per capsule in open-pollinated individuals was found to be 813.33 ± 2.52.

To understand the mechanism of self-pollination, observations were made on flower and corolla tube length at intervals during the night. Corolla tube length was measured for 10 flowers from 10 individuals using thread and ruler. This was done after every 1 h from the evening time of blooming (1800 h) till 0600 h in the morning. Observations were repeated weekly on different sets of flowers (10 in number). The data are shown graphically in Figure 1 and as photographs in Figure 2.

The stigma of the flower lies about 5–7 mm above the anthers at the time of flower opening during 1700–1800 h. The corolla tube length gradually increases with time, raising the level of the anthers. However, the length of the style does not increase. Between 2300 and 0100 h at midnight, the dehisced anthers come in contact with the stigma resulting in autogamy (Figure 2). The corolla tube length continues to increase till morning when the stigma comes to lie 2–4 mm below the anther level. By morning the flowers start withering and the corolla fades. By 0800 h, the corolla lobes close and flower colour changes from white to dull brown. The flowers of *R. longiflora* with long, narrow corolla tube are showy enough to advertise themselves and provide reward by being nectariferous. The corolla tube bears stipitate glandular hairs on the outer surface and a narrow neck with dense white hairs inside. Nectary is located at the base of the corolla tube. Only Lepidoptera members, particularly moths (since majority of butterflies are diurnal) with their long mouth-organs modified into proboscides can have access to the nectar. This specificity restricts the pollinators to moths only. Species-specific, pollination-dependent plants are at risk of pollination failure owing to pollinator limitation as a result of environmental change or disturbance[3]. Also, autogamy is more reliable when compared with cross-pollination[4]. In the absence of pollinators (for whatever reason), the species has adopted to self-pollination through corolla tube elongation bringing the anthers at the level of the stigma, thus leading to autogamy. Some species of *Myosotis* (Boraginaceae) show similar phenomenon and they are termed as initially herkogamous, i.e. the stigma protrudes but the corolla extension lifts the anthers above the stigma during anthesis[5]. There are two hypotheses for the evolution of self-pollination. One is ‘automatic selection’, whereas the other is ‘reproductive assurance’[6]. Self-pollination in this species seems to have evolved in the absence of pollinators for reproductive assurance. Like *R. longiflora*, there are many examples of evolution of self-pollination in plants[7,8]. Indeed, the adoption of self-pollination is one of the most common trends in the evolutionary history of angiosperms[9].

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Cosmic rays and global warming

In this paper we discuss the paper ‘Contribution of the changing galactic cosmic ray to global warming’ by Rao[1]. It is well known that the saturation vapour pressure over a curved liquid surface is larger than that over a flat one. This inhibits the formation of condensation nuclei at sizes of nanometres in clouds. In the standard picture such nuclei form on atmospheric impurities such as sulphates, or on microscopic dust or salt particles. Yu[2] has shown that ionization can also act to overcome this inhibition. The crucial question is the extent to which cosmic rays (CR) can provide enough ionization to change significantly the rate of droplet growth compared to that provided by the standard known processes.

In his article, Rao[1] relies heavily on the work of the geologist Veizer[3], who uses the work of Svensmark *et al.*[4]. These works imply that CR provide a significant effect in helping such condensation nuclei to form. In this way changing CR can influence cloud cover and hence the climate. We examine this implication below.

Rao[1] asserts that the correlation between CR and low cloud cover (LCC) is well established, citing Veizer[3]. Veizer has shown some impressive correlations between temperature proxies and CR proxies on geological timescales. These correlations could be explained by a strong connection between the earth’s temperature and CR, but several other processes were happening on these timescales, many of which were correlated. The observation of a correlation between two processes does not prove that one causes the other, if each is correlated to

