Extrêmes, Climate & Environment
A General Overview

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LSCE & IPSL, Gif-sur-Yvette

Acknowledgements

- P. Naveau, M. Vrac, R. Vautard, M. Nogaj, J. Cattiaux (LSCE)
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Does variance explain everything?

- Most statistical techniques used in geosciences are based on decompositions of variance (cycles, modes, regimes…)
  - Concentration on “typical” values
- What happens when the considered physical system is sensitive to large variations of one parameter?

Extreme Events

- Society and eco-systems are generally more sensitive to a few extreme events (heatwaves, storms, cold spells, droughts…) than slow environmental variations
- Extreme phenomena are by essence rare and require ad hoc techniques of analysis

Examples

Cold, wet, hot, dry…

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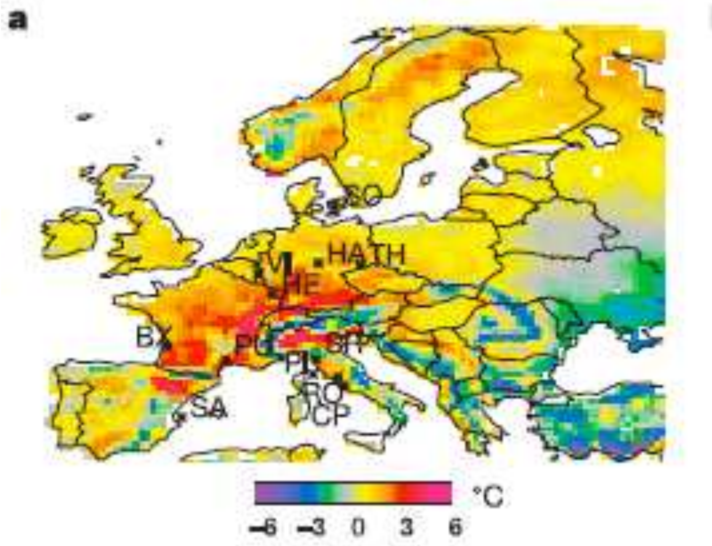
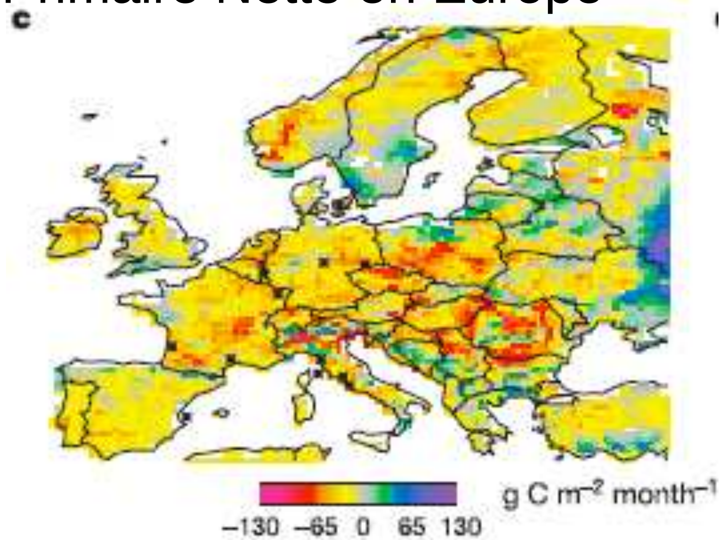
Impacts of the 2003 heatwave

- On ecosystems (observation and modeling)

Anomalie de Température en 2003



Anomalie de Productivité Primaire Nette en Europe



Net primary production stopped in summer 2003: 6 months of carbon sink suppressed

Ciais et al., Nature, 2005

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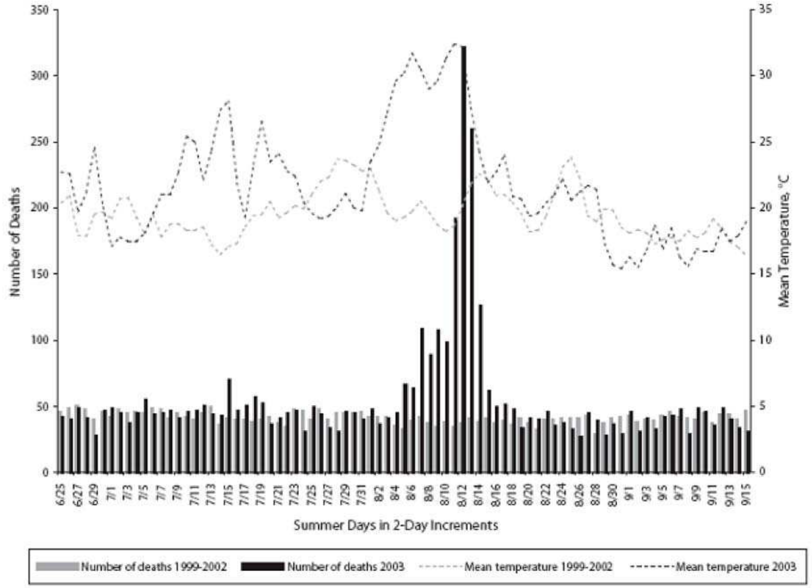
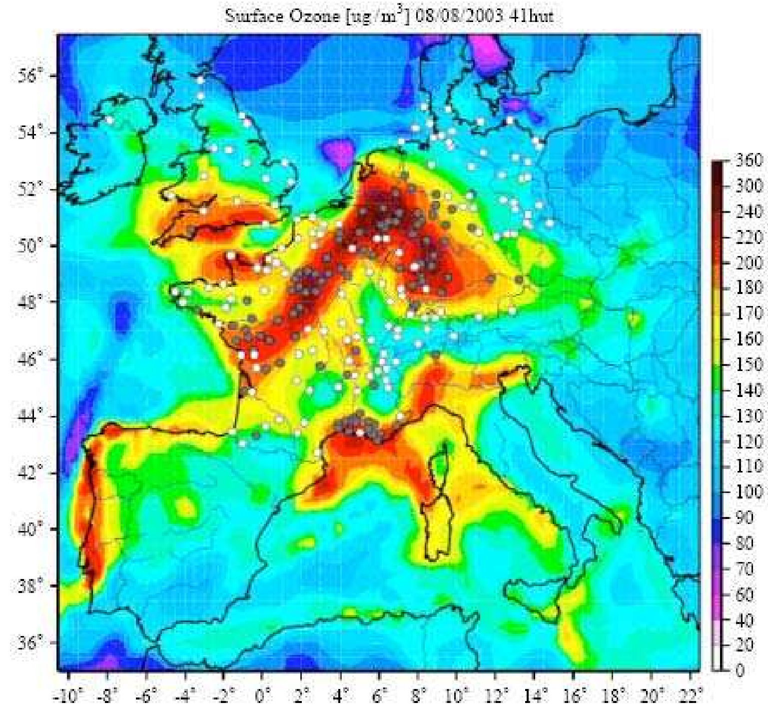
Impacts of the 2003 heatwave



Surmortalité pendant l'été 2003
Vandentorren et al., 2004



Pollution photochimique à grande échelle
Vautard et al 2005

- Drought: crop losses, eco-system damages
- Reduced river flow, increased temperatures (impacts on energy production)
- Fires : pollution, carbon loss

Role of precipitation for HW (1/2)

Frequency of precipitation, computed for each month preceding the summer:

$$\phi(t) = \begin{cases} 1, \text{ if } P > 5\text{mm}, \\ 0, \text{ otherwise}. \end{cases}$$

$$F(t) = \sum_i \phi(i)/30$$

F(t) is a proxy for soil moisture. It avoids temporal and spatial heterogeneity of precipitation.

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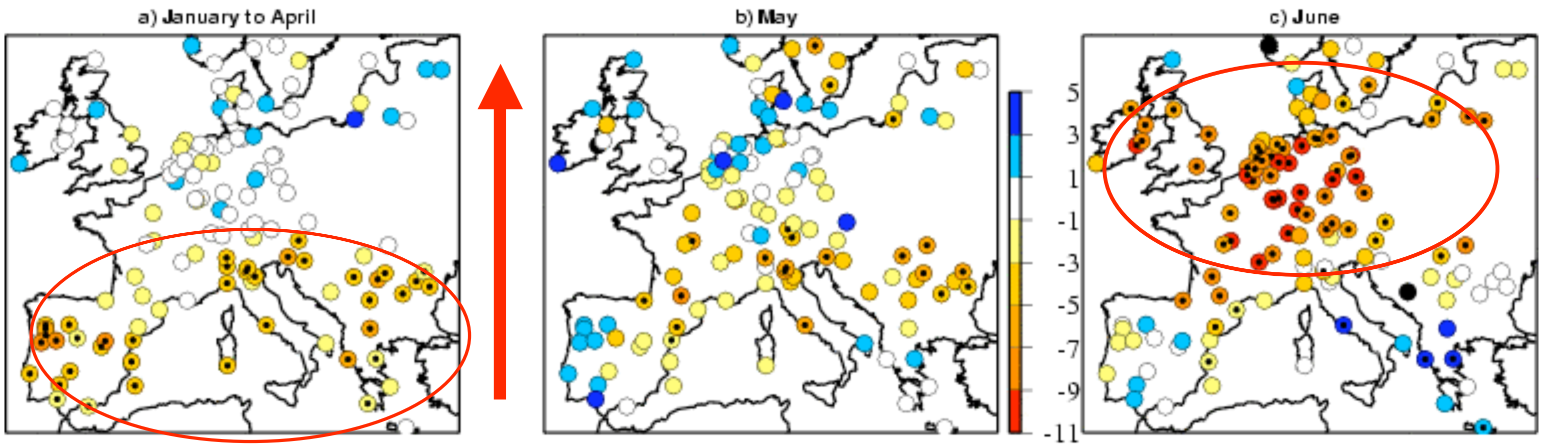
Role of precipitation for HW (2/2)

Precipitation frequency before summer is computed for the 10 hottest summers in Europe, between 1948 and 2006.

