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**SMR 2333-44**

**Workshop on Science Applications of GNSS in Developing Countries (11-27 April), followed by the: Seminar on Development and Use of the Ionospheric NeQuick Model (30 April-1 May)**

*11 April - 1 May, 2012*

# Automated Detection of Depletions

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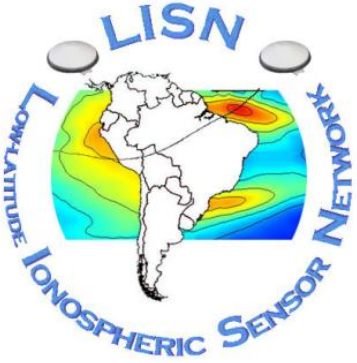



# Automated Detection of Bubbles

Cesar E. Valladares

# Outline

First and second derivatives Method by Conker and El Arini.

Two bandwidths analysis by Gopi Seemala

Detrending the background ionosphere by C. E. Valladares.

Spectra of dTEC and TIDs detection.

This algorithm could be used in an SBAS ground system. It identifies those lines of sight between SBAS receivers and GPS satellites that are affected by depletions. In addition, the location, duration, and depth of depletions can be determined in real-time. The SBAS could conceptually use this information to raise the error bounds at the appropriate ionospheric grid points (IGPs) in order to protect user aircraft using ionospheric pierce points (IPPs) located in grid cells affected by depletions.

They currently use windows of 20 steps, which for 30 sec data spans 10 **minutes. The first derivative to be less than $\gamma_1$** to identify the start of a **depletion and the absolute value of the second derivative to be less than $\varepsilon_1$**

$$\text{if } f'(t) \le \gamma_1 = -0.28\text{m/min, start depletion,}$$

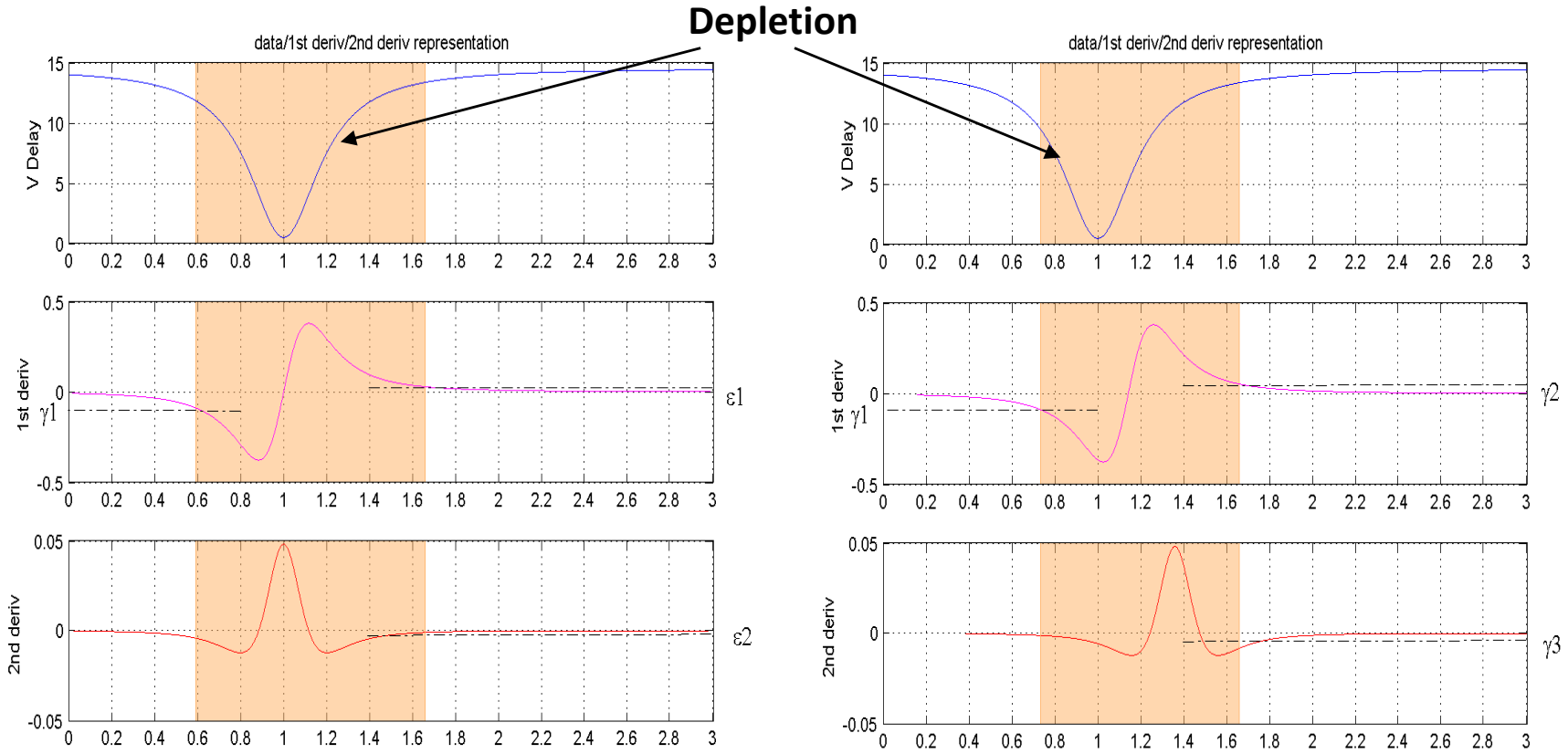
$$\text{if currently in a depletion and}$$

$$\begin{cases} 0 \le f'(t) < \gamma_2 = 0.2\text{m/min and } f''(t) < \gamma_3 = -0.008 m/\min^2, \text{or} \\ \sqrt{\dfrac{\sum_{w_1} (f'(t))^2}{w_1}} < \varepsilon_1 = 0.1 m/\min \text{ and } \sqrt{\dfrac{\sum_{w_2} (f''(t))^2}{w_2}} < \varepsilon_2 = 0.008 m/\min^2, \text{or} \\ f'(t),\ f'(t-1), \ldots f'(t-n) \text{ cannot be calculated} \end{cases}$$

