Biography of Veerabhadran Ramanathan

Atmospheric brown clouds—wandering layers of air pollution as wide as a continent and deeper than the Grand Canyon—are enough to dim atmospheric physicist Veerabhadran Ramanathan's innate optimism. In fact, studying the effect of these clouds on the climate has landed him in the peculiar role of a scientist who wants to be wrong. "The most pessimistic scenario for me would be that what our model is suggesting for the future turns out to be true," he says.

Dark particles floating throughout these brown clouds threaten to reduce rainfall, dry the planet's surface, cool its tropics, and stifle its sunlight. Yet Ramanathan, who has spent most of his career studying the atmospheric checks and balances of the Earth, does not want to wait to see what will happen. "I'm hoping that our findings will be taken as an early warning, and corrective measures taken now, so we don't have to test the model." Ramanathan and his coauthors discuss their most recent findings about atmospheric brown clouds in his Inaugural Article in this issue of PNAS (1).

Elected to the National Academy of Sciences in 2002, Ramanathan is a distinguished professor of atmospheric sciences and the director of the Center for Atmospheric Sciences at the Scripps Institution of Oceanography at University of California, San Diego (La Jolla, CA). He is a fellow of the American Academy of Arts and Sciences, American Association for the Advancement of Science, American Meteorological Society, and American Geophysical Union. In 2004, he was elected to the Pontifical Academy of Sciences at the Vatican by Pope John Paul II. Ramanathan is the current cochief scientist of the Atmospheric Brown Cloud Project, past cochief scientist of the Indian Ocean Experiment, past chief scientist of the Central Equatorial Pacific Experiment, and the principal investigator of the National Aeronautics and Space Administration (NASA) Earth Radiation Budget Experiment.

Opening a Pandora's Box of Greenhouse Gases

Veerabhadran Ramanathan

Ramanathan's first taste of independent research came at age 11, when he moved from Madurai, India, to Bangalore, a town in India where classes were not taught in his native Tamil tongue because of lingering British influences. "I didn't understand what they were saying, because it was all in English," he says. His normally stellar grades suffered, "but it had a huge positive impact," Ramanathan says. "I basically lost the habit of listening to my teachers and had to figure out things on my own. I just lost the fear of the unknown."

Ramanathan studied engineering at the Annamalai University in Bangalore, graduating with a bachelor's degree in engineering in 1965. After spending a couple of unhappy years at a refrigeration manufacturing company, Ramanathan joined the Indian Institute of Science, also in Bangalore, for graduate school. Working mostly at night to avoid traffic vibrations, he painstakingly built India's first Mach–Zehnder interferometer, a sensitive piece of optical equipment used to measure minute temperature gradients in turbulence research. He set his sights on eventually doing graduate work in the United States, though not necessarily for the research opportunities. "My interest at that time in coming to the U.S. was to enjoy the good life," he says. "I wanted to drive big, fast cars."

Ramanathan never bought his gas guzzler, because his global warming knowledge grew faster than his salary did. When he arrived at the State University of New York at Stony Brook, now Stony Brook University (Stony Brook, NY), in 1970 to work on the university's new interferometer, he found his engineering career had been rerouted into the atmospheric sciences. His advisor, Robert Cess, was no longer interested in interferometer research. "I don't think he ever even saw the equipment," says Cess, now a distinguished professor and distinguished service professor emeritus at the Marine Sciences Research Center at Stony Brook University. "The first task I gave him was a literature search on the atmosphere of Venus. He took it in good stride. He's very flexible." The planetary atmosphere work turned into a doctoral thesis, which Ramanathan defended in December 1973.

