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Contribution Of Changing Galactic Cosmic Ray Flux To Global Warming

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Galactic Cosmic Rays, Low Clouds And Global Warming: A Commentary

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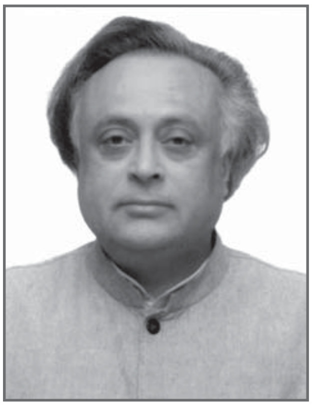
From the Minister's Desk



I have great pleasure in introducing to you the Discussion Paper: **'Contribution of Changing Galactic Cosmic Ray flux to Global Warming'** by Prof U. R. Rao, Chairman PRL Council, Department of Space, and Former Chairman of ISRO, and a commentary on **'Galactic Cosmic Rays, Low Clouds and Global Warming'** by Prof V Ramanathan, Scripps Institution of Oceanography, University of California at San Diego. This Paper is part a series we are publishing under the Indian Network of Climate Change Assessment (INCCA) to enable frank and data-driven discussion and debate on important scientific issues related to climate change.

Prof Rao's paper focuses on the keenly debated issue of Galactic Cosmic Rays (GCRs). Based on recent empirical evidence, Prof Rao argues that future prediction of global warming requires a relook to take into account long term changes in GCR intensity. It is interesting to note that the impact of GCR intensity on climate change has thus far been largely ignored by the mainstream scientific consensus, and Prof Rao argues that this an important omission.

Prof Ramanathan, in his very comprehensive commentary, commends Prof Rao's attempts and outlines some practical scientific challenges going forward.

Prof Rao's paper has been accepted for publication by the Current Science. I am sure that the paper would find keen interest among climate researchers. I invite the scientific community to offer their response to the emerging findings of these studies, and look forward to good data-driven debate on the subject.

Jairam Ramesh
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Contribution Of Changing Galactic Cosmic Ray Flux To Global Warming

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Abstract

The well established excellent correlation between low-level clouds and primary cosmic ray intensity, which act as nuclei for cloud condensation, clearly shows that a decrease in primary cosmic ray intensity results in lesser low cloud cover. Reduced albedo radiation reflected back into space, due to lesser low cloud cover, results in an increase in the surface temperature on the earth. Extrapolation of the intensity of galactic cosmic radiation using ^{10}Be measurements in deep polar ice as the proxy, clearly shows that the primary cosmic ray intensity has decreased by 9% during the last 150 years, due to the continuing increase in solar activity. We present highly persuasive evidence to show that the radiative forcing component due to the decrease in primary cosmic ray intensity during the last 150 years is 1.1Wm^{-2}, which is about 60% of that due to CO_2 increase. We conclude that the future prediction of global warming presented by IPCC4 requires a relook to take into the effect due to long term changes in the galactic cosmic ray intensity.

Introduction

The working group of the Fourth Inter-Governmental Panel on Climate Change[1] (IPCC-4), has made a comprehensive assessment of the effect of anthropogenic Green House Gases on global warming and its consequences under different scenarios for the increase in Green House Gas emission. Since the average growth rate of CO_2 (1.9 PPM/year) is by far the largest compared to other Green House Gases and is also expected to increase due to the growing global demand for energy, a realistic assessment of the actual contribution of CO_2 to global warming is essential to accurately predict the increase in temperature and its consequences on weather and climate. In addition to the uncertainties involved in predicting the rate of growth rate of CO_2, many scientists believe there are additional causes contributing to the global climate change, which have not been fully taken into account in the report. New experimental evidence provides persuasive evidence to show that the primary galactic cosmic ray changes, which generate cloud condensation nuclei, can significantly affect global temperature.

The role of primary galactic cosmic rays in generating low-level cloud condensation nuclei, which reflect solar energy back into space affecting the temperature on earth, was first reported by Svensmark and Christensen[2]. The effect of long term changes in galactic cosmic ray intensity on low level cloud cover formation and its impact on global warming was however not clearly understood due to non-availability of reliable estimate of cosmic ray intensity changes over a long period. In this paper we present recent results on galactic cosmic intensity changes since 1800, obtained using accurate measurements of Be^{10} derived from deep ice core measurements[3] as proxy, in order to estimate the realistic contribution of long term cosmic ray intensity changes to climate warming.

