The Abdus Salam
International Centre for Theoretical Physics

United Nations
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Cultural Organization

IAEA
International Atomic Energy Agency

SMR/1849-25

Conference and School on Predictability of Natural Disasters for our Planet in Danger. A System View; Theory, Models, Data Analysis

25 June - 6 July, 2007

Climate Change and European Heat Waves

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Swiss Federal Institute of Technology

NFS NCCR climate

PRUDENCE

Climate Change and European Heat Waves

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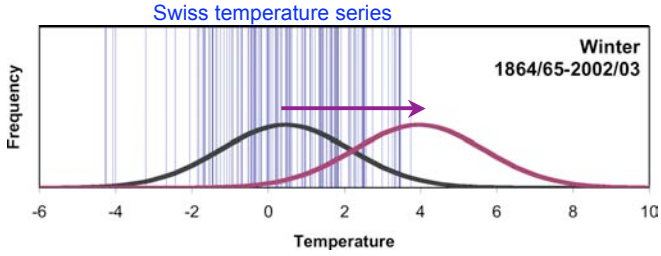
Conference on predictability of Natural Disasters
June 25-26, ICTP, Trieste

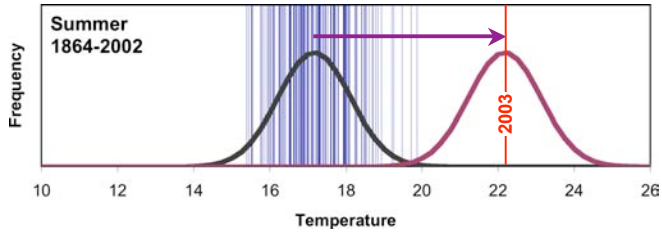
Climate Change in the Extratropics – Basic Considerations

Swiss temperature series



Warming until 2100: +3 K

About every second winter should fit the warm winters of the past.



Stronger warming: +4.5 K
Smaller interannual variability

Yields an essentially new climate!

European Summer 2003 looks like a glimpse of the future

Extreme European summers: 2002 … 2003 … 2005 …

August 2002, Dresden

August 2003, Töss

August 2005, Brienz

Outline

Summer 2003
• Temporal and spatial structure •
• Impacts •
• Statistical analysis •

Heat waves and interannual variability

Associated processes

Some scenario Results

Spatial Extent of Heat Wave

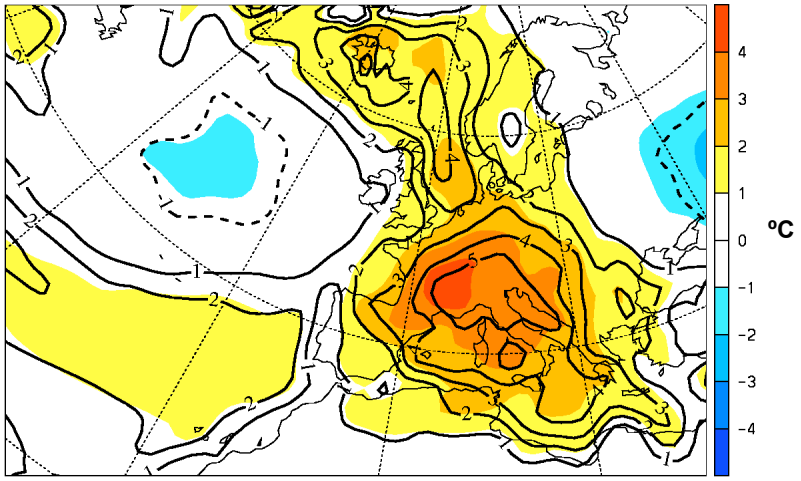
Summer 2003

Deviation from 1961-1990 mean

Color: temperature anomaly

Bold contours: normalized by standard deviation

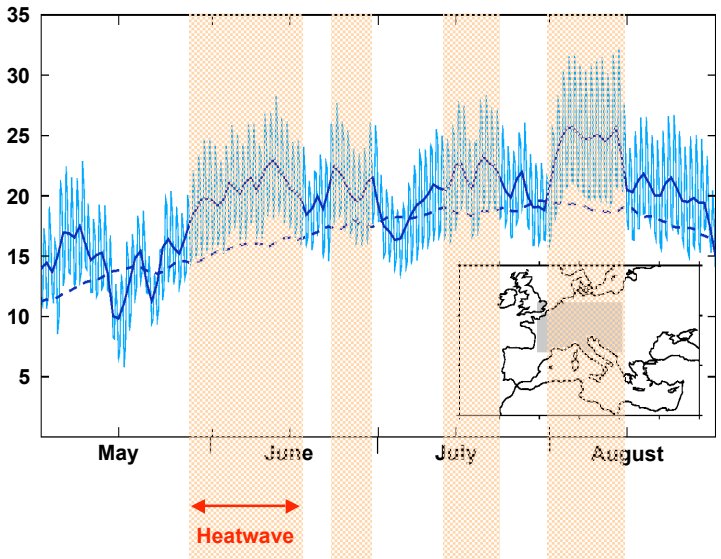
Data: ECMWF / ERA-40



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

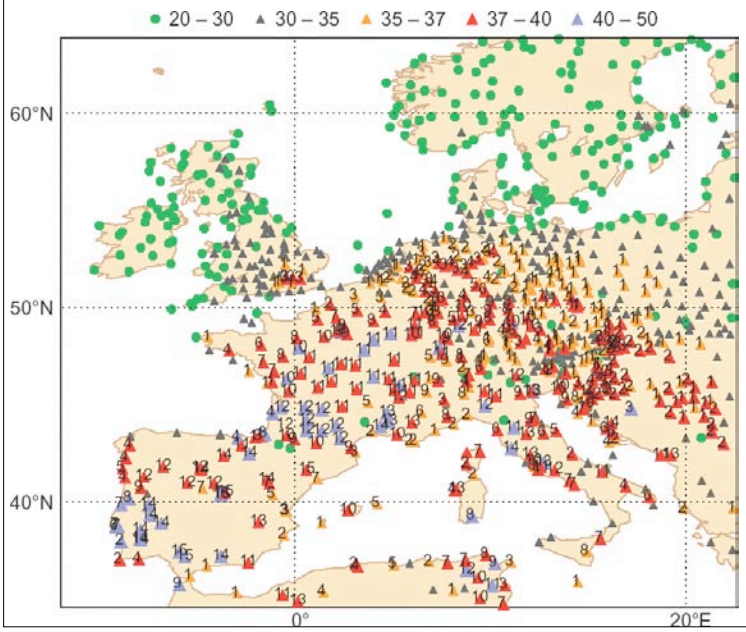
Temporal Variations

Central European Surface Temperature



(Black et al. 2004)

T_{max} in August 2003



Period August 1-15

Symbols:
maximum T_{max}

Numbers:
numbers of days with T_{max}>35ºC

(Grazzini 2004)

Geopotential Height, 500 hPa

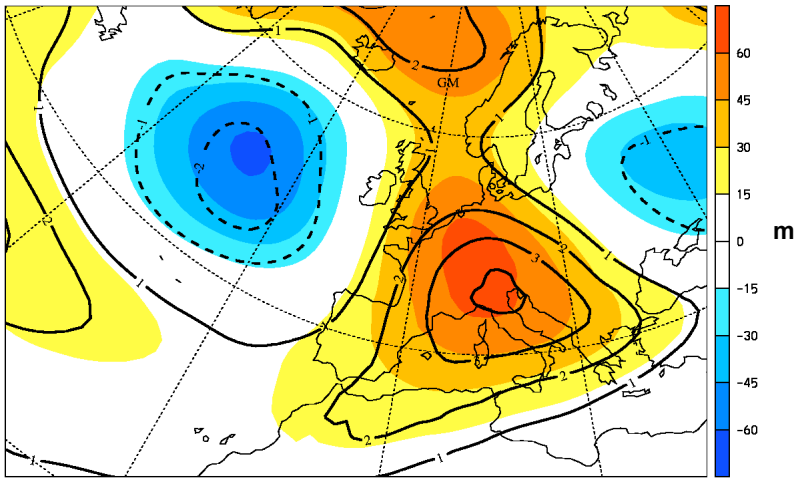
Summer 2003

Deviation from 1961-1990 mean

Color:
height anomaly

Bold contours:
anomalies normalized by standard deviation

Data:
ECMWF / ERA-40



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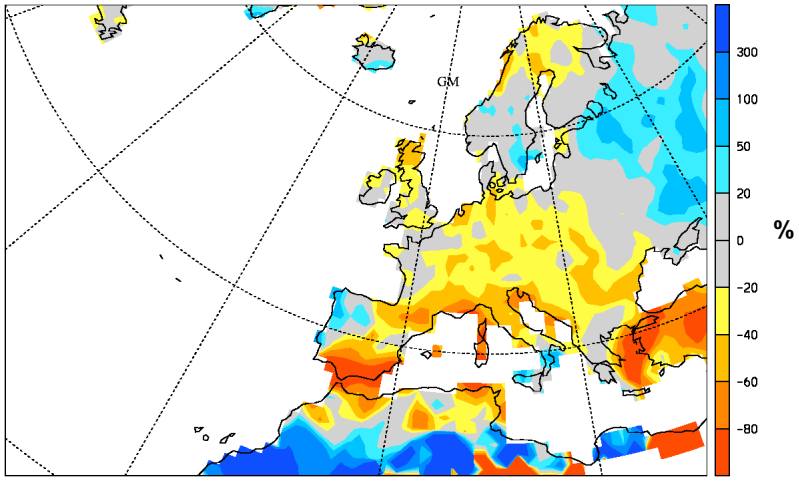
Mark Liniger

