Chapter 23. Global Habitability and Exxon

Great expectations had a basis! Richard Goody and Mike McElroy had met with Hans Mark at NASA Headquarters. They were persuasive in their suggestion that NASA should lead a major program to assess global change. That was the origin of the Woods Hole workshop.

Goody chaired the Executive Committee. Other members were McElroy, Ichtiaque Rasool, Moustafa Chahine and John Steele. Steele was an intellectual leader of the oceanographic community and Director of Woods Hole Oceanographic Center. It was probably no accident that the Committee included a representative of West Coast NASA (Chahine of the Jet Propulsion Laboratory) and East Coast NASA (Rasool of Headquarters, with Goddard experience).

Forty-some other attendees included several with origins in planetary science, including Jim Pollack, Ron Prinn and me Appropriately, there were more Earth scientists, including Wally Broecker, Paul Crutzen, John Houghton, Lynn Margulis and Vern Suomi.

The workshop proposed a science-driven mission to the home planet. Goody was the perfect leader, an outstanding scientist, polite, intellectual, a master of the Queen's English. He ran a congenial meeting, accepting inputs from all quarters with appropriate discrimination.

A science-driven program to assess global change quantitatively made great sense. Optimism overflowed in the bright sunshine at workshop lunch breaks, taken on the lawn or on the porch of the large meeting house overlooking the harbor. I missed the gravel-voiced interjections of Don Hunten, who was not an attendee, but otherwise it had the hallmarks of a NASA Space Science program in which scientific requirements determine the nature of the mission.

The report issued by the Executive Committee, titled "Global Change: Impacts on Habitability" with subtitle "A Scientific Basis for Assessment" began:

> The earth is a planet characterized by change, and has entered a unique epoch when one species, the human race, has achieved the ability to alter its environment on a global scale. This report outlines a scientific strategy that would offer the basis for the difficult choices that lie ahead and for the complex decisions that must be made now to protect the integrity of the earth.
>
> NASA could play a central role in this task. The unique perspectives of space observational systems, the ability to manage complex interdisciplinary science programs realized in two decades of planetary exploration, and the overall technical expertise of NASA are essential to the success of the endeavor.

This seemed too good to be true. It was. Mission to Planet Earth devolved into a mundane Earth Observing System (EOS). I intend to tell the story one day, but for now I have deleted the chapters on EOS from *Sophie's Planet* for the sake of focusing and finishing the book.

Let me be clear: there were many brilliant Earth scientists participating in the EOS program. However, unlike Pioneer Venus and the ozone program, science was not driving the bus. I have severe compunctions about my clumsy attempts to draw attention to the program shortcomings, especially because of resulting negative impacts on some younger scientists' careers. Once again, my poor communication ability played a role. But EOS is a tangential story.

Warm feelings from the optimistic 1982 summer endured for a time. We completed the paper describing our three-dimensional global climate model that summer. The paper[1] was not published until a year later, because of referee objection to the model's coarse resolution. Eventually, one referee said, in effect, "darn it, you must let them publish, the model was used for the Charney study." Often the identity of anonymous referees can be surmised from their review. In this case, I guessed that the referee was Warren Washington, in part because of his generous personality. I also realized how much we owed Jule Charney.

When we got back from Cape Cod, I rented a truck. Andy, Larry and David helped load it with our belongings from the apartment. Our favorite, very long, couch, which Anniek had made, would not fit in the truck, but our friendly superintendent sawed it in half, to be reassembled later. We unloaded the truck at our new home on South Irving Street and went to Renato's for pizza. Anniek, Erik, Kiki and I became suburbanites, for the next 20 years.

Wally Broecker had a great suggestion: I should work with Taro Takahashi to organize a Ewing Symposium on climate at Lamont. Maurice Ewing was the founder and first Director of Lamont. Symposia on various geophysical topics were held irregularly in his honor.

It would be a lot of work, mainly to cajole speakers to write their papers, and to edit these into a book, a Geophysical Monograph, published by the American Geophysical Union. However, it was an opportunity to bring in the best relevant scientists in the world, learn from them, and contribute our own paper to the book.

The Symposium, *Climate Processes and Climate Sensitivity*, was held in late October 1982. It took a year to finish the Ewing monograph,[2] which was published by AGU in early 1984.

