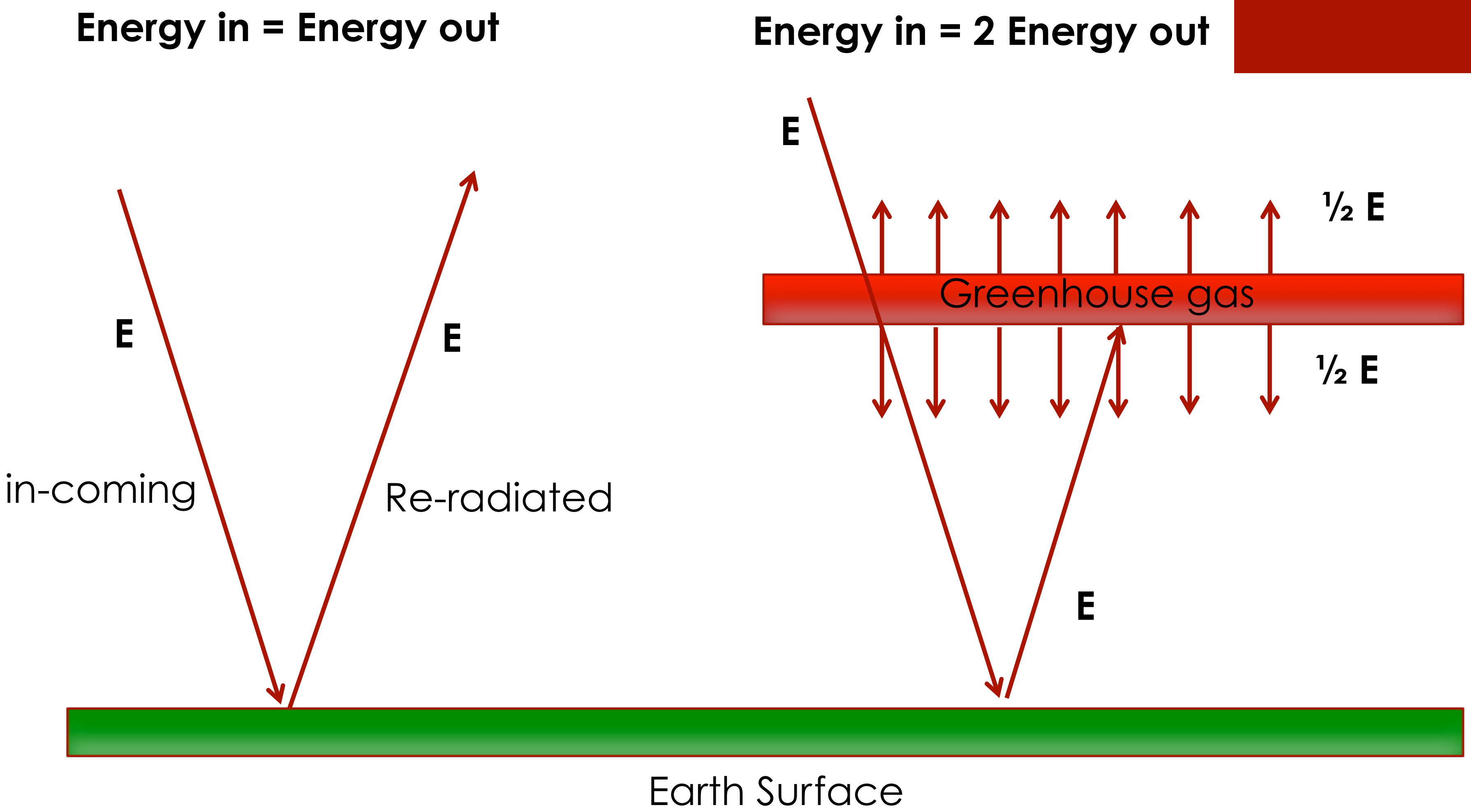
The challenges of climate change

Lecture 3 – Forcings and Feedback

Outline of course

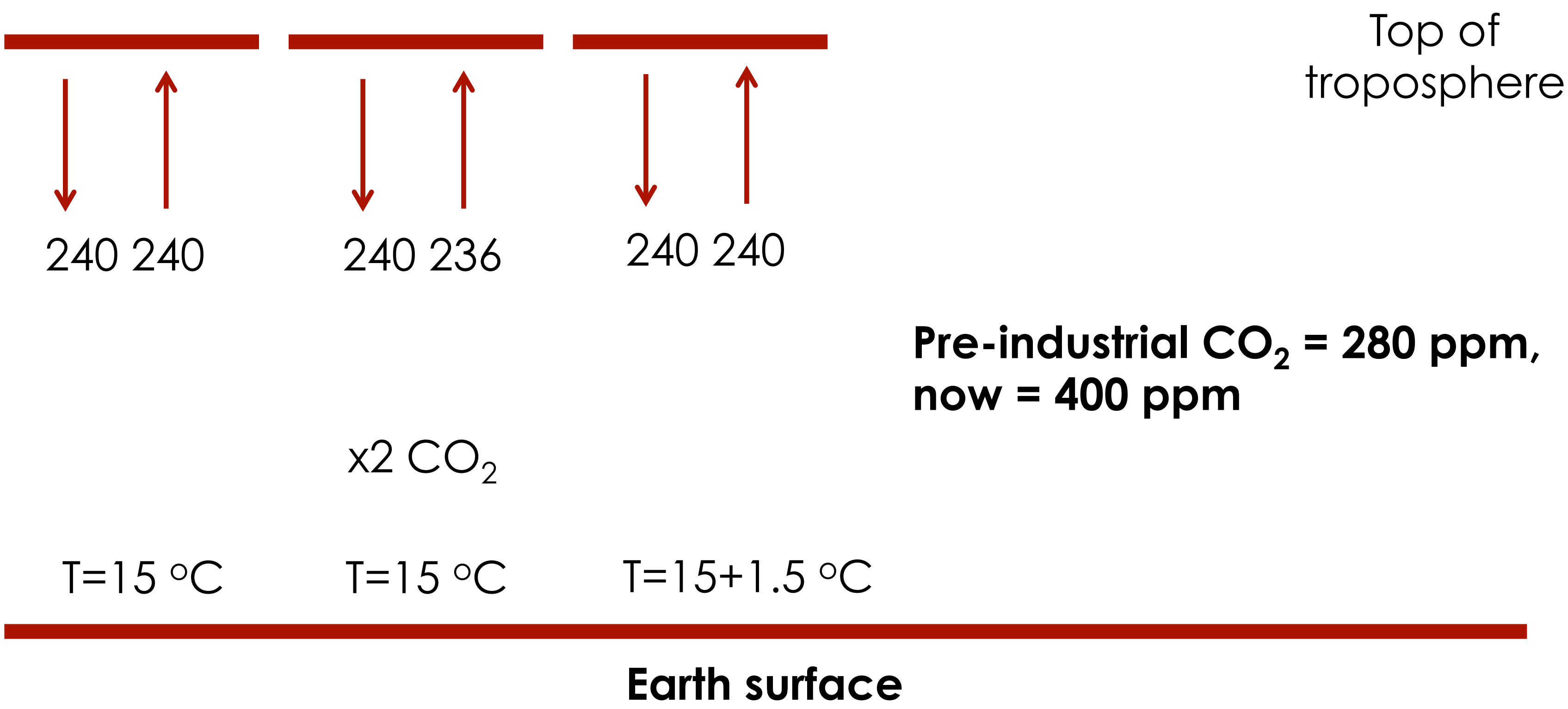
- **Do we understand the science behind climate change?**
  - Historical climate
  - ***<u>Basics of climate science</u>***
  - ***<u>Modeling the climate</u>***
  - Understanding the uncertainty
- **What are the implications of climate change?**
  - Biological/environmental implications
  - Economic political implications
- **What human actions can be taken to address climate change?**
  - Individual action
  - Political action
  - Technology
  - Economic action
  - Sources of inertia

A greenhouse



Radiative forcing

- Imbalance in incoming and outgoing radiation



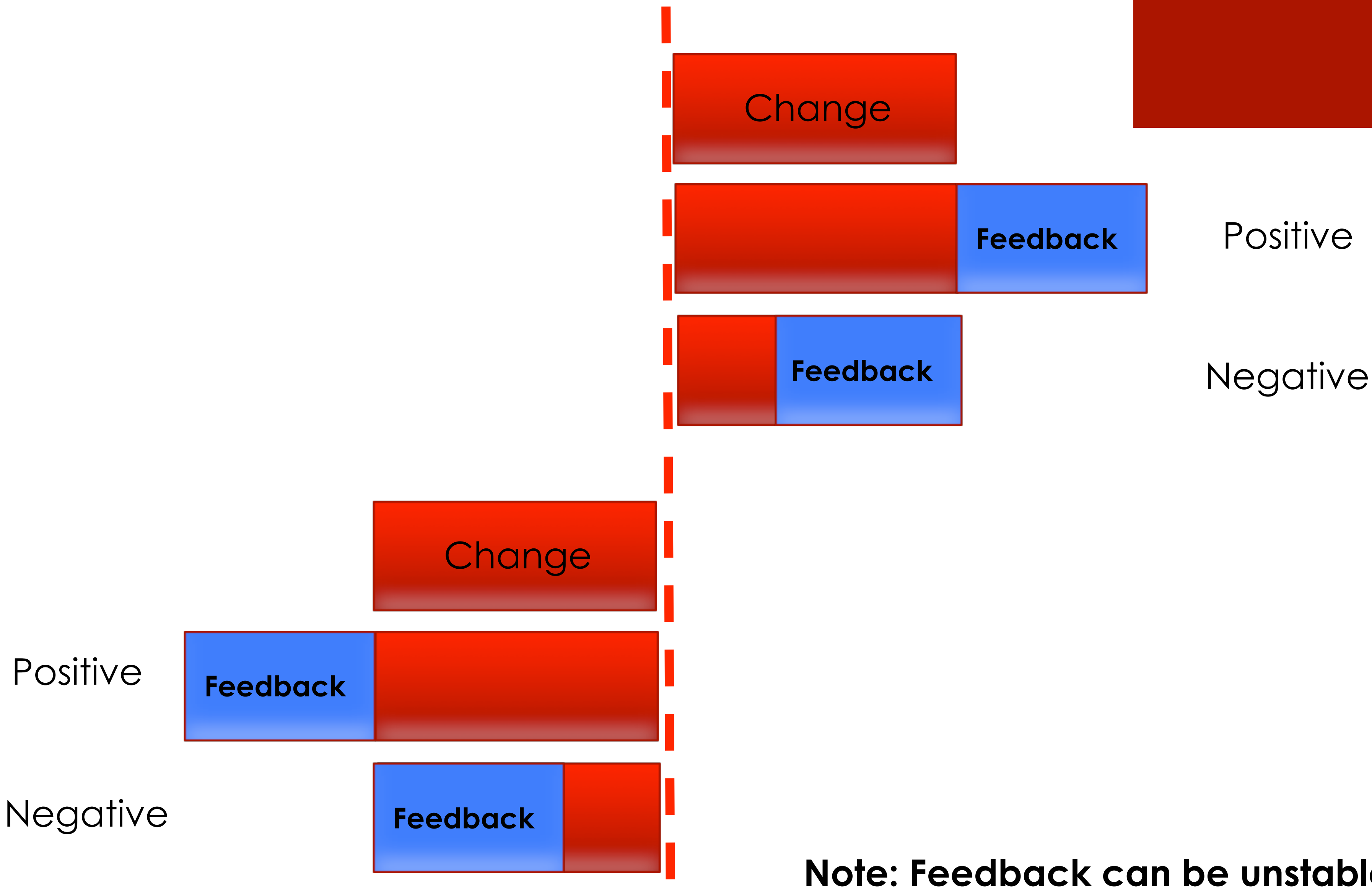
Radiative forcing arises from all greenhouse gases, and can be assessed via global warming potential

Climate Sensitivity

- Change in temperature for a given radiative forcing
- G_0= Change in temperature / Change in forcing = 0.27 ^{o}C/W/m^2

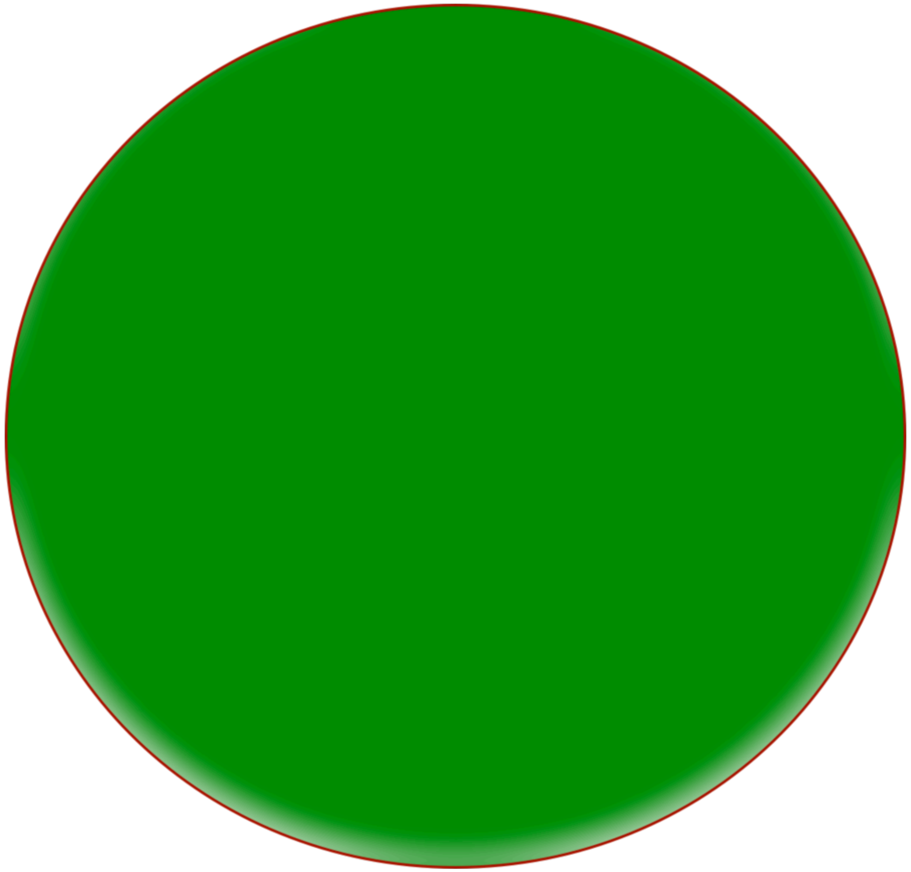
$$G_0 = \frac{\delta T}{\delta F} = 0.27^\circ \ \mathrm{C} \ \mathrm{W}^{-1} \ \mathrm{m}^2$$

