SOCIETÀ ITALIANA DI FISICA
101° CONGRESSO NAZIONALE
ROMA, 21-25 SETTEMBRE, 2015

SEZIONE 4: Geofisica, fisica dell'ambiente

16/09/2015

CORRECTION'S METHOD OF THE ELECTRON DENSITY MODEL IN IONOSPHERE BY RAY TRACING TECHNIQUES

***Alessandro Settimi*(1)*, *Michael Pezzopane*(1), *Marco Pietrella*(1),**
***Carlo Scotto*(1), *Silvio Bianchi*(2), *James A. Baskaradas*(3)**

(1)Istituto Nazionale di Geofisica e Vulcanologia (INGV),
Sezione di Geomagnetismo, Aeronomia e Geofisica Ambientale (ROMA 2),
Via di Vigna Murata 605, I-00143 Rome, Italy

(2)Università Sapienza, Dipartimento di Fisica, p.le Aldo Moro 2, I-00185 Rome, Italy

(3)School of Electrical & Electronics Engineering,
Shanmugha Arts, Science, Technology & Research Academy (SASTRA) University,
Tirumalaisamudram, Thanjavur, 613 401 Tamilnadu, India

*****Corresponding author: email, alessandro.settimi@ingv.it; phone, +390651860719; fax, +390651860397

ATTICON 8909

This abstract focuses on the lead role
that is played by the variation of the electron density grid into the ray tracing algorithm,
which is correlated to the change of the electron content along the ionospheric ray path,
for obtaining a ray tracing as much reliable as possible.

In many cases of practical interest,
the group delay time depends on the geometric length and the electron content of the ray path.

The issue is faced theoretically, and a simple analytical relation, between
the variation of the electron content along the path and
the difference in time between the group delays,
calculated and measured, both in the ionosphere and in the vacuum,
is obtained and discussed.

An example of how an oblique radio link can be improved
by varying the electron density grid
is also shown and discussed.

Keywords: *ionospheric ray tracing*; *electron density model*; *ray path correction; electron content*.

INDEX

1. Introduction

The group delay time t_c,
calculated step by step along the ionospheric ray path,
is particularly interesting for this talk.
The reason is that the calculated group delay time t_c is easily comparable
with the effective measured group delay time t_m in some technological applications,
such as the Over The Horizon Radar (OTHR), oblique synchronized sounding
or ionospheric backscatter (Davies, 1990).

