Studies of TEC in Ecuador using Global Positioning System (GPS) data

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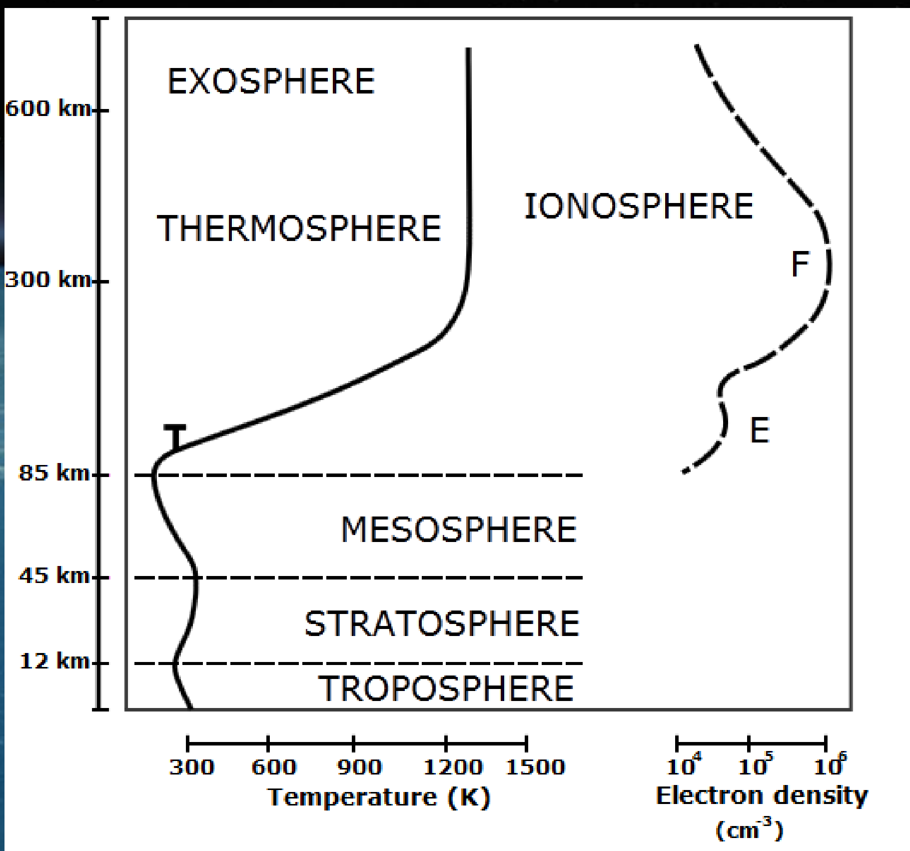
What is the ionosphere?

The ionosphere is a region of the upper atmosphere.

The ionosphere is a shell of electrons and electrically charged atoms and molecules around the Earth.



600 Km

500 Km

300 Km

85 Km

effective ionosphere

Why do we study the ionosphere?

The ionosphere has a role in the propagation of radio waves and in the propagation of interference from electrical-shock. **.**

Frequencies < 30 MHz

Changes in the ionospheric parameters produce variations in the magnetic field and electromagnetic emissions

One of the most important parameter is the total electron content (TEC)

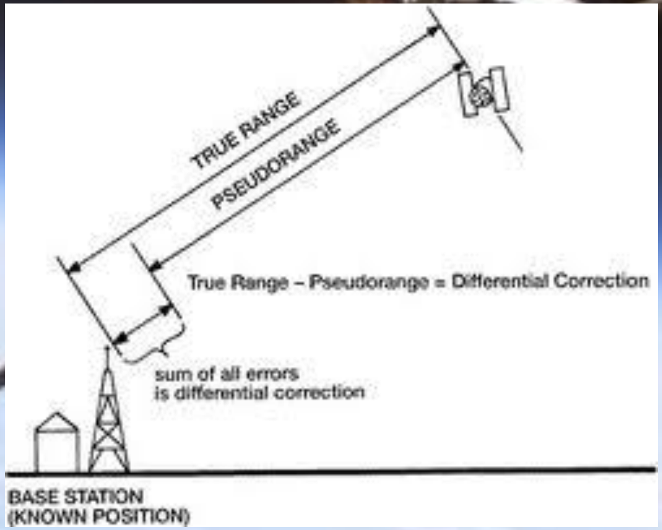
How do we study TEC?

It's introduced a delay for frequencies over 30 MHz.