Precipitation frequency anomalies before a summer heatwave



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

Spring drought in southern Europe is a necessary condition to the genesis of a heatwave

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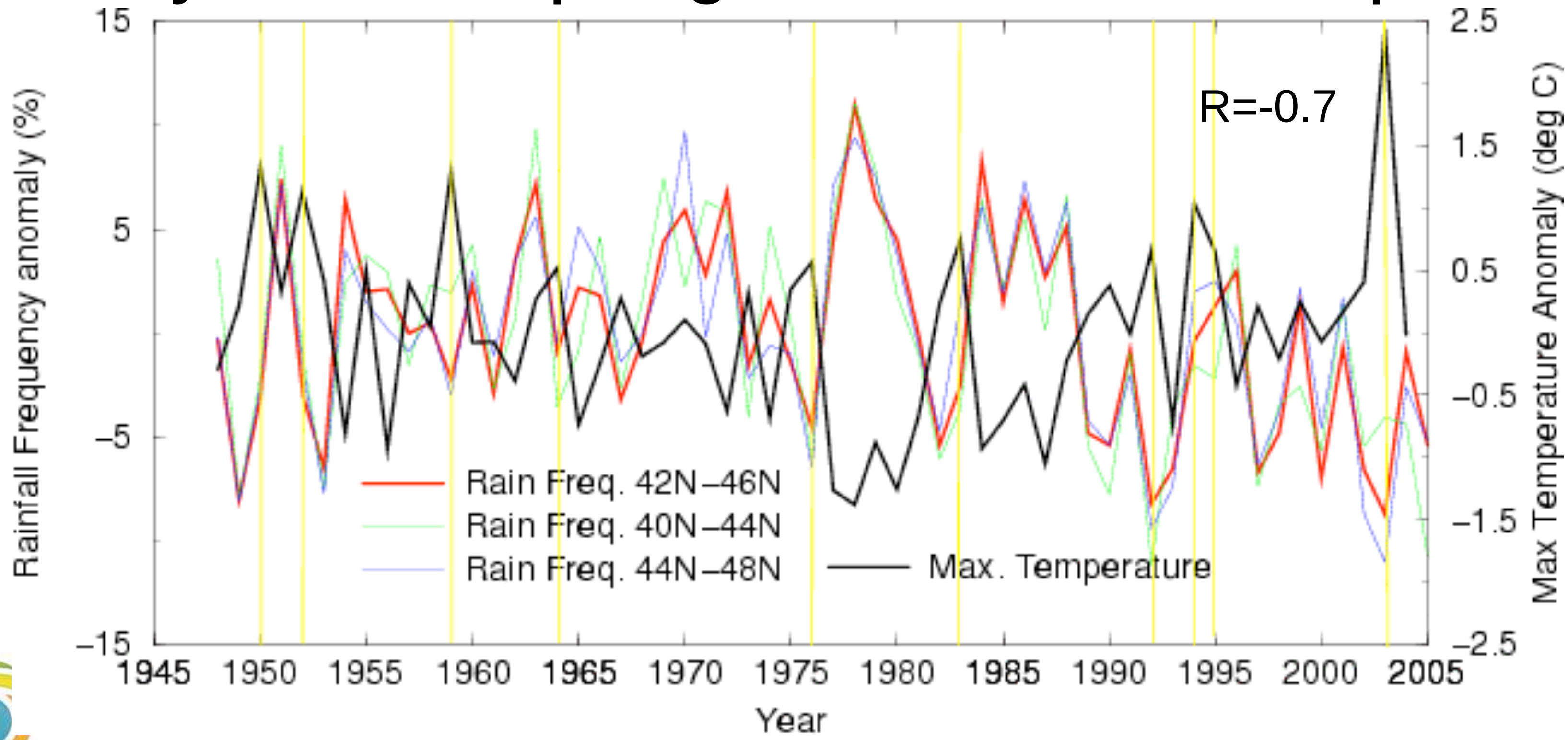
Triggering mechanisms of HW

- Anticyclonic summer conditions ("blocking")
- Dry soils in spring in Southern Europe



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

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How extreme?

- Some idea on the physical mechanisms leading to meteorological extreme events
- Build a climatology of extreme events
- Need for a consensus definition of extreme events
  - Extreme temperatures, precipitation, wind speed
  - Duration of events?
  - Focus on high impact events?

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Motivation of Extreme Value Theory

- Diagnose the probability of rare events from sparse observations
  - E.g., centennial floods from 50 years of observations
- Computation of return levels, and the impact of secular climate change on some extremes

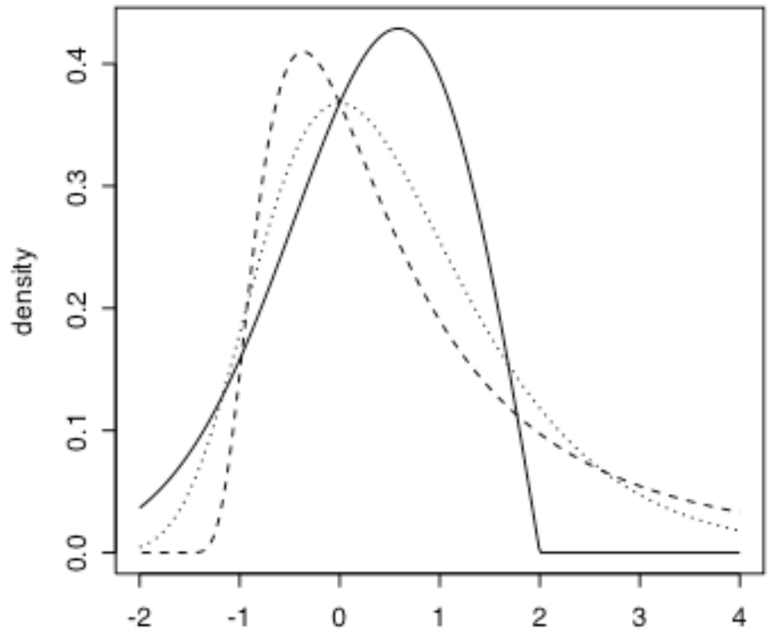
Generalized Extreme Value Distributions (GEV)

GENERALIZED EXTREME VALUE

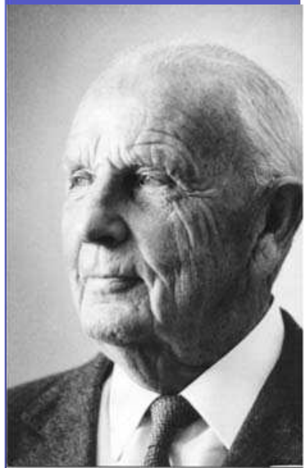
Maxima

Extreme Value Theory

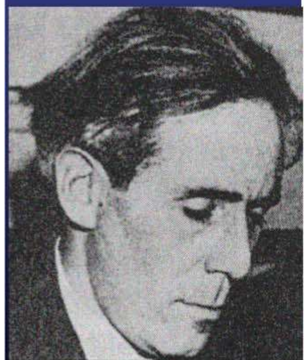
GEV



Fréchet



Weibull



Gumbel

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Framework

$$X_1, \ldots, X_n : \text{ IID climate variable}$$

$$M_k = \max_{i \in B_k}(X_i),\ B_k \text{ block of fixed size (year, season)}$$

Probability distribution of M_k (if it converges)?

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

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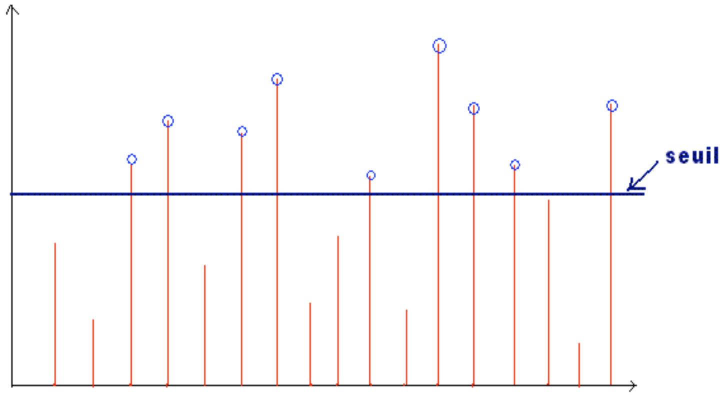
Peak Over Threshold (POT)

Distribution de Pareto Généralisée (GPD)

- F_N empirique des Y?
- $F_N \rightarrow G$



Depassements de seuil

- Candidats: Pareto
- Conditions ↔ extrêmes

Generalized Pareto Distribution (GPD)

For a “large” threshold u:

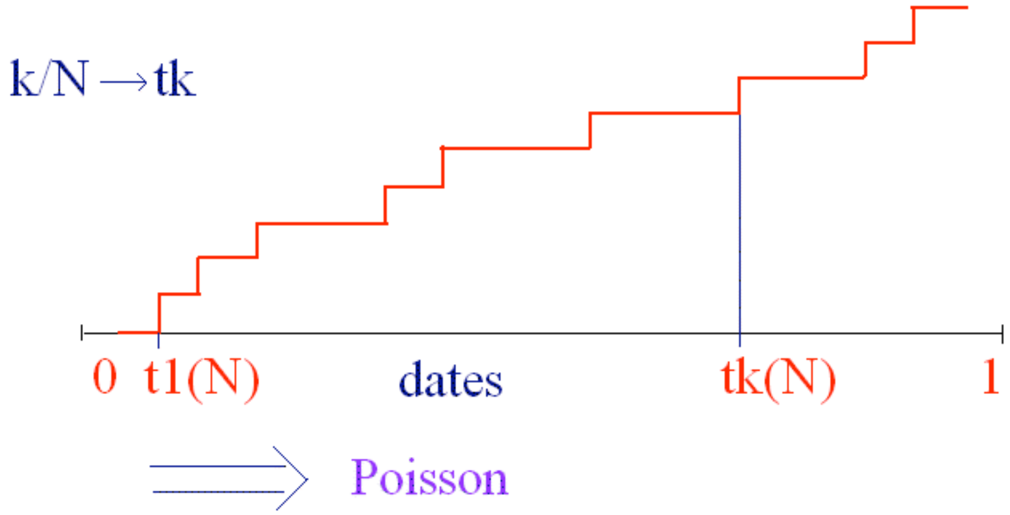
Seuil fixe

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

Shape parameter

Scale parameter

Convergence vers Poisson



$t_1^N \quad \rightarrow \quad Y_1^N$ Au dessus du seuil

$\vdots \quad \rightarrow \quad \vdots$ " "

$t_k^N \quad \rightarrow \quad Y_k^N$ " "

Poisson distribution for exceedances

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

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

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Examples

Application

Changes in temperature RL_{20} in simulations of a General Circulation Model, for A2 scenario.

