Agronomy 406
World Climates

April 10, 2018

Predicting climate change: Models.

Projected changes in temperature and precipitation.

Projections of climate change

The main way we predict future climate is by using climate **models.**

In the most basic sense, what is a model? (Not necessarily a climate model, but **any** model.)

What is a model?

A model is a **representation** of a something.

Since the model is a **representation**, it can never be exactly like the real thing.

> "All models are wrong, but some are useful." (George E.P. Box, statistician)

Model of the U.S. Capitol, constructed from 478,000 matchsticks.
Matchstick Marvels, Gladbrook, Iowa.

Climate models

Climate models are **mathematical** models that predict the motions and thermodynamics of the climate system.

They are based on equations for fundamental physical principles:

- First Law of Thermodynamics, Stefan-Boltzmann Law, equations of motion, surface energy balance, etc. You have seen some of these.
- They **do not** use past trends as input.

How do we build a climate model?

Suppose we want to model Earth's climate and how it changes over time.

What processes would we need to include in our climate model? Think of everything that the **climate system** includes.

Climate models

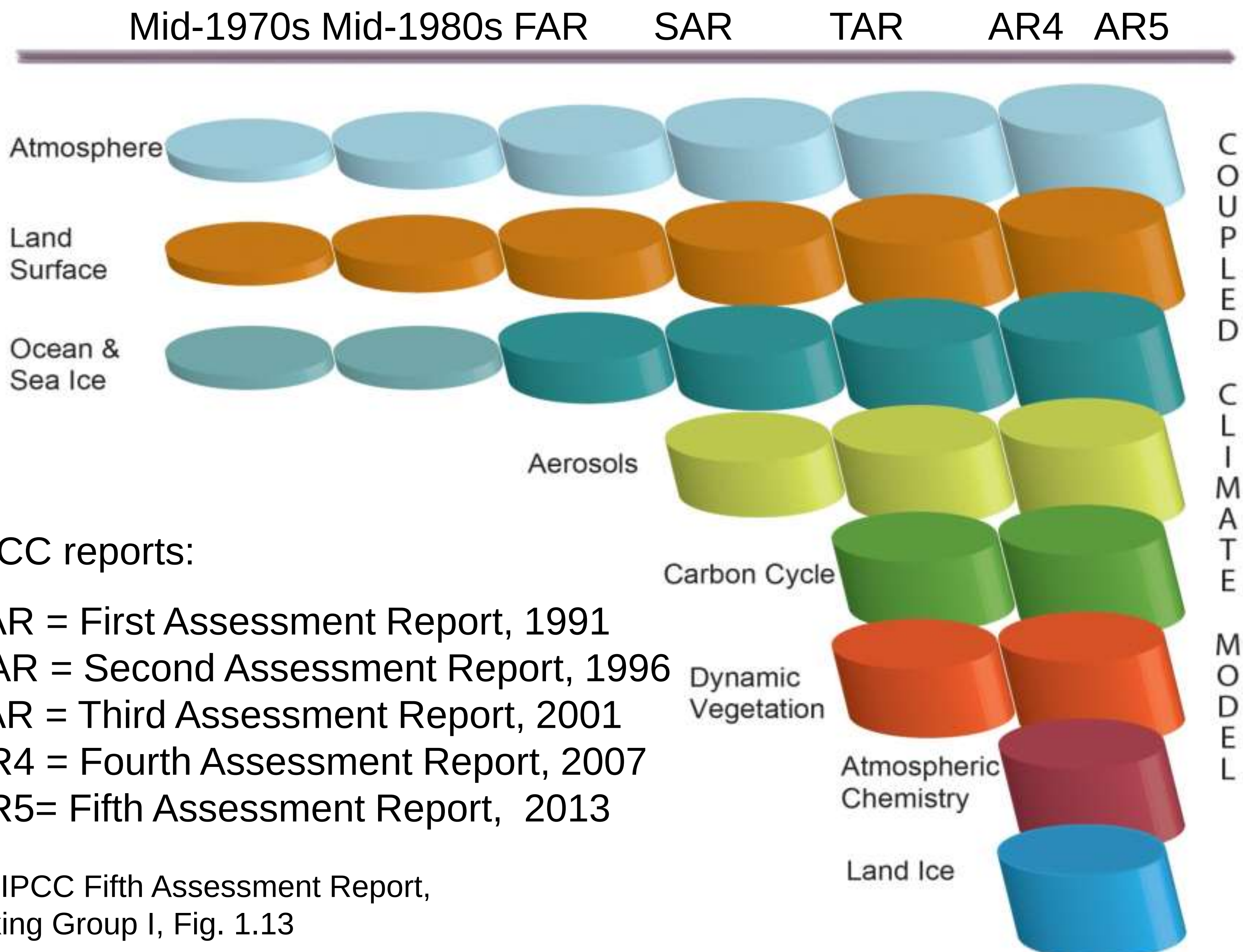
Earliest climate models only simulated the atmosphere.

Since then, climate models have evolved into **climate system models** or **earth system models.**

Modern climate models are actually **multiple, interacting models** for components of the climate system:

- Atmosphere model
- Ocean model
- Cryosphere model (sea ice and land ice models)
- Other models: Land surface model, chemistry model, etc.

Evolution of climate system models



IPCC reports:

FAR = First Assessment Report, 1991
SAR = Second Assessment Report, 1996
TAR = Third Assessment Report, 2001
AR4 = Fourth Assessment Report, 2007
AR5= Fifth Assessment Report, 2013

from IPCC Fifth Assessment Report, Working Group I, Fig. 1.13

Problems with models

Many parts of the system are hard to include in models.

Example: Sea ice. Models up to the late 2000s greatly under-predicted the decline of Arctic sea ice.

The system is complex and **nonlinear**:

Different models use different methods to get **approximate** solutions.

