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A study of secondary cosmic ray flux variation during the annular eclipse of 15 January 2010 at Rameswaram, India

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ABSTRACT

The gamma ray flux was measured during the annular solar eclipse on January 15, 2010 at Rameswaram, India using NaI (Tl) scintillator detectors and the variation in charged particles and gamma rays was monitored using Geiger Müller (GM) counters. The gamma ray flux variation was studied in energy range of 0.1–3.5 MeV. Weather parameters (temperature and humidity) were continuously recorded throughout the duration of the eclipse at the site and correlation between gamma ray flux and weather parameters was examined. Analysis of the secondary cosmic ray flux using Fast Fourier Transform (FFT) was carried out to study the impact of the eclipse on the flux modulation. An overall decrease in flux was observed by both GM counters and scintillator detectors. A relative enhancement observed for short time during the eclipse which could be associated with the presence of counter electrojet observed at Rameswaram. This is suggestive of an increase in secondary cosmic ray flux at the geomagnetic equator during every counter electrojet due to decrease in geomagnetic rigidity.

1. Introduction

Solar eclipse is a very important and large scale celestial event occurring in nature. The rapid reduction in solar irradiation during the eclipse causes many secondary effects on the Earth's atmosphere. The annular solar eclipse of January 15, 2010 provided an opportunity to investigate these effects. The Earth reached perihelion (minimum distance from the sun) on January 3, 2010, so the sun was nearly at its maximum apparent diameter on the eclipse day of January 15, 2010. The Moon reached aphelion (maximum distance from the Earth) on January 17, 2010 (01:41 UT) and hence it was close to its minimum apparent diameter during the eclipse. The combination of these factors resulted in an unusually long duration of annularity (11 min 16 s) with wide path of about 300 km. This was the longest annular eclipse of the third millennium and it is expected that this duration would not be exceeded until the annular eclipse of the year 3043 AD [1]. Fig. 1(a) shows the path of the antumbral shadow of the moon that began in Africa and passed through Chad, Central African Republic, Democratic Republic of the Congo, Uganda, Kenya, and Somalia. After reaching Africa, the path crossed the Indian Ocean where the maximum duration of annularity was reached. The central path then continued into Asia through India, Sri Lanka, Bangladesh, Burma and ended in China. The magnitude of the eclipse was 0.91 in Rameswaram, a small town, situated in the southern part of India where the study was carried out. Fig. 1(b) illustrates that selected site was near the central line of the eclipse and was one of the best sites for the eclipse observation. The experiments were performed at Bangur Dharmashala (Geographical latitude: 9°17′12″N, longitude: 79°19′1″E). The total duration of the eclipse observed at the site was about 3 h 53 min and the annularity lasted for about 10 min 10 s.

In the past there have been several observation reports of decrease in the secondary cosmic ray (SCR) flux during a solar eclipse. The experimental studies carried out by Bhattacharyya et al. [2] observed the maximum drop of 25% in the secondary gamma ray flux in energy interval of 2.4–2.7 MeV. The total solar eclipse of August 1, 2008 was studied by Nayak et al. [3]. They observed a steady decrease of about 4% during the eclipse. Also, just prior to the first contact a sharp variation of 9% was seen. The measurements of γ-ray and X-ray background during the total solar eclipse which occurred on October 24, 1995 were carried out by Chintalapudi et al. [4]. They observed 9–10% reduction in both γ-ray and X-ray

