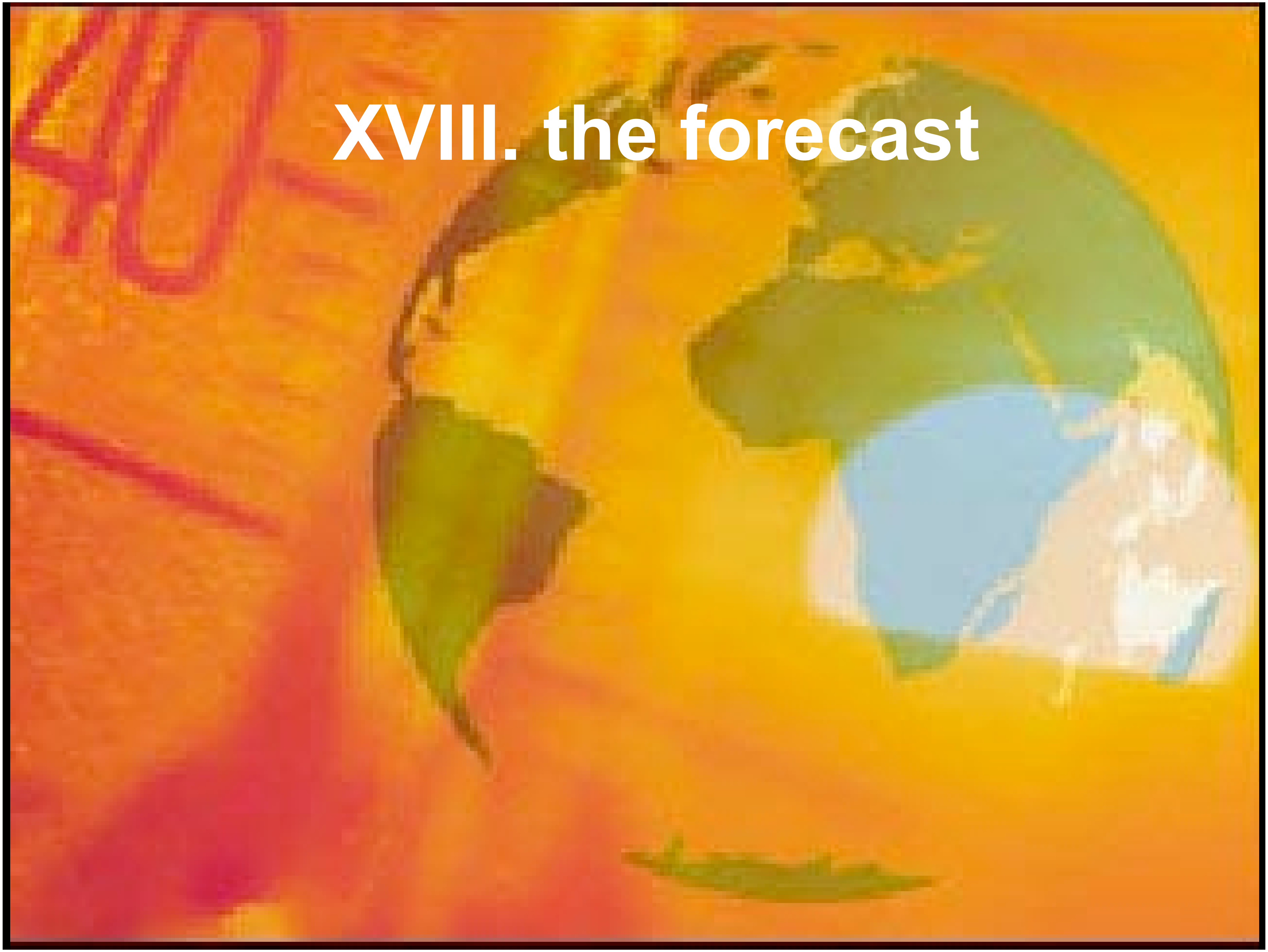
XVIII. the forecast

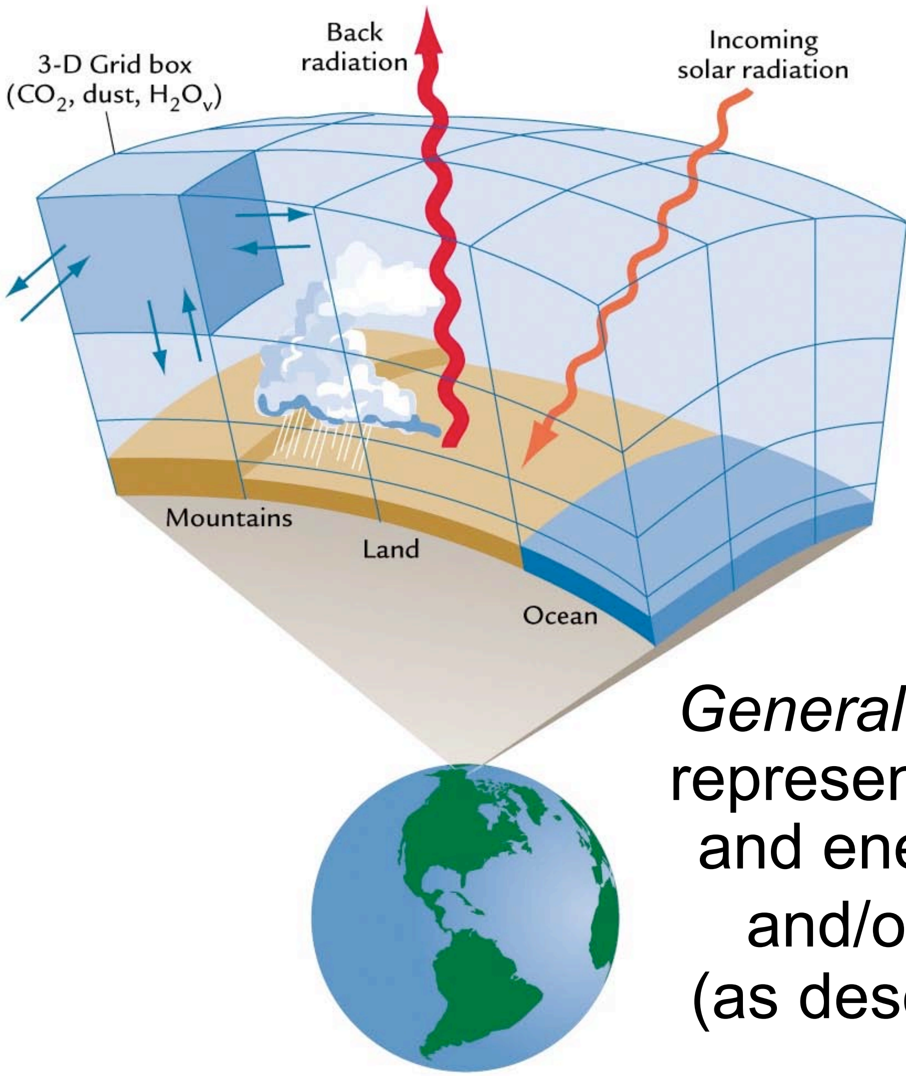


outline

- forecasts make use of climate models
  - a mathematical description of the climate system
  - “transient” vs. “equilibrium” climate response
- are the models reliable?
  - validation from hindcasts
- simple forecast strategy
  - define emissions scenarios (human behavior)
  - compare different models (physical uncertainty)
- “commitment warming”
  - warming already “in the pipeline”
- beyond global temperature and precip. trends and patterns
  - regional forecasts
  - probability of extreme conditions

climate models:

a mathematical description of the climate system



can also include:

- *sea ice*
- *vegetation*
- *carbon cycle etc.*

General Circulation Models (GCM's) represent motions (transfers of mass and energy) within the *atmosphere* and/or *ocean* based on *physics* (as described earlier this semester)

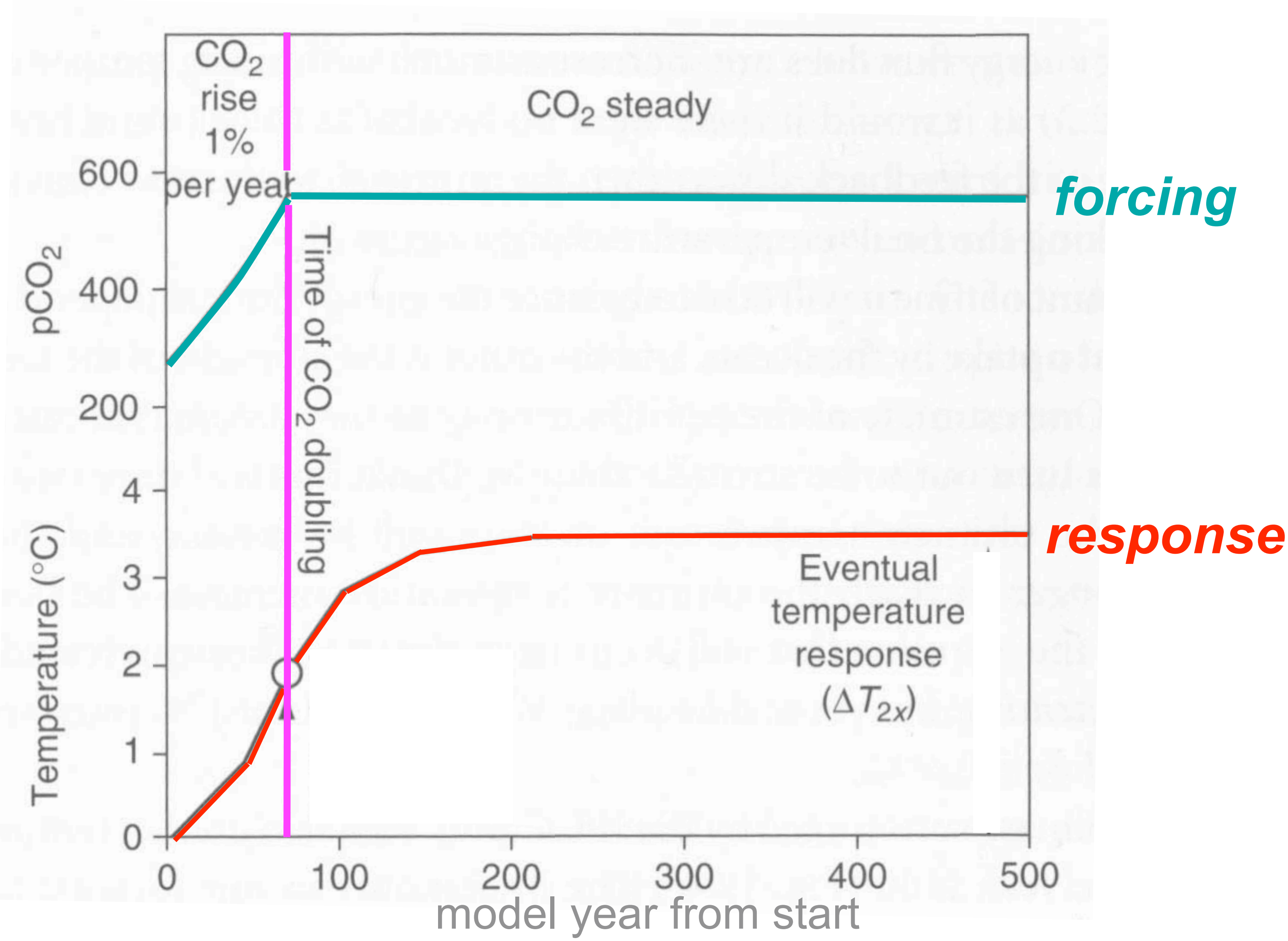
review

- **climate forcing** - any mechanism that influences the amount of energy received or stored by the climate system, often expressed as a *radiative forcing* in W/m^2

- **climate response** - the response of the climate system to a particular forcing (or forcings), where the response may include climate *feedback* processes (*example: the climate response to CO_2 forcing is dominated by water vapor feedback*)

- **climate sensitivity -** the ratio of response to forcing at equilibrium, often therefore expressed as temperature change per W/m^2 (or per "CO_2 doubling")

