Learning about anthropogenic climate change

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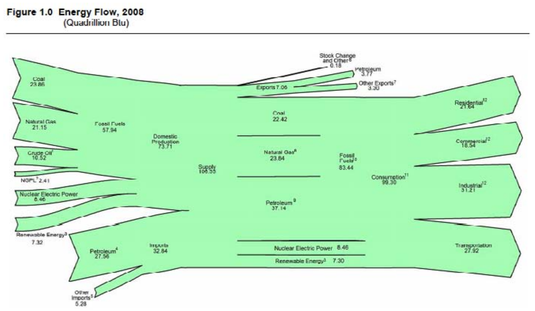
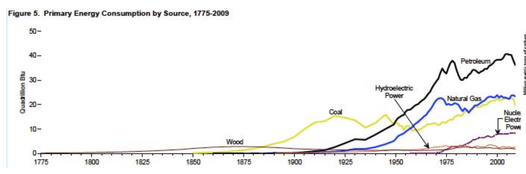
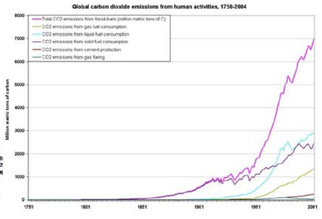
The Evidence …

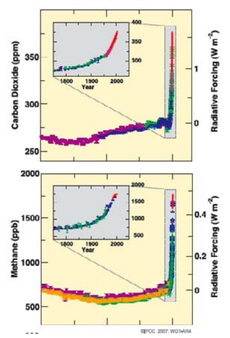
1. ~30 Gt/yr CO2 emissions; 40% increase in CO2 concentration since the start of the Industrial Revolution; Earth is not at 255 K.



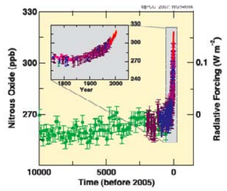
US energy flow, 2008; note the reliance on fossil fuel, left. US energy profile, 1775-2009, lower left. World CO_2 emissions, 1750—, below. 10.000 years of emissions of greenhouse gases, IPCC, down below on left.

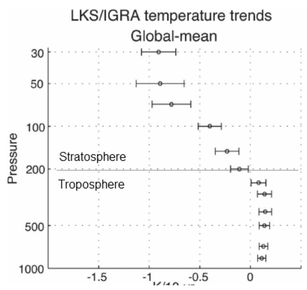




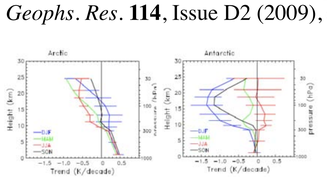


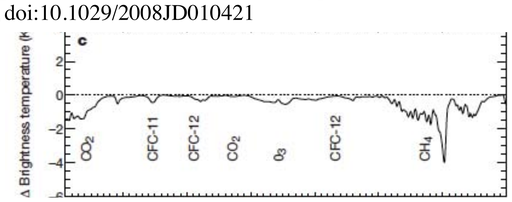
Putting this into 10,000 year perspective, humans have had a big effect, **particularly lately**!





2. Earth's stratosphere is cooling while the troposphere is warming. Data above right are from D. W. J. Thompson and S. Solomon, "Recent Stratospheric Climate Trends as Evidenced in Radiosonde Data: Global Structure and Tropospheric Linkages," *J. Climate* **18**, 4785–4795 (2005). doi: 10.1175/JCLI3585.1; below left, from W. J. Randel et al., "An update of observed stratospheric temperature trends," *J. Geophys. Res.* **114**, Issue D2 (2009), doi:10.1029/2008JD010421





3. Satellite measurements show that less radiation escapes to space. J. E. Harries, H. E. Brindley, P. J. Sagoo, and R. J. Bantge, "Increases in greenhouse forcing inferred from the outgoing longwave radiation spectra of the Earth in 1970 and 1997," *Nature* **410**, 355-356 (2001), above, right..

4. Weather stations' locations have been blamed for "false" warming. In a peer-reviewed article, even the originator conceded no support exists: "average temperature trends... are relatively insensitive to CRN classification." S. Fall, A. Watts, J. Nielsen-Gammon, E. Jones, D. Niyogi, J. R. Christy, and R. A. Pielke Sr., "Analysis of the impacts of station exposure on the U.S. historical climatology network temperatures and temperature trends," *J. Geophys. Res.-Atmospheres* **116**, D14120, doi:10.1029/2010JD015146 (2011). Others found the same result. M. I. Menne, C. N. Williams Jr., and M. A. Palecki, "On the reliability of the U.S. surface temperature record," *J. Geophys. Res.* **115**, 011108 (2010), doi: 10.102912009JDOI3094; R. A. Muller, J. Curry, D. Groom, R. Jacobsen, S. Perlmutter, R. Rohde, A. Rosenfeld, C. Wickham, and J. Wurtele, "Earth atmospheric land surface temperature and station quality in the United States," Berkeley Earth preprint, October 2011.

