Traveling ionospheric disturbances observed by GPS networks

Tak Tsugawa (Postdoctoral Fellow)

Massachusetts Institute of Technology Haystack Observatory

on leave from Solar-Terrestrial Environment Laboratory, Nagoya University, Japan
Derivation of TEC Using GPS

- Total electron content (TEC) can be derived by comparing the phase delays of the two GPS signals.
- TEC is a measure of integrated electron density in 1m$^2$ column.
- 1 TECU = $10^{16}$ electrons/m$^2$
GPS Networks in the World

(a) GEONET GPS STATIONS

(b) IGS GPS STATIONS

(c) CORS GPS STATIONS
Medium-Scale Traveling Ionospheric Disturbances (MSTID)

- South-southeast propagation
- Winter daytime

- Southwest propagation
- Summer and Winter nighttime

- South-southeast propagation
- Winter daytime
### Morphology of MSTID in Japan

<table>
<thead>
<tr>
<th>Nighttime MSTID</th>
<th>Daytime MSTID</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Occurrence Rate</strong></td>
<td>~ 80 %</td>
</tr>
<tr>
<td><strong>Amplitude</strong> (in 2002)</td>
<td>0.4 - &gt;1.2 TECU</td>
</tr>
<tr>
<td><strong>Wavelength</strong></td>
<td>150-500 km</td>
</tr>
<tr>
<td><strong>Velocity</strong></td>
<td>50-150 m/s</td>
</tr>
<tr>
<td><strong>Direction</strong></td>
<td>southwestward</td>
</tr>
<tr>
<td><strong>Seasonal dependence</strong></td>
<td>summer (1st max), winter (2nd max)</td>
</tr>
<tr>
<td><strong>Geomagnetic activity dependence</strong></td>
<td>no</td>
</tr>
<tr>
<td><strong>Solar activity dependence</strong></td>
<td>negative</td>
</tr>
<tr>
<td><strong>Remarks</strong></td>
<td>Electrodynamite forces play an important role in their generation.</td>
</tr>
</tbody>
</table>

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1 Nov, 2006

MWA-LFD Meeting
An anomalous MSTID on Jul 27, 2004

- Their wavelength and propagation direction are similar to those of typical nighttime MSTIDs.

- Their amplitudes are larger than 10 TECU.
Dawn and Dusk MSTID

Dawn MSTID
- Northeast propagation
- At dawn in summer

Dusk MSTID
- Northwest propagation
- At dusk in summer
Large-Scale Traveling Ionospheric Disturbances (LSTID)
Occurrence of LSTID

- Statistical analysis (Apr. 1999 – Dec. 2002) [Tsugawa et al., 2004]
Summary of Medium- and Large-Scale TIDs

GPS-TEC maps make it possible to reveal spatial structures and temporal variations of the ionospheric phenomena including TIDs.

**Large-Scale Traveling Ionospheric Disturbances (LSTID)**
- Amplitude: \(\sim 20\%\)
- Wavelength: 1,000 - 3,000 km
- Propagation velocity: 300 - 600 m/s, equatorward
- Occurrence: Geomagnetic activity (Kp) dependence

**Medium-Scale Traveling Ionospheric Disturbances (MSTID)**
- Amplitude: \(\sim 10\% \ (0.5 - >1.5 \text{ TECU})\)
- Wavelength: 100-500 km, Propagation velocity: 50-200 m/s
- Nighttime: Southwestward propagation, Summer and Winter
- Daytime: South-southeastward propagation, Winter
- Day-to-day variation: No geomagnetic activity dependence
• A dense GPS receiver network in Japan, consisting of about 1,200 GPS receivers.

• All receivers provide GPS data every 30 sec (now 1 sec).

• Total Electron Content (TEC) maps over Japan can be obtained at 30 sec intervals.

• Absolute TEC is derived with a weighted least squares fitting technique assuming that hourly TEC average is uniform within an area covered by a GPS receiver [Otsuka et al., 2002].
MSTID Activity from 1994 - 2001

MSTID activity ($\Delta TEC/TEC_0$)
Nighttime MSTID (TEC, Airglow)

[Saito et al., 2001]
Relation between MSTID and F-region FAI

TEC variation and 3-m scale F-region field aligned irregularity (FAI) observed in the nighttime of Jun. 11, 1997.

