Uncertainties in projections of climate change

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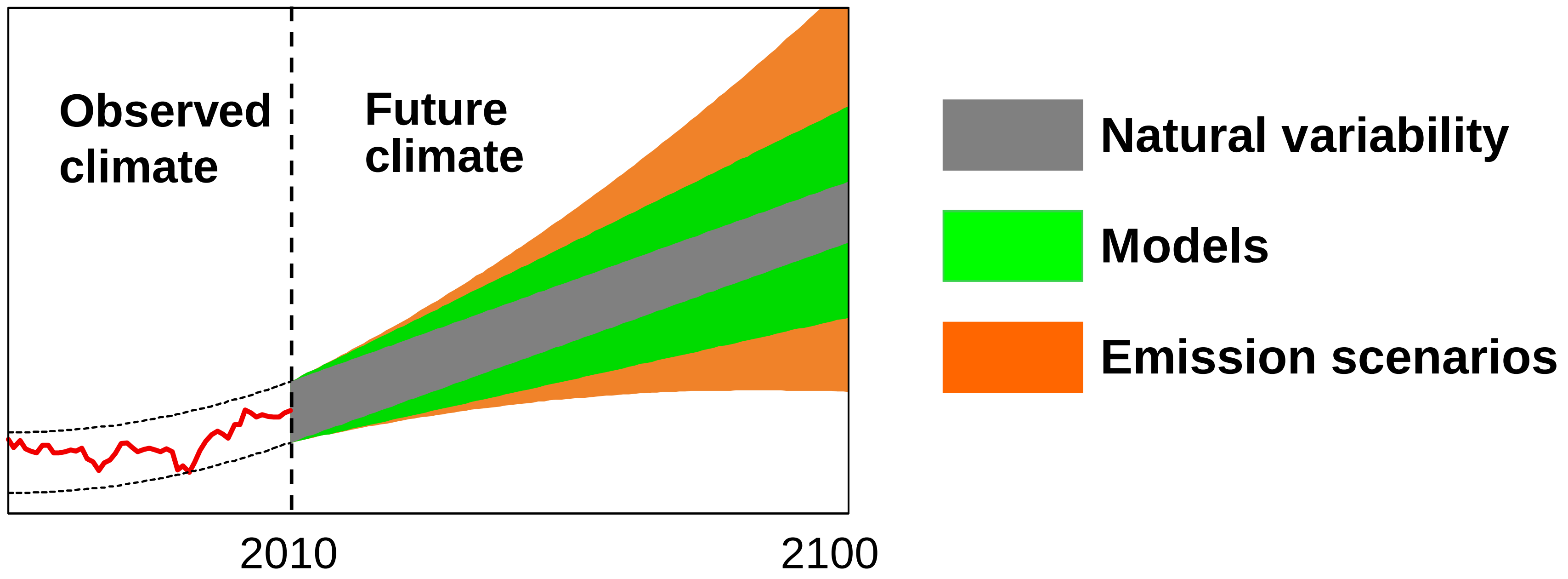
Sources of uncertainty in climate change projection

- **Emission scenarios**
  - Future behaviour of mankind
- **Modelling uncertainty**
  - Climate response to changes in atmospheric composition
  - Modelling of carbon cycle, etc.
- **Natural climate variability**
  - Solar activity, volcanic eruptions
  - Internal (=unforced) variability generated by the non-linear dynamics of the climate system

Uncertainties in climate change - a schematic view



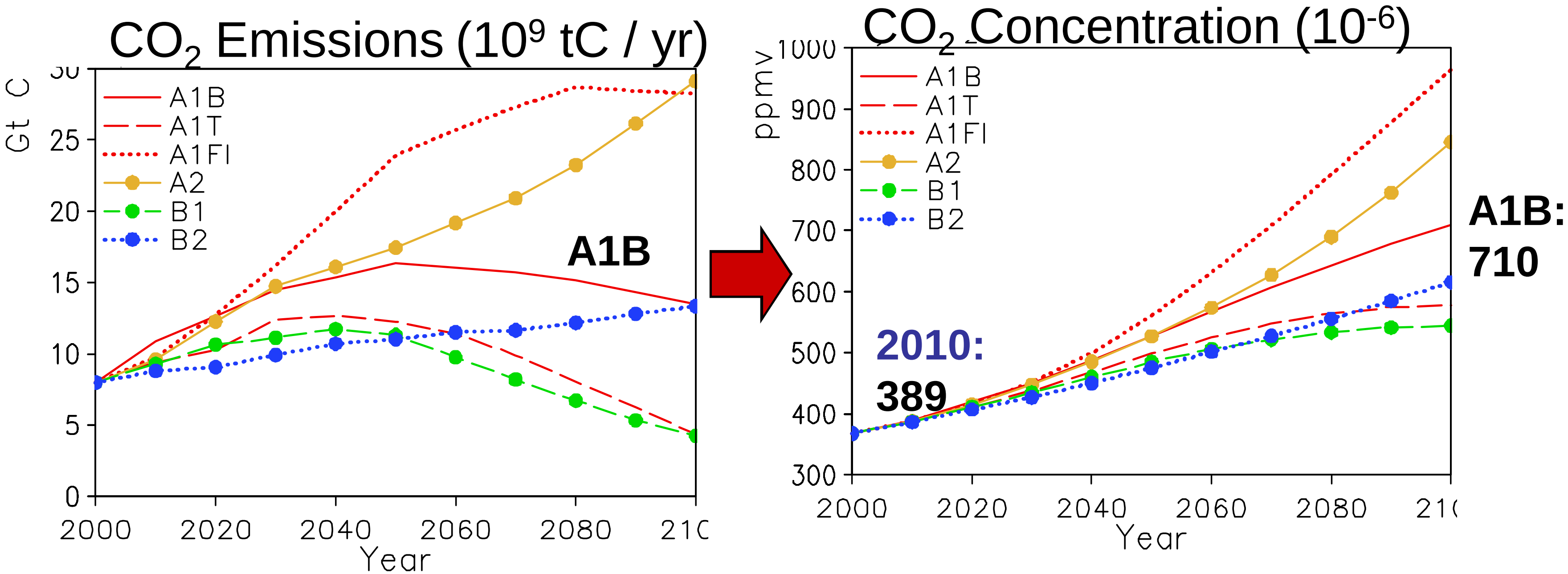
- **Modelling uncertainty increases with increasing greenhouse gas forcing**

- **Scenario uncertainty increases as emission scenarios diverge,** with time lag caused by the delayed response of concentrations to changes in emissions

Rest of the talk

- **Parts 1-2:** attempts to quantify the three sources of uncertainty, based on the variation of global climate model results
- **Part 3:** attempts to estimate present-day (~2010) temperature climate
- **The uncertainty in the real world may be larger than the model results suggest, because**
  - The range of emission scenarios used may not cover the full range of possibilities
  - Models may not be different enough
  - Some components of modelling and forcing uncertainty are not considered in the simulations

Part 1:
climate change under the A1B scenario



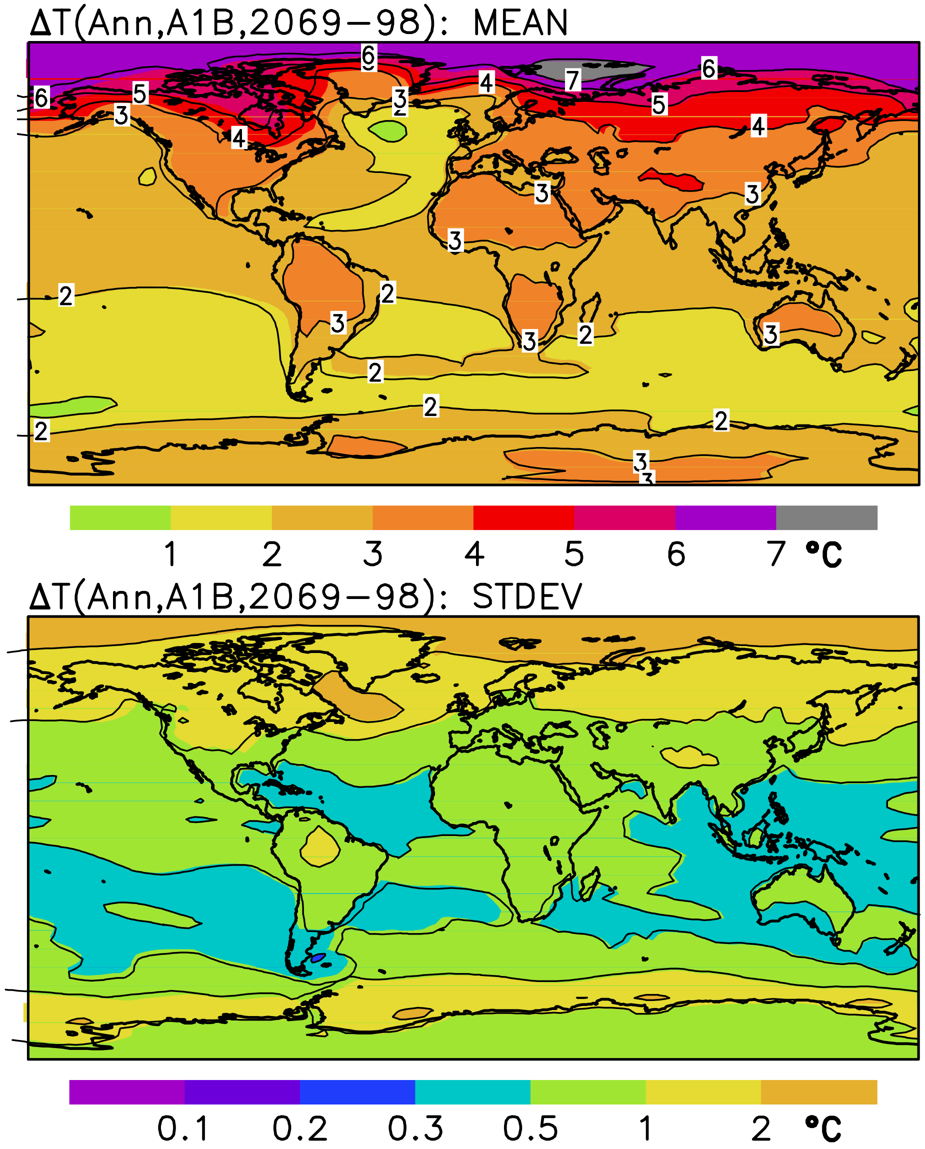
Questions

- **How well do climate models agree with each other?**
- **How much of the differences in climate change can be explained by simulated internal variability?**

Data set used (CMIP3, Meehl et al. 2007)

- **51** simulations by **22** global climate models
  - **1** to **7** simulations per model, with different initial conditions to generate different realizations of internal variability
  - Carbon cycle uncertainty and forced (Sun, volcanoes) natural variability excluded

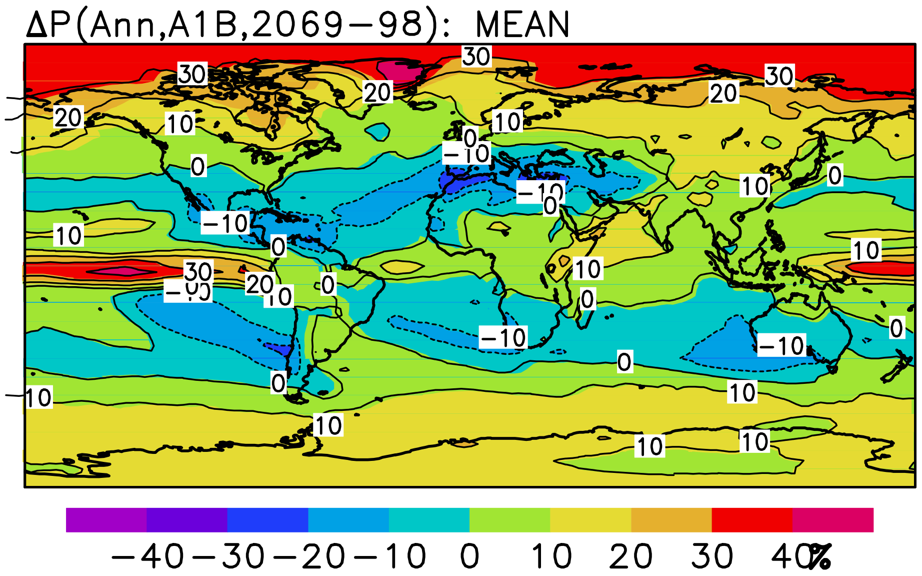
Annual mean temperature change, from 1971-2000 **to** 2069-2098

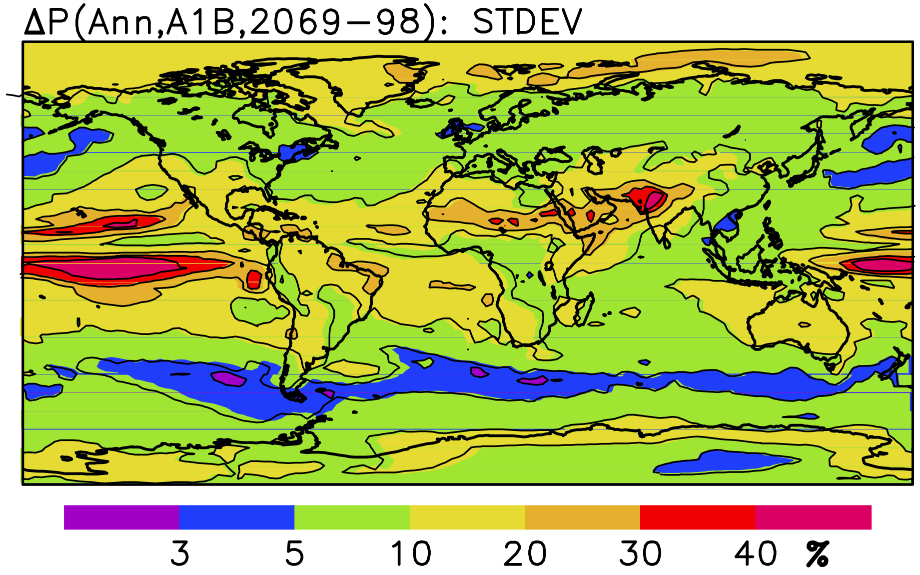


22-model mean temperature change (top) generally much larger than the **standard deviation** between the simulations (bottom).

