Some Basic Modeling of Atmospheric Carbon Dioxide and Global Temperature

I started along modest lines to see what kind of relatively simple modeling could be done to first match and then extend (a) the pattern of observed CO2 concentrations from about 1800-2012 and (b) the relationship between CO2 concentrations and temperature. I've been paying attention enough to know there are other climate forcing factors to consider, both positive (e.g., methane, nitrous oxides, chlorofluorocarbons) and negative (e.g., sulfate aerosols, ice sheets, changing land use), but it seemed worthwhile for a novice to try something simple as a starting point.

I did not want to restrict myself to the Climate and Carbon Cycle Models at the University of Chicago, since they did not directly or easily address my needs, and since I am a competent analyst quite capable of downloading and analyzing material on my own. I also wanted to explore available sources of data, such as:

- NOAA's National Climatic Data Center (NCDC) (1),
- NASA National Aeronautics and Space Administration, Goddard Institute for Space Studies (2),
- The Scripps CO2 Program (3),
- Carbon Dioxide Information Analysis Center (4), and
- The World Bank's World Development Indicators (5).

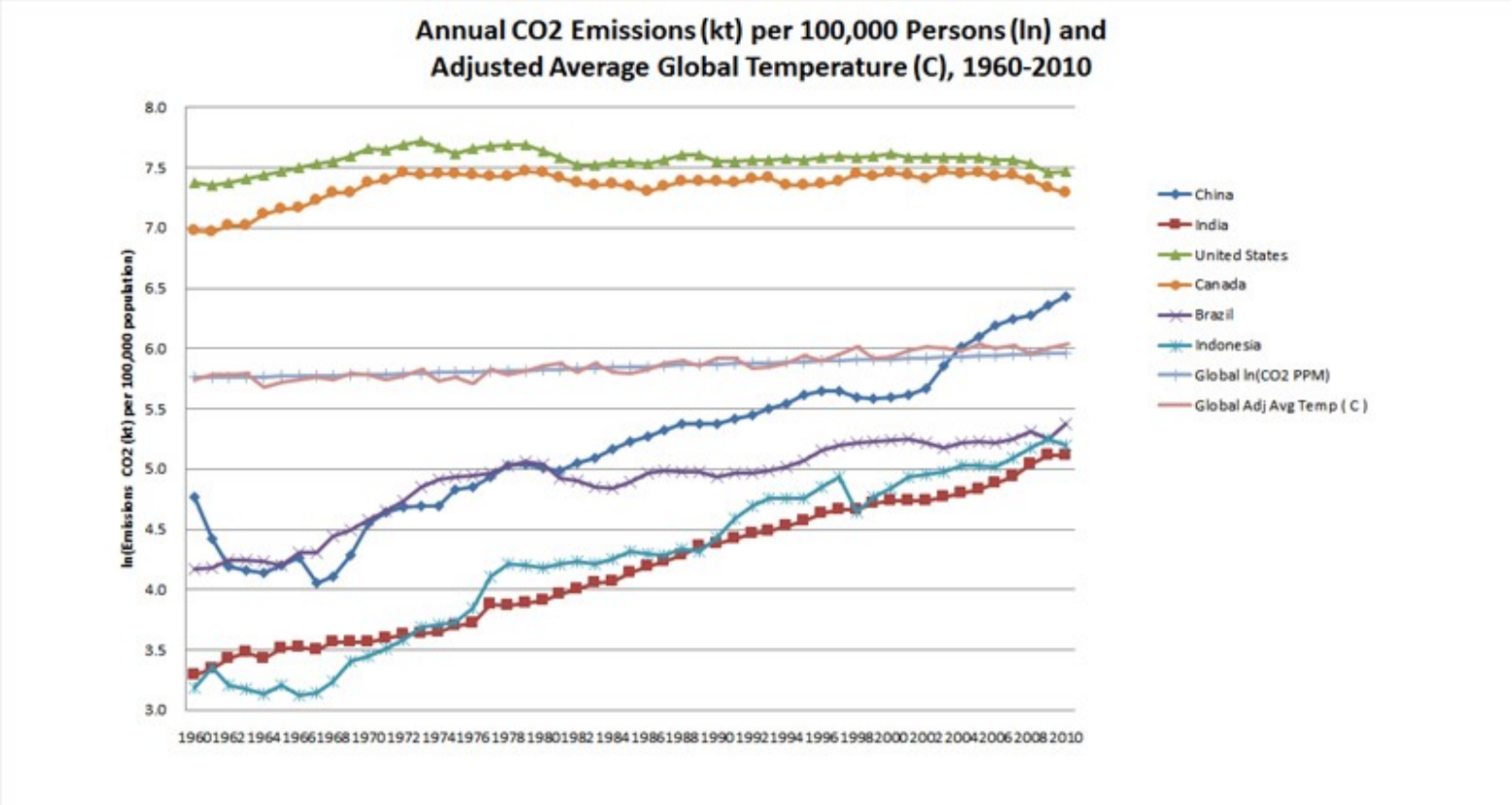
One of the first issues was to look at why things have been changing so rapidly in the last 50 years. In lectures and published material, David Archer (6) talked about the 'smoking gun,' and likewise Thomas Friedman (7) (and many others: the IPCC, Bill McKibben, Al Gore, Jim Hansen, etc.) has commented, with some gravity, about the increasing extent of the emissions and the likelihood of problems that will result.