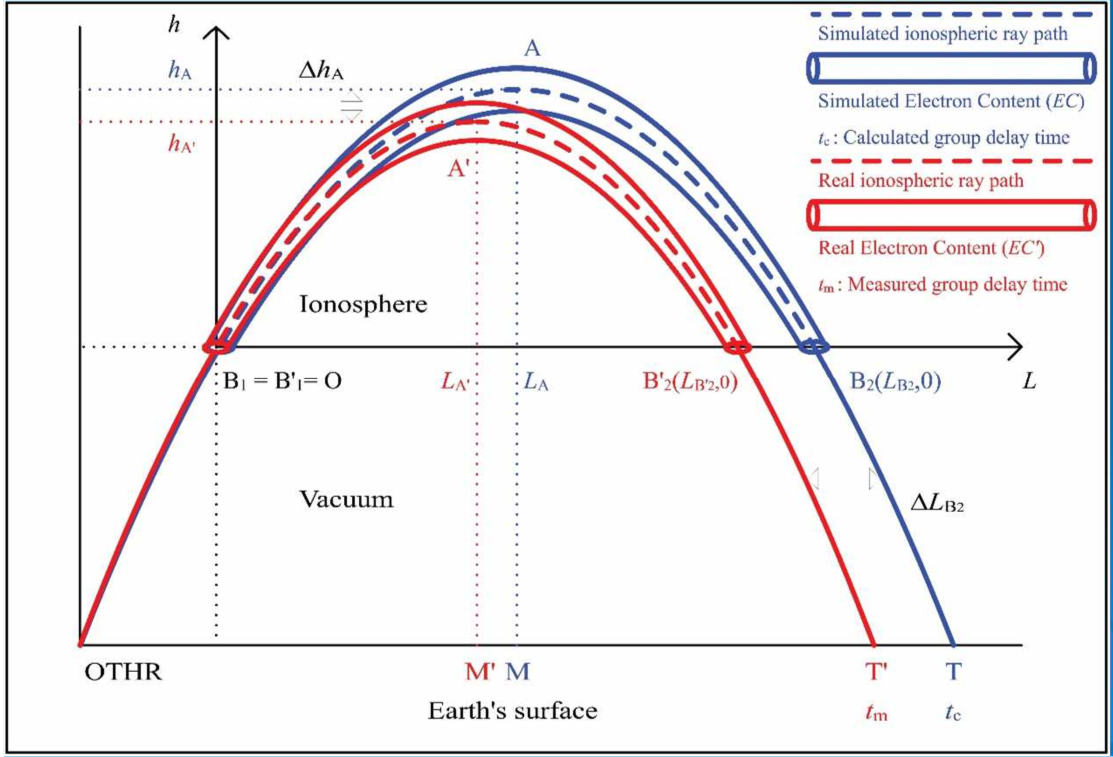


Figure 1 –
A little change of Electron Content (EC)
can imply great refractive effects:
large variations for
both the Apogee (A) location
and the path length
of ionospheric ray tracing.
The two ionospheric ray paths experience
two different group delay times t_c and t_m,
respectively the calculated
and the measured group delay times.

2. Ray path and ionospheric models

Ray tracing is a deterministic process
of which the ionospheric ray path accuracy is arbitrarily chosen
through the computational algorithm step (Haselgrove, 1955).

$$Z = 0 \quad \Rightarrow \quad n^2 = 1 - \frac{X}{1 - \frac{1}{2}\frac{Y_T^2}{(1-X)} \pm \sqrt{\frac{Y_T^4}{4(1-X)^2} + Y_L^2}}$$

$$Y_L = Y_T = 0 \quad \Rightarrow \quad n^2 = 1 - X = 1 - \frac{\omega_p^2}{\omega^2}$$

3. Group delay time calculation

For those radio waves propagating scarcely into the ionosphere,
which is penetrated in corrispondence to an oblique incidence, i.e. with low elevation angles,
an approximate refractive index can hold throughout the HF band, i.e. 3-30 MHz.

$$t_{\mathrm{c}} = \int_{\mathrm{OTHR}}^{\mathrm{T}} \frac{\mathrm{d}l}{\mathrm{v_g}(l)} = \frac{1}{c}\int_{\mathrm{OTHR}}^{\mathrm{T}} n_{\mathrm{g}}(l)\,\mathrm{d}l =$$

$$= \frac{1}{c}\int_{\mathrm{OTHR}}^{\mathrm{T}} \frac{\mathrm{d}l}{n(l)} = \frac{1}{c}\int_{\mathrm{OTHR}}^{\mathrm{T}} \frac{\mathrm{d}l}{\sqrt{1-\frac{\omega_{\mathrm{p}}^2(l)}{\omega^2}}} \cong$$

$$\cong \frac{1}{c}\int_{\mathrm{OTHR}}^{\mathrm{T}} \left[1+\frac{\omega_{\mathrm{p}}^2(l)}{2\omega^2}\right]\mathrm{d}l = \frac{l_0}{c} + \frac{e^2}{2cm\varepsilon_0}\frac{1}{\omega^2}\int_{\mathrm{OTHR}}^{\mathrm{T}} N(l)\,\mathrm{d}l$$

