Regional Ionospheric Irregularities Mapping at Different Temporal Scales Using GNSS Networks and Its Applications

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Outline

- Ionospheric Irregularities/Scintillation
  - ROTI and scintillation indices
  - Irregularities monitoring using GNSS

- Regional Ionospheric Irregularities Mapping
  - Crustal Movement Observation Network of China
  - ROTI at different sampling rates
  - ROTI maps

- Summary
Ionospheric Irregularities/Scintillation

1. Range errors

\[ r \propto \frac{40.3 \cdot \text{TEC}}{f^2} \]

Ionosphere 50~1000 km

Total electron content (TEC)

Radio signals

Plasma irregularities

2. Scintillation

Figure courtesy of C. Carrano

Ascension Island, 2002

- Rate of change of TEC index (ROTI)

\[ \text{ROT} = \sqrt{\langle \text{ROT}^2 \rangle - \langle \text{ROT} \rangle^2} \]

\[ \text{ROT} = \frac{\text{TEC}(i) - \text{TEC}(i - 1)}{(t_i - t_{i-1})} \]

Low frequency GNSS data (e.g., 30s, 1s) (Pi et al., 1997)

- ROTI, detect the presence of ionospheric irregularities that cause scintillations.

(Basu et al. 1988)
ROTI and Scintillation Indices

(a) ROTI & $S_4$

(b) ROTI & $\sigma_\phi$

Ascension Island, Feb-Mar 1998, 15 Minute Mean

(Basu et al., 1999)

GPS Data from Yellowknife 08/26/2005 and 10/03/2005

(Pi et al., 2013)

(Yang et al., 2015)
Irregularities Monitoring Using GNSS

ROTI maps: IGS new official ionospheric product

1. ROTI maps
   UWM ROTIPOLARMAP product
   The daily ROTI map are generated on a regular basis at UWM using data from more than 700 GPS permanent stations of the IGS, UNAVCO and EUREF networks.
   The Rate of TEC index is presented in a Magnetic Local Time reference frame.
   00-24 MLT time frame.
   8 min MLT bin.
   89.0-51.0 magnetic latitude range.
   2.0 magnetic latitude bin.

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START OF ROTIPOLARMAP
2017 1 1
89.0 1.0 359.0
0.1083 0.0914 0.0704 0.1002 0.0675 0.0766 0.1109 0.1007 0.0771 0.0874
0.0756 0.0850 0.0921 0.0930 0.1194 0.0976 0.0965 0.1187 0.0789 0.0764
0.0599 0.0662 0.0782 0.1100 0.0933 0.0795 0.0617 0.0692 0.0637 0.0706
0.0455 0.0603 0.0728 0.0604 0.0536 0.0764 0.0768 0.0712 0.1088 0.0967
0.0820 0.0773 0.0845 0.0673 0.0642 0.0604 0.0668 0.0610 0.0611 0.0973
0.0745 0.0835 0.0743 0.0683 0.0721 0.1057 0.0886 0.1157 0.0913 0.0963
0.0867 0.1058 0.0726 0.1268 0.0882 0.0694 0.1099 0.0813 0.0838 0.0769
0.0689 0.1058 0.0983 0.0874 0.0717 0.0778 0.0741 0.0597 0.1054 0.1278
0.0669 0.0693 0.0941 0.0801 0.0832 0.0833 0.0863 0.0660 0.0900 0.0880
0.0910 0.0875 0.0920 0.0942 0.0950 0.0936 0.1031 0.0945 0.1329 0.0744
**Regional Ionospheric Irregularities Mapping**

- **GNSS network, CMONOC**
  - Crustal Movement Observation Network of China
  - more than 260 GNSS sites (Trimble receiver)
  - 1s, 30s GPS data
  - March-April, 2015
- **ROTI calculated based on**

\[
ROTI = \sqrt{\langle ROT^2 \rangle - \langle ROT \rangle^2}
\]

\[
L_{GF}(i) = L1(i) \times \lambda_1 - L2(i) \times \lambda_2
\]

\[
RO = \frac{L_{GF}(i) - L_{GF}(i-1)}{\Delta t \times 10^{16} \times 40.3 \times \left(\frac{1}{f_1^2 - f_2^2}\right)}
\]

<table>
<thead>
<tr>
<th>Sampling</th>
<th>Time interval (running window)</th>
<th>Samples (Number)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1s</td>
<td>5 min</td>
<td>300</td>
</tr>
<tr>
<td>5s</td>
<td>5 min</td>
<td>60</td>
</tr>
<tr>
<td>15s</td>
<td>5 min</td>
<td>20</td>
</tr>
<tr>
<td>30s</td>
<td>5 min</td>
<td>10</td>
</tr>
</tbody>
</table>

- **ROTI, at different sampling rates**
  - 1s, 5s, 15s and 30s
- **ROTI mapping over China region**
  - 260 GPS sites, CMONOC
  - every 10 min, 30 min and 1 hour
  - ionospheric response to geomagnetic storms
ROTI at different sampling rates

PRN10, Sanya April 13, 2015

STD=0.955

STD=1.070

STD=2.180

Sanya, April 15, 2015

Correlation coefficient between ROTI and S4

Sanya, April of 2015

Value

30s-5m  15s-1m  15s-5m  1s-1m  1s-5m

Corr. coef: 0.888

Corr. coef: 0.789

Corr. coef: 0.750

ROT/S4=3.828

ROT/S4=2.074

ROT/S4=1.695
ROTI at different sampling rates (cont.)

