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Changes in variability and extremes from the CMIP3 ensemble.

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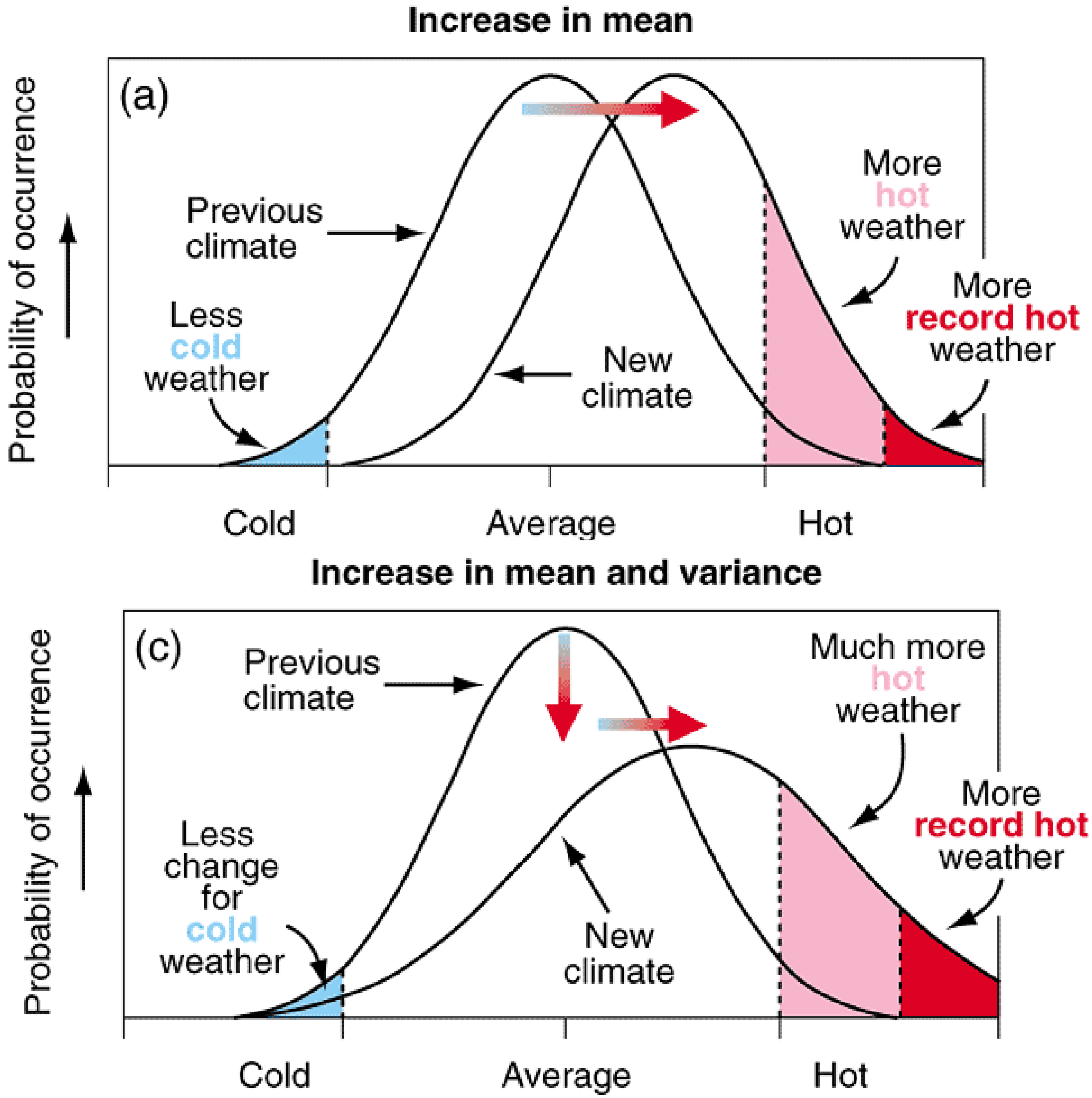
Outline

- Mean climate, variability and extremes: some statistical issues
- Changes in interannual variability from CMIP3
- Changes in extremes of daily temperature and precipitation
- Brief remarks on wind extremes

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

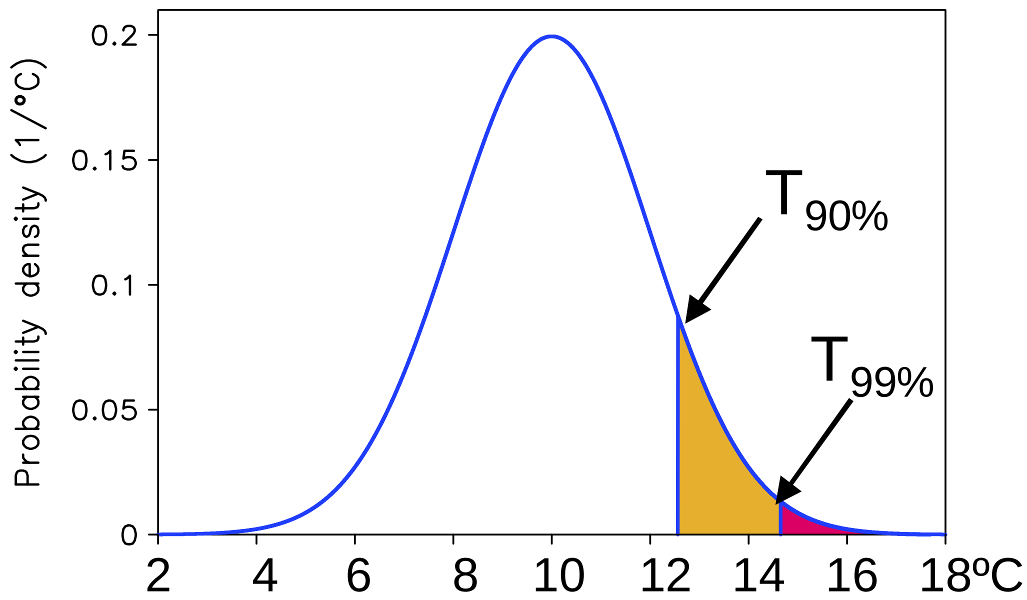


IPCC WG1 (2001) Fig. 2.32

In some cases, changes in the shape of the distribution might also matter (but information on them is very limited)

Hypothetical example 1 (1)

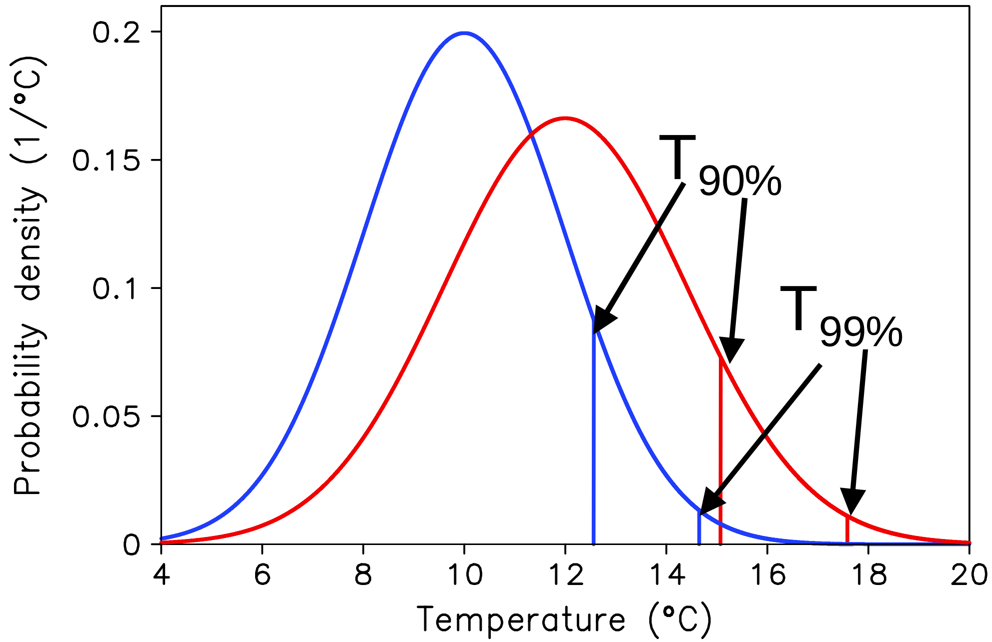
- Assume that present-day monthly mean temperature at location X in month Y is **normally distributed** with **mean = 10ºC** and **standard deviation = 2ºC**.
- The **90th percentile** of the distribution is then **12.56ºC** and the **99th percentile** is **14.66ºC**



Hypothetical example 1 (2)

- Now assume that the **mean temperature increases** by **2ºC** and the **standard deviation** by **20%** (=0.4ºC)
- The **90th percentile** of the distribution **increases** from 12.56ºC to 15.07ºC (**2.51ºC**) and the **99th percentile** from 14.66ºC to 17.59ºC (**2.93ºC**)
- Without the change in variability, both the 90th and 99th percentiles would have increased by **2ºC**.

- **Changes in variability are most important in the extreme tail of the distribution** (but even there, they may be less important than the change in the mean).



Hypothetical example 2

- As Example 1, but for **daily temperatures** with present-day **mean = 10ºC** and **standard deviation = 4ºC**
- The **90th** and the **99th percentiles** in different cases:

	90th percentile	99th percentile
Present-day	15.13ºC	19.31ºC
Mean +2ºC	17.13ºC (**Δ = 2.00ºC**)	21.31ºC (**Δ =2.00ºC**)
Mean +2ºC, StDev +20%	18.15ºC (**Δ = 3.02ºC**)	23.17ºC (**Δ =3.86ºC**)

- **Changes in variability are potentially more important for extremes on short** (daily) **than long** (monthly-to-annual) **time scales** – provided that relative changes in variability do not depend strongly on time scale.