Feedback

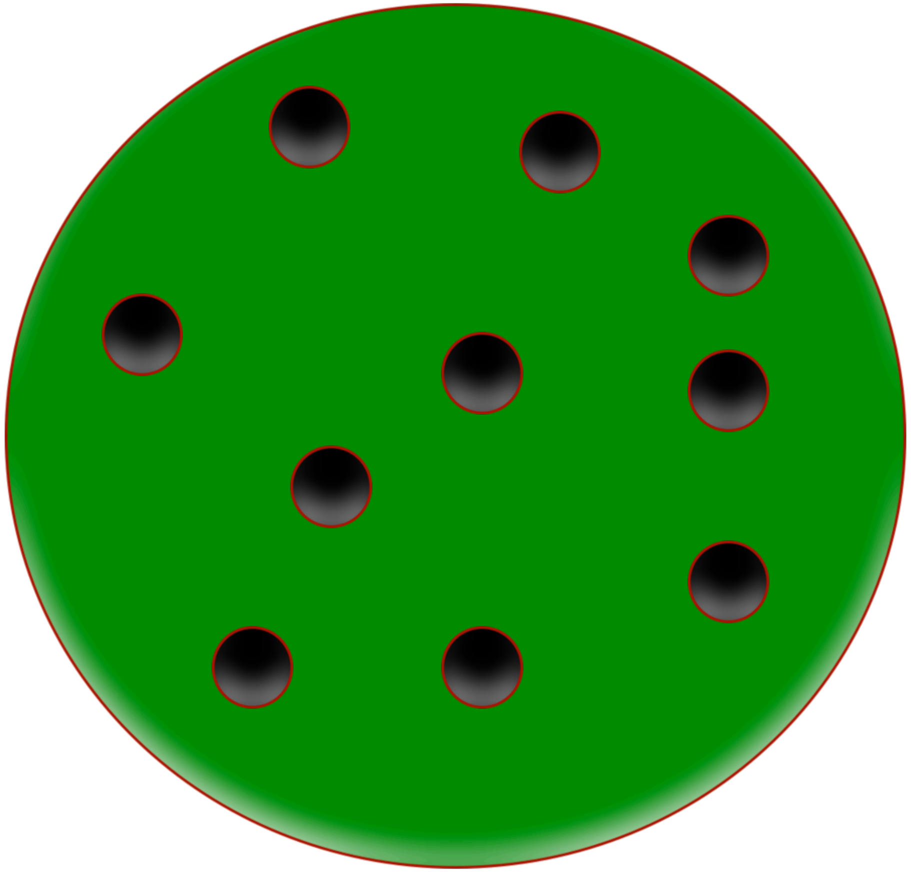


Note: Feedback can be unstable

Daisyworld

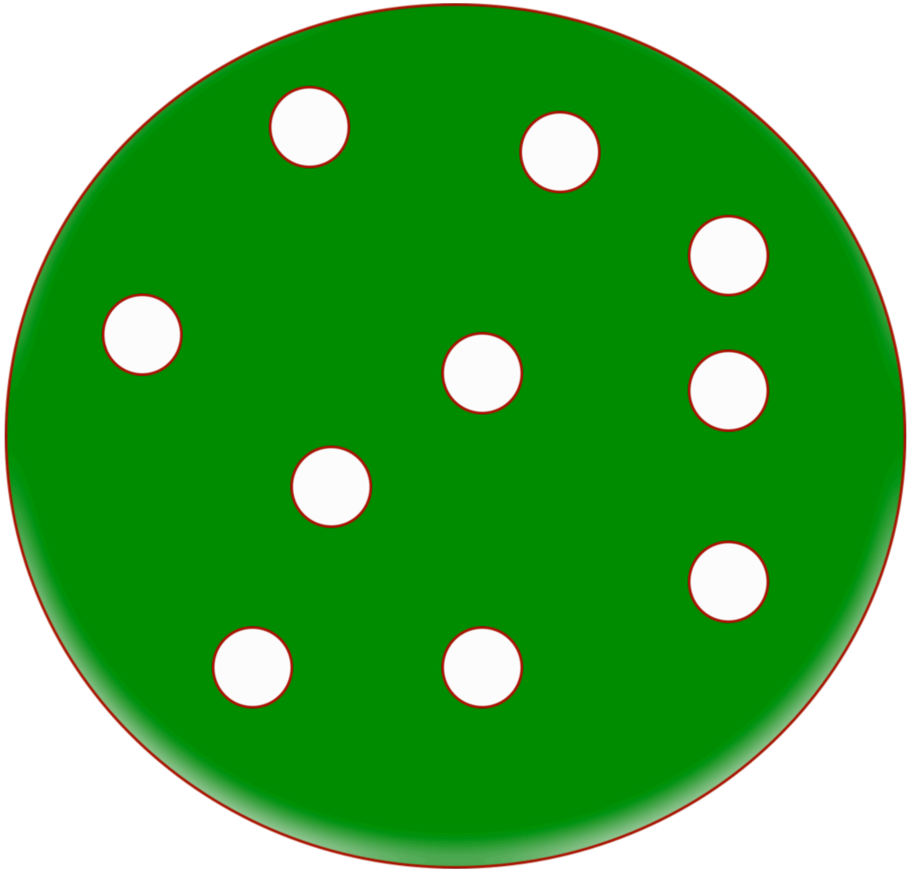


Daisyworld



Black daisies like it cool

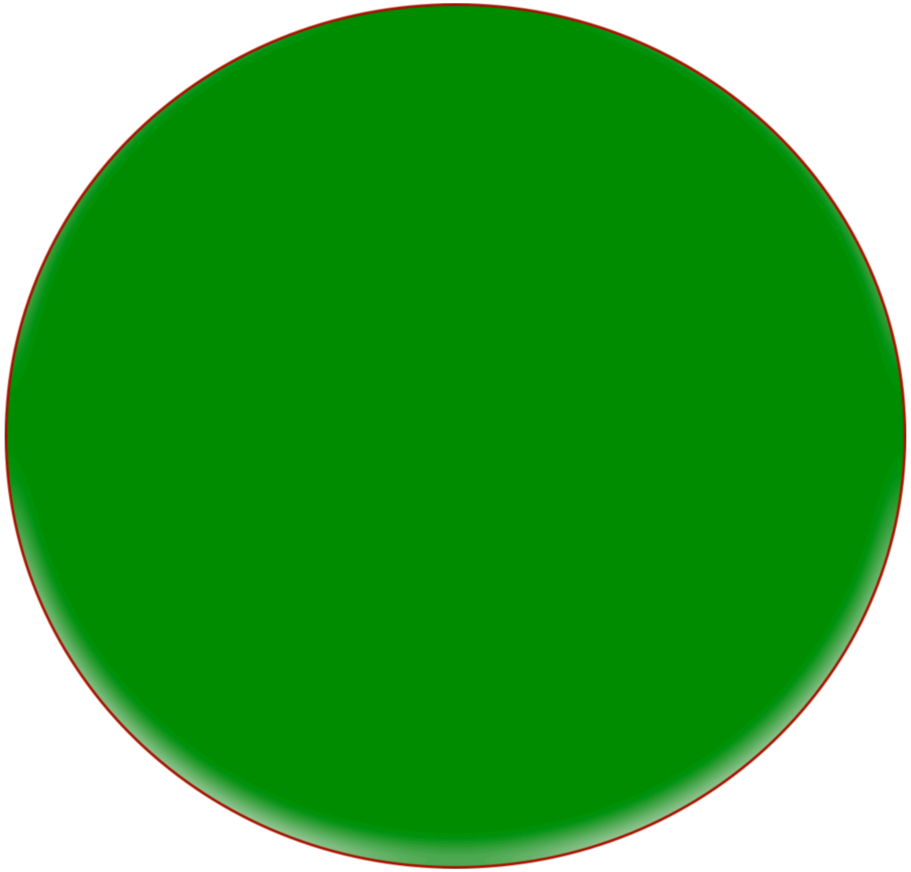
Daisyworld



Black daisies like it cool

White daisies like the heat

Daisyworld

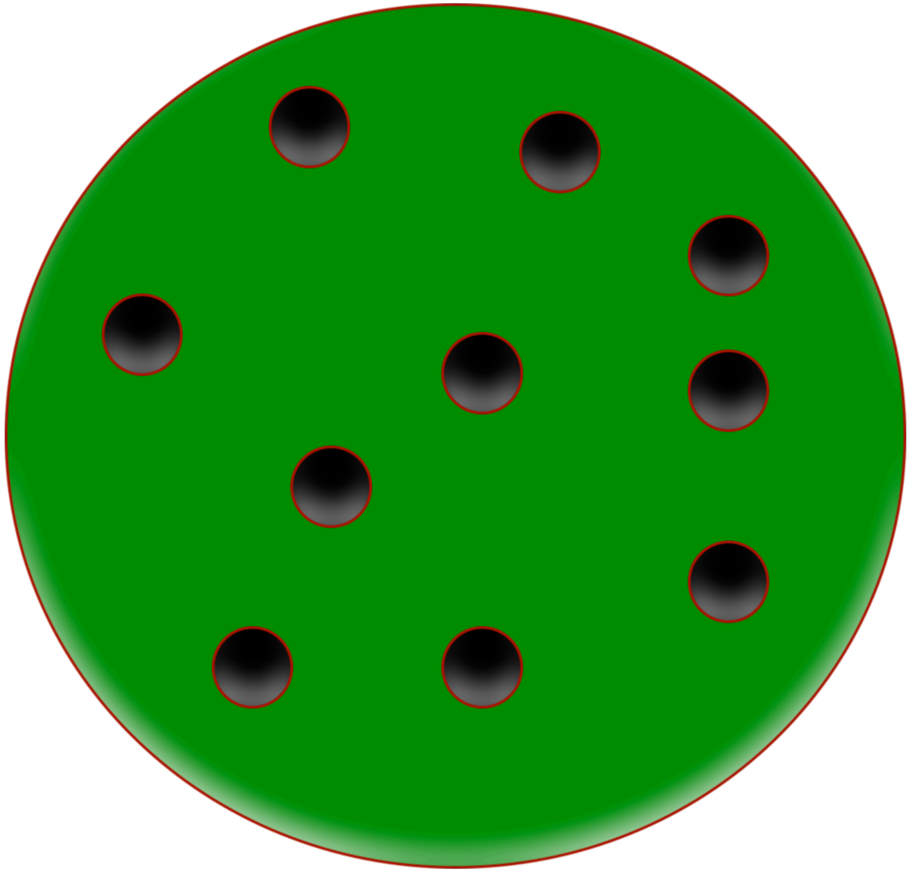


Black daisies like it cool

White daisies like the heat

At early times the star is faint (like the sun)

Daisyworld



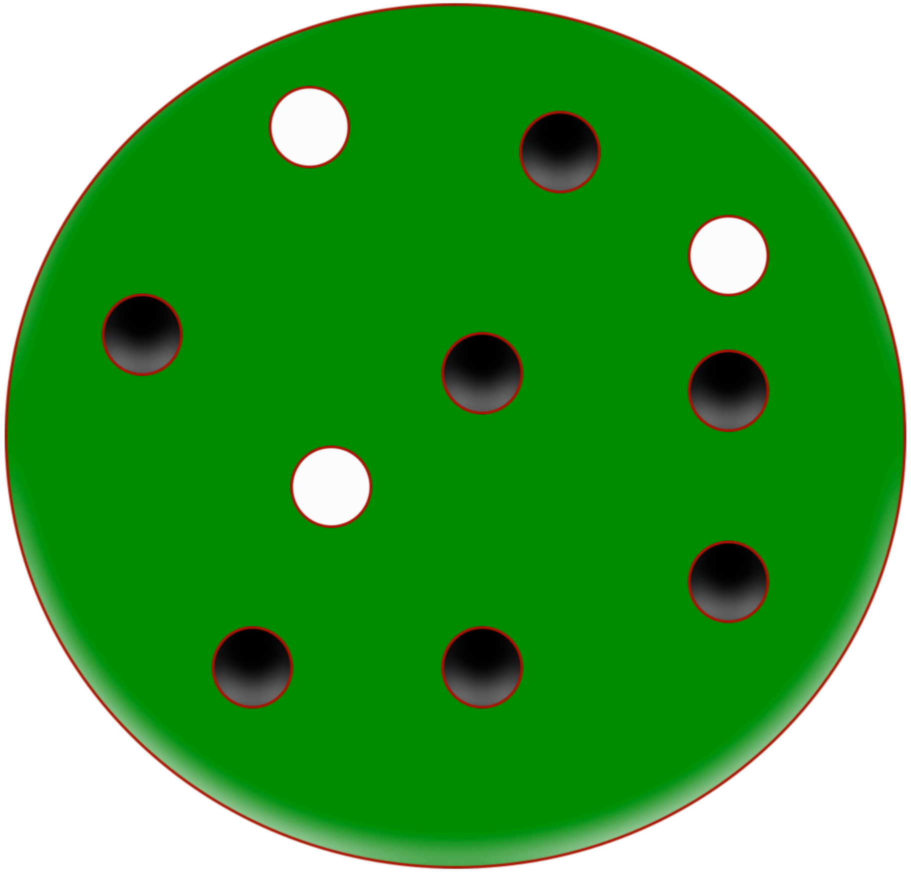
Black daisies like it cool

White daisies like the heat

At early times the star is faint (like the sun)

Black daisies dominate, albedo is low, and temperature rises.

Daisyworld



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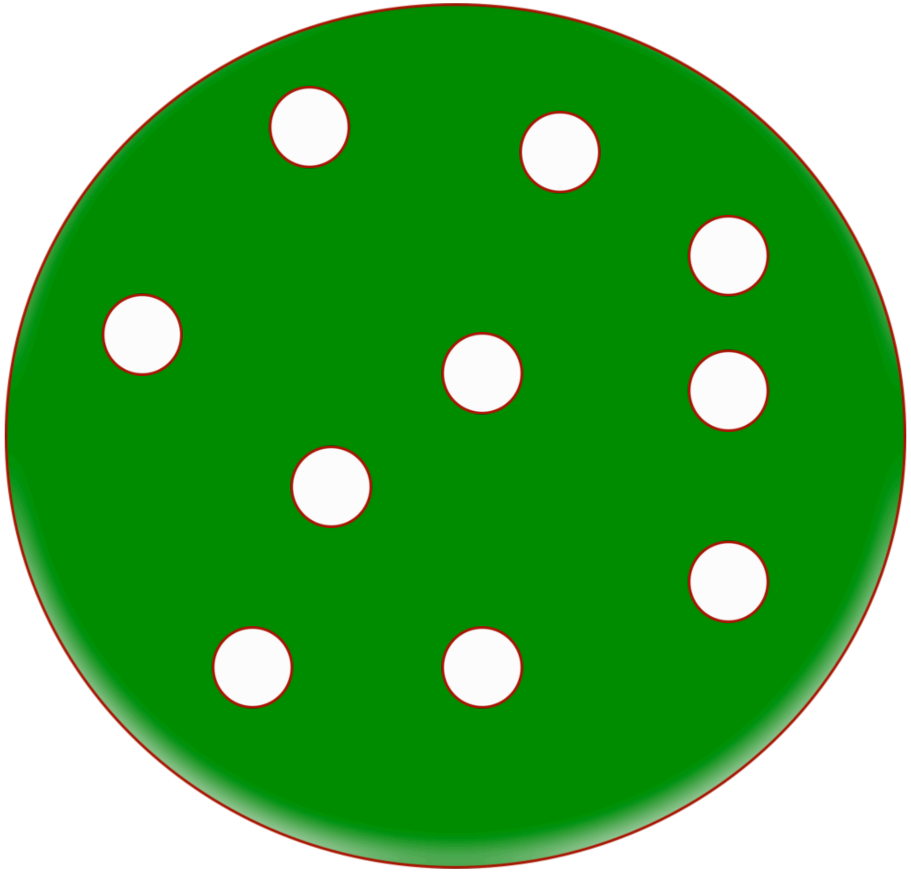
White daisies begin to grow, albedo rises

