Signal Solar in δDeuterium from Antarctic and Greenland

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Abstract

A time series study was conducted in order to identify dominant variability of deuterium/hydrogen ratios obtained in snow, firn snow and ice samples of an ice core from: Lange Glacier (King George Island/Antarctic Peninsula, lat 62º 07'S, long 58º 37'W), Dronning Maud Land in the Atlantic sector of Antarctica (71°35'S, 3°26'W), and from GISP2, Greenland (72°36'N, 38°30'W). Periodicities were estimated by using classical spectral analysis (iterative regression) and multiresolution analysis. The 11 yr solar cycle was clearly identified in the spectral analysis. The 11 yr frequency band has been reconstructed from the parameters found in spectral analysis (amplitude, frequency and phase). It was observed a high cross-correlation (r>0.6) between δD and solar activity indexes (sunspot number, *aa* index, protons high energy, >100 MeV). A multiresolution analysis also has been performed in all-time series and has shown a high cross-correlation between this time series for the frequency level D_2, D_3, D_4, D_5 e A_5. This suggests the hypothesis that part of the deuterium (^{2}H) measured at Earth comes from the Sun as part of the solar wind or that high-energy solar protons produce the deuterium in the Earth atmosphere.

Introduction

The environment at the surface of the Earth, as we know it, only exists because of the energy flux that our planet receives from the Sun. Solar radiation influences atmospheric and oceanic circulations that also influence the biosphere, without solar radiation, photosynthesis stops (National Research Council, 1994). Solar radiation and high energy particles are colliding continuously on gases and plasmas, components of the atmosphere and magnetosphere the role of which is to protect life at the surface of the planet (Raisbeck and Yiou, 1984).

One of the most important characteristics of solar variability is the sunspot variation at the Sun surface, quantified through the sunspot number (Stuiver and Quay, 1980). The observed records of the sunspot number show a regular mean cycle close to 11 yr. Data obtained from satellites monitoring solar activity indicate a variation of 0.1% of the solar luminosity during the 11-yr cycle, with an emission greater during the periods of maximum sunspot number (Wilson and Hudson, 1988; Frölich and Lean, 1998).

The stable isotope ratios δD have provided significant information on long term and recent climate changes and on the physical processes involving the world hydrological cycle. According to Merlivat and Jouzel (1979) and Froehlich et al. (2002), δD values from sites at moderate and high latitude continental regions are associated to surface air temperature and precipitation.

In the present paper, the stable isotope ratios δD from two locations in Antarctic and one in Greenland are analysed. Both multiresolution and spectral analysis methods are employed to investigate solar activity signal present in this natural record time series. Some hypotheses are also discussed to explain the obtained results.

Method

Our study makes use of three observational data sets of the deuterium/hydrogen ratios obtained in ice core from: Lange Glacier (King George Island/Antarctic Peninsula, 62°07'S, 58°37'W) (Evangelista et al., 2007), values covering the period from 1951 through 1994 (Figure 1A), Dronning Maud Land in the Atlantic sector of Antarctica (71°35'S, 3°26'W), 1951 through 1994 (Figure 1B); data were obtained from PANGAEA - Publishing Network for Geoscientific & Environmental Data, www.pangaea.de, and from GISP2, Greenland (72°36'N, 38°30'W), 1951 through 1985 http://www.ncdc.noaa.gov/paleo/icecore/greenland/summit/document/gispisot.htm (Figure 1C). The time series representative of the solar activity used was: Zürich Sunspot Number (Rz), 1951 through 1994 (Figure 1D), time series were obtained from National Geophysical Data Center, Boulder, Colorado, http://www.ngdc.noaa.gov/, and occurrence rate of Solar Protons Events (SPE) of high energy (Ep > 100 MeV), 1958 through 1994 (Figure 1E) (Bazilevskaya et al., 2002). The original series of δD, Rz and SPE annual series were also analyzed by cross-correlation and iterative regression method.

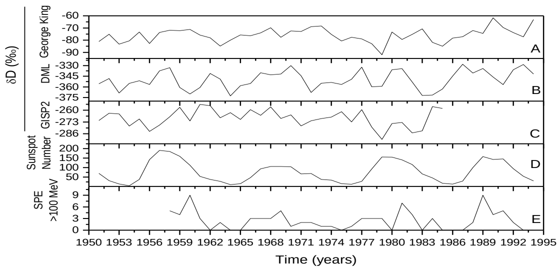

Figure 1 – The δD Annual average time series from: Antarctica - George King island (A), and Dronning Maud Land (B); Greenland - GISP2 (C); Suspot Number (D); SPE (Ep > 100 MeV)(E) time series.