Precipitation Anomaly

Summer 2003

Deviation from 1961-1990 mean

Data: GPCC



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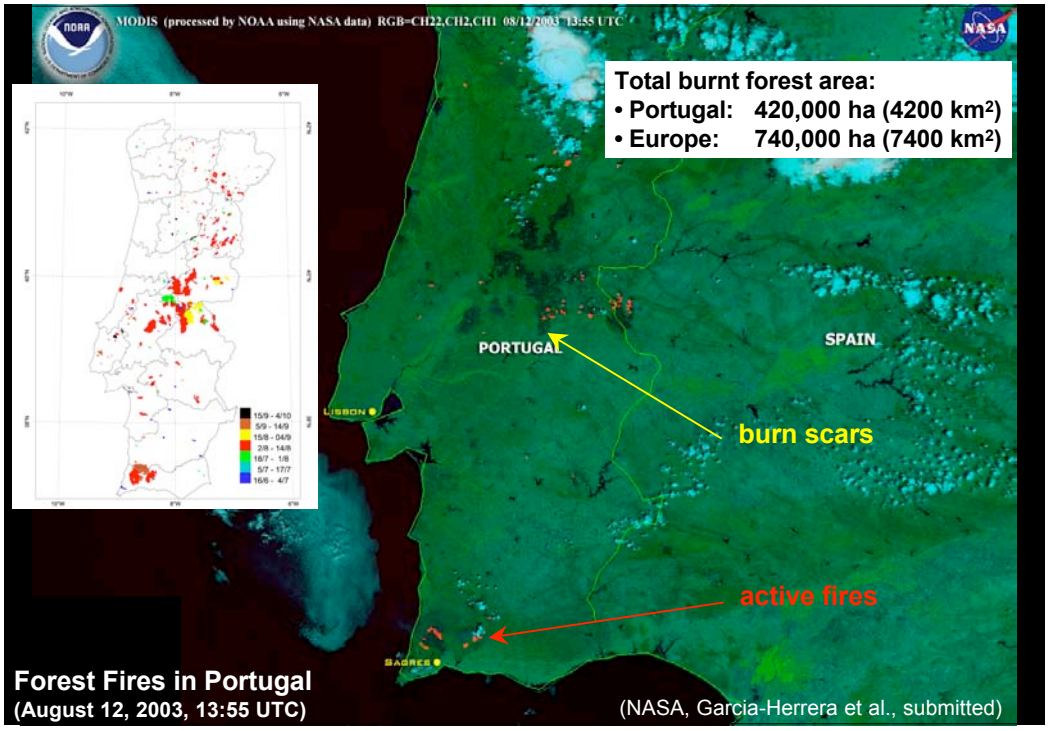
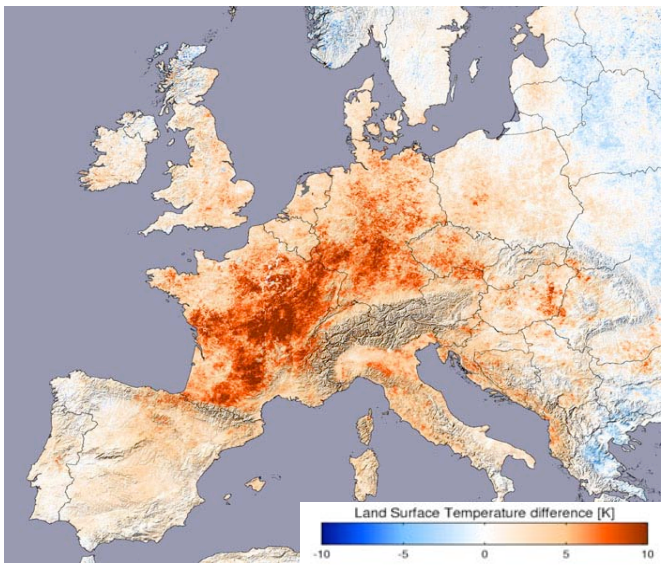
Töss, 28. August 2003



Impact 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)

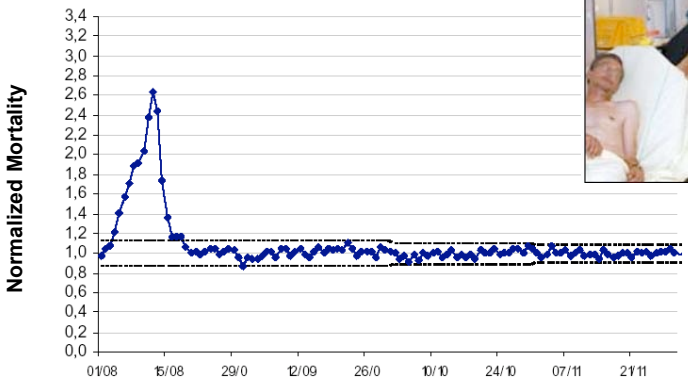
Shortage of electricity,
peak prices on spot market
(EEX, Leipzig)

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



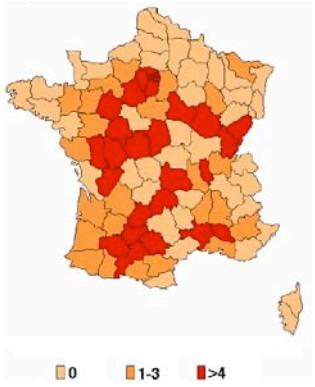
Date: August 1 - November 30, 2003

Schär, ETH Zürich

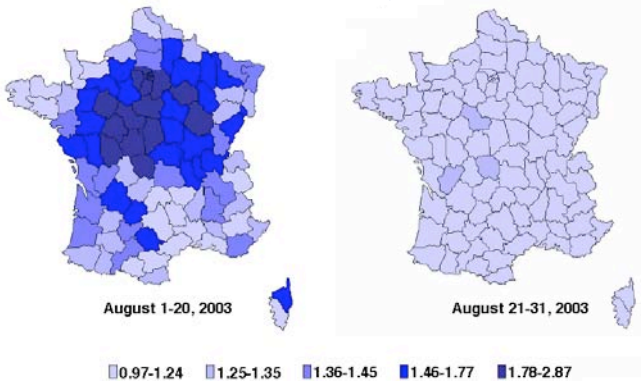
(INSERM 2004)

Excess Mortality in France

Number of days with Tmin>20°C and Tmax>37.5°C



Normalized mortality: mortality 2003 / longterm mean



Schär, ETH Zürich

(INSERM 2004)

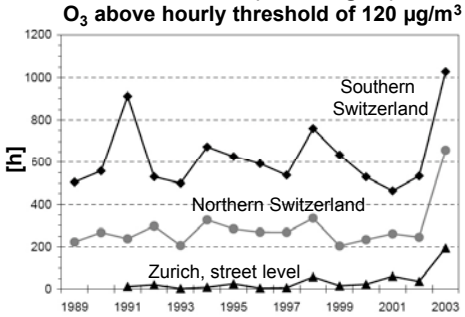
Role of warm nights

	Excess mortality	Number of hot days T_{max} > 30°C T_{min} > 20°C
Basel	128 = 24.4%	10
Berne	10 = 1.7%	0
Geneva	123 = 17.5%	14
Zürich	47 = 4.9%	1

(Gritze et al. 2005, Swiss Medical Weekly)

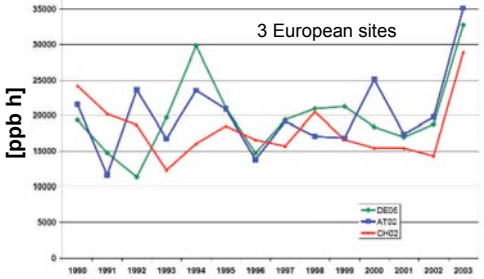
Role of ozone

Accumulated time (June-August) with O_3 above hourly threshold of 120 µg/m³



(Eidg. Kommission für Lufthygiene, 2004)

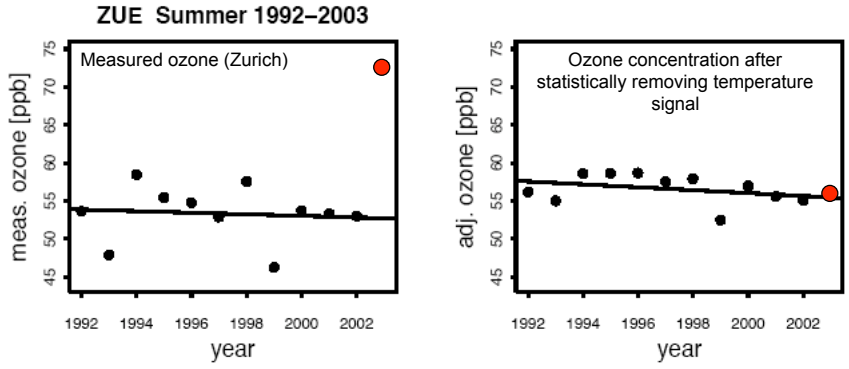
Accumulated O_3 exposure (April-September) above threshold 40 ppb