Daisyworld



Black daisies like it cool

White daisies like the heat

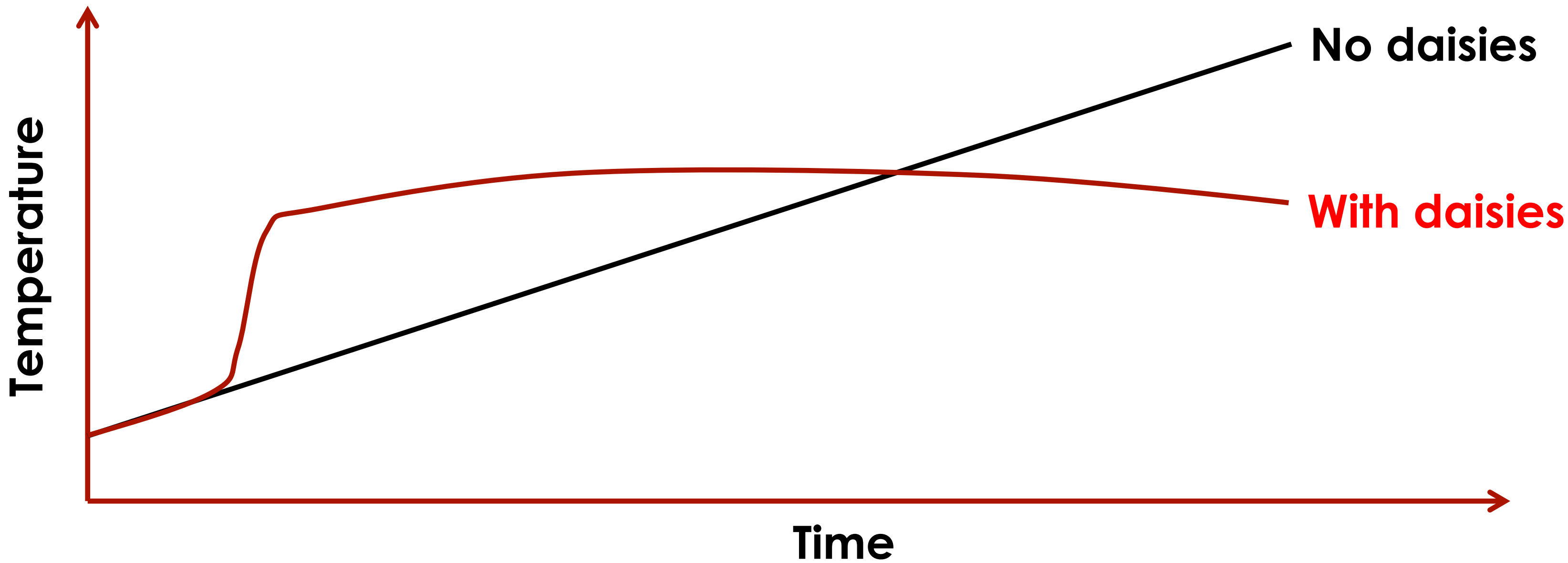
At early times the star is faint (like the sun)

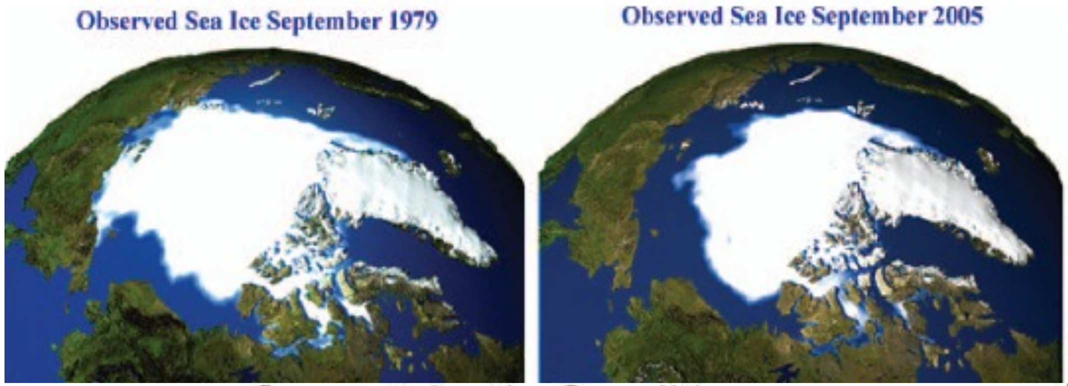
Black daisies dominate, albedo is low, and temperature rises.

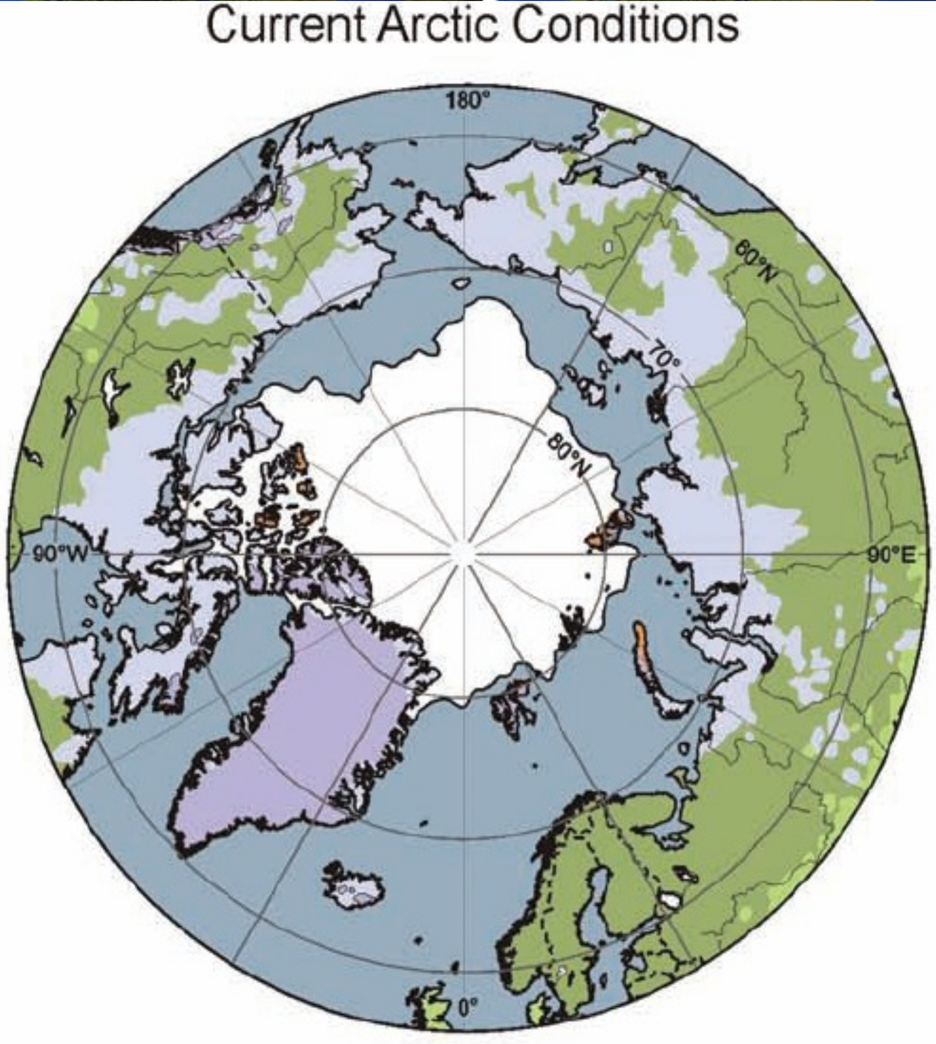
White daisies begin to grow, albedo rises.

As planet gets much hotter, white daisies dominate.

Daisyworld







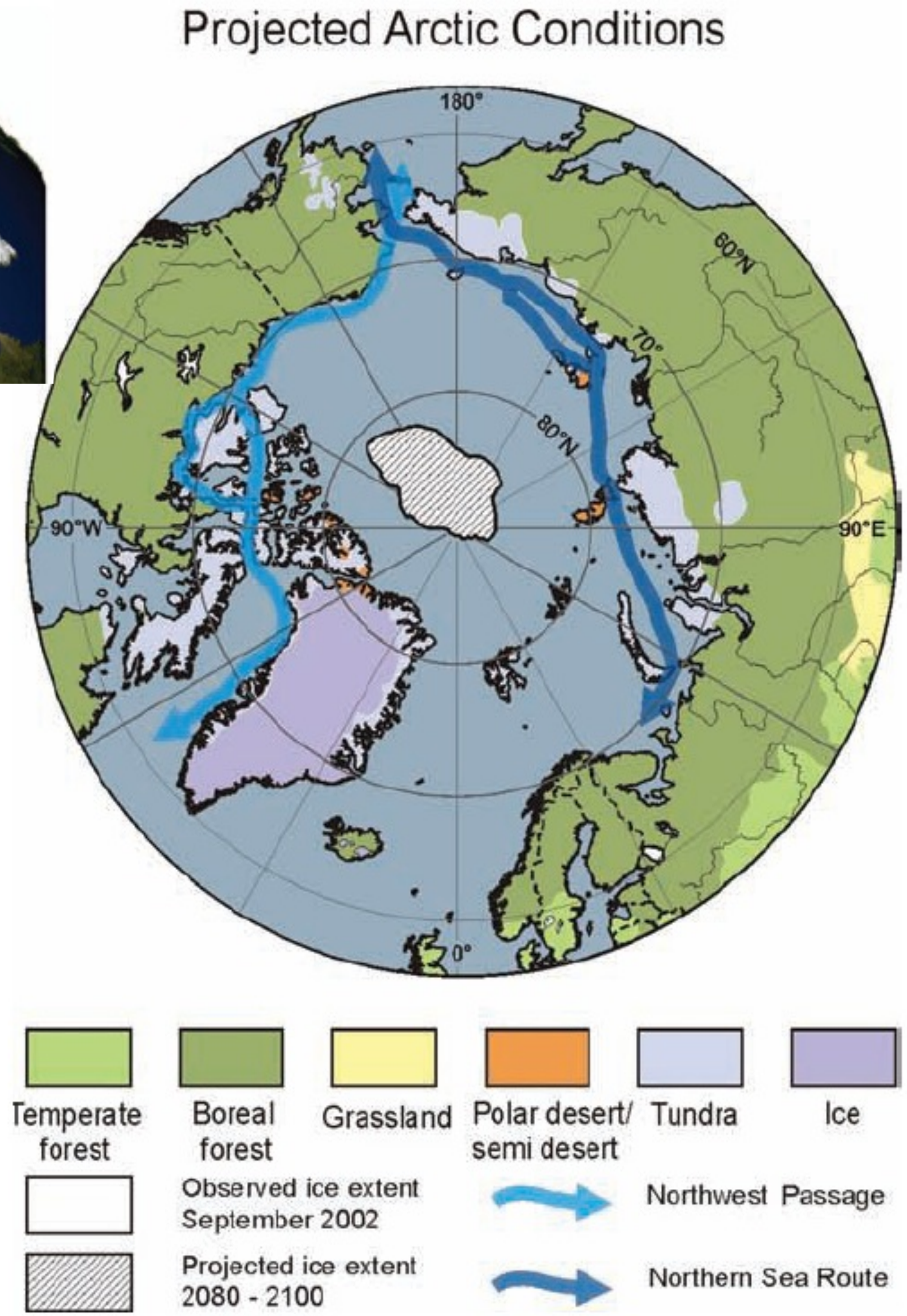
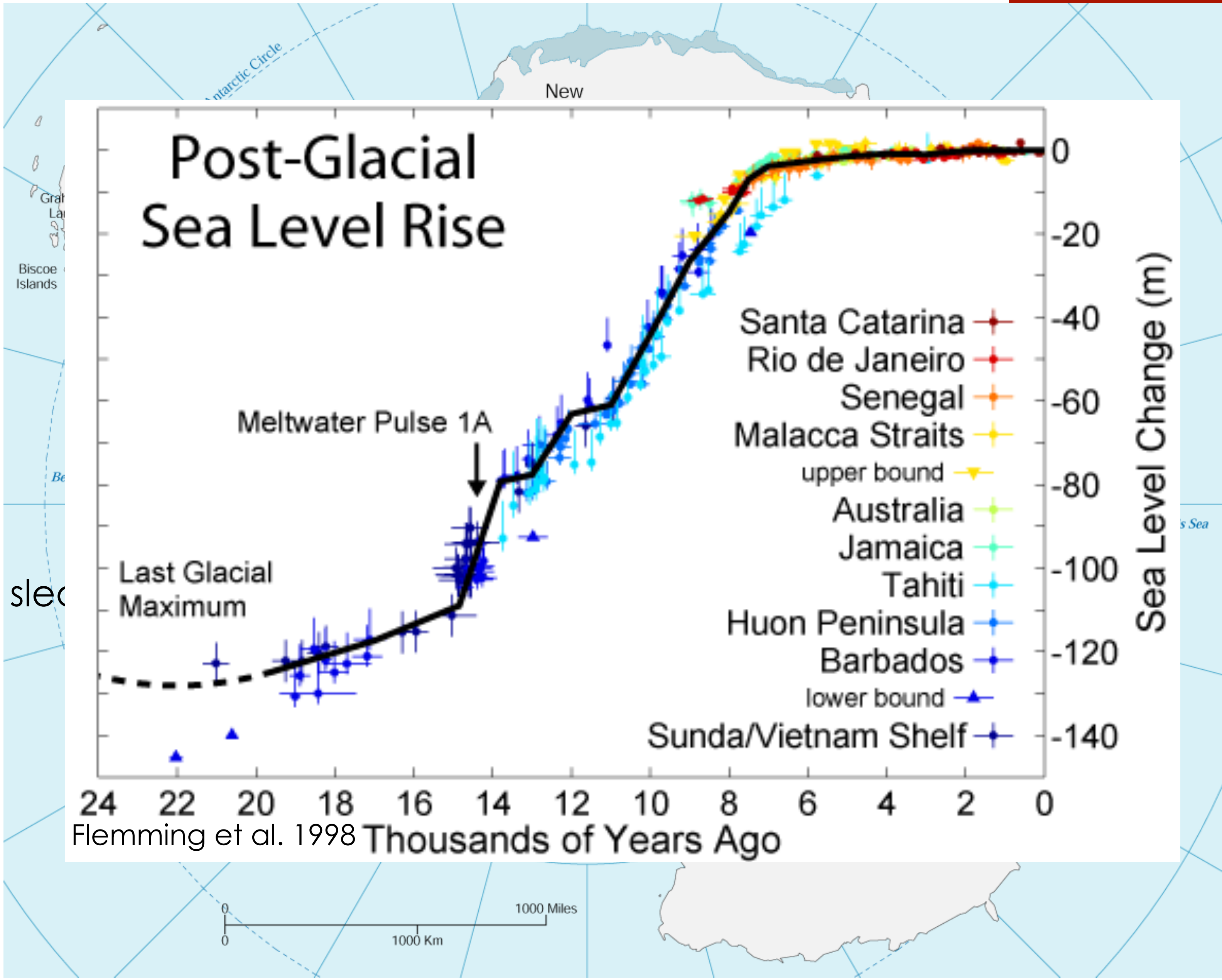


Figure TS.16. *Vegetation of the Arctic and neighbouring regions. Top: present-day, based on floristic surveys. Bottom: modelled for 2090-2100 under the IS92a emissions scenario. [F15.2]*

