# COSMIC RAYS AND GLOBAL WARMING

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***Is global warming man made or is it caused by the effects of solar activity on cosmic rays as claimed by some? Here we describe our search for evidence to distinguish between these claims.***

The year 2009 marks the 50th anniversary of the paper by Ney [1] drawing attention to possible effects of cosmic rays on clouds. With Global Warming a well known fact, some have followed up this possibility, sometimes with great publicity [2]. Their argument is that the observed increasing solar activity during the last century caused a decrease in the ionization due to cosmic rays since the lower-energy cosmic particles are deflected by the magnetic field created by the increased solar wind. This would lead to a decrease in cloud cover, if there is a connection, allowing more heating of the Earth by the sun. Hence they propose that such a natural phenomenon, rather than man-made greenhouse gases causes the warming. Meteorologists on the International Panel on Climate Change IPCC [3] have put forward strong reasons that man-made greenhouse gases are most likely responsible for global warming. However, there is still an outside chance, which has been estimated to have probability of about 10%, that there is some other cause. In this case the models used by the meteorologists to calculate the effects of the increased greenhouse gases would need to be wrong. In addition, there has to be some, as yet, undiscovered mechanism which would cause the unusually rapid global warming seen over the half last century. Could the undiscovered mechanism be the proposed effect of cosmic rays on cloud formation?

Positive evidence for an effect of cosmic rays on clouds was first presented by Friis-Christensen and Svensmark and later by Marsh and Svensmark and Palle-Bago and Butler [4] using newly available satellite data on clouds [5]. They noticed that as the sun went through the maximum activity in its 11 year cycle in 1990 the new data on the globally averaged low-level cloud cover showed a decrease (see figure 1a). Using this observation they proposed that ionization from cosmic rays was a big contributor to cloud formation and the changing solar activity was responsible for the observed global warming via cosmic rays. Several papers followed pointing out possible flaws in the argument. One flaw was that other measures of cloud cover did not show the same structures as those shown in figure 1a.

**▲ The 'man-made global warming-denier' will have to look elsewhere: cosmic ray-driven clouds will not do the job.**

Notwithstanding this, since the effect would be so important and far reaching, a group of us got together to try to find evidence to corroborate or otherwise the hypothesis that changing cosmic ray activity has something to do with either cloud cover or global warming.

## The solar cycle peaking in 2000

Another solar cycle has passed since the one which produced the dip in low level cloud cover in 1990 shown in figure 1a. Figure 1b shows the data sample up to 2008 covering both solar cycles. The dip in low cloud cover seen in 1990 is clearly visible. During the following solar cycle from 1996-2007 the low-level cloud cover decreases rather smoothly and this is observed to be matched by an equivalent increase in cloud cover at higher altitude. However, there is no clear dip at the next solar maximum in 2000. Hence the following solar cycle does not provide corroborative evidence of the connection between changing cosmic rays and changing cloud cover, at least on a global scale.

▲ Radioactive 'events' and their influence on cloud cover: Tchernobyl, April 26, 1986. Very considerable amounts of fall-out. No increase in cloud cover: η(conversion ions to cloud droplets) < 3%

A clever statistical analysis by Voiculescu et al [6] showed that there were local geographical regions of strong correlation between cloud cover both with the cosmic ray rate and with solar irradiance variation. We examined these regions using both completed solar cycles of data. We found that both solar cycles gave visible structures in the cloud cover for the high correlation regions with solar irradiance. However, both solar cycles were not clearly visible for those with cosmic rays. Hence any effect of solar activity on clouds and the climate is likely to be through solar irradiance rather than cosmic rays. We could not find any geographical characteristics which would explain such behaviour for these regions, however. Nevertheless since solar irradiance transfers 8 orders of magnitude more energy to the atmosphere than cosmic rays it is more plausible that this can produce a real effect. Indeed, such an effect has been modelled [7].

## Chernobyl, bombs and radon

Another place to look for corroborative evidence for ionization playing a part in cloud formation is to examine whether ions from other sources give rise to clouds. We have searched for excesses of cloud cover associated with the Chernobyl disaster in 1986, fall out from nuclear bomb tests (specifically the 15 MT BRAVO test of 1954) and natural radon emissions over India [8]. In no case could a change in clouds, caused by changing ionization, be identified. The upper limits to the efficiency for converting ions to cloud droplets being, respectively, 3%, 0.01% and 25%; a value of nearly 50% would be needed to explain the dip in low-level cloud cover seen in Figure 1a. In addition, we examined times of changing cosmic radiation, the so called Forbush decreases and ground level events [9]. Again, no statistically significant change in cloud cover during such events could be identified. However, in a recent paper [10], the Svensmark group reports evidence that the water content in clouds decreases at a time of about 7 days after selected large Forbush decreases. It is difficult to envisage how such a time delay can occur given that the lifetime of ions in the atmosphere is thought to be much shorter than 7 days [11].

