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CLIMATE CHANGE

Cosmic link

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Scientists argue that cloud formation modulated by galactic cosmic rays has an impact on climate change.

BY SPECIAL ARRANGEMENT

The SKY experimentin a laboratory of the Danish Space Research Institute.

IN January, the Ministry of Environment and Forests (MoEF) issued a discussion paper authored by the space scientist U.R. Rao, and this has revived the 14-year-old debate about the role of galactic cosmic rays (GCR) in climate change, which, despite scores of published papers and experiments carried out to settle the issue, remains unresolved. Rao's paper was published in the January 25 issue of the Indian journal Current Science. The Ministry also issued a commentary by the noted atmospheric scientist V. Ramanathan, of Scripps Institute of Oceanography, University of California at San Diego, as an accompanying discussion paper. The commentary, an invited submission to Current Science, is yet to be published.

The paper has basically argued that experimental results published in a paper by K.G. McCracken and J. Beer in Journal of Geophysical Research in 2007 – why Rao has called it “new” is not clear – provided “persuasive evidence” to show that changes in GCR flux into the earth's atmosphere can significantly affect global temperature. The argument is based on the high degree of correlation between GCR intensity and cloud cover (CC) that Henrik Svensmark and Eigil Friis-Christensen of the Danish Space Research Institute (DSRI) found in 1997 using satellite observations of global cloud cover. Now protons in cosmic rays are the primary cause of ionisation of atoms – stripping them into charged electrons and nuclei – in the atmosphere. The mechanism that they proposed was that, by ionisation, primary GCR generated low-level cloud condensation nuclei (CCN), which are potential nucleating sites for cloud formation.

It is well established that the presence of certain chemical species, such as sulphuric acid, in the atmosphere facilitates formation of molecular clusters and increases the probability of forming bigger clusters by coagulation. These then attain a critical size to exist as aerosol particles. Indeed, an experiment called SKY (meaning cloud in Danish) by the DSRI has established in the laboratory the formation of such clusters (a few nanometres in size) that tend to grow. Now Svensmark and Friis-Christensen argue that these are indeed building blocks for CCN 0.5-2 micrometres in diameter.

Given the right conditions of humidity and vertical velocity, these CCN can result in the formation of cloud drops. The crucial question is whether the particles thus formed do indeed lead eventually to cloud drops and clouds. In 2000, Svensmark and Nigel D. Marsh refined the 1997 argument and showed that this correlation was particularly strong for low-level or lower troposopheric (less than 3.2 km above) cloud cover. It may be pointed out here that, according to P. Laut, the correlation noted by Svensmark and Friis-Christensen seems to be valid only for 1984-1994 and is not as clear for the later periods.

Cloud cover has a dual role; it causes solar irradiance to reflect back into space (albedo), which has a cooling effect, and also traps the heat emanating from the earth below. It is, however, known that the former effect is much larger. Conversely, reduced CC allows more solar irradiance to fall on the earth, which has a warming effect. So cloud formation modulated by GCR flux changes potentially has an impact on the global temperature.

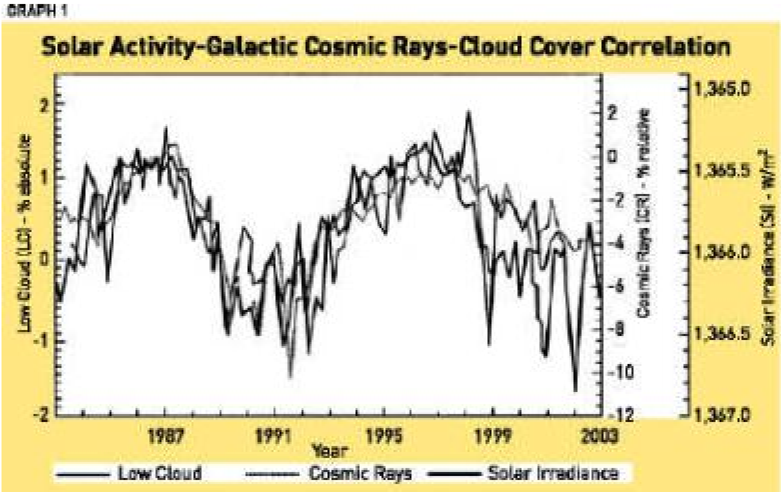
SOLAR ACTIVITY

A known cause of GCR flux changes is the change in solar activity (sunspots and solar wind). Variations in solar activity lead to changes in the solar magnetic field and charge particle carrying solar wind extending into space. The more active the sun, the stronger the solar magnetic field and the solar wind. As GCR diffuse into the centre of the solar system from outside, these deflect the GCR and cause a reduction in its energy as well as its intensity near the earth. That is, solar activity and GCR flux are anti-correlated. Reduced GCR flux will in turn lead to a reduction in ionisation which, in turn, can lead to a decrease in the CC and the consequent increased warming of the planet.

