Natural disasters and low ionospheric disturbances detected by Belgrade VLF/LF receiver station

Aleksandra Nina, Giovanni Nico, Luka Č. Popović, Vladimir M. Čadež, Milan Radovanović
Content

• VLF/LF radio signals - low ionospheric observations
• Description of research in Serbia (disturbance detections and modelling)
• Ionosphere and natural disasters:
  • connections
  • Influence of D-region disturbances on remote sensing
Observations

3 kHz – 30 kHz    VLF
30 kHz – 300 kHz   LF

Time resolution of data

0.001 s – 1 s
1 Hz - 1 kHz

Size:
several tens of GB/day
several TB/year
• Continuous receiving
  - Detections of unperiodical perturbations
  - Periodical variations: diurnal, seasonal, solar cycle

• High time resolution
  - Detection of short-term disturbances and relevant events and phenomena

• Global experimental setup – transmitter and receiver networks
  - Analyses of large part of the low ionosphere
  - Detection of local perturbations
Belgrade VLF/LF receiver station

AbsPAL
AWESOME

Operable since: 2003 2008
Simultaneously monitor: 5 signals 15 signals
Time resolutions: 0.1 s 0.02 s

During this period we have collected a large database containing a written information about numerous low ionospheric responses to different natural and human induced events.

Time resolutions:
0.1 s 0.02 s
Research

DETECTION OF LOW IONOSPHERIC DISTURBANCES

MODELING OF PLASMA PARAMETERS
Detection of low ionospheric disturbances

DEVELOPMENT OF PROCEDURES FOR DETECTIONS OF DISTURBANCES

• Detection of short-term disturbances – statistical study


• Detection of hydrodynamic waves

Detection of low ionospheric disturbances

- Detection of mid-term disturbances in periods around tropical depression beginnings


- Detection of disturbances in periods around the earthquakes

Modelling


- HORIZONTAL UNIFORM IONOSPHERE
- EXPONENTIAL Ne ALTITUDE DISTRIBUTION
- SOLAR X-RAY FLARE
Ionosphere – natural disasters: two fold connection

Ionospheric disturbances connected with disasters

- Earthquakes
- Tropical cyclones
- Lightnings
- Volcano lightnings
- Solar radiation
- Gamma radiation

Ionosphere – medium which affects remote sensing of natural disasters by satellites

Hazards SoS, Petnica, 2019
Ionospheric disturbances connected with disasters

Ionosphere – medium which affects remote sensing of natural disasters by satellites
Earthquakes - ionosphere

Hazards SoS, Petnica, 2019
Analysis of the low ionospheric disturbances in period around the Kraljevo earthquake occurred on November 3, 2010

Aleksandra Nina, Sergey Pulinets, Giovanni Nico, Srdjan Mitrovic, Milan Radovanovic and Luka Č. Popovic

- Amplitude noises
- Short-term amplitude peaks (spikes)
- Hydrodynamic waves

Three proceedings

- Terminator times
Low ionospheric reactions on tropical depressions prior hurricanes

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- Detection of deviation
- Determination of typical profiles of amplitude time evolutions that can be considered as deviation
• **Detection of deviation**

\[
\sigma_N(t) = \sqrt{\frac{1}{n_N(t)} \sum_{i=1}^{n_N(t)} (A_i(t) - A_{mN}(t))^2},
\]

\[
r(t) = \frac{\text{abs}(\sigma_2(t) - \sigma_1(t))}{\sigma_1(t)}.
\]

• The deviation of signal at time \( t \) in the day of a depression is significant if \( r(t) \geq 100\% \).

• Deviation for the TD event is recorded if at least 50\% of values \( r(t) \) is significant within one hour.

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In the case of 36 out of 41 TD events (88%)

• Disturbances during daytime, nighttime and ST periods
• Before, during, after TD beginnings

Hazards SoS, Petnica, 2019
• Typical profiles

• Three types of signal variations (80 %)

**MAIN CONCLUSIONS:**
Possible connection of low ionospheric disturbances and TD

Pioneer study – the need for future research
Y radiation - ionosphere
Gamma-Ray Bursts (GRBs) are known as **THE MOST ENERGETIC PHENOMENA IN THE UNIVERSE.**

**Sources:** supernova explosions, collisions of celestial bodies such as neutron stars, white dwarfs, and Helium stars with black holes.

**Frequency of impact in the Earth’s atmosphere:** several times per month.

**How much can a GRB event disturb the Earth atmosphere?**

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Detection of short-term response of the low ionosphere on gamma ray bursts

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MAIN CONCLUSION:
GRBs induce short-term disturbances in the low ionosphere
Ionospheric disturbances connected with disasters

Ionosphere – medium which affects remote sensing of natural disasters by satellites
Remote sensing, positioning and telecommunications

Propagation of EM waves in ionosphere

Low ionosphere, mid and low latitude: SOLAR X-RAY FLARES
Modelling of signal propagation significantly depends on the signal frequency $f$ because of influence of the collision processes.

