

# Black swans and butterflies: analogues of atmospheric circulation

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# Motivations

- Study climate events and relate them to large-scale atmospheric circulation
- If there is a climate attractor, how to measure a qualitative alteration?
  - Link with forcings (solar, volcanoes, GHG...)
- Detection, attribution and emergence?

# Circulation analogues (1)

- *Reference* database **R**, containing consistent pressure (SLP and/or geopotential heights), temperature, precipitation etc. data during a reference period of observations
  - E.g. Reanalysis data for a fixed period, model control simulation
- *Target* dataset **T**, with only pressure data (SLP or geopotential height)
  - E.g. Observation during a period outside of the reference

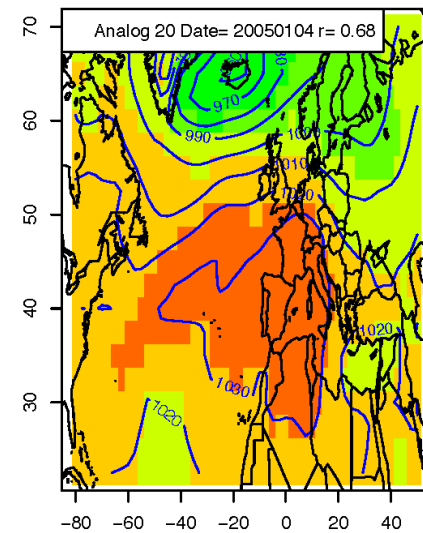
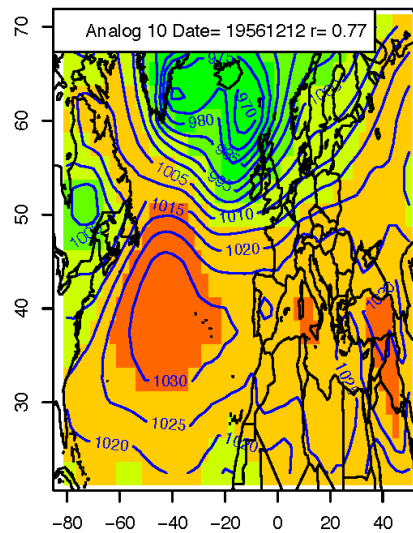
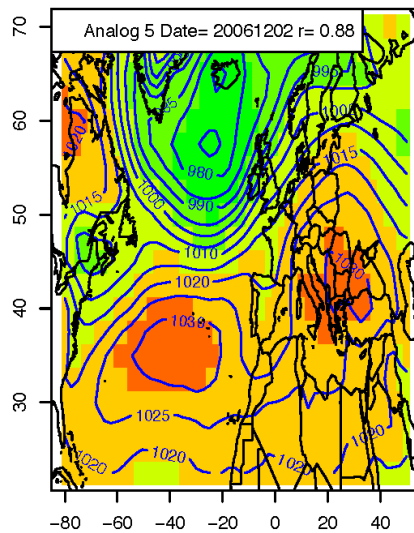
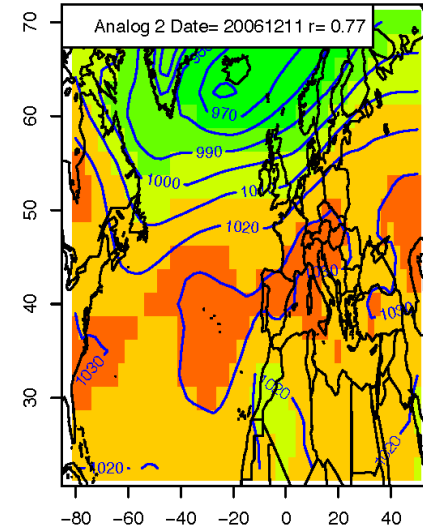
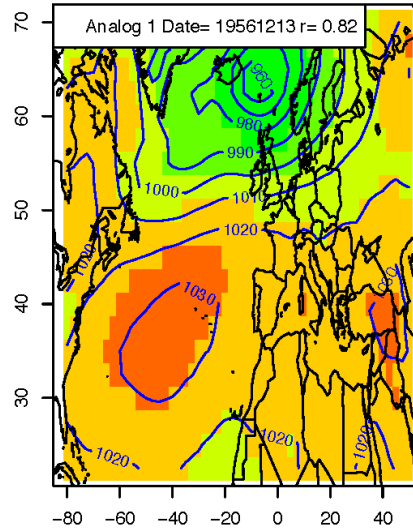
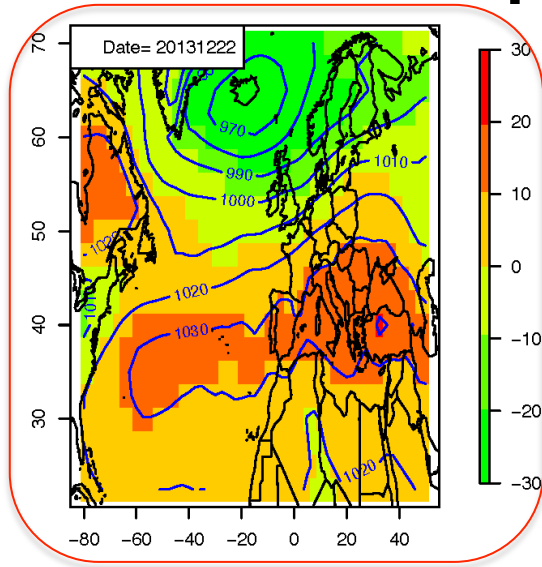
# Circulation analogues (2)

