Ionogram inversion *F*1-layer treatment effect in raytracing

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Abstract

This paper shows the importance of the *F*1-layer shape in the electron density profiles obtained from ionograms with different inversion techniques when the profiles are used in ray tracing. This layer often controls the propagation on the path with ranges less than about 2000 km, particularly for spring and summer periods. Ionograms from two different stations, Hainan (19.4N, 109E) and El Arenosillo (37.1N, –6.7E), obtained during the month of July 2002 (average sunspot number: 99.6) during geomagnetic quiet conditions (*Ap*-index between 9 and 15) are analyzed. The profiles obtained with two different inversion techniques with different options are used together with the ray tracing program of the Proplab-Pro software. This program calculates the features of the received signal as angle of arrival, path length, height of reflection and range for each given profile assumed to define a spherically symmetric ionosphere in the region along the path. For each ionospheric condition (location, day, hour) the difference between range values obtained with Proplab-Pro program using profiles from the two techniques and the different options (*POLAN no valley*, *POLAN valley*, *POLAN*1*-layer* and *NHPC*) are considered.

Key words *raytracing* – F*1 region* – *electron density profile*

1. Introduction

The aim of this paper is to show how different ionogram inversion techniques, *POLAN* (Titheridge, 1985, 1988, 1990) and *NHPC* (Huang and Reinisch, 1996), can affect ray tracing results used to characterize a radio propagation link in particular with the propagation parameters: range, group path and height of reflection (apogee).

It is shown in different studies (Sprague, 1994) that the *F*1-layer often controls the propagation path for ranges less than about 2000 km, particularly for spring and summer periods.

In order to analyze the problem of *F*1-layer effect on propagation a ray tracing program of Proplab-Pro software has been used to calculate how the signals are propagated through the ionosphere in the presence of the *F*1-layer looking at features of the received signal, such as its angle of arrival, path length, height of reflection and range.

The results of improving the propagation model by means of ray tracing techniques could be applied in several communications problems including those related to Over-The-Horizon (OTH) radar operation.

2. Methodology

The software used to calculate the behavior of the radio signals (3-30 MHz) as they travel through the ionosphere is known as Proplab-

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Pro (Solar Terrestrial Dispatch, Canada). This program (http://www.spacew.com/Docs/propman.pdf) simulates the path between transmitter and receiver taking into account a realistic ionosphere by using ray tracing techniques.

For the computation of the signals, the ray tracing technique called *comprehensive* is chosen as a Proplab-Pro's option. It includes the effects of the Earth's magnetic field and electron collisions with neutral particles by using the Appleton-Hartree formulation (Ratcliffe, 1959). Although Proplab-Pro program can use the International Reference Ionosphere (IRI) to model profiles of the ionosphere, this paper shows the possibility to consider electron density profiles inverted from ionograms. These ionograms are measured by digisondes designed by the University of Massachusetts Lowell and located at Hainan (19.4N, 109E) and El Arenosillo (37.1N, –6.7E). To avoid possible problems derived from automatic scaling of the ionograms all the characteristics are edited using the software Sao-Explorer. Proplab-Pro considers these electron density profiles (which can be interpreted as refractive index profile for a ray tracing technique) as the state of the ionosphere at the mid-path but extended as spherically stratified over the geographical region seen by the projected ray over the earth surface.

In each case, a link is defined by means of the transmitter and receiver coordinates (table I).

The short distance between transmitter and receiver in both links allows us to consider one single hop condition.

Data used correspond to July 2002 with a sunspot number of 99.6. Four geomagnetically quiet days are chosen with A*p*-index between 9 and 15.

The ray paths under each ionospheric condition (location, day, hour) given by the electron density profiles obtained with the different inversion procedures are traced sweeping elevation angles (15-85 with a step of 5) and operation frequencies (3-14 MHz with a step of 1MHz). Proplab-Pro calculates for each propagating mode parameters as the ground range, the latitude/longitude of the ray, geometrical path distance (that is, the total distance travelled by the ray), group path, etc.

Table I. Transmitter and receiver geographic coordinates.

	Transmitter	Receiver
Hainan link	(19.4N, 109E)	(19.4N, 106E)
El Arenosillo link	(40.2N, 3.29E)	(37.1N, –6.7E)

One of the most common techniques of ionogram inversion is the Polynomial Analysis or *POLAN*, developed by Titheridge (1985, 1988, 1990). This technique solves the inversion problem by breaking up the profile into simpler sections for which physically expectable solutions can be found and using extrapolation and interpolation for the remaining part of the profile.