$$t_{\mathrm{c}} \cong t_{\mathrm{c0}} + \frac{k}{f^2}EC$$

$$t_{\mathrm{m}} \cong t_{\mathrm{m0}} + \frac{k}{f^2}EC'$$

$$\Delta t = t_{\mathrm{c}} - t_{\mathrm{m}} \cong$$

$$\cong \Delta t_0 + \frac{k}{f^2}\Delta EC =$$

$$= t_{\mathrm{c0}} - t_{\mathrm{m0}} + \frac{k}{f^2}\left(EC - EC'\right)$$

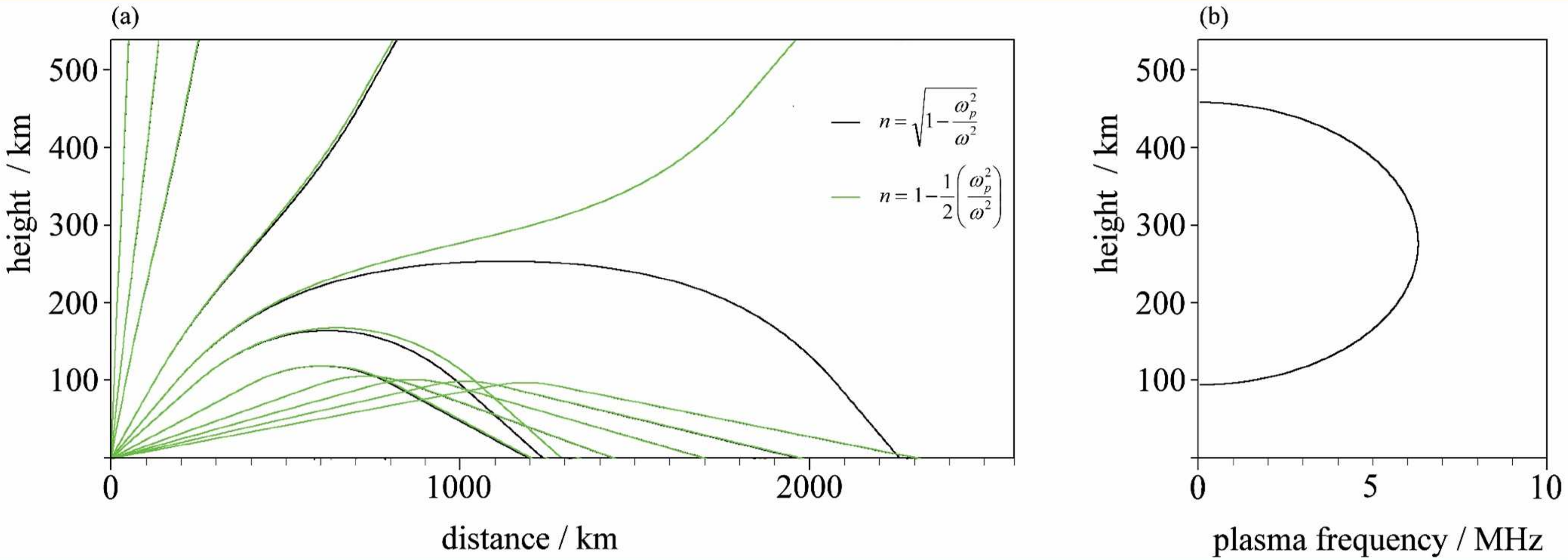


Figure 2 –

a) *The ionospheric ray paths associated with a high frequency (HF) signal emitted from a transmitter (OTHR) at different elevation angles for a radio wave of frequency* f=13.4 MHz. *The ray paths are computed with the exact and first-order Taylor's series expansion of the phase refractive index* n.

b) *The corresponding plasma frequency profile* $f_p(h)$ *of parabolic shape*, *with maximum* $f_p^{(max)}$= 6.784 MHz *at a height of* 277 km, *assuming* $f_p(h)$=0 MHz *under* 95 km *and above* 459 km.

4. Correction of the electron density model

Such a condition is quite common
when the frequency f is below the plasma frequency f_{p}
and the radio wave is reflected beneath the electron density maximum (Davies, 1990):

$$\Delta EC \to 0 \Rightarrow \Delta t \approx \Delta t_0$$

Assuming that both the simulated and real ray paths can be modelled by parabolic curves:

$$\Delta L_{\mathrm{B}_2} << L_{\mathrm{B}_2} \qquad \Delta h_{\mathrm{A}} << h_{\mathrm{A}} \qquad \Delta L_{\mathrm{B}_2} \cdot \Delta h_{\mathrm{A}} \to 0$$

$$c\Delta t_0 \cong \frac{1}{8h_{\mathrm{A}}^2}\left\{ 4L_{\mathrm{B}_2} h_{\mathrm{A}} \sqrt{1+16\left(\frac{h_{\mathrm{A}}}{L_{\mathrm{B}_2}}\right)^2}\,\Delta h_{\mathrm{A}} + \right.$$
$$\left. + L_{\mathrm{B}_2}\left(2h_{\mathrm{A}}\Delta L_{\mathrm{B}_2} - L_{\mathrm{B}_2}\Delta h_{\mathrm{A}}\right)\ln\left[4\frac{h_{\mathrm{A}}}{L_{\mathrm{B}_2}} + \sqrt{1+16\left(\frac{h_{\mathrm{A}}}{L_{\mathrm{B}_2}}\right)^2}\right]\right\}$$

