

PENNSTATE



CReSIS

Center for Remote Sensing of Ice Sheets

G. Comer  
Foundation

Please note:

I work for  
Pennsylvania  
State

University,

And help UN  
IPCC, NRC,  
etc.,

But I am not  
representing  
them,

Just me.

# Climate Science: Key Questions and Answers



**Richard B. Alley**, Evan Pugh Professor of Geosciences and Associate of the Earth and Environmental Systems Institute, Pennsylvania State University, May 11, 2010

## With high scientific confidence:

- We are raising  $CO_2$ , mostly from fossil fuels;
  - This is warming the climate;
  - Changes to date are small compared to those expected under business as usual;
  - This will affect economies and ecosystems in major ways.
- 
- (Please note: this does not tell us what if anything to do—this is science, not policy.)

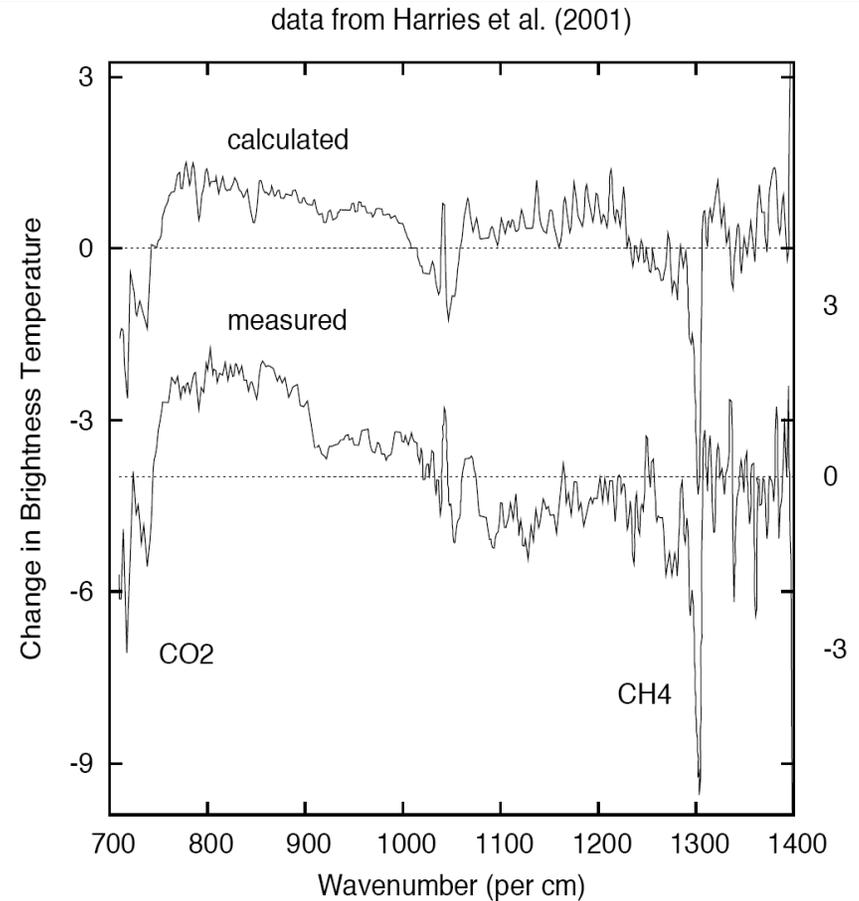
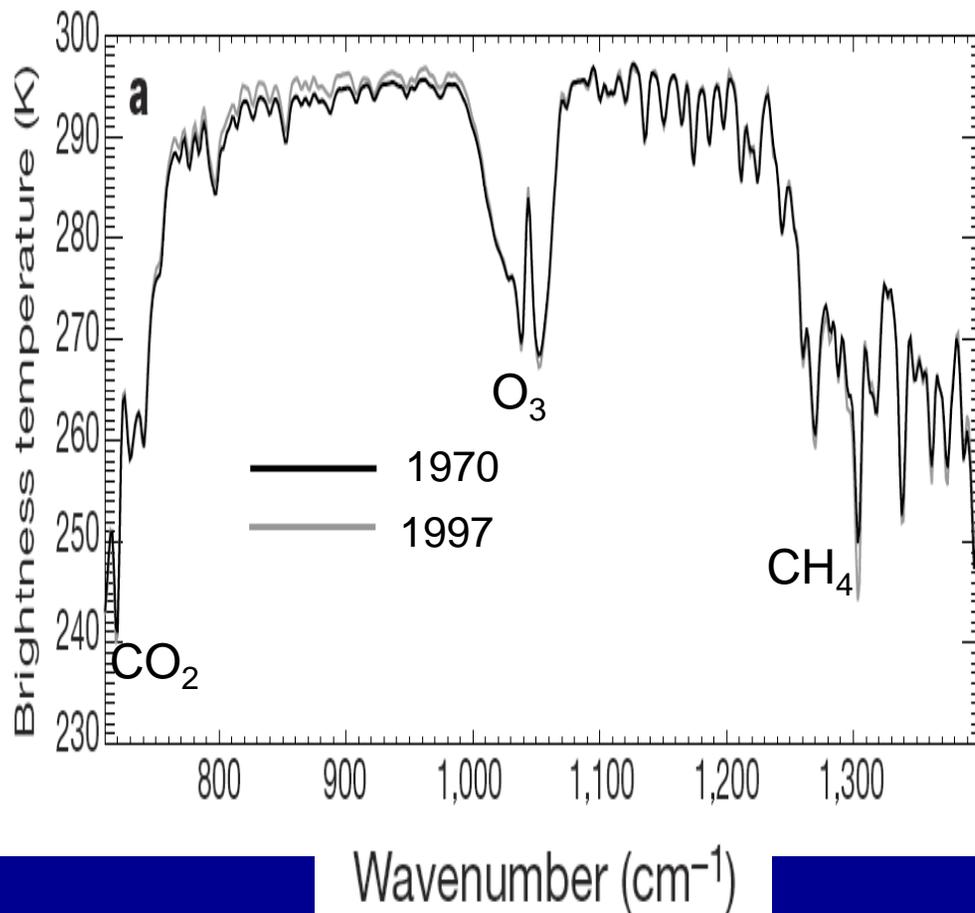
# High scientific confidence means:

- No single mistake, or small set of mistakes, could notably change these results;
- Because the results do not depend on any single fact, or data set, or model, or analysis, or investigator, or laboratory;
- Instead, major results depend on multiple lines of evidence, from many investigators and many labs, collected in many ways, and independently assessed by many groups such as the US National Academy of Sciences;
- Think of a braided rope, not a single hair—cutting one or a few strands will not break it;
- I'll try to show a little of the evidence here.

# Adding more $\text{CO}_2$ has warming influence

- Well-understood physics;
- Known for over 100 years;
- Especially clarified by military research after WWII addressing non-climate issues;
- (A heat-seeking missile won't see its target if it looks in a wavelength that  $\text{CO}_2$  absorbs)
- Can measure  $\text{CO}_2$  interaction with Earth's energy from space (next slide), or from the ground, or in the laboratory, or can calculate the effects.

# Increased greenhouse effect from CO<sub>2</sub>, CH<sub>4</sub>, and other gases is observed; Satellite-measured spectra over central Pacific, 1970-1997:



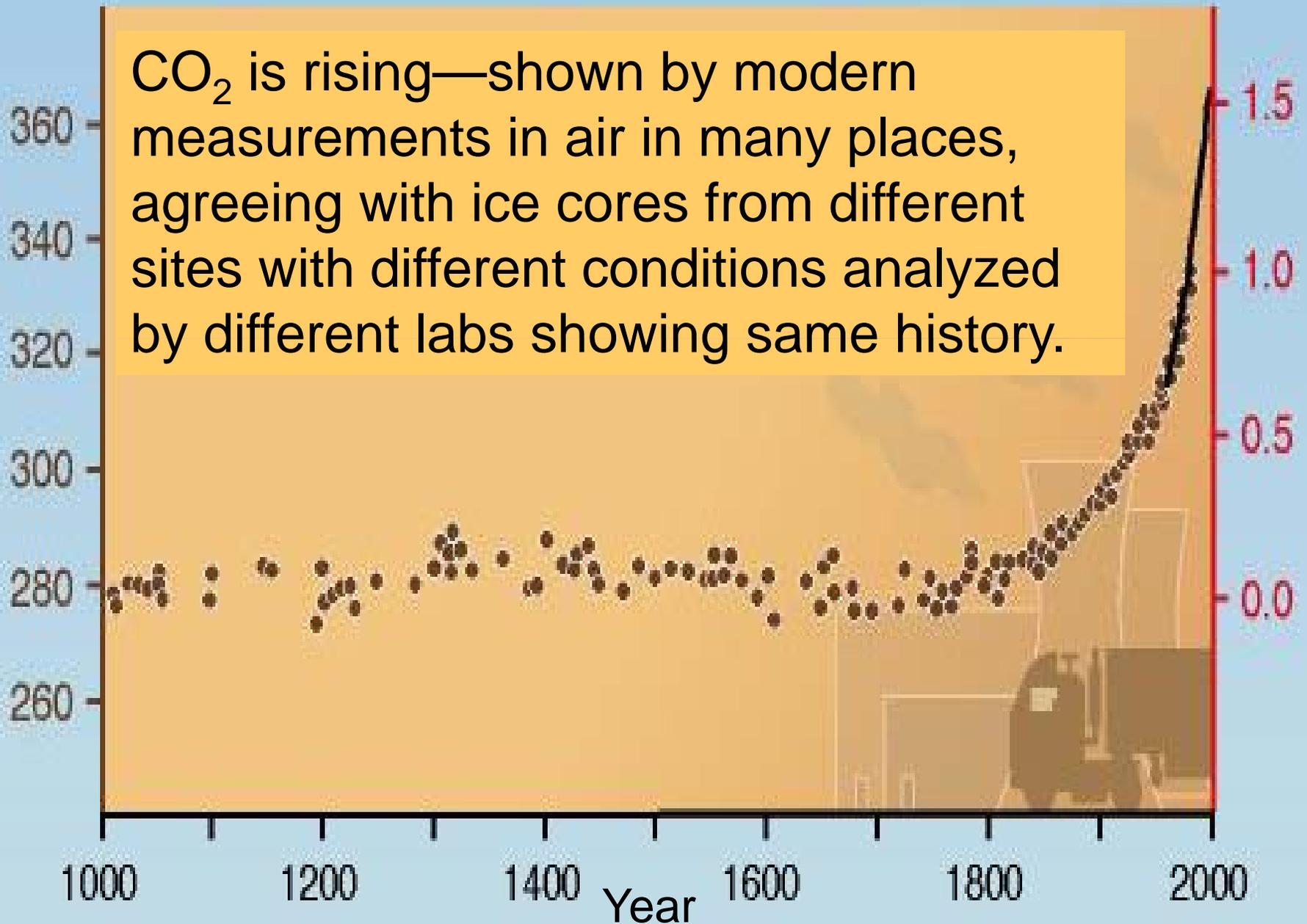
Harries et al. (2001)

CO<sub>2</sub> (ppm)

IPCC, 2001

Radiative forcing (Wm<sup>-2</sup>)

CO<sub>2</sub> is rising—shown by modern measurements in air in many places, agreeing with ice cores from different sites with different conditions analyzed by different labs showing same history.