# Mitre Algorithm Parameters

Without a sliding window

With a sliding Window

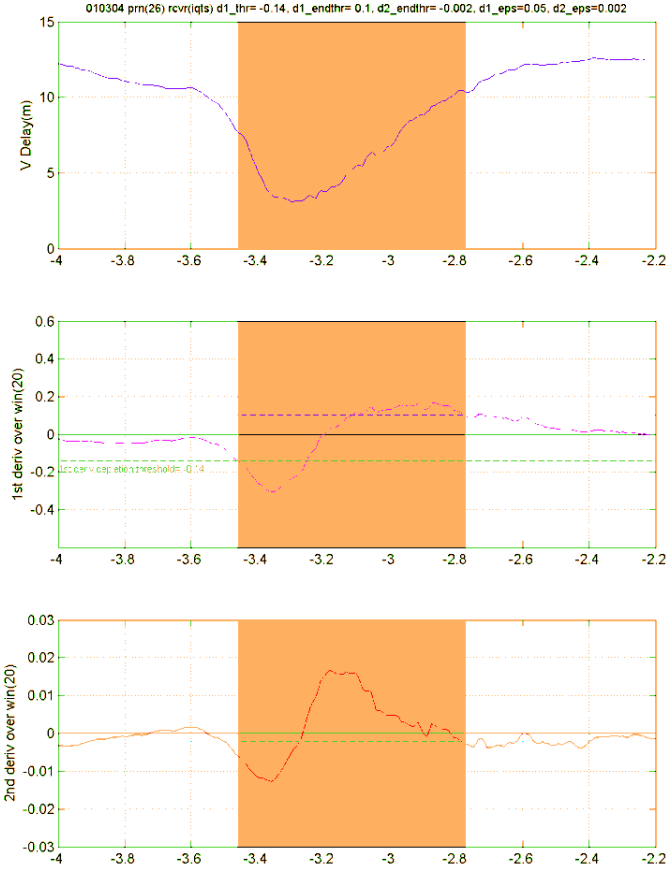



if $f'(t) \le \gamma_1 = -0.28\text{m/min}$, start depletion,

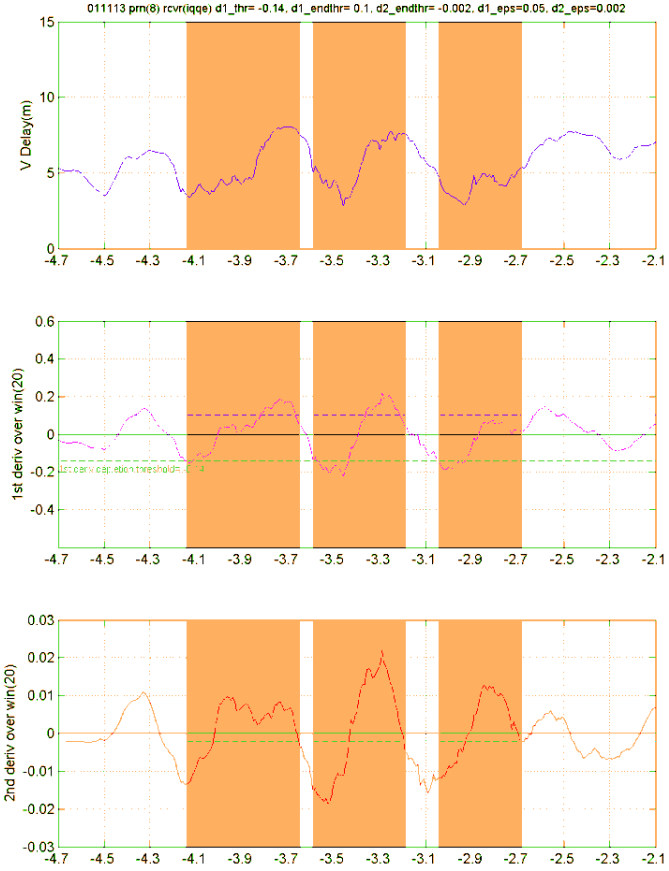
if currently in a depletion and

$$\begin{cases} 0 \le f'(t) < \gamma_2 = 0.2\text{m/min} \text{ and } f''(t) < \gamma_3 = -0.008 m/\min^2, \text{or} \\ \sqrt{\dfrac{\sum_{w_1} (f'(t))^2}{w_1}} < \varepsilon_1 = 0.1 m/\min \text{ and } \sqrt{\dfrac{\sum_{w_2} (f''(t))^2}{w_2}} < \varepsilon_2 = 0.008 m/\min^2, \text{or} \\ f'(t),\ f'(t-1), \ldots f'(t-n) \text{ cannot be calculated} \end{cases}$$

# Examples of Detecting A Single Depletion and 3 Depletions




**PRN26 at Iquitos, Peru, March 4, 2001**



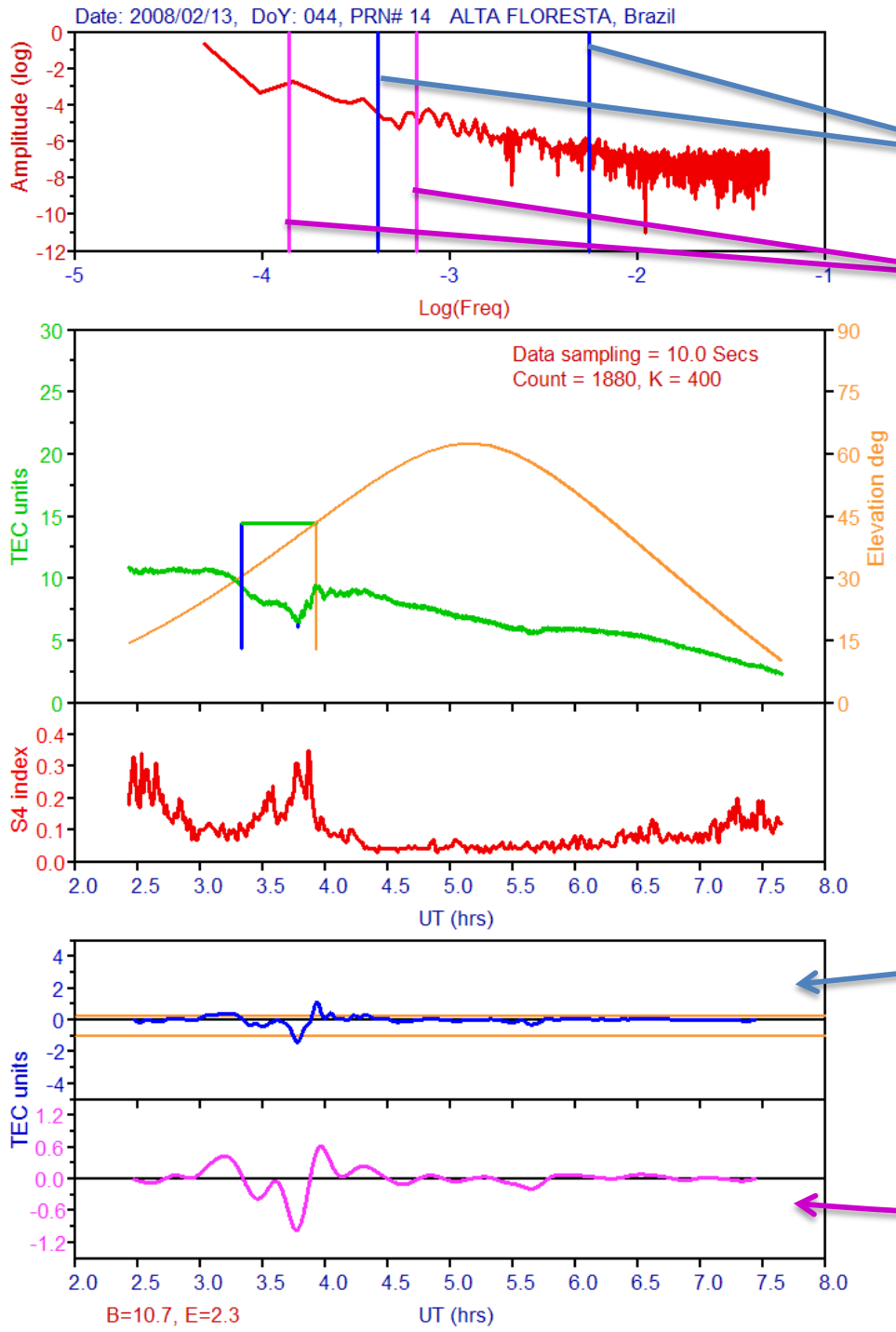

**PRN8 at Iquique, Chile, November 13, 2001**

# **Seemala's** detection algorithm

- In order to identify both narrow and wide TEC depletions, two spectral bands are filtered from the actual vertical TEC of each GPS satellite by using a simple digital band pass filter to get structures of 3 min to 40 min durations and second filter with 25 to 120 min durations.

