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Sensing Space Weather with Distributed Observatories and the Human Network

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Sensing Space Weather with Distributed Observatories and the Human Network

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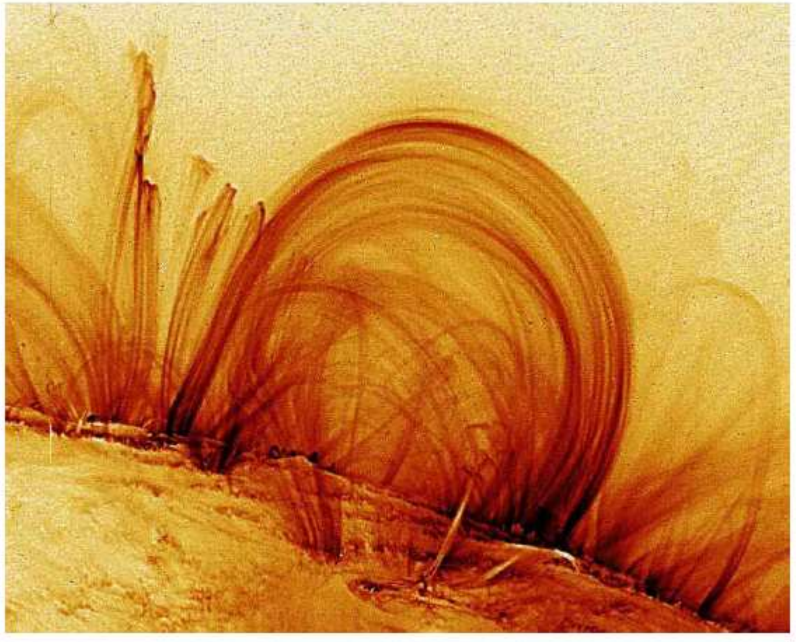
Outline

- Space Weather Definition.
- The Distributed Observatory Concept.
- The LISN observatory. Description of instruments, TEC values, scintillations, ionograms obtained with VIPIR ionosonde, assimilation efforts and campaigns.
- The importance of the Human Network for the success of a distributed observatory.
- Concluding remarks.

Space Weather Definition

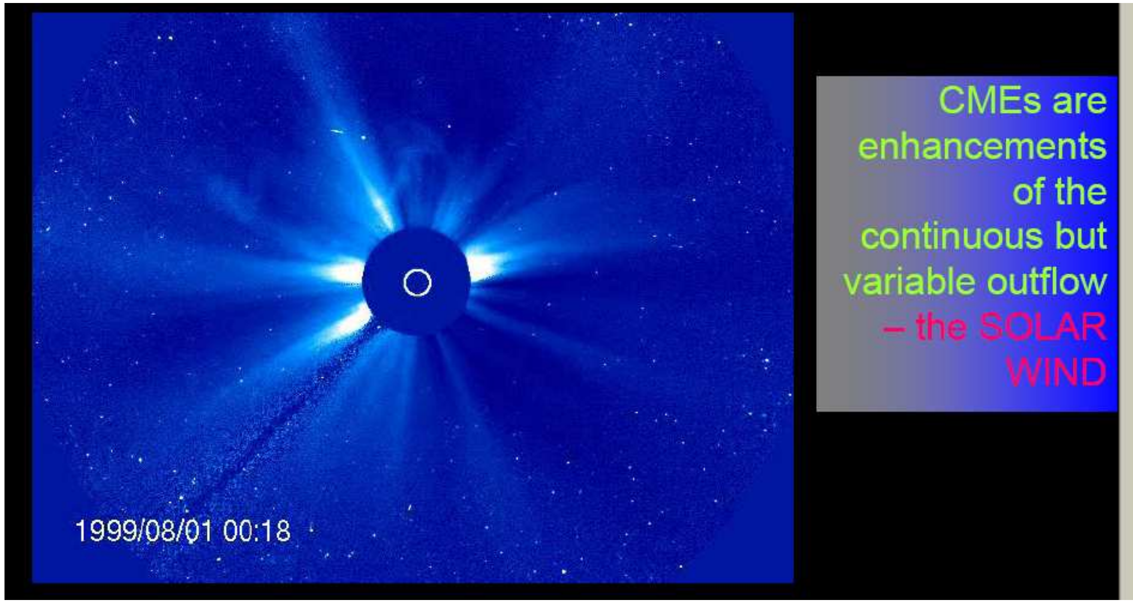
The **NSWP** defines **Space weather** as “the conditions on the Sun and in the solar wind, magnetosphere, ionosphere and thermosphere that can influence the performance and reliability of space-borne and ground-based technological systems and can endanger human life or health.”



Solar Magnetic Fields and Variability

Physical Processes Associated with Space Weather

Coronal Mass Ejections and their associated shock waves are drivers of space weather as they can compress the magnetosphere and trigger geomagnetic storms.



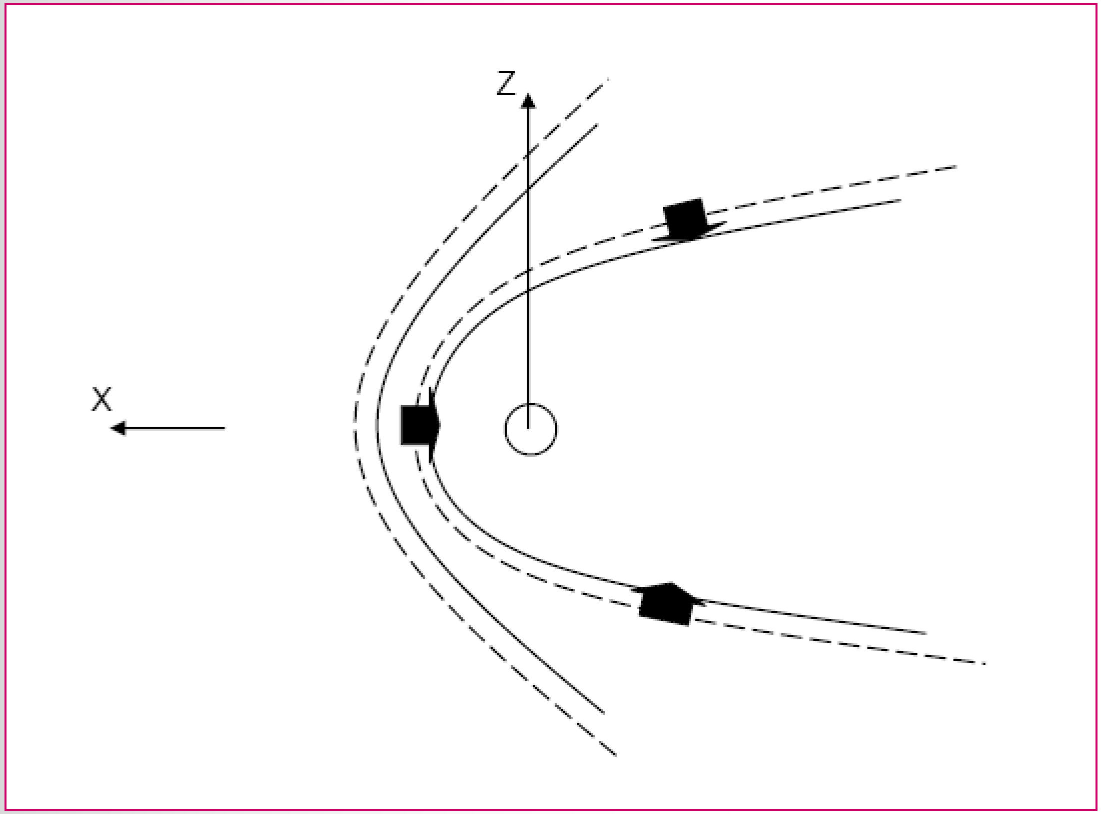
The effects are more pronounced where the Earth's magnetic field is connected to the interstellar medium (e.g. polar regions). The closed field lines of mid- and low-latitudes protect the ionospheres from many effects.

Coronal Mass Ejections

- sun loses 10^{14} kg per day in total solar wind
- each CME ejects about 10^{13} kg at about 350 km s^{-1}
- on average 1 CME occurs every 4 days at sunspot minimum, but 2 CMEs per day at sunspot maximum
- 1 CME hits Earth every 2 weeks at sunspot minimum, 4 per week at sunspot maximum
- total energy in each CME about 10^{24} J
- at one every 2 days this is 50,000 power stations' worth hitting Earth.

Solar Wind Pressure Changes

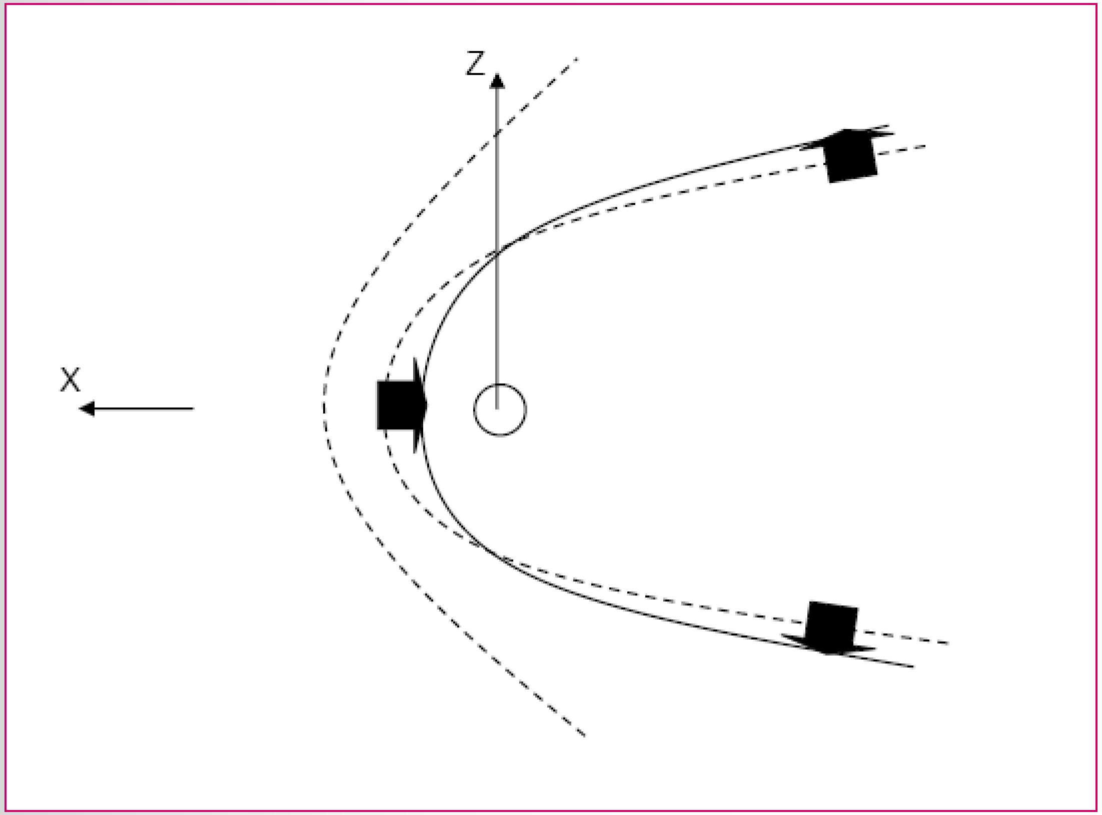
- P_{sw} variations largely caused by changes in N_{sw} (interplanetary number density). An x% rise in N_{sw} in increases both P_{sw} and P_{th} in sw equally



- compresses magnetosphere in a roughly shape-preserving manner

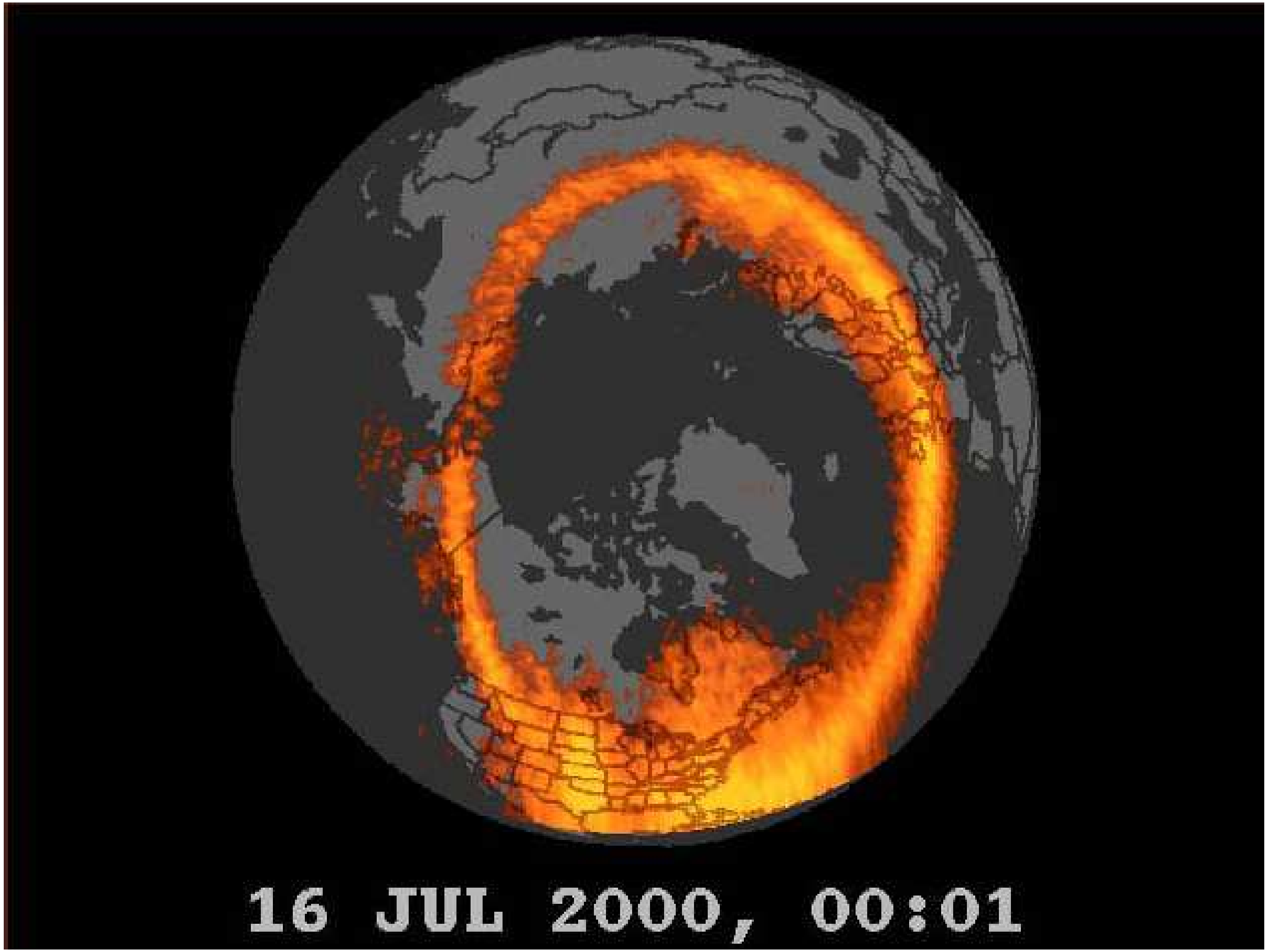
Reconnection Changes

- opened dayside flux is appended to tail. In asymptotic limit $B_{TL}^2/(2\mu_o) = N_{SW}\,k\,T$, so reconnection does not change B_{TL}. Which is constant at constant N_{SW}. But open flux $F_{PC} = N_{SW}\,B_{TL}A_{TL}/2$ so appended extra open flux causes the area of each lobe A_{TL} to rise

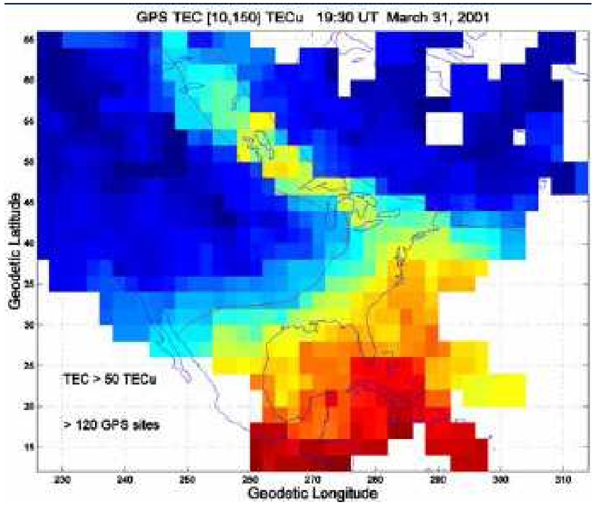


- dayside erodes and tail flares

The Bastille Day Storm, Electron Aurora

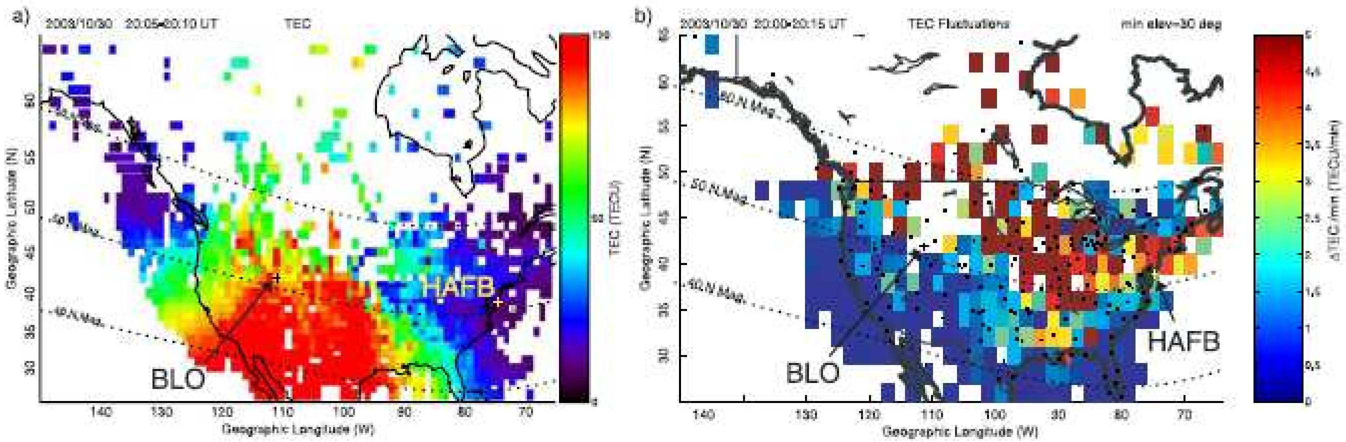


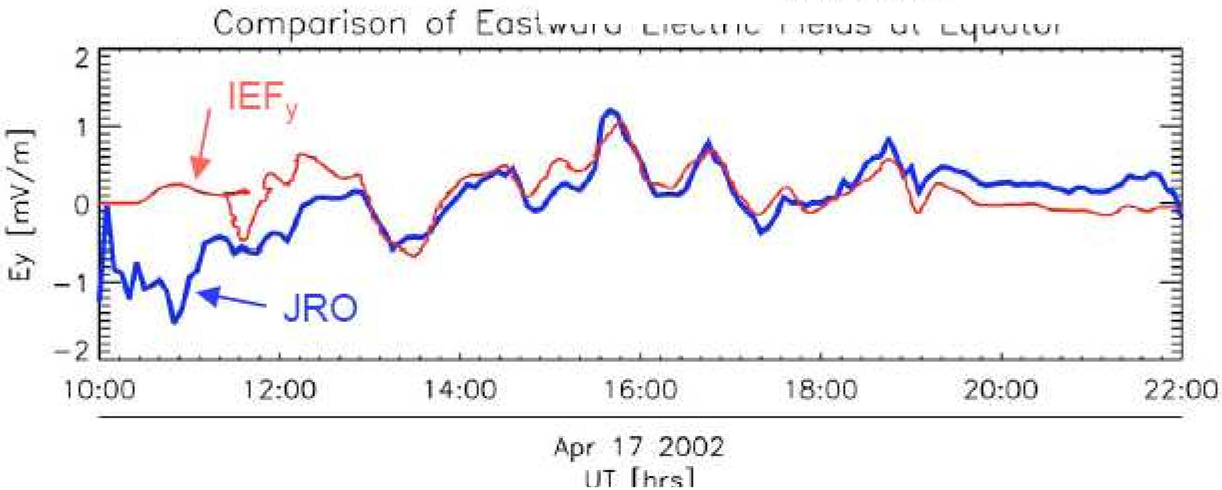
Ionospheric Effects of Geomagnetic Storms



Storm Enhanced densities (SED) entering the polar cap through the dayside convection [Foster et al. 2005].

