Revista Brasileira de Geofísica
RBGf
Brazilian Journal of Geophysics

Revista Brasileira de Geofísica (2007) 25(Supl. 2): 163-167

ISSN 0102-261X
www.scielo.br/rbg

MULTITAPER SPECTRAL ANALYSIS OF COSMIC RAYS SÃO MARTINHO DA SERRA'S MUON TELESCOPE AND NEWARK'S NEUTRON MONITOR DATA

Marlos Rockenbach da Silva[1], Walter Demetrio Gonzalez Alarcon[2], Ezequiel Echer[3], Alisson Dal Lago[4], Luis Eduardo Antunes Vieira[5], Fernando Luís Guarnieri[6], Aline de Lucas[7], Nelson Jorge Schuch[8] and Kazuoki Munakata[9]

Recebido em 13 fevereiro, 2006 / Aceito em 22 fevereiro, 2007
Received February 13, 2006 / Accepted February 22, 2007

ABSTRACT. In this work we present an analysis on the correction efficiency of atmospheric effects on cosmic ray São Martinho da Serra's muon telescope and Newark's neutron monitor data. We use a Multitaper spectral analysis of cosmic rays time series to show the main periodicities present in the corrected and uncorrected data for the atmospheric effects. This kind of correction is very important when intends to study cosmic rays variations of extra-terrestrial origin.

Keywords: multitaper spectral analysis, cosmic rays, atmospheric effects, pressure and temperature correction.

RESUMO. Neste trabalho apresentamos a eficiência da correção dos efeitos atmosféricos nos dados de raios cósmicos do telescópio de muons de São Martinho da Serra e do monitor de nêutrons de Newark. Utilizamos a análise espectral Multitaper das séries temporais dos raios cósmicos, para mostrar as principais periodicidades presentes nos dados corrigidos e não corrigidos dos efeitos atmosféricos. Este tipo de correção é de extrema importância quando se pretende estudar as variações de raios cósmicos de origem extraterrestre.

Palavras-chave: análise espectral multitaper, raios cósmicos, efeitos atmosféricos, correção da pressão e temperatura.

[1]National Institute for Space Research – INPE-MCT, Av. dos Astronautas, 1.758 – Jd. Granja, 12227-010 São José dos Campos, SP, Brazil. Phone: +55 (12) 3945-6808 – E-mail: marlos@dge.inpe.br

[2]National Institute for Space Research – INPE-MCT, Av. dos Astronautas, 1.758 – Jd. Granja, 12227-010 São José dos Campos, SP, Brazil. Phone: +55 (12) 3945-6979 – E-mail: gonzalez@dge.inpe.br

[3]National Institute for Space Research – INPE-MCT, Av. dos Astronautas, 1.758 – Jd. Granja, 12227-010 São José dos Campos, SP, Brazil. Phone: +55 (12) 3945-6797 – E-mail: eecher@dge.inpe.br

[4]National Institute for Space Research – INPE-MCT, Av. dos Astronautas, 1.758 – Jd. Granja, 12227-010 São José dos Campos, SP, Brazil. Phone: +55 (12) 3945-6979 – E-mail: dallago@dge.inpe.br

[5]Universidade do Vale do Paraíba – UNIVAP, Av. Shishima Hifumi, 2911 – Bairro Urbanova, 12244-000 São José dos Campos, SP, Brazil. Phone: +55 (12) 3947-1000 – E-mail: levieira@univap.br

[6]Universidade do Vale do Paraíba – UNIVAP, Av. Shishima Hifumi, 2911 – Bairro Urbanova, 12244-000 São José dos Campos, SP, Brazil. Phone: +55 (12) 3947-1000 – E-mail: guarnieri@univap.br

[7]National Institute for Space Research – INPE-MCT, Av. dos Astronautas, 1.758 – Jd. Granja, 12227-010 São José dos Campos, SP, Brazil. Phone: +55 (12) 3945-6808 – E-mail: delucas@dge.inpe.br

[8]Southern Regional Space Research Center – CRSPE/INPE-MCT, Faixa de Camobi, Km 9, Campus Universitário, 97105-900 Santa Maria, RS, Brazil. Phone: +55 (55) 3220-8021 – E-mail: njschuch@lacesm.ufsm.br