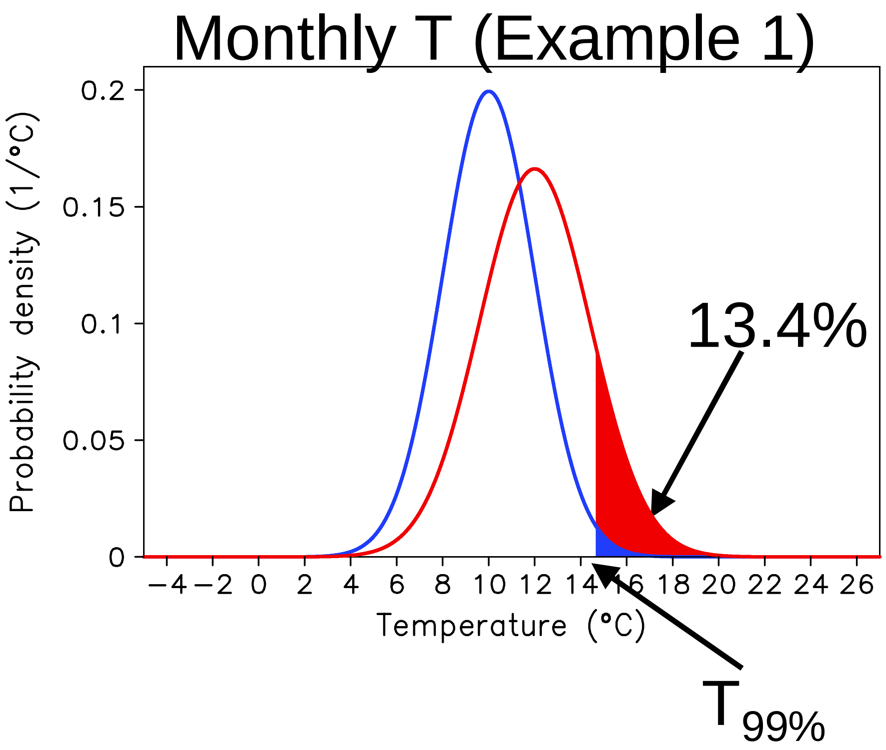
Probability of exceeding present-day extremes

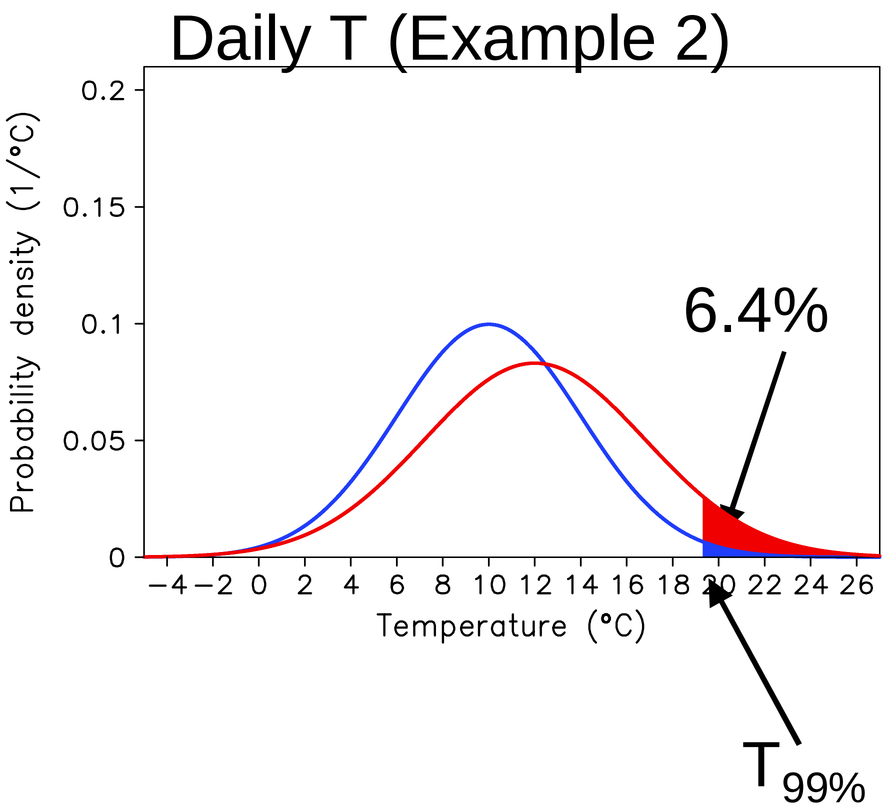
- **How frequently would temperature exceed the present-day 99th percentiles** (monthly: 14.66ºC daily: 19.31ºC) in the previous examples?

	$T_{mon} > T_{mon}(99\%)$	$T_{day} > T_{day}(99\%)$
Mean +2ºC	P = **9.2%**	P = **3.4%**
Mean +2ºC, StDev +20%	P = **13.4%**	P = **6.4%**

- Relatively small changes in mean climate and variability can lead to **large changes in the frequency of extremes**
- Changes in the frequency of extremes are **potentially larger on long** (monthly-to-annual) **than short** (daily) **time scales**, because the same change in the mean produces a larger relative shift in a narrower distribution

Probability of exceeding present-day extremes (2)





Changes in the magnitude versus in the frequency of extremes: precipitation

- Assume that present-day precipitation in location X in month Y is normally distributed with **mean = 100 mm** and **StDev= 50 mm** → **90th percentile** = 100 + 1.2816 × 50 mm = **164 mm**.
- Assume that **both the mean and the standard deviation increase by 20%.** After these changes:
  - 90th percentile = 120 + 1.2816 × 60 mm = 197 mm **(relative change = 20%)**
  - probability of exceeding the old 90th percentile of 164 mm: **23%**, i.e., **relative change** = (23-10)/10 x 100% **= 130%!**
- **Changes in the magnitude and frequency of extremes must not be mixed** (even when they may be expressed in similar units)!

Changes in interannual climate variability

Ways to characterize changes in interannual variability

- **Changes in modes of variability:** ENSO, NAO, etc.
  - process-level insight (hopefully?)
  - in most parts of the world, a single mode explains only a limited part of all variability
- **Changes in the magnitude of local variability**
  - simple to do → <u>approach adopted in this talk</u>
  - net effect of all phenomena
  - physical interpretation often difficult

Changes in interannual variability of temperature and precipitation in CMIP3

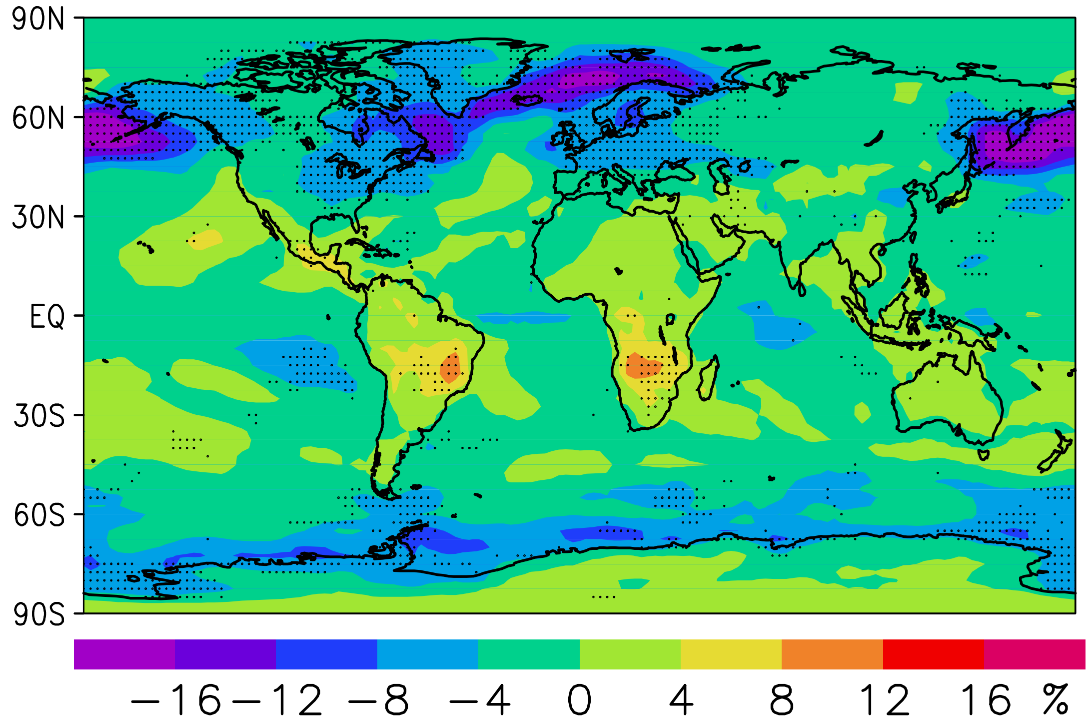
- **Analysis using data from 22 models**, for the period 1901-2098 (A1B scenario)

- Regression-based approach – magnitude of interannual variability of **monthly T** and **monthly P** regressed against global mean T

- **Results shown in normalized form:** per cent change in standard deviation per 1ºC global mean warming

- **3-month averaging** over DJF and JJA seasons

Change in interannual StDev of monthly mean temperature per 1ºC global warming:
Northern Hemisphere winter (DJF)



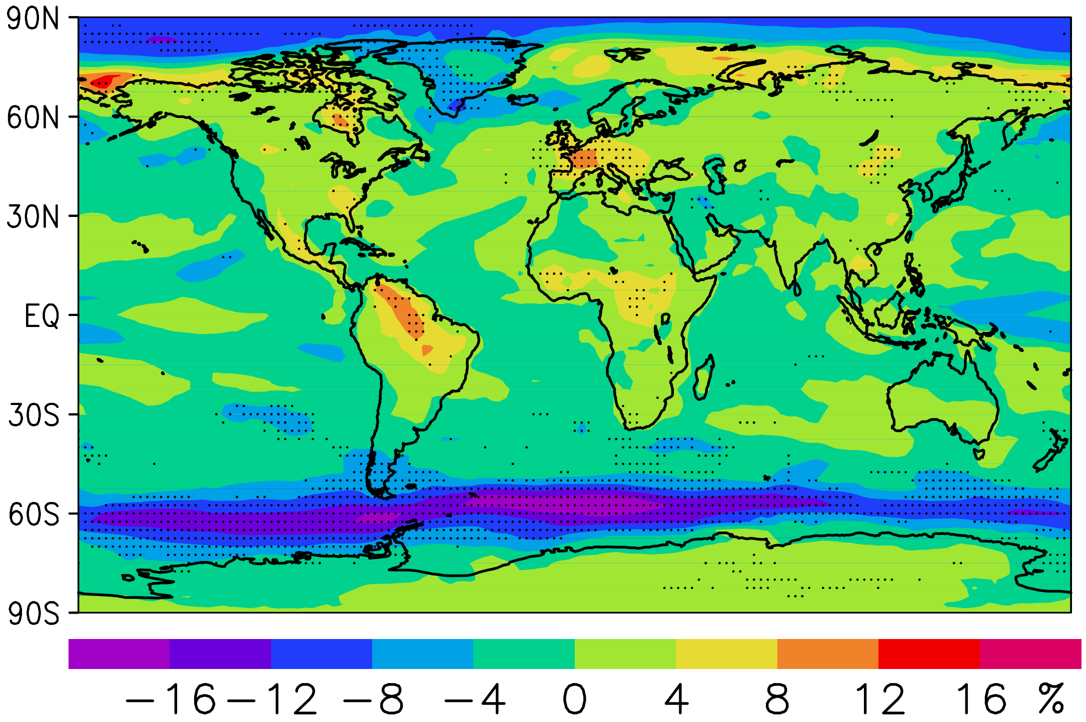
Colours: 22-model mean change
Stippling: at least 80% of the models agree on the sign of the change

- Multi-model mean changes below 5% / ºC in most land areas
- Decrease in variability where ice and snow retreat
- Increase in variability in many low-latitude / Southern Hemisphere land areas (decrease of soil moisture, increase in land-sea T contrast?)

