CAMBIOS EN EL OZONO ESTRATOSFÉRICO Y SU RELACIÓN CON LA ACTIVIDAD GEOMAGNÉTICA EN LATITUDES ALTAS

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Para estimar el comportamiento de la atmósfera frente a los eventos de precipitación de electrones, se llevaron a cabo estudios de la correlación cruzada entre el índice geomagnético Ap -- como dato sustituto del flujo de energía de los electrones precipitados-- y la columna de O_3 medida con espectrofotómetros Dobson en estaciones ubicadas en la zona subauroral y la capa polar de ambos hemisferios.
Se encontró que existe significativa correlación entre el contenido total de ozono y el índice Ap en las estaciones ubicadas en la zona subauroral, con menor o nula significación estadística para estaciones exteriores a dicha zona. En las estaciones subaurorales puede observarse que las medias móviles de 30 días de ozono y de Ap tienen una correlación negativa que alcanza su máximo cuando el ozono está retrasado respecto de Ap entre diez a catorce días y luego una correlación positiva a los 20 a 30 días de retraso. Tales efectos son más intensos en invierno que en verano. Estos resultados se discuten en el contexto de la evolución del contenido total de ozono luego de una tormenta geomagnética y se sugieren posibles mecanismos a la luz de las teorías actuales, basadas en una combinación de los llamados nitrógenos impares con el ozono y la circulación atmosférica.

To assess the atmospheric behavior related with relativistic electron precipitation events, studies about the relationship between the index Ap -as a proxy data for REP energy flux- and the ozone column. To do so, total ozone data from ground-based Dobson spectrophotometers sited at subauroral belt and polar cap locations were selected from both the southern and the northern hemispheres.
It was found that the correlation between Ap and ozone is quite significant at subauroral stations and has less statistical significance, if any, at stations located outside that zone. The correlation between total ozone content and Ap 30-day running means has a maximum negative value at time lag values from 10 days to two weeks of ozone with respect to Ap, and a positive correlation for a time lag that varies between 20 and 30 days. Both effects are considerable stronger in winter than in summer. These results are discussed in terms of the evolution of total ozone content after a geomagnetic storm and some suggestions on the underlying mechanism are given in the light of present theories.

I. INTRODUCTION

Thorne[(1)] proposed a mechanism by which the effect of the precipitation of relativistic electrons (hereinafter REP) at subauroral latitudes may lead to ozone depletion by increasing ionization in the upper stratosphere and lower mesosphere with attendant odd nitrogen production. It has been suggested by Callis *et al.*[(2, 3)] that odd nitrogen produced in this region of the atmosphere by REP's may be followed by downward transport (depending upon season) with significant accumulation. Based in their analysis and models, these authors conclude that there exists an appreciable effect of REP events on ozone content that varies with solar cycle). Empirical evidences of a relationship between geomagnetic indices and meteorological conditions have also been found by Bucha and Bucha Jr.[(4)].

Particle precipitation

The term "precipitated particles" involves many species such as protons, alphas and electrons. The scope of the present paper involves only the effects of the electron precipitation since it is more closely related with geomagnetic activity, than the other species[(5,6)].

As has been pointed by Thorne[(7)] particle precipitation is observed mainly at auroral latitudes. Particularly sensitive is the region between 60 and 70 degrees of geomagnetic latitude, i.e. below the subauroral belt. from electron energy flux measurements taken by satellites at the upper atmosphere modeled as a function of latitude and geomagnetic activity indices[(8,9)], we have analyzed the relationship between electron energy and geomagnetic index Ap daily averages as a function of latitude. We found that the electron energy flux increases linearly with Ap within the subauroral belt, while in the inner zone of the polar cap decreases sharply with Ap for Ap < 20 and the relationship is lost beyond Ap=20, as shown in fig. 1 which coincides with geomagnetic latitudes covered by the subauroral belt[(10)]. The statistical models take into account energy ranges until

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500 keV, therefore our estimations must be regarded as extrapolations.

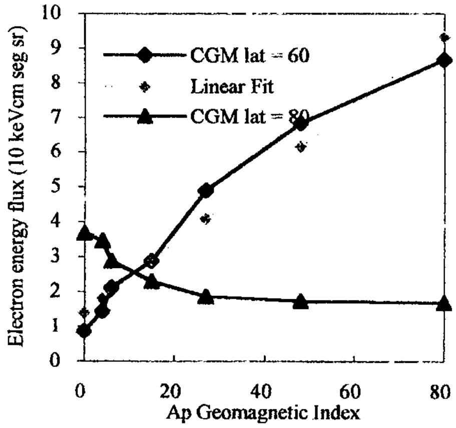

Fig. 1: Relationship between geomagnetic activity and electron energy flux.