These series were wavelet transformed using the orthonormal discrete Meyer wavelet transform. Using the wavelet analysis called multiresolution analysis (or multi-level or multi-decomposition), cross-correlation analysis is performed between series 1 and series 2. A positive lag implies that series 1 maximum occurs after series 2 maximum while a negative lag implies that series 1 maximum occurs before series 2. The discrete wavelet transform may be used in multiresolution analysis, which is concerned with the study of signals or processes sampled at different resolutions and developing an efficient mechanism for going from one resolution to another (Percival and Walden, 2000). In this work the best wavelet packet decomposition tree was used to decompose the time series data in 6^{th} frequency levels (Figure 2). This method is a generalization of the wavelet decomposition and it offers a rich range of possibilities for signal analysis. In the wavelet decomposition analysis, the signal (S) is decomposed in an approximation (A) and in a detail (D). The detail contains the high-frequency part of the signal, whereas the approximation contains most of the characteristic frequencies of the signal. In the first step of the decomposition, $S = A_1 + D_1$. In a next step, the approximation itself is split in a second level approximation, $A_1 = A_2 + D_2$, and $S = A_2 + D_2 + D_1$. The most suitable decomposition of a given signal is selected on an entropy-based criterion and the process is repeated until this criterion is reached (Percival and Walden, 2000).

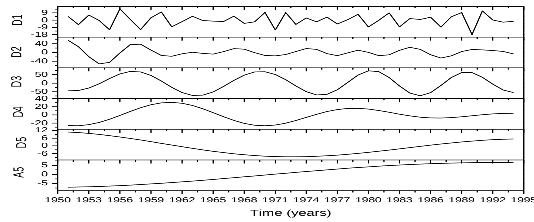

Figure 2 – Wavelet decomposition bands for the Sunspot Number time series 1950-1994.

In order to identify the main periodicities, their amplitude and phase in each time series, an iterative multiple regression model, labeled ARIST-"Análise por Regressão Iterativa de Séries Temporais"- Iterative Regressive Analysis of Time Series (Rigozo et al., 2005) was used. This method can be applied to the fit of any function, including the search for periodicities in time series, using, for each period, a sine function with three unknown parameters, amplitude, period and phase.

In this work the ARIST was applied to each one of time series and the most significant periods at 95% (amplitude higher than two times the standard deviation) were analyzed and used in the reconstruction of the signal found, wave form, using the expression:

$$f(t) = \sum_{1}^{n} r_n \sin(w_n t + \phi_n) \qquad (2)$$

where n represents of the periods numbers and r_n, w_n and φ_n are amplitude, frequency and phase, respectively

Results

This study has been performed by using two distinct methods: multiresolution analysis and spectral analysis.

3.1 Multiresolution Analysis

The multiresolution analysis was performed on the time series in order to study the dependence of δD on solar activity and its variations on different timescales. The decomposition was performed until D_5 level. The D_j levels and the A_5 approximations for the Rz time series are shown in Figure 2, as an example. The band frequencies are approximately D_1 (2-4yr), D_2 (4-8yr), D_3 (8-16yr), D_4 (16-32yr), and D_5 (32-64yr). A_5 is the scaling level, corresponding to the long term periods (> 64yr). Table 1 shows the results found for this cross-correlation for level to level between the time series.

Table 1 – The wavelet decomposition bands cross-correlation level to level between solar parameters and δD.

Sunspot Number	George King	Lag	DML	Lag	GISP2	Lag
D1	-0.5494	0	0.5333	-2	-0.492	-3
D2	0.5397	9	0.214	5	0.452	2
D3	0.8408	1	0.850	-1	0.649	5
D4	-0.1543	-4	-0.307	3	0.527	4
D5	-0.5230	-4	0.359	0	-0.932	0
A5	0.9982	0	0.999	0	0.565	7

SPE E_p>100 MeV	George King	Lag	DML	Lag	GISP2	Lag
D1	0.7099	-1	0.5094	-4	0.4856	-4
D2	0.6496	0	-0.558	0	-0.402	5
D3	0.7436	1	0.902	0	0.6254	6
D4	-0.9138	0	-0.798	3	0.8286	6
D5	0.9569	0	-0.735	-3	0.9900	0
A5	0.9840	0	0.9377	0	0.9942	0

D_3 levels correspond to the 11yr solar cycle. The high correlation coefficients were obtained between solar parameters and δD time series. The following correlation coefficients were obtained between R_z x δD: for King George r = 0.84, for DML r = 0.85, for GISP2 r = 0.65. The correlation coefficients obtained between SPE x δD were: for George King r = 0.74, for DML r = 0.90 and for GISP2 r = 0.63.