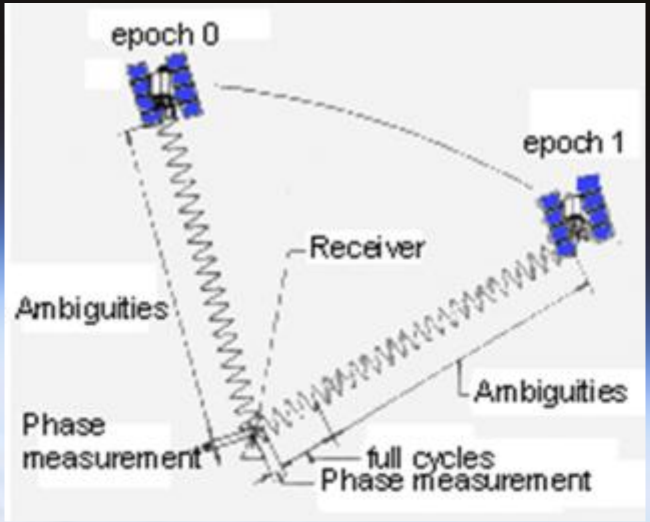
GPS frequencies

1575.42 MHz
1227.60 MHz

Pseudorange



Carrier Phase

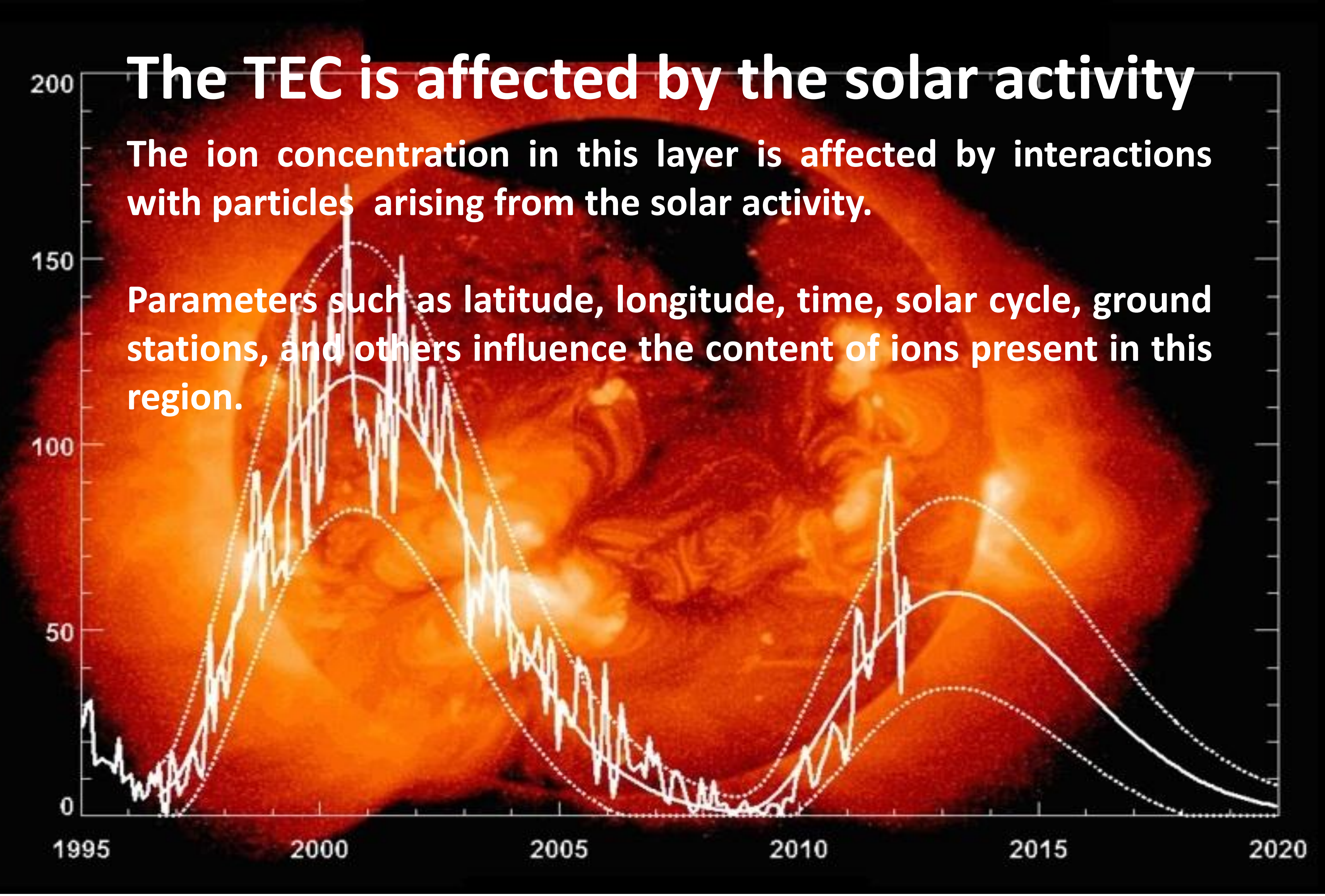


We can study the total electron content (TEC), using GPS Data (pseudorange and carrier phase)

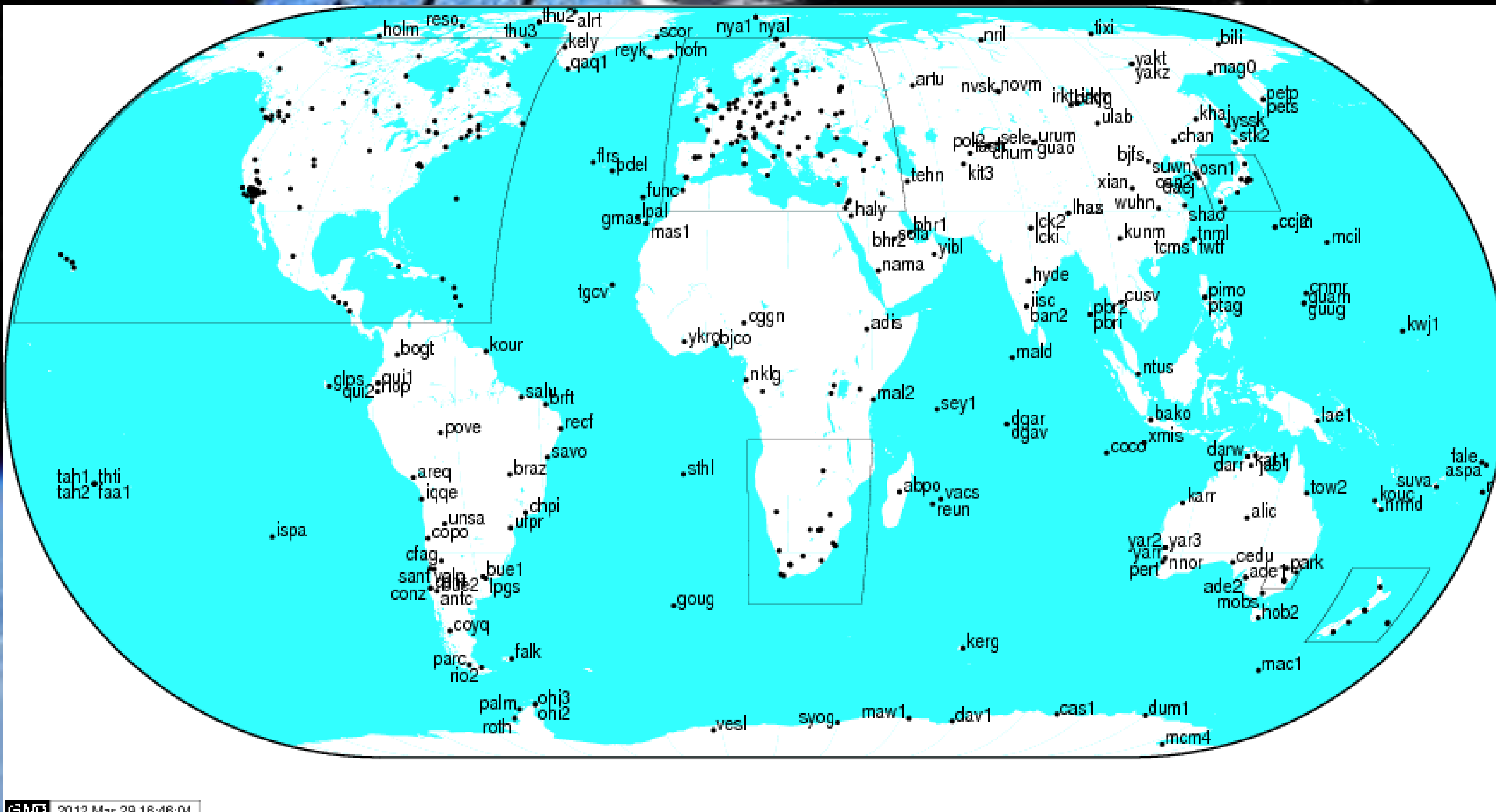
The TEC is affected by the solar activity