II. DATA ANALYSIS AND DISCUSSION

The data

Geomagnetic activity controls the shape and position of the auroral oval[11,12], and thus, the zones of the upper atmosphere where the particles are deposited. Therefore, a first criteria for selecting stations in this study is that the sites must lie in geomagnetic latitudes, Λ, in the interval 60 < Λ < 70. The stations selected were Syowa, Reykjavik - which is the nearest Dobson station to the geomagnetically conjugated point of Syowa - and Murmansk. For comparison, other stations that lay outside the subauroral belt were also selected: Amundsen-Scott, in the inner zone of the polar cap, and Lerwick, in the outer edge of the subauroral belt. Other important criterion to select stations was the availability of uninterrupted time series. Finally, we considered only time periods that are previous to those on which the "ozone hole" was reported[13], with this restrictions all the available data are that listed in table i. on that table, CGM refers to the corrected geomagnetic coordinates of the stations.

The relationship between ozone and Ap

The correlation coefficient between total ozone measured by the ground-based Dobson spectrophotometers, as a

TABLE 1: GEOGRAPHIC AND GEOMAGNETIC COORDINATES OF THE STATIONS AND PERIODS STUDIED.

Station	Geographic Coordinates		CGM Coordinates		Period
------------	Lat.	Lon.	Lat.	Lon.	--------
Am.-Scott	-89.59	-24.48	-73.66	20.73	64-75
Syowa	-69.00	40.0	-66.2	71.15	66-72
Lerwick	60.08	-1.64	58.22	82.18	64-71
Murmansk	68.58	33.03	64.45	114.41	64-71
Reykjavik	64.08	-21.54	65.48	69.16	64-71

function of the time lag with respect to the Ap day-running means were computed for all cases of Table 1 (two examples are shown in figures 2 and 3). The corresponding significance levels (i.e. one minus the probability of a chance occurrence) of these coefficients were obtained by the Student's t - test. We have taken into account only the features that had a significance level greater than 0.8

According with the t-test two time lag intervals where the correlation coefficient is meaningful were found for the subauroral station Syowa (see fig. 2). These are: from 6 to 14 days of time lag, for which is negative and has its maximum magnitude at day 9, and after day 30 where it takes high positive values. This positive correlation between total ozone content- and geomagnetic activity at Syowa, for a time lag of about a month was also found by Duhau and Favetto[14] by comparing monthly means of ozone content and Ap index in the interval 1965-1985.

For the polar station (Amundsen - Scott) all the values of the significance level are below 0.6 so we may conclude that for this station there is not apparent in the data a relationship between Ap and total ozone content.

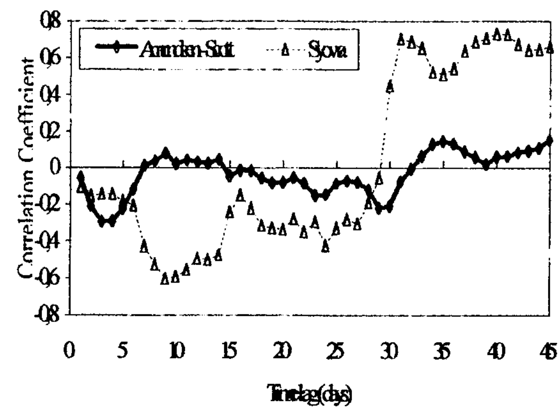

Fig.2: Cross correlation between total ozone and Ap monthly means vs. time lag for the Southern Hemisphere in summer.

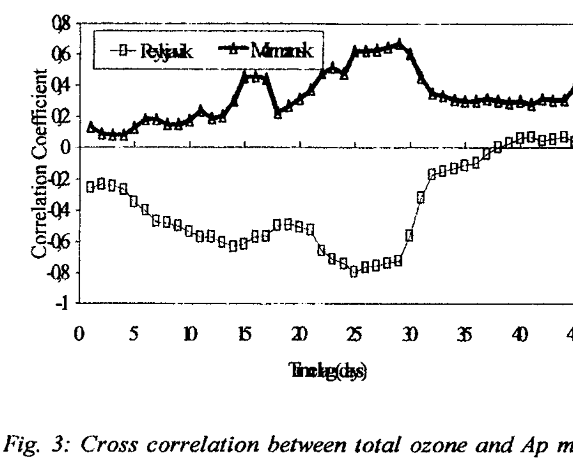

Fig. 3: Cross correlation between total ozone and Ap monthly means vs. time lag for the Northern Hemisphere in winter.

The same happens with data from Lerwick that is located in the outer edge of the northern subauroral belt.

For the subauroral stations Murmansk and Reykjavik located at the subauroral belt in the Northern Hemisphere a relationship between the ozone column and geomagnetic activity is apparent in the data, as expected, which is more important during winter than in summer.