An unexpected benefit of the Symposium was insight into the thinking, about climate change, of the big oil company, Exxon. Exxon Research and Engineering Company (Exxon R&E) was the prime sponsor of the Symposium. It was not unusual for oil companies to provide funding to geological institutions, because of the relevance of geology to discovery of oil deposits. The fossil fuel industry was also aware of the potential for fossil fuel emissions to affect climate.

Edward E. David, Jr., President of Exxon R&E, was the dinner speaker on the first day of the Symposium. He was appropriate for several reasons. Not only did Exxon R&E support the Symposium financially, Exxon also allowed Taro Takahashi and Wally Broecker to collect oceanographic CO_2 data from Exxon ships. Science and industry were cooperating effectively.

David had a doctorate from MIT in electrical engineering. He worked at Bell Labs, becoming Executive Director of Research. In August 1970 he became Science Adviser to President Nixon, but had difficulty getting the President to listen. David quit in frustration in January 1973, citing "disappointment that his advice had not been heeded."[3]

Dinner talks are often forgettable. Not E.E. David, Jr.'s. The audience was rapt. David's presence, career, and current position demanded respect. He was using notes, if not an exact text, for his presentation, which was carefully thought out. It was fitting a scientific symposium, and it had broader implications. (Anniek whispered that he was wearing a "bad hairpiece.")

David began by pointing out the power of science and technology to shape the future. He noted:

> "Exxon is a hundred years old this year; we have a long corporate memory of the very profound social and economic transformations that our business activities have helped bring about, and of how we and society have had to adapt further in response."
>
> "But faith in technologies, markets, and correcting feedback mechanisms is less than satisfying for a situation such as the one you are studying at this year's Ewing Symposium. The critical problem is that the environmental impacts of the CO_2 buildup may be so long delayed. A look at the theory of feedback systems shows that where there is such a long delay, the system breaks down, unless there is anticipation built into the loop."

E.E. David was stunningly perceptive about the implications of delayed response and climate feedbacks for energy policy and the oil industry. Appreciation of his analysis requires that we first discuss the buildup of CO_2, the slow climate response, and climate feedbacks.

Exxon's public position on climate change eventually diverged from that of E.E. David, but not in the way one might guess. I will discuss the climate physics, then the policy implications.

Climate feedbacks cause the biggest uncertainty in climate predictions. Most of the forcing factors that drive climate change can be measured or calculated accurately. Human-made forcings include changes in the amount of atmospheric greenhouse gases and aerosols. Natural forcings include changes of the Sun's brightness and volcanic eruptions that occasionally inject aerosols into the stratosphere.

Climate change in response to forcings is the issue. Charney made a limited investigation of climate sensitivity, the climate response to a specified forcing. He chose an idealized case, in which some parts of the climate system, such as ice sheets, are fixed. His resulting estimate for climate sensitivity, the fast-feedback climate sensitivity, had large uncertainty. It is uncertain because it is hard to know how accurately a climate model can simulate fast feedbacks – indeed, it is hard to know whether all the important feedbacks are even included in the model.

Our paper[4] in the Ewing monograph pointed out the merit of comparing two different climate states of the real world. In particular, we compared the climate of the last ice age, which peaked about 20,000 years ago, with the climate of the current interglacial period, the Holocene.

Comparison of equilibrium climate states allows inference of the Charney (fast feedback) climate sensitivity, potentially to high accuracy. Moreover, this empirical evaluation includes all fast feedbacks, because it is derived from the real world, not from a model.

We only need to recognize that the planet is in quasi-equilibrium in both climate states, the glacial and interglacial states. Proof is simple. Imagine the contrary. Say the planet is out of balance by 1 W/m^2. That's enough energy to melt all the ice on the planet or change ocean temperature by a large amount, which is inconsistent with reality revealed by paleoclimate data.

Climate sensitivity is in the range 2.5-5°C for doubled CO_2, our paper in the Ewing volume concluded. Four decades later there has been almost no tightening of that range. We will make a case later for tightening the range to 2.5-4°C, with a most probable sensitivity near 3°C, but that modest tightening is neither certain nor important. The main point is that climate sensitivity is high, and the Charney analysis was remarkably accurate.