- We want to infer the value of climate variables (e.g. T, Prec., Wind speed) in the dataset **T**, from information in the database **R**.
- For each day in **T**, find best analogues of pressure in **R**.
  - Minimize distance (Euclidean, Mahalanobis...)
  - Maximize spatial correlation (rank)

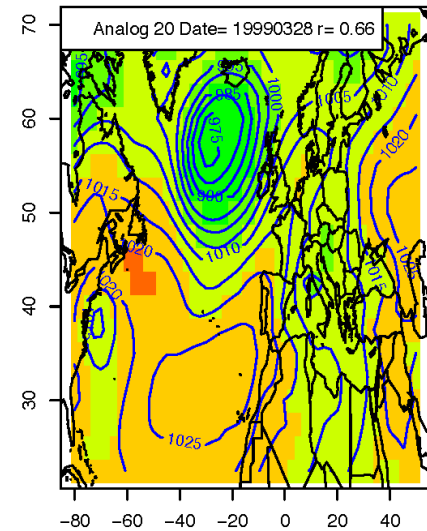
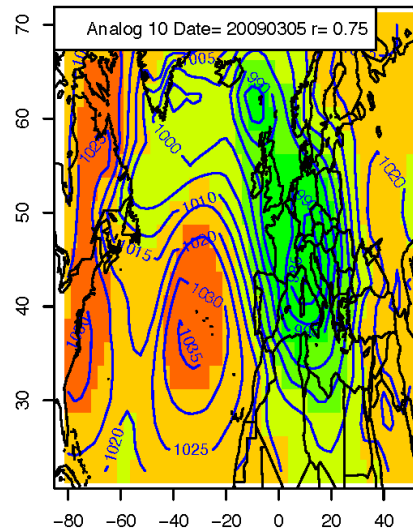
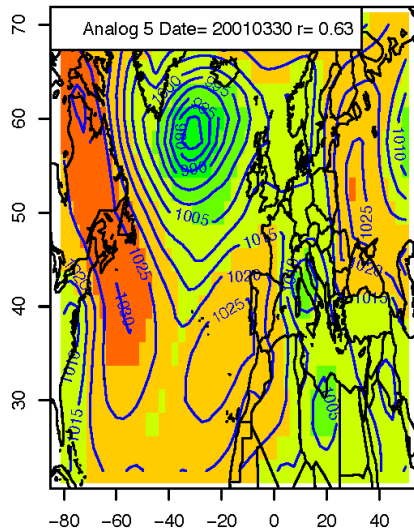
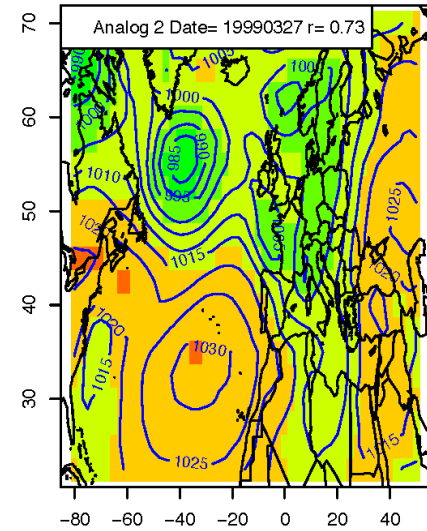
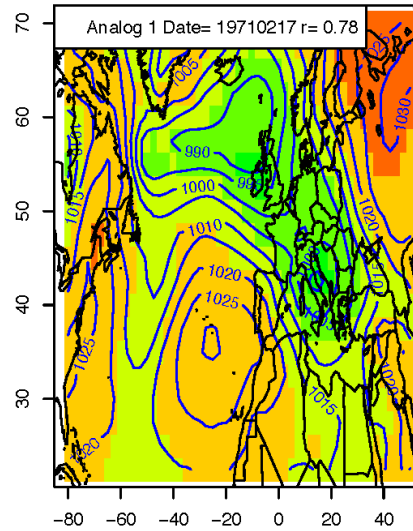
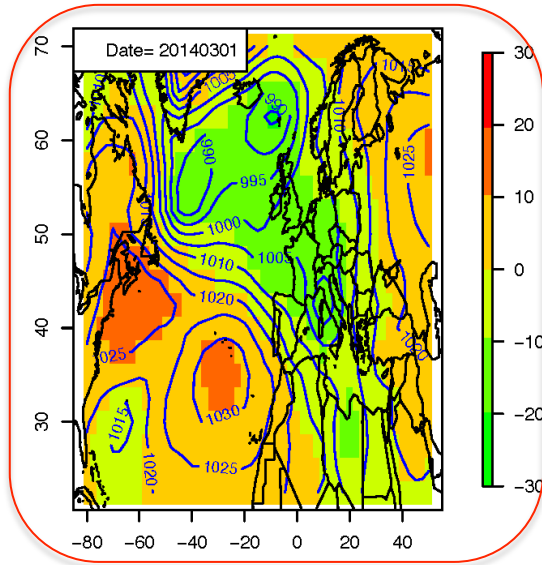
# Circulation analogues (3)