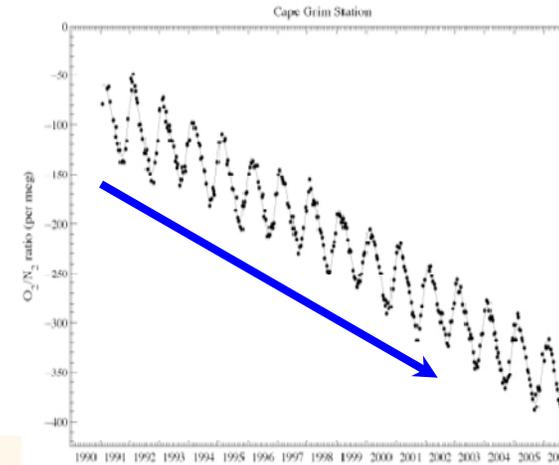


# Is it our $\text{CO}_2$ ? Yes

- Bookkeeping: quantitative match between known burning and observed extra  $\text{CO}_2$  in system;
- No other possible explanation adequate (volcanic source 1-2% of ours...);
- Air shows fossil fuels mainly responsible:
  - Atmospheric  $\text{O}_2$  drop--excess  $\text{CO}_2$  is from burning (not from ocean or volcanoes) (Keeling, 1996, *Nature*; Bender et al., 2005, *Global Biogeochemical Cycles*)—See next slide
  - Dilution of  $^{13}\text{C}$  in air—extra  $\text{CO}_2$  is or was living (not volcano, rock, etc.) (Battle et al., 2000, *Science*)
  - Dilution of  $^{14}\text{C}$  in air—extra  $\text{CO}_2$  from old source (not modern plants) (Suess, 1955, *Science*; Turnbull et al., 2009, *JGR*)

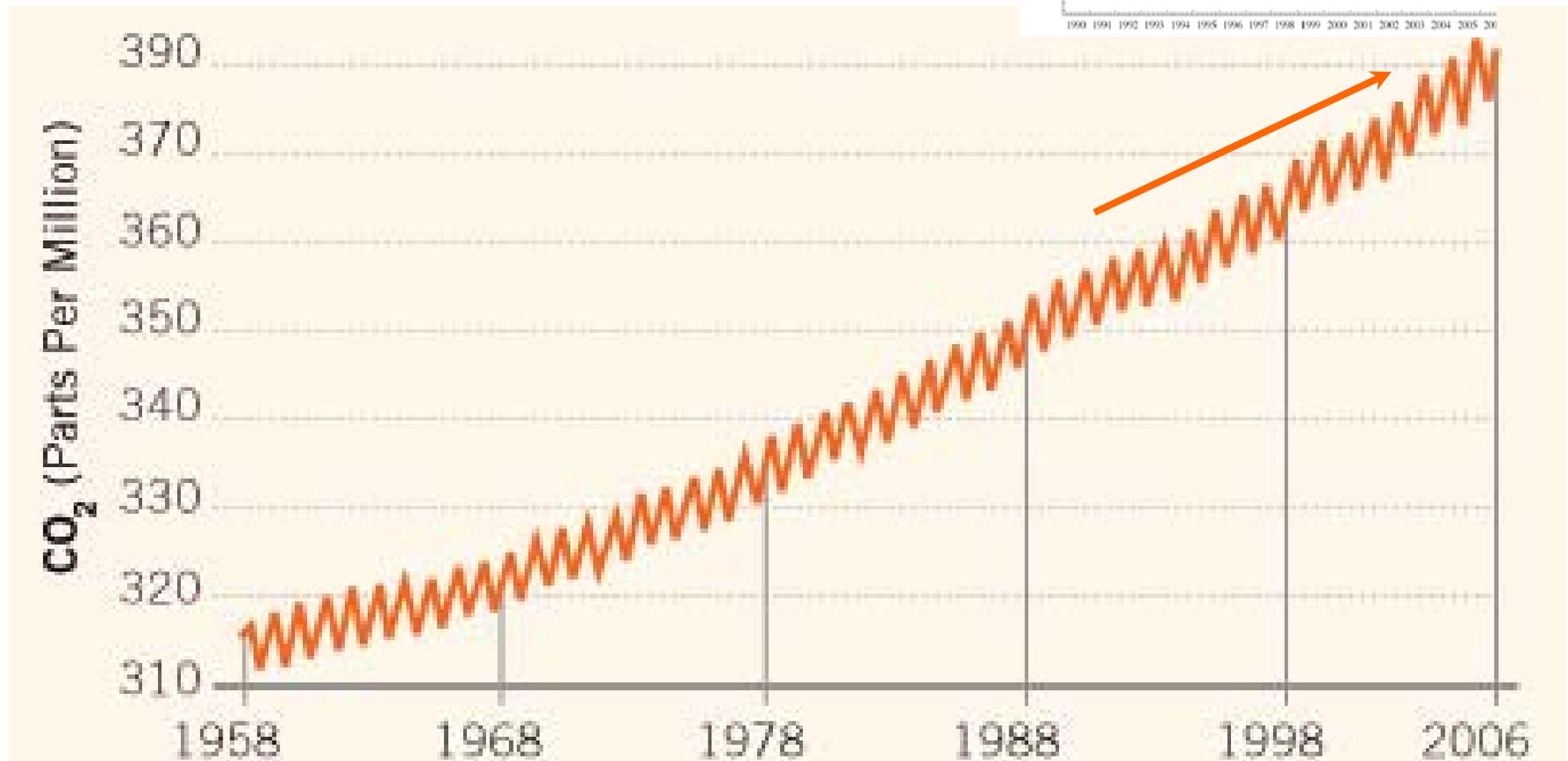
Record since 1958 of atmospheric CO<sub>2</sub> (below) and the shorter record of atmospheric O<sub>2</sub> (right). These are related--oxygen is being used to burn fossil fuels to make the CO<sub>2</sub>. We'll be able to breathe, but CO<sub>2</sub> is from burning plants, not from ocean or volcanoes.

