Ionosonde spread F and GPS L-band scintillation occurrence during moderate geomagnetic storms near the southern crest of the EIA in Argentina

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In this work we present the study of the occurrence of ionospheric irregularities during geomagnetic storms at a low latitude station in the Southern American longitudinal sector (Tucuman – Argentina, 26.9 ° S, 294.6 ° E; magnetic latitude 15.5 ° S), near the southern crest of the equatorial ionization anomaly (EIA). We analyze data recorded during three moderate geomagnetic storms; May 27, 2017 (a month of low occurrence rates of spread – F), October 12, 2016 (a month of transition from low to high occurrence rates of spread-F) and November 7, 2017 (a month of high occurrence rates of spread-F) from Global Positioning System (GPS) receivers and ionosondes. The Total electron content (TEC) estimated with a GPS-TEC calibration technique, GPS Ionospheric L-band scintillation, the virtual height of the F-layer bottom side (h'F) and the critical frequency of the F2-layer (foF2) scaled from the ionograms, are considered. Furthermore, each ionogram is manually examined for the presence of spread-F signatures.
The main results are:

- For the storm occurred on May 27, range spread-F (RSF) is present during the second part of the main phase, between 23 - 5 LT in coincidence with a rapid F layer uplift and a positive ionospheric storm effect. GPS-TEC present wave-like oscillations on May 28 at ~ 22 – 4 LT for all the satellites in view, the Fast Fourier Transform (FFT) analysis of the TEC perturbations for each satellite-receiver pair shows dominant periods of ~70 and ~40 minutes. Besides, a weak scintillation activity was observed during the day of the storm, with S4 values between 0.1 and 0.3.
  The spread-F generation is likely associated with the presence of eastward disturbance dynamo electric fields (DDEF) driven by disturbed thermospheric winds. The DDEF during nighttime can cause large increase in plasma vertical drift and lead to instability growth by the Rayleigh-Taylor mechanism.
- For the storm of October 12, strong range spread-F (SSF) is observed during the recovery phase on October 14 at 5:50 – 8:50 LT. Simultaneously, a positive storm effect is present. For the same period the TEC behavior shows a wave-like configuration with periods of ~40 and ~60 minutes. Moreover, strong scintillation activity (i.e., S4 ≥ 0.5) is observed on October 14 at 5 – 8 LT in coincidence with the ionosonde spread-F observations.

The decrease in the AE index indicates an over-shielding situation and a prompt penetration electric field (PPEF) can reach low latitudes. This electric field added to the DDEF cause an upward perturbation in the vertical drift which may result in spread-F/plasma bubbles (PBs) development. Field-aligned irregularities (FAIs) with a few hundred meters confined within the PBs are likely the cause of the amplitude scintillation observed.

- For the storm of November 7, SSF appears on ionograms on November 8 at 4:43 – 6:48 LT, during the recovery phase in coincidence with an enhancement in h'F and foF2. Additionally, wave-like oscillations of TEC are observed at ~4 – 7 LT on November 8, with a dominant period of ~40 minutes. Regarding the scintillation activity, S4 is higher than 0.5 on November 8 at about 5 – 7 LT.

For this storm, the eastward DDEF present during the recovery phase can produce the F layer uplift and contribute to the generation of the spread-F.
It is worth mentioning that the F3 layer was present during the main phase of the storm on November 7 at 9:18 – 12:32 LT in coincidence with a sudden increase in h´F followed by a rapid

decrease. This is a characteristic feature of F3 layer development and could be an indicator of daytime eastward PPEF.

In conclusion, in the three case studies from three different seasons, spread-F development due to eastward over-shielding PPEF and DDEF is observed, even during low PBs occurrence season. What is more, during October and November, strong GPS L band scintillation is observed associated with SSF, that is, irregularities extending from the bottom-side to the top side of the F region.