ETH
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Climate Change and Extreme Events

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Thanks to:
Erich Fischer, Cathy Hohenegger, Daniel Lüthi

408th Heraeus Seminar, May 26-29, Bad Honnef, Germany
A Physics Perspective on Energy Supply and Climate Change

Reto Stöckli (ETH Zürich, NASA Modis)

Outline

Motivation

Basic considerations

Inherent difficulties

Scenarios

Focus of this talk:
European summer climate

Extreme European summers: 2002 … 2003 … 2005 …

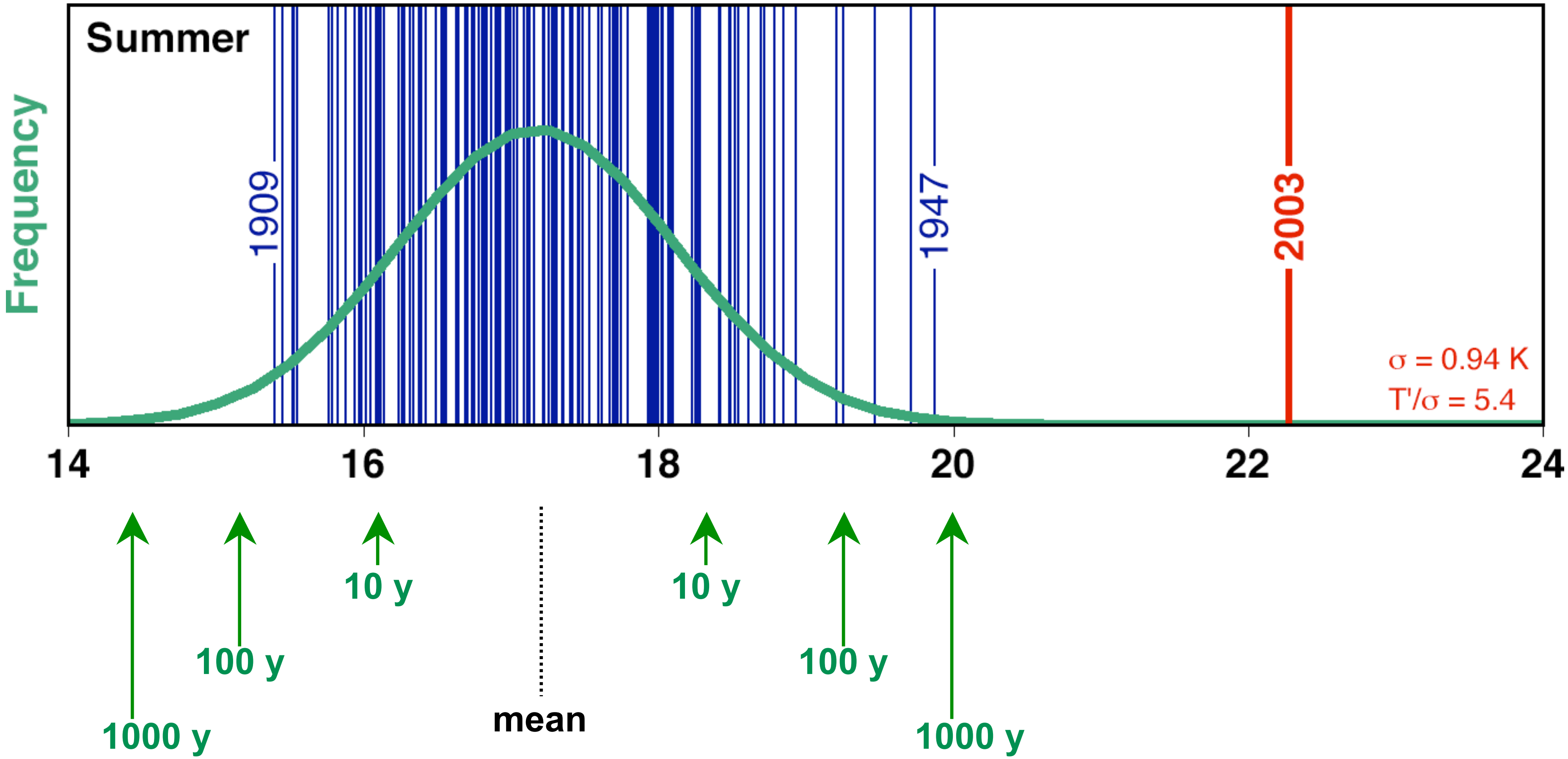
August 2002, Dresden

August 2003, Töss

August 2005, Brienz

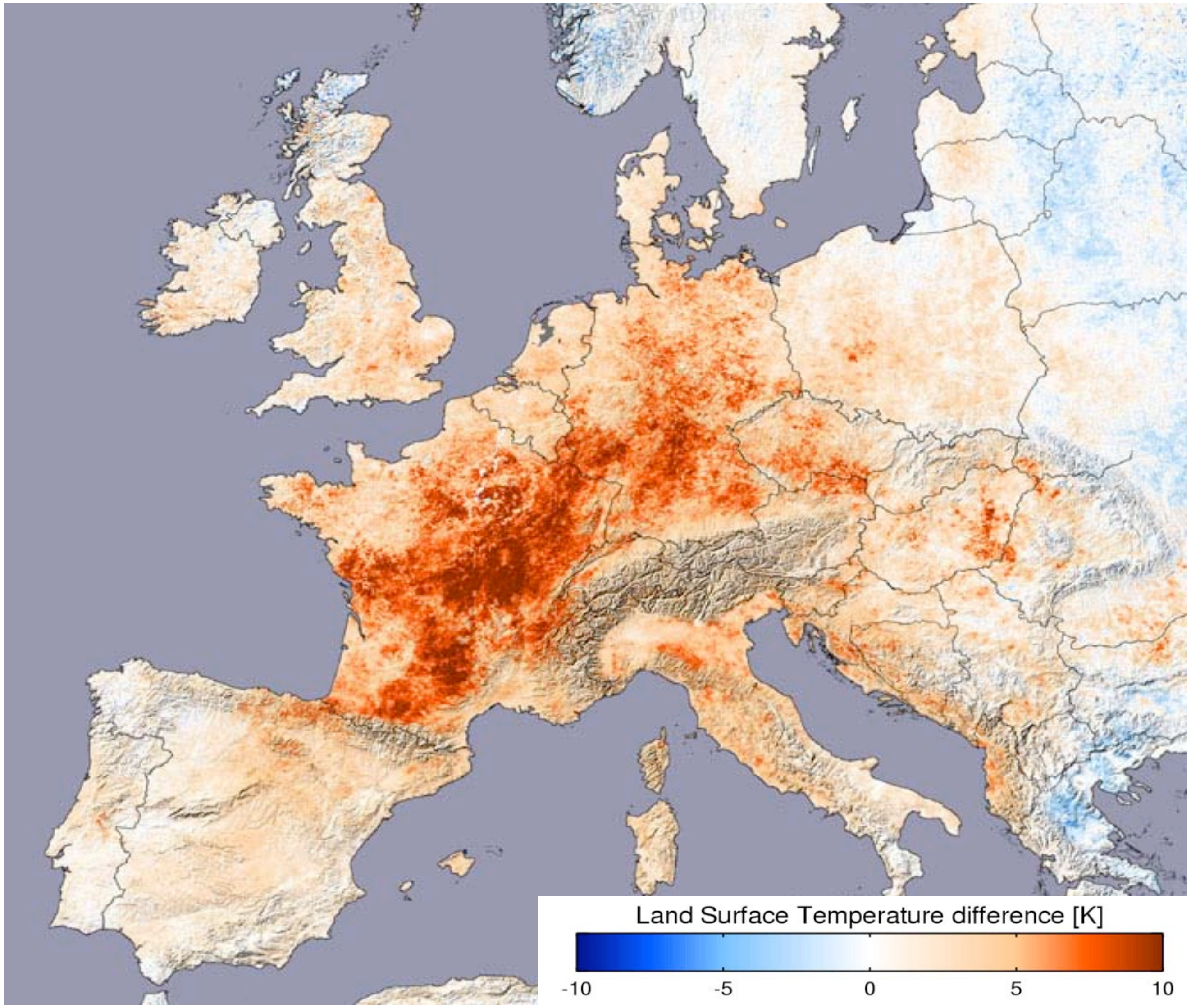
Swiss Temperature Series 1864-2003

Average of 4 Stations: Zürich, Basel, Berne, Geneva



(Schär et al. 2004, *Nature*, **427**, 332-336)

Impacts of the summer 2003 in Europe



August 2003 temperatures relative to 2000-2002, 2004
(Reto Stöckli, ETH/NASA, MODIS)

Agricultural losses:
12.3 Billion US$
(SwissRe estimate)

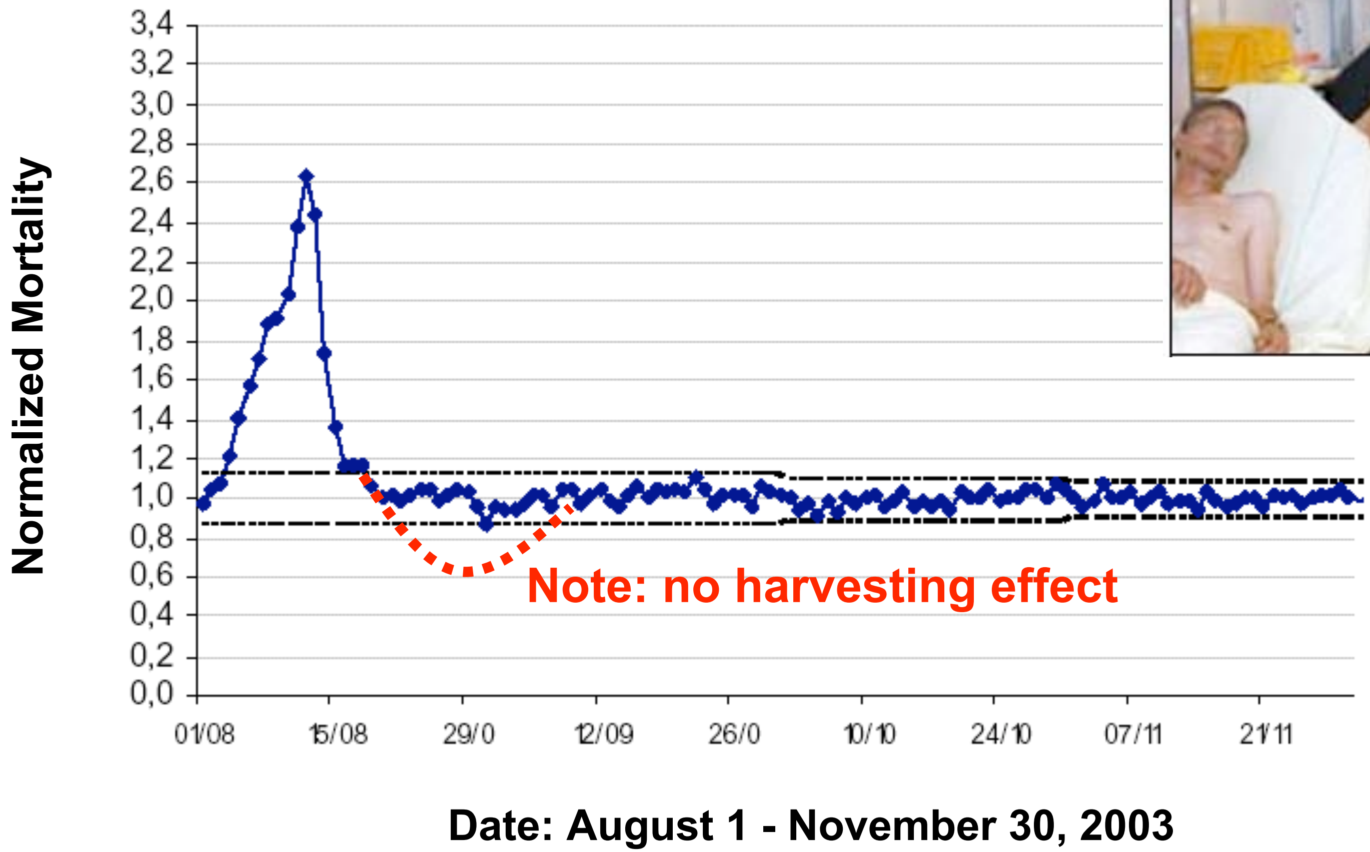
Shortage of electricity,
peak prices on spot market
(EEX, Leipzig)

Serious problems with
- freshwater resources (Italy)
- forest fires (Portugal)
- freshwater fish (Switzerland)

Estimated 22,000 to 35,000
heat deaths (excess mortality)

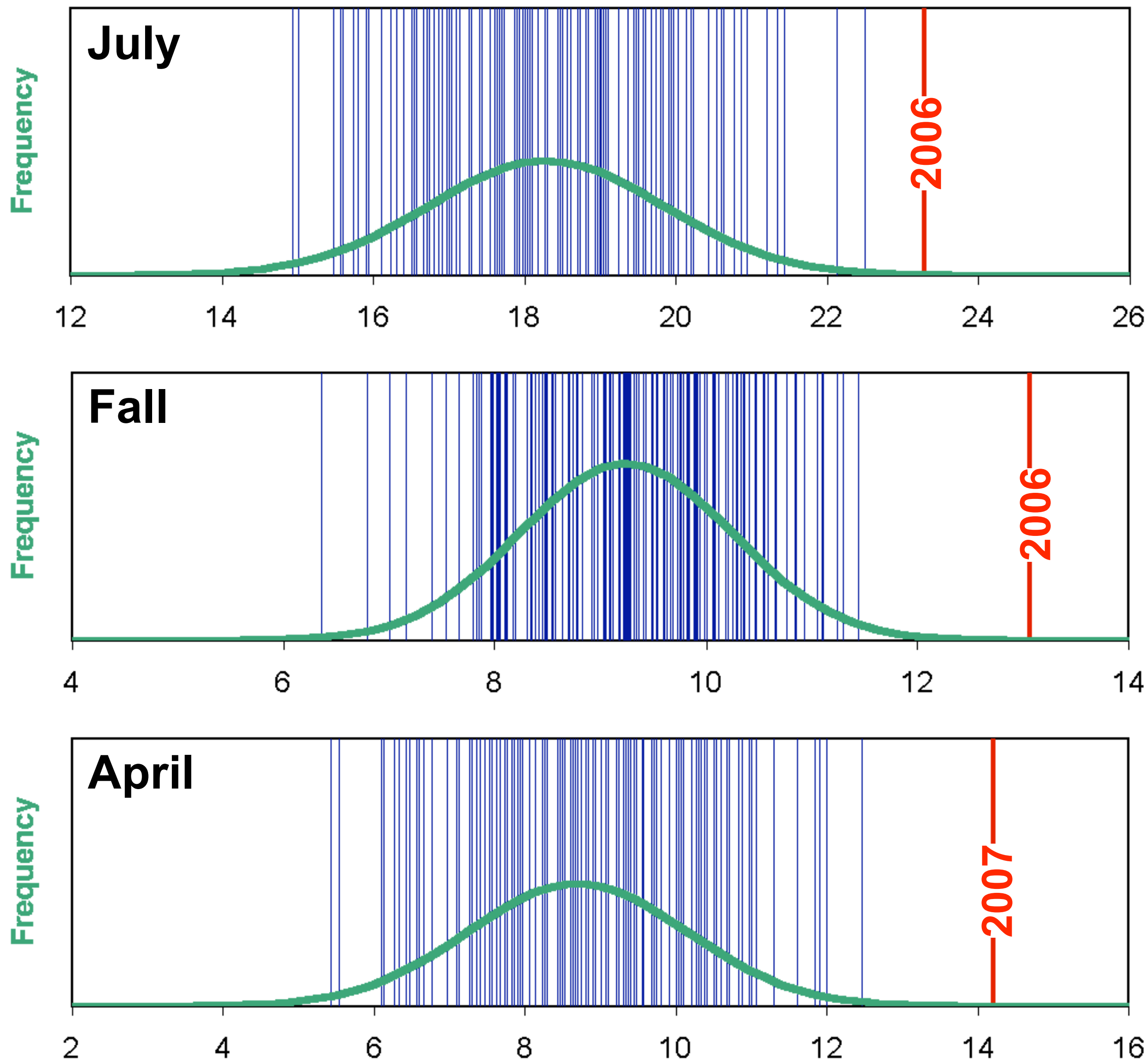
Excess mortality in France

Normalized mortality = mortality 2003 / longterm mean



(INSERM 2004)

Other recent temperature records



(Schär and Fischer 2008, based on Swiss temperature data)

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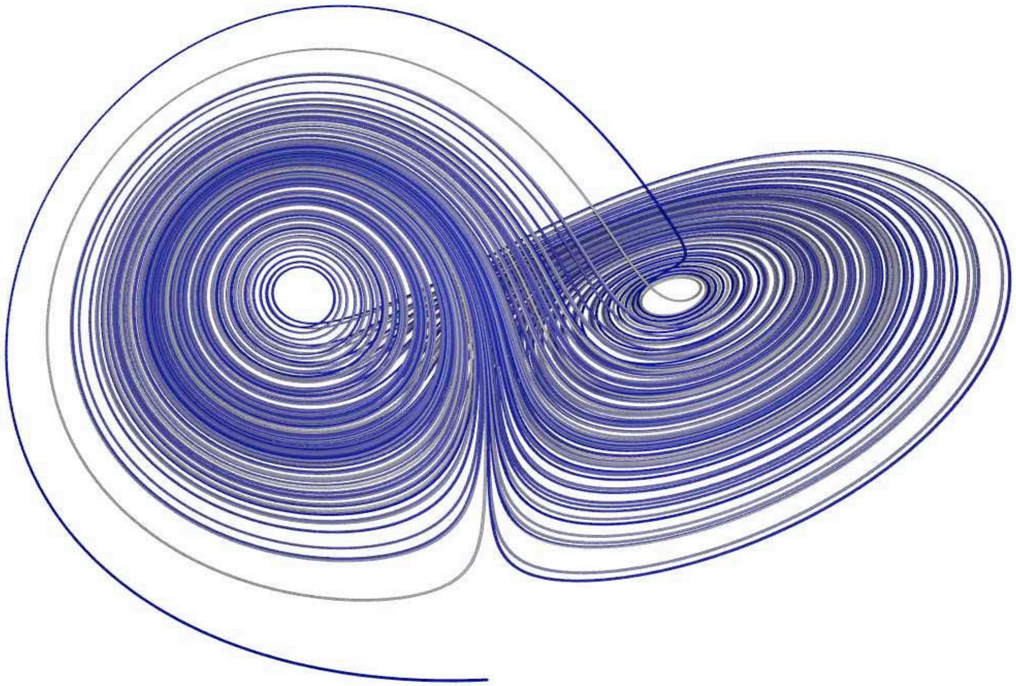
Climate defined

