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 789–792

ID 1222

30TH INTERNATIONAL COSMIC RAY CONFERENCE

ICRC'07 Mérida, México

On a plausible relation between Cosmic Rays and the Antarctic ozone hole size

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Abstract: In this work we are looking for an evidence of relationships between the Antarctic Ozone Hole Size (OHS) and the Solar Cycle (SC) periodicities, as well as with the Galactic Cosmic Rays (GCR) fluxes. With this goal in mind we also analyze the Antarctic temperature anomalies, linked with the OHS, and their response to the SC and GCR variations. By means of the Morlets wavelet, it is found that OHS shows a prominent periodicity frequency at $\sim$ 3.5 yrs. Then, applying the Wavelet Coherence analysis to two time-series, it is found that: There is a common signal (since 1996) of $\sim$ 3.5 yrs. between OHS and GCR, but the relationship is not of linear nature. A preliminary inference seems to indicate that there is a complex relationship between the OHS and GCR

Introduction

Conventionally, it is considered that there is an ozone hole (OH) when the ozone abundance is $\leq$ 220 Dobson units (DU) ($1DU = 0.001$ atm cm) in a specific geographic place (Fig.1). Since the discovery of the Antarctic OH by Farman et al. [1] a considerable effort has been focused on observing these ozone losses, understanding the chemical, dynamical and radiative processes, and predicting the future of the polar ozone [2]. Although the main cause of this stratospheric ozone reduction is ascribed to the anthropogenic activity, but the precipitating charged particles influence ozone and other atmospheric constituents, complicating the interpretation of OH trends. The OH has two basic characteristics: depth and size, which are inferred from the ozone abundance data. In the early works [3] it has been estimated the contribution of the precipitating fast charged particles to the quantity of ozone mass destruction (OH depth), but, at the present is not clear if their contribution will be perceptible on the OHS trends. The charged particles effects that influence the atmosphere can roughly be grouped into tree types of perturbations: (1) solar particles events, which are primarily protons entering the polar regions and

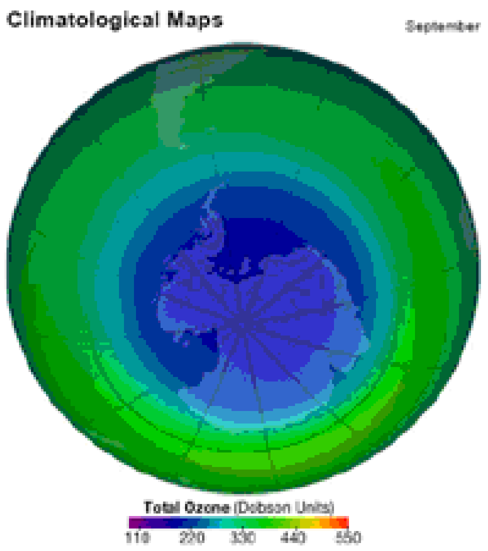

Figure 1: September 2006 monthly average ozone map. The dark blue and violet colors, corresponds to the OH. The average size reaches 24.8 million of square km

thereby often are referred to as solar protons events (SPE); (2) energetic electrons precipitating in the auroral zone and lower latitudes; and (3) galactic cosmic rays. GCR continually create odd nitrogen and odd hydrogen constituents in the lower stratosphere and upper troposphere, but, nowadays it is considered that play a small role in the polar ozone variations [2].

SPE and energetic precipitating electrons influence, also, the polar ozone levels. The solar protons primarily deposited their energy in the mesosphere and stratosphere, whereas the energetic electrons primarily deposited their energy in the thermosphere and upper mesosphere. Since Crutzen et al. [4] and Heath et al. [5] early works, a number of papers have been published that document the SPE-caused polar changes [6]. However the area in which the SPE deplete the ozone has been estimated as a minor one, in relation to the area of the chlorine catalyzed depletion [7]. In this work we are looking for a long term relationships between an extraterrestrial influences (GCR) and/or solar activity on the ozone hole size (OHS) evolution. Taking into account this complex situation, in this work we carry out a wavelet analysis, since this statistical tool of analysis allows to compute the frequency components, in despite of their relative intensity, and also permit the comparison of two power spectra, in order to show the common frequencies of the series, in the so called coherence analysis [8].

Data and Analysis Tecnique

The GCR influence over the global stratospheric ozone has been documented before [3]. The understanding of this kind of relationship is relevant to differentiate the nature of the processes induced in the atmosphere. The causes of such processes could be endogenous and/or exogenous. In order to assess much better the impact of the environmental protective policies, it is important to identify all the natural sources of atmospheric variations. With this goal in mind we are looking for the evidence of a noticeable effect of the GCR, and the SC over the OHS.

