Proceedings of the 30th International Cosmic Ray Conference
Rogelio Caballero, Juan Carlos D'Olivo, Gustavo Medina-Tanco,
Lukas Nellen, Federico A. Sánchez, José F. Valdés-Galicia (eds.)
Universidad Nacional Autónoma de México,
Mexico City, Mexico, 2008
Vol. 1 (SH), pages 509–512

30TH INTERNATIONAL COSMIC RAY CONFERENCE

Modulation Cycles of GCR Diurnal Anisotropy Variation

Y. YI[1], S. Y. OH[1].
[1]*Department of Astronomy & Space Science, Chungnam National University, Dajeon, Korea*
euyiyu@cnu.ac.kr ; osy1999@cnu.ac.kr

Abstract: The diurnal variations of GCR intensity observed by the ground NM stations represent the anisotropic GCR flow at 1 AU. It is generally believed that the variation of the local time of the GCR maximum intensity (*phase*) has 22-year period of two sunspot cycles. However, there even exists doubt on such anisotropy variation cycle. In order to determine the cycle of GCR anisotropy variation, we carried out the statistical study on the diurnal variation of phase. We examined the 52 years data of Huancayo (Haleakala), 38-year data from Rome, 42-year data from Oulu NM stations. We applied the F-test to determine the statistically meaningful period of anisotropy phase variation. The phase variation has two components of 22-year and 11-year cycles. The NM station in the high latitude (low cut-off rigidity) shows mainly the 22-year cycle. However, the lower the latitude of NM station is, the higher contribution from 11-year cycle.

Introduction

The diurnal variation of GCR count rate measured by the ground NM station represents the anisotropic flow GCR at 1 AU. The indication that the local time of the GCR maximum intensity (*phase*) of GCR diurnal anisotropy varies with a period of two sunspot cycles ([1], [2], [3]).

However, the other researchers ([4], [5], [6]) has questioned the existence of 20 year wave as well as its interpretation in terms of drift theory.

The papers of [7], [8], [9], [10], and [11] mentioned that the diurnal anisotropy consists of two components of the dominant wave with a period of two sunspot cycles and the minor wave with a period of one sunspot cycle. However, [12] suggested that the dominant 11-year periodicity wave was observed from Deep River and Goose Bay NM data. Thus, interpretation of the mechanism in the diurnal variation has been still a matter of debate. [13] suggested that the important contributions in the variation of the diurnal anisotropy are the rigidity of particles and $B \times \nabla n_p$.

From the results of [7], [8], [9], [10], [11], and [13], we caught out an idea for the phase of diurnal anisotropy. That is, the intensities of high-energy and low-energy particles are controlled by the different effect such as drift or diffusion. Thus, the *phase* of the diurnal anisotropy consists of two components, such as one and two sunspot cycles.

The previous studies on the diurnal variation are concentrated on the mechanism and anisotropy of diurnal variations. Now we examined the statistical study on the diurnal variation with the following aims. First, we examine the characteristic differences of the phase variations among the NM stations sited at different latitudes and longitudes (Oulu, Rome, and Huancayo-Haleakala). Secondly, we investigate the long-term change of the phase during the solar cycle 20-23 and find the dependency on the solar activity of the diurnal variations.

Data and Results

1. Data and Analysis

We analyzed the hourly GCR intensity data archived at Huancayo (Haleakala), Rome and Oulu NM stations, and examined the latitudinal effect (cut-off rigidity effect mentioned by [13]) on the *phase*. We used the data from Huancayo NM station for the period of 1953-1991 and the data for the period of 1992-2005 from Haleakala NM station as the replacement of Huancayo NM station.

Table 1 describes the location and the configuration of NM stations whose data are used in this work.

In the previous studies, the yearly mean vector of the diurnal variation (*phase* direction and variation amplitude) is derived by the vector sum of the daily vector of the diurnal variation. We call this procedure as the 'pick-up' method. However, here we introduced new method in determining the yearly mean *phase* direction. [14] first applied this method in the past. It would be called as the 'pile-up' method. The GCR intensity of the each local time is summed up for the whole year deleting the data of FD event or GLE event dates. The yearly mean vector of diurnal variation is derived from the harmonic analysis on this yearly averaged GCR intensity.

In short, the 'pile-up' method does the harmonic analysis one time for the yearly averaged GCR intensity hourly distribution instead of doing the analysis on daily noisy data like Figure 1.a as an example and later summing up the vectors for the whole year. Thus our new method has three advantages. 1) It uses very smoothly distributed data without applying any smoothing filters as shown in Figure 1.c. 2) It also gives a view on the yearly mean GCR intensity directional variation with respect to the sun. 3) It saves the time and labor in calculation of harmonic analysis.

Figure 1 compares the results from the data of the year 1999 at Haleakala NM station. Figure 1.a is an example of diurnal variation for one day (1999.02.28). Figure 1.b and Figure 1.c are the results from the pick-up and pile-up method for whole year of 1999.

2. Results

Figure 2 indicates the yearly mean *phase*. As it goes from the high-latitude to low-latitude, the *phase* gets at the earlier time. And the *phase* variation with the period of two sunspot cycles gets weaker and disappears. We found the *phase* variation by the latitude from Figure 2.