Scripps Institution of Oceanography



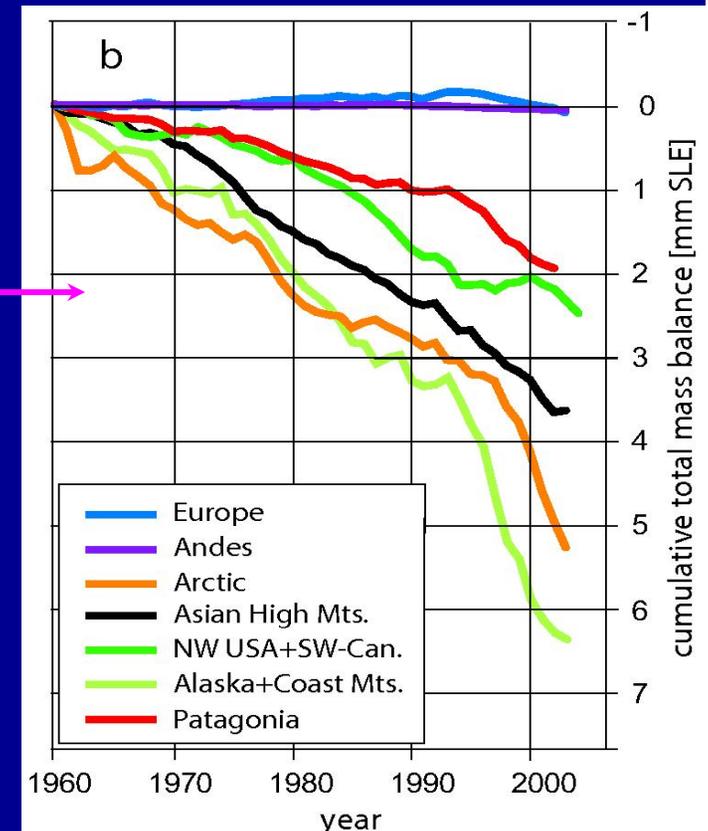
[http://explorations.ucsd.edu/Features/Keeling\\_Curve/slideshow/](http://explorations.ucsd.edu/Features/Keeling_Curve/slideshow/)

<http://www.npr.org/templates/story/story.php?storyId=9885767>



# Warming over last century:

- **UNEQUIVOCAL, from cautious IPCC**
- Direct thermometer measurements:
  - In air (including far from cities);
  - In ocean water;
  - In ground;
  - On balloons;
  - From satellites;
- Mass loss from almost all glaciers, including those getting more snow;
- Great majority of biology shifts in direction expected for warming;
- There still is weather, but average across the variable weather and climate is warming.