Nowadays it is considered as small effect the role of GCR to the global ozone depletion [2], in spite that, the GCR penetrates the atmosphere reaching the Earth surface at all latitudes. However, as the GCR are constituted of charged particles, and the geomagnetic field lines are perpendicular to the Earth surface at the polar latitudes, the GCR flux reaches their maximum at such latitudes, and consequently their influence on the ozone destruction, may reach also the maximum at these places. Besides, the Antarctic severe ozone depletion (OH) occurs at polar latitudes, at heights between $10-20$ km, and the ionization and disso-ciation provoked by GCR is maximum also at these heights. For this reason we consider, as a first option, looking for some kind of relationship between both phenomena. The analysis is made on basis of the monthly average of the OHS and the GCR data. We select the monthly data because, exists a differentiated monthly behavior, in the evolution of OHS [9]. The GCR data flux corresponds to the South Pole Station, located at 90^o S of latitude (data available at:http://neutronm.bartol.udel.edu/). The Antarctic OHS data it is considered as it is reported by the National Oceanic and Atmospheric Administra-tion (NOAA) Southern Hemisphere winter summary 2006.From NASA available at http://ozonewatch.gsfc.nasa.gov/. The dark blue and violet colors, corresponds to the OH. The average size reaches 24.8 million of square km.

Figures $5c - 5e$. With these data, we have computed the wavelet Morlets spectra [10] for the OHS and GCR. In Fig. $2, 3, 4$ we show the OHS results, for each analyzed month (September, October and November, respectively). In Fig 2 we can see that, during September, the OHS wavelet spectrum shows a periodicity in $2.5 - 3.5$ year interval, from 1985 to 2002, and a quasi 5-year periodicity from 1987 to 1998, but their confidence are below 95% of confidence (dashed line). In Fig. 3, the spec-trum for October OHS, shows the 3-year perio-dicity during 1985 to $1990, 2000$ to 2002, and though attenuated it is also present during $1993 - 1997$, this periodicity is below the 95% of confi-dence.

In Fig. 4, the OHS for November show a 3-year periodicity, during 1985 to 2002 with more that 95% of confidence. All analyzed months show periodicities around of 3 year, but only during November it is above 95% of confidence. In Fig $5, 6, 7$, we illustrate the power spectra for the GCR monthly

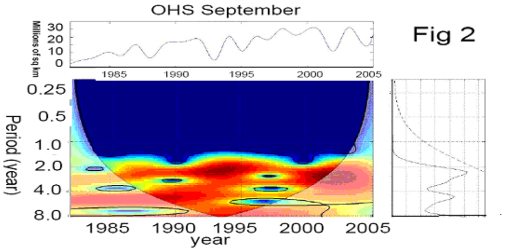

Fig 2

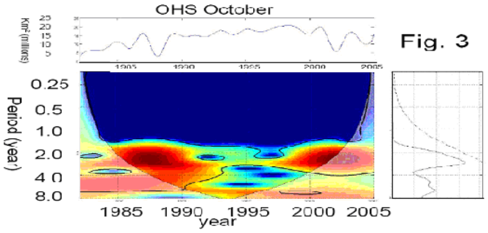

Fig. 3

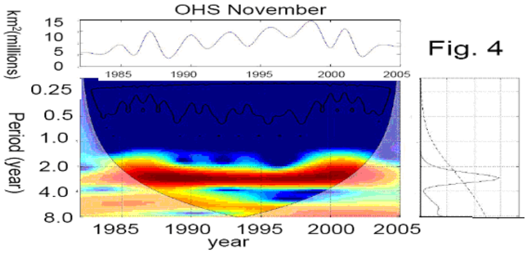

Fig. 4

average data, for September, October and November respectively. In Fig. 5, we can see that during September, GCR shows a quasi 5-year periodicity at high level of confidence ($> 95\%$) during 1987 to 1998. It also shows a 3-year periodicity during $1986 - 1992$ and $1998 - 2002$ but below 95% confidence, In Fig. 6 for October, the GCR power spectrum shows the quasi 5-year periodicity, with more than 95% of confidence, during $1987 - 1998$. It also shows the 3 year periodicity during $1986 - 1992$ and $1998 - 2002$ but be-low 95% of confidence. In Fig 7, the November GRC power spectrum shows a quasi 5-year period but, below 95% of confidence from 1989 to 1995 and the 3-year periodicity, also below the 95% of confidence, but present from 1986 to 1992 and 1998 to 2002. From the power spectra of OHS and GCR we can see that both phenomena have similar periodicities, so that it should be expected the influence of GCR to be noticeable on the OHS data. In order to confirm this assumption, we compare both power spectra, in a coherence analysis [8], computing the Global Wavelet Coherence Spectrum (GWCS) for OHS vs. GCR for each analyzed month.

