Impact of geomagnetic storms and ionospheric disturbances on mid-latitude station's coordinates using static and kinematic PPP

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Introduction

Geomagnetic storms can cause irregularities in the ionospheric electron density, which can affect GNSS positioning and even cause signal's scintillations. The first order ionospheric effect can be eliminated through an ionosphere-free solution, but higher order terms remain and may cause artificial coordinate variations to be considered in precise GNSS applications.

In this study, we investigate effects of severe space weather events on coordinate estimation using Precise Point Positioning (PPP) in mid-latitude region and the significance of remaining high-order ionospheric (HOI) terms. The European Permanent Network (EPN) station SRJV (Sarajevo, Bosnia and Herzegovina) was used as station of interest. The analysis covers the periods March 2015 and September 2017, when the two strongest geomagnetic storms of the solar cycle 24 occurred.

Methodology

Study periods:

- March 2015 (a year after the solar maximum),
- September 2017 (toward next solar minimum).

Solar cycle (SC) 24 reached its maximum in April 2014.

Data used in this research:

- Space weather indices [1]
- List of the international most disturbed (D) and quietest days (Q) [2]
- GNSS (GPS+GLONASS) observations of the EPN station SRJV [3]
- CODE products (orbits, EOPs, clocks and ION files) [4]
- EPN weekly solutions [3].

GNSS (GPS+GLONASS) observations were applied to:

- Calculate **the total electron content (TEC)** in the ionosphere
  - The single-layer model at the fixed height of 400 km
  - Calibration by Ciraolo methodology [5]
  - Sampling time rate 300 s
- Perform two methods of coordinate estimation (IGS08):
  - **Static PPP**, providing daily-based results
    - HOI corrections not applied (**L3**)
    - HOI corrections applied (**L3 + HOI**)
  - **Pseudo–Kinematic PPP** with 300 s sampling interval.

The PPP methods were carried out using the Bernese v.5.2 GNSS scientific software package [6]. The HOI delays were obtained by difference between the static PPP estimations. Positioning results were compared to the EPN weekly combined position solutions.

YYYY	MM	Q1	Q2	Q3	Q4	Q5
2015	03	10	30	5	14	9
		Q6	Q7	Q8	Q9	Q10
		15	13	27	26	12
		D1	D2	D3	D4	D5
		17	18	2	19	1

YYYY	MM	Q1	Q2	Q3	Q4	Q5
2017	09	26	9	25	23	22
		Q6	Q7	Q8	Q9	Q10
		21	10	24	03	19
		D1	D2	D3	D4	D5
		08	28	27	15	07

Tab. 1: List of the international D- and Q- days (left: March 2015, right: September 2017)

