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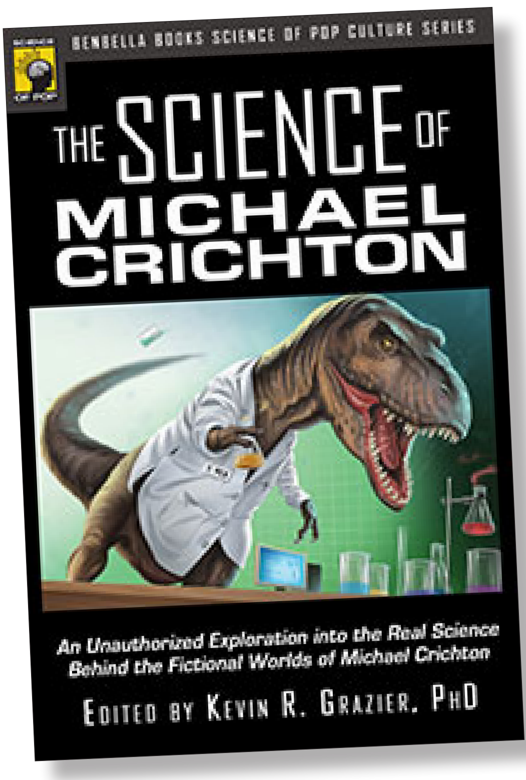
THE SCIENCE OF MICHAEL CRICHTON



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BE AFRAID. BE VERY AFRAID: MICHAEL CRICHTON'S *STATE OF FEAR*

David M. Lawrence

If there's anything that Michael Crichton makes clear in State of Fear *it is that the factors influencing climate change—and climate change research—are extremely complex at the very least. I'm afraid that it's going to take somebody like David Lawrence to even begin sort it all out for us.*

> Now we are engaged in a great new theory, that once again has drawn the support of politicians, scientists, and celebrities around the world. Once again, the theory is promoted by major foundations. Once again, the research is carried out by prestigious universities. Once again, legislation is passed and social programs are urged in its name. Once again, critics are few and harshly dealt with.
>
> Once again, the measures being urged have little basis in fact or science. . . .
>
> —Michael Crichton, *State of Fear*

AT LEAST AS FAR BACK as *The Andromeda Strain*, Michael Crichton has revealed in his writings skepticism about the limitation of science and technology as a tool in humanity's efforts to stave off disaster. Hubris and ignorance have led to the downfall of more than one of Crichton's protagonists, whether they be eaten by dinosaurs of their own creation or trapped in a lab with a deadly and spreading disease that they have unwittingly released. Often, such skepticism is warranted. Scientists are just as fallible as any other human, making mistakes large and small. Some mistakes lead to great disasters, such as the thalidomide scandal of the 1950s and 1960s, in which an inadequately tested medicine was, because of its efficacy in mitigating the effects of morning sickness, administered to the worst possible pool of patients: pregnant women. The problem, undiscovered until too late, was that thalidomide could cause severe birth defects in their children. Thousands of thalidomide babies, many born with shortened, even missing limbs, were the legacy of this failure by the scientific community.

That science can go wrong is no secret. The theme has been a staple of science fiction since the birth of the genre in the nineteenth century. The classic scientist-villain in these stories is usually evil, demented, or brilliant yet clueless, working alone or within a small organization, and almost always working beyond the fringes of the mainstream science of the time.

In *State of Fear*, Crichton takes this paranoia of science, and scientists, to new levels.

The book begins with an apparently authentic introduction by "MC" about a lawsuit to be filed on behalf of a small Pacific island nation, Vanuatu, against the U.S. Environmental Protection Agency for its failure to prevent global warming, which will apparently endanger the small nation through rising sea levels which flood the residents out of their homeland. Intrigue quickly follows, with a murder in Paris, a mysterious purchase in Malaysia, another killing in London, and mention of a radical environmental cause. The cause? Global warming, of course.

