Jule Charney

Chapter 17. Charney's Puzzle: How Sensitive is Earth?

Jimmy Carter was concerned about growing United States dependence on oil from the Middle East. On 18 April 1977, three months after assuming the Presidency, he delivered an *Address to the Nation on Energy* while sitting in the White House, wearing a sweater, with the White House thermostat turned down. Oil and gas supplies are limited, Carter said, so "we need to shift to plentiful coal" and "we must start now to develop the new, unconventional sources of energy that we will rely on in the next century." Carter also put solar panels on the White House, but fossil fuels were, and still are, the source of most energy in the United States and the world as a whole.

Conventional fossil fuels are oil, gas and coal extracted from the ground without unusual energy expenditure. Unconventional energies include tar sands, "tight" gas and oil deposits extracted by high pressure hydraulic fracturing (fracking) of rock formations, and coal gasification. It takes energy to extract these fuels, so they are more carbon-intensive than conventional fossil fuels, that is, they emit more CO_2 per unit of useful energy.[1] Most unconventional fossil fuels also produce local and regional pollution, including expanding plumes of polluted groundwater.

"We've always been proud of our leadership in the world. Now we have a chance again to give the world a positive example," President Carter concluded. Indeed. United States actions matter. Between 1915 and 1950 the United States emitted 45 percent of global fossil fuel emissions, with almost 200 other nations emitting 55 percent. Emissions from other nations climbed, but during Carter's presidency U.S. emissions were still more than one-quarter of global emissions.

Carter's Science Adviser, Frank Press, requested advice from Philip Handler, President of the National Academy of Sciences in 1979. The charge to the Academy was broad, ending:

> ***"To summarize in concise and objective terms our best present understanding of the carbon dioxide/climate issue for the benefit of policymakers."***

That charge was a license to provide broad advice on energy policy. It was clear that President Carter needed advice on climate. Fourteen years had passed since the 1965 PSAC CO_2 study headed by Roger Revelle. Understanding of climate change had advanced. The Academy committee was a stellar group of atmospheric physicists, meteorologists and oceanographers: Akio Arakawa, D. James Baker, Bert Bolin, Jule Charney, Robert Dickinson, Richard Goody, Cecil Leith, Henry Stommel and Carl Wunsch. Charney, a pioneer in dynamic meteorology and climate physics, with an infectious enthusiasm for the science, was a perfect chair for the study.

Charney focused the Academy study on climate sensitivity. A limited task was consistent with the brevity of the study – the group met for five days, 23-27 July 1979 – and Charney's choice of objective was ingenious. He focused on the most fundamental quantity and produced a framework for thinking about climate change that became more useful over time.

Charney defined an idealized gedanken problem (thought experiment): how much will global temperature increase if CO_2 in the air is doubled from its preindustrial amount, estimated as 280 ppm (parts per million)? As one idealization, Charney asked only for the equilibrium response, that is, the eventual response after energy balance is restored, with Earth emitting to space the same amount of energy that it receives from the Sun. As a second idealization, Charney kept the area and volume of ice sheets fixed. Via his brilliance, and perhaps some good fortune, Charney thus avoided pitfalls that could have limited the long-term relevance of the Academy study. These very pitfalls plagued later efforts of the United Nations to understand the climate problem, so they warrant mention here.

Pitfall number 1 is the delay in climate response caused by the ocean's thermal inertia. Charney could have chosen to focus on time-dependent climate change during the coming decades and century, which was probably the main interest of Jimmy Carter and Frank Press. If the group had focused on the world's transient response to increasing CO_2, their estimates would have soon gone awry, as their only comment about ocean delay was "we believe it is quite possible that the capacity of the intermediate waters of the oceans to absorb heat could delay the estimated [equilibrium] warming by several decades." Within a few years, it was realized that this delay is not a simple function of ocean physics. Instead, the delay depends strongly on climate sensitivity itself, and amounts to centuries, not decades. One implication of the long delay is that heat is now continuously being pumped into the ocean, which in turn affects pitfall number 2.

