Ionospheric monitoring in a single station mode

M. Cokrlic\textsuperscript{1)}, K. Wezka\textsuperscript{1)}, N. Jakowski\textsuperscript{2)}, R. Galas\textsuperscript{1)}

1) Technische Universität Berlin, Department for Geodesy and Geoinformation Science
2) German Aerospace Center (DLR), Institute of Communication and Navigation
Overview

- Short introduction
- Methodology
- Algorithms
- Equipment and Data specification
- Flow chart of software
- Results
- Further development
Short introduction

- Ionospheric Scintillation Phenomena: short time fluctuation in received signal phase or power
- It happens because of electron irregularities in ionosphere
- Scintillation depends on solar and geomagnetic activity, season, local time and location
- Amplitude scintillation can be monitored by interpretation SNR time series – rapidly changing values indicate scintillation activity
- SNR are stored in raw data
- Total Electron Content (TEC): number of electrons present along the path between two points
- Rate of TEC shows absolute electron content, also it is suitable for detection scintillation and traveling ionospheric disturbances
Methodology

- In our Navigation Laboratory we have Septentrio PolaRxS Pro (scintillation) receiver
- We are gathering GNSS data, and converting data to internal BinEx format and then the data are sent to preprocessor
- The T-BinEx is our standard input format to TUB-NavSololutions software package which we are still developing
- One of the software tool is under development for calculation of scintillation and Total Electron Content
- Septentrio software is used for validation of our results (S4 and TEC at the moment)
**Algorithms**

**1. Scintillation**

- At the moment we have Signal to Noise Ratio stored in raw binary receiver format

\[
SNR = \frac{P_{\text{signal}}}{P_{\text{noise}}}
\]

- SNR is given in dB so we changed in linear scale [Watt]

\[
P = 10^{\frac{SNR}{10}}
\]

- Scintillation index calculated for every satellite in 1min observation

\[
S4 = \sqrt{\frac{\langle P^2 \rangle - \langle P \rangle^2}{\langle P \rangle^2}}
\]

Where

\[
\langle P \rangle = \frac{1}{N} \sum_{0}^{N-1} P
\]

\[
\langle P^2 \rangle = \frac{1}{N} \sum_{0}^{N-1} P^2
\]
Algorithms
2. Total Electron Content

- TEC we are calculating, at the moment, only from code observations and form linear combination as below
- TEC is calculated every minute on the base of following equation

\[ TEC = \frac{1}{40.3} \frac{f_1^2 f_2^2}{f_1^2 - f_2^2} (P_1 - P_2) \]
3. Rate of Total Electron Content (RoT) and Rate of Change of Total Electron Content (ROTI)

- Rate of TEC characterizes relative spatial changes of TEC along the satellite passes.
- TEC is affected with code biases (between frequency biases and hardware delays), therefore we measure Rate of TEC (ROT).
- Rate of Change of TEC: standard deviation of ROT over 5 min period (Pi et al. 1997)

\[
ROT = \frac{TEC_t - TEC_{t-1}}{\Delta t}
\]

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

ROT is calculated every 15 sec for each satellite.
Data and Data Sampling Rates

- I, Q Data: 20ms
- Measurement Epoch: 1s
- Receiver Status: 10s
- Channel Status: 10s
- GPS Navigation: On Change

Septentrio PolaRxS Pro
Flow Chart

START

Data recording in receiver internal binary format

Conversion of Receiver data to T-BinEx TUB internal format

Data preprocessing

Preparation of input files

Data processing

Output files

END
Flow Chart

START

Data recording in receiver internal binary format

Conversion of Receiver data to T-BinEx TUB internal format

Data preprocessing

Preparation of input files

Data processing

Output files

END
Flow Chart

START

Data recording in receiver internal binary format

Conversion of Receiver data to T-BinEx TUB internal format

Data preprocessing

Preparation of input files

Data processing

Output files

END
Flow Chart

Input files for software

Sampling

SNR on L1

SNR on L2

P1

P2

TEC
Flow Chart

Example: input file for calculation ROT and ROTI

<table>
<thead>
<tr>
<th>GPS week</th>
<th>Day in week</th>
<th>Sec in day</th>
<th>Local time</th>
</tr>
</thead>
<tbody>
<tr>
<td>P1</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>P2</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>TEC</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
Flow Chart

