Data Interpretation and projects

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OUTLINE

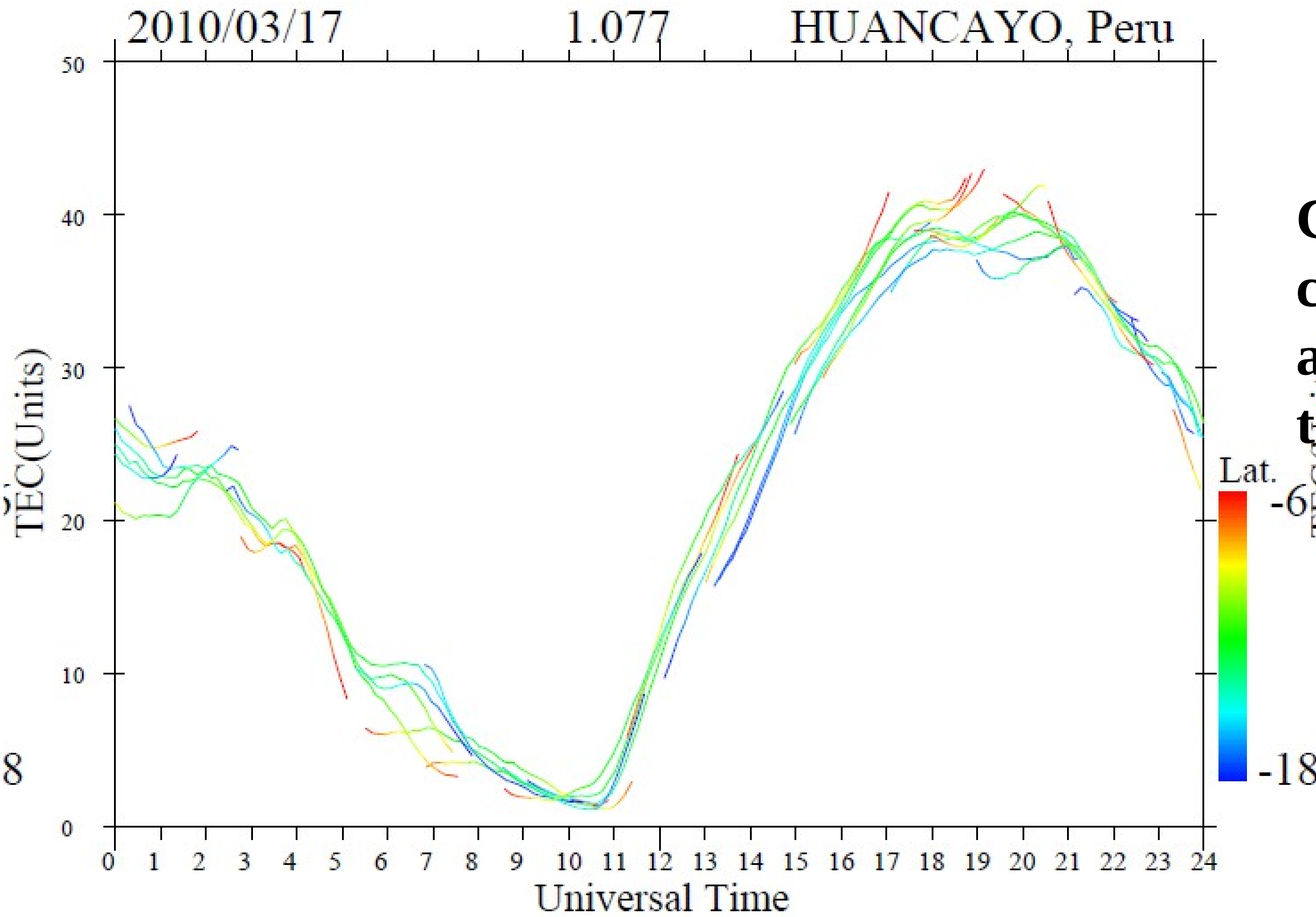
- **Near midnight TEC enhancements [Valladares and Chau, Radio Sci., 2012].**

- **Detection of Gravity waves (TIDs). Large-scale GWs. Middle-scale GWs measured using GPS interferometry and cross-correlation techniques [Valladares and Hei, IJG, 2012].**

- **TEC depletions and scintillations [Seemala and Valladares, Radio Sci., 2011].**

- **Tropical TEC enhancements [Valladares and Eccles, 2013].**

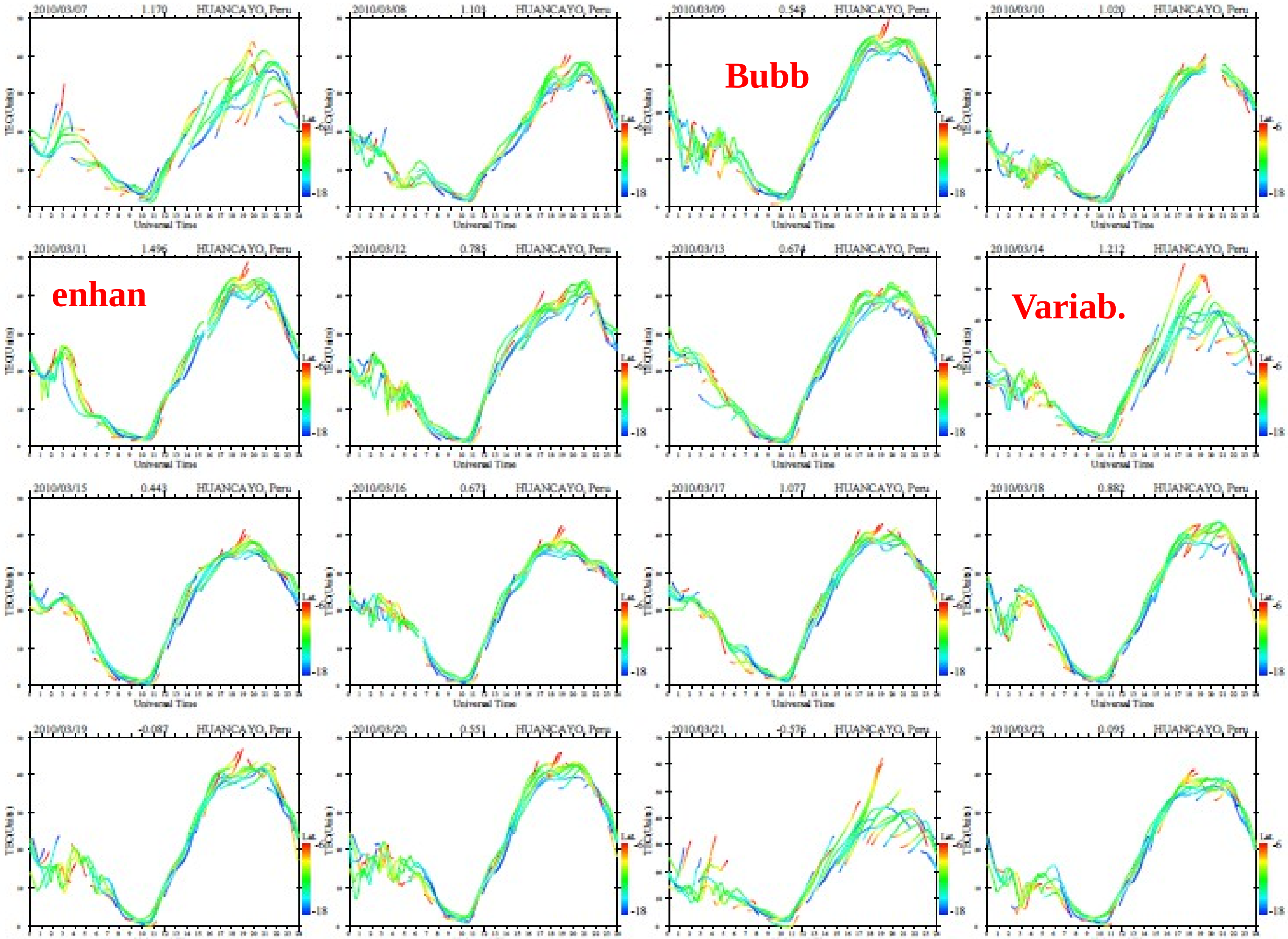
24-hr TEC values for Huancayo (mag. Lat ≈ 0°)



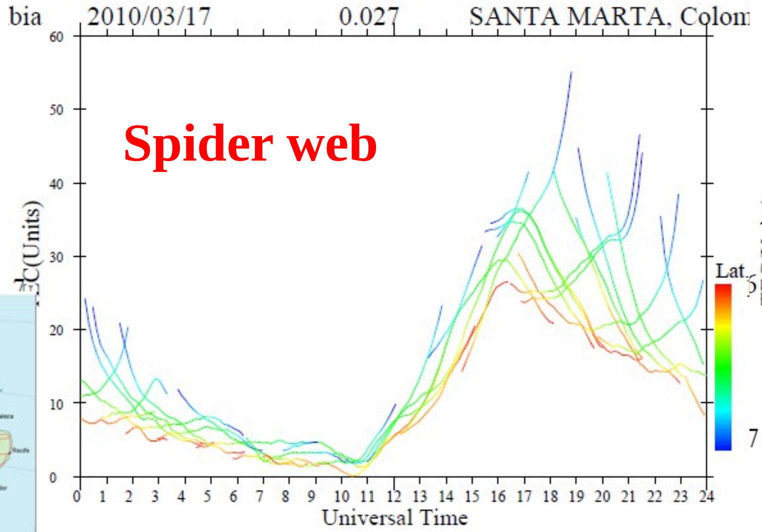
Color-coded according to Latitude

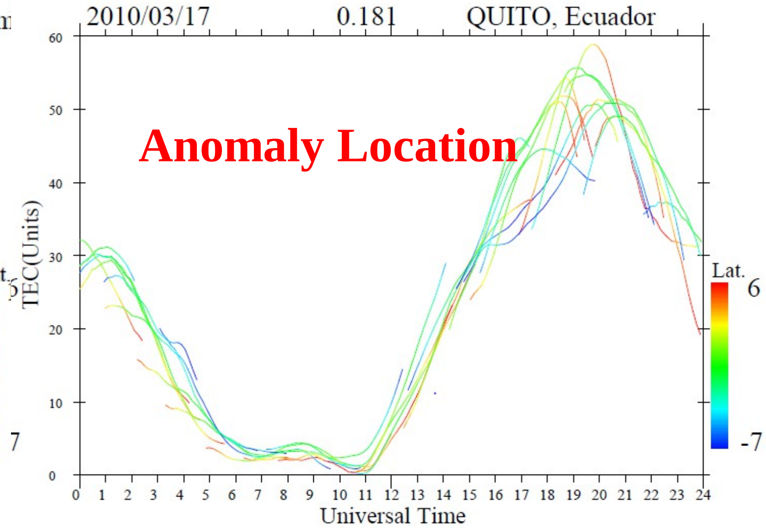
8

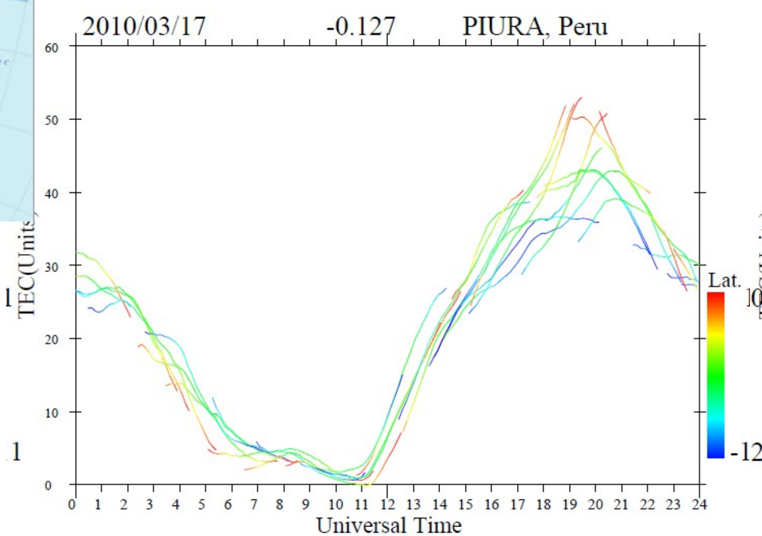
24-hr TEC values for 16 consecutive days from Huancayo