Global warming is an oft-used phrase. It, along with its lexicological cousins, climate change and the greenhouse effect, is blamed for many problems affecting human and natural systems. Many believe that the *tres amigos* will be the source of much mischief in the decades and centuries—even millennia—to come.

Despite Crichton's claim in an appendix to *State of Fear* that there is little basis for concern in fact or science, the existence of and mechanisms behind global warming, i.e., the greenhouse effect, are pretty established science. It was first described by the French mathematician Jean Baptiste Joseph Fourier in 1827.[1] The Swedish chemist Svante Arrhenius[2] measured the heat-trapping ability of carbon dioxide (or car-

[1] Jean Baptiste Joseph Fourier, "Mémoire sur les températures du globe terrestre et des espaces planétaires," *Mémoires de l'Académie royale des sciences de l'Institut de France* 7 (1827): 570–604.

[2] Svante Arrhenius, "On the Influence of Carbonic Acid in the Air upon the Temperature of the Ground," *Philosophical Magazine and Journal of Science*, 5th ser., 5. 41 (1869): 239–276.

bonic acid, as he called it) in a series of experiments he reported on in 1896. In fact, we would not be able to survive on the surface of our planet without it, for it is an important part of the radiation balance, which ultimately governs temperature, of the surface of the Earth.

Most of the energy that drives life and physical processes (such as photosynthesis, weather and atmospheric circulation, oceanic circulation, and physical and chemical weathering of soils) comes from the sun in the form of shortwave radiation—primarily visible and ultraviolet light. Some of that energy is scattered by molecules and particles in the atmosphere. Some is reflected back into space by clouds, for example, or by the surface. What is not reflected or scattered is absorbed. The molecules and materials that make up the atmosphere and surface of the Earth cannot absorb heat indefinitely. Some of that energy is used to do work, as in the coupling of carbon dioxide and water to make sugars via photosynthesis. What is not otherwise used, however, is given off as longwave radiation—infrared radiation, much of what we sense as heat. If that heat was allowed to pass freely back into space, the temperature at the surface of the Earth would be below freezing, about -19 degrees Celsius, or -2 degrees Fahrenheit. But the average surface temperature of the Earth is 14 degrees Celsius, or 57 degrees Fahrenheit. How can that be? [3]

The difference is the Earth's natural greenhouse effect. Gases in the atmosphere, such as water vapor (the most abundant), carbon dioxide (which, with water vapor, is an end product of the burning of fossil fuels), and methane (one of the most potent natural greenhouse gases), trap heat near the surface like a blanket, keeping the temperature about thirty-three degrees Celsius, or fifty-nine degrees Fahrenheit, warmer than otherwise possible. The Earth's two nearest planetary neighbors, Venus and Mars, serve as bookends, so to speak, on the influence of greenhouse gases on surface temperatures.

Though the Martian atmosphere is about 95 percent carbon dioxide, the atmosphere is thin, much more like a sheet than a blanket. While one would expect the surface temperatures of Mars to be some-

[3] Hervé Le Treut, Robert Somerville, Ulrich Cubasch, Yihui Ding, Cecilie Mauritzen, Abdalah Mokssit, Thomas Peterson, and Michael Prather, "Historical Overview of Climate Change," in *Climate Change 2007: The Physical Science Basis. Contribution of Working Group I to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change*, eds. Susan Solomon, Dahe Qin, Martin Manning, Zhenlin Chen, Melinda Marquis, Kristen Averyt, Melinda M.B. Tignor, and Henry Leroy Miller Jr. (New York: Cambridge University Press, 2007), 93–127.

what cooler than that of Earth because of its increasing distance from the Sun, Mars is much cooler—about fifty degrees Celsius, or ninety degrees Fahrenheit, cooler than Earth. Mars was much warmer, with liquid water at the surface, but the planet apparently entered a reverse greenhouse effect: carbon dioxide was removed from the atmosphere, reacting with and binding to rocks at the surface. As the carbon dioxide was removed from the atmosphere, the gaseous envelope surrounding the planet thinned, temperatures dropped, and the other major greenhouse gas present, water vapor, froze, becoming ice on the surface. The loss of atmospheric water vapor further aggravated the cooling.[4,5]

