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IONOSPHERIC TOTAL ELECTRON CONTENT ABOVE ECUADOR

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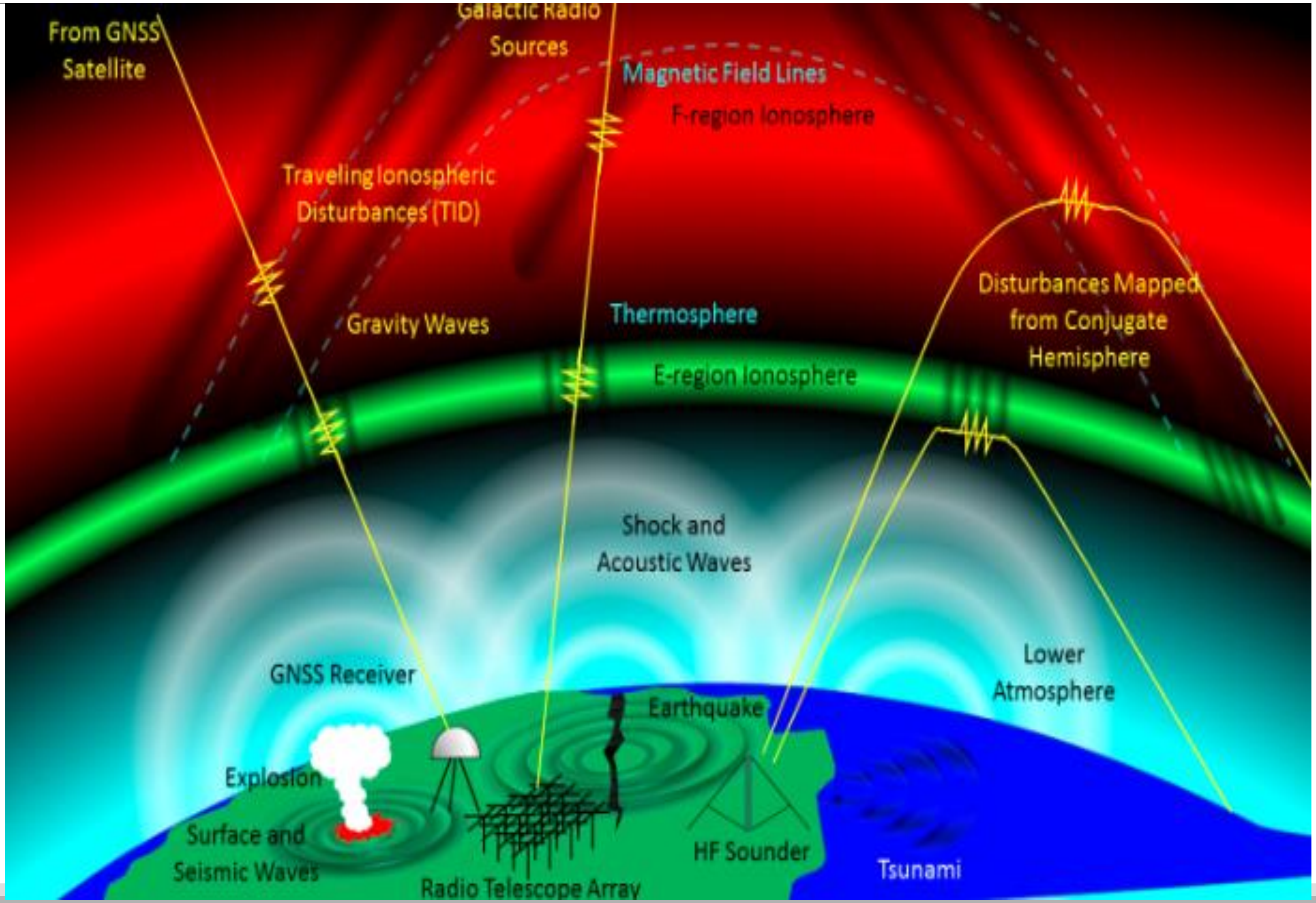
ECUADOR

INTRODUCTION

The ionosphere is defined as the region of the upper atmosphere where radio signal propagation is affected by charged particles.

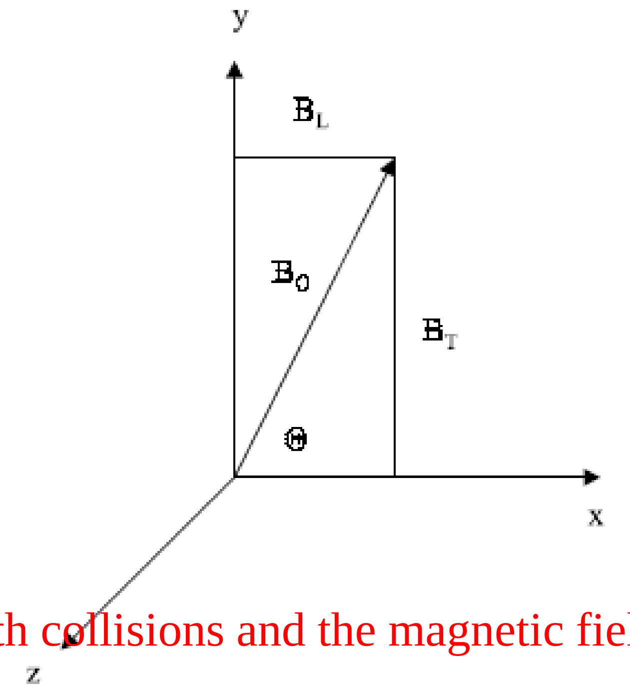
The ionosphere is highly variable in space and time



Credit: Huang et al. [2019], F

IONOSPHERE: DISPERSIVE MEDIUM PROPERTIES

- The ionosphere acts as a refractive medium to radio signals
- The index of refraction depends on the amount of ionisation.
- The Appleton-Hartree equation (see e.g., Komjathy [1997]):



$$n^2 = 1 - \frac{X}{(1 - jZ) - \left[\frac{Y_T^2}{2(1 - X - jZ)}\right] \pm \left[\frac{Y_T^4}{4(1 - X - jZ)^2} + Y_L^2\right]^{1/2}}$$

where:

$$X = \frac{\omega_N^2}{\omega^2} = \frac{f_N^2}{f^2}$$

$$Y = \frac{\omega_H}{\omega} = \frac{f_N}{f}$$

$$Y_L = \frac{\omega_L}{\omega}, \quad Y_T = \frac{\omega_T}{\omega}, \quad and \quad Z = \frac{\omega_C}{\omega}$$

When both collisions and the magnetic field are negligible

$$n = 1 - \frac{1}{2}X = 1 - \frac{Ne^2}{2\epsilon_o m\omega^2}.$$

The phase refractive index appropriate for the carrier phase observations.

$$n_{\varphi} \cong 1 - \frac{40.3 \cdot N}{f^2},$$

The group refractive index appropriate for the pseudorange observations (Langley [1996]):

$$n_g \cong 1 + \frac{40.3 \cdot N}{f^2}.$$

. THE IONOSPHERIC DELAY IS DEFINED AS:

$$d_{ion} = \int_{Sat}^{Rec} (n-1) ds,$$

The first order approximation of the Appleton-Hartree formula also gives an expression for the ionospheric delay in terms of TEC:

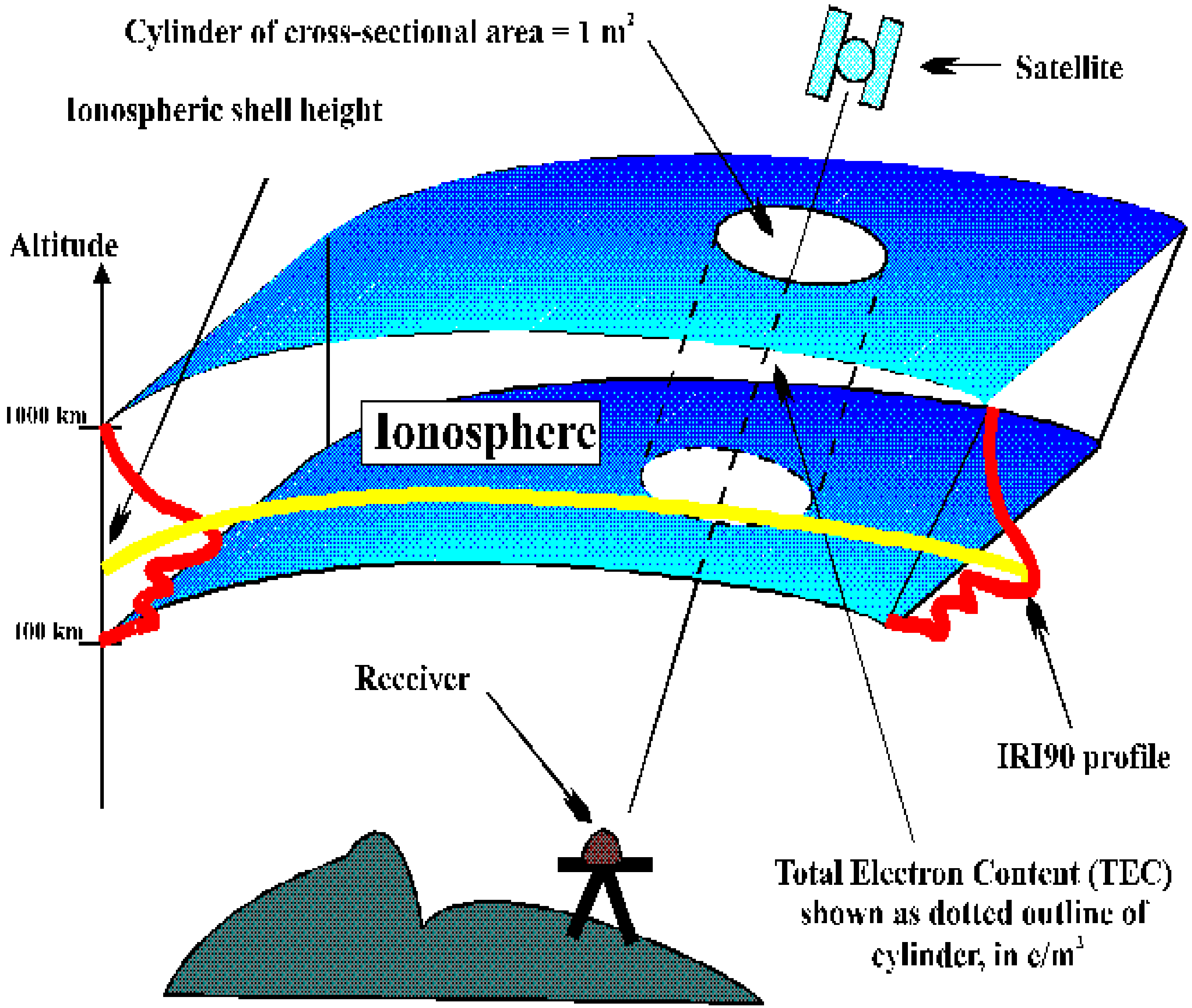
The ionospheric delay

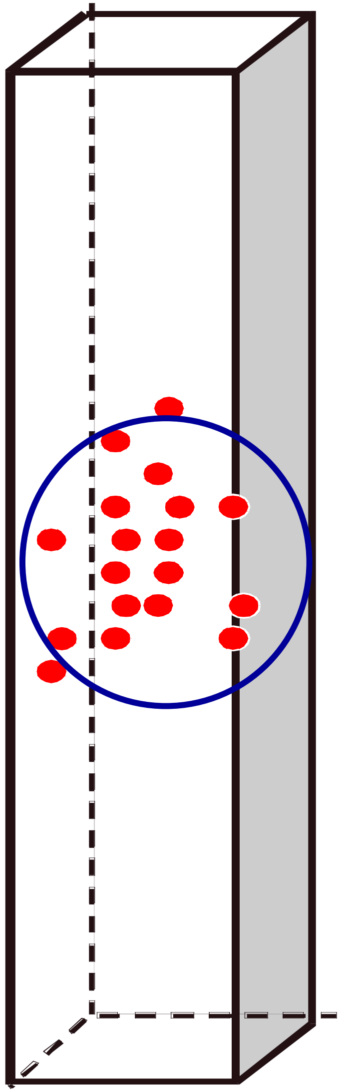
$$d_{ion} = \frac{40.3}{f^2} TEC$$

gives cm level accuracy for the ionospheric delay.

where TEC is the total electron content in TEC units $(1\ \mathrm{TECU} = 10^{16}\ 1/\mathrm{m}^2)$.

TOTAL ELECTRON CONTENT (TEC)



