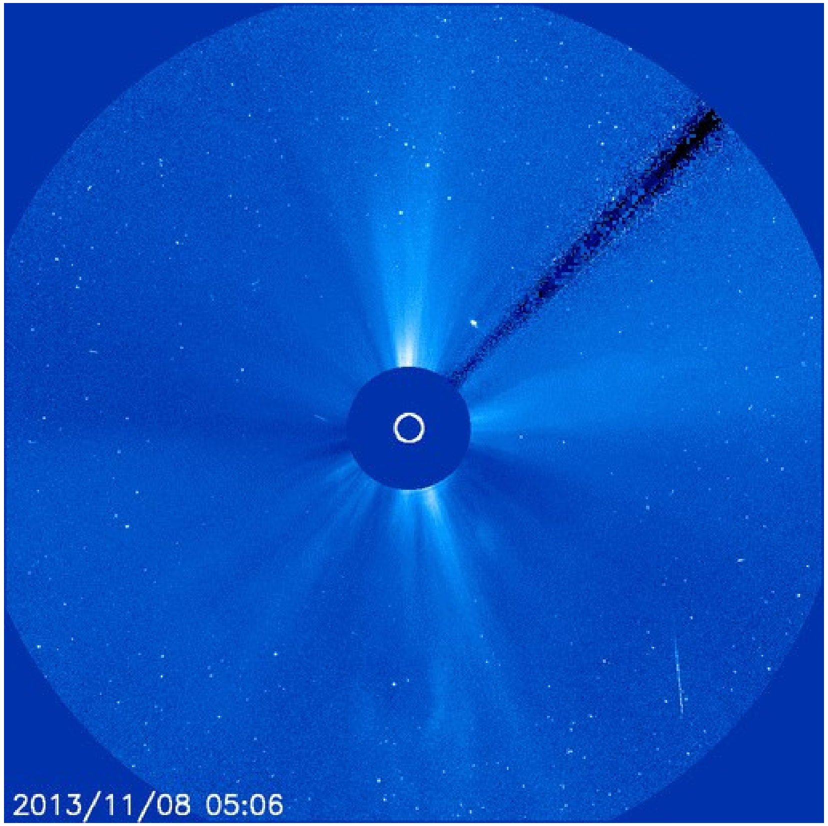
Space Weather – Jicamarca VIPIR School



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Outline

- **Space Weather definition. SW events. The Sun and the Solar Wind.**

- **Inputs from above (Sun, solar wind and magnetosphere). Magnetic storms. Storms during previous solar cycle. During present solar cycle.**

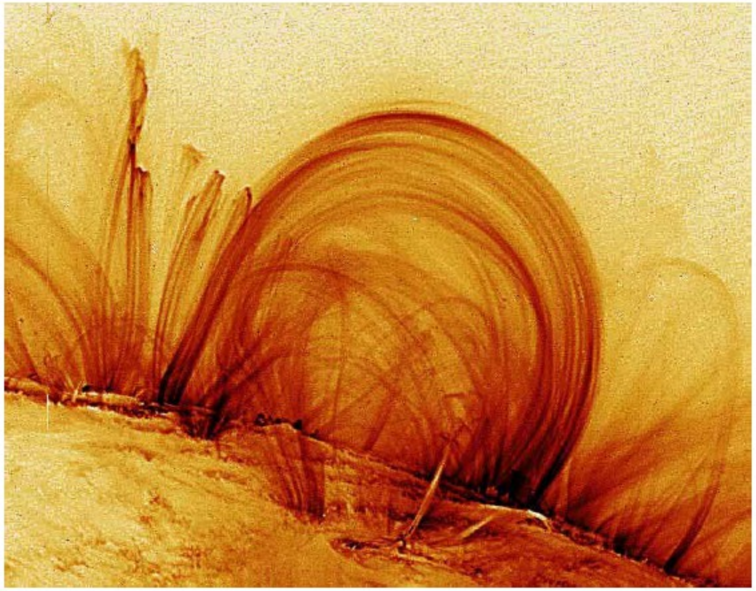
- **Sources from Below: Ionospheric plasma structures also named plasma bubbles. Tides and other type of waves. ESF, scintillations.**

- **About distributed observatory. Concept.**

- **Summary.**

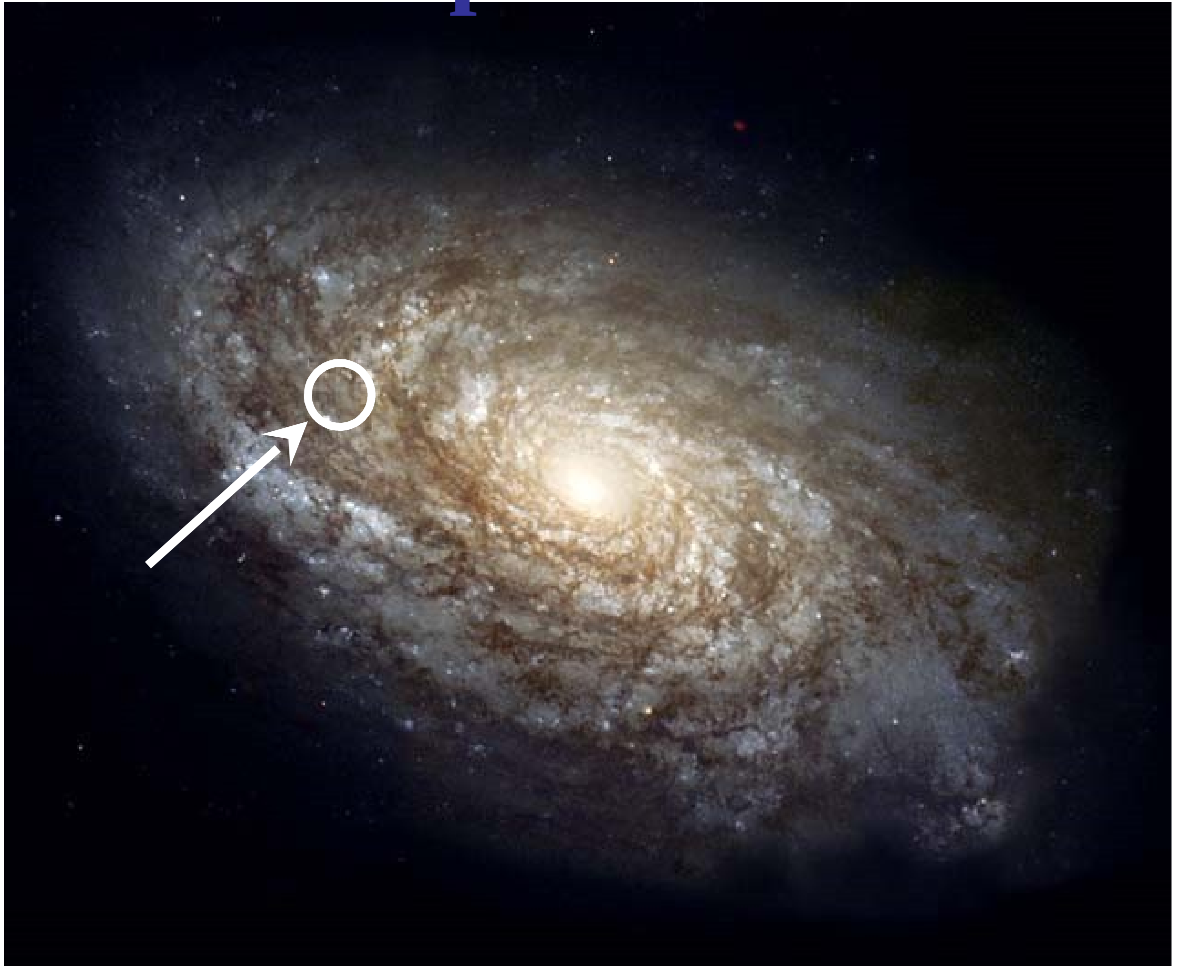
Space Weather Definition

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.”



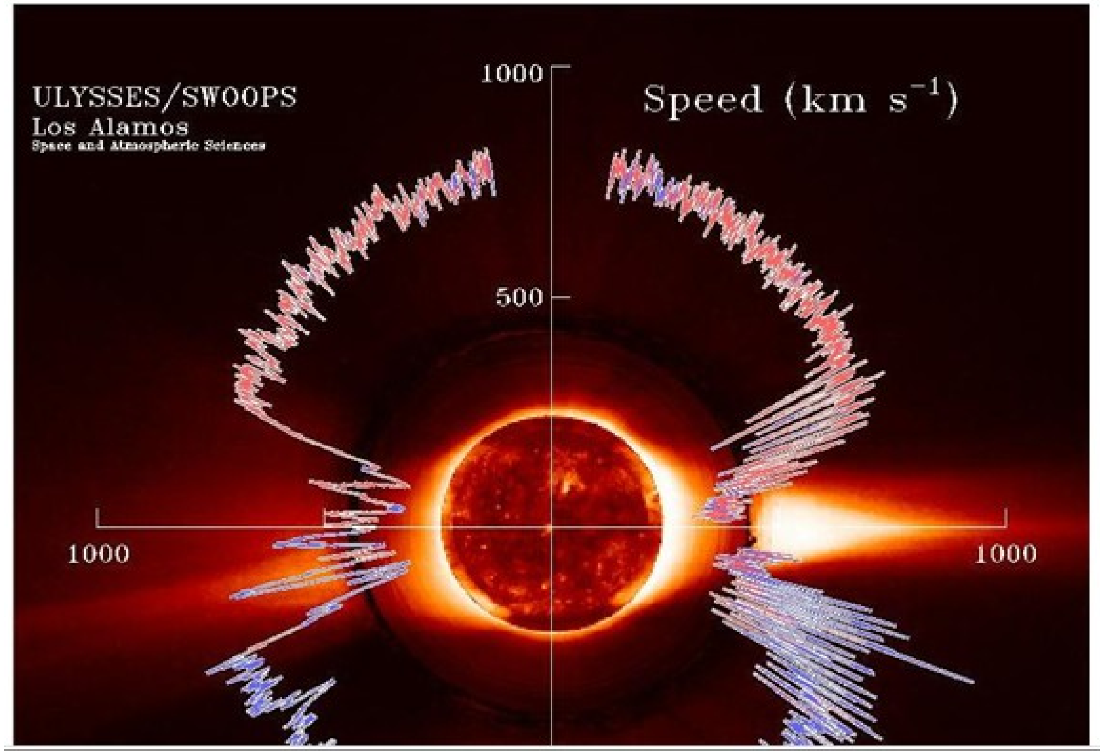
Solar Magnetic Fields and Variability

The Sun's place in the Galaxy



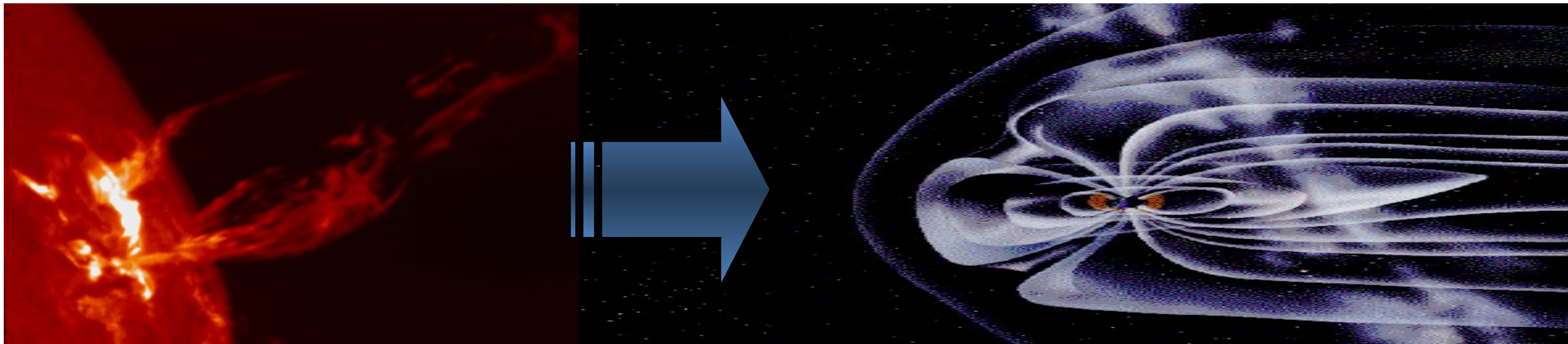
The Sun is one of about 200 billion stars in a galaxy we call Milky Way. It resides on the outskirts, about 28,000 light years from the center.

On the Solar Wind

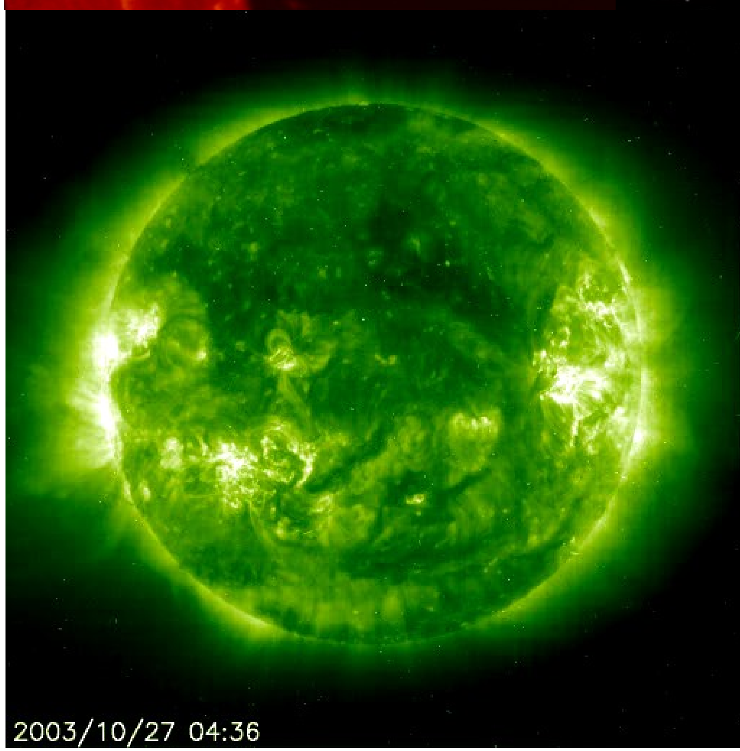


The solar wind streams off of the Sun in all directions at speeds of about 400 km/s (about 1 million miles per hour). The source of the solar wind is the Sun's hot corona. The temperature of the corona is so high that the Sun's gravity cannot hold on to it.