We applied the F test on the sine curve fits using the results by the least sum of squares. Table 2 indicates the results of the F test at each NM station. We compared the sine curve fit with superposed period of one sunspot cycle and two sunspot cycles, with the sine curve fit with the period of two sunspot cycles respectively in application of

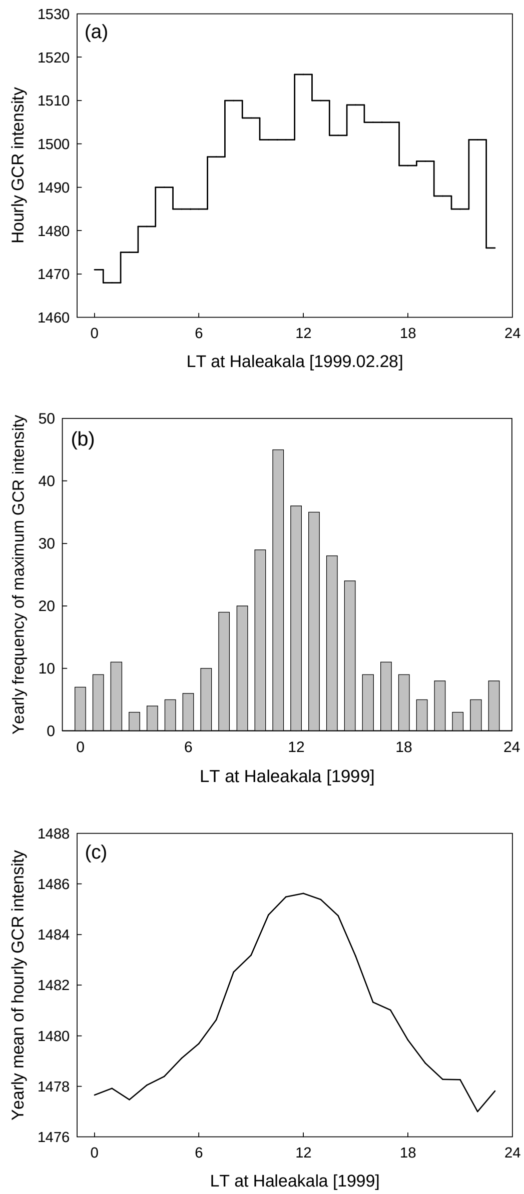

Figure 1: Examples of result (Haleakala on 1999).

Table 1: Configurations of the NM stations.

	Geographic		Geomagnetic				
NM Station	Latitude	Longitude	Latitude	Longitude	Cut-off rigidity	Data period	Local Time
Huancayo	12.03 S	75.33 W	2.06 S	3.47 W	12.92 GV	1953-1991	UT−05h
Haleakala	20.72 N	156.28 W	21.35 N	88.44 W	12.91 GV	1992-2005	UT−10h
Rome	41.90 N	12.50 E	42.09 N	93.55 E	6.32 GV	1967-2004	UT+01h
Oulu	65.05 N	25.47 E	61.97 N	117.07 E	0.81 GV	1964-2005	UT+02h

the F statistic. At the level of significance with the value of 0.05, the critical F-ratio for rejection region, P-value, the F-ratio of comparing among the sine curve fits are listed in Table 2.

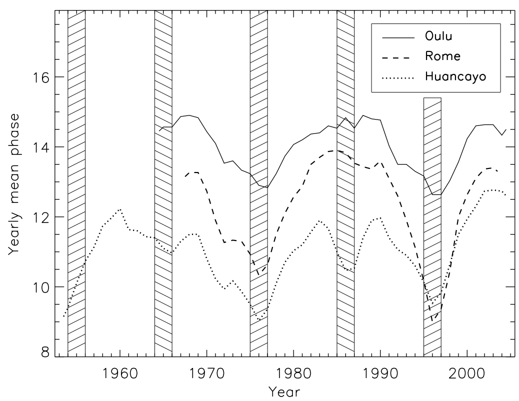

Figure 2: Yearly mean *phases* at Oulu, Rome, & Huancayo NM stations. The solid line stands for Oulu, the dashed line indicates Rome, and the dotted line represents the Huancayo NM station.

From the comparison between the sine curve fit with the superposed period and that with the period of two sunspot cycles, the sine curve fit with the superposed period is also more appropriate. The small F-ratio at Oulu and Rome NM stations suggests that the yearly mean *phase* varies with the period of two sunspot cycles rather than with the period of one sunspot cycle.

As the NM station is located at higher latitude and has lower cut-off rigidity, the sine curve fit with the period of two sunspot cycles is consistent with the real yearly mean *phase* better. As the NM station has higher cut-off rigidity and is located at lower latitude, the yearly mean *phase* varies with the superposed period. As Forbush ([7], [8], [9]) suggested in the past, the yearly mean *phase* consists of one sunspot cycle and two sunspot cycles, but the two components are all major at low-latitude NM station on this study.