Galactic cosmic intensity changes

It is well known that ^{10}Be nuclei in deep polar ice is a reliable proxy measure of the ~ 2 Gev/nucleon cosmic ray intensity impinging on the earth. By merging long time cosmogenic ^{10}Be data derived from deep ice core measurements with actual cosmic ray observations during 1933 to 1965, McCracken *et al*[4] have reconstructed the long term changes in cosmic ray intensity during 1428 – 2005. Fig. 1 shows the long term changes in cosmic ray intensity as seen in neutron monitor counting rates and corresponding changes in helio-magnetic field during 1800–2000, reproduced from McCracken's Papers[5,6]. From a critical analysis of the data, the above author has shown that the average cosmic ray intensity near the earth

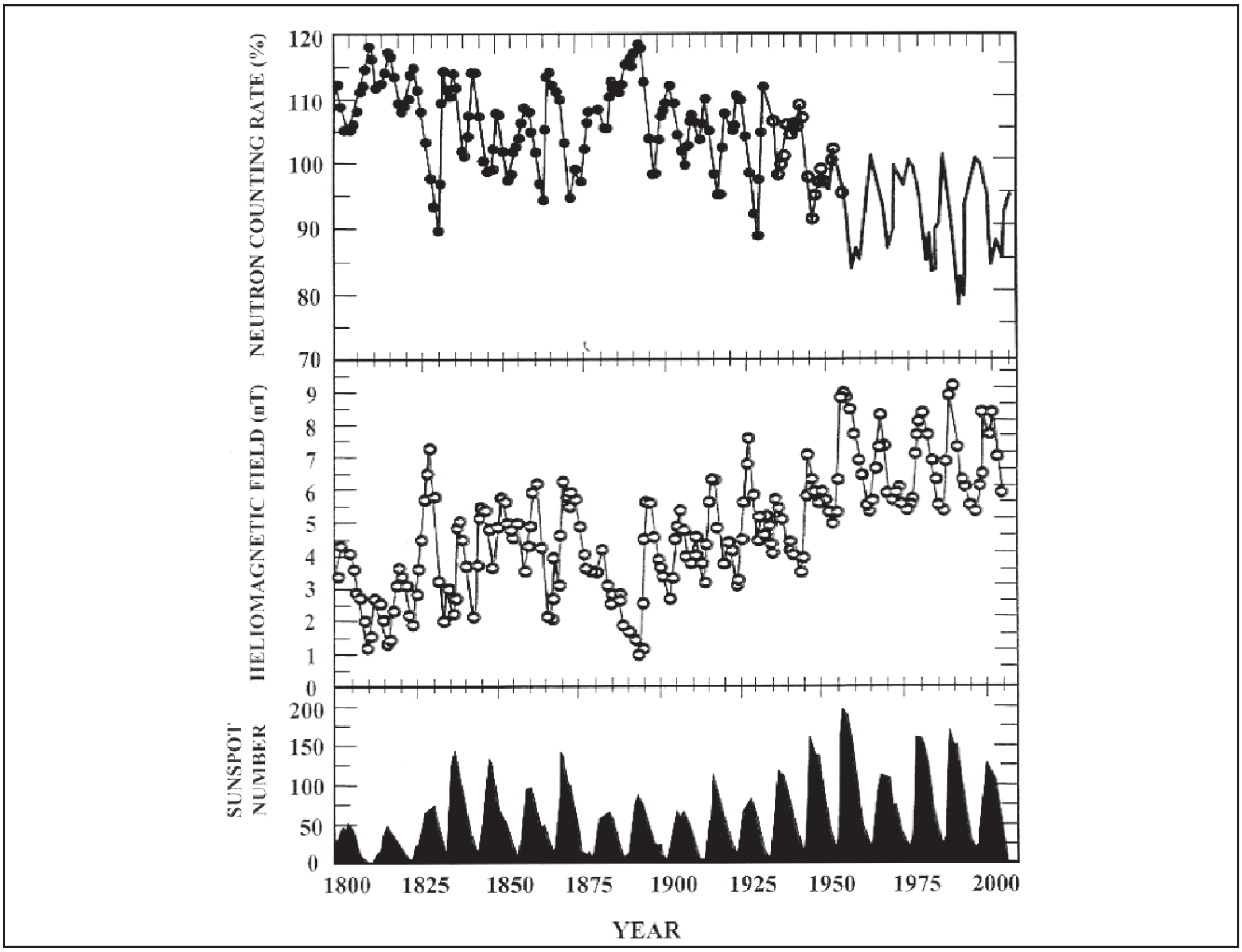

Fig.1: Long term changes in cosmic ray intensity (top panel) along with the corresponding variation in near-earth heliomagnetic field (middle panel) obtained by inversion of cosmic ray data and sun spot number (bottom panel). In the top panel showing cosmic ray intensity, continuous line represents estimated Climax neutron monitor counting rate (1956 – 2000), open circles denote ionization chamber measurements during (1933 – 1956) and filled circles represent cosmic ray intensity derived from Be10 (1801 – 1932) (reproduced from K.G. McCracken[6]).