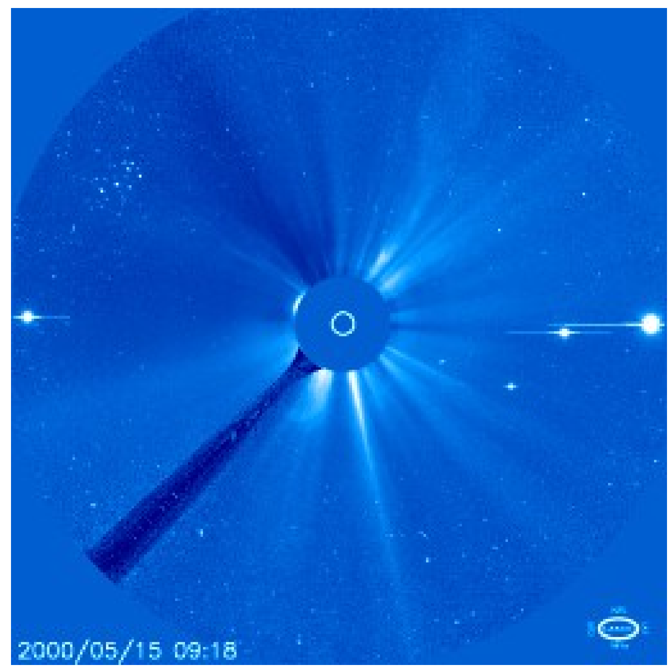
Solar radiation and high energy particles
Event on 2000/05/15 and 2003/10/27 observed by satellite SOHO



CME: Coronal Mass Ejection



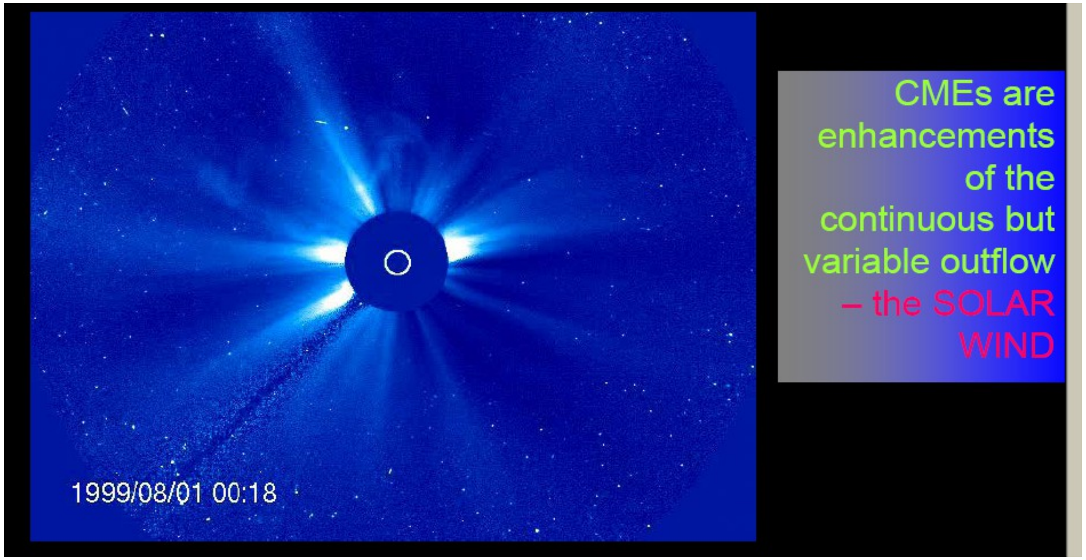
EIT on SOHO



LASCO-C3 on SOHO

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.

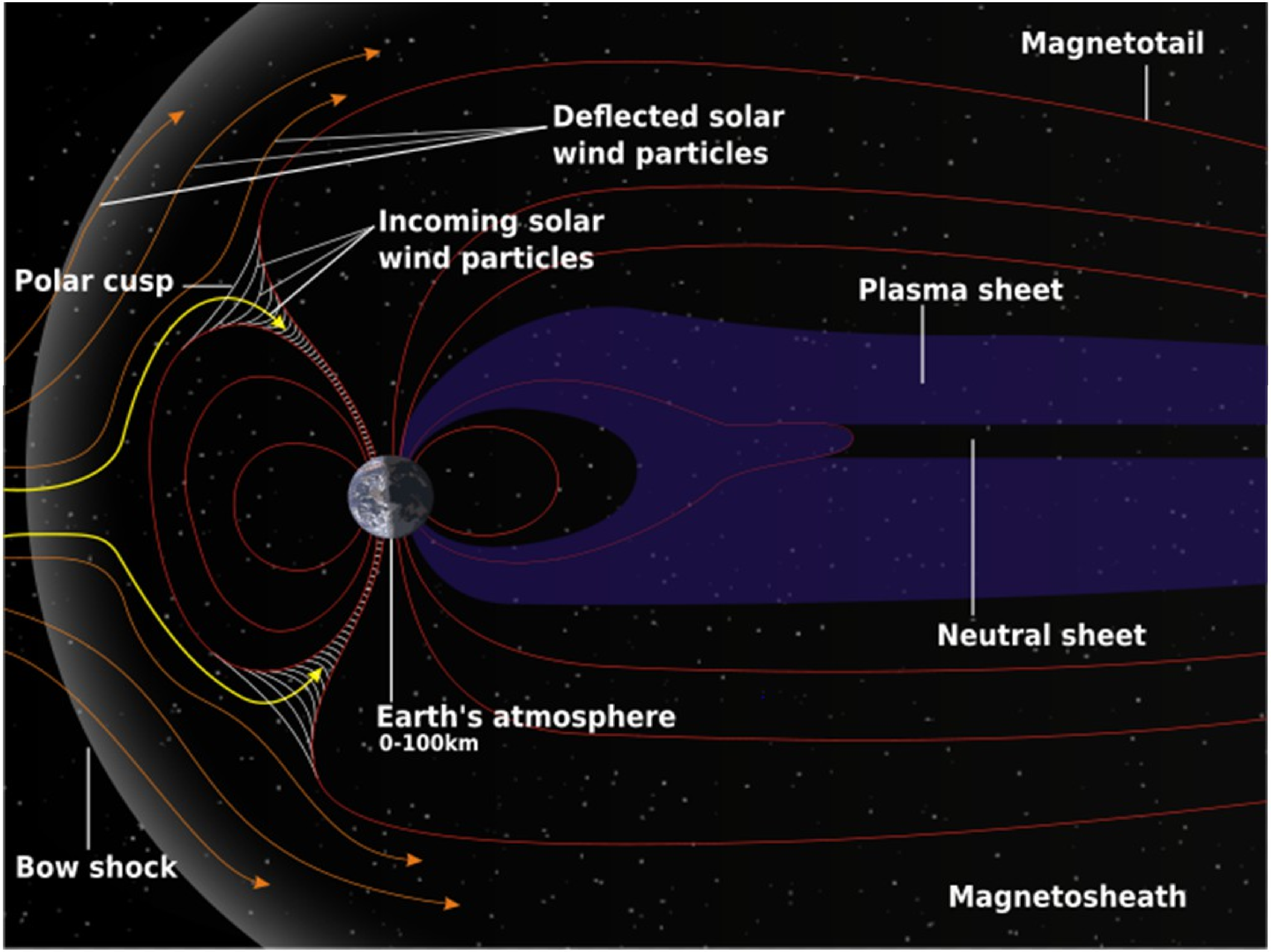


The effects are more pronounced where the Earth's magnetic field is connected to the interstellar medium (e.g. polar regions). The closed field lines of mid- and low-latitudes protect the ionospheres from many effects.

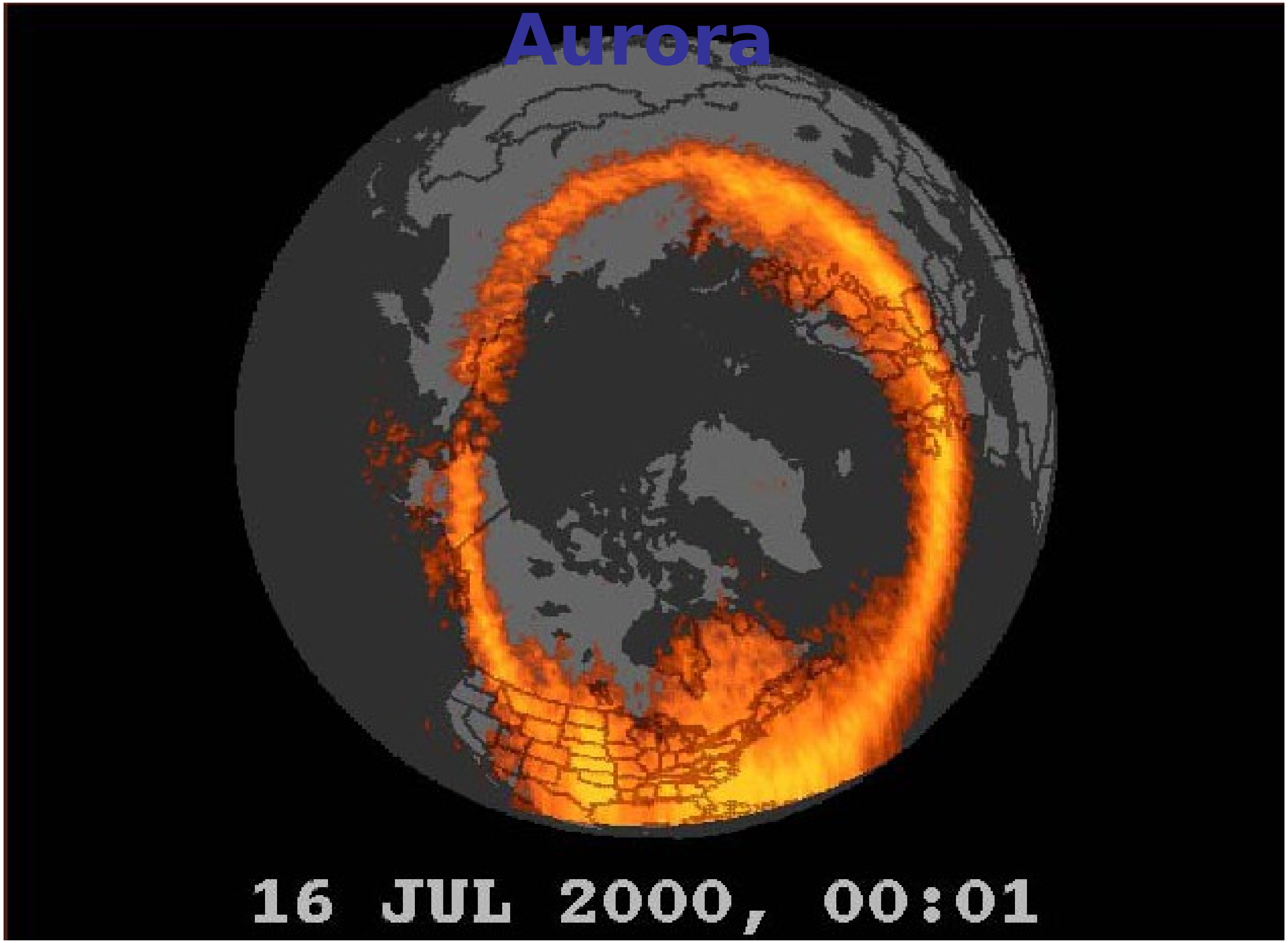
Coronal Mass Ejections

- 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.

The Earth, the magnetosphere and solar wind



The Bastille Day Storm, Electron Aurora



Space Weather impact on Power Grids

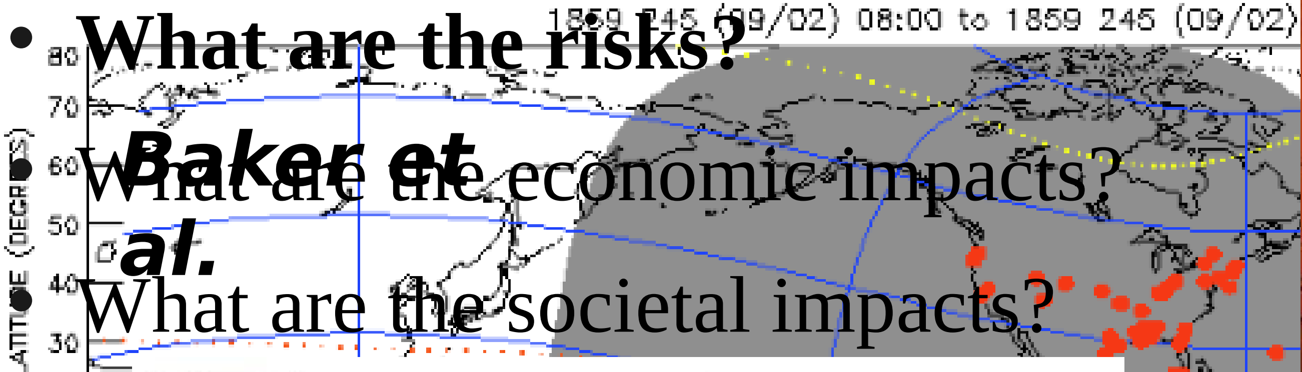
- What are the issues?

September 2, 1859 Even

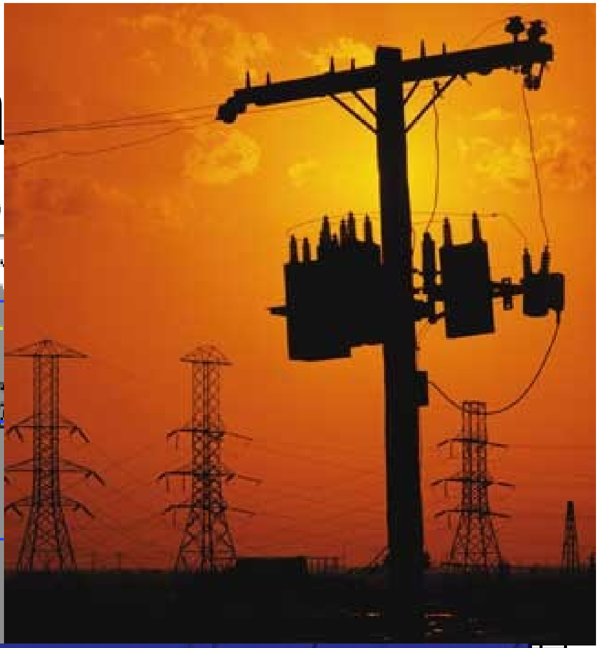
- **What are the risks?**

Baker et al.

- What are the economic impacts?
- What are the societal impacts?



A large space storm in 1989 caused currents which damaged this transformer and shut off power for six million people for nine hours.