The ion concentration in this layer is affected by interactions with particles arising from the solar activity.

Parameters such as latitude, longitude, time, solar cycle, ground stations, and others influence the content of ions present in this region.

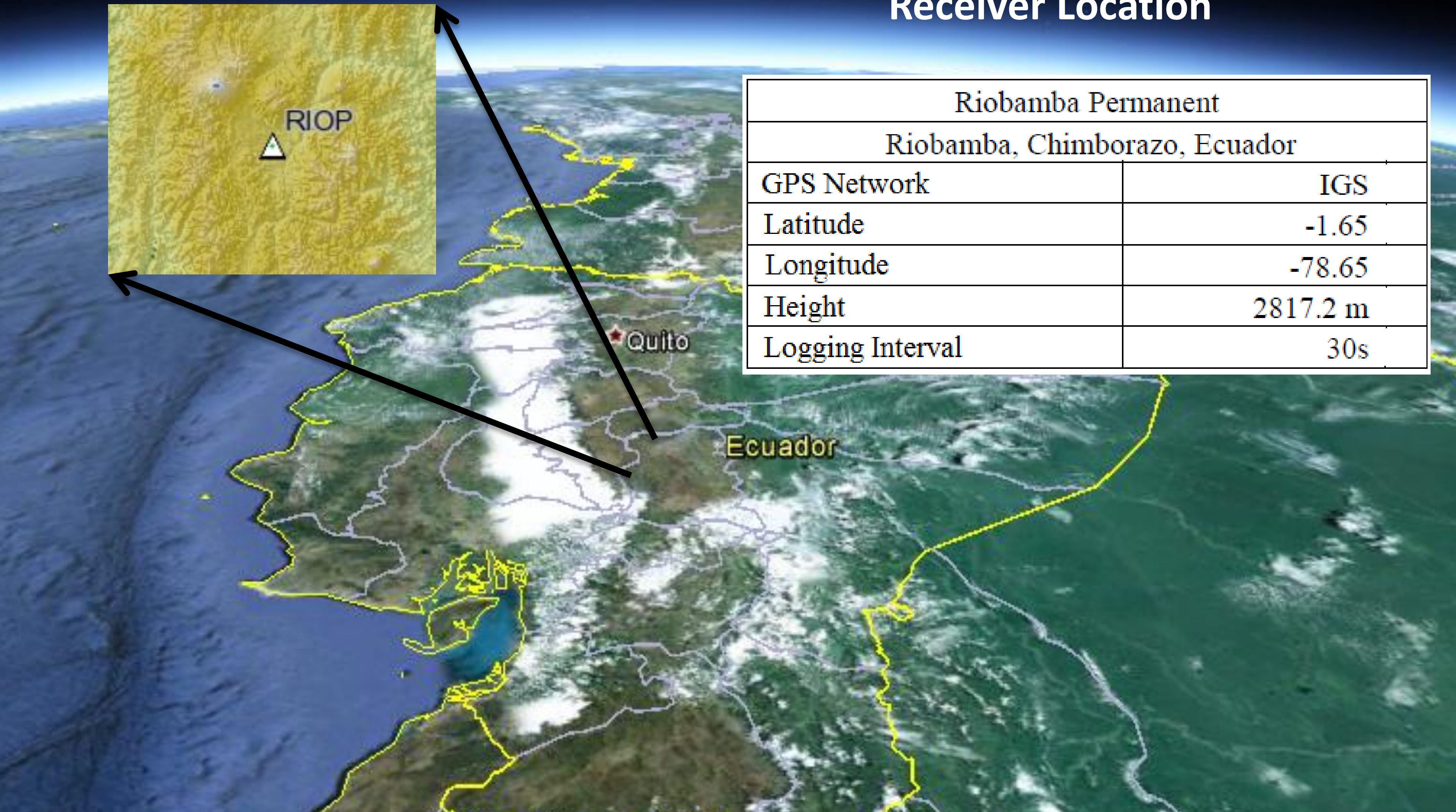


International GNSS Service (IGS) network receivers



Receivers in Ecuador

Receiver Location



Riobamba Permanent	
Riobamba, Chimborazo, Ecuador	
GPS Network	IGS
Latitude	-1.65
Longitude	-78.65
Height	2817.2 m
Logging Interval	30s