Input files for software

Example:
Input file for calculating S4

<table>
<thead>
<tr>
<th>SEPT</th>
<th>Unknown</th>
<th>SEPT POLARXS 2.1.1</th>
<th>MARKER NAME</th>
</tr>
</thead>
<tbody>
<tr>
<td>Unknown</td>
<td>20033894 Unknown</td>
<td>3785222.8505</td>
<td>MARKER NUMBER</td>
</tr>
<tr>
<td></td>
<td>896643.5623</td>
<td>5037783.9018</td>
<td>REC # / TYPE / VERS</td>
</tr>
<tr>
<td>1</td>
<td>L1</td>
<td>L2</td>
<td>ANT # / TYPE</td>
</tr>
<tr>
<td>0.0000</td>
<td>0.0000</td>
<td>0.0000</td>
<td>APPROX POSITION XYZ</td>
</tr>
<tr>
<td>0.0000</td>
<td>0.0000</td>
<td>0.0000</td>
<td>ANTENNA: DELTA H/E/N</td>
</tr>
<tr>
<td>0.0000</td>
<td>0.0000</td>
<td>0.0000</td>
<td># / TYPES OF OBSERV</td>
</tr>
<tr>
<td>0.0000</td>
<td>0.0000</td>
<td>0.0000</td>
<td>INTERVAL</td>
</tr>
<tr>
<td>0.0000</td>
<td>0.0000</td>
<td>0.0000</td>
<td>TIME OF FIRST OBS</td>
</tr>
<tr>
<td>0.0000</td>
<td>0.0000</td>
<td>0.0000</td>
<td>TIME OF LAST OBS</td>
</tr>
<tr>
<td>0.0000</td>
<td>0.0000</td>
<td>0.0000</td>
<td>END OF HEADER</td>
</tr>
</tbody>
</table>

| 2012    | 5 17             | 0 0 0.00000000    |                             |
| 2012    | 5 17             | 23 59 59.00000000 |                             |

| 1684    | 4 775.00         | 34.000            | 13.7500                     |
| 1684    | 4 776.00         | 33.250            | 14.0000                     |
| 1684    | 4 777.00         | 33.750            | 14.2500                     |
| 1684    | 4 778.00         | 33.750            | 14.2500                     |
| 1684    | 4 779.00         | 33.750            | 14.2500                     |
| 1684    | 4 780.00         | 34.500            | 14.5000                     |
| 1684    | 4 781.00         | 34.500            | 14.5000                     |
| 1684    | 4 782.00         | 34.500            | 14.5000                     |
| 1684    | 4 783.00         | 34.500            | 14.5000                     |
| 1684    | 4 784.00         | 34.500            | 14.5000                     |
| 1684    | 4 785.00         | 34.500            | 14.5000                     |
| 1684    | 4 786.00         | 34.500            | 14.5000                     |
| 1684    | 4 787.00         | 34.500            | 14.5000                     |
| 1684    | 4 788.00         | 34.500            | 14.5000                     |
| 1684    | 4 789.00         | 34.500            | 14.5000                     |
| 1684    | 4 790.00         | 34.500            | 14.5000                     |
| 1684    | 4 791.00         | 33.750            | 13.7500                     |
| 1684    | 4 792.00         | 33.250            | 13.0000                     |
| 1684    | 4 793.00         | 33.250            | 13.0000                     |
| 1684    | 4 794.00         | 33.750            | 13.0000                     |
| 1684    | 4 795.00         | 34.500            | 13.5000                     |
| 1684    | 4 796.00         | 34.500            | 13.5000                     |
| 1684    | 4 797.00         | 34.500            | 13.5000                     |
| 1684    | 4 798.00         | 34.500            | 13.5000                     |
| 1684    | 4 799.00         | 34.500            | 13.5000                     |
| 1684    | 4 800.00         | 34.500            | 13.5000                     |
| 1684    | 4 801.00         | 34.500            | 13.5000                     |
| 1684    | 4 802.00         | 34.500            | 13.5000                     |
| 1684    | 4 803.00         | 34.500            | 13.5000                     |
| 1684    | 4 804.00         | 34.500            | 13.5000                     |
| 1684    | 4 805.00         | 34.500            | 13.5000                     |

GPS week: 1684
Day in week: 4
Sec in day: 775.00
SNR on L1: 13.7500
SNR on L2: 13.7500

6th GNSS Vulnerabilities And Solutions Conference
**Flow Chart**

**START**
- Data recording in receiver internal binary format
- Conversion of Receiver data to T-BinEx TUB internal format
- Data preprocessing
- Preparation of input files
- Data processing
- Output files

**END**
Flow Chart

START

Data recording in receiver internal binary format

Conversion of Receiver data to T-BinEx TUB internal format

Data preprocessing

Preparation of input files

Data processing

Output files

END
**Flow Chart**

1. **START**
2. Data recording in receiver internal binary format
3. Conversion of Receiver data to T-BinEx TUB internal format
4. Data preprocessing
5. Preparation of input files
6. Data processing
7. Output files
8. END
Flow Chart

Data processing

START

File is readable

YES

End of the file?