μ

σ

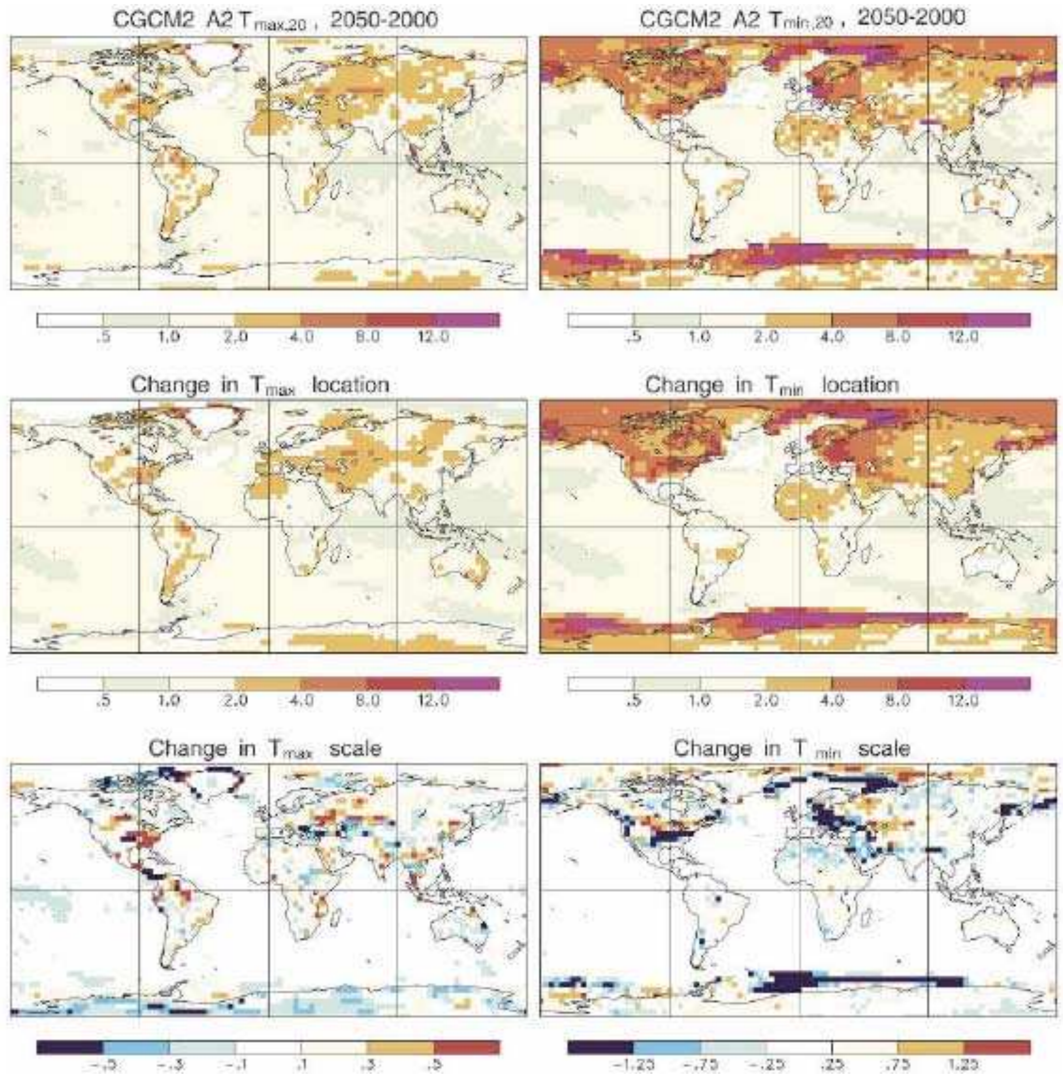

FIG. 6. Change in 20-yr return values of annual extremes of (top left) daily maximum surface temperature and (top right) daily minimum surface temperature, and the corresponding changes in the (middle) fitted GEV location parameter ξ and (bottom) scale parameter α as simulated by CGCM2 in 2050 relative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

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

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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):

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

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

How do σ(t) and λ(t) vary in time?

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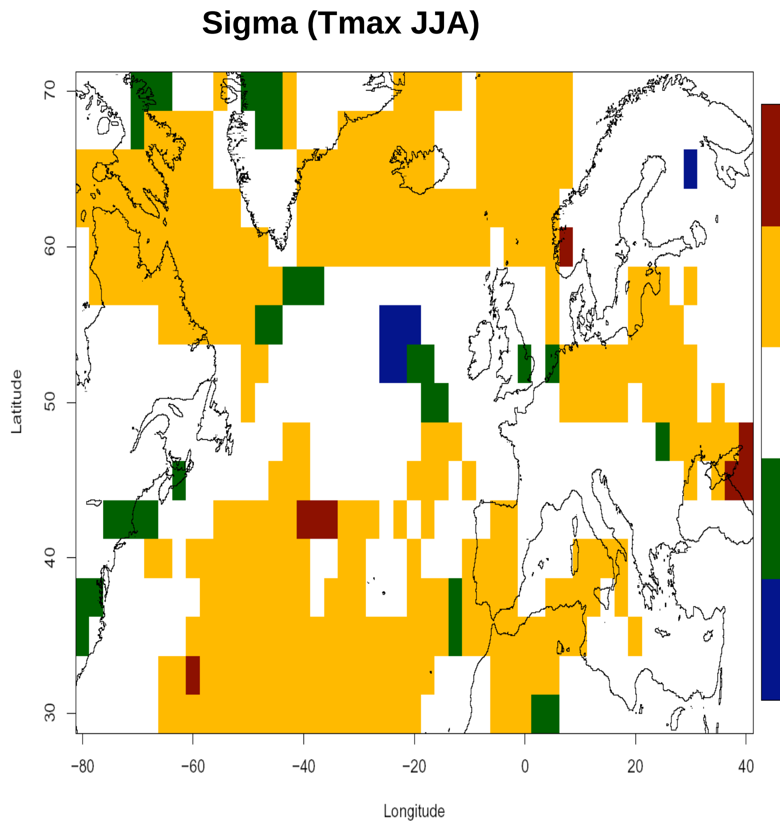
Trends of Tmax JJA – Pareto/Poisson

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

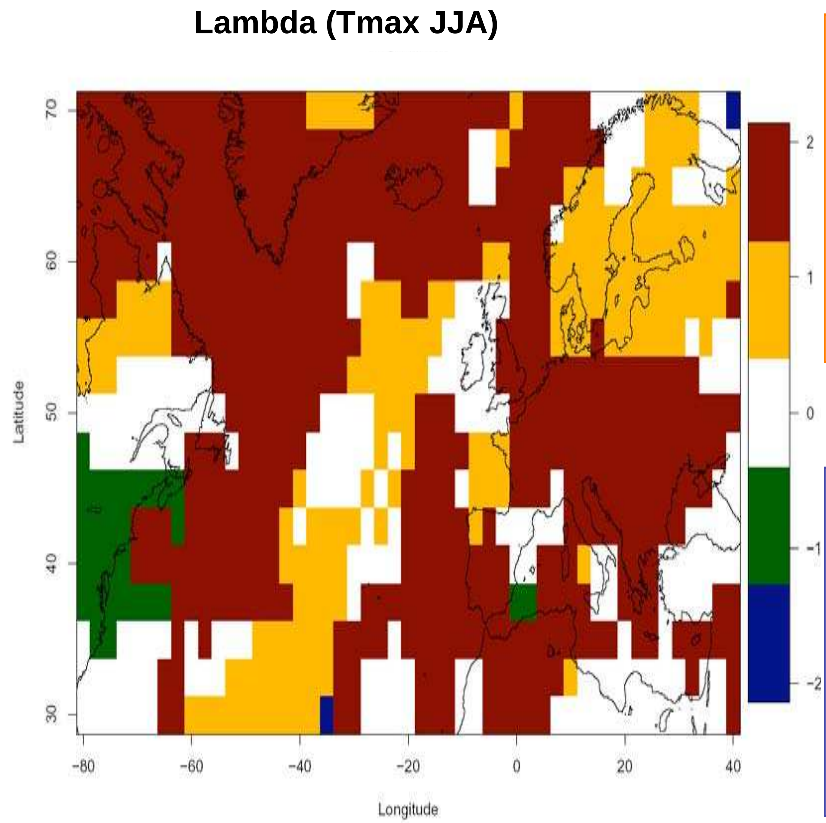
$$\begin{cases} \lambda(t) = \lambda_0 \\ \lambda(t) = \lambda_0 + \lambda_1 t \\ \lambda(t) = \lambda_0 + \lambda_1 t + \lambda_2 t^2 \end{cases}$$



σ increasing

σ decreasing

Amplitude of heat waves



λ increasing

λ decreasing

Frequency of heat waves

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Nogaj et al. GRL 2006

Downscaling

- Relate large scale and local scale
- A zoo of statistical methods!
- “Difficult” climate variables
  – Precipitation
  – Wind speed

Source: M. Vrac (LSCE)

Definitions

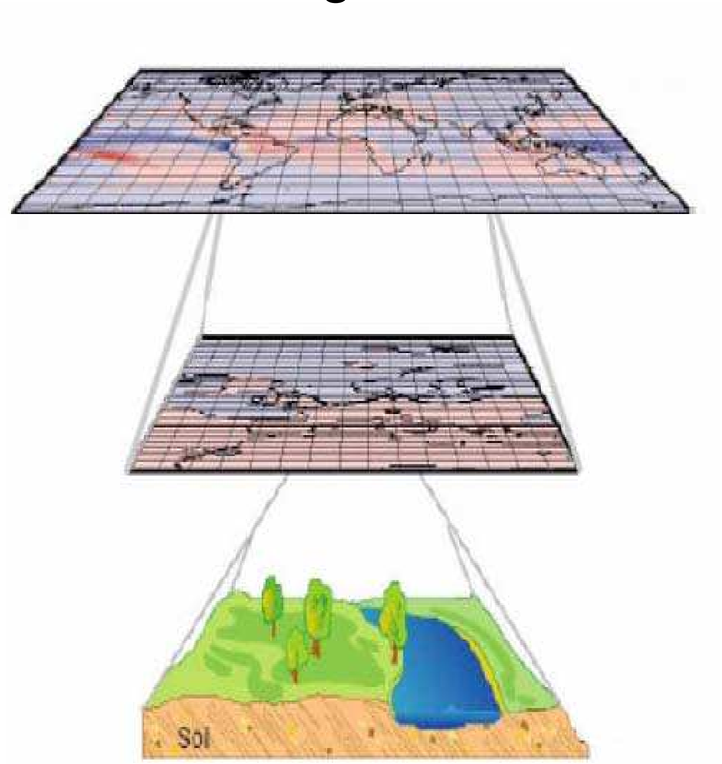
Definition 1:

Downscaling is the process of making the link between the state of some variable representing a "large scale" and the state of some variable representing a much "smaller scale".