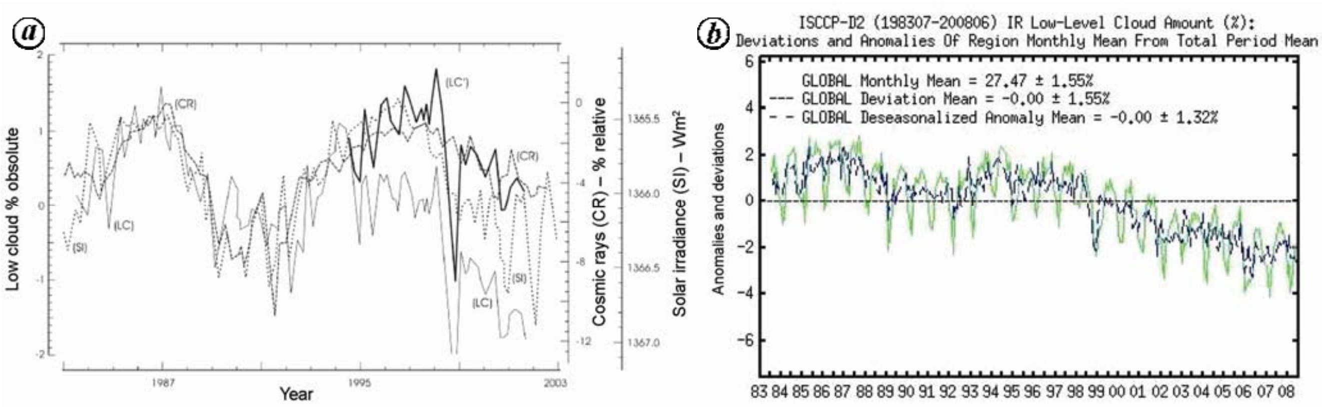

Figure 1. *a*, Figure 2 from Rao's[1] paper which comes from figure 2 of Veizer[3], which originates from the work of Svensmark *et al.*[4]. The plot shows the lower level cloud cover (LCC) against time from 1983 to 2002 (thin solid line) with Svensmark's recalibration (thick solid line). The cosmic ray data are labelled CR. The dotted line labelled SI shows the variation of solar irradiance. ***b***, ISCCP LC (D2 IR) data from 1983 to 2010 covering the solar maximum in the next solar cycle. The plot shows the deviations from the monthly averages. The blue curve is corrected for seasonal variations, whereas the green curve shows the data before correction.

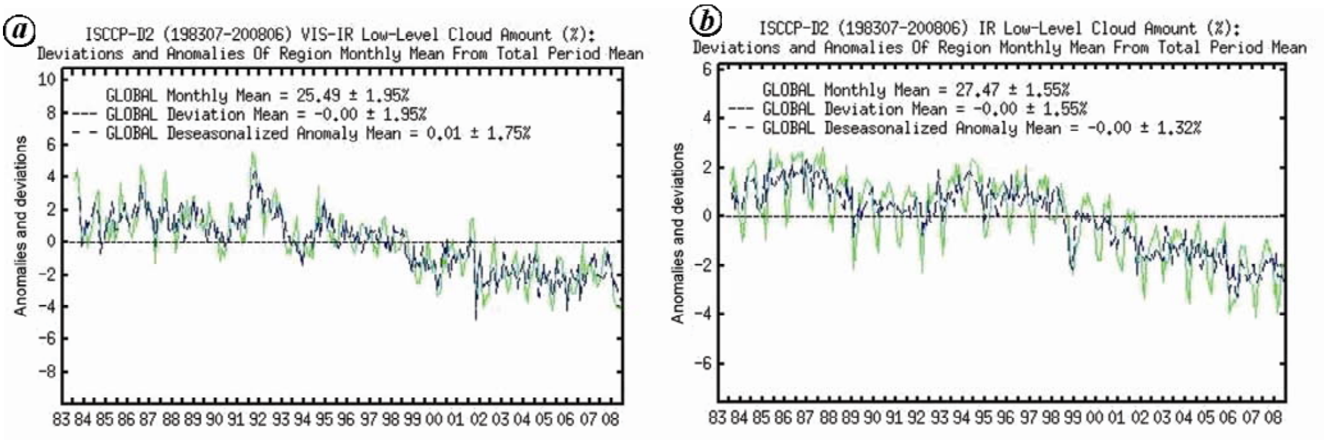

Figure 2. *a*, ISCCP (D2 Vis–IR) lower cloud cover data from the ISCCP. ***b***, Lower cloud cover from the IR data is shown in Figure 1 *b*. The blue curves are corrected for seasonal variations, whereas the green curves show the data before correction.