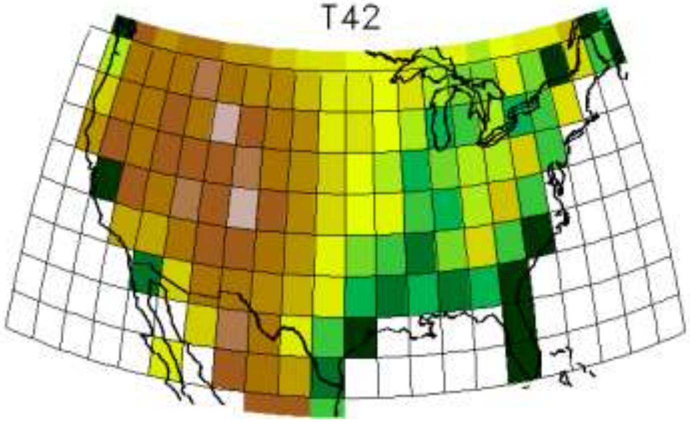
Using several different models with different methods helps us decide whether projections are believable **(convergence of evidence).**

Equations are "solved" at **specific points in space:**

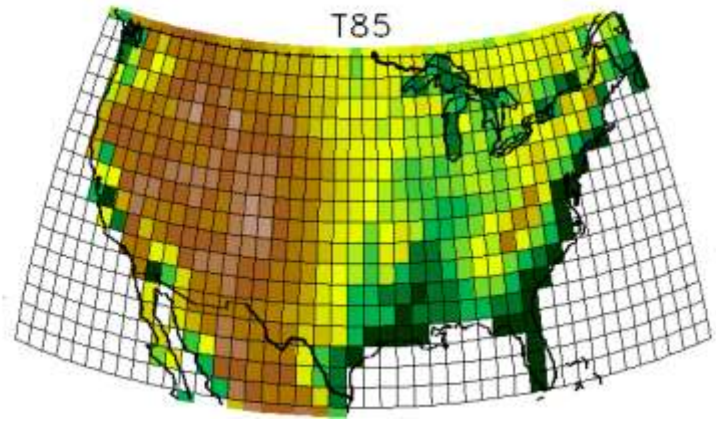
Accuracy depends on separation between points.

Realism improves as space between grid points becomes finer

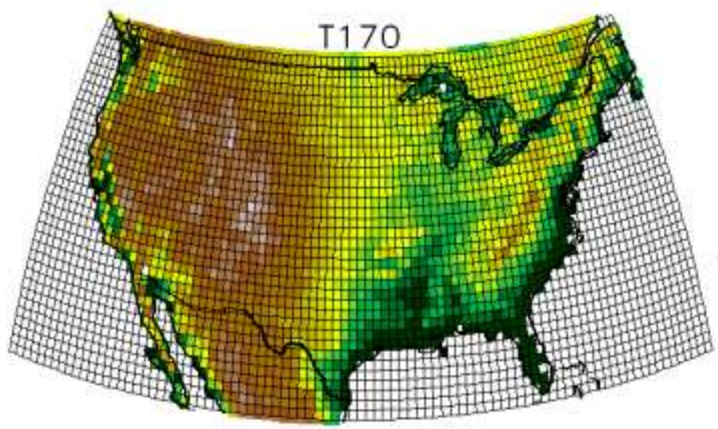
typical for IPCC Third and Fourth Assessment Reports

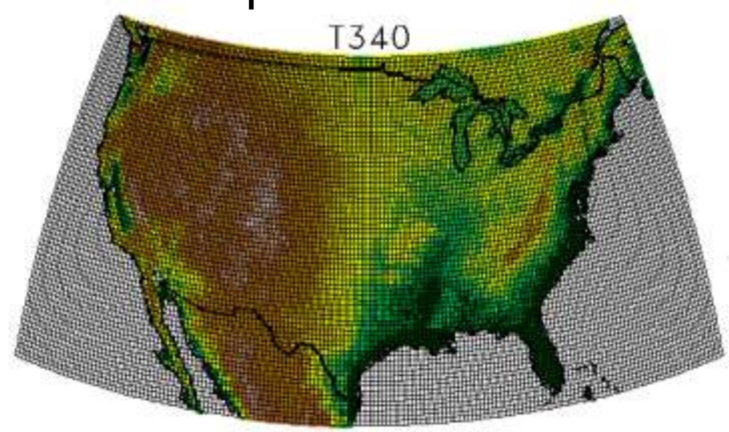


typical for IPCC Fifth Assessment Report



some models for next report





T42 ~ 2.9º latitude-longitude (320 km)

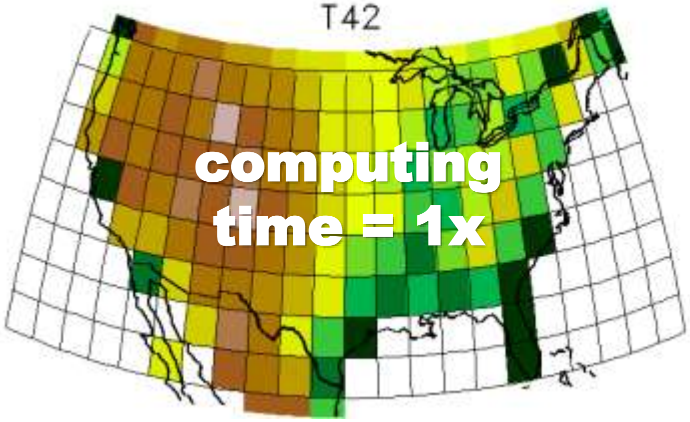
T85 ~ 1.4º latitude-longitude (150 km)

T170 ~ 0.7º latitude-longitude (75 km)

T340 ~ 0.35º latitude-longitude (40 km)

Realism improves as space between grid points becomes finer… but at a cost.

typical for IPCC Third and Fourth Assessment Reports



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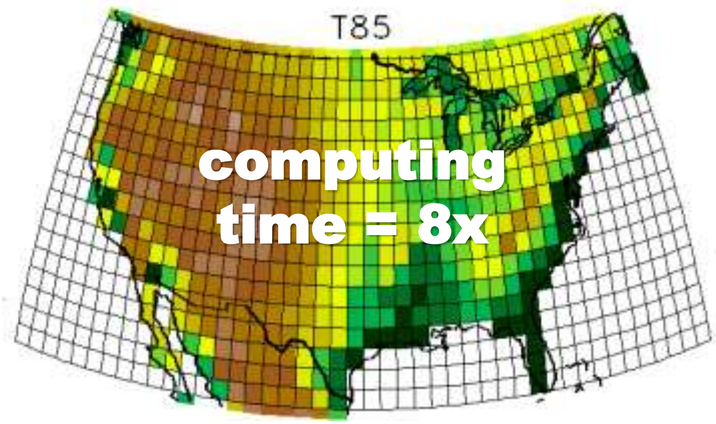

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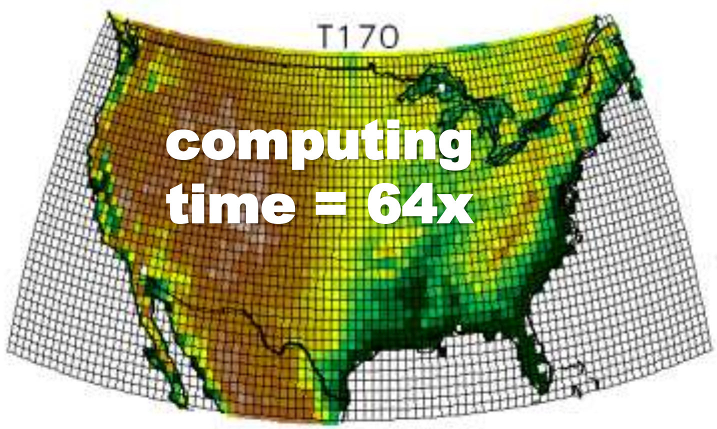