Ca 6m sle



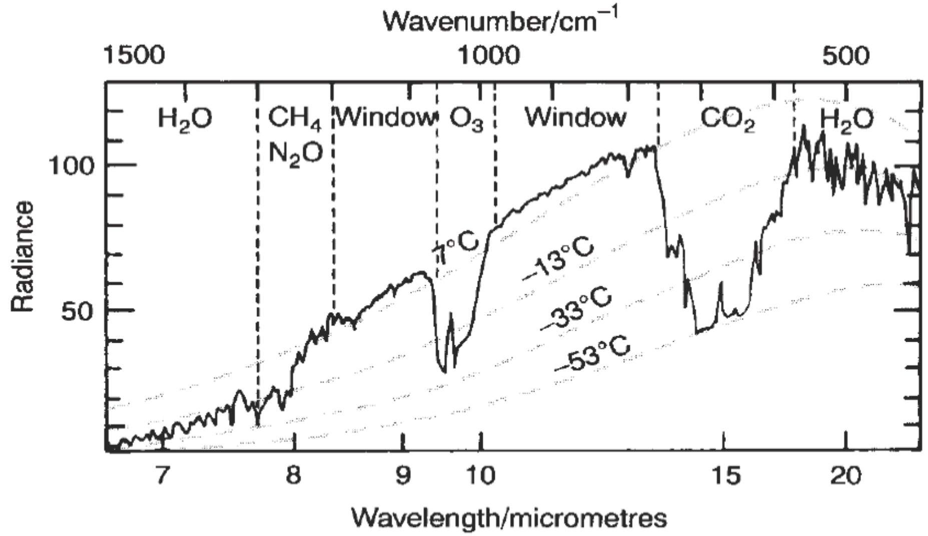
Flemming et al. 1998

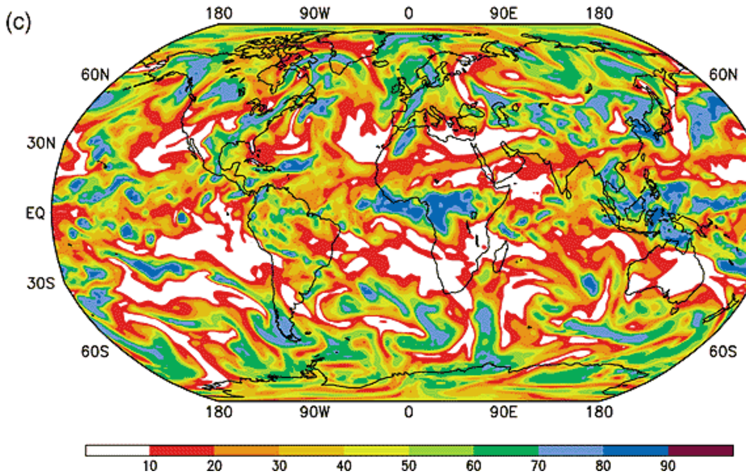
Water Vapour Feedback

Water vapour is dominant greenhouse gas

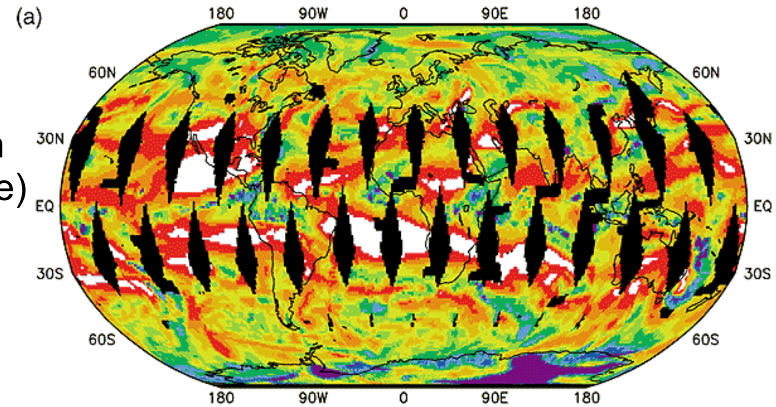
Increased water vapour increases absorption in IR

Causes additional increases in temperature





Water saturation (mid troposphere)
<-Simulation
Observed->

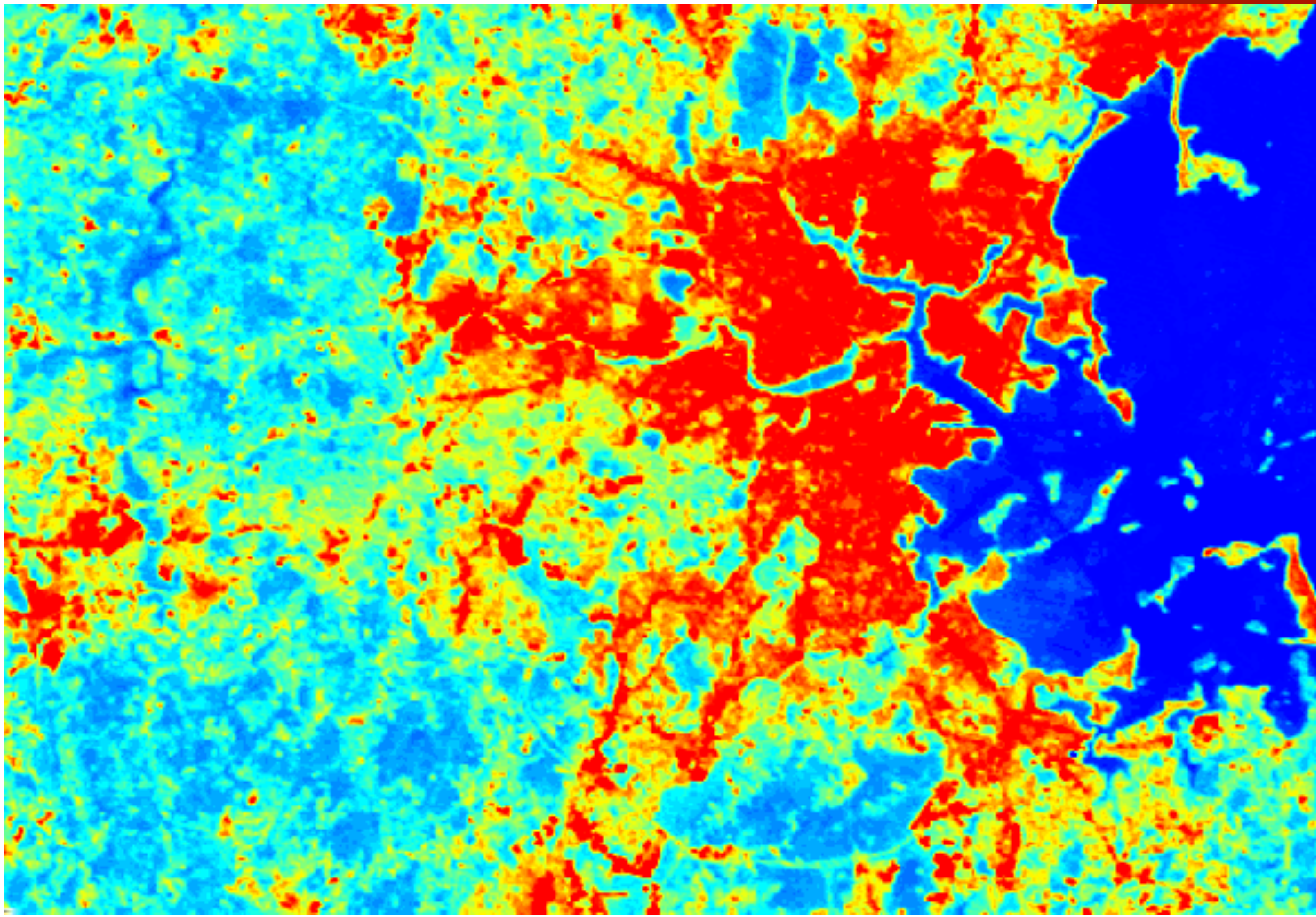


Clouds?

- Complex and controversial
  - Clouds are white, they reflect sunlight (negative feedback)
  - Clouds have high humidity, so lots of water vapour (positive feedback)

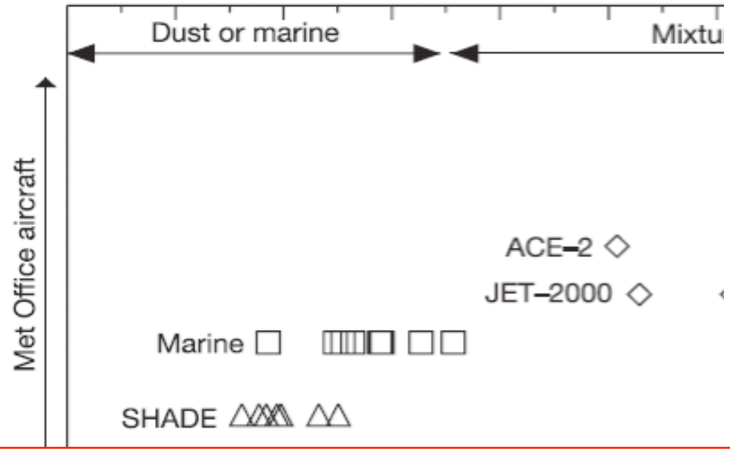
- Probably a negative feedback, but level of scientific understanding still poor (but improving, see IPCC AR5).

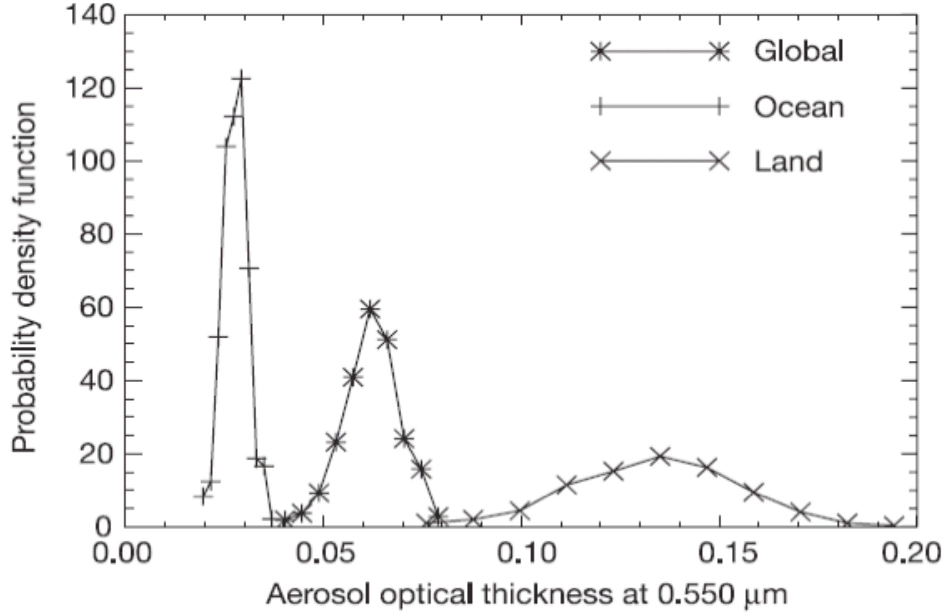
Land Use



Aerosol direct forcing

Nature **438,** 1138 (Dec 2005)





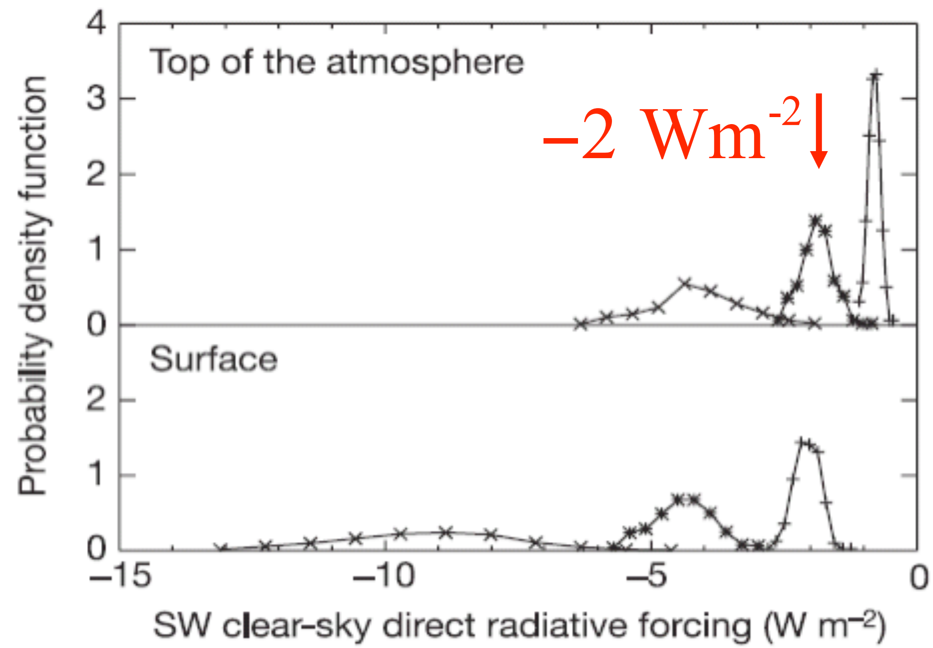
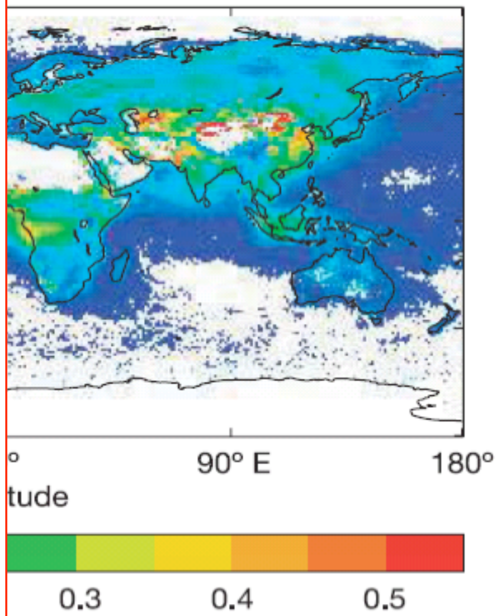


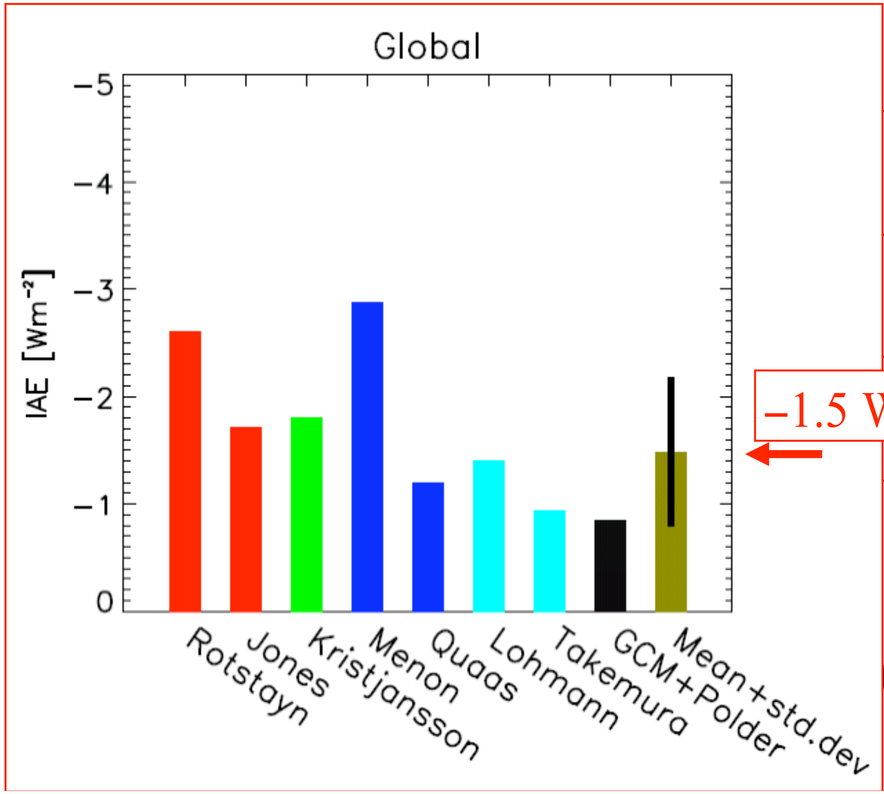
Figure 3 | PDFs of the clear-sky shortwave aerosol DRF on an annual, global average. Symbols are as used in Fig. 2a.



