

Extreme climatic events



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Changing climates, changing impacts

climatiques
changements climatiques

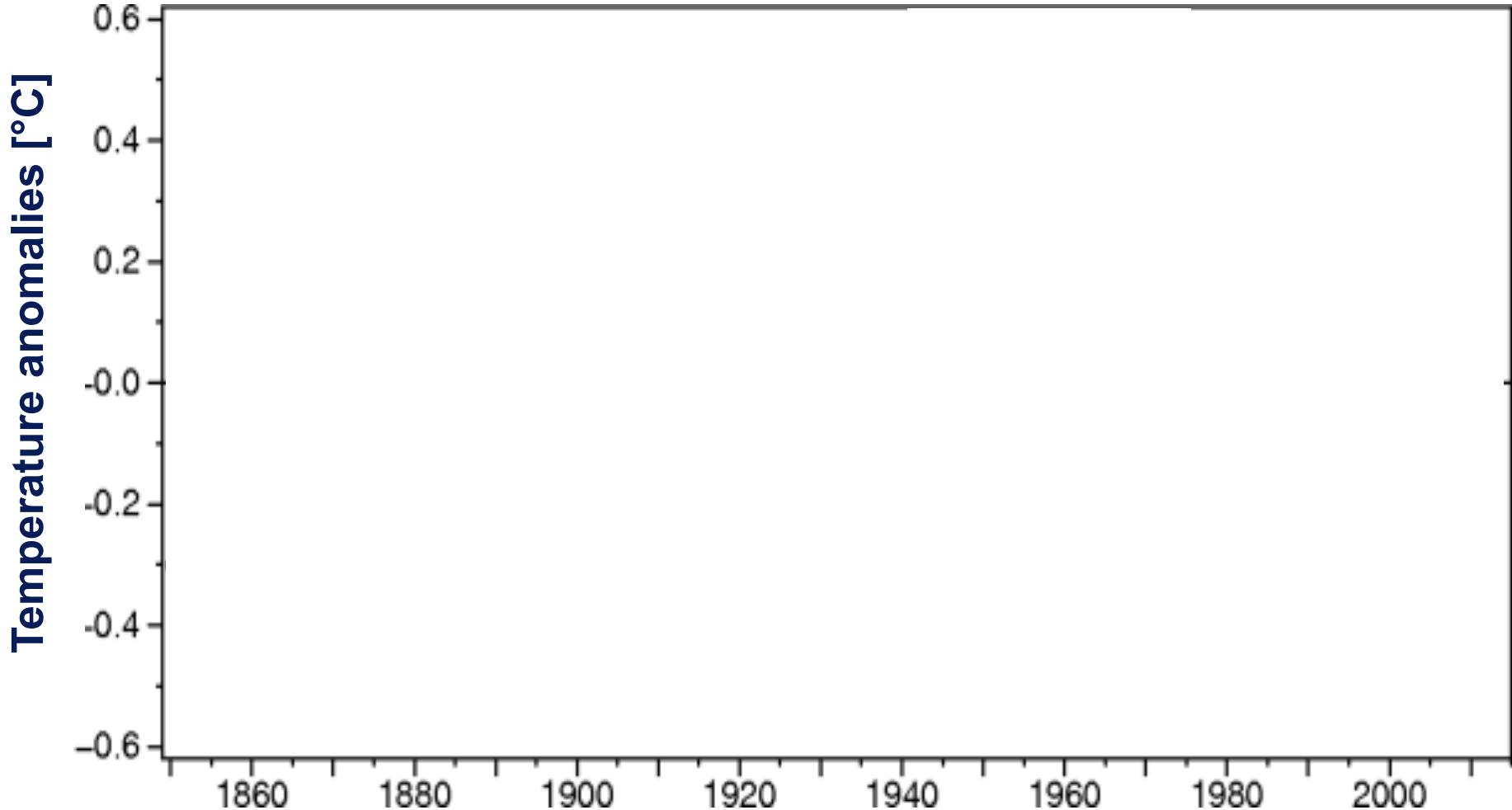
Climatic impacts...

IPCC, 2007

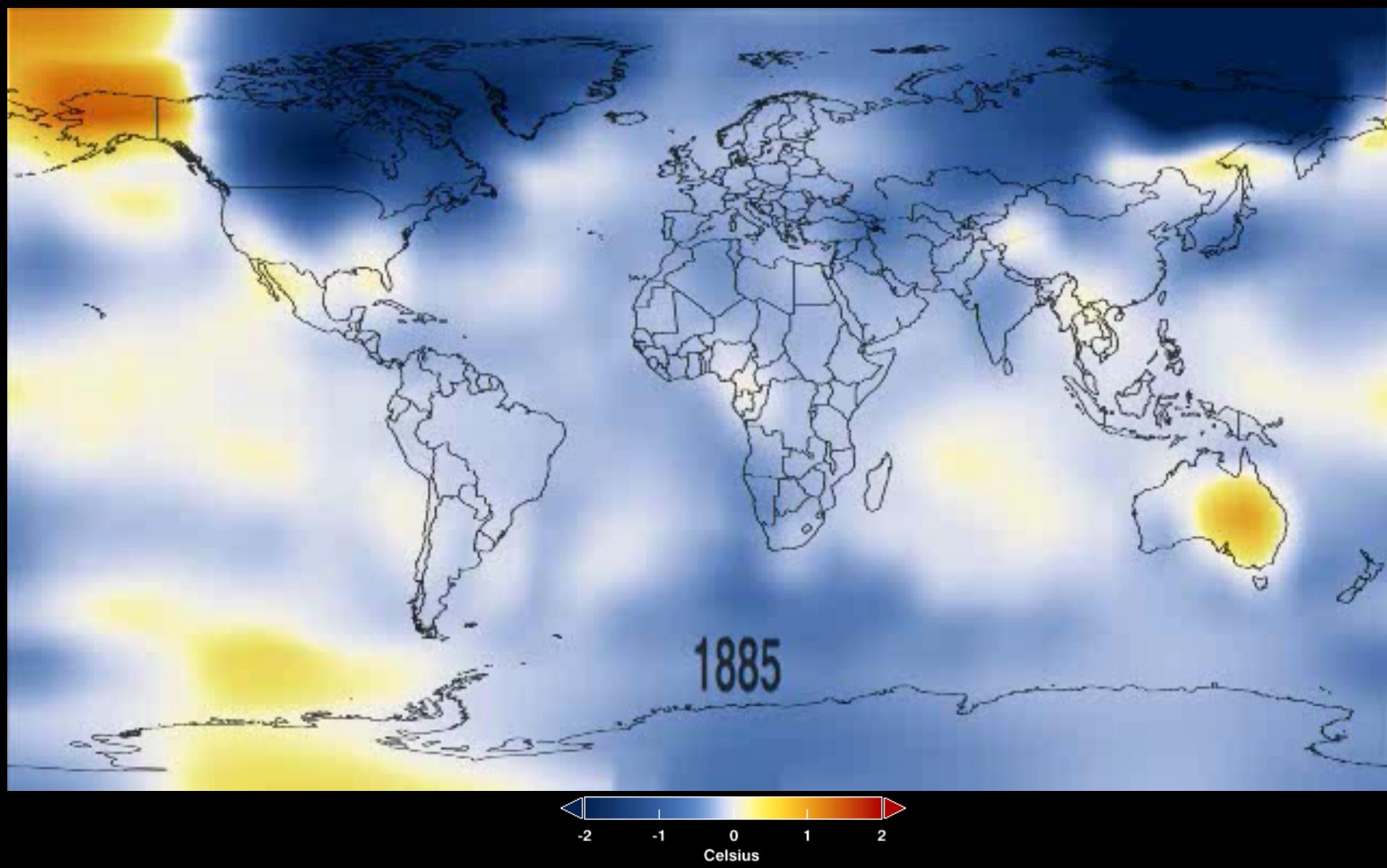
ΔT compared to 1980-1999



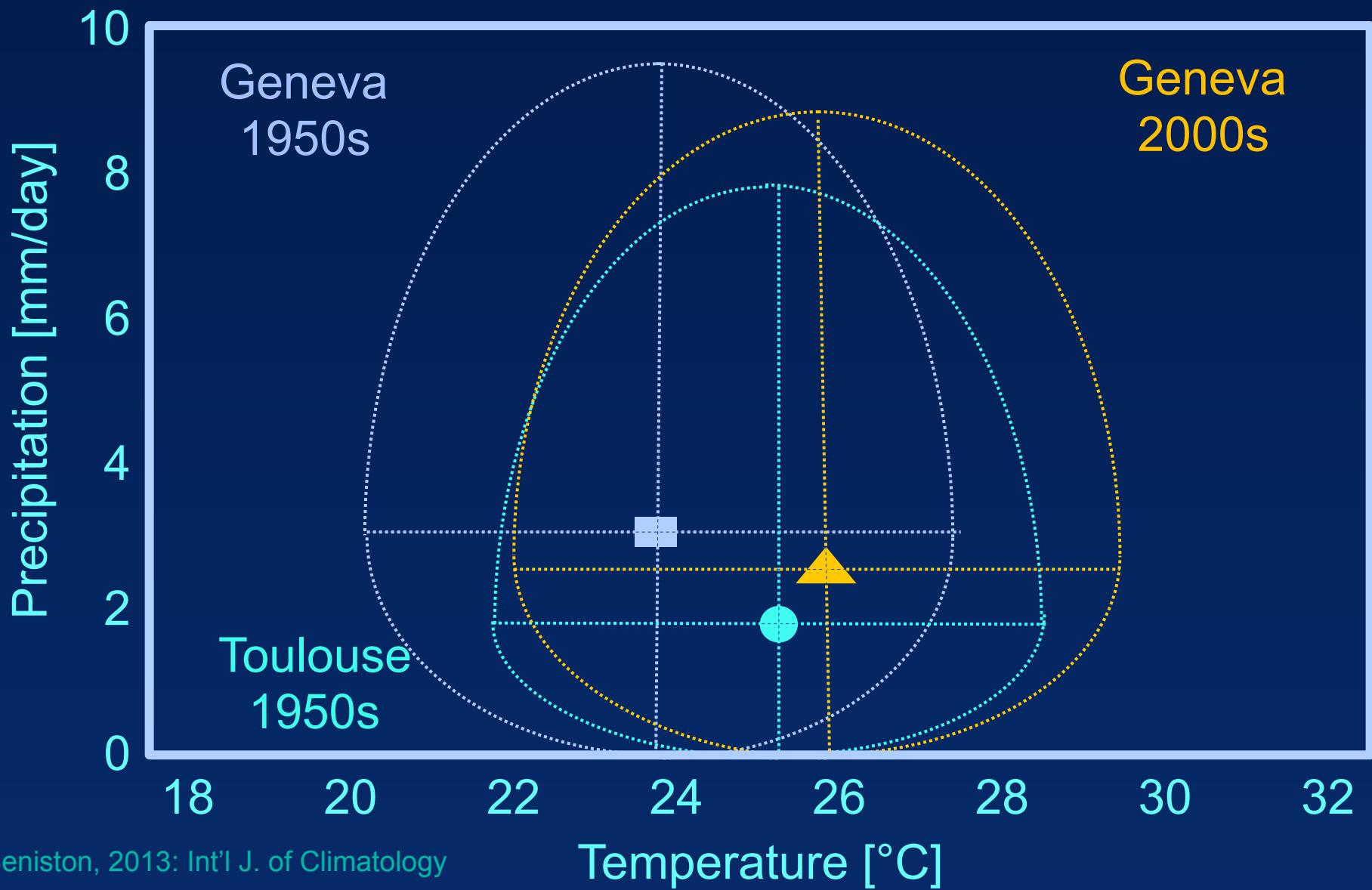
Mean global temperature change



Global temperature changes, 1885-2010



«Analog climates»: another view of climate change

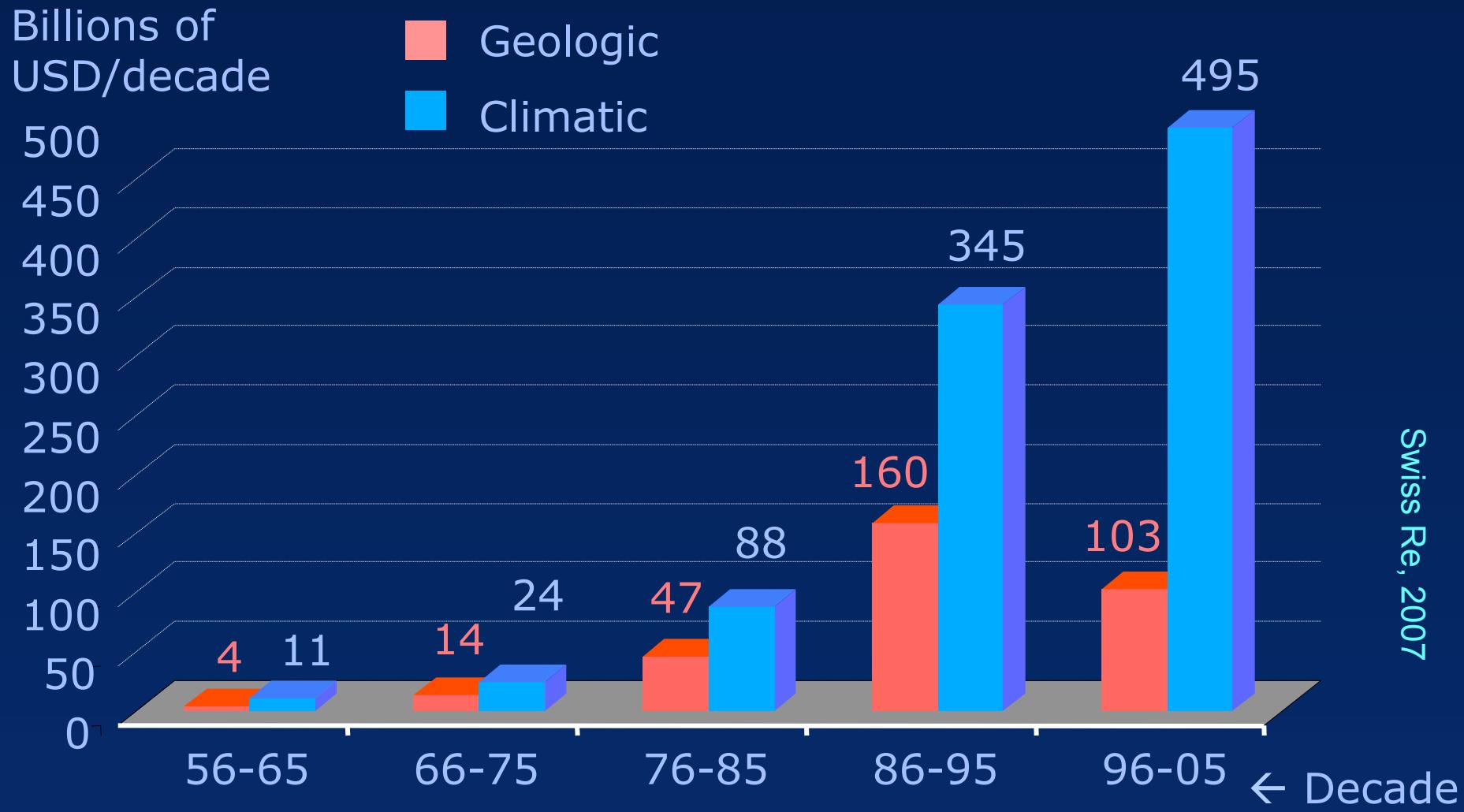


Beniston, 2013: Int'l J. of Climatology

Costs of extremes

Costs of extremes

Costs related to natural hazards



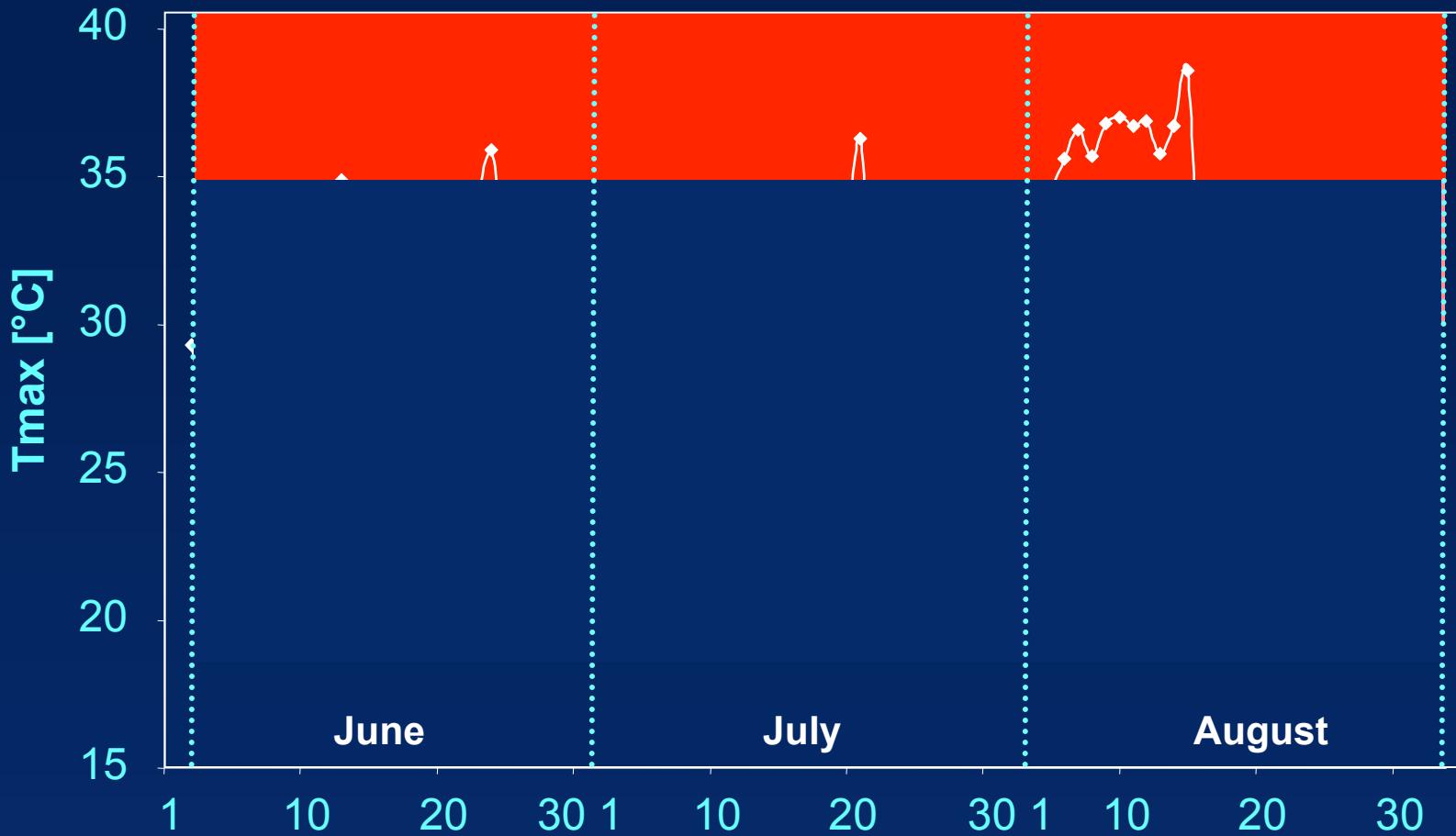
What is an extreme?

What is an extreme?

What is a climatic extreme?

- An intense event?
 - ◆ Approaches based on threshold exceedances

Beyond the 30°C and 35°C thresholds in Geneva during the 2003 heatwave



What is a climatic extreme?

■ An intense event?

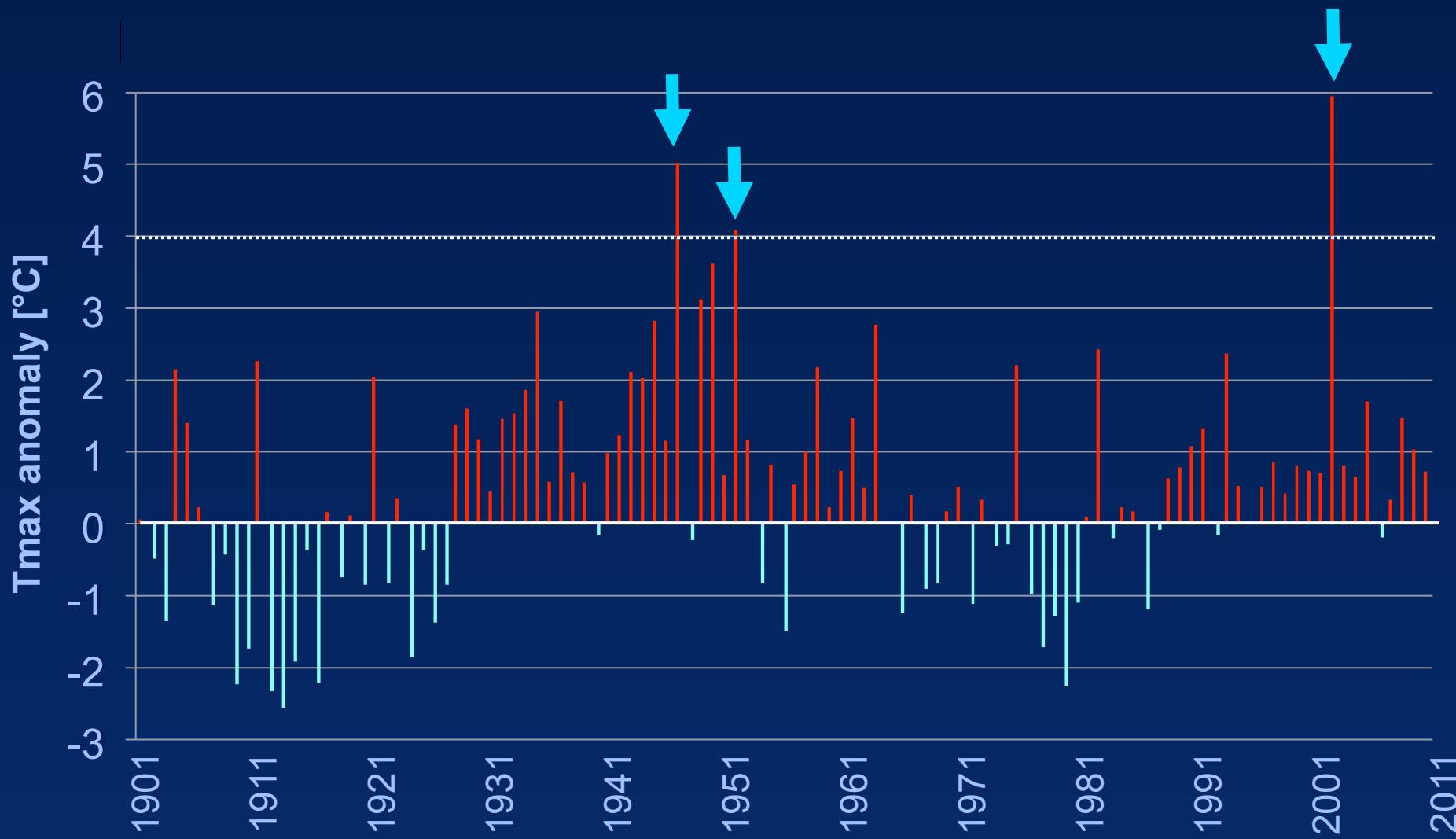
- ◆ Approaches based on threshold exceedance

■ A rare event?

- ◆ Approaches based on frequency of occurrence

Beniston, M., 2004:
Geophys. Res. Letters

Summer T_{\max} in Basel



What is a climatic extreme?

■ A rare event?

- ◆ Approaches based on frequency of occurrence

■ An intense event?

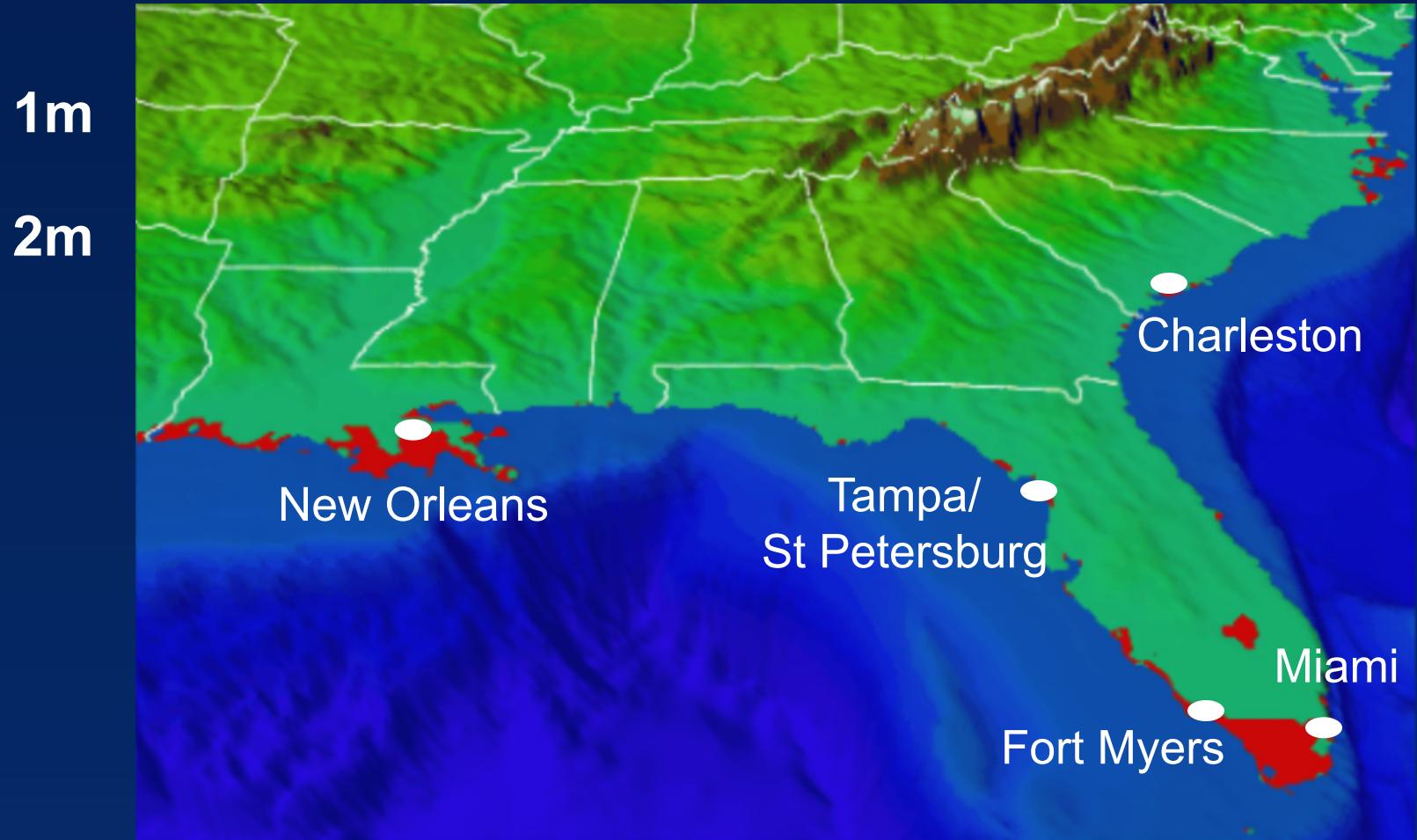
- ◆ Approaches based on threshold exceedance

■ An extreme with respect to the impacts?

- ◆ Need to deal with the vulnerability and adaptability of systems

- ◆ An extreme impact is not always associated with a weather extreme!

Coastal vulnerability to sea-level rise in the southeastern United States



An example of an extreme event: rare (hopefully!) *and* damaging...



Tacoma Narrows Bridge, USA
November 7, 1940

Where do extremes come from?