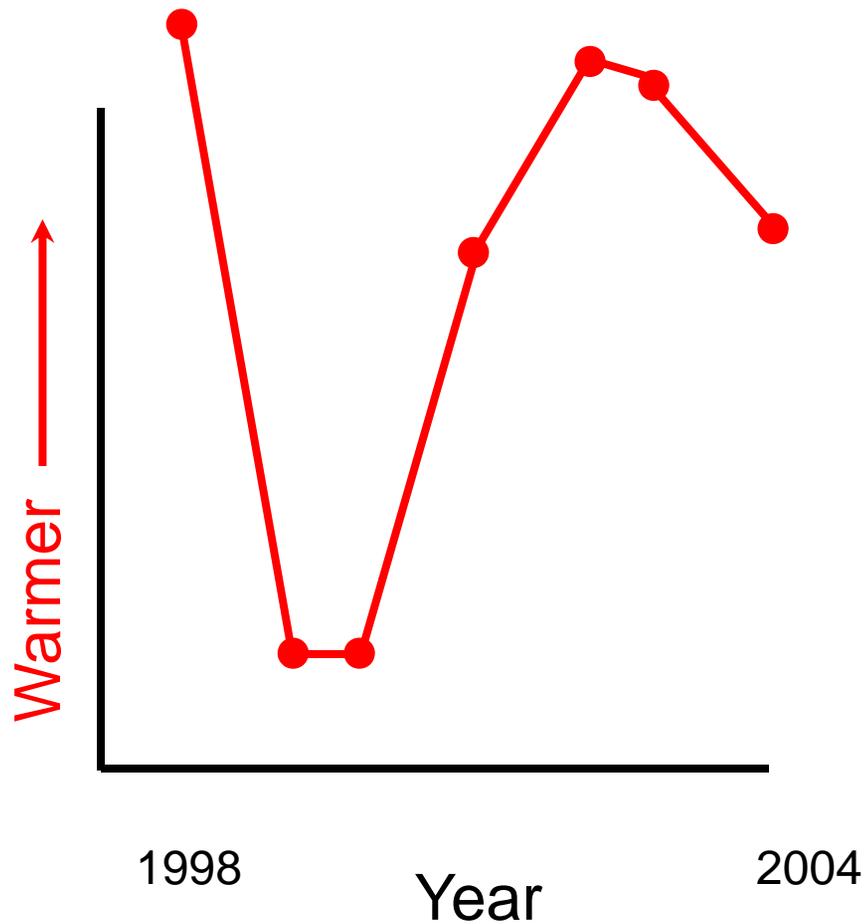




Muir Glacier, Alaska, August 13, 1941, photo by W.O. Field



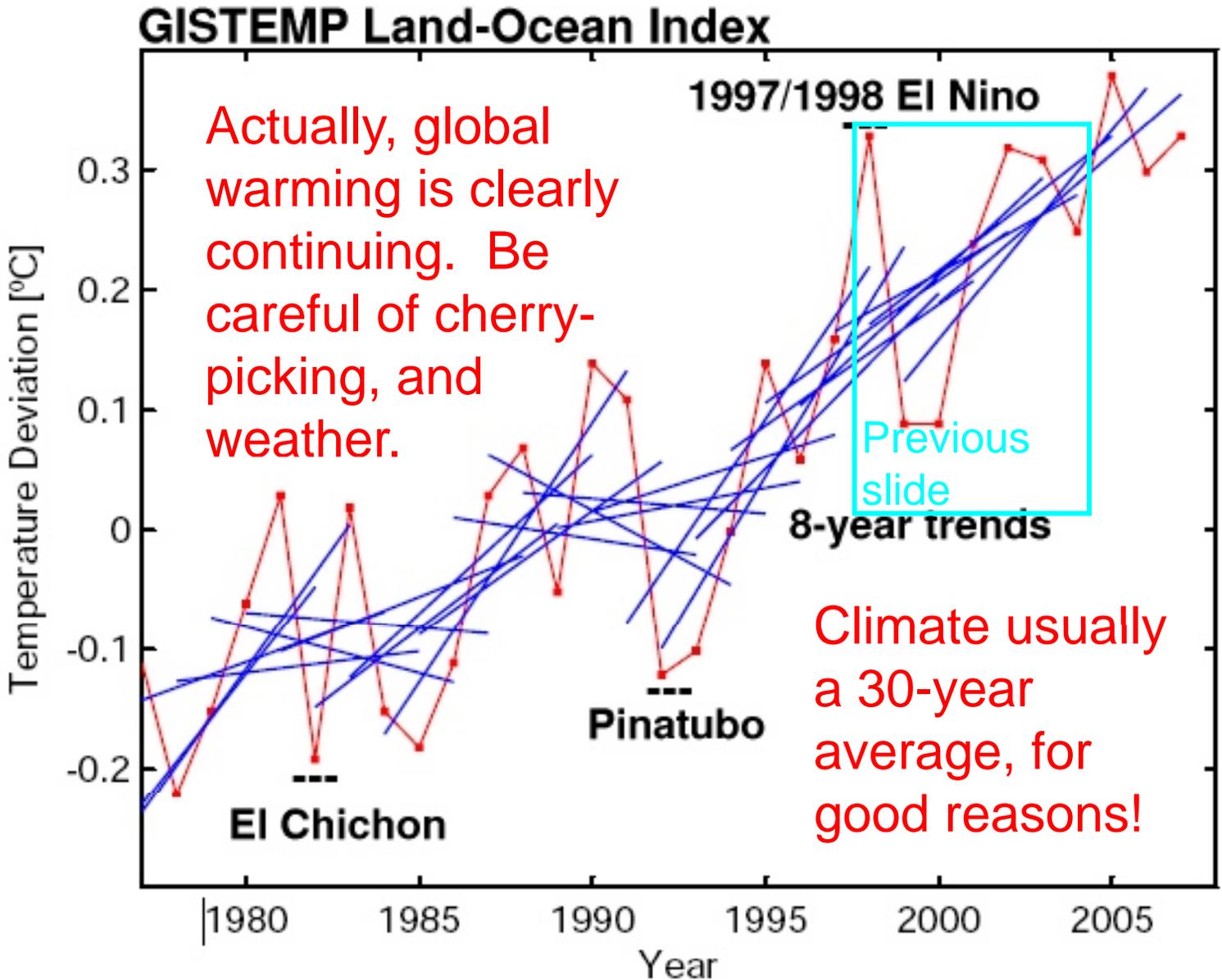
Muir Glacier, Alaska, August 31, 2004, photo by B.F. Molnia



Has global warming stopped?

“Global warming stopped in 1998” LOTS of search-engine “hits”.

Here are temperatures from 1998 to 2004, from GISTEMP. No warming there, right??? (Actually, a regression on this shows warming, but not with especially high confidence.)



