TOTAL OZONE CONTENT CHANGES ASSOCIATED TO SOLAR DYNAMO MAGNETIC FIELD VARIATIONS

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ABSTRACT

There are some evidences that support the occurrence of total ozone content changes by high energetic particle flux intensity variations. In turn, these last are strongly linked to sudden commencement storms (SSC´s). Therefore, an analysis of total ozone content in selected ground stations, radiative input and *SSC* index yearly means time series, the last defined as the product of the amplitude by the duration time of each storm, is performed. It is found that long-term ozone variations are mostly related to *SSC* index long-term variations in all the stations, with different behaviours that depend on geographical location. In particular, the strong decrease of total ozone content during cycle 22 is related to the very high *SSC* values that occurred during that sunspot cycle and is remarkably strong in Faraday and Halley Bay stations. In all the stations the minimum in total ozone content long term variation is reached around 1993 and is followed by an steady increase, that would continue along the forthcoming years following the descending chaotic transition that solar global magnetic field dynamo system started around 1993.

1 INTRODUCTION

Solar activity manifests itself in several ways. Some of them, in turn, act on those Earth's parameters that conform the so-called "climatic change". The ozone layer plays a key role because the sensitivity of the atmospheric circulation, chemistry and radiative processes to its changes. Ozone itself is sensitive to many influences, either in short term or in long term.

In the short term, i. e. the daily or monthly basis, particle precipitation has been subject of many studies and most authors agree in the influence of particle precipitation on the ozone content. However, most fo the research on this area has been done focusing on high latitudes, where particles (mainly relativistic electrons) reach the lowest altitudes, where its subsequent production of odd nitrogen (NOy) works more efficiently. Relativistic electron precipitation (REP) events have been suggested to affect odd nitrogen content in several studies [1][2][3][4]. This phenomenon has been verified by comparing model computation of ozone high distribution with ozone data from various instruments such as the Total Ozone Mapping Spectrometer (TOMS), Solar Backscattering Ultraviolet (SBUV), and those onboard the Upper Atmosphere Research Satellite (UARS) [5][6][7].

Particular attention has been drawn to high-energy electron flux into earth's atmosphere, measured by particle detectors onboard satellites [8][9]. On that basis, Martinez and Duhau [10] found a linear relationship between geomagnetic activity and electron energy flux at the subauroral belt. Therefore, they interpreted a negative correlation found between Ozone content and geomagnetic index Ap as a manifestation of the Ozone depletion by REP's at upper stratospheric heights. Also, they interpreted a delayed positive correlation found in the data as an evidence of an afterward effect of REP's on atmospheric circulation by the cooling of the upper stratosphere by ozone depletion. In fact, in the pioneering work of W. O. Roberts [11] a relationship between geomagnetic activity and meteorological vorticity was found, that might be related to the afterward cooling effect of REP's.

Regarding with middle and low latitudes, other authors [12][13][14] found statistical associations, between geomagnetic storms and ozone, sensitive to the phase of the Quasi Biennial Oscillation of the Stratosphere (QBO). On the dynamic side, Jadin [15] found effects in global scale such as those driven by variations in Longitude of day (LOD). LOD can be related with the AAM (atmospheric angular momentum) in interannual and decadal time scales, which, in turn, accounts for the planetary wave activity relevant for global ozone distribution

Regarding to the long-term ozone variations, the features of the solar magnetic fields in that scale has been studied with [16][17][18] the help of the wavelet analysis. This technique and particularly, the multi-resolution analysis allow us to identify cyclical behaviour in the characteristic time scales [19] in the Sun and its correspondents in any parameter. In

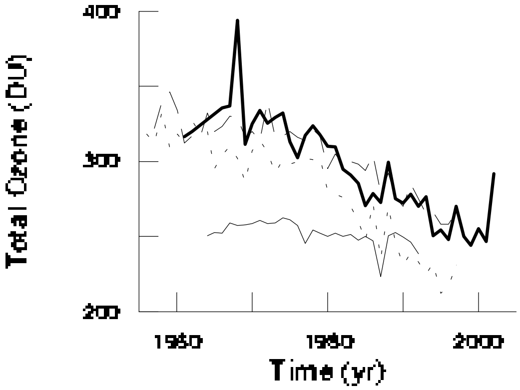

Fig. 1: Annual means of total ozone at the Southern Hemisphere high latitudes. Thick solid line corresponds to Syowa (1961-2002), the dashed line is for Faraday (1957-1997), the dotted line is for Halley Bay (1956-1997) and the solid thin line is for Amundsen-Scott (1964-1992)

this paper we apply that tool in seeking solar signals in the ozone data. For the sake of a further physical modelling of the problem correlation were made with some relevant indicators of solar activity: Solar radiation, the *SSC* index [20], Aa geomagnetic index and the variation in LOD.