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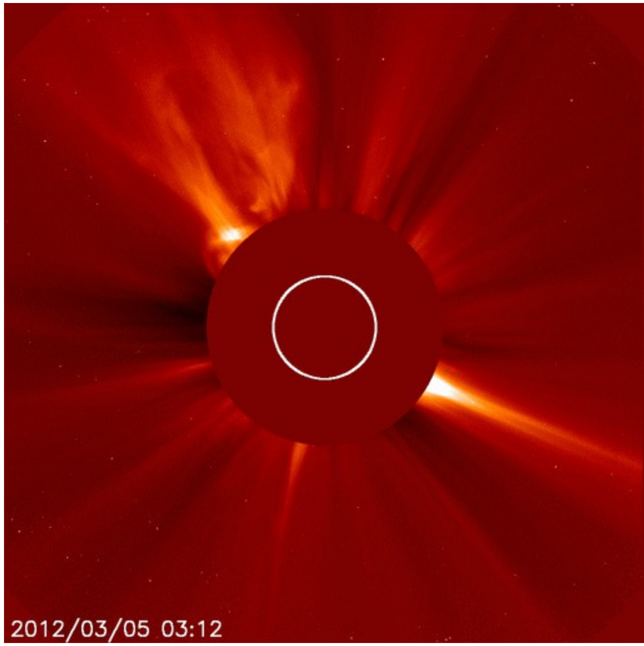
Why is space weather so important?

Solar wind-Earth interaction



- **Generates Electrical Currents and cause a power outage, energizes particles (radiation), moves plasma and affect our communication and navigation systems**
- **heat the upper atmosphere, causing it to expand, increasing drag on LEO satellites**

The 2008 US National Research Council report estimated the cost if a September 1859 sized CME hit us; first it could take us 10 years to recover, and cost could be between $1 trillion and $2 trillion (in the first year alone) to repair the damage.

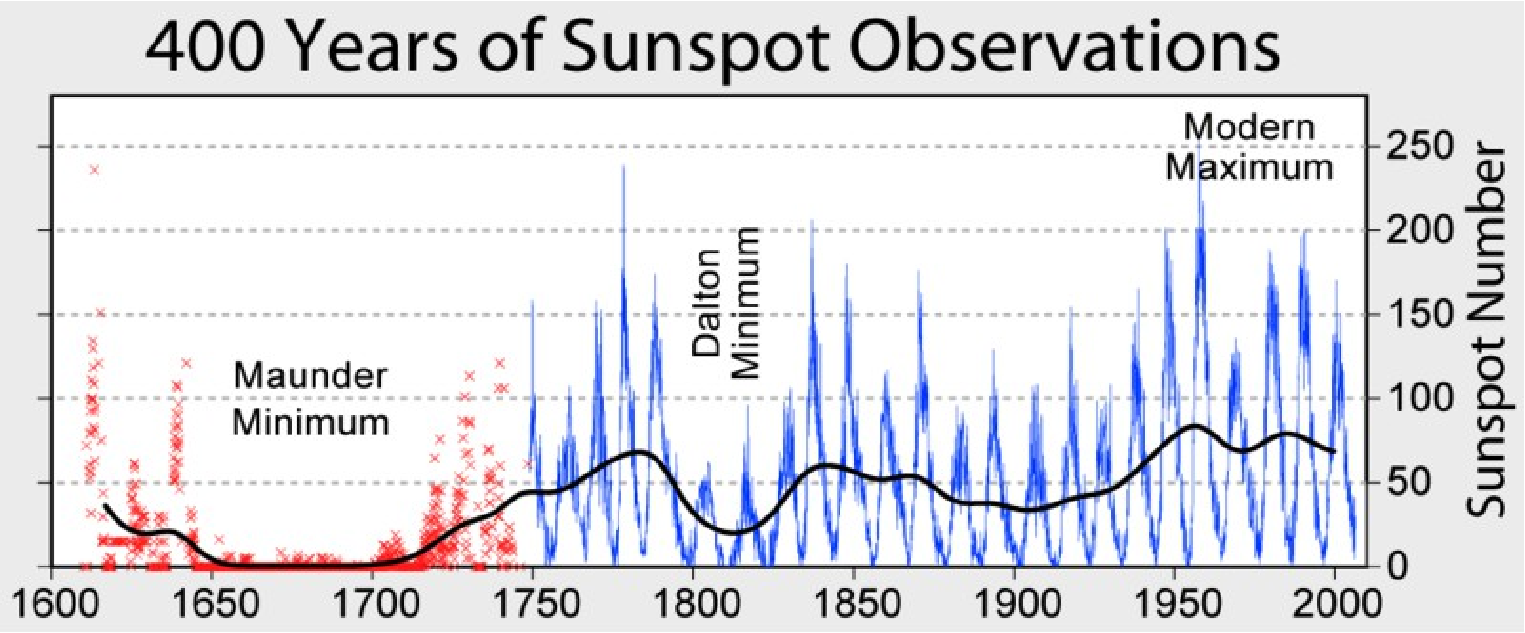
Other large economic events

- San Francisco Earthquake ….. 1906 ………….$ 500B
- Hurricane Katrina ……………. 2005 ………… 120B
- Annual loss from Electric interruption ……..$ 80B
- North American Power Grid Blackout ……..$ 30B
- GEO satellite revenue loss ………………… $ >25B
- Blackout of East Coast ………. 1955 …………..$ 10B
- Mt Lassen Volcanic Eruption .. 1915 ………….$ 5B
- Quebec Blackout ………………. 1906 ………….$ 2B

Baker et al.

Few notes about the solar cycle of the Sun

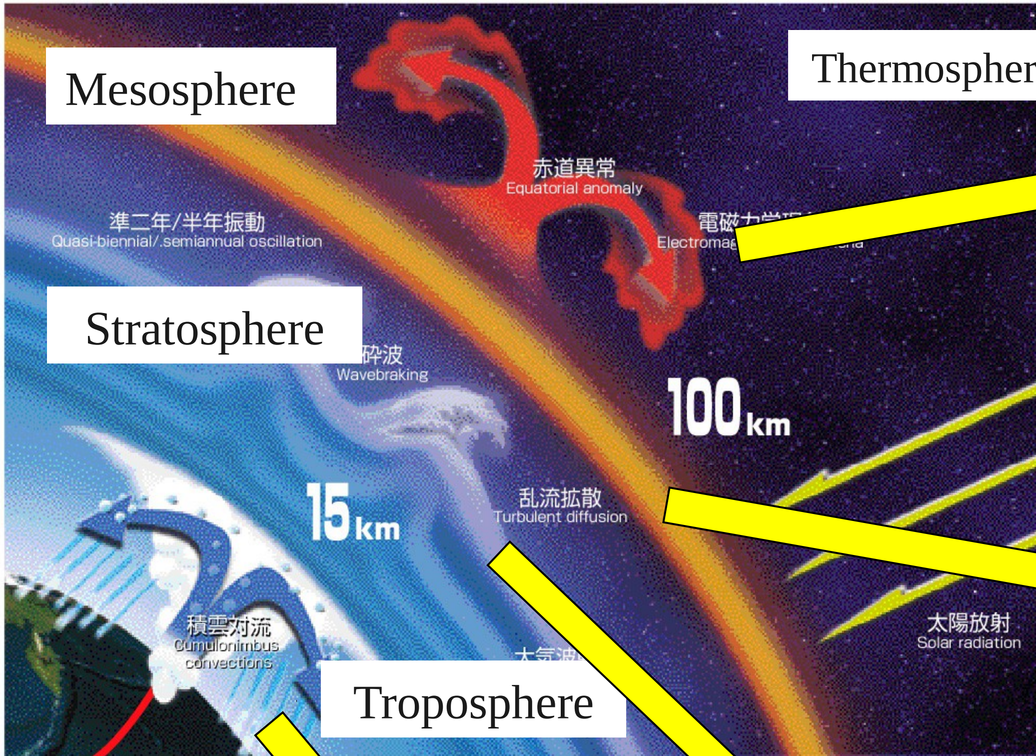
The **solar cycle** (or **solar magnetic activity cycle**) has a period of about 11 years. The cycle is observed by counting the frequency and placement of sunspots visible on the Sun. Solar variation causes changes in space weather and to some degree weather and climate on Earth.

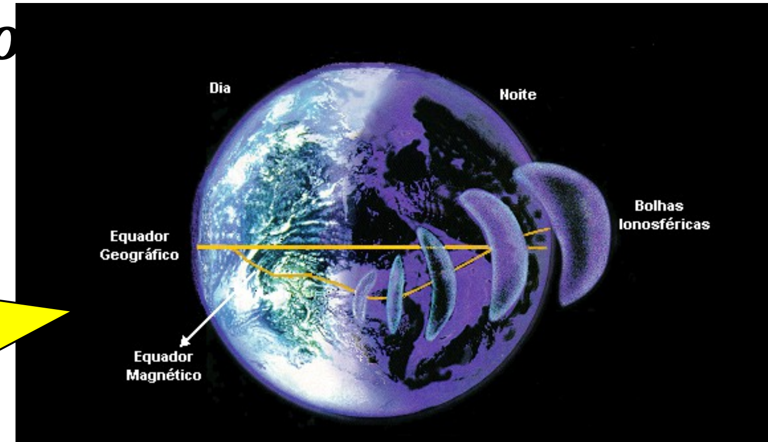


Space Weather:

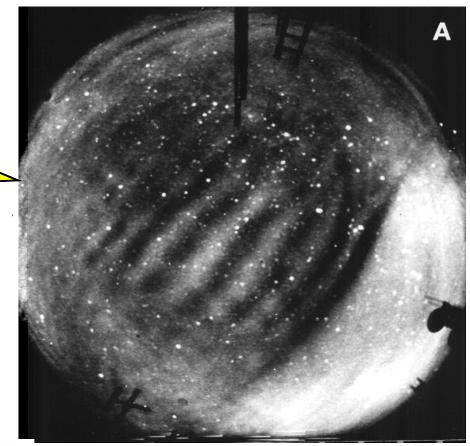
Sources from BELOW

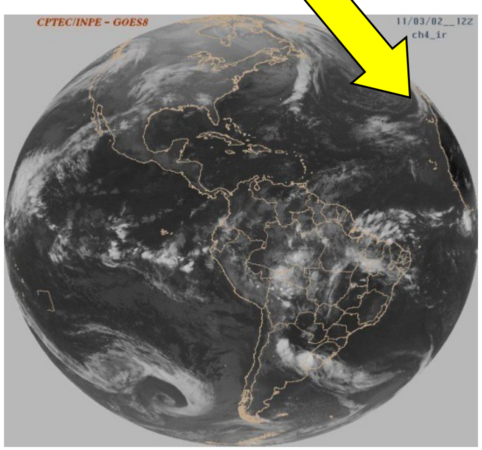
Convections and wave energy propagation



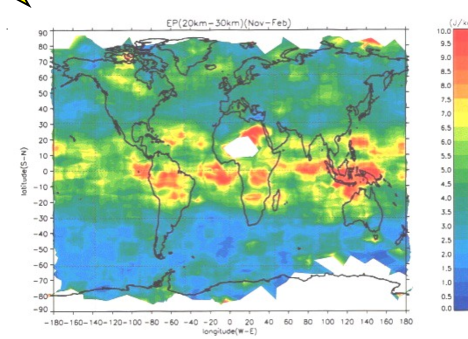


Plasma bubbles in the ionosphere





Tropospheric convections



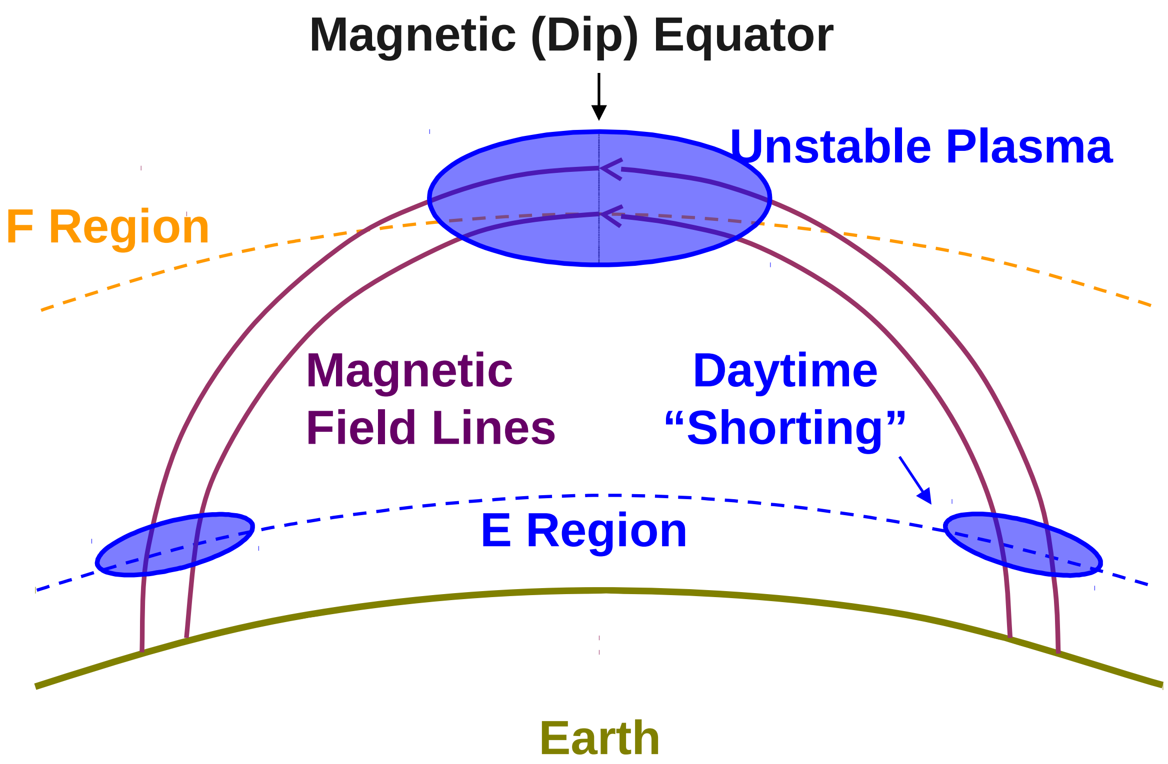
Upward Gravity wave propagation

Why Do Disturbances Form?