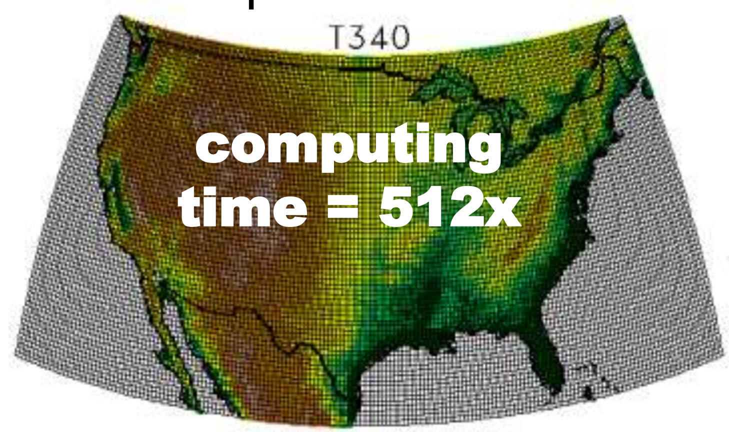

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Making projections when there is uncertainty

Uncertainty is a fact of life. People (including you!) deal with uncertainty all the time.

Uncertainty means we cannot make specific "predictions":

- Different models give somewhat different results.
- Human actions (such as emissions) are uncertain.

Instead establish a **range of possible outcomes:**

- A **scenario** is a possible course of events.
- We use a **range** of emissions scenarios to produce a **range** of climate projections using different models. The goal is to **span the range of possible outcomes in the real world.**

Scenarios

Example: Assume emissions of greenhouse gases continue as they are now.

Run climate models to estimate what the future climate could be if this happens.

Another example: Assume emissions increase rapidly as consumption grows in the developing world.

Run climate models again to estimate what the future climate could be if this happens.

What other **realistic** scenarios can you think of?

Scenarios in the IPCC Fifth Assessment Report

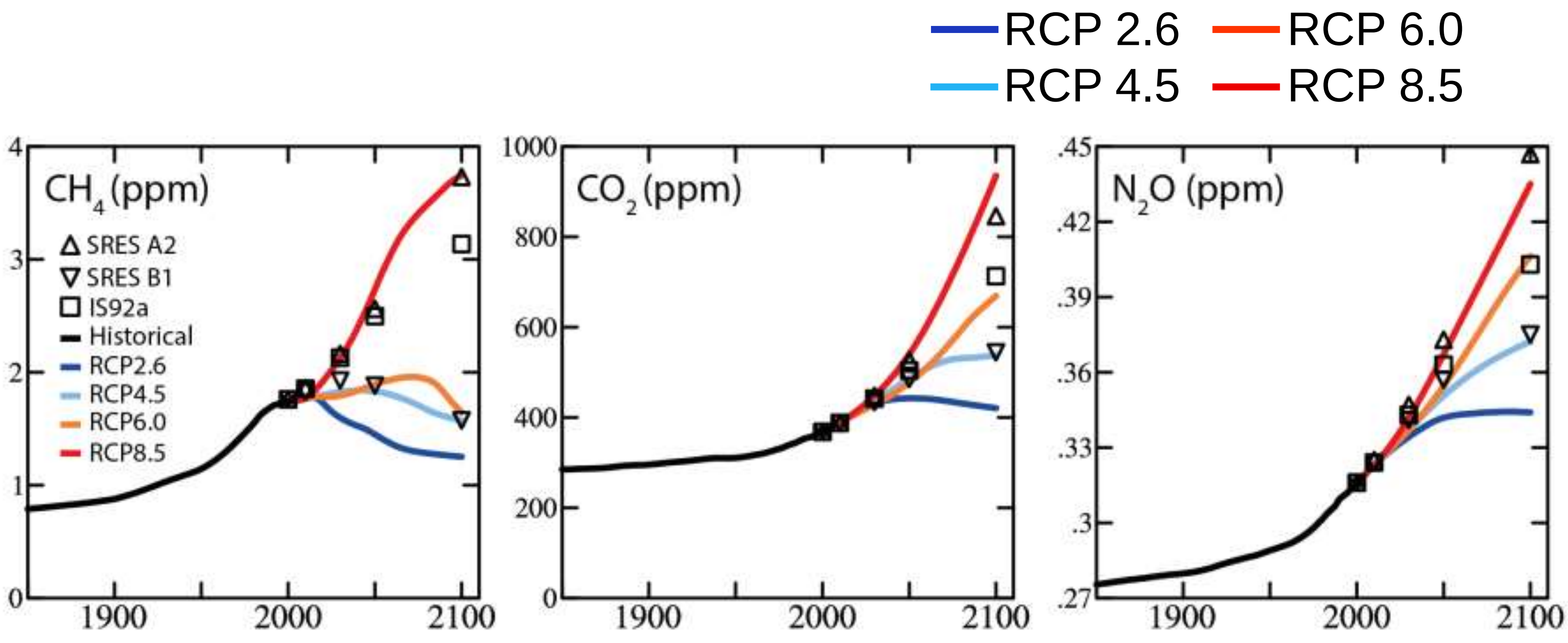
Scenarios are based on specified values of **radiative forcing** at the year 2100:

- Radiative forcing is the change in **net incoming radiation** (both SW and LW) at the tropopause compared to pre-industrial times.
- The specific values used in the report are changes of 2.6, 4.5, 6.0, and 8.5 W m^{-2} in radiative forcing.

Each value of radiative forcing is reached by following a **representative concentration pathway** from now into the future.

- These **scenarios** are referred to as RCP2.6, RCP4.5, RCP6.0 and RCP8.5

Concentrations of methane, CO_2 and nitrous oxide for each RCP



Black curves show historical measurements.

Symbols give values from some older scenarios.