Definition of climate (Edward Lorenz, 1961):

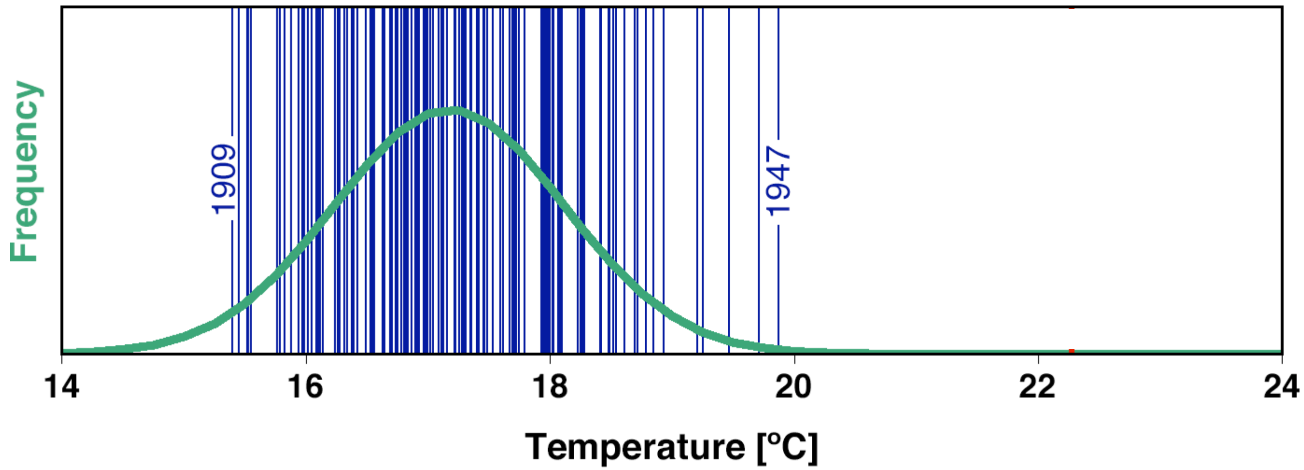
“Climate is what you expect, weather is what you get.”



Climate defined

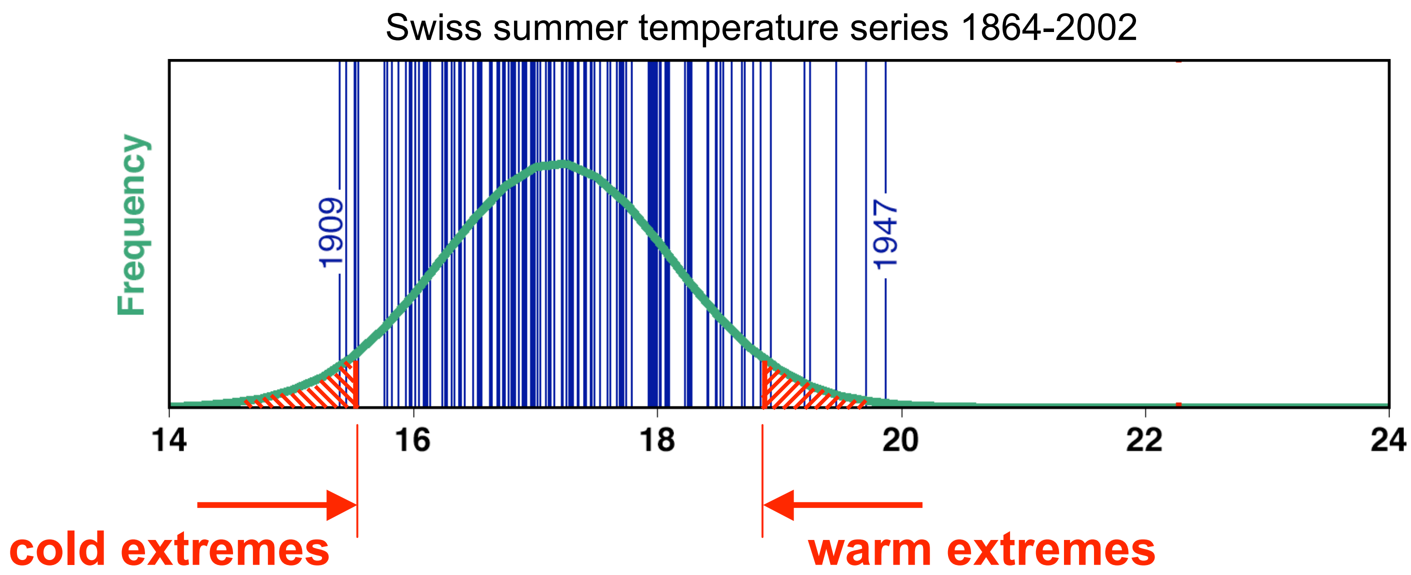
Climate is a statistical concept.
Best defined as a probability density function (PDF)

Swiss summer temperature series 1864-2002



Extreme events defined

***Extreme events* are events that deviate strikingly from the statistical mean.**



Definition employs some threshold exceedance with respect to reference climatology

Extreme event (statistical view) ≠ Natural disaster (socio-economic view)

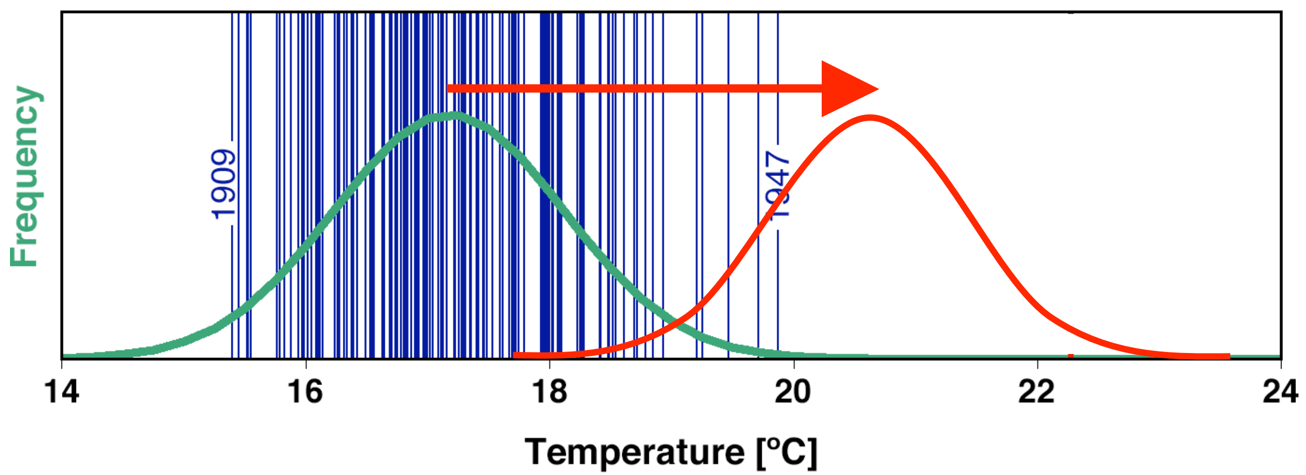

FELDSCHLOSSCHEN
BIER
„Statistical mean“

„Striking“ deviation from statistical mean

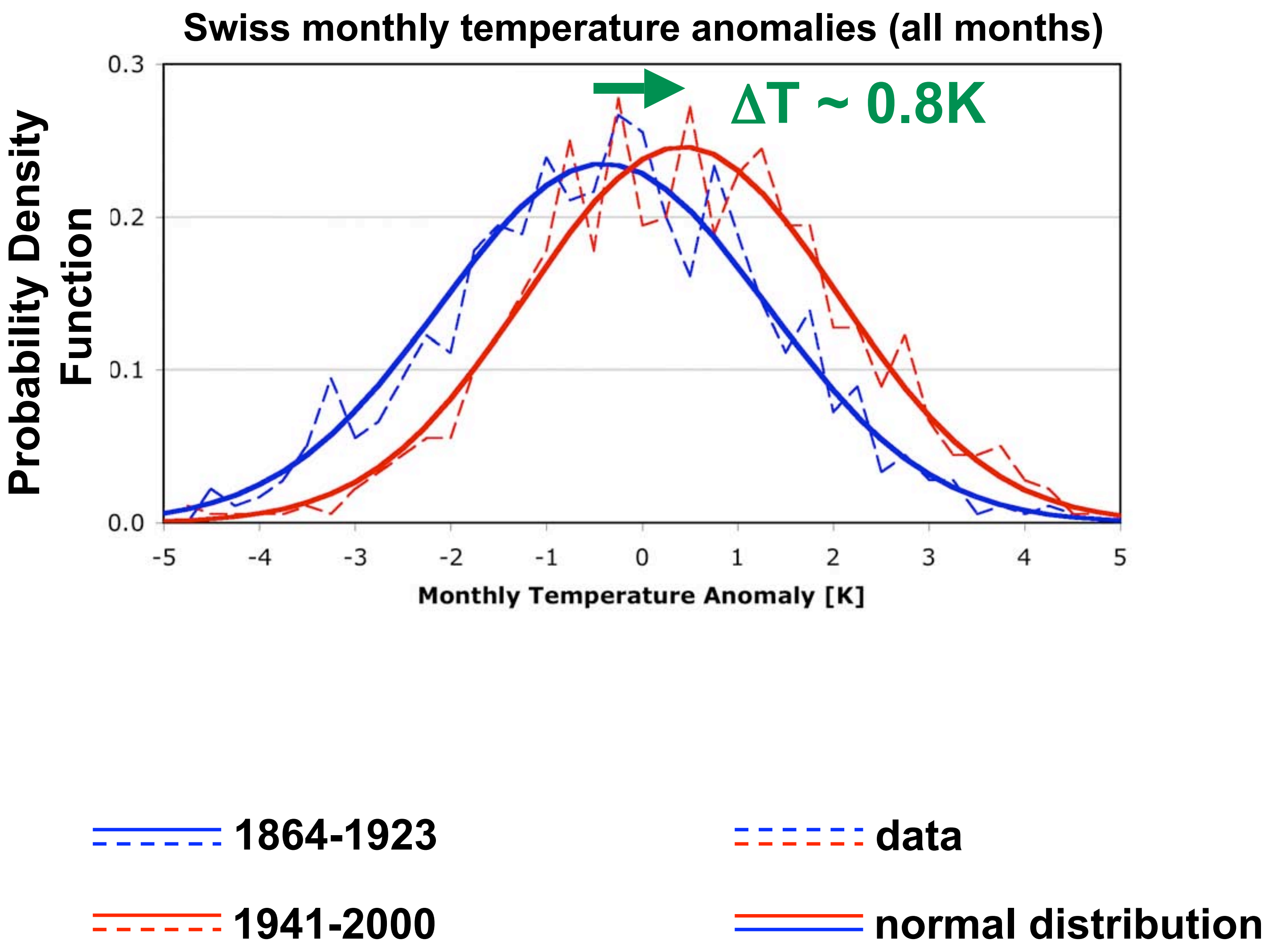
Climate change defined

Climate change **refers to a significant change of the statistical climate distribution with time**

Swiss summer temperature series 1864-2002



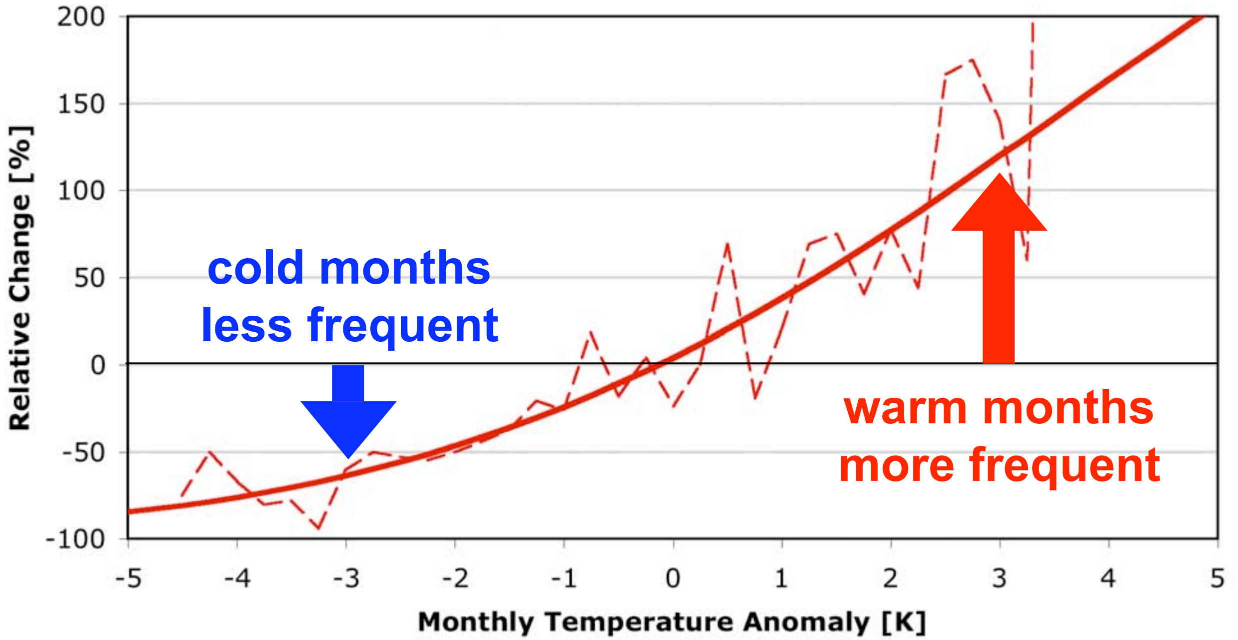
Observed climate change



(Schär et al. 2004, *Nature*, **427**, 332-336)

Relative Change

Relative frequency change 1941-2000 versus 1864-1923

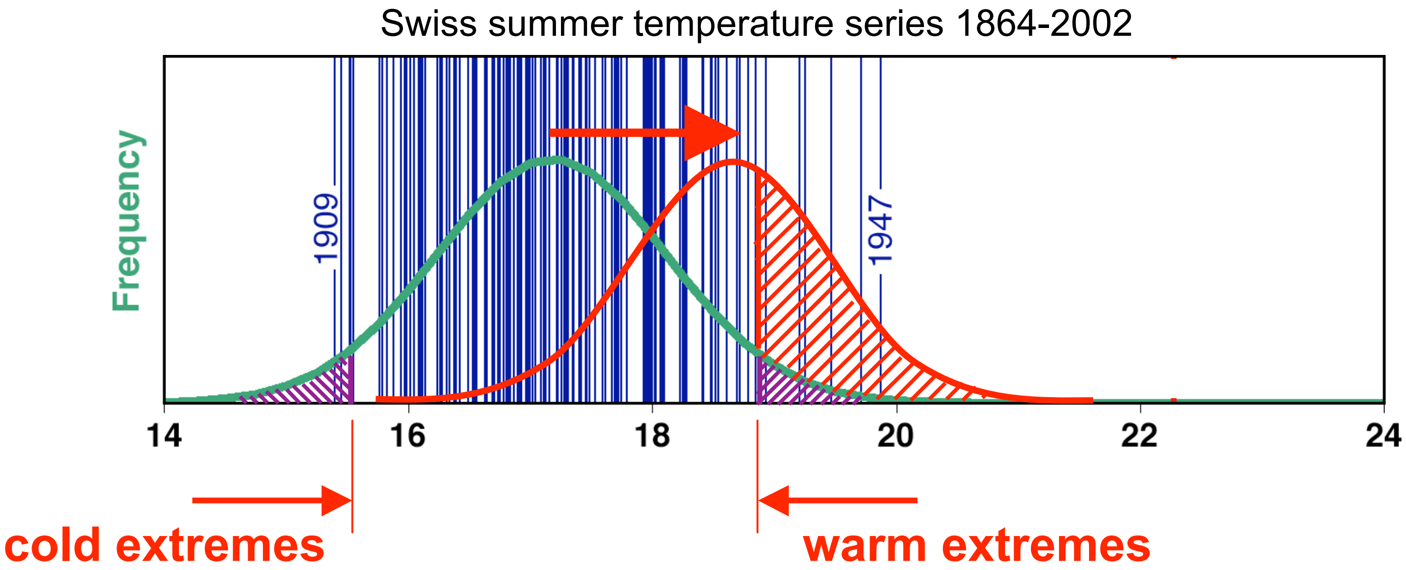


------ **data**

—— **normal distribution**

(Schär et al. 2004, *Nature*, **427**, 332-336)

Climate change and extreme events



Significant climate change <u>inevitably</u> leads to changes in the frequency of extremes

Critical if: ΔT >≈ σ

Summer temperature scenarios: $\Delta T \approx 5°C$ >> $\sigma \approx 1°C$

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Extreme events in the IPCC

IPCC = Intergovernmental Panel on Climate Change (UNO / UNEP)

Early IPCC-statements (SAR 1996):

"... it can be expected that changes in *hydrological extremes* will be more significant than changes in hydrologic mean conditions"

"In evaluating the societal ramifications of water resource changes, attention must be focused on changes in the *frequency and magnitude of floods and droughts*"

Early IPCC (WG1) coverage of extreme events did not match these claims:

IPCC 1990: 7 pages (of 364)
IPCC 1996: 12 pages (of 572)
IPCC 2007: several hundred pages

"This apparent neglect is not due to a failure to appreciate the importance of extreme events, but rather a result of *well-founded scientific caution*."

