REPORT ON THE STUDIES ABOUT THE LONG-TERM IONOSPHERIC BEHAVIOUR IN ANTARCTICA

By

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In the last decade several studies have been addressed to the possible consequences of the atmospheric greenhouse effect on the long-term behaviour of the ionospheric parameters (Roble and Dickinson, 1989; Rishbeth, 1990; Rishbeth and Roble, 1992). Starting from the following hypothesis (Rishbeth, 1990):

- the applicability of the perfect gas law to reproduce the behaviour on global scale of the middle-upper atmosphere,
- the hydrostatic equilibrium in the meso-thermospheric regions,
- a doubling mixing ratios of CO_2 and CH_4 at 60 km,

and by using the MSIS-86 (Hedin, 1987) and the TIGCM (Roble et al., 1988), the ionospheric parameters variations listed in the table 1 should be expected.
According to the Intergovernmental Panel on Climate Change (IPCC), between the late 50's and the middle 90's the increasing of CO_2 and CH_4 global concentration is about 20% (Houghton et al., 1996) so the expected ionospheric long-term variations should be about 1/5 of those predicted by the theoretical calculations of Rishbeth (1990) and Rishbeth and Roble (1992) (tab.1). But investigations obtained by using new satellite data of some thermospheric parameters, seem to show that the Rishbeth results could be underestimated (Keating et al, 2000). So, e.g., while the negative trend of the real height and plasma frequency in the F2 layer should be unquestioned, the real rate of the long-term ionospheric trend (if any) is still an open question.

Ionospheric regions	Parameters	Long-term variations
E	h'E f0E	-2.5 km 0.05 ÷ 0.08 MHz
F1	f0F1	0.3 ÷ 0.5 MHz
F2	hmF2 f0F2	-10 ÷ -20 km -0.2 ÷ -0.5 MHz

Table 1. Expected long term variations of different ionospheric parameters due to atmospheric greenhouse effect.

In the last ten years several investigations, mainly based on mid-high latitude ionosonde data, have been carried on in order to verify the theoretical long-term trend predictions (Bremer, 1992, 1998; Ulich and Turunen, 1997, Jarvis et al, 1998), even if some authors do not agree with the possibility of a greenhouse effect in the ionosphere (Mikhailov et al., 2000). Naturally, other causes could be accountable of the ionospheric long-term trend such as: connection between magnetopause position and ionospheric ionisation level (Makarova et al., 1998), planetary waves and quasi-biennal oscillation of the semidiurnal tide (Jarvis, 1996), enhancement of magnetic activity over the last 130 years (Clivered et al., 1998), long-term decreasing trend of the horizontal thermospheric wind (Jarvis et al., 1998), long-term increasing/decreasing geomagnetic activity (Mikhailov et al., 2000).

To contribute to the planetary investigations on the long-term ionospheric behaviour, in 1999 the research group of INGV, Upper Atmosphere Physics Department, has begun to work on these topics in attempt to verify the Rishbeth theory by analysing ionosonde Antarctic data. The novel aspect of this analysis is represented by the geographical remoteness of the Antarctic stations from other already used (see, e.g., Bremer, 1998; Ulich and Turunen, 1997).
After a validation of the experimental data available, simply based on the calculation of the standard deviation respect to the ITU-R modelled data (ITU-R, 1995), the monthly median f0F2 values coming from the station listed in table 2 have been considered for the period from 1957 to 1990 (Alfonsi et al., 2001).

Stations	**Geographic co-ordinates**	**Geomagnetic co-ordinates**
TERREADELIE	66,7°S 140,0°E	75,3°S 232,4°E
MAWSON	67,6°S 62,9°E	73,3°S 105,1°E
SYOWA	69,0°S 39,6°E	69,9°S 79,2°E

Table 2 Stations used in the analysis (from Alfonsi et al, 2001).

The analysis applied can be summarised in the following main steps.

- Firstly, three models have been used for the monthly medians calculation as function of solar and magnetic activity:

$$f0F2(mod1) = a + b\cdot R + c\cdot Ap \qquad (1.a)$$
$$f0F2(mod2) = d + e\cdot R + f\cdot AE \qquad (1.b)$$
$$f0F2(mod3) = g + h\cdot R \qquad (1.c),$$

  R is the Zurich sunspot number (monthly value) and Ap and AE are the well-known geomagnetic indices (monthly values) (see e.g. Mayaud, 1980). The set of coefficients a, b,…h, is calculated by the least square method;

- Then the residuals, δf0F2, are calculated between experimental and modelled data:

$$\delta f0F2 = f0F2(exp) – f0F2(mod) \qquad (2),$$

  In this way, solar and magnetic activity should not affect the δf0F2's and the long term trend of the selected ionospheric parameter can be investigated as function of some other cause.

