Fig. 34.1. Eruption of Mount Pinatubo in 1991 (David Harlow/U.S. Geological Survey)

This chapter still needs some revisions suggested by Carolyn Harris

Chapter 34. Research Education

"Research education" is what we gathered to talk about, even though I didn't use that phrase until later. I was getting ready to rush off to the first "roundtable" meeting in Senator Gore's office in December 1989. The roundtable agenda was a series of questions, mostly about big national and international Earth science programs. The last question on the three-page agenda was: "Are there any innovative ways to tie science education into the Mission to Planet Earth program? Can students participate, help and learn?"

A few GISS staff members and I discussed that around our conference table. For example, one idea was to have students in a science class measure and record the circumference of trees at a fixed height. The same class could repeat the measurements the next year and use the observed changes to estimate carbon storage in the trees as they grow. The aim was to get them to make real measurements and understand scientific objectives.

Gore's first roundtable led to our Climsat proposal. I wondered: why not get high school students to work with Climsat data? Planned measurements were fundamental: sunlight reflected by Earth to space and heat radiation emitted by Earth (Fig. 31.1). The data include complicated polarization, but also simple brightness of the area observed. Spatial resolution of the instruments is coarse – the field of view about 8 kilometers (5 miles) in diameter – so the amount of data is small enough to transmit to schools. Students could produce global maps.

It is easy to think of dozens of projects for high school science students. Students could examine seasonal changes of reflected radiation. In polar regions, sea ice would grow in one hemisphere while shrinking in the other. Continental brightness and color would change in the spring as plants grew and in the fall as vegetation decayed. The data would also reveal year-to-year changes, raising questions about whether the changes are natural or human-made. These topics include the sort of research that the most senior scientists are working on.

The next few years were a struggle at GISS, as the Climsat mission remained on hold. Mother Nature, however, had her own timetable and would be about her business.

We were waiting for a big volcanic eruption. Anticipation was fueled by an event three decades earlier: Mount Agung, on the island of Bali, Indonesia, erupted on 16 March 1963. I was 21 then, in my last undergraduate year. Later that year Prof. Satoshi Matsushima suggested that we observe the eclipse of the Moon that would occur in December 1963 – Andy Lacis and I were budding graduate students. It was a great opportunity for "research education." We were just learning to use a telescope and write computer programs (Chapter 5).

Fifteen years later, in 1978, we used data from the 1963 Agung eruption to test our first climate model. The hot plume of a large volcano (Fig. 34.1) provides a thermal lift that injects the gas and dust into the stratosphere to heights as great as 30 kilometers (20 miles). There, depending upon the direction of stratospheric winds, the gas and aerosols can be spread around much of the world. We estimated the opacity of the Agung aerosol layer from observations of astronomers at several observatories around the world, based on how much the aerosols reduced the intensity of starlight passing through the aerosol layer. The effect of the Agung aerosols in our first climate model (Chapter 16) was to cool Earth's surface – because less sunlight reached the ground – and warm the stratosphere – because the aerosols absorb both solar radiation and Earth's heat radiation. Observations following the Agung eruption showed these cooling and warming effects, but the magnitudes were not much larger than natural variability.

So, we were waiting for a bigger eruption, one that could produce a clear climate change signal that stood out above the noise of natural climate variability. Pinatubo did not disappoint.

Mount Pinatubo, in contrast to Mount Agung, erupted in the space age. Both NASA and NOAA had satellites in space that might be able to measure and track the Pinatubo gas and aerosols. On 11 September 1991, three months after the Pinatubo eruption, Miriam Baltuck and Lou Walter of NASA organized a meeting on Pinatubo in Washington, which I attended.

NASA had an instrument, the Stratospheric Aerosol and Gas Experiment (SAGE), that was launched on a small satellite in 1984 and was still functioning in 1991. However, no SAGE data were available yet: SAGE was partially blinded by the huge Pinatubo aerosol amount. When SAGE tried to observe the Sun through the aerosol layer, it could not detect the Sun – the aerosol layer was too opaque! They needed more time to analyze the measurements.[1]

Fortunately, Larry Stowe of NOAA was able to estimate Pinatubo aerosol amount from weather satellite images. Such images, which look straight down through the aerosol layer, include light reflected by the ground and clouds. The accuracy of aerosol information from such images is thus limited, but I thought that it was good enough for an interesting climate model test.

On the flight back to New York – this was still in the era when flying was unencumbered by security, so flying was faster than the train – I made plans for numerical climate experiments. The natural climate experiment that the Pinatubo eruption provided would be most powerful if we made a prediction of climate effects before they actually occurred.

I had been GISS Director for 10 years at that point. Administrative responsibilities made it hard for me to do hands-on research, so I had long since given up computer programming. However, Larry Travis generously agreed to take much of the administrative burden as my deputy. So, I had some time for climate experiments, but I would need help with the programming.

I needed help from two people to work quickly. First was Makiko Sato. Makiko was my student in the 1970s when she worked on light scattering by Jupiter, but I abandoned planetary research. For the past decade she had worked mainly with Andy Lacis and with David Coffeen on Voyager Jupiter studies, but recently she had worked on a data set for stratospheric aerosols.