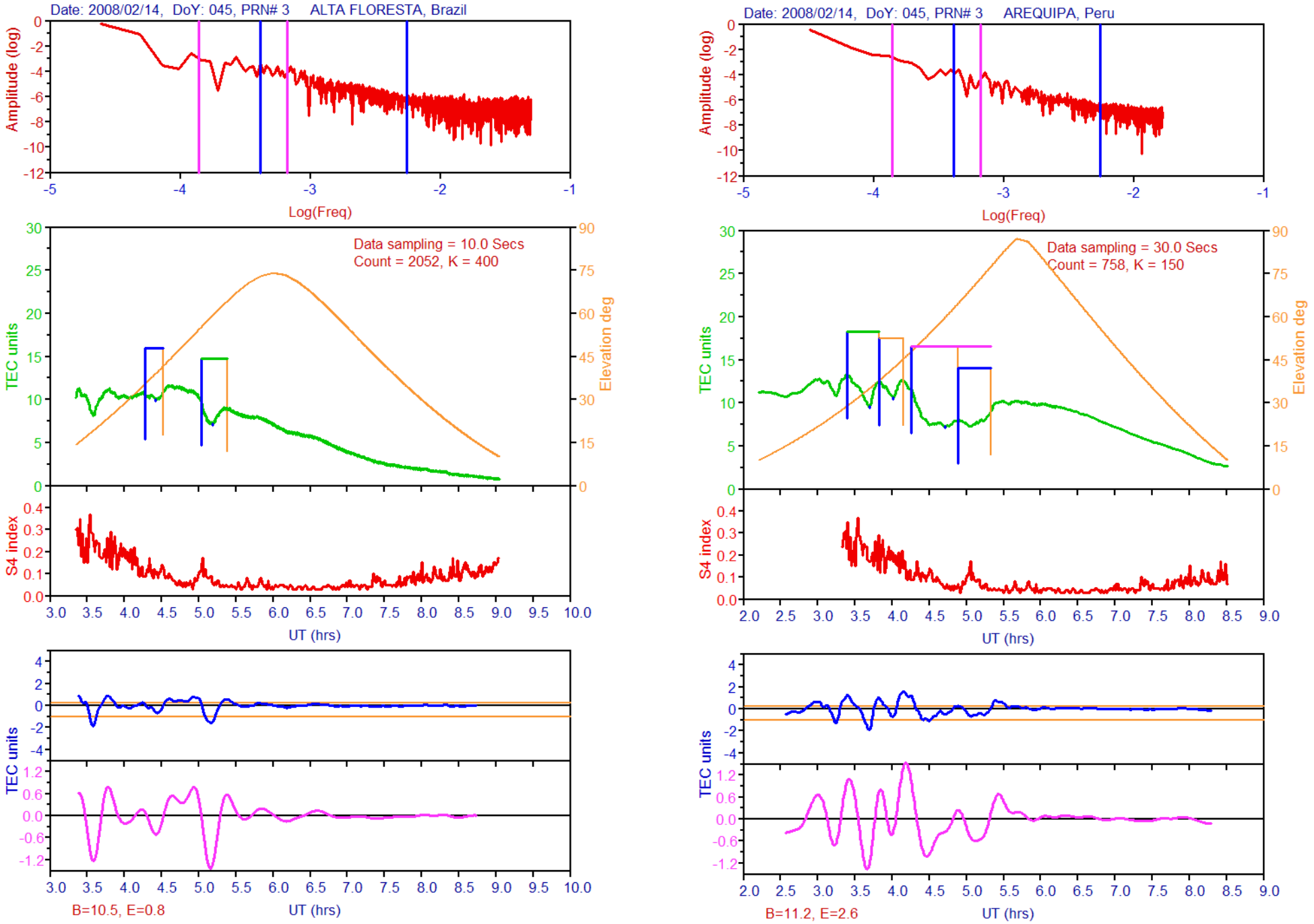
- The bubble detection is confirmed if the elevation angle is above 30 and TEC recovers to a value similar to the starting TEC.

- These identified depletions are validated by their onset times (post sunset time), geomagnetic location of occurrence and false detections arising due to TEC gradients at low elevation angles and data breaks.