Both are largest over the Arctic

Annual mean precipitation change, from 1971-2000 **to** 2069-2098

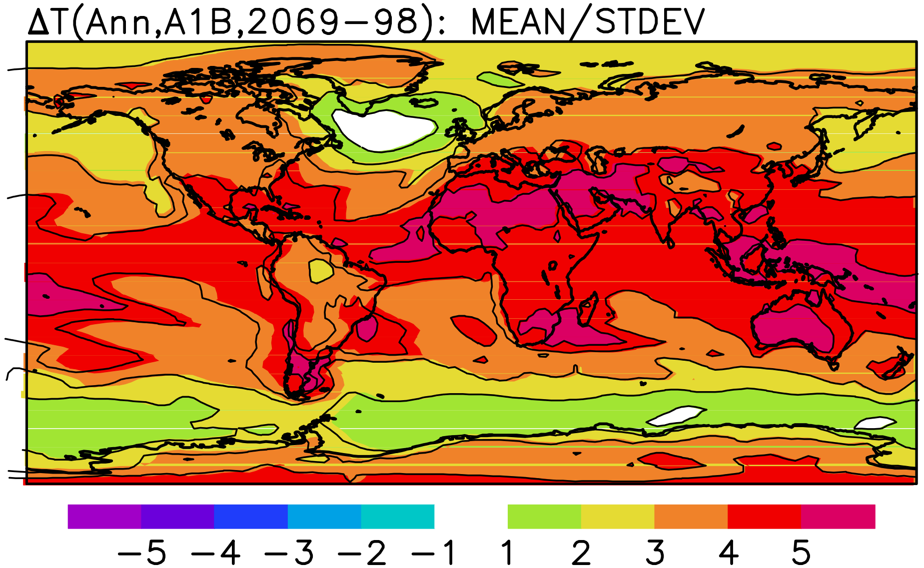


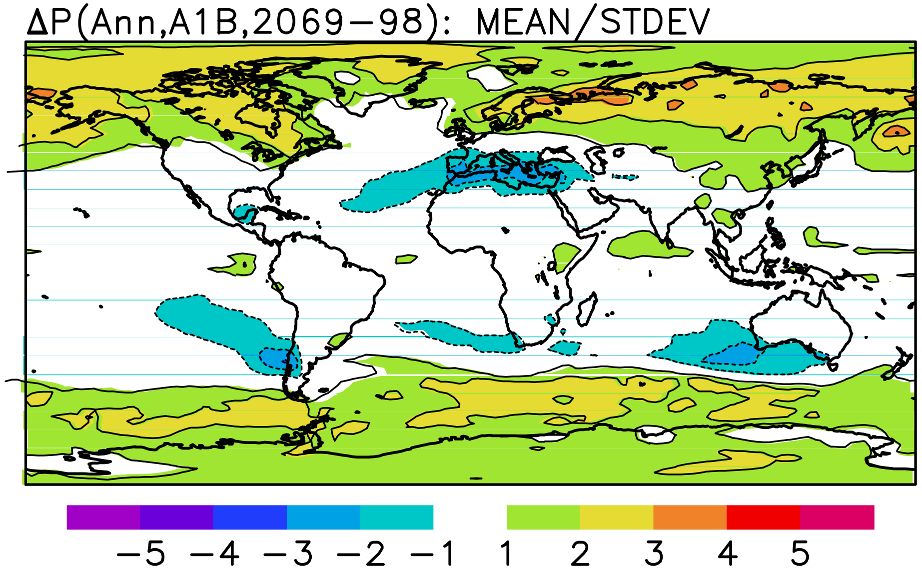


22-model mean precipitation change (top) and the **standard deviation** between the simulations (bottom) are comparable with each other.

Minimum in standard deviation in higher midlatitudes.

Annual mean T and P change:
ratio mean / standard deviation





1) Better relative agreement for temperature than precipitation
2) Best agreement on temperature change in the tropics
3) Best agreement on precipitation increase over northern Eurasia

Rule-of-thumb interpretation

R = 1: 5 models out of 6 agree on the sign of change

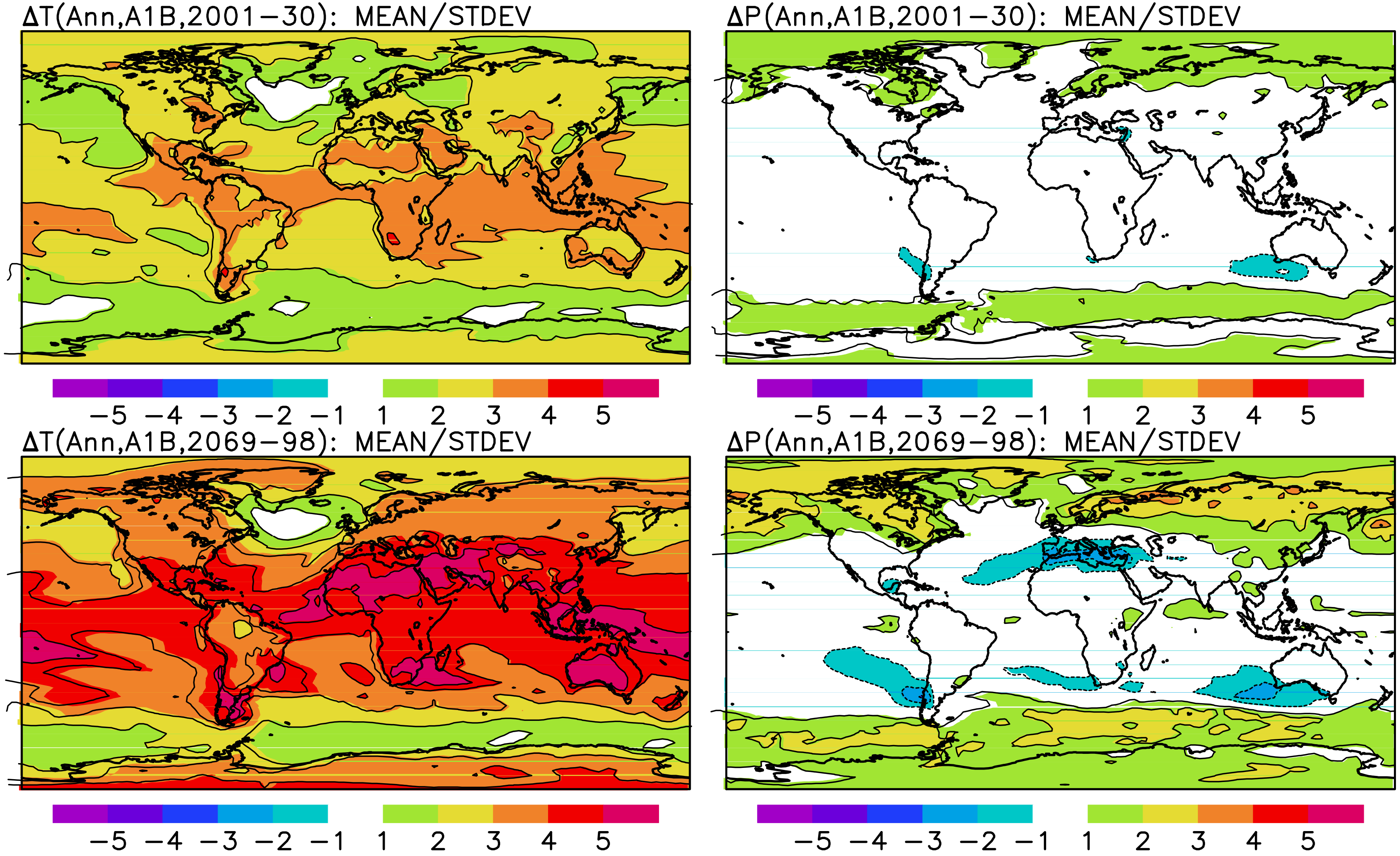
R > 2: virtually all models agree on the sign of change

The relative agreement between model simulations improves with time, as the common signal grows stronger…

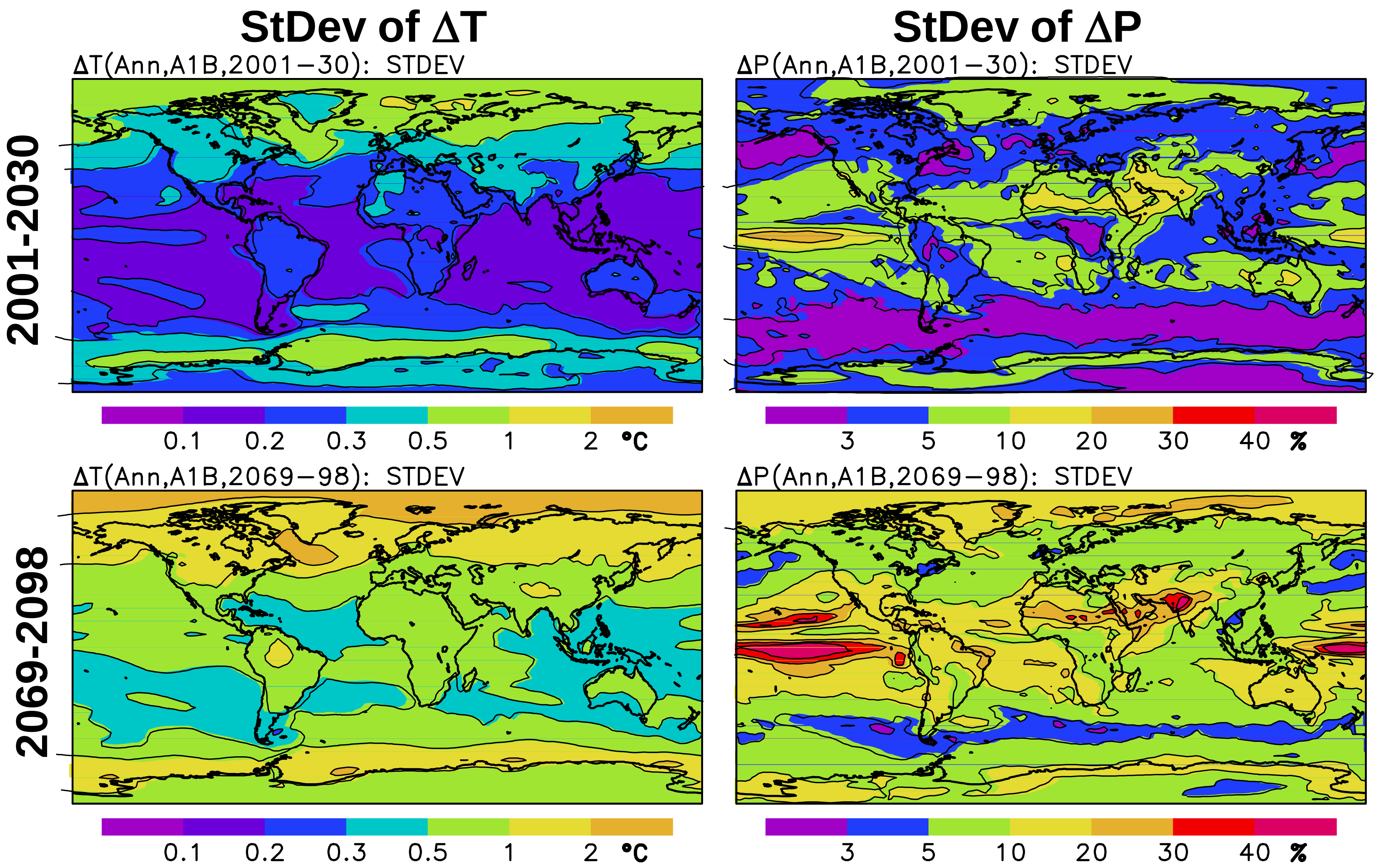
Mean / StDev of ΔT **Mean / StDev of ΔP**

