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Extreme Events in a Changing Climate

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Thanks to: Peter Brockhaus, Christoph Buser, Cathy Hohenegger, Sven Kotlarski, Hans-Ruedi Künsch, Dani Lüthi, Elias Zubler

WCRP Workshop on Regional Climate, Lille, June 14-16, 2010

Extreme events in the IPCC

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 SAR: 12 pages (of 572)

"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*."

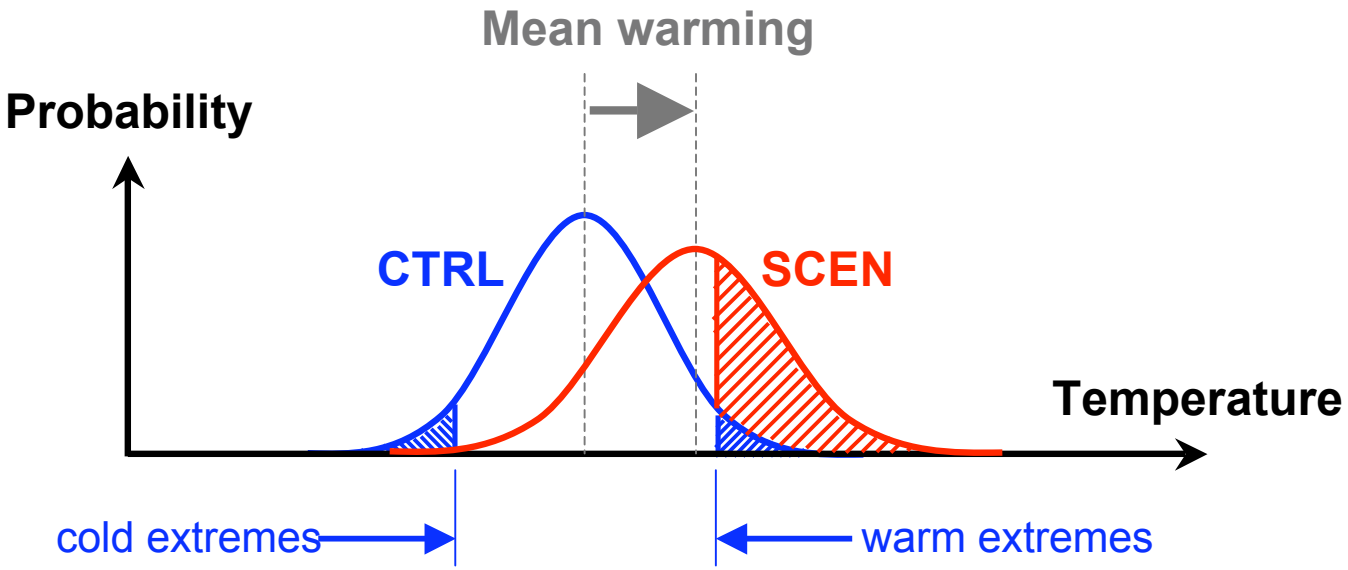
(Fowler and Hennessy, 1995)

More recent IPCC reports included rapidly growing coverage of extremes:

IPCC 1990: 7 pages (of 364)
IPCC 1996 SAR: 12 pages (of 572)
IPCC 2001 TAR: 25 pages (of 881)
IPCC 2007 AR4: 48 pages (of 994)

Note:
Doubling time = 1 assessment report

Extreme events defined



Extreme events are defined in statistical terms, as events that deviate strikingly from the statistical mean.

Climate change implies changes in frequency of extremes.

Generally needs to account for changes of the whole statistical distribution (i.e. mean, variability, skewness, etc)

Statistical versus socio-economic definitions

Extreme events
are defined in statistical terms,
as events that deviate strikingly
from the statistical mean.

Natural hazards
are defined in terms of impacts,
losses, damages, casualties, etc.

Extreme event ≠ natural hazard

Assessing natural hazards in a changing climate requires an impact and/or damage model, or the consideration of some impact indices.

Example 1: flood => hydrological model

Example 2: heat waves => health indices

Extreme events

Contents

Introduction

Distribution changes beyond changes in mean?

- theory: precipitation intensity
- model: European heat waves
- observations: heat waves

Role of impact models / indices? Example of heat waves

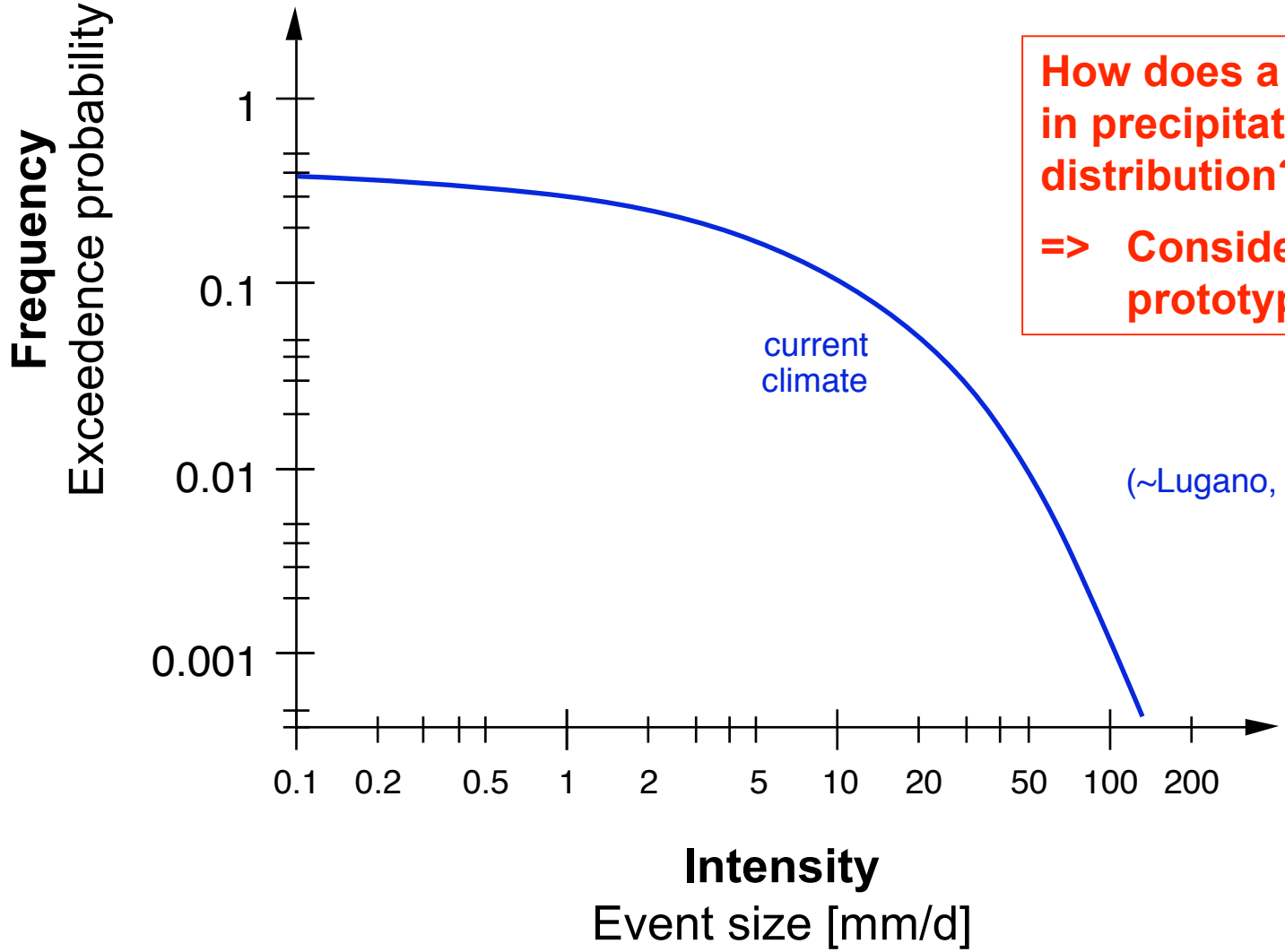
Role of model biases in assessing extremes

Role of computational resolution

Sensitivity to model physics (parameterizations)

Frequency / intensity effects

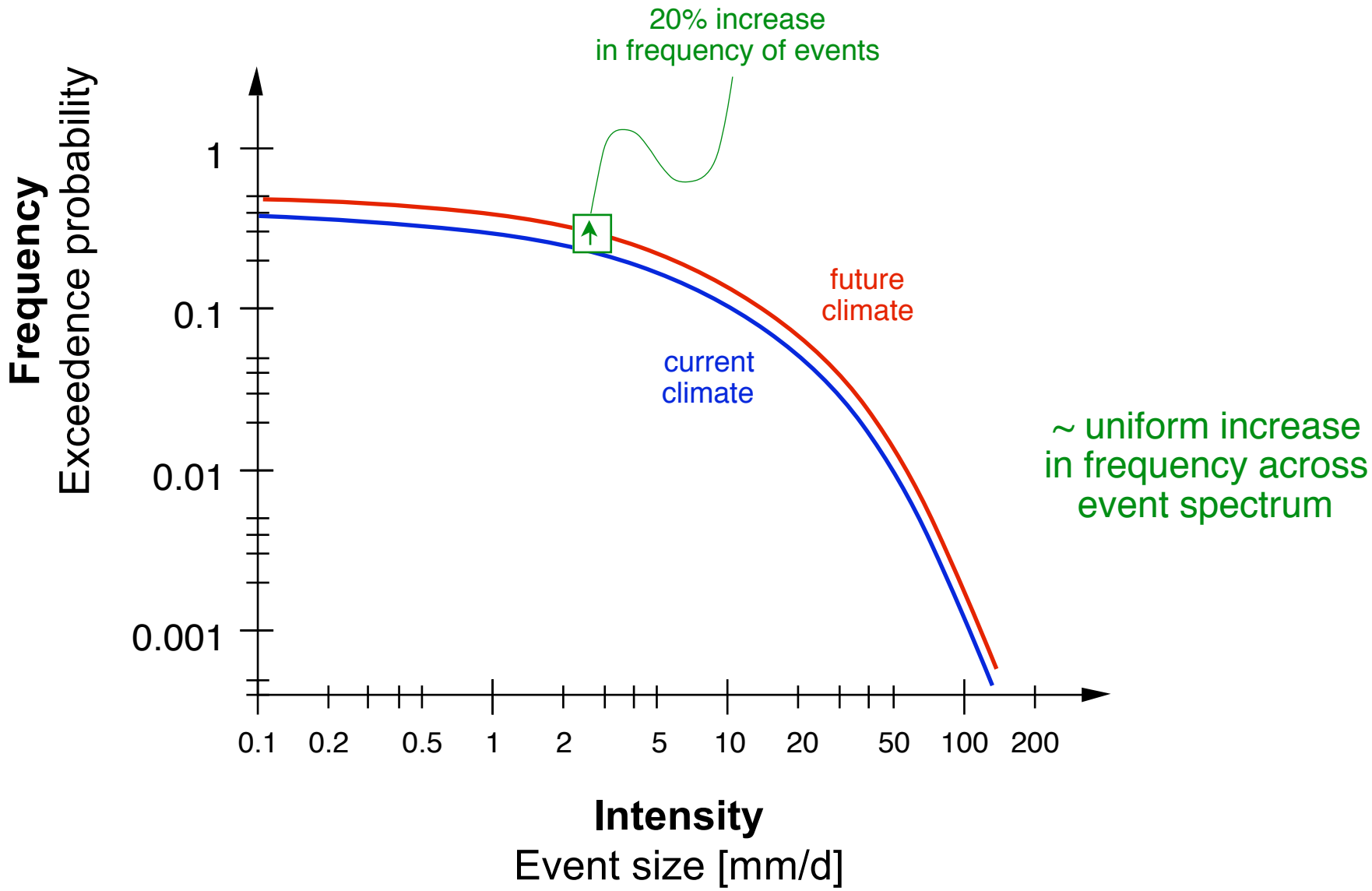
Frequency Distribution of Daylong Precipitation Events



