Extremes in a changing climate

- an illustration of some generic issues

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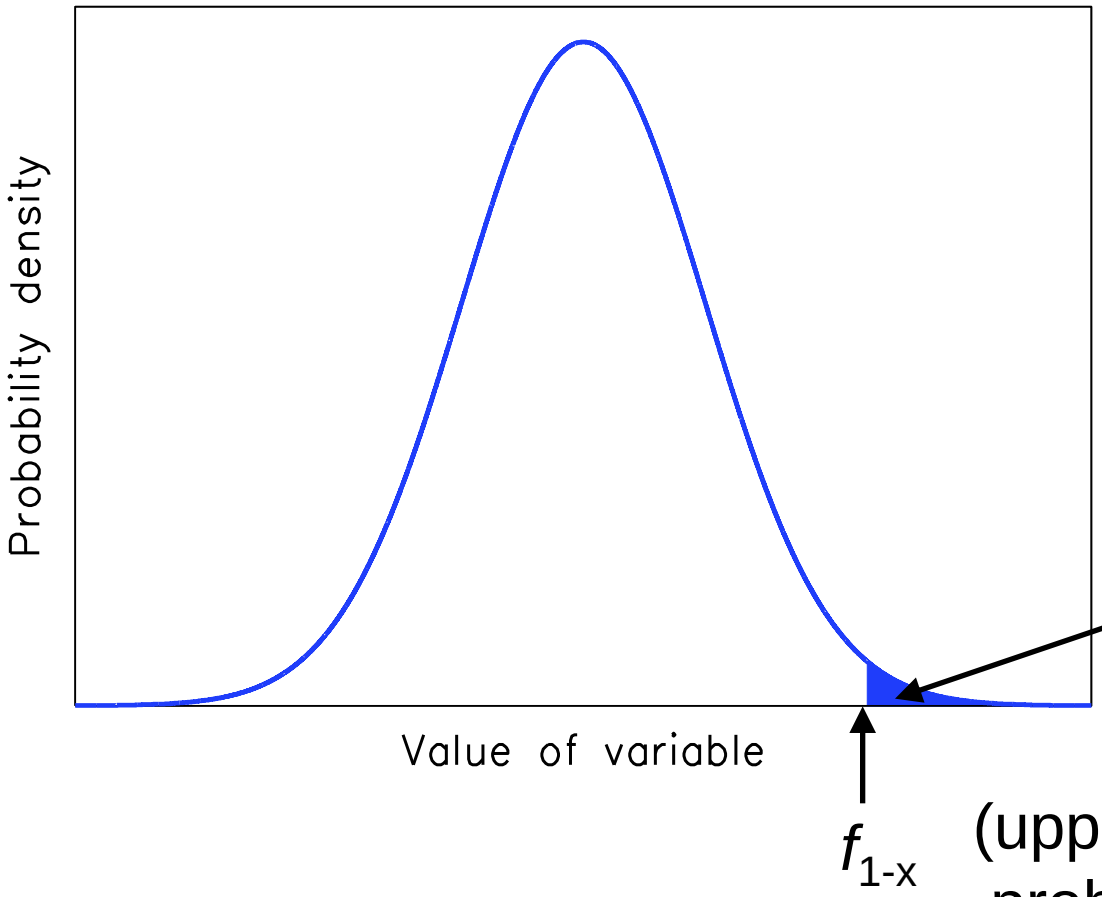
Things to be covered

- **Characterization of changing extremes:** magnitude vs. frequency
- **Changes in mean vs. changes in variability?**
- **Effect of time scale**: daily vs. monthly
- **Can we predict extremes in future climate, and how?**

Examples for temperature only

Extremes in the present climate

(a univariate view…)

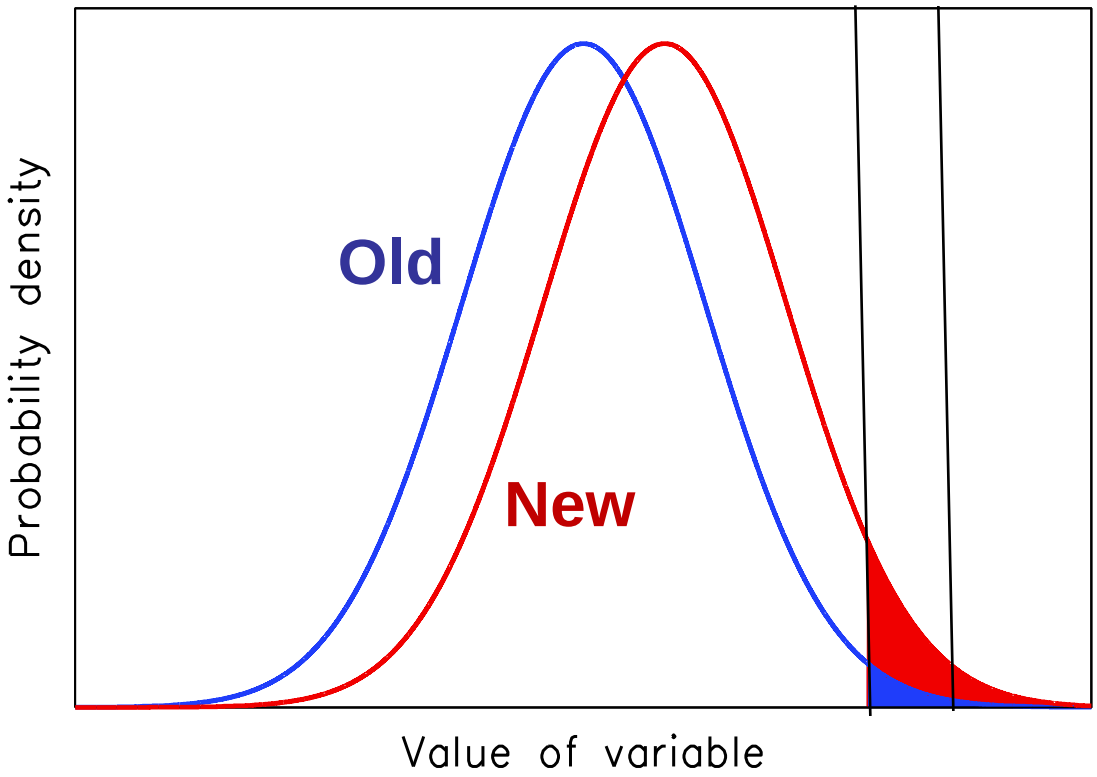


The value of variable *f* is considered extreme if it is ”far enough” in the upper (or lower) tail of the probability distribution of *f*.

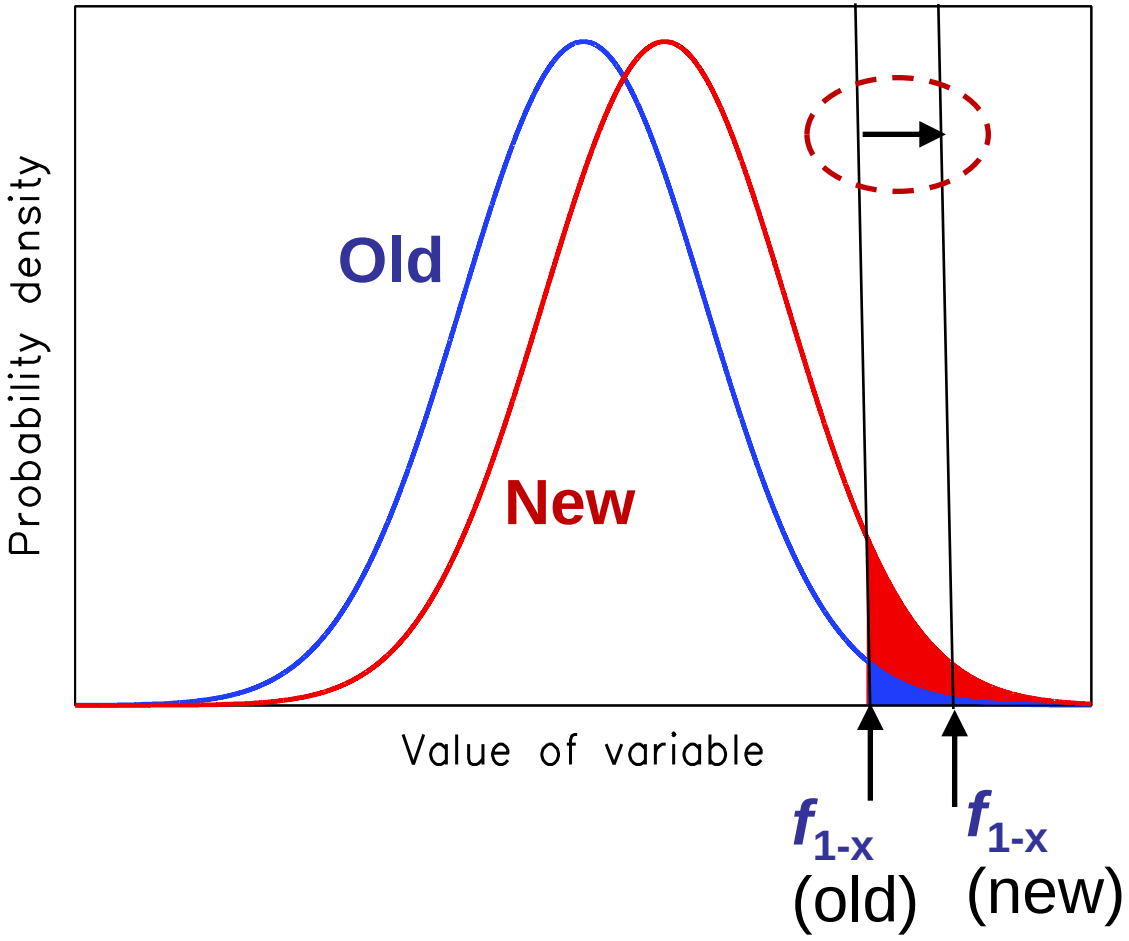
p = x (x << 1)

(upper return value for probability x)