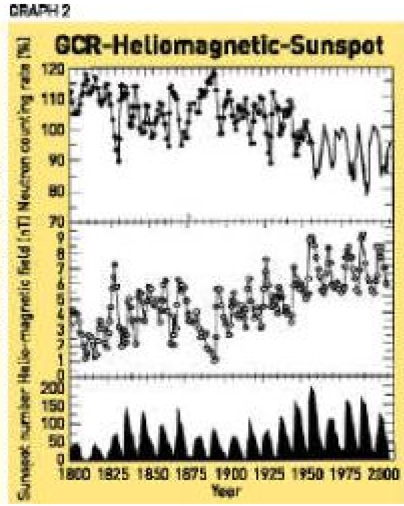
Data in Graph 1, as reported by Jan Veizer in 2005, show a high degree of correlation between solar activity, GCR flux changes (as measured by the cosmic ray neutron monitor in Huancayo, Peru) and low-level CC changes (as derived from the infrared datasets of the ISCCP, or the International Satellite Cloud Climatology Project). That is, besides the direct effect of solar irradiance on the earth, the sun also can have an indirect effect on the global temperature by modulating the GCR flux and CC formation near the earth. Reduction in CC results in reduced albedo radiation back into space, which causes increased warming of the atmosphere and increased global surface temperature.

This, if true, implies that the effect of anthropogenic causes of global warming, like greenhouse gas (GHG) emissions, would be that much lesser if GCR-induced cloud formation effects were properly taken into account. But the indirect effect has been hotly debated among scientists with the proponents of the effect even being equated with climate sceptics.

GRAPH 1



GRAPH 2



This is not to say that the Intergovernmental Panel on Climate Change (IPCC), which in its latest assessment report of 2007 (AR4) has held anthropogenic carbon emissions to be chiefly responsible for the observed global warming of 0.75°C in the last 150 years since industrialisation began, has not taken cognizance of the possible impact of GCR on global climate. This is what AR4 has to say on the issue: "Various scenarios have been proposed whereby solar-induced GCR fluctuations might influence climate…Because of the difficulty in tracking the influence of one particular modification brought about by ins through the long chain of complex interacting processes, quantitative estimates of GCR-induced changes in aerosol and cloud formation have not been reached."

Specifically, with regard to the uncertainties in radiative forcing due to cosmic rays, it said, the evidence was insufficient, scientific consensus was low, the level of scientific understanding of the process was very low and, while there was some empirical evidence as well as microphysical models that suggested a linkage to cloud formation, there was a general lack of understanding of the physical mechanism and there was uncertainty in correlation studies. Rao has basically sought to revisit the issue with his arguments based on correlation studies that provide more conclusive evidence of the link.

According to Rao, one of the reasons why the effect of long-term changes in GCR intensity on low-level CC and its impact on global warming was not clearly understood was the absence of reliable estimate of GCR flux changes over a long period. This has now become available following the works of McCracken and associates who have estimated these flux changes through accurate proxy measurements of beryllium-10 (Be^{10} obtained from deep polar ice core. What the authors have done is to merge the long-term cosmogenic data of Be^{10} with actual GCR measurements from 1933 to 1965 and reconstruct the long-term changes in GCR intensity during 1428-2005. Further, McCracken and colleagues inverted this long-term cosmic ray data to yield helio-magnetic field and observed a clear correlation with the observed sunspot data (Graph 2). The increase in magnetic field so determined agreed with that directly measured by the Advanced Composition Explorer (ACE), the satellite mission of the National Aeronautics and Space Administration (NASA), launched in 1997.

What the above data show is that the average GCR intensity near the earth during 1954-1996 was lower by 16 per cent compared with the average for the period 1428-1944 and that the primary cosmic ray intensity recorded during 1960-2005 was the lowest in 150 years. The data also show that during the last 150 years, when the carbon dioxide intensity increased from around 280 ppm to 380 ppm, the corresponding decrease in GCR intensity was about 9 per cent. Graph 1 tells you that a 9 per cent decrease in GCR intensity corresponds to a 2 per cent reduction in low-level CC. Extrapolating this short-term correlation to the long-term data of McCracken and company, Rao has argued that the 9 per cent decline in GCR intensity over the last 150 years would likewise correspond to a 2 per cent reduction in absolute low-level CC, which in turn implies an increase in the earth's radiation budget by 1.1 $watt/m^2$. This, Rao has pointed out, is nearly two-thirds of the estimated increase in radiative forcing of 1.66 W/m^2 due to increased carbon emissions during the same period.