Changes in temperature variability: a few possible mechanisms

- **Decrease in sea ice**
  - Air temperature over open water dictated by SST
- **Decrease in snow cover**
  - Stronger ground-air heat exchange over snow-free than snow-covered ground
- **Decrease in soil moisture**
  - soil moisture abundant → evaporation tends to increase with increasing temperature, (i) cooling the surface, and possibly (ii) increasing cloudiness
  - soil moisture limited → evaporation unable to limit temperature variability
- **Changes in time-mean temperature gradient**
- **Others?**

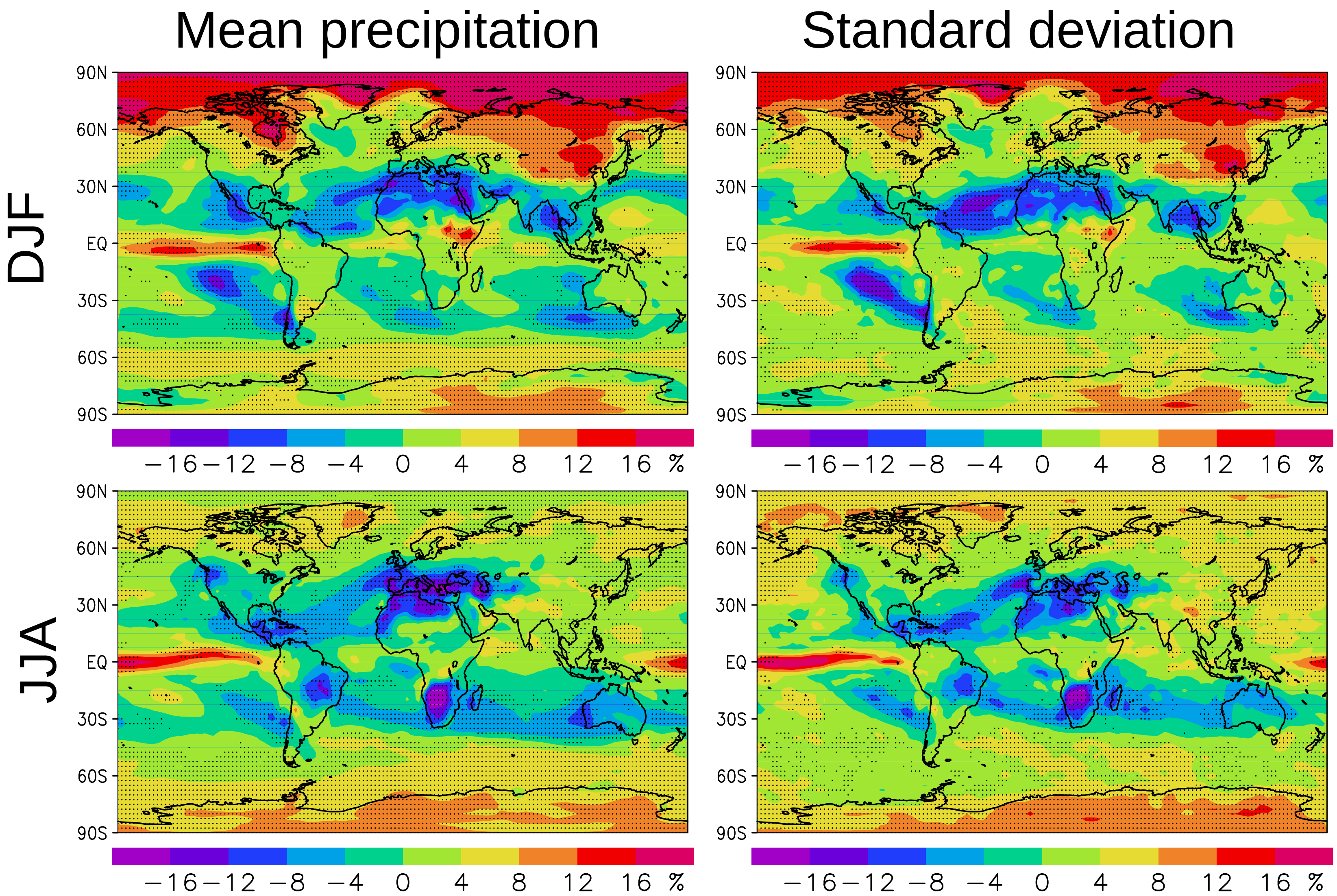
Change in interannual StDev of monthly mean temperature per 1ºC global warming:
Northern Hemisphere summer (JJA)



Colours: 22-model mean change
Stippling: at least 80% of the models agree on the sign of the change

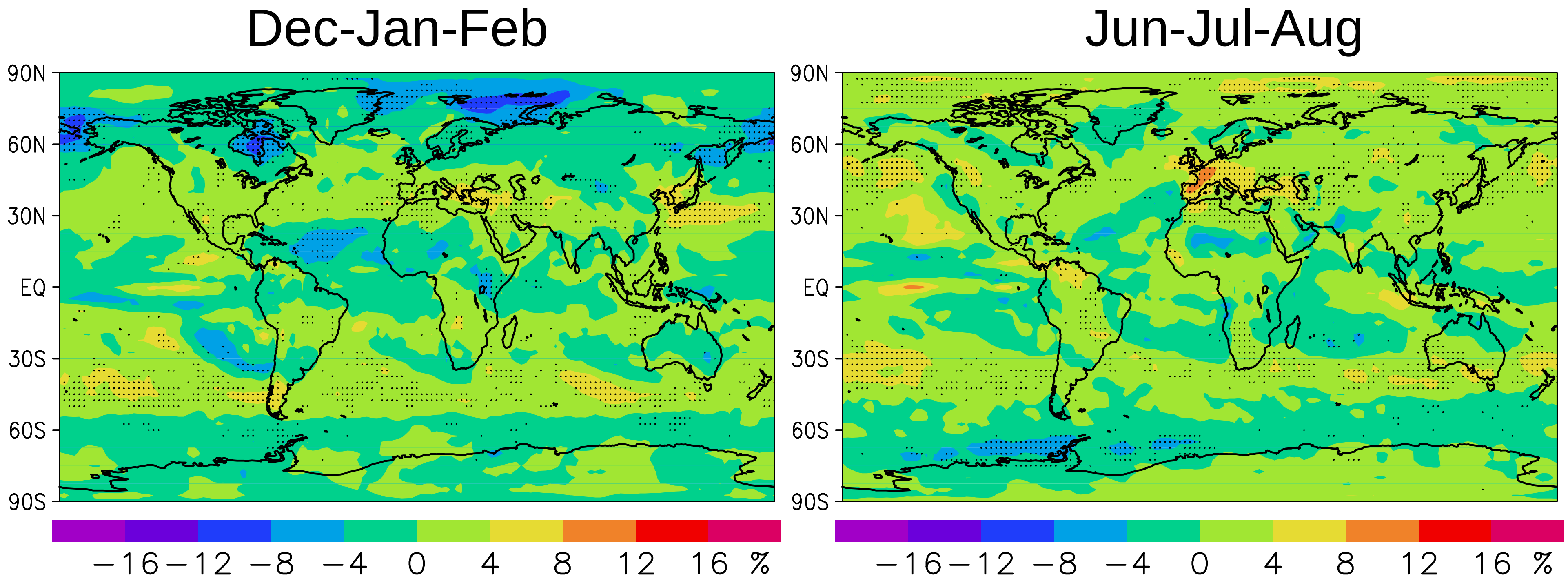
- Increase in variability over most of the Northern Hemisphere continents (note central Europe)
- Few land areas with good agreement between models, partly because the signal-to-noise ratio is low in many areas

Changes in mean precipitation and interannual StDev of precipitation per 1ºC global warming



First approximation: changes in StDev follow changes in mean!

Change in the coefficient of variation (standard deviation / mean) of monthly precipitation per 1ºC global warming



1) **Changes generally small**
2) **Tendency to increase in most areas where mean precipitation decreases** (connection to decreasing number of precipitation days? – Räisänen (2002), J. Clim, 15, 2395-2411)
3) **Changes of varying sign where mean precipitation increases**

Changes in extremes and variability on the daily time scale

This part is mostly based on

Kharin, V.V., et al. (2007): Changes in temperature and precipitation extremes in the IPCC ensemble of global coupled model simulations. Journal of Climate, 20, 1419-1444.

Some figures are also shown from

Sun, Y., et al. (2007): How often will it rain? Journal of Climate, 20, 4801-4818.

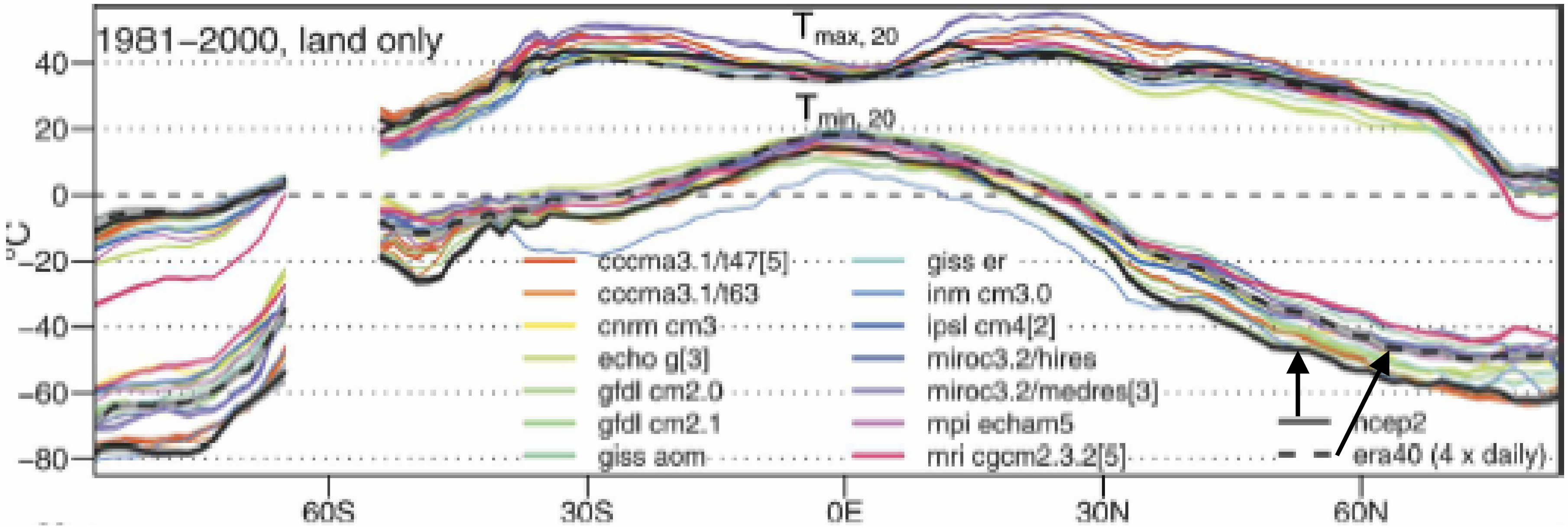
Kharin et al. (2007)

- **12-14** CMIP3 models for T, **14-16** for P
- **B1**, **A1B** and **A2** scenarios (focus on **A1B**)
- Near past: **1981-2000**
- Mid-century: **2046-2065**
- End-of-century: **2081-2100**
- **20-year return values** of
  - minimum temperature
  - maximum temperature
  - maximum one-day precipitaiton
- Generalised extreme value theory (**GEV**) for estimating extremes

How well can models simulate extremes in the present climate?

