Testing the IONORT-ISP system: a comparison between synthesized and measured oblique ionograms

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The idea of obtaining artificial oblique ionograms is not new.  
**Kopka and Möller [1968]:**  
A ray-tracing program including the effects of the Earth’s magnetic field.  
**Gething [1969]:**  
The ionosphere was supposed to be composed of stratified concentric spheres with equal electron density.  
**Chen et al. [1992]:**  
Assumption of spherical stratification, no ionospheric tilts.

In principle, IONORT uses a method that does not adopt any of these simplifying hypotheses and it is in line with the state of art results obtained by other groups [e.g. Bamford, 2000].


IONORT ray tracing algorithm has been used, in conjunction with the 3-D ionospheric electron density grids generated by the ISP model, to synthesize oblique ionograms over the radio link between Rome (41.8°N, 12.5°E), Italy, and Chania (35.7°N, 24.0°E), Greece. The reference ionospheric stations considered as input for the ISP model were those of Rome, Gibilmanna (37.8°N, 14.0°E), Italy, and Athens (38.0°N, 23.5°E), Greece.
IONORT (IONOspheric Ray-Tracing) [Azzarone et al., 2012] is a software application for calculating a 3-D ray-tracing of high frequency waves in the ionospheric medium, using an integration algorithm derived from the one coded by Jones and Stephenson [1975].

As regards the numerical 3-D representation of the ionosphere, the present study considered electron density grids computed both by the IRI (International Reference Ionosphere) and by the ISP (IRI-SIRMUP-P) models. In this work, IONORT was used, in conjunction with these two different 3-D electron density grids, to synthesize oblique ionograms that were compared with measured oblique ionograms.

The transmitting system is based on a VOS-1 chirp ionosonde produced by the Barry Research Corporation, Palo Alto, California, USA [1975] sweeping from 2 to 30 MHz at 100 kHz/s with an average power of less than 10 W. The receiver is a RCS-5B chirp produced by the Barry Research Corporation [1989].
At present, the IONORT program is not optimized with an automatic homing-in feature. However, IONORT allows users to specify ranges of frequency $[F_{\text{START}}, F_{\text{END}}]$ (in MHz), elevation $[E_{\text{START}}, E_{\text{END}}]$ and azimuth $[A_{\text{START}}, A_{\text{END}}]$ angles of transmission (in degrees), including those rays that are thought to arrive at the receiver. For each sounding frequency, the algorithm goes over a candidate pool of ray elevation and azimuth angles to exit when the ray’s landing point is close to the receiver location.
Results and discussion.
If IONORT were optimized with a *homing-in feature*, then a suitable adaptive procedure would return *the ionogram trace as a continuous line*.

Hence, although IONORT is not optimized with a homing-in feature, *even one azimuth cycle may produce an ionogram as an almost continuous line*. 
It is worth noting that, for these examples, even though the ionosphere is not characterized by large horizontal gradients, the loop cycle in azimuth angle was applied. Moreover, the elevation angle step was set to 0.2° and the RX accuracy was set to 0.1%, and the corresponding synthesized oblique ionograms do not present any discontinuous piecewise trace and/or significant frequency gaps.
The IONORT-ISP system is more accurate than the IONORT-IRI system.
Conclusions

The results presented in this talk suggest that:

• the assimilation by IRI of data measured at multiple ionospheric reference stations is very important to obtain as reliable an image of the ionosphere as possible;
• the combination IONORT – ISP, and more generally IONORT, can be proposed as a valid tool for operational use.

Future developments

• More oblique sounding measurements need to be conducted

It is planned the inclusion of:
• an horizontal gradients procedure;
• a collision frequency model;
• additional ionospheric reference stations in the region of interest, especially located around the mid point of the path considered.