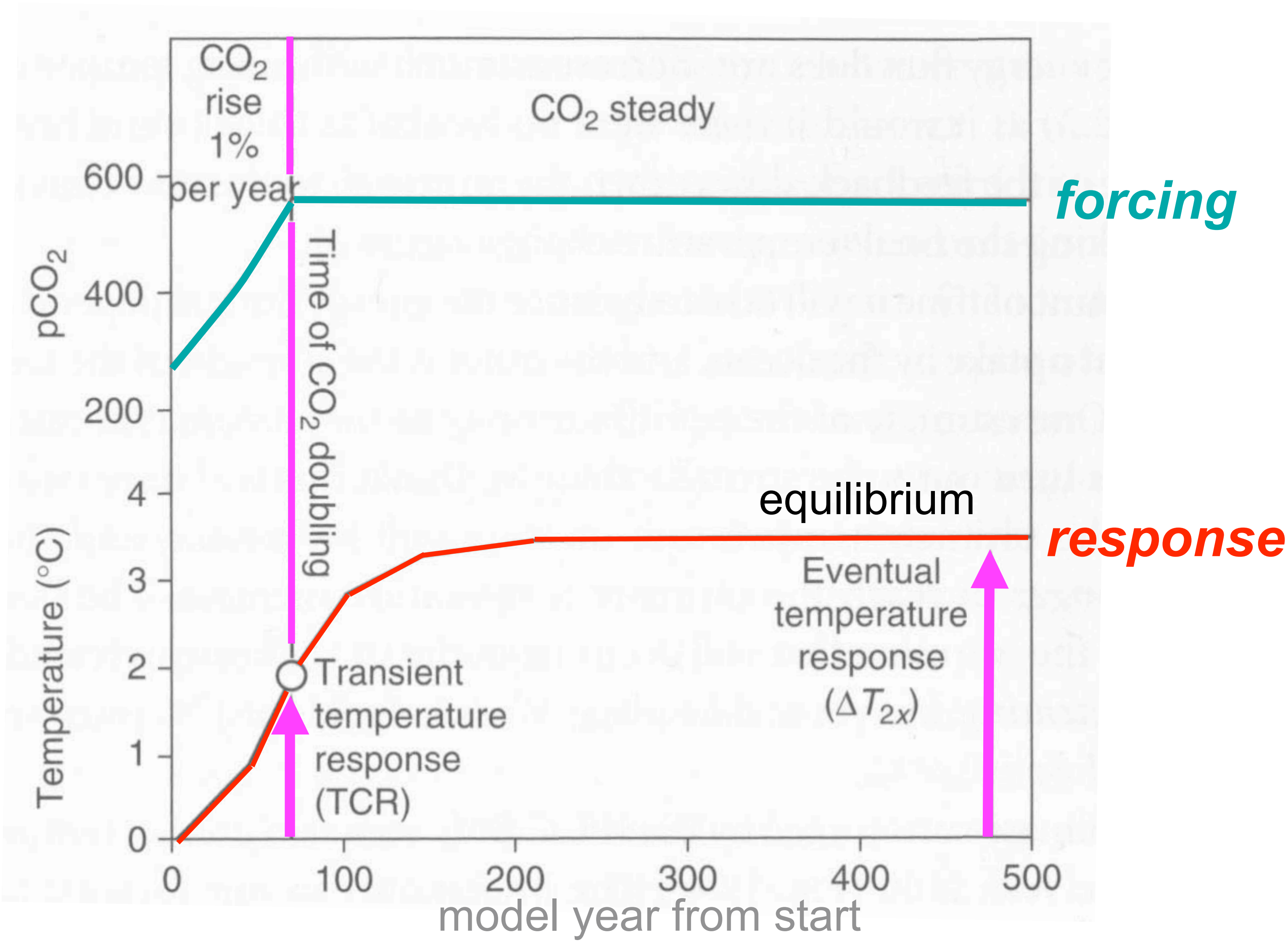
transient vs. equilibrium climate response



what is the equilibrium response or “climate sensitivity (ΔT_{2x})”?

how long did it take to achieve?

transient vs. equilibrium climate response



the transient climate response is always less than (~2/3) the eventual equilibrium climate response

clicker question

the *transient climate response* to radiative forcing will be less than the eventual *equilibrium response* because....

a) there may be some slow feedbacks within the climate system

b) there may be some slow responding reservoirs of mass and energy in the climate system

c) it takes a long time to emit radiation once it is absorbed

d) <u>both a) and b)</u>

e) none of the above

clicker question

a slow responding reservoir of mass and energy in the climate system might be...

a) the atmosphere

b) the land surface

c) the ocean

d) the cryosphere

e) any of the above

An answer: It takes a thousand years or more for the *whole ocean* to warm or cool in response to a change in radiative forcing….

is forcing steady or always changing?

- which seems more relevant to predicting the trajectory of future climate?
  - tracking an eventual equilibrium response?
  - tracking the transient response?

transient forcing and response

- forcing is changing over time (i.e. is *transient*)

- because there is inertia in the climate system (i.e. it has some slowly reacting components such as the oceans) *transient* and *equilibrium climate responses* are not the same

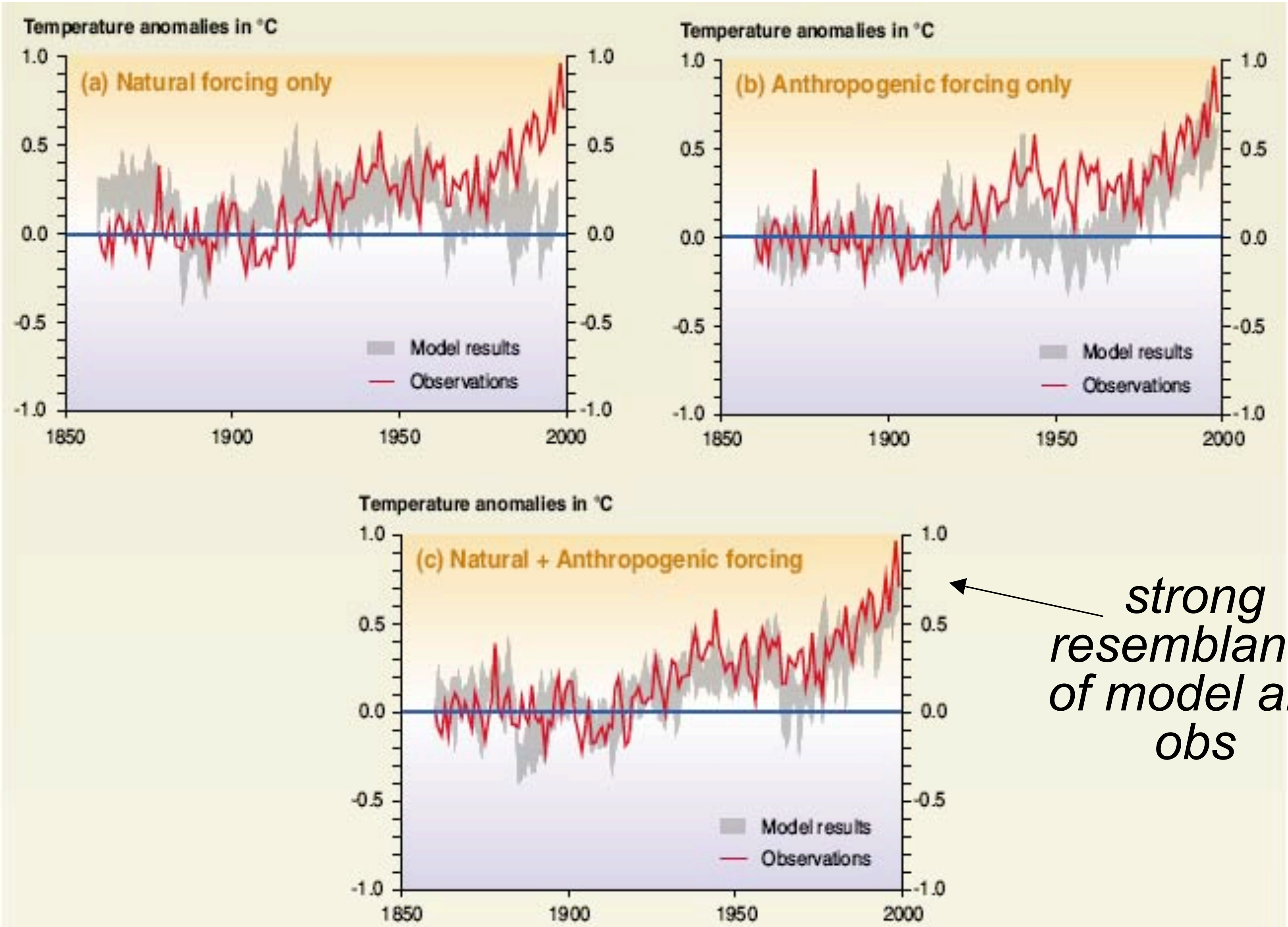
- tracking the *transient* climate forcing and response requires more computing power and information

challenges

- computing time
- data storage

NCAR MSS: 5+ Petabytes of data as of 2008, 3+ Terabytes growth/day,
5 silos containing 30,000 tapes (1000+ GB each)
http://www.cisl.ucar.edu/hss/mssg/mss.jsp

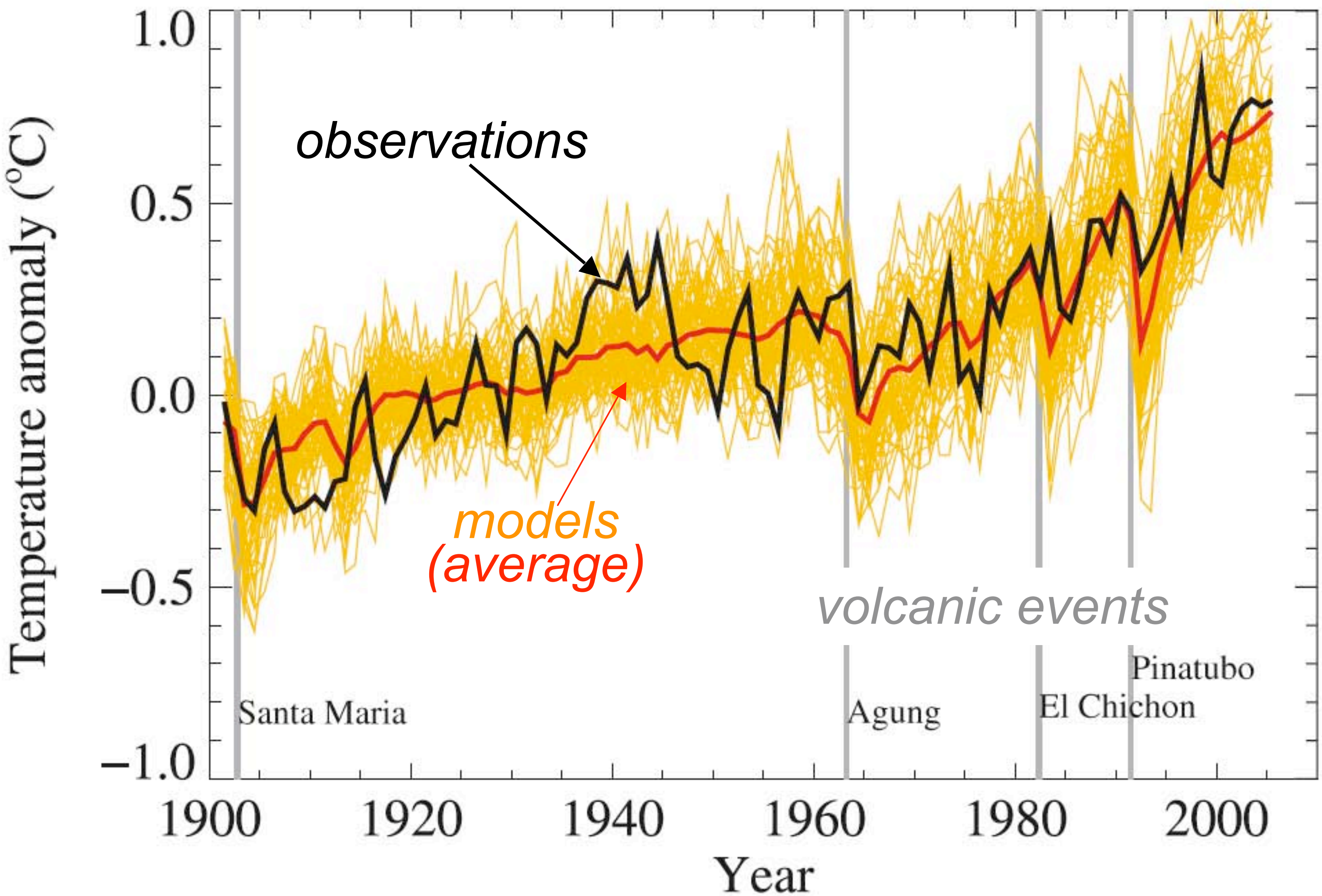
how reliable? consider the hindcasts



strong resemblance of model and obs

IPCC TAR (2001)

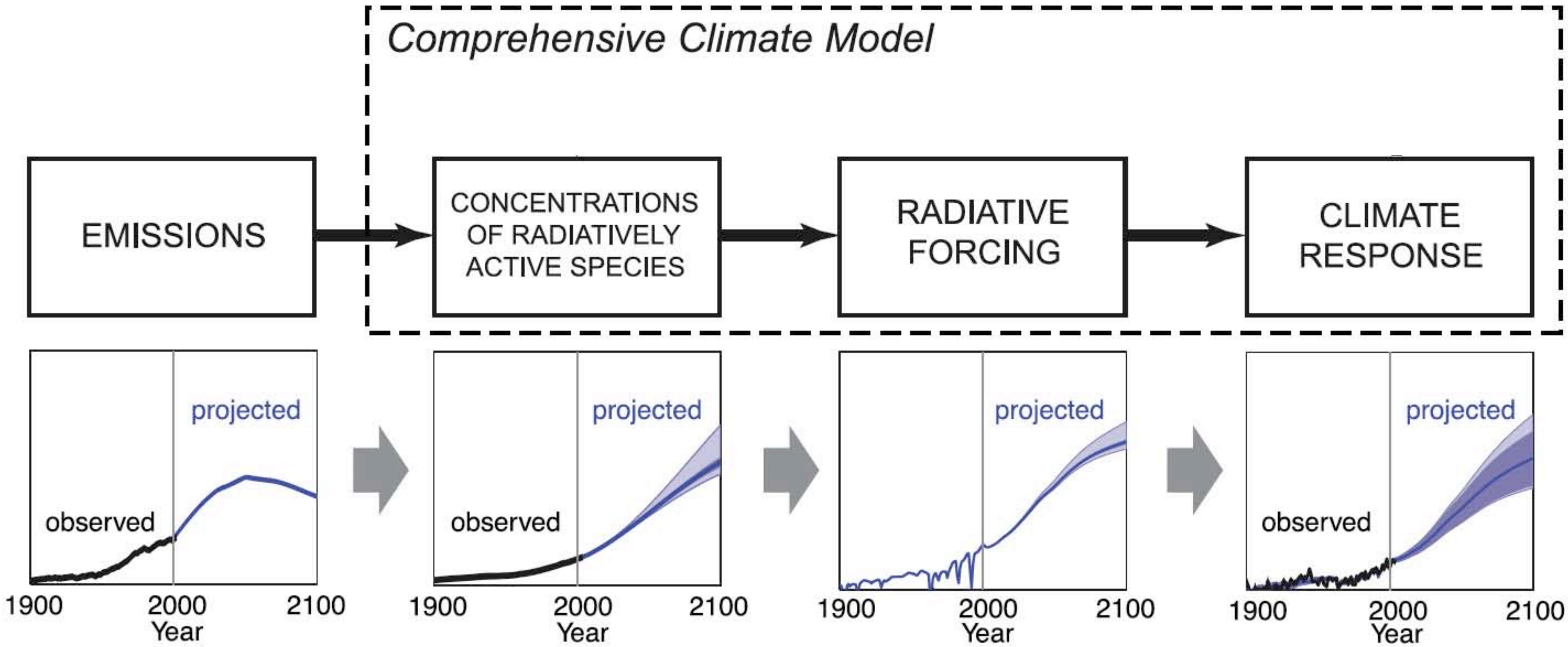
how reliable? consider the hindcasts



58 simulations (fr. 14 models) vs. observations

IPCC AR4 (2007)

