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

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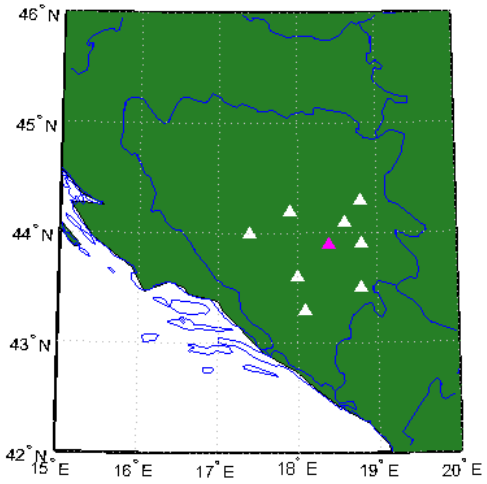
OBJECTIVES

- 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)

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

E_{nm} - TEC coefficients of the Taylor series,

β_0, s_0 - coordinates of the origin of the development,

β - 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°x 2.5°** (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° x 1°**
- Temporal resolution: **1h**
- **The data sources**: ionosondes, incoherent scatter, topside sounders, in situ instruments on satellites and rockets.
- Currently: The service under reconstruction!

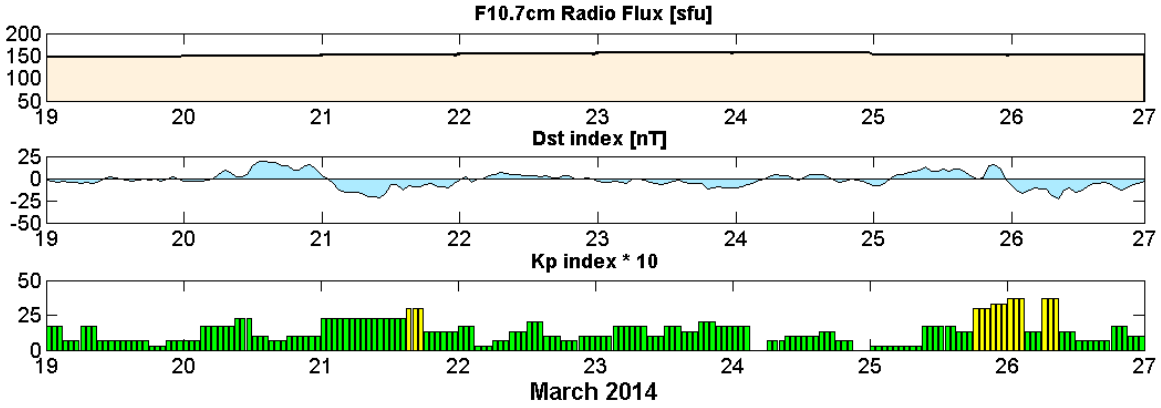
Multi-layer Ionospheric Model (MLM)

- **For European region from TU Vienna**
- Spatial resolution **1° x 1°**
- 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



