Effects of major solar flares on ionospheric plasma density over the Southeast Asian Region using GNSS

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Space weather
• Concerned with varying conditions in the environment between the Sun and Earth

Solar flares
• Electromagnetic (EM) Waves ➔ X-ray ➔ EUV ➔ Ionization of atmosphere
<table>
<thead>
<tr>
<th>Classification</th>
<th>Peak flux range at 1–8 Ångstrom (W/m²)</th>
</tr>
</thead>
<tbody>
<tr>
<td>A</td>
<td>&lt; $10^{-7}$</td>
</tr>
<tr>
<td>B</td>
<td>$10^{-7}$ – $10^{-6}$</td>
</tr>
<tr>
<td>C</td>
<td>$10^{-6}$ – $10^{-5}$</td>
</tr>
<tr>
<td>M</td>
<td>$10^{-5}$ – $10^{-4}$</td>
</tr>
<tr>
<td>X</td>
<td>&gt; $10^{-4}$</td>
</tr>
</tbody>
</table>

(Investigated) Solar flares

<table>
<thead>
<tr>
<th>SC</th>
<th>Start (UT)</th>
<th>Max (UT)</th>
<th>End (UT)</th>
<th>Max (LT)</th>
<th>Region</th>
<th>Class</th>
</tr>
</thead>
<tbody>
<tr>
<td>9 Aug 2011</td>
<td>07:48</td>
<td>08:05</td>
<td>08:24</td>
<td>16:05</td>
<td>1263</td>
<td>X6.9</td>
</tr>
<tr>
<td>20 Apr 2022</td>
<td>03:41</td>
<td>03:57</td>
<td>04:04</td>
<td>11:57</td>
<td>2992</td>
<td>X2.25</td>
</tr>
<tr>
<td>21 Apr 2022</td>
<td>01:47</td>
<td>01:59</td>
<td>02:05</td>
<td>09:59</td>
<td>2993</td>
<td>M9.7</td>
</tr>
</tbody>
</table>
Objective

• To analyze the ionospheric effects generated by strong SFs on 9 August 2011, 20-21 April 2022

GNSS stations (low-latitude regions)

9 August 2011
PIMO: 14.63571966°N, 121.07773220°E
(Quezon city)

20-21 April 2022
PTGG: 14.5354022°N, 121.04126541°E
(Taguig city)
Absorption of increased solar X-ray and EUV

Increased ionization in D & E ionospheric regions

Electron density changes

**Total electron content (TEC)**
in 1 TECU = $10^{16}$ electrons/m$^2$
The global geomagnetic field is quiet (no large-scale disturbance)
For flares with visible changes
August 09, 2011 (X6.9)

PRN7

∆STEC (TECU)

UT (hours)

PRN11

PRN24

PRN27

April 21, 2022 (M9.7)

PRN4

Flare start

EUV peak

Flare end

Xray peak/Flare peak

<table>
<thead>
<tr>
<th></th>
<th>∆STEC (TECU)</th>
<th></th>
<th>∆STEC (TECU)</th>
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</thead>
<tbody>
<tr>
<td>PRN7</td>
<td>0.62</td>
<td>PRN4</td>
<td>0.71</td>
</tr>
<tr>
<td>PRN11</td>
<td>0.67</td>
<td>PRN8</td>
<td>0.45</td>
</tr>
<tr>
<td>PRN24</td>
<td>0.43</td>
<td>PRN27</td>
<td>0.50</td>
</tr>
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</table>
Summary & Conclusions

• Solar radiation (Xray, EUV) are observed.
• Using two GNSS stations, STEC increases are found to be coincident with EUV enhancements because the TEC is mostly from the E & F regions, through which the EUV penetrates.
• Conversely, the ionization of the D region due to solar flares (Xray radiation) is insignificant compared to that of the E & F.

The EUV portion of the spectrum is dominantly responsible for the ionization in the E & F regions, which was reflected in more TEC increases for an X17.2 than for an X28.

• Strong solar flares don’t necessarily produce the largest TEC enhancements.

Recommendations

• Include other parameters: solar zenith angle, ionospheric pierce points
• Additional stations
Acknowledgement

We would like to acknowledge the following:

- Geostationary Operational Environmental Satellite
  - X-ray & EUV flux data
- GFZ-Potsdam, NASA/GSFC & Kyoto University
  - global geomagnetic data
- NASA Crustal Dynamics Data Information System
  - TEC calculations