forecast strategy



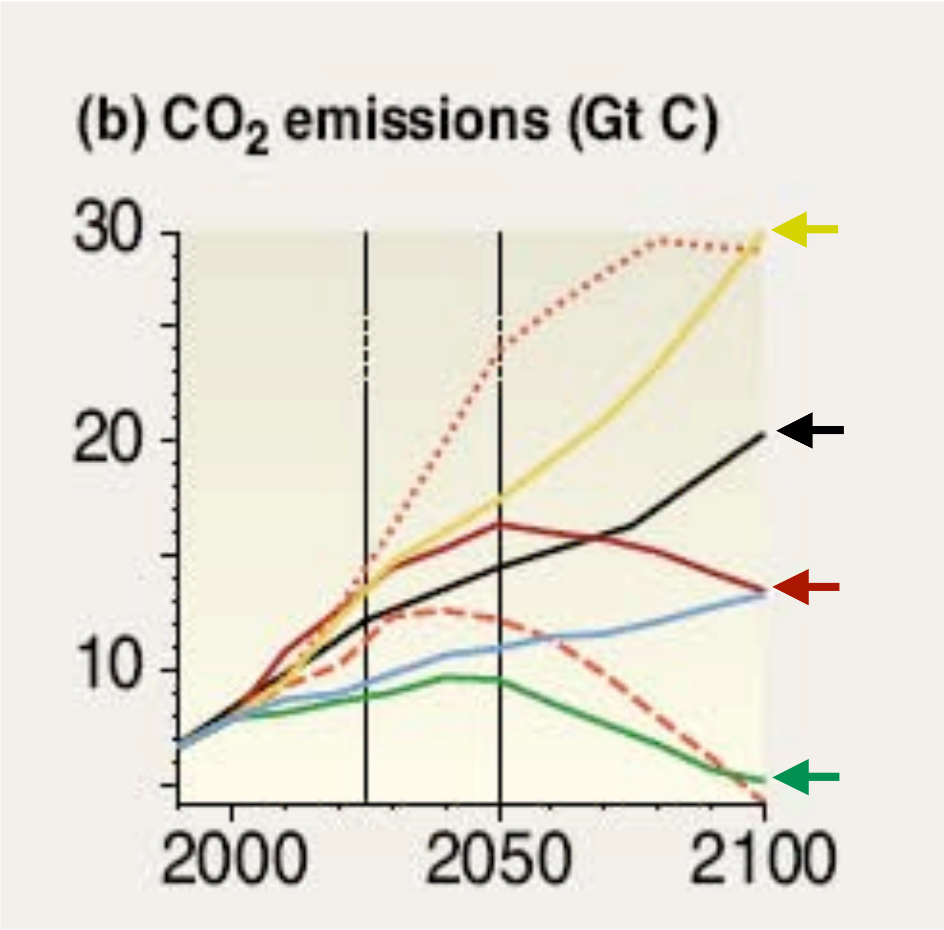
differences in forecasts arise from:

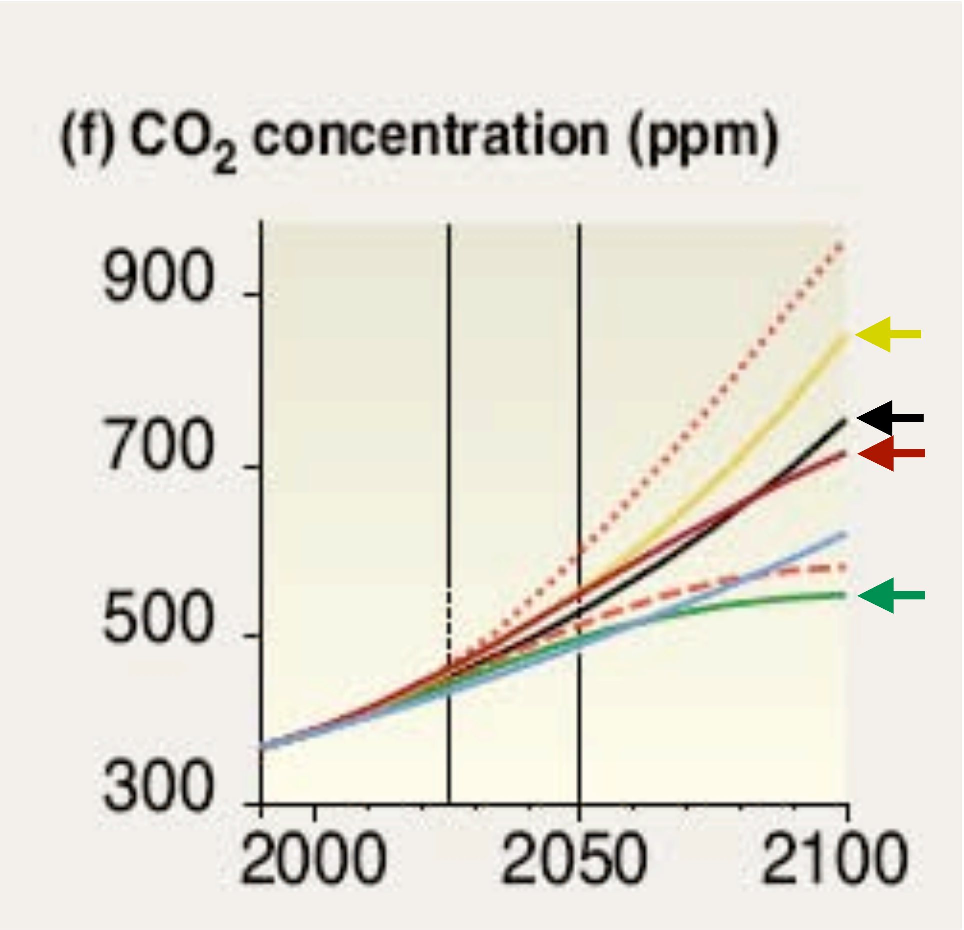
1) differences in emissions scenarios (assumptions)

2) differences amongst models (physics)

any forecast should include a "validation" hindcast

IPCC future forcing scenarios

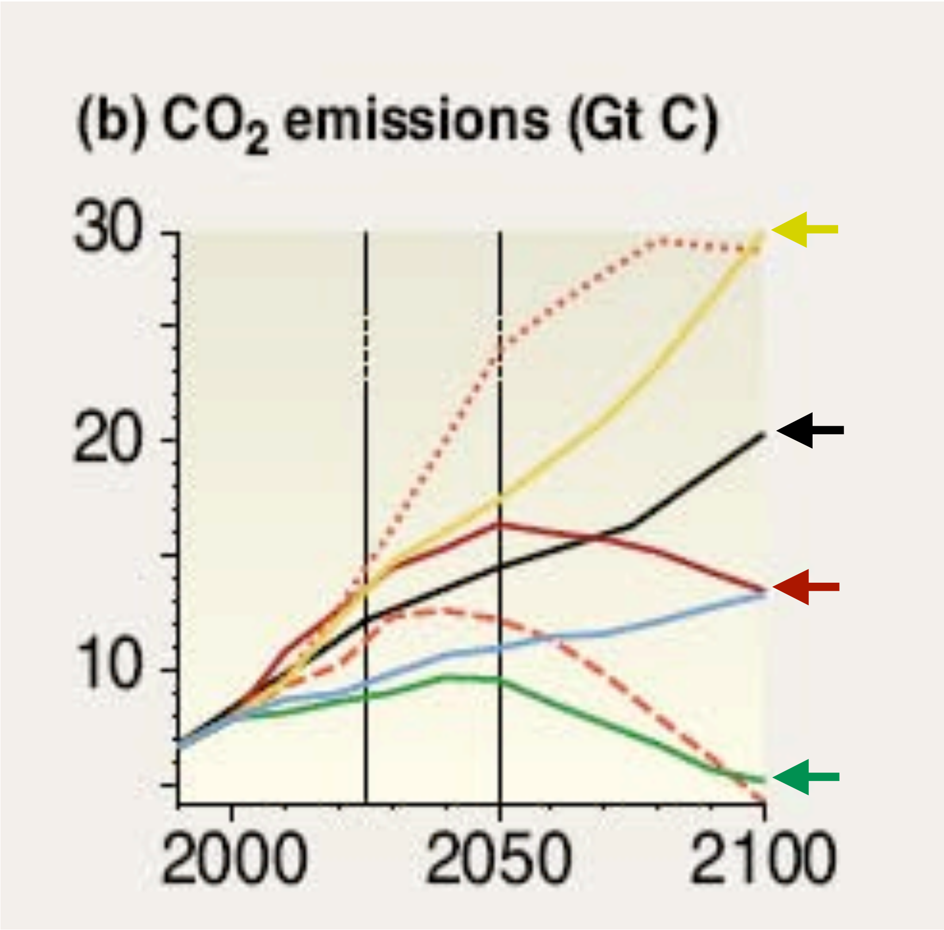


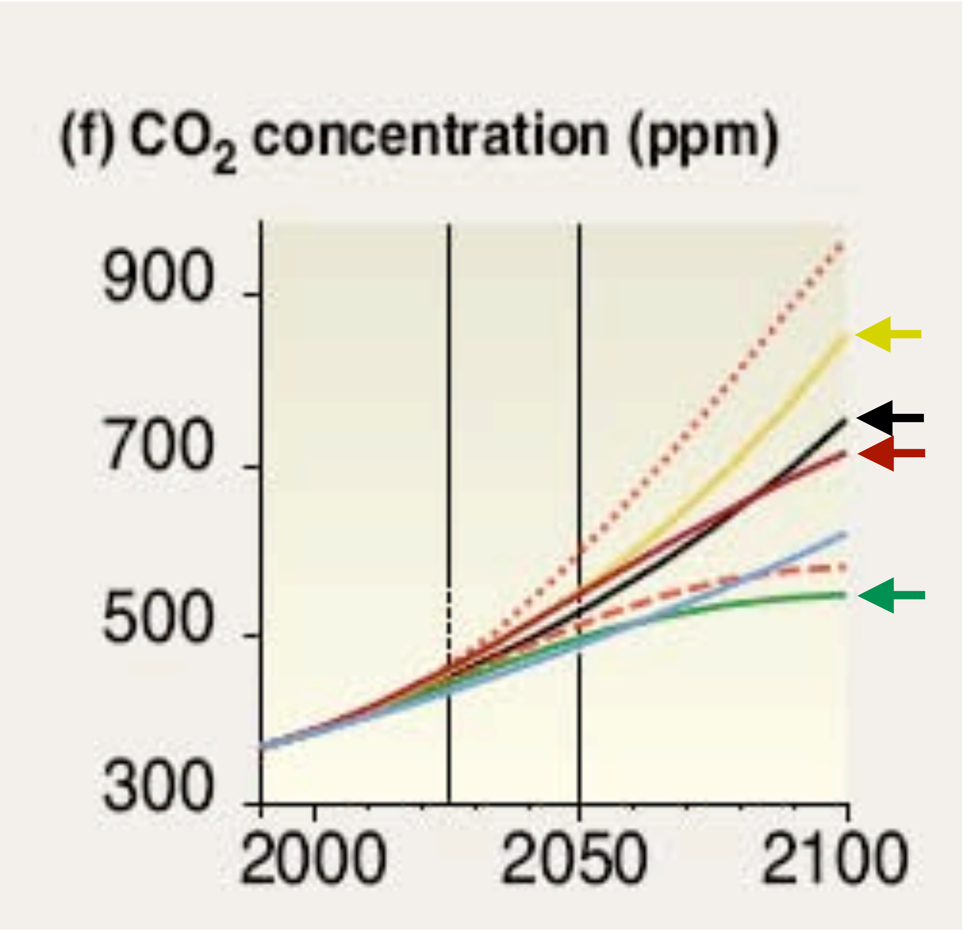


old “BAU” (IS92A)
A2 “non intervention”
A1B some intervention
B1 “green”

scenarios include projections for all GHG’s and aerosols (not just CO_2 as shown)

