X_N$ Independent, Identically Distributed (IID)
- Tail of the distribution that tends to 0
  - Regular heavy tails
  - Any light tails

Basic Limit Theorems (2)

- Large numbers law

$$E|X| < \infty \quad \Rightarrow \quad \frac{X_1 + \ldots + X_N}{N} \to EX$$

- Central Limit Theorem

$$EX^2 < \infty \quad \Rightarrow \quad \frac{X_1 + \ldots + X_N - NEX}{\sigma\sqrt{N}} \xrightarrow{loi} N(0,1)$$

Generalized Extreme Distributions

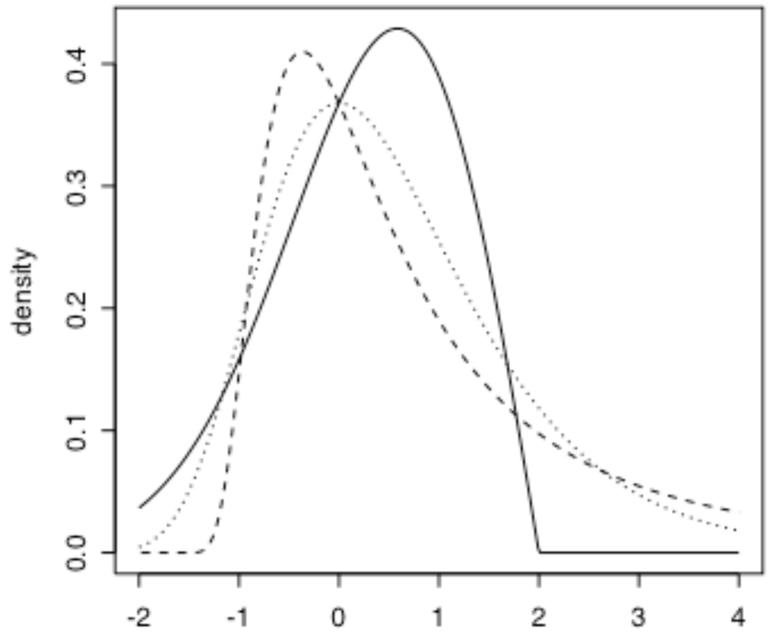
GENERALIZED EXTREME VALUE

Maxima

↓

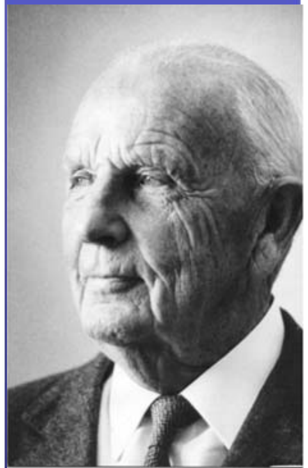
Extreme Value Theory

GEV

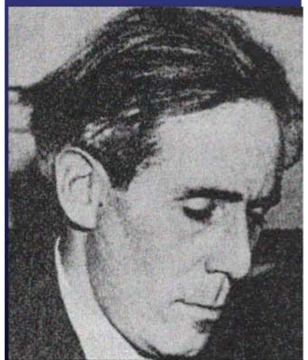


P. Yiou, SOFIE PKU 2013

Fréchet



Weibull



Gumbel

GEV distribution

Location parameter

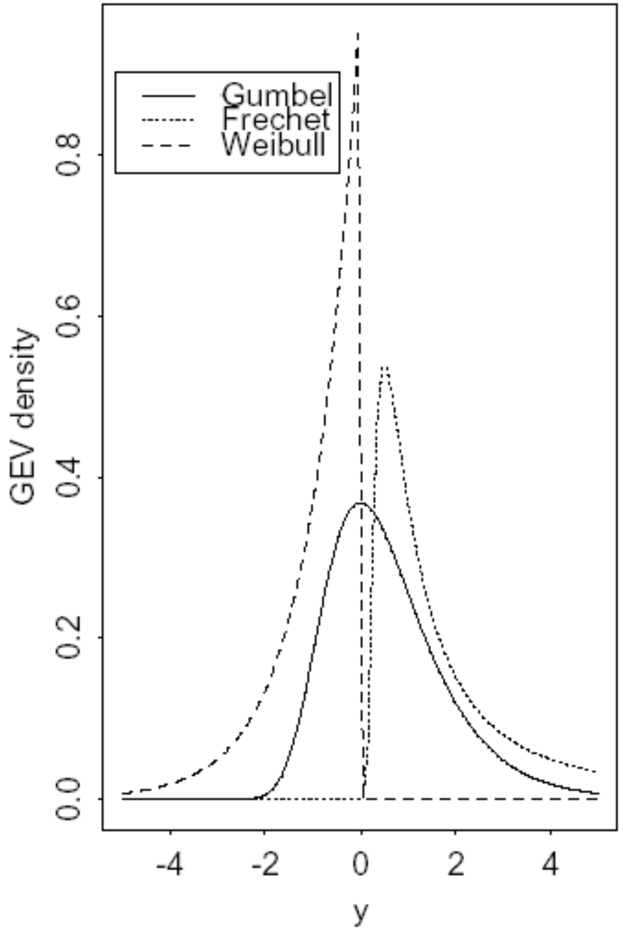
$$P(X < x) = \exp\left(-\left[1 + \frac{\xi (x - \mu)}{\sigma} \right]^{-\frac{1}{\xi}} \right)$$