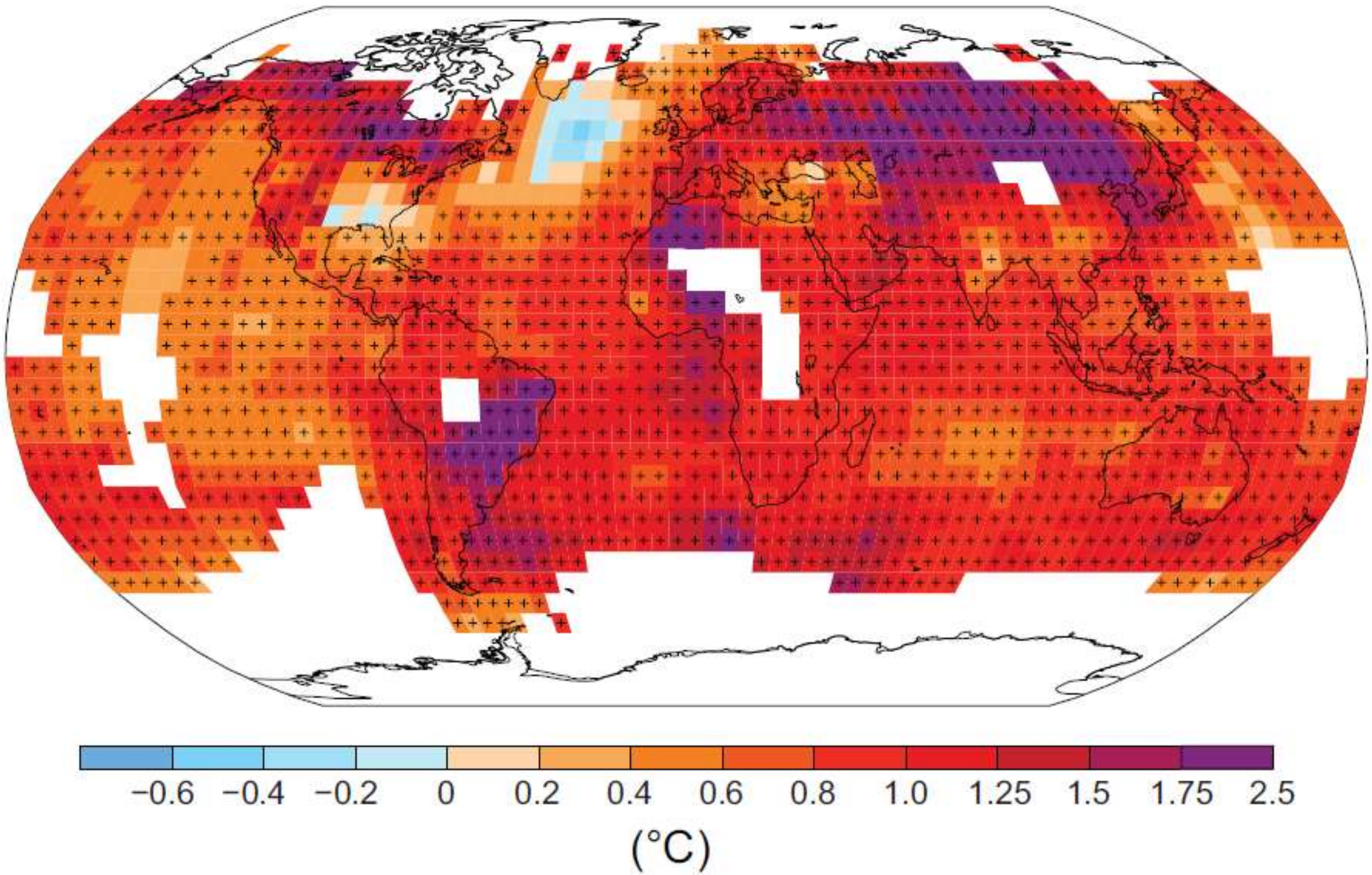
IPCC Fifth Assessment Report, Working Group I, Figure 8.5

Projected 21st century climate change

We will start with a look at **observed changes** in temperature and precipitation during recent decades. This gives a context for the projections.

In the IPCC Fifth Assessment Report Summary for Policymakers, look at **Figure SPM.1(b).** This shows observed temperature trend from 1901-2012 in ^{o}C per decade.

(b) Observed change in surface temperature 1901–2012



Observed warming in the 20th century

Figure SPM.1(b) shows average temperature trend from 1901-2012 in ^{o}C per decade.

White areas have insufficient data.

+ signs show where the trend is statistically significant.

Where has **statistically significant** warming been greatest?

Where has **statistically significant** warming been least?

For what land area has statistically significant warming been <u>greatest?</u>

HOLD UP YES OR NO CARD

- Europe
- Russia (Siberia)
- Southeastern United States
- Eastern South America
- Australia

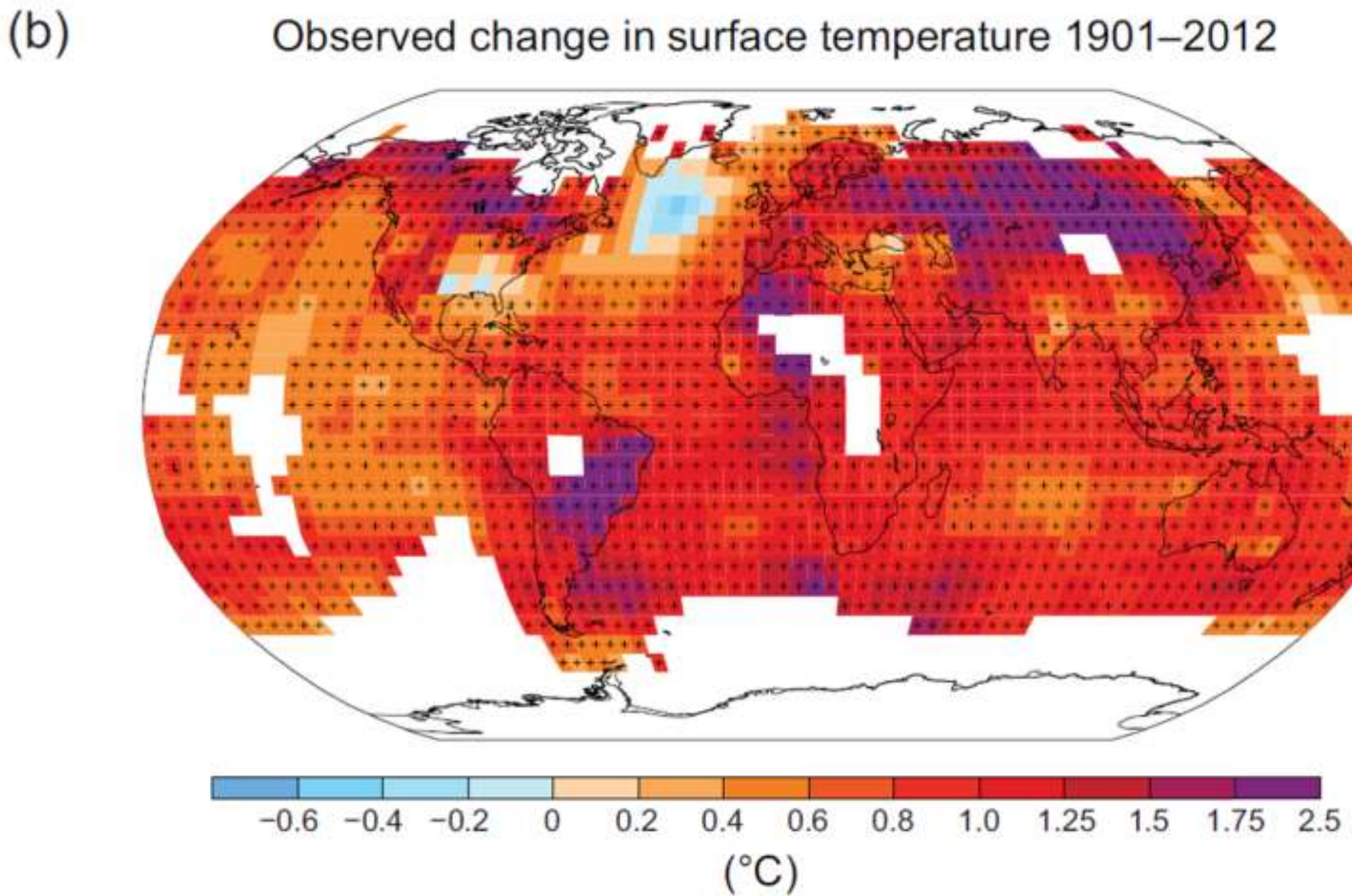
For what land area has statistically significant warming been <u>smallest or negative?</u>

