3D geolocation of ionospheric plasma irregularities by combination of RO, in situ, and ground-based GNSS measurements

Iurii Cherniak
Sergey Sokolovskiy
William Schreiner
UCAR
COSMIC Program Office

Irina Zakharenkova
SRRC UWM
Occurrence of L band scintillation during high and low solar activity


Different physical drivers leading to the structures generation
Spatial structure of ionospheric plasma irregularities

High-latitude irregularities over Chatanika incoherent scatter radar

Altitudinal extent of equatorial irregularities observed by Jicamarca radar

Uncertainties to locate ionospheric plasma irregularities along RO line of sight

On base of Yokoyama et al., JGR, 2014
Mutiinstrumental approach to specify 3d structure of ionospheric plasma irregularities

Challenge - source of irregularities / scintillations location and size estimation by single instrument

Using multiply instruments to detect plasma irregularities in 3D

On base of Yokoyama et al., JGR, 2014
Ionospheric irregularities can be characterized by measuring its impact on amplitude and phase of the received GPS signal.

*Pi et al.* [GRL, 1997] introduced into the use two GPS-based indices:

- **ROT** (Rate of TEC change, $\frac{d\text{TEC}}{dt}$) as a measure of GPS signal phase fluctuations

\[
\text{ROT} = \frac{s\text{TEC}_k - s\text{TEC}_{k-1}}{t_k - t_{k-1}}
\]

- **ROTI** (Rate of TEC Index, standard deviation of ROT) characterizes the severity of the GPS phase fluctuations

\[
\text{ROTI} = \sqrt{\langle \text{ROT}^2 \rangle - \langle \text{ROT} \rangle^2}
\]
GNSS as global observational network for ionosphere monitoring

Year 1996
More than 100 GPS stations
Courtesy Manucci et al, 1998

Year 2019
~ 6300 stations
~3500 multi-GNSS stations (GPS + GLONASS)
Ionospheric plasma irregularities location. SED-TOI structures ROTI vs TEC maps

Ground based GNSS observations

2015 St. Patrick’s Day storm

Cherniak et al,
Space Weather, 2015
Ionospheric irregularities location. ROTI maps vs LEO GPS and in-situ observations.
Formation of the SED/TOI topside structures over Southern hemisphere, March, 2015 geomagnetic storm.

Superimposing to the TEC/ROTI maps vs LEO GPS and in-situ observations.

Ionospheric plasma irregularities location. SED/TOI signatures in the COSMIC RO...
Ionospheric plasma irregularities location. SED/TOI signatures in the COSMIC RO

Formation of the SED/TOI topside structures over Northern hemisphere, December, 2015 geomagnetic storm.

Superimposing to the TEC/ROTI maps vs LEO GPS and in-situ observations
High-latitude ionospheric irregularities location vs Space Weather drivers

22/06/2015 00:00

Ground-based ROTI.

June 2015 geomagnetic storm
Ground-based ROTI.

23/06/2015  0000 UT

The June 2015 geomagnetic storm

Cherniak et al, JGR, 2019
The plasma bubbles in signatures space-borne GPS ROTI and Ne from Swarm satellites passes and DMSP in situ ion density.

The June 2015 geomagnetic storm
Plasma bubbles on midlatitudes

Cherniak&Zakharenkova, GRL, 2016
Swarm and C/NOFS in situ

The June 2015 geomagnetic storm

Cherniak et al, JGR, 2019
Ionospheric plasma irregularities location by back propagation approach

(a) Diagram showing forward and back propagation paths from GPS to LEO orbit.

(b, c, d, e) Graphs illustrating Z coordinate vs. Y coordinate for different data sets, showing normalized RMS amplitude fluctuations.
COSMIC RO S4

a) 22.06.2015 16–18 UT

b) 22.06.2015 18–20 UT

c) 22.06.2015 20–22 UT

d) 22.06.2015 22–24 UT

e) 23.06.2015 00–02 UT

f) 23.06.2015 02–04 UT

g) 23.06.2015 04–06 UT

h) 23.06.2015 06–08 UT

Cherniak et al, JGR, 2019
## Ionospheric plasma irregularities location by multi-instrumental observations

<table>
<thead>
<tr>
<th>Measurements technique</th>
<th>Area of application</th>
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<tbody>
<tr>
<td>GNSS RO</td>
<td>Altitudinal distribution</td>
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<tr>
<td>RO BP</td>
<td>Distance from receiver, altitudinal distribution</td>
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<tr>
<td>GNSS POD</td>
<td>Location above satellite orbit</td>
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<tr>
<td>Ground based GNSS</td>
<td>Geographical location</td>
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<tr>
<td>In situ LP/IVM</td>
<td>Location along satellite orbit</td>
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</table>
Summary

- Combination of different ground-based and space-borne observations can allow to assess plasma irregularities parameters in geographical and altitudinal domain.

- Independent multi-instrumental measurements provide a consistent global view on the ionospheric density irregularity distribution and dynamics and allow estimating space weather drivers for plasma irregularities generation.

- Results confirm a high potency of the COSMIC-2 mission for ionospheric irregularities monitoring as it’s equipped by both in situ plasma probes and GNSS remote sensing payload, including RO and POD instruments.

Thank you!