m. **a**, PDFs of the annual, global
Distribution for the year 2002. This

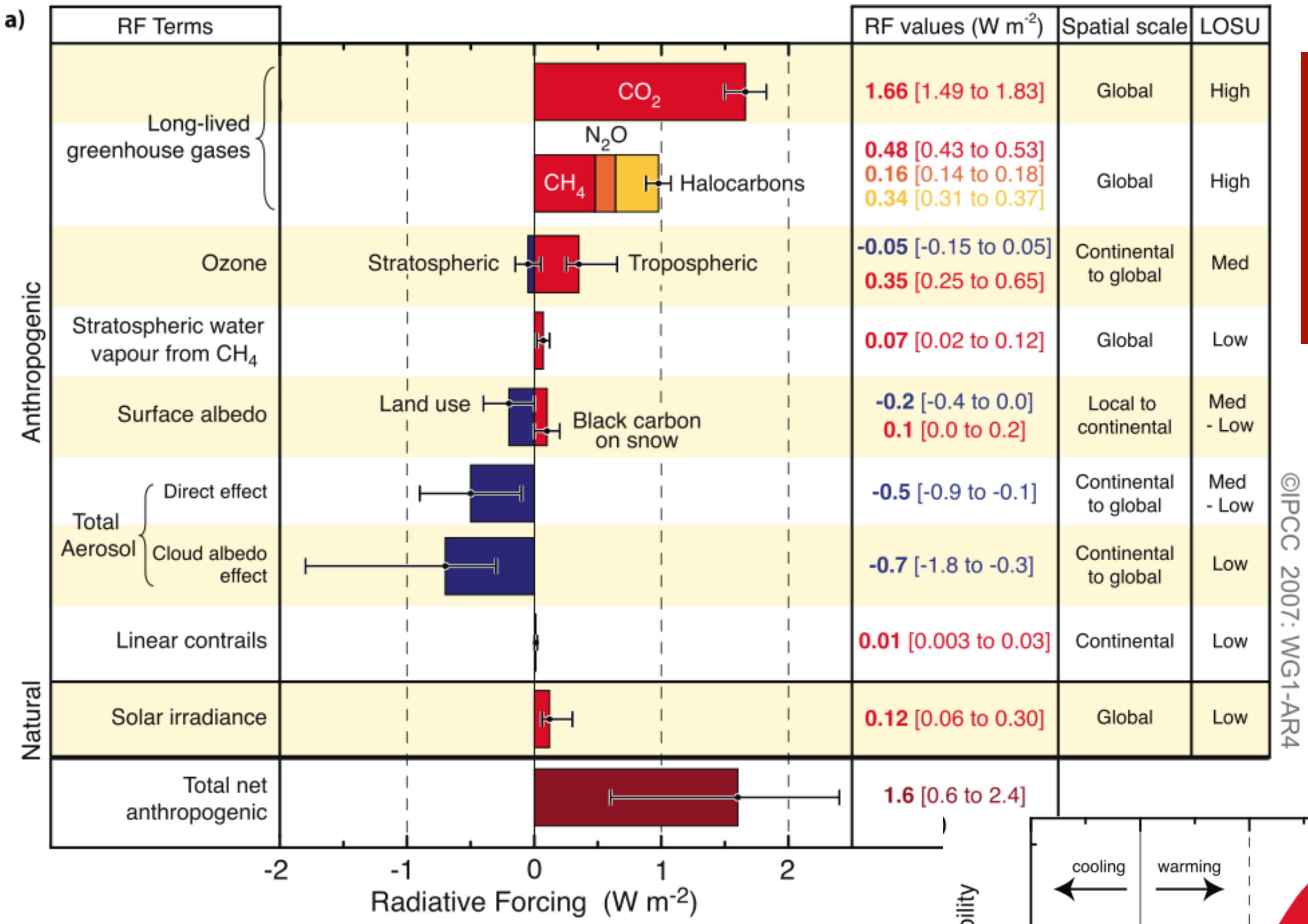
Aerosol indirect forcing effect

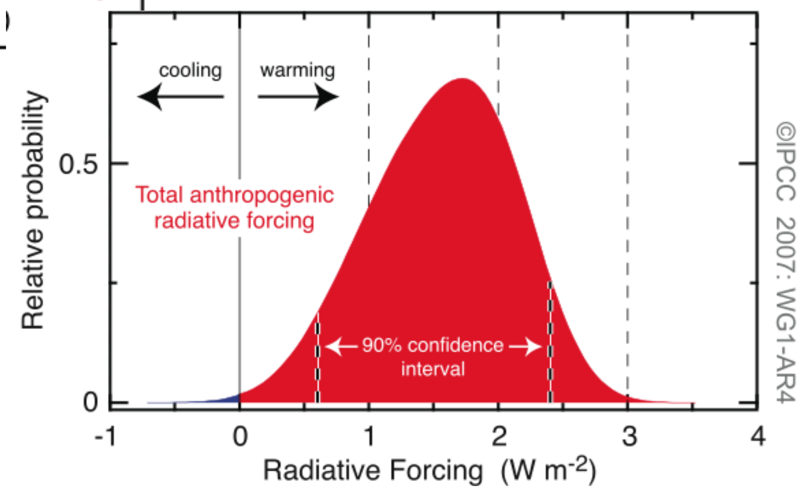
Effect	Cloud type	Description	F_{TOA}	F_{SFC}
Indirect aerosol effect for clouds with fixed water amounts (cloud albedo or Twomey effect)	All clouds	The more numerous smaller cloud particles reflect more solar radiation	−0.5 to −1.9	similar to F_{TOA}
Indirect aerosol effect with varying water amounts (cloud lifetime effect)	All clouds	Smaller cloud particles decrease the precipitation efficiency thereby prolonging cloud lifetime	−0.3 to −1.4	similar to F_{TOA}
Semi-direct effect	All clouds	Absorption of solar radiation by soot may cause evaporation of cloud particles	+0.1 to −0.5	larger than F_{TOA}
		Smaller cloud droplets delay the onset of freezing	?	?
		More ice nuclei increase the precipitation efficiency	?	?
		aller cloud droplets decrease the riming efficiency	?	?
		Increased aerosol and cloud optical thickness decrease the net surface solar radiation	n/a	−1.8 to −4