- Amplification of perturbations embedded within the general circulation of the atmosphere
- Modulation of « normal weather » by decadal-scale climate variability (ENSO, NAO, AO, ...)
- Enhancement of the energy required to trigger extremes by a warmer climate forced by increased atmospheric greenhouse-gas concentrations

Governing equations: atmospheric dynamics (Navier-Stokes)

- $\frac{\partial u}{\partial t} = -u \frac{\partial u}{\partial x} - v \frac{\partial u}{\partial y} - w \frac{\partial u}{\partial z} - \frac{1}{\rho} \frac{\partial p}{\partial x} + 2\Omega v \sin \phi + \tau_x$
- $\frac{\partial v}{\partial t} = -u \frac{\partial v}{\partial x} - v \frac{\partial v}{\partial y} - w \frac{\partial v}{\partial z} - \frac{1}{\rho} \frac{\partial p}{\partial y} - 2\Omega u \sin \phi + \tau_y$
- $\frac{\partial w}{\partial t} = -u \frac{\partial w}{\partial x} - v \frac{\partial w}{\partial y} - w \frac{\partial w}{\partial z} - \frac{1}{\rho} \frac{\partial p}{\partial z} - g + 2\Omega u \cos \phi + \tau_z$
- $\frac{\partial u}{\partial x} + \frac{\partial v}{\partial y} + \frac{\partial w}{\partial z} = 0$

Governing equations: atmospheric thermodynamics

- $\partial u / \partial t = -u \frac{\partial u}{\partial x} - v \frac{\partial u}{\partial y} - w \frac{\partial u}{\partial z} - 1/\rho \frac{\partial p}{\partial x} + 2\Omega v \sin \phi + \tau_x$
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- $\partial w / \partial t = -u \frac{\partial w}{\partial x} - v \frac{\partial w}{\partial y} - w \frac{\partial w}{\partial z} - 1/\rho \frac{\partial p}{\partial z} - g + 2\Omega u \cos \phi + \tau_z$
- $\frac{\partial u}{\partial x} + \frac{\partial v}{\partial y} + \frac{\partial w}{\partial z} = 0$
- $\frac{\partial T}{\partial t} = -u \frac{\partial T}{\partial x} - v \frac{\partial T}{\partial y} - w \frac{\partial T}{\partial z} + C_T + R_T + F_T$
- $\frac{\partial q}{\partial t} = -u \frac{\partial q}{\partial x} - v \frac{\partial q}{\partial y} - w \frac{\partial q}{\partial z} + C_q + F_q$

Governing equations: gas/pressure

- $\partial u / \partial t = -u \partial u / \partial x - v \partial u / \partial y - w \partial u / \partial z - 1/\rho \partial p / \partial x + 2\Omega v \sin \phi + \tau_x$
- $\partial v / \partial t = -u \partial v / \partial x - v \partial v / \partial y - w \partial v / \partial z - 1/\rho \partial p / \partial y - 2\Omega u \sin \phi + \tau_y$
- $\partial w / \partial t = -u \partial w / \partial x - v \partial w / \partial y - w \partial w / \partial z - 1/\rho \partial p / \partial z - g + 2\Omega u \cos \phi + \tau_z$
- $\partial u / \partial x + \partial v / \partial y + \partial w / \partial z = 0$
- $\partial T / \partial t = -u \partial T / \partial x - v \partial T / \partial y - w \partial T / \partial z + C_T + R_T + F_T$
- $\partial q / \partial t = -u \partial q / \partial x - v \partial q / \partial y - w \partial q / \partial z + C_q + F_q - F$
- $p = \rho RT$
- $\partial p / \partial z = -\rho g = -pg / -RT$

Governing equations

- $\frac{\partial u}{\partial t} = -u \frac{\partial u}{\partial x} - v \frac{\partial u}{\partial y} - w \frac{\partial u}{\partial z} - \frac{1}{\rho} \frac{\partial p}{\partial x} + 2 \Omega v \sin \phi + \tau_x$
- $\frac{\partial v}{\partial t} = -u \frac{\partial v}{\partial x} - v \frac{\partial v}{\partial y} - w \frac{\partial v}{\partial z} - \frac{1}{\rho} \frac{\partial p}{\partial y} - 2 \Omega u \sin \phi + \tau_y$
- $\frac{\partial w}{\partial t} = -u \frac{\partial w}{\partial x} - v \frac{\partial w}{\partial y} - w \frac{\partial w}{\partial z} - \frac{1}{\rho} \frac{\partial p}{\partial z} - g + 2 \Omega u \cos \phi + \tau_z$
- $\frac{\partial u}{\partial x} + \frac{\partial v}{\partial y} + \frac{\partial w}{\partial z} = 0$
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- $p = \rho RT$
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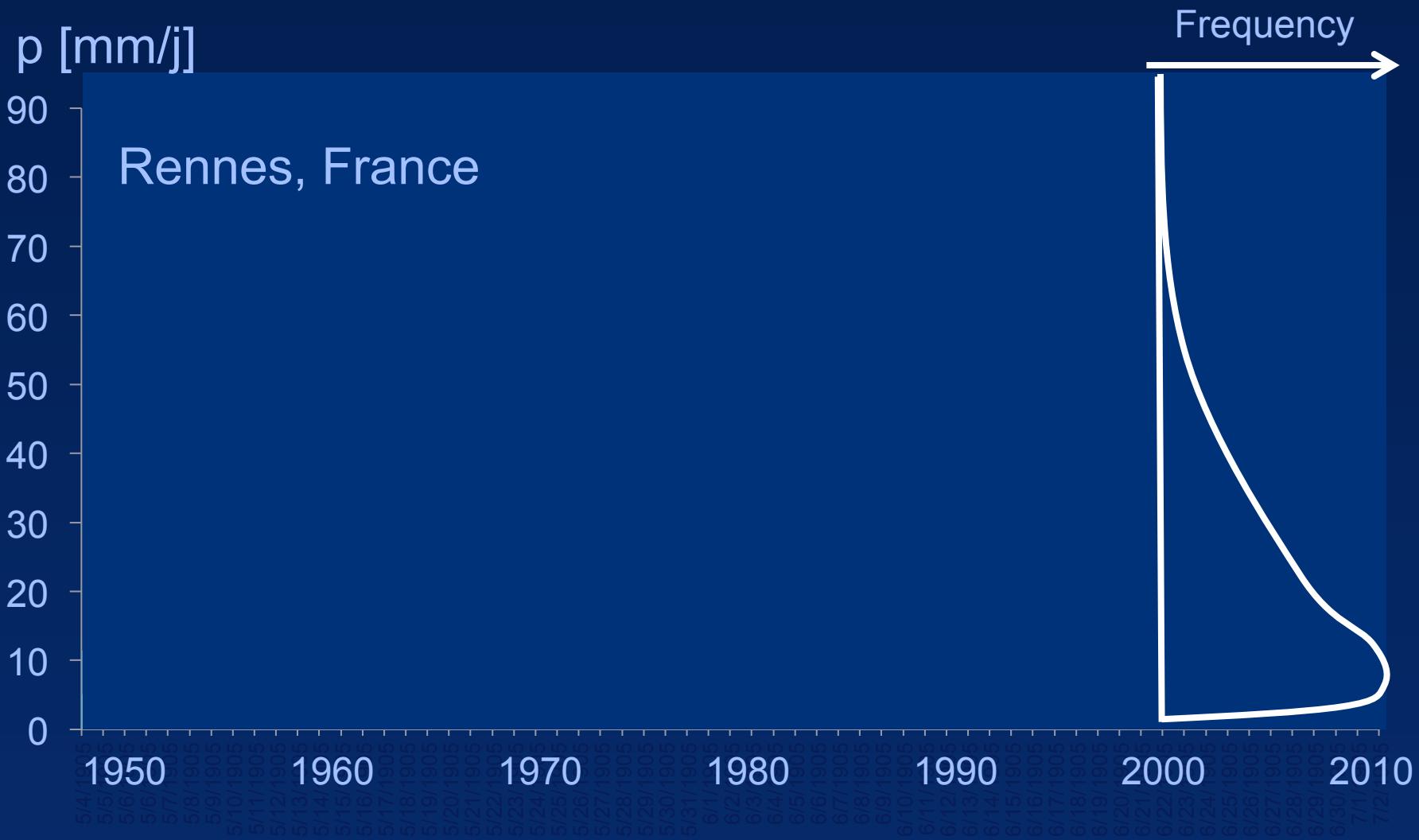
Viewing extremes from a statistical viewpoint

statistical viewpoint
Viewing extremes from a

Statistical analyses of extremes (T)



Statistical analysis of extremes (Pr)



Curve fitting: Peak-over-Threshold, GEV and Pareto

Peak-over-Threshold, GEV and Pareto
Curve fitting:

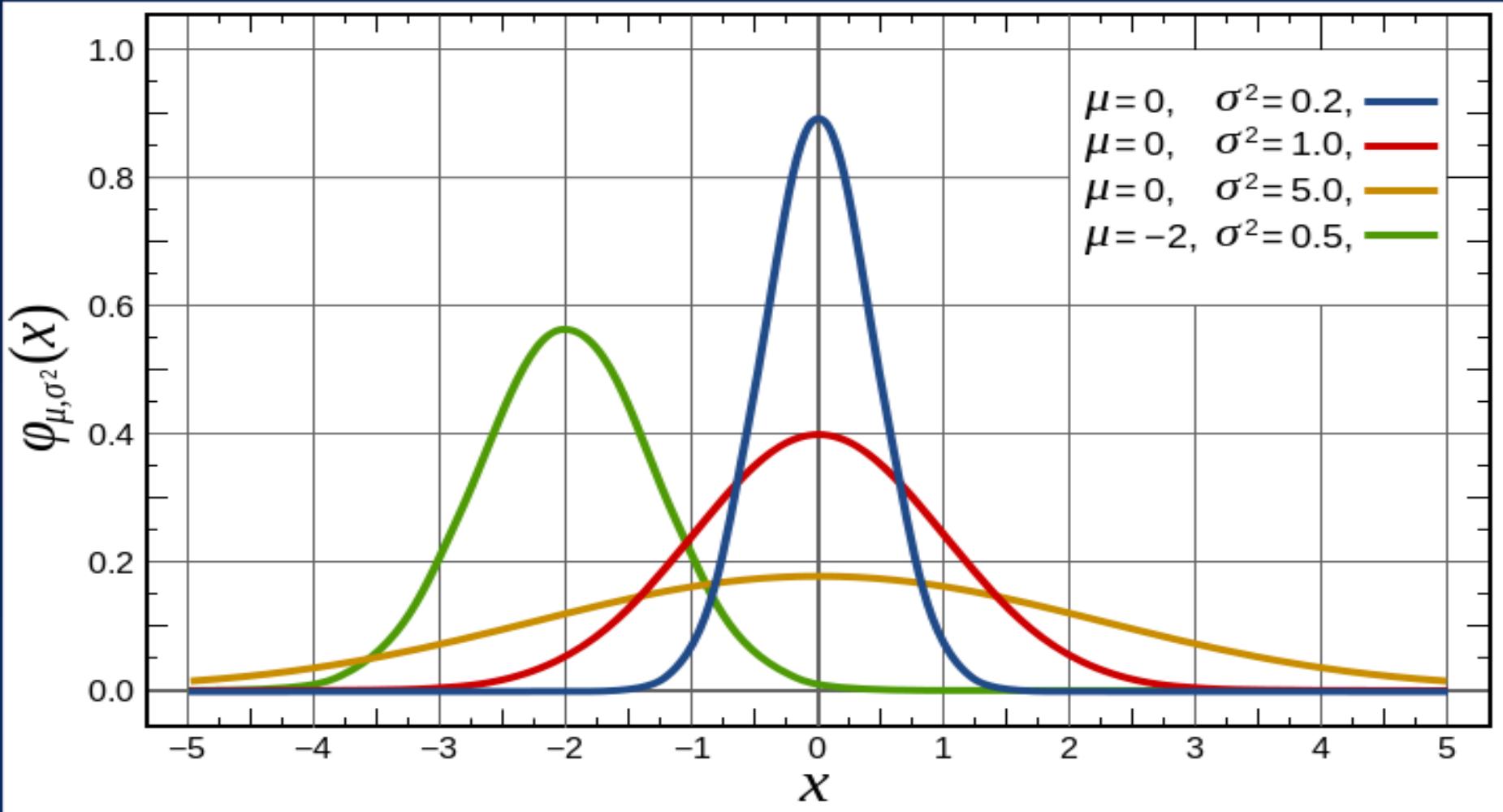
Selecting extremes

- In many instances, one can select extremes of a continuous distribution in different manners, the most common being:
 - ◆ Extracting the maximum value in a given time interval (e.g., maximum annual temperature)
 - ◆ Selecting the parts of a distribution that are located above (or below) a particular threshold (e.g., number of events above 30°C)
- It then remains to see whether the extremes thus selected can be described by particular statistical distributions

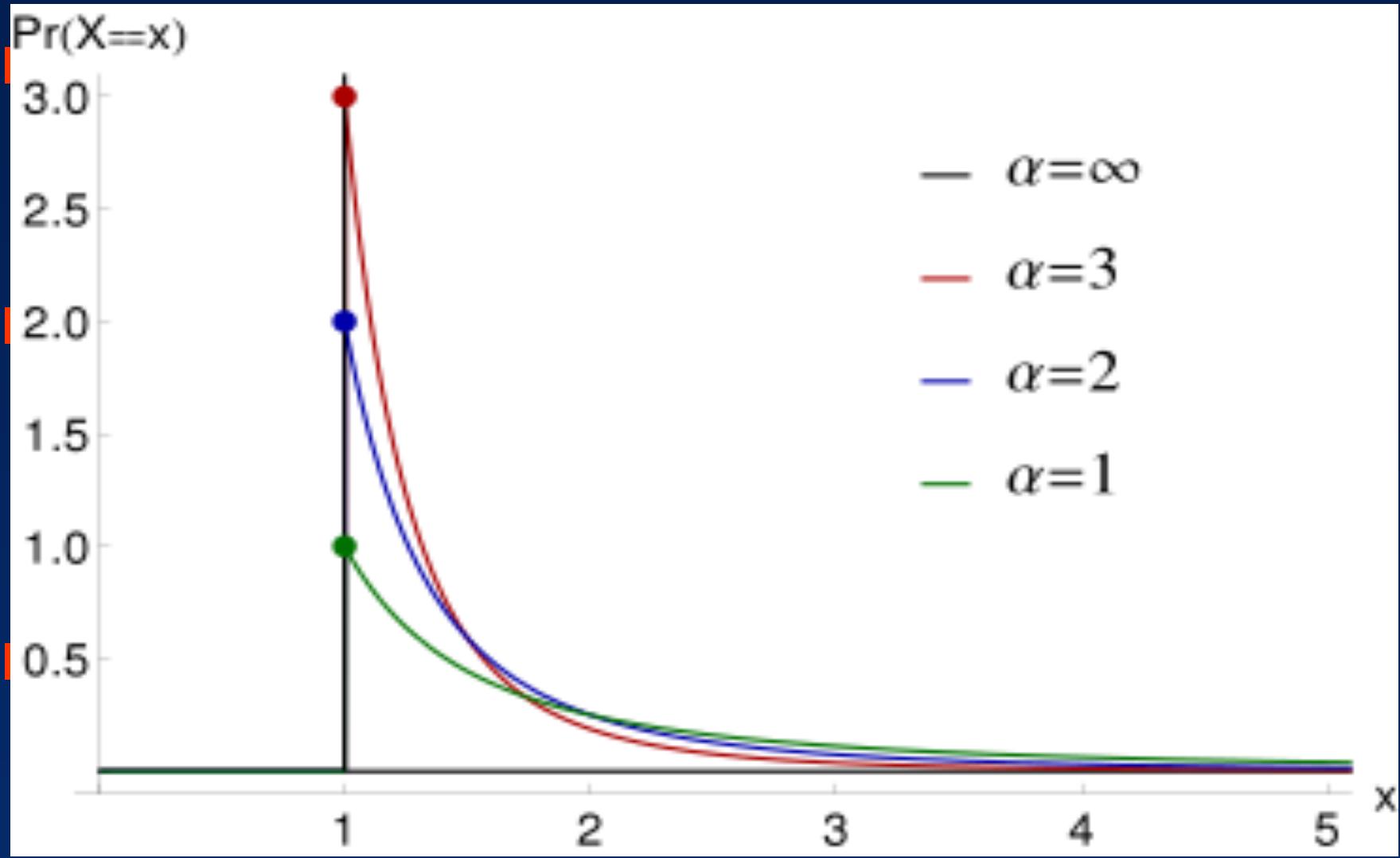
GEV: Generalized Extreme Value Theory

- *Extreme value theory* is a branch of statistics that deals with extreme events. It is based on the *extremal types theorem*, stating that there are only three types of distributions that are needed to model the maximum or minimum of the collection of random observations from the same distribution.
- If N data sets from the same distribution are generated, and a new data set is created that includes the maximum values from these N data sets, the resulting data set can *only* be described by one of the three models - specifically, the Gumbel, Fréchet, and Weibull distributions.

GEV: Generalized Extreme Value Theory



Pareto distribution



Probability Density Functions and extremes

Probability Density Functions and extremes

PDFs and extremes

Frequency
of occurrence

30%

20%

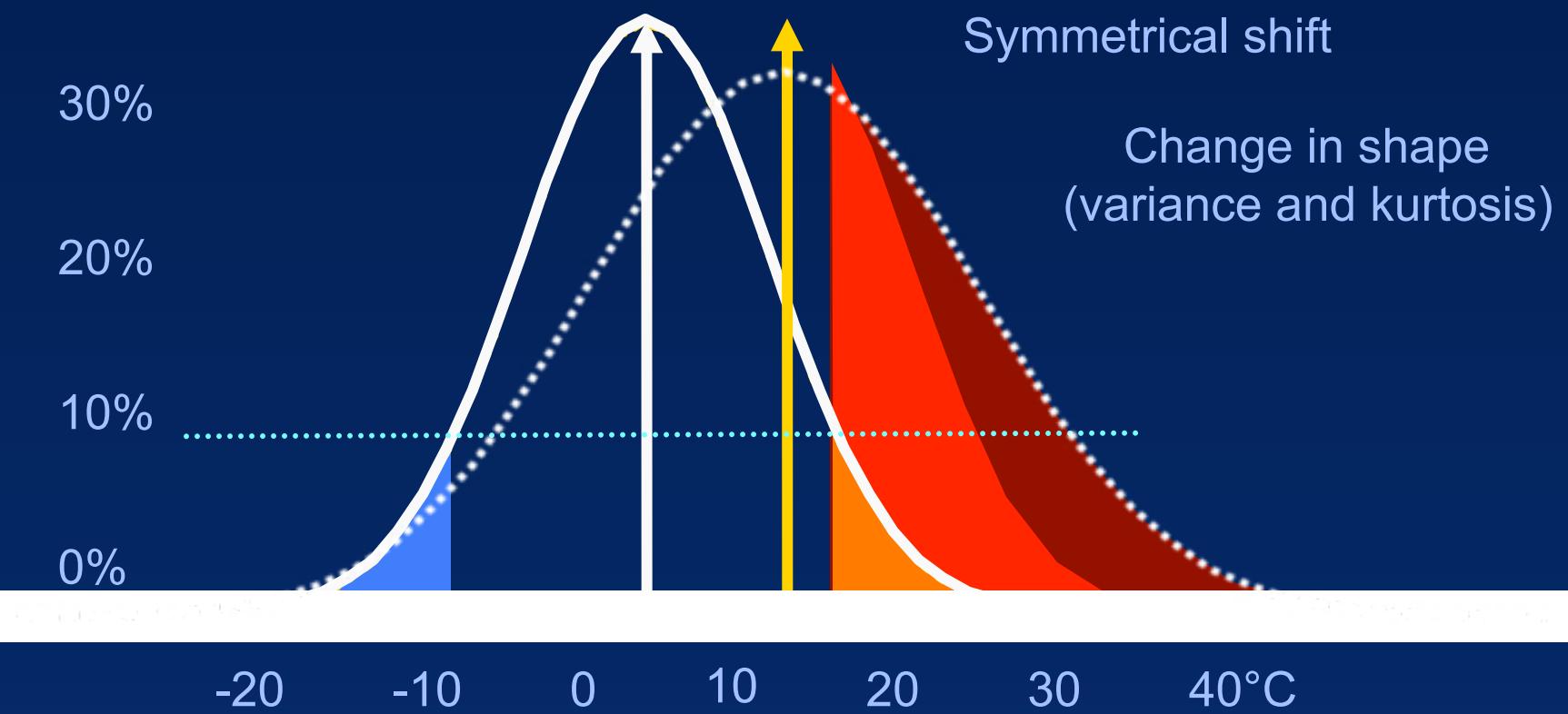
10%

0%



Symmetrical shift

Change in shape
(variance and kurtosis)



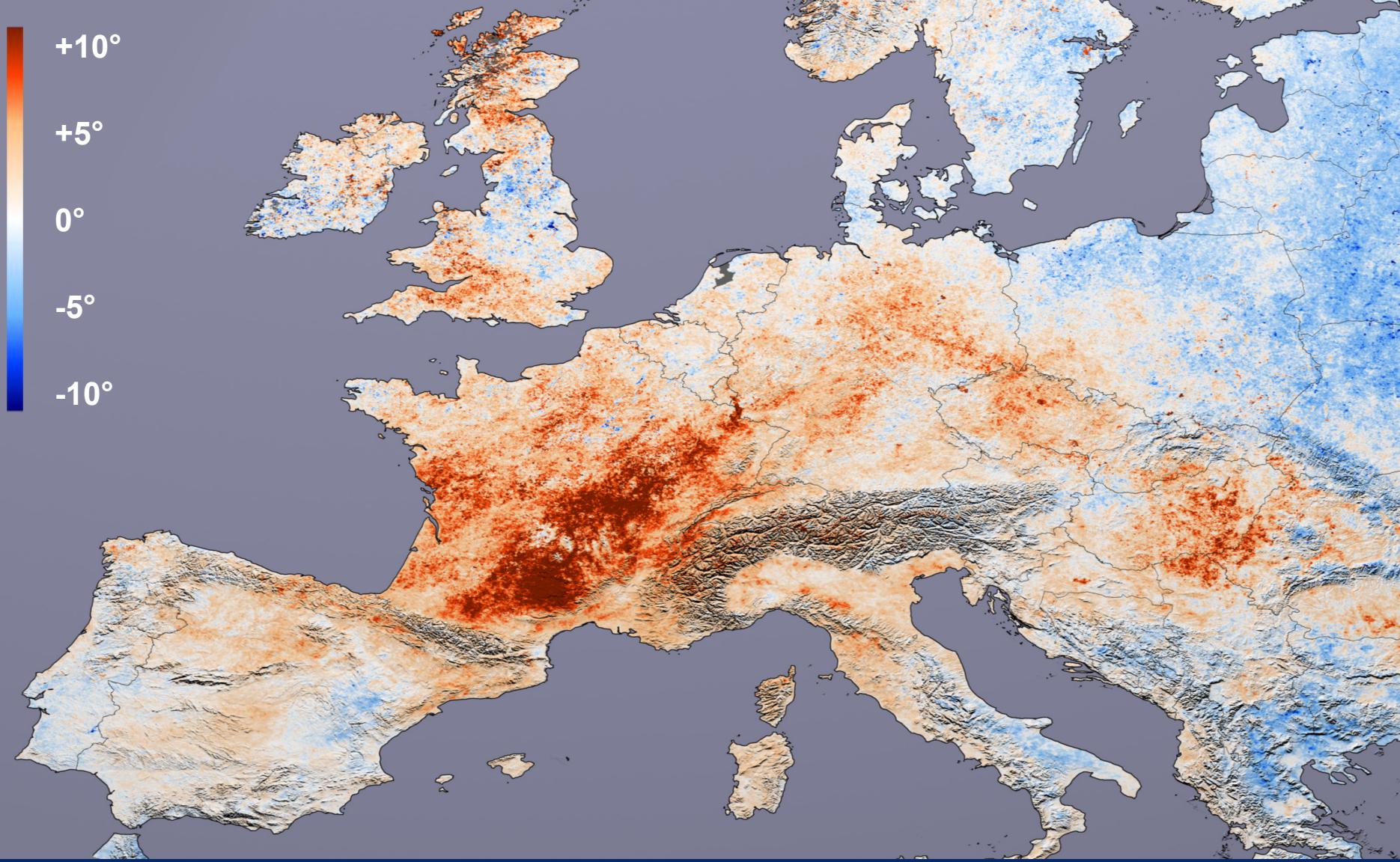
Some examples from the real world

but most seldom
below

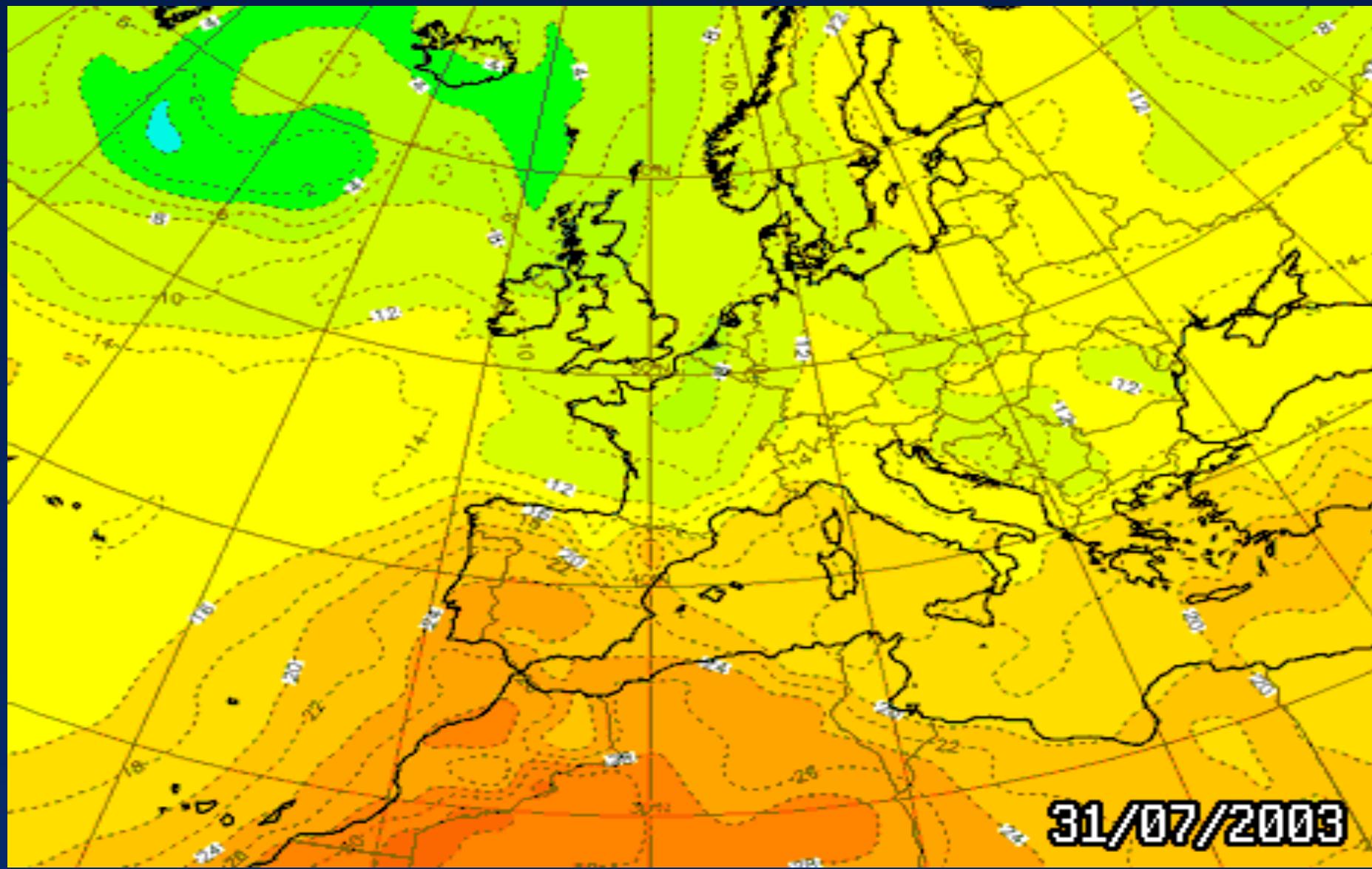
Heat waves

Heat waves

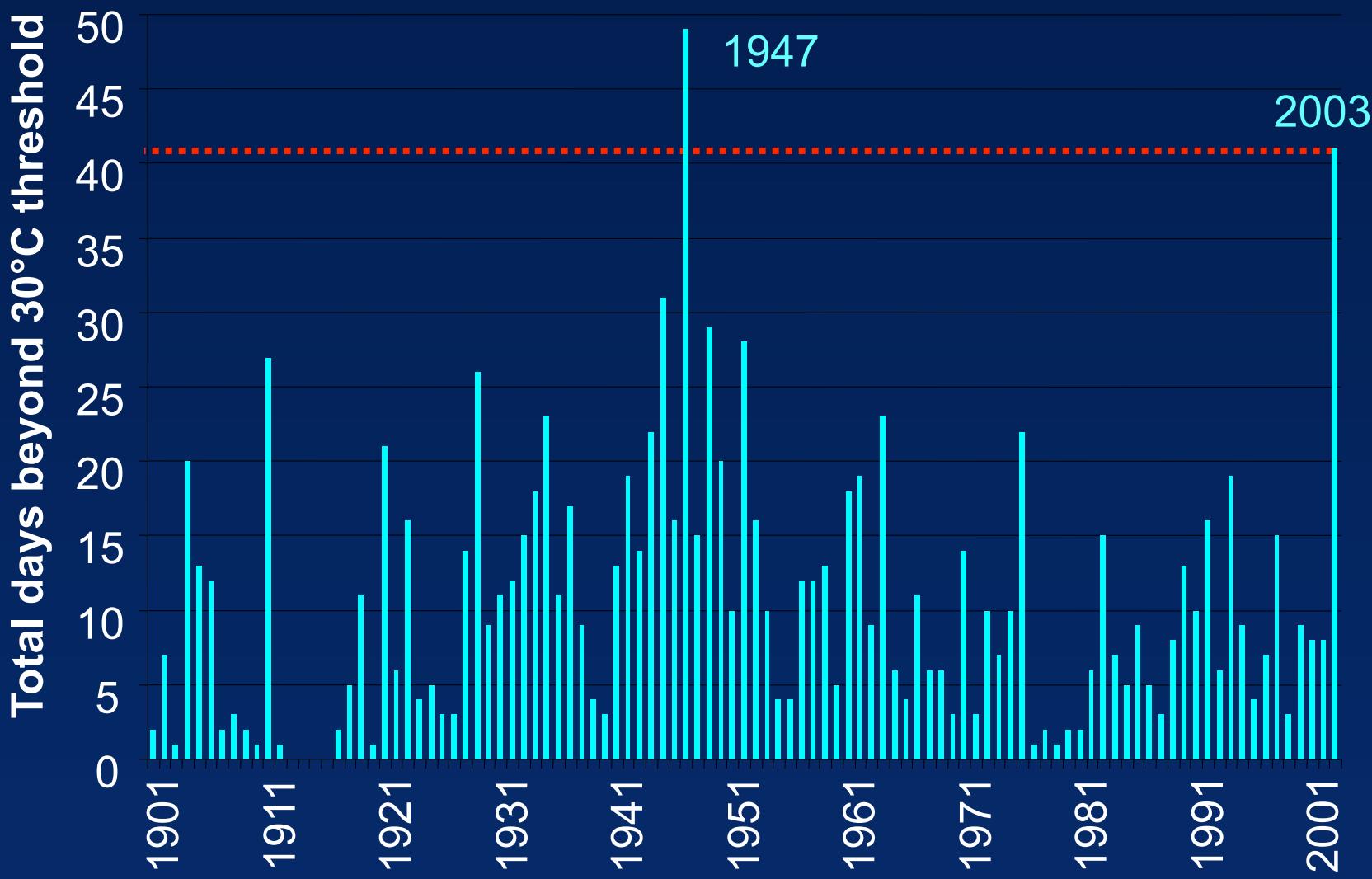
Temperature anomalies (August 2013)