According to the IPCC, the contribution of increased solar irradiance to the radiation budget is 0.12 W/m^2. So, the net contribution of non-anthropogenic solar-induced effects would become 1.22 W/m^2. Consequently, argues Rao, the contribution of increased carbon emissions to the observed global warming of 0.75 ^oC would only be 0.42 ^oC, considerably less than the 90 per cent projection by the IPCC, the rest 40 per cent being due to GCR-induced changes in low-level CC. From this perspective, Rao has argued that GCR-induced effect is quite significant and needs to be factored into the predictions of global temperature increase and climate change.

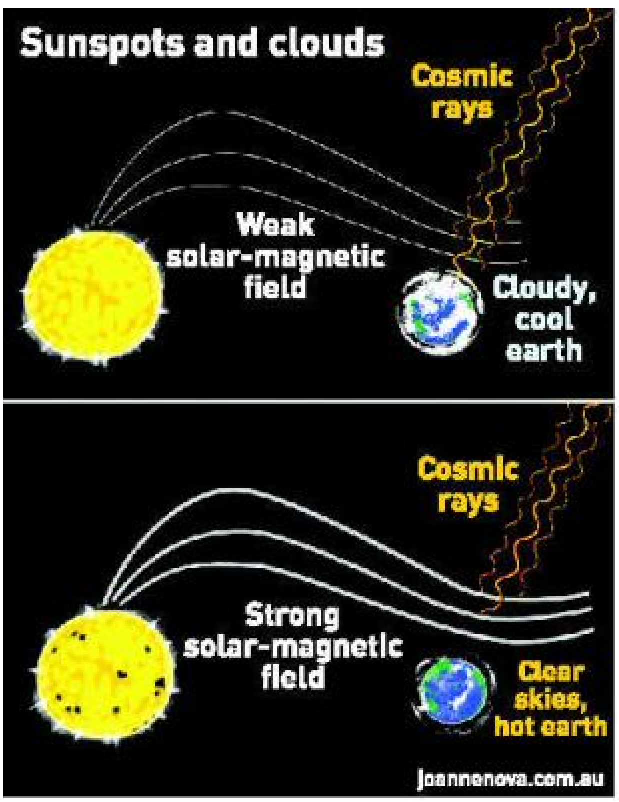
In the commentary, Ramanathan makes the following observation: “[T]he observed rapid warming trend during the last 40 years cannot be accounted for by the trends in GCRs. This does not by itself negate the importance of GCRs as a forcing factor of climate change, but strengthens the case for GHG forcing as the primary driver of climate change.”

Specifically, Ramanathan has pointed out that while quantitative modelling studies do provide evidence for (a) ion production by GCRs and the formation of CCN; and, (b) solar activity and increased CCN production and cloud drops at less than 3 km altitude, there are substantial differences and discrepancies in the various studies that attempt to establish the 'solar activity-CCN production-low clouds' link. These, he has pointed out, stem essentially from the problems with the ISCCP data.

"Given this…," he says, "we can neither categorically rule out a GCR-cloud connection, nor conclude affirmatively about such a connection."

Even if the satellite data were reliable, Ramanathan feels that the correlation between GCR flux changes and cloudiness may not be straightforward for the following reasons:

(a) While due to man-made emissions of aerosols, the abundance of CCNs in all continental regions and oceanic regions is in the range of 1,000-5,000 particles/cm ^{3}, cloud drop concentrations in most low-level clouds are less than 500 particles/cm ^{3}. In such heavily polluted regions, additional ionic sources from GCRs are not required to account for the observed cloud drop number concentrations. (b) Satellite cloud data began only in the 1980s. The large warming trends during this period would itself impact the cloudiness at regional and global scales. Thus analyses that attempt to attribute all cloudiness trends to GCRs may be misplaced. (c) Observations of global average during the 20th century reveal three basic periods: warming trend during 1900-1940, slight cooling during 1940-1970, and the rapid warming trend that is continuing.