20-year warm and cold extremes, zonal means over land, 1981-2000

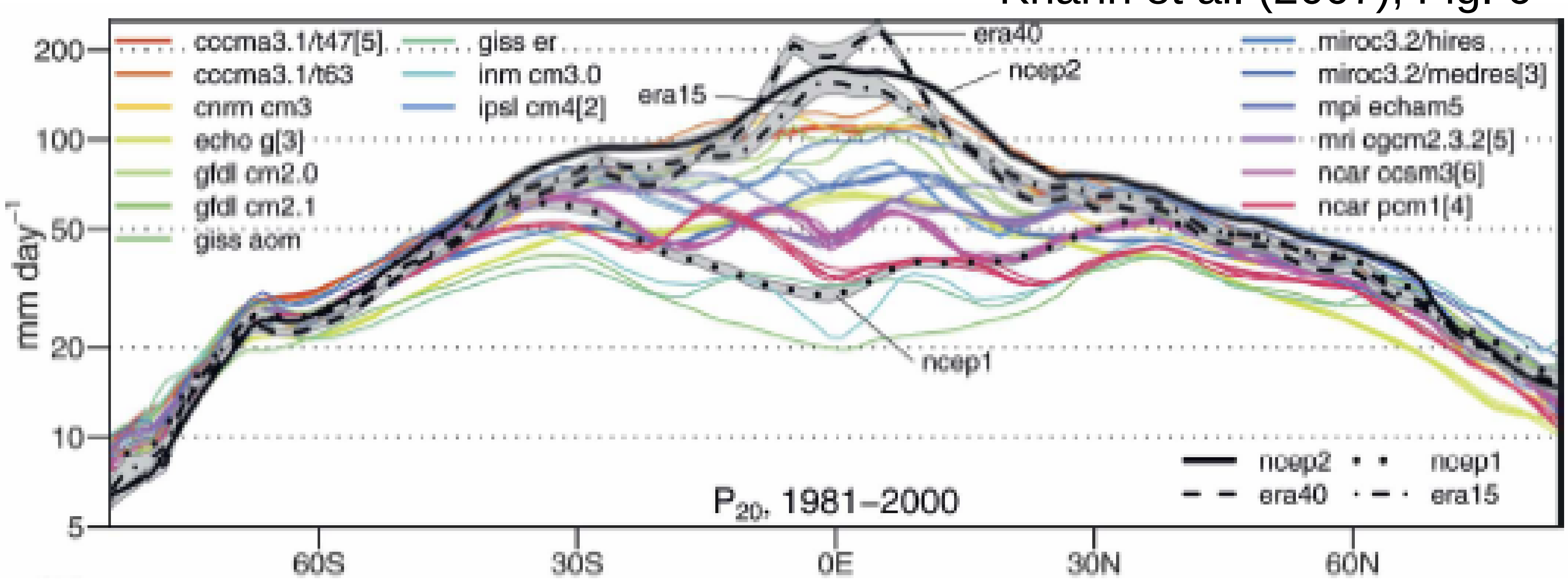
Kharin et al. (2007), Fig. 3



1) Large inter-model variability in cold extremes in the extratropics
2) Large differences in cold extremes between the NCEP2 (—) and ERA40 (- -) reanalyses (→ station data badly needed for real verification!)

20-year return values of one-day precipitation, zonal means, 1981-2000

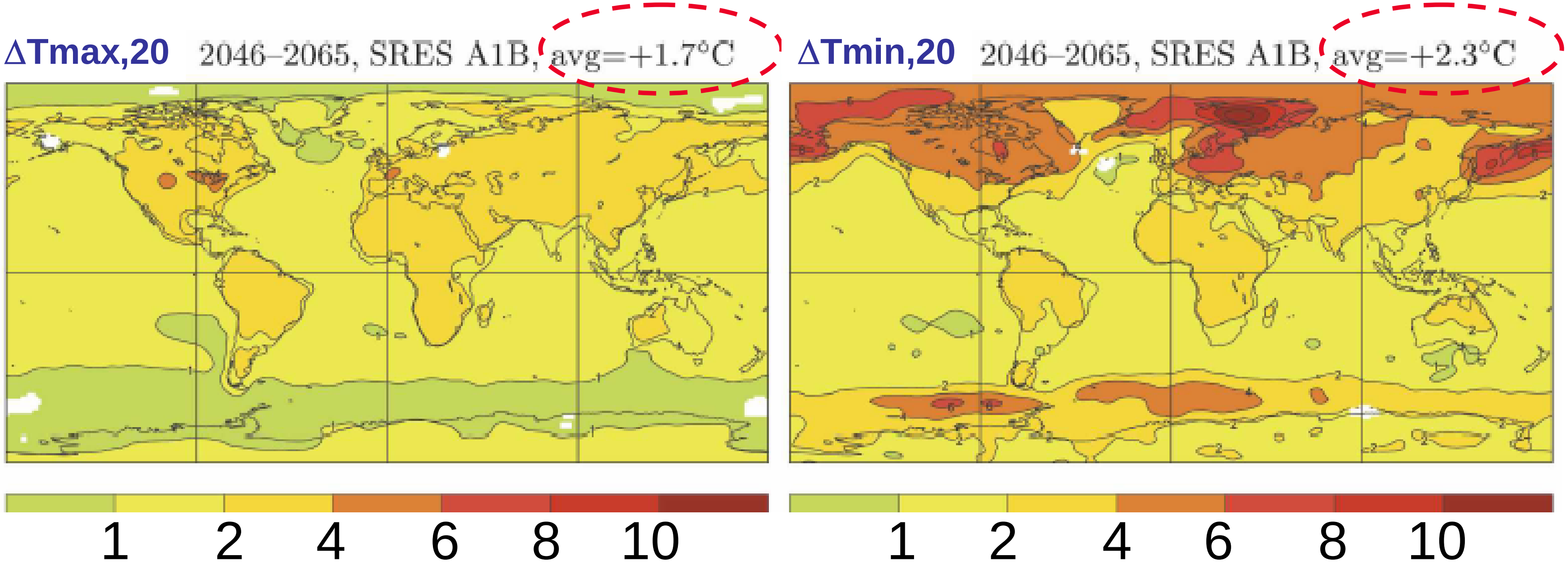
Kharin et al. (2007), Fig. 6



1) Not too bad in extratropical latitudes, although a slight tendency to underestimation of extremes
2) Explosion of inter-model differences in the tropics (factor of five range in zonal mean!)
3) General underestimation of extremes in the tropics, compared with the most recent reanalysis products

How are temperature extremes simulated to change in the future?

Multi-model mean changes in 20-yr warm and cold extremes: A1B, 1981-2000 → 2046-2065



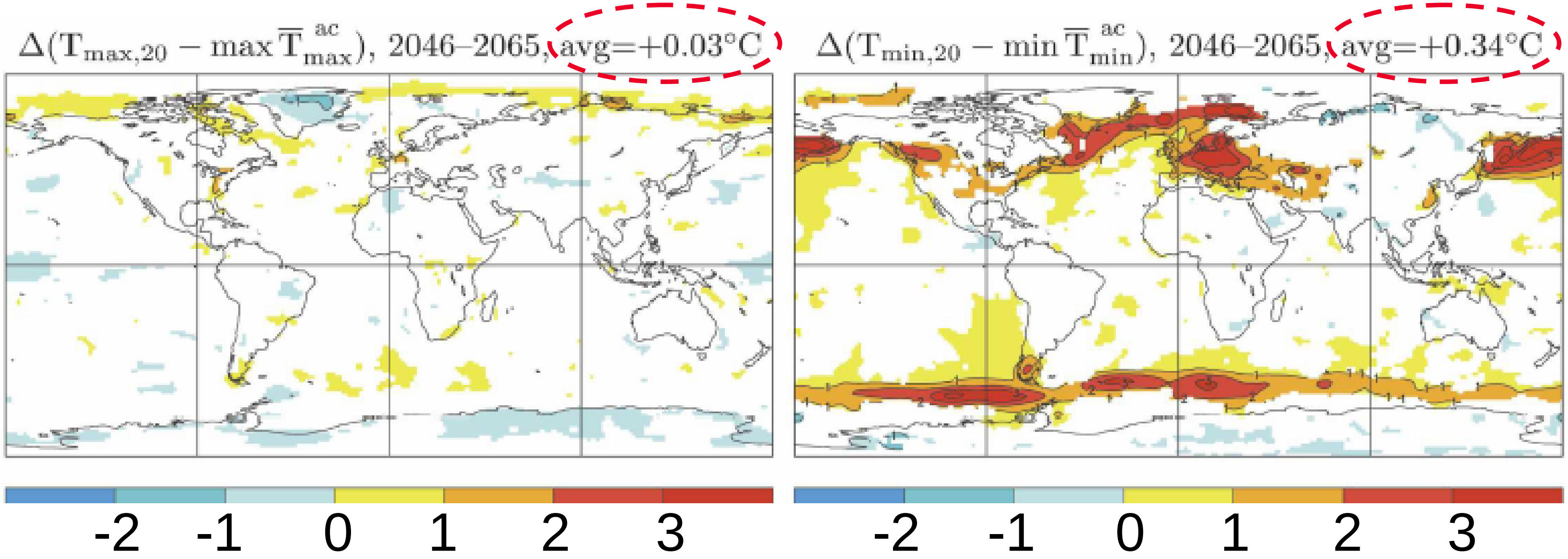
1) Both warm and cold extremes become warmer
2) In high latitudes, cold extremes rise more than warm extremes
3) No systematic W/C-difference in low latitudes

Kharin et al. (2007), Fig. 9

Changes in 20-year temperature extremes versus changes in mean temperature

Change in 20-year maximum minus average change in warmest month

Change in 20-year minimum minus average change in coldest month

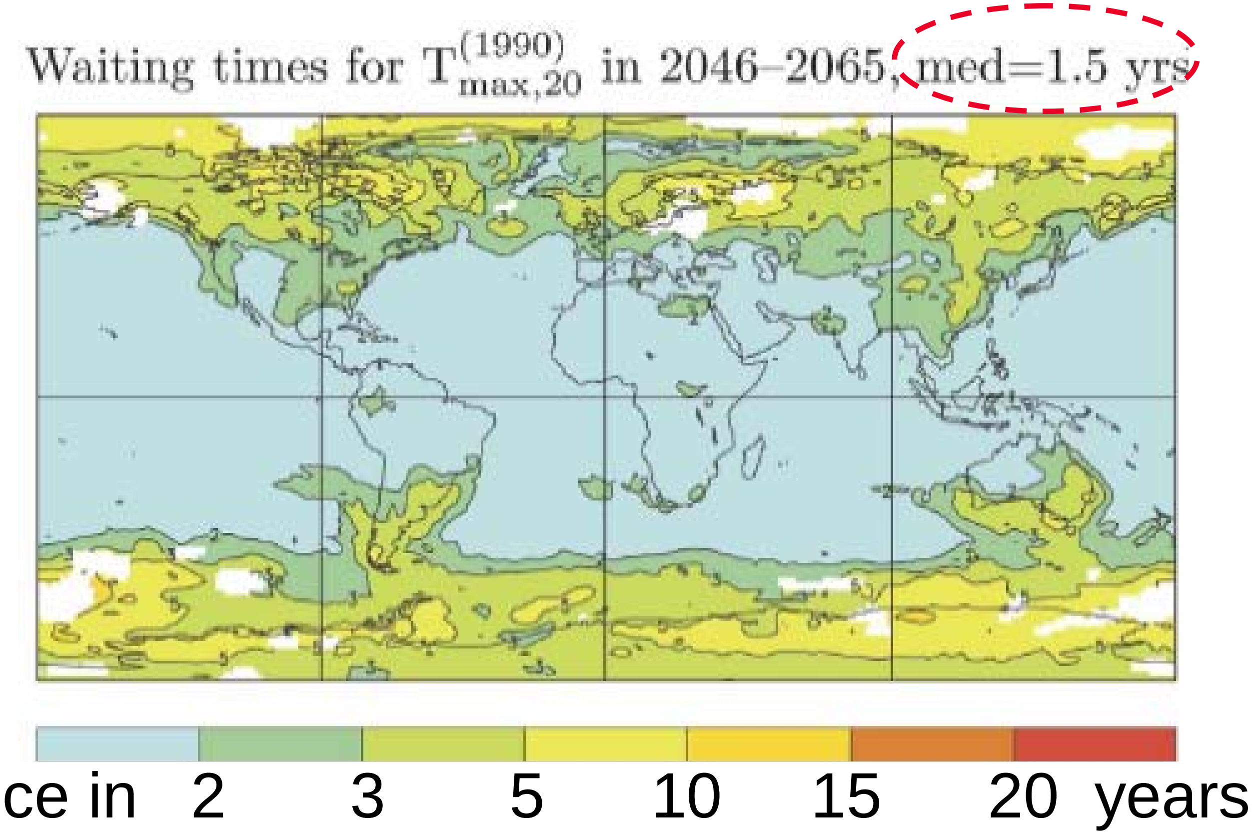


Kharin et al. (2007), Fig. 9

1) **Warming of warm extremes** broadly follows the average summer warming (or, even if there are differences, they are not very consistent between models).

