DEVELOPMENT OF GPS-BASED LOCAL IONOSPHERE TEC MODEL WITH TAYLOR SERIES EXPANSIONS

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OBJECTIVES

- Development of local ionosphere model (LIM) for Bosnia and Herzegovina (BiH)
  - Utilizing GPS observations of permanent reference stations:
    - Bosnia and Herzegovina Positioning Service (BIHPOS)
    - EUREF Permanent GNSS Network (EPN)
    - 8 BIHPOS stations circularly located around EPN station in Sarajevo (SRJV)
    - Maximum distance from EPN SRJV: 80 km
  - Temporal resolution: 1h
  - Spatial resolution: 1° x 1°

Map of BiH, stations: BiHPOS (white) and EPN (pink coloured triangles).
INPUT DATA

- RINEX observation files obtained from BiHPOS and EPN
- Earth rotation parameters obtained from CODE
- Precise orbit files obtained from CODE
- Differential satellite (P1-C1) code biases (DCBs) from CODE
- Clock (CLK) files obtained from CODE
DATA PROCESSING AND IONOSPHERE MODEL ESTIMATION IN BERNESE GNSS SOFTWARE V.5.2

I. Preparation of orbit and Earth orientation information
   • POLUPD (ERP files), PRETAB (tabular orbits), ORBGEN (standard orbits)

II. Preparation of satellite clock correction files (RNXCLK and CCRNXC)

III. Import RINEX observation data into Bernese format (RXOBV3)
     • Receiver clock synchronization (CODSPP)

IV. Estimation of ionosphere model (IONEST)
IONOSPHERE MODEL ESTIMATION – IONEST

- Local TEC models based on two-dimensional Taylor series expansions.
- Geometry-free (L4) linear combination of zero-difference PHASE observations (GPS).
- Set up a new ambiguity parameter for each cycle slip detected (IONEST preprocessing).

### The model specific options (the recommended ones):

1. “Elevation cutoff angle” : 15°
2. “Height of the single layer” : 450 km
3. “Degree of development in latitude”: 1 (nmax in Eq.)
4. “Degree of development in hour angle”: 2 (mmax in Eq.)
5. Maximum degree in mixed coefficients” : 2 (n+m)

\[
E(\beta, s) = \sum_{n=0}^{n_{\text{max}}} \sum_{m=0}^{m_{\text{max}}} E_{nm}(\beta - \beta_0)^n (s - s_0)^m
\]

- **E_{nm}** - TEC coefficients of the Taylor series,
- **\beta_{0}, s_{0}** - coordinates of the origin of the development,
- **\beta** - geographic latitude of the ionospheric intersection point of the receiver-satellite signal line.
- **s** - the sun-fixed longitude of the ionospheric pierce point.
# Model’s Evaluation

## Global Ionospheric Maps (GIM)
- **CODE, ESA, JPL, IGS**
- **Spatial resolution** $5^\circ \times 2.5^\circ$ (lon. and lat.)
- **Temporal resolution** $2h$ (in 2018 CODE: $1h$).
- **VTEC modeling:**
  1. spherical harmonics expansion (CODE, ESA)
  2. bi-cubic splines on a spherical grid (JPL)
  3. IGS combined maps

## International Reference Ionosphere (IRI)
- **IRI 2012 and IRI 2016**
- **Spatial resolution** $1^\circ \times 1^\circ$
- **Temporal resolution:** $1h$
- **The data sources:** ionosondes, incoherent scatter, topside sounders, in situ instruments on satellites and rockets.
- **Currently:** The service under reconstruction!

