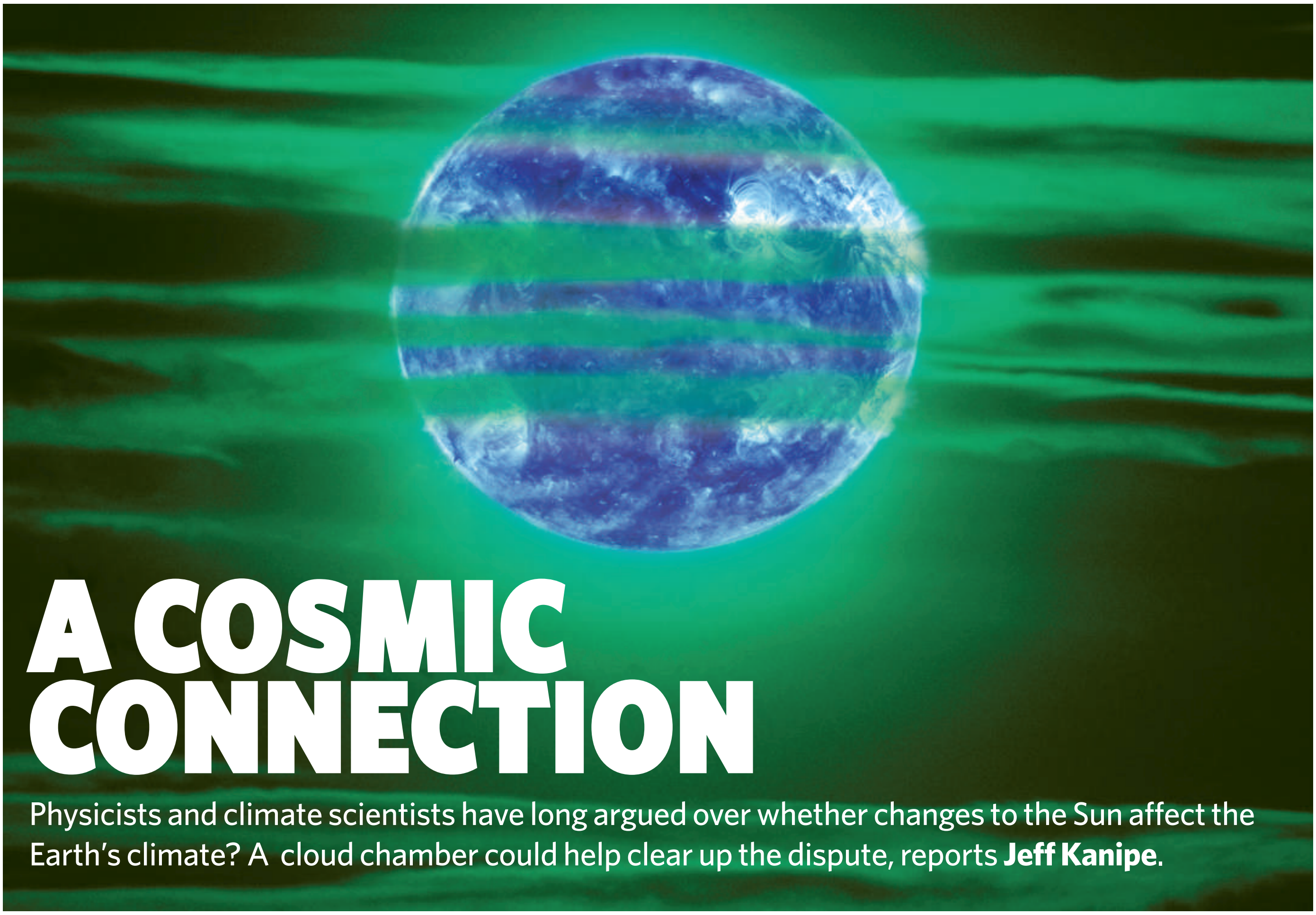


A COSMIC CONNECTION

Physicists and climate scientists have long argued over whether changes to the Sun affect the Earth's climate? A cloud chamber could help clear up the dispute, reports **Jeff Kanipe**.

The cloud chamber, invented by C. T. R. Wilson at the start of the twentieth century, opened a new microcosmos to human examination. Droplets of water coalescing around ions in a chamber saturated with water vapour provided physicists with a way of visualizing particles; tracks left by the particles were preserved like contrails across the sky (see 'The first cloud maker', overleaf). In the second half of the century, though, the technology was eclipsed — first by bubble chambers and then by a range of other devices.