Venus on paper, on the other hand, should have been the Earth's twin. But there are differences. The Earth, because it was farther from the sun, had somewhat cooler surface temperatures which allowed vast oceans of liquid water to cover the surface. These surface waters could dissolve carbon dioxide from the atmosphere. Life on the surface could use atmospheric carbon as biological building blocks. Venus was closer to the sun, therefore hotter because of the greater amounts of solar radiation it received. Oceans of liquid water either could not form, or, as its atmosphere warmed, more and more water evaporated from the surface. Greenhouse gases otherwise dissolved in the early Venusian oceans or bound in its surface rocks were released to the atmosphere as well. As the concentration of greenhouse gases increased, so did the temperatures, leading to further release of greenhouse gases into the atmosphere and further warming—in other words, a runaway greenhouse.[6,7] The surface temperature of Venus now averages about 460 degrees Celsius, or 860 degrees Fahrenheit.

Humans, by the combustion of fossil fuels such as coal and petroleum and by the conversion of natural landscapes to agricultural and urban uses, have triggered an increase in the concentration of several greenhouse gases in the atmosphere. The concentrations of carbon dioxide, methane, and nitrous oxide have increased markedly since the

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[4] James F. Kasting, Owen B. Toon, and James B. Pollack, "How Climate Evolved on the Terrestrial Planets," *Scientific American* 256 (1988): 90–97.

[5] Donald M. Hunten, "Atmospheric Evolution of the Terrestrial Planets," *Science* 259 (1993): 915–920.

[6] Andrew P. Ingersoll, "The Runaway Greenhouse: A History of Water on Venus," *Journal of the Atmospheric Sciences* 26 (1969): 1191–1198.

[7] Hunten, "Atmospheric Evolution of the Terrestrial Planets."

beginning of the Industrial Revolution in 1750. Carbon dioxide has increased from a pre-industrial level of 280 ppm (parts per million) to 379 ppm in 2005. If current emission trends continue unabated, it will likely double pre-industrial levels by the end of this century.[8] Atmospheric methane has more than doubled, from 715 ppb (parts per billion) in pre-industrial times to 1774 ppb in 2005, although the growth rate in the methane concentration has decreased somewhat since the early 1990s.[9] The nitrous oxide concentration has risen from a pre-industrial level of 270 ppb to 310 ppb in 2005.[10] Data from ice cores suggest that the current levels of carbon dioxide and methane exceed anything seen in the last 650,000 years.[11]

The concern is that greenhouse gases will do as they are known to do: trap more heat near the surface of the Earth, therefore altering temperature patterns and triggering potentially catastrophic environmental changes. Many argue that significant changes in our behavior are required to stem the increase and stave off disaster. Some, including Crichton, argue otherwise.

In an appendix to *State of Fear*, Crichton compares the scientific consensus of concern over global warming to a number of scientific abuses during the twentieth century. One was eugenics, in which many sought to improve the quality of humanity by encouraging the breeding of desirables—essentially intelligent, wealthy, blueblood, "white" people, and discouraging or even preventing the breeding of undesirables. Undesirables included people of color (or of mixed race), so-called "white trash," homosexuals, petty criminals, and people considered mentally deficient. Many leaders and institutions in the United States promoted eugenics and conducted eugenics research. Adolf Hitler drew aid and comfort from what was happening in the United States, learning much of what he needed from America to implement

[8] Piers Forster, Venkatachalam Ramaswamy, Paolo Artaxo, Terje Berntsen, Richard Betts, David W. Fahey, James Haywood, Judith Lean, David C. Lowe, Gunnar Myhre, John Nganga, Ronald Prinn, Graciela Raga, Michael Schulz, and Robert Van Dorland, "Changes in Atmospheric Constituents and in Radiative Forcing," in *Climate Change 2007*, 129–234.

[9] Ibid.

[10] Ibid.

