

# **K39: The Key Evidence That Current Global Warming is Human-Caused**

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Here are 13 lines of Evidence...

**GW = AGW (Global Warming =  
Anthropogenic Global Warming)**

# K39: Summary of Key Evidence – Global Warming is Real and Human-Caused

- **We Know global warming is due to GHG's; Evidence -**
- --- Rising tropo + falling strato temps
- --- Rising height of tropopause
- --- Night temps rising faster than day temps (weak)
- --- Measured decrease in outgoing IR by satellites
- --- Measured increase in downward IR from our atmosphere to ground of  $3.5 \text{ W/m}^2$  can only be explained by increased GHG's
- --- Climate models: ~0% of climate forcing is due to natural causes
- **And we know these GHG's are due to Human Activities -**
- --- known emission rate from fossil fuel burning agrees with rise rates in atmosphere + ocean + photosynthesis
- --- **CO2 rise confirmed due to fossil fuel burning:**
- ----- C13/C12 ratio falling trend
- ----- fossil fuel burning consumes oxygen, beyond photosynthetic effects. Observations show indeed dropping O2 content of our atmosphere
- ----- CO2 gradients show it is produced where humans are
- ----- CO2 rise rates slow during economic recessions
- ----- measured volcanic emissions only ~1% vs. humans
- Water vapor GHG is human-caused indirectly: rising CO2-induced warming produces positive feedback since atmosphere holds 7% more water vapor per additional degree temperature rise (simple, well-understood physics, in and out of the lab)
- Also see human "scene of the crime" [SkepticalScience website has a good page](#)

# Evidence #1: A Warming Troposphere with a Cooling Stratosphere

- This is a unique signature of rising greenhouse gases; for many scientists it is the #1 most convincing “fingerprint” that global warming is human-caused, since we’ll see that the evidence is overwhelming that it is OUR greenhouse gases that are responsible for what’s in the atmosphere.
- No other physical cause we know of can produce this combination of temperature changes
- Why? It’s a bit complicated, because both ozone and CO<sub>2</sub> affect the stratosphere’s temperature...

# Humans have 2 Major Influences on Stratospheric Temperatures – CO<sub>2</sub>, and Ozone

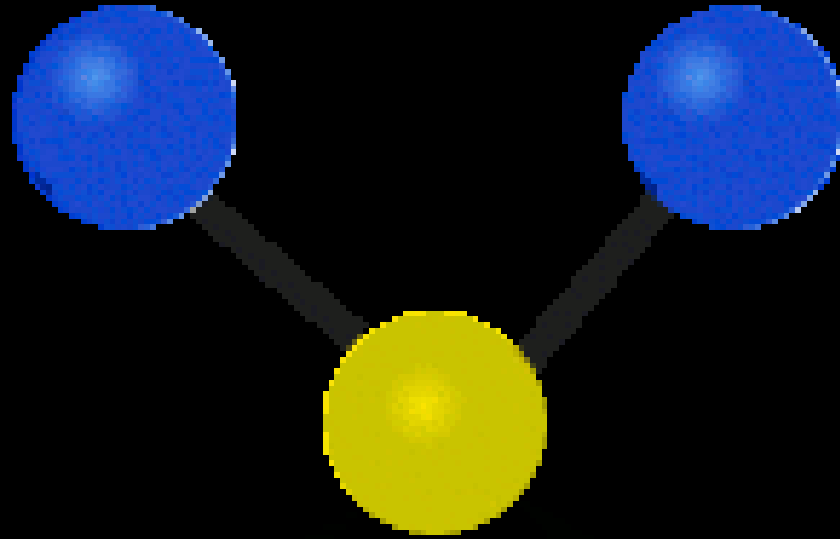
Ozone absorbs solar UV and this heats the stratosphere from its upper layers

- But Human-made CFC's (chlorofluorocarbons) progressively destroyed stratospheric ozone till the Monteral Accords banned CFC's in 1989.
- So while ozone levels were dropping, that too would contribute to a cooling stratosphere...
- BUT, since 1989, ozone has been re-accumulating in the stratosphere, no longer cooling it.
- So if we continue to see a cooling stratosphere even after 1989, that's strong evidence for rising GHG's

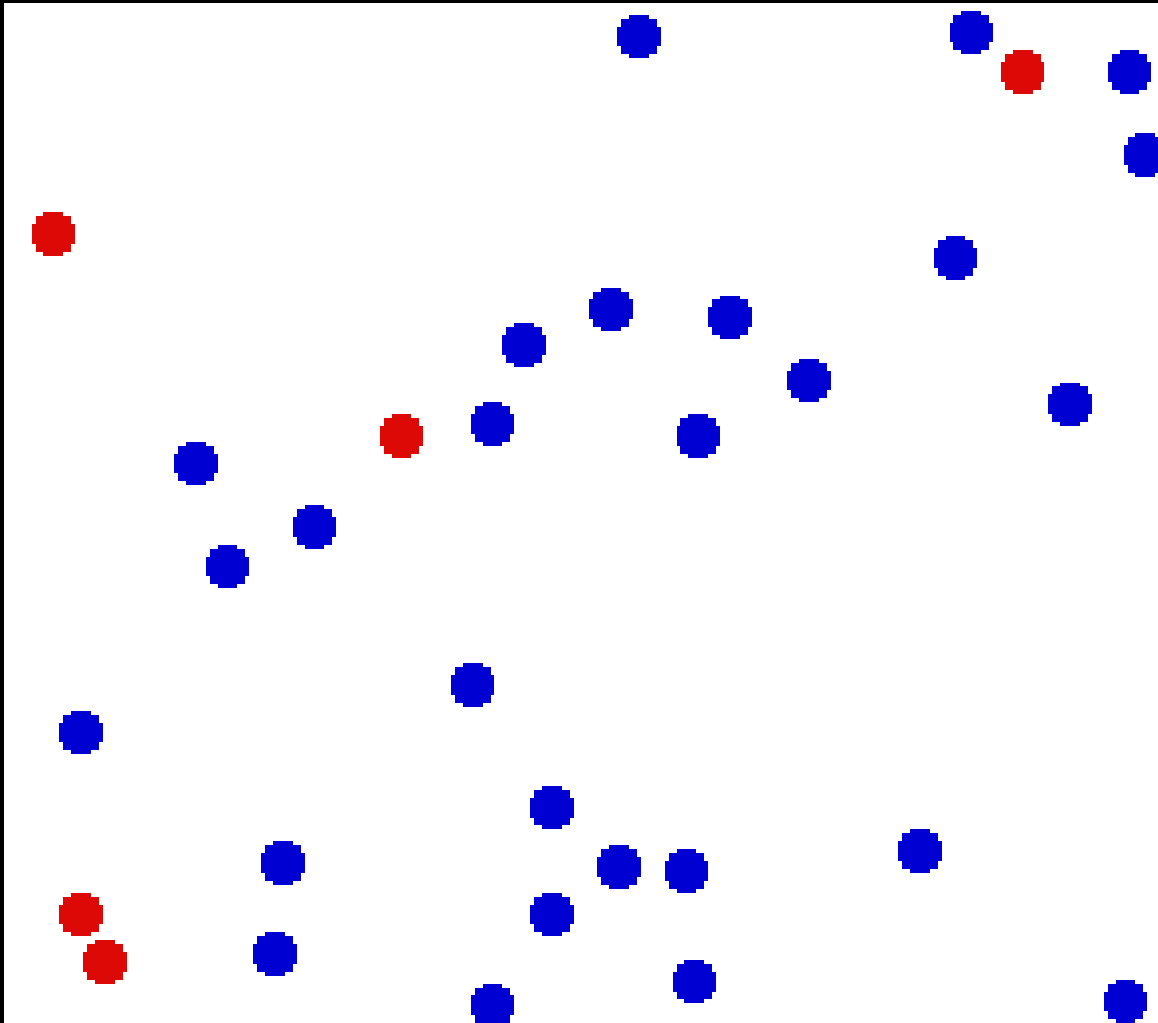
# How Does Rising Stratospheric CO<sub>2</sub> Acts as a Coolant?

- First, the stratosphere sees less upgoing radiation because it is trapped by the troposphere (*i.e.* global warming!),
- And higher CO<sub>2</sub> levels mean more frequent CO<sub>2</sub> collisions, causing molecular collisional excitation, which can then de-excite by IR photon emission. Many of these photons go out to space because the stratosphere has so much lower density than the troposphere. The stratosphere is “optically thin” to long wave IR.
- The net result? Enhanced kinetic energy (=temperature) converted to light energy and radiated away to space, hence net cooling.

Molecules have internal motions.  
Collisions with other particles can  
excite these internal motions



**But temperature only has to do with the average bulk motion of the entire molecule, not the internal vibrations. So when collisions absorb some of that collision energy and they ricochet off slower, that means a cooler temperature for the gas**



# Now You May Say...

- But Rick, isn't that excited internal state just going to de-excite and give off a photon which will get re-absorbed somewhere else, like we talked about in the chapter 5?
- Yes, it will de-excite and give off a photon, an infrared photon. But this is the stratosphere, and the density is very low, and that IR photon now has a very good chance of escaping to outer space.
- That means, the process is a net COOLANT for the stratosphere

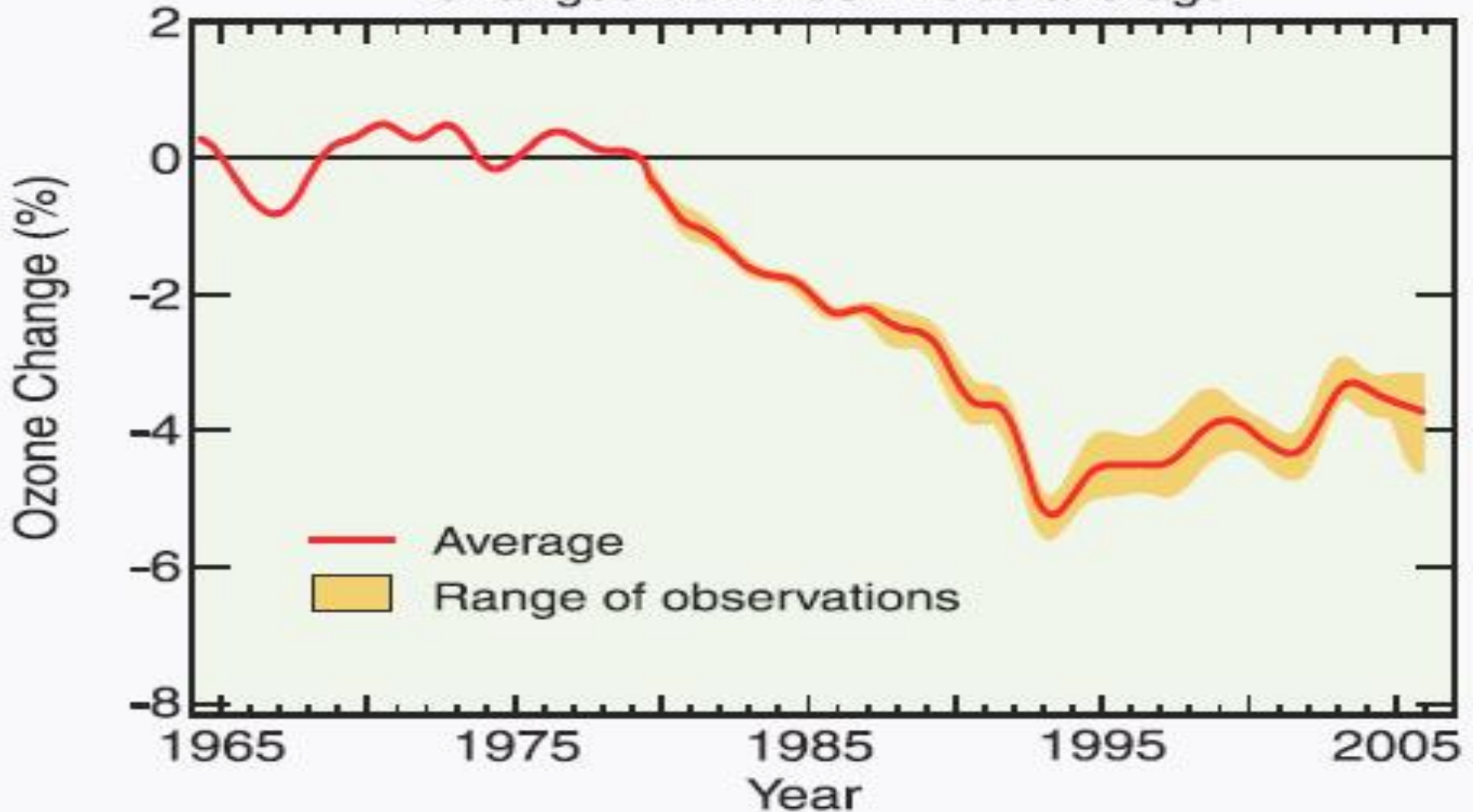


# You May Ask, Why Doesn't this Same Thing Happen in the Troposphere?

- It does! But down here, air is so dense the odds of a CO<sub>2</sub> band IR photon escaping to space is near zero, the radiated IR just continues to get trapped, and each photon emission is another chance to hit the ground and heat the ground.
- Climate modelling must include both the ozone changes, and GHG cooling effects together, at all levels of the stratosphere, of course.
- The effects of rising CO<sub>2</sub> are dominant over the ozone effects, and clear even when anthropogenic CO<sub>2</sub> was only a small fraction of today's values (Schwarzkopf and Ramaswamy 2008)