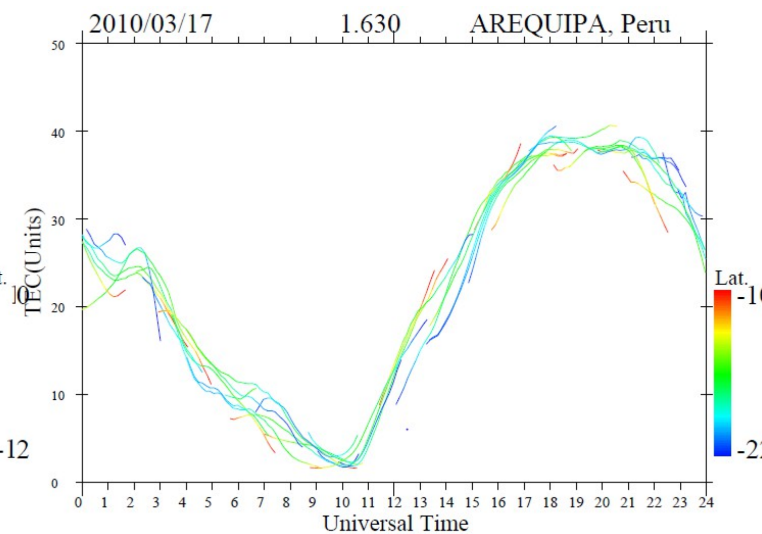


Latitudinal Variability of TEC due to anomaly









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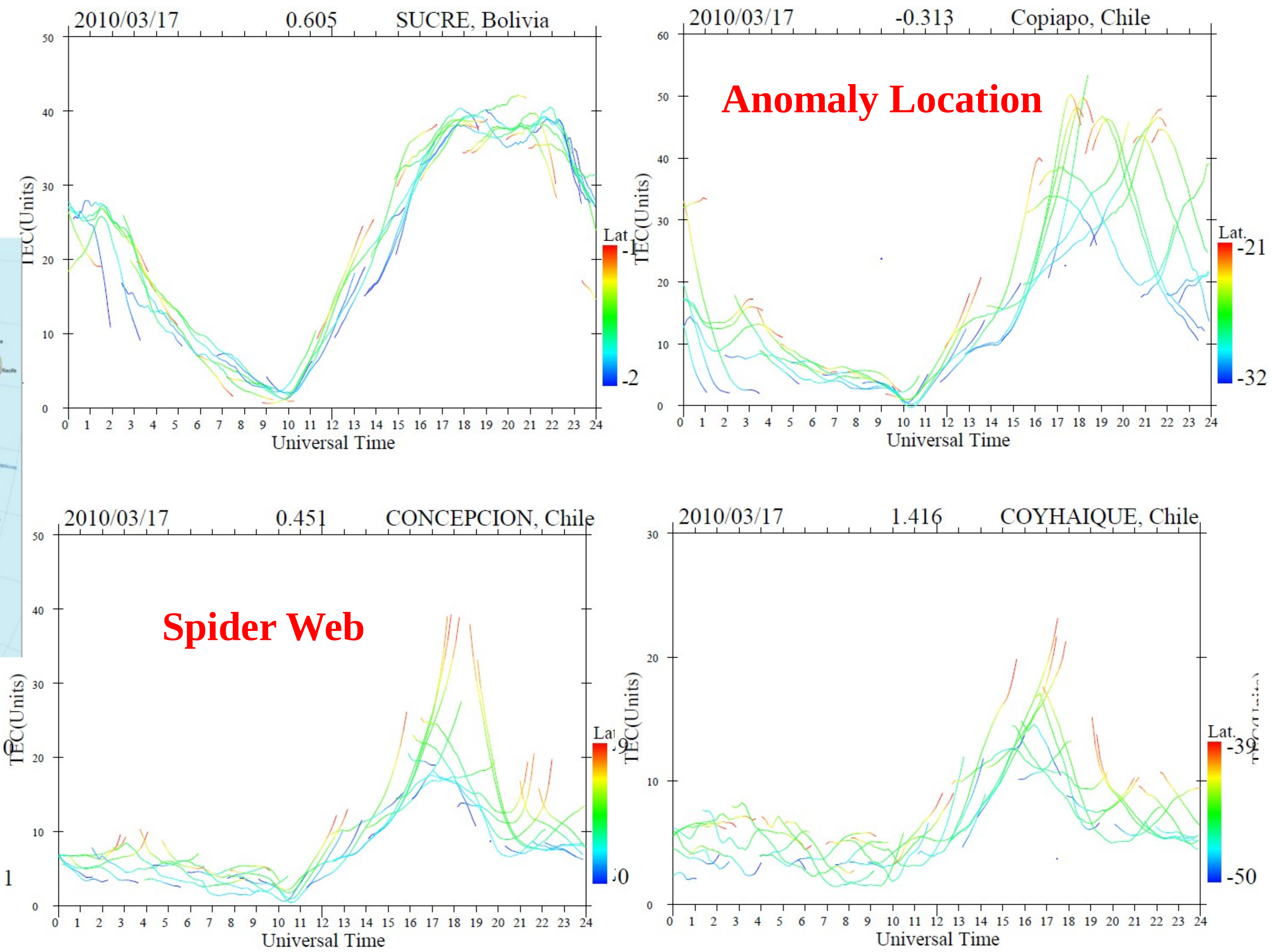
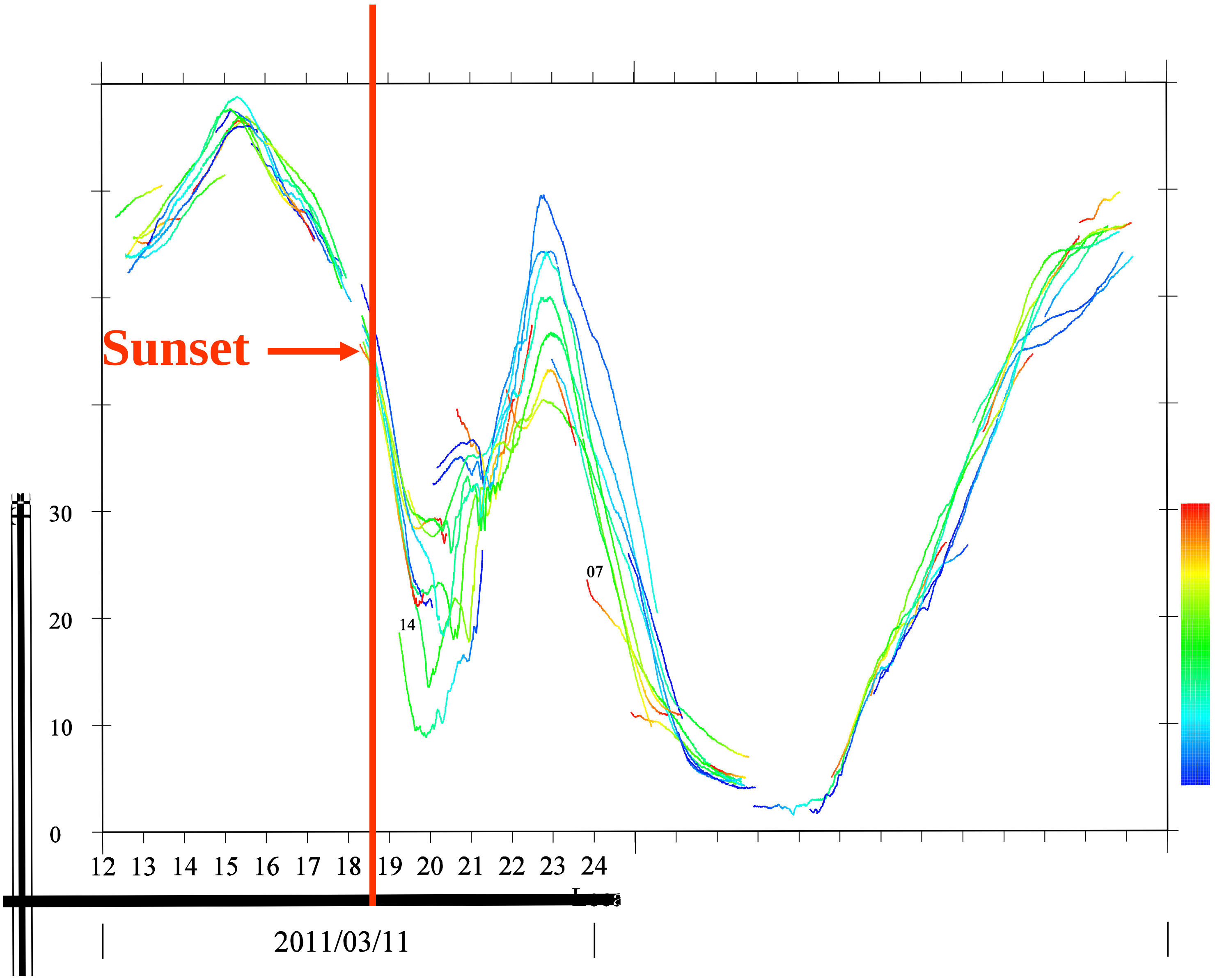
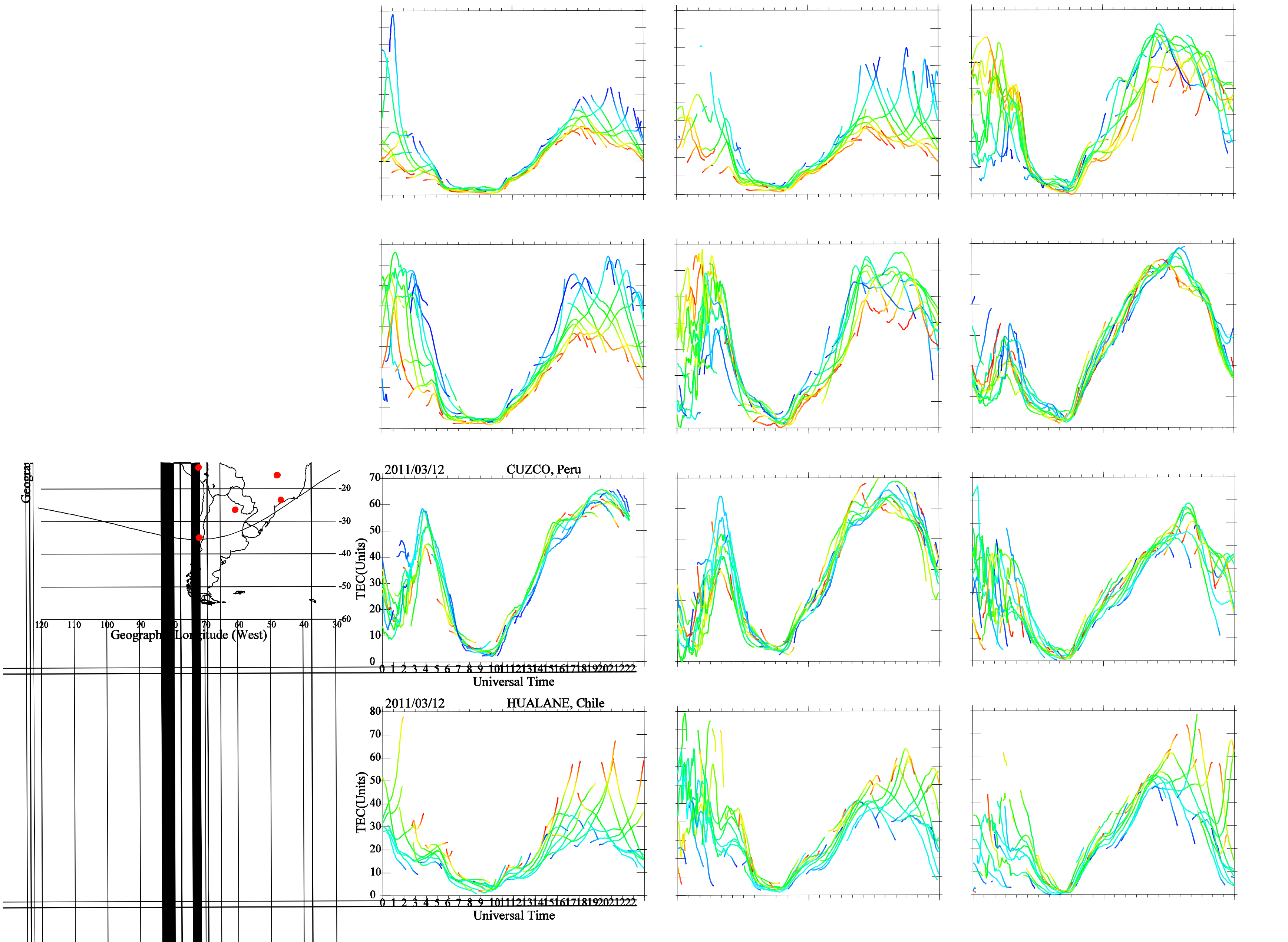


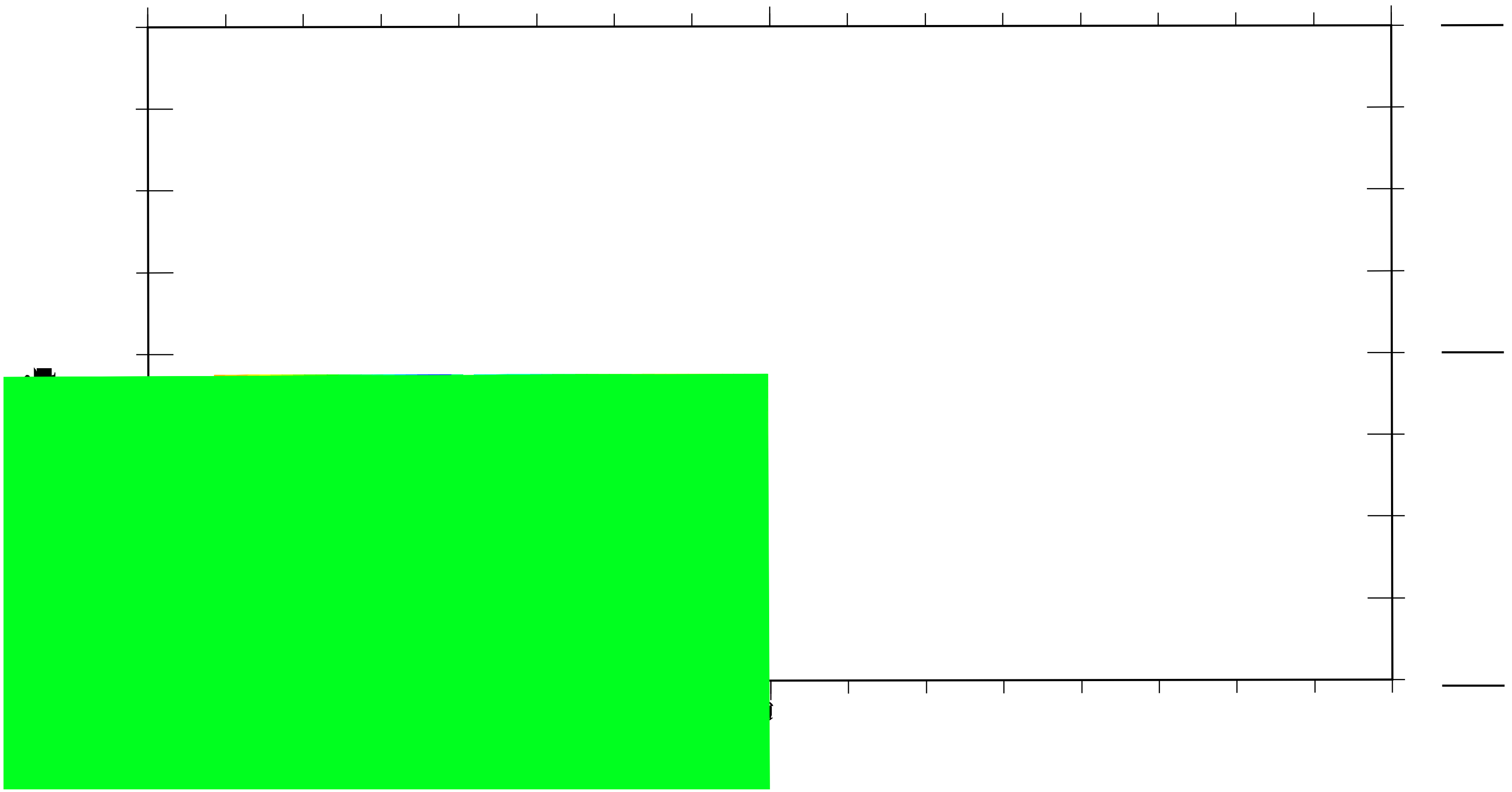
Largest Midnight TEC enhancement



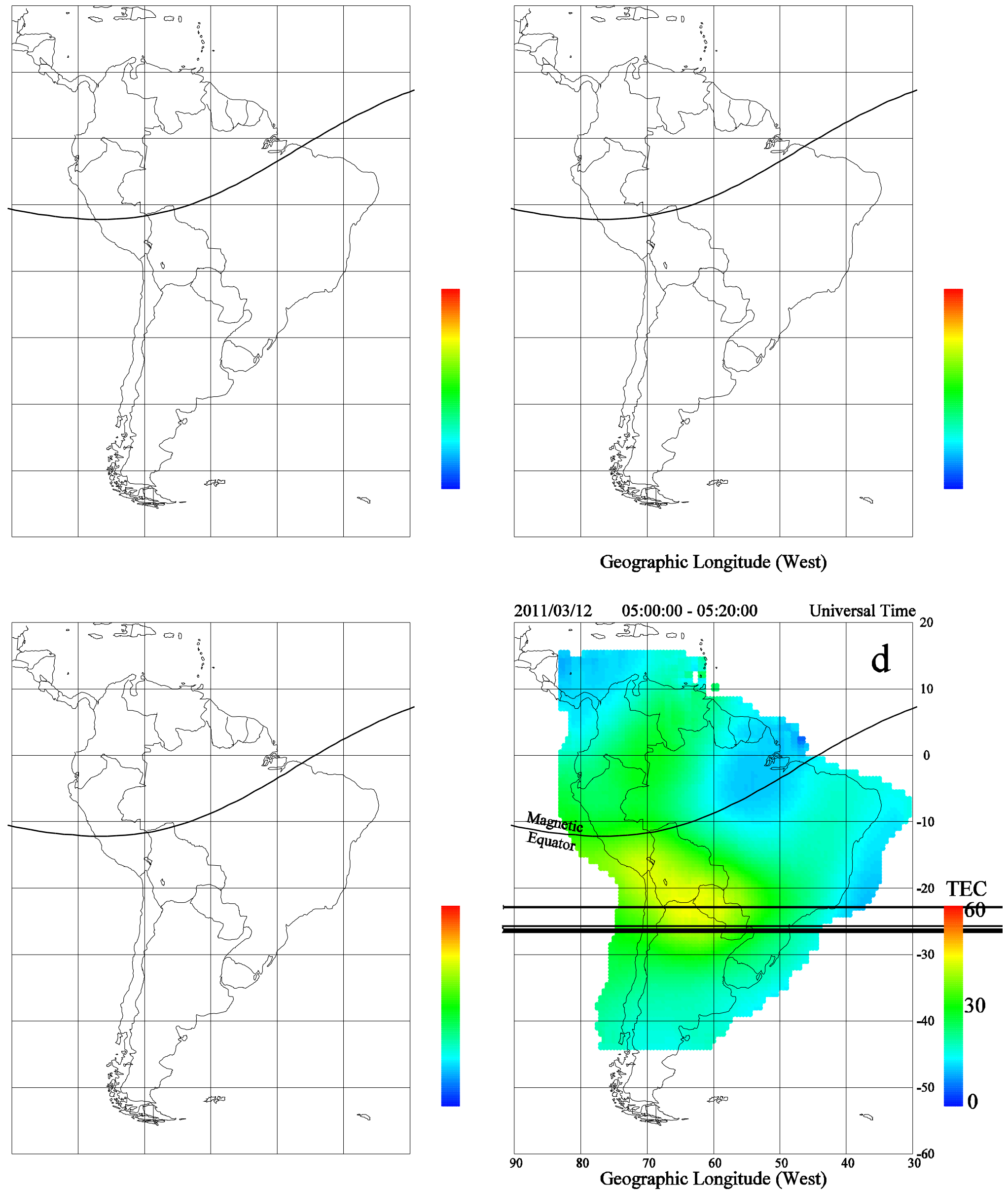
24-Hour plots for several stations during the near-midnight TEC enhancement



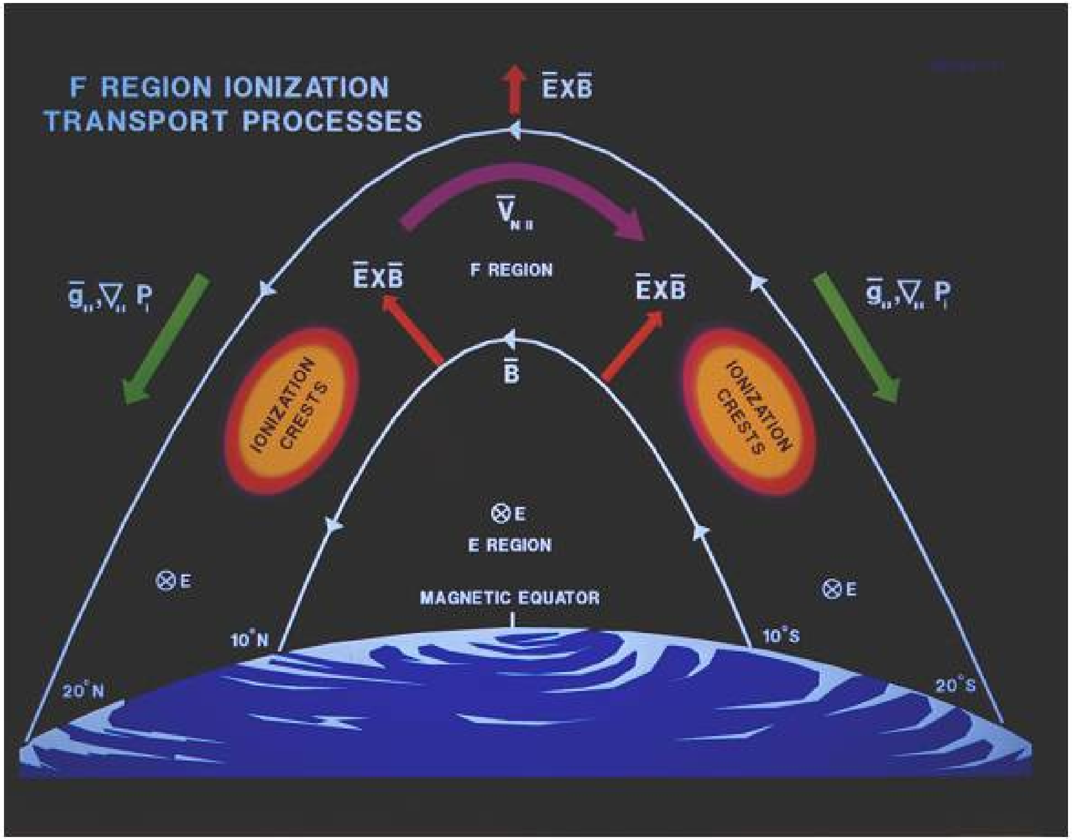
Jicamarca density observations for the same day (March 11-12, 2011)



