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

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INTRODUCTION

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].

References

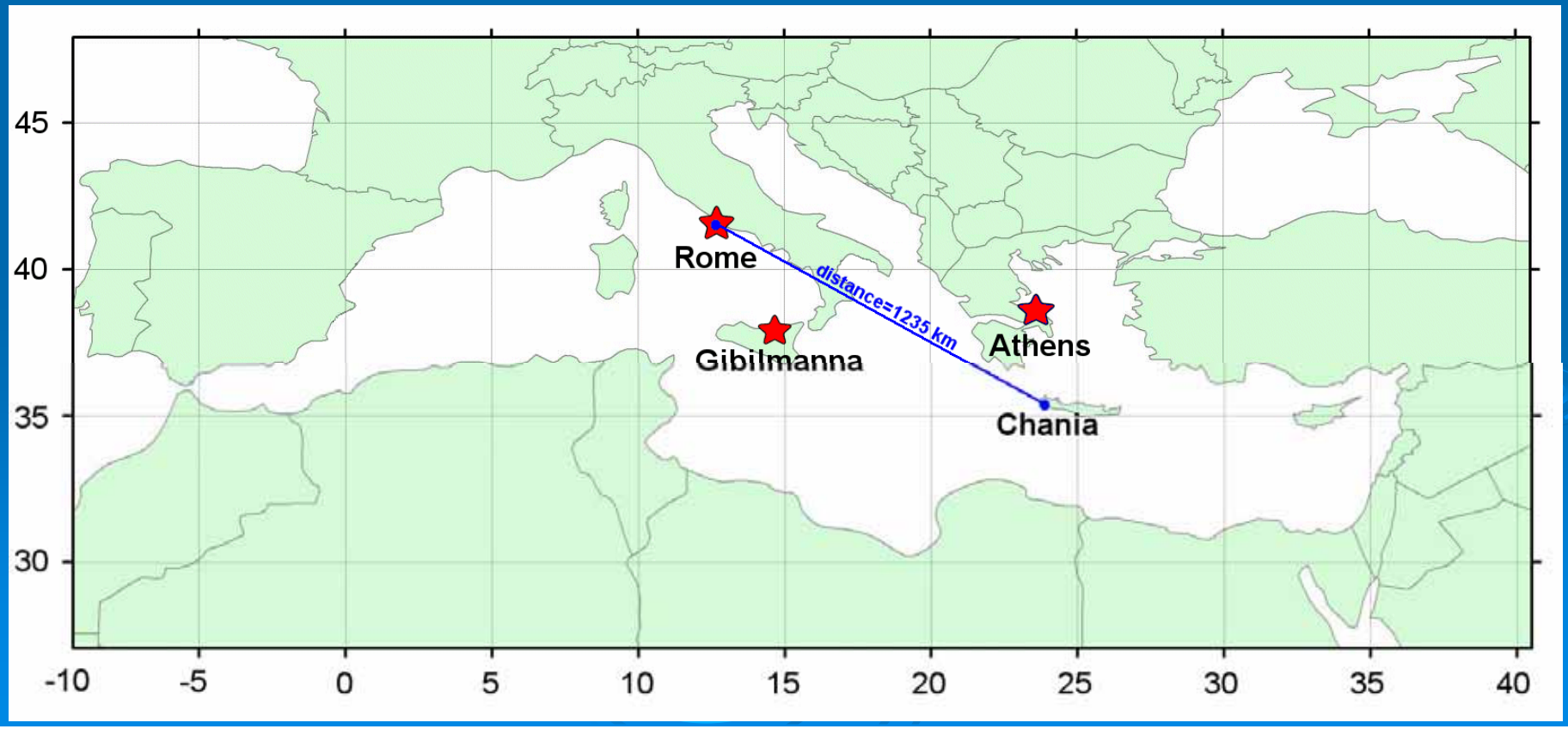
- Settimi, A., M. Pezzopane, M. Pietrella, C. Bianchi, C. Scotto, E. Zuccheretti, J. P. Makris (2013), *Testing the IONORT-ISP system: a comparison between synthesized and measured oblique ionograms,* Radio Sci., 48, RDS20018, 1-13 (2013), doi:10.1002/rds.20018.

- Azzarone, A., C. Bianchi, M. Pezzopane, M. Pietrella, C. Scotto, and A. Settimi (2012), *IONORT: A Windows software tool to calculate the HF ray tracing in the ionosphere*, Comp. Geosc., 42, 57-63, doi:10.1016/j.cageo.2012.02.008.

- Pezzopane, M., M. Pietrella, A. Pignatelli, B. Zolesi, and L. R. Cander (2011), *Assimilation of autoscaled data and regional and local ionospheric models as input sources for real-time 3-D International Reference Ionosphere modeling*, Radio Sci., 46, RS5009, doi:10.1029/2011RS004697.

Abstract

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.