[9]Physics Department, Shinshu University, Matsumoto, Japan – E-mail: kmuna00@gipac.shinshu-u.ac.jp

INTRODUCTION

Muons and neutrons are high energy particles originated from the interaction between a primary high-energy proton and atmosphere's components. Their creation and propagation inside the atmosphere depend on the atmospheric effects, such as pressure and temperature. According to Pomerantz & Duggal (1971) the principal component of daily variations of the cosmic rays are atmospheric changes. After removing the atmospheric changes, another small daily variation remains, related to a local anisotropy of cosmic ray fluxes and the Earth rotation (Mursula & Usoskin, 2003). At high energies, the cosmic ray variations are probably due to processes occurring outside the interplanetary medium, resulting in a sidereal diurnal variation. However, at low energies, the fluctuating component of the interplanetary magnetic field appears to have a significant effect, causing an apparent co-rotation of cosmic rays with the Sun (in a first approximation) and hence producing a diurnal variation of the intensity with phase and amplitude which are in good agreement with observations (Axford, 1965).

Pressure and temperature effects constitute interferences in the study of true primary cosmic rays intensity variations. Since the absorption mean free path of the primary interaction is of the order of 150 g/cm^2, it is clear that changes of air mass produce changes in the cosmic ray flux entering the detectors (Simpson et al., 1953; Dorman & Yanke, 1975). Because of this effect, cosmic ray data must be corrected for the atmospheric effects due to pressure and temperature variations (Kurguzova & Charakhchian, 1979). To remove the barometric and temperature effects the following equation is used

$$\frac{\Delta I}{I} = \beta \Delta p + \int \alpha(h) \Delta T(h) dh, \qquad (1)$$

where Δp is the atmospheric pressure variation, and ΔT is the atmospheric temperature variation as a function of the altitude h. The first term in the right-hand side of the equation represents the barometric effect, where β is the barometric coefficient. The second term on the right-hand side represents the temperature effect, where α is the temperature coefficient, which depends on the altitude (Bercovitch, 1967). In order to verify whether the correction of the atmospheric effects is being made satisfactorily, a Multitaper spectral analysis on muon and neutron time series (corrected and non-corrected) was performed. Data from São Martinho da Serra (29.3°S, 53.5°W, Brazil) muon telescope and Newark (39.7°N, 75.7°W, United States) neutron monitor were used in this analysis.

MULTITAPER SPECTRAL ANALYSIS

Usually, in spectral time series analysis, a time series is multiplied by window before performing the Fourier transform in order to reduce the spectral leaking. Without windowing, the higher part of high frequency of the spectrum may be biased by spectral leaking (Park et al., 1987). However, every time when a single window is used, the statistical variance of the spectral estimate will increase, because this single window generally unevenly weighting of data points. There will be a balance between spectral leaking resistance and the spectral estimate variance (Park et al., 1987).

Thomson (1982) introduced the multitaper spectral analysis technique that has been applied widely to signal analysis (Jeffrey et al., 1987). In multitaper analysis the data are multiplied by several leakage-resistant tapers. The statistical information discarded by the first window is partially recovered by the second one. The information discarded by the first two tapers is partially retrieved by the third taper and so on.

So, the multitaper estimative is not limited by the balance between leaking and variance, as occurs in the estimation by a single window. The Multitaper method uses orthogonal tapers in order to obtain approximately independent estimation and then to combine them into a global estimate. This estimate shows more degrees of freedom and allows an easier qualification of bias and variance trade-off, when compared to the conventional Fourier analysis. The Multitaper method is able to detect small amplitude oscillations in a short-time series without the use of signal filtering.

OBSERVATIONS AND RESULTS

We have used data from neutron monitor installed at Newark, Delaware (39.7°N, 75.7°W, magnetic rigidity approximately 10 GV operating since 1978, with a sampling observation time of 1 hour), available in the Bartol Research Institute website, in a file ASCII containing corrected and uncorrected data. This neutron monitor data were compared to muon scintillator telescope data installed at the Southern Space Observatory – SSO/CRSPE/INPE-MCT – in São Martinho da Serra, Brazil (29.3°S, 53.5°W, magnetic rigidity approximately 14 GV, operating since 2001, with a sampling observation time of 1 hour). A detailed description of this muon telescope may be found in Da Silva et al. (2004). Muon and neutron are complementary in term of energy. Neutron energy range extends from 3 to 50 GeV while muon energy range extends from 10 to above 1000 GeV. We used a time series from October 2001 to October 2002, since in this period there are no gaps in the data series and they are long enough to show important periodicities.