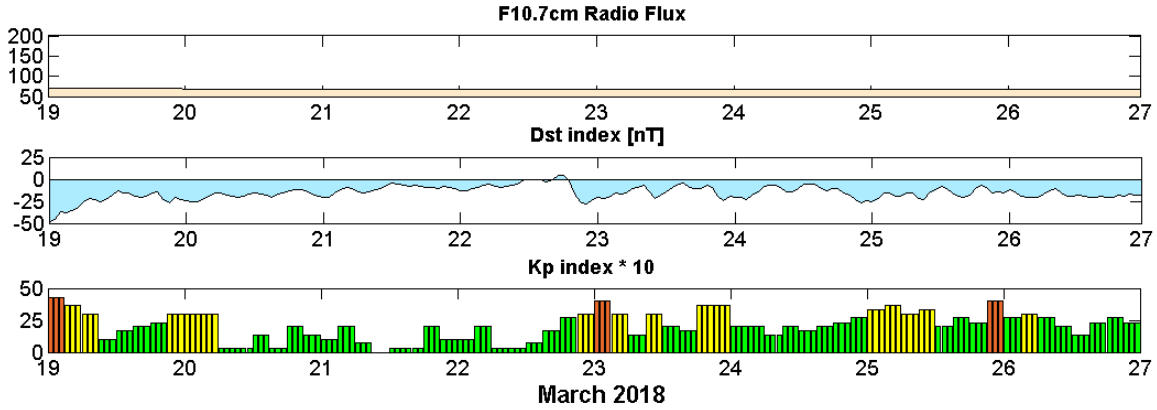
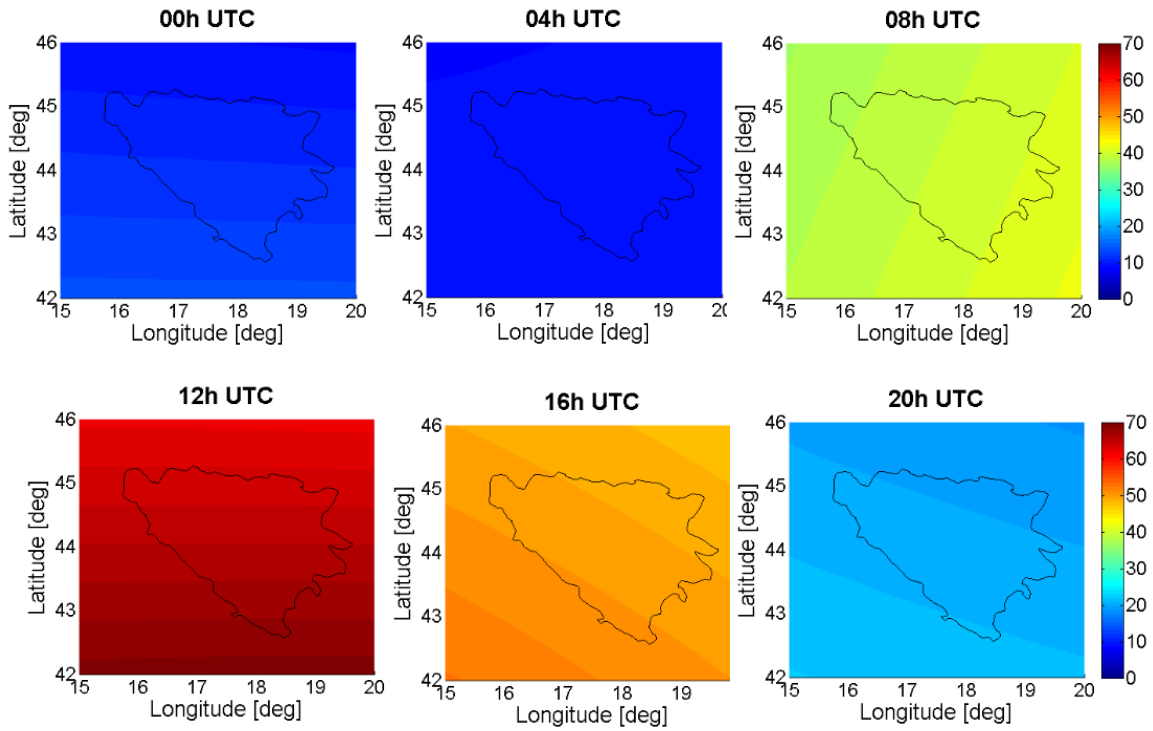


