Atmosphere, Water, People, Climate

OCN 623 – Chemical Oceanography

Most slides from Barry Huebert and/or IPCC

Webster:

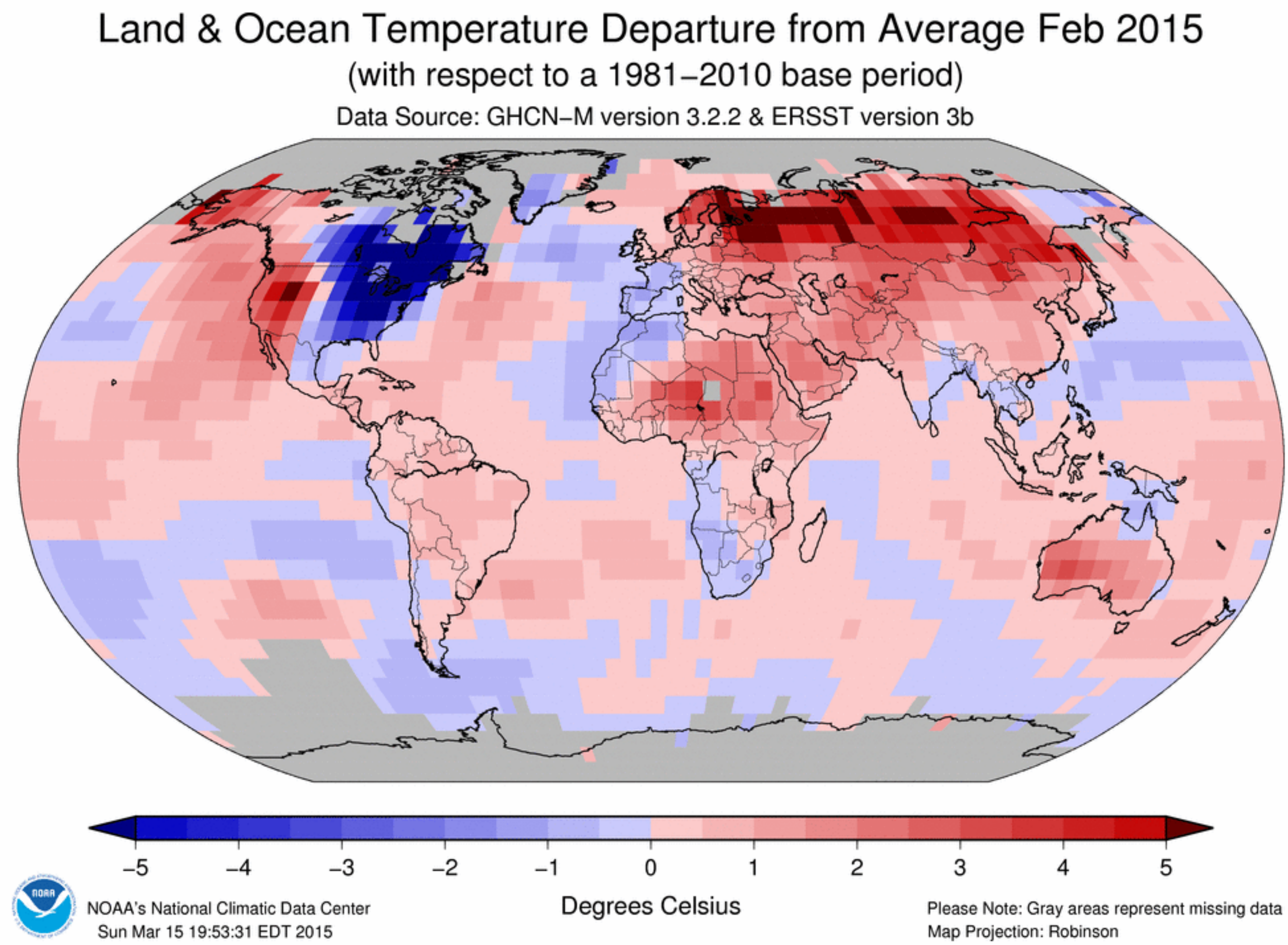
"Climate: the average condition of the weather at a place over a period of years as exhibited by temperature, wind velocity, and precipitation"

So "climate" refers not to the weather today or this week or this year, but rather to the range of weather (including hot and cold years, wet and dry years) that is typical of each region.

- Climate change is a natural process that has happened for billions of years
- Human activities are changing the rate of climate change
- Aerosols affect the climate, sometimes offsetting part of the greenhouse gas warming.
- Climate change includes many more effects than warming

"In case we had forgotten, because we keep hearing that 2014 has been the warmest year on record, I ask the chair, do you know what this is? It's a snowball, just from outside here. It's very, very cold out."

Chair, U.S. Senate Committee on Environment & Public Works



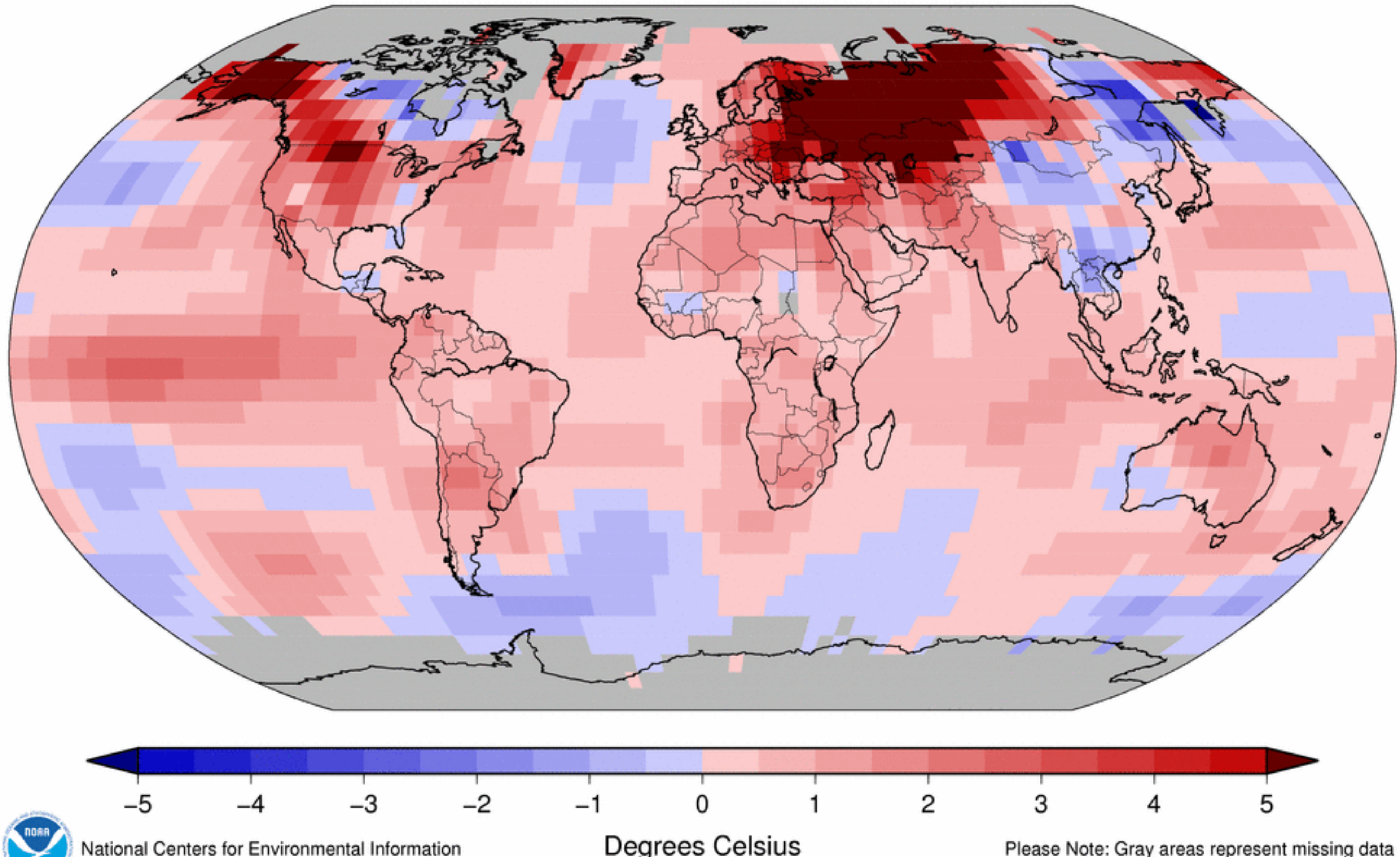
Combined average temperature over global land and ocean surfaces for February 2015 was the second highest for February in the 136-year period of record


LOL "SCIENCE" SAYS THE SHIP IS SINKING
MY END IS UP 200FT

Land & Ocean Temperature Departure from Average Feb 2016

(with respect to a 1981–2010 base period)

Data Source: GHCN–M version 3.3.0 & ERSST version 4.0.0



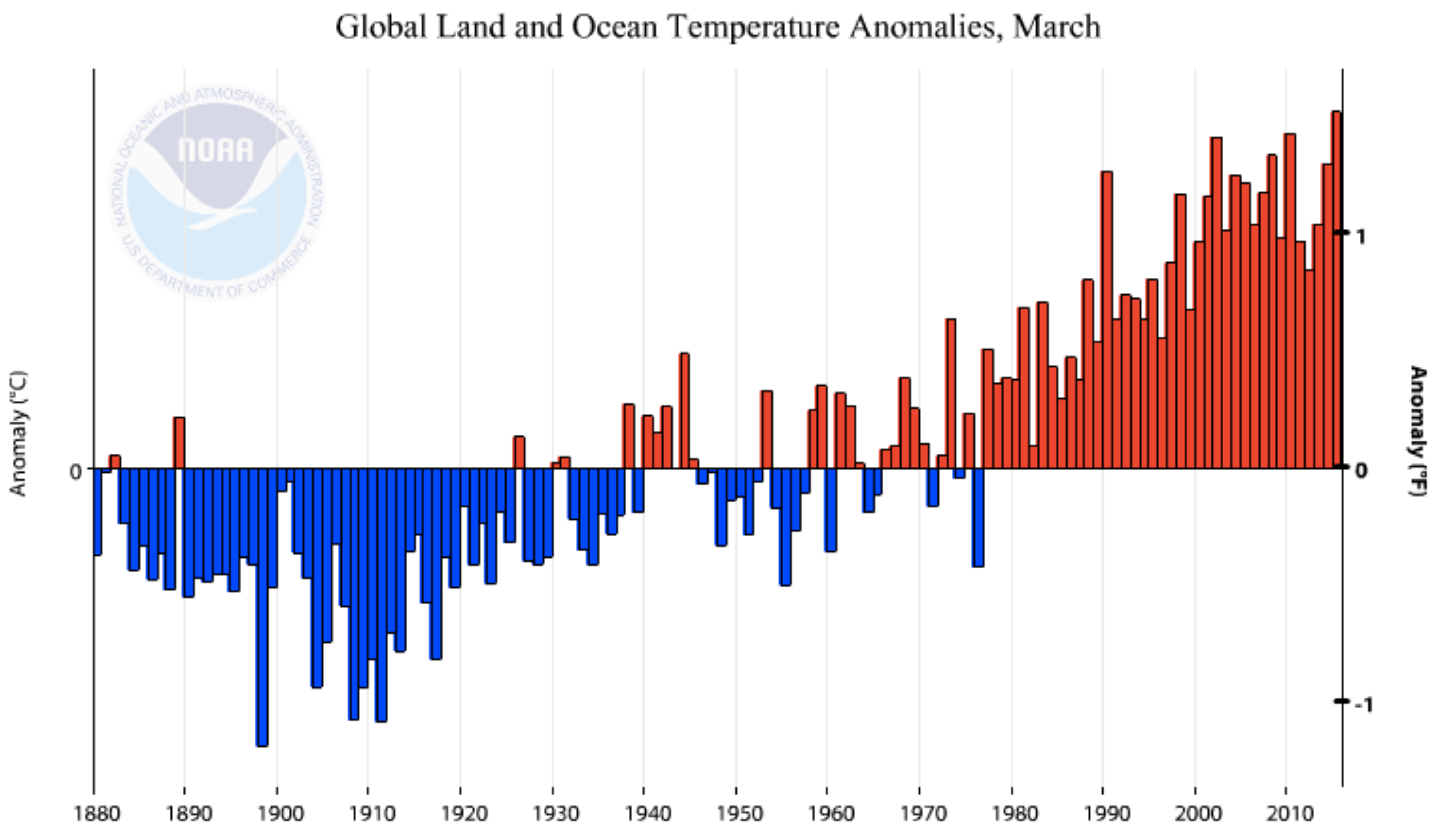
National Centers for Environmental Information
Mon Mar 14 07:22:03 EDT 2016

Please Note: Gray areas represent missing data
Map Projection: Robinson

Is Climate Change / Global Warming happening or not?

Global mean surface temperature has increased >0.5˚C in this time.

Is this natural variability or anthropogenic climate change?

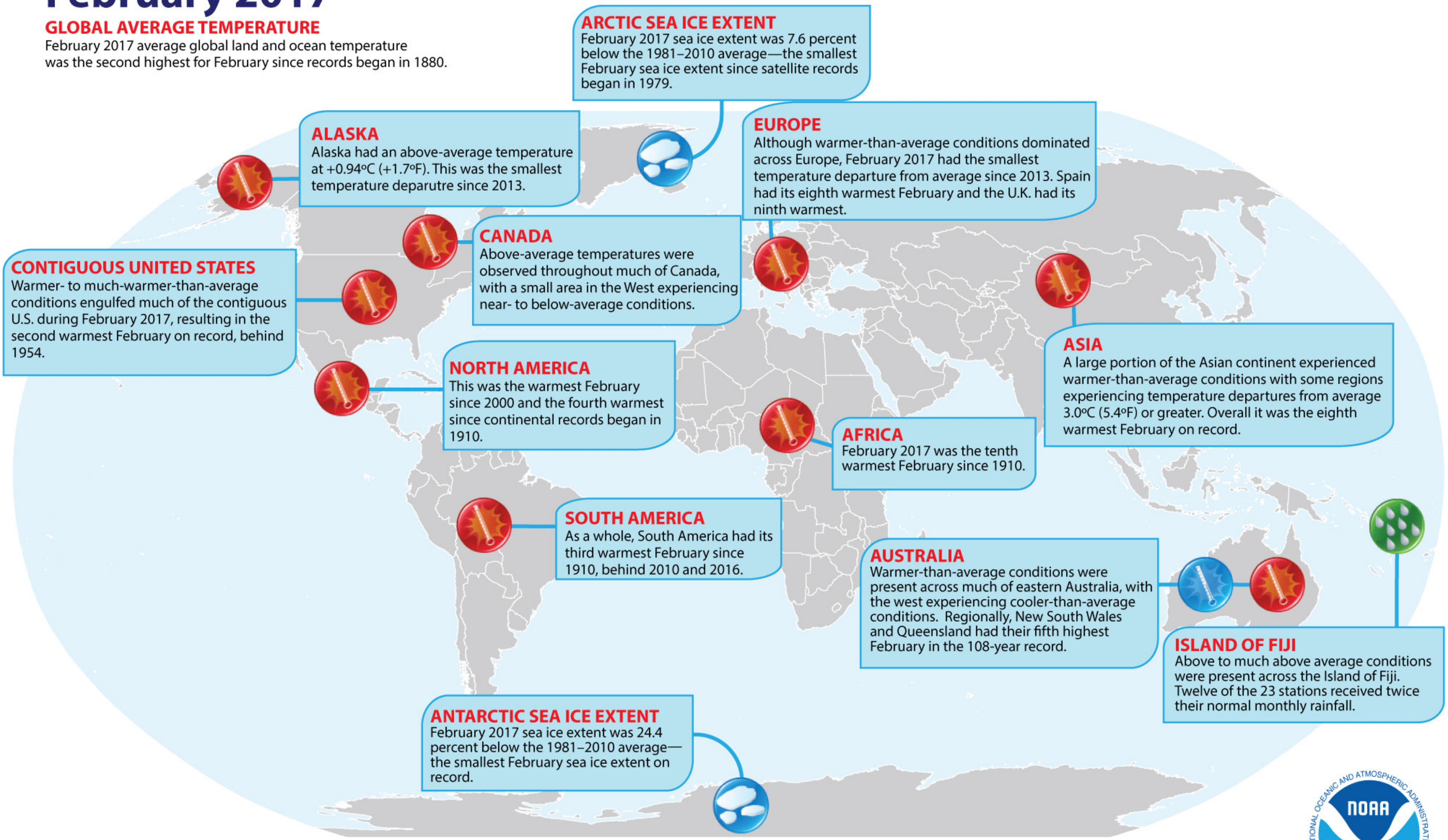


global & hemispheric anomalies are provided with respect to the period 1901-2000, the 20th century average

Selected Significant Climate Anomalies and Events
February 2017

GLOBAL AVERAGE TEMPERATURE

February 2017 average global land and ocean temperature was the second highest for February since records began in 1880.



Please Note: Material provided in this map was compiled from NOAA's State of the Climate Reports. For more information please visit: http://www.ncdc.noaa.gov/sotc

NATIONAL OCEANIC AND ATMOSPHERIC ADMINISTRATION
NOAA
U.S. DEPARTMENT OF COMMERCE

Likely Impacts

Why should we worry about global warming?

Would an extra degree or two of warming hurt anything?

What changes might we see?

Global mean surface temperature has increased >0.5˚C in this time.
Is this natural variability or anthropogenic climate change?

Would an extra degree or two of warming hurt anything?

YES!! It's NOT just warming.

"Climate Change" includes:

Sea-level Rise

Droughts & Flooding

Severe Storms Increasing

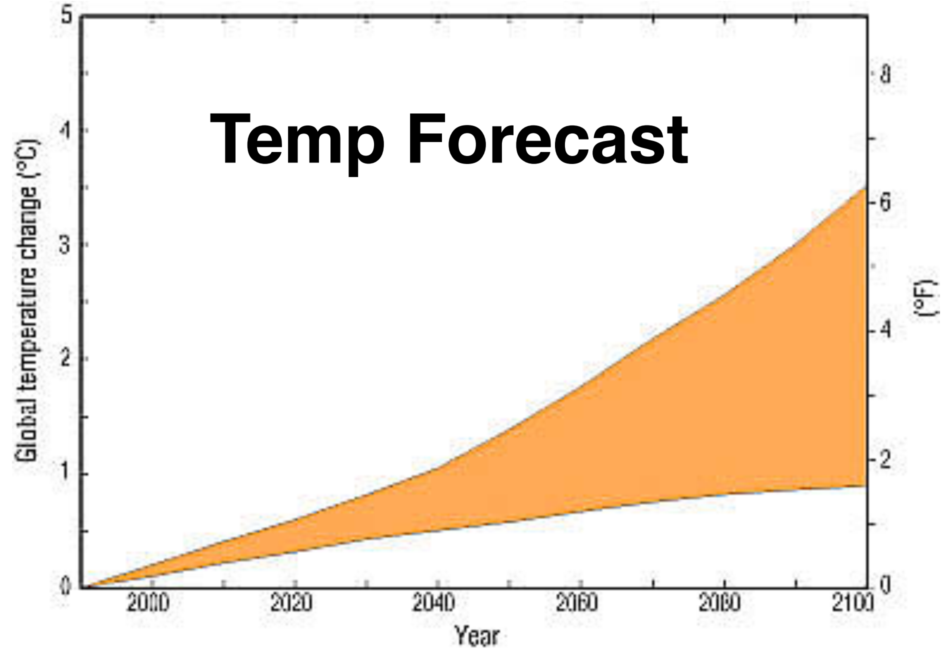
Diseases Spread to New Areas

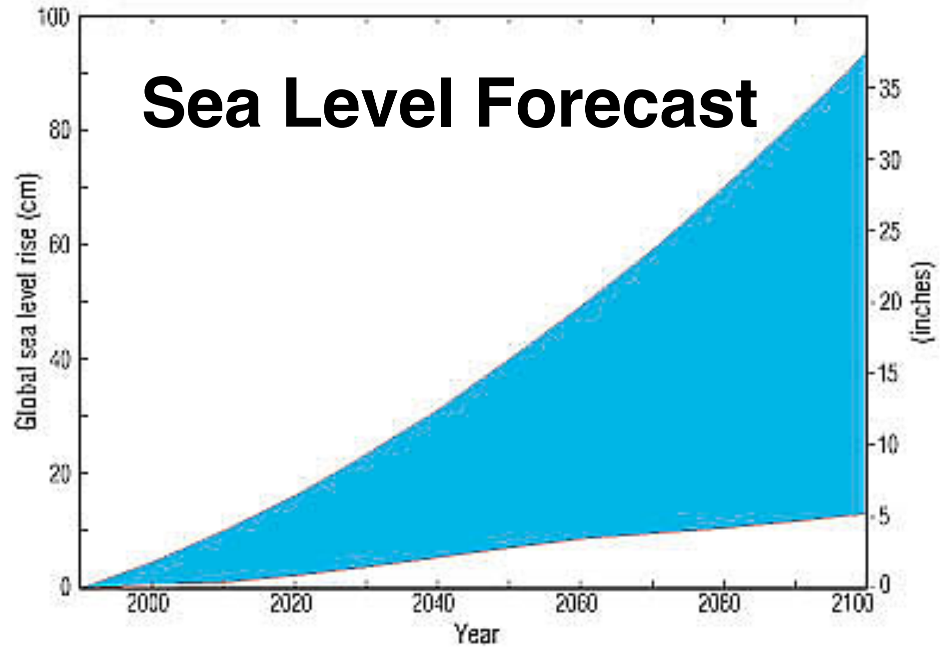
A warmer climate melts glaciers, expands the ocean, and submerges many islands

Temperature Rise
+1 to 3° C

⇓

Sea Level Rise
+10 to 90 cm (5 to 37")



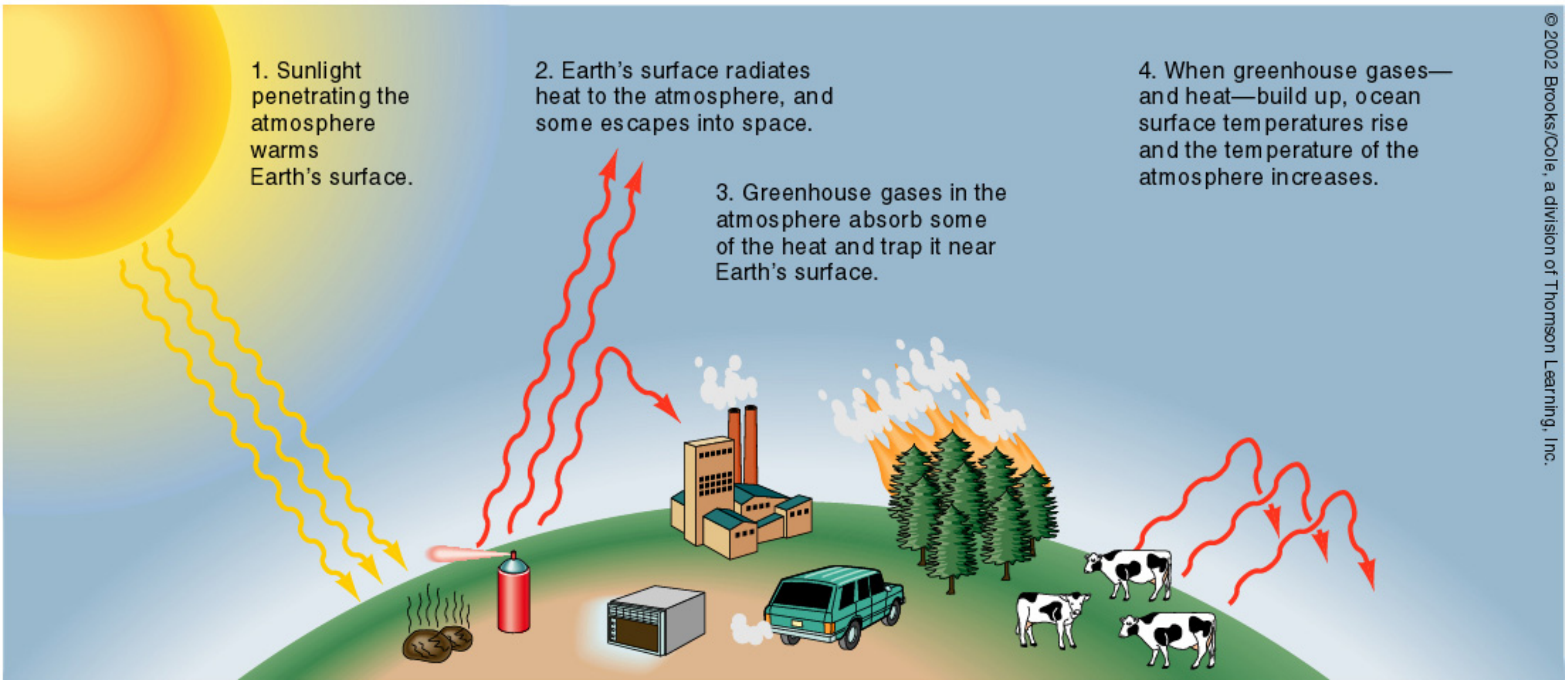


It's NOT just warming. "Climate Change" includes:

- Sea-level Rise
- Severe Storms Increasing
- Droughts & Flooding
- Diseases Spread to New Areas

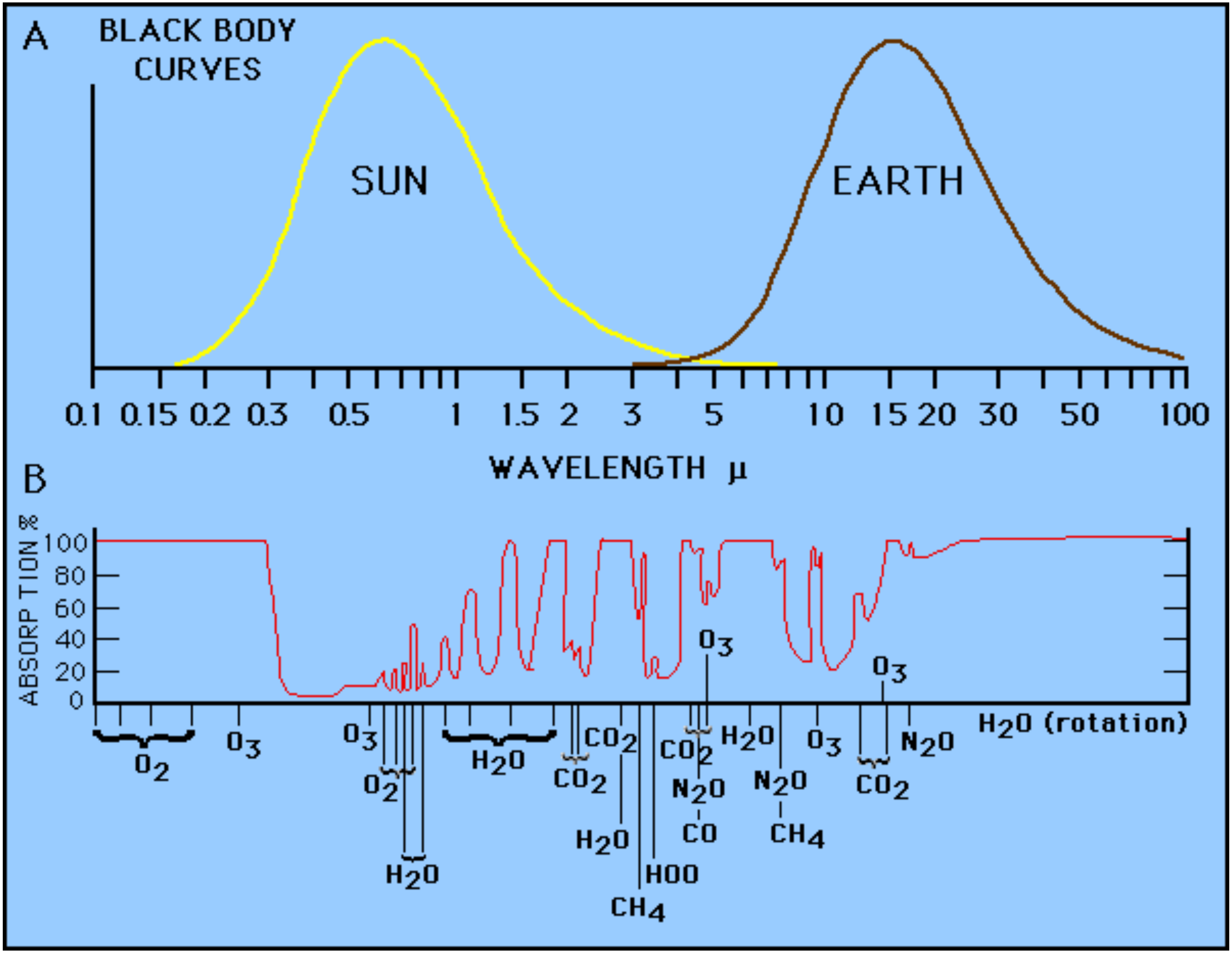
How does climate change work?

The Earth's temperature is set by a *Radiation Balance*:
If more heat arrives from the sun than can escape as infrared (IR) rays, the Earth gets warmer.



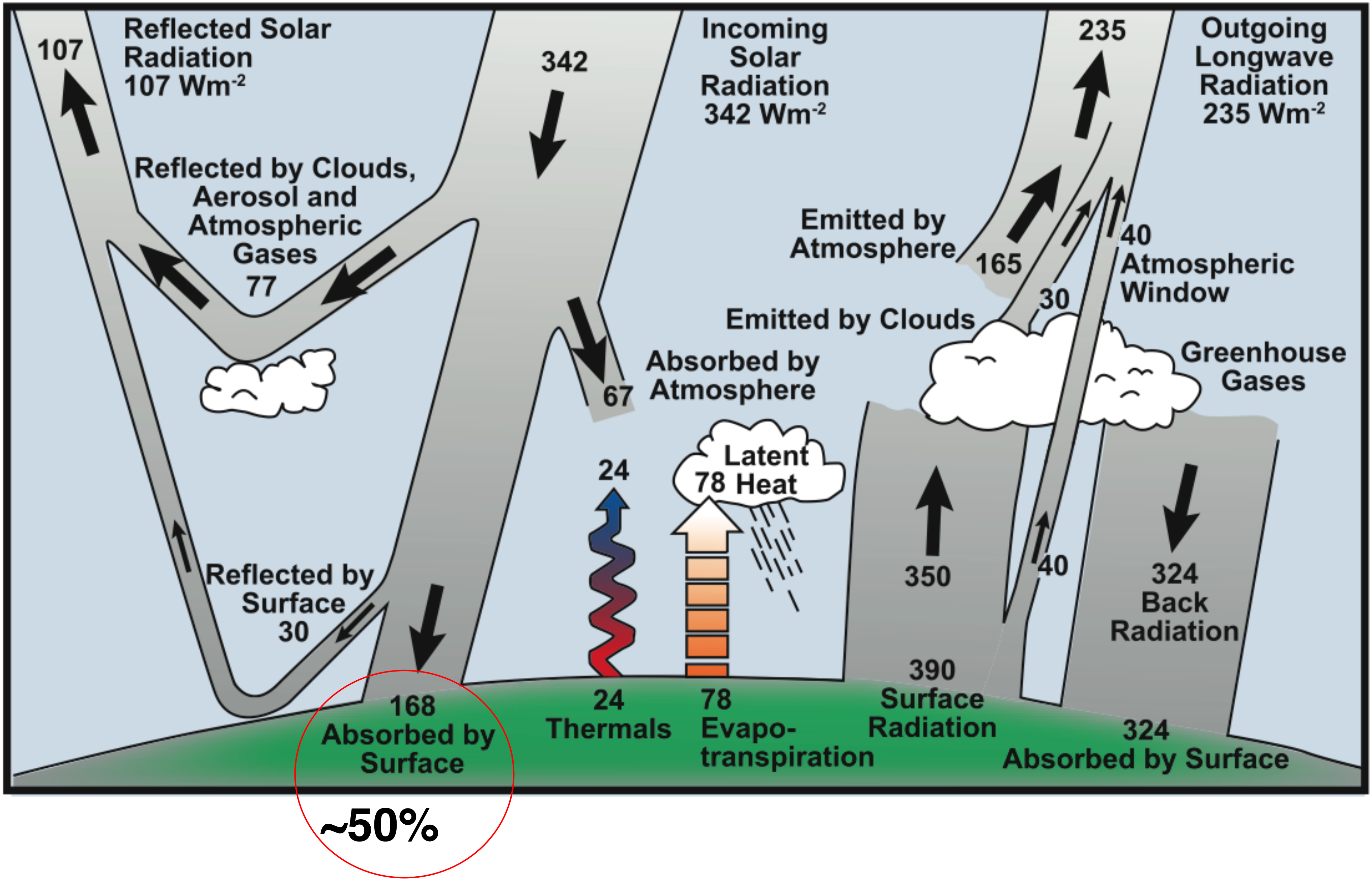
CO_2 and other greenhouse gases absorb IR, so an increase in CO_2 causes an increase in temperature.

Radiation Balance and Greenhouse Gases



The average Albedo (reflectivity) of Earth is 0.3

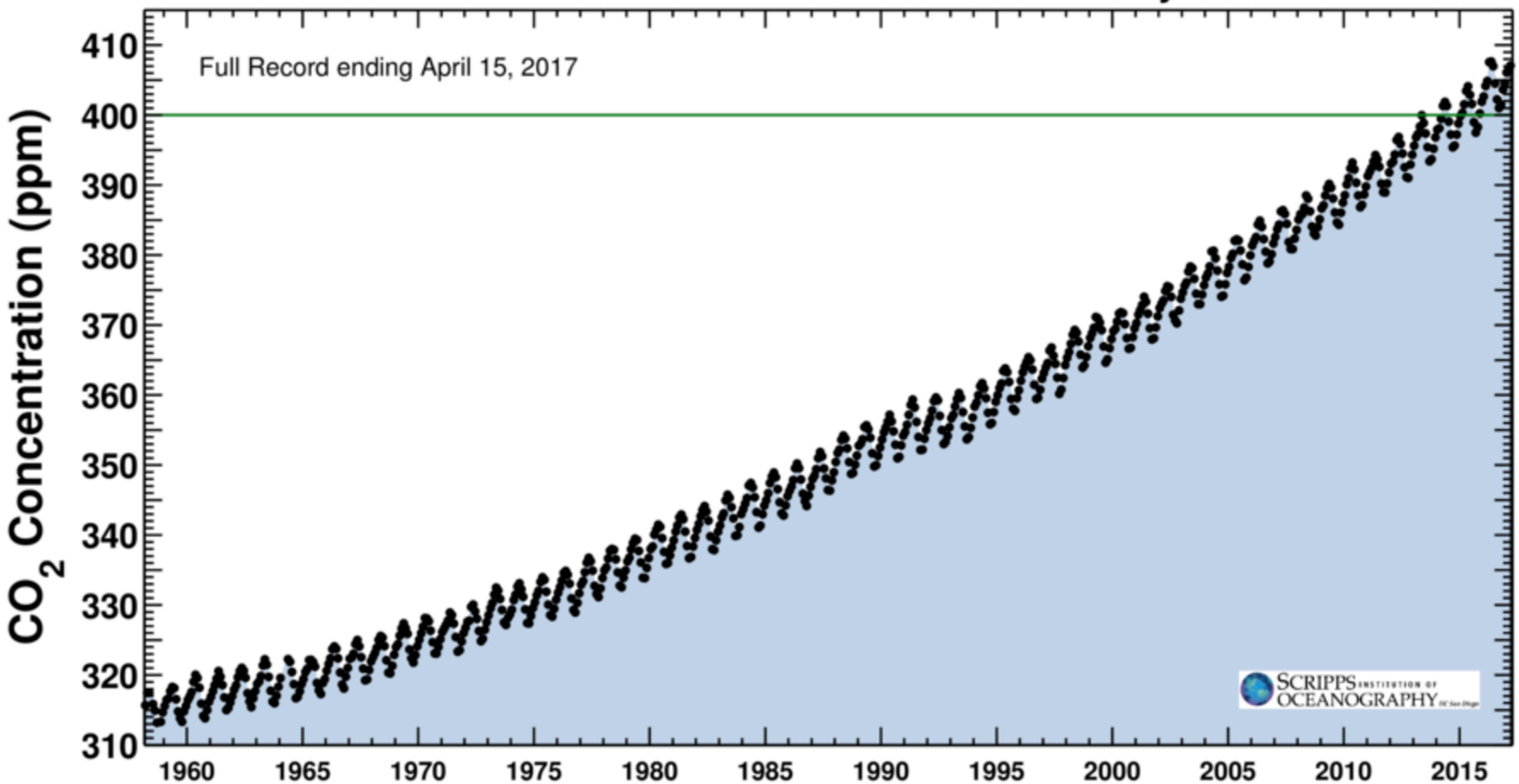
The majority of outgoing IR comes from gases

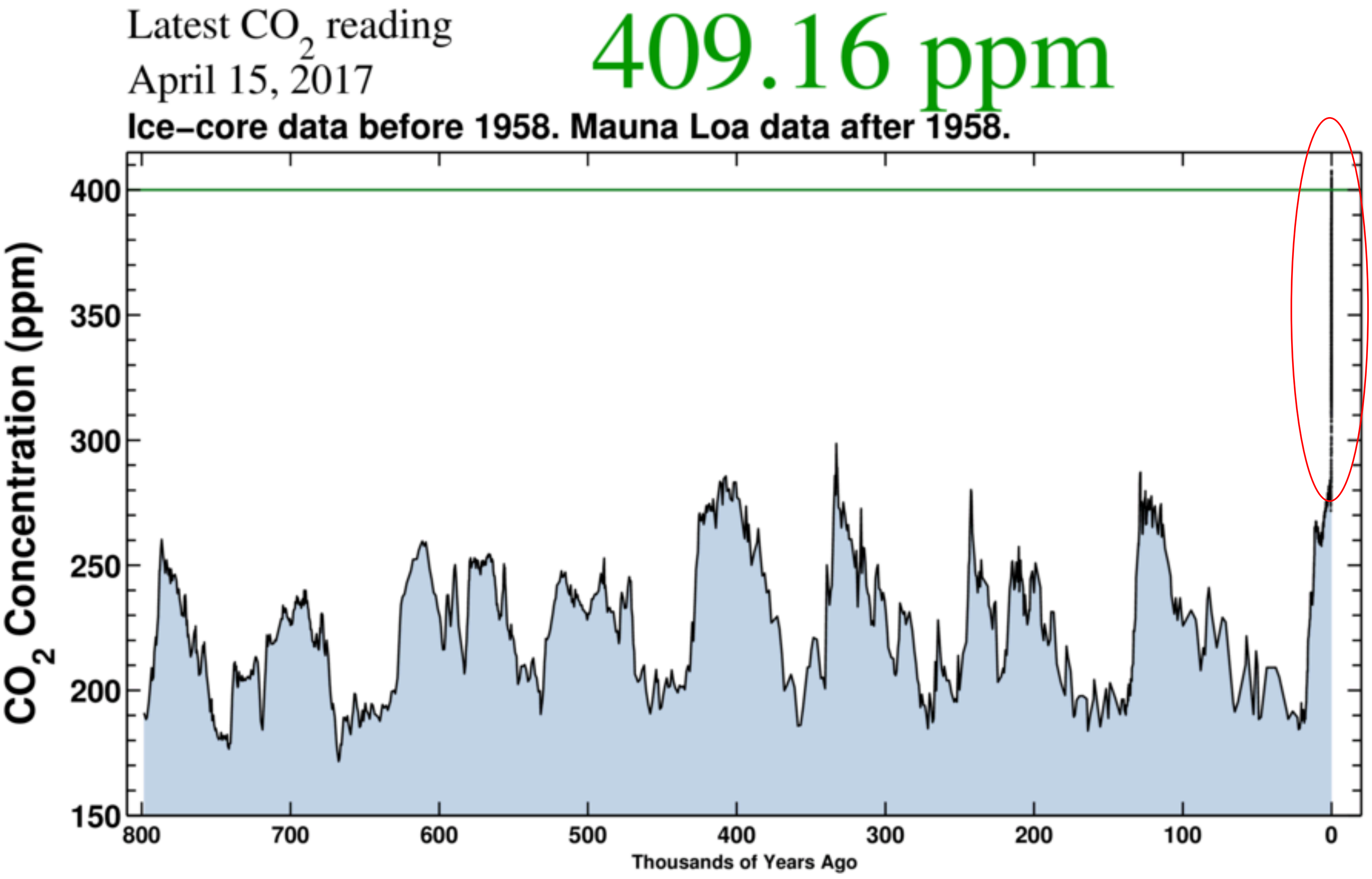


Latest CO_2 reading
April 15, 2017

409.16 ppm

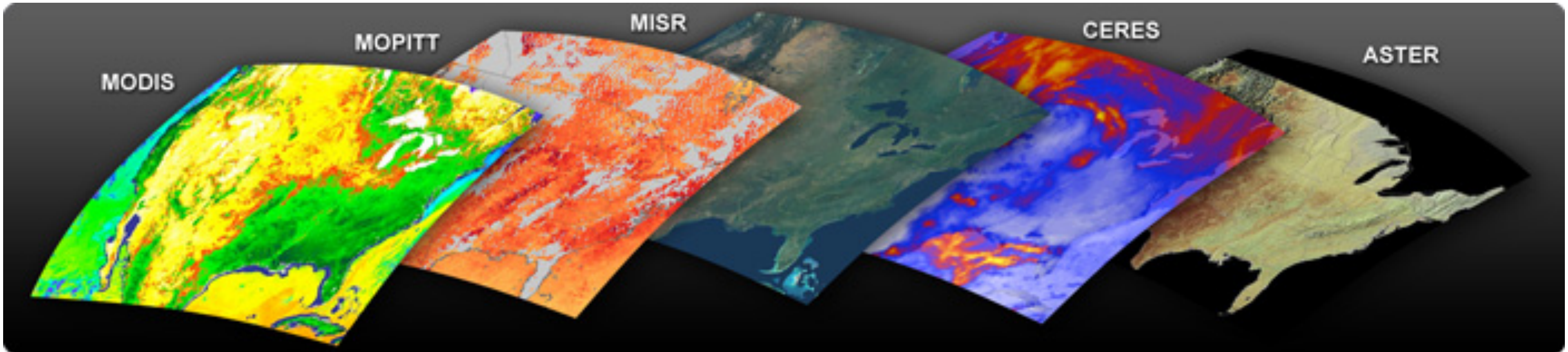
Carbon dioxide concentration at Mauna Loa Observatory

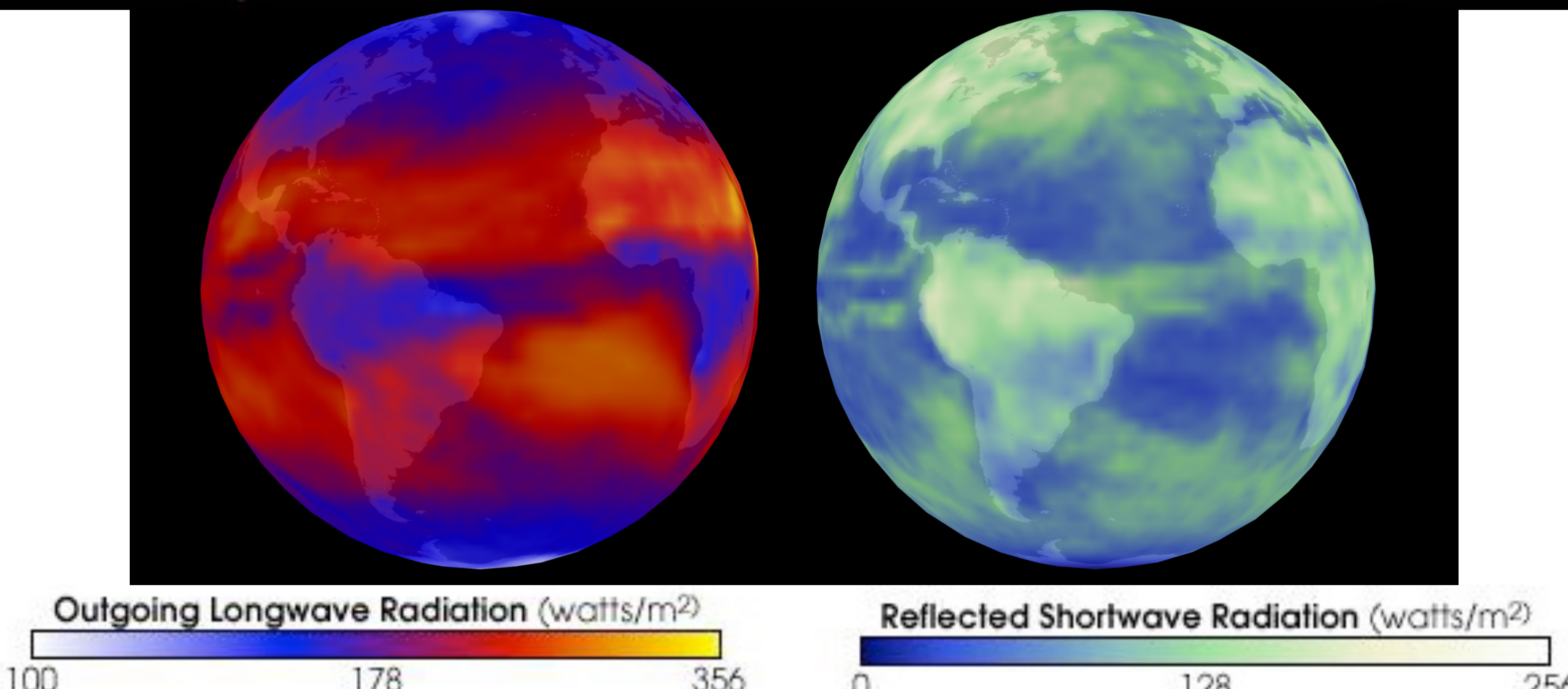




Uncertainty is a few ppmv

From the Terra satellite, you can actually see the regions where IR radiation escapes (left) and solar radiation is absorbed (right)





The Earth's temperature is set by a *Radiation Balance*: If more heat arrives from the sun than can escape as infrared (IR) rays, the Earth gets warmer.
CO_2 and other greenhouse gases absorb IR, so increase in CO_2 causes increase in T.

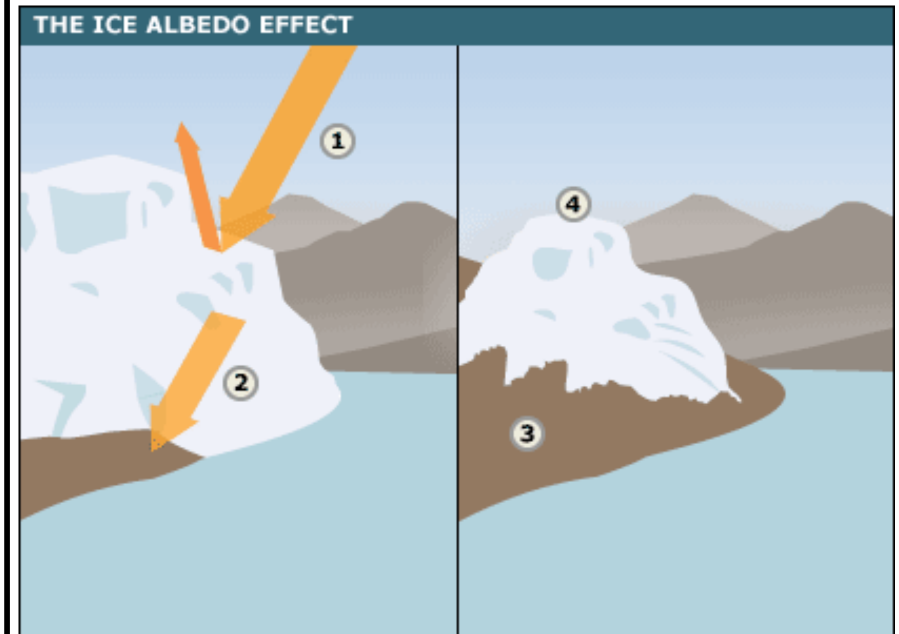
Positive Feedback: Warming Causes *More* Warming!

1 Light colored ice reflects back the Sun's energy efficiently.

2 Exposed land is darker and absorbs more energy; warming.

3 As the ice melts, more land is exposed. This absorbs more heat, melting more ice, and causing further warming.

4 The altitude of the melting ice is reduced so it becomes harder for new ice to form (esp for Greenland).



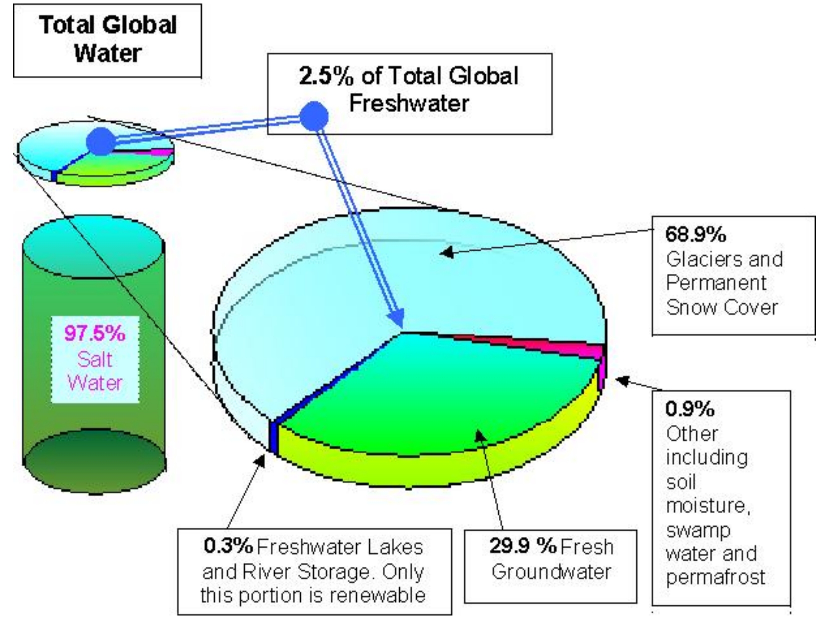
Melt water flows to the base of the Greenland ice sheet.