(Solberg, 2005, Ambio)

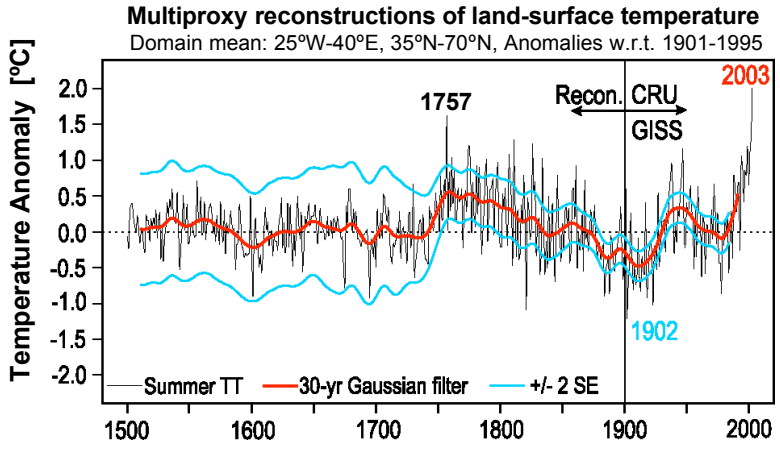
Temperature dependence of ozone

**Statistical analysis of Swiss data:
Afternoon temperature and morning global radiation account for most of the seasonal ozone variability**

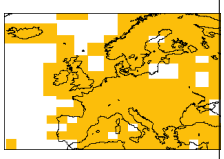


(Ordonnez et al. 2005, Atmos. Chem. Phys)

European Summer Temperatures 1500-2003

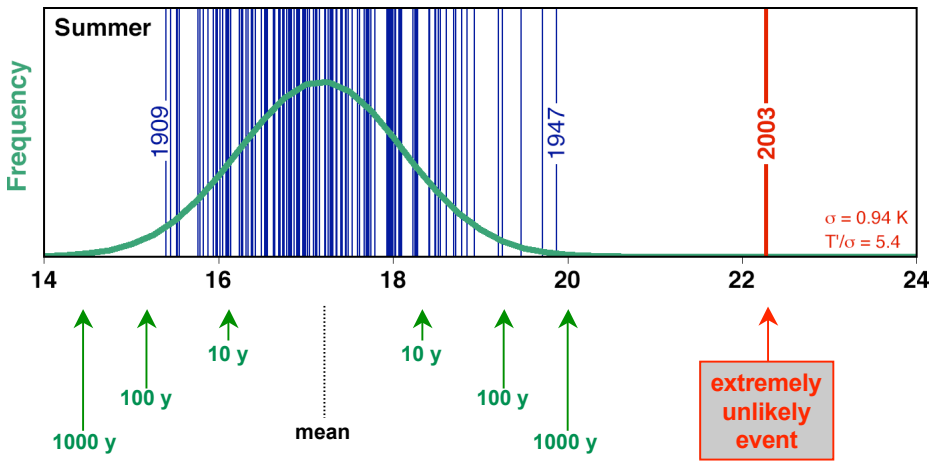


2003
***T'/σ* = 3.9**
warmest summer since 1500 (90% certainty)



(Luterbacher et al. 2004)

Estimation of Return Periods



Outline

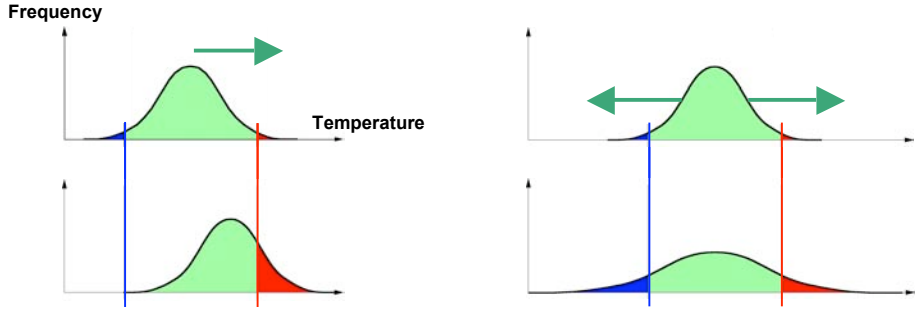
Summer 2003

Heat waves and interannual variability
• Hypothesis •
• Tested with RCM simulations •
• Model intercomparison •
• Analysis of long-term observational trends •

Associated processes

Some scenario results

Changes in Mean versus Changes in Variability



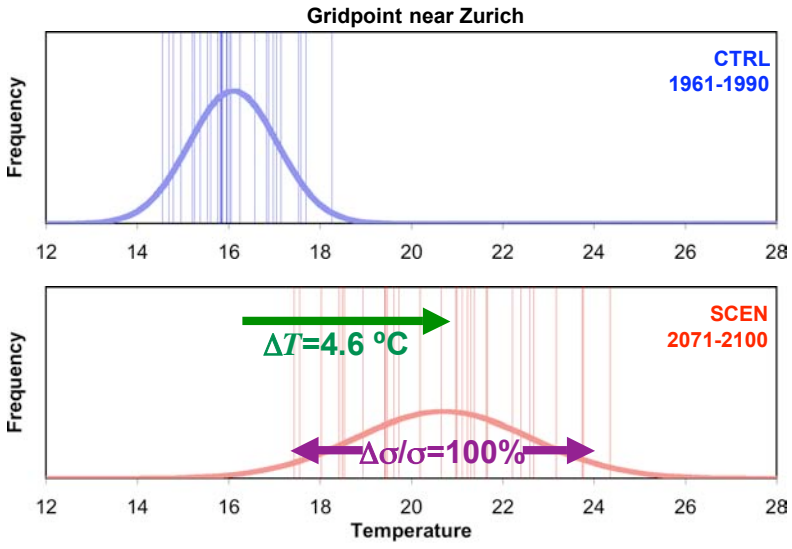
increase in the frequency of extreme warm conditions

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

Summer Surface Temperatures



Simulated:
T = 16.1 °C
σ = 0.97 °C

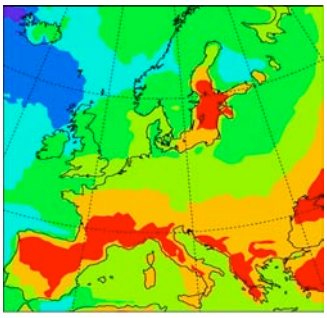
Observed:
T = 16.9 °C
σ = 0.94 °C

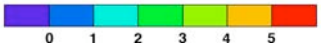
strong increase in variability

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

Summer Temperatures and Heatwaves (2070-2100)

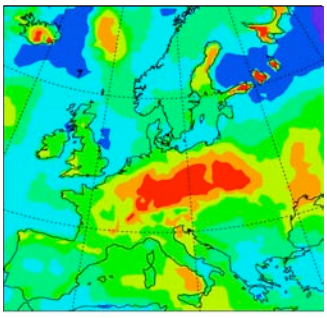
Change in Temperature ΔT

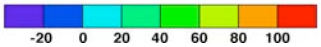




[°C]

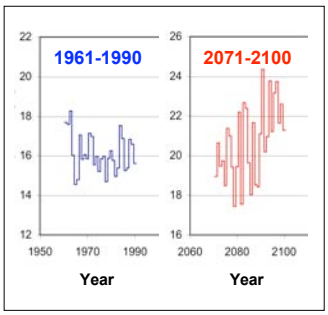
Change in Variability Δσ/σ (StdDev of seasonal T)





[%]

Zurich Temperature Series

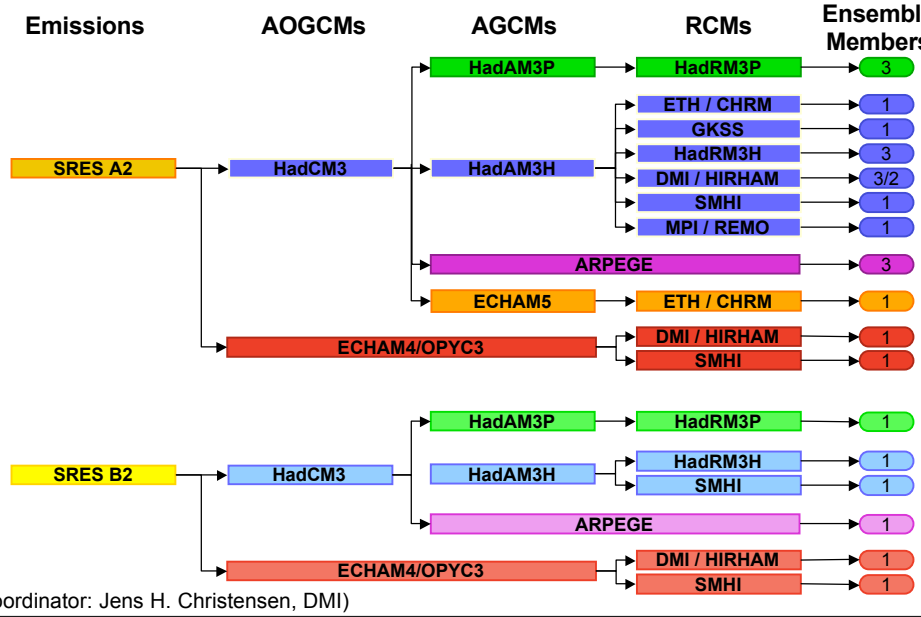


- Not only changes in mean, but also changes in variability
- Together these combine to increase the frequency of heatwaves
- By 2070, a typical summer might be as warm as 2003, many summers even warmer and dryer