one or more other processes. In order to prove a connection, Veizer used the modern correlation demonstrated by Svensmark *et al.*[4]. They observed that the ISCCP D2 IR measures of global cloud cover at low level showed a strong correlation with the observed variation of CR during solar cycle 22 from 1984 to 1998. The CR variation is caused by the 11-year cycle of solar activity. Figure 1 *a* shows figure 2 of the Veizer[3] paper which is also figure 2 of Rao's paper[1]. Clearly, there was a good correlation between low-level clouds and CR in this solar cycle. Figure 1 *b* shows the same cloud data now covering the timescale from 1983 through to 2010. This encompasses the next solar cycle (solar cycle 23) which peaked in 2002. It can be seen that the lower level cloud does not show a dip in this solar cycle during 2002, similar to that in 1991. It seems therefore very likely that the dip (and correlation) reported by Svensmark *et al.*[4] is spurious. The data do show a steady decreasing low cloud cover which is matched by an increase in middle-level cloud cover (http://isccp.giss.nasa.gov/climanal7.html). This could be caused by a small shift in cloud height which could generate an apparent correlation between the lower level cloud and CR (ref. 5).

Another measure of cloud cover produced by the ISCCP group does not show the dip in 1991, which is clear in Figure 1 (see Figure 2). It is difficult to determine the cloud cover from the measurements made by the ISCCP group. The uncertainties on the cloud data are subtle[6] and interpretation of structures, such as the small dip in 1991, is probably done using the data at a precision beyond their accuracy. Hence the data cannot be used to support the hypothesis. This is emphasized by Ramanathan[7] in his follow-up to Rao's paper[1].

We conclude from this that the correlation between low-level clouds and CR is not well established.

In his paper Rao cites new evidence for the effect he proposes. This evidence is displayed in Figure 3, which shows the CR rate as a function of time. Note that this is the neutron rate measured directly in the Climax neutron monitor from 1953 and the equivalent rate deduced from ^{10}Be ice core data before 1953 (ref. 8). It can be seen that the CR rate exhibits a strong 11-year cycle due to the modulation effect of the solar wind, with an average peak-to-peak amplitude of 18% between 1953 and 2005. Figure 3 also shows that the average CR rate decreases