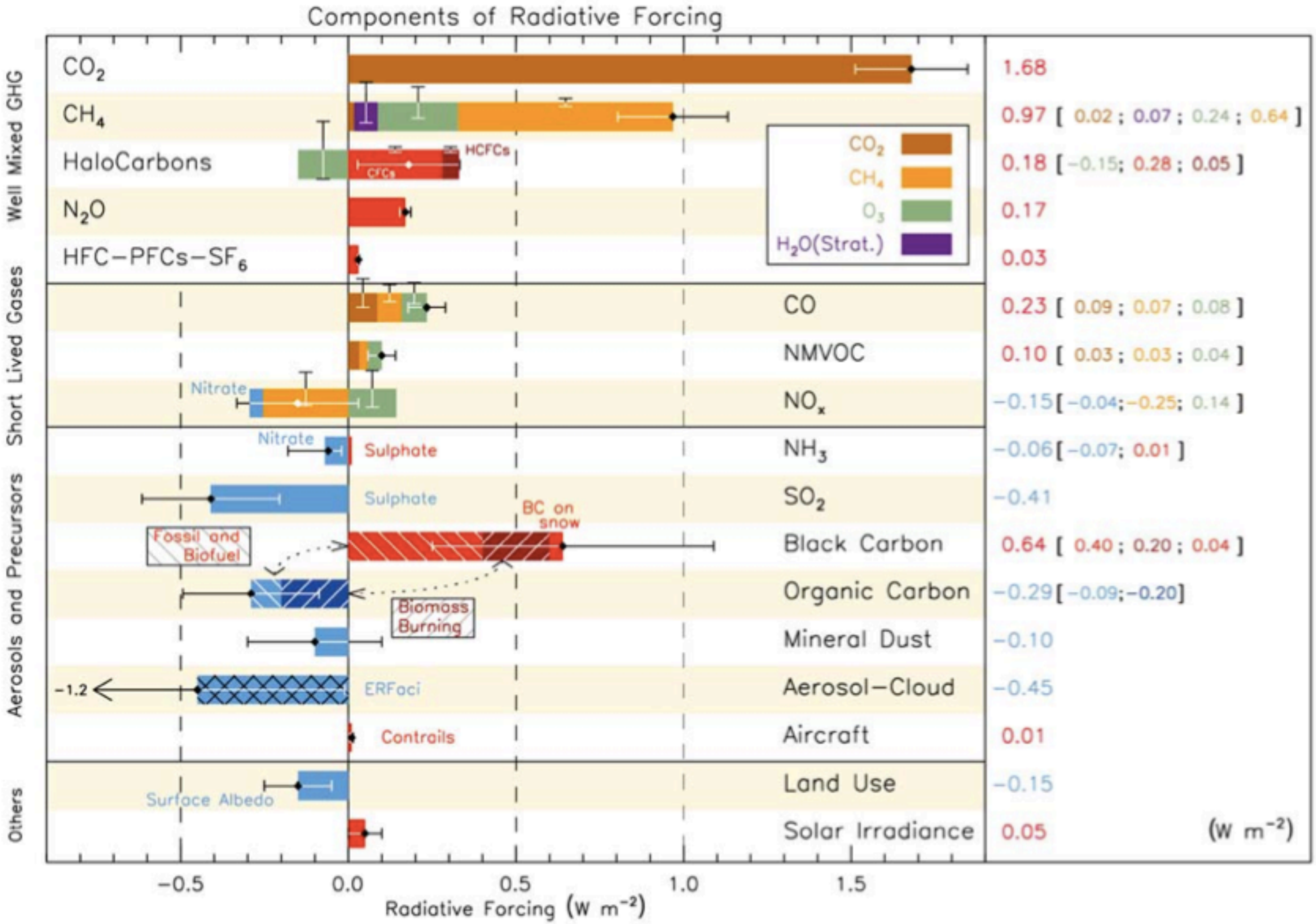
review

Atmos. Chem. Phys., 5, 715–737, 2005
www.atmos-chem-phys.org/acp/5/715/





Radiative Forcings
IPCC AR4 2007



IPCC AR5 2013

"Real" Climate Sensitivity

$$G_0 = \frac{\delta T}{\delta F} = 0.27^\circ\ \mathrm{C\ W^{-1}\ m^2}$$

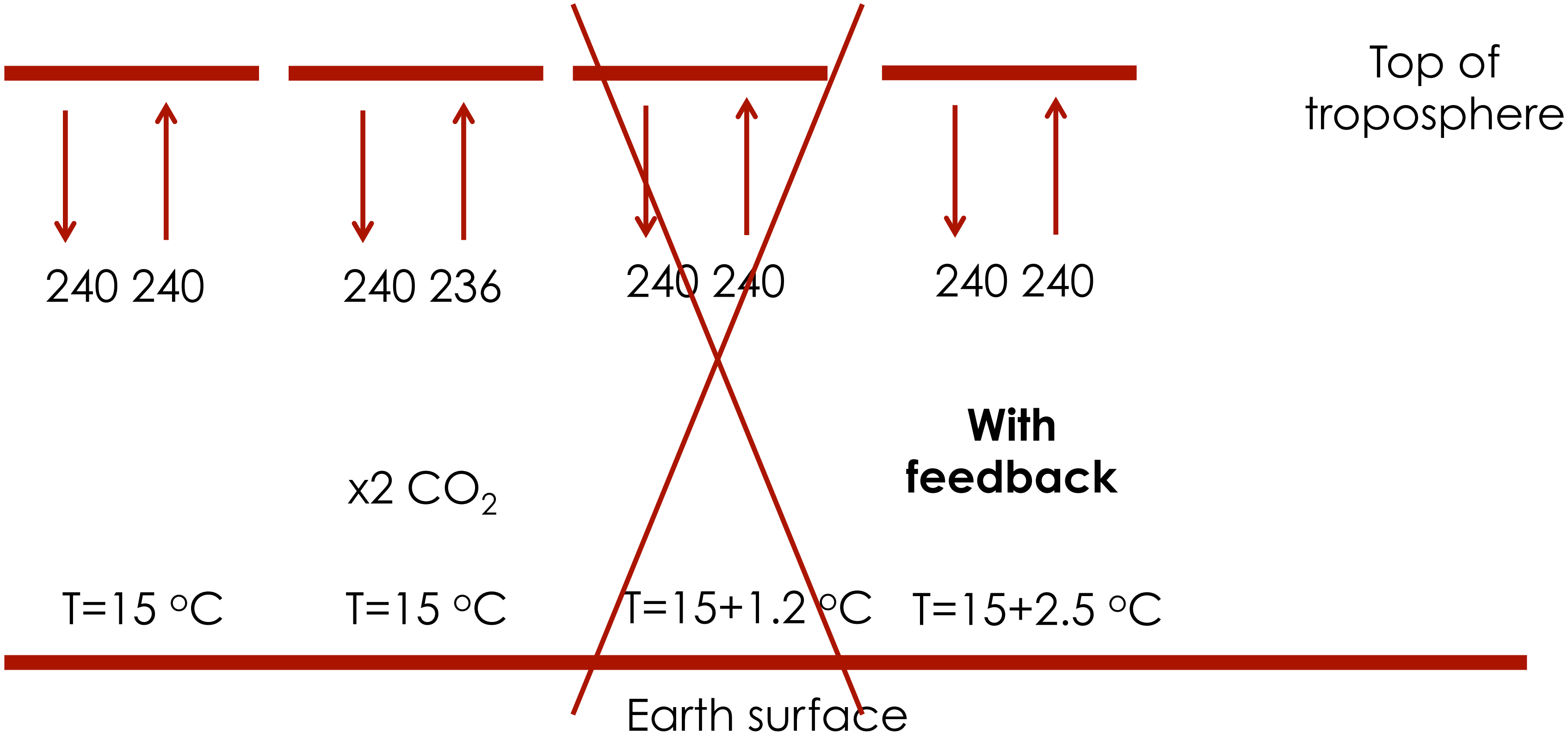
No feedback

$$G_0 = \frac{\delta T}{\delta F} = 0.60^\circ\ \mathrm{C\ W^{-1}\ m^2}$$

With feedback

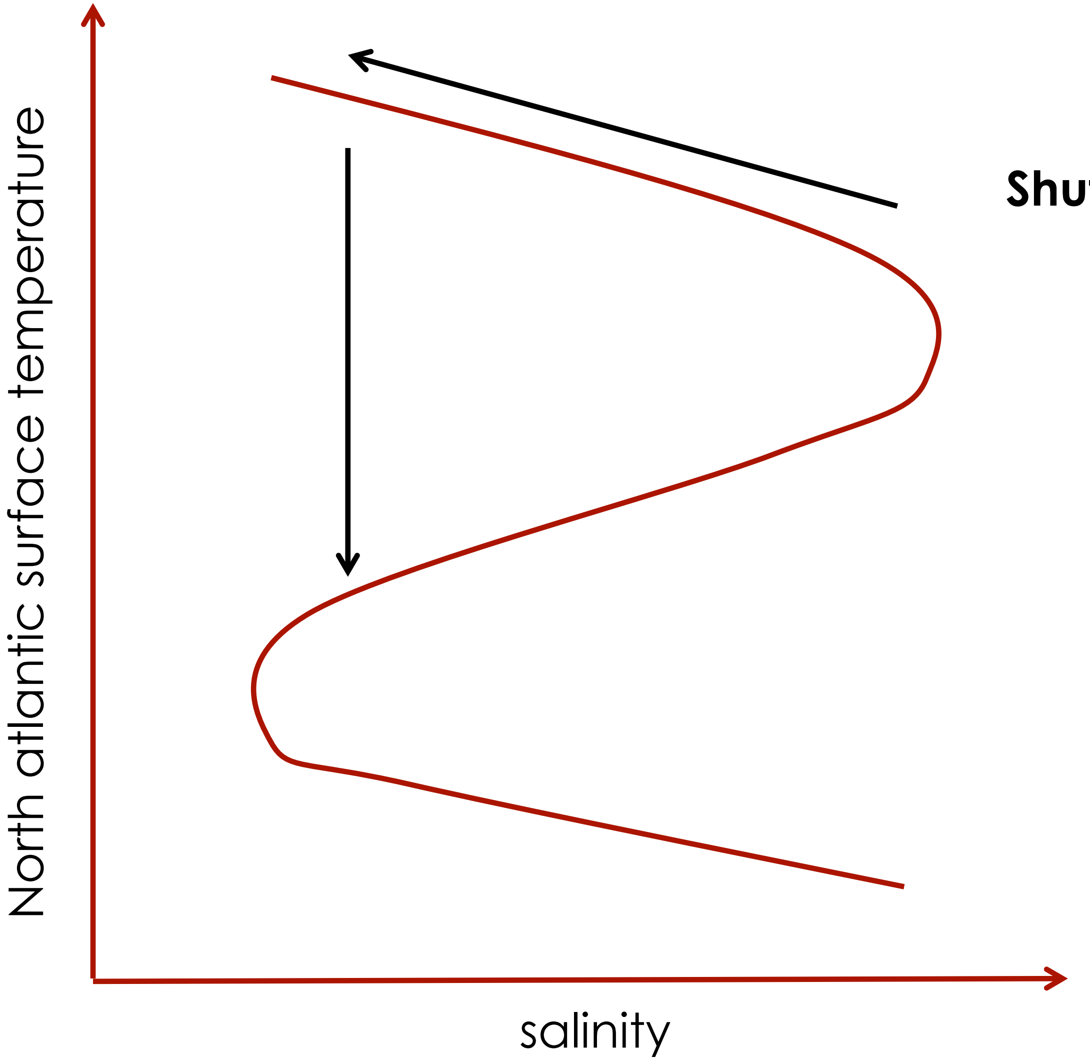
Radiative forcing

- Imbalance in incoming and outgoing radiation



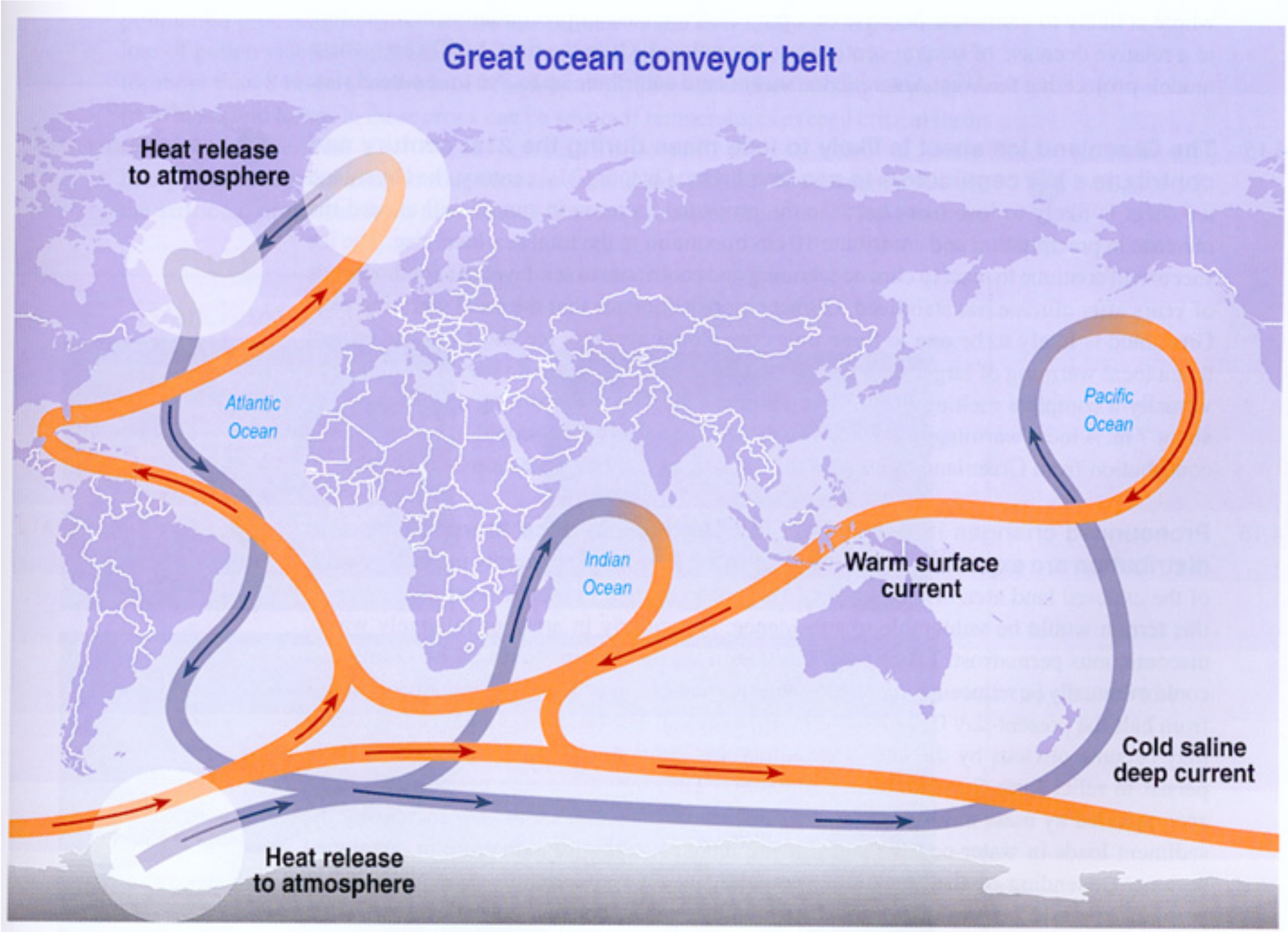
Pre-industrial CO_2 = 280 ppm, now = 400 ppm

The scary stuff – non-linear feedback



Shutting down of the North Atlantic Thermohaline circulation

Ocean Circulations



Heat sink, CO_2 sink – but not impact free (see next week)

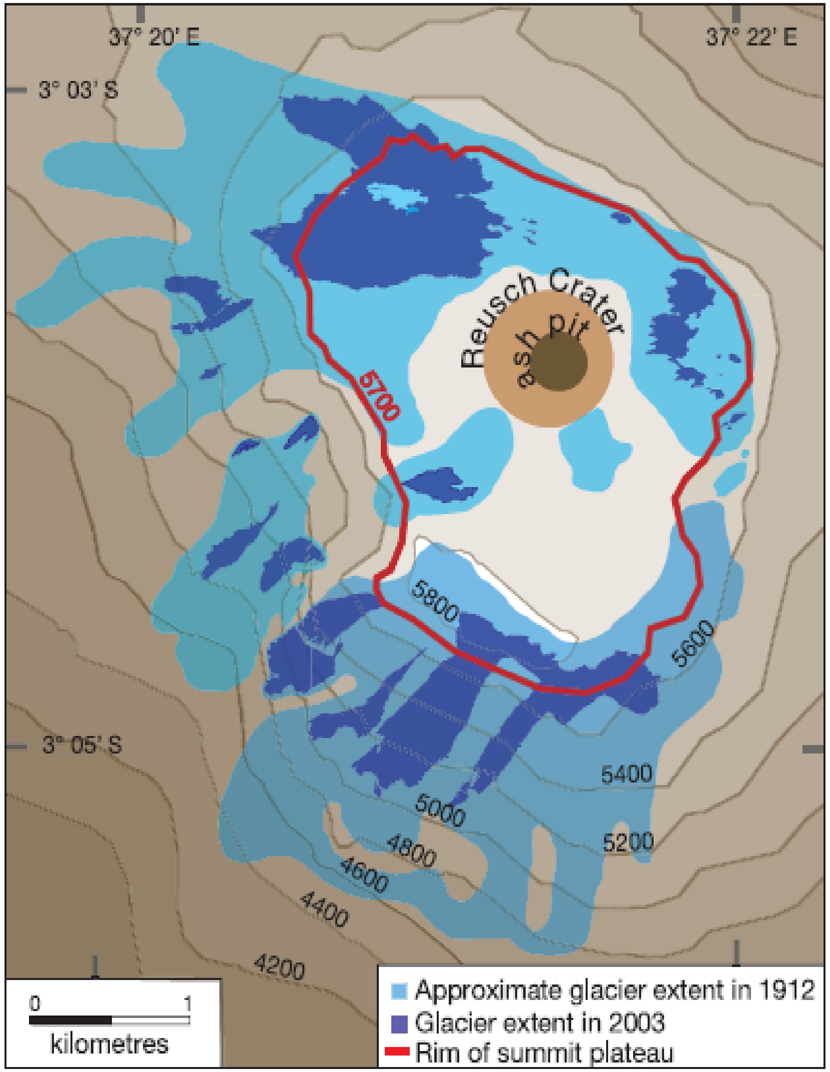
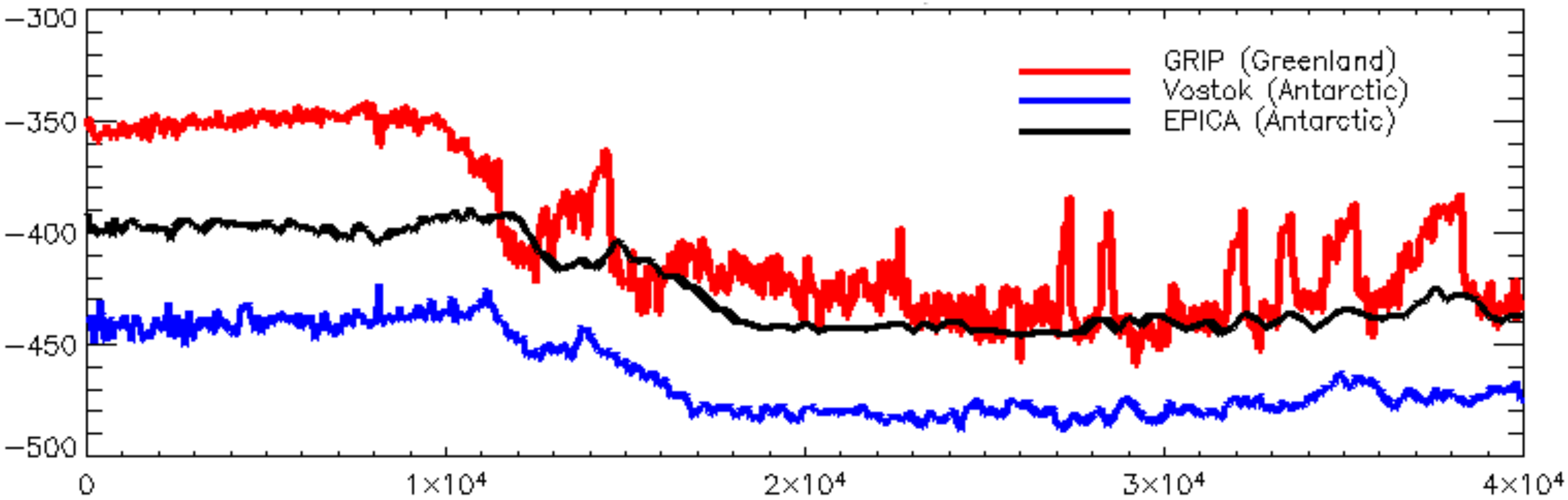


Figure TS.10. *Changes in the Mt. Kilimanjaro ice cap and snow cover over time. Decrease in surface area of Kilimanjaro glaciers from 1912 to 2003. [F9.2]*

Figure TS.11. *Projected future changes in the northern Asia permafrost boundary under the SRES A2 scenario for 2100. [F10.5]*

The younger dryas



Avoiding “non-linear” events

- The risk of irreversible change increases with temperature rises
  - Vulnerability of ice sheets increases
  - Larger degree of permafrost melting
  - Breakdown of biomass in rainforests
- Smaller rises minimize this risk, 2 degrees is thought to be reasonable (450 ppm CO_2) but there is still much uncertainty (week 4).

Conclusions

- Detailed measurements enable the degree of imbalance between incoming and outgoing radiation from various physical processes to be calculated as a ***radiative forcing***
- Anthropogenic changes are amplified by feedbacks, which makes climate ***twice as sensitive*** to changes as might otherwise be expected.
- Potential for major, *and* ***irreversible*** (on the short term) changes exist.

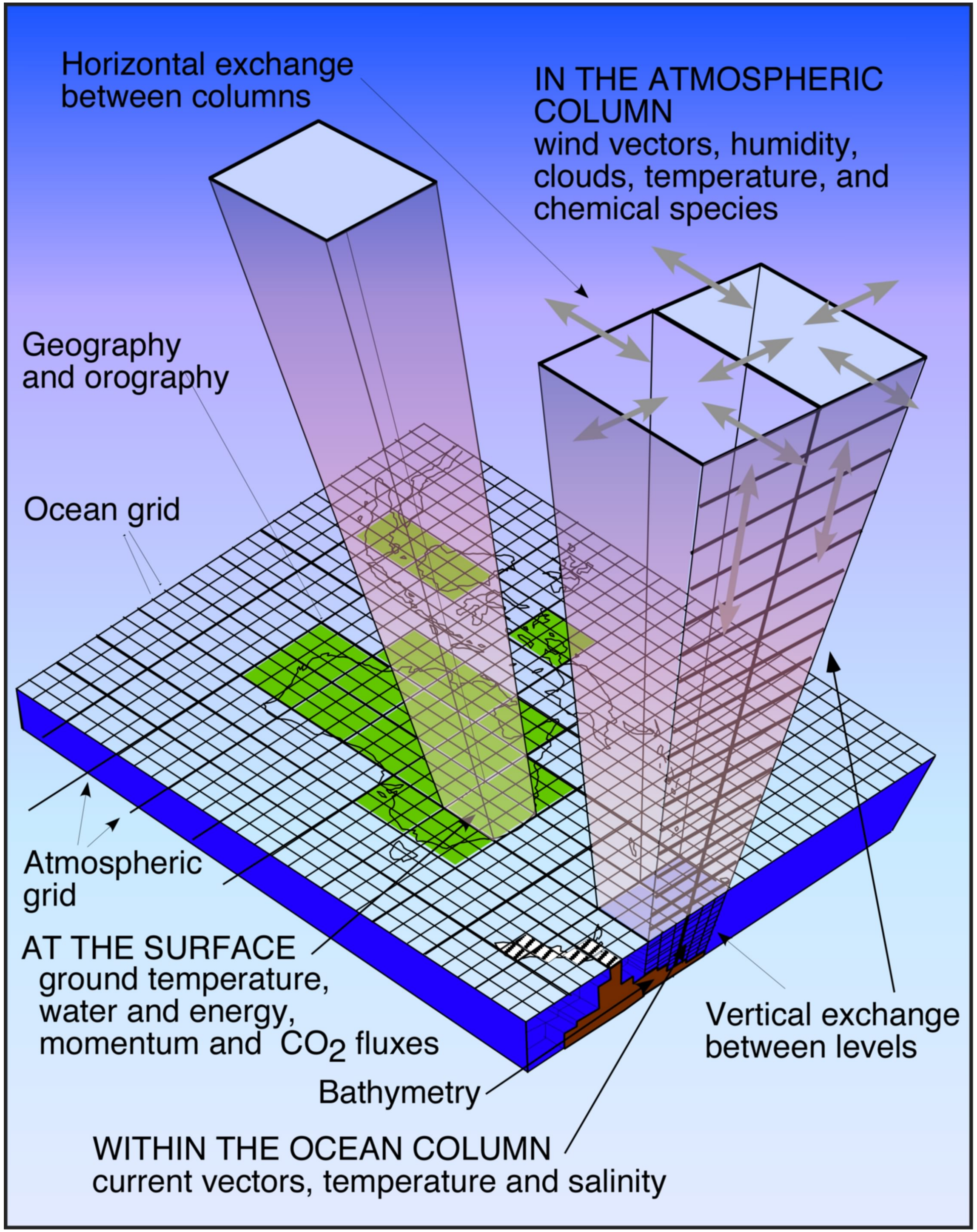
The challenges of climate change

Lecture 4 – Modeling the Climate

Weather is not climate

Ocean Atmosphere General Circulation Models (OAGCM)