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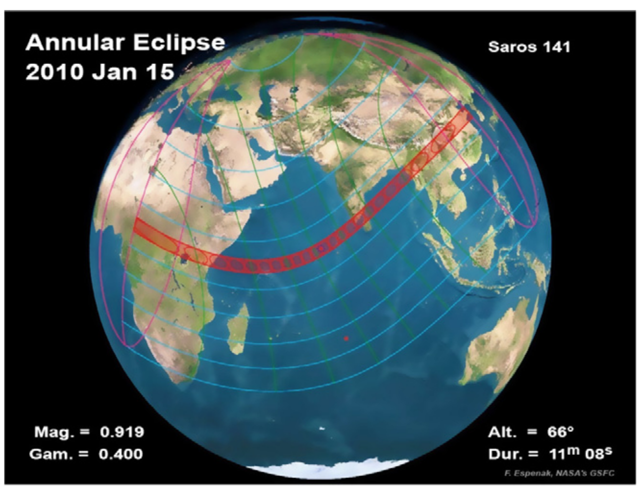
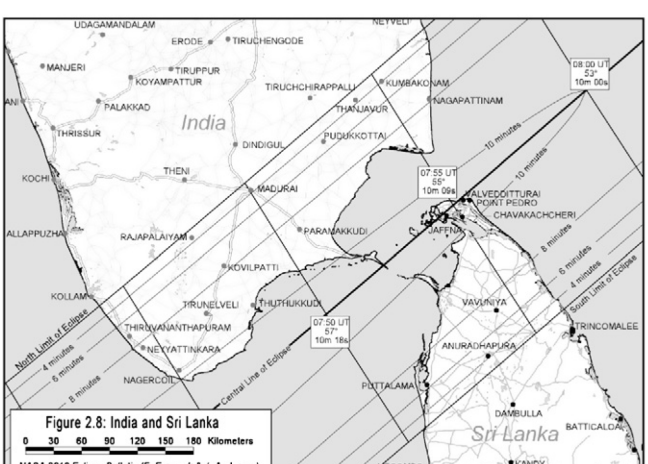
flux during the eclipse. The observed profile of SCR flux variation was different in each of the above studies. The primary aim of our study is to measure the SCR flux during the eclipse and to examine its correlation with weather parameters and geomagnetic field which could give more insight in the phenomenon of decrease in the SCR flux which is not yet well established. Also the eclipse being annular, presented a unique opportunity to study its effect on cosmic rays.

This paper is arranged as follows, first section discusses the eclipse parameters and past observations of SCRs during solar eclipses. The experimental setup is explained in Section 2 of the paper. Sections 3 and 4 present the weather and interplanetary conditions respectively on the eclipse day. In Section 5, we discuss our observations of SCR flux temporal variation during the eclipse. Section 6 elaborates the obtained results of correlation and Fast Fourier Transform (FFT) analysis. The paper ends with a discussion of the physical phenomenon causing the decrease of SCR during eclipse and conclusions obtained from present study.



(a) Shadow path of January 15, 2010 annular eclipse on the earth



(b) Annularity path in southern India

Fig. 1. Annular solar eclipse path of January 15, 2010.

2. Experimental setup

Two different NaI (Tl) scintillator detectors having dimensions of 5.08 cm × 5.08 cm (N-1) and 7.62 cm × 7.62 cm (N-2) were used to measure the variation of cosmic ray flux during the eclipse. Two Geiger Müller (GM) counters were used for studying the flux variation of charged particles and gamma rays. The pressure and humidity of the atmosphere were monitored using thermometer and a digital humidity sensor. The top view of the scintillator detectors N-1, N-2 and GM tubes shielded by lead bricks is shown in Fig. 2. Both the scintillator detectors were calibrated using radioactive sources ^{137}Cs (0.662 MeV), ^{60}Co (1.173 MeV and 1.332 MeV) and ^{22}Na (1.278 MeV). In addition to these, peaks originating from ^{40}K (1.462 MeV) and ^{208}Tl (2.161 MeV) were observed in the background spectra. Each detector pulse is processed through preamplifier, linear amplifier, multi-channel analyzer (MCA) and then stored in computer. A schematic of the arrangement of the setup is shown in Fig. 3.

An experiment to observe the effect of shielding was carried out one day prior to the day of eclipse. A rectangular arrangement of lead bricks was used to remove background from the Earth. The bottom part of detectors were placed on a 10 cm thick lead bricks and other sides were shielded with 5 cm thick lead bricks. Fig. 4 shows the background spectrum with and without shielding in

Fig. 2. Top view of the scintillator detectors N-1 and N-2 with GM tubes shielded by lead bricks.

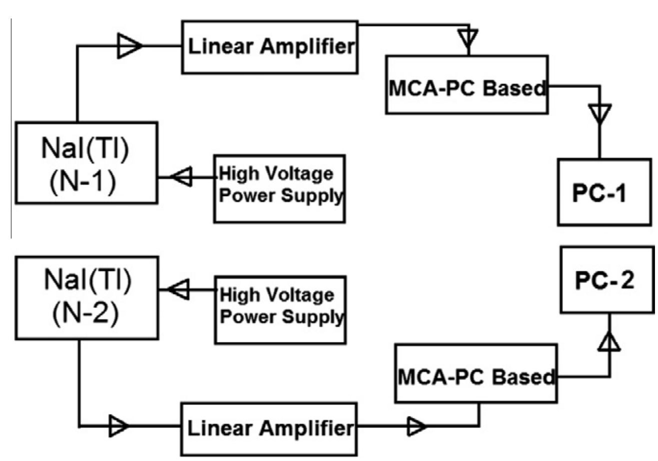


Fig. 3. The schematics of the arrangement of the setup used for SCR flux measurement.