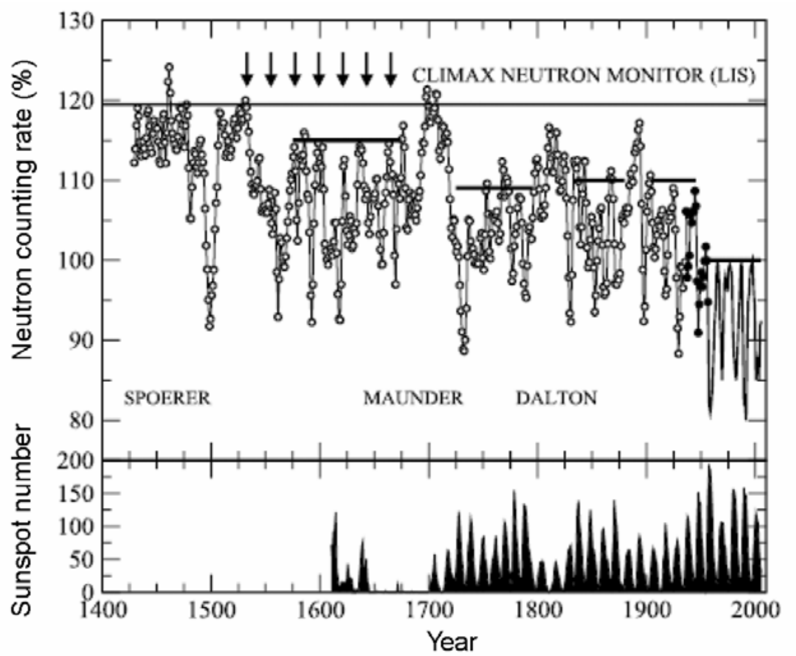

Figure 3. Climax neutron monitor rates as a function of time. The rates from 1953 to 2006 are the direct measurements. The rates from 1936 to 1964 are the equivalent rates deduced from ion chamber data and those from 1428 to 1936 are deduced from the ^{10}Be data from ice cores[8].

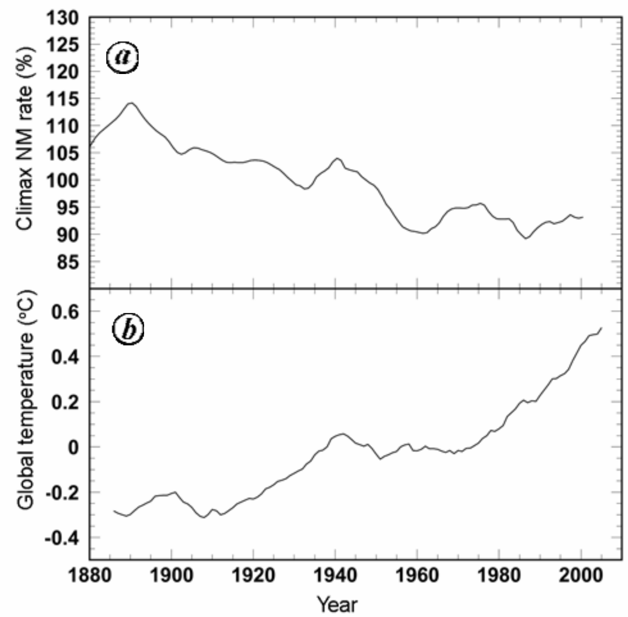

Figure 4. ***a***, Neutron monitor rate from Figure 3 with 11-year smoothing to illustrate the trend. ***b***, Mean global surface temperature from the GISS data with the same 11-year smoothing applied.

by a similar amount between 1880 and 1950, and remains roughly constant thereafter. This is illustrated further in Figure 4, which shows the data from Figure 3 and the mean global surface temperature each with 11-year smoothing. Such smoothing removes the effects of the solar cycle from the CR data in order to illustrate the trends.

The decrease in the averaged CR rate from 1880 to 1950 is, by chance, approximately equal in magnitude to the peak-to-peak amplitude for the solar cycle. Therefore, if the decrease in CR rate were to have made a significant contribution to global warming, there ought to be a matching 11-year wave on the mean global surface temperature, similar to the one seen on the Climax data. Figure 5 shows that it is difficult to discern such a wave. Lean and Rind[9] have measured a small peak-to-peak amplitude, 11-year wave on the surface temperature to be ~ 0.06° in the last century. They attribute this wave to the changing solar insolation. If we assume that part of the wave they observed is due to CR rather than solar insolation and that this wave has amplitude which matches the warming due to changing CR since 1880, as in the CR case, then CR could have contributed up to 0.06° over this period. During the period the observed warming is ~ 0.8°. Hence CR cannot have contributed more than 0.06/0.8 = 7.5% to the increase in the global surface temperature since 1880. A direct comparison of Fourier analyses of both the Climax data shown in Figure 3 and the temperature data shown in Figure 5 proves that a wave similar to that seen on the temperature data must have peak-to-peak amplitude of less than 0.07°, which is compatible with the observation of Lean and Rind[9].

Importantly, the shape of the change in CR shown in Figure 4 does not match the changing temperature. It can be seen that from 1880 to 1950 the CR rate changed rapidly, whereas the temperature changed rather slowly. From 1950 to 2000 the temperature changed rapidly, whereas the CR rate hardly changed at all. Hence the shape of the long-term CR variation does not match the temperature variation. This demonstrates again that there cannot be a strong connection between CR and the global mean surface temperature.