Model computations of the evolution of the ozone reduction by Callis et al.[3,4] indicate that the ozone total content decreases after an isolated REP event, reaching its lowest value by about 15 days, and slowly recovering after that. Also, these authors have suggested that an stronger negative delayed effect may be produced by increasing levels of odd nitrogen at 1 mbar due to advective descent, that in winter is rather rapid (0.7 - 0.8 km/day). Our results are consistent with this picture, since during summer (Syowa – Figure 2- and Murmansk). The maximum negative correlation occurs around a time delay of 10 days lasting only for a few days, while in winter (at Reykjavik - Figure 3) the correlation coefficient continues decreasing having two relative minima at day 15 and 25 respectively.

The slope of the linear relationship between total ozone content and Ap index that roughly estimates the relative importance of the REP effect over ozone is shown in table II. Negative slopes are three to five times larger in winter than in summer. This fact supports Callis's suggestion regarding vertical descending winds flowing during winter that enhance the effect of REP's in that season. Moreover, as the lifetime of nitric oxide and most of the odd nitrogen species increases sharply with height, the even stronger negative value that appears two weeks later on Reykjavik, may be interpreted also as due to an enhancement of odd nitrogen particles by descending masses of air.

While at Reykjavik the correlation tends to zero and so, the relationship fades beyond day 35, in Syowa (fig. 3), a significant positive correlation occurs after day 30 (m = 2.7) and the same occurs in Murmansk after day 29 (m = 13.7). This effect requires a complementary explanation. According to Solomon[13], the ozone represents the principal source of heating in the Polar cap, so ozone changes would turn in yield appreciable changes in temperature at high latitudes. Relativistic electrons precipitate in a very narrow interval of geomagnetic latitudes (see fig. 1) and then chemical perturbation caused by REP's would produce sharp gradients in the temperature by cooling the narrow subauroral band. Therefore, we suggest that the positive correlation observed in Syowa and in Murmansk, may be due to ozone transport associated with waves[15] excited by cooling due to ozone depletion after a REP event. This picture is consistent with the fact that the positive effect is farther stronger in winter than in summer. Namely: in winter m=13.7 on day 29 for Murmansk and in summer m=2.7 on day 31 for Syowa, respectively, i.e. the strength of the positive delayed effect on ozone total content follows the seasonal change of the previous negative effect, directly associate with the REP events.

TABLE II: LINEAR FITTINGS OF TOTAL OZONE VS. AP MONTHLY MEANS

Station	**Season**	**time lag (days)**	**Slope m (DU/Ap unit)**
Syowa	Summer	31	2.7
Syowa	Summer	10	-2.1
Murmansk	Summer	10	-3.0
Reykjavik	Winter	10	-10.5
Reykjavik	Winter	15	-15.3
Reykjavik	Winter	25	-19.9
Murmansk	Winter	29	13.7

The geographical and geomagnetic poles are several degrees apart, so the subauroral belt is tilted with respect to any latitude circle. Therefore, the fact that Reykjavik is out of the polar oval, while Syowa and Murmansk lay on the subauroral, belt, might explain why the strong negative effect observed in all these stations is followed by and strong positive effect only at Syowa and Murmansk.

III. CONCLUSSIONS

We have found that geomagnetic index Ap is an accurate proxy data for the amount of energy deposited by REP events in the sub auroral.

So we have determined ozone evolution after REP events in the subauroral belt by studying the relationship between total ozone content as a function of its time lag with respect to Ap and by this mean we have isolated the effect of high energy precipitated electrons on ozone depletions.

Our results support Callis et al.'s suggestion that high energy electrons are able to destroy the upper part of the ozone column by producing odd nitrogen species (mostly NO) at the lower thermosphere. Moreover, we have found that such effect is stronger in winter, when advection of masses of air enriches with odd nitrogen the upper stratosphere where ozone concentration is still considerable.

We have found that at subauroral stations ozone depletion is strong 9 to 15 days after a REP event and a positive effect delayed by about a month do a also exists, which strength follows that of the previous depletion.. To explain this last phenomenon we suggest that stratospheric cooling by ozone depletion generates horizontal temperature gradients strong enough to drive horizontal waves.

Therefore besides to fully support Callis et al.'s[5,6] suggestion of high energy precipitate electrons ability to produce ozone depletion, our analysis indicates the existence of an afterward remarkable effect of REP events at high latitudes. Namely the driving of planetary waves by chemical cooling by ozone depletion in the stratosphere at the subauroral belt. The scarcity of reliable data makes this conclusion preliminary, but the potential of this phenomenon of modifying atmospheric circulation at high latitudes provides a new insight that deserves further investigations on ozone depletions induced by REP's and afterwards effects.

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