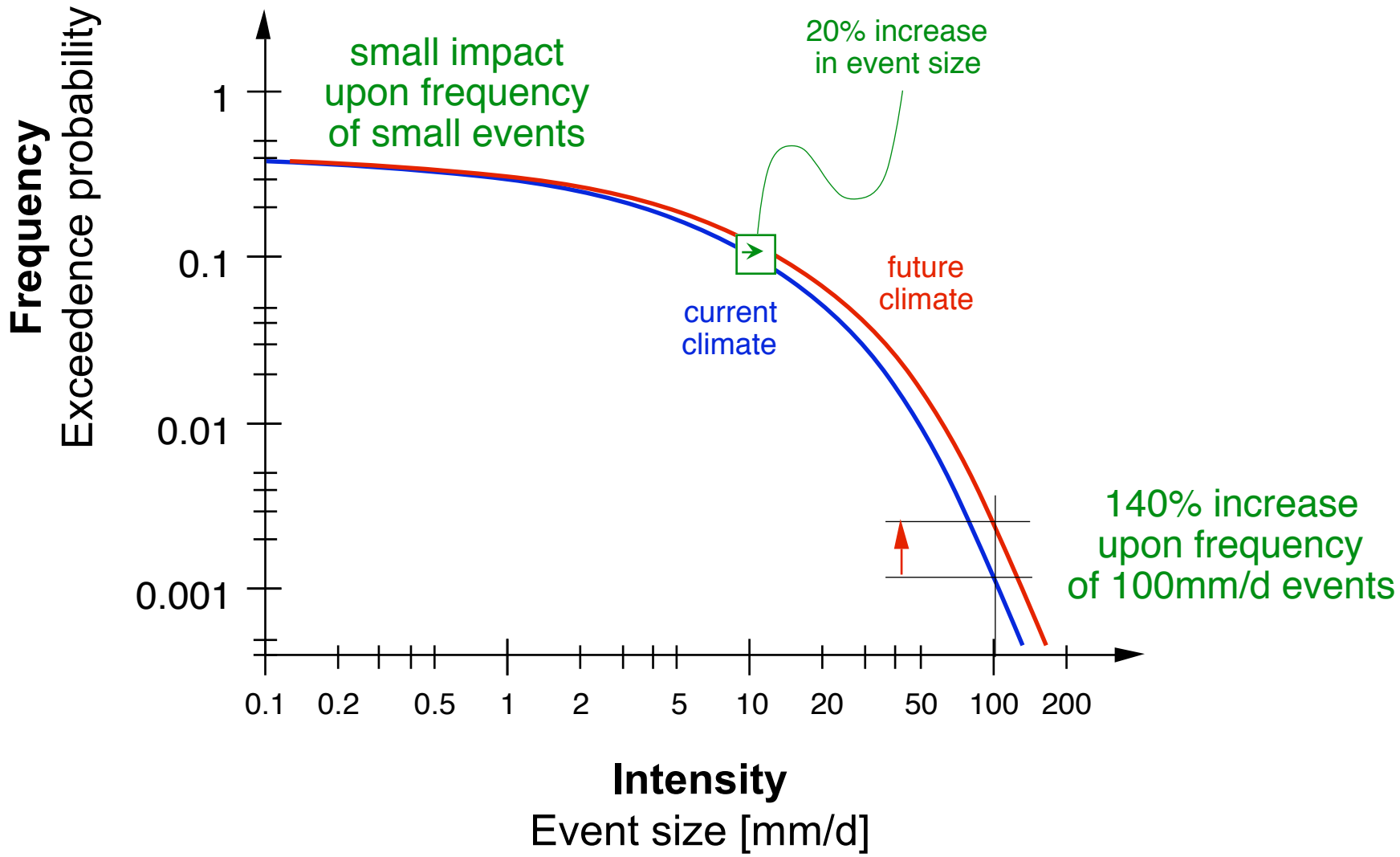
How does a 20% increase in precipitation affect the distribution?

=> Consider two idealized prototype scenarios

Change in frequency of events



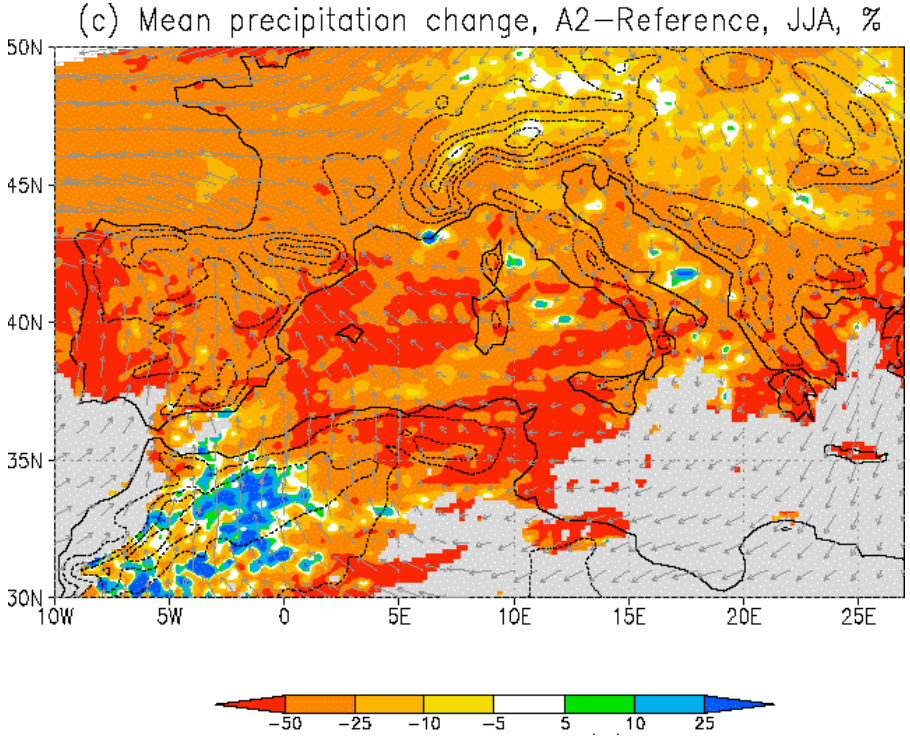
Change in intensity of events



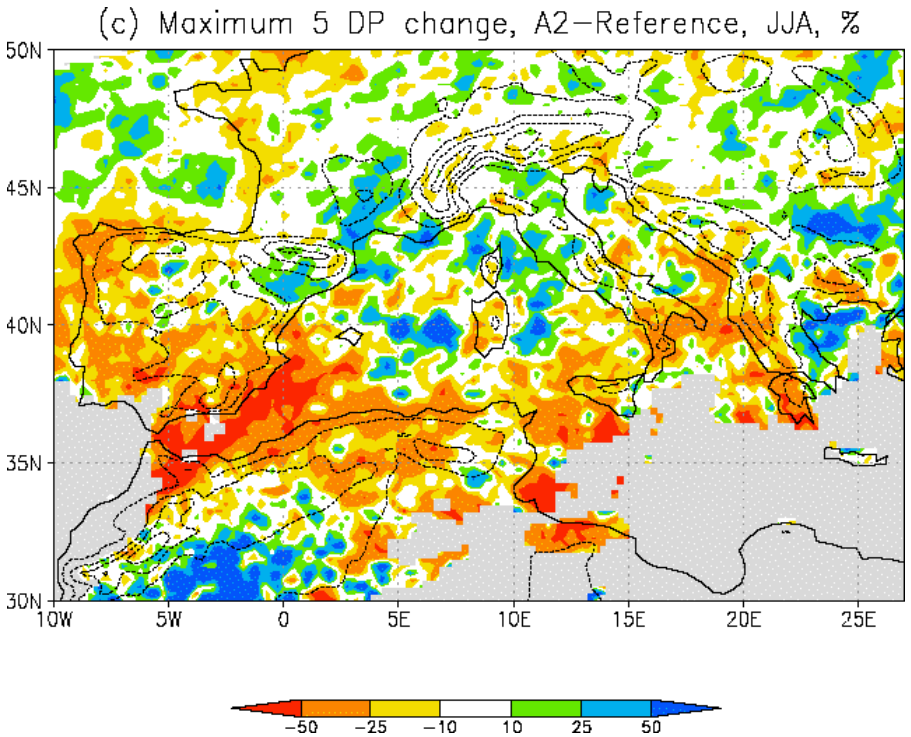
(Fowler and Hennessy 1995)

Summer precipitation changes in Europe

Mean changes [%]



Maximum 5-day precipitation [%]

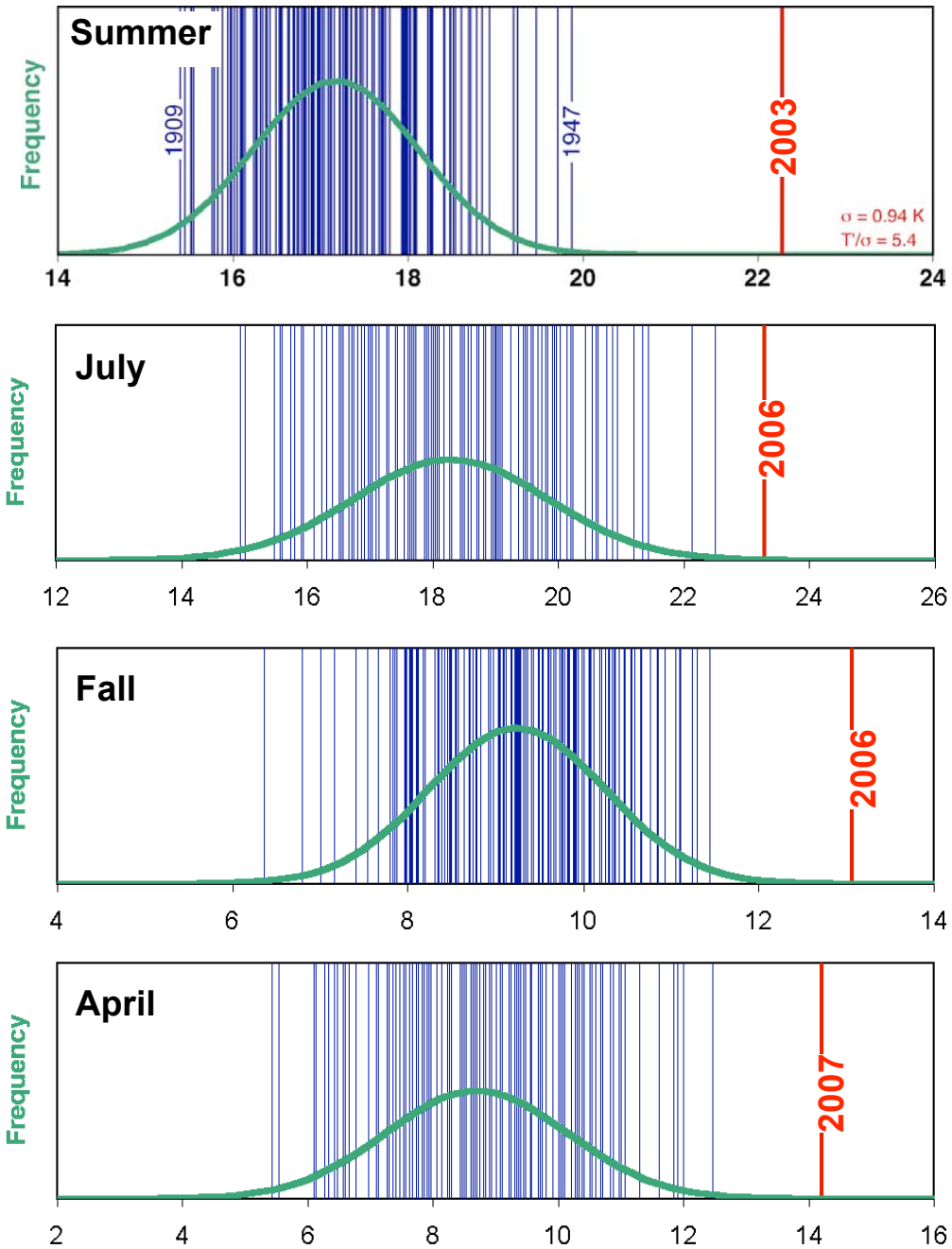


=> Increase in peak precipitation despite reduction in mean amounts <=

(Gao, Pal and Giorgi 2006; see also Christensen and Christensen 2003; Frei et al. 2006; Knote et al. 2010)

Recent European temperature extremes

Can variability changes help to explain these outliers?