Formulation of the TEC measurement

The ionospheric time delay is determined from simple ray optics using the first-order ionospheric index of refraction (Budden, 1961) $\mu = \sqrt{1 - {f_p}^2/f^2}$ where $f_p = \frac{e^2 n}{4\pi^2 \epsilon_0 m_e}$ is the plasma frequency. Then the ionospheric time delay is given by:

$$I = \int (1-\mu) \frac{ds}{c} \qquad (1)$$

For GPS frequencies, we have to $\frac{f_p}{f} \ll 1$.

Then

$$I = \int (1-\mu) \frac{ds}{c} \approx \frac{e^2}{8\pi^2 c \epsilon_0 m_e} \frac{1}{f^2} \int n ds \approx \frac{1.345 \times 10^{-7}}{f^2} STEC \quad (2)$$

Formulation of the TEC measurement

Where the slant sTEC is measured in TECU (1 TECU = 10^{16} e/ m^2)

If we multiply the expression (2) for "c" we obtained the ionospheric range delay.

$$d_{ion} = \frac{40.3}{f^2} sTEC \qquad (3)$$

GPS pseudorange P^i_{kj} and carrier phase L^i_{kj} for two frequencies (k = 1 or 2) can be represented as follows:

$$P^i_{1j} = \rho^i_0 + d^i_{ion1j} + c\left(\tau^i - \tau_j\right) + b^i_{q1} + b_{q1j} + b^i_{resj} \qquad (4.1)$$

satellite-receiver distance

ionospheric delay

instrument biases

other biases of noise and multipath

Formulation of the TEC measurement

$$P_{2j}^{i} = \rho_0^i + d_{ion2j}^{i} + c\left(\tau^i - \tau_j\right) + b_{q2}^{i} + b_{q2j} + b_{resj}^{i} \qquad (4.2)$$

The carrier phases $L_{1j}^{i} = \lambda_1 \phi_{1_j}^{\ i}$ and $L_{2j}^{i} = \lambda_2 \phi_{2_j}^{\ i}$ are expressed in range.

carrier wavelength

other biases of noise and multipath

$$L_{1j}^{i} = \rho_{0j}^{i} - d_{ion1j}^{i} + c\left(\tau^i - \tau_j\right) - \lambda_1 N_{1j}^{i} + B_{q1j} + B_{resj}^{i} \qquad (4.3)$$

the integer numbers of the carrier phase.

instrument biases

$$L_{2j}^{i} = \rho_{0j}^{i} - d_{ion2j}^{i} + c\left(\tau^i - \tau_j\right) - \lambda_2 N_{2j}^{i} + B_{q2j} + B_{resj}^{i} \qquad (4.4)$$

Formulation of the TEC measurement

Combining equations (4.1) and (4.2), equations (4.3) and (4.4) respectively with equation (3), we obtain that:

$$sTEC = \frac{1}{40.3}\left(\frac{f_1^2 f_2^2}{f_1^2 - f_2^2}\right)\left(P_{2j}^i - P_{1j}^i - b^i - b_j + \varepsilon_p\right) \qquad (5)$$

$$sTEC = \frac{1}{40.3}\left(\frac{f_1^2 f_2^2}{f_1^2 - f_2^2}\right)\left(L_{1j}^i - L_{2j}^i - B^i - B_j + \lambda_1 N_{1j}^i - \lambda_2 N_{2j}^i + \varepsilon_L\right)_{arc} \qquad (6)$$

Where $b^i = b_{q2}^i - b_{q1}^i; b_j = b_{q2j} + b_{q1j}.$

$$B^i = B_{q2}^i - B_{q1}^i; B_j = B_{q2j} - B_{q1j}.$$

Formulation of the TEC measurement

The "leveling carrier to code" algorithm is widely used to reduce the ambiguities from the carrier-phase observable.
We define:

$$L_I = L_1 - L_2 \quad (7)$$

$$P_I = P_2 - P_1 \quad (8)$$

By combining Eqs. (5) and (6) above, then by using the mean operator over an arc, we get:

$$\langle L_{I,arc} - P_I \rangle_{arc} = \lambda_1 N_{1j}^{i} - \lambda_2 N_{2j}^{i} + B_j - b_j + B^i - b^i - \langle \varepsilon_p \rangle_{arc} \quad (9)$$

We obtain the mean value of the differences between two direct measurements by computing their differences for every continuous arc:

Formulation of the TEC measurement

The effect of additional noise and multi-path on carrier-phase observations was neglected because it is very small compared to the effect of those for the code-delay observations.

Subtracting Eq. (9) from LI in the same arc, we can remove the integer ambiguity terms.

$$\widetilde{L}_{I,arc} = L_{I,arc} - \langle L_{I,arc} - P_I \rangle_{arc} \qquad \textbf{(10)}$$

Finally, by the so called, "carrier to code leveling process", we obtain precise measurements for sTEC:

$$sTEC = \frac{1}{40.3}\left(\frac{f_1^2 f_2^2}{f_1^2 - f_2^2}\right)\left(\widetilde{L}_{I,arc} - b_j - b^i - \langle \varepsilon_p \rangle_{arc} + \varepsilon_L\right) \qquad \textbf{(11)}$$