Schär, ETH Zürich

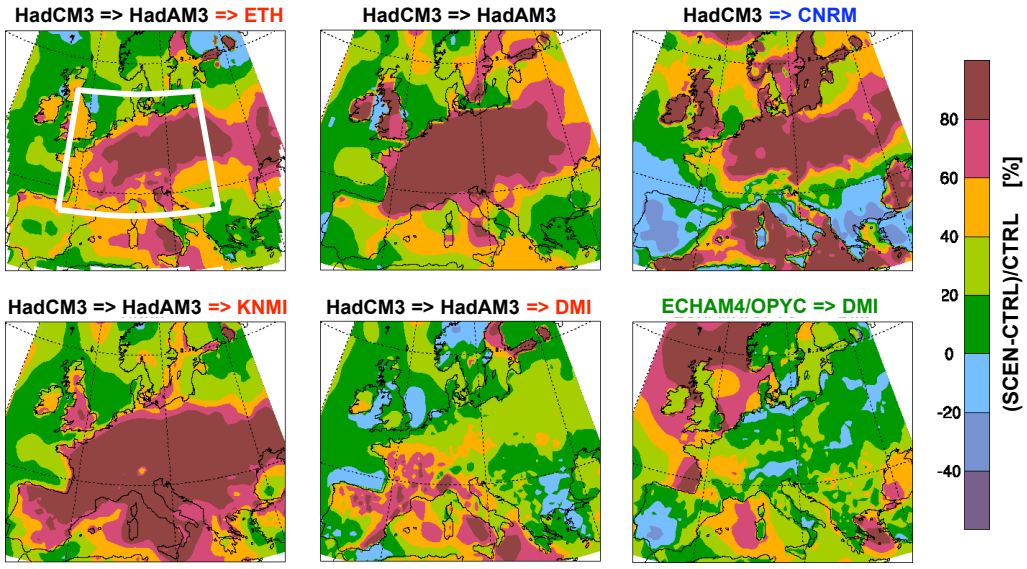
(Schär et al. 2004, *Nature*, **427**, 332-336)

Model Chains of the extended EU Project PRUDENCE



(Coordinator: Jens H. Christensen, DMI)

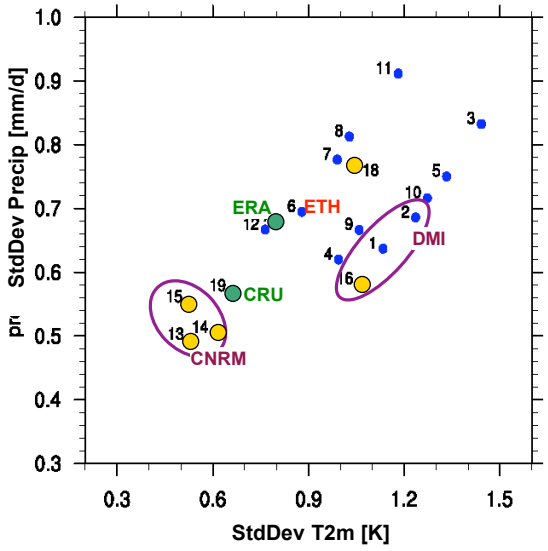
Intercomparison of Variability Changes



Schär, ETH Zürich

(Vidale et al. 2005)

Validation of CTRL variability



observations

driven by HadCM3/AM3

driven by other AGCM

1) DMI, HC1
2) DMI, HC2
3) HC, achgi (HadRM3H)
4) HC, acdhd (HadAM3H, Ens.1)
5) HC, acdhe (HadAM3H, Ens.2)
6) ETH, HC_CTL
7) GKSS, CTL
8) MPI, 3003
9) SMHI, HCCTL
10) UCM, control
11) ICTP, ref
12) KNMI, HC1
13) CNRM, DA9
14) CNRM, DE3
15) CNRM, DE4
16) DMI, e ctrl
17) ERA40_ANA,
18) ETH, ERA40_CTL
19) CRU,

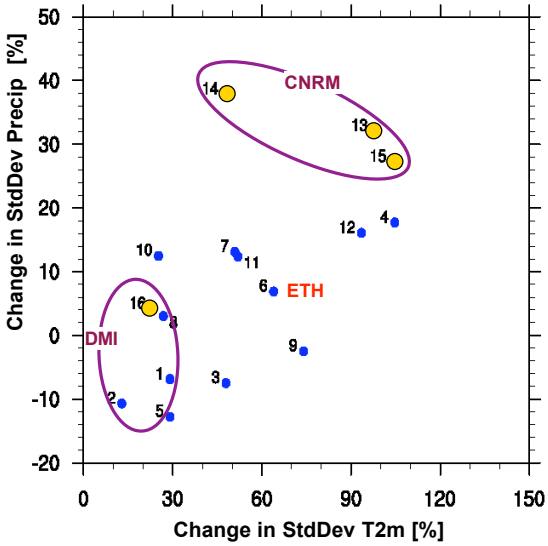
Large spread between results

Simulations with same RCM cluster, irrespective of the driving GCM / ensemble member

Schär, ETH Zürich

(Vidale et al. 2005)

Changes in variability



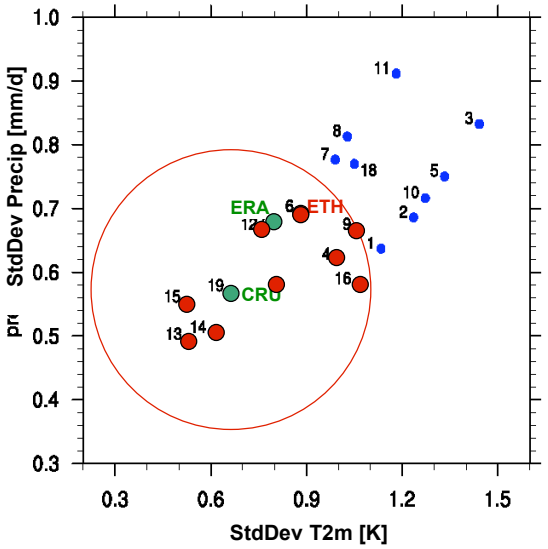
Large spread between results

ETH model shows intermediate sensitivity.

Simulations with same RCM cluster, irrespective of driving GCM / ensemble member.

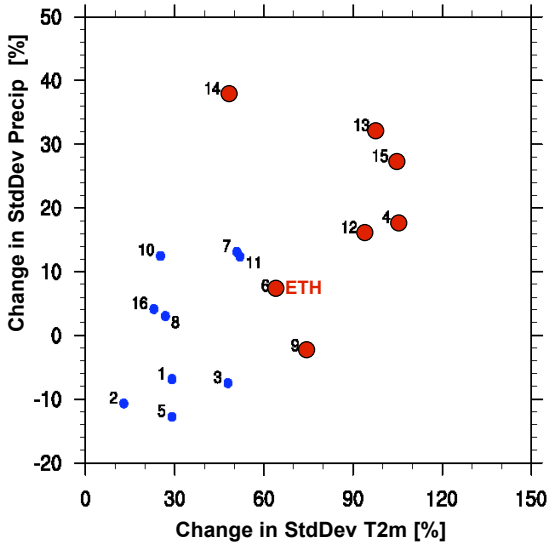
(Vidale et al. 2005)

Validation of CTRL variability



(Vidale et al. 2005)

Changes in variability



poorer validation

better validation

1) DMI, HC1
2) DMI, HC2
3) HC, achgi (HadRM3H)
4) HC, acdhd (HadAM3H, Ens.1)
5) HC, acdhe (HadAM3H, Ens.2)
6) ETH, HC_CTL
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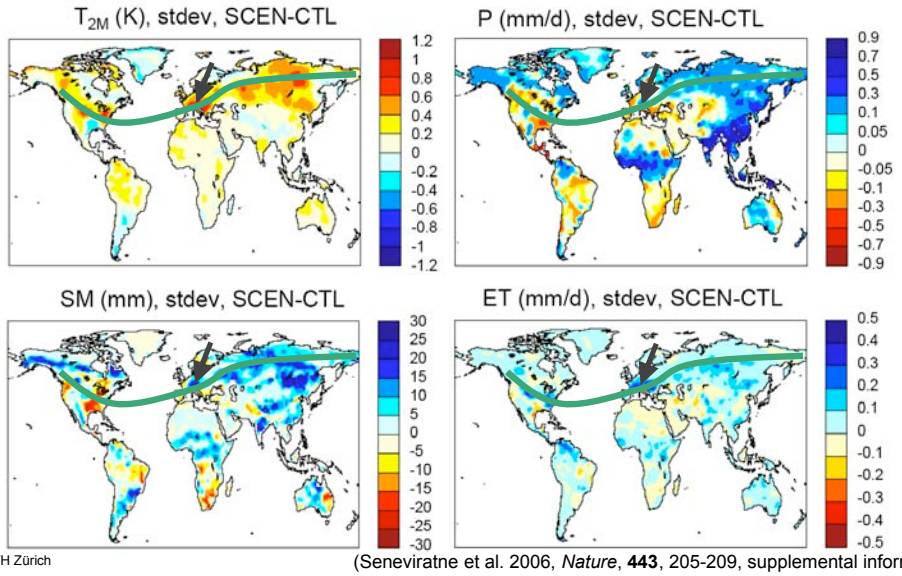
8) MPI, 3003
9) SMHI, HCCTL
10) UCM, control
11) ICTP, ref
12) KNMI, HC1
13) CNRM, DA9
14) CNRM, DE3
15) CNRM, DE4
16) DMI, e ctrl

Simulations with better validation simulate larger variability increase.