# Global Total Ozone Change

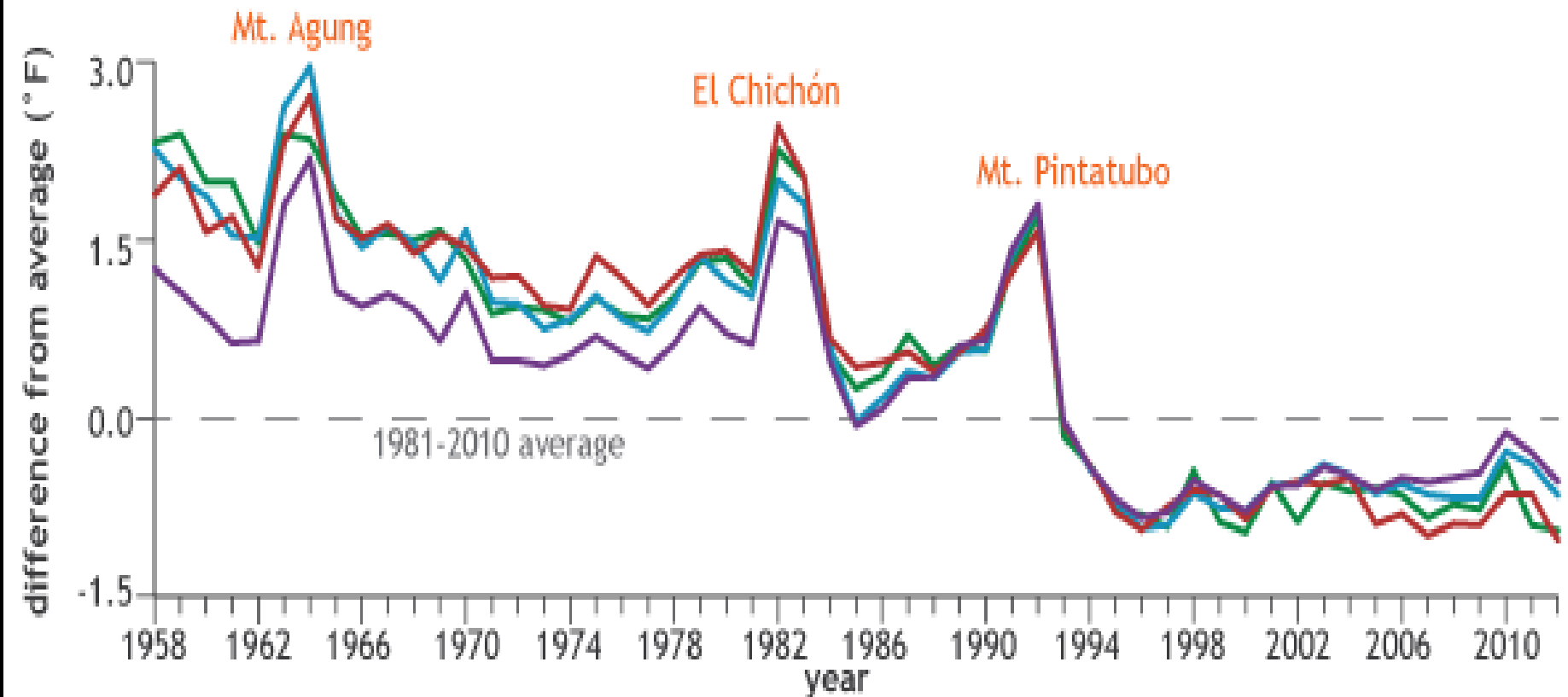
Changes from 1964-1980 average



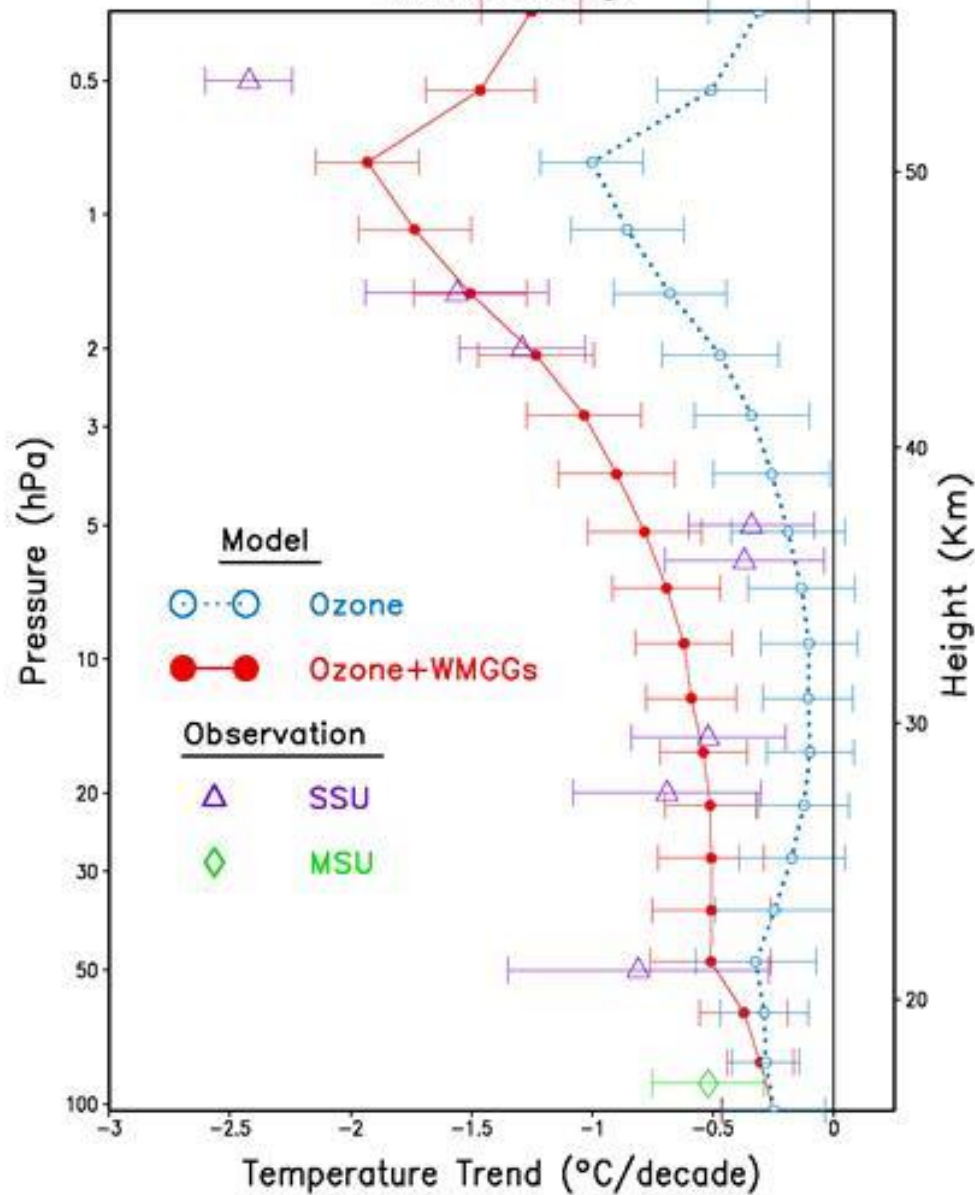
Global total ozone ( $O_3$ ). Chlorofluorocarbons (CFC's), increasingly used post-WWII, migrated to the stratosphere and destroyed  $O_3$  beginning about 1975, until globally banned in 1989 when a slow healing began.  $O_3$  levels are not expected to recover fully until about 2060. Recovering  $O_3$  levels provide stratospheric heating, yet the cooling effect of stratospheric  $CO_2$  has cancelled out this heating, as later slides will show.

So; What do we actually see? A cooling stratosphere (except at major volcanic eruptions which temporarily add heat-absorbing ash), exactly as predicted by rising GHG's and slightly rising ozone since 1989

Yearly stratospheric temperature anomalies 1958-2012



## Attribution of Stratospheric Climate Change



Rising “**Well Mixed Greenhouse Gases**” (WMGG’s here) cool the stratosphere more than due to the loss rate of ozone, so that the combined effect was more than a doubling of cooling rate (red curve) compared to ozone loss alone (blue curve). From GFDL

Adapted from [Karl et al. 2006](#) "Temperature Trends in the Lower Atmosphere" for the U.S. Climate Change Science Program, p. 22. Note the lower stratosphere continues to cool (due to rising CO<sub>2</sub>) even after the Montreal Protocol ban of CFC's in 1989 (spikes due to major volcanic eruptions)

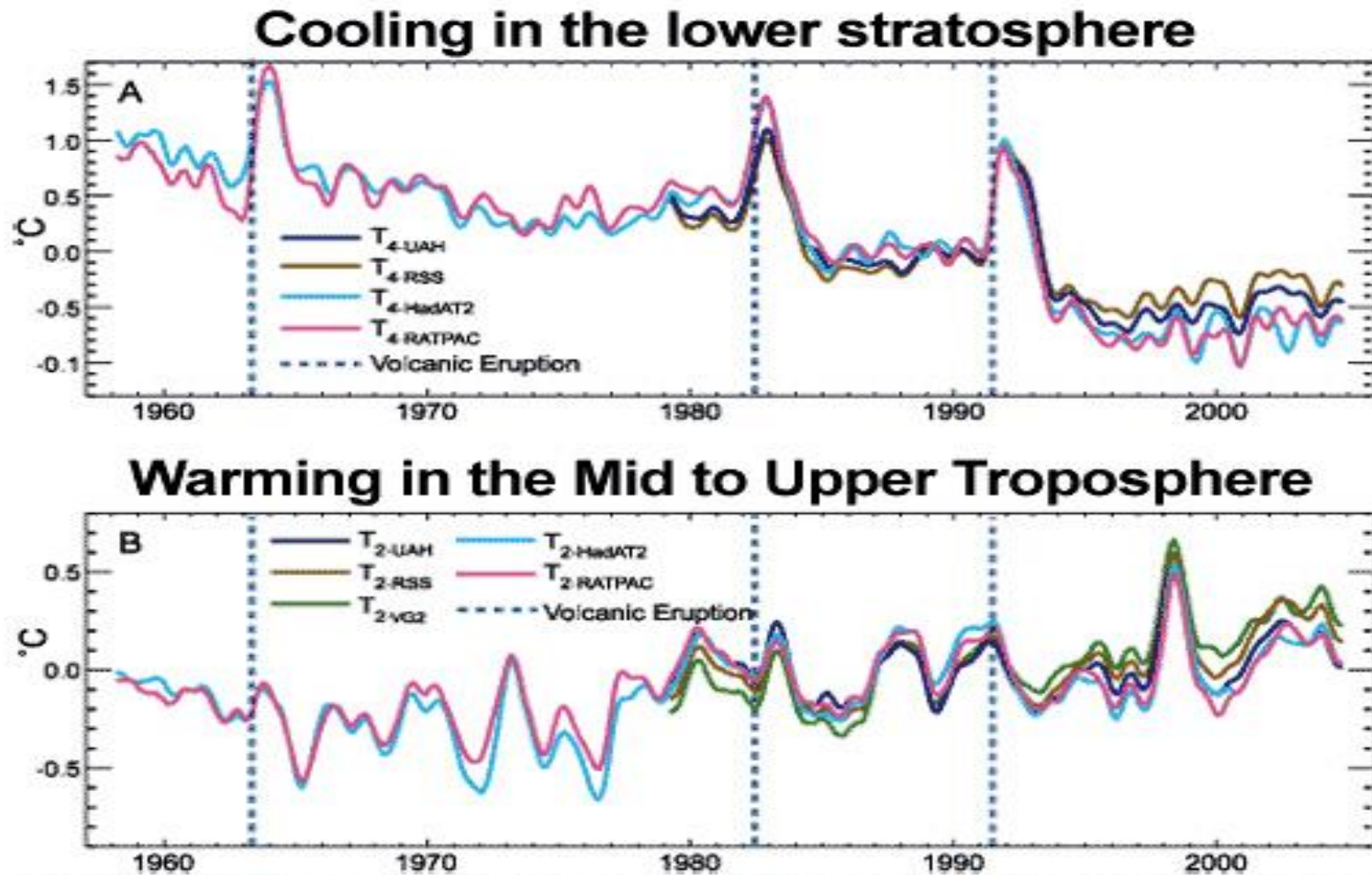
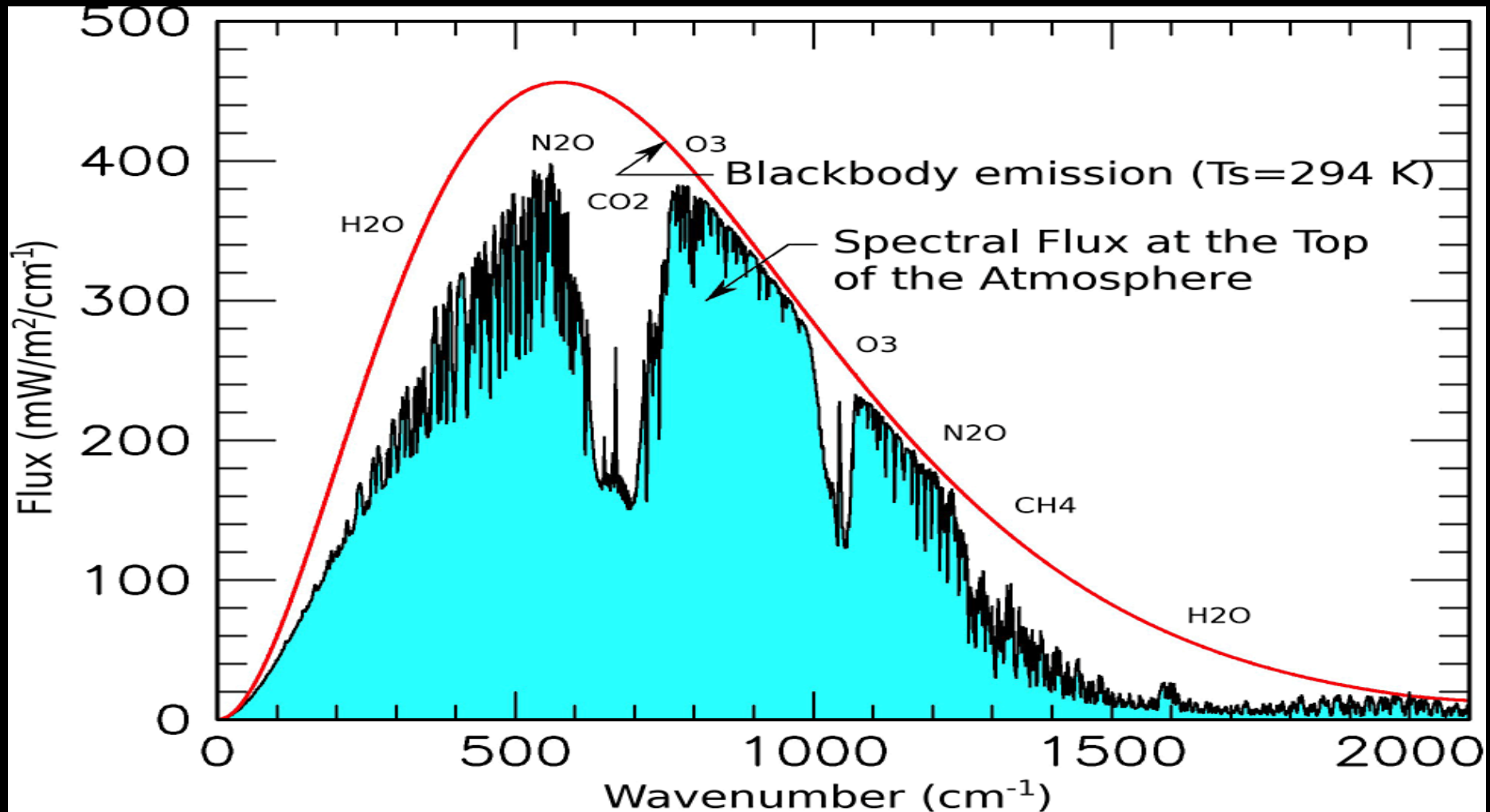


Figure 6: (A) Change in lower stratospheric temperature, observed by satellites (UAH, RSS) and weather balloons (HadAT2 and RATPAC), relative to period 1979 to 1997, smoothed with seven month running mean. Major volcanic eruptions indicated by dashed blue lines (Karl 2006).

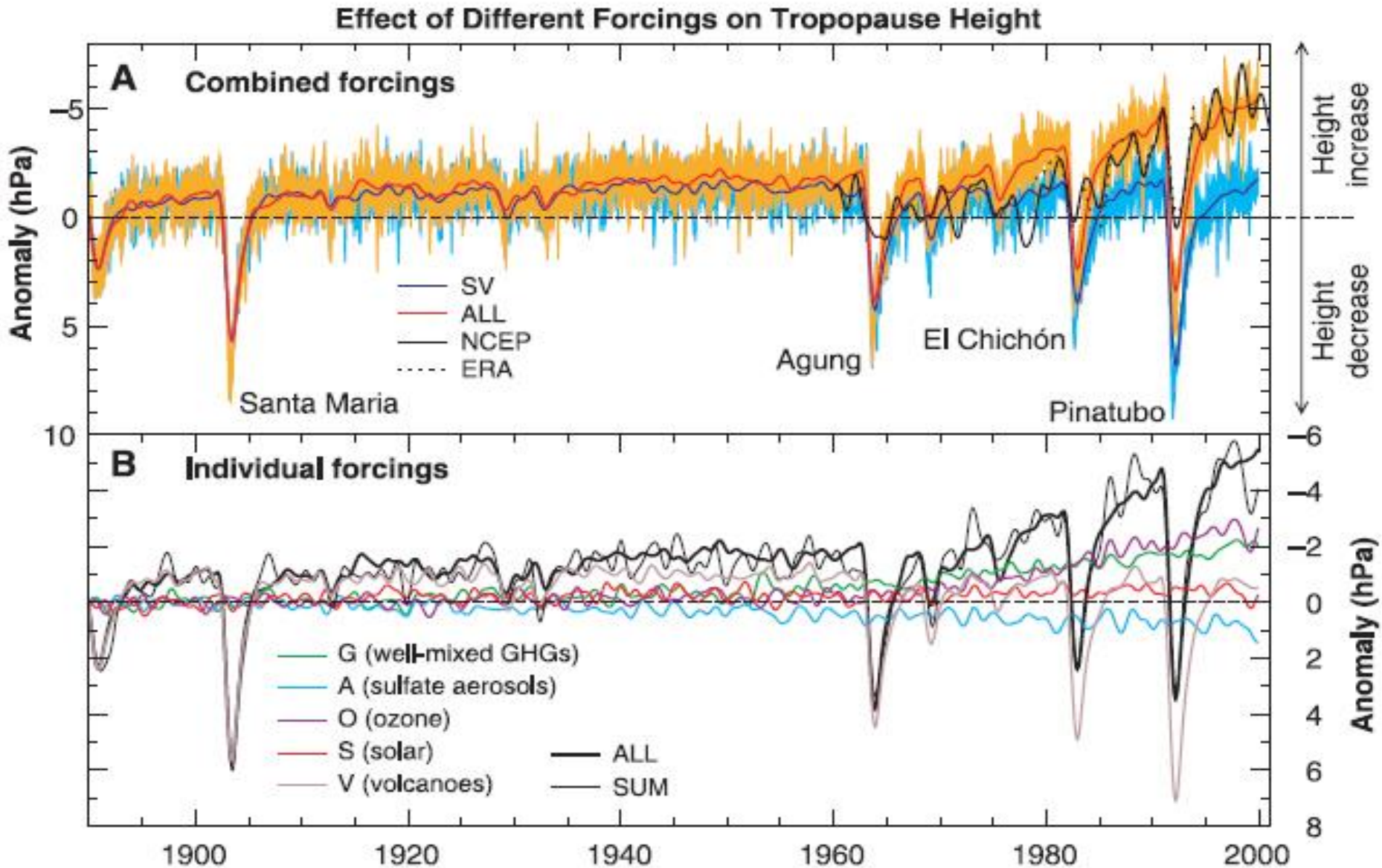
**Evidence #2:** We know CO<sub>2</sub> is a powerful Greenhouse Gas. Straight-forward physics. Below: the IR absorption spectrum for oxygen, ozone, CO<sub>2</sub>, and water vapor, together with the emitted spectrum of the outgoing IR radiation of the Earth surface. Note CO<sub>2</sub> and water absorption bands are fairly well offset from each other, so one does not blanket the other.