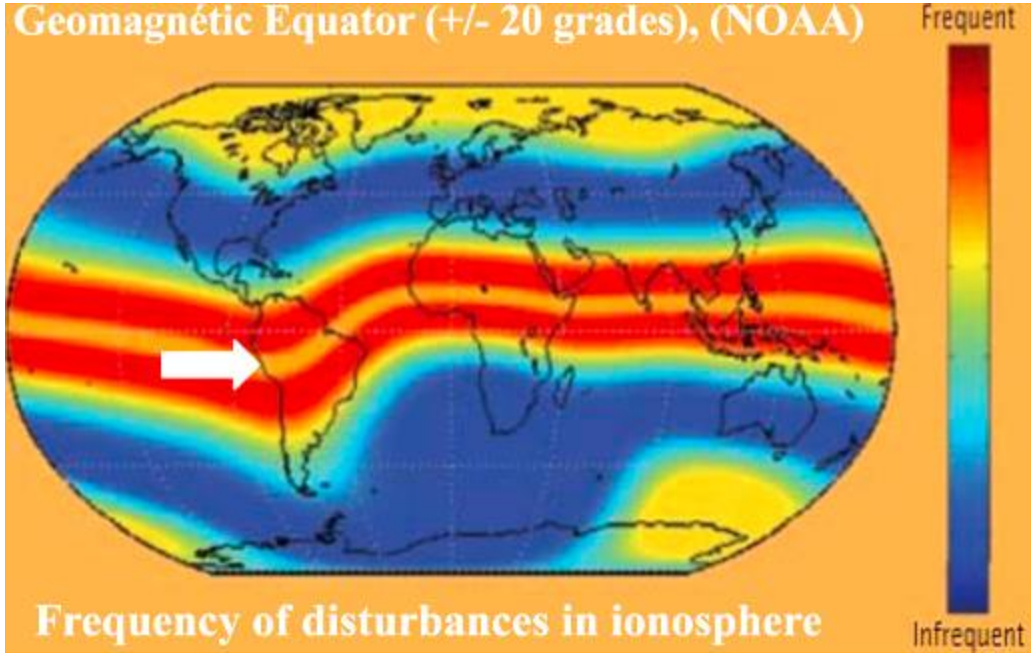


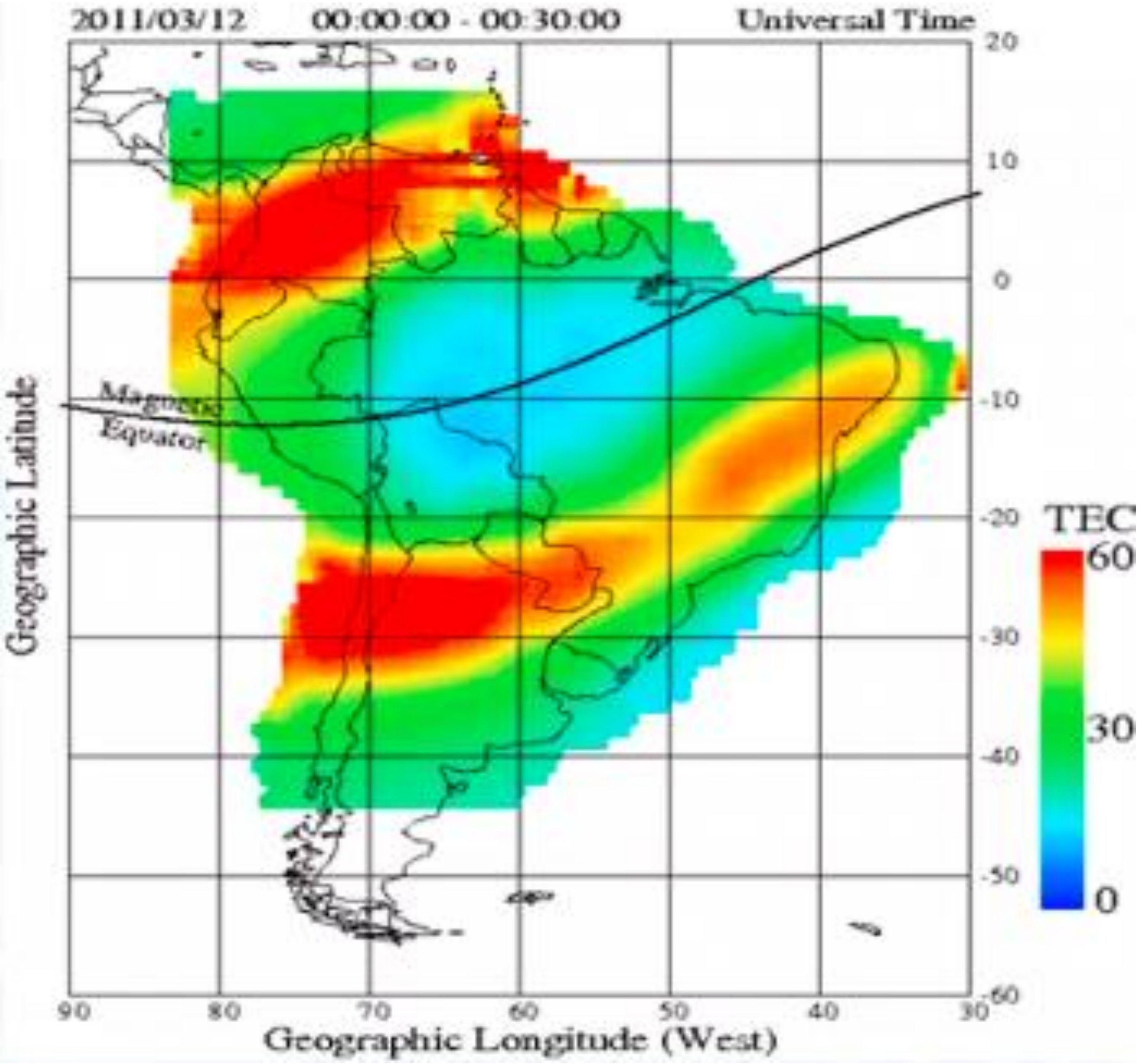
Total number of electrons in a column with cross section of $1m^2$

(1 TECU = 10^{16} electrons/m^2)