(Vidale et al. 2005)

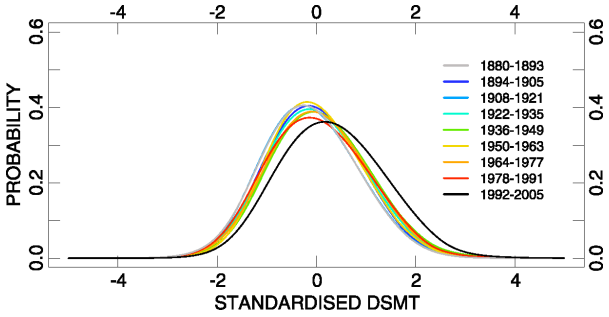
Intercomparison of IPCC AR4 GCMs

3 GCMs: ECHAM5, HadGEM, GFDL (selection based on analysis of van Ulden 2006)



(Seneviratne et al. 2006, *Nature*, **443**, 205-209, supplemental information)

Is there a variability signal in the data?



Analysis of 54 high-quality homogenized temperature records from 1880-2005.

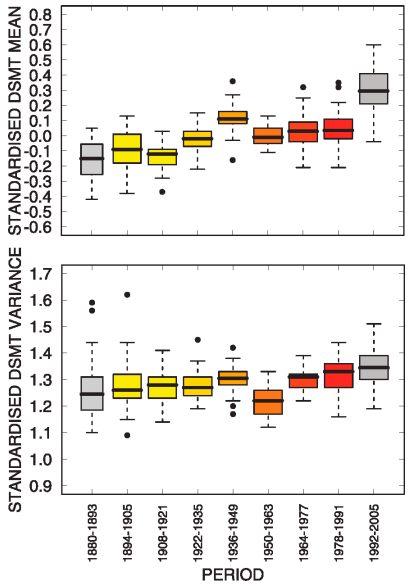
Finds a statistically significant signal.

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

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

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

Is there a variability signal in the data?



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

Outline

Summer 2003

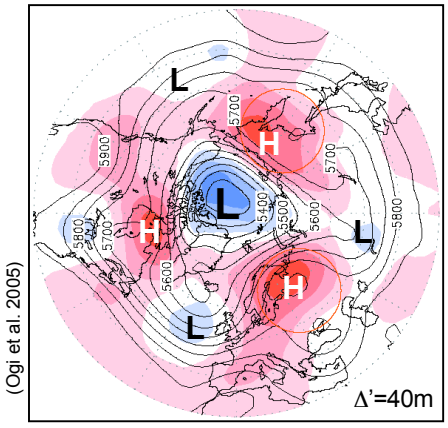
Heat waves and interannual variability

Associated processes
• Overview •
• Land-surface processes •

Some scenario results

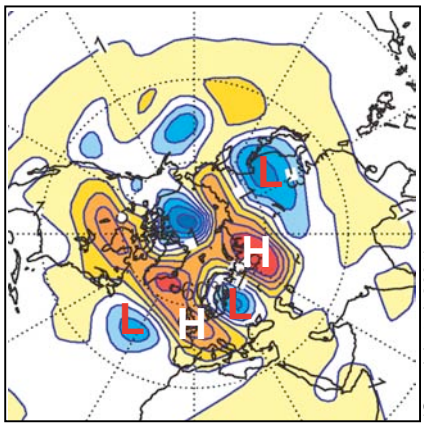
Atmospheric Circulation

Anomaly 500 hPa Circulation
(17. Juli – 6. August 2003)



(Ogi et al. 2005)

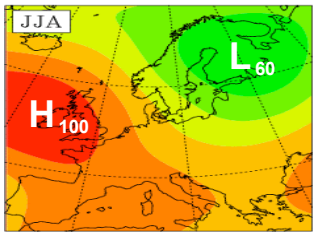
Anomaly 500 hPa Circulation
(August 2003)



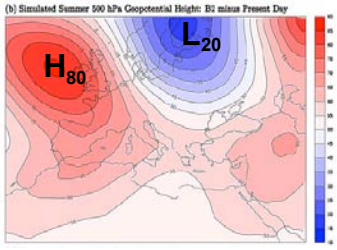
(Grazzini et al. 2004)

Sequence of blocking high-pressure systems
- **Summer Northern Hemisphere Annular Mode, wave-number 3** (Ogi et al. 2005)
- **Rossby wave train** (Grazzini et al. 2004, Black et al. 2005, Orsolini and Nikulin 2005)

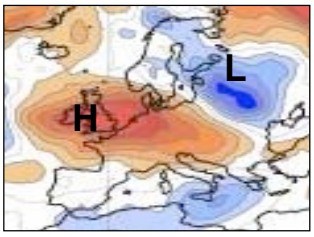
500 hPa Circulation Changes / Anomalies



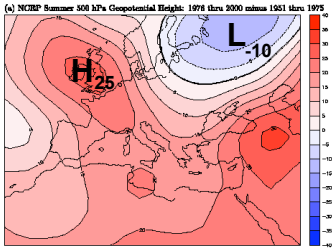
A2 Scenario (HadCM3/AM3=>ETH)
(Vidale et al. 2005)



B2 Scenario (HadCM3/AM3=>RegCM)
(Pal et al. 2004)

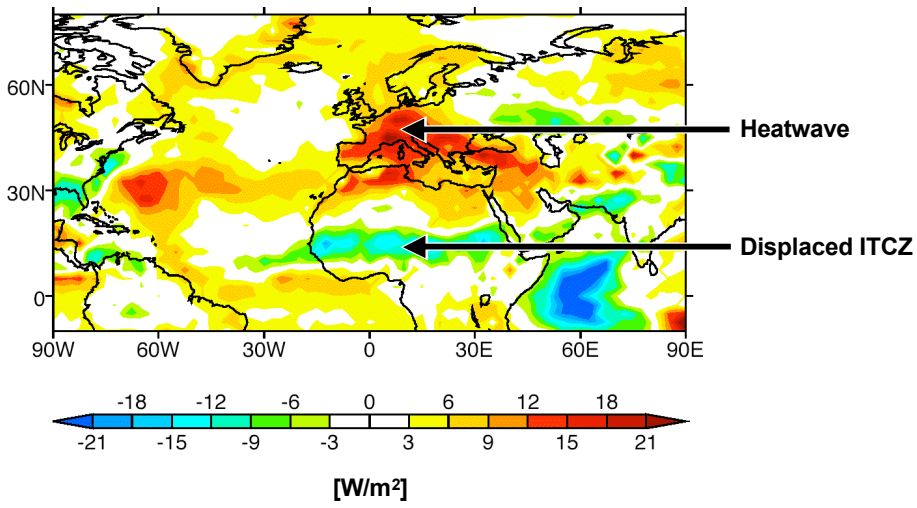


Anomaly August 2003
(Schwierz et al., ETH Zürich)



Observed Trend 1976-2000 (NCEP)
(Pal et al. 2004)

Outgoing Longwave Radiation (Anomaly JJA 2003)



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(Black et al. 2004)

SST Anomaly

13.-20. August 2003

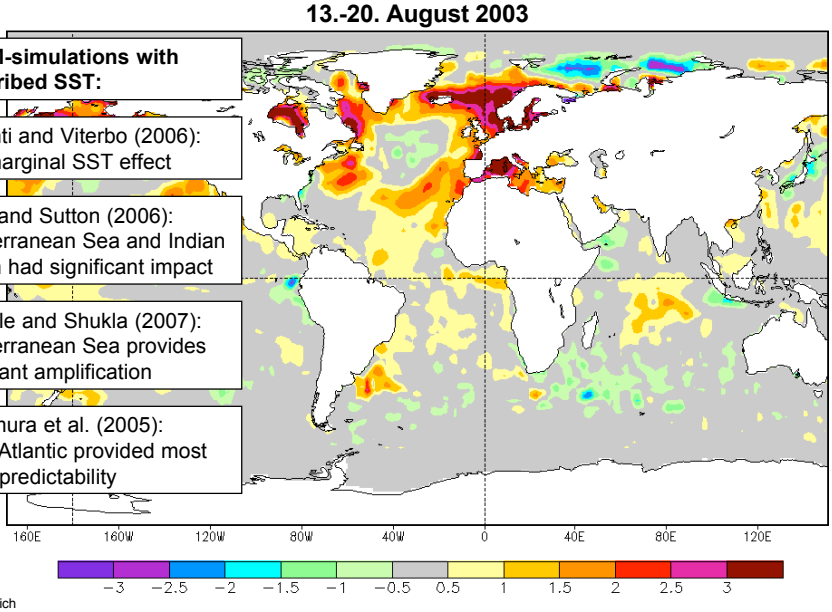
AGCM-simulations with prescribed SST:

Ferranti and Viterbo (2006): only marginal SST effect

Black and Sutton (2006): Mediterranean Sea and Indian Ocean had significant impact

Feudale and Shukla (2007): Mediterranean Sea provides important amplification

Nakamura et al. (2005): North Atlantic provided most of the predictability



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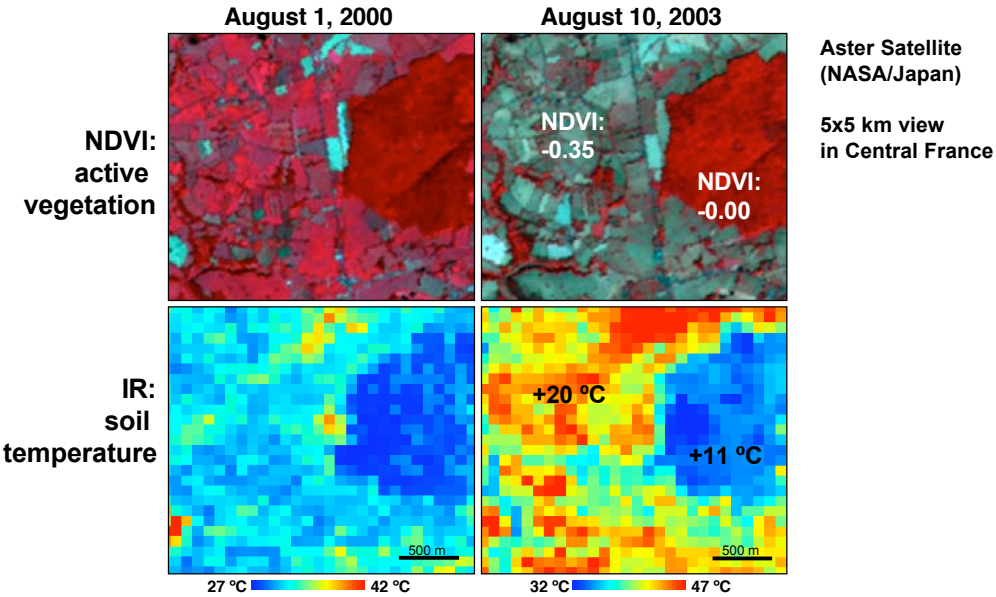
High-resolution Temperature Analysis



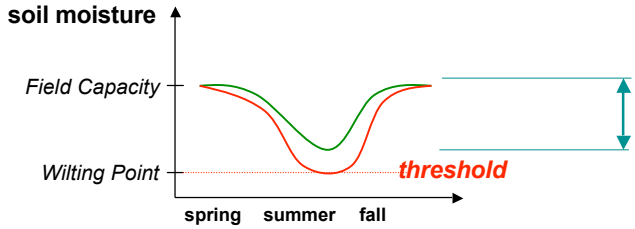
Aster Satellite (NASA/Japan)

5x5 km view in Central France

Schär, ETH Zürich

Zaitchik et al. 2005 (Yale University)

Soil-moisture threshold effect



Δ ~ 150 mm

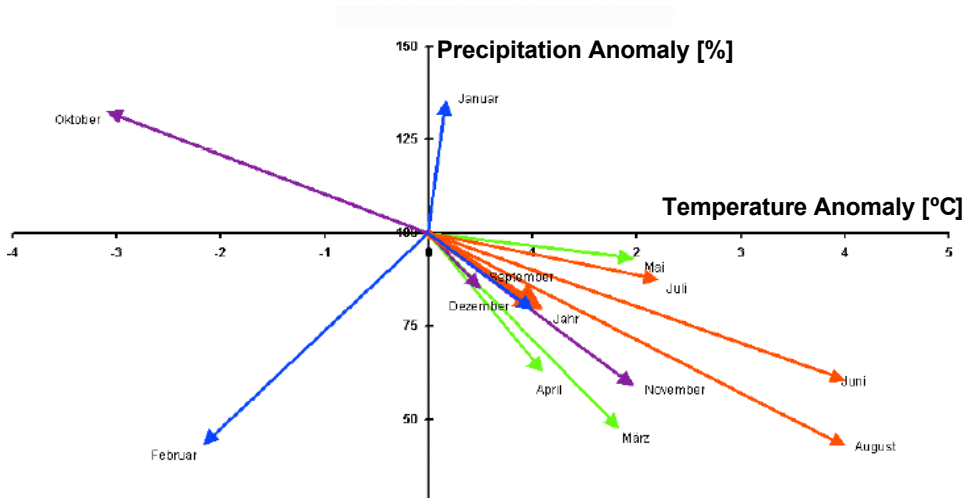
latent cooling corresponds to ~43 W/m²

Importance of land-surfaces is consistent with a series of recent studies:

- **Land-surface processes affect seasonal cycle of the extratropical summer climate** (Koster et al. 2004, Betts et al. 2004, Schär et al. 1999)
- **Climate change increases potential for mid-latitude summer droughts** (Wetherald and Manabe 1995, IPCC 2001, Seneviratne et al. 2004)

Precipitation / Temperature Anomalies Summer 2003

(Germany, Reference 1961-1990)



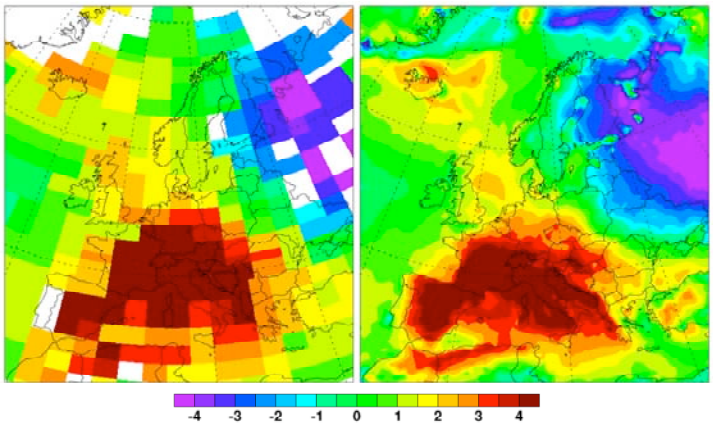
(Müller-Westermeier, DWD, KSB 2003; Schönwiese et al. 2005)

Simulations with a Regional Climate Model (RCM)

Simulations of the year 2003: RCM driven by ECMWF analysis

Validation of 2m-Temperatur, June 2003 (Anomaly w.r.t. 1970-2000):

Observation (GISS) **Simulation (CHRM)**

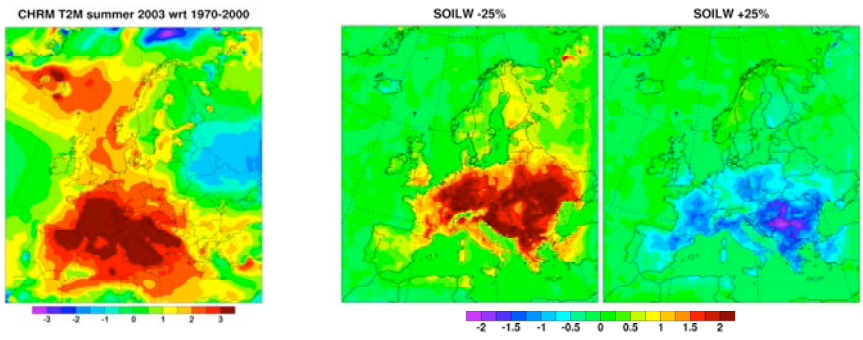


(Fischer et al. 2007, in press)

Role of Initial Soil Moisture for Summer 2003

Sensitivity experiments: Modification of soil moisture content on April 1, 2003

CTRL – Climatology **DRY – CTRL** **WET – CTRL**



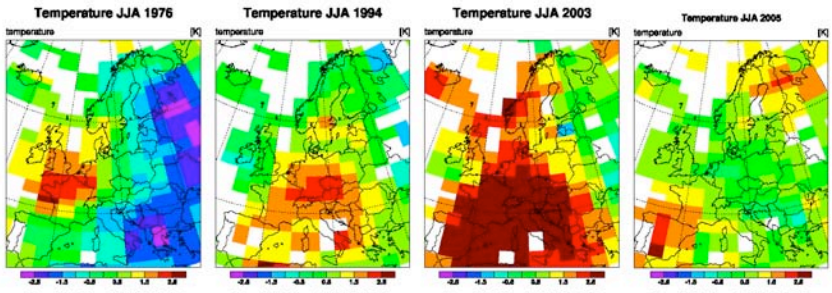
Dry soils => reduced evapotranspiration => reduced "latent" cooling

(Fischer et al. 2007, in press)