Changes in extremes: future vs. present

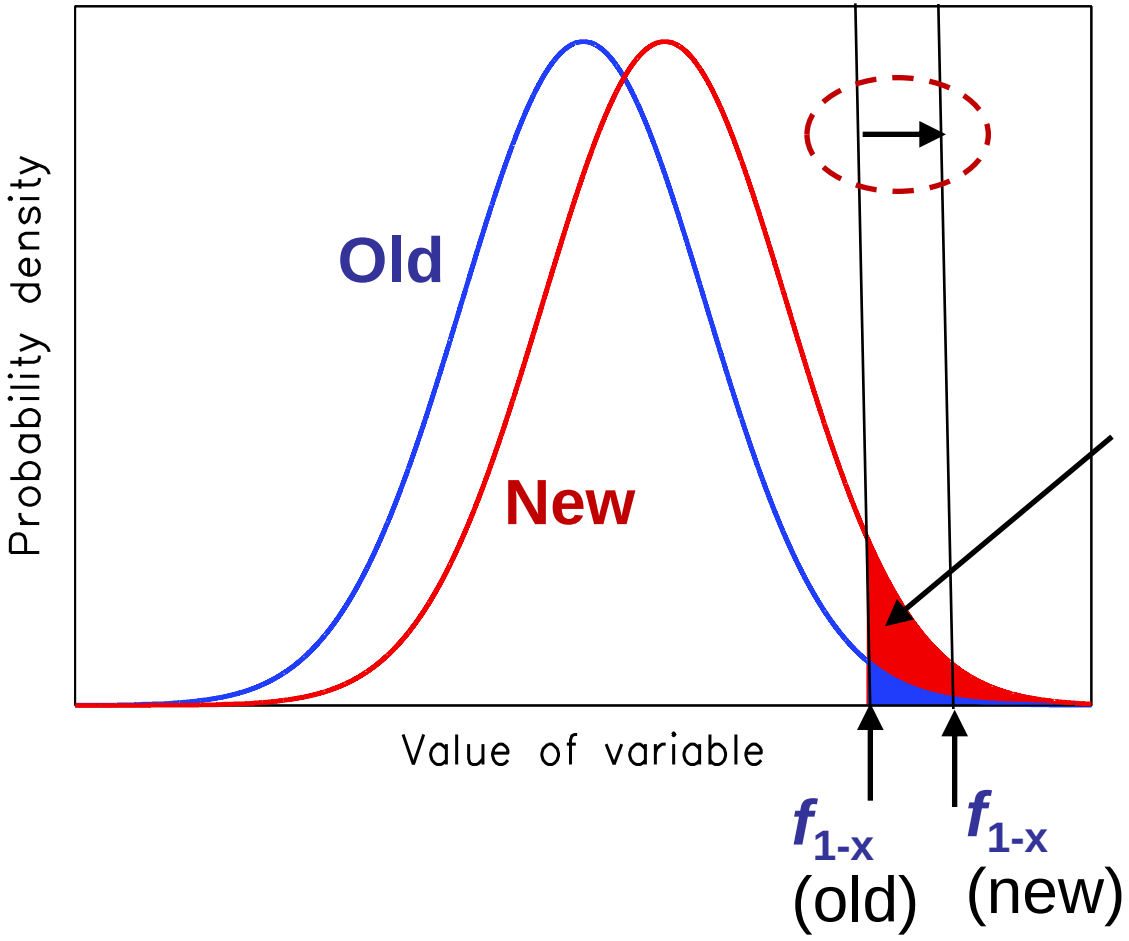


Changes in extremes: future vs. present



Change in the magnitude of extremes
= change in return value

Changes in extremes: future vs. present



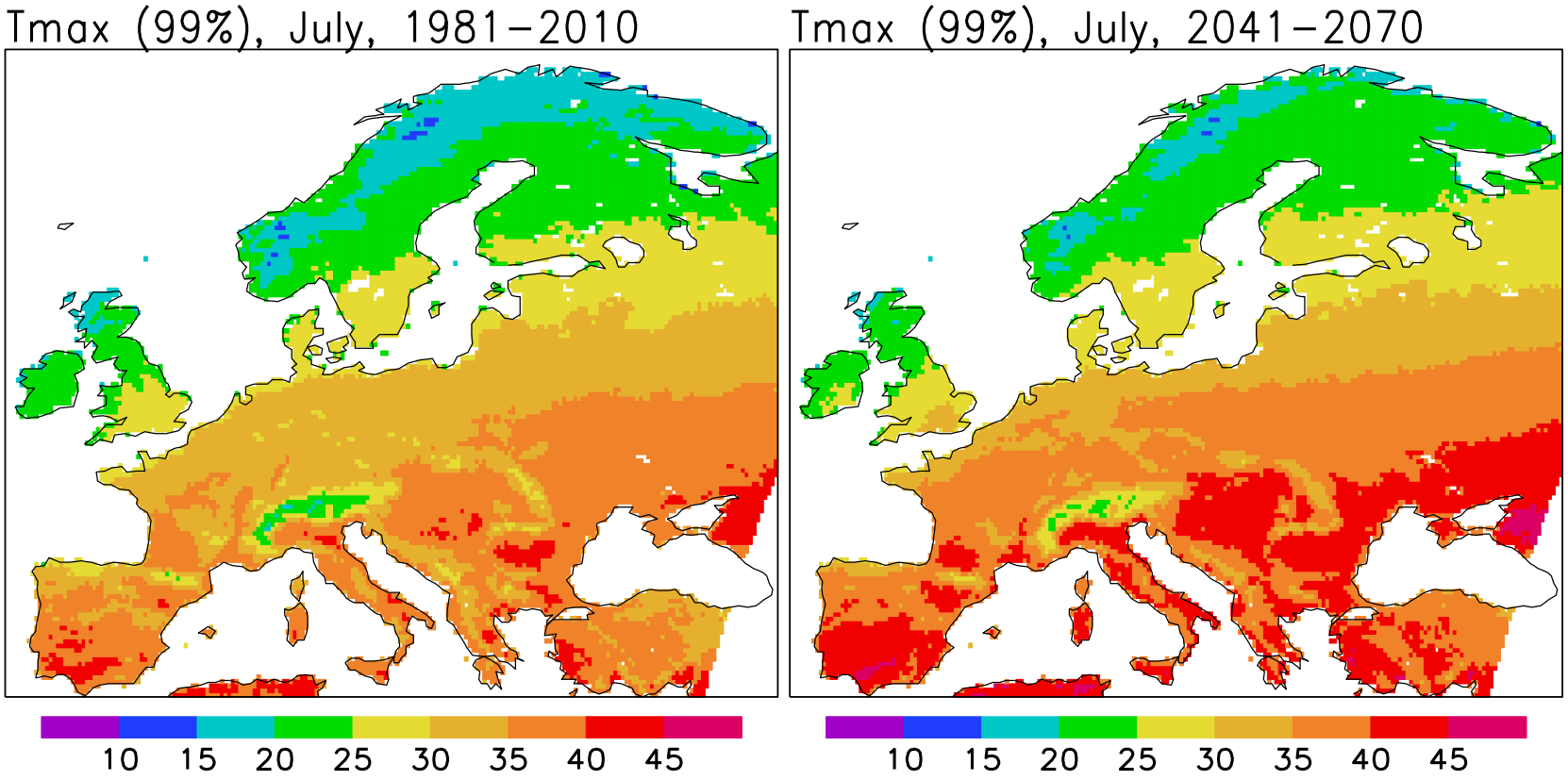
Change in the magnitude of extremes
= change in return value

Change in the frequency of extremes:
probability of exceeding the old return value in the new climate

Model data for illustration

- **ENSEMBLES** regional climate model simulations
- **25 km** horizontal resolution
- **SRES A1B** scenario
- Here: **6 simulations** with non-overlapping GCM-RCM combinations
- **For most of the talk:**
  - ”Old” climate = **1981-2010**
  - ”New” climate = **2041-2070**
  - Results of the 6 models averaged
  - High extremes of daily **T_{max} in July** + low extremes of daily **T_{min} in January**

99th percentile of daily Tmax in July



1981-2010:

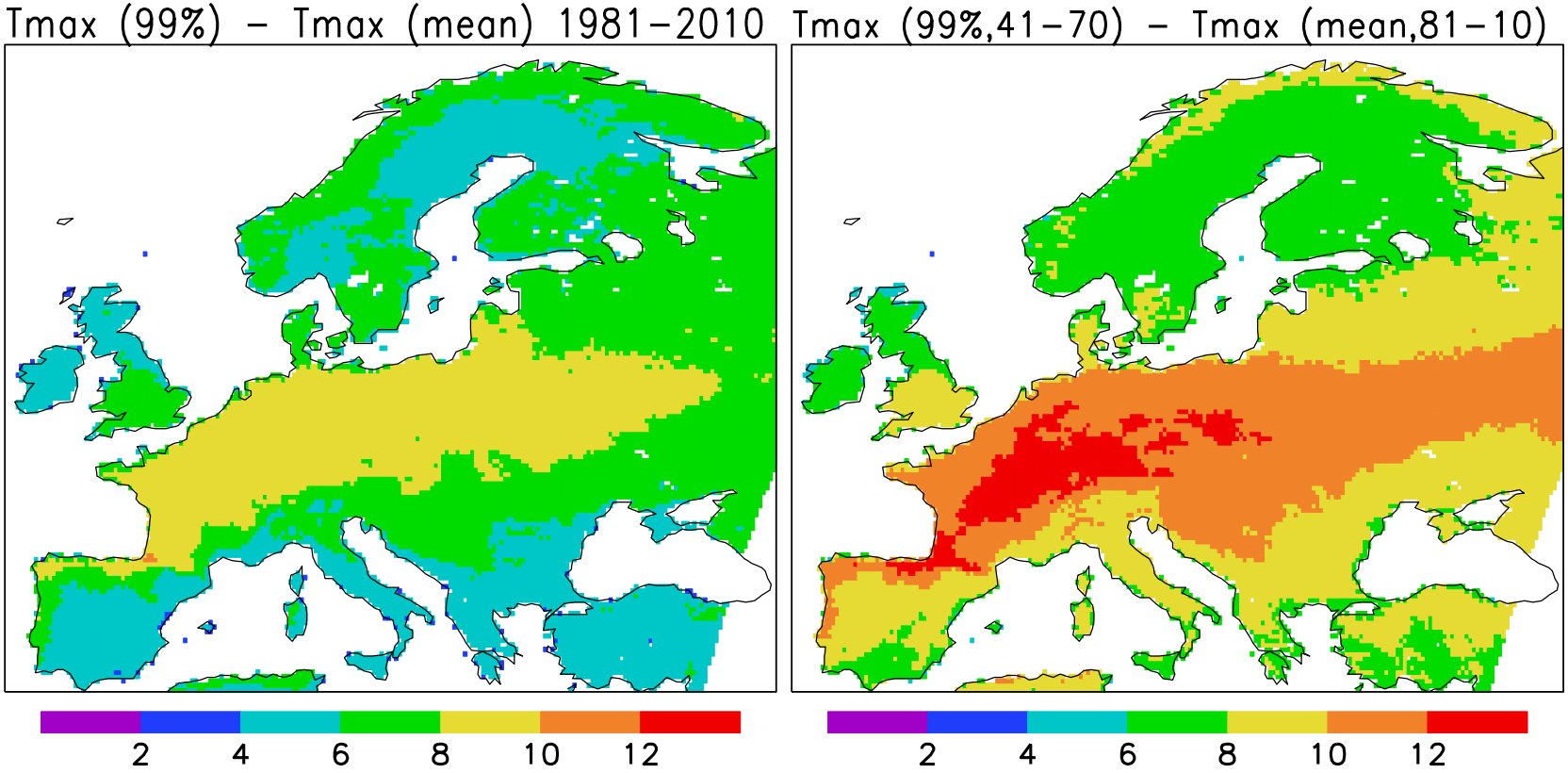
area mean = **+31.7ºC**

2041-2070:

area mean = **+34.1ºC**

99th percentile of daily Tmax in July

minus Tmax (mean) in 1981-2010



1981-2010: mean = **6.9ºC**

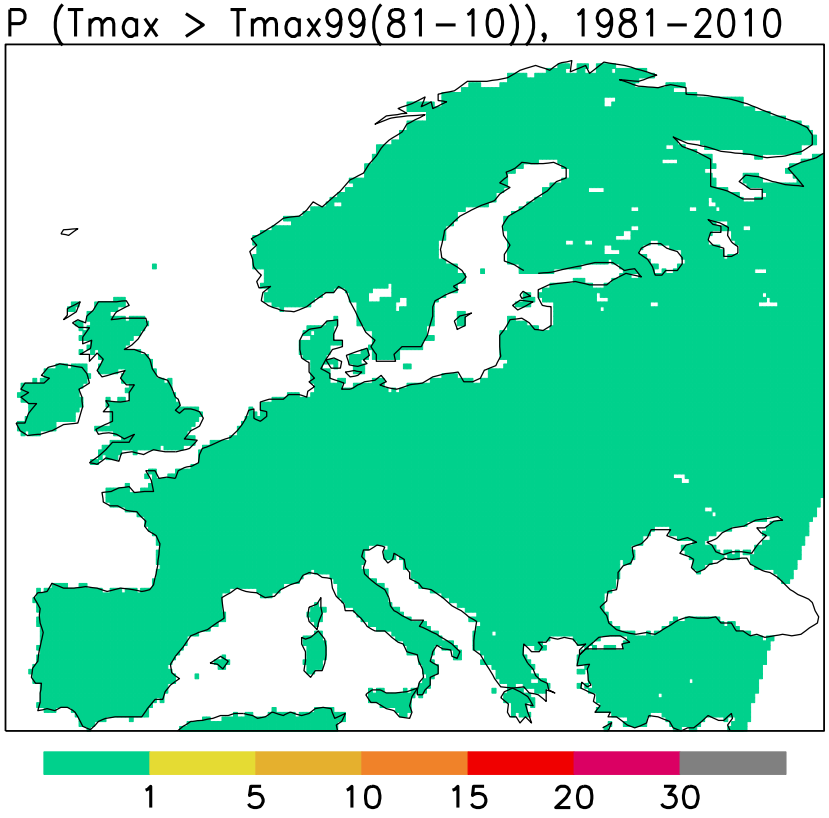
2041-2070: mean = **9.2ºC**

A 34% increase in the magnitude of extremes

(as measured in this way)