HKST, March 15, 2015

March 15, 2015

March 16, 2015

y = 1.1917 x + 0.14073
Coef = 0.99424

y = 0.75473 x + 0.09531
Coef = 0.45475

y = 1.9729 x + 0.27065
Coef = 0.91141

y = 1.7289 x + 0.07315
Coef = 0.93886

y = 1.0981 x + 0.15366
Coef = 0.77827

y = 0.76945 x + 0.2609
Coef = 0.32269

y = 1.9729 x + 0.27065
Coef = 0.91141

Disturbed

Quiet

Data Linear regression y=x
• ROTI with a high sampling rate
  - represents small scale-size of ionospheric irregularities
    (1s-ROTI, 200 m; 5s-ROTI, 1 km; 30s-ROTI, 6 km)
  - 1s-ROTI may indicate irregularities (~400 m scale-size) that cause scintillations of GPS L1 signal.
  - a larger magnitude (high-frequency parts of the ROT spectrum)

• Correlation between ROTIs
  - 1s and 5s ROTIs, higher correlation
  - 1s and 30s ROTIs, lower correlation
  - correlation level is higher on disturbed days
Flowchart of ROTI Mapping

Are 30-s ROTI maps capable of reflecting the ionospheric irregularity?

1. cycle slips detection/repair
2. outlier remove
3. elevation cutoff angle (10)

Batch processing GPS data from CMONOC (1s, 30s)

Ready for 1s, 30s GPS data from CMONOC
• ROTI maps, output in the IONEX-like format

**Region:** 10°N-55°N, 70°E-140°E;
**Grid:** 2° in latitude and 2° in longitude;
**Height:** 350 km at IPPs;

```
1.0  ROTI MAPS  GPS  IONEX.VERSION / TYPE
   ROTIMAP.V1.0  SHAO  28-9-2018 21:58  PGH / RUN BY / DATE
Regional ROTI maps are generated on a daily basis at SHAO DESCRIPTION
using data from about 260 GNSS sites of Crustal Movement DESCRIPTION
Observation Network of China DESCRIPTION
  2.0  ELEVATION CUTOFF
  350.0 350.0  0.0  HGT1 / HGT2 / DHGT
  10.0  54.0  2.0  LAT1 / LAT2 / DLAT
  70.0 140.0  2.0  LON1 / LON2 / DLON
ROTI values in 1.0 TECU; NaN, if no value available COMMENT

START OF ROTIMAP
  2015 3 17 10 0 0
  24.0  70.0 140.0
   NaN   NaN   NaN   0.202  0.136  0.316  0.164  0.053  0.084  0.076
   0.054 0.091 0.037 0.047 0.046 0.057 0.065 0.055 0.059 0.072
   0.051 0.062 0.067 0.086 0.062 0.085 0.053 0.056 0.072 0.159
   NaN   NaN   NaN   NaN   NaN   NaN   NaN   NaN   NaN   NaN
   NaN   NaN   NaN   0.176   NaN   0.261  0.088  0.167  0.065  0.075
   0.070 0.081 0.088 0.066 0.061 0.085 0.058 0.055 0.058 0.080
   0.067 0.079 0.067 0.055 0.055 0.052 0.054 0.065 0.063 0.103
   NaN   NaN   NaN   NaN   NaN   NaN   NaN   NaN   NaN   NaN
```
• Geomagnetic storm, on March 17, 2015
  - The most intensive one in the solar cycle 24 so far;
  - Kp index had a maximum value of 8-;
  - A sudden commencement, at around 04:45 UT;
  - Recovery phase started on March 18, 2015;

• Ionospheric irregularities/scintillations
  - occurred before the storm commenced;
  - but absent in the south of China on March 17, 2015;

• ROTI mapping during this large storm
  - 1s and 30s GPS data from CMONOC;
  - 10-18 UT (18-02 LT), March 16-17, 2015;
  - 10 min, 30 min and 1 hour;
  - Grid: 2° in latitude and 2° in longitude;
  - Height: 350 km at IPPs;
ROTI Maps (March 16-17, 1 hour)
ROTI Maps (March 16-17, 30 min)

March 16 (10:30-11:00 UT)

March 17 (10:30-11:00 UT)
Summary

- ROTIs at 1s, 5s, 30s sampling rates
  - ROTIs correlated with scintillation indices
  - show a high correlation level on disturbed days

- ROTI maps, 10-min, 30-min and 1-hour GPS data
  - can reveal temporal/spatial evolutions of ionospheric irregularities
  - representation effect: 30-s ROTI maps are comparable to 1-s ROTI maps
  - 30-s observation is capable in irregularities monitoring.
  - The quantitative difference between 1-s ROTI and 30-s ROTI for monitoring the ionospheric irregularities will be studied further.

- ROTI maps, developed as one of routine products at SHAO
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Thank You!