2001-2030

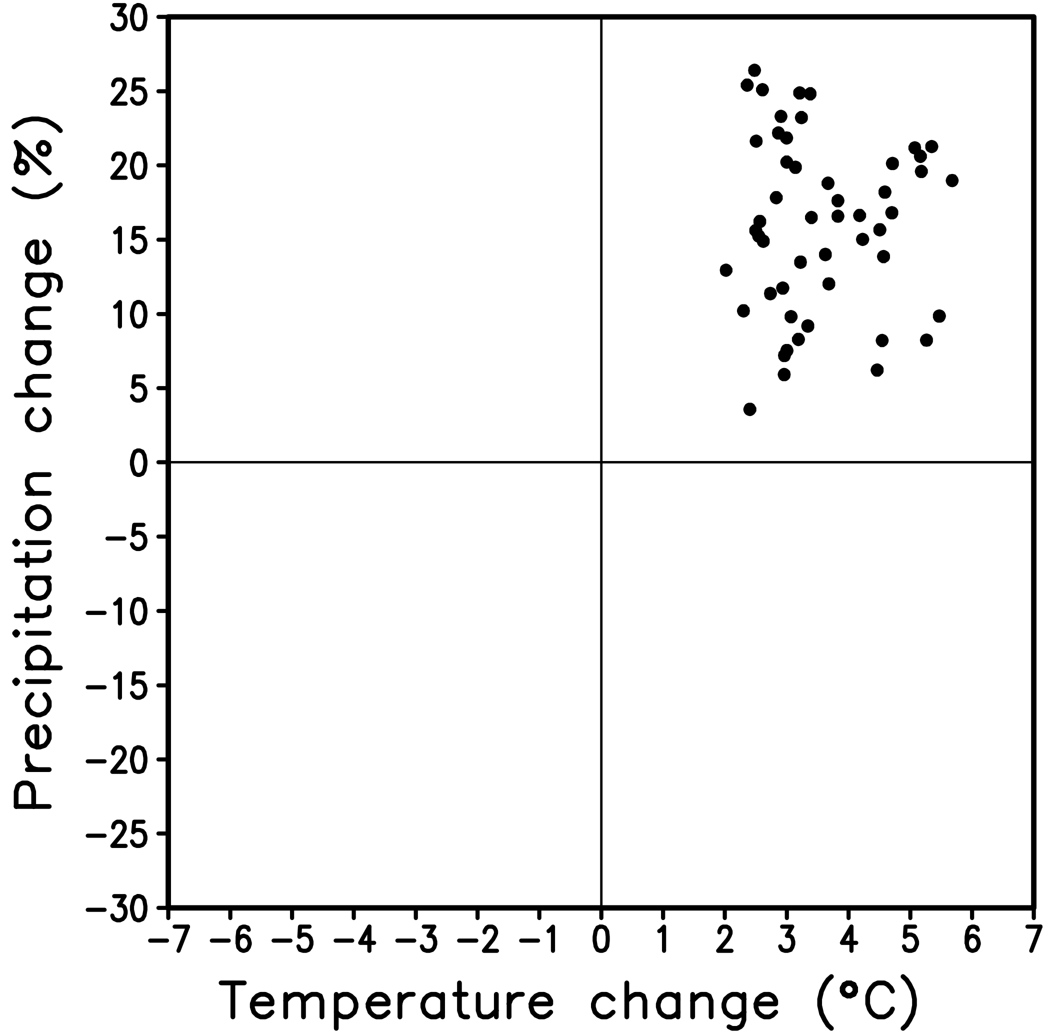
2069-2098



… but absolute differences nevertheless increase with time!



Annual mean T and P changes, from 1971-2000 to 2069-2098, in southern Finland (60°N, 25°E)



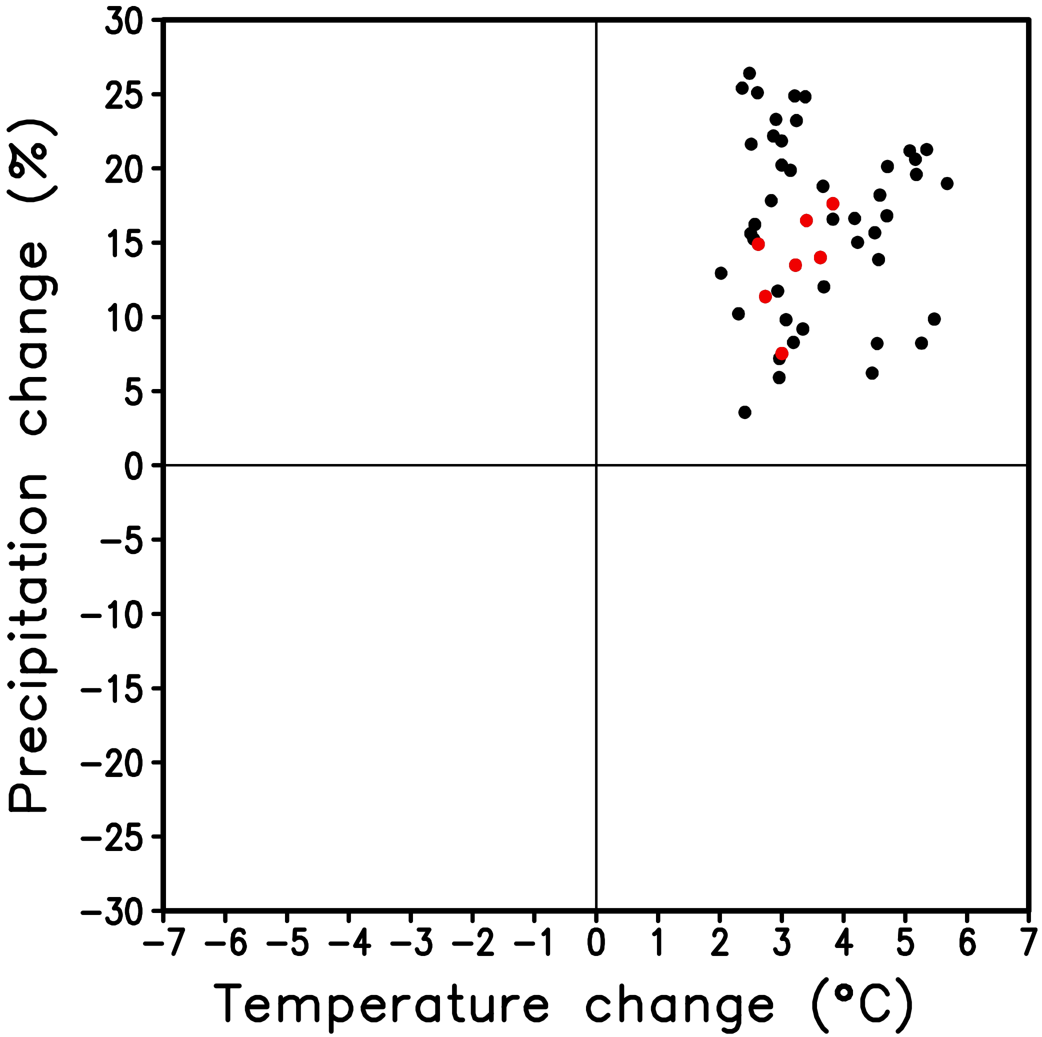
51 simulations by **22 models**, all for A1B scenario

How much of the variability is caused

a) genuinely by model differences?

b) by internal climate variability in the simulations?

Annual mean T and P changes, from 1971-2000 to 2069-2098, in southern Finland (60°N, 25°E)



51 simulations by **22 models**, all for A1B scenario

Red dots:
7 simulations by one model (NCAR-CCSM3) from **different initial conditions**

Implication:
Internal variability far from sufficient to explain all differences in simulated climate change

A more quantitative analysis

- Estimate the **variance caused by internal variability** from **within-model variability of climate changes** (i.e., differences between simulations made with the same model but different initial conditions)

$$V_{INT} = \left[\sum_{i=1}^{M} \sum_{k=1}^{N_i} (x_{ik} - \bar{x}_i)^2 \right] / \sum_{i=1}^{M} (N_i - 1)$$

M = 22 = number of models
N_i = 1-7 = number of simulations for model i

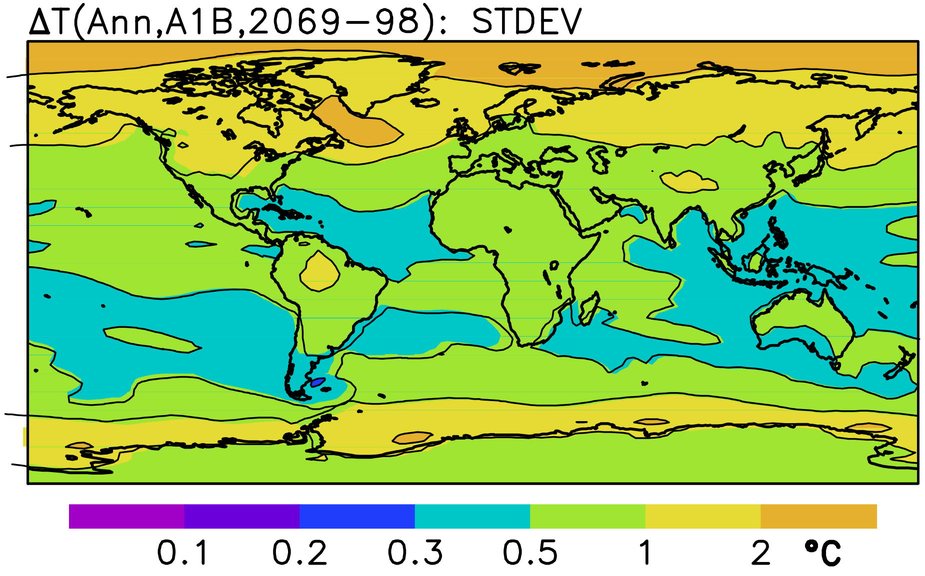
- By implication: **variance caused by model differences** is

$$V_{MOD} = V_{TOT} - V_{INT} \text{ (+sampling uncertainty)}$$

where V_{TOT} is the total variance between individual simulations made by different models

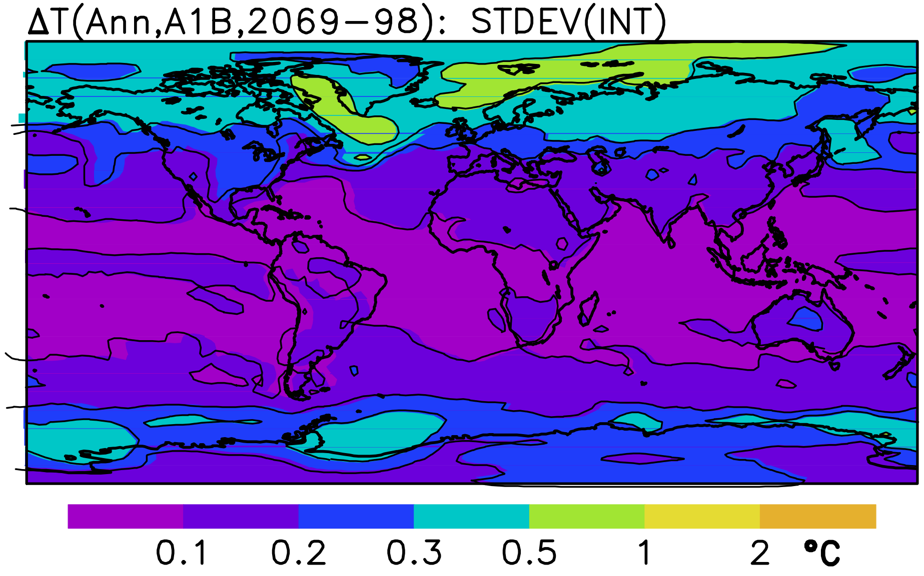
Annual mean T change from 1971-2000 to 2069-2098, A1B scen.

Total standard deviation
(model diff. + internal variability)



Variance = 0.70(°C)^2

Standard deviation explained by internal variability

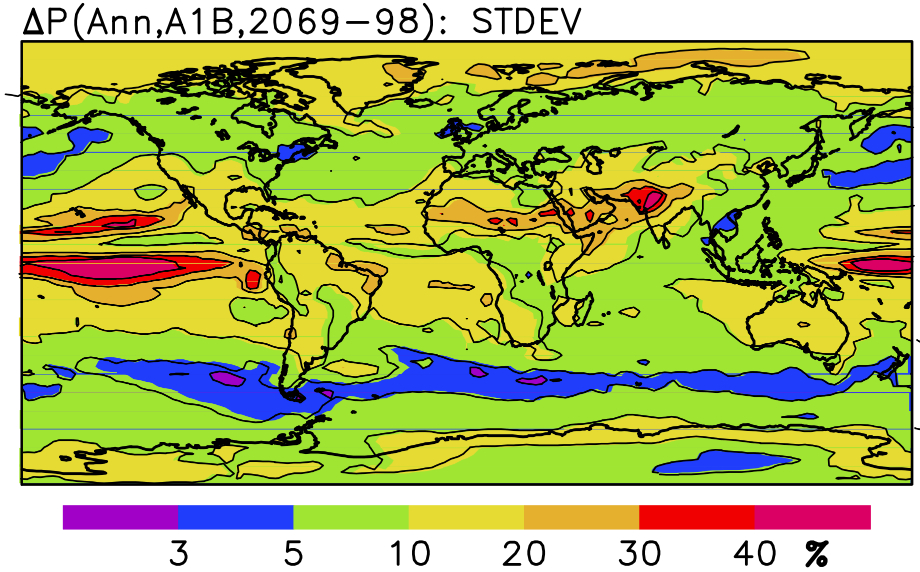


Variance = 0.035(°C)^2

Internal variability explains (on the average) **only 5%** of the variance of temperature changes → model differeces dominate!