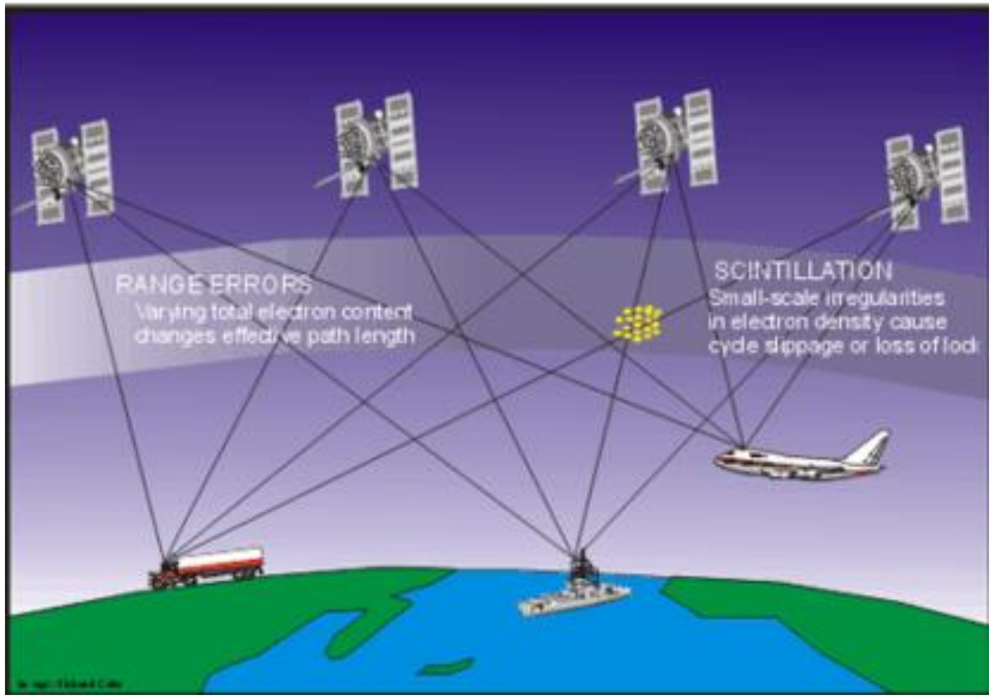
$1m^2$

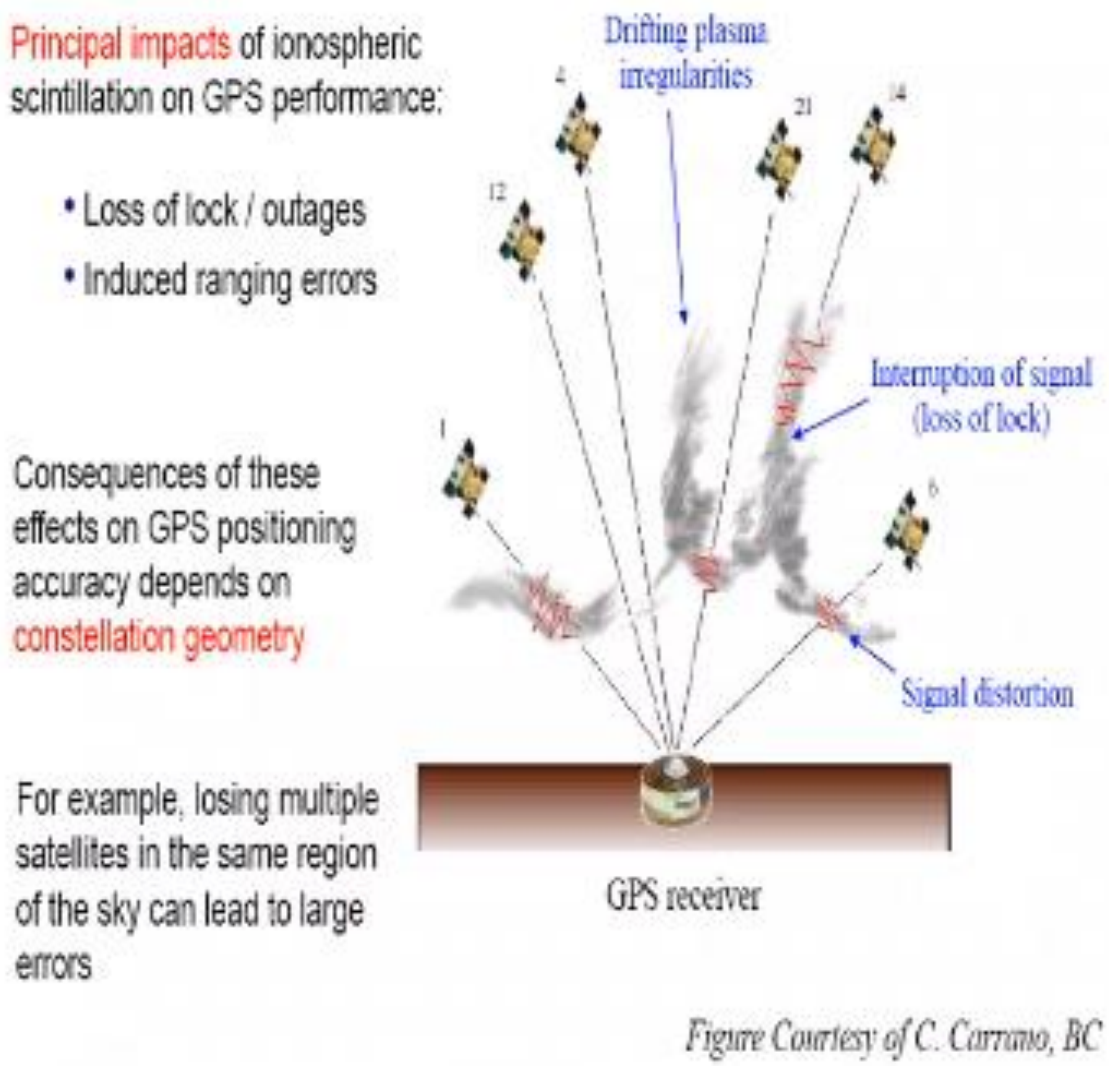
TOTAL ELECTRON CONTENT





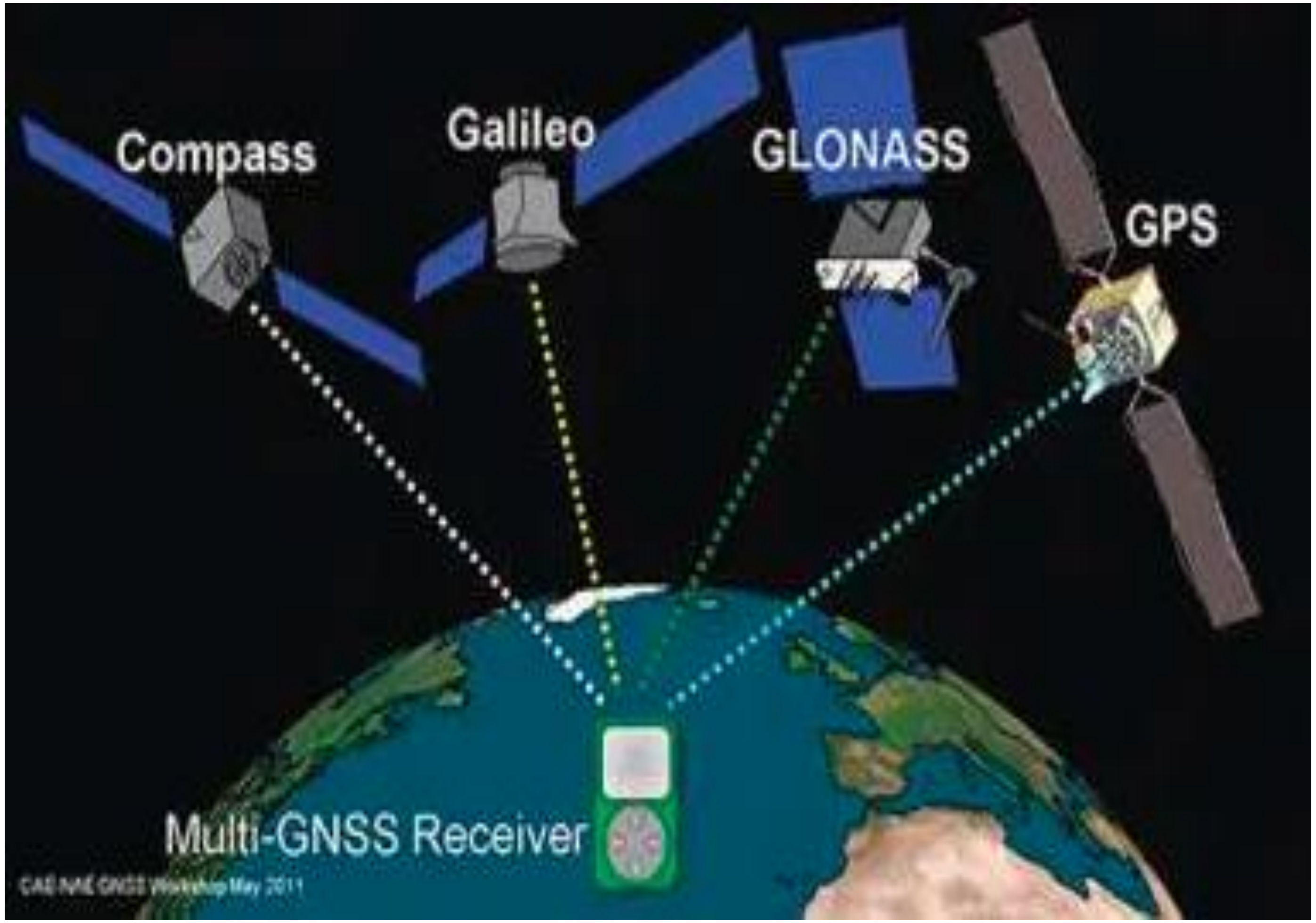
SCINTILLATION





0.19 TEC causes problems for the GPS receiver.

ONE TOOL USED TO MEASURE TEC IS THE GLOBAL NAVIGATION SATELLITE SYSTEM (GNSS).



Modelling TEC gives scientists the opportunity to study the temporal and spatial variation of the global ionosphere

ionospheric corrections for navigation, surveillance and communication systems

IONOSPHERIC MODELING USING GPS DATA

The Total Electron Content (TEC) is the amount of free electrons along the path of the electromagnetic wave between each satellite and the receiver.

TEC is calculated by:

$$TEC = \int_A^B N(s)ds,$$

where N is the electron density in ($^{e}/_{m^3}$),
ds is the path integral differential a
the integral is calculated along the path that joins points A and B.