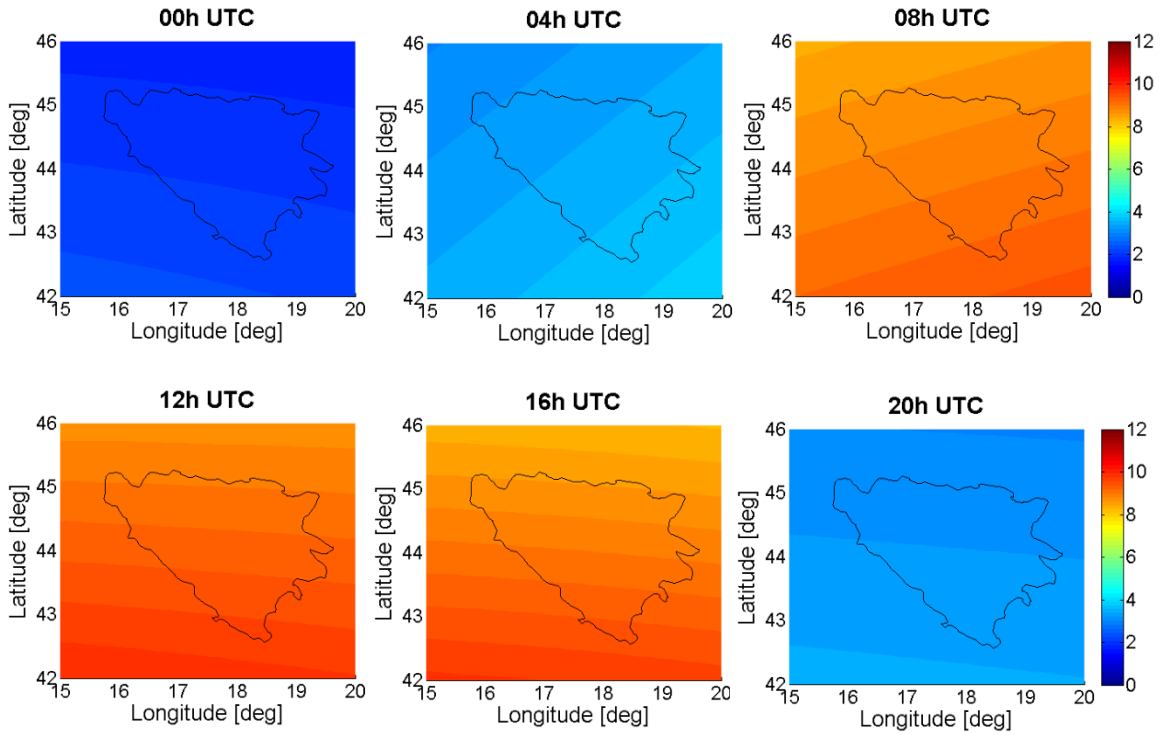
Fig.: Solar radio flux f10.7cm in sfu (solar flux units), Dst index in nT (nanotesla), Kp index multiplied by 10 (**Quiet Kp<3**, **Moderate 3≤Kp<4**, **Active 4≤Kp<5**, **Storm 5≤Kp**). Obtained from OMNIWeb of Goddard's Space Physics Data Facility.

TEC MAPS LIM_BIH



VTEC diurnal variations to 70 TECU.

21.03.2014.