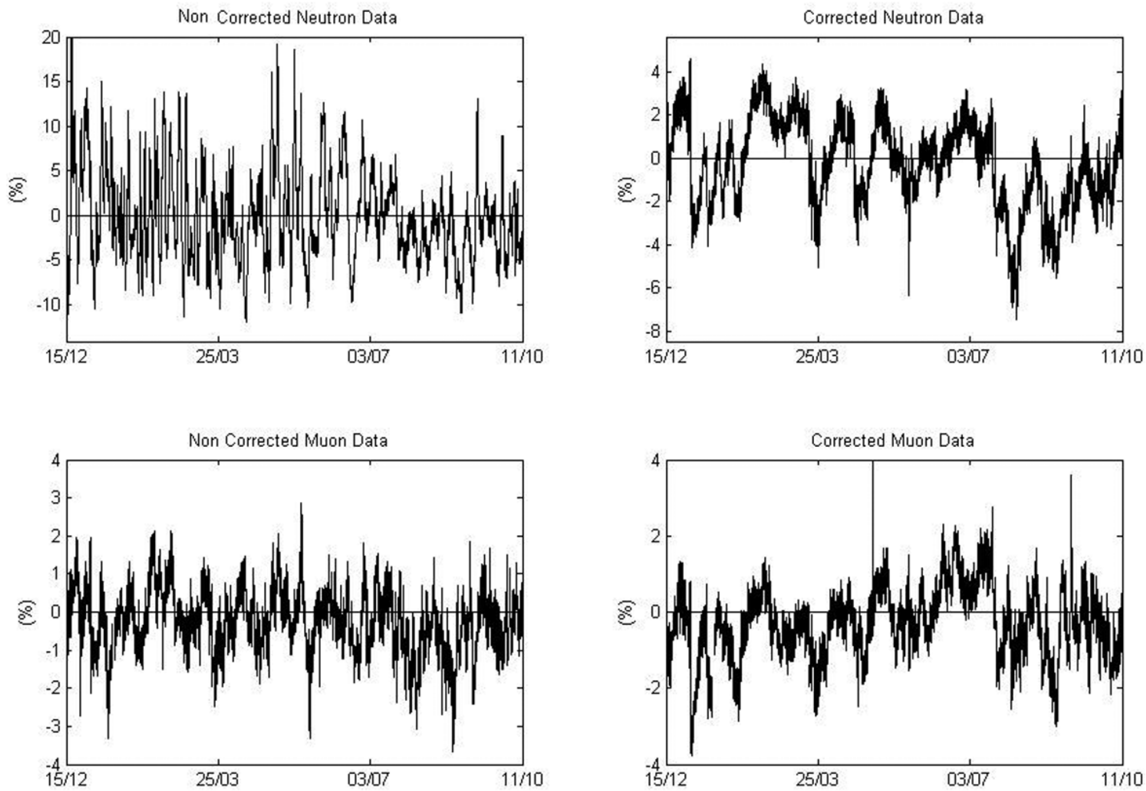

Figure 1 – Time series analyzed. Top panels show the non-corrected and corrected neutron data, and in the bottom the non-corrected and corrected muon data, from October 2001 to October 2002.

Figure 1 shows the neutron (top panels) and muon (bottom panels) cosmic ray time series used in this work, and we compare the corrected (right column) and uncorrected (left column) data.

In this figure we can see how the atmospheric effects correction is important, due to the great difference between uncorrected and corrected time series.

Figure 2 is organized similarly as Figure 1 for the Multitaper analysis. We can see in the neutron analysis, that the power spectrum of uncorrected data shows peaks around 8, 12 and 24 hours, which are most likely caused by atmospheric variations and the Earth's rotation; the peak at 15 and 29 days, that are related to half and complete solar rotation, respectively. On the power spectrum of corrected neutron data it is clear that the 8 and 12-hours peaks disappear completely.