AIM: **To enable projections of future climate**



What's in a model

- Basic physics
- Conservation laws
- Equations of state

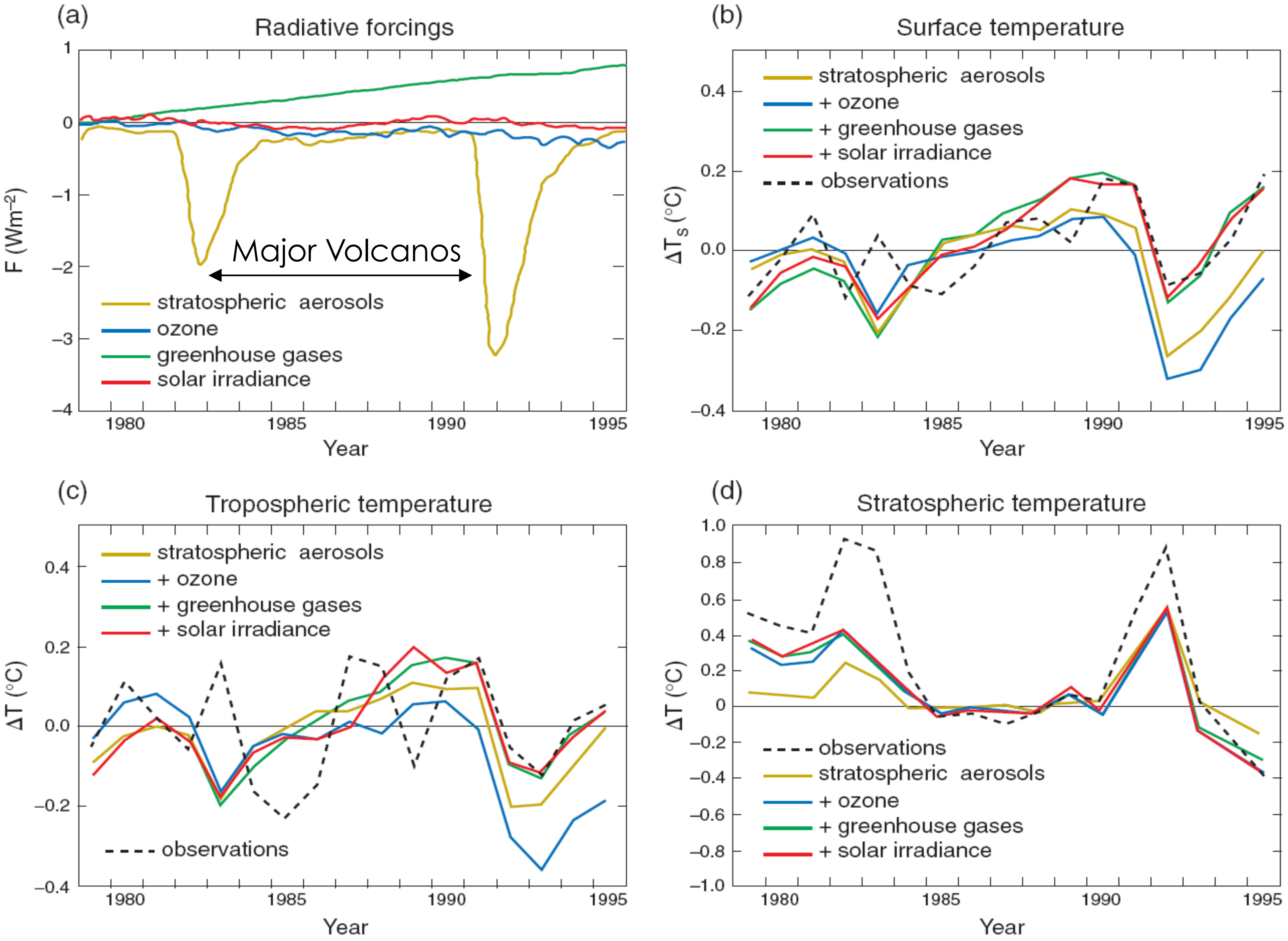
Ab initio

- Transport of energy via convection/radiation
- Moist processes (evaporation/condensation etc)

Parameterization

- Geography/resolution

State of art ca 1997



-> Major volcanic eruptions are a visible and predictable perturbation on the climate.

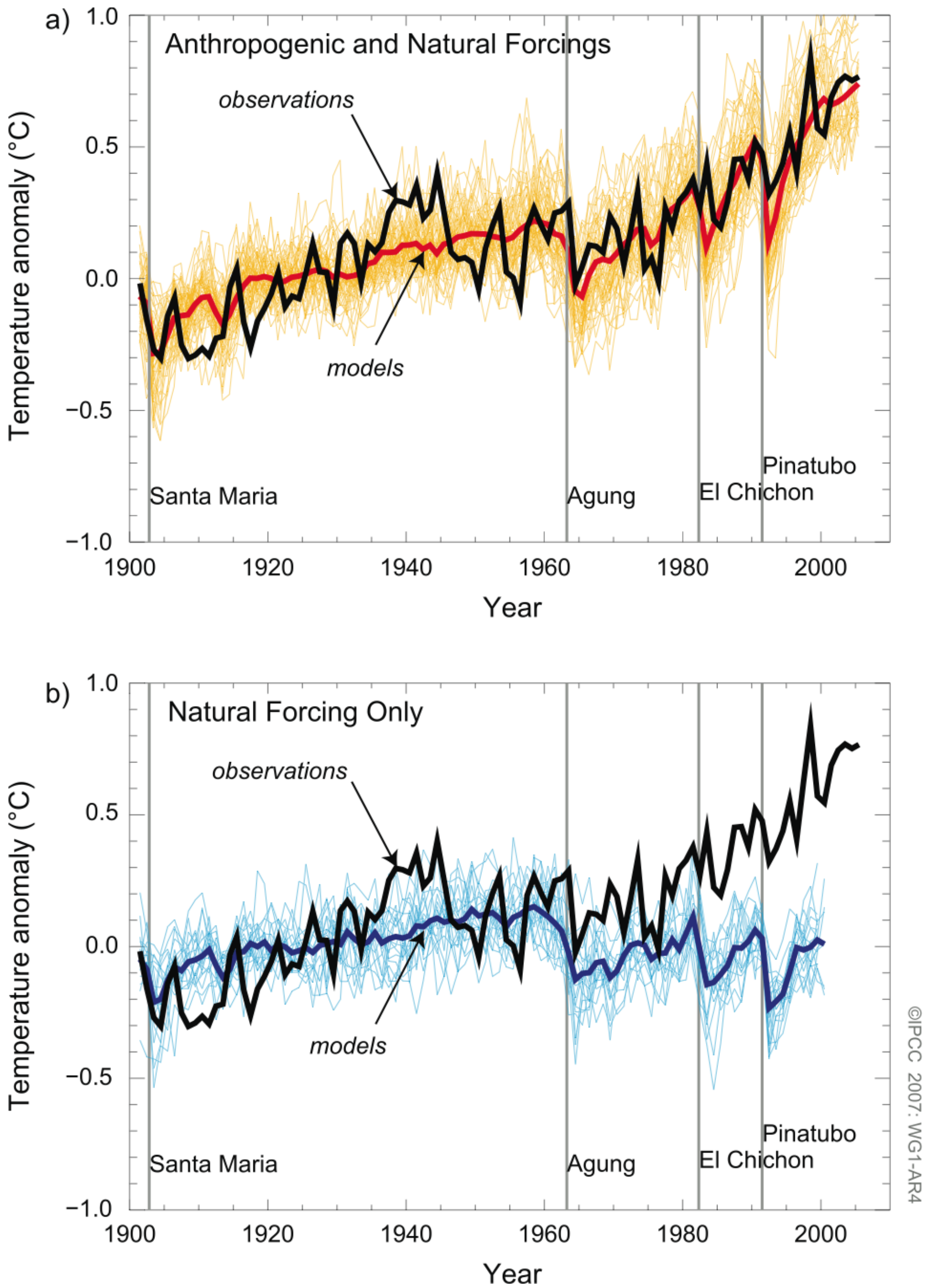
Climate

Weather

Seasonal and climate configurations of the Unified Modelling system				
Configuration	Atmosphere Resolution	Ocean Resolution	Initial Conditions	Typical Run Length
Seasonal	38 levels to 40 km 1.875° x 1.25° ~140 km at mid-latitudes	42 levels 1.0° x 1.0°	Atmos: Met Office global analyses Ocean: data assimilation based on FOAM Sea ice: present-day conditions taken from previous climate model 20th century simulation	40-member ensembles of ~7 month runs, updated monthly
Decadal	19 levels to 40 km 3.75° x 2.5° ~280 km at mid-latitudes	20 levels 1.25° x 1.25°	Atmos: ECMWF global analyses Ocean: data assimilation of observed anomalies	10-member ensembles of ~10 year runs, updated annually
Centennial	38 levels to 40 km 1.875° x 1.25° ~140 km at mid-latitudes	40 levels 1.0° x (1.0° increasing smoothly from 30°N/S to 0.33° at equator)	Atmos: Met Office global analyses representative of current climate Ocean: Levitus present-day observed ocean conditions Sea ice: present-day conditions taken from previous climate model 20th century simulation	~100s years
Earth System	38 levels to 40 km 1.875° x 1.25° ~140 km at mid-latitudes	40 levels 1.0° x (1.0° increasing smoothly from 30°N/S to 0.33° at equator)	Atmos: Met Office global analyses representative of current climate Ocean: Levitus present-day observed ocean conditions Sea ice: present-day conditions taken from previous climate model 20th century simulation	~100s years
Regional climate	19 levels 0.22° x 0.22° (~24km) to 0.44° x 0.44° (~50km) limited area	-	Met Office global analyses; ECMWF reanalyses used at lateral boundaries	~10 years, or up to 150 years for climate change runs

Model	Grid length in mid-latitudes	Grid points	Vertical levels	Forecast length	Run times (UTC)	Initial conditions
Global	25 km	1024 x 769	70 (lid ~80 km)	144 hrs (for 00z and 12z)	00, 06, 12, 18	Incremental 4D-Var
North Atlantic European (NAE)	12 km	600 x 360	70 (lid ~80 km)	48 hrs	00, 06, 12, 18	Incremental 4D-Var
UK4	4 km	288 x 360	70 (lid ~40 km)	36 hrs	03, 09, 15, 21	Incremental 3D-Var
UKV	1.5 km inner 4 km outer	744x928	70 (lid ~40 km)	36 hrs	03, 09, 15, 21	Incremental 3D-Var
MOGREPS Global ensemble	60 km	432 x 325	70 (lid ~80 km)	72 hrs	00, 12	Global analysis + 24 member ETKF perturbations
MOGREPS Regional ensemble	18km	400 x 240	70 (lid ~80km)	54 hrs	06, 18	NAE analysis + 24 member perturbations interpolated from global ensemble

IPC 2007



"Warming of the climate is unequivocal", "It is extremely likely that human influence has been the dominant cause of the observed warming"

IPCC 2013

"Greenhouse gas forcing has very likely [90%] caused most of the observed global warming over the last 50 years."

IPCC 2007

….likely [67%]..
IPCC 2001

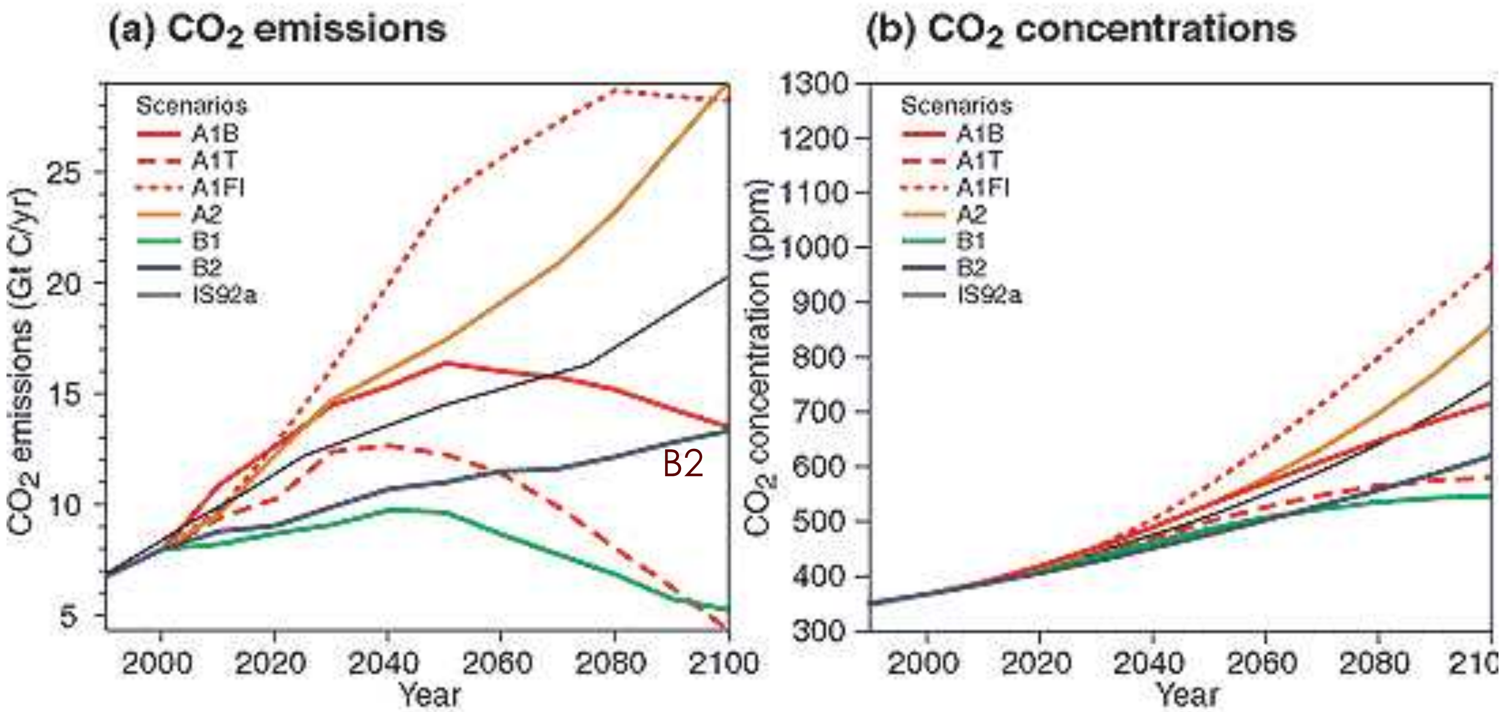
Inevitable Problems of projection

- Even with a perfect model:
  - Anthropogenic changes in future climate depend on human activity – need different scenarios (SRES)
  - Some natural variations (e.g. volcanoes) are unpredicatable, so can't be easily folded in.

Potentially soluble problems with projection

- Garbage in = Garbage out (GIGO)
- Real world is complex
  - Geography
  - Ocean cycles (El Nino etc)
- Real physics is complicated and not all well understood.
  - Water
  - Radiative transfer

Special Report on Emissions Scenarios

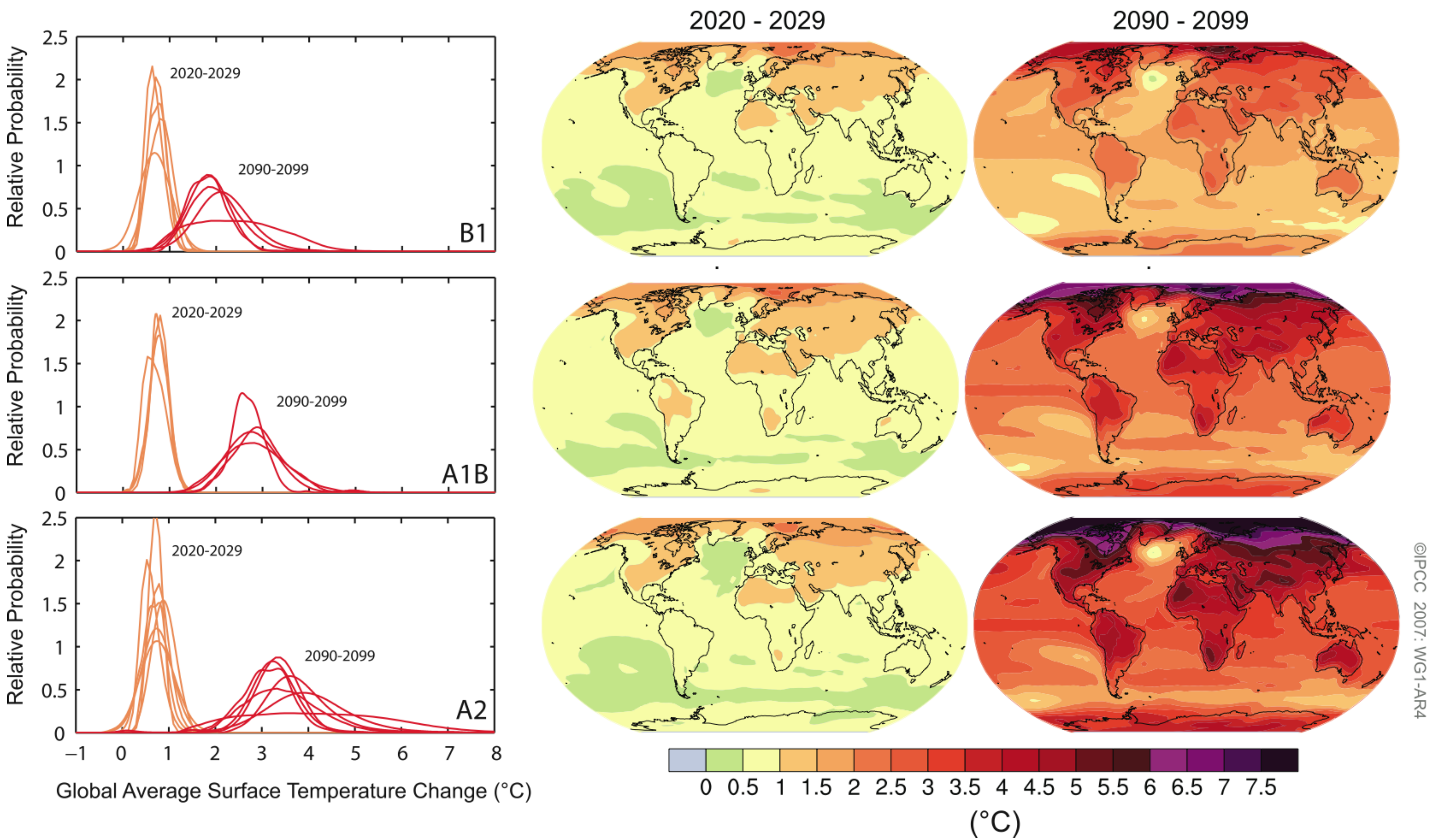


1. Population peaks mid century.
   A1: technology-led economy,
   F fossil fuels vs (B "balanced") vs T non-fossil fuelled.

