GHGs and the Nexus with Natural and Human Induced Climate Change

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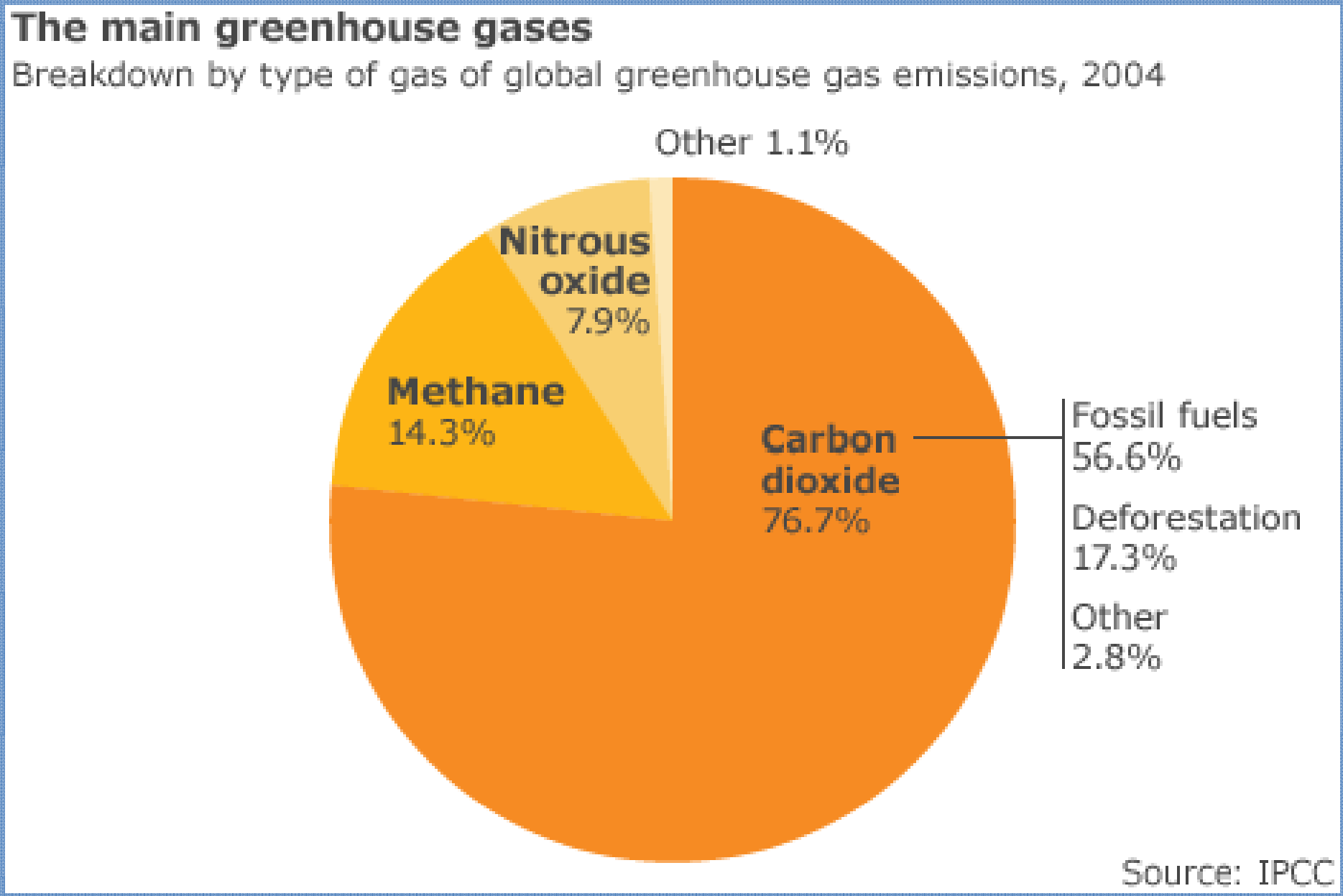
Nexus = to bind; a form of connection; the center of something

My goal for the next half hour is to provide an overview of the basic physics regarding drivers of climate change on Earth including the role of those Greenhouse Gases (GHGs)

- I will first identify the major GHGs and provide a context for a need to have an improved understanding of 'the physics'
- The emphasis will be on forcing by electro-magnetic radiation [solar and terrestrial] and the 'Greenhouse' metaphor
- I will cover both natural and human-induced changes in radiative forcing and the role that greenhouse gases [GHGs] have in regulating surface temperatures
- A handout is available with several key graphics that are used in the presentation

Those GHGs (Greenhouse Gases)



But, what about water vapor?

Those GHGs (Greenhouse Gases)

But, what about water vapor?

Water vapor = the most important natural GHG

Accounts for about 2/3 of the Earth's natural Greenhouse Effect

In 1937, Glenn Trewartha introduced the metaphor of a 'Greenhouse' to help explain how certain gases help keep the planet warm

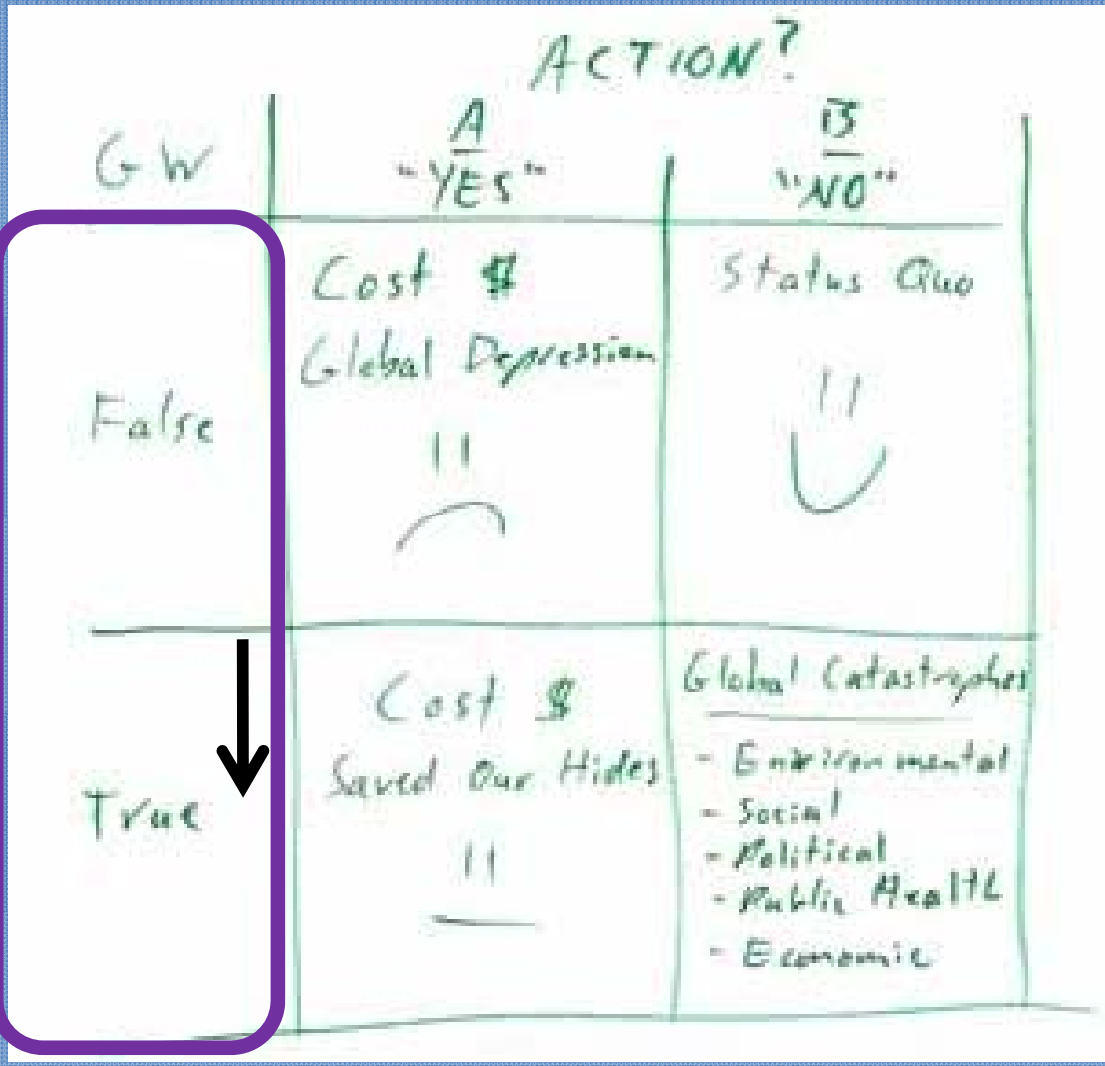
The gases keep energy in the system, in the same way that the greenhouse glass roof presents a barrier to heat loss

Positive feed back → with warmer temperatures → more evaporation → more water vapor → results in warmer temperatures → …

Water vapor tends to be restricted to the lowest most layers of the atmosphere; other GHGs work better at elevation in the atmos

Now, the context: Greg Craven's: What's the Worst that Could Happen

- Risk and decision making
- Rows = the physics or will global warming happen?
- Columns = a human response or do we take action? [something we have some control over]



If human-induced global warming does not make sense, then shift the horizontal line downward

Greg Craven's: What's the Worst that Could Happen

- Risk and decision making
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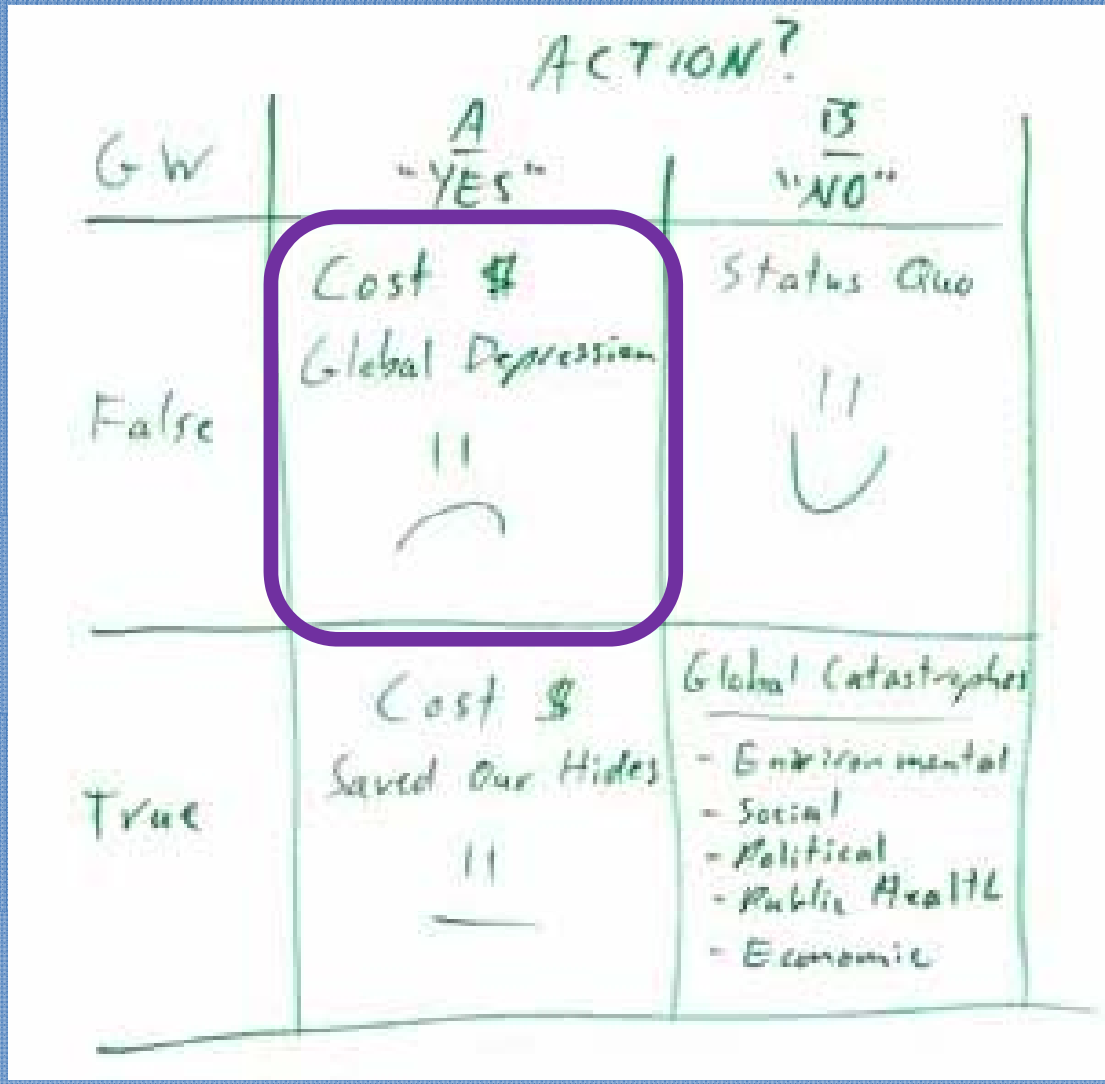

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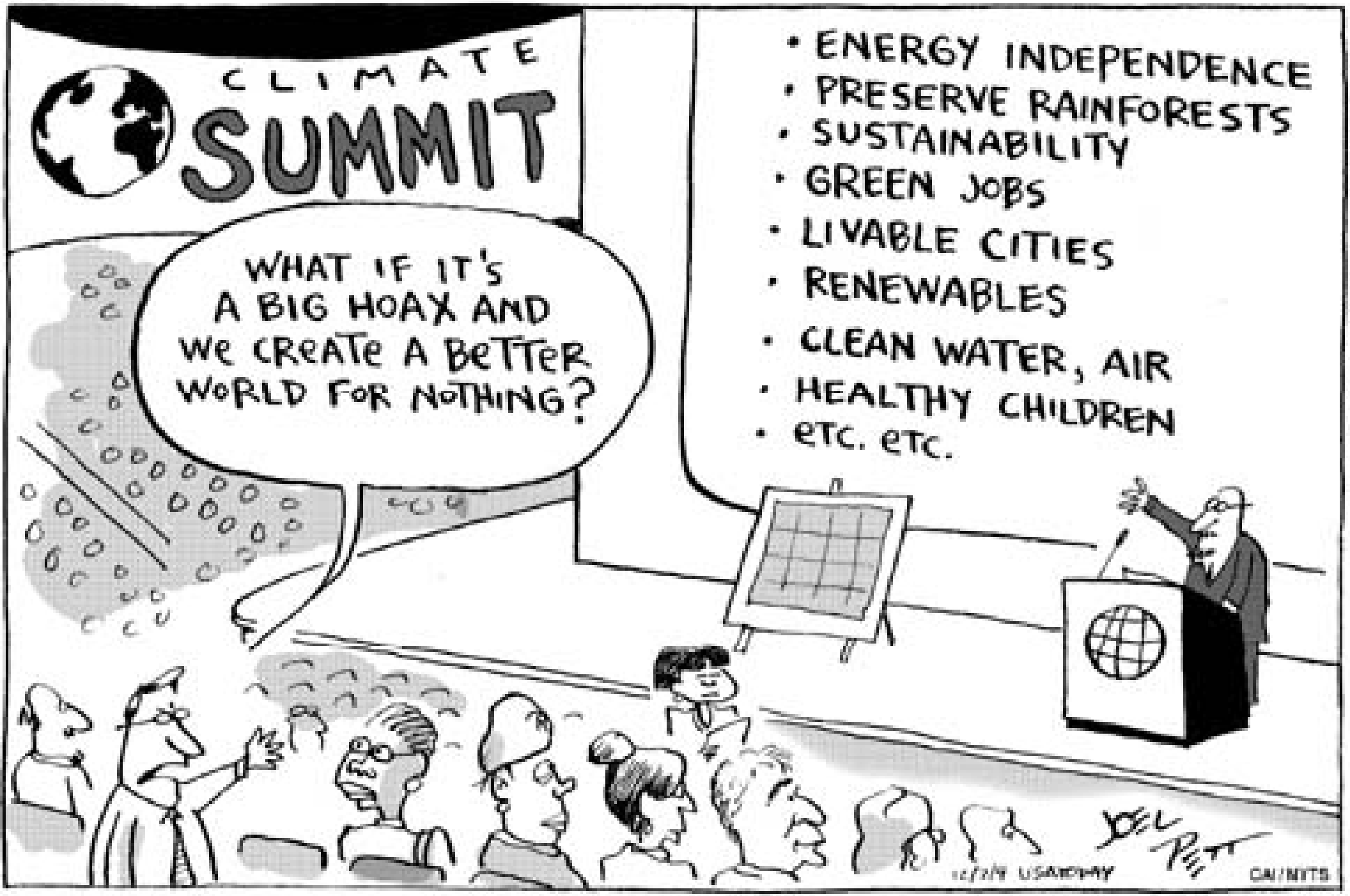
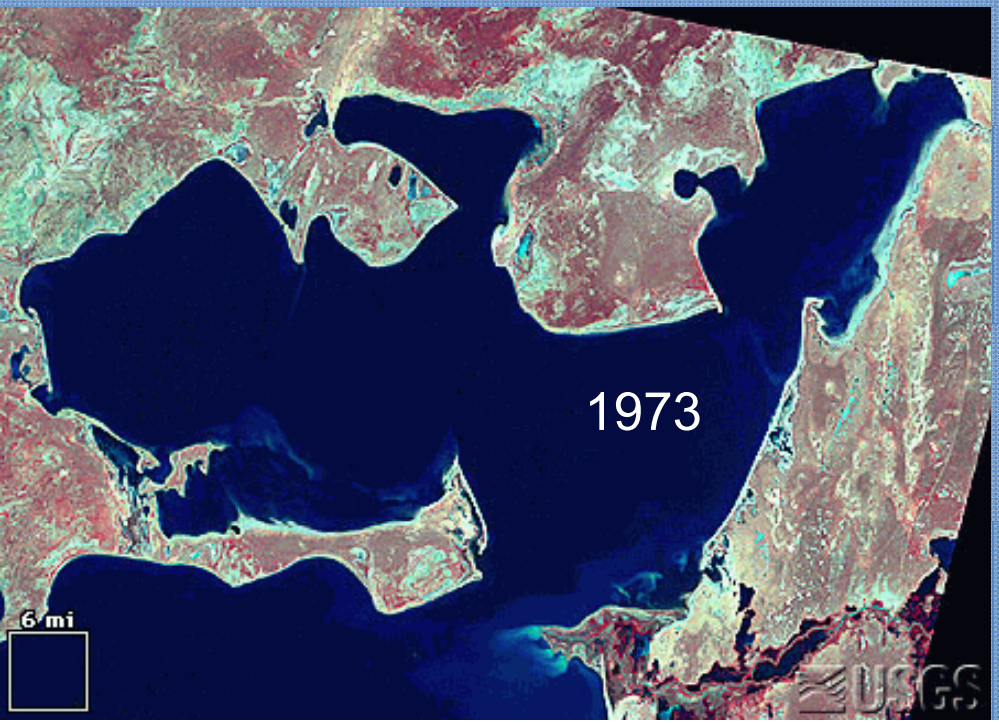
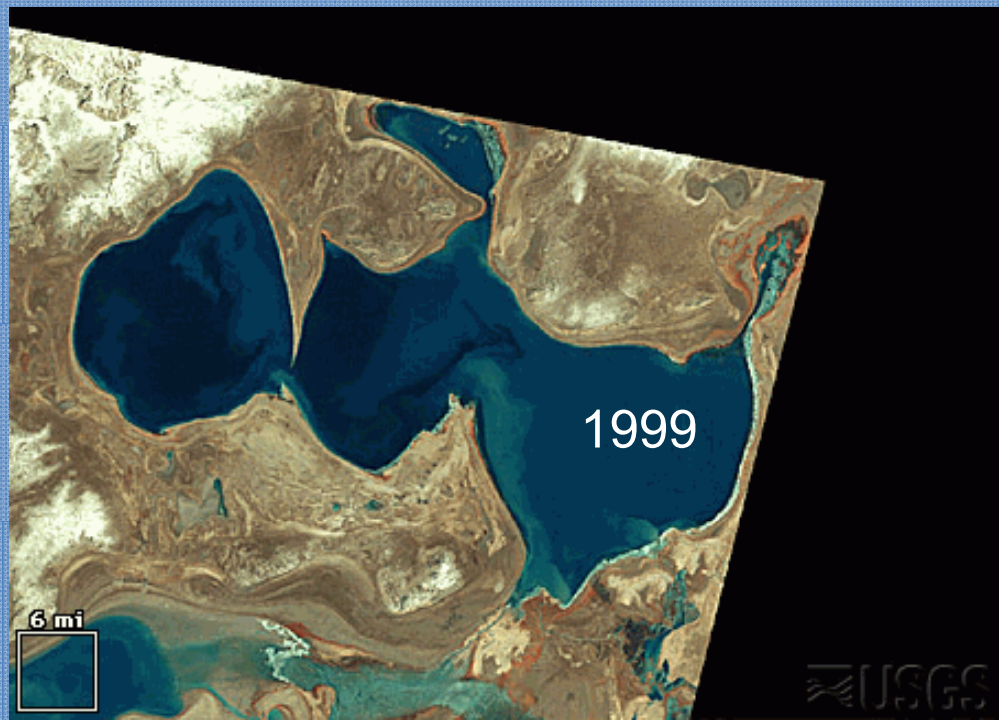


When I go to the doctor, they take my temperature and …

Some of Earth's symptoms:

- warming temperatures (slight fever)
- change in gaseous composition (atmos)
- rapid change in surface appearance (LUCC)
- changes in chemical indicators (nitrogen)
- loss of key biotic components
- new organisms have been introduced
- rapid depletion of stored reserves (water)
- rapid depletion of stored reserves (energy)
- the rates of change are increasing





Global change is much more than just climate change

Some of Earth's symptoms:

- warming temperatures (slight fever)
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- loss of key biotic components
- new organisms have been introduced
- rapid depletion of stored reserves (water)
- rapid depletion of stored reserves (energy)
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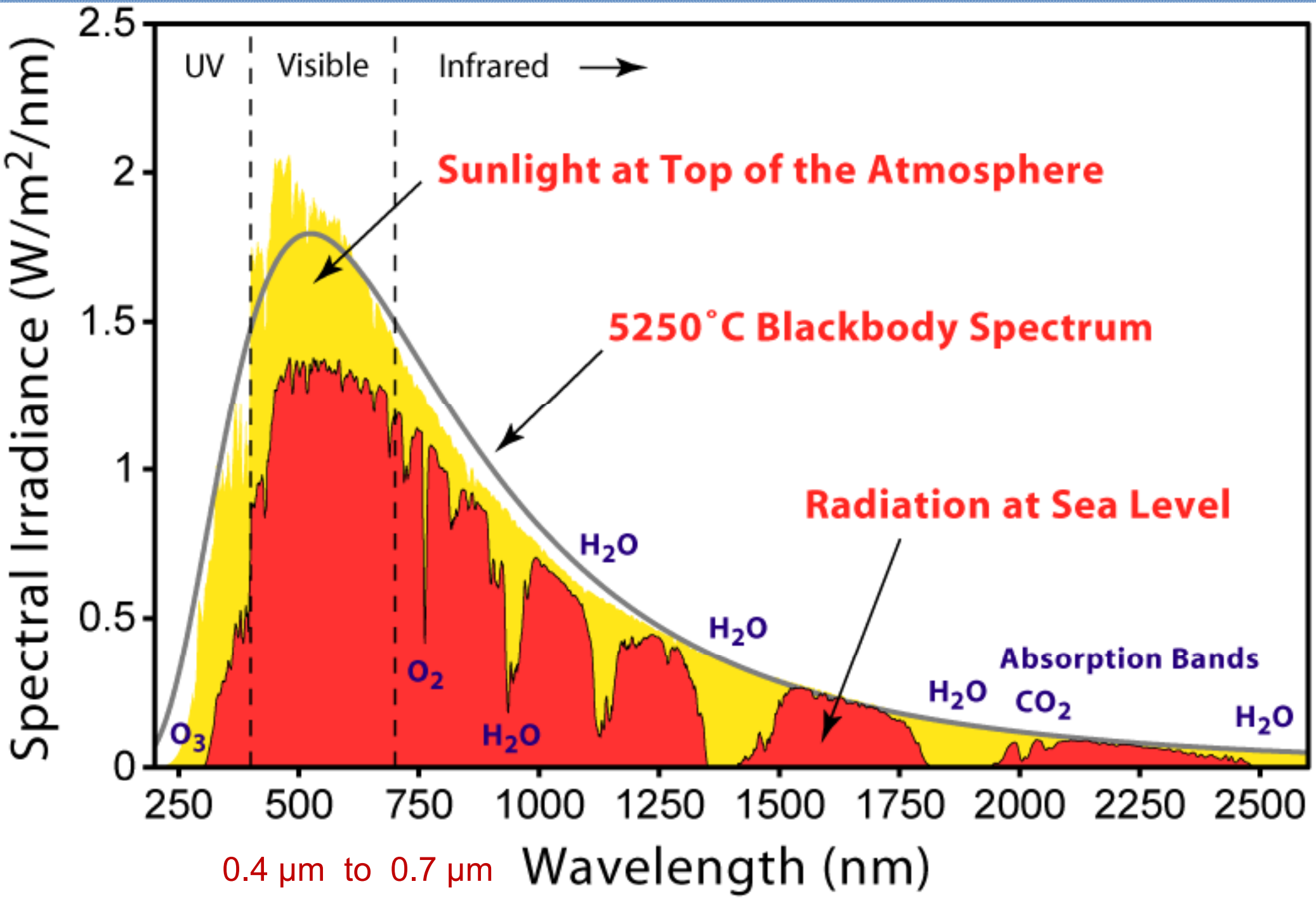
There is a complexity of interactions across the atmosphere, the biosphere, the hydrosphere, and the cryosphere

We have a longer scientific history of understanding the causes of human-induced climate change compared with our understanding of the complexity of global change

Human forcing of climate change is something we can (and many would say should) do something about

So let's work on understanding radiative forcing of the climate

Solar Radiation is the primary energy source for our planet



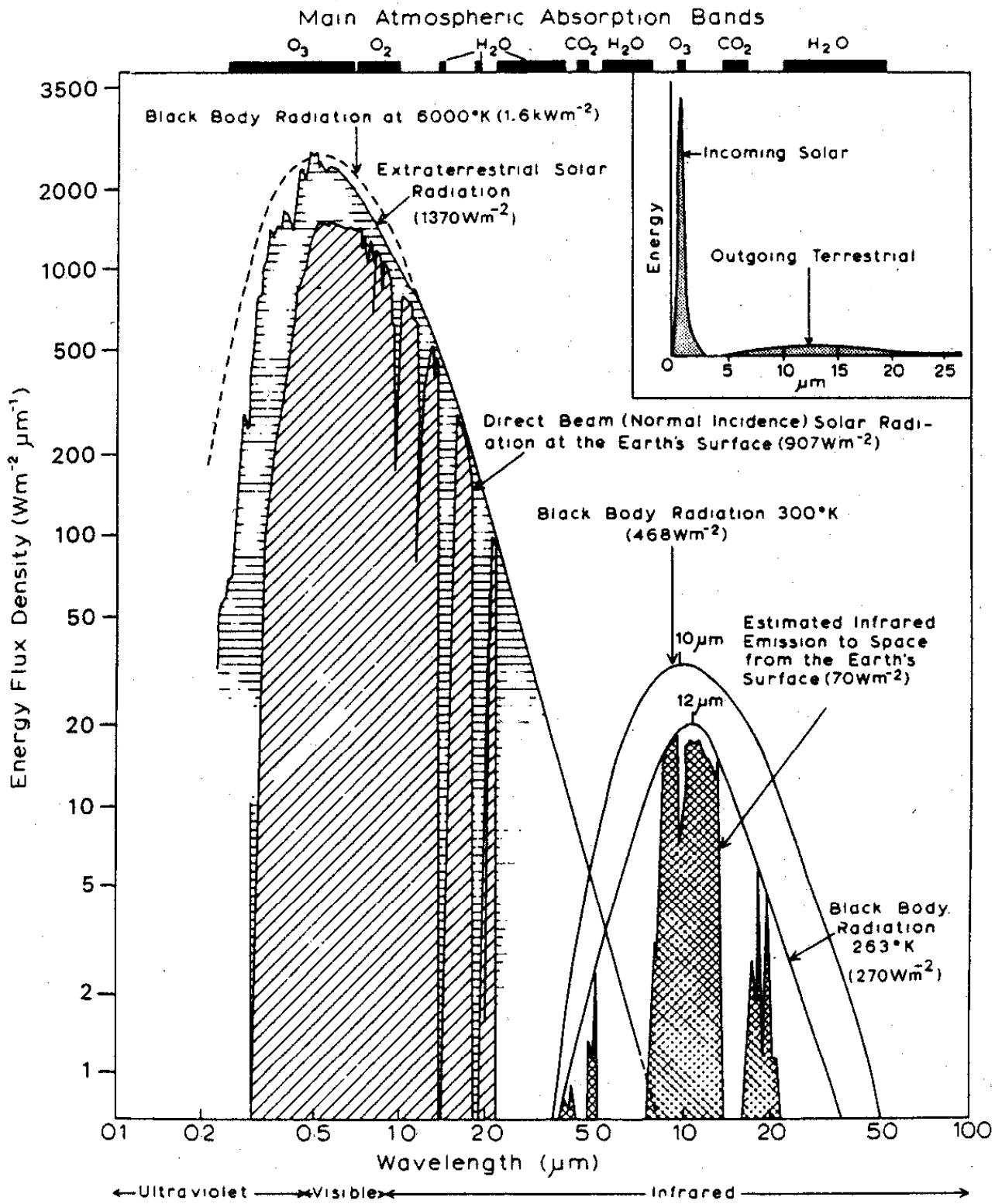


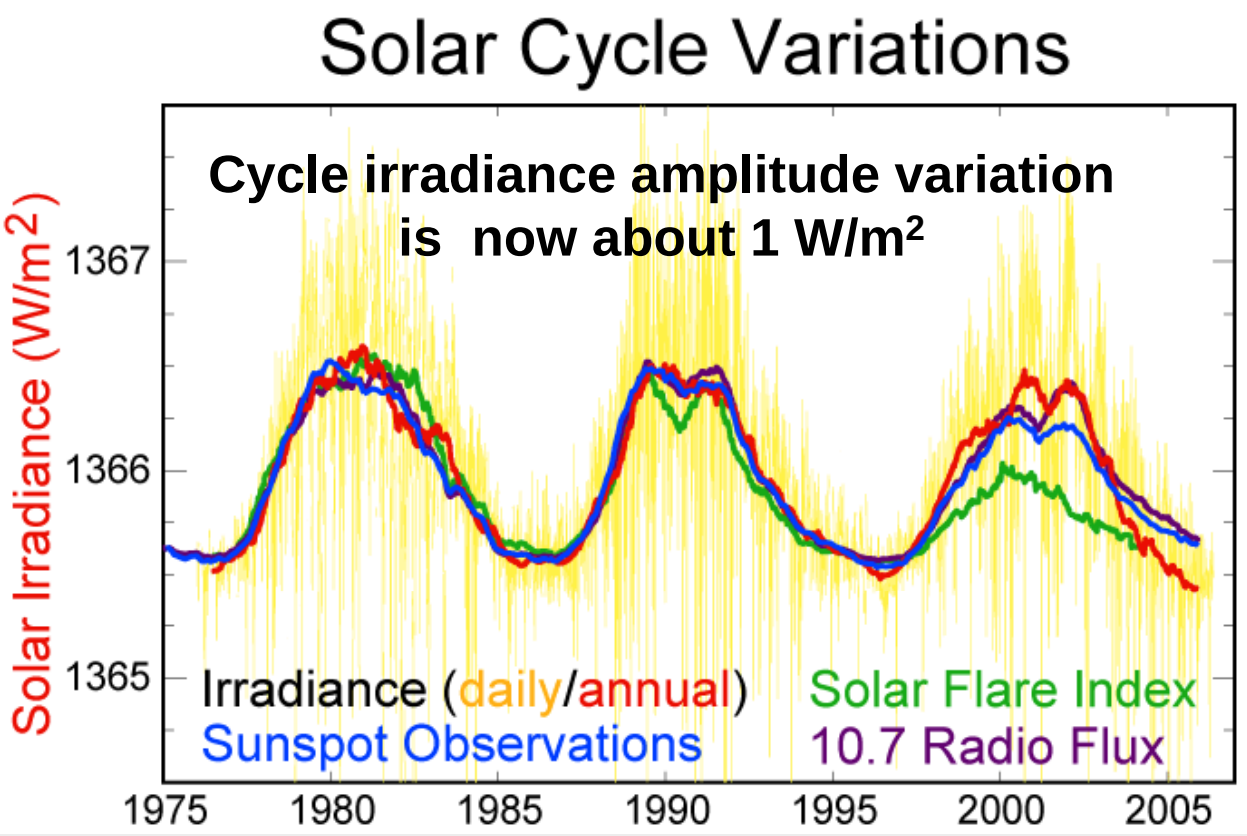
Figure 2.1 Spectral distribution of solar and terrestrial radiation, plotted logarithmically, together with the main atmospheric absorption bands. The cross-hatched areas in the infrared spectrum indicate the 'atmospheric windows' where radiation escapes to space. The black-body radiation at 6,000 K is that proportion of the flux which would be incident on the top of the atmosphere. The inset shows the same curves for incoming and outgoing radiation with the wavelength plotted arithmetically on an arbitrary vertical scale.

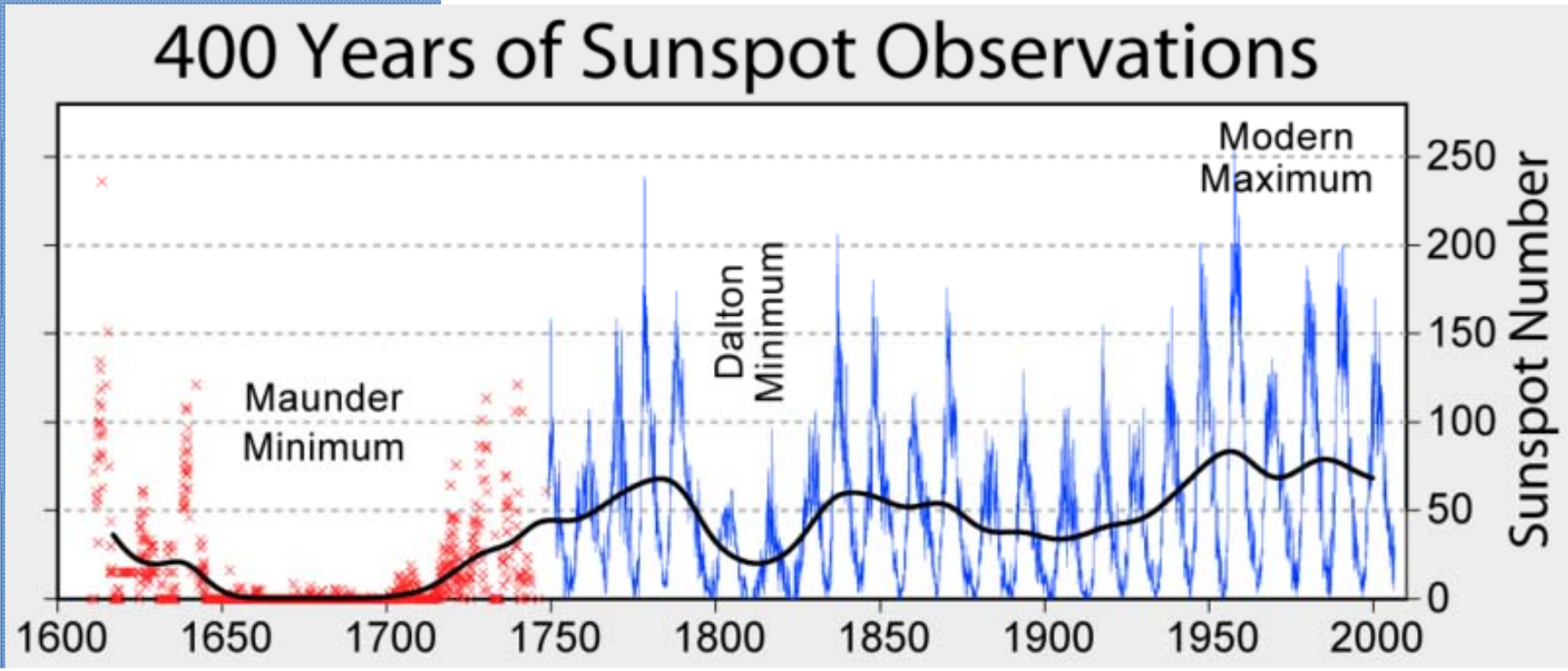
Using the Stefan-Boltzman and Wien's Displacement laws – we get more energy at shorter wavelengths (Solar) from the hotter Sun compared with the (Thermal) cooler Earth

Amount and wavelengths of Energy emitted are a function of the temperature of the emitting object.
Warmer ➔ more + shorter λ

Source: Mostly after Sellers 1965.

- **Isn't the recent warming related to a cooler Sun and few sunspots during the Little Ice Age?**
- **0.5°C cooler during the Maunder Minimum**





Recent satellite measurements document an 11 year cycle

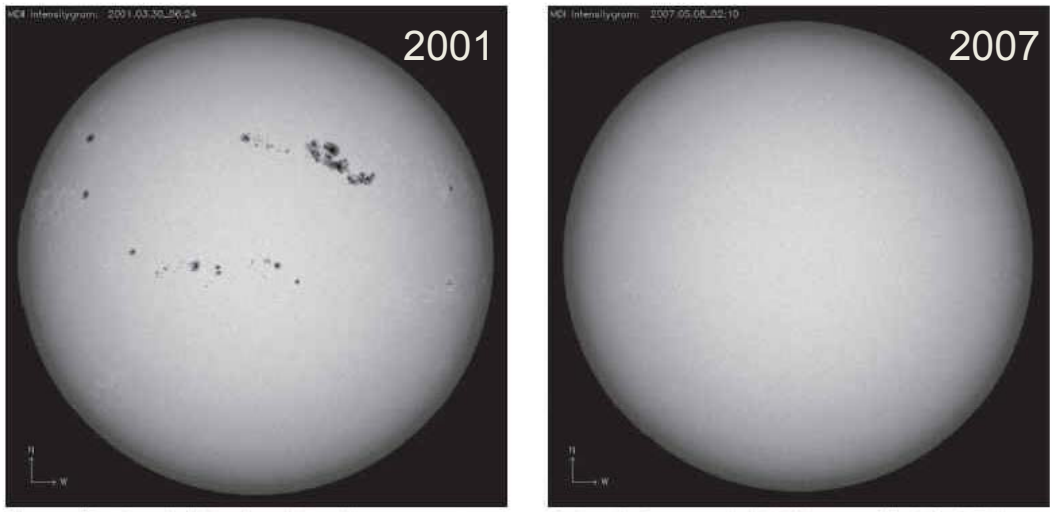
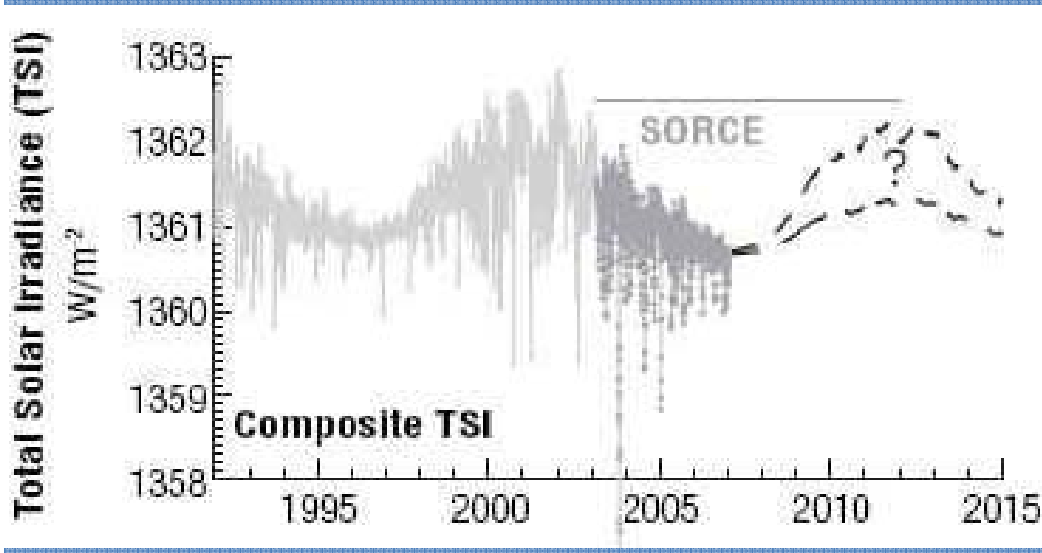
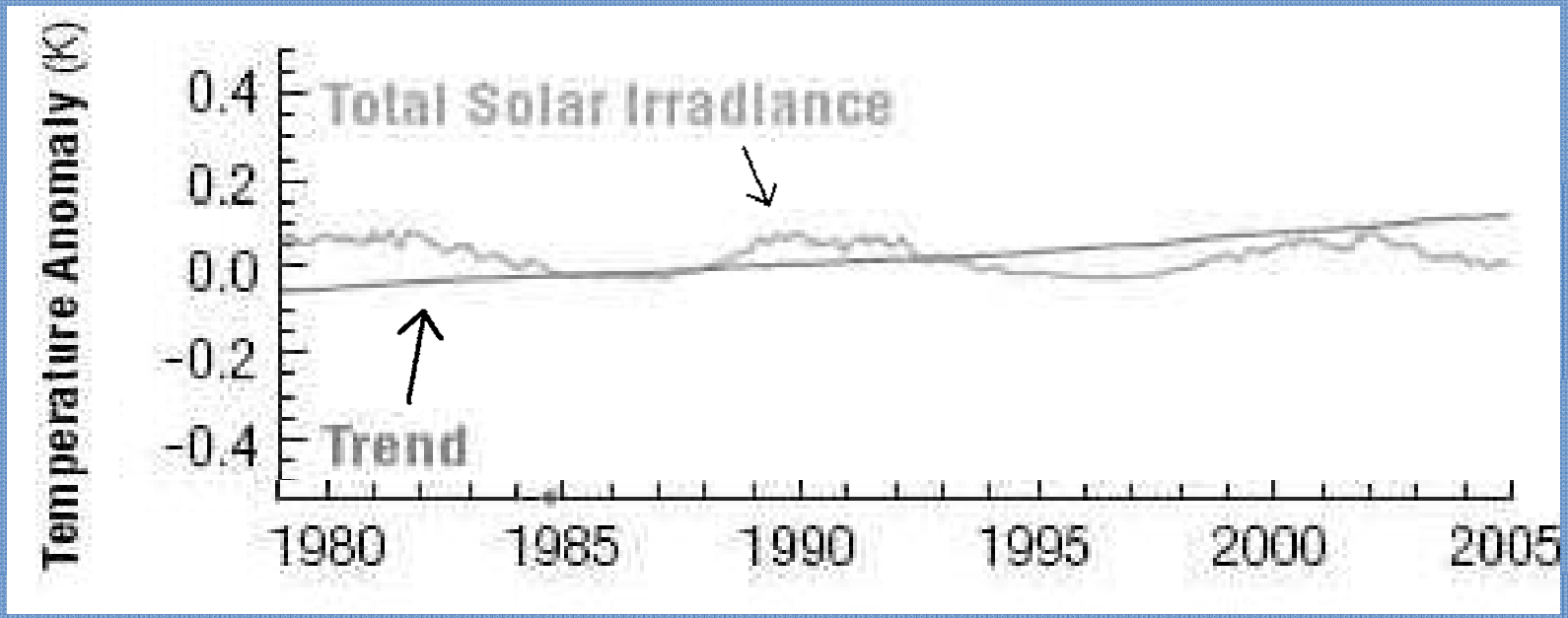


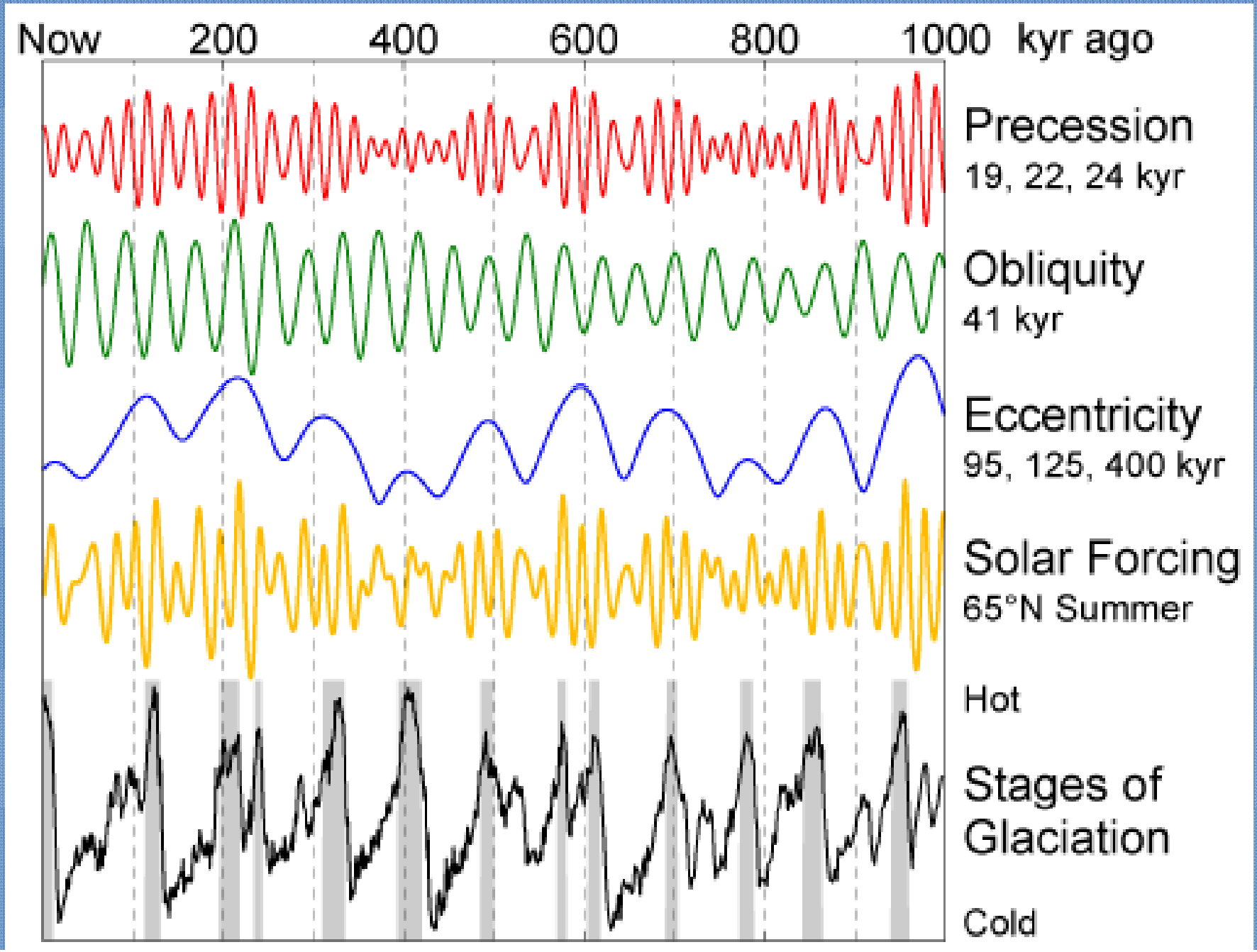
Figure 1. Near the peak of the solar activity cycle many sunspots appear regularly on the Sun, as seen in the left image on March 30, 2001, in *Cycle 23*. Currently, solar activity is near the minimum of the 11-year cycle and sunspots may be absent entirely, as seen on May 8, 2007, in the right image. The images are of the intensity of a narrow band of visible light, made by the Michelson Doppler Imager (MDI) instrument on the Solar and Heliospheric Observatory (SOHO).