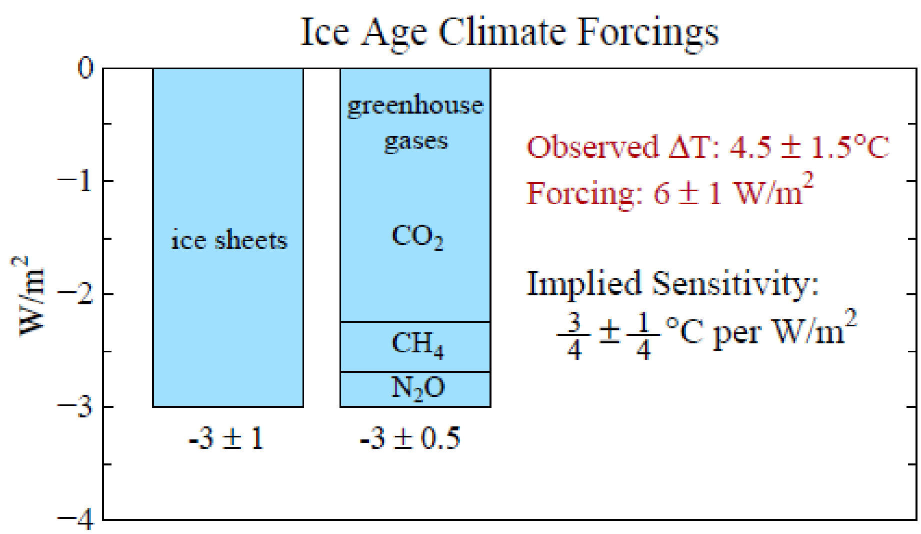

Fig. 23.1. Ice Age cooling 4.5°C implies a sensitivity of ~3°C for 2×CO_2 (4 W/m^2) forcing.

The essence of how ice age cooling is used to derive the fast-feedback climate sensitivity is explained by the bar chart "Ice Age Climate Forcings" (Figure 23.1). Increased CO_2, CH_4 and N_2O in the Holocene, compared to the Ice Age 20,000 years ago, caused a forcing of about +3 W/m^2. The smaller area of ice sheets in the Holocene – ice sheets covered most of Canada and parts of the United States and Eurasia during the Ice Age – also yields a surface reflectivity (albedo) forcing of about +3 W/m^2. This total forcing of 6 W/m^2 caused Earth to be warmer by 4.5°C. Therefore, climate sensitivity is about 4.5/6 = ¾°C for each W/m^2 of climate forcing.

Doubled CO_2 is a forcing of 4 W/m^2, so this paleo-derived climate sensitivity is 3°C for doubled CO_2, the same as Charney's estimate. The advantage of the paleo analysis is that it includes all processes operating in the real world and it has the potential to yield greater accuracy.

The error estimates in Fig. 23.1 at face value suggest a climate sensitivity range of 2-4°C for 2×CO_2. However, in our Ewing paper we corrected that estimate based on the fundamental requirement that the planet be in energy balance. We obtained the correction by running our climate model with Ice Age boundary conditions: reduced greenhouse gases, increased ice sheet area, increased sea ice cover, and cooler ocean temperature, all as provided by the CLIMAP reconstruction[5] of Ice Age conditions.

With these Ice Age boundary conditions Earth was out of energy balance by between -1.6 W/m^2 and -2.1 W/m^2, depending on the range of CLIMAP surface conditions. This imbalance meant that the CLIMAP forcings (atmosphere and surface properties) were inconsistent with the CLIMAP-specified sea surface temperatures. The model "wanted" to cool the planet further. Either the actual ocean surface during the Ice Age was colder than CLIMAP estimated, which we argued was likely the case, or the climate forcings were smaller than the estimated 6 W/m^2.

In either case, this requirement of energy balance implied that the correct sensitivity range was higher than 2-4°C for 2×CO_2. This energy balance requirement and a feedback analysis in our Ewing paper both yielded a best estimate for climate sensitivity of 2.5-5°C for 2×CO_2.

Our paper in the Ewing volume made a second contribution: it revealed that the delay in climate response to a forcing was longer than commonly assumed. This long delay is important, because it implies that the people burning fossil fuels may not feel most of the effects; instead, the impacts largely will be visited upon their children, grandchildren and later generations.

