Statistics of ionospheric disturbances and their correlation with GNSS positioning errors at high latitudes

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Data source

- 9 GNSS receivers, 1 Hz sample rate
- Time period: 2012 (the entire year)
Calculations

Every 5 minutes, for each satellite observed by each receiver, we calculated:

- ROTI (A measure of ionospheric disturbance level)
  - Standard deviation of Rate-of-TEC

- 3D position
  - Calculated using GIPSY

The 3D position error was calculated by taking the difference between the instantaneous values of the coordinate time series and its median value, after removing the linear trend from the coordinate time series by subtracting its linear fit for the year.

Geomagnetic coordinates were calculated for all measurement points, using AACGM.
Relevant space weather regions at high latitudes

- The Auroral Oval
- The Polar Cusp
Amount and distribution of measurements

- 10.3 million satellite measurement points
- 0.94 million receiver coordinates
Result 1 – ROTI vs Elevation

- At elevations below 30 degrees, the value of ROTI depends strongly on elevation. The value of ROTI increases exponentially with the length of the signal path through the atmosphere.

- At elevations above 40, other effects dominate over the elevation dependence.
Elevated ROTI values occur mainly in the cusp region and in the nightside auroral oval.

Enhanced ROTI values most commonly occur in the cusp region, but when they occur in the nightside auroral oval, they are higher.
Calculations
Characterizing the connection between ROTI and position error

![Graph showing the relationship between Mean ROTI (TECU/min) and Standard deviation of 3D position error (mm).](image1)

![Graph showing the 3D PPP position error with associated standard deviation.](image2)
Result 3 – The connection between ROTI and position error

Graphs showing the 3D PPP position error for different locations:
- LYRS (78° N)
- TRO1 (70° N)
- VEGS (66° N)
- HFS4 (60° N)

Each graph plots the 3D position error against ROTI (TECU/min) with a ±1 standard deviation range.
Result 3 – The connection between ROTI and position error

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<th>ID</th>
<th>Latitude</th>
<th>Corr. coeff.</th>
<th>b</th>
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\[ \text{PosErr}_{3D, \, 1h} = a \cdot e^{(b \cdot \text{ROTI}_{\, \text{Avg, \, 1h}})} \]
Result 4 – Risk of simultaneous disturbance

ROTI risk at LYRS (78° N)

ROTI risk at TRO1 (70° N)

ROTI risk at VEGS (66° N)

ROTI risk at HFS4 (60° N)
Conclusions

- PPP position error is strongly correlated with ROTI.
- PPP position error increases exponentially with ROTI.
- At elevations below 30 degrees, the length of the signal path through the atmosphere is the dominating factor for the average ROTI value.
- Elevated ROTI values occur mainly in the cusp region and in the nightside auroral oval.
- Enhanced ROTI values most commonly occur in the cusp region, but when they occur in the nightside auroral oval, they are higher.
- The risk of having multiple satellites simultaneously disturbed is greater at higher latitudes.