Space weather impacts to GPS at mid latitudes: Signal scintillation and positioning errors

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Space weather effects on the GPS (GNSS)

Refraction: effects phase
- Incorrect range estimate
- Deterministically scale with frequency
- Fast fluctuations => lock of locks
- (Multi frequency mitigation)

Diffraction: effects amplitude
- Signal fading effects signal tracking
- Signal multipath: stochastic
- Deep fading => signal lost
- No straight forward mitigation

Both effect GNSS purpose:
P Position
V Velocity
T Time

Measuring ionospheric scintillation via scintillation indices

Phase Scintillation [rad, degree, cycles]
\[ \sigma_\phi = \sqrt{\langle \phi^2 \rangle - \langle \phi \rangle^2} \]

Amplitude Scintillation [dB]
\[ S_4 = \sqrt{\frac{\langle I^2 \rangle - \langle I \rangle^2}{\langle I \rangle^2}} \]
Scintillation occurrence - Climatology

High Latitudes: Sub-auroral and auroral zone, polar cap: **Phase scintillation**
- TEC fluctuations at scales they don’t facilitate diffraction.
- All longitudes, most pronounced near magnetic local midnight (substorms, enhanced sub-auroral drifts)

Equatorial region – Low latitudes: **Phase and amplitude scintillation**
- Plasma density irregularities due to internal plasma instability (Reyligh-Taylor).
- All longitudes, most pronounced near magnetic local midnight (substorms, enhanced sub-auroral drifts)

A whole lot of nothing? Majority of population lives here.
Global morphology of GNSS scintillation?

- What is scintillation occurrence at middle latitudes?
- How does space weather affects the PVT?
- There is only one prominent example available in the literature, recorded by at Cornell.
- But there is no permanent GNSS scintillation receivers deployed at the (CONUS, Europe) territory to comprehensively characterize the space weather effects.

Ledvina et al.. First observations of intense GPS L1 amplitude scintillations at midlatitude. Geophysical Research Letters, 2002
Utilizing geodetic GPS receivers by UNAVCO

UNAVCO GPS receivers:
- Diverse hardware selection;
- Data availability at 1s resolution (scintillation receivers usually operate at 50-100 Hz);

Missing reliable measurements of signals phase and amplitude
- Phase $\Rightarrow$ TEC (Phase combination)
- Amplitude $\Rightarrow$ Signal-Noise-Ratio (SNR)

Scintillation index substitutes:

$$\sigma_{TEC} = \sqrt{< TEC^2 > - < TEC >^2}_{60s}$$

$$SNR_4 = \sqrt{< SNR^2 > - < SNR >^2}_{60s}$$

The UNAVCO dataset enables a unique opportunity to study GPS scintillation and space weather impacts at mid latitudes.
- Bias in spatial sampling! (Rocky mountains)
- 400 receivers available in 2013 $\Rightarrow$ 750 in 2018!
Data and processing and presentation

$Ts = [2, 10] \text{ s}$
Example: 1 June 2013 (a moderate geomagnetic storm)
Scintillation development
High-rate (1 Hz): GPS receiver array by UNAVCO
Scintillation statistics. Normalized to # of receivers

Low latitudes: \(|\text{MLAT}| < 30\)

Mid latitudes: \(30 < |\text{MLAT}| < 60\)

High latitudes: \(60 < |\text{MLAT}|\)
Positioning errors: Dual frequency, static estimate

Receivers from California and Oklahoma:
Increased error:
• Horizontal positioning ~ 2m
• Vertical positioning ~>5m
Receivers from central Mexico:
Increased errors:
  • Horizontal positioning ~ 5m
  • Vertical positioning ~>10m

Receivers from Montana:
Increased errors:
  • Horizontal positioning ~ 2m
  • Vertical positioning ~>2m
Summary

- We discussed utilization of geodetic GNSS receivers for scintillation studies at middle latitudes.
- We introduce alternative signal processing as a proxy we the established scintillation indices.
- A case study of a moderate storm is presented, where low- and high- latitude ionospheric disturbances converged over the continental United States.
- Long lasting GPS scintillation is observed, causing increased positioning errors. Horizontal errors exceeded 2m, whereas vertical error increased for >5m at all (US) latitudes.
- The presented space weather effects on the GPS took place during a moderate storm, at moderate solar and geomagnetic activity.
- Climatology and thorough analysis of scintillation characteristics at mid latitudes is underway.