2 OZONE DATA

Total ozone data from selected ground stations (spectrophotometers) are presented here in the form of annual means. They were grouped by geographic latitude in order to show in a qualitative way the different sensitivities of ozone column to the different inputs considered here. As an example, and taking into account its time span, only data from Arosa (Switzerland) are discussed in depth here. Table I shows the geographic and geomagnetic coordinates of each station.

Table I: Geographic and Geomagnetic Coordinates of stations.

	Latitude		Longitude	
	Geogr.	Geomg.	Geogr.	Geomg.
Am. Scott	-89.98	-78.79	-21.8	0.0
Arosa	46.78	47.55	9.68	92.2
Buenos Aires	-34.58	-23-79	-58.48	14.6
C. Paulista	-22.68	-12.54	-45.00	24.30
Faraday	-65.15	-54.01	-64.16	4.70
Halley Bay	-73.52	-64.31	-26.73	27.10
Lerwick	60.13	62.17	-1.18	89.70
Murmansk	68.97	64.84	33.05	128.2
Natal	-5.84	3.28	-35.21	35.40
New Delhi	28.65	19.02	77.22	150.05
Reykjavik	64.13	69.78	-21.90	72.00
Syowa	-69.00	-70.06	39.58	80.10

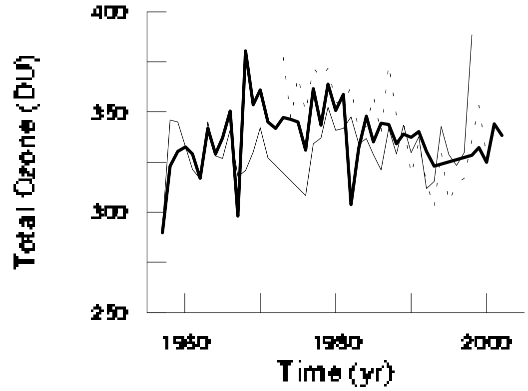

Fig. 2: Annual means of total ozone at high latitudes in the Northern Hemisphere. Includes Reykjavik, Iceland (1957-1998), in thick solid line, Murmansk, Russia (1973-2001), in dotted line and Lerwick, UK (1957-2002), in solid thin line

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3 GEOGRAPHICAL DISTRIBUTION OF TOTAL OZONE CONTENT

In figures (1) to (4) ozone total content data has been grouped in high North (HN), high South (HS), medium (M) and low (L) latitudes, respectively.

It can be noticed that each group shares a common behaviour. Is quite remarkable the steady decrease since the 1970 decade and its steepening around 1990 (near sunspot cycle maxima 22) in the HS (Fig.1) with the exception of Amundsen-Scott station, that shows lower but almost constant total ozone levels. Due to the mentioned decrease annual means become comparable at Faraday to those of Amundsen-Scott. This is consistent with the dependence of electron energy distribution on longitude in NH stations and the expected effect on ozone total content in latitudinal distribution as found in ref. [10].

A similar but less abrupt behavior can be observed in the HN latitudes (Fig. 2) with differences mostly related with dynamics. Also, in both NH and HH a recovering of higher ozone total content values is started at the end of the 1990 decade, being this recovery more abrupt at HN latitude stations

ML stations (Fig 3) show behaviour similar to that of high latitude stations, but strongly weakened.

LL stations follow the general behaviour, but even more weekend than in ML stations in such amount that fluctuations in the decadal time scale are very

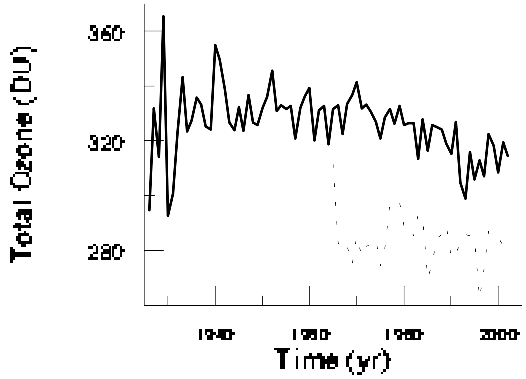

Fig. 3: Annual means of total ozone at midlatitudes. Arosa, Switzerland, from 1926 to 2002 and Buenos Aires, Argentina from1965 to 2002 (dotted line)