Frequency of July days with

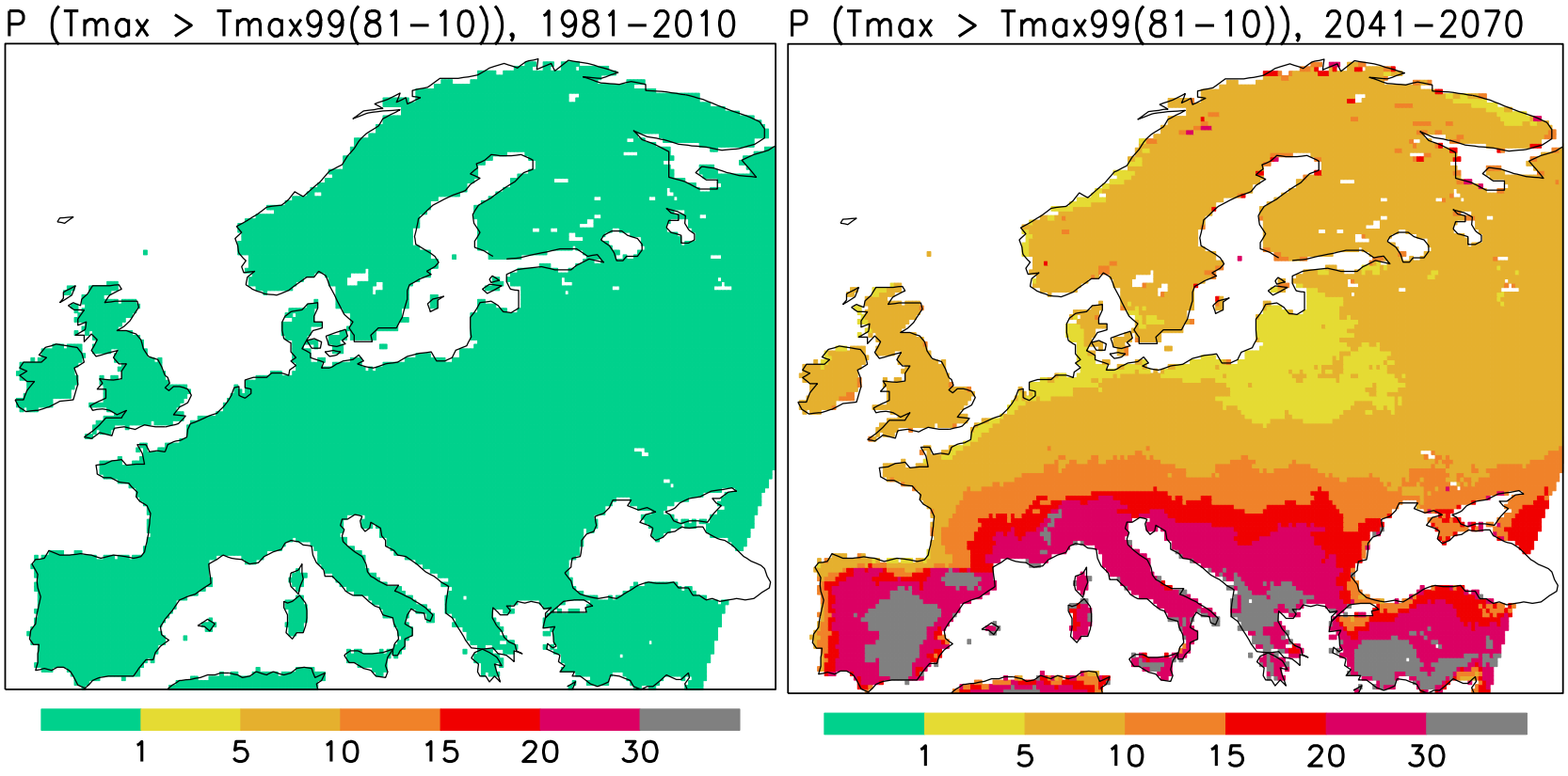
Tmax > Tmax (99%, 1981-2010)



1981-2010: mean = **1%**

Frequency of July days with

Tmax > Tmax (99%, 1981-2010)



1981-2010: mean = **1%**

2041-2070: mean = **12.8%**

Over 12-fold increase in the frequency of extremes

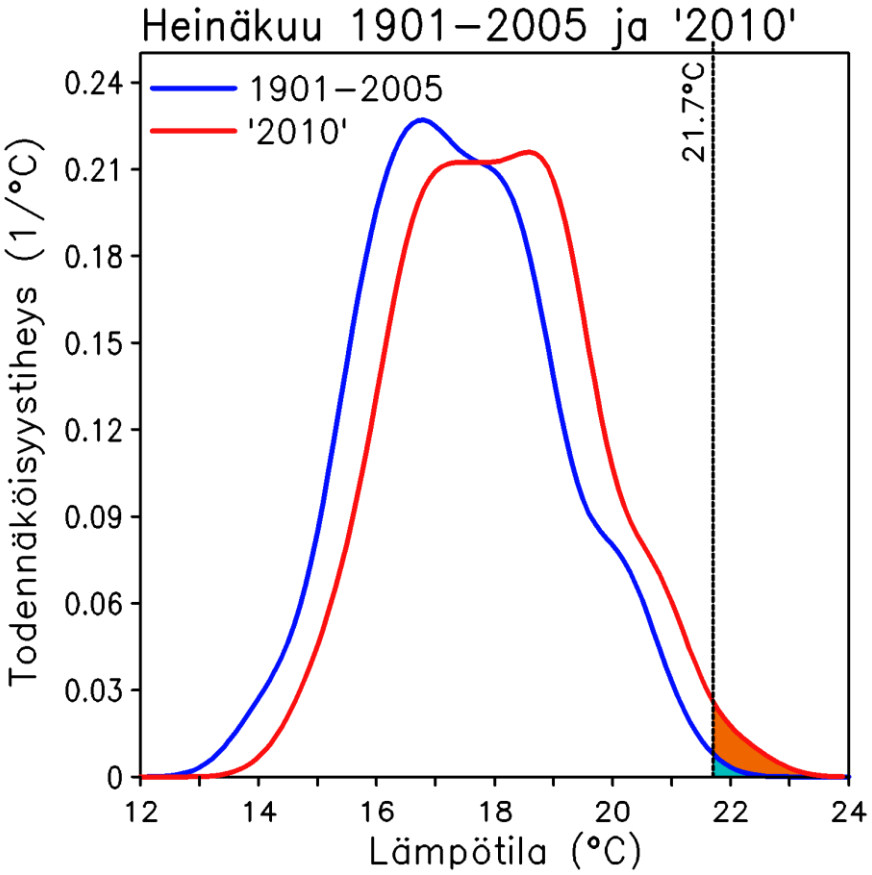
Which broadly means that…

- **Every time T_{max} is ”extremely high” in 2041-2070 most of the warm anomaly is due to natural variability** (rather than climate change)

- **In a vast majority of these cases** (> 90%), **T_{max} would never have crossed the threshold of being ”extreme” without the effect of climate change**

- **This difference** (change in frequency >> change in magnitude) **is a classic source of confusion in the discussion of observed extremes**

The record-warm July 2010 in Helsinki



Mean T: **+21.7ºC**

Difference from mean of 1901-2005: **+4.4ºC**

If we believe climate models: **~15%** of the anomaly due to climate change?

→ **Mostly natural variability**

Method: Räisänen & Ruokolainen (2008, Geophysica)

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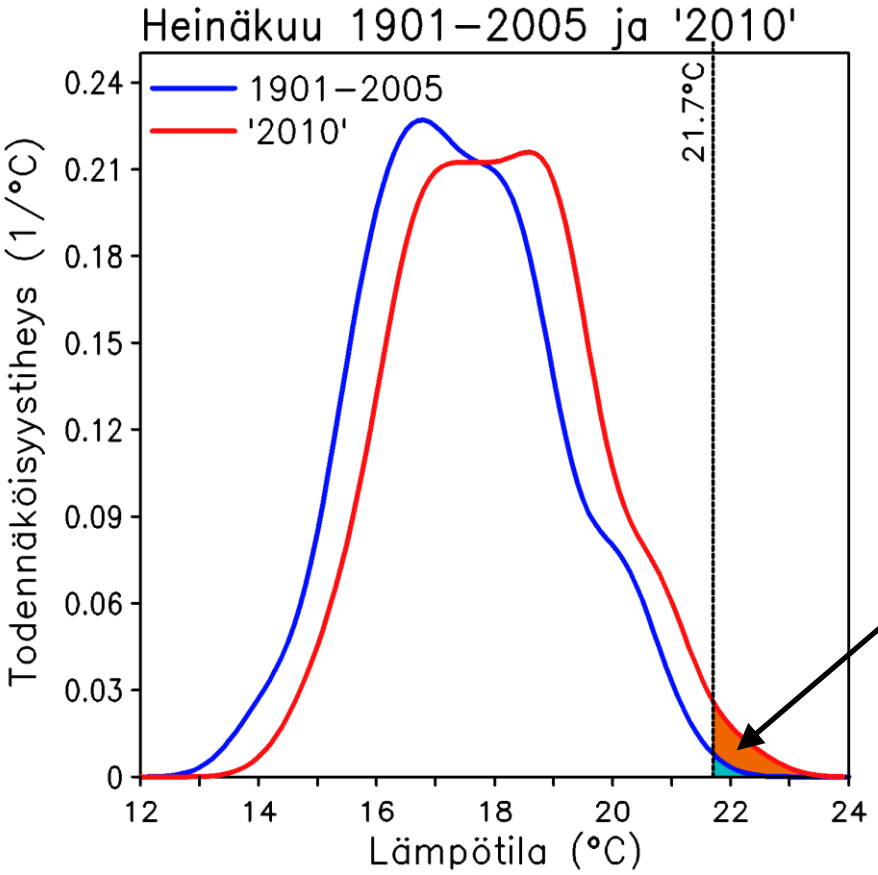

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Mean T: **+21.7ºC**

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If we believe climate models: **~15%** of the anomaly due to climate change?