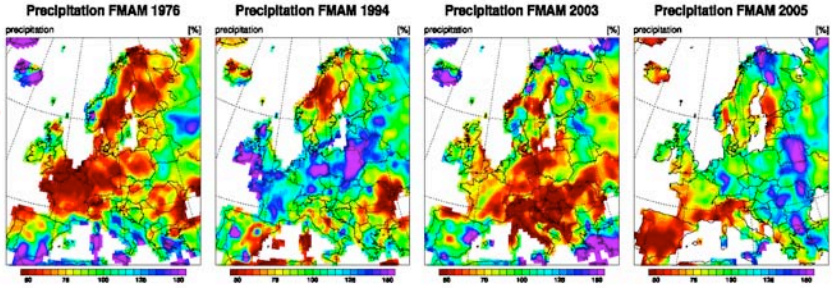
Heatwaves 1976, 1994, 2003, 2005

Heatwaves follow spring droughts

T(JJA)



P(FMAM)



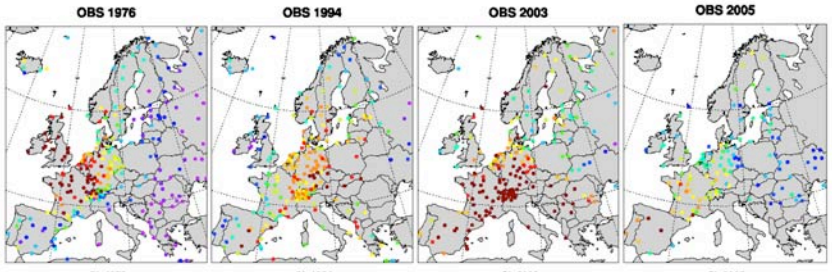
Schär, ETH Zü

(Fischer et al. 2007, GRL)

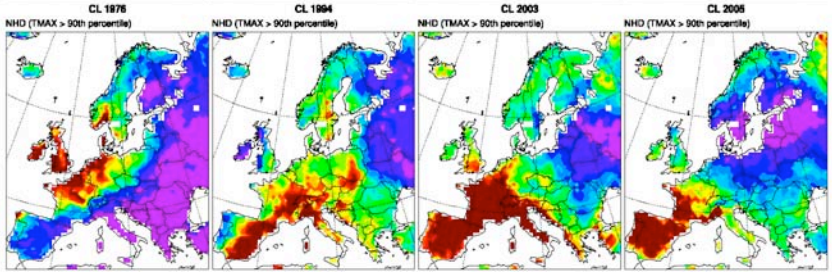
Heatwaves 1976, 1994, 2003, 2005

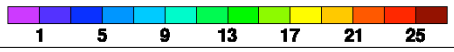
Model validation: Number of hot days (T_{max} > 90th percentiles)

OBS



SIM





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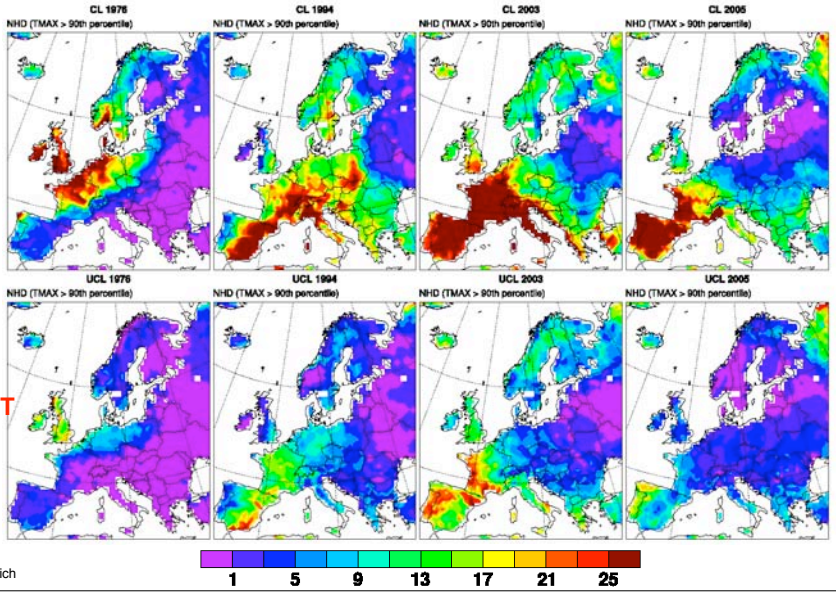
(Fischer et al. 2007, GRL)

Heatwaves 1976, 1994, 2003, 2005

Simulations with and without land-surface coupling

WITH

WITHOUT



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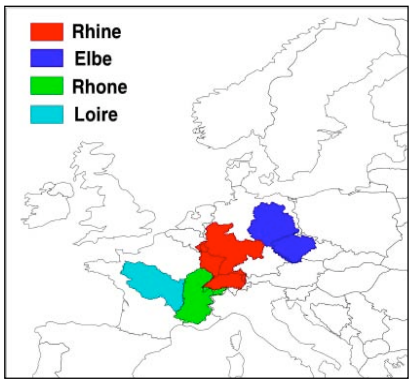
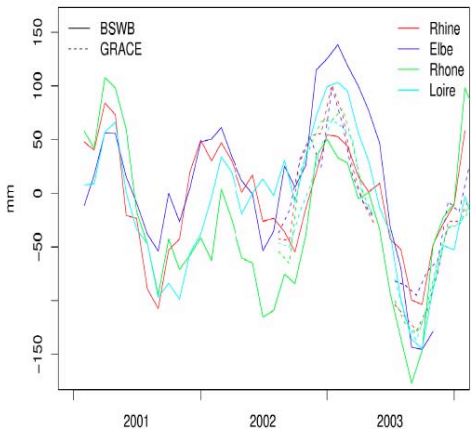
(Fischer et al. 2007, GRL)

Observational data of terrestrial water

Terrestrial water storage = soil moisture + ground water + surface water + snow



(Seneviratne et al. 2004, J. Climate)
(Hirschi et al. 2006, J. Hydrometeor)
(Hirschi et al. 2006, GRL)



Full lines:
diagnostic estimation (using ERA-40 and runoff)

Dashed lines:
GRACE satellites (gravimetric observations

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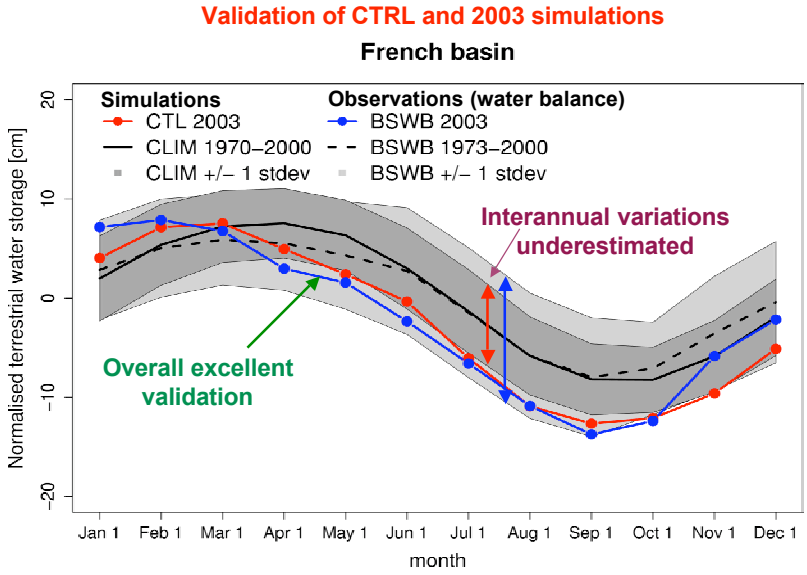
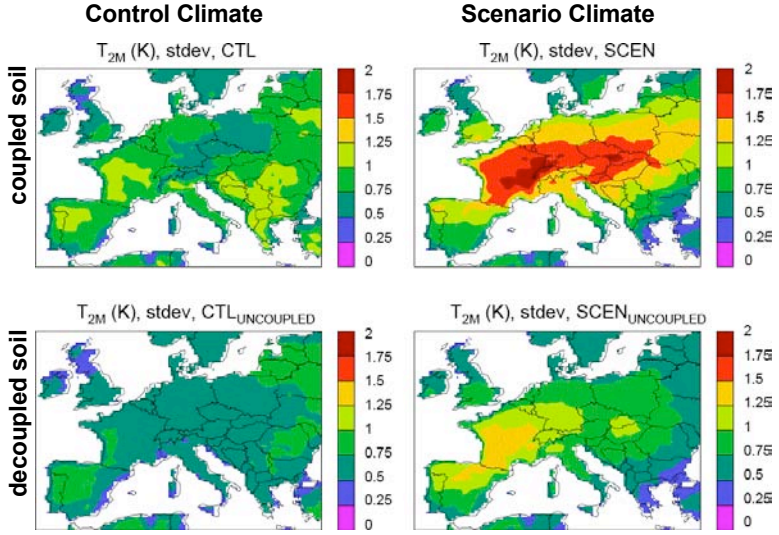
Validation of terrestrial water storage



(Fischer et al. 2007, in press)

Experiments with decoupled land-surface



Variability of summer T2m is strongly affected by land-atmosphere coupling

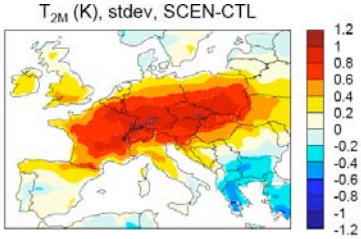
Decoupled simulations have prescribed seasonal cycle of soil moisture