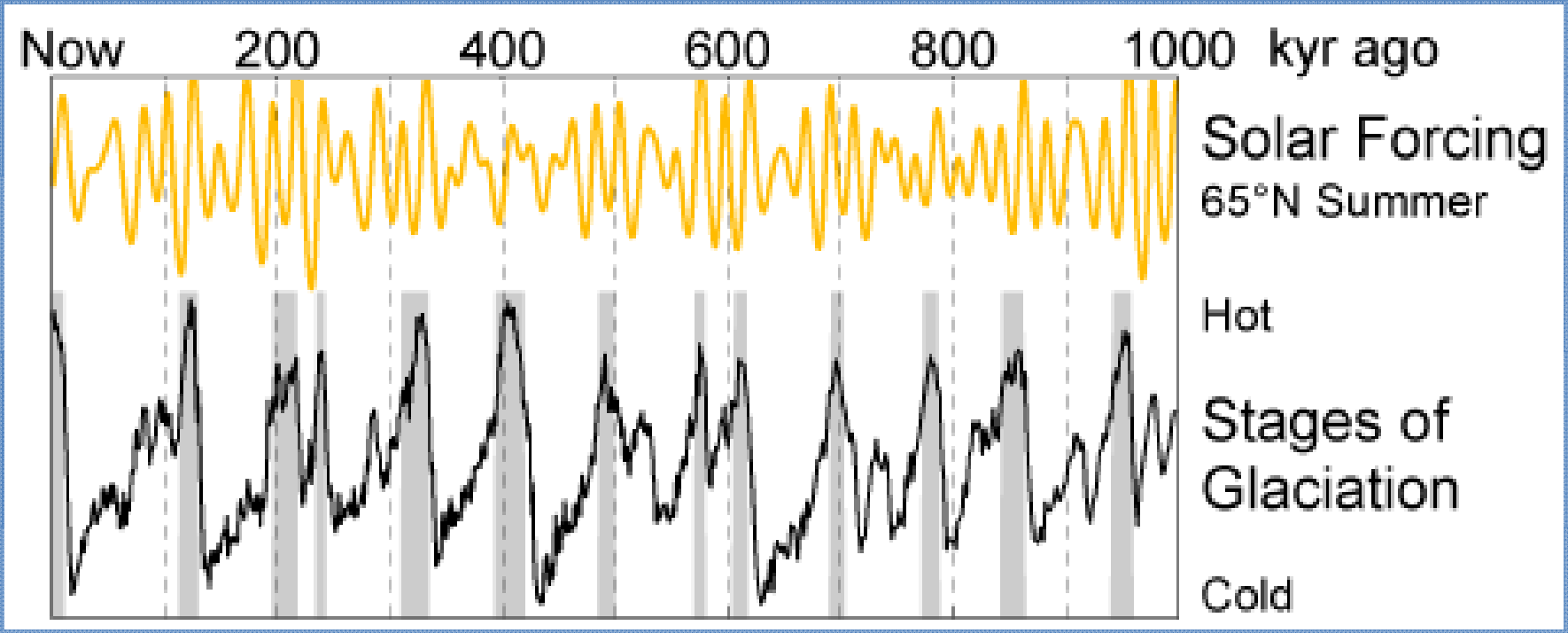


The upward trend in global temperatures is not matched by the cycles in solar irradiance

Earth-Sun relationships or ‘The Milankovich Mechanism’ changes in orbit shape, axis wobble, changes in axial tilt



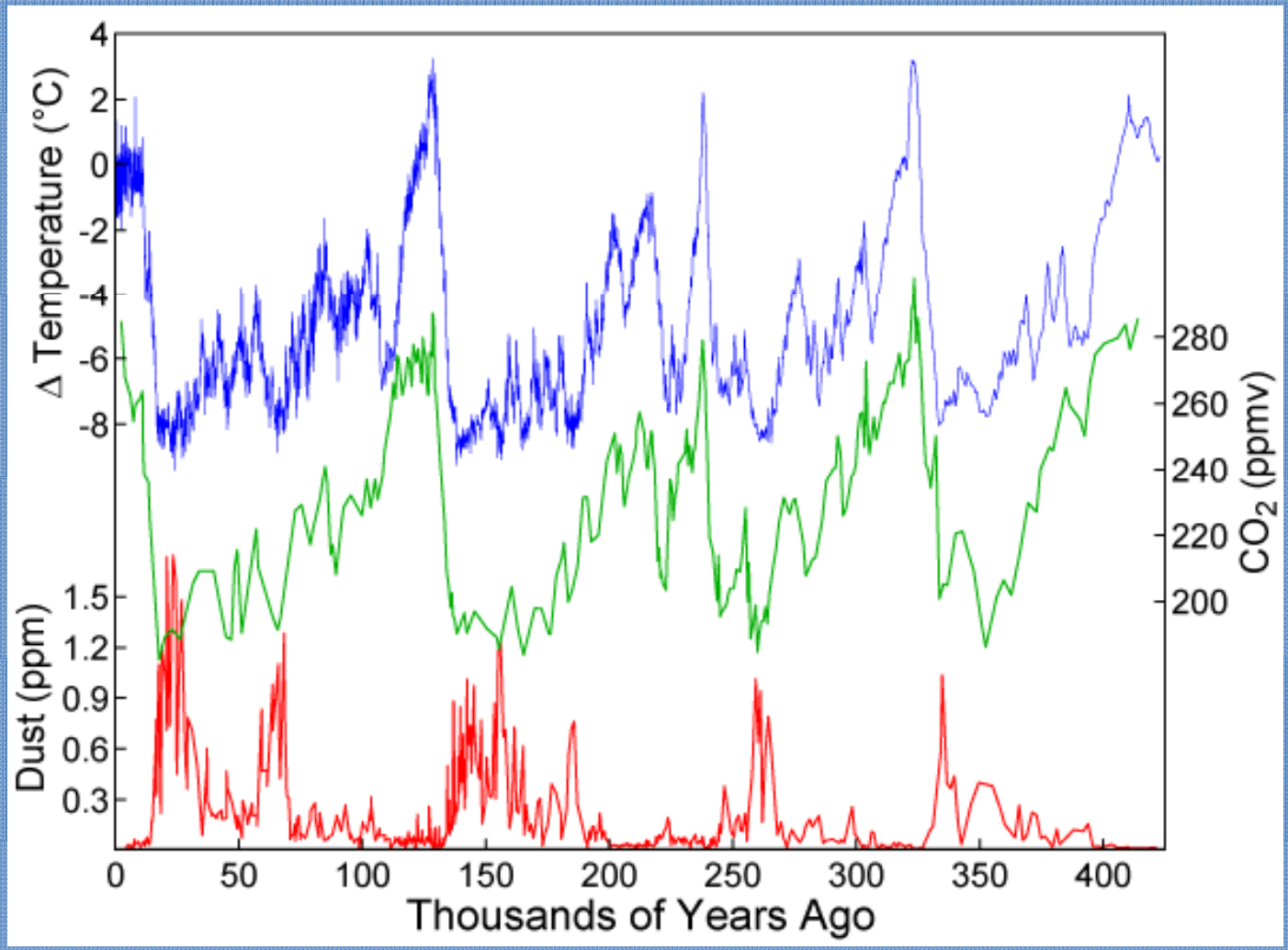
Milankovich ideas suggest that ice ages are started by minima in summer insolation at 65°N
(so the snow does not melt in the summer)
then, internal postive feedbacks involving ice cover, vegetation, and GHG amounts 'take over'



We do not need a change in solar irradiance, just a change in the pattern of how it is distributed on Earth

Vostok – ice core analysis

Petit *et al*. (1999) Climate and Atmospheric History of the Past 420,000 years from the Vostok Ice Core, Antarctica". *Nature* 399: 429-436.



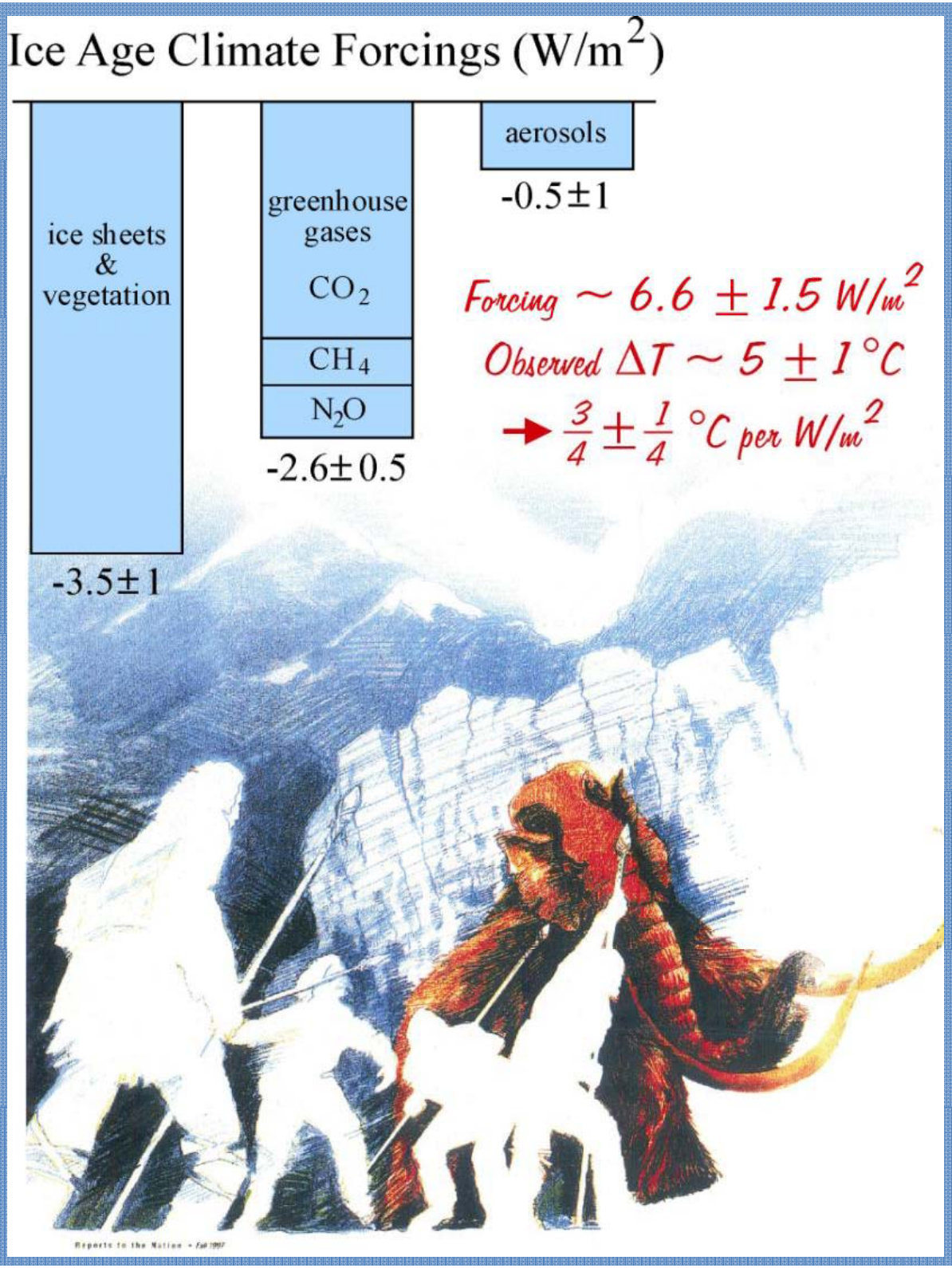
During the cooler glacial periods, there was less CO_2 and more dust in the atmosphere

Ice Age Forcings Imply Global Climate Sensitivity of ~ ¾°C per W/m².

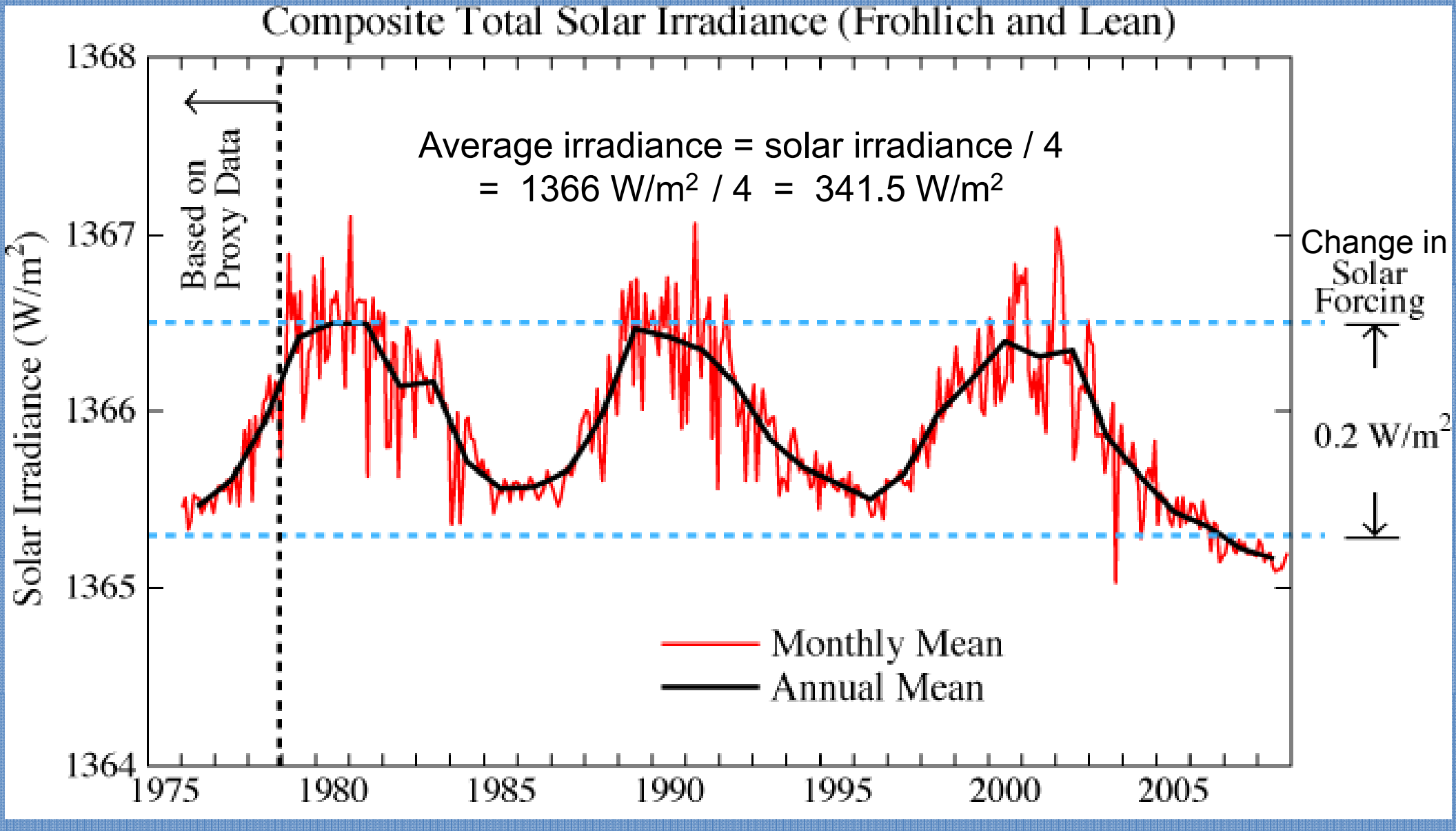
Source: **Hansen et al., *National Geographic Research & Exploration,* 1993, Vol. 9: 141.**

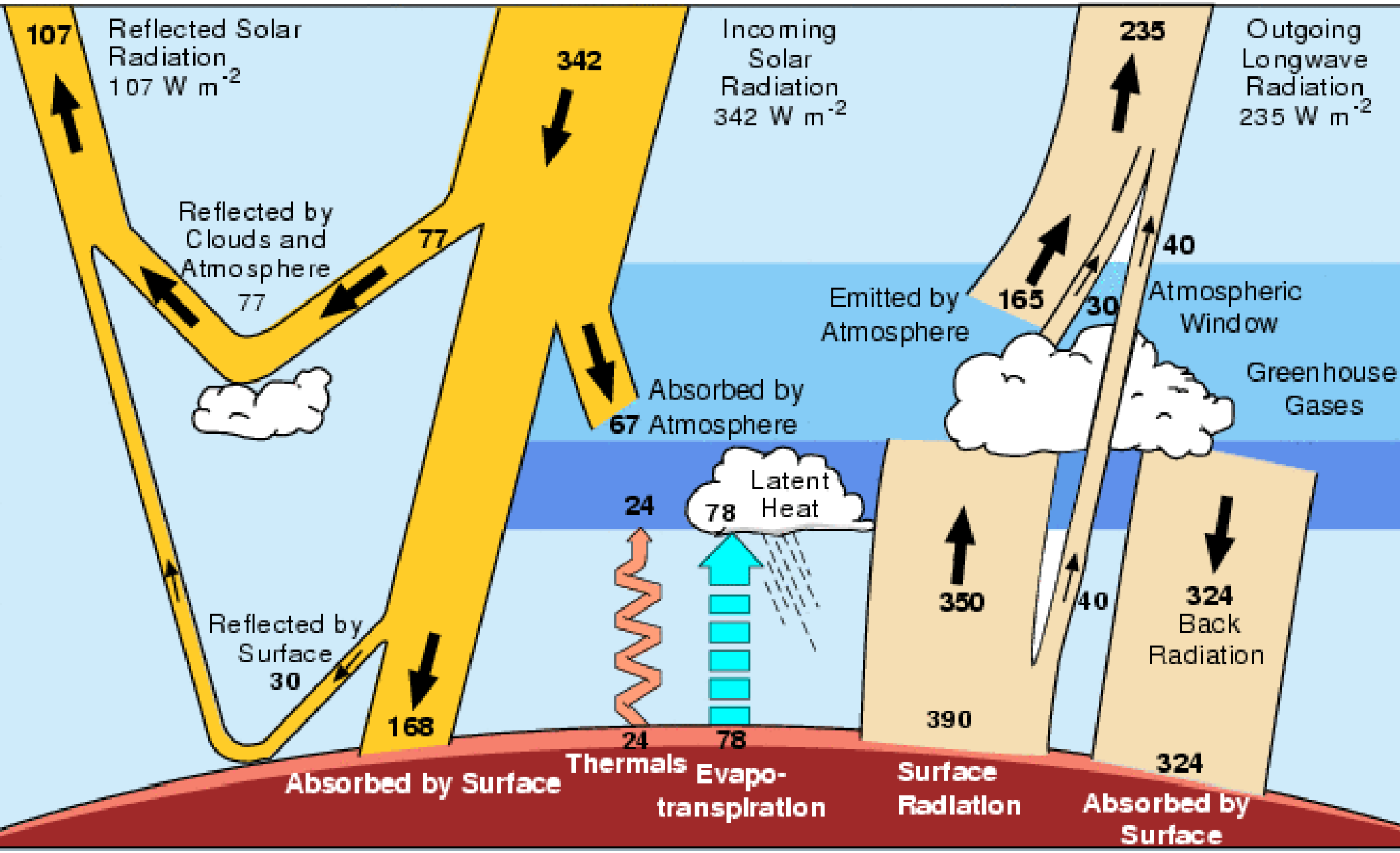
Internal feedbacks influence the process, including the ice-albedo positive feedback:

cooler → more snow/ice → higher albedo → cooler →

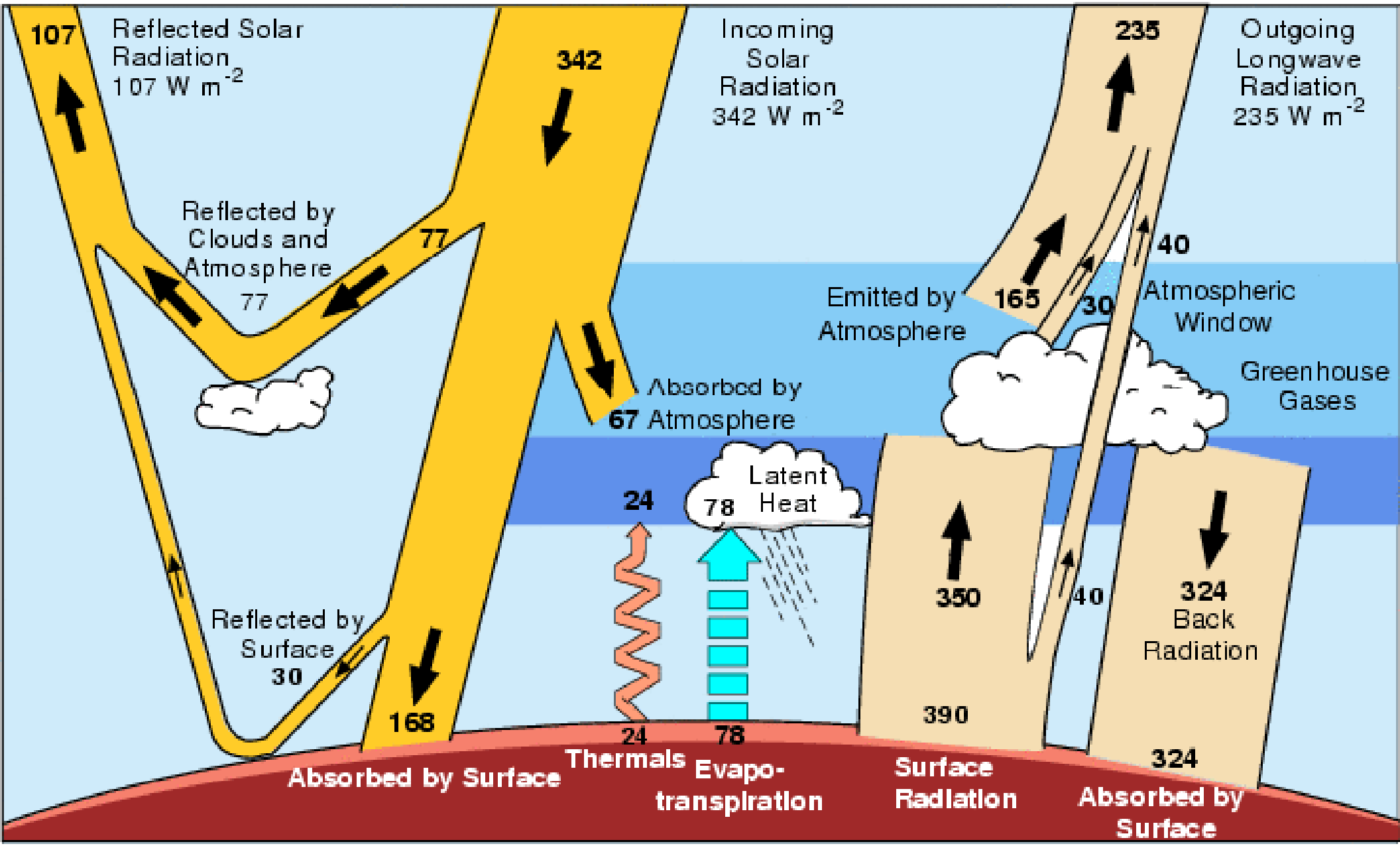


Solar Irradiance = the intensity of the energy stream coming at Earth
But, not all the Earth is receiving energy (the dark side!)
To get the average amount radiative forcing for the whole Earth,
we need to compare the area of the circle being illuminated (irradiated) [Area = πr^2]
with the area of the spherical Earth = 4 πr^2

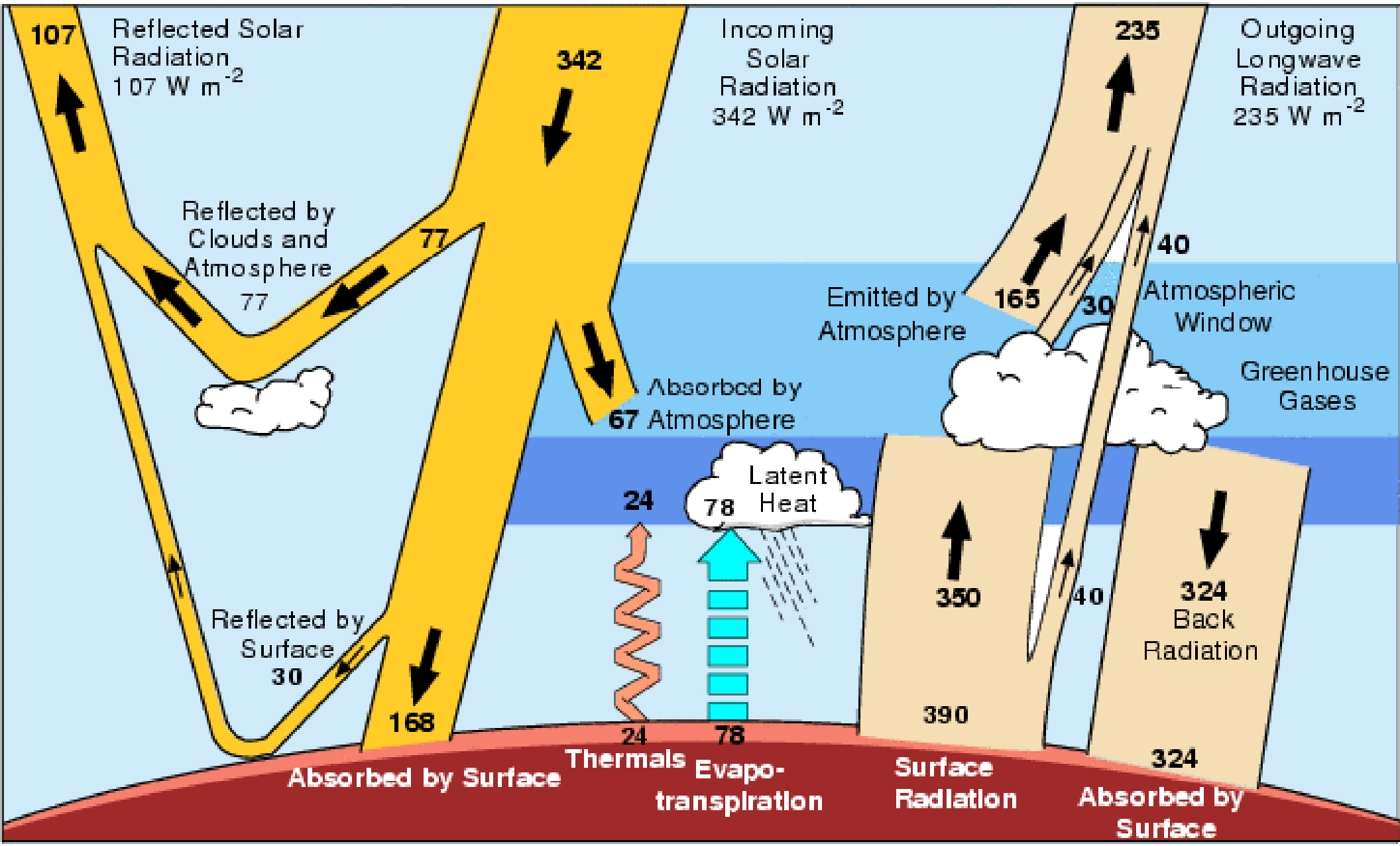




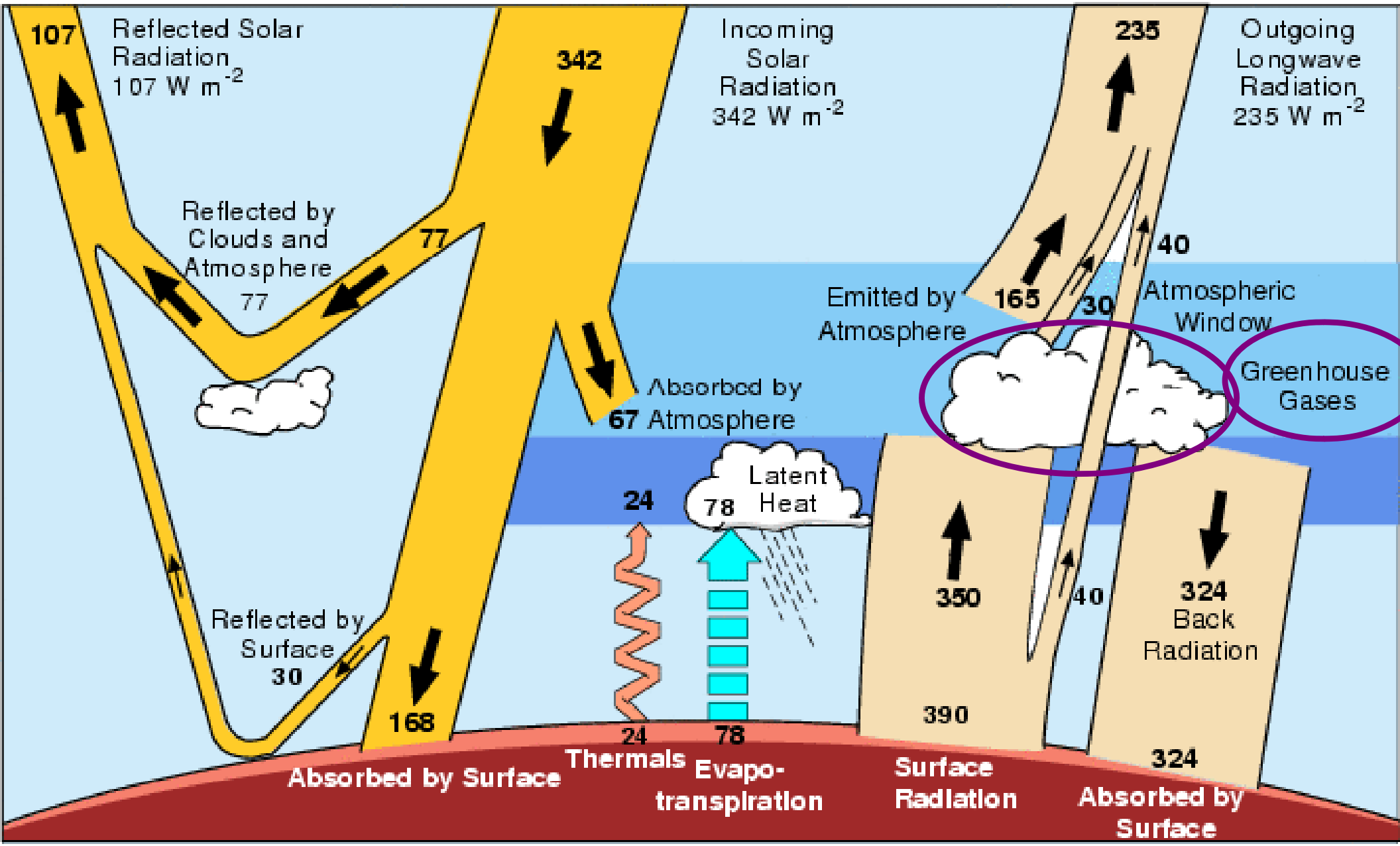
Kiehl, J. T. and Trenberth, K. E. (1997). "Earth's Annual Global Mean Energy Budget". *Bulletin of the American Meteorological Association* 78: 197-208.



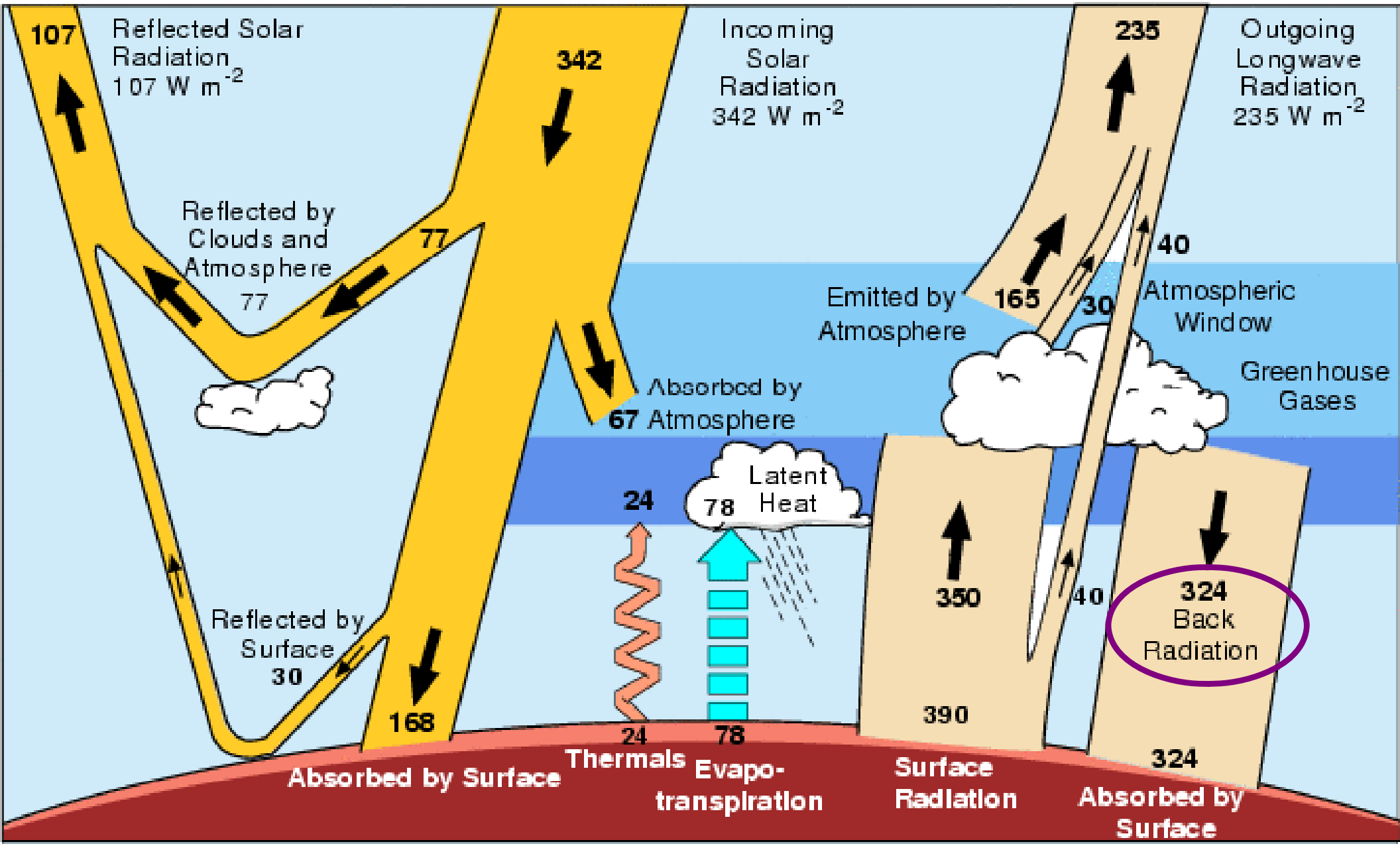
Solar radiation is shown in yellow-orange and the pale pink is thermal or long-wave radiation. The ice ages begin with a change in surface reflectivity and the 'ice-albedo' positive feedback.



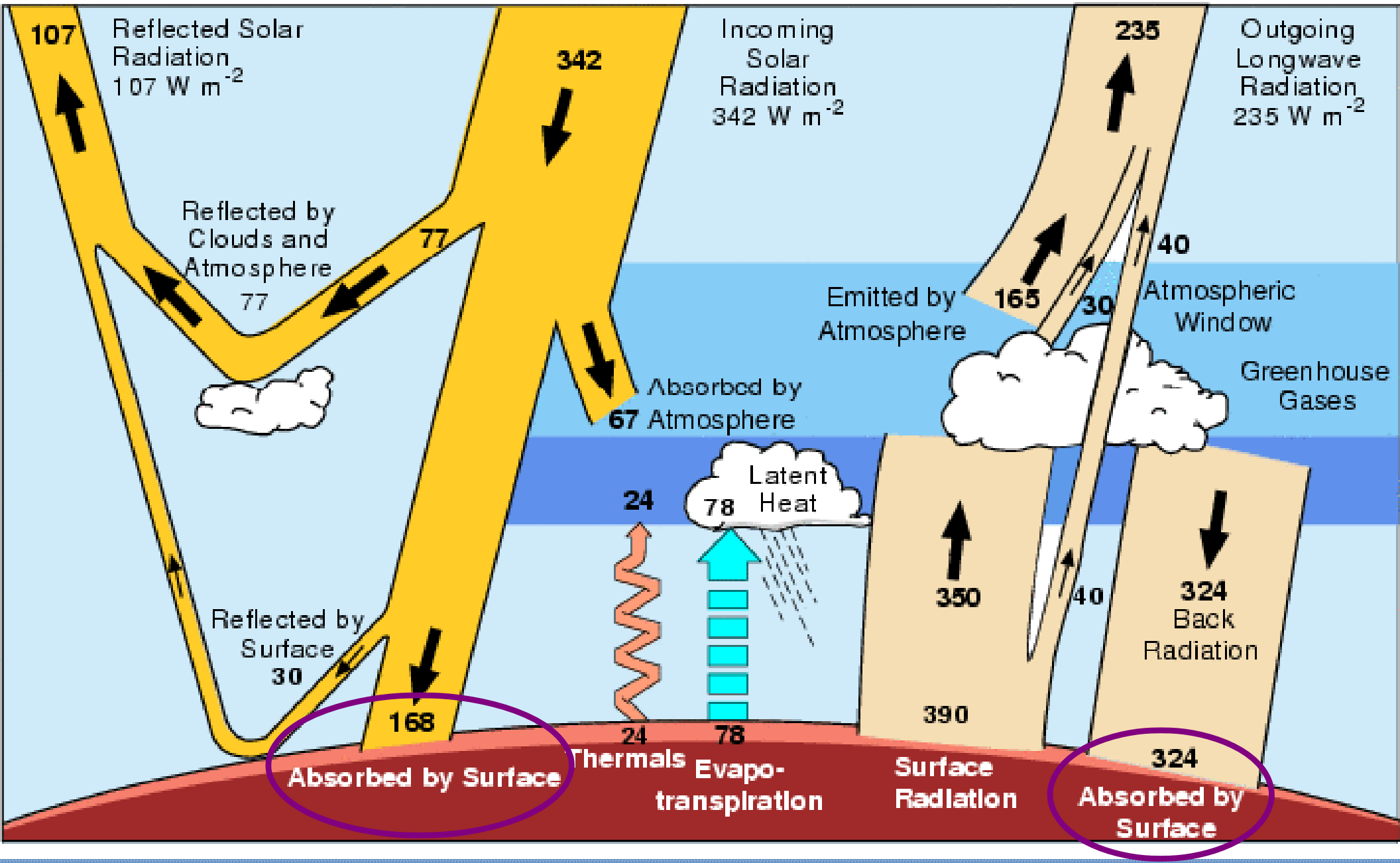
Greenhouse gases and clouds help trap (absorb) thermal radiation and produce (emit it all directions) new thermal radiation. Much of that newly emitted thermal becomes back radiation.



This diagram summarizes the movements of energy in the Earth-atmosphere system. On the right-hand side, greenhouse gases and clouds help trap energy and produce considerable back radiation.



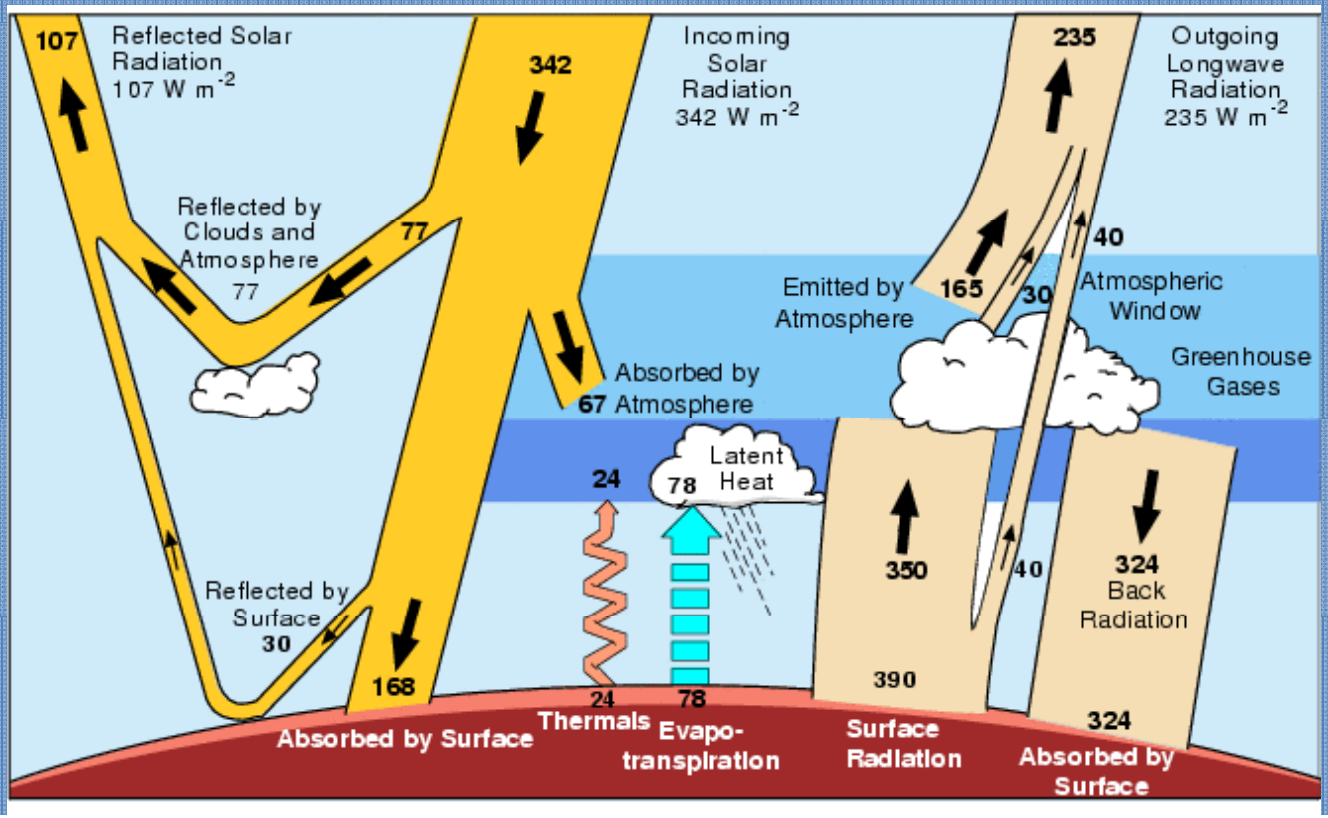
A major effect of the back radiation is to keep the Earth's surface warm. Scientists calculate that the Earth would be 32ºC cooler without this natural 'greenhouse effect.'