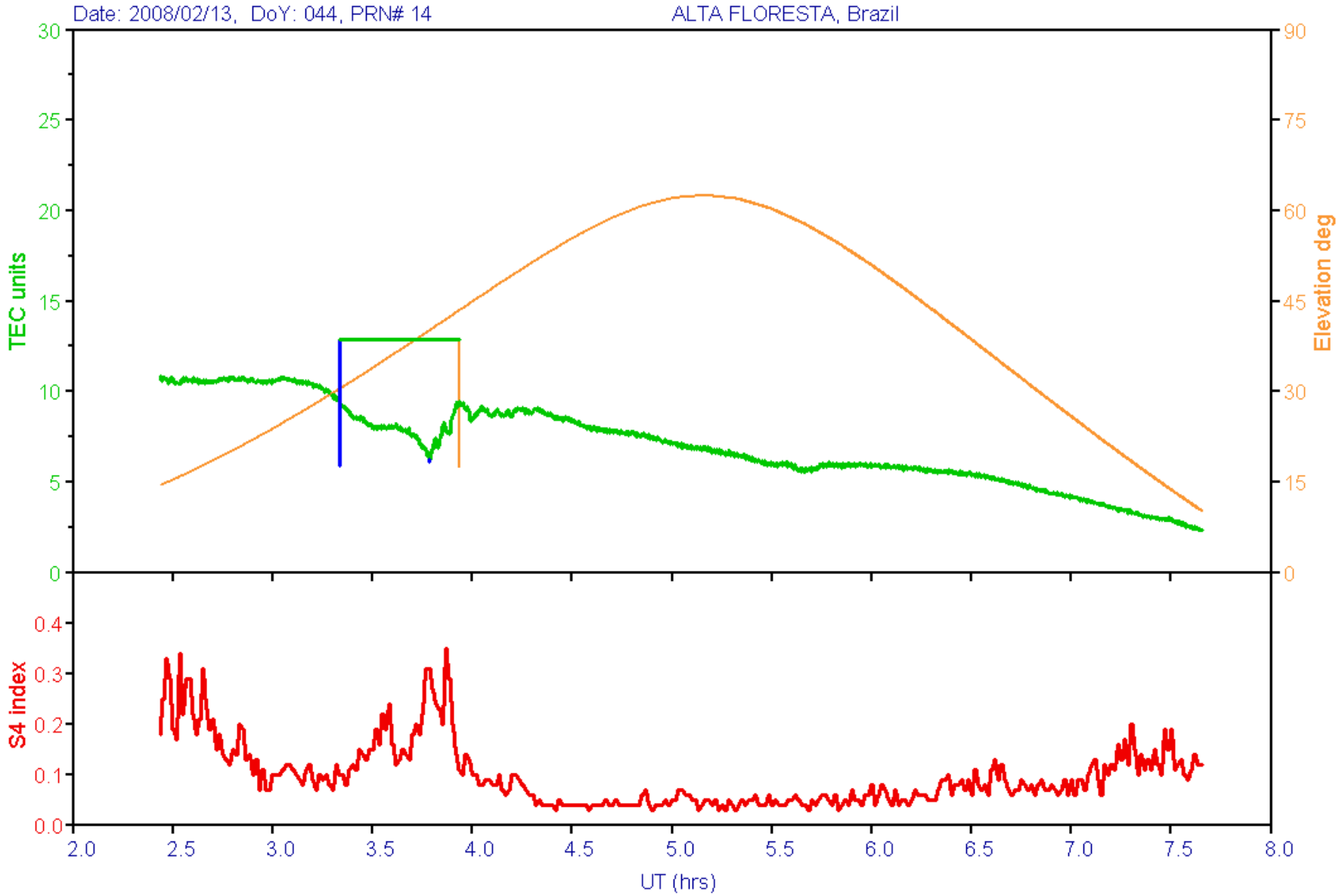


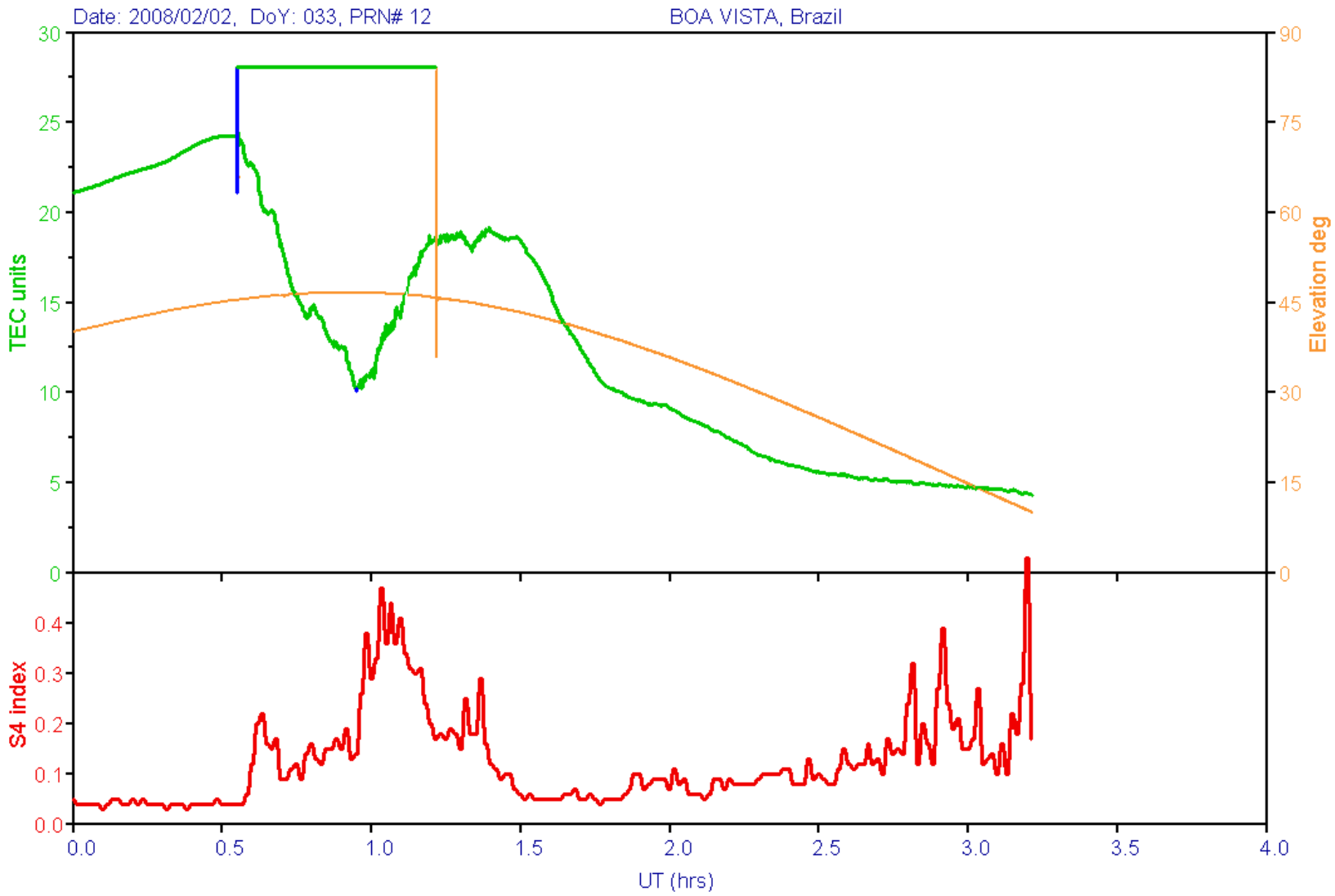

Spectrum to filter 3 to 40 mins

Spectrum to filter 25 to 120 mins

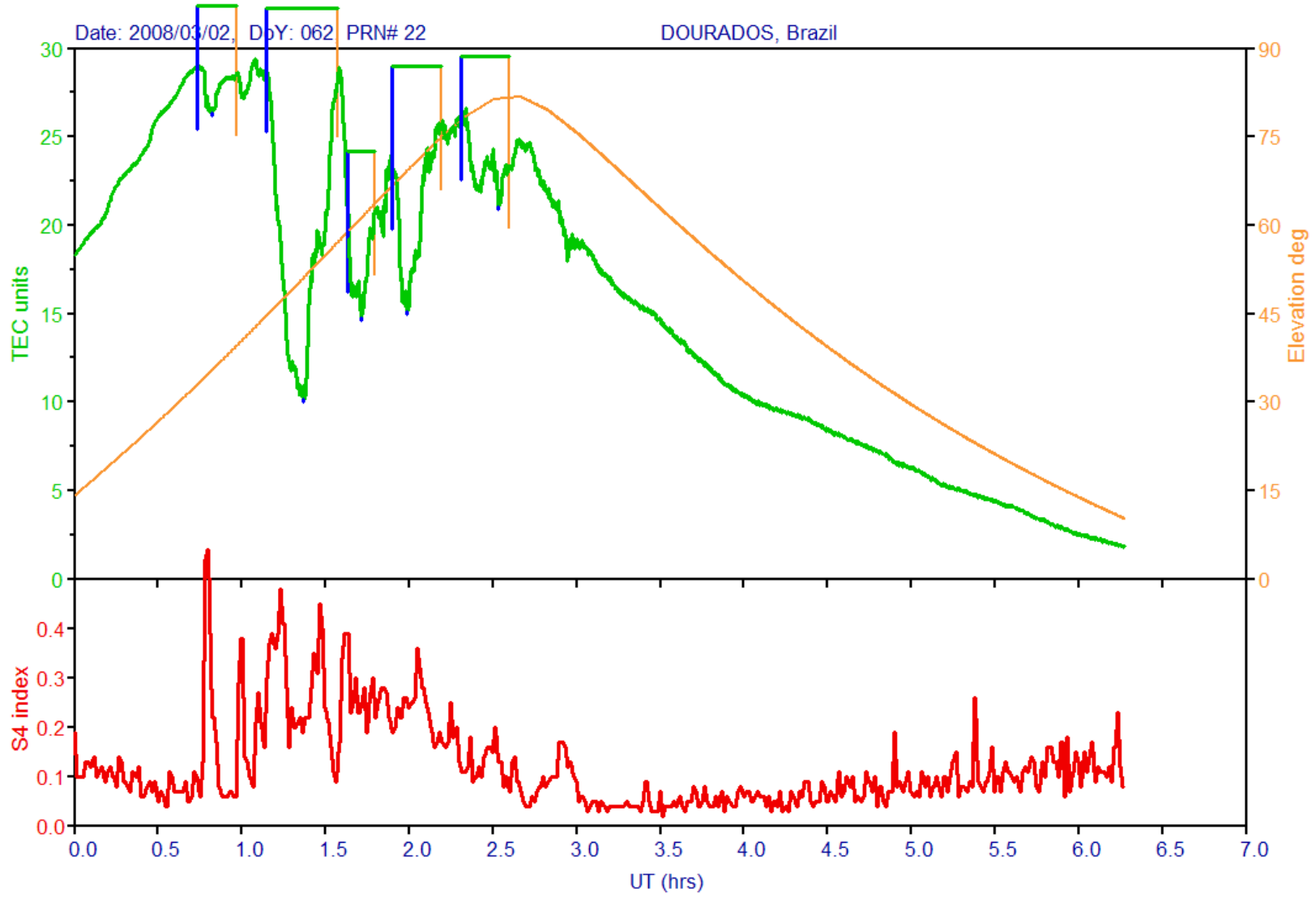

Date: 2008/02/14, DoY: 045, PRN# 3 ALTA FLORESTA, Brazil
Amplitude (log)
Log(Freq)
Data sampling = 10.0 Secs
Count = 2052, K = 400
TEC units
Elevation deg
S4 index
UT (hrs)
TEC units
B=10.5, E=0.8
UT (hrs)
Date: 2008/02/14, DoY: 045, PRN# 3 AREQUIPA, Peru
Amplitude (log)
Log(Freq)
Data sampling = 30.0 Secs
Count = 758, K = 150
TEC units
Elevation deg
S4 index
UT (hrs)
TEC units
B=11.2, E=2.6
UT (hrs)

# Plasma Depletions are observed as decrease in TEC




Date: 2008/02/02, DoY: 033, PRN# 12
BOA VISTA, Brazil
TEC units
Elevation deg
S4 index
UT (hrs)
0
5
10
15
20
25
30
0
15
30
45
60
75
90
0.0
0.1
0.2
0.3
0.4
0.0
0.5
1.0
1.5
2.0
2.5
3.0
3.5
4.0