It is an important geophysical parameter:

$$TEC = \int_{receiver}^{satellite} N \cdot ds$$

* The TEC also has been measured for decades using the Faraday Rotation effect on a linear polarized propagating plane wave (Klobuchar, 1985 and 1996).

IONOSPHERIC OBSERVABLE

The GPS pseudorange (P) and carrier phase (Φ), observable parameters, are given, for the two GPS frequencies: L1 = 1575.42 MHz and L2 = 1227.6 MHz.

The GPS observation equations are well known from the various references such as Langley [1992; 1996], Wells et al. [1987], Chao et al. [1996], etc

$$P_1 = \rho + c(dT - dt) + d_{ion,L_1} + d_{trop} + \eta_{P_1} + \epsilon_{P_1}$$

$$P_2 = \rho + c(dT - dt) + d_{ion,L_2} + d_{trop} + \eta_{P_2} + \epsilon_{P_2}$$

$$\Phi_1\lambda_1 = \rho + c(dT - dt) + \lambda_1 N_1 - d_{ion,L_1} + d_{trop} + \eta_{\Phi_1} + \epsilon_{\Phi_1}$$

$$\Phi_2\lambda_2 = \rho + c(dT - dt) + \lambda_2 N_2 - d_{ion,L_2} + d_{trop} + \eta_{\Phi_2} + \epsilon_{\Phi_2}$$

BUT TODAY TEC MEASUREMENTS ARE MADE MOSTLY USING GNSS DATA

Pseudorange and raw carrier phases that can be measured with high precision.

Modern receivers are typically at the 0.9 mm level

$$TEC_P = 9.52 \cdot (P_2 - P_1)$$

unambiguous but noisy and therefore imprecise observable

$$TEC_\Phi = 9.52 \cdot (\Phi_1\lambda_1 - \Phi_2\lambda_2).$$

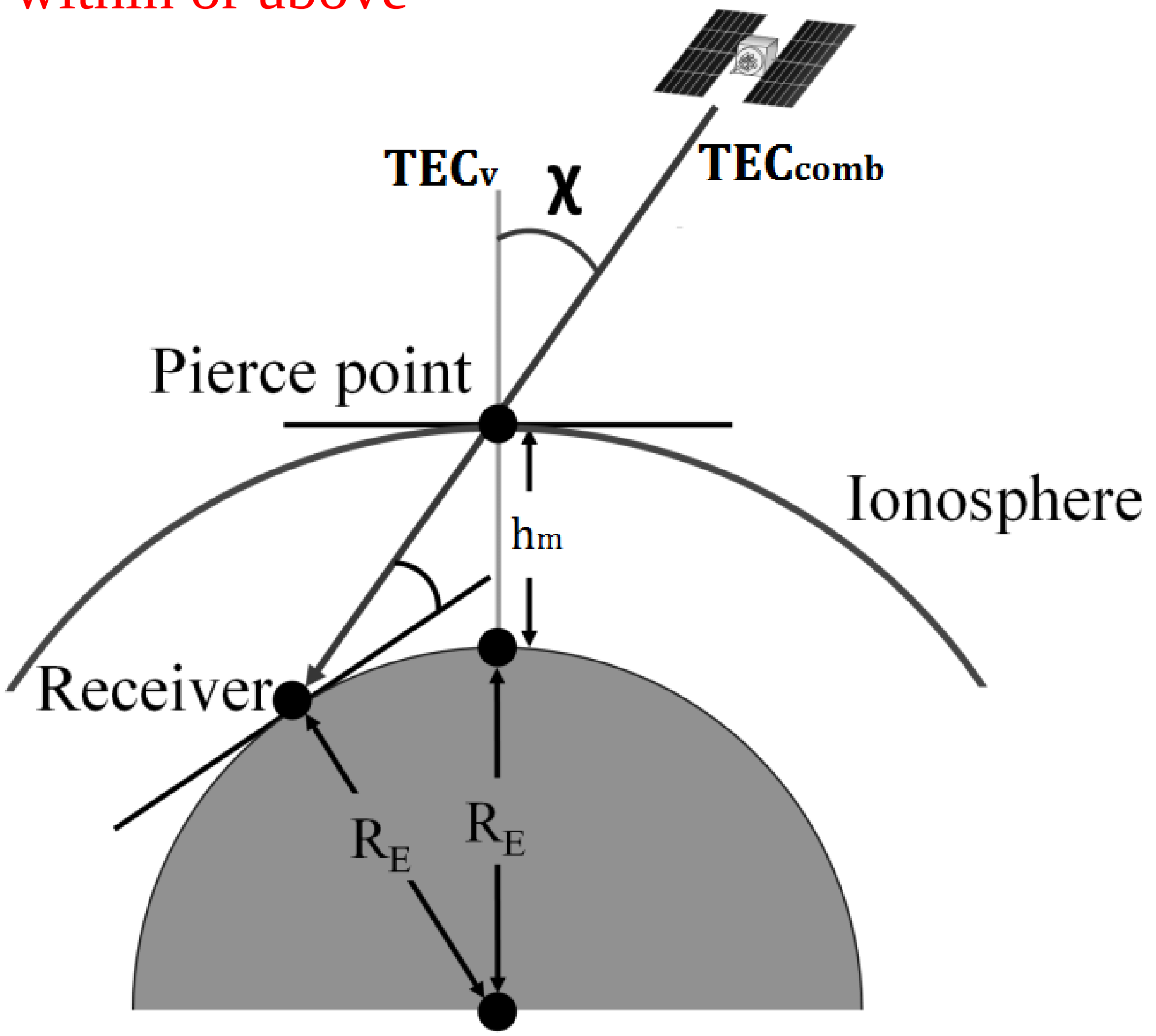
very precise but ambiguous observable

Satellite-based techniques available to measure TEC up to the altitude of the satellite which can be anywhere within or above the ionosphere.