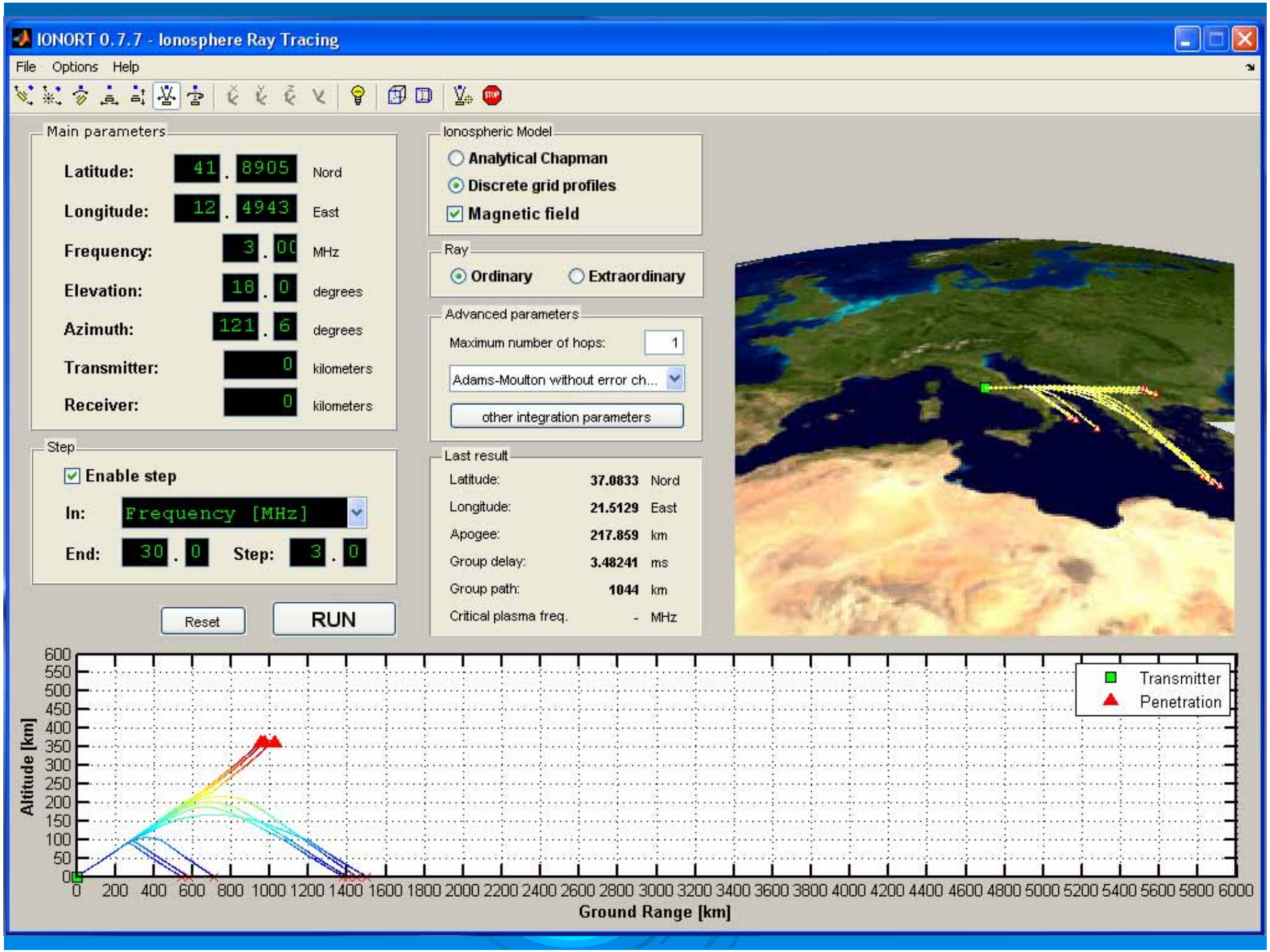


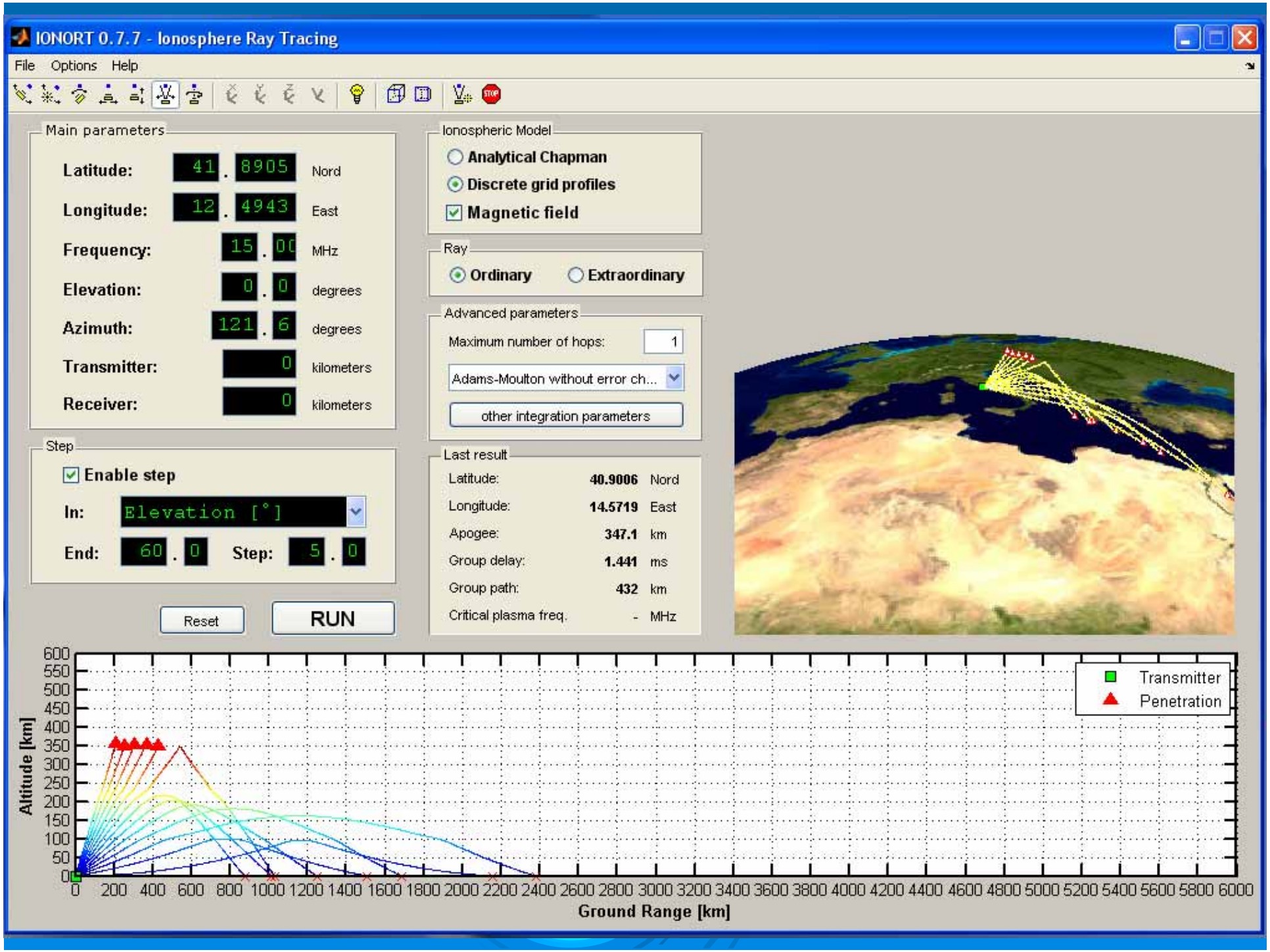
IONORT-ISP system: a brief description.

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]*.