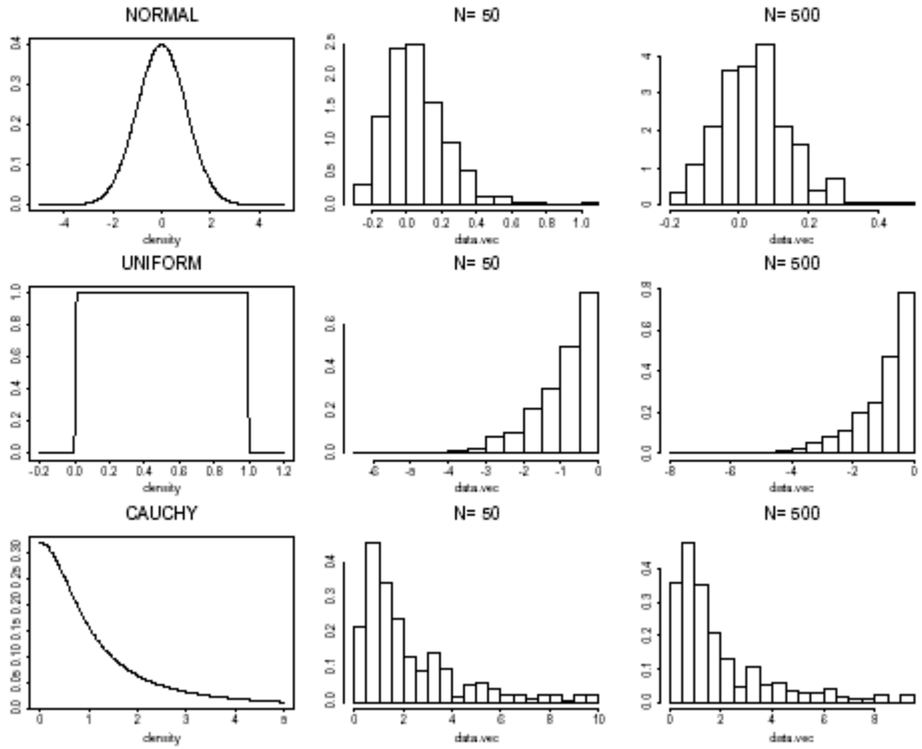
Shape parameter

Scale parameter

Extreme values

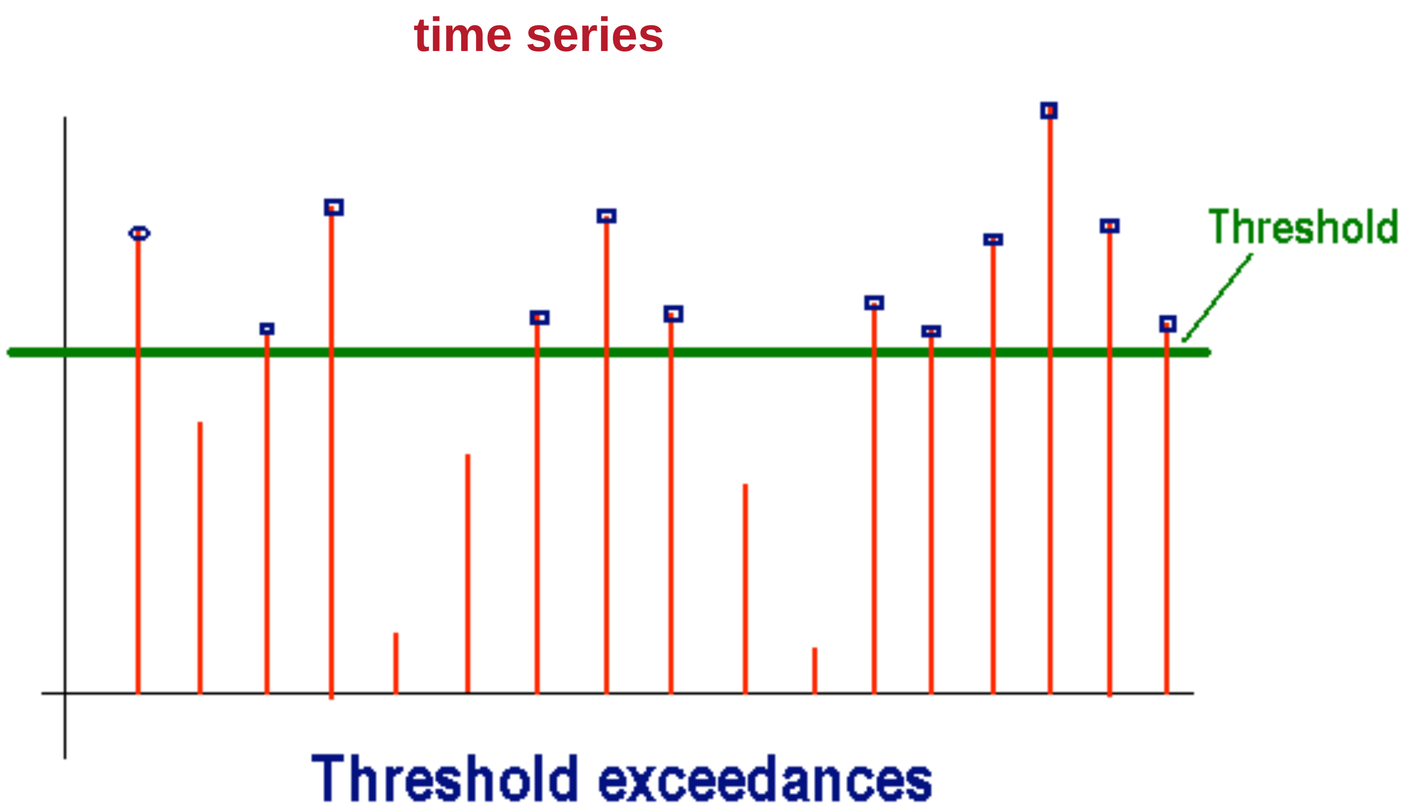
$$\frac{M_n - b_n}{a_n} \to G(x) = \begin{cases} \exp(-\exp(-x)), & \text{Type I Gumbel } (\alpha = 0) \\ \exp\left(-x^{-\alpha}\right), & \text{Type II Fréchet } (x > 0), \\ \exp\left(-(-x)^{\alpha}\right), & \text{Type III Weibull } (x < 0). \end{cases}$$





Peak Over Threshold (POT)

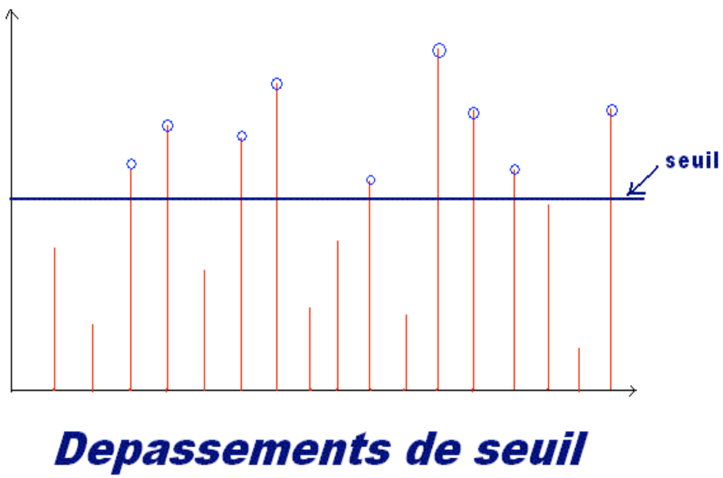
Threshold Exceedances



Probability distribution of X, knowing that X>u.

Generalized Pareto Distribution (GPD)

- Empirical distribution F_N of Y?
- $F_N \rightarrow G$



- Candidate: PARETO
- Conditions ↔ extremes

« 20% of population owns 80% of property in Italy »

Generalized Pareto Distribution (GPD)

For a high thresold u :

$$P(X < x | X > u) = \left[1 + \frac{\xi(x-u)}{\sigma}\right]^{-\frac{1}{\xi}}$$

Threshold

Shape parameter

Scale parameter

Poisson law for times

Number of extreme events N (e.g. summer heat waves):

$$\Pr(N(t) = n) = \frac{(\lambda)^n \exp(-\lambda)}{n!}$$

The parameter is the intensity of the Poisson law, i.e. the frequency of events (nothing to do with a periodical phenomenon).