In the muon analysis (bottom of Figure 2) we can see approximately the same effects that are observed in the neutron analysis. For instance, the 8 hours peak disappears completely. However, the 12 hours peak remains in the spectrum, but with a smaller power than the power spectrum of non-corrected data. This occurs most likely because the correction of the temperature effect (the second term of right-hand side of equation 1) on muon data was not performed. We could not perform this correction because both the temperature and the temperature coefficient are varying with the altitude and a vertical profile for these parameters would be needed. In this way, only the pressure effects were removed from the muon data.

The 24 hours peak is still present in the corrected spectra. Its power was reduced for neutron data but was more or less the same for muon data. This means that this periodicity in cosmic ray data is not only due to atmospheric effects, but it has an extra-terrestrial component, which seems to be associated with the earth's rotation the sidereal variation (Axford, 1965).

CONCLUSION

In this work we have used Multitaper spectral analysis on the cosmic ray Newark's neutron monitor and São Martinho da Serra's muon telescope data, and we could verify the efficiency of the atmospheric effects correction. The periodicities of 8 and 12 hours due to the atmospheric effects were totally removed from neutron

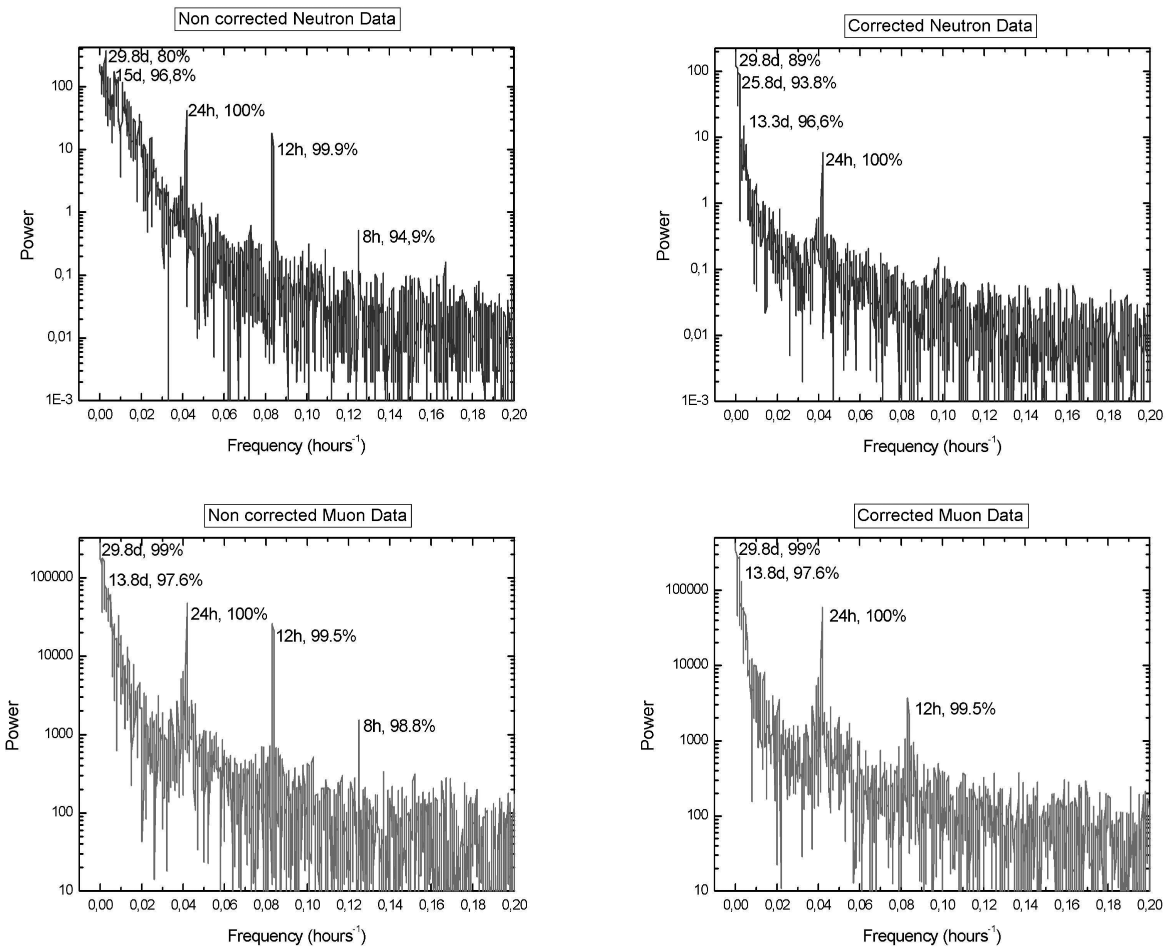

Figure 2 – Power spectrum by Multitaper analysis of neutron and muon data. The top panels show non-corrected and corrected neutron spectrum. The bottom panels contain non-corrected and corrected muon spectrum.

data using the correction procedure. On the other hand, for muon data only the 8-hours periodicity was completely removed. The 12-hours periodicity remains even in the corrected data, however, with a smaller power than in the non-corrected serie. This occurs because the temperature effect on muon data was not corrected. The effect of the temperature on cosmic ray data becomes important in cases where the sampling rate is relatively high, as occur in the muon Telescope at the Southern Space Observatory. For this instrument, the sampling time is 1 hour, and then the temperature effect does not affect severely the data.

