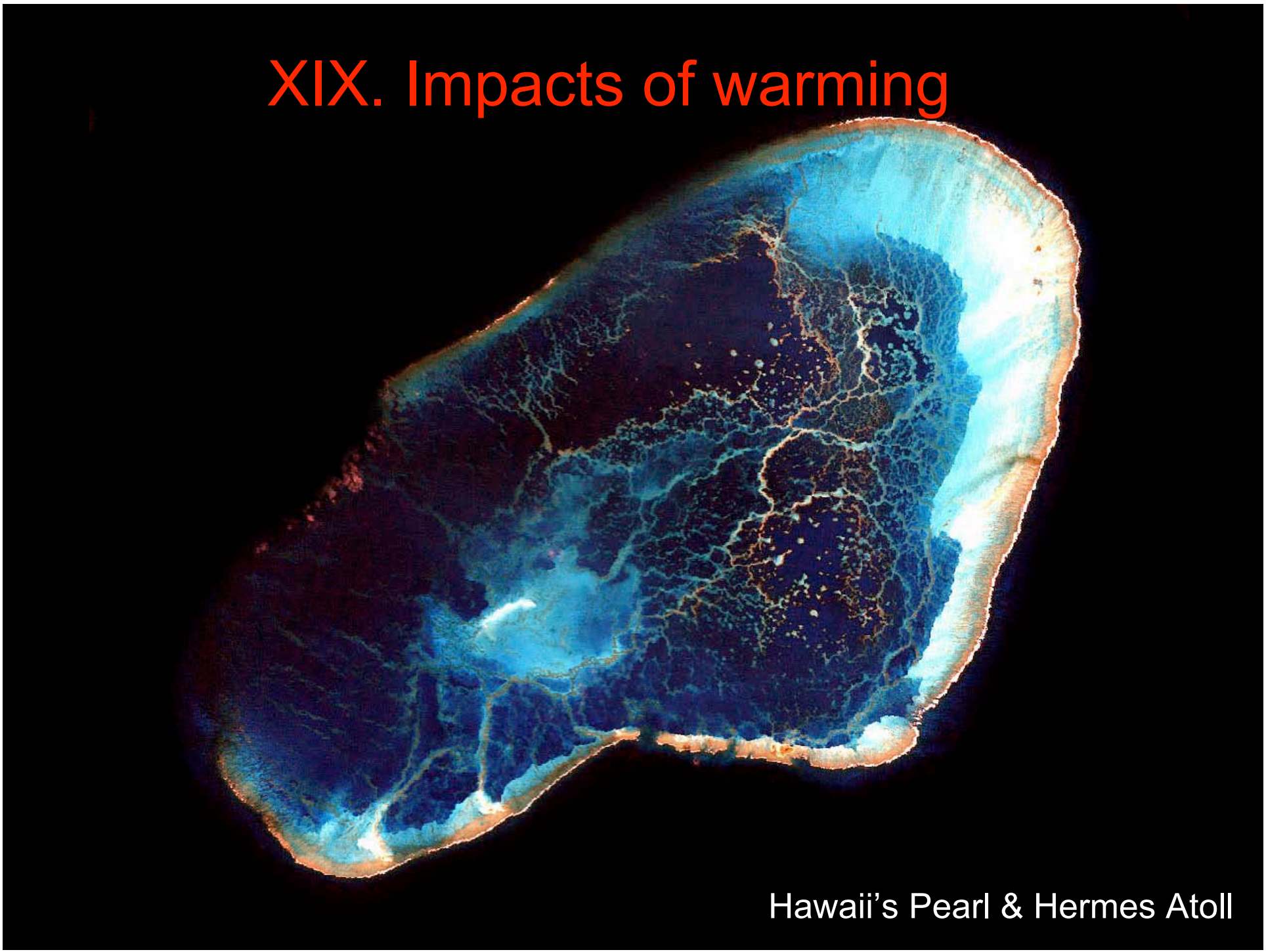
XIX. Impacts of warming



Hawaii's Pearl & Hermes Atoll

review

- 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 assoc. sea level rise) (all as of yr 2000)
- the long atmospheric lifetime of CO_2 and timescale of ocean mixing (and of A-O equilibrium) lead to long term changes in climate and sea-level that are irreversible (i.e., human activities will permanently alter climate and sea level)
- extreme weather conditions are likely to become more common for all emissions scenarios (more so for greater emissions)
- the latter may represent a greater challenge than the change in global average Temp. or Precip.

old 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

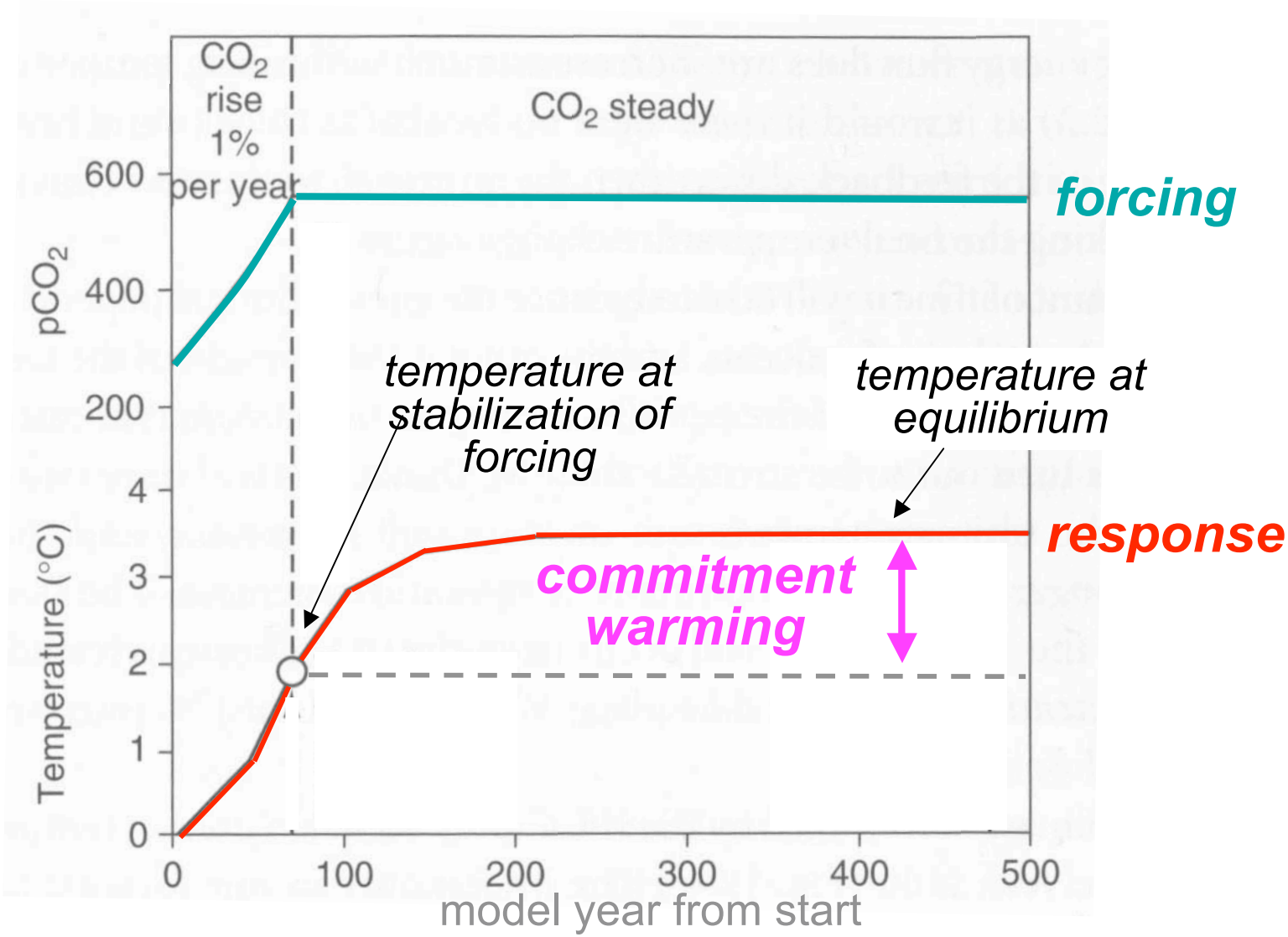
b) there may be some slow responding reservoirs of mass and energy in the climate system

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

d) both a) and b)