HOLD UP YES OR NO CARD

- Europe
- Russia (Siberia)
- Southeastern United States
- Eastern South America
- Australia

What broad trends or patterns do you see in the map?

Discuss in your teams.



Observed precipitation changes in the 20th century

Now look at Figure SPM.2. The right-hand side shows average precipitation trend observed from 1951-2010, in (mm/year) per decade.

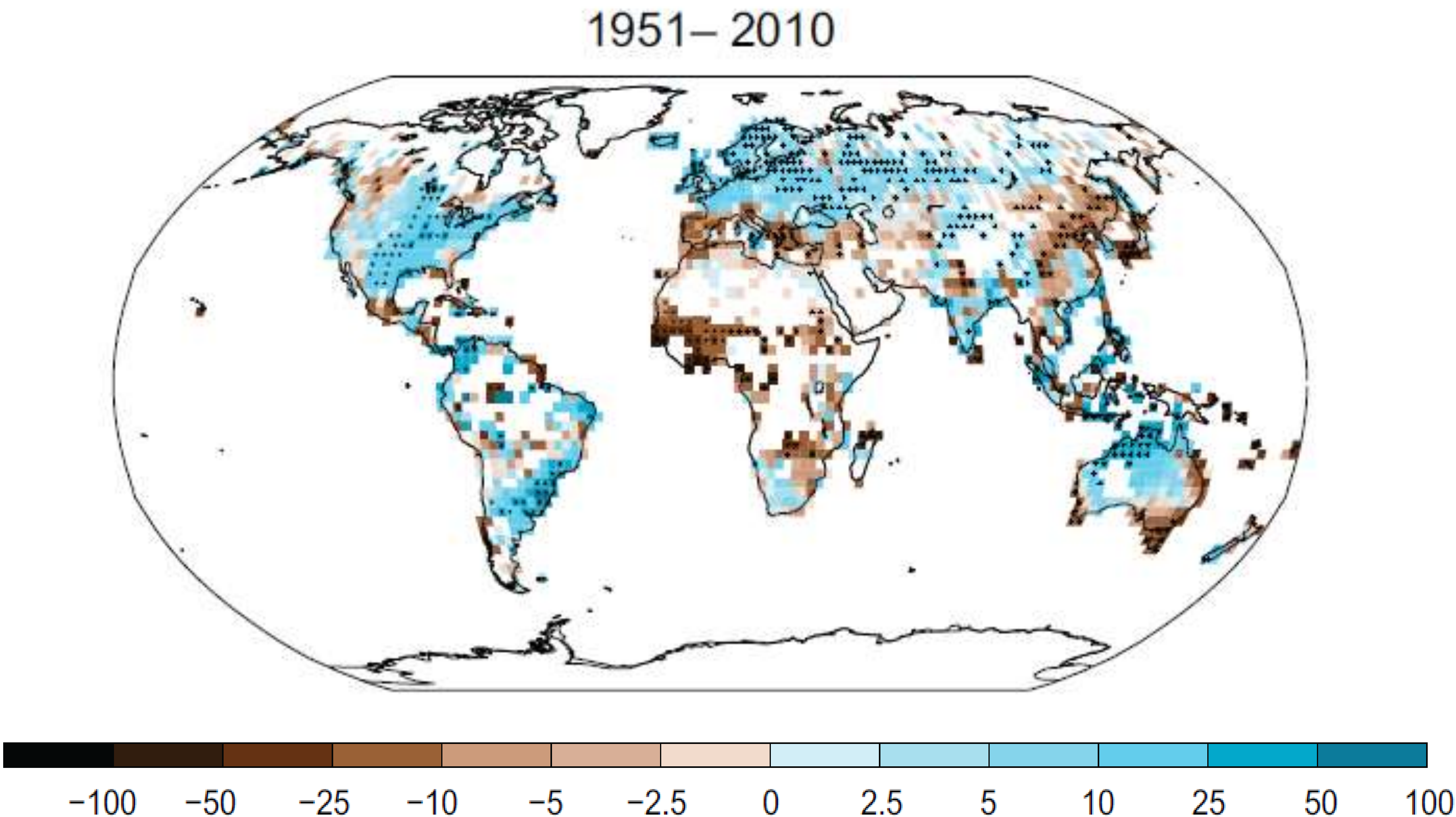
White areas have insufficient data.

+ signs (may look like dots) show where the trend is statistically significant.

What regions had **statistically significant** increases?

What regions had **statistically significant** decreases?

Observed change in annual precipitation over land



What regions had statistically significant increases in precipitation?

HOLD UP YES OR NO CARD

Central United States

SE Australia

Antarctica

Northern Europe

Southern Europe

Western Africa

What regions had statistically significant decreases?

