

## QnAs with Benjamin D. Santer

**W**hen Benjamin Santer began studying the Earth's climate in the late 1970s, he simply wanted to understand the links between human behavior and global climate change. Computer models and statistical analysis enabled him to measure this relationship. By developing "fingerprints" that distinguish between human and natural influences on climate, Santer, a recently elected member of the National Academy of Sciences and atmospheric scientist at the Lawrence Livermore National Laboratory in Livermore, California, became one of the first scientists to prove the existence of human-induced climate change. Many groups have since independently confirmed those findings. Santer's work has put him at the heart of the political debate surrounding anthropogenic climate change. The fight, at times, has turned vicious: in 1996, the Global Climate Coalition accused him of "scientific cleansing," a spiteful claim, he says, given the ethnic cleansing going on in Bosnia at that time. Undeterred, Santer continued his "fingerprint" research and received two awards for this work in 1998: the prestigious MacArthur Fellowship and the Norbert Gerbier-MUMM International Award from the World Meteorological Organization, given annually to the researcher with the year's best climate science study. Here, Santer discusses how his research helps shift discussions of climate change from ideology to science.

**PNAS:** The heart of your work relies on a method known as fingerprinting. Can you describe the process?

**Santer:** Fingerprinting relies on the fact that different influences on climate have unique patterns of climate response. So changes in the sun's energy output don't do exactly the same thing to the climate system as human-caused changes in greenhouse gases. For example, some people have speculated that all of the warming observed over the 20th century is due to a slight increase in the sun's energy output. That's a testable hypothesis. If all warming really were some slight "dialing up" of the sun over the 20th century, we'd expect to see heating through the whole vertical extent of the atmosphere. However, in weather balloon and satellite data, we see warming of the lower atmosphere (the troposphere) and cooling of the upper atmosphere (the stratosphere). This fingerprint is fundamentally inconsistent with the hypothesis that the sun explains all of the 20th century surface warming.

**PNAS:** How have you been applying this fingerprinting work over the years?

**Santer:** Our initial fingerprinting work in the early 1990s focused on changes in Earth's surface temperature. Critics of this work argued that if there really is a human-caused climate change signal lurking in observa-



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tions, we should see that signal in many different aspects of the climate system, not surface temperature alone. Research groups around the world took this criticism seriously. The science has now moved well beyond "surface temperature only" fingerprint studies. At Livermore, we've looked at changes in ocean heat content, the height of the tropopause, the temperature of the troposphere and the stratosphere, and the amount of water vapor in the atmosphere. The take-home message from this work is that natural causation alone cannot explain observed changes in all these different aspects of the climate system. The best explanation for these changes has to involve a substantial human contribution.

**PNAS:** Your Inaugural Article creates a fingerprint for atmospheric temperature. Why did you study this climate variable?

**Santer:** For well over a decade, many people in our community have been interested in atmospheric temperature changes in the lowest five kilometers of the atmosphere, or the lower troposphere. Since 1979, scientists have monitored atmospheric temperature from space using Microwave Sounding Units. These instruments are carried on NOAA [National Oceanic and Atmospheric Administration] polar-orbiting satellites and measure the microwave emissions of oxygen molecules, which are fairly evenly distributed throughout the atmosphere. It turns out that the microwave emissions of oxygen molecules are proportional to temperature at different layers of the atmosphere. So by measuring these microwave emissions at different frequencies, you can then reconstruct atmospheric temperature.

Initially, the only group looking at these satellite-based measurements of microwave emissions was from the University of Alabama at Huntsville. That work suggested that the lower atmosphere was cooling—

a huge puzzle. Surface thermometer measurements indicated that land surface and ocean surface had warmed since 1979, so how could the air above the surface be cooling? People who did not want to believe in a human effect on climate cited these satellite measurements. Subsequent studies have shown that the Alabama group's data contained several serious errors.

Our most recent work is perhaps the most complete exploration to date of climate fingerprinting for atmospheric temperature. We've used results from phase 5 of the Coupled Model Intercomparison Project (CMIP-5). Started in the mid-1990s, CMIP allows us to compare results from essentially all of the world's computer model simulations of climate change. Using these model simulations, we showed that the geographical pattern of atmospheric temperature change due to human influences is unambiguous across all available satellite datasets.

**PNAS:** Your work has put you in the thick of the ongoing political debate surrounding human-induced climate change. How prepared were you for the political fallout?

**Santer:** I was clueless. In 1990, I participated as a contributing author to the first assessment report of the Intergovernmental Panel on Climate Change [IPCC]. My only concern was getting the science right. I had no idea whatsoever of the political context in which this "fingerprint" work was embedded; and indeed, it was difficult to have that context back in 1990. We didn't know enough back then to say definitively whether there really was a human-caused climate change signal. The IPCC's first assessment report concluded that the jury is still out. The situation completely changed in 1996, with one historic sentence from the IPCC's second assessment report: "The balance of evidence suggests a discernible human influence on global climate." It's funny to think that for the rest of your life, you will be inextricably linked with one sentence.

**PNAS:** However, you have continued on the same path. What motivates you to keep going?

**Santer:** I'm not the naive blue-eyed young man I was back in 1996, that's for sure. However, powerful forces of unreason are still claiming that human-induced climate change is all a hoax or a conspiracy. I truly believe that the best defense against such arguments is good science. If the leaders of this nation and this world are to make informed decisions on how to address the problem of human-caused climate change, they need the best-available scientific information. So I've hunkered down and tried to continue to improve our scientific understanding of the nature of climate change.

Sujata Gupta, *Freelance Science Writer*

This is a QnAs with a recently elected member of the National Academy of Sciences to accompany the member's Inaugural Article on page 26.