Monitoring the Occurrence Probability of Steep Ionospheric TEC Gradients Associated with Equatorial Plasma Bubbles

using Network of GNSS Receivers in South America

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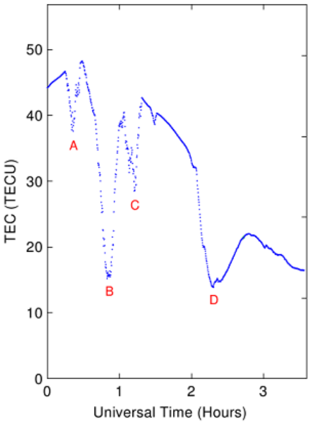
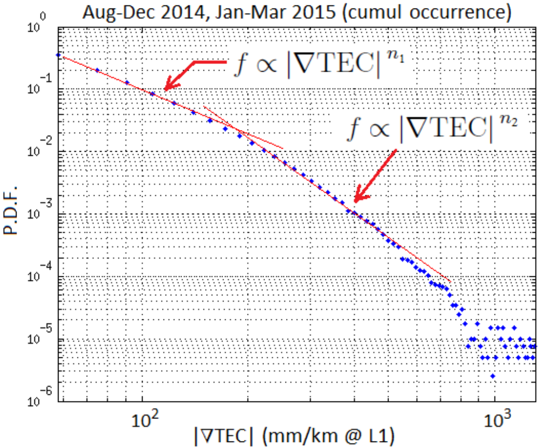
30 June 2016

International Beacon Satellite Symposium 2016
ICTP - Trieste, Italy

An Executive Summary





Large/steep ionospheric TEC gradients over the Brazilian sector due to:

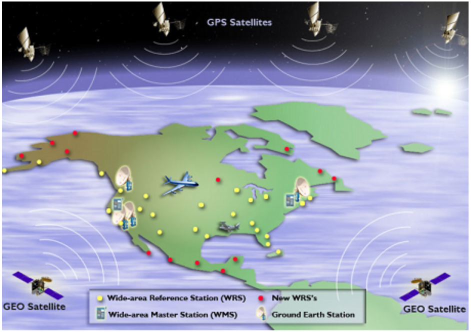
- steep side walls of the equatorial plasma bubbles
- density irregularities inside the equatorial bubbles

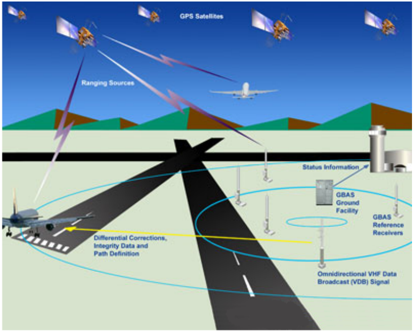
TEC gradient magnitudes extend up to ∼1000 mm/km at L1 frequency, and they follow a double-power-law distribution.

Main Outline

- Threats to SBAS/GBAS Systems
  - midlatitude scenario: plumes of storm-enhanced density
  - equatorial scenario: plasma bubbles (TEC depletions)
- Brazil Case Study 2014/2015
  - basic setup of the study
  - TEC gradient calculation
- Statistical distribution of TEC gradient magnitudes
  - seasonal and spatial variability
  - double-power-law distribution
- Summary and Conclusions