Definition 2:

Downscaling is the action of generating climatic or meteorological values and/or characteristics at a local scale, based on information (e.g., from GCM/reanalyses) given at a large scale.

Large scale



Local scale

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Source: M. Vrac (LSCE)

Why downscaling?

Main reason:

General Circulation Models (GCM) have a spatial resolution too low for many climate studies

⇨ needs for simulations at higher resolution

- For present climate: To help to understand local-scale physical processes (e.g. fine scale water cycle)
- For future climate: To derive future GCM output at the scale(s) needed for impacts studies (e.g. prec. extremes are very local)
- For past climate: To compare climate reconstructions (from proxies) at given locations to (downscaled) palaeo-GCM/EMIC outputs

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Source: M. Vrac (LSCE)

How to downscale?

≈ 200 km

Coarse atmospheric data
Precipitation, temperature, humidity, geopotential, wind, etc.

Dynamical downscaling:

- GCMs to drive regional models (10-50km) determining atmosphere dynamics
- Requires a lot of computer time and resources ⇨ Limited applications

Statistical downscaling (SDM):

- Based on statistical relationships between large- and local-scale variables
- Low costs and rapid simulations applicable to any spatial resolution
- Uncertainties (results, propagation, etc)

Region, city, fields, point

Local variables (e.g., precip., temp.)
(small scale water cycle, impacts – crops, resources – etc.)

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Source: M. Vrac (LSCE)

Weather typing approach

<u>Principle</u>: *The weather typing approach consists first in defining large-scale circulation patterns (e.g., clustering), and then in adapting one statistical model per pattern (weather type).*

<u>Clustering</u>:

- *Subjective* WT (Lamb, 1972, for the UK; Hess & Brezowsky, 1976, EU)
- *Objective* WT: Mathematical clustering methods

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Local vs. Synoptic variability

- Relations between precipitation extremes and the atmospheric circulation?
- How to add physical insight to statistical modeling…

Exercice…

- Geopotential height at 500mb (z500) of NCEP reanalyses (1948-2008)
  - Summer anomalies over the North Atlantic
- Surface temperature of the reanalysis
  - Western Europe in summer
- Classification with kmeans of z500 into four weather regimes

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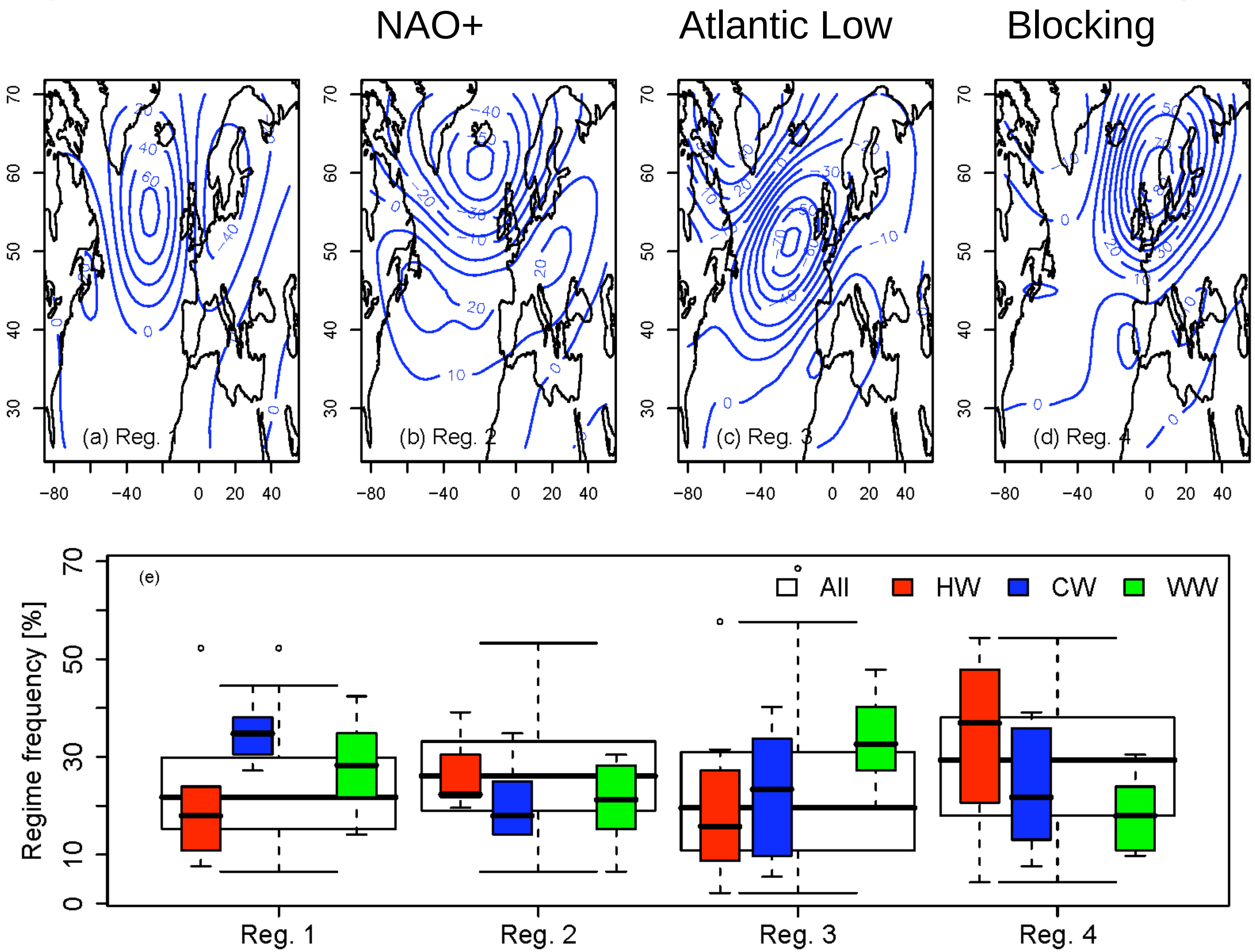
A Dynamical Predictor: Summer Weather Regimes



Regime Dependence

Conditional GPD

We compute GPD parameters for each of the regimes (i), for temperature and precipitation, with the underlying confidence intervals:

$$\mathrm{P}\left(X(t) > x \mid X(t) > u \;\; \& \underbrace{Y(t)}_{\text{Weather pattern}} \in \underbrace{R_i}_{\text{Regime } i} \right) = \left[1 + \frac{\xi_i \left(x - u \right)}{\sigma_i} \right]^{-\frac{1}{\xi_i}}$$