$$\Delta EC \simeq \frac{f^2}{k}\left(\Delta t - \Delta t_0\right)$$

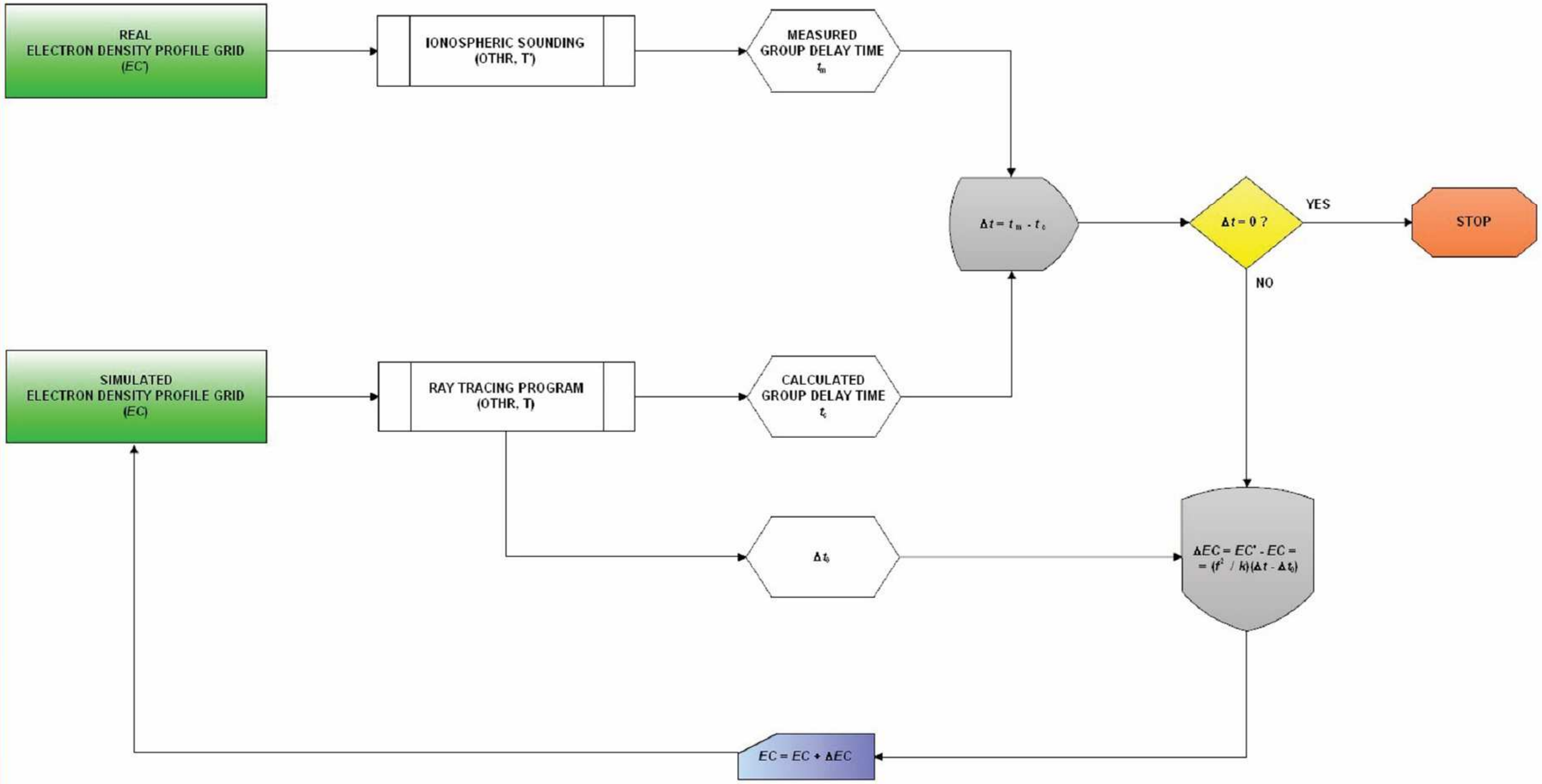


Figure 3 –

Logic flowchart of an algorithm for

the correction’s method of the electron density model in ionosphere by ray tracing techniques.