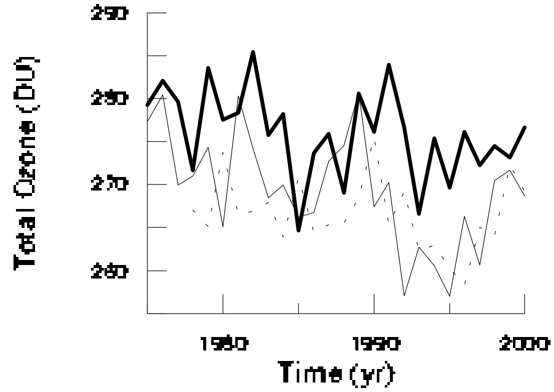

Fig. 4: Annual means of total ozone at low latitudes. New Delhi, India, from1975 to 2000 (thick solid line), Cachoeira Paulista, Brazil from 1975 to 2000 (thin solid line) and Natal, Brazil, from1978 to 2000 (dotted line).

stronger as compared with long term trend but the sharp increases after 1990 and posterior recovering is also apparent on the two Brazilian stations.

The difference in the total ozone content behaviour between the two Brazilian station LL station that are only 10º apart and in the East hemisphere with New Delhi that is in the east hemisphere is indicative of a longitudinal dependence of the phenomenon. On that regards it may be noted that Cachoeira Paulista is the nearest station to the South Atlantic geomagnetic anomaly and natal is not that far away either. Therefore as precipitating electron energy flux becomes more intense near this station its effect is strong enough to overcome hydrodinamical fluctuations there.

3. A WAVELET ANALYSIS OF OZONE TOTAL CONTENT AT AROSA

We analyse by this methodology Arosa station data that is the longer data set of total ozone content (1926 to present).

Figure 5 shows the long-term variations in ozone, *SSC* and Total Solar Irradiance. It is noticeable how ozone variations go with irradiance before 1960 and with *SSC* after 1960. The semi-secular component curve for total ozone (Fig. 6) doesn't follow so closely the SSC or the LOD variations, probably due to boundary effects of the short data series. However, comparison with *SSC* looks , face value, quite similar to above results.

4. CONCLUSIONS

The strong decrease that *SSC* index undergone after 1960 has been followed by a decreases in total ozone content in almost all the stations, pointing this to the fact that SSCs has been so strong during the last 40 years that overcame the other sources of variability including atmospheric circulation. Also the descending transition that started the sun magnetic field after year 1993 is being synchronic with and steady increases in ozone total content.

As the decrease of mean solar magnetic field will be continued for the next decade SSCs will became weaker, and so we may expect that total ozone content will recover the higher average values that have prevailed before 1960.

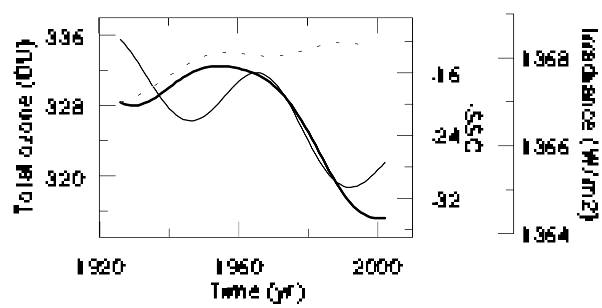

Fig. 5: Long-term variations in total ozone content (heavy line), SSC index (light line) and solar total irradiance (dashed line), respectively

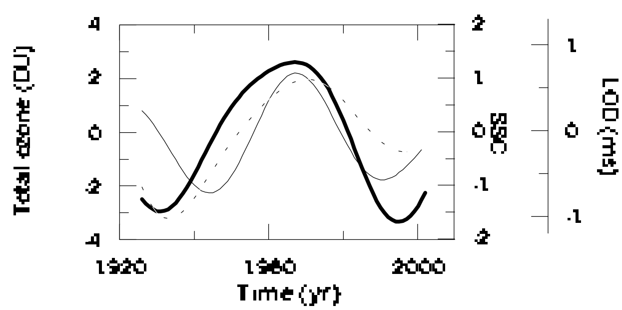

Fig. 6: Semi-secular cycle in total ozone content (heavy line), SSC index (light line) and LOD, (dashed line) respectively.

5. REFERENCES

1. Thorne, R. M., Energetic Radiation Belt Electron Precipitation: A Natural Depletion Mechanism for Stratospheric Ozone, *Science* Vol. 195, 287-289, 1977.

2. Thorne, R. M., The Importance of Energetic Particle Precipitation on the Chemical Composition of the Middle Atmosphere, *Pure Appl. Geophys.* Vol. 118, 129-151, 1980.