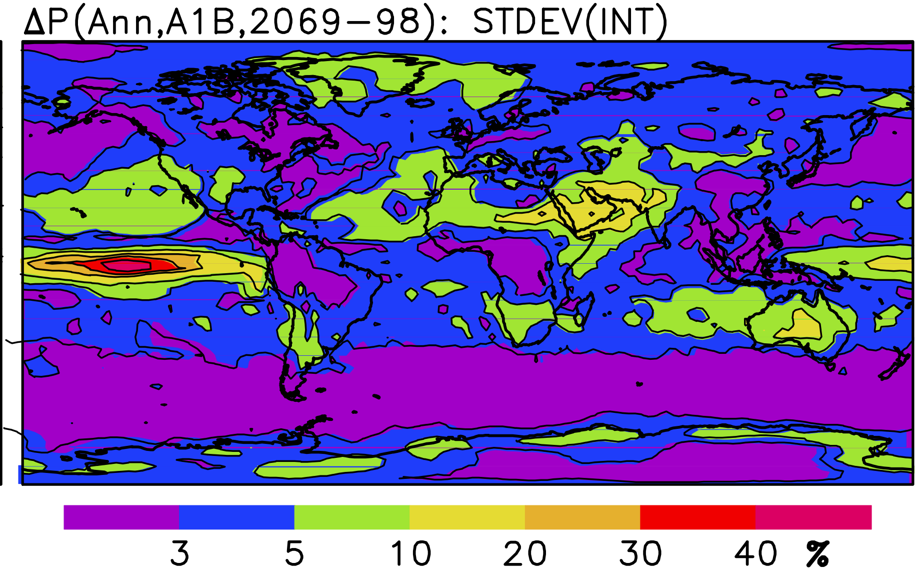
Annual mean P change from 1971-2000 to 2069-2098, A1B scen.

Total standard deviation
(model diff. + internal variability)



Variance = 184 $(\%)^2$

Standard deviation explained by internal variability

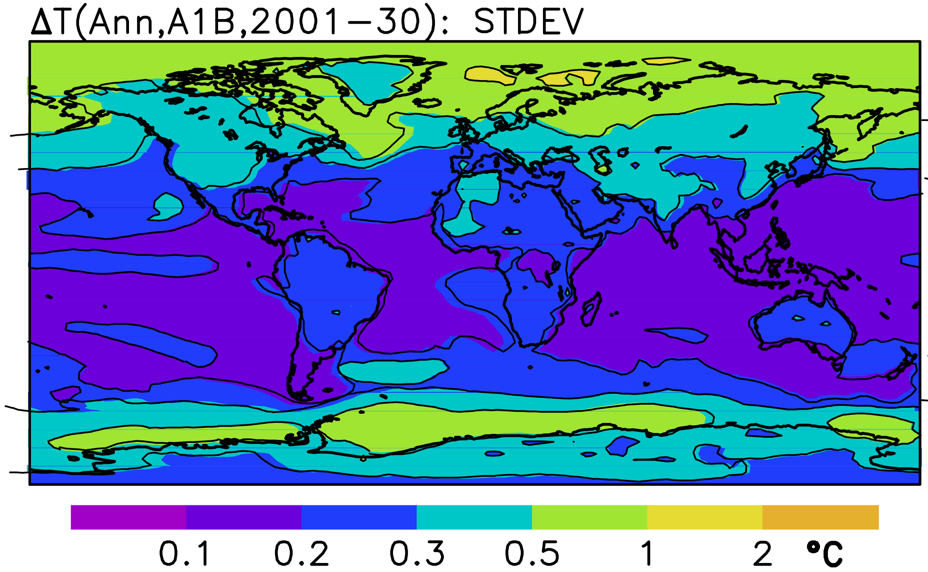


Variance = 35 $(\%)^2$

Internal variability explains (on the average) **19%** of the variance of precipitation changes → model differences dominate, but not as much as for temperature.

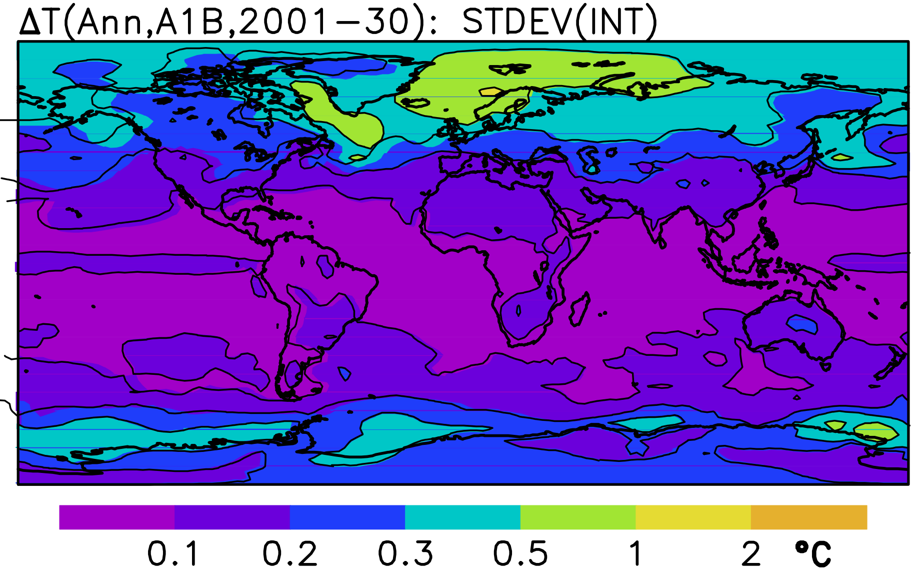
Annual mean T change from 1971-2000 to 2001-2030, A1B scen.

Total standard deviation
(model diff. + internal variability)



Variance = 0.10(°C)^2

Standard deviation explained by internal variability

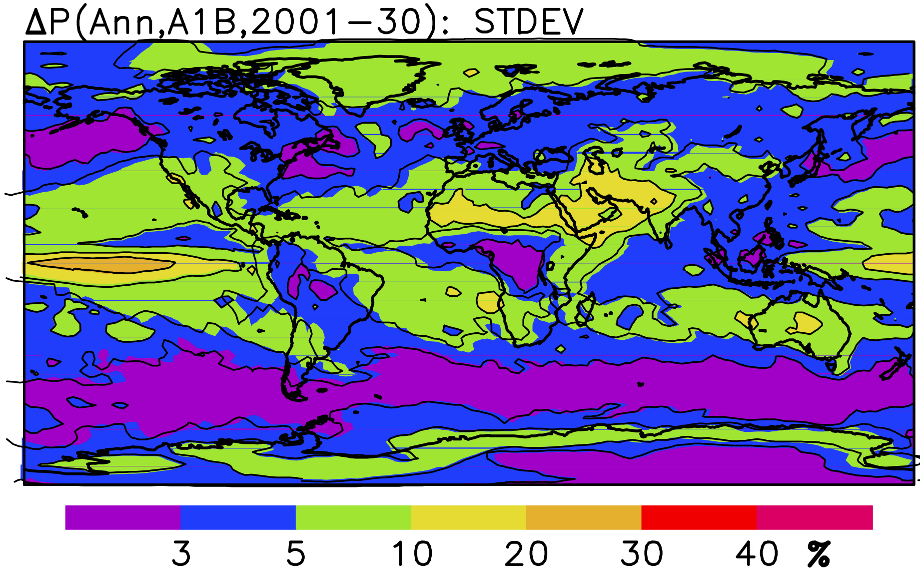


Variance = 0.038(°C)^2

Internal variability explains (on the average) **38%** of the variance of temperature changes to 2001-2030.

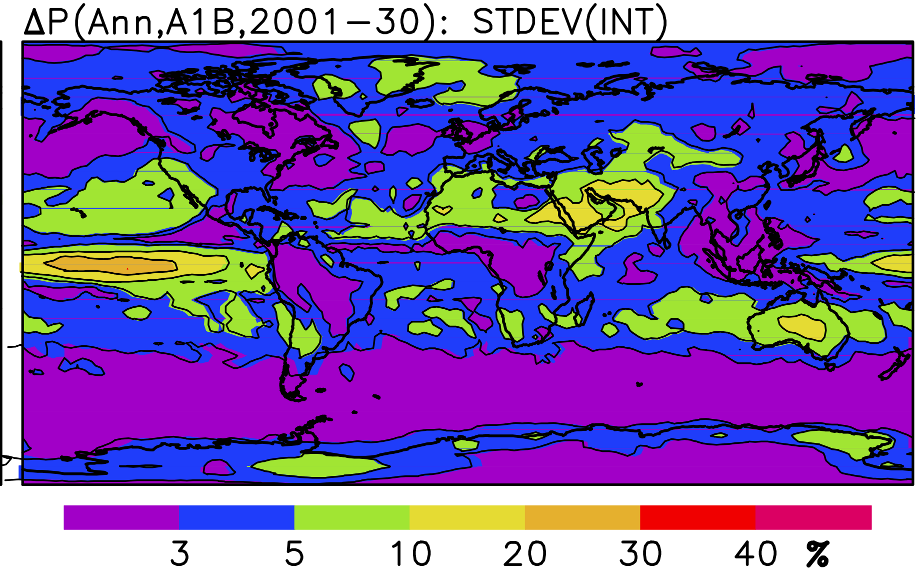
Annual mean P change from 1971-2000 to 2001-2030, A1B scen.

Total standard deviation
(model diff. + internal variability)



Variance = 37 (%)^2

Standard deviation explained by internal variability



Variance = 26 (%)^2

Internal variability explains (on the average) **71%** of the variance of precipitation changes to 2001-2030
→ model differences play a secondary role.

Contribution of internal variability to the variance of climate changes

(global means for grid box scale data)

Temperature

Change from 1971-2000 to	Annual means	Seasonal means	Monthly means
2069-2098	5%	7%	10%
2035-2064	12%	16%	22%
2001-2030	38%	46%	56%
2011-2020	46%	56%	66%

Precipitation

Change from 1971-2000 to	Annual means	Seasonal means	Monthly means
2069-2098	19%	27%	38%
2035-2064	30%	44%	56%
2001-2030	71%	77%	82%
2011-2020	80%	83%	85%

Same for Northern Europe (50-70ºN, 0-40ºE)

Temperature

Change from 1971-2000 to	Annual means	Seasonal means	Monthly means
2069-2098	**11%**	**14%**	**18%**
2035-2064	**25%**	**29%**	**36%**
2001-2030	**92%**	**90%**	**84%**
2011-2020	**96%**	**94%**	**86%**

Precipitation

Change from 1971-2000 to	Annual means	Seasonal means	Monthly means
2069-2098	**31%**	**35%**	**50%**
2035-2064	**51%**	**52%**	**67%**
2001-2030	**97%**	**88%**	**94%**
2011-2020	**86%**	**87%**	**92%**

Internal variability more important in northern Europe than global statistics would suggest (although sampling noise may become a problem when calculating statistics from a small area)

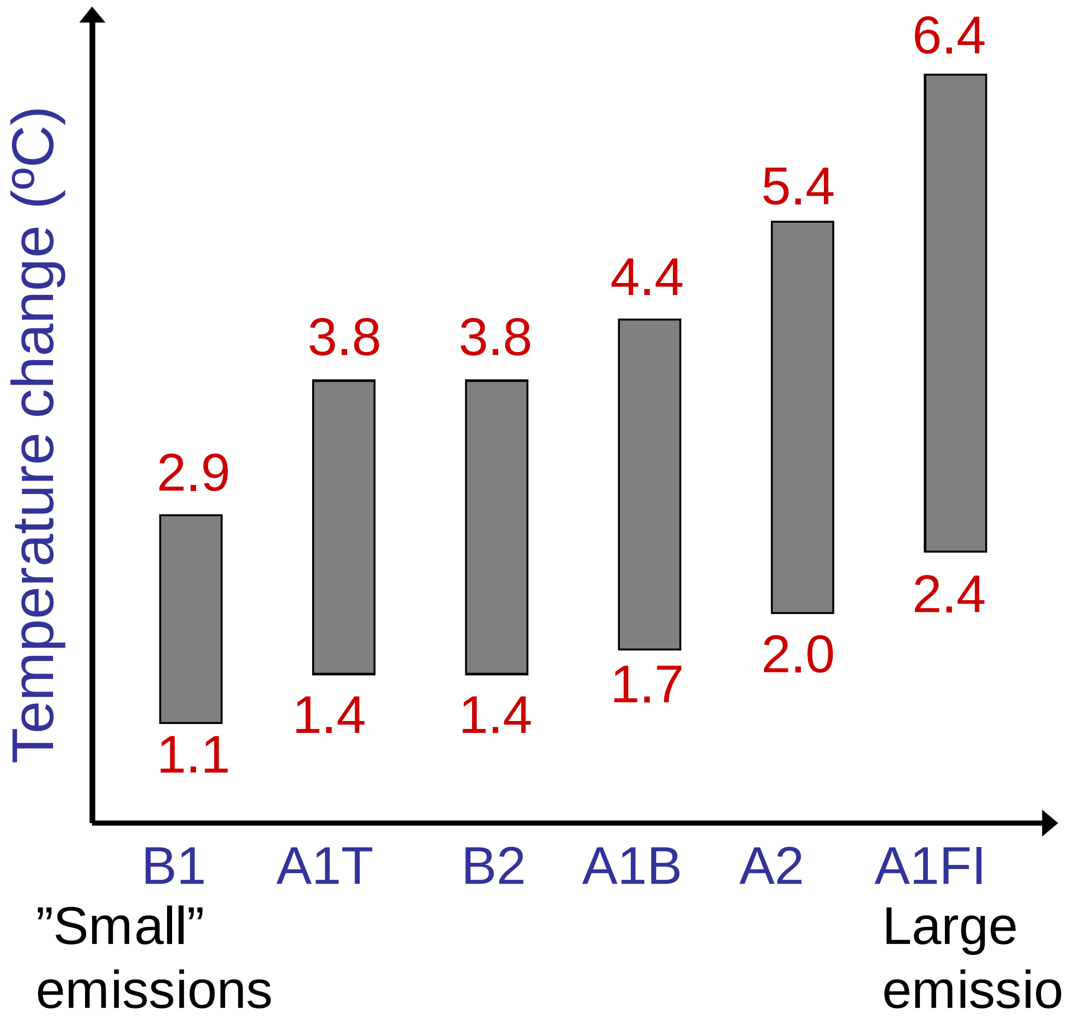
Uncertainty due to internal variability

- **Increases with decreasing averaging**
  - Monthly means > Seasonal means > Annual means
  - 10-year means > 30-year means
  - Grid point data >> global mean values
- **Is relatively most important for short-term climate change**
  - Other uncertainties (and climate change signal) increase with time
- **Is relatively more important for precipitation than temperature**
- **Is relatively more important in northern Europe than in most other areas**
  - very large natural temperature variability, particularly in winter
  - model-related differences in precipitation change smaller than in many other regions

Part 2:

What about different emission scenarios?