- Use of daily sea-level pressure (SLP) from NCEP reanalyses
- For all days between Jan. 1st 1948 and March 31st 2013, pick the 10 days within 30 calendar days but different year with the closest SLP:
  - largest correlation (rank or linear)
  - Smallest Euclidean distance

# Example (1) Storm Dirk



# Example (2)



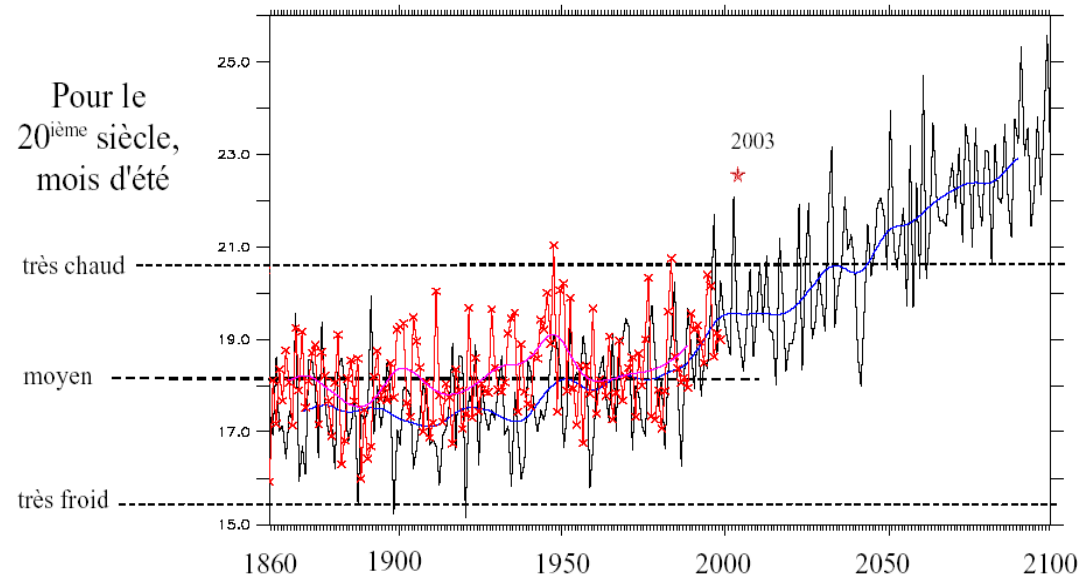
# Temperature analogues

- 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



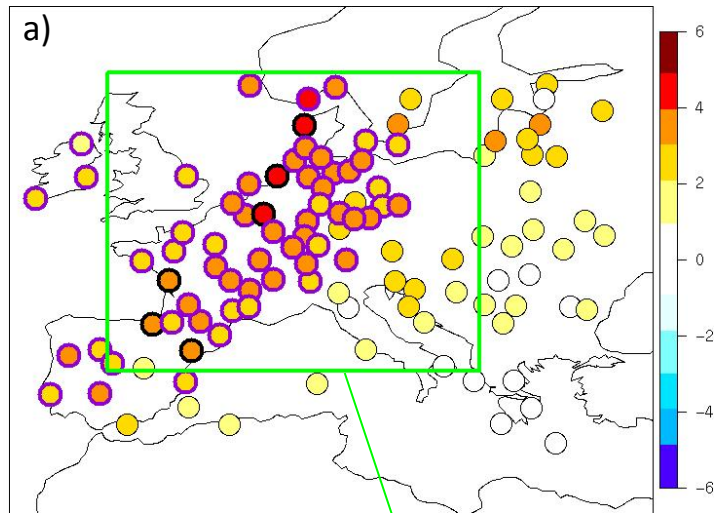
# Black Swans

- Extreme events never seen before...
  - E.g.: AIDS virus, Sept. 11 2001, 2003 heatwave...
- ...That (could) become a norm