Pitfall number 2 is the response of ice sheets to human-made global warming. The stability of global sea level for the past several thousand years may have encouraged Charney to believe that changes of the ice sheets on the century time scale will be small. But we now realize that such an assumption is unlikely. Human-made climate forcing dwarfs any natural climate forcing in at least the past million years. Ice sheet response in a century is uncertain and depends on future climate forcings, but potential sea level rise may be the greatest threat that humanity faces.

Charney avoided both climate pitfalls. His genius was to address climate sensitivity in a way that included only feedbacks that could be addressed in climate models available in 1979. When later analyses defined an all-feedback "Earth system sensitivity," including ice sheet changes, Charney's climate sensitivity remained as the core of this expanded Earth system sensitivity.

Climate feedbacks were the central topic in Charney's study. Climate sensitivity would be an easy problem, if there were no climate feedbacks. Earth's thermal (heat) radiation to space, to a good approximation, is that of a black surface at temperature T = −19°C, the temperature needed for a perfect radiator to emit the radiation that Earth absorbs from the Sun. Doubled atmospheric CO_2 ($2\times CO_2$) reduces Earth's heat radiation to space by about 4 W/m^2, i.e., $2\times CO_2$ is a forcing of 4 W/m^2. With more energy coming in than going out, Earth warms until energy balance (equilibrium) is restored. The temperature rise required to emit 4 W/m^2 more radiation to space is given by the Stefan-Boltzmann equation (Chapter 10: Runaway Greenhouse). The answer is 1.2°C (2.2°F) warming would restore energy balance, if there were no feedbacks.

Syukuro Manabe estimated climate sensitivity using a 1-D model,[2] a model with idealized sector geography,[3] and a 3-D global model.[4] Charney was happy that our model gave a different global warming than Manabe's global model, because comparison of the models allowed Charney to examine how different assumptions about physical processes affect simulated climate sensitivity. Charney arranged for discussions with Manabe and with me; in my case it was via a telecon; Charney said that I was "a voice from a black box" on their meeting room table.[I] Manabe's global model yielded 2°C global warming for 2×CO_2, while our model yielded about 4°C.

Both models had realistic CO_2 radiative forcings, so the different responses reflected differences in the major climate feedbacks. It took three years for us to analyze quantitatively the feedbacks in our model, as we will discuss in Chapter 23 (Global Habitability and Exxon). Here we only note that there are three main feedbacks in our climate model: water vapor, ice/snow albedo, and clouds. All of these are amplifying feedbacks in our model. In a warmer world the atmosphere holds more water vapor (a strong greenhouse gas), the area of ice/snow decreases (exposing a darker surface that absorbs more sunlight), and, at least in our model, cloud cover decreases slightly (making the planet slightly darker).

Water vapor and ice/snow feedbacks were reasonably well understood at the time of the Charney report. In our model, those two feedbacks together increased the 2×CO_2 response from 1.2°C to 2.4°C (Chapter 23). Manabe's model kept clouds fixed, so, if we take the climate response as being the result of the three major feedbacks, we would say that the water vapor and ice/snow albedo feedbacks increased the 2×CO_2 response of Manabe's model from 1.2°C to 2.0°C. Other versions of Manabe's model were more sensitive, so the Manabe and GISS models were in good agreement that the first two feedbacks amplify climate sensitivity substantially.

Cloud feedback is the major uncertainty, and understandably so, because even a small decrease of cloud cover with global warming, as occurred in our model, can amplify global warming a lot. Forty-five years after Charney's report the cloud feedback continues to be the big uncertainty. If climate models were our only tool to evaluate climate sensitivity, the answer would be elusive because the result is so sensitive to small cloud changes, which are difficult to simulate. Fortunately, we will find that real world observations provide ways to constrain the models.