The first task was simply to look at emissions per capita in six of the countries that contribute most to the problem. The US and Canada are the North American entries in this dubious contest, and both actually appear to be decreasing their emissions somewhat: per Friedman, much of this is due to a change from coal to natural gas in the generation of electricity. Likewise, although far from optimal, fuel efficiency standards (mpg) for automobiles (19) have made some difference. But, as a preliminary reviewer (thanks, Bill!) pointed out, much of those reductions are offset by factors as fossil fuel exports and continued exploration for and development of new fossil fuel resources (8).

Indonesia and Brazil are included as representatives of the 'deforestation' side of the problem, as emphasized in recent lectures and by Friedman (he specifically mentions Indonesia and Brazil as #3 and #4 on the overall 'problem child' list). China (#2) and India (about #6, depending on where you look) are the obvious examples of emerging economies that are growing both rapidly and 'inefficiently' in terms of economic output per unit of energy consumed.

Data in the chart below is from the World Bank data site (6), for the period 1960-2010. [Additional data were obtained from the Earth Policy Institute Data Center (9)].

The chart below shows trends for the countries mentioned, plotted as CO2 in kilotons per 100,000 population.



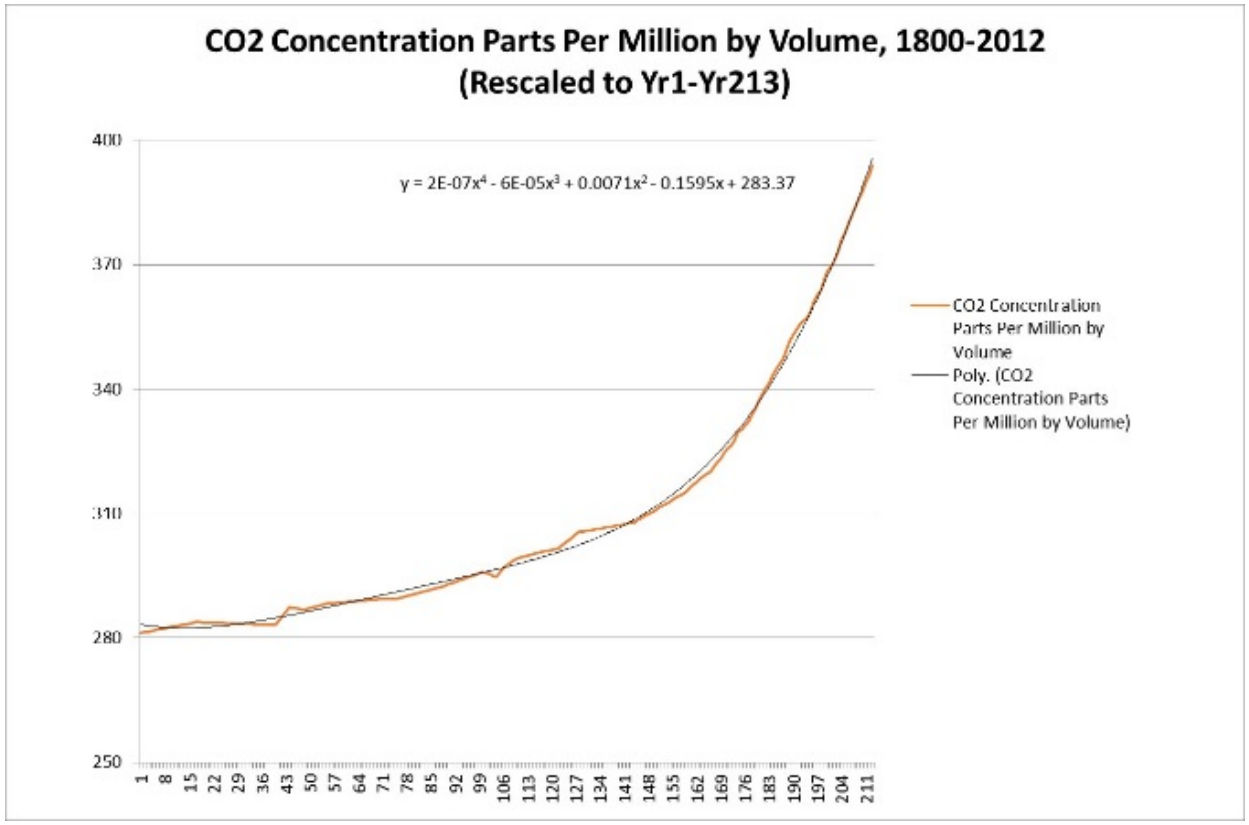
As expected, China and India show sharply upward emissions levels over the last 50 years; Indonesia tracks India closely, though the absolute amount is much less. Brazil is a bit more variable in trend, but nonetheless a significant contributor to the overall problem. Though the US and Canada were mentioned briefly above, it is quite clear from this chart that they have not come anywhere close to reducing emissions in accord with the Kyoto Protocol or Copenhagen Accord standards. No surprises here...