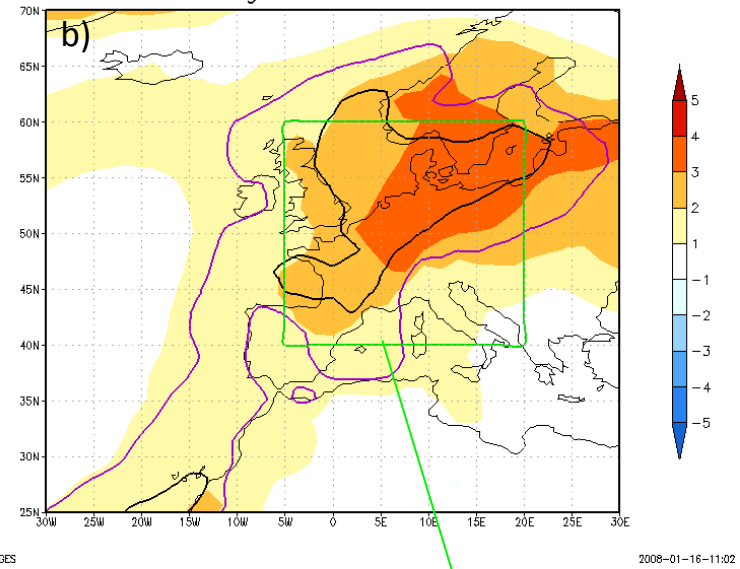


# A European record in 2006

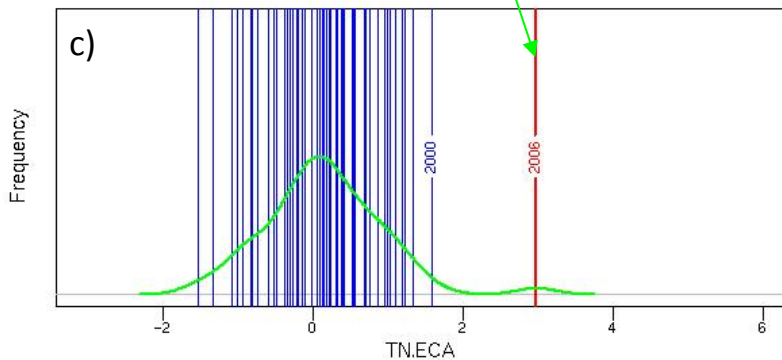
Anomalies TN en SON 2006



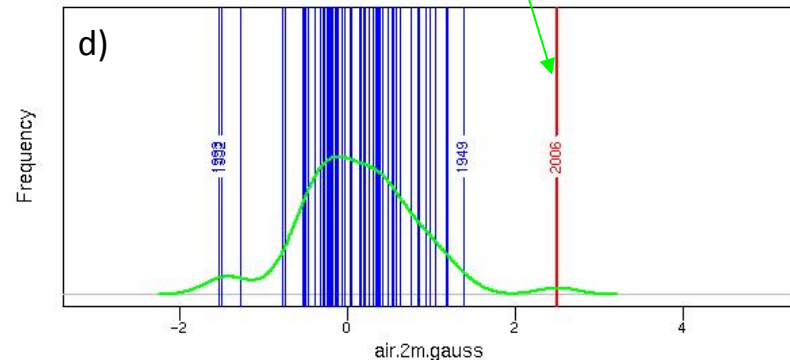
air.2m.gauss.anom.SON.2006



TN.ECA.anomalies.SON Distribution



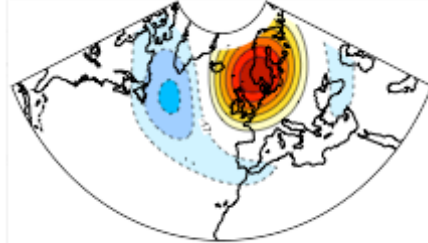
air.2m.gauss.anomalies.SON Distribution



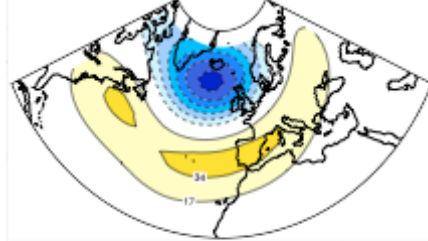
(courtesy of J. Cattiaux)