→ **Mostly natural variability**

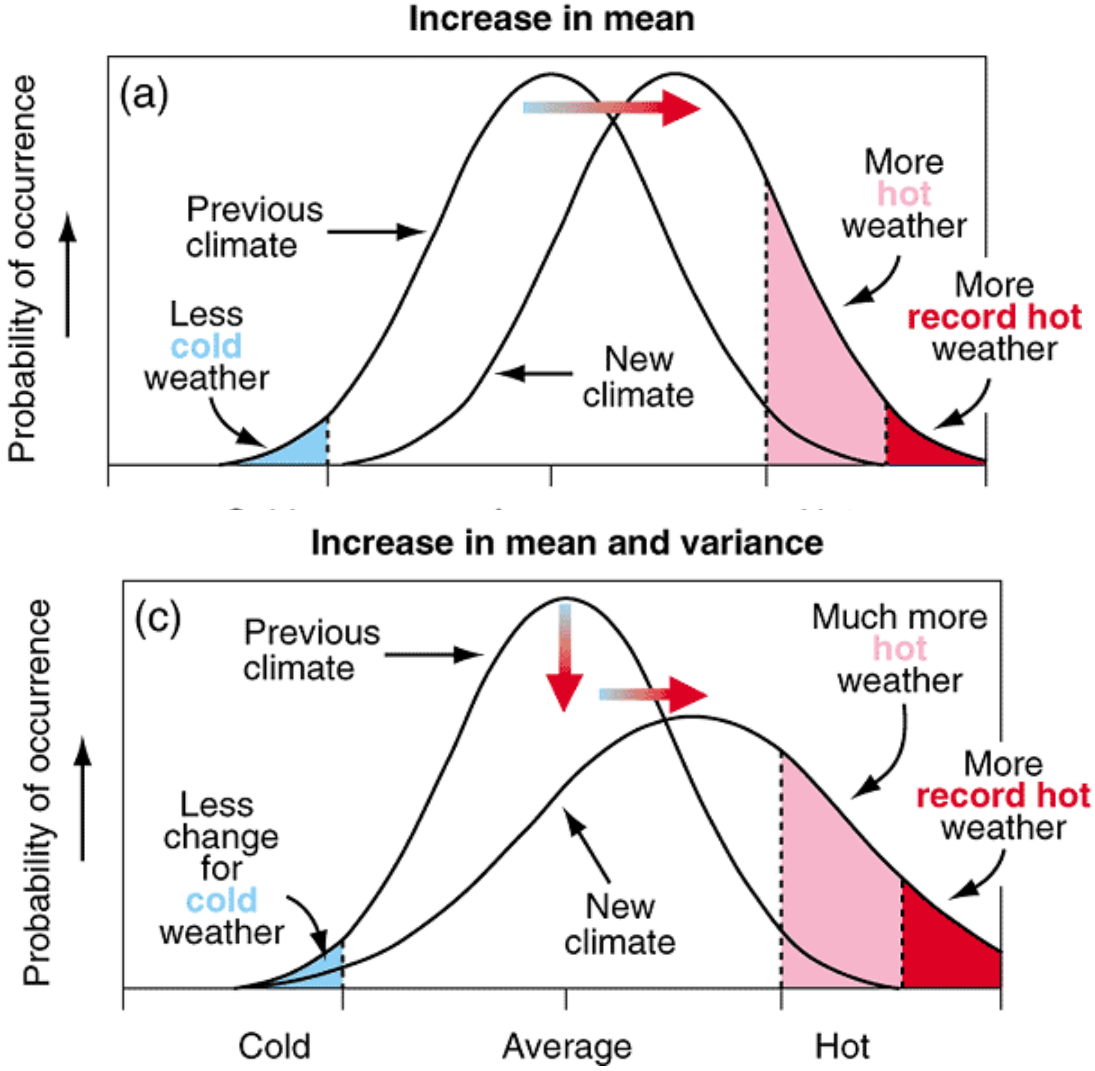
Yet … probability for T ≥ +21.7ºC:

'Old climate' (1901-2005) ~ 0.3% (?)

'Present climate' (2010) ~ 1.7% (?)

→Climate change has made the probability of such extreme warmth several times larger?

Changes in extremes depend on both changes in mean climate and variability



IPCC WG1 (2001) Fig. 2.32

EXTREME EVENTS IN A CHANGING CLIMATE: VARIABILITY IS MORE IMPORTANT THAN AVERAGES

RICHARD W. KATZ and BARBARA G. BROWN

Environmental and Societal Impacts Group, National Center for Atmospheric Research, Boulder, CO 80307, U.S.A.*

Climatic Change (1992)

Is this true in practise?

A theoretical example

- If *T* is normally distributed, then

$$T(99\%) \approx Mean(T) + 2.3StD(T)$$

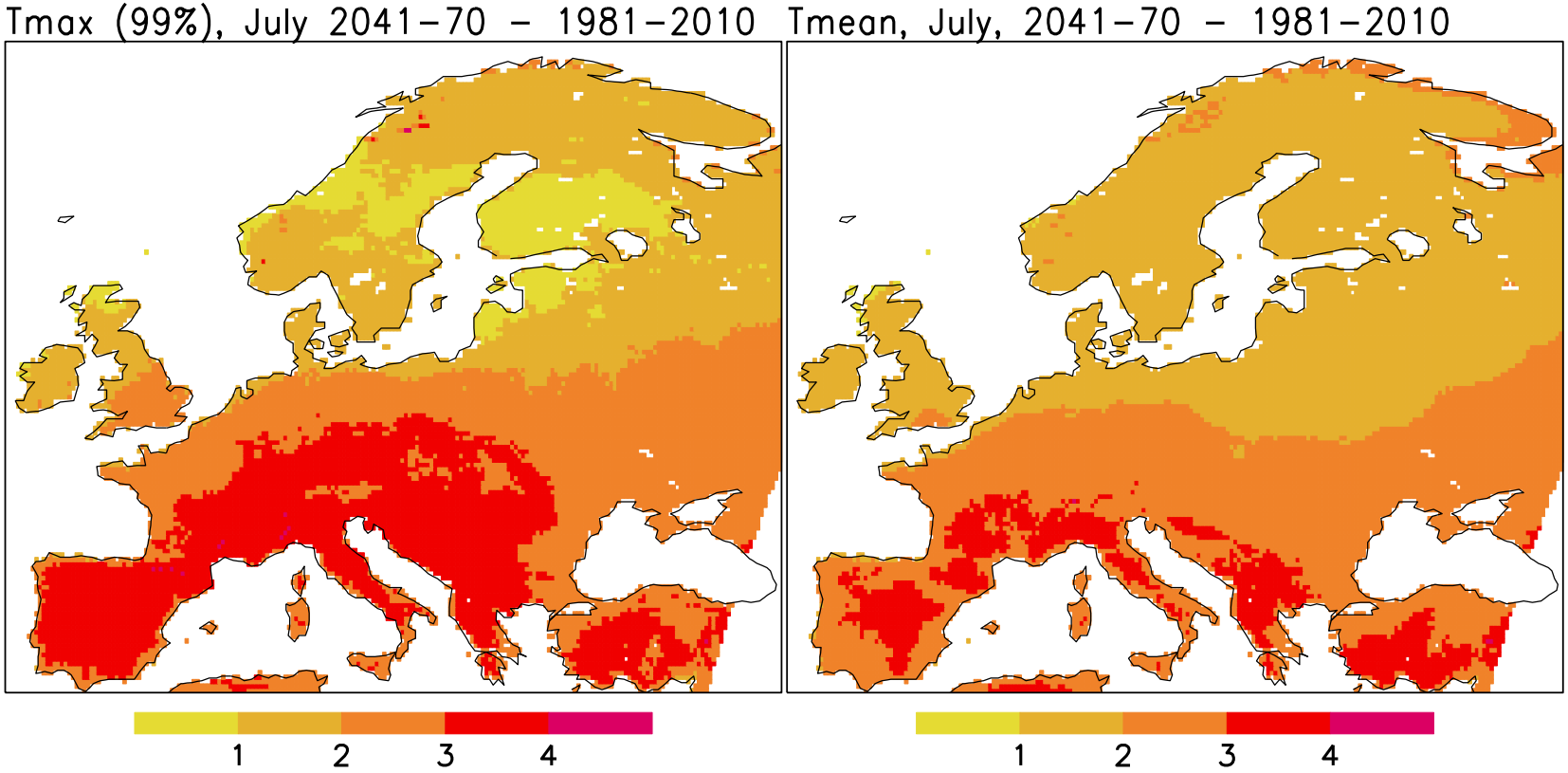
- If ***Mean(T)*** increases by **1ºC**, with no change in *Std(T),* ***T(99%)*** will increase by **1ºC**.
- If ***Std(T)*** increases by **1ºC**, with no change in *Mean(T)*, ***T(99%)*** will increase by **2.3ºC**.

- Yes, **change in standard deviation is more important** for the extremes **than the change in the mean** …

- … **assuming that the change in the mean and the standard deviation are of similar magnitude**!

Changes in temperature in July:

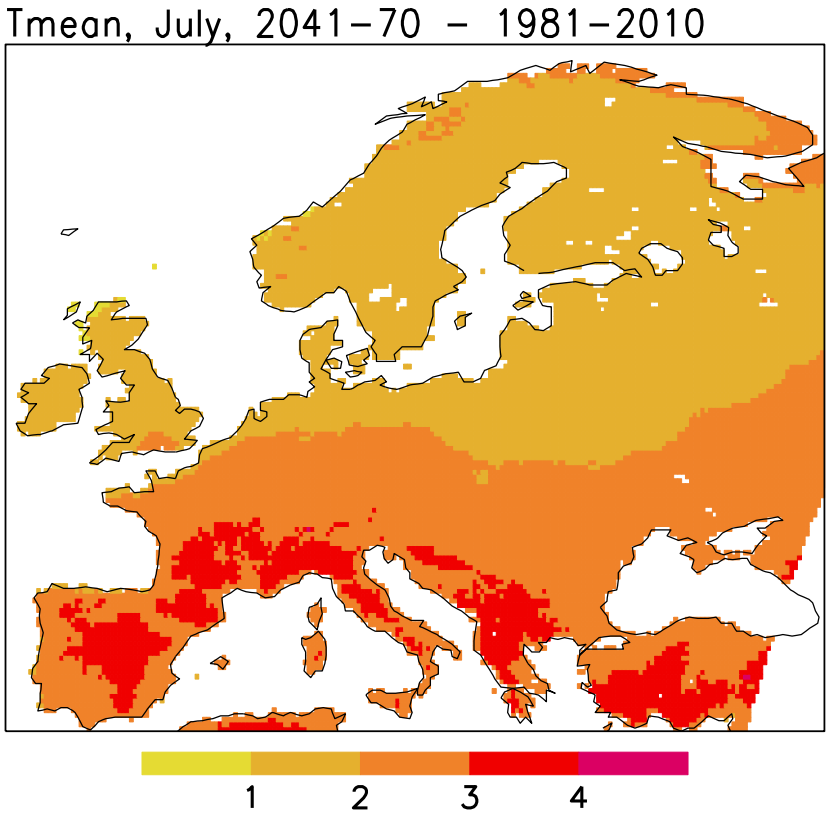
1981-2010 → 2041-2070



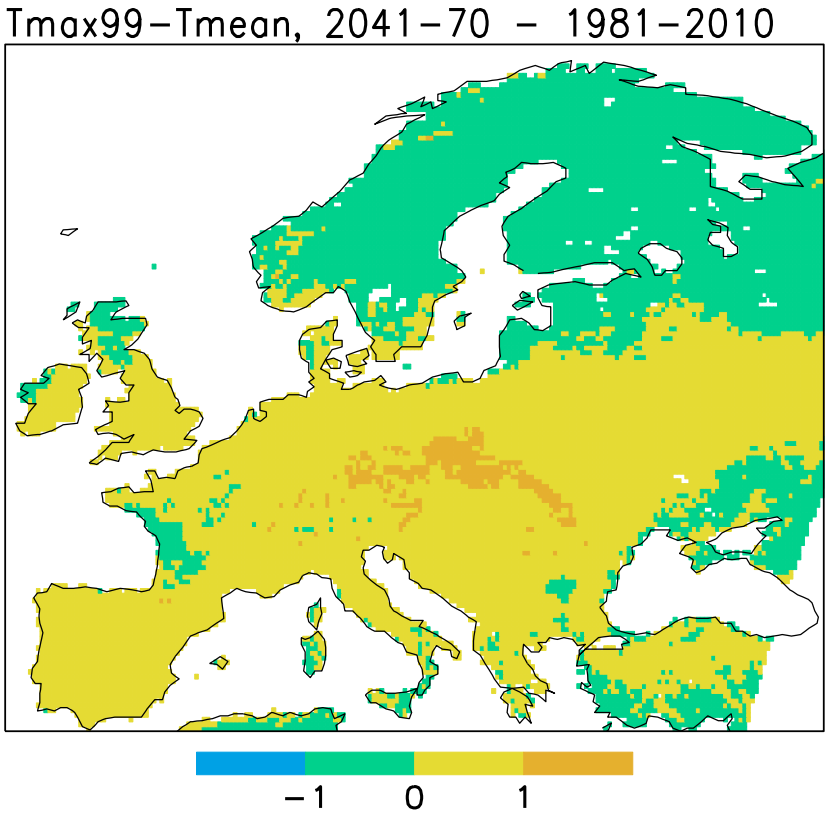
Tmax (99%): mean = **2.3ºC** **Mean T:** mean = **2.2ºC**