2) **Warming of cold extremes** exceeds the winter mean warming where snow and ice retreat

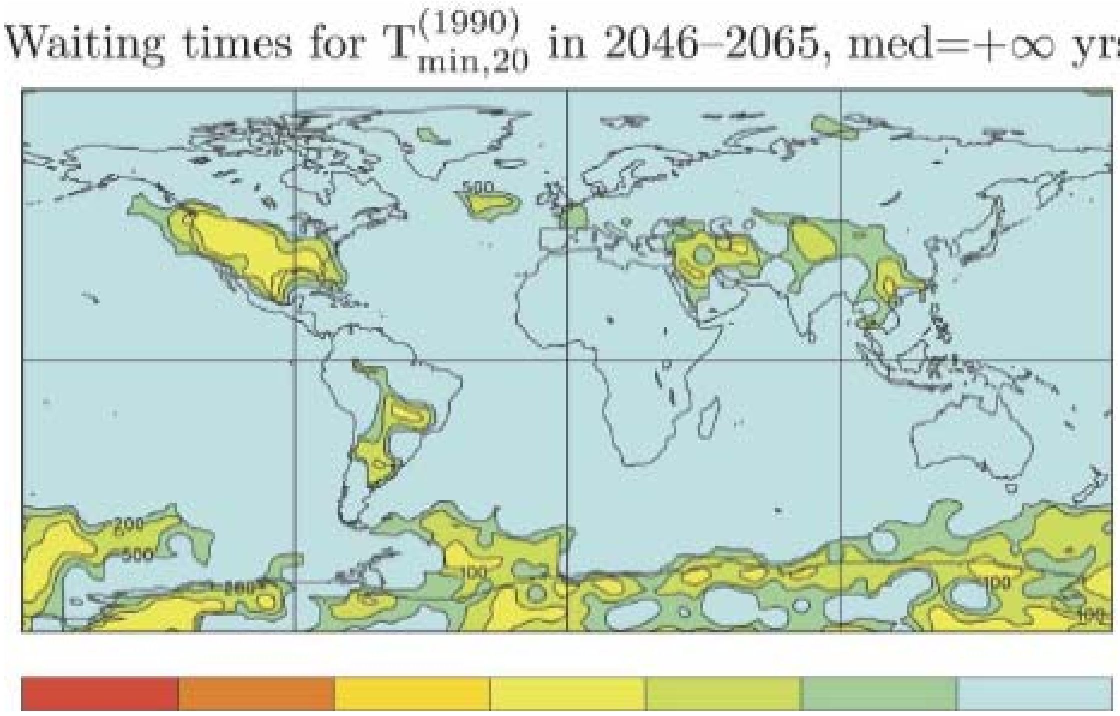
How often will 20-year T maxima from 1981-2000 be exceeded in 2046-2065?



Largest increase in frequency in low latitudes,
where interannual temperature variability is small

Kharin et al. (2007), Fig. 9

How rare will temperatures below the 20-year minima from 1981-2000 be in 2046-2065?

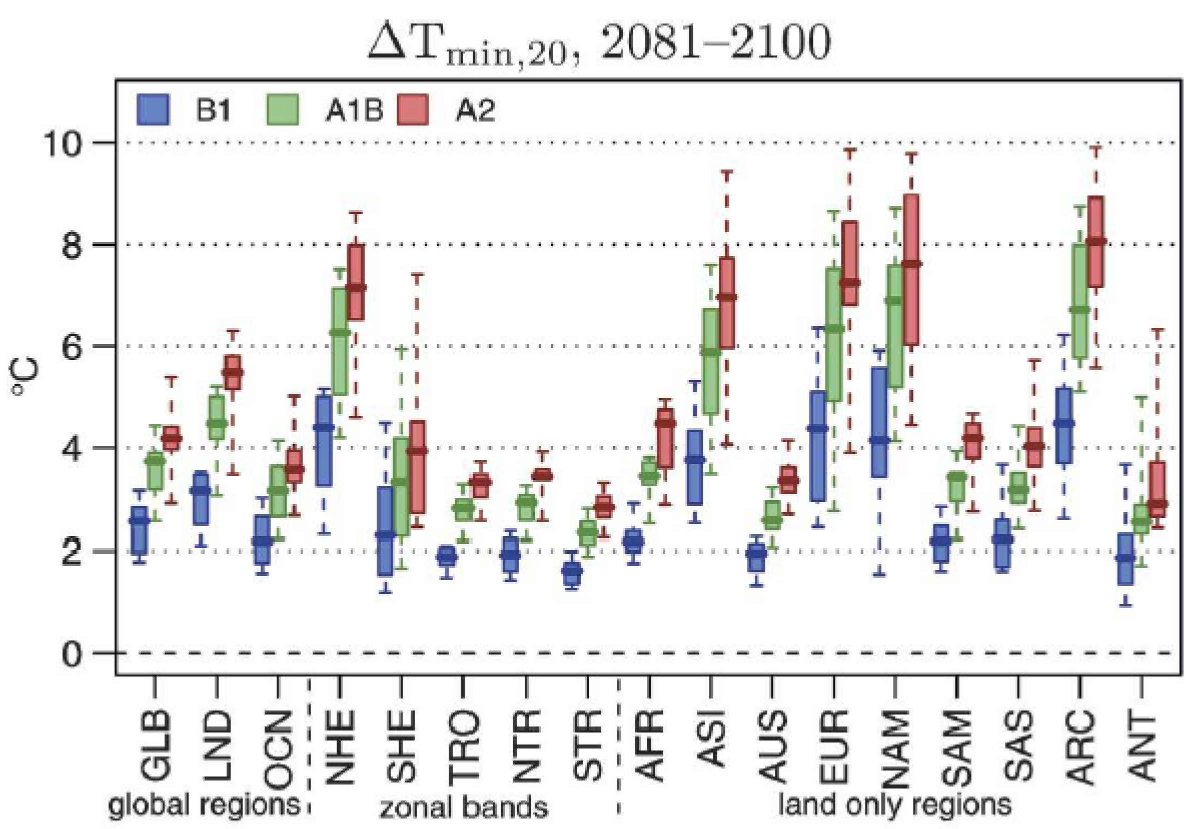


Once in 20 30 50 100 200 500 years

Kharin et al. (2007), Fig. 9

In most parts of the world, cold extremes (as we know them today) **are projected to become almost non-existent by the mid-21st century**

Example of variation between models and forcing scenarios: Change in T_{min20} from 1981-2000 to 2081-2100



Intermodel range = factor of 2-3 in many regions

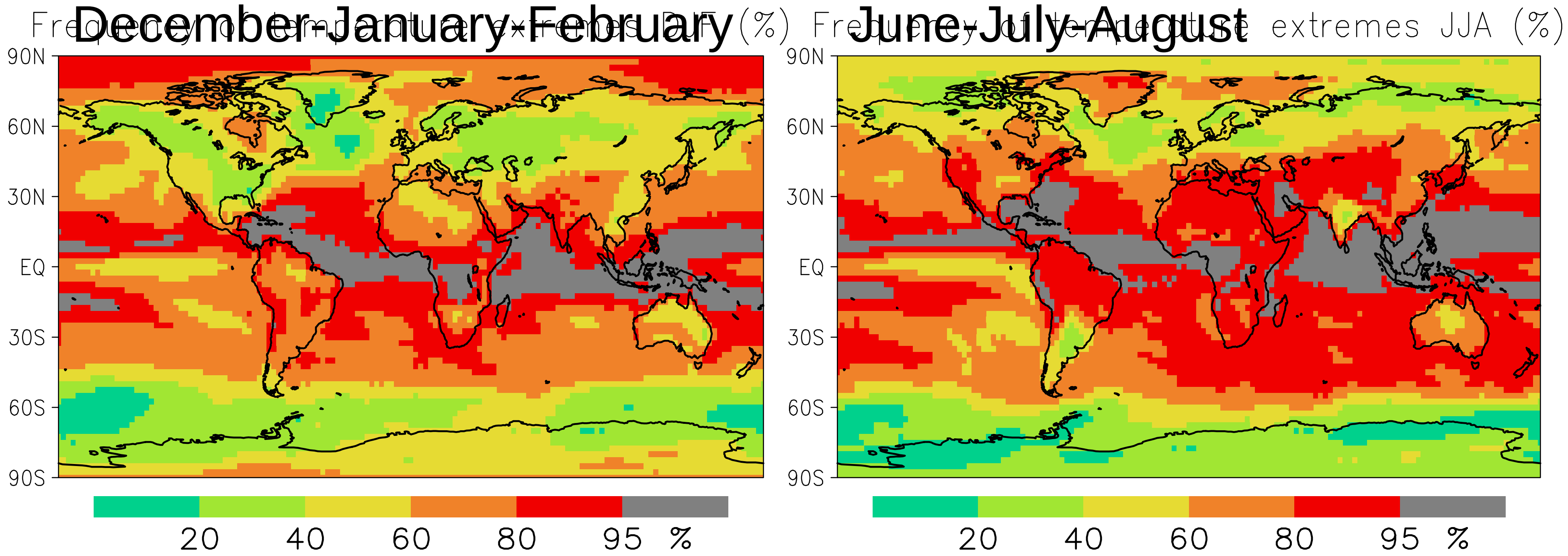
Substantial overlap between scenarios in the extratropics

GLB = Global mean, LND = Global land mean,....,
AFR = Africa, ASI = Asia,....,etc.

Kharin et al. (2007), Fig. 12

What about extremes of seasonal mean temperature?