# Weather Regimes

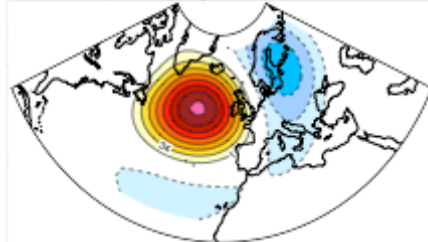
a. Blocking 26%



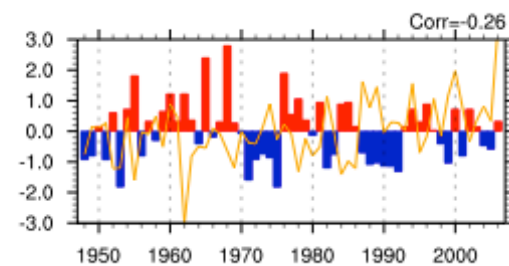
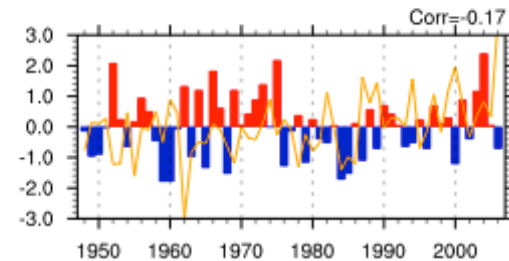
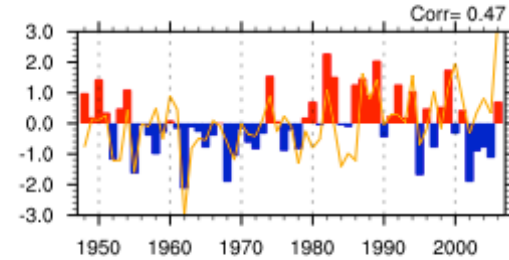
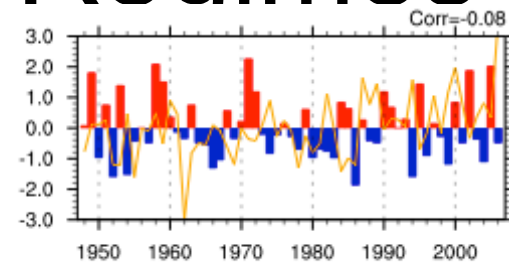
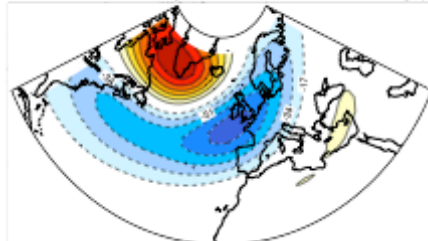
b. Zonal 31%