during 1954 – 1996 was lower by 16% compared to the average for the period 1428 – 1944. The primary cosmic ray intensity recorded during the space era 1960-2005 is the lowest in the last 150 years. Similar conclusion has been independently reached by Taricco *et al*[7] by analyzing the ^{44}Ti activity in meteorites. During the last 150 years when the carbon-dioxide intensity increased from around 280 ppm to 380 ppm, we find the corresponding decrease in cosmic ray intensity is about 9% as seen from the data presented by McCracken and Beer[3,4].

The changes in galactic cosmic ray flux due to its modulation by helio-magnetic field is a very well established fact. Enhancement in solar magnetic activity increases the galactic cosmic ray modulation potential φ which is given by $\varphi = V_p / K(r)$, where V_p is the solar wind velocity and K(r) is the cosmic ray diffusion coefficient[8], which in turn causes a corresponding reduction in cosmic ray flux impinging on the earth. The actual cosmic ray flux in interplanetary space derived from ^{10}Be observations during 1800-2000 has been used to calculate the average helio-magnetic-field (HMF) which clearly shows that HMF has increased[6,9] by a factor of 3.5 from a 11 year average of about 2 nano-tesla to about 7 nano-tesla, which is consistent with the magnetic field observations by the Advanced Composition Explorer[10].

There are at least two ways in which galactic cosmic ray intensity variation can affect global temperature. Cosmic rays, composed predominantly of high-energy protons, are the primary source of ionization in the upper atmosphere, which act as nuclei for cloud condensation[11,12]. Fig.2, which is reproduced from Jan Veizer[13] clearly shows the excellent correlation between cosmic ray intensity, low cloud coverage and variation in solar irradiance. The modulation due to increased helio-magnetic field resulting from increased solar activity reduces galactic cosmic ray intensity, which in turn reduces low level cloud coverage. Reduction in low level clouds due to the decrease in cosmic ray intensity results in reducing the albedo radiation reflected back into space thus causing warming of the atmosphere and increasing the global surface temperature. A 8% decrease in galactic cosmic ray intensity during the last 150 years as derived from ^{10}Be records will cause a decrease of 2.0% absolute in low cover clouds[12] which in turn will result in increasing earth's radiation budget by 1.1Wm^{-2}, which is about 60% of the estimated increase of 1.66Wm^{-2} forcing due to increased CO_2 emission during the same period.

The second effect due to long term changes in cosmic ray intensity arises through stratospheric chemistry. A 9% decrease in cosmic ray flux and NO will cause 3% increase in ozone as per the well established relationship[14,15] .

$$\frac{3}{8} \quad \frac{\Delta NO}{NO} = - \frac{\Delta O_3}{O_3}$$

Ramanathan *et al*[16] have shown that 14% increase in O_3 results in the increase in earth's surface temperature by 0.13°C. Thus, 3% increase in ozone will increase the earth's surface temperature by about 0.05°C, which is relatively small.

If we account for the contribution of 1.1 Wm^{-2} from galactic cosmic ray induced warming, the net contribution from non- anthropogenic factors including solar irradiance towards global warming goes upto 1.22 Wm^{-2}, as against the total net contribution from anthropogenic factors of 1.6 Wm^{-2}. Consequently the contribution of increased CO_2 emission to the observed global warming of 0.75°C would be only 0.42°C, considerably less than that predicted by the IPCC model, the rest being caused by the long term decrease in primary cosmic ray intensity and its effect on low level cloud cover, due to the increase in the helio-magnetic field.

The IPCC working group report has also projected globally averaged surface warming and sea level raise at the end of the 21st century under different scenarios which ranges between 1.8°C (1.1 – 2.9°C) under the best scenario to 4°C (2.4 – 6.4°C) under worst scenario. The effect of cosmic ray intensity over long periods, however, could add or subtract to the global warming depending on the weather the long term variation of primary Cosmic Ray intensity shows a decreasing or an increasing trend. We conclude that the contribution to climate change due to the change in galactic cosmic ray intensity is quite significant and needs to be factored into the prediction of global warming and its effect on sea level raise and weather prediction.

Acknowledgements

The author is indebted to Dr. K.G. McCracken for very fruitful discussions and permission to reproduce Figure 1 shown in the text from his papers. The author is also indebted to Dr. Jan Veizer[13] for permission to reproduce Figure-2 shown in the text. The author also thanks Prof. S.K. Satheesh, CAOS, IISc., Bangalore, who provided valuable assistance in preparing this manuscript.