Ice is melting MUCH faster than glaciologists had forecast

Positive Feedback can cause Runaway Warming, by darkening originally-light surfaces.

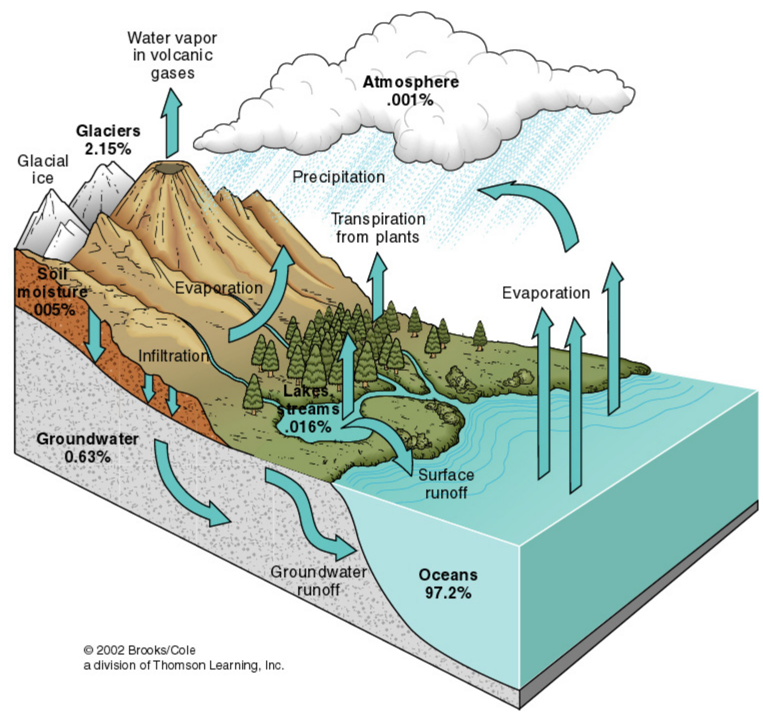
The climate system is full of feedbacks

“The annual circulation of H_2O is the largest movement of a chemical substance at the surface of the Earth”

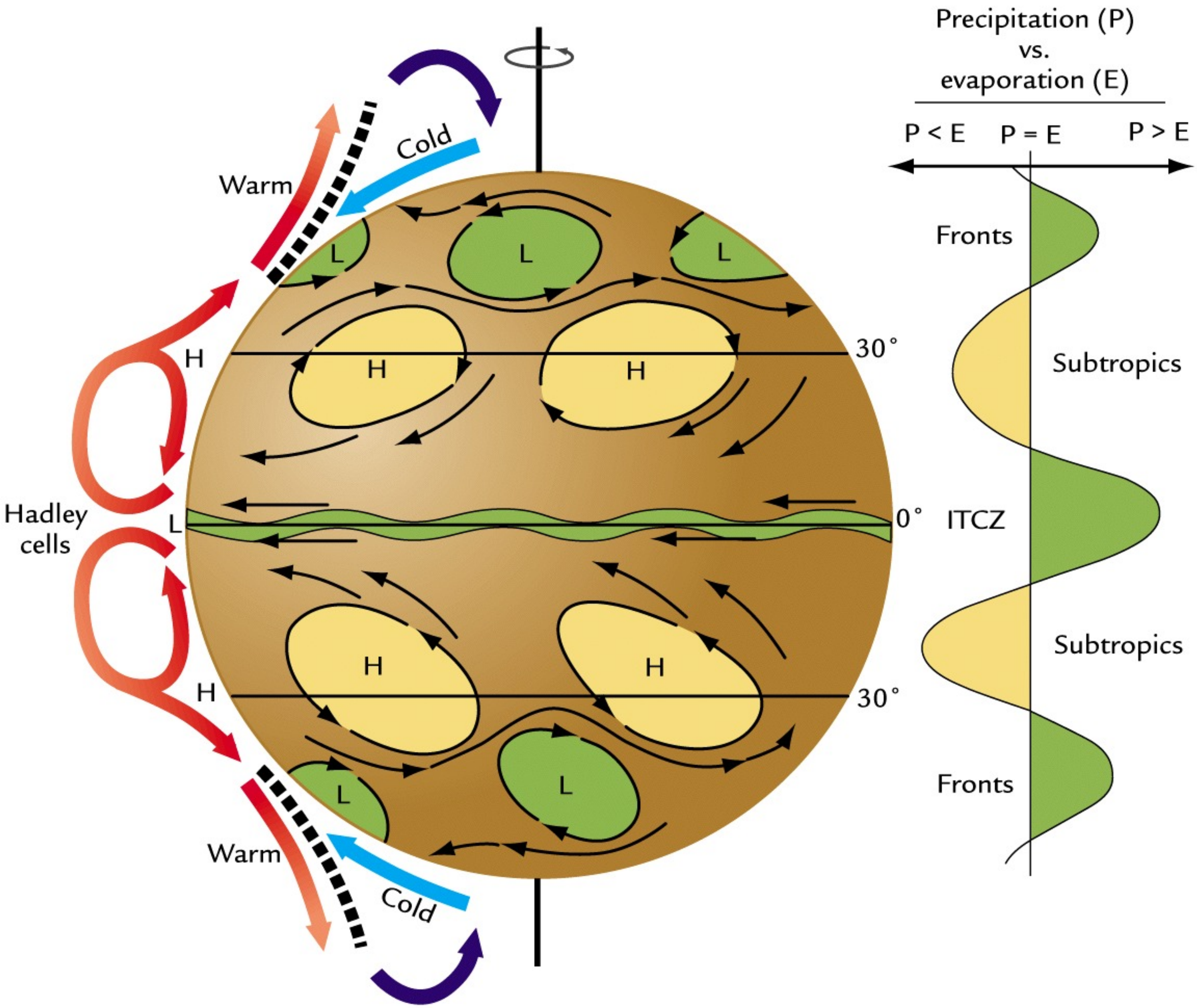


The distribution of water at the Earth's surface

	% of total
Oceans	97.25
Ice caps and glaciers	2.05
Groundwater	0.68
Lakes	0.01
Soils	0.005
Atmosphere (as vapor)	0.001
Rivers	0.0001
Biosphere	0.00004
Total	100 %



Three-cell model of atmospheric circulation

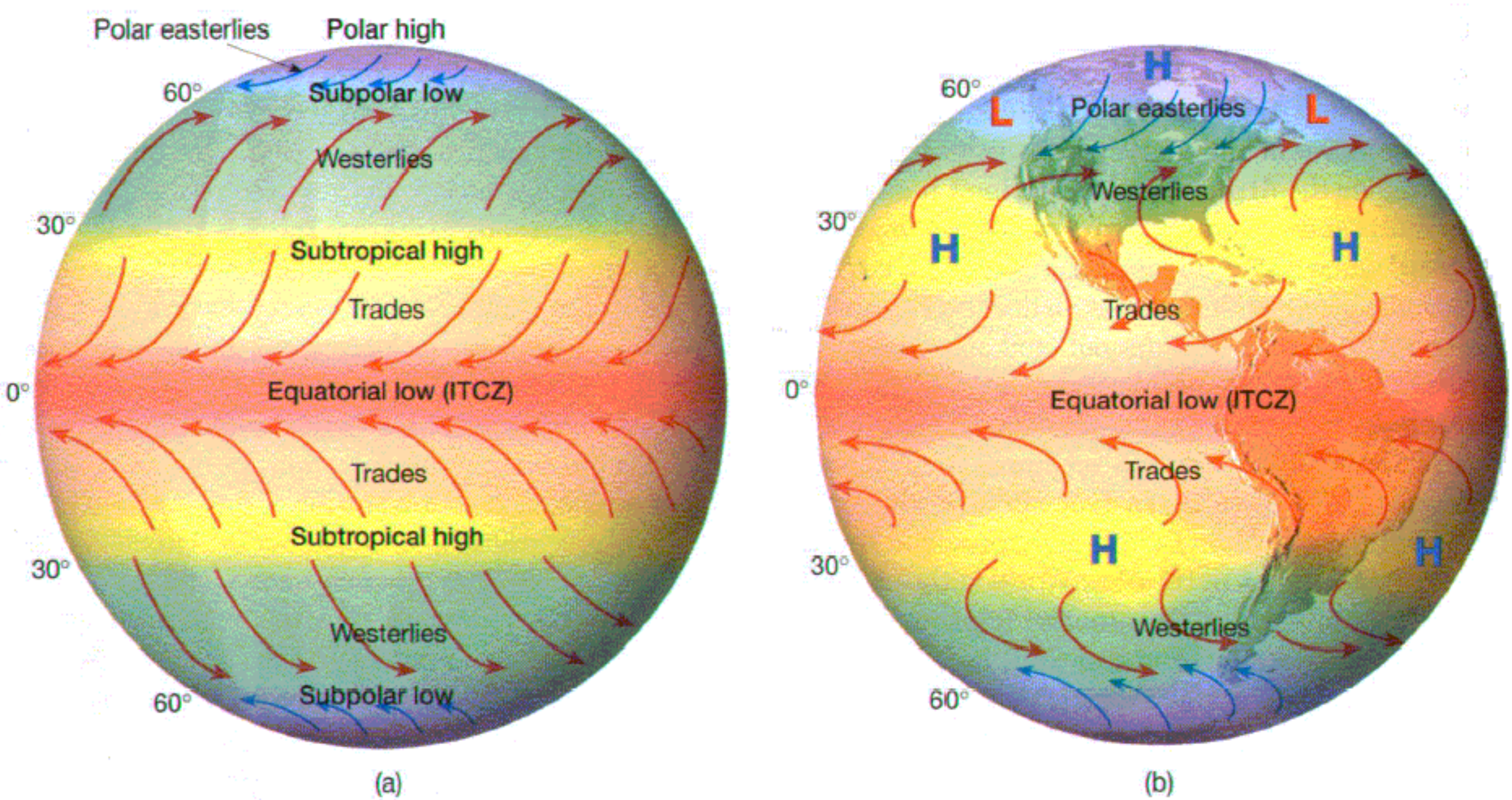


(1) Polar cells

(2) Midlatitude cells

(3) Hadley cells

Idealized vs. actual zonal pressure belts

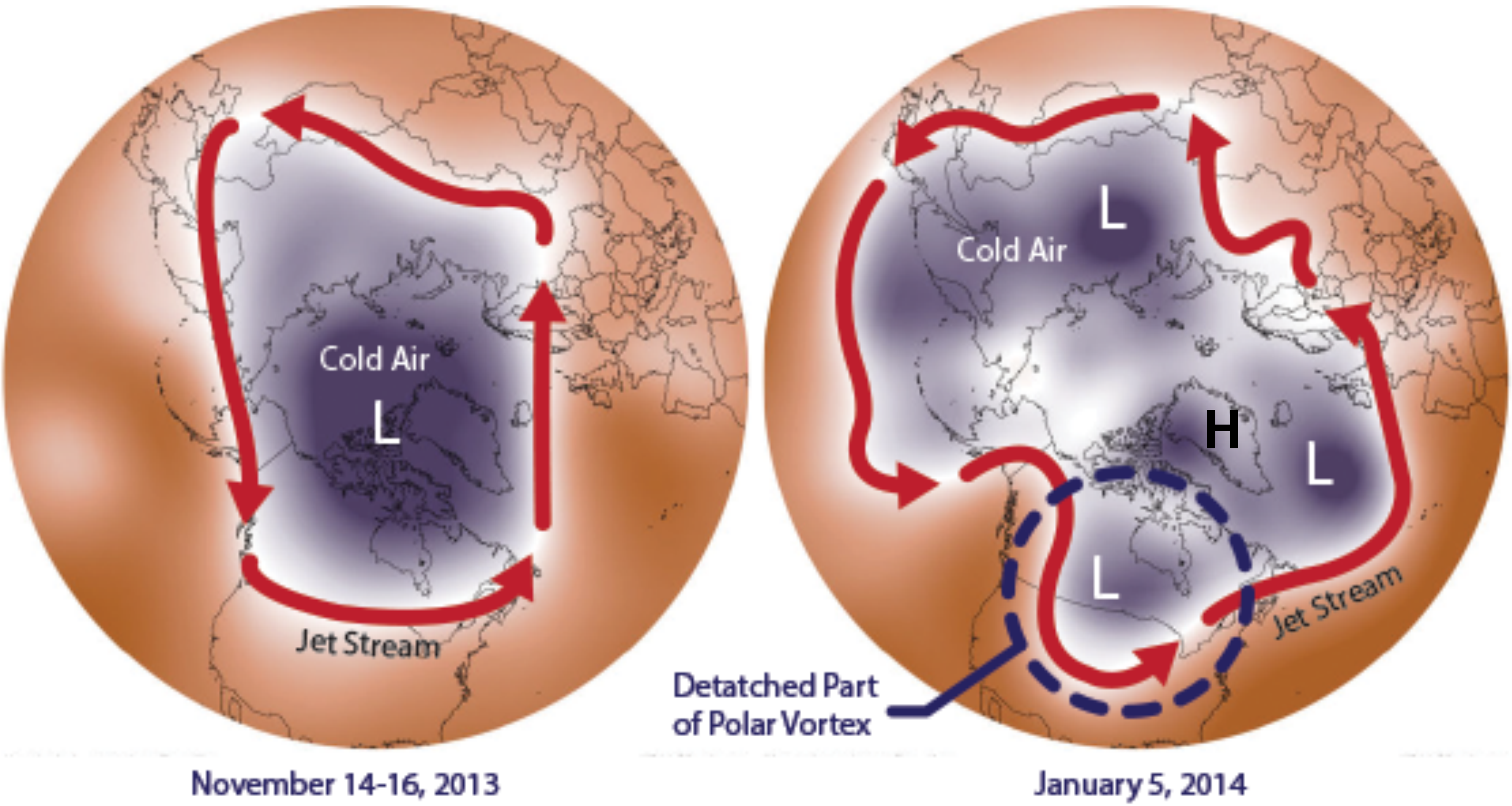


Non-uniform surface = uneven heating

Unstable windflow = eddies

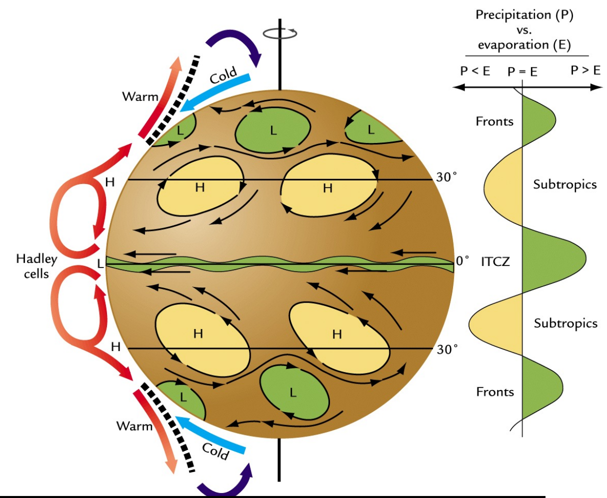
Sun doesn't remain over the equator year-round = 23.5N-23.5S

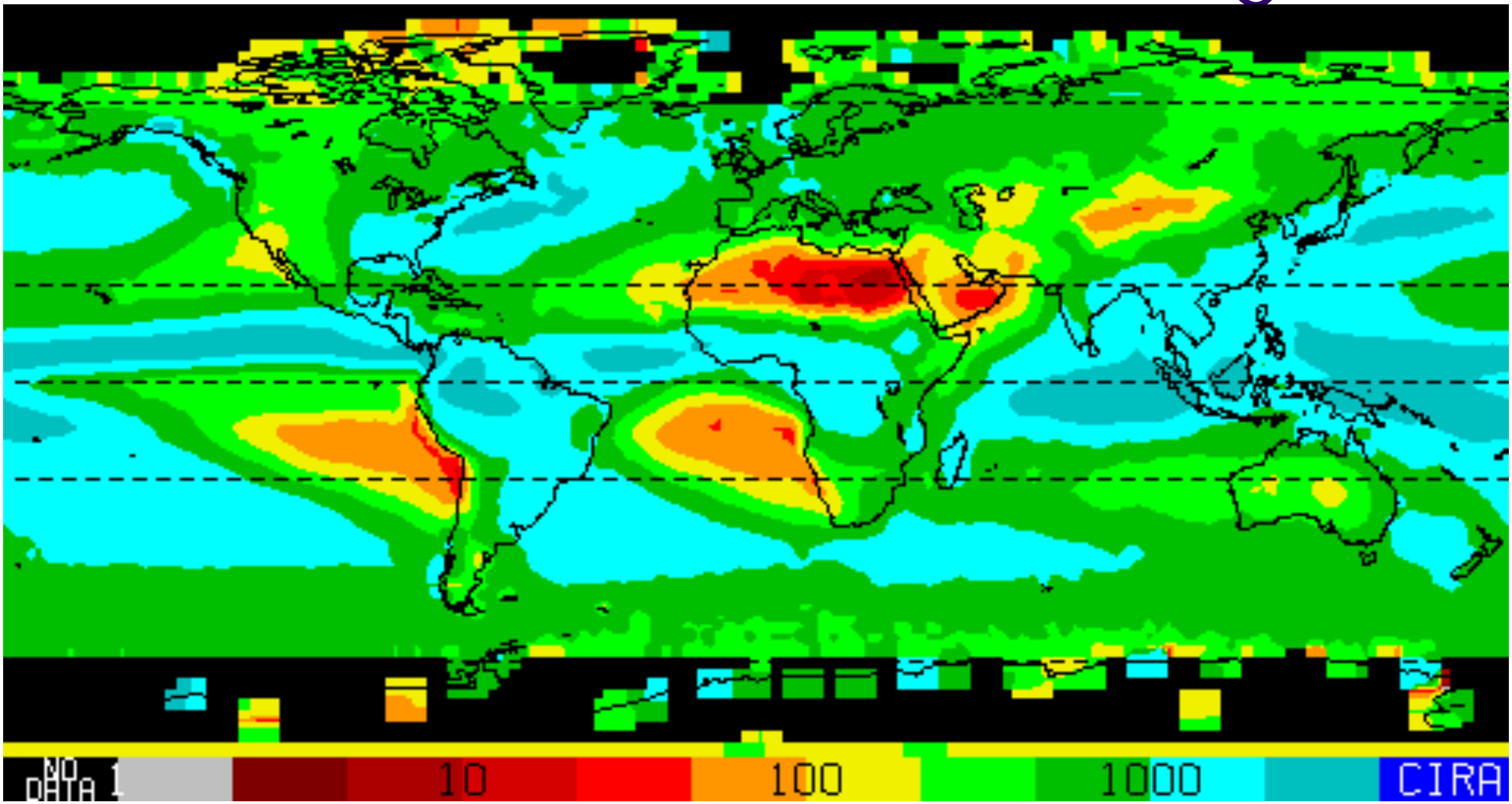
Polar vortex



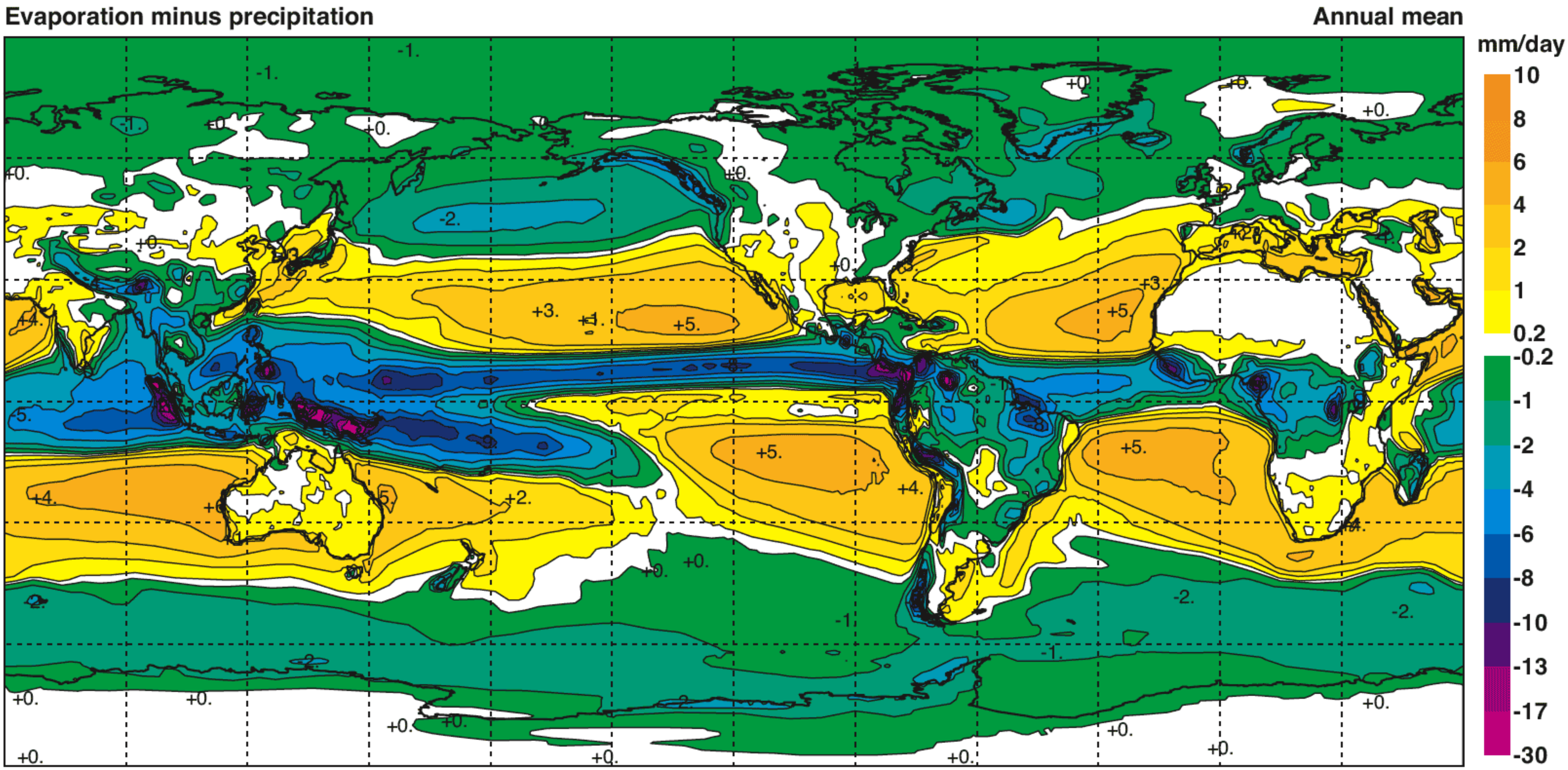
Weakening of the vortex, H over Greenland → detachment

Movement of H_2O through the atmosphere determines the distribution of rainfall; global average precip ~943mm





Net evaporation from the surface ocean affects surface water salinity in the ocean and increases surface water density controls thermohaline circulation of ocean



Surface water salinity in the Atlantic Ocean

The maxima in evaporation-precipitation results in the highest surface water salinities in the mid-latitudes around 30 N and 30S