   B1: info & service economy; sustainability & global sol'ns.

2. Population continues to increase.
   A2: very heterogeneous world ("business as usual")
   B2: lower growth rate; emphasis on local solutions (smart but *laissez-faire*)

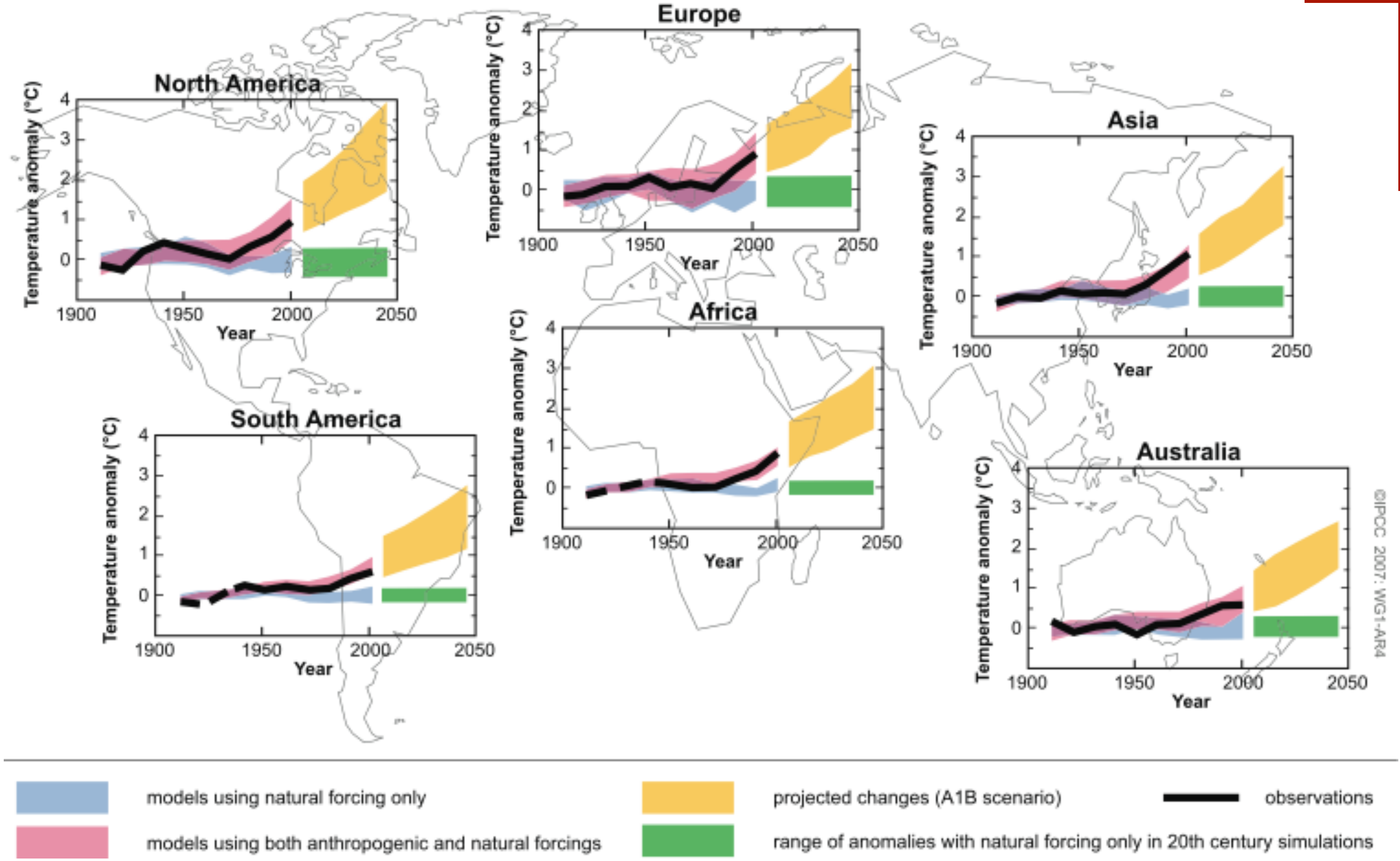
not predictions, but a range of plausible assumptions



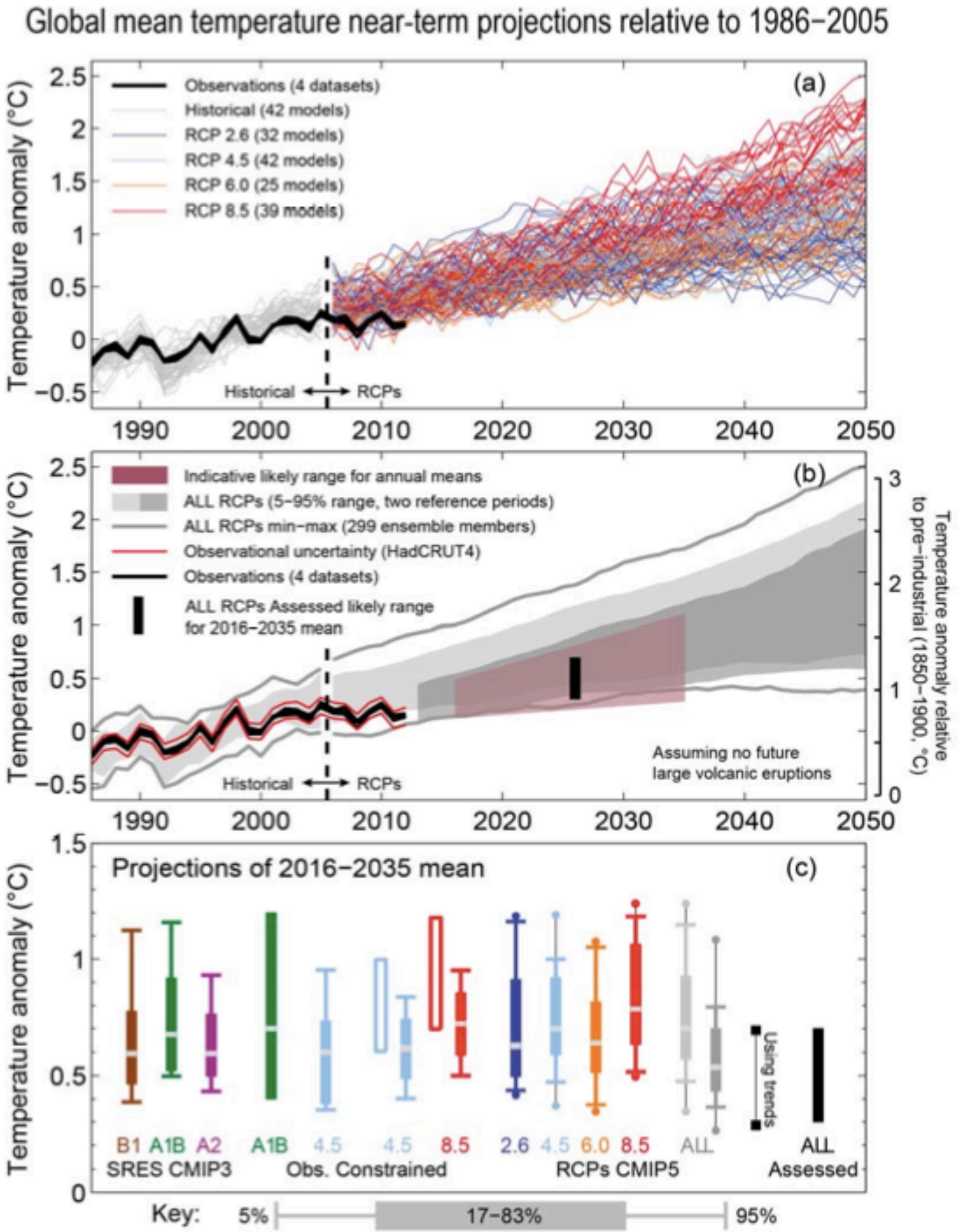
IPCC 2007: Scenario -> OAGCM -> Climate prediction

Phenomenon[a] and direction of trend	Likelihood that trend occurred in late 20th century (typically post-1960)	Likelihood of a human contribution to observed trend	D	Likelihood of future trend based on projections for 21st century using SRES[b] scenarios
Warmer and fewer cold days and nights over most land areas	*Very likely*[c]	*Likely*[e]	*	*Virtually certain*[e]
Warmer and more frequent hot days and nights over most land areas	*Very likely*[d]	*Likely* (nights)[e]	*	*Virtually certain*[e]
Warm spells / heat waves: Frequency increases over most land areas	*Likely*	*More likely than not*		*Very likely*
Heavy precipitation events. Frequency (or proportion of total rainfall from heavy falls) increases over most areas	*Likely*	*More likely than not*		*Very likely*
Area affected by droughts increases	*Likely* in many regions since 1970s	*More likely than not*	*	*Likely*
Intense tropical cyclone activity increases	*Likely* in some regions since 1970	*More likely than not*		*Likely*
Increased incidence of extreme high sea level (excludes tsunamis)[f]	*Likely*	*More likely than not*[g]		*Likely*[h]

IPCC 2007


North America
Europe
Asia
Africa
South America
Australia
Temperature anomaly (°C)
Year
1900
1950
2000
2050
0
1
2
3
4
models using natural forcing only
models using both anthropogenic and natural forcings
projected changes (A1B scenario)
range of anomalies with natural forcing only in 20th century simulations
observations
©IPCC 2007: WG1-AR4

The last 20 years



IPCC 2013

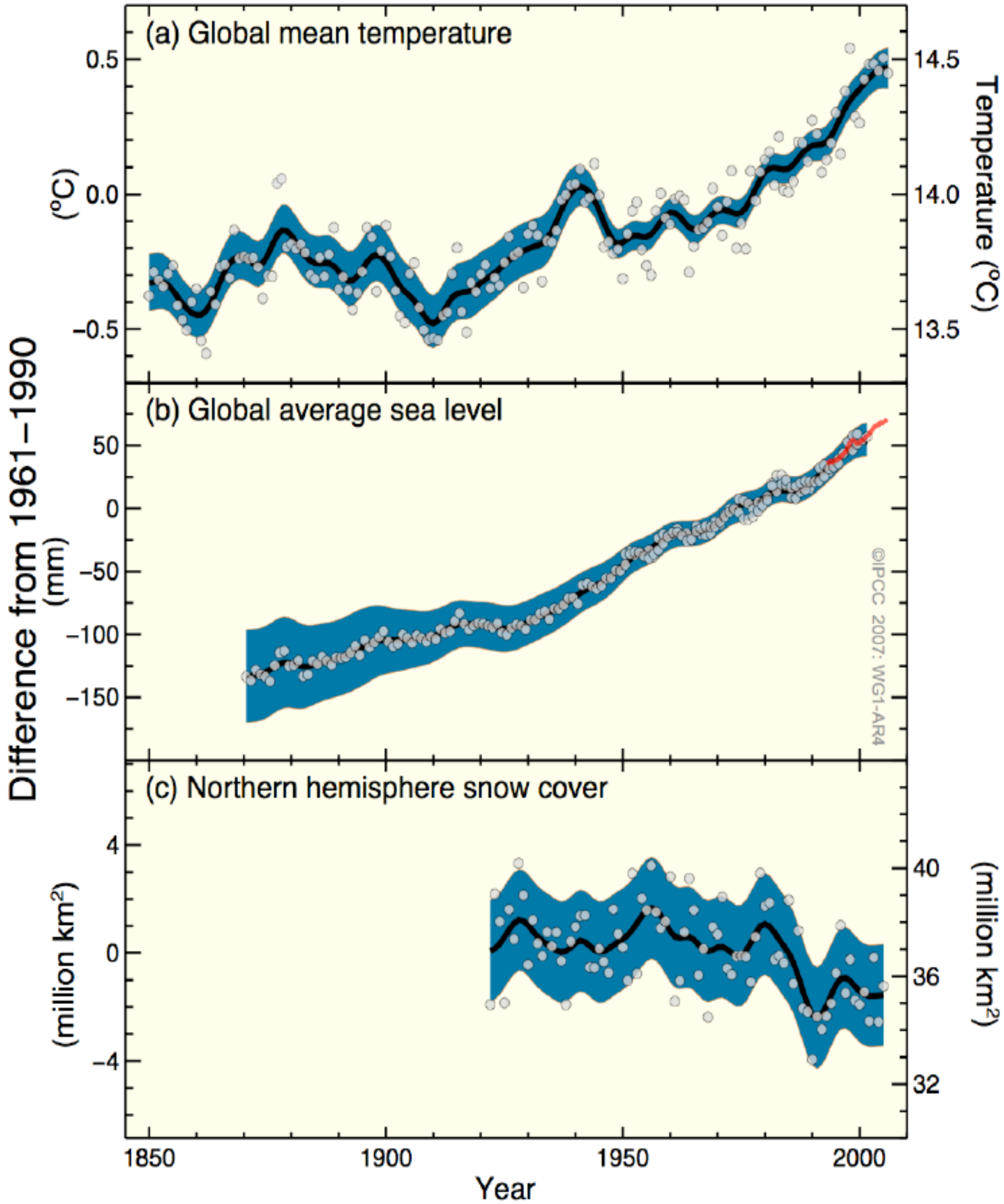
Hallmarks of real warming

- Carbon dioxide and other greenhouse gases can have their radiative forcing directly measured.
- Stratospheric cooling, more heat is being returned to Earth than escapes.
- The re-radiated IR emission has been directly observed.

- Models only re-create recent past temperature trends with the addition of anthropogenic forcing
- Nights are warming faster than days
- The ocean is warming from the top down

Not only global warming

- Sea level rises – loss of habitat, fish spawning grounds etc.
- CO_2 absorbed in the ocean causes acidification
- More on implications next lecture.



Doubting voices

- Massive, non-anthropogenic climate change has occurred in the past, and will happen in the
- **Think about how you might now answer these critics**
- Evidence for recent warming depends critically on the data and time range chosen.
- There is insufficient evidence to conclude that anthropogenic global warming is occurring.