Regional ionospheric mapping and modelling over Antarctica

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Abstract
The performance of regional and global models has been investigated when applied for long term mapping of ionospheric characteristics and modelling the Total Electron Content in the polar cap over an Antarctic region. Comparison results between modelled data and a short period of experimental values available for low solar activity in December 1993 and January 1994 are presented and discussed.

Key words *ionospheric mapping and modelling – polar cap ionosphere*

1. Introduction

Over the polar caps, and mostly inside the auroral oval, the extreme variability in time and space of solar-terrestrial phenomena requires great effort in producing and collecting a large amount of statistics to be able to attempt to set some order in interpretation schemes and models. With the aim of contributing to this topic, a preliminary analysis was carried out to test the reliability degree of the ionospheric models when applied in «polar conditions», meaning the difficulties of treating a multidimensional system under particular physical conditions as well as the difficulties of operating with a poor coverage of ground-based observational points and related spatial/temporal database.

In this paper the Simplified Ionospheric Regional Model, SIRM (Zolesi *et al.*, 1993, 1996) and the DiGiovanni-Radicella, DGR (Radicella and Zhang, 1995) vertical electron density profile model are briefly described and the results are shown and discussed when applied to the available experimental data over Antarctica. The global ITU-R (Radiocommunication Sector of the International Telecommunication Union) (CCIR, 1994) and IRI90 (International Reference Ionosphere) (Bilitza, 1990) models are also used for comparison. Concluding remarks are then summarised as suggested from what was pointed out by this investigation.

2. Ionospheric models application

SIRM (Zolesi *et al.* 1993, 1996) is a long-term mapping smoothed technique able to reproduce, over a restricted region, the median behaviour of the critical frequencies of the E-F_1-F_2 layers (f_0E, f_0F_1, f_0F_2) and the $M(3000)F_2$ factor. The SIRM numerical procedure solves the set of equations generated to describe a selected ionospheric parameter as a function of the geographic coordinates, of LT (Local Time) or UT (Universal Time) and of the solar activity represented by the R_{12} index, *i.e.* the 12-month smoothed sunspot number. This model is also based on the assumption that, at constant LT, the selected parameter is inde-

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pendent of longitude. A Fourier interpolation is adopted to generate its diurnal and seasonal behaviours.

SIRM has been here applied for the long-term mapping of f_0F_2 over an Antarctic region ranging from 80°S to 60°S and from 110°E to 165°E. To calculate the SIRM model coefficients, we used the f_0F_2 monthly medians of a past reference data set from a sparse network of ionospheric stations, *i.e.* Casey (66.3S, 110.5E), Terre Adelie (66.7S, 140.0E) and Scott Base (77.9S, 166.8E), covering in-homogeneous periods of observations with several data gaps: January 1965-January 1975 (Casey), January 1965-December 1986 (Terre Adelie), January 1970-December 1983 (Scott Base). To improve the SIRM model accuracy, the Fourier synthesis is here applied month by month to generate the f_0F_2 diurnal behaviour, *i.e.* 12 sets (one for each month) of SIRM coefficients have been calculated.

A monthly median map of f_0F_2 modelled by SIRM is shown in fig. 1 for December 1993 at 00 UT when the solar actitvity was $R_{12} = 40$. In fig. 2 a sufficient agreement can be observed between the f_0F_2 monthly medians observed at Terra Nova Bay ionospheric station (74.70S, 164.12E) and those predicted by SIRM and ITU-R for December 1993 and January 1994 ($R_{12} = 37$). An average error of about .4 MHz exists between SIRM and/or ITU-R modelled and observed values.

The DGR (Radicella and Zhang, 1995) model is based on the Epstein layer introduced by Rawer (1988) and is able to reproduce the electron density height profile in the *E-F* and topside regions of the ionosphere, without discontinuities in the first and second derivatives. It uses simple analytical formulations and the critical frequencies of the *E-F* layers (f_0E, f_0F_1, f_0F_2) and $M(3000)F_2$ factor as input data, available by routine scaling ionograms (the so-called instantaneous condition) or by long-term ionospheric models as well (median condition). Total Electron Content (TEC) values can be also computed by DGR with an analytical expression derived from the Epstein layer formulation of the model up to the height of 1000 km.