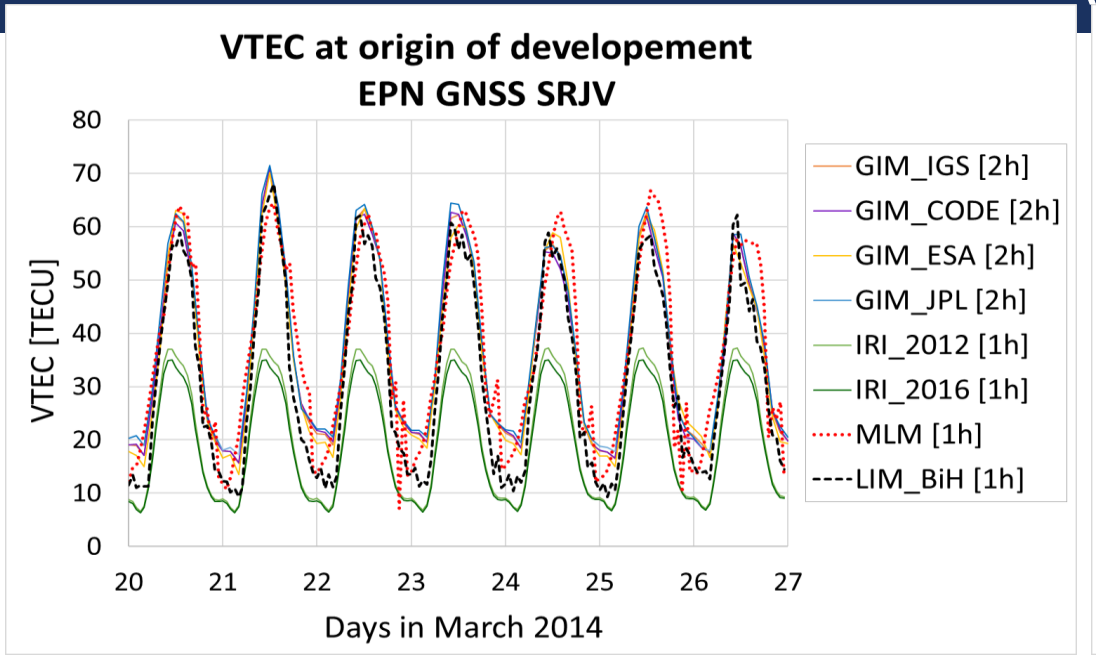


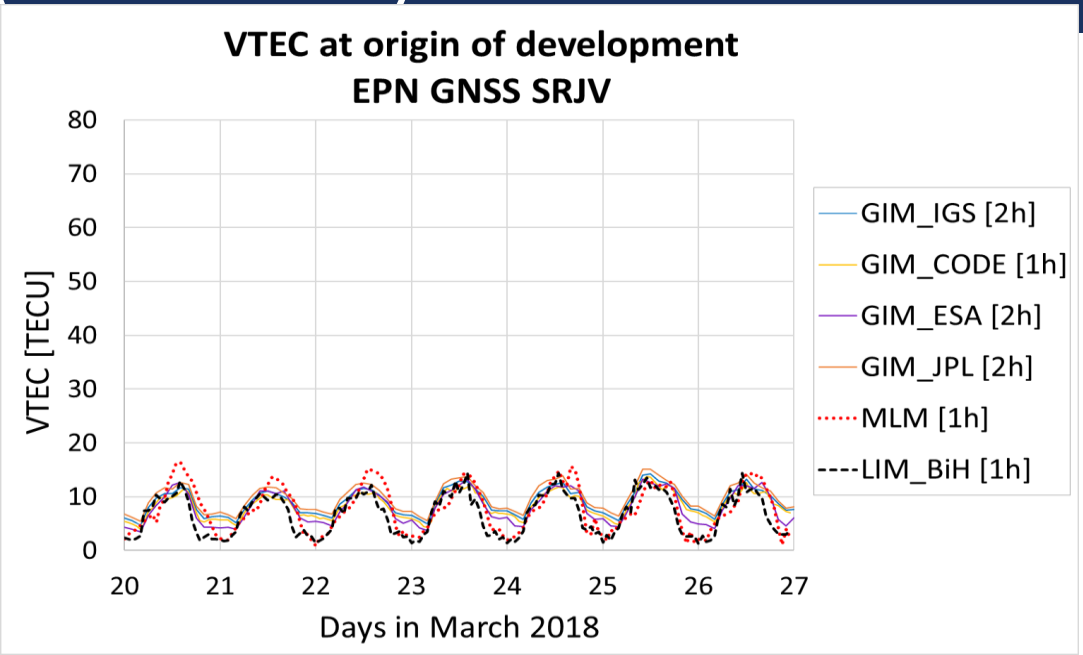
VTEC diurnal variations to 12 TECU.

21.03.2018.

Note different colourmap limits!

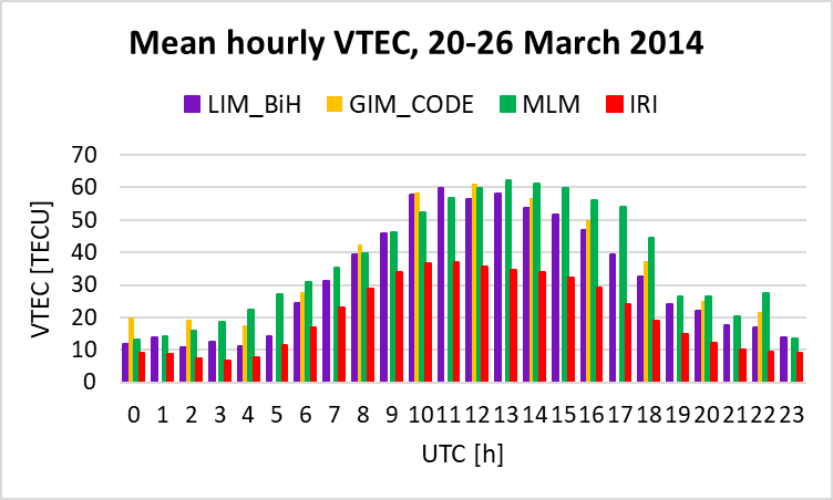
VTEC AT ORIGIN OF DEVELOPMENT OF LIM_BIH 44°N 18°E (EPN SRJV)

