COSMIC RAYS AND THE ENVIRONMENT

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The changing cosmic ray rate has been proposed as a mechanism which could have contributed significantly to the global warming seen during the last century. The evidence for this is discussed and upper limits for the effect axe derived from the evidence. The effects of cosmic rays on lightning and its effect on the global electric circuit will also be discussed.

Keywords: Cosmic rays; global warming; lightning.

1. Introduction

Since industrialisation in the 19th century the carbon dioxide (C02) concentration in the atmosphere has increased from 280 ppmv to 380 ppmv and at present this is rising exponentially. At the same time the mean global surface temperature has increased by roughly 0.8 degrees C. Climatologists' models of the atmosphere predict that the measured rise in the C02 concentration will cause the observed rise in temperature. Hence the hypothesis of man-made global warming.

The Intergovernmental Panel on Climate Change (IPCC), representing the view of the majority of climatologists, consider that it is "very likely" that the observed global warming is man-made. The term "very likely" is defined to be 90% probable. However, this is disputed by some, mainly non-climatologists, mostly claiming that the effect could be natural since the Earth has seen larger swings in temperature in the more distant past than the one observed since industrialisation. For this to be case, the climatologists' models have to be wrong. In addition, there has to be an as yet undiscovered phenomenon of the right sign to cause the global warming seen during the last 150 years.

Assuming that the climatologists', models are wrong, one such mechanism proposed for a new undiscovered effect is the influence of cosmic rays on clouds. Ney[1] first proposed such an effect. More recently, the effect has received much publicity following the observation of a correlation between a change in the low level cloud cover and the cosmic ray rate during the solar maximum in solar cycle 22 (1985-1997).[2, 3] The latter authors went on to hypothesise that the decreasing cosmic ray rate over the last century caused less ionization and so less low cloud. This would lead to smaller reflection of the solar radiation and hence warming of the Earth.

In the first part of this paper this observation is discussed in some detail and the attempts made to corroborate the hypothesis are described. In the second part of the paper the mechanism by which cosmic rays are thought to cause lightning will be discussed.

2. The influence of cosmic rays on cloud formation.

The condensation of water droplets is a familiar process in cloud chambers used to display charged particle tracks. However, the conditions in such chambers are roughly a 4 times supersaturated vapour pressure in an ultraclean environment. The condensation process in clouds in the atmosphere is a much different process. In the atmosphere dust particles, salt particles from sea spray and many other impurities axe present and inside a cloud the supersaturation level is unlikely to exceed a fraction of 1%.

Water molecules have a large electric dipole moment so that two molecules can readily cohere. However, it is less clear how more molecules come together to form larger aerosol particles. It is thought that such particles containing multiple water molecules are formed by their attraction to microscopic impurity particles made from deliquescent materials such as sulphuric acid or sea salt. It has been shown that ionization could enhance such formation.[4] Indeed, the latest results from the CLOUD experiment at

CERN[5] and from Enghoff et al.[6] show that ionization helps the formation of aerosol particles in the presence of sulphuric acid. However, the experiments show that this is only one process which affects cloud formation in the presence of many others which are not yet identified.

Aerosol particles, once formed, diffuse in the atmosphere until they reach a region where the water vapour pressure is large enough so that they can grow either by condensation or by merging with other aerosol particles. In this way the droplets seen in clouds (radius of order 10 m) are formed. In clouds these continue to grow until they are large enough to fall as raindrops (radius ~ mms).

If ionization from cosmic rays influences this process then a change in the cosmic ray rate would imply a change in the total cloud cover. Indeed the cosmic ray rate has been observed to decrease between the years 1850 to 1950,[7] presumably due to decreases in the solar wind. Solar radiation is reflected from low level clouds. If cosmic rays influence low cloud cover, as hypothesised in Marsh and Svensmark,[3] then the decreasing cosmic ray rate leads to decreasing low level cloud cover which allows more solar energy to fall on the Earth leading to more warming.

Marsh and Svensmark noticed a correlation between low level cloud cover (measured from the ISCCP satellite data) and the cosmic ray neutron monitor count rates in solar cycle 22 which lasted from 1985 to 1995. These authors showed that if they assume that the dip due to the decreased cosmic ray rate at solar maximum (1992) is a global phenomenon the decreasing cosmic ray rate, seen over the last century, could have produced radiative forcing (i.e. warming) at a similar level to that produced by C02.

Much work has gone into attempting to corroborate this hypothesis.[8] Detailed analysis shows that there are many problems with the hypothesis as follows.