Which is why it is surprising that an international team of scientists at the biggest particle-physics laboratory in the world, CERN in Geneva, Switzerland, is hard at work on a cloud chamber remarkably like those used by the physicists who founded the lab in 1954. The difference is that scientists will not use the clouds in this chamber to look for subatomic particles; they will use the particles in the chamber to try and understand clouds.

The experiment, called CLOUD (for Cosmics Leaving Outdoor Droplets), is designed to shed light on a sometimes acrimonious debate between a small number of physicists and astronomers, who believe that cosmic rays have a substantial influence on Earth's climate, and many in the mainstream climate community who don't. In CLOUD, a beam of particles from CERN's Proton Synchrotron will stand in for the cosmic rays. And a team of atmospheric physicists, chemists and space scientists from nine countries will try to see how they affect cloud formation[1].

The CLOUD chamber has various bells and whistles that its particle-focused forerunners lacked, such as control systems to simulate parcels of air rising through the atmosphere and a 'field cage' to generate an electric field similar to that found in fair-weather clouds. The chamber can generate a range of water-vapour supersaturations (relative humidity values above 100%) that will allow droplets to form on particles between 0.1 nanometres (the size of small ions) and 100 nanometres (the size of the nuclei around which drops form in natural clouds).

Sun trap

The CLOUD prototype currently under construction will see its first subatomic particles from the synchrotron in October, according to team leader Jasper Kirkby. The machine will be fully operational in 2010, unless there are hitches with its €9.1-million (US$11.6-million) budget. "Although this is a much simplified version of the final CLOUD experiment," says Kirkby, "we feel confident that, as this will be the first experiment of this kind on a particle beam, there will be very interesting new physics results."

One of the earliest connections between clouds and cosmic rays was made in 1997 in the *Journal of Atmospheric and Solar-Terrestrial Physics* by Henrik Svensmark and his colleague Eigil Friis-Christensen[2]. The two researchers were then with the Danish Meteorological Institute in Copenhagen, Denmark, and are now at the Danish Space Research Institute, also in Copenhagen. Svensmark and Friis-Christensen noted that from 1987 to 1990, global cloudiness fell by approximately 3% and that the number of cosmic rays reaching the Earth dipped by 3.5%, a fluctuation that coincided with a peak in sunspot numbers. Looking at sea and land temperatures and cosmic-ray data from 1970 to 1989, they concluded that variations in cosmic-ray intensity that depended on the sunspot cycle might be influencing global cloud cover[2].

The idea that changes in the Sun's activity can influence Earth's climate is a long-standing one. In the 1970s, US astronomer Jack Eddy found a link between the Maunder minimum — a dearth of sunspots in the seventeenth and eighteenth centuries, which reflects a change in solar activity — and the 'little ice age', as indicated by the width of tree rings. But the problem with such links was that the changes in the Sun's overall energy output seemed much too small to account for the change in the climate[3].

The cosmic-ray hypothesis provided a way around that problem. It was not, the Danes argued, a change in the Sun's output of photons that so affected Earth, it was a change in the way the stream of particles ejected from the Sun, the solar wind, interacted with Earth's magnetic field. The Sun's activity waxes and wanes in regular cycles, as revealed by changes in sunspots. Decades of data from balloon-borne radiosondes and particle detectors show that the number of cosmic rays reaching the Earth goes down when this activity is at its height, because the strengthened magnetic field associated with the solar wind deflects them. During quiescent periods, the solar wind weakens, allowing more cosmic rays to penetrate to Earth's lower atmosphere.

There the rays ionize atoms. They also occasionally hit the nuclei of atoms hard enough to create new isotopes such as carbon-14 and beryllium-10. These isotopes, stored in layered receptacles such as tree rings and ocean sediments, provide a record of solar activity going much further back than human observations — a record that, at some points, does seem to fluctuate in step with the climate[4].

Clouding the issue

Svensmark's idea was that trails of ionization in the atmosphere caused by cosmic rays created condensation nuclei on which cloud droplets could form. More cosmic rays would mean more cloud condensation nuclei and either more numerous clouds, whiter clouds, or both. These clouds would increase the rate at which sunlight was reflected away from the planet and so cool it down. Svensmark and his colleagues cite studies[5] showing that, since 1964, galactic cosmic-ray intensity has declined by about 3.7%, and that the trend indicates that this decline could have been going on since the early twentieth century. This, they argue, could account for a significant amount of the global warming that's occurred over the past 100 years[6].

This cosmic-ray connection drew a lot of media attention for several years, but never found favour with the mainstream of climate science, which holds that the twentieth century's global warming was caused by people, not particles. To many in the community, the attention paid to Svensmark and Friis-Christensen seemed to be at best a diversion, at worst a counter-attack. The connection with the Sun was played on by organizations with connections to oil companies, such as the right-wing George C. Marshall Institute in Washington DC.