He then joined a small group of scientists at NASA Langley in Hampton, VA, who were studying reentry physics. While there, he visited the National Center for Atmospheric Research (NCAR) in Boulder, CO, and learned about research that Mario Molina and Sherwood Rowland were conducting on chlorofluorocarbons (CFCs) and the ozone hole. Ramanathan immediately connected this research with two previous experiences—his engineering job in India dealing with CFCs leaking from refrigerators and his graduate research at Stony Brook studying the role of carbon dioxide in trapping atmospheric infrared radiation on Mars and Venus. After consulting with his former advisor, Cess, Ramanathan began investigating how CFCs compare with carbon dioxide in their greenhouse effect on Earth's climate.

After a few months of calculations, Ramanathan found an answer that would change how scientists viewed climate change. "Until 1975, we used to think the global warming problem was mainly from carbon dioxide," he says. His result suggested otherwise (2), showing that "adding one molecule of CFC to the atmosphere would have the same greenhouse effect as adding more than 10,000 molecules of carbon dioxide." That CFCs, which are relatively rare in the atmosphere, could be such a powerful force in global warming was met with disbelief, not in the least from Ramanathan himself. "I was surprised that even at a part per billion they can have such a large impact," he says. He gave up his dream of fast cars and embraced his new field of research: "For me, that was the turning point. I was shocked at the capacity of technology and human beings to change the environment."

This is a Biography of a recently elected member of the National Academy of Sciences to accompany the member's Inaugural Article on page 5326.

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The scientific community balked, too—one researcher reportedly called the result "crazy," but after a few years other groups reproduced and accepted Ramanathan's estimates. The finding opened a Pandora's Box of greenhouse gases, Ramanathan says, as he and other researchers began to uncover additional trace greenhouse gases such as stratospheric and tropospheric ozone, carbon tetrachloride, methane, and nitrous oxide. "It made the whole greenhouse effect and global warming problem much larger and more urgent," he says. His trace gas research contributed to the creation of the field of climate–chemistry interactions, culminating in the 1985 paper "Trace Gas Trends and Their Potential Role in Climate Change" with Jeffrey T. Kiehl, Hanwant B. Singh, and current president-elect of the National Academy of Sciences, Ralph J. Cicerone (3). Ramanathan also chaired a 1987 World Meteorological Organization report establishing the importance of trace gases other than carbon dioxide to global warming (4). Much of this work was carried out at NCAR, which Ramanathan joined in 1976 as a postdoctoral fellow.

Ramanathan could not ignore his own compelling evidence for the powerful contribution of trace gases to the greenhouse effect. He became convinced that predicted global warming trends would manifest earlier than imagined—during his lifetime, not a century hence. Ramanathan teamed up with climatologist Roland Madden to try to pin down a more exact date for the coming effects. Their study, published in 1980, concluded that global warming would become large enough to be detected as early as 2000 (5). In 2001, the Intergovernmental Panel of Climate Change, consisting of over a thousand scientists from around the world, released a report confirming what Ramanathan and Madden had predicted two decades before: the human impact on Earth's surface temperatures was already discernable.

Our Faustian Bargain with Air Pollution

Trace gases are only part of the atmospheric puzzle, however. Through his initial work in climate–chemistry interactions, Ramanathan began to study how various factors create stable patterns in the Earth's climate—and what happens when the pieces fall out of balance. He turned to research with large-scale models of the climate and helped to develop the NCAR community climate model in 1983, which included the radiative effects of greenhouse gases and cirrus clouds on atmospheric circulation (6). The uncertain effect of clouds, in what Ramanathan calls the "Gordian knot of the climate problem," held his attention. "On the one hand, water drops and ice crystals have an enormous greenhouse effect, so they heat the planet," he explains. "But clouds also reflect sunlight, so they have a cooling effect. We didn't know which of those two dominated."

To answer this question, Ramanathan needed data. In 1979, he collaborated with NASA to design the Earth Radiation Budget Experiment (ERBE). Over 14 years and with a budget of $150 million, the project collected observations from three satellites and provided a wealth of data for many studies. In 1989, while a professor in the Department of Geophysical Sciences at the University of Chicago (Chicago, IL), Ramanathan authored a paper using these ERBE data to show that clouds did in fact cool the planet more than heat it (7).