A Brief Overview of SBAS/GBAS Systems





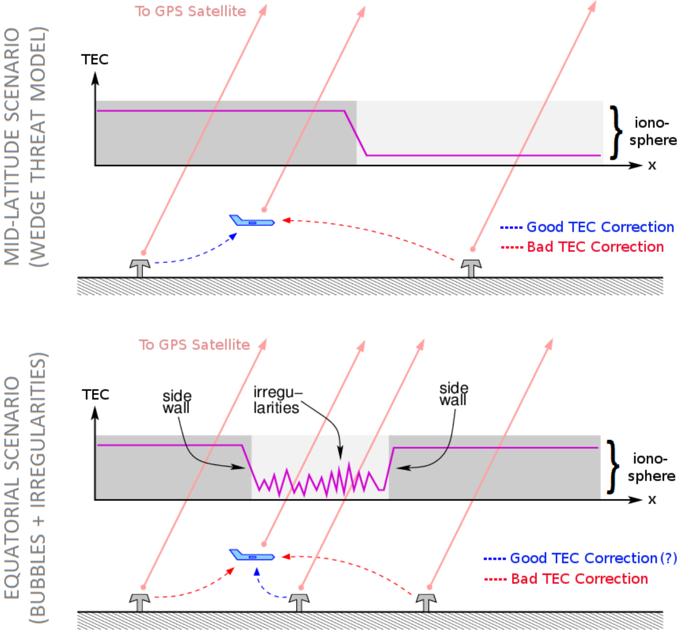
images from http://www.faa.gov/

SBAS: wide-area or regional scale

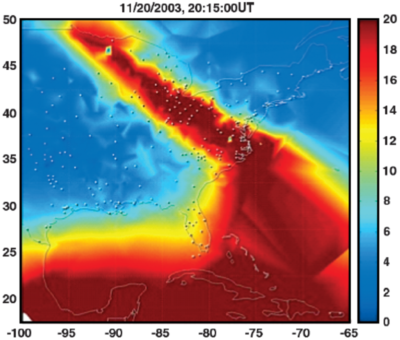
GBAS: localized/airport service

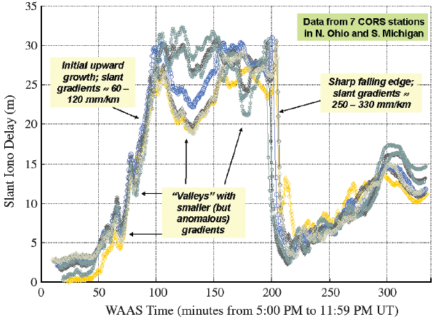
- important role in aviation safety to ensure accuracy, availability and integrity of navigation information
- broadcast correction messages - allowing navigation/control systems to take ionospheric delays into account for precise positioning
- steep ionospheric gradients and scintillations can be serious threats

Threats to SBAS/GBAS from Steep Ionospheric Gradients



Midlatitude Threat: Storm Enhanced Density (SED)



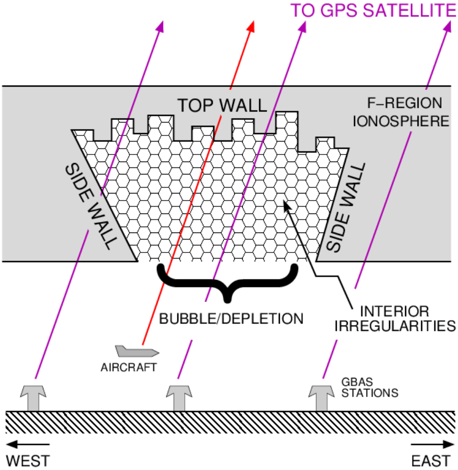


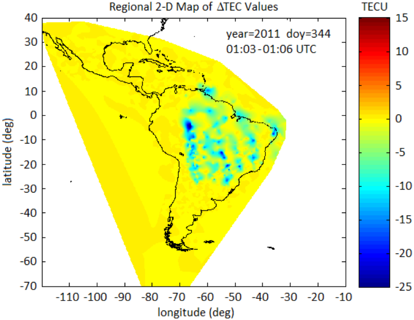
(Datta-Barua et al., 2010)

- Nominal upper bound for CONUS during SED: ∼425 mm/km
- Quiet-time TEC gradients for CONUS: ∼40 mm/km or lower
- On average, there are roughly 30 geomagnetic storms per year (30% of them are major geomagnetic storms)

[Datta-Barua et al., 2010; Vijaya-Lekshmi et al., 2011]

Low-latitude Threat: Equatorial Plasma Bubbles (EPBs)