Unique Equatorial Magnetic Field Geometry

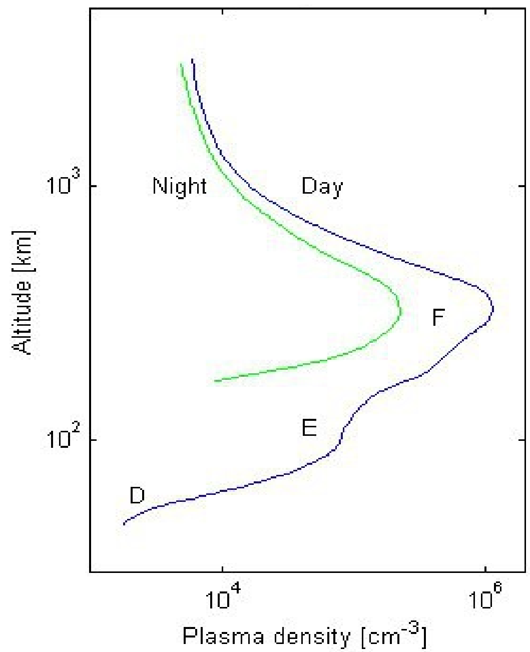
Equatorial scintillation occurs because plasma disturbances form with horizontal magnetic field

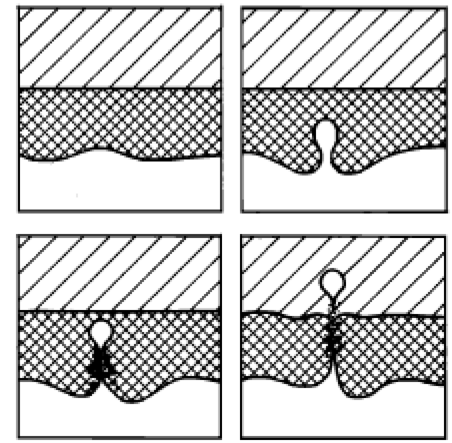
- Plasma moves easily along field lines, which act as conductors
- Horizontal field lines support plasma against gravity– unstable configuration
- E-region "shorts out" electrodynamic instability during



Development of plasma structures

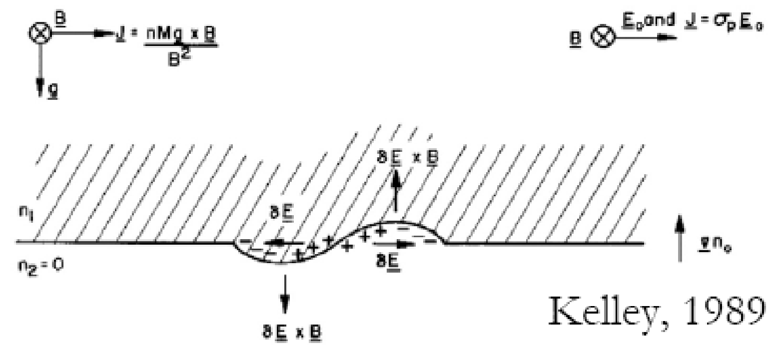
- **The dense density near the F-region peak is supported against gravity by a horizontal magnetic field resulting in a "heavy fluid" on a "light fluid".**





Woodman and LaHoz, 1976

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

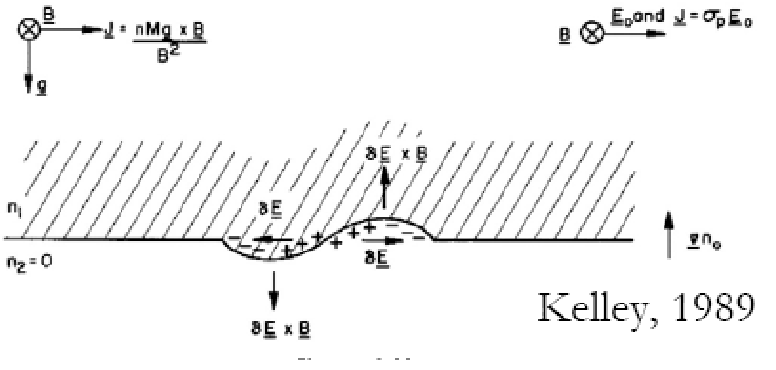


Kelley, 1989

Influences from below

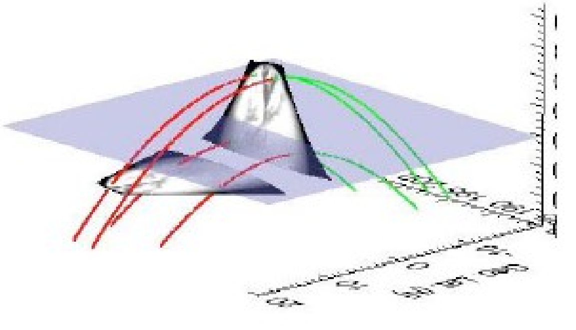
- The dense density near the F-region peak is supported against gravity by a horizontal magnetic field resulting in a "heavy fluid" on

- A small perturbation in the interface generates an electric field
  - δE×B pushes the interface further up

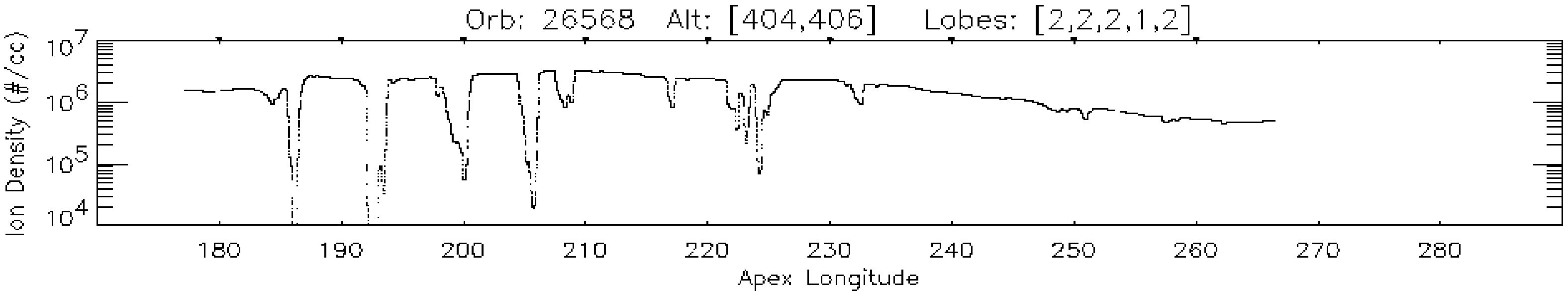


- Radio waves passing through the irregularities diffract producing signal fading and strong scintillations even at L freque

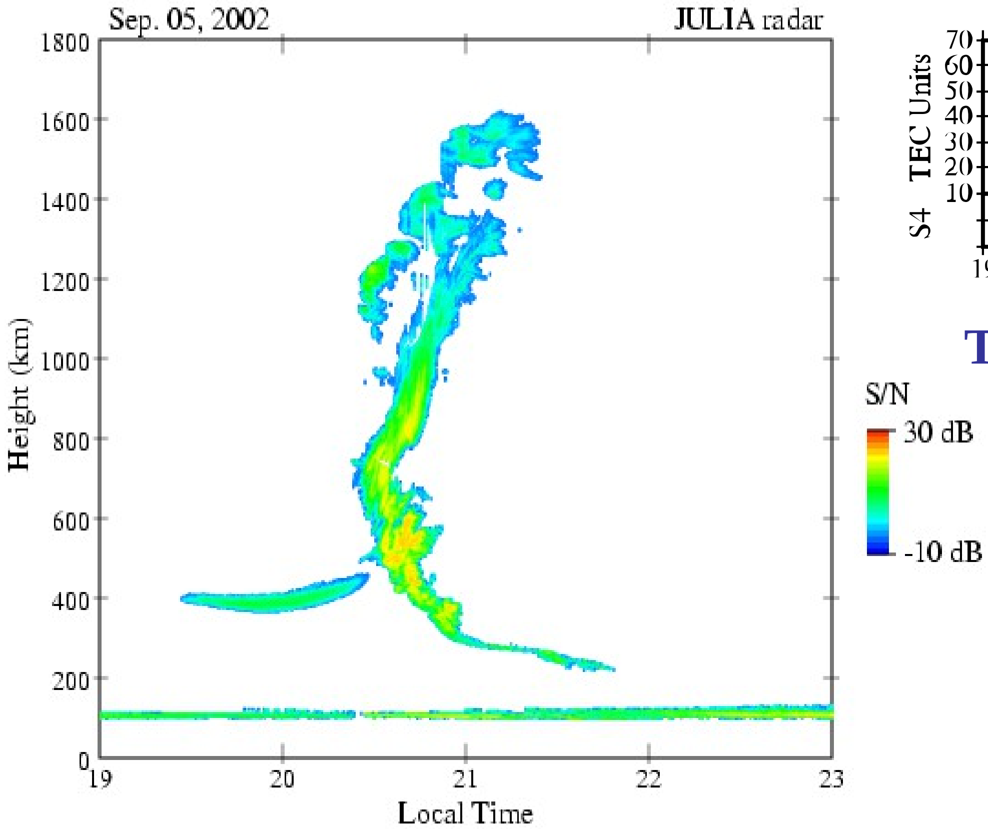
- Must know what is going on along the entire field line to understand all the physics.



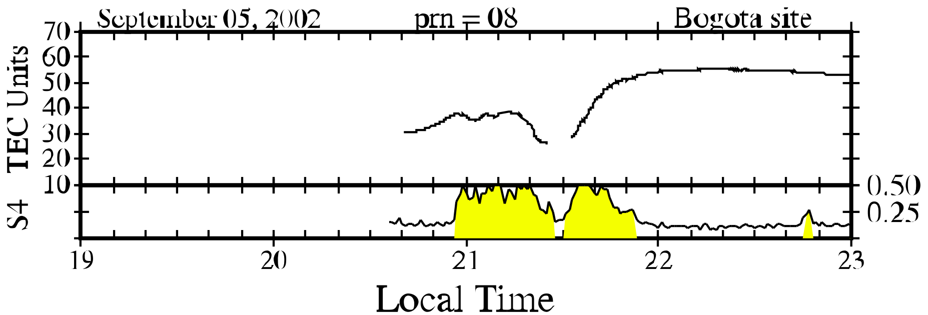
Plasma Bubbles observations using different techniques