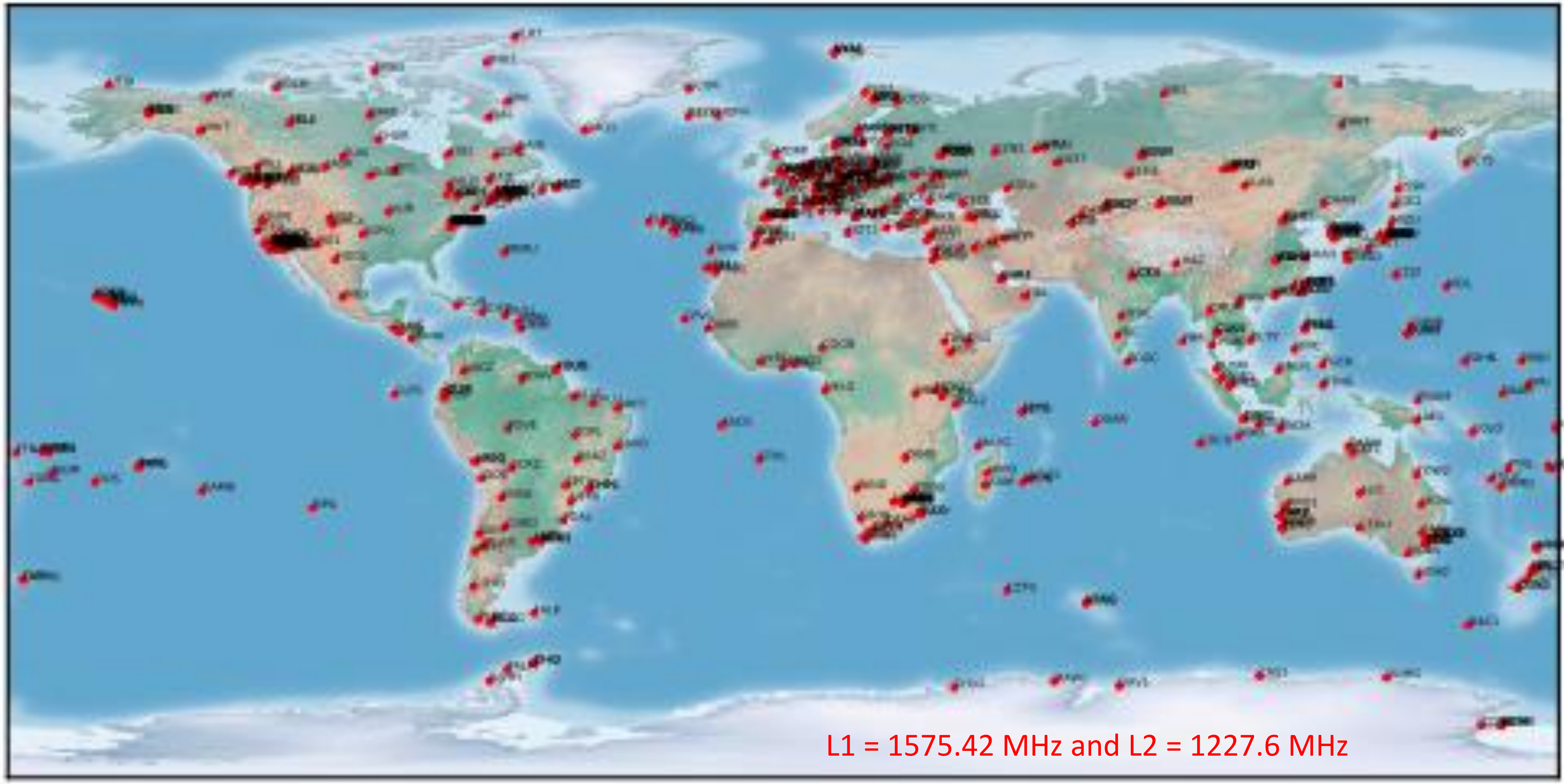
$$TEC_{comb_i} = TEC_{\Phi_i} - \frac{\sum_{j=1}^{n} p_j \left[TEC_{\Phi_j} - TEC_{P_j}\right]}{\sum_{j=1}^{n} p_j}$$

$$TEC_v = TEC_{comb}\left(cos\chi'\right)$$

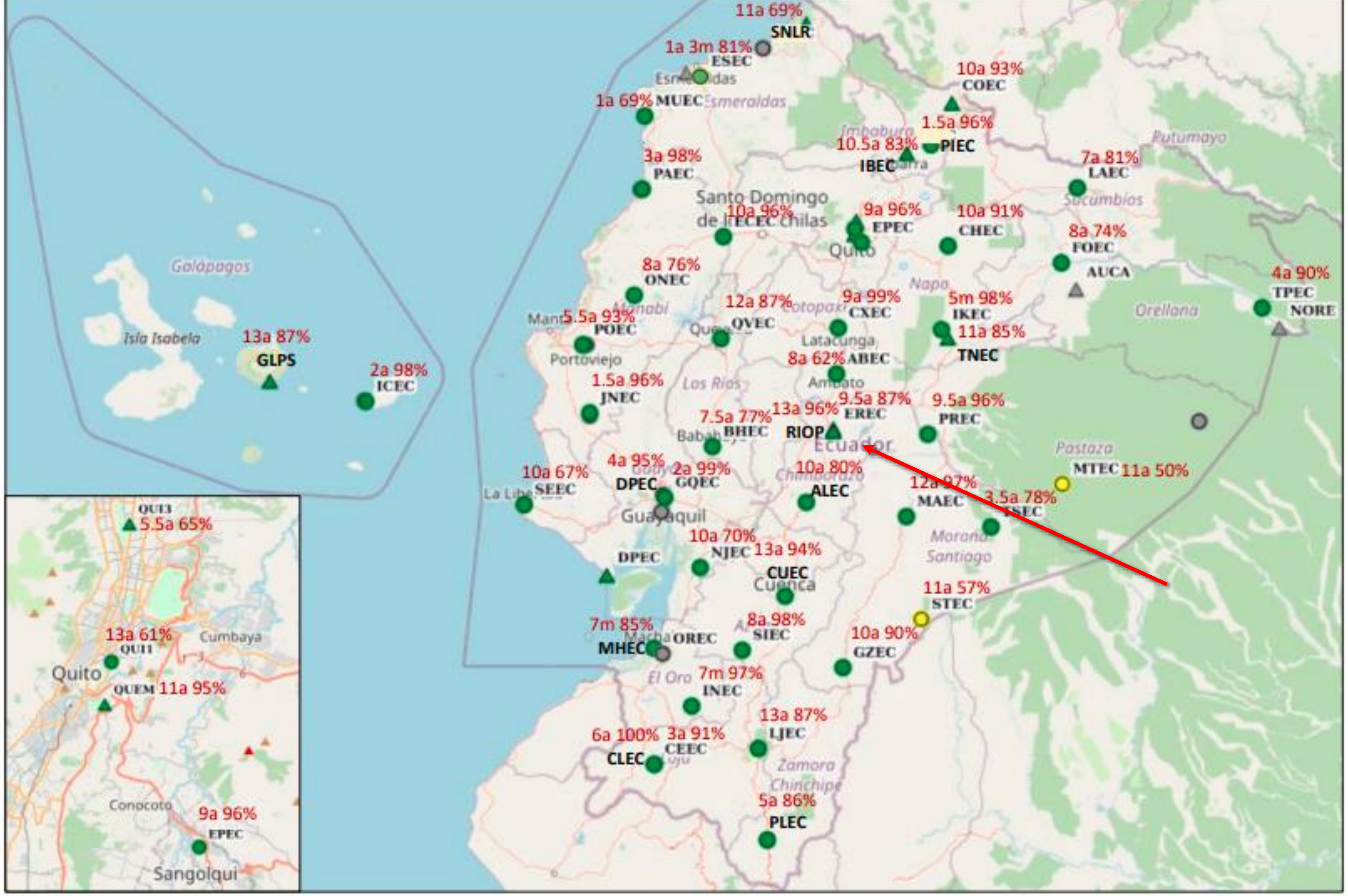
$$sin\chi' = \frac{R_e}{R_e + h_m} sin(z)$$