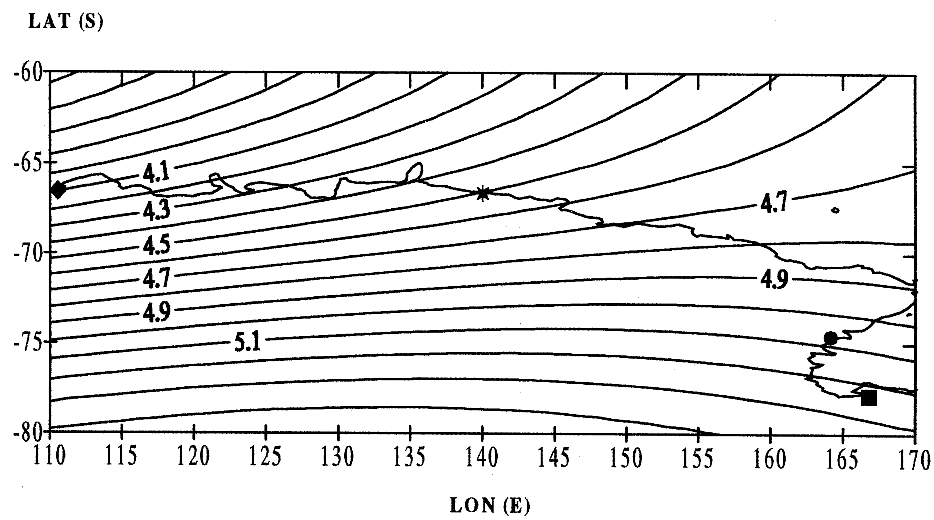

Fig. 1. Regional monthly median map of f_0F_2 obtained by SIRM for December 1993 ($R_{12} = 40$) at 00UT. The ionospheric stations used for calculating the SIRM coefficients are: ◆ Casey (66.3S, 110.5E), ⁕ Terre Adelie (66.7S, 140.0E), and ■ Scott Base (77.9S, 166.8E). f_0F_2 monthly medians from ● Terra Nova Bay (74.70S, 164.12E), not included in the database for the SIRM coefficients evaluation, are used for comparison with SIRM modelled values.

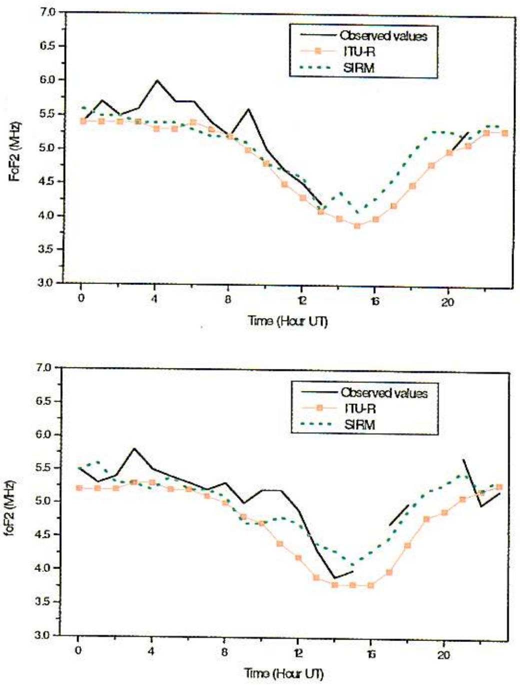

Fig. 2. Diurnal behaviour of f_0F_2 monthly medians as observed at Terra Nova Bay (solid line), modelled by ITU-R (■) and by SIRM (dotted line) for December 1993 (top) and January 1994 (bottom). Missing values in the observed monthly medians are due to the lack of hourly data for the spread *F* occurrence.

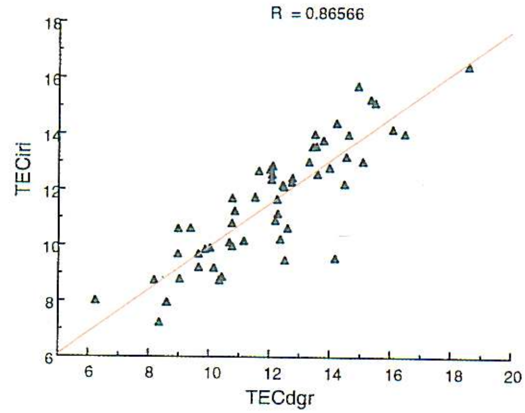

Fig. 3. TEC values by IRI90 *versus* TEC values by DGR (in TEC unit) obtained by applying these two models on the basis of routine scaled ionograms performed at Terra Nova Bay in the period 15-29 January 1994.

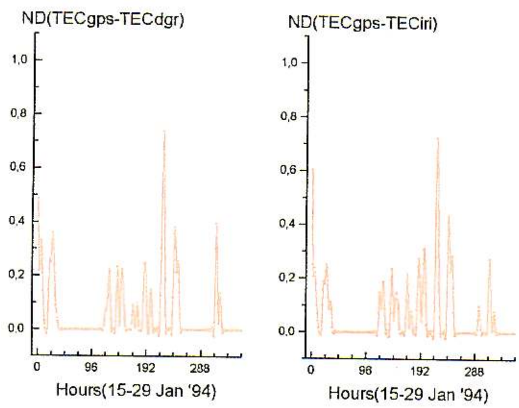

Fig. 4. Daily behaviours of the normalized difference ND in absolute value between TEC obtained by GPS measurements and TEC calculated by DGR (left) and IRI (right) in the period 15-29 January 1994.