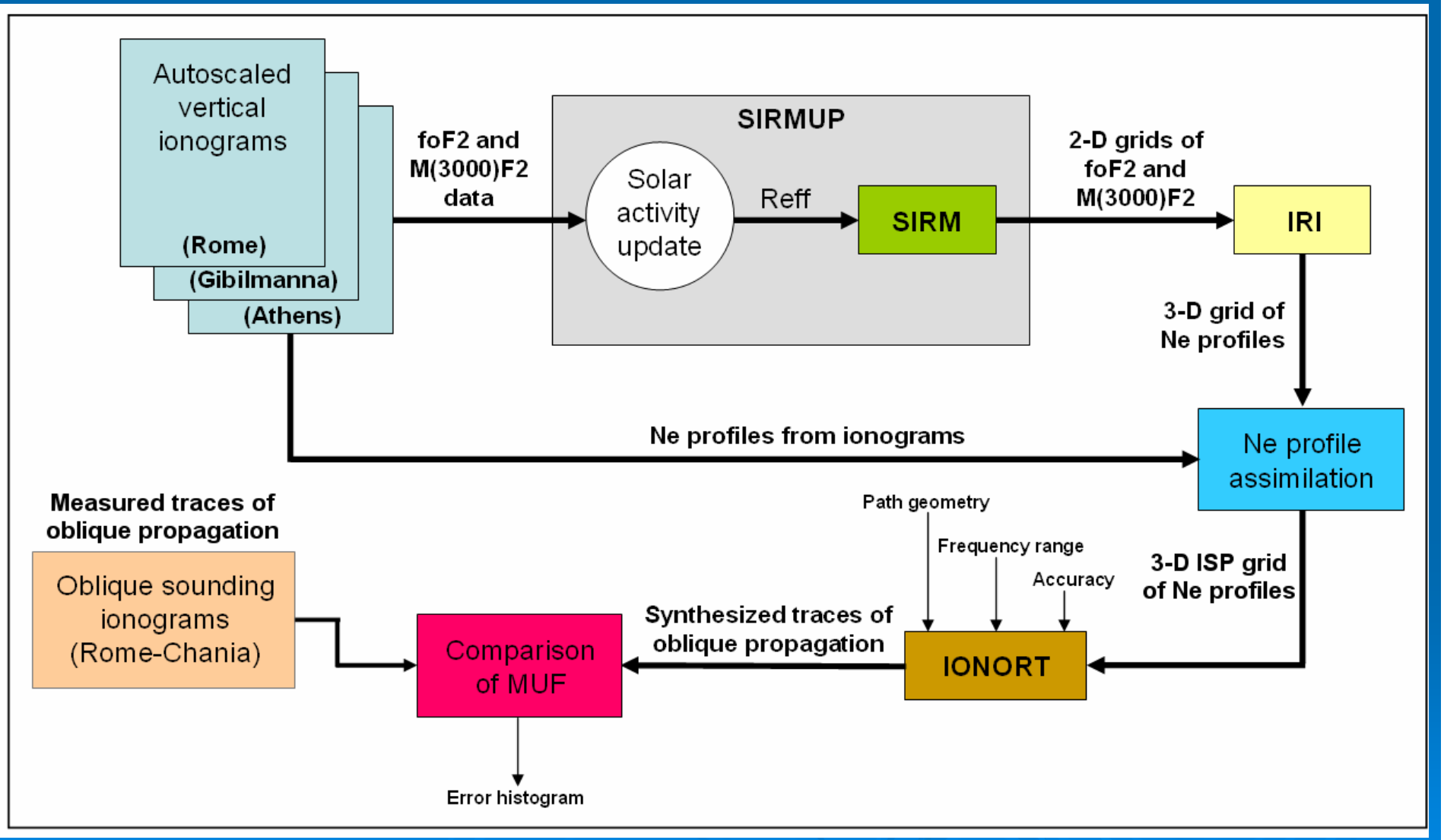
As regards the numerical 3-D representation of the ionosphere,
the present study considered electron density grids
computed both by the *IRI (*International Reference Ionosphere*)*
and by the *ISP (*IRI-SIRMUP-P*) models*.
In this work, IONORT was used,
in conjunction with these two different 3-D electron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


IONORT 0.7.7 - Ionosphere Ray Tracing
File Options Help
Main parameters
Latitude: 41.8905 Nord
Longitude: 12.4943 East
Frequency: 3.00 MHz
Elevation: 18.0 degrees
Azimuth: 121.6 degrees
Transmitter: 0 kilometers
Receiver: 0 kilometers
Step
Enable step
In: Frequency [MHz]
End: 30.0 Step: 3.0
Reset
RUN
Ionospheric Model
Analytical Chapman
Discrete grid profiles
Magnetic field
Ray
Ordinary
Extraordinary
Advanced parameters
Maximum number of hops: 1
Adams-Moulton without error ch...
other integration parameters
Last result
Latitude: 37.0833 Nord
Longitude: 21.5129 East
Apogee: 217.859 km
Group delay: 3.48241 ms
Group path: 1044 km
Critical plasma freq. - MHz
Transmitter
Penetration
Altitude [km]
Ground Range [km]