However, the GCR trends (as seen in Graph 2) underwent monotonic decrease from 1900 to 1970 and then levelled off. The trends do not seem to reflect the large warming trend during 1970-2010, he points out.

A recent paper in the journal Atmospheric Chemistry and Physics (November 2010) by B.A. Laken and associates from the University of Sussex reports results that add credence to the GCR-climate link and serves to buttress Rao's arguments. Rao's paper, however, does not cite these results as he was perhaps not aware of the new paper. In the abstract of their paper,

Laken and colleagues note: “These results provide perhaps the most compelling evidence presented thus far of a GCR-climate relationship. From this analysis we conclude that a GCR-climate relationship is governed by both short-term GCR changes and internal atmospheric precursor conditions.”

The authors used a novel approach that sampled measurements around periods of significant cloud changes and found a statistically significant relationship between short-term GCR flux changes (data sourced from multiple neutron monitors) and the most rapid cloud decrease in mid latitudes (60 ^{o}–30 ^{o} N/S) over daily time scales (sourced from ISCCP data).

More interestingly, the authors directly manipulated the radiation budgets in a General Circulation Model (GCM) and forced it to reproduce the observed anomalous cloud changes. The GCM thus tweaked was found to reproduce well the observed surface level air temperature (SLAT) changes. “Results indicate,” write the authors, “that the anomalous cloud changes were responsible for producing the observed SLAT changes, implying that if there is a causal relationship between significant decreases in GCR flux and decreases in cloud cover, an increase in SLAT can be expected (emphasis added.)”

The authors, however, add a caveat that the GCM results were somewhat limited by the ability of the model to successfully reproduce the observed cloud cover.

MISSING LINK

The emphasised part above, namely the lack of a demonstrable causal relationship between GCR flux changes and cloud cover, has been the crucial missing link all along, a point raised in all the critiques of the theory beginning from the oft-cited work of the British scientists T. Sloan and A.W. Wolfendale. While the GCR-induced particle/aerosol formation seems fairly well understood, and also demonstrated as in the SKY experiment, whether the mechanism does result in the creation of an adequate number of CCNs of the right size, which can in turn lead to cloud drop formation in sufficient concentrations, is a question that has not yet been answered satisfactorily. One of the points raised by Sloan-Wolfendale was that if there was a causal connection, the correlation should be stronger for middle levels (3.2-6.5 km) and high levels (more than 6.5 km altitude) since ionisation increased with altitude, and this was not seen. However, a modelling study by F. Yu in 2002 had shown that GCRs produced more CCNs at lower levels than at higher levels and had thus answered this question. Sloan and Wolfendale pointed out that if both GCR variation and CC are correlated to a third variable, the GCR-CC link could emerge as an artefact and further evidence would be required to establish a causal connection.

Recently, U.B. Gunturu of the Massachusetts Institute of Technology (MIT) offered another critique of Rao's paper. According to him, GCR and CC may not be mechanistically correlated at all; he speculates that the correlation is random. He argues thus: solar variability affects GCR flux and solar irradiance is the dominant forcing on the earth's atmosphere. So, it is possible that both GCR flux and some geophysical fields on the earth, which have very high sensitivity to solar irradiance, show the same variation. Thus they seem correlated because they are forced by the same field, solar irradiance.

In his commentary, Gunturu has pointed out that recent advances in aerosol microphysics and their model representations have shown that CCN concentrations, in fact, are insensitive to GCR fluctuations. As a consequence of this insensitivity, the maximum radiative forcing due to GCR changes is only 0.005 W/m^2 as against 1.1 W/m^2 arrived at by Rao, he writes. According to him, ionisation of the atmospheric atoms results in ultrafine particles of diameter less than 9 nm. On the basis of the results of an experiment by S.H. Lee and others in 2003, which involved gathering data from aboard a NASA aircraft, Gunturu has pointed out the following:

(a) The newly formed aerosol particles are very sensitive to the scavenging by pre-existing aerosol particles; (b) particle formation occurs only in the upper troposphere and lower stratosphere; and, (c) particles do not form at temperatures higher than 270 K, which also means they can form only in the middle and upper troposphere. Since these particles are ultrafine, Gunturu argues that these have too low a terminal velocity to reach the lower troposphere, which is necessary for them to act as CCN.

Gunturu specifically raises two important questions: (1) If there are n aerosols, how many CCN will result? (2) If there are n CCN, how many cloud droplets will result? It is these two questions, he says, that have been defying a theoretical understanding and remain a great challenge in the understanding of the GCR-cloud relationship. In particular, since the timescale required for the ultrafine particles to grow into micrometre-sized CCN would be longer than the timescale of aerosol depleting processes like coagulation and scavenging (by existing larger aerosols), the contribution of these ultrafine particles to CCN is small, he has argued.