The other elements of interest on the chart lie in the center, where I scaled CO2 [ln(ppm)] and temperature (in degrees C) to track as nearly linearly as possible. The transform for temperature was to take the original Fahrenheit values and convert to Centigrade, and then simply subtract 3.67 to get a magnitude similar to the natural log of CO2 [ln(CO2)] for plotting.

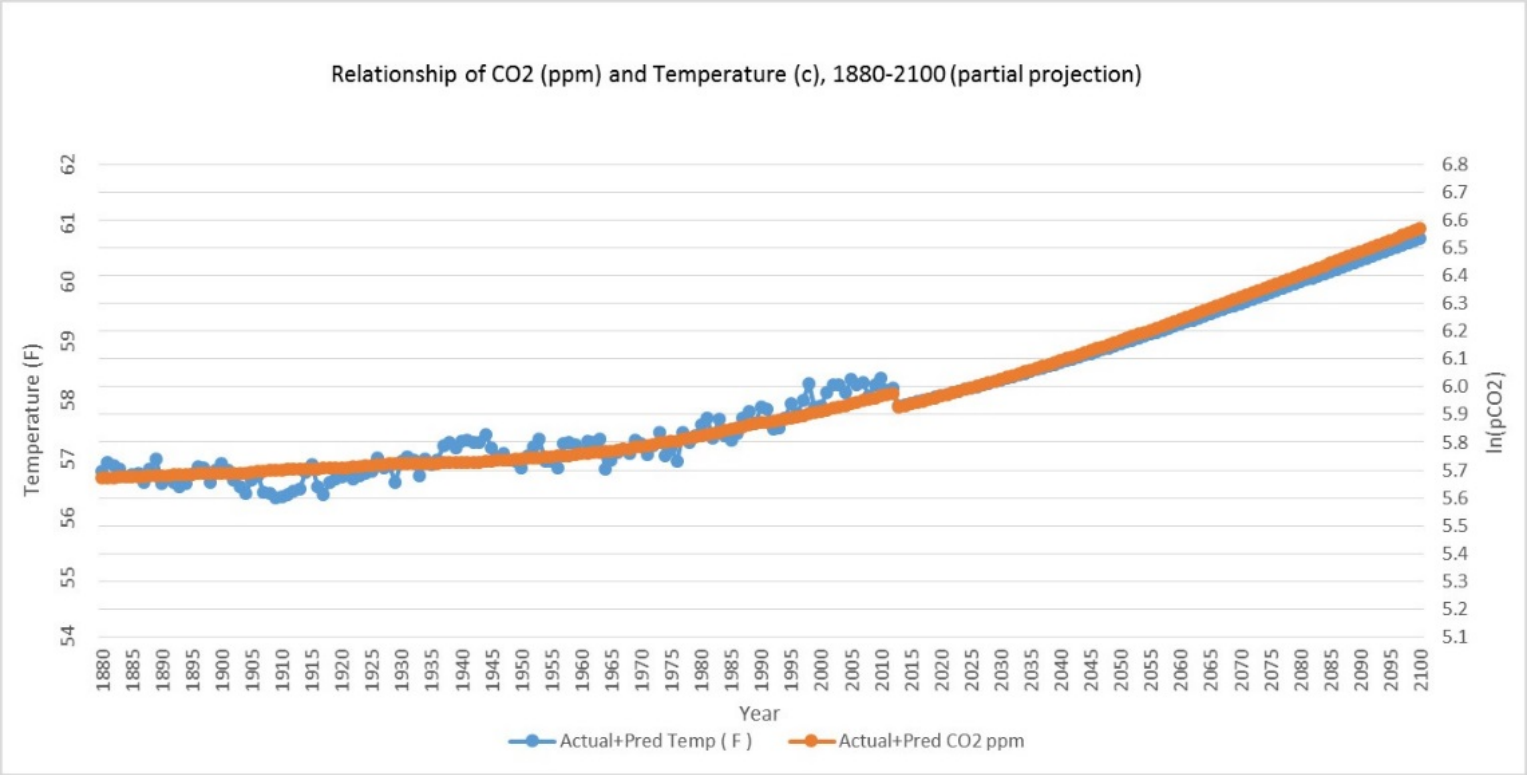
What I wanted to try next was an experiment: in some sense, it seems to me that the CO2/ temperature relationship is not unlike the relationship of body mass and energy expenditure (Kleiber's Law; 10). Yes, it's metaphoric – the question is, how well might it work? As shown, the correlation is quite good, so so far, so good. The actual Excel equation is "(((5/9)*(E21-32))-3.67)^(3/4)", where the cell in E is Fahrenheit temperature.