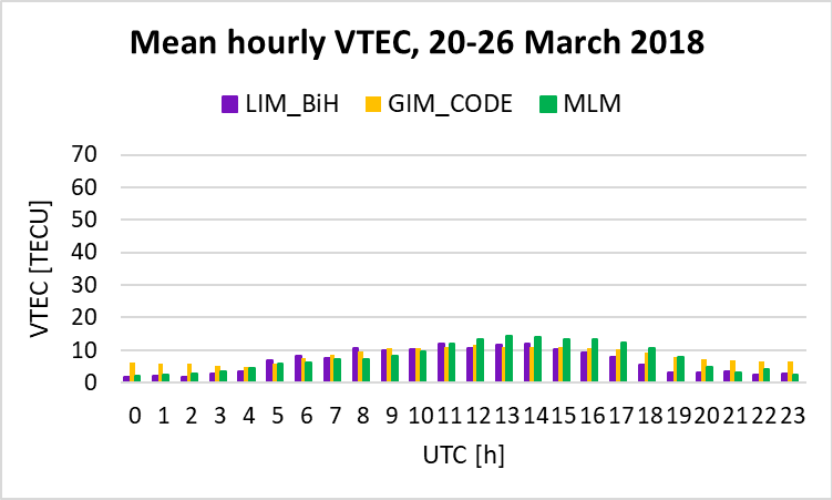




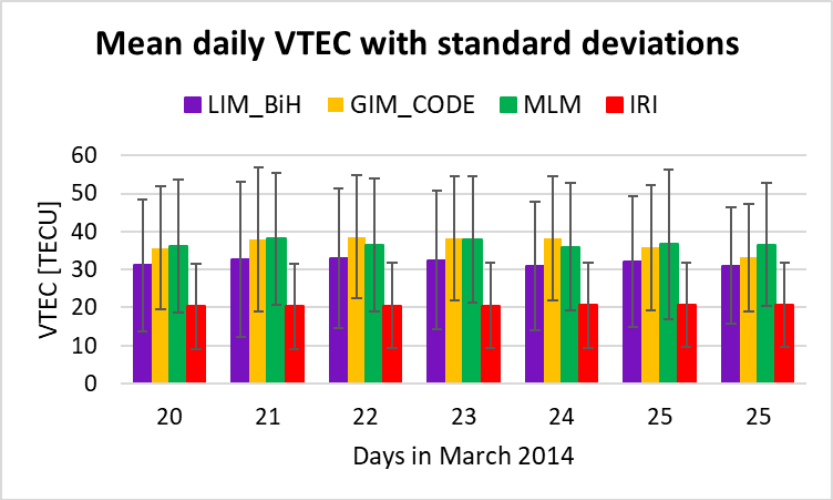
- Different behavior of ionosphere VTEC in high (2014) and low (2018) solar activity periods
- LIM_BiH VTEC daily peaks correspond to GIMs VTEC.
- During night GIMs VTEC is overestimated compared to LIM_BiH.
- VTEC from IRI models is underestimated compared to other models.
- LIM_BiH VTEC variability in 2014 is at least 5x higher than in 2018.

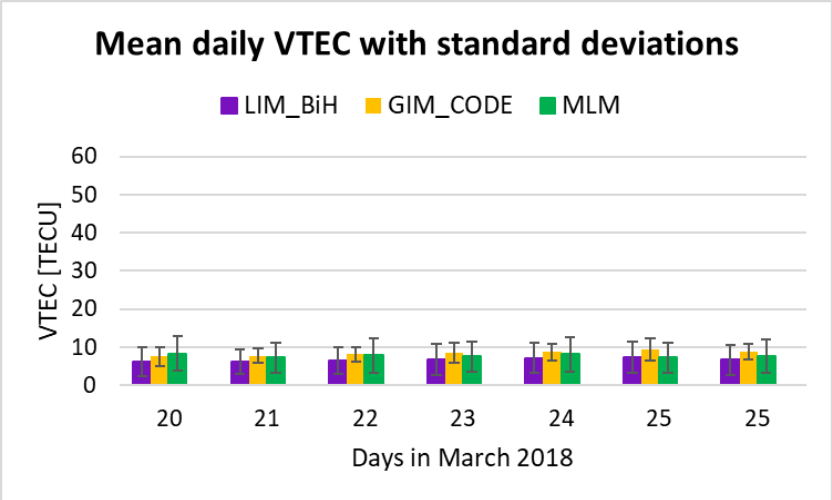
COMPARISON OF VTEC FROM DIFFERENT MODELS