850 hPa temperatures (1-15 August, 2003)

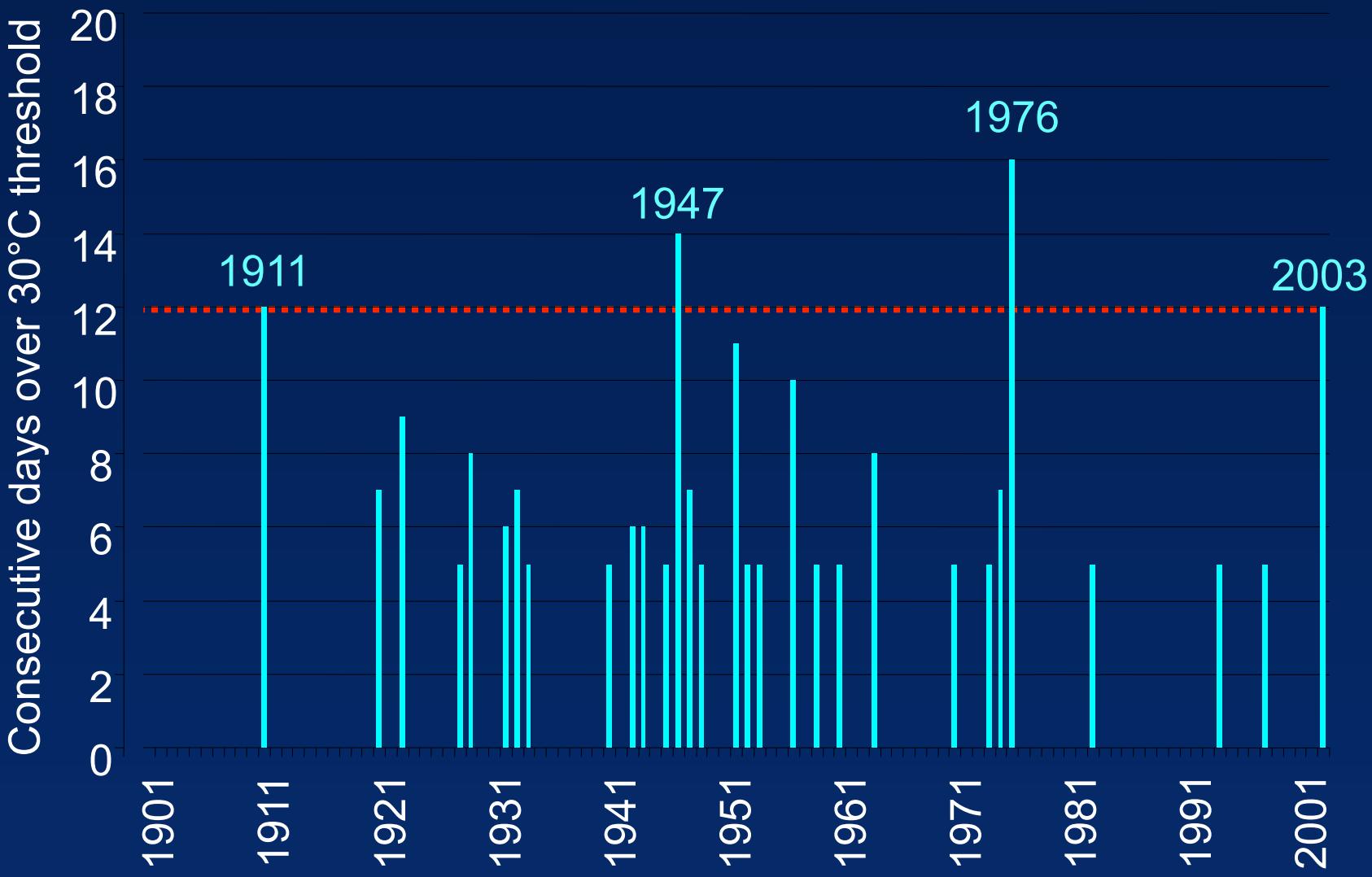


30°C threshold exceedance: Number of days per year



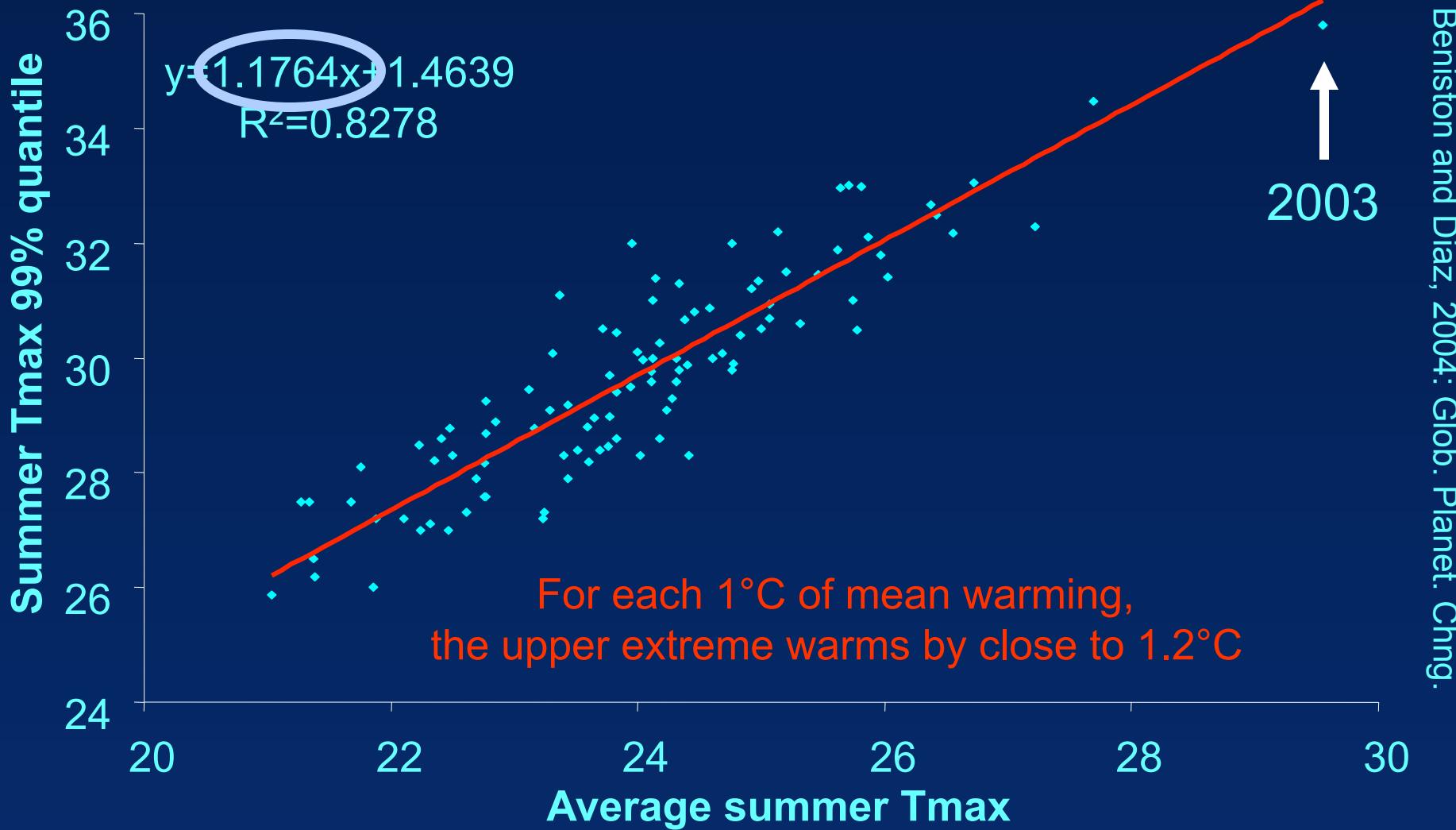
Beniston, M., 2004: Geophys. Res. Letters

30°C threshold exceedance: Number of consecutive days per year



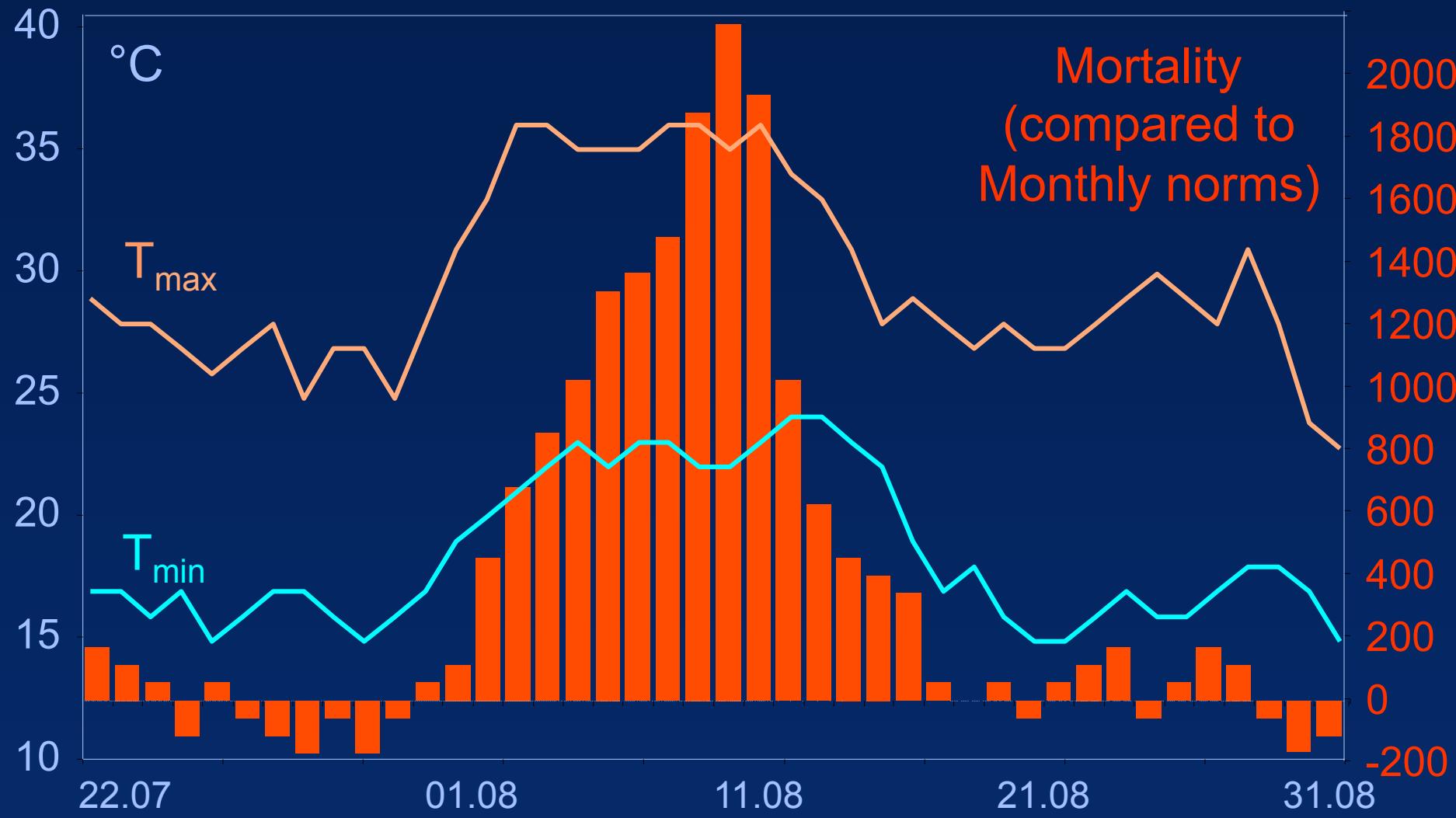
Beniston, M., 2004: Geophys. Res. Letters

Links between average summer Tmax and extreme value of Tmax (20th century)



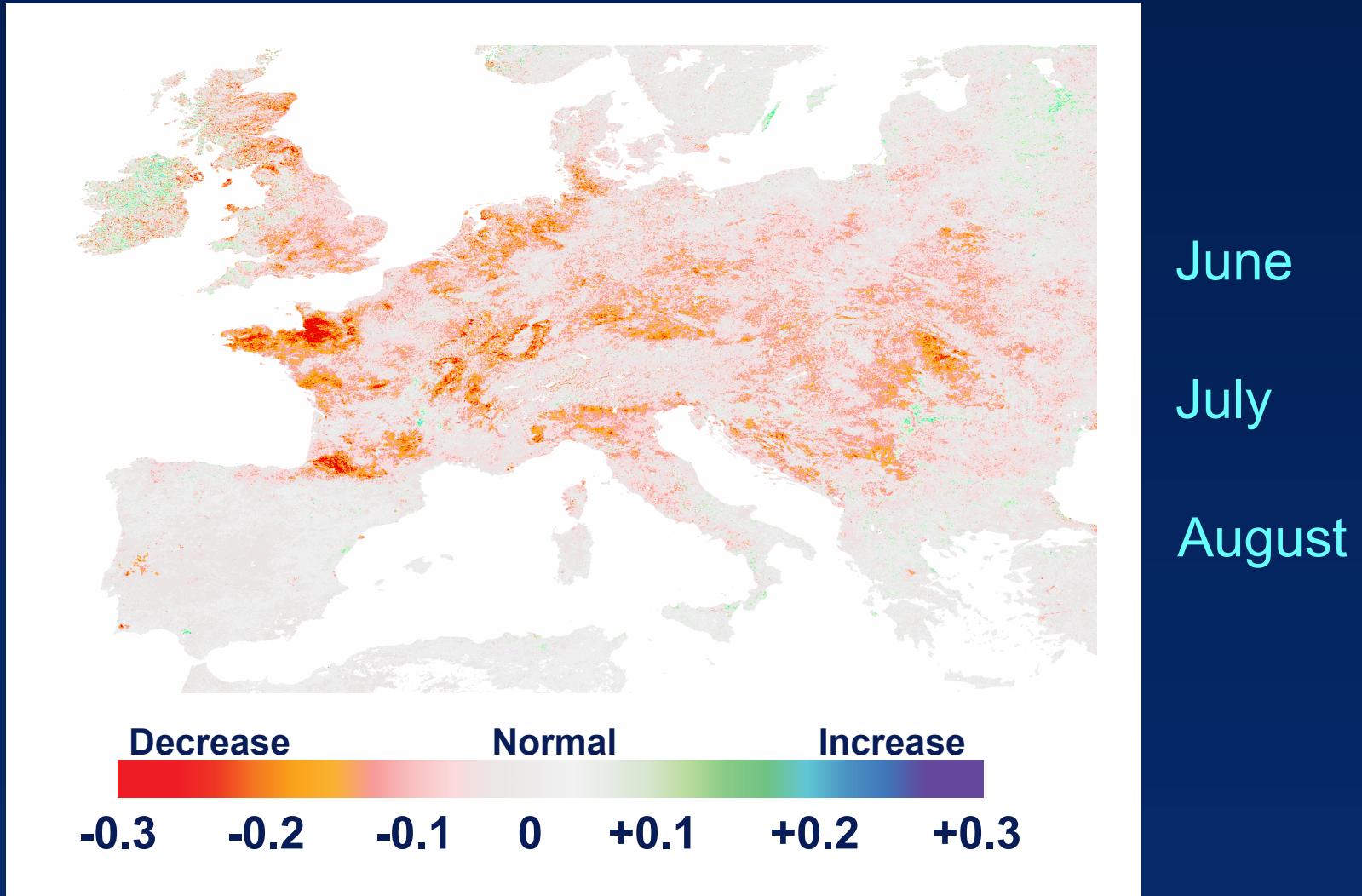
2003 heat-wave impacts: mortality in Paris

Fouillet et al., 2006: Env. Health



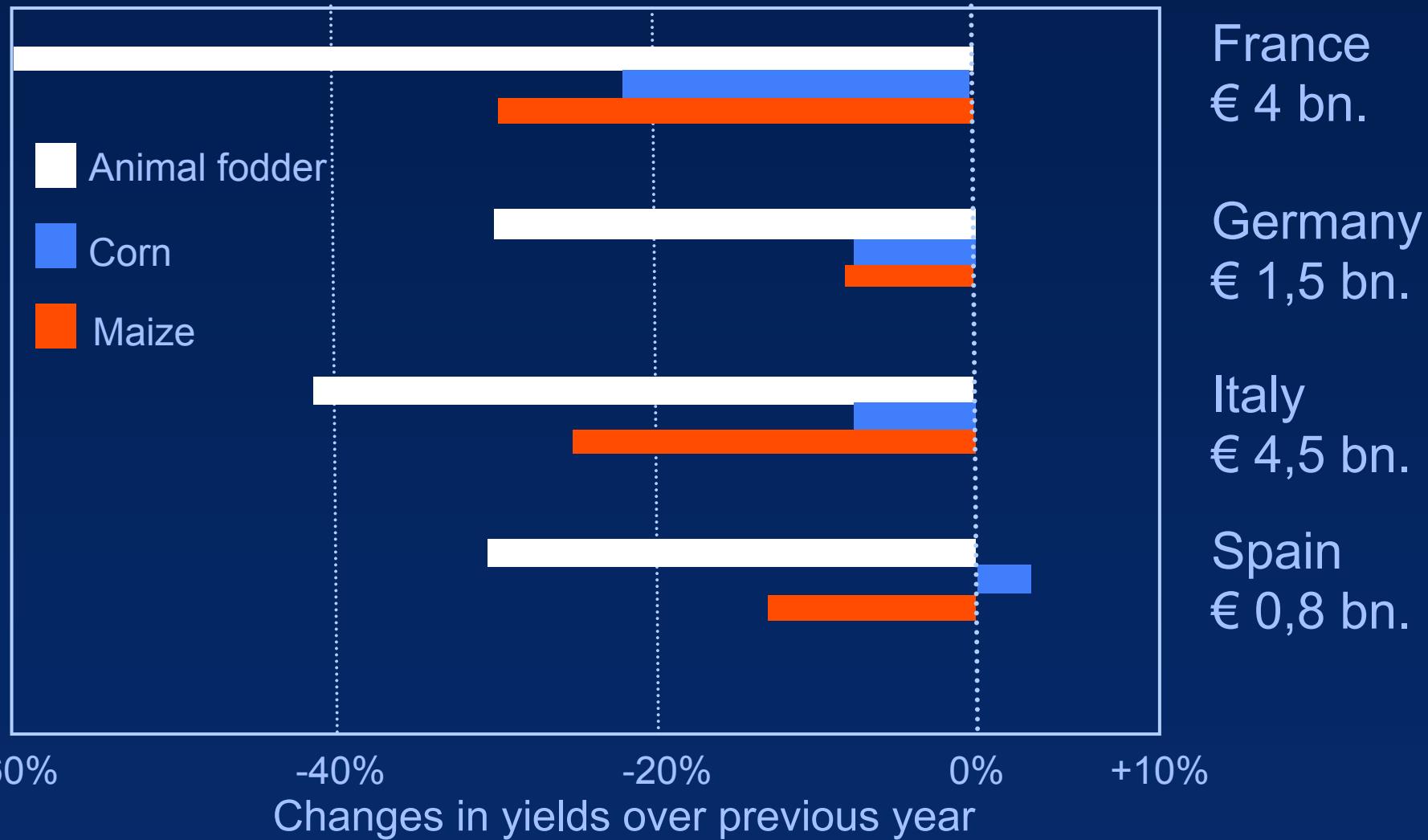
Stress on vegetation

(FAPAR anomalies)



Losses for EU agriculture as a result of the heat wave

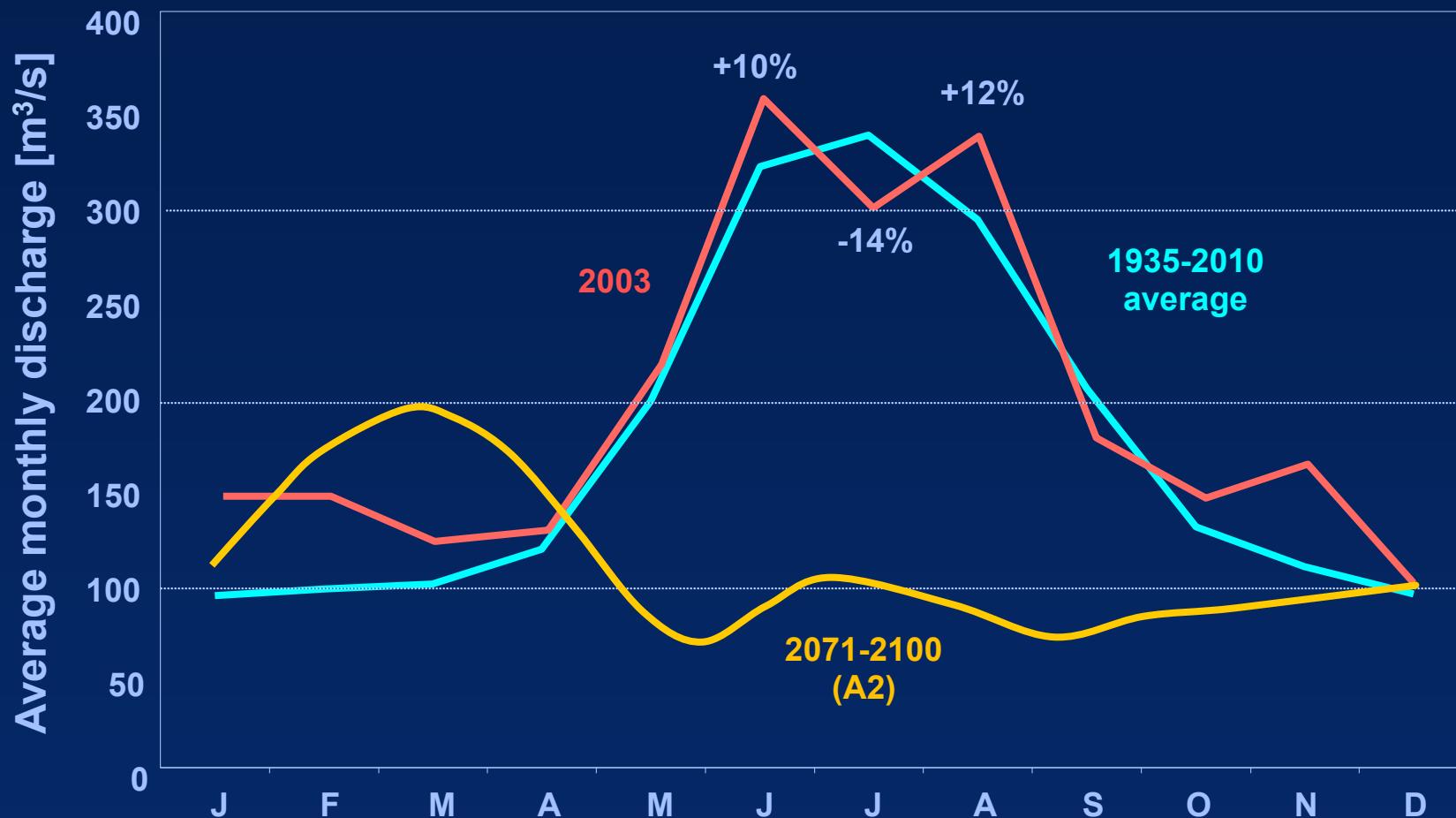
UNEP, 2004:
Environmental Alert Bulletin



Other collateral effects

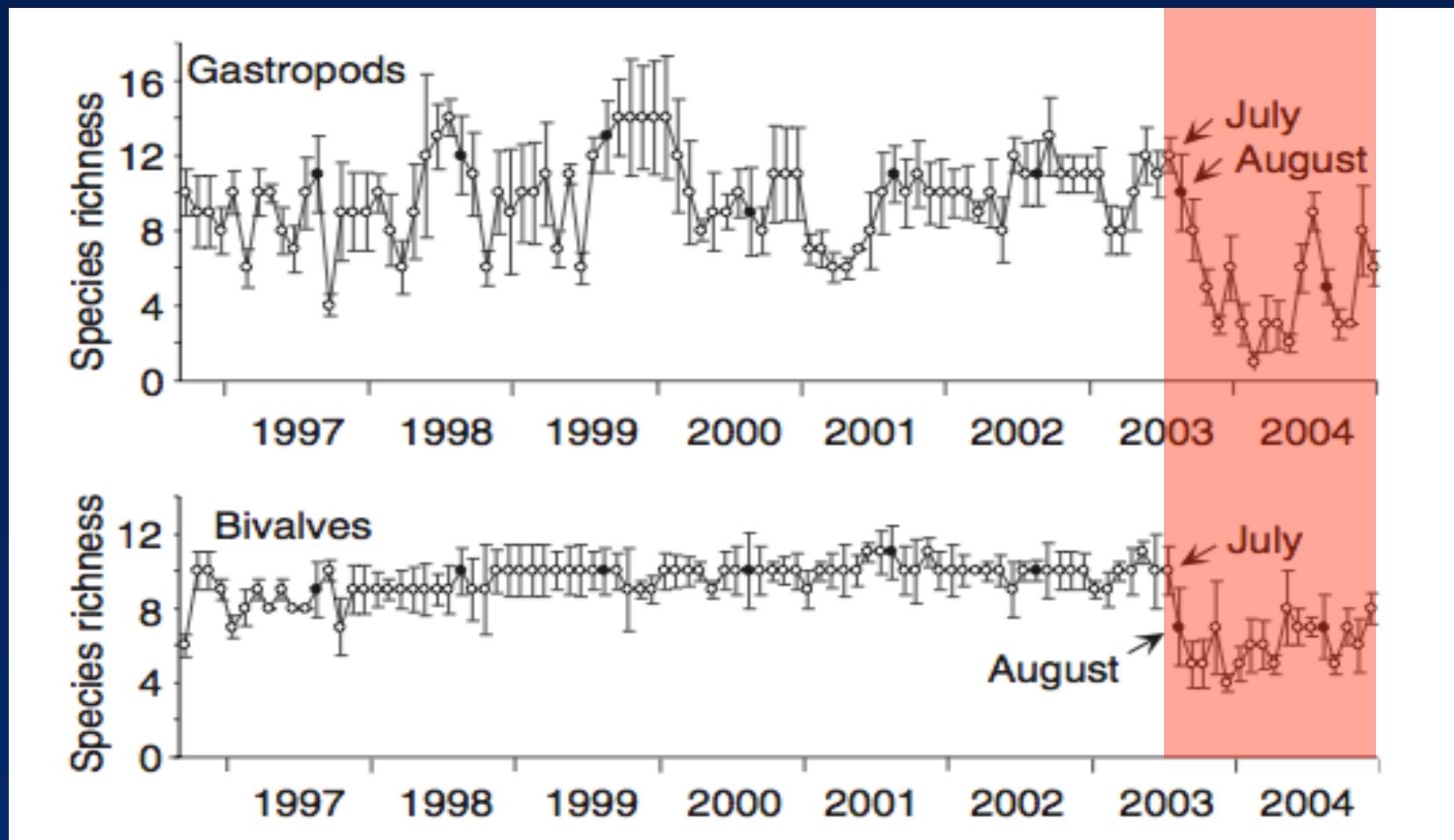
- Numerous forest fires in Spain, Portugal, France with widespread destruction
- 17 of France's nuclear reactors used for energy production were shut down or slowed down:
 - ◆ water levels in some rivers that had sharply declined
 - ◆ water temperatures in some of the rivers that had risen significantly beyond legal environmental thresholds
- Aquifers in many parts of Europe have not yet reverted to their pre-2003 levels
- Some Alpine glaciers lost 10% of their ice volume just in 2003, accelerating the general trend of glacier retreat