# **Evidence #3. Rising altitude of the tropopause – Also unique to GHG-induced warming**

- Remember; the tropopause is the level where the temperature trend with altitude goes from cooling to warming (the stratosphere is warmer with higher altitude). The tropopause is the inflection point of the temperature.
- Trend slopes being relatively unchanged, this inflection point would be expected to rise if the troposphere is warming and the stratosphere is cooling.
- It has risen about **0.2 km during 20<sup>th</sup> century.**

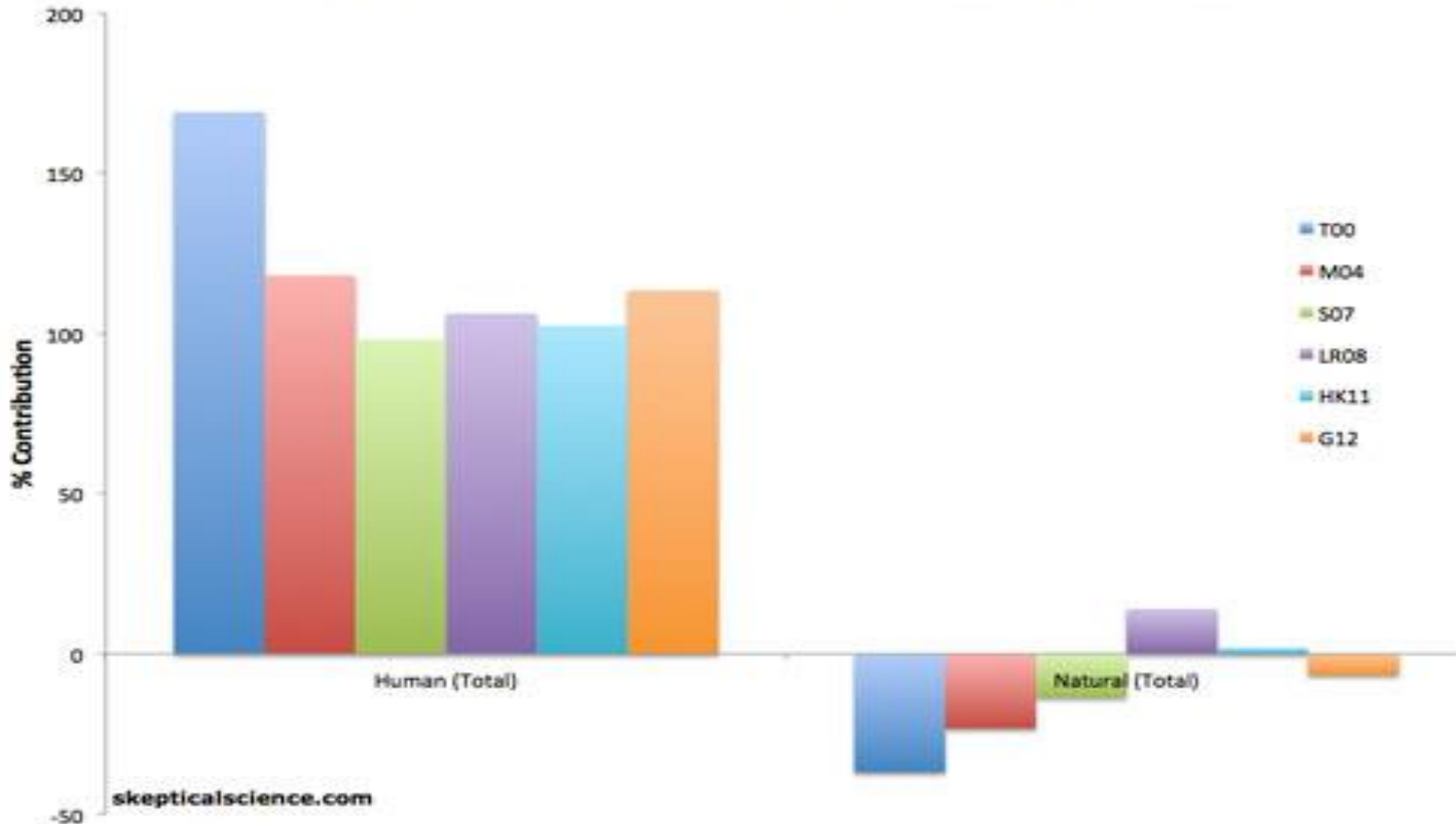
**Predicted tropopause height from five most significant forcings. From [Santer et al. 2004](#). (Note decreasing pressure vertical scale, goes with increasing atmospheric height). Now compare to observed height change across the globe (Occasional major volcanic eruptions labelled)....**



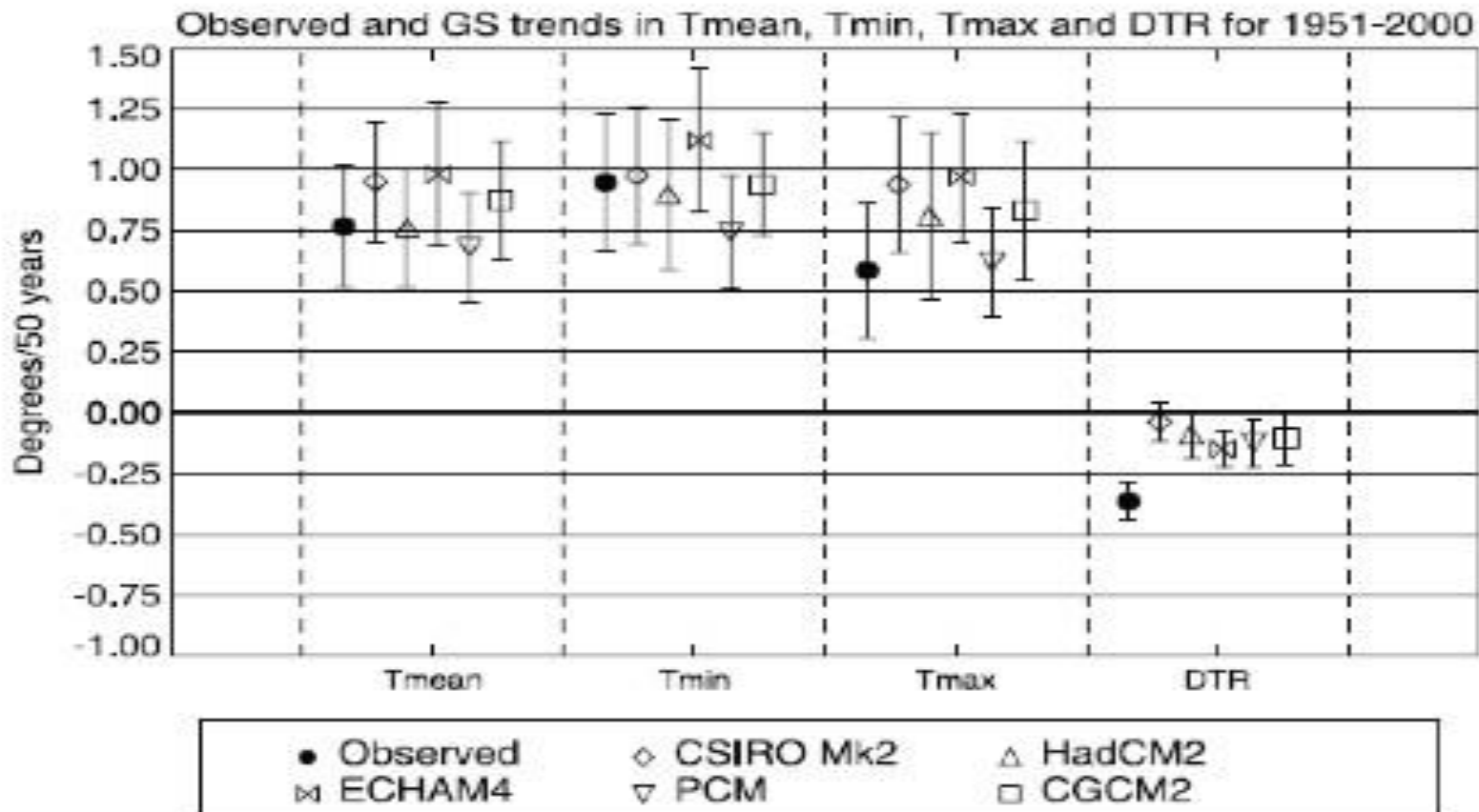


# Evidence #4. Attribution Analysis is consistent - Six representative studies (among many) break apart causes of climate change. Humans Account for 100% of the Warming

Contributors to Global Warming over the Past 50-65 Years



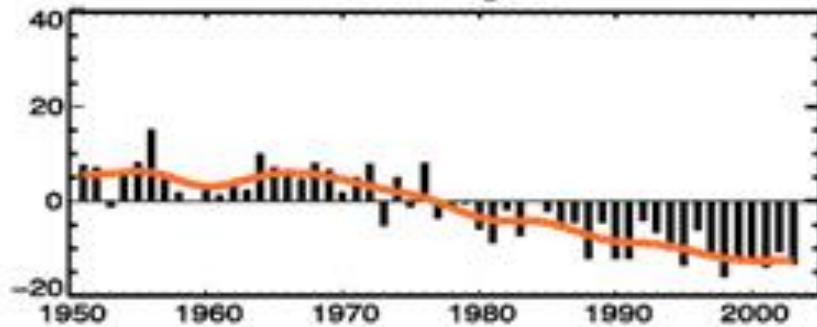
**Evidence #5:** Night-time temperatures are rising faster than daytime temperatures: Daily Temperature Range (DTR) trend is negative, *i.e.* getting smaller between 1951 and 2000: Night temps are rising even faster than day, as GHG's inhibit outgoing IR, which is most in the evening, after solar heating



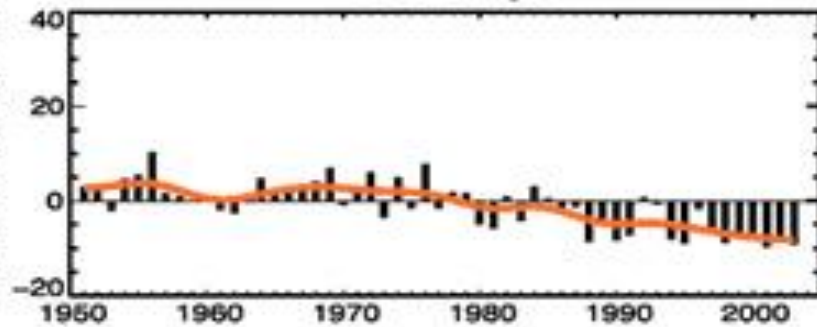
Number of warm nights and warm days both increasing, but warm nights are increasing more (Alexander 2006)

## Frequency of cold and warm days and nights

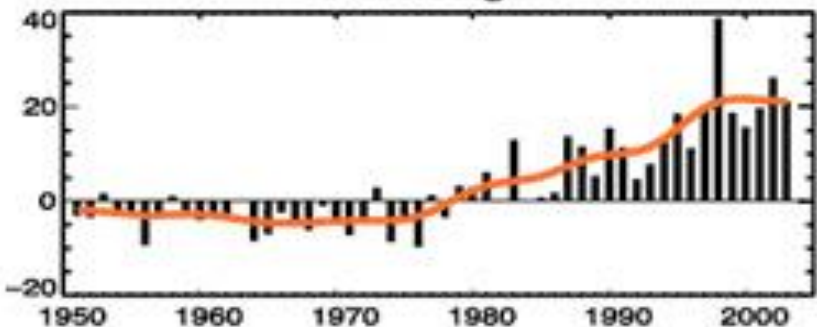
Cold nights



Cold days



Warm nights



Warm days

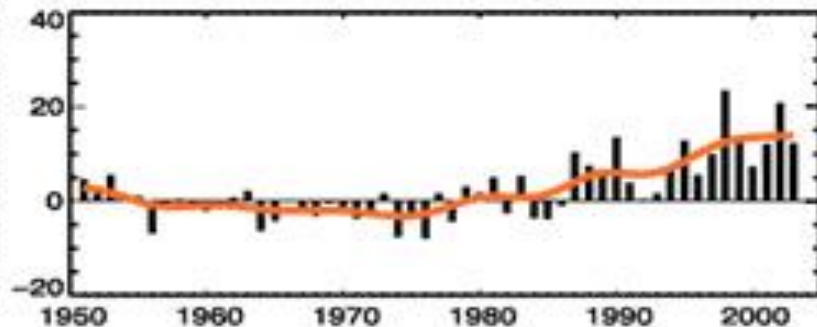
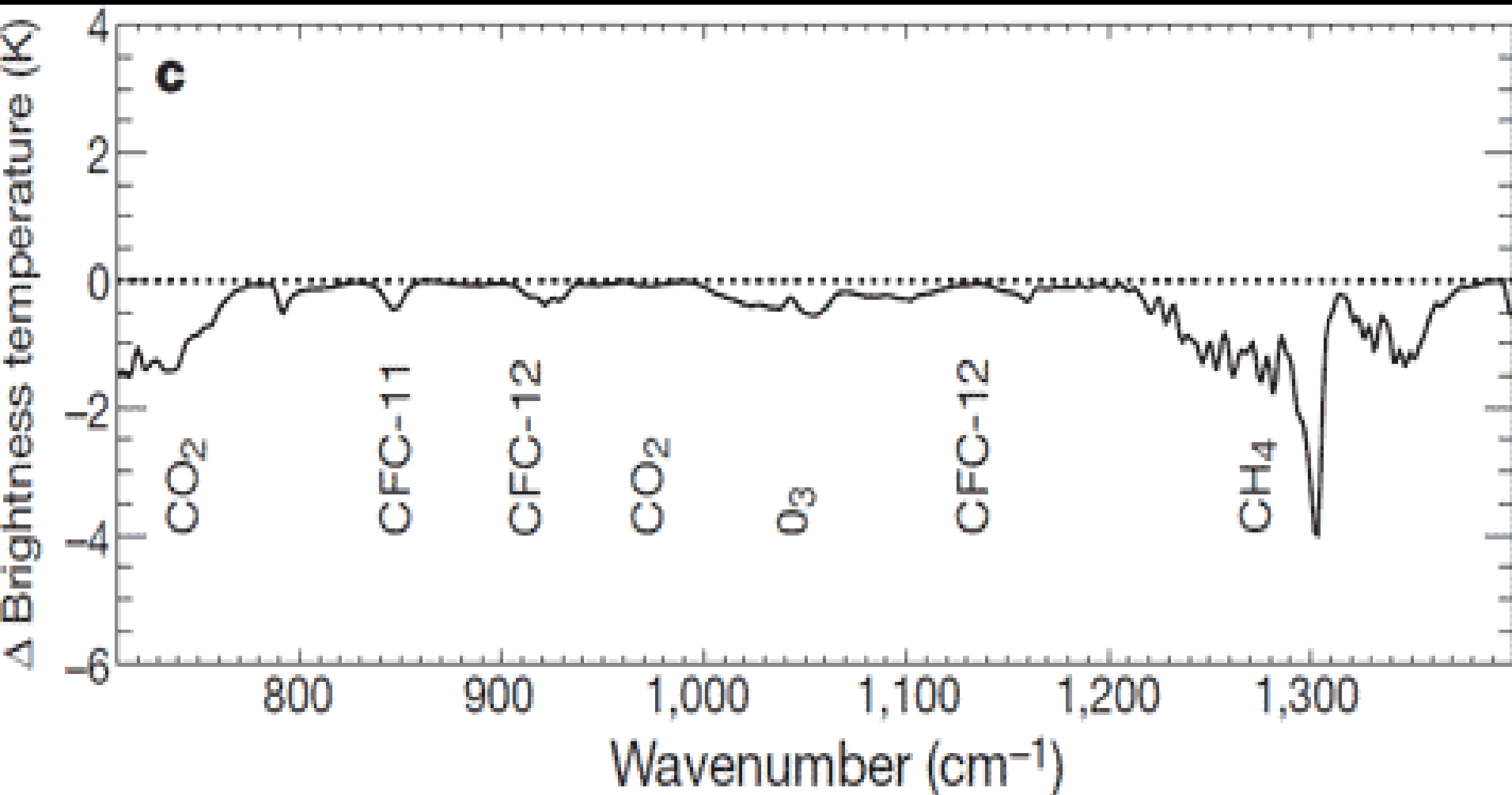


Figure 7: Observed trends (days per decade) for 1951 to 2003 in the number of extreme cold and warm days and nights per year. Cold is defined as the bottom 10%. Warm is defined as the top 10%. Orange lines show decadal trend (IPCC AR4 FAQ 3.3 adapted from Alexander 2006).

**Evidence #6.** The Earth's outgoing radiation at the GHG absorption bands is declining. Graph below shows the DIFFERENCE between 1970 and 1996 outgoing spectrum of Earth IR radiation. This also implies we should see increased DOWNward greenhouse IR radiation from the air above us as well.