The removal of the atmospheric effects of cosmic rays data observed in the terrestrial surface allows the study of cosmic rays variations of extraterrestrial origin, with this, correction done in the São Martinho da Serra's muon telescope data is satisfactory, making possible the deepened study of the interplanetary or interstellar affects of the cosmic rays.

ACKNOWLEDGEMENTS

The authors are grateful to Bartol Research Institute neutron monitor program, which is supported by National Science Foundation grant ATM-0000315 and by Centro Regional Sul de Pesquisas Espaciais, which offers the operating and maintenance of the muon telescope. We are also grateful to Shinshu University by the support and to Fundação de Amparo à Pesquisa do Estado de São Paulo through the projects 02/12723-2, 03/11194-9, 04/14784-4, 05/03501-4 and 05/54800-1.

REFERENCES

AXFORD WI. 1965. The modulation of galactic cosmic rays in the interplanetary medium. Planetary and Space Science, 13: 115–130.

BERCOVITCH M. 1967. Atmospheric Effects on Cosmic Ray Monitors. Proceedings of the 10th International Cosmic Ray Conference, Calgary, Canada, June 19-30, p. 269.

DA SILVA MR, CONTREIRA DB, MONTEIRO SO, TRIVEDI NB, MUNAKATA K, KUWABARA T & SCHUCH NJ. 2004. Cosmic Ray Muon Observation at Southern Space Observatory – SSO (29°S, 53°W). Astrophysics and Space Science, 290: 389–397.

DORMAN LI & YANKE VG. 1975. Development of the Theory of Meteorological Effects in Cosmic Rays. Proceedings from the 14th International Cosmic Ray Conference, München, Germany, 15-29 August, 1975. Volume 4 (MG Session and Pioneer Symposium), p. 1385.

JEFFREY P, LINDBERG CR & VENRON III FL. 1987. Multitaper Spectral Analysis of High Frequency Seismograms. J. Geophys. Res., 92(B12): 12675–12684.

KURGUZOVA AI & CHARAKHCHIAN TN. 1979. Temperature effect of the muon component of cosmic rays in the atmosphere. Geomagnetism and Aeronomy, 18: 403–407.

MURSULA K & USOSKIN I. 2003. Heliospheric Physics and Cosmic Rays. Lecture Notes, American Geophysics Union, Washington DC. p. 37–66.

PARK J, LINDBERG CR & VERNON FL III. 1987. Multitaper spectral analysis of high-frequency seismograms. Journal of Geophysical Research, 92 (B12): 12,675–12,684.

POMERANTZ MA & DUGGAL SP. 1971. The cosmic ray solar diurnal anisotropy. Space Science Reviews, 12: 75–130.

SIMPSON JA, FONGER W & TREIMANT SB. 1953. Cosmic radiation intensity-time variations and their origin. I. Neutron intensity variation method and meteorological factors. Physical Review, 90(5): 934–950.