The Covid-19 pandemic shows the havoc that a delayed response can cause. There the delay time is days-weeks between infection, symptoms and consequences. With climate the delay time is decades-centuries. In both cases, as E.E. David realized, the delay can cause system breakdown unless you have "anticipation" and act before the consequences are out of control.

Our 2×CO_2 climate simulations for the Charney study included the ocean heat capacity of only the ocean's upper wind-driven mixed layer. The purpose of the mixed layer was to include enough heat capacity to achieve a realistic seasonal cycle of surface temperature, while also allowing the model to obtain its equilibrium (long-term) response in a reasonable computer time.

Charney realized the importance of deeper ocean heat capacity, but he overlooked the fact that climate response time depends strongly on climate sensitivity. Charney noted the effect of exchange of water between the mixed layer and the ocean layers beneath it, concluding that "…it could delay the attainment of ultimate global thermal equilibrium by the order of a few decades."

This conception got its way into a massive subsequent report under the auspices of the U.S. National Academy of Sciences. After President Jimmy Carter signed into law the Energy Security Act in 1980, with a focus on synthetic fuels, the U.S. Congress expressed concern about potential climate change from CO_2 emissions and requested the National Academy of Sciences and the President's Office of Science and Technology Policy to prepare an assessment.[6]

The resulting report, *Changing Climate,* [7] included in its Synthesis and in the full report a graphical relationship of inferred climate sensitivity as a function of observed global warming. This relationship implied, for realistic pre-industrial CO_2 levels, that climate sensitivity must be near the low end of Charney's range (1.5-4.5°C for 2×CO_2).

We showed that the *Changing Climate* analysis was flawed by an assumption that the climate response time was 15 years, independent of climate sensitivity. In reality, the response time is much longer for a realistic climate sensitivity.

The physical basis of the delayed surface temperature response is a combination of two factors.

First, the initial flux of heat into the ocean surface is independent of climate sensitivity. Higher climate sensitivity is a result of feedbacks, such as atmospheric water vapor amount or sea ice area. These feedbacks come into play not in response to the climate forcing, but rather in response to global temperature change. Thus, if Earth's heat capacity were due simply to the ocean's mixed layer, the climate response time would be three times longer for climate sensitivity 4.5°C than for sensitivity 1.5°C for 2×CO_2.

Second, the slower response for high sensitivity allows exchange of water between the mixed layer and greater ocean depths. Based on observed mixing of transient tracers, such as tritium sprinkled on the ocean's surface during atomic testing in the 1960s, we showed numerically and analytically[8] that the response time increases approximately as the square of climate sensitivity. Thus, the climate response time is about nine times longer for climate sensitivity 4.5°C than for sensitivity 1.5°C for 2×CO_2.

The upshot, in contradiction to the *Changing Climate* study, was that the high climate sensitivity we inferred from paleoclimate data was consistent with observed 20th-century global warming.

Delayed response, warming 'in the pipeline,' was thus a concept that policymakers needed to understand. Warming 'in the pipeline' is the unrealized portion of the equilibrium response, the warming that will occur without any additional change of atmospheric composition. By the time the public witnesses a climate change that it does not like, there will be more climate change coming that is unavoidable – potentially a whole lot more change.

First, there is the delayed response caused by the thermal inertia of the ocean. Even if the greenhouse gases in the air suddenly stopped increasing, Earth would continue to warm on time scales of decades and centuries. How much additional warming due to the ocean's thermal inertia depends on climate sensitivity and the history of emissions, but the warming in the pipeline is substantial, of the order of half of the warming that has already occurred.

Second, there is additional delayed response (in the pipeline) warming due to slow feedbacks. We have been discussing the "Charney" climate sensitivity problem, which neglects slow feedbacks. However, we know, for sure, that there are also "slow" feedbacks, such as the melting of ice sheets, as Earth warms. We know, from Earth's history, that the slow feedbacks are substantial and they are amplifying. Because the human-made forcing is growing so rapidly, these slow feedbacks will come into play faster than they did in nature's world – just how fast eventually became the focus of our research – it makes a world of difference if sea level rise of several meters is to occur in 50-100 years rather than say 500-1000 years.

Third, there is another delay, not in the climate system, but in the energy system that is the principal producer of the greenhouse gases that are driving climate change. Humanity cannot instantly replace its energy sources, because of the enormous investment in infrastructure. This is a delay that E.E. David surely understood well.