IPCC future forcing scenarios

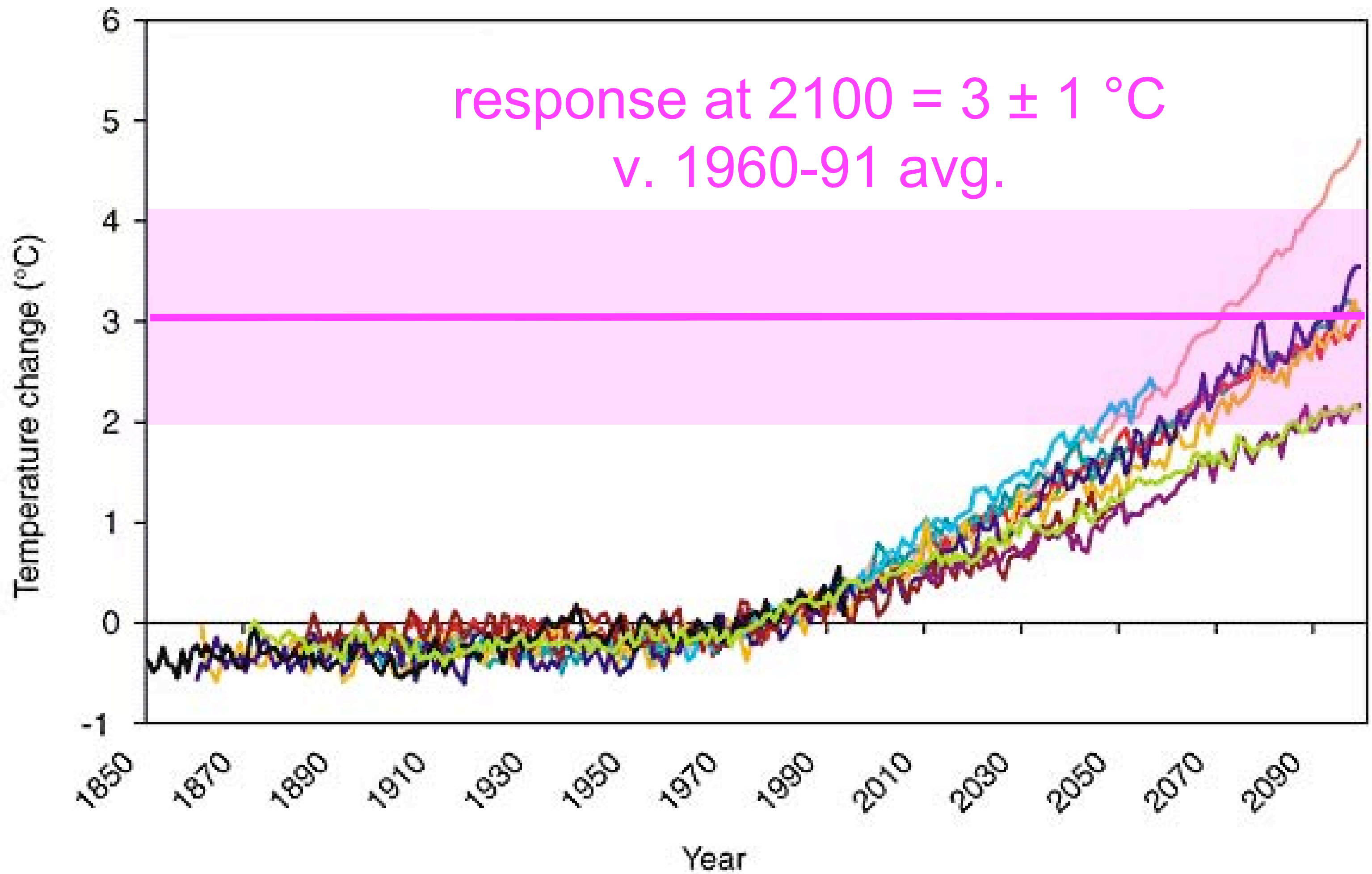




old "BAU" (IS92A)
A2 "non intervention"
A1B some intervention
B1 "green"

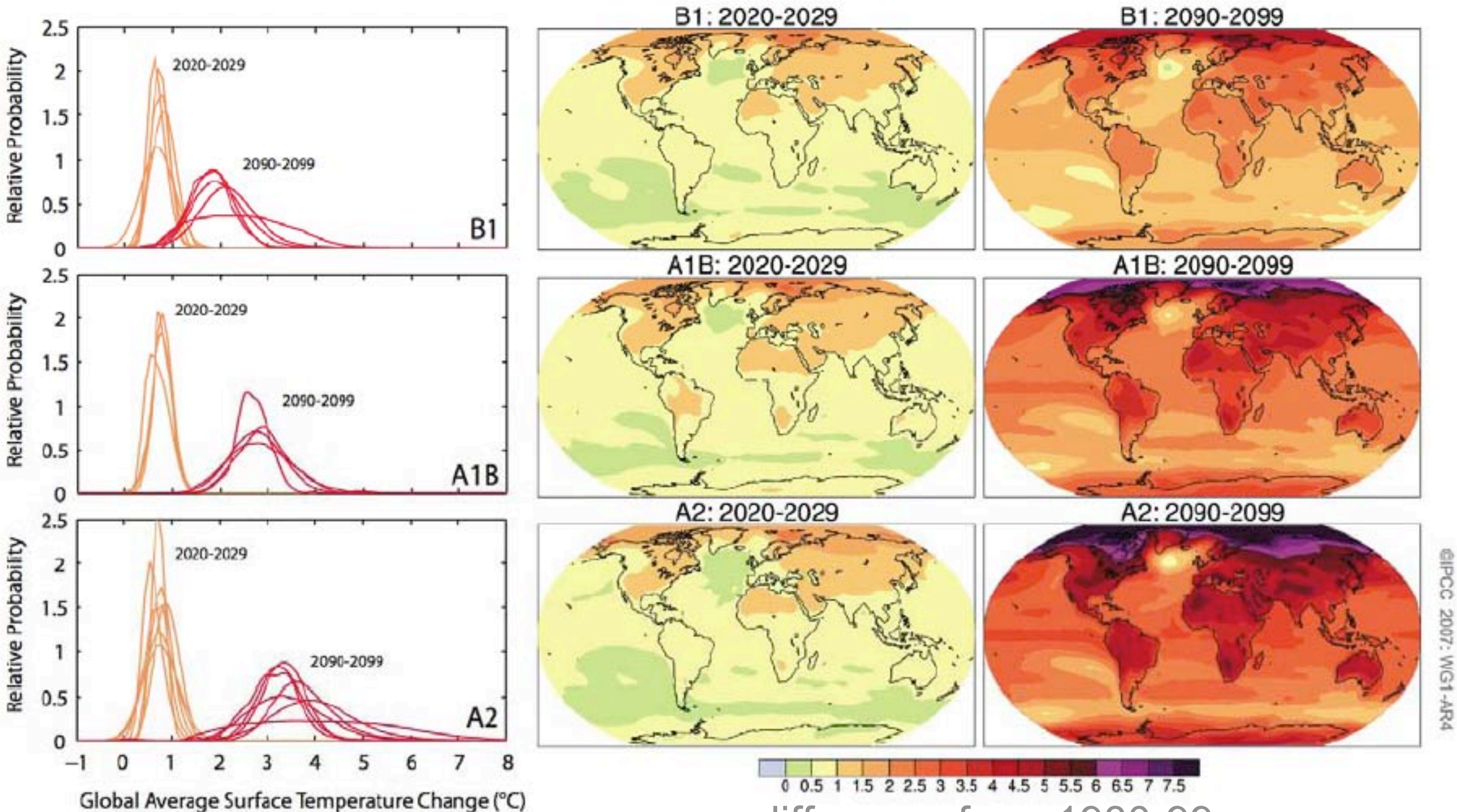
BTW, notice CO_2 continues to rise even for scenarios in which emissions eventually fall… Why?

differences amongst models



IPCC TAR “BAU” (IS92A) forecasts (rel. to 1961-90)
(individual models have different climate sensitivities and amounts of ocean heat uptake)

IPCC AR4 projected surface temperatures



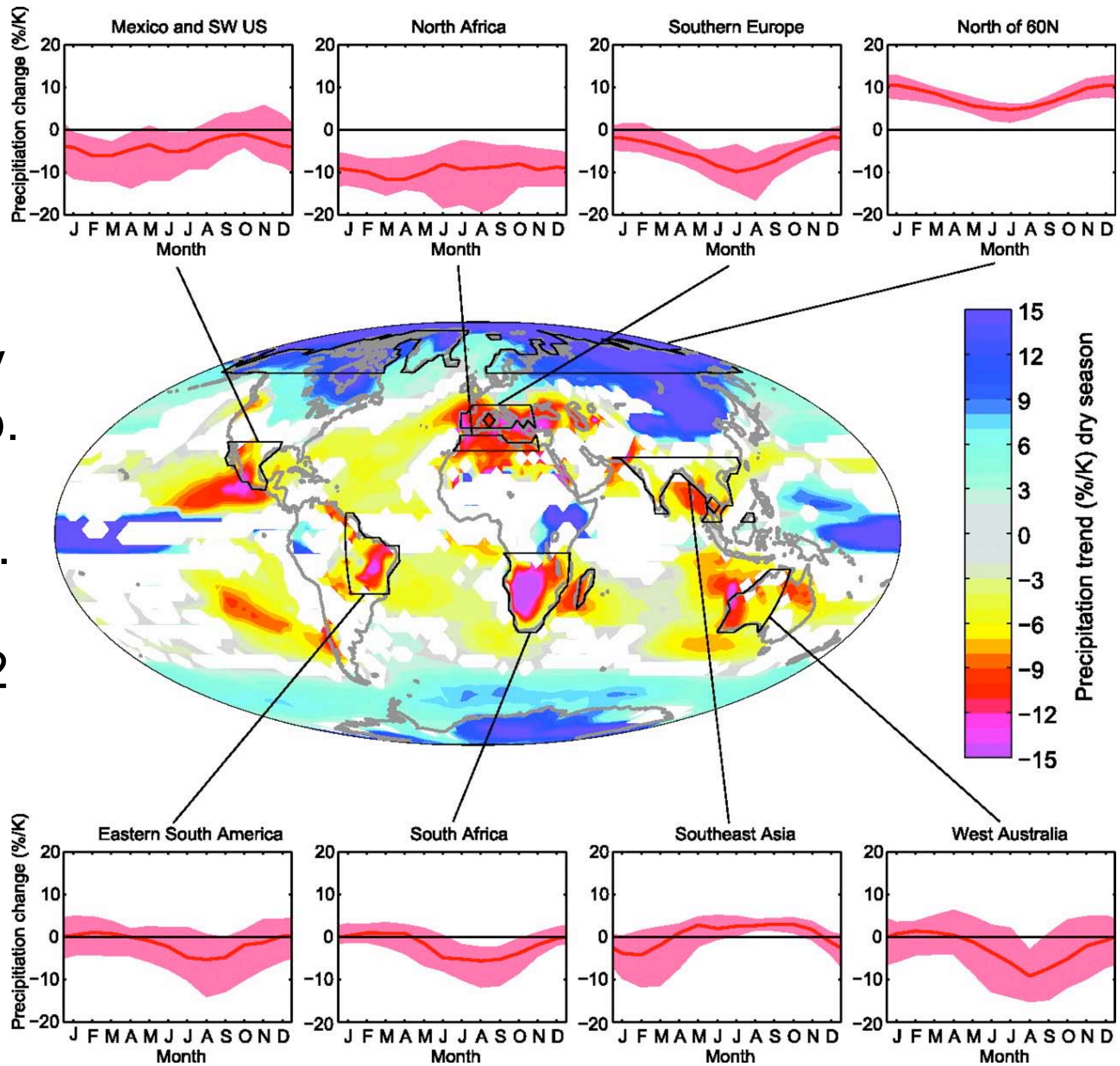
difference from 1980-99

probability of T change amount for each time & scenario

different time frames and scenarios

precip. change (% per °C)

change in dry season precip. per °C global warming w.r.t. 1900-1950, average of 22 models



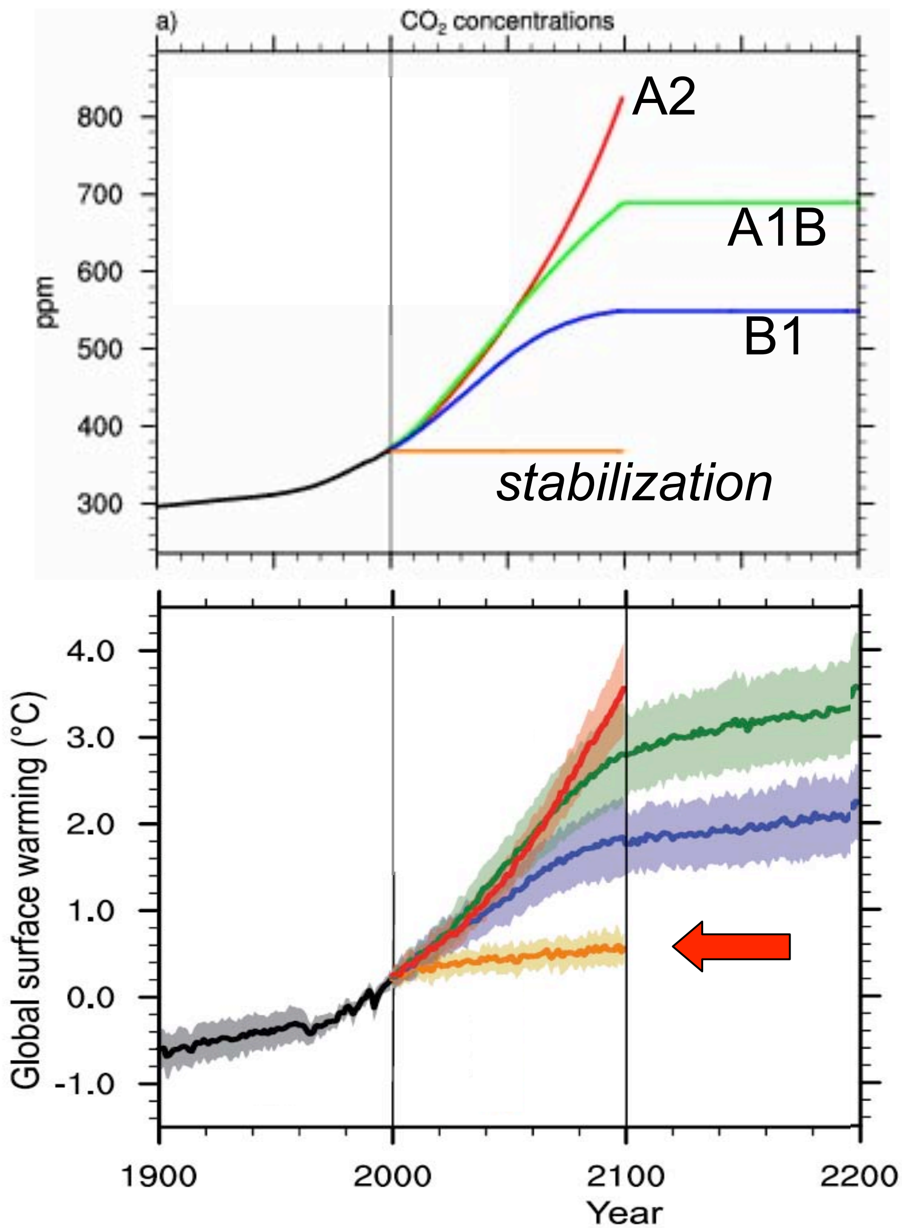
what explains pattern?