On the other hand, modern digisondes use *NHPC* algorithm developed by Huang and Reinisch (1996) to define a profile from the base of the *E*-layer to *hmF*2 implemented automatically into the digisonde operation.

In order to define the different electron density profiles used in the ray tracing procedure these two techniques have been used including different options for *POLAN* (*POLAN no valley*, *POLAN valley*, *POLAN*1*-layer*).

*POLAN*1 *layer* considers the whole profile as a «single layer» by not inputting explicitly the critical frequency of *F*1-layer when giving the input (*f*, *hv*) array. This means treating *F* region as having only a *F*1 cusp without specifying *foF*1. Whereas *POLAN no valley* and *POLAN valley* consider the F region as consisting of two layers (*F*1+*F*2) by inputting explicitly the critical frequency *foF*1 when giving the input (*f*, *hv*) array. However, in order to re-create the true-height-profile with valley, the ionisation in this region must be estimated as the information on the ionisation between the layers cannot be measured by an ionosonde. The electron concentration there is less than the critical frequency of the lower layer, and any wave which has a frequency sufficient to penetrate the first layer will not be reflected back by these lower density electrons. A possible estimation for the true-height of the upper layer can be made by assuming that the ionisation between the layers is the same as the peak density of the lower layer, so that there is no valley but a simple cusp to merge the $F1$- and $F2$-layers. *POLAN no valley* is based on this estimation. On the other hand, *POLAN* can take into account the variation in height and depth of the valley with time of day, date and latitude. This is done automatically in *POLAN valley* option (see Titheridge 1985, 1988, 1990).

In this context, previous studies have shown the difficulties introduced by the ionogram inversion techniques in the presence of $F1$-layer. Bamford (2000) shows the differences found by comparing experimental oblique ionograms with the one reconstructed with ray tracing and electron density profile inverted from vertical ionogram.

3. Results

For each ionospheric condition (location, day, hour) the difference between range values obtained with Proplab-Pro program using profiles from the two techniques and the different options are calculated. These radio propagation values are filtered in order to obtain radio frequencies and elevation angle in such a way that reflection heights are located in the $F1$ region and the lower part of $F2$-layer (150-250 km).

It is seen that there are important differences between results obtained with the two techniques and the different options, reflecting the fact that the $F1$ mode trace depends strongly on the electron density height profile between the E- and $F1$-layers (Krasheninnikov *et al.*, 1996).

The option *POLAN1-layer* is chosen as the reference for these differences taking into account that this option is the only one that gives an electron density profile that is always continuous in the values and in the first derivative dN/dh. This point has been verified in some cases where dN/dh presented discontinuities and the results produced by the ray tracing technique Proplab-Pro showed problems for frequencies and angle values with height of reflection close to this region.

Maximum values of these differences in range are shown in tables II and III for El Arenosillo and Hainan link respectively. In general, the results show that the differences are lower in the case of the no valley *POLAN* op-

Table II. Maximum range differences for El Arenosillo link. Modes (NH=*NHPC*, 1L=*POLAN1-layer*, NV=*POLAN no valley*, V=*POLAN valley*). Manually scaled ionograms are indicated with the word ‘edited’. APOG1 and APOG2 are the apogee heights obtained with first and second option in column Modes and RANG1 and RANG2 their ranges.

Day	Hour	Modes	Edited	Freq (MHz)	Angle	APOG1	RANG1	APOG2	RANG2	Difference range
182	11:00	NH-1L	Edited	14	15	150	1402	199	2396	−994
182	11:00	NV-1L	Edited	9	30	185	1176	186	1202	−26
182	11:00	V-1L	Edited	14	15	202	2320	199	2396	−76
182	14:00	NH-1L	Edited	11	25	117	1253	189	1443	−190
182	14:00	NV-1L	Edited	11	25	201	2295	189	1443	852
182	14:00	V-1L	Edited	13	20	227	2383	202	1950	433
183	11:00	NH-1L	Edited	11	25	162	1156	201	1382	−226
183	11:00	NV-1L	Edited	14	15	174	1941	175	2004	−63
183	11:00	V-1L	Edited	6	60	216	588	192	409	179
183	15:00	NH-1L	Edited	8	40	183	1026	184	753	273
183	15:00	NV-1L	Edited	11	25	189	1414	182	1308	106
183	15:00	V-1L	Edited	11	25	204	1760	182	1308	452

Table III. Maximum range differences for Hainan link. Modes (NH=*NHPC*, 1L=*POLAN*1-*layer*, NV=*POLAN no valley*, V=*POLAN valley*). Manually scaled ionograms are indicated with the word 'edited'. APOG1 and APOG2 are the apogee heights obtained with first and second option in column Modes and RANG1 and RANG2 their ranges.