SPACE WEATHER EFFECTS ON GPS

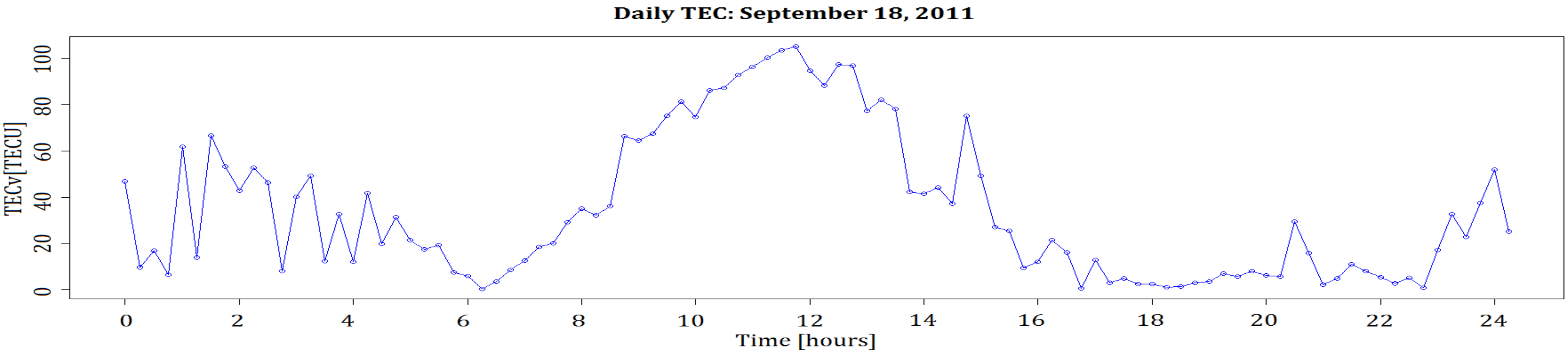

L1 = 1575.42 MHz and L2 = 1227.6 MHz

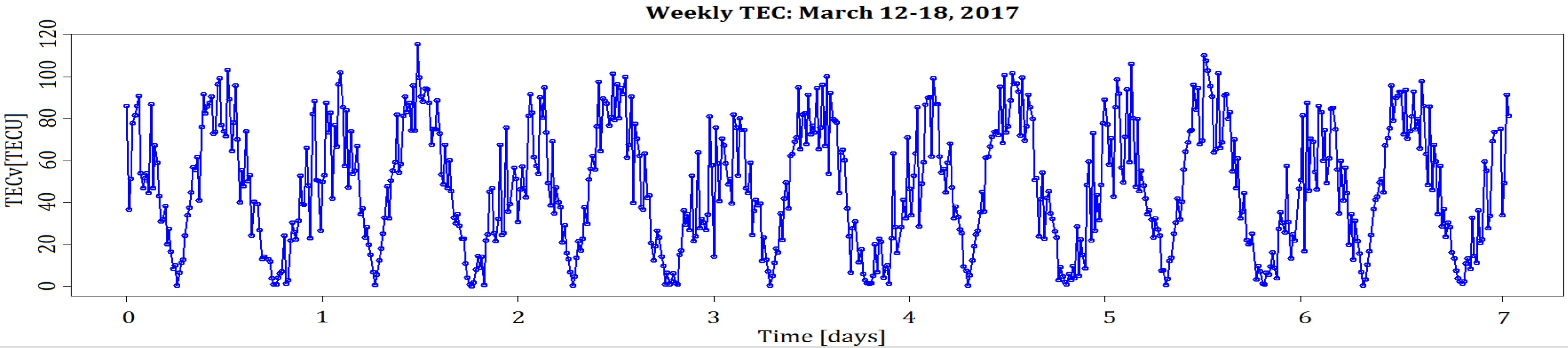
GPS stations in Ecuador



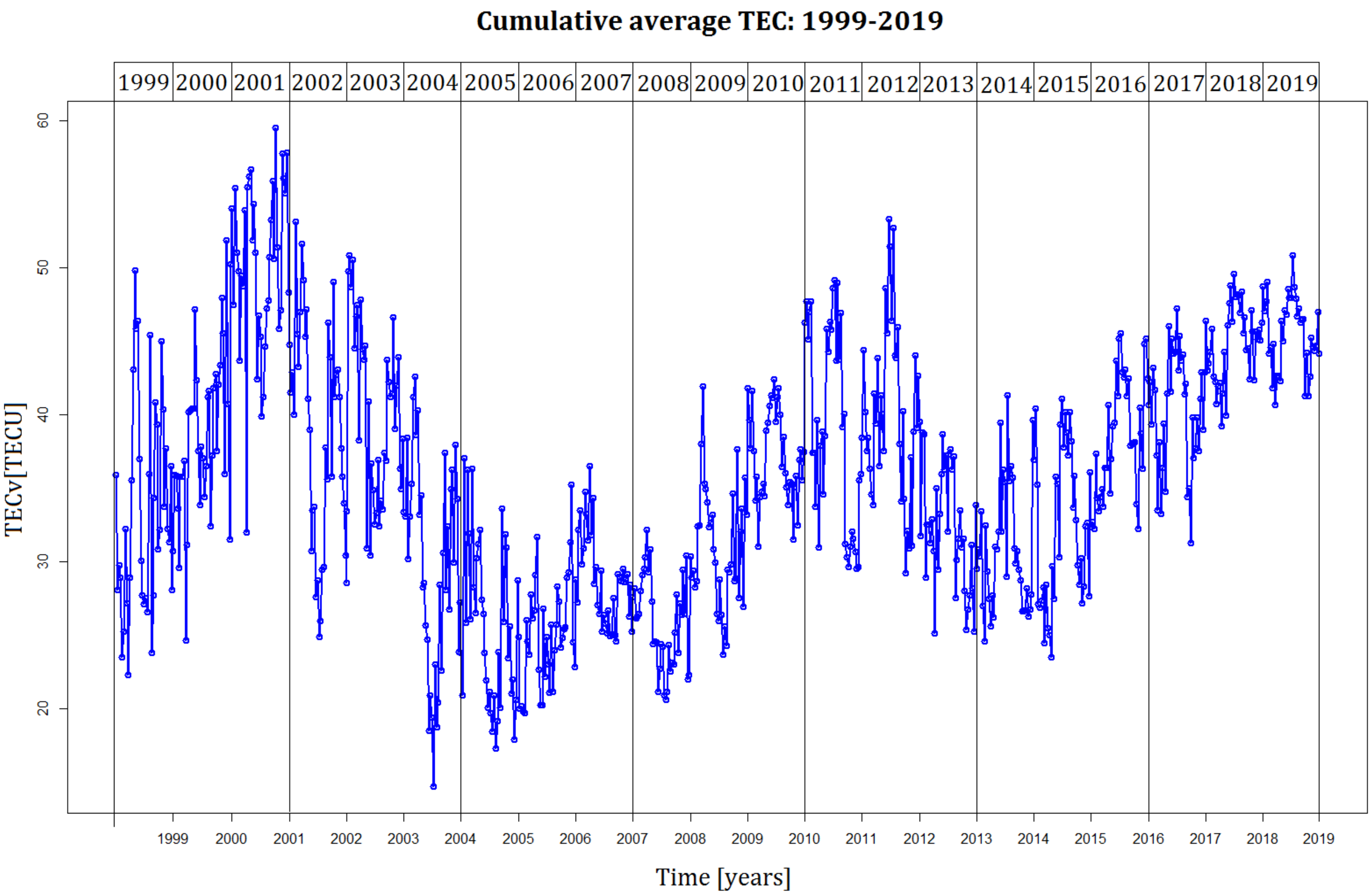
ESTIMATION OF THE TEC OVER ECUADOR

Riobamba RIOP station:
(latitude -1.65 longitude -78.65)