Return Levels

Return levels and EVT

- Extreme levels (T, Pr) that are exceeded each 1/p years (with a probability p)
- GEV

$$z_p = \begin{cases} \mu - \sigma \log\left[-\log(1-p)\right], \text{ si } \xi = 0, \\ \mu - \frac{\sigma}{\xi}\left[1 - \left\{-\log(1-p)\right\}^{-\xi}\right], \text{ si } \xi \neq 0. \end{cases}$$

- GPD (*m*-return level)
  - $m = Nn_y$

$$z_N = \begin{cases} u + \sigma \log\left[Nn_y \zeta_u\right], \text{ si } \xi = 0, \\ u + \frac{\sigma}{\xi}\left[\left(Nn_y \zeta_u\right)^{\xi} - 1\right], \text{ si } \xi \neq 0. \end{cases}$$

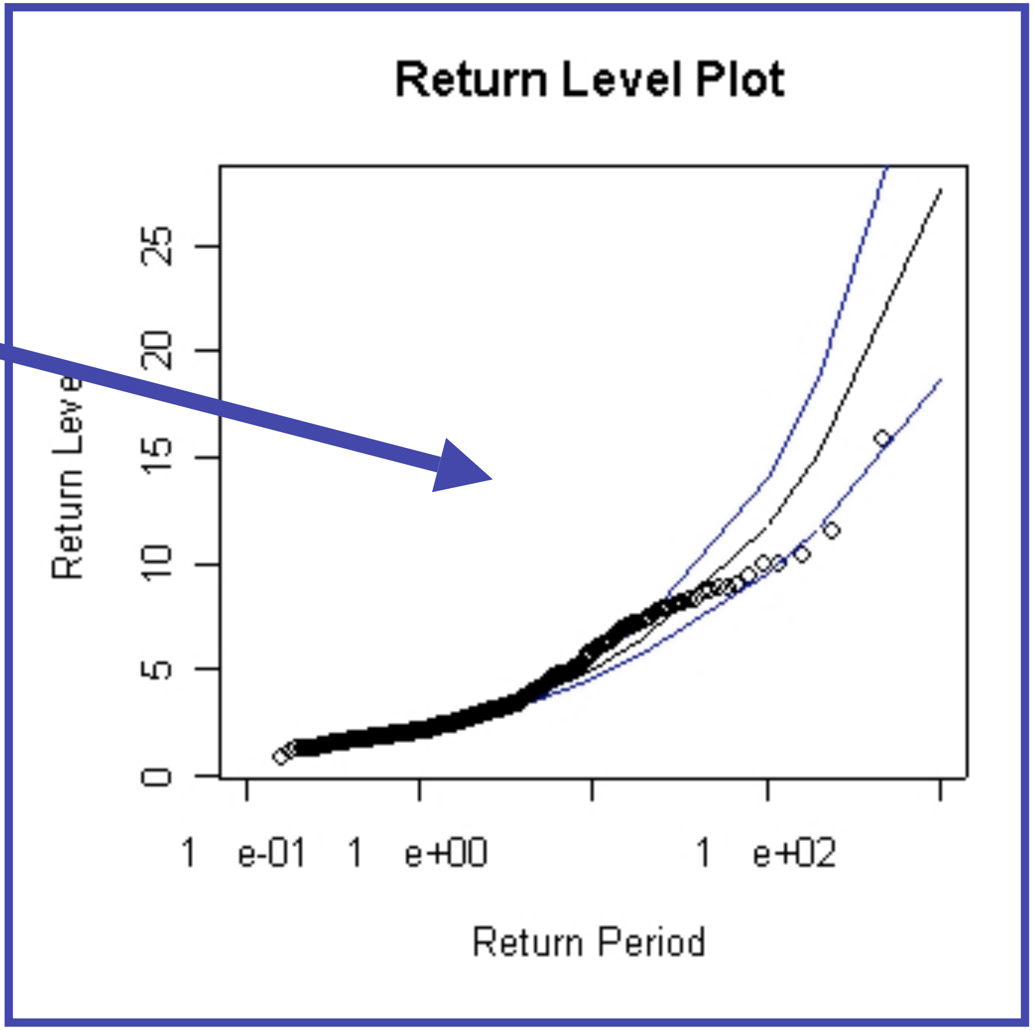
Examples

Relation NR/PR

ξ controls the *convexity* of return level variations

Precipitation in Western Europe

ξ>0: Fréchet distribution
(*no variance*)



Application

20 year return levels for extremely warm temperatures

μ

σ

Hotter extremes but less variable?