Makiko is an excellent scientist who can understand the many types of data needed in climate studies, and, almost as important, she is artistic. We developed a collaboration in trying to present climate data as clearly as possible. Clear presentation of data spurs understanding of the science. Makiko became an essential collaborator in all of our climate studies.

Reto Ruedy was the other person we needed. Gary Russell discovered Reto when Reto was a visiting mathematics instructor at Columbia University. On Gary's recommendation, we hired Reto to work on the climate model. While Gary worked on developing an improved model, Reto worked with Makiko and me in running numerical experiments with the existing model.

We ran the global climate model including the estimated Pinatubo aerosol amount, wrote a paper, and submitted it to *Geophysical Research Letters* on 3 October 1991. The editors saw the need for rapid publication. The paper[2] was quickly refereed and accepted for publication on 17 October. This was the first step in our Pinatubo investigation, which continued for several years.

Meanwhile, we were fighting the Climsat battle. On 16 October I was in the office of the Goddard Director, John Klineberg, when he informed me that "the administration" had decided to reject the Climsat mission and return to the government the $15M that Congress had allocated for Climsat. It was a moment that I won't forget. As Klineberg left the conference room, he turned and said "look, Jim did not eat his cake, ho ho ho." (A secretary had earlier brought in saucers with pieces of someone's birthday cake.) Another participant in the meeting, an engineer, looked at Klineberg and then at me, with a puzzled look on his face.[3]

It was a setback, but the Climsat concept was too good to give up on. Data from a small satellite could be packaged for transmission to schools – Climsat data would make a great contribution to science education. But what could we do prior to the existence of a Climsat mission?

Young people can understand research best by getting involved in it. If students and teachers work with scientists on their top research problems, the activity will be the researchers' priority. Recognized significance of the work will capture the interest of the students and educators.

Our idea was to get students and teachers to work with us on our research, mainly in the summer, and then, in some way, take this experience back to their classrooms. Easier said than done! I needed someone who understood teaching and had the will and energy to take on an ambitious project for which we had no funding.

Carolyn Harris walked into my office in the fall of 1993. Carolyn had run a program in a Washington, DC high school that involved students and teachers in problem solving motivated by NASA missions. She was starting work on a graduate degree at Columbia Teachers College.

I hired her on the spot. I had no education funding, but paid her from our science research budget. Thus began our Institute on Climate and Planets (ICP) program, which would dominate our summers for a decade. Students and educators worked together on one of several teams, each headed by a NASA scientist.

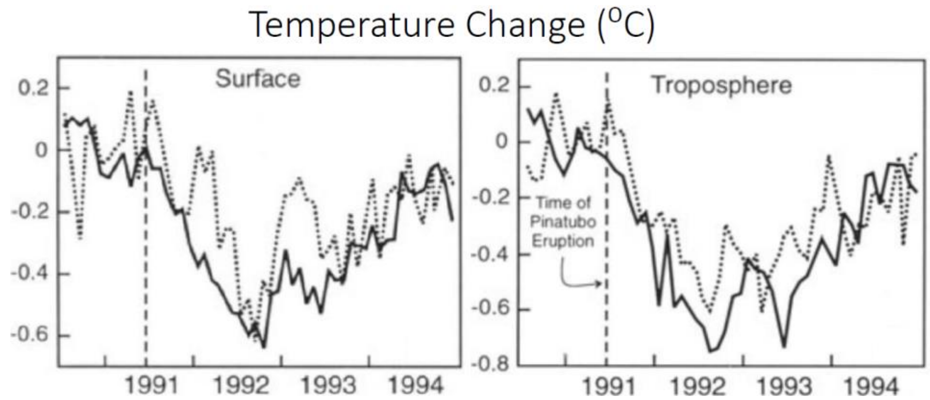

Fig. 34.2. Predicted (solid line) and observed temperatures of Earth's surface and troposphere.[4]

We squeezed a few dozen students and teachers into our small institute each summer. Some students and teachers came in during the school year to continue participation. Bob Harris, a NASA science program manager, supported ICP from his science budget for several years, while we attempted to obtain long-term funding from NASA education offices.

My research team was initially named "Pinatubo."[5] The Pinatubo team included two students and one or two teachers from each of two high schools (Far Rockaway and Bronx Science) and one college (York) in the City University system. Our team aimed to produce publishable research results.

First, we compared the most accurate available data on Pinatubo aerosols with the quick estimate that I used in 1991 based on NOAA weather satellite images. We found that I had overestimated the aerosol opacity by about 20 percent.

Second, we compared observed temperatures with the model's predictions. As observations of Earth's temperature came in month-by-month following the Pinatubo eruption, it had seemed that the model was wrong.[6] Even after one year, there was no cooling. However, that year coincided with an El Niño. As the El Niño faded, the volcanic aerosol effect took over and the surface cooled by almost the predicted amount (Fig. 34.2). Also, the troposphere cooled and the stratosphere warmed, in good agreement with the predictions. The fit of observations and model would have been even closer, if I had not overestimated the forcing by 20 percent.

Third, we showed that we got the right answer for the right reason. Although satellites cannot measure Earth's absolute energy imbalance accurately, they can define changes in Earth's radiation budget over a few years. The satellite data showed a reduction of Earth's radiation balance – less sunlight absorbed than heat energy emitted to space – by 2-3 watts per square meter following the Pinatubo eruption, in agreement with the climate model.[7]

So, the Pinatubo volcanic eruption provided a significant climate model test for a sudden, large climate forcing. The next IPCC (Intergovernmental Panel on Climate Change) report[8] highlighted this result as one basis for confidence in the capability of climate models.