Frequency of 'record warm'* winter and summer seasons in 2050-2099: a simple analysis of SRES A1B simulations by 22 models

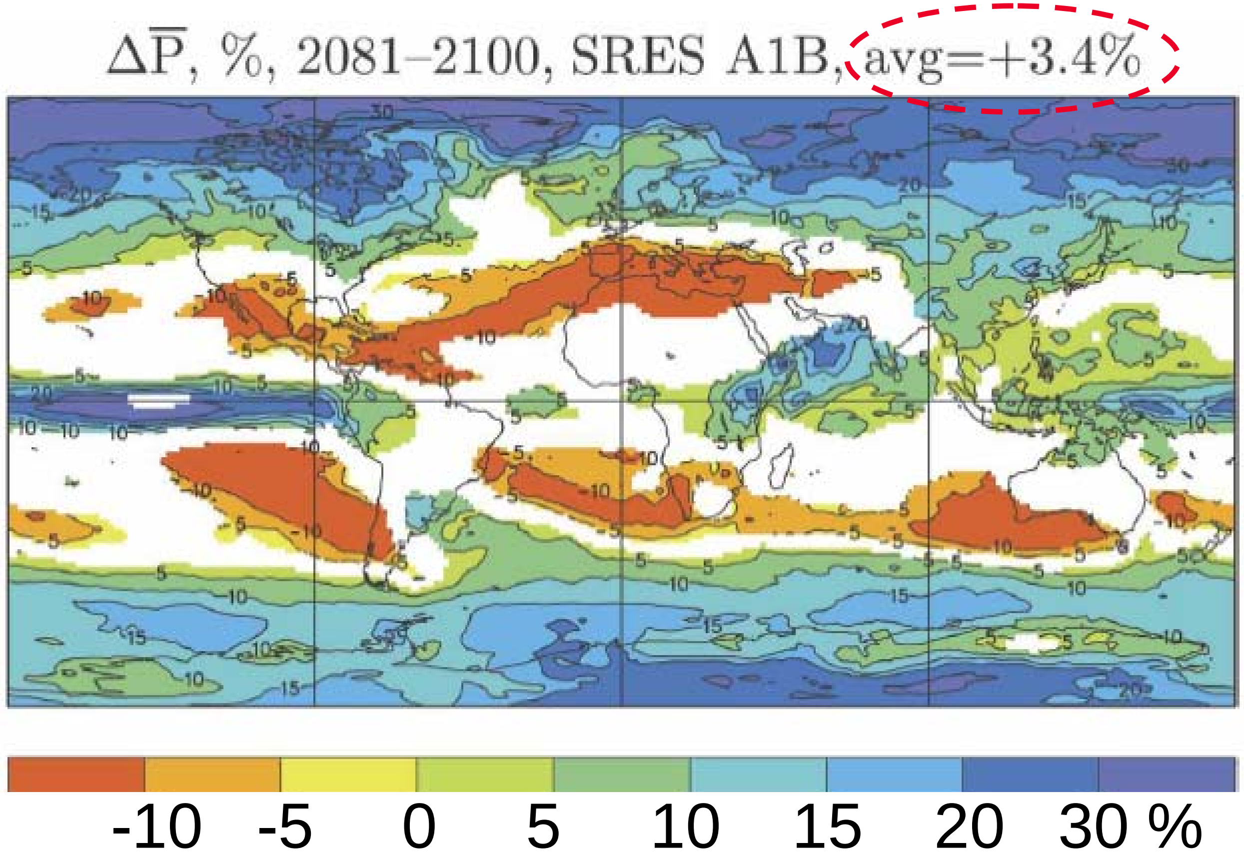


- If the warming proceeds as simulated, almost all seasons in the late 21st century will exceed the 20th century records in the tropics where the interannual variability is smallest, and a considerable fraction of them will also exceed these records in extratropical latitudes

*** Warmer than any simulated winter/summer in 1901-2007**

Simulated changes in extreme one-day precipitation

Multi-model median changes in annual mean precipitation: A1B, 1981-2000 → 2081-2100

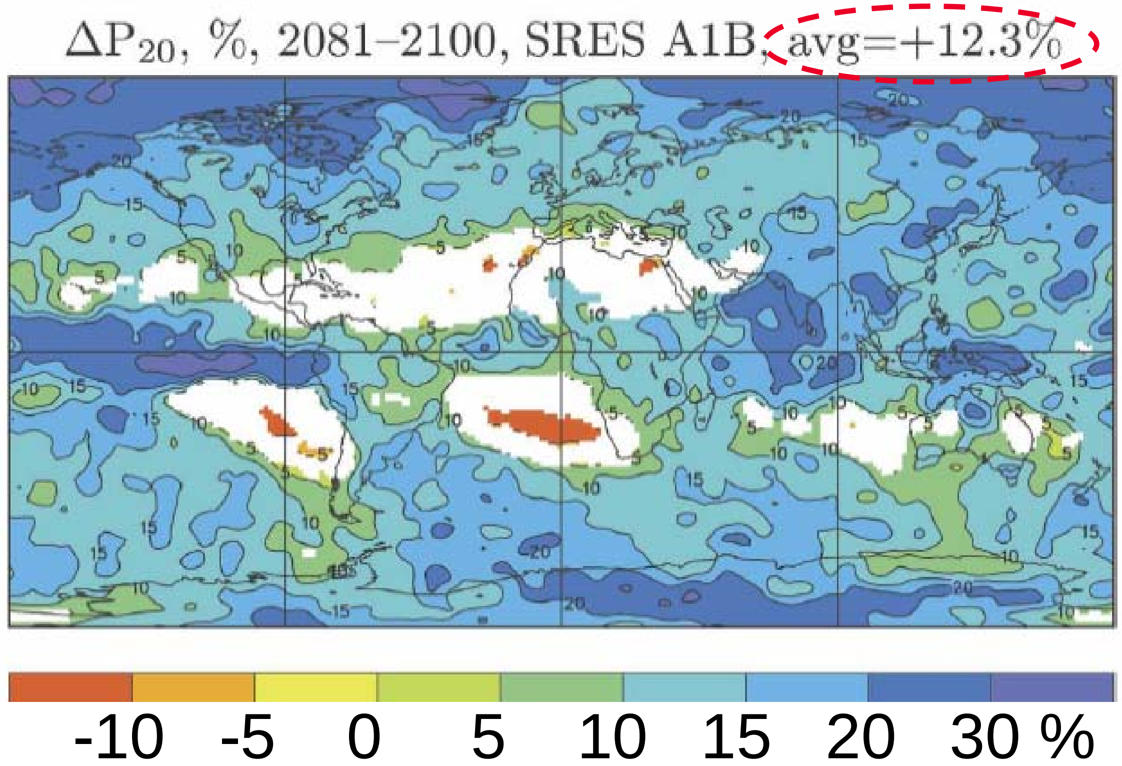


Areas with no significant change (at the 10% level, using a Wilcoxon test) **are left blank**

Kharin et al. (2007), Fig. 13

Multi-model median changes in 20-year return value of one-day precipitation:

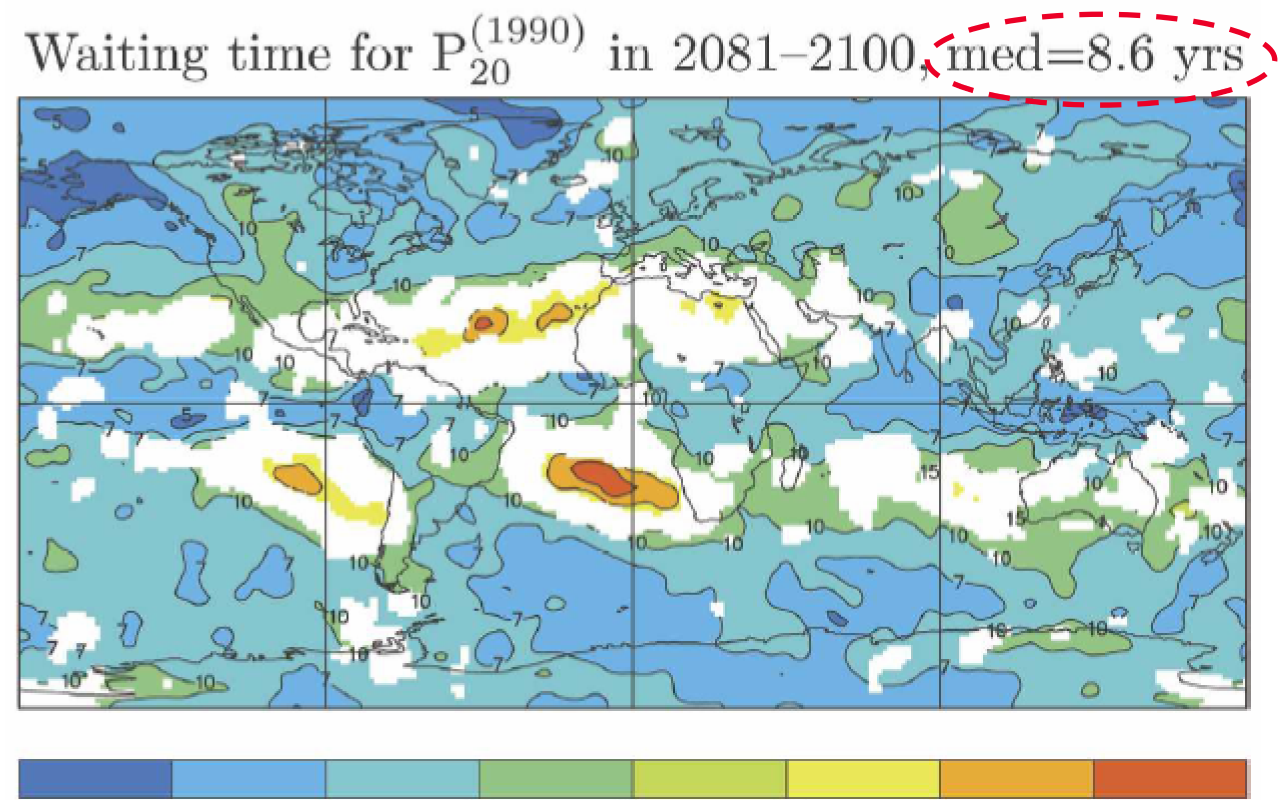
A1B, 1981-2000 → 2081-2100



Kharin et al. (2007), Fig. 13

1. Widespread increase
2. Areas of decrease coincide with decreasing mean precipitation
3. Where mean precipitation increases, the change in 20-year return value may be %-wise larger (e.g., Tropics) or slightly smaller (Arctic) than the change in the mean

How often will 20-year precipitation maxima from 1981-2000 be exceeded in 2081-2100?