# Detection of Multiple Plasma Depletions

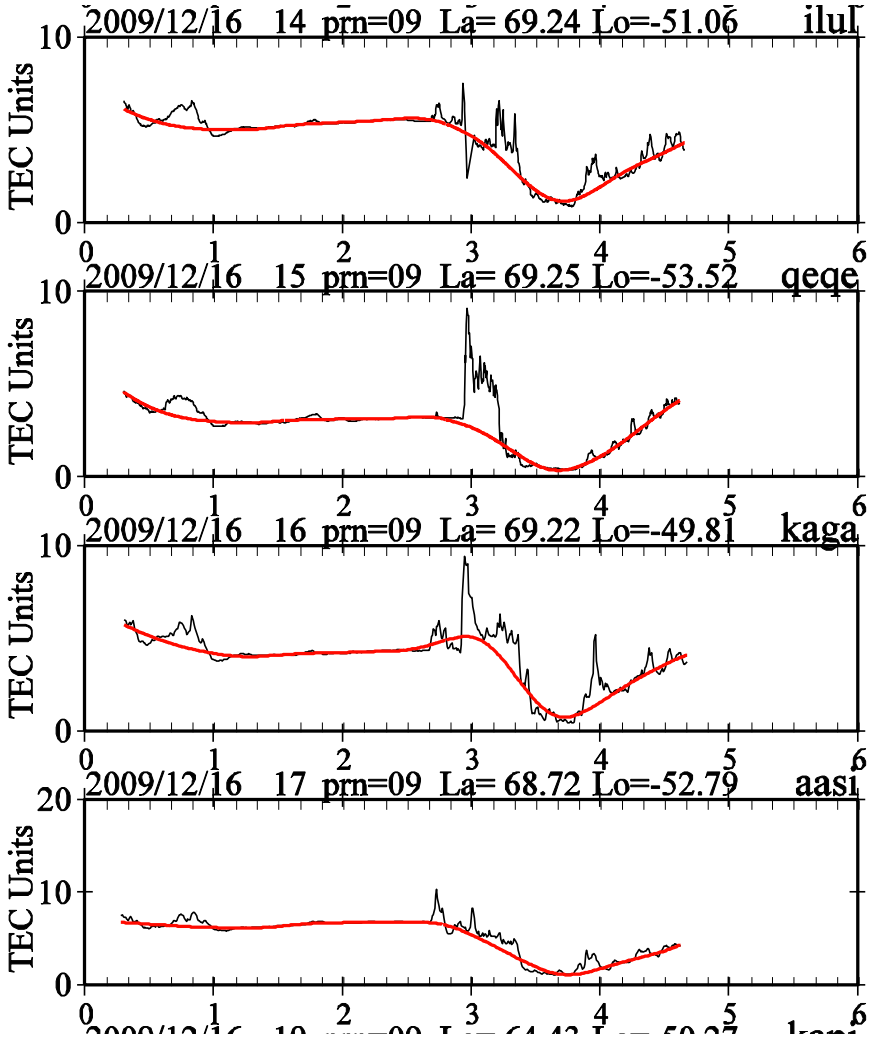


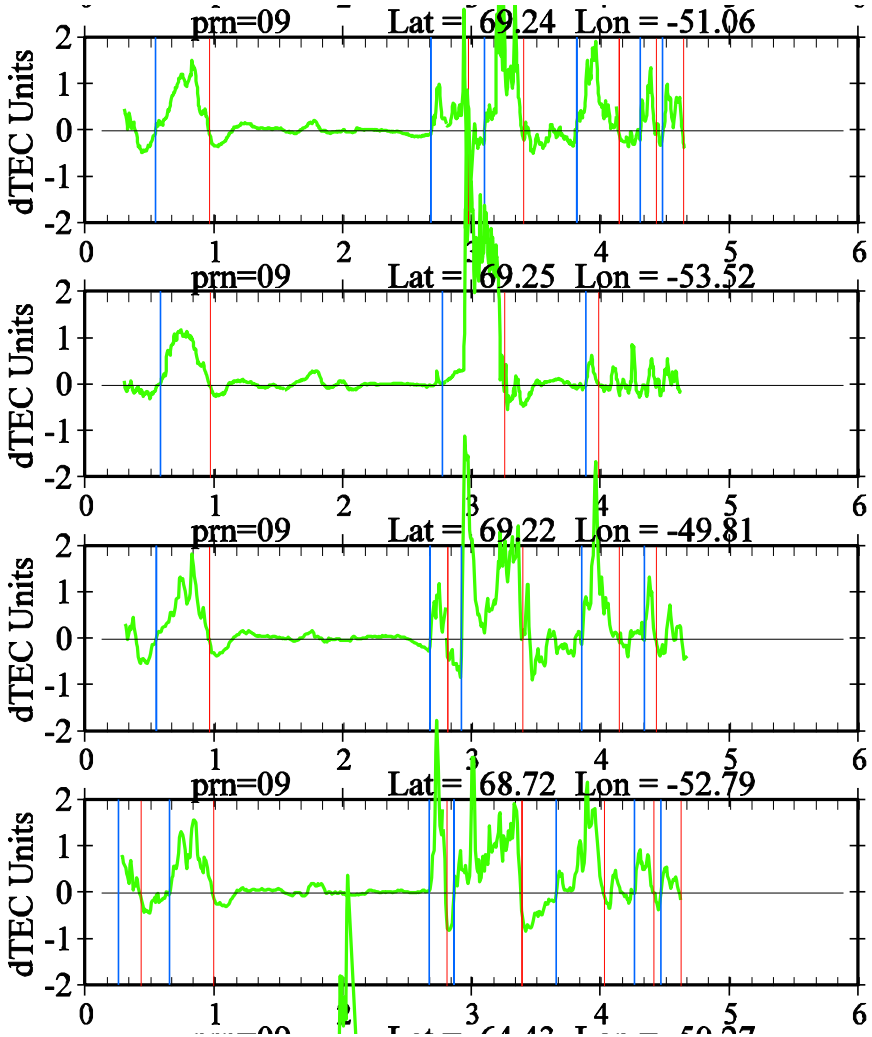
# CEV's Method

1) Fit a $4^{th}$ order polynomial to every 3 hours of TEC data.
2) Find the difference between TEC and fitted TEC : dTEC[1].
3) Determine cases when dTEC[1] is below a threshold level, say 0.7 TECu.
4) Make a second fit to TEC, but avoid periods when dTEC[1] is below the threshold value.
5) Find the difference between TEC and the second fit : dTEC[2].
6) Search for the beginning and end of depletions based on the derivatives of original TEC.
7) A low pass filter is also used to eliminate periods < 3 min.

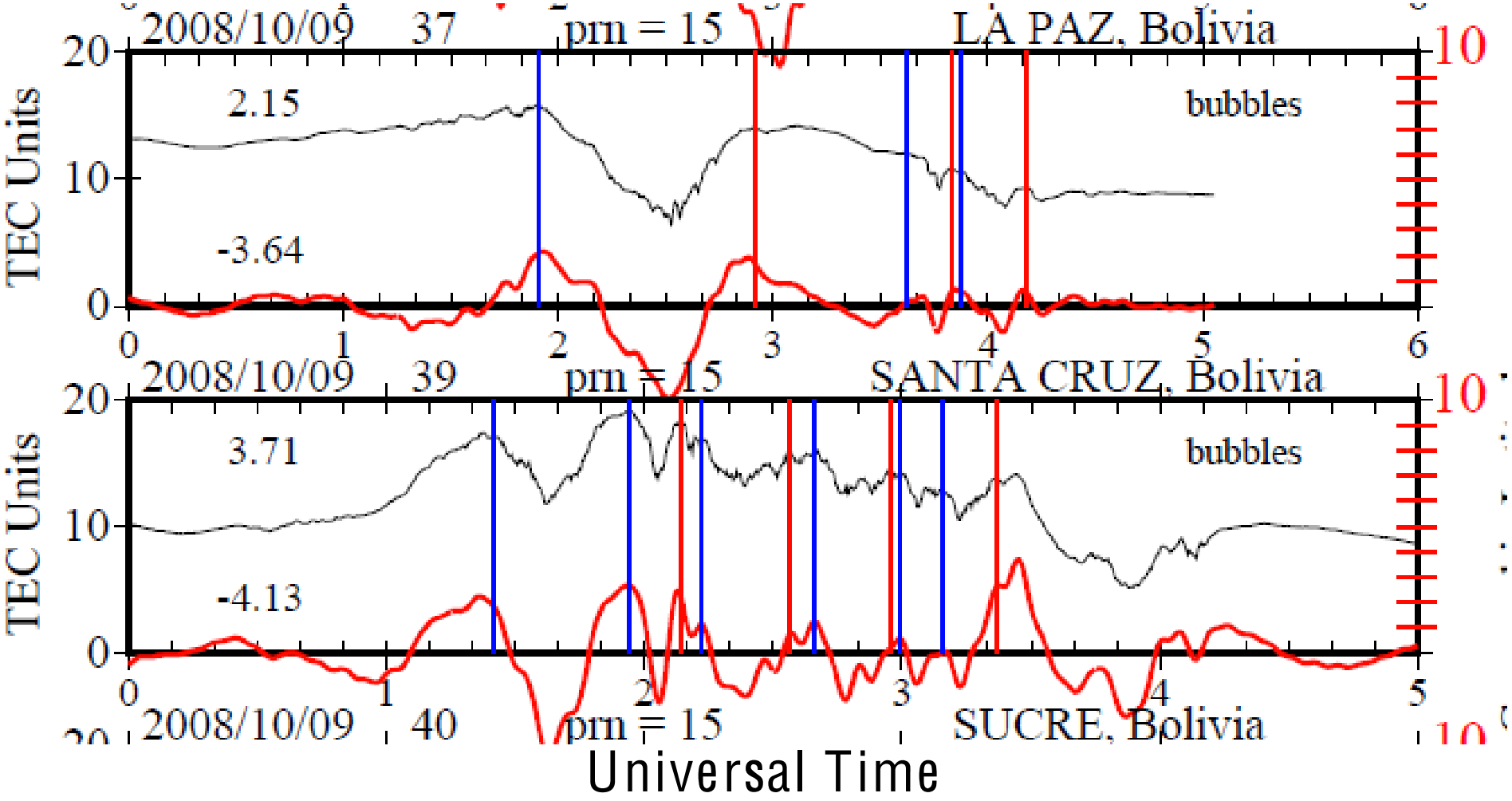
Black trace is the measured TEC, red line displays 2nd fit.

