Ionospheric Scintillations Probabilities of Occurrence

Yannick Béniguel
IEEA, France
Contents

Low Latitudes

- Dependency on latitude, season & Local time
  1 Hz data vs 50 Hz data

- Probability of occurrence for one or several satellites

- Signal characteristics / Fade depths & inter frequency correlation

High Latitudes

- Correlation with the magnetic indices

- Probability of occurrence for one or several satellites

Cycle slips occurrence
### Low Latitudes Receivers Network

<table>
<thead>
<tr>
<th>Station Name</th>
<th>Project</th>
<th>Latitude</th>
<th>Longitude</th>
<th>Equipment</th>
<th>Sampling frequency</th>
</tr>
</thead>
<tbody>
<tr>
<td>Dakar (Senegal)</td>
<td>SAGAIE</td>
<td>14.765° N</td>
<td>342.62° E</td>
<td>PolaRxS + Novatel FlexPack 6</td>
<td>50 Hz / 1 Hz</td>
</tr>
<tr>
<td>HOUagadougou (Burkina Faso)</td>
<td>SAGAIE</td>
<td>12.368° N</td>
<td>358.47° E</td>
<td>Novatel FlexPack 6</td>
<td>1 Hz</td>
</tr>
<tr>
<td>Lomé (Togo)</td>
<td>SAGAIE</td>
<td>6.132° N</td>
<td>1.223° E</td>
<td>PolaRxS + Novatel FlexPack 6</td>
<td>50 Hz / 1 Hz</td>
</tr>
<tr>
<td>Douala (Cameroon)</td>
<td>SAGAIE</td>
<td>4.049° N</td>
<td>9.699° E</td>
<td>Novatel FlexPack 6</td>
<td>1 Hz</td>
</tr>
<tr>
<td>N’Djamena (Chad)</td>
<td>SAGAIE</td>
<td>12.113° N</td>
<td>15.048° E</td>
<td>Novatel FlexPack 6</td>
<td>1 Hz</td>
</tr>
<tr>
<td>Abidjan (Ivory Coast)</td>
<td>Monitor 2</td>
<td>5.27° N</td>
<td>356.08 E</td>
<td>PolaRxS</td>
<td>50 Hz</td>
</tr>
<tr>
<td>Cotonou (Benin)</td>
<td>Monitor 2</td>
<td>6.352° N</td>
<td>2°383 E</td>
<td>PolaRxS</td>
<td>50 Hz</td>
</tr>
<tr>
<td>Niamtogou (Togo)</td>
<td>Monitor 2</td>
<td>9.774° N</td>
<td>1.098° E</td>
<td>PolaRxS</td>
<td>50 Hz</td>
</tr>
<tr>
<td>Bamako (Mali)</td>
<td>Monitor 2</td>
<td>12.540° N</td>
<td>7.949 W</td>
<td>PolaRxS</td>
<td>50 Hz</td>
</tr>
</tbody>
</table>
Number of Events (1 mn)
Northern Hemisphere vs Southern Hemisphere

North hemisphere wrt magnetic equator
weak : $0.2 < S4 < 0.4$
medium : $0.4 < S4 < 0.6$
strong : $0.6 < S4 < 0.8$

South hemisphere wrt magnetic equator
Number of Events (1 mn)
1 Hz vs 50 Hz

North hemisphere wrt magnetic equator

50 Hz data
1 Hz data

About 2 times more events
Probability of scintillation occurrence
1 Hz vs 50 Hz recording / Comparison of results

1 Hz

Probability of scintillation occurrence in Dakar latitude 14.765° N, longitude 34.62° E / 1 Hz Data

50 Hz

Probability of occurrence for at least one event Dakar latitude 14.765° N, longitude 34.62° E / 50 Hz Data

Probability of scintillation occurrence in Lomé latitude 6.132° N, longitude 1.223° E / 1 Hz Data

Probability of occurrence for at least one event Lomé latitude 6.132° N, longitude 1.223° E / 50 Hz Data
How many links simultaneously affected with scintillations

North hemisphere

50 Hz data

South hemisphere
Dependency on the Latitude

50 Hz receivers network (3 years of data)
S4 and TEC maps
Low Latitudes

S4 map : measurements
Median cumulated values over years 2014 - 2016

TEC map : modelling
Average in October 2015
Dependency on Local Time

\[ f(t) = 0.05 + 0.63 \frac{t - 19}{\sigma^2} \exp \left( -\frac{(t - 19)^2}{2\sigma^2} \right) \]

with \( \sigma^2 = 5 \) and \( t \) in hours

\[ \int_{19\,pm}^{2\,am} f(t) \, dt = 0.98 \]

Scintillation also at day time
Raw Data Analysis

1 hour of data at a high level of scintillations

Using all data recorded
% of time a fade depth level is exceeded

\[ P = p(S4) \times p(\text{Fade Depth}) \]
Inter Frequency Correlation

Tahiti Galileo N° 12 doy 85 / 2013
S4(L1) = 0.59 ; S4(E5a) = 1.36

Galileo satellites
S4 (E5a) = 1.27 * S4(L1) + 0.22 * (S4(L1))^2
**High Latitude Receivers Network**

<table>
<thead>
<tr>
<th>Station Name</th>
<th>Project</th>
<th>Latitude</th>
<th>Longitude</th>
<th>Equipment</th>
<th>Sampling frequency</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sodankylä (Finland)</td>
<td>Monitor</td>
<td>67.25° N</td>
<td>26.36° E</td>
<td>GSV4004B</td>
<td>50 Hz</td>
</tr>
<tr>
<td>Kevo (Finland)</td>
<td>Monitor</td>
<td>69.75°N</td>
<td>27.019° E</td>
<td>GSV4004B</td>
<td>50 Hz</td>
</tr>
<tr>
<td>Kiruna (Sweden)</td>
<td>Monitor</td>
<td>67.743° N</td>
<td>21.06° E</td>
<td>PolaRxS</td>
<td>50 Hz</td>
</tr>
</tbody>
</table>

*MONITOR site*
High Latitudes Fluctuations

Sodankyla: Novatel GSV 4004B receiver
Kiruna: Septentrio PolaRxS receiver

Distance Sodankyla – Kiruna: 280 km
Relationship Phase fluctuation / AE & Kp Indices High Latitudes

December 2015 magnetic storm
December 2015 Magnetic Storm
Phase fluctuation

No fluctuations outside these 6 minutes

Scintillation intensity not significant for GNSS application

Receiver: PolaRxS Septentrio
High latitude fluctuations

Distance between receivers: 280 km
Drift velocity: around 2 km/s, westward
TEC & ROTI High Lat
Probability of occurrence

GSV4004B receiver

1 order of magnitude lower with the PolaRxS receiver
How many links at the same time

The % of time is lower with the PolaRxS receiver
High Latitudes Number of Links

Peak value at about 65° of latitude
Fluctuations Map / High Latitudes

SigmaPhi 2015

Scandinavian sector

sigma phi median values at IPPs cumulated over the year
Cycle Slips
Low Latitudes vs High Latitudes

Rinex input data files (1 Hz)

Blewit algorithm
Conclusion

Scintillation occurrences

- The probability of scintillation events was derived depending on the season, latitude and local time for one and several satellites.

Signal characteristics

- Fade and inter fades durations were given, depending on the S4 value.
- Fades depth probabilities have been derived.
- Statistics of cycle slips have been calculated and dependencies exhibited.