TEC Variability and Scintillation at Low Latitudes Measured Using High-Rate GPS Receivers

Charles S. Carrano[1] **Keith M. Groves[2]**

(1) Atmospheric and Environmental Research, Inc., 131 Hartwell Ave, Lexington, MA (ccarrano@aer.com)

(2) Space Vehicles Directorate, Air Force Research Laboratory, Hanscom AFB, MA (keith.groves@hanscom.af.mil)

Abstract

We characterize TEC variability and scintillation activity at low latitudes using the AFRL-SCINDA network of high rate dual-frequency GPS receivers maintained by Air Force Research Laboratory. A statistical analysis of large-scale TEC gradients as a function of magnetic latitude and local time is presented. Small-scale TEC fluctuations are quantified in terms of the 60-second standard deviation of the rate of change of TEC, sampled at 10-50 Hz. These high sampling rates make this quantity sensitive to small-scale ionospheric structures (roughly 5-25 meters in size) which lead to ionospheric scintillation.

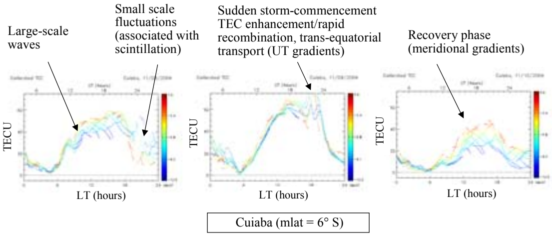
The AFRL-SCINDA Network

Ground Stations of the AFRL-SCINDA Network

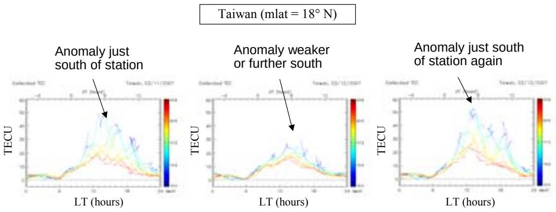
- The dual frequency receivers of the AFRL-SCINDA network (yellow) measure S_4, TEC, and ROTI using 10-50 Hz samples of amplitude and phase.
- We use these receivers to characterize TEC gradients/fluctuations and scintillation as functions of local time, magnetic latitude, and solar flux.

Structural Features in the Low-Latitude TEC

- We generate daily plots of vertical equivalent TEC versus local time for each station. The TEC from each satellite is colored according to the geomagnetic latitude of the corresponding IPP.
- Plotting in this format facilitates examination of TEC gradients in local time and magnetic latitude, as measured by a stand-alone GPS receiver.
- Typical examples of structural features we observe in the diurnal TEC include:



TEC Structure Near Appleton Anomaly

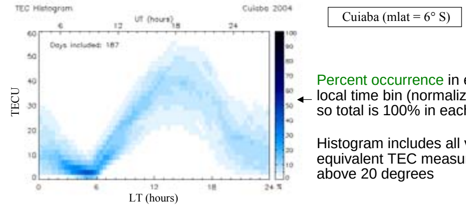


- TEC to the north was nearly the same these 3 days. TEC to the south dramatically different (nearly double) due to expansion/contraction of Appleton anomaly.
- Variability in anomaly structure has daily, seasonal, and solar cycle components
- Stations near anomaly crests experience high variability on daily and seasonal timescales

Statistics of TEC Variability at Low-Latitudes

We generate annual TEC histograms which include contributions from several effects:

- Appleton anomaly variations
- Solar flux variations (diurnal, seasonal, solar cycle)
- Storm time perturbations
- ... and others (solar flares, gravity waves, etc.)
- Plasma turbulence and scintillation

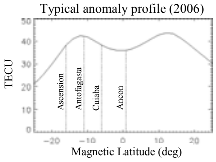


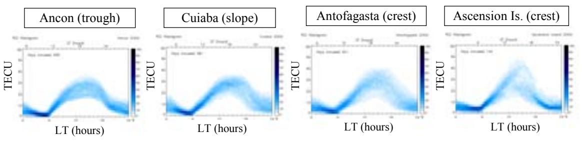
Percent occurrence in each local time bin (normalized so total is 100% in each bin)

Histogram includes all vertical equivalent TEC measurements above 20 degrees

TEC Variability Versus Magnetic Latitude

Location of 4 stations in roughly same longitude sector relative to typical Appleton anomaly meridional profile

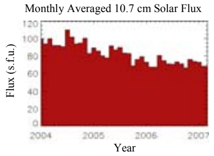


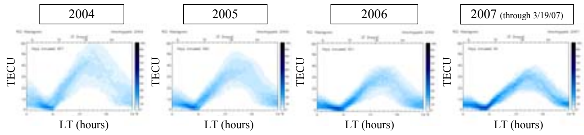


On average, both TEC magnitude and variability increase with distance from magnetic equator for stations between the Appleton anomaly crests.

TEC Variability Versus Solar Flux

Antofagasta (mlat = 11° S)





On average, both TEC magnitude and variability decrease with decreasing solar flux.