"Air pollution has to be reduced, if not eliminated. It's just a Faustian bargain we have made without realizing it."

Ramanathan wondered how the planet would look after another century of greenhouse warming. He suspected he could find clues by looking at locales that were already warm and humid, such as the western Pacific Ocean. Ramanathan used ERBE data to show that water vapor in this area traps even more infrared radiation than expected, in a "super greenhouse effect." This finding led him to question how these ocean temperatures remained remarkably stable despite the super greenhouse effect. In 1993, shortly after he joined the Scripps Institution of Oceanography, Ramanathan launched the Central Equatorial Pacific Experiment in Fiji. Although his initial interest lay in measuring how clouds might act as a thermostat to regulate surface temperatures in the western Pacific Ocean, his unexpected observations sent him on another quest. "The models were overpredicting how much sunlight was reaching the surface," he says, and the western Pacific Ocean was ≈8% darker than expected (8). Ramanathan suspected the culprit might be aerosols—tiny, floating particles of dust or pollution that could absorb and scatter sunlight.

For studying atmospheric particulates, Ramanathan actually grew up in an ideal region. Every year, India and the rest of south Asia send clouds of air pollution to hover over the Indian Ocean during the dry winter months. To look further at this pollution and its effects on sunlight, Ramanathan and Paul J. Crutzen, a German atmospheric chemist interested in air pollution, together designed the Indian Ocean Experiment (INDOEX) in 1995 (9). Originally conceived as a small experiment with only a few instruments on a ship, INDOEX eventually expanded to include six aircraft and 200 scientists from six countries. "The idea caught fire," Ramanathan says. "It's probably one of the most comprehensive and detailed experiments wherein we can directly observe how humans are impacting the environment."

The impacts were more worrisome than expected. From their INDOEX observations, Ramanathan and his colleagues found that a haze of air pollution 3-km thick lies over most of the Arabian Sea, Bay of Bengal, and the Indian subcontinent, spreading across an area larger than the continental United States. "The surprise was the vastness of it," Ramanathan says, "and that it could spread on a continental scale." This so-called brown cloud reduces sunlight by as much as 10% to 15%, the INDOEX researchers found (10, 11). The main problem was the amount of black carbon suspended in the haze, which results from coal burning, diesel fuel combustion, and inefficient cooking. "I finally found my dark substance that was reducing sunlight," Ramanathan says. In 2001, the United Nations Environment Program initiated the Atmospheric Brown Clouds (ABC) research program, led by Ramanathan and Crutzen, with countries including India, China, Japan, Korea, Thailand, and the Maldives actively involved. This interdisciplinary group aims to understand the impact of air pollution worldwide, especially on monsoons, agriculture, and public health.

The effects of aerosols in brown clouds are particularly insidious because they seem to have the opposite effect of greenhouse gases. "By sheer, dumb luck, we are adding particles that are trapping sunlight and cooling the planet," Ramanathan says, but these particles only mask global warming without eliminating it. A sudden drop in global air pollution would be like removing the mask, he explains, and the climate may play catch-up to compensate. "Many of us, including myself, are concerned we could see a huge acceleration of global warming if we unmask the beast.” Yet ignoring air pollution is not the solution either, as studies clearly show its serious health effects, he says. “Air pollution has to be reduced, if not eliminated. It’s just a Faustian bargain we have made without realizing it.”

In his Inaugural Article in this issue of PNAS, Ramanathan and his coauthors (1) reveal that atmospheric brown clouds may be perturbing and decreasing seasonal rainfall patterns in addition to reducing sunlight. The group reports that from 1930 to 2000, emissions from fossil fuel and black carbon increased 6-fold in India, whereas monsoon rainfall and surface sunlight both decreased. Ramanathan and his team ran computer simulations to identify the various factors contributing to these changes and found that greenhouse gases alone were not enough to account for the trends. Atmospheric brown clouds seemed to play a crucial role in the regional climate changes. The study suggests that if current trends in air pollution emissions continue, droughts on the Indian subcontinent could double in the coming decades. The study took 4 years to complete and was a joint research project with Warren Washington, chairman of the National Science Foundation’s National Science Board and senior scientist at NCAR, and his community climate model group.