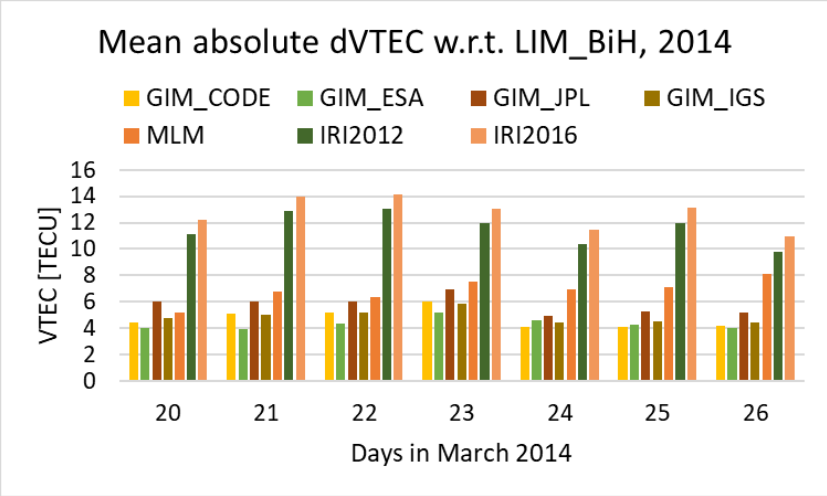
- Daytime: well agreement between **LIM** and **CODE**
- **MLM** higher TEC values
- Biggest differences w.r.t. **IRI**