e) none of the above

commitment warming



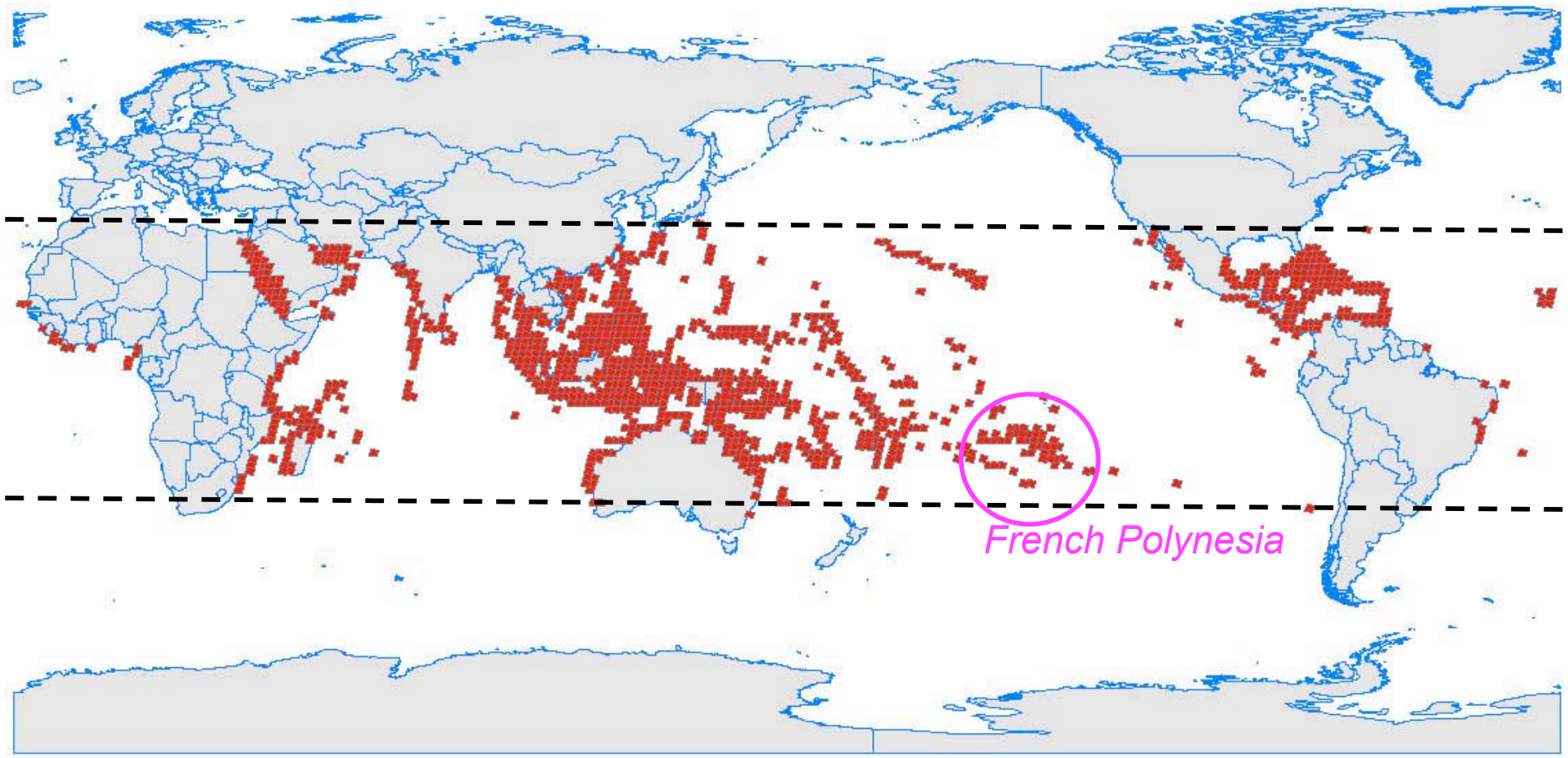
commitment warming is result of time needed for climate to adjust to energy already added to climate system

today's outline

- a closer look at some likely, prominent impacts
  - widespread coral reef bleaching and mortality
  - widespread extinction
  - widespread subtropical drought
  - wildfire
  - grain shortages and hunger
  - disappearance of sea-ice, aldedo flip
  - disappearance of mtn. glaciers (water resources, geo-hazards)
  - progressive sea level rise due to thermal expansion of sea water and ice melting
  - coastal flooding (vulnerable highly-populated African and Asian mega-deltas)
  - more intense storms
  - weakened thermohaline circulation
  - irreversible ice sheet instability (catastrophic sea level rise)
- what is "dangerous climate interference"
  - Venus Syndrome*?

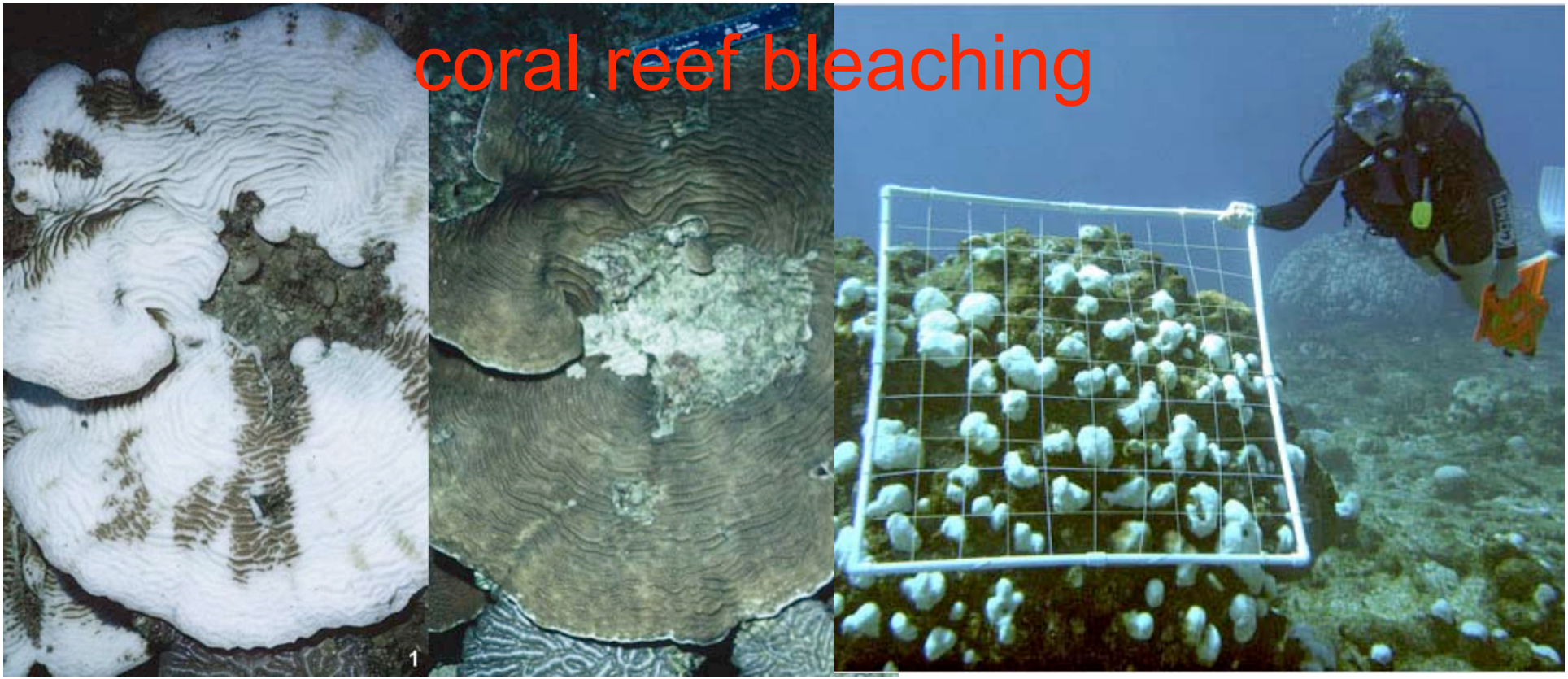
**runaway greenhouse and planetary destruction*

distribution of coral reefs



reef building corals have narrow range of environmental tolerance, needing lot's of sunlight and nutrients, and clear, warm water- these conditions occur only in shallow (<100 m depth) waters of the tropics

coral reef bleaching



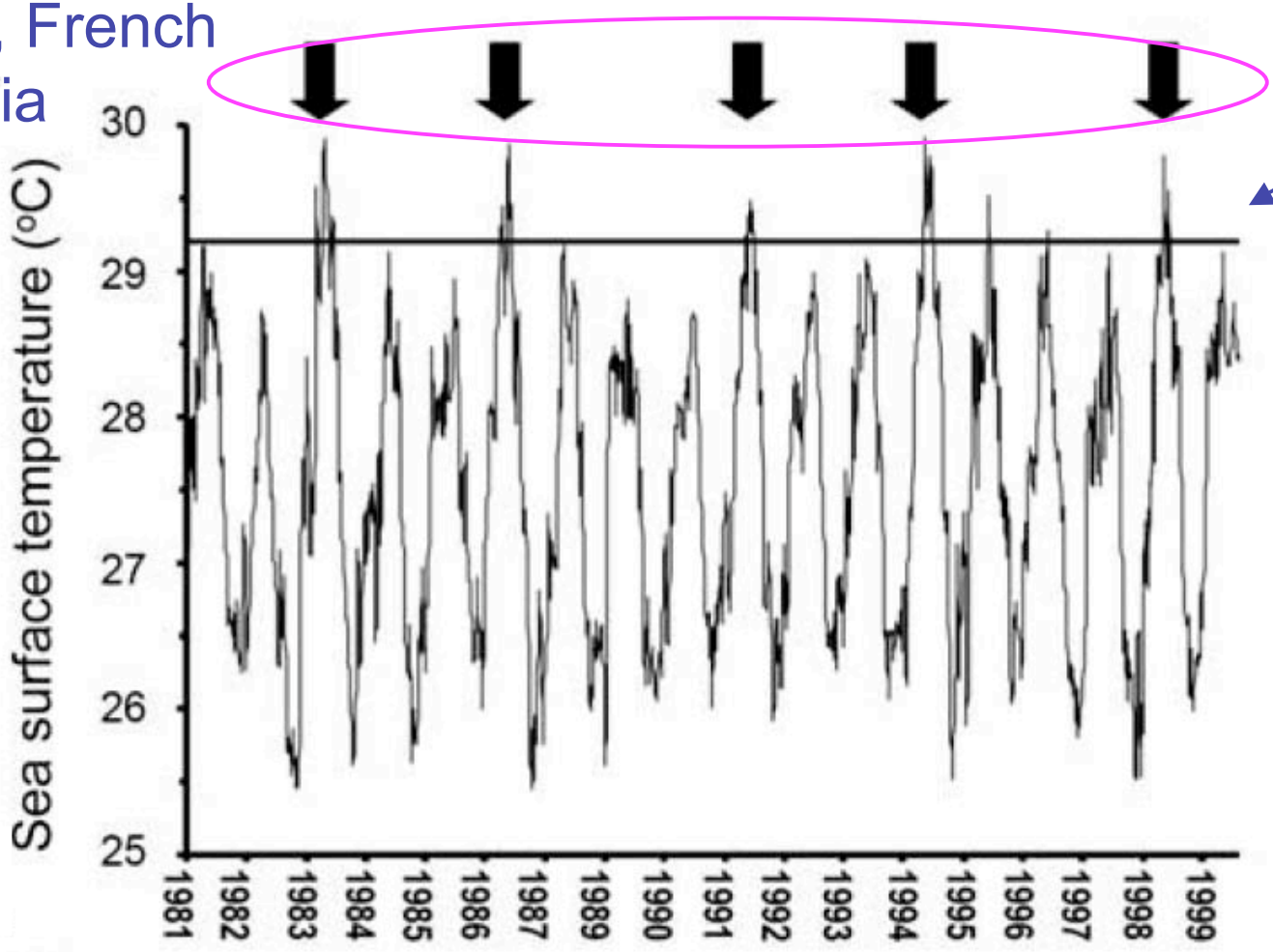
corals have narrow range of environmental tolerance...., needing temperatures that are *warm but not too warm*- heat stress associated with sustained high temperature leads to *bleaching* (death/dysfunction of symbiont algae)- too much heat stress can kill corals outright

it is estimated that, globally, 30% of corals have been lost since 1980....