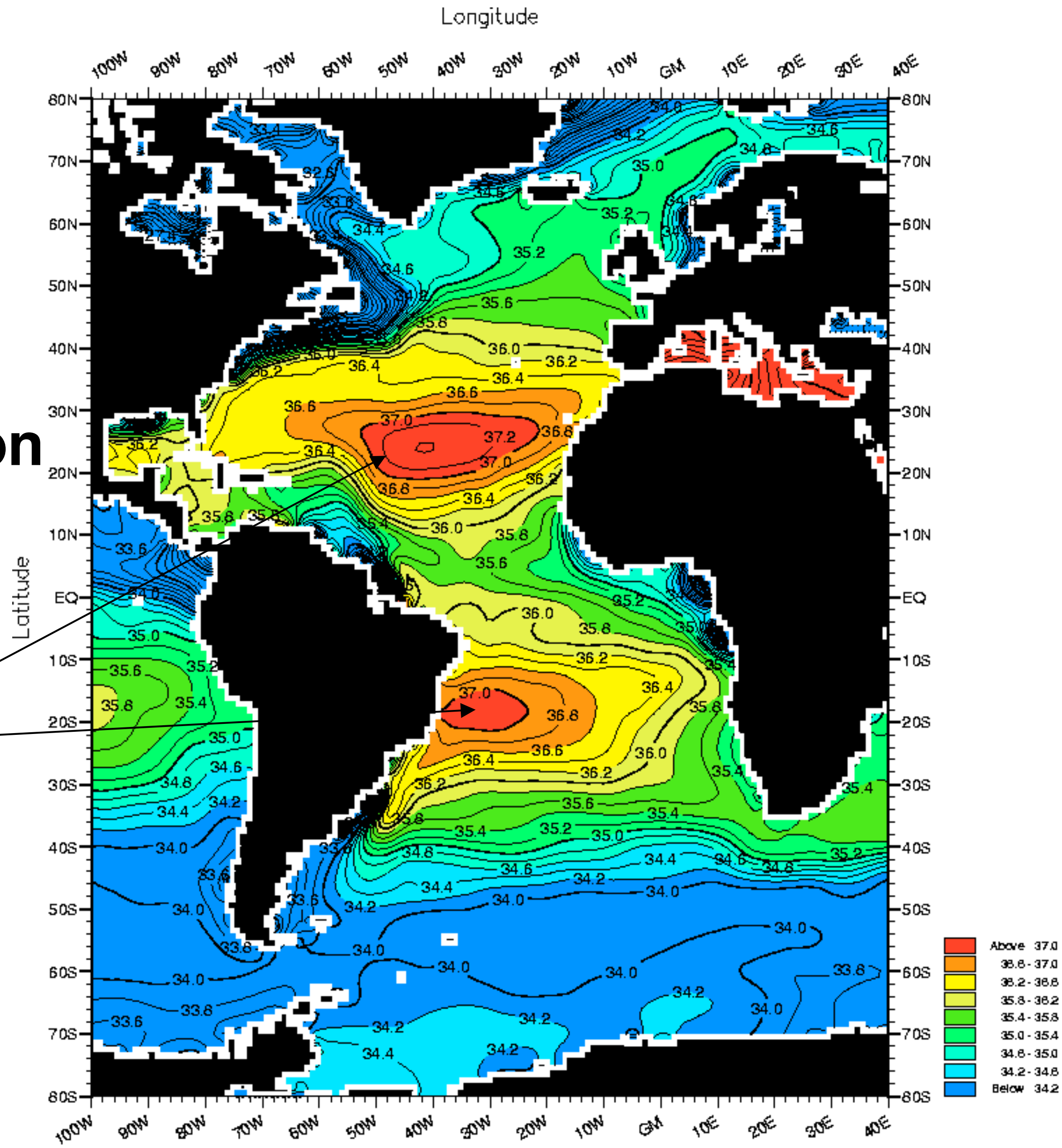
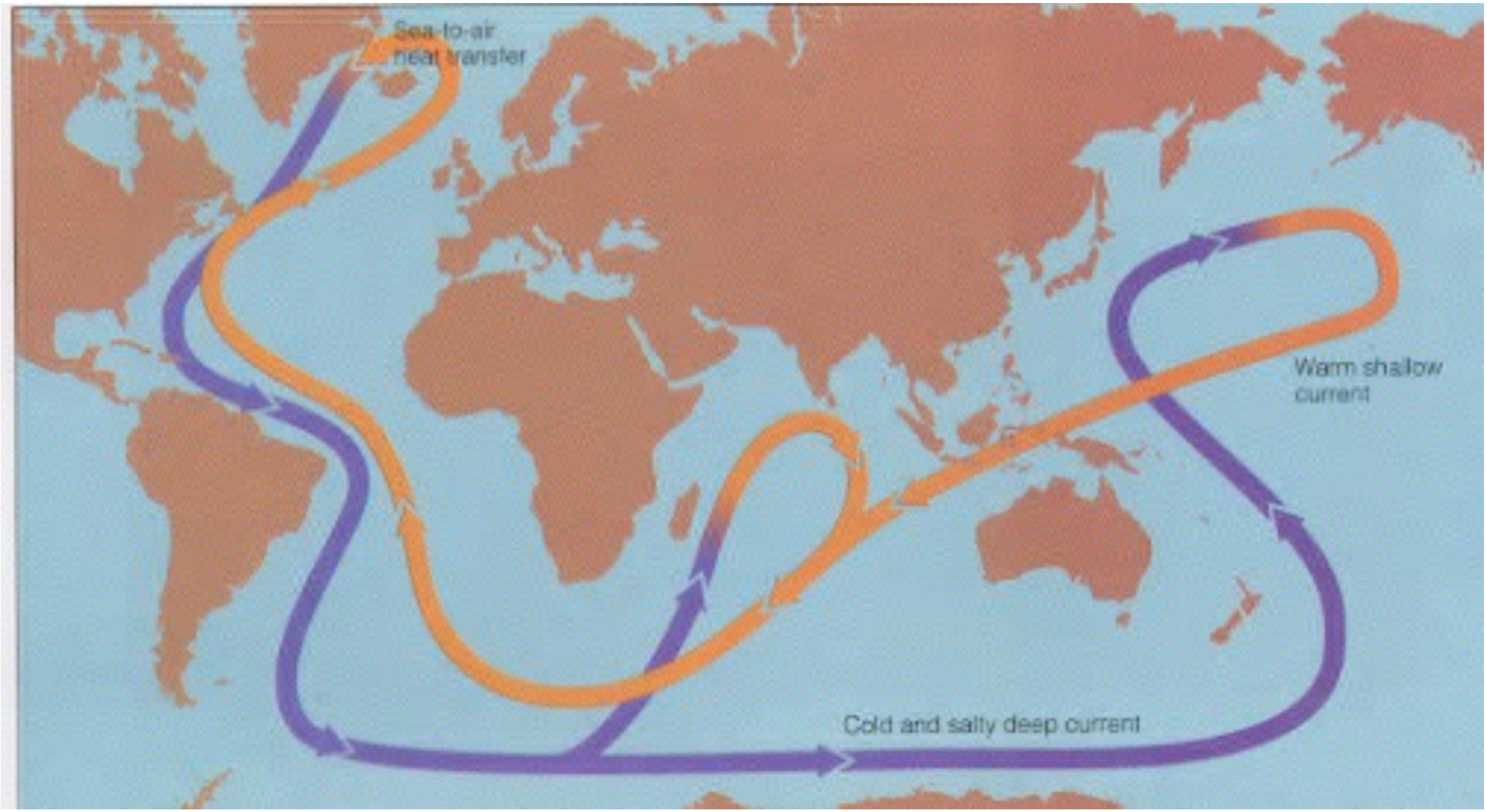


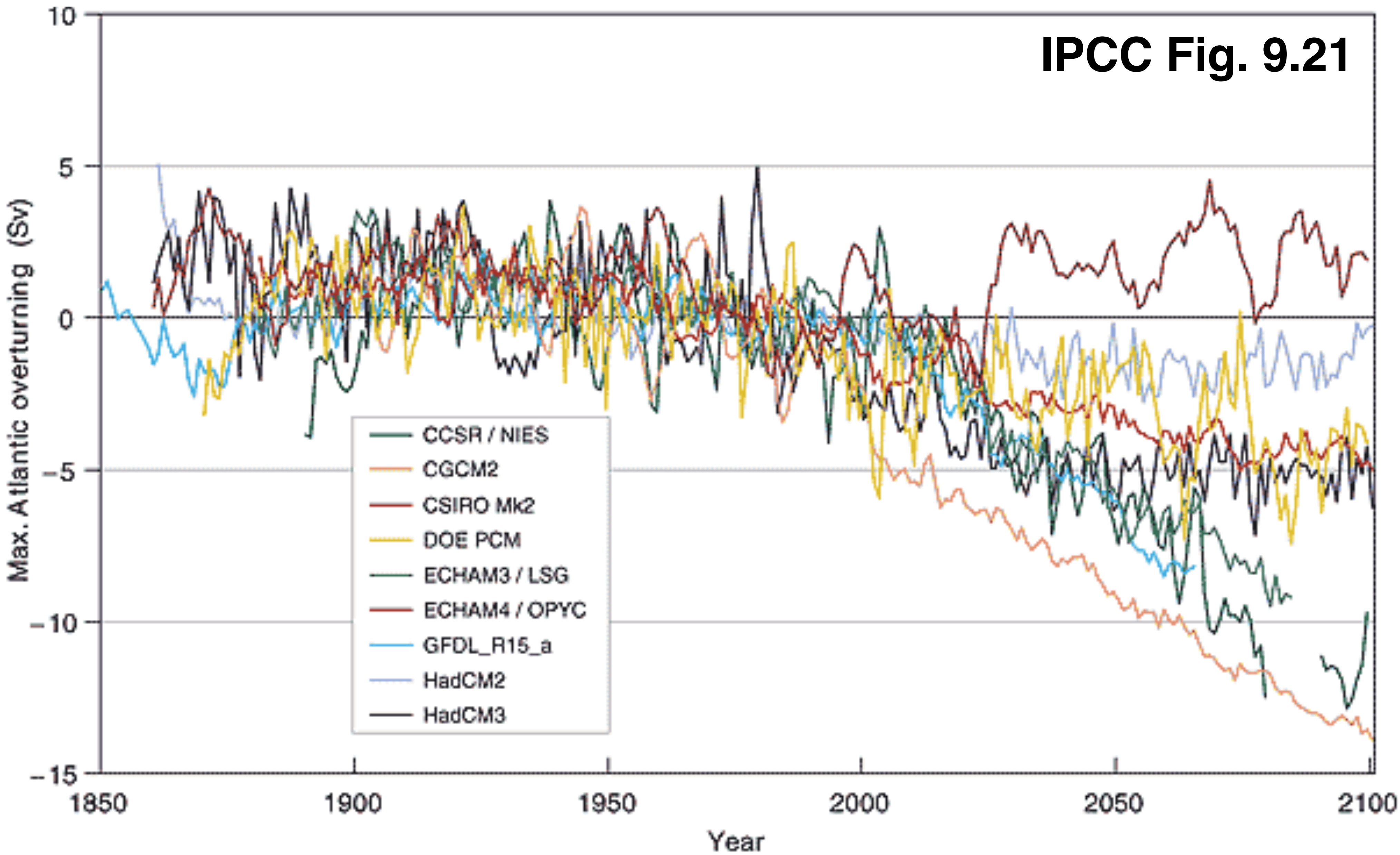
Fig. A2-1. Annual mean salinity (PSS) at the surface.

Minimum Value= 3.57 Maximum Value= 39.76 Contour Interval: 0.20

Remember the Thermohaline Circulation and this Global Conveyor Belt?

Freshening the North Atlantic (due to melting of Greenland and Arctic ice) could Shut it Down



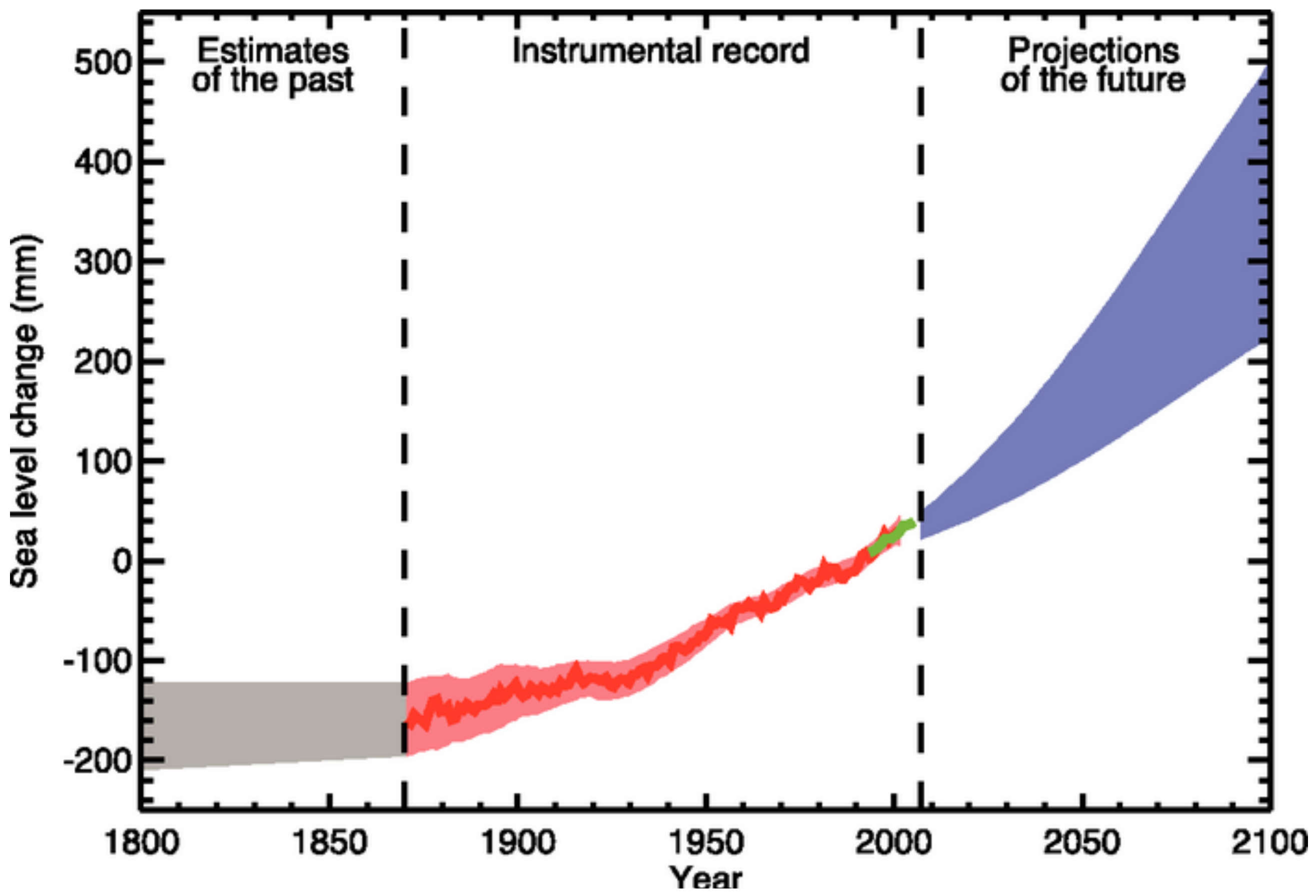


Weakening of the THC in the Atlantic reduces poleward heat transport. This leads to a minimum in the surface warming in the northern North Atlantic and/or in the circumpolar Ocean.

Intergovernmental Panel on Climate Change

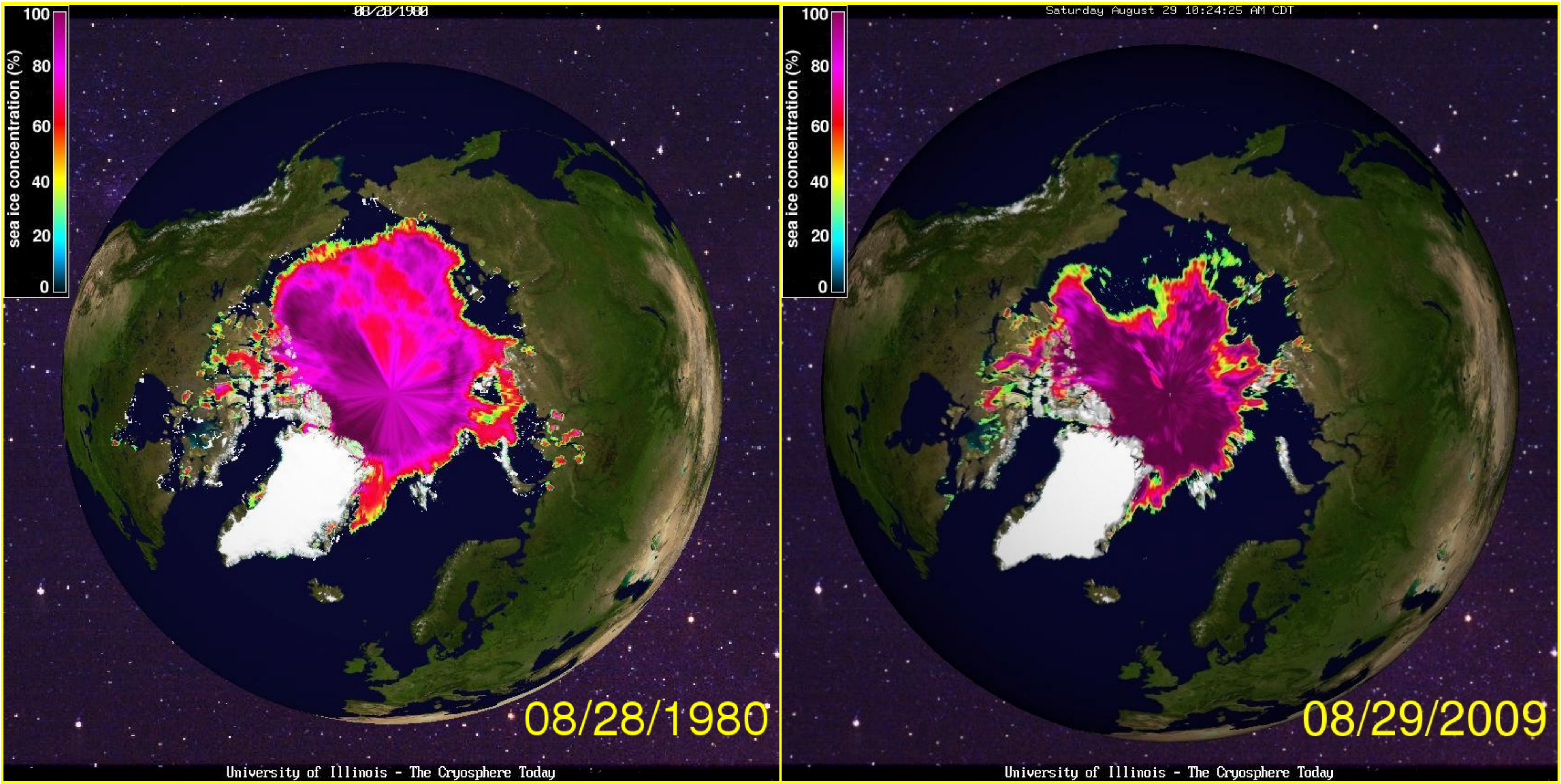
4th Assessment Report (FAR)   Feb 2007

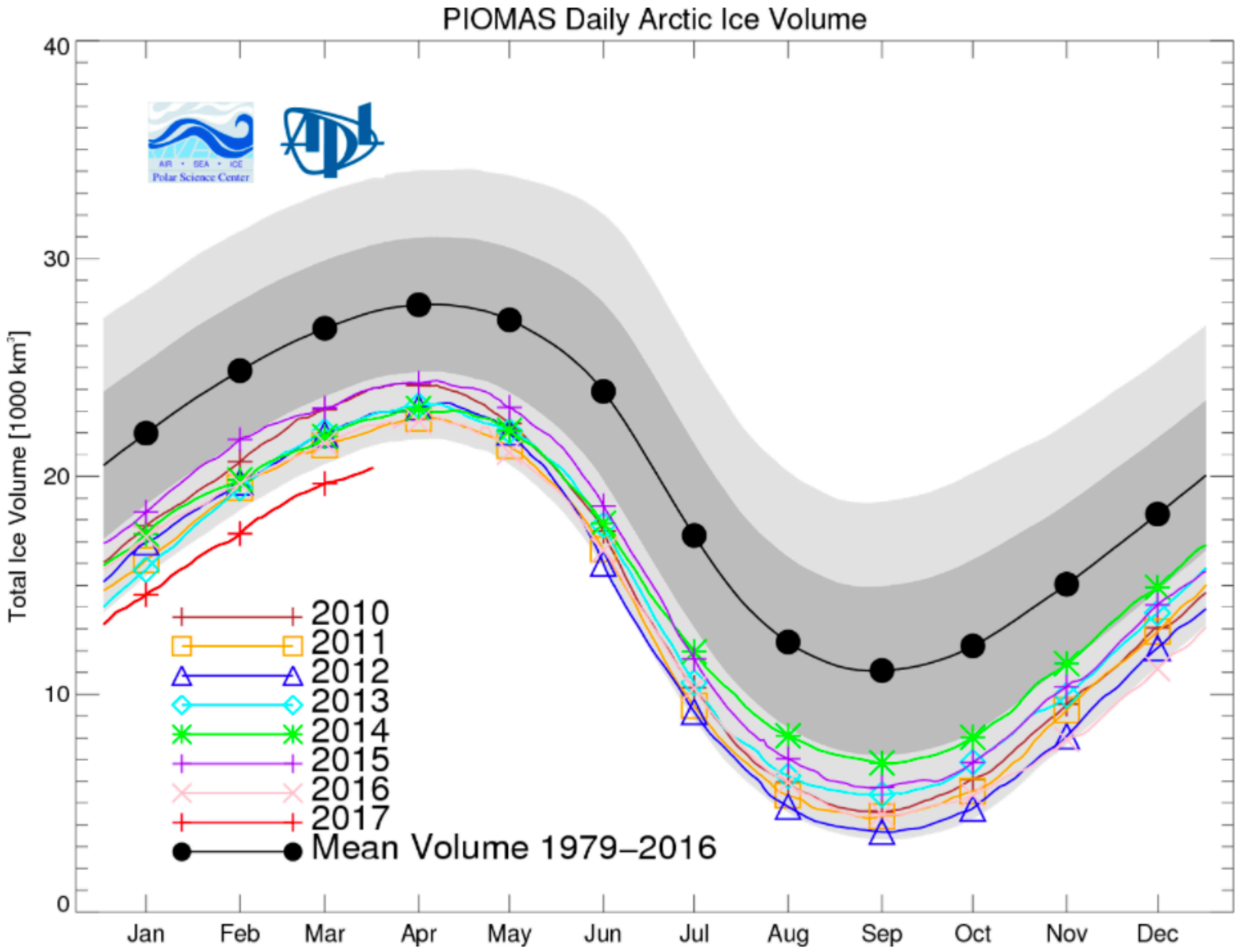
The last time the polar regions were significantly warmer than present for an extended period (about 125,000 years ago), reductions in polar ice volume led to 4 to 6 metres of sea level rise."