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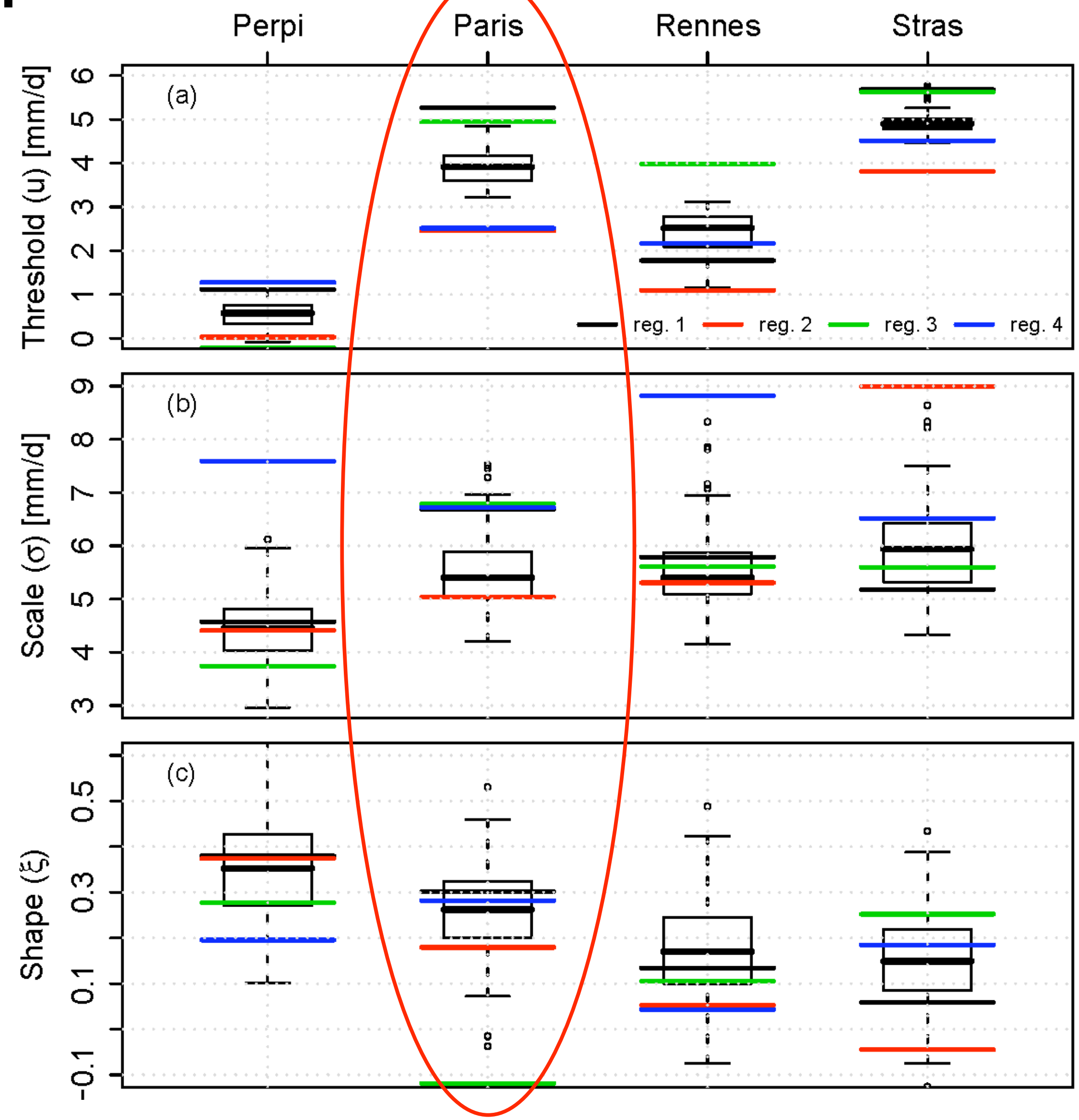
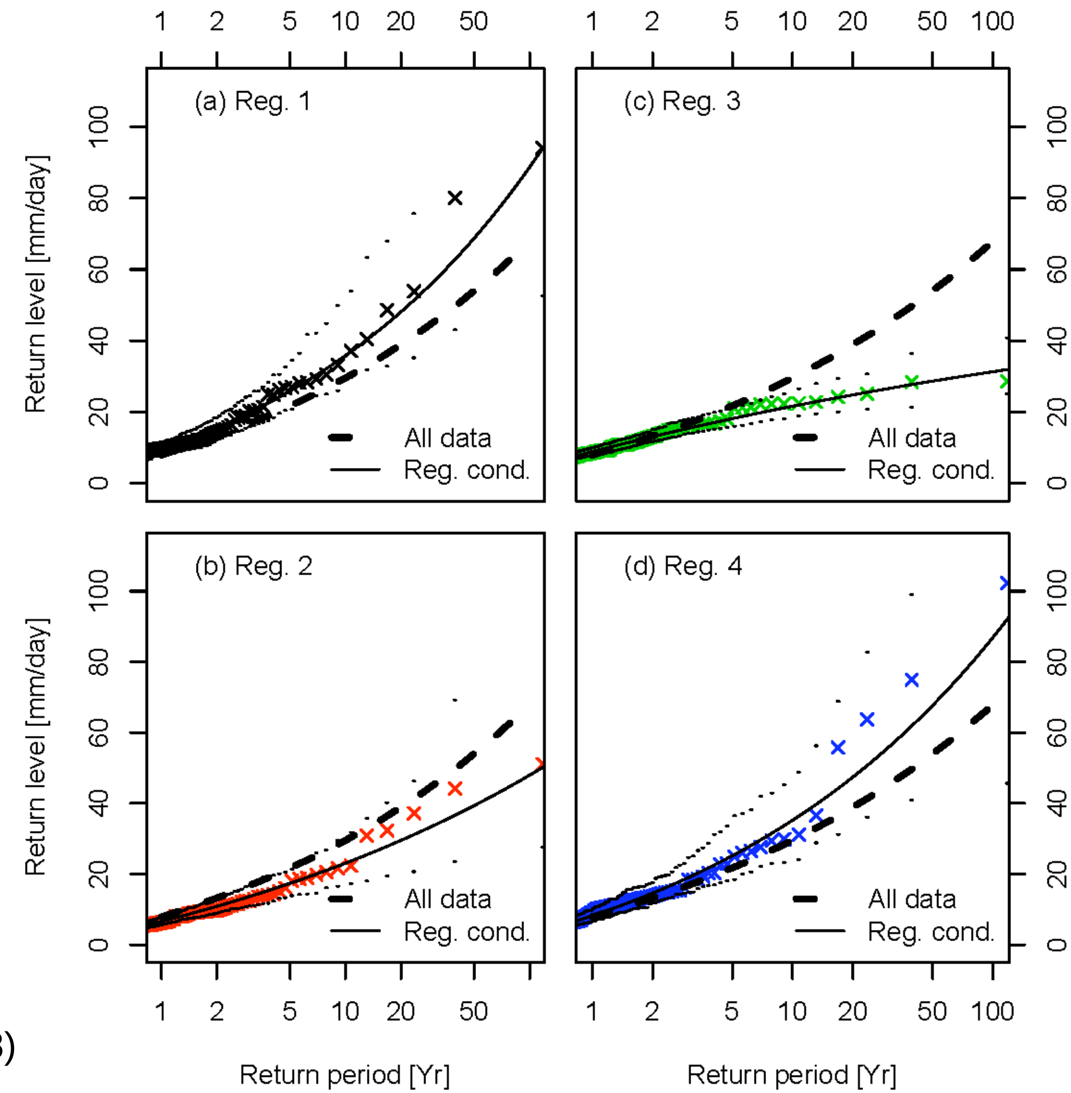
Circulation Dependent GPD parameters



Monte Carlo experiments for the range of GPD parameters for precipitation, in four cities in France

Circulation Dependent Return Levels

Precipitation return levels in Paris, and their dependence to weather regimes.



(Yiou et al., Nonlin. Proc. Geophys., 2008)

GPD Conclusion

- Strong refinement of GPD "prediction" when weather regime information
- A non intuitive result:
  - Wet European summers (regime 3: ***Atlantic Low***) do not have precipitation extremes
  - Dry and warm summers (e.g. regime 4: ***Blocking***) increase the chance of extremes

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Influence of the circulation on temperature

letters to nature

Signature of recent climate change in frequencies of natural atmospheric circulation regimes

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* *CINECA-Interuniversity Computing Centre, Via Magnanelli 6/3, 40033 Casalecchio di Reno, Bologna, Italy*
† *European Centre for Medium-Range Weather Forecasts, Shinfield Park, Reading, RG2 9AX, UK*

A crucial question in the global-warming debate concerns the extent to which recent climate change is caused by anthropogenic forcing or is a manifestation of natural climate variability[1]. It is commonly thought that the climate response to anthropogenic

interpreted in terms of changes in the frequency of occurrence of natural atmospheric circulation regimes. We conclude that recent Northern Hemisphere warming may be more directly related to the thermal structure of these circulation regimes than to any anthropogenic forcing pattern itself. Conversely, the fact that

surface temperature and satellite-based temperature in the free atmosphere[4–6].

Corti et al. Nature 1999

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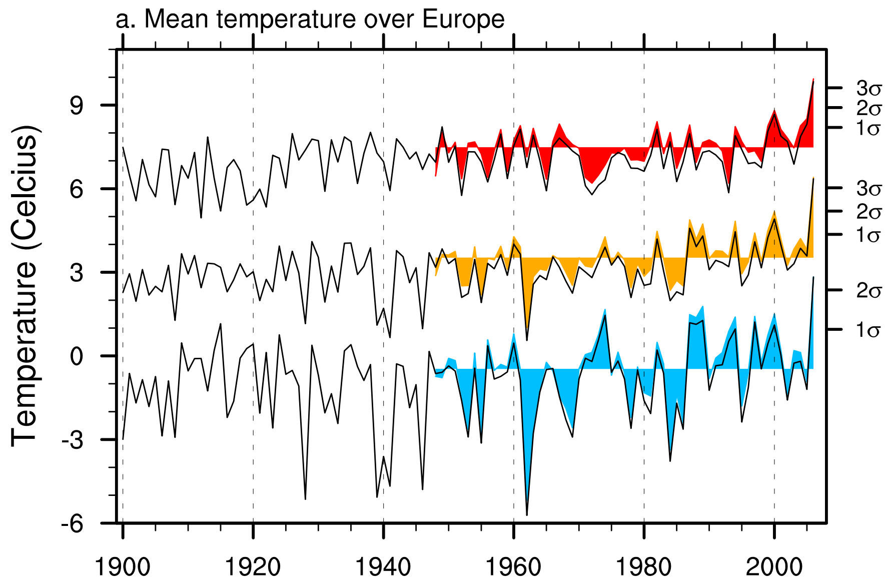
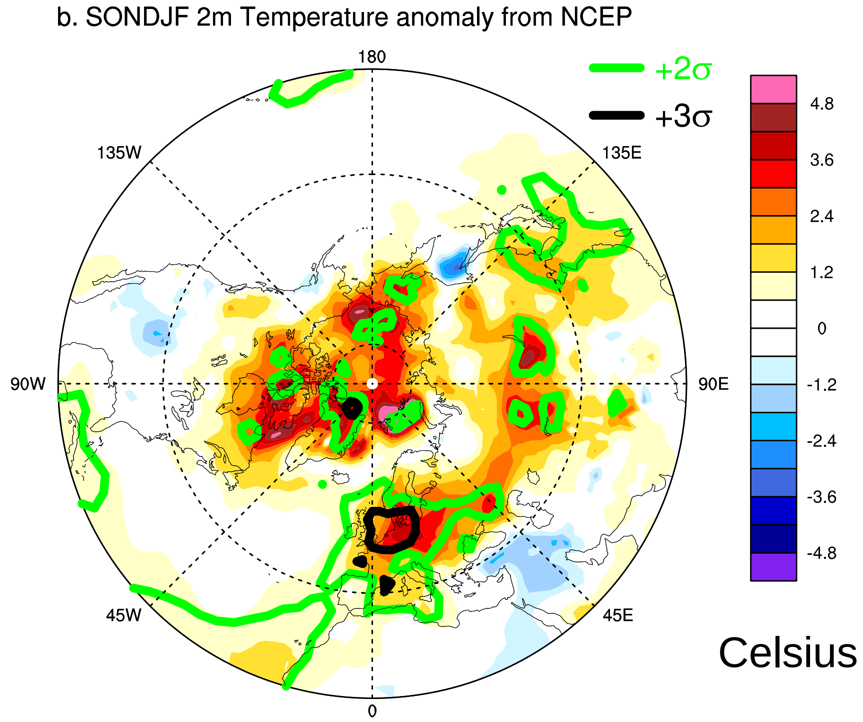
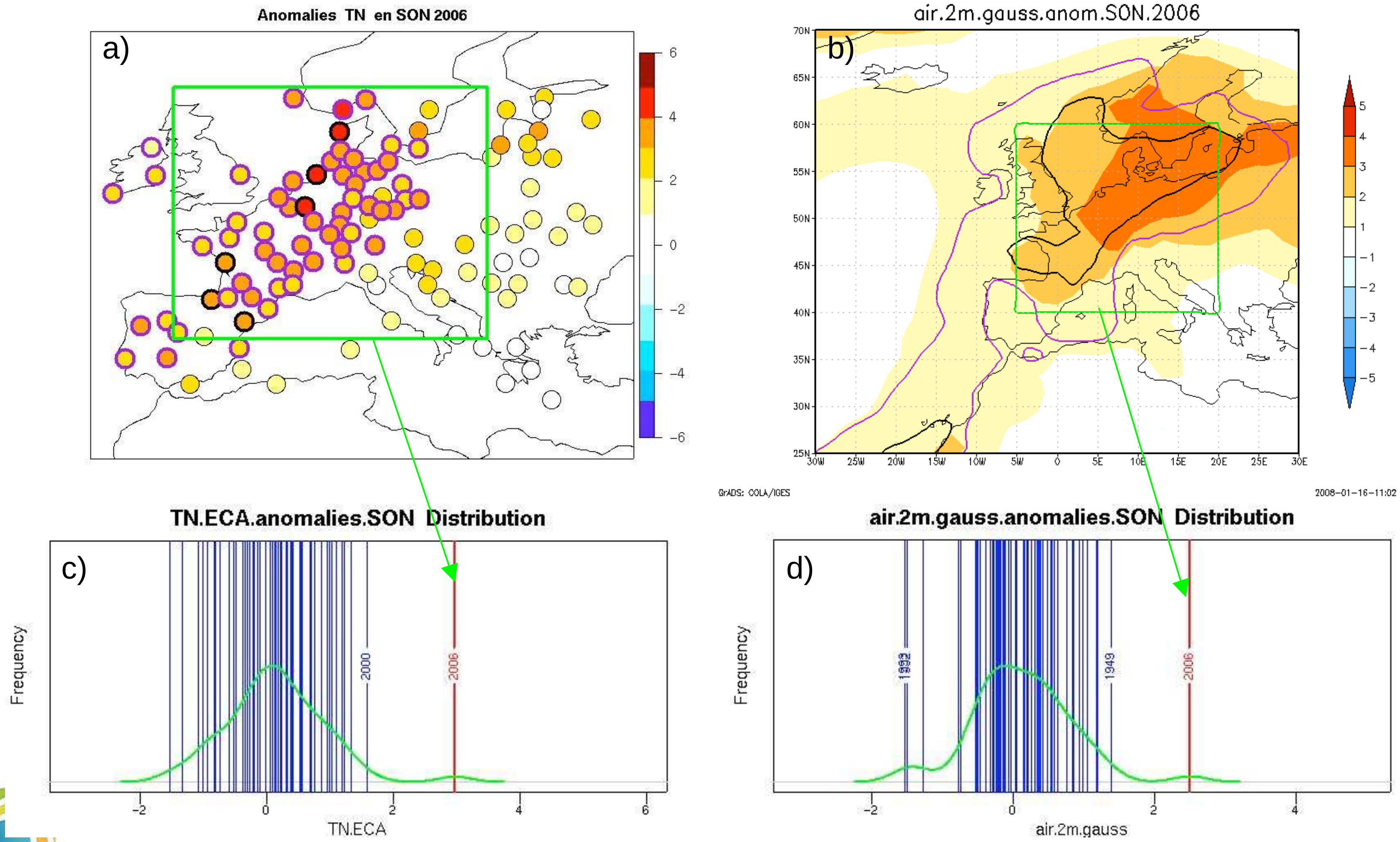
A warm anomaly in 2006/2007