**Do we?.....**



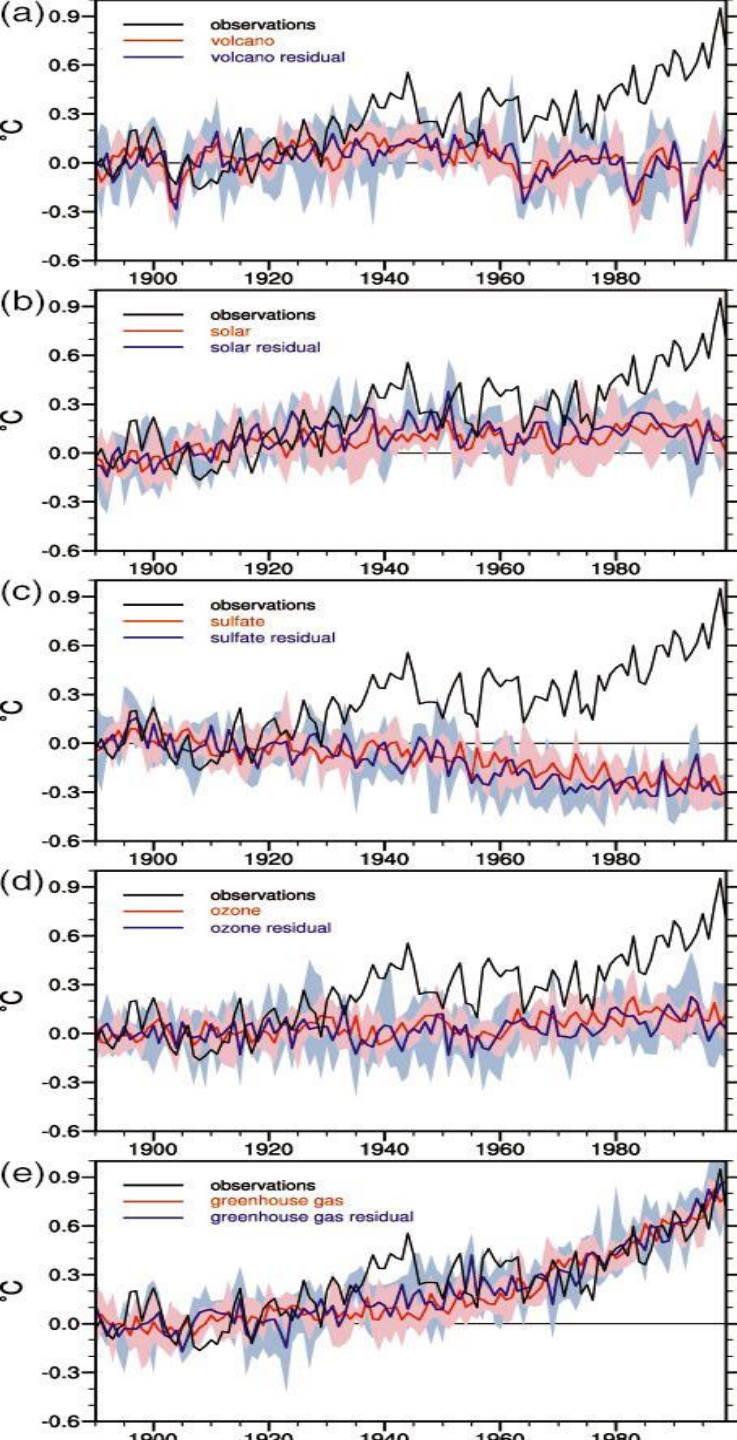
*Change in spectrum from 1970 to 1996 due to trace gases. 'Brightness temperature' indicates the equivalent blackbody temperature (Harries 2001).*

**Evidence #7. Yes!** Since pre-industrial times (see IPCC 1995 data), observed GHG infrared emission downward to the ground has increased by  $3.52 \text{ W/m}^2 = 2.3\%$  of total greenhouse IR radiation (not including water vapor) (from [Evans et al. 2006](#))

**Table 4: Comparison of Measured and Model Increases in Downward Surface Flux**

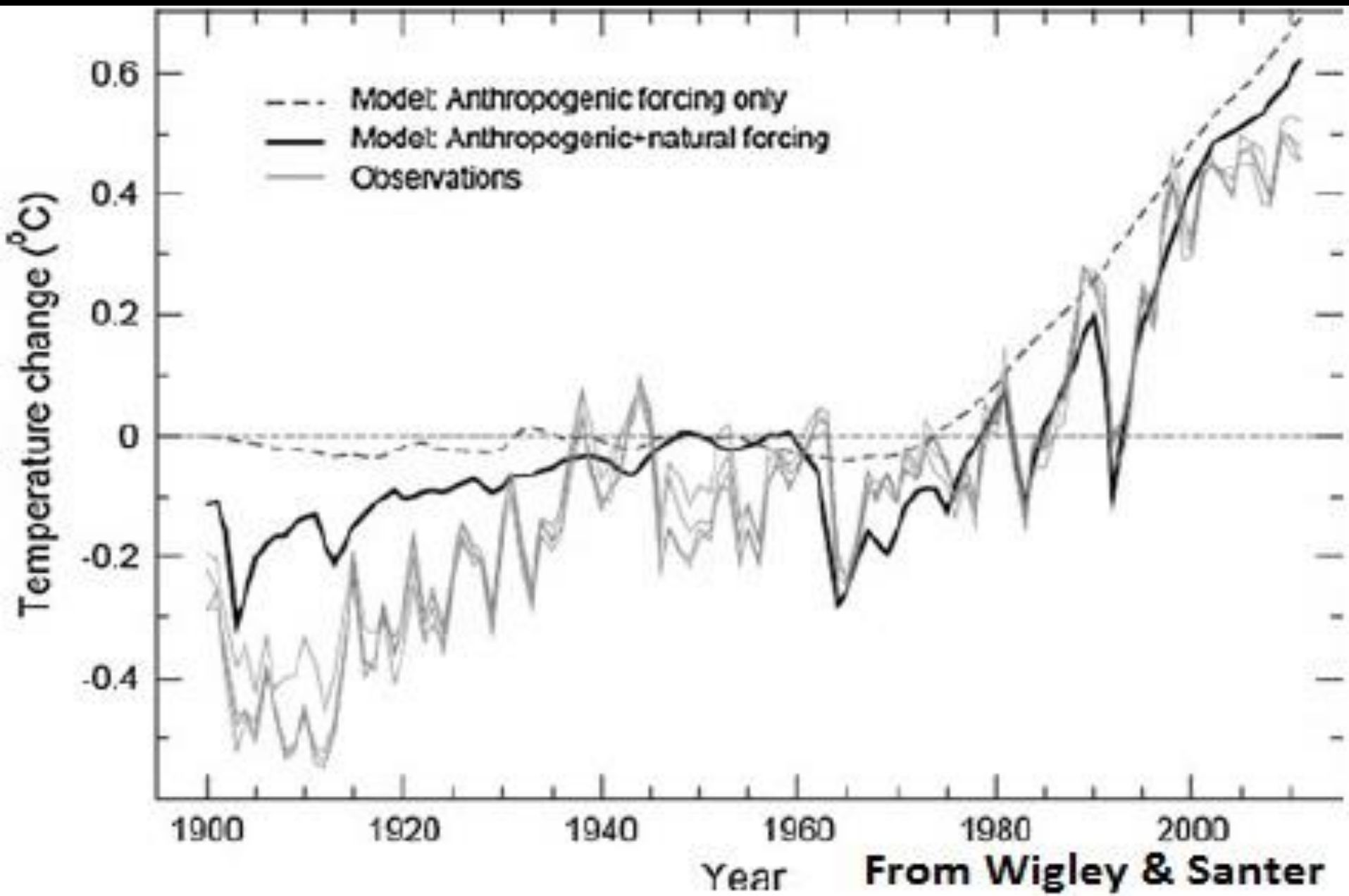
Greenhouse Gas	Measured Flux Increase ( $\text{W/m}^2$ )	Model Flux Increase ( $\text{W/m}^2$ )
CO <sub>2</sub>	2.10	1.30
CH <sub>4</sub>	0.38	0.33
N <sub>2</sub> O	0.15	0.13
Trop. O <sub>3</sub>	0.40	0.40
CFC11	0.14	0.14
CFC12	0.28	0.28
CFC113	0.00	0.033
HCFC22	0.031	0.031
CCl <sub>4</sub>	0.046	0.046
Total	3.52	2.55 (-3.1)

## Evidence #8. Climate Modelling Agrees with Observations, But Only when Human Activities Are Included.

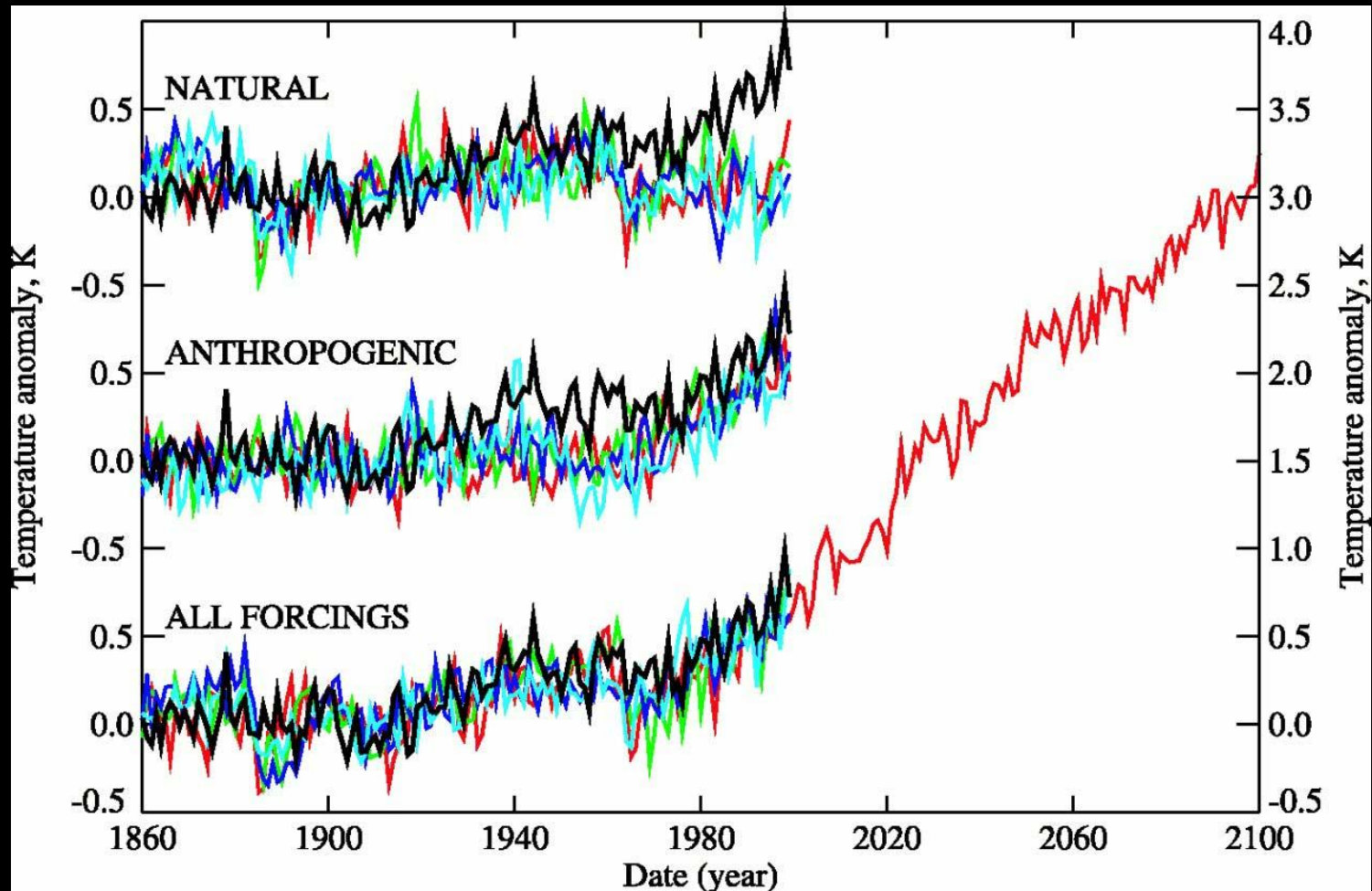


Meehl et al. (2004) FIG. 1. (a) The four-member ensemble mean (red line) and ensemble member range (pink shading) for globally averaged surface air temperature anomalies ( $^{\circ}\text{C}$ ; anomalies are formed by subtracting the 1890–1919 mean for each run from its time series of annual values) for volcanic forcing; the solid blue line is the ensemble mean and the light blue shading is the ensemble range for globally averaged temperature response to volcanic forcing calculated as a residual  $[(\text{volcano} + \text{solar}) - \text{solar}]$ ; the black line is the observations after Folland et al. (2001); (b) same as (a) except for solar forcing, and a solar residual  $[(\text{solar} + \text{GHG} + \text{sulfate} + \text{ozone}) - (\text{GHG} + \text{sulfate}) - \text{ozone}]$ ; (c) same as (a) except for sulfate forcing, and sulfate residual  $[(\text{GHG} + \text{sulfate}) - \text{ozone}] - (\text{GHG} + \text{ozone})$ ; (d) same as (a) except for ozone forcing, and ozone residual  $[(\text{GHG} + \text{sulfate} + \text{ozone}) - (\text{GHG} + \text{sulfate})]$ ; (e) same as (a) except for GHG forcing and GHG residual  $[(\text{GHG} + \text{sulfate})] - \text{sulfate}$

**The overall trend is determined by human forcings. Including the varying natural forcings matches even the wiggles**

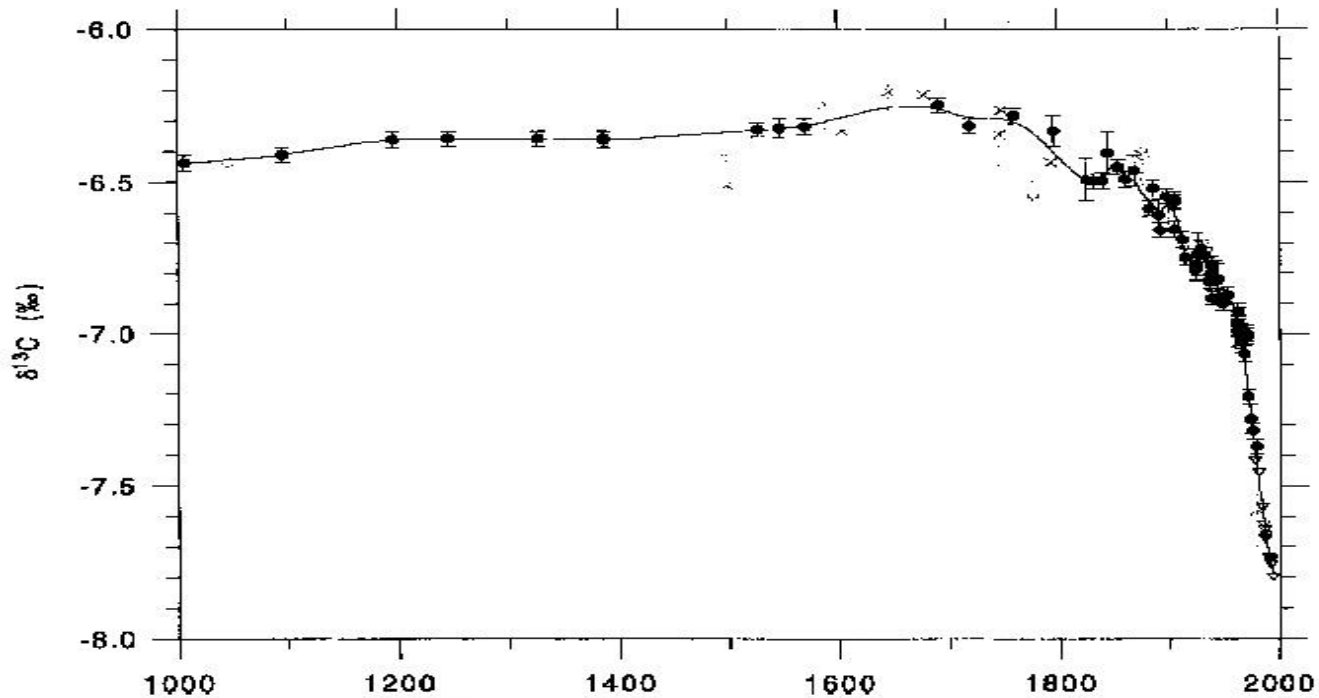


# Underlying Natural Variations in Temperature (colored lines in top set) during the 20<sup>th</sup> Century Appear Net Near Zero (Stott et al. 2009)





**Evidence #9:** Plants (hence, fossil fuels) preferentially take up  $C^{12}$  carbon - it is lighter so undergoes chemistry more easily. As fossil fuel generated carbon is pumped into the atmosphere since the dawn of the Industrial Age,  $C^{13}$  thus is expected to make up a diminishing fraction of total carbon – exactly what the past 1000 years show below. From known emission rates, the predicted  $C^{13}/C^{12}$  ratio agrees with the observations below. Note how rapid is the drop in  $C^{13}$  fraction after 1950 (see at right), with the discovery of the Saudi Arabia Oil fields. The conclusion is clear - the rapidly rising  $CO_2$  we see is from fossil fuels=organic carbon, not volcanoes. (From [Francey et al. 1999](#))



**Fig. 9.** The complete record of  $CO_2$  and  $\delta^{13}C$  from the Law Dome ice cores and firn. The smoothing spline is weighted by the statistical error in, and density of, data; effective smoothing is 25 years after 1800 AD and  $\sim 130$  years before 1800 AD. (Light grey symbols are rejected points from the section “Summary of data selections and corrections” and are included here only to provide a perspective on the selection processes. Crosses indicate ethanol contaminated samples, open circles are other rejections).