(Fowler and Hennessy, 1995)

Some of the difficulties

1. **Extreme events are rare by definition**
   => inherent sampling problem (in models and observations)

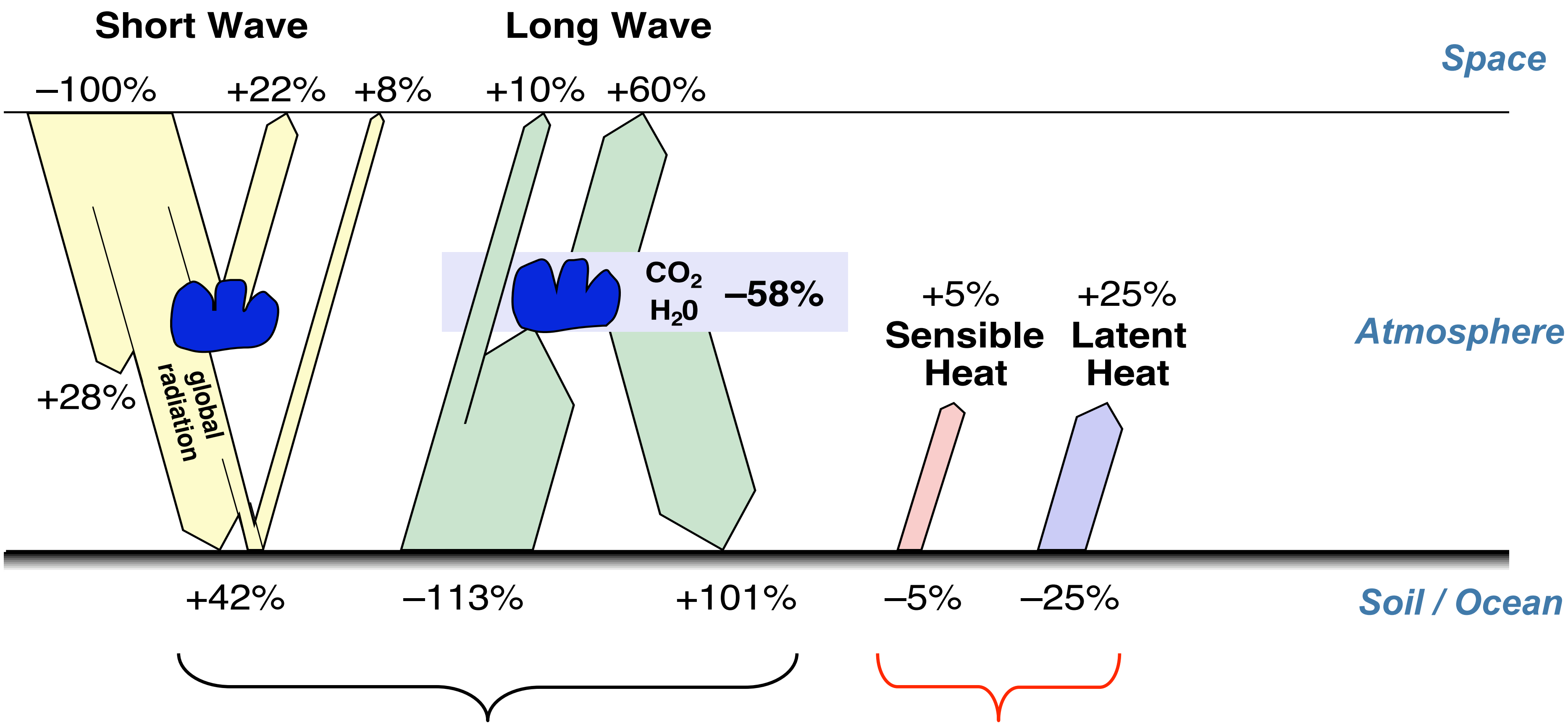
2. **Most extremes are linked to water cycle**
   => understanding of both the energy *and* water cycles needed

3. **Most extremes are of small scale, and/or depend on multi-scale interactions**
   => high resolution needed

4. **Intrinsic predictability limitations**
   => short-term (unpredictable) variability competes with long-term (predictable) trends

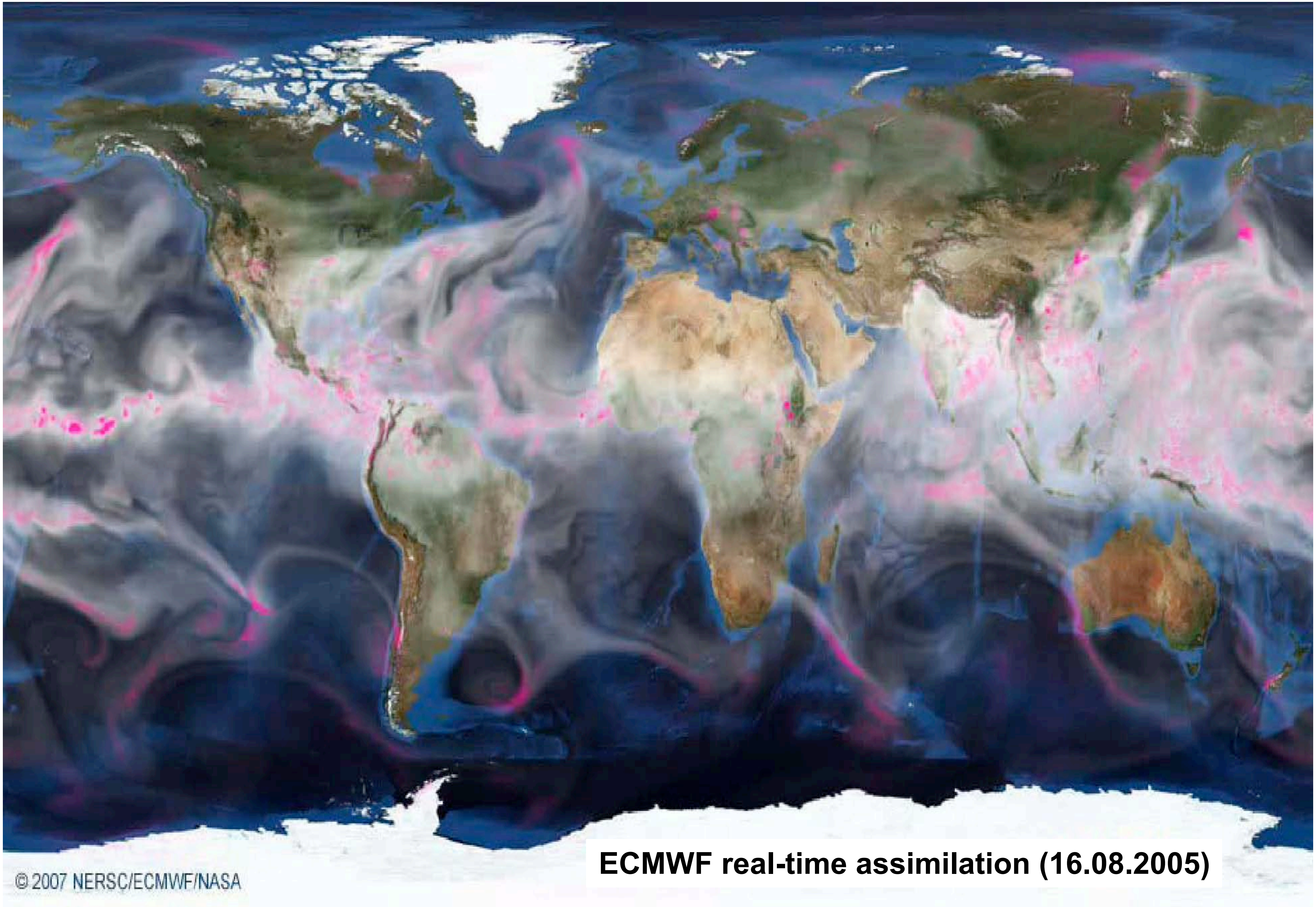
5. **Impacts of extremes are affected by socio-economic factors**
   => extreme event versus natural disaster

Global Energy Balance



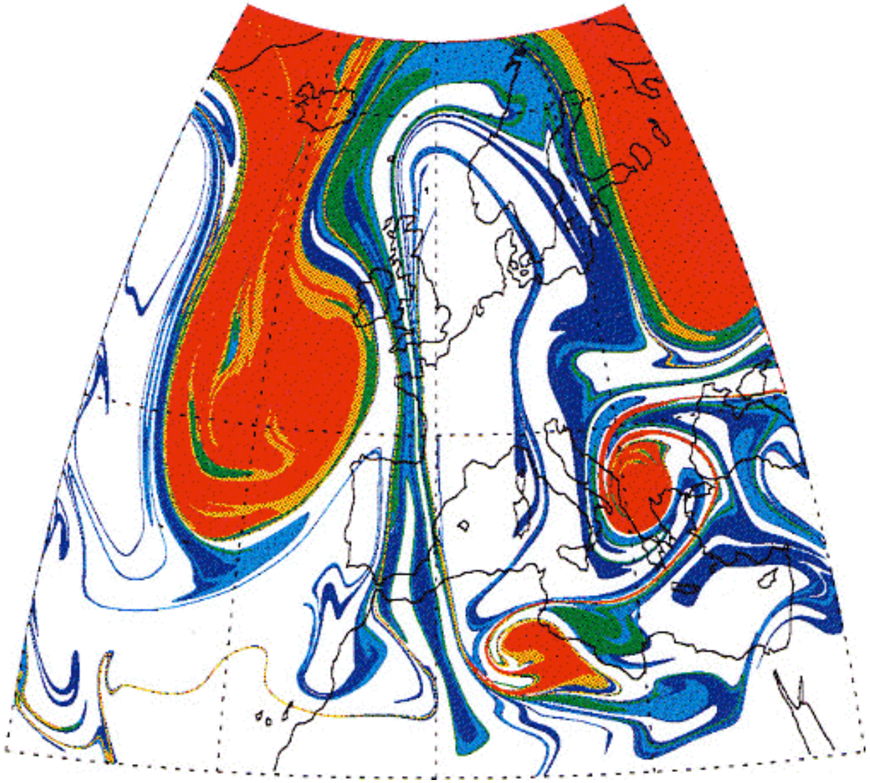
Net radiation
=
30% of extraterrestrial solar input

More than 80% of the net radiation is converted into *evapotranspiration* rather than *heating*

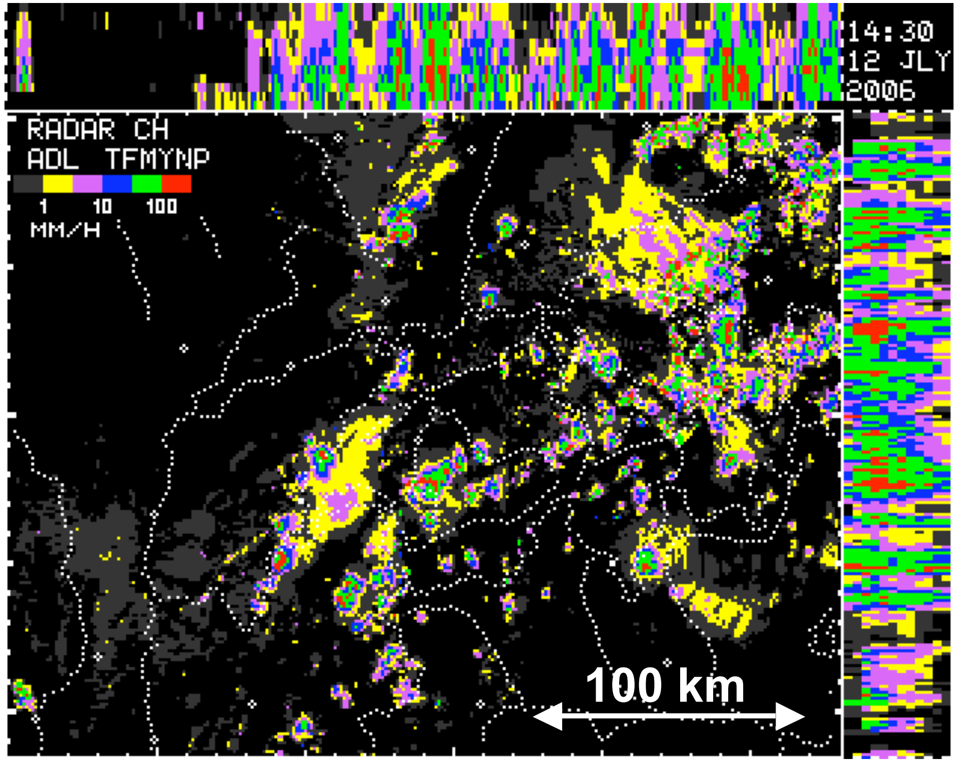


ECMWF real-time assimilation (16.08.2005)

Multi-scale interactions in the climate system



Fragmentation of stratospheric intrusion
(Appenzeller, Davies and Norton 1996)



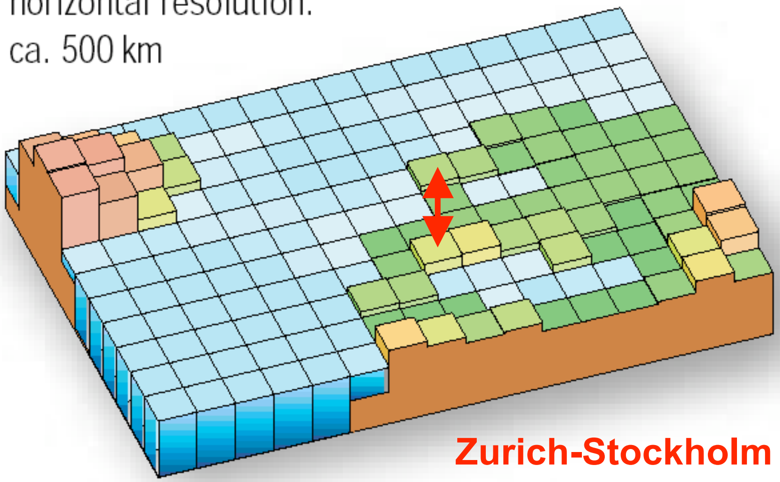
Atmospheric convection
(Radar composite, MeteoSchweiz)

Partly represented in atmospheric models

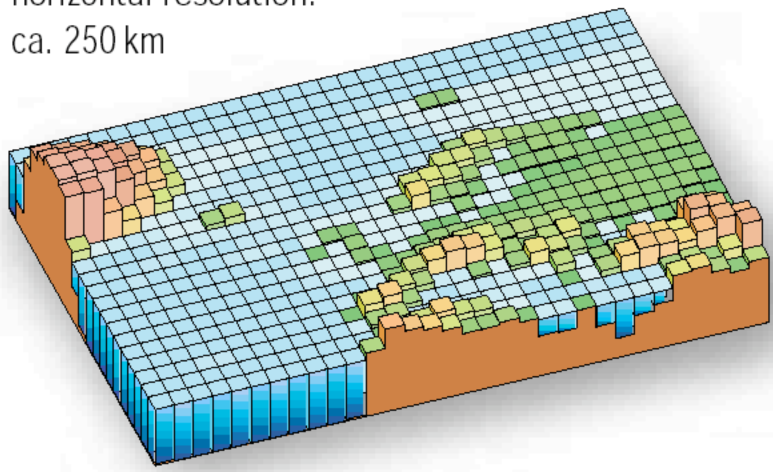
Usually parameterized in atmospheric models

Horizontal Discretization

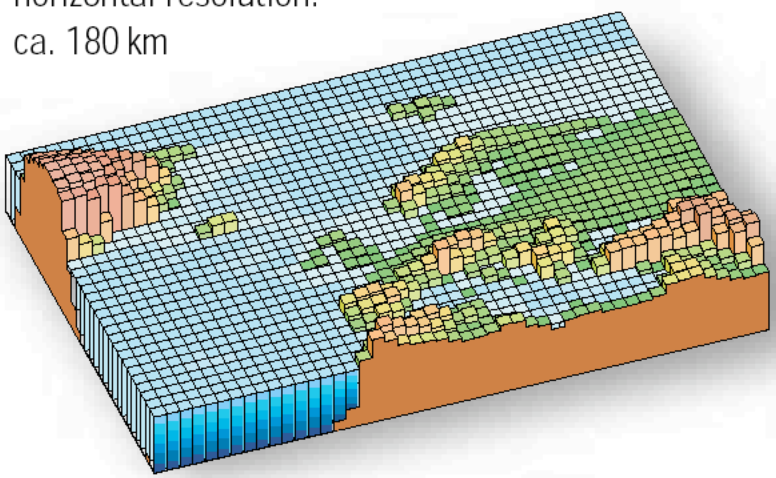
Model T21
horizontal resolution:
ca. 500 km