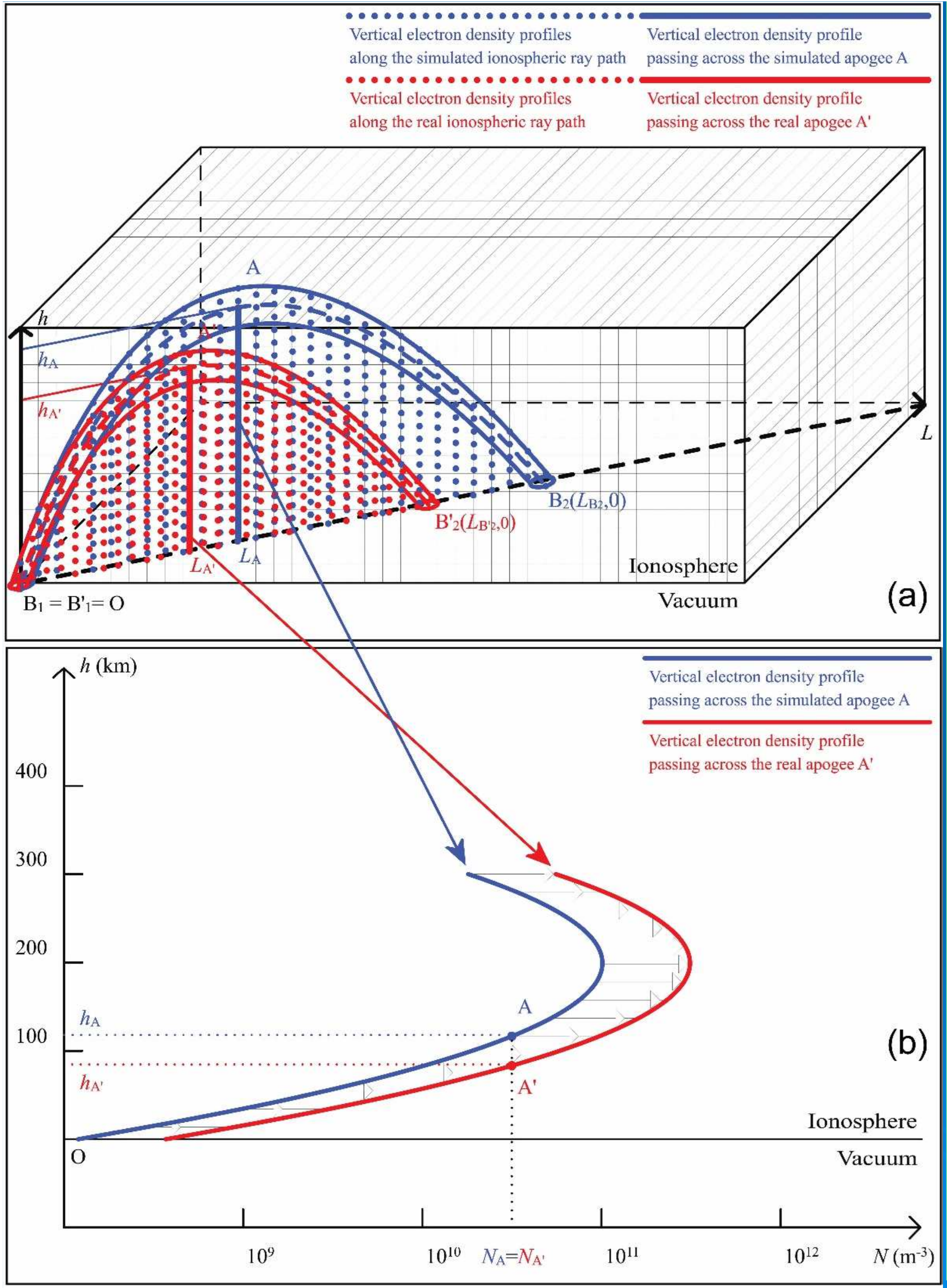


Figure 4 –

a) *Vertical electron density profiles along the ionospheric ray path that have to be corrected compensating the time difference between the calculated and measured group delays in ionosphere.*

b) *The two vertical electron density profiles, plotted as a function of height, refer to the plumb lines passing across the simulated (A) or real (A´) apogees. The two vertical profiles correspond to the simulated (N) or real (N´) electron densities over the simulated (M) or real (M´) midpoints between the transmitter (OTHR) and the simulated (T target) or real (T´ target) receiver of* **Fig. 1**.