Extreme gradients produced at mid latitudes and TEC gradients [Basu et al., 2005]





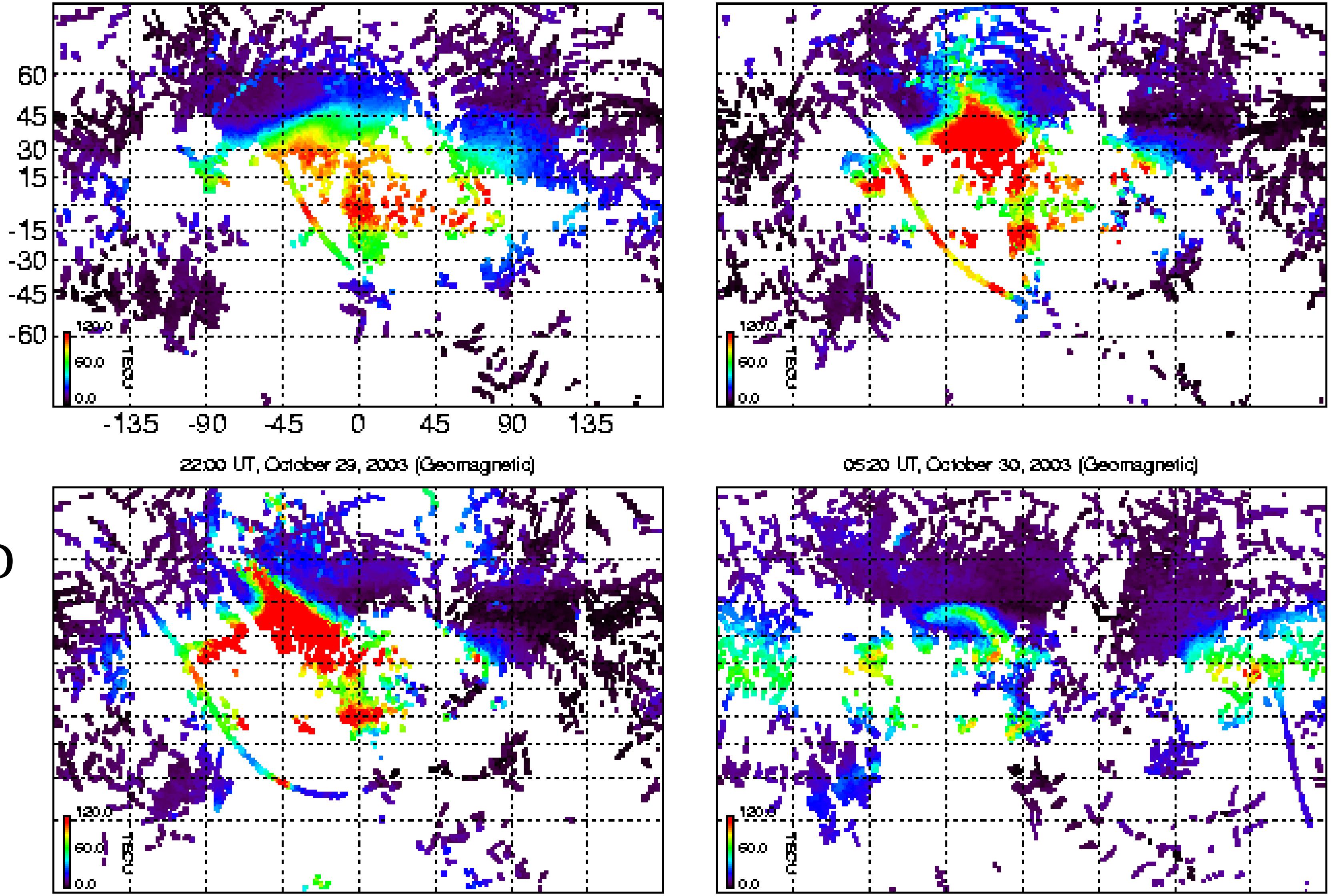
Correlation between interplanetary electric field and drifts measured at Jicamarca.

TEC variability during the Halloween Storm observed at 1810, 2005, 2200, and 0520 UT

1810 UT **2005 UT**

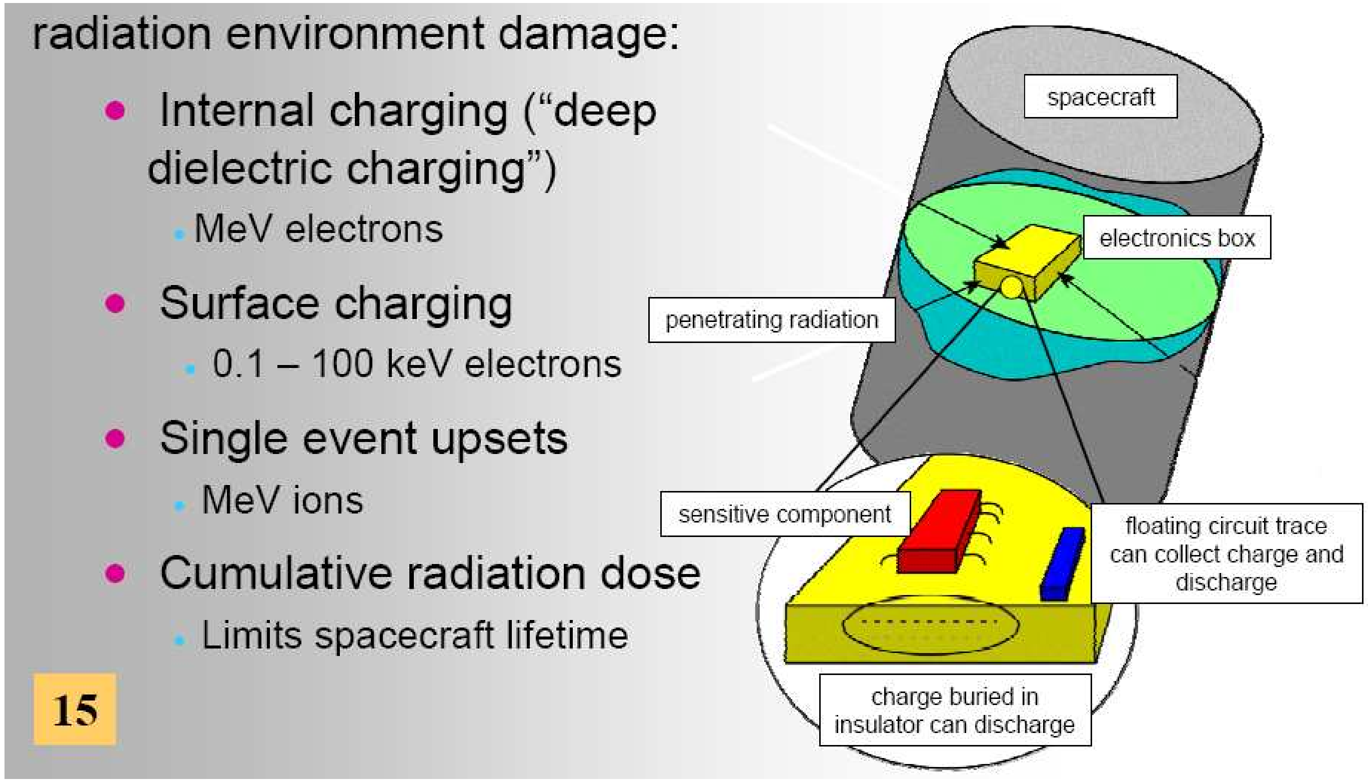
SED

SED



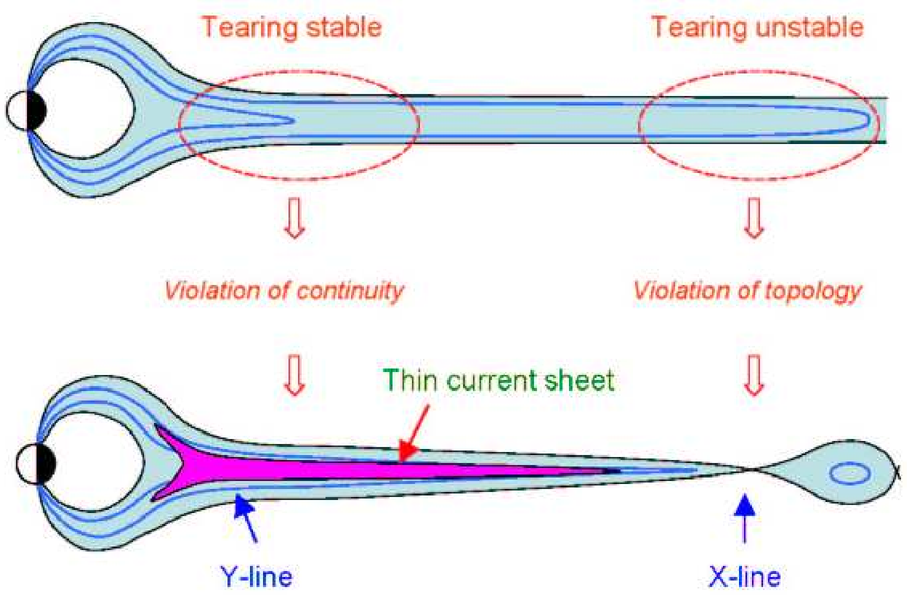
Physical Processes Associated with Space Weather

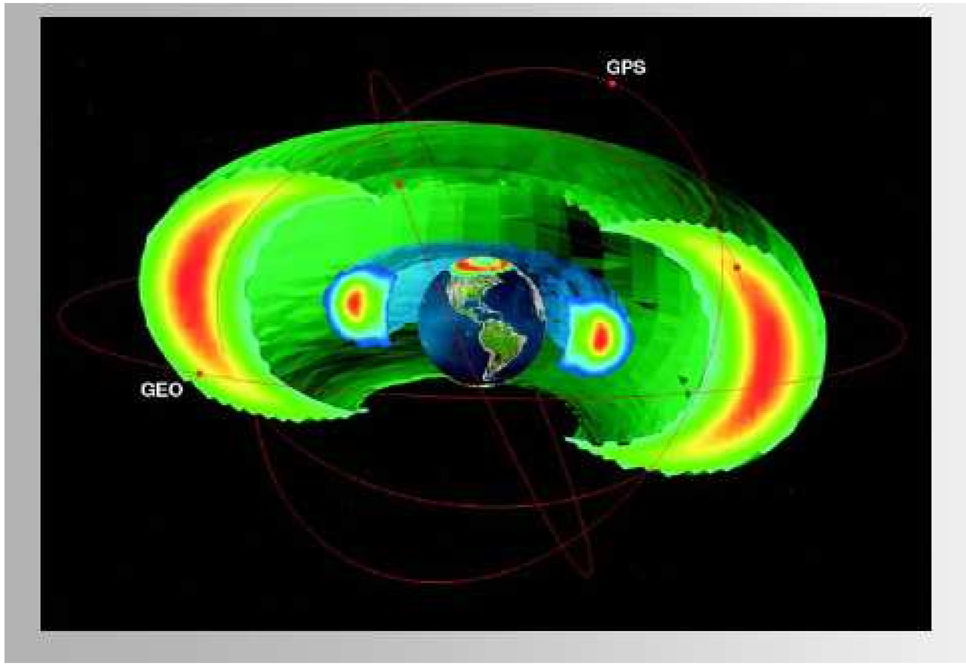
Solar Energetic Particles, accelerated by coronal mass ejections or solar flares, are also an important driver of space weather as they can damage electronics onboard spacecraft through induced electric currents.



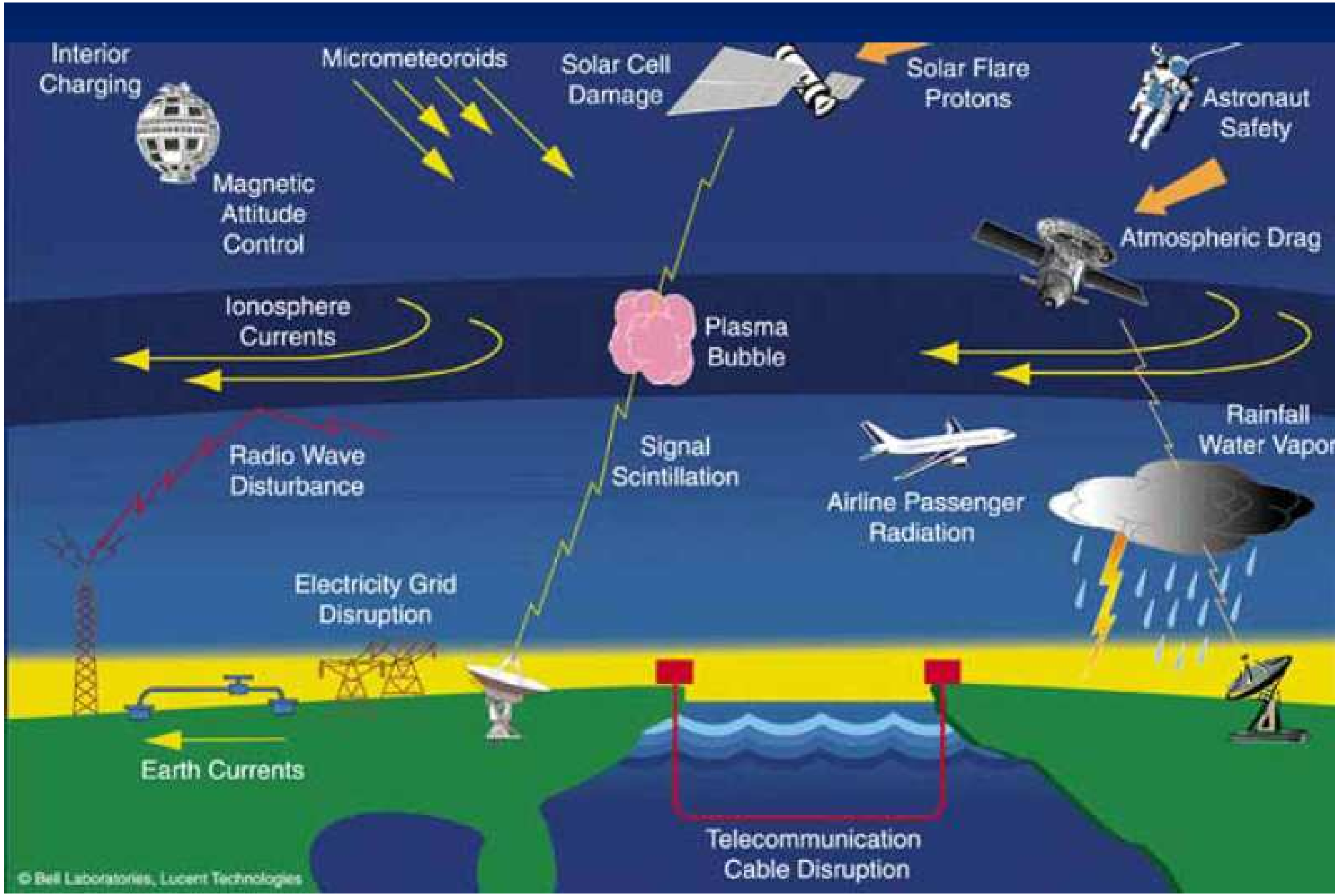
Physical Processes Associated with Space Weather

Other phenomena associated with space weather include: geomagnetic storms and substorms, energization of the Van Allen radiation belts, ionospheric disturbances and scintillation, aurora and geomagnetically induced currents at Earth's surface.





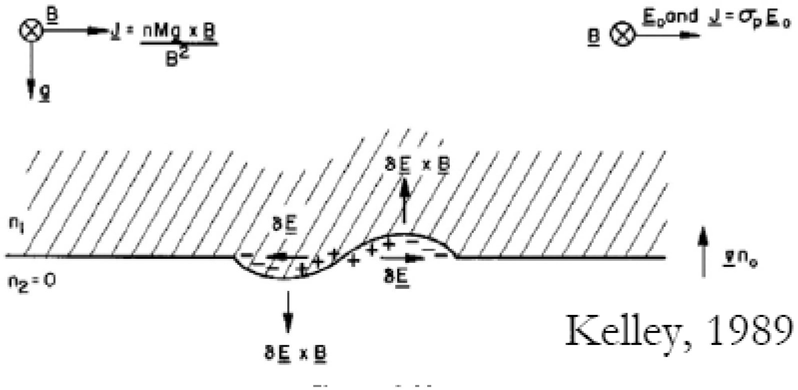
Near Earth Space Weather Events



Influences from within

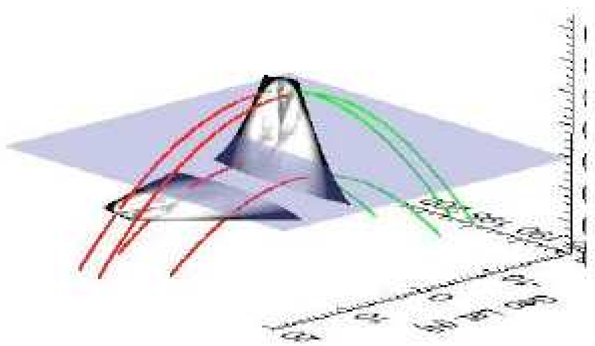
- The dense density near the F-region peak is supported against gravity by a horizontal magnetic field resulting in a “heavy fluid” on a “light fluid”.

- A small perturbation in the interface generates an electric field
  - $\delta\mathbf{E}\times\mathbf{B}$ pushes the interface further up

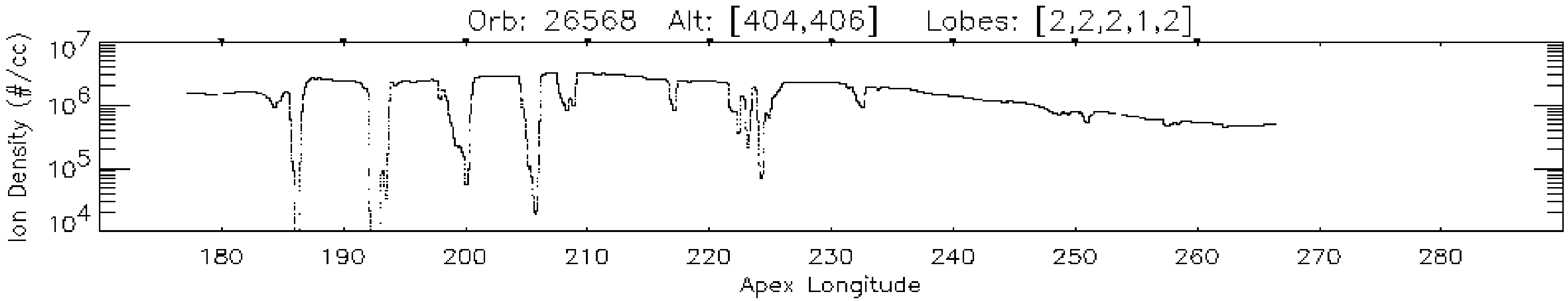


- Radio waves passing through the irregularities diffract producing signal fading and strong scintillations even at L frequencies.