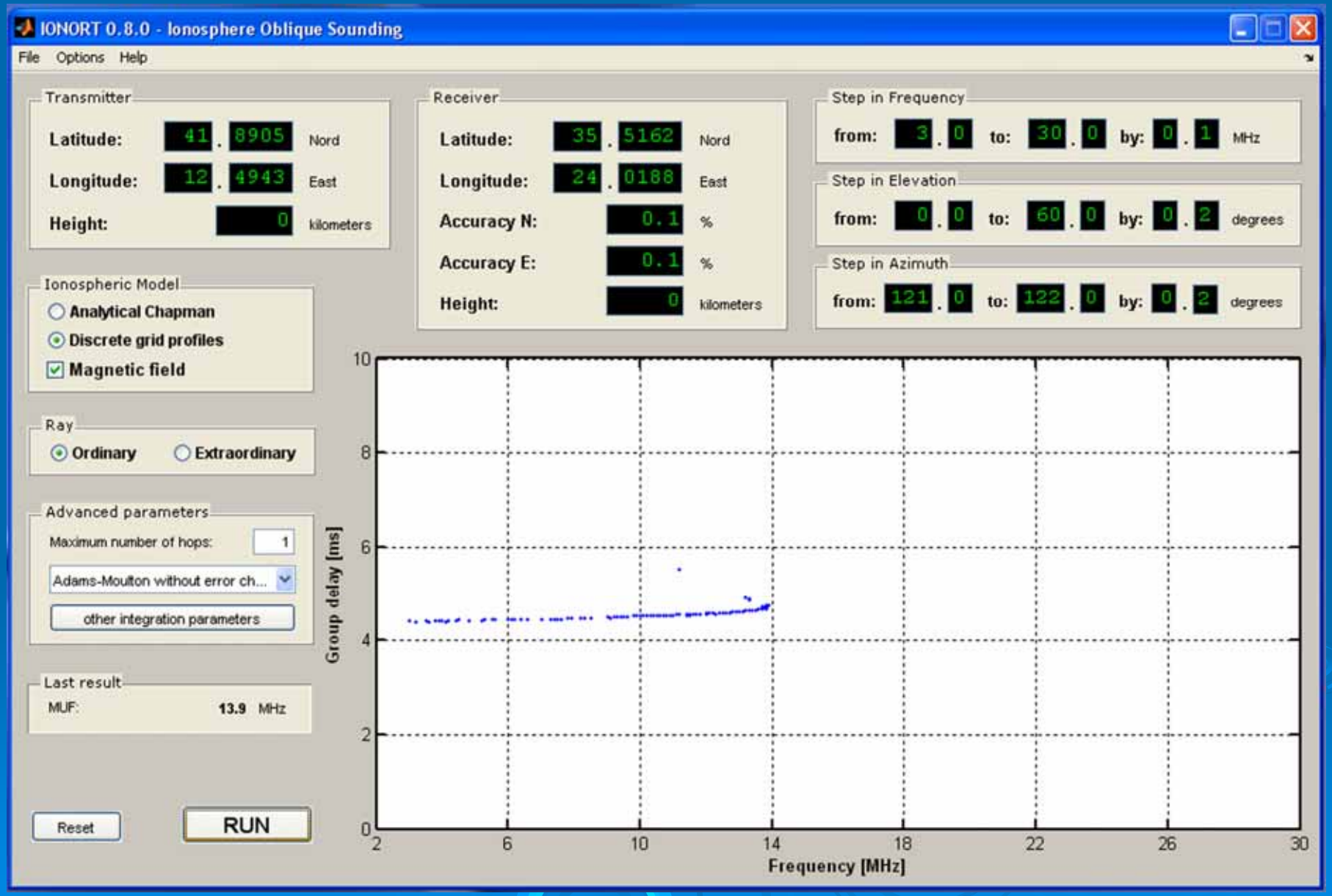

IONORT 0.7.7 - Ionosphere Ray Tracing
File Options Help
Main parameters
Latitude: 41.8905 Nord
Longitude: 12.4943 East
Frequency: 15.00 MHz
Elevation: 0.0 degrees
Azimuth: 121.6 degrees
Transmitter: 0 kilometers
Receiver: 0 kilometers
Step
Enable step
In: Elevation [°]
End: 60.0 Step: 5.0
Reset
RUN
Ionospheric Model
Analytical Chapman
Discrete grid profiles
Magnetic field
Ray
Ordinary
Extraordinary
Advanced parameters
Maximum number of hops: 1
Adams-Moulton without error ch...
other integration parameters
Last result
Latitude: 40.9006 Nord
Longitude: 14.5719 East
Apogee: 347.1 km
Group delay: 1.441 ms
Group path: 432 km
Critical plasma freq. - MHz
Transmitter
Penetration
Altitude [km]
Ground Range [km]

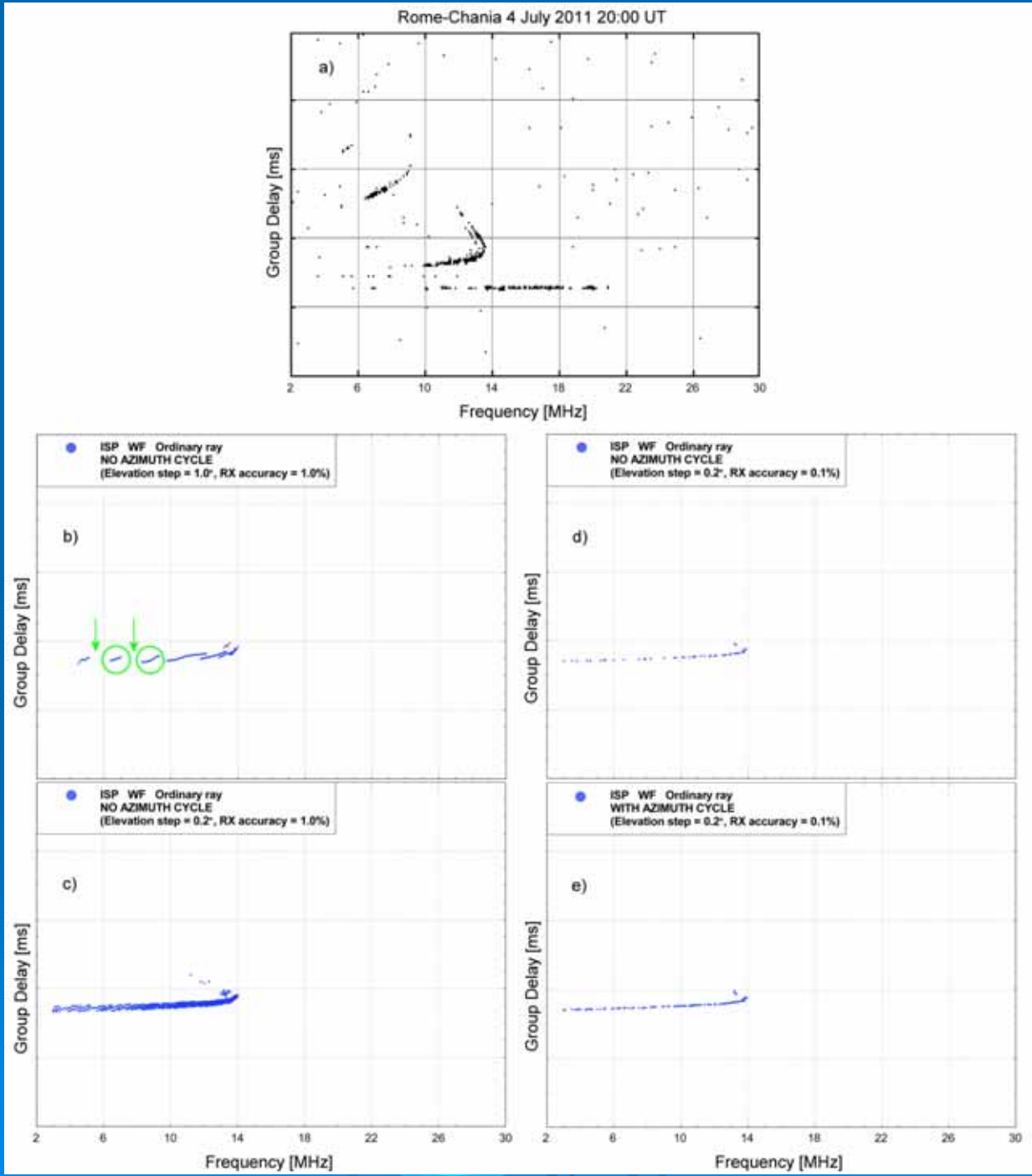
IONORT - ISP system: analysis and discussion.