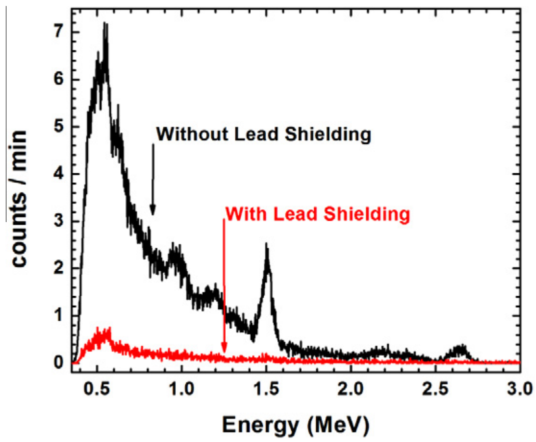


Fig. 4. The background spectrum obtained in scintillator detector (N-1) counted for 1 h with and without lead shielding.

N-1 counted for 1 h. As expected, there was a considerable reduction in the background counts when the detectors were shielded with lead bricks [5,6]. The SCR spectra were recorded for every 5 min for N-2 detector and 10 min for N-1 detector. The detector systems were calibrated at regular intervals on the day of eclipse. The counts in GM counters were recorded every 2 min. The data from scintillator detector and GM counter were recorded from 5:30 (IST) on January 15 to 5:30 (IST) on January 16.

3. Weather parameters

Weather parameters were continuously monitored during the eclipse. Temperature and relative humidity of the atmosphere were recorded every 5 min time interval. Fig. 5 shows the plot of percentage relative humidity and temperature variation during the eclipse. It is seen clearly in Fig. 5, that the temperature of the atmosphere started to decrease after the first contact and reached its minimum value at maximum eclipse. After the third contact, the temperature started to increase and reached about 30 °C and it remained steady around the fourth contact. The variation of weather parameters is consistent with the observations done by Sharma et al., during annular eclipse of 15 January 2010 [8]. The maximum temperature observed just prior to the first contact was 32.1 °C and was at a minimum of 27.4 °C near the maximum eclipse. Temperature decrease of 14.6% was observed during the eclipse. It is observed that humidity increases during the eclipse. A sharp change in relative humidity was observed just after the annularity and also after the fourth contact as seen in Fig. 5. The time delay between maximum eclipse and maximum relative humidity was 16 ± 5 min. A change of 18% in relative humidity was observed during the eclipse.

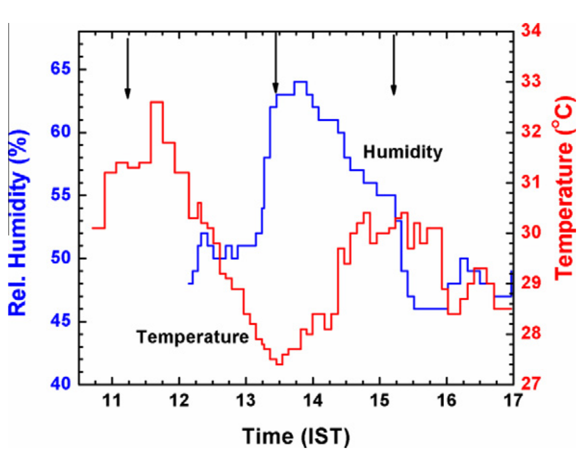


Fig. 5. Temperature and percentage relative humidity variation during the eclipse. The arrows from left to right indicate the first contact, the maximum eclipse and the fourth contact respectively.

4. Interplanetary and geomagnetic parameters

The influence of geomagnetic and interplanetary parameters on SCR flux was studied. The geomagnetic activity indices indicate the degree of disturbance in the geomagnetic field. The activity indices were obtained from CDAWeb database [7]. The data of primary cosmic rays (10–20 GeV) obtained from Moscow cosmic ray observatory [10]. The Moscow cosmic ray observatory was outside the eclipse shadow region. The cosmic ray flux in Fig. 6(A) shows reasonably constant cosmic ray counts (impacts/min) during the eclipse. The average interplanetary magnetic field (IMF) shown in Fig. 6(B) did not change much during the eclipse which also supports the less disturbed interplanetary medium near the Earth. The Disturbed Storm Time (Dst) index is the strength of symmetric westward ring current which encircles the Earth in the equatorial belt of ±30°, notably during a geomagnetic storm. Fig. 6(C) shows the ring current strength which was close to 0 nT during the eclipse indicating low geomagnetic disturbance. The disturbance in horizontal (H) component of geomagnetic field reflects activity in geomagnetic equatorial, low latitude and auroral locations. The planetary 3-hourly K_p index which is derived from H varies from 0 to 9. The index $K_p = 9$ indicates a variation of 300 nT in the H component at low geomagnetic latitudes [9]. As seen in Fig. 6(D) the planetary K_p index remained very low during the eclipse which indicates a global geomagnetically quiet period.