Hoegh-Guldberg '04

coral “mass bleaching” events

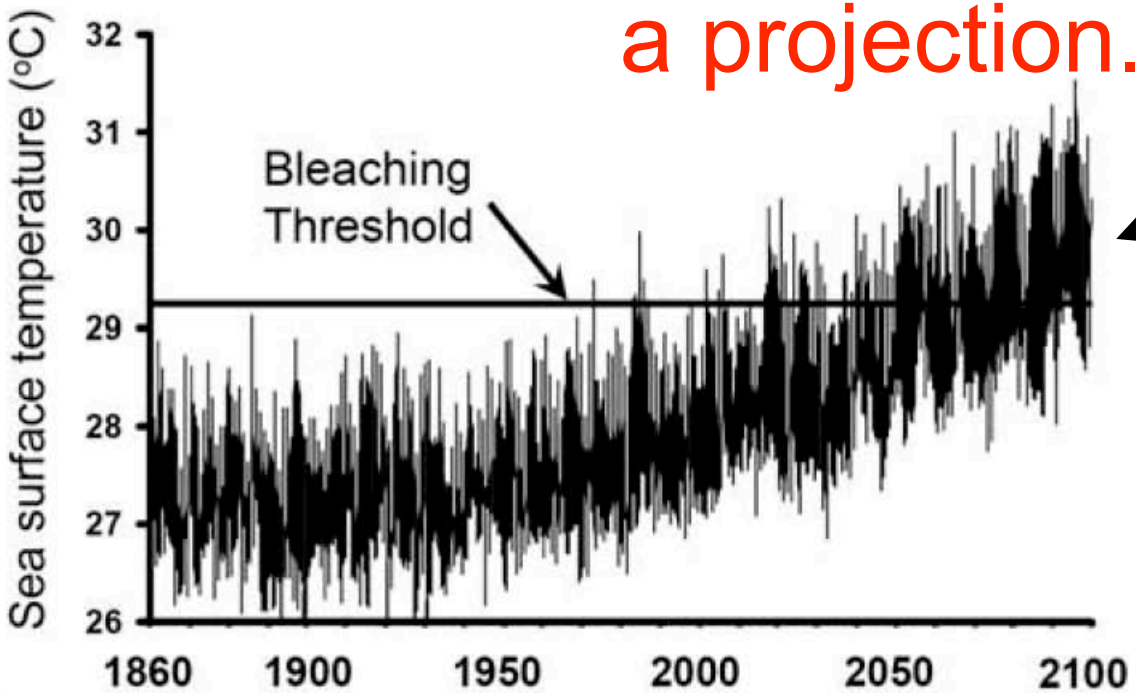
Moorea, French Polynesia



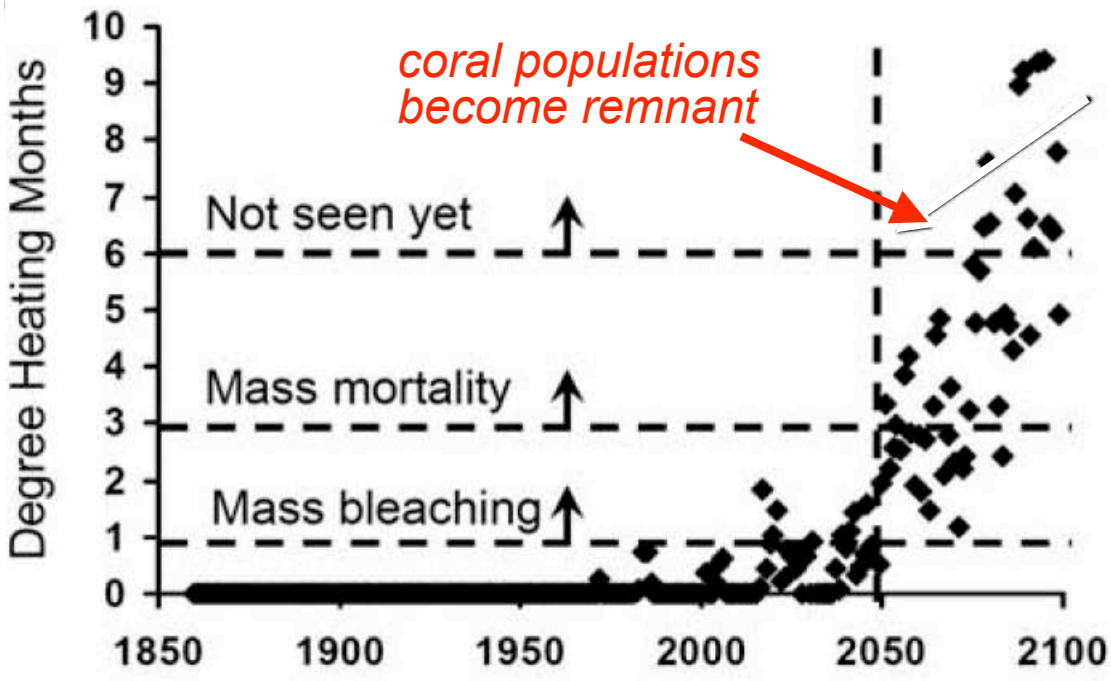
mass bleaching events are clearly associated with thermal stress.....

Hoegh-Guldberg ‘04

a projection.....



"BAU" (IS92A) SST forecast for Moorea



cum. heat stress expressed as Degree Heating Months (degrees above threshold times time above threshold)

once mortality events occur every few years, reefs can not regenerate and become relict.....

no living reefs after 2050!

Hoegh-Guldberg '04

loss of diversity (one example)

- we have so far treated corals monolithically
- there are ~800 species of warm-water reef-building corals and >560 of these are judged to be susceptible to climate change [IUNC 2008]
- this is an enormous loss of biological diversity
- we do not know what impact such a loss of diversity will have on reef ecosystems as a whole
- (recall, corals also threatened by ocean acidification)

increased rate of extinction?

- many extant species susceptible to climate change (altered range and reduced abundance due climate change last 30 yrs)

- many climate-change susceptible species already under pressure due to habitat loss from land use change

- estimates from one comprehensive study suggest 15-37% of species will be "committed to extinction" by 2050 due to warming [Thomas et al., 2004]

increased rate of extinction?

- estimates from one comprehensive study suggest 15-37% of species will be "committed to extinction" by 2050 due to warming [Thomas et al., 2004]

- projection of "bioclimate" and species loss intrinsically difficult, but all or most climate and environmental change factors deliver negative impacts (we have seen example from corals)

- we are risking loss of ecological services and runaway ecological effects we do not yet understand

estimating the risk of extinction

An example:

- obtain statistical relationship between species range and “bioclimate” (i.e. T, precip., and seasonality)
- use GCMs to project change in geographical range of bioclimate envelope for different groups of organisms with similar habitat
- exploit *power law relationship* between habitat size and species diversity:

$$S = cA^z$$

S = no. of species, ***A*** = area, ***c*** and ***z*** are constants

(***z*** = 0.25 seems to work well explaining species loss from past land use disturbance)

- allow dispersal to new disjunct ranges (or not)

Thomas et al. 2004

species-area based estimate

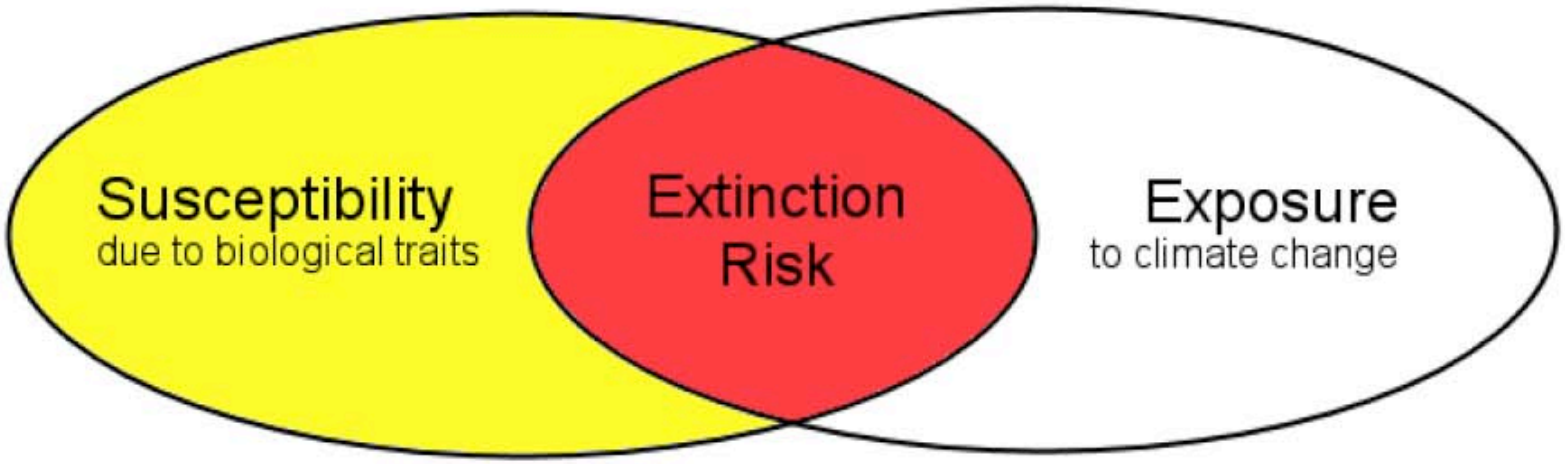
- 15 - 37% of species committed to extinction by 2050