What if we were to explore this approach a little further? We need a model to take CO2 from some base year to the present, then extrapolate forward to some convenient year like 2100, as both the IPCC AR4 (11) and AR5 Working Group I reports (12) have done. We can fit a variety of polynomial equations to the data on purely empirical grounds. I tried both 3rd and 4th order forms, and found the latter to fit best. Likewise, we can use 1800-2012 or 1880-2012 as the base period; the formulas come out about the same. So we model change over time, starting at a base year rescaled to 1, for the period 1880-2012.

In Excel, the formula is "(-0.0000001*((H6)^4)) + (0.0001*((H6)^3)) -(0.0112*((H6)^2)) +(0.5932*H6) + 288.27), where H is the serial year value. A chart a similar pattern, though for 1800-2012 is shown below (years scaled as 1-213). Empirically this is an excellent fit, but what about projections forward?

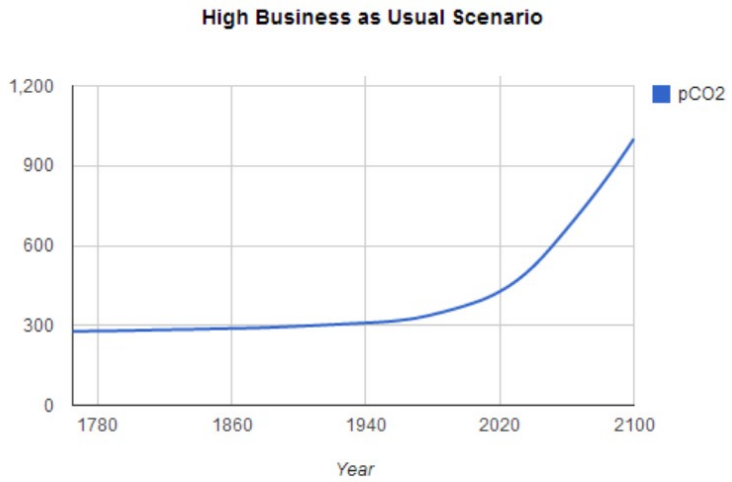


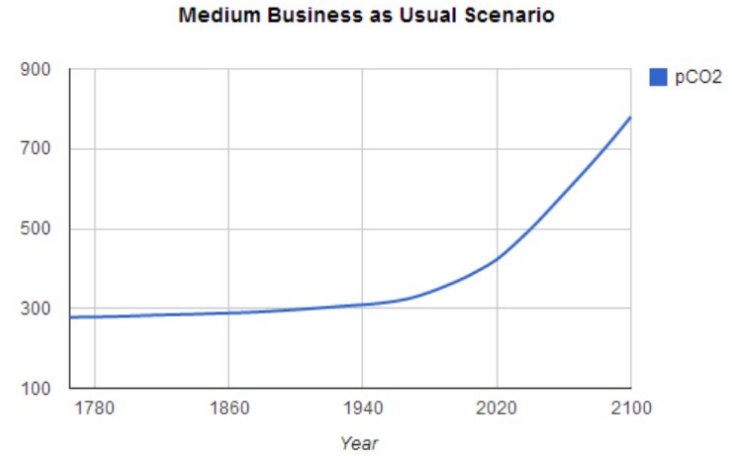
If we take the actual values from 1880-2012, use the quadratic formula to extend the CO2 values, estimate Fahrenheit temperature from that value, then derive predicted Centigrade values for 2013-2100, we end up with the chart below. There's some discontinuity at the transition point (2013), but the overall concordance with actual trends is quite good.