<u>3.2 Spectral Analysis</u>

The spectral analysis results in time series (Figure 3) shows amplitude as a function of frequency as determined by the ARIST. The periods indicated are significant at 95% confidence level (amplitude > 2xSD). This figure shows periodicities of 11.1 and 7.8 yr. for Deuterium from George King (Figure 3A), 10.8 yr. for Deuterium from DML (Figure 3B), and 12.3 and 8.1 yr. for Deuterium from GISP2 (Figure 3C). It was observed that there exist peaks with a high statistical estimate close to 11 yr. Assuming that these signals have a solar origin, it would appear that the length of the solar cycle during this interval was close to 11 years. These results were observed in sunspot number where periods were found at 10.7 and 7.9 yr (Figure 3D), and 10.3 and 7.5 yr for SPE (E_P>100 MeV) (Figure 3E) time series.

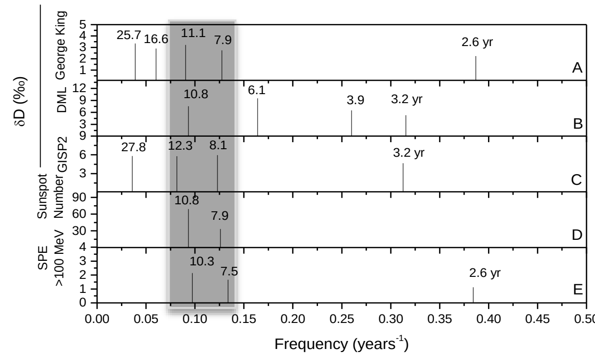

Figure 3 – Amplitude spectrum for δD Annual average time series from George King island (A), and Dronning Maud Land (B), GISP2 (C), Sunspot Number (D), and SPE (Ep > 100 MeV) (E).

Using Eq. (2) to reconstruct the solar signal from the periodicities of 7 to 12 yr in time series (Figure 4), a correlation analysis between the solar parameters reconstructed and δD reconstructed, in signal of 7 to 11 years, time series was performed and gave high correlation coefficients (Table 2). The correlation coefficients obtained between R_z x δD, for George King r = 0.94, for DML r = 0.90, for GISP2 r = 0.63. The correlation coefficients obtained between SPE x δD for George King r = 0.83, for DML r = 0.94, for GISP2 r = 0.90.

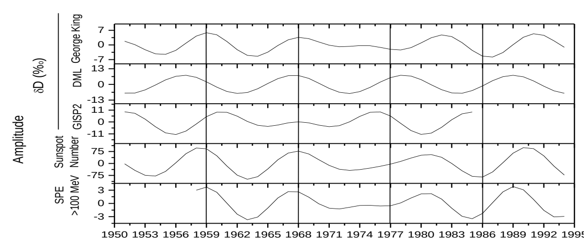

Figure 4 – Signal of 7+12 years reconstruction from time series.

Table 2 – Cross-correlation between solar parameters and δD in signal of 7 to 12 years.

	George King	Lag	DML	Lag	GISP2	Lag
Sunspot	0.94	1	0.90	-1	0.63	3
SPE E_P>100	0.83	1	-094	-1	-0.90	1

To explain the results obtained by two different methods of analysis, about a possible modulation or contribution of the deuterium measured at Earth for 11yr solar cycle, we suggest some possible hypothesis.

The first hypothesis, and the most accepted by the scientific community, is an increase in the solar irradiation that arrives at the Earth surface that can cause alterations in the parameters associated to hydrologic cycles responsible for the δD concentration in the ice (Merlivat and Jouzel, 1979; Perry, 1995; Levitus and Antonov, 2000; Froehlich et al., 2002; Masson-Delmotte et al., 2005). However only this hypothesis does not explain the relationship obtained between the δD and SPE of high energy, once these phenomenon (quantified by SPE) is dependent on the particles emitted by the Sun and not of the radiation. Thus, some hypotheses are presented here to explain that relationship.

The second hypothesis is that the deuterium comes from the Sun (where it is produced by solar flares through proton acceleration) through the solar wind. This physical mechanism is presented for Mullan and Linsky (1999). Evidence that indicates that some of the D created in a flare actually escapes from the Sun has been reported by Anglin et al. (1973) and Anglin (1975). These authors used Interplanetary Monitoring Platform data from IMP-5 and IMP-6 to detect energetic deuterons (8-13 MeV/nucleon) from a sample of 25 flares that occurred during the interval 1969-1972, i.e., close to the maximum of solar cycle 20.

Conclusions

In our analysis a possible contribution or modulation of the deuterium measured at Earth (in ice from Antarctic and Greenland) by the 11yr solar cycle was detected. This was determined by two different methods of analysis, multiresolution and spectral analysis.

Some hypotheses were also suggested about a possible modulation or contribution of the Sun to the δD measured in the ice of Antarctica and Greenland. It is now necessary to verify these hypotheses in order to determine what exactly is happening.

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