Summary

1. At the solar maximum, the *phase* gets later about 2-3 hours than at the solar minimum.

2. In view of the location, that is, the latitude of NM station, there exists the period of two sunspot cycles in the yearly *phase* exclusive of Huancayo with high cut-off rigidity. The yearly *phase* oscillates with the superposed period of one sunspot cycle and two sunspot cycles at Huancayo NM station.

3. As the latitude of NM station gets higher, the *phase* gets delayed, that is, the *phase* is from near the noon to afternoon.

Acknowledgements

The data we used are archieved by Oulu NM station operated by Sodankyla Geophysical Observatory (NSF Grant ATM-0339527), Huancayo & Haleakala NM stations controlled by Space Physics Data System in University of New Hampshire (NSF Grant ATM-0339527), and Rome NM station (SVIRCO NM) supported by IFSI/INAF-UNIRoma3 COLLABORATION. We thank all these NM station managers, Dr. Ilya Usoskin, Dr. Clifford Lopate, and Dr. Marisa Storini.

References

[1] J. W. Bieber, J. Chen, Cosmic-Ray Diurnal Anisotropy, 1936-1988 - Implications for

Table 2: Results of the F test on the possibility of two sine curve fits at each NM station.

NM station	critical F (α=0.05)	input data	22-year vs. 11+22 year		
			P value	F (DFn, DFd)	probability
Oulu	< 2.86627	raw	0.0026	5.741 (3,36)	96 %
		3-hr moving averaged	0.0406	3.056 (3,36)	
		5-hr moving averaged	0.0123	4.174 (3,36)	
Rome	< 2.90112	raw	0.0240	3.599 (3,32)	98 %
		3-hr moving averaged	0.0193	3.807 (3,32)	
		5-hr moving averaged	0.0162	3.980 (3,32)	
Huancayo	< 2.80236	raw	P$<$0.0001	12.26 (3,47)	99 %
		3-hr moving averaged	P$<$0.0001	10.80 (3,47)	
		5-hr moving averaged	P$<$0.0001	11.16 (3,47)	

Drift and Modulation Theories, Astrophys. J. 372 (1991) 301–313.

[2] M. Singh, Badruddin, Study of the Cosmic Ray Diurnal Anisotropy During Different Solar and Magnetic Conditions, sol. phys. 233 (2006) 291–317.

[3] T. Thambyahpillai, H. Elliot, World-Wide Changes in the Phase of the Cosmic-Ray Solar Daily Variation, Nature 171 (1953) 918–920.

[4] W. Fillius, W. I. Axford, D. Wood, Time and Energy Dependence of the Cosmic Ray Gradient in the Outer Heliosphere, in: International Cosmic Ray Conference, 19th, Vol. 5, 1985, pp. 189–192.

[5] C. Lopate, R. B. McKibben, K. R. Pyle, J. A. Simpson, Pioneer 10 and 11 Gradients of Galactic Cosmic Ray Nuclei and Anomalous Components through the Period of Solar Minimum and to 46 AU from the Sun, in: International Cosmic Ray Conference, 21th, Vol. 6, 1990, pp. 128–131.

[6] F. B. McDonald, T. T. Von Rosenvinge, N. Lal, P. Schuster, J. H. Trainor, M. A. I. Van Hollebeke, The Large Scale Dynamics of the Outer Heliosphere and the Long-Term Modulation of Galactic Cosmic Rays, in: International Cosmic Ray Conference, 19th, Vol. 5, 1985, pp. 193–196.

[7] S. E. Forbush, A Variation with a Period of Two Solar Cycles in the Cosmic-Ray Diurnal Anisotropy, J. Geophys. Res. 72 (1967) 4937.

[8] S. E. Forbush, Variation with a Period of Two Solar Cycles in the Cosmic-Ray Diurnal Anisotropy and the Superposed Variations Correlated with Magnetic Activity, J. Geophys. Res. 74 (1969) 3451–3468.

[9] S. E. Forbush, Cosmic-Ray Diurnal Anisotropy 1937 to 1977.5, in: International Cosmic Ray Conference, 17th, Vol. 10, 1981, pp. 209–212.

[10] S. P. Duggal, S. E. Forbush, M. A. Pomerantz, Variations of the Diurnal Anisotropy with Periods of One and Two Solar Cycles, in: Acta Phys. Acad. Sci. Hung., Vol. 29, 1970, pp. 55–59.

[11] S. P. Duggal, S. E. Forbush, M. A. Pomerantz, The Variation with a Period of Two Solar Cycles in the Cosmic Ray Diurnal Anisotropy for the Nucleonic Component, J. Geophys. Res. 75 (1970) 1150–1156.

[12] A. G. Fenton, J. E. Humble, T. Thambyahpillai, Long-term Changes in the Solar Diurnal Variation, in: International Cosmic Ray Conference, 18th, Vol. 10, 1983, pp. 186–189.

[13] S. P. Agrawal, Solar Cycle Variations of Cosmic Ray Intensity and Large-Scale Structure of the Heliosphere, Space Sci. Rev. 34 (1983) 127–135.

[14] W. H. Fonger, Cosmic Radiation Intensity-Time Variations and Their Origin. II. Energy Dependence of 27-Day Variations, Phys. Rev. 91 (1953) 351–361.