A European record



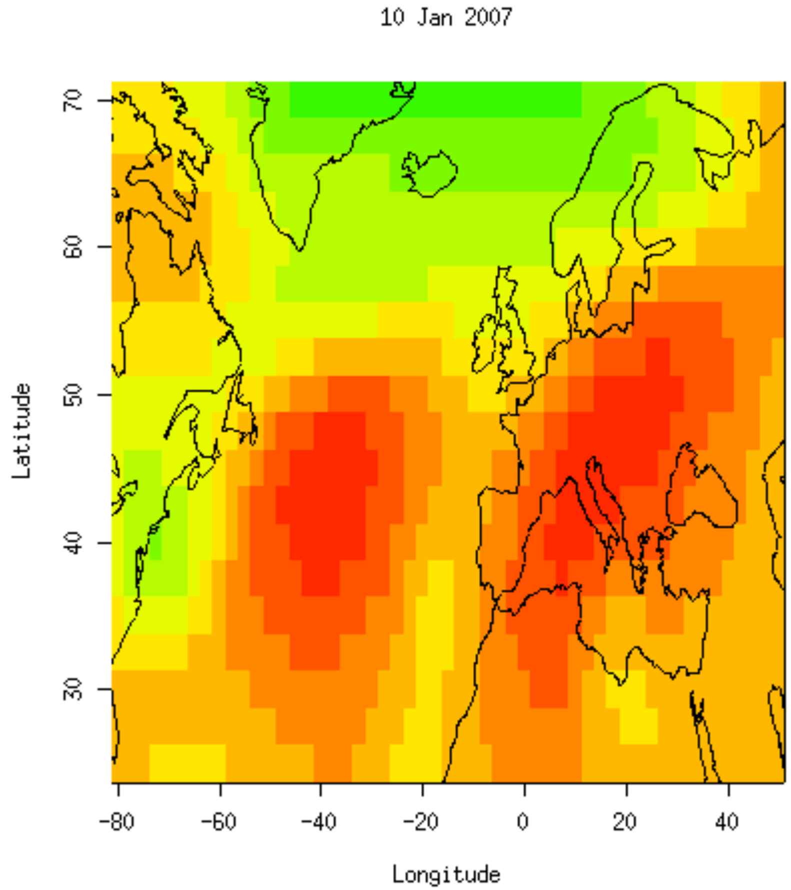
Consequences?

- Impacts on plant phenology & carbon cycle
  - Delayed dormancy
  - Increased risk of bud frost

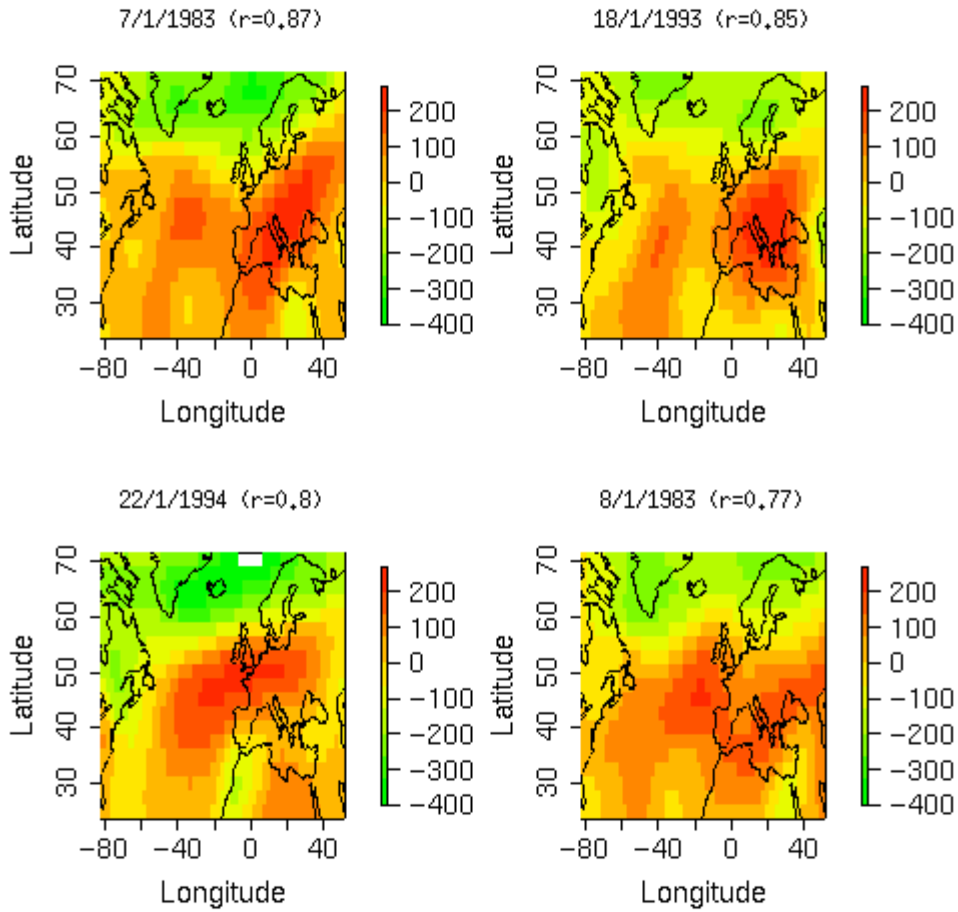
Circulation analogues

- Use of daily geopotential height at 500mb from NCEP reanalyses
- For all days between Jan. 1st 1948 and March 31st 2010, pick the 10 days within 30 calendar days but different year with the closest z500:
  - largest correlation (rank or linear)
  - Smallest Euclidean distance