DGR and the well known IRI90 (Bilitza, 1990) have been here applied under instantaneous condition on the base of hourly vertical ionospheric soundings performed at Terra Nova Bay in the period 15-29 January 1994. TEC modelled values by DGR, TECdgr, and IRI90, TECiri, were then compared with experimental TEC data obtained by GPS measurements, TECgps, at McMurdo (77.9S, 166.8E) station in the same epoch, available via computer network at IGS (International GPS Service). TEC(gps) values are based on the estimation of the vertical TEC every ten minutes from a set of observed slant TEC's in a solution providing the biases affecting the differential pseudoranges *P2-P1*, according to the method described by Ciraolo (1993). Figure 3 shows that values of TECdgr and TECiri are comparable meaning that both the models give similar results.

Figure 4 plots the behaviours *versus* time of the absolute values of the Normalised Difference, ND, between TECgps, TECdgr and

TECiri. It is interesting to note that well pronounced ND maxima are obtained for 24th and 15th January characterised by a negative B_y and a positive B_z component of the Interplanetary Magnetic Field (fig. 5).

Figure 6 gives an example of the comparison between modelled TECdgr, TECiri and experimental TECgps for which the correlation coefficients by a linear interpolation calculated over a set of 56 data points available are $R_{(DGR\ vs.\ GPS)} = 0.37$ and $R_{(IRI90\ vs.\ GPS)} = 0.43$, respectively. Then, the correlation analysis was carried out by grouping the 56 data on the basis of two time intervals (from 20.00 to 06.00 UT and from 07.00 to 14.00 UT) and the presence of the spread F phenomenon. The results are summarised in table I.

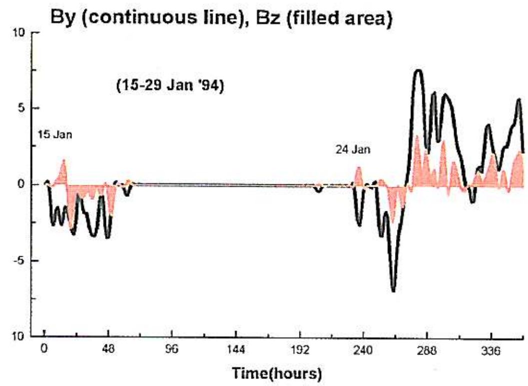

Fig. 5. Behaviours of the B_y and B_z components of the Interplanetary Magnetic Field *versus* time in the period 15-29 January 1994.