However, the short-lived Pinatubo climate forcing was a limited test. Greenhouse gas climate forcing, in contrast, builds slowly over decades. On long time scales, exchange of ocean surface water with the deep ocean becomes important. Also, there are other competing forcings that may be important, and climate can fluctuate without any forcing. So, our ambitions increased.

We changed our team's name to "Forcings and Chaos" when our research focus changed. Our objective was to investigate the role of different climate forcings in causing climate change in the 18-year period 1979-1996, and to compare forced climate change with chaotic variability. By the latter, we meant unforced climate fluctuations that are essentially unpredictable.

Why did we pick 1979-1996 to study? Several climate forcings were measured accurately in that period. The Nimbus-7 satellite, launched in late 1978, measured stratospheric aerosol and ozone changes. Solar irradiance began to be measured, from a different satellite, at almost the same time, and accurate ground-based measurements were available for the well-mixed greenhouse gases such as carbon dioxide and methane.

We learned one important thing in our study. We found it by accident – the result of an error.

We made several runs of the climate model, adding in the several climate forcings one-by-one. When all the known forcings were included, the calculated temperature change at Earth's surface and throughout the atmosphere was in good agreement with observations. "Great," we thought.

Then we realized that we had made an error. The radiation calculation was slightly different in the climate model runs with added forcings, as compared to the radiation in the long model control run that was used to create initial conditions for experiment runs. That change caused the model to be out of energy balance at the beginning of the experiments by 0.65 W/m^2.

After we corrected the programming error, the simulated climate did not agree with observations. Contrary to observations, the model yielded no significant global warming trend. Cooling by aerosols and ozone depletion offset the warming by other greenhouse gases.

Then the implication dawned on us. Earth must have been out of energy balance by about 0.65 W/m^2 in 1979. We called it a "disequilibrium forcing." Humans had added greenhouse gases to the air rapidly in the 2-3 decades leading up to 1979, but because of the ocean's large thermal inertia, Earth's temperature had not fully responded. Earth was out of energy balance in 1979, more energy coming in than going out. During 1979-1996, two negative forcings, Pinatubo and ozone depletion, approximately balanced additional positive forcings from increasing CO_2, CH_4, N_2O and CFCs, but warming continued because of the overall energy imbalance.

We had obtained an approximate measure of Earth's energy imbalance, by accident. That imbalance was not surprising. The imbalance is directly related to the warming "in the pipeline" that we discussed at the Ewing Symposium.

The imbalance is tiny when compared to the total energy coming from the Sun. However, 0.65 W/m^2 is large from a climate change perspective. A climate sensitivity of 3°C for doubled CO_2, corresponds to 0.75°C per W/m^2. Thus, an imbalance of 0.65 W/m^2 implies that a warming of about 0.5°C was still "in the pipeline." Such additional warming would almost double the actual warming that had occurred during the century up to 1996.

As long as Earth is out of energy balance – with more energy coming in than going out -- we must expect Earth to keep getting warmer. Within several years, Earth's energy imbalance would become the principal focus of my research. However, the "Forcings and Chaos" team was focused on a different objective: how much of observed climate change during 1979-1996 was driven by climate forcings as opposed to noise – unpredictable natural climate variability?

Most people probably have a predilection for deterministic explanations of climate variations. However, climate varies chaotically without any forcing. Indeed, the climate system exemplifies "complexity," a combination of deterministic behavior and unpredictable variations with complex dynamical patterns that never precisely repeat. This behavior results from the basic laws (equations) that govern the dynamics.[9] However, the same laws limit the behavior, and numerical simulations can yield a range of possible outcomes and a probability distribution.

We investigated that topic by making several models runs, each with the same climate forcing but slightly different initial atmospheric temperatures. We realized that the model was an imperfect tool for this purpose – for example, it did not produce realistic El Niños. However, the year-to-year weather fluctuations were nevertheless reasonably realistic.

We found in the modeled temperature change a clear signature of climate forcings that exceeded the unforced variability. Specifically, the volcanic aerosols caused measurable stratospheric warming and surface cooling, and ozone depletion caused a long-term trend of stratospheric cooling and a steepening of the vertical temperature gradient in the troposphere. Observations of the real world supported the reality of these effects.

When we sent our "Forcings and Chaos" paper[10] with student and teacher co-authors to a journal, the editor invited us to write an introductory article describing how we worked with students and teachers. This was a chance to describe our "research education" objectives.[11]

We thought that research laboratories could help improve science education in schools and prepare students with skills they will need in the workforce. We wanted to provide females and underrepresented minorities an opportunity to be involved in science early enough in their schooling to make a difference in career motivation. We might also help more of the public appreciate the way scientific understanding advances via iterative research.

Carolyn Harris's work with the Institute on Climate and Planets was widely acclaimed. Almost all of the student participants went on to attend and graduate from college. A brief, revealing discussion of the program by several of its graduates is available.[12]

The Institute on Climate and Planets was born as an adjunct to our planned Climsat project. Climsat measurements would be analogous to Keeling's CO_2 monitoring, but richer in several climate forcings and feedbacks. The interferometer data yield atmospheric temperature, so it would monitor climate as well. The measurement data is so fundamental that the best students may be able to make discoveries, consistent with our aim to involve students in research.