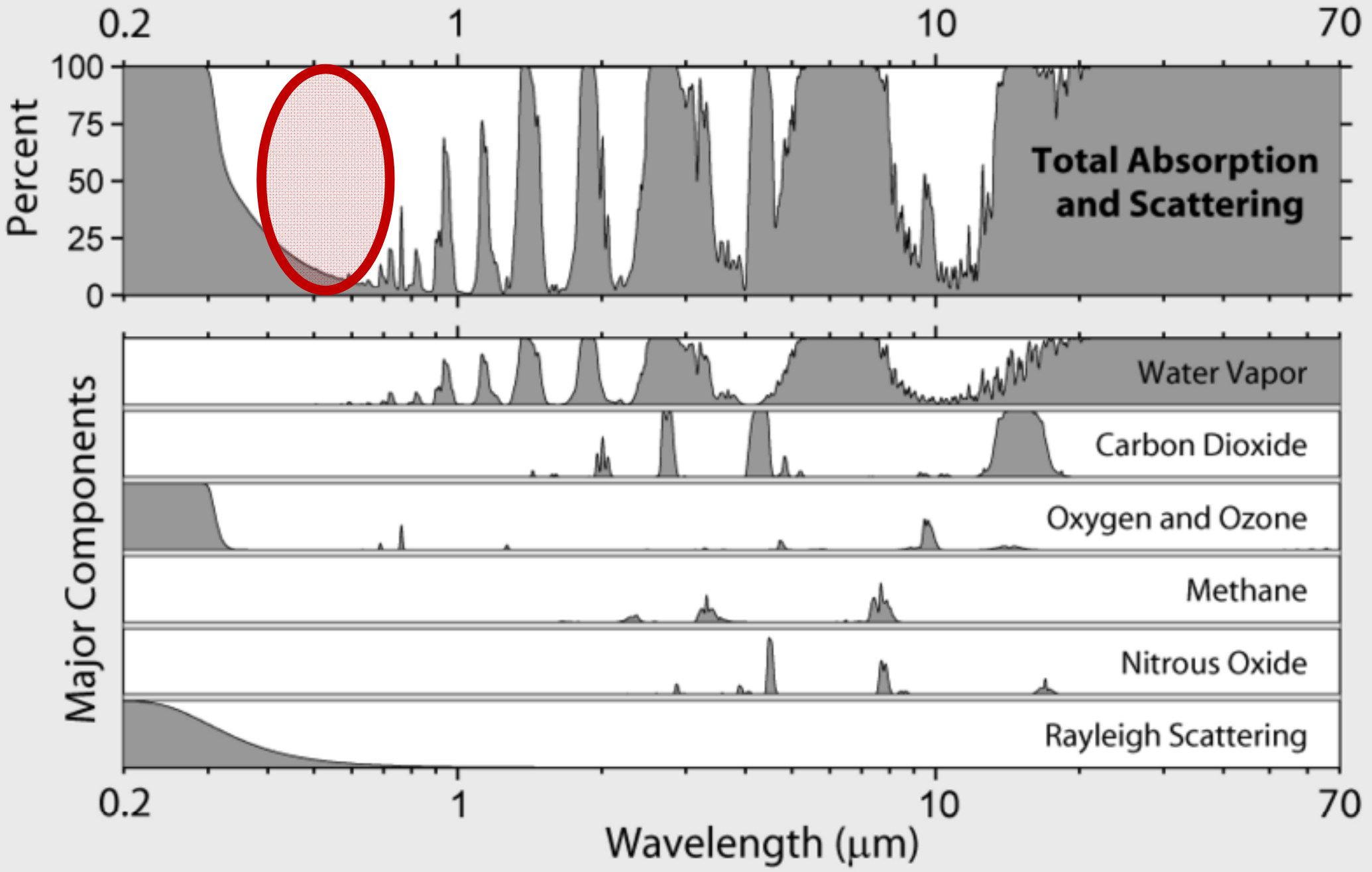
Notice that the amount of energy absorbed by the surface from incoming solar radiation (168 Wm^{-2}) in about ½ the amount of back radiation (324 Wm^{-2}) that is absorbed.

The reuse or recycling of energy due to our natural 'greenhouse' helps keep our planet at a reasonable average temperature of about 15ºC.

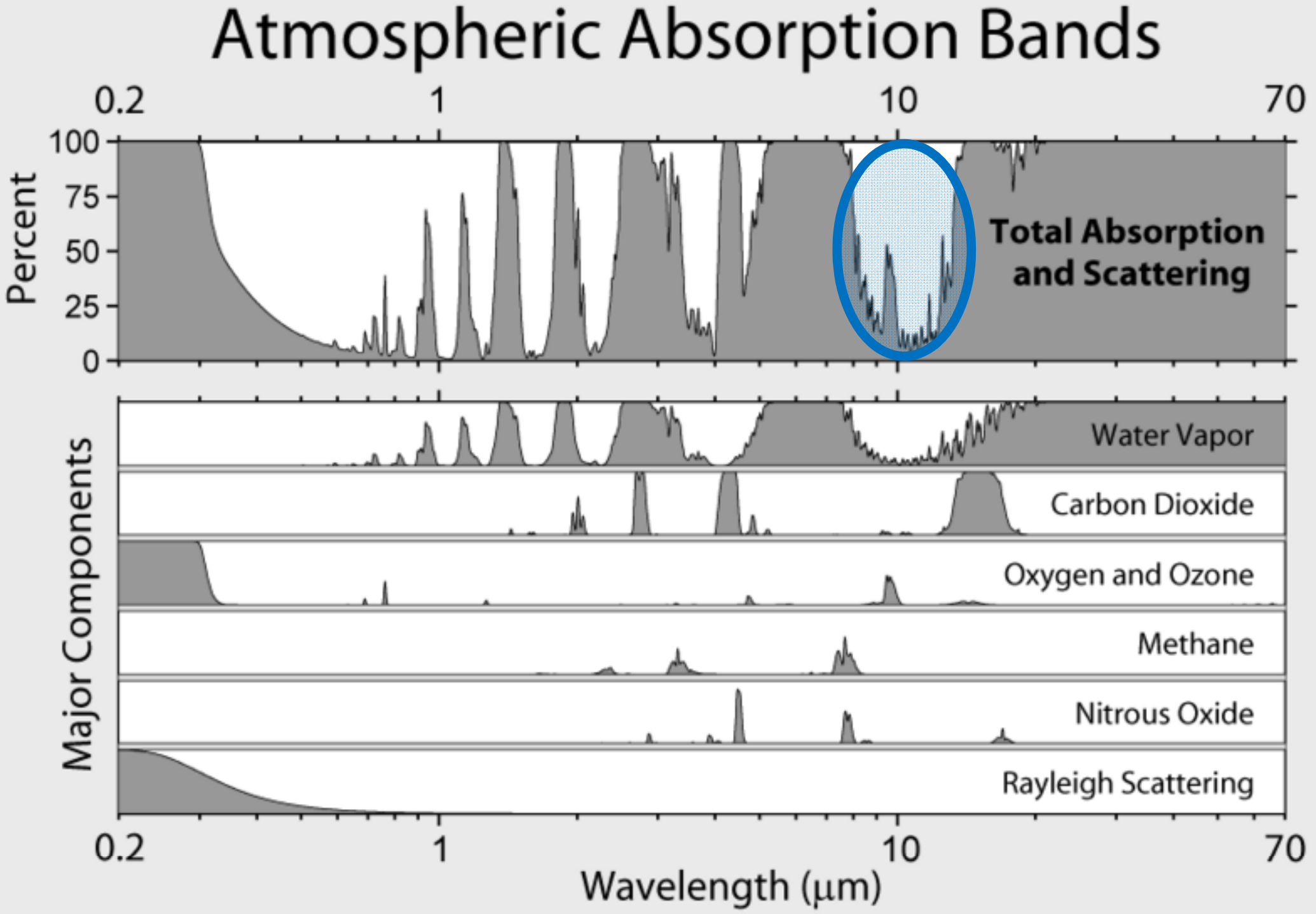
And, human experience with nighttime radiation loss differences (and temperature changes) between a clear night and a cloudy night (or when it is more humid) should help most people realize that this works.



Atmospheric Absorption Bands



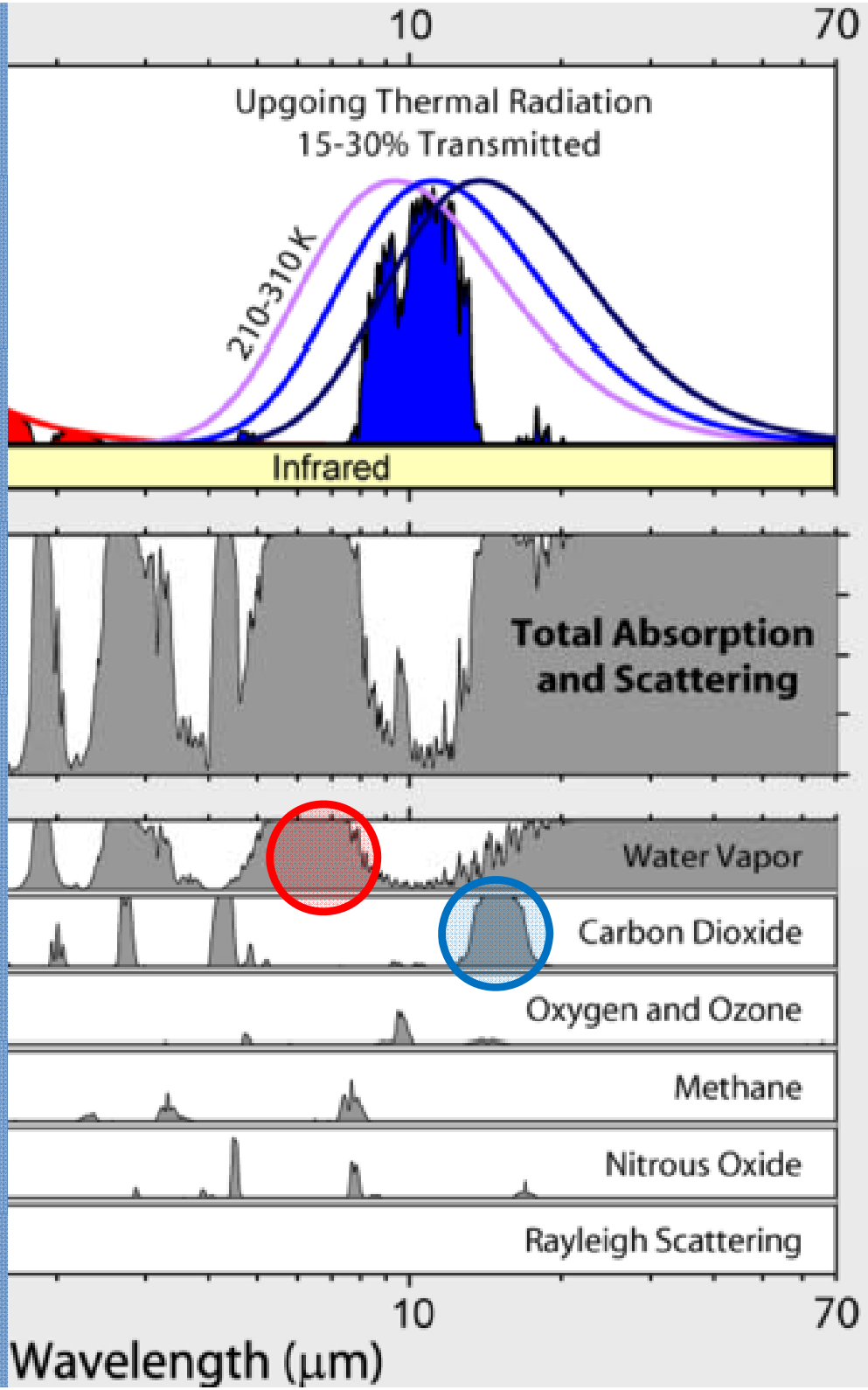
We gain solar energy through a wavelength band – the visible window



We lose long-wave energy through a wavelength band – the thermal window

- Warmer areas on Earth will emit slightly shorter wavelengths and water vapor is the main GHG

- Cooler areas on Earth will emit slightly longer wavelength energy and CO_2 is the main GHG



With more CO_2, the polar environments should warm up

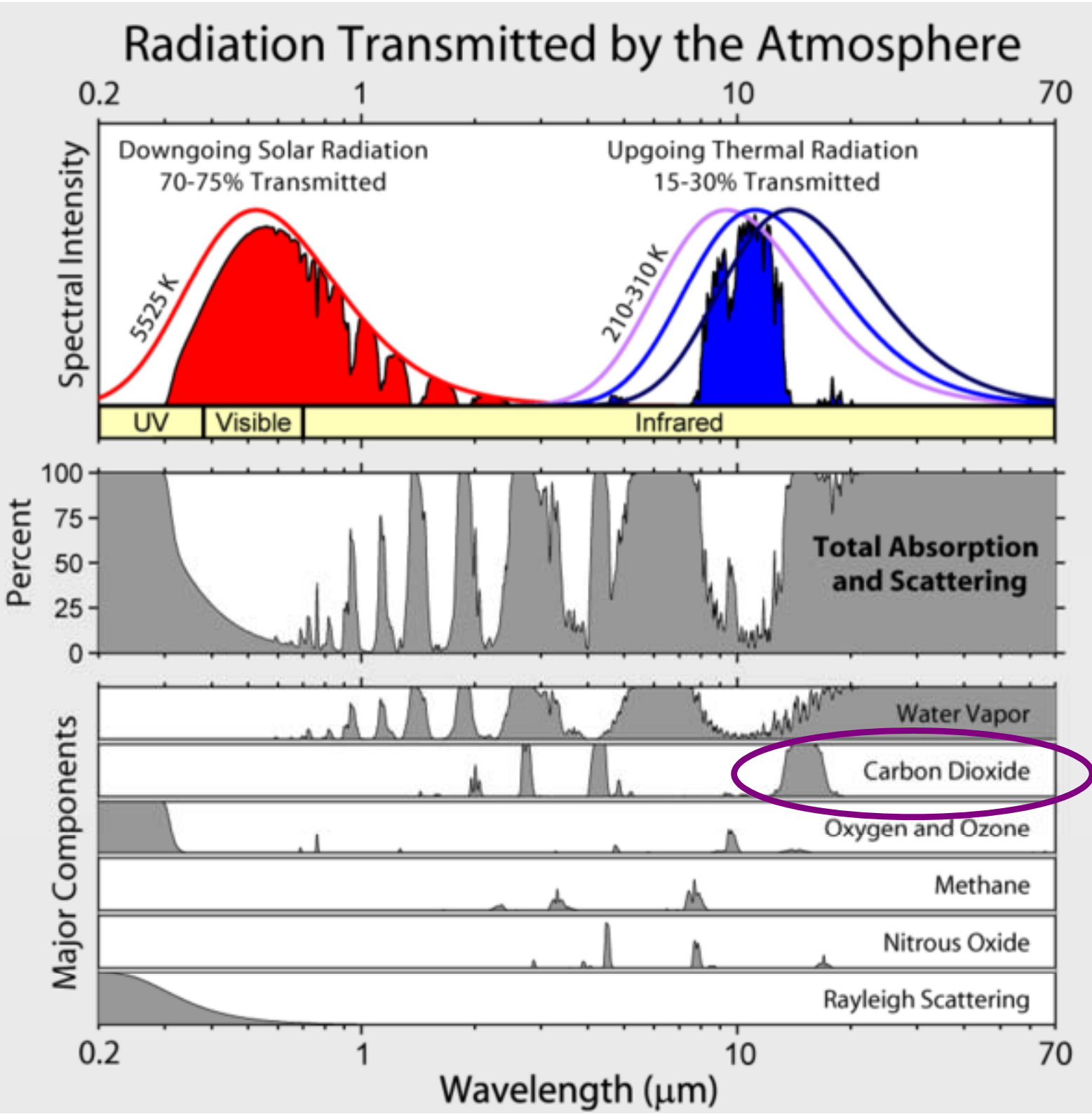


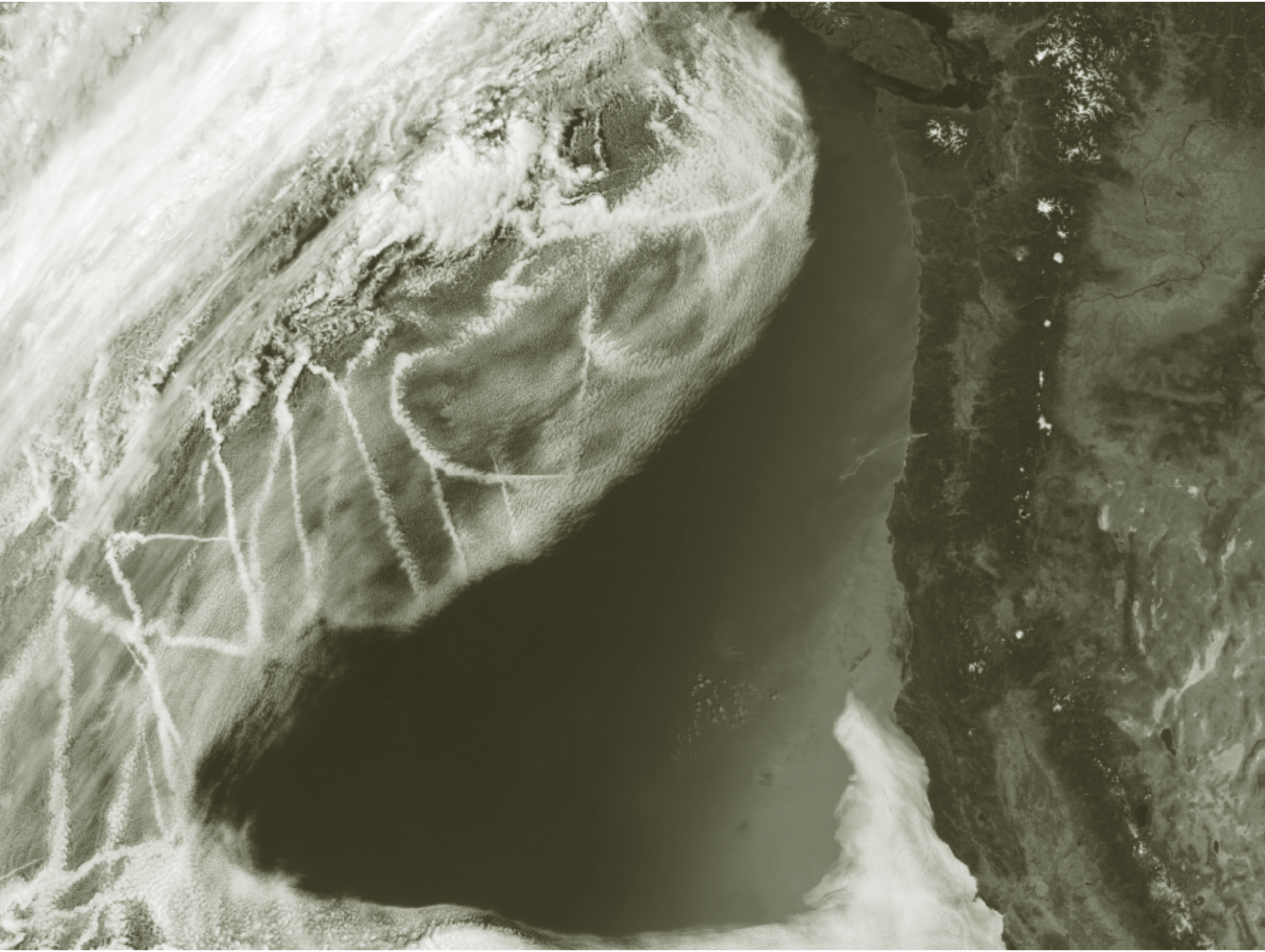
Table 5.1
Estimates of global average temperature changes under different assumptions about changes in greenhouse gases and clouds.