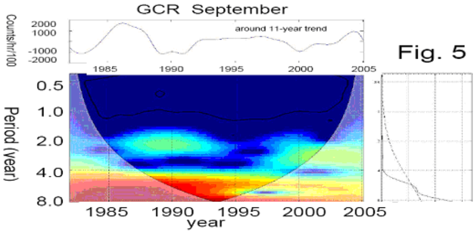

Fig. 5

The results are showed in Fig. $8, 9, 10$, for September, October, and November respectively. In these figures the red color illustrate a high coherence (1) and the blue color illustrate the low coherence (0).

According to results in Fig. 8, the periodicity of 1.3-year has a 0.9 of coherence and the periodicity of 3-year has a coherence of 0.7 form $1986 - 1995$ and increase to 0.9 during September from $1995 - 2002$. In Fig 9, the October GWCS shows a coherence of 0.85 in 1.7-year periodicity $(1990 - 1993)$ and a coherence of $0.65(1993 - 2002)$, but in anti-correlation phase. In this figure we can observe that, all periodicities have a low level of coherence. Therefore, a relationship between OH and GCR is not conclusive, and only during September may be established this kind of a long term relation. During November the signal of a long term relation is present, but at a low level of coherence. From Fig. 8, the relationship between OHS and GCR is not in the linear way, (the ar-rows change their orientation) then, in order to explore the nature of such an indirect connection, we analyze the stratospheric temperature anoma-lies and the GCR flux in the Antarctic region.

The temperature anomalies in the Antarctic stratosphere are a good explanatory variable for interannual variability of the OHS anomalies [11]. This result has been obtained in a basis of annual indicators. Then, to explore this possibility, as a second step of this search, we obtain the coherence between GCR and AT at 15 km height using an average of the AT anomalies and GCR fluxes, for the analyzed months, as an indicators. The results are showed in Fig. 11. In this figure we can appreciate a 0.85 coherence level in the $1.7 - 3$ year periodicity from the GWCS, with a tendency to opposite phase. This anti-correlation it is present from 1987 to 1993 only. To confirm the GCR influence, we obtain the GWCS in similar conditions (September-November average) for AT (15 km) vs. 10.7 cm solar flux (as it is reported by NOAA at: ftp://ftp.ngdc.noaa.gov/STP/), which is a typical indicator of solar irradiance. The results are illus-trated in the Fig. 12, showing a coherence of 0.85in a $1.1 - 3$ year periodicity, limited only to $1987 - 1993$ period, and reappearing until $2000 - 2001$ approximately.

Conclusions

The GCR and OHS have similar periodicities around of 3.5 year. The coherence analysis shows that, the relationship is not of linear nature. The relation may be noted principally during September, since 1986. In the period of $1986 - 1995$ it is attenuated, perhaps due to the atmospheric perturbation induced by the mayor volcano eruptions: in 1982 El Chichn and 1991 Mt. Pinatubo. After1995 the relationship may be clearly perceived. This preliminary inference seems to indicate that there is a non-linear relationship between the OHS and GCR. However, a further research is needed, in order to clarify the possible contribution of the SC before 1995.

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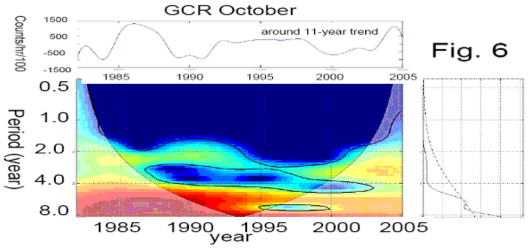

Fig. 6

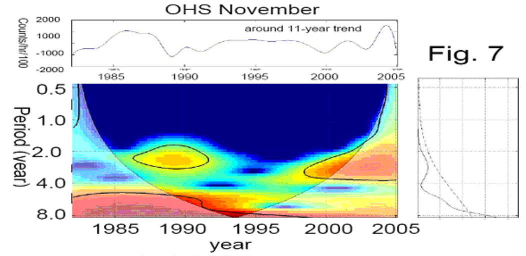

Fig. 7

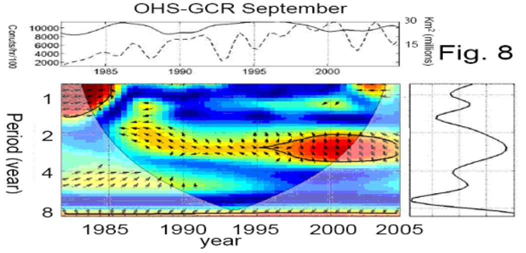

Fig. 8

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