The cost of a Climsat project, had it been approved, would have been of the order of $100 million, with continuing annual data processing costs of several million dollars per year. A project on that scale could support preparation of a data stream for schools and development of suggested research pathways and tasks for students and teachers.

With my failure to achieve the Climsat mission, we had to struggle each year to find support for the ICP program at GISS. When Bob Harris (no relation to Carolyn) left NASA, we lost our main source of funding from NASA Headquarters.

Fig. 34.3. Carolyn Harris (upper left) and several ICP high school teachers and students.

If we could get a government position for Carolyn, that would reduce the ICP cost and likely save the program, buts odds for that were not good. After six civil service hires in 1984-1987, I was allowed to hire only one scientist (Cynthia Rosenzweig) in the next 10 years, while losing two (Michael Prather and Inez Fung) to prestigious universities. That long hiring drought was intentional – a response to my criticism of the Earth Observing System.

Carolyn Harris' talents could not be denied. NASA Administrator Dan Goldin, who came to speak with the students, was impressed by them and their presentations. Most of the students were underrepresented minorities, about half of them female, in contrast to the NASA science and engineering workforce, which was mostly white male.

I appealed to the Goddard Director for a civil service position. Goddard offered Carolyn a civil service job, but she would have to report to an education official at Greenbelt, not to me, and her work would need to fit within the framework of their education programs. Their education programs did not appeal to her; she had her own ideas. She declined the civil service position.

The Institute for Climate and Planets was an affair of the heart for both of us. We struggled for a few years trying to keep ICP on life support. Eventually Carolyn moved back to Washington.

It seems to me that to do something innovative, you need to be a bit of a maverick. I don't think that Carolyn caught that disease from me. It was already in her blood.

I was about to get into bigger trouble. I had been working quietly on climate modeling for a decade with Reto and Makiko – a welcome change from the hullabaloo around my 1988 and 1989 testimonies to Congress. We wrote papers about the mechanisms of climate change and we continually tracked climate change and the forcings that drive climate.

The problem was that our findings led me to an unusual perspective, one that would not sit well with the powers that be. Polarized political positions about climate had developed. The trouble with my perspective was that it would force me to criticize both the left and the right.

So be it. We would publish what we thought and let the chips fall where they may.

Chapter 35. Dangerous Interference

The 1992 Framework Convention on Climate Change made sense. Nations agreed to take actions on greenhouse gas emissions to avoid dangerous human-made interference with nature.

The 1997 Kyoto Protocol, the instrument of the Framework Convention, was nearly worthless. It didn't require anybody to do much of anything that they wouldn't be doing anyhow.

In conjunction with the Framework Convention an Intergovernmental Panel on Climate Change (IPCC) was organized by the United Nations to assess the climate science status every 5-6 years.

It was agreed that the scientists would not get into the policy implications of the science – that would be left to the policymakers. It made sense, but it was a constraint that I had never felt or adhered to. In our first climate paper, in 1981, we concluded that if we burned all the coal, the world would lose its coastal cities – including more than half of the large cities in the world. That seemed to be unacceptable – so I argued that we needed to phase out coal emissions.

We – Makiko and I – liked to continually track real-world data. Global temperatures. Greenhouse gas amounts. Climate forcings. And we calculated expected climate change for comparison with observations. That's how physics works; it's a description of the real world. You check theory against observations. As data sets become longer, the picture becomes clearer.

In 2000 we published *An Alternative Scenario,*[13] which annoyed the White House and many liberals. I wanted to draw attention to climate forcings other than CO_2. Also, our Alternative Scenario would provide an estimate of how fast the annual growth of the human-made climate forcing must decline to avoid dangerous global warming. Curiously, the IPCC did not attempt to estimate what changes were needed to avoid "dangerous" climate change.

We pointed out that CO_2 was only half of the forcing that drove global warming. The rest was from methane (CH_4), chlorofluorocarbons (CFCs), nitrous oxide (N_2O), ozone (O_3), and black carbon aerosols ("black soot"[14]). We suggested near-term emphasis on reducing air pollution and non-CO_2 greenhouse gases, while developing carbon-free electricity for the long-term.

"Such a focus on air pollution has practical benefits that unite the interests of developed and developing countries," we noted. Future CO_2 emissions were expected to come mainly from developing countries. Pollution effects were already staggering. Kirk Smith estimated that 270,000 Indian children were dying each year from acute respiratory infections caused by air pollution.[15] The World Health Organization later found that air pollution deaths in India were more than a million per year. A similar number of air pollution deaths were occurring in China.

The *Washington Post* published a detailed, favorable, editorial (Hot News on Global Warming[16]). Our paper was the "Editor's Choice" and summarized accurately in *Science* on 8 September. However, *Nature* published a "news" article in which every scientist interviewed criticized our paper. *Nature* declined to publish my objections. The *Nature* "news" article stated that we "assumed" low growth rates for CO_2. In fact, we said that low growth rates required technological cooperation between developed and developing countries.