There were also questions about Svensmark's use of data. In a 2004 article published in *Eos,* Paul Damon of the University of Arizona in Tucson and Peter Laut of the Technical University of Denmark discussed several examples of what they called "unacceptable handling of observational data" by Svensmark and Friis-Christensen which exaggerated the correlation[7].

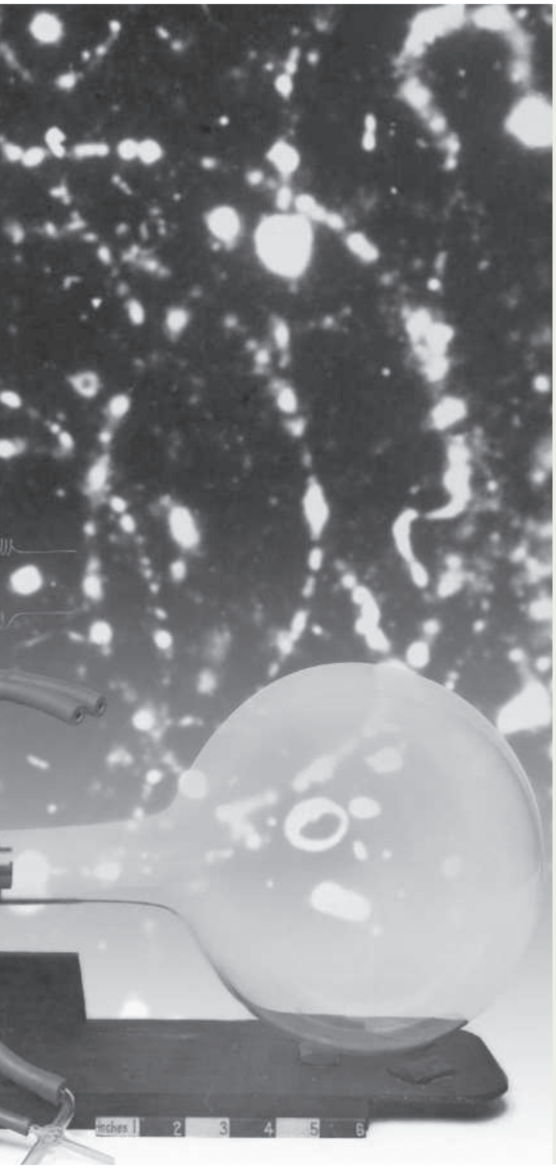
Among several flaws, including arithmetical errors, they noted that the cloud data that had been used originally did not represent total global cloud cover, and that when the correct data were used the correlation broke down. Svensmark began to use a different measure of cloudiness, justifying this by arguing that the new measure made more sense than the original one as something that the cosmic rays might be influencing.

"We feel confident that there will be very interesting new physics results." — Jasper Kirkby

CLOUD, which Kirkby has been trying to get off the ground for years, is an attempt to move beyond such arguments. It is not a completely neutral attempt — Kirkby gives talks that put a strong emphasis on the cosmic-ray interpretation of climate history, and Svensmark is a member of the CERN team. But it will produce fresh data. "CLOUD can compare processes when the 'cosmic-ray' beam is present and when it is not," says Kirkby, " and all experimental parameters can be controlled and measured."

One of those who will be watching is Nir Shaviv, an astrophysicist at the Racah Institute of Physics in Jerusalem, Israel. Shaviv bases a belief that global warming may not be solely the result of anthropogenic causes on studies of climate over extremely long timescales — hundreds of millions of years. From an analysis he has made of 80 iron meteorites, Shaviv claims to have discovered a periodicity in cosmic-ray exposure, with a peak every 143 million years, give or take 10 million years. He says this corresponds to the mean time between four crossings of the Sun through the Galaxy's spiral arms[8].

The spiral arms of a galaxy hold the greatest concentrations of massive stars, stars which over the course of tens of millions of years explode as supernovae. As cosmic rays are thought to be generated in supernova shockwaves, the Sun's passage through a spiral arm would mean greater cosmic-ray exposure, more clouds, and colder temperatures for Earth. Shaviv thus argued that these periodic crossings and the high cosmic-ray flux they bring with them correspond to four major ice-age epochs on Earth. If this could be confirmed it



THE FIRST CLOUD MAKER

In September 1894, Charles Thomas Rees Wilson, an expatriate Scot, climbed to the summit of Ben Nevis, the highest mountain in his homeland. He was fascinated with the beauty of coronae and the dazzling, rainbow-like rings encircling human-shaped shadows called Brocken spectres. He returned to the Cavendish laboratory in Cambridge keen to create controlled clouds and so study such effects.