TEC variability over South America measured at 01, 03, 04, and 05 UT



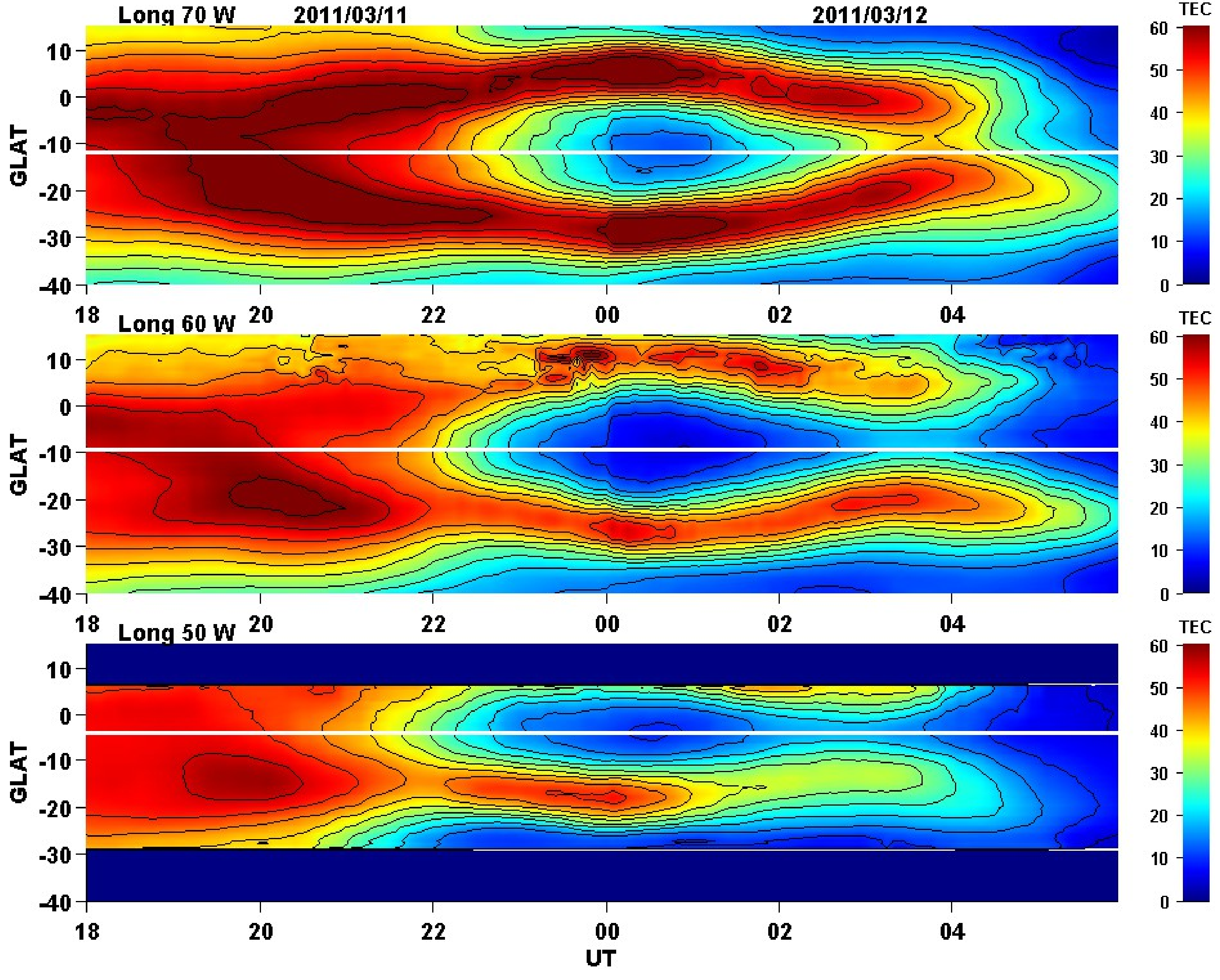
The combination of upward, daytime ExB drift velocity perpendicular to B and downward diffusion parallel to B by gravity and pressure gradient forces create crests in ionization at +/- 15 to 20 degrees magnetic latitude known as the equatorial anomaly. If the daytime, ExB drift velocities are significantly lower or are absent, then the crests in ionization are significantly closer to the magnetic equator or are absent



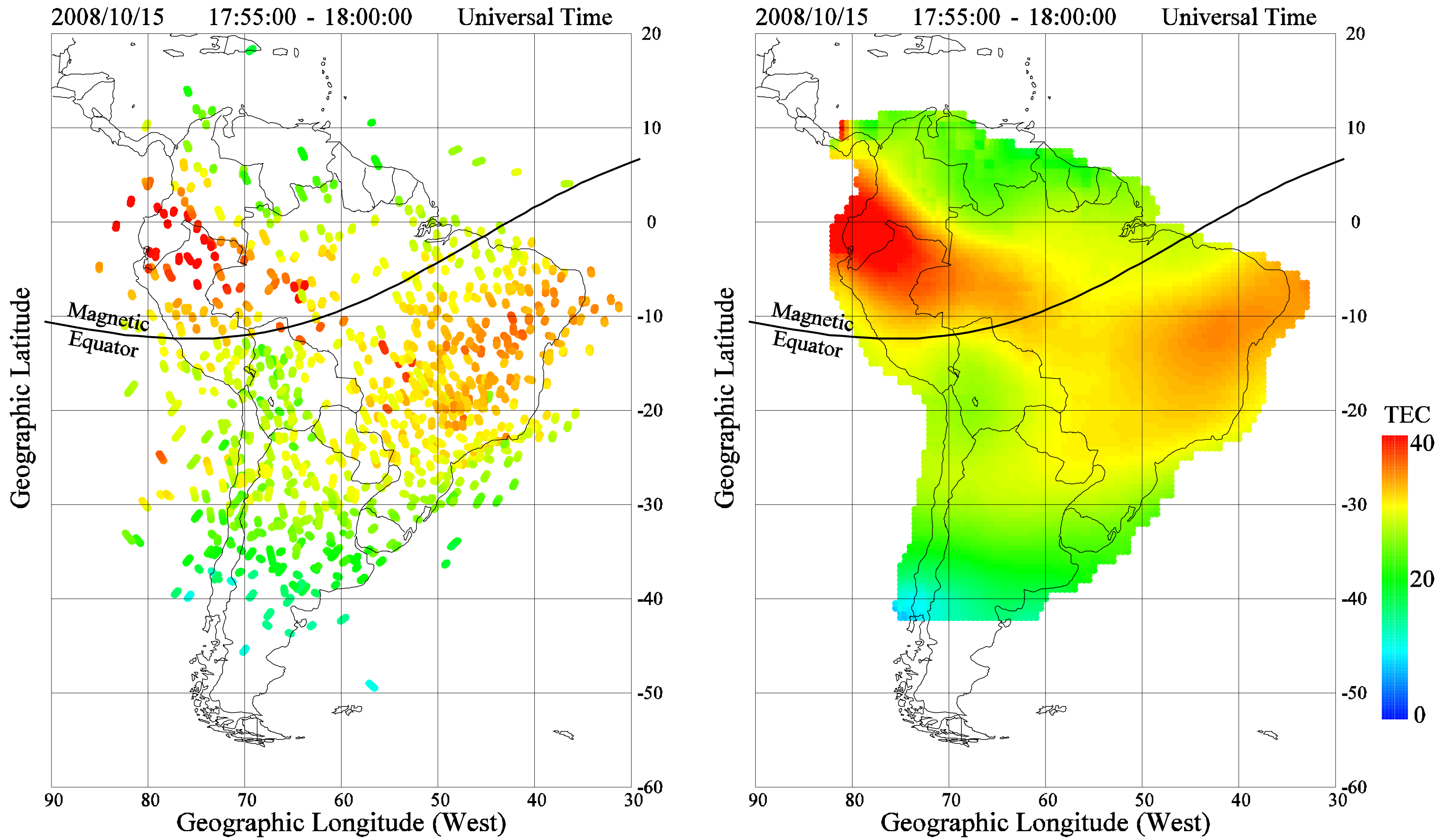
Provided by D. Anderson

Low Latitude Transport Mechanisms

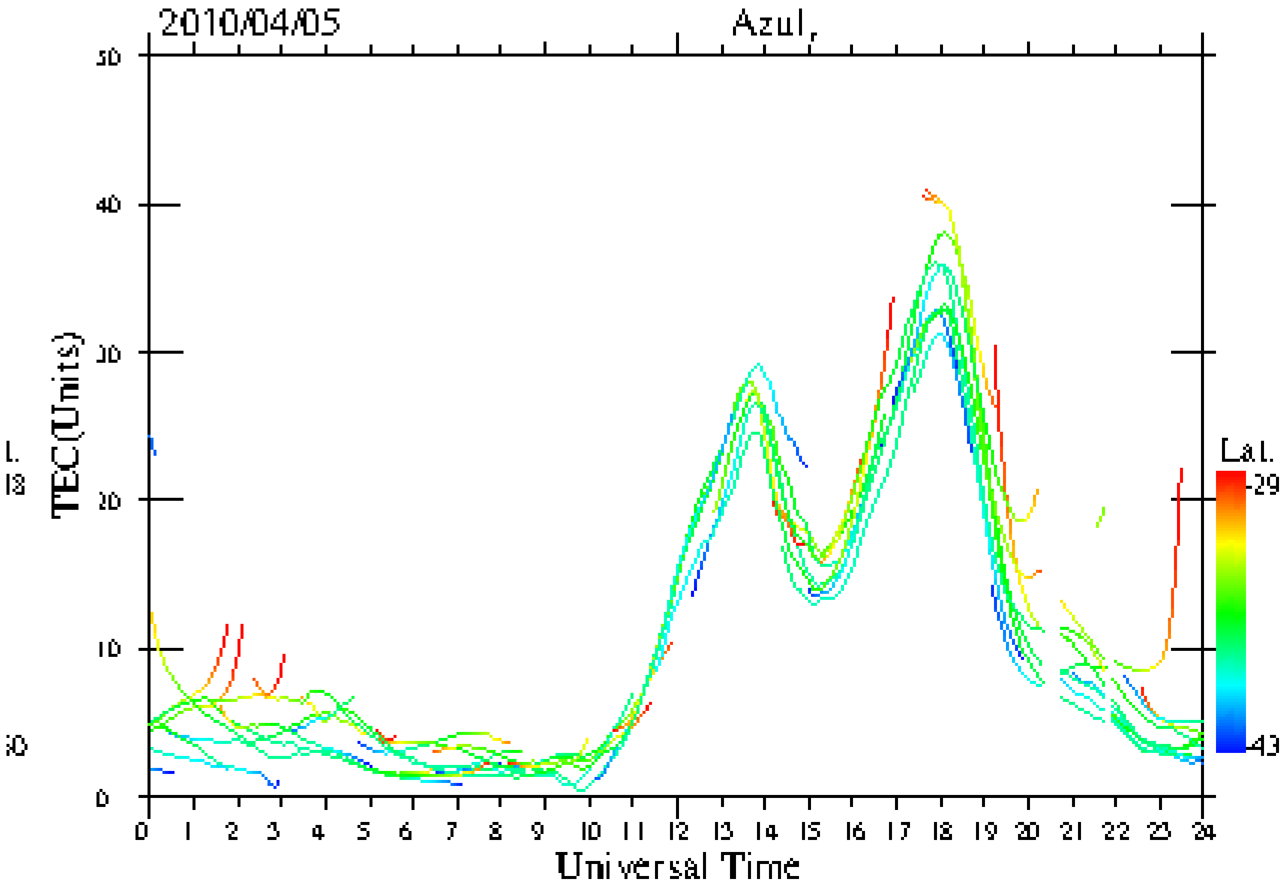
TEC values along 3 field lines



How TEC values are filled in: TEC for October 16, 2008



Daytime double peak (Kp = 7+)



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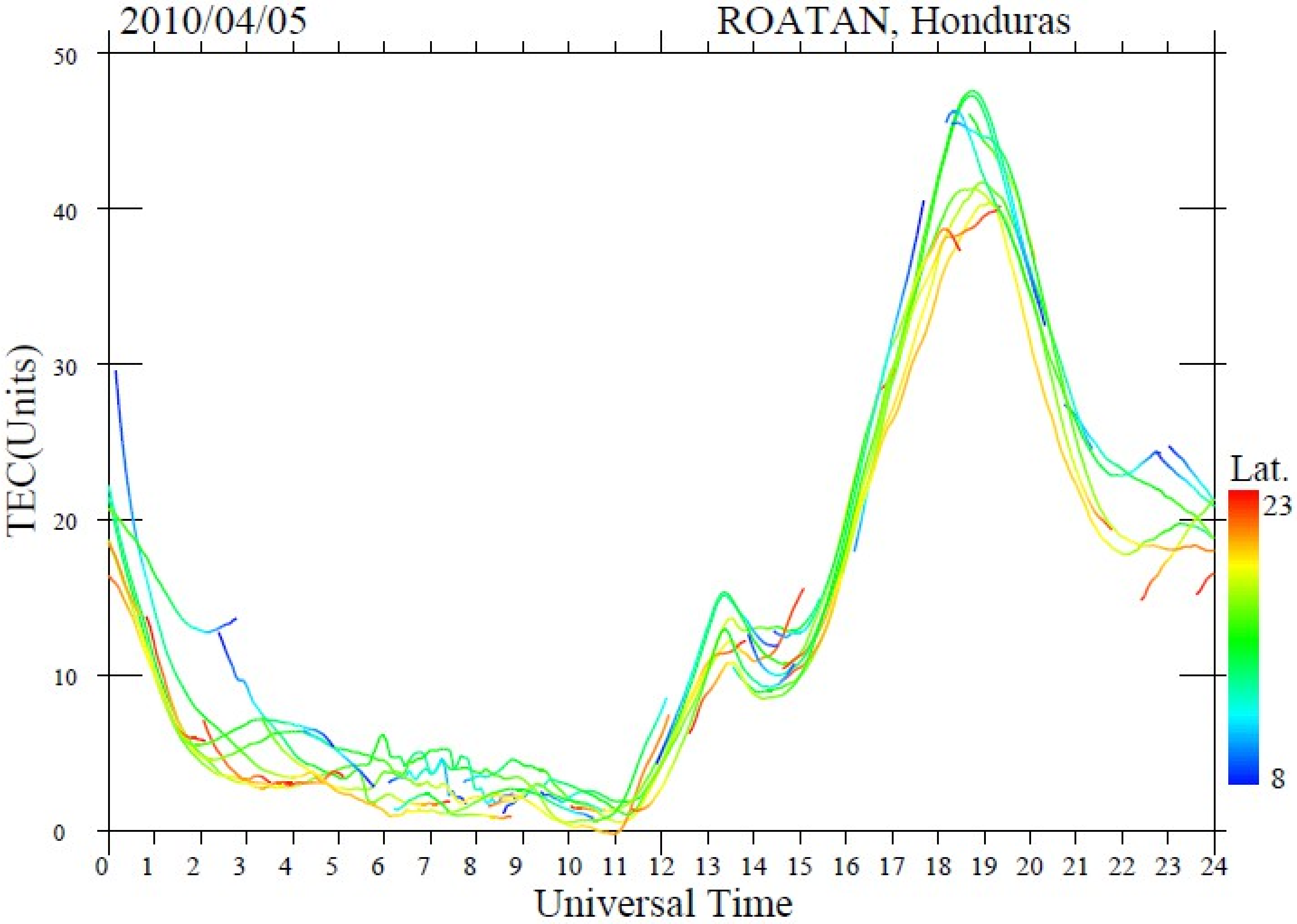
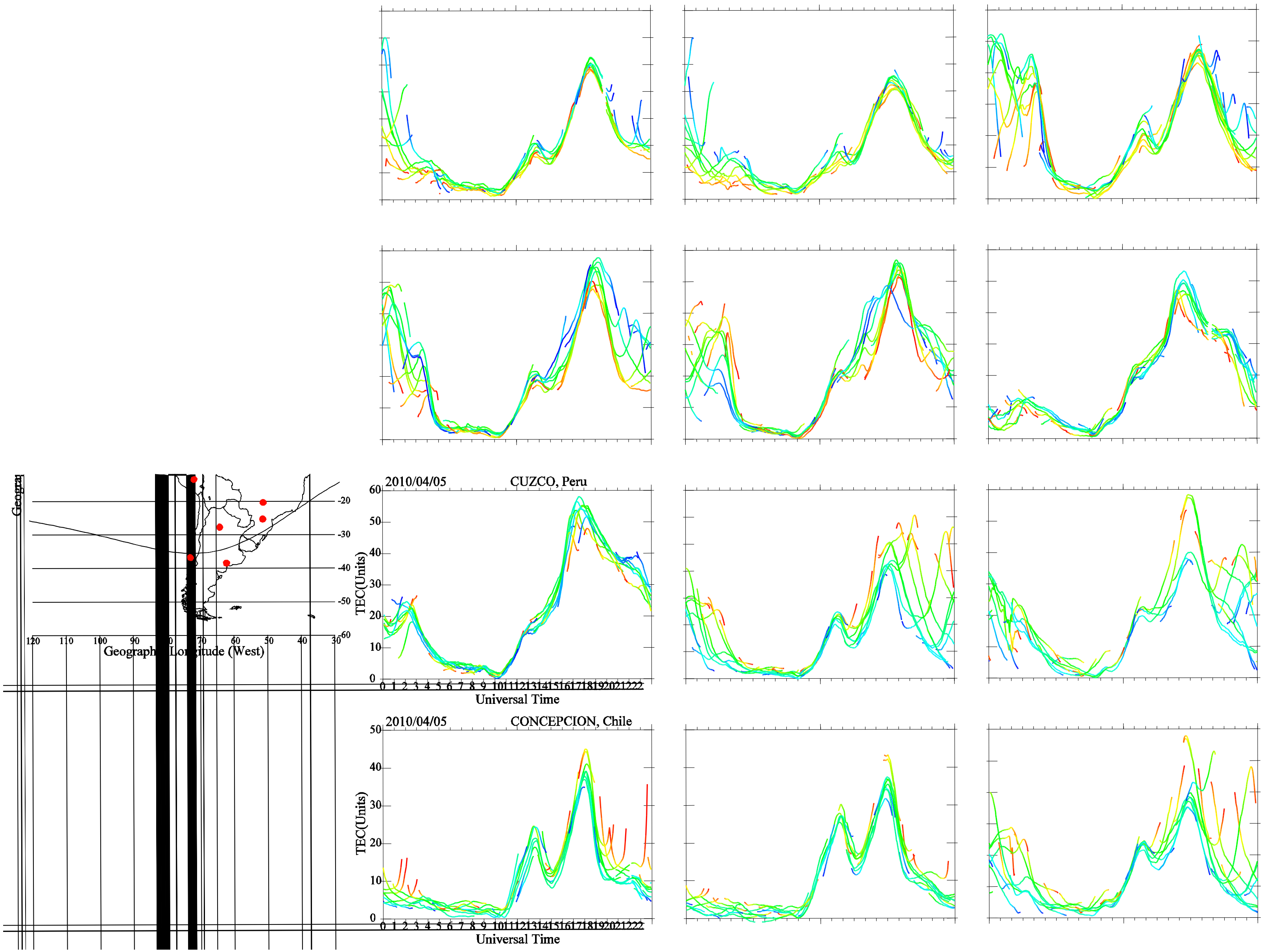


TEC values during magnetically disturbed conditions



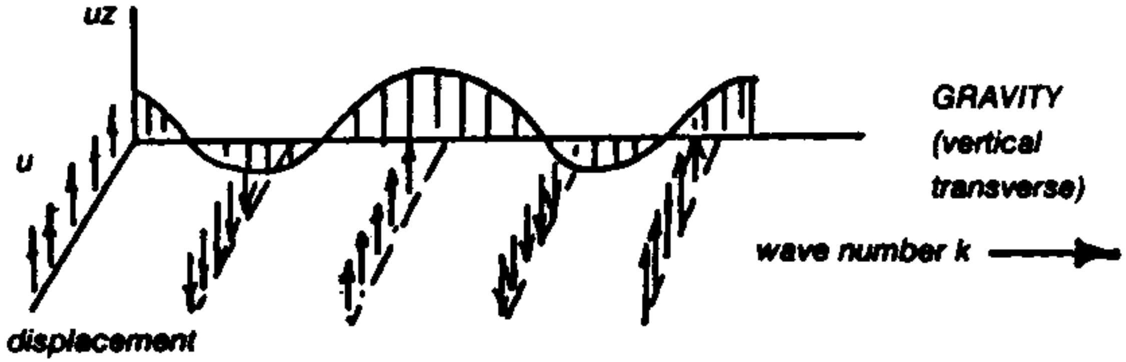
Atmospheric Gravity Wave Origin and Dynamics

GW are produced by any disturbance in the atmosphere on a time scale of a few minutes to several hours. The restoring force is gravity.