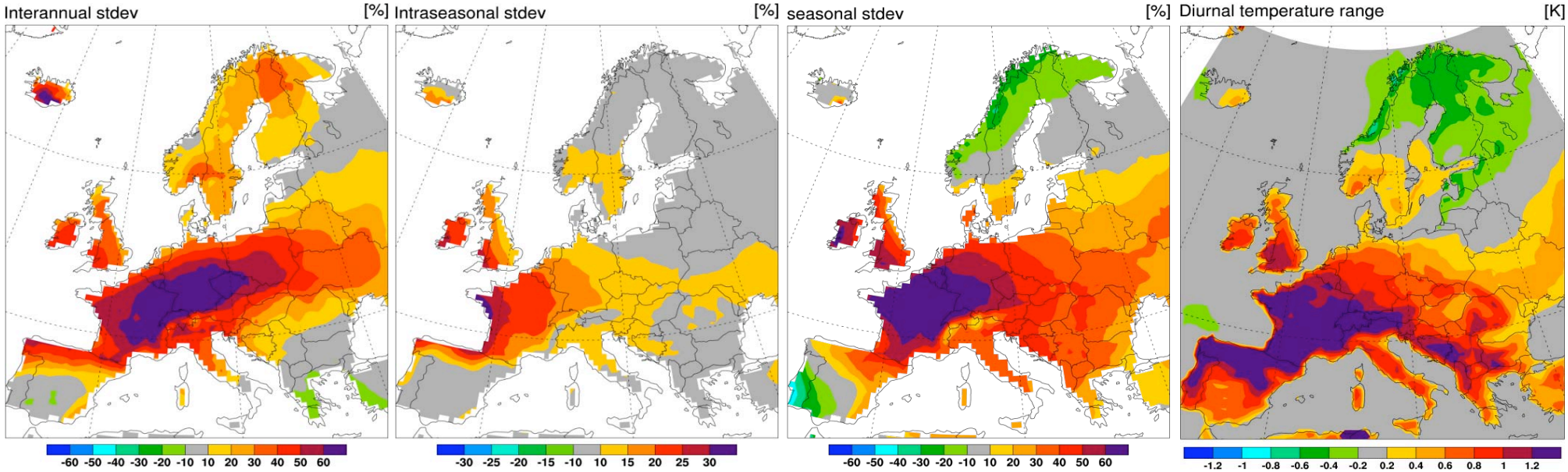
Data since 1864;
Average of 4 Swiss stations:
Zürich, Basel, Berne, Geneva

Schär et al. 2004, *Nature*, **427**, 332-336; plus updates

Variability changes in a changing climate

2070-2099 versus 1961-1990 (A2 scenario)

Interannual var | **Intraseasonal var** | **Seasonal var** | **Diurnal temp range**



[%] | **[%]** | **[%]** | **[K]**

=> Pronounced variability increases on all time-scales <=

Schär et al. 2004; Vidale et al. 2007; Fischer and Schär 2009 (mean of 8 PRUDENCE RCMs)

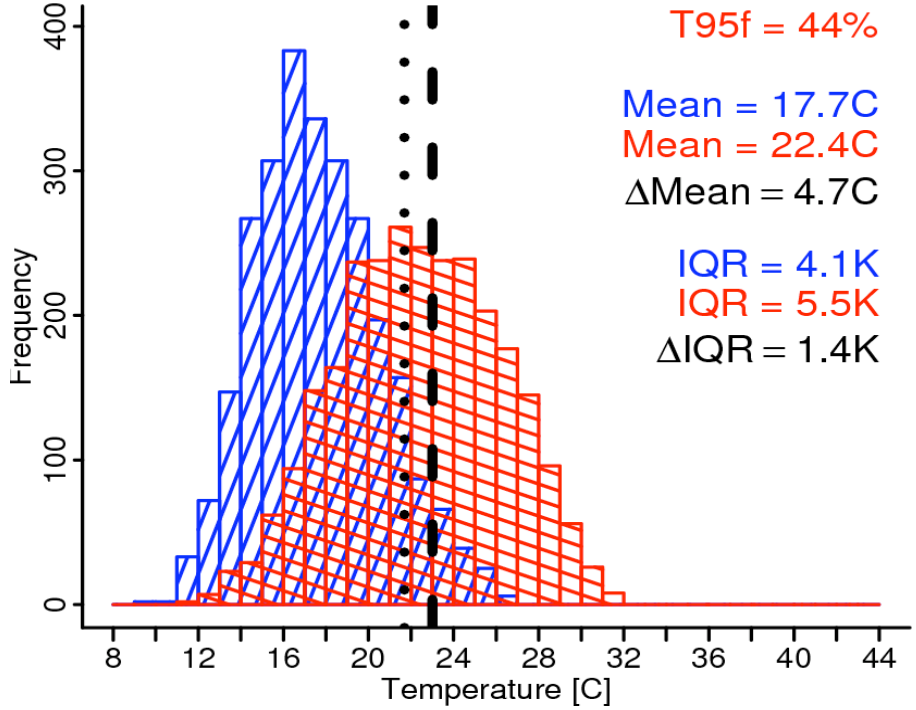
Regional response to climate change

ETH model (CHRM) driven by HadAM3

CTL: 1961-1990

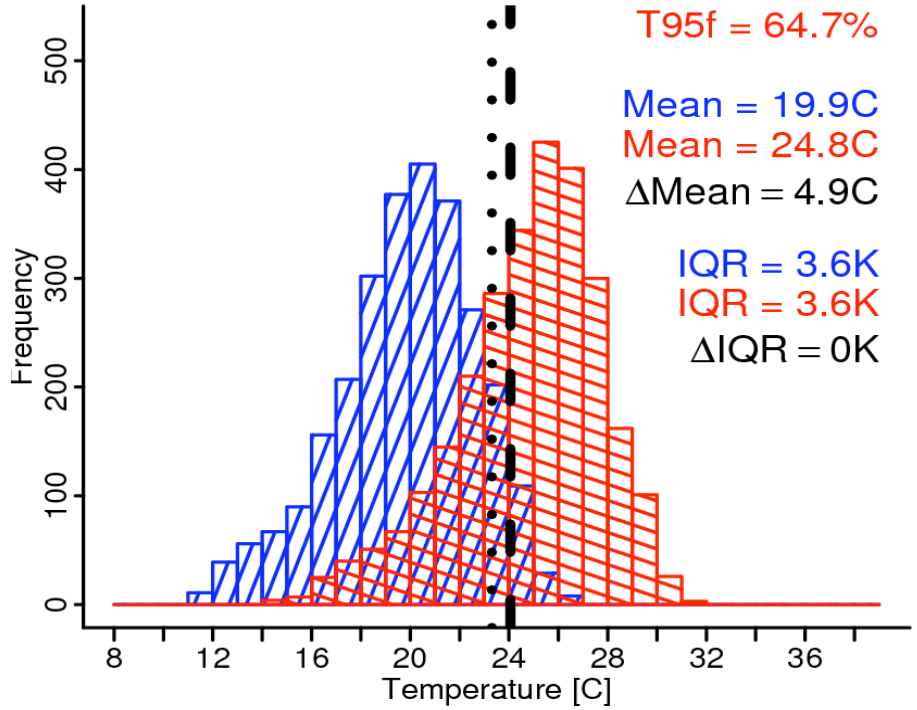
SCN: 2071-2100

France



Variability increase

Iberian Peninsula



Increase in skewness

PRUDENCE, CHRM model

Fischer and Schär 2009; Clim. Dynam, Observations from Haylock et al. 2008

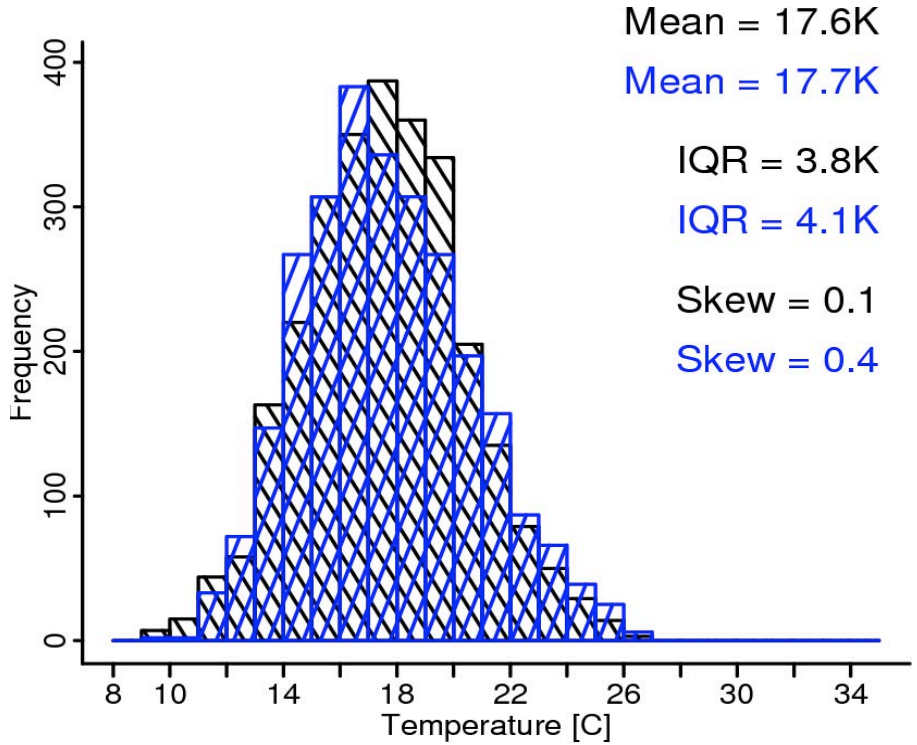
Validation of daily summer temperatures

ETH model (CHRM) driven by HadAM3 (1961-1990)