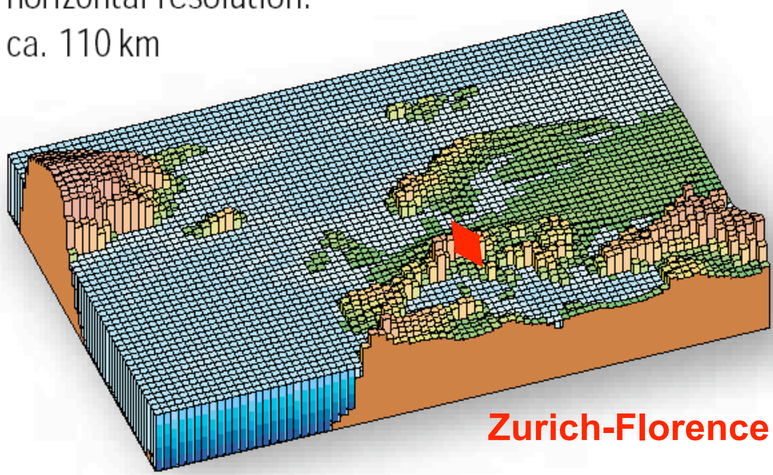
Model T42
horizontal resolution:
ca. 250 km



Model T63
horizontal resolution:
ca. 180 km



Model T106
horizontal resolution:
ca. 110 km



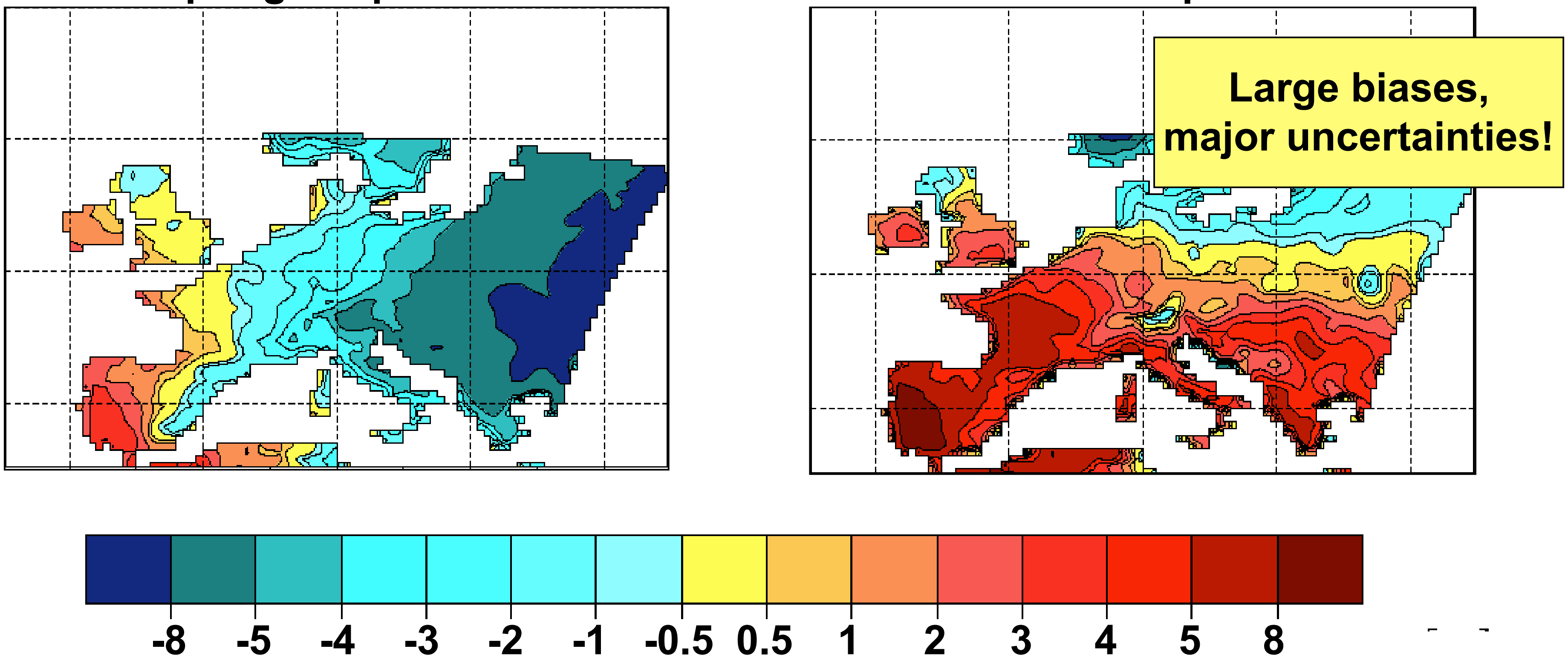
(MPI Hamburg)

Climate simulations 10 years ago

ECHAM4 (T42, 250 km) => RegCM2 (70 km)

Bias of control run (CTRL-OBS), 5 years

Spring temperature **Summer temperature**

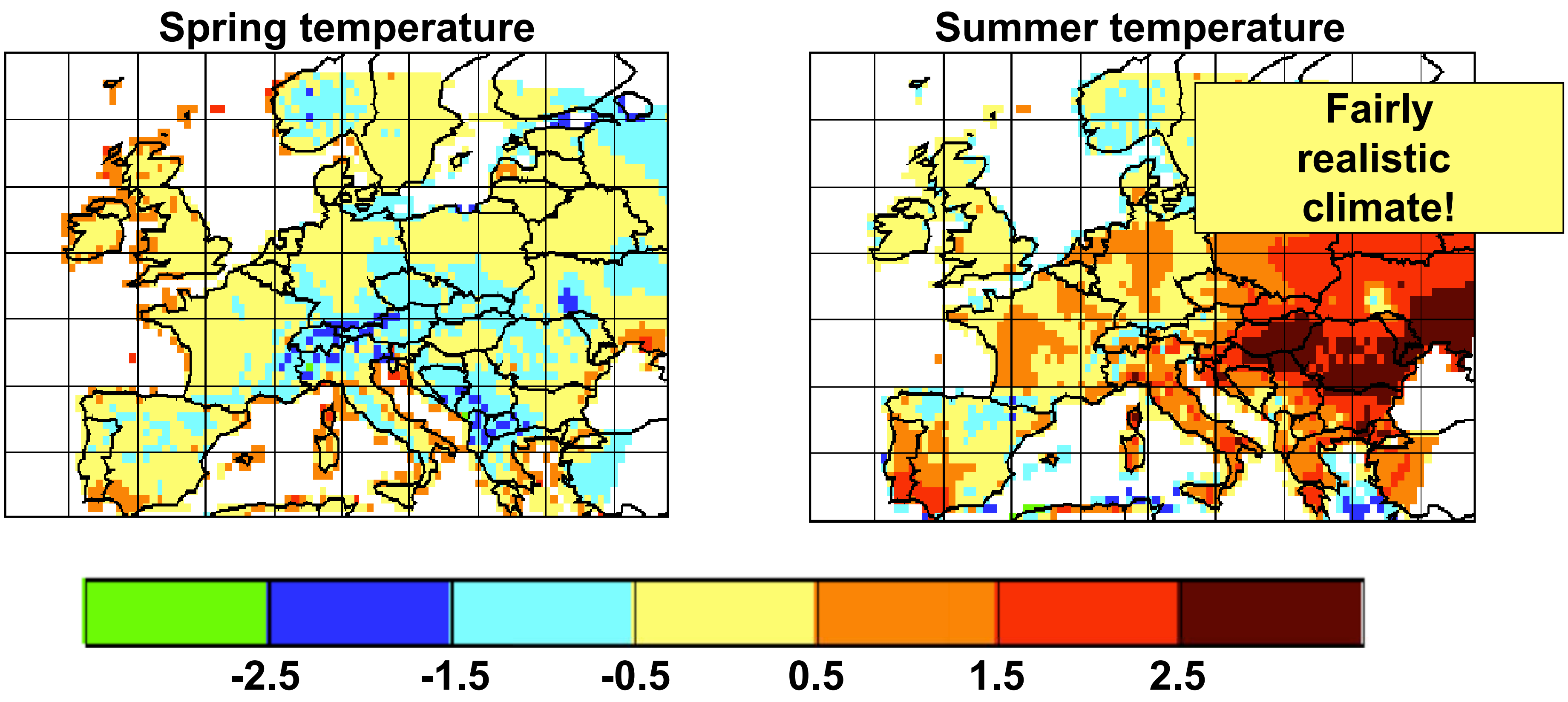


 EU Projects REGIONAL and RACCS (1992-1996); Machenhauer et al. (1998, MPI-Report 275)

Climate simulations today

HadAM3 (120 km) => PRUDENCE Regional Models (50 km)

Bias of control run (CTRL-OBS), 30 years



EU Project PRUDENCE (2001-2004). Coordinator: Jens H. Christensen, DMI, Copenhagen

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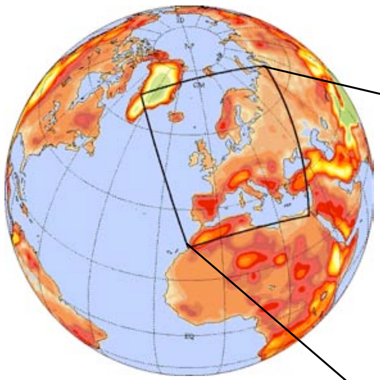
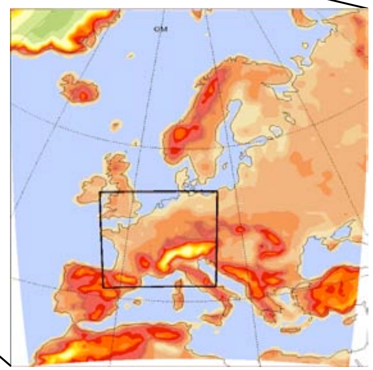
Climate Scenarios for Europe





Greenhouse-Gas Scenario
(e.g. IPCC SRES A2)

Coupled GCM
(~300 km)

Atmospheric GCM
(>120 km)

IPCC considers 21 AOGCM model simulations

Regional Climate Model (RCM)
(50-25 km)

Over Europe about 20 simulations available

Situation of Europe is exceptional, many other regions must primarily rely on low-resolution models.

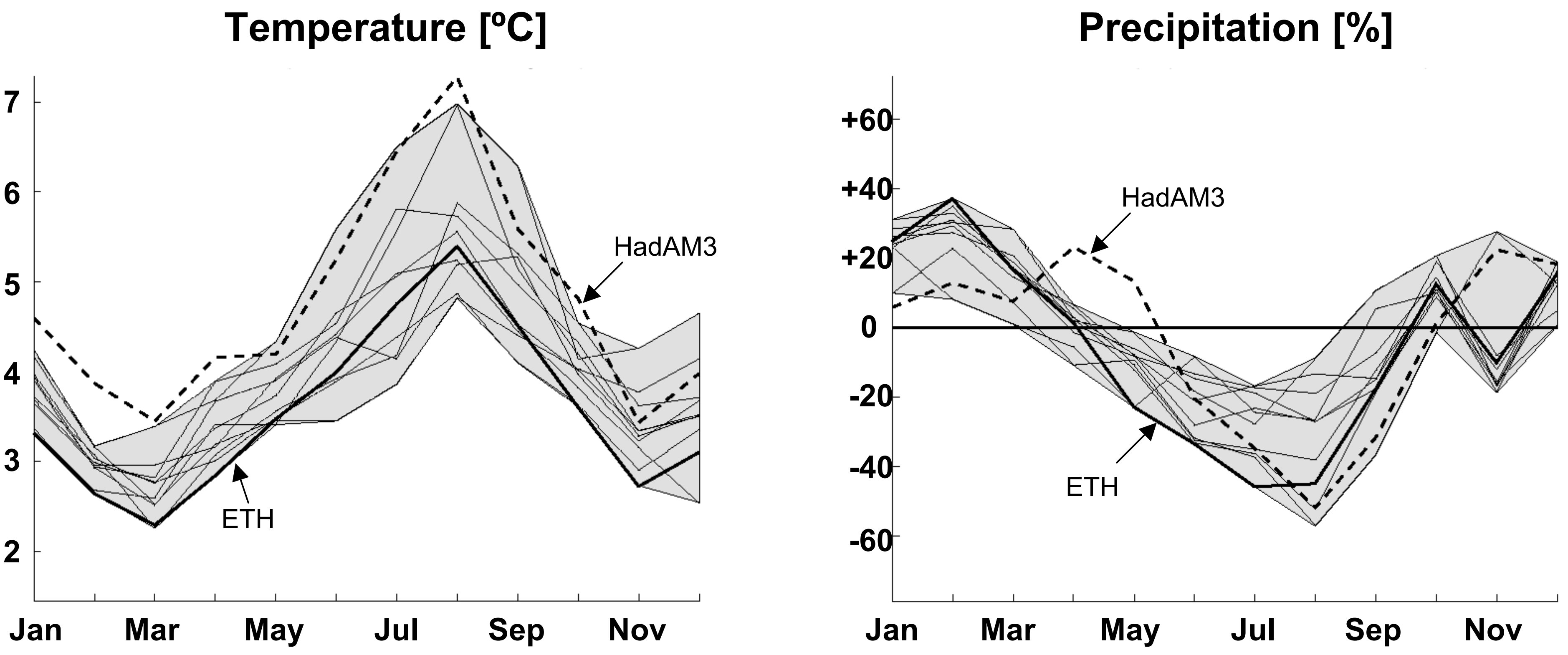
Associated EU-Projects

Regionalization	1993 - 1995
RACCS	1994 - 1996
MERCURE	1997 - 2001
PRUDENCE	2001 - 2004
ENSEMBLES	2004 - 2009

(EU-Project PRUDENCE, scenario data available at http://www.prudence.dmi)

Scenario Alps

2071-2100 versus 1961-1990
Changes in seasonal cycle (2 AGCMs, 9 RCMs)

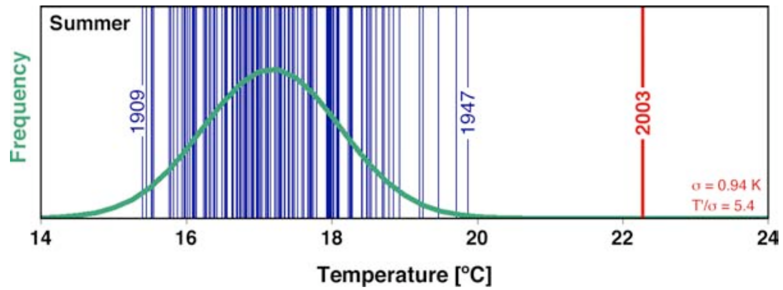


(Jacob et al. 2007, SRES A2, PRUDENCE)

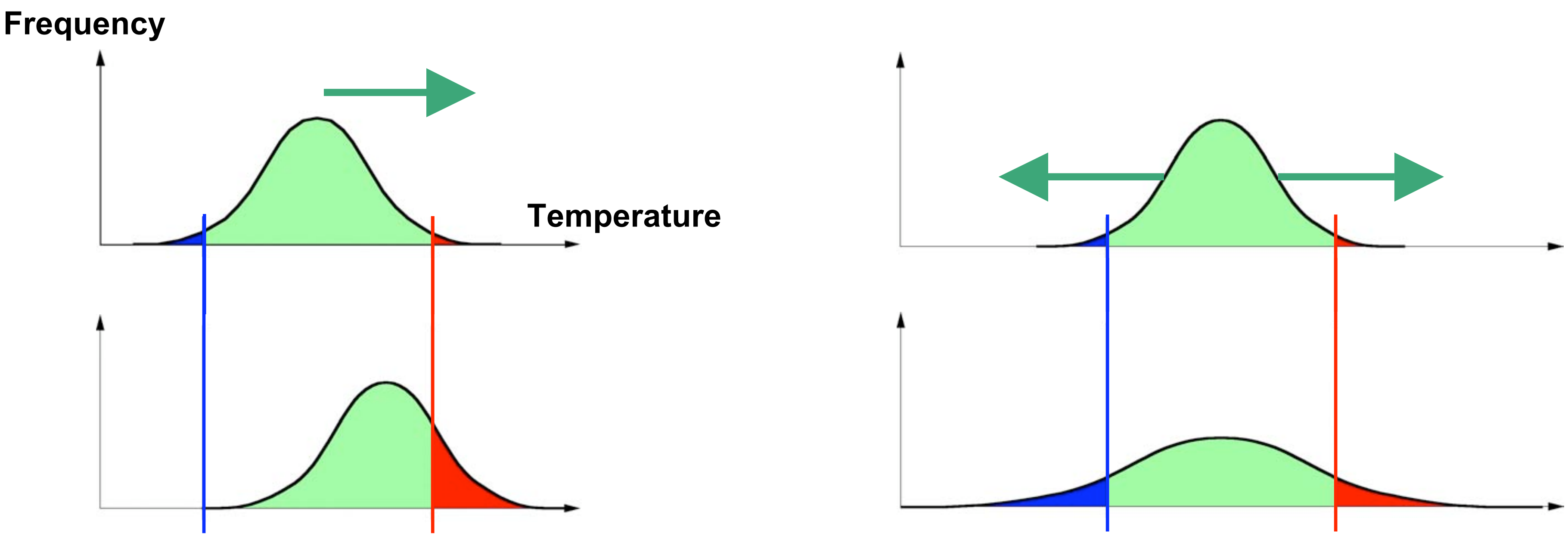
How to reconcile observations of anomalous European summers?