Tropospheric disturbances such as: weather fronts, depressions, jet streams, severe storms, wind blowing over topographical features. – And, nuclear explosions.

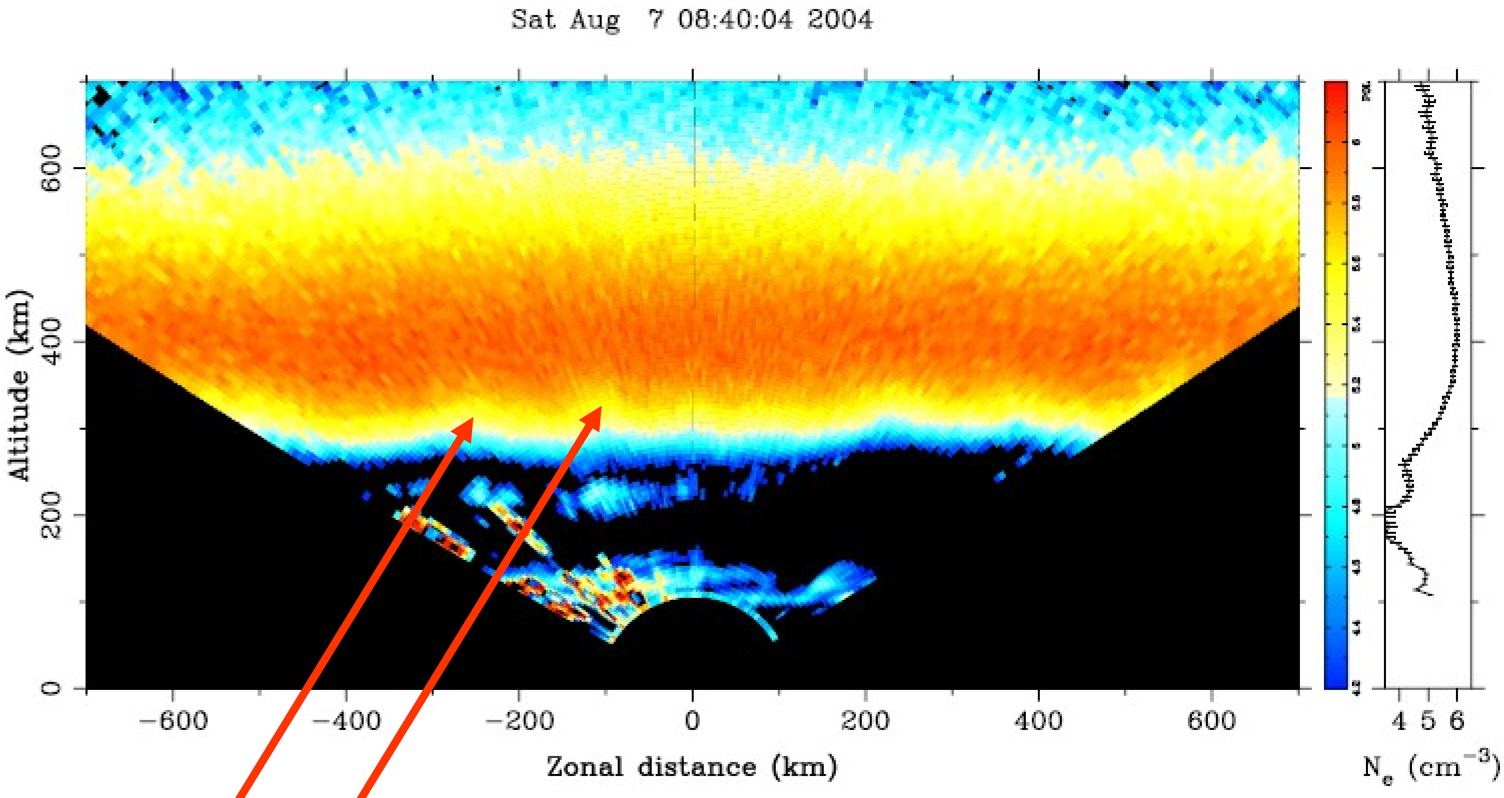
Intense Joule heating deposited at high latitudes during Super magnetic storms (data from the Oct 2003 super storm to be presented).

Energy flow



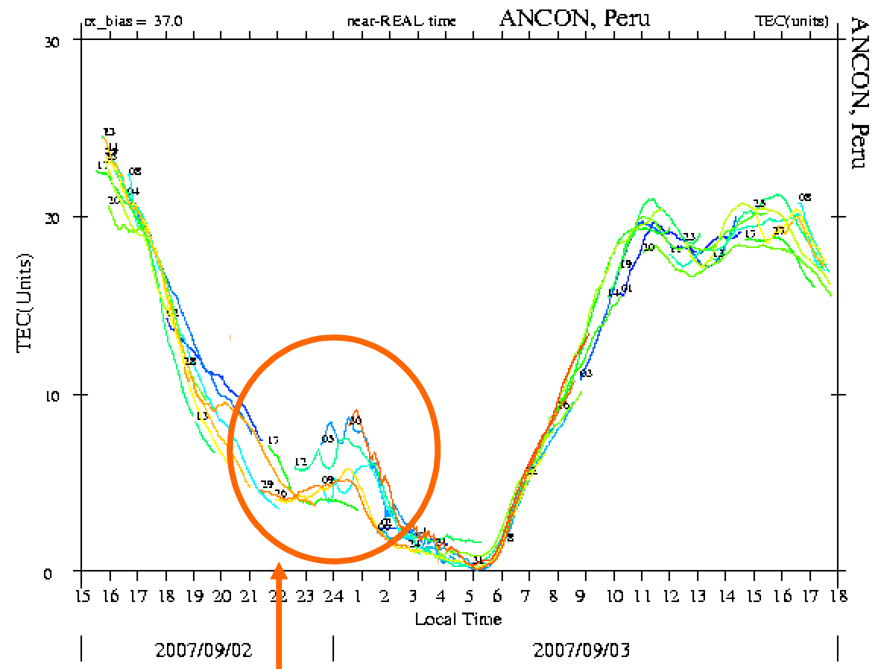
Phase Propagation

ALTAIR Zonal Scan [Hysell et al., Ann. Geophys. 2006]

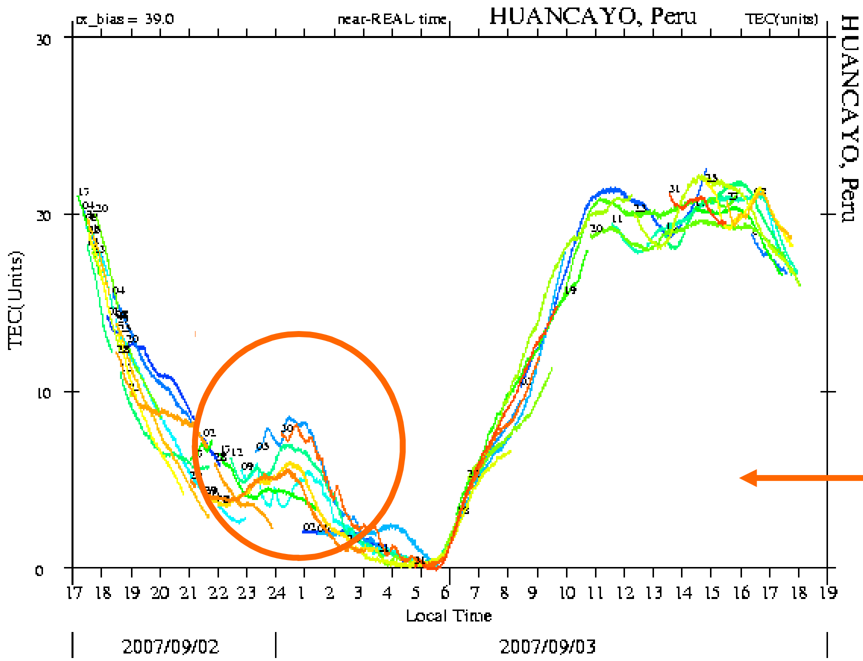


Bottomside altitude modulation probably due to AGW.

TEC wave Perturbations associated with TIDs



1 TEC unit fluctuations seen moving from Huancayo to Ancon (westward direction).



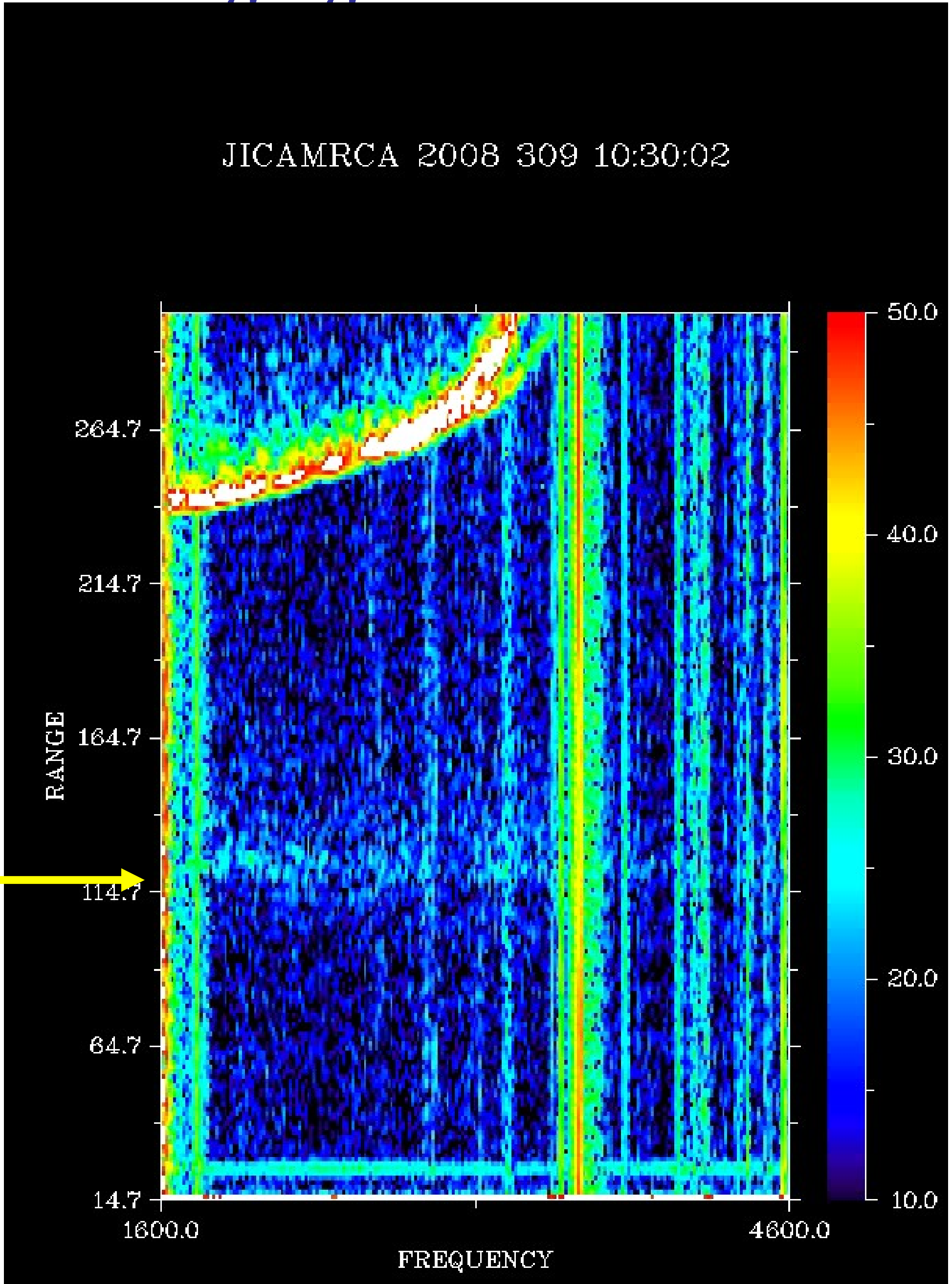
Ancon

Huancayo

Be careful: TEC is an integrated quantity.

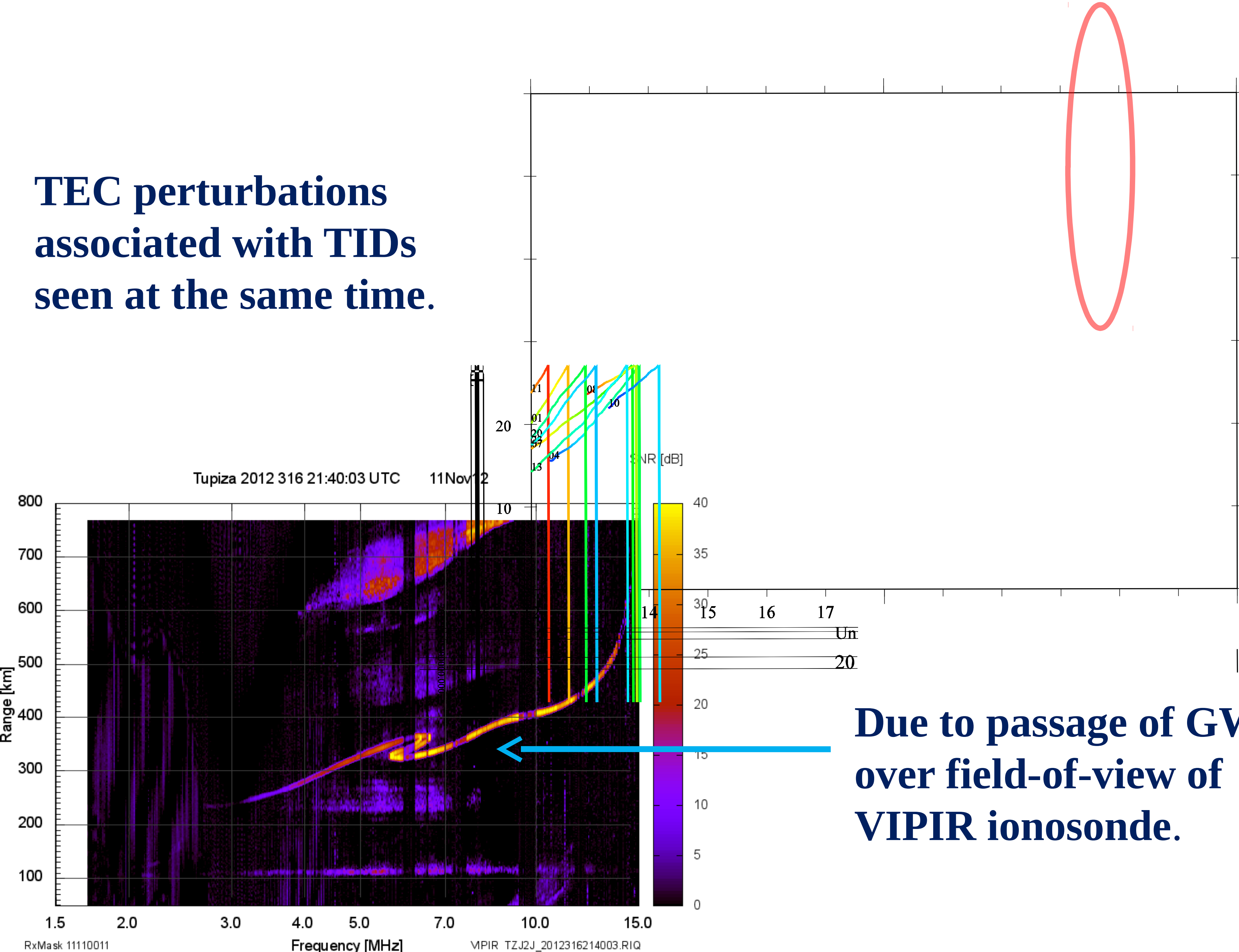
GW/TIDs Observations using high-resolution VIPIR ionograms

High Resolution E-region meas. around sunrise



E-region altitude

TEC perturbations associated with TIDs seen at the same time.