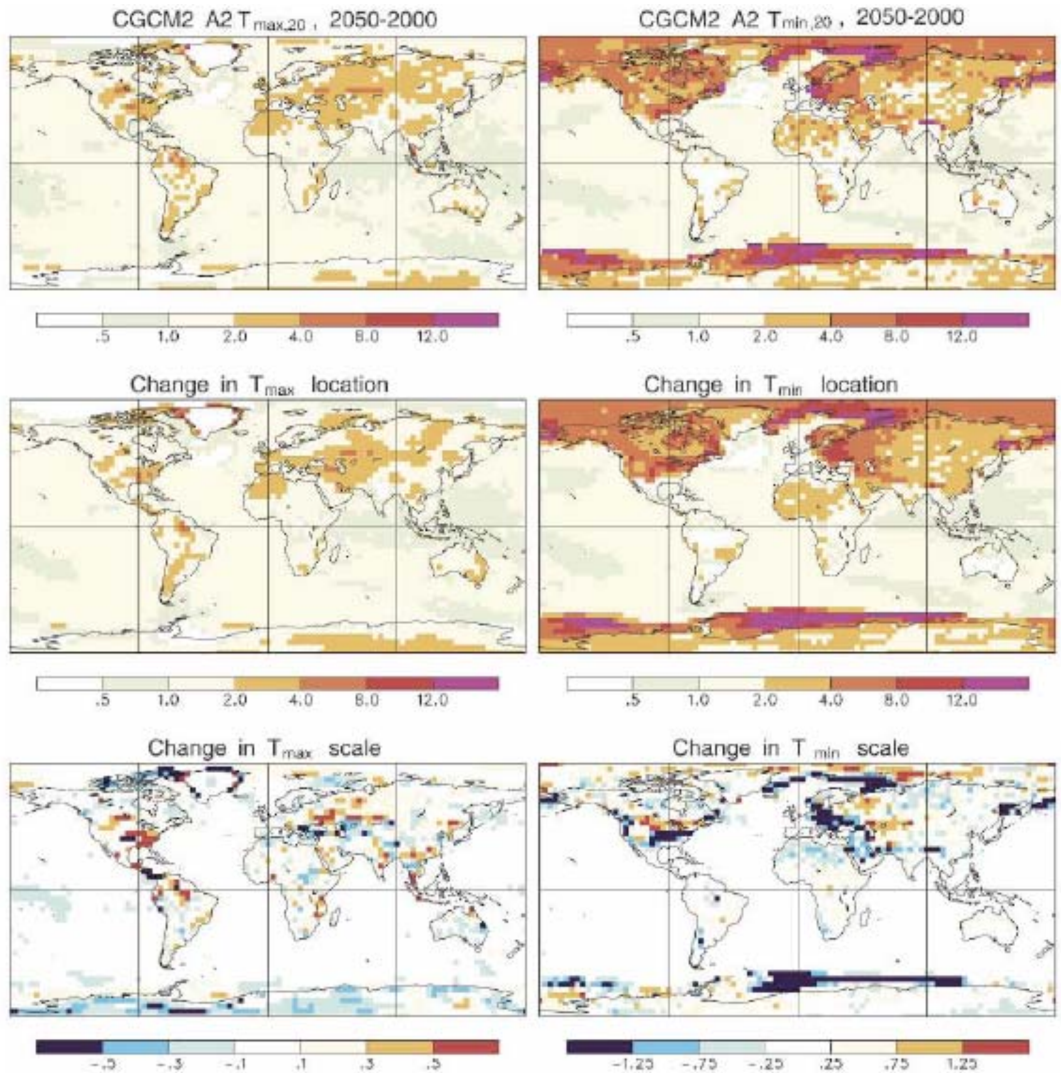


FIG. 6. Change in 20-yr return values of annual extremes of (top left) daily maximum surface temperature and (top right) daily minimum surface temperature, and the corresponding changes in the (middle) fitted GEV location parameter ξ and (bottom) scale parameter α as simulated by CGCM2 in 2050 relative to 2000 with the A2 emission scenario.

(Kharin et al., J. Clim., 2007)

Nonstationary Extremes

Probability distribution when temperature X exceeds a threshold *u*:

$$\Pr(X < x \mid X > u) = \left[1 + \frac{\xi(x-u)}{\sigma(t)}\right]^{-\frac{1}{\xi}}$$

Pareto distribution with varying scale parameter (σ) representing the typical magnitude of heat waves.

Number of extreme events N (e.g. summer heat waves):