What about benchmarks? We're not getting values identical to those in other models using this technique, but running quite close to such projections nonetheless. While the real atmosphere has crossed 400 ppm CO2 this year (2013; 13), this model doesn't get to 400 ppm CO2 until 2025 (and 58.2 deg F). And we only reach 713 ppm CO2 in 2100 (and 60.75 deg F). Still, that's a 2.5 degree increase (F) in temperature from 2012 to 2100, and 3.95 increase (F) from 1880. Good prediction. Bad implication.

One last issue is relevant. We'd like a reference point, a business-as-usual type scenario. Specifically relevant to this class, I chose two from the ISAM Integrated Impacts of Climate Change model (14). These are shown below as 'High Business as Usual' and 'Medium Business as Usual.' In terms of outcome in 2100, we're quite close to the 'medium' scenario. It should be recognized that factoring in other GHGs, and accounting for the simplicity of this model, actual levels would likely be higher. Even accounting for some increased cooling effects (aerosols, volcanos, geo-engineering, changes in behavior), these projections are likely modest, though in line with expectations.





So that's what I did for my Thanksgiving vacation. I told myself I wasn't going to do a modeling analysis, but it is part of the assignments for the class, after all, so here you have it.

But: I find, sitting here in Salt Lake City, with the Winter inversions (my first) soon to be upon us, that it is far more important to be concerned about actual practical mitigation and adaptation options than to continue modeling a circumstance whose outcome, whatever the particulars, is essentially already known. And that's the real inconvenient truth. Yes?

In a very recently published article (15), Jim Hansen is joined by an elite team of researchers, in multiple disciplines and from multiple institutions, in assessing the implications of the commonly cited goal of keeping total global warming to 2 degrees centigrade or lower (11). It is noteworthy that in announcing the publication of this paper, the PLOS ONE editors state:

> For PLOS ONE, which has in the past primarily published biomedical research, this paper represents a broadening in scope. As often happens at our journal, it comes about in response to a need from the scientific community—in this case, the need to publish fully peer-reviewed climate research in a high-profile venue, fully accessible to the entire world for free.
>
> Few areas can benefit as much from the force of Open Access as climate change research: the combination of public, scientific, and governmental interest with the mounting misinformation, unsubstantiated opinions, and unsourced data make public access to original, well-reported, and peer-reviewed climate change research of utmost importance. We hope that this paper will be the first of many that deal with this rapidly growing area of multidisciplinary research. (16)

I also note, with great appreciation for the opportunity to study with him, that not only is David Archer's work cited in the scientific references, he is specifically acknowledged as a reviewer of early work on the publication – high praise, indeed.

The article deserves close attention, and I will let the reader make their own assessment. But the main argument is that current estimates of the deleterious effect of our current course are simply unacceptable; even at the currently expressed temperature rise since 1900 (about 0.8 degrees C), the effects are becoming ominous, and they will continue to accumulate according to planetary laws of physics and chemistry - the carbon cycle (6) and related phenomena. If left unaddressed and unmitigated, the effects will be both irreversible and catastrophic, leading to "a very different planet than the one that humanity knows." (15, pg 2).

Beyond claims of this type, they also explicitly discuss the twin topics of intergenerational justice (for our children, and their children, and …) and human rights (for those affected by but not contributing to the emissions problem). Like David Suzuki's discussion of 'willful ignorance,' which oft-times passes into 'criminal negligence' (17), they conclude this section with the following comment:

> Our parent's generation did not know that their energy use would harm future generations and other life on the planet. If we do not change our course, we can only pretend that we did not know. (15, pg 20)

In this context, the use of climate models has largely fulfilled its mission, to inform the debate, in so far as it was once a debate, and to guide the discussion of viable transformation strategies, away from fossil fuels, now that the need for substantial and immediate change is clear. It will be disruptive, it will be expensive, and it will require the coordinated efforts of governments and industries, organizations and individuals.