YES

NO

1. Read line

NO

END

1.

YES

New Epoch?

YES

NO

1.

NO

1.

YES

Extract data from the file

- Calculate S4

Time %15 == 0

NO

YES

Calculate ROT

Time %300 == 0

- Calculate ROTI
Flow Chart

START

Data recording in receiver internal binary format

Conversion of Receiver data to T-BinEx TUB internal format

Data preprocessing

Preparation of input files

Data processing

Output files

END
Flow Chart

START

Data recording in receiver internal binary format

Conversion of Receiver data to T-BinEx TUB internal format

Data preprocessing

Preparation of input files

Data processing

Output files

END
Flow Chart

START

Data recording in receiver internal binary format

Conversion of Receiver data to T-BinEx TUB internal format

Data preprocessing

Preparation of input files

Data processing

Output files

END
Software architecture

Output files

Sampling

S4
Scintillation

ROT
Rate of TEC

ROTI
Rate of change of TEC
**Software architecture**

Output files

| ROT: 20715.000000 | -0.221467 |

### Example:
Output file for ROT and ROTI calculation

| ROT: 21615.000000 | 0.034267 |
| ROT: 21630.000000 | 0.078067 |
| ROT: 21645.000000 | -0.070467 |
| ROT: 21660.000000 | 0.210733 |
| ROT: 21675.000000 | -0.061600 |
| ROT: 21690.000000 | 0.052733 |
| ROT: 21705.000000 | 0.014533 |
| ROT: 21720.000000 | -0.268400 |
| ROT: 21735.000000 | -0.022867 |
| ROT: 21750.000000 | -0.119933 |
| ROT: 21765.000000 | 0.395333 |
| ROT: 21780.000000 | 0.123133 |
| ROT: 21795.000000 | 0.024133 |
| ROT: 21810.000000 | -0.010800 |
| ROT: 21825.000000 | -0.099333 |
| ROT: 21840.000000 | 0.086333 |
| ROT: 21855.000000 | -0.153000 |
| ROT: 21870.000000 | 0.104133 |
| ROT: 21885.000000 | -0.001267 |
| ROT: 21885.000000 | 0.143812 |
| ROT: 21900.000000 | 0.116733 |
| ROT: 21915.000000 | 0.149133 |
| ROT: 21930.000000 | -0.052000 |
| ROT: 21945.000000 | 0.130067 |
| ROT: 21960.000000 | -0.059667 |
| ROT: 21975.000000 | 0.055867 |
| ROT: 21990.000000 | -0.001267 |
ROT and ROTI

PRN 1

TEC on PRN1
Time of day [sec]
ROT and ROTI

PRN 1
ROT and ROTI

PRN 2

TEC on PRN2
Time of day [sec]

Time [TECU]

Time of day [sec]
ROT and ROTI

PRN 2

 ROT
Time of day [sec]

dTEC

Time of day [sec]
ROT and ROTI

![Graph showing ROT and ROTI over time]

- ROT and ROTI over time [sec]
- aTEC

Time of day [sec]

0.0 0.2 0.4 0.6 0.8 1.0 1.2 1.4

3600 7200 10800 14400 18000 21600 25200 28800 32400 36000 39600 43200 46800 50400 54000
S4 on PRN2

S4 on L1
Septentrio's S4
S4 on L2
Septentrio's S4
S4 on PRN2

S4 on L1
S4 on L2
Septentrio's TEC
Further development of the software tools

- Solve problem with code biases (receiver and satellite) for absolute TEC determination
- Development software for calculation scintillation and TEC form carrier phases
- Make chain for monitoring ionosphere in real time
- Put in operation a receiver in Ethiopia for scintillation monitoring (TBC)
- Challenge: real time processing and data communication
Conclusion

- Small elevation angle implies larger fluctuation in Total Electron Content
- Calculation of S4 form SNR in most cases has the same trend as S4 calculated in Septentrio's PolaRxS Pro receiver
- The time when we observe bigger differences between S4 calculated form SNR we assume that this is random noise- we will know for sure after upgrading TUB-NavSolutions Software
Thank you for your attention!