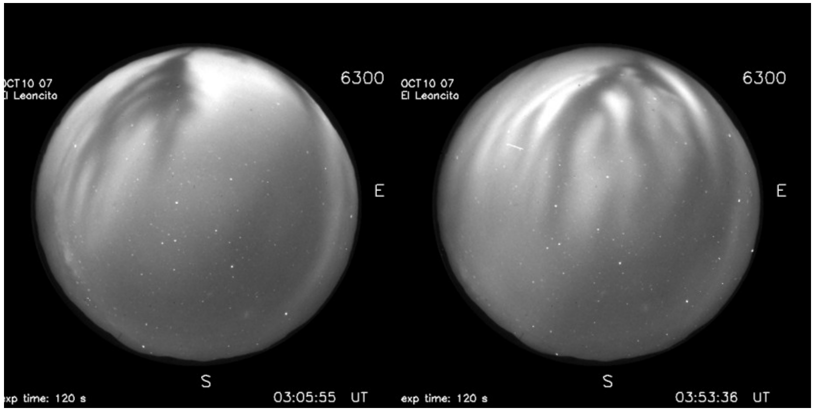
AE-E Satellite



Jicamarca Coherent radar

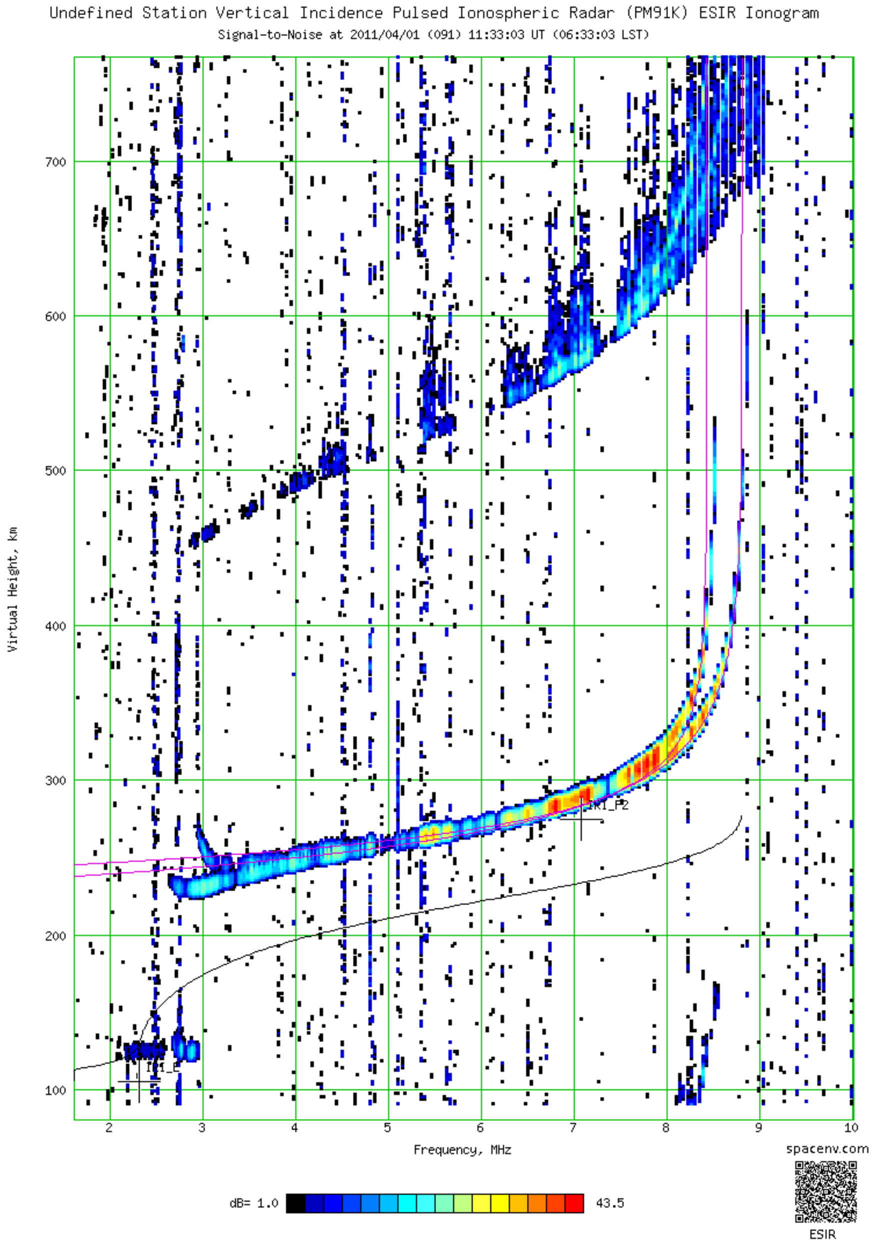


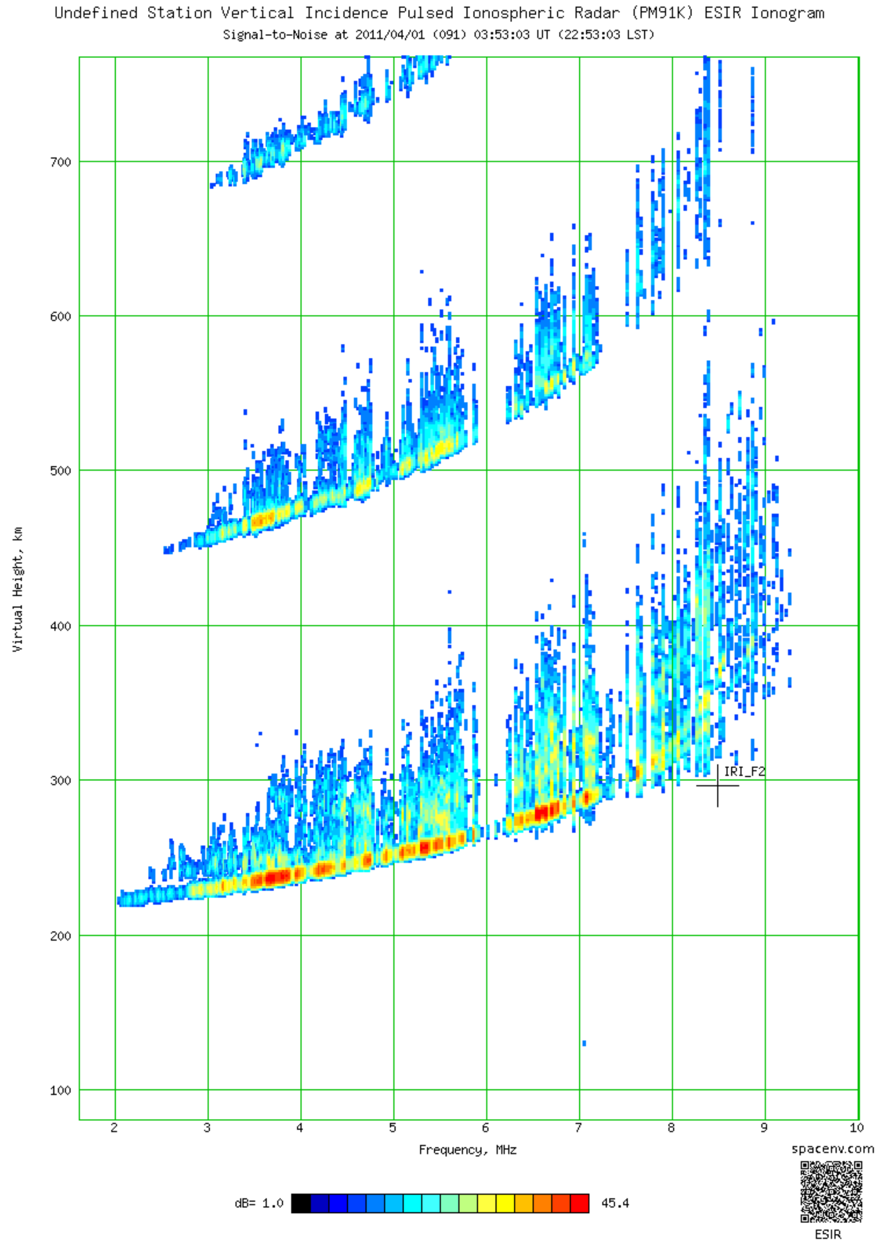
TEC depletion and GPS scintillations



Airglow imager

Real –Time calculation of densities using ESIR





Global Positional System (GPS)

The GPS system is made up of a satellite constellation of 24 working satellites and three spares. Each one circles the Earth twice each day at an altitude of 20,200 km. The orbits are designed so at least four satellites are always within line of sight from almost any place on earth.

A constellation of GPS satellites broadcasts precise timing signals by radio to GPS receivers which allow them to accurately determine their location (longitude, latitude, and altitude) in real time.

Impacts due to Ionospheric Scintillations

Principal impacts of ionospheric scintillation on GPS performance:

- Loss of lock / outages
- Induced ranging errors

Consequences of these effects on GPS positioning accuracy depends on constellation geometry

For example, losing multiple satellites in the same region of the sky can lead to large errors

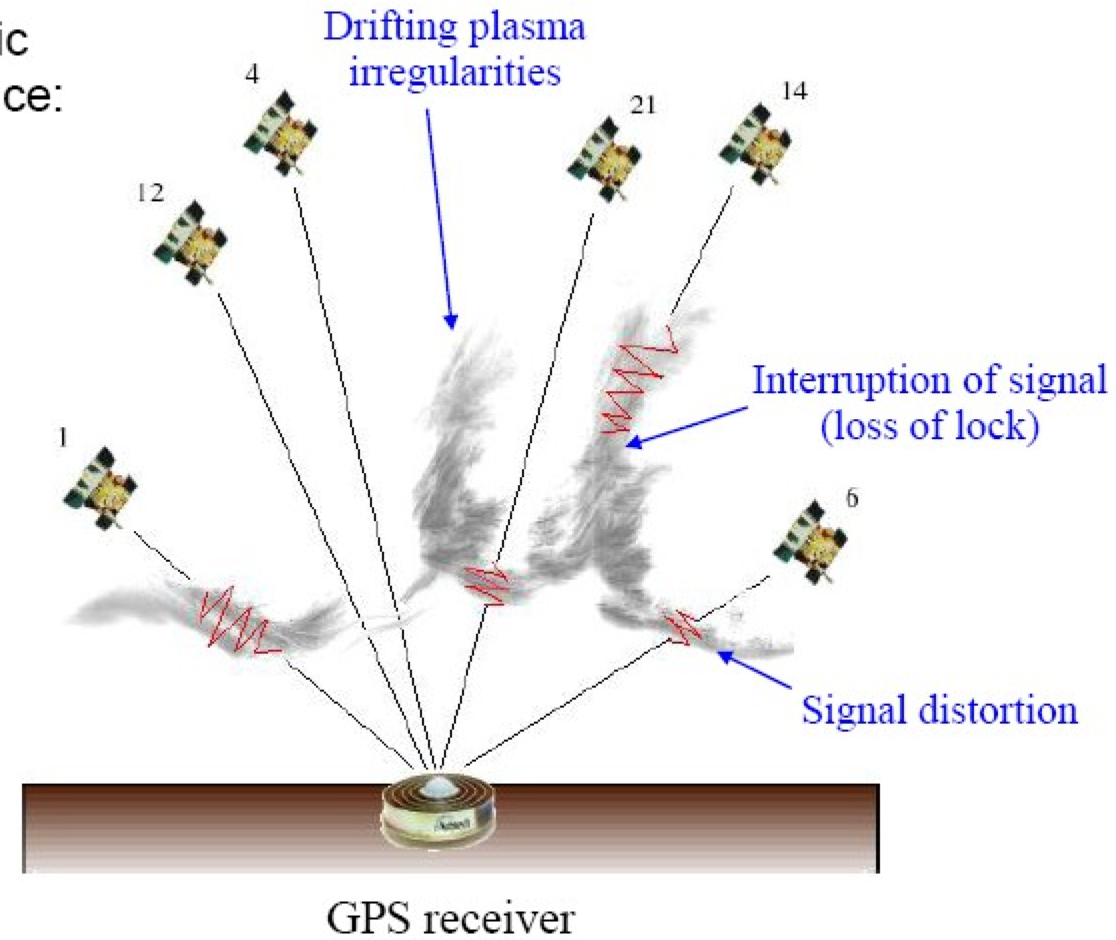


Figure Courtesy of C. Carrano, BC

What happens to a radio-wave when it crosses a plasma bubble

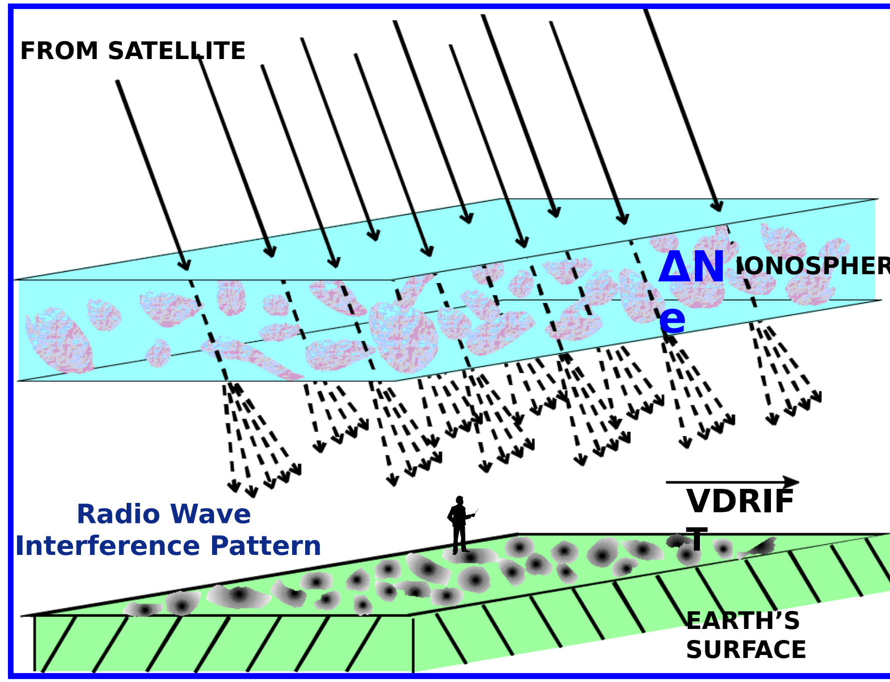
$$\tau_d = R/c + \frac{r_e c}{2\pi}\frac{N_{tot}}{f^2}$$

$$N_{tot} = \int N_e(z)dz$$

$$\varphi = 2\pi f R/c - r_e c \frac{N_{tot}}{f}$$

Phase change due to ionized layer $\delta\varphi$

$$\delta\varphi \approx 5 \times TEC \text{ radians}$$



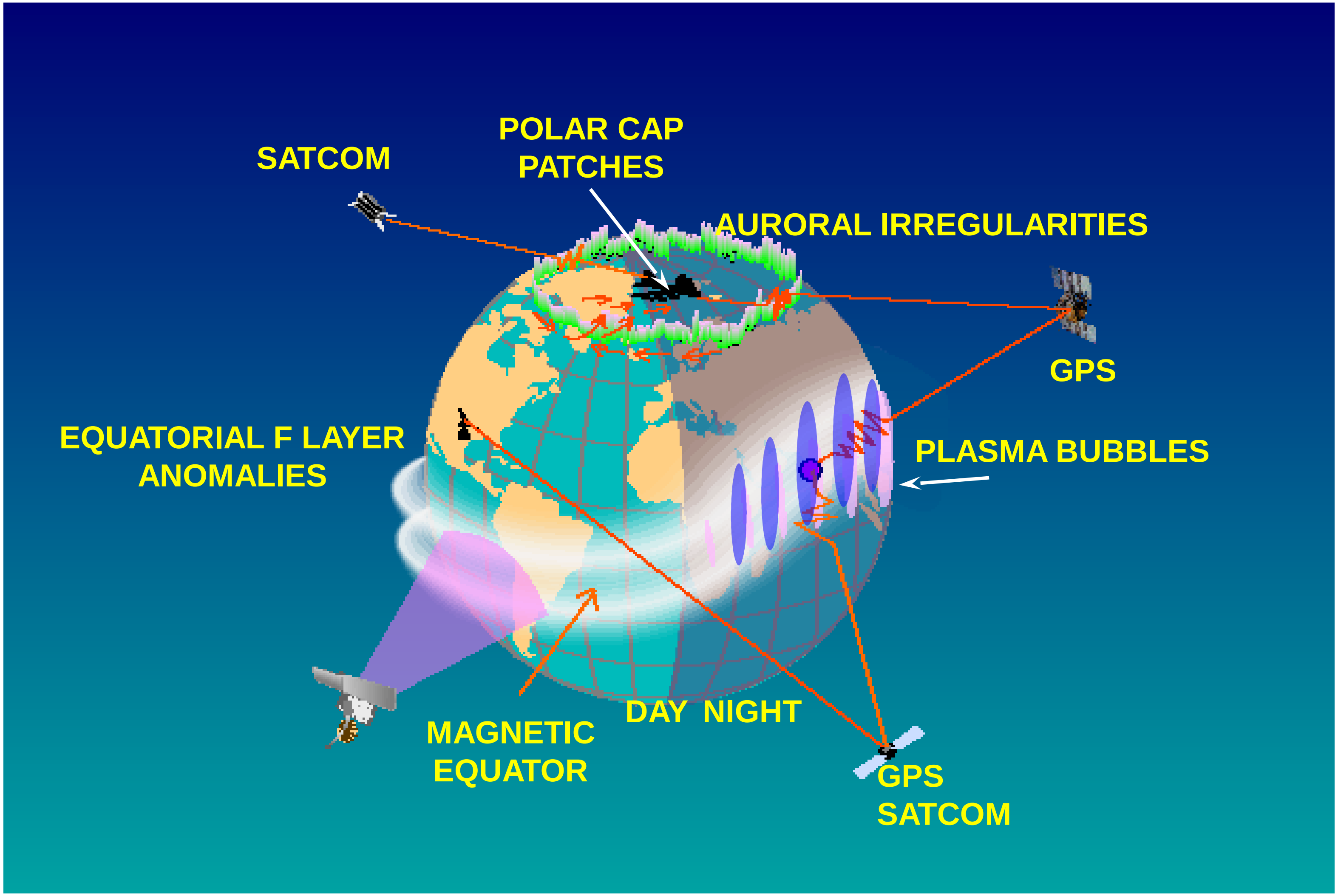
- Phase variations on wavefront cause diffraction pattern on ground
- A phase changes of ~ π radians (i.e., 0.6 TEC units) required for total destructive interference
- But the variations must occur over limited spatial scale (Fresnel zone)

Implications for the Ionosphere

So that means at L1 we need ~0.6 TEC unit variations over spatial scales of a few 100 meters to achieve strong scintillation; lesser variations will cause correspondingly weaker intensity fluctuations

- Solar max TEC ~ 50-100
  - Small relative density fluctuations required
- Solar min TEC ~ 1-5 (nighttime)
  - Large relative density fluctuations required
- Consistent with expectations, GPS scintillations are generally weak during solar minimum
- Scintillation impacts on GPS are limited to solar max periods (3-4 years around peak)