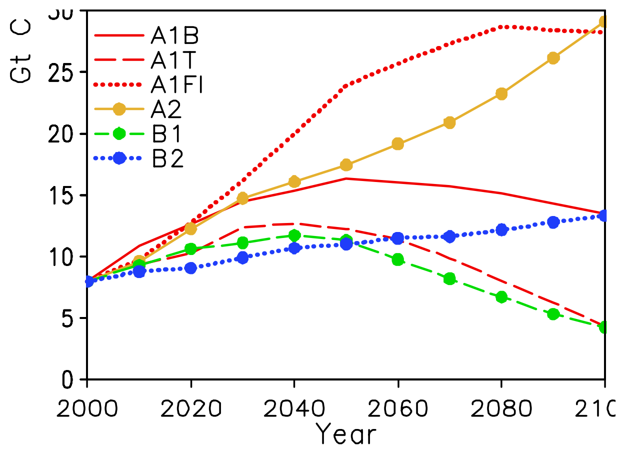
Projected change in global mean temperature, from 1990 to 2095



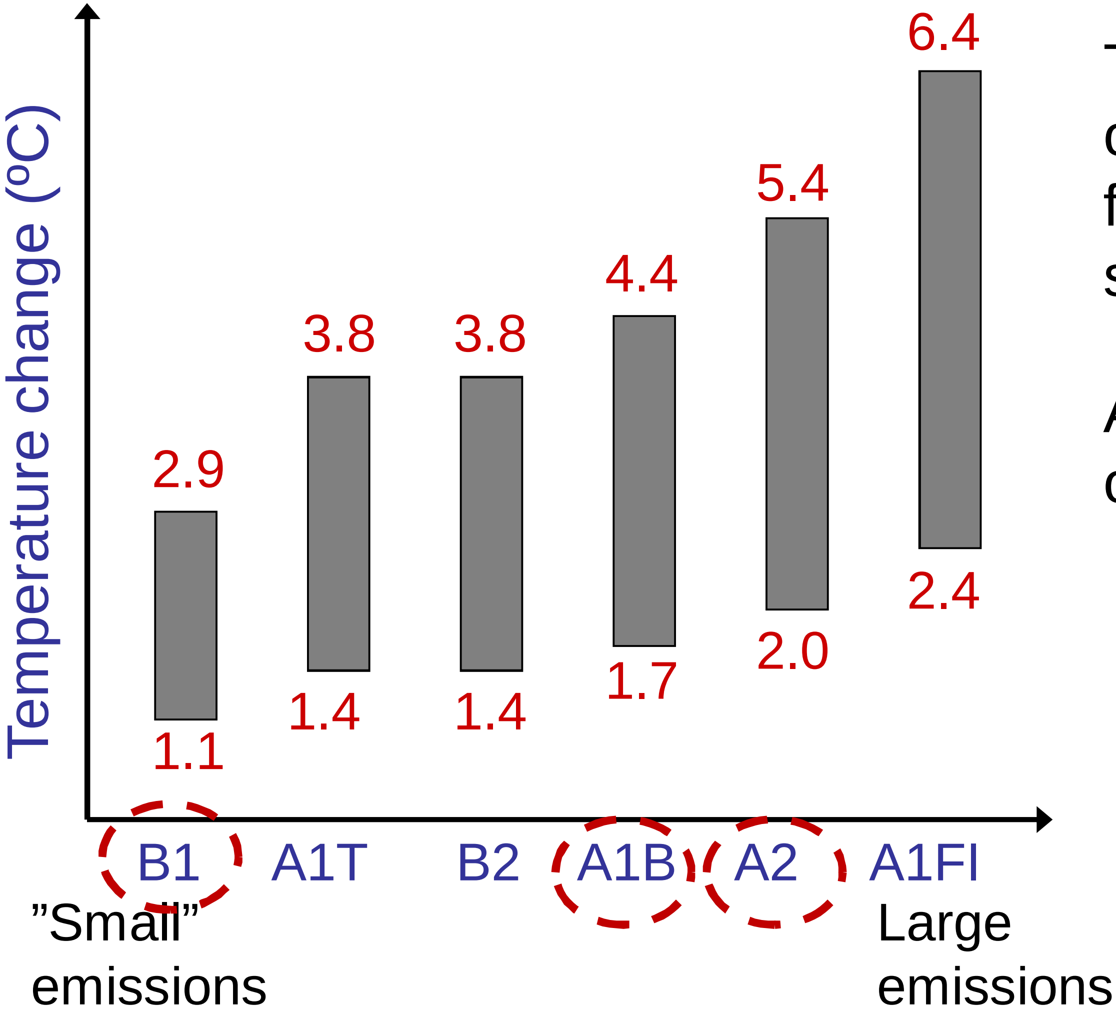
Uncertainties taken into account

(i) climate models

(ii) carbon cycle



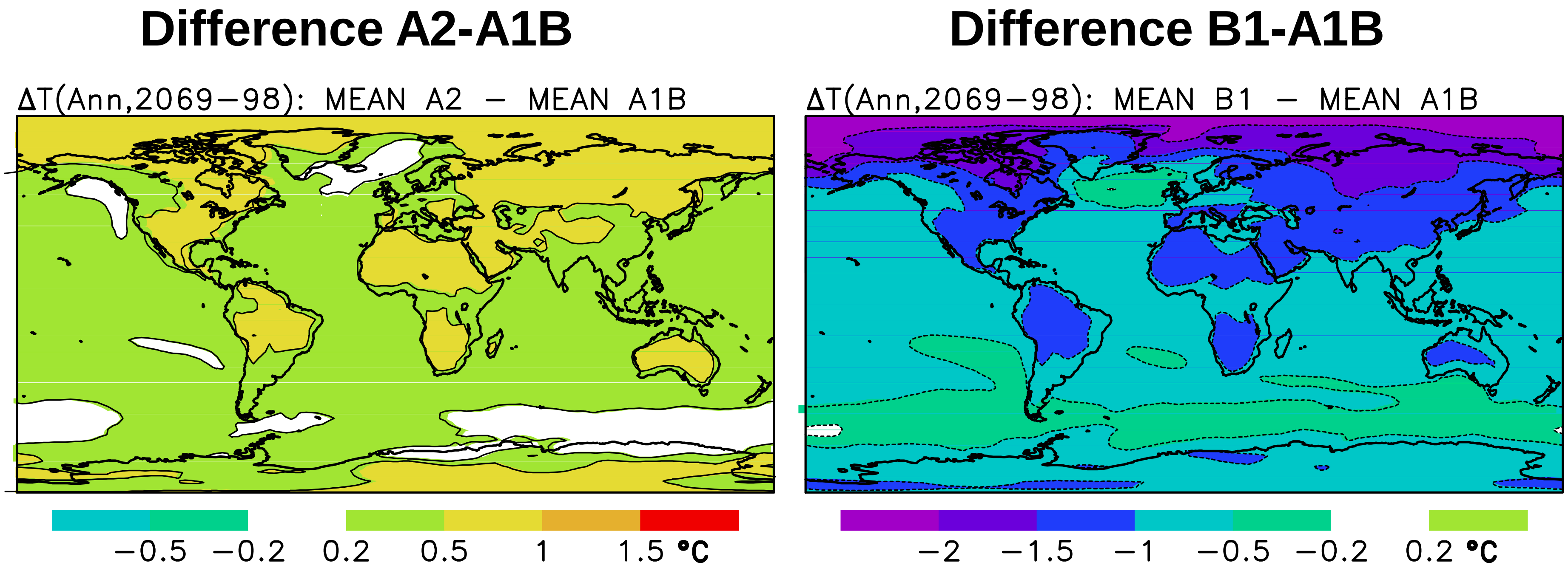
Projected change in global mean temperature, from 1990 **to** 2095



The CMIP3 data set only includes simulations for the **B1**, **A1B** and **A2** scenarios.

All three scenarios are only available for **15** models.

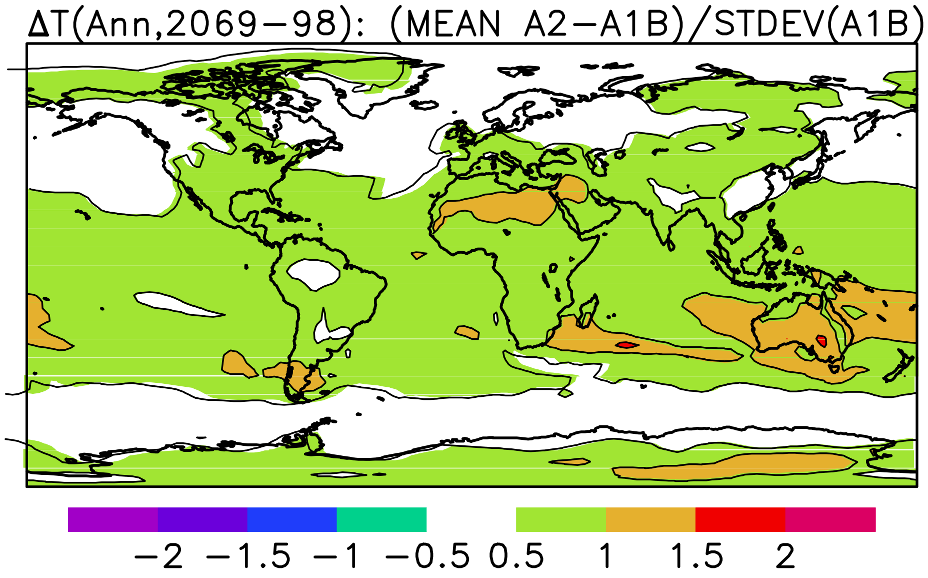
15-model mean temperature change from 1971-2000 to 2069-2098



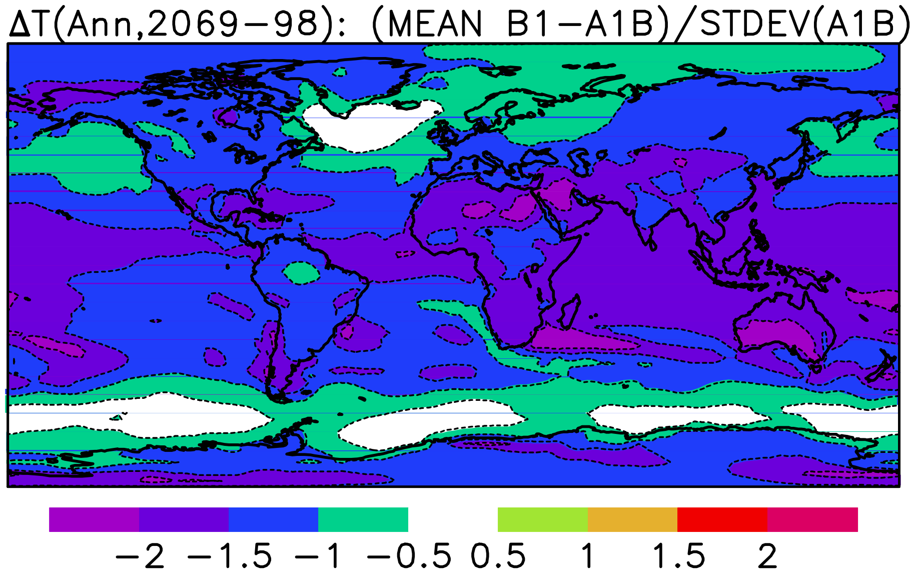
These differences are substantial (particularly for B1-A1B), but how do they compare with differences between different models under the same scenario?

