Earth Science Applications of Space Based Geodesy

DES-7355

Tu-Th 9:40-11:05

Seminar Room in 3892 Central Ave. (Long building)

Bob Smalley
Office: 3892 Central Ave, Room 103
678-4929
Office Hours – Wed 14:00-16:00 or if I'm in my office.

http://www.ceri.memphis.edu/people/smalley/ESCI7355/ESCI_7355_Applications_of_Space_Based_Geodesy.html

Class 15

Does GPS make us dumber…?

GPS directions send Mercedes downstream…

Driver follows GPS directions onto train tracks…

Bus driver follows GPS directions, ignores signs, plows into overpass…

Sat-nav lorry stuck in farm lane - Trucker drives past sign, becomes wedged in small farm lane…

http://www.engadget.com/tag/gps+crash/
http://news.bbc.co.uk/2/hi/uk_news/wales/north_east/7257555.stm

Does GPS make us dumber…?

http://www.engadget.com/tag/gps+crash/
http://news.bbc.co.uk/2/hi/uk_news/wales/north_east/7257555.stm

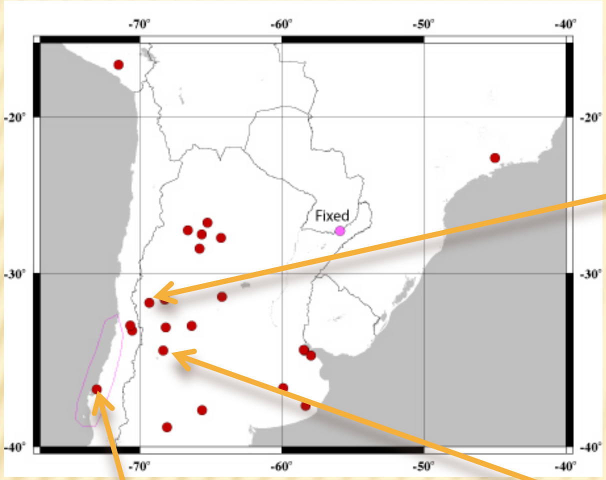
Does GPS make us dumber…?

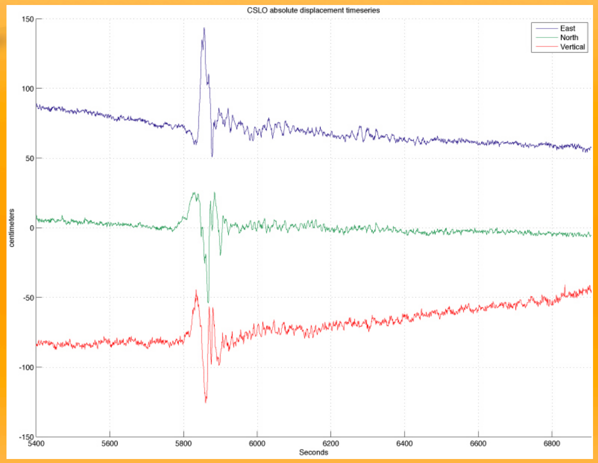
Al Byrd's three-bedroom home, built by his father on the western outskirts of Atlanta, was mistakenly torn down by a demolition company. "I said, 'Don't you have an address?' " a distraught Byrd later recounted. "He said, 'Yes, my GPS coordinates led me right to this address here.' "

http://www.walrusmagazine.com/articles/2009.11-health-global-impositioning-systems/
http://www.calfinder.com/blog/calfinder-news/oops-how-gps-led-contractors-to-demolish-the-wrong-house/

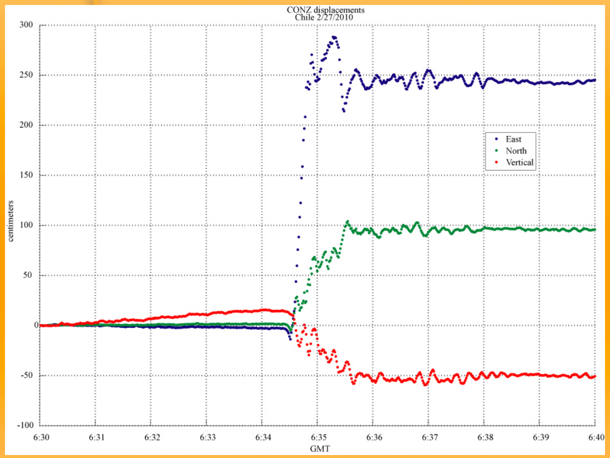
More Hi-Rate GPS from “LARGE” earthquake.