TEC Variability and Scintillation at Low Latitudes Measured Using High-Rate GPS Receivers

Quantifying TEC Fluctuations and their Relationship to Scintillation

The scintillation intensity index, S_4, can be related to electron density fluctuations through phase screen theory (Rino, 1979), shown in simplified form below:

$$S_4^2 \sim \frac{K}{f^2}\left\langle \Delta N^2 \right\rangle G' F'(k_N, p_N, f)$$

The function *F'* has vanishing amplitude for irregularity scale sizes larger than the Fresnel scale,

$$F_r = \sqrt{2\lambda z} \sim \sqrt{2(0.19\,m)(350000\,m)} = 365\,m \quad \textit{typical value}$$

We parameterize TEC fluctuations in terms of ROTI, the standard deviation of the rate of change of TEC:

$$ROTI^2 = \frac{\left\langle \Delta N^2 \right\rangle - \left\langle \Delta N \right\rangle^2}{\Delta t^2}$$

The standard definition of ROTI, i.e. the standard deviation (over 5 min) of dTEC/dt sampled at every 30 seconds, captures scale sizes on the order

$$d = 2\Delta t V_r \sim 2(30\,s)(120\,m/s) = 7200\,m \quad \textit{typical value}$$

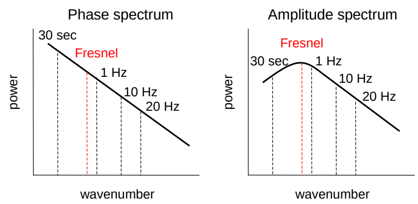
which is generally much larger than Fresnel scale. These scale sizes do not contribute to scintillation.

TEC Fluctuations and Scintillation

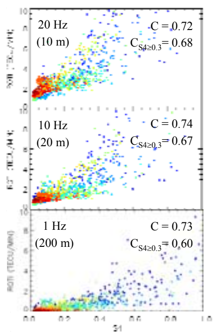
We evaluate ROTI in a non-standard way, by taking the standard deviation (over 60 sec) of the dTEC/dt sampled at ≥1 Hz. This captures scale sizes on the order

$$d = 2\Delta t V_r \sim 2(1\,s)(120\,m/s) = 240\,m \quad \textit{typical value}$$

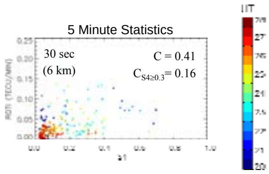
which is generally smaller than Fresnel scale and can contribute to scintillation



Correlation Between TEC Fluctuations and Scintillation

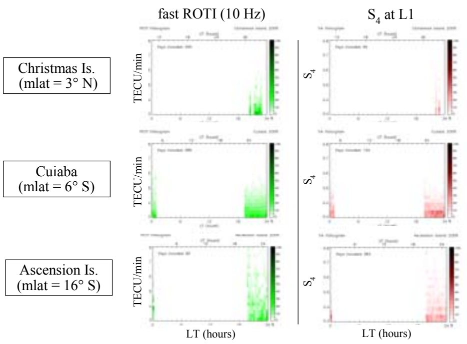


Ascension Island, 16 March 2002
Vertical drift ~ 100 m/s
Fresnel scale ~ 365 m



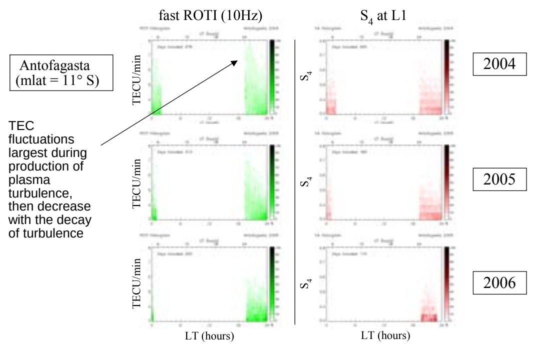
Correlation between ROTI and S4 is poor when TEC sampled at larger scale than the Fresnel scale

TEC Fluctuations and Scintillation Versus Magnetic Latitude



On average, onset and duration of TEC fluctuations and scintillation coincide. Both TEC fluctuations and scintillation are stronger near the anomaly crests.

TEC Fluctuations and Scintillation Versus Solar Flux



On average, the onset and duration of TEC fluctuations coincide with scintillation activity at the L1 frequency. TEC fluctuations and scintillation increase with solar flux.

Conclusions

- Large scale gradients and small scale fluctuations in TEC near the equatorial zone result from several physical mechanisms (dynamics of the Appleton anomaly, magnetic activity, plasma turbulence and scintillation, solar flux variations, etc.).
- TEC magnitude and variability increase with distance from the magnetic equator for stations between Appleton anomaly crests.
- TEC magnitude and variability increase with increasing solar flux.
- TEC fluctuations and scintillation are stronger and last longer near the anomaly crests. Both increase with increasing solar flux.
- On average, the onset and duration of TEC fluctuations (as parameterized by fast ROTI at 10 Hz which is sensitive to irregularities smaller than Fresnel scale) coincide with onset and duration of scintillation at L1.
- Fast ROTI can be a useful indicator of scintillation activity, but a more direct relationship requires accounting for drift velocity, spectrum of the irregularities, and receiver noise limitations.
- Widespread availability of 1 Hz RINEX data may be useful for global specification of ionospheric irregularities.