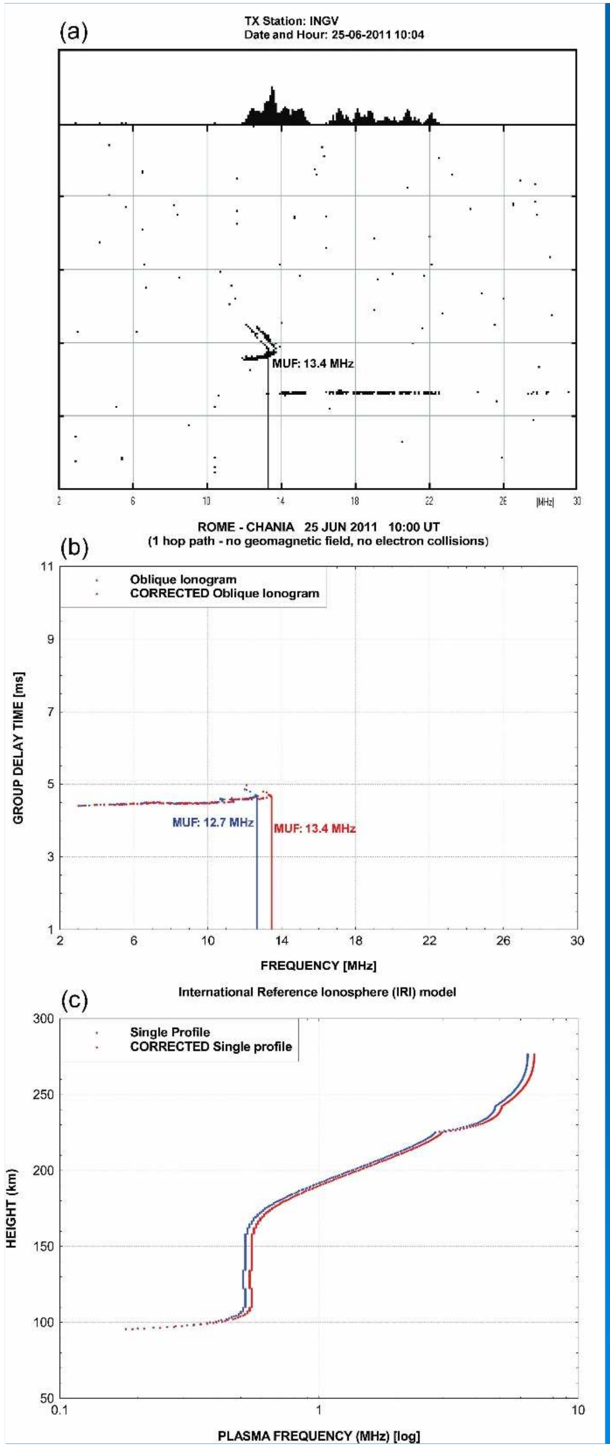


Figure 5 –

a) *Oblique ionogram recorded*
on the 25 *June* 2011 *at* 10.00 UT
along the Rome-Chania radio link, for which
the maximum usable frequency MUF=13.4 MHz *value is highlighted*.

b) *Oblique ionogram synthesized by the IONORT-IRI system*
showing two ordinary traces
corresponding to a plasma frequency profile $f_p(h)$ (*trace in blue colour*),
with a MUF=12.7 MHz (*signed in blue colour*),
and to a corrected plasma frequency profile $f_p(h)+0.06 \cdot f_p(h)$ (*trace in red*),
with a MUF=13.4 MHz (*signed in red*).