High-Rate GPS Seismograms from the 27 Feb. 2010, M=8.8, Maule Chile Earthquake.

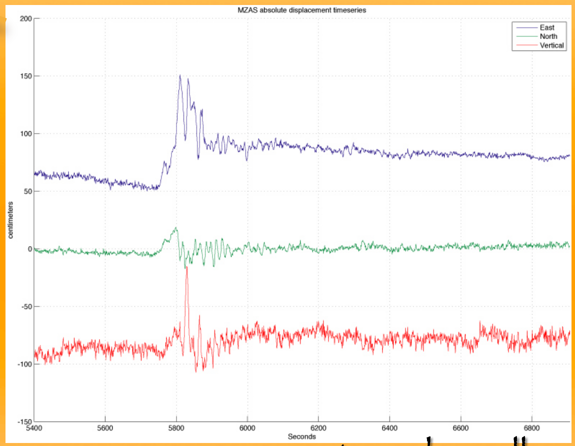




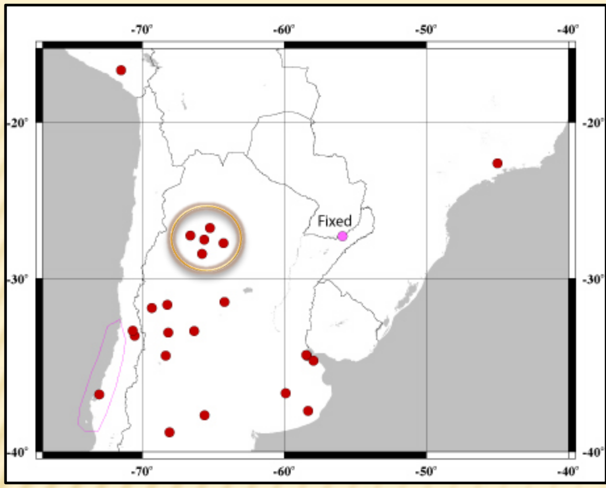
Near-Field, absolute displacement time series with static displacements.



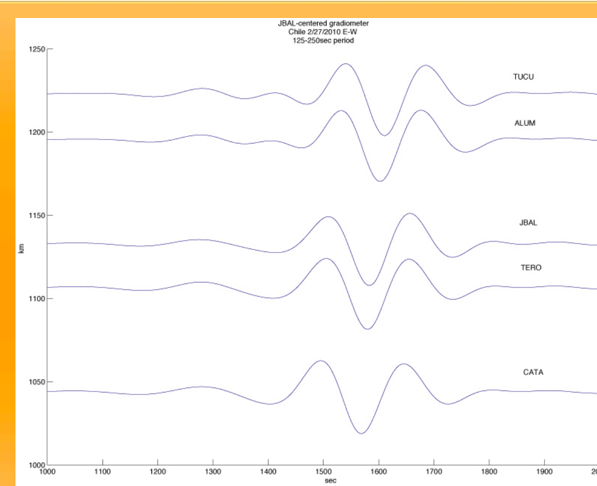
CONZ –absolute displacement coseismic time series