Source: Gavin Schmidt, NASA GISS

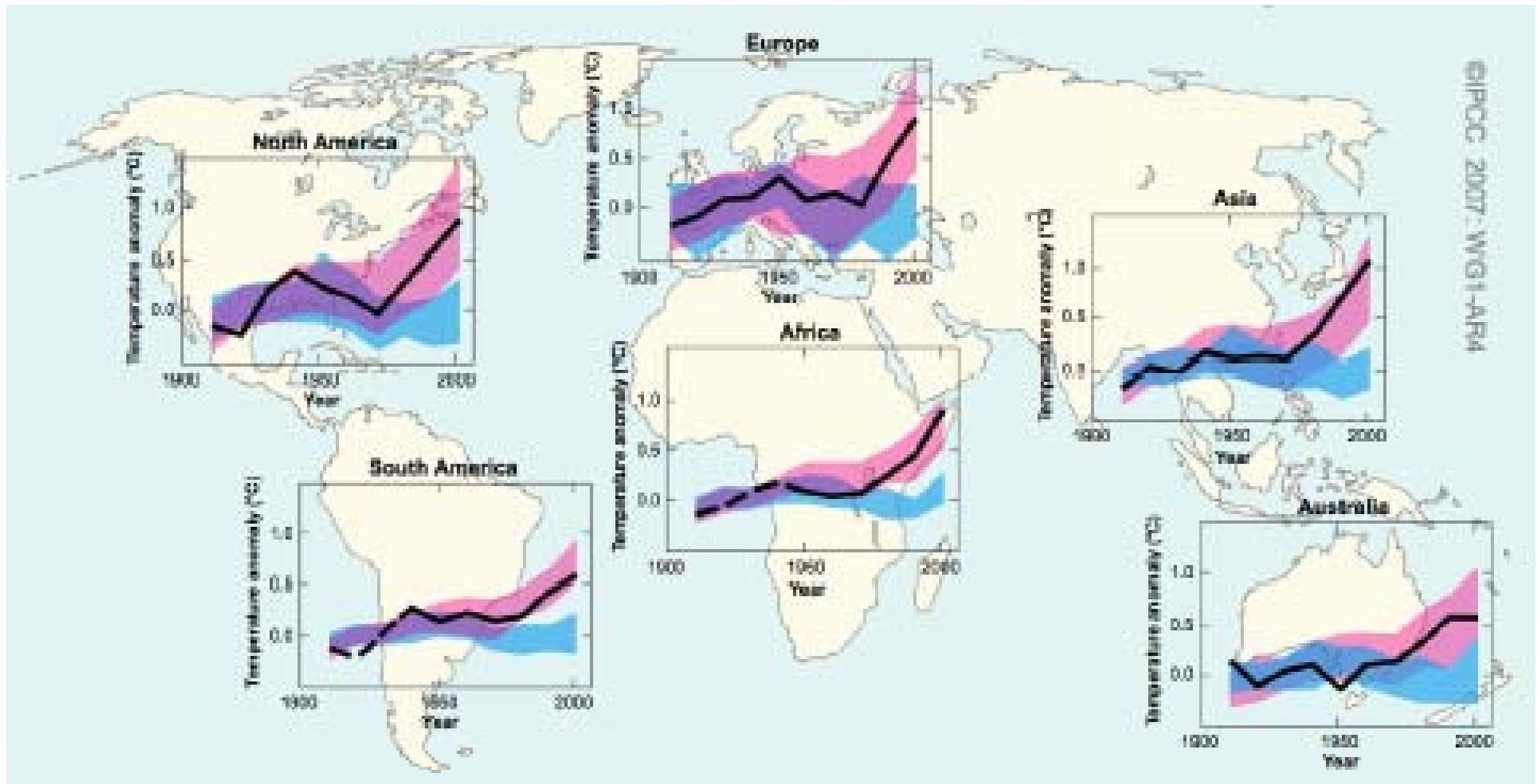
<http://www.realclimate.org/index.php/archives/2008/01/uncertainty-noise-and-the-art-of-model-data-comparison/#more-523>

# A few words on data

- All data, techniques, codes, etc. in previous slide are publicly available (<http://data.giss.nasa.gov/gistemp/>);
- Much public angst occurred over a different global analysis (UEA CRU) because a small subset of data was not publicly available, because the national meteorological services that collected the data were charged with selling them, so did not release (<http://www.cru.uea.ac.uk/cru/data/temperature/>);
- Note: The UEA analysis omitted parts of the Arctic, and so showed slower increase than estimated by NASA GISS (the more-criticized record showed less warming...)

# High confidence warming from our CO<sub>2</sub>

- **PHYSICS:** warming influence of rising CO<sub>2</sub> is unavoidable, observable physical reality;
- **FORCINGS:** Nothing else pushing warming (sun not brightening, cosmic rays not changing, etc.);
- **FINGERPRINTS:** Quantitative match between modeled and observed warming in time and space if and only if CO<sub>2</sub> included, with mismatch for any other possible cause of warming.