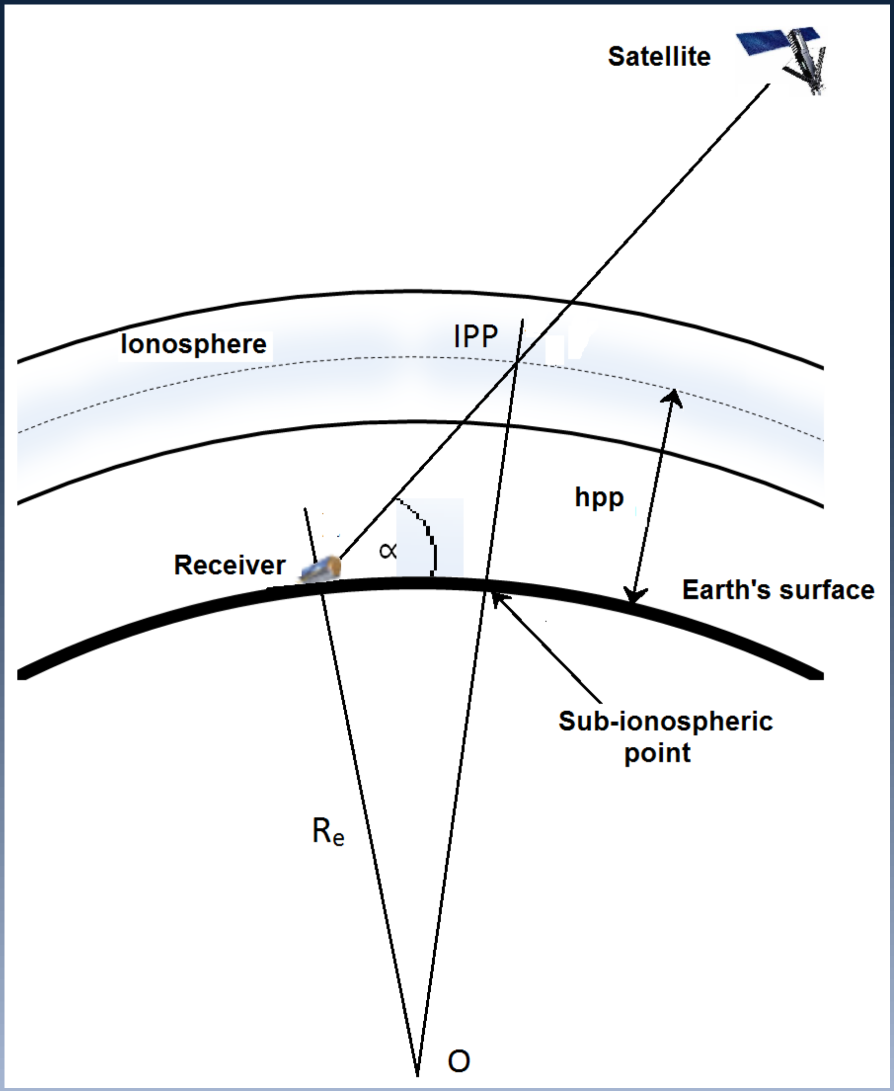
Vertica Total Electron Content vTEC

$$vTEC = sTECx\frac{\sqrt{(R_e + h_{pp})^2 - {R_e}^2 cos^2 \propto}}{R_e + h_{pp}}$$

