

## Article

# Ionospheric–Thermospheric Responses to Geomagnetic Storms from Multi-Instrument Space Weather Data

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**Abstract:** We analyze vertical total electron content (vTEC) variations from the Global Navigation Satellite System (GNSS) at different latitudes in different continents of the world during the geomagnetic storms of June 2015, August 2018, and November 2021. The resulting ionospheric perturbations at the low and mid-latitudes are investigated in terms of the prompt penetration electric field (PPEF), the equatorial electrojet (EEJ), and the magnetic H component from INTERMAGNET stations near the equator. East and Southeast Asia, Russia, and Oceania exhibited positive vTEC disturbances, while South American stations showed negative vTEC disturbances during all the storms. We also analyzed the vTEC from the Swarm satellites and found similar results to the retrieved vTEC data during the June 2015 and August 2018 storms. Moreover, we observed that ionospheric plasma tended to increase rapidly during the local afternoon in the main phase of the storms and has the opposite behavior at nighttime. The equatorial ionization anomaly (EIA) crest expansion to higher latitudes is driven by PPEF during daytime at the main and recovery phases of the storms. The magnetic H component exhibits longitudinal behavior along with the EEJ enhancement near the magnetic equator.

**Keywords:** ionosphere; geomagnetic storms; total electron content; prompt penetration electric field

## 1. Introduction

The Sun triggers space weather events such as geomagnetic storms that can cause negative impacts on the communication and navigation through transionospheric electromagnetic signals on the Earth. Geomagnetic storms result from large-scale disturbances of the Earth's magnetosphere under variable solar activity, leading to anomalous ionosphere variability. These disturbances occur at short-term scales (hours to a few days). They are usually triggered by coronal mass ejection (CME), co-rotating interaction regions (CIRs), or fast-moving solar wind streams. Anomalous ionospheric variations were observed from plasma content variability during the geomagnetic storms of 6 April and 29 May 2010 [1,2]. Several studies have investigated the ionospheric variations during storms at different