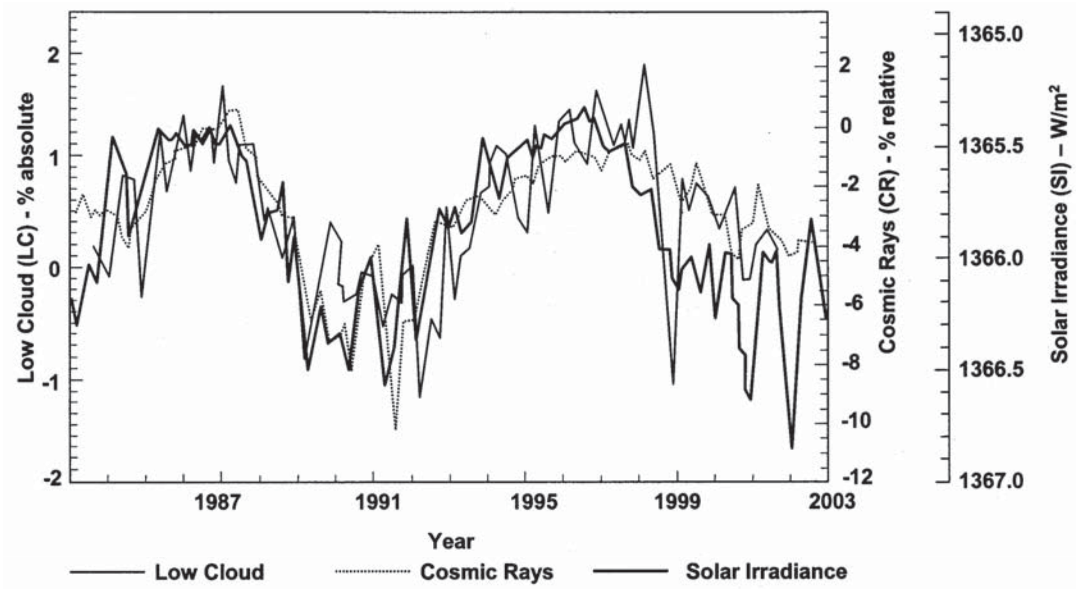

Fig.2: Correlation between cosmic ray intensity as measured by neutron monitors and the low level cloud intensity during 1983-2003. The corresponding values of solar irradiance is also shown in the figure (reproduced from Jan Veizer[12]).

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Galactic Cosmic Rays, Low Clouds and Global Warming: A Commentary

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Abstract

It is well known that incoming solar energy is the primary energy source for the climate system. It has also been well established that variations in the incoming solar energy (irradiance) regulates variations in climate on time scales ranging from 11 years (the sunspot cycle), thousand years (the little ice age and the Maunder minimum) to thousands of years or more (glacial-inter glacial cycles). The current debate on sun-climate connection is around the role of the sun in the multi-decadal scale warming observed during the twentieth century. Professor Rao's[1] paper focuses on the hotly debated issue of Galactic Cosmic Rays (GCRs). The data presented in his paper[1] synthesizes recent data to provide a strong case for including the changes in planetary albedo, due to cloudiness changes induced by solar modulation of GCRs, in our interpretation of the observed climate changes. A review of recent literature lends credence to Rao's model, but the 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 rather strengthens the case for greenhouse forcing as the primary driver of the recent warming trends.

Causal Linkages in the GCR-Cloud-Climate Change

GCRs produce ions in the atmosphere which leads to cloud condensation nuclei (CCN)[2]. Given the right conditions of humidity and vertical velocity, the CCN can lead to cloud drops. The drops in turn scatter solar radiation, both back to space and towards the surface (hence the cloudy sky). The back reflection to space enhances the albedo (brightness) of the planet and causes cooling. The large radiative cooling effect by clouds has been experimentally determined by satellite radiation budget measurements[3]. Thus GCRs can affect climate. Now, let us bring the role of the sun. The flux of GCRs is modulated by solar activity (e.g. sun spots), and thus the role of GCRs in climate can vary with solar activity. This in a nut shell is the proposed connection between solar variations and climate change. Now let us examine the various linkages and summarize available empirical or modeling evidence:

i) Ion production by GCRs and CCN: Quantitative modeling studies (e.g. Yu[2]) have shown that GCRs produce CCN.

ii) Solar cycle and CCN production: Similar modeling studies have also shown that variations in ion production due to modulation of GCRs by solar activity are large enough to significantly perturb CCNs. For lower atmosphere (<3 km altitude) increase in ion production leads to more CCN and more cloud drops.