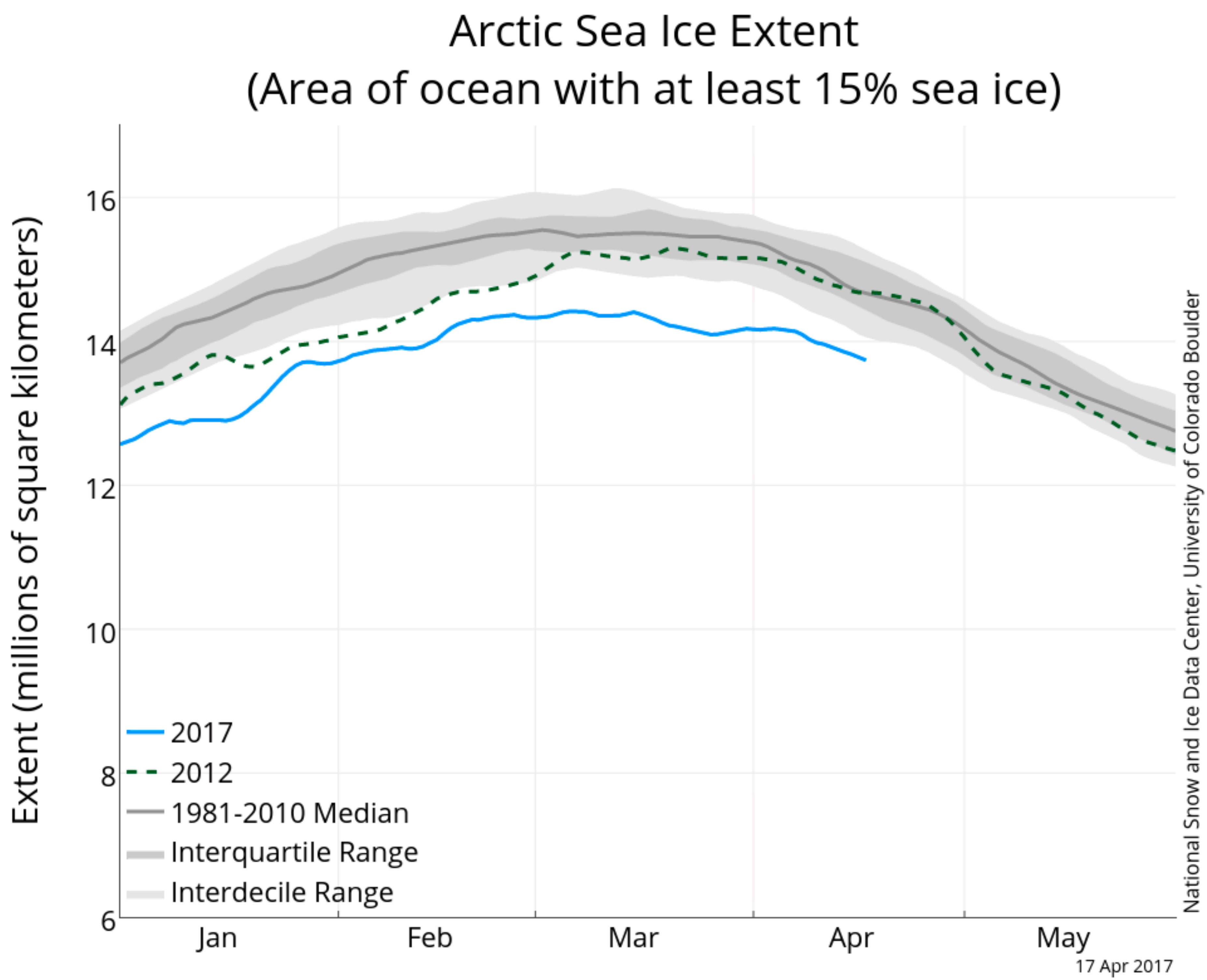
Arctic Sea-Ice Extent is Shrinking Rapidly

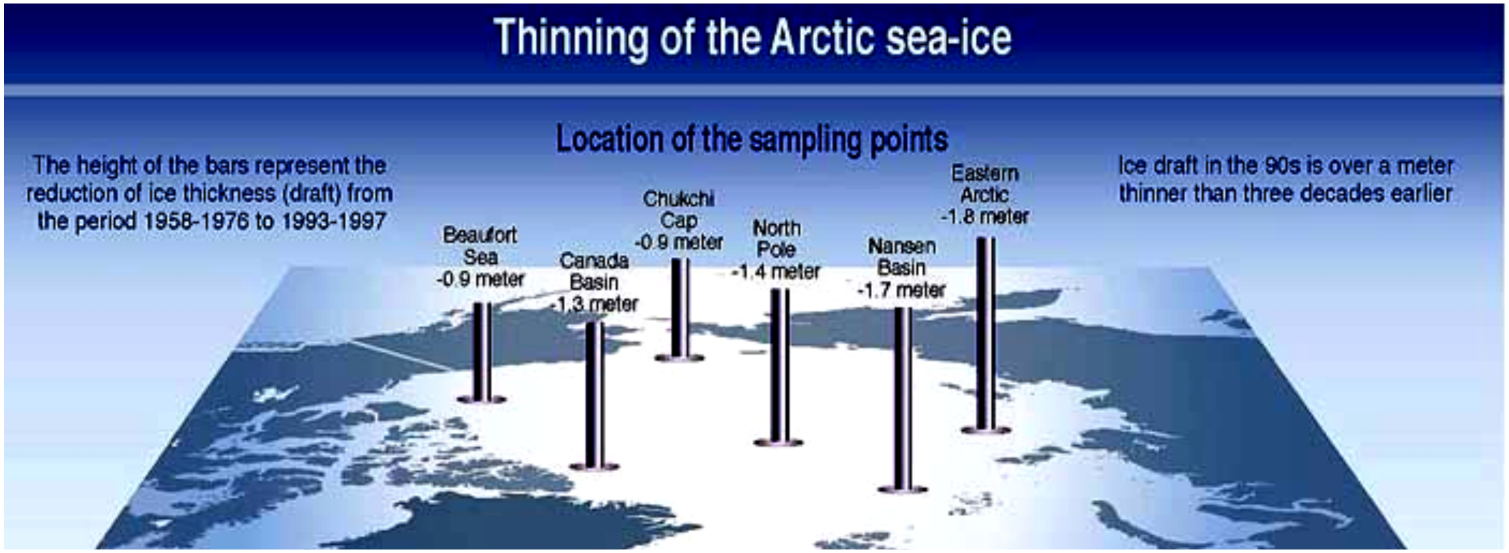
Change from 1980 to 2009





PIOMAS Daily Arctic Ice Volume
Total Ice Volume [1000 km³]
40
30
20
10
0
Jan
Feb
Mar
Apr
May
Jun
Jul
Aug
Sep
Oct
Nov
Dec
2010
2011
2012
2013
2014
2015
2016
2017
Mean Volume 1979–2016
AIR • SEA • ICE
Polar Science Center


Arctic Sea Ice Extent
(Area of ocean with at least 15% sea ice)
Extent (millions of square kilometers)
16
14
12
10
8
6
Jan
Feb
Mar
Apr
May
2017
2012
1981-2010 Median
Interquartile Range
Interdecile Range
National Snow and Ice Data Center, University of Colorado Boulder
17 Apr 2017



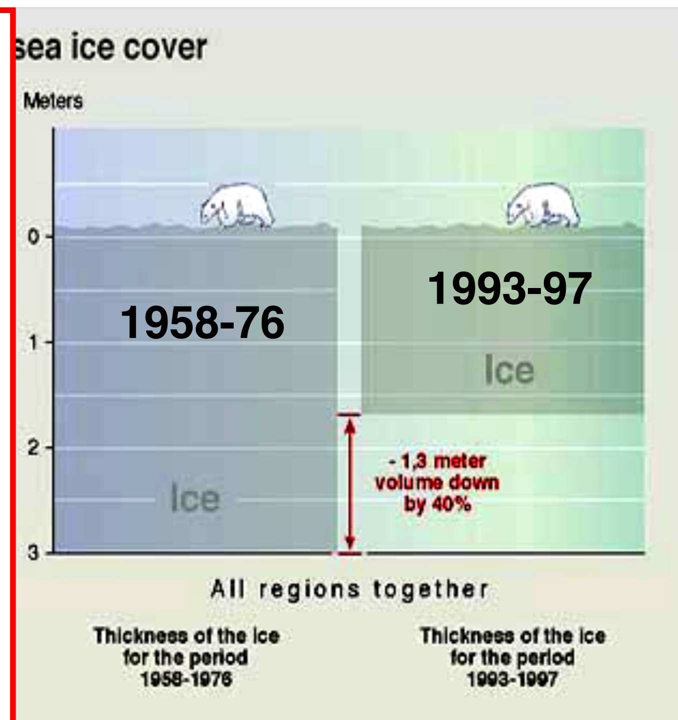
Arctic sea ice has lost half its thickness.

Warming IS having effects on other parts of the Earth System.

Science, 23 Mar 06:

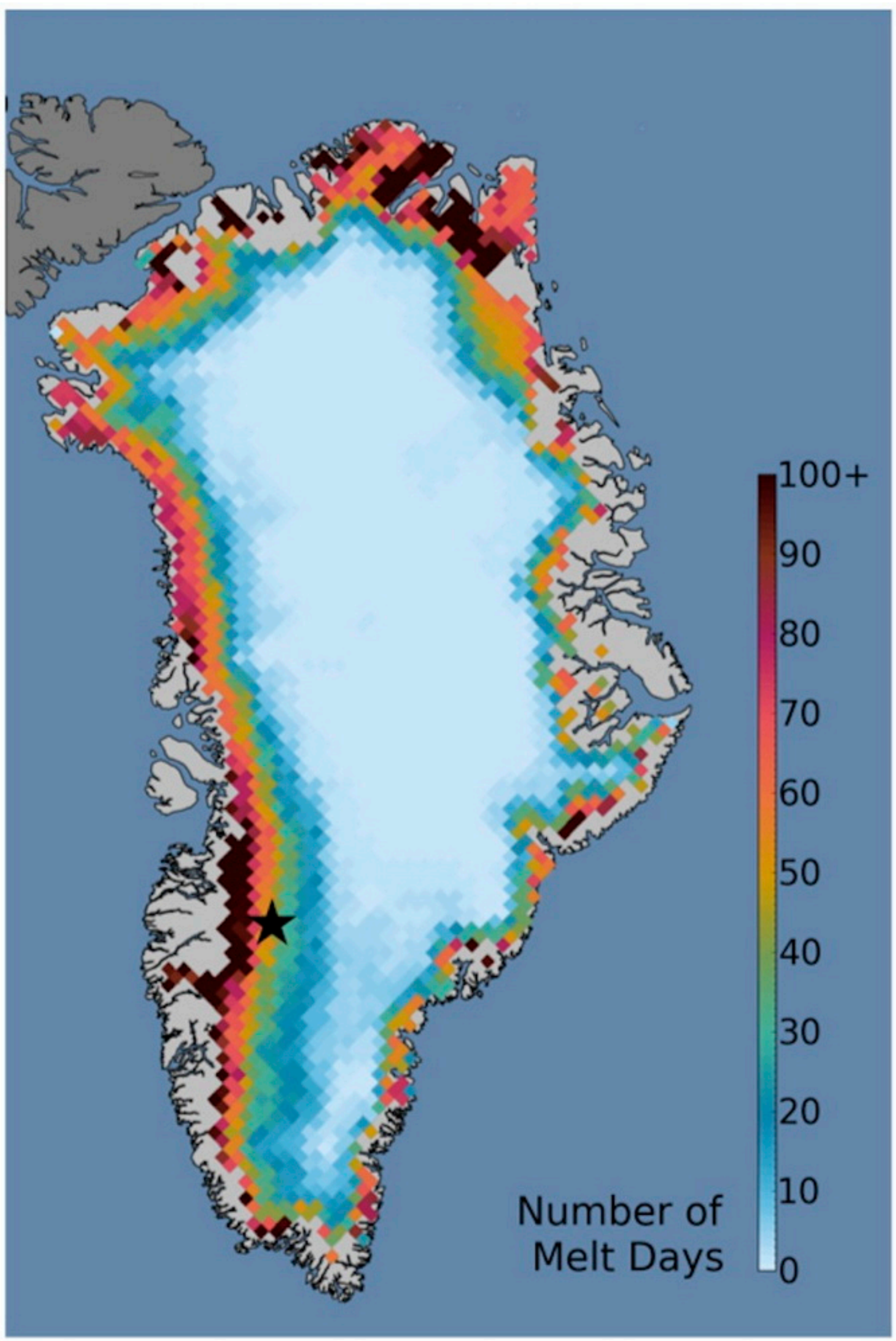
"Although the focus of our work is polar, the implications are global," says Otto-Bliesner. "These ice sheets have melted before and sea levels rose. The warmth needed isn't that much above present conditions."

The two studies show that greenhouse gas increases over the next century could warm the Arctic by 5-8 degrees Fahrenheit (3-5 degrees Celsius) in summertime. This is roughly as warm as it was 130,000 years ago, between the most recent ice age and the previous one.



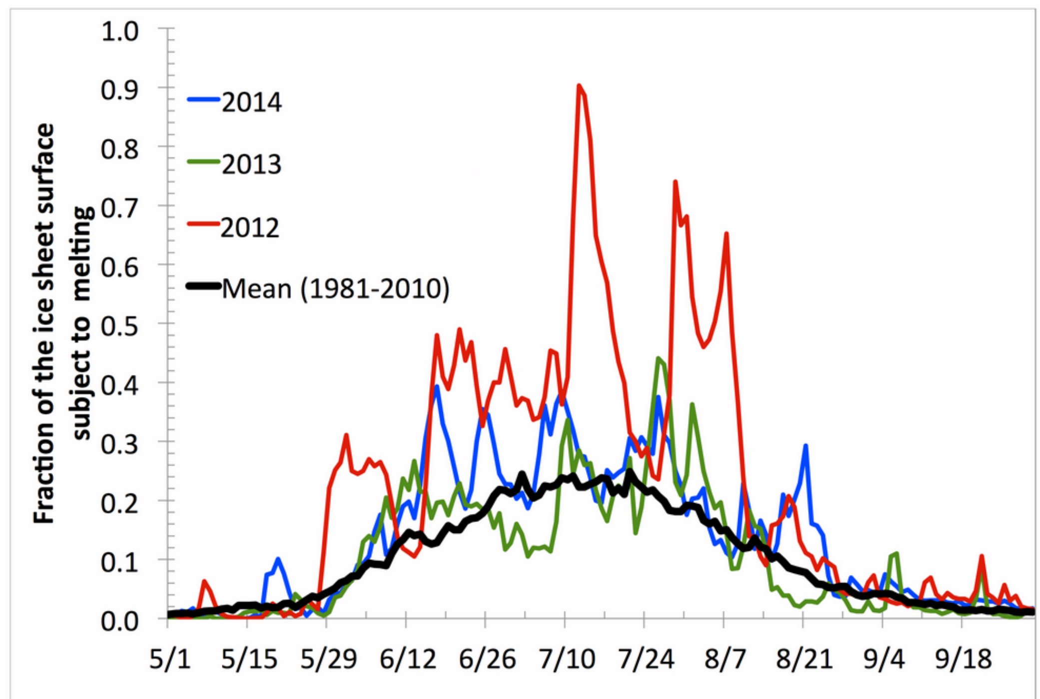
Source: http://www.grida.no/climate/vital/30.htm

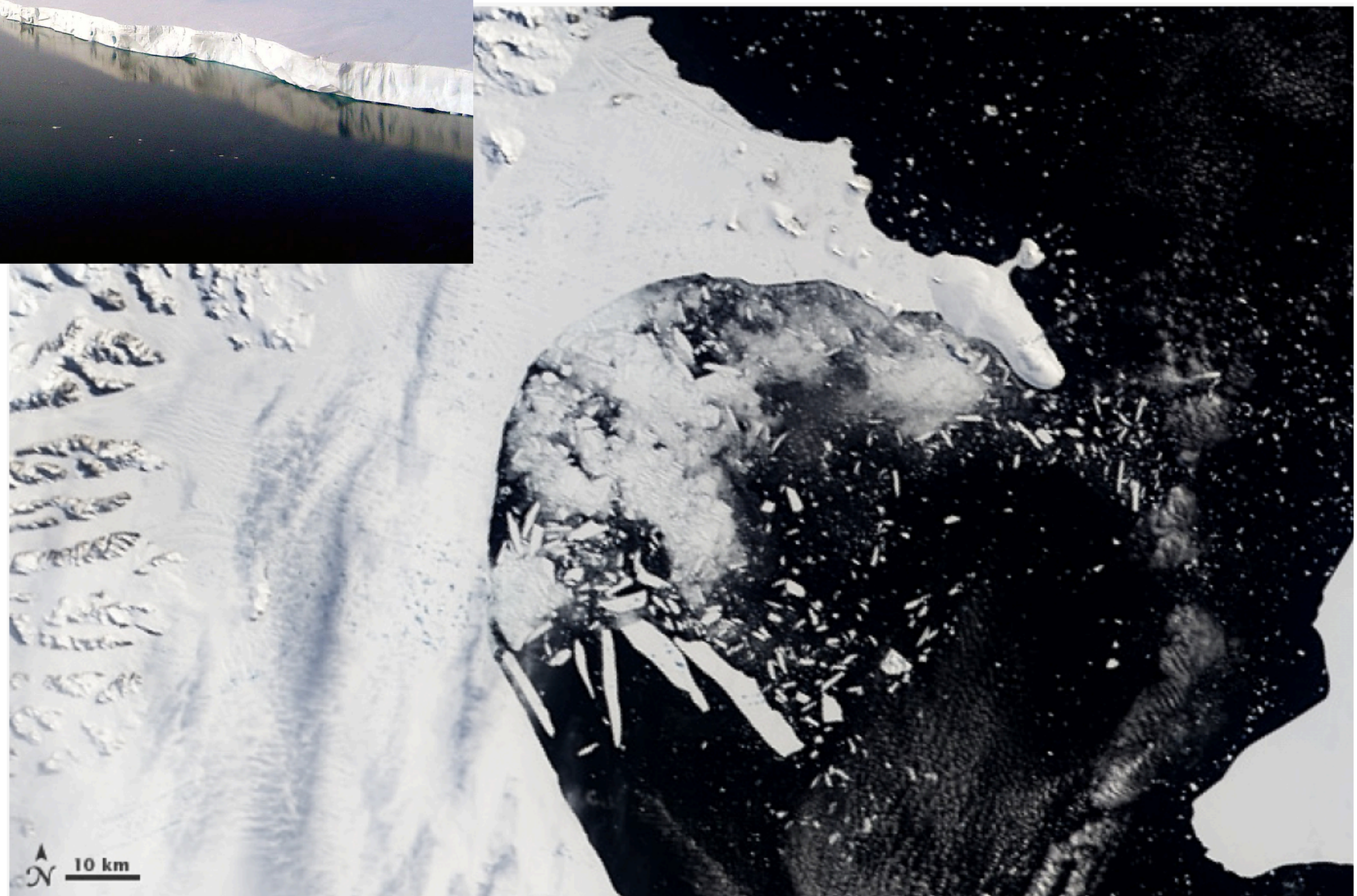
Greenland Ice Sheet



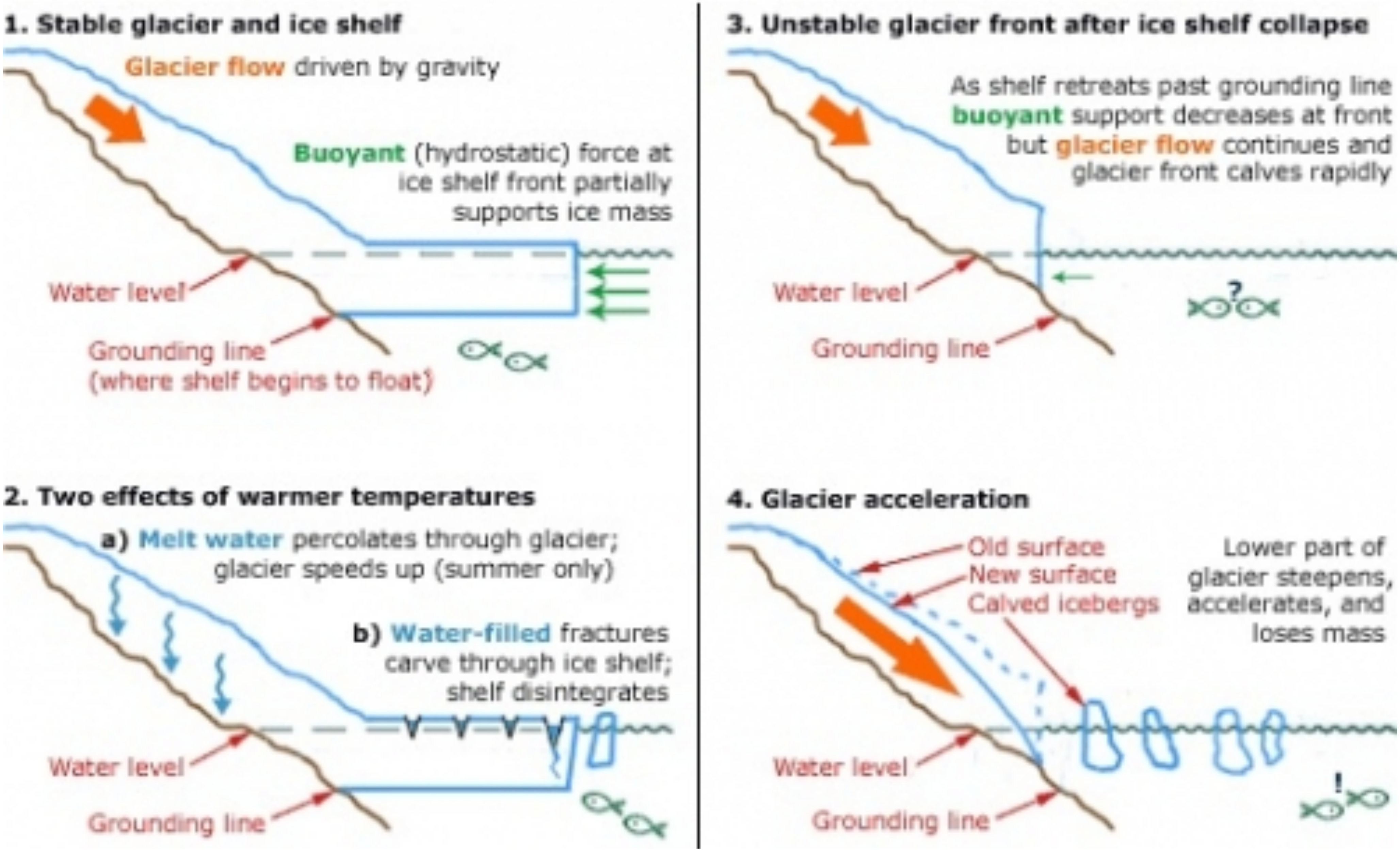
1.71 million km^2 &
volume of 2.85 million km^3

sea level equivalent of +7.4 m

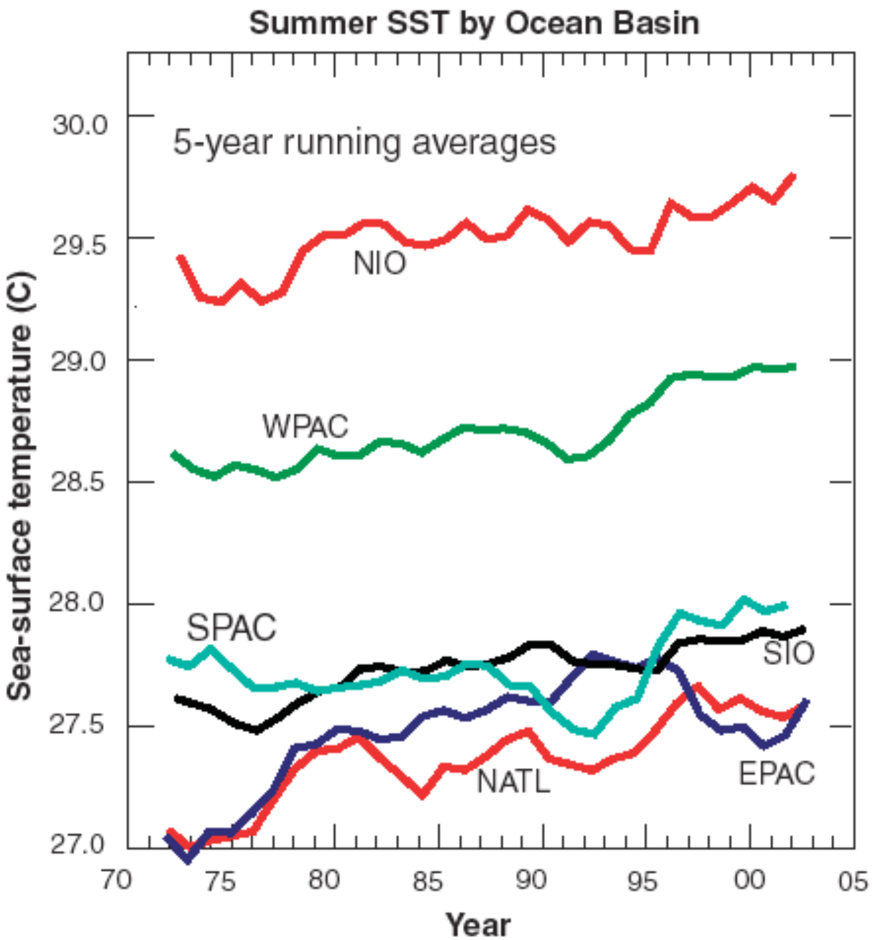


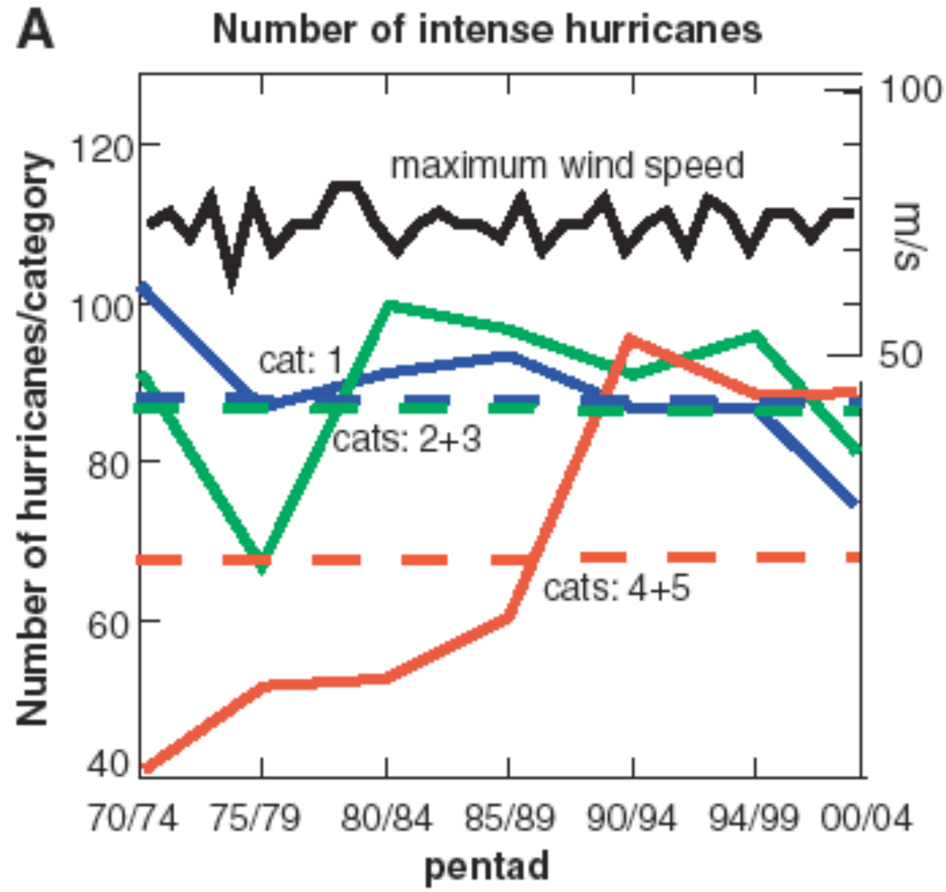


A warmer climate would melt glaciers, expand the ocean, and submerge many islands!!
Temperature Rise +1 to 3° C ⇓
Sea Level Rise +10 to 90 cm (5 to 37”)