- range in estimate results from 3 different climate scenarios (2x), dispersal (or not, 2x), and other species-area assumptions (1.4x)

- current rates of extinction already 100 - 1000 times faster than background (*based on assumption of steady state between evolution of new species and extinction, where evolution of new species is 1 - 4 MY process*)

IUCN Red List

- Red List is compendium of expert judgments of extinction risk for individual species based on biological traits
- IUCN now beginning to consider threat posed by climate change



International Union for Conservation of Nature and Natural Resources 2008

amphibians (double whammy)

Amphibians		Threatened		
Climate Change Susceptible		YES	NO	TOTAL
	YES	1,488 24%	1,729 28%	52%
	NO	503 8%	2,502 40%	48%
	TOTAL	32%	68%	6,222

3/4 of all amphibians previously considered to be "threatened" by IUCN now also seen as "climate change susceptible" based on biological traits

more than 1/2 of all known amphibians considered to be "climate change susceptible"

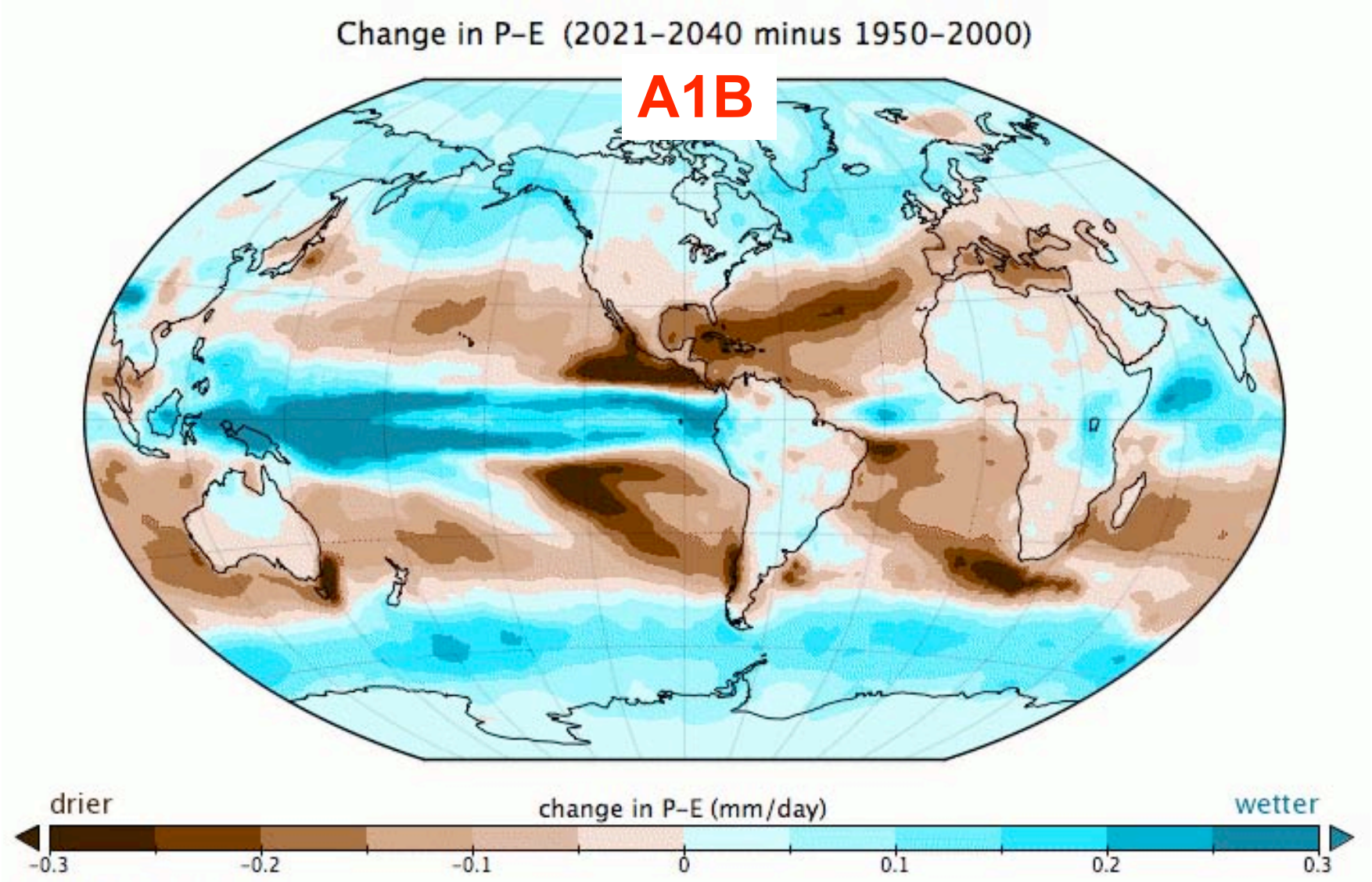
IUCN 2008

birds

Birds	Threatened			
Climate Change Susceptible		YES	NO	TOTAL
	YES	976 10%	2,462 25%	35%
	NO	246 2%	6,172 63%	65%
	TOTAL	12%	88%	9,856

more than a third of all studied birds are considered to be “climate change susceptible” (vs. 12% currently consider threatened)

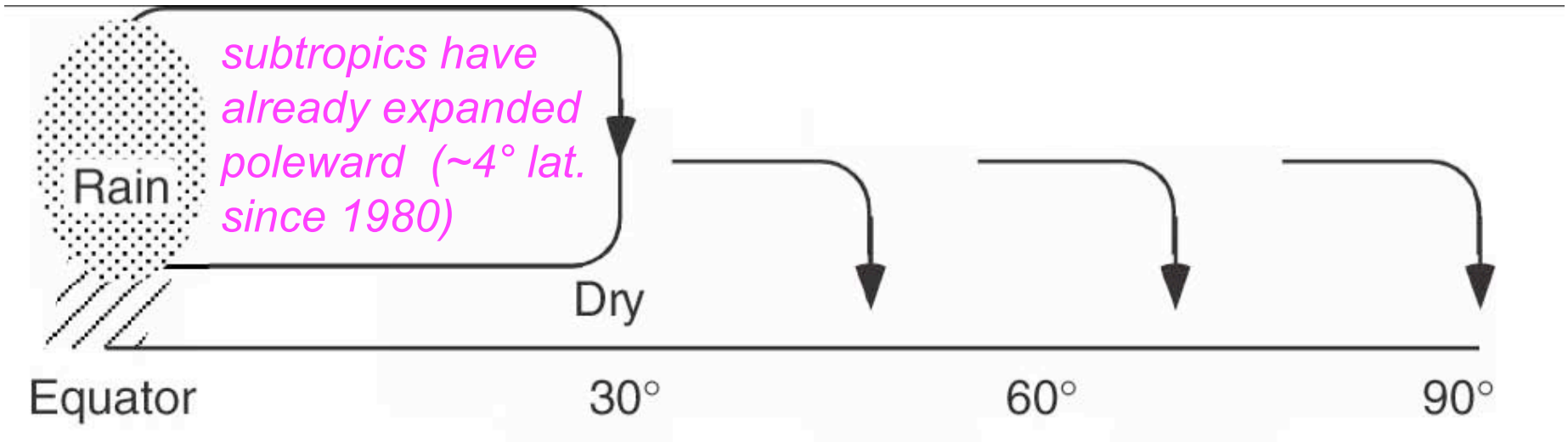
Drought: what is the pattern?.....



"Results averaged across 19 different models. P-E is net flux of water at surface that, over land, sustains soil moisture, ground water, and river runoff"