- Wet extremes (2002, 2005)

- Dry and hot extremes(2003)
- Unexpected large anomalies (much larger than can easily be explained by mean warming)



Changes in Mean **versus** Changes in Variability



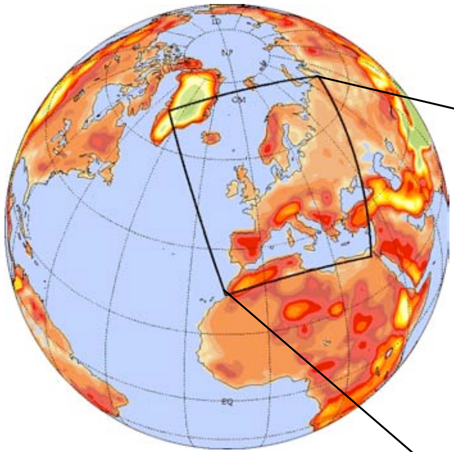
increase in the frequency of extreme warm conditions

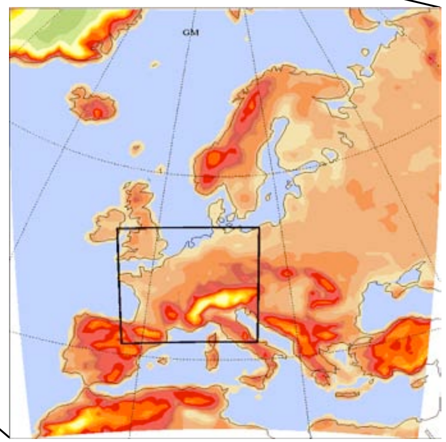
increase in the frequency of extreme warm/cold conditions

For extremes far away from mean,
"variability is more important than mean"

Katz and Brown 1992
Folland et al, IPCC, 2001

Testing the hypothesis





Greenhouse-Gas Scenario
(IPCC SRES A2)

Coupled GCM
(HadCM3, ~300 km)

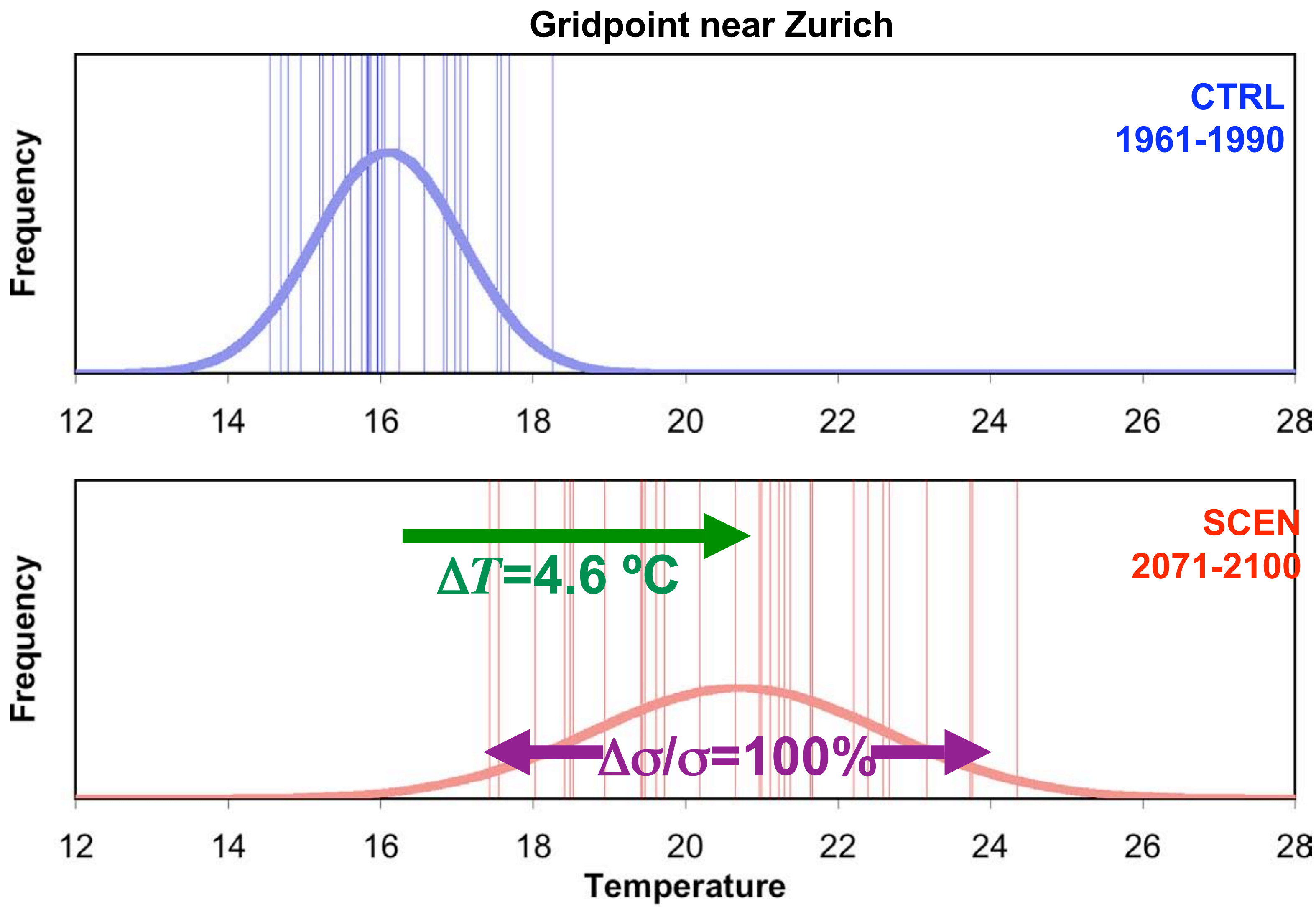
Atmospheric GCM
(HadAM3, ~120 km)

Regional Climate Model (RCM)
(CHRM / ETH, 56 km)

Time slice experiments
CTRL (1961-1990)
SCEN (2071-2100)

(EU-Project PRUDENCE, NCCR Climate)

Summer Surface Temperatures



Simulated:
T = 16.1 ºC
σ = 0.97 ºC

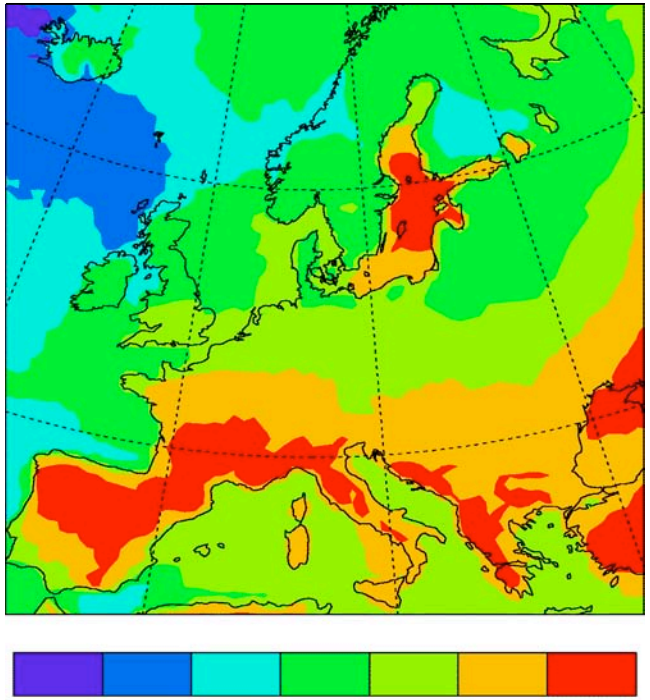
Observed:
T = 16.9 ºC
σ = 0.94 ºC

strong increase in variability

(Schär et al. 2004, *Nature*, **427**, 332-336)

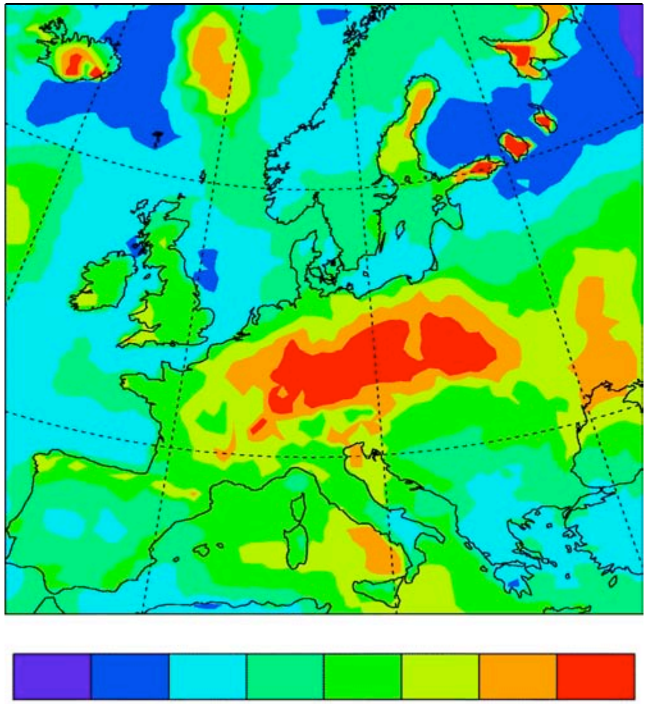
Summer Temperatures (2070-2100)

Change in Temperature ΔT



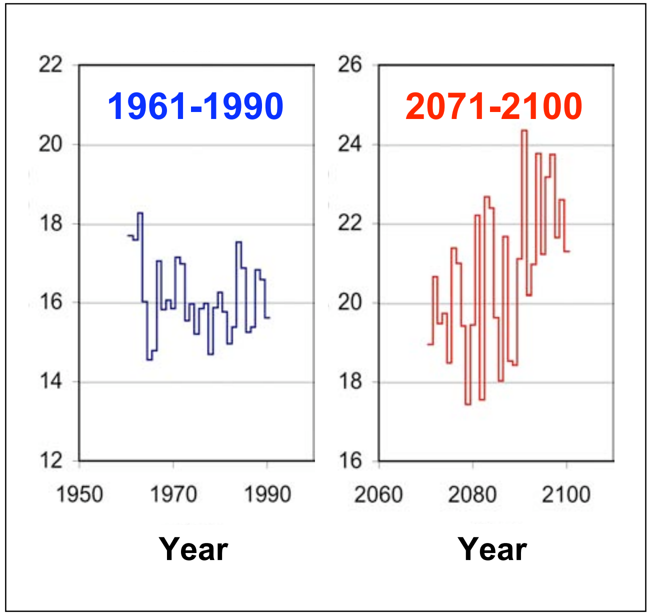
[ºC]

Change in Variability Δσ/σ (StdDev of seasonal T)



[%]

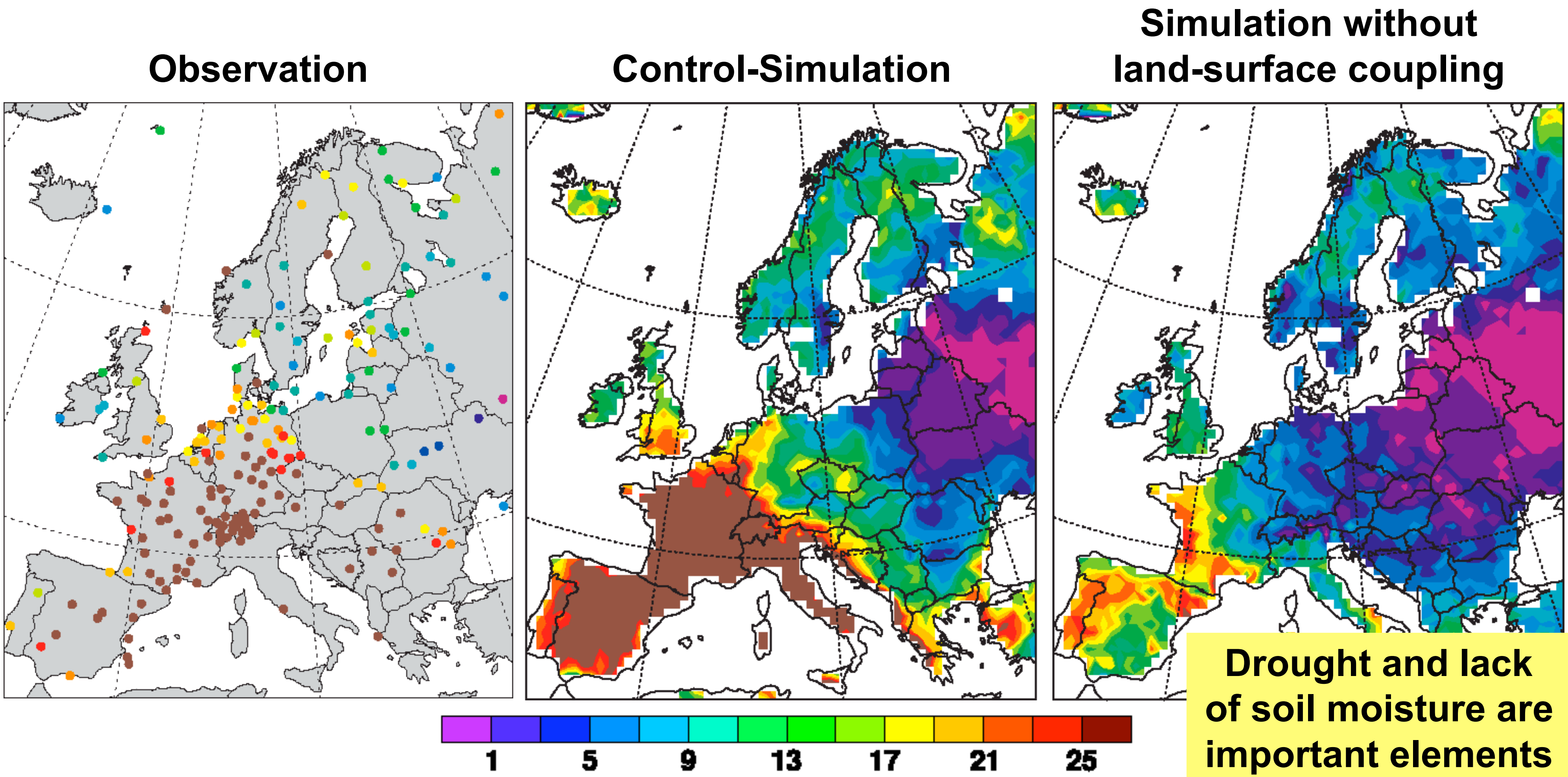
Zurich Temperature Series



=> Not only changes in mean, but also changes in variability <=

(Schär et al. 2004, *Nature*, **427**, 332-336)

Summer 2003: role of land-surfaces



Number of hot days (T_{max} > 90th percentiles)

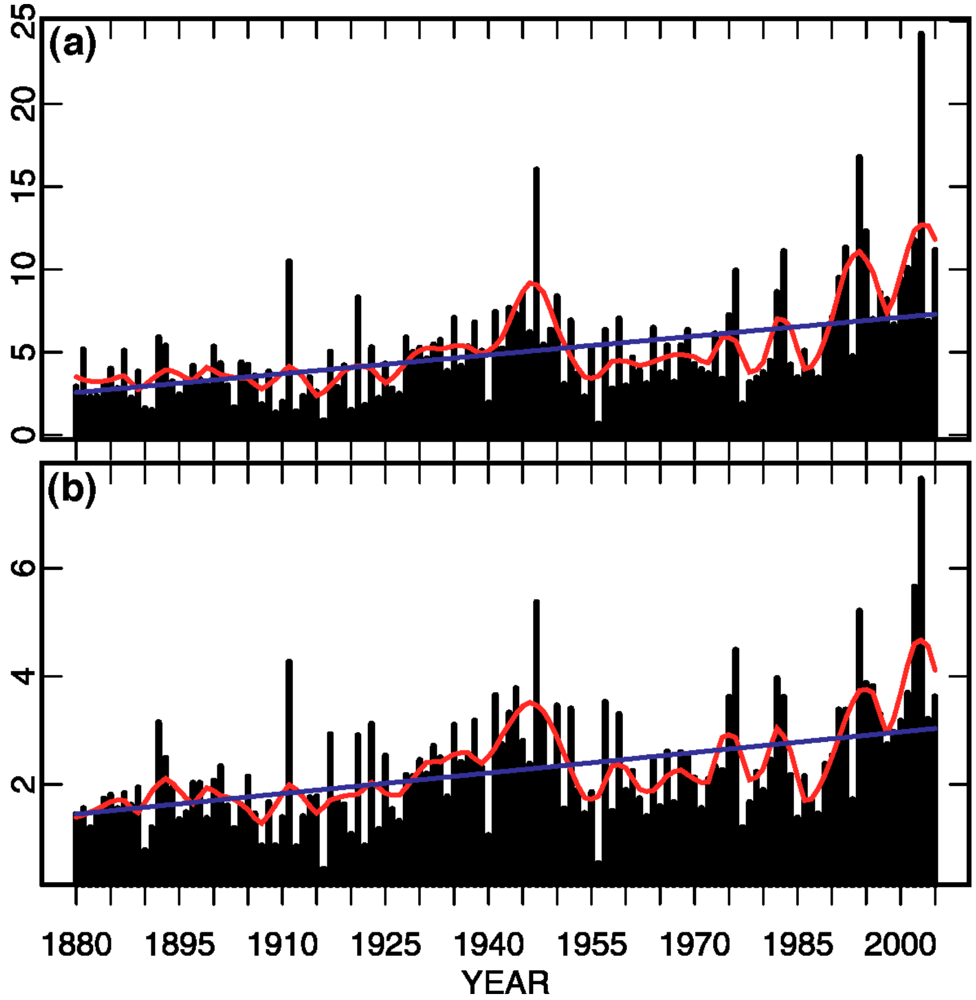
Drought and lack of soil moisture are important elements of heat wave

(Fischer et al. 2007, GRL; Seneviratne et al. 2006, Nature; Fischer et al. 2007, JC)

European heatwave trends

Number of hot days [%]

Maximal length of heatwaves [days]



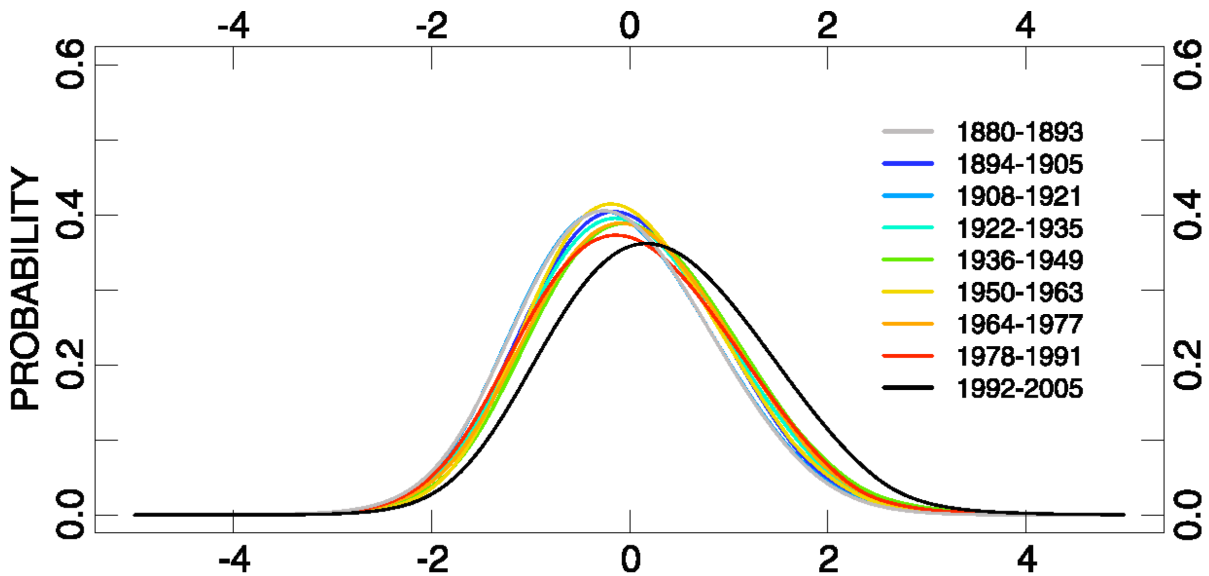
Analysis of 54 homogenized temperature series (1880-2005).