[11] Eystein Jansen, Jonathan Overpeck, Keith R. Briffa, Jean-Claude Duplessy, Fortunat Joos, Valérie Masson-Delmotte, Daniel Olago, Bette Otto-Bliesner, W. Richard Peltier, Stefan Rahmstorf, Rengaswamy Ramesh, Dominique Raynaud, David Rind, Olga Solomina, Ricardo Villalba, and De er Zhang, "Paleoclimate," in *Climate Change 2007*, 433–497.

the Holocaust. (There was "scientific" cooperation between America and the Nazis prior to the onset of World War II.)

Crichton draws another cautionary lesson from Josef Stalin's Soviet Union. Trofim Denisovich Lysenko, an agricultural scientist who rejected the developments of modern genetics and evolution in favor of the old, discredited theory of Larmarckism—inheritance of acquired characteristics—promised increased agricultural yields without fertilizing fields. He promoted a process called vernalization that was purported to improve flowering of crops in spring by exposing the seeds to prolonged cold in the winter. Such treatment does increase flowering in some crops, but Lysenko took the idea a step further, claiming that the descendants of treated individuals would inherit the increased ability to flower without having to undergo the cold treatment. This became known as Lysenkoism. His ideas were a godsend to a Soviet Union reeling from famines in which millions died, for they promised far greater crop yields without a corresponding increase in investment. The problem was they did not work.

Eugenics is offered as a warning against social movements sold as scientific programs. Lysenkoism is offered as a warning against the politicization of science. Crichton believes that both phenomena lie at the heart of the concern over global warning. It is from this point of view that *State of Fear* is written.

Crichton expresses most of his skepticism through the voice of one character, John Kenner, a Massachusetts Institution of Technology professor-cum-secret agent—a man just as lethal, but much better educated, than Ian Fleming's literary (not celluloid) James Bond. The philosophical aspect of Kenner seems to be based on a living MIT professor, Richard S. Lindzen, who is a prominent global warming skeptic. He is not, so far as I know, an intelligence agent. But the secret agent aspect is not that farfetched, as academics are known to work overtly or covertly for intelligence agencies.

Crichton doesn't wait for Kenner to appear in the book before taking his first shot at the current concern over global warming. The setting for the shot is, appropriately, Iceland, where George Morton, a wealthy backer of environmental causes, Peter Evans, Morton's attorney and chief protagonist, and Nicholas Drake, head of the National Environmental Resource Fund (NERF) and chief villain, visit a glaciologist working on a project supported by NERF with the help of Morton's money. While Morton and Evans are being distracted by the local scenery (in the form of beautiful Icelandic geologists), Drake and the principal investigator are arguing about the researcher's findings: that temperatures are cooler in Iceland at the time the novel takes place (2004) than they had been early in the twentieth century; and that the glaciers, which had receded during the earlier warm period, were now surging. The researcher wants to publish his results without obfuscation; Drake, the "environmentalist," wants the facts withheld so as not to confuse the public over the inevitability and seriousness of the oncoming global catastrophe.

It is at this point that Crichton introduces the first of many references to actual scientific literature to bolster his argument that concern over global warming is overblown: this first offering is the paper "Global Warming and the Greenland Ice Sheet," published in the journal *Climatic Change* in 2004. In his footnote, he quotes the article, "Since 1940 . . . data have undergone predominantly a cooling trend. . . . The Greenland ice sheet and coastal regions are not following the current global warming trend." [12] All this appears damning, but this barely scratches the surface of the article; the quote Crichton selected is actually from the abstract, not the more meaty discussions of the research in the body of the text.