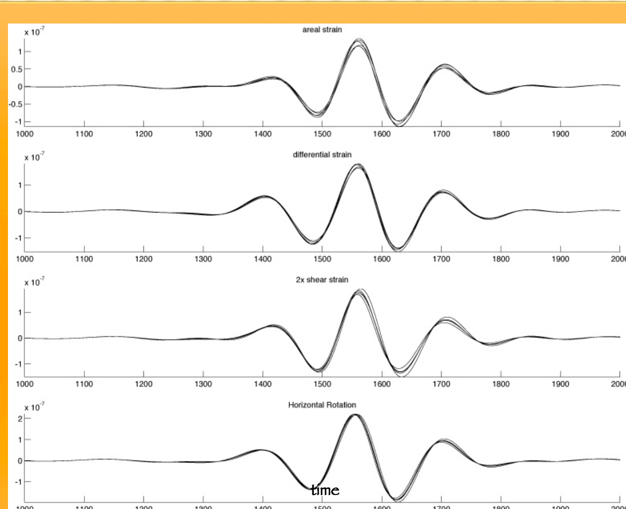
Davis and Smalley, 2009

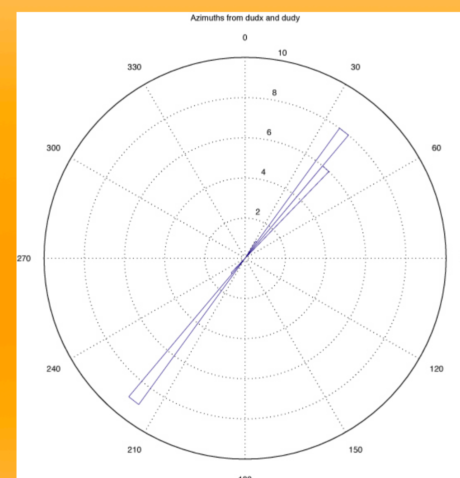


Absolute displacement, band passed (125-250 sec), phase matched filter for dispersion and gradiometry ("array" where wavelength>> spacing).