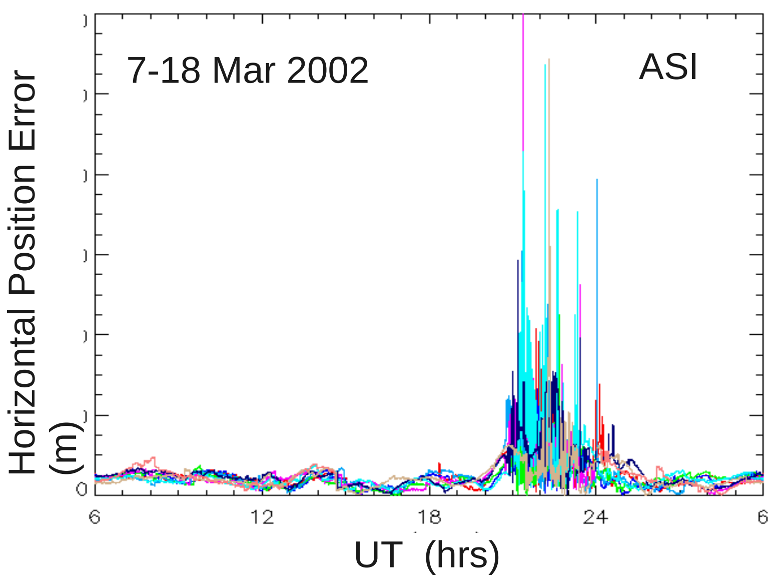
Disturbed Ionospheric Regions and Systems Affected by Scintillation



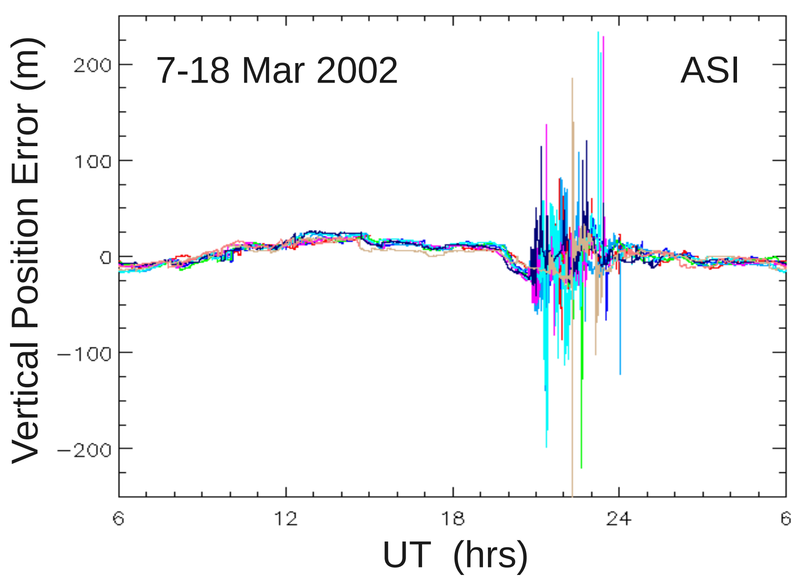
Representative Positioning Errors Near Solar Maximum