$$\Pr(N(t) = n) = \frac{(\lambda(t))^n \exp(-\lambda(t))}{n!}$$

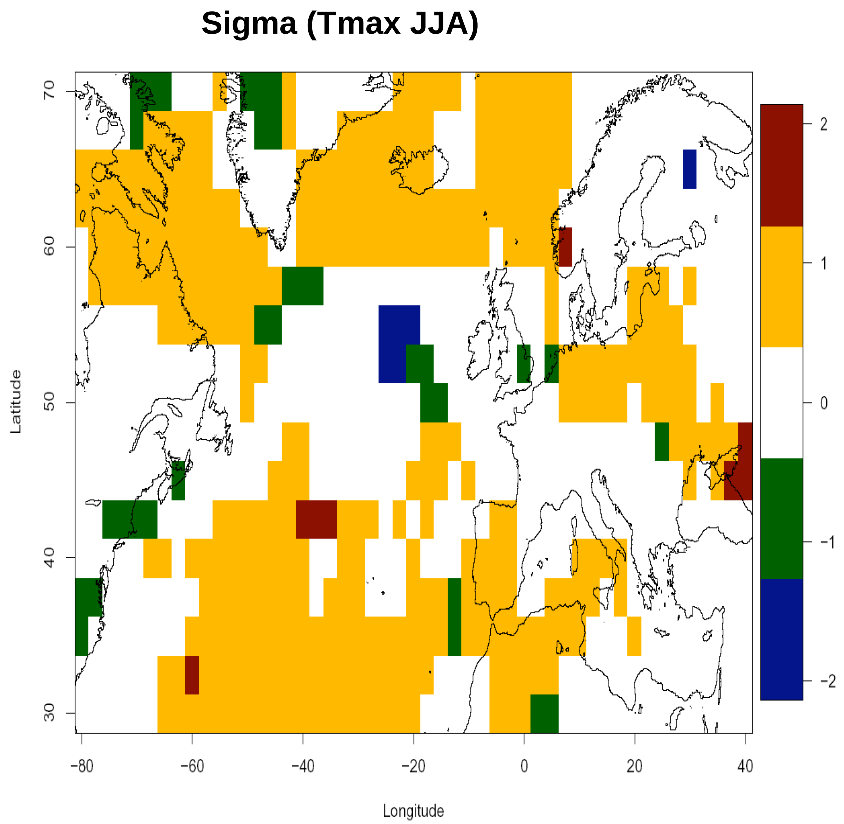
Poisson distribution with varying intensity parameter (λ) representing the frequency of extremes.

How do σ(t) and λ(t) vary in time?

Trends of Tmax JJA – Pareto/Poisson

Non-stationary σ
$$\begin{cases} \sigma(t) = \sigma_0 \\ \sigma(t) = \sigma_0 + \sigma_1 t \\ \sigma(t) = \sigma_0 + \sigma_1 t + \sigma_2 t^2 \end{cases}$$

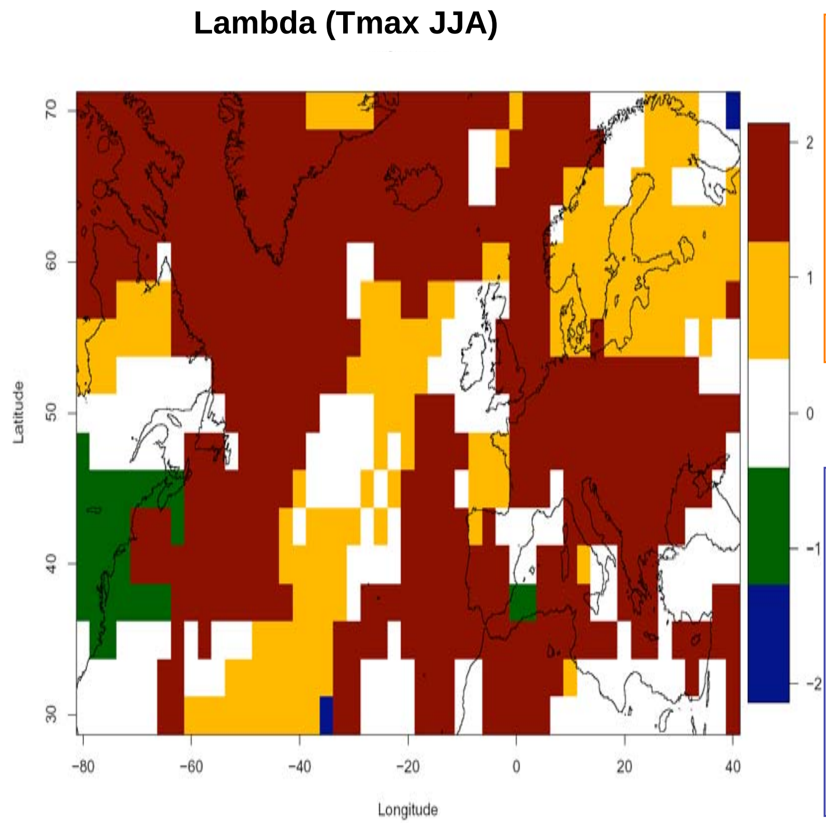
Non-stationary *λ*
$$\begin{cases} \lambda(t) = \lambda_0 \\ \lambda(t) = \lambda_0 + \lambda_1 t \\ \lambda(t) = \lambda_0 + \lambda_1 t + \lambda_2 t^2 \end{cases}$$