There are unknown climatic effects surrounding all of these tests. So no doubt a good lawyer would think of reasons why such analyses are not appropriate for the cosmic ray case. However, we can conclude that these tests do not provide corroborative evidence of the proposed link between ionization and cloud formation.

## Cosmic rays over the Earth

Figure 1 represents the results for cloud cover averaged over the Globe. However, both the cosmic ray intensity variation and that of clouds varies over the Earth's surface, the former for reasons of the geomagnetic field and the latter for meteorological reasons. Thus, Figure 1 is a gross over-simplification.

We have examined the equivalent of Figure 1 from place to place over the Earth's surface [9]. The cloud cover variation is identified by the dip, the difference between the low-level cloud cover (LCC) for 1990 and the adjacent maxima. The cosmic ray intensity variation (over the 11-year cycle) is characterised by the 'vertical rigidity cutoff', VRCO (see, *e.g.*, [12]). High VRCO-values occur near the Equator, where the geomagnetic field is nearly orthogonal to the cosmic ray arrival directions. Here, the cosmic ray intensity and its variation is low since low energy particles are deflected and prevented from entering the atmosphere. Low VRCO-values are to be found near the Poles where low energy particles can enter the Earth's atmosphere along the field lines. In consequence the amplitude of their 11-year cycle is much bigger.

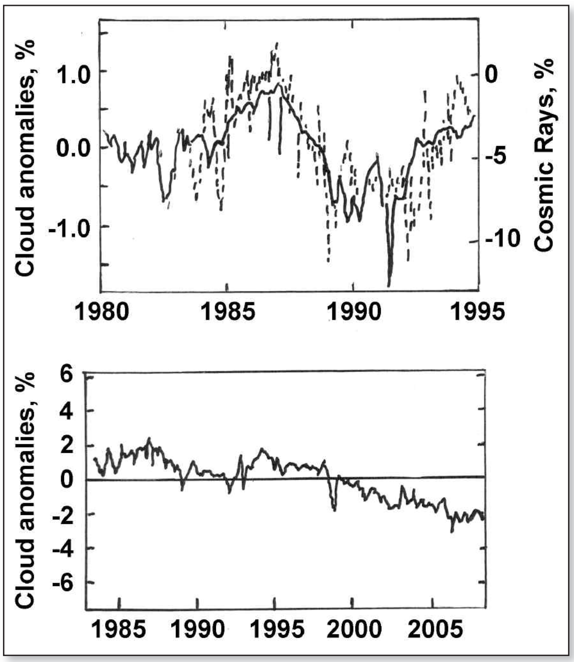
Figure 2 shows the situation. The data are divided into latitude bands, as indicated. The (very useful) variation of

VRCO with longitude along a particular latitude bin arises because of the obliquity of the Earth's magnetic dipole. The result is that going along a particular geographic latitude, the meteorological conditions should vary less and a correlation of dip with VRCO will be more meaningful. 'Expectation', the observed fractional cosmic ray variation in Figure 2, is marked as NM. It is evident that the magnitudes of the dip depths are independent of VRCO, *i.e.*, that variations in cloud cover do not follow variations in cosmic rays intensity. Hence this evidence fails to corroborate the connection between cosmic rays and clouds.

We went on to show that, when averaged over the 11 year solar cycle, there was a common oscillation of four quantities: the global mean surface temperature of the Earth, the cosmic ray ionization rate in the atmosphere, the mean daily sun spot number and the solar irradiance [13]. This showed a period of roughly twice that of the 11 year solar cycle. The temperature, solar irradiance and sun spot number were observed to be in phase whereas the cosmic ray flux lagged behind by 2-4 years. Hence the temperature variation is unlikely to be caused by the cosmic ray variation. The amplitude of the observed oscillating temperature variation was ±0.07°C. Let us assume that this oscillating temperature is caused by either the solar irradiance oscillation or, despite our arguments, that from cosmic rays. The overall long-term variation of both the solar irradiance and the cosmic rays was much less than the amplitude of the oscillation for each. It follows that the total global warming must be less than the amplitude of the temperature oscillation of 0.07 degrees. This is 14% of the observed 0.5 degrees. Hence the total contribution of variable solar activity to global warming must be less than 14% of the total temperature rise.