1. Stable glacier and ice shelf
Glacier flow driven by gravity
Buoyant (hydrostatic) force at ice shelf front partially supports ice mass
Water level
Grounding line (where shelf begins to float)
2. Two effects of warmer temperatures
a) Melt water percolates through glacier; glacier speeds up (summer only)
b) Water-filled fractures carve through ice shelf; shelf disintegrates
Water level
Grounding line
3. Unstable glacier front after ice shelf collapse
As shelf retreats past grounding line buoyant support decreases at front but glacier flow continues and glacier front calves rapidly
Water level
Grounding line
4. Glacier acceleration
Old surface
New surface
Calved icebergs
Lower part of glacier steepens, accelerates, and loses mass
Water level
Grounding line

Hurricanes are becoming more intense





Webster et al., *Science*, *309*, 1844-1846, 2005

The number of Category 4 and 5 hurricanes worldwide has nearly doubled over the past 35 years, even though the total number of hurricanes has dropped since the 1990s. The shift occurred as global sea surface temperatures have increased over the same period. This is compelling evidence that *global climate change is making tropical storms more powerful and more damaging.*

SCIENTIFIC REPORTS

OPEN

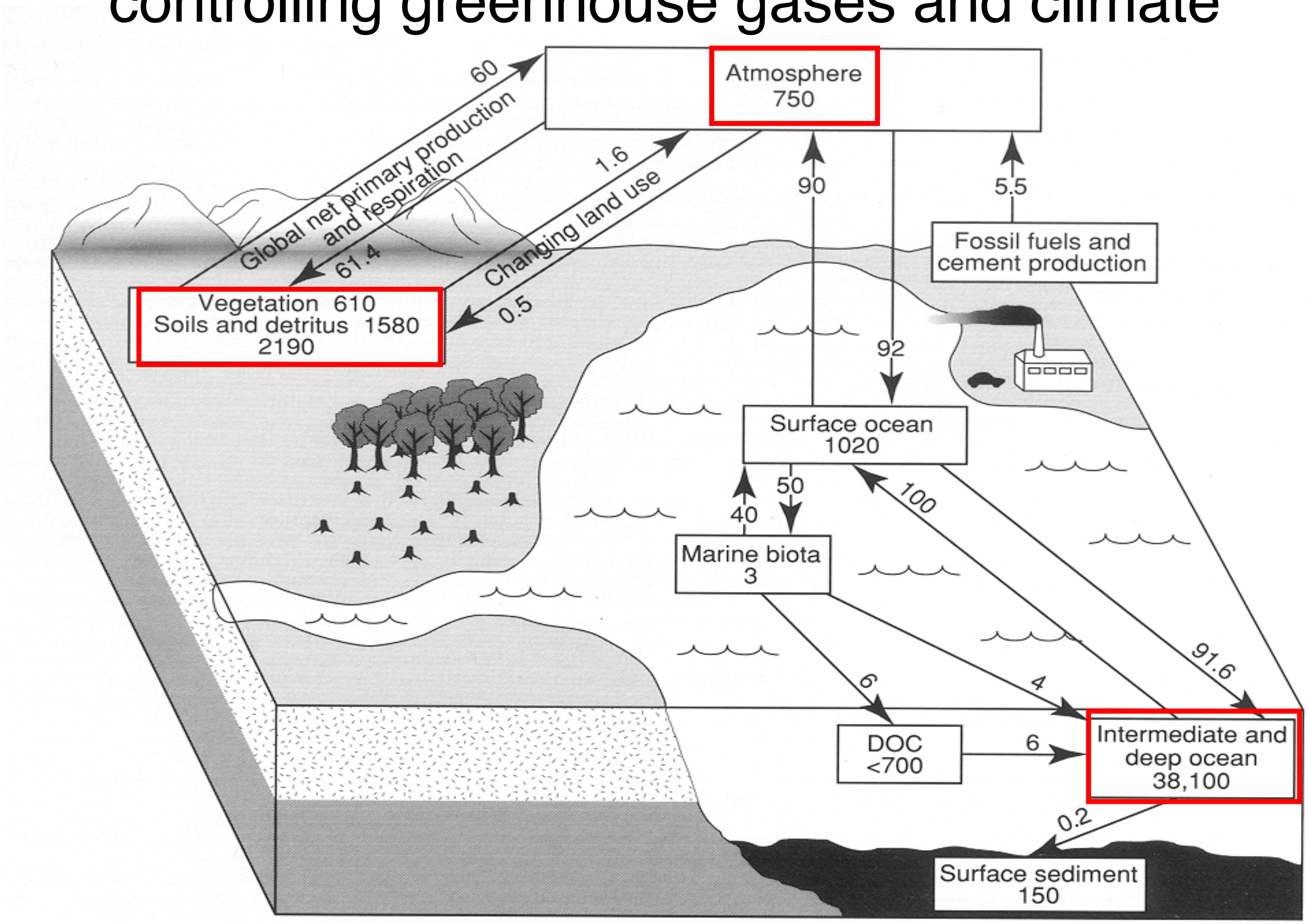
Influence of Anthropogenic Climate Change on Planetary Wave Resonance and Extreme Weather Events

Received: 03 January 2017
Accepted: 20 February 2017
Published: 27 March 2017

Michael E. Mann[1], Stefan Rahmstorf[2], Kai Kornhuber[2], Byron A. Steinman[3], Sonya K. Miller[1] & Dim Coumou[2,4]

Persistent episodes of extreme weather in the Northern Hemisphere summer have been shown to be associated with the presence of high-amplitude quasi-stationary atmospheric Rossby waves within a particular wavelength range (zonal wavenumber 6–8). The underlying mechanistic relationship involves the phenomenon of quasi-resonant amplification (QRA) of synoptic-scale waves with that wavenumber range becoming trapped within an effective mid-latitude atmospheric waveguide. Recent work suggests an increase in recent decades in the occurrence of QRA-favorable conditions and associated extreme weather, possibly linked to amplified Arctic warming and thus a climate change influence. Here, we isolate a specific fingerprint in the zonal mean surface temperature profile that is associated with QRA-favorable conditions. State-of-the-art ("CMIP5") historical climate model simulations subject to anthropogenic forcing display an increase in the projection of this fingerprint that is mirrored in multiple observational surface temperature datasets. Both the models and observations suggest this signal has only recently emerged from the background noise of natural variability.

Most carbon has been stored in the ocean*. It plays a huge role in controlling greenhouse gases and climate



Global Carbon Cycle   Reservoirs in GtC and fluxes in GtC/yr

*although most of the CO_2 man has released is still in the atmosphere.

Since 1800 - Sources: Land Use Chg 140; Fossil Fuel 265 Gt C

Uptake: Oceans 115; Terrestrial 110; Atmosphere 189 Gt C

Burning of coal, oil, and natural gas is converting fossil C to CO_2. Much stays in the air!

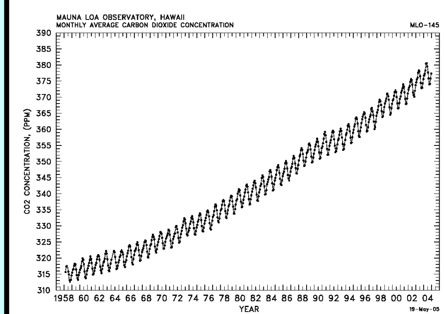
CO_2 Emissions and uptake since 1800 (Gt C)

CO_2 Emissions

Deforestation	140 **Land use change**
Coal, Oil, Natural gas, Cement making	265 **Fossil emissions**

Where the CO_2 goes

115 **Oceans**	28% has gone into the ocean
110 **Terrestrial**	Reforestation
180 **Atmosphere**	



Our fuel burning is converting fossilized carbon (coal, oil, and natural gas) into CO_2.

45% of it stays in the air

We can look at ice cores to see that CO_2 was pretty constant for the last 1000 years. The rapid increase began about the time of the industrial revolution

Climate models are of necessity *gross simplifications of reality*.

By comparing them with the past behavior of the planet, as found in paleoclimate records such as sediments and ice cores.

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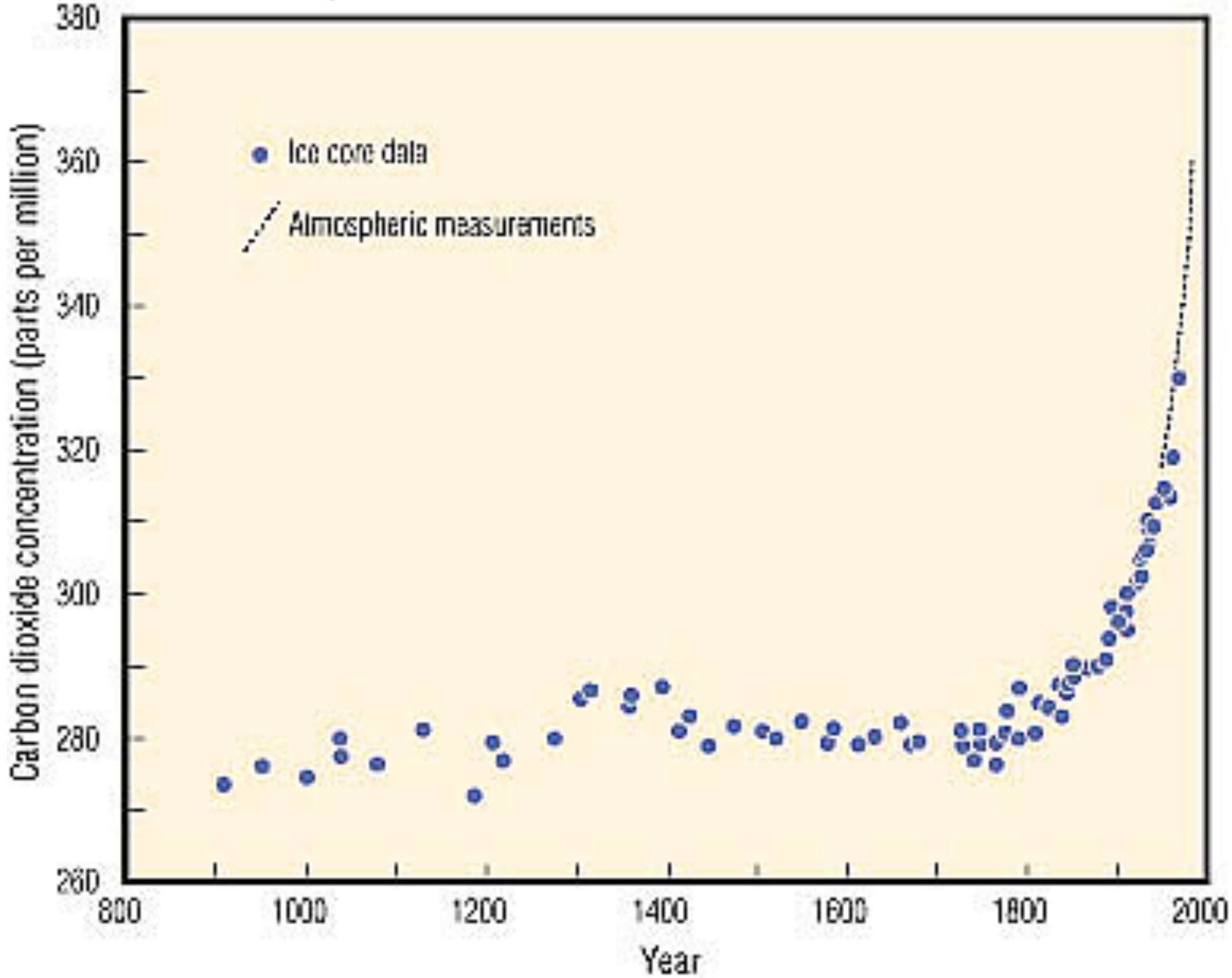
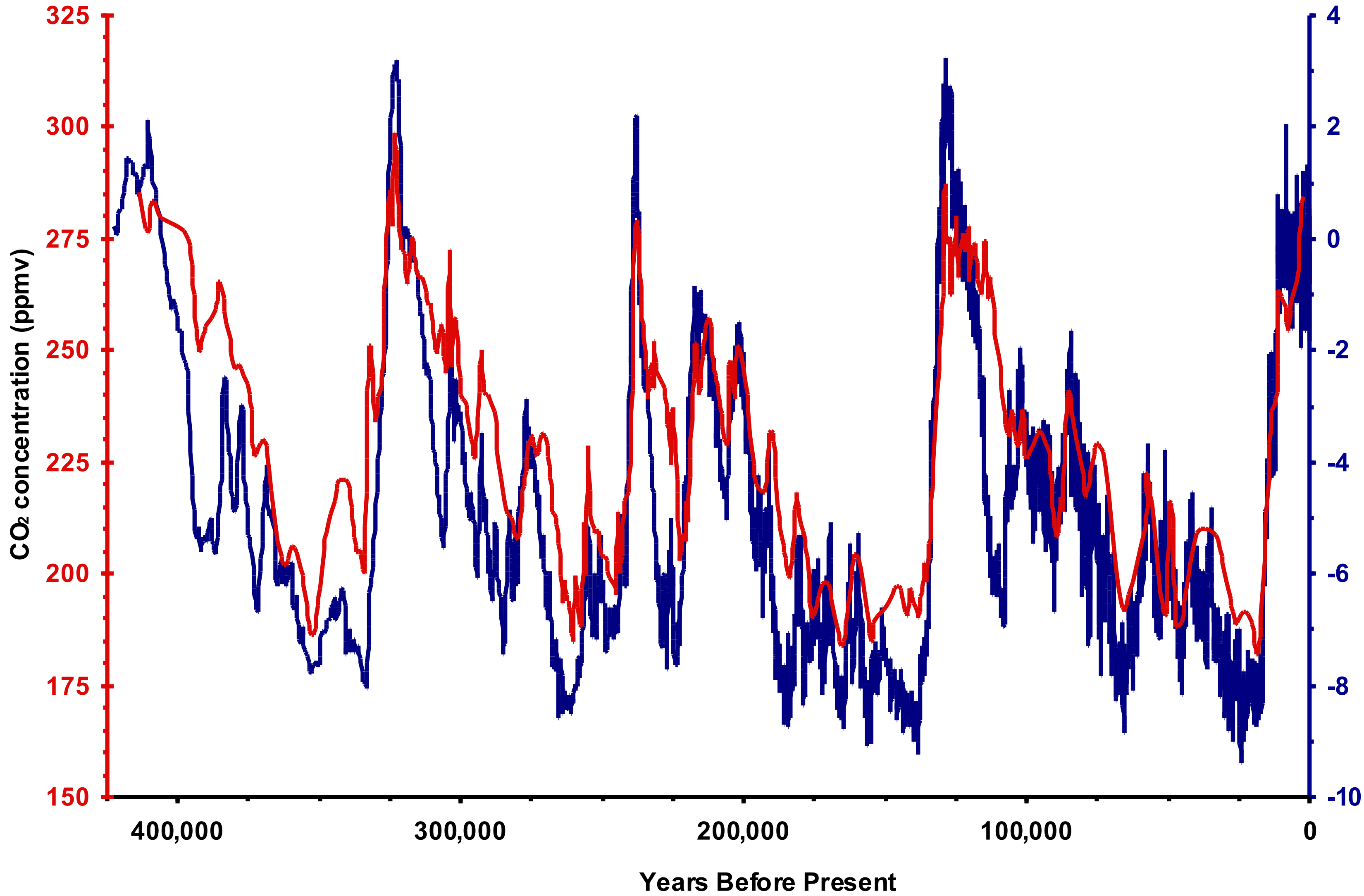
The rapid increase began about the time of the industrial revolution



Mauna Loa Monthly Carbon Dioxide Record: Keeling Record 1958 - 1999
CO_2 is the most important greenhouse gas, which prevents the escape of IR that would normally cool the Earth.

Are global temperatures linked to atmospheric CO_2 ?

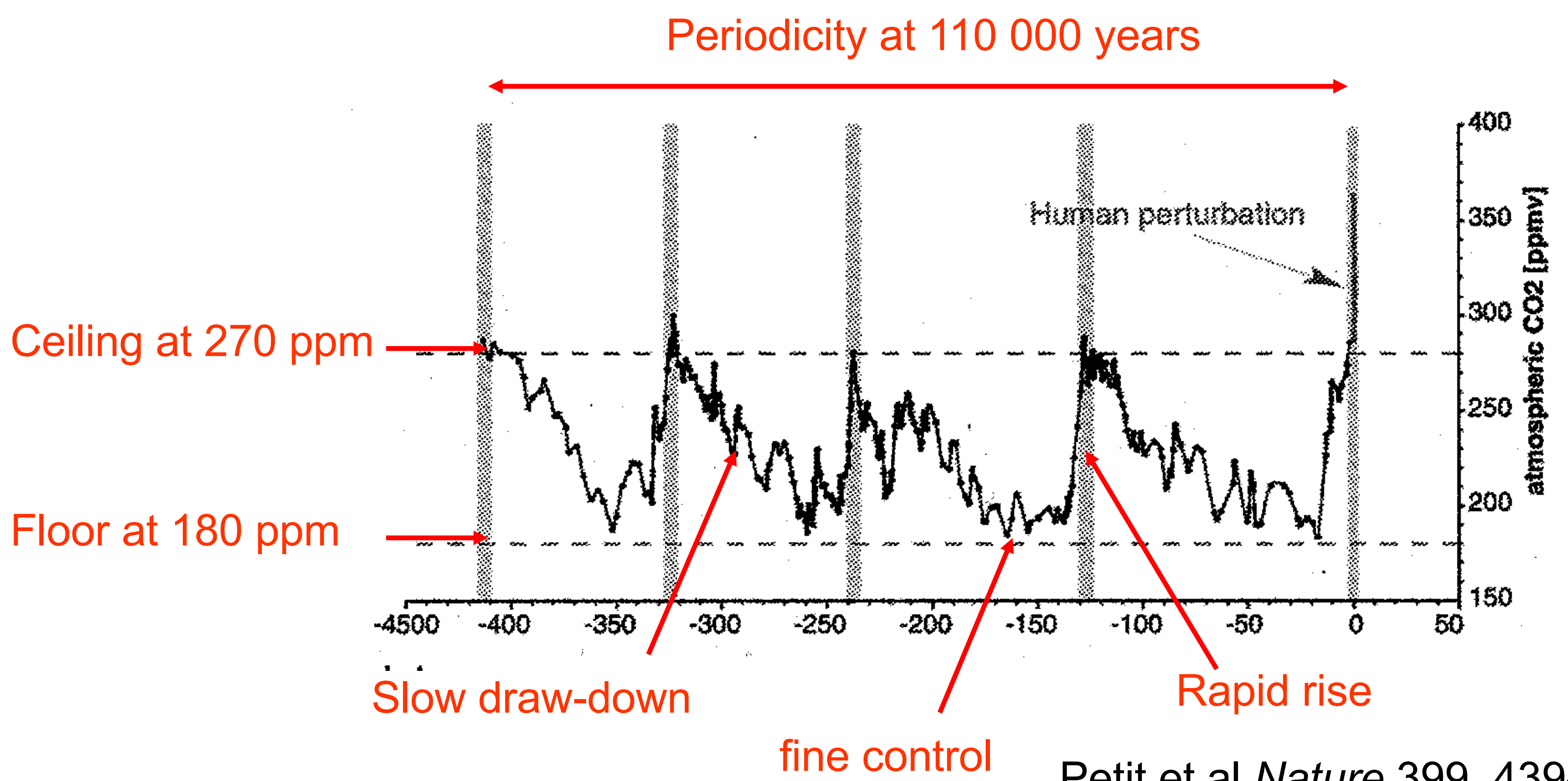
Vostok Ice Core CO_2 Concentration and Temperature Variation Record



IPCC: "Global mean surface temperature has increased more than 0.5˚C since the beginning of the 20th century, with this warming likely being the largest during any century over the past 1,000 years for the Northern hemisphere."

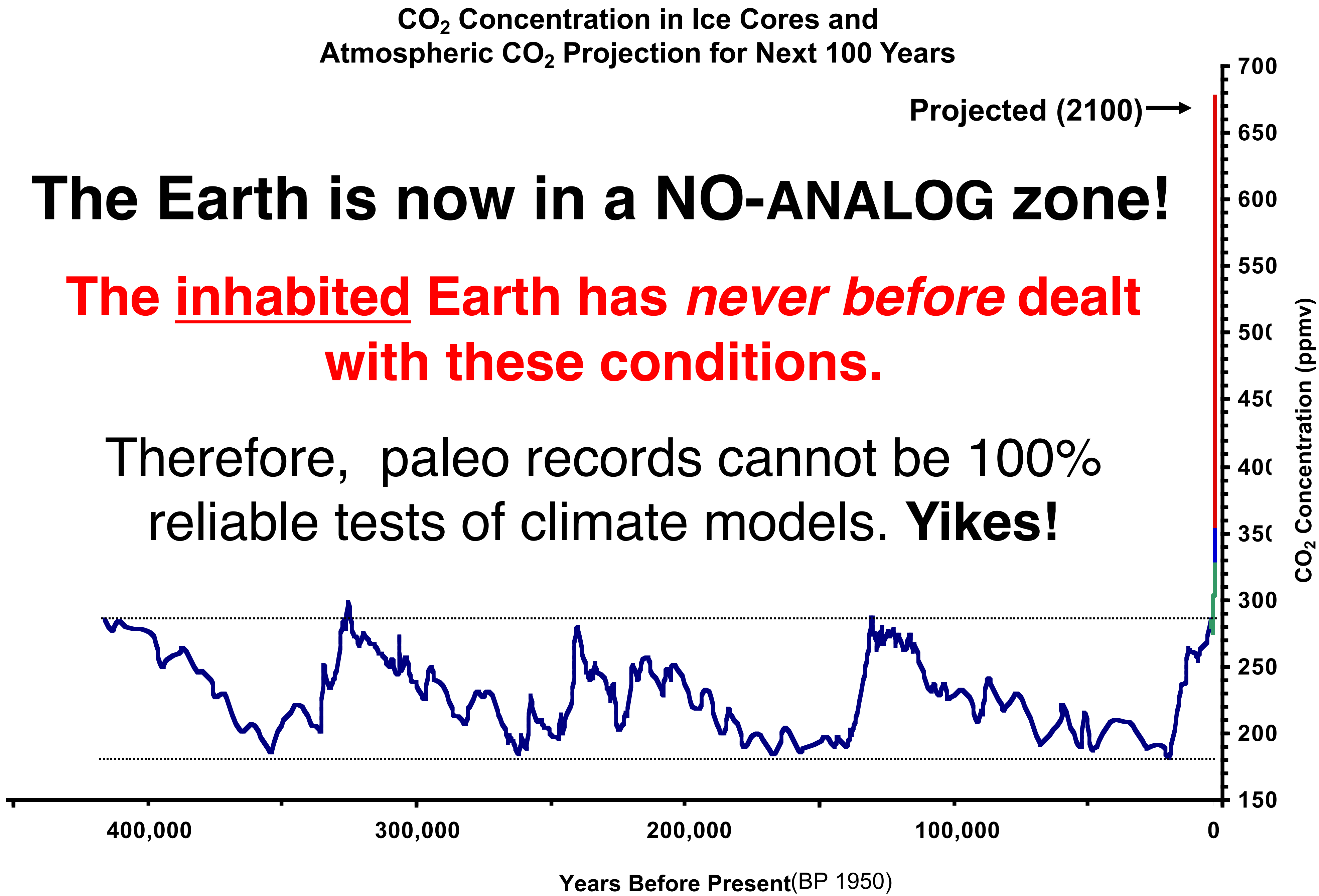
What can we learn from these records?

Does CO_2 *cause* temperature change, or is it a *response* to temperature change?



Petit et al *Nature* 399, 439-46

Temperature and CO_2 vary in concert over the last 400,000 years.



The Earth is now in a NO-ANALOG zone!