[Saito et al., 2002]
Day-to-day Variation of MSTID Amplitude

May 16-24, 1998

Standard deviation of TEC over the MU radar

[Saito et al., 2001]
Polarized Electric field in Nighttime MSTID

[Shiokawa et al., 2003]
Relation between Electric field and MSTID

\[ J = \sum_{wp} (E + U \times B) \]

- Eastward E-field
- ExB drift
- South North
- Ionospheric layer↓
- Air glow↑

[Shiokawa et al., 2003]
Location and Sight of Air Glow Imagers

Koto Tabang

Geomagnetic equator

Shigaraki

Conjugate of Renner Springs

Renner Springs
Conjugate Observation of MSTID

Jun 1, 2003  630nm airglow

Shigaraki

[Images of data plots showing longitudinal and latitudinal variations at different times, 13:32 UT, 14:02 UT, and 14:32 UT]

Renner Springs

[Images of data plots showing longitudinal and latitudinal variations at different times, 13:32 UT, 14:02 UT, and 14:32 UT]

[Otsuka et al., 2004]
Conjugate Observation of MSTID

Jun 1, 2003    630nm airglow

Shigaraki

Conj. of Renner Springs
Symmetric Structures of MSTID

Conj. of Renner Springs

Shigaraki
Relationship: nighttime MSTID - Es layer

[Otsuka et al., 2006]
Correlation: nighttime MSTID - Es layer

\[ \text{Otsuka et al., 2006} \]

<table>
<thead>
<tr>
<th>year</th>
<th>2001</th>
<th>2002</th>
<th>2003</th>
<th>2004</th>
<th>2005</th>
</tr>
</thead>
<tbody>
<tr>
<td>( f_o E_s )</td>
<td>0.62</td>
<td>0.48</td>
<td>0.58</td>
<td>0.65</td>
<td>0.54</td>
</tr>
<tr>
<td>( f_o E_s - f_b E_s )</td>
<td>0.56</td>
<td>0.48</td>
<td>0.58</td>
<td>0.63</td>
<td>0.61</td>
</tr>
</tbody>
</table>
GPS Total Electron Content

- Introduction of GPS-TEC database
- Two-dimensional TEC map over Japan (since April 20, 1999)
- TEC plot over a single point in Japan

For questions and comments, please contact:
Akinori Saito: saitoua@kugi.kyoto-u.ac.jp

http://stegps.kugi.kyoto-u.ac.jp/
- TEC maps over Japan are available for a quick look.
Future Works for MSTID

- **Northern and southern limit of MSTID’s propagation**
  - MSTID is also observed in the auroral zone [Bristow et al., 1996].
  - Few MSTIDs are observed by the all-sky imager in the equatorial region.

- **Width of MSTID’s wavefront**
  - Southwestward propagation of the nighttime MSTID could be explained by Finite NW-SE structure [Kelley and Makela, 2001].

- **Latitudinal and temporal evolution of MSTID**
  - As MSTIDs propagate, their amplitudes increase and propagation directions turn clockwise.
- Width of MSTID’s wavefront

Finite NW-SE structure
\[\downarrow\]
Northwestward $E_p$
\[\downarrow\]
Southwestward propagation

Figure 2. Polarization of a low Pedersen conductivity region in the presence of a wind-driven current.

[Kelley and Makela, 2001]
● Northern and southern limit of MSTID’s propagation
  - MSTID is also observed in the auroral zone [Bristow et al., 1996].
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● Latitudinal and temporal evolution of MSTID
  - As MSTIDs propagate, their amplitudes increase and propagation directions turn clockwise.
Latitudinal evolution of MSTID

As MSTIDs propagate to lower latitudes, their amplitudes increase and propagation directions turn clockwise.

These evolutions apply to the temporal variation of MSITD.
Temporal evolution of MSTID

630nm Airglow at Sakata 16 Jun, 2004
Future Works for MSTID

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