σ increasing

σ decreasing

Amplitude of heat waves



λ increasing

λ decreasing

Frequency of heat waves

Nogaj et al. GRL 2006

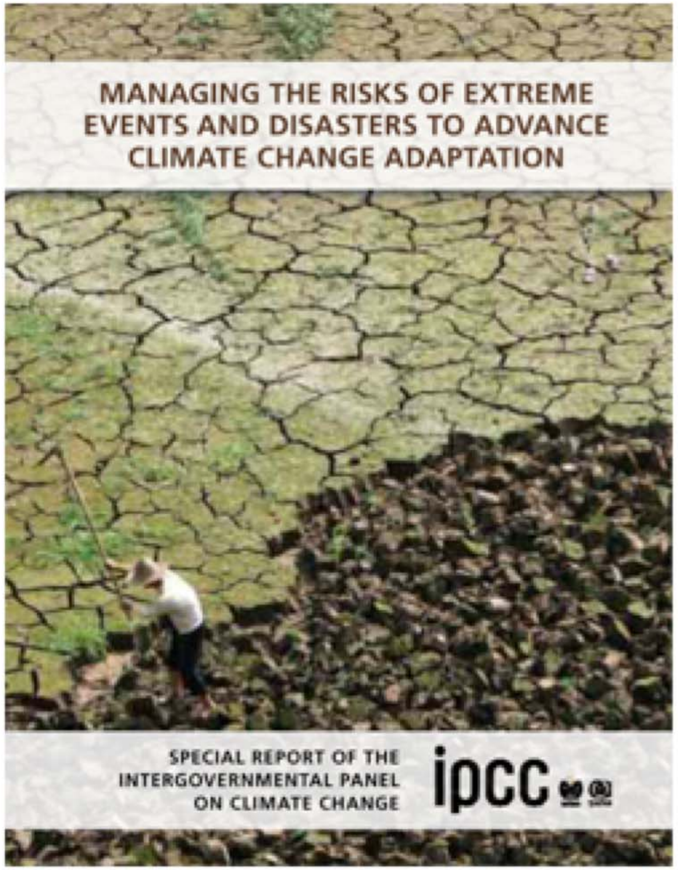
Applications of EVT

- Hydrology:
  - Flood, overflow: centenal events
- Construction and transports:
  - Dimensioning buildings to resist storms
- Finance:
  - ré-insurance for natural catastrophes
- Energy:
  - Production, consumption, safety
- Agriculture:
  - Crop destruction

Other extremes

- Cold spells
  - Other physical processes
- Intense precipitation
  - Small spatial scales
- Wind extremes
  - Large scale: extra-tropical storms (Lothar, Martin (1999), Klaus (2009), Xynthia (2010))
  - Small scale: Mediterranean cyclones
- …