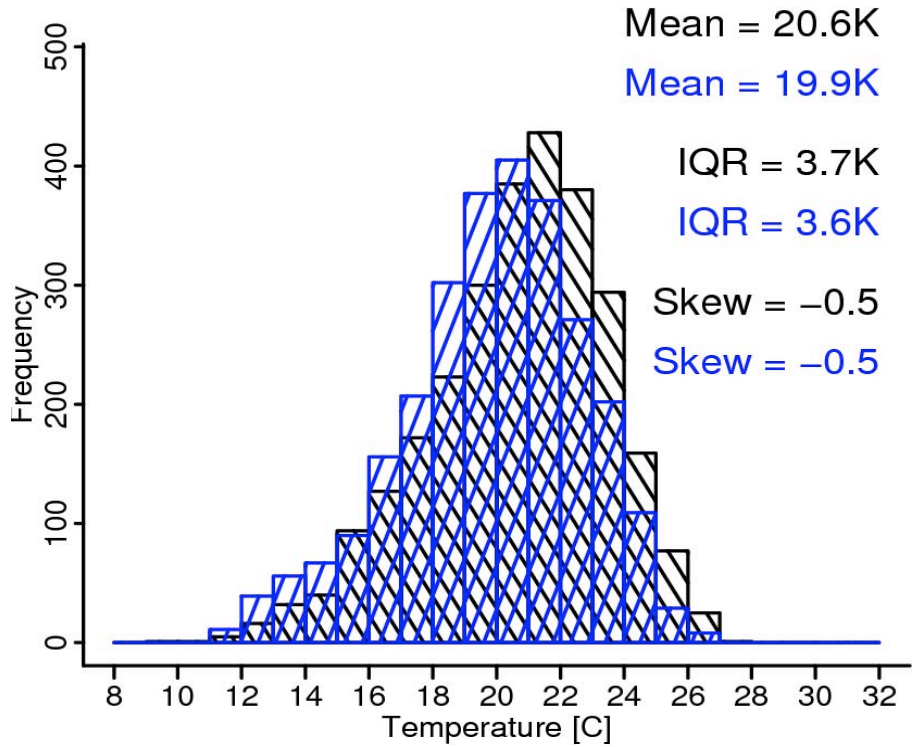
OBS: 1961-1990

CTL: 1961-1990

France



Iberian Peninsula



Regional variations captured!

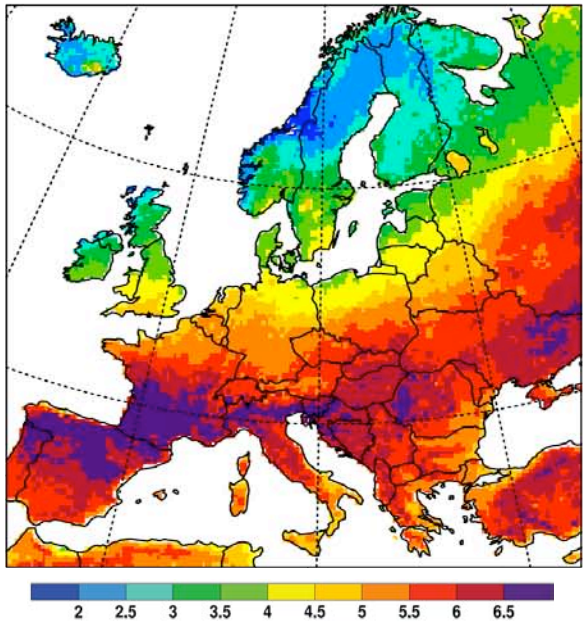
PRUDENCE, CHRM model

Fischer and Schär 2009; Clim. Dynam, Observations from Haylock et al. 2008

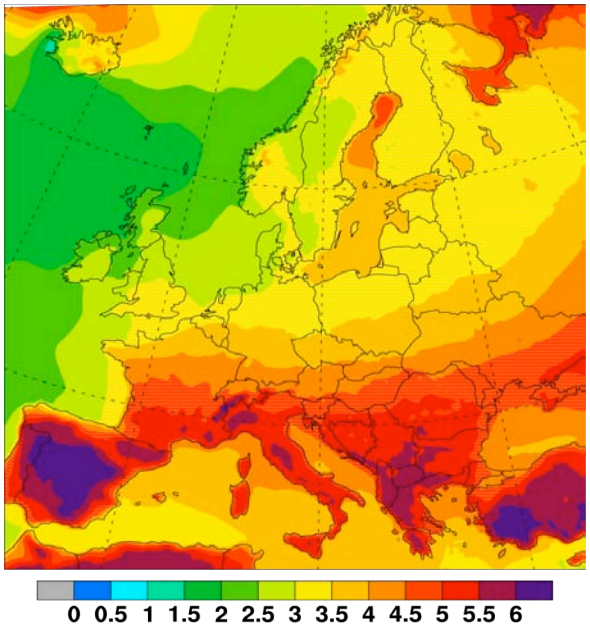
How will the warming proceed?

2071-2100 versus 1961-1990

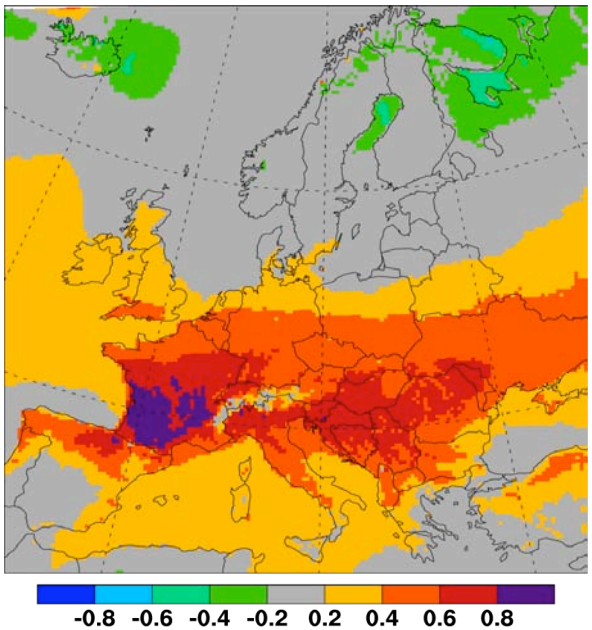
JJA T2m change 99th percentile [K]



JJA mean warming [K]



Change in JJA daily variability [K]



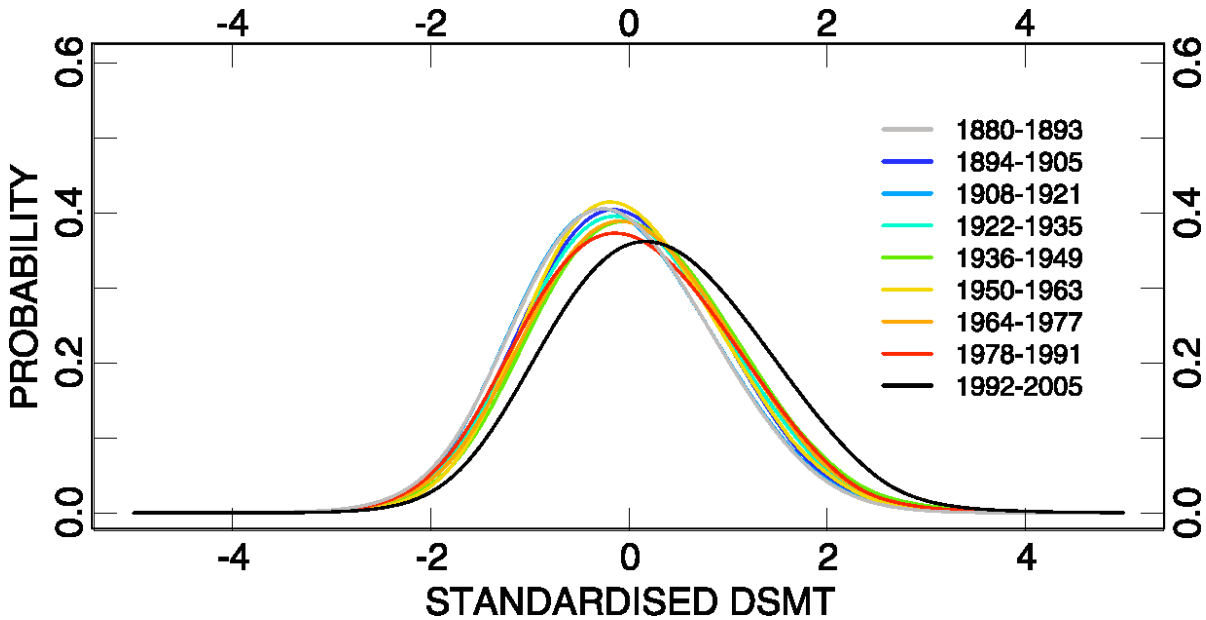
Strongest 99th percentile increase to the north of strongest mean warming

Good agreement with PRUDENCE results (Kjellström et al. 2007, Fischer and Schär 2009)

Differences between mean and 99th percentile is due to variability changes

ENSEMBLES, mean of 6 models
Fischer and Schär 2010, *Nature Geoscience*

Observed increases in temperature variability?



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)	$+1.7 \pm 0.7$	$+4 \pm 6$	$+9 \pm 6$

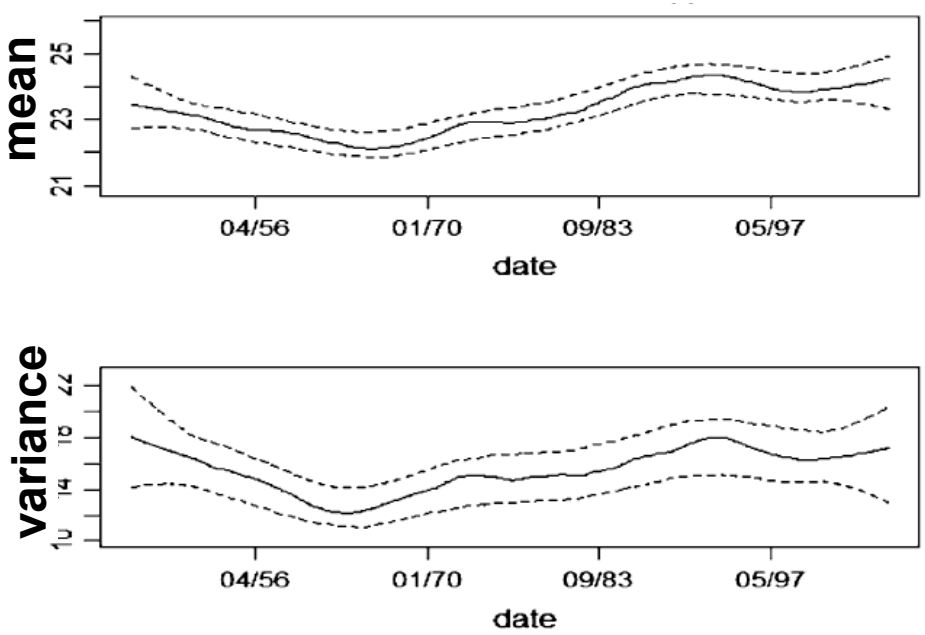
Geographical pattern of trends is consistent with climate change scenarios:

- **variability increases has maximum in Central Europe**
- **warming has maximum in Iberian Peninsula**

(Della Marta et al., 2007, JGR)

Observed relationship between mean and variance?