HOLD UP YES OR NO CARD

India

Western United States

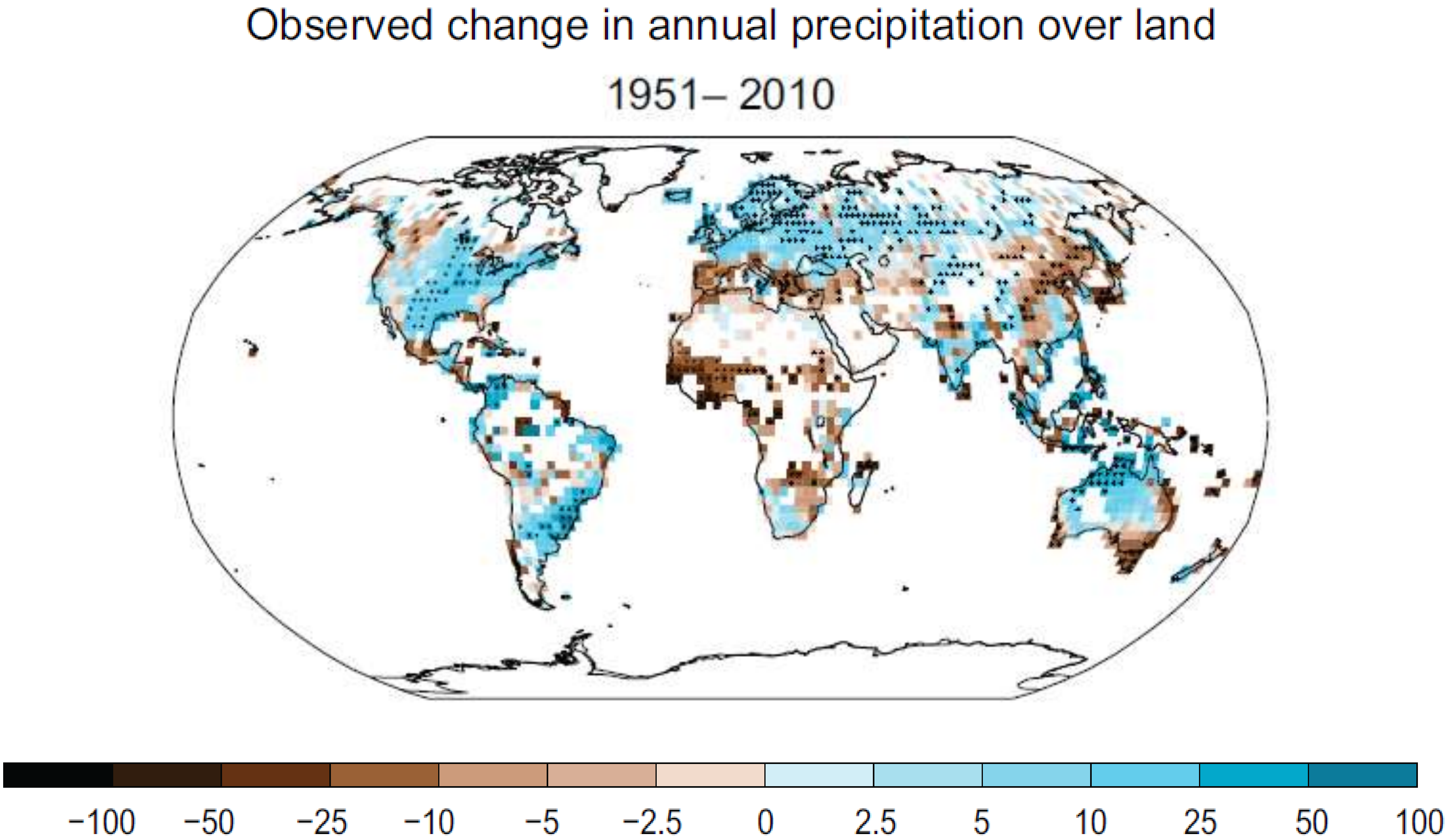
Canada

Northern Europe

Southern Europe (Mediterranean)

Western Africa

What patterns can you see in the increases and decreases?



Future climate change in the IPCC Fifth Assessment Report

The plots contain a lot of information:

Colors indicate the sign and amount of the change. Usually the change is in comparison to the late 20th century (1986-2005).

Dotted areas show where projected change is large compared to natural variations **and** at least 90% of models agree on the sign of the change.

> IPCC calls this **"large change with high model agreement."**

Cross-hatched areas show where average change is **small compared to natural variability.**

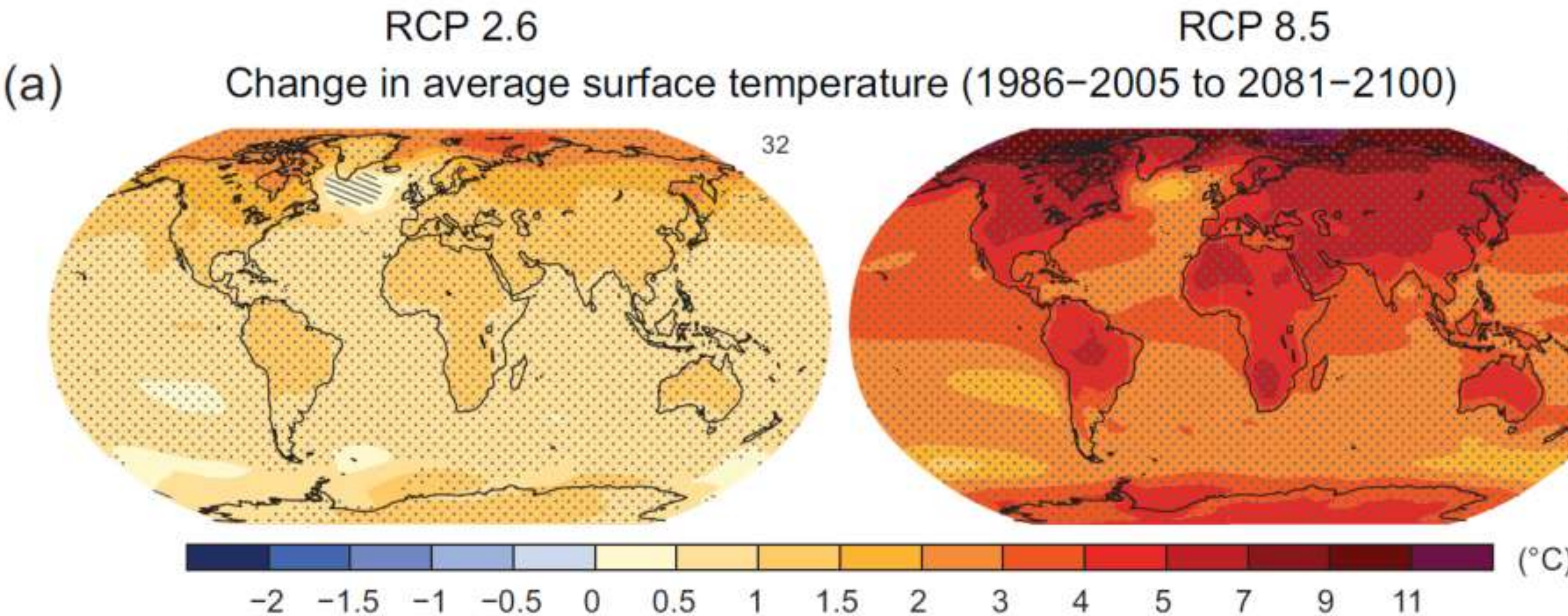
Projected 21st century temperature changes

Look at Figure SPM.8(a). Scenario RCP2.6 is on the left and RCP8.5 is on the right.