Another upper limit on the effect of CR on temperature has been deduced from the data in Figure 4. Plotting the temperature anomalies from the lower plot in Figure 4 against the CR rates from the upper plot, we arrive at Figure 6. The data appear to follow a linear relationship between 1890 and 1930, with slope of $dT/dCR = -0.011 \pm 0.002°$ per per cent change in CR rate (the equivalent Climax neutron monitor rate). After 1950 (avoiding the anomalous peak around 1940), the total change in Climax rate is less than ~ 3%. Hence, if the value of dT/dCR obtained from before 1930 is valid, the change in temperature due to CR after 1950 should be ~ 0.03° compared to an observed change in temperature of the order of 0.5°, i.e. a fraction up to 0.03/0.5 = 6% of the global warming after 1950 could have come from CR.

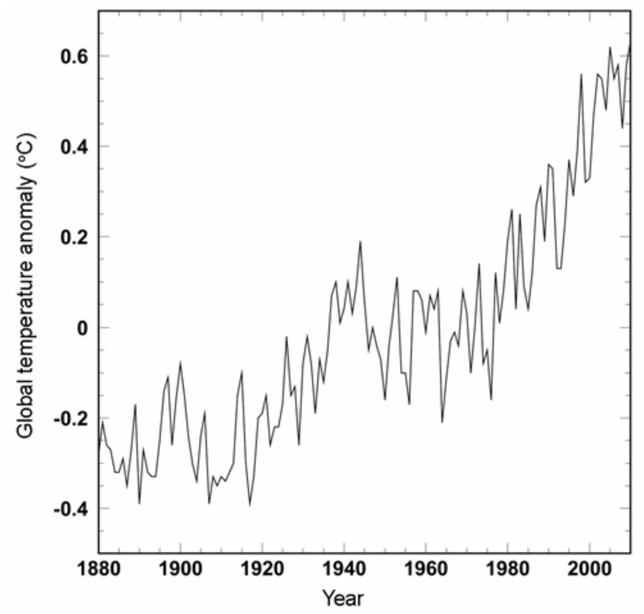

Figure 5. The yearly averaged global temperature anomalies (GISS data) against time.

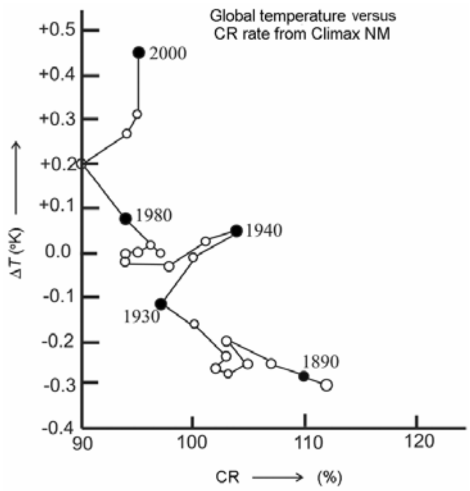

Figure 6. Variation of temperature anomaly ΔT against the CR rate each taken from Figure 4. The solid circles correspond to the marked years and the open circles to other years which are not marked. Both the temperature and CR variations between 1930 and 1950 are anomalous, although, remarkably, the anomalies appear to be unconnected.

Hence Rao's new evidence shows that the warming effect of CR cannot be large and the radiative forcing must be much less than the value of 1.1 W/m^2, which he quotes.

We have shown that Rao's[1] claim of a well-established correlation between LCC and CR is not justified. It is also shown that the new evidence which he cites predicts the wrong variation of temperature with time, if there were such a strong correlation. The absence of an appreciable 11-year wave on the global temperature also indicates that the effect of cosmic rays on the global mean surface temperature must be small. Each effect indicates that the fraction of the temperature increase observed in the last century due to changing CR rates must be less than roughly 6% of the observed global warming. This shows that the effects of CR on cloud formation must be minor in comparison to those from known standard processes, and the effect of CR on the global temperatures during the last century is small.

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