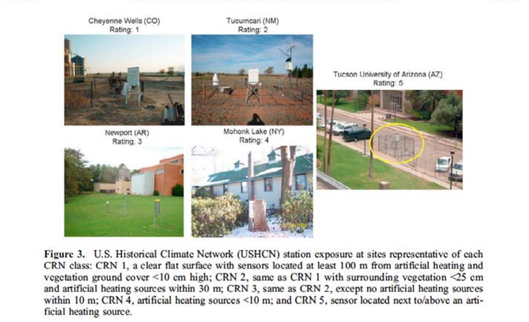
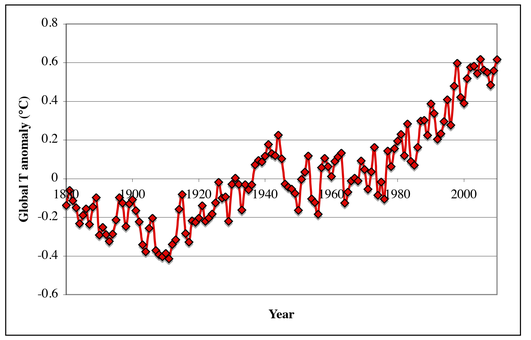
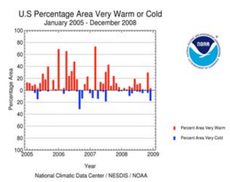
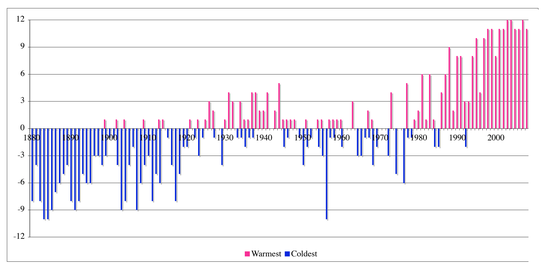


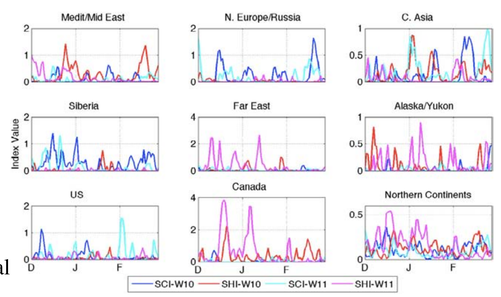
Figure 3. U.S. Historical Climate Network (USHCN) station exposure at sites representative of each CRN class: CRN 1, a clear flat surface with sensors located at least 100 m from artificial heating and vegetation ground cover <10 cm high; CRN 2, same as CRN 1 with surrounding vegetation <25 cm and artificial heating sources within 30 m; CRN 3, same as CRN 2, except no artificial heating sources within 10 m; CRN 4, artificial heating sources <10 m; and CRN 5, sensor located next to/above an artificial heating source.

5. Earth's temperature is rising, particularly since 1980. NOAA data, right; top, T from 1880-; bottom, individual years and number of months in that year among the 25 warmest (+) or coldest (-). You can see that 1883, 1884, and 1956 were anomalously cold and 1995, 1997-1999, and 2001 onward were anomalously warm.



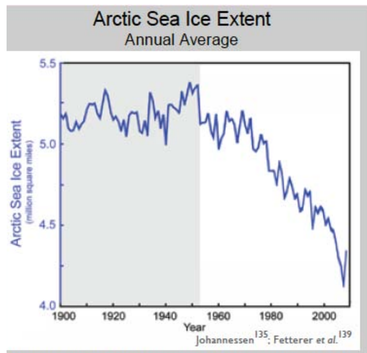






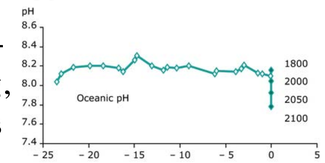
Above, NOAA US % warm & cold, 2005-08; right, K. Guirguis, A. Gershunov, R. Schwartz, and S. Bennett, "Recent warm and cold daily winter temperature extremes in the Northern Hemisphere," *Geophys. Res. Lett.* **38**, L17701, doi:10.1029/2011GL048762 (2011); Fig. 3, Daily SCI and SHI for W10 and W11. Seasonal Severe Cold Index (SCI, blue) and Severe Heat Index (SHI, red).