Steve Schneider invited me to write an essay in *Climatic Change* to clarify this story. I titled it *A Brighter Future*.[17] Its penultimate paragraph was the summary: "Global warming is a long-term problem. Strategies will need to be adjusted as we go along. However, it is important to start now with common-sense economically-sound steps that slow emissions of greenhouse gases, including CO_2, and air pollution. Early emphasis on air pollution has multiple immediate benefits, including the potential to unite interests of developed and developing countries. Barriers to energy efficiency need to be removed. Research and development of alternative energies should be supported, including a hard look at next generation nuclear power. Ultimately strategic decisions rest with the public and their representatives, but for that reason we need to make the science and alternative scenarios clearer."

Wally Broecker called. He said that I was in trouble. I should give a seminar at Lamont to explain our paper. Concern was widespread, he said, including Vice President Al Gore's office, that our paper aided opponents of the Kyoto Protocol. Gore had a major role in negotiating the Protocol, which aimed to constrain growth of CO_2 and five other gases, but not ozone or soot.

Failure to include these pollutants was not the biggest problem with the Protocol. The problem was failure to address future emissions of developing countries including China and India. These countries needed massive amounts of energy to raise living standards. There would be mutual benefits in cooperation to develop clean, carbon-free energy.

On 11 September 2000 I walked up a hill with Wally toward the building at Lamont where I was to give a seminar. Wally didn't call me "Buster" this time, but he made clear that I was on trial. Gore's top science policy people were scheduled to visit Lamont and Columbia. Given the abilities of Columbia Executive Vice Provost Michael Crow, who, Wally said, "could run General Motors," Wally[18] anticipated increased support for Columbia and Lamont, if Gore were elected President. My response was: "are you a great grandfather yet?"

My first viewgraph at the seminar was an MSNBC news article that described me as the "grandfather of global warming." I denied that, because Tyndall explained the global warming story 150 years earlier. My second viewgraph was a photo of two-year-old Sophie, proving that at least I was a real grandfather. And, I pointed out, Wally was a real great grandfather.

When the Supreme Court elected George W. Bush, there were a lot of long faces, but none as long as Wally's. Wally was right about Mike Crow. Crow could run GM. Crow soon left Columbia for Arizona State University, which he transformed into an exceptional university.

The hullabaloo about our paper can be explained with a simple bar graph for human-made climate forcings[19] in 2000 relative to preindustrial conditions (Fig. 35.1). CO_2 and non-CO_2 greenhouse gas (GHG) forcings were each about 1.5 watts per square meter (W/m^2).[20] Aerosol forcing[21] is the net effect of all aerosols, which range from non-absorbing (sulfates), to slightly absorbing (desert dust, organic carbon), to strongly absorbing (black soot).

Here's the interesting part. Aerosol cooling approximately balanced warming by either the CO_2 or the non-CO_2 GHGs. It was common to say that aerosol cooling offset non-CO_2 GHG global warming, so CO_2 could be viewed as the basic cause of global warming up to year 2000.

Our paper noted that aerosols and CO_2 are mainly products of fossil fuel burning, so, for the sake of understanding past climate change, it makes sense to lump the aerosols with the CO_2 rather

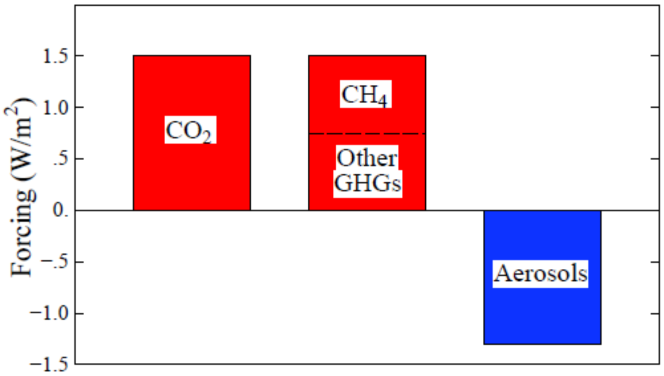

Fig. 35.1. Human-made climate forcings circa 2000.

than with the other greenhouse gases. In that case, the observed warming can largely be blamed on the non-CO_2 gases, mainly CH_4, N_2O and CFCs (chlorofluorocarbons)!

Is that just semantics? I don't think so. This perspective helps explain why global warming began to rise above the noise when CFC forcing became large. My basic point was that we must look at all data with an open mind. As Richard Feynman says: "The only way to have real success in science…is to describe the evidence very carefully without regard to the way you feel it should be. If you have a theory, you must try to explain what's good about it and what's bad about it equally. In science you learn a kind of standard integrity and honesty."[22]

It's important to question authority. The authority here is the IPCC. All the extant IPCC scenarios led to large climate change. Why not define a scenario that keeps global warming under 2°C – a level of warming that was widely considered to offer a safety guardrail – and then explore what policies it requires?

Makiko and I aimed to make a figure with a clarity that nonscientists, including policymakers, could appreciate. The result was Fig. 35.2, which shows the amount of greenhouse gas climate forcing added each year. Typical values in the late 20th century are about 0.04 W/m^2 per year, which doesn't sound like much, but in 100 years its 4 W/m^2, equivalent to doubled CO_2.

Fig. 35.2 reveals a decline from 0.05 to 0.03 W/m^2 at about 1990 in the annual growth of the greenhouse gas climate forcing. In part this was testament to the global community's success in slowing the growth of greenhouse gases via the Montreal Protocol. Also, the growth of methane sources had slowed and CO_2 growth slowed temporarily, this latter reduction at least in part a result of the temporary global cooling caused by Pinatubo aerosols.