Changes in temperature in July:

1981-2010 → 2041-2070



Mean T: mean = **2.2ºC**

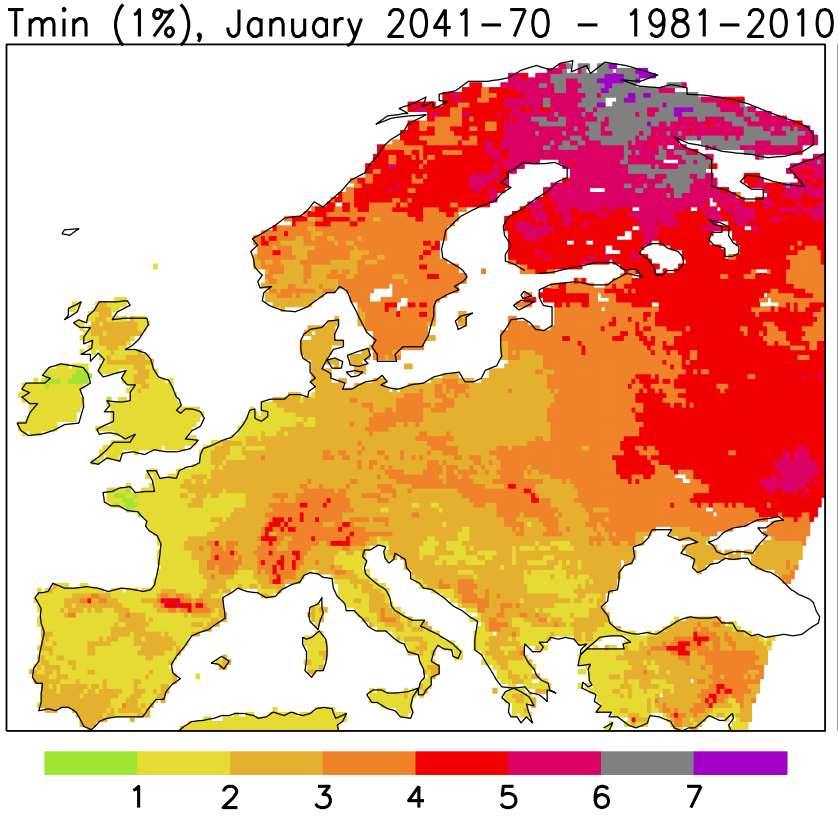


99% - mean T: mean = **0.2ºC**

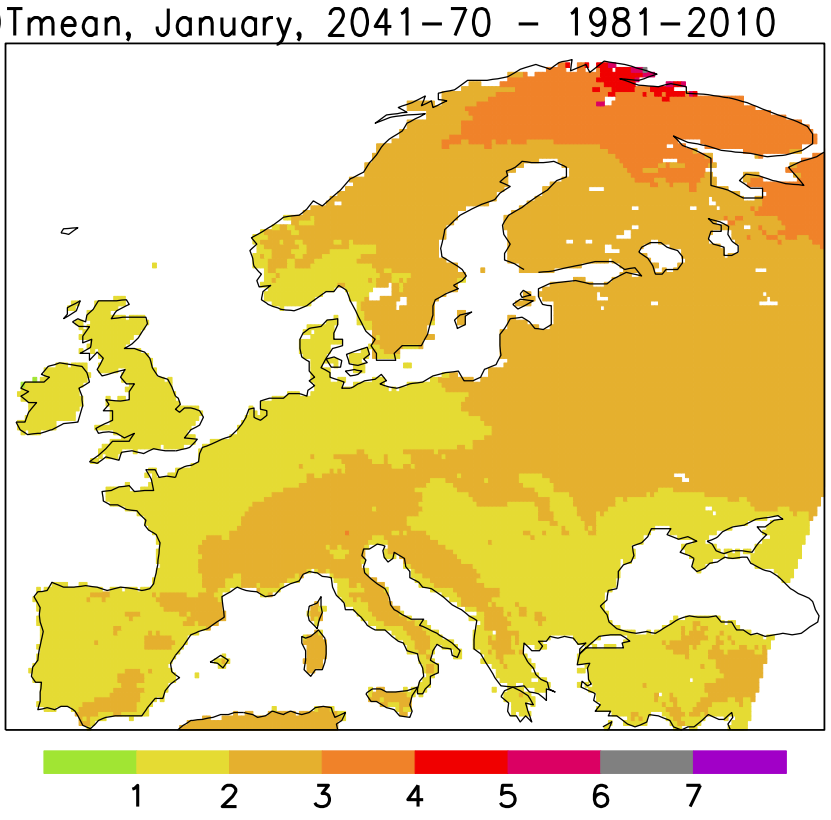
Changes in variability are <u>less important</u> than the change in the mean (in this case)

Changes in temperature in January:

1981-2010 → 2041-2070



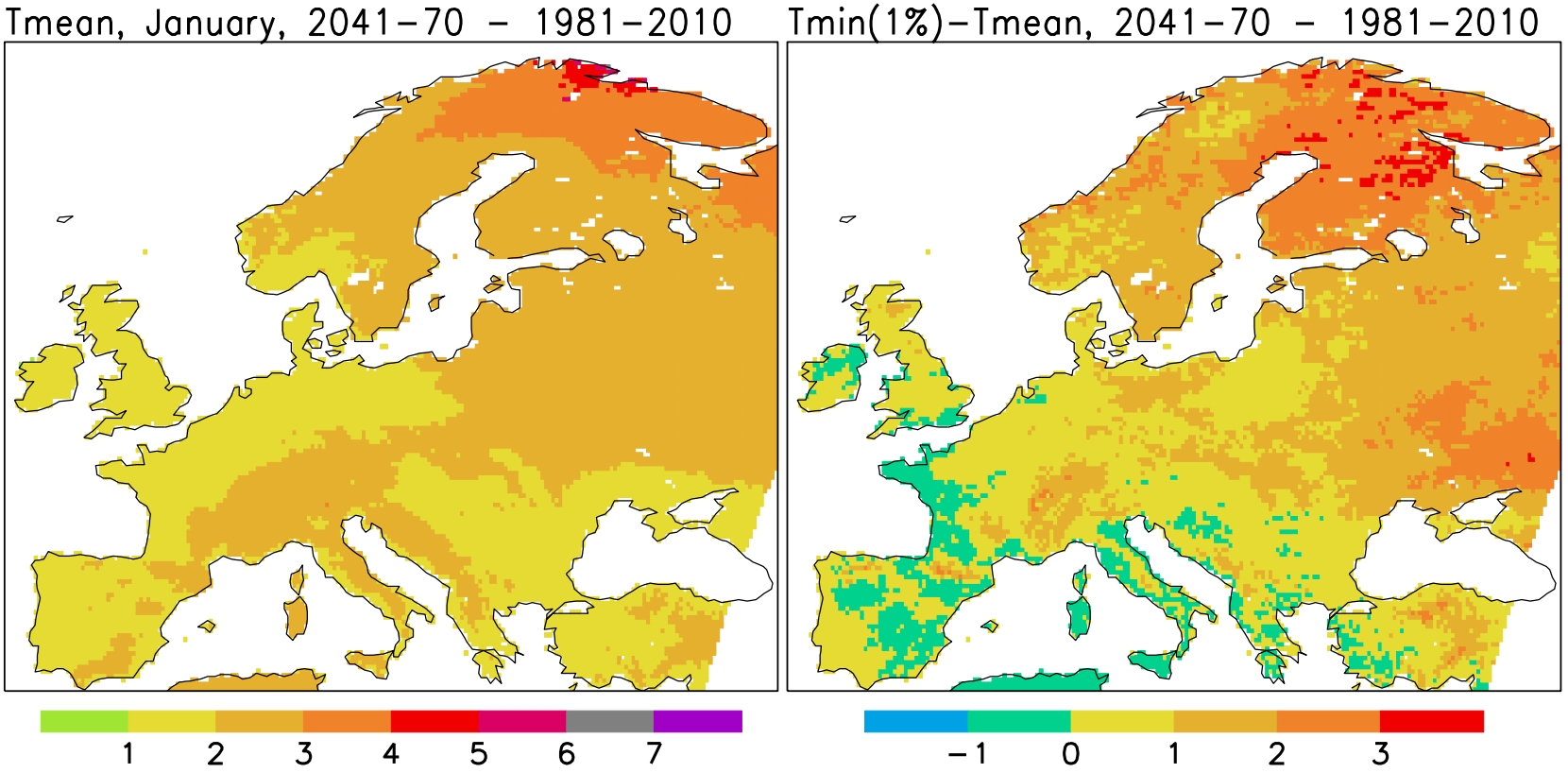
Tmin (1%): mean = **3.2ºC**



Mean T: mean = **2.2ºC**

Changes in temperature in January:

1981-2010 → 2041-2070



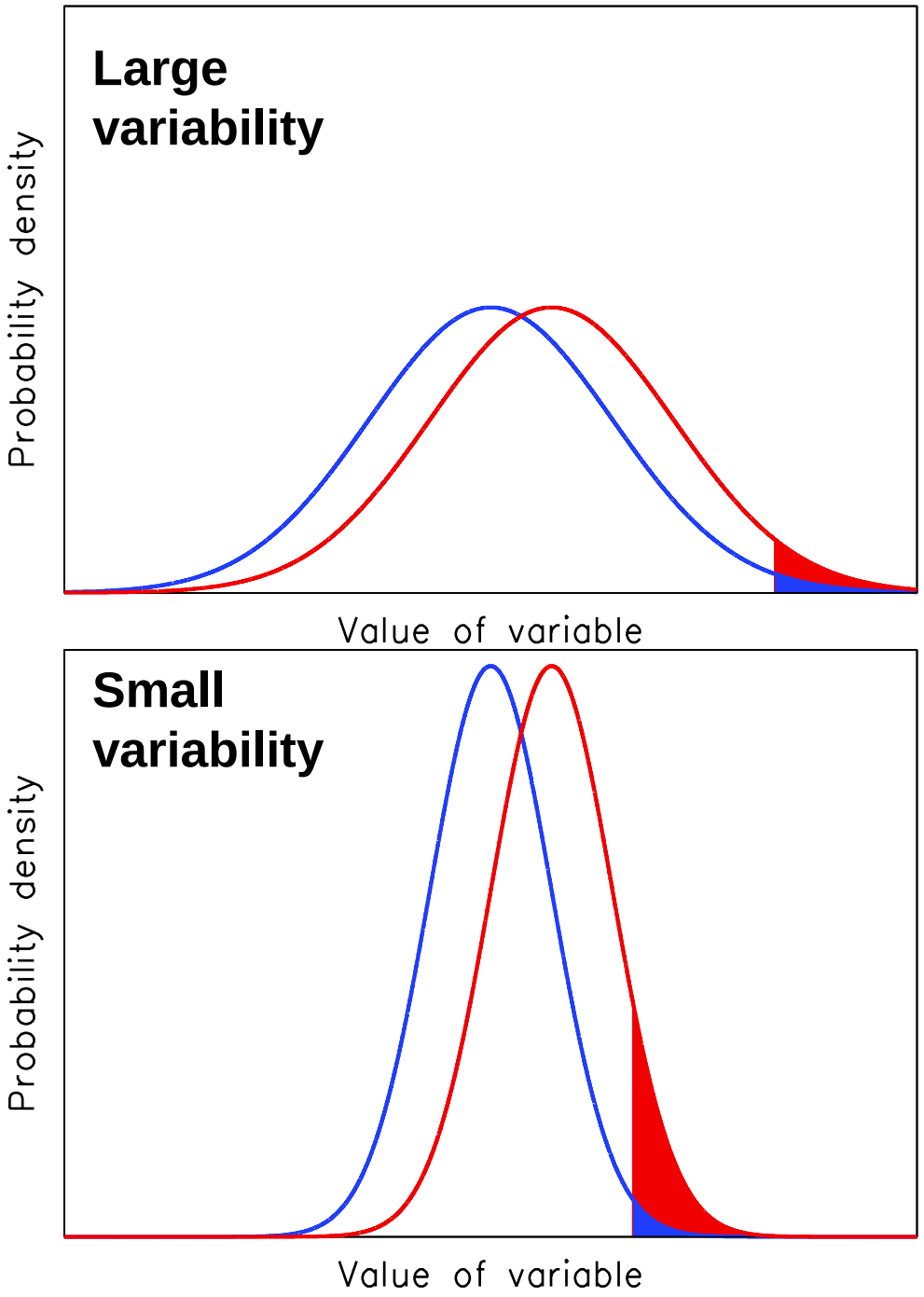
Tmean: mean = **2.2ºC**

1% - mean T: mean = **1.0ºC**

Reduced variability also ameliorates cold winter extremes in Northern + Eastern Europe

