CLIMATE

Physicists Watch Global Change Mirrored on the Moon

The big problems in science usually cost big bucks to explore. But not always. A handful of physicists "moonlighting" in another field have rediscovered a 70-year-old technique to study one aspect of climate change—and they're doing it for a price that is several orders of magnitude below the billion-dollar cost of the global change program.

With nothing more than a small telescope, some imaging equipment, and a view of the moon, interdisciplinary teams at the University of Arizona and the California Institute of Technology are measuring the 30% of incoming solar radiation that is reflected back to space by clouds, snow cover, and haze. This earthshine, as it's called, is visible to us on Earth as the faint glow on the dark portion of a crescent moon. Its intensity is a measure of Earth's albedo, or reflectivity, which plays a vital role in climate: Decrease the albedo by as little as 1%, for example, and global temperatures will rise by 2 degrees Fahrenheit. Conversely, change global temperatures, and the albedo might change in response, resulting in a feedback that could reduce or amplify a climate shift. For this reason, trustworthy long-term measurements of the albedo are vital to understanding greenhouse warming.

The usual way to monitor albedo is by satellite, but satellite measurements have several drawbacks. For one thing, satellites cost hundreds of millions of dollars to build and launch. They are also subject to delays and instrument failures, and the satellite record so far spans only a couple of decades. What's more, says Ari Patrinos, director of the Global Change program at the Department of Energy (DOE), satellites measure albedo across small patches of the planet, and errors can creep in when those small-scale measurements are integrated across the entire Earth.

Then there's the moon-watching technique, conceived by French astronomer André Danjon in 1925 and practiced by him and then his student, J.E. Dubois, through the 1950s. The equipment and computing time cost at most a few tens of thousands of dollars. That low cost makes it a tempting "pet project," in the words of earthshine watcher Donald Huffman, a University of Arizona physicist better known for pioneering a technique to mass-produce C_{60}, the all-carbon "buckyball" molecule. And for measuring overall albedo, says Steven Koonin, a theoretical physicist at Caltech, the technique's accuracy may be at least as good as that of satellites, providing a reliable way to calibrate and extend the satellite data. "When you're looking for trends," adds Patrinos, "the key is to be as simple as possible. The earthshine measurements provide an ideal way to get an integrated measure of albedo."

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Dark reflection. The sun lights the bright crescent moon, but the glow on the dark part of the disk is earthshine.

Huffman began his earthshine work in 1989 after Sean Twomey, a now-retired Arizona atmospheric scientist, suggested that they try reproducing Danjon's measurements to see whether the albedo had changed over the intervening decades. Danjon had built a telescope in which a prism split the moon's image into two identical images, which appeared side-by-side in the eyepiece. By adjusting a diaphragm along one of the light paths, Danjon could dim one image until a sunlit spot appeared to have the same brightness as an Earth-lit spot in the untouched image. Quantifying his adjustment of the diaphragm gave Danjon a measure of the brightness of the earthshine—and hence of Earth's albedo.

To resurrect the technique, Huffman and Twomey got an exploratory 1-year grant from the National Science Foundation to go to France and hunt up Danjon's instruments. Huffman had already built an accurate model of the Danjon telescope in his garage. But he picked up additional details at "this historic old observatory [the Paris Observatory], where the present director at that time, the head astronomer in all of France, came out carrying Danjon's instrument." Huffman dutifully photographed and diagrammed the old telescope. Since then, he has been taking measurements of earthshine twice a month, morning and evening, when the moon is in its crescent phase.

Meanwhile, Koonin and Gordon MacDonald, an earth scientist at the University of California, San Diego, began exploring the question of whether earthshine is a reliable gauge of albedo. Koonin says he was skeptical when he first heard about Danjon's work from MacDonald in 1990, while the two of them were overseeing a review of a proposed DOE small satellite program to study climate change. "Basically, the moon samples the light from the equator. Light hitting the polar ice caps can scatter out in ways that never hit the moon at all. You worry about missing that light, and [whether] the earthshine might not be a good measure of albedo." But by building a computer model of how sunlight is reflected off Earth and the moon, says Koonin, "we proved it was. And we showed that if you could measure earthshine to 1%, you would know the albedo to 0.2%, which is a number quite competitive with satellites."

Koonin was also able to reconcile Danjon's calculation of an average albedo of 36% with satellite measurements showing a value closer to 30%. What Koonin knew, and what Danjon had failed to account for adequately, was that the moon demonstrates an opposition effect: Its reflectivity is highest when it is bouncing light straight back to the source, as it does with earthshine. Modern instruments, Koonin realized, provide a much more accurate estimate of the opposition effect. And, indeed, when he fed the modern data into Danjon's calculations, Danjon's albedo numbers dropped into the right ballpark.

With those problems solved, Koonin and MacDonald joined with Hal Zirin, who runs the Big Bear Solar Observatory for Caltech, to create a demonstration telescope using a sensitive charge-coupled device camera left over from the cancelled NASA Orbiting Solar Laboratory. For the past year, Koonin and his colleagues have been refining their apparatus and their observing procedures while collecting data. By pooling

their results with Huffman's, they hope to detect any trends in earthshine since 1925 and provide a benchmark for future satellite measurements.