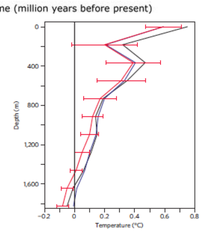
6. Most continental glaciers are receding. The Greenland Ice Sheet is melting faster than previously. Arctic sea ice is declining. Data, above on left, from O. M. Johannessen, "Decreasing Arctic Sea Ice Mirrors Increasing CO_2 on Decadal Time Scale." *Atm. Oceanic Sci. Lett.* **1**, 51-56.(2008); F. Fetterer, K. Knowles, W. Meier, and M. Savoie. Sea Ice Index - National Snow and Ice Data Center. Boulder, CO, 2002. Permafrost could melt. R. M. DeConto, S. Galeotti, M. Pagani, D. Tracy, K. Schaefer, T. Zhang, D. Pollard, & D. J. Beerling, "Past extreme warming events linked to massive carbon release from thawing permafrost," *Nature* **484**, 87 (2012).

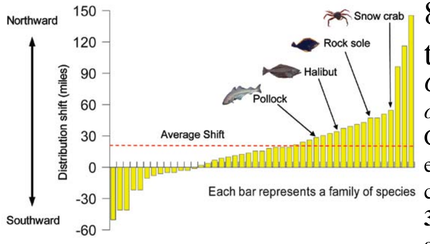


Observations of annual average Arctic sea ice extent for the period 1900 to 2008. The gray shading indicates less confidence in the data before 1953.

7. Sea level is rising, the oceans are warming, and the oceans' pH is changing. http://www.eea.europa.eu/data-and-maps/figures/ocean-acidity-over-the-past; D. Roemmich, W. J. Gould, and J. Gilson, "135 years of global ocean warming between the Challenger expedition and the Argo Programme," *Nature Clim. Change* **2**, 425–428 (2012), doi:10.1038/nclimate1461.

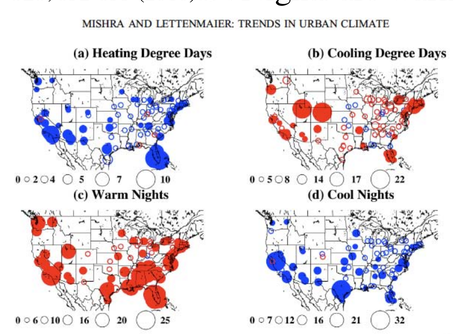


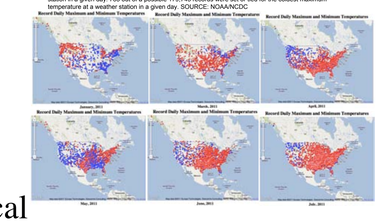




8. Species are moving toward the poles. Data From *Global Climate Change Impacts in the United States: A State of Knowledge*, Report from the U.S. Global Change Research Program, p.144.; B. Sinervo et al., "Erosion of lizard diversity by climate change and altered thermal niches," *Science* **328**, 894-899 (2010). R. B. Huey, J. B. Losos, and C. Moritz, "Are lizards toast?," *Science* **328**, 832-833 (2010)..

9. Nights are warming faster than days. Data, left, from V. Mishra and D. P. Lettenmaier, "Climatic trends in major U.S. urban areas, 1950–2009," *Geophys. Res. Lett.* **38**, L16401 (2011); below, NCDC.





10. It's just basic physics, statistical analyses, & simulations. **That's the Evidence.**

What can we physics teachers do? In G. J. Aubrecht, "Helping scientists communicate to people," *Am. J. Phys.* **79**, 437-439 (2011), I suggest that ending the "information deficit" as many suggest (e.g., R. C. J. Somerville and S. J. Hassol, "Communicating the science of climate change," *Phys. Today* **64**(10), 48-53 (2011)) is not enough. My best current communication advice:

•Filling the "information deficit" is necessary but not sufficient. •Science is about data and theory, not about belief. •Give students experience with nature. •Help students know what theory means and that science works by ***disproof*** rather than proof. •Communicate in words, not just equations or in jargon. •Pay attention to mental models and framing.•Pay attention to confirmation bias.•Plausibility matters—and scientists, luckily, are plausible.•Proximity matters (spatially & temporally).•Response times matter (fast vs. slow).•Scales matter.