Performance of low-cost GNSS receivers for ionospheric studies

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Special thanks to: Elijah Oyeyemi & Busola Olugbon (Nigeria), Olivier Obrou (Cote D'ivoire), Solomon Lomotey (Ghana), Babatunde Rabiu & Aderonke Ekemi (Nigeria), Marco Rainone (Italy)
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Ionosphere

- Ionized part of the atmosphere from ~60 to a few thousand km above the ground, so-called magnetized cold plasma or weakly ionized gas
- Formed by solar radiation, namely by photochemical absorption processes
- Loss is due to recombination processes
- Due to different ionization production and loss processes the electron density profile with altitude shows a layered structure that changes with time, location and solar activity
- The borders between layers are inflection points in the ED profile
- It is accepted to distinguish D, E and F (F1 and F2) layers
- Structure is highly dynamic and depends on many parameters
Ionosphere effects on GNSS signals

- Range errors
  - Group delay
  - Phase advance
  - Depend on the electron density along the ray path

\[ d = \frac{40.3}{f^2} \int_{sat}^{rec} n_e \, dl \]

- Highly variable with time/space

- Scintillation
  - Rapid random changes in amplitude and/or phase of the signal

- Doppler shift
  - Change in carrier frequency
How to estimate TEC

Dual frequency GNSS receivers

\[ TEC \sim \frac{1}{40.3} \left( \frac{f_1^2 f_2^2}{f_1^2 - f_2^2} \right) (L_2 - L_1) \]

Total electron content (TEC) is the number of electrons in a column with a cross section of one square meter along the signal path.
Research studies: TIDs

Tsugawa, T., Kotake, N., Otsuka, Y. et al. Medium-scale traveling ionospheric disturbances observed by GPS receiver network in Japan: a short review. GPS Solut 11, 139–144 (2007)

Zakharenkova, I., Astafyeva, E., and Cherniak, I. (2016), GPS and GLONASS observations of large-scale traveling ionospheric disturbances during the 2015 St. Patrick’s Day storm, J. Geophys. Res. Space Physics, 121, 12,138–12,156
Research studies: Solar Eclipse


Research studies: Data assimilation

NeQuick VTEC  month: 4  UT: 14:00  F10.7: 190 s.f.u.
Devices under test (DUT)

- Septentrio PolaRx5S, up to 100Hz, >10k $
- Swift Piksi Multi, up to 20 Hz, 1k $
- U-Blox ZED-F9P, up to 20 Hz, 250 $
Low latitudes
- Lagos, Nigeria
- Abidjan, Côte d'Ivoire
- Abidjan, Ghana
- Abuja, Nigeria

Mid latitudes
- Fredericton, Canada

High latitudes
- Qikiqtarjuaq, Canada
Data: geomagnetic activity level
Results: uncalibrated TEC

Credits: Elijah Oyeyemi, Busola Olugbon
Results: uncalibrated TEC

Nigeria, Abuja, 9.1° N, 7.4° E
Results: cycle slips

Nigeria, Abuja, 9.1° N, 7.4° E
Results: calibrated TEC

Côte d'Ivoire, Abidjan, 5.34° N, 3.99° W

Credits: Olivier Obrou
Results: model validation  Côte d'Ivoire, Abidjan, 5.34° N, 3.99° W

**STEC**

**VTEC**
Conclusions

• Low-cost dual frequency GNSS receivers are a great alternative to geodetic/scientific grade receivers to estimate TEC values

• Their performance is comparable across different latitudes: low, middle, and high

• More investigations must be done in order to understand whether they can be used for scintillation monitoring
Proposed setup

- ArduSimple U-BLOX F9P evaluation board - $235 USD

- TOPGNSS AN-105L antenna - $65 USD
  [https://www.aliexpress.us/item/3256802908957760.html](https://www.aliexpress.us/item/3256802908957760.html)

- LMR-240 cable 15m - $80 USD

- Raspberry Pi 4B, 4GB, 32 GB - ~$100 USD (pre-covid times)
  any other single board computer with one USB port, Ethernet/WiFi and Linux/Windows OS will work