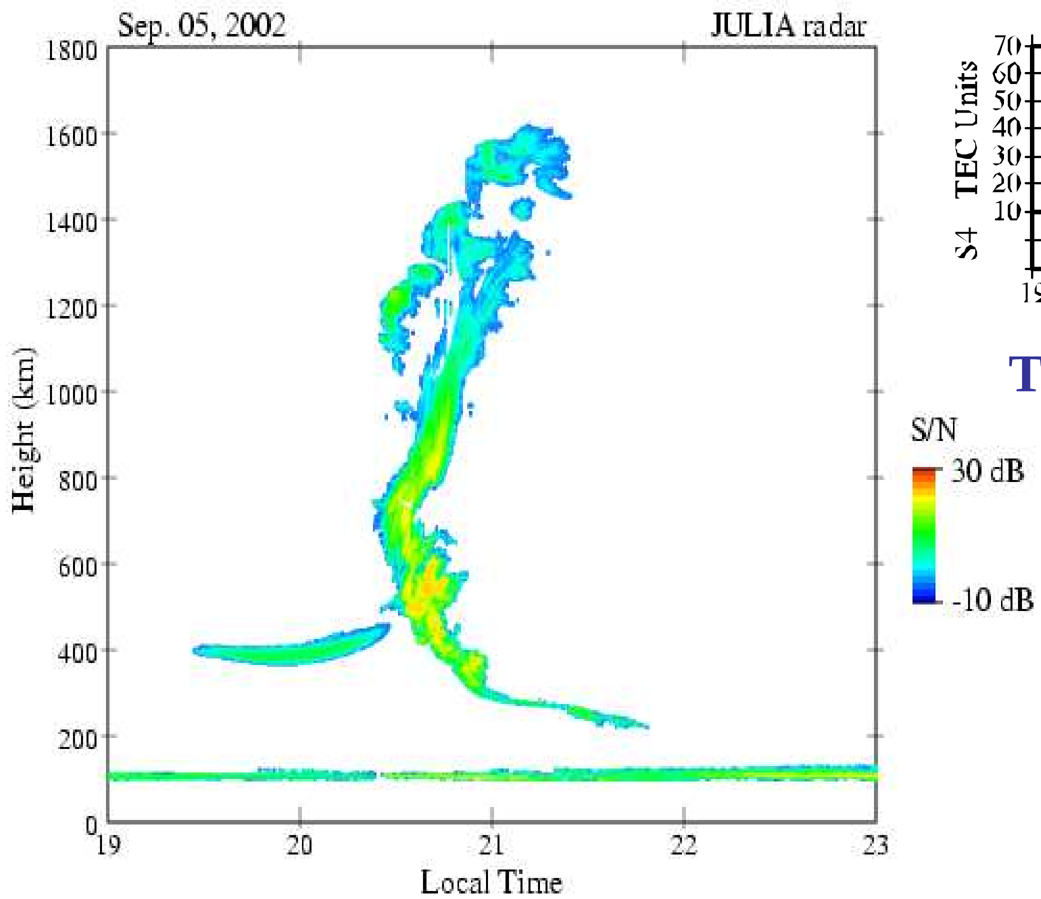
- Must know what is going on along the entire field line to understand all the physics.



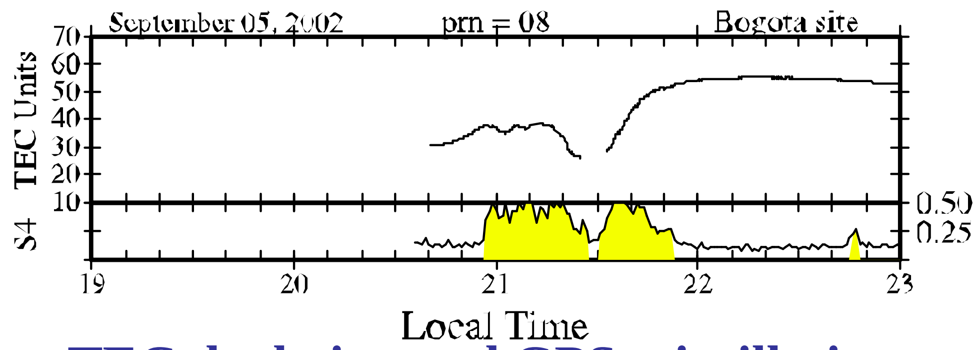
Plasma Bubbles observations using different techniques



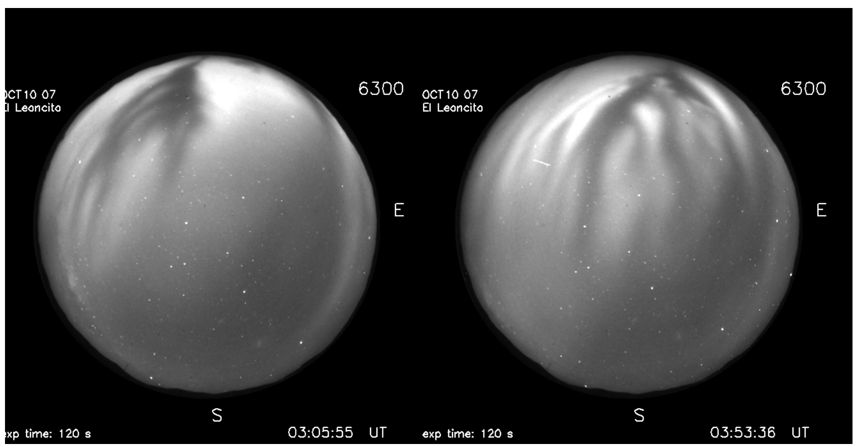
Satellite



Coherent radar



TEC depletion and GPS scintillations



Airglow imager

Formation Mechanisms of Plasma Bubbles

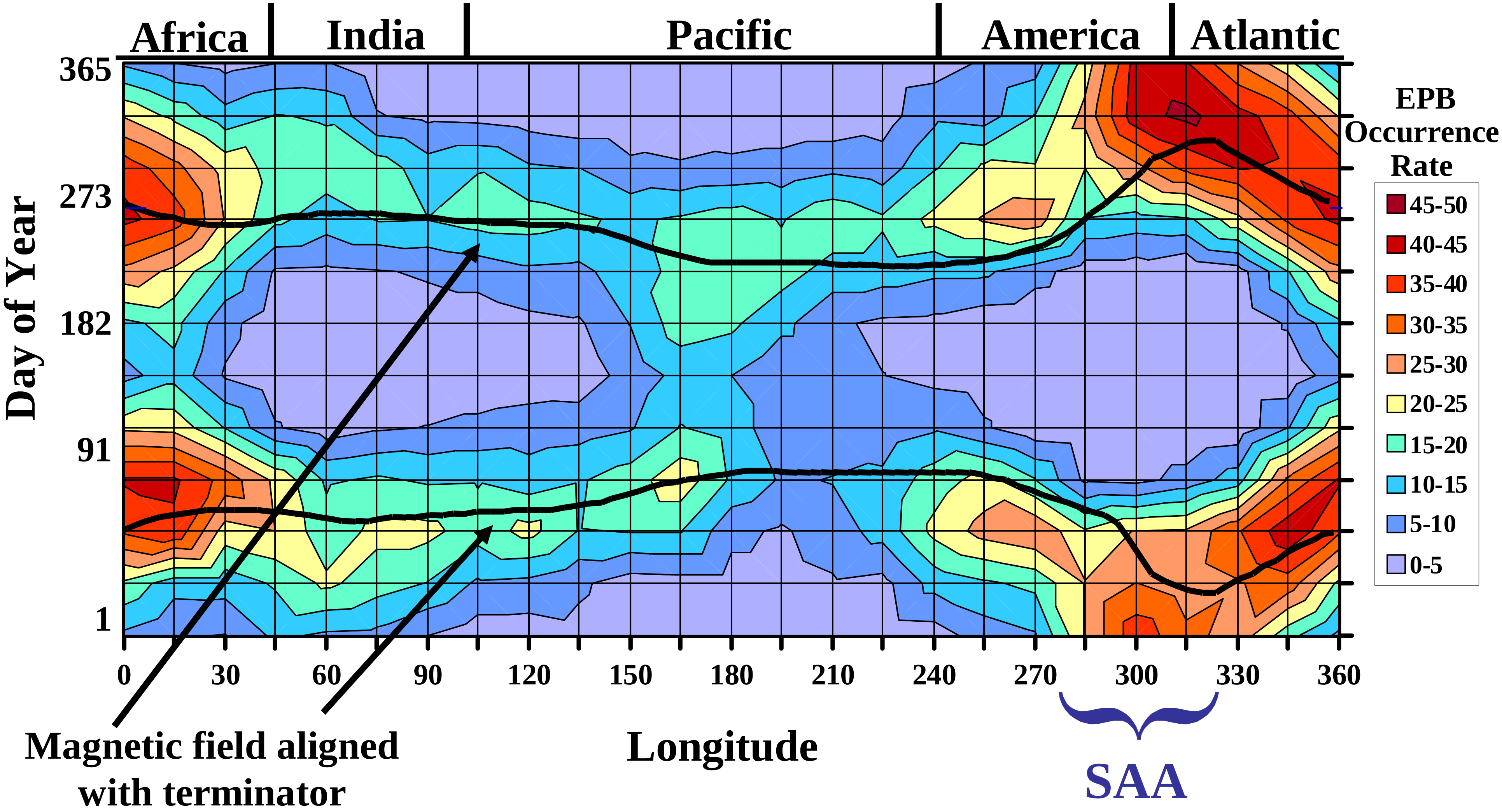
Rayleigh-Taylor instability seeded by Gravity waves [Rottger, 1973; Kelley et al., 1981; Singh et al., 1997].

Large Scale Wave Structure (LSWS): An altitude-modulated sporadic E (E_s) layer produces an electric field that maps to the F region, raising the layer and helping trigger plasma bubbles [Tsunoda, 2005, 2006].

Wind-driven gradient drift instability [Kudeki et al., 2007]. This theory suggest the development of westward tilted wave-fronts resulting in wave-vectors tilted 45º that become unstable by a large zonal wind.

Collisional Shear Instability: large scale waves (>100 km) are created by this instability that seed the bubbles [Hysell and Kudeki, 2004].

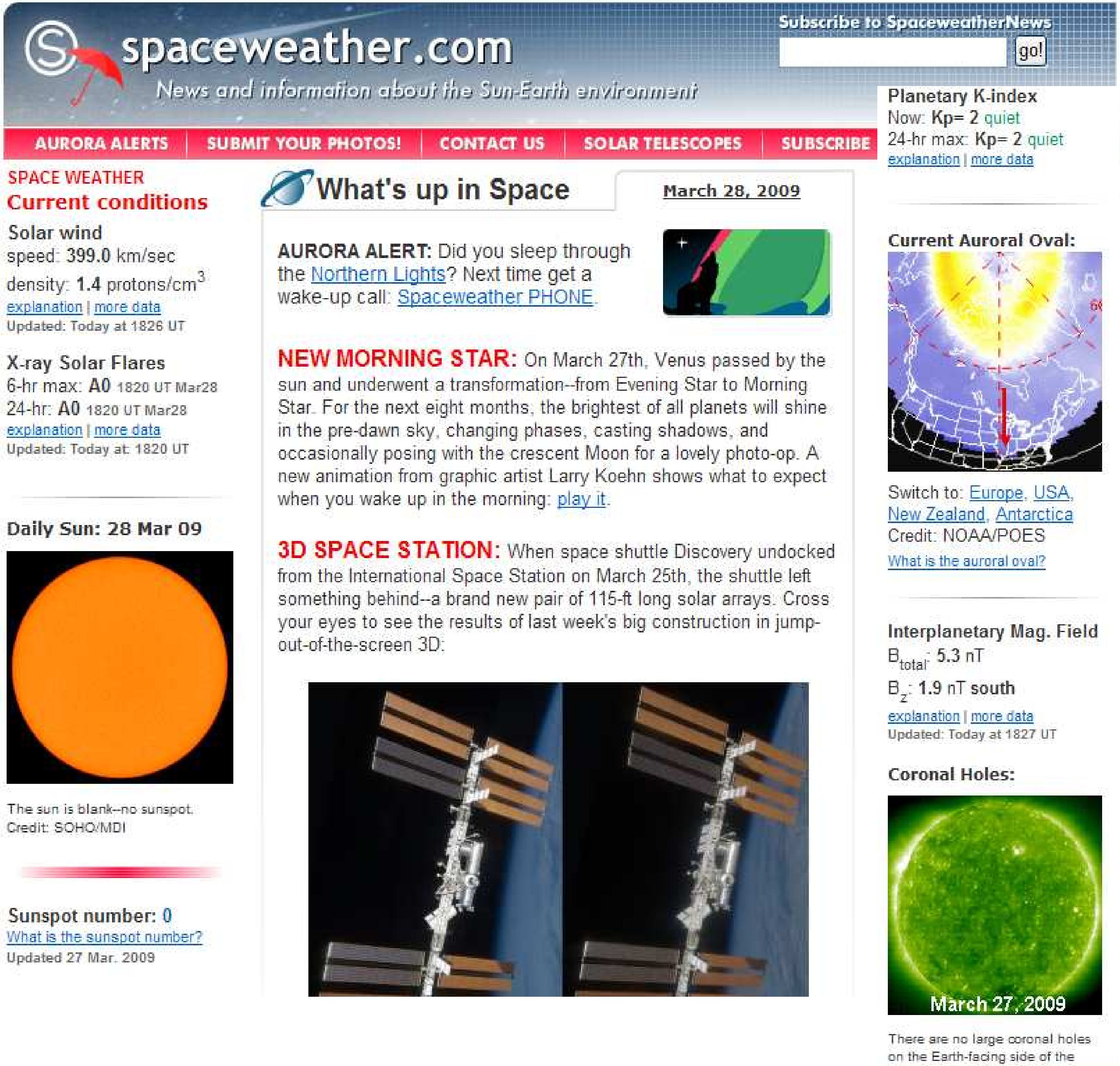
DMSP EPBs 1989 – 2002



Solar-cycle averaged monthly rates of equatorial plasma bubbles encounter by DMSP (8300 bubbles). Longitudinal variability at 75º W due to radiation belt precipitation that can enhance Σ_E and lower growth rate.

Burke et al., Annales Geophys, 2004

http://www.spaceweather.com/



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SPACE WEATHER

Current conditions

Solar wind

speed: **399.0** km/sec

density: **1.4** protons/cm^3

explanation | more data

Updated: Today at 1826 UT

X-ray Solar Flares

6-hr max: **A0** 1820 UT Mar28

24-hr: **A0** 1820 UT Mar28

explanation | more data

Updated: Today at: 1820 UT

Daily Sun: 28 Mar 09

The sun is blank--no sunspot.

Credit: SOHO/MDI

Sunspot number: 0

What is the sunspot number?

Updated 27 Mar. 2009

What's up in Space

March 28, 2009

AURORA ALERT: Did you sleep through the Northern Lights? Next time get a wake-up call: Spaceweather PHONE.

NEW MORNING STAR: On March 27th, Venus passed by the sun and underwent a transformation--from Evening Star to Morning Star. For the next eight months, the brightest of all planets will shine in the pre-dawn sky, changing phases, casting shadows, and occasionally posing with the crescent Moon for a lovely photo-op. A new animation from graphic artist Larry Koehn shows what to expect when you wake up in the morning: play it.

3D SPACE STATION: When space shuttle Discovery undocked from the International Space Station on March 25th, the shuttle left something behind--a brand new pair of 115-ft long solar arrays. Cross your eyes to see the results of last week's big construction in jump-out-of-the-screen 3D:

Planetary K-index

Now: **Kp= 2** quiet

24-hr max: **Kp= 2** quiet

explanation | more data

Current Auroral Oval:

Switch to: Europe, USA, New Zealand, Antarctica

Credit: NOAA/POES

What is the auroral oval?

Interplanetary Mag. Field

B_{total}: 5.3 nT

B_z: **1.9** nT **south**

explanation | more data

Updated: Today at 1827 UT

Coronal Holes:

March 27, 2009

There are no large coronal holes on the Earth-facing side of the

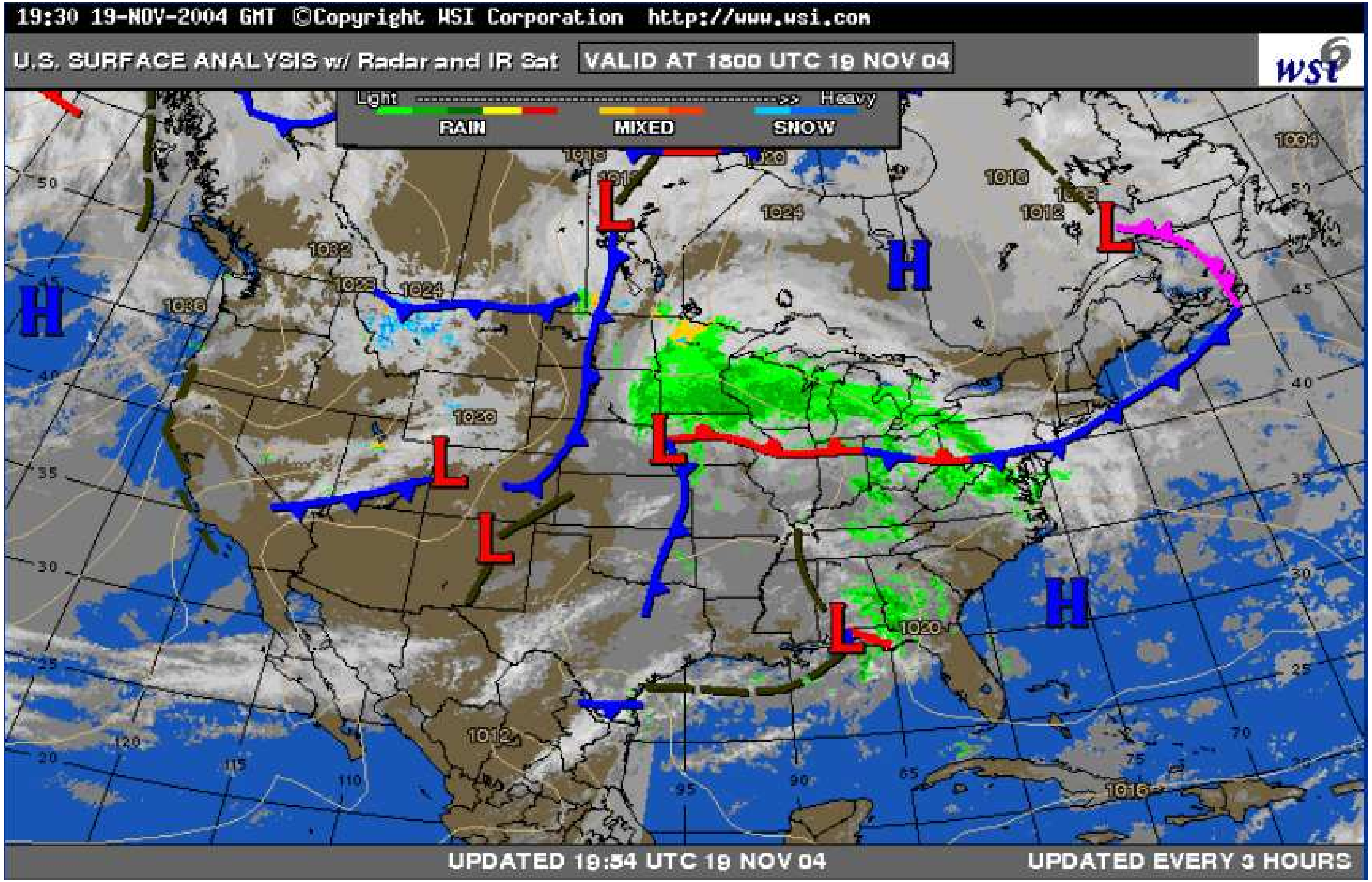
From: "SpaceWeather.com" <swlist@spaceweather.com>**Subject:** Solar Minimum is a Big Event**Date:** Thu, 02 Apr 2009 15:49:00 -0600**To:** "SpaceWeather.com" <swlist@spaceweather.com>view source Space Weather News for April 2, 2009 http://spaceweather.com

SPOTLESS SUNS: Yesterday, NASA announced that the sun has plunged into the deepest solar minimum in nearly a century. Sunspots have all but vanished and consequently the sun has become very quiet. In 2008, the sun had no spots 73% of the time, a 95-year low. In 2009, sunspots are even more scarce, with the "spotless rate" jumping to 87%. We are currently experiencing a stretch of 25 continuous days uninterrupted by sunspots--and there's no end in sight.

This is a big event, but it is not unprecedented. Similarly deep solar minima were common in the late-19th and early-20th centuries, and each time the sun recovered with a fairly robust solar maximum. That's probably what will happen in the present case, although no one can say for sure. This is the first deep solar minimum of the Space Age, and the first one we have been able to observe using modern technology. Is it like others of the past? Or does this solar minimum have its own unique characteristics that we will discover for the first time as the cycle unfolds? These questions are at the cutting edge of solar physics.

You can monitor the progress of solar minimum with a new "Spotless Days Counter" on spaceweather.com. Instead of counting sunspots, we're counting no sunspots. Daily updated totals tell you how many spotless days there have been in a row, in this year, and in the entire solar cycle. Visit http://spaceweather.com for data.