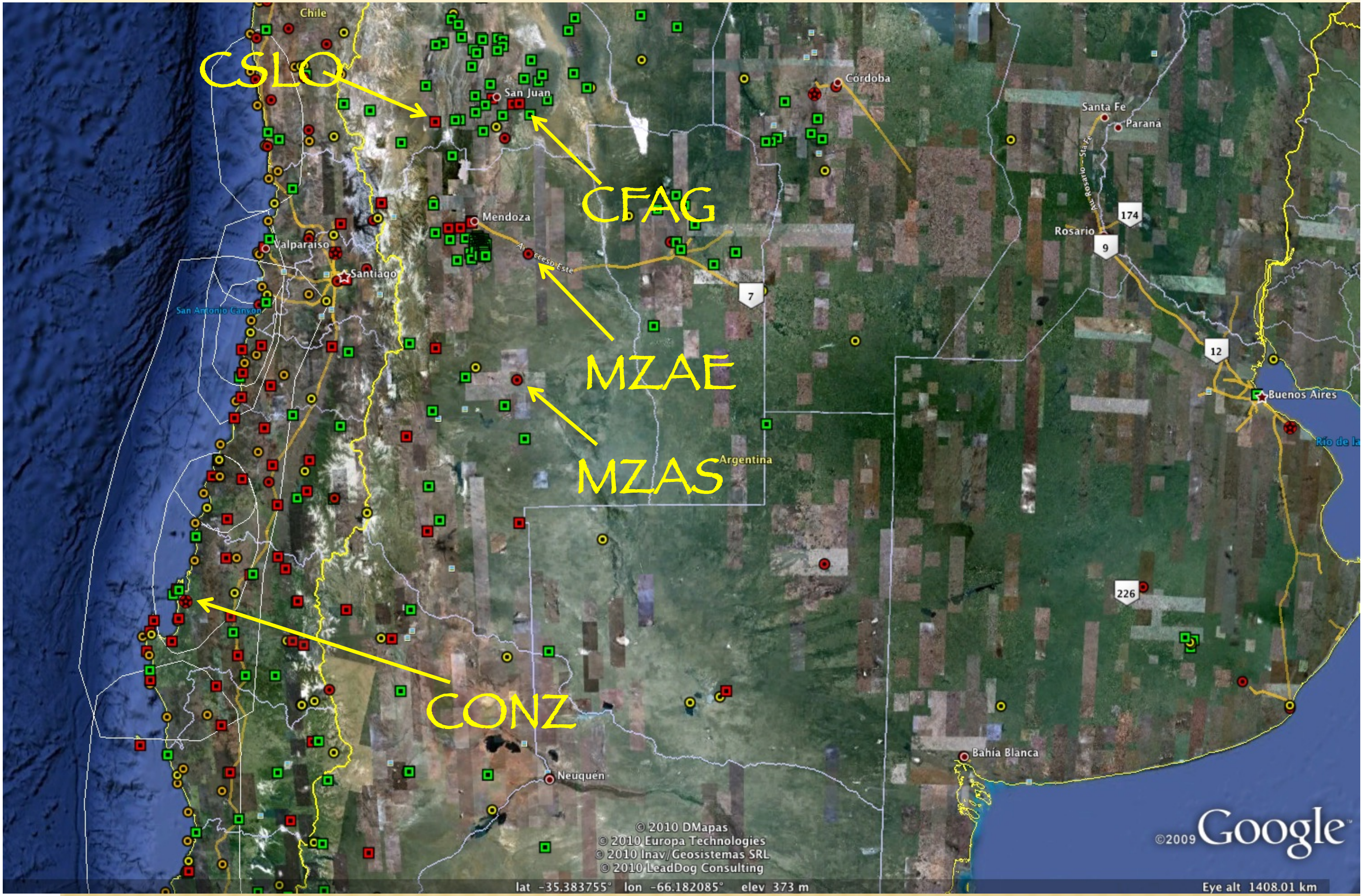


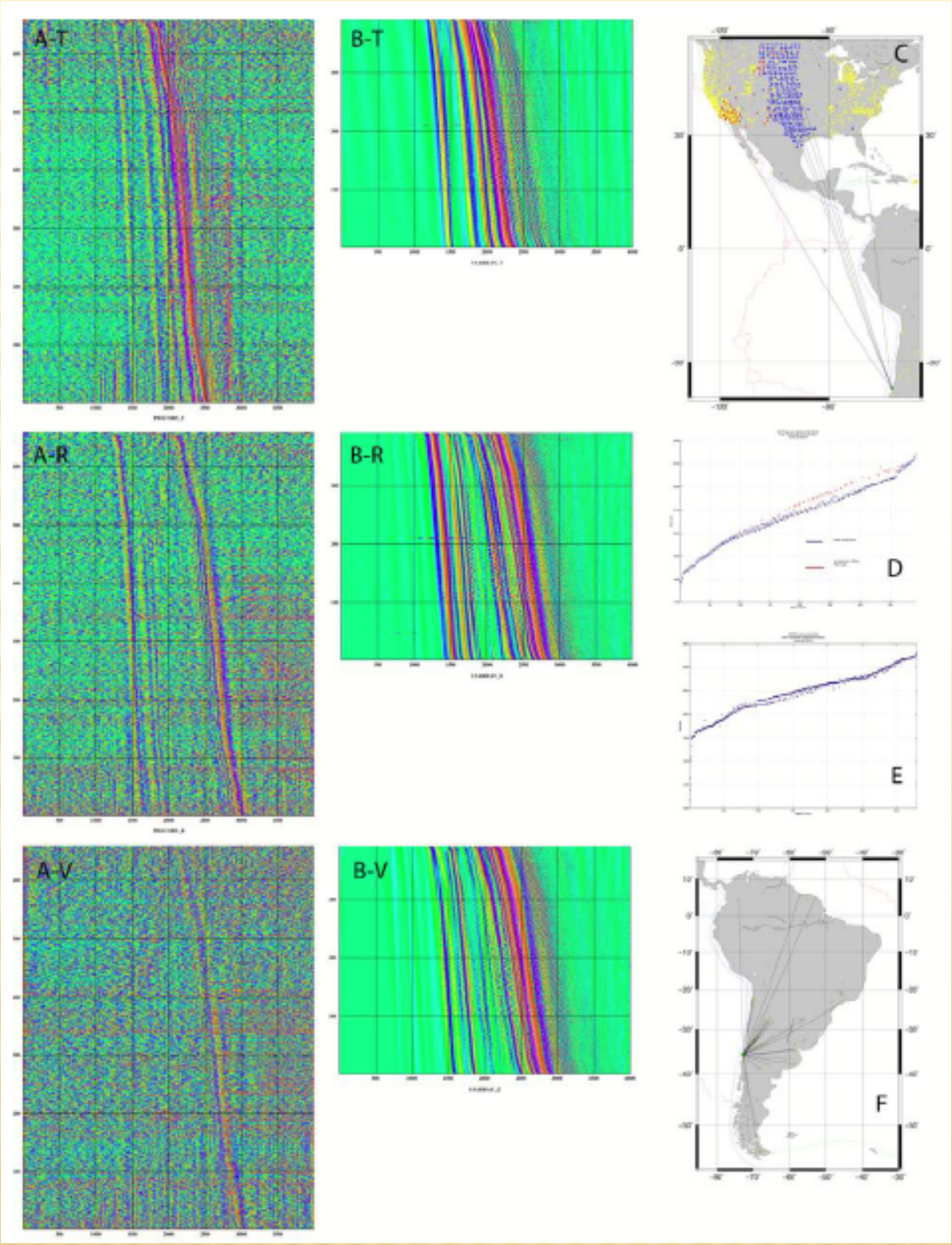
Gradiometry – dynamic strains, apparent velocity, azimuth.