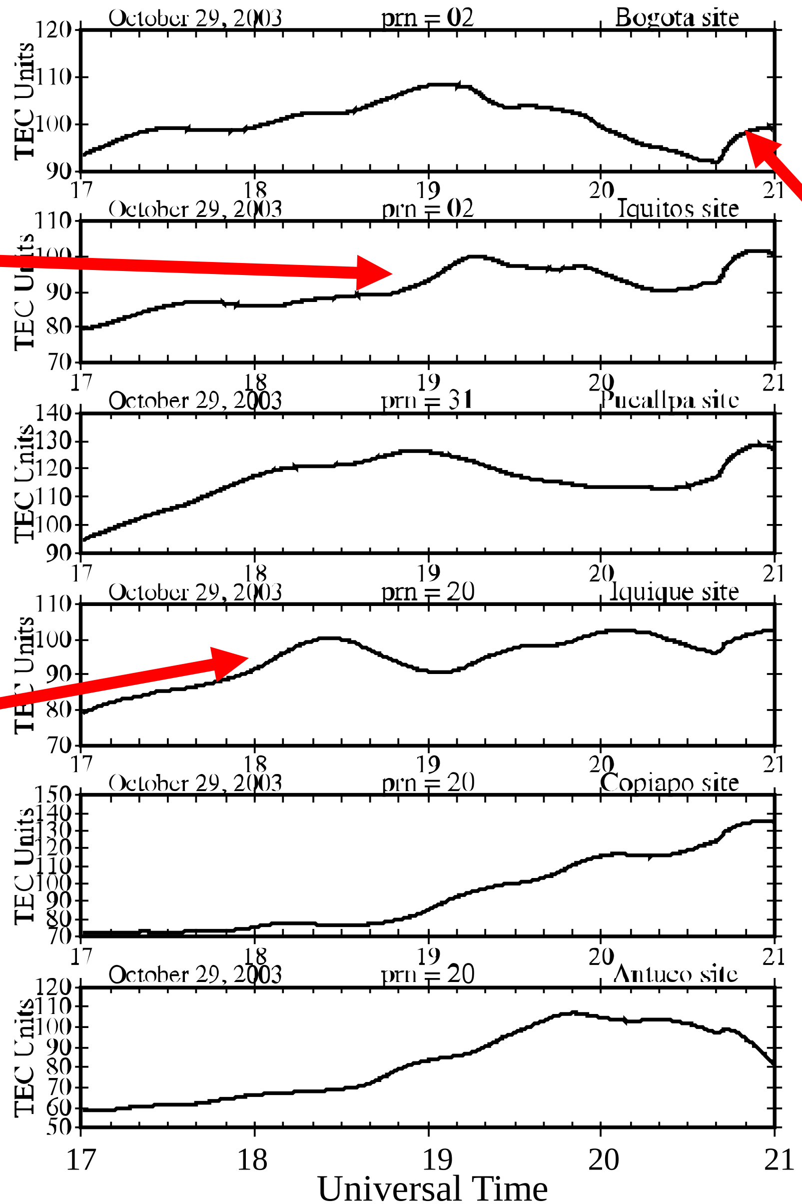


Due to passage of GW over field-of-view of VIPIR ionosonde.

Measurements of large-scale gravity waves during the super storm of Oct, 2003 (Halloween storm)

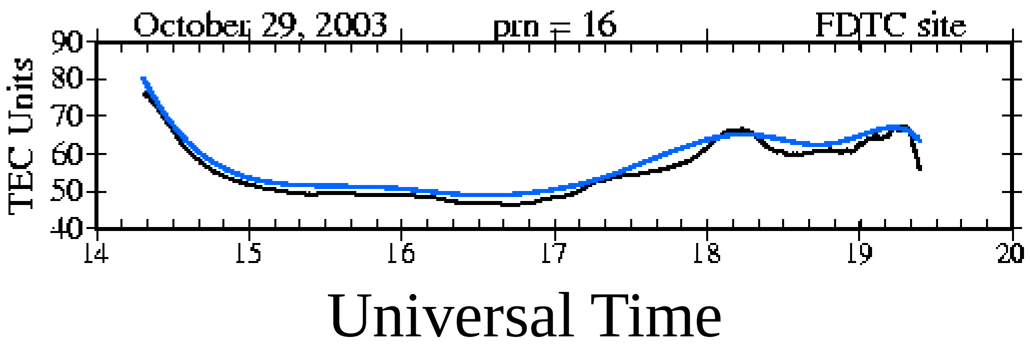
Large-scale TEC variations seen in South America on October 29,2003

TEC variations with time scales of many tens of minutes produced by the passage of Atmospheric Gravity Waves (AGW)

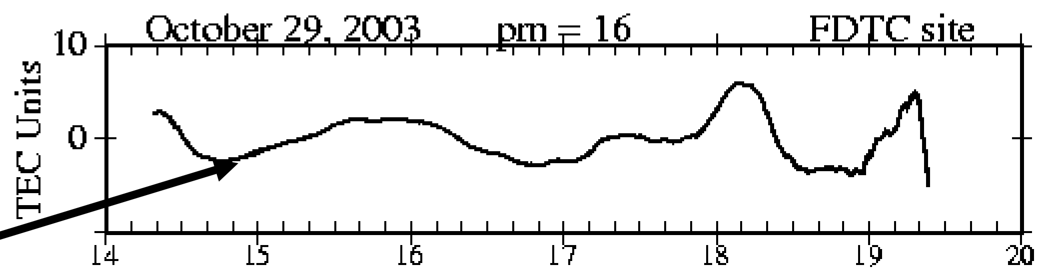


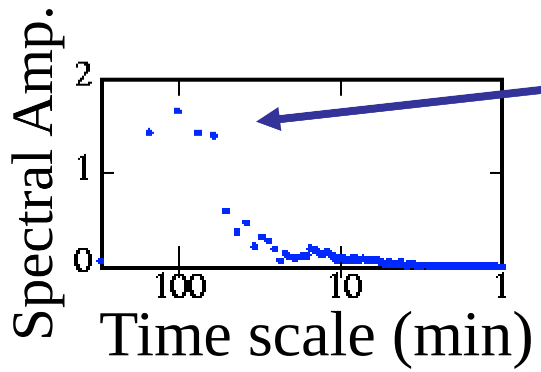
SITEC, sudden increase in TEC (associated with solar flares)

Large-scale TEC perturbations at Lat=34°N, Long=80°W.



Difference between both curves or TEC perturbation associated with TID.



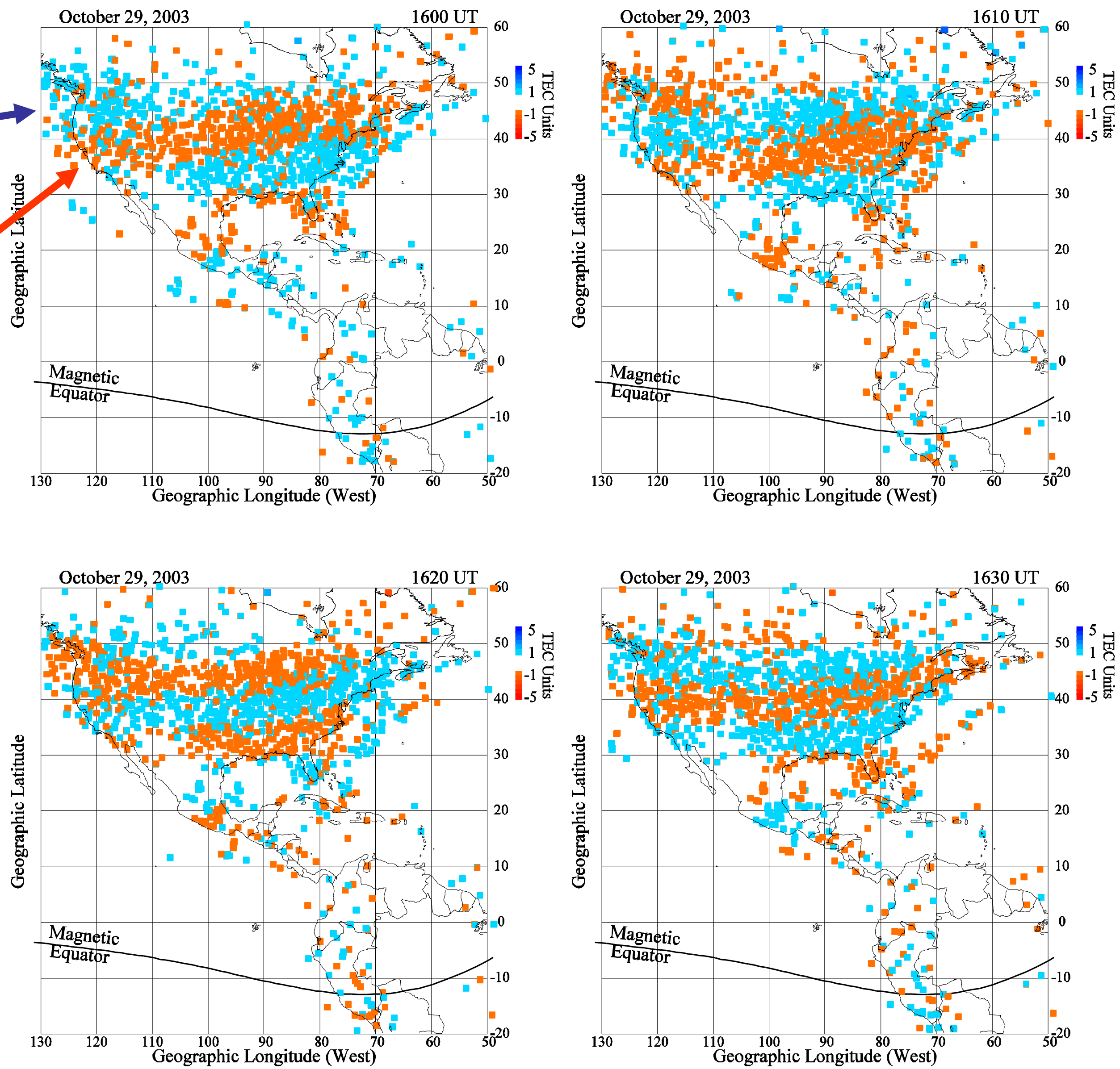


Spectral peak at 100 min time scale.

TEC perturbation in North America (October 29, 2003)

Positive part of TID

Negative or decreased TECP

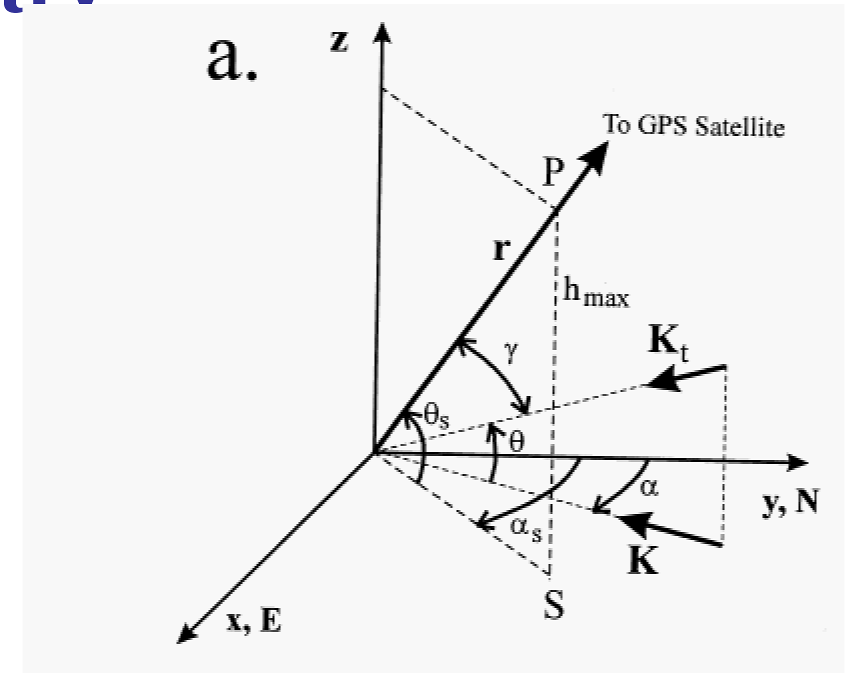


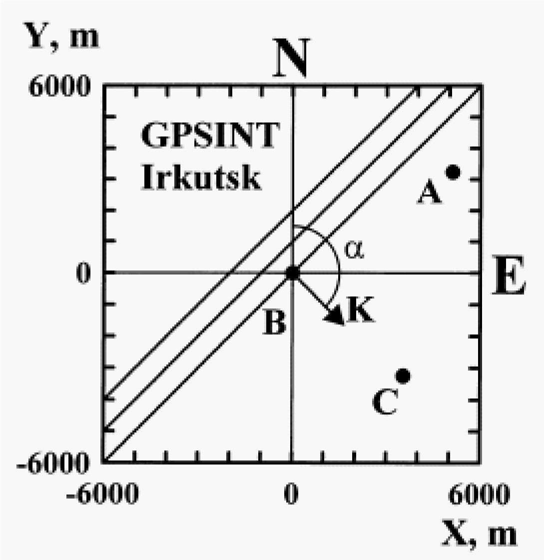
[Valladares et al., Ann. Geophys. 2009]

Dedicated campaign to detect atmospheric gravity waves using 3 GPS receivers

GPS Radio-interferometry

Radio interferometers are arrays of two or more ground receivers that use phase differences measured at various stations to determine TID velocity, propagation azimuth, amplitude, and period.

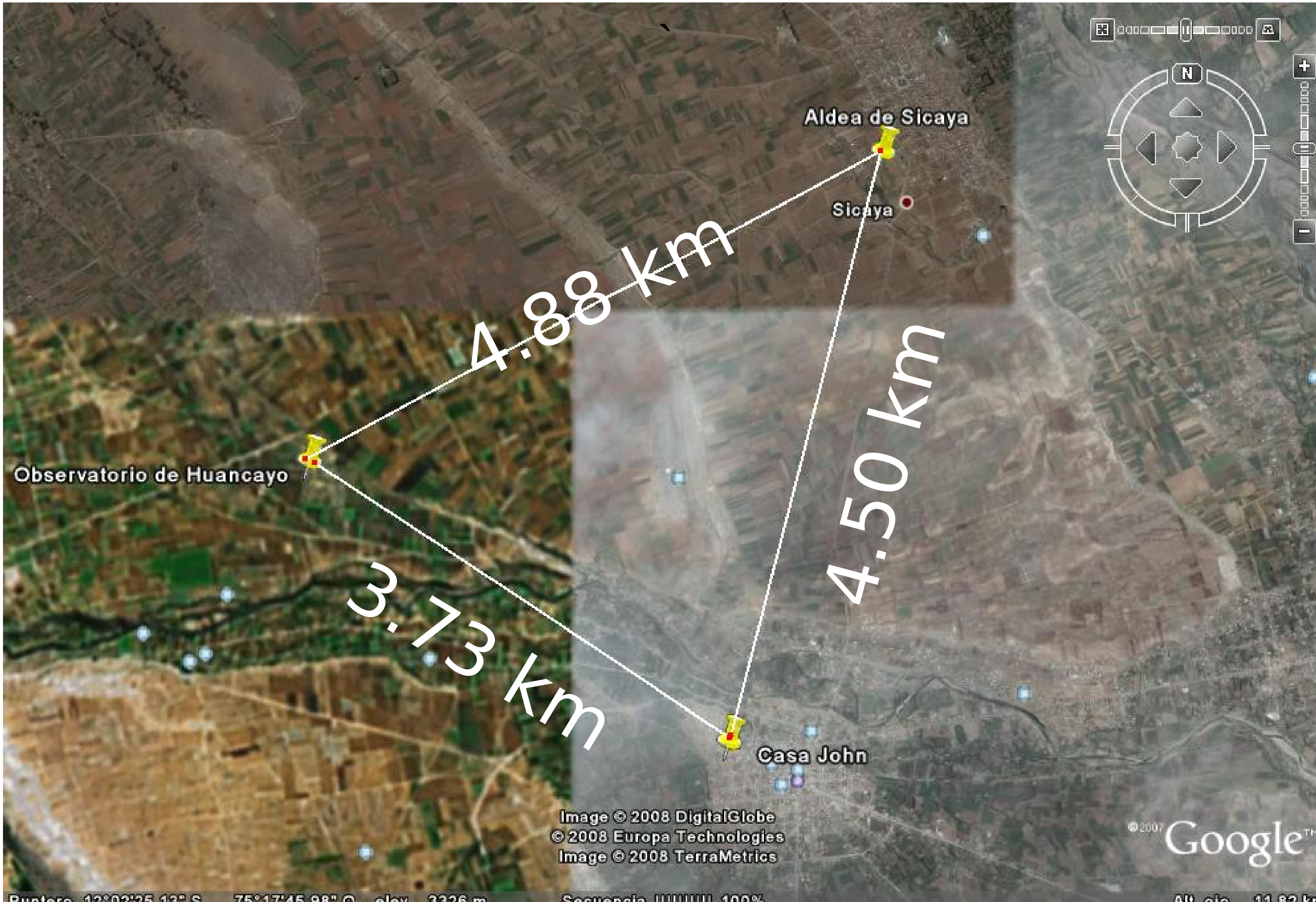




For geo-stationary spatial and time derivatives of the phases give phase interference pattern. GPS radio-interferometry uses the spatial and temporal derivatives of TEC.