Green curve dTEC[2], blue line start of TEC enhancements, red line indicates the end of enhan.

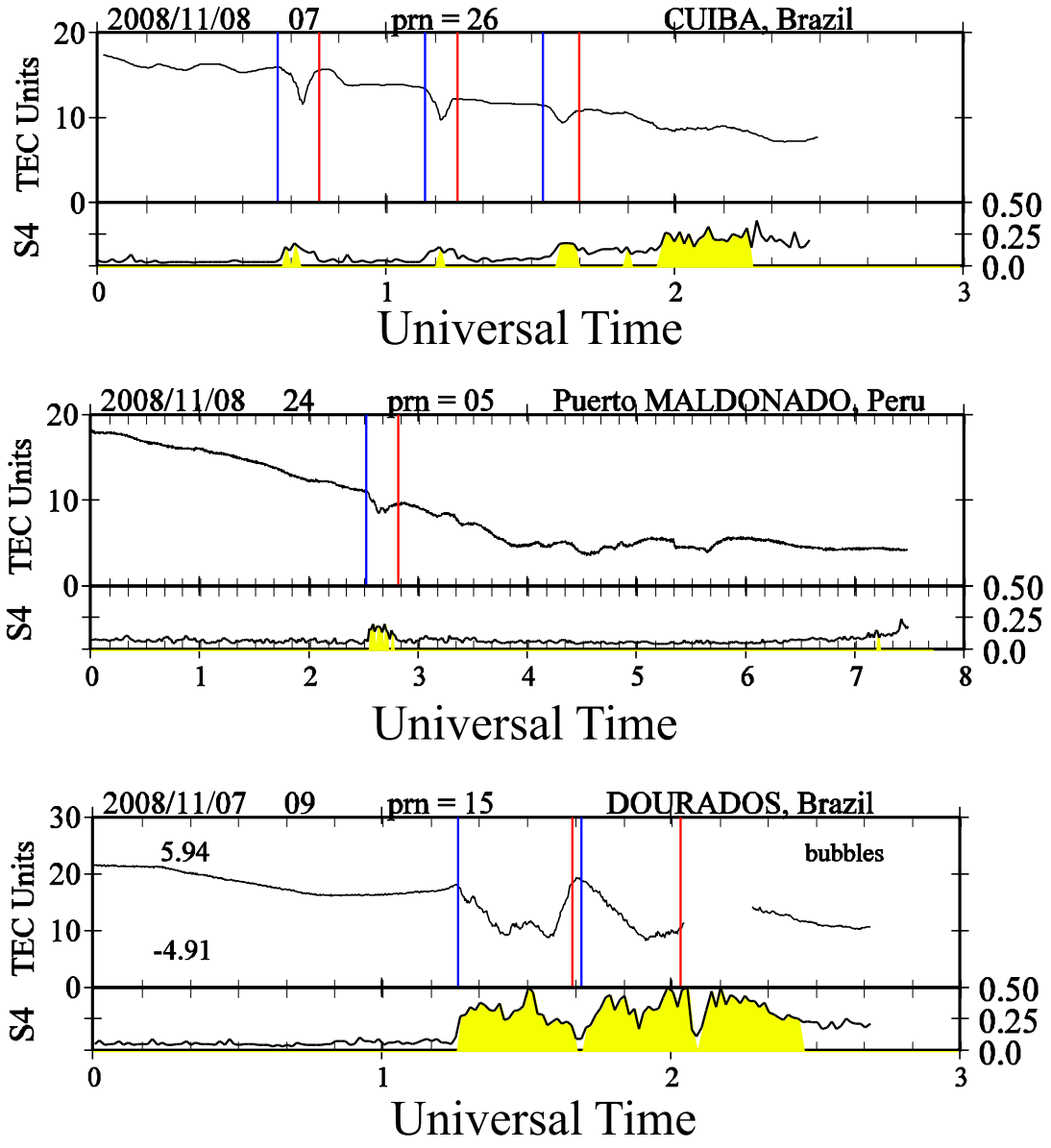


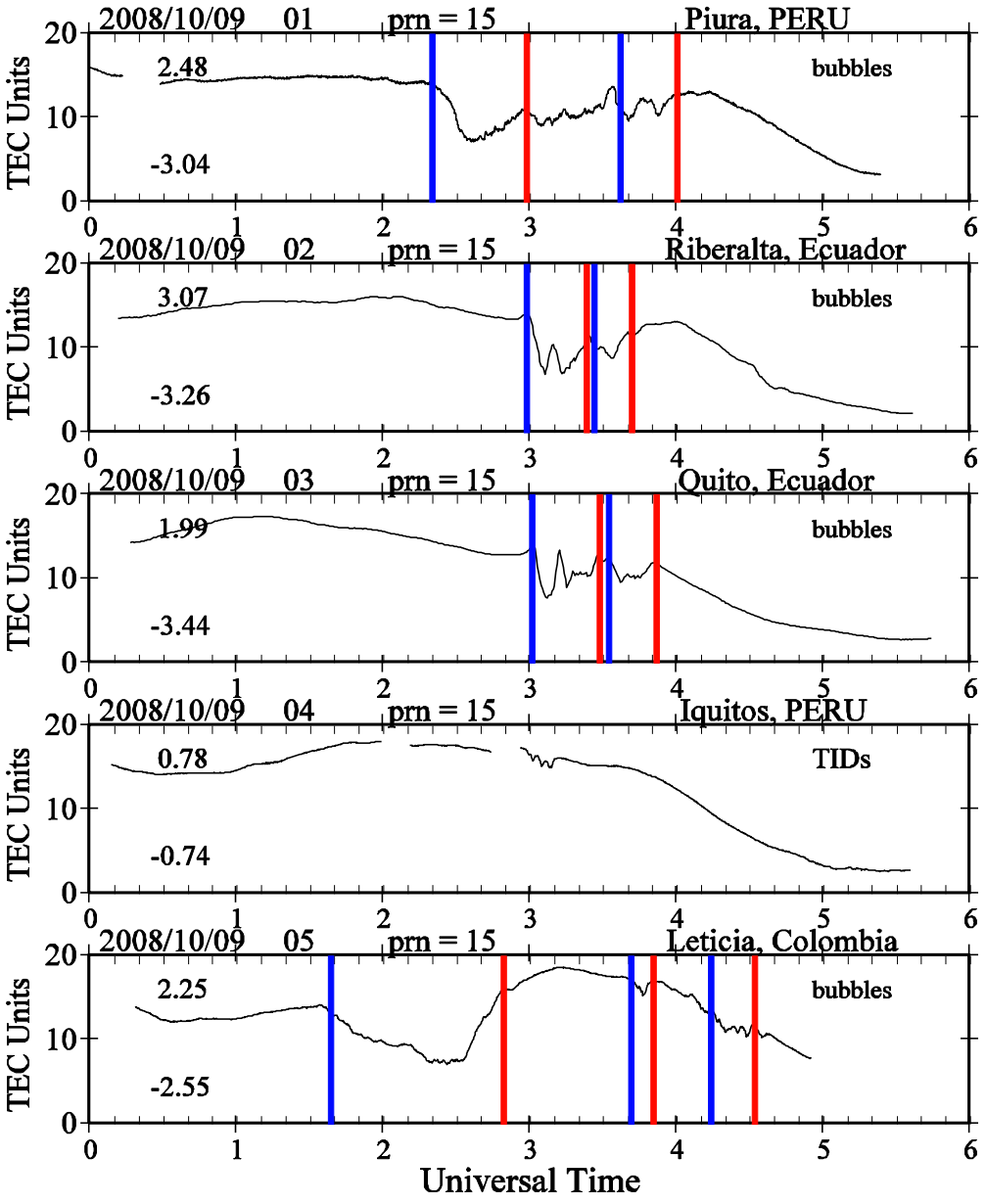
The black trace is TEC, the red line at the bottom of each frame is dTEC[1]. Note the scale for dTEC at the right side.