At present,
the IONORT program is not optimized with an automatic homing-in feature.
However, IONORT allows users to specify ranges of frequency [F_{START}, F_{END}] (in MHz), elevation [EL_{START}, EL_{END}] and azimuth [AZ_{START}, AZ_{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.

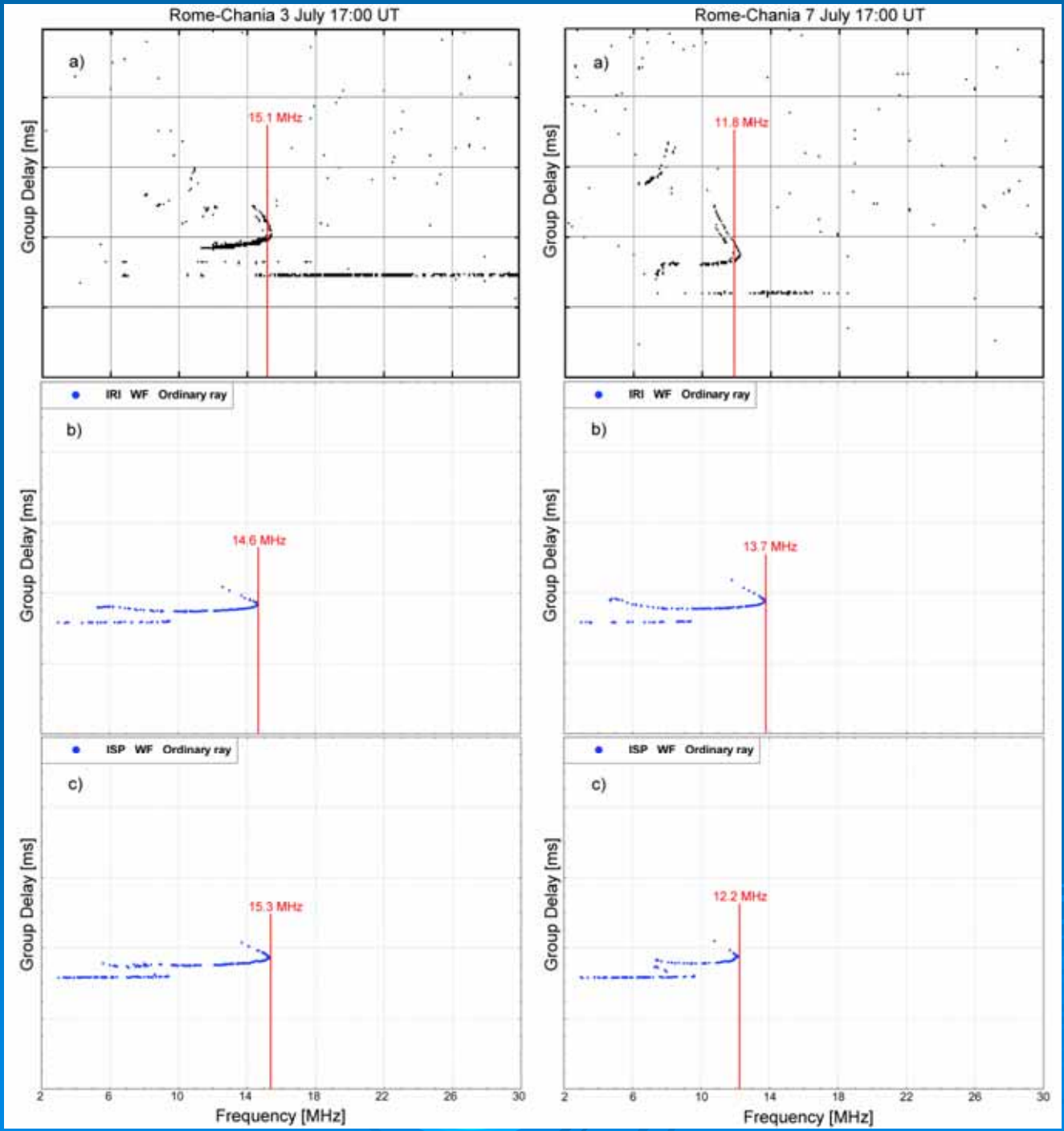
Results and discussion.