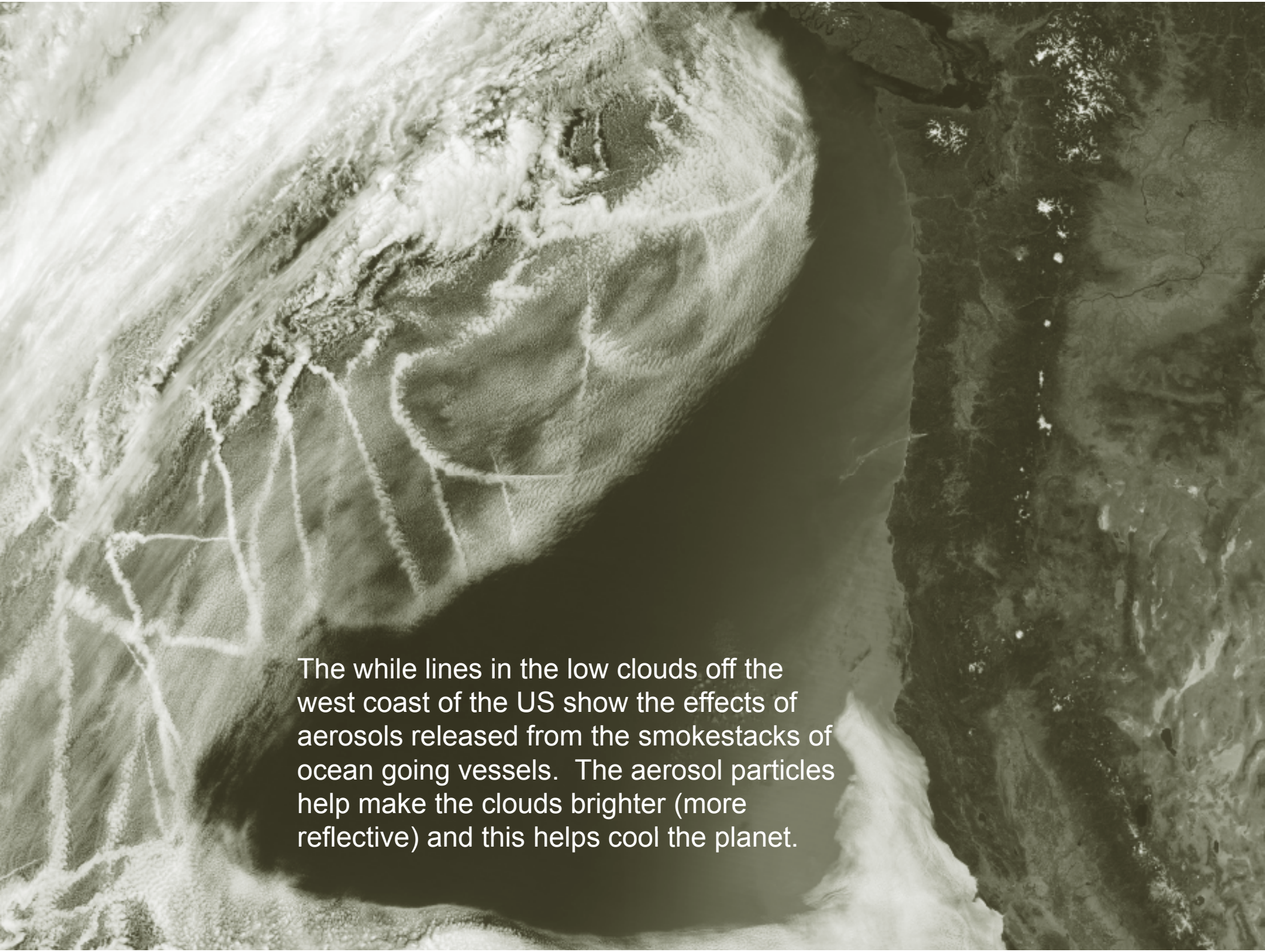
Greenhouse gases	Clouds	Change in °C from current average global surface temperature of 15 °C
As now	As now	0
None	As now	–32
None	None	–21
As now	None	4
As now	As now but + 3% high cloud	0.3
As now	As now but + 3% low cloud	–1.0
Doubled CO_2 concentration; otherwise as now	As now (no additional cloud feedback)	1.2
Doubled CO_2 concentration + best estimate of feedbacks	Cloud feedback included	2.5

This table provides the results of old computer model runs for our Earth-atmosphere system.

The second row (no greenhouse gases) suggests that **the natural greenhouse** gas effect **produces a warming of 32°C**.

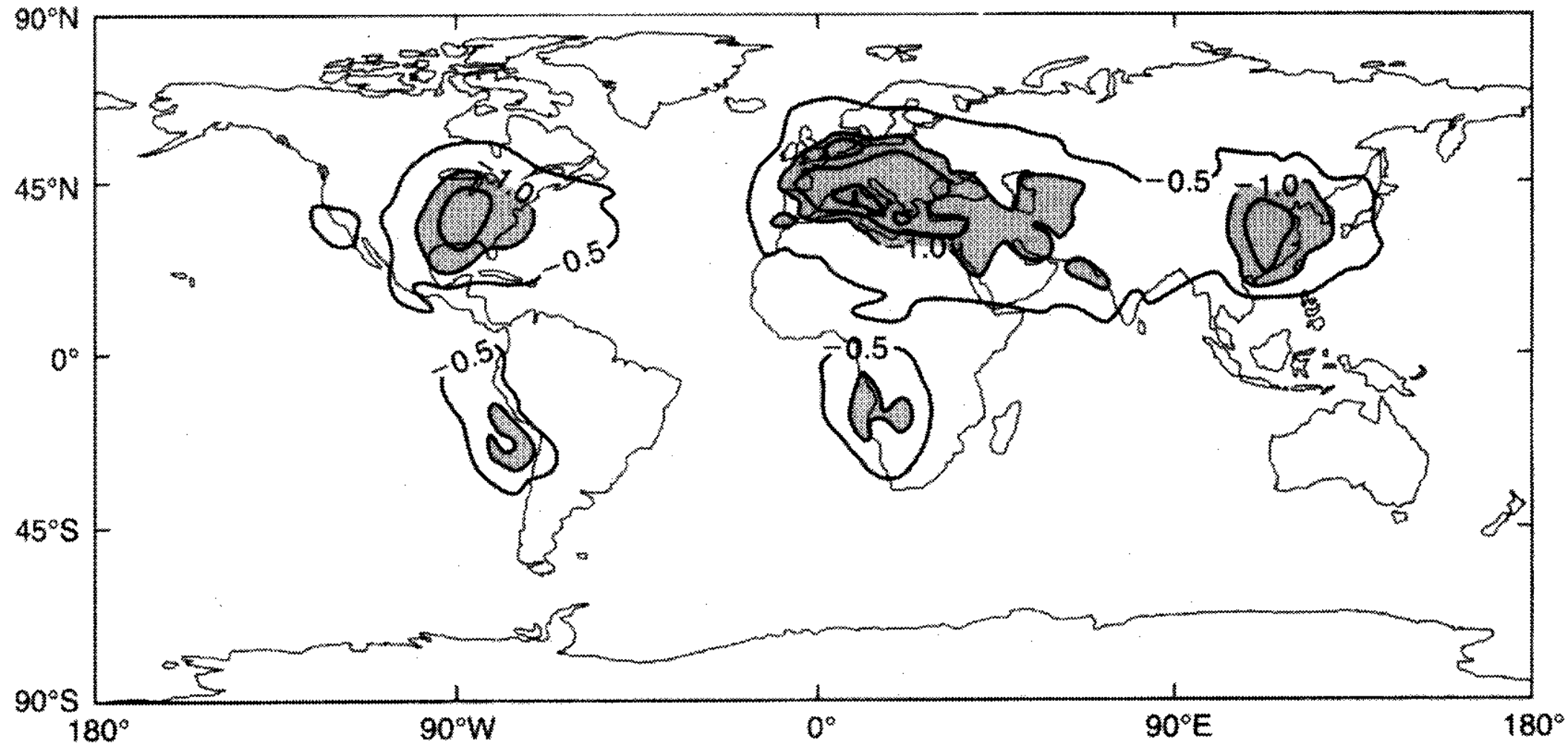
The bottom row suggests that a doubling the CO_2 concentration in our atmosphere warms us up by 2.5 °C.





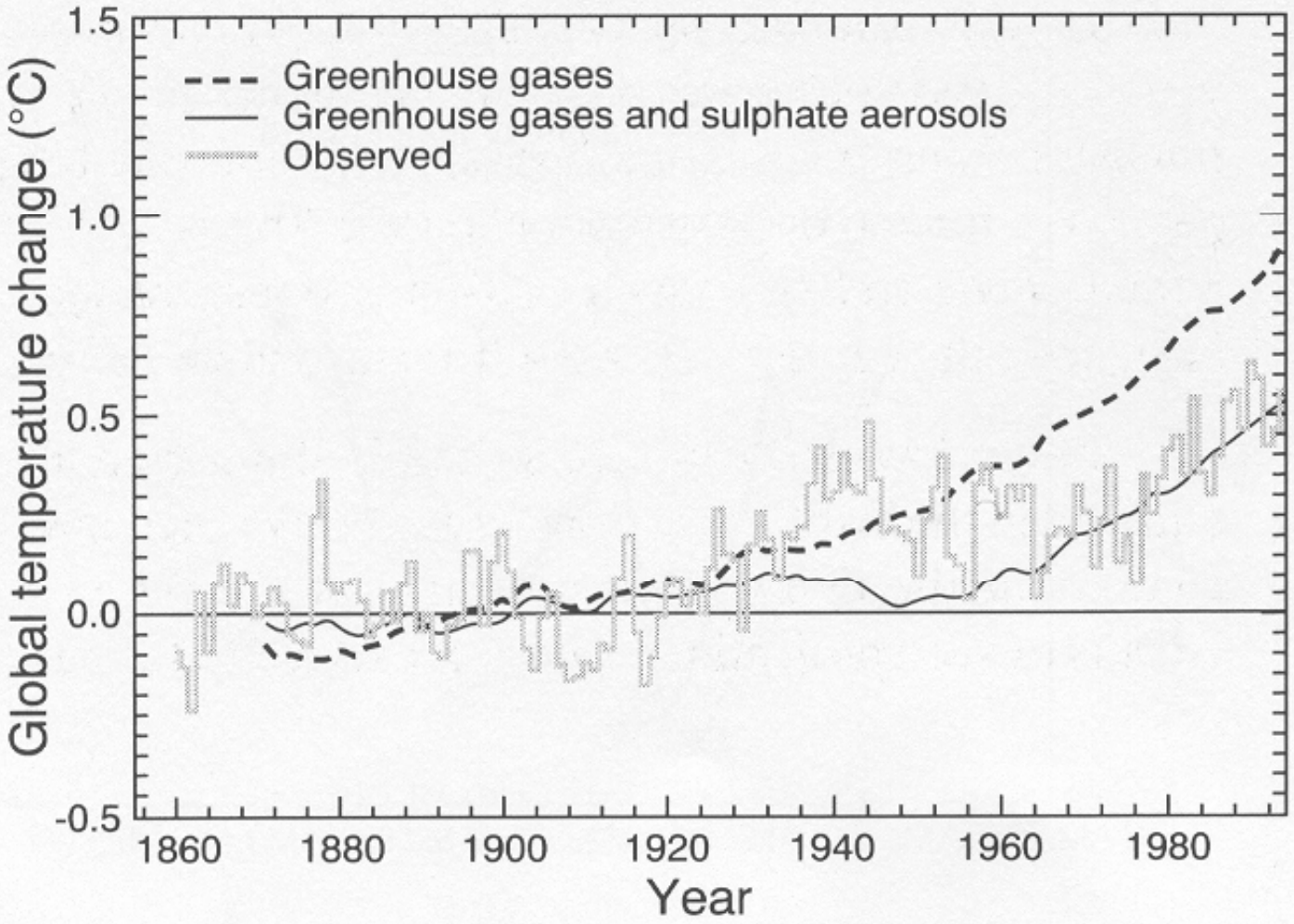
The while lines in the low clouds off the west coast of the US show the effects of aerosols released from the smokestacks of ocean going vessels. The aerosol particles help make the clouds brighter (more reflective) and this helps cool the planet.

When climate models add in the effects of aerosols, certain areas are cooled (those areas where we release more pollutants into the air).
This map shows the modeled distribution of the change in annual direct radiative forcing (Wm^{-2}) from anthropogenic sulfate aerosols. Negative values indicate a cooling effect.



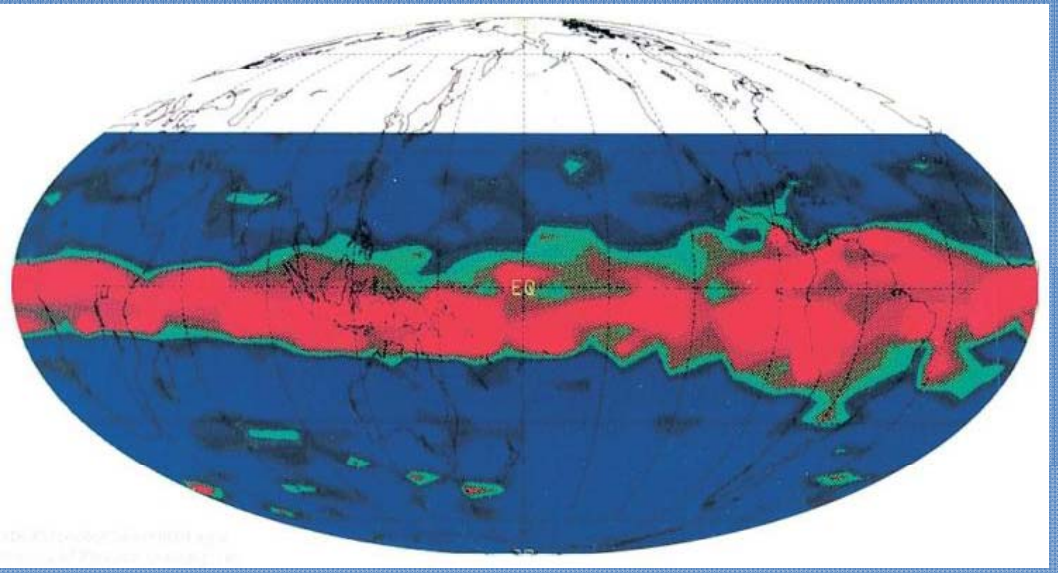
The process of science improves our understanding over time. The planet was not warming as much as the early modeling efforts suggested.
With the addition of the 'whiter/brighter cloud effect' of sulfate aerosols, the models provided a much better match with observed data (reality).

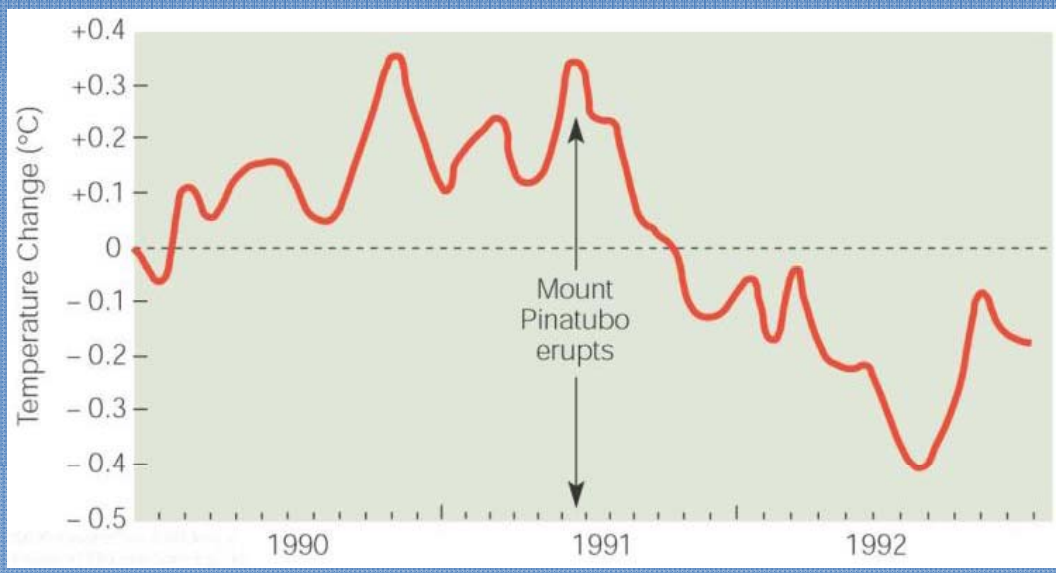
Fig. 5.22
Simulated global annual surface air temperature from 1860 to 1990 allowing for increases in greenhouse gases only (dashed curve) and greenhouse gases and sulphate aerosols combined (full curve) compared with observed changes over the same period[30].



Climate models are tested to see if they handle known (measured) events well. One test, is how well the models perform with the changes associated with a volcanic eruption.

Mt. Pinatubo erupted in June 1991 and its impact on global temperatures was to cool the planet (about 0.5ºC) for a short time.

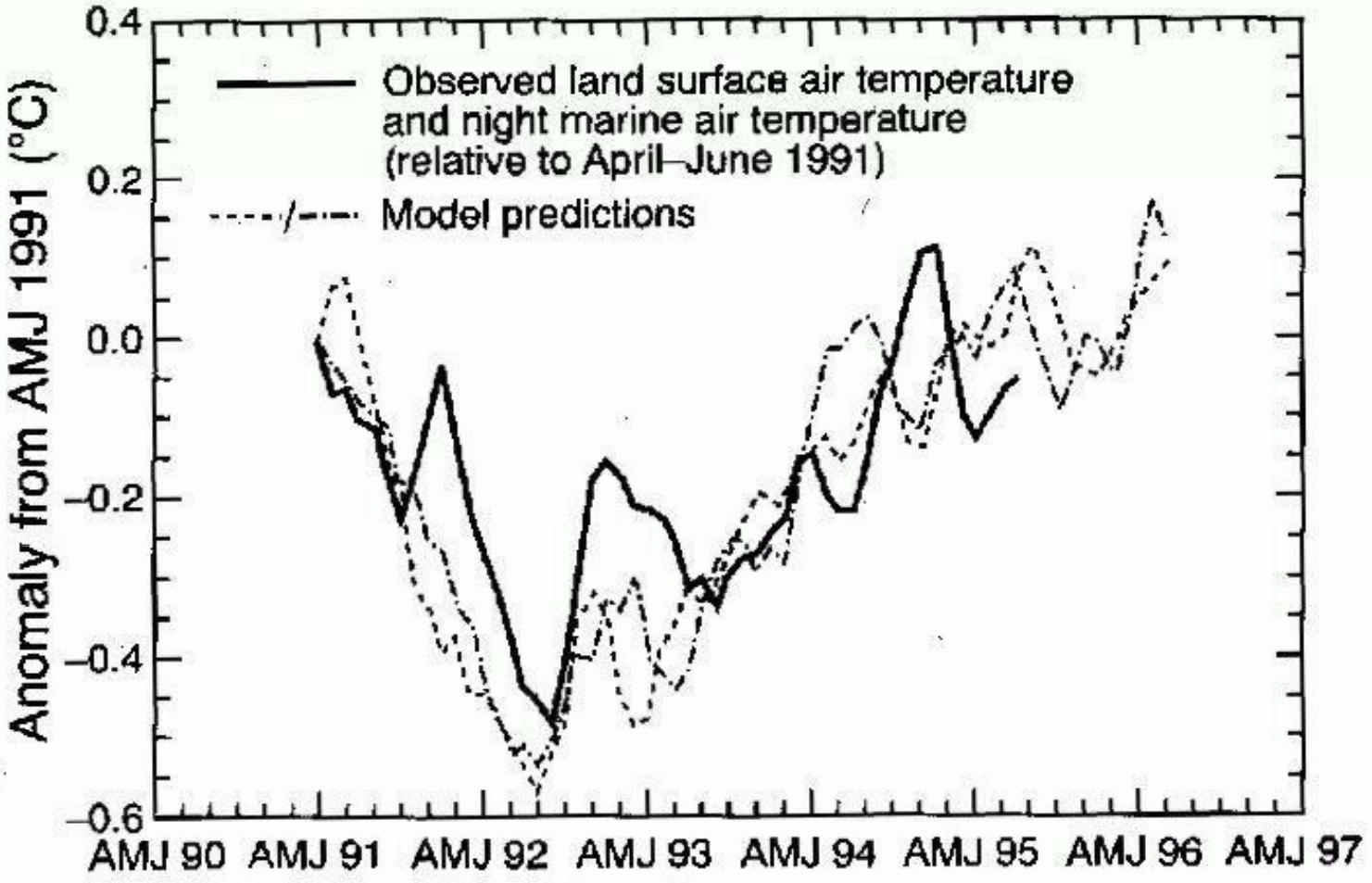


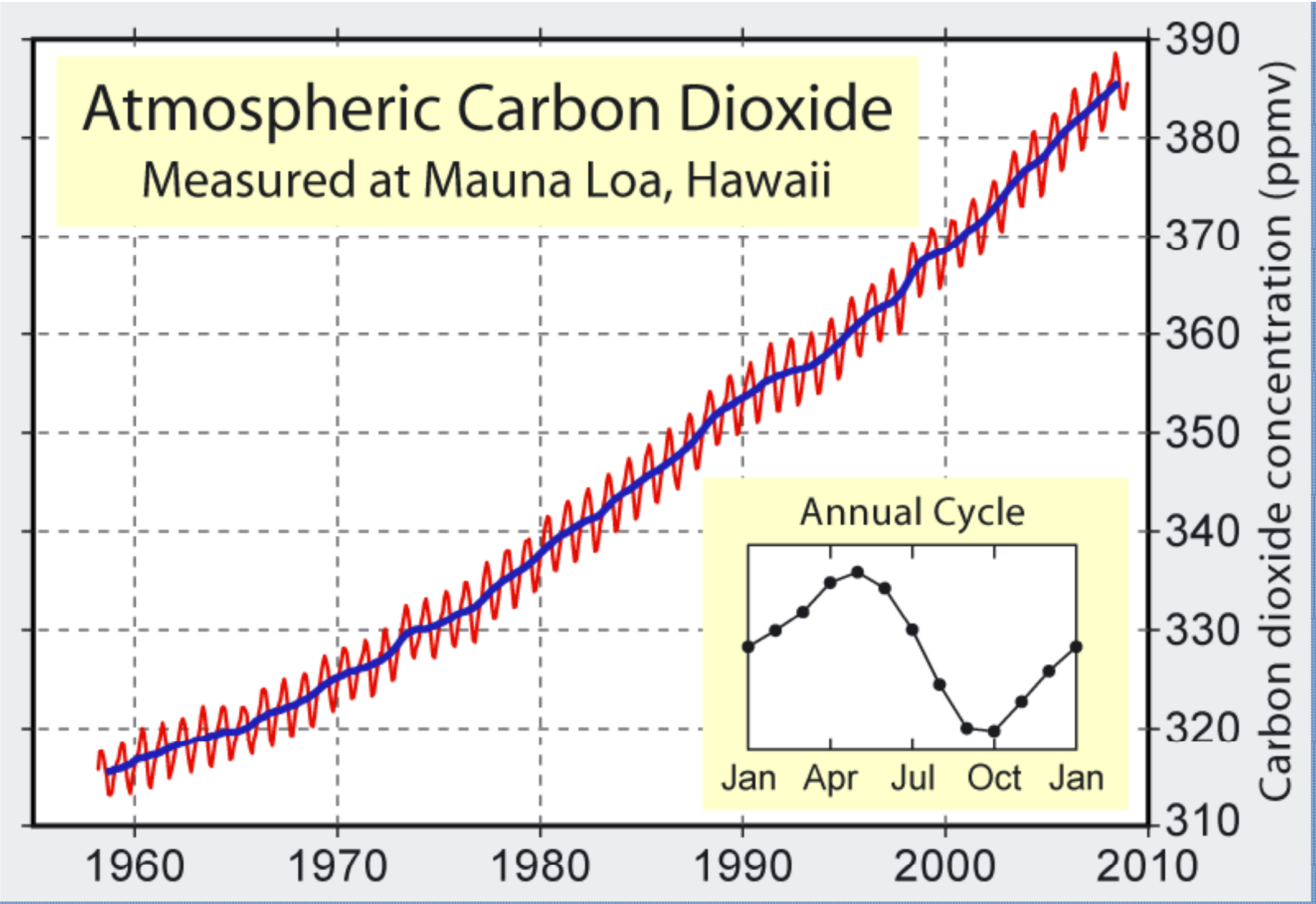


Three months after the June 1991 eruption of this Philippine volcano, much of the 20 million tons of ejected sulfur dioxide had been directed by zonal stratospheric winds and girdled the equator.