All three of these delays were recognized. Compared with the medical understanding of Covid-19 at its outbreak, the climate science in the 1980s was already at a better level of understanding. The threat posed by these delays was already discussed in our 1981 *Science* paper, including the implications for energy policies.

These delays are not all bad. The slow response of the climate system means that we have time to make changes before a new climate equilibrium is reached. Much of the warming in the pipeline need never occur. Slow feedbacks can be short-circuited, largely prevented from ever happening. This does not need to be a "gloom and doom" story. We can take advantage of slow response times, but it is important to have good understanding of the system.

This picture was clear enough, despite uncertainties in climate sensitivity and the carbon cycle, by the time of a 1983 National Academy of Sciences report of the Carbon Dioxide Assessment Committee (called the Nierenberg report, after the name of its chairman, W.A. Nierenberg). The report beginss:

> "There is a broad class of problems that have no 'solution' in the sense of an agreed course of action that would be expected to make the problem go away. These problems can also be so important that they should not be avoided or ignored until the fog lifts. We simply must learn to deal more effectively with their twists and turns as they unfold. We require sensible regular progress to anticipate what these developments might be with a balanced diversity of approaches. The payoff is that we will have had the chance to

> consider alternative courses of action with some degree of calm before we may be forced to choose among them in urgency or have them forced on us when other – perhaps better – options have been lost. Increasing atmospheric CO_2 and its climatic consequences constitute such a problem."

Scientists always recommend more research. Research *is* needed if we are to help lift the "fog." Yet by focusing on uncertainties, as we do in our reports that are too thick to read, do we risk failure to inform policymakers of what we know? Did we not know enough to say with unambiguous clarity that development of unconventional fossil fuels and termination of serious R&D on the most promising potential source of massive amounts of clean energy – advanced generation nuclear power – was awful energy policy? We must return later to examine the forces that could drive such a seemingly irrational decision.

Scientists are discouraged from foraying into policy. There was no doubt in my mind: Koomanoff took his hatchet to our CO_2 research program not because it was bad science, but because our 1981 *Science* paper got too much attention and concluded: "An appropriate strategy may be to encourage energy conservation and develop alternative energy sources, while using fossil fuels as necessary during the next few decades." He made an example of us.

DoE, at least in that era, did not appreciate policy advice. Scientific fog seemed to suit their purpose. The fog was lifting for some, however: E.E. David, Jr. and Exxon.

E.E. David, Jr. was prescient to focus on the climate system's delayed response. He inferred that delayed response demands <u>anticipation</u> to avoid system breakdown, where system breakdown implies catastrophic climate change for today's young people and future generations.

David's "Summary and Conclusion" began: "To sum up, the world's best hope for inventing an acceptable energy transition is one that favors multiple technical approaches subject to correction – feedbacks from markets, societies, and politics, and <u>scientific feedback</u> about external costs to health and the environment." (emphasis in original.)[9]

The magnitude of "external costs to health and the environment" and the level of global warming needed to make those costs alarming was debatable. However, our 1981 *Science* paper and research of others made it clear that burning all conventional fossil fuels was not acceptable. David understood that climate's delayed response and feedbacks created a problem, and he articulated the implication: "anticipation" was needed in developing global energy systems.

Required "anticipation," unambiguously, must be development of energy sources that do not emit CO_2 to the atmosphere. David understood well the multi-decadal time scale required for major energy transitions. It seemed that this could be a historic moment, the world's leading energy company would move to invest in carbon-free energies!

Umm, not so much. Incredibly, Exxon and the fossil fuel industry, with complicity and subsidies from the U.S. government and other governments, chose instead to invest massively in development of hydraulic fracturing ('fracking'). Fracking is a method of extracting oil and gas reserves such as tight oil, oil shale and bitumen that are difficult to access. Various chemicals and sand are mixed in water and injected in drill-holes under high pressure to create fractures in the underlying geology and increase the quantity of hydrocarbons that can be extracted.

This deliberate "anticipation" of the oil and gas industry and governments, this fracking pathway chosen for future energy sources, prevailed quietly behind the scenes for decades, not attracting much public attention. As a predictable consequence, David's concern was realized: the absence of effective "anticipation" meant that "faith in technologies, markets, and correcting feedback mechanisms" was necessarily misplaced.