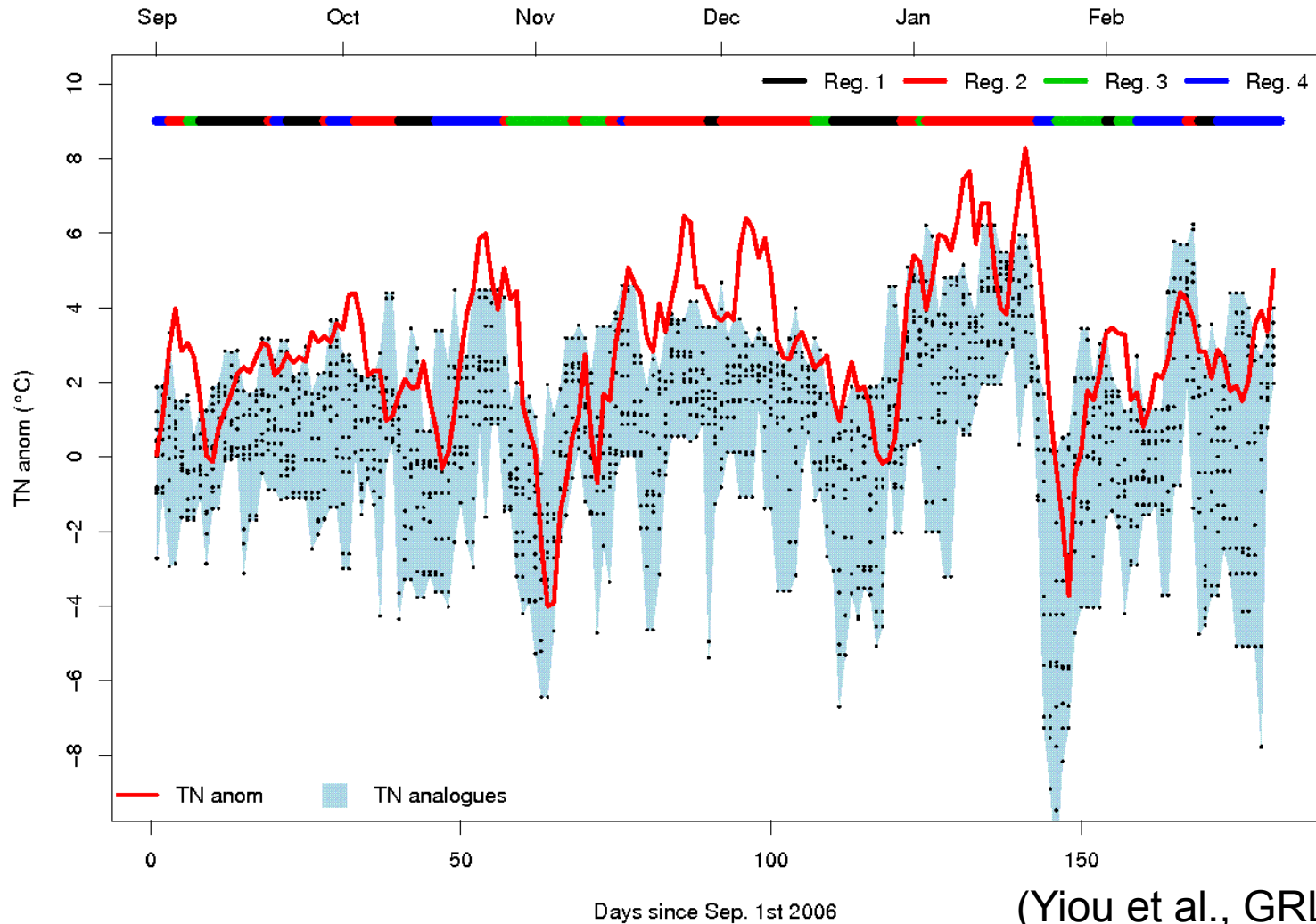
c. Atl. Ridge 23%



d. Greenland Anticyclone 19%



# Analogue temperatures in Fall/Winter 2006/2007



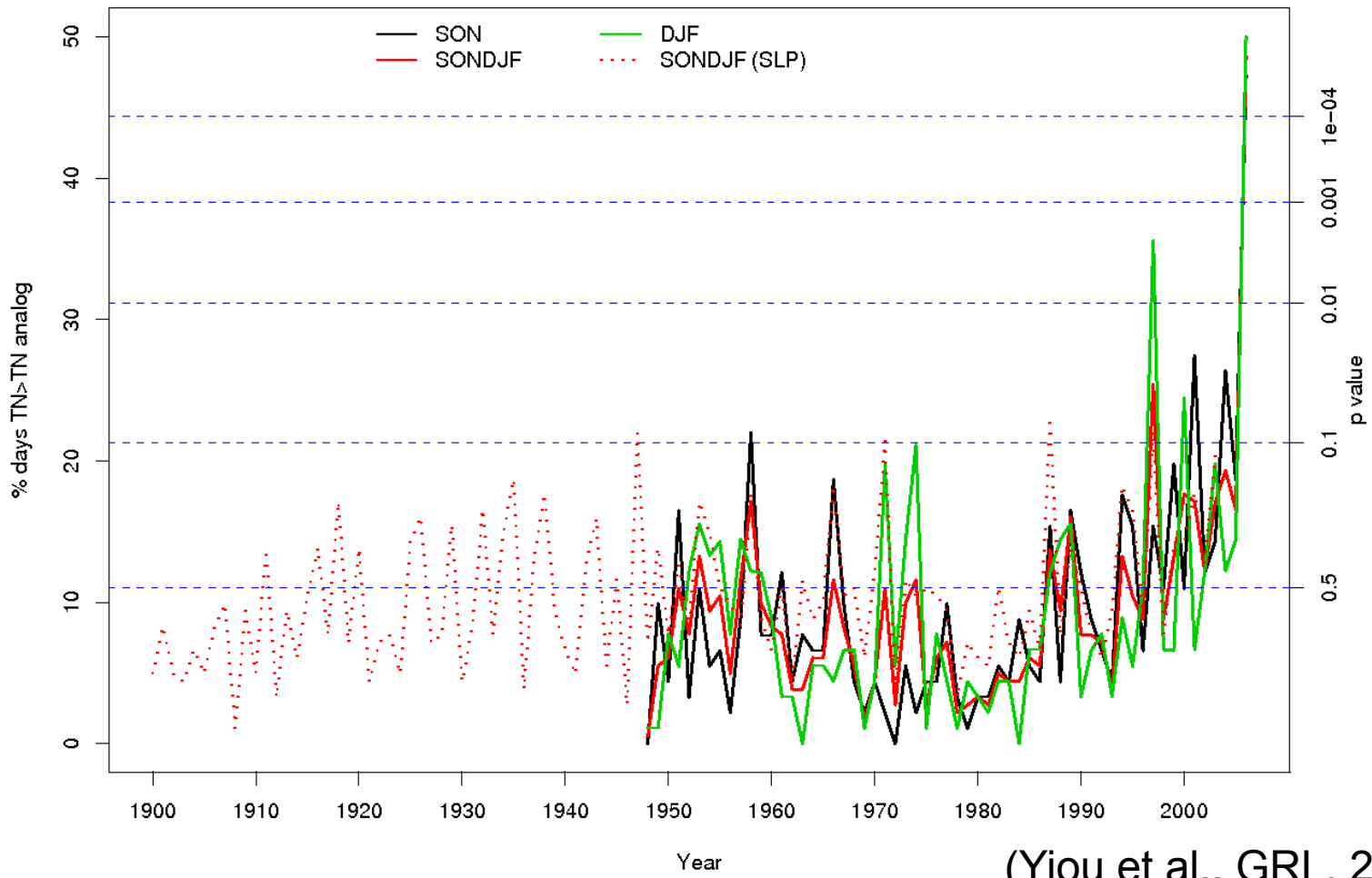
(Yiou et al., GRL, 2007)

# A European black swan?

- How unusual is the winter 2006/2007
- Odds that  $N$  days (out of 90) are above all temperature analogues?