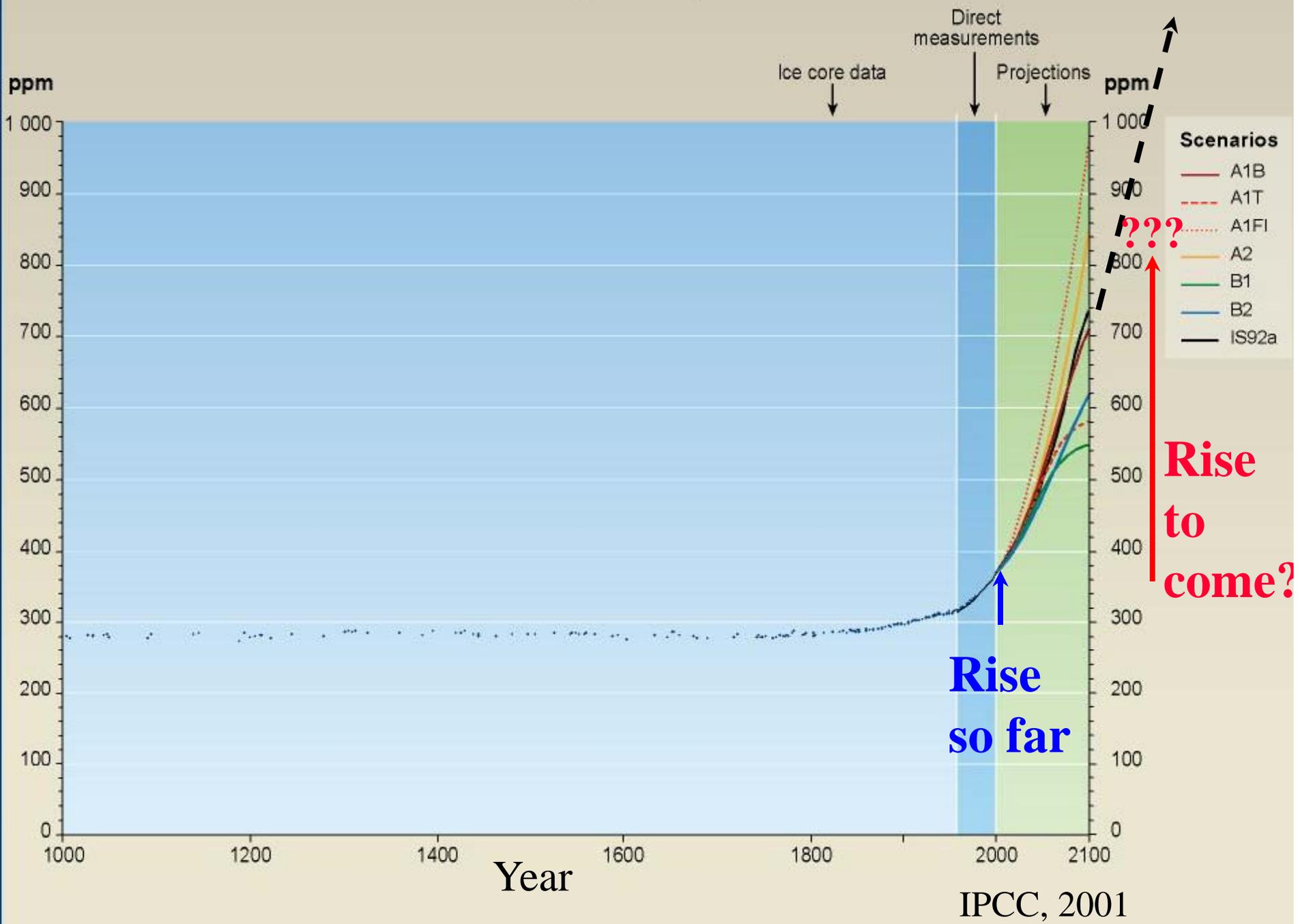


©IPCC: 2007: WG1-AR4

**Blue=Nature Only**  
**Pink=Humans+Nature**  
**Black=What Happened**

Warming is occurring  
because of us

# Past and future CO<sub>2</sub> atmospheric concentrations



## Multi-model Averages and Assessed Ranges for Surface Warming

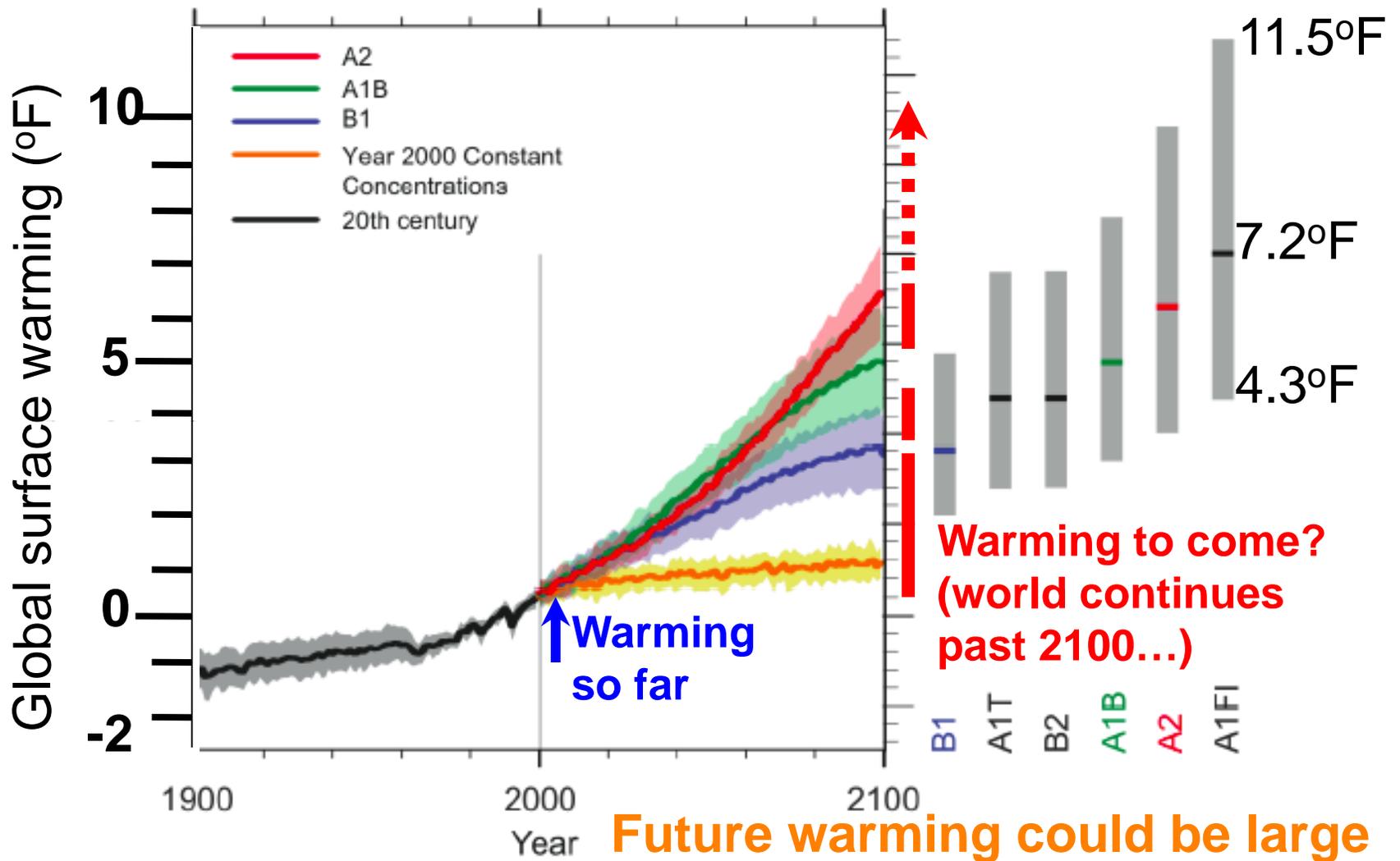


FIGURE SPM-5. Solid lines are multi-model global averages of surface warming (relative to 1980-99) for the scenarios A2, A1B and B1, shown as continuations of the 20<sup>th</sup> century simulations. Shading denotes the plus/minus one standard deviation range of individual model annual averages. The orange line is for the experiment where concentrations were held constant at year 2000 values. The gray bars at right indicate the best estimate (solid line within each bar) and the *likely* range assessed for the six SRES marker scenarios. The assessment of the best estimate and *likely* ranges in the gray bars includes the AOGCMs in the left part of the figure, as well as results from a hierarchy of independent models and observational constraints. {Figures 10.4 and 10.29}