Temporal evolution of mean and variance, Summer daily maximum temperature (La Rochelle, France)

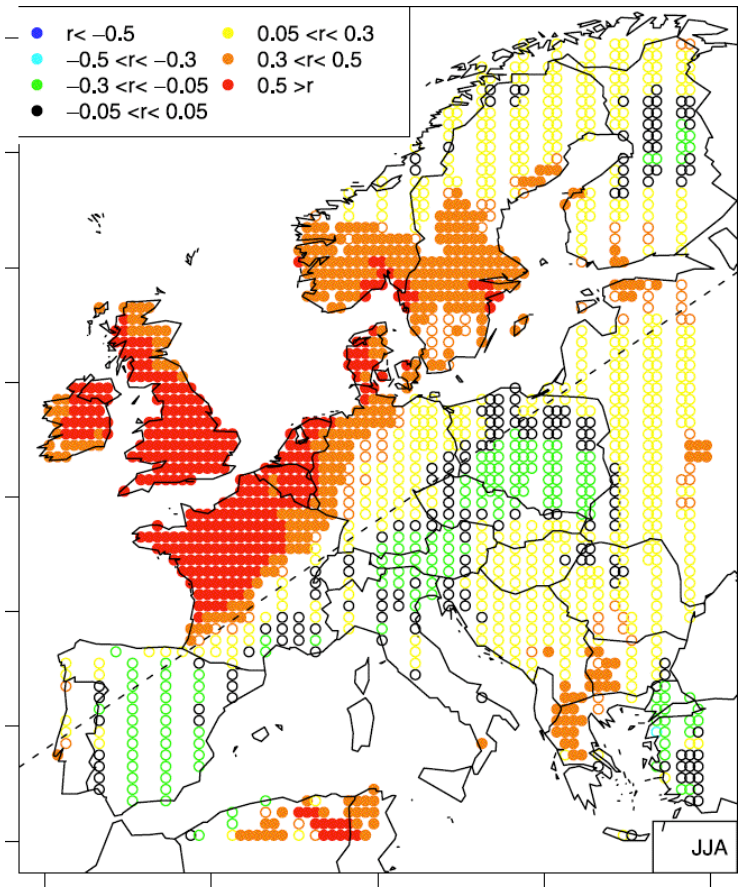


Evolution of mean and variance correlate!

Warm periods have higher variability

(Parey et al., 2010)

Correlation between mean and variance over Europe, summer (ECA&D data set)



(Yiou et al., 2009)

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Key health impact factors

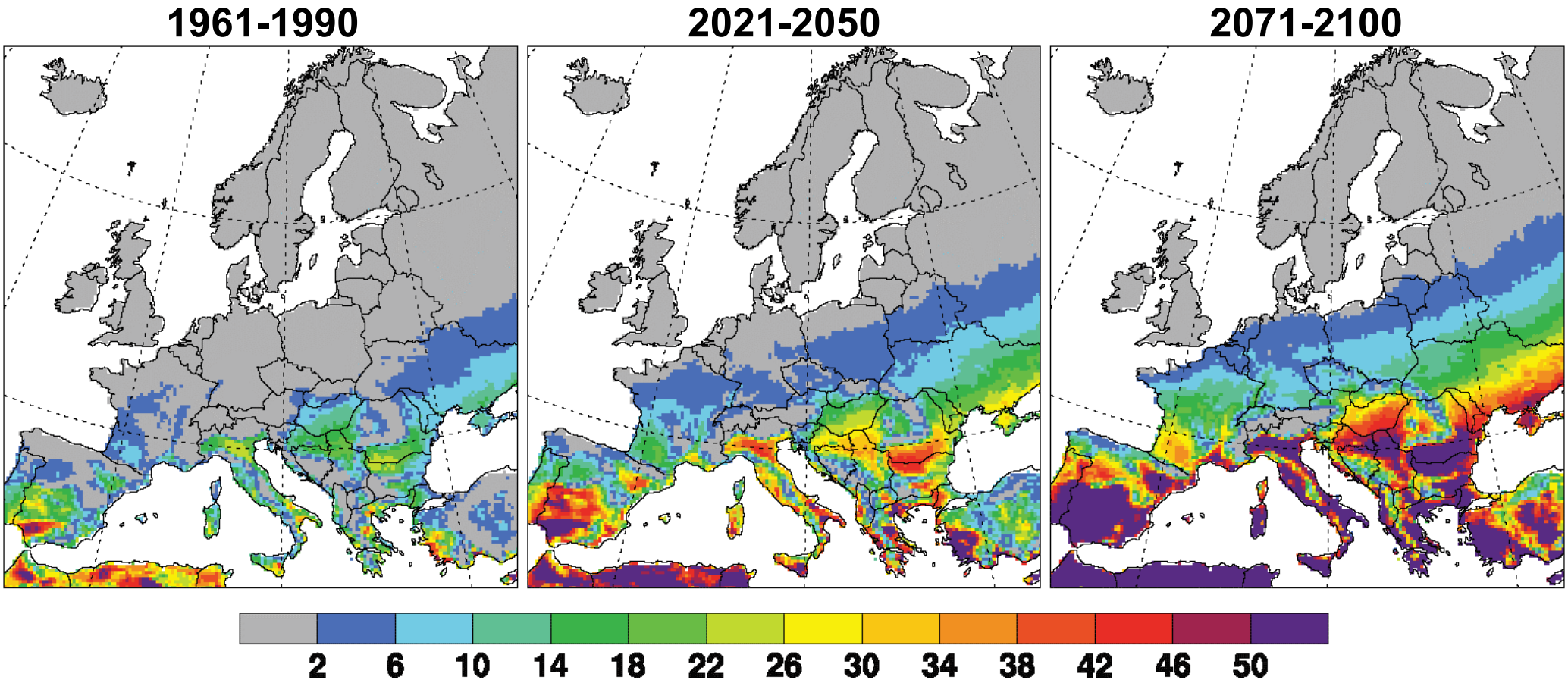
Health impacts of heatwaves are not only affected by peak temperatures. Studies of previous heat waves have isolated 3 key factors:

(1) Extended length of heat wave (accumulation effect)
=> study heat wave duration

(2) High daytime AND nighttime temperatures (sleep deprivation)
=> study number of hot days / tropical nights

(3) High relative humidity (reduces evaporative cooling)
=> study "apparent temperature" or "heat index"

Hot days and tropical nights

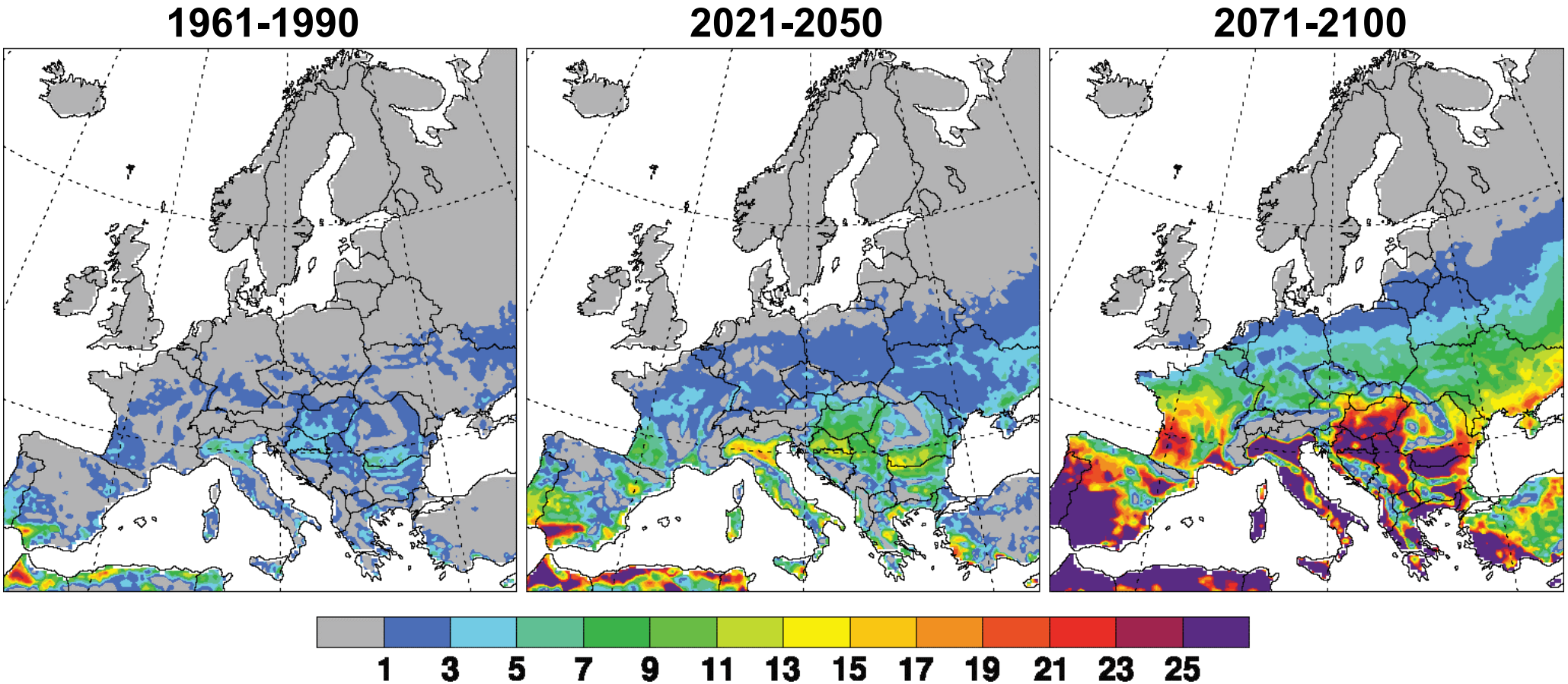


Number of days with Tmax > 35°C and Tmin > 20°C

Dramatic increases in low-altitude Mediterranean (river basins and coasts)

ENSEMBLES, mean of 6 models, scenario A1B
Fischer and Schär 2010, *Nature Geoscience*

Apparent temperature



Number of days with apparent temperature ≥ 40.6°C
(large heat stroke risk with extended exposure)

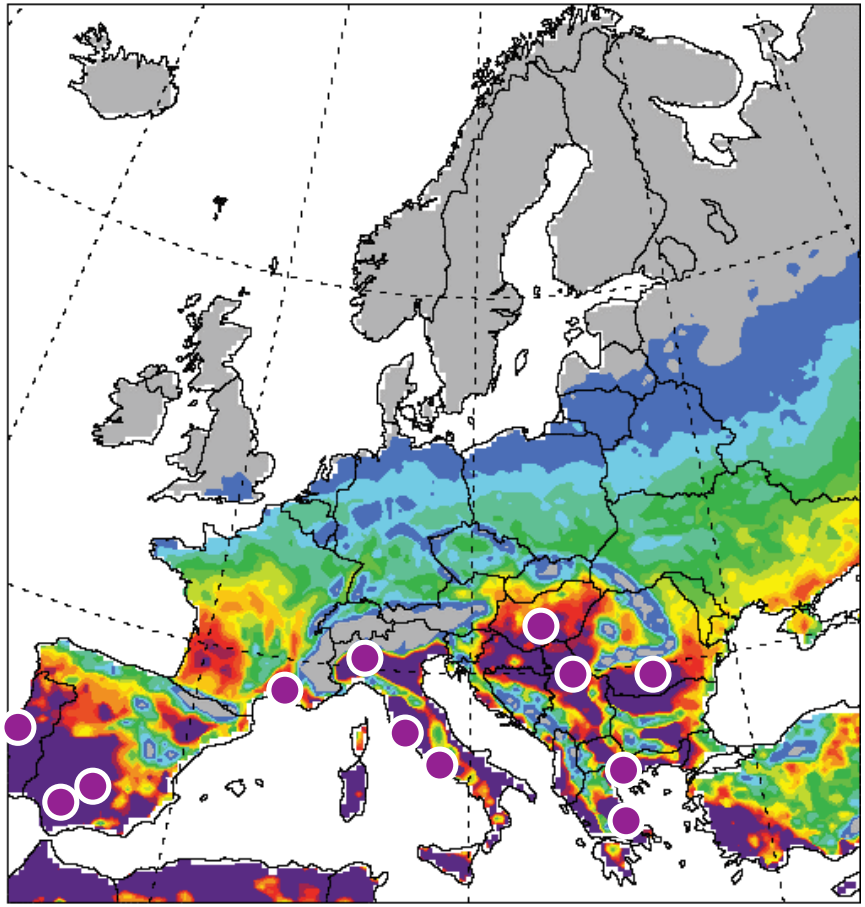
Dramatic increases in low-altitude Mediterranean (river basins and coasts)