The lead author of the study, Petr Chylek, now of Los Alamos National Labs, is often listed as a global warming skeptic. He is on record saying there is insufficient evidence to link climate conditions today with global warming. Nevertheless, nowhere in this article does he say his findings should be used to discount current concerns. The article points out something that all climate scientists know: there is considerable local variation in weather and climate. The growth or decline of glaciers derives from a complex balance of temperature and moisture ability. Warmer temperatures do melt ice, but warmer temperatures may also bring more precipitation—warm air holds more water vapor, which can be transported far from the source to increase rain or snowfall elsewhere. If more ice is lost through melting than is gained through precipitation, the glaciers shrink. If more ice

[12] Petr Chylek, Jason E. Box, and Glen Lesins, "Global Warming and the Greenland Ice Sheet," *Climatic Change* 63 (2004): 201–224.

is gained through precipitation than is lost through melting, the glaciers grow. The nature of the balance can lead to perverse effects: glaciers can shrink during cooler times and grow during warmer times.

In Greenland's case, Chylek and his colleagues suggested that Greenland is strongly affected by the North Atlantic's version of the notorious El Niño, the North Atlantic Oscillation (NAO). El Niño is associated with a fluctuating atmospheric pressure pattern in the Pacific known as the Southern Oscillation. Normally, atmospheric pressure is higher in the eastern Pacific (off Ecuador) and lower in the western Pacific (in the neighborhood of Australia). As a result, strong tropical winds blow from east to west; arid conditions prevail in the eastern Pacific and humid conditions prevail in the west. During an El Niño, the pressure and wind patterns reverse, triggering weather anomalies that can have catastrophic effects around the globe.

The North Atlantic Oscillation is a similar pressure fluctuation between a region of typically high pressure over the Azores and a region of typically low pressure in the neighborhood of Iceland. The pressure differences between these two locations affect the mid-latitude westerly winds blowing across the Atlantic. When the pressure differences are high, strong westerly winds bring stronger, more frequent storms to Europe in winter. As a result, Europe has warmer, wetter winters, as does the eastern United States. Canada and Greenland, however, have colder and drier winters. When the pressure differences are low, weaker westerlies lead to fewer and weaker winter storms in Europe. Northern Europe experiences colder conditions, southern Europe experiences humid conditions. Outbreaks of cold air sweep over the eastern United States, bringing more frequent snowstorms. Weather conditions over Greenland, however, are milder.

By now, it should be clear that the North Atlantic Oscillation has a tremendous influence on Greenland's weather, therefore it has a tremendous influence on Greenland's glaciers and may even counteract the effect of global warming. Subsequent studies by Chylek have borne this out. Despite Chylek's skepticism about global warming, he was the lead author of a study published in the journal *Geophysical Research Letters* in 2005 that supports the concern over global warming. The study, written with Ulrike Lohmann of the Swiss Federal Institute of Technology, focused on northeastern Greenland, a portion not affected by the North Atlantic Oscillation. The two scientists found late twentieth-century *warming*, not cooling, that is consistent with global warming predictions.[13] In fact, temperatures in that part of Greenland are rising twice as fast as in the rest of the globe! The last sentence in the paper's concluding section says, "Our analysis suggests an agreement between observation and climate model predictions of the rate of temperature change due to global warming in Greenland and its ratio to the rate of global temperature change."

Kenner addresses the questions of ice sheets and glaciers in other parts of the world in at least two other places in the book. One of these passages, accompanied by nine references from the scientific literature, addresses whether or not Antarctica is melting. Much of Antarctica is not melting—no serious climate scientist expects the ice mass in the interior of the vast southern continent to do so. Antarctica is isolated from other continents by the Southern Ocean, a vast, cold body of water accompanied by weather systems that acts as a chiller—the cold waters absorb heat from southward-moving air masses that pass over them en route to the southern pole. The interior of the continent is a vast, high plateau. In the troposphere—the lower layer of the atmosphere in which almost all "weather" occurs—the higher you go, the colder it gets. Thus, the high elevations of Antarctic interior likewise serve to keep temperatures frigid. Thus, there's little reason to expect much, if any, warming in the Antarctic interior.