Tropospheric Weather Displays



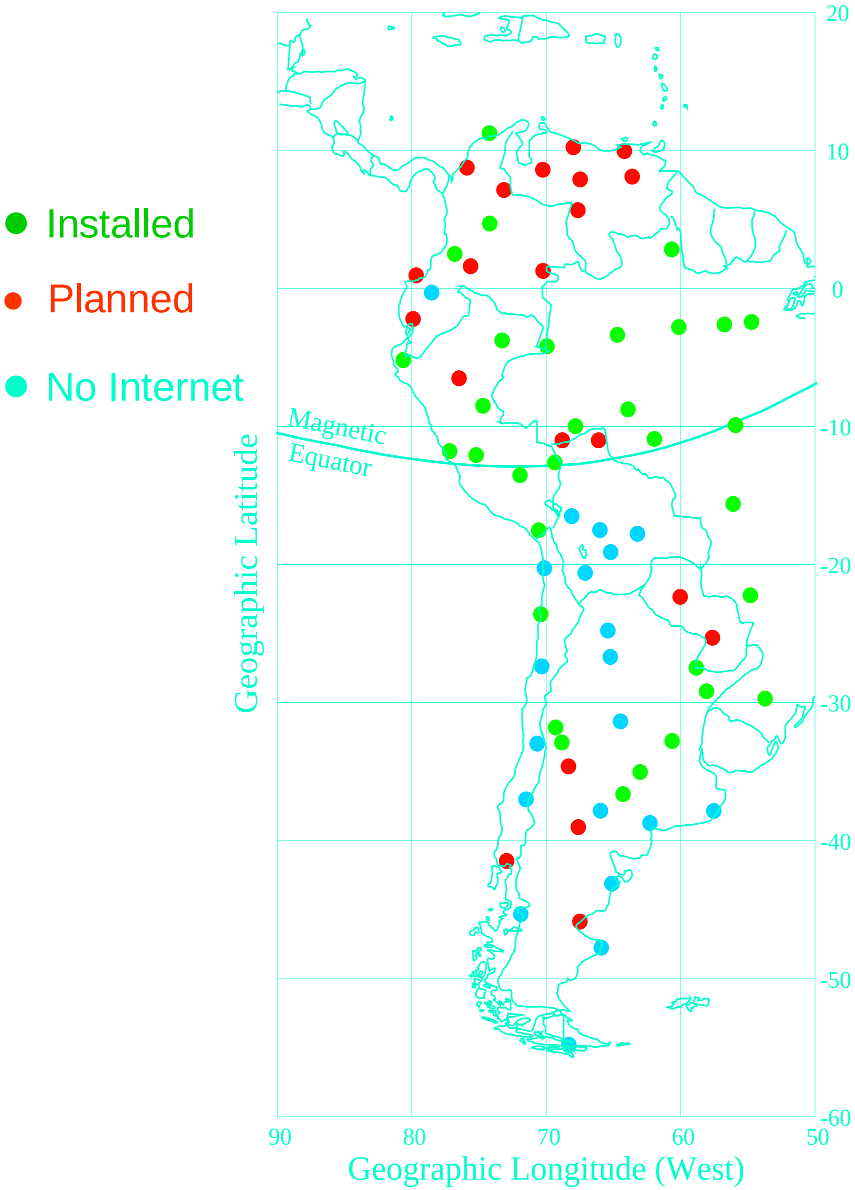
- **The Distributed Observatory Concept.**

  Large number of coordinated ground-based arrays of small instruments whose individual field of view can be integrated to provide spatial coverage and resolution needed to address space physics processes and space weather effects.

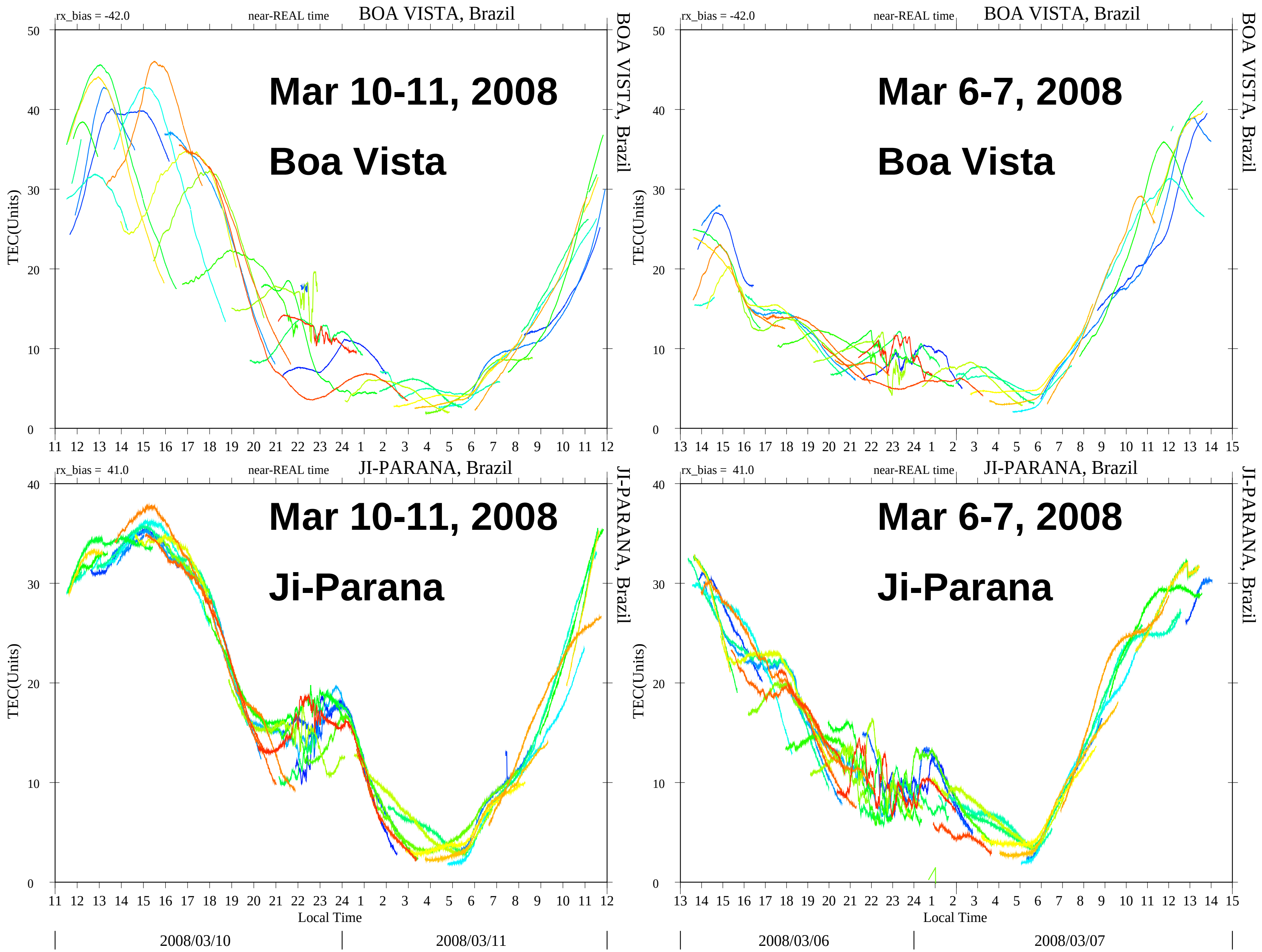
- **The LISN Observatory was designed to:**

1. **do continuous measurements of TEC and scintillations using GPS, and densities using VIPIR ionosondes.**
2. **Provide a nowcast of TEC, S4 index, and other derived parameters.**
3. **Equipped with assimilation tools to conduct research investigations of the low-latitude ionosphere.**

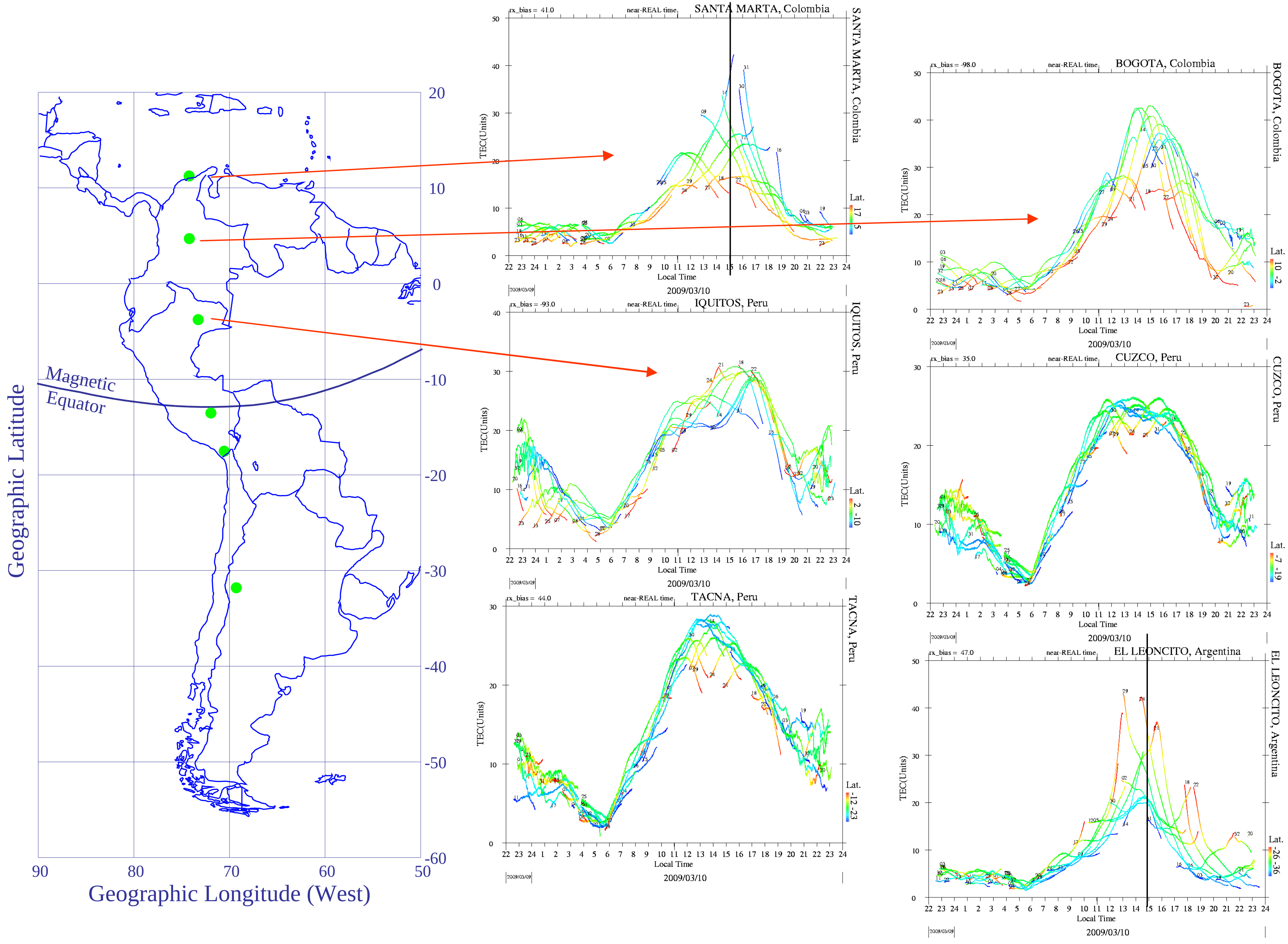
The Low Latitude Ionospheric Sensor Network (LISN)



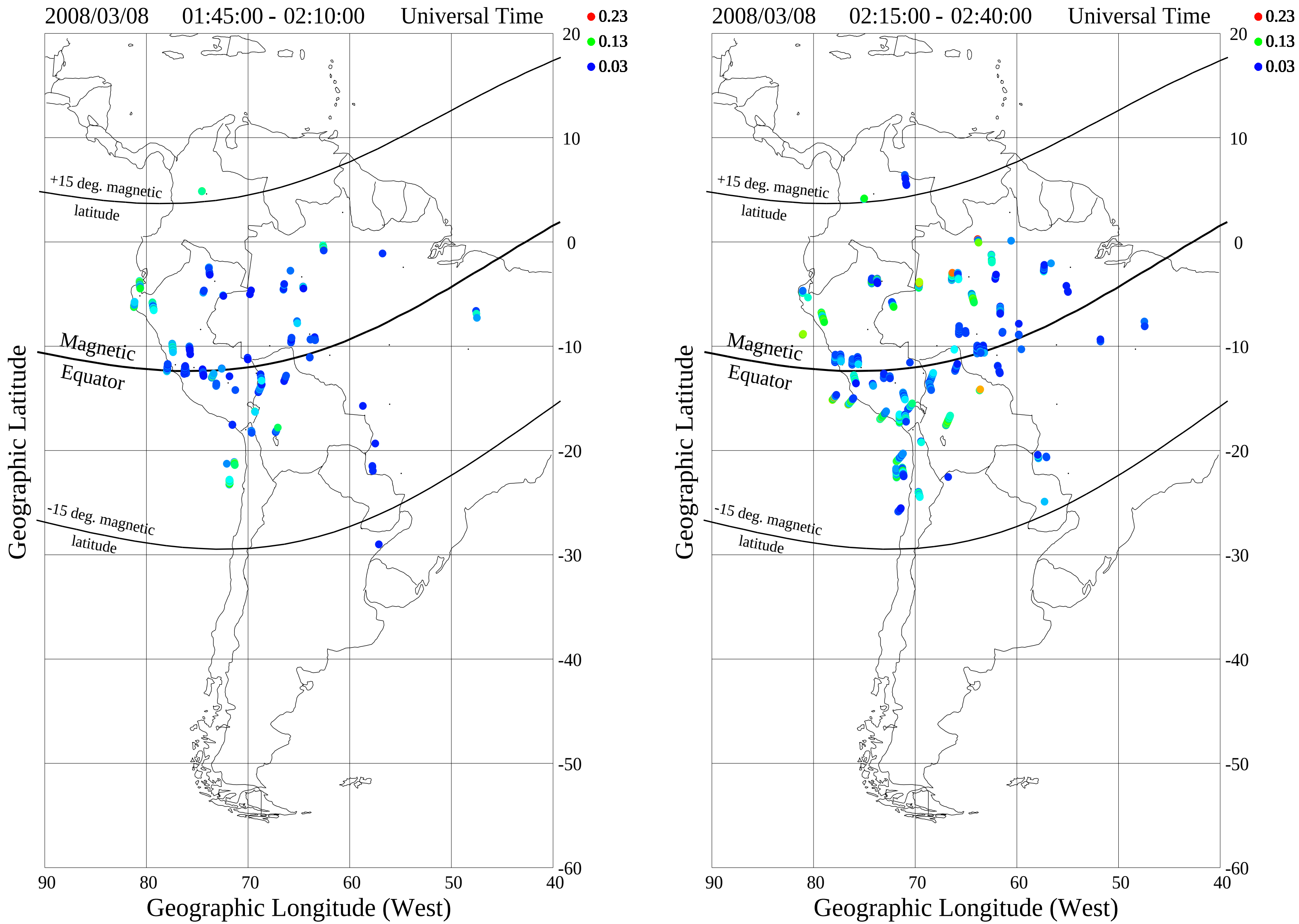
TEC Values Observed near the Crest (BoaVista) and Magnetic Equator (Ji-Parana)



TEC Values Observed along a Field Line



S4 Scintillation Index observed in SA on March 08, 2008



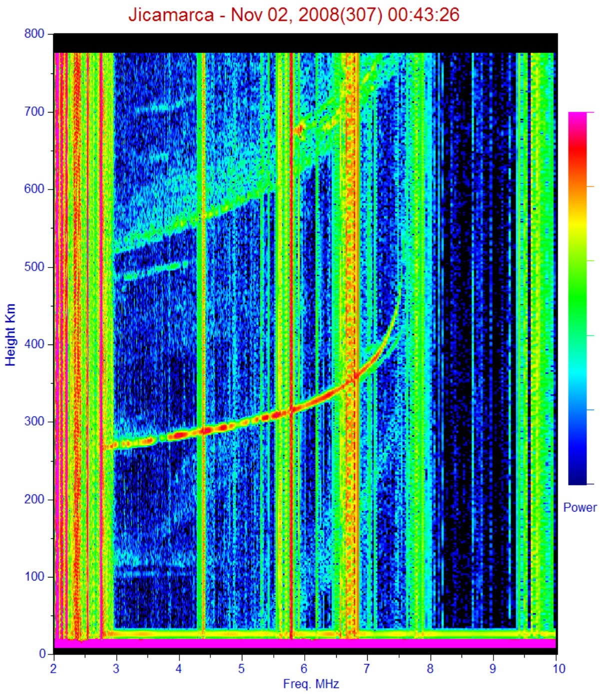
New bubble formation seen at 60° W

VIPIR Ionosonde, (Bullett, Livingston, and Grubb)

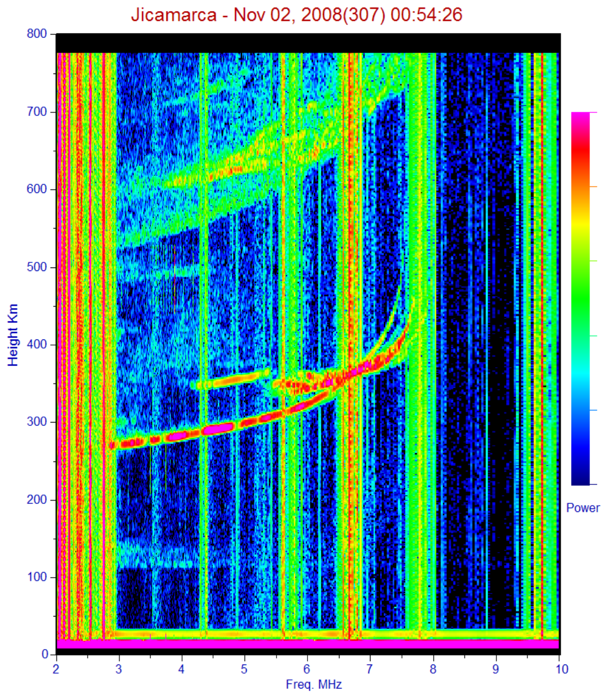
Vertical Incidence Pulsed Ionospheric Radar (VIPIR)
Designed for extreme performance and flexibility
8 Receiving Antennas – dipoles (4 N/S and 4 E/W)
4 Transmitting Antenna towers (Log periodic)

Jicamarca Field Site

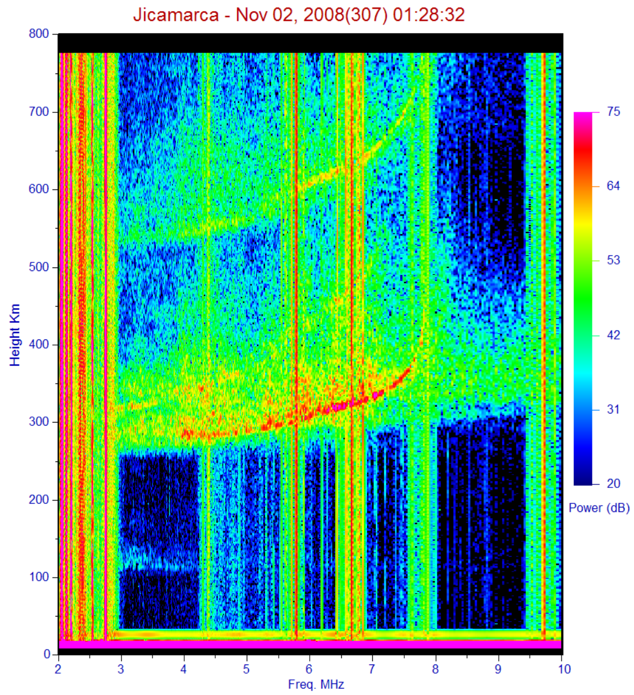
High Resolution ionograms (6 Seconds) during the development of ESF near 8 pm LT on November 02