(recall Hadley circulation)

plots show 22-model average (and +/- 2/3 range) of local precip. change per °C of global warming (significant drying seen)

Solomon et al. ‘09

projections and "commitment warming"



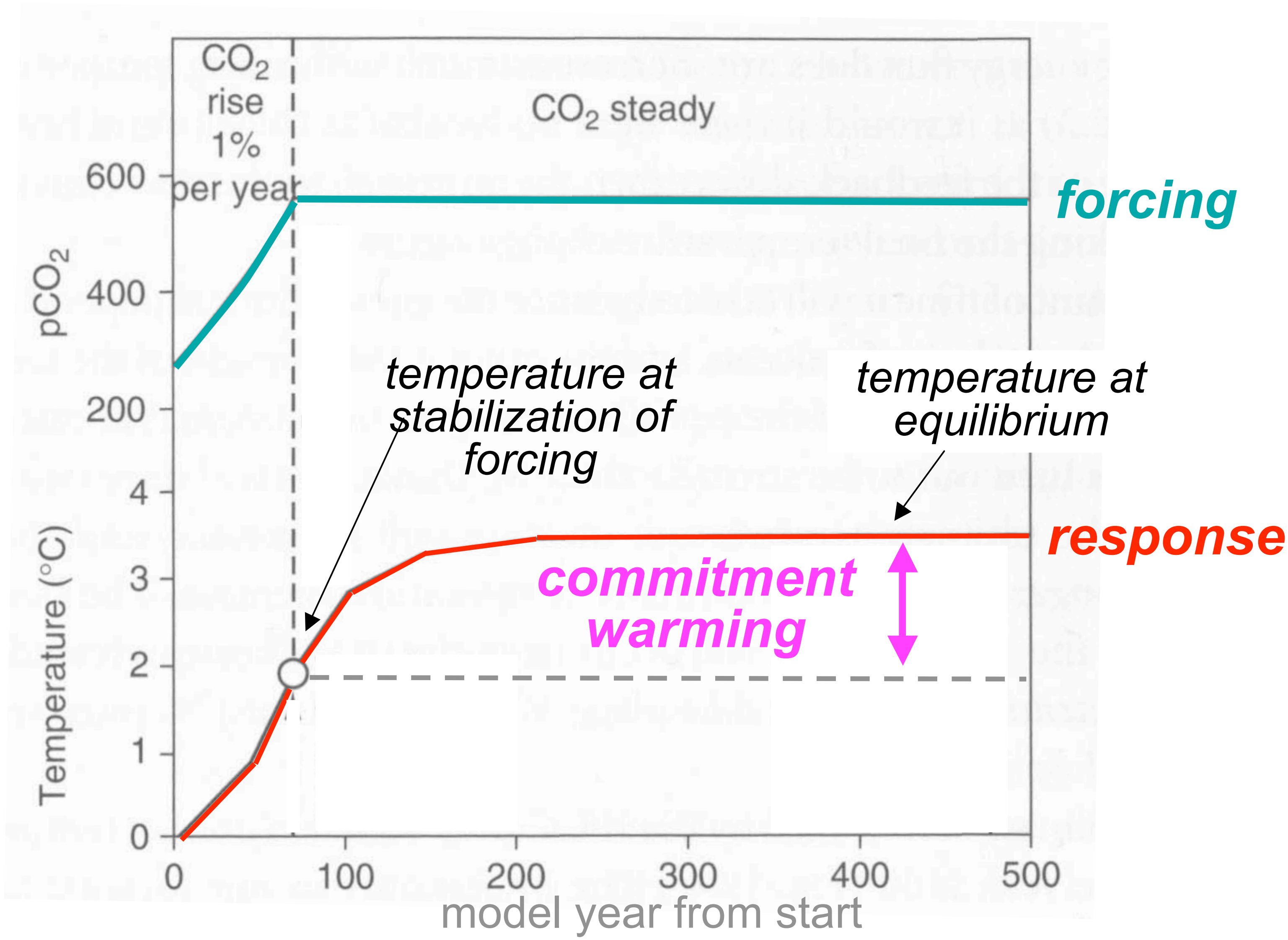
• as expected, high CO_2 scenarios result in greater warming

•ranges for a given scenario are due to model differences and physical uncertainties

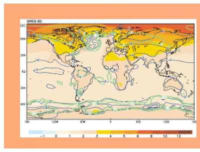
• additional warming of 0.4 - 0.6 °C occurs even for CO_2 stabilization at yr 2000 due to energy already in the system

•more commitment warming for later stabilization of forcing

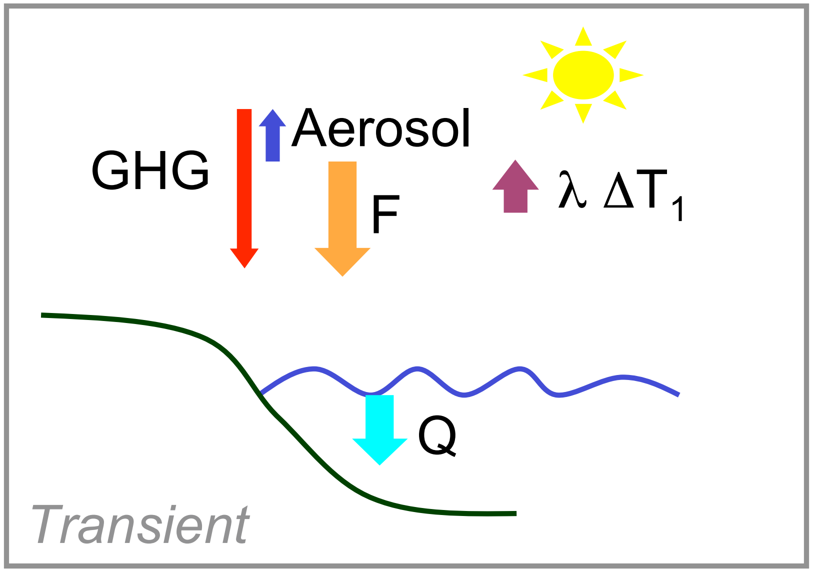
commitment warming



commitment warming is result of time needed for climate to adjust to energy already added to climate system



commitment warming



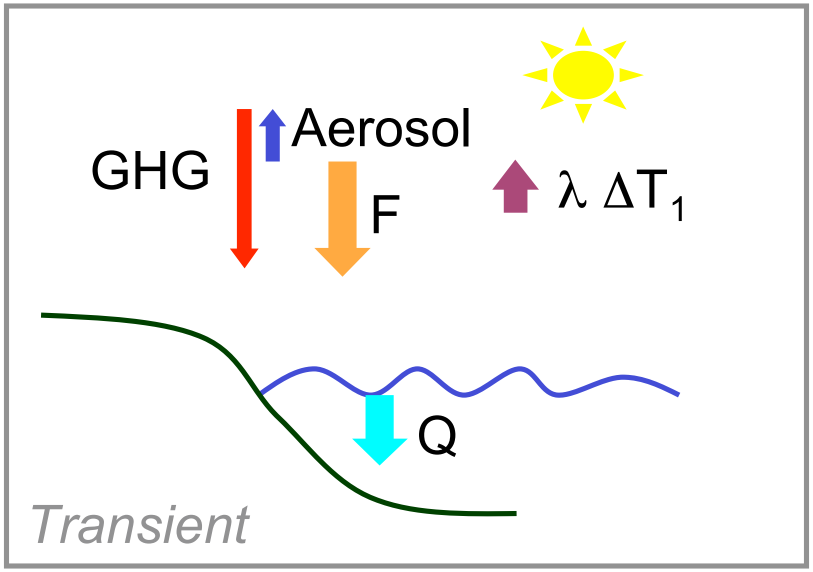
transient: $Q > 0$

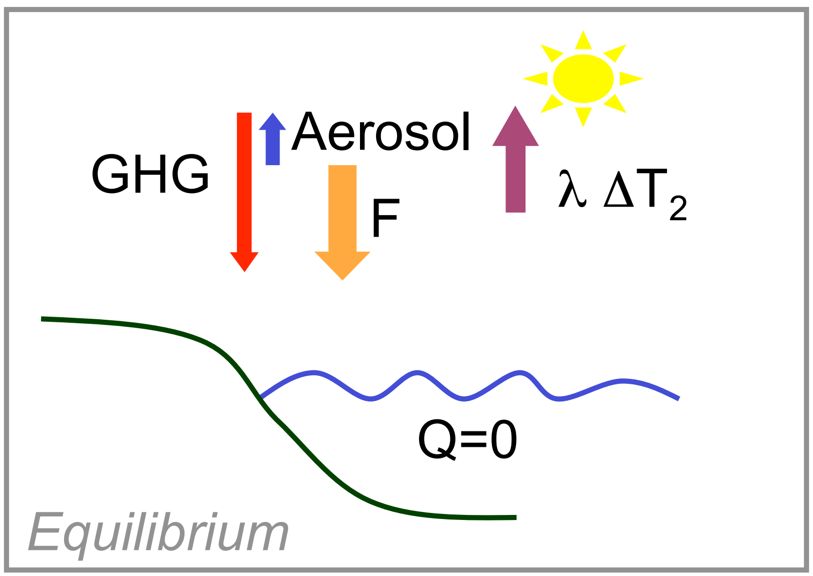
$\Rightarrow F \neq \lambda \, \Delta \, T_1$

(instead, $F - Q = \lambda \, \Delta \, T_1$)

In the transient case, the ocean does not keep up with the transient heating of the atmosphere that results from the increase in net radiative forcing (F). This implies a net flow of energy from the atmosphere into the ocean (Q). The energy available for heating the atmosphere and surface is thus F-Q. This sets the temperature of the atmosphere and surface (ΔT_1). Notice that there is an imbalance at the top of the troposphere (i.e., $F \neq \lambda \, \Delta \, T_1$). ($\lambda$ is a simple scalar relating T and F, analogous to the Stefan Boltzmann constant).

commitment warming





At equilibrium (lower figure) the system is defined to be in balance, so the atmosphere and ocean are in thermal equilibrium. Thus the net flux of energy between the ocean and atmosphere (Q) is zero. The energy fluxes into and out of the top of the troposphere are also in balance (i.e., $F = \lambda\ \Delta\ T_2$).

equilibrium: $Q = 0$

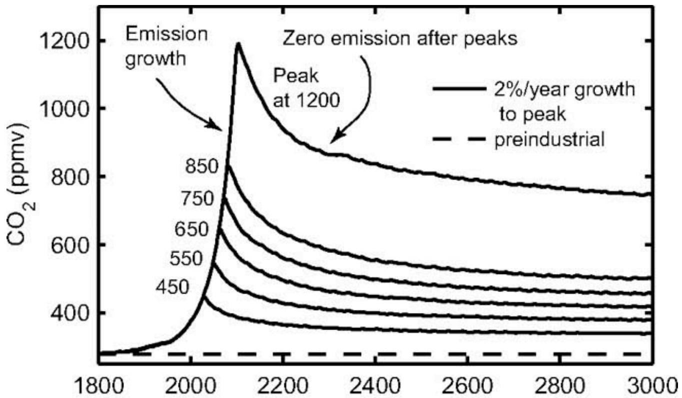
$\Rightarrow$ in = out

$\Rightarrow F = \lambda\ \Delta\ T_2$

$\Rightarrow \Delta T_2 > \Delta T_1$

commitment warming = $\Delta T_2 - \Delta T_1$

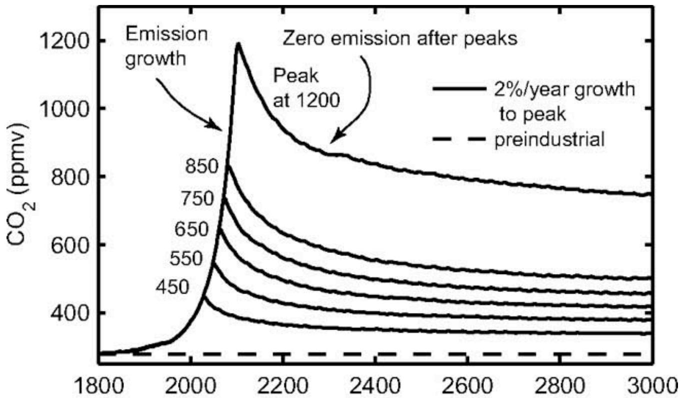
stop press!: long term commitment



commitment CO_2:

growth to peak emissions at 2%/yr (doubling time = ~35 yr) and then zeroed out

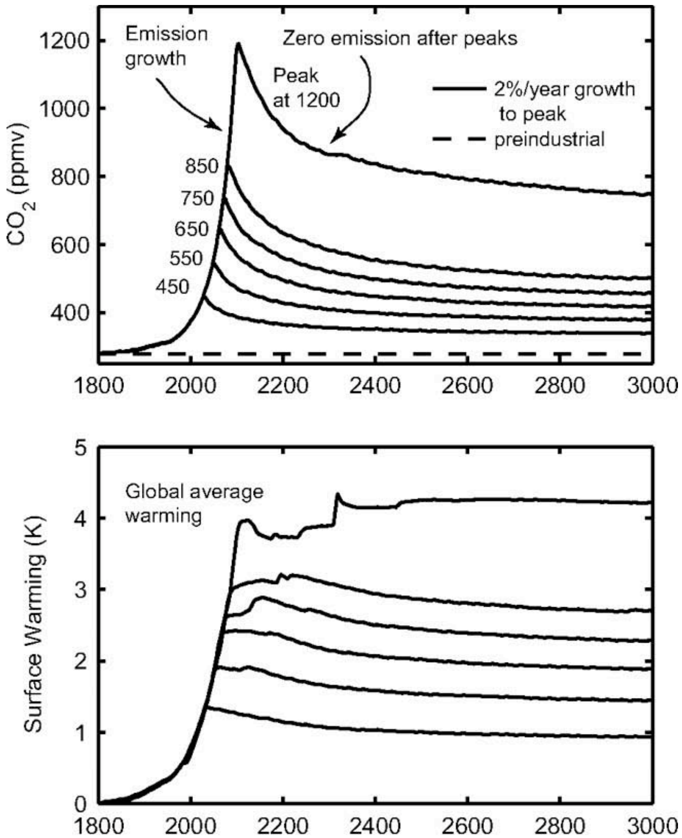
stop press!: long term commitment



commitment CO_2:

initial airborne fraction is 50% and about half of that remains in atmosphere after several thousand yrs due to limitations on CO_2 sink from ocean mixing and carbonate chemistry

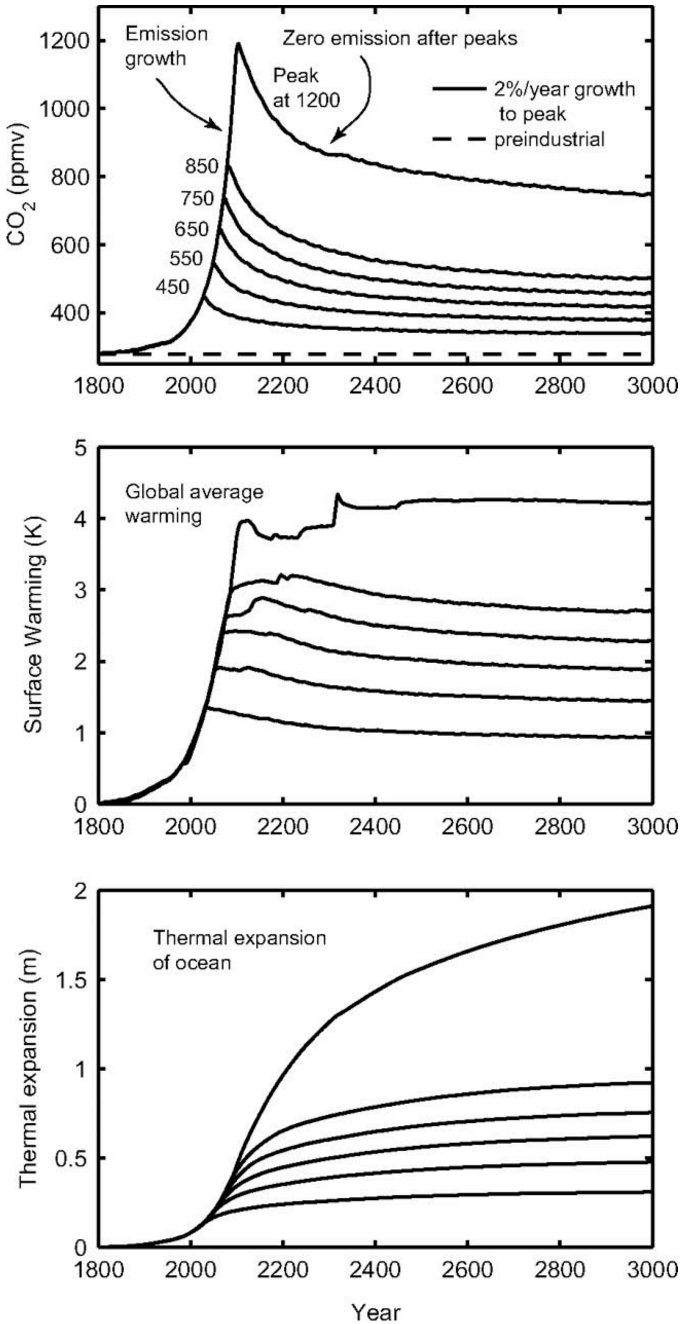
stop press!: long term commitment



commitment warming:

although CO_2 radiative forcing decreases, an increasing fraction of energy is available to warm atmosphere (i.e. as ocean and atmosphere approach thermal equilibrium)

stop press!: long term commitment



commitment sea level:

warming ocean continues to expand as long as additional energy enters from atmosphere (slows as atmosphere and ocean approach thermal equilibrium) *does not include melting or sliding ice*

Solomon et al. '09

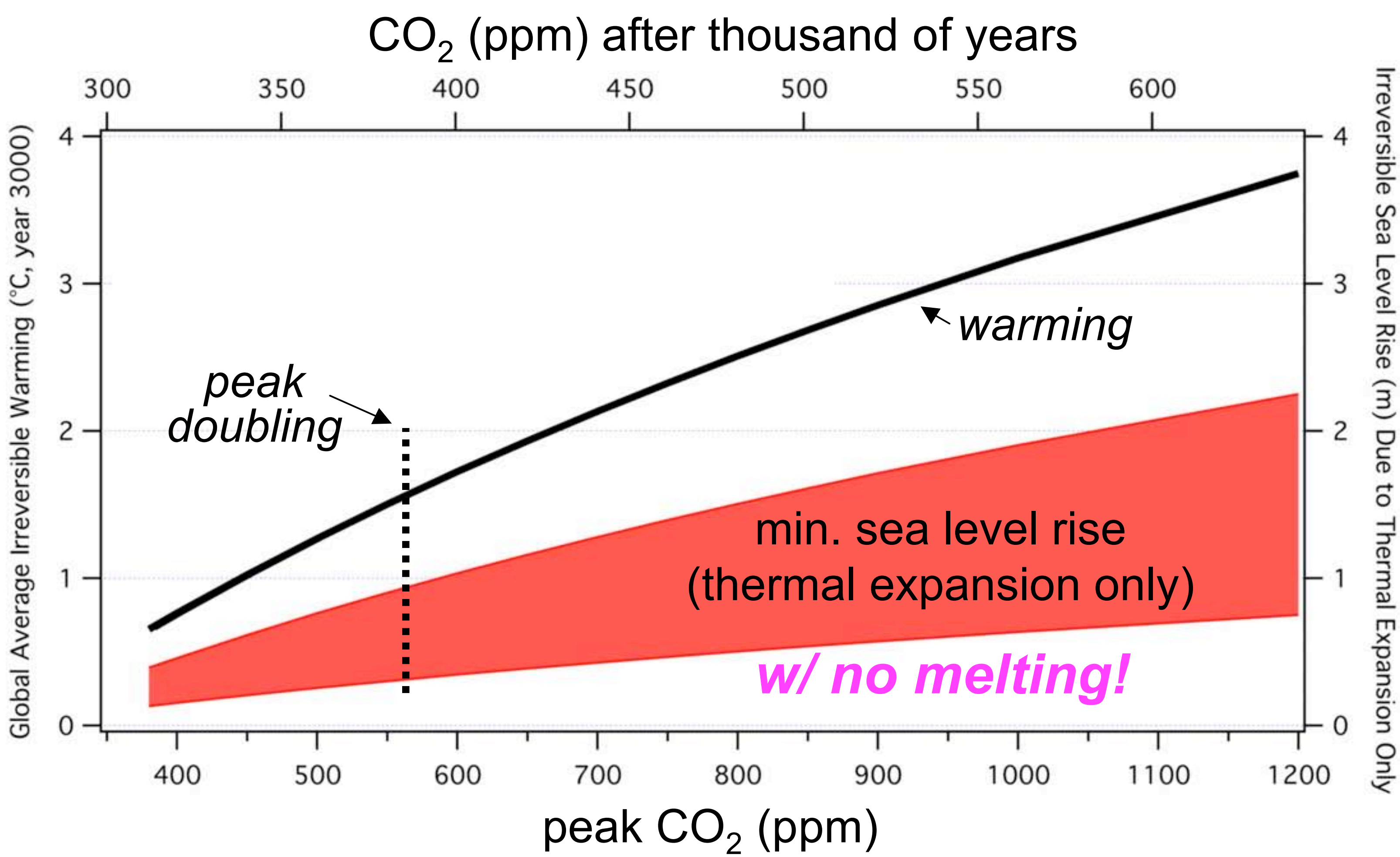
commitment warming

- the amount of warming that will be realized ***after*** forcing (CO_2 and other GHGs) has stabilized
- mostly a response to slowly adjusting reservoirs (ocean heat uptake)
- *~ 0.8-0.9 °C warming has been realized since the late 1800’s*
- *we are committed to 0.4-0.6 °C even if we stop emitting entirely tomorrow (where tomorrow was 2000)!*
- *this is unavoidable warming already “in the pipeline”!*

long term commitment

- *about 1/4 of CO_2 of added to atmosphere remains after several thousand yrs*
- *this leads to irreversible warming*
- *long term ocean warming is associated with thermal expansion of sea water and irreversible sea level rise*
- *human activities permanently alter the climate and sea level!*
- *this will produce "the long melt"*
- *the future is not what it used to be!*

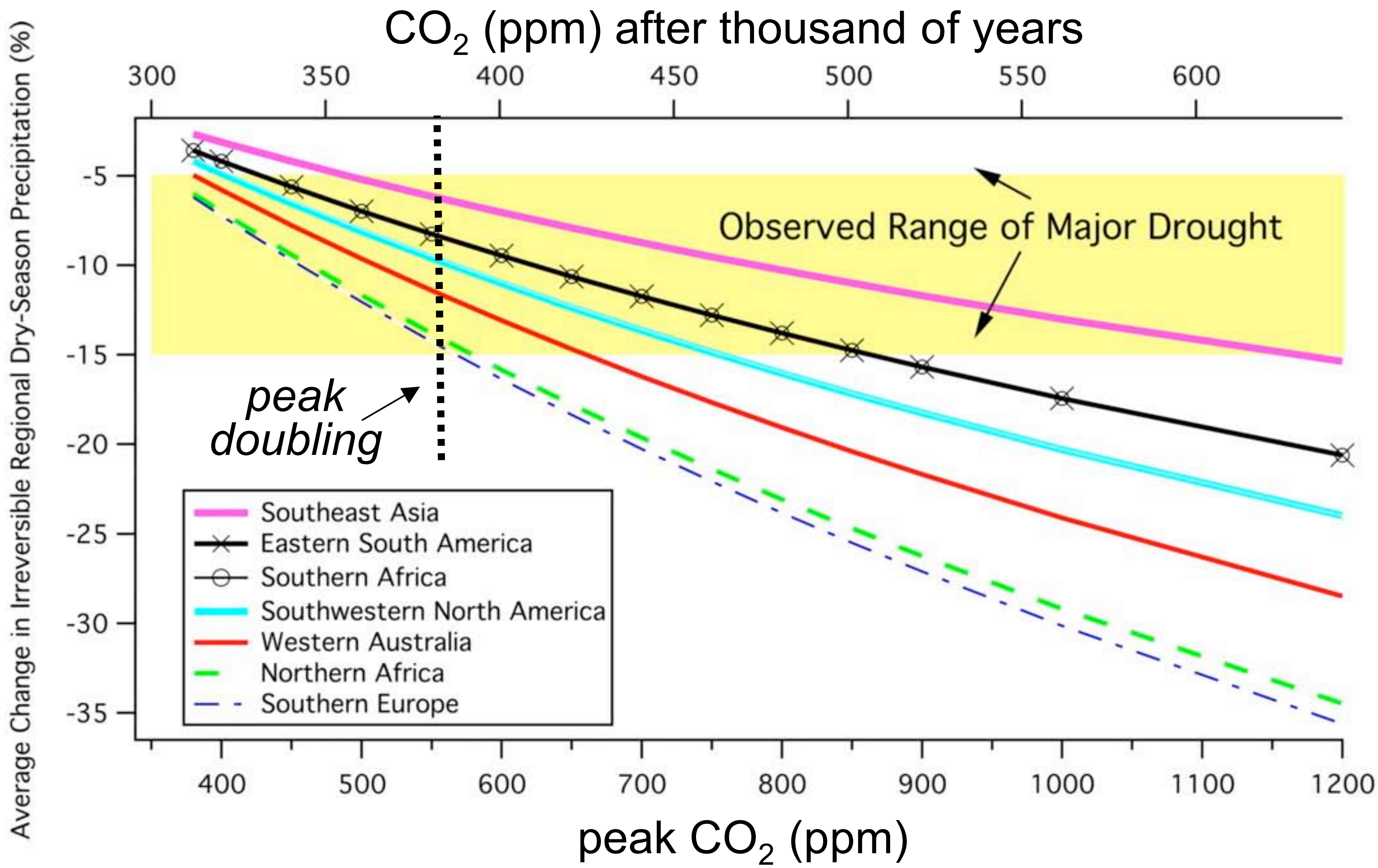
irreversible warming and sea level rise



commitment climate responses thousands of years after peak CO_2 reached

Solomon et al. ‘09

irreversible drought



% change in irreversible dry season precip. for different regions

Solomon et al. '09

clicker question:

as a thoughtful citizen, I am most concerned about...

a) the average temperature of the planet

b) the average temperature where I live

c) extremes of temperature where I live

d) extremes of precipitation where I live

e) both c) and d)

clicker question:

as a policy maker, I might be most concerned about...

a) the average temperature of the planet

b) average environmental conditions in my district

c) extreme environmental conditions in my district

d) the economy in my district

e) both c) and d)

forecasts for real people!