Rhone River discharge (m³/s) as it enters Lake Geneva



Beniston, 2010: Journal of Hydrology

Visible impacts on aquatic ecosystems (Saône River, France)



Mauthon and Dufresne, 2006: Global Change Biology

Ratios of extreme heat
to extreme cold

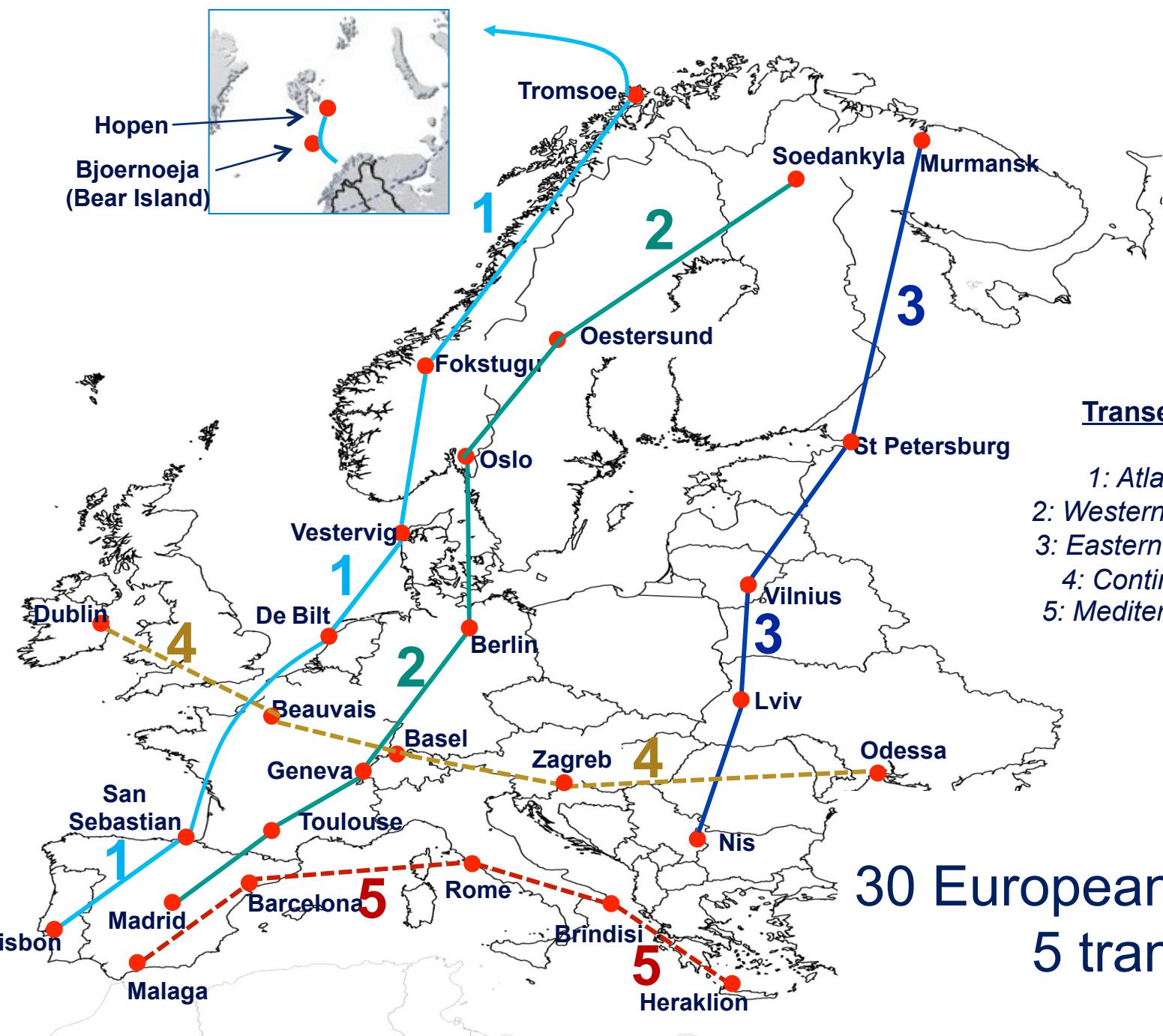
Ratios of extreme heat

Starting point for this study

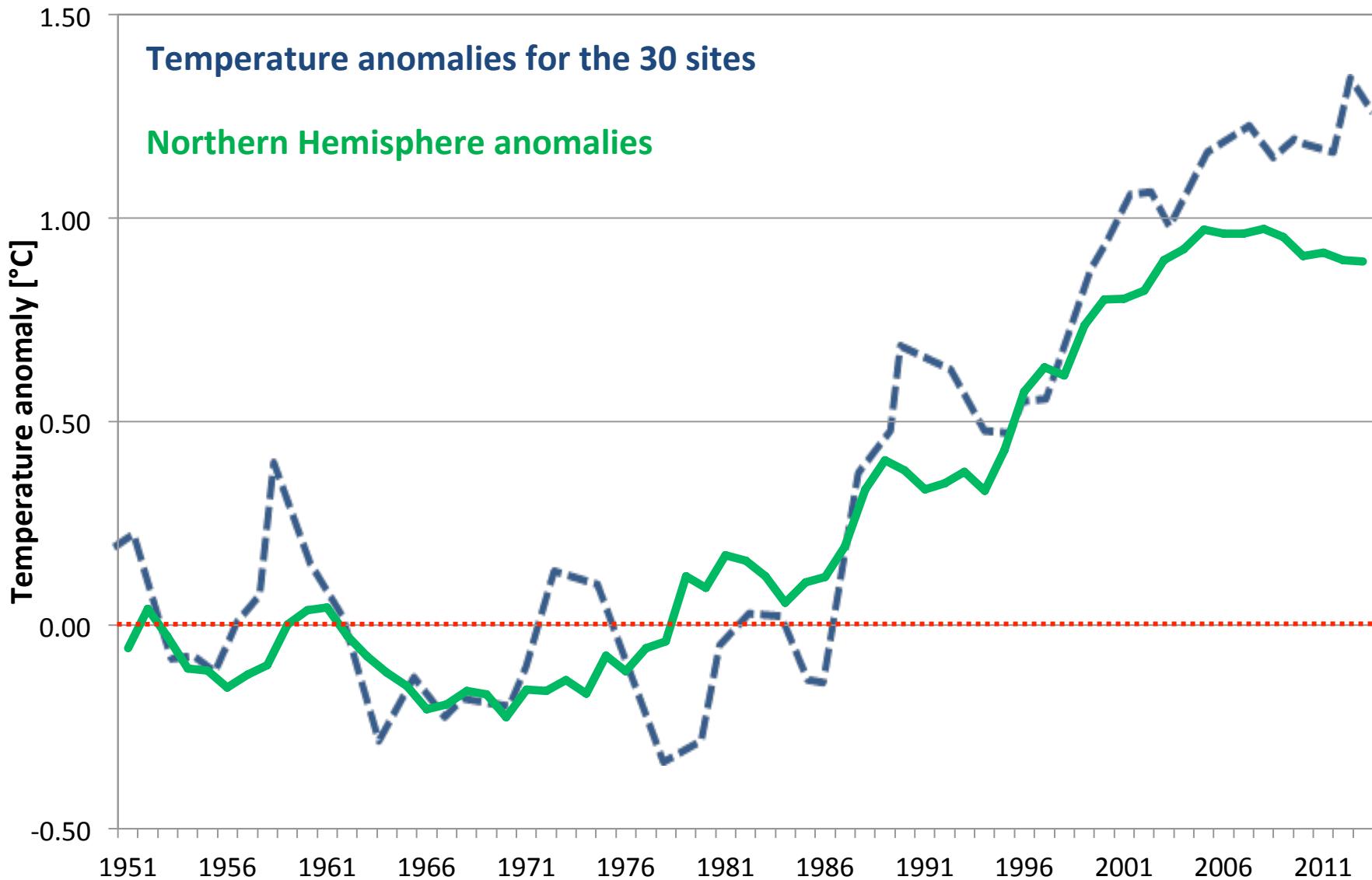
- Paper by Gerry Meehl *et al.* (2009) in *Geophysical Research Letters*, assessing the evolution of the ratio of the number of Tmax:Tmin record temperatures in the United States
- That paper shows that since the 1950s, record Tmax for over 50'000 stations progressively outnumber record Tmin by 2:1
- Modeling work for the 21st century suggests that this ratio could be more than 50:1

Study in Europe

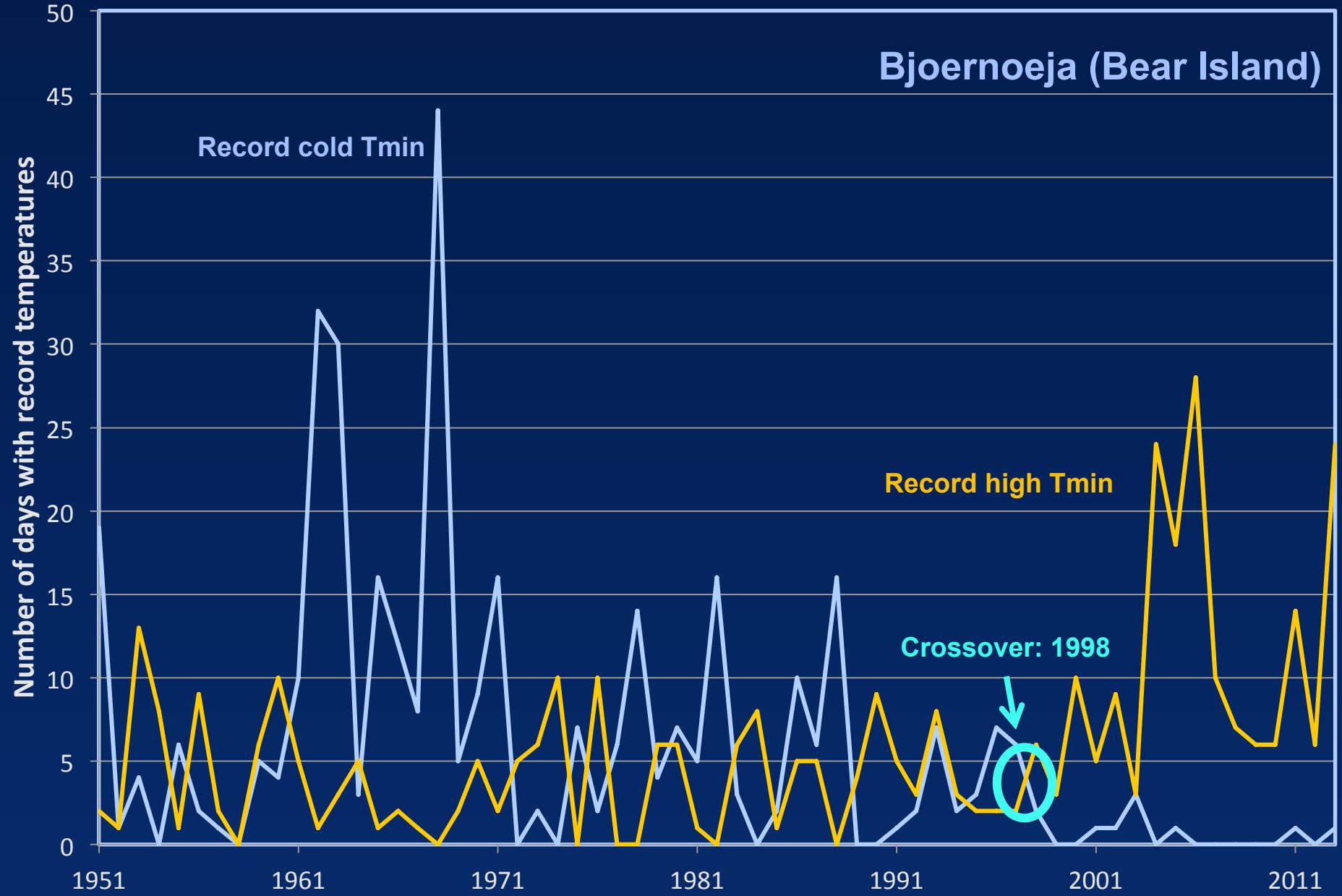
- In this study, we look at the high and low records of Tmin and Tmax on a daily basis (i.e., records for each Jan 1, 2... >> Dec 30, 31) for the period 1951-2013
- The year during which record upper and lower values of Tmin and Tmax occur for each calendar day is identified for the period 1951-2013
- This leads to 365 sets of Tmin/Tmax high/low records for the 63-year time period for each selected location



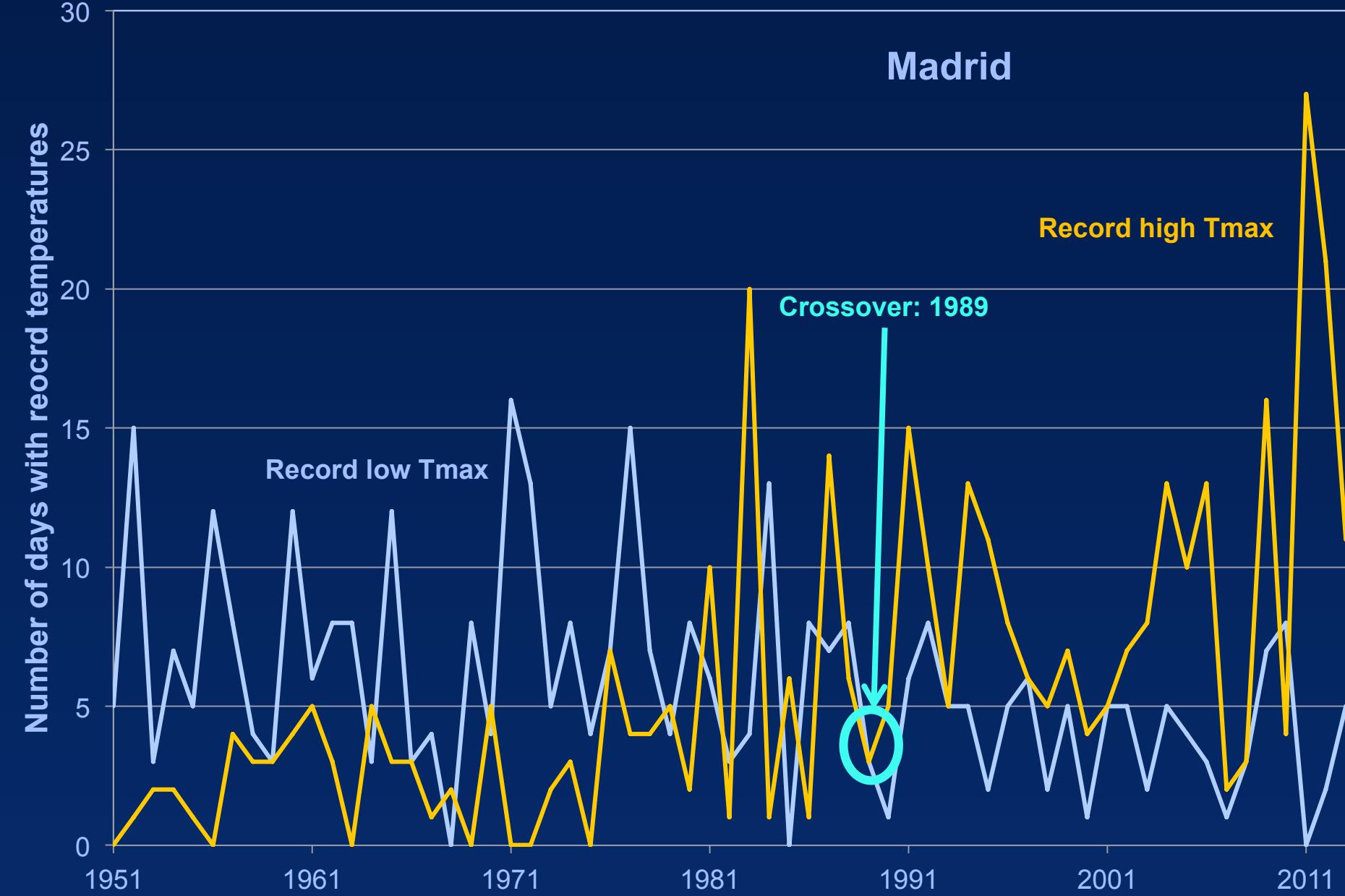
Temperature trends for the European sites and the Northern Hemisphere



Tmin: number of record highs and record lows



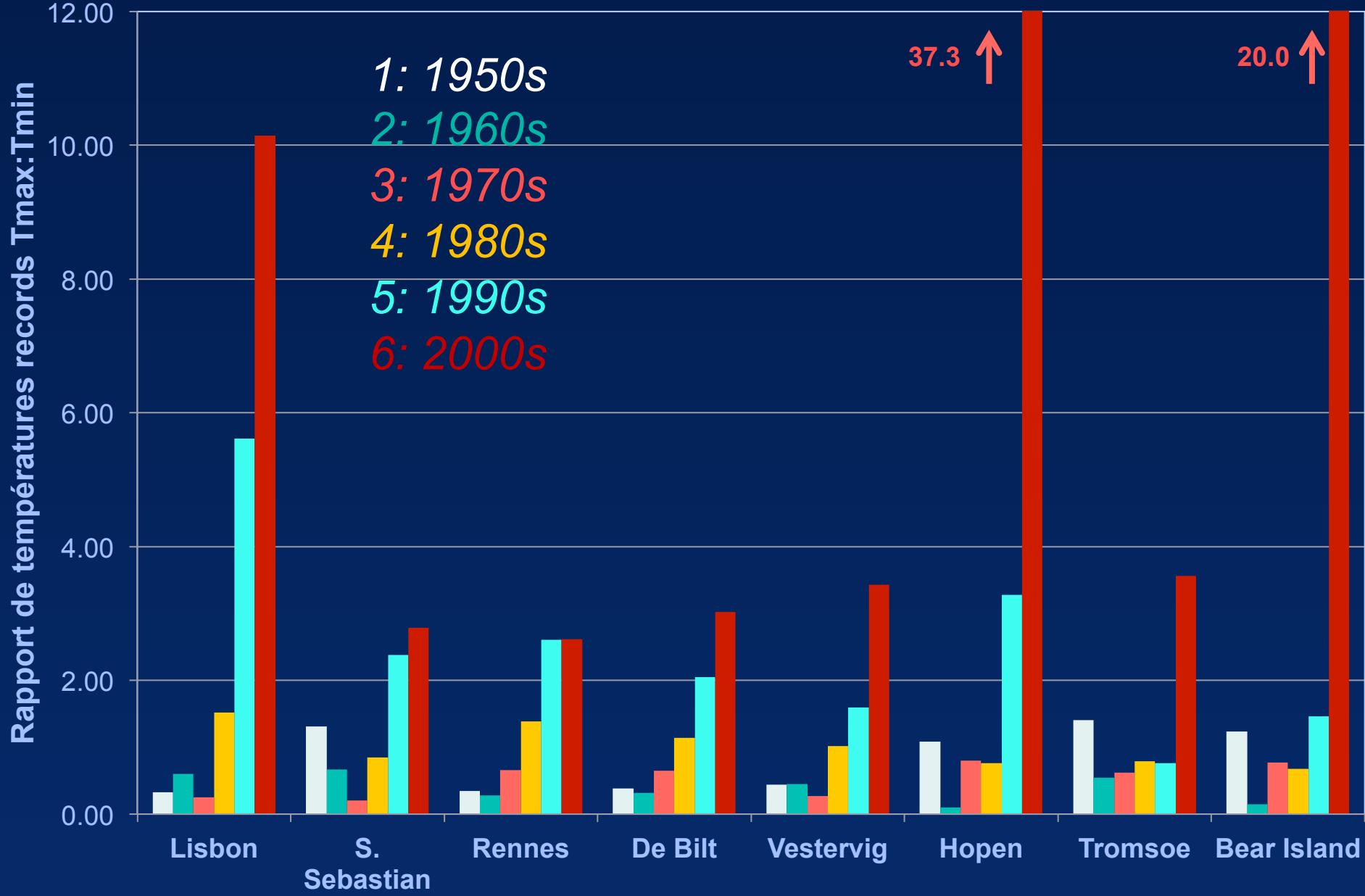
Tmax: number of record highs and record lows



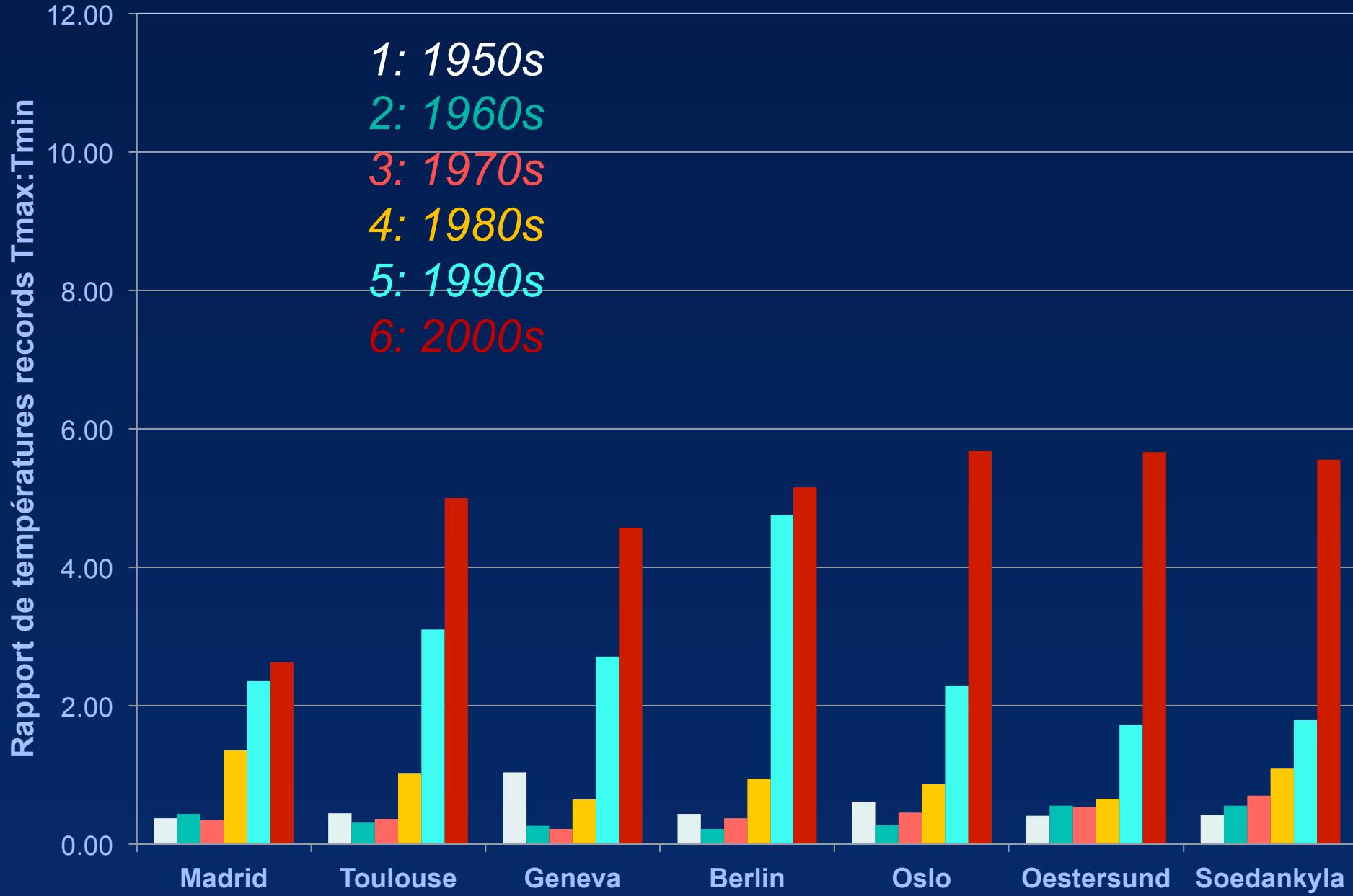
Main questions

- Why does the ratio of record high:record low increase substantially in the last decade, despite the fact that the rise in mean temperatures has (momentarily?) slowed down?
- What are some possible explanations for this apparent paradox?