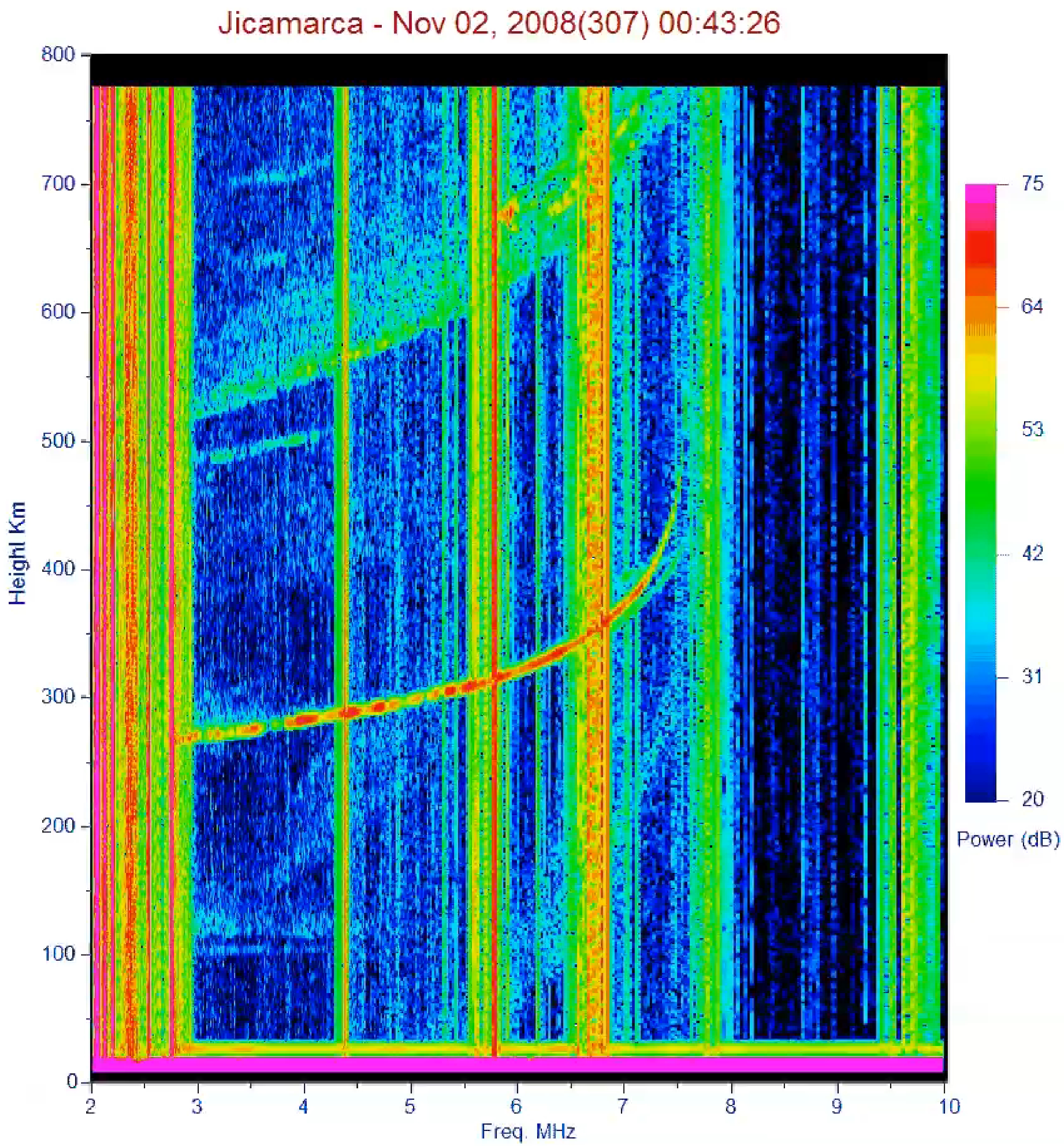
004326 UT



005426 UT

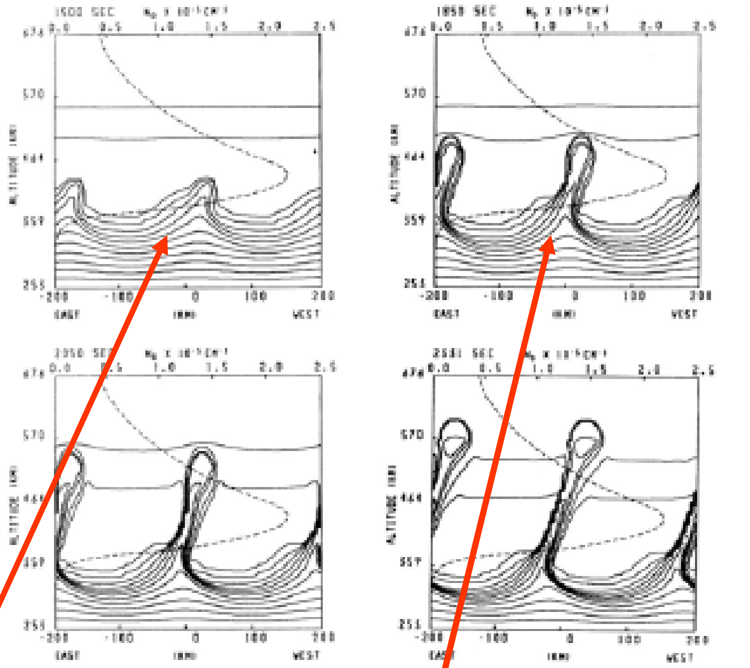


012832 UT

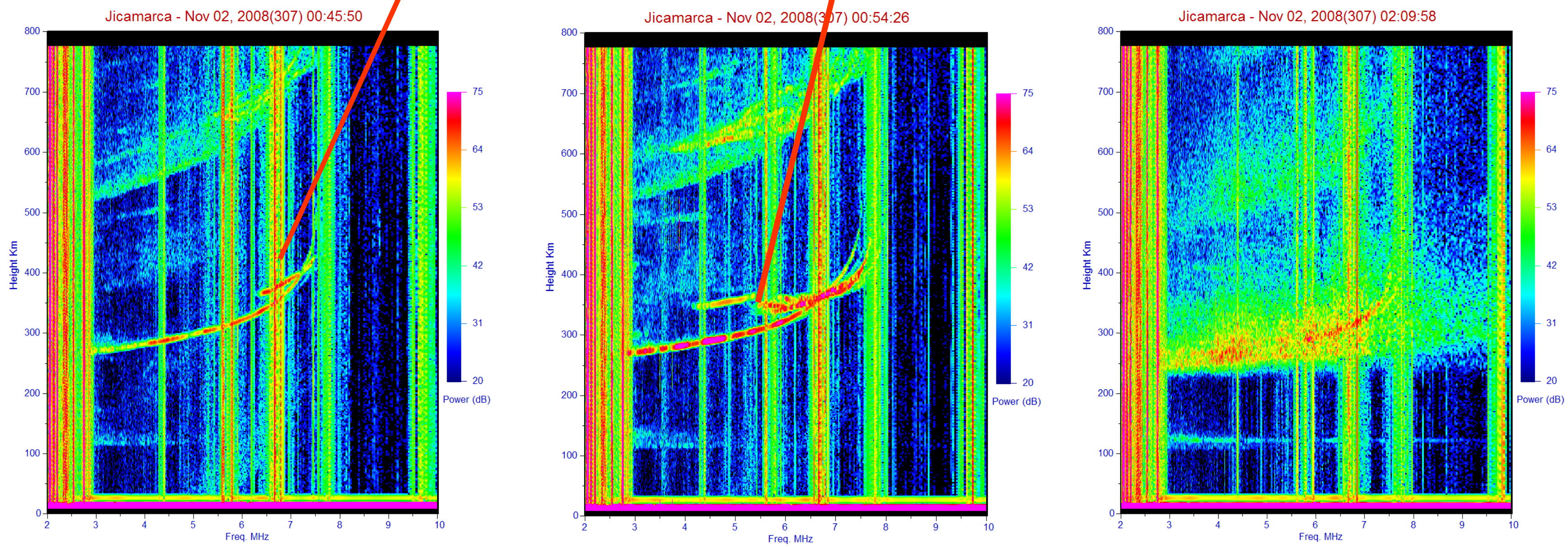

Jicamarca - Nov 02, 2008(307) 00:43:26
Height Km
800
700
600
500
400
300
200
100
0
2
3
4
5
6
7
8
9
10
Freq. MHz
75
64
53
42
31
20
Power (dB)

movie

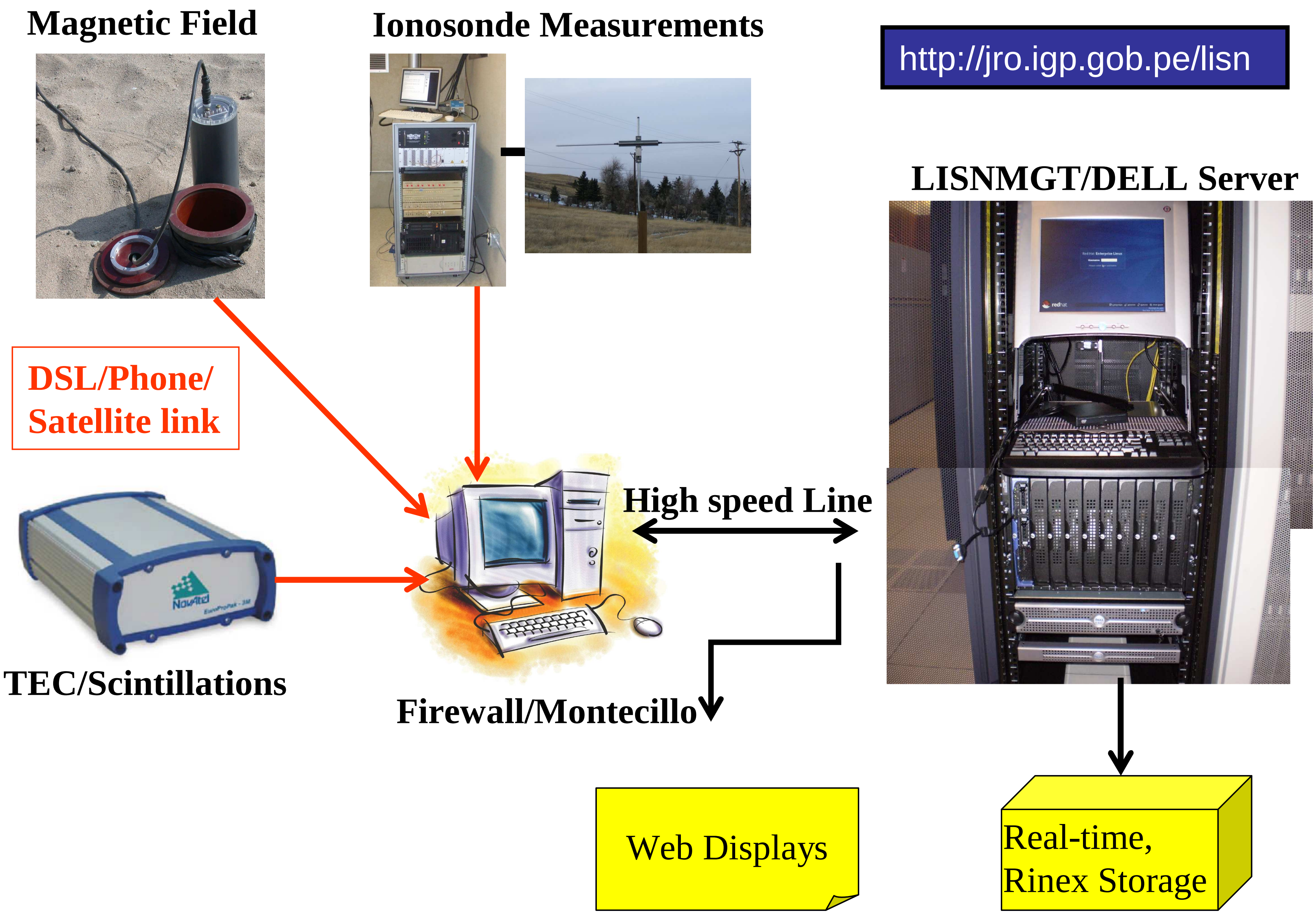
Comparison of Ionosonde measurements and a numerical model



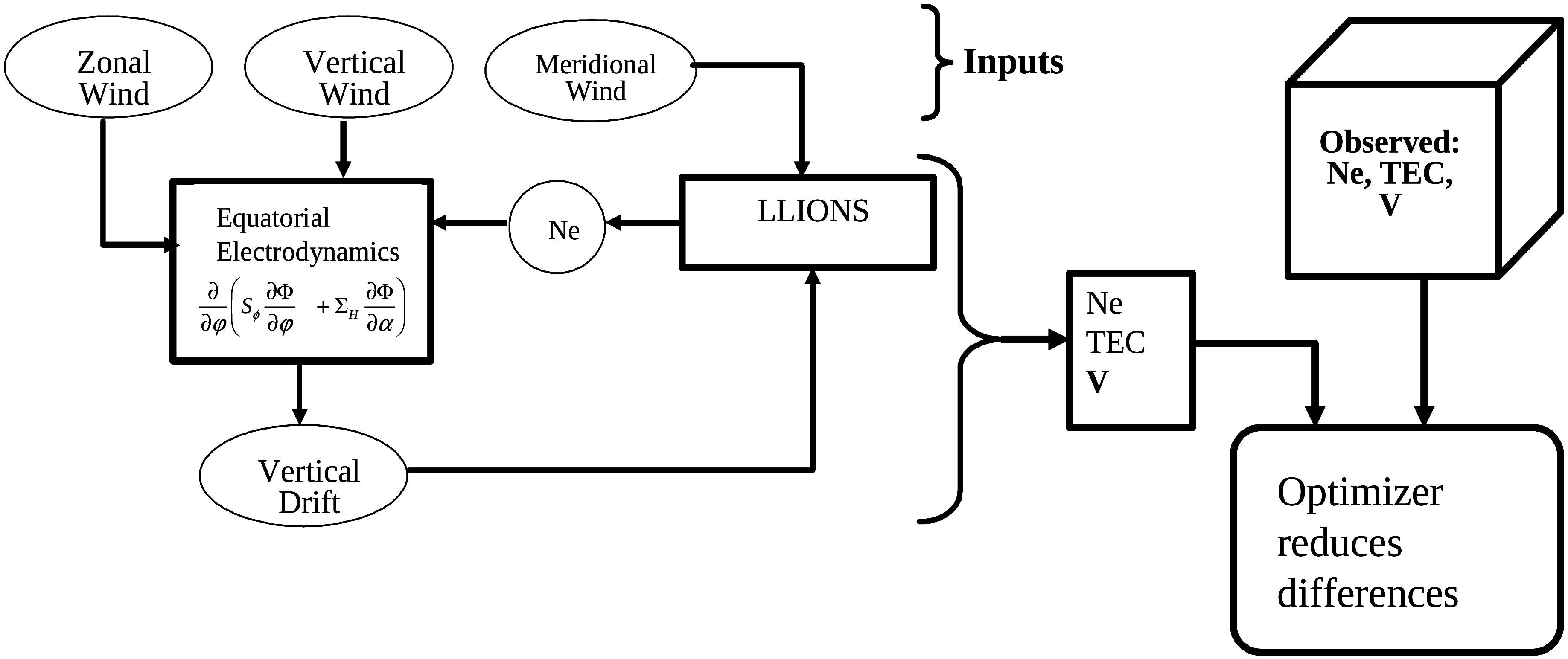
Zalezak et al., 1982, theoretical simulation



LISN - Data Flow Diagram

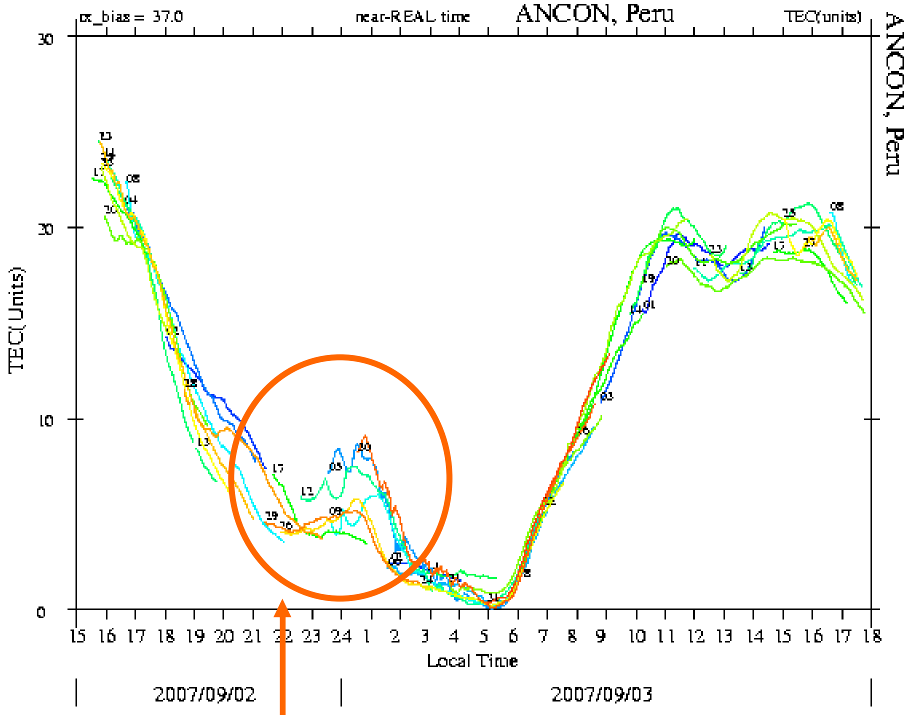


Several assimilation, Inverse Modeling and tomography reconstruction (NeQuick) efforts underway

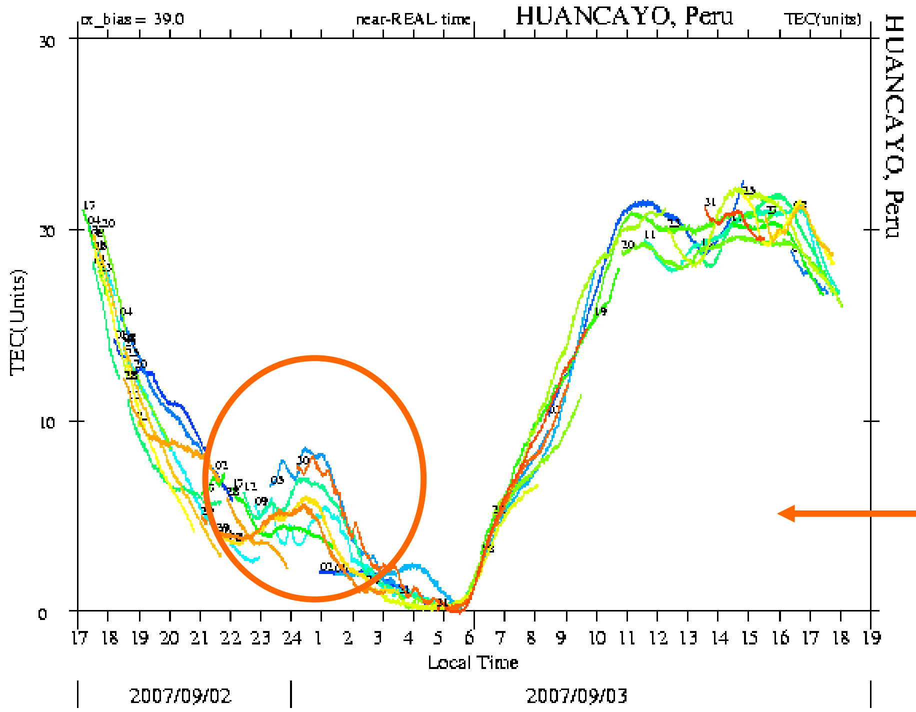


The goal is to determine the drivers of the low latitude ionosphere: meridional winds and vertical drifts, and help achieve a short-term forecast capability.