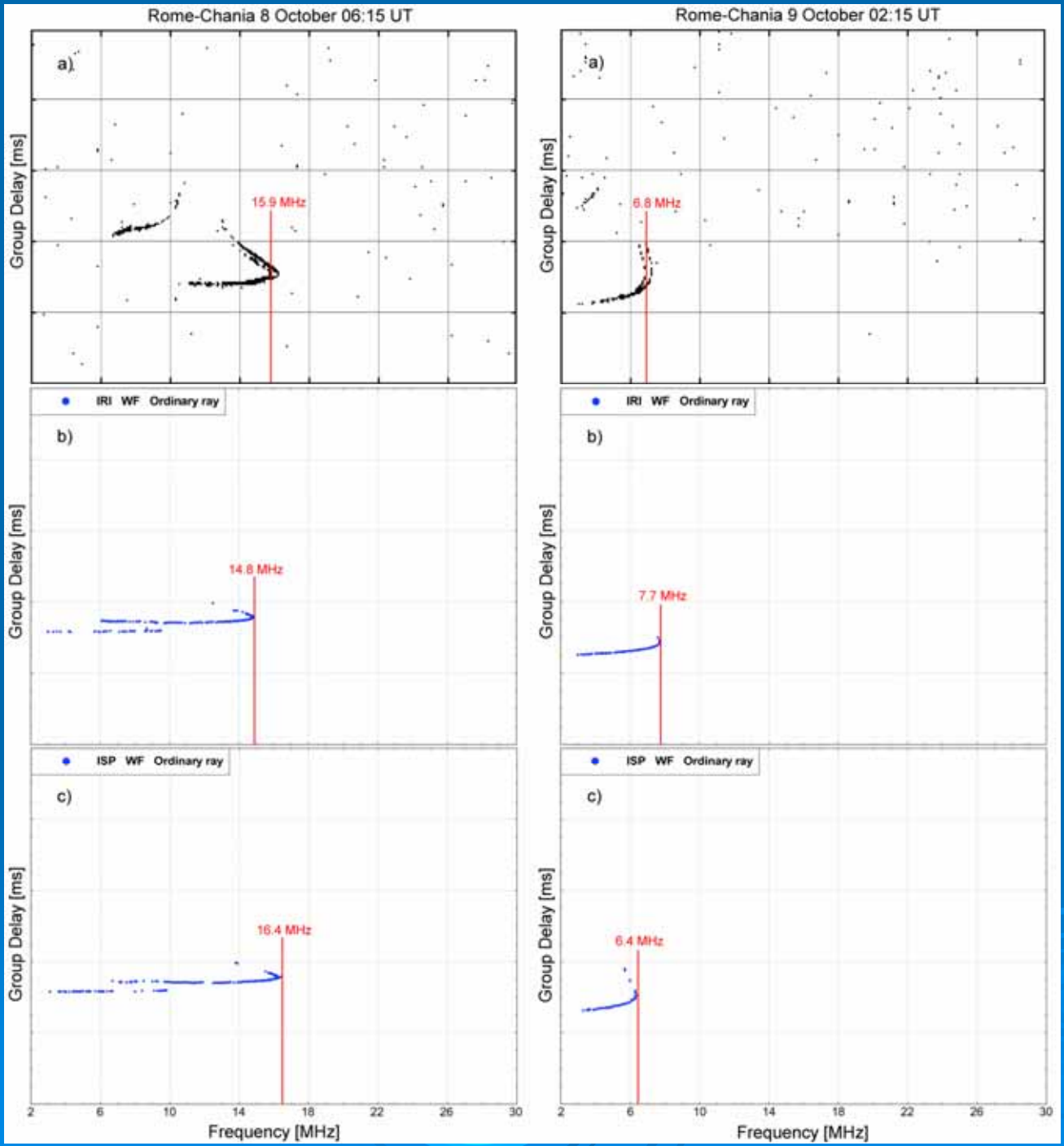



Rome-Chania 4 July 2011 20:00 UT
a)
Group Delay [ms]
Frequency [MHz]
ISP WF Ordinary ray
NO AZIMUTH CYCLE
(Elevation step = 1.0°, RX accuracy = 1.0%)
b)
ISP WF Ordinary ray
NO AZIMUTH CYCLE
(Elevation step = 0.2°, RX accuracy = 0.1%)
d)
ISP WF Ordinary ray
NO AZIMUTH CYCLE
(Elevation step = 0.2°, RX accuracy = 1.0%)
c)
ISP WF Ordinary ray
WITH AZIMUTH CYCLE
(Elevation step = 0.2°, RX accuracy = 0.1%)
e)
2
6
10
14
18
22
26
30

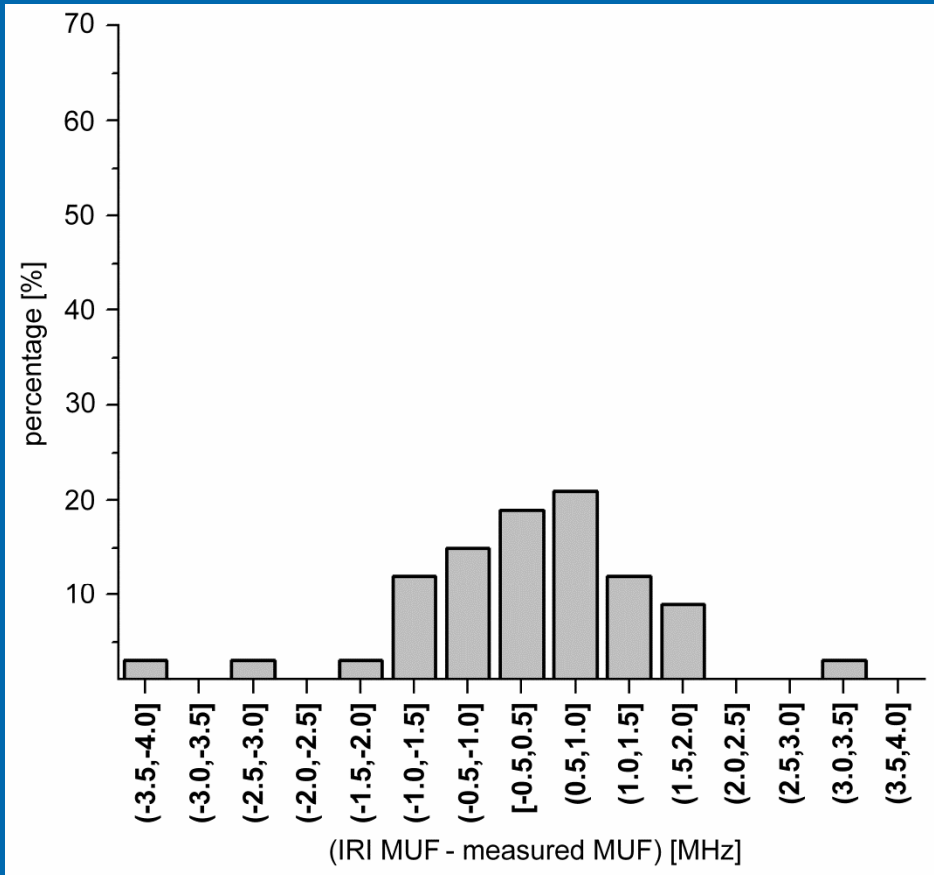
If IONORT were optimized with a *homing-in feature*,
then a suitable adaptive procedure would return *the ionogram trace as a continuous line*.