But there are data to suggest that parts of Antarctica are cooling—this is the evidence that Crichton highlights to dispel notions of any real global warming. The problem with Crichton's argument is that the data series that show this cooling are of fairly short duration—most are series of less than fifty years—way too short to draw any statistically sound conclusions about trends. Another problem is that, while a slight majority of the continent appears to be cooling—about 60 percent according to Peter Doran of the University of Chicago, the author of one of the papers Crichton cites—the rest is, well, warming.[14] One

[13] Petr Chylek and Ulrike Lohmann, "Ratio of the Greenland to Global Temperature Change: Comparison of Observations and Climate Modeling Results," *Geophysical Research Letters* 32 (2005): L14705, doi:10.1029/2005GL023552.

[14] Peter T. Doran, John C. Priscu, W. Berry Lyons, John E. Walsh, Andrew G. Fountain, Diane M. McKnight, Daryl L. Moorhead, Ross A. Virginia, Diana H. Wall, Gary D. Clow, Christian H. Fritsen, Christopher P. McKay, and Andrew N. Parsons, "Antarctic Climate Cooling and Terrestrial Ecosystem Response," *Nature* 415 (2002): 517–520.

of the areas that is warming, the Antarctic Peninsula, a fingerlike projection that points north toward the tip of South America, is warming at a far higher rate than the rest of the planet. Several large ice sheets that used to cling to the edges of Antarctica, the Larsen A, Larsen B, and the Wilkins ice shelves, each have collapsed suddenly in the last fifteen years. Warmer temperatures overall, longer melt seasons, and the destabilizing effects of surface meltwater as it seeps into the ice below have contributed to the disintegration of these massive accumulations of ice. The Larsen B ice shelf faced a double whammy: warm air temperatures and meltwater eating at it from above and warm currents eating at it from below. Most of it broke up in a matter of days.

Crichton mentions a 1999 study in the journal *Nature* that found that maximum temperatures during the last four interglacials—warm periods in between the ice ages—were warmer than today.[15] That may be true, but the last four interglacials are long since over. Crichton fails to note the fallacy of comparing an ongoing event to similar events that have run their course. None of the four previous interglacials can get any warmer; they are all finished. The current warm period, called the Holocene by earth scientists, has not yet run its course. No one will *know* whether or not it ends up warmer, colder, or about the same as the previous four interglacials for several hundred, or even several thousand, more years.

It might not be wise to wait until the year 3000 to make sure the current warm period is hotter than its predecessors before taking action to combat global warming.

A number of studies have found that the glacial (ice age)/interglacial cycles are closely related to characteristics of the Earth's orbit around the sun as well as the Earth's tilt on its axis. The two factors largely control the amount and distribution of solar radiation that strikes the Earth. Few climate scientists would challenge that statement today. Nevertheless, there is considerable room for the influence of greenhouse gases. The 1999 study cited by Crichton in an effort to cast doubt upon the concept of global warming instead finds greenhouse gases important.

[15] J. R. Petit, J. Jouzel, D. Raynaud, N. I. Barkov, J. M. Barnola, I. Basile, M. Bender, J. Chappellaz, M. Davisk, G. Delaygue, M. Delmotte, V. M. Kotlyakov, M. Legrand, V. Y. Lipenkov, C. Lorius, L. Pépin, C. Ritz, E. Saltzmank, and M. Stievenard, "Climate and Atmospheric History of the Past 420,000 Years from the Vostok Ice Core, Antarctica," *Nature* 399 (1999): 429–436.

> These results suggest that the same sequence of climate forcing operated during each termination [of an ice age]: orbital forcing (with a possible contribution of local insolation changes) followed by two strong amplifiers, greenhouse gases acting first, then deglaciation and ice-albedo feedback.

The final sentences of the 1999 study go even further to remind readers that it is premature to be as dismissive as Crichton is of the threat of global warming.