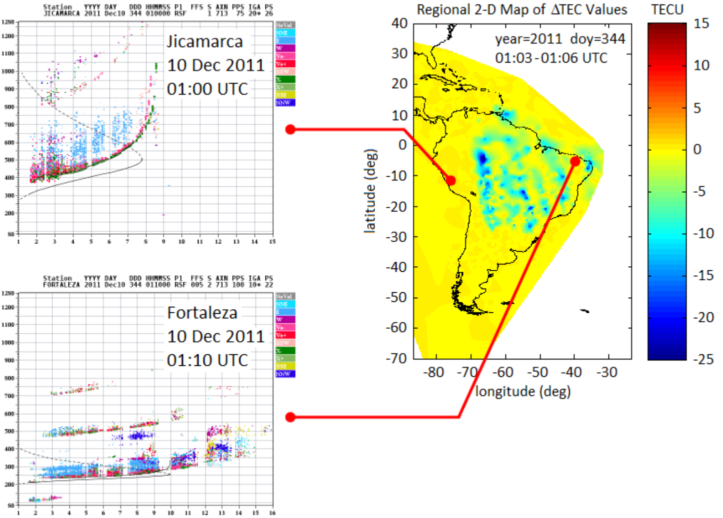


Pradipta et al. (2015, 2016)

Steep TEC gradients can come from the side walls as well as irregularities inside the bubble (may cause scintillation and/or loss-of-lock).

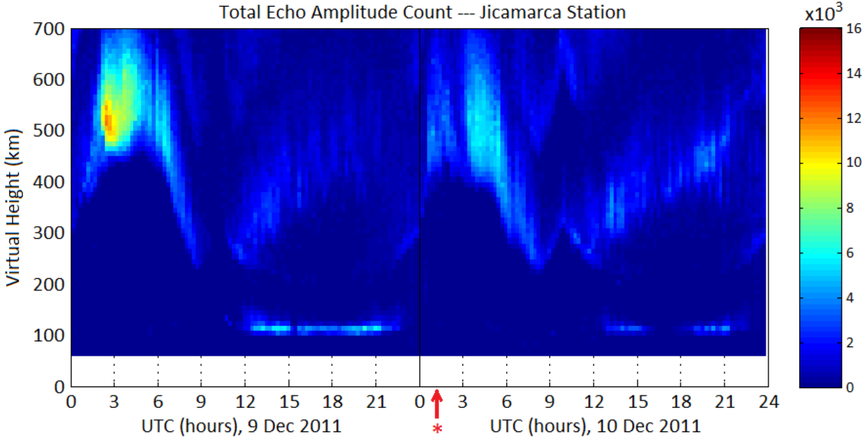
EPBs can occur night-after-night for the duration of several months.

GPS TEC and Ionosonde Observations of EPBs



EPBs can also adversely affect HF, VHF, and UHF radio communication links. Most notably, spread-F echoes in HF radio sounding data.

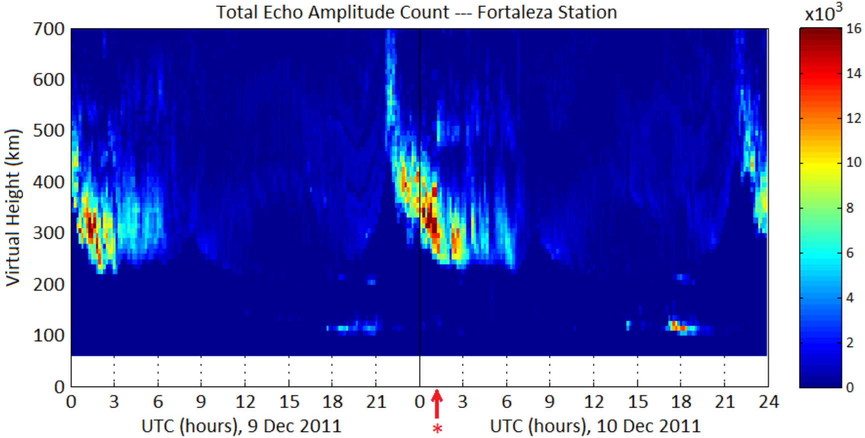
GPS TEC and Ionosonde Observations of EPBs (cont.)



No bubble → relatively little or no spread echoes in radio sounding data.

There is generally low probability of experiencing GPS scintillation.