ENSEMBLES, mean of 6 models, scenario A1B
Fischer and Schär 2010, *Nature Geoscience*

Affected regions

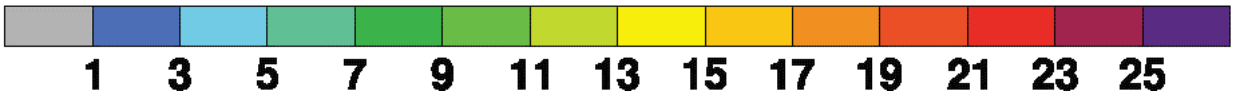
2071-2100

Affected river basins
Tejo
Ebro
Rhone
Po
Tiber
Danube



Affected towns
Lisbon
Seville
Cordoba
Marseille
Milan
Roma
Napels
Budapest
Belgrade
Bucharest
Thessalonica
Athens

Geographical pattern is consistent across all model chains and health indices considered, but amplitude strongly depends upon model



Number of days with apparent temperature ≥ 40.6°C

(Fischer & Schär, 2010, *Nature Geoscience*)

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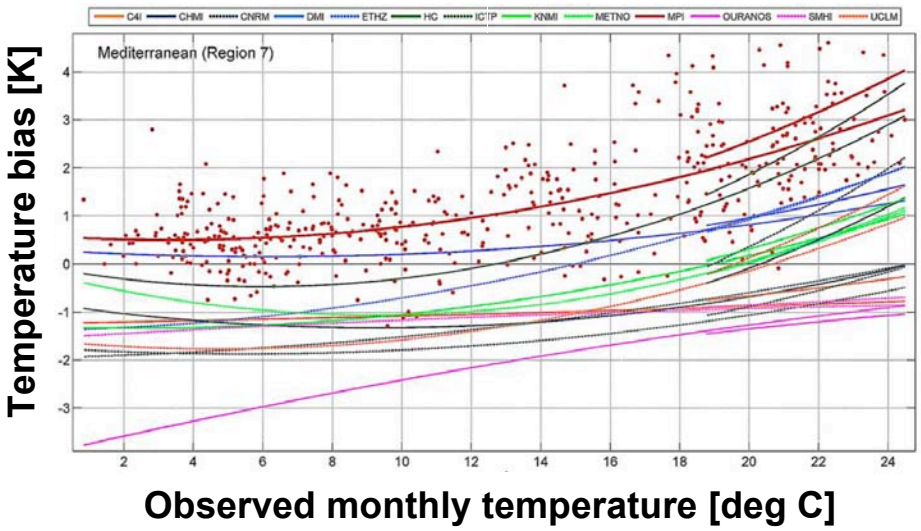
Role of model biases

Special role of biases for analysis of extremes:

- **biases in statistical distribution beyond biases in means (i.e. in variability)!**
- **impacts often depend on absolute thresholds => biases particularly crucial!**

Model biases are state dependent!

Analysis of ERA-40 driven RCM simulations (ENSEMBLES)

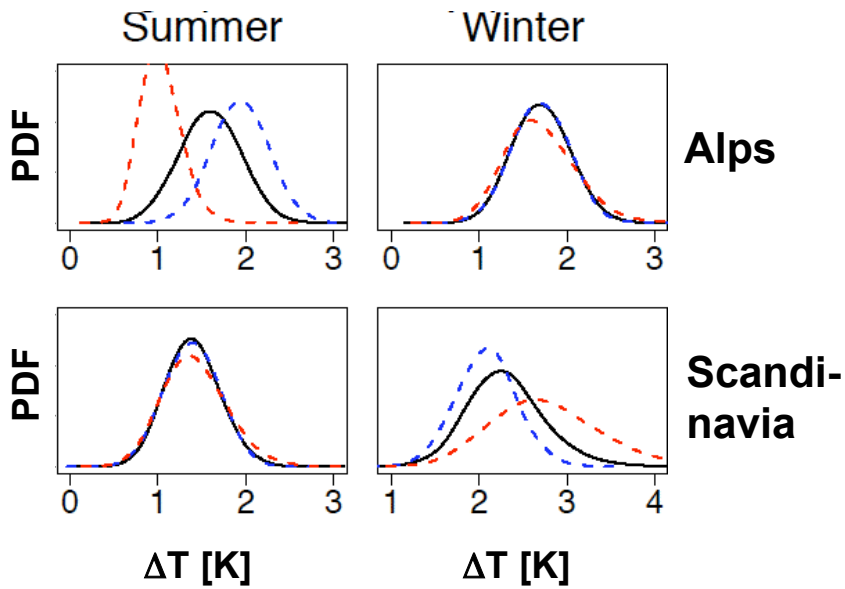


(Christensen et al. 2008)

Assumptions about bias changes matter!

Bayesian methodology using ENSEMBLES results (2021-2050) with TWO bias assumptions:

constant bias | constant relation | joint estimate



(Buser et al. 2009, Buser et al., sub)

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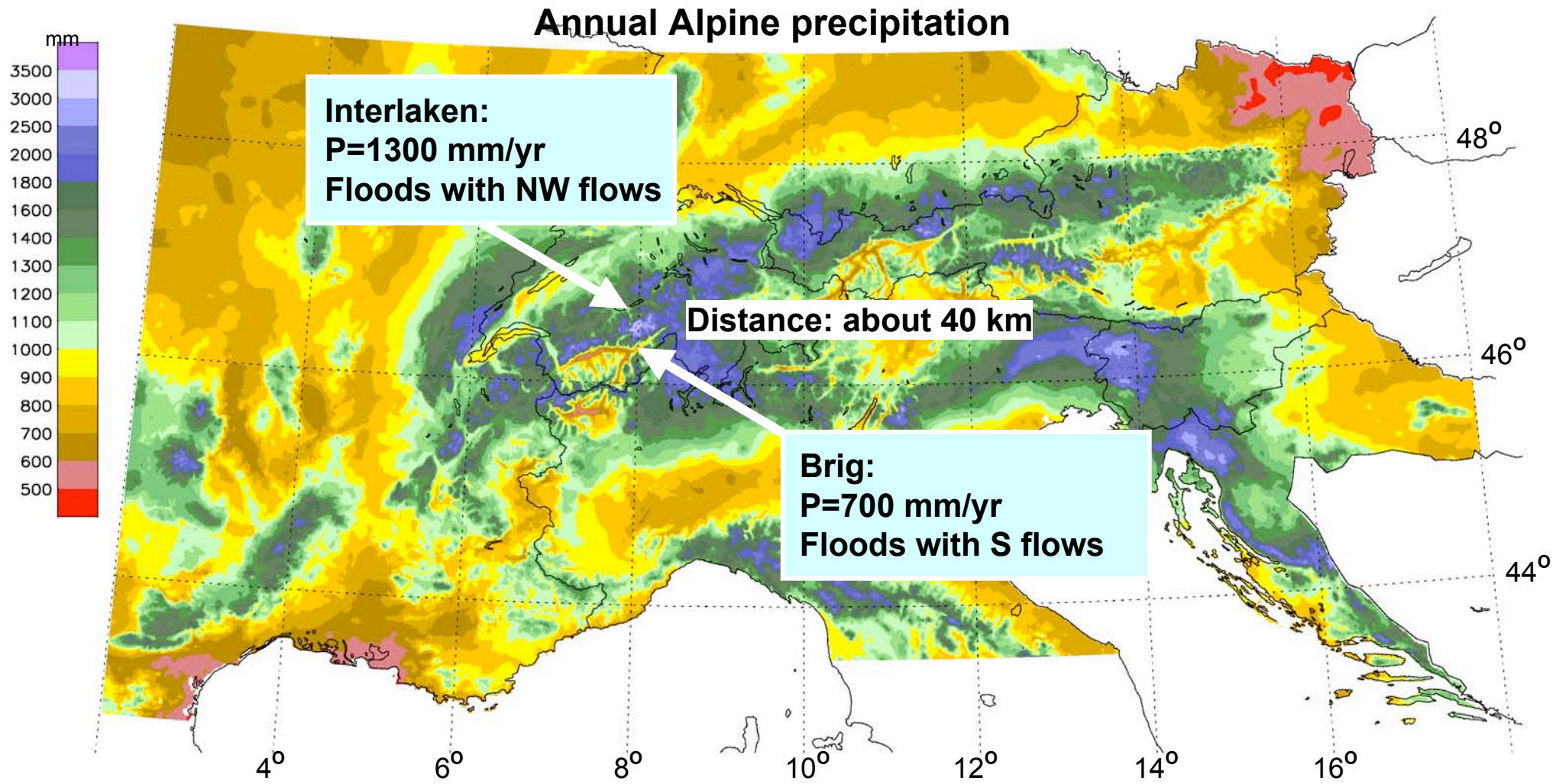
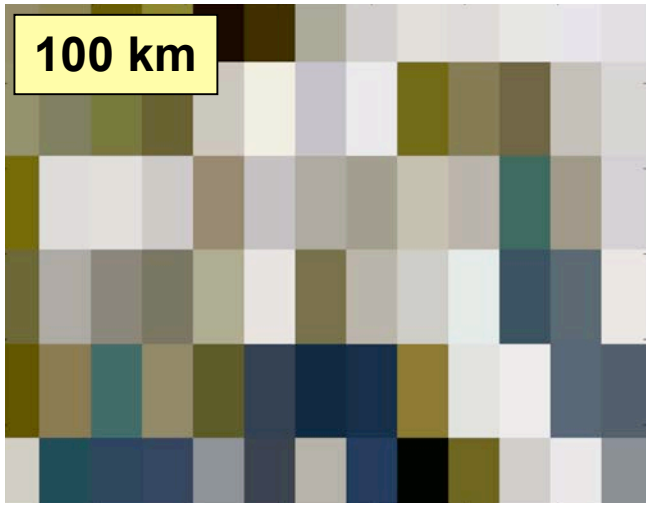
Spatial variations in extremes

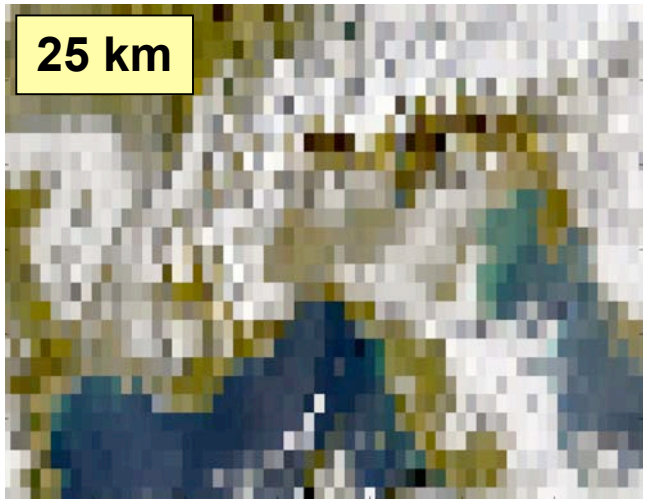


(Parameter-Elevation Regression on Independent Slopes Model, PRISM, Schwarb et al. 2001)