iii) Solar cycle-CCN production-Low Clouds: It is in establishing this link, that I note substantial differences and discrepancies between various studies (e.g. see discussions in Palle[4] and others[5,6]). Most if not all of these studies rely on the so-called ISCCP satellite cloud cover observations[4]. The ISCCP data are available from 1983 onwards and most analyses have focused on the 1983 to 2005 period, covering the solar cycles 22 and 23. Focusing just on the most skeptical of the available studies[4-6], they do find positive correlations between solar cycle variations and cloudiness but the magnitude of the correlations vary considerably among these studies. In the Palle study, positive correlation between GCR intensity and low clouds is observed, but the correlations are confounded by an anti-correlation between low and high clouds. It is interesting to note that the modeling study by Yu anticipates this result by pointing out GCRs, while producing more CCN at lower levels (<3 km altitude) leads to a reduction of CCN at higher levels. The Sloan and Wolfendale study[6] finds significant correlation for solar cycle 22 but not for cycle 23. Such mixed correlations are not surprising, given the problems with ISCCP data. Several studies (see summary in Evan *et al*[7]) have documented spurious negative cloud trends in cloudiness in ISCCP data due to time-varying satellite configurations, diurnal coverage, satellite viewing angles, to name a few. Given this problem with ISCCP data, all we can conclude from published ISCCP-based studies on GCRs and cloudiness, is that there are potentially tantalizing links between trends in GCRs and cloudiness. We can neither categorically rule out a GCR-cloud connection (of the sort suggested by Rao[1]), nor conclude affirmatively about such a connection.

Even if the ISCCP data are reliable for trend analyses, the correlation between GCRs and cloudiness may not be straight forward. I list below some of the reasons:

a) Due to anthropogenic emissions of aerosols, there is abundance of CCNs in all continental regions and most oceanic regions of the world. The CCNs in continental air mass are in the range of 1000 to 5000 particles per cc. The cloud drop concentrations in most low level clouds are less than 500 per cc (see summary in Ramanathan *et al*, 2001[8]). In the N Indian ocean and in the N Atlantic Ocean, the CCNs are in the range of 1000 per cc. In such heavily polluted regions, additional ionic sources (from GCRs) are not required to account for the observed cloud drop number concentrations. Thus analyses looking for GCR-Cloud connection should focus on non-polluted regions such as remote oceans in the Northern Hemisphere Pacific or southern hemisphere oceans.

b) Satellite cloud data begin only in the 1980s, the period which is witnessing large warming trends. We expect regional and global cloudiness to respond to the warming trends. Thus, analyses that attempt to explain all of the cloudiness trends in terms of trends in GCRs may be inadequate.

iv) Trends in GCRs and Global Mean Temperatures: Observations of global average temperatures during the twentieth century, reveal 3 basic periods: A) Warming trend from 1900 to 1940; B) followed by a slight cooling trend from 1940 to 1970; C) which terminated in the current rapid warming trend which is continuing unabated until now. Keeping this pattern in mind, if we examine Figure 1 of Rao[1], we note that GCRs (top two panels) underwent a monotonic decrease in intensity from 1900 to about 1970 and then leveled off from 1970 onwards (revealed more clearly in the middle panel). Clearly, the variations in GCRs can not account for the large warming trend from 1970 to 2010.

CONCLUDING DISCUSSIONS

The basic recommendation emerging from Rao's model is that cloud albedo variations caused by GCR variations should be included in studies that attempt to attribute the observed temperature trends in terms of greenhouse forcing. Rao[1] estimated a radiative forcing of about 1.1 Wm^{-2} due to the GCR-cloud link, which compares with the CO_2 forcing of 1.7 Wm^{-2} from pre-industrial to 2005 (IPCC-AR4, 2007). Even if the GCR-Cloud forcing is smaller by a factor of 2 to 4, this mechanism should still merit attention. Physically as well as mechanistically, detailed aerosol modeling studies[2], have concluded ionization by GCRs can produce cloud condensation nuclei. But serious difficulties have been encountered by studies that attempted to take this proposal beyond the mechanistic stage. Empirical studies that have attempted to either prove or disprove the GCR-cloud linkage are not conclusive since they have to rely on flawed satellite cloudiness data. One way to make some progress is to conduct detailed field studies with airborne instrumentation that experimentally examine the link between CCN produced by ions and cloud albedos. Given that the planet's future hinges in quantifying the impact of greenhouse gases, such an attempt is worthwhile. To this extent, Rao's paper should be commended for drawing attention to this important issue, which is struggling to gain entry into main stream climate change science.

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