Gunturu has also cited a 2009 work of J.R. Pierce and P.J. Adams that sets an upper limit on the CCN concentrations resulting from GCR changes. The work used a GCM with advanced aerosol microphysics inputs to study the sensitivity of the formation of aerosols to GCR changes. Then, assuming that every ion produced resulted in the formation of a particle, they could set upper bounds for particle and CCN concentrations. On the basis of a computed sensitivity of 0.04 per cent, Price and Adams conclude that the change in albedo would only be 0.005 W/m^2, much less than Rao's 1.1 W/m^2. This, he has argued, means that global climate is insensitive to GCR fluctuations.

SKY EXPERIMENT

The SKY experiment, the results of which started to come out in 2006, deserves to be mentioned in this context. The experiment used natural muons (the heavy cousins of electrons) that could reach a 7 m^3 reaction chamber in a basement laboratory of the DSRI. The experiment was designed to verify that electrons released in the air by the passing muons promote the formation of molecular clusters, which act as building blocks for CCN. The reaction chamber contained a mixture of gases at realistic concentrations to replicate the chemistry of lower atmosphere.

Ultraviolet light, mimicking solar irradiance, created sulphuric acid through a photochemical process.

When sulphuric acid was added in concentrations below a critical value, vast numbers of aerosol particles appeared in the chamber, which were clusters of sulphuric acid and water molecules. Muon flux, electron density and the numbers and sizes of the molecular clusters, temperature, pressure and relative humidity were all measured.

The data revealed that electrons released by cosmic rays acted as catalysts, which significantly accelerated the formation of stable, ultra-small clusters of sulphuric acid and water molecules, believed to be the building blocks for CCN.

A strong electric field was applied through two electrodes mounted on opposite sides of the chamber to sweep away the electrons. The expectation was that this would greatly reduce the number of molecular clusters and confirm that electrons enhanced their production.

But Svensmark and colleagues observed an unexpected result: electrons with a lifetime of approximately 20 seconds made little difference to the cluster count. Contrary to the theoretical expectation that periods greater than 80 seconds would be required to make the clusters, this meant that electrons made clusters more rapidly than previously thought. The timescale issue raised by Gunturu should probably find an answer in this result. Further, data from the ongoing SKY experiment should also be able to answer the queries with regard to the relationship between aerosol and CCN numbers that Gunturu has raised.

MOLECULAR CLUSTERS

On the basis of SKY results, Svensmark theorises the formation of CCN from molecular clusters as follows. Stripped by cosmic rays, electrons in the atmosphere attach themselves to fragile clusters of sulphuric acid and water molecules. Their electric charges stabilise the clusters, while more molecules join them. When the molecular clusters are big enough, the electrons leave them in a stable state and catalyse other clusters to grow. In previous theories of cluster growth, Svensmark points out, each electron was supposed to remain with just one cluster. “The catalytic behaviour of the electrons is much more efficient,” he adds. This theory, he says, explains in detail the surprising quick production of droplets seen in the SKY experiment by his team. But it would seem that this picture does not quite match the cloud microphysics picture outlined by Gunturu.

A more ambitious project called CLOUD (Cosmics Leaving Outdoor Droplets) at the European Organisation for Nuclear Research (CERN), has just begun to produce the first results that are yet to be published. The aim here, as in SKY, is to investigate the possible influence of cosmic rays on the earth's clouds and climate by studying the microphysical interactions involved. Whereas SKY used cosmic ray muons, CLOUD will use a beam from the high-energy particle accelerator.

This is the first time that an accelerator is being used to study atmospheric and climate science. The initial stage of the experiment uses CERN's proton synchrotron to send a beam of particles into an ultra-clean reaction chamber filled with atmospheric gases. The effect of the beam on aerosol production will be recorded and analysed.

The CLOUD project, after many hiccups, kicked off in 2006 and the experiment began in November 2009. This experiment should provide more detailed results on the GCR-cloud cover linkages and settle many of the outstanding questions. As of now, CLOUD has seen sulphuric acid and water combine to make particles when blasted by the CERN beam in a way that matches predictions of the most recent models. Data in the near future should tell us whether these are indeed precursors to CCN.

URL: http://www.hindu.com/fline/fl2806/stories/20110325280610700.htm