Significant increase in mean temperature.

Significant increase in number and duration of heat waves.

(Della Marta et al. 2007)

Is there a variability signal in the data?



Analysis of 54 high-quality homogenized temperature series (1880-2005).

Statistically significant variability signal.

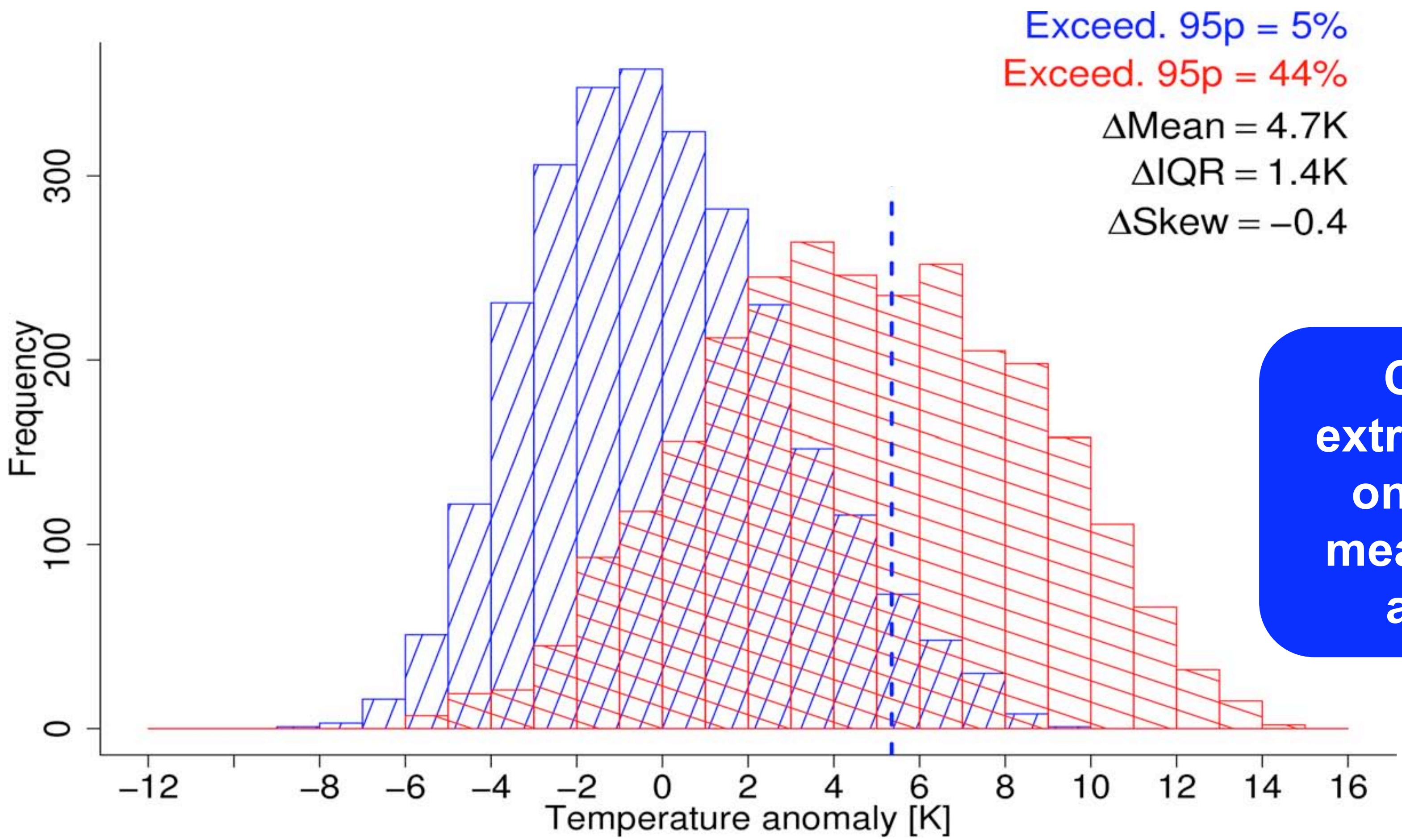
Region, R (n_s)	$\Delta\mu_R$ ($^\circ C$)	$\Delta\sigma_R$ (%)	$\Delta\gamma_R$ (%)
Western Europe (54)	+1.6 ± 0.4	+6 ± 2	+0 ± 7
Central Western Europe (36)	+1.3 ± 0.5	+11 ± 2	+0 ± 6
Iberian Peninsula (12)	+2.6 ± 0.6	-7 ± 3	-1 ± 12
Scandinavia (6)	+1.7 ± 0.7	+4 ± 6	+9 ± 6

Geographical pattern of trends in σ has maximum amplitude in Central Europe, consistent with scenarios

(Della Marta et al., 2007, JGR)
(see also Scherrer et al. 2005, 2007)

Daily summer temperature distribution

(ensemble mean of 8 regional climate models)



Changes in extremes depend on changes in mean, variability and shape!

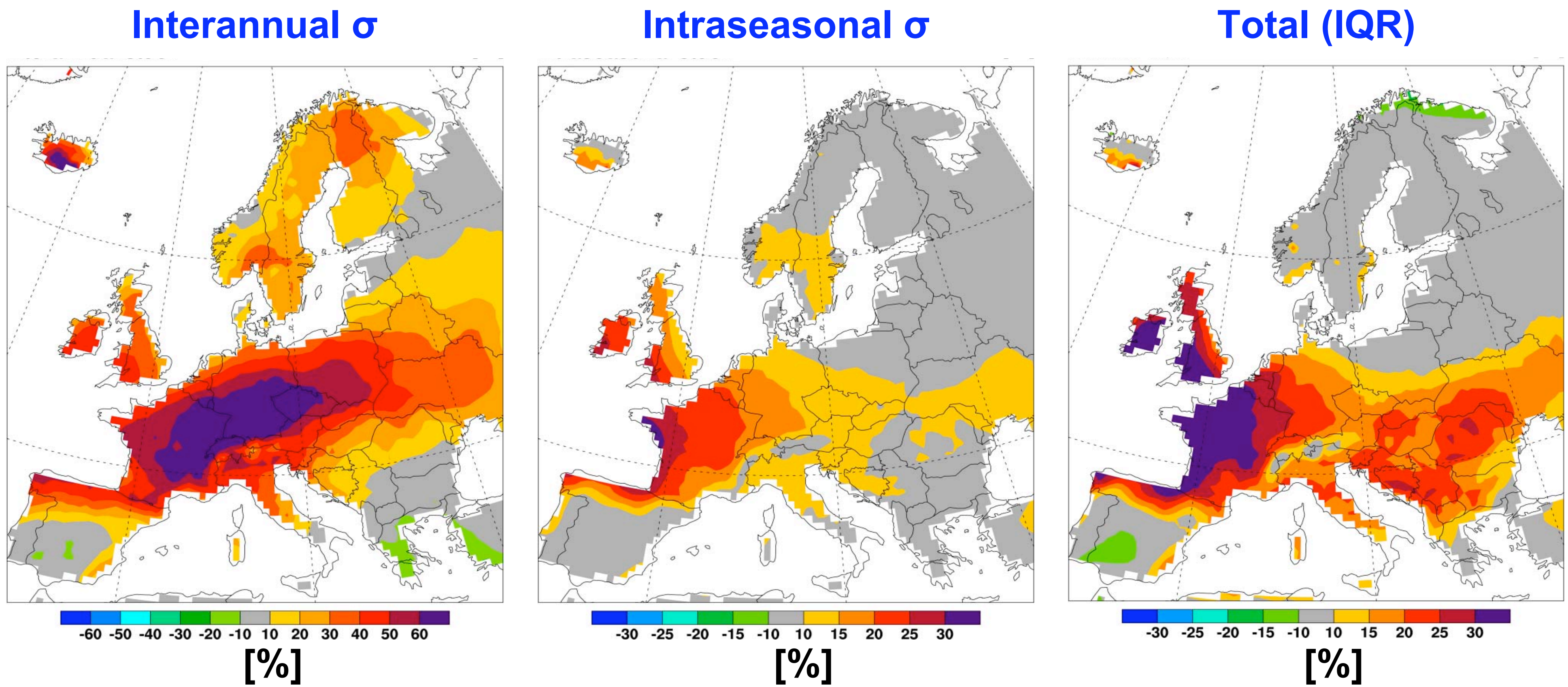
CTL: 1961-1990

SCN: 2071-2100

(Fischer and Schär, submitted)

Changes in variability

(SCN-CTL, ensemble mean of 8 regional climate models)

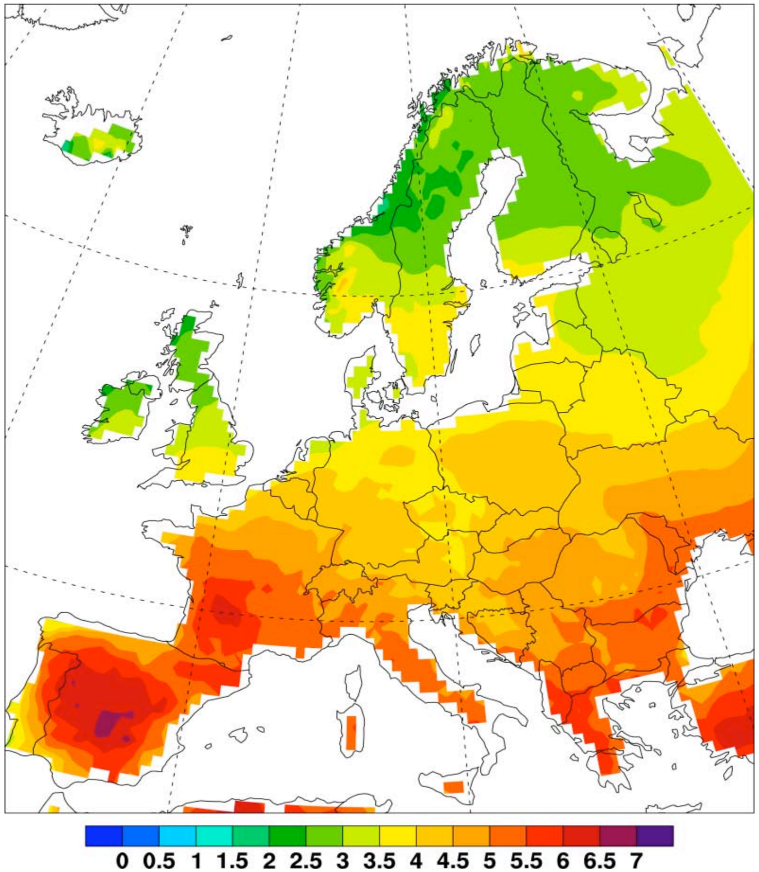


(Fischer and Schär, submitted)

Change in mean and 95th percentile

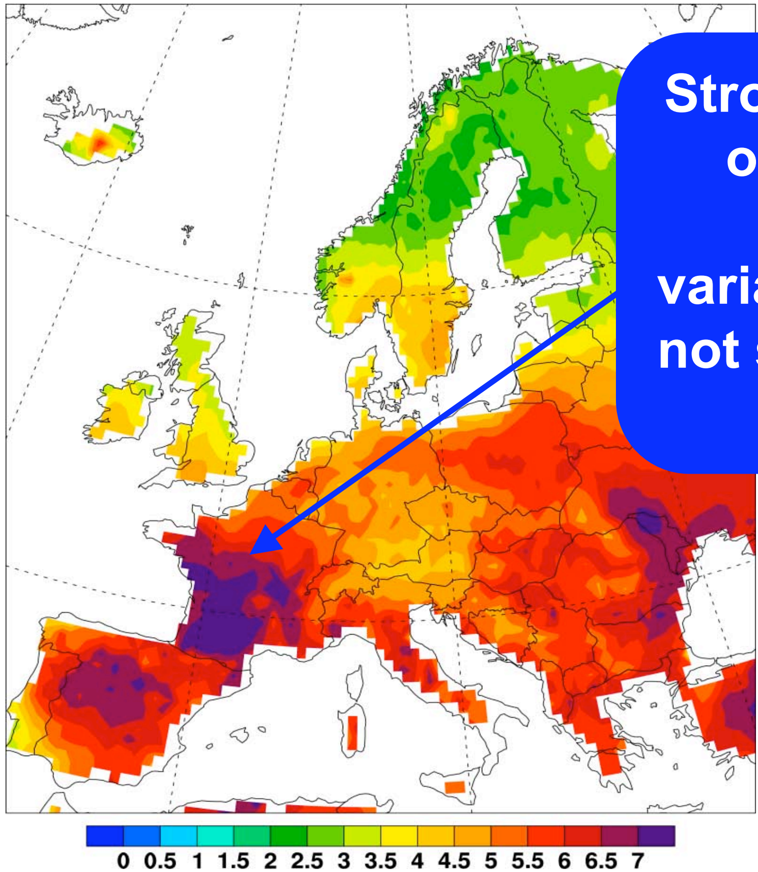
(SCN-CTL, ensemble mean of 8 regional climate models)

Mean warming



[°C]

Change in 95th percentile



[°C]

Strongest increase over area with strongest variability increase, not strongest mean warming

(Fischer and Schär, submitted)

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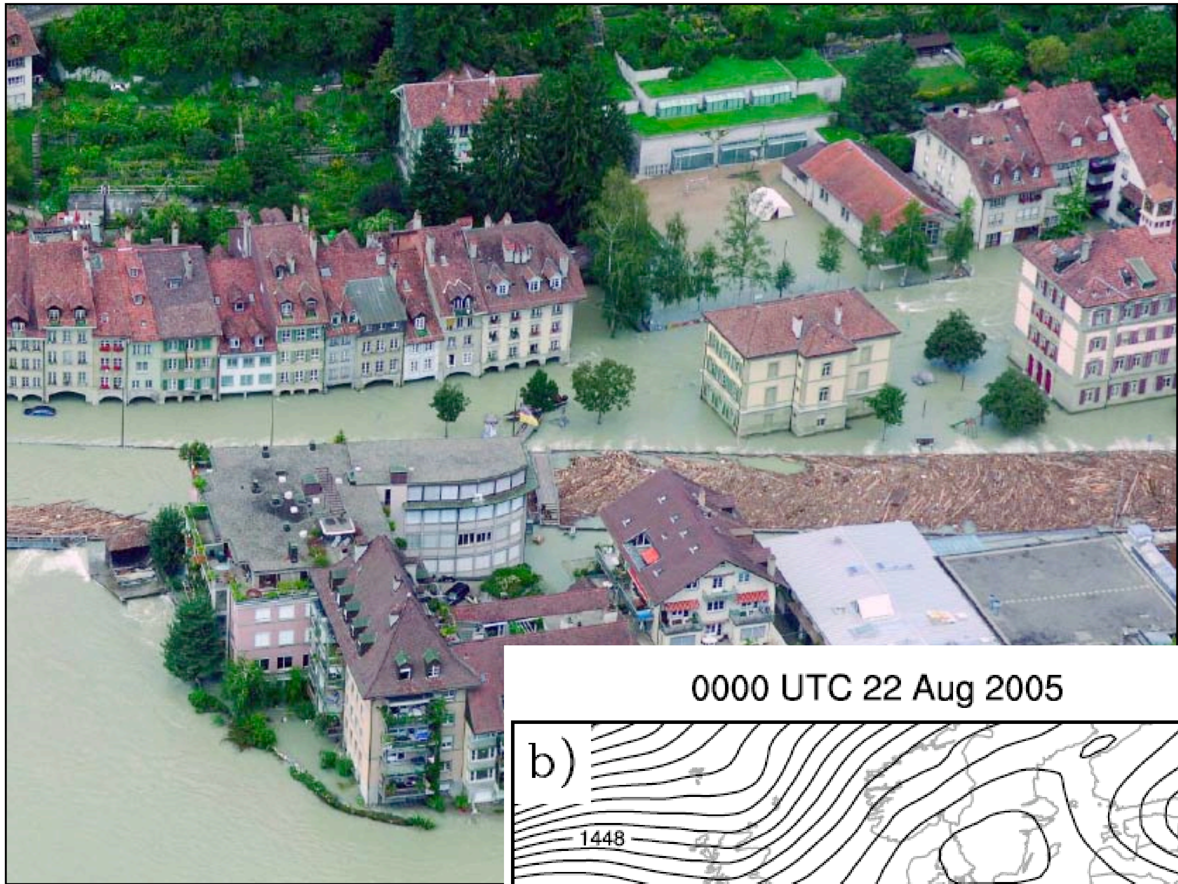
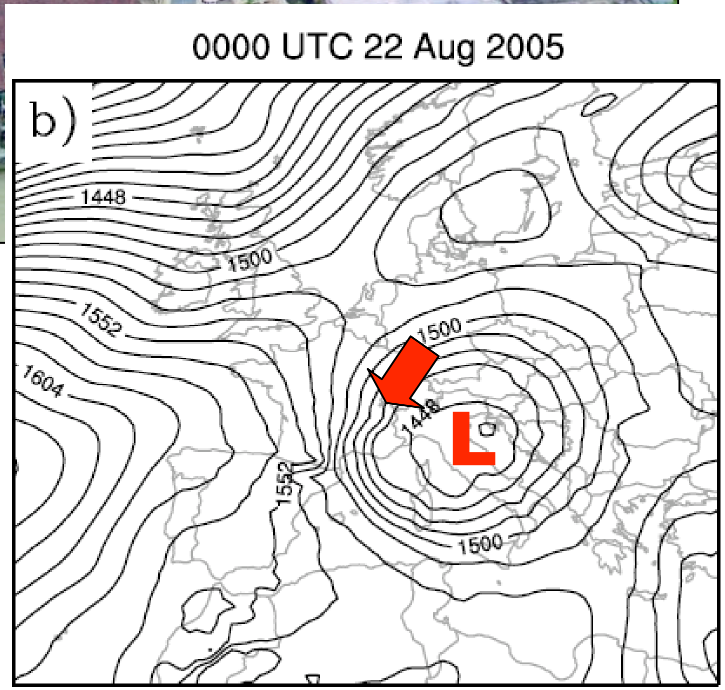
Scenarios (European perspective)