Results

Space Weather Indices

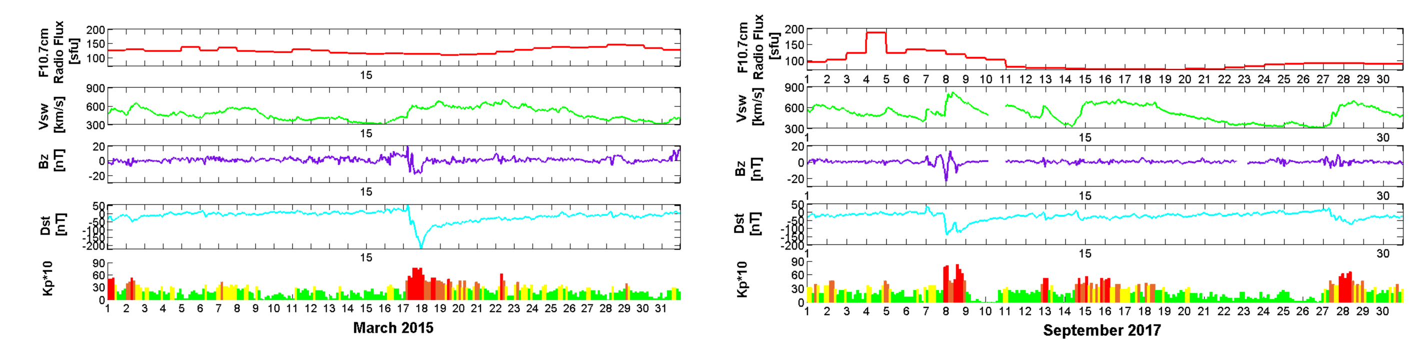

Fig.1: From top to bottom: Solar radio flux F10.7cm, Solar wind speed, Bz component of the interplanetary magnetic field, Dst index, Kp*10 (Quiet Kp<3, Moderate 3≤Kp<4, Active 4≤Kp<5, Storm 5≤Kp). Solar activity in March 2015 was moderate (~110 to 150 sfu). In September solar activity was mainly low (<100 sfu), except moderate and high activity (>180 sfu) observed at the beginning of the month (until 11/09), unusual for this period of SC. Geomagnetic storms on 17/03/2015 (St. Partick's Storm) (Dst<-200nT, Kp=8-) and 08/09/2017 (Dst=~-150nT, Kp=8+) are the first and the second strongest geomagnetic storms in SC 24, respectively.

PPP Processing Results

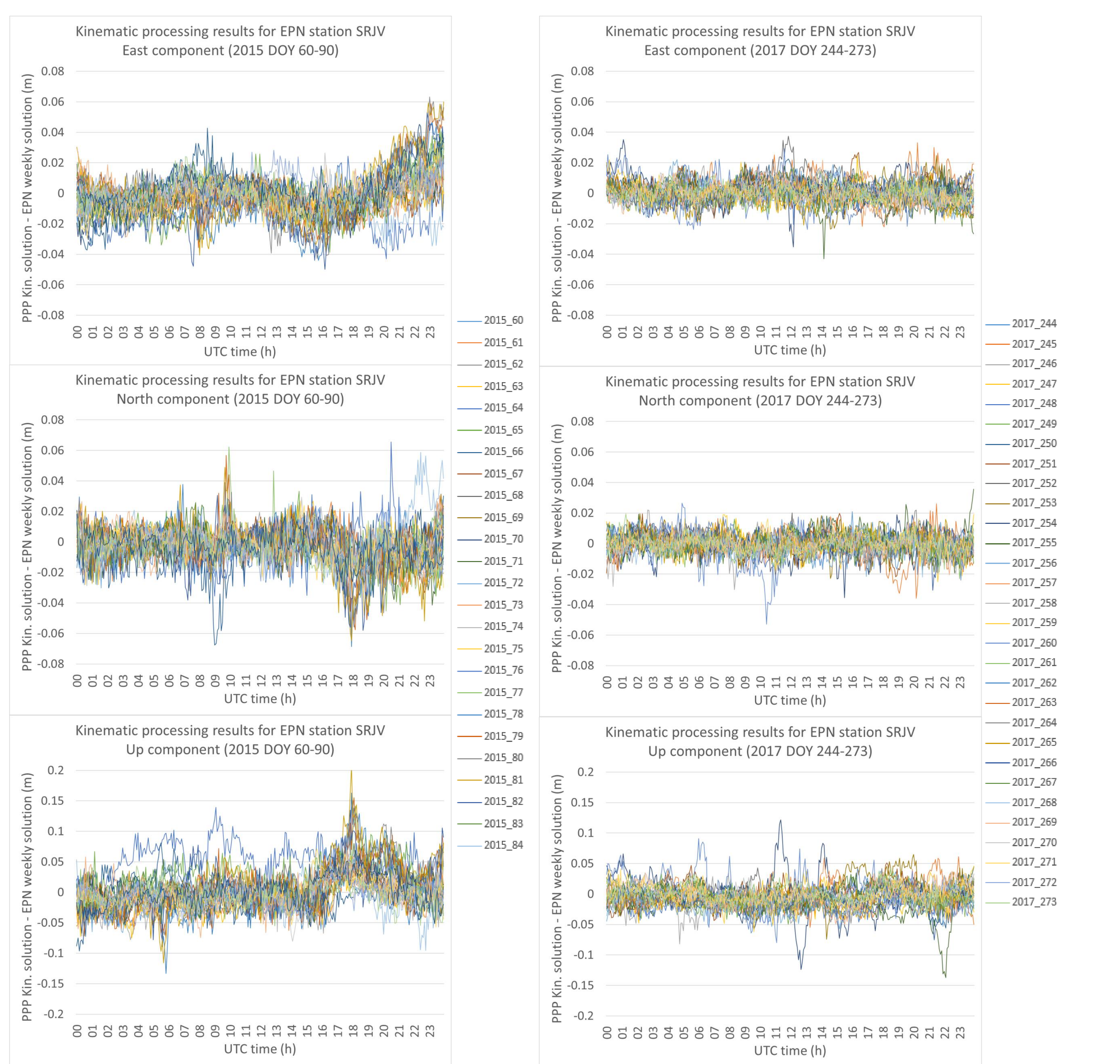

Fig.4: Hourly kinematic processing results in ENU components - PPP Kinematic solution minus EPN weekly solution (left: March 2015, right: September 2017). Higher differences during the day are noticeable for the period of March 2015 (max. 0,22 m in Up component) compared to September 2017 (max. 0,13 m in Up component).