> Finally, CO_2 and CH_4 concentrations are strongly correlated with Antarctic temperatures; this is because, overall, our results support the idea that greenhouse gases have contributed significantly to the glacial-interglacial change. *This correlation, together with the uniquely elevated concentrations of these gases today, is of relevance with respect to the continuing debate on the future of Earth's climate.* (emphasis added)

Later in the book, Crichton engineers a scene where Kenner the MIT professor engages a character named Ted Bradley, a Hollywood actor active in environmental causes such as those espoused by NERF, in a rather uneven duel over the scientific evidence for or against global warming. Bradley gets flustered, at one point muttering "all the glaciers melting" in a list of warning signs of global warming. Kenner twists the statement so that it seems those concerned with global warming believe literally that all glaciers are melting. (Kenner does this twice in less than one page of text.) No one who is properly informed—not even Al Gore—believes all glaciers are melting. But this piece of literary trickery implies such, casting doubt on the sanity and/or scientific competence of those concerned about global warming.

Kenner concedes that some glaciers are shrinking, while others are not. But he presses his argument further: No one knows whether the majority of glaciers are getting smaller. Then he says there is no way we can know: detailed mass balance data (measures of the amount of ice that accumulates via precipitation versus that lost through melting or other processes) are available for only a small number of glaciers worldwide. This latter point sounds convincing, but it's got a major problem. There isn't a single field across the entire spectrum of academic disciplines in which a large percentage of the population of interest has been scientifically sampled. Everything scientists know in any discipline in which scientists are involved is based on the analysis of a small subset of the whole. In order to damn the work of those who study glaciers, Crichton damns all sciences.

Crichton accurately quotes Roger J. Braithwaite, who wrote a review article in *Progress in Physical Geography* on the status of glacier mass balance studies in the latter part of the twentieth century, that "There is no obvious common global trend of increasing glacial melt in recent years."[16] The time period analyzed by Braithwaite ended in 1995. His criticisms were that most records were too short (generally less than ten years) to draw reliable conclusions; that there was a lack of adequate representation of glaciers from regions outside of North America, Europe, and the former Soviet Union; that most glaciers analyzed were from moist, maritime environments rather than from the dry, cold environments characteristic of many alpine glaciers; and that the methods traditionally used to estimate mass balance were fraught with error—the errors stemming from difficult field conditions and the complicated nature of the environments in which the glaciers are found.

Many of the weaknesses cited by Braithwaite have since been addressed. More glaciers in the Andes and Patagonia, the Eurasian Arctic, the mountains of central and southern Asia, and the Sub-Antarctic islands have been studied, thus improving the global coverage of mass-balance analyses. Improved methods have been applied and ways to reduce errors inherent in traditional methods of obtaining mass balance data. Short records have been lengthened by additional data.

With this new and improved data, it is reasonable to conclude that glaciers in many parts of the world are shrinking. According to the National Snow and Ice Data Center (NSIDC), which uses satellite data instead of the traditional field-based methods to obtain mass balance data, large volumes of ice have been lost from glaciers in Alaska, northwestern United States, southwestern Canada, the mountain spine of Asia, and Patagonia. The findings of the NSIDC project are supported by those of other glacier studies using other—including traditional—methods. The most recent revision to the Glacier Mass Balance and Regime database, compiled by Mark Dyurgerov of the University of Colorado's Institute of

[16] Roger J. Braithwaite, "Glacier Mass Balance: The First 50 Years of International Monitoring," *Progress in Physical Geography* 26 (2002): 76–95.

Arctic and Alpine Research, lists traditionally derived mass balance data for 304 glaciers worldwide, including some from areas originally listed as underrepresented in the Braithwaite review, over a collective period from 1946 to 2003. The data are somewhat difficult to compare because of the variation in lengths of the samples. About one-third of the dataset consists of a series of less than five years; of those, forty-five series contain only one year of measurements. A series of more than forty years in length makes up one-tenth of the dataset; the longest series spans fifty-eight years. Of those data series with more than ten years of measurements, 102 glaciers had a net negative mass balance (loss of ice); only fifteen had a net positive mass balance. When a series of three or more years in length is analyzed, 185 have a net negative mass balance; only forty-nine have a net positive mass balance.[17] The trends in both series are similar. Ice mass losses averaged about 290 mm/year in equivalent water depth—the way precipitation amounts are measured—from 1951 through 1955, increasing to just over 300 mm/year during the next five-year period. Ice mass losses decreased to about 80 mm/year during 1971 through 1975. Losses have steadily increased since, to about 500 mm/year from 1996 through 2000. The years 2001 through 2003 (the last year for which sufficient data are available) were even higher, averaging about 1000 mm/year.[18] The regions in which ice mass losses have occurred are widespread: North America, much of Eurasia (including Europe, the former Soviet Union, and South Asia), Iceland, Kenya, South America (including Patagonia), New Zealand, and some of the Sub-Antarctic islands.[19]

