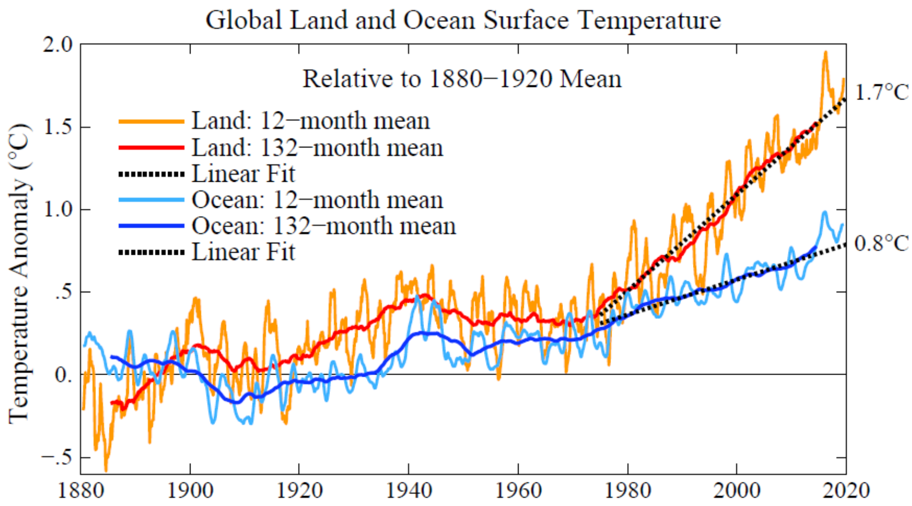

Climate Models vs. Real World

03 February 2020

James Hansen

Climate models are most useful when used so as to help us understand climate mechanisms in the real world, and thus improve our ability to understand ongoing and future climate change.

Comparison of climate model predictions against real world outcome provides one way to gain improved understanding. There is recent discussion in the media of early predictions of human-caused global warming, including simulations made with early climate models at the Goddard Institute for Space Studies (GISS), specifically (1) 1981 paper in Science[1] that used a simple one-dimensional (1-D) column climate model, and (2) 1988 paper in JGR[2] that used our first coarse-resolution 3-D climate model. The media discussions miss the most important lessons.

The 1981 model did a pretty good job, slightly underpredicting global warming. The main reason for this was that the 1-D model has ocean heat capacity at its foot. Although we reduced the ocean's heat capacity by the factor 0.7 to account for the fact that ocean covers only 70 percent of Earth's surface, a 1-D model using that procedure yields a result closer to that for the ocean (see figure above) than it should. This is discussed in Chapter 20 of *Sophie's Planet*.

A 1-D model can be doctored to do a better job of accounting for land and ocean fractions, but, because of the dynamical exchange of marine and continental air, it is still better to use a 3-D model that allows realistic mixing of marine and continental air.

Our group had the good fortune to interact with Jule Charney when we started to build a 3-D climate model in the late 1970s. We were at least a decade behind Suki Manabe, and our computer, more than 10 years old, was much slower than those at GFDL and NCAR. Yet Charney treated us with the respect accorded more established researchers, despite the coarse resolution and unpublished status of our climate model (Chapter 17 of *Sophie's Planet*).

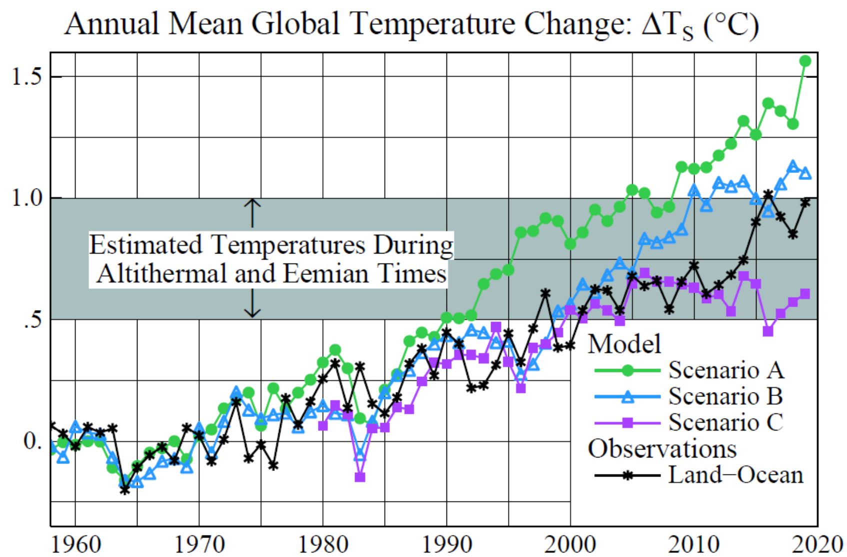

Fig. 2. Climate model simulations in our 1988 paper and subsequent real-world data.