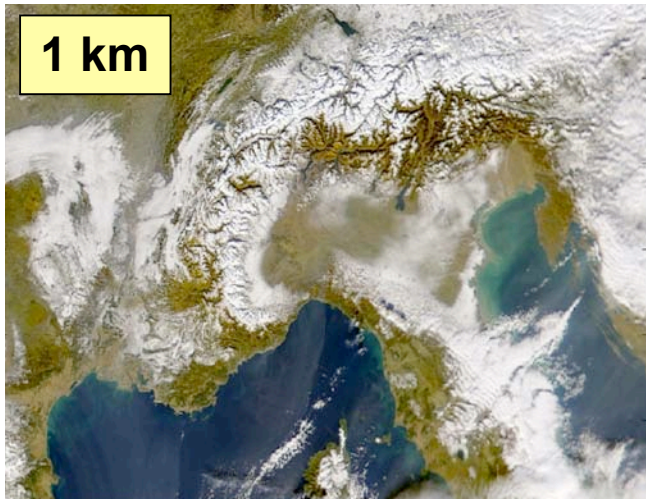
Role of resolution



GCM



RCM



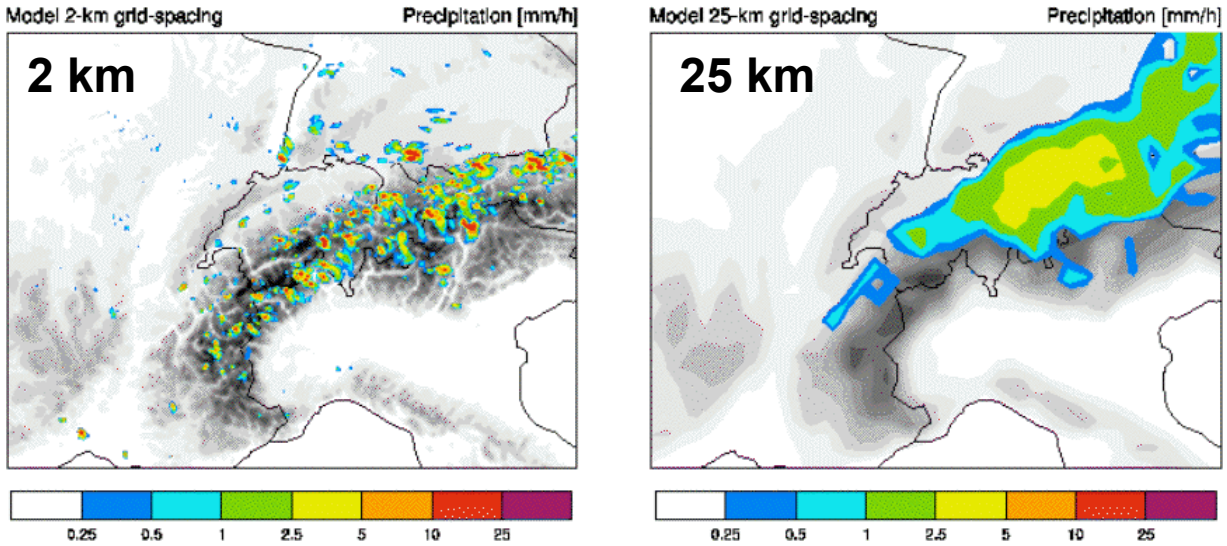
CR RCM

Extreme events are often of small spatial extent
=> Computational resolution particularly important <=

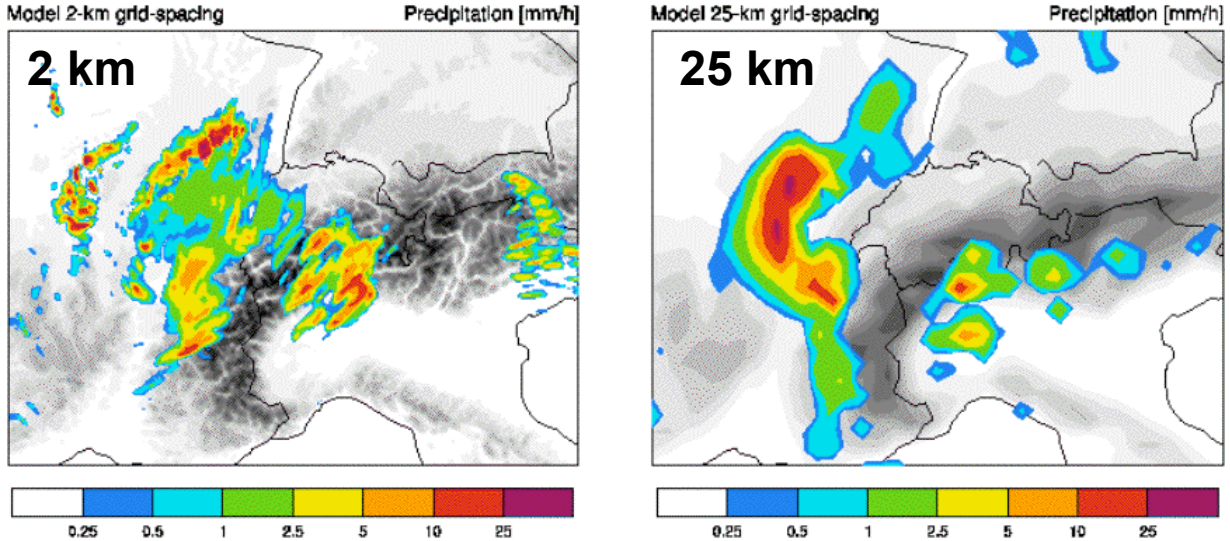
(Figure: Elias Zubler)

Precipitation at two resolutions

23 July 2006 18 UTC



28 July 2006 06 UTC



Precipitation snapshots [mm/h] in two month-long simulations using
- **explicit (2 km) and**
- **parameterized (25 km) convection,**

Simulations exhibit large differences in
- **diurnal cycle,**
- **spatial structure and**
- **peak amounts.**

The high-resolution domain encompasses 501x301x45 grid points.

Schär,

Hohenegger et al. 2008
Hohenegger et al. 2009

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- theory: precipitation intensity
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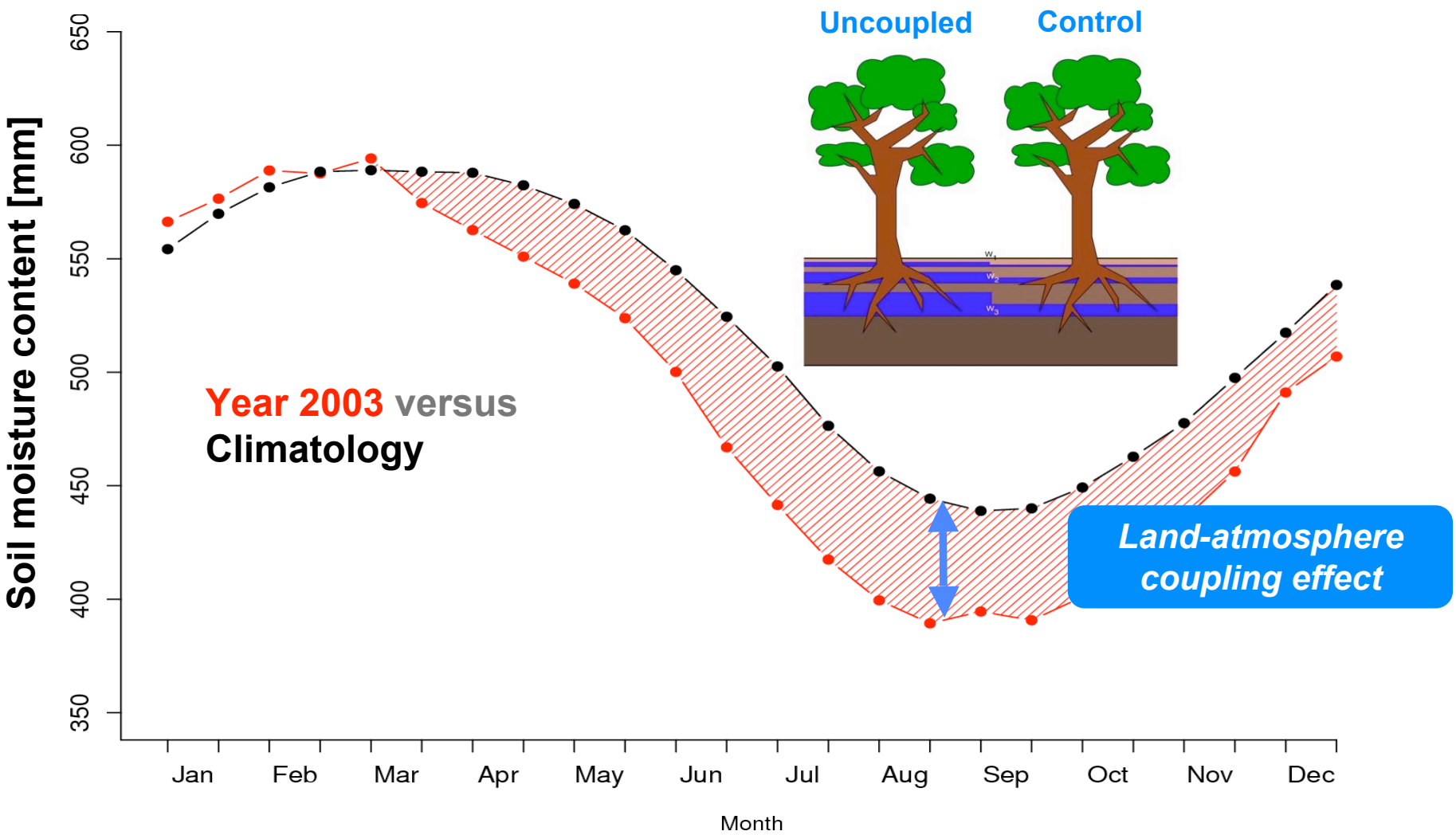
Role of impact models / indices? Example of heat waves

Role of model biases in assessing extremes

Role of computational resolution

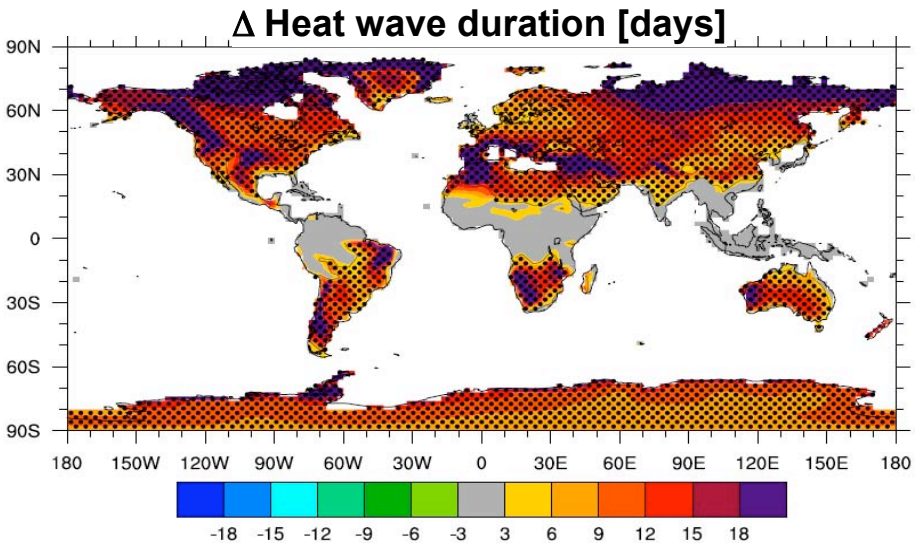
Sensitivity to model physics (parameterizations)

Role of land-surface processes



(Fischer et al. 2009, Fischer and Schär 2009, see also Seneviratne et al. 2006, Vidale et al. 2007)

Perturbed physics ensemble (land-srf proc.)