• Heatwaves and droughts •

• Heavy precipitation events •

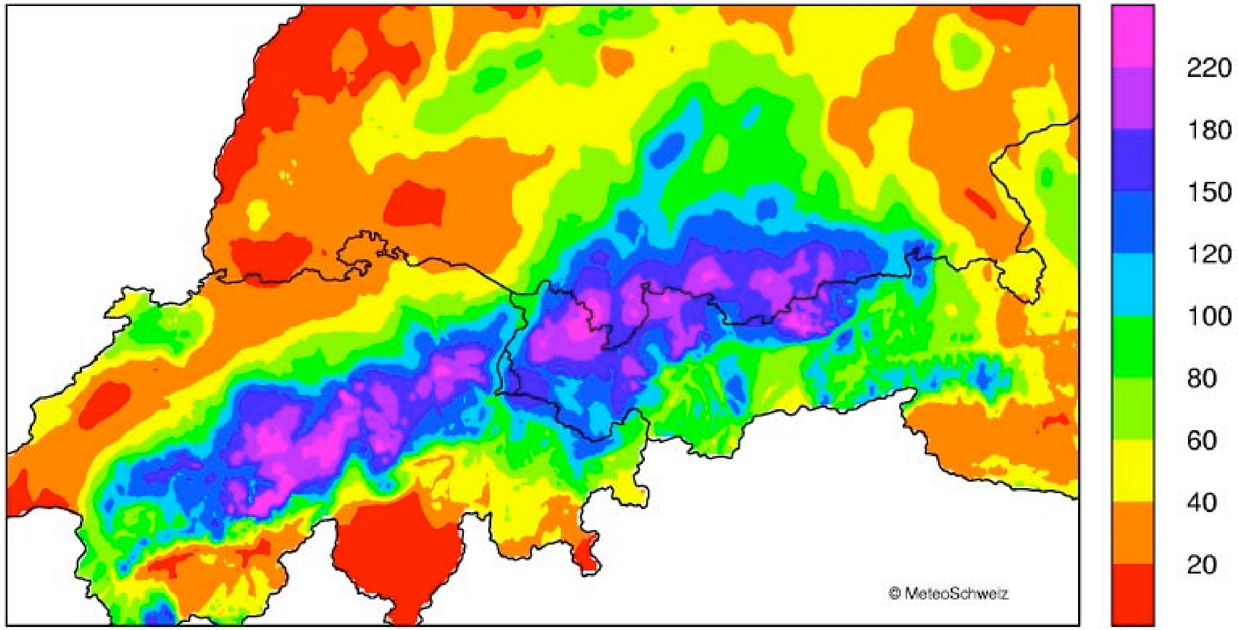
Example 1: August 2005



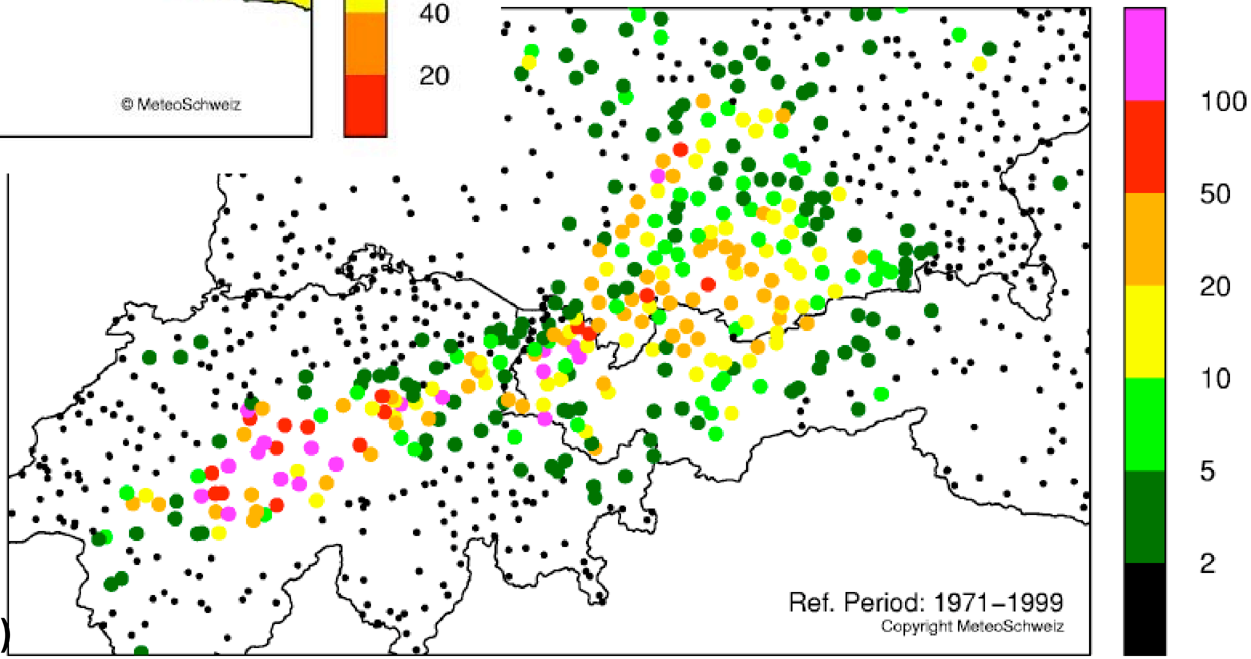


(MeteoSwiss 2005, Beniston 2006, Hohenegger et al. 2008, Jaun et al. 2008)

Observed precipitation



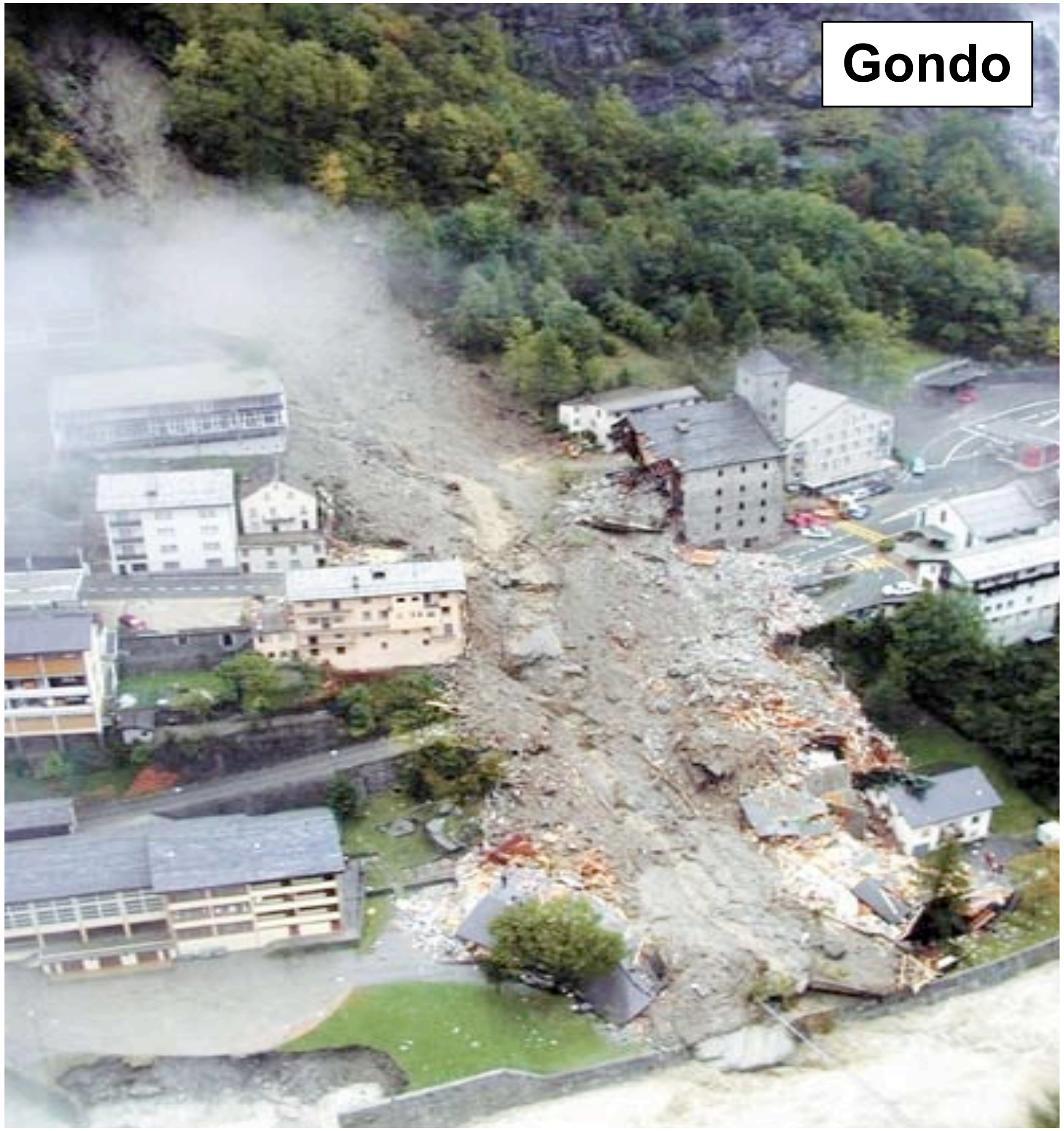
Precipitation total (mm / 3 days)
21.-24.08.2005 (06 UTC-06 UTC)



Return period (years)

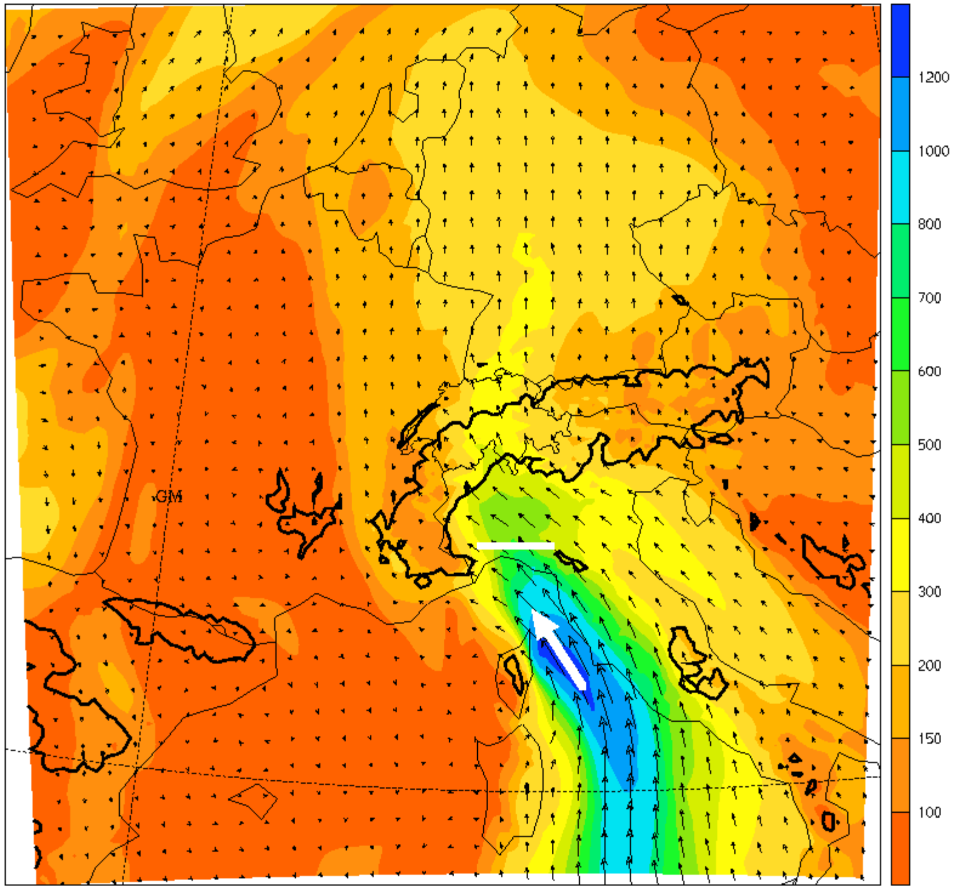
(Frei 2005, Bericht MeteoSchweiz #213)

Example 2: October 2000



Associated moisture flux

Vertically integrated moisture flux
15. Oktober 00 UTC (+24h forecast)



[kg s^{-1} m^{-1}]

Cross-section Liguria:

Total water transport: 55,000 m^3/s

Comparison:

Rhein (Rotterdam)		2,200 m^3/s
Mississippi	(Rank 8)	18,000 m^3/s
Kongo	(Rank 2)	42,000 m^3/s
Amazonas	(Rank 1)	210,000 m^3/s

(based on SM forecasts of MeteoSwiss)

Climate change will inevitably affect the water cycle!

Reasons:

(i) The water holding capacity of air increases by 7% per ºC (Clausius Clapeyron)

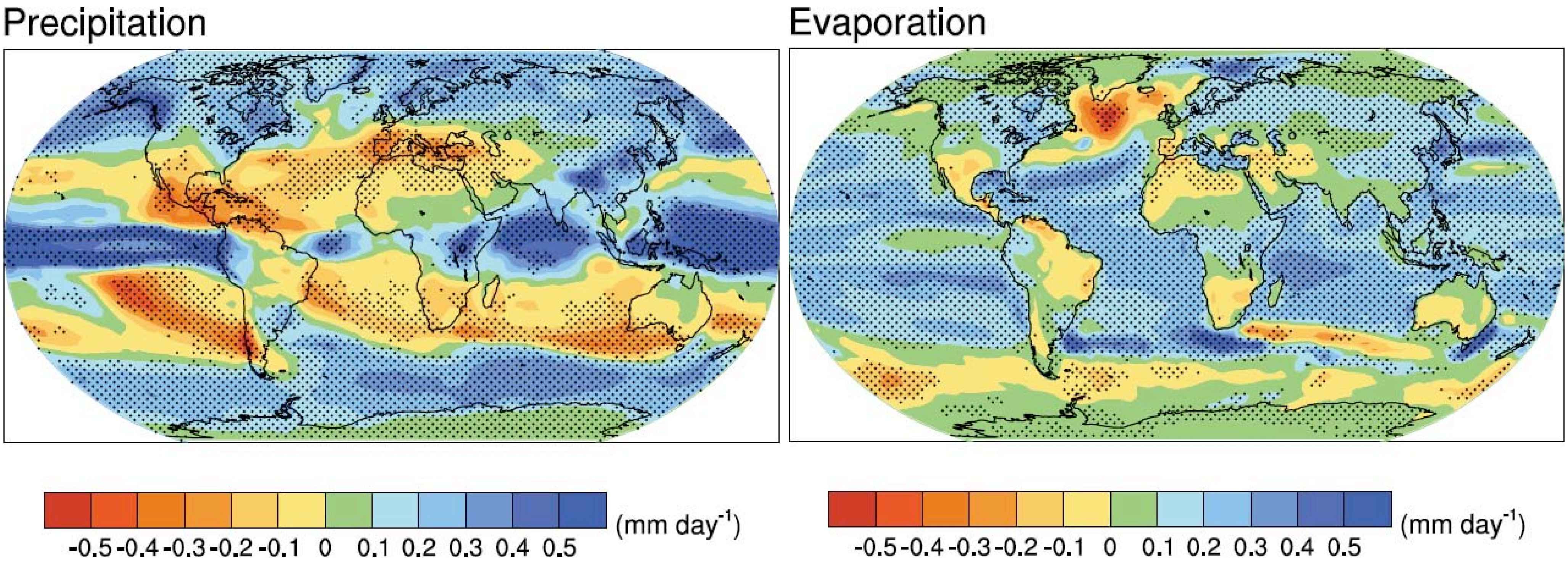
(ii) Under current climatic conditions, about 82% of the energy reaching the Earth's surface is used for evapotranspiration

(iii) Water vapor is the fuel of many atmospheric circulation systems (Hadley circulation, extratropical storms, hurricanes, etc)