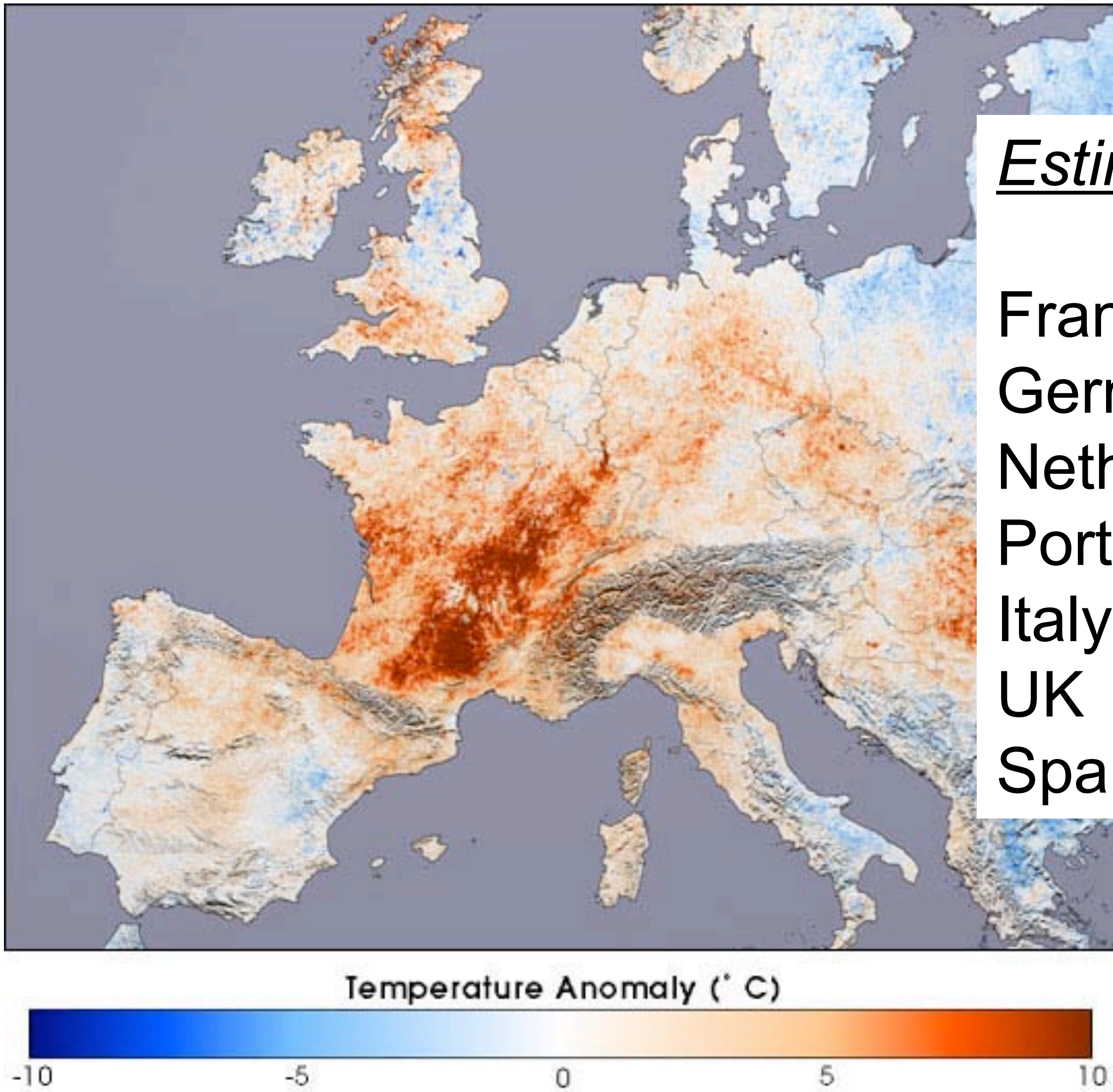
- we are most affected by extreme events where we live

- the climate science community has done a good job of assessing future changes in global average surface air temperature and (to a lesser extent) precip. patterns, based on understanding of *radiative forcing* and *feedbacks*.....

- what will be needed increasingly are regional to local forecasts that include assessments of extremes and not just average conditions

we are affected most by extreme events……

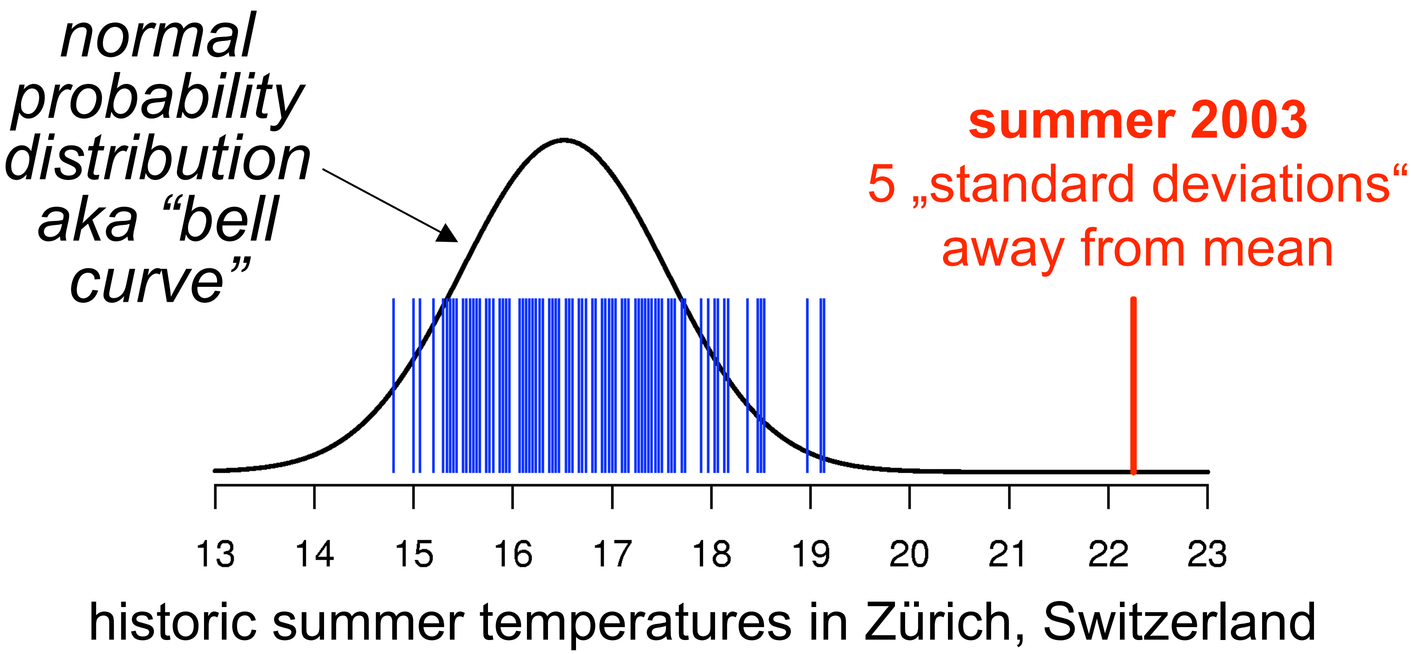
European heat wave of July 2003



Estimated dead:

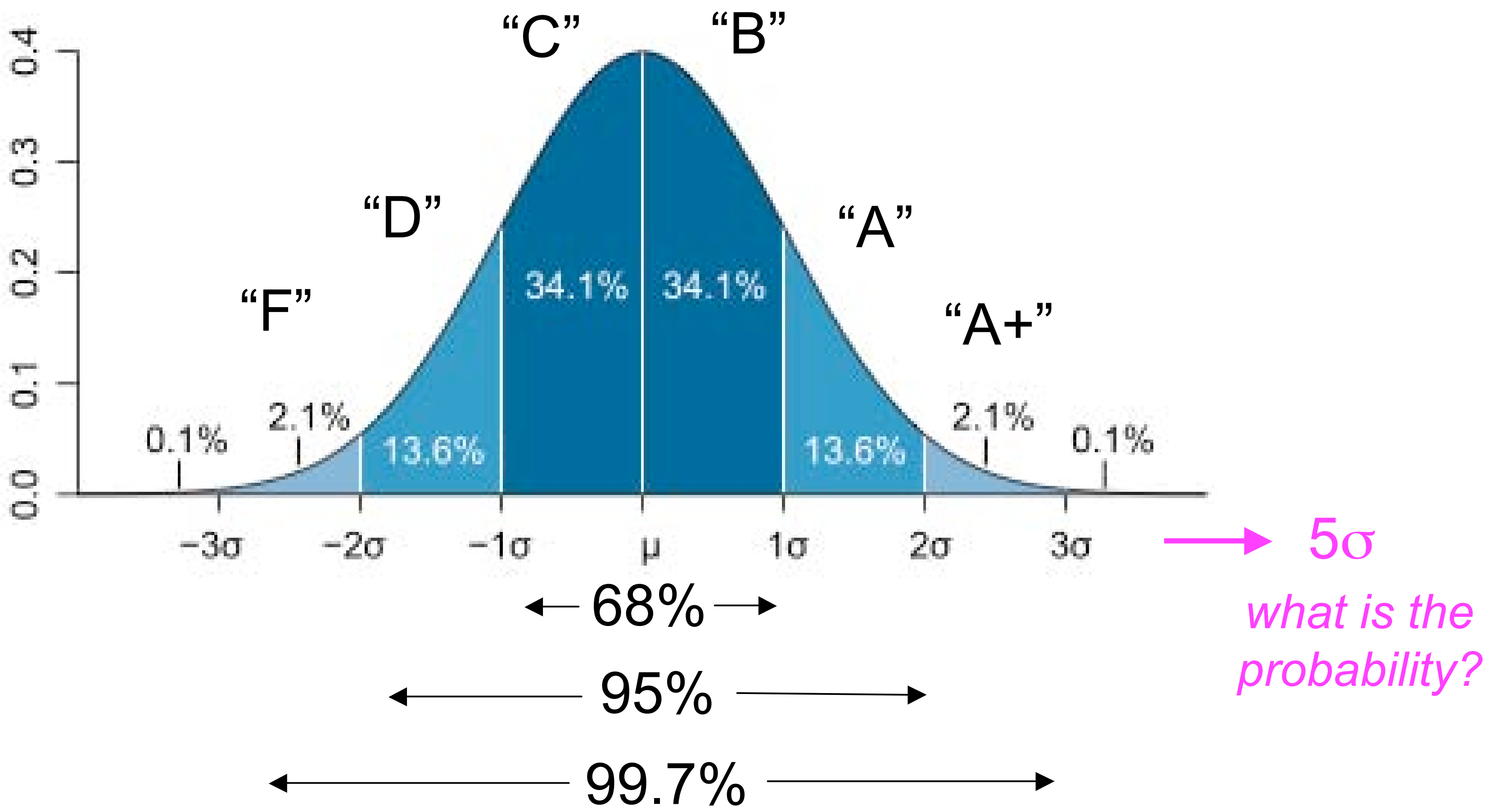
France	14,000
Germany	7,000
Neth.	1,400
Portugal	1,300
Italy	4,000
UK	2,000
Spain	4,000

was this a chance occurrence?