I know where I stand (20), and in closing will recall the words attributed to Benjamin Franklin, at the signing of the American Declaration of Independence, July 4, 1776: "We must all hang together, or assuredly we shall all hang separately." (18)

References and Notes

(1) National Oceanic & Atmospheric Administration (NOAA), National Climatic Data Center. http://www.ncdc.noaa.gov/.
(2) NASA National Aeronautics and Space Administration, Goddard Institute for Space Studies, http://data.giss.nasa.gov/.
(3) The Scripps CO2 Program. http://scrippsco2.ucsd.edu/data/atmospheric_co2.html.
(4) Carbon Dioxide Information Analysis Center, http://cdiac.ornl.gov/trends/emis/meth_reg.html.
(5) The World Bank's World Development Indicators. http://data.worldbank.org/data-catalog/world-development-indicators
(6) David Archer, "Global Warming: Understanding the Forecast." Wiley-Blackwell, 2006.
(7) Thomas L. Friedman, 'Hot, Flat and Crowded: Release 2.0." Picador/Farrar, Straus & Giroux, 2009.
http://www.thomaslfriedman.com/bookshelf/hot-flat-and-crowded.
(8) Ryan Lizza, "The President and the Pipeine." The New Yorker magazine, September 16, 2013.
http://www.newyorker.com/reporting/2013/09/16/130916fa_fact_lizza.
(9) Earth Policy Institute Data Center, 'Eco Economy Indicators.' http://www.earth-policy.org/indicators/C51.
(10) Wikipedia, "Kleiber's law." http://en.wikipedia.org/wiki/Kleiber's_law.
Kleiber's law, named after Max Kleiber's biological work in the early 1930s, is the observation that, for the vast majority of animals, an animal's metabolic rate scales to the ¾ power of the animal's mass.
(11) Contribution of Working Group I to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change, 2007.
http://www.ipcc.ch/publications_and_data/ar4/wg1/en/contents.html.
(12) IPCC. Climate Change 2013: The Physical Science Basis. http://www.climatechange2013.org/report/.
Full PDF at http://www.climatechange2013.org/images/uploads/WGIAR5_WGI-12Doc2b_FinalDraft_All.pdf.
(13) National Oceanic & Atmospheric Administration, Earth System Research Laboratory, Global Monitoring Division.
http://www.esrl.noaa.gov/gmd/ccgg/trends/mlo.html.
(14) University of Chicago, Climate Models. ISAM Integrated Impacts of Climate Change. http://climatemodels.uchicago.edu/isam/.

(15) James Hansen, et al. "Assessing 'Dangerous Climate Change': Required Reduction of Carbon Emissions to Protect Young People, Future Generations and Nature." http://www.plosone.org/article/info%3Adoi%2F10.1371%2Fjournal.pone.0081648.
(16) Damian Pattinson, "James Hansen and Colleagues Offer Evidence for a Disruptive Call to Action." PLOS ONE, December 3, 2013. http://blogs.plos.org/everyone/2013/12/03/james-hansen-and-colleagues-offer-evidence-for-a-disruptive-call-to-action/.
(17) David Suzuki, "2013 Jack Beale Lecture on the Global Environment: Foresight over Hindsight." The University of New South Wales, September 23, 2013. http://newsroom.unsw.edu.au/news/science/david-suzuki-blasts-environmental-%E2%80%98barbarians%E2%80%99. Full lecture at: http://www.youtube.com/watch?v=UC2XeS1aTYk.
(18) Attributed to Benjamin Franklin, at the signing of the Declaration of Independence, July 4, 1776. http://en.wikiquote.org/wiki/Benjamin_Franklin, accessed 11/29/2013.
(19) Bill McKibben, "Global Warming's Terrifying New Math." Rolling Stone, July 19, 2012. http://www.rollingstone.com/politics/news/global-warmings-terrifying-new-math-20120719. "Barack Obama, for instance, campaigned more aggressively about climate change than any president before him – the night he won the nomination, he told supporters that his election would mark the moment 'the rise of the oceans began to slow and the planet began to heal.' And he has achieved one significant change: a steady increase in the fuel efficiency mandated for automobiles. It's the kind of measure, adopted a quarter-century ago, that would have helped enormously. But in light of the numbers I've just described, it's obviously a very small start indeed." (pg 5-6)
(20) Ani DiFranco, "Which Side Are You On?" http://www.youtube.com/watch?v=MzQ-n4RLMC4.