TEC wave Perturbations associated with TIDs



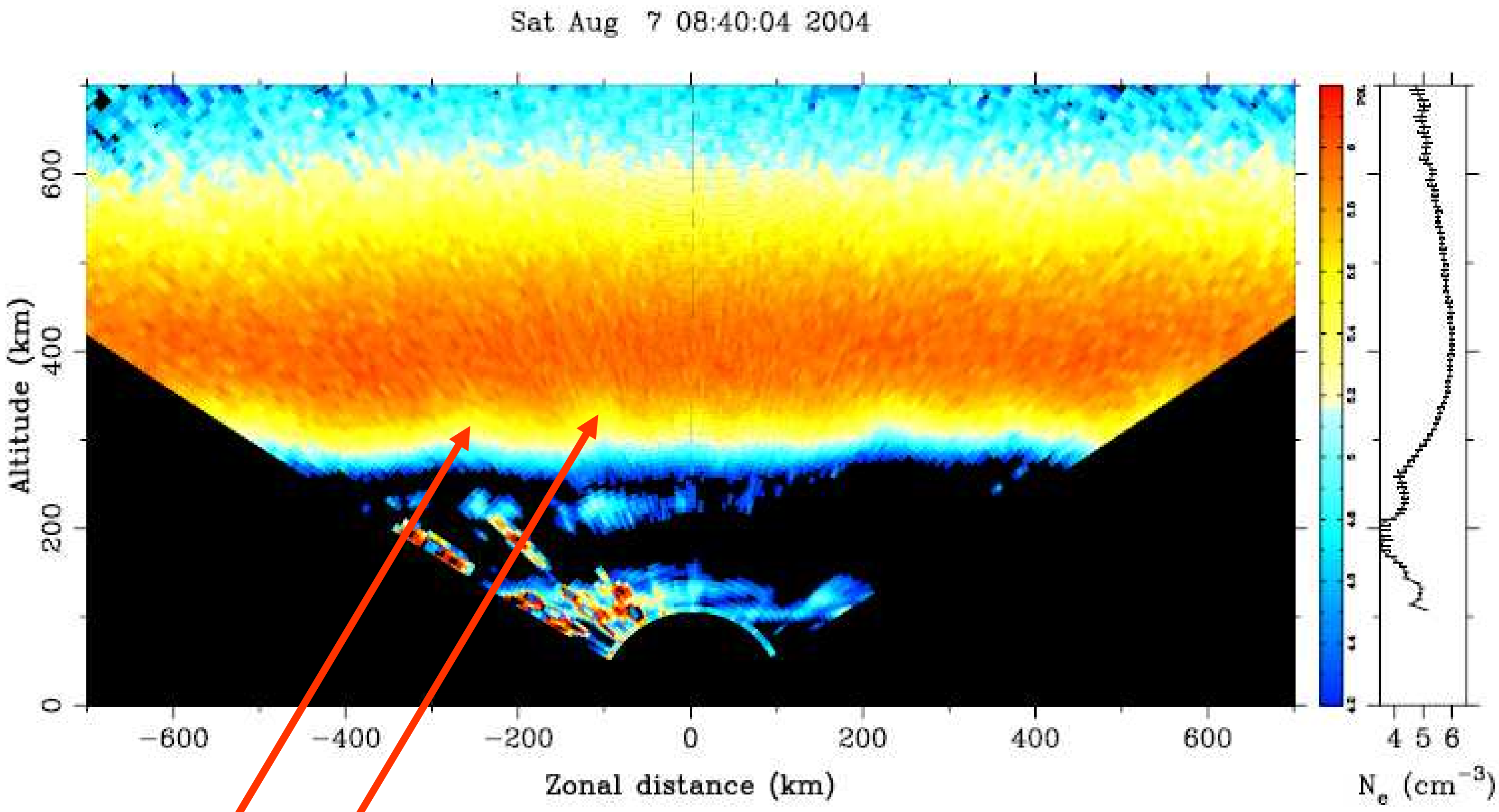
1 TEC unit fluctuations seen moving from Huancayo to Ancon (westward direction).



Ancon

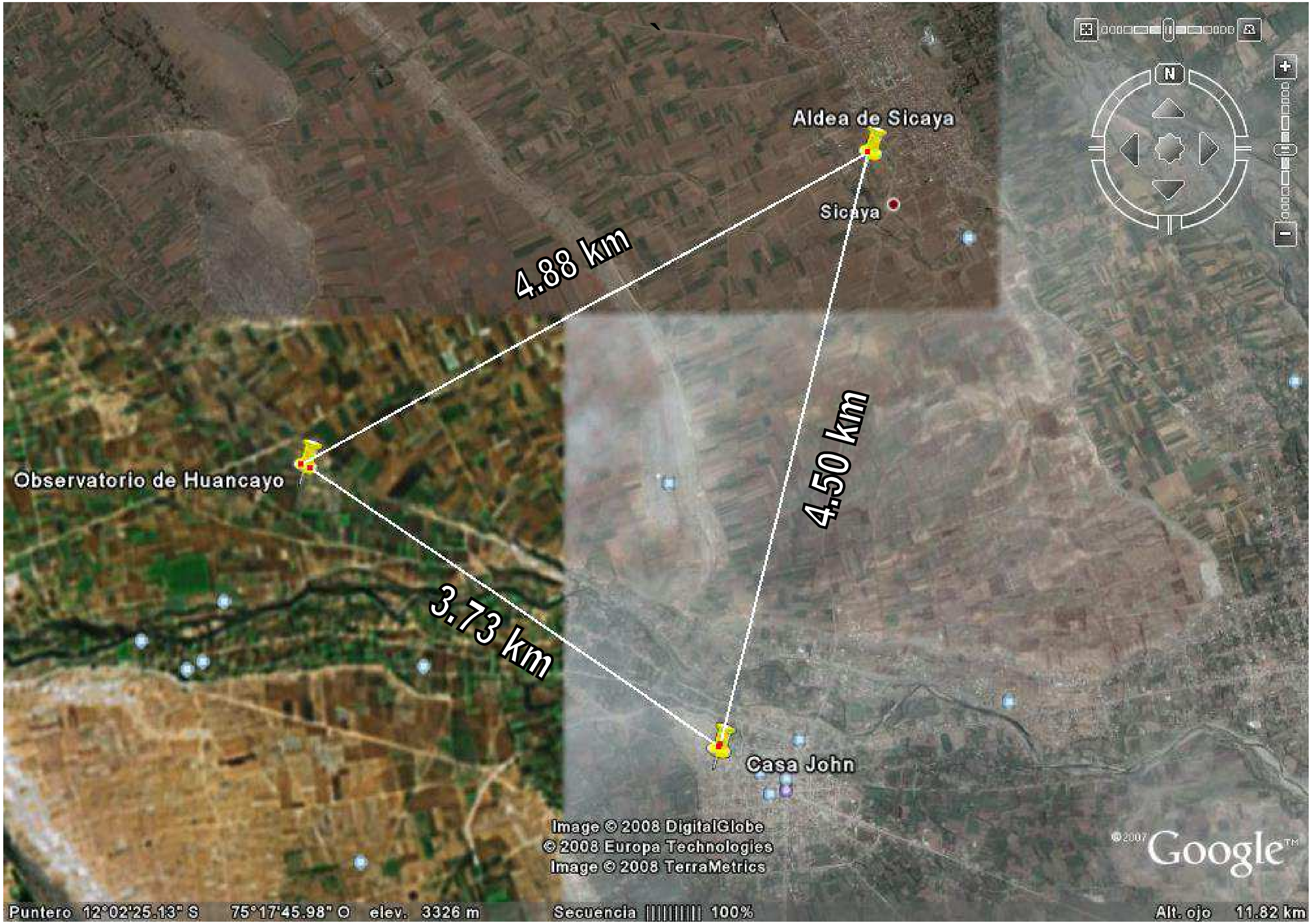
Huancayo

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



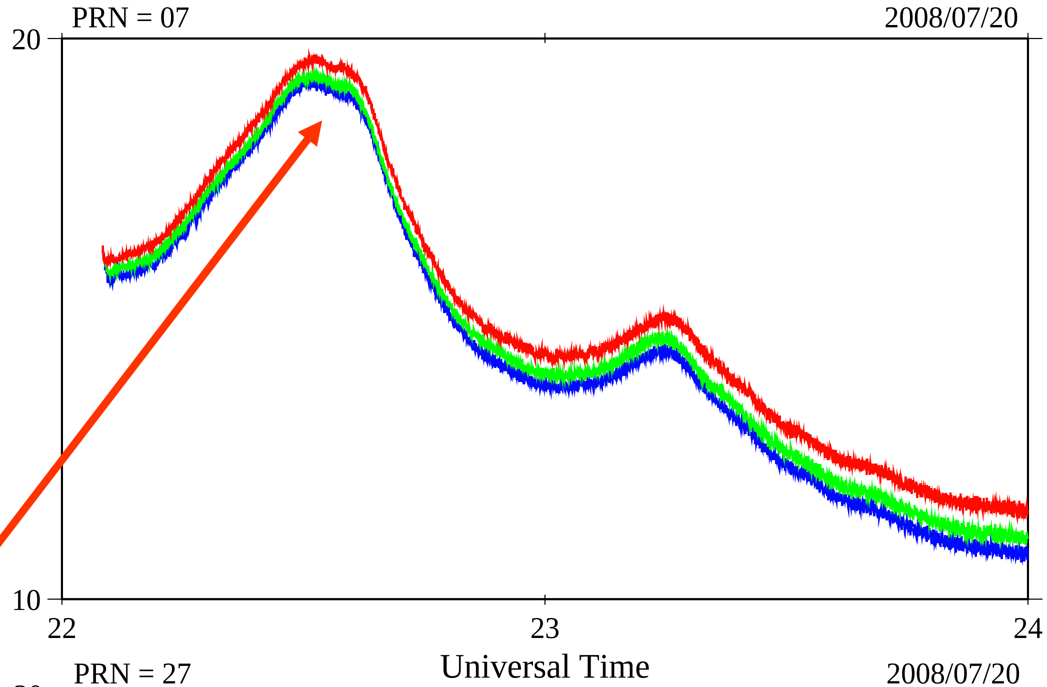
Bottomside altitude modulation probably due to AGW.

Location of 3 GPS receivers near Huancayo

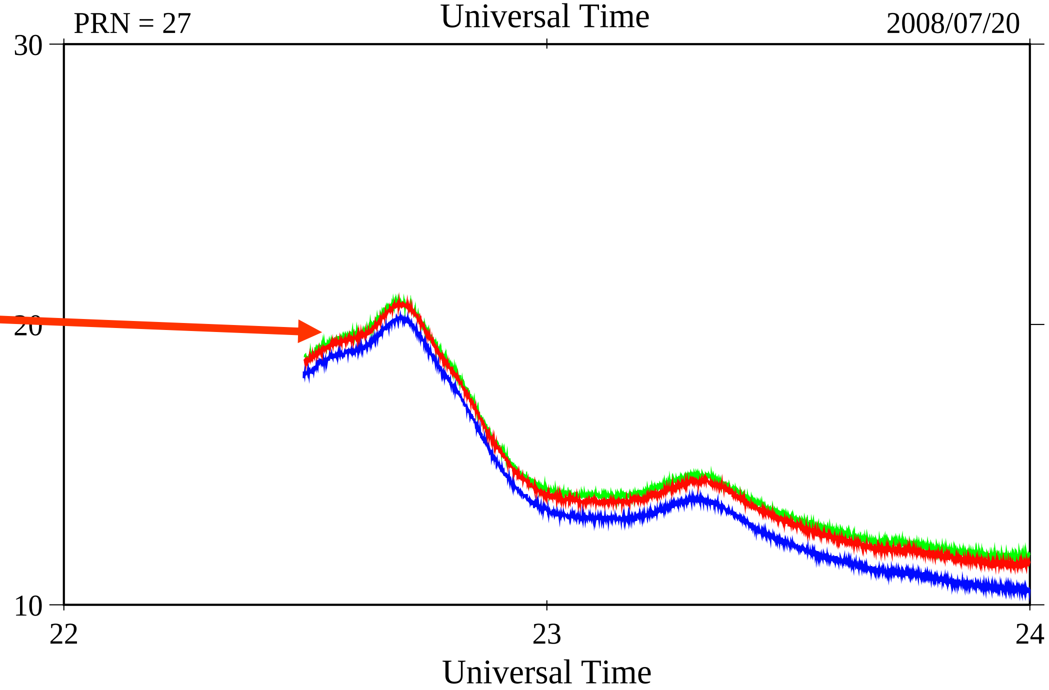


TEC values measured at Huancayo using GPS satellites 07 and 27

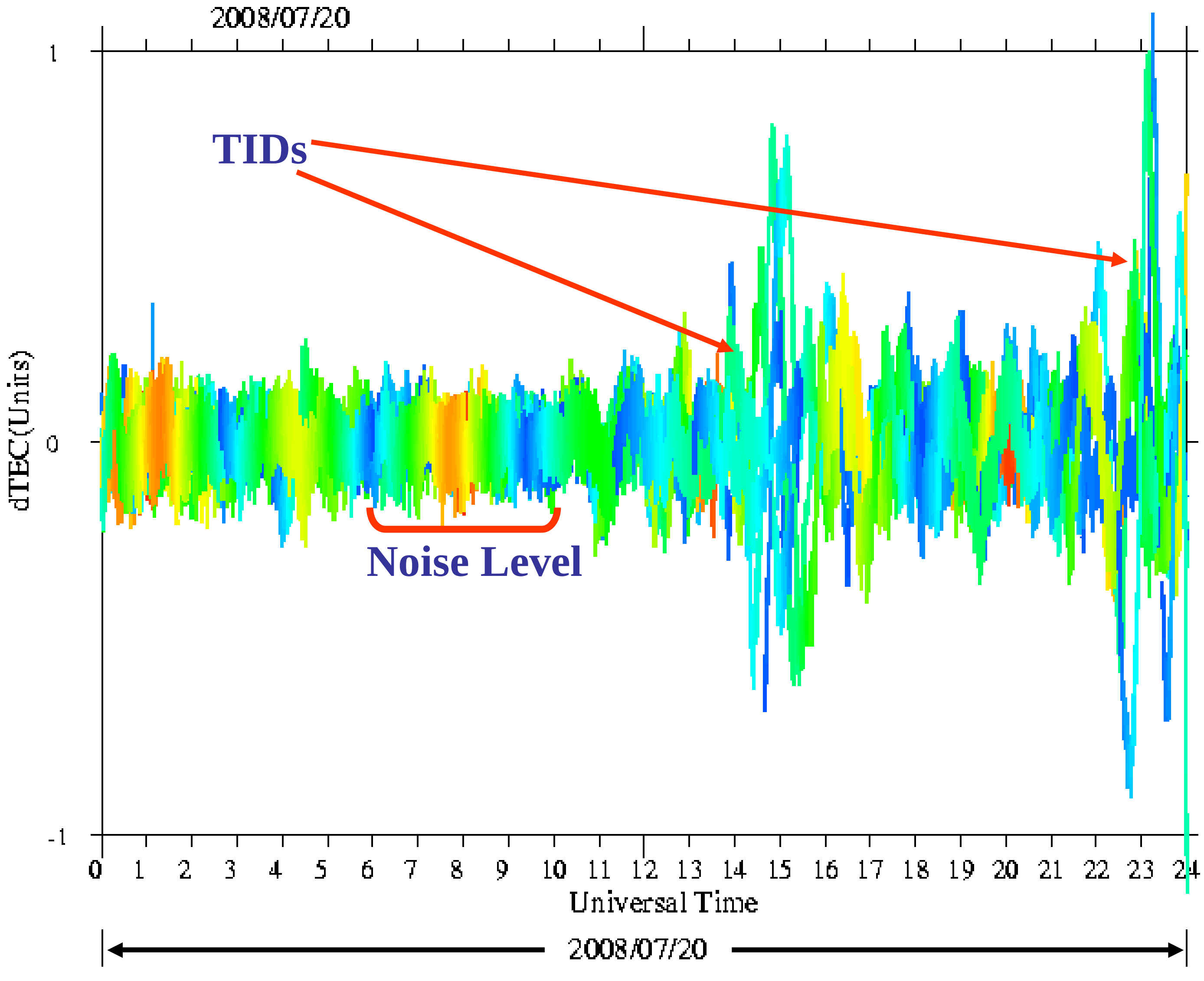
TEC observed on July 2008 using GPS satellites 07 and 27. Small differences in time due to variability of the sub-ionospheric intersection points.



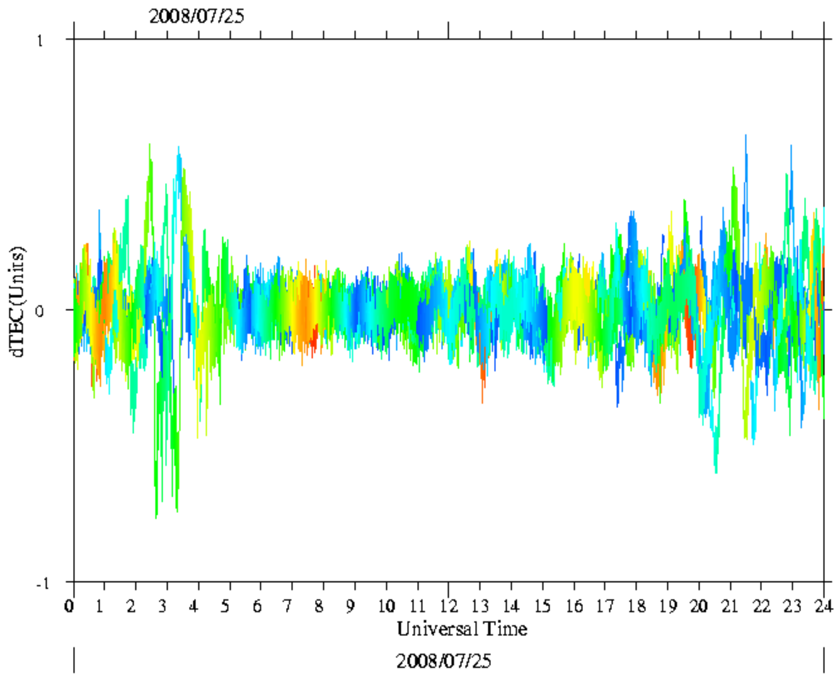
TEC perturbations associated with a TID with a ~40 min periods.

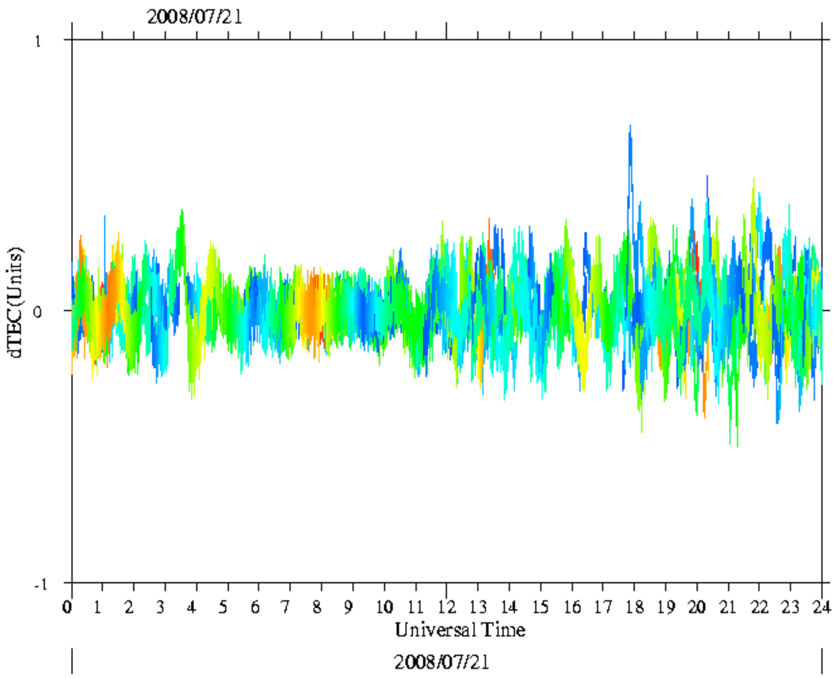


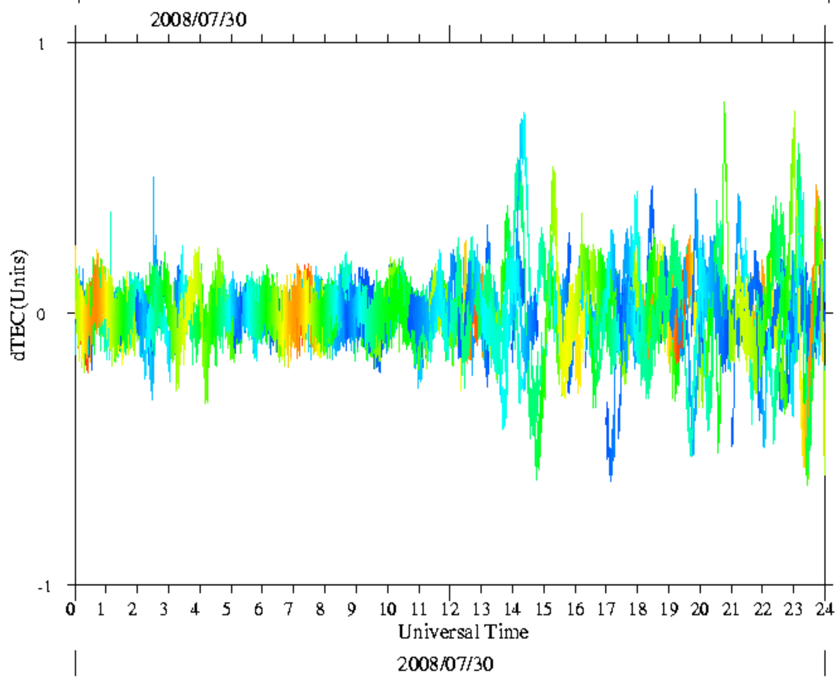
TIDs observed on July 20, 2008



TIDs observed on 3 days during campaign: July 21, 25 and 30, 2008.