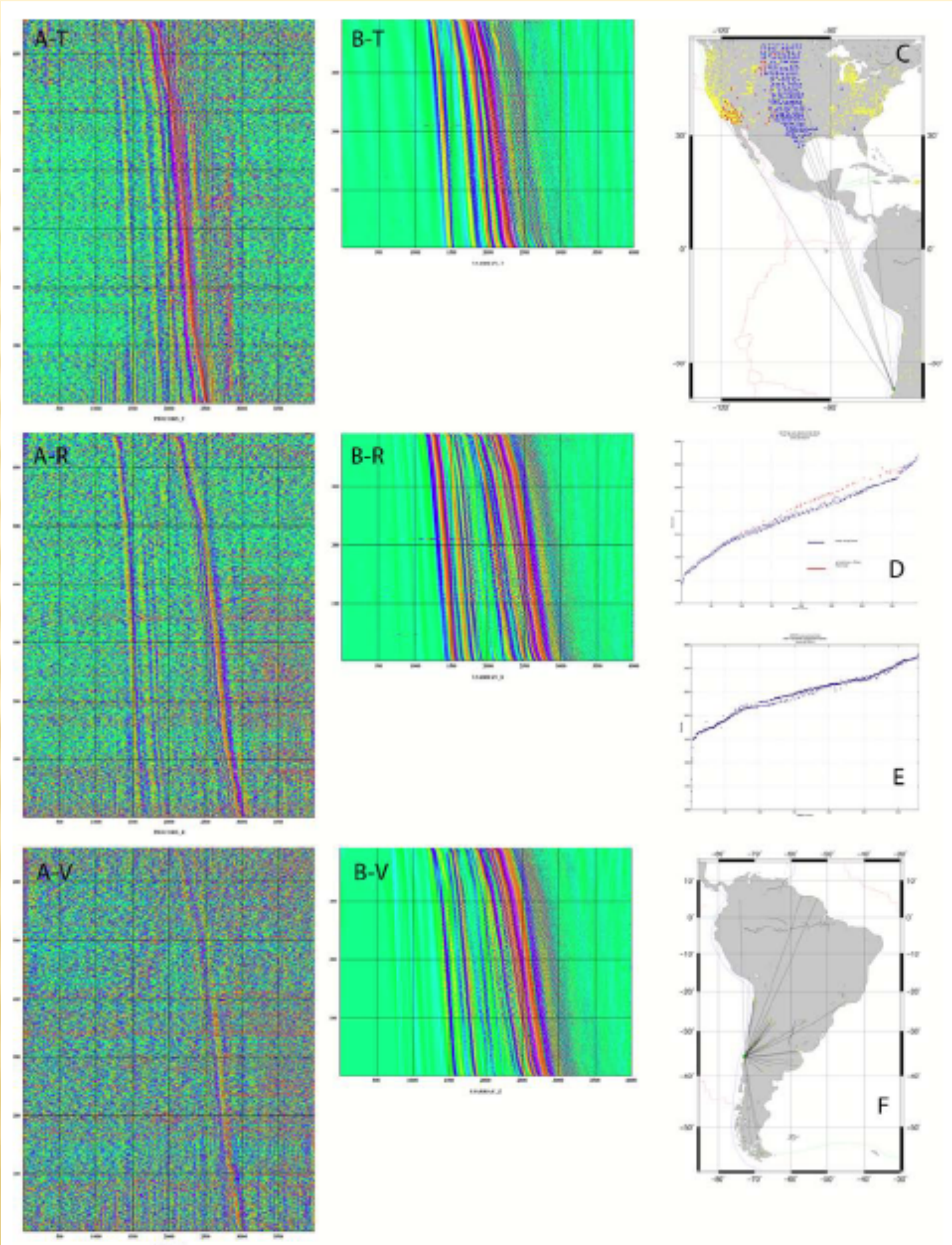
Davis and Smalley, 2009


CSLO
CFAG
MZAE
MZAS
CONZ
Chile
San Juan
Cordoba
Santa Fe
Parana
Mendoza
Rosario
174
9
7
12
Valparaiso
Santiago
San Antonio Canyon
Buenos Aires
Argentina
226
Bahia Blanca
Neuquen
© 2010 DMapas
© 2010 Europa Technologies
© 2010 Inav/Geosistemas SRL
© 2010 LeadDog Consulting
©2009 Google
lat -35.383755° lon -66.182085° elev 373 m
Eye alt 1408.01 km



Three componet HRGPS displacement sesimograms (660) and USArray displacement seismograms (400) plotted (sorted by distance, not record section).