Ionospheric TEC

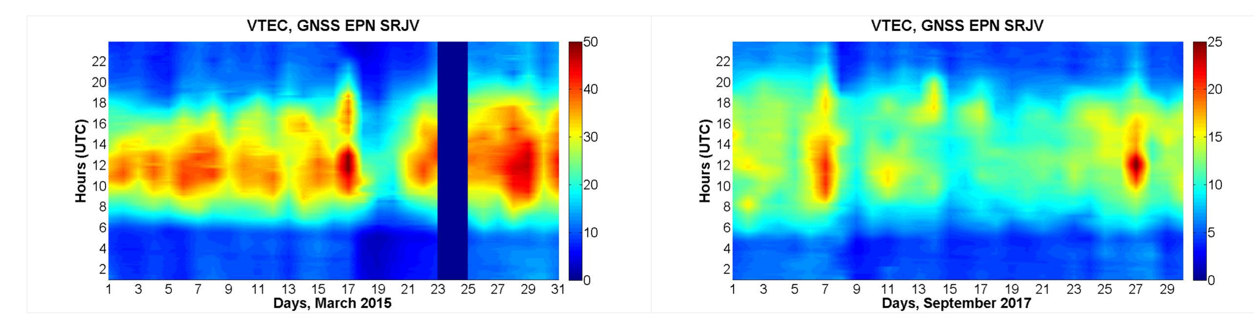

Fig.2: VTEC for March 2015 (left) and September 2017 (right). VTEC increase (positive phase of ionospheric storm), followed by VTEC decrease (negative phase of ionospheric storm) are presented during geomagnetic storms periods. About twice higher TEC values were in March 2015.

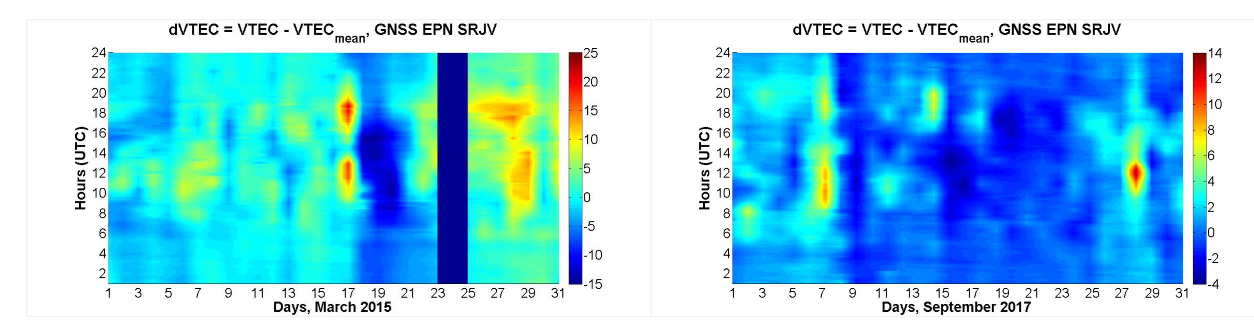

Fig.3: Differences between observed VTEC and mean VTEC for the quietest days in the month regarding geomagnetic conditions (Tab 1). Higher deviations observed for the geomagnetic storms on 17/03/2015 (to ~25TECU) followed by a decrease (to ~-15 TECU) until 22/03/2017 as well as increase on 08/09 (to ~10TECU) and 28/09/2017 (to ~14 TECU) followed by decrease (to ~-4 TECU) 2 days after.

Concerning entire period, deviations are approximately twice higher during March 2015 than in September 2017.