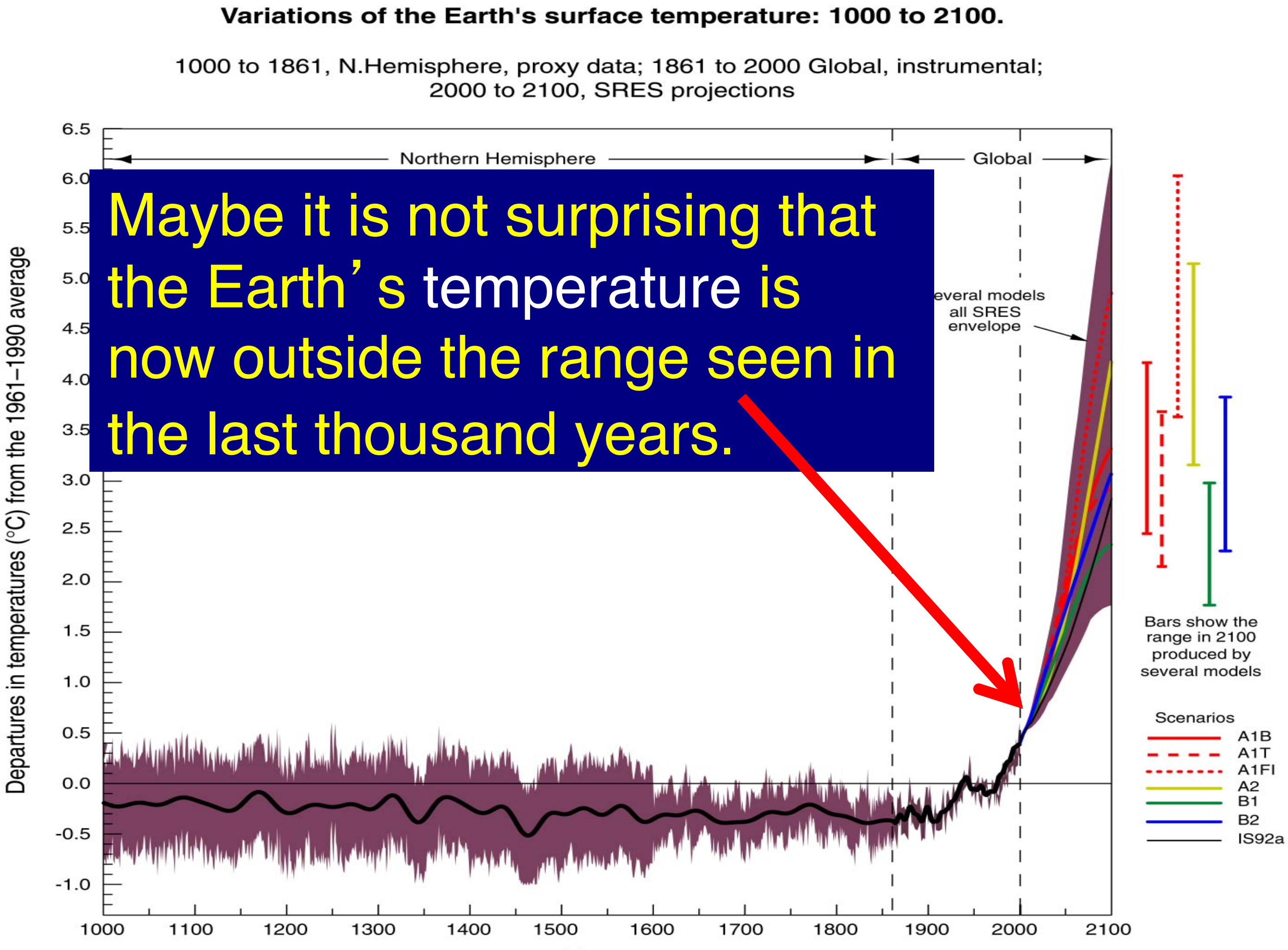
The <u>inhabited</u> Earth has *never before* dealt with these conditions.

Therefore, paleo records cannot be 100% reliable tests of climate models. **Yikes!**

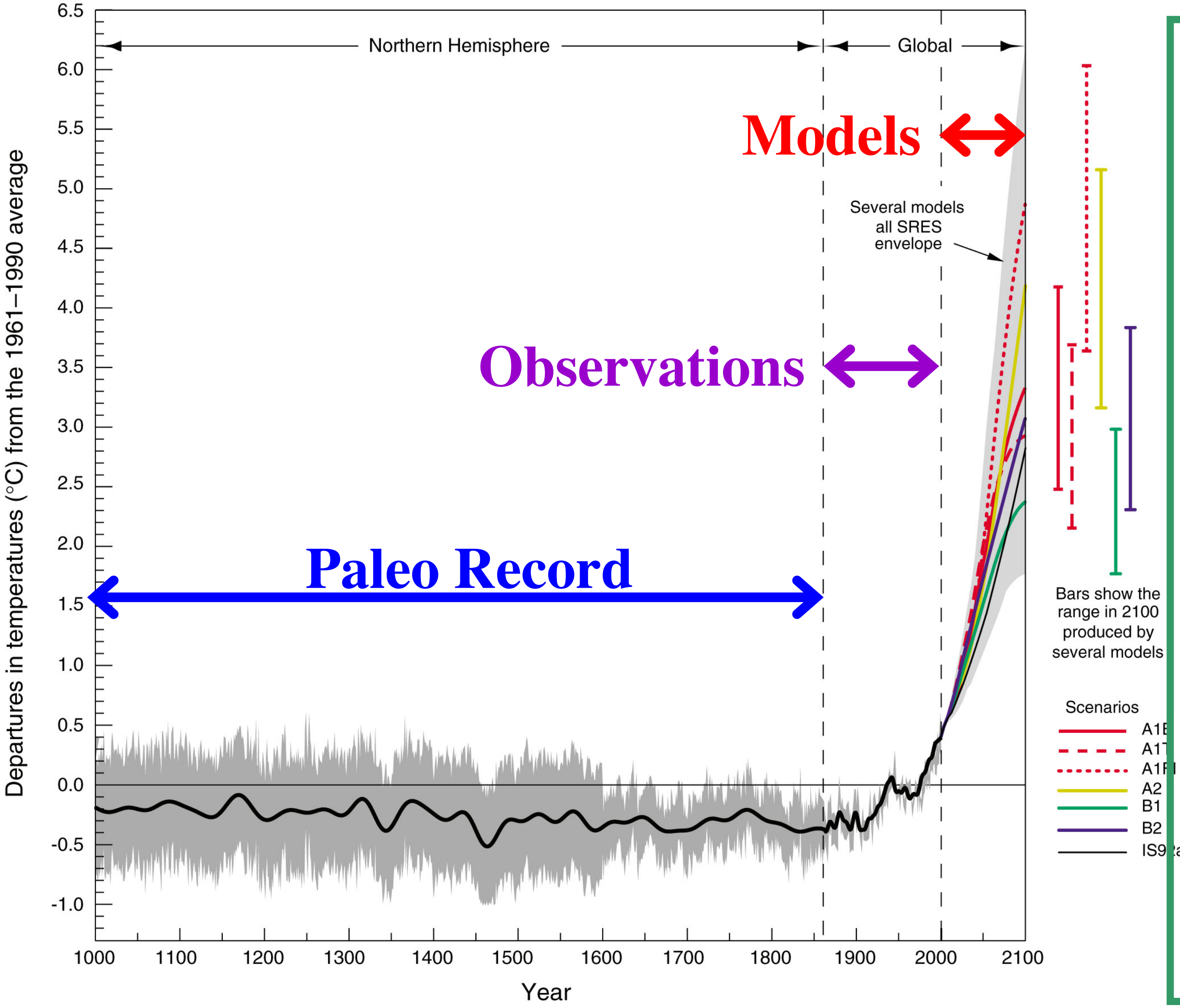
What can we learn from these records?

Does CO_2 *cause* temperature change, or is it a *response* to temperature change?

What about the recently-rising temperatures - are they natural variability? **No way!**



The Earth is now in a NO-ANALOG zone!
The inhabited Earth has *never before* dealt with these conditions.
Therefore, paleo records cannot be 100% reliable tests of climate models.



Model predictions from IPCC:

"Global temperature will rise from 1.4-5.8˚C over this century *unless greenhouse gas emissions are greatly reduced.*"

Those predictions come from **Numerical Computer Models** to synthesize all our quantitative knowledge of the Earth's energy flows, greenhouse gases, land use changes, etc.

This is an extremely complex system, so the models are of necessity *gross simplifications of reality*.

How can we be sure models are giving us realistic predictions?

By comparing them with the past behavior of the planet, as found in paleoclimate records such as sediments and ice cores.

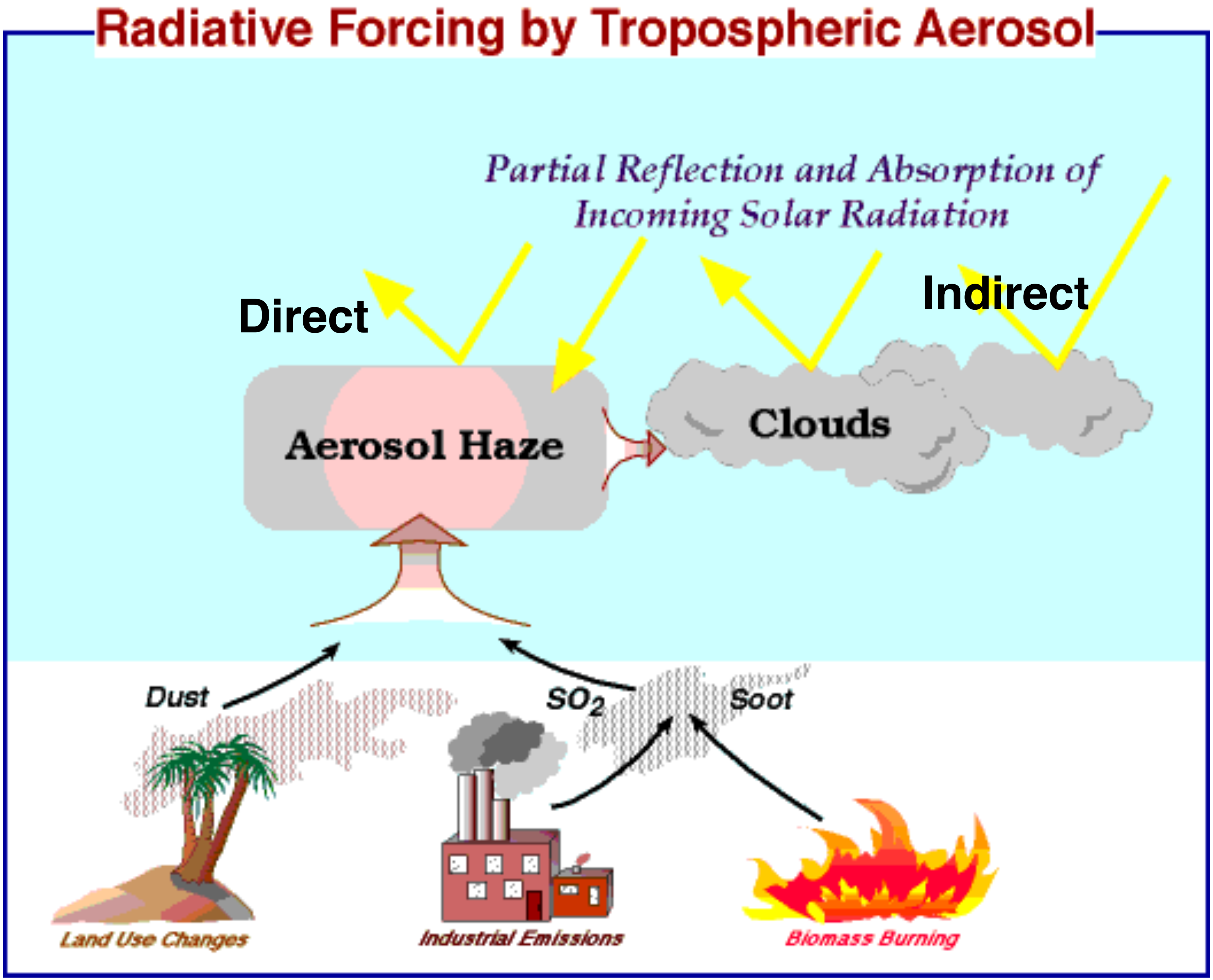
Climate Forcing vs Response

Climate Forcing is a change from pre-industrial radiation budget values, for either incoming shortwave (solar) radiation or outgoing longwave (thermal IR) radiation. It is a straightforward energy flux measure. The forcing depends on gas and aerosol concentrations as well as cloud distributions and properties, so it is not independent of the response.

Climate Response is the climatic result of forcing plus all the related feedback processes that determine winds, precipitation, and temperatures. The response can only be determined by models that simulate the whole range of processes affecting climate.

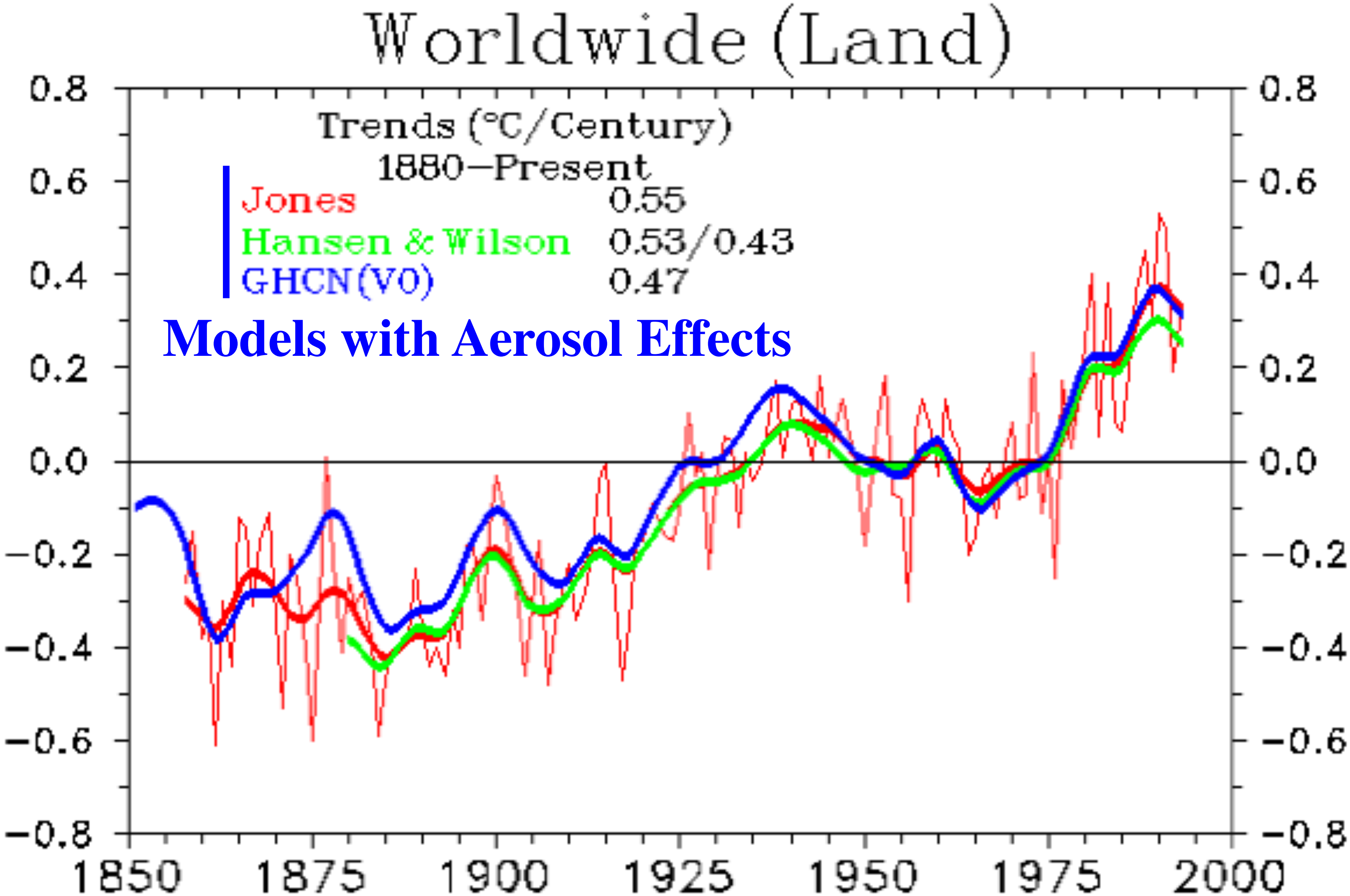
Why is the light at Miyajima different in these two photos?

Beijing “haze alerts”



Radiative Forcing by Tropospheric Aerosol
Partial Reflection and Absorption of Incoming Solar Radiation
Direct
Indirect
Aerosol Haze
Clouds
Dust
SO2
Soot
Land Use Changes
Industrial Emissions
Biomass Burning

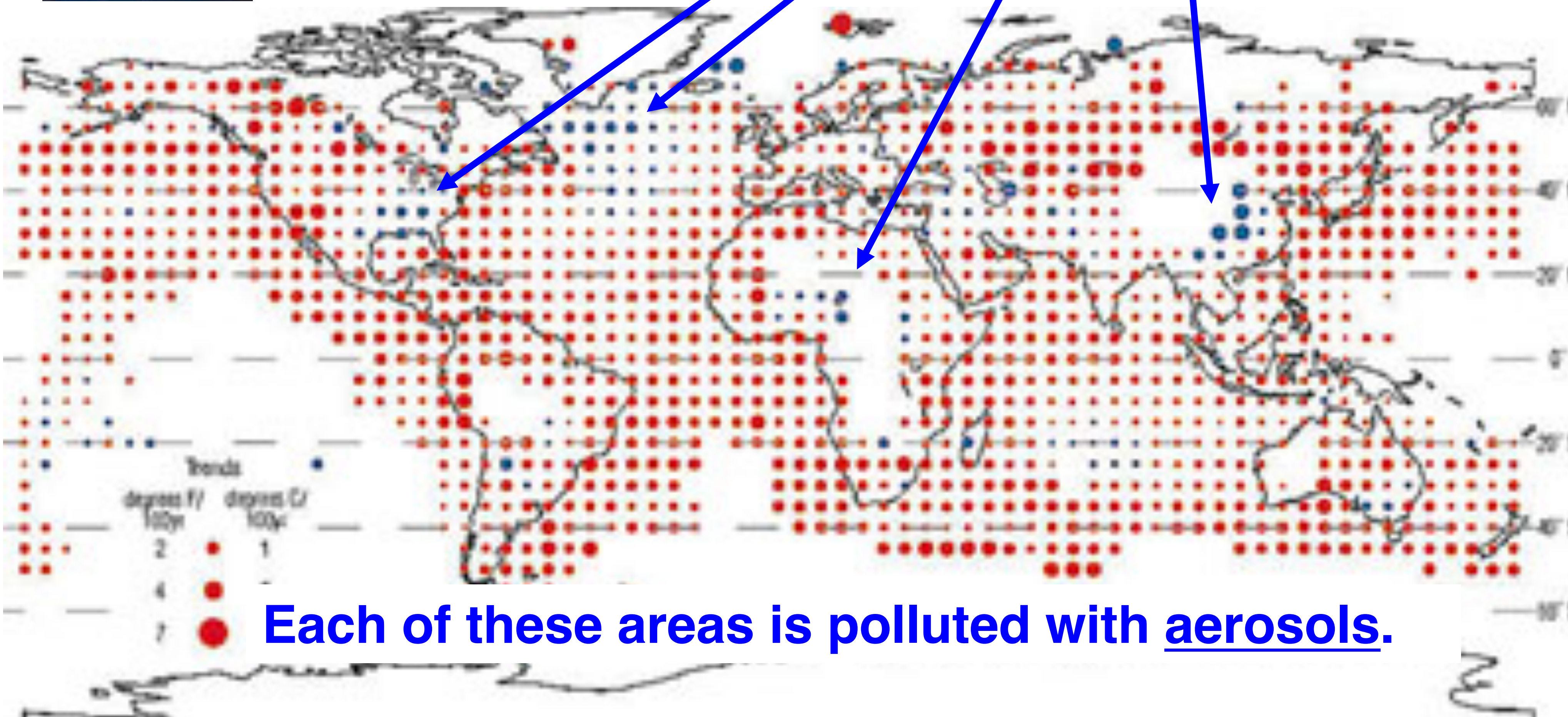
Models do much better when they include aerosols, even using crudely understood aerosol effects.



Climate Models didn't do a very good job of reproducing temperature trends in the last 150 years when they did not include aerosol impacts.

Not every place is warming, though - the **blue spots** are areas that have been **cooling**.

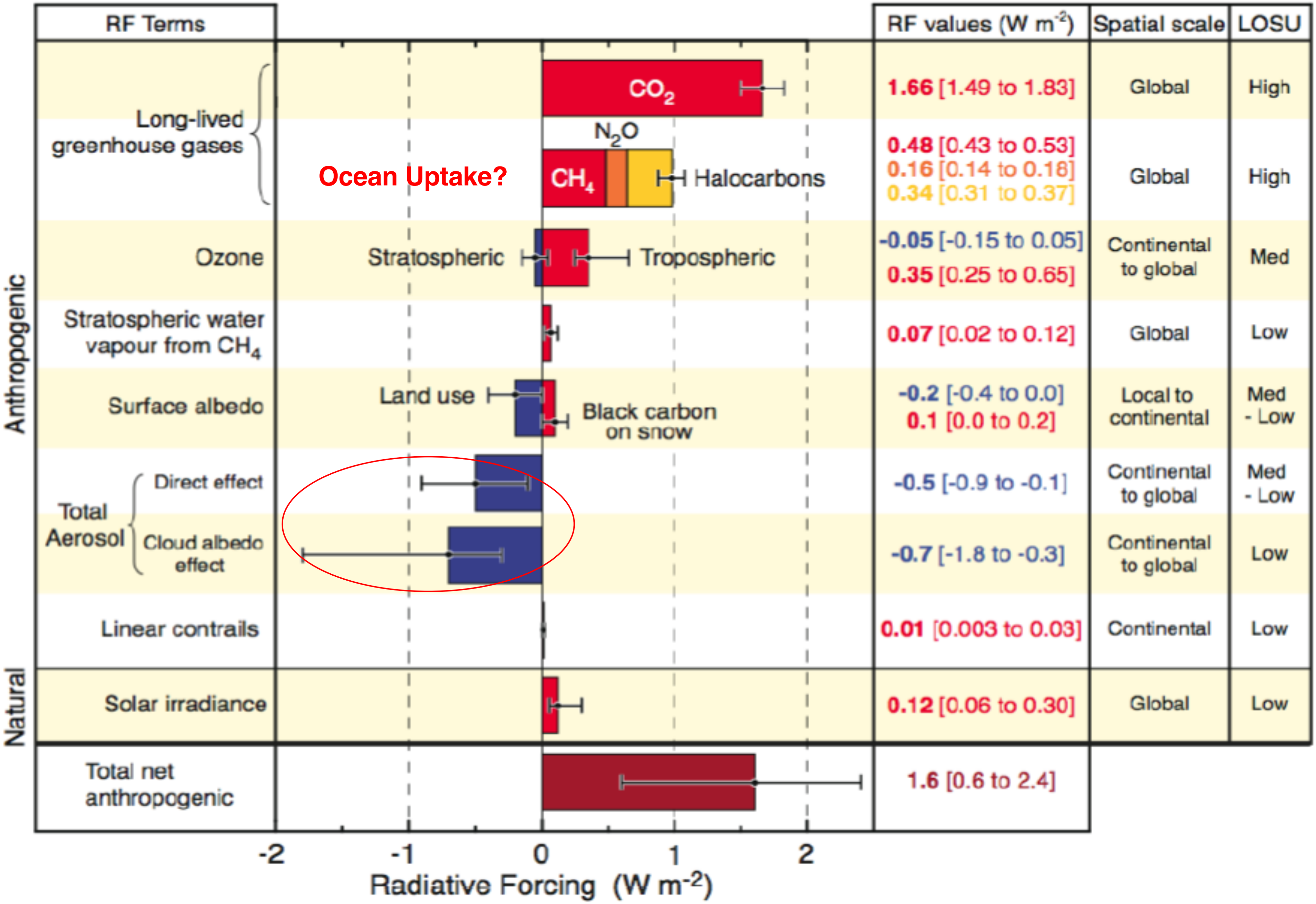
How could that be?