To know more about extremes



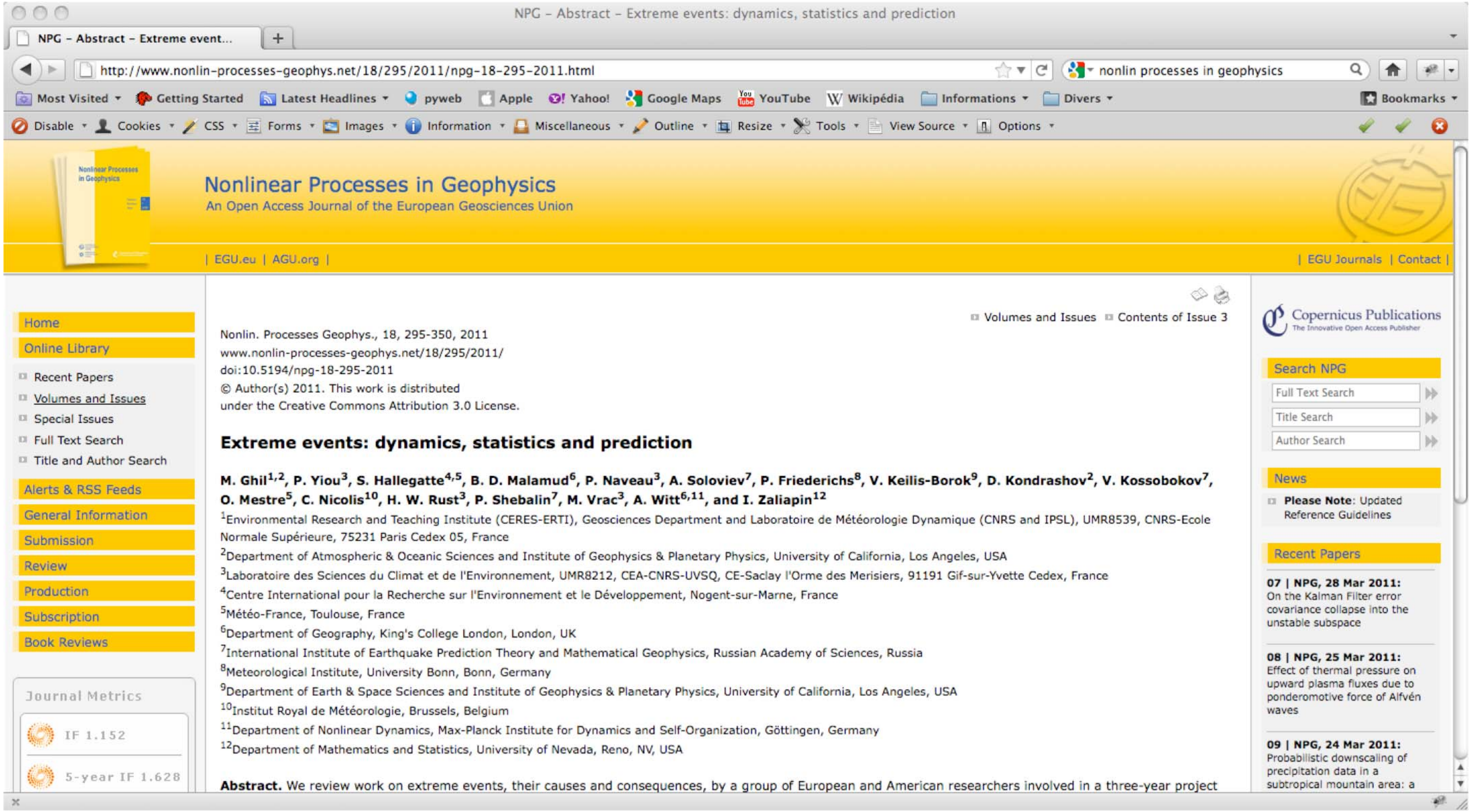
FULL SREX REPORT

PDF - 594 pages - 31MB

SUMMARY FOR POLICYMAKERS

PDF - 20 pages - 11.8MB

To know more about extremes



NPG - Abstract - Extreme events: dynamics, statistics and prediction

http://www.nonlin-processes-geophys.net/18/295/2011/npg-18-295-2011.html

Nonlinear Processes in Geophysics

An Open Access Journal of the European Geosciences Union

Volumes and Issues | Contents of Issue 3

Nonlin. Processes Geophys., 18, 295-350, 2011
www.nonlin-processes-geophys.net/18/295/2011/
doi:10.5194/npg-18-295-2011
© Author(s) 2011. This work is distributed
under the Creative Commons Attribution 3.0 License.

Extreme events: dynamics, statistics and prediction

M. Ghil[1,2], P. Yiou[3], S. Hallegatte[4,5], B. D. Malamud[6], P. Naveau[3], A. Soloviev[7], P. Friederichs[8], V. Keilis-Borok[9], D. Kondrashov[2], V. Kossobokov[7], O. Mestre[5], C. Nicolis[10], H. W. Rust[3], P. Shebalin[7], M. Vrac[3], A. Witt[6,11], and I. Zaliapin[12]

[1]Environmental Research and Teaching Institute (CERES-ERTI), Geosciences Department and Laboratoire de Météorologie Dynamique (CNRS and IPSL), UMR8539, CNRS-Ecole Normale Supérieure, 75231 Paris Cedex 05, France
[2]Department of Atmospheric & Oceanic Sciences and Institute of Geophysics & Planetary Physics, University of California, Los Angeles, USA
[3]Laboratoire des Sciences du Climat et de l'Environnement, UMR8212, CEA-CNRS-UVSQ, CE-Saclay l'Orme des Merisiers, 91191 Gif-sur-Yvette Cedex, France
[4]Centre International pour la Recherche sur l'Environnement et le Développement, Nogent-sur-Marne, France
[5]Météo-France, Toulouse, France
[6]Department of Geography, King's College London, London, UK
[7]International Institute of Earthquake Prediction Theory and Mathematical Geophysics, Russian Academy of Sciences, Russia
[8]Meteorological Institute, University Bonn, Bonn, Germany
[9]Department of Earth & Space Sciences and Institute of Geophysics & Planetary Physics, University of California, Los Angeles, USA
[10]Institut Royal de Météorologie, Brussels, Belgium
[11]Department of Nonlinear Dynamics, Max-Planck Institute for Dynamics and Self-Organization, Göttingen, Germany
[12]Department of Mathematics and Statistics, University of Nevada, Reno, NV, USA

Abstract. We review work on extreme events, their causes and consequences, by a group of European and American researchers involved in a three-year project

Références

- Ghil M. et al., Extreme events: dynamics, statistics and prediction, Nonlin. Proc. Geophys., 18, 295-350, 2011
- S. Coles, *An Introduction to Statistical Modeling of Extreme Values*. Springer Series in Statistics. Springer-Verlag, London, 2001
- H. von Storch et F. W. Zwiers, *Statistical Analysis in Climate Research*, Cambridge University Press, Cambridge, 1999
- D. S. Wilks, *Statistical Methods in the Atmospheric Sciences*, Academic Press, San Diego, 1995
- http://www.r-project.org