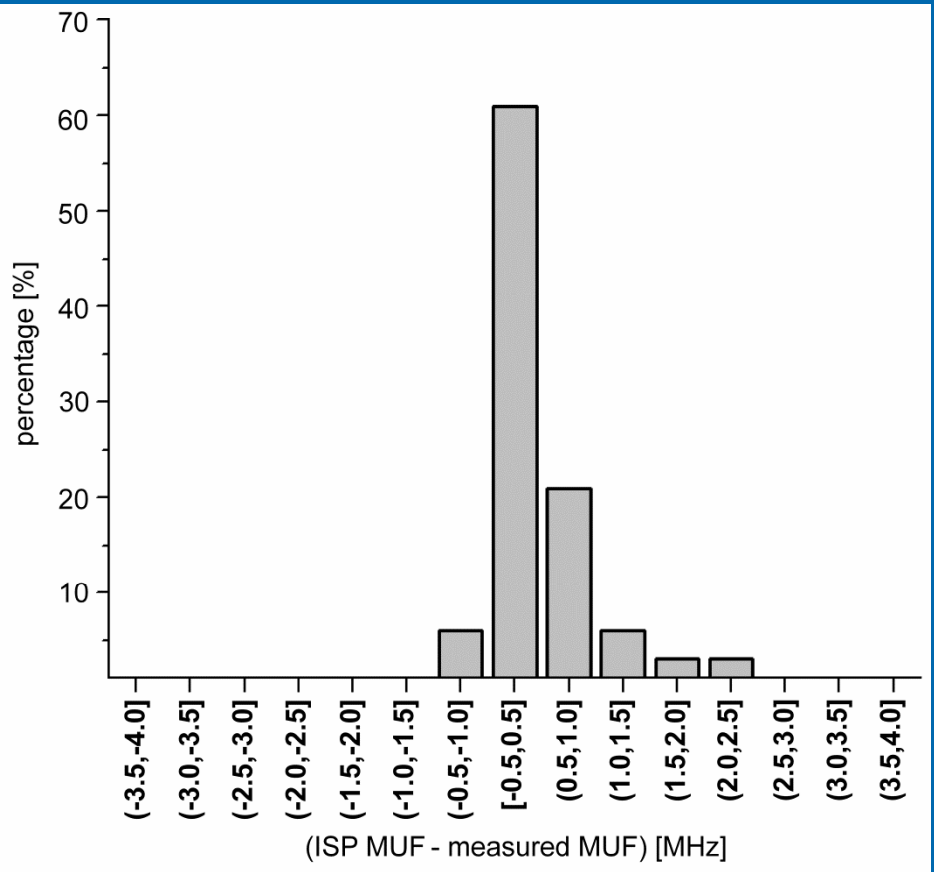
Hence, although IONORT is not optimized with a homing-in feature,
***even one azimuth cycle may produce an ionogram as an almost continuous line*.**


Rome-Chania 3 July 17:00 UT
Rome-Chania 7 July 17:00 UT
a)
15.1 MHz
11.8 MHz
IRI WF Ordinary ray
b)
14.6 MHz
13.7 MHz
ISP WF Ordinary ray
c)
15.3 MHz
12.2 MHz
Group Delay [ms]
Frequency [MHz]
2
6
10
14
18
22
26
30


Rome-Chania 8 October 06:15 UT
Rome-Chania 9 October 02:15 UT
a)
15.9 MHz
6.8 MHz
IRI WF Ordinary ray
b)
14.8 MHz
7.7 MHz
ISP WF Ordinary ray
c)
16.4 MHz
6.4 MHz
Group Delay [ms]
Frequency [MHz]
2
6
10
14
18
22
26
30