Jule called me four or five times while writing his famous 1979 report[3] on climate sensitivity, as he was trying to understand the physical mechanisms that caused our model to have a sensitivity of almost 4°C for doubled CO_2, while Manabe's current model had 2°C sensitivity. Cloud feedbacks were to be the biggest factor causing this difference.

We had to keep our 3-D model fixed once the climate runs were started, because it required a few years to complete them on our computer! So all runs were done with the model having sensitivity near 4°C, even though we had reasons to believe that real-world climate sensitivity was closer to 3°C for doubled CO_2. The 1-D model used in our 1981 paper specified climate sensitivity as 2.8°C, which was probably a good choice.

Real world climate forcing turned out to be close to that in our Scenario B, which is the scenario that we expected to be most realistic. So what are the main reasons for the moderate overshoot of Model B (see figure) compared to the real world?

In the spirit of Jule Charney, we should look not only under the street light (factors that we can quantify), but also at other factors that we know about and believe to be important. The list I come up with in *Sophie's Planet* is, in order of estimated importance:

1. Aerosol (direct and indirect) forcing: no aerosol forcing is included in our 1988 model
2. Model sensitivity (equilibrium and response time, i.e. modeling of ocean inertia effect)
3. Energy imbalance at model start (warming in pipeline): zero imbalance in 1958
4. Ice sheet/ice shelf freshening effect: Southern Ocean/North Atlantic cooling
5. Greenhouse gas (GHG) forcing errors

1. Global aerosols presumably increased during 1958-present, reducing the global warming caused by increasing GHGs, but we have no good observations. This is a sad state of affairs that I dwell on in *Sophie's Planet*, so much so that I am removing the aerosol chapters and some of the planetary chapters to another book (*Battleship Galactica*, if I can get away with that name). Ignorance allows speculation. Could aerosols from the enormous upshoot in global coal burning between 2000 and 2015 (Fig. 3) contribute to the minimal warming during that period (Fig.2)?

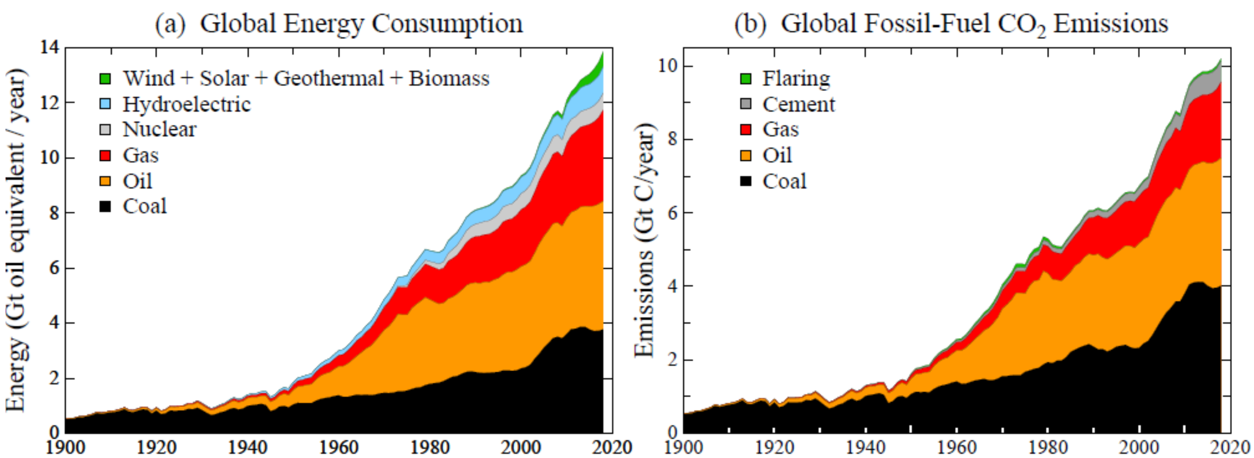

Fig. 3. Global energy consumption and fossil fuel CO_2 emissions.

