Impact of Geomagnetic Storms and Ionospheric Disturbances on Mid-Latitude Stations’ 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 SRV (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 (CQ) [2]
- GNSS (GPS+GLONASS) observations of the EPN station SRV [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 Ciraoio methodology [5]
- Sampling 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.

Results

Space Weather Indices

Fig.1: From top to bottom: Solar radio flux F10.7, Solar wind speed, Bz component of the interplanetary magnetic field, Chr index, Kp10 (green, yellow, blue) Auroral Borealis, Auroral Storm Stagg. Solar activity in March 2015 was moderate (~130 to 150 nGy), except moderate and high activity (~350 nGy) observed at the beginning of the month (up to 14/03, unusual for this period of SC. Geomagnetic storms on 17/03/2015 (St. Patrick's Storm) and 08/09/2017 (min=150 nGy, Kp=14) are the first and the second strongest geomagnetic storms in SC 24, respectively.

Ionospheric TEC

Fig.2: TEC for March 2015 (left) and September 2017 (right). TEC increase (positive phase of geomagnetic storm) is followed by TEC decrease (negative phase of geomagnetic storm) by means of VTEC values were in March 2015.

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

PPP Processing results

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 (by ~15 TECU) followed by a decrease (~15 TECU) until 22/03/2015 as well as increase on 08/09 (to ~10 TECU) and 28/09/2017 (to ~14 TECU) followed by decrease (by ~4 TECU) 2 days after.

Fig.4: Daily standard deviations in ENU components with respect to differences from the EPN weekly solution (left: March 2015, right: September 2017). Outliers in ENU components caused standard deviation increase.

Fig.5: Daily kinematic processing results in ENU components with respect to differences from the PPP kinematic solution (left: March 2015, right: September 2017). Higher differences compared to EPN are noticeable 4-7 and 18-22 March and 10-12 and 17 September. 18-23 March and 10-12 September correspond to the recovery phase of the geomagnetic storms, during TEC decrease (negative phase of ionospheric storms). Additionally, the earth axis was under the influence of high-speed solar-wind stream (FSS).

Fig.6: Hoyt corrections in ENU components – PPP static (HDI applied) minus PPP static (left: March 2015, right: 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. Patrick’s geomagnetic storm) which can be attributed to the recovery phase.

Acknowledgements

The authors acknowledge to Ljupčo Cristov and ICTP Abdus Salam in Trieste for providing the program for TEC calibration. Many thanks to following institutions and organizations, which kindly provide their data online: Goddard Space flight center; World Data Center for Geomagnetism operated by Data Analysis Center for Geomagnetism and Space Magnetism at Kyoto University, Japan, European Permanent Network and the Center for Orbit Determination (CODE).

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