Wilson designed a glass tank with a piston tightly inside it (see left). He misted the air in the tank with water until it was saturated, then rapidly pulled out the piston. This expanded and chilled the air, causing the water vapour to collect around dust particles and form a small cloud. As long as the piston was pulled out far enough, clouds would form even if the air inside the chamber was thoroughly filtered. Wilson suspected, but couldn't prove, that the water droplets were forming around electrically charged ions.

In February 1896, Wilson projected a beam of X-rays into his cloud chamber, and the mini clouds formed even faster, thus lending support to his theory. A year later, after Joseph John Thomson discovered the electron, it became clear that the X-rays ionized the air molecules and the electrons and ions created cloud nuclei. Wilson continued his experiments for another decade, during which he discovered that particles colliding with atoms in the chamber left wispy tracks of ions in their wake. When subjected to a magnetic field, the curve of a track indicated whether the ion was negatively or positively charged. In 1927, Wilson was awarded the Nobel prize in physics for his cloud chamber. By then, though, he had left particle physics to study the atmosphere. When CERN was founded in 1954 he was retired but still active, working on a theory of thunderclouds. **J.K.**

would link changes in the solar neighbourhood directly to climate. This idea was first considered by the great American astronomer Harlow Shapley, who speculated in 1921 that an 80% change in solar radiation due to the irregularity of interstellar clouds "would completely desiccate or congeal the surface of the Earth"[9].

Shaviv's findings have found favour with some astronomers, such as Douglas Gies, an astrophysicist at the Center for High Angular Resolution Astronomy at Georgia State University in Atlanta.

Based on the Sun's current position as determined from the distances and motions of nearby stars, Gies and a colleague, John Helsel, tracked the path of the Solar System through the Galaxy for the past 500 million years. Their findings indicate that the Sun could indeed have crossed four times through segments of the spiral arms, each passage corresponding with four major ice ages[10].

Again, climate scientists disagree. They think that the history of Earth's glaciations is pretty well accounted for by changes in the amount of carbon dioxide in the atmosphere. And in this instance, too, the climatologists contend that the astrophysicists' claims, specifically Shaviv's, are unfounded and even misleading. A paper[11] coauthored by Shaviv and Ján Veizer, now an emeritus professor at the University of Ottowa in Canada, was dressed down by no less than 11 scientists led by Stefan Rahmstorf of the Potsdam Institute for Climate Impact Research in Germany. The scientists contended among other things that Shaviv and Veizer had misinterpreted the cosmic-ray data derived from their meteorite samples[12].

A century on

A follow-up analysis of the same data set a year later by Knud Jahnke, from the Max-Planck-Institute for Astronomy in Heidelberg, Germany, showed no evidence of significant changes in cosmic-ray exposure with a 143-million-year period — or any other between 100 million and 250 million years[13]. Again, there was a heated to and fro (see Shaviv's blog at www.sciencebits.com).

Gies doesn't think the controversy changes Shaviv's findings relating Earth's spiral-arm crossings to ice-age epochs or taints the idea that cosmic rays may influence Earth's climate. "I think the findings in our paper are still valid and add weight to arguments about the possible cosmic ray–climate connection advocated by Shaviv and colleagues." Shaviv and Veizer, too, stand by their findings.

Rahmstorf, who led the charge against Shaviv and Veizer, agrees that solar variability has an influence on climate, but he is adamant that galactic cosmic rays cannot explain the global warming of the past decades. "We know that the observed climate response is the sum of several forcing factors, including the Sun, which is probably responsible for some part of the warming up to about 1940, but not for warming after that. The Sun simply shows no trend there, and neither does the cosmic-ray flux."

Perhaps the irony here is that the current emphasis on global warming is encouraging people from outside the field of climate studies to try out ideas, perhaps exaggerating their promise. At the same time those within the climate community are mindful of lobbies that seek to discredit their work, and believe enough doubt has been cast on the cosmic-ray theory to discredit it, if not ignore it completely.

Yet for a connection between cosmic rays and climate to be interesting, it does not have to account for the already well-explained climate history of the past 100 years. Even a small effect, to which Earth is only sensitive under some conditions, would be an exciting find. The CLOUD experiment does not have to overturn the consensus of the world's climatologists to be a success; it just has to throw a little light on some physics. "In a nutshell," says Kirkby, "we want to go after the microphysics between a cosmic ray and a cloud droplet or ice particle. How significant are they in the atmosphere, or in certain parts of the atmosphere?"

And even if the results prove undramatic, or inconclusive, they will still carry a certain sense of historical redress. Wilson did not set out to invent a tracker for particles; he wanted to understand the nature of clouds. For his technology to be returned to that aim more than a century on would undoubtedly have pleased him. ■

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