Active Ionosphere
21:00-23:30 UT

Position from dual frequency receiver



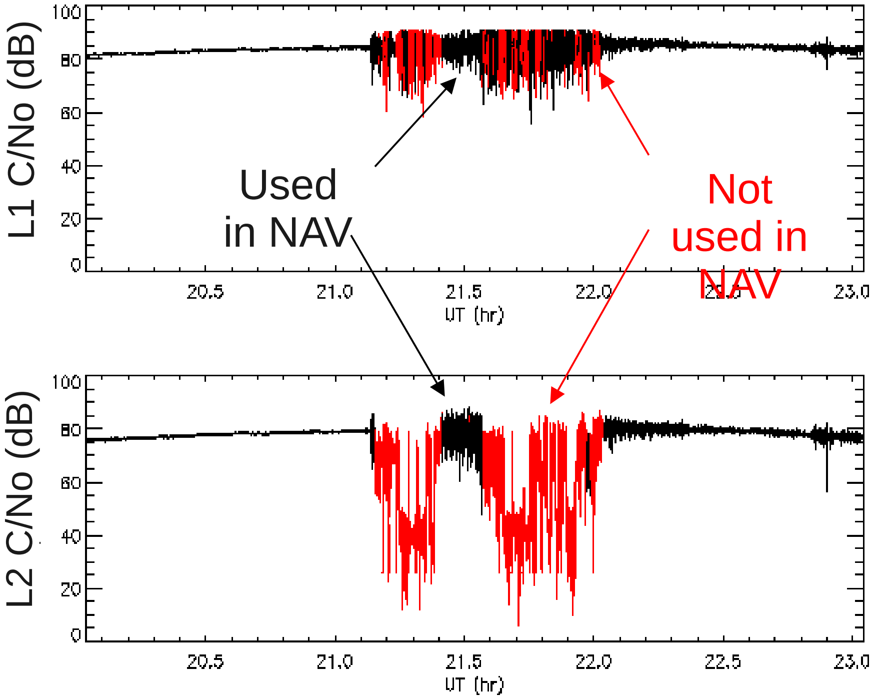
Horizontal Error >100 m



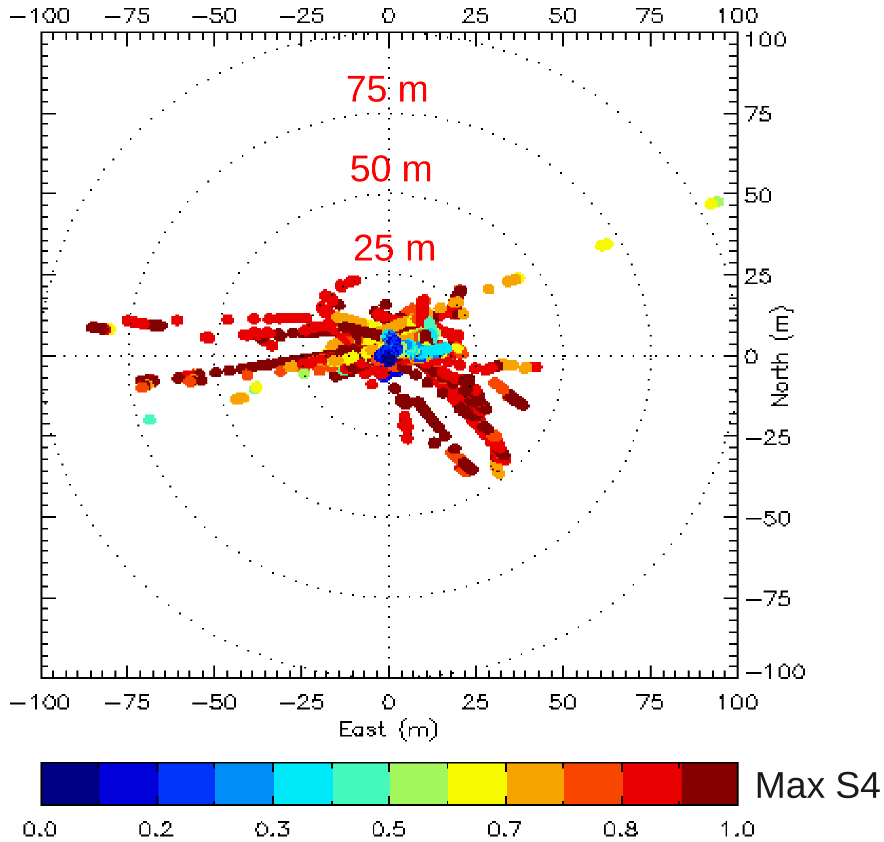
Vertical Error > +/- 200 m

Modelling Effects on Positioning Accuracy

16 Mar 2002, ASI

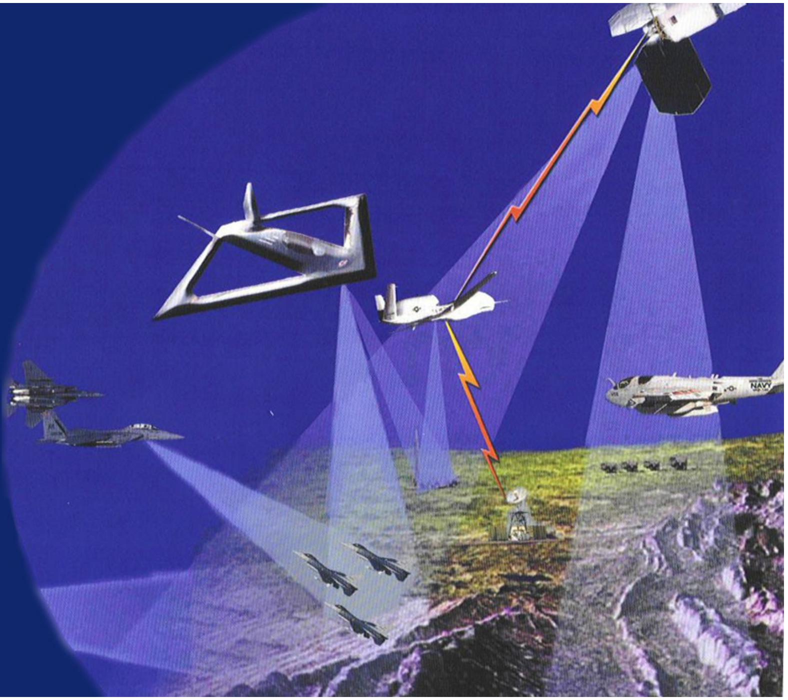


Scintillation Causes Fading of L1 and L2 GPS Signals



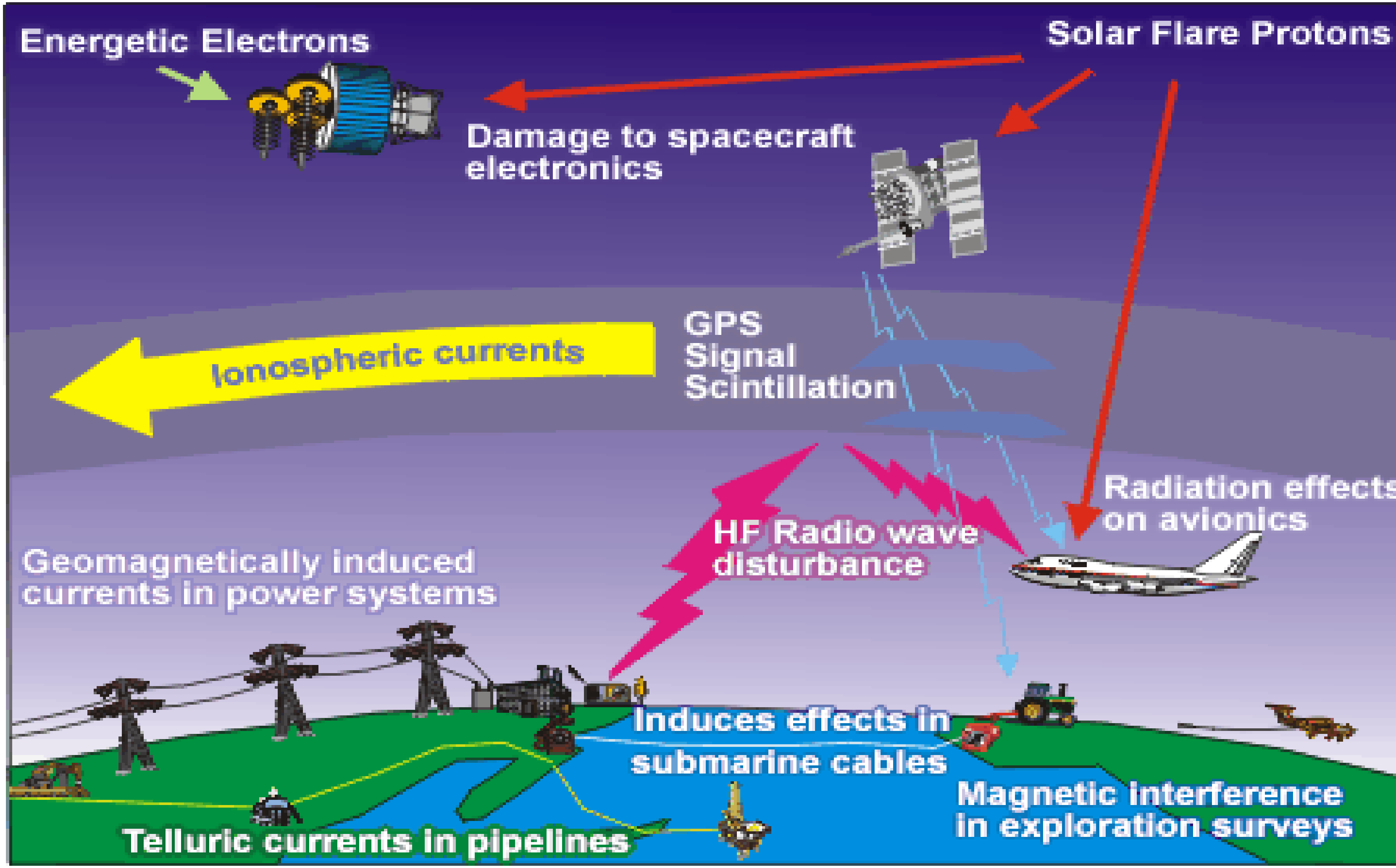
Resulting Positioning Error

Space weather and our communication and navigation systems

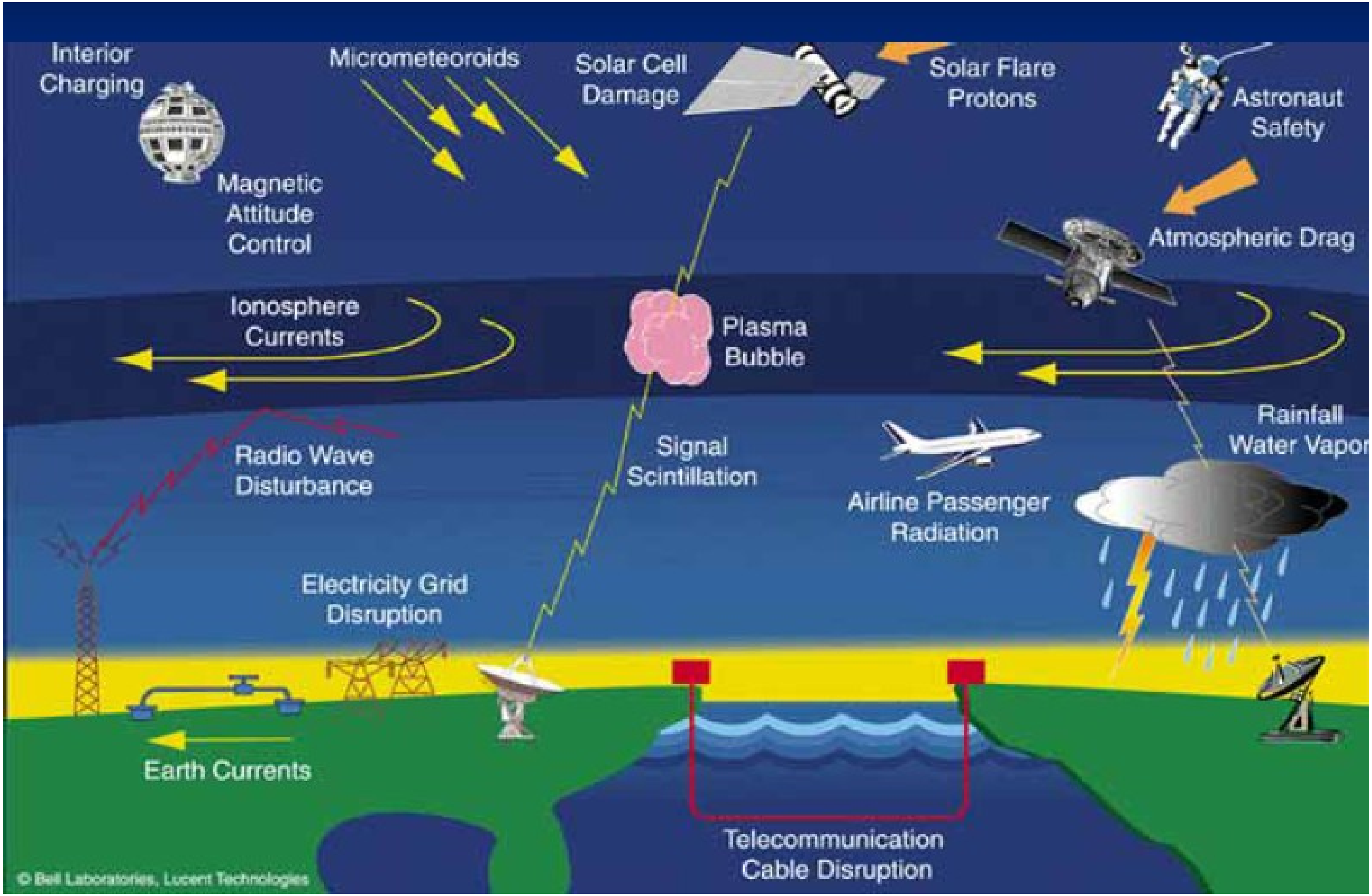


The main factor that affect the navigation and communication system is the variability of structure and dynamics of plasma in our atmosphere.

Space Weather Events



More Space Weather Events

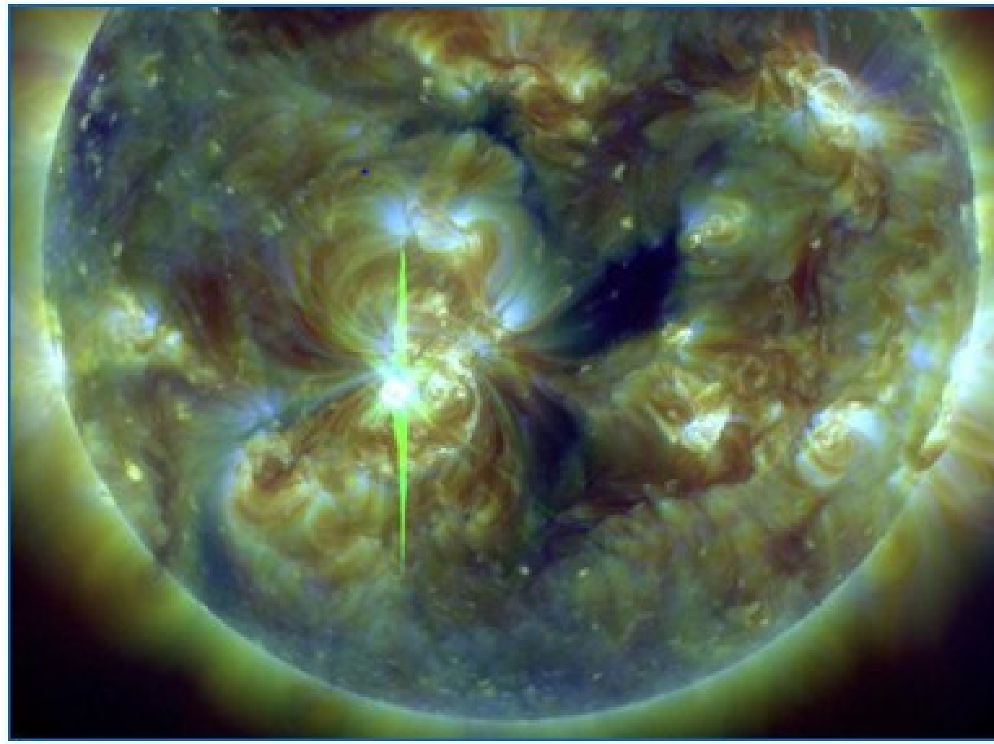


from SpaceWeather.com about a storm reaching Earth on the 10-11 of November.

More from spaceweather.com

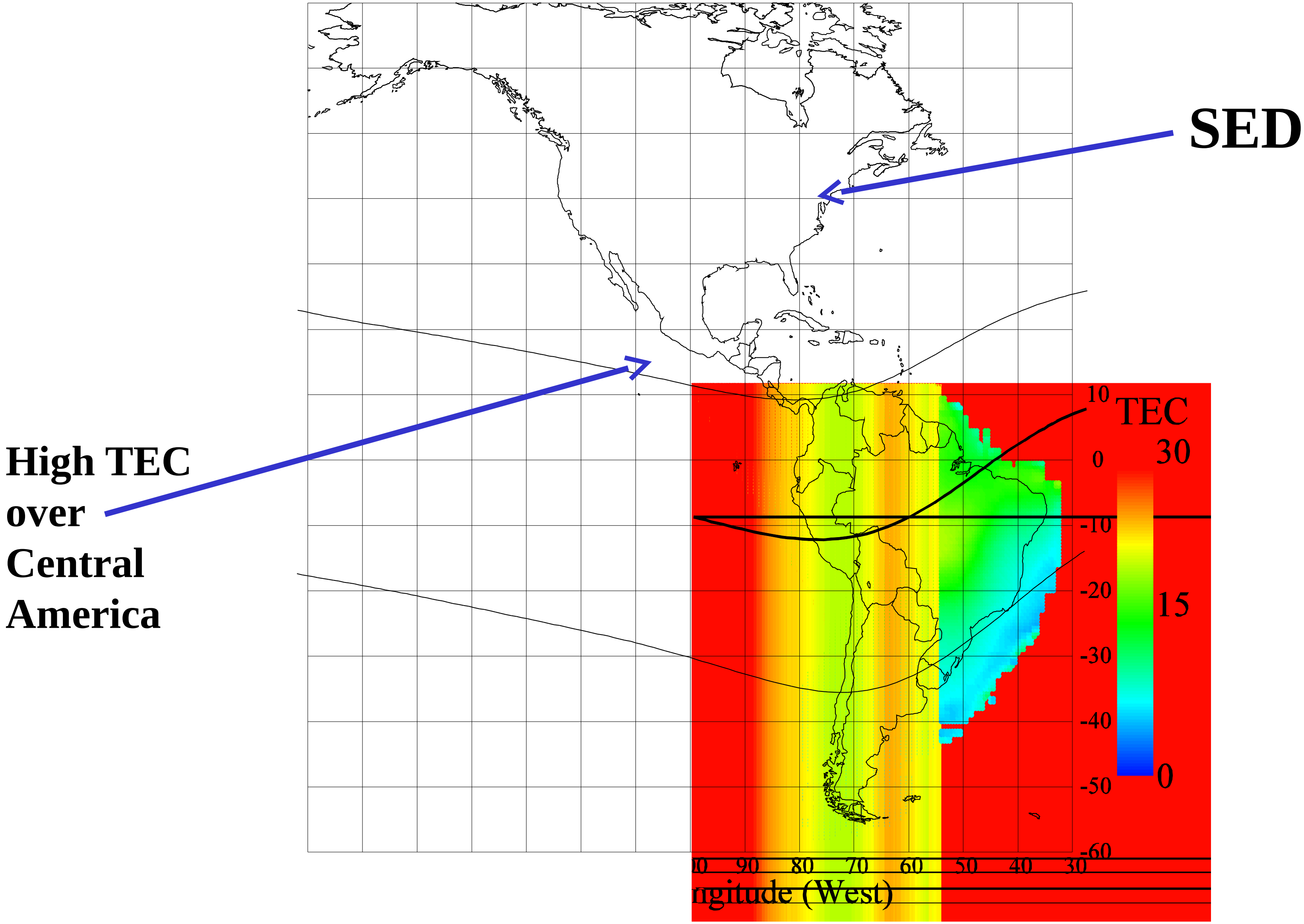
Space Weather News for Nov. 8, 2013
http://spaceweather.com
HIGH SOLAR ACTIVITY: This week, Jupiter-sized sunspot AR1890 unleashed two brief but intense X-class solar flares and numerous M-class solar flares. More eruptions are in the offing as the sunspot turns to directly face Earth over the weekend. X-flare alerts are available from http://spaceweathertext.com (text) and http://spaceweatherphone.com (voice).

ANOTHER X-FLARE: Big sunspot AR1890 is crackling with strong flares. The latest, which peaked on Nov. 8th at 04:32 UT, registered X1 on the Richter Scale of Flares. (Note: Earlier, we underestimated the intensity of this flare as M8.) NASA's Solar Dynamics Observatory recorded a flash of extreme UV radiation from the blast site:

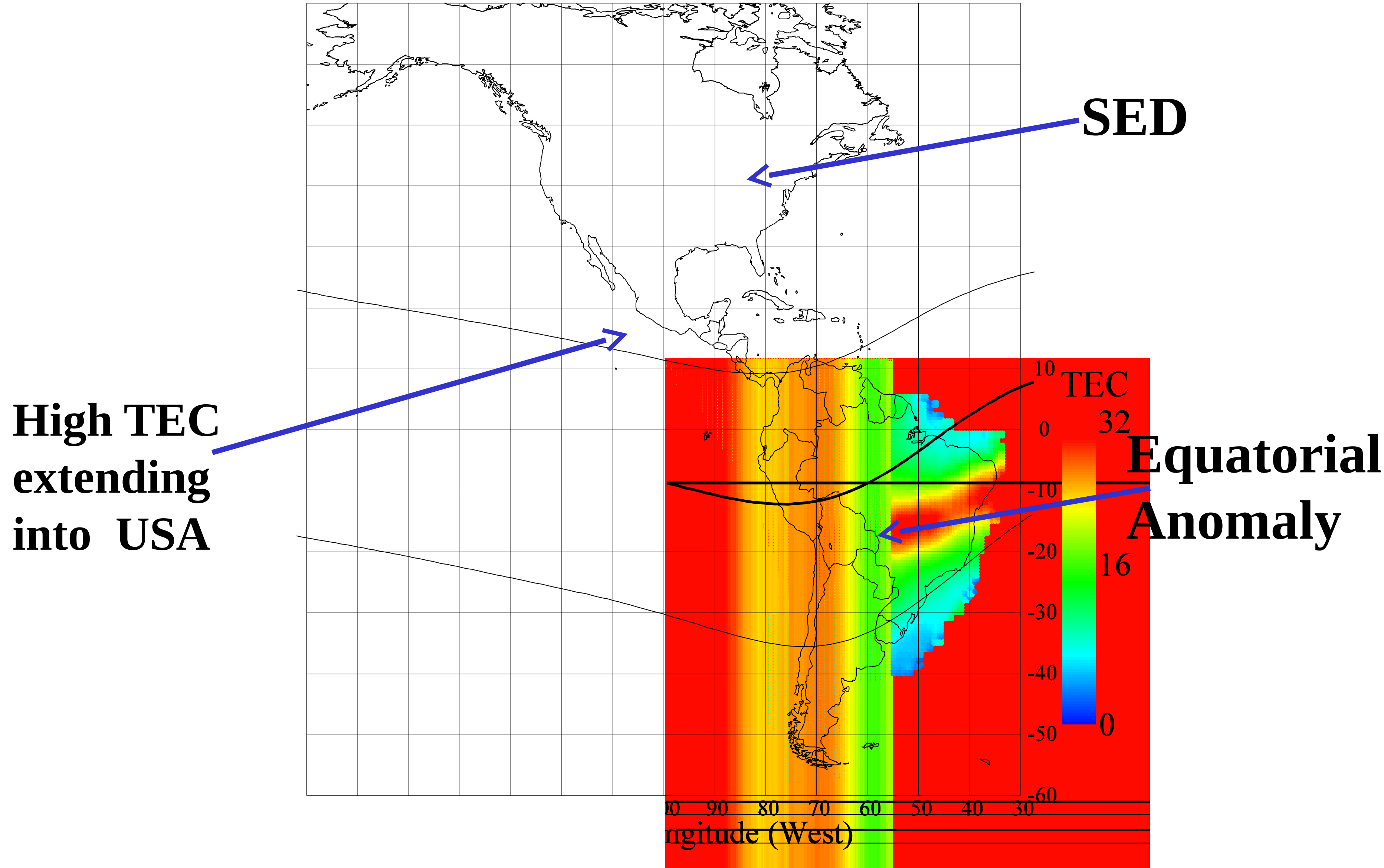


This sunspot has a signature: It tends to produce very brief flares. The X1-flare was no exception as it lasted barely a minute. Brevity mitigates Earth-effects, so this intense flare was not strongly geoeffective--at least, not at first. The explosion also hurled a CME into space: movie. The cloud could deliver a glancing blow to Earth's magnetic field on Nov. 10-11, possibly sparking polar geomagnetic storms.