Seismic stations (red and blue) and GPS stations (yellow).



Can see S (on transverse),

Shear coupled P_L (on Radial and Vertical,

Love (on transverse) and

Rayleigh (on Radial and Vertical)

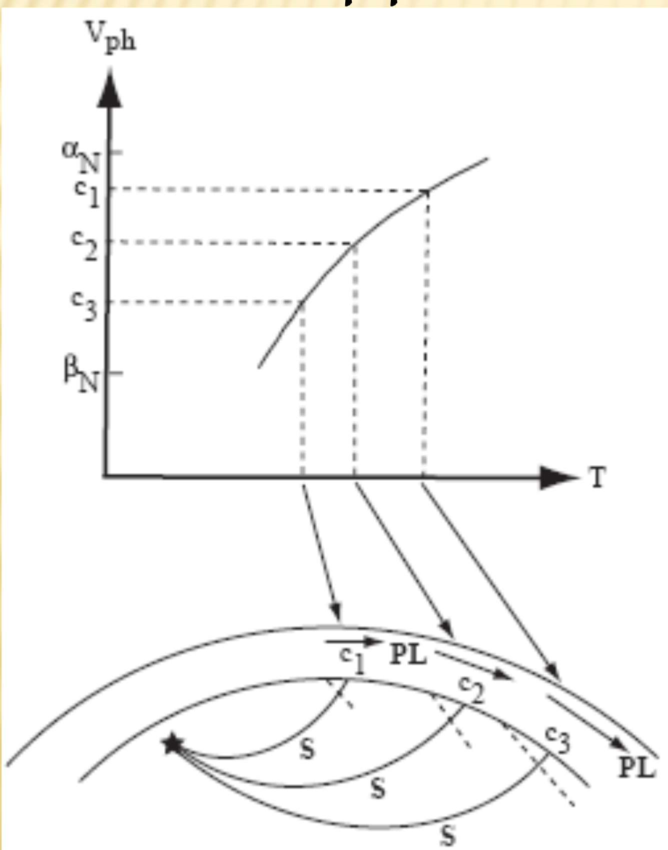
waves.

Davis and Smalley

What is Shear (or S) coupled P_L ?

"L" stands for Leaky (originally stood for Long period, lucked out again).

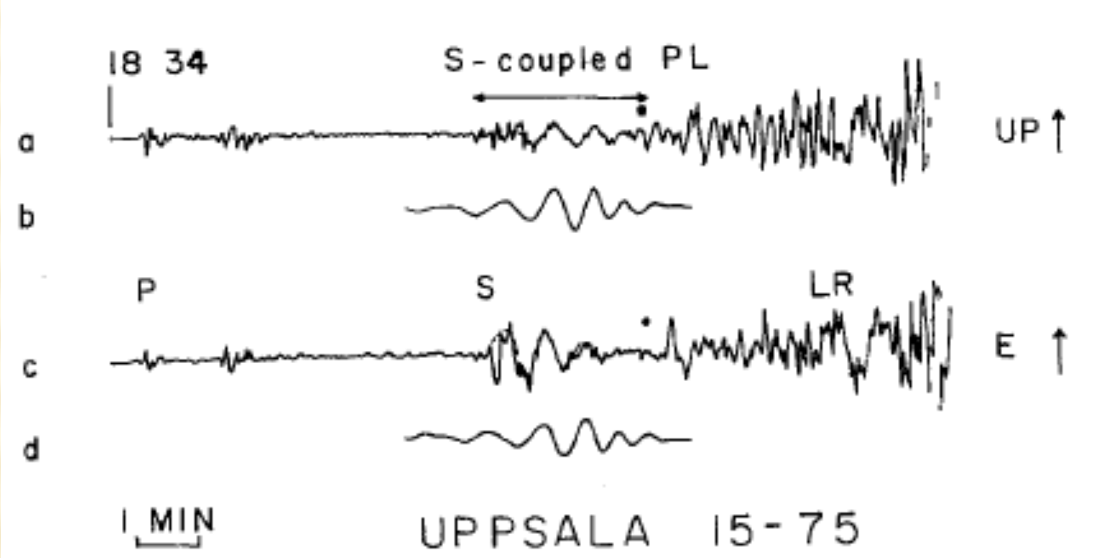
S apparent velocity same as P_L velocity.