Transect 1: Lisbon - Hopen



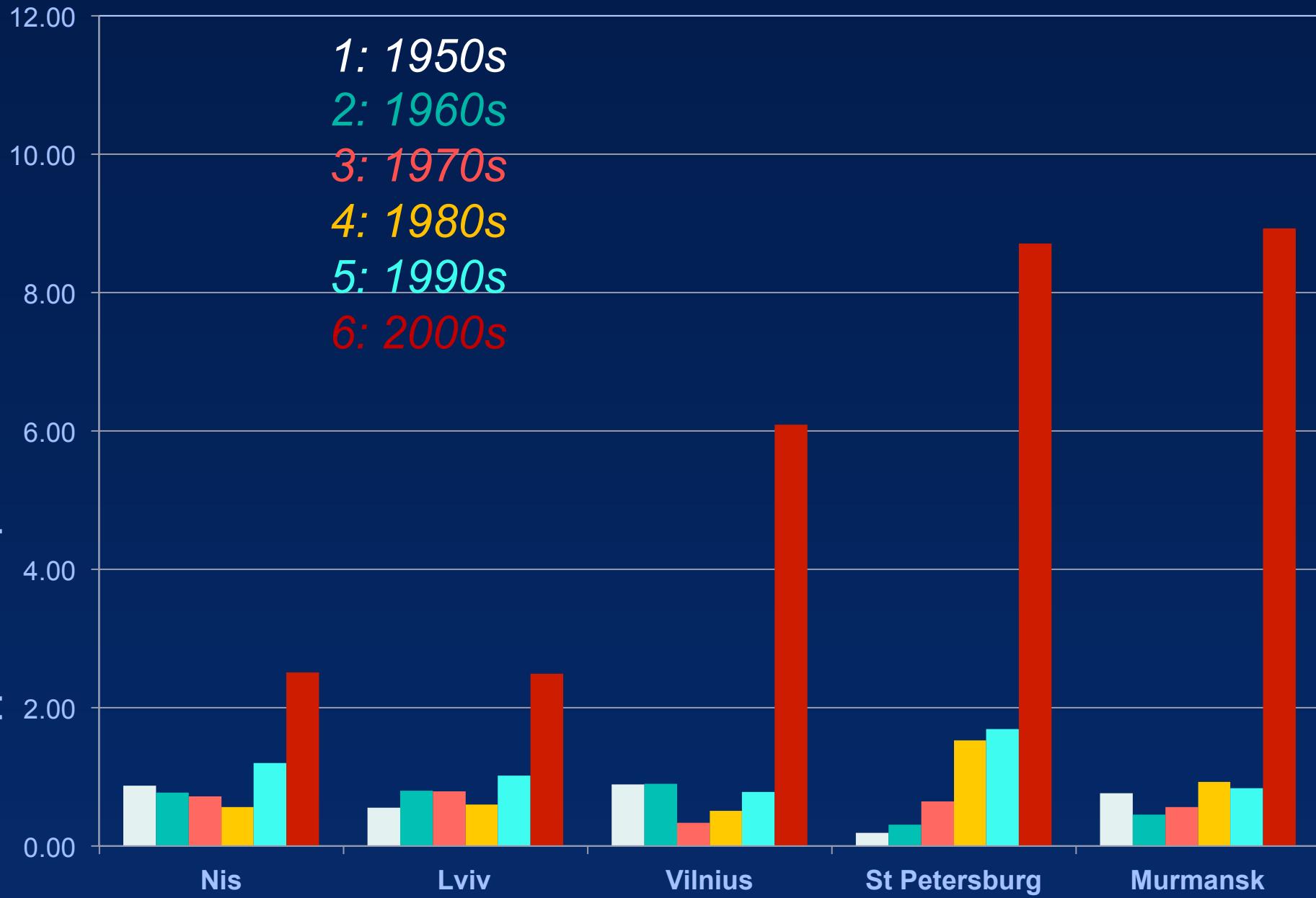
Transect 2: Madrid - Södankylä



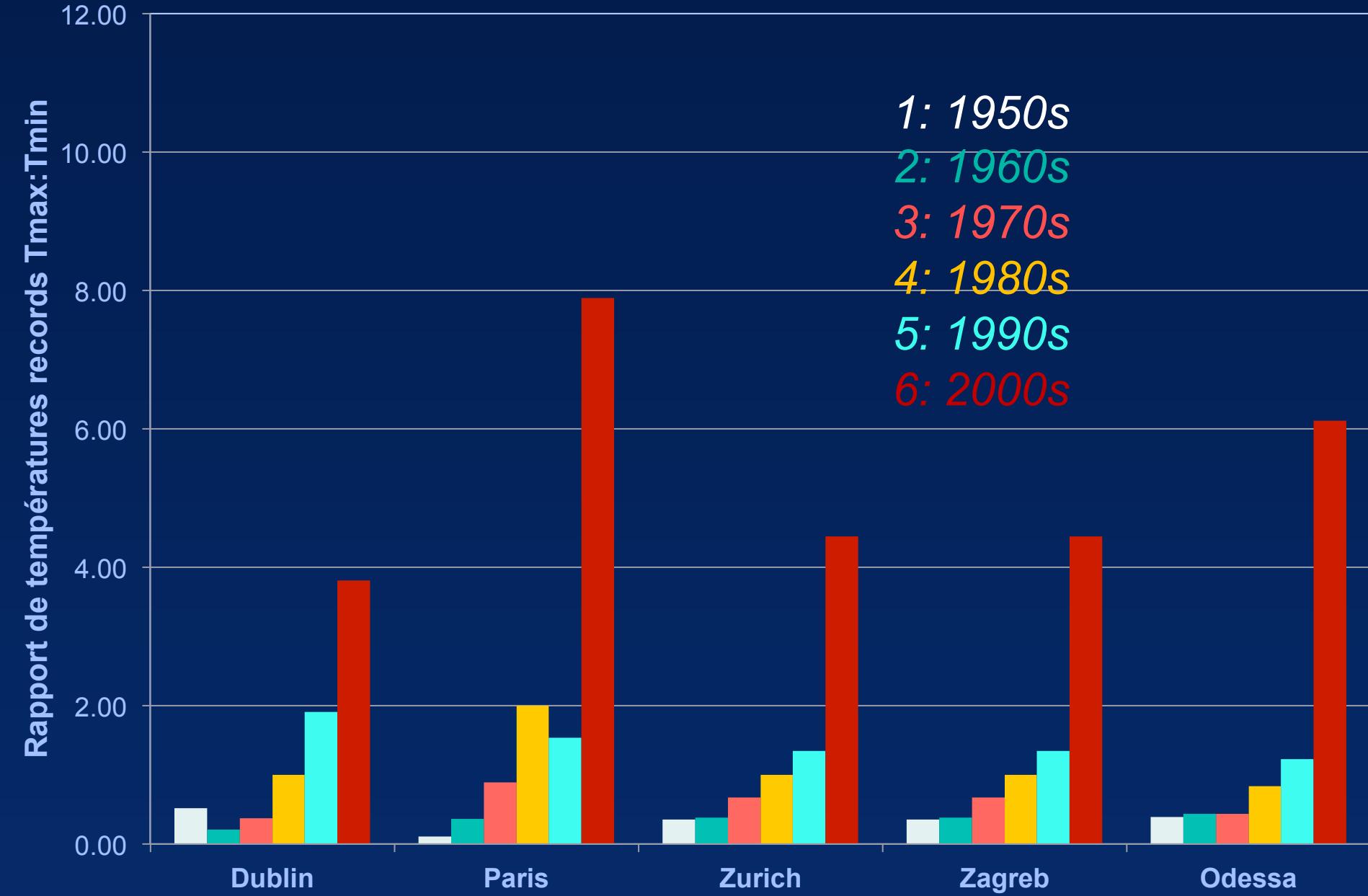
Transect 3: Nis - Murmansk

- 1: 1950s
- 2: 1960s
- 3: 1970s
- 4: 1980s
- 5: 1990s
- 6: 2000s

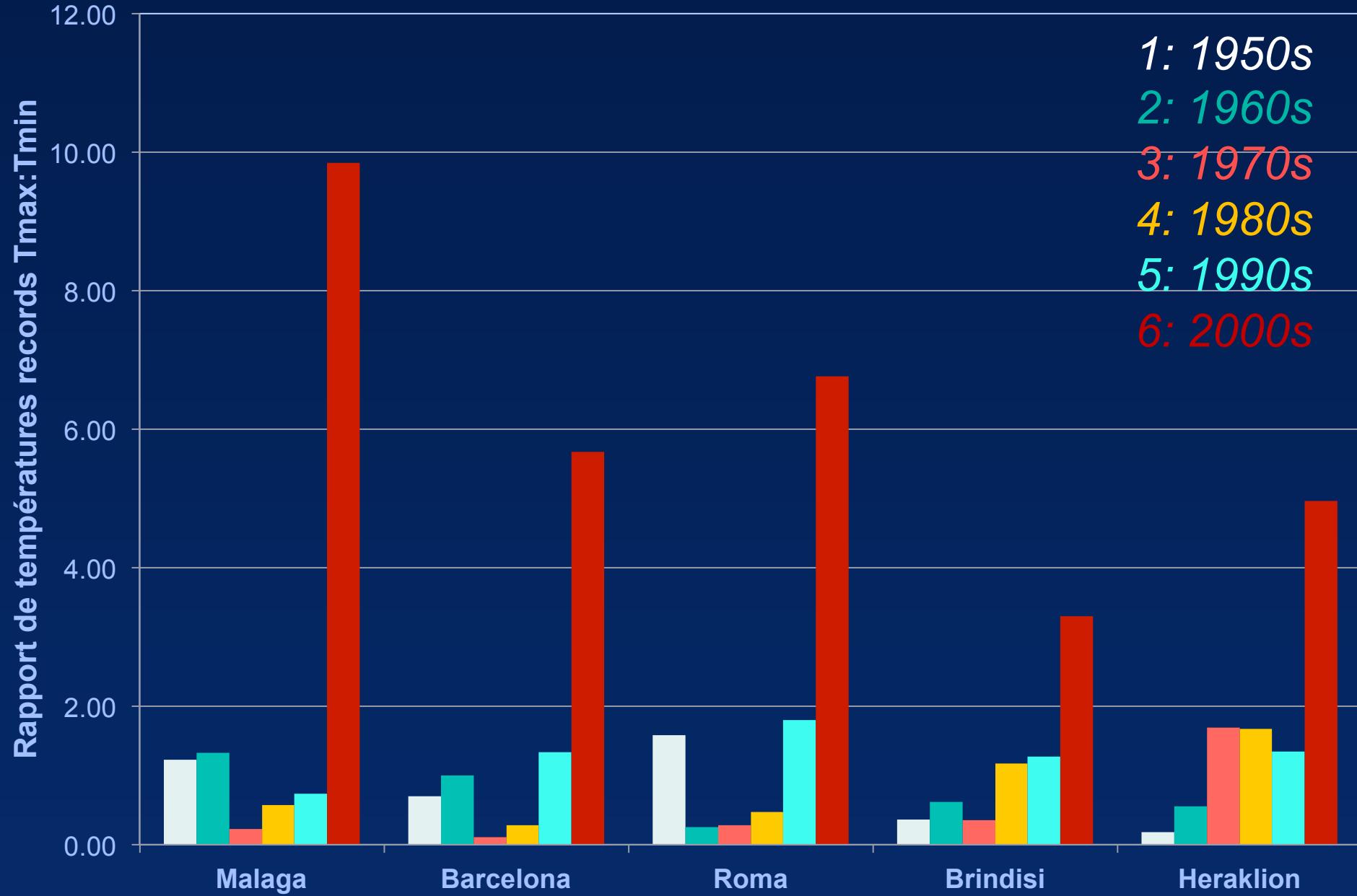
Rapport de températures records Tmax:Tmin



Transect 4: Dublin - Odessa

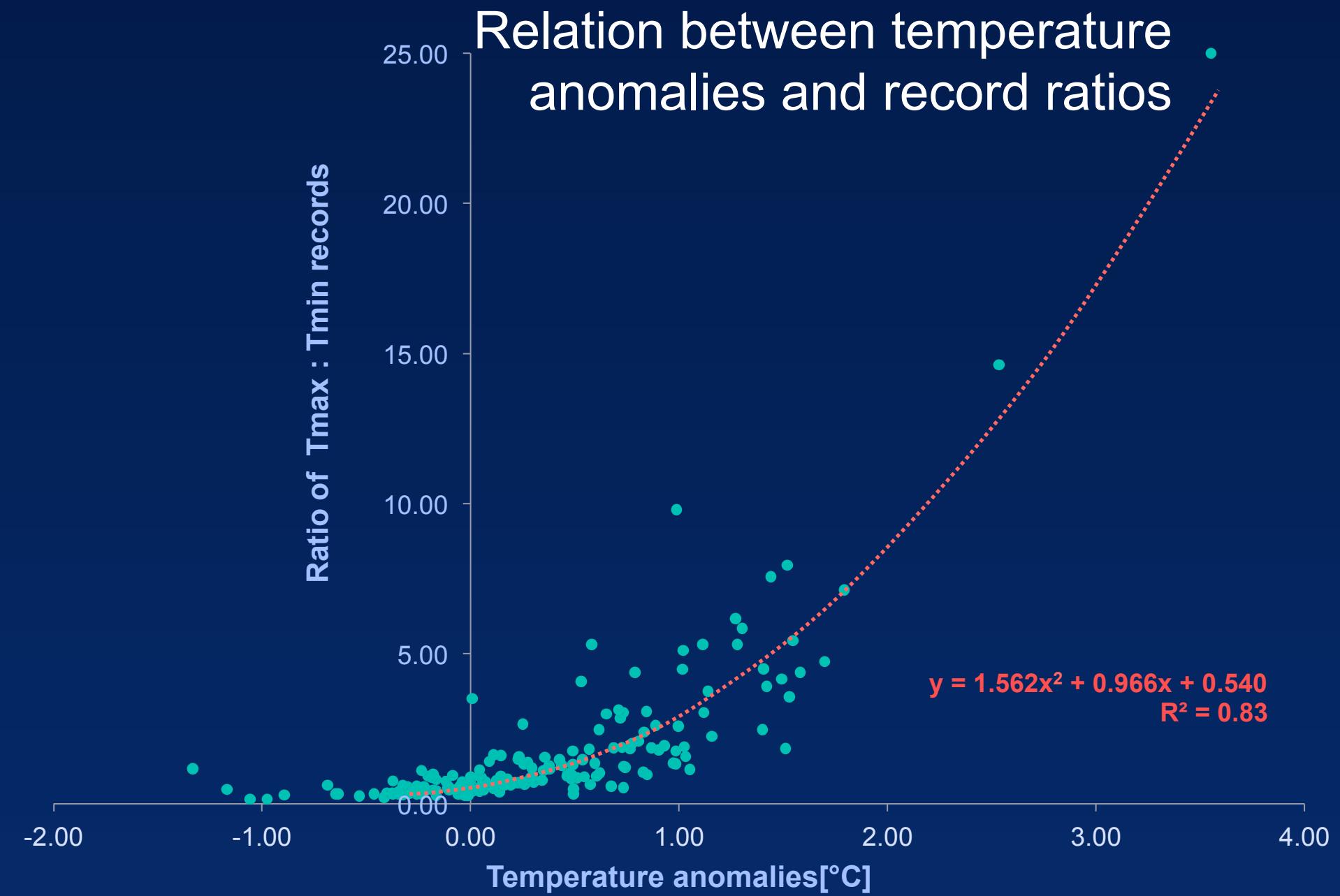


Transect 5: Malaga - Heraklion



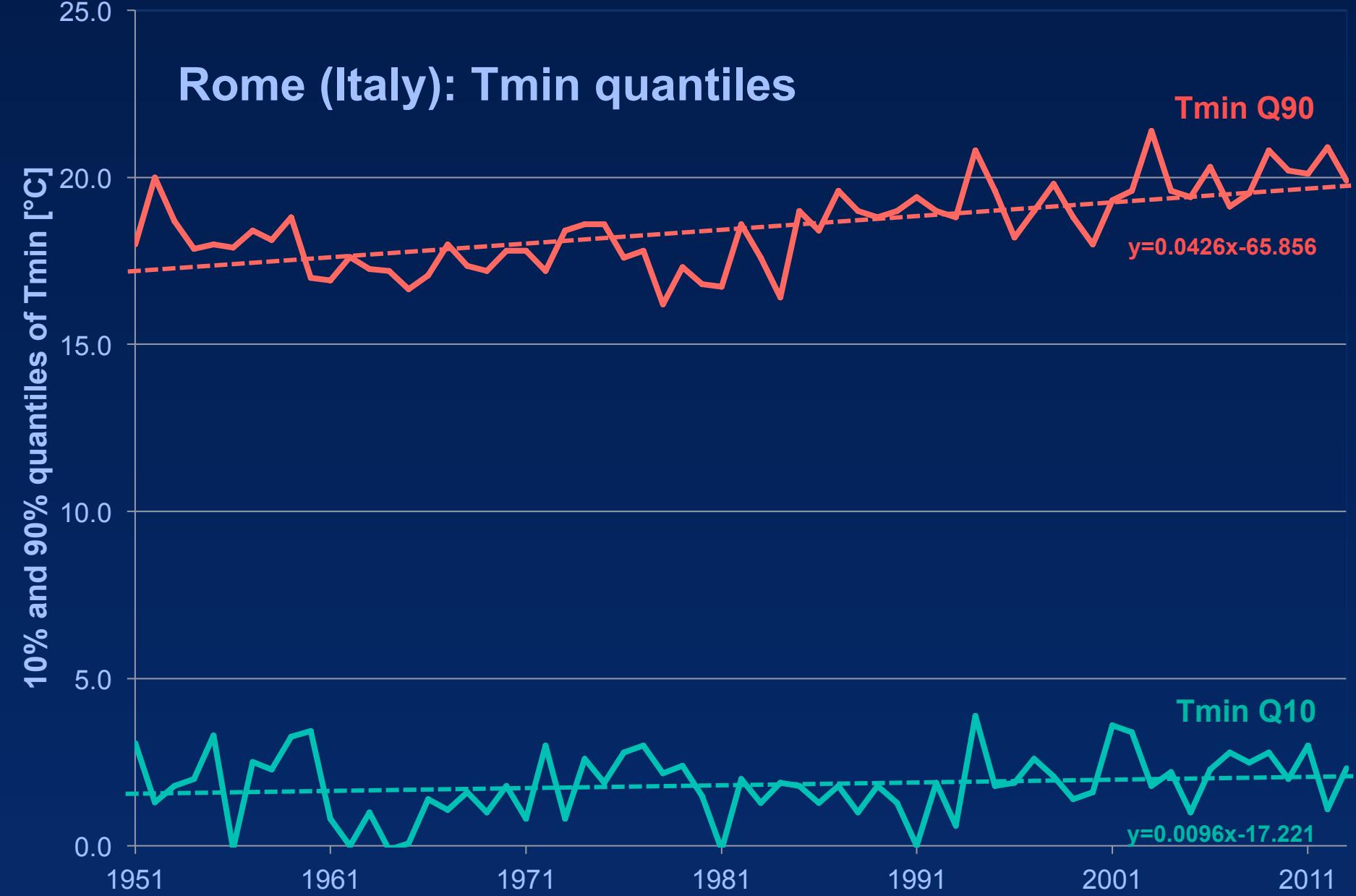
UNIVERSITÉ
DE GENÈVE

Relation between temperature anomalies and record ratios

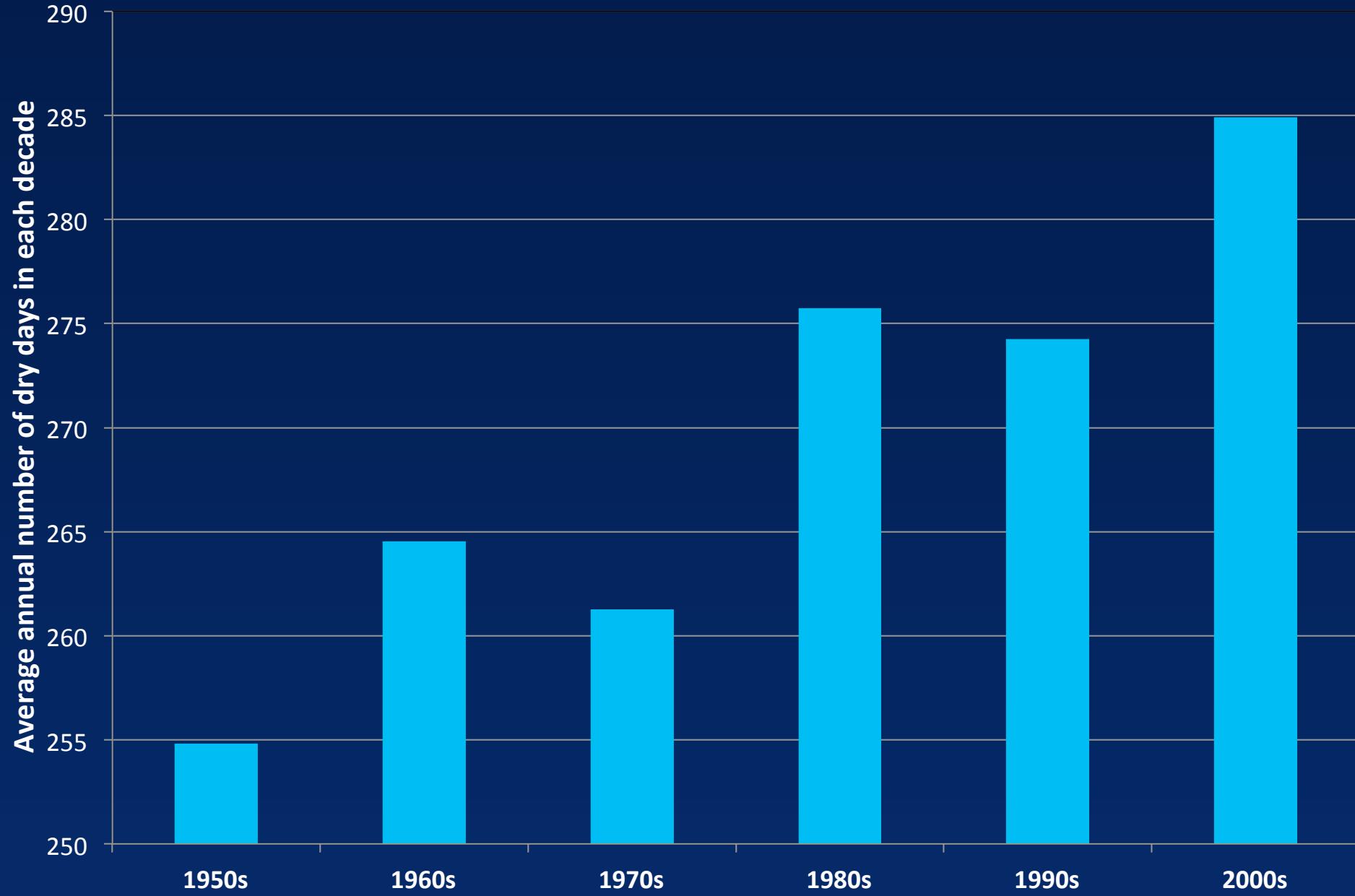


Evolution of 10% and 90% quantiles in Rome

Rome (Italy): Tmin quantiles



Changes in dry days in Rome



Evolution of 10% and 90% quantiles in Hopen

Hopen (Norway): Tmin quantiles

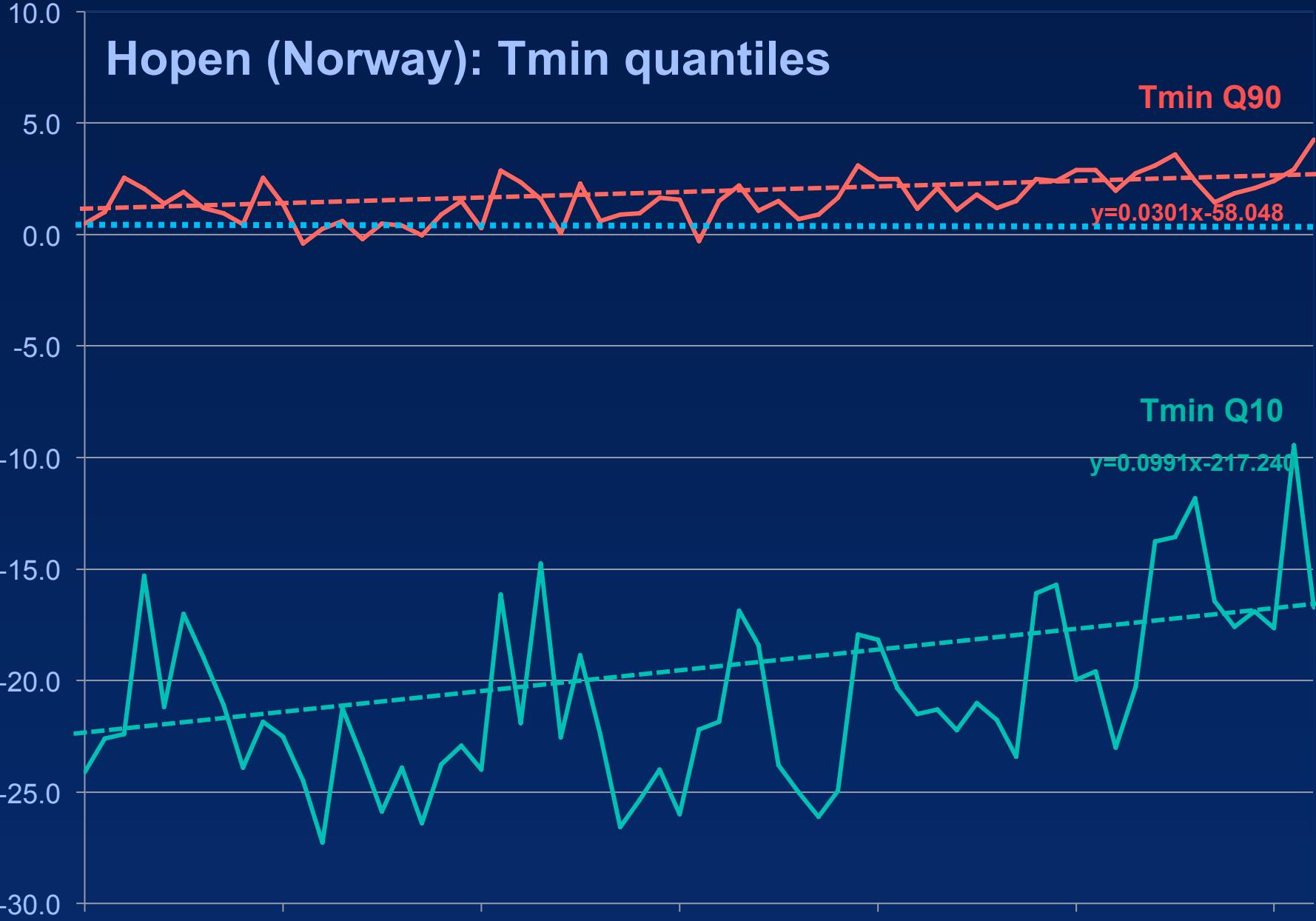
Tmin Q90

$$y=0.0301x-58.048$$

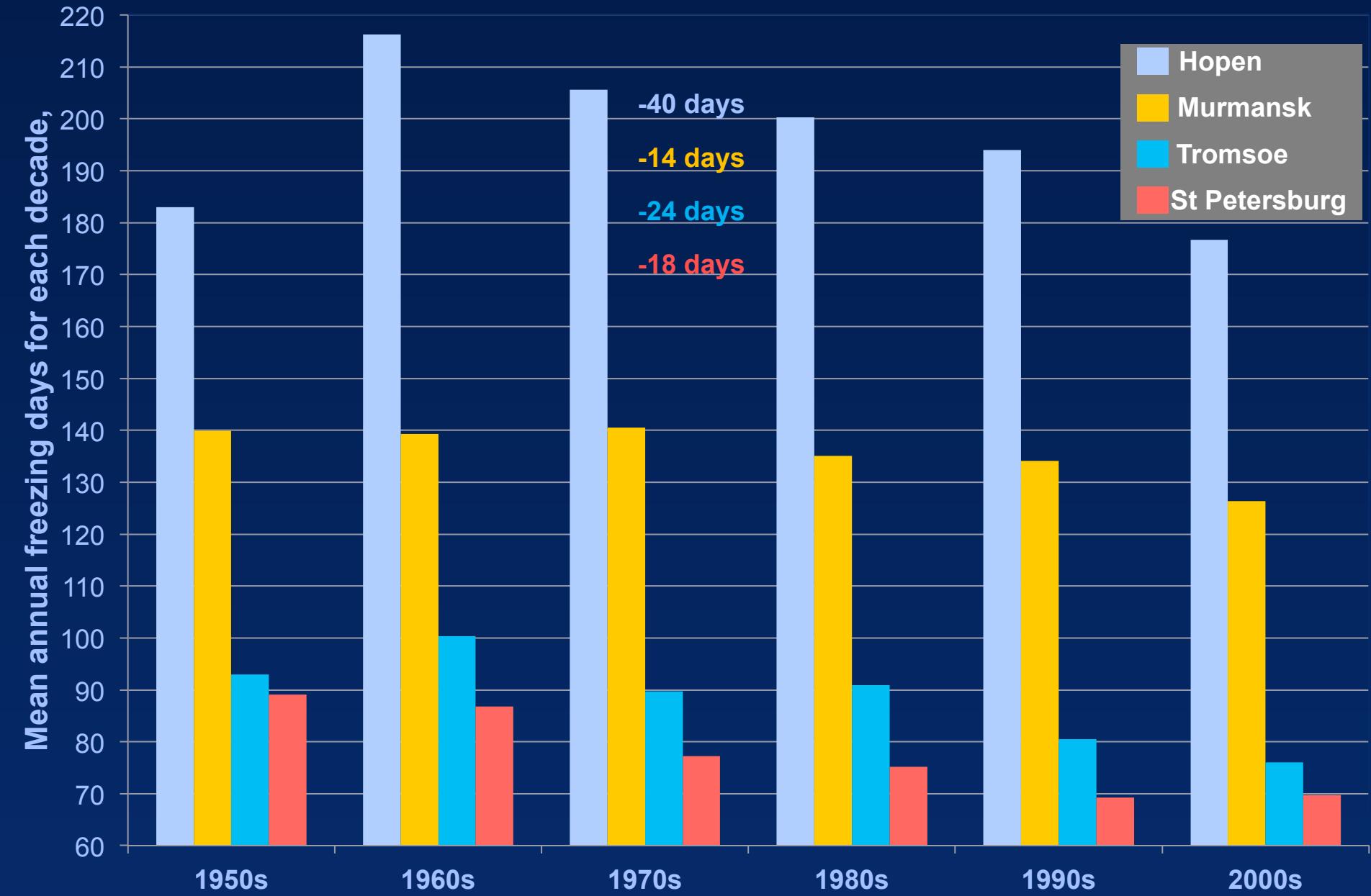
Tmin Q10

$$y=0.0991x-217.240$$

10% and 90% quantiles of Tmin [°C]



Changes in days with snow on the ground



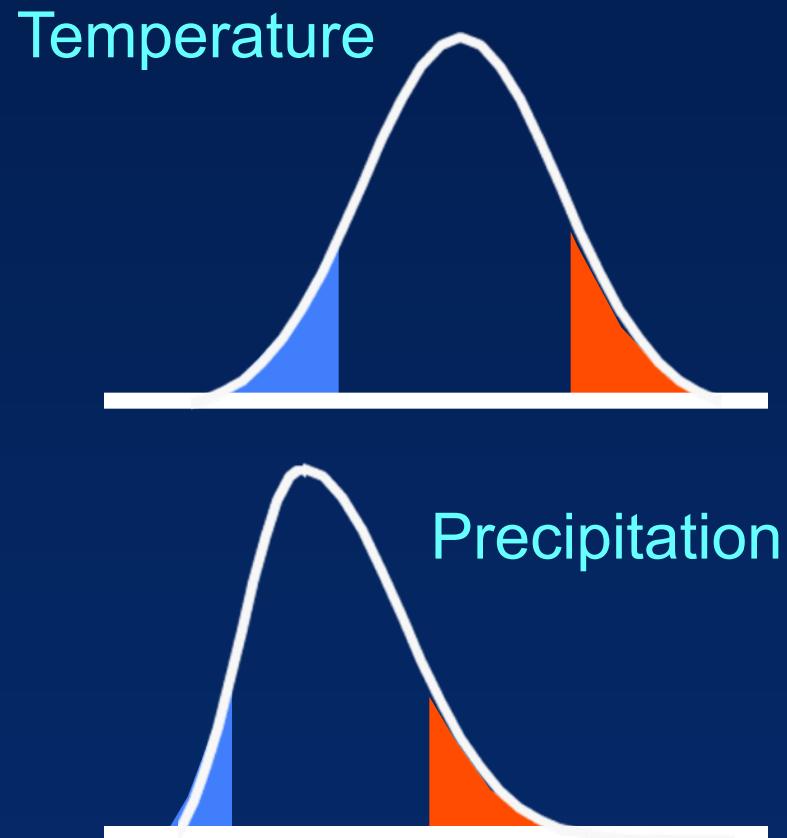
Joint distribution statistics

Joint distribution statistics

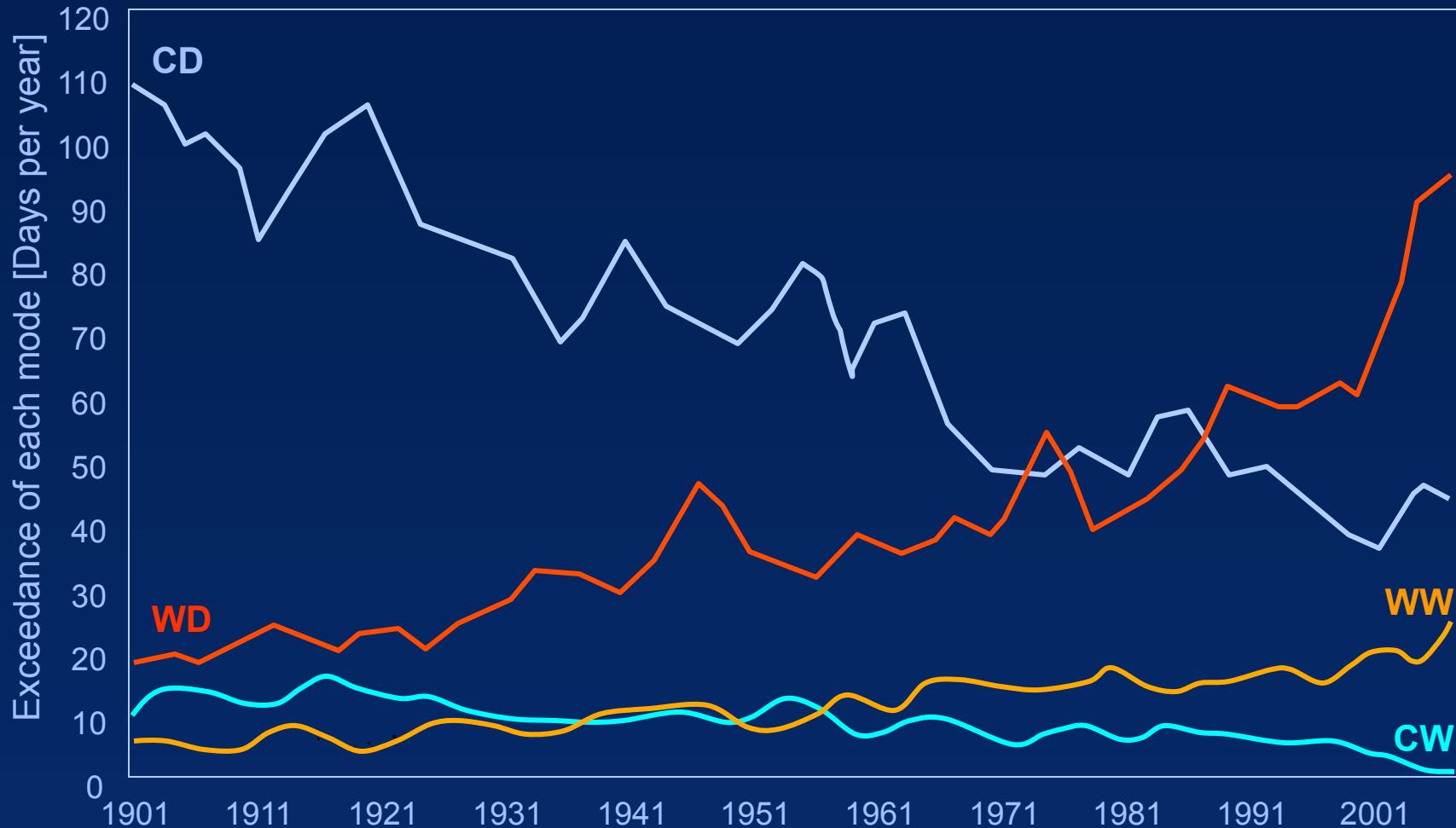
Joint quantile distributions as one objective measure of weather regimes