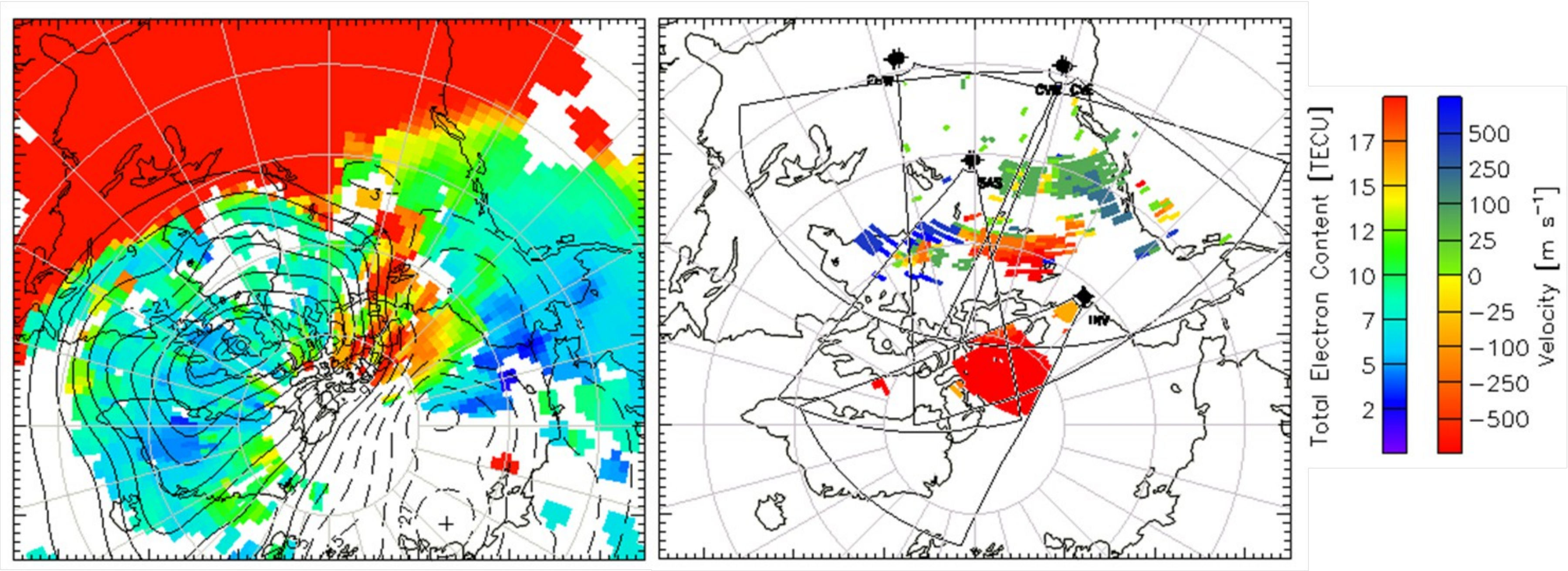
Two channels of high TEC formed over the Americas on August 3, 2010, during a magnetic storm.



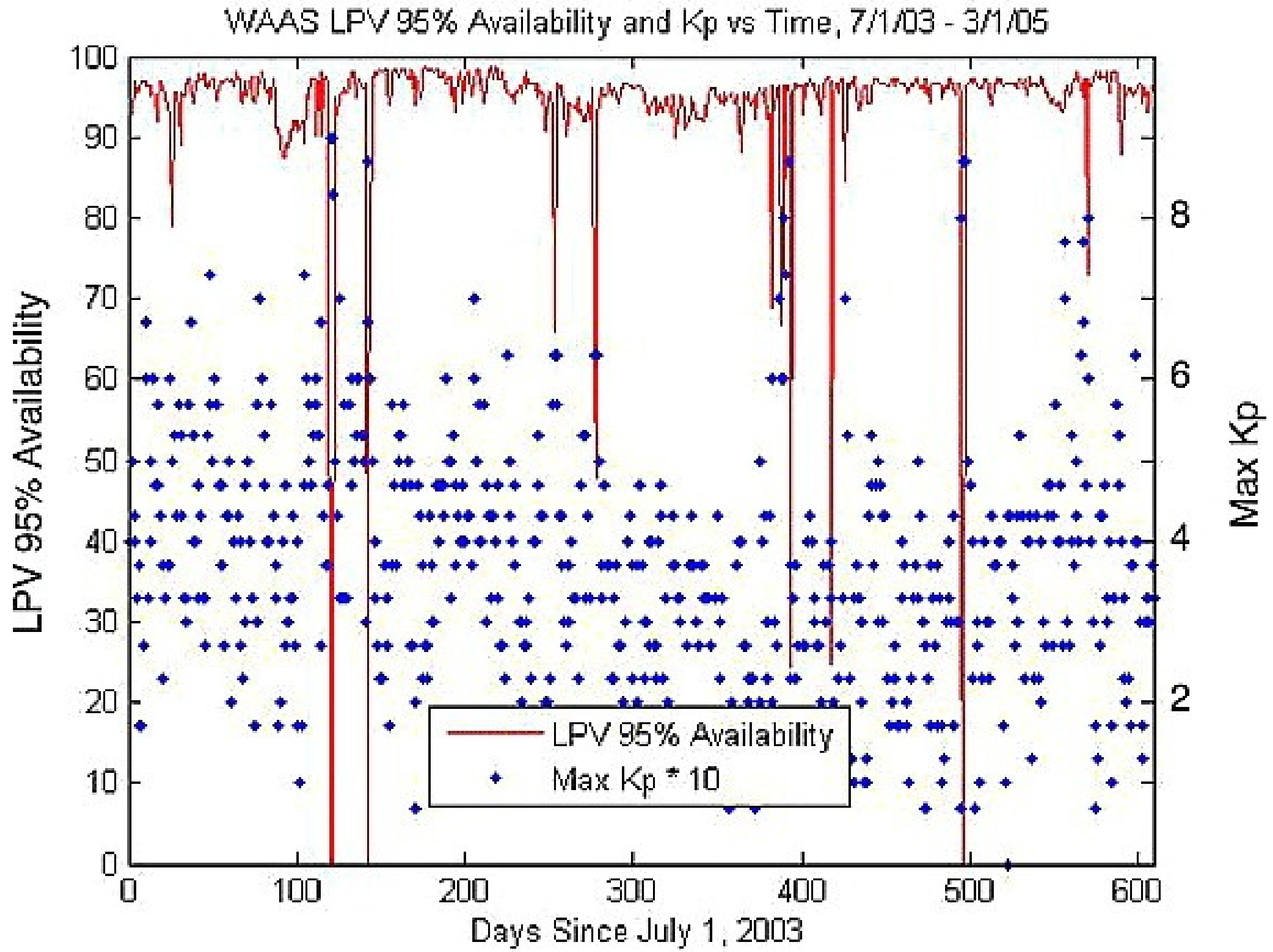
TEC values observed on August 5-6, 2011. Two regions of enhanced TEC were seen, similar to previous plot.



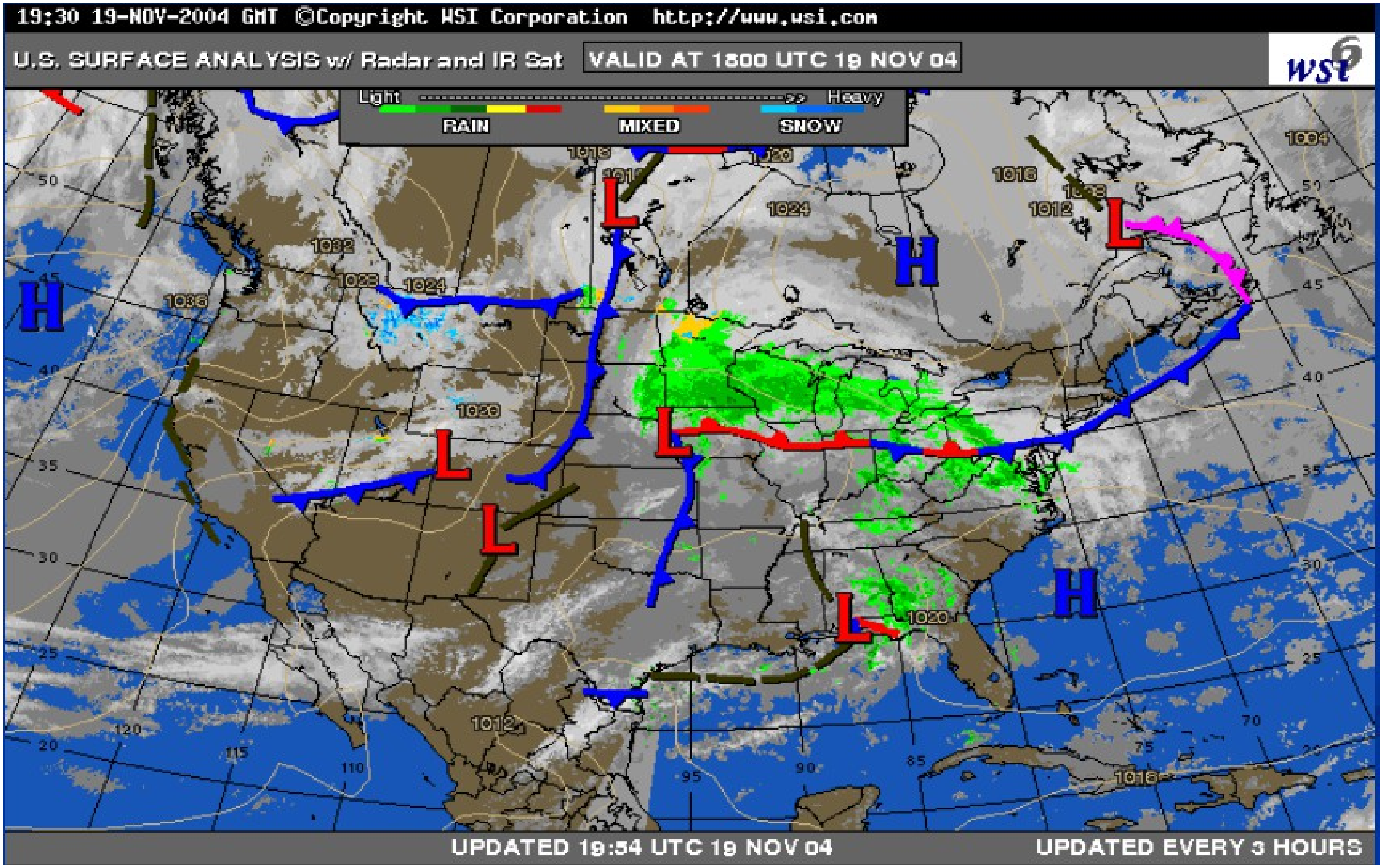
September 26, 2011 19:30 UT (a) Overlay of SuperDARN convection map on GPS/TEC plot showing an SED generating a TOI. (b) Plots of the line-of-sight velocity measured by the SuperDARN radars that observed across the SED feature. The locations of the radars and their fields of view are indicated.



Percent coverage of precision approach service (red line) of the WAAS Localizer Performance with Vertical Guidance (LPV) for 1 July 2003 to 1 March 2005. The "worst case" situation for each day is shown.

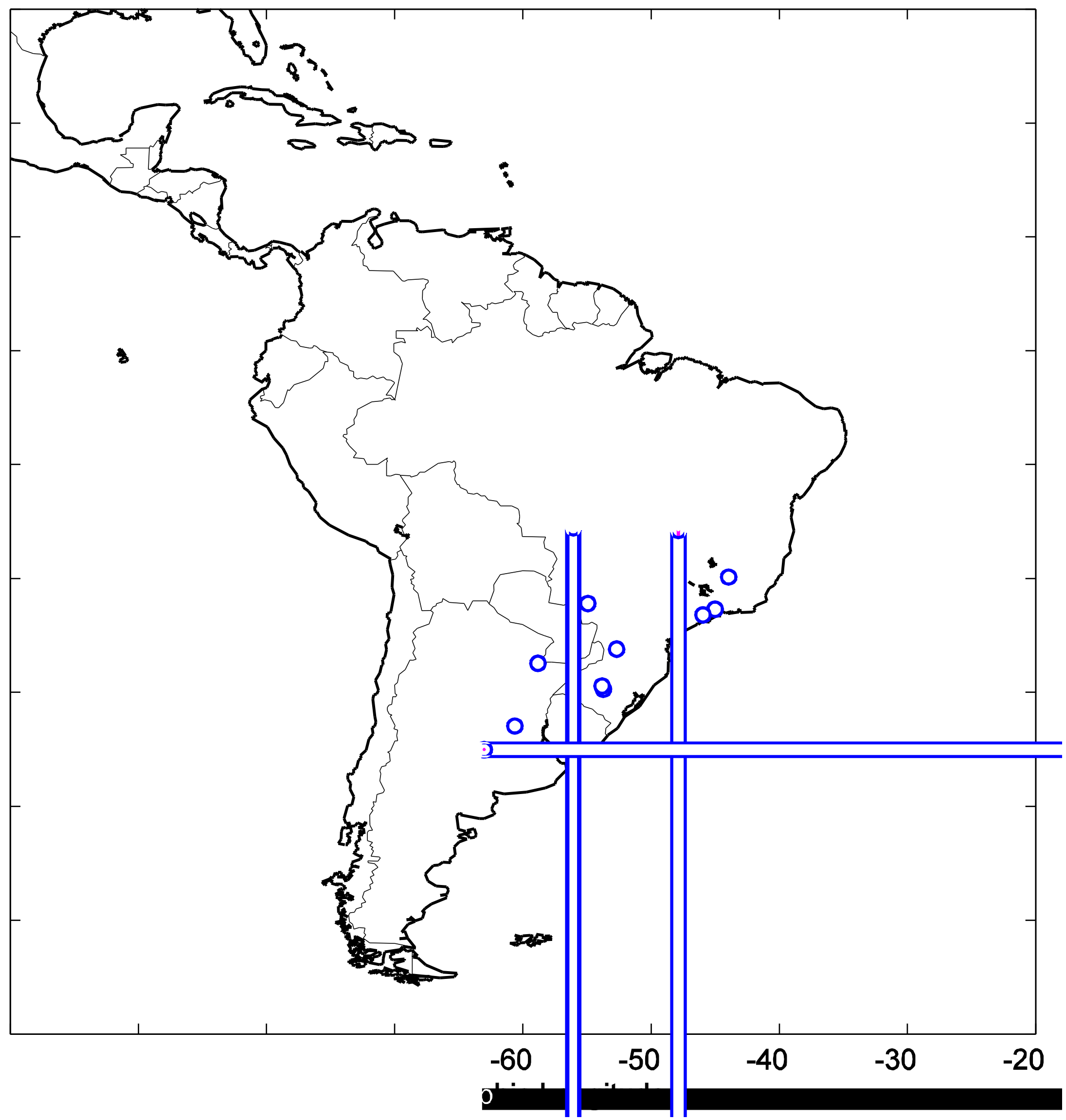


Tropospheric Weather Displays



Need similar displays for Space Weather

Locations of LISN GPS Receivers (47)



Conclusions

- **Space weather is a potential threat to several technological systems. It disrupts communication and navigation systems at all latitudes.**
- **Distributed observatories are the best tool to study space weather issues.**
- **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.**