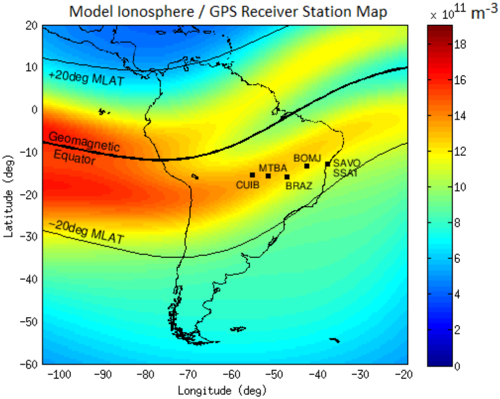
GPS TEC and Ionosonde Observations of EPBs (cont.)

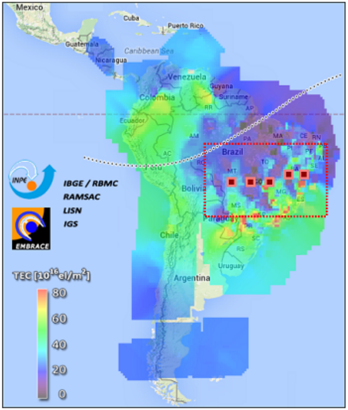


Extensive EPBs → stronger spread echoes in the radio sounding data.

There is generally higher chance of experiencing GPS scintillation.

Brazil Case Study: August 2014 - February 2015





TEC data from 6 receiver stations (RBMC network) extending east/west, situated roughly underneath the southern crest of the equatorial anomaly.

We expect to capture some of the worst TEC gradient cases.

Brazil Case Study: August 2014 - February 2015 (cont.)

Two independent ways to estimate the TEC gradients:

$$\nabla_{\perp}\text{TEC} = \left.\frac{\text{TEC}_{\text{station 1}} - \text{TEC}_{\text{station 2}}}{\delta s_{12}}\right|_{\text{station pair}}$$

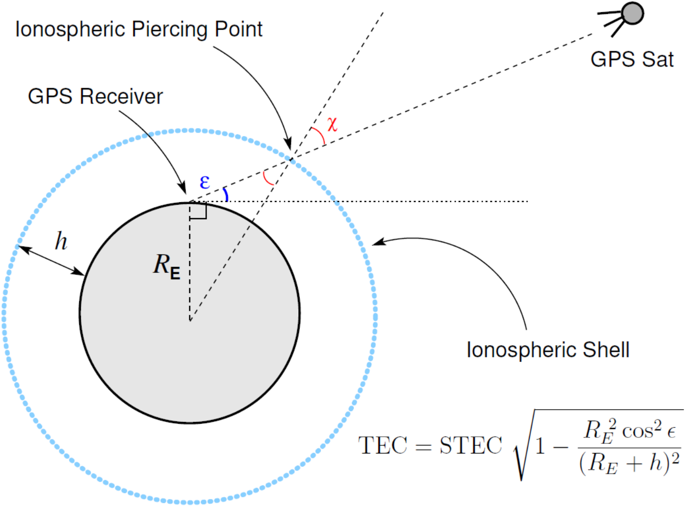
$$\nabla_{\parallel}\text{TEC} = \frac{1}{v_{\text{IPP}}}\frac{d\text{TEC}}{dt} = \left.\frac{d\text{TEC}}{ds}\right|_{\text{single station}}$$

The 1st method (station-pair method) gives us the TEC gradient values along a fixed direction dictated by the station geometry.
Advantage: instantaneous measurement of the TEC gradient;
Disadvantage: need two closely-spaced receiver stations;

The 2nd method (single-station method) gives us the TEC gradient values parallel along the IPP trajectory.
Advantage: not constrained by the availability of station pair;
Disadvantage: intertemporal measurement from consecutive epochs;

The estimated TEC gradient might be inflated/deflated – this can be improved if plasma drift velocity is known from observations or models.