Temperature decreases with altitude in the troposphere. This temperature gradient can affect the local mass balance on a glacier. In the upper portion, cooler temperatures may lead to an accumulation (net mass gain) of ice. In the lower portion, warmer temperatures may lead to a net mass loss of ice. The elevation where the balance is zero (no net gain or loss over the course of a year) is the equilibrium-line altitude. During warmer climate phases, the equilibrium-line altitude will

[17] Mark Dyurgerov, *Glacier Mass Balance and Regime Measurements and Analysis*, 1945–2003, eds. Mark Meier and Richard Armstrong. (Boulder, Colo.: Institute of Arctic and Alpine Research, University of Colorado; distributed by the National Snow and Ice Data Center, Boulder, CO, http://nsidc.org/data/g10002.html, accessed 30 Aug. 2007).

[18] Ibid.

[19] Ibid.

be higher. During cooler phases, it will be lower. Dyurgerov reported in 2002 that the equilibrium line has risen globally by about 200 meters in the latter half of the twentieth century.[20]

Kenner is closer to the truth when he addresses one of the poster children of global warming: the shrinking snows of Mount Kilimanjaro. Kilimanjaro is a massive volcano located near the equator in Tanzania. For as far back as anyone can remember, its summit has been covered with snow and ice. But the glaciers have been receding since the late 1800s. The decline continues, although the pace of the decline is much reduced, today. Despite the imagery depicting the shrinking glaciers of Kilimanjaro in discussions of global warming, however, global warming per se may have little to do with it. For one, the glaciers began receding decades before the effects of global warming were noticeable. While there is evidence of a slight warming at lower elevations, there is no evidence of warming at the level of the summit—in part because no long-term temperature measurements exist. Satellite measurements of the temperature of the upper part of the troposphere, balloon-based measurements, and computer models all indicate little or no warming in the last few decades in the elevation band where Kilimanjaro's glaciers are located.[21,22] While these data are suggestive, they do not constitute proof. Nevertheless, it is reasonable to conclude that temperature changes have little to do directly with the loss of Kilimanjaro's ice cap.

What has changed? Land use surrounding the mountain, for one. The clearing of forests for human uses has altered the local climate regime, resulting in a reduction of precipitation. Trees typically pump a lot of water vapor back into the atmosphere via a process called transpiration. The vegetation that has replaced the forests—grasses and agricultural crops—does not transpire as much as trees. As the atmospheric moisture source dries up, precipitation goes down. Georg Kaser, a scientist at the University of Innsbruck, has suggested that such changes have altered the mass balance of ice at Kilimanjaro's sum-

[20] Mark Dyurgerov, *Glacier Mass Balance and Regime: Data of Measurements and Analysis*, eds. Mark Meier and Richard Armstrong. Institute of Arctic and Alpine Research, Occasional Paper No. 55 (Boulder, Colo.: Institute of Arctic and Alpine Research, University of Colorado, 2002).

[21] Georg Kaser, Douglas R. Hardy, Thomas Mölg, Raymond S. Bradley, and Tharsis M. Myera, "Modern Glacier Retreat on Kilimanjaro as Evidence of Climate Change: Observations and Facts," *International Journal of Climatology* 24 (2004): 329–339.

[22] Philip W. Mote and Georg Kaser, "The Shrinking Glaciers of Kilimanjaro: Can Global Warming Be Blamed?" *American Scientist* 95 (2007): 318–325.