Charney's famous summary statement in his 33-page report[5] is: "…we have tried but have been unable to find any overlooked or underestimated physical effects that would reduce the currently estimated global warmings due to a doubling of atmospheric CO_2 to negligible proportions…" Given the primitive status of the climate models that he relied on, Charney concluded only that the idealized equilibrium response to 2×CO_2 is 3°C ± 1.5°C global warming. He later clarified the uncertainty range as meaning that there was at least a 50% chance that true climate sensitivity was in the range 1.5-4.5°C for 2×CO_2.

Global warming of 3°C may not seem so great at first glance. However, observations and models concur that warming over land is about half again as large as global average warming, so global warming of 3°C is about 4.5°C warming over land, which is 8.1°F. Such warming would make Earth at least as warm as in the Early Pliocene, five million years ago, when sea level was 15-25

[I] I was glad that the Academy workshop occurred while I was running our first Summer Institute on Climate and Planets. I was only beginning to understand feedbacks in our model and was not eager to reveal my ignorance before Charney's stellar committee. Besides, there was no need: a member of Charney's team, Bob Dickinson, who was recognized to be a genius, knew everything that I knew about climate feedbacks, and much more.

m (50-80 feet) higher than today. Rapid passage from today's climate toward that of the early Pliocene, we will later conclude, would be a great threat to civilization. The final sentence of Charney's summary was "It appears that the warming will eventually occur, and the associated regional climatic changes so important to the assessment of socioeconomic consequences may well be significant, but unfortunately the latter cannot yet be adequately projected."

The Preface to the Charney report, written by Verner E. Suomi, Chairman of the National Academy of Sciences Climate Research Board, states "The conclusions of this brief but intense investigation may be comforting to scientists but disturbing to policymakers. If carbon dioxide continues to increase, the study group finds no reason to doubt that climate changes will result and no reason to believe that these changes will be negligible. The conclusions of prior studies have been generally reaffirmed. However, the study group points out that the ocean, the great and ponderous flywheel of the global climate system, may be expected to slow the course of observable climatic change. A wait-and-see policy may mean waiting until it is too late."

Suomi thus noted the fundamental policy problem: the delayed response of climate. The public will not clamor for action until they see significant effects, but by then much greater effects will be in the pipeline, effects that may be very difficult to avoid. Were we, the scientific community, clear enough, strong enough, in our warnings to policymakers? Given the last line of the charge to NAS: *"To summarize in concise and objective terms our best present understanding of the carbon dioxide/climate issue for the benefit of policymakers"* and given the energy policies that the Carter administration was pursuing, was stronger, clearer, advice about the implications of alternative energy policies not in order?

For my group, the chance to interact with Charney was a privilege and good fortune. Charney, treated us with the respect accorded more established researchers, despite the coarse resolution and unpublished status of our climate model. Perhaps Charney's approbation played a role in the decision of NASA to fund both our CO_2 and cloud research proposals. We received $100K funding immediately for the CO_2 research and approval for $230K per year beginning the next fiscal year. The cloud research also was funded, beginning at a level of $100K per year.

We now had a clear justification for our research focus on long-term climate change and I had ammunition, in case Jastrow queried about the absence of work on farmers' forecast. The next two years were probably the best years of my research career. We had money for students and research associates, and I worked assiduously on a paper on CO_2 and climate. I wanted to say more than the Charney report had said about expected global warming and its implications. Before any altercation with Jastrow about research objectives could occur, a referee intervened: the NASA Inspector General. He altered our courses, both Jastrow's and mine.

[1] Bruckner, T and I.A.Bashmakov. Energy Systems, in Climate Change 2014, IPCC WG III, 2014.
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[3] Manabe S, Wetherald RT. The effects of doubling the CO_2 concentration on the climate of a general circulation model, *J Atmos Sci* **32**, 3-15, 1975
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[5] Charney J, Arakawa A, Baker D *et al*. *Carbon Dioxide and Climate: A Scientific Assessment*, Natl Acad Sci, Washington, DC, 33 pp, 1979