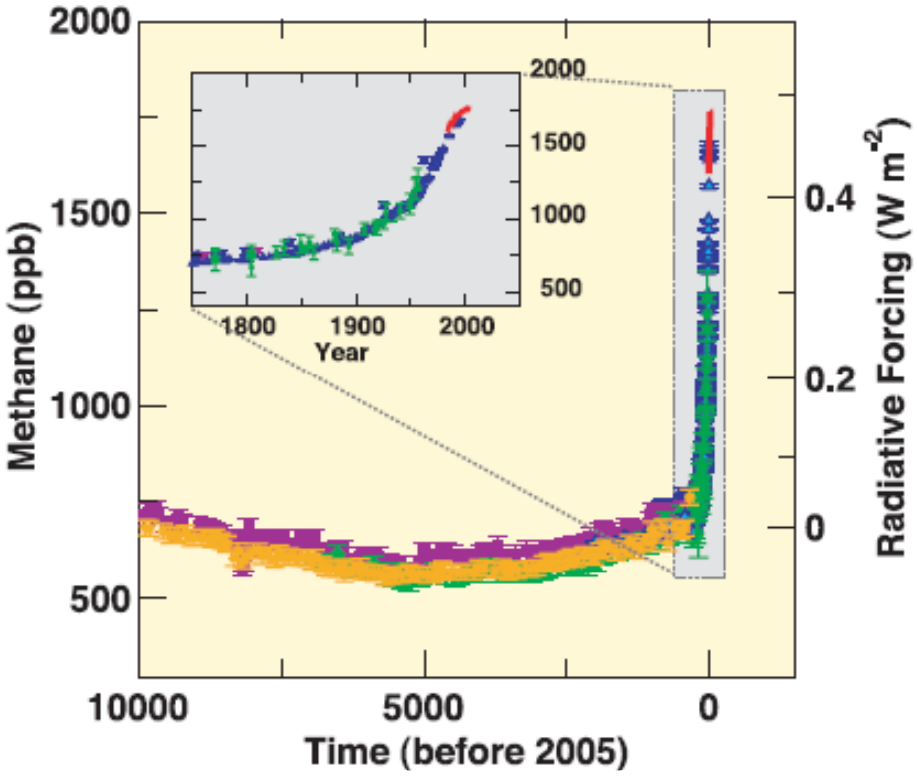
Climate model runs for the Mt Pinatubo 'perturbation' did a good job of getting the magnitude of the temperature change correct; the models also did a nice job of tracing the impact over time.

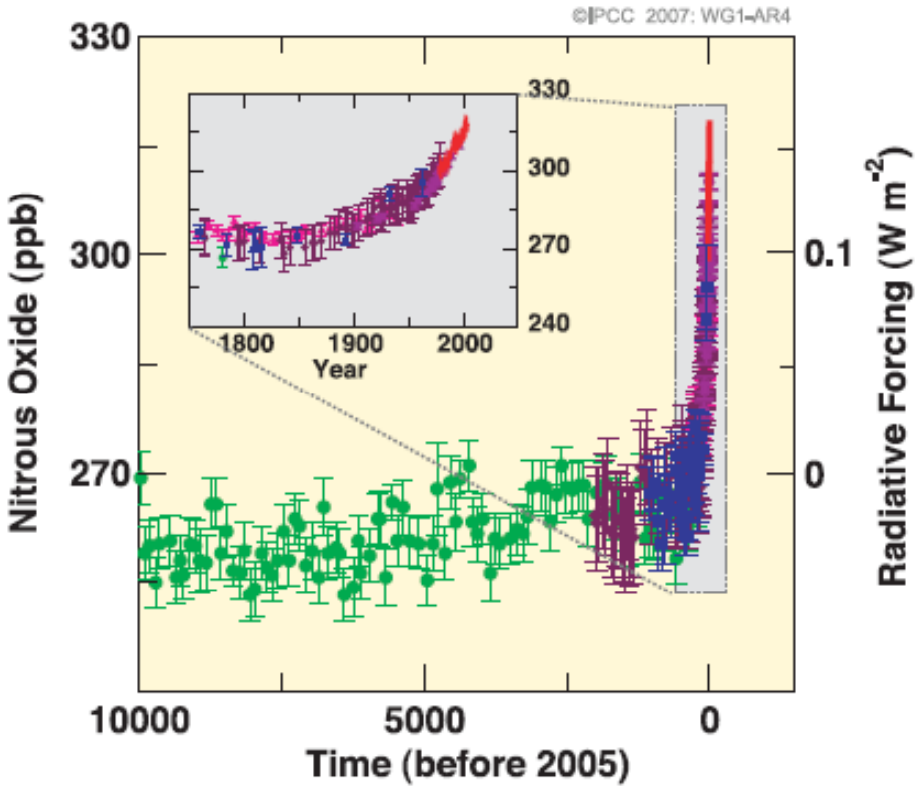
Fig 5.21
The predicted and observed changes in global land and ocean surface air temperature after the eruption of Mount Pinatubo, in terms of three-month running averages from April to June 1991 to March to May 1995[28]





For the 21st Century, carbon dioxide rates are rising faster than the BAU IPCC scenario



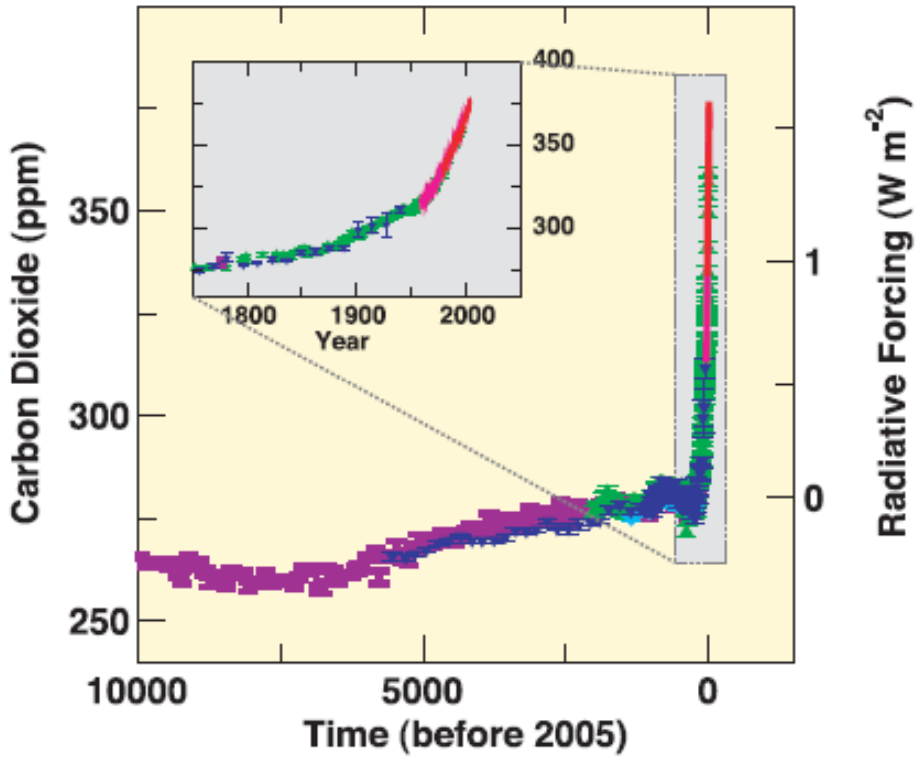


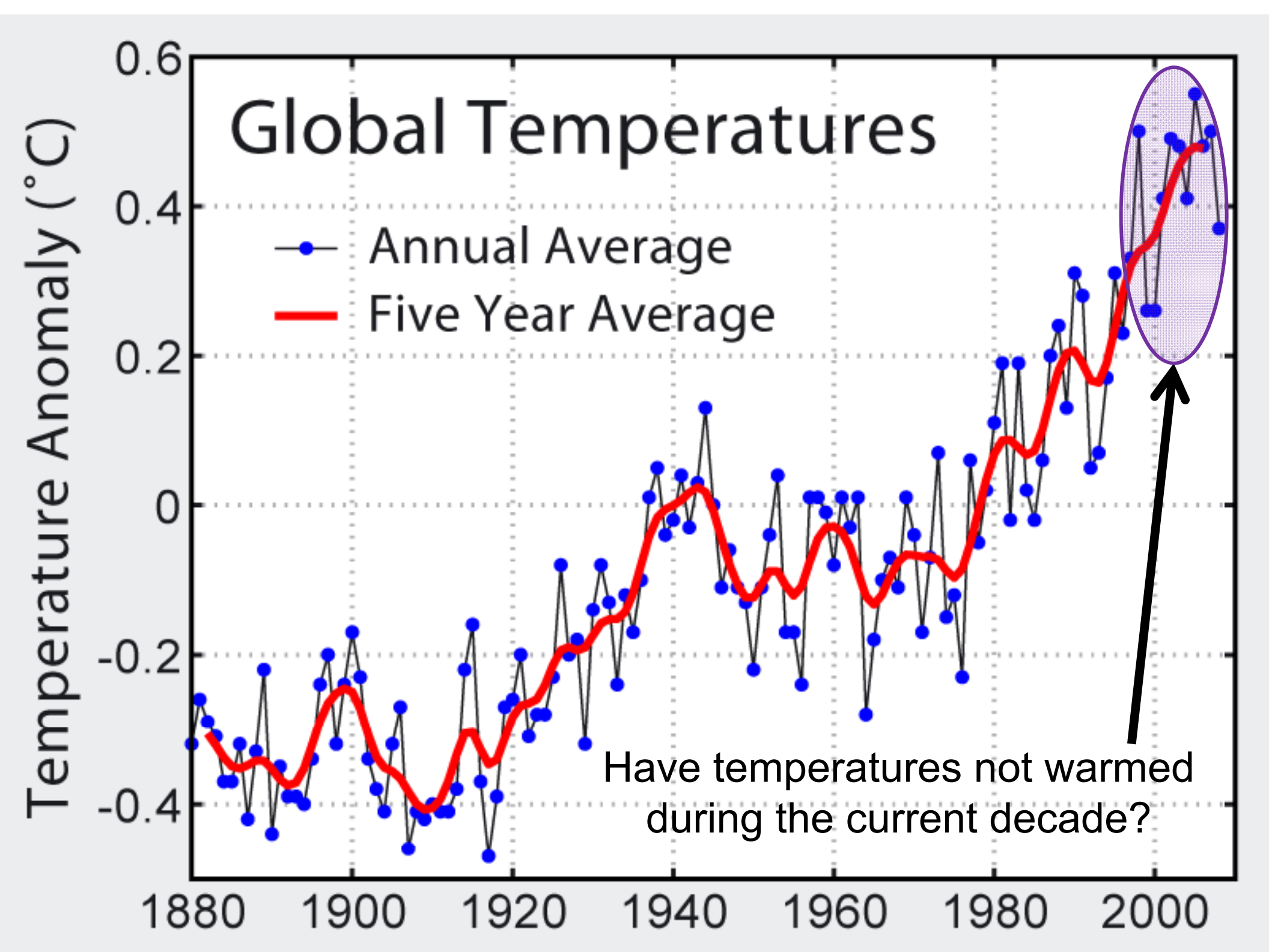
GWP (global warming potential) depends on a time window

GWP is a relative value $CO_2 = 1$

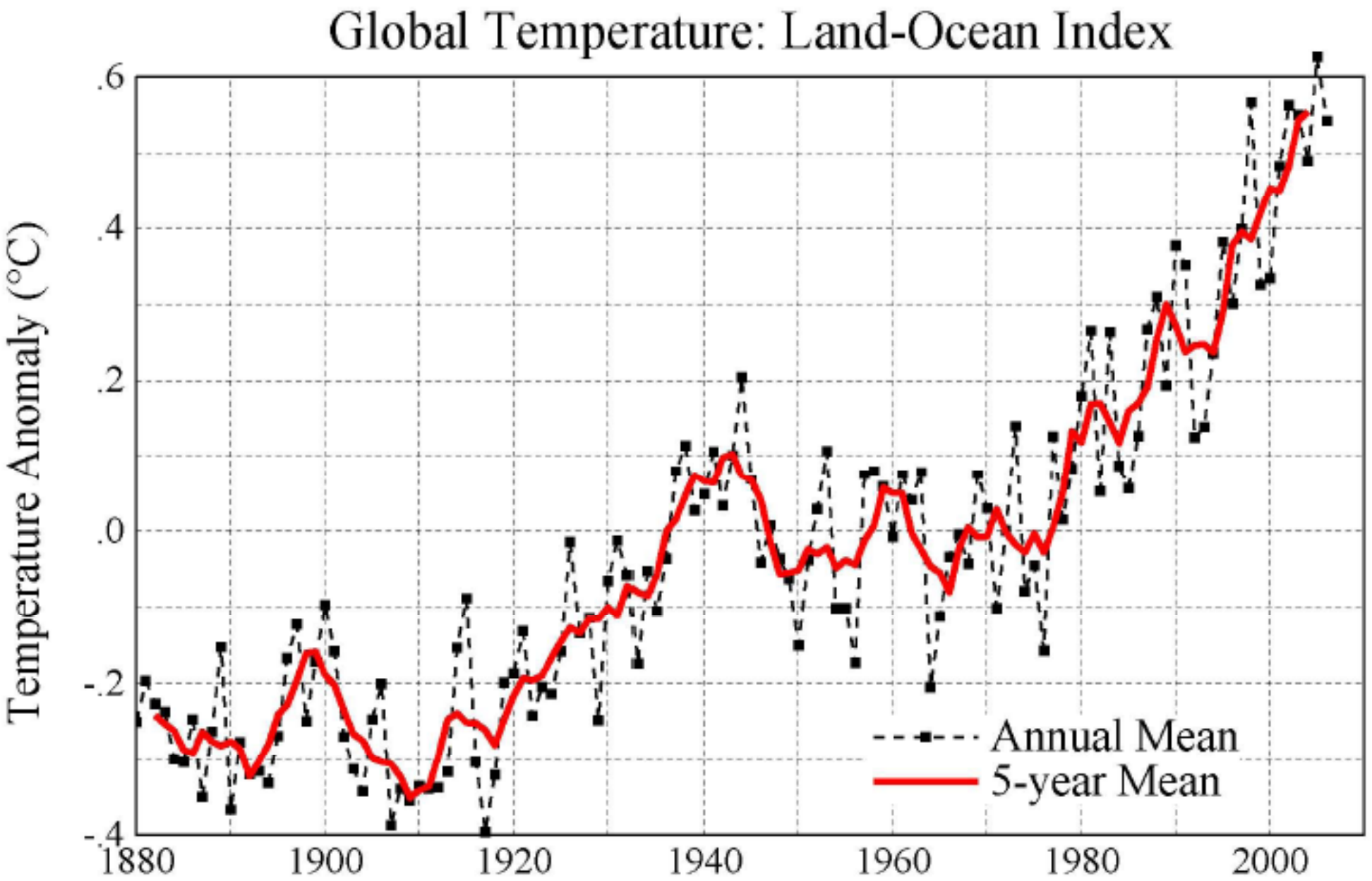
IPCC AR4 figures for 100 years:

CO_2	1
CH_4	25
N_2O	298

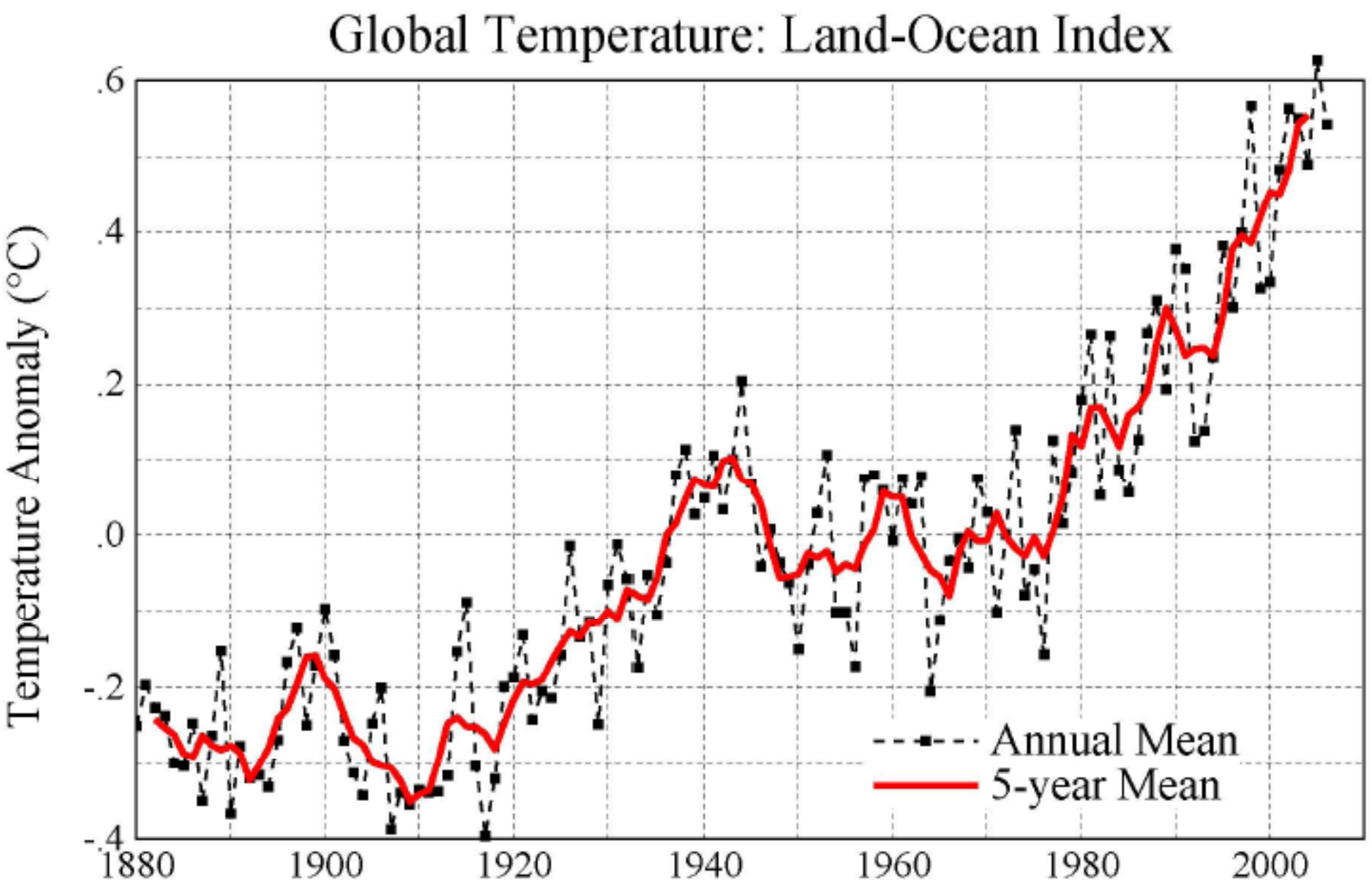



Global Temperatures
Annual Average
Five Year Average
Temperature Anomaly (°C)
0.6
0.4
0.2
0
-0.2
-0.4
1880
1900
1920
1940
1960
1980
2000
Have temperatures not warmed during the current decade?

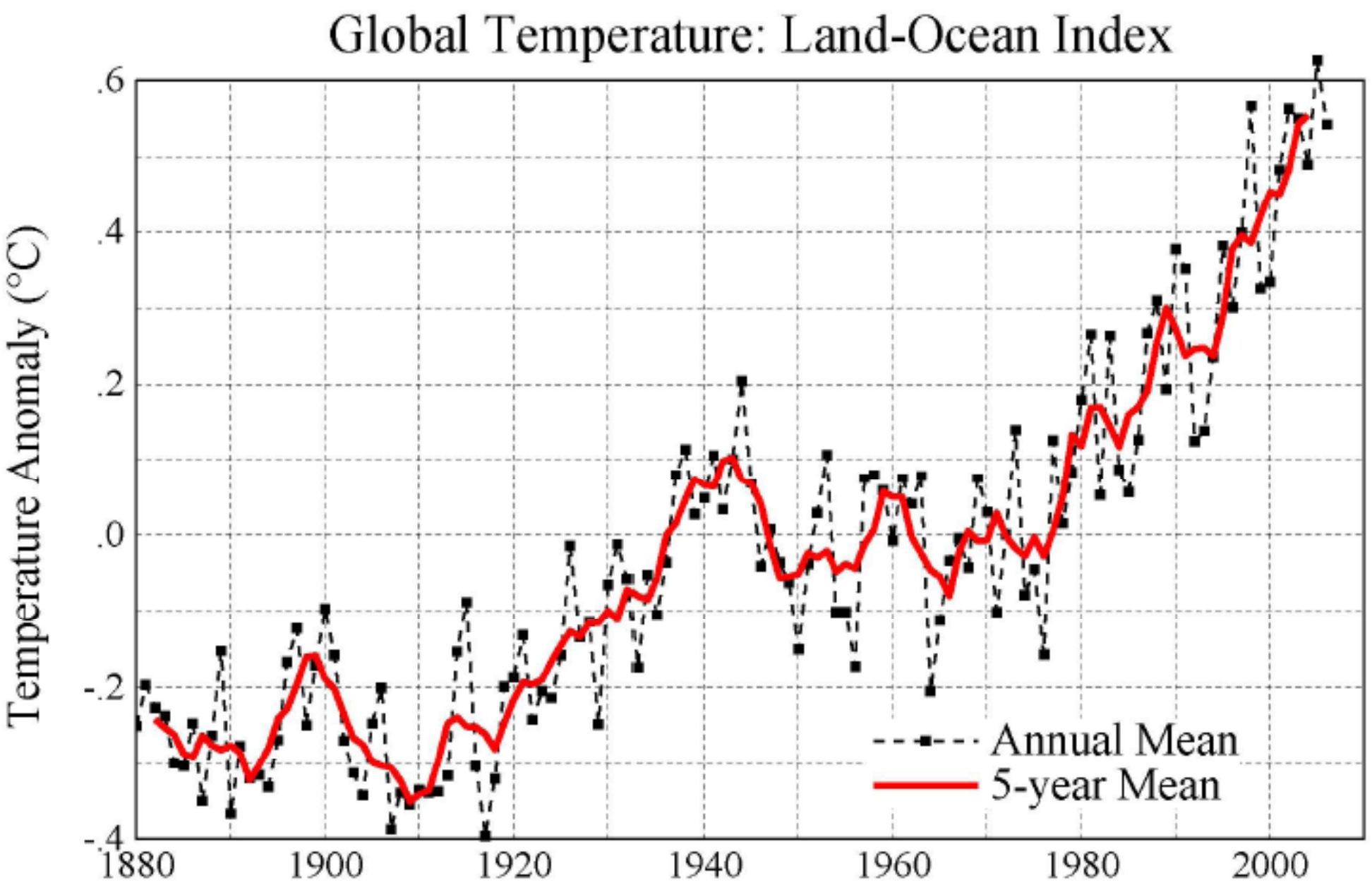
The instrument-based temperature record shows nearly 0.8°C (1.4°F) warming since 1880.