One thing already clear from the existing earthshine record, says Huffman, is that it won't be easy to prove the existence of a human-induced greenhouse effect. Dubois's measurements show years-long variations in the albedo that are much larger than can be explained by noise, Huffman says—large enough to have left their mark on the global temperature record, blurring any signature of greenhouse warming.

Pursuing such mysteries, says Huffman, "requires a long-term commitment, the kind of commitment that transcends [normal] funding [patterns]." Huffman, who hasn't asked for additional government support, and Koonin, whose group still has 18 months of funding, say they owe their success so far to Danjon's ingenuity 70 years ago. "You realize," says Koonin, "that those old guys were awfully clever....They didn't have the technology, but they invented ways of getting around without it."

–Gary Taubes

HEPATITIS STUDY

Drug Trial Deaths Deemed Unavoidable

Researchers at the National Institutes of Health (NIH) who ran a drug trial in 1993 in which five patients died were relieved last week to hear a panel of NIH-appointed experts absolve them of even a hint of blame. Their relief was understandable: Last year, a Food and Drug Administration (FDA) review questioned their procedures, and just last month a separate investigation by FDA compliance officials resulted in "warning letters" for apparent violations of FDA's reporting requirements.

The clinical trial at issue was designed to test a new drug—fialuridine (FIAU)—as a means of combating hepatitis B virus. Of the 15 patients enrolled for a 6-month course of FIAU treatment in March 1993, five died after suffering liver or pancreatic damage in June, July, and August. Two of the survivors were saved with emergency liver transplants.

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No fault found. NIH panel co-chair David Challoner.

In December 1993, a review led by FDA staffer Roger Williams found signs that the NIH researchers and drug company sponsors of the trial may have been too "optimistic" in the way they interpreted early toxicity data—blaming patients' symptoms on their pre-existing diseases rather than on FIAU treatment. The Williams report contended that data pointing to liver toxicity "were not analyzed or reported in a way that might have led to some understanding of FIAU's possible hepatic or pancreatic toxicity," but that researchers might have obtained the data before the trial began.

These findings are not discussed in detail in the NIH review, commissioned by NIH director Harold Varmus last fall. But the NIH panel concluded that the tragedy could not have been averted by better monitoring of patients or more careful review of animal data, because the toxic effects were of a "novel" late-appearing type that had not been seen before. David Challoner, vice president for health affairs at the University of Florida, Gainesville, and a co-chair of the NIH panel, says that even in hindsight, it is not easy to see how the researchers could have anticipated the toxic effects that killed these patients.

Indeed, the Challoner panel offered nothing but praise for the way NIH investigators and nurses ran the trial, saying they were "first-rate" and that they had provided "exceptional" care of the patients. It even said the research represented "the best of current practice in clinical investigations and exceeded regulatory requirements" in all respects. Challoner and co-chairman David Kipnis, an expert in metabolism at the Washington University School of Medicine in St. Louis, presented these findings on 2 June to the advisory board to the director of NIH.

Challoner said that he and the other panel members had begun the inquiry with "considerable skepticism," assuming that "a tragedy of such monumental proportions was likely to be explained by some error" of judgment or lapse in research process. But after interviewing all the researchers and the surviving patients in the FIAU trial, studying every medical record, and talking to ethics officers at all the institutions involved, the Challoner committee decided that the deaths were due to an "unavoidable accident."

Kipnis said one plausible explanation for the pattern of toxicity observed is that FIAU binds to DNA and remains in the body much longer than early research indicated. Investigators had assumed that the drug would be cleared from the body in 2.5 hours. But they had no way of learning that this assumption was wrong until after the trial was halted, when a sensitive radioimmunoassay became available. The assay showed that the drug lingers in the body for perhaps 10 times longer than expected, probably because it creates "reservoirs" as it binds to mitochondrial and genomic DNA. The binding also may cause cumulative mitochondrial injury, and this may explain why toxic effects were not detected until many weeks—in some cases, months—after administration of the first dose of FIAU.

As for the conflict between the NIH and FDA findings, the authors of the NIH report suggest that their work focused on substance while the FDA simply produced "a technical audit of record keeping and protocol compliance." Challoner made clear that, in his view, any deficiencies found in FDA's audit were not responsible for the tragedy. Asked for his own explanation of the conflict, Challoner said the FDA had declined to share its audit data, adding: "There is a discussion to be had about the accuracy of the FDA audit." A spokesman for FDA, meanwhile, said, "We think we did a very thorough review and stand by our reports."

The Department of Health and Human Services hopes to resolve some of the conflict between these two investigations with yet another study—this one to be conducted by the Institute of Medicine. The Institute hasn't received funding or chosen panel members yet, but staffers expect the report to be completed in 1995.

In the meantime, the Challoner report makes no firm recommendations for changing clinical procedures at NIH or FDA. However, it suggests that it would be wise in future to test a drug with two animal studies of the same duration and the same route of exposure as planned for a human drug trial—before beginning the human trial. A long-term tube-feeding study in rats—which eventually gave evidence of liver toxicity—was done for FIAU, but wasn't completed until after the human trial was halted. In addition, the report recommends enrolling patients in long-duration studies in staggered cohorts, so that later enrollees may be protected from unanticipated side effects that turn up in early ones. Finally, Challoner and his colleagues urge NIH to undertake a program of research on "nucleoside" drugs like FIAU that are capable of modifying DNA, focusing especially on ways to measure damage to mitochondrial DNA.

–Eliot Marshall