Examples of z500 analogues



Z500 anomaly on Jan. 10th 2007

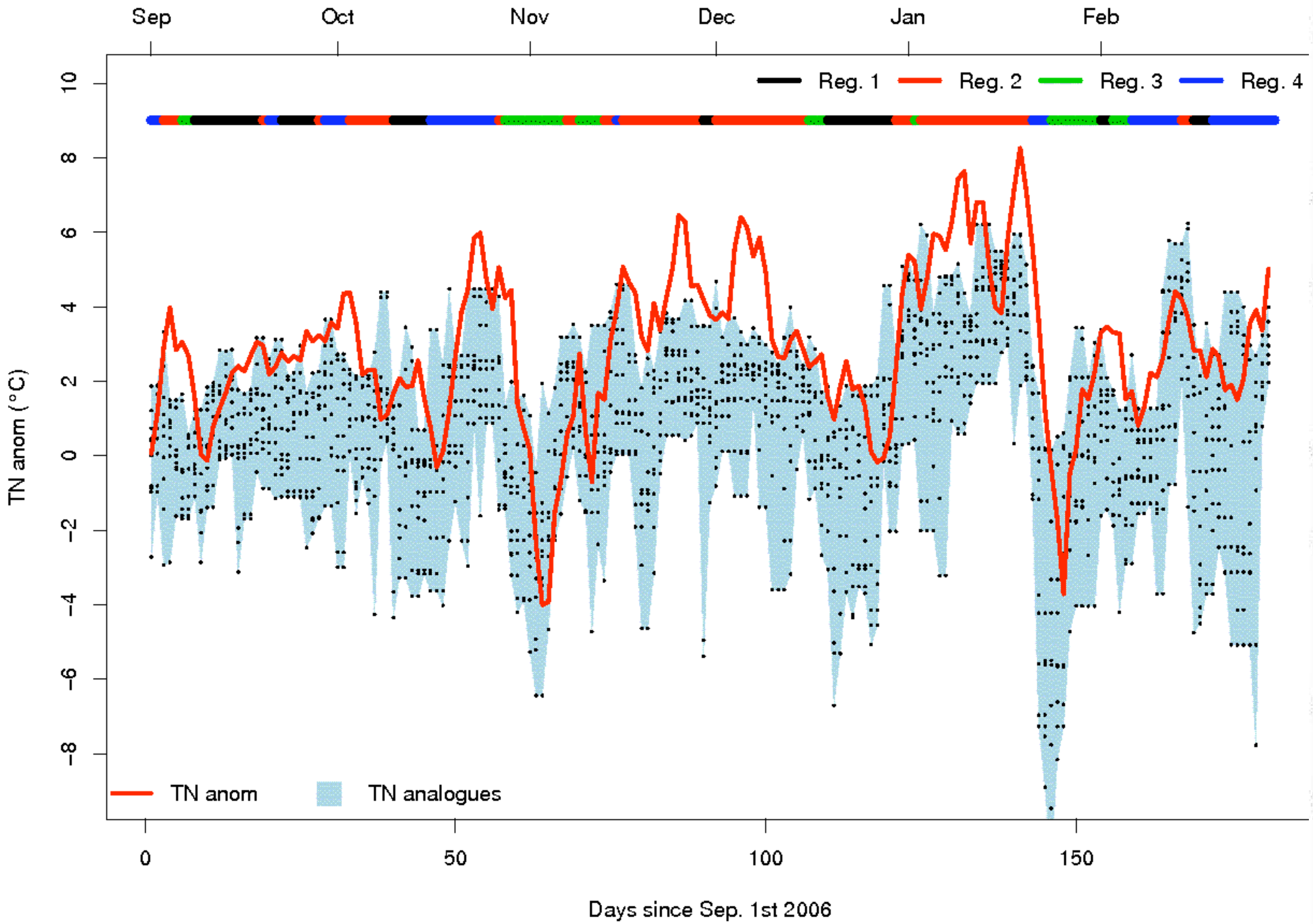


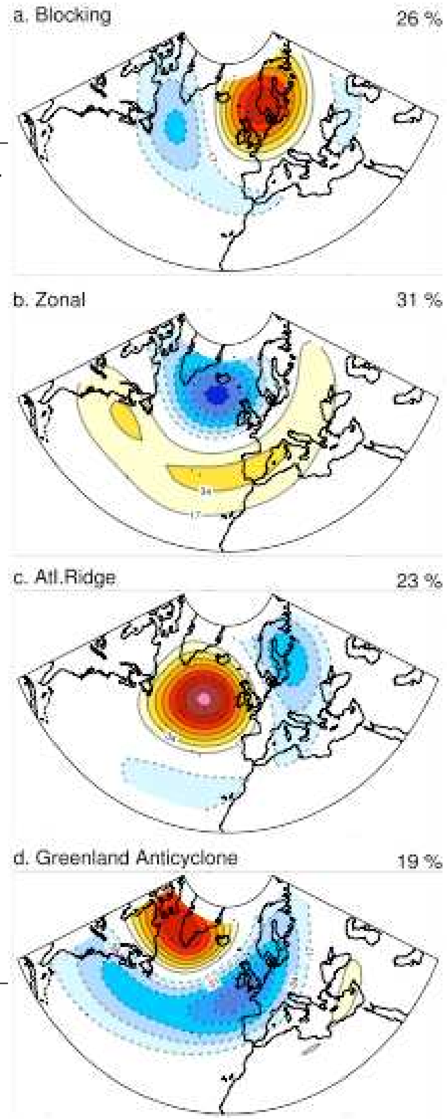
4 best circulation analogues

Temperature analogues

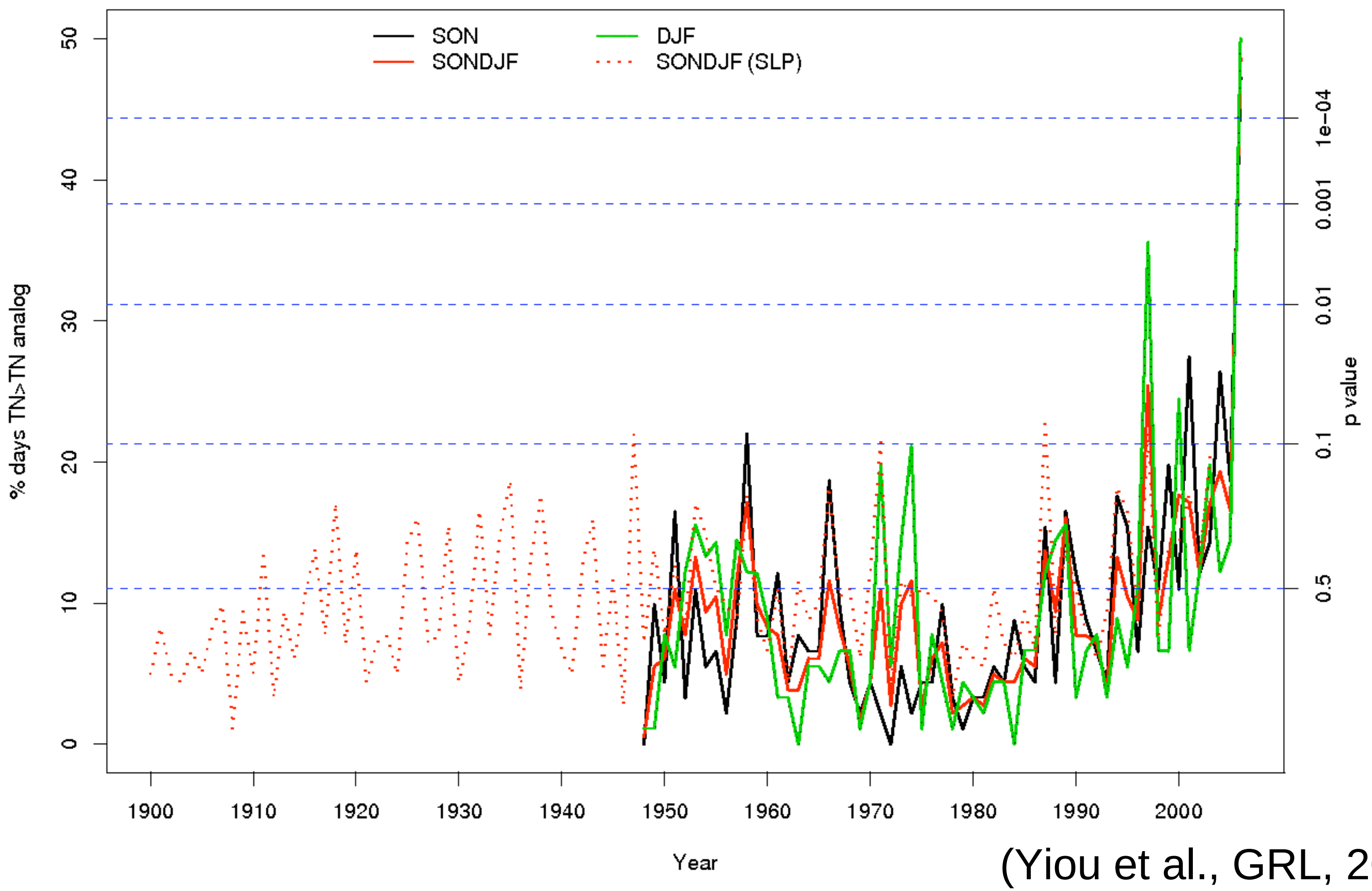
- Average daily minimum temperature (TN) anomalies over Europe
  – ECA&D database
- Compute the median temperature for 10 circulation analogue days
  – Analogue temperature & spread of analogues

Analogue temperatures in Fall/Winter 2006/2007





Probability of high fall/winter high temperatures



(Yiou et al., GRL, 2007)

Circulation/temperature relationship?

- Atmospheric circulation variability explains most of temperature anomalies…
- … up to ~1995
- The record anomaly in 2006/2007 is probably also connected with warm SST around Europe

Winter 2009/2010?

- Record breaking snowfall and low temperatures in the US
- Anomalous number of snow events in Europe
- …During the Copenhagen conference in Dec. 2009