GPS Radio-interferometry

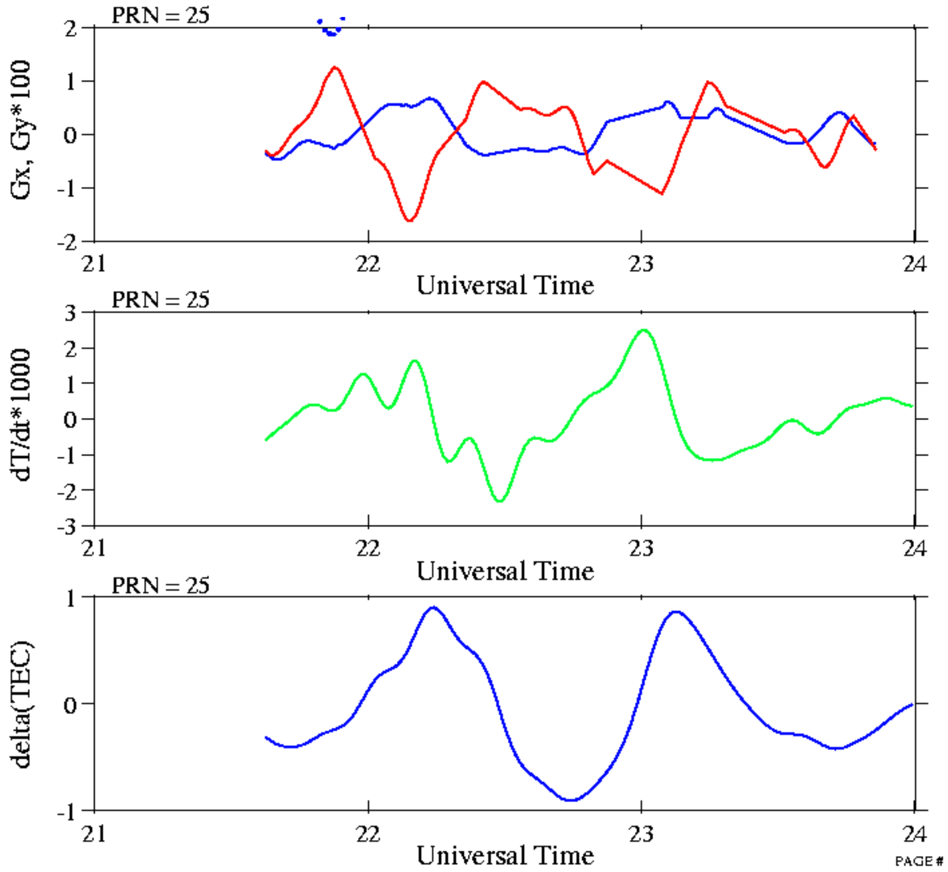
Radio interferometers are arrays of two or more ground receivers that use phase differences measured at various stations to determine TID velocity, propagation azimuth, amplitude, and period.

It is assumed that the TEC perturbation follows the formula:
$\Phi(\mathrm{TEC}) = \delta\sin(\Omega t - K_x X - K_y Y + \varphi)$

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

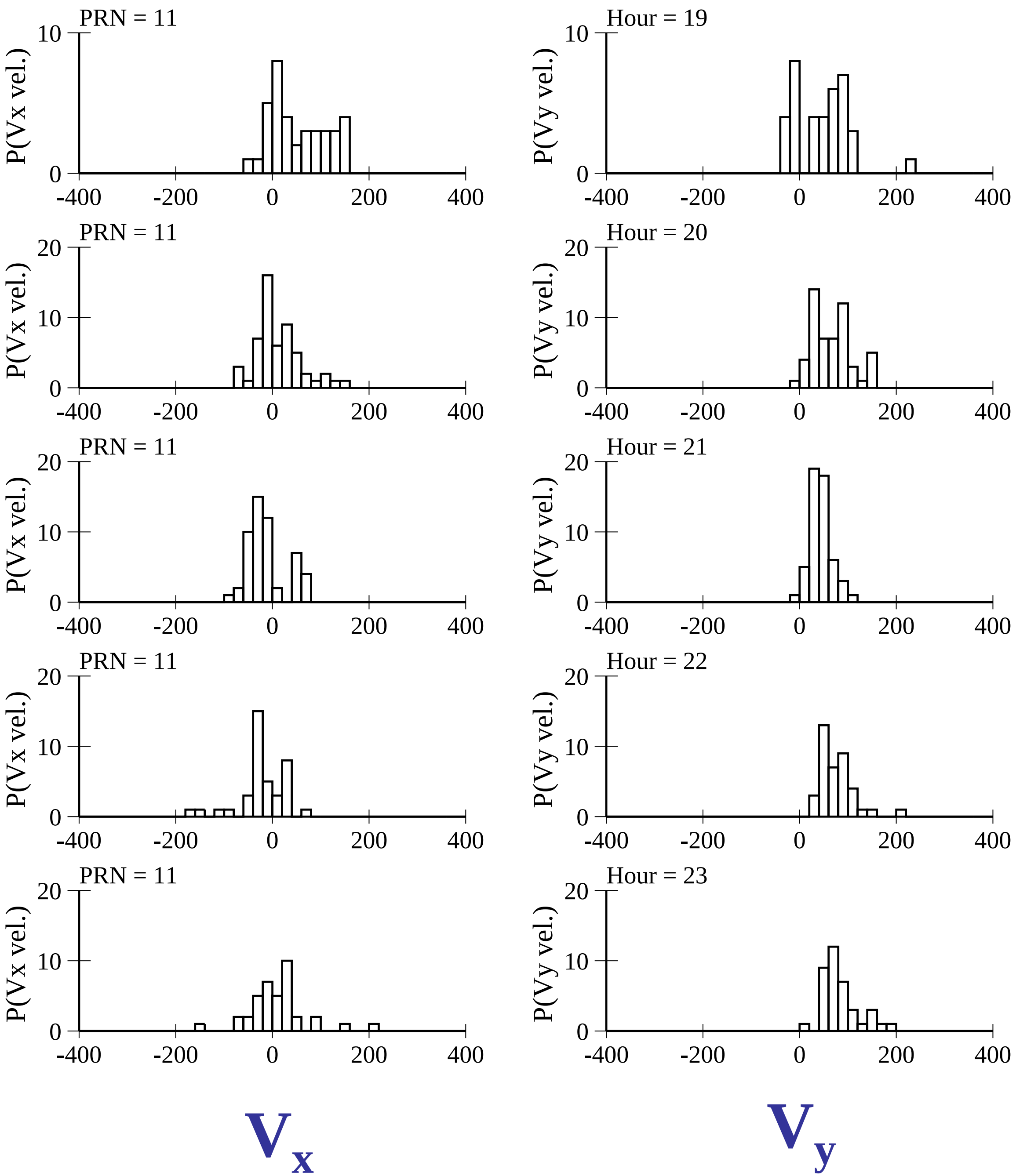
$$u_x(t) = \phi'_t(t)/\phi'_x(t) = u(t)/\sin\alpha(t)$$

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

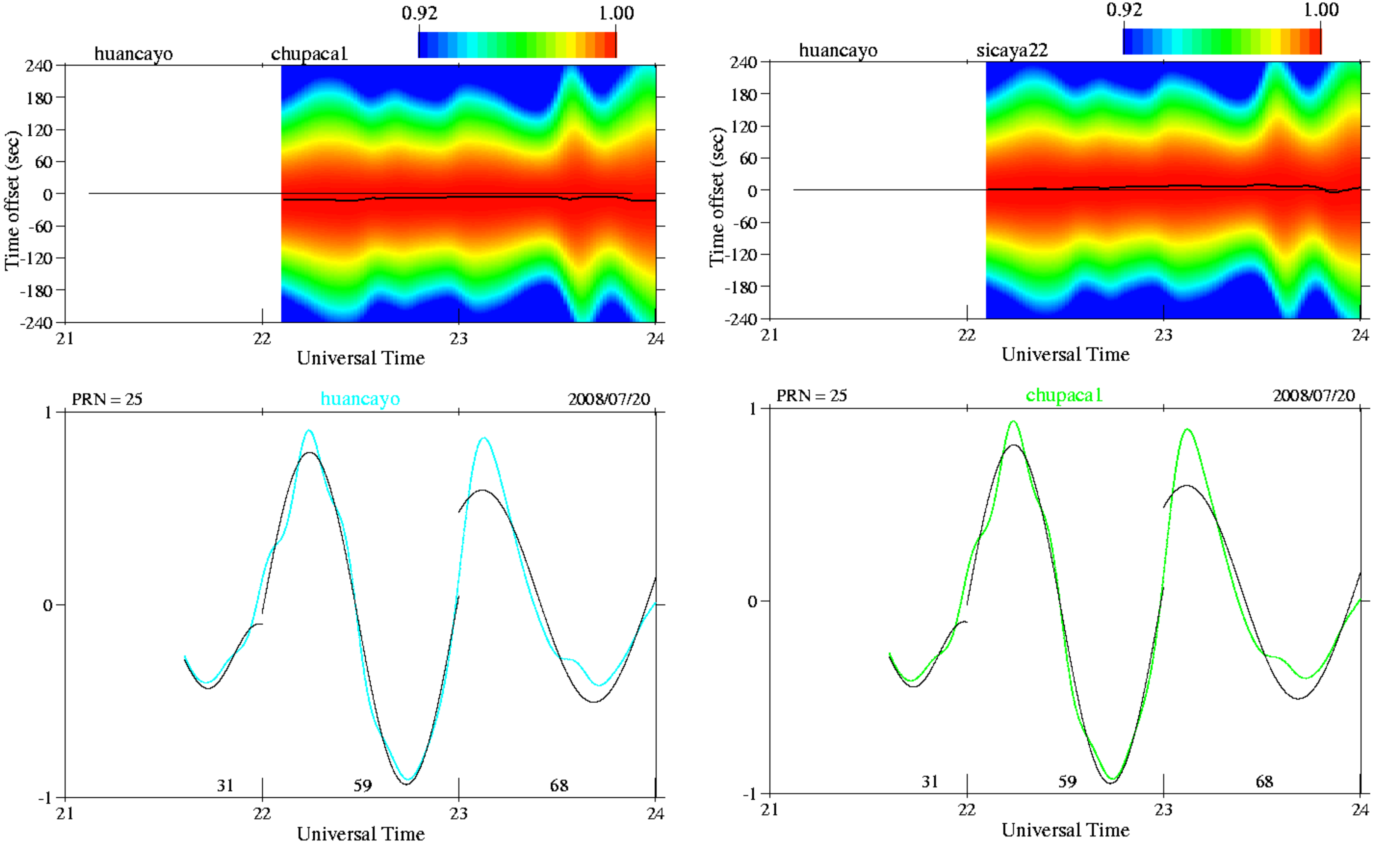


For geo-stationary spatial and time derivatives of the phases give phase interference pattern. GPS radio-interferometry uses the spatial and temporal derivatives of TEC.

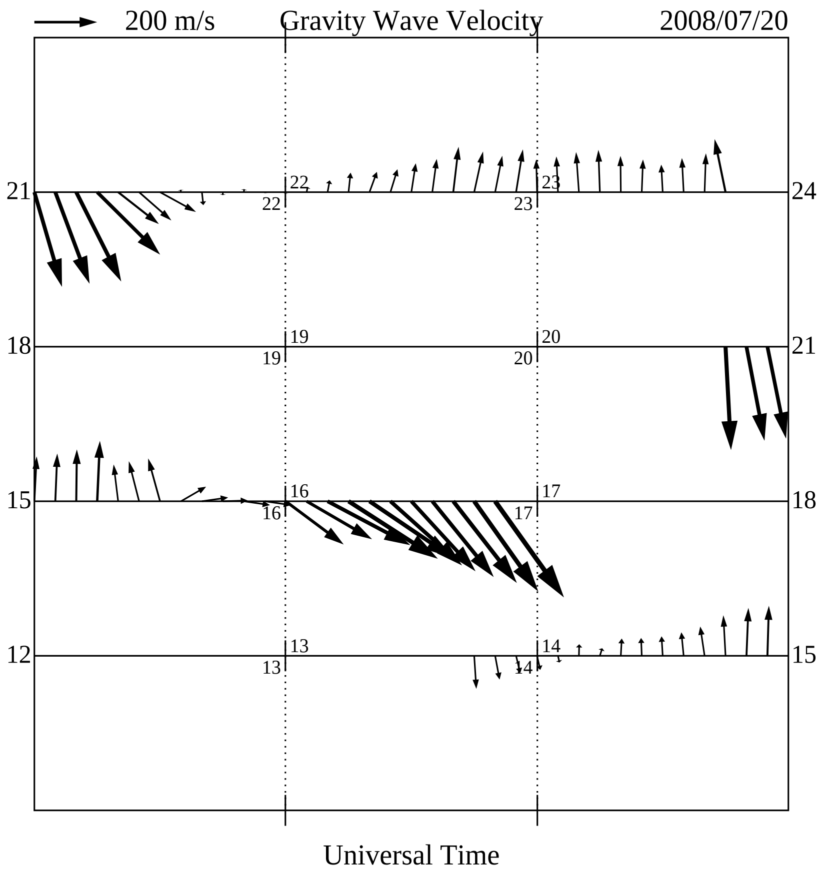
***Afraimovich et al.*, 1998; 2000; 2003**

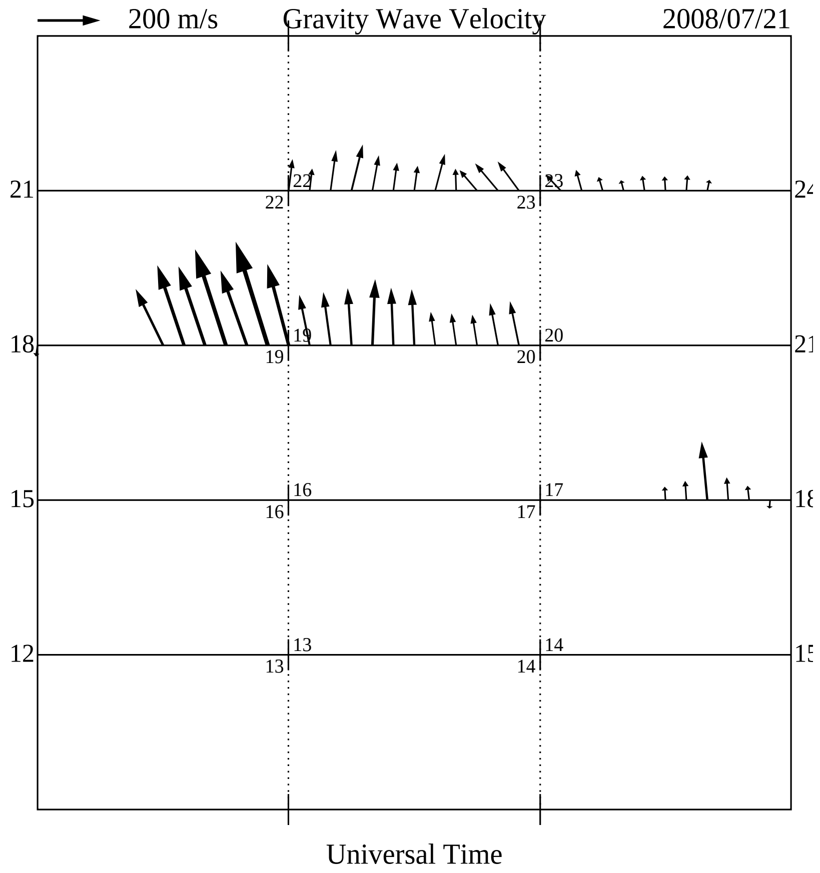

PRN = 11
PRN = 11
PRN = 11
PRN = 11
PRN = 11
P(Vx vel.)
Hour = 19
Hour = 20
Hour = 21
Hour = 22
Hour = 23
P(Vy vel.)
-400
-200
0
200
400
V_x
V_y

Cross Correlation of TEC from stations Huancayo-Chupaca (B-C) and Huancayo-Sicaya (B-A)



Phase velocity for 2 consecutive days between 12 and 24 UT

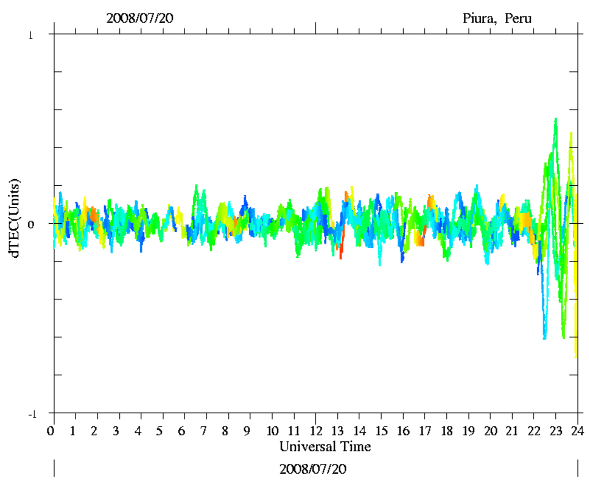


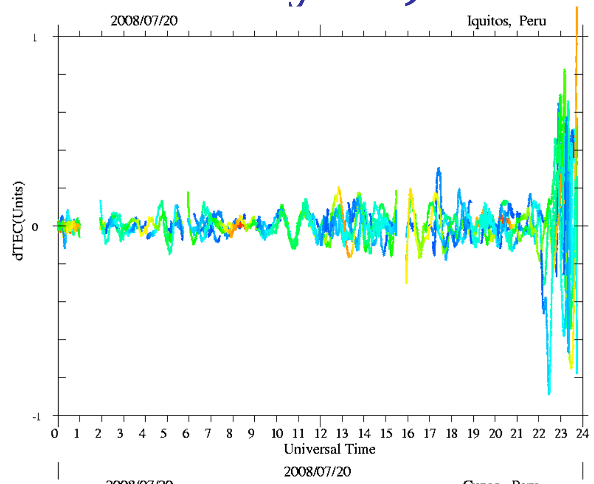


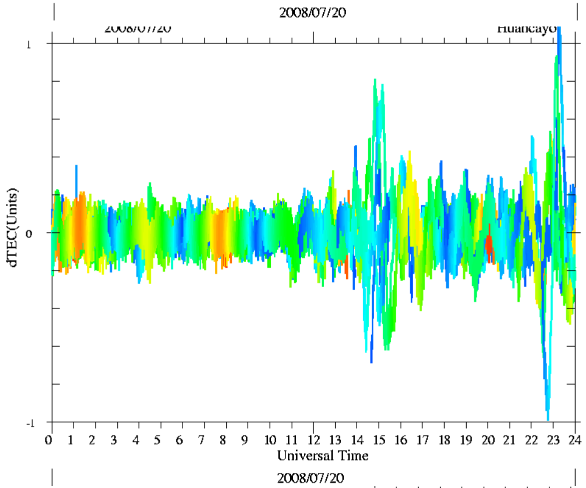
July 20, 2008

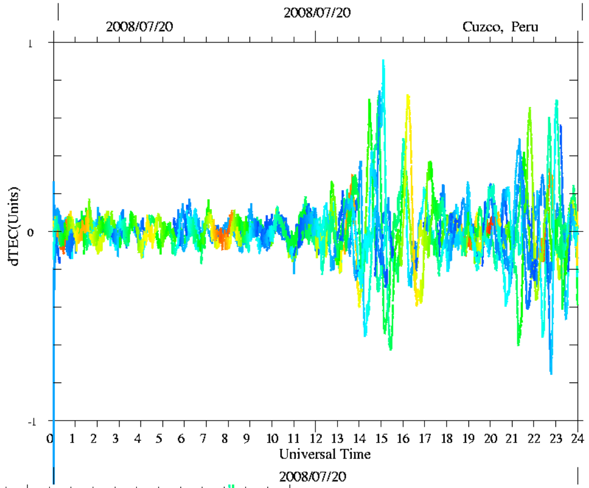
July 21, 2008

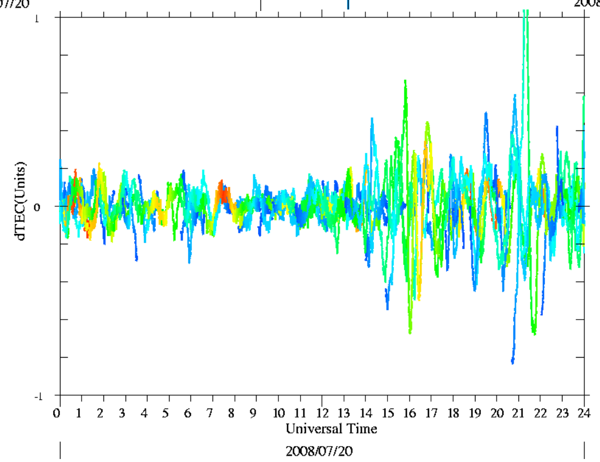
dTEC perturbations observed in other stations on July 20, 2008