Day	Hour	Modes	Edited	Freq (MHz)	Angle	APOG1	RANG1	APOG2	RANG2	Difference range
197	04:15	NH-1L	Edited	14	15	215	3115	237	2288	827
197	04:15	NV-1L	Edited	12	15	170	2227	175	2518	−291
197	04:15	V-1L	Edited	12	15	170	2227	175	2518	−291
197	05:15	NH-1L	Edited	12	20	202	3158	168	2061	1097
197	05:15	NV-1L	Edited	12	20	164	1954	168	2061	−107
197	05:15	V-1L	Edited	6	60	200	584	177	430	154
200	04:30	NH-1L	Edited	11	25	208	1767	199	1522	245
200	04:30	NV-1L	Edited	11	25	208	1839	199	1522	317
200	04:30	V-1L	Edited	11	25	232	2199	199	1522	677
200	05:30	NH-1L	Edited	8	40	224	1147	203	982	165
200	05:30	NV-1L	Edited	11	25	209	1697	207	1766	−69
200	05:30	V-1L	Edited	8	40	243	1143	203	982	161

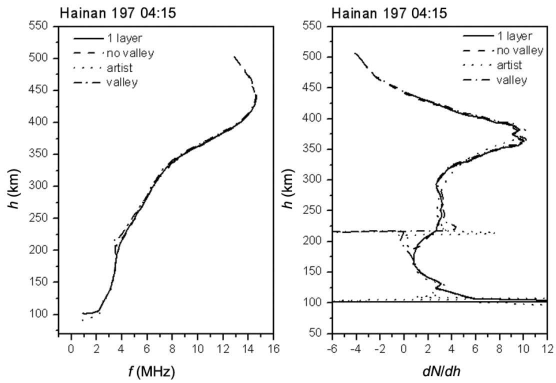

Fig. 1. Electron density profiles and first derivatives *dN*/*dh* with different inversion techniques for day 197 and hour 04:15 UT corresponding to Hainan link.

tion and can reach large values with the *NHPC* technique.

Figures 1-4 show as examples the comparison between electron density profiles and the first derivatives obtained by different inversion techniques and the worst cases for the range values differences during different ionospheric conditions.

These plots show that cases where electron density profiles are the same in comparison to those obtained with the reference option *POLAN*1-*layer* but not their corresponding first

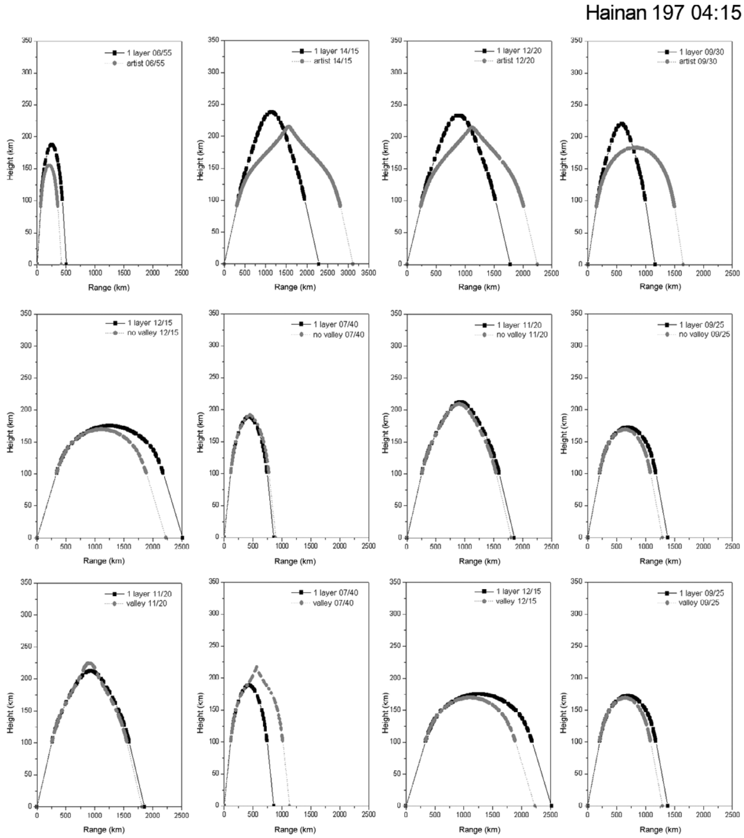

Fig. 2. Worst cases for the range values differences during the ionospheric conditions described by fig. 1.