Three factors contribute to the drying effect, Ramanathan says. First, brown clouds blot out sunlight, which cuts down on the evaporation from the planet’s surface. With less moisture in the atmosphere, rainfall decreases. Second, the solar absorption by the black carbon in the brown clouds heats the atmosphere, while at the same time cooling the surface by shielding it from sunlight. Such a redistribution of solar heating leads to temperature inversion, where warmer air overlies colder surfaces, which inhibits normal convection patterns and suppresses rainfall. Last, the effects are not uniform across the entire Indian Ocean because the northern area receives more pollution compared with the southern area. Hence, the north grows cooler than the south, which slows the monsoon circulation that normally brings rainfall to more than 1.3 billion people in south Asia. Although the study needs to be verified by other research groups, Ramanathan says if these conclusions are widely accepted, they could be among the most compelling reasons for the global community to regulate air pollution.

An Honest Reporter of Findings

In Ramanathan’s eyes, a bit of questioning by the scientific community is not a negative thing. “The worst that can happen is that people ignore it,” he says. “So resistance is good. It means they are paying attention.” Any resulting discussion is invariably constructive, Ramanathan says, because researchers bring their own tools to bear on the problem. Yet in reference to his recent findings, he points to lingering skepticism in the United States about the entire global warming issue and says that simple discussions might not be enough to bring about changes in south Asian air pollution. “This is a very complex problem, and I don’t think it is something India can do by itself,” he says. “Even in the U.S., we are saying we can’t afford to reduce greenhouse gases because it’s going to ruin the economy. What chance does a developing nation have?”

Politics are inherently built into the brown cloud problem, Ramanathan says, because atmospheric brown clouds literally cross national and continental boundaries. “We see pollution coming from the U.S. going across the Atlantic into Europe, and you see pollution from east Asia crossing the Pacific coming to the U.S.,” he says. “So who is polluting whom?” Ramanathan admits that it is difficult to avoid politics completely in global warming research, but he still prefers to stay out of it as much as possible. “I’ve always taken the approach that I just have to present what my data show,” he says. “Sometimes it’s not going to be the right thing for the politics, but I can’t worry about this.” Ramanathan also has fielded his fair share of inquiries from journalists, and he notes that most of his funding comes from taxpayers’ money. “They have a right to know, and so I feel scientists have an obligation to explain to the media when they call us.”

Perhaps more important than media or political attention, Ramanathan suggests, are constructive policy discussions of global warming issues. “I’m not saying to solve the problem is impossible, but getting the people together to solve it is the issue.” In fact, Ramanathan will be speaking at the ABC project update in China in April of this year. “We’ll be meeting with the environmental ministers of the regions to bring them up to speed.” Ramanathan says he is particularly excited to be working on the ABC project with Klaus Toepfer, the head of the United Nations Environment Program and a former environmental minister of Germany. Toepfer is highly committed to air pollution problems, Ramanathan says.

To find Ramanathan, who was once a nocturnal and solitary engineer, now leading international efforts to understand Earth’s large atmospheric systems is not entirely surprising to Jeffrey Kiehl, a former postdoctoral student and current coauthor of Ramanathan’s. “He’s the kind of person that when he decides to do something, he just throws himself into it completely,” says Kiehl, now a senior scientist at NCAR. “And if he gets interested in a problem and you’re around him, it’s inevitable that you’re going to get excited about the problem as well. He’s infectiously enthusiastic.”

Regina Nuzzo, *Science Writer*

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