GNSS-based Regional Ionosphere Modeling over Bosnia and Herzegovina

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1. Introduction

The ionospheric delay is one of the main error-sources in applications that rely on Global Navigation Satellite System (GNSS) observations. Although Global Ionospheric Models (GIM) broadcasted by the satellite systems exist, they have limited resolution and precision. Thus regional ionospheric models, based on a dense local GNSS network, are necessary to describe detailed features of the local ionosphere. Available in near-real time they can provide high accuracy in GNSS positioning.

This study aims to establish the first regional ionospheric model (RIM) utilizing data of GNSS permanent stations belonging to the BiH Positioning Service (BiHPOS) and the European Permanent Network (EPN) in BiH and Western Balkan.

2. Methodology

2.1. Permanent GNSS stations selection

Dual frequency GPS measurements of permanent stations in Bosnia and Herzegovina (BiHPOS and EPN) are processed. The chosen network comprises **8 BiHPOS stations** circularly located in a distance of **80 km** from the **central EPN station SRJV** in Sarajevo (Fig. 1).

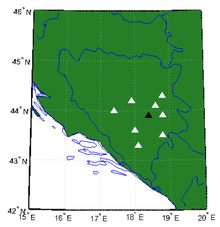

Fig. 1: Map of BiH, stations: BiHPOS (white) and EPN (black)

2.2. Selection of study period

A period of 7 days was selected for the study:
- **20.03. - 26.03.2014**,
- the period of **solar maximum** (reached in April 2014),
- **spring equinox** (effect of the season on the ionosphere).

Space weather indices, obtained from OMNIWeb interface of Goddard's Space Physics Data Facility [1], were examined as well.

2.3. Data processing and ionospheric model estimation

Processing of data and model estimation is carried out in **Bernese GNSS Software v.5.2** [2]. The local ionospheric model is estimated using the **geometry-free (L4) linear combination of zero-difference phase measurements**. Modelling of the vertical total electron content (VTEC) is performed by a **two-dimensional Taylor series expansions of degree and order 2 in a Sun-fixed reference frame** (Eq. 1). **The origin of the development** is close to the **EPN station SRJV**. The model has temporal resolution of **1h** and spatial resolution of **1^o x 1^o**.

$$E(\beta,s)=\sum_{n=0}^{n_{\max}}\sum_{m=0}^{m_{\max}}E_{nm}(\beta-\beta_0)^n(s-s_0)^m \qquad \text{(Eq. 1)}$$

$n_{\max}, m_{\max}$ - maximum degrees of the two–dimensional Taylor series expansion in latitude β and in longitude s,
E_{nm} - TEC coefficients of the Taylor series,
β_0, s_0 - coordinates of the origin of the development,
β - geographic latitude of the intersection point of the receiver-satellite signal line with the ionospheric layer,
s - the sun-fixed longitude of the ionospheric pierce point,
h= 450 km - the height of the single layer above the Earth´s surface.

2.4. Model's evaluation

The model's applicability and validity are evaluated with respect to:
•Global Ionospheric Maps (**GIM**) [3],
•International Reference Ionosphere (**IRI**)[4]
• the Multilayer ionospheric Model (**MLM**) developed at the TU Vienna [5].

The international standard empirical model **IRI** is based on the worldwide network of ionosondes, incoherent scatter radars, topside sounders and in situ instruments on several satellites and rockets. VTEC values were calculated online through IRI web interface with the same spatial (**1^o x 1^o**) and temporal (**1h**) resolution as the regional model.

GIMs are provided in IONEX format by IGS Associate Analysis Centres :
- **CODE** (Center for Orbit Determination in Europe, AIUB, Bern, Switzerland)
- **ESA/ESOC** (European Space Operations Center, Darmstadt, Germany)
- **JPL** (Jet Propulsion Laboratory, Pasadena, U.S.A) and
- **gAGE/UPC** (Technical University of Catalonia, Barcelona, Spain).

GIMs are generated using observations of IGS and other institutions. Spatial resolution is **5^o x 2.5^o** in longitude and latitude respectively, while the temporal resolution is **2h**. VTEC values for the comparison with the regional model are interpolated from GIMs to obtain a spatial resolution of 1^o x 1^o.

Parameters in **Multilayer Model (MLM)** for European region are estimated with **1h** time resolution and **1^o x 1^o** spatial resolution utilizing global IGS observation data.

3. Results

3.1. Space Weather Indices

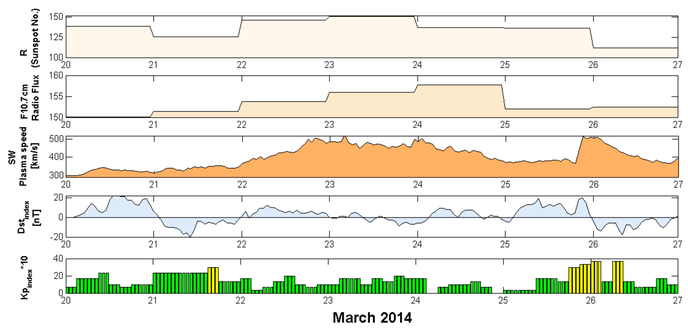

Fig. 2: From top to bottom: Sunspot number, Solar radio flux f10.7cm, solar wind speed Vsw, Dst index, Kp multiplied by 10 (Quiet Kp<3, Moderate 3≤Kp<4, Active 4≤Kp<5, Storm 5≤Kp). The study period is characterized by high solar activity and generally quiet conditions in the geomagnetic field.