(1) The correlation is not present if the ISCCP Vis-IR cloud data are used rather the IR data i.e. another set of data does not show the correlation. Furthermore the IR data now available through to 2010 clearly shows the decrease peaking in 1992 but there is no discernible dip in the low level cloud cover in the following solar cycle which peaked in 2003. I.e. another solar cycle does not exhibit the dip which should have been there if there had been a significant contribution of cosmic rays to the global cloud cover. This can be seen from the plots on the ISCCP web site, http://isccp.giss.nasa.gov/climanal7.html .

(2) If the minimum in 1992 is caused by the decreasing cosmic ray ionization as the solar activity reaches a maximum then this minimum should vary with the magnetic latitude of the Earth since the influence of the solar activity is much smaller near the magnetic equator than near the poles. The amplitude of the dip in 1992 is observed to be constant with magnetic latitude. A statistical analysis shows that less than 23% of the dip comes from the variation with the cosmic ray rate at 90% confidence level.

(3) Only the low cloud cover shows the dip at 1992. The middle and higher level cloud covers, where the variation in cosmic ray ionization rate is larger, show no discernible correlation.

(4) The was a large burst of solar activity on 29 September 1989. This so called ground level event (GLE) was visible in neutron monitors around the World and it was seen in the Nagoya muon telescope. Hence it should have produced a significant change in the atmospheric ionization. The was no significant change in the global cloud cover from before to after the GLE event.

(5) There was no significant change in cloud cover in the region of the Chernobyl reactor from before to after the nuclear accident in 1986 when large amounts of radioactivity were released into the atmosphere.

(6) There is a wealth of data on the effects of nuclear bomb tests on the weather. Some effects are felt in the region of the bomb blast. However, at large distances where the ionization level is still high but the effects of the blast are small, there are no recorded effects of ionization on cloud cover or the weather.

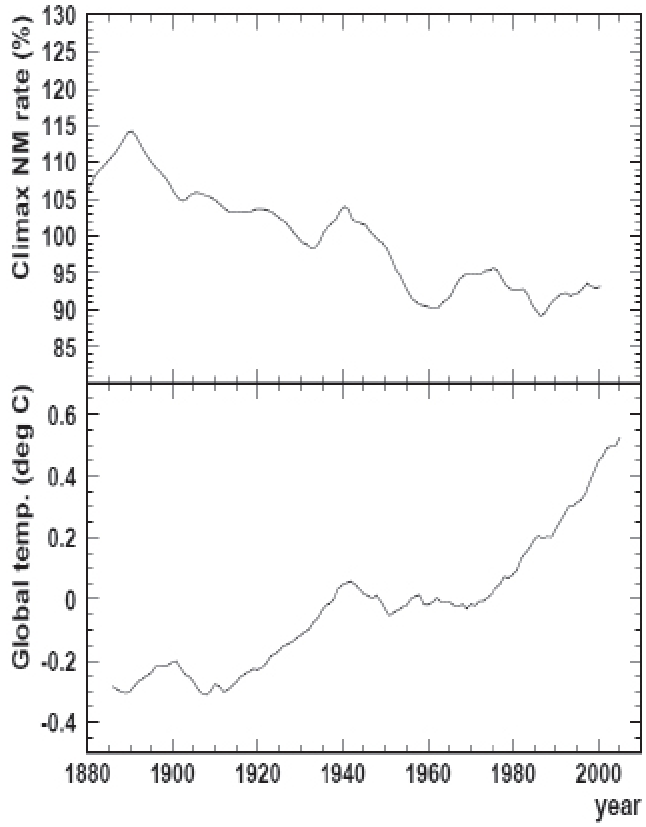

Fig. 1. **Upper** plot shows the equivalent Climax neutron monitor rate as a function of time, after 11 year smoothing has been applied. **Lower** plot shows the mean global surface temperature with the same smoothing.

None of these effects corroborate the hypothesis that a significant amount of the cloud cover is caused by ionization from cosmic rays.

Further attempts were made to correlate the long term variation in the global mean surface temperature with the ionization from cosmic rays and with solar activity via both the observed sun spot numbers and the reconstructed irradiance. A small correlation was observed from which it was deduced that less than 14% of the global warming seen since 1950 comes from the variation in solar activity.

Furthermore, the cosmic ray data were compared with the mean global surface temperature (see figure 1). It can be seen from figure 1 that the changing cosmic ray rate occurred mainly in the first half of the twentieth temperature when there was little change in the mean temperature. However, the cosmic ray rate has been almost constant since 1950 while the temperature has increased rapidly. A statistical analysis of this effect shows that less than 10% of the global warming seen in the twentieth century comes from the variation in the cosmic ray rate.