(Schär et al. 2004)

idealized normal distribution of grades

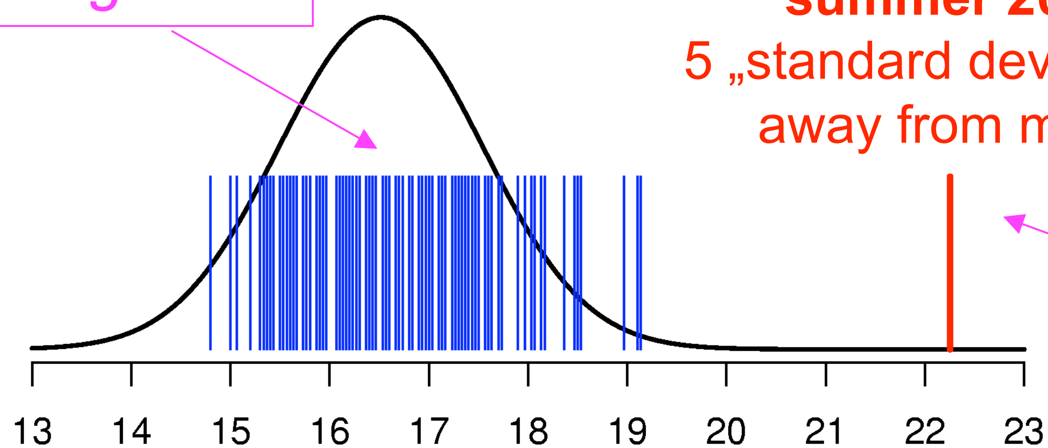


tails of distribution drop off rapidly, meaning the probability of occurrence becomes very very small beyond 3 sigma

was this a chance occurrence?

your grades

summer 2003
5 „standard deviations“
away from mean



chance of being next “Einstein”

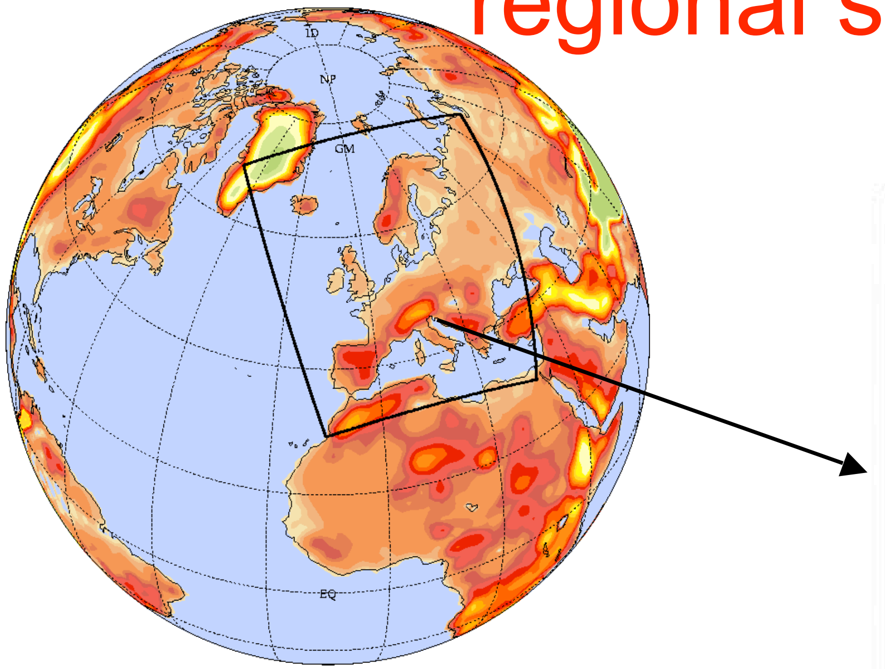
historic summer temperatures in Zürich, Switzerland

probability of exceeding 5 standard deviations in a normal distribution: about one in three million!

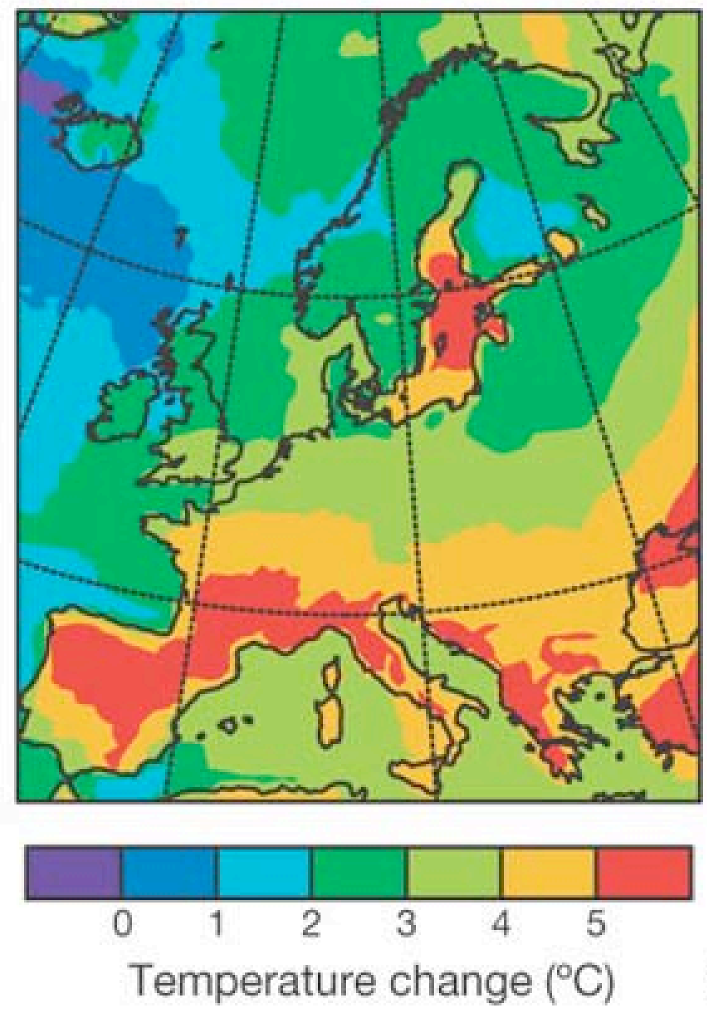
most reasonable answer is that it was not strictly chance, but that the distribution is changing (i.e. it will be forced to the right)

(Schär et al. 2004)

regional simulations

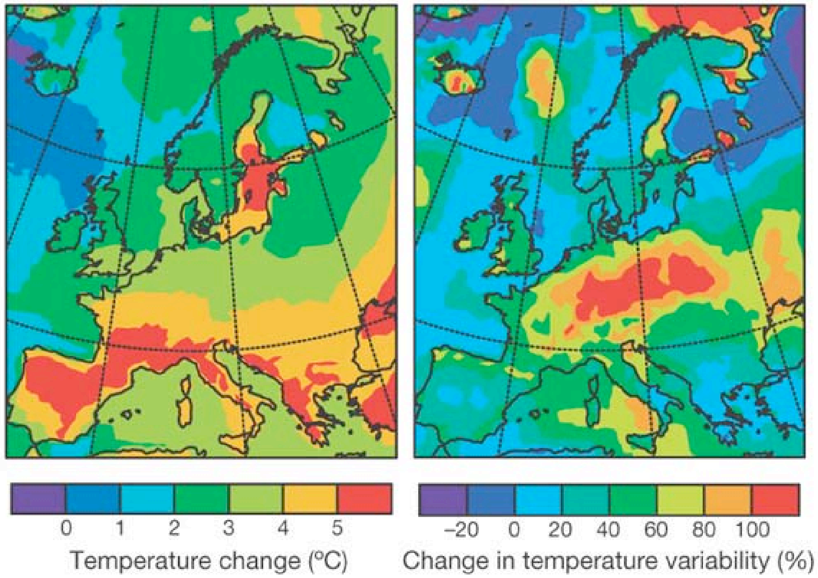


a detailed regional model can be embedded w/in a global GCM



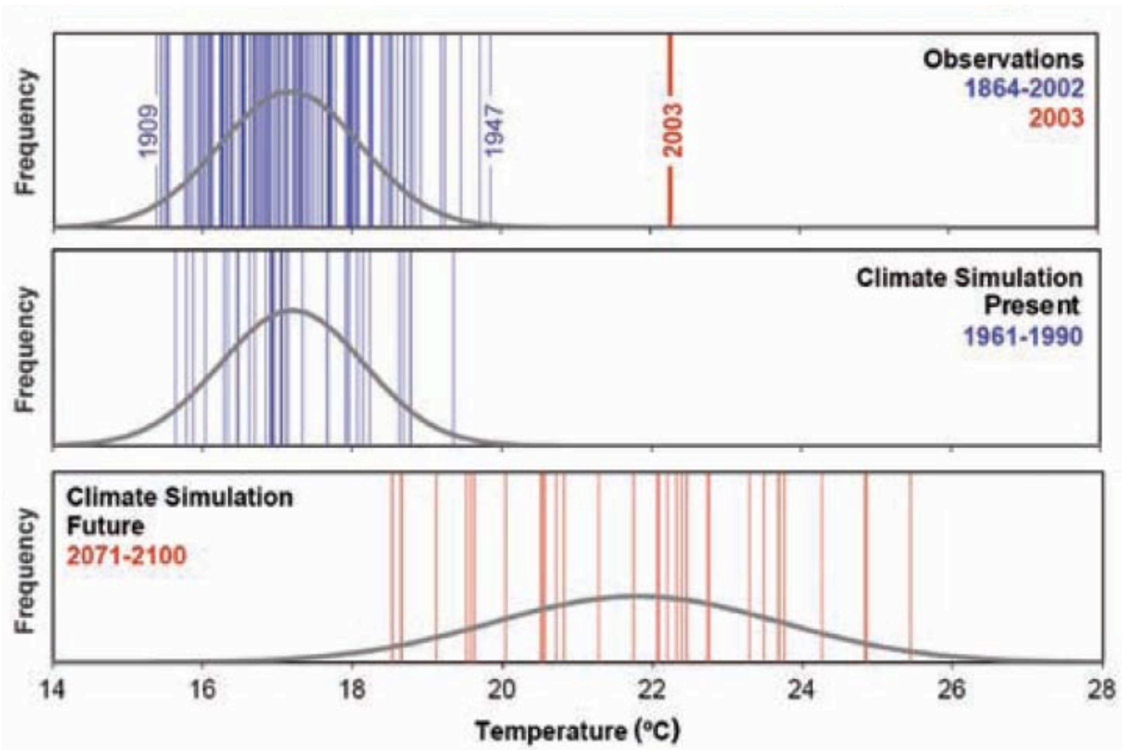
this example shows summer warming in Europe in 2071-00 vs. 1961-90 (for IPCC A2 scenario)

regional simulations



- *Not only are simulated summer temps higher, but the variability of temp is much greater (in 2071-'00)*

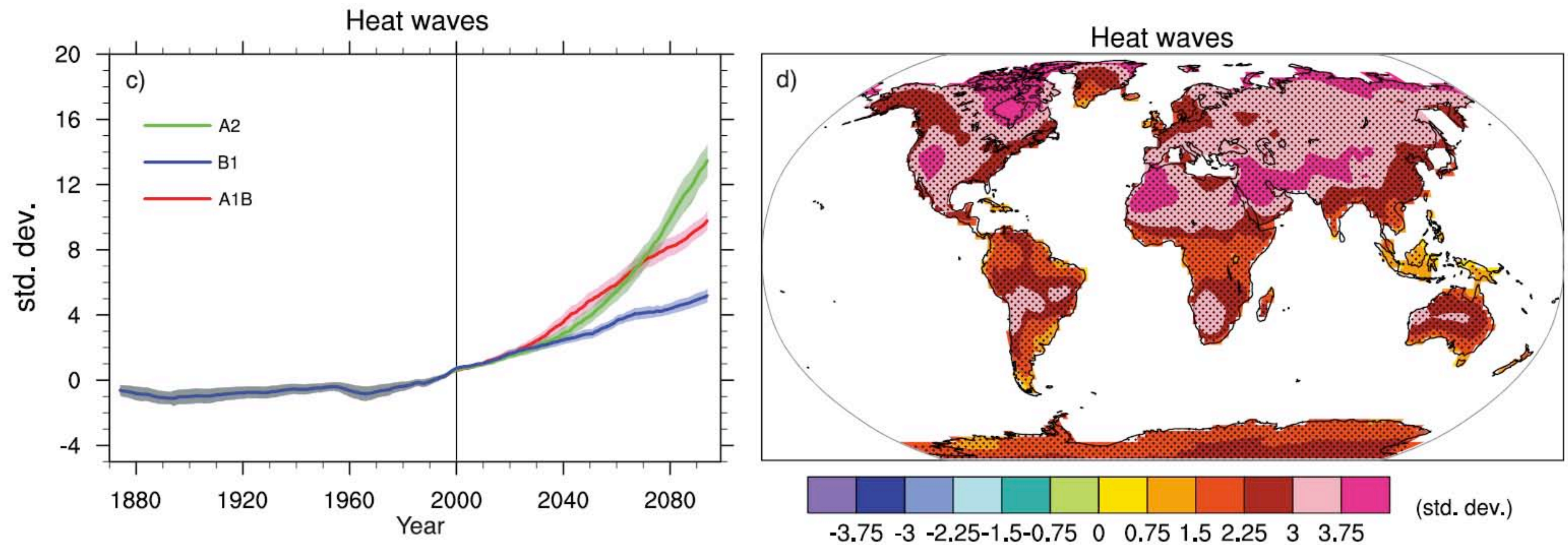
Zurich temperature:



- *Distribution of Zurich summer temps extracted from model 1961-90 are similar to observed, but in 2071 -'00 the distribution is warmer and much wider. This will be extremely challenging.....*

why?

heat waves



A1B 2080-99 vs. 1980-99

what are now the rare extremes will become more common

key points…..

- forecasts rely on models w/ uncertainties and emissions scenarios (human behavior!) w/ uncertainties
- all forecasts are for continued warming, with a BAU outcome of ~+3 ± 1 °C by 2100 (vs. yr 2000)
- we are already "committed" to additional warming of ~0.4-0.6 °C (and sea level rise), and the amount of additional commitment warming will increase w/ the total forcing
- even with some intervention (equ. to scenario A1B), extreme weather conditions are likely to become much more common
- the latter will represent a greater challenge than the change in average T or P

key points…..

- modelers will focus increasingly on regional scale forecasts of climate extremes and variability
- …. and on mitigation scenarios (a later lecture re. *carbon policy*)
- in a later class *"what constitutes dangerous climate interference?"*
- *EXAM Thurs.!*

learning goals

- understand the concept of *future emissions scenario* as used by IPCC
- understand the difference between uncertainty in the *future emissions scenario* and the uncertainty in *model climate forecasts* for a given scenario
- be able to explain the difference between a *transient* and an *equilibrium* climate simulation
- be able to explain the value of a model *hindcast*
- be able to state the amount of warming anticipated to occur by the end of the century for a BAU-type scenario
- be able to explain what is meant by *commitment warming* and the approx. magnitude of our current commitment...
- be able to explain why some fraction of man-made climate change is “irreversible”
- be able to explain why regional forecasts of extremes will become more valuable than simply knowing the global average forecast