# Probability of high fall/winter high temperatures



(Yiou et al., GRL, 2007)

# Circulation/temperature relationship?



A2C2  
Atmospheric flow Analogues for Climate Change

- 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

# Butterflies

- Sensitivity to initial conditions
  - Chaotic climate system
- Ensembles of trajectories to estimate a probability density for key variables



# Stochastic Weather Generator(s)

- Simulate *many and long* sequences of climate variables with plausible statistical and physical properties
- Use of analogues to generate random sequences of dates (in reference dataset **R**)
  - Generate large ensembles of seasons (~90 days) from random or chosen initial conditions
  - Generate long sequences of a stationary climate

# Analogue weather generators

- Randomized initial conditions
- *Static* weather generator
  - Perturbation of observed trajectories with random trials of best analogues
- *Dynamic* weather generator
  - Iterative computation of new trajectories from best analogues
- The WGs essentially determine random sequences of dates in the NCEP reanalysis

# Analogue weather generators

- Static

Each day ( $d=yyymmdd$ ) is replaced by one of its 20 best analogues. The probability of drawing an analogue  $d'$  is proportional to the correlation of  $SLP(d)$  and  $SLP(d')$

- Dynamic

For each day  $d (=yyymmdd)$ , the next day is chosen among  $yyymm(dd+1)$  and its 20 best analogues

Weight of probabilities proportional to correlation and calendar distance to desired simulated date

# Simulation of temperatures

- Temperature observations from ECA&D
  - Choice of 291 stations with few missing data between 1948 and 2012
- WG simulates the sequences of temperature for each station, with a global constraint from the atmospheric circulation patterns
- Possibility of adding a GPD “residual” when the temperature exceeds a threshold
  - E.g. 90<sup>th</sup> quantile

# Main uses

## Static weather generator

- Simulate surrogates of observed sequences
  - Events, seasons or years

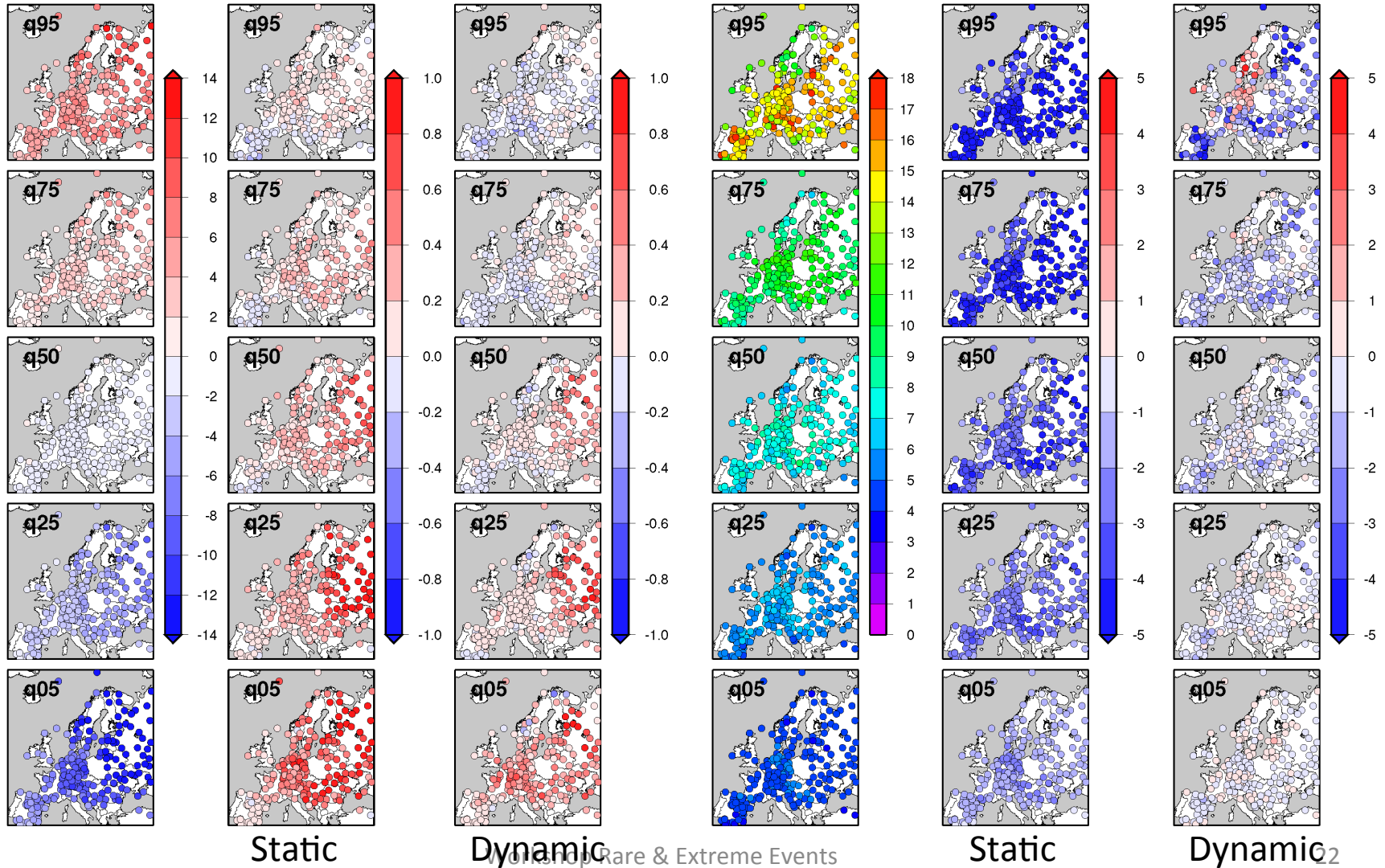
## Dynamic weather generator

- Simulate new sequences (from observed data)
  - Events or seasons
- Low cost seasonal prediction