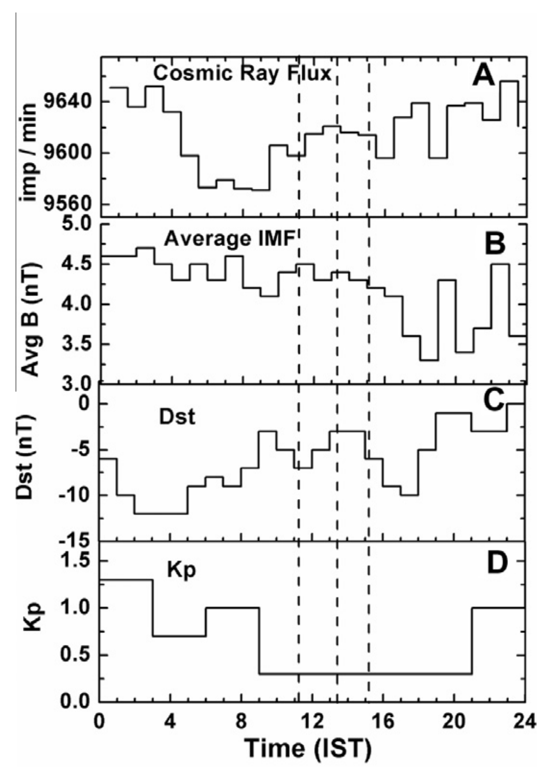


Fig. 6. Cosmic ray neutron flux and geomagnetic parameters. (A) Cosmic ray flux. (B) Average interplanetary magnetic field (IMF). (C) Disturbed storm Time Index (Dst). (D) Planetary 3-h range index (Kp). Dotted vertical lines from left to right indicate the first contact, the maximum eclipse and the fourth contact respectively.

The absence of large variations in these geomagnetic and interplanetary parameters ensures the absence of any major magnetospheric disturbance of solar origin during the eclipse.

5. Secondary cosmic ray flux variation

The spectra obtained from both the scintillator detectors were analyzed. The energy dependence of variation is examined in 0.1–3.5 MeV range with 0.5 MeV energy window. The energy bands studied are 0.1–0.5 MeV, 0.5–1.0 MeV, 1.0–1.5 MeV, 1.5–2.0 MeV, 2.0–2.5 MeV, 2.5–3.0 MeV and 3.0–3.5 MeV. The counts were integrated in 0.5 MeV energy window for each of the recorded energy spectrum. It is to be noted that Fig. 7(A) shows the variation of the total SCR flux in N-1 while the variation of SCR flux in energy range 1.0–1.5 MeV in the same detector is given in Fig. 7(B).

The observations were carried out near the geomagnetic equator where the vertical threshold rigidity for cosmic ray particles was maximum, therefore the measured count rate was relatively low compare to high geomagnetic latitude region [15]. Also the size of the scintillator detectors used was small which is reflected in statistical errors of SCR counts [11]. As shown in Fig. 7 the overall decrease of SCR flux is observed for the total count, where the decrease is more prominent in the energy band 1.0–1.5 MeV. The variation in remaining energy bands however, is not seen clearly. The variation of integrated SCR flux over whole energy spectrum and variation of integrated SCR flux in energy interval 1.0–1.5 MeV has similar profiles. The percentage variation in SCR flux during the eclipse in energy range 1.0–1.5 MeV recorded by N-1 is shown in Fig. 8. The maximum drop observed in 1.0–1.5 MeV SCR flux is 21 ± 7% near the annularity. It is to be noted that the flux recovered after the fourth contact. The time gaps in SCR flux variations indicate the time duration when the calibration of scintillator detectors were carried out.