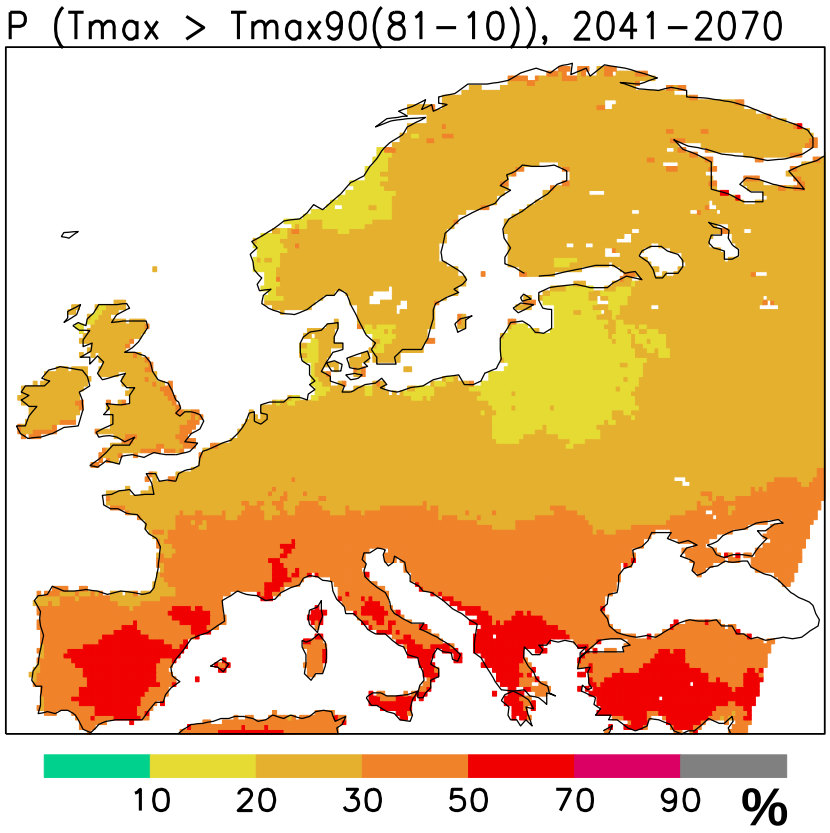
Role of present-day variability

- For the same shift in the mean, the change in the frequency of extremes increases with decreasing present-day variability

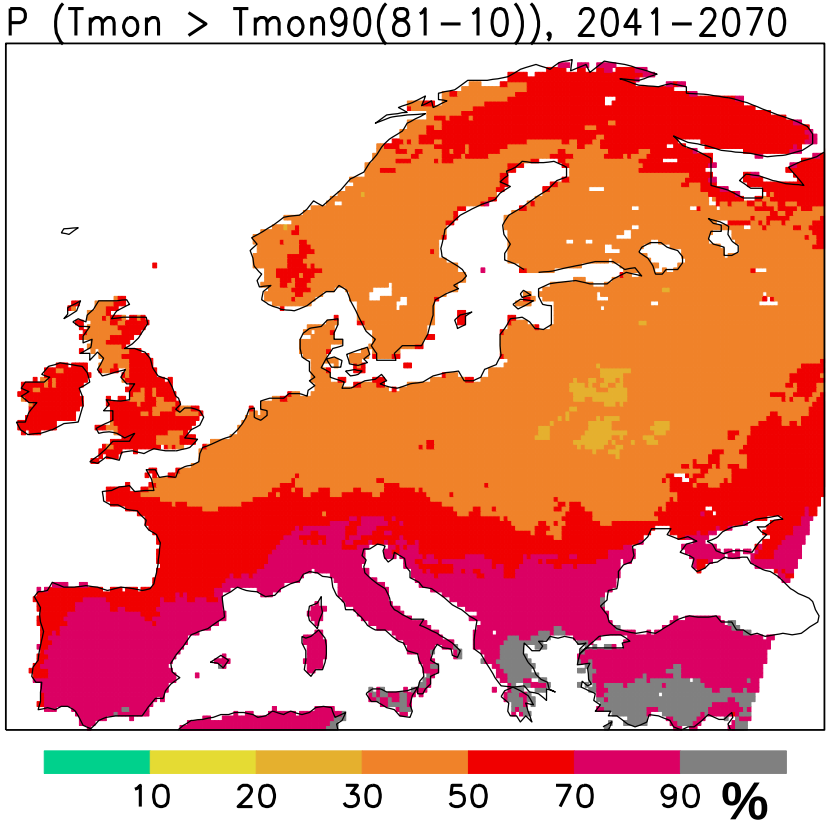


Frequency of July cases with

T > T (90%, 1981-2010) in 2041-2070



Daily Tmax: mean = **32%**

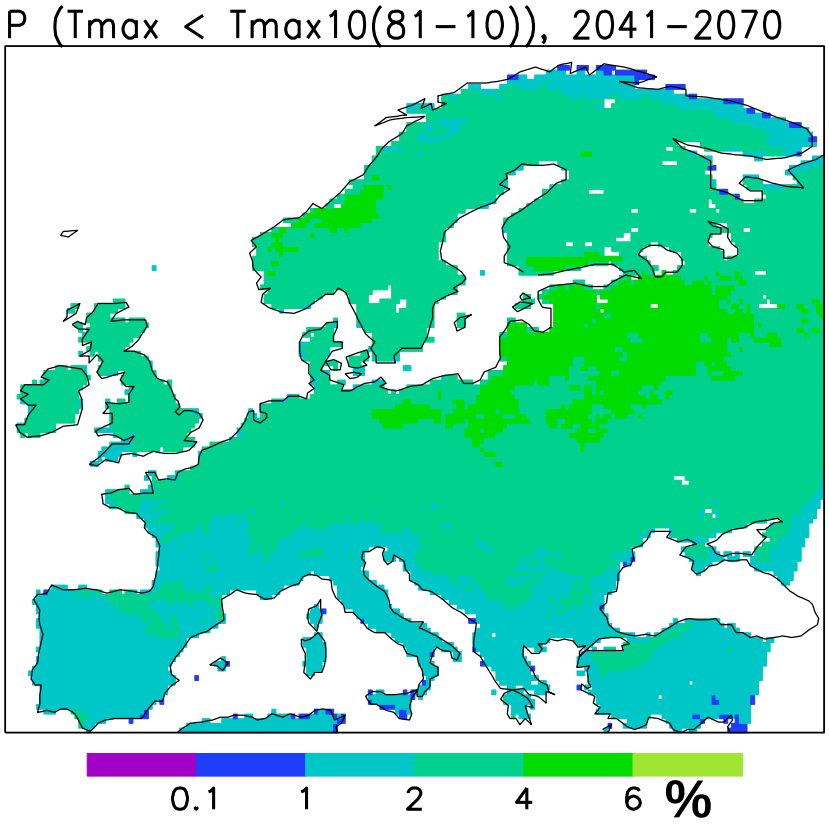


Montly mean T: mean = **56%**

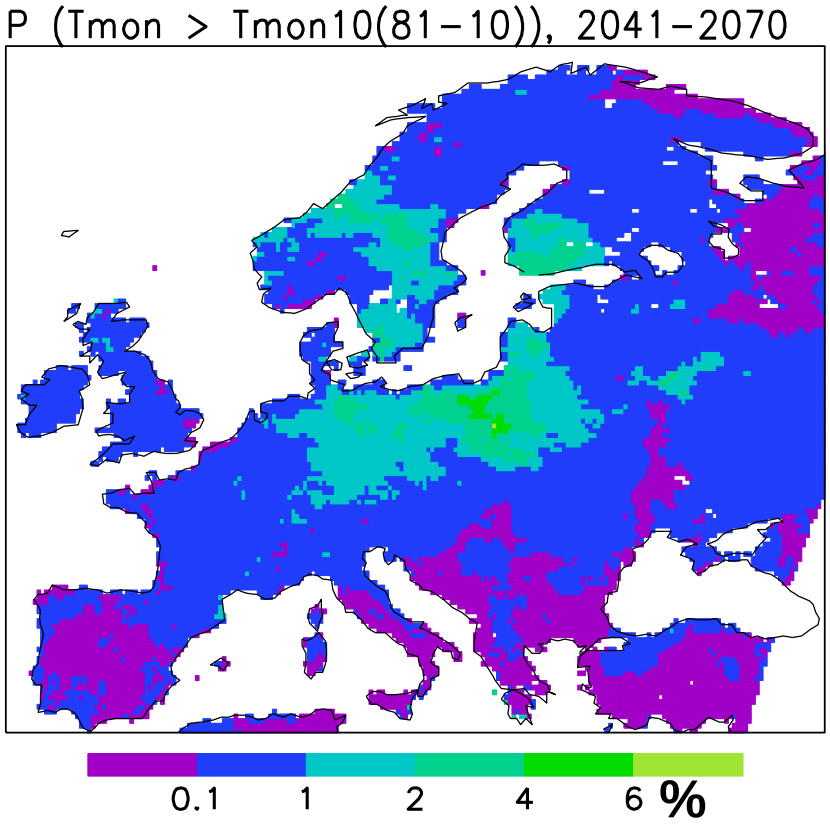
A narrower baseline distribution translates into a larger change in the frequency of extremes