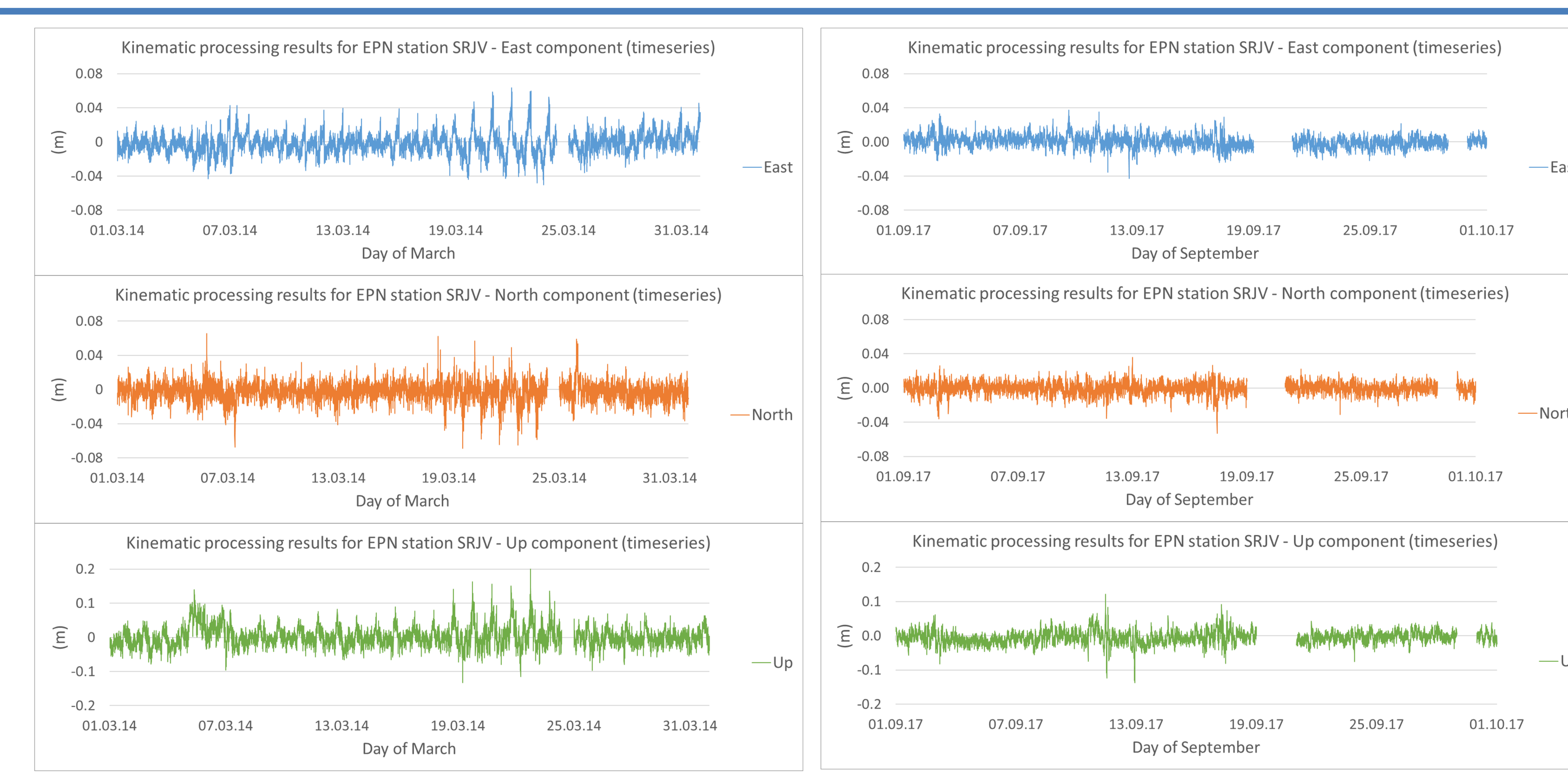

Fig.5: Daily kinematic processing results in ENU components - PPP Kinematic solution minus EPN weekly solution (left: 03/2015, right: 09/2017). Higher differences compared to EPN are noticeable 4-7 and 18-23 March and 10-12 and 17 September. 18-23 March and 10-12 September correspond to the **recovery phase** of the geomagnetic storm, during TEC decrease (negative phase of ionospheric storm). Additionaly, the Earth was under the influence of **High-speed solar-wind stream** (HSS).