Seager et al., Science in press

recall simple mechanistic forecast



more intense heating, more convection, rainfall and flooding

more descending dry air, more & longer drought

warmer, wetter, more snowfall

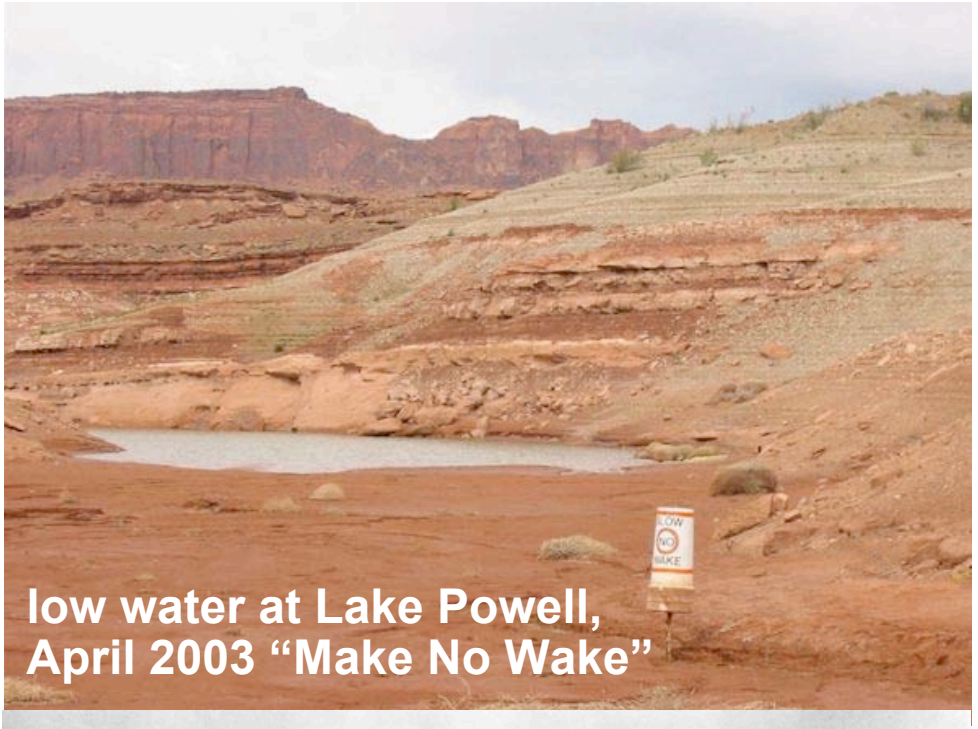
Archer (fig.)
Seidel & Randel 2006

widespread drought

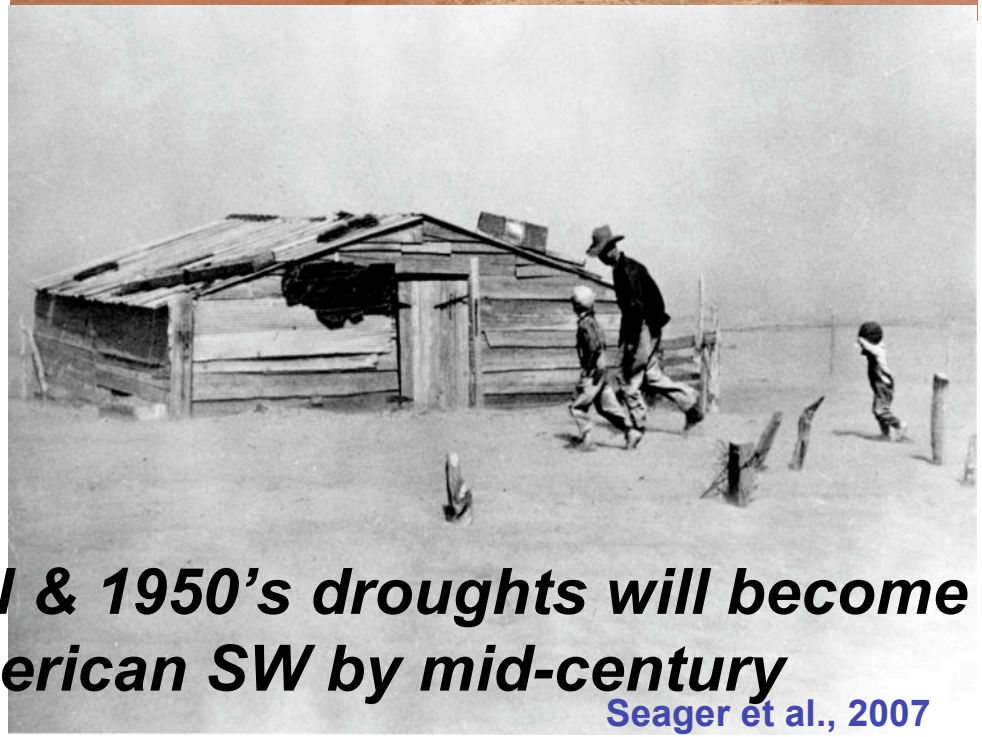
American SW *and other subtropical regions* will become increasingly arid

transition to drier climate *already underway* and will become well established in coming decades with "permanent drought"

a robust finding across 19 IPCC model projections- assoc. with amplification and poleward displacement of the hydrologic cycle



low water at Lake Powell, April 2003 "Make No Wake"

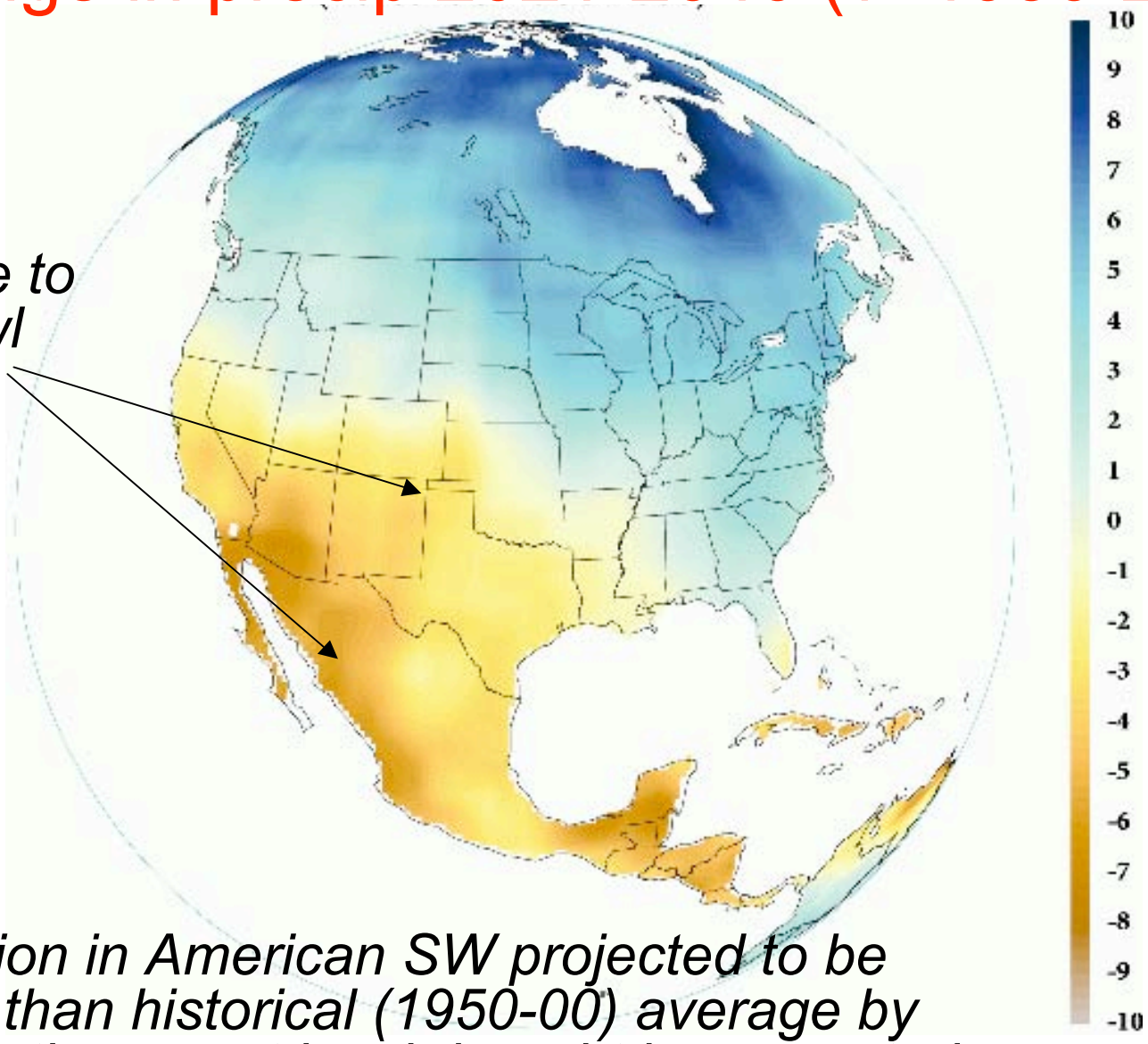


Aridity levels of The Dust Bowl & 1950's droughts will become the new climatology of the American SW by mid-century

Seager et al., 2007

% change in precip 2021-2040 (v. 1950-2000)