For small frequencies ($f$), the model is:

$$n(h, t) = \sqrt{1 - \frac{f_p^2(h, t)}{f^2}} \frac{1 + \frac{\nu(h, t)}{2\pi f}}{1 + \left(\frac{\nu(h, t)}{2\pi f}\right)^2}$$

For large frequencies ($f$), the model is:

$$n(h, t) = \sqrt{1 - \frac{f_p^2(h, t)}{f^2}}$$

where $\nu = 1.7 \times 10^{-11} [N_2] T_e + 3.8 \times 10^{-10} [O_2] \sqrt{T_e} + 1.4 \times 10^{-10} [O] \sqrt{T_e}$.
VARIATIONS IN IONOSPHERIC D-REGION RECOMBINATION PROPERTIES DURING INCREASE OF ITS X-RAY HEATING INDUCED BY SOLAR X-RAY FLARE

Aleksandra Nina, Vladimir M. Čadež, Maša Lakićević, Milan Radovanović and Luka Č. Popović

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EARTH-AFFECTING SOLAR TRANSIENTS

Analysis of the Relationship Between the Solar X-Ray Radiation Intensity and the D-Region Electron Density Using Satellite and Ground-Based Radio Data

Aleksandra Nina, Vladimir M. Čadež, Jovan Bajčetić, Srdjan T. Mitrović, Luka Č. Popović

Hazards SoS, Petnica, 2019
Upcoming research

- altitude distribution of photoionization maximum
- $\alpha_{\text{eff}}$ for whole time period
- $T_e$ for whole time period
- $\nu$ for whole time period
- $n$ for whole time period

Propagation path and other calculations
Positioning and Earth observations

Applications

- Oceans and ice
- Changing lands
- Emergency response

Monitoring hydrometeorological and geological events: landslides, floods, earthquakes, wind and waves (they can be used to track the paths of oil slicks and other pollutants)
## Satellite signal propagation

<table>
<thead>
<tr>
<th>Source</th>
<th>Delay</th>
</tr>
</thead>
<tbody>
<tr>
<td>Satellite orbit</td>
<td>2.5 – 5 cm</td>
</tr>
<tr>
<td>Satellite clock errors</td>
<td>up to 2 cm</td>
</tr>
<tr>
<td>Satellite hardware delay</td>
<td>1 m</td>
</tr>
<tr>
<td>Receiver hardware delay</td>
<td>up to 3 m</td>
</tr>
<tr>
<td>Ionospheric delay</td>
<td>3 – 5 m</td>
</tr>
<tr>
<td>Tropospheric delay</td>
<td>2.3 m</td>
</tr>
<tr>
<td>Multipath</td>
<td>6 cm</td>
</tr>
<tr>
<td>Phase center variation and offset</td>
<td>1 cm</td>
</tr>
</tbody>
</table>

- **The ionosphere has the largest influence on the delay.**
- **The delay of 1 cm is included in modeling.**


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Ionospheric influence on satellite signals: modelling and problems

- Determination of ionospheric delay is based on calculation of the total electron content (TEC)
- Lack of data for the electron density with enough good space and time resolution: many approximations must be included in modelling of TEC.
- Approximations in the electron density space distribution:
  - SLM (it is assumed that all free electrons are concentrated in an infinitesimally thin layer at a fixed height in F-region)
  - MLM (for example up to the peak of the F2 layer, the NeQuick uses a profile formulation which includes five semi-Epstein layers (above 90 km) with modelled thickness parameters)
  - Models relevant for quiet conditions (IRI)

TEC is number of electrons between satellite and receiver along a tube of 1 m² cross section

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- Are these expressions applicable during intensive disturbances?
- Can local disturbances (localized altitude domain) be important?
Our study: Can the D-region delay be important for modelling?

Some events primarily disturbs the low ionosphere

D-region electron can be increase two orders of magnitude and input parameters are unchanged

Can the perturbed low ionosphere sufficiently affect the GNSS and SAR signals so that the inclusion of the D-region in models becomes necessary for measurements?
D-region contribution in delay

MAIN CONCLUSION
The perturbed D-region can significantly affect GNSS and SAR signals
Summary

• Analyses based on data collected by the Belgrade VLF/LF receiver station
• Detection of the low ionospheric variations in period of natural disasters and high energy EM radiation
• Influence of intensive low ionospheric disturbances on EM wave propagation – telecommunication, positioning, Earth observation
ASTRONOMERS
- Solar physics
- Galactic and extragalactic

GEO-SCIENTISTS – upper atmosphere
- Magnetosphere
- Ionosphere F-region

GEO-SCIENTIST – low ionosphere

ATMOSPHERIC SCIENTISTS
- Troposphere

GEO-SCIENTISTS – lithosphere
- Seismologist
- Vulcanologist

PROGRAMMERS

EXPERTS FOR DATABASES

PHYSICISTS
- Atomic
- Molecular
- Wave propagations

ENGINEERS
- Antennas
- GNSS
Thank you for your attention!