We defined the Alternative Scenario arbitrarily with a continuing slow decline of the growth rate of greenhouse gas climate forcing. Additional climate forcing in 2000-2050 is 1 W/m^2. With a continuing slower decline during the second half of the century global warming would be less than 2°C, assuming that climate sensitivity is about 3°C for doubled CO_2.

We hoped that our "colorful diagram" (Fig. 35.2) would be adopted by IPCC. An annual update would provide a status check on the real world each year. If real world data began to fall well above the Alternative Scenario line, it would show that a policy change was needed to avoid global warming that exceeds 2°C. Such a clear quantitative signal could serve as a useful, cold, hard, slap in the face to policymakers – unless scientists preferred not to annoy the politicians.

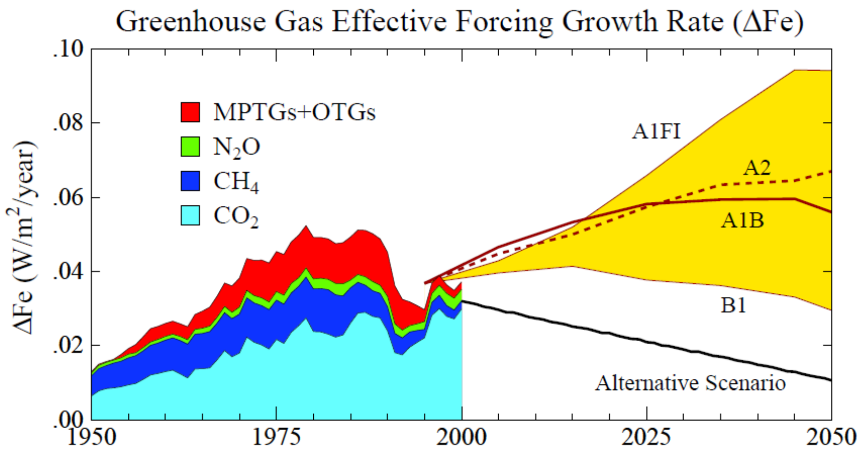

Fig. 35.2. Annual growth of greenhouse gas climate forcing. MPTGs = Montreal Protocol Trace Gases; OTGs = Other Trace Gases; Yellow area = IPCC scenarios for the future.

It was still possible in 2000 to follow a path approximating the Alternative Scenario. Growth of non-CO_2 greenhouse gases could be halted (or reversed) by reducing emissions to the rate (or less) at which gases are lost due to their finite lifetimes in the air. Policies may be required to achieve those reduced emission levels.

The main requirement for CO_2 was to move steadily toward abundant, affordable carbon-free electricity. It was well understood already in the 1980s that global CO_2 emissions in the 21st century would depend especially on China and India. It was also well understood that, if nothing were done to avoid it, the increased energy use in those countries would be mainly from coal.

Given that knowledge, what significant energy policy decisions were made? President Clinton, in his 1993 State-of-the-Union address announced “We are eliminating programs that are no longer needed, such as nuclear power research and development.” Germany, as host to the Conference of the Parties in 2001, used its position to exclude nuclear power as a Clean Development Mechanism[23] under the Kyoto Protocol. The energy industry in the United States, with government subsidies, invested heavily in hydro-fracturing to extract more oil and gas. Unconventional fossil fuel use is inconsistent with any scenario intended to avoid dangerous global warming. Governments and the fossil fuel industry pretended to be unaware of that fact.

Coal became the only viable power option for China and India. Unconventional fossil fuels also became mainstream. Without earnest policies to develop non-carbon energies, the Alternative Scenario did not have a chance. Accelerating global warming would soon be locked in.

I felt isolated. Most of the climate research community seemed to be involved in IPCC and support the Kyoto Protocol. However, in my view, the Kyoto Protocol did little to slow the growth of global fossil fuel CO_2 emissions. What we needed was not a slight slowdown in growth, but a phaseout of fossil fuel emissions at a pace indicated by the Alternative Scenario.

Predictably our discussion about the competing causes of climate change, as summarized in Fig. 35.1, was used by climate change deniers to muddy the waters about human-made climate change. Concern about such effects, in my opinion, was not a good reason for us to avoid raising the issues that we did. Our article also called for a long-term phaseout of fossil fuel emissions.

Many scientists criticized our paper, however, and it became hard for me to publish my perspective. I do not agree with the criticisms. There is a complex set of climate forcings and we need to understand them, including aerosols, for the sake of managing climate change. We should be able to explain that to policymakers and the public.

I decided to write an article[24] “Can we defuse the global warming time bomb?” that I made available on the web. I did not try to publish it in the scientific literature because I expected referees to try to force it to be more consistent with the IPCC perspective. It seemed to me that most referees were involved in IPCC and wedded to the Kyoto Protocol. However, expecting Kyoto to alter the world’s climate change pathway was wishful thinking, in my opinion.

In June 2003, I received an invitation from Jim Connaughton, Chairman of the White House Council on Environmental Quality (CEQ) to give a seminar.