## Cosmic Ray effects in the Upper Atmosphere

It is clear that if there is going to be a cosmic ray effect anywhere it should be at high altitude. The reason is that the cosmic ray ionization rate increases strongly with altitude - the phenomenon observed by Viktor Hess which led to his deduction, in 1912, that the radiation responsible for the observed ionization was cosmic. We have searched for the correlation of cloud cover with altitude for the 3 height bands into which the cloud cover is divided: low cloud cover (LCC) below 3.2 km, middle cloud cover (MCC) for the range 3.2 to 6.5 km and high cloud cover (HCC) above 6.5km. Figure 3 shows the results [14], presented as a function of latitude. The upper plot shows the absolute amounts of the cloud cover in the 3 altitude bands. The middle plot shows the correlation coefficients between the cosmic ray rates and the cloud cover from each altitude band. The lower plot shows the correlation coefficient between the LCC and MCC and a

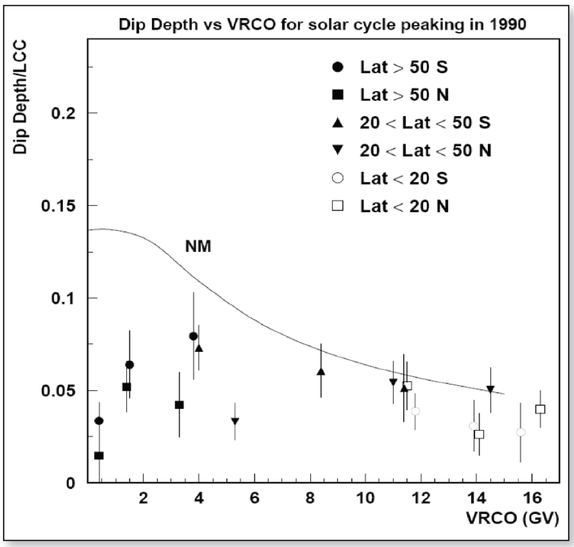



**◀ FIG. 1:** a) Upper plot shows the ISCCP D2 IR data on the low cloud cover anomalies (dashed curve) and the cosmic ray intensity (solid curve) as measure by the Huancayo neutron monitor for the solar cycle 1986-95. 'Anomalies' are cloud cover deviations from the average corrected for seasonal variations. b) Lower plot shows the same anomalies from 1983-2008 covering the two solar cycles.

quantity to measure the sensitivity of one to the other. The latter plot is an indicator that some of the correlations are due to the vertical transference of clouds from one region to another.

It is seen that the correlation with the cosmic ray rate is largely negative for the high altitude clouds, MCC and HCC, opposite to expectation if there were a causal link between cosmic rays and clouds. This is yet another reason why we should discount the effect of cosmic rays on the cloud cover, at least by way of their direct effect on cloud formation. This proviso is put in because there is just a small chance that, following [15], there may be an effect of cosmic rays on the upper atmosphere, which affects its transparency and thereby surface temperatures.

These effects seem to demonstrate that there could be a small effect of solar variability on clouds. However, as we showed above, the effects are more likely to be