3.2. Regional Ionospheric Model BiH – VTEC maps

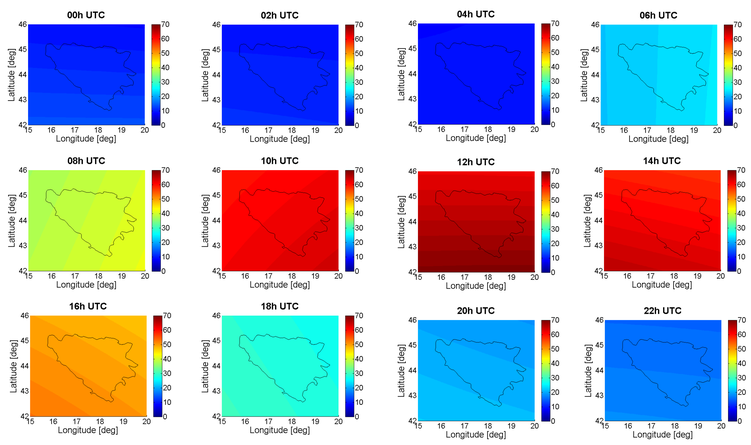

Fig. 3: 2h VTEC maps of RIM over BiH, 21.03.2014. VTEC diurnal variations to 70 TECU.

3.3. Model's validation

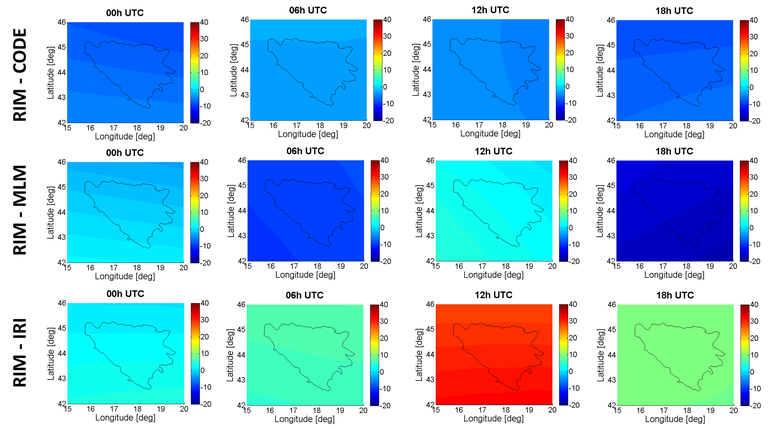

Fig. 4: RIM over BiH compared with (from top to bottom): the CODE GIMs, MLM and IRI, 21.03.2014. 6h VTEC differential maps.
RIM has the smallest deviations compared to GIMs CODE (under 10 TECU). The biggest differences are between RIM and IRI during daytime (to 40 TECU), while in nighttime they are smaller (under 10 TECU). MLM significantly deviates from RIM (to 20 TECU). Similar results were obtained comparing MLM to CODE for the BiH region. MLM does not include observations from BiH and nearby countries, which do not have IGS stations. Also GIMs do not include stations in BiH.

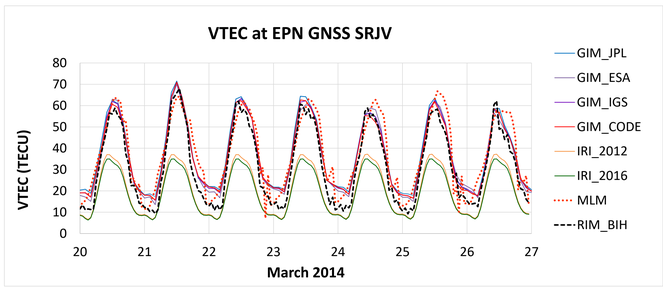

Fig. 5: VTEC at the origin of the development of regional ionospheric model, EPN SRJV. Comparison with GIMs, IRIs and MLM.

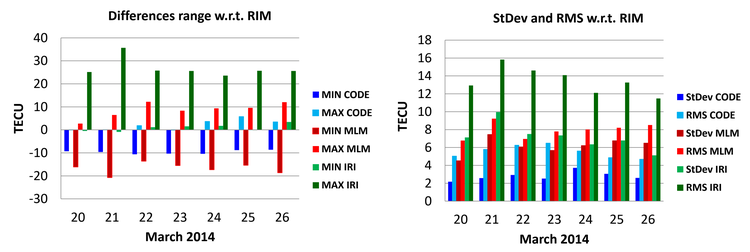

Fig. 6: a) Differences of CODE, MLM, IRI w.r.t. RIM b) Standard deviations and Root mean square. **The best agreement between RIM and CODE GIMs** (differences < 10, StDev < 4 and RMS ~ 5 TECU).

SUMMARY AND CONCLUSION

The Regional Ionospheric Model over BiH is developed and tested for the period of the spring equinox and high solar activity.
Results demonstrated that the model is **well consistent** with **GIM** during solar maximum, especially concerning GIM from **CODE** in detailed analyses.

In the further steps, model will be tested for **different periods of solar activity and geomagnetic conditions**.
Future work could be done toward **implementation of this model in near-real time processing** in order to improve the positioning accuracy.
Local ionospheric variations and irregularities could be also monitored.
L4 residuals, which can be produced as separate output files during ionospheric parameter estimation, can be used for studying **short-term TEC variations** like **scintillations or Travelling Ionospheric Disturbances (TIDs).**

Aknowledgements

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