Can we defuse the global warming time bomb? was the title for my talk. Consistent with the paper published on the web, I criticized both climate change deniers and IPCC. I made clear that the Alternative Scenario required phasing down fossil fuel emissions, which in principle could be accomplished via burning fossil fuels with carbon capture and storage but more likely would require more clean energy sources and energy efficiency. The discussion after my talk was friendly, but I did not get a feeling that they embraced everything I said.

In July 2003, Goddard Space Flight Center Director’s Office was abuzz about an upcoming visit by NASA Administrator Sean O’Keefe. O’Keefe, according to Mark Bowen, was a protégé of and golfing partner of Vice President Dick Cheney. O’Keefe had been NASA Administrator for 18 months, but this was only his second visit to Goddard and he would be receiving his first presentation on Earth Science. Goddard wanted to describe their Earth Observing System satellites. To their dismay, O’Keefe asked to first hear from me about climate.

I decided to base my talk on “Can We Defuse the Global Warming Time Bomb?” I sent a copy of that paper to Ghassem Asrar, NASA Associate Administrator for Earth Science. O’Keefe and Asrar arrived at Goddard together. Asrar pulled me aside to say that he had given the paper to O’Keefe after changing the title to something innocuous like “Climate Change” and making a few other changes to make the paper less incendiary.

O’Keefe, a pleasant, soft-spoken person, made only one comment during my presentation. When I showed a chart with title “What Determines ‘Dangerous Anthropogenic Interference’?”, O’Keefe interjected that I should not talk about “dangerous climate change,” because we did not understand climate change well enough to say what constitutes danger.

I did not argue the point. I tried not to offend him. I moved ahead quickly to discuss the potential of satellite observations to measure atmospheric aerosols.

Anxiety during O’Keefe’s visit was palpable. Goddard Director Alphonso Diaz and Associate Administrator Asrar feared that something might be said that upset O’Keefe. And I had played along with this by not objecting to O’Keefe’s interjection about “dangerous climate change.”

On the trip home, I felt bad. Why did I not object to O’Keefe’s comment? The United States, and all nations, agreed that we must avoid “dangerous anthropogenic interference” with climate.

That topic should be a prime objective of NASA Earth Science. We must talk about it. We, NASA, should be a source of unfettered technical expertise for the nation.

In one sense, Diaz and Asrar were right, though. There was no point to upset the Administrator. Nothing could alter O'Keefe's conviction. His conviction was Cheney's. We had no power to alter that. If the political party in power appoints agency heads based on their politics rather than their technical ability to lead the agency, we are in trouble.

But didn't we scientists have a responsibility to science like the physician's Hippocratic Oath?

The hullabaloo about the "alternative scenario" paper forced me to think more about the "dangerous" climate change issue and the responsibility of scientists. From my discussion in the "Can we defuse" document it's apparent that I was still trying to accept the constraint that scientists should describe the science as well as possible and leave policy to policymakers.

However, this did not work out well. Our alternative scenario paper described how fossil fuel emissions needed to decline to avoid 2°C global warming, but we did not attempt to define in practical terms what that meant for energy policies. As a result, policymakers could misstate implications of our paper for policy any way they liked.

Another problem was beginning to emerge. The level of global warming needed to constitute "dangerous" was probably a lot lower than most people assumed.

Earth's history shows that 2°C warming is a large climate change. That would make Earth much warmer than at any time in the Holocene, the period in which civilization developed, and at least as warm as the prior interglacial period, 120,000 years ago, when sea level reached about 6-9 meters (20-30 feet) higher than today.

Global warming had reached 0.8°C. More warming was 'in the pipeline' without additional growth of greenhouse gases. Energy infrastructure – such as power plants, steel mills, aircraft – won't be replaced quickly. This assures that atmospheric greenhouse gases will increase further. So, already it was getting to a point that 2°C warming would be difficult to avoid.

Shouldn't IPCC have been flapping its arms about danger? It was not. Perhaps that was because IPCC paid little attention to paleoclimate and focused mainly on global climate models.

In early 2004 the "dangerous" issue became clearer, thanks in part to papers by Steve Schneider and his student Michael Mastrandrea. They used the IPCC "burning embers" method to estimate the dangerous level of global warming. Their conclusions are described in Steve's "inaugural" paper[25] upon Steve's election to the National Academy of Sciences.

Using multiple "reasons for concern," each represented by a burning ember that turns red-hot at some level of global warming, they concluded that a 50 percent chance of exceeding the dangerous threshold was reached at global warming 2.85°C relative to late 20th century climate, which is 3.45°C relative to 1880-1920 temperature.

That answer comports with common sense. Warming of 2-3°C does not seem to be disastrous.

Fig. 35.3. Sophie, age 4, on kitchen floor drawing for her uncle, our son Erik. Sophie was our only grandchild for more than five years.

Paleoclimate data suggests that we should be crying out a warning. But who wants to be labeled "Chicken Little?" When not much happens in a year, or even a decade, people will say, "look, stupid Chicken Little!" However, Chicken Little is not talking about the next several years, he is concerned about time scales of a few decades, even centuries. Chicken Little has a tough job.

I did not want that job, but our grandchildren helped drag me into it. Grandchildren did not suddenly change my perspective. I was too busy. It was not until the government began to reveal its true allegiance that I began to see the bigger picture.