To study the effect of the eclipse on SCR flux mainly charged particles and low energy gamma ray components, two GM counters were used which were placed within the lead shielding. For better statistics we have summed the GM counter data of five successive runs to generate a new data set every 10 min. Fig. 9 shows a sharp decrease in count after the first contact with 30 min delay

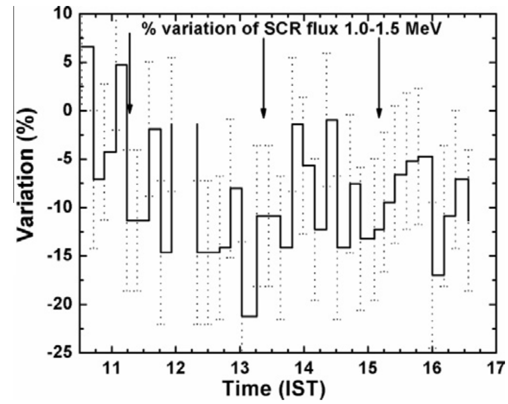


Fig. 8. SCR flux variation in energy interval of 1.0–1.5 MeV as recorded by detector N-1. The arrows from left to right indicates first contact, maximum eclipse and fourth contact respectively.

which remained low until a sharp increase in count occurred after the fourth contact having a time delay of about 60 min. The observed count variation profile is consistent with observations done by Bhattacharya et al. [12].

The Earth's geomagnetic equatorial region shows high amplification of horizontal (H) component of geomagnetic field during noon time due to unique horizontal geomagnetic field configuration in that region. This effect is known as equatorial electrojet. Some times, generally on solar quite days the diurnal pattern of H component shows depression which is known as equatorial counter electrojet (CEJ) phenomenon. It has ±3° spread around the geomagnetic equator. The geomagnetic latitude of Rameswaram is 0.48°N so it is located in the equatorial electrojet (EEJ) region. On the eclipse day, the Tirunelveli geomagnetic observatory (Geomagnetic latitude 0.03°N) observed a CEJ during the eclipse

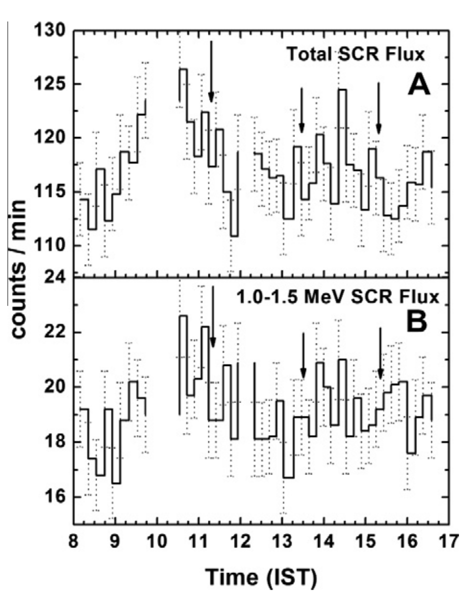


Fig. 7. (A) The variation of the total SCR flux recorded by detector N-1. (B) The variation of SCR flux in energy range 1.0–1.5 MeV in N-1. The arrows from left to right indicate first contact, maximum eclipse and fourth contact respectively.

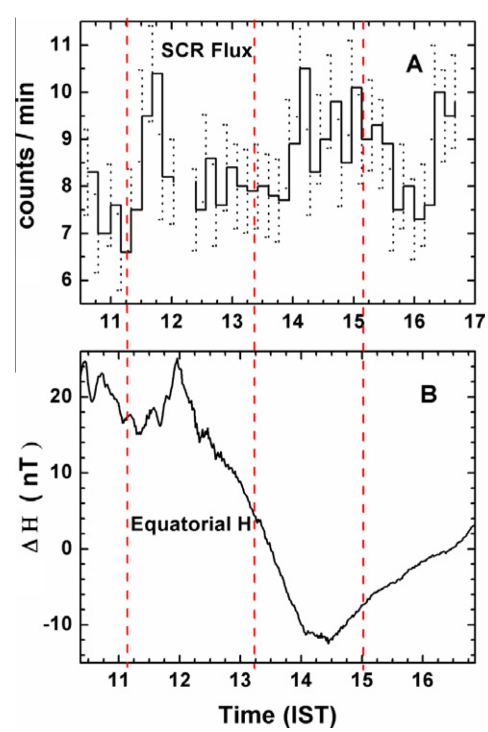


Fig. 9. (A) SCR Charged particles and low energy gamma rays variation seen by GM counter during eclipse. (B) Variation of ΔH component of geomagnetic field at Tirunelveli. Dotted lines from left to right indicate start, maximum and end of the eclipse respectively.

which could be attributed to the eclipse effect [13]. The longitudinal difference between Tirunelveli and Rameswaram is about 1.5°, so CEJ must have been present at Rameswaram too. The signature of CEJ is seen in GM counter and scintillator data. There is an increase of SCR flux seen during 13:55 (IST) to 15:40 (IST) which could be attributed to a decrease in geomagnetic field which is seen in Fig. 9. The increase in SCR flux is also observed in the scintillator detector. This could be explained, when geomagnetic field of the Earth decreases the geomagnetic cut-off rigidity also decreases and it favors the cosmic rays of low rigidity to access the Earth's atmosphere resulting in flux increase [14].