Frequency of July cases with

T < T (10%, 1981-2010) in 2041-2070



Daily Tmax: mean = **2.6%**



Montly mean T: mean = **0.5%**

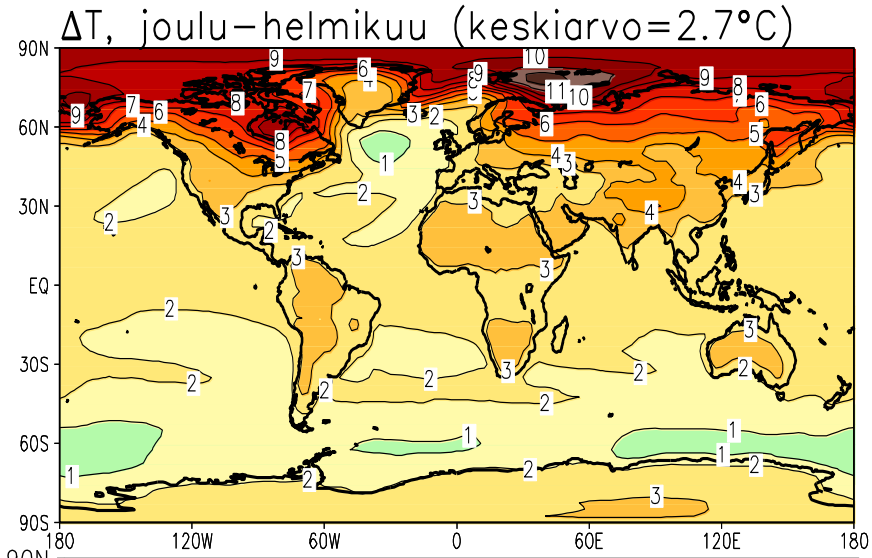
Cold individual days will still occur, but cold months will become a rarity

Changes in ”winter” (Dec-Jan-Feb) climate

(SRES A1B scenario, mean of 22 CMIP3 models)

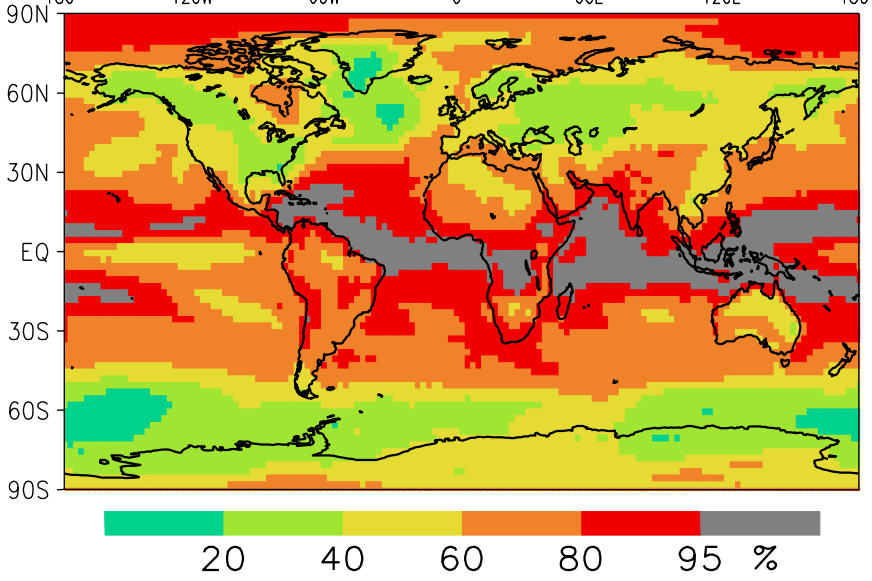
Change in DJF mean temperature

(1971-2000 → 2070-2099)



Frequency of DJF seasons warmer than any DJF in years 1901-2007

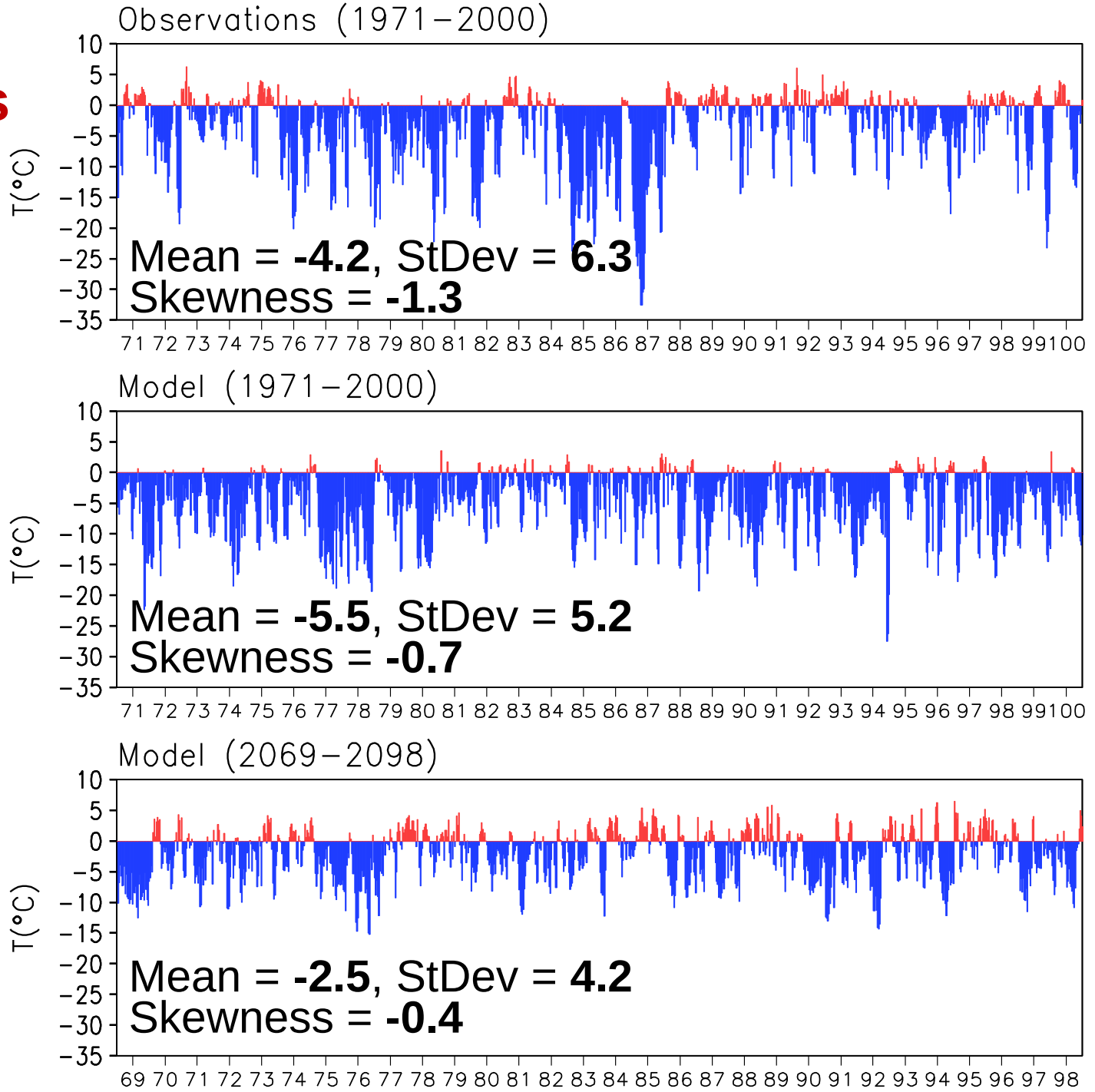
(in 2050-2099)



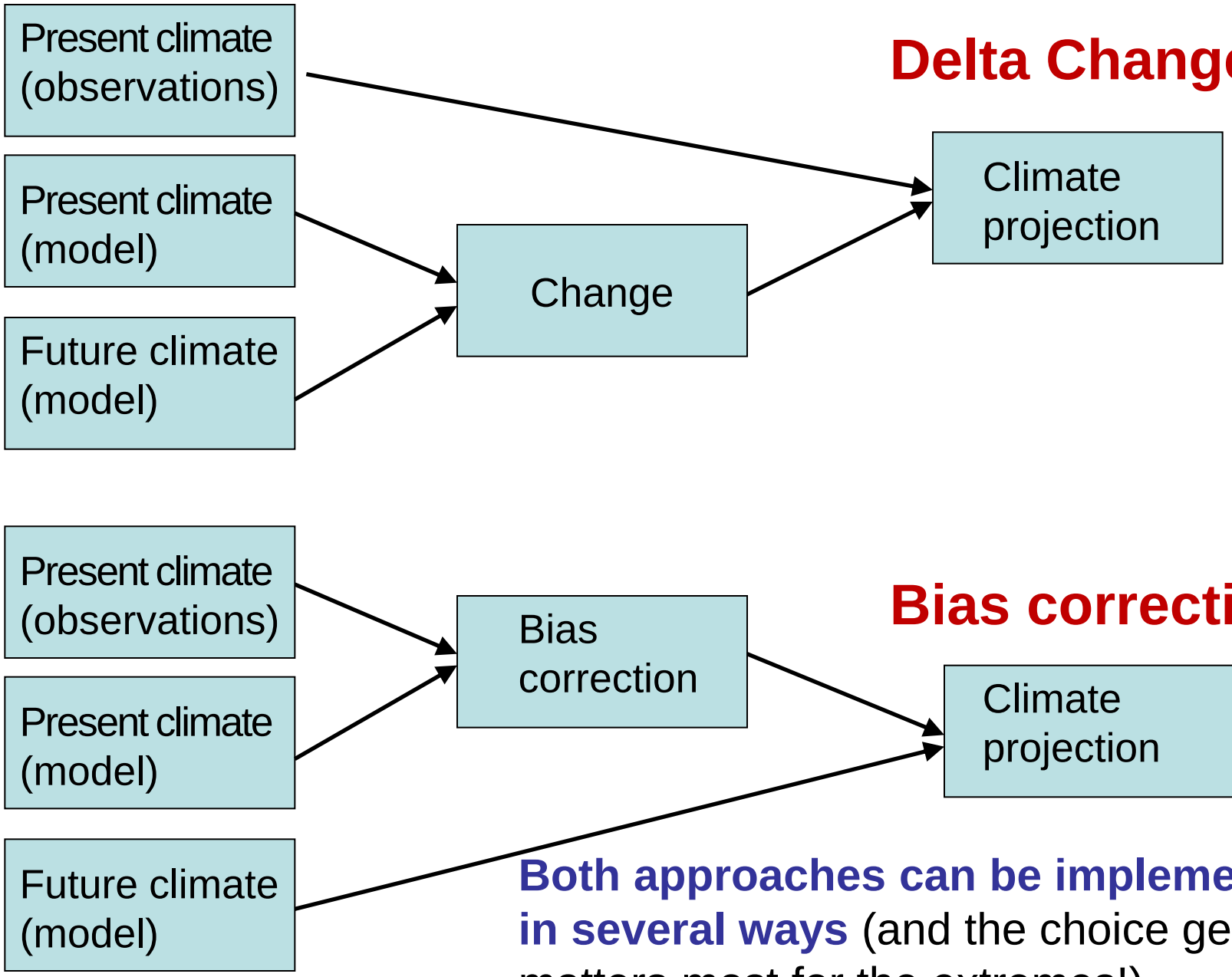
Challenges in estimating extremes in future climate

- **Effect of model error on simulated climate change**
  - Larger for extremes than mean values?
- **Estimation of climate change signal in models**
  - larger sampling variability in tails
  - estimates based on changes in ’bulk’ properties (mean, StDev etc.) may or may not be representative
- **Model error for present-day climate calls for bias correction or ’delta change’ methods**
  - Both require information of observed present-day climate
- **Observed present-day climate less well determined for extremes than the mean**
  - larger sampling variability in the tails

Daily mean temperatures in Helsinki in January



What about ”Observations 2069-2098”?