Characterize weather patterns in a quantitative manner based on combinations of quantiles of temperature and precipitation at the 25% and 75% quantile levels

- ◆ Cold/dry (CD): T25/p25
 - ◆ « Stable winters »
- ◆ Cold/wet (CW): T25/p75
 - ◆ « Perturbed winters »
- ◆ Warm/dry (WD): T75/p25
 - ◆ « Stable summers »
- ◆ Warm/wet (WW): T75/p75
 - ◆ « Perturbed Summers »

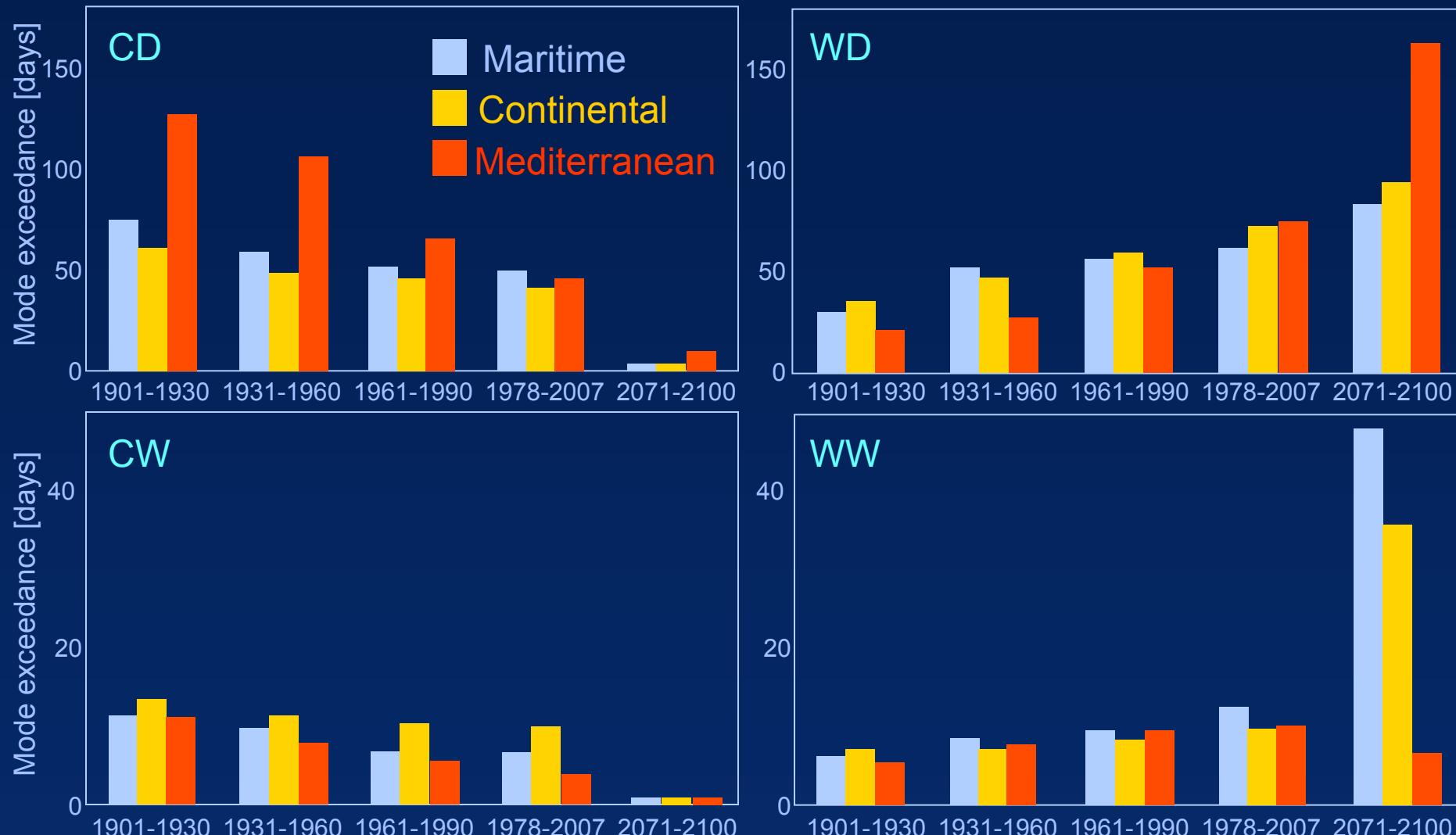


Observed changes in joint extreme quantiles in Geneva



Beniston, 2009: Geophysical Research Letters

Changes in the frequency of each combination of quantiles

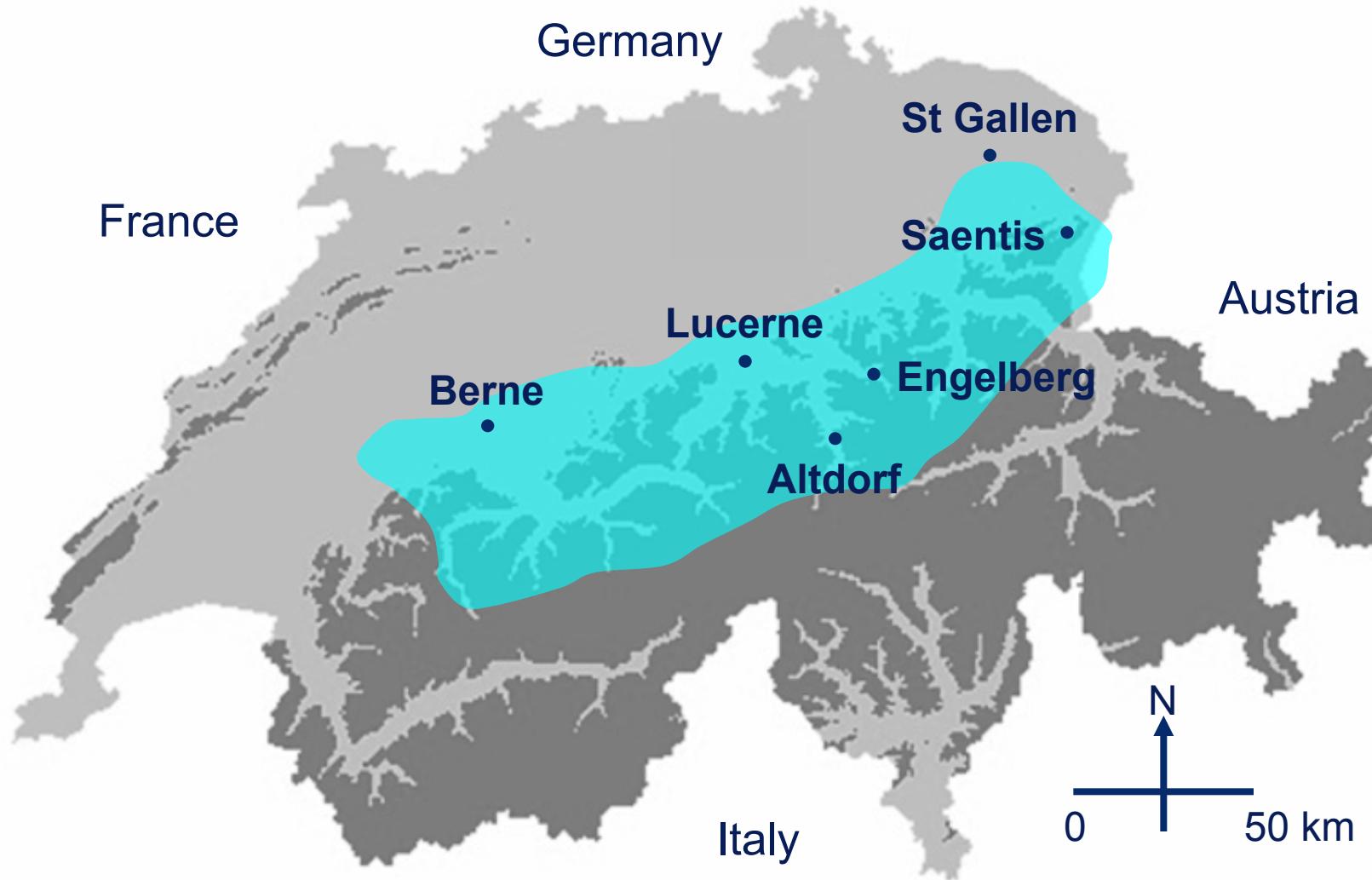


Beniston, 2009: Geophysical Research Letters

Extreme precipitation

Extrême précipitation

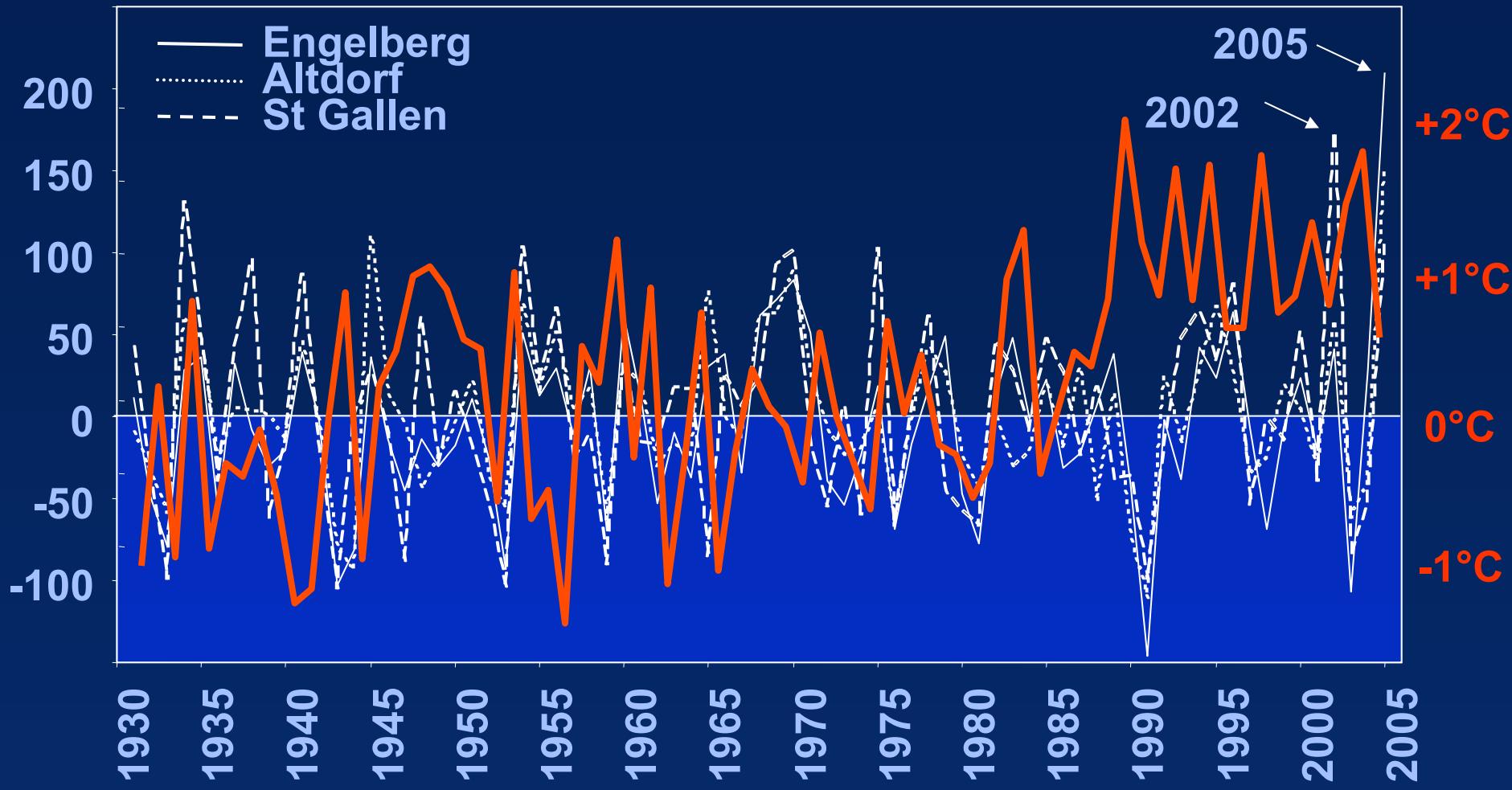
August 2005 floods: Worst affected areas



Summer rainfall in the central Swiss Alps

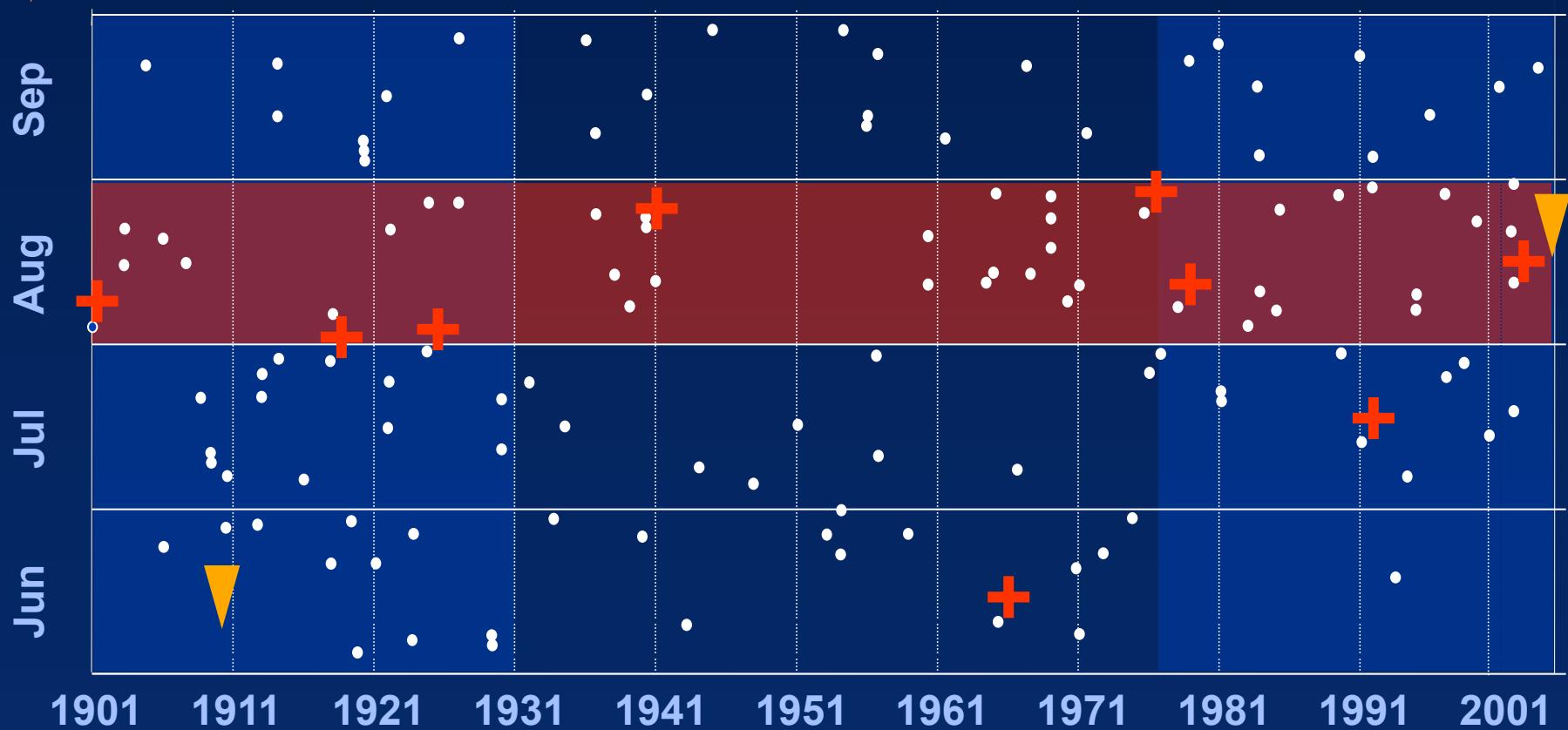
Precipitation anomalies [mm]

Temperature anomalies [°C]

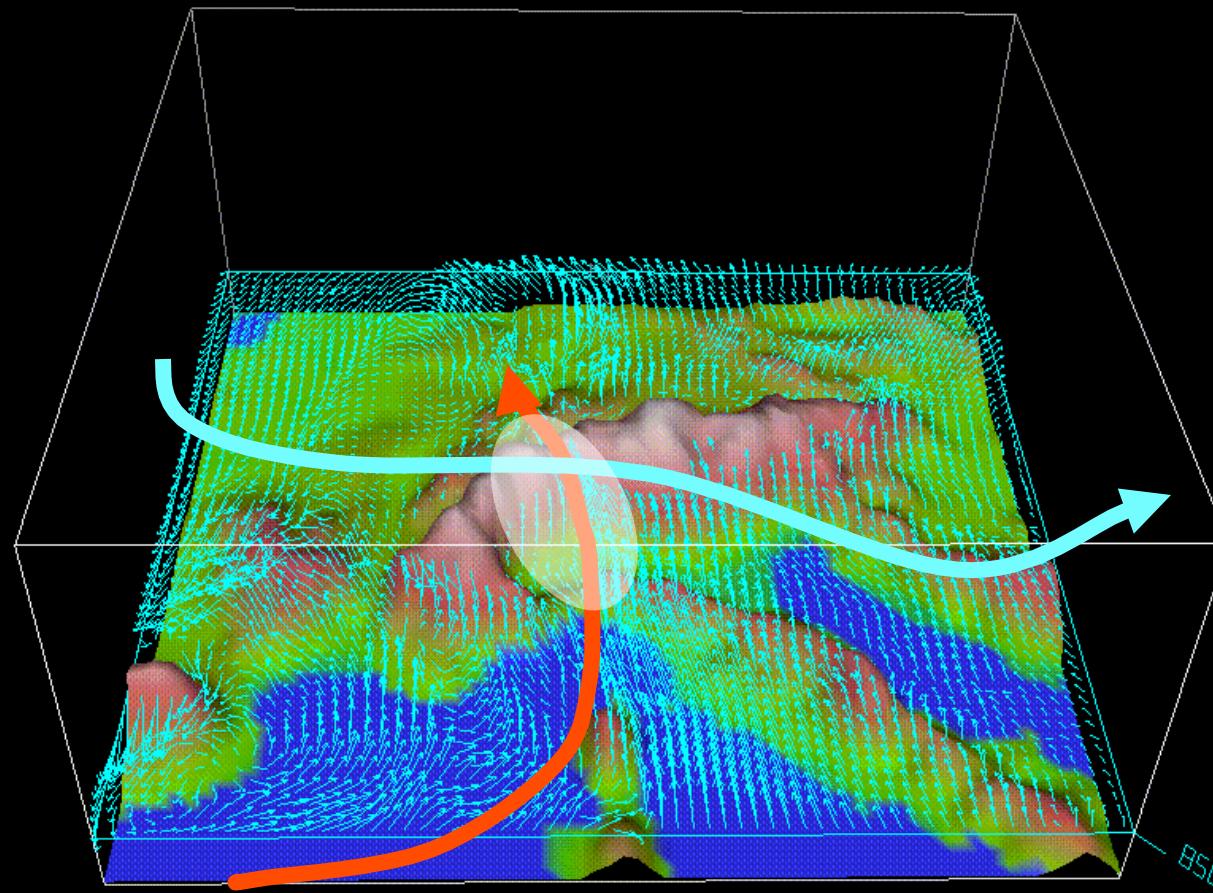


Summer extreme precipitation (Säntis)

- >quantile 99% (61 mm/day)
- ✚ >100 mm/day
- ▼ >150 mm/day



Convergence of moisture-laden air leading to extreme precipitation



Types of floods in the Alps

Courtesy: Markus Stoffel
Universities of Geneva and Berne



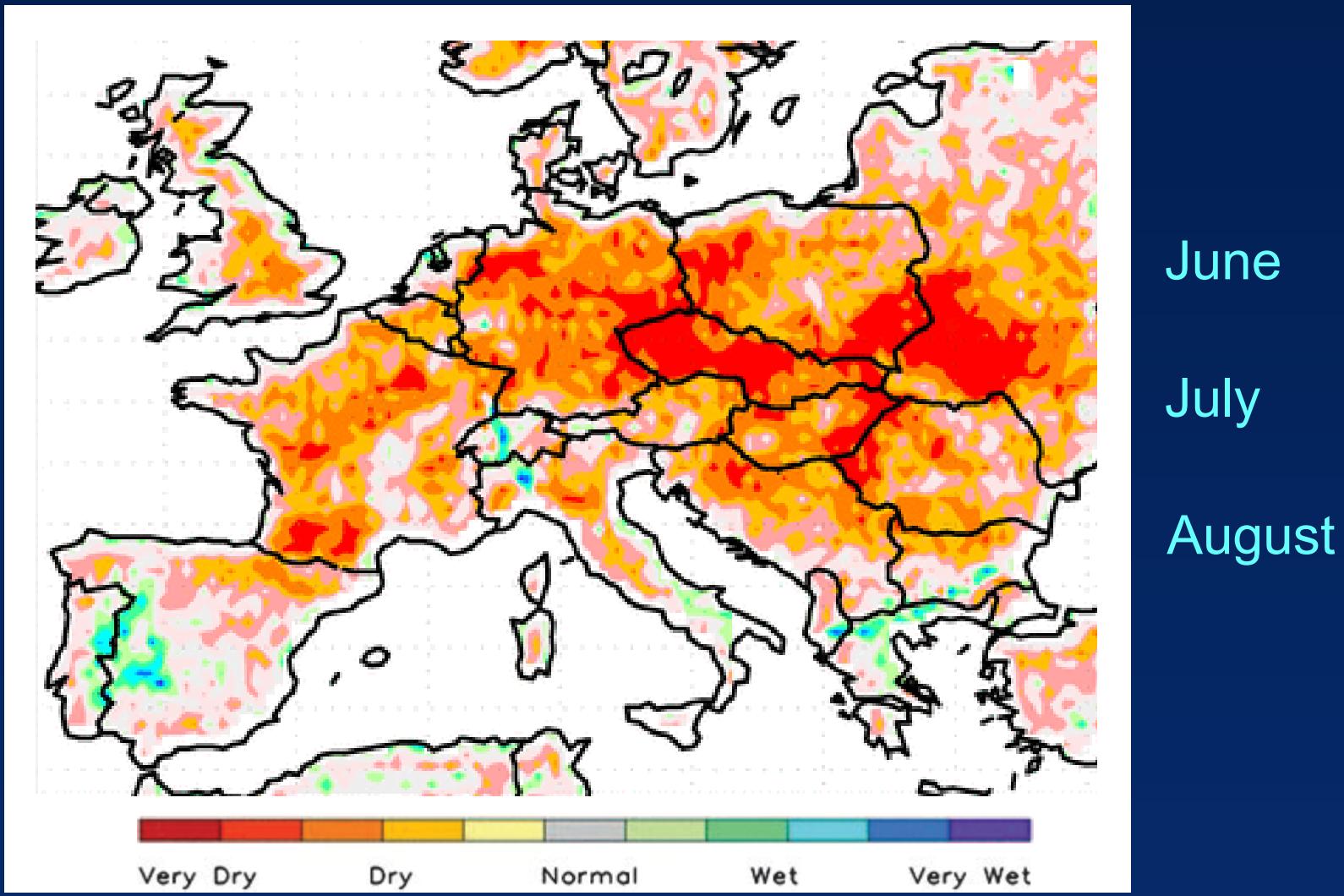
18.09.17

Summer drought

(wetness indicator derived by US Climate Data Center based on **special sensor microwave/imager** (SSM/I) on MERIS platform)

Gobron et al., 2005: Int'l J. Remote Sensing

Source: <http://lwf.ncdc.noaa.gov/>.



Principle questions

- What is the link between dry days and temperature?
 - ◆ According to different definitions of «drought» or «dry days»
- What are the trends in dry days over the course of the 20th century?
- Can these trends explain the observed warming?

Approaches to quantify links between dry days and temperature (Summer, JJA)

- Number of rainless days
 - ◆ Difference between average Tmax during dry days with average Tmax for the entire summer season ($\Delta T_{dd} = T_{dd} - T_{jja}$)
- Clusters of days without rain
 - ◆ Same as above, except for *consecutive* dry days for periods of 4, 8, 12 days
- SPI: Standardized Precipitation Index

Definition of SPI

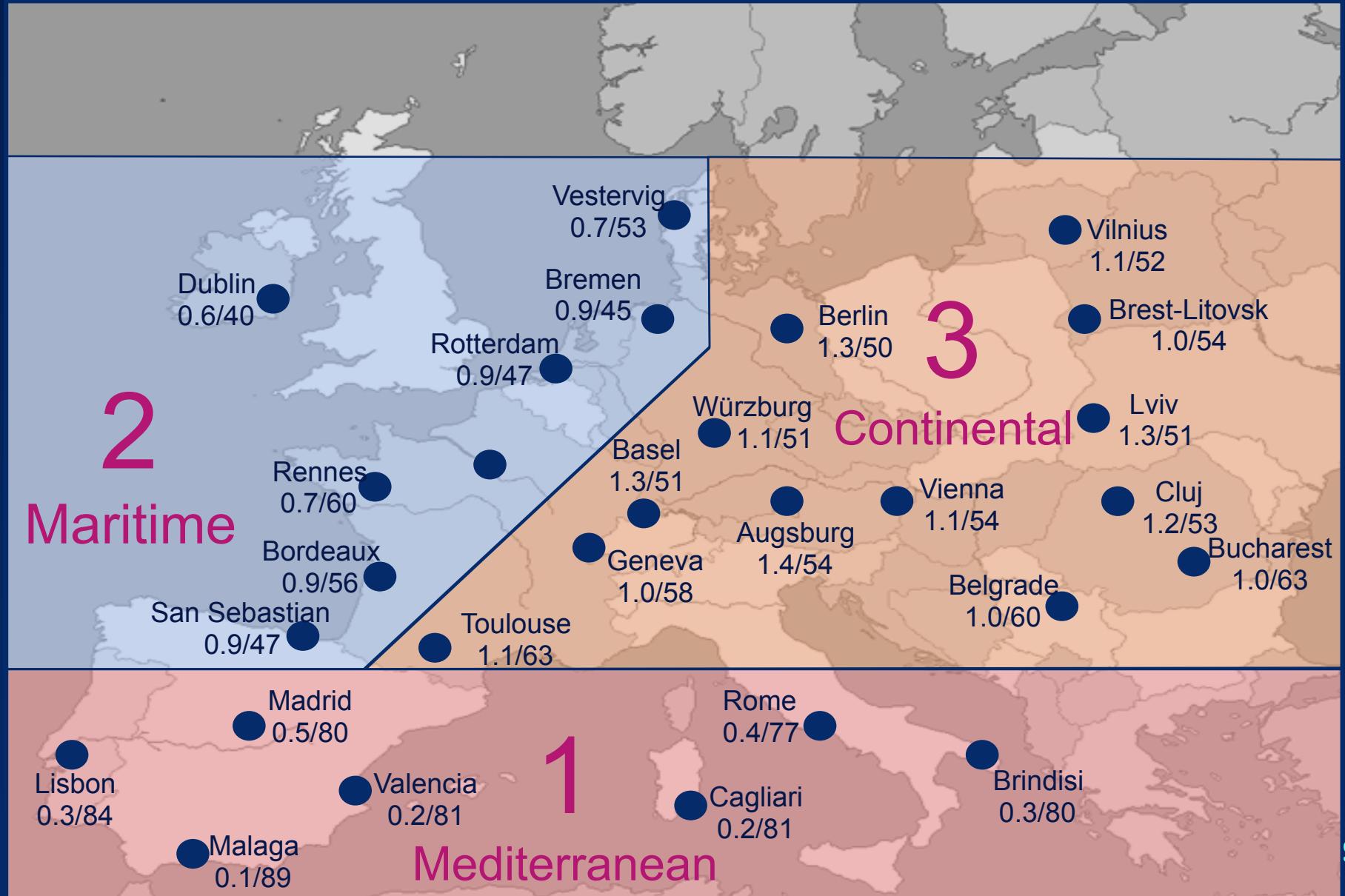
■ The Standardized Precipitation Index (SPI)

- ◆ The SPI compares total cumulative precipitation at a given location for a specific time interval (e.g. 1, 3, or 6 months) to the average cumulative precipitation for those same months for the entire length of the record.
- ◆ The SPI is thus a transformation of a time series of precipitation into a standardized normal distribution
- ◆ Severe droughts are considered to occur for $\text{SPI} < -2$ and very wet conditions for $\text{SPI} > +2$
- ◆ Normal conditions generally $-1 < \text{SPI} < +1$.