2. The equilibrium sensitivity of our GCM in 1988 (4°C for doubled CO_2)[4] is higher than our best estimate for the real world (3°C for doubled CO_2). This difference by itself might approximately account for the difference between the model B simulation and observations.

3. By starting the model in energy balance in 1958 we do not account for any 'unrealized warming' that is 'in the pipeline.' This reduces the warming, perhaps as much as 0.1-0.2°C, thus partially compensating for the above two overestimates.

4. We do not include the effect of increasing meltwater on the North Atlantic and Southern Oceans (our ocean 'model' consisted of specified, unchanging dynamical transport of heat), which has been shown to already be occurring.[5] Observations confirm that minimal warming, or even slight cooling, is occurring southeast of Greenland and in the Southern Ocean.

5. Real-world GHG forcing turned out to be almost exactly Scenario B, when we examine effective forcings. There are several definitions for radiative forcings (instantaneous forcing, adjusted forcing, effective forcing, etc.). The most relevant forcing should be the effective forcing, which accounts for the 'efficacy' of each forcing.

Furthermore, it makes sense to include within the effective forcings those indirect GHG forcings that are reasonably well understood. For example, an increase of methane leads to an increase of stratospheric water vapor via simple chemistry. A methane increase also causes an increase of tropospheric ozone, because methane and ozone are competing for the hydroxyl radical (OH), which is the cleansing agent in the troposphere.

The bottom line is that #1 and #2 almost surely caused our model to yield too much warming, but this was partly compensated by #3. #4 reduces the real-world warming, contributing to the gap between predicted and observed global temperatures. #4 will become more important in the future, if the rate of mass loss from the ice sheets and ice shelves increases.

The sad part of this story is that the biggest uncertainty, #1, is not being measured to a useful accuracy. It is hard to measure, because it includes the effect of aerosols on clouds, but there is no good excuse for why we are not monitoring the aerosol direct and indirect climate forcings. That is the main subject of *Battleship Galactica*.

[1] Hansen, J., D. Johnson, A. Lacis, S. Lebedeff, P. Lee, D. Rind, and G. Russell, 1981: Climate impact of increasing atmospheric carbon dioxide. *Science*, **213**, 957-966, doi:10.1126/science.213.4511.957.

[2] Hansen, J., I. Fung, A. Lacis, D. Rind, S. Lebedeff, R. Ruedy, G. Russell, and P. Stone, 1988: Global climate changes as forecast by Goddard Institute for Space Studies three-dimensional model. *J. Geophys. Res.*, **93**, 9341-9364, doi:10.1029/JD093iD08p09341.

[3] Charney, J., Arakawa, A., Baker, D., Bolin, B., Dickinson, R., Goody, R., Leith, C., Stommel, H., and Wunsch, C.: Carbon Dioxide and Climate: A Scientific Assessment, Natl. Acad. Sci. Press, Washington, DC, 33p, 1979.

[4] Hansen, J., A. Lacis, D. Rind, G. Russell, P. Stone, I. Fung, R. Ruedy, and J. Lerner, 1984: Climate sensitivity: Analysis of feedback mechanisms. In *Climate Processes and Climate Sensitivity*. J.E. Hansen, and T. Takahashi, Eds., AGU Geophysical Monograph 29, Maurice Ewing Vol. 5. American Geophysical Union, 130-163.

[5] Hansen, J., M. Sato, P. Hearty, R. Ruedy, M. Kelley, V. Masson-Delmotte, G. Russell, G. Tselioudis, J. Cao, E. Rignot, I. Velicogna, B. Tormey, B. Donovan, E. Kandiano, K. von Schuckmann, P. Kharecha, A.N. Legrande, M. Bauer, and K.-W. Lo, 2016: Ice melt, sea level rise and superstorms:/ evidence from paleoclimate data, climate modeling, and modern observations that 2 C global warming could be dangerous *Atmos. Chem. Phys.*, **16**, 3761-3812. doi:10.5194/acp-16-3761-2016.