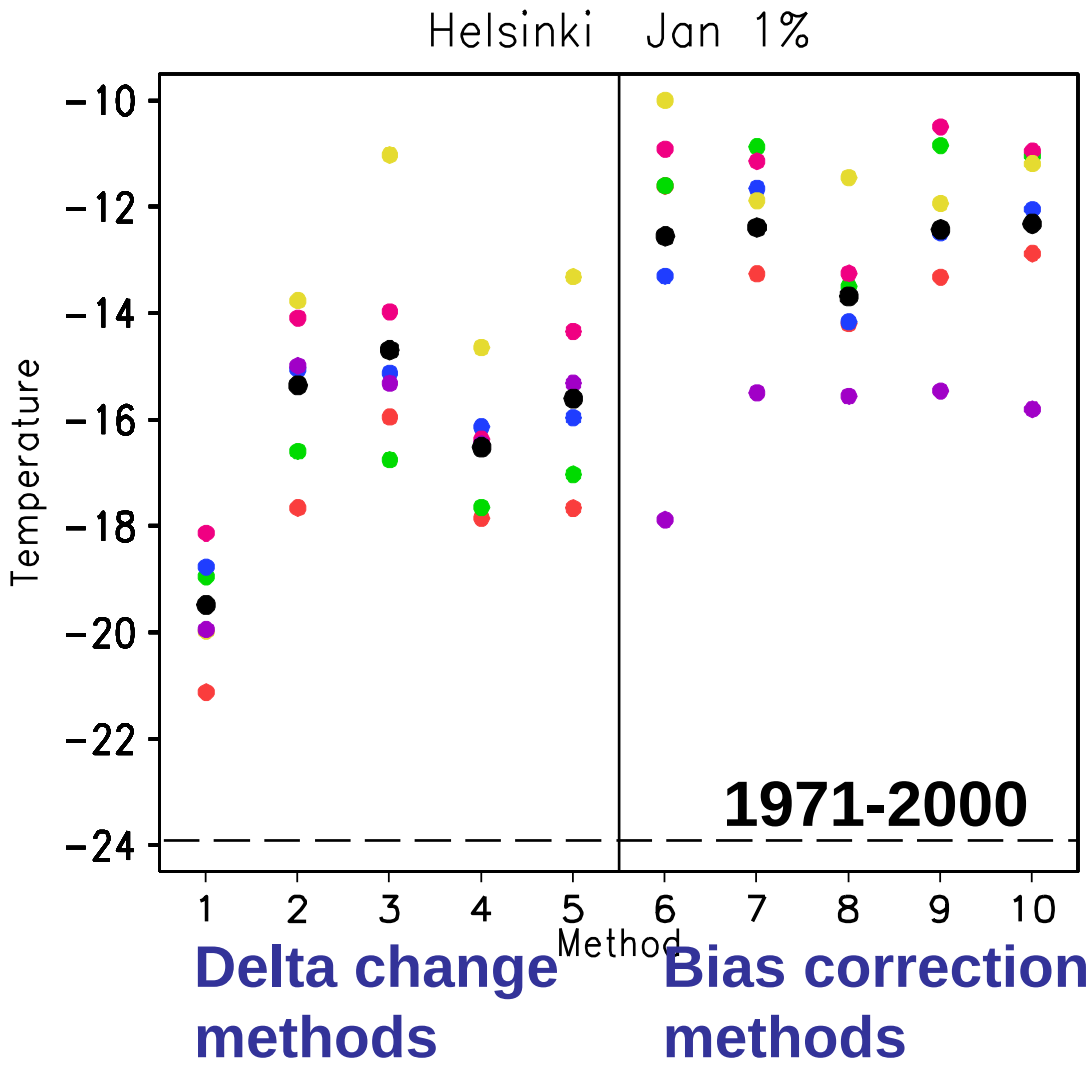
Both approaches can be implemented in several ways (and the choice generally matters most for the extremes!)

The next slide will show projections of the **1st percentile** of daily mean T in **Helsinki** in **January** in **2069-2098**, using **6 ENSEMBLES RCM simulations** and **10 projection methods**

changed / corrected	**Delta change**	**Bias correction**
Mean	1	6
Mean + StDev	2	7
Mean + StDev + Skewness	3	8
Quantile mapping (non-parametric)	4	9
Quantile mapping (linear fit)	5	10

- Details: Räisänen & Räty, Climate Dynamics (2013)

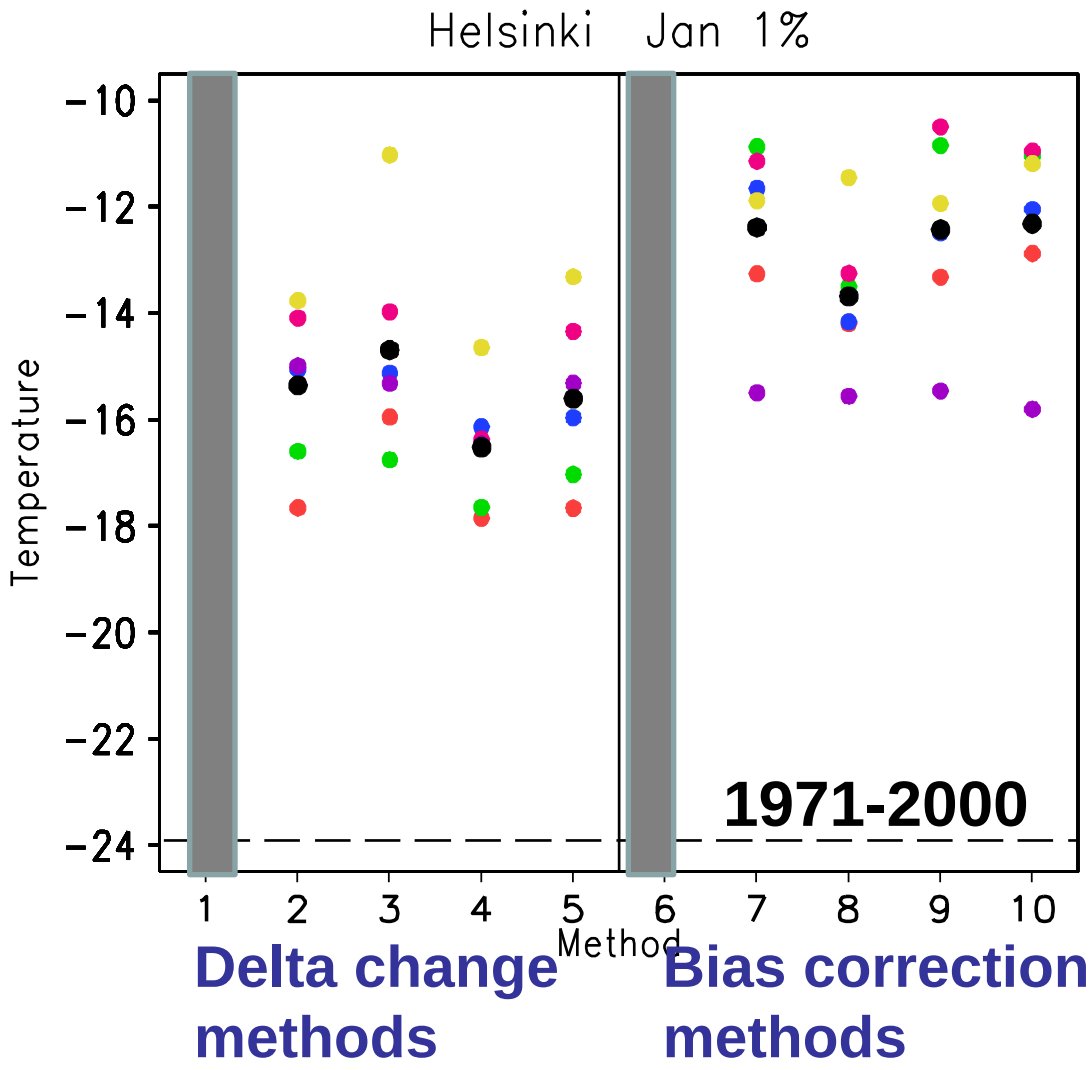
Example: 1st percentile of daily mean T in January, Helsinki, 2069-2098



Black = ensemble mean from 6 RCM simulations

Other colors: 6 RCM simulations separately

Example: 1st percentile of daily mean T in January, Helsinki, 2069-2098



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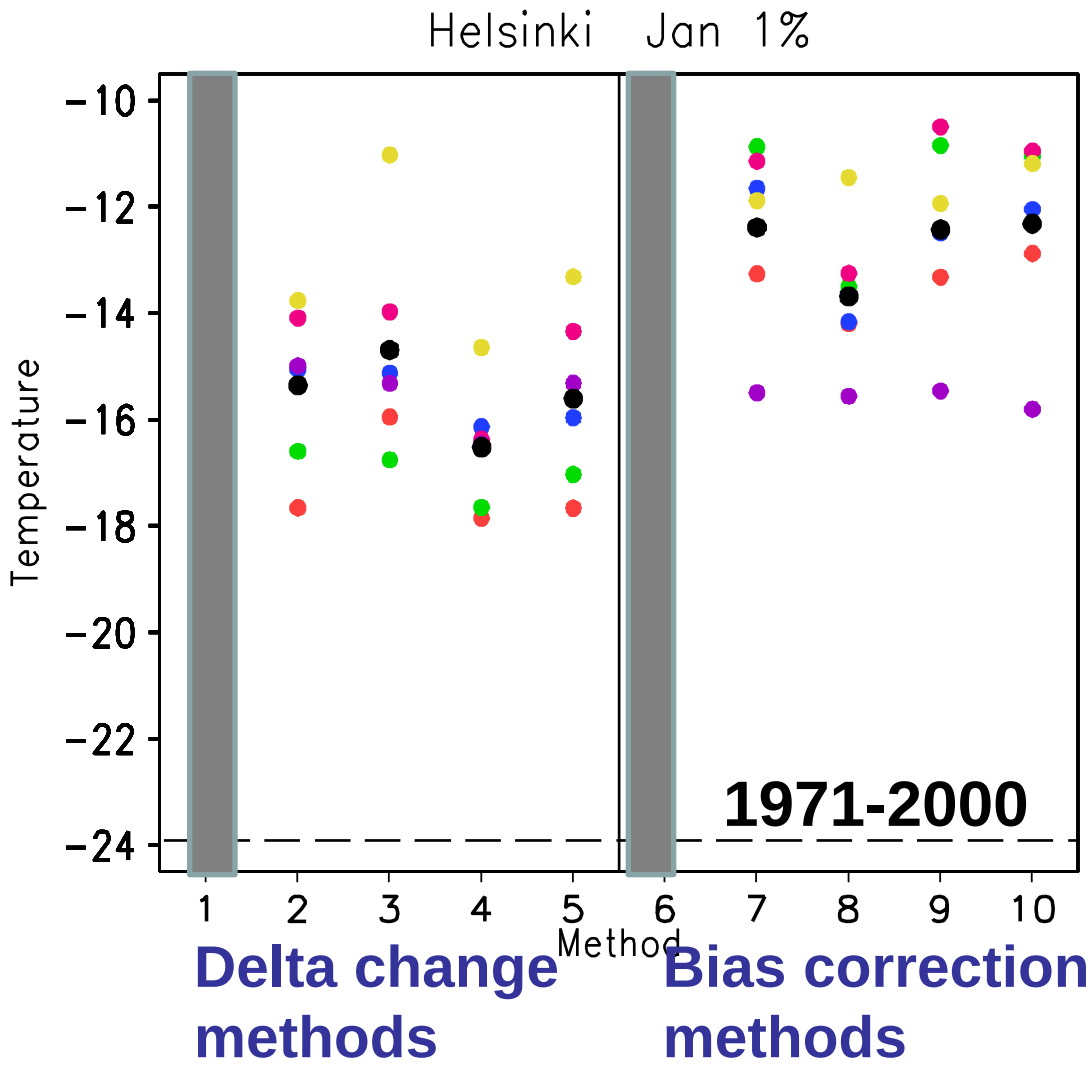

Substantial method-
(as well as model-)
dependence of the results, even when excluding two methods that perform badly in cross-validation tests

Key messages

- **Don’t mix changes in the magnitude and the frequency of extremes**
  - The latter are often larger than expected from the former
- **Changes in variability are not always more important than changes in the mean**
- **A narrower present-day distribution translates into a larger change in the frequency of extremes**
  - Daily vs. monthly temperatures
  - Tropics vs. higher latitudes
- **Projections of future extremes sensitive to both the model used and the delta change / bias correction method chosen**