THOMSON DJ. 1982. Spectrum estimation and harmonic analysis. Proceedings of IEEE, 70(9): 1055–1096.

NOTES ABOUT THE AUTHORS

Marlos Rockenbach da Silva is physicist from Universidade Federal de Santa Maria – UFSM (2003). Master in Space Geophysics in the National Institute for Space Research – INPE (2005). Nowadays is Ph.D. student of Space Geophysics in the National Institute for Space Research, being grant holder of the Fundação de Amparo à Pesquisa do Estado de São Paulo – FAPESP, through the project number 05/54800-1.

Walter Demetrio Gonzalez Alarcon is graduated in Physics at Universidad Nacional de Ingeniería, UNI, Peru. Master's degree in Space Geophysics at the National Institute for Space Research – INPE, Ph.D. in Physics at University of California – Berkeley, United States, Titular Researcher of Space Geophysics Division – DGE, Space and Atmospheric Sciences – CEA of INPE, Boss of the Research Line in Magnetosphere and Heliosphere (MAGHEL) of INPE. He studies the interplanetary origin of the geomagnetic storms.

Ezequiel Echer is Doctor in Space Geophysics (2003) by INPE, is a researcher of the Space Geophysics Division of INPE. He has developed doctorate Thesis in the study of the interplanetary structures. He accomplished pos-doctorate (2005) in the Max Planck Institute of Solar System Research, Germany, studying the answer of the terrestrial magnetosphere to the solar wind disturbances with the Cluster constellation. Now he studies the solar wind-magnetosphere coupling, interplanetary MHD shock and discontinuities propagation in the interplanetary space and plasma waves in planetary magnetospheres.

Alisson Dal Lago is physicist from Universidade Federal de Santa Maria (1996), Master's degree (1999), and Ph.D. (2003) in Space Geophysics at National Institute for Space Research – INPE, Researcher (since 09/2004) of the Space Geophysics Division – DGE, Space and Atmospheric Sciences – CEA of INPE, where he works in Space Weather area, with geomagnetic disturbance occurrence forecasting, using space and terrestrial observations.

Luis Eduardo Antunes Vieira is physicist from Universidade Federal de Santa Maria (1995), Master's degree (1998) and Ph.D. (2002) in Space Geophysics at National Institute for Space Research – INPE, Pos Doc. of the Division of Space Geophysics – DGE, Space Sciences and Atmospheric – CEA of INPE. Nowadays he is professor at Universidade do Vale do Paraíba – UNIVAP, and researcher in the area of Space Weather, with interest on the solar activity on the terrestrial climate.

Fernando Luís Guarnieri is an Engineer from Universidade Federal de Santa Maria – UFSM (1999), Master's degree (2001) and Ph.D. (2005) in Space Geophysics at National Institute for Space Research – INPE. Nowadays, he is professor at Universidade do Vale do Paraíba – UNIVAP, and researcher in the area of Space Weather.

Aline de Lucas is a mathematician from Universidade Federal de Santa Maria – UFSM (2003). Master's degree in Space Physics at the National Institute for Space Research – INPE (2005). Nowadays is a Ph.D. student in Space Physics at INPE.

Nelson Jorge Schuch is graduated in Physics at Universidade Federal de Santa Maria – UFSM (1972). Master's degree in Astrophysics at Universidade Presbiteriana Mackenzie (1975). Ph.D. in Astrophysics at Cambridge University (1979). Pos Doc. in Astrophysics at Cambridge University (1980). From 1980 to 1995, work as Researcher Titular/Vice-Director of the National Observatory – ON. In 1996 was named coordinator of the Radio-Astronomy Project, in agreement between INPE – UFSM. Nowadays is boss of the Centro Regional Sul de Pesquisas Espaciais – CRSPE, and coordinator of the action 1275 and 6237 of implantation and operation of the CRSPE.

Kazuoki Munakata is a Doctor in Physics, Teacher of the Department of Physics of the Shinshu University, Japan, and works with cosmic ray research. Now he studies the cosmic rays application for Space Climate research, being the coordinator, for the Japanese part, of the implantation of the Cosmic Rays Detectors Network.