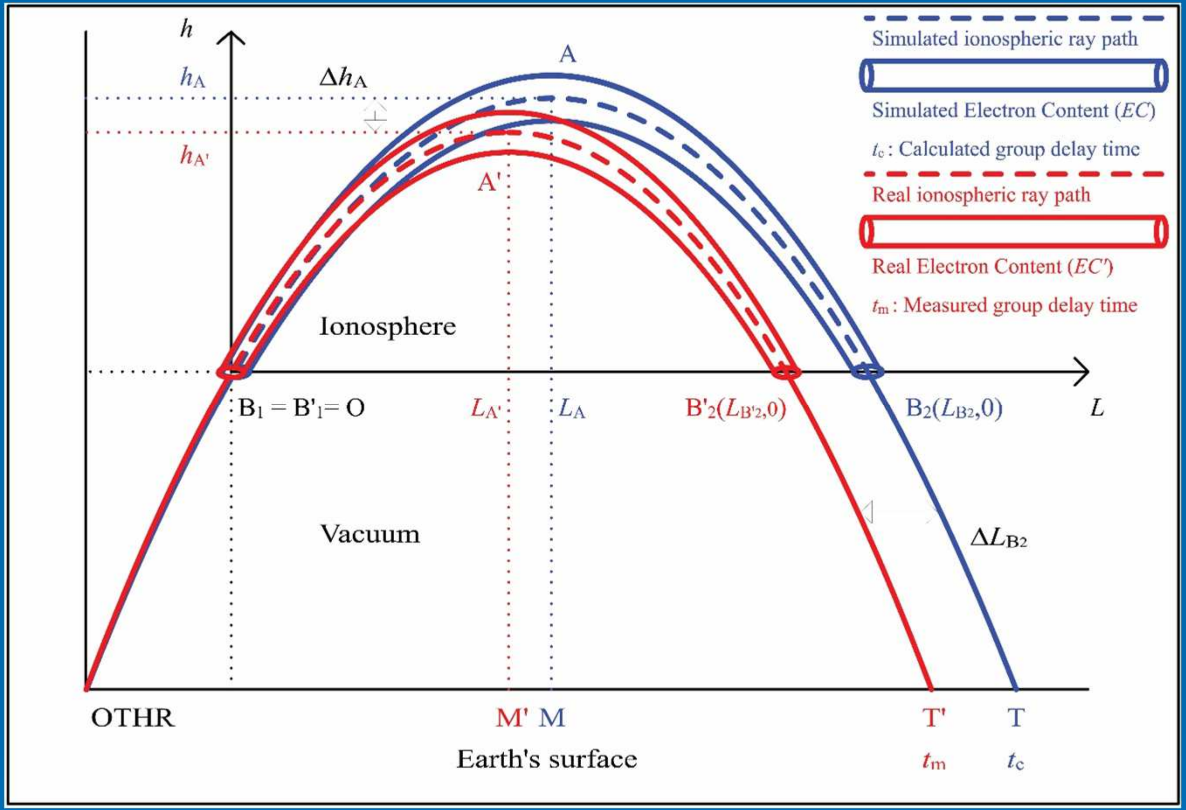
c) *The plasma frequency profile* $f_p(h)$ (*in blue*)
and the corrected plasma frequency profile $f_p(h)+0.06 \cdot f_p(h)$ (*in red*)
used by IONORT to synthesize the traces shown in **b)**.

5. Conclusions

Being a RT program a deterministic computational procedure
whose accuracy depends on the integration step,
the only source of error is mainly referable to the electron density model
representing the input parameter.

This talk demonstrated theoretically that,
after the only possible measurement,
which is the measured group delay time t_m,
the correction can be performed:
indeed, this quantity, compared with the calculated group delay time t_c,
allows to calculate the time difference Δt between the group delays in ionosphere.

6. Appendix



$$\Delta L_{B_2} << L_{B_2}$$

$$\Delta h_A << h_A$$

$$\Delta L_{B_2} \cdot \Delta h_A \to 0$$

$$\Delta\Gamma = 0$$

$$\Delta L_{B_2} \simeq \Delta h_A \left\{ \frac{1}{2}\frac{L_{B_2}}{h_A} - 2\frac{\sqrt{1+16\left(\frac{h_A}{L_{B_2}}\right)^2}}{\ln\left[4\frac{h_A}{L_{B_2}} + \sqrt{1+16\left(\frac{h_A}{L_{B_2}}\right)^2}\right]} \right\}$$

REFERENCE

Settimi, A., Pezzopane, M., Pietrella, M., Bianchi, S., Scotto, C., Baskaradas, J. A.,
"*Correction's method of the electron density model in ionosphere by ray tracing techniques*",
Adv. Space. Res., **55** (6), 1630-1639 (2015),
DOI: 10.1016/j.asr.2014.12.035
[IMPACT FACTOR 1.238]