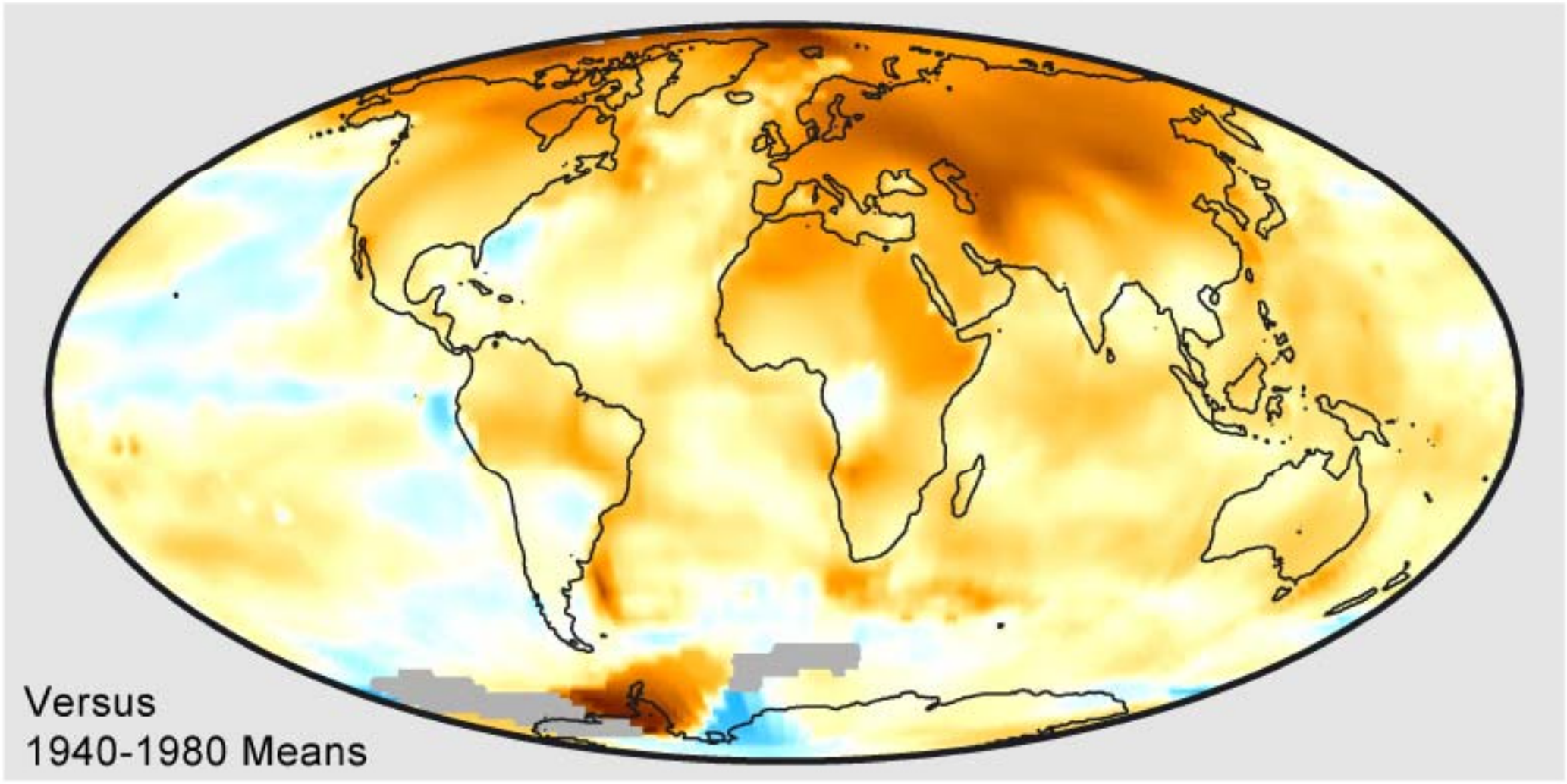
There have been two periods of distinct warming: From 1910 – 1945 and since the mid-1970s

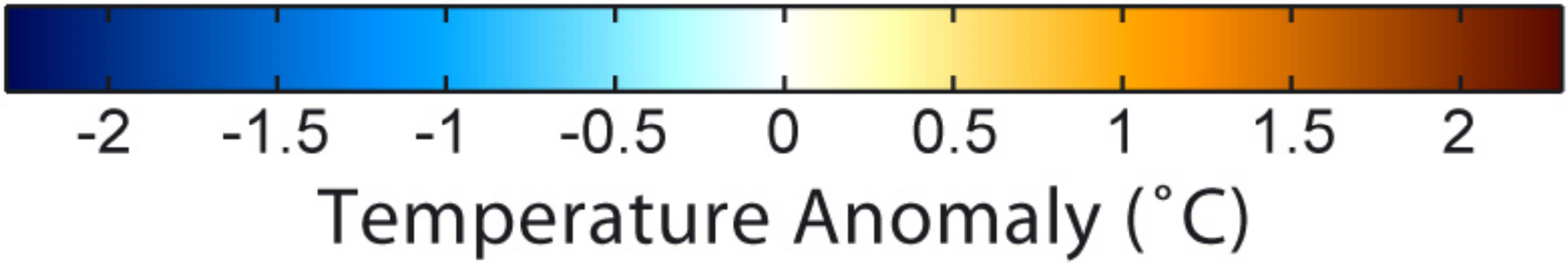


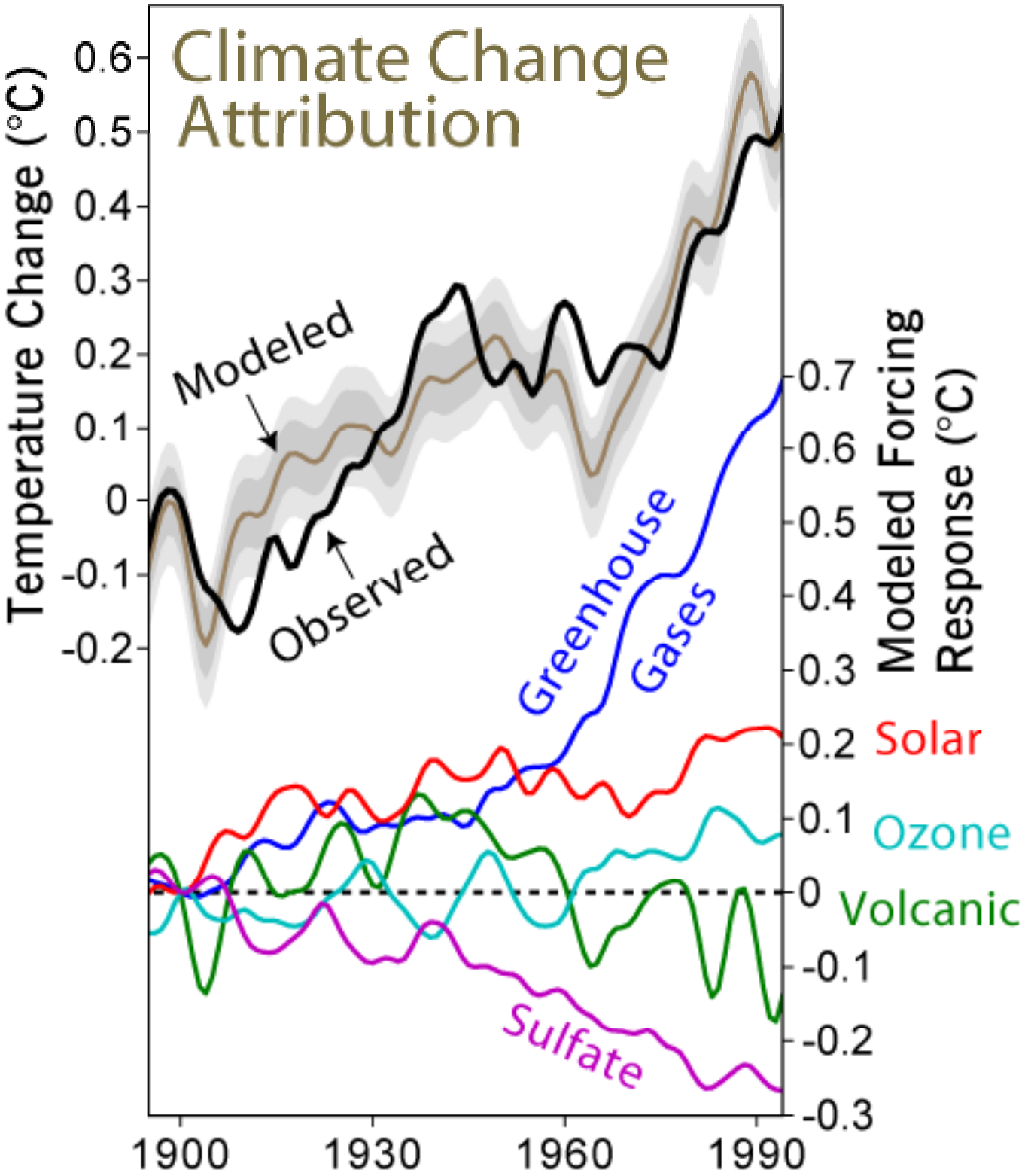
During the 20th Century, the planet warmed at a rate of 0.06°C per decade; that rate has increased to 0.18°C per decade for the last 30 years.



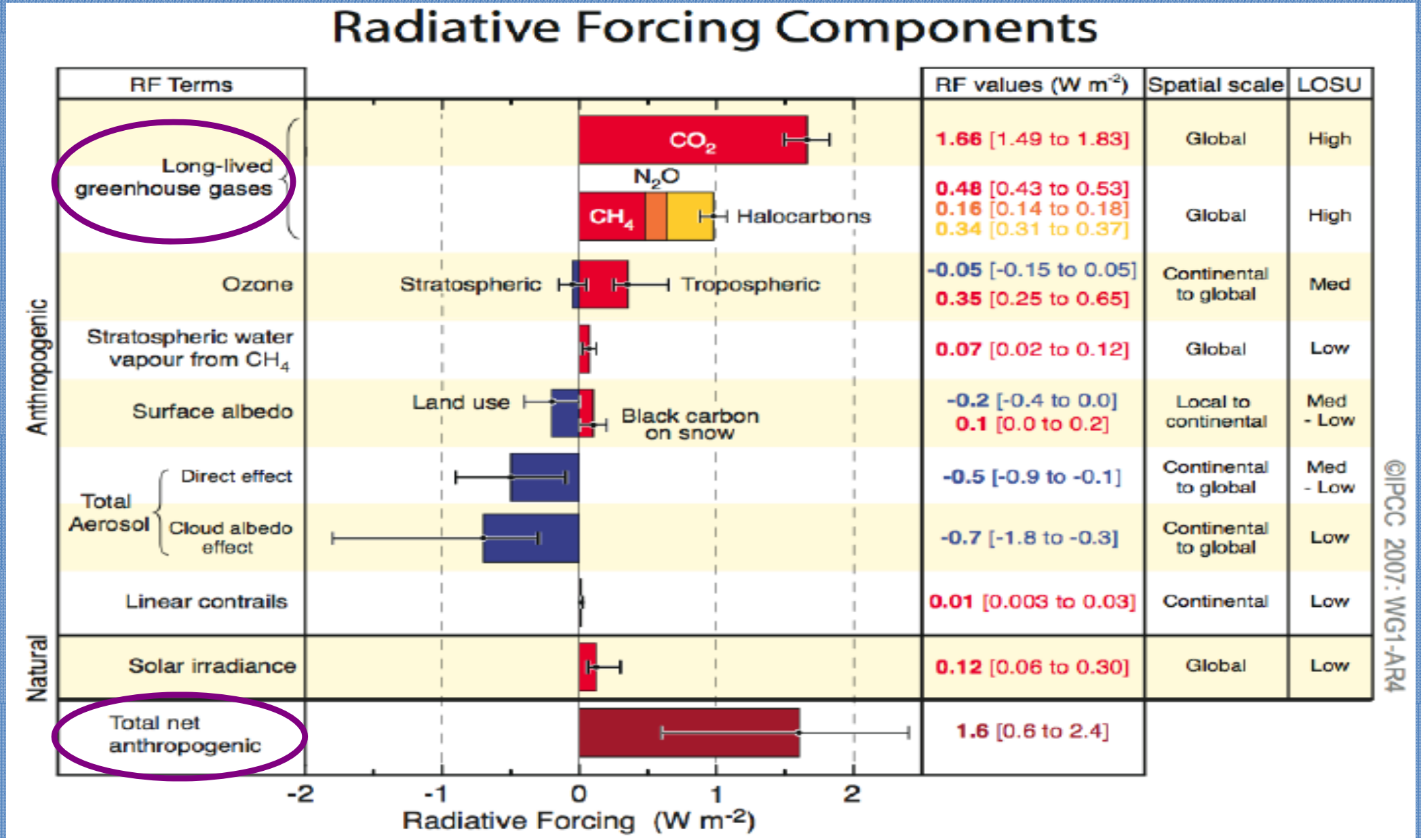
1999-2008 Mean Temperatures

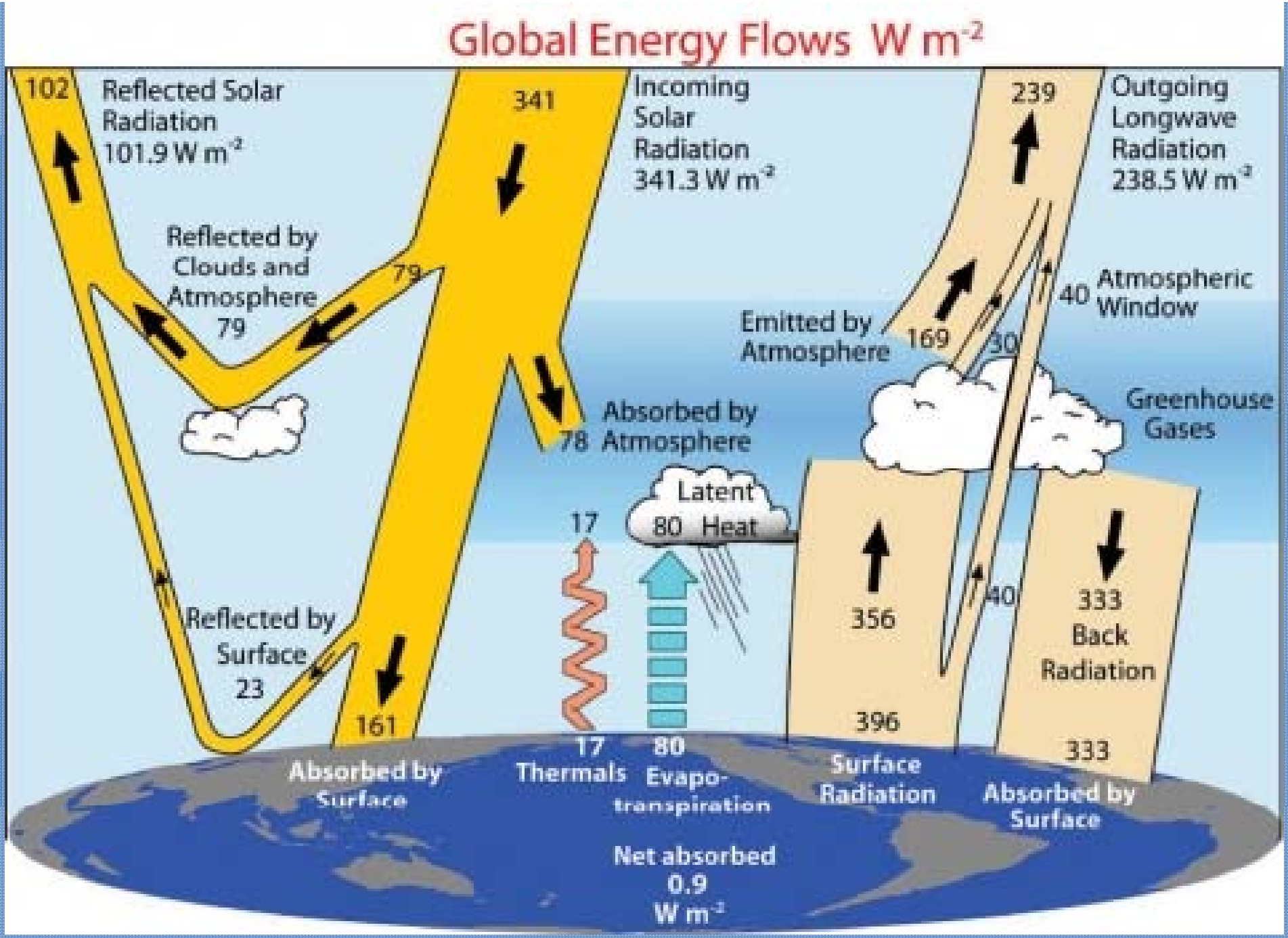





Climate Change
Attribution
Temperature Change (°C)
0.6
0.5
0.4
0.3
0.2
0.1
0
-0.1
-0.2
Modeled
Observed
Modeled Forcing
Response (°C)
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
-0.1
-0.2
-0.3
Greenhouse
Gases
Solar
Ozone
Volcanic
Sulfate
1900
1930
1960
1990

A summary of what we know (and how well we understand it) for the model components that influence global warming. Notice that the magnitude of the effect of increased CO_2 is far greater than the warming from solar irrandiance (more energy from the sun).





Trenberth, K.E., Fasullo, J.T., and Kiehl, J. (2009) Earth's Global Energy Budget, in *Bulletin of the AMS*, Vol 90, pp 311-323.

A Parrot Head Looks at the IPCC

"wasted away in Margaritaville"

- FAR = First Assessment Report 1990
  - **'Its nobody's fault' [Jimmy Buffett – Margaritaville]**
  - **"Thus the observed increase could be largely due to this natural variability: alternatively this variability and other human factors could have offset a still larger human-induced greenhouse warming."**
- SAR = Second Assessment Report 1996
  - **'It could be my fault'**
  - **"The balance of evidence suggests that there is a discernible human influence on global climate. "**
- TAR = Third Assessment Report 2001
  - **'It's my own damn fault'**
  - **"There is new and stronger evidence that most of the warming observed over the last 50 years is attributable to human activities."**

So, why is this type of editorial humor way too easy?

Suggested temperature increase with 'global warming' = **2.5° C**

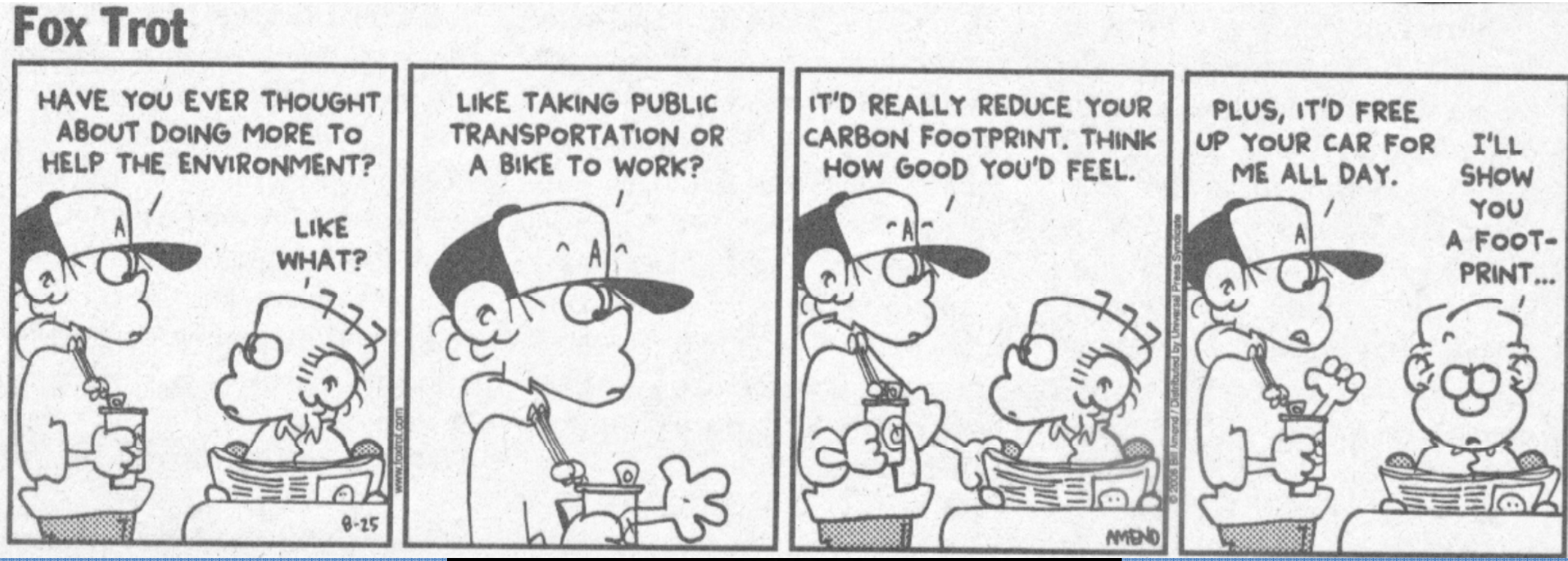
Detroit: Jan = 22° F Jul = 72° F Seasonal difference = 50° F or **27.8° C**

Interannual variability in Jan temps 15° F or **8.3° C**

Are we like the frog in the pot on the stove?

The Physics and Implications:

1. The major cause of paleoclimate change was weak external forcing
2. The major mechanism for cooling the planet (or warming it back up) was change in ice sheet area, vegetation, and GHGs through feedbacks
3. Human-induced radiative forcings due to increases in GHGs are much larger than the radiative forcings that triggered the ice ages
4. Perhaps humans should do something to modify their forcing of on-going & future climate change


Fox Trot
HAVE YOU EVER THOUGHT ABOUT DOING MORE TO HELP THE ENVIRONMENT?
LIKE WHAT?
8-25
LIKE TAKING PUBLIC TRANSPORTATION OR A BIKE TO WORK?
IT'D REALLY REDUCE YOUR CARBON FOOTPRINT. THINK HOW GOOD YOU'D FEEL.
PLUS, IT'D FREE UP YOUR CAR FOR ME ALL DAY.
I'LL SHOW YOU A FOOT-PRINT...