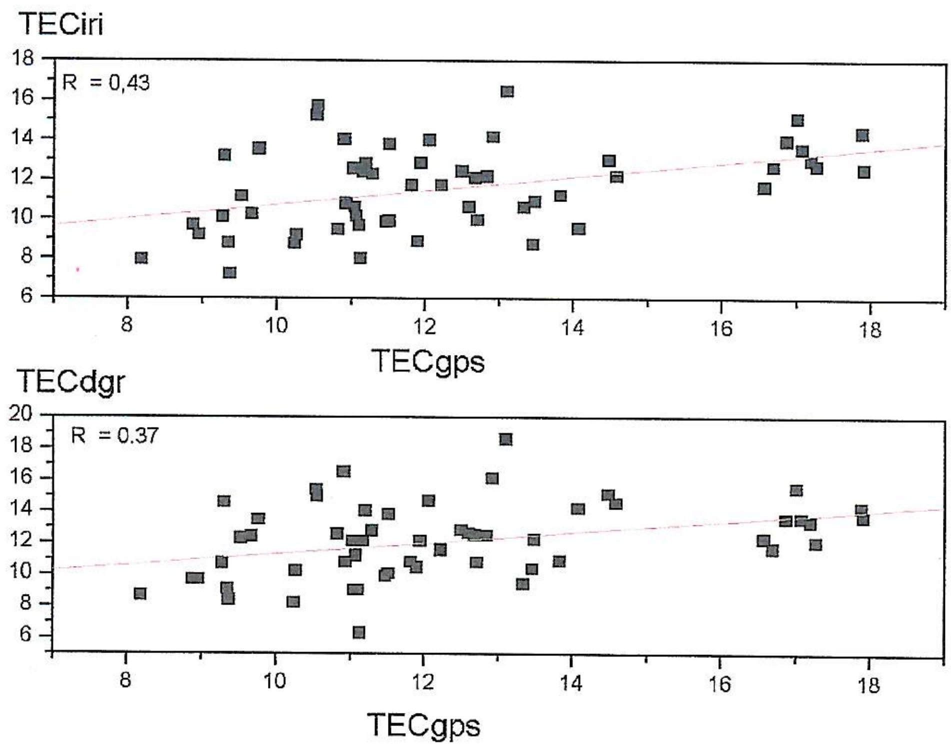

Fig. 6. TEC modelled by IRI90 (top) and by DGR (bottom) *versus* experimental TEC derived by GPS measurements performed at McMurdo station during the period 15-29 January 1994. Correlation coefficients R are also indicated. Values are in TEC units.

Table I. Results obtained by comparing the TECgps values at McMurdo (77.9S, 166.8E) and those calculated by the DGR and IRI models applied to the VI soundings at Terra Nova Bay (74.60S, 164.12E) for the period 15-29 January 94. The question mark means that the correlation analysis is applied to all data available in the time range as indicated with any selection by spread *F* occurence.

Comparison	Time of the day	Spread *F*	Corr. coeff. *R*	SD	No. points
TEC (GPS, DGR)	20.00-14.00 UT	?	0.37	2.24	56
TEC (GPS, IRI)	20.00-14.00 UT	?	0.43	1.94	56
TEC (GPS, DGR)	20.00-06.00 UT	?	0.27	2.35	40
TEC (GPS, IRI)	20.00-06.00 UT	?	0.3	1.93	40
TEC (GPS, DGR)	07.00-14.00 UT	?	***0.56	1.88	16
TEC (GPS, IRI)	07.00-14.00 UT	?	***0.64	1.77	16
TEC (GPS, DGR)	20.00-14.00 UT	No	0.27	1.99	34
TEC (GPS, IRI)	20.00-14.00 UT	No	0.44	1.58	34
TEC (GPS, DGR)	20.00-14.00 UT	Yes	0.49	2.53	22
TEC (GPS, IRI)	20.00-14.00 UT	Yes	0.45	2.38	22
TEC (GPS, DGR)	20.00-06.00 UT	No	**0.29	2.13	24
TEC (GPS, IRI)	20.00-06.00 UT	No	**0.45	1.6	24
TEC (GPS, DGR)	20.00-06.00 UT	Yes	**0.27	2.62	16
TEC (GPS, IRI)	20.00-06.00 UT	Yes	**0.13	2.27	16
TEC (GPS, DGR)	07.00-14.00 UT	No	0.18	1.81	10
TEC (GPS, IRI)	07.00-14.00 UT	No	0.33	1.55	10
TEC (GPS, DGR)	07.00-14.00 UT	Yes	*0.84	1.78	6
TEC (GPS, IRI)	07.00-14.00 UT	Yes	*0.85	1.88	6

3. Concluding remarks

The study of regional ionospheric techniques, either for instantaneous or median mapping and modelling purposes, emerges from the necessity to improve their performance when applied in situations of great spatial/temporal variability as in the case of the polar ionosphere. A preliminary testing analysis was carried out over Antarctica where the results obtained by applying an improved version of SIRM (Zolesi *et al.* 1993, 1996) and DGR (Radicella and Zhang, 1995) models, developed for mid-latitudes in the frame of COST238 Project (PRIME, 1995), were compared with those obtained from global models (ITU-R, IRI90) and with experimental data. It has been shown that regional and global long-term mapping accuracy is comparable but not yet completely satisfactory unlike the case of mid-latitude regions, where a dense network of ionospheric stations with more than one solar cycle data series allow regional modelling to give better results than the global one (PRIME, 1995; Wang *et al.*, 1997; Zolesi *et al.*, 1997). On the other hand, it is not completely obvious that a regional technique should *always* give better results than the global methods. In fact, an incorrect application of the database or simply the use of non validated measurements of a poor network of ionospheric stations may emphasise virtual local variations, very far from the real behaviour. This is the case presented here of modelling the Antarctic ionosphere with SIRM on the basis of just three stations with a short interrupted history of data. So, major efforts should first be addressed to collecting and validating experimental data covering different seasons, time of day and heliogeophysical conditions.

Some interesting evidence, that needs a larger amount of statistic results, has been obtained by comparing the experimental TEC data and those calculated by DGR and IRI models. In particular, in this case study, the maximum difference between the modelled and experimental TEC values is found for B_y and B_z in opposite phase, meaning a direct dependence on IMF that needs deeper investigations. In general, on the basis of the 56 different cases available, a better correlation between experimental and modelled TEC values has been found in the time range 07.00-14.00 UT without any consideration of spread F occurrence (table I).

Acknowledgements

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