The cumulative average TEC for the whole period from 1999 to 2019



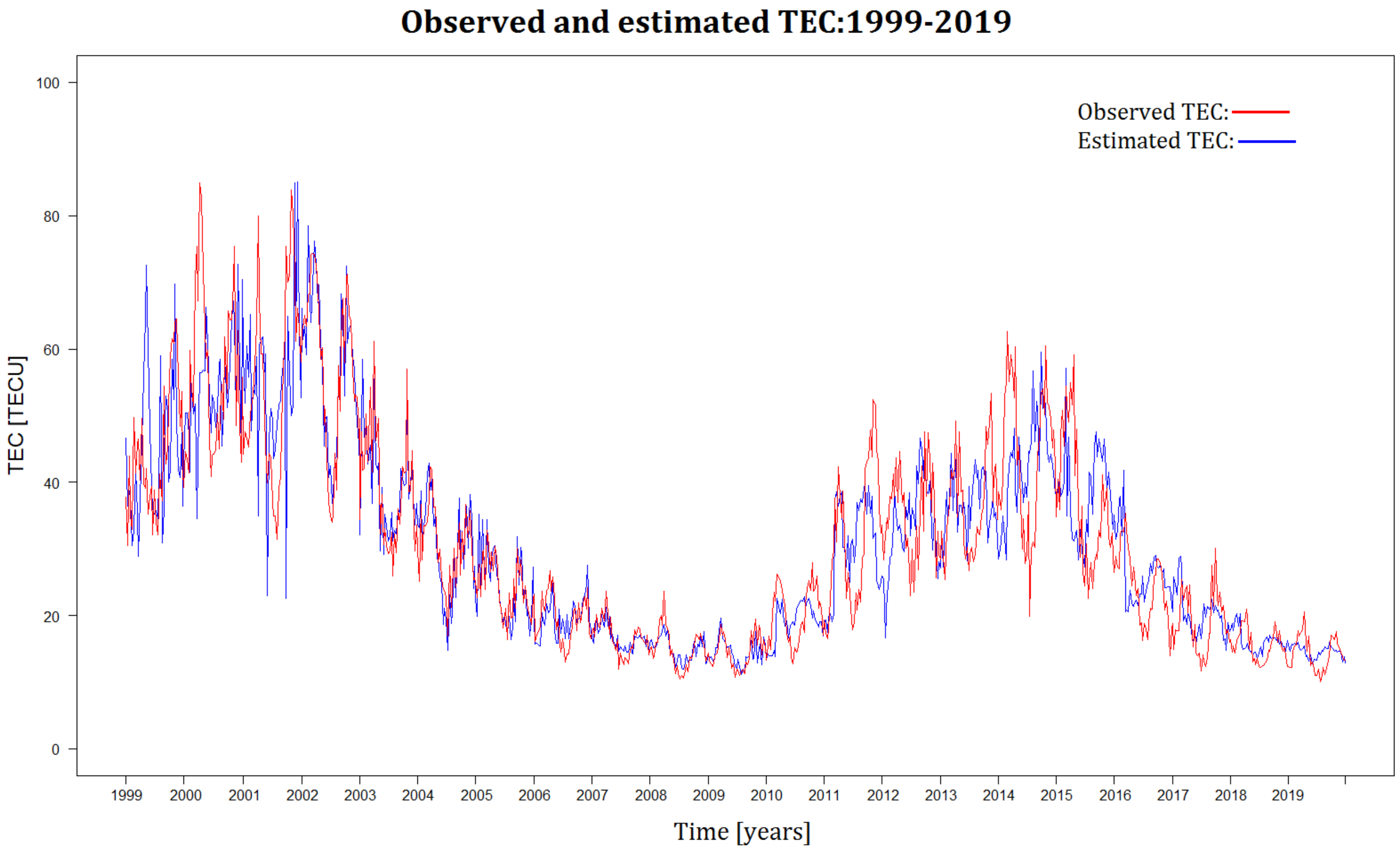
TEC calculated vs. observed

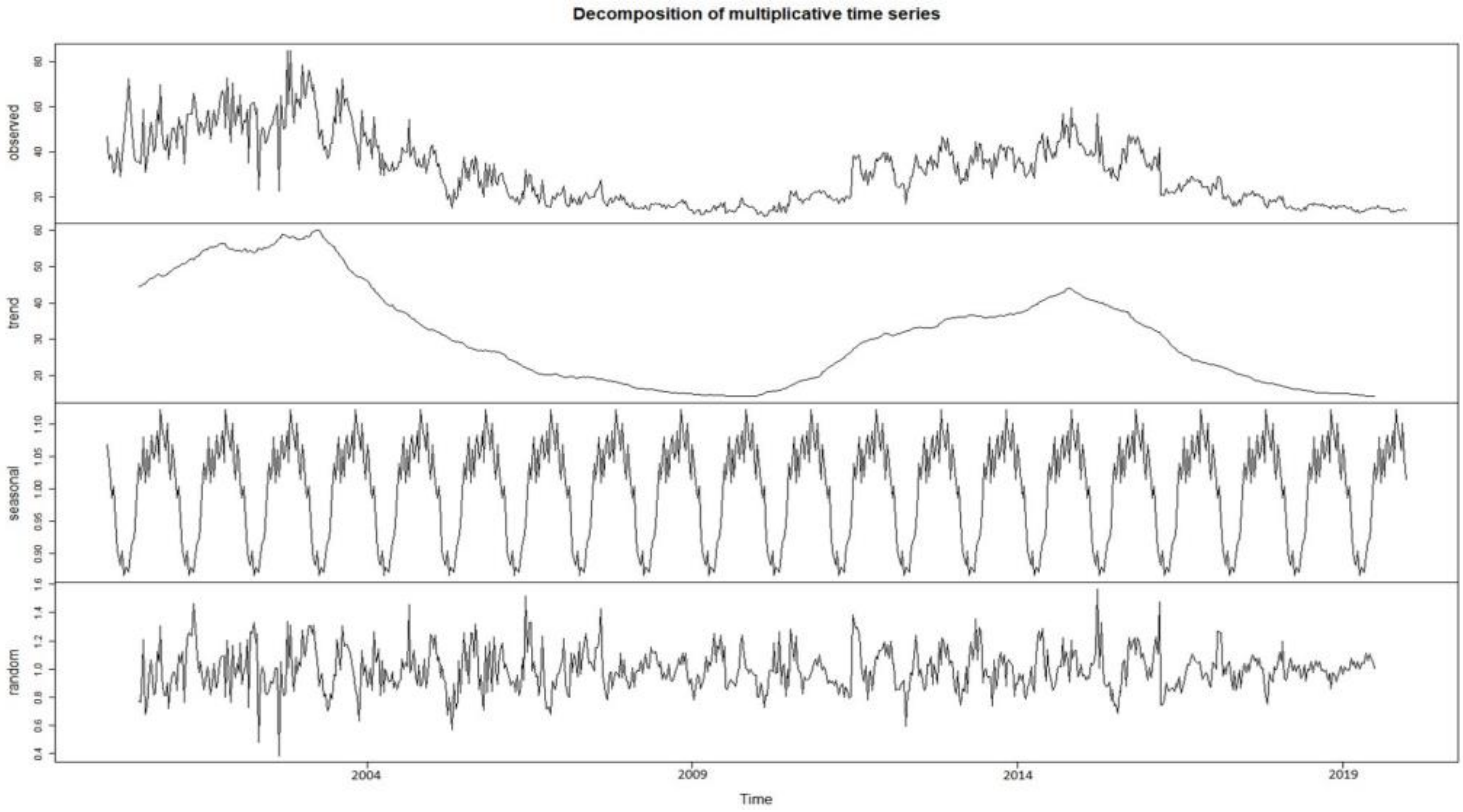
The chi square test:

$$\chi^2 = \Sigma \frac{(O_i - C_i)^2}{C_i}$$

O_i observed values
C_i calculated values

goodness of the fit about 0.88





Time series analysis of the annual TEC from 1999 to 2019 period.

Thank you!