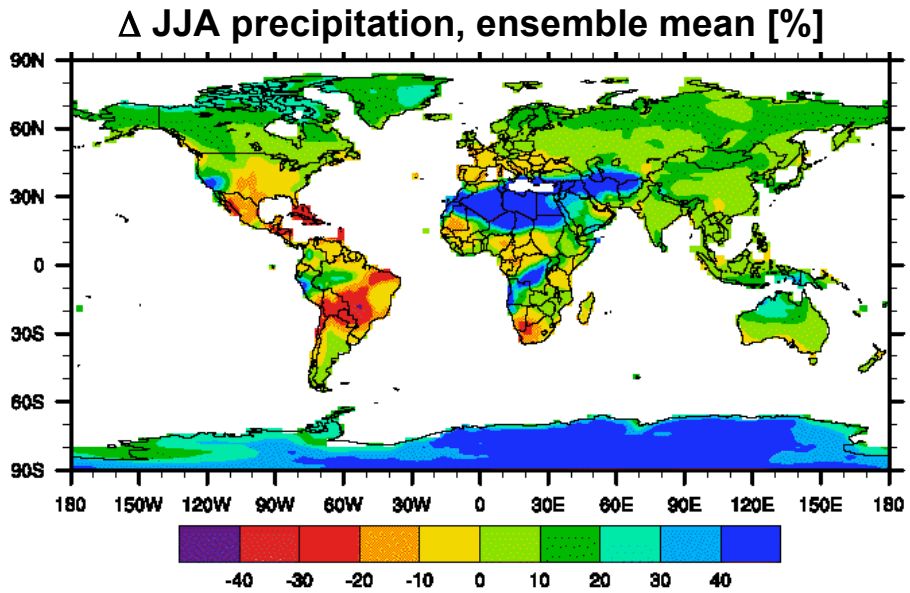
Perturbed physics ensemble testing the role of land-surface physics parameters at 2xCO2 (108 simulations, 2x2.5 deg).

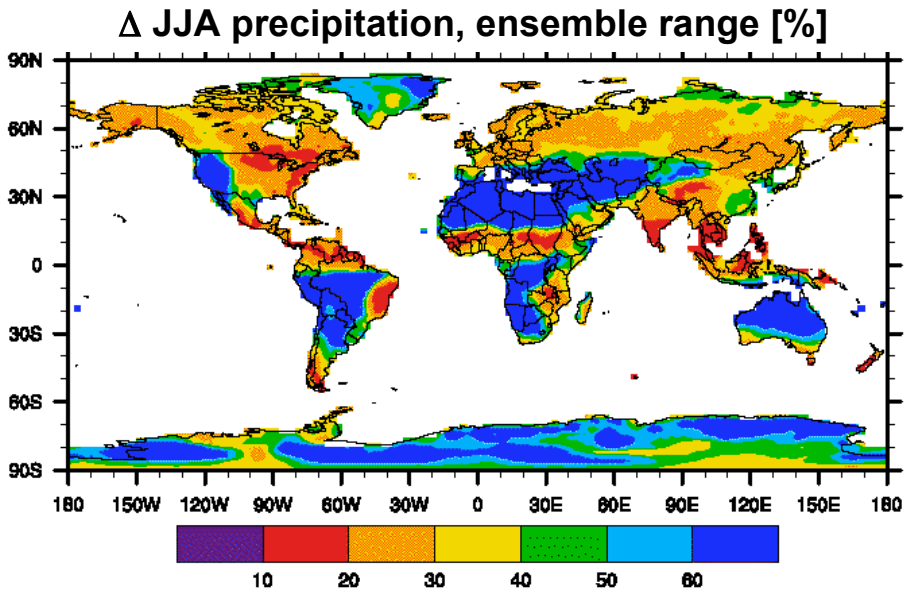
Δ heat wave duration (left):

- robust signal, uncertainty in amplitude

Δ JJA precipitation (bottom):

- global land: min=+14, max=+22%
- Mediterranean: min=–9%, max=+20%



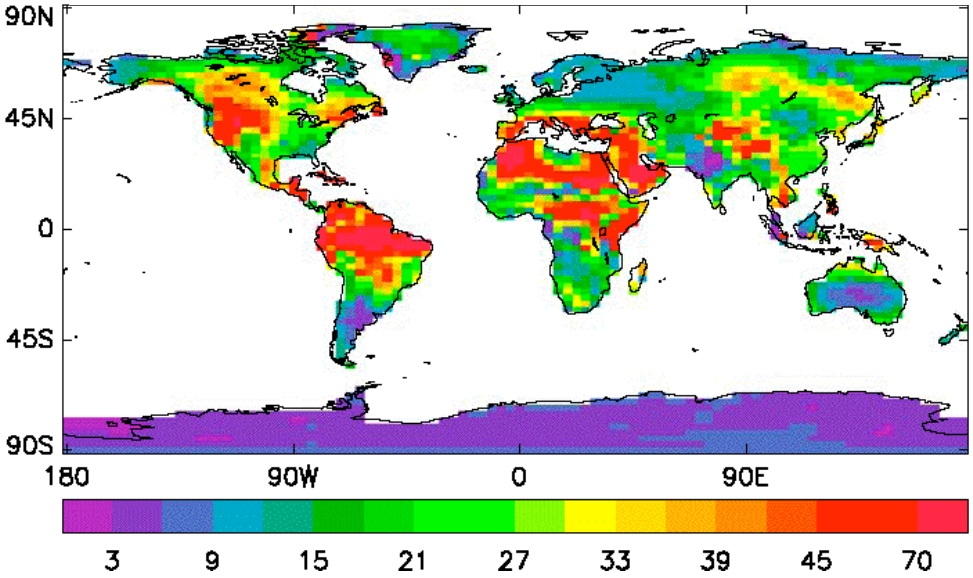


Fischer et al. (2010), *submitted*

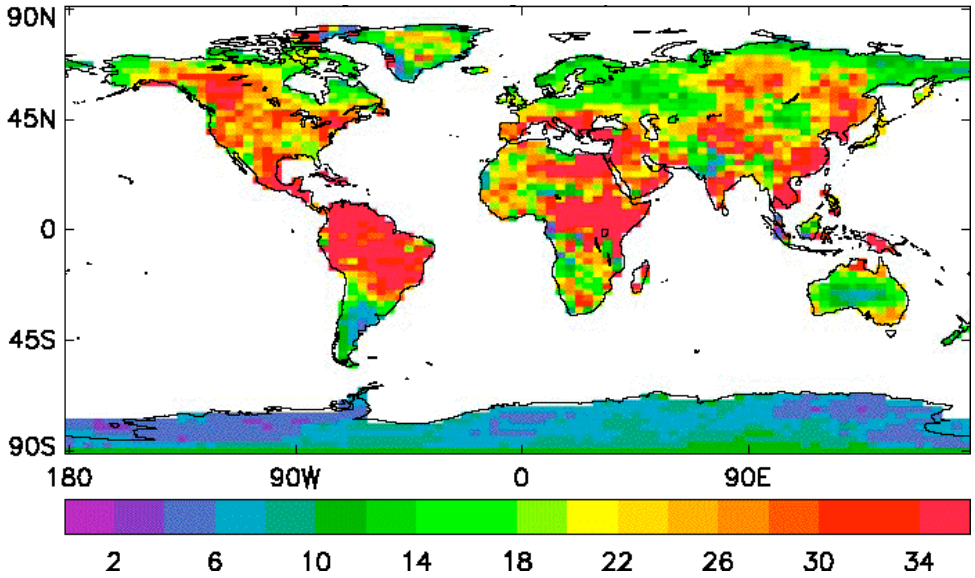
Perturbed physics ensemble (full physics)

Perturbed physics ensemble testing the key physics parameters at 2xCO2 (53 simulations, 2.5x3.75 deg).

Increase in July temperature extremes [factor] (99th percentile of Tmax)



Ensemble range (80% range)



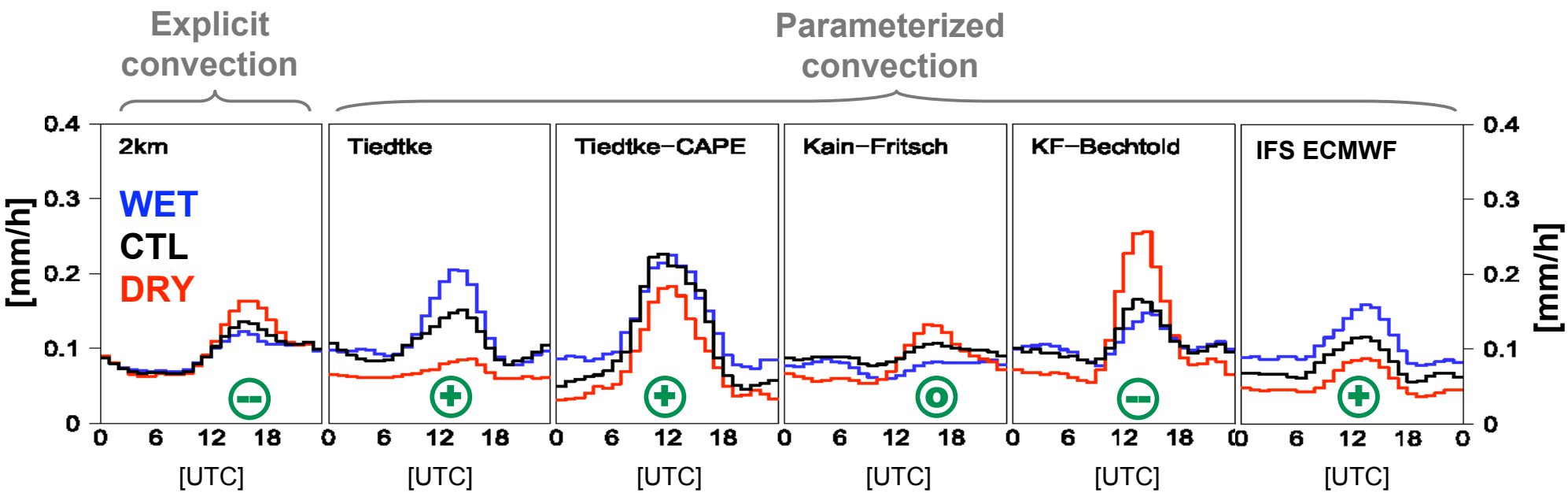
(Barnett et al. 2006)

Role of convection

Convection => soil-moisture precip feedback

Previous studies suggest EUROPE has ⊕ positive soil-moisture precipitation feedback.

APPROACH: Test mean diurnal cycle of precipitation in July simulations with perturbed (wet, dry) initial soil moisture.



=> Dramatic differences between explicit and parameterized convection, and between different schemes!

=> Convection governs sign of feedback!

(Hohenegger et al, 2009; Brockhaus et al. 2010)

Summary

- **Consideration of extreme events implies the consideration of statistical distributions. Variability and shape changes do matter! Accounted for by appropriate statistical methods (i.e. block maxima, peak over threshold).**

- **Consideration of impacts (natural hazards) usually requires the use of impact and/or damage models, or at least the consideration of appropriate impact indices.**

- **Model biases are particularly crucial (biases in distribution, fixed thresholds).**

- **High computational resolution is desirable.**

- **Uncertainties due to model physics are more important than when considering means, better understanding needed, large ensembles useful.**

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