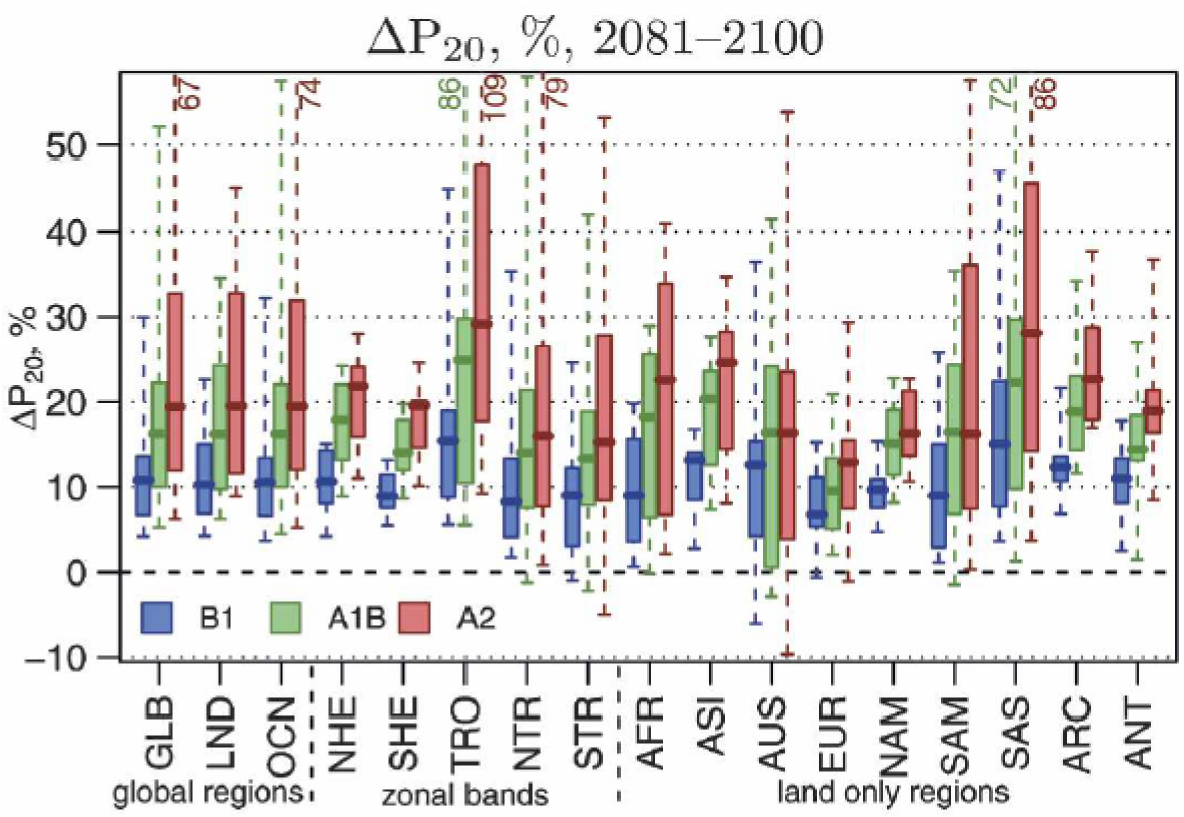


Once in 5 7 10 15 20 30 40 years

Kharin et al. (2007), Fig. 13

1. Changes in frequency %-wise much larger than changes in return value (as expected)
2. Frequency of precipitation extremes changes much less than that of temperature extremes

Example of variation between models and forcing scenarios: Change in $P_{max,20}$ from 1981-2000 to 2081-2100



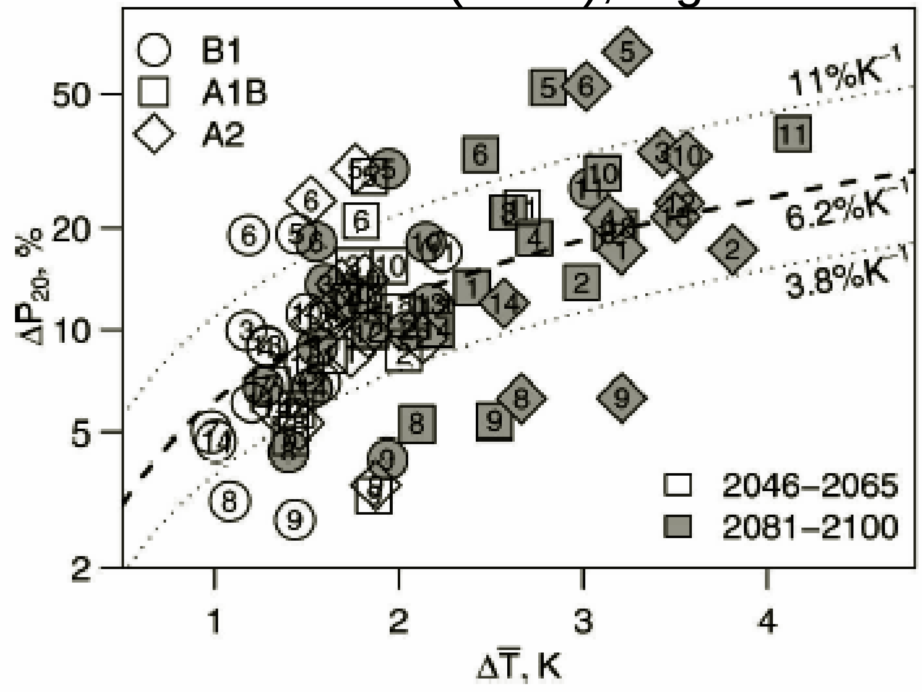
Very large intermodel range particularly in low-latitude regions, but few cases of decrease.

GLB = Global mean, LND = Global land mean,....,
AFR = Africa, ASI = Asia,....,etc.

Kharin et al. (2007), Fig. 15

How do changes in extreme precipitation relate to global mean warming?

Kharin et al. (2007), Fig. 16



6.2% K^{-1}

cf. Clausius-Clapeyron:
~7% K^{-1}

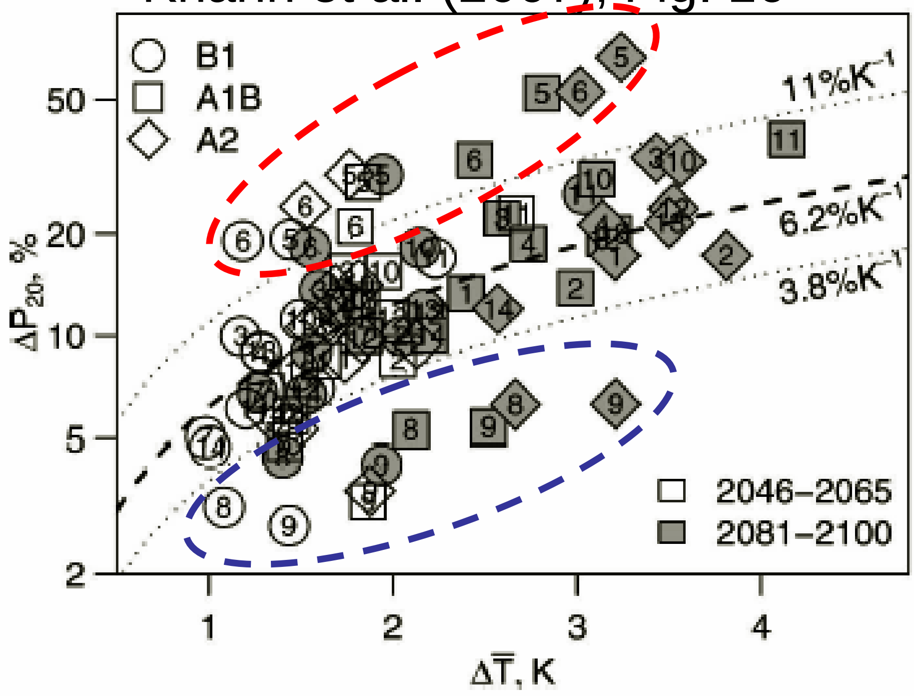
Vertical axis: global-mean changes in 20-year one-day precipitation (logarithmic scale)

Horizontal axis: global mean temperature change

Symbols: 14 models, two periods, three forcing scenarios

How do changes in extreme precipitation relate to global mean warming? (2)

Kharin et al. (2007), Fig. 16



11% K^{-1}

6.2% K^{-1}

3.8% K^{-1}

In most models, the <u>global average magnitude of extremes</u> increases by **4-11%** for each 1ºC global warming.

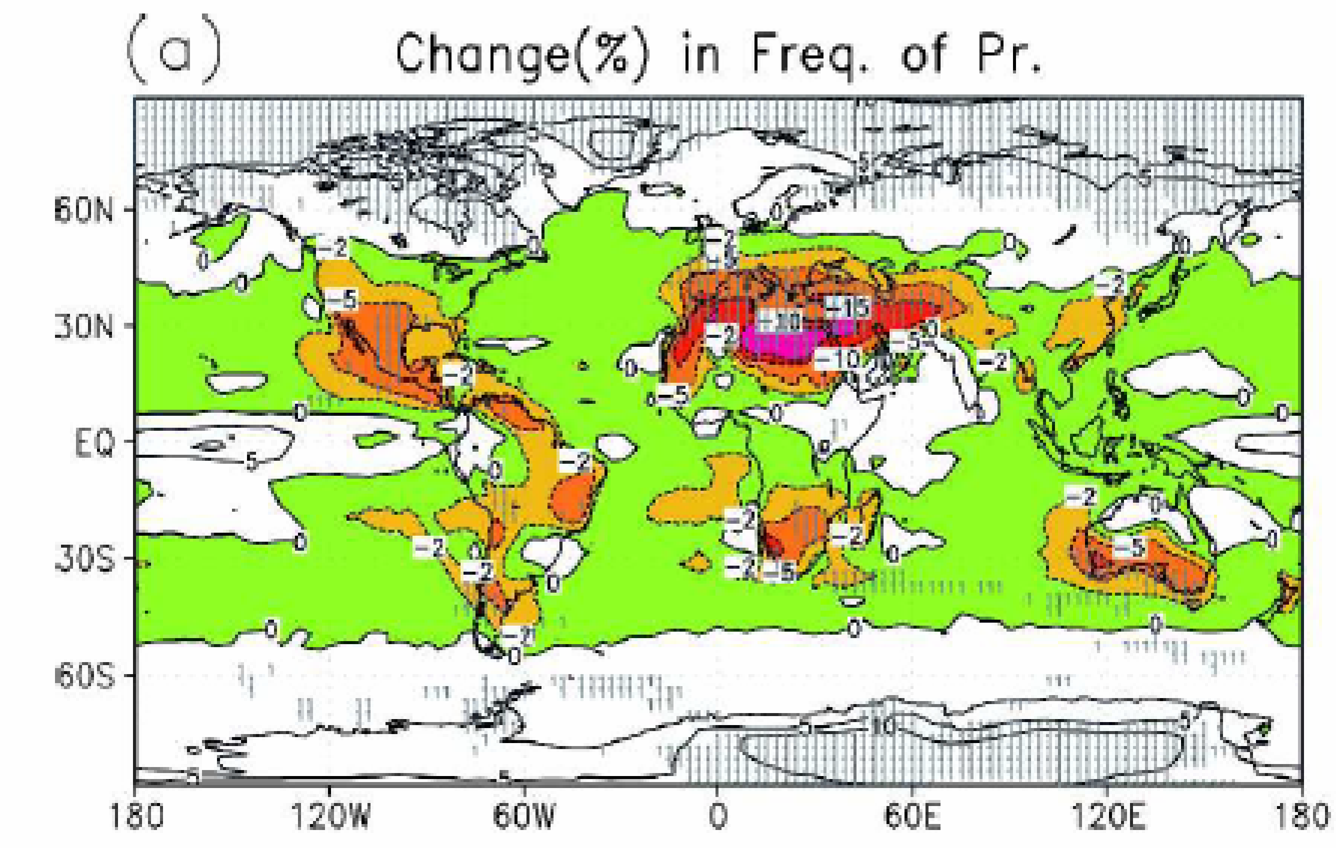
Outliers on the low side: GISS ER (8), INM CM3.0 (9)