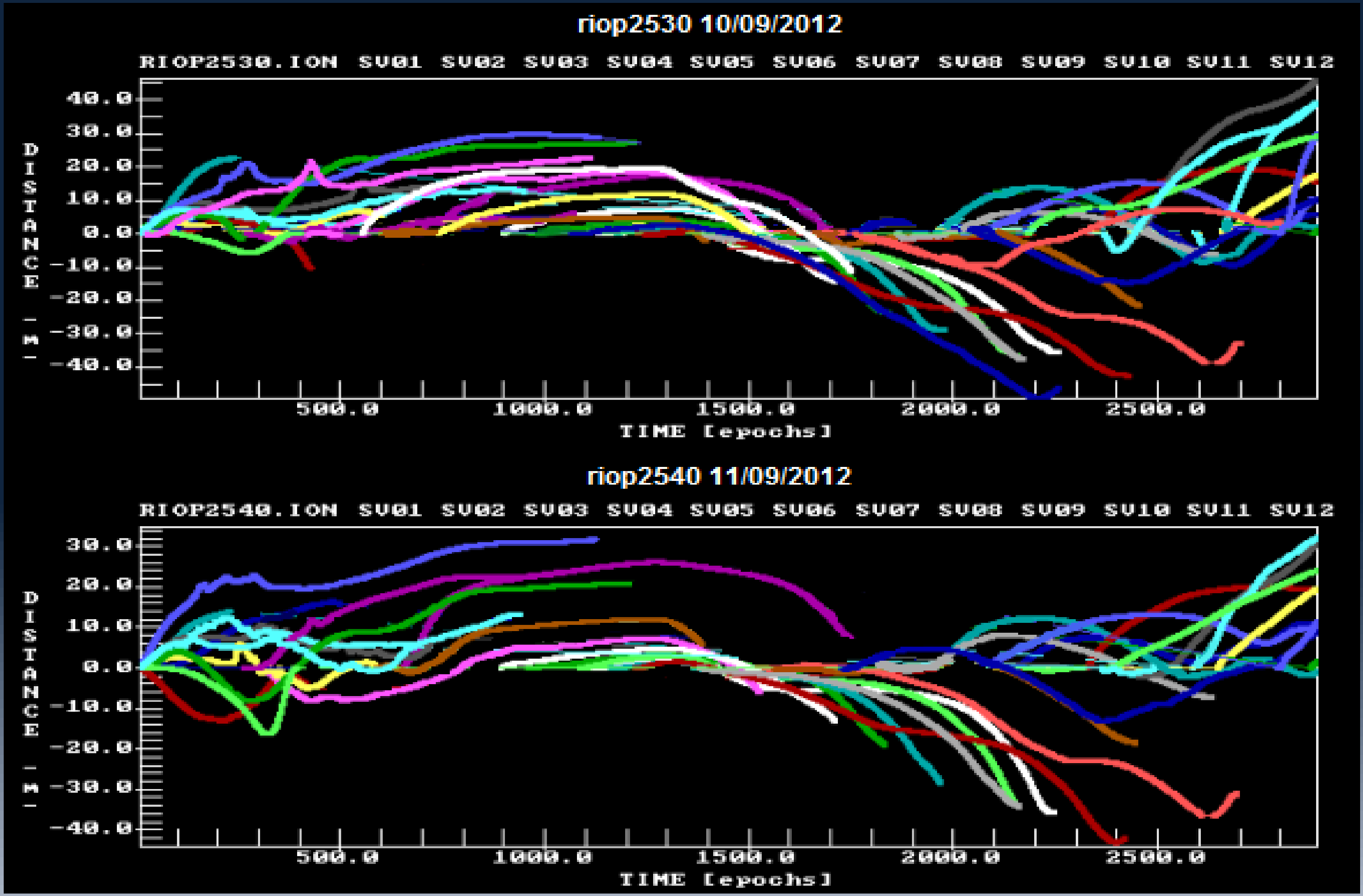
R_e = earth's radius

h_{pp} = is the chosen height of the ionospheric pierce point (300 Km)

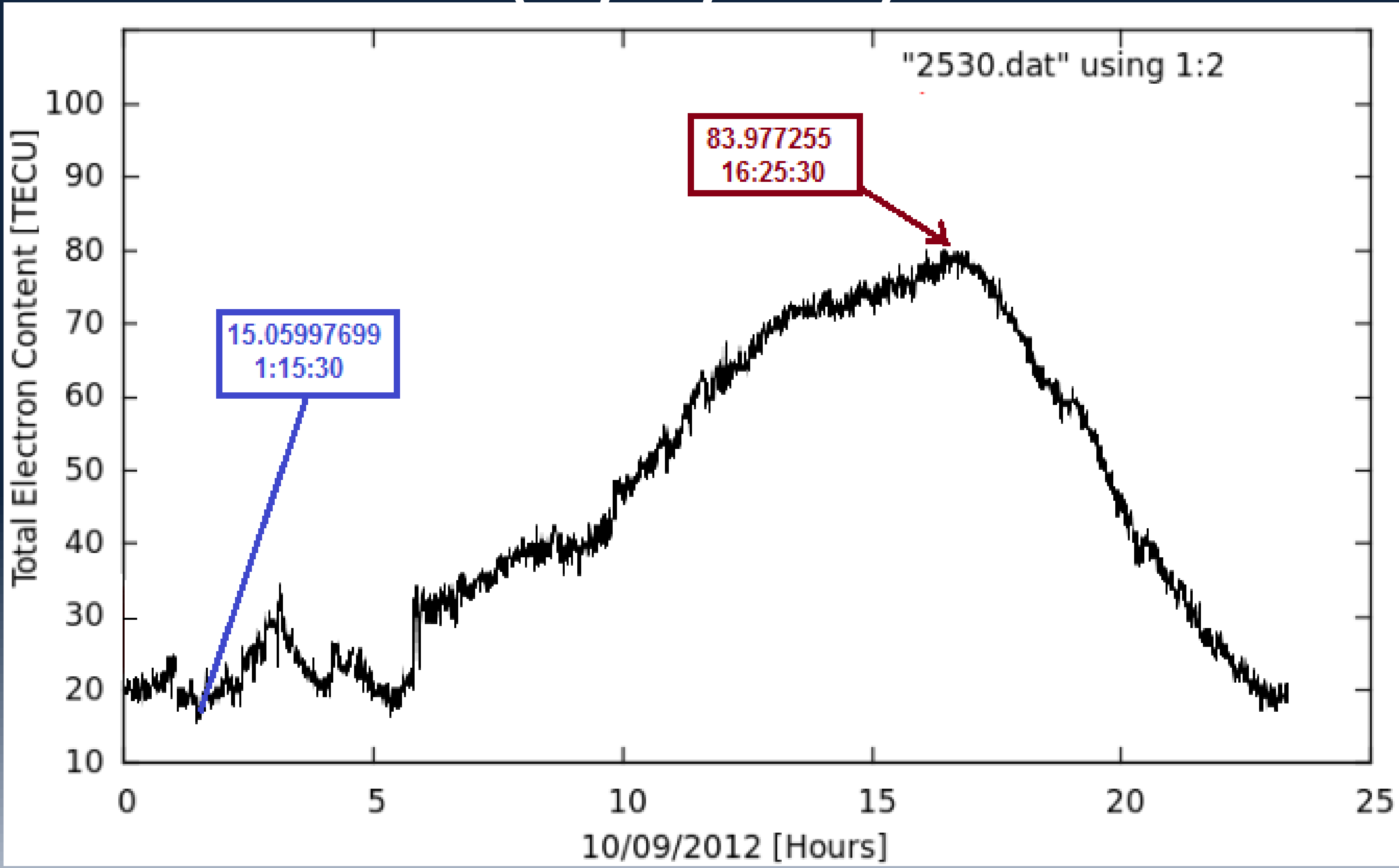
$\propto$ = is the elevation angle of the ray