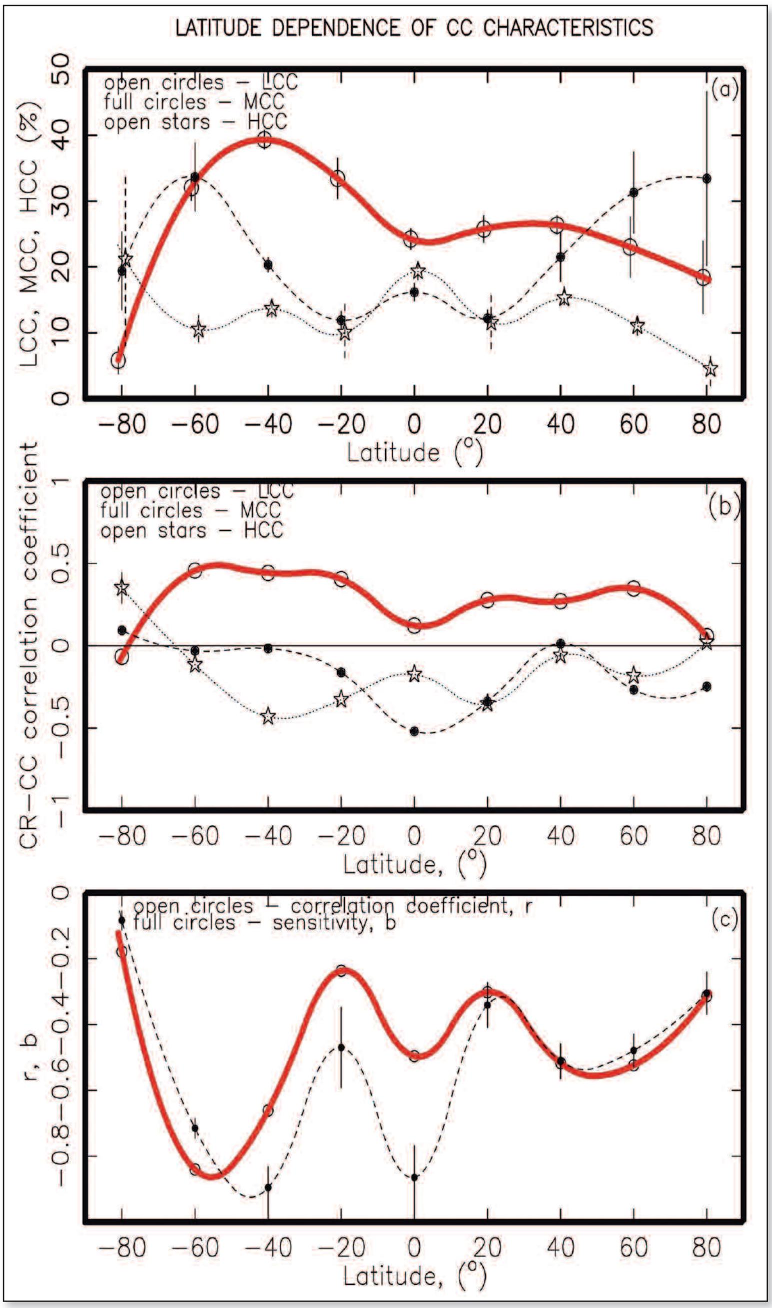



**◀ FIG. 2:** The observed modulation of the low-level cloud cover (LCC) as measured from the fit to solar cycle peaking in 1990 data from Figure 1a. On the horizontal axis is the 'Vertical Rigidity Cut-Off' (see text). The `modulations' are expressed by the dip amplitude (maximum to minimum) at the time of the solar maximum in 1990 divided by the mean LCC. The smooth curve labeled NM shows the expected fractional modulation of the rate of cosmic ray ionization at low-level cloud height.

something to do with changes in solar irradiance - given the much greater energy input from this source - than from cosmic rays.

## Conclusions

In our view the jury is back and the verdict is that cosmic rays and solar irradiance are not guilty for most of the Global Warming. Nevertheless, they could be responsible for a contribution and we look forward to future experiments such as CLOUD at CERN which should be able to quantify to what extent ionization plays a part in the production of aerosols, the precursors of cloud formation. ■




▲ **FIG. 3: The latitude dependence of Low-, Medium- and High-Cloud Cover characteristics (a) absolute values of LCC, MCC and HCC; (b) correlations with cosmic ray intensity (Climax neutron monitor); (c) the correlation coefficient (red) and sensitivity (black dashed curve) of MCC to LCC, from [12].**

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## References


[1] E.P. Ney, *Nature* **183**, 451 (1959).

[2] N. Calder and H. Svensmark *"The Chilling Stars – A New Theory of Climate Change"* (Totem Books USA and Icon Books UK 2007); H. Svensmark, *News Rev. Astron. Geophys.* **48**, 1.18 (2007).

[3] IPCC Climate Change 2007: The Physical Basis, CUP.

[4] H. Svensmark and E. Friis-Christensen, *J. Atmos. Solar- Terr. Phys.* **59**, 1225 (1997); N. Marsh and H. Svensmark, *Phys. Rev. Lett.* **85**, 5004 (2000); E. Palle-Bago and C.J. Butler *Astron.Geophys.* **41**,18 (2000)

[5] The ISCCP D2 data/images were obtained from the International Satellite Cloud Climatology Project web site http://isccp.giss.nasa.gov maintained by the ISCCP research group at the NASA Goddard Institute for Space Studies, New York, NY, see W.B. Rossow, and R.A. Schiffer, 1999: Advances in Understanding Clouds from *ISCCP. Bull. Amer. Meteor. Soc.* **80**, 2261.

[6] M. Voiculescu, I.G. Usoskin and K. Mursala, *Geophys. Res. Lett.* **33**, L21802 (2006).

[7] J. Haigh, *Nature* **370**, 544 (1994).

[8] A.D. Erlykin, G. Gyalai, K. Kudela, T. Sloan and A. W. Wolfendale, *J. Atmos. Solar-Terr. Phys.* **71**, 823, (2009).

[9] T. Sloan and A. W. Wolfendale, *Environ. Res. Lett.* **3**, 024001 (2008).

[10] H. Svensmark, T. Bondo and J. Svensmark, *Geophys. Res. Lett.* **36**, L15101 (2009).

[11] J.A. Chalmers *"Atmospheric Electricity",* Oxford, Clarendon Press (1949).

[12] G.A. Bazilevskayza *et al.*, *Space Science Rev.* **137**, 1 (2008).

[13] A.D. Erlykin, T. Sloan and A.W. Wolfendale, *Environ. Res. Lett.* **4**, 014006, (2009).

[14] A D Erlykin, G. Gyalai, K. Kudela, T. Sloan and A.W. Wolfendale, *J. Atmos. Solar-Terr. Phys.* 2009, doi:10.1016/j.jastp.2009.06.012; (arXiv:0906.4442).

[15] I.V. Kudryavstev and H. Jungner, *Geomagnetism and Aeronomy* **45**, 641 (2005).