(Seneviratne et al. 2006, *Nature*, **443**, 205-209)

Experiments with decoupled land-surface

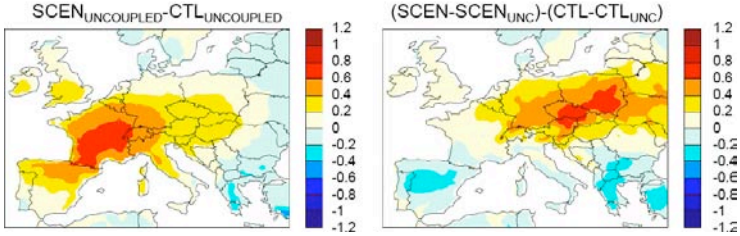
Change in variability

T_{2M} (K), stdev, SCEN-CTL



Large-scale forcing + **Land-surface feedbacks**

$SCEN_{UNCOUPLED}$-$CTL_{UNCOUPLED}$ | (SCEN-$SCEN_{UNC}$)-(CTL-CTL_{UNC})



Changes in variability strongly affected by land-surface processes

(Seneviratne et al. 2006, *Nature*, **443**, 205-209)

Outline

Summer 2003

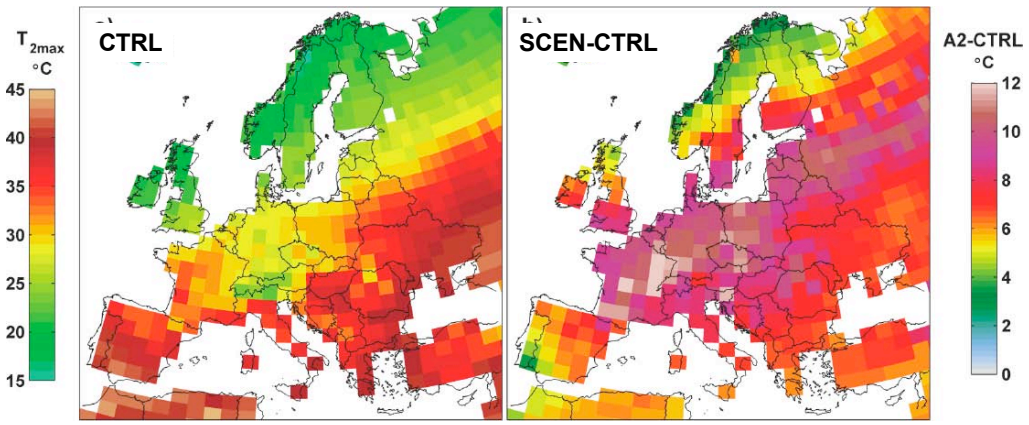
Heat waves and interannual variability

Associated processes

Some scenario results
• Analysis of PRUDENCE simulations •

95th percentile of T_{max}

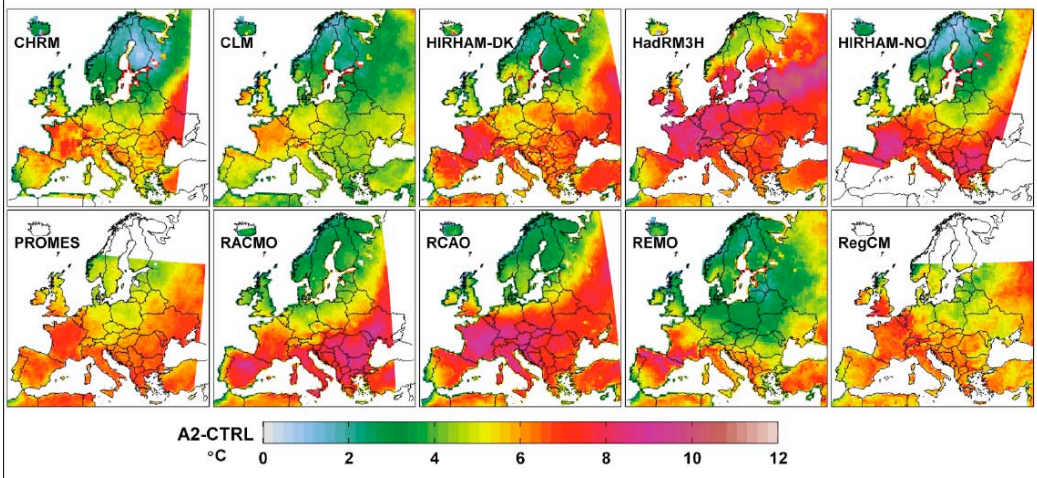
2071-2100 versus 1961-1990, Scenario A2, HadAM3H



Note:
maximum signal is not where ΔT is largest,
but where Δσ is largest

(Kjellstrom et al. 2007, Climatic Change)

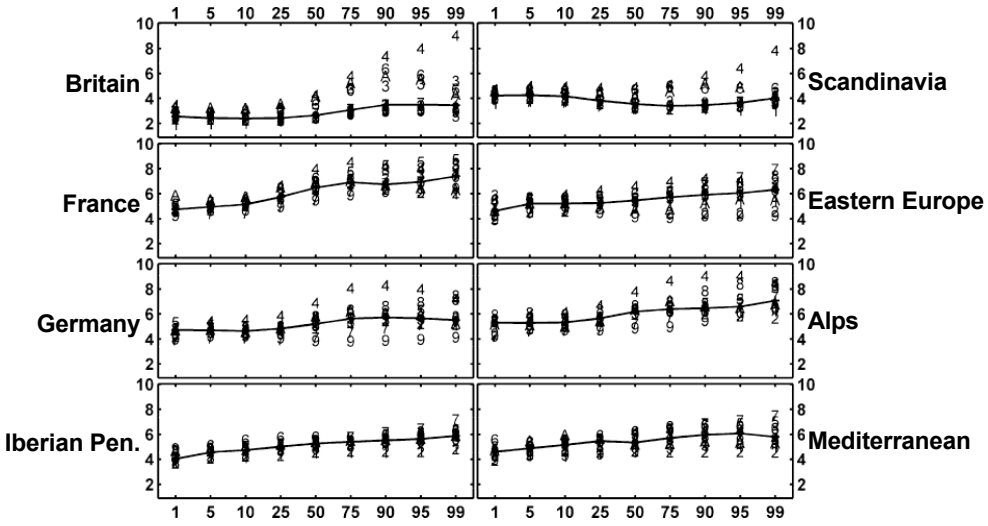
Change in 95th percentile



Large spread between models

(Kjellstrom et al. 2007, Climatic Change)

Changes of daily temperature as a function of percentiles



Upper Percentiles experience stronger changes

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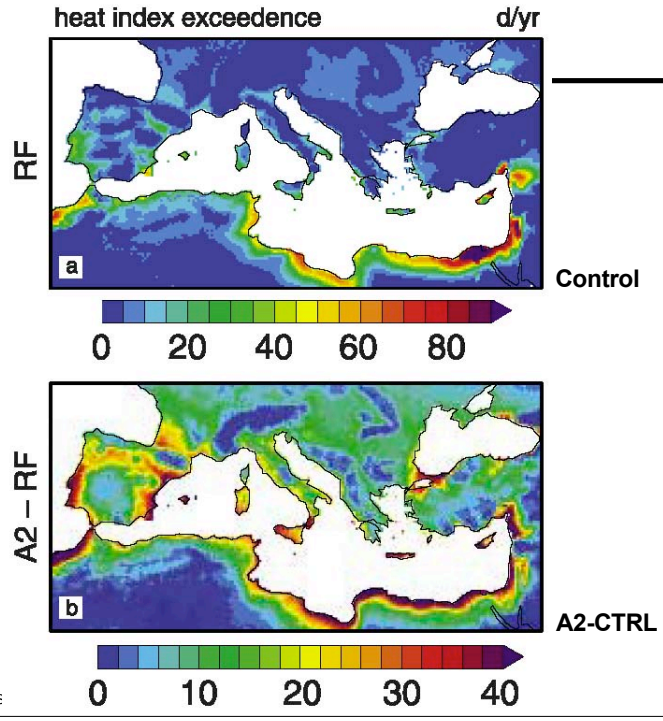
(Kjellstrom et al. 2007, Climatic Change)

Health index

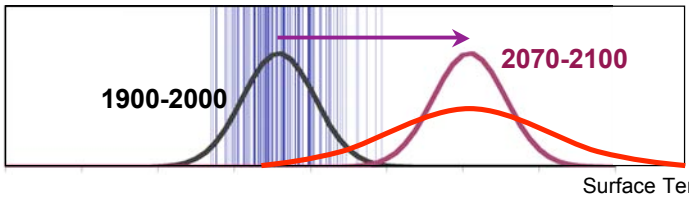
Health index based on temperature and relative humidity



(Diffenbaugh et al. 2007, GRL)

Conclusions: Changes in Variability versus Mean

Traditional view: temperature distribution is shifted



For Central European summer, variance may strongly increase:

- **affected by water cycle, land-surface processes**
  => substantial uncertainties
- **most models agree on presence of effect**
- **effect is detectable in observational data**

Implications for climate change:

- **relevant for occurrence of extremes**
- **difficult to adapt to increase in variance**