***Afraimovich et al.*, 1998; *Afraimovich et al.*, 2002**

Location of 3 GPS receivers near Huancayo



Formulas

It is assumed that the TEC perturbation (gravity wave packet) follows the formula:

Φ(TEC) = δsin(Ωt – K*x*X – K*y*Y + φ)

The Angle of arrival α(t), in the horizontal plane, is given by:

$$\alpha(t) = \arctan\left(G_x(t)/G_y(t)\right) = \arctan\left(\phi'_x(t)/\phi'_y(t)\right) \qquad (5)$$

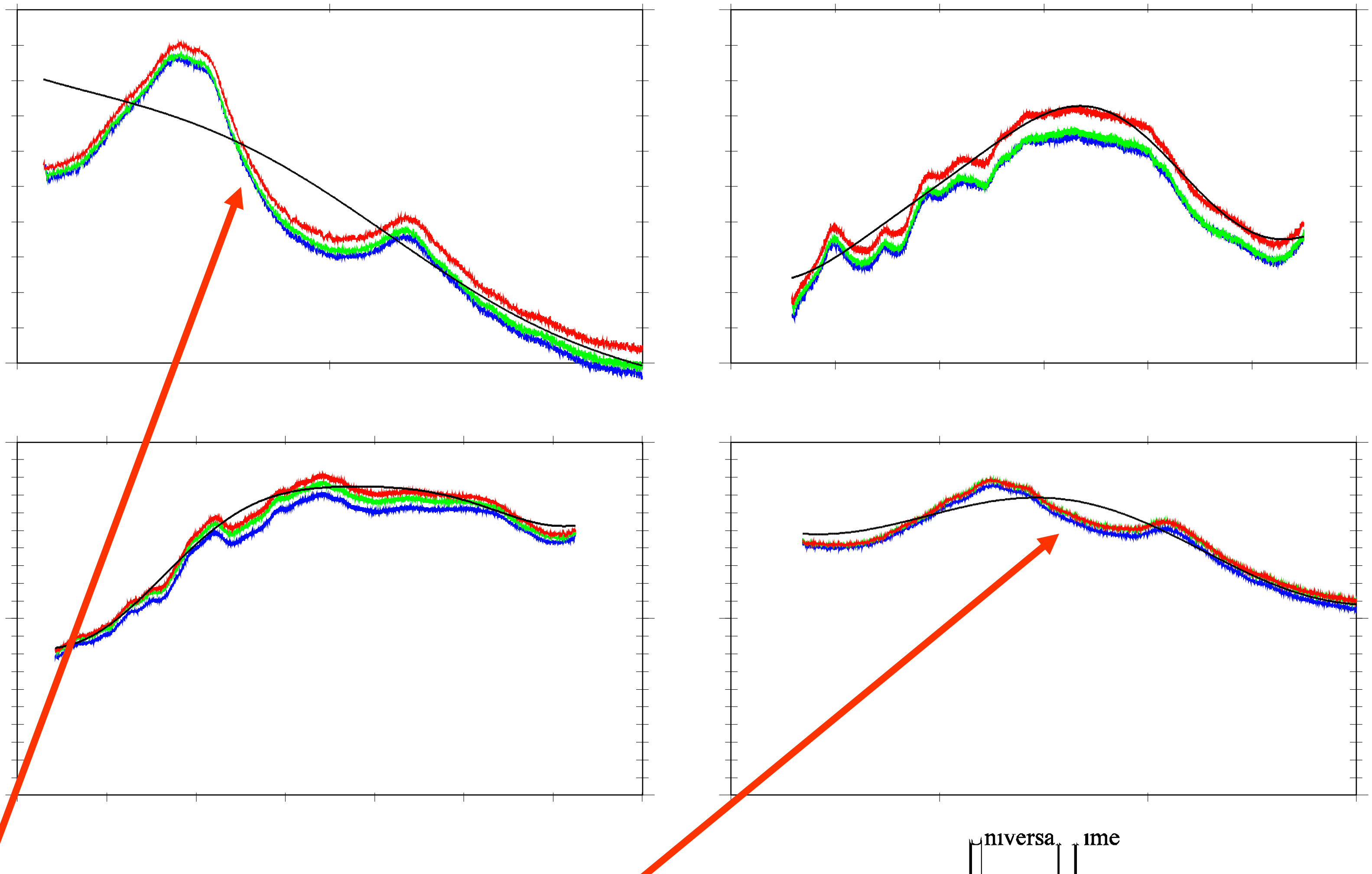
Phase velocity μ(t) in GPS satellite frame of reference:

$$u_x(t) = \phi'_t(t)/\phi'_x(t) = u(t)/\sin\alpha(t)$$

$$u_y(t) = \phi'_t(t)/\phi'_y(t) = u(t)/\cos\alpha(t)$$

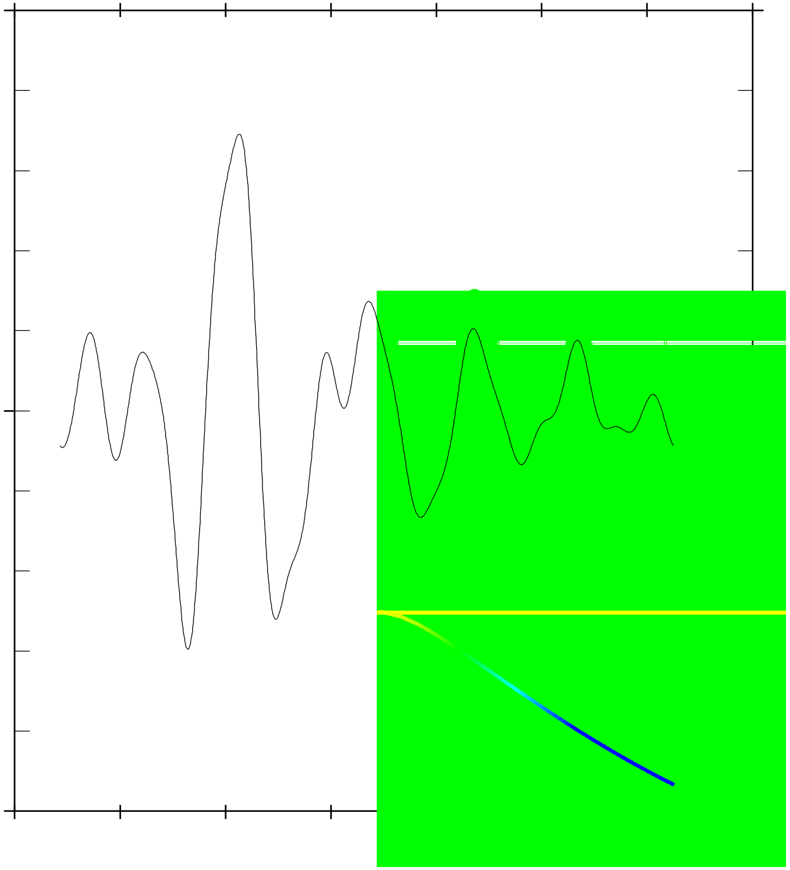
$$u(t) = |u_x(t)u_y(t)|\left(u_x^2(t)+u_y^2(t)\right)^{-1/2} \qquad (8)$$

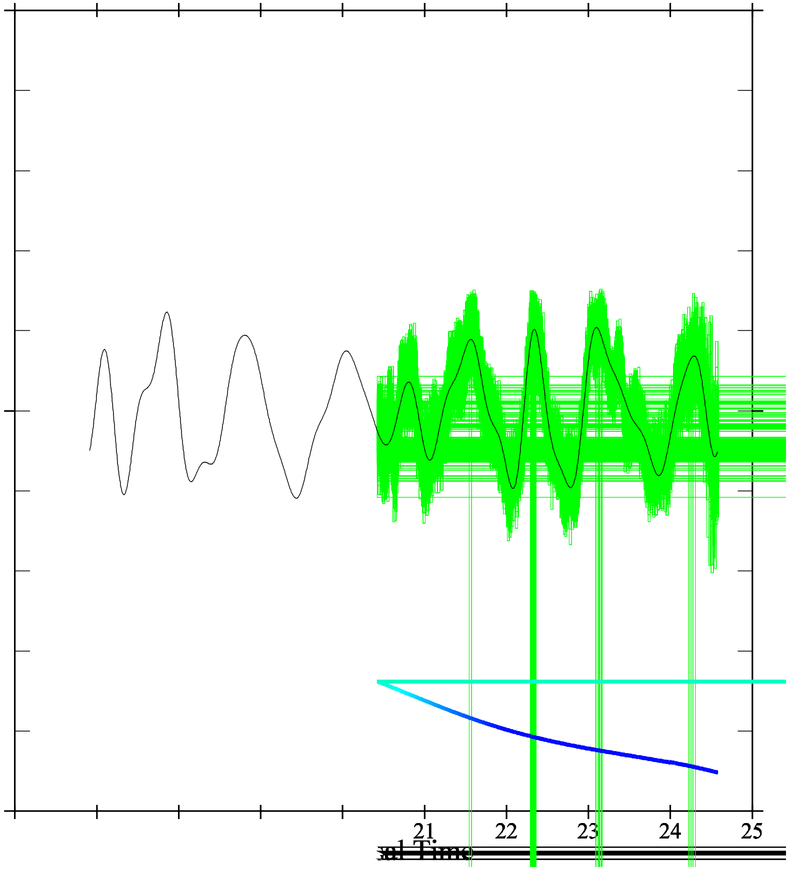
TEC values measured at Huancayo on July 20, 2008



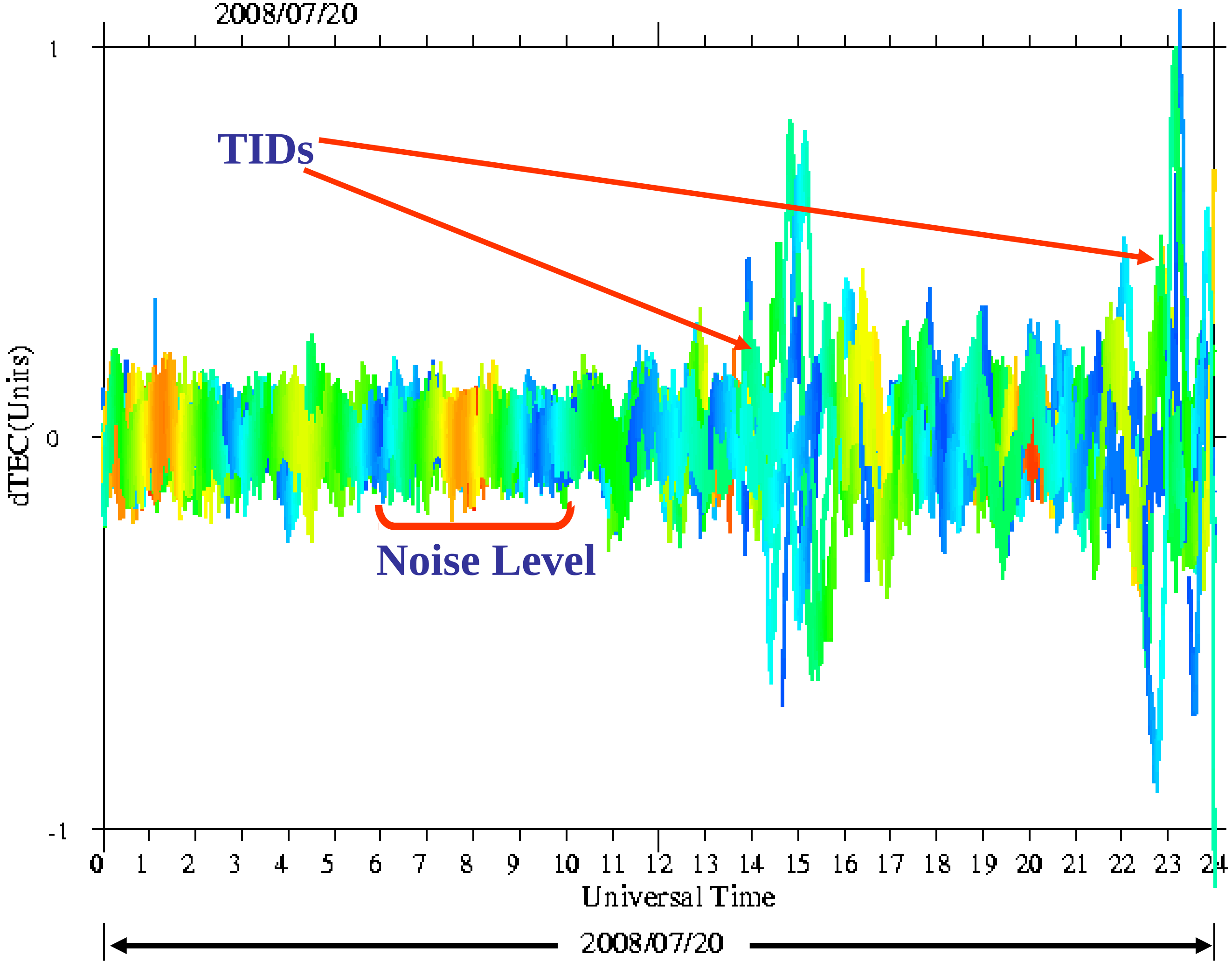
TEC perturbations associated with a TID that has a ~40 min period.