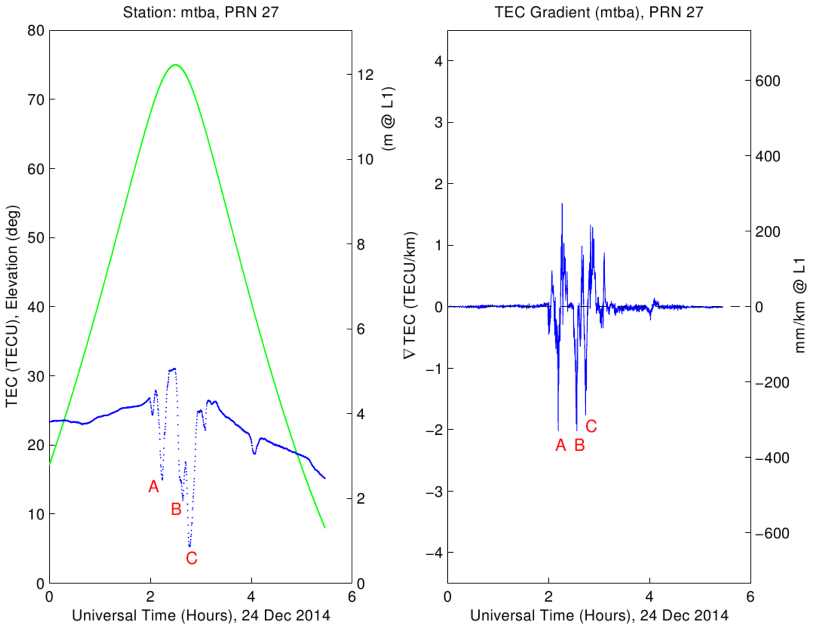
Brazil Case Study: August 2014 - February 2015 (cont.)



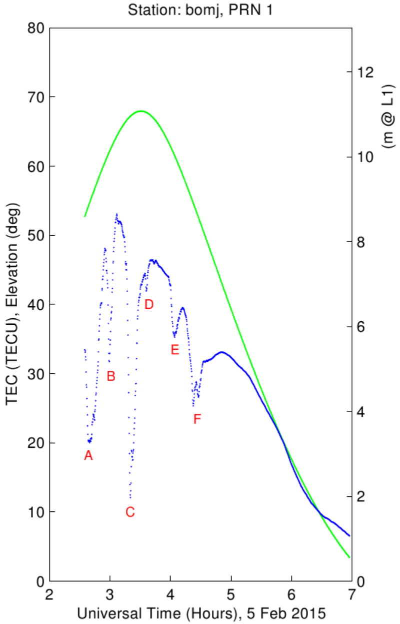
$$\mathrm{TEC} = \mathrm{STEC}\sqrt{1 - \frac{R_E^2 \cos^2 \epsilon}{(R_E + h)^2}}$$

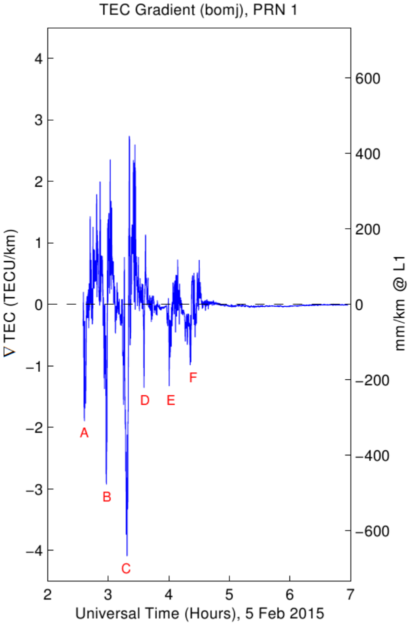
In this study, we are working in terms of equivalent vertical TEC. Thus, the TEC gradient estimates (esp. those at lower elevation angles) might be rather conservative.

TEC Gradient Case Examples (1 of 4)