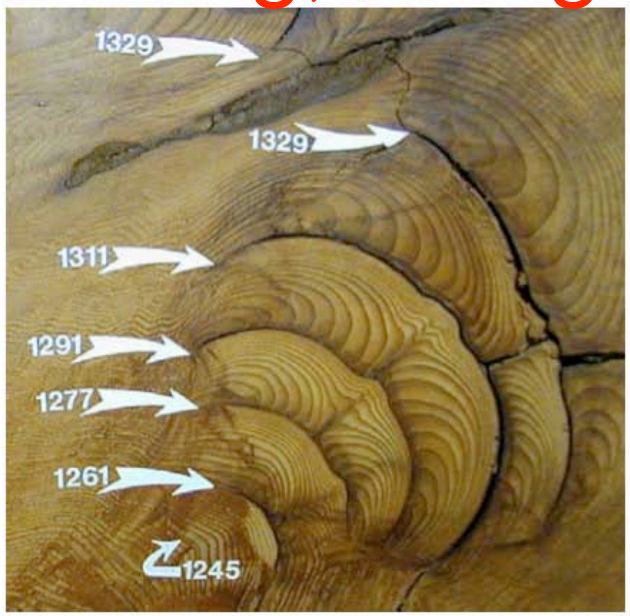
comparable to Dust Bowl deficits

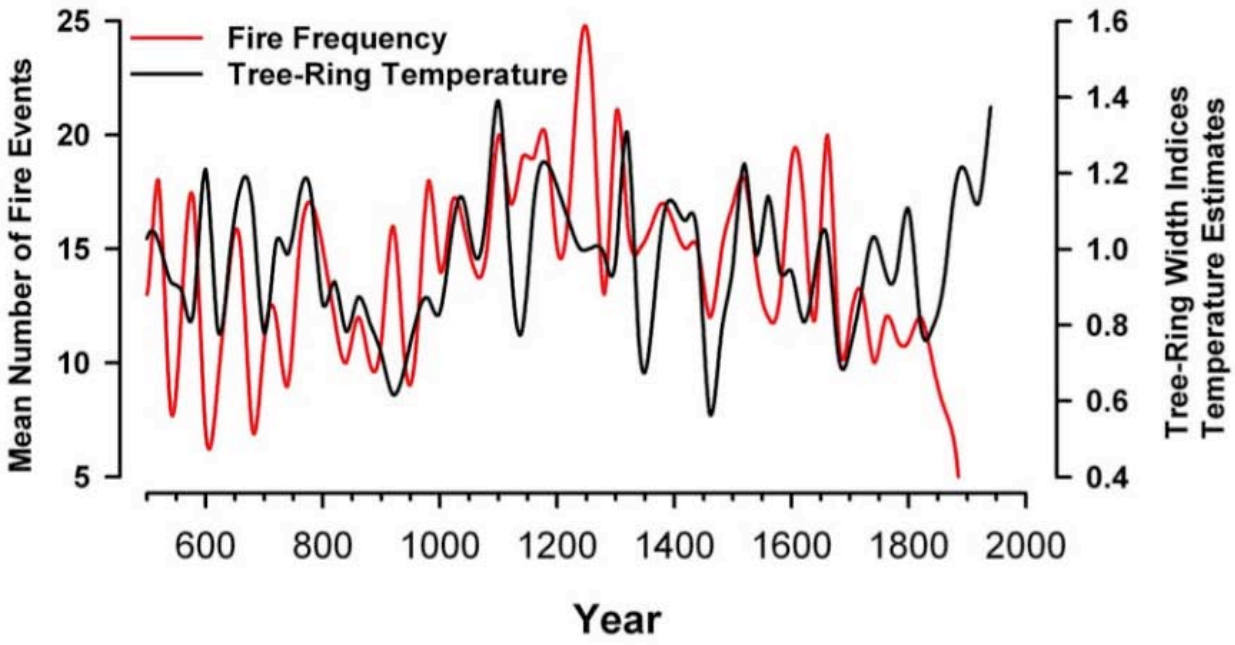


precipitation in American SW projected to be much less than historical (1950-00) average by mid-century- the recent local drought is suggested to be beginning of transition to permanent drought

Seager et al., Science in press

warming, drought & fire



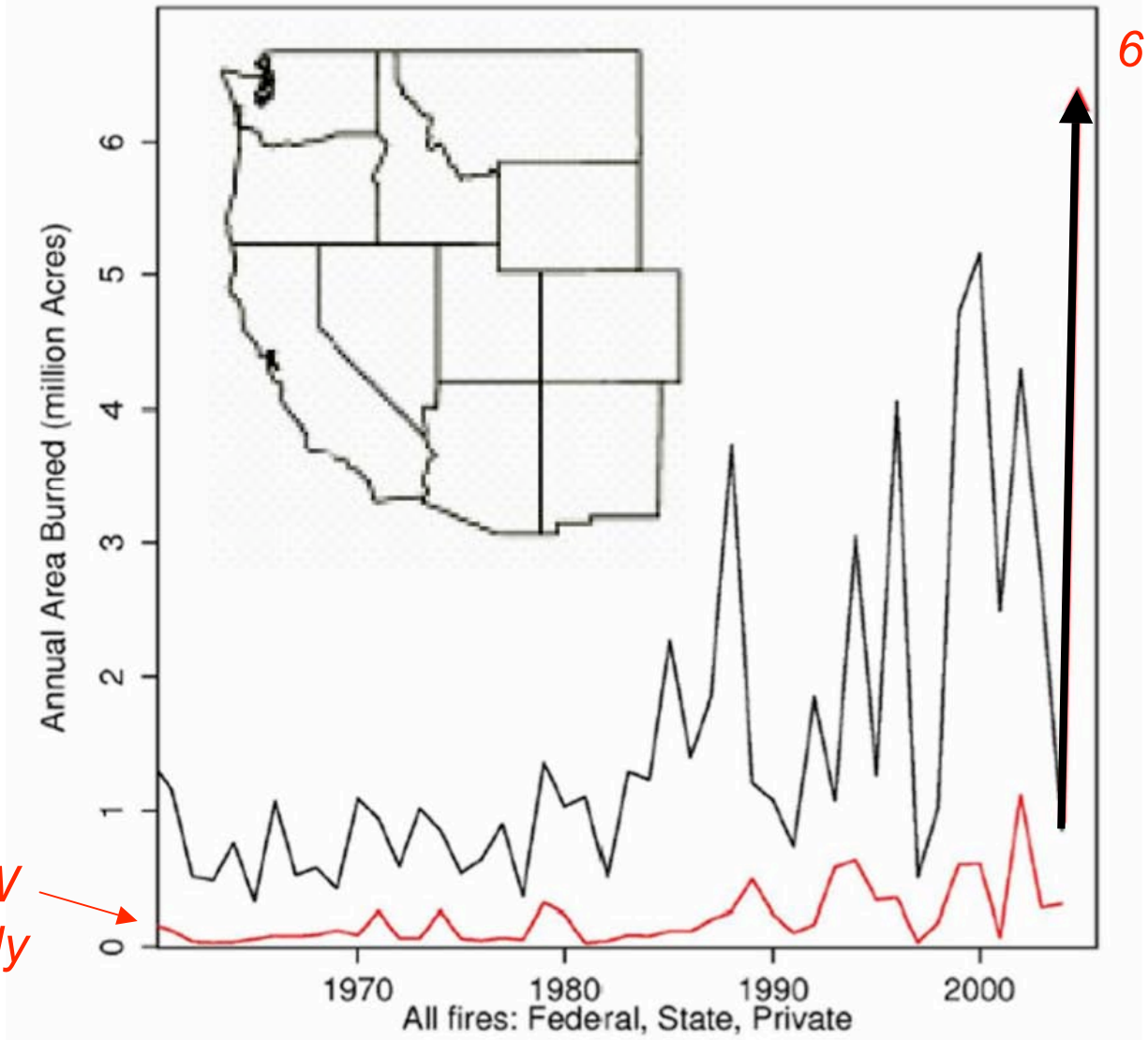


In the American west there is a natural relationship between warming and fire…

Here we see that the record of fires from fire-scar wounds in Sequoia groves corresponds with evidence of relative warmth from tree ring width in Bristlecone Pine.

Swetnam et al.

warming, drought & fire



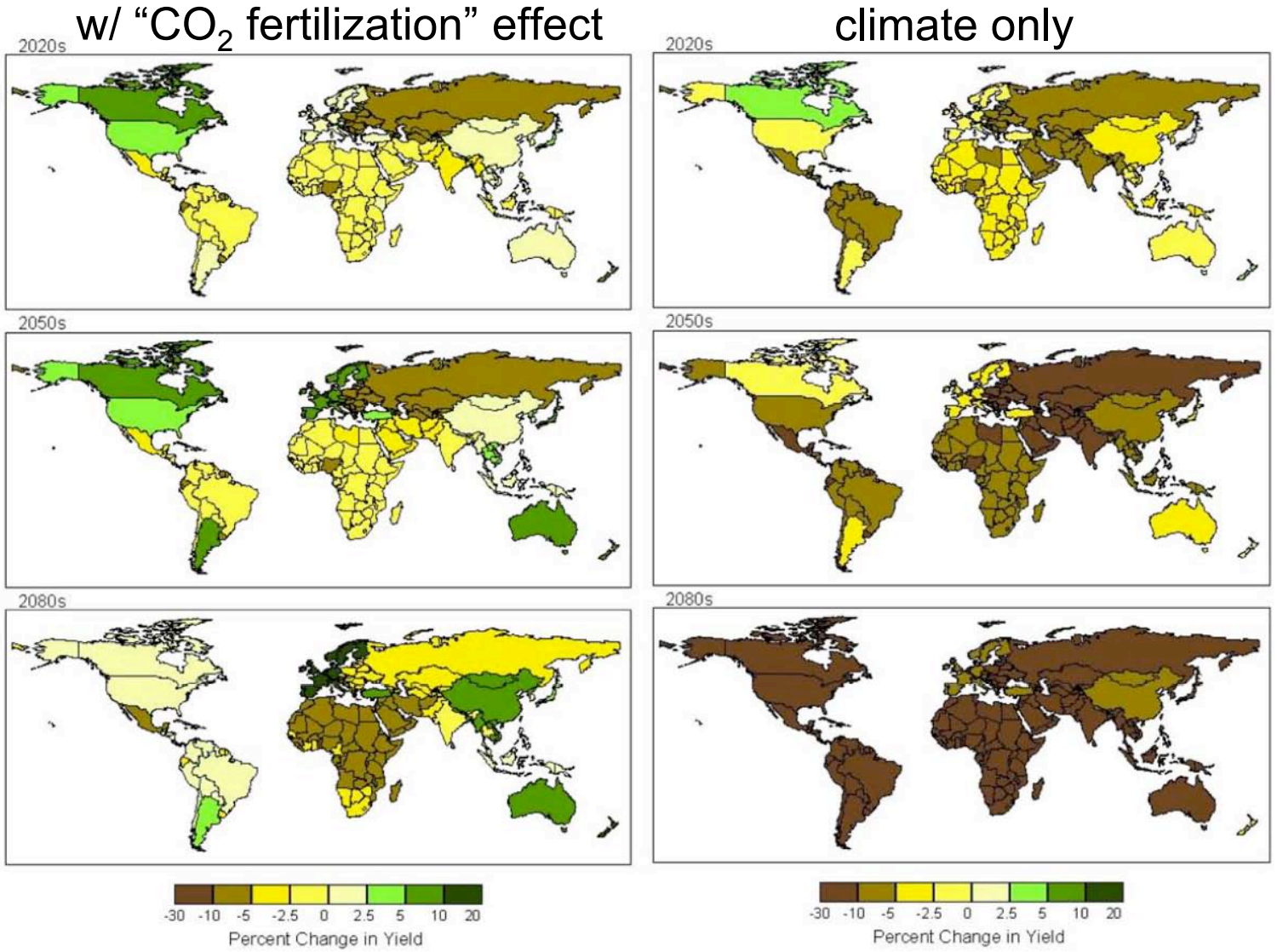
6 M acres as of 13 Sept. '07

SW only

four-fold increase in area burned since 1980, related to Spring-Summer temperature and timing of snow melt