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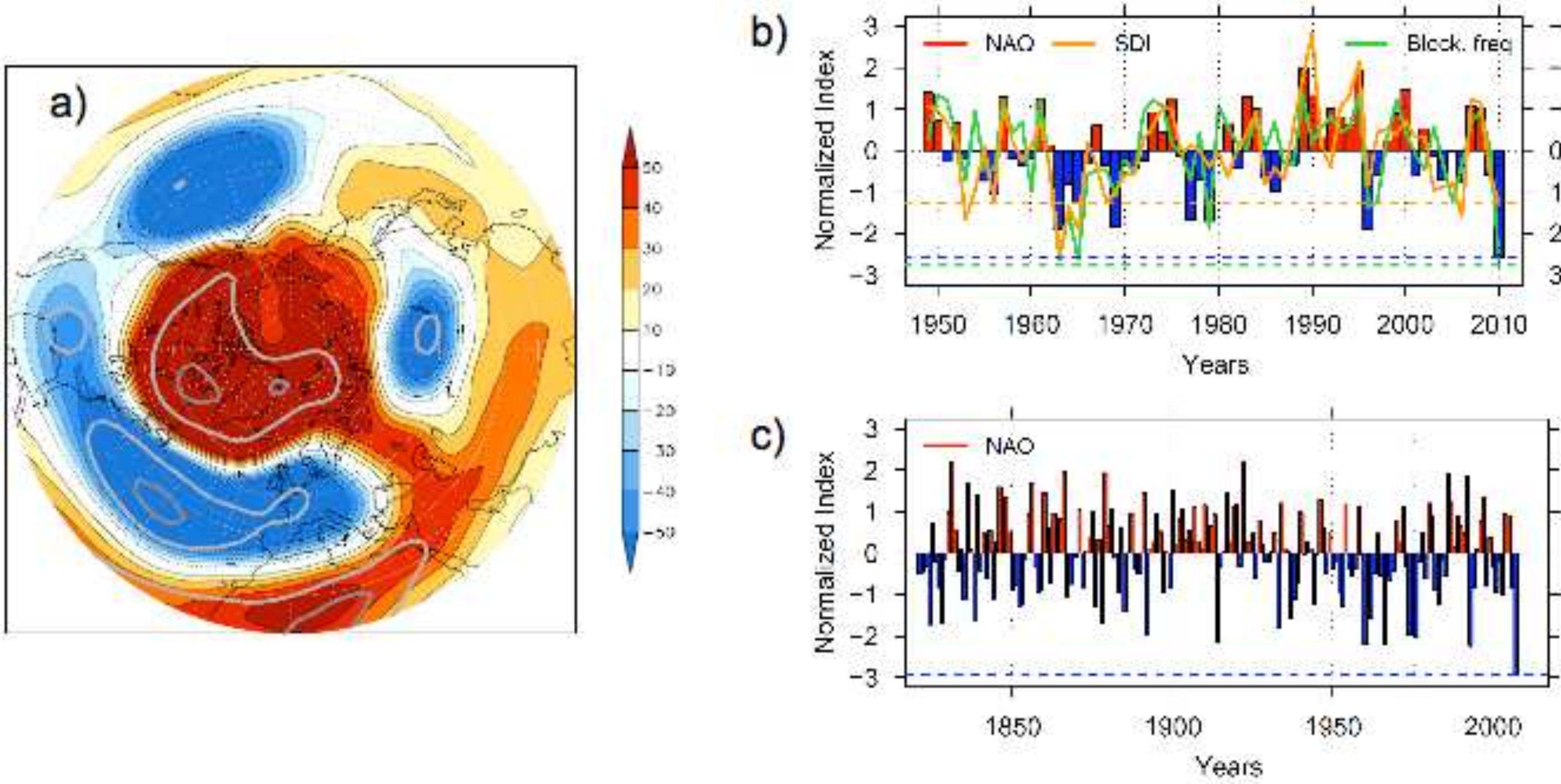
An Anomalous NAO-



(Cattiaux et al., GRL, 2010)

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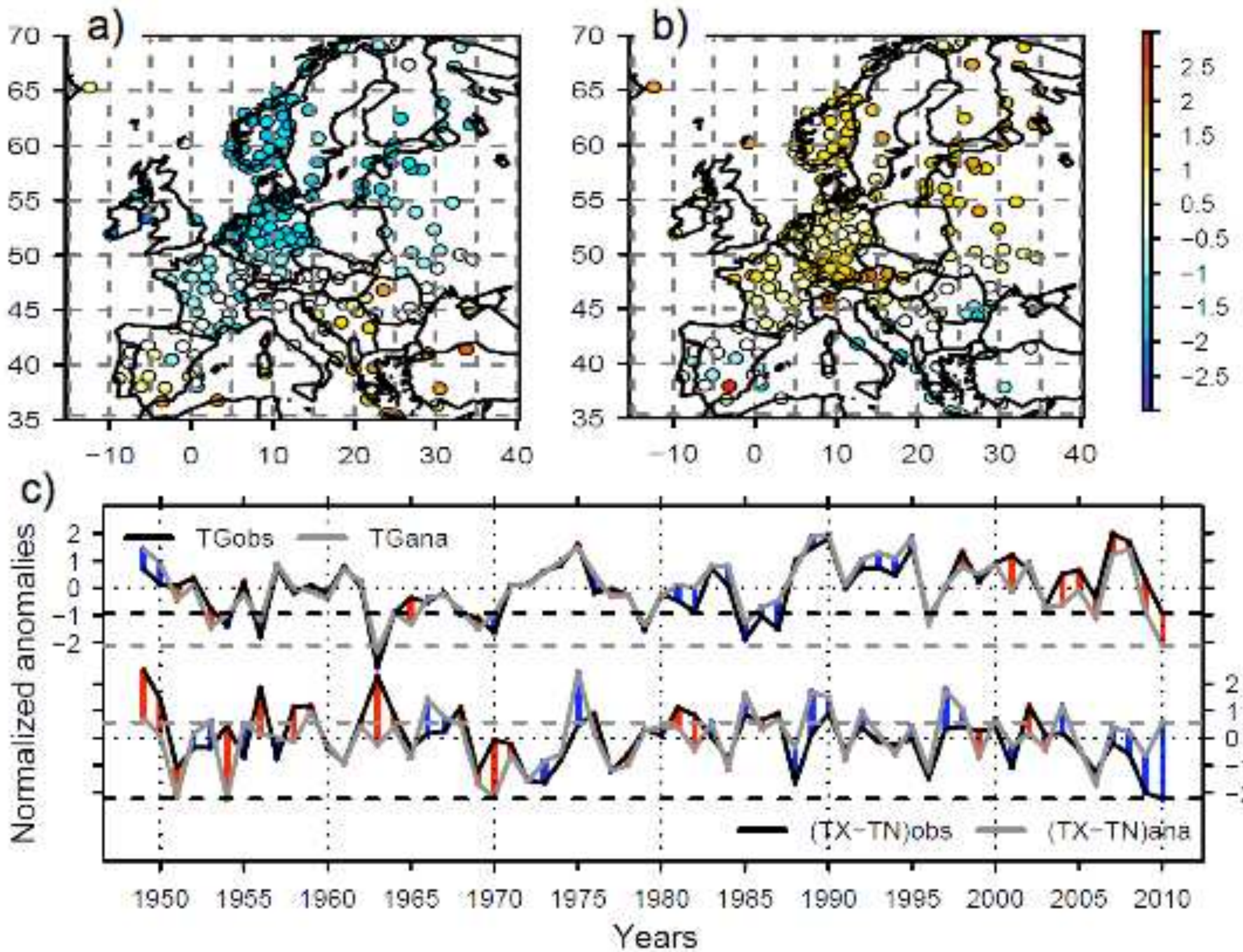
But not that cold



(Cattiaux et al., GRL, 2010)

Winter 2009/2010

- Synoptic circulation leading to cold temperatures in Europe (potentially record breaking)
- Cold but not extreme in Europe
- A record cold for the 21st century?

Still a long way to go

- Small scale extremes vs. Large scale climate change
- No real statistical modeling of “lasting events” (e.g. droughts)
- Detection & Attribution of changes in extremes?
- Physical understanding of extremes:
  - Are extremes like normal events, just more intense? (see “The Great Gatsby”, S.F. Fitzgerald)

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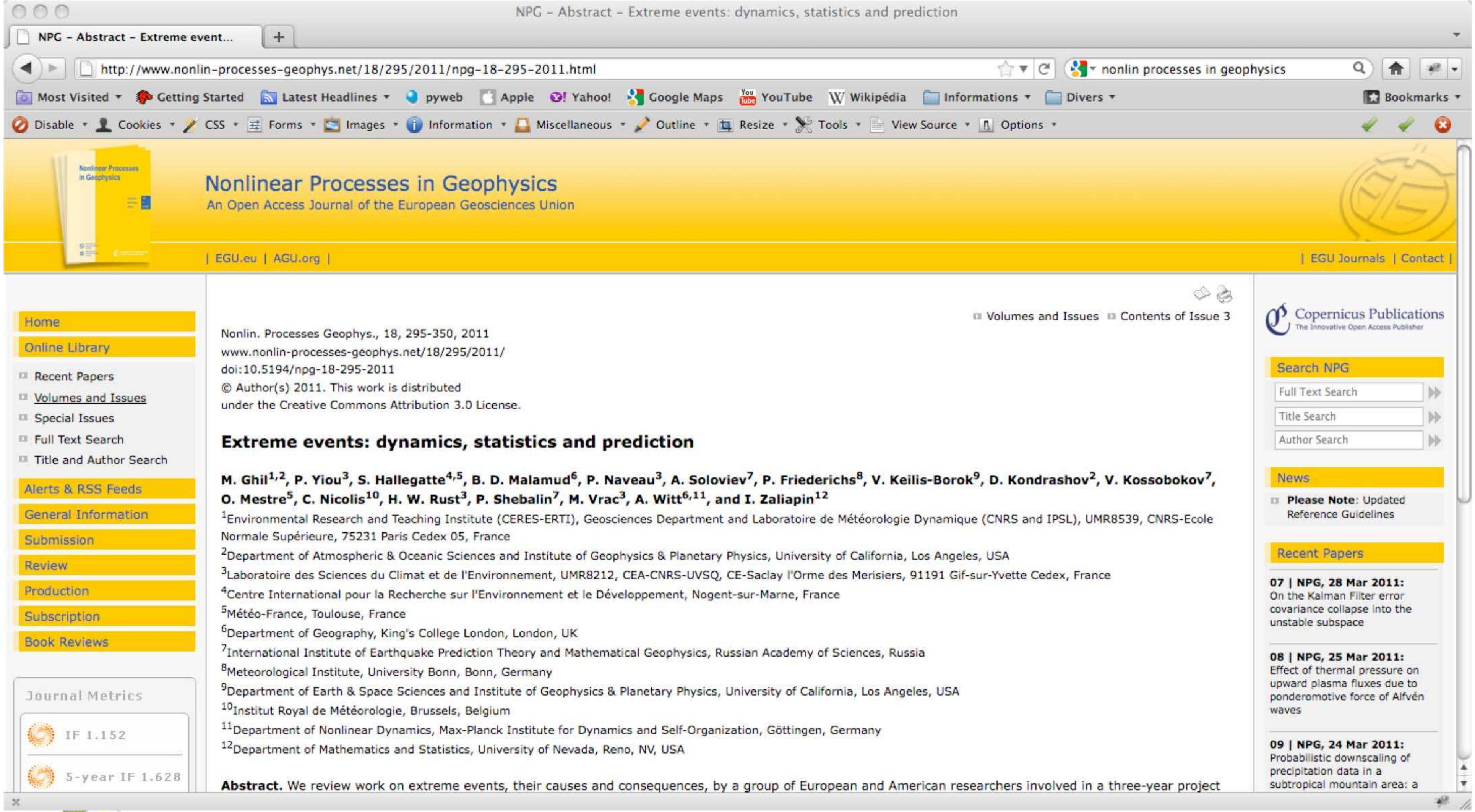
References…


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

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doi:10.5194/npg-18-295-2011

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]

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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

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