"Correcting feedback mechanisms" can still be effective, because we have barely dipped our toes into unconventional fossil fuels. We can still avoid a headlong dive into that murky pool of unconventional fuels, but we need honest, comprehensive understanding of alternatives.

Exxon did not hesitate, however, as it invested more and more into fracking. Perhaps this aided a rewiring of E.E. David's thinking, as he became a climate change denier and remained so to his dying days in 2017. A possible explanation would be the famous quotation of Upton Sinclair: "It is difficult to get a man to understand something when his salary depends upon his not understanding it." However, William Jenning Bryan's[10] "it is useless to argue with a man whose opinion is based upon a personal or pecuniary interest; the only way to deal with him is to outvote him" is more comprehensive and relevant.

David, it seems to me, violated the scientific method. Did he study all available data, was he very skeptical of his interpretation, did he honestly reassess as new data came in? We do not know for sure. However, it is hard to avoid a conclusion that he violated the fourth requirement, to not allow his preference or ideology affect his assessment. There was overwhelming evidence for the role of fossil fuels in climate change well before he died.

William Jenning Bryan's solution, "to outvote him," is fine, but there is a fly in that ointment. Governments almost worldwide, including democracies, are heavily under the influence of money. That is the ultimate problem, which I want to discuss later in this book.

David left Exxon in 1986. Exxon's public position on climate belatedly diverged from that of David, but not before Exxon committed acts of dubious morality and legality. That, too, is a topic for further discussion.

Colorful leaves were falling on the Lamont campus as E.E. David spoke at the Ewing Symposium in October 1982. The mixed emotions that usually accompany autumn were appropriate – winter was setting in. Meredith's freeze on hiring at GISS and the loss of our CO_2 research funding combined to create a long, harsh winter.

We had left Venus, for good or for ill, and our ship had landed on the home planet at an interesting place, but the inhabitants there had to forage for food. Prospects for the returning explorers looked dim – we had returned at the most stringent time – until suddenly an angel appeared. Or was it two angels? Sometimes it is hard to distinguish an angel from a real person.

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[2] Hansen, J.E. and T. Takahashi, *Climate Processes and Climate Sensitivity*, Geophysical Monograph 29, Maurice Ewing Volume 5, American Geophysical Union, Washington, D.C., 1984.
[3] Lyons, Richard D., Science adviser to Nixon leaving for industry job, New York Times, 3 January 1973.
[4] Hansen, J., A. Lacis, D. Rind, G. Russell, P. Stone, I. Fung, R. Ruedy and J. Lerner, Climate sensitivity: analysis of feedback mechanisms, in American Geophysical Union *Geophysical Monograph* **29,** 130-163, 1984.
[5] CLIMAP project members: Seasonal reconstruction of the Earth's surface at the last glacial maximum, Geol. Soc. Amer., Map and Chart Series, No. 36, 1981.

[6] Senator Abraham Ribicoff added an amendment to the 1978 National Climate Act, which was incorporated into the Energy Security Act signed by President Carter in 1980. See Naomi Orestes and Erik M. Conway, *Merchants of Doubt*, pp. 176-177, Bloomsbury Press, 2010.
[7] Nierenberg, W.A. (Chairman), *Changing Climate: Report of the Carbon Dioxide Assessment Committee*, Washington, DC, National Academies Press, 519 pages, https://doi.org/10.17226/18714, 1983.
[8] Hansen, J., G. Russell, A. Lacis, I. Fung, D. Rind and P. Stone, Climate response times: dependence on climate sensitivity and ocean mixing, *Science*, **229**, 857-859, 1985. This paper is seldom referenced, but is one of the few that I am most proud of. Suki Manabe sometimes joked, when he wrote some equation, "see, I can do more than run a model." I was in the same modeling boat as Suki.
[9] E.E. David, Jr., Inventing the Future: Energy and the CO_2 "Greenhouse" Effect, pp. 1-5 in *Climate Processes and Climate Sensitivity*, J.E. Hansen and T. Takahashi, *Geophys. Monogr.* **29**, American Geophysical Union, 1984.
[10] Sources and discussion of Sinclair and Bryan quotes are at https://quoteinvestigator.com/2017/11/30/salary/