European droughts

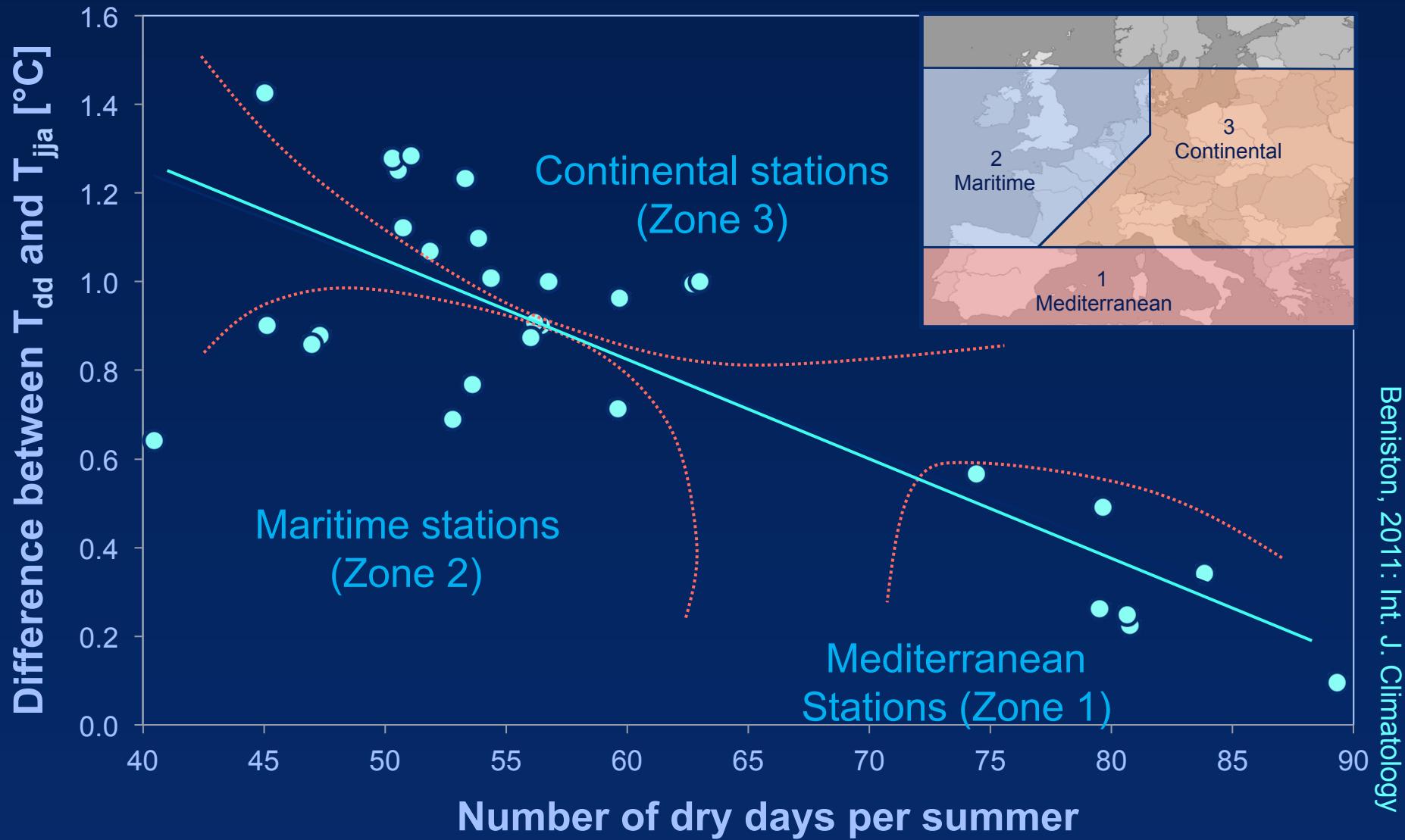
Ευρωπαϊκοί ανημόδραστοι

Average ΔT_{dd} and dry days (1951-2010)

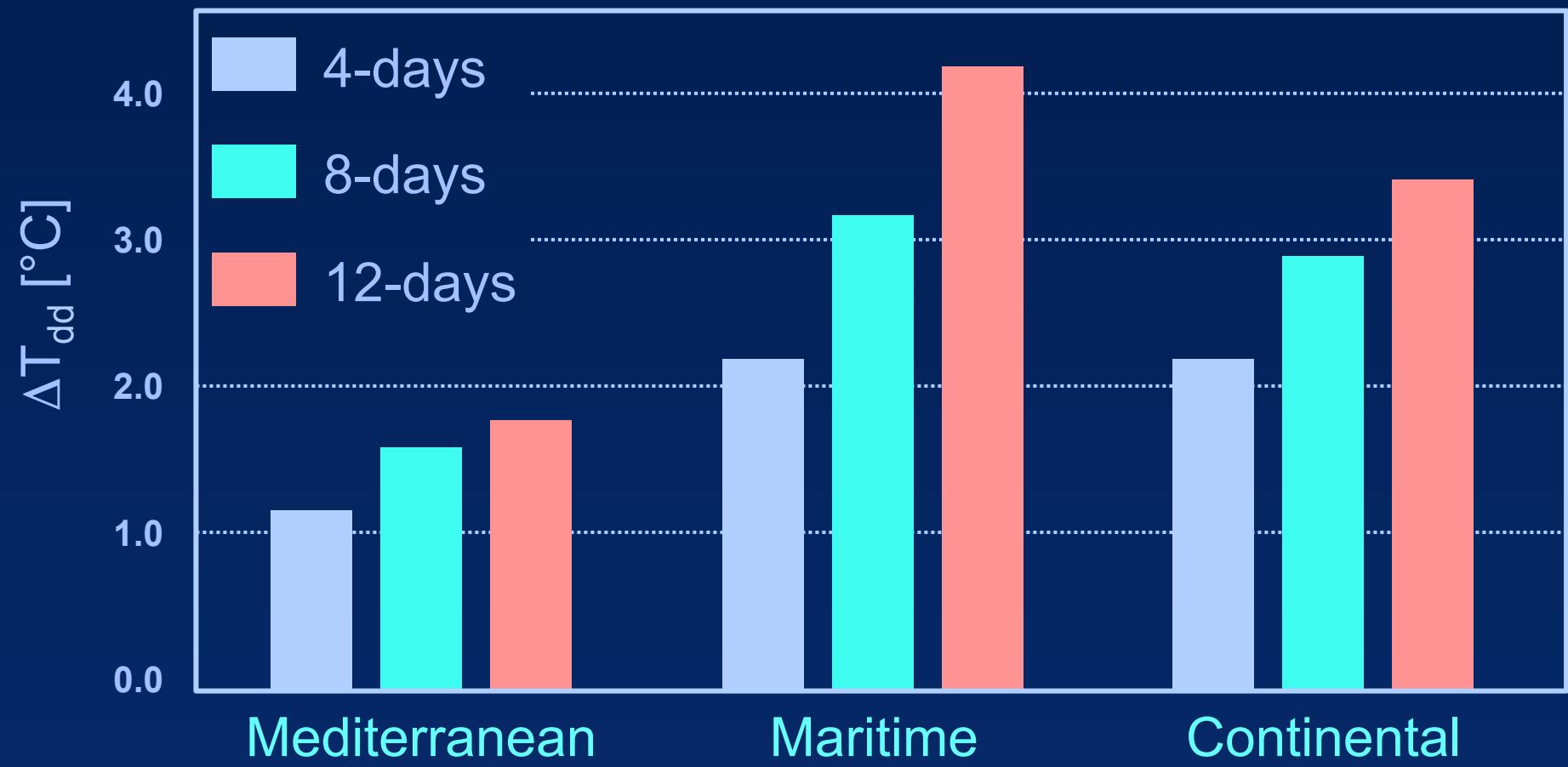


Beniston, 2011: Int. J. Climatology

Link between ΔT_{dd} and dry days (1951-2010)

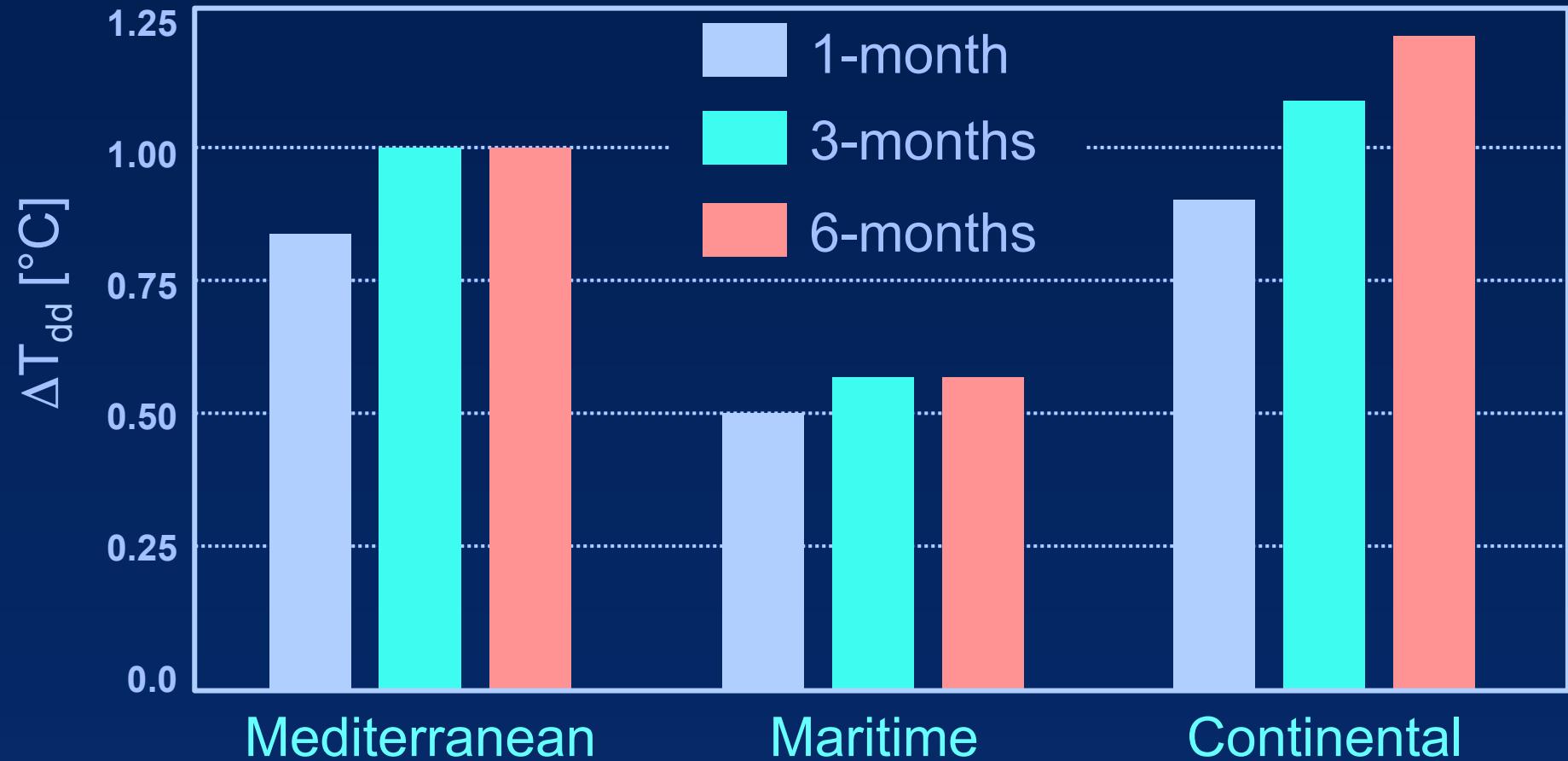


Link between ΔT_{dd} and consecutive dry days (1951-2010)



Beniston, 2011: Int. J. Climatology

Link between ΔT_{dd} and SPI (1951-2010)



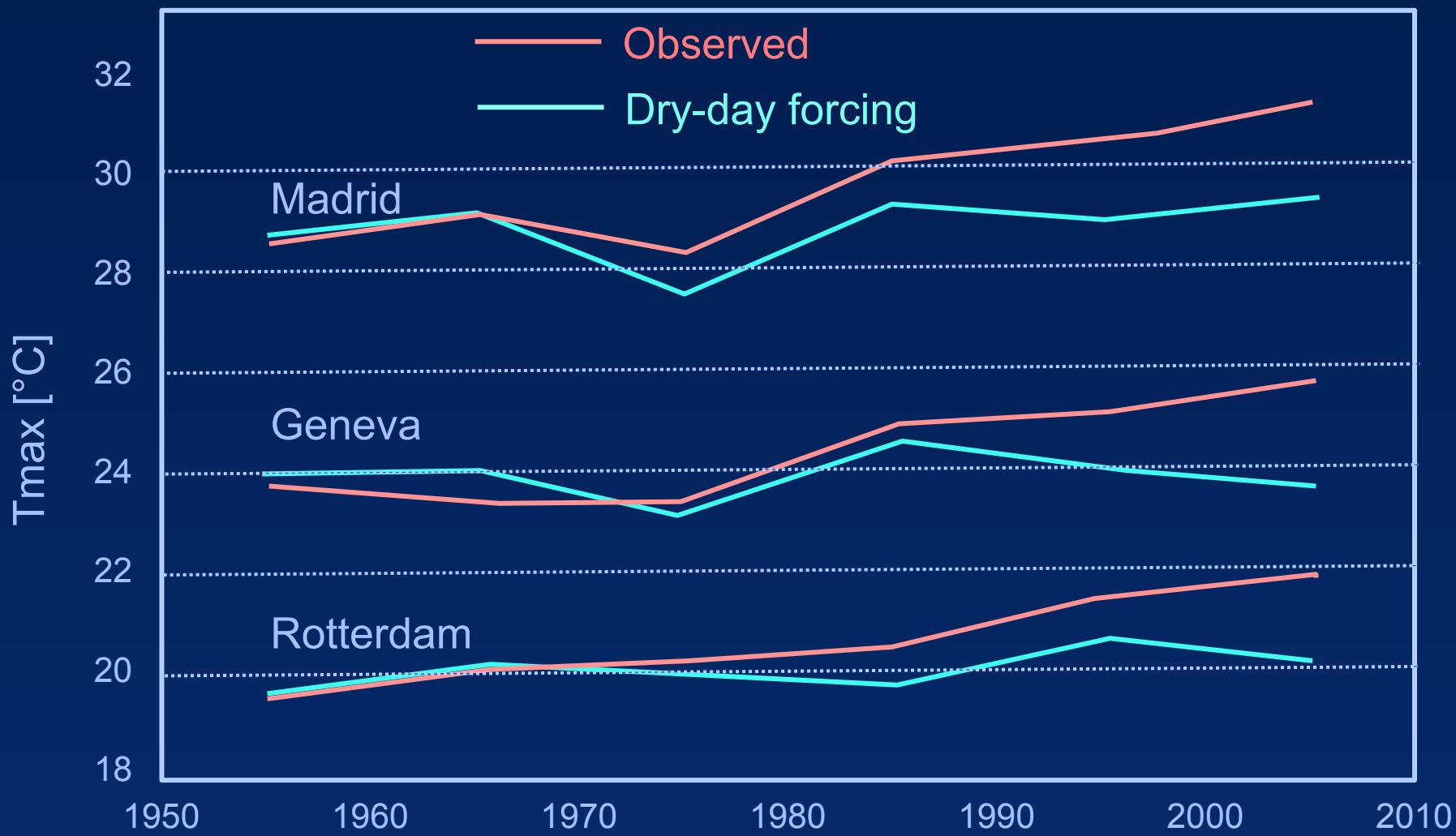
Beniston, 2011: Int. J. Climatology

Incremental change in ΔT_{dd} : each additional dry day; unit decrease in SPI

	Mediterranean	Maritime	Continental
Change of 1 dry day			

	Mediterranean	Maritime	Continental
Change of 1 SPI unit 1-month scale	1.1°C	1.1°C	1.1°C
Change of 1 SPI unit 6-month scale	0.7°C	0.7°C	0.7°C

Change in temperature according to change in dry days



Beniston, 2011: Int. J. Climatology

Extremes in a warming climate

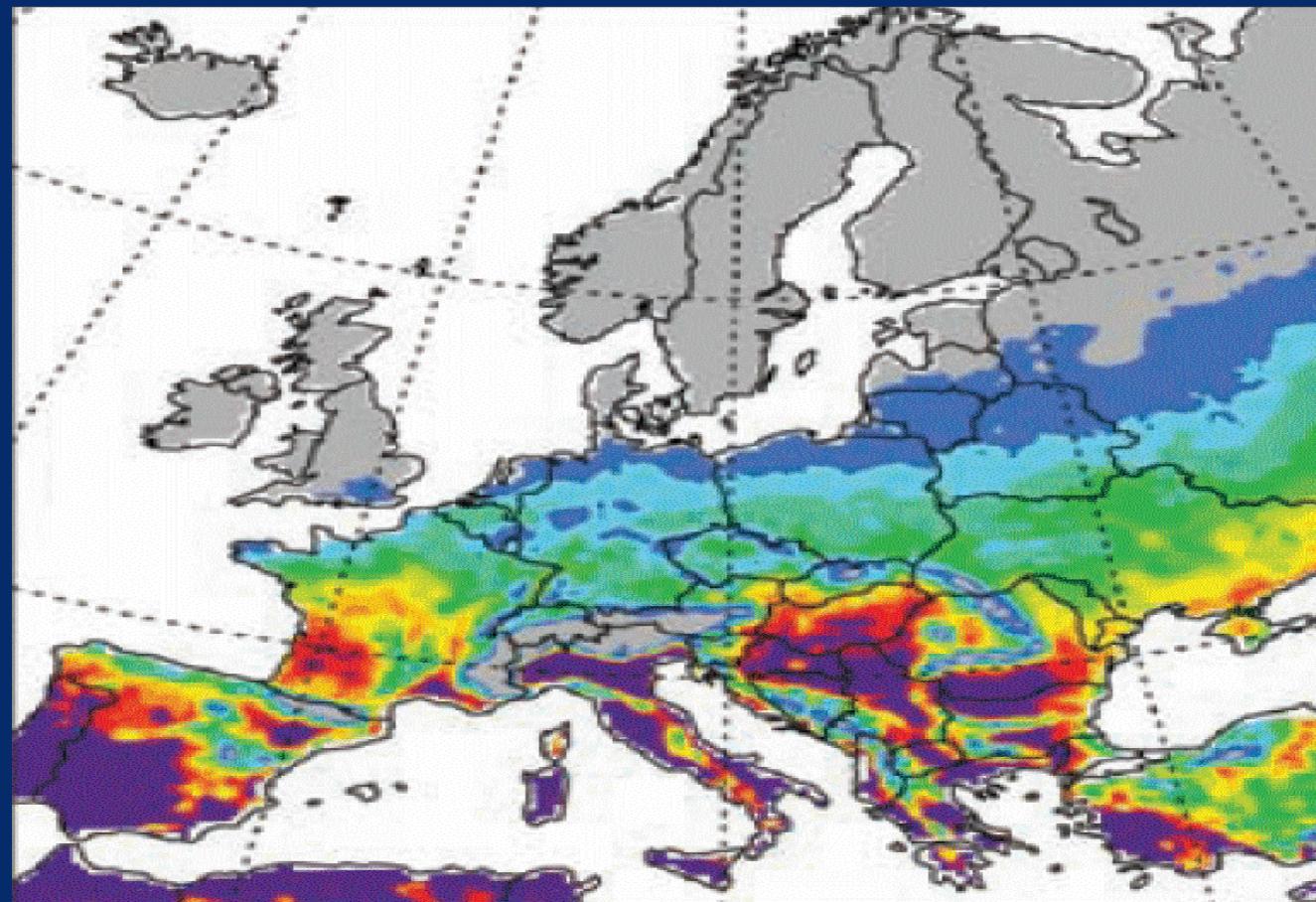
Extremes in a warming climate

Excedance of the 40°C threshold in Europe

1961-1990

2021-2050

2071-2100

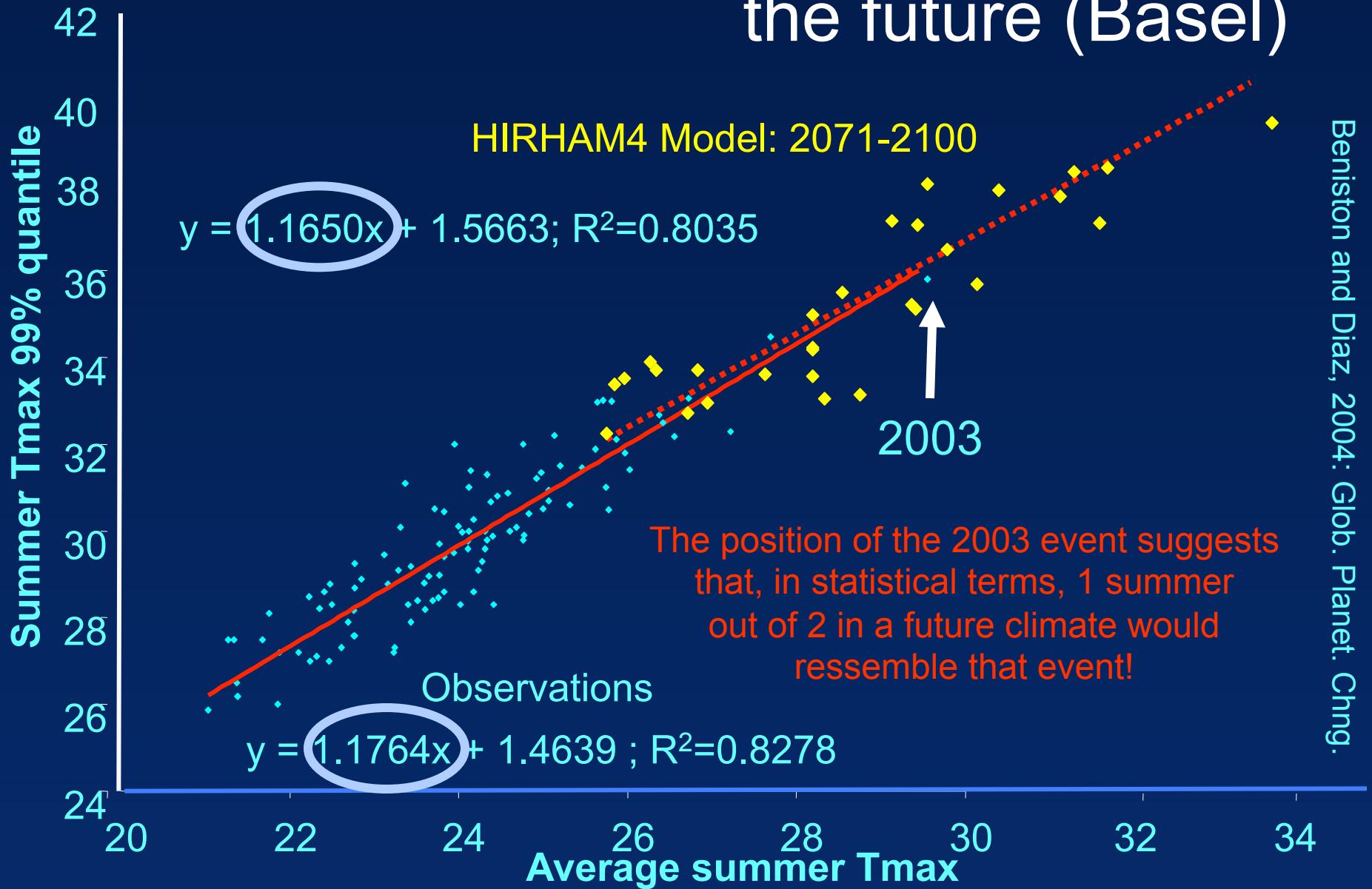


1 5 10 15 20 25 Days



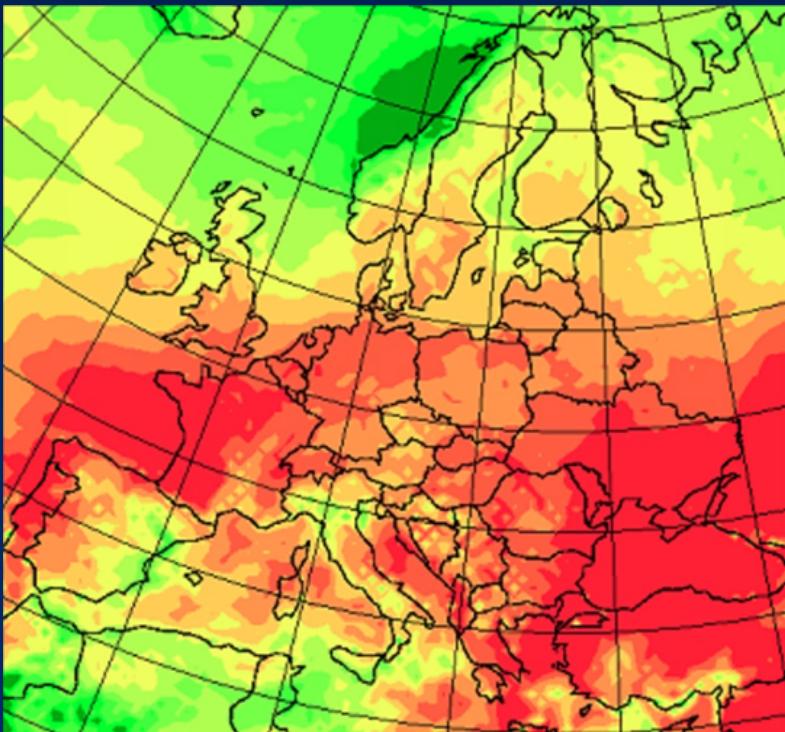
UNIVERSITÉ
DE GENÈVE

Mean-extreme Tmax relations into the future (Basel)