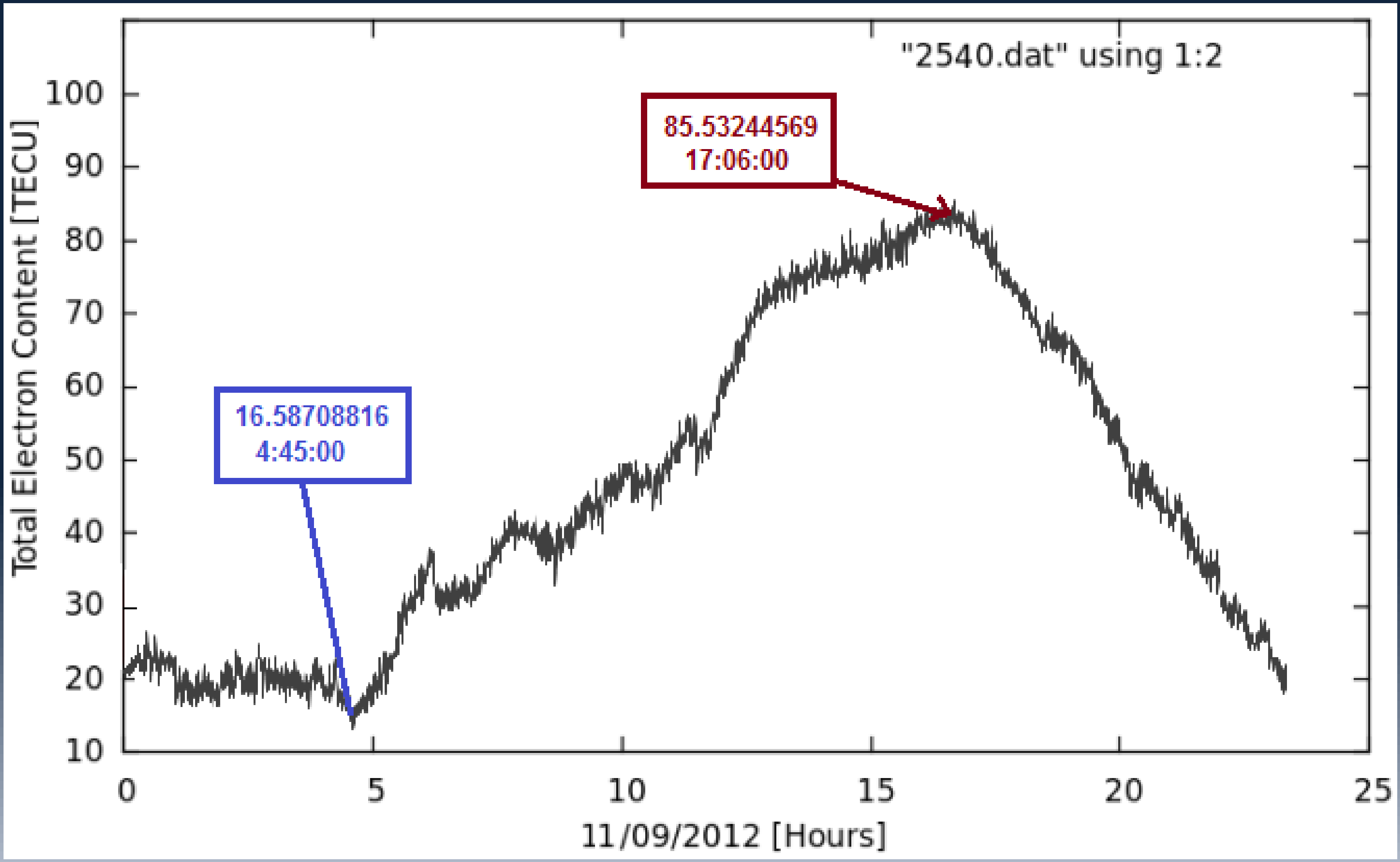
Ionospheric delay



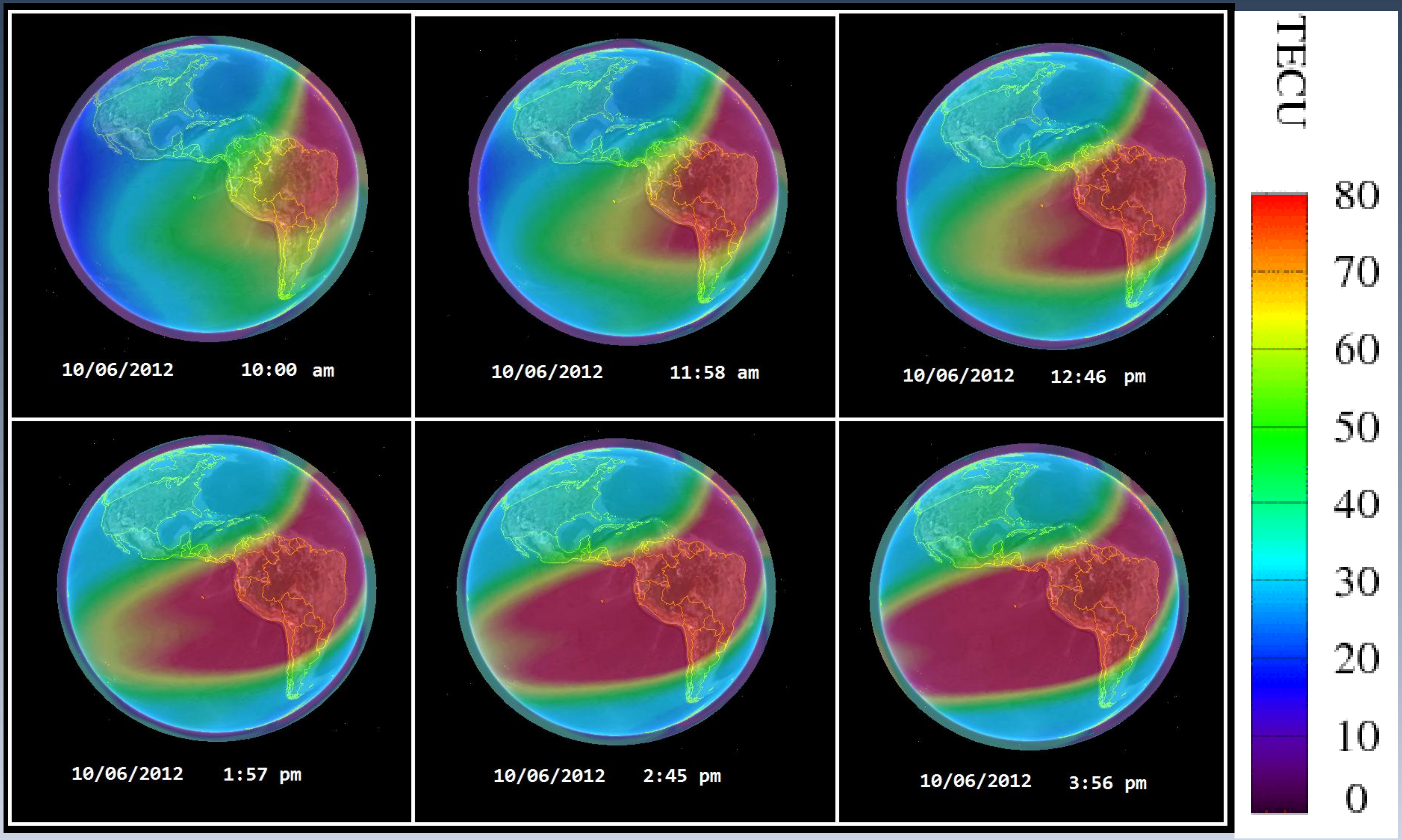
TEC (10/09/2012)