**As human emissions rise, the atmospheric  $C^{13}/C^{12}$  ratio variations closely follow the emission trends, including the Gulf War oil shock of the early 90's, and the post-collapse of the Soviet Union in the late '90's: Atmospheric  $CO_2$  is from fossil fuels**

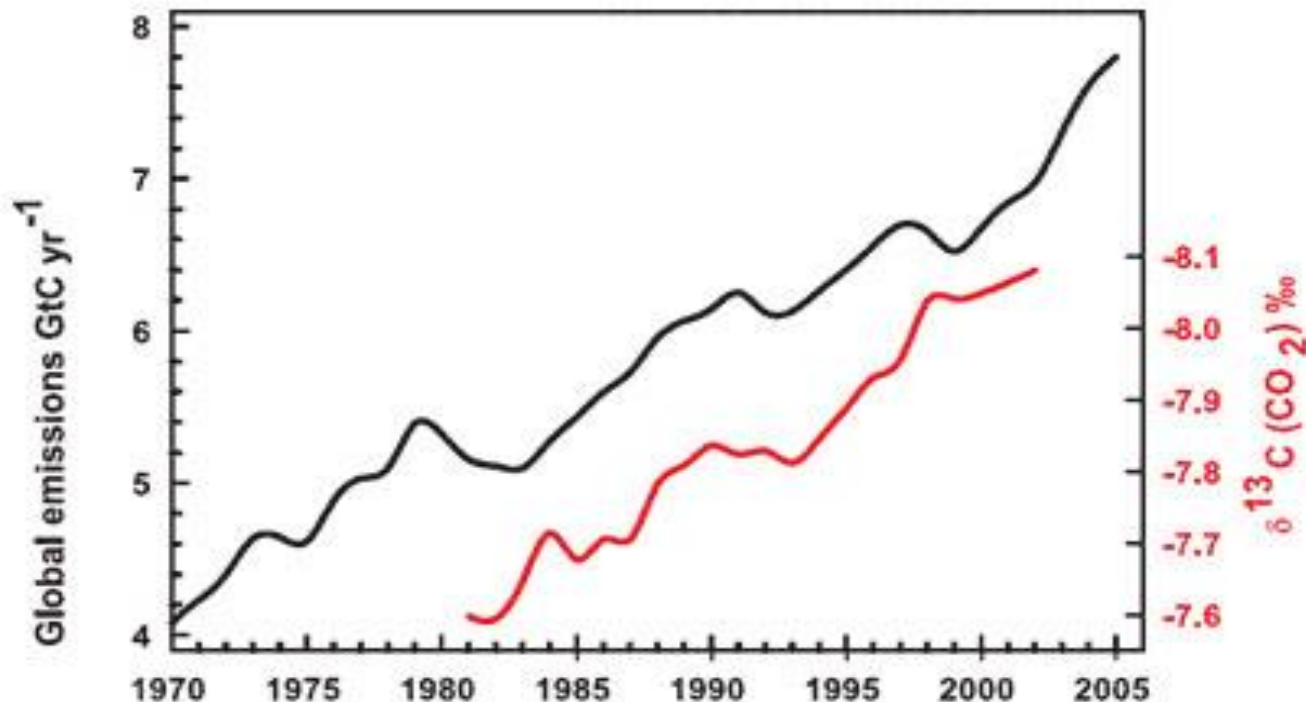
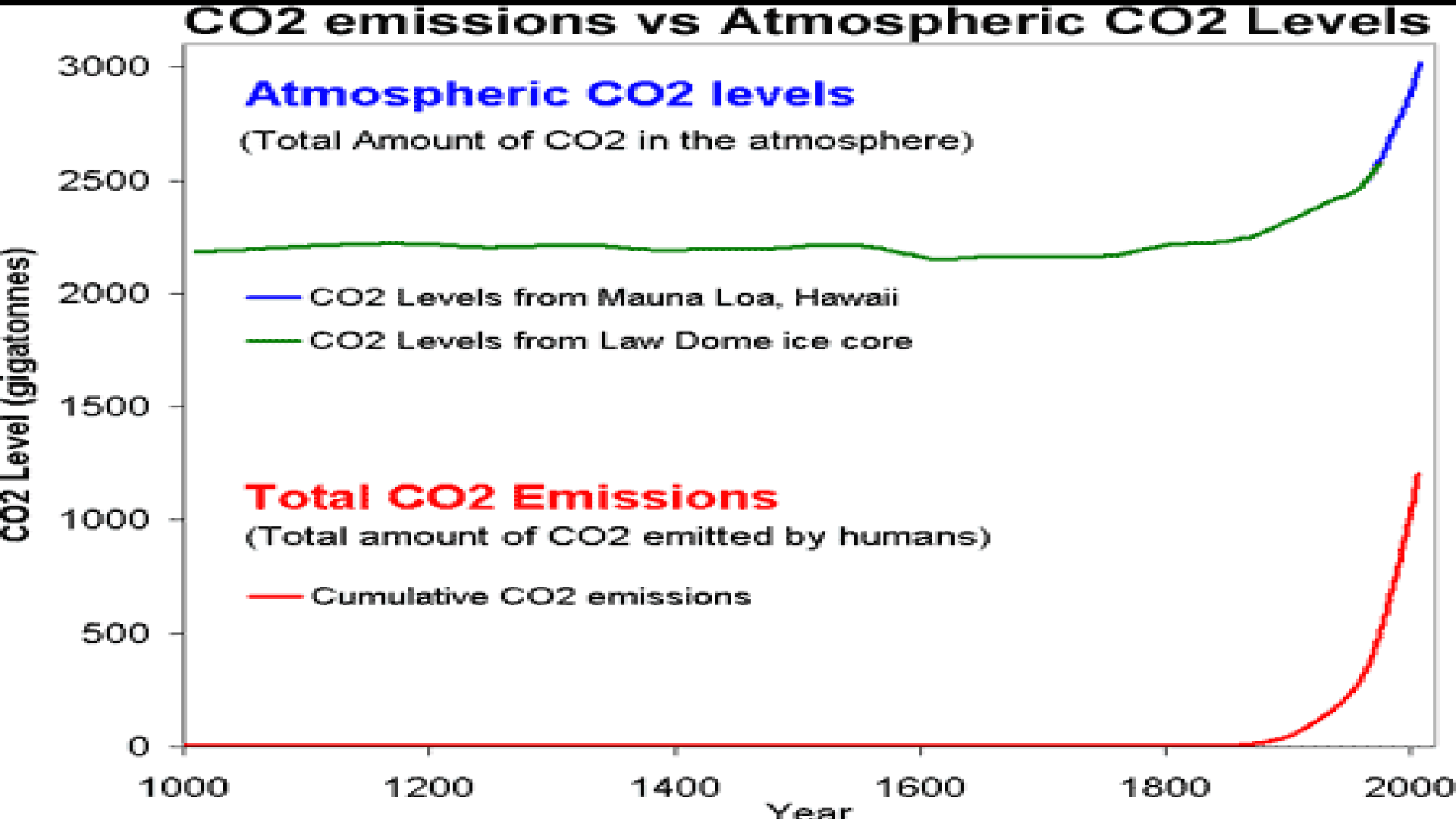
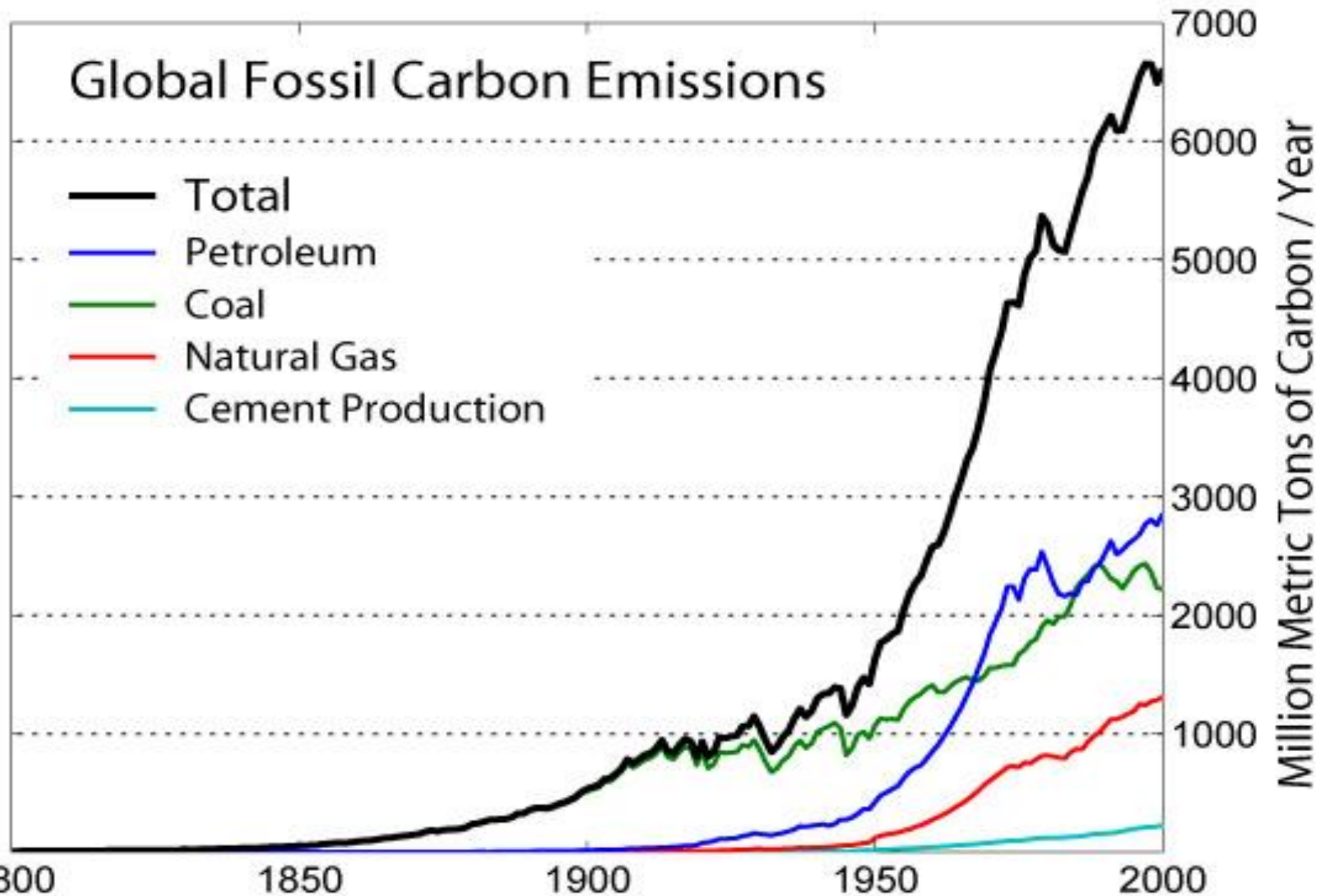


Figure 2: Annual global  $CO_2$  emissions from fossil fuel burning and cement manufacture in  $GtC\ yr^{-1}$  (black), annual averages of the  $^{13}C/^{12}C$  ratio measured in atmospheric  $CO_2$  at Mauna Loa from 1981 to 2002 (red). The isotope data are expressed as  $\delta^{13}C(CO_2)$  ‰ (per mil) deviation from a calibration standard. Note that this scale is inverted to improve clarity. (IPCC AR4).

# Evidence #10 – We're burning carbon and generating atmospheric CO2 at rates even higher than the atmosphere's CO2 rise rate. Some is absorbed by the ocean and land.



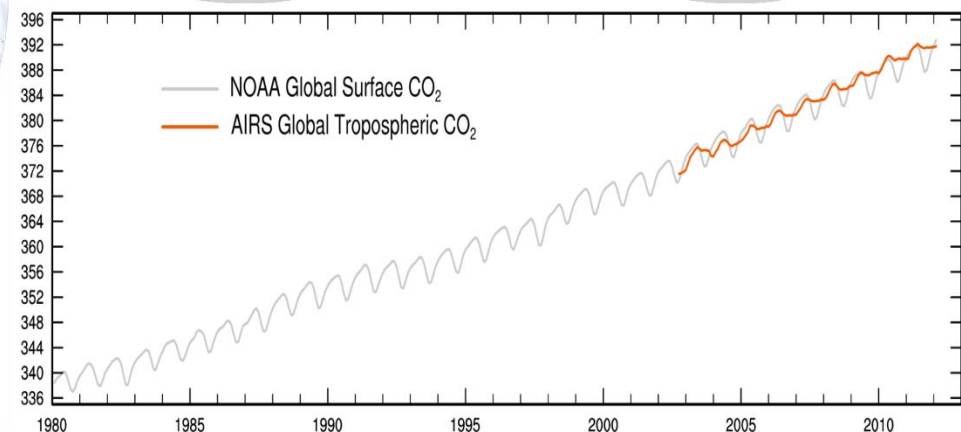
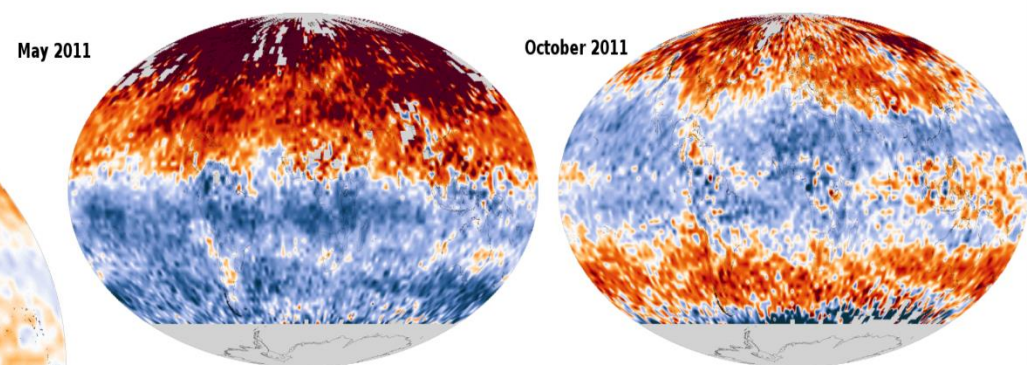
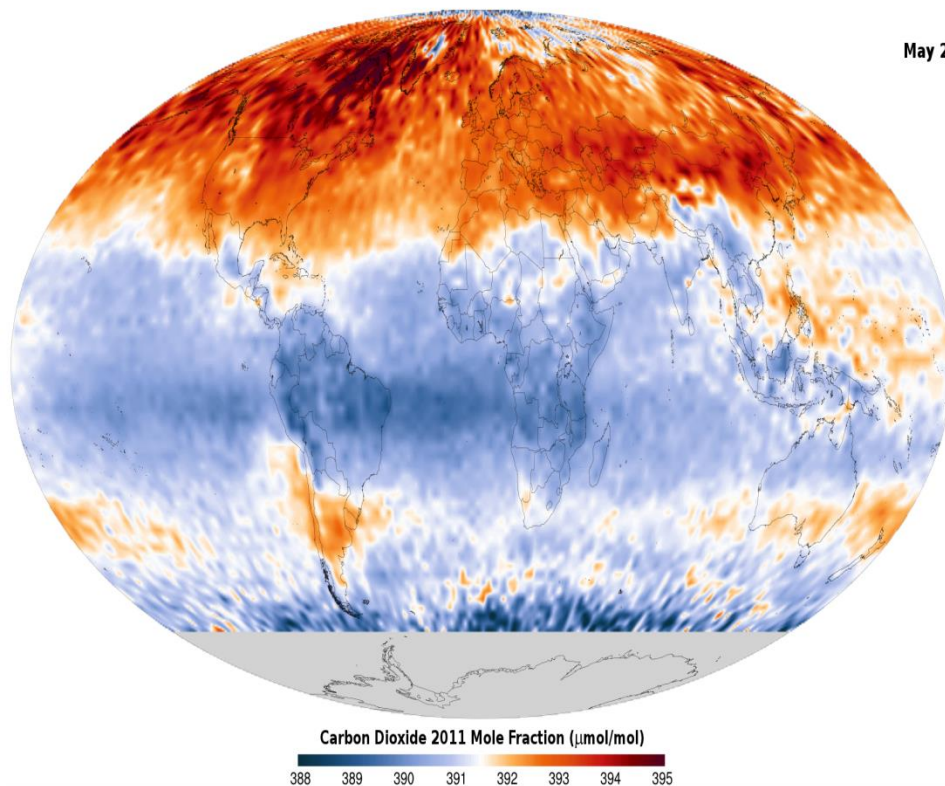
...From known emission rates...



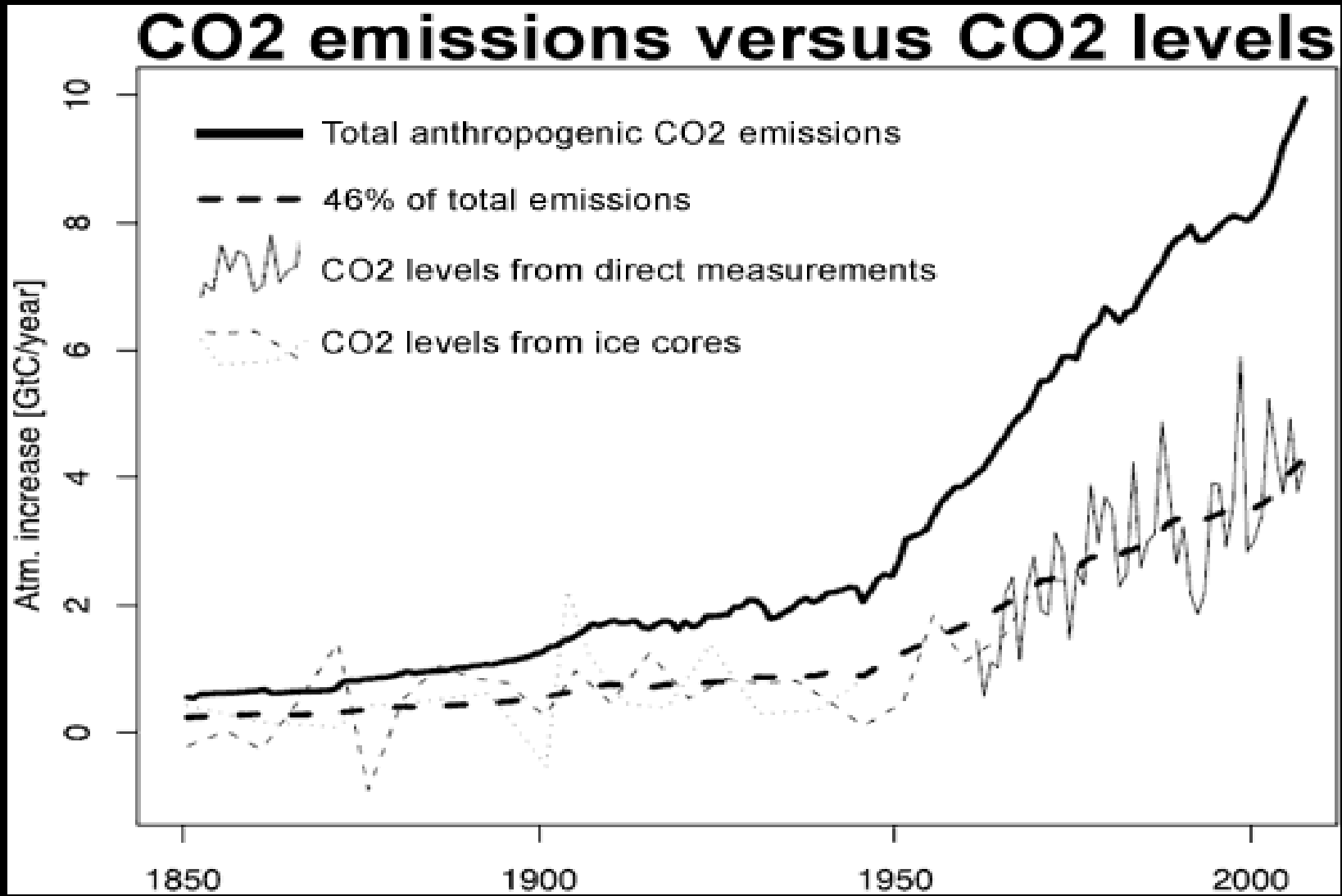
# Evidence #11: Not Just Global Totals, but The Exact Sources on the Global Map, Show it Mostly Comes from Fossil Fuel heavy Countries

- The OCO – Orbiting Carbon Observatory – gives unprecedented accuracy in CO2 emissions sources. ([1 yr of CO2 Concentrations Across the Globe from OCO](#), (3:10 )
- This kind of knowledge is, of course, unacceptable in the Trump Era, and they have terminated funding for the comprehensive program tying together satellite and ground based carbon monitoring – the CMS “Carbon Monitoring System”

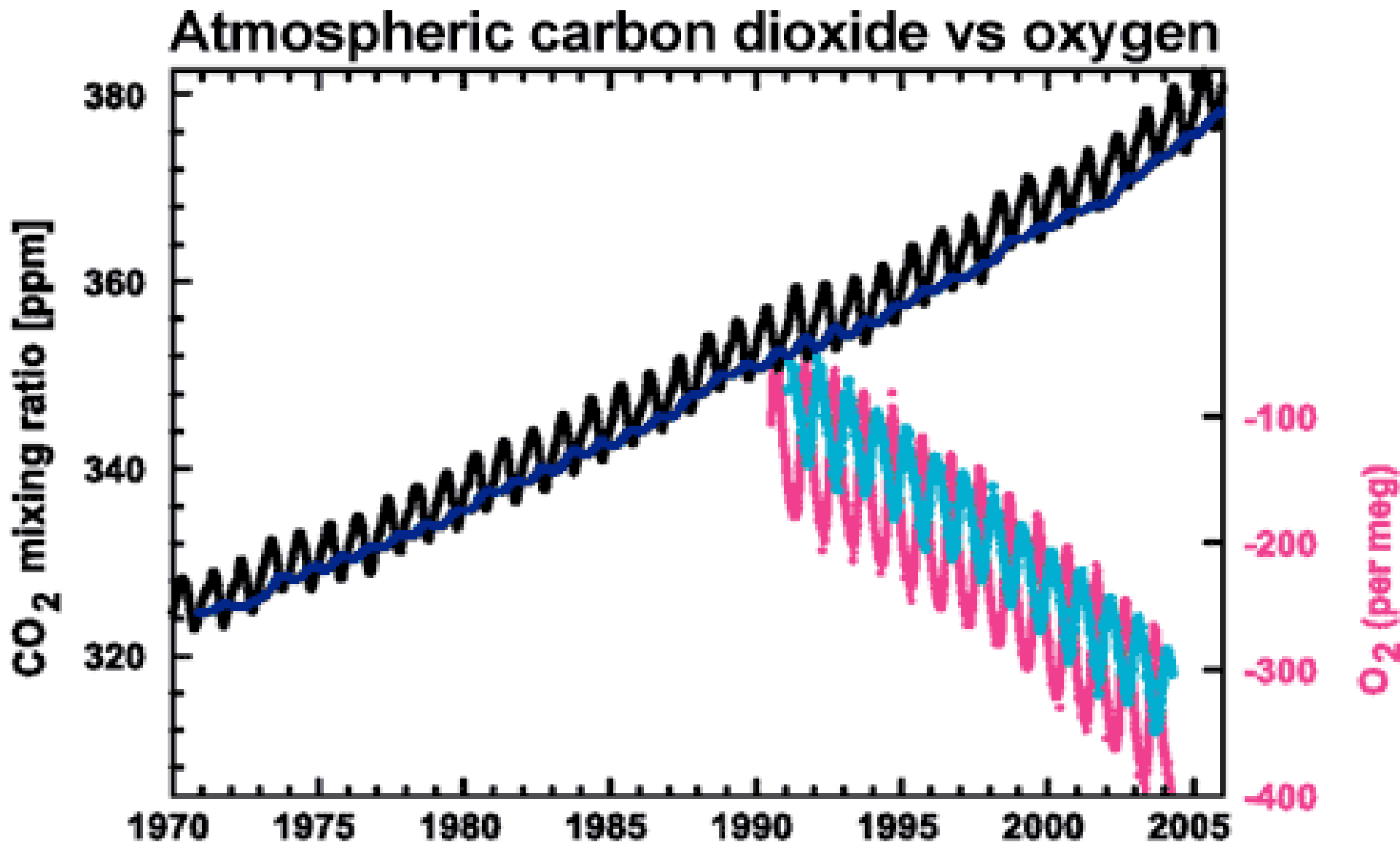
**Atmospheric CO<sub>2</sub> Concentration Distribution Shows It is Generated Where Industrialized Populations Are. While well mixed (i.e. note how narrow is the scale), there is still a concentration gradient. The clear source = human population, which is focused across the densely industrial mid-northern latitudes. Note the surface CO<sub>2</sub> seasonal cycle more pronounced (due to plants) than tropospheric average. Ferrel Cell tropospheric winds blow fresh CO<sub>2</sub> northward toward the Arctic... not good.**



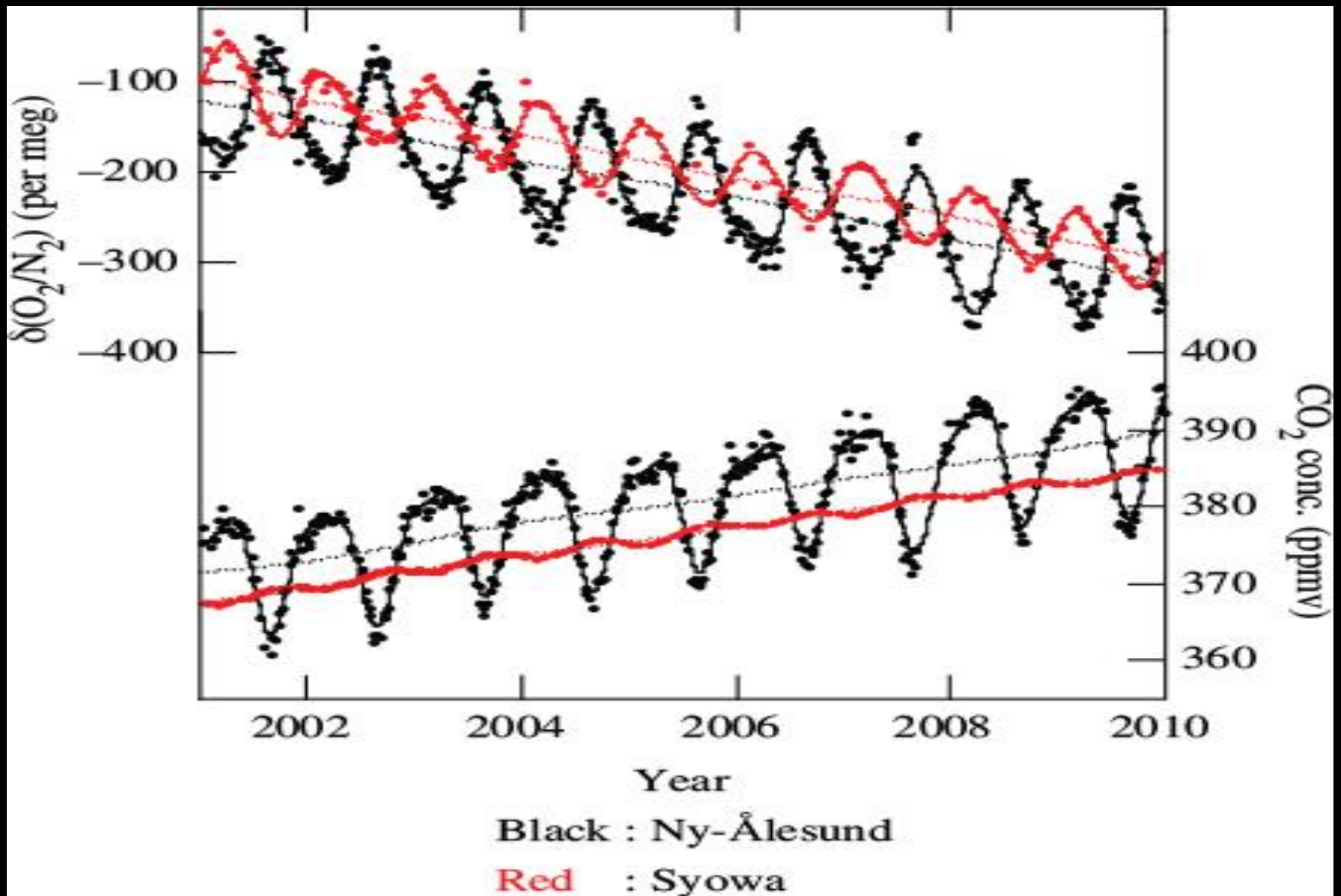
# CO2 Emission Rates Are Still Increasing, and So is the Atmospheric Concentration



**Evidence #12: Fossil Fuel Burning Depletes Oxygen (pink), creating CO<sub>2</sub> (black) – Observed rates are in agreement with theory (IPCC AR4, adapted from Manning 2006), and also...**

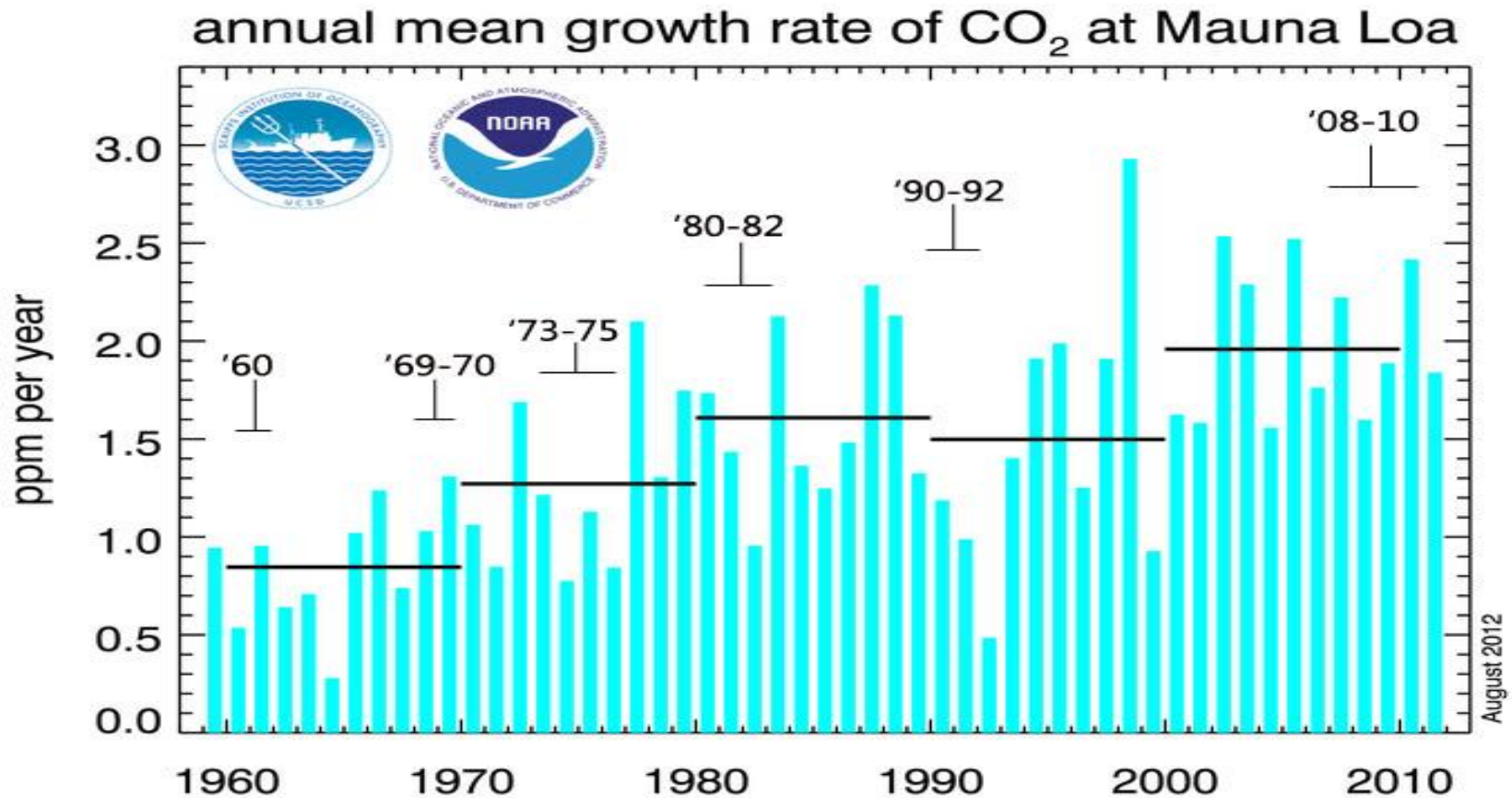






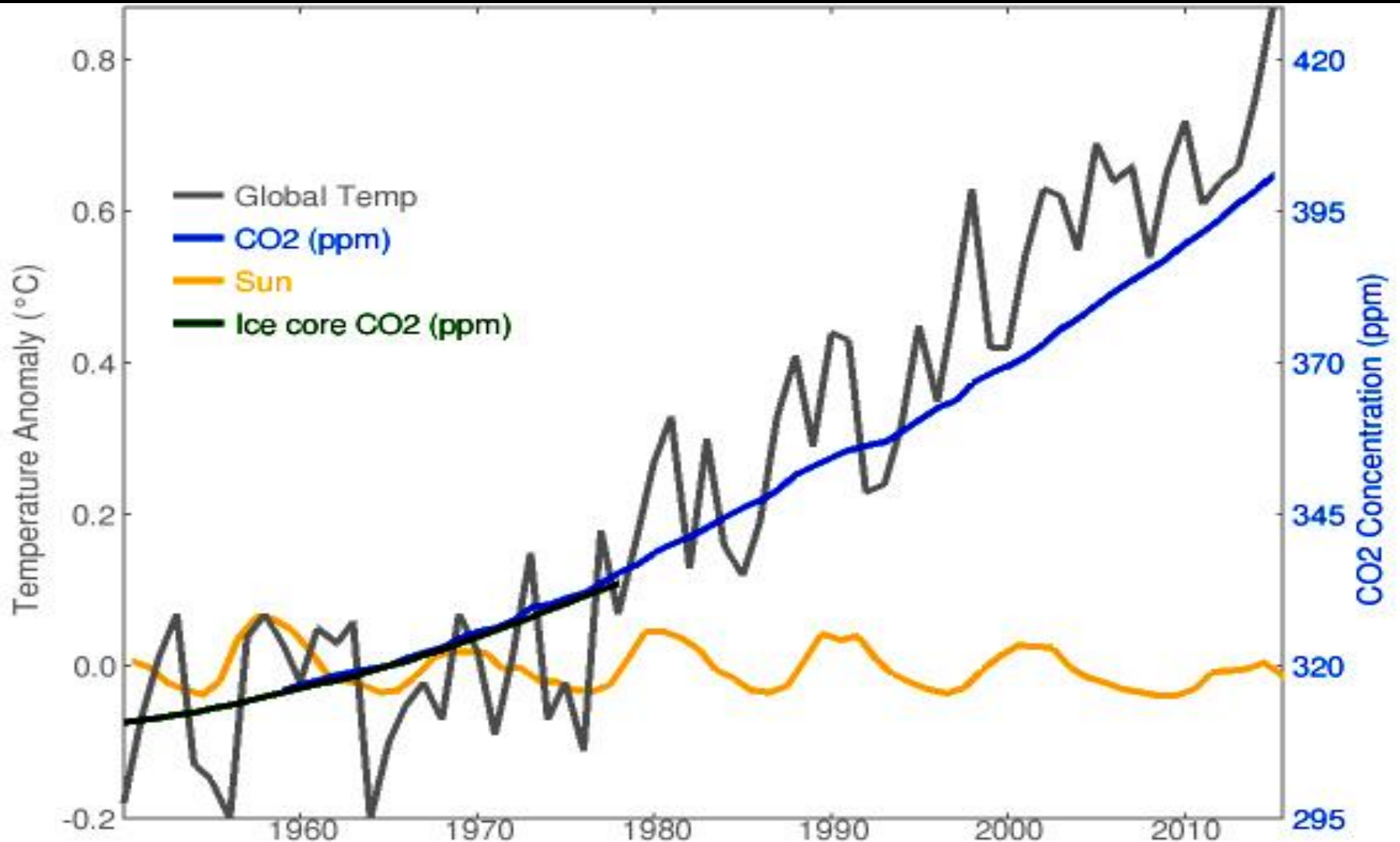
Oxygen levels dropping:  $\text{O}_2/\text{N}_2$  ratio dropping (top curve) as  $\text{CO}_2$  levels rising (bottom curve), in agreement with theory as fossil fuel carbon pulls  $\text{O}_2$  from the atmosphere and is converted to  $\text{CO}_2$ . Data from Norway (black) and Antarctica (red) ([Ishidoya et al. 2012](#))

**Evidence #13.** The growth rate of CO<sub>2</sub> concentration drops during economic recessions. 10 year averages are the unmarked bars. I've added economic recessions (Fed data) labelled with years. The "oil shock" recessions of '74 (Arab oil embargo) and the '91 (Gulf War) are particularly obvious, as is the most severe recession in modern times, in '08/'09.



**Here's What Global  
Warming Is NOT  
caused by...**

# It's NOT the Sun

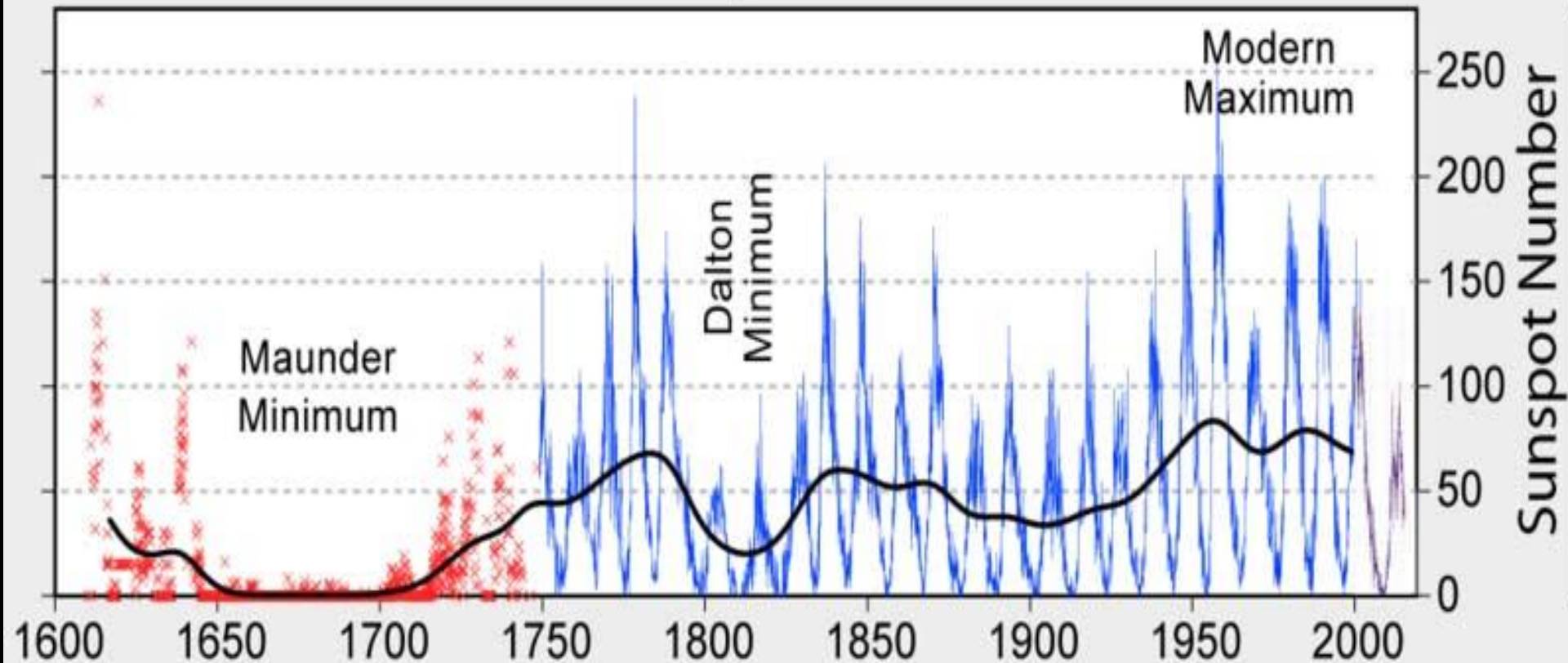


# Could The Sun Be Implicated in Longer Term Climate Heating?

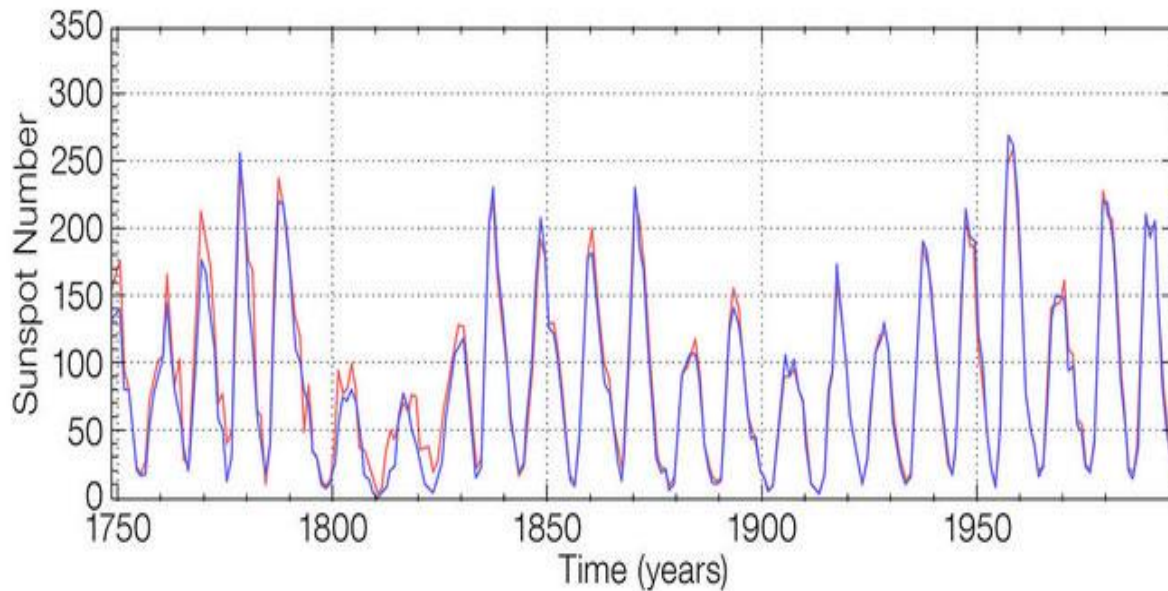
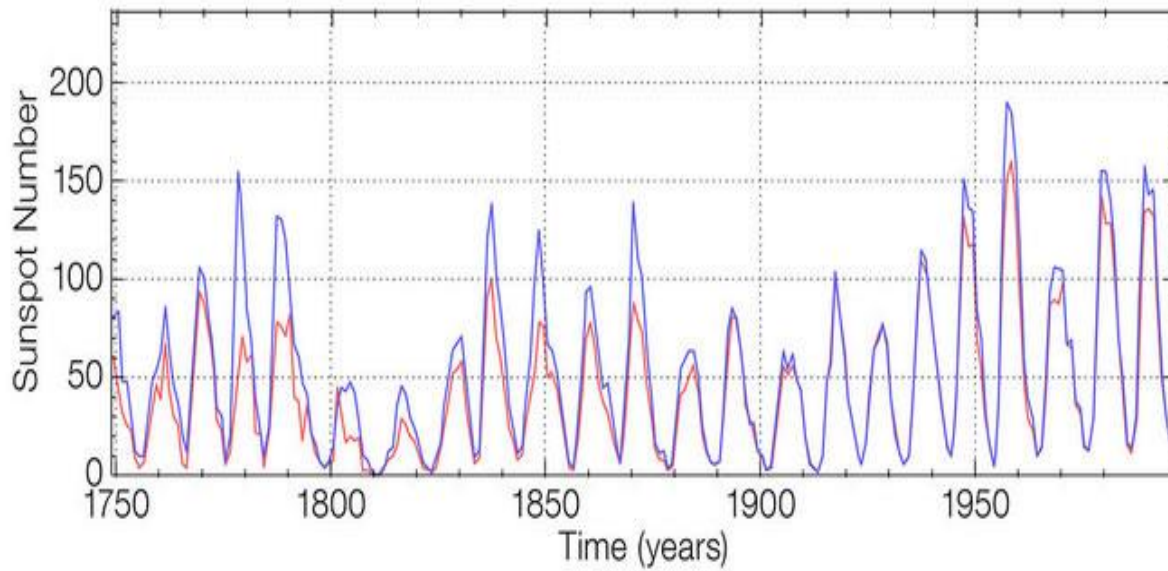
- The “Wolf Sunspot Number” has been the standard measure of solar activity for 4 centuries, but a persistent difference between this measure and that of sunspot groups – made difficult by a wide variety of observers, telescopes, visual skills - has recently been resolved (Clette et al. 2015).
- This recalibration resolves and removes an apparently spurious secular increase in solar activity over this period

There was an apparent rise in sunspot numbers, averaging over the shorter term cycles

## 400 Years of Sunspot Observations

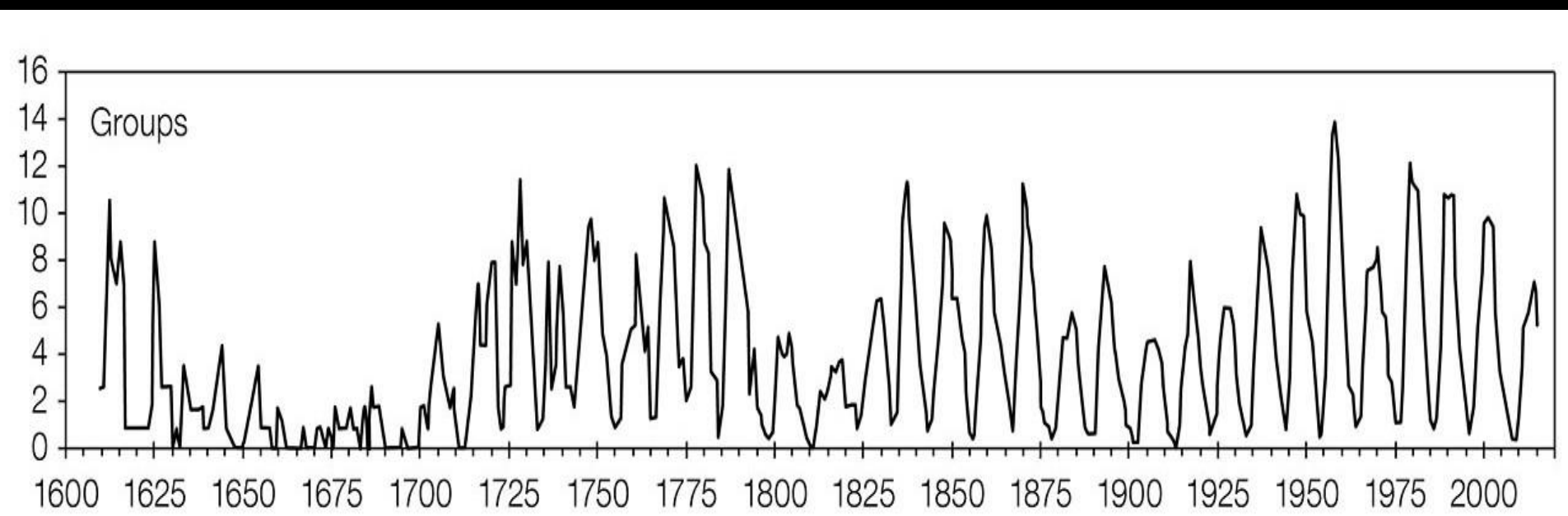


Now  
Recalibrated  
(bottom) The  
sunspot cycle,  
and the  
century  
modulation  
remains, the  
but longer  
term trend is  
now flat



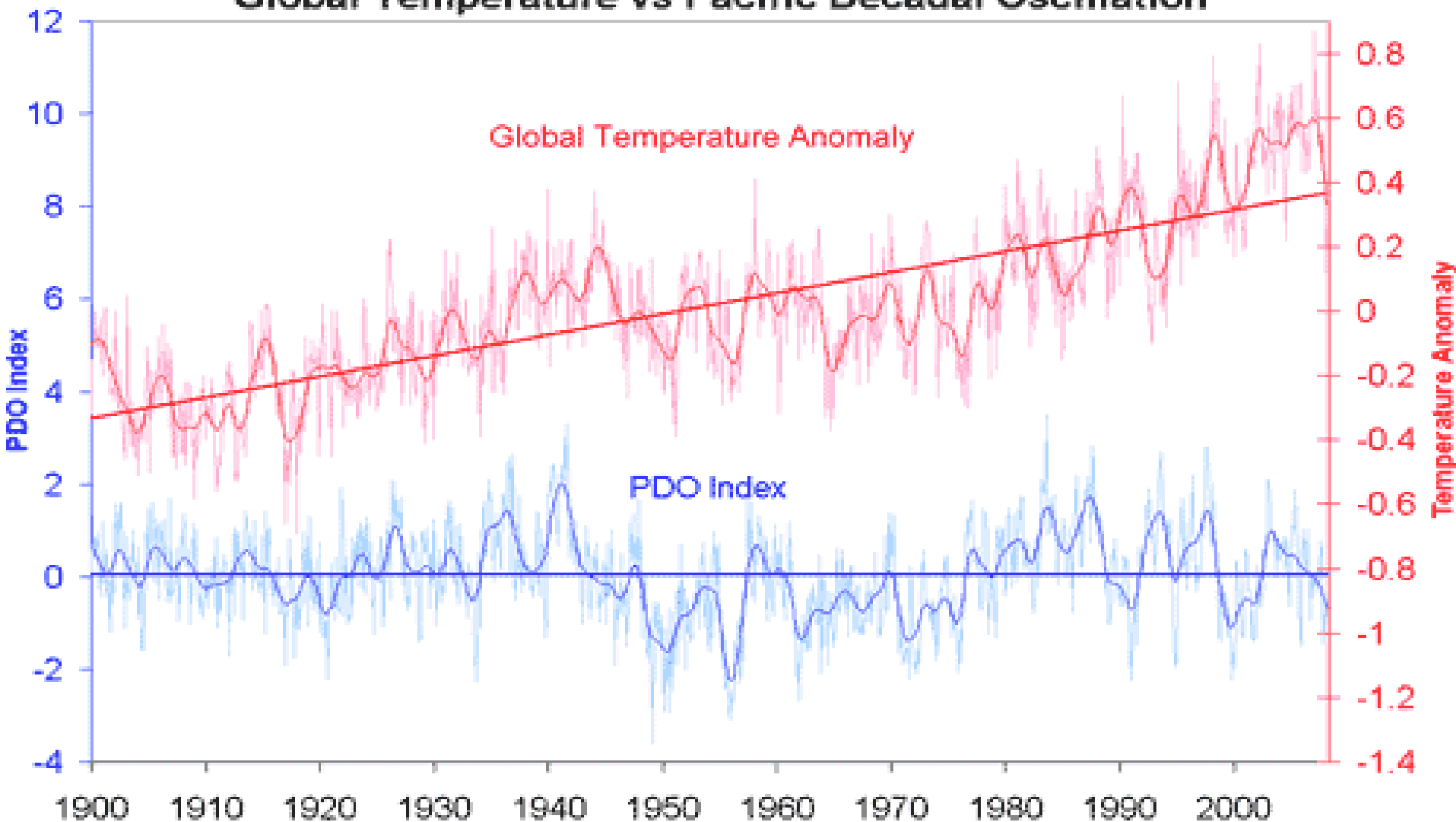
The top graph shows the level of disagreement between the old Wolf Sunspot Number (blue) and the old Group Sunspot Number (red). The lower graph demonstrates the increase in similarity between the two after being recalibrated. Image credit: WDC-SILSO.

**New Calibration of Sunspot Group Number. The Maunder Minimum remains, as does the Dalton Minimum, and the current ~centennial minimum. No long term trend, implying no trend in solar luminosity over these 400 years**





# Global Temperature vs Pacific Decadal Oscillation



**It's NOT the Ocean Warming the Air.**

As CO2 levels rise and more completely dominate climate changes, the mild correlation between the PDO and global temperatures faded when emissions became very dominant by the mid '80s. Also, 20<sup>th</sup> Century shows no long term trend in PDO, but strong upward trend in temps

# It's NOT Volcanic CO<sub>2</sub>; which contributes less than 1% of what humans emit

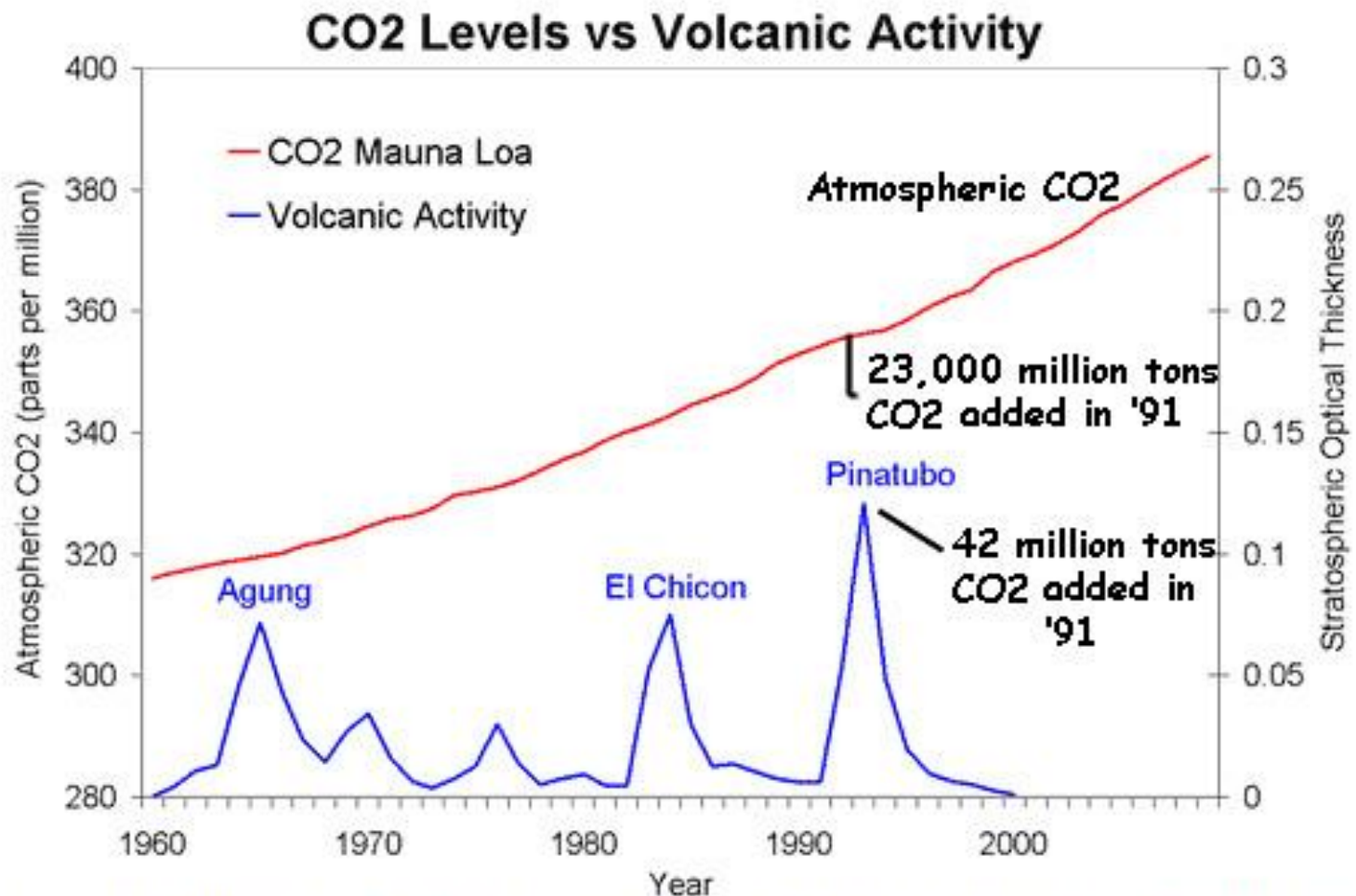
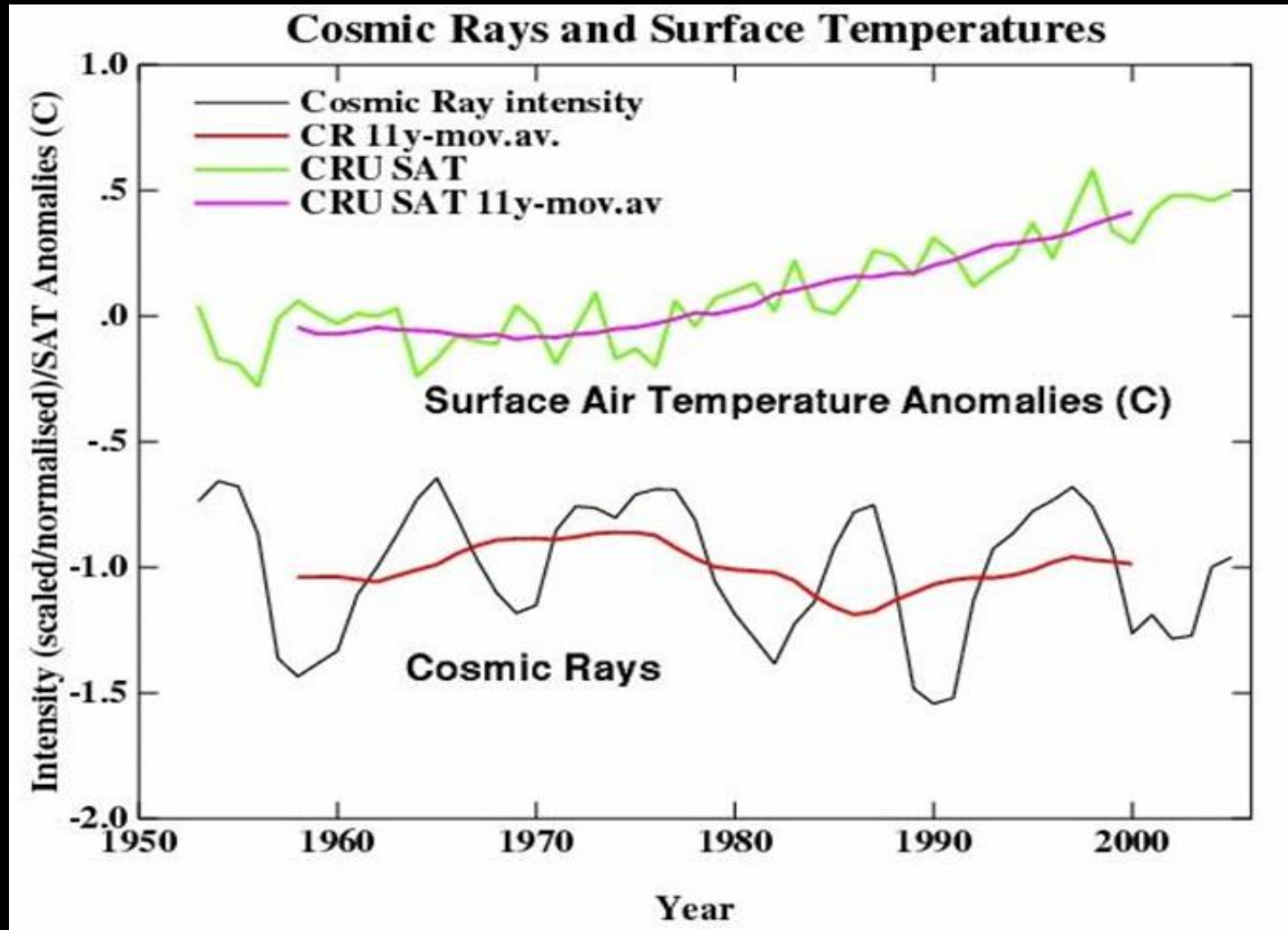
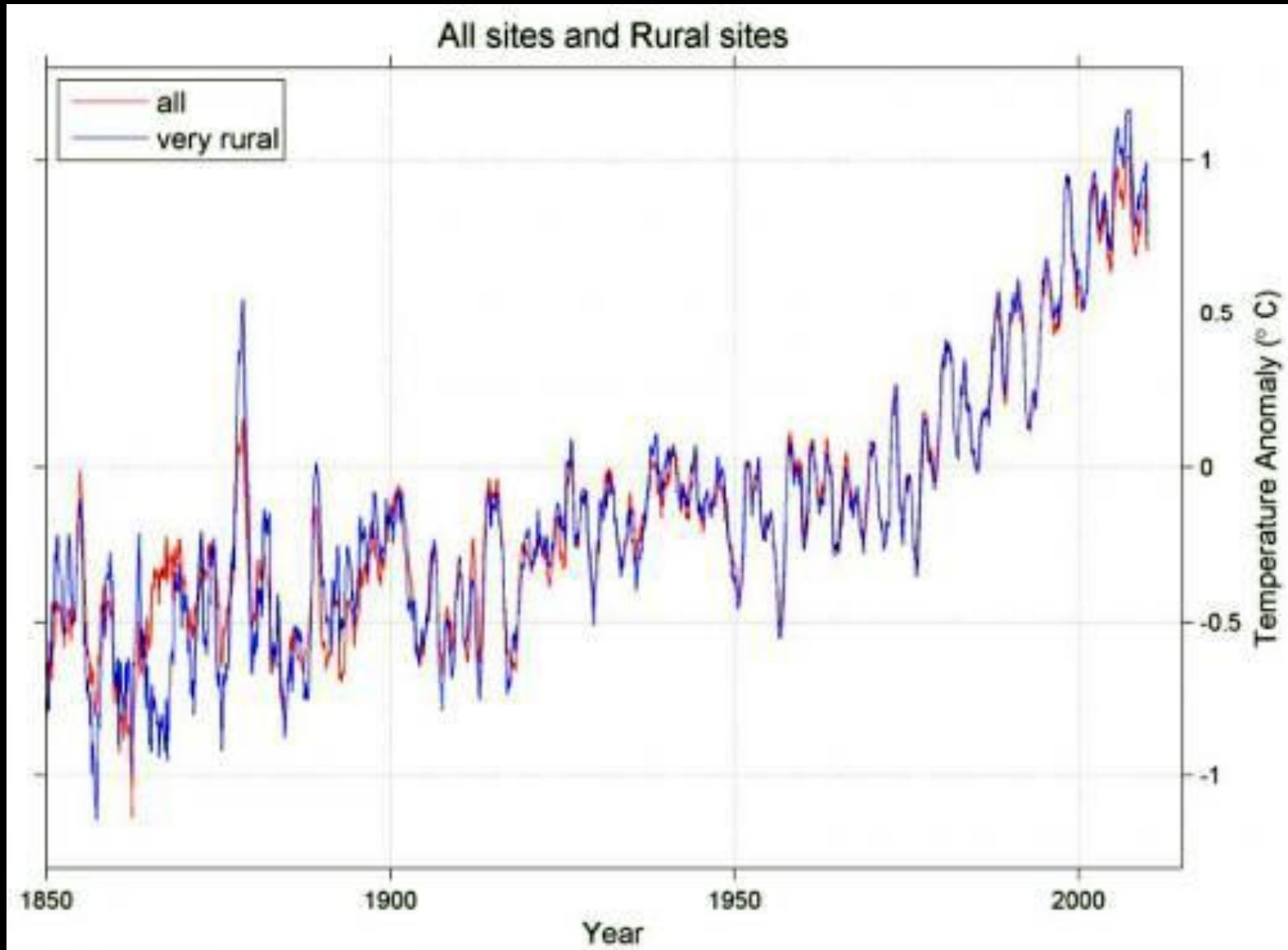


Figure 1: Atmospheric CO<sub>2</sub> levels measured at Mauna Loa, Hawaii (NOAA) and Stratospheric Aerosol Optical Thickness at 50nm (NASA GISS).

**It's NOT Cosmic Rays-seeded clouds.  
Cosmic Rays show no multi-decadal trend,  
while strong temperature rise**



# It's NOT the "Urban Heat Island" Effect, which doesn't Exist



Here is a Good Summary Graphic of the Natural and Human Forcings to Climate Change, Expressed as Temperature Change, Together with the Actual Surface Temperature Trend

- <http://www.bloomberg.com/graphics/2015-whats-warming-the-world/>

**We've looked at over a dozen different lines of strong evidence showing that 20<sup>th</sup>-21<sup>st</sup> Century global warming is caused by humans, primarily by fossil fuel burning**

**It's not the sun, it's not "natural variation", it's not cosmic rays, it's not the Pacific Decadal Oscillation, El Ninos, or other ocean cycles...**

**It's US. Humans. WE are responsible.**

**What did we know? A lot. And when did we Know it?**  
**For a long time.**

So why has there been so much denial of evidence that has been solid for decades? **Denialism**; its roots, politics, and debunking – that's coming up next

# K39: Summary of Key Evidence – Global Warming is Real and Human-Caused

- **We Know global warming is due to GHG's; Evidence -**
- --- Rising tropo + falling strato temps
- --- Rising height of tropopause
- --- Night temps rising faster than day temps (weak)
- --- Measured decrease in outgoing IR by satellites
- --- Measured increase in downward IR from our atmosphere to ground of  $3.5 \text{ W/m}^2$  can only be explained by increased GHG's
- --- Climate models: ~0% of climate forcing is due to natural causes
- **And we know these GHG's are due to Human Activities -**
- --- known emission rate from fossil fuel burning agrees with rise rates in atmosphere + ocean + photosynthesis
- --- **CO2 rise confirmed due to fossil fuel burning:**
- ----- C13/C12 ratio falling trend
- ----- fossil fuel burning consumes oxygen, beyond photosynthetic effects. Observations show indeed dropping O2 content of our atmosphere
- ----- CO2 gradients show it is produced where humans are
- ----- CO2 rise rates slow during economic recessions
- ----- measured volcanic emissions only ~1% vs. humans
- Water vapor GHG is human-caused indirectly: rising CO2-induced warming produces positive feedback since atmosphere holds 7% more water vapor per additional degree temperature rise (simple, well-understood physics, in and out of the lab)
- Also see human “scene of the crime” [SkepticalScience website has a good page](#)