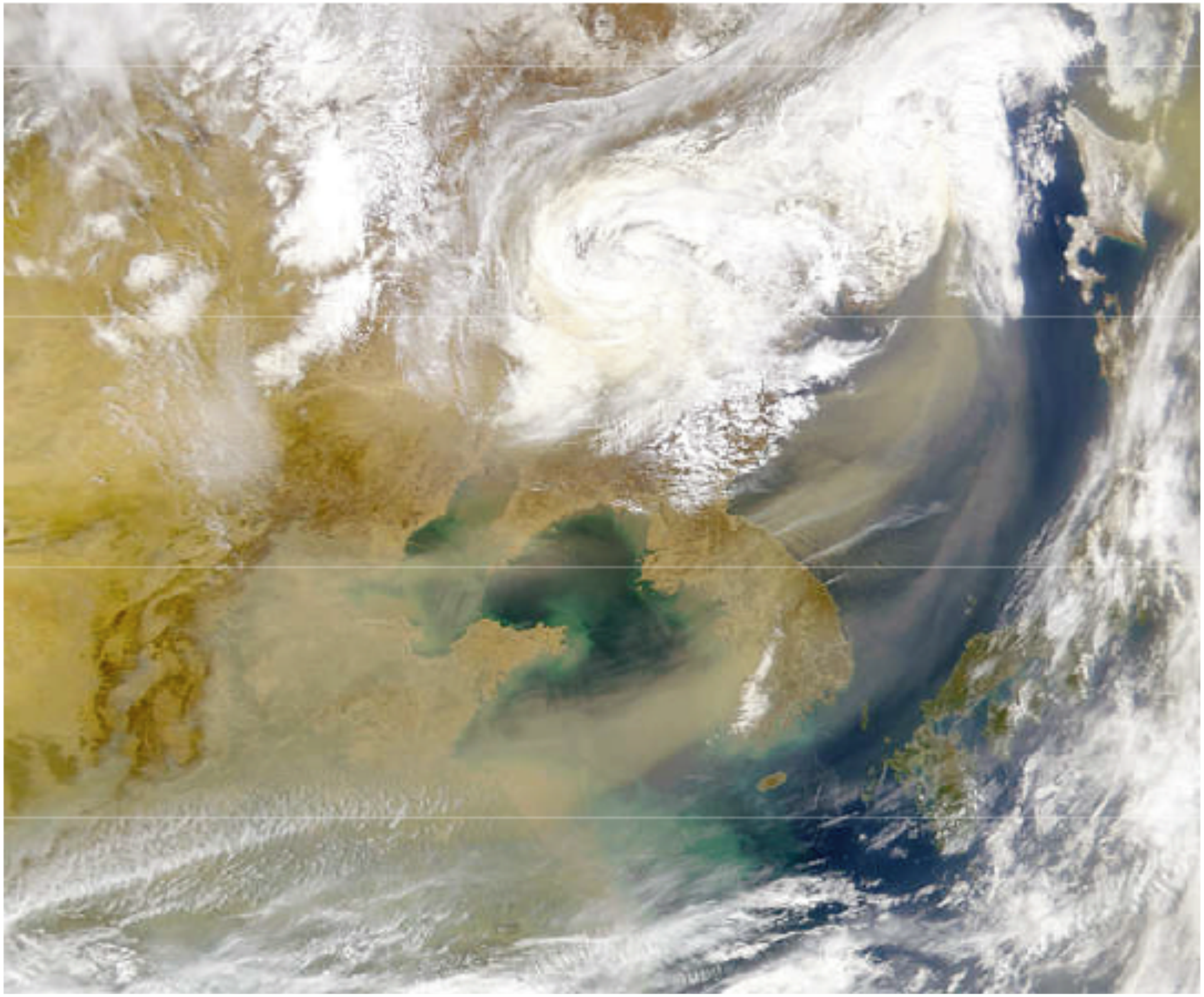
Each of these areas is polluted with aerosols.

Model predictions from IPCC: Global temperature will rise from 1.4-5.8˚C over this century unless greenhouse gas emissions are greatly reduced

Radiative Forcing Components



Smoke and dust both affect the climate



The **whitest** things (most reflective of sunlight) in this SeaWiFS image are **clouds**.

Changing the extent or density of clouds is called the radiative **indirect effect on climate**

Dust can impact climate, both by reflecting light to space and by absorbing light
Where dust is, there is more light reflected back to the satellite than over the dark ocean

Intergovernmental Panel on Climate Change

5th Assessment Report (FAR) Nov 2014

"Human influence on the climate system is clear, and recent anthropogenic emissions of green- house gases are the highest in history. Recent climate changes have had widespread impacts on human and natural systems."

"Warming of the climate system is unequivocal, and since the 1950s, many of the observed changes are unprecedented over decades to millennia. The atmosphere and ocean have warmed, the amounts of snow and ice have diminished, and sea level has risen."

IPCC, 2014: *Climate Change 2014: Synthesis Report. Contribution of Working Groups I, II and III to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change*

Intergovernmental Panel on Climate Change

5th Assessment Report (FAR)   Nov. 2014

"Ocean warming dominates the increase in energy stored in the climate system, accounting for more than 90% of the energy accumulated between 1971 and 2010 (*high confidence*), with only about 1% stored in the atmosphere. On a global scale, the ocean warming is largest near the surface, and the upper 75 m warmed by 0.11 [0.09 to 0.13] ° C per decade over the period 1971 to 2010. It is *virtually certain* that the upper ocean (0–700 m) warmed from 1971 to 2010, and it *likely* warmed between the 1870s and 1971."

IPCC, 2014: ***Climate Change 2014: Synthesis Report. Contribution of Working Groups I, II and III to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change***

Intergovernmental Panel on Climate Change
5th Assessment Report (FAR) Nov. 2014

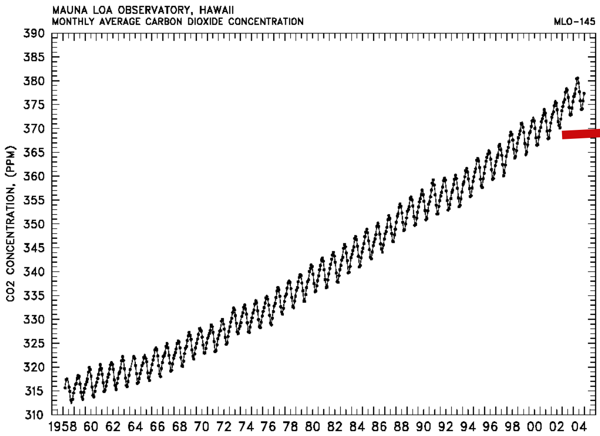
"Averaged over the mid-latitude land areas of the Northern Hemisphere, precipitation has increased since 1901 (*medium confidence* before and *high confidence* after 1951). For other latitudes, area-averaged long-term positive or negative trends have *low confidence*.

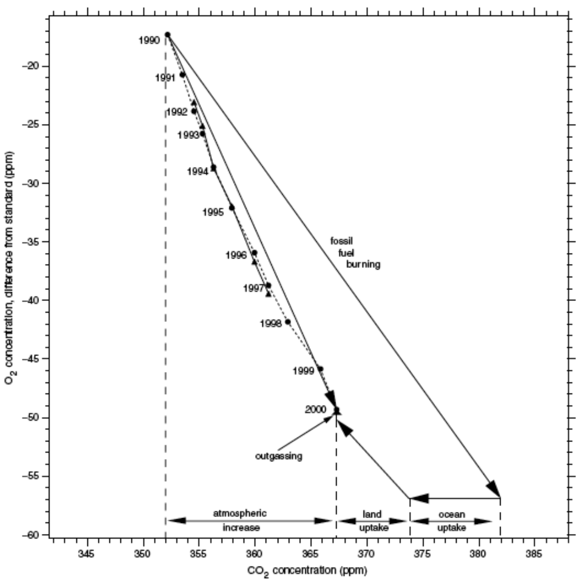
Observations of changes in ocean surface salinity also provide indirect evidence for changes in the global water cycle over the ocean (*medium confidence*). It is *very likely* that regions of high salinity, where evaporation dominates, have become more saline, while regions of low salinity, where precipitation dominates, have become fresher since the 1950s.

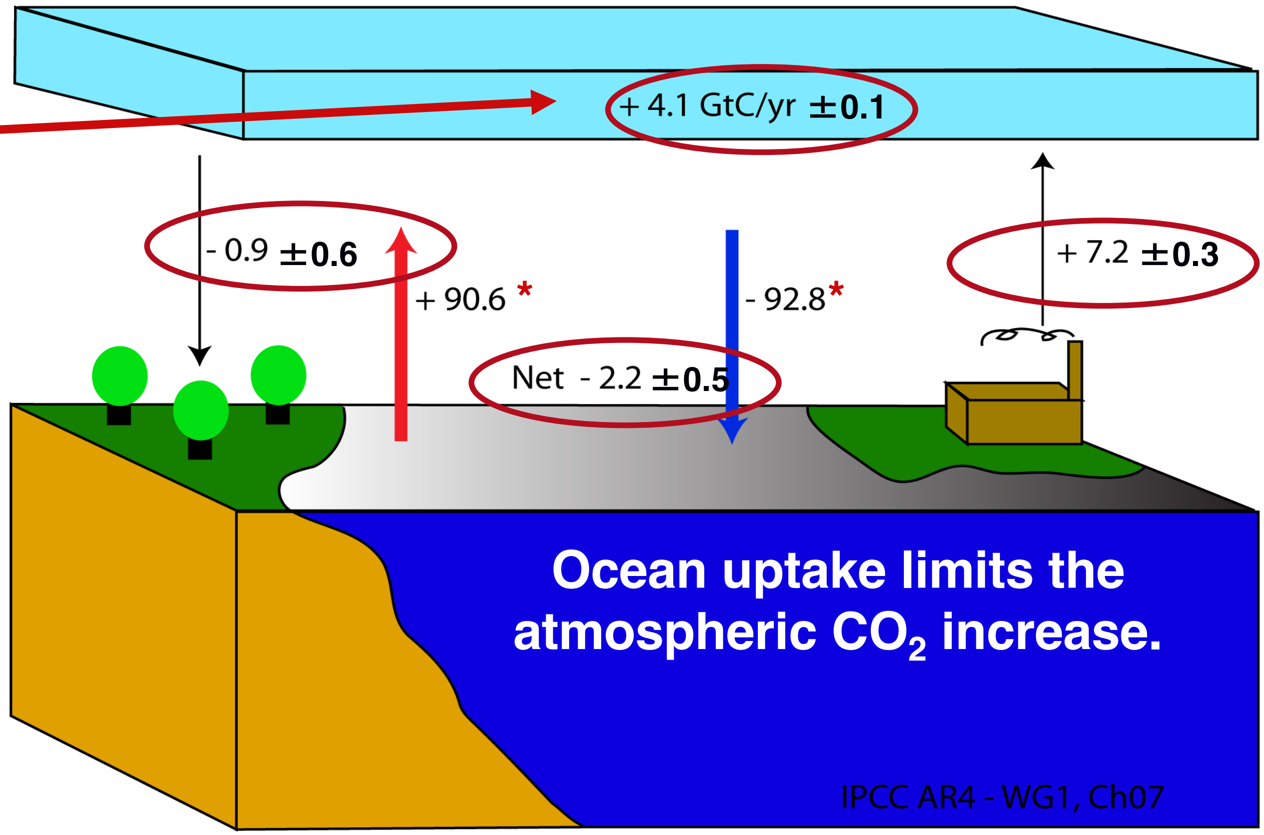
Since the beginning of the industrial era, oceanic uptake of CO2 has resulted in acidification of the ocean; **the pH of ocean surface water has decreased by 0.1 (*high confidence*), corresponding to a 26% increase in acidity**, measured as hydrogen ion concentration."

IPCC, 2014: *Climate Change 2014: Synthesis Report. Contribution of Working Groups I, II and III to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change*

The contemporary carbon budget is well constrained, by $[CO_2]_{Atm}$, isotopic, and precise O_2/N_2 measurements.







Carefully note GtC vs. $GtCO_2$

In 2013, global CO_2 emissions due to fossil fuel use (and cement production) were 36 gigatonnes ($GtCO_2$); this is 61% higher than 1990 (the Kyoto Protocol reference year) and 2.3% higher than 2012.

How Can Climate be Stabilized?

Must Restore Planet's Energy Balance

Modeled Imbalance: $+0.75 \pm 0.25$ W/m^2

Ocean Data Suggest: $+0.5 \pm 0.25$ W/m^2

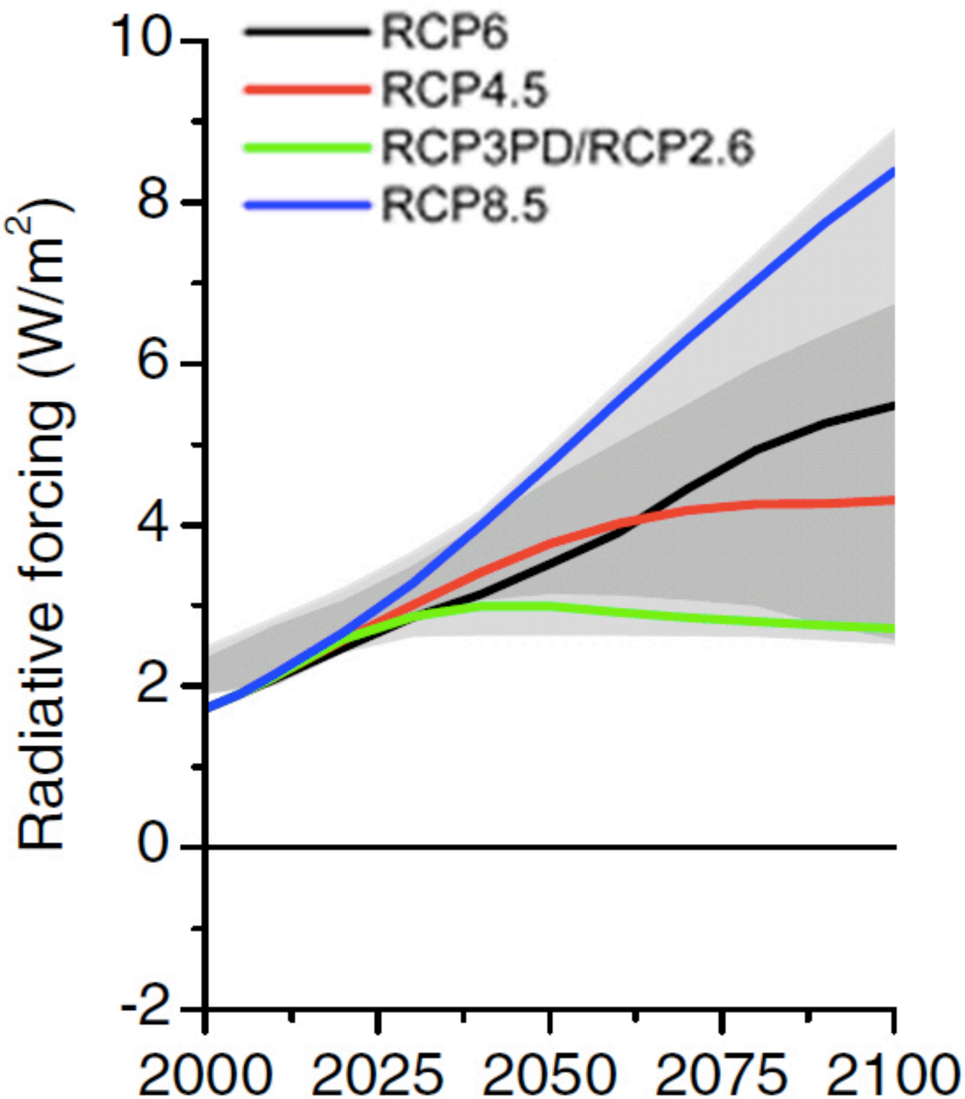
Requirement Might be Met Via:

Reducing CO_2 to 350 ppm or less

&

Reducing non-CO_2 forcing ~ 0.25 W/m^2

IPCC AR5 Scenario Process

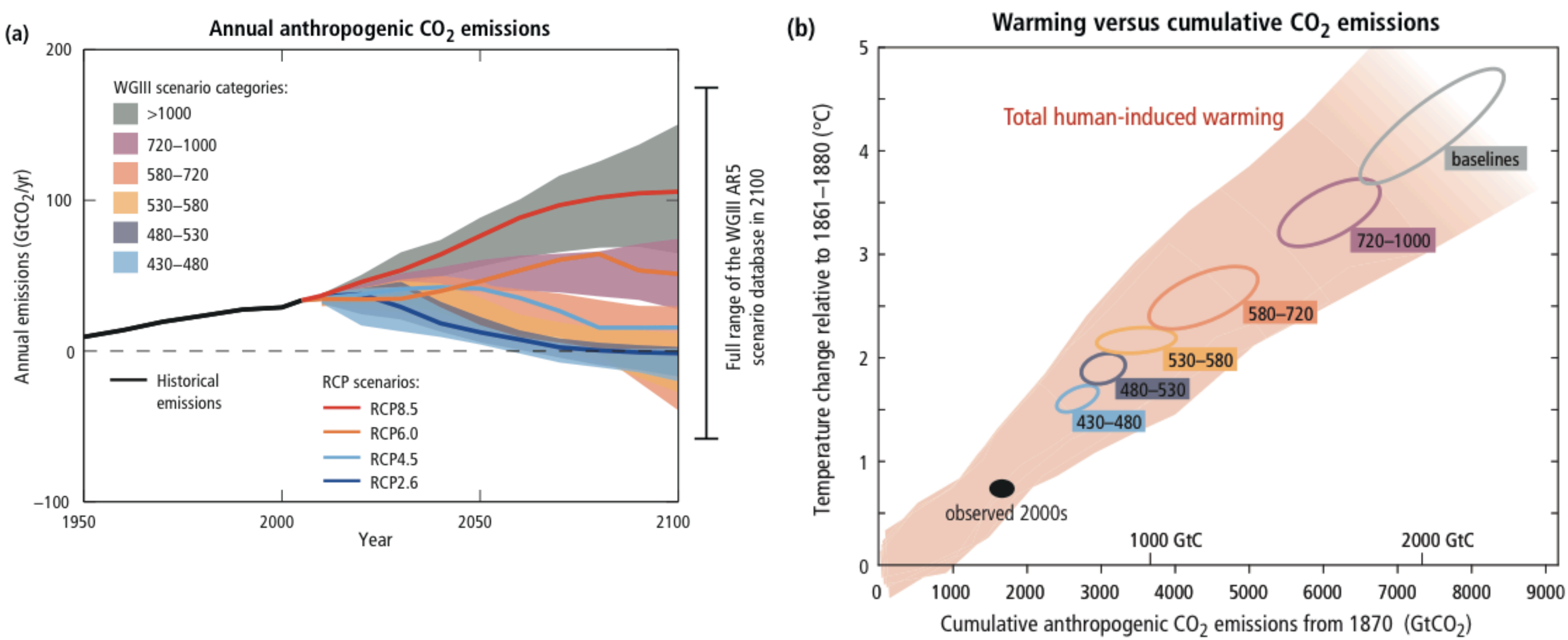


Four RCPs were selected and defined by their total radiative forcing

Each RCP could result from different combinations of economic, technological, demographic, policy, and institutional futures

e.g., the second-to-lowest RCP could be considered as a moderate mitigation scenario.

The nature of our future environment depends strongly on which "scenario" forecasters use.
The scenarios differ only in the extent of society's effort to conserve and reduce fossil-fuel use.

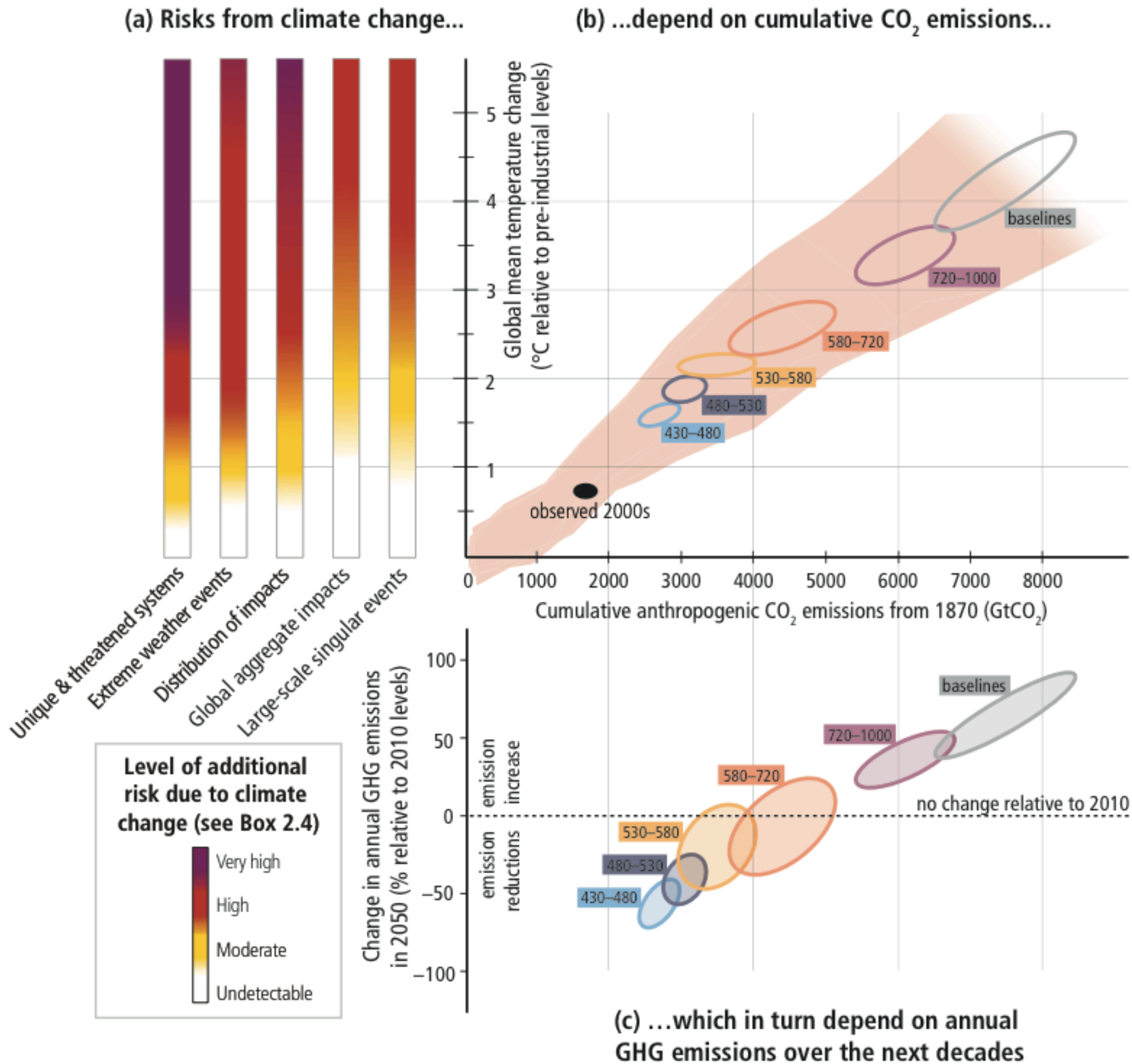


Multi-model results show that limiting total human-induced warming to less than 2° C relative to the period 1861–1880 with a probability of >66%7 would require cumulative CO_2 emissions from all anthropogenic sources since 1870 to remain below about 2900 $GtCO_2$ (with a range of 2550 to 3150 $GtCO_2$ depending on non-CO_2 drivers). About 1900 $GtCO_2$ had already been emitted by 2011.

Warming will continue beyond 2100 under all RCP scenarios except RCP2.6. Surface temperatures will remain approximately constant at elevated levels for <u>many centuries after a complete cessation of net anthropogenic CO_2 emissions</u>. A large fraction of anthropogenic climate change resulting from CO_2 emissions is irreversible on a multi-century to millennial timescale, except in the case of a large net removal of CO_2 from the atmosphere over a sustained period.

There is *high confidence* that ocean acidification will increase for centuries if CO_2 emissions continue, and will strongly affect marine ecosystems.

It is *virtually certain* that global mean sea level rise will continue for many centuries beyond 2100, with the amount of rise dependent on future emissions. The threshold for the loss of the Greenland ice sheet over a millennium or more, and an associated sea level rise of up to 7 m, is greater than about 1° C (*low confidence*) but less than about 4° C (*medium confidence*) of global warming with respect to pre-industrial temperatures. Abrupt and irreversible ice loss from the Antarctic ice sheet is possible, but current evidence and understanding is insufficient to make a quantitative assessment.


(a) Risks from climate change...
(b) ...depend on cumulative CO_2 emissions...
Unique & threatened systems
Extreme weather events
Distribution of impacts
Global aggregate impacts
Large-scale singular events
Level of additional risk due to climate change (see Box 2.4)
Very high
High
Moderate
Undetectable
Global mean temperature change (°C relative to pre-industrial levels)
baselines
720–1000
580–720
530–580
480–530
430–480
observed 2000s
Cumulative anthropogenic CO_2 emissions from 1870 ($GtCO_2$)
0
1000
2000
3000
4000
5000
6000
7000
8000
1
2
3
4
5
Change in annual GHG emissions in 2050 (% relative to 2010 levels)
100
50
0
−50
−100
emission increase
emission reductions
no change relative to 2010
(c) …which in turn depend on annual GHG emissions over the next decades