Westerling et al. 2006

projected crop yield (as % of 1990), A2

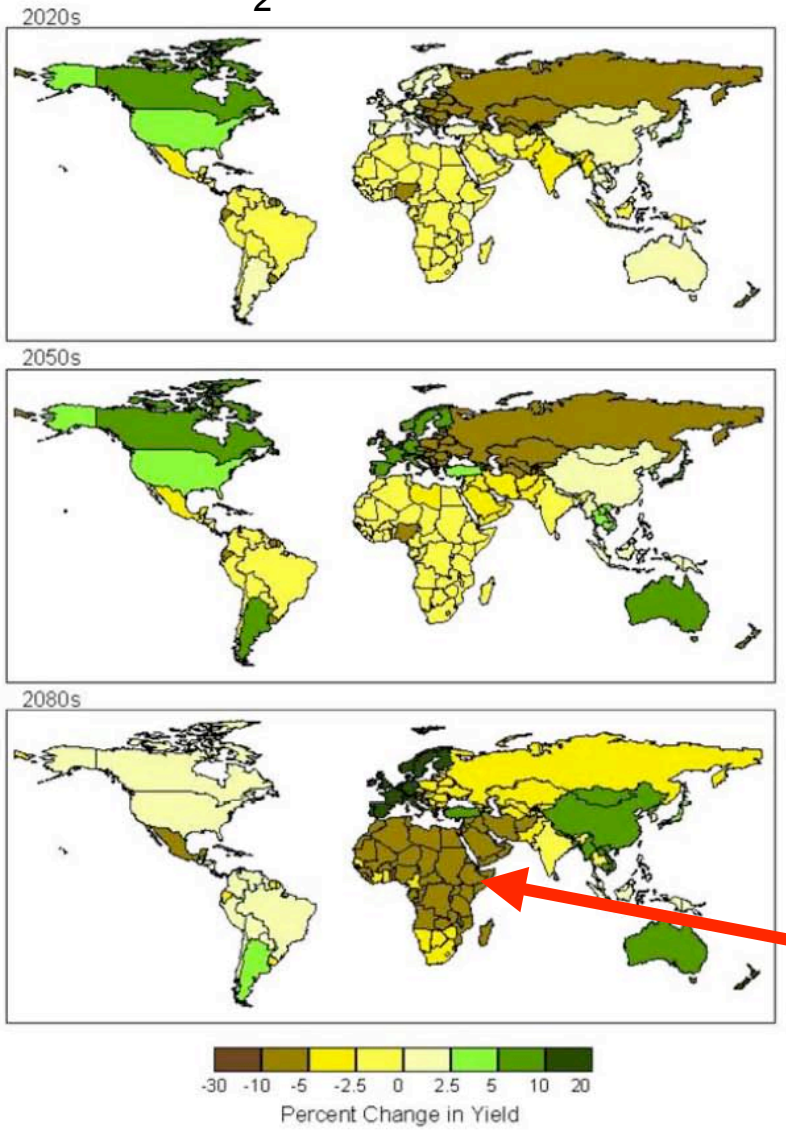


projected deficits are primarily in developing countries (benefit fr. CO_2 fertilization effect is highly uncertain)

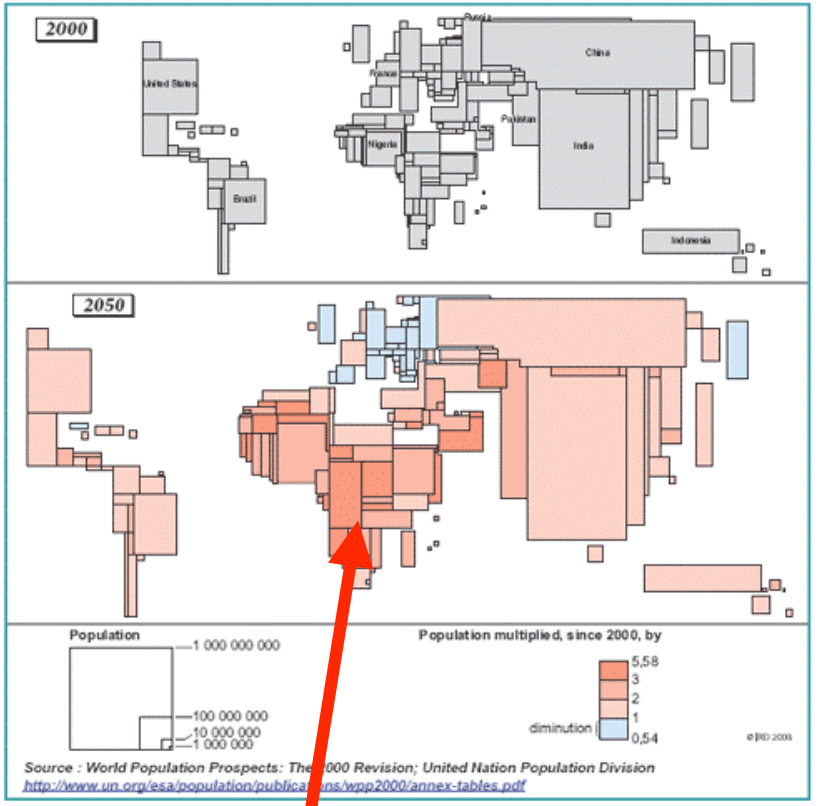
Parry et al. 2004

projected crop yield (as % of 1990), A2

w/ "CO_2 fertilization" effect



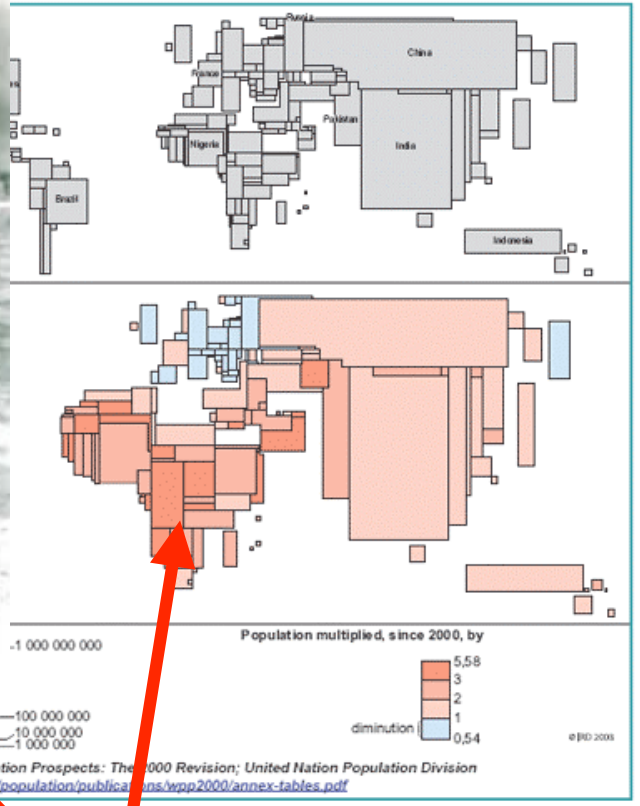
population change (UN)

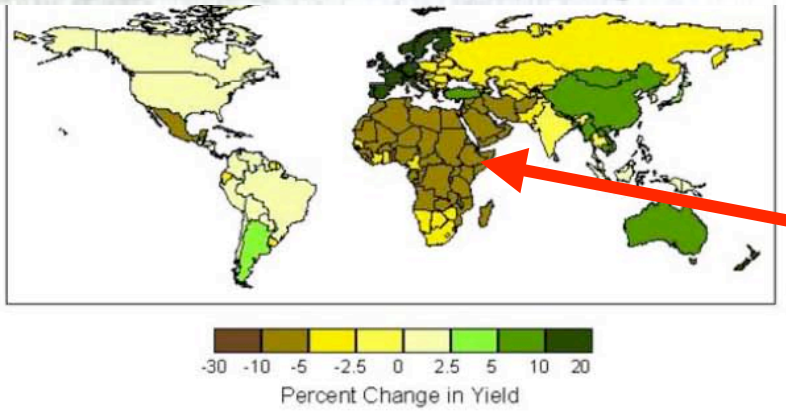


projected deficits are greatest in areas of greatest expected population growth

projected crop yield (as % of 1990), A2

ulation change (UN)