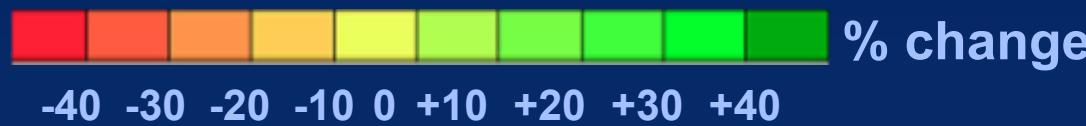
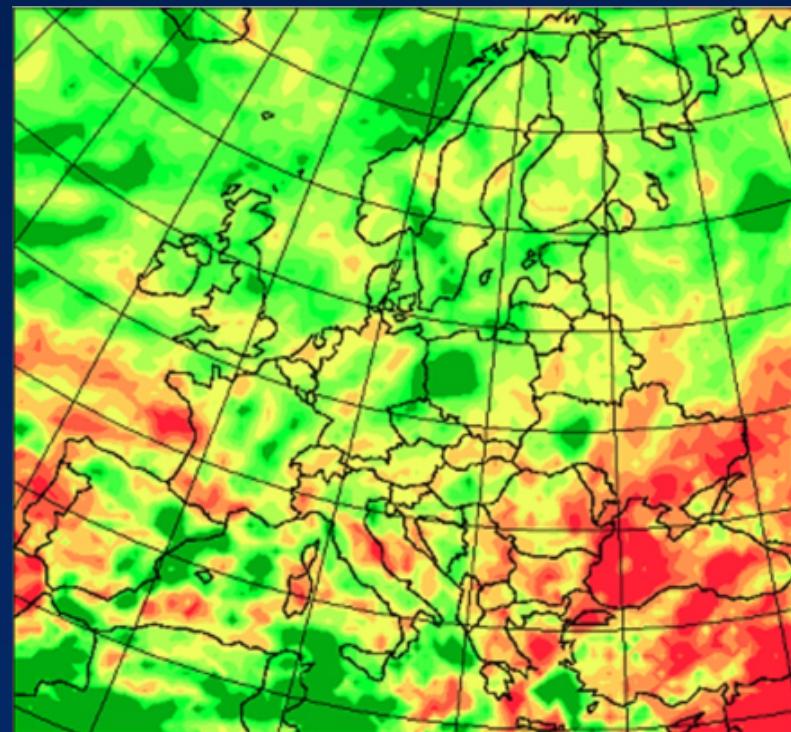


Changes in summer precipitation (june-july-august) (Differences in % between 2071-2100 and 1961-1990) (HIRHAM RCM; A-2 Scenario)

Seasonal precipitation



Precipitation > 50 mm/day

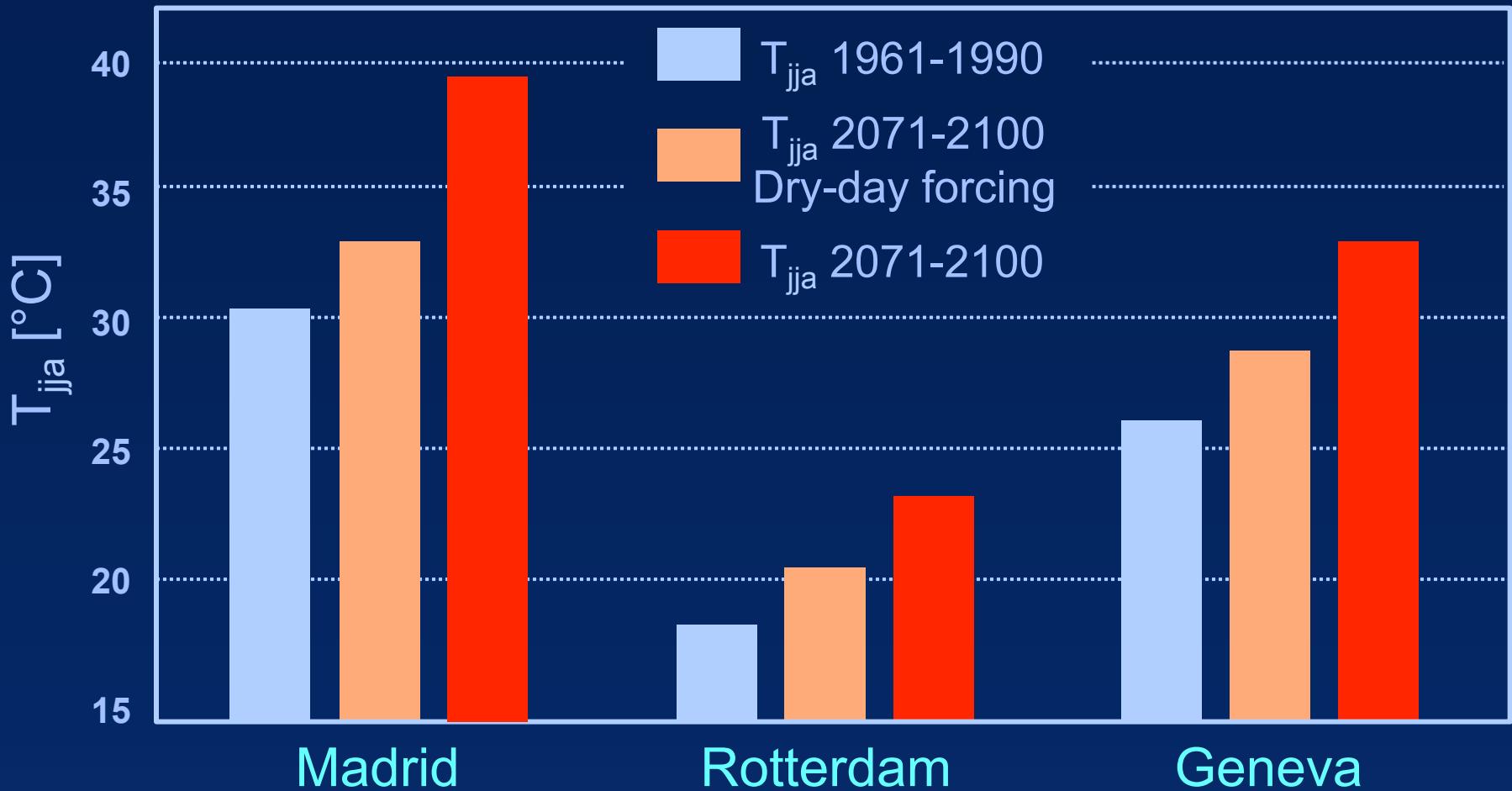


Changes in dry days

(A-2 scenario / Observed 1961-1990)

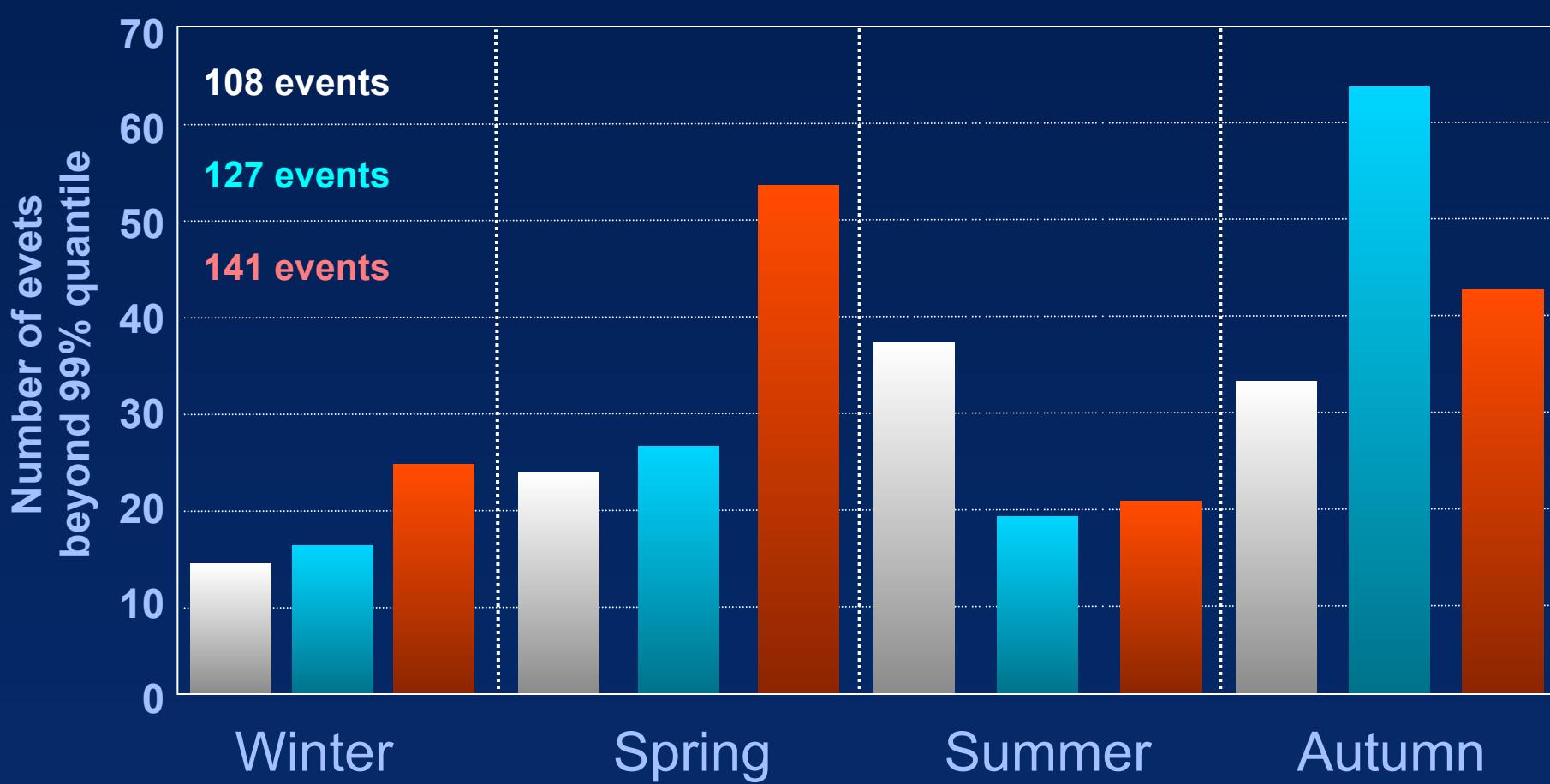
	Madrid	Rotterdam	Geneva
1961-1990			
2071-2100			

Comparison of dry-day forcing vs greenhouse-gas forcing by 2100



Beniston, 2011: Int. J. Climatology

Changes in extreme precipitation in the Alps (HIRHAM RCM)



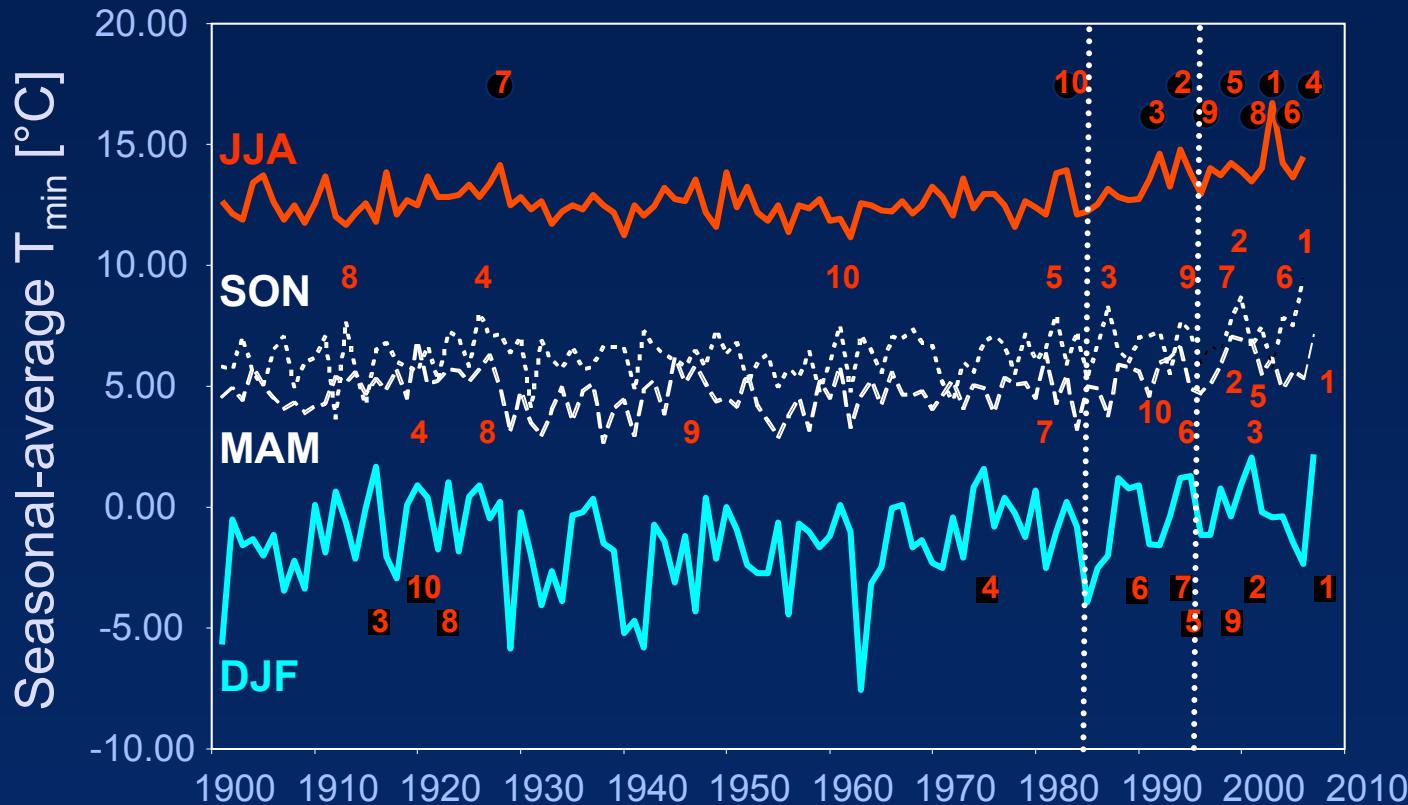
Consequences for floods



Recent extremes: analogies for the future?

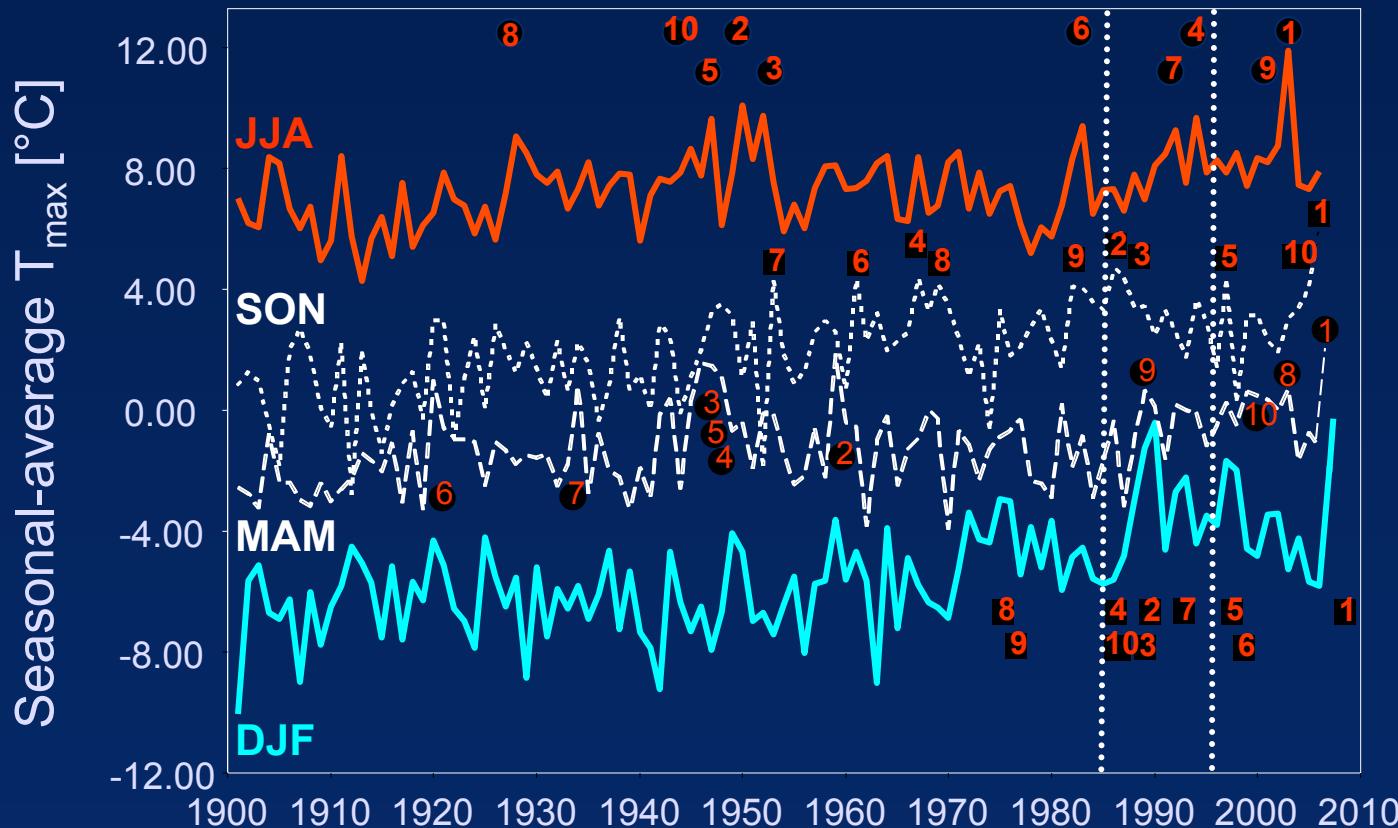
Recent extremes: analogies for
the future?

T_{\min} : 10 warmest seasons (Basel, 317 m above sea level)



Beniston, 2007: Geophysical Research Letters

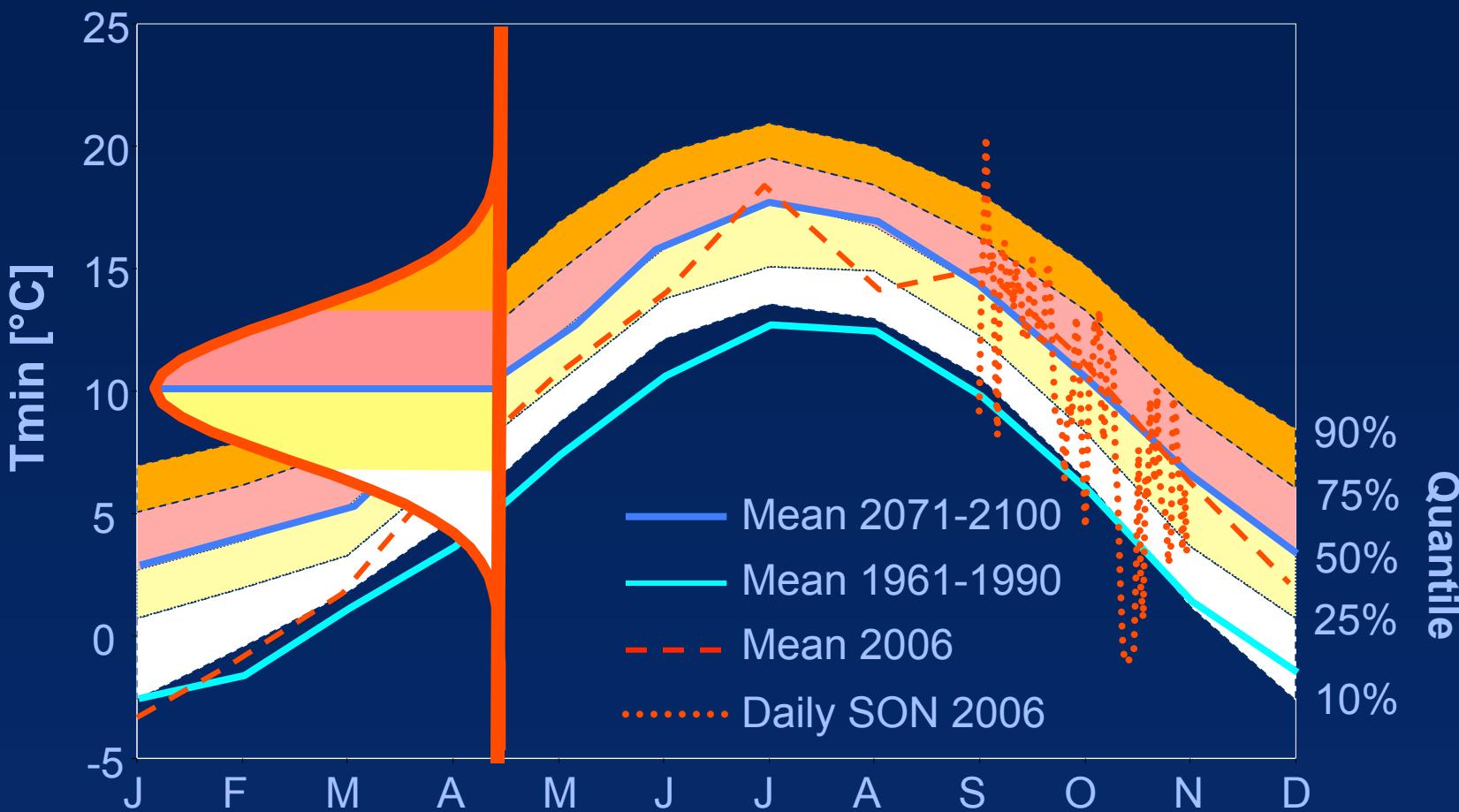
T_{\max} : 10 warmest seasons (Saentis, 2500 m above sea level)



Beniston, 2007: Geophysical Research Letters

Tmin in Basel:

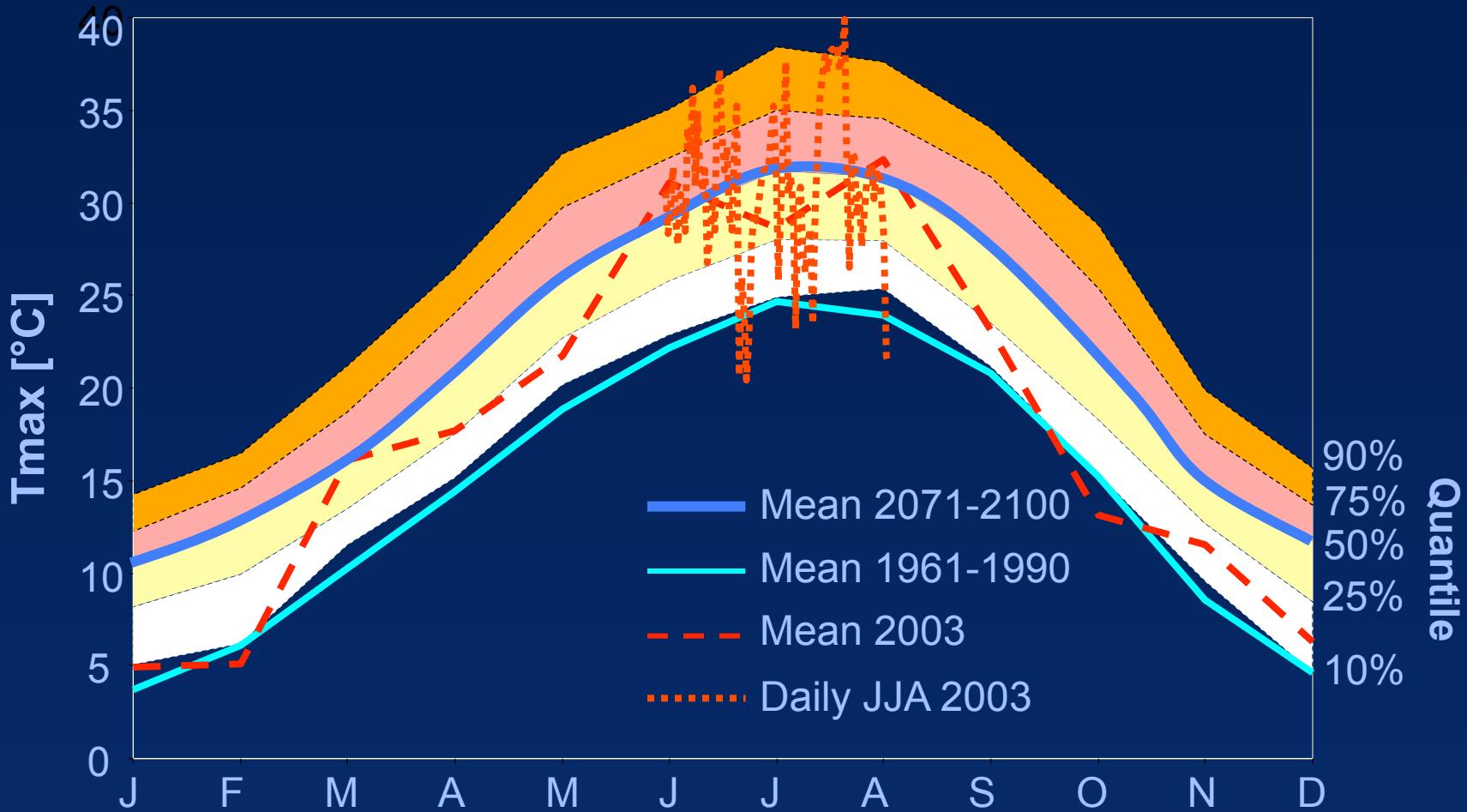
1961-1990
2071-2100
Autumn 2006 statistics



Beniston, 2007: Geophysical Research Letters

Tmax in Basel:

1961-1990
2071-2100
Summer 2003 statistics



Beniston, 2007: Geophysical Research Letters

How close do these recent seasons come to those projected by 2100?

6 out of 10 winters (DJF) will be like the 2006/2007 season

7 out of 10 springs (MAM) will be like the 2007 season

5 out of 10 summers (JJA) will be like the 2003 season

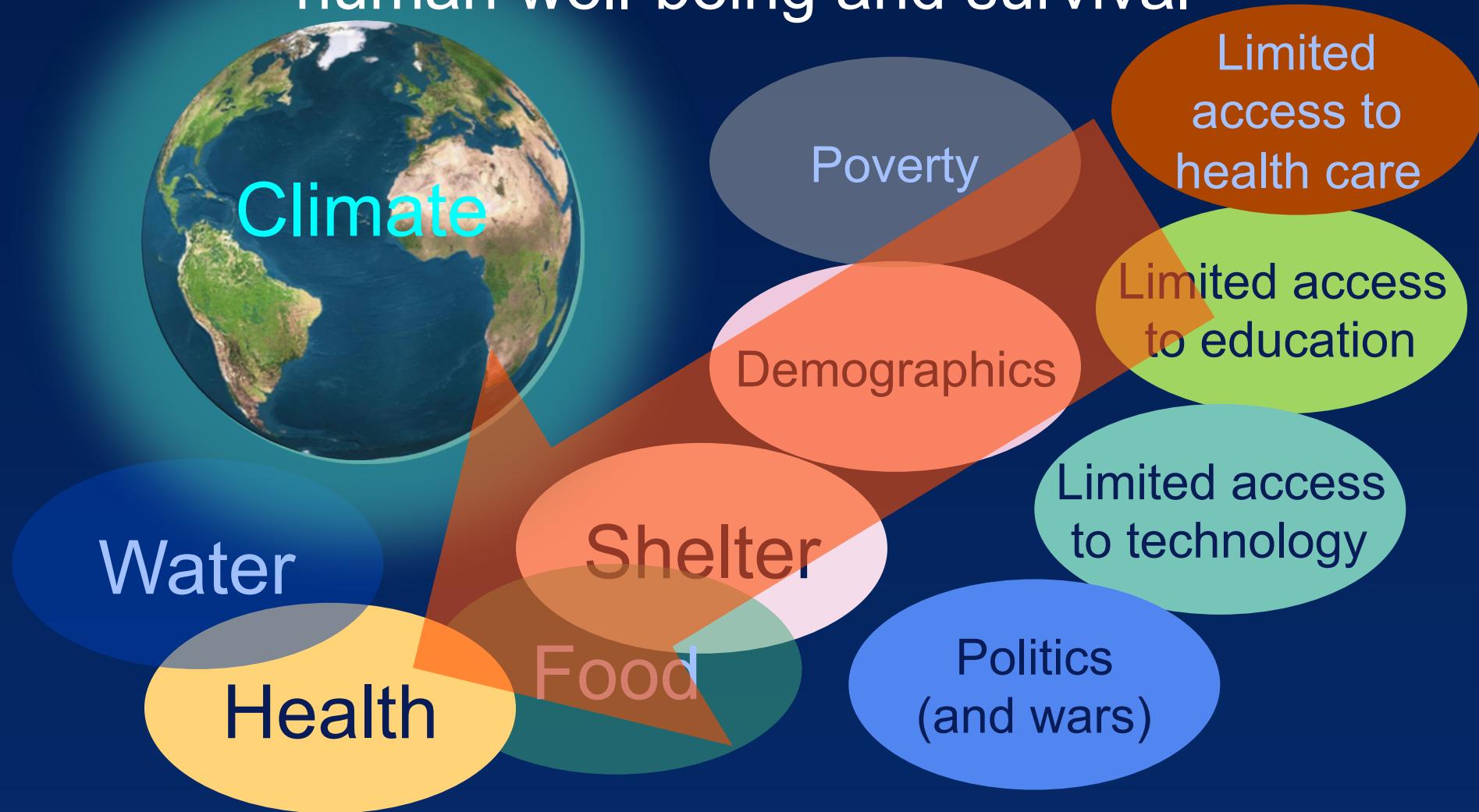
6 out of 10 autumns (SON) will be like the 2006 season

So what?

- The recent record seasons can be used as «proxies» to conditions that will likely become the norm by 2100
- The impacts of abnormal heat on environmental and socio-economic systems can be assessed on the basis of these recent seasons
- Advance planning based on expected impacts can help minimize the risks associated with excessively warm seasons

Adapting to extremes:
climate is not the only determinant!
climat eis nof tne ouly determinant
Adaptin gto extremes:

Climate as ~~one~~ determinant for human well-being and survival



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Many thanks for your attention