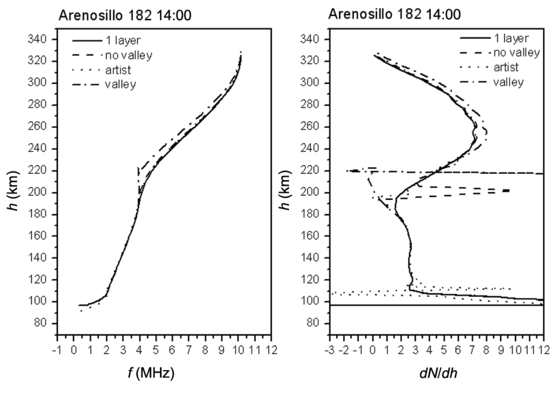

Fig. 3. Electron density profiles and first derivatives *dN*/*dh* with different inversion techniques for day 182 and hour 14 UT corresponding to El Arenosillo link.

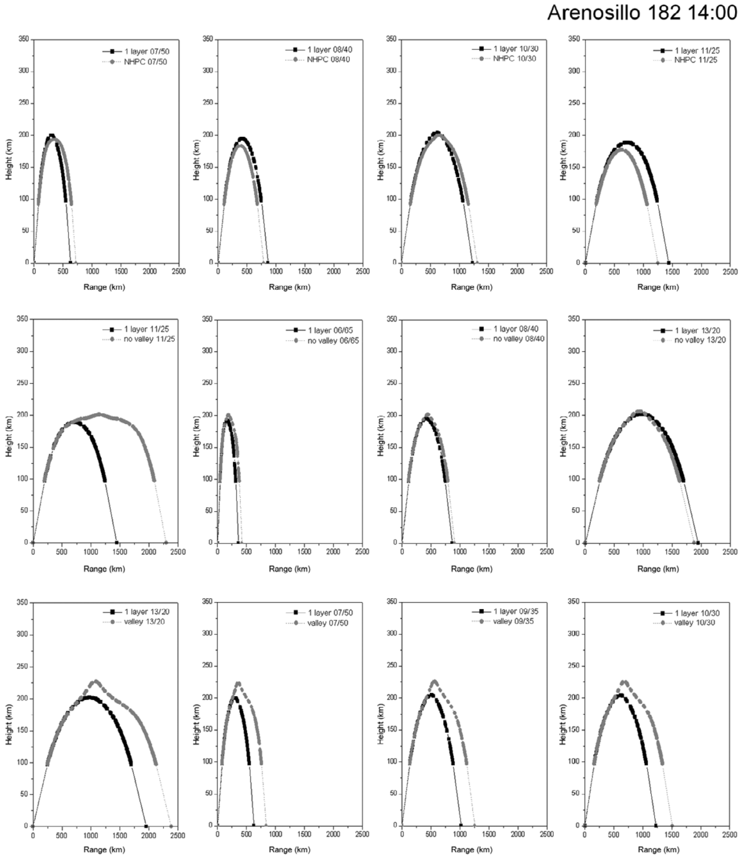

Fig. 4. Worst cases for the range values differences during the ionospheric conditions described by fig. 3.

derivatives, can produce very different propagation results. This is the case of results corresponding to day 197 and hour 04:15 UT at Hainan with *NHPC* technique where the range difference reaches 827 km (figs. 1, 2 and table III). On the other hand, table III shows for the same period a maximum range difference of 291 with *no valley* and *valley* options. However, figure 1 shows that the corresponding profiles and *dN*/*dh* look similar up to the apogee region (170-175 km).

Another result is that no relationship is found between plasma frequency changes and range reached as seen in figs. 3 and 4. There is no defined trend between these differences and frequency and angle values. Frequencies and angles of arrival obtained cover from 6 to 14 MHz and from 15 to 70 degrees respectively.

It is interesting to note that the same results are found for the two links considered that are at very different geographical longitude.

4. Conclusions

The main results obtained in this paper can be summarized as follows:

– For operation conditions the height of reflection and range obtained with ray tracing depends on the inversion technique chosen mainly with a reflection height in the *F*1 region.

– The differences in range reach largest values using the *NHPC* and *valley* options.

These differences were also found in cases where electron density profiles look similar.

– In general, the lowest range differences were found for *no valley* option because this option gives a profile very similar to the reference one. However, there are cases with similar profiles and first derivatives that show differences in range of about 300 km.

– No dependence was found between differences in range and frequency, angle or geographical longitude.

Further studies will be done to check these results during different ionospheric conditions.

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