3. Baker, D. N., Blake, J.B., Gorney, D. J. Higbie, P. R. Klebesadel, R.W and King, J. H., Highly relativistic Magnetospheric electrons: A role in coupling to the middle atmosphere, *Geophys. Res. Lett* Vol. 14, 1027-1030, 1987.

4. Baker, D. N., Goldberg, R. A., Herrero, F. A., Blake, J.B. and Callis, L. B., Satellite and rocket studies of relativistic electrons and their influence on the middle atmosphere, *J., Atmos. Terr. Physics* Vol. 55, 1619-1628, 1993.

5. Callis L. B., Baker, D. N., Blake, J. B., Lambeth, J. D., Boughner, R. E., Natarajan, M., Klebesadel, R. W. & Gorney, D. J., Precipitating relativistic electrons: Their long-term effect on stratospheric odd nitrogen levels, *J. Geophys. Res.* Vol. 96, 2939-2976, 1991a.

6. Callis L. B., Boughner, R. E., Natarajan, M., Lambeth, J.B., Baker, D. N., & Blake, J. B., Ozone depletion in the high-latitude lower stratosphere, *J. Geophys. Res.* Vol. 96, 2921, 1991b.

7. Callis, L. B., Boughner, R.B., Baker, D. N., Mewaldt, R. A., Blake, J. B., Selesnick, R. S., Cummings, J. R., Natarajan, M., Mason G., and Masur, J. E., Precipitating electrons: Evidence for effects on mesospheric odd nitrogen, *Geophys. Res. Lett.* Vol. 23, 1901 - 1904, 1996.

8. Callis L. B., Natarajan, M., Lambeth, J. D., Boughner, R. E, *J. Geophys. Res.* Vol. 102, 1215 1997.
Callis L. B., Natarajan, M., Lambeth, J. D. y Baker, D. N., Solar atmospheric coupling by electrons (SOLACE) 2, Calculated stratospheric effects of precipitating electrons, *J. Geophys. Res.* Vol. 103, 28421-28438, 1998.

9. Gaines, E., E., Chenette D.L., Imhof, W. L., Jackman, C. H., and Winningham, J. D., Relativistic electron fluxes in May 1992 and their effect in the middle atmosphere, *J., Geophys. Res.* Vol. 100, 1027-1033, 1995.

10. Martinez, E. A., and Duhau, S., Changes In stratospheric Ozone and its relationship with geomagnetic activity in high latitudes, *Anales AFA* Vol. 13 256-259, 2002.

11. Roberts, W. O. and Olson, R. H., Geomagnetic Storms 300-mb Trough Development in the North Pacific-North America Area, *J. Atmos. Sci.* Vol. 30, 135-140, 1973.

12. Mlch P., and Lastovicka, J., Total ozone response to major geomagnetic storms and changes in meteorological situations, *Studia Geoph. Geod.* Vol. 39, 189-207, 1995.

13. Lastovicka, J., The response of the lower ionosphere, stratospheric ozone and the vorticity area index to geomagnetic storms. *Geomagnetism and Aeronomy* Vol. 30, 380-383 (translated from Russian by the American Geophysical Union), 1991

14. J. Bochnicek, J. Hejda P., Bucha, V. And Pycha, J., Possible geomagnetic activity effects on weather, *Ann. Geophysicae*, Vol. 17, 025-932, 1998.

15. Jadin, E. A. Interannual Variation of Total Ozone and Stratospheric Angular Momentum, *Int J. of Geomagnetism and Aeronomy* Vol. 1, 2, pp. 169-180, 1999.

16. Duhau, S., An early prediction of maximum sunspot number in solar cycle 24, *Solar Physics* Vol. 213, 203-212, 2003.

17. Duhau, S. and Chen, Ch. Y., The sudden increase of solar and geomagnetic after 1923 as a manifestation of a non-linear solar dynamo, *Geophys. Res. Lett.* Vol 29, 13, 6-1 to 6-4, 2002.

18. Duhau, S. and Chen, C. Y., On the causes of the sudden increase of solar dynamo magnetic field after 1923, *Anales AFA* Vol. 13, 41-44, 2002.

19. Duhau, S., Two coupled 88 and 22 year oscillators in the modulation in sunspot cycle, *Anales AFA* Vol. 13, 3740, 2002

20. Duhau, S., On the nature of the steep changes in solar and geomagnetic activity after 1705, 1923 and 1993. International Solar Cycle Studies Symposium 2003:"*Solar Variability as an Input to the Earth`s Environment"*

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