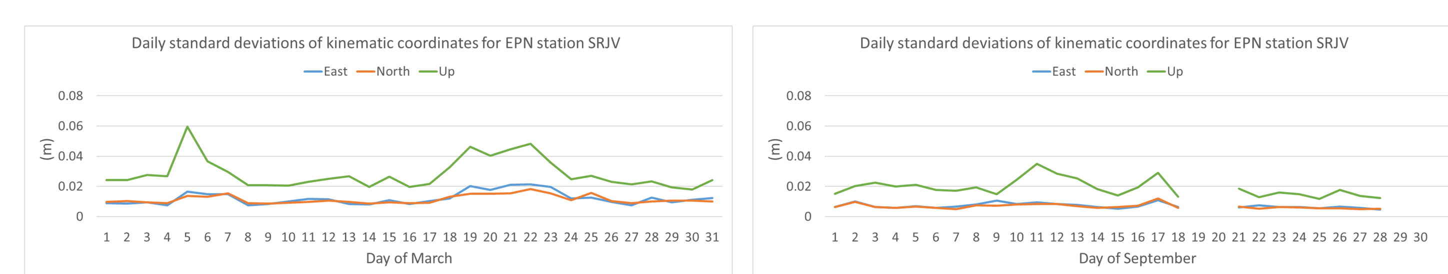

Fig.6: Daily standard deviations in ENU components with respect to the differences from the EPN weekly solution (left: March 2015, right: September 2017). Outliers in ENU components caused standard deviation increase.

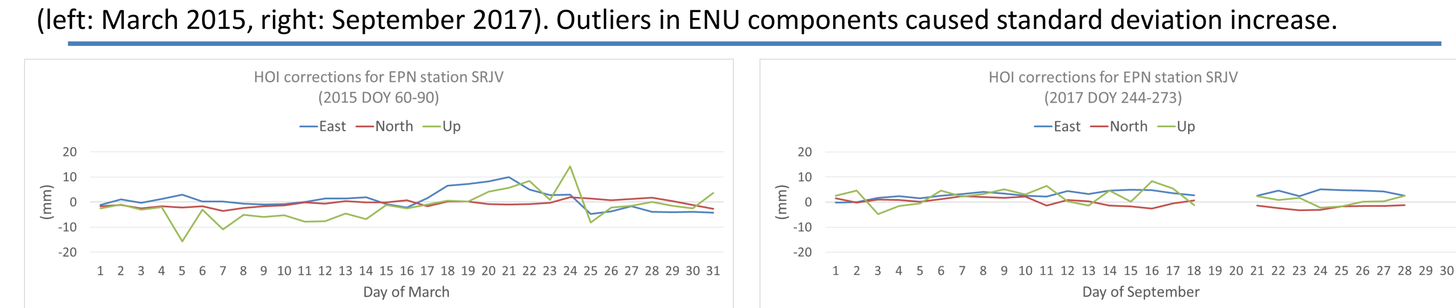

Fig.8: HOI corrections in ENU components – PPP static (HOI applied) minus PPP static (left: March 2015, right: September 2017).

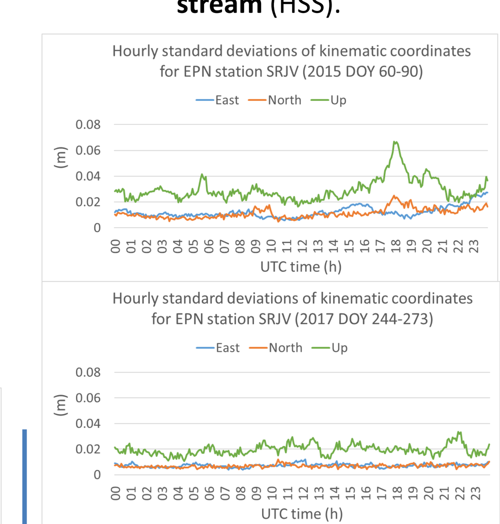

Fig.7: Hourly standard deviations in ENU components with respect to the differences from the EPN weekly solution (top: March 2015, bottom: September 2017).

Conclusions

- TEC variations about twice higher in March 2015 than in September 2017
- Geomagnetic activity impact increase of VTEC values followed by decrease in next days
- Kinematic coordinate variations in ENU components 2-3 times higher in March 2015 (-0,13 – 0,22 m in Up) compared to September 2017 (-0,13 – 0,13 m in Up)
- Standard deviation values increased according to outliers in ENU components
- Kinematic coordinate variations higher during recovery phase of the strongest geomagnetic storms
- HOI corrections show for East component higher values (~10mm) after 17 March (St. Partick's geomagnetic storm) which can be attributed to the recovery phase.

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[4] Center for Orbit Determination in Europe (CODE): http://www.aiub.unibe.ch/research/code___analysis_center/index_eng.html
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