In the RCP8.5 scenario, what fraction of the world has "large change with high model agreement"?

Where is warming greatest? Where is warming least?

Do you see any **patterns** in the regions that warm strongly or weakly?


RCP 2.6
RCP 8.5
(a)
Change in average surface temperature (1986−2005 to 2081−2100)
32
39
(°C)
−2 −1.5 −1 −0.5 0 0.5 1 1.5 2 3 4 5 7 9 11

Projected 21st century precipitation changes

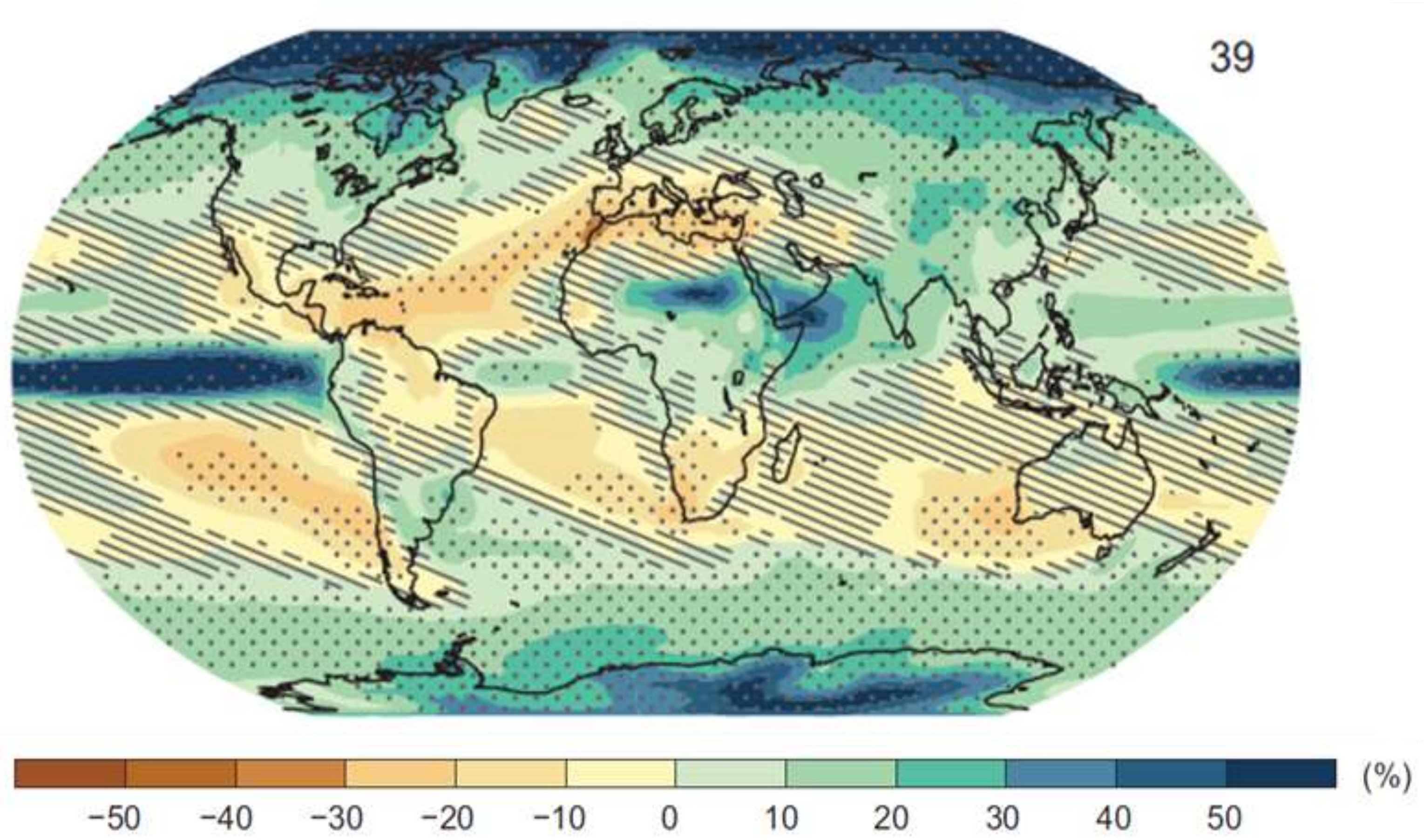
Now look at Fig. SPM.8(b), for the RCP 8.5 scenario (right-hand side).

Where are precipitation **increases** largest? Do you see a pattern to these locations?

Where are precipitation **decreases** largest? Do you see a pattern to these locations?

For what fraction of the world is there "large change with high model agreement"?