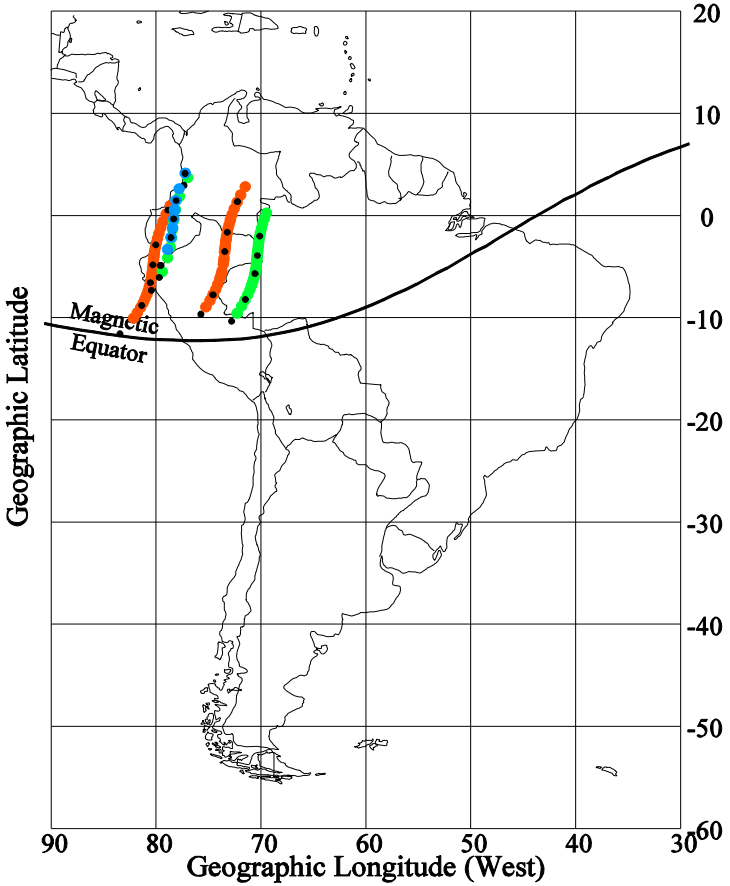


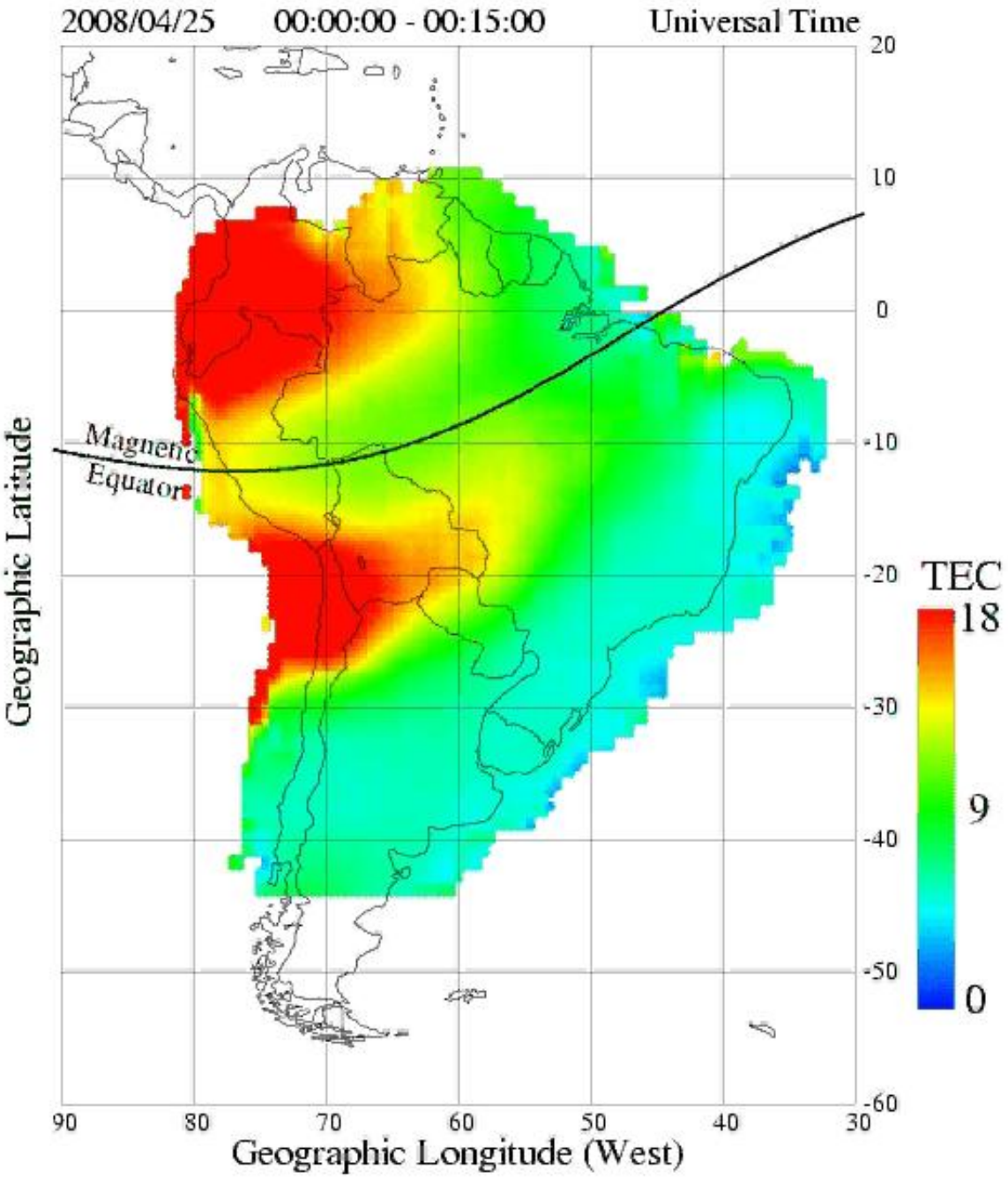
# TEC depletions observed in November 07 and 08, 2008



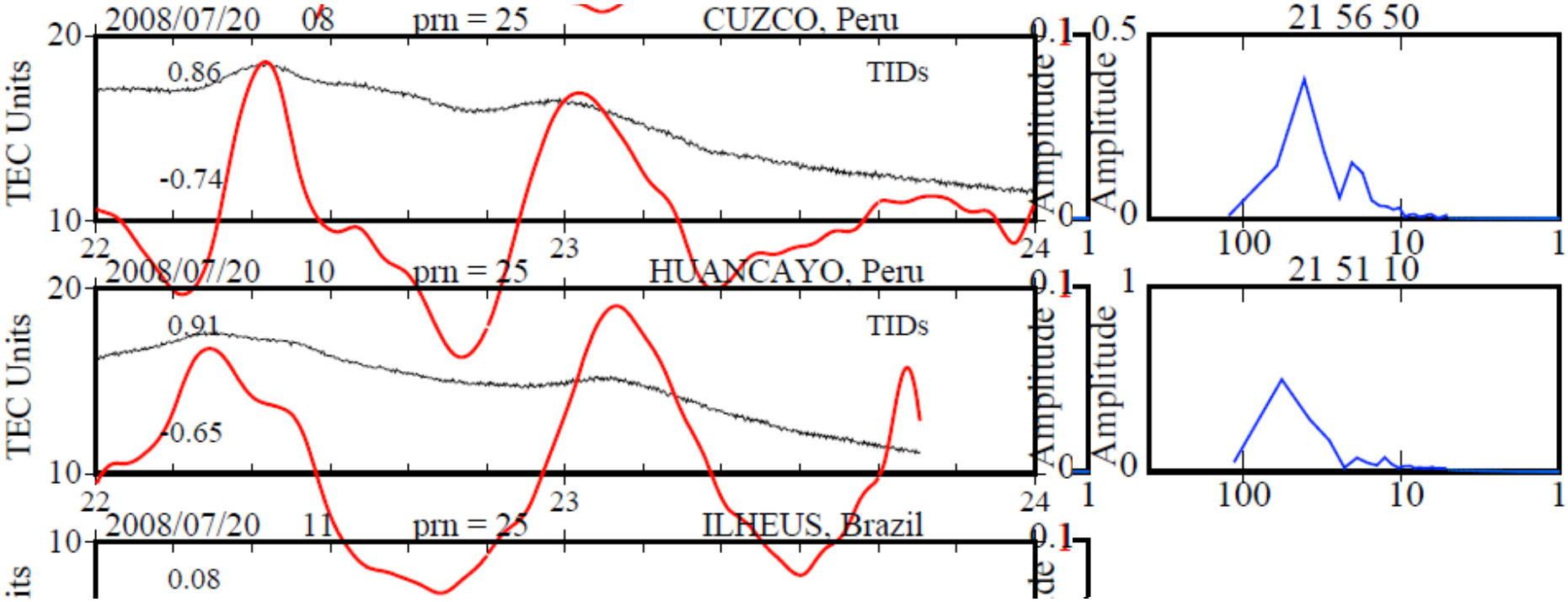
# TEC depletions seen on 5 stations aligned east-west