=> Climate change implies not only a warming, but also an intensification of the hydrological cycle:

- In global mean: increases in evaporation and precipitation
- On regional scale: impacts depend upon region

Intensification of the water cycle



Global mean:

Moisture content: ~7% / K (Clausius Clapeyron)

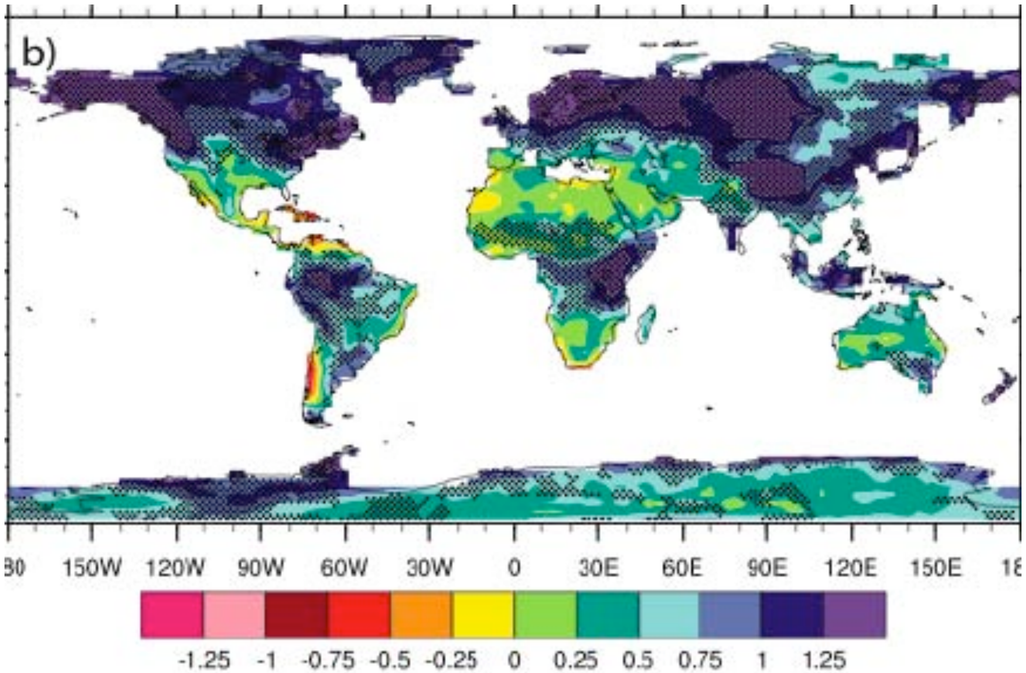
Precipitation: ~1-3% / K

Evaporation: ~1-3% / K

(IPCC AR4, Chapter 10, SRES A1B)

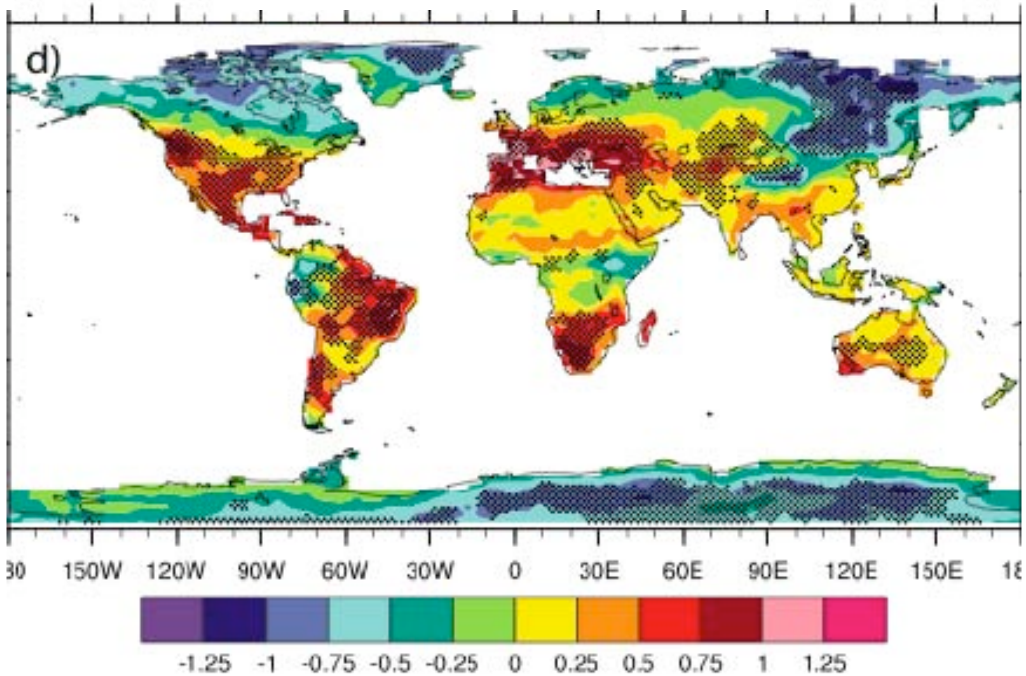
Increase of (moist and dry) extremes

Increase of intense precipitation events



[normalized by standard deviation]

Increase of droughts

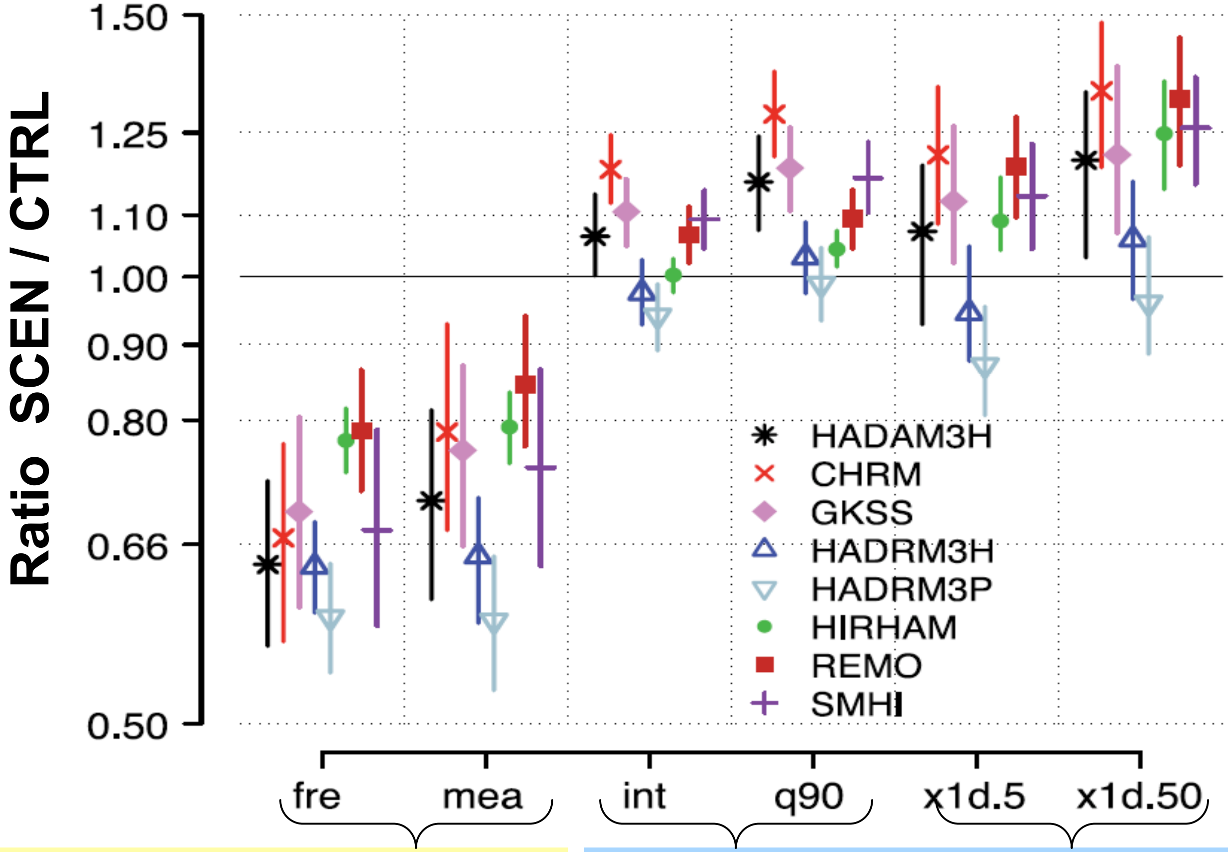


[normalized by standard deviation]

In many regions, both MOIST and DRY extremes increase!

(IPCC AR4, Chapter 10, SRES A1B)

Summer precipitation in Central Europe



Results from PRUDENCE models

Significant in all models considered

Decrease in frequency and amount

Increase in intensity

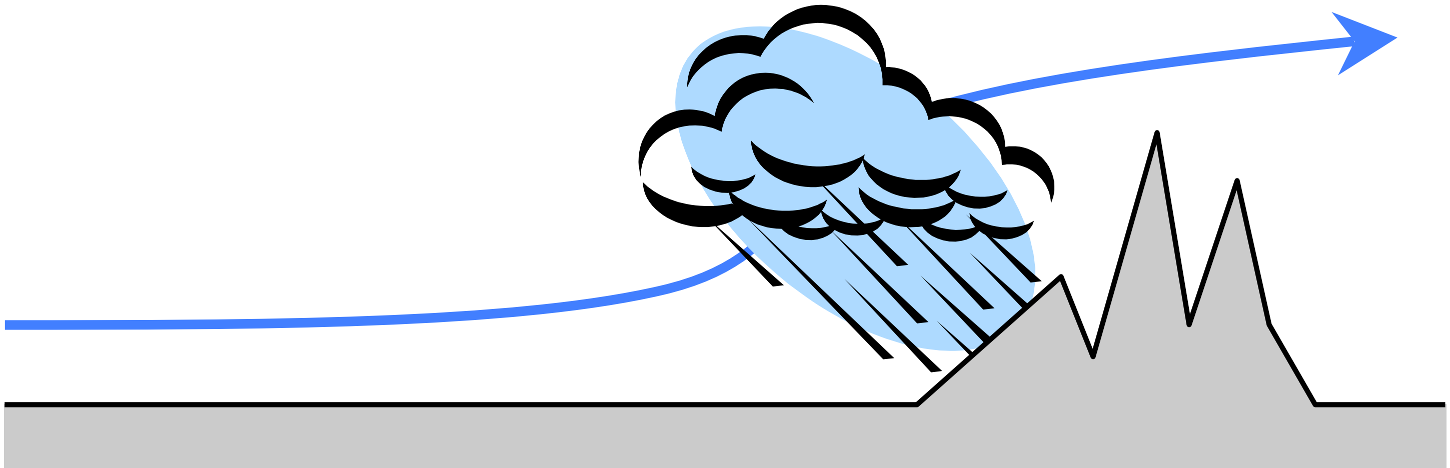
Increase in heavy events

Significant in some but not all models.

(IPCC AR4, Chapter 11, SRES A2, PRUDENCE, Frei et al. 2006)

Orographic precipitation

How will orographic precipitation change with climate change?



Orographic precipitation will likely scale with ambient moisture flux (+7 %/K) rather than global mean precipitation (+1-3 %/K)

Cloud-resolving simulations in climate mode

Moist convection is an important small-scale atmospheric process.

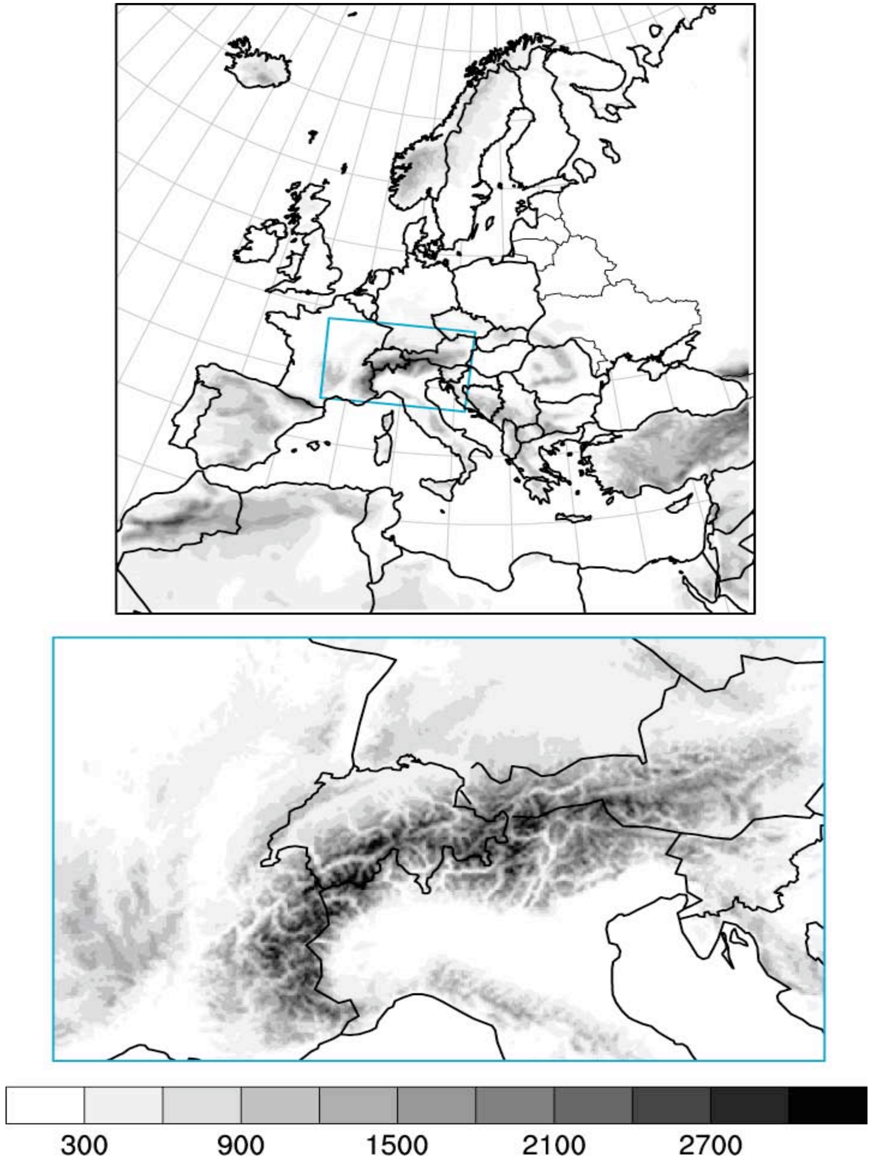
Parameterized in current climate models. Represents major uncertainty.

Use high-resolution models (Δx=2 km) for climate process studies:

- Model: COSMO (CCLM)
- Grid spacing: 0.02° (2.2 km), 501x301x45
- Boundary conditions, 0.22° (25 km)
- Integration period: months to years

Requirements (for 1 month):

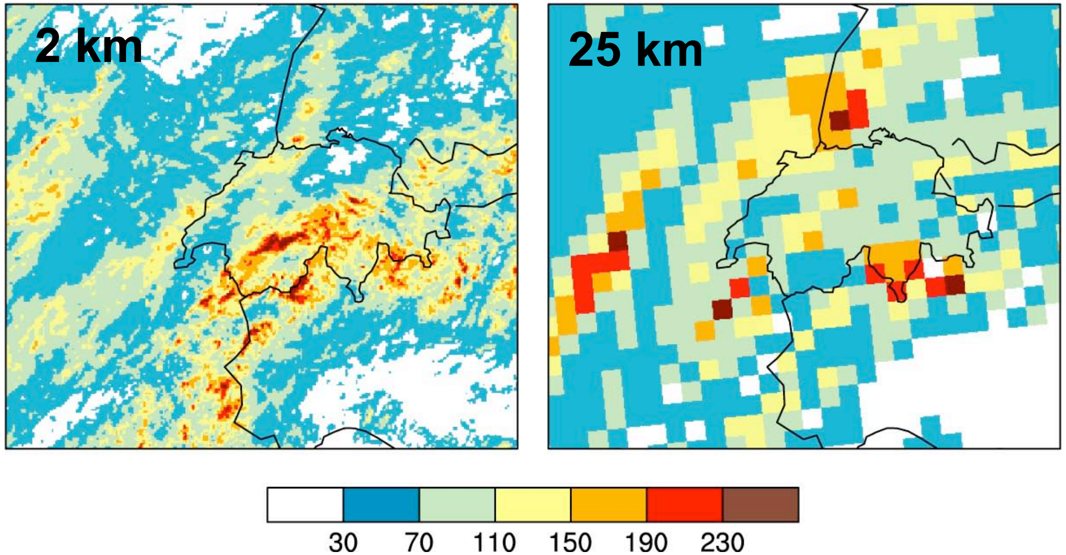
- 12 CPU h on 128 dual-cores on CRAY XT-3
- 43.2 GB of data



(Hohenegger et al. 2008, in press)

Cloud-resolving simulations in climate mode

Monthlong integration (July 2006)



Precip 2 km

Clouds 2 vs 7 km (wo conv.)

Clouds 2 vs 7 km (with conv.)

Results show improved representation of diurnal cycle of convection and better representation of peaks.

Currently still too expensive for scenario simulations, but feasible for process studies. Application to analysis of soil precipitation feedback.

(Hohenegger et al. 2008, in press)

Summary

Basic considerations:
Significant climate change inevitably leads to significant changes in extremes.

Observations:
Increasing evidence for trends in extremes,
but trend ≠ attribution,
trends in damages dominated by other factors.

Intensification of the hydrological cycle:
Overwhelming evidence from theory, observations and models.
Affects frequencies of floods, droughts, heatwaves, etc.

Climate change implies changes in mean and variance:
Important implications for extremes

Scenarios:
Climate models show pronounced changes in many event categories, still major uncertainties at regional scales