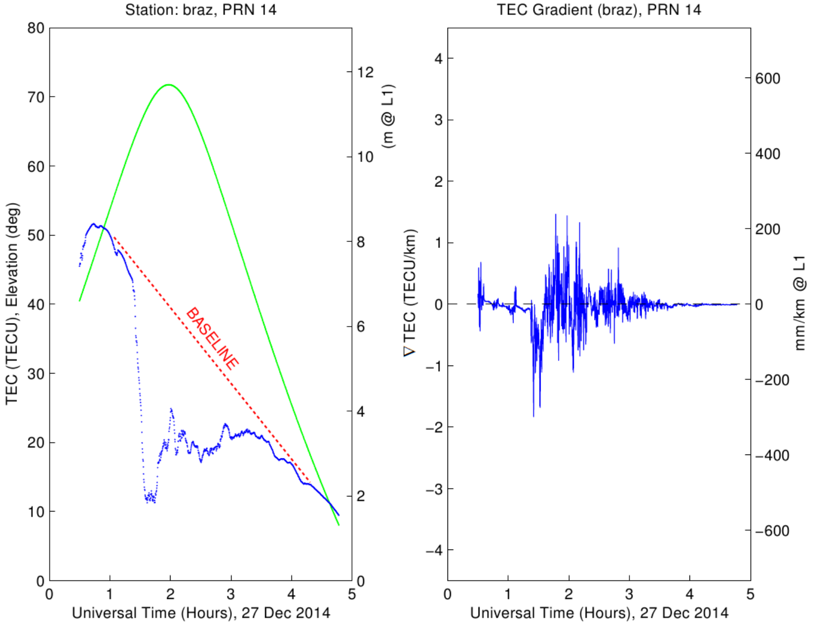


TEC Gradient Case Examples (2 of 4)

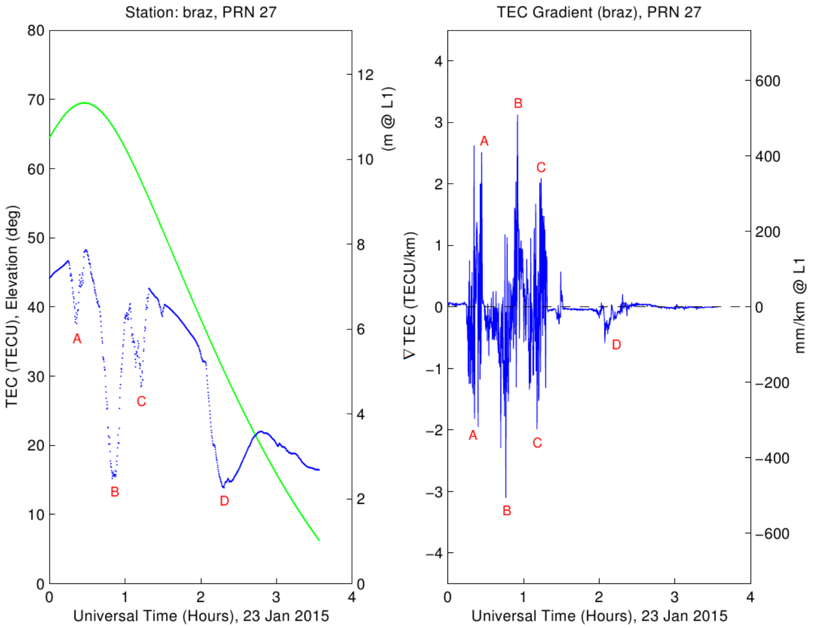




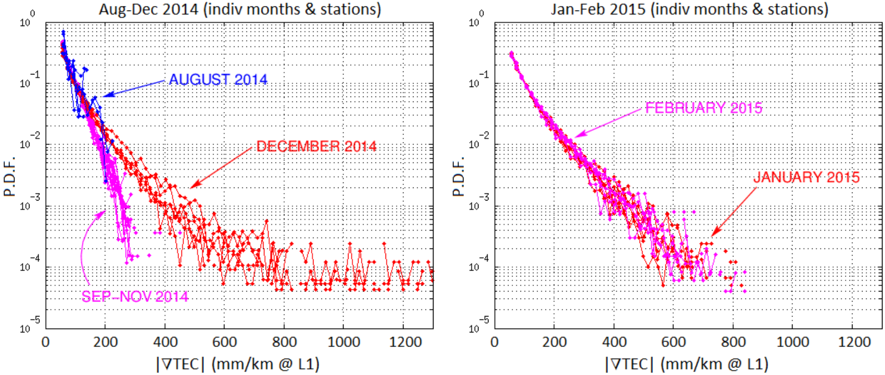
TEC Gradient Case Examples (3 of 4)