Precipitation change, 2081-2100 versus 1986–2005



Climate doesn't move in a straight line

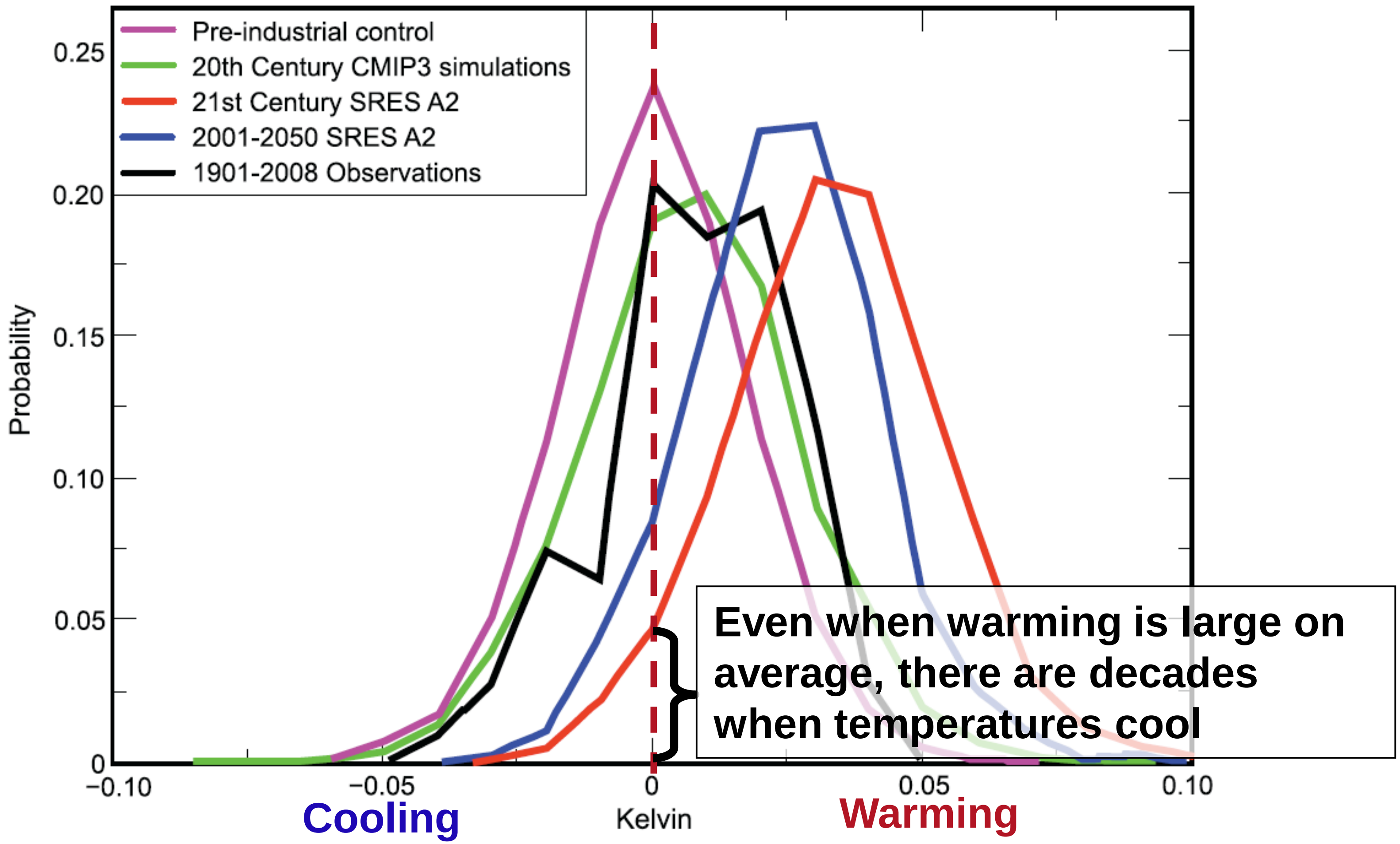
Human influence does not mean natural variability disappears.

There will still be year-to-year and decade-to-decade variations: ENSO, PDO, etc.

This means that the overall warming trend sometimes can be canceled out by natural variations.

How likely is a decade of cooling during a century of warming?

Probability distribution functions for decadal trends (°C/year) in globally averaged surface air temperature



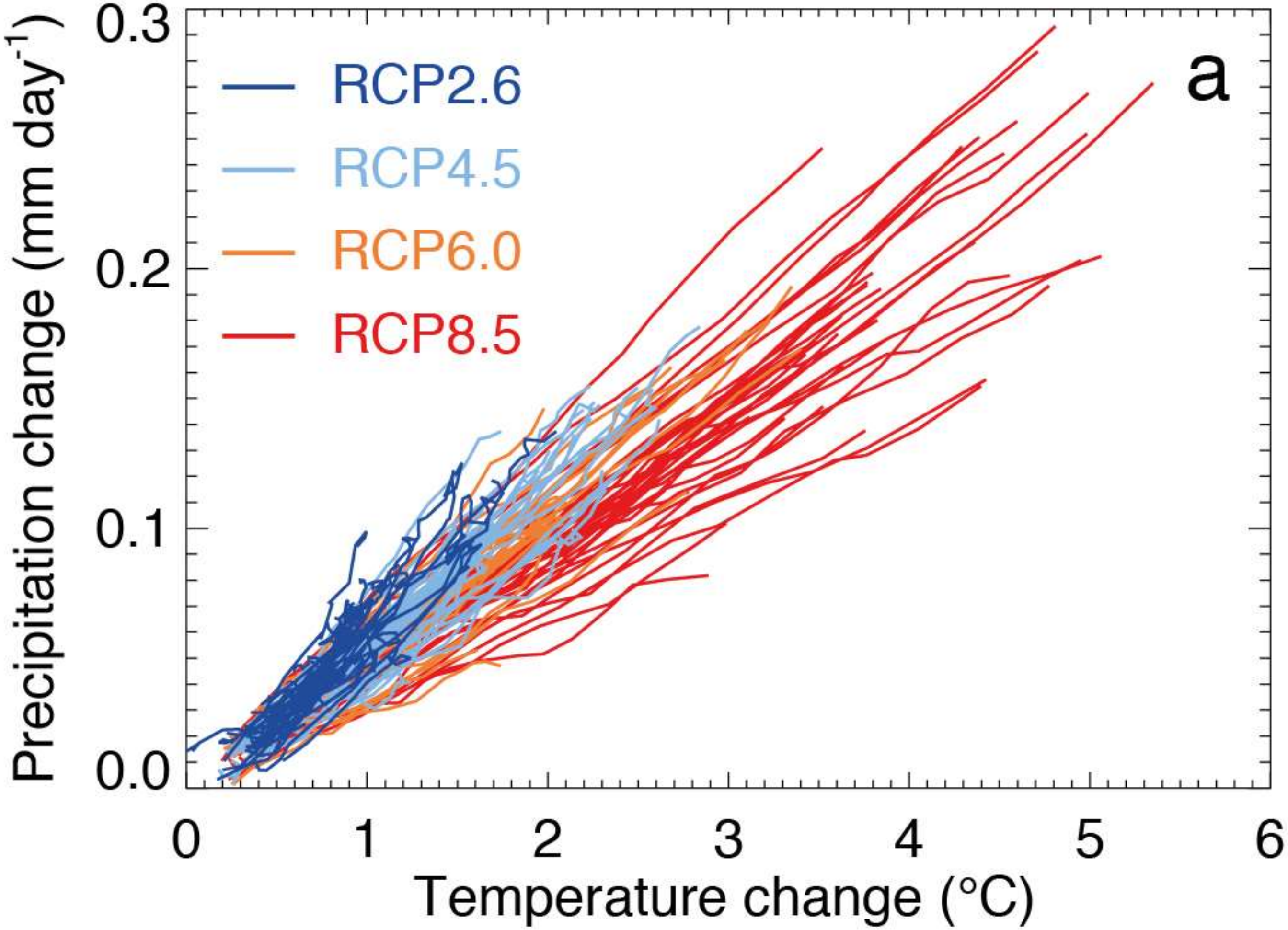
Easterling and Wehner (2009), *Geophys. Res. Lett.*

Relation between temperature and precipitation

We expect that as temperature increases precipitation should also increase.

- A warmer atmosphere evaporates more, and what goes in must come out (that is, P = E when averaged over the whole Earth).
- Recall this relationship was part of the CO_2-rock weathering "thermostat": warmer climate means more precipitation which means more weathering of the rocks.

Relationship between temperature and precipitation in various scenarios and models



IPCC Fifth Assessment Report, Fig. 12.6