In summary, much work has been done to corroborate the hypothesis that solar activity, either through cosmic ray rate variations or otherwise, contributes significantly to the global warming seen in the twentieth century. No evidence has been found to corroborate the hypothesis and we deduce that the contribution of such an effect is less than 10% of the observed warming.

3. Lightning

Lightning is an electrical discharge between clouds or between a cloud and the Earth. The observed electric field gradients in the vicinity of charged clouds is of the order of kV/cm i.e. small compared to the breakdown potential of air (30 kV/cm). Hence lightning discharges must be caused by a different mechanism than the one responsible for ordinary spark discharges in the air.

The principle of the mechanism is thought to originate from the fact that the gain in energy between collisions with atoms of air of a particle approaching minimum ionizing is greater than the energy loss in the collision. This is illustrated in figure 2 which shows a curve of the stopping power, dE/dx, of a charged particle as a function of the kinetic energy of the particle. At an energy greater than a threshold, K_{th}, the energy gained per centimetre, which is proportional to the electric field E, is greater than the energy lost due to collisions with atoms i.e. the particle accelerates. Eventually it will gain enough energy to knock out an electron from an atom which has energy greater than the threshold K_{th} In this way a particle in the electric field of a thunder cloud can, over distances of hundreds of metres, produces other electrons which are capable of being accelerated. And so the discharge builds up into a lighting bolt. This process is illustrated in figure 3 which shows a Monte Carlo simulation of an energetic electron in an electric field building up into several further energetic electrons which are each accelerated.

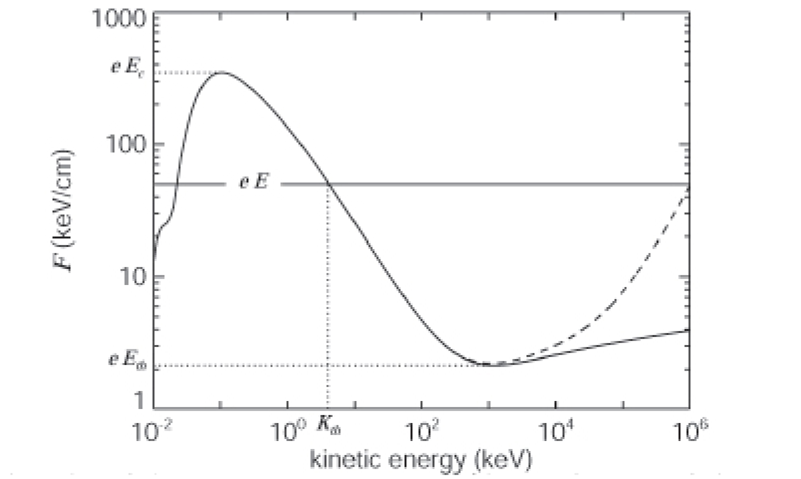

Fig. 2. The value of the stopping power $F = dE/dx$ as a function of electron kinetic energy. For kinetic energies above the threshold K_{th} the energy gained from the electric field in the thunder cloud is greater than that lost by collision losses. Hence the particle accelerates.

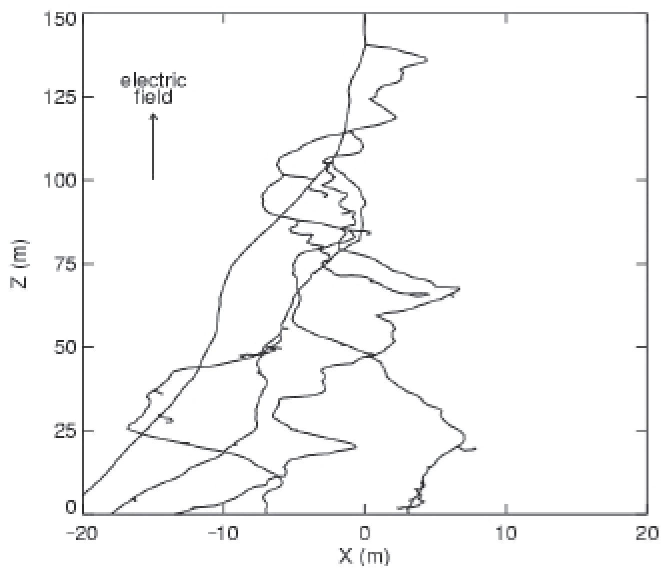

Fig. 3. Monte Carlo simulation of an electron (uppermost particle) of energy large enough to accelerate in the electric field of a thundercloud. Further accelerating electrons are produced over distances of hundreds of metres from energetic knock-on electrons. This leads to the build up of a lightning discharge.

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