1st LISN Team Meeting – Jicamarca, Peru - August 2007
31 Participants – 7 countries from South America

LISN has motivated the following new projects:

- **Argentina – Brunini – New methods for calculations of TEC.**
- **Peru – Veliz – Development of magnetometer prototype.**
- **Colombia – Villalobos – Space Physics School at the Universidad Nacional.**
- **Brazil – dePaula – Scintillation measurements using different sensors. Maps of scintillation in SA.**

Lesson Learned

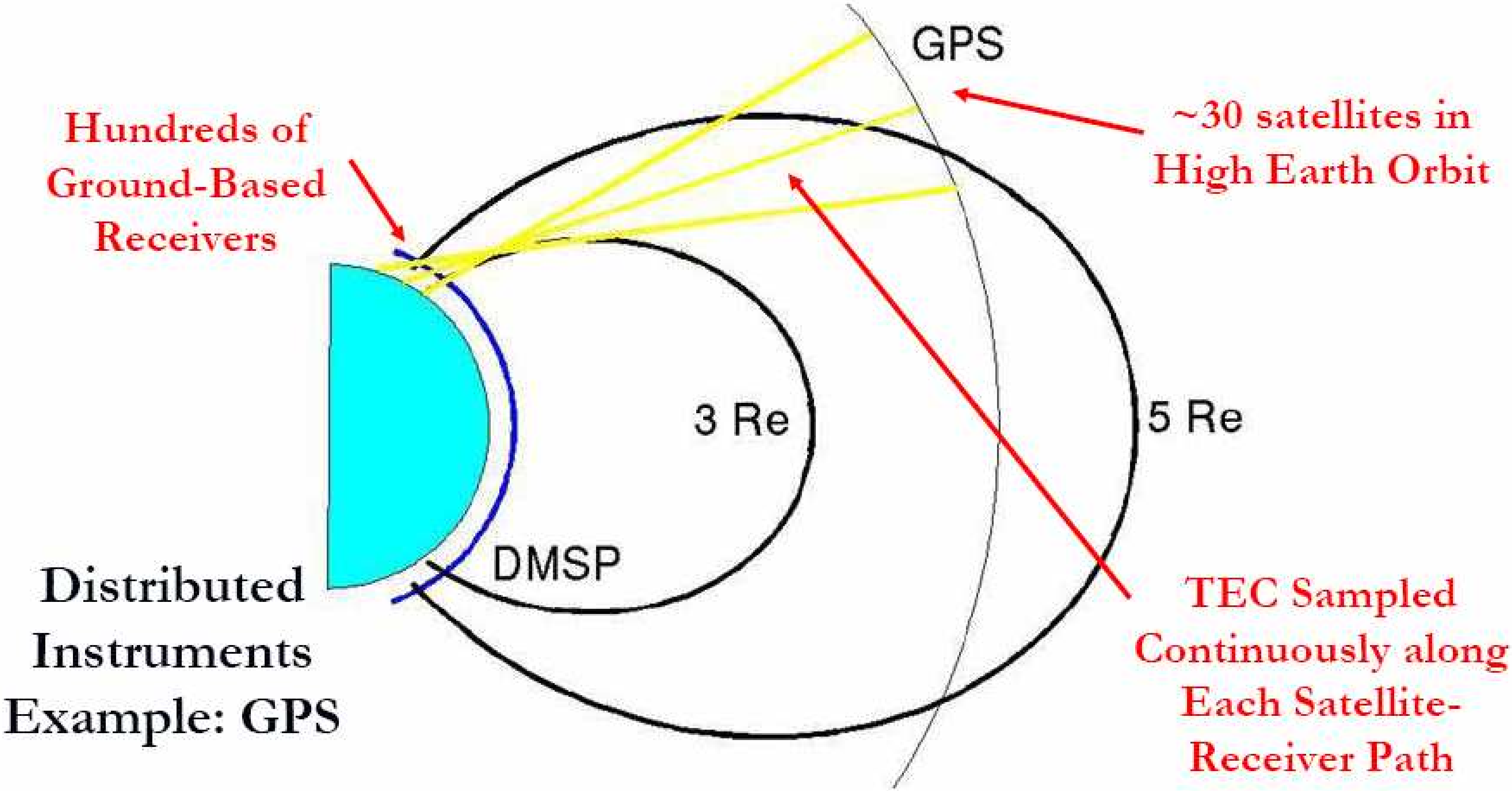
- **The successful operation of the LISN instruments depends upon local persons willing to provide proper logistic and maintenance support and initiating a scientific interest from Professors, investigators and students.**

Conclusions

The most important issue for the success in building a distributed observatory is to initiate collaboration with local scientists working on Space Weather problems. The science has to be strong enough to motivate researchers and students in local countries by providing science projects in space physics and creating programs for instrument development.

There are several outstanding question in space physics that the need of distributed observatories is of high priority. A distributed observatory in Africa will make it possible to address science questions regarding: the effect of E and Es layers on inhibiting ESF, the role of Gravity Waves on seeding plasma bubbles, or verify the role of alternative theories for ESF. It will also provide clues to understand the causes of day-to-day variability of the low-latitude ionosphere in Africa.

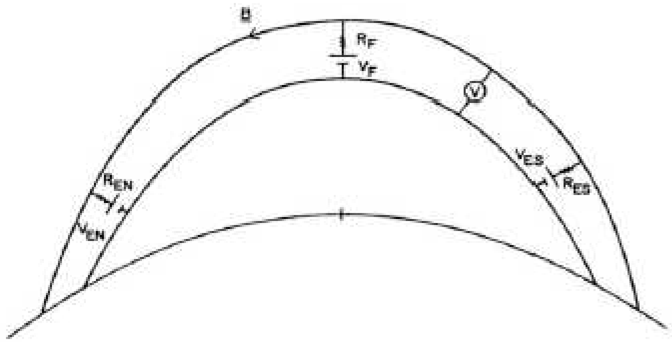
GPS measures the Ionosphere and Plasmasphere up to 20,000 km
Dual frequency Observations gives TEC

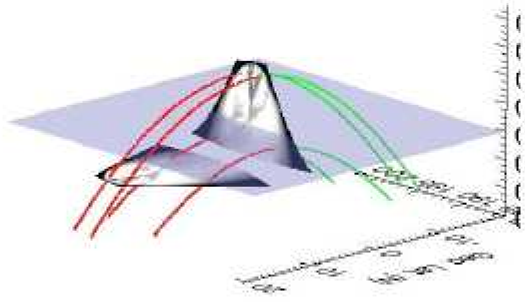


TEC is a measure of integrated density in a 1 m^2 column

1 TEC unit = 10^{16} electrons m^{-2}

- The Earth's magnetic field acts like highly conducting wires
  - This couples the two hemispheres together and creates a large, complex system to study
  - Must know what is going on along the entire field line to understand all of the physics



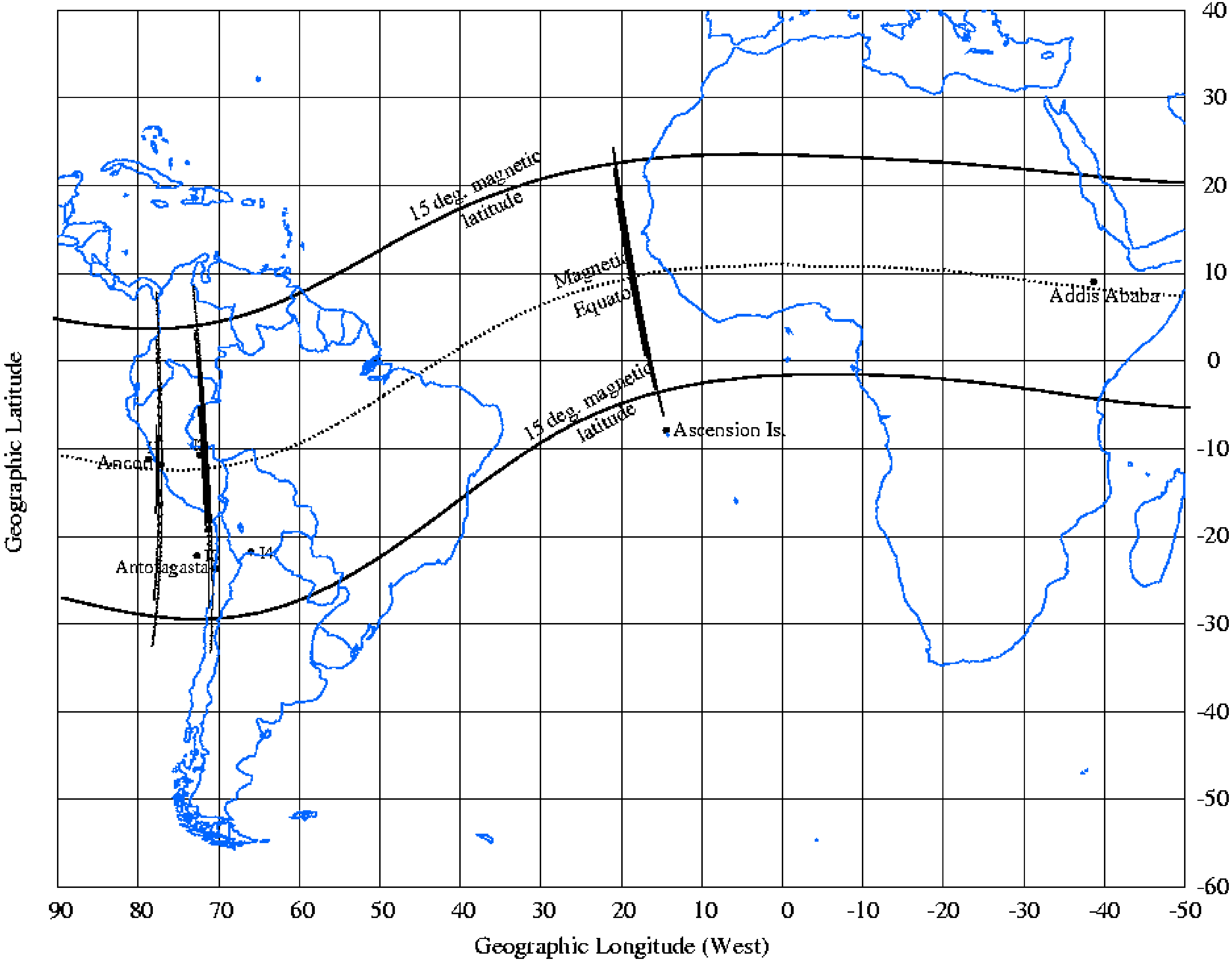


Some Impacts of Space Weather

During times of high solar activity, polar airline routes are often diverted to lower latitudes to prevent loss of radio communications and avoid human exposure in case of increased radiation from solar energetic particles.

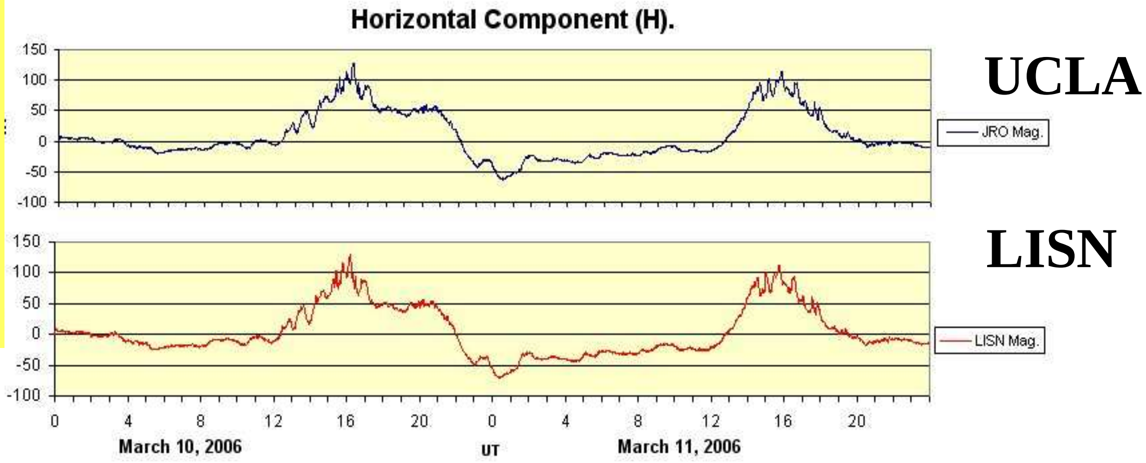
Many elements of society have become dependent on global positioning, navigation, and timing systems.

Disturbed ionospheric conditions can severely impede radio communication signal propagation (e. g. scintillations)


15 deg. magnetic latitude
Magnetic Equator
15 deg. magnetic latitude
Ancon
Antofagasta
I4
Ascension Is.
Addis Ababa
Geographic Latitude
Geographic Longitude (West)
40
30
20
10
0
-10
-20
-30
-40
-50
-60
90
80
70
60
50
40
30
20
10
0
-10
-20
-30
-40
-50

Development of a prototype magnetometer

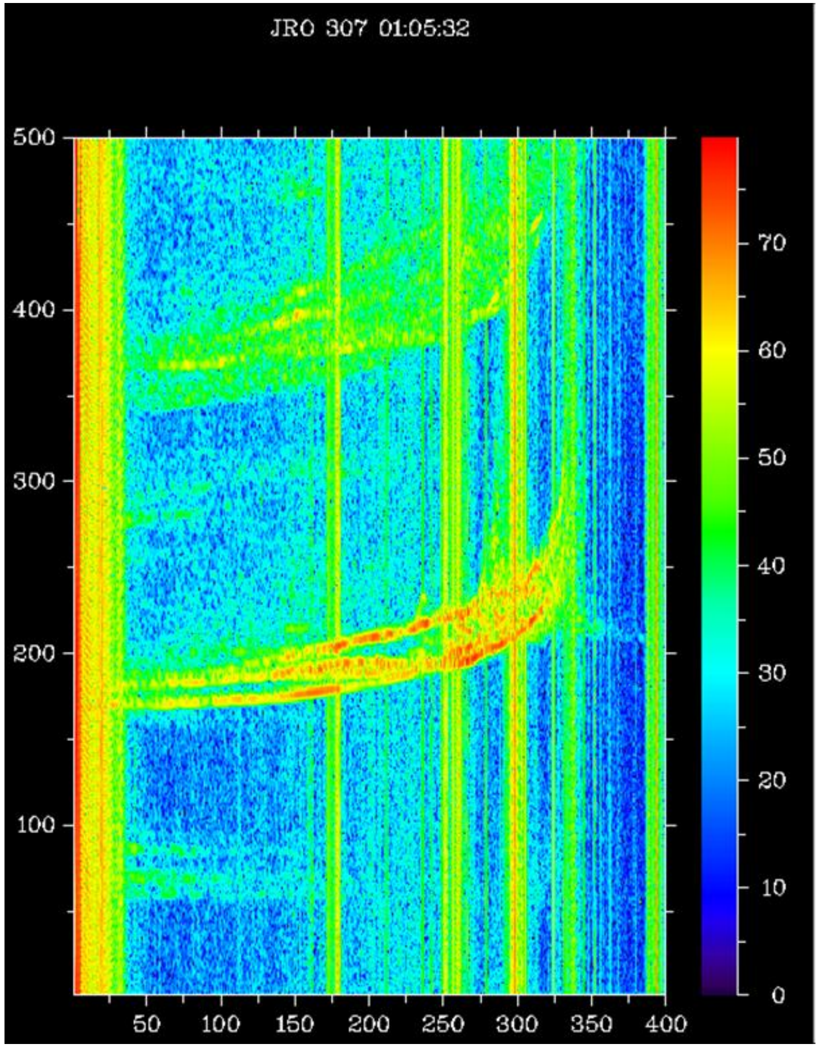
LISN funded the design of a prototype magnetometer by Oscar Veliz. Right Figure shows a comparison with UCLA magnetometer.

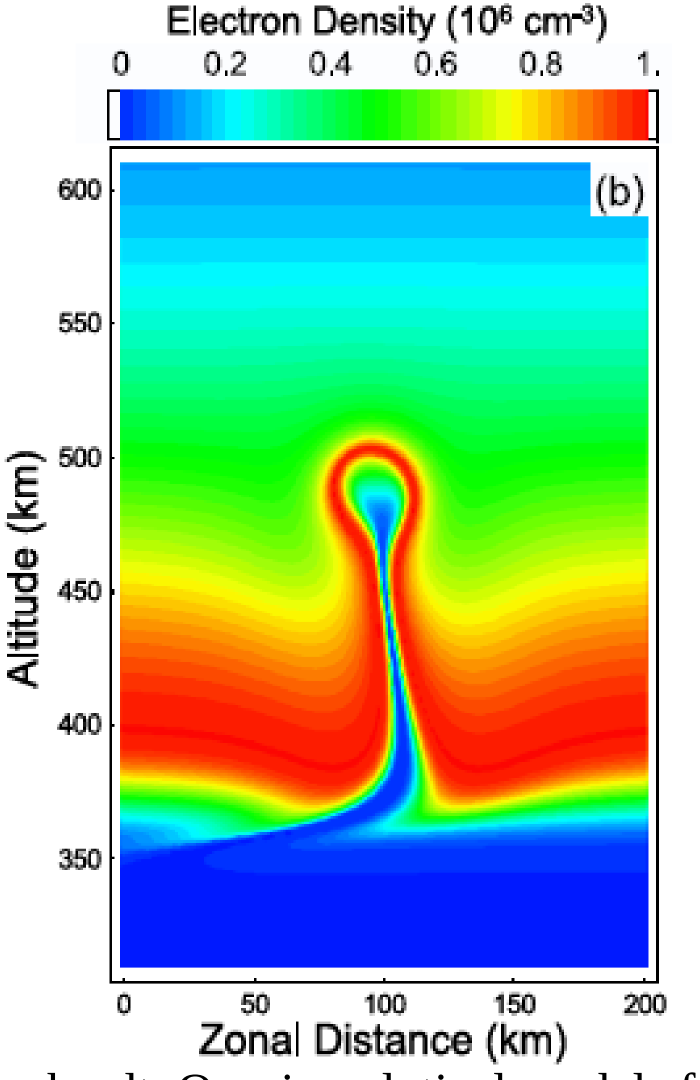


Characteristics of Jicamarca's Triaxial ring core fluxgate magnetometer:

- **High Sensitivity and field resolution (0.1nT)**
- **Long term mechanical and thermal stability**
- **Highly robust electronics and system reliability (multi-layer circuitry).**
- **Low power consumption**
- **Data readily available to Internet uploading (5 min cadence time).**

Comparison of Ionosonde measurements and numerical model





Bernhardt, Quasi-analytical models for density bubbles and plasma clouds in the equatorial ionosphere, 2. JGR, 2007

Processing of GPS radio-interferometry dTEC

$$\Phi(TEC) = \delta \sin(\Omega t - K_x X - K_y Y + \varphi)$$

Spatial Derivatives

Time Derivative

Delta (TEC)