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[1] That problem does not occur with SAGE III, proposed as a potential 3rd instrument on Climsat, in addition to EOSP and MINT, because SAGE III adds a channel at 1.55 micron wavelength that can penetrate thicker layers.
[2] Hansen, J., A. Lacis, R. Ruedy and M. Sato, Potential climate impact of Mount Pinatubo eruption, *Geophy. Res. Lett.* **19**, 215-218, 24 January 1992.
[3] In my opinion, the cavalier rejection of Climsat was an example of how bureaucracies often treat innovative ideas: they stamp them out. Big NASA centers prefer billion-dollar missions. Decisions were made between a Headquarters manager and a NASA Center Director. This is a relationship that Noel Hinners described as too cozy.
[4] Hansen, J. and 30 co-authors, A Pinatubo climate modeling investigation, NATO ASI Series Vol. I 42, The Mount Pinatubo Eruption, Eds. G. Fiocco, D. Fua, G. Visconti, Springer-Verlag, Berlin Heidelburg, 1996.
[5] Other teams included "Aerosols," "Oceans," "Clouds," "Polarimetry," "Methane" and "Climate Impacts."
[6] McKibben, B.. James Hansen, Getting Warmer, *Outside Magazine*,116-120, 186-187, May 1993.
[7] Hansen, J., M. Sato, R. Ruedy, A. Lacis, K. Asamoah, S. Borenstein, E. Brown, B. Cairns, G. Caliri, M. Campbell, B. Curran, S. de Castro, L. Druyan, M. Fox, C. Johnson, J. Lerner, M.P. McCormick, R.L. Miller, P. Minnis, A. Morrison, L. Pandolfo, I. Ramberran, F. Zaucker, M. Robinson, P. Russell, K. Shah, P. Stone, I. Tegen, L. Thomason, J. Wilder, and H. Wilson: A Pinatubo climate modeling investigation. In *The Mount Pinatubo Eruption: Effects on the Atmosphere and Climate*, NATO ASI Series Vol. I 42. G. Fiocco, D. Fua, and G. Visconti, Eds. Springer-Verlag, 233-272, 1996.
[8] Houghton, J.T., et al., editors, Climate Change 1995, Summary for Policymakers, Fig. 14, Contribution of Working Group I to the Second Assessment Report of IPCC, Cambridge Univ. Press, Cambridge, CB2 1RP, U.K.
[9] Lorenz, E.N., Deterministic nonperiodic flow, J. Atmos. Sci., 20, 130-141, 1963.
[10] Hansen, J. and 42 co-authors, Forcings and chaos in interannual to decadal climate change, *J. Geophys. Res.*, **102**, D22, 25,679-25,720, 1997.
[11] Hansen, J., C. Harris, S. Borenstein, B. Curran and M. Fox, Research education, *J. Geophys. Res.*, **102**, D22, 25,677-25,678, 1997.
[12] https://www.youtube.com/watch?v=9MO_pI9gBHo
[13] Hansen, J., M. Sato, R. Ruedy, A. Lacis and V. Oinas, Global warming in the twenty-first century: an alternative scenario, Proc. Natl. Acad. Sci 97, 9875-9880, 2000.

[14] By black soot I refer to carbonaceous aerosols that are given off during incomplete combustion of fossil fuels, wood, field residue and cow dung. Most of the aerosols are invisibly small, so small that they enter the blood stream. They cause cardiac and pulmonary disease that kills more than 10,000 people per day.

[15] Smith, K., National burden of disease in India from indoor air pollution, *Proc.Natl.Acad.Sci*. **97**, 13286-93, 2000.

[16] Editorial board, Hot news on warming, Washington Post, 28 August 2000.

[17] Hansen, J.E., A brighter future. *Climatic Change*, **52**, 435-440, 2003.

[18] Wally long had his eye on GISS. When, during Goldin's administration, NASA considered having some NASA centers run as "institutes" by universities, Wally had my name replaced with David Rind's as GISS Director in the Lamont phone directory. I dismissed that as Wally being Wally. NASA decided against the "institutes" plan.

[19] These are effective forcings that include indirect effects, e.g., increased CH_4 (methane) causes tropospheric O_3 and stratospheric H_2O to increase, which enhances the CH_4 forcing. Hansen, J. and 44 co-authors, Efficacy of climate forcings, *J. Geophys. Res.* **110**, D18104, 2005.

[20] 1 W/m^2 does not sound like much, but remember that each watt will yield eventual global warming of about one degree Celsius (°C), or two degrees Fahrenheit. Fast-feedback climate sensitivity is about ¾°C per W/m^2, so a moderate allowance for slow feedbacks yields the rounded-off global warming response, 1°C ~ 2°F per W/m^2. But the slow feedback response requires at least centuries, which is why countermeasures can still save Sophie's planet.

[21] Aerosol forcing includes the effect of human-made aerosols on clouds, so the magnitude of the forcing is very uncertain, by at least 50 percent. The principal objective of our proposed Climsat was to measure this forcing.

[22] Richard P. Feynman, What do you care what other people think?

[23] The Clean Development Mechanism is intended to spur technology development in developing countries.

[24] Hansen, J., Can we defuse the global warming time bomb? *naturalScience*, posted Aug. 1, 2003.

[25] Schneider, S.H. and M.D. Mastrandrea, Probabilistic assessment of "dangerous" climate change and emissions pathways, Proc. Natl. Acad. Sci. 102, 15728-15735, 2005.