6. Correlation and Fast Fourier Transform analysis

To explain the decrease of SCR flux, correlation analysis and Fast Fourier Transform (FFT) was used and is discussed here. Temperature during eclipse decreases and it has been reported that gamma ray flux decreases during the eclipse. It is expected that the correlation between the count and temperature must be positive. The correlation coefficient was determined for temperature and detector count during the eclipse. We have used the Pearson correlation, estimated with two tailed test of significance. The positive correlation is obtained for counts in energy interval 0.1–0.5 MeV and 1.0–1.5 MeV. For energy band 0.1–0.5 MeV, correlation coefficient (r) is 0.31 with the significance probability of correlation $P = 0.08$ and for 1.0–1.5 MeV energy interval, $r = 0.30$ and $P = 0.09$. The obtained correlation coefficient of integrated count over energy interval 0.1–3.5 MeV with temperature is $r = 0.33$ with $P = 0.06$ where P is an estimate of the probability that the result has occurred by statistical accident. Hence the obtained correlation is statistically significant. The positive correlation indicates that the count decreased during the eclipse. The correlation of counts of remaining energy intervals with temperature was very low and not significant. This may be due to low count or absence of the eclipse induced modulation of gamma rays of these energies. These supports the decrease of gamma ray flux during the eclipse. Similarly correlation analysis is performed on count and relative humidity. The significant correlation of humidity was observed only with 0.5–1.0 MeV gamma ray counts ($r = 0.36$, $P = 0.09$). The temperature is better correlated with gamma ray counts as compared to humidity but this might not indicate any cause and effect relationship between temperature and gamma ray count or humidity and gamma ray count.

Anti-correlation between temperature and relative humidity was observed. Pearson correlation coefficient (r) was found to be -0.55 with significance probability (P), 9.7×10^{-5} which, as expected, indicates the observed anti-correlation is significant.

The observed annular eclipse had a duration of 3 h 53 min and hence it is expected that the low frequency component of 8 h periodicity be present in the SCR flux variation and must be amplified during the eclipse. The equal number of data points ($N = 32$) of SCR flux were selected during (10:32–16:22 IST) the eclipse and after (17:59–00:26 IST) the eclipse. Mean value each time series were subtracted from it, which removes the zeroth frequency peak in estimated Fourier power spectrum. Both time series were filtered with low pass Butter-worth filter in Interactive Data Language (IDL 8.0.1), with cut-off frequency 0.0004 Hz. FFT was performed on this filtered data by using IDL's inbuilt FFT function which uses Cooley–Tukey algorithm. To measure the estimated Fourier power relative to white noise spectrum was normalized by $N/2\sigma^2$ where σ^2 is variance of respective time series [16,17]. Fig. 10 shows the estimated power spectrum for 0.1–0.5 MeV SCR flux during and after the eclipse. The dotted lines indicate the white noise level. The peaks at 0.00005 and 0.0002 are above the white noise level. The FFT of SCR counts was done for 0.1–3.5 MeV energy interval.

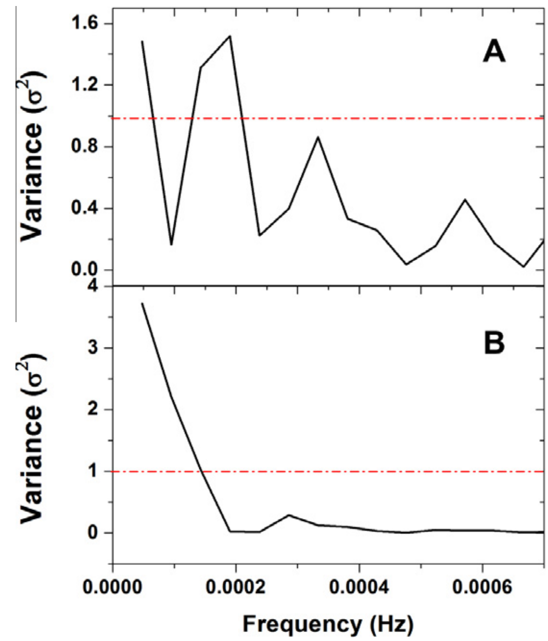


Fig. 10. The FFT normalized power spectrum obtained from SCR flux measured. (A) During the eclipse and (B) after the eclipse, in energy range 0.1–0.5 MeV.