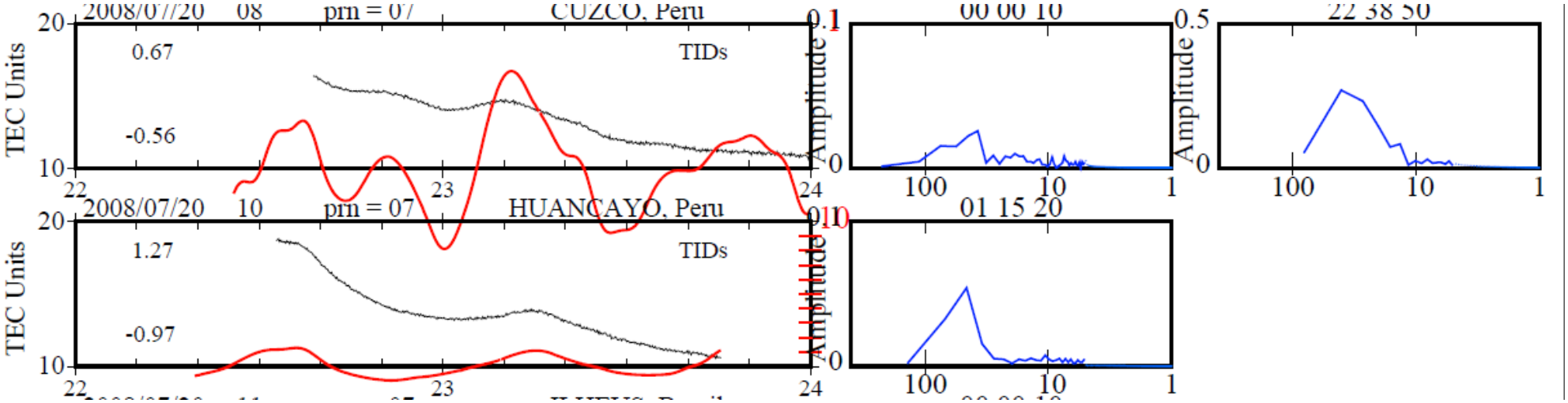




2008/04/25 00:00:00 - 00:15:00 Universal Time
Geographic Latitude
Geographic Longitude (West)
Magnetic Equator
20
10
0
-10
-20
-30
-40
-50
-60
90
80
70
60
50
40
30
TEC
18
9
0

# TEC (black line) dTEC[1] in red and spectrum of dTEC in blue (right frame)



# TEC (black line) dTEC[1] in red and spectrum of dTEC in blue (right frame)




Universal Time

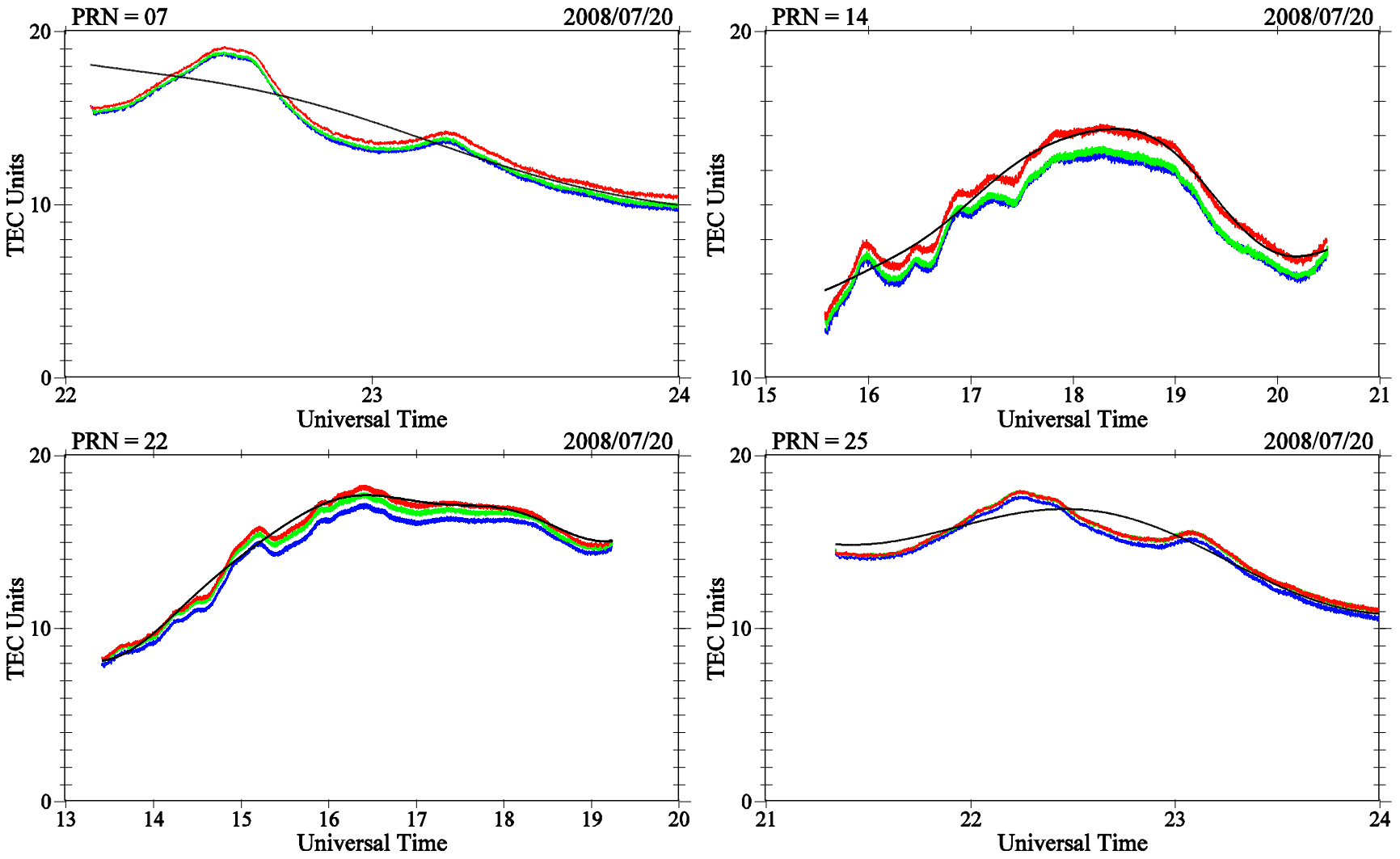
# Conclusions

All 3 methods perform quite well. **Gopi's and CEV's** methods have been compared for all South America data corresponding to 2008 (126 GPS stations). The results indicate a 99% agreement.

More complete correlative studies between dTEC and scintillations are desired.

A 2-dimensional reconstruction of TEC depletions (plasma bubbles) can initiate more precise studies of the amount of scintillations within the bubbles.

# TEC values measured at Huancayo using several GPS satellites




TEC perturbations associated with TIDs with ~40 min periods.