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.***

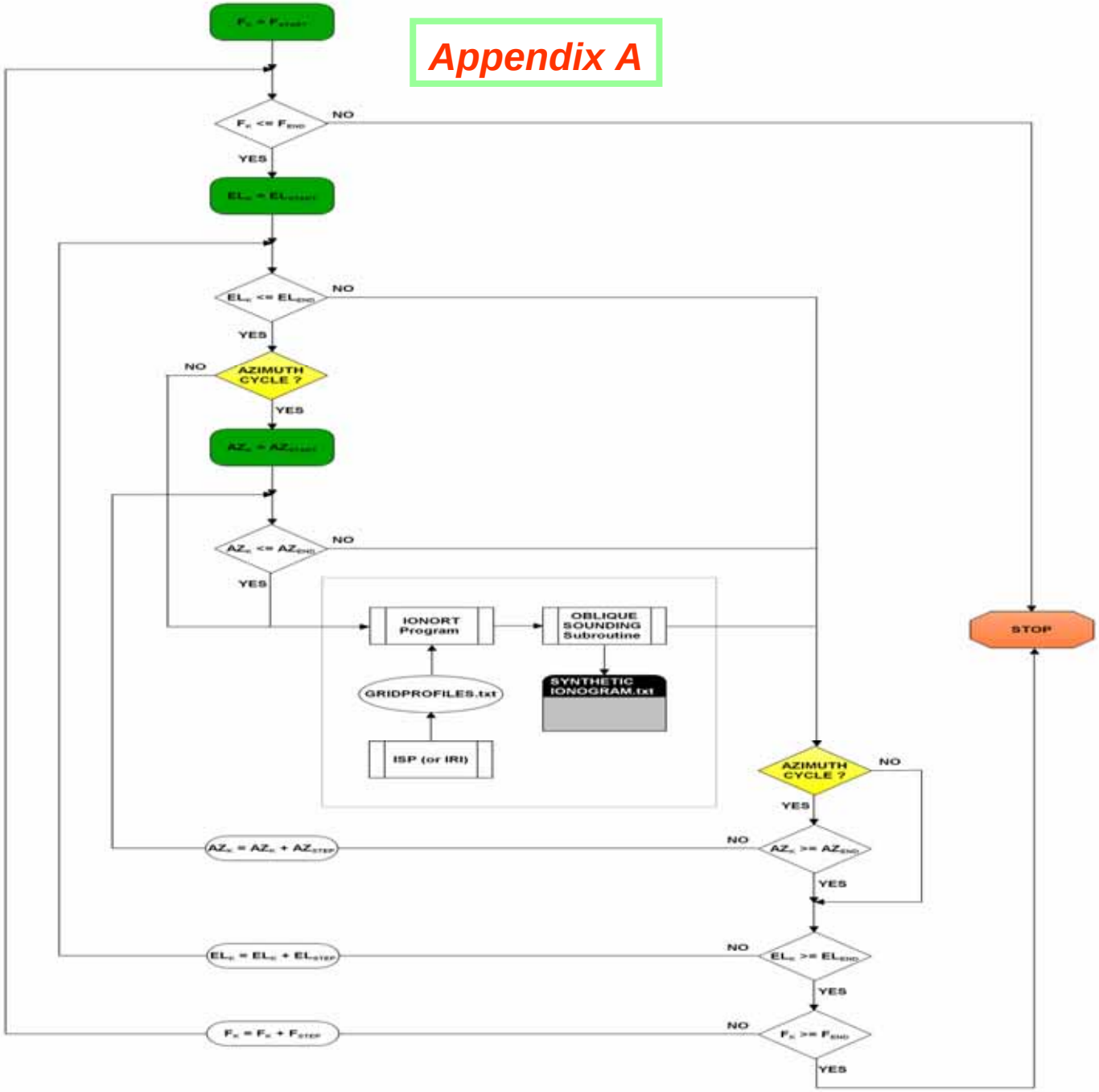
Future developments

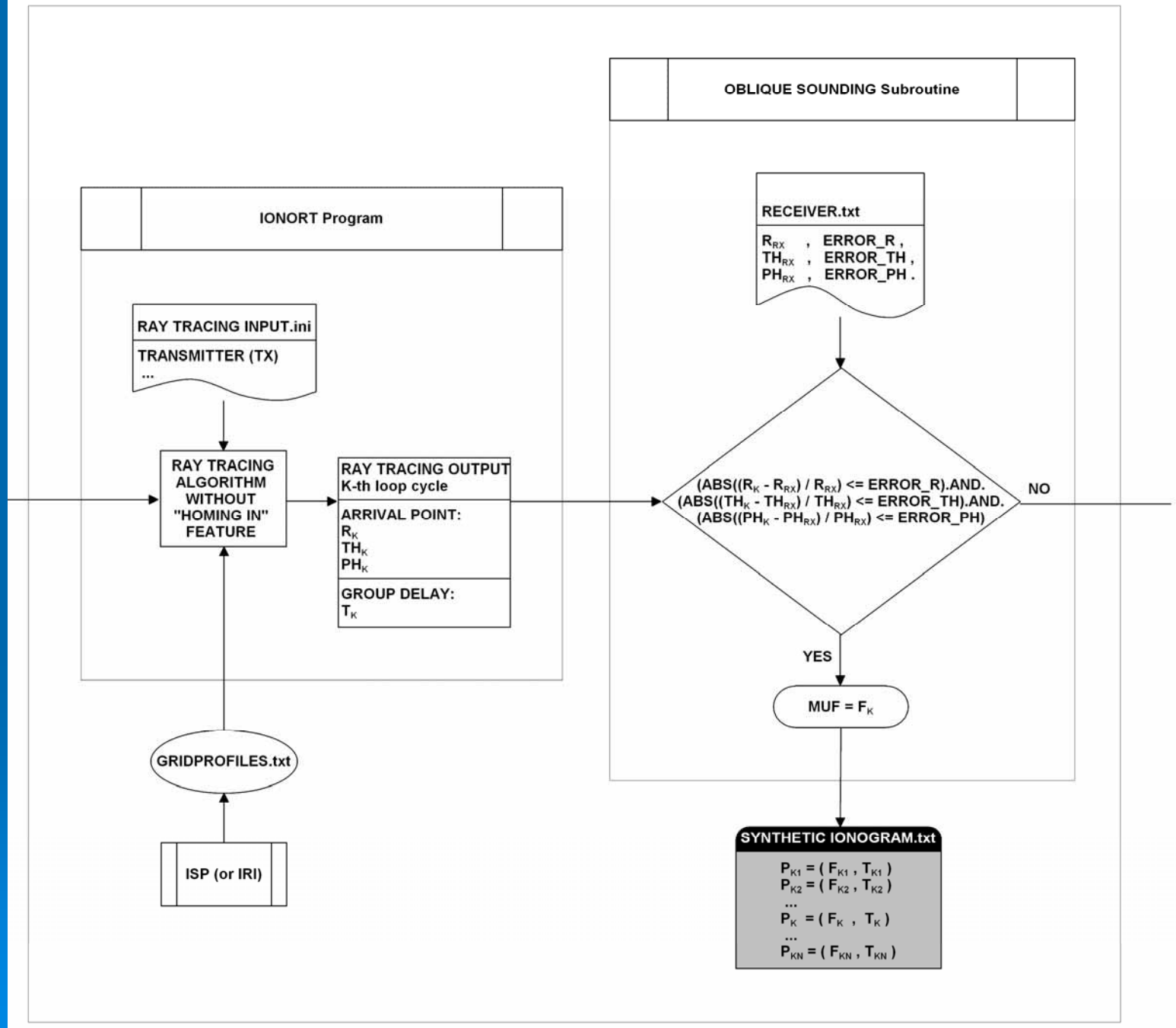
- *More oblique sounding measurements need to be conducted*

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.**

Appendix A


NO
YES
NO
YES
NO
AZIMUTH CYCLE ?
YES
NO
YES
IONORT Program
OBLIQUE SOUNDING Subroutine
GRIDPROFILES.txt
SYNTHETIC IONOGRAM.txt
ISP (or IRI)
STOP
AZIMUTH CYCLE ?
NO
YES
NO
YES
NO
YES
NO
YES


OBLIQUE SOUNDING Subroutine
IONORT Program
RECEIVER.txt
R_{RX} , ERROR_R ,
TH_{RX} , ERROR_TH ,
PH_{RX} , ERROR_PH .
RAY TRACING INPUT.ini
TRANSMITTER (TX)
...
RAY TRACING ALGORITHM WITHOUT "HOMING IN" FEATURE
RAY TRACING OUTPUT
K-th loop cycle
ARRIVAL POINT:
R_K
TH_K
PH_K
GROUP DELAY:
T_K
(ABS((R_K - R_{RX}) / R_{RX}) <= ERROR_R).AND.
(ABS((TH_K - TH_{RX}) / TH_{RX}) <= ERROR_TH).AND.
(ABS((PH_K - PH_{RX}) / PH_{RX}) <= ERROR_PH)
NO
YES
MUF = F_K
GRIDPROFILES.txt
ISP (or IRI)
SYNTHETIC IONOGRAM.txt
P_{K1} = (F_{K1} , T_{K1})
P_{K2} = (F_{K2} , T_{K2})
...
P_K = (F_K , T_K)
...
P_{KN} = (F_{KN} , T_{KN})