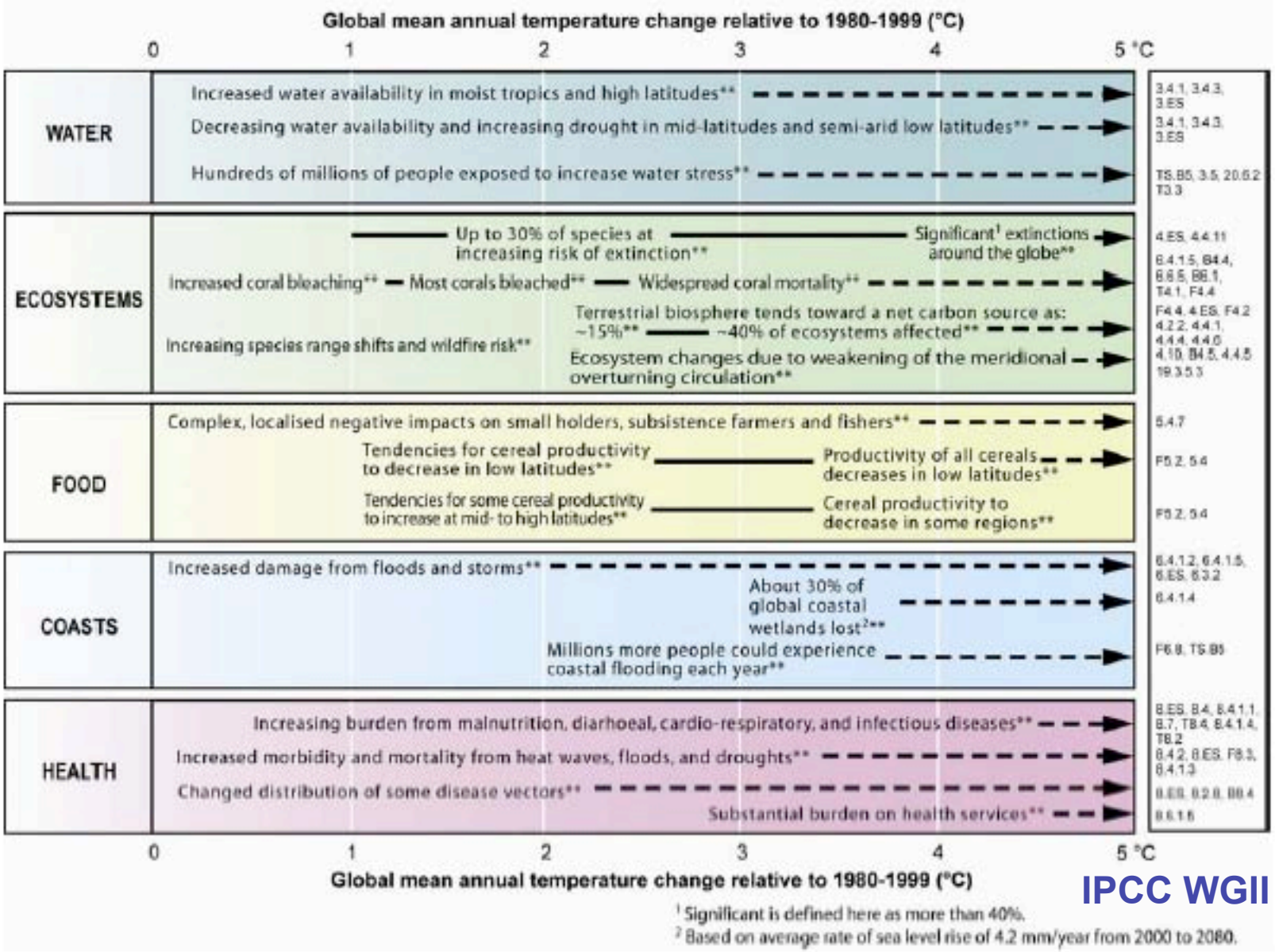
these areas are seriously vulnerable to food shortages already!

dangerous climate interference?

- UN Framework Convention on Climate Change (which charters the Kyoto Protocol) has the long term objective of stabilizing GHG concentrations at levels that will avoid "dangerous anthropogenic interference with the climate system"
- how do we define "dangerous anthropogenic interference"?
  - *science informs but can not settle the issue because it depends on values*

how much is "harmful"?

key impacts w.r.t. temperature increase



IPCC WGII AR4

many impacts already underway- number and severity of impacts will increase with additional warming

dangerous climate interference?

- UN Framework Convention on Climate Change (which charters the Kyoto Protocol) has the long term objective of stabilizing GHG concentrations at levels that will avoid "dangerous anthropogenic interference with the climate system"
- how do we define "dangerous anthropogenic interference"?
  - *science informs but can not settle the issue because it depends on values*
- assuming we could define some mutually agreed "harm threshold" which we do not which to cross, how do we define the associated GHG stabilization target?

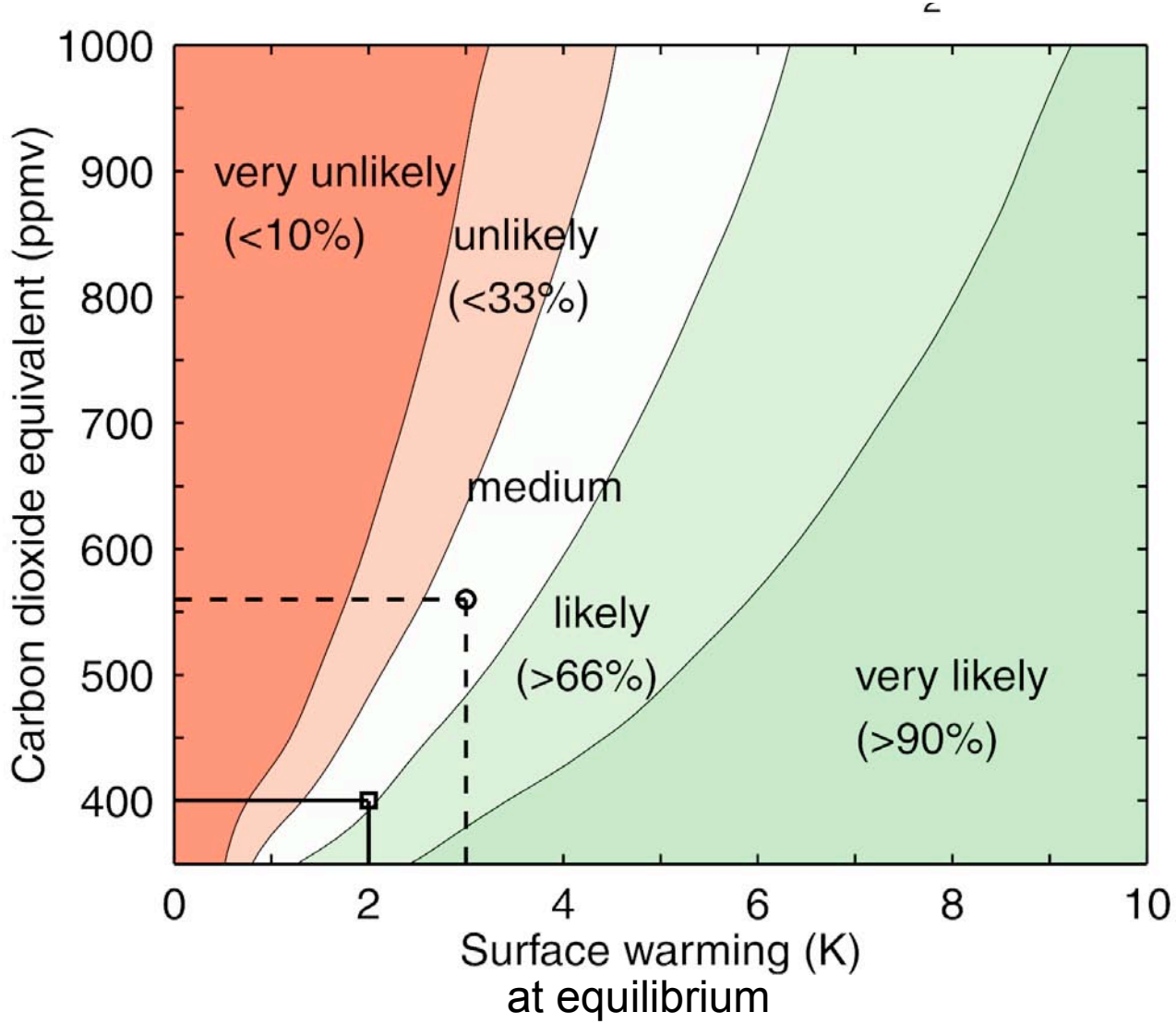
how much is harmful?

- if we accept the view of most scientists that impacts become *unacceptably severe* for global mean surface temperatures >2 °C above pre-industrial levels, what are the related GHG concentration limits?

- there are uncertainties in the relationship between CO_2 and climate, but they are quantifiable

- here is a useful (I think) “probabilistic” assessment

Probability of remaining below a global mean temperature level for a given CO_2 (equivalent) stabilization level, taking into account uncertainty in climate sensitivity and ocean heat uptake. Likelihood terminology from IPCC.



Knutti et al., 2005

how much is too harmful?

- recalling the table of prominent impacts for given amounts of temperature change, most scientists argue that impacts become *unacceptably severe* for global mean surface temperatures >2 °C above pre-industrial levels
- since impacts and their severity are not uniformly distributed in space (or time) individual, regional and national views are likely to vary widely
- probably only certain knowledge of a large sea level rise (> 1 m) by the end of century would provoke a widespread consensus, but sea level projections remain uncertain.....

key points

- for the first time, the IPCC (in 2007) has documented widespread impacts from climate change that has *already occurred*
- impacts are certain to increase in number, range and severity as warming continues
- it may be difficult to agree on a “harm threshold” that must be avoided
- but, many scientists maintain that impacts for warming in excess of >2 °C (v. pre-industrial) will be unacceptably severe
- this suggests a prudent CO_2 concentration cap of <400 ppm (v. 385 ppm now)

“Impacts” (April ‘07)

“For the first time we [the IPCC] concluded anthropogenic warming has [already] had an influence on many physical and biological systems....”

“....looking ahead, global warming’s impacts will only worsen.”

“The climate impacts, mostly negative, would fall hardest on the poor, developing countries, and flora and fauna- that is, on those least capable of adapting to change.”

“Although the report emphasizes the vulnerability of poorer developing countries, it foresees no real winners. Every population has vulnerable segments..... In the European heat wave of 2003 that killed perhaps 30,000, it was mostly the elderly.....”

IPCC WGII & *Science*

learning goals

- be able to describe the cause of coral bleaching and the basis for the projected loss of coral reefs in the future
- be able to describe the impact of continued warming and intensification of the hydrologic cycle on the climate of the American SW
- be able to describe other areas that will be similarly impacted by drying, and why…
- be able to describe the areas where crop yields will be most impacted by warming
- be able to define your own warming “harm threshold” and describe how you might determine what the CO_2 concentration cap would need to be to avoid that level of warming

next

- Reading: Ch. 9
- HMWK 4 (in prep. for in-class exercise)

- *“Powering the planet”*
- *“Emissions pathways to climate safety”*
- *“Carbon policy”*
- *“Engineering and science solutions”*