TEC Gradient Case Examples (4 of 4)



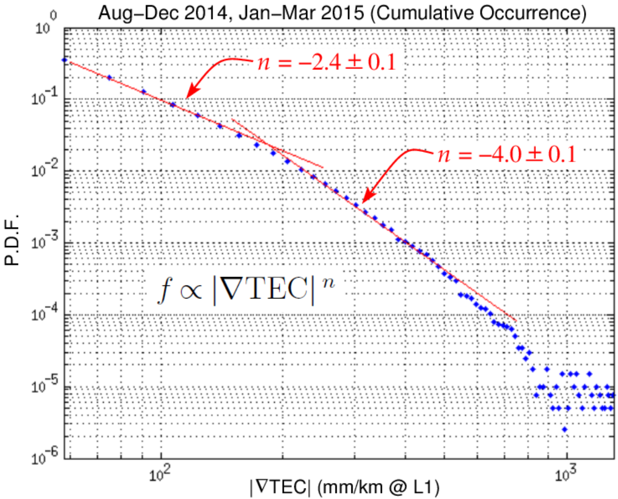
Distribution of |∇TEC| Values – 2014/2015 data



The TEC gradient magnitudes associated with equatorial plasma bubbles extend up to ∼1000 mm/km at GPS L1 frequency.

The distribution of TEC gradient magnitude varies with season, but no apparent spatial variability across longitudes within the Brazilian sector.

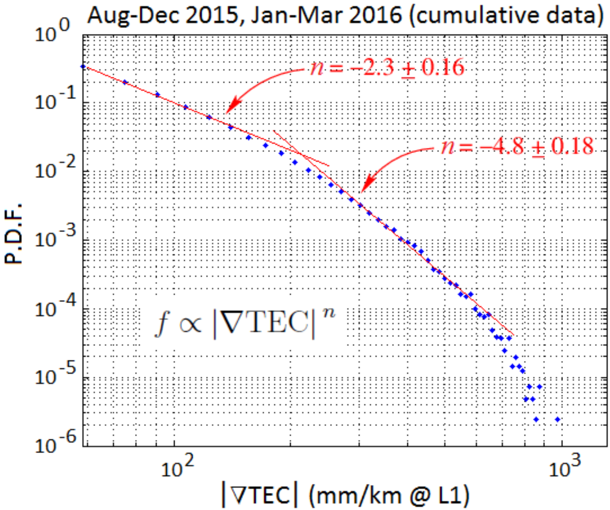
Distribution of |∇TEC| Values – 2014/2015 data (cont.)



A double-power-law distribution for the TEC gradient magnitudes:

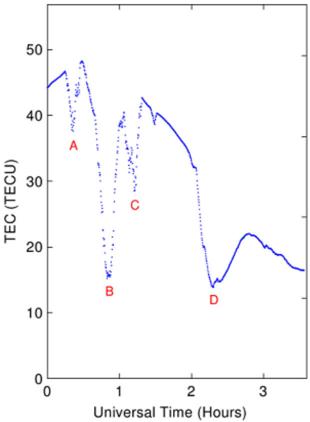
- break at ∼200 mm/km
- final drop at ∼800 mm/km

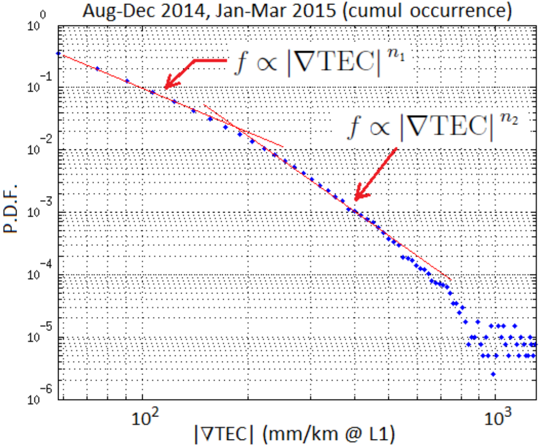
Some Preliminary Results from 2015/2016 Data



More precise physcial mechanism responsible for this double-power-law is the subject of ongoing research.

Summary and Conclusions





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