Outliers on the high side: GFDL CM2.0 (5), GFDL CM2.1 (6)

Changes in other aspects of precipitation variability

(Sun et al. 2007)

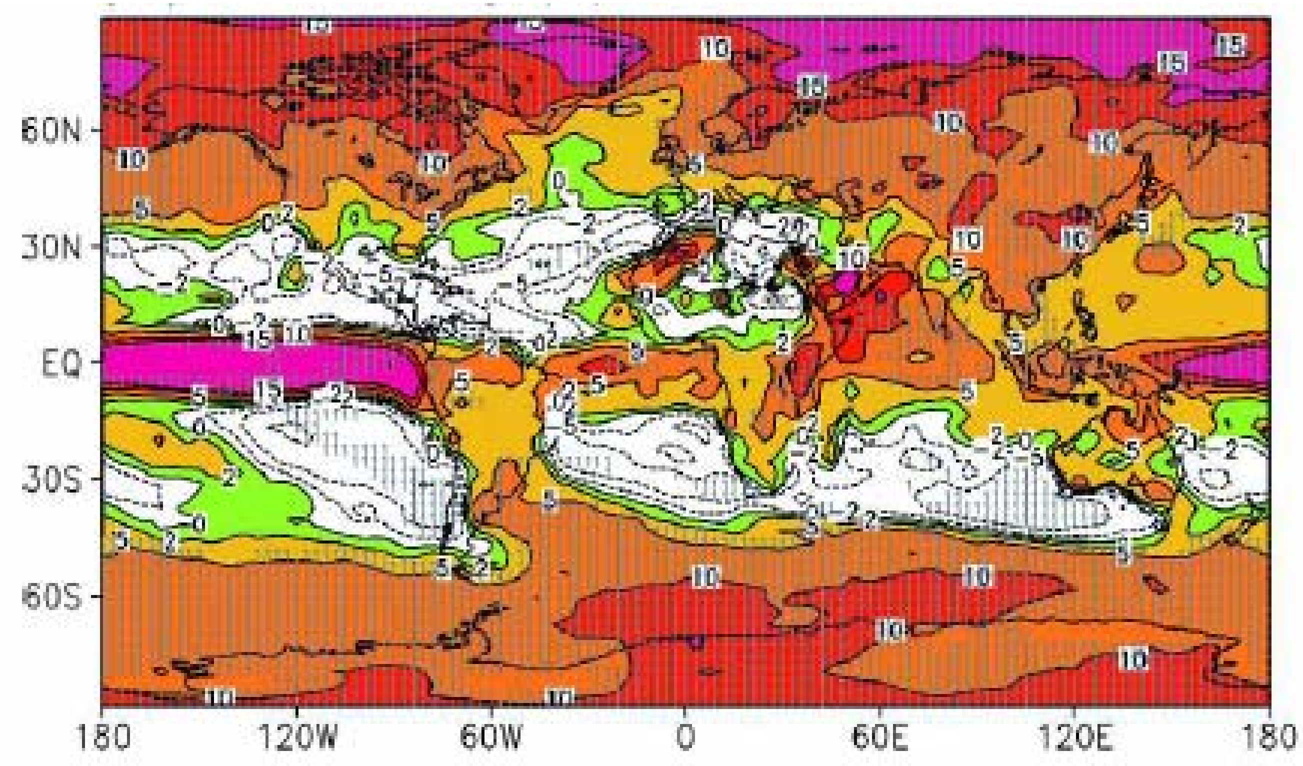
Change in the average number of precipitation days (Sun et al. 2007)



colours = decrease

* B1 scenario, 14 models, 1980-1999 → 2080-2099
* All days with P > 0.1 mm counted as precipitation days

Change in average precipitation intensity (Sun et al. 2007)

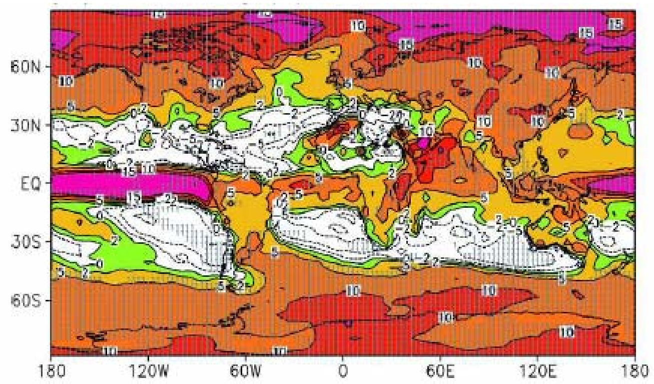


colours = increase

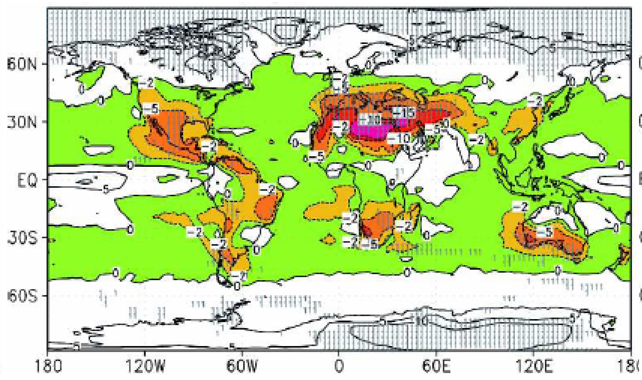
Precipitation intensity = mean precipitation of all ’wet’ days with P > 0.1 mm.

Changes in intensity vs. frequency vs. total precipitation (Sun et al. 2007)

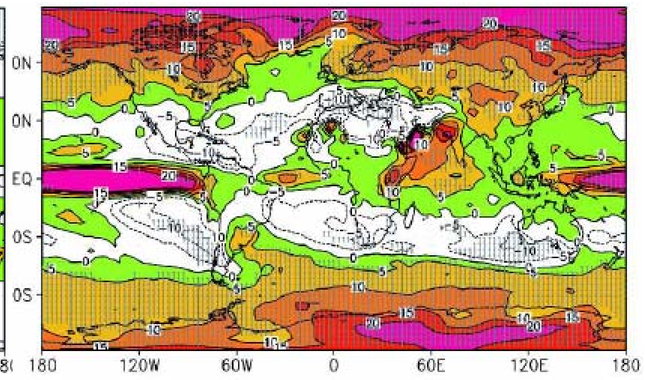
Intensity (>0 in colour)



Frequency (< 0 in colour)



Total precip (>0 in colour)

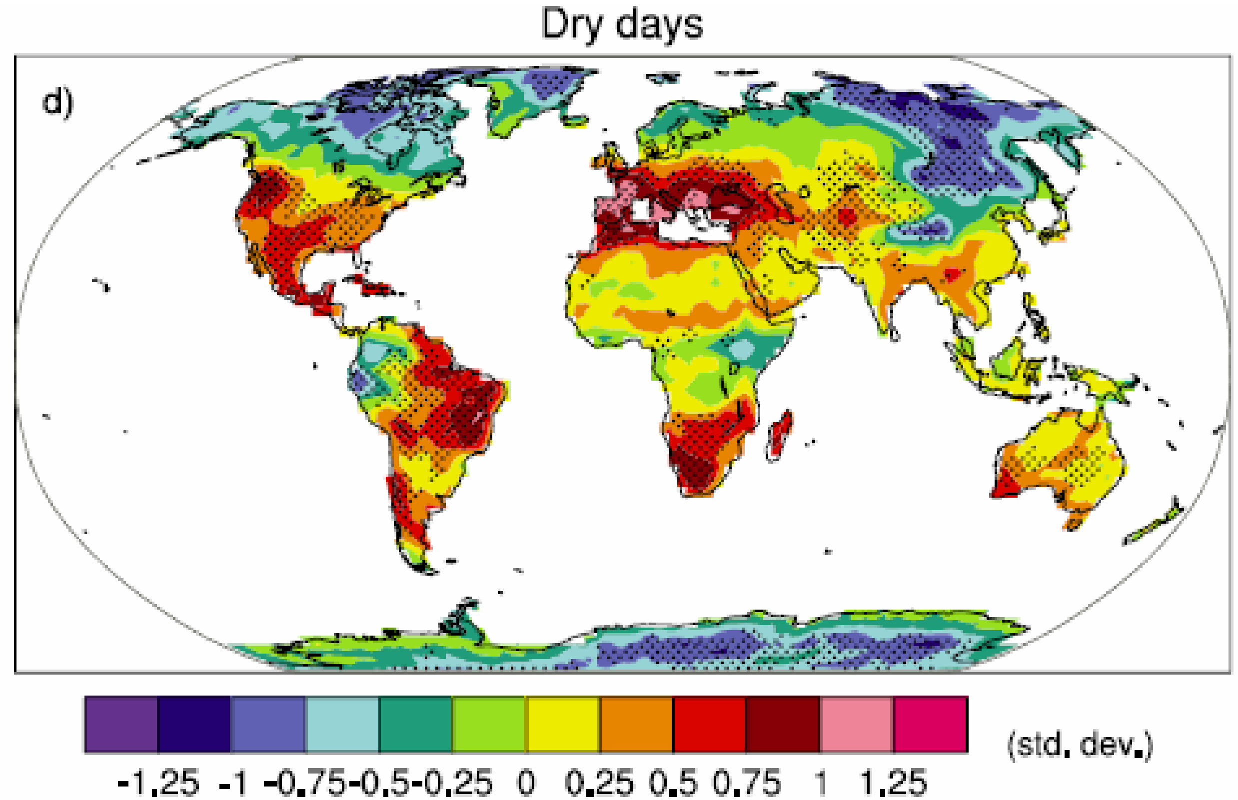


- **Where total precipitation increases**, more precipitation falls in an average precipitation day

- **Where total precipitation decreases**, the number of precipitation days decreases

- **Where the change in total precipitation is small**, both may happen.

Change in the maximum length of dry spells
(1980-1999 → 2080-2099), A1B, 9 models



Tebaldi et al.
(2006: Clim. Change, 79, 185-211)
IPCC WG1
(2007: Fig. 10.18)

Unit: interannual standard deviations

Where the total number of precipitation days decreases, the longest dry spells generally become longer.

Changes in precipitation variability and extremes: summary

	Fraction of global area (schematic only) →						
Number of precipitation days	+	+	+	--	--	--	--
Total annual precipitation	+	+	+	+	--	--	--
Average precipitation intensity	+	+	+	+	+	--	--
Extreme precipitation	+	+	+	+	+	+	--

– avoid over-generalization: changes not the same in all areas (or all models)

– resolution of current models might still be a problem in some areas: (i) geography, (ii) convective storms, (iii) tropical cyclones, etc.

What about wind extremes?

- **Changes in surface wind speeds**
  - we don't really know what the models are doing
  - <u>scalar</u> wind speed not included in CMIP3

- **Phenomenological view from IPCC AR4**
  - poleward shift in extratropical cyclone activity
  - 'a number of modeling studies have projected a general tendency for more intense but fewer* storms outside the tropics...'
  - stronger but possibly fewer* tropical cyclones

* Stronger but fewer… Perhaps the balance conditions of the general circulation "do not need" as many storms when a few stronger storms suffice to do whatever storms are supposed to do …?