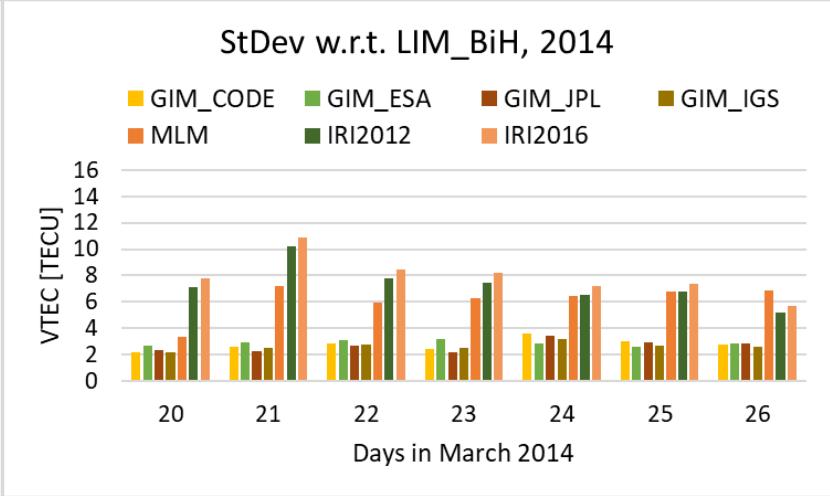


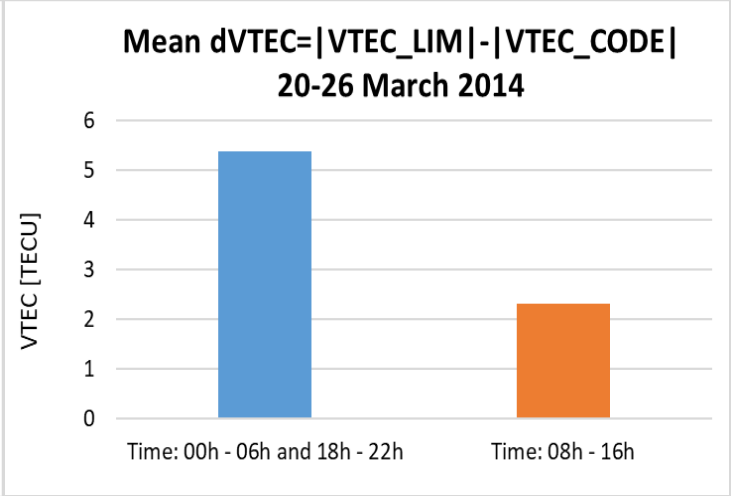


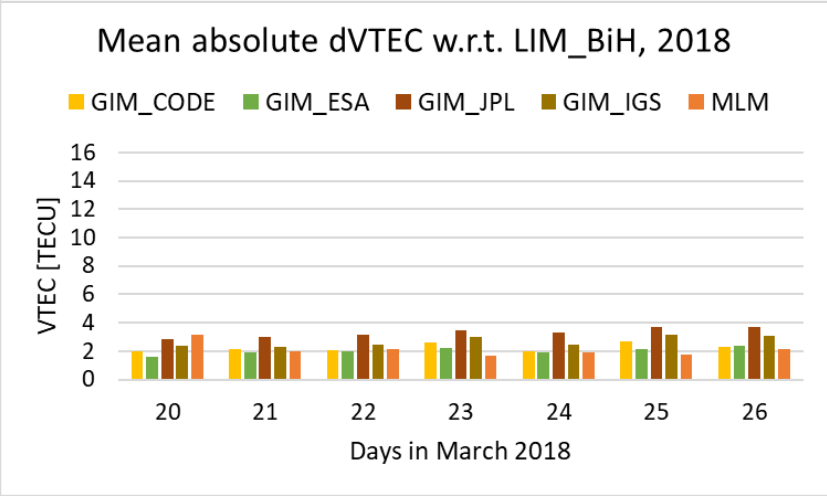
- Impact of different phase of Solar cycle on VTEC variability
- Smaller dicrepancies between models in solar minimum.

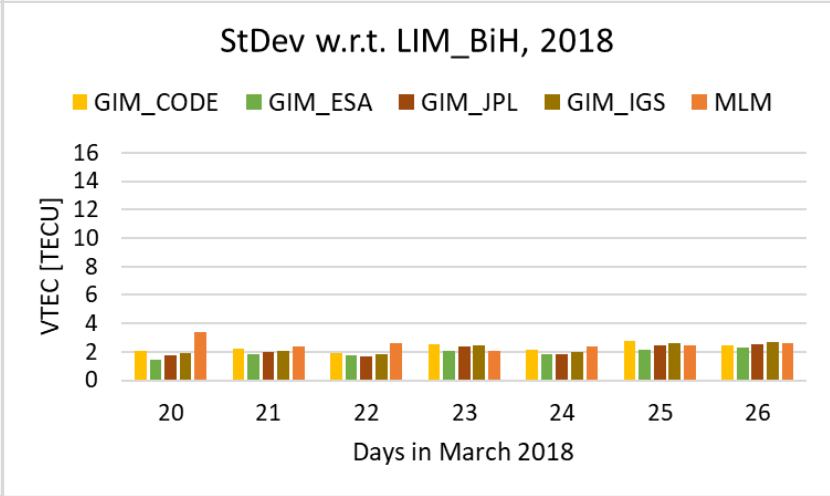
MEAN DIFFERENCES (DVTEC) & STANDARD DEVIATIONS (STDEV)

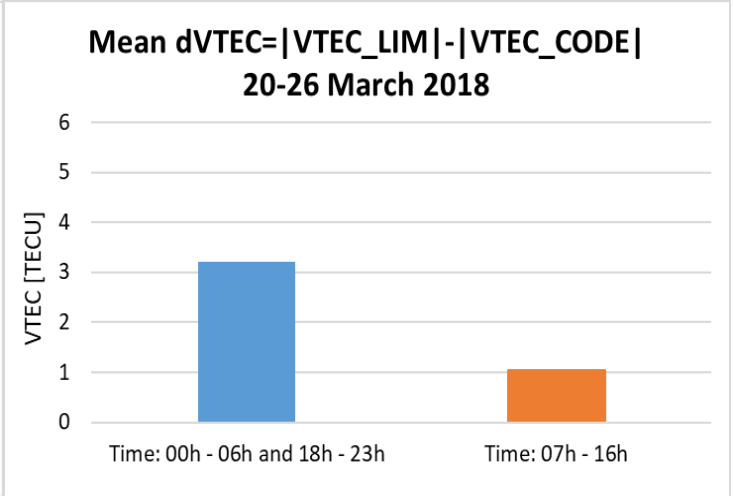












MEAN DIFFERENCES (DVTEC) & STANDARD DEVIATIONS (STDEV)

- 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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