To see which frequencies were amplified during the eclipse, the ratios of FFT normalized power during the eclipse to FFT normalized power after the eclipse were obtained for different frequencies and plotted with corresponding frequencies. The energy windows 1.0–1.5, 1.5–2, 2–2.5 MeV shows amplification of modulation of SCR flux having periodicity of ~6 h. The energy band 0.1–0.5 MeV shows the amplification of modulation of period ~1.5 h which is clearly seen in Fig. 11. Quasi-periodic waves of 1.5 h periodicity were observed in the Earth's ionosphere during total solar eclipse of 29 March 2006 [18]. This periodicity of 1.5 h in SCR flux might be related with such waves. More study is required to verify

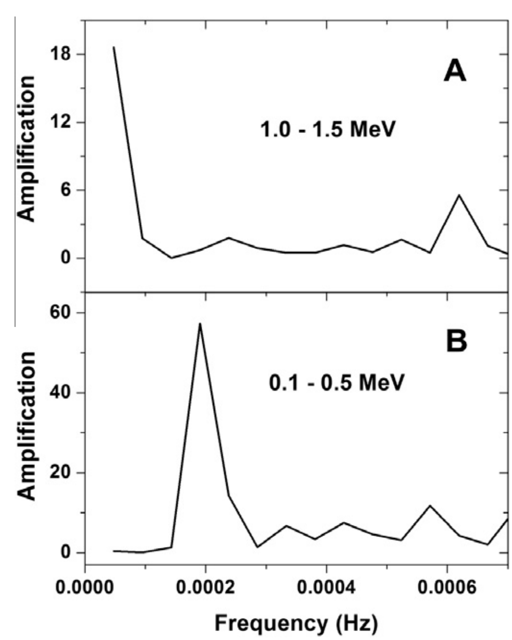


Fig. 11. The ratio of FFT normalized power obtained for during eclipse SCR flux to FFT normalized power obtained for after eclipse SCR flux in the energy range 1.0–1.5 MeV and 0.1–0.5 MeV.

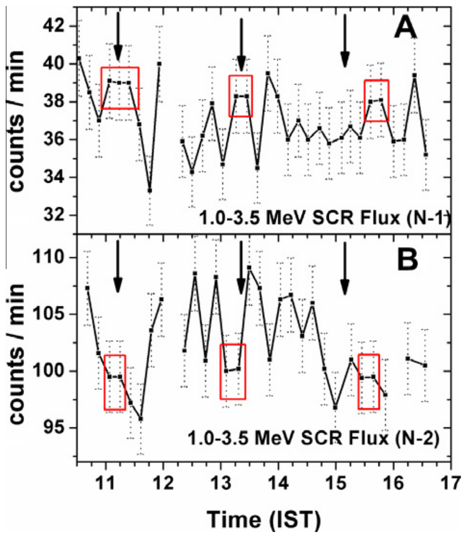


Fig. 12. The SCR flux in the energy region 1.0–3.5 MeV observed in N-1 and N-2 during the eclipse. The boxes show the constant SCR flux. The arrows from left to right indicate first contact, maximum eclipse and fourth contact respectively.

this. No amplification is observed in the rest of the studied energy windows.

Observations of SCR flux variation profile (Fig. 12) shows that the counts of both the scintillator detectors appear to be constant during the first contact, during the annularity and after the fourth contact though the statistical error bars are high in scintillator data. The data was collected during the annularity such that integration time of data points lay in the annularity time duration. Each constancy of count is generally observed for 20 min duration. The box shows the apparent constant SCR flux. The observed constancy is seen in different energy intervals 0.5–1.0 MeV, 1.0–1.5 MeV, 1.5–2.0 MeV, 2.5–3.0 MeV simultaneously, which indicates the constant flux is real in nature and not occurred coincidentally. After fourth contact the observed time delay in reaching constant flux might indicate the relaxation time of the system causing this effect.

7. Discussion

We note that in general, the SCR flux observed is seen to recover after the eclipse. Nayak et al. [3] observed steady decrease but flux did not recover after the eclipse. These observations were done at high latitude, and hence CEJ was not experienced. Bhattacharyya et al. [12] and Kandemir et al. [19] observed a recovery in count after the eclipse. However, our observation of SCR flux as seen in Fig. 9(A), shows gradual decrease and then recovery in counts after the fourth contact.