TEC perturbations for PRNs 22 and 32 recorded on July 20, 2008

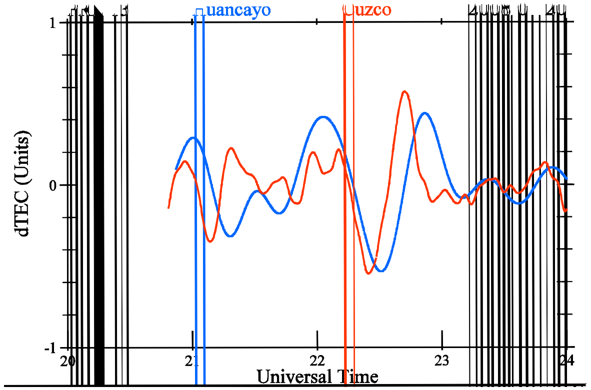




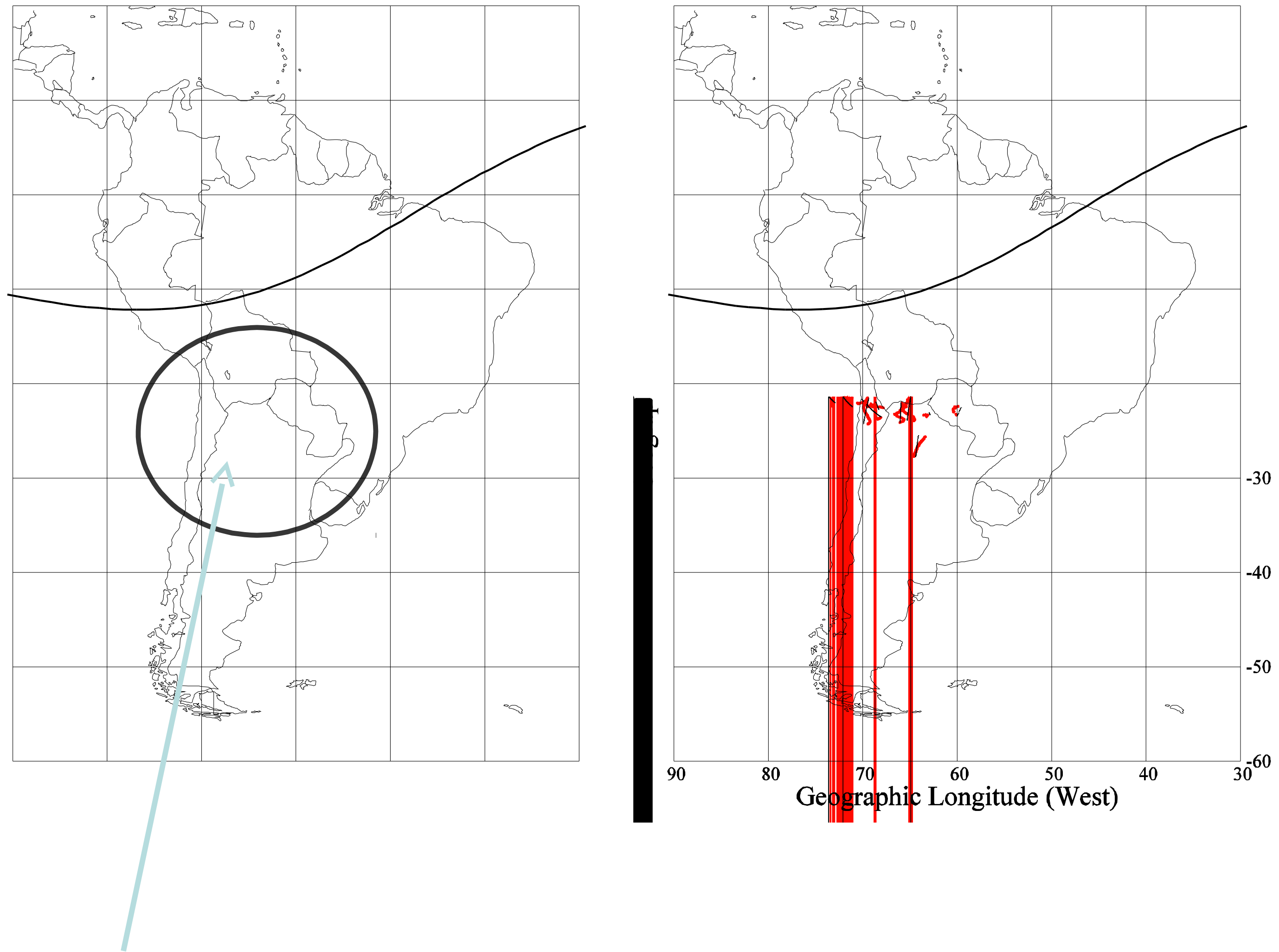
TIDs observed on July 20, 2008



X-Correlation Functions for HYO – Cuzco and HYO - Piura

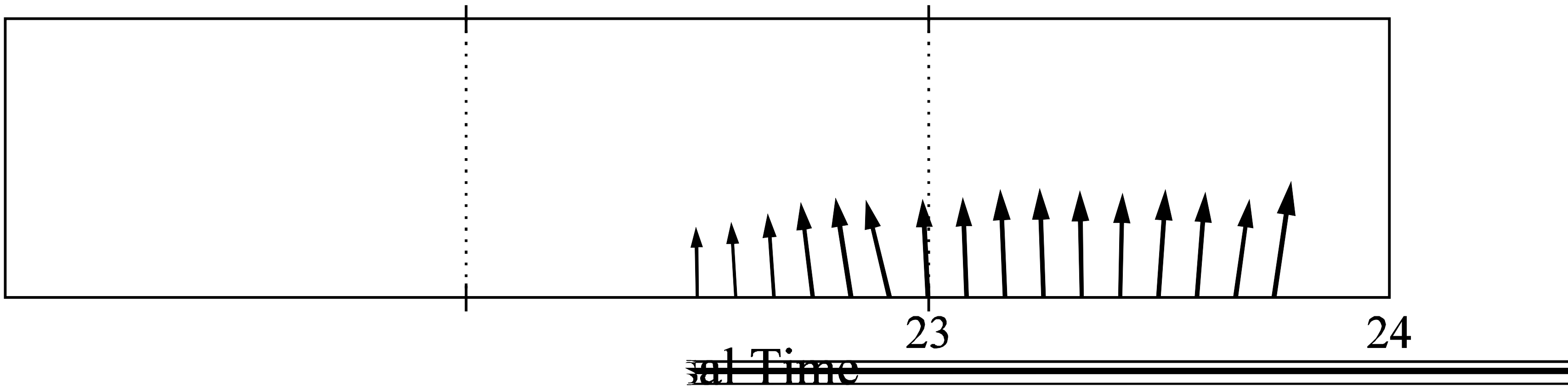


Map of TEC perturbations (associated with TIDs) in South America



In 1 hour this patch of TIDs moved further north

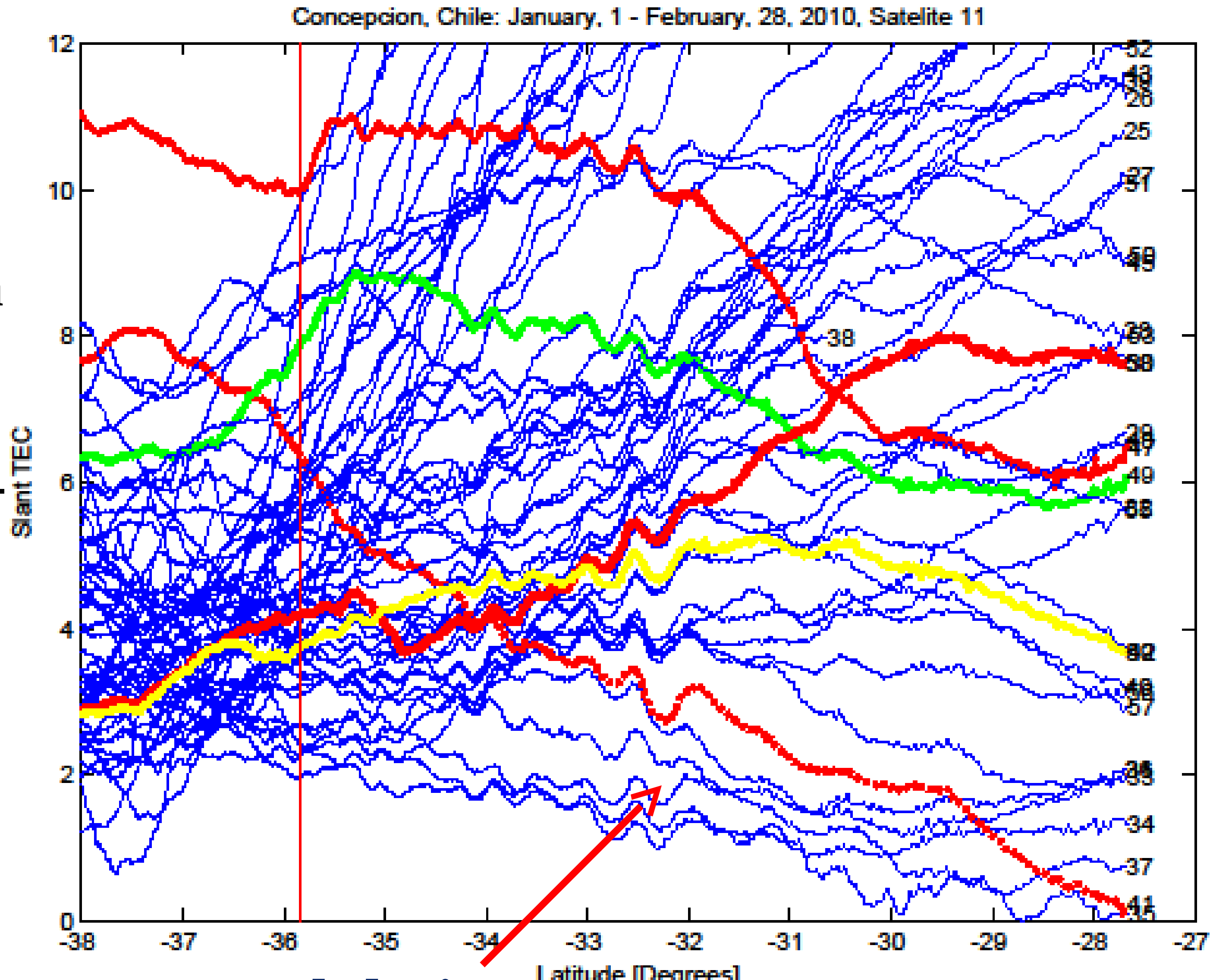
GW phase velocities measured on July 20, 2008 during a 3-week campaign



Phase velocity calculated at Huancayo using 3 closed-spaced GPS receivers. Similar velocities were measure by Valladares and Chau, [2012] using GPS placed hundreds of km apart.

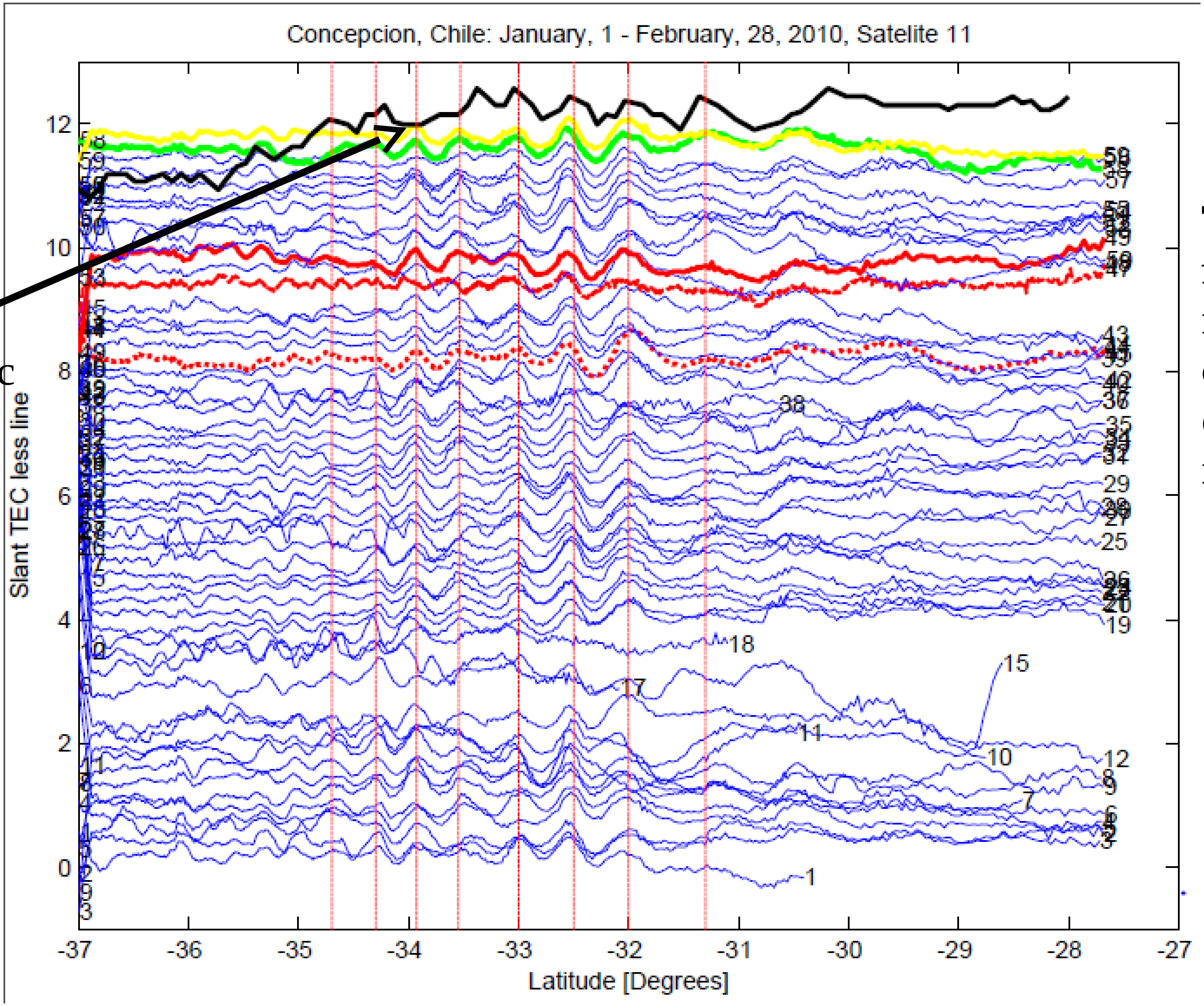
TEC perturbations after detrending daily variability

Satellite passes for several days are shown in different colors to emphasize day-to-day variations.



Undulations

Mountain Waves near Concepcion, Chile



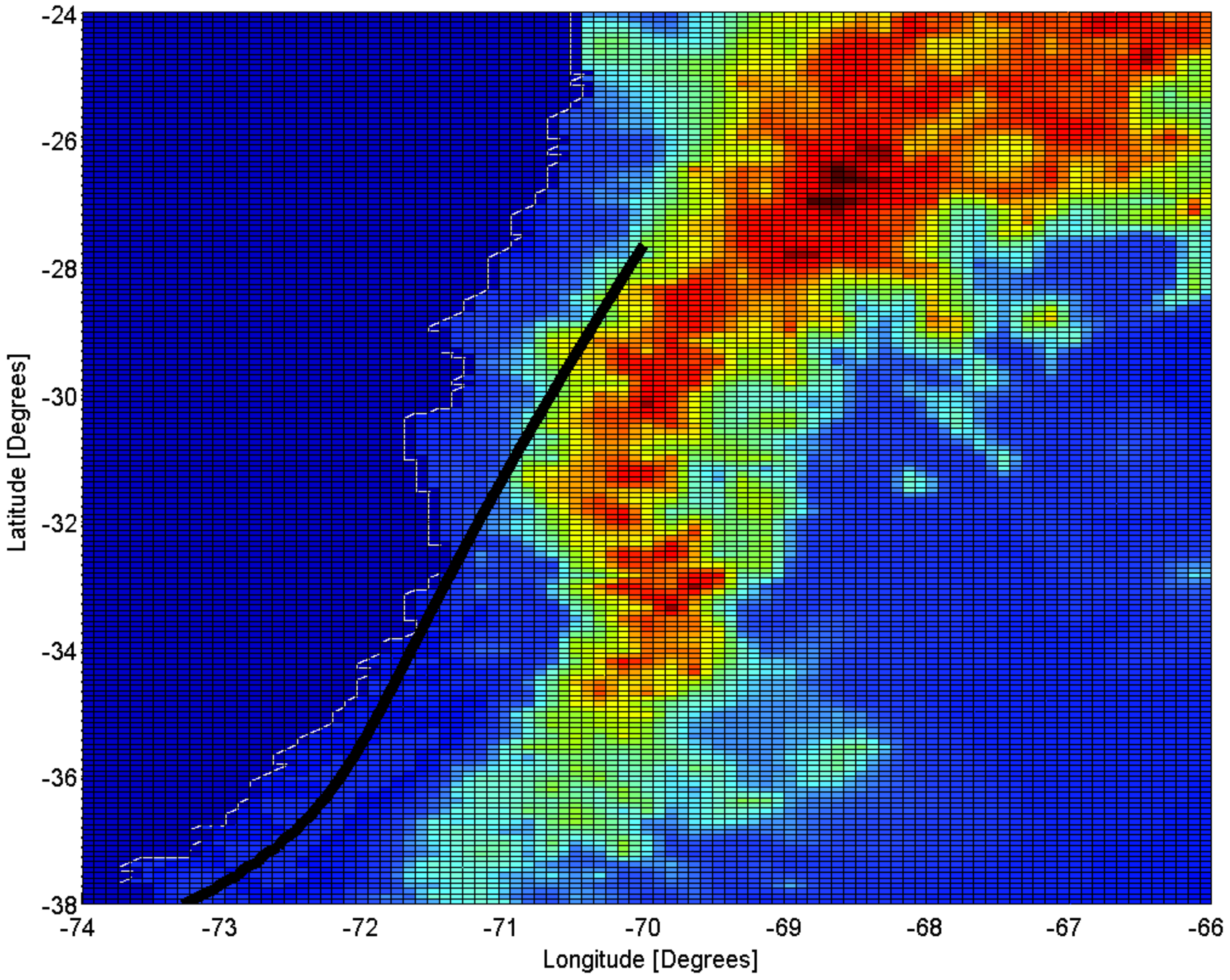
Orographic profile of the Andes

TEC fluctuations measured on consecutive days during 2 months,

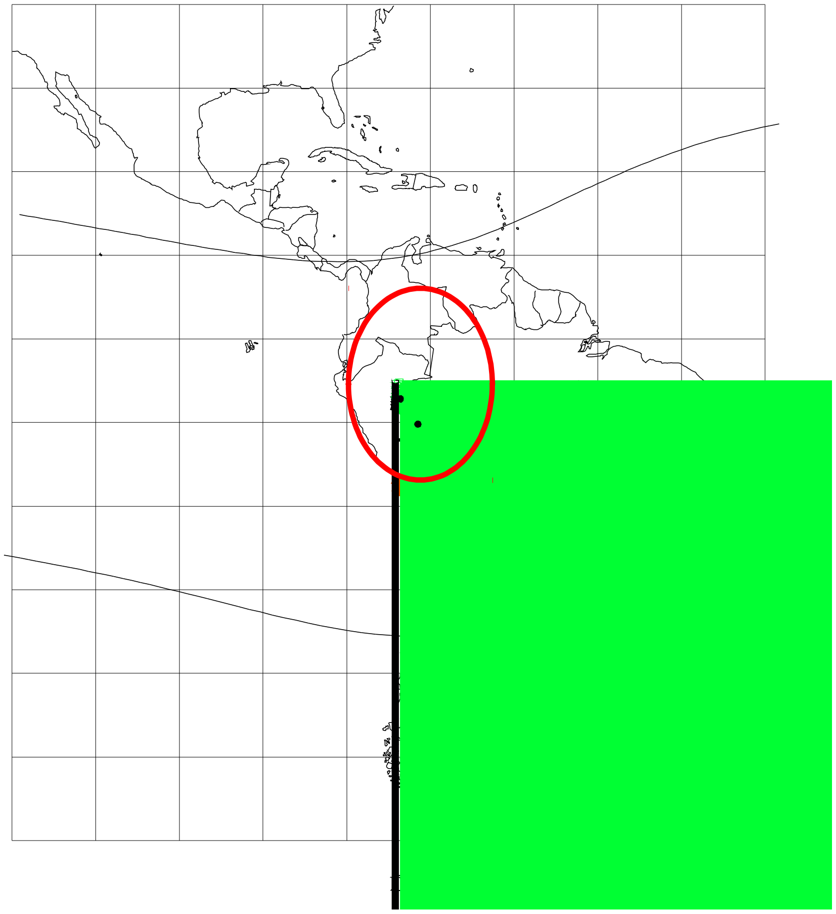
Slide Provided by Wes Swartz

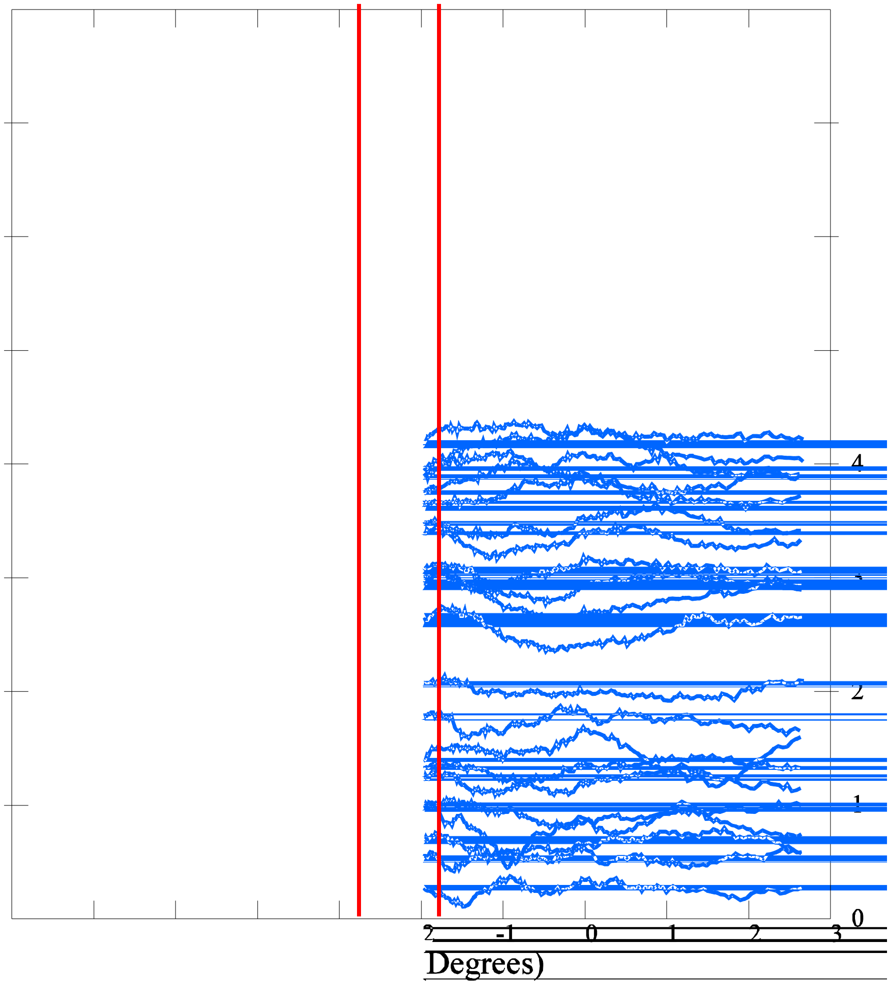
Satellite 11 Path and Andes Topography

- The distance from the satellite to the Andes ridge line varies quite a bit from -35° to -30° latitude.
- Apparently, the varying distance has little effect on undulations.
  - The altitude of the ridge line has the most effect.