15-model mean temperature change from 1971-2000 to 2069-2098

Difference A2-A1B / StDev of A1B simulations



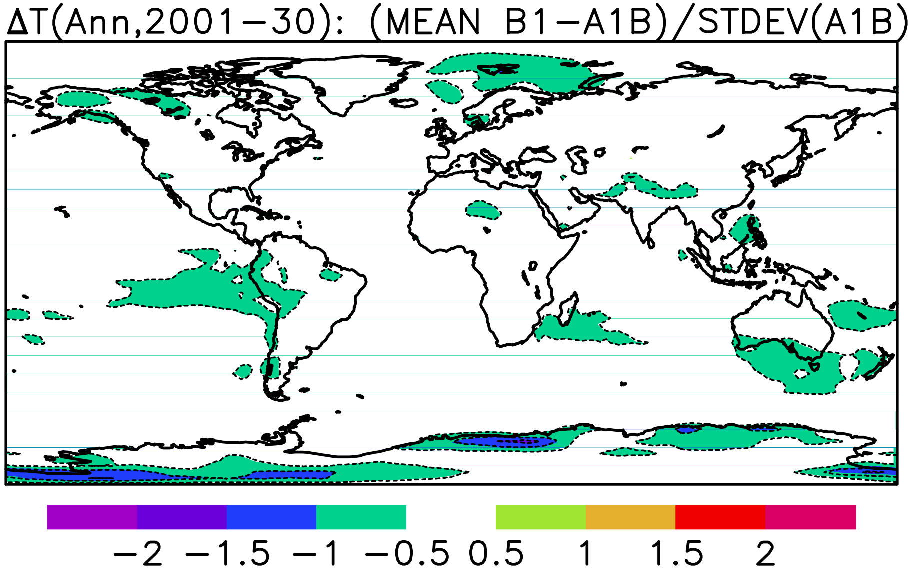
Difference B1-A1B / StDev of A1B simulations



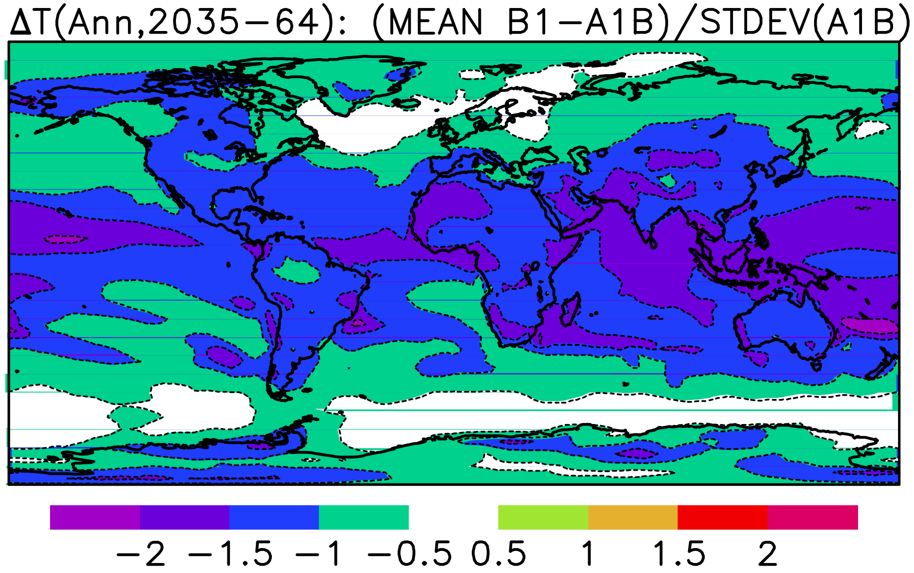
For late 21st century temperature change, differences between scenarios are comparable with differences between climate models

15-model mean temperature change from 1971-2000 to 2001-2030 and 2035-2064

Difference B1-A1B (2001-2030)
StDev of A1B simulations



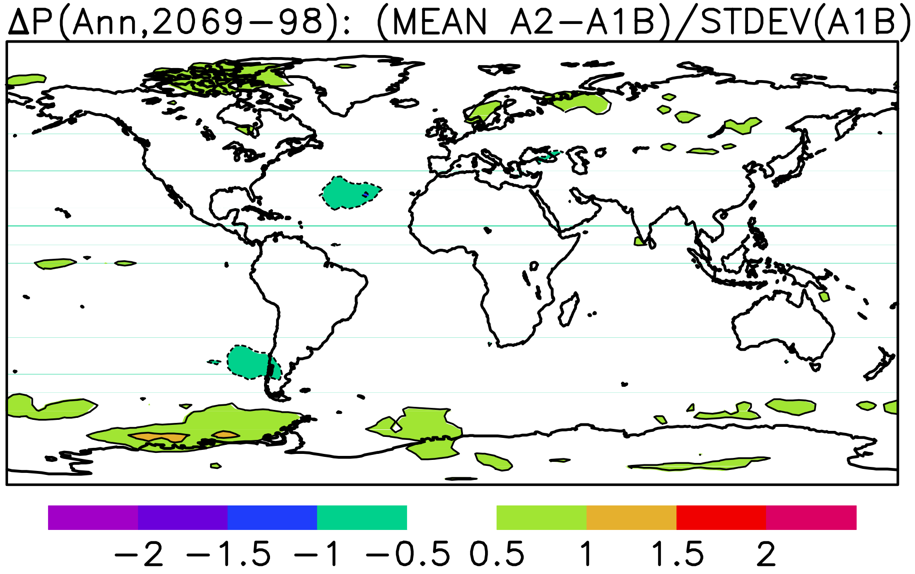
Difference B1-A1B (2035-2064)
StDev of A1B simulations



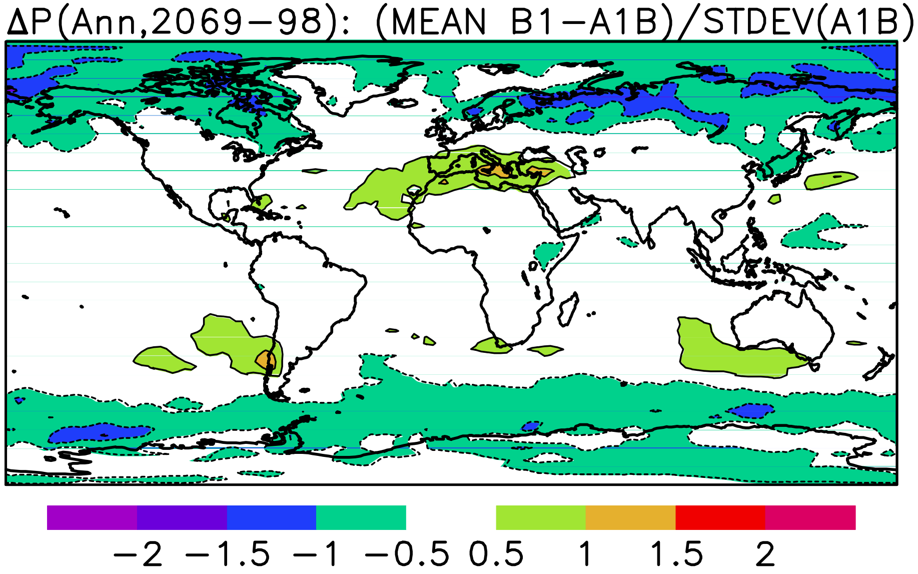
Differences between emission scenarios are negligible for the next few decades, but begin to grow more important in the mid-21st century.

15-model mean precipitation change from 1971-2000 to 2069-2098

Difference A2-A1B / StDev of A1B simulations

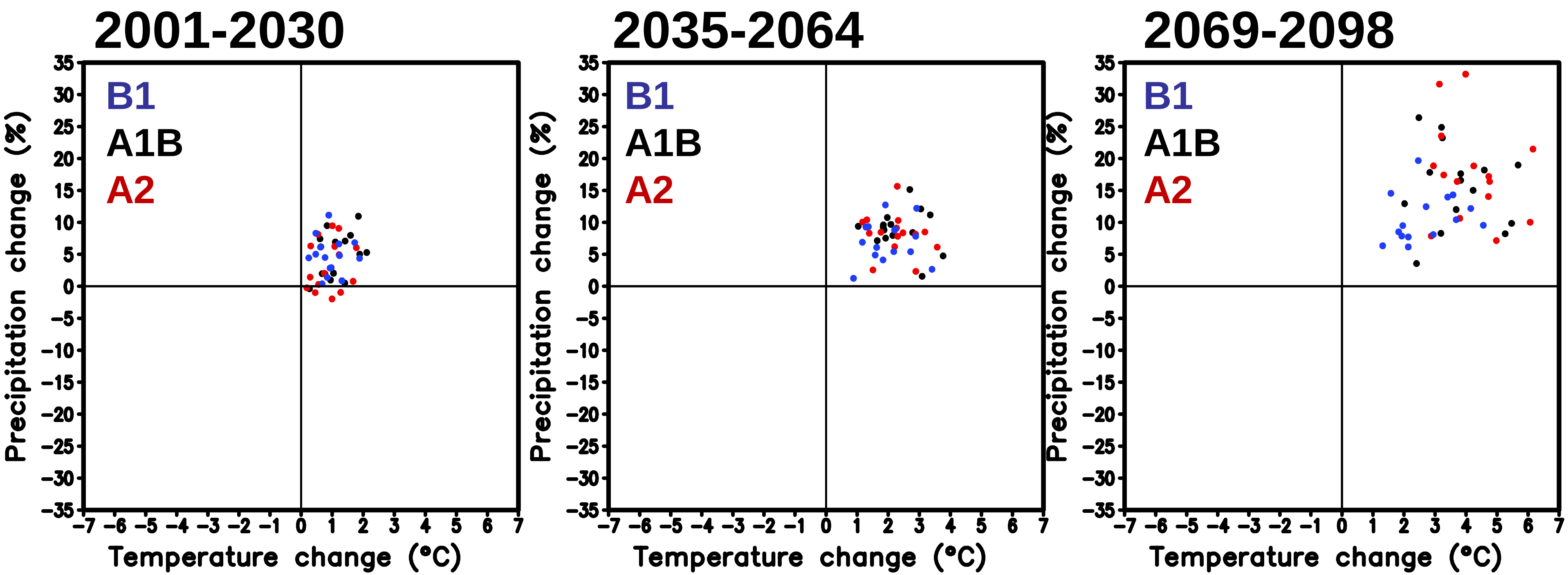


Difference B1-A1B / StDev of A1B simulations



Even in the late 21st century, differences between climate models are generally a more important uncertainty for precipitation change than differences between emission scenarios.

Annual mean T and P changes in southern Finland – 15 models, 3 scenarios



No separation between scenarios

Little separation between scenarios

More separation between scenarios, but also larger differences between models

Uncertainty due to emission scenarios

- **Increases strongly with time**
  - May or may not surpass differences between climate models by the end of the century, depending on variable, geographic area etc.

- **Seems to be small in the short run**
  - Caveat: eventual rapid changes in emissions of aerosol and other short-lived forcing agents, the possibility of which is not covered by the scenarios

Part 3:

What is present climate?

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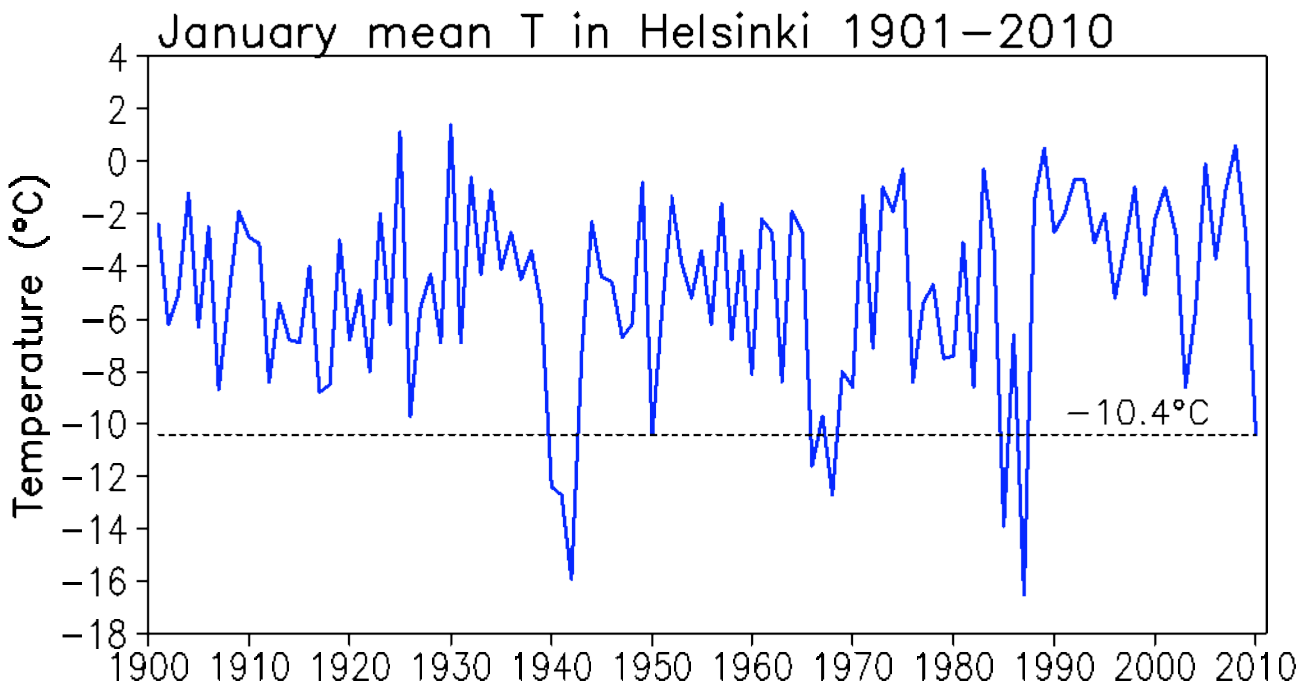
What is present climate?

~ **2010**, not (e.g.) 1971-2000, or 1961-1990, or 1901-2005

~ Statistics of weather during a period of (at least) **30** years

Motivation



- **Many people perceived January 2010 as exceptionally cold** (e.g., in Helsinki and elsewhere in southern Finland)
- **Observations from 20th century suggest that this was not the case, but …**
- **… do past observations give a fair idea of the present-day probability of cold winters**, or should climate change be taken into account?