## Multi-layer Ionospheric Model (MLM)
- **For European region from TU Vienna**
- **Spatial resolution** $1^\circ \times 1^\circ$
- **Temporal resolution** $1h$
- **VTEC modelling** using 5 parameters (global VTEC maximum and 2 weighting functions)
- **Utilizing global network of IGS stations**
SELECTION OF STUDY PERIODS

- **20.03.2014 – 26.03.2014**
  - High solar activity (>150 sfu)
  - Solar maximum in April 2014
  - Spring equinox
  - Geomagnetic activity low to moderate

- **20.03.2018 – 26.03.2018**
  - Low solar activity (< 70 sfu)
  - Spring equinox
  - Geomagnetic activity moderate to active

Fig.: Solar radio flux f10.7cm in sfu (solar flux units), Dst index in nT (nanotesla), Kp index multiplied by 10 (Quiet Kp<3, Moderate 3≤Kp<4, Active 4≤Kp<5, Storm 5≤Kp). Obtained from OMNIWeb of Goddard’s Space Physics Data Facility.
TEC MAPS LIM_BIH

VTEC diurnal variations to 70 TECU. 21.03.2014.

VTEC diurnal variations to 12 TECU. 21.03.2018.

Note different colourmap limits!

LIM_BiH VTEC daily peaks correspond to GIMs VTEC.

During night GIMs VTEC is overestimated compared to LIM_BiH.

VTEC from IRI models is underestimated compared to other models.

LIM_BiH VTEC variability in 2014 is at least 5x higher than in 2018.
COMPARISON OF VTEC FROM DIFFERENT MODELS

- Daytime: well agreement between LIM and CODE
- MLM higher TEC values
- Biggest differences w.r.t. IRI

- Impact of different phase of Solar cycle on VTEC variability
- Smaller discrepancies between models in solar minimum.
MEAN DIFFERENCES (DVTEC) & STANDARD DEVIATIONS (STDEV)

Mean absolute dVTEC w.r.t. LIM_BiH, 2014
- GIM_CODE
- GIM_ESA
- GIM_JPL
- GIM_IGS
- MLM
- IRI2012
- IRI2016

StDev w.r.t. LIM_BiH, 2014
- GIM_CODE
- GIM_ESA
- GIM_JPL
- GIM_IGS
- MLM
- IRI2012
- IRI2016

Mean dVTEC = |VTEC_LIM| - |VTEC_CODE|
20-26 March 2014

Mean dVTEC = |VTEC_LIM| - |VTEC_CODE|
20-26 March 2018
MEAN DIFFERENCES (DVTEC) & STANDARD DEVIATIONS (STDEV)

- dVTEC in 2014 at least 2x higher than in 2018 (increased VTEC variability).
- dVTEC w.r.t. GIMs ~4 TECU in 2014 and 2 TECU in 2018.
- Slightly higher differences w.r.t. MLM in 2014.
- dVTEC w.r.t. IRI >10 TECU.
- StDev ~2 TECU GIMs in both periods. StDev ~6 TECU MLM and IRI in 2014.
- Twice higher differences from GIMs during nighttime.
- During daytime better agreement (CODE: <3 TECU in 2014 and 1 TECU in 2018).
CONCLUSIONS I

- Local Ionosphere Model (LIM) developed for region of Bosnia and Herzegovina
  - Utilizing GPS observations of permanent stations belonging to BiHPOS and EPN

- Period of processing:
  - Solar maximum and spring equinox (20-26 March 2014)
  - Solar minimum and spring equinox (20-26 March 2018)

- VTEC variability (LIM_BiH) at least 5x more expressive in March 2014, than in March 2018
  - Different behavior of ionosphere activities in low and high solar activity periods
  - Effect of different phase of solar cycle -> different level of solar activity

- LIM_BiH VTEC daily peaks correspond to GIMs VTEC during solar maximum and minimum
  - Mean difference <3 TECU in 2014 and 1 TECU in 2018.
  - The biggest discrepancy contribution is during nighttime, where GIMs overestimate VTEC values.
CONCLUSIONS II

- MLM higher deviations from LIM_BiH in 2014 (~6 TECU), while in 2018 agreement is better (~2 TECU).

- The biggest differences are observed compared to IRI
  - Daytime to 40 TECU, nighttime < 10 TECU (IRI VTEC is underestimated).

- Discrepancies between models higher in 2014 (higher level of ionization).

- Future work could be done towards implementation of this model in near-real time processing!

Note:
- MLM does not include observations from BiH and nearby countries, where are no IGS stations.
- GIMs do not include stations in BiH.
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THANK YOU FOR YOUR ATTENTION!

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