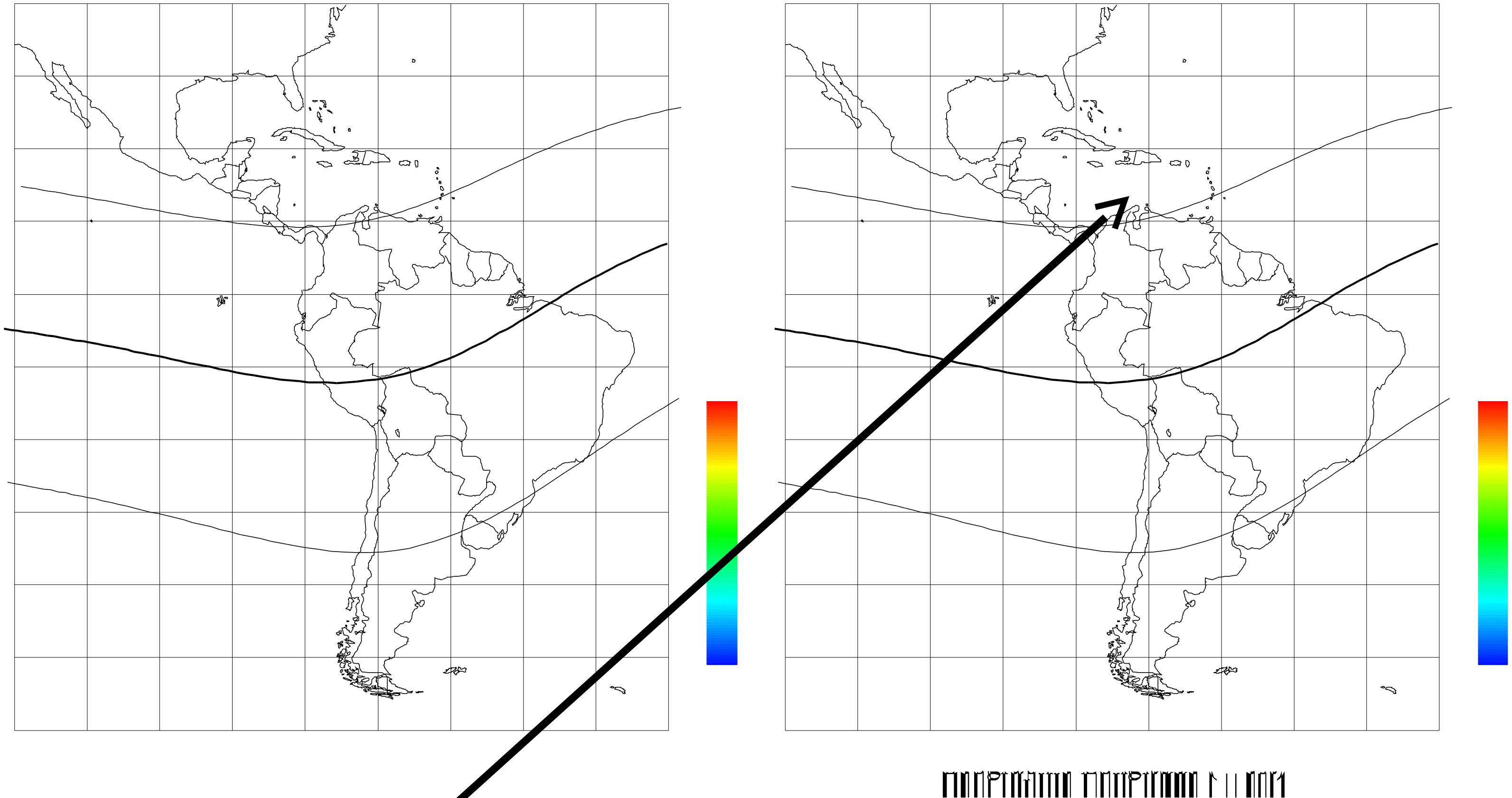


Satellite 08 Path and TEC perturbations at Iquitos



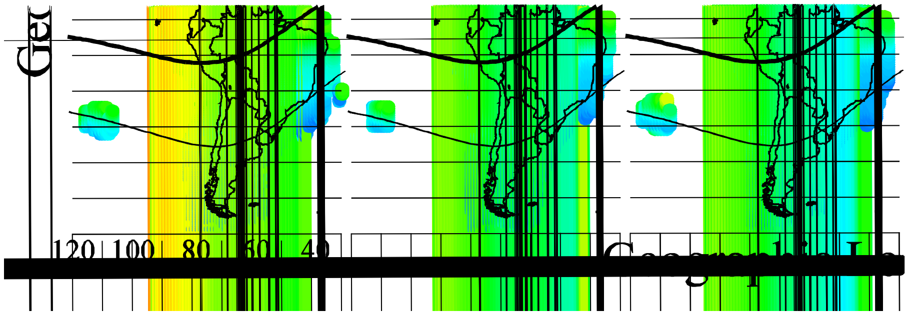


TEC values for July 12, 2011 (quiet conditions)

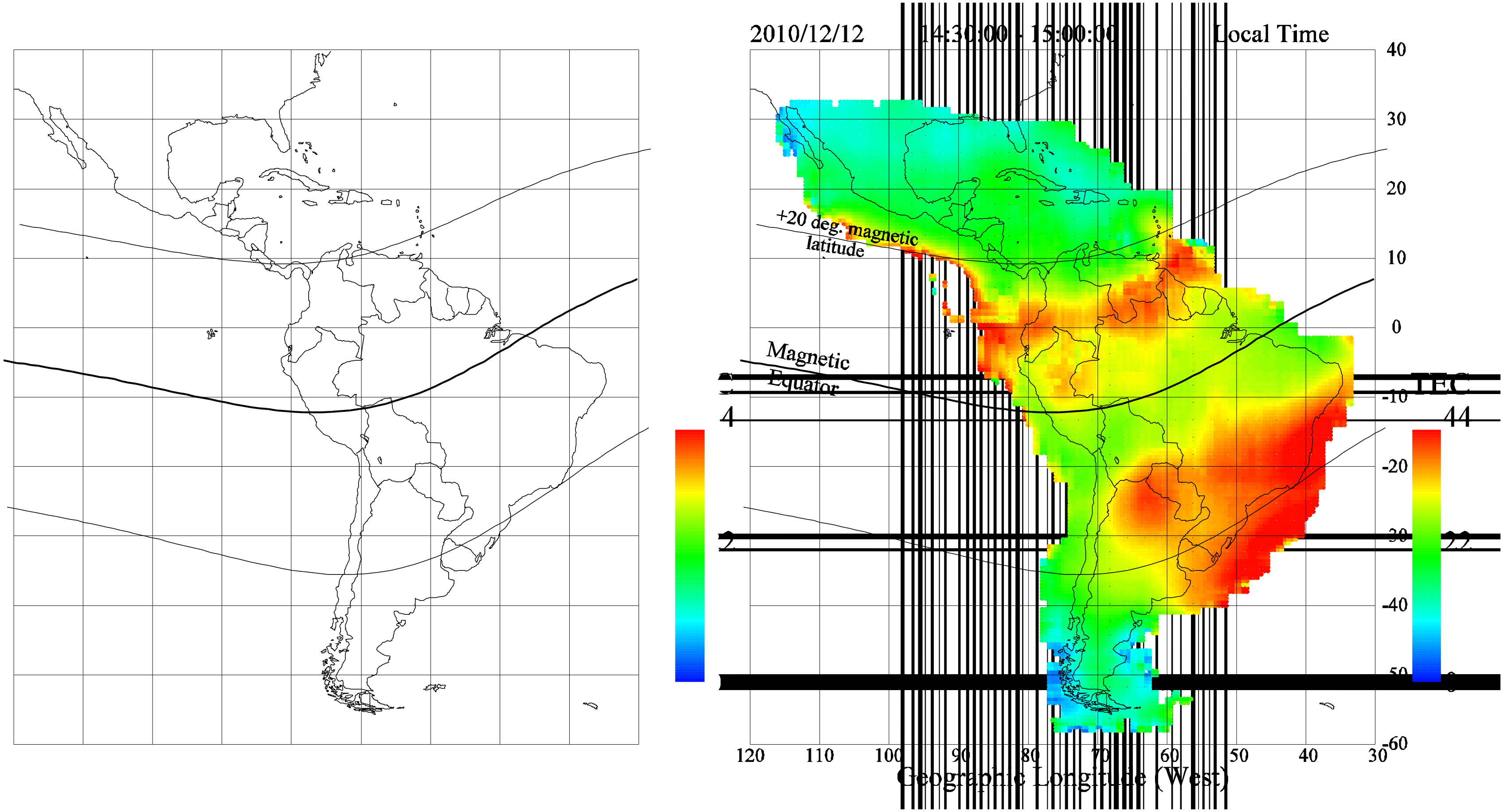


Abrupt termination of TEC enhancement where declination changes

TEC values for June 7, 2011 between 12 and 23 LT.

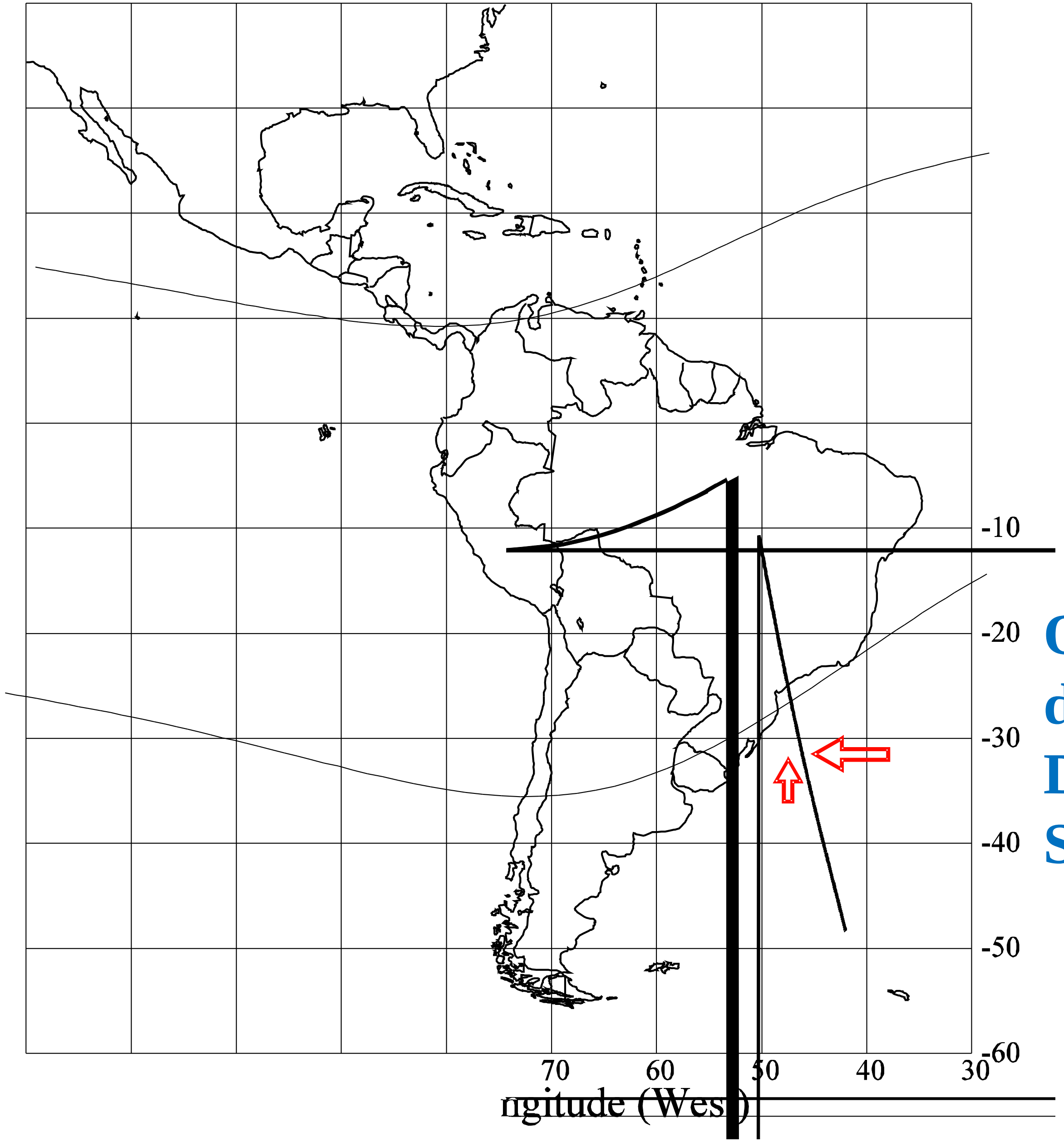


TEC values for December 12, 2011



Wind system associated with tropical TEC enhancement

Operates during the June Solstice



Both the westward & North-south wind move plasma up the field lines.

Operates during the December Solstice

TEC results of the numerical model LLIONS using 90 planes along parallel field lines. One every degree between 120° W and 30° W.

Conclusions

- **Networks of GPS receivers are the best tool to make new discoveries on space weather.**

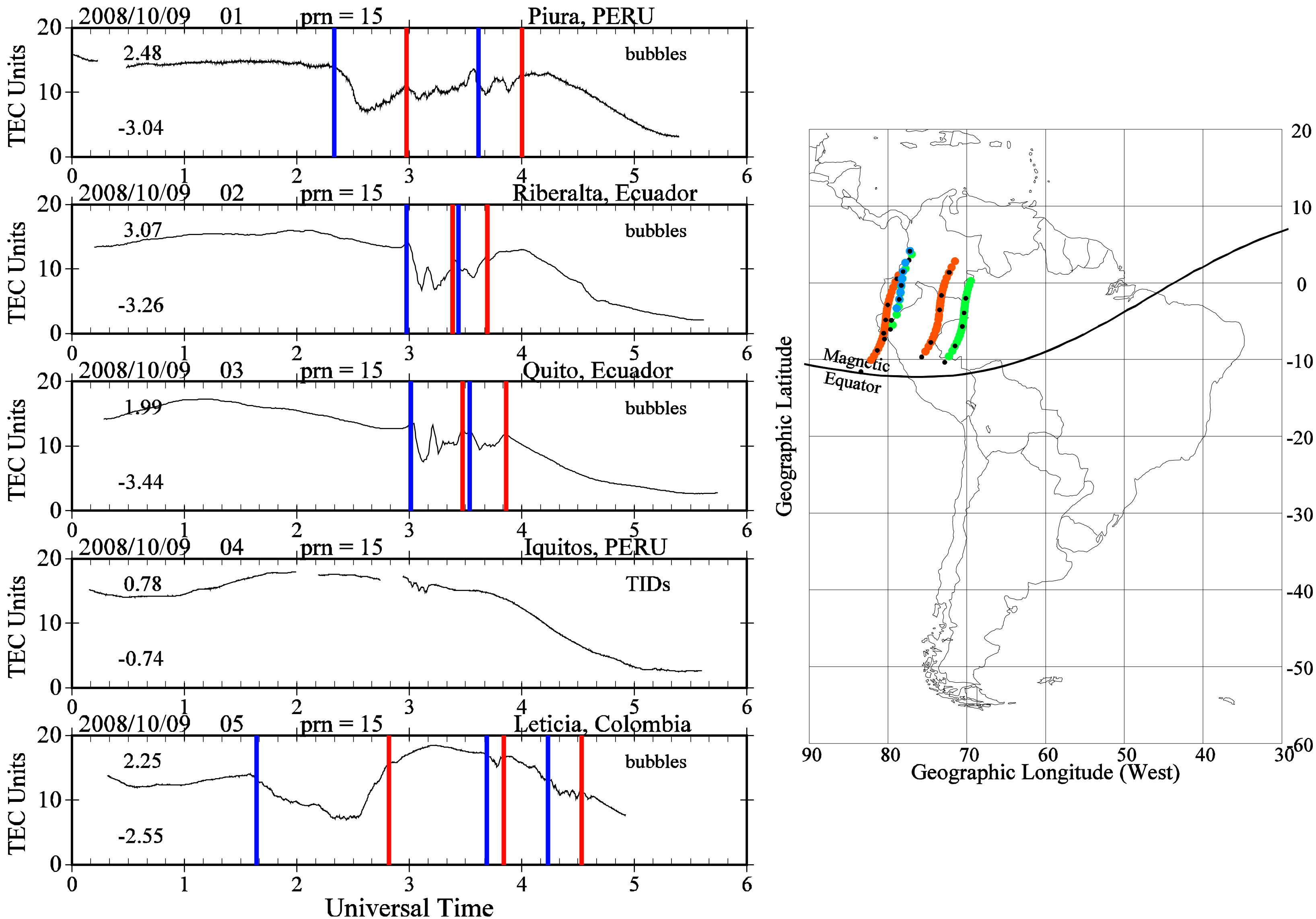
- **TEC values are very variable depending on solar and magnetic conditions.**

- **LISN is a distributed observatory to study some aspect of space weather (plasma bubbles, ESF). It provides regional coverage of the day-to-day variability of the ionosphere over South America.**

CEV's Method

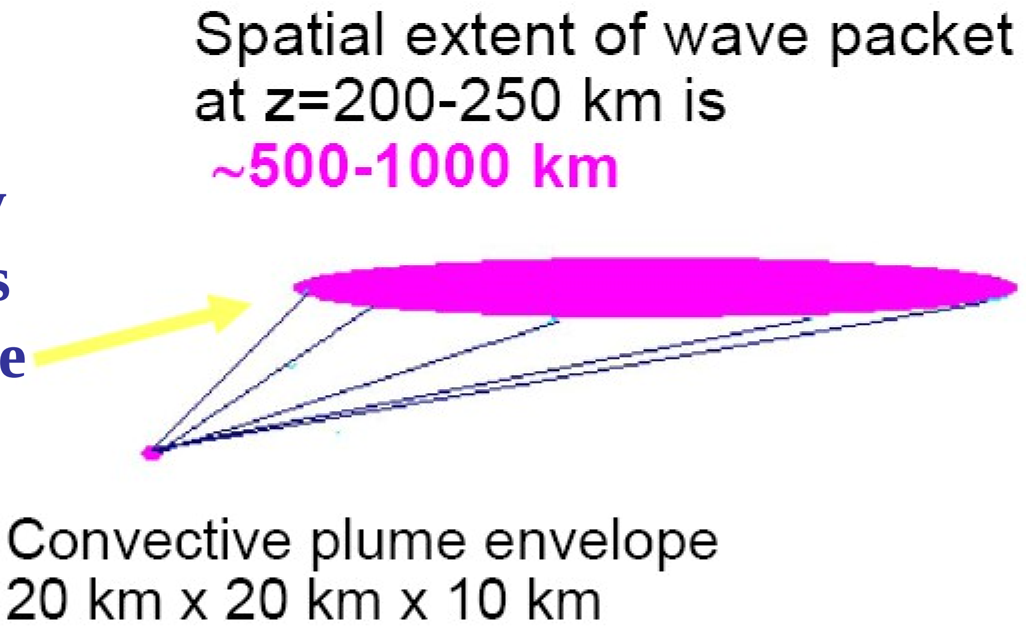
1) **Fit a 4th order polynomial to every 3 hours of TEC data.**
2) **Find the difference between TEC and fitted TEC : dTEC[1].**
3) **Determine cases when dTEC[1] is below a threshold level, say 0.7 TECu.**
4) **Make a second fit to TEC, but avoid periods when dTEC[1] is below the threshold value.**
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.**

TEC depletions seen on 5 stations aligned east-west



Temporal Evolution of a Gravity Wave Packet

Due to wave dispersion, a gravity wave packet spreads out to a large volume in thermosphere.



Gravity Waves move upwards and away from the source region, carrying energy and momentum flux.