Estimating present climate in a changing climate

Räisänen & Ruokolainen 2008 (Climate Dynamics)

1) **Local** (e.g., Helsinki) **climate is assumed to depend linearly on the global mean temperature**

- **the mean temperature increases** by A^{o}C for each 1^{o}C of global mean warming
- **interannual temperature variability** increases or decreases B % for each 1^{o}C of global warming

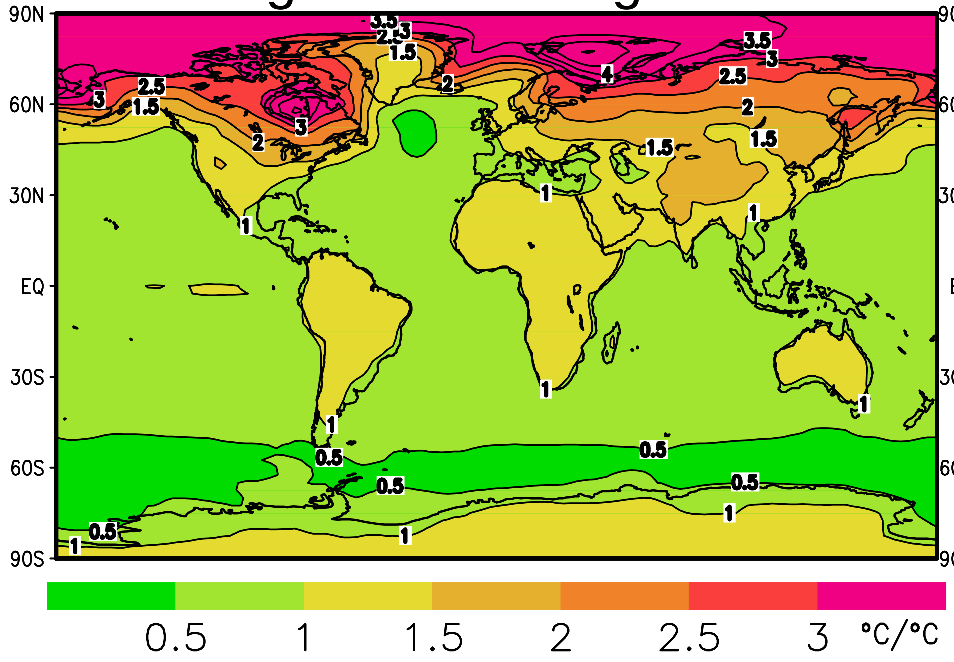
2) **The regression coefficients are estimated from bi-centennial** (1901-2098) **"greenhouse simulations" by the CMIP3 global climate models**

3) **The regression coefficients together with observed global mean temperature change are used to adjust past observations**, to make them more representative of present climatic conditions

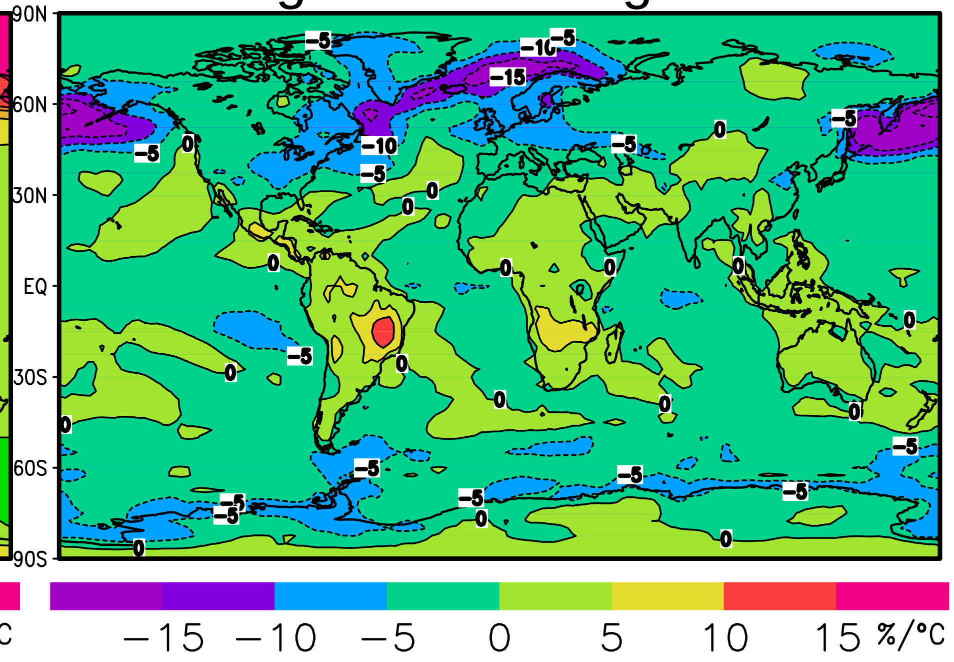
Regression coefficients for January mean T

(22-model mean)

Change in local January mean T
for 1ºC global warming

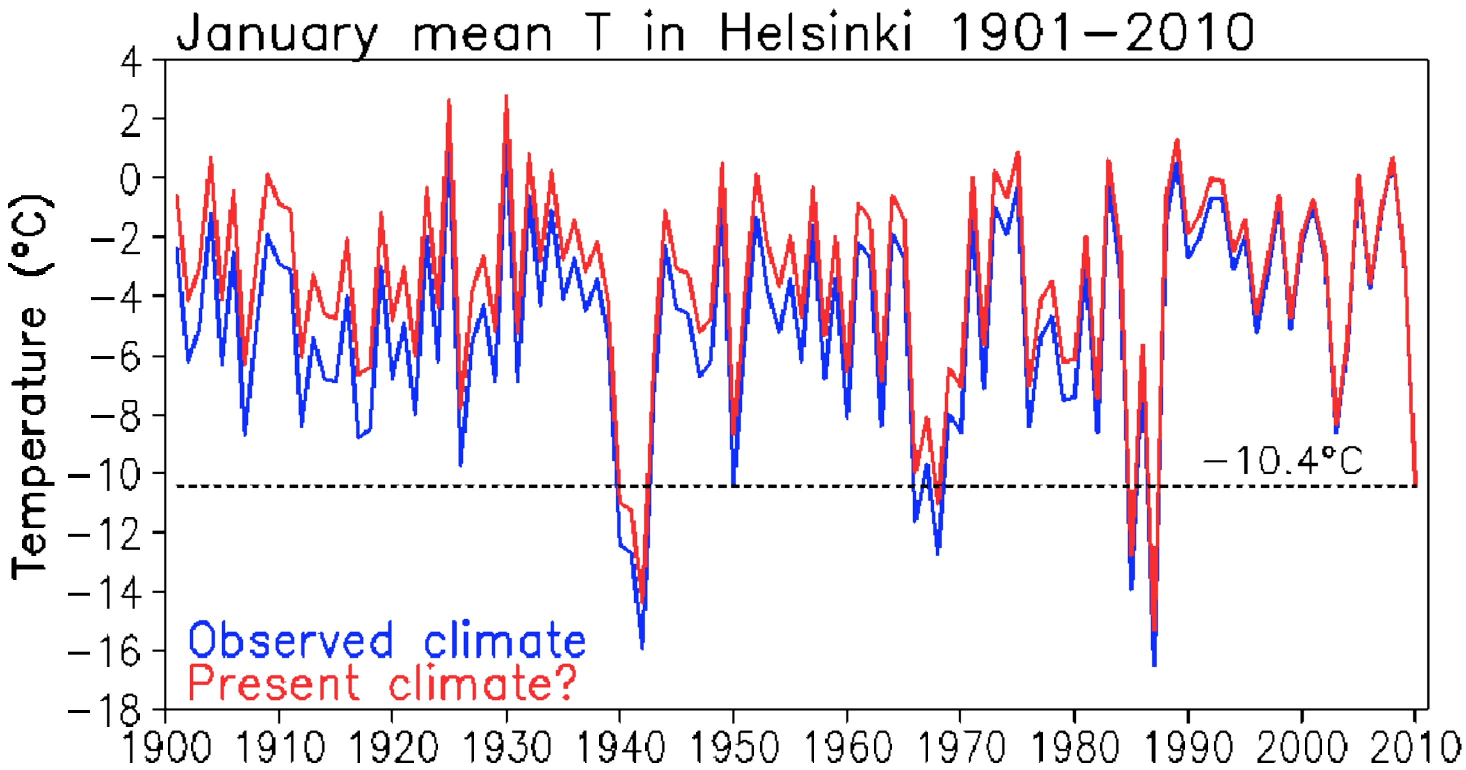


Change in variability (%)
for 1ºC global warming



<u>Helsinki (60ºN, 25ºE):</u> The January mean temperature increases by **2.2ºC** (range between models: **1.3-3.2ºC**), and the interannual standard deviation decreases by **6%,** (range of change: **-15%** … **+10%**) when the simulated global mean temperature increases by 1ºC.

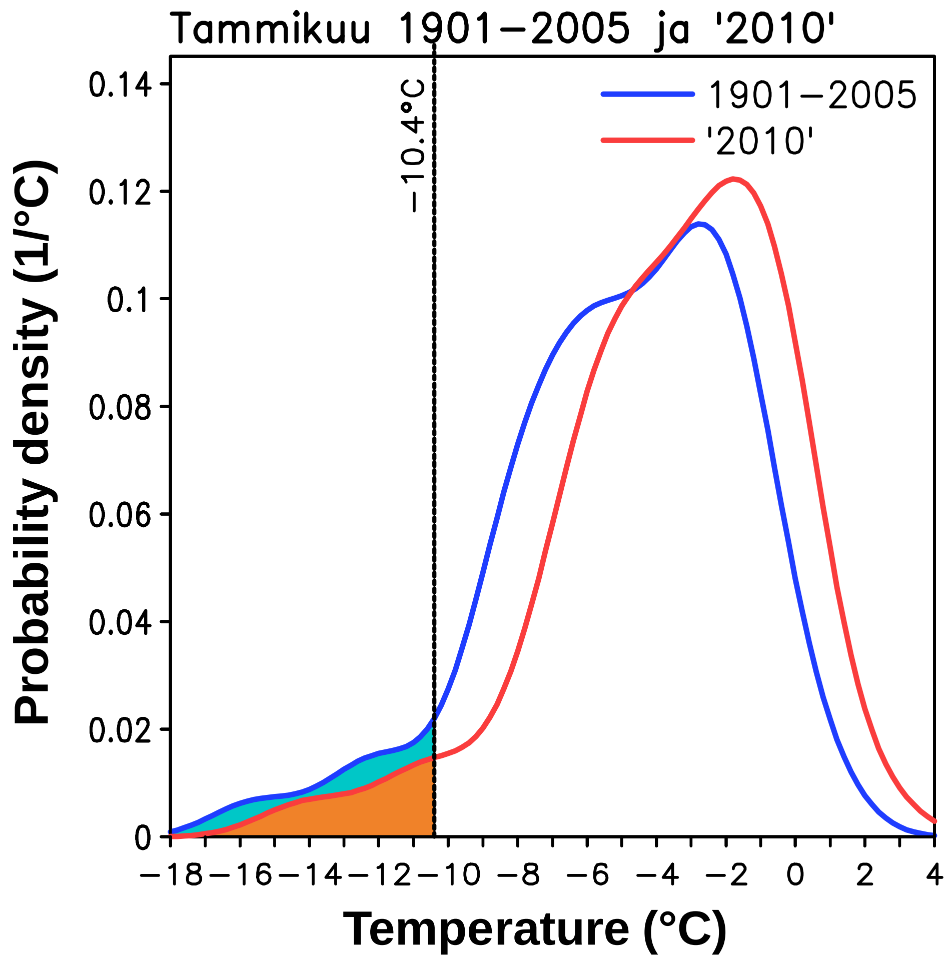
January mean temperature in Helsinki, 1901-2010 – effect of global climate change?



BLUE = observed temperatures as such

RED = temperatures adjusted for the observed global warming
(multi-model mean estimate only!)

January mean temperature in Helsinki: distributions estimated from **original** and **adjusted** observations



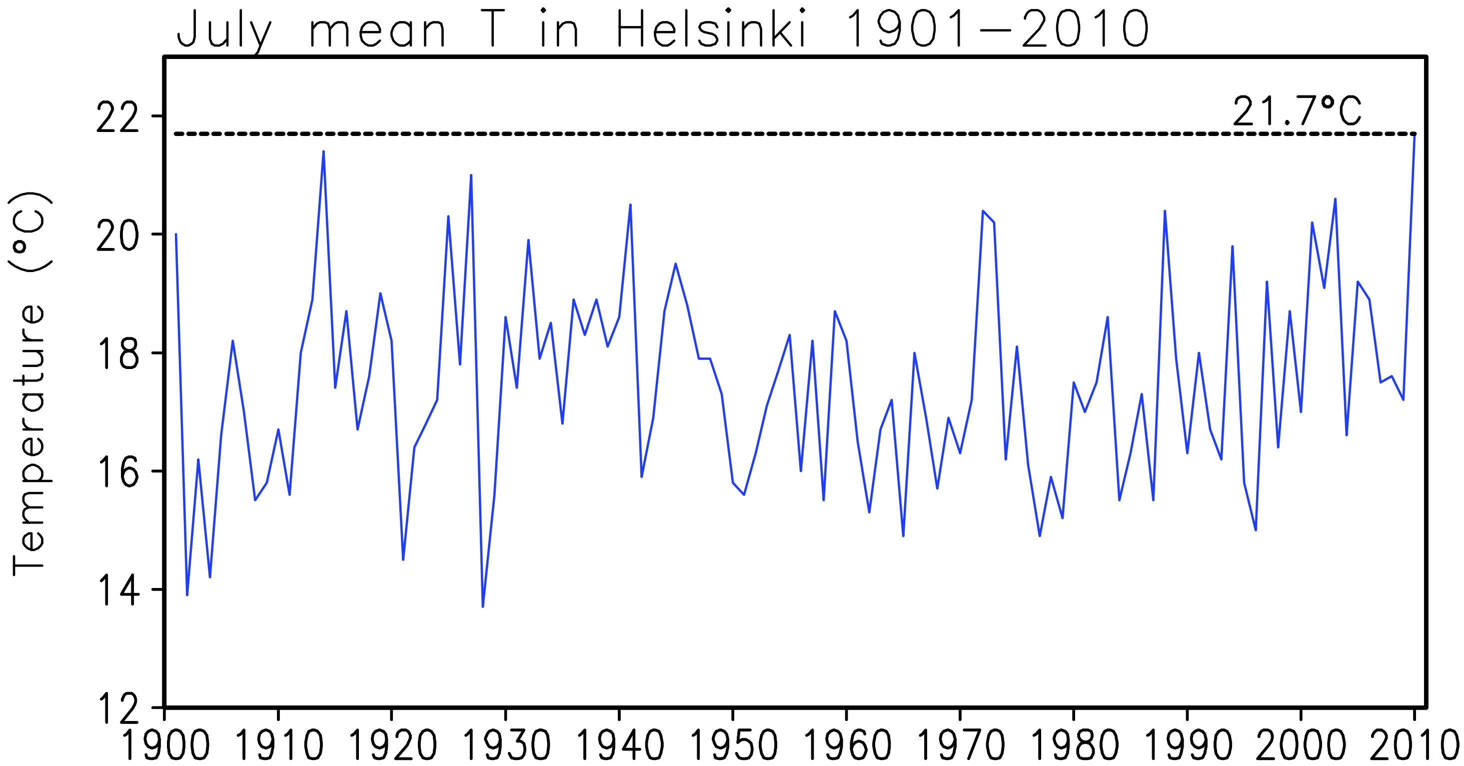
How frequently -10.4ºC
(as observed in 2010)
or colder?

