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Cosmic meddling with the clouds by seven-day magic

Billions of tonnes of water droplets vanish from the atmosphere, as if by magic, in events that reveal in detail how the Sun and the stars control our everyday clouds. Researchers of the National Space Institute in the Technical University of Denmark (DTU) have traced the consequences of eruptions on the Sun that screen the Earth from some of the cosmic rays – the energetic particles raining down on our planet from exploded stars.

"The Sun makes fantastic natural experiments that allow us to test our ideas about its effects on the climate," says Prof. Henrik Svensmark, lead author of a report newly published in Geophysical Research Letters. When solar explosions interfere with the cosmic rays there is a temporary shortage of small aerosols, chemical specks in the air that normally grow until water vapour can condense on them, so seeding the liquid water droplets of low-level clouds. Because of the shortage, clouds over the ocean can lose as much as 7 per cent of their liquid water within seven or eight days of the cosmic-ray minimum.

"A link between the Sun, cosmic rays, aerosols, and liquid-water clouds appears to exist on a global scale," the report concludes. This research, to which Torsten Bondo and Jacob Svensmark contributed, validates 13 years of discoveries that point to a key role for cosmic rays in climate change. In particular, it connects observable variations in the world's cloudiness to laboratory experiments in Copenhagen showing how cosmic rays help to make the all-important aerosols.

Other investigators have reported difficulty in finding significant effects of the solar eruptions on clouds, and Henrik Svensmark understands their problem. "It's like trying to see tigers hidden in the jungle, because clouds change a lot from day to day whatever the cosmic rays are doing," he says. The first task for a successful hunt was to work out when "tigers" were most likely to show themselves, by identifying the most promising instances of sudden drops in the count of cosmic rays, called Forbush decreases. Previous research in Copenhagen predicted that the effects should be most noticeable in the lowest 3000 metres of the atmosphere. The team identified 26 Forbush decreases since 1987 that caused the biggest reductions in cosmic rays at low altitudes, and set about looking for the consequences.

Forgetting to sow the seeds

The first global impact of the shortage of cosmic rays is a subtle change in the colour of sunlight, as seen by ground stations of the aerosol robotic network AERONET. By analysing its records during and after the reductions in cosmic rays, the DTU team found that violet light from the Sun looked brighter than usual. A shortage of small aerosols, which normally scatter violet light as it passes through the air, was the most likely reason. The colour change was greatest about five days after the minimum counts of cosmic rays.

Why the delay? Henrik Svensmark and his team were not surprised by it, because the immediate action of cosmic rays, seen in laboratory experiments, creates micro-clusters of sulphuric acid and water molecules that are too small to affect the AERONET observations. Only when they have spent a few days growing in size should they begin to show up, or else be noticeable by their absence. The evidence from the aftermath of the Forbush decreases, as scrutinized by the Danish team, gives aerosol experts valuable information about the formation and fate of small aerosols in the Earth's atmosphere.

Although capable of affecting sunlight after five days, the growing aerosols would not yet be large enough to collect water droplets. The full impact on clouds only becomes evident two or three days later. It takes the form of a loss of low-altitude clouds, because of the earlier loss of small aerosols that would normally have grown into "cloud condensation nuclei" capable of seeding the clouds. "Then it's like noticing bare patches in a field, where a farmer forgot to sow the seeds," Svensmark explains. "Three independent sets of satellite observations all tell a similar story of clouds disappearing, about a week after the minimum of cosmic rays."

Huge effects on cloudiness

Averaging satellite data on the liquid-water content of clouds over the oceans, for the five strongest Forbush decreases from 2001 to 2005, the DTU team found a 7 per cent decrease, as mentioned earlier. That translates into 3 billion tonnes of liquid water vanishing from the sky. The water remains there in vapour form, but unlike cloud droplets it does not get in the way of sunlight trying to warm the ocean. After the same five Forbush decreases, satellites measuring the extent of liquid-water clouds revealed an average reduction of 4 per cent. Other satellites showed a similar 5 per cent reduction in clouds below 3200 metres over the ocean.

"The effect of the solar explosions on the Earth's cloudiness is huge," Henrik Svensmark comments. "A loss of clouds of 4 or 5 per cent may not sound very much, but it briefly increases the sunlight reaching the oceans by about 2 watt per square metre, and that's equivalent to all the global warming during the 20th Century."

The Forbush decreases are too short-lived to have a lasting effect on the climate, but they dramatize the mechanism that works more patiently during the 11-year solar cycle. When the Sun becomes more active, the decline in low-altitude cosmic radiation is greater than that seen in most Forbush events, and the loss of low cloud cover persists for long enough to warm the world. That explains, according to the DTU team, the alternations of warming and cooling seen in the lower atmosphere and in the oceans during solar cycles.

The director of the Danish National Space Institute, DTU, Eigil Friis-Christensen, was co-author with Svensmark of an early report on the effect of cosmic rays on cloud cover, back in 1996. Commenting on the latest paper he says, "The evidence has piled up, first for the link between cosmic rays and low-level clouds and then, by experiment and observation, for the mechanism involving aerosols. All these consistent scientific results illustrate that the current climate models used to predict future climate are lacking important parts of the physics".

Notes for editors

The full reference to the new paper is: Henrik Svensmark, Torsten Bondo, and Jacob Svensmark, "Cosmic ray decreases affect atmospheric aerosols and clouds," Geophysical Research Letters, doi:10.1029/2009GL038429, Vol. 36, L15101, 2009.

Torsten Bondo is a graduate student with a special interest in aerosols and modeling. Jacob Svensmark (Henrik Svensmark's son) is an undergraduate student who contributed especially to the ranking of the Forbush decreases.

Forbush decreases take their name from the American physicist Scott E. Forbush who first noticed such events more than 70 years ago. Nowadays they are known to be the result of ejections of magnetized gas from the Sun that pass near our planet and sweep aside some of the incoming cosmic rays. The team analysed dozens of Forbush decreases since 1987. They used data from 146 stations around the world that count cosmic-ray neutrons, and from a multi-directional telescope in Japan that observes muons, the most important cosmic-ray particles near the Earth's surface. Each solar outburst altered the pattern of cosmic-ray energies in a distinctive way, making it possible to calculate cosmic ray intensities in the lower air.

In the AERONET project, coordinated by NASA, automatic instruments at hundreds of ground stations world-wide monitor the Sun's complexion at various wavelengths, from red to ultraviolet, to detect aerosols in the atmosphere.

As for the cloud measurements, several satellites of the US Defense Meteorological Satellite Program carry an instrument called the Special Sensor Microwave Imager, which measures the liquid-water content of clouds over the oceans. The Moderate Resolution Imaging Spectroradiometer on NASA's Terra and Aqua satellites detects the extent of liquid-water clouds, while the International Satellite Cloud Climatology Project pools infra-red observations from spacecraft of several nations to report the extent of clouds below 3200 metres.

For further information, please contact:

Henrik Svensmark at the National Space Institute, DTU, e-mail: hsv@space.dtu.dk, phone +45 3532 5741 or mobile +45 2237 0711