# Winter initial conditions

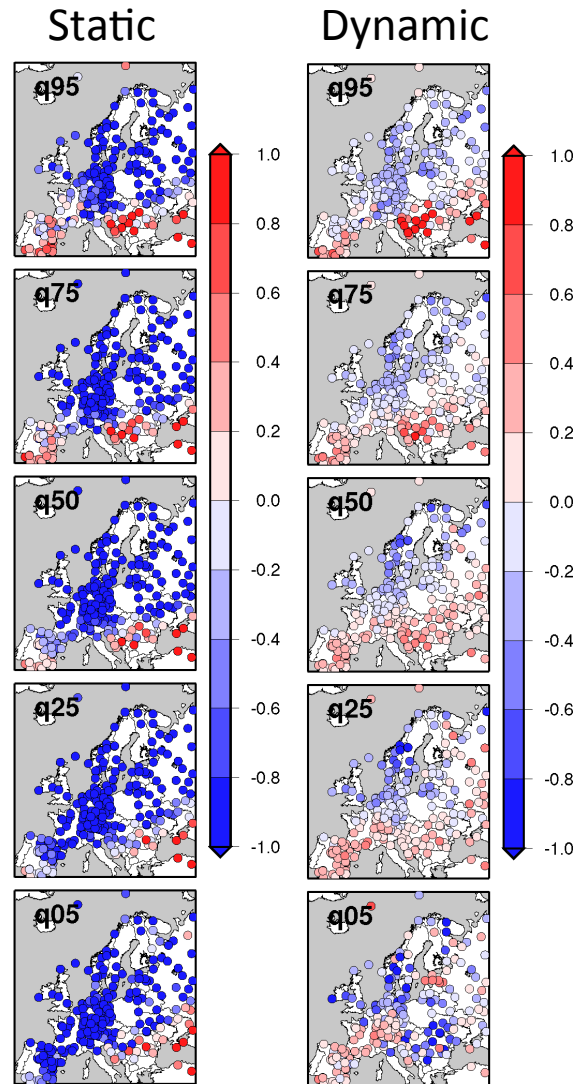
Temperature

Decorrelation time



# Cold winter initial conditions

Initial conditions on Dec. 21 2009



# Analogues of circulation

- What is a good analogue? (*butterflies*)
  - Hypothesis of recurrent patterns in a phase space to be defined
  - Probability distribution of distances of analogues
- Cases without analogues (*black swans*)
  - Extremes of the probability distribution of distances
- Re-construction of 3D field from the constraint on a boundary of the domain?



# Conclusion & Perspectives

- Flexible approach to investigate the likelihood of some extreme events from atmospheric variability
  - Special issues of the BAMS (2012, 2013, 2014)
- Analysis of the probability of “black swans” (i.e. events with no analogues in the past)
- Simulation of catalogues of extreme events (e.g. storms):
  - 1000 samples out of 30 years of observations

Thank you

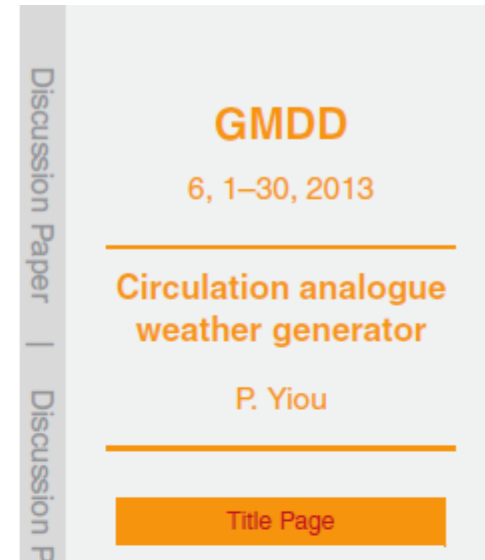
# Description in GMDD

Geosci. Model Dev. Discuss., 6, 1–30, 2013  
www.geosci-model-dev-discuss.net/6/1/2013/  
doi:10.5194/gmdd-6-1-2013  
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This discussion paper is/has been under review for the journal Geoscientific Model Development (GMD). Please refer to the corresponding final paper in GMD if available.

## AnaWEGE: a weather generator based on analogues of atmospheric circulation



With free and open source code and data in R