Directly from observations:
p = 7-8%
(once in ~13 years)

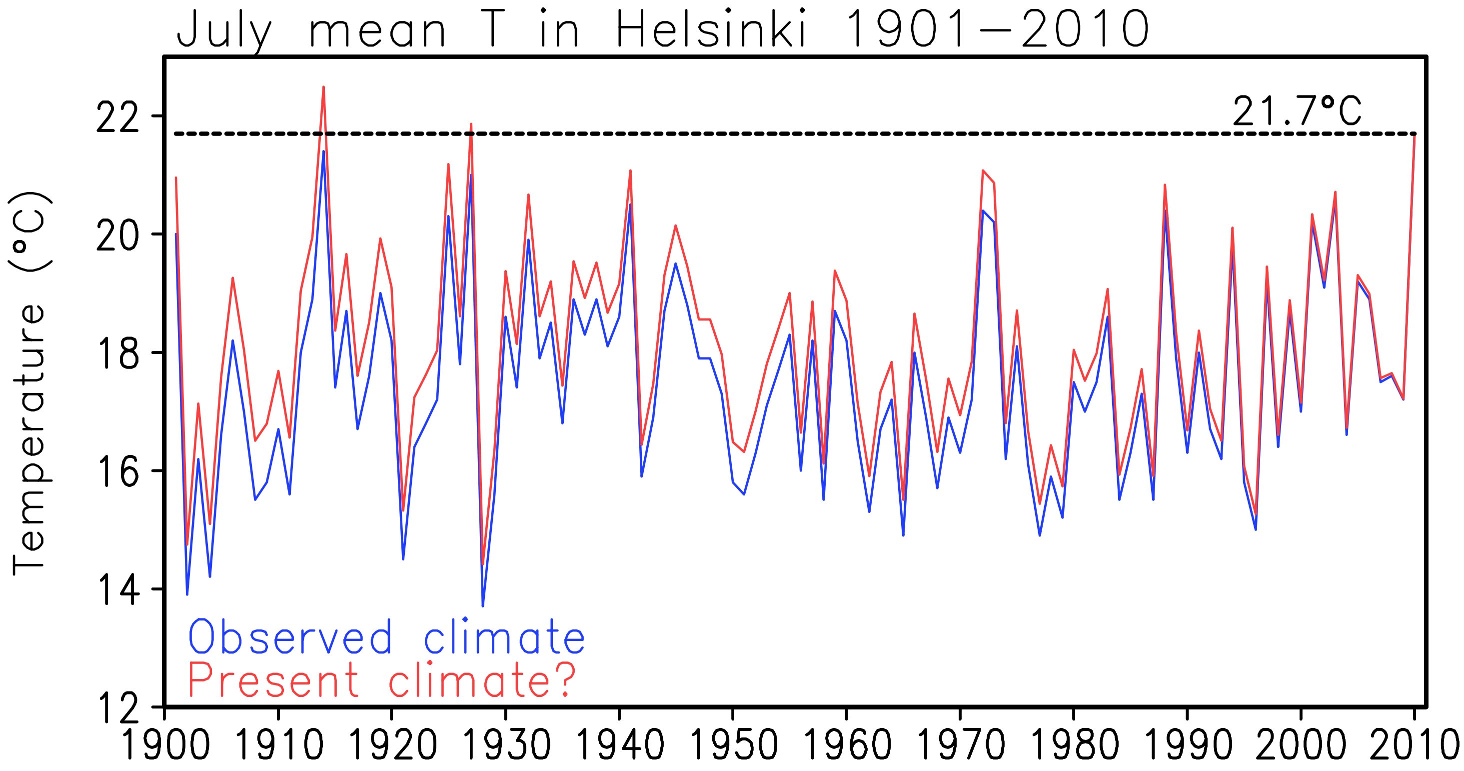
Estimate for present climate:
p = 5%
(once in 20 years)

→Not yet an exceptional event.

July 2010: warmest ever in Helsinki

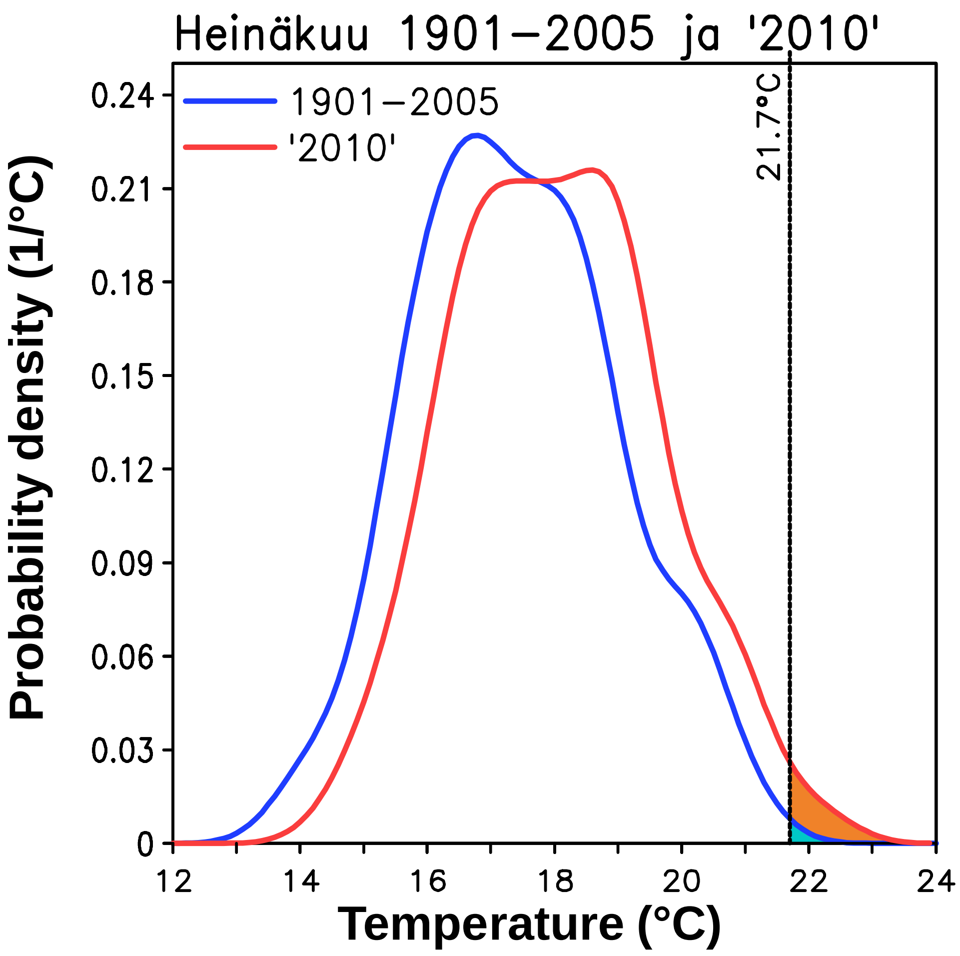


July 2010: warmest ever in Helsinki



Again, the **adjusted** temperatures tell a different story than the **original** observations

July mean temperature in Helsinki: distributions estimated from **original** and **adjusted** observations



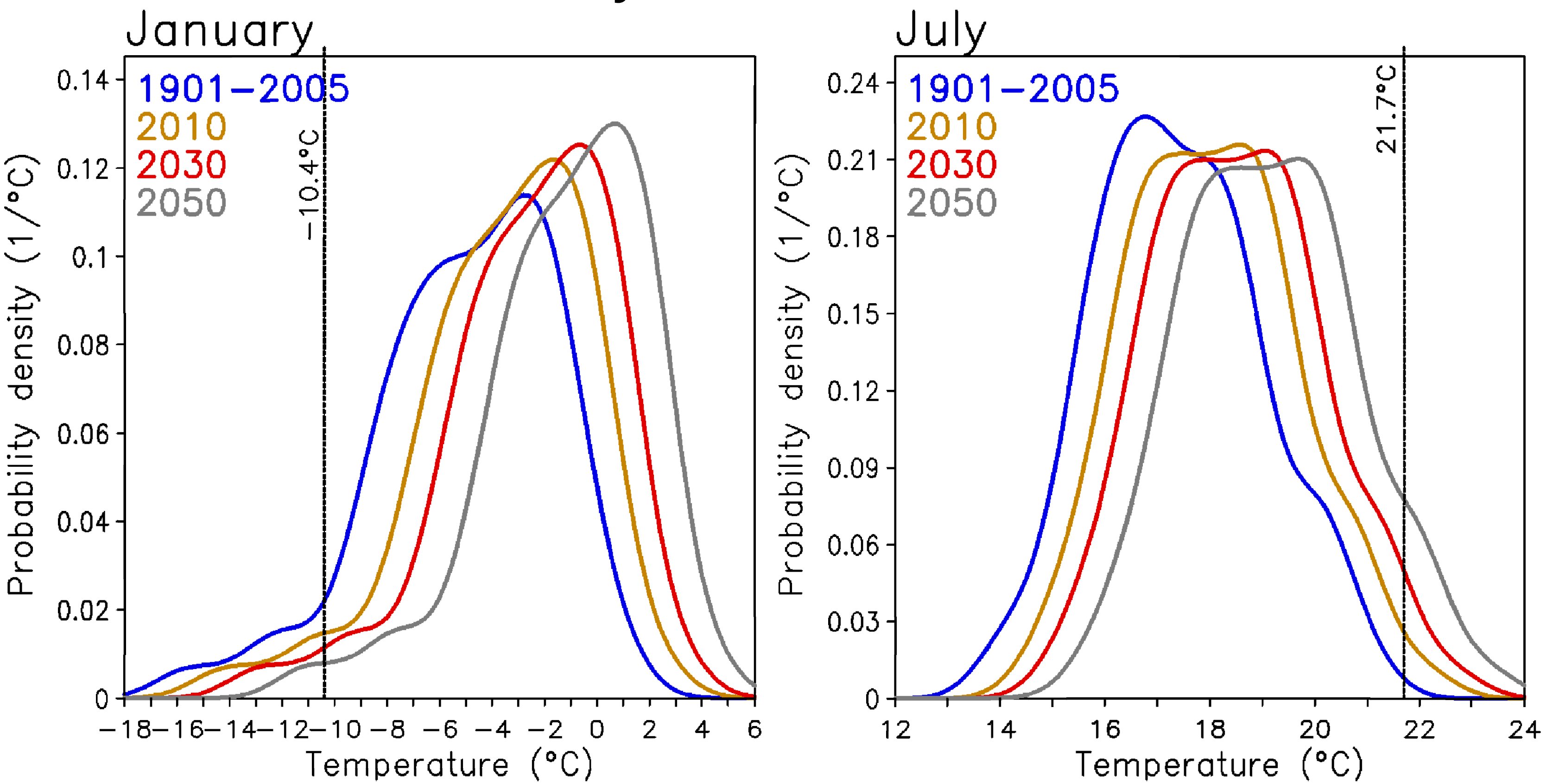
How frequently +21.7ºC
(as observed in 2010)
or warmer?

Directly from observations:
p ~0.3%
(once in ~300 years??)

Estimate for present climate:
p ~ 1.7%
(once in ~60 years?)

→Not yet an ordinary July, but not as exceptional as past observations would suggest

Question: what will happen to the probability of cold Januaries and hot Julys in the future?



Answers, for Helsinki in 2050:

$p\ (T_{jan} \leq -10.4°C) \sim 1.5\%$ $p\ (T_{jul} \geq +21.7°C) \sim 8\%$

assuming that the rate of climate change follows the current best estimates from climate models

Three main points

- **Uncertainty in climate change projections increases with time,** at least in absolute if not in relative terms!
- **Uncertainty initially dominated by natural variability, but modelling uncertainty and scenario uncertainty take over later**
- **Present climate can not be estimated well from past observations alone,** at least not for temperature

Questions or complaints?