- Finally, the slope, b, of the f0F2 long-term trend can be evaluated from the linear regression:

$$\Delta f0F2 = a + b\cdot y \qquad (3),$$

  where Δf0F2 is the average of the δf0F2's over all hours of the day and y is given by the difference between each year and the starting year considered (1957);

To test the significance of the results, the Fisher criterion has been adopted (Taubenheim, 1969). In our investigation the confidence level for which b (eq. 3) is significantly different from zero is very often greater than 95% and, in some cases (e.g. Mawson station), greater than 99%.
A general f0F2 decreasing from 1957 to 1990, estimated on the base of eq. (3), has been obtained for all the stations considered as expected. In particular the f0F2 total variation obtained for

Mawson ranges between –0,50 MHz and –0,82 MHz, depending on the regression models used (eq.s 1.a-c). Figure 1 shows Mawson (MA), Terre Adelie (TA) and Syowa (SY) long term behaviours.

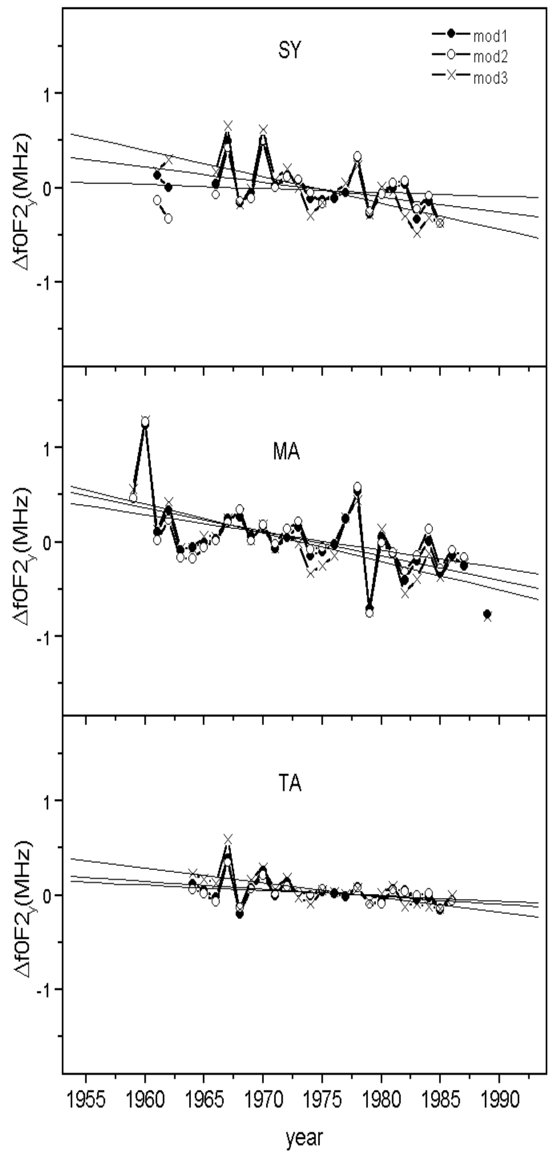

Figure 1. Yearly trends of foF2 values, $\Delta foF2_y$, for each stations and for each regression models (from Alfonsi et. al, 2001)

In spite of the real difficulties to find long series of data (at least 22 years) from polar ionospheric observatories, in order to carry on a deeper investigation on the long-term ionospheric behaviour, the preliminary results have been presented on the f0F2 long-term changes based, *for the first time*, on the *hourly* f0F2 data from Mawson station (Alfonsi et al, 2001a) (XXVI General Assembly of the European Geophysical Society, 25-30 March 2001, Nice, France). To reduce the uncertainty on the scaled values, due to physical disturbance causes (e.g. spread F or sporadic E layer phenomena) and/or to technical problems, only the f0F2 hourly data with no qualification letter (e.g. U;D;I…) have been selected. Moreover the data analysis has been developed by adopting the following regression model (instead of the eqs. 1.a-c):

$$f0F2(mod4) = A + B \cdot R_d + C \cdot ap(\tau) \qquad (4),$$

in which R_d is the daily value of the Zurich sunspot number and ap(τ) is the 3-hourly value of the time-weighted magnetic index ap, firstly introduced by Wrenn (1987), and already used, even if for different purposes, for Antarctic f0F2 data processing (Perrone and De Franceschi, 1999). ap(τ) should better take into account the magnetic influence on foF2 in respect to the monthly mean Ap and/or AE values used in the previous investigation (eq.s 1a,b).
By following the same steps described (eqs. 2-3), this analysis has confirmed a negative f0F2 long-term trend for Mawson whose rate is closer to that expected in table 1 with a quite acceptable error, i.e. –0,42 MHz ± 0.15.

It's important to underline the meaning of these studies. In fact, if the connection between anthropogenic causes and ionospheric effects will be verified, the scientific community will have at its disposal a rich data bank (about 40 years of hourly data from all over the world), instead of the very poor satellite measurements of the upper atmosphere parameters, to be used as a fundamental contribution for "Global Change" studies.

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