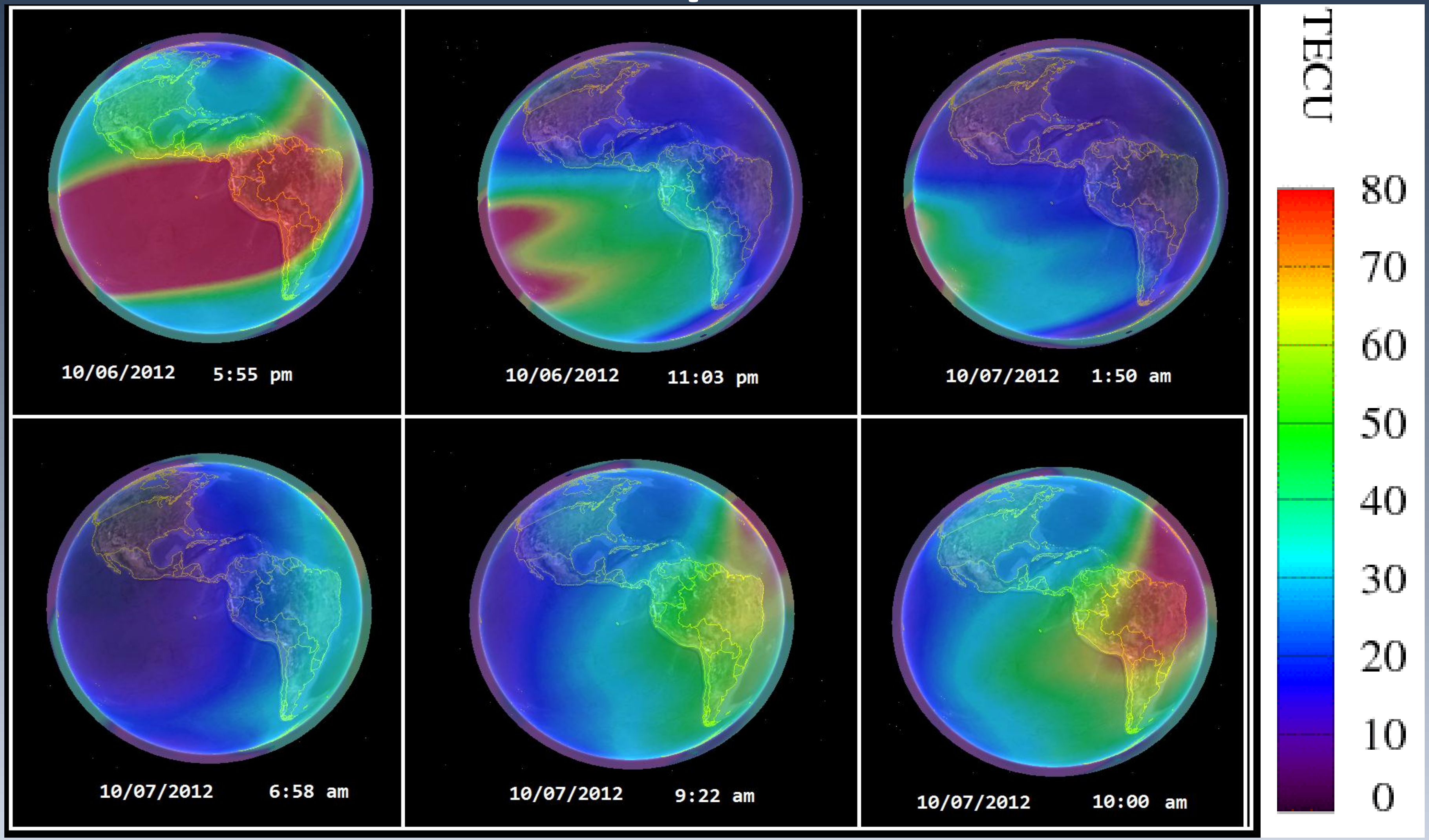
TEC (11/09/2012)



Changing nature of the TEC in the equatorial ionosphere



Changing nature of the TEC in the equatorial ionosphere



Conclusions

Due to solar activity in this epoch the TEC reaches very high values.

The Total Electron Content (TEC) in the equatorial region reaches high values, with a maximum of 85.532 TECU.

For two days analyzed we observe that the TEC changes very quickly, with a difference of 1.555 TECU ; 40 minutes 30 seconds and 1.528 TECU; 4 hours 30 minutes for maximum and minimum values respectively.

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