The recent observations of Bhattacharya et al. [12] using GM counter shows a sharp decrease in SCR flux after first contact with about 1.0 h time delay and recovery after eclipse ended having about 2.0 h time delay. Our observations of GM counter reflects this time delay, with difference being 0.5 h after first contact and 1.0 h after eclipse end. The SCR flux measured using scintillator detector is mainly gamma ray flux and GM counter measures mainly charged particles. The scintillator count shows almost instantaneous decreasing trend in gamma ray flux while GM counter shows decrease in charged particle flux after finite time delay. This important observation reflects the characteristics of the system responsible for this decrease.

Bhattacharyya et al. [2] have attributed the decrease in SCR flux during the eclipse to atmospheric cooling. Chintalapudi et al. [4] explained the decrease in γ-ray and X-ray flux as a blocking of central portion of the sun. We suggest two different processes which could explain these observations, firstly the gradual decrease in SCR flux measured by detector could be due to blocking of direct solar cosmic rays by the moon as put forward by Chintalapudi et al.. Secondly the time delay indicates some atmospheric process which takes time to adjust with rapid change in solar radiation. We observed prominent variation in 1.0–1.5 MeV which might be due to modulation of certain atmospheric γ-ray emission lines produced by interaction of cosmic rays and solar-energetic particles on the Earth's atmosphere. Okabe et al. [20] observed the diurnal looping variation of environmental gamma rays. They observed the contribution of gamma rays produced by atmospheric radon daughters to the environmental radiation count is 10–25%. This observed variation of the concentration of radon daughters is influenced by the meteorological parameters. A detailed investigation is required to understand the impact of radon looping variation on observed variation of SCR flux during eclipse.

8. Conclusions

The present study shows that there is a decrease in SCR flux during the eclipse. The variation is clearly seen in 1.0–1.5 MeV energy window. Correlation analysis of SCR flux with temperature also supports the decrease in flux during the eclipse. FFT analysis indicates the amplification of flux modulation having ~6 h periodicity during the eclipse which could be ascribed to the eclipse effect. The observed amplification of SCR flux modulation having ~1.5 h periodicity might be related to ionospheric waves generated during eclipse. The interplanetary parameters do not show any apparent effect on SCR flux. The absence of large variations in interplanetary parameters suggest the eclipse duration was geomagnetically quiet, except the occurrence of CEJ during the eclipse. Since the decrease in H component of Earth's geomagnetic field increases the count, we conclude that the observed decrease in SCR flux is not due to the decrease in the geomagnetic field observed during the eclipse. The physical process responsible for the observed constancy in SCR flux observed in N-1 and N-2 is not understood yet, more observations and theoretical study is required in future to understand and confirm this interesting phenomenon. We plan to do a detailed study of the impact of atmospheric parameters like temperature, pressure, humidity on diurnal SCR flux variation.

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References

[1] F. Espena, J. Anderson, Annular and Total Solar Eclipses of 2010, 2008 (NASA/TP2008214171).

[2] A. Bhattacharyya et al., Astro. Space Sci. 250 (1997) 313.
[3] P.K. Nayak et al., Astropart. Phys. 32 (2010) 286.
[4] S.N. Chintalapudi et al., Kodaikanal Obs. Bull. 13 (1968) 225.
[5] A. Stenberg, I.U. Olsson, Nucl. Instrum. Methods 61 (1968) 125.
[6] R.R. Finck et al., Nucl. Instrum. Methods 135 (1976) 559.
[7] Available from: <http://cdaweb.gsfc.nasa.gov/>.
[8] S.K. Sharma et al., Ann. Geophys. 28 (2010) 1199.
[9] Girija. Rajaram, P.R. Pisharoty, The Earth's Magnetic Field, Oxford and IBH Publishing Co. Pvt. Ltd., New Delhi, 1998.
[10] Available from: <http://helios.izmiran.troitsk.ru/>.
[11] M. Galli et al., Durban 2 (1997) 409.
[12] R. Bhattacharya et al., Curr. Sci. 98 (2010) 1609.
[13] A.T. Tomas et al., J. Atmos. Solar-Terr. Phys. 70 (2008) 1497.
[14] Cosmic rays in the Magnetosphere of the Earth and other Planets, Lev Dorman, 2009, p. 231.
[15] J. Thompson, Phys. Rev. 54 (1938) 93.
[16] C. Torrence, G.P. Compo, Bull. Am. Meteor. Soc. 70 (1998) 61.
[17] J. Javaraiah, M.H. Gokhale, Soar Phys. 158 (1995) 173.
[18] V.P. Antonova et al., Bull. Russ. Acad. Sci. Phys. 71 (2007) 1054.
[19] G. Kandemir et al., ASP Conf. Series 205 (2000) 202.
[20] S. Okabe et al., Nucl. Instrum. Methods A 255 (1987) 371.