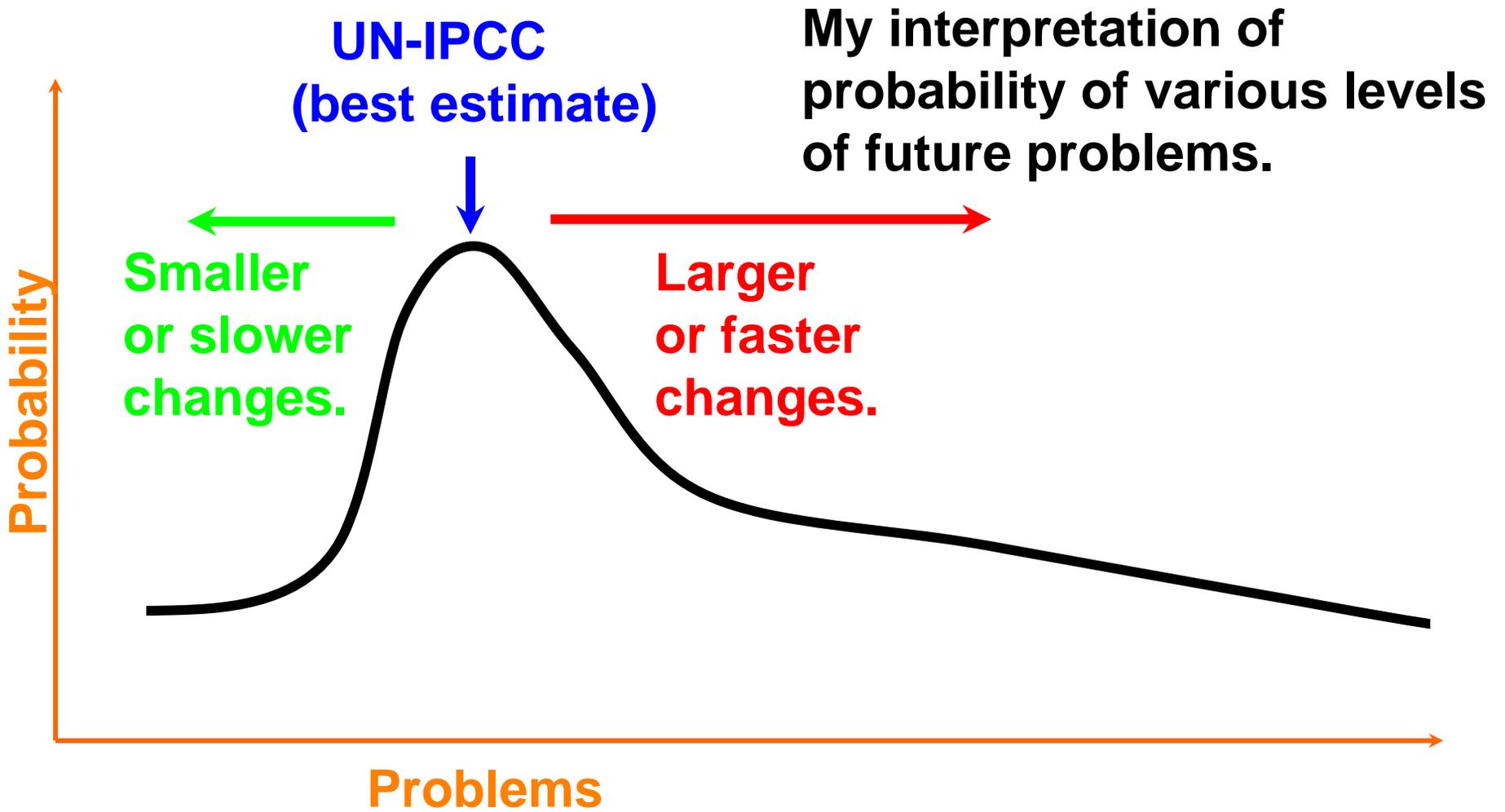
## With high scientific confidence:

- We are raising  $\text{CO}_2$ , mostly from fossil fuels;
- This is warming the climate;
- Changes to date are small compared to those expected under business as usual;
- The many, many threads of evidence woven into these results mean that no single error could change them—break the “hockey stick”, or discredit the Climate Research Unit, or erase one or a few climate scientists from history, and the main results would be unaffected.
- Similarly strong evidence (which I did not present here) shows that business-as-usual changes will notably affect economies and ecosystems, and that most uncertainties are on the “bad” side (larger or faster changes).

Thank you!

# Tipping Points

- Best estimate is that climate will “behave itself”;
- Small but nonzero chance we will cause a big, fast, widespread change (north Atlantic shutdown, ice-sheet collapse, ecological collapse in Brazilian rain forest, etc.);
- This probably becomes more likely for larger and faster forcing of climate change;
- Slight chance of really bad outcomes raises issues of insurance—“hedging against uncertainty”;
- I know of no offsetting scholarship indicating chance of “tipping point” into really good outcomes (“adjusting a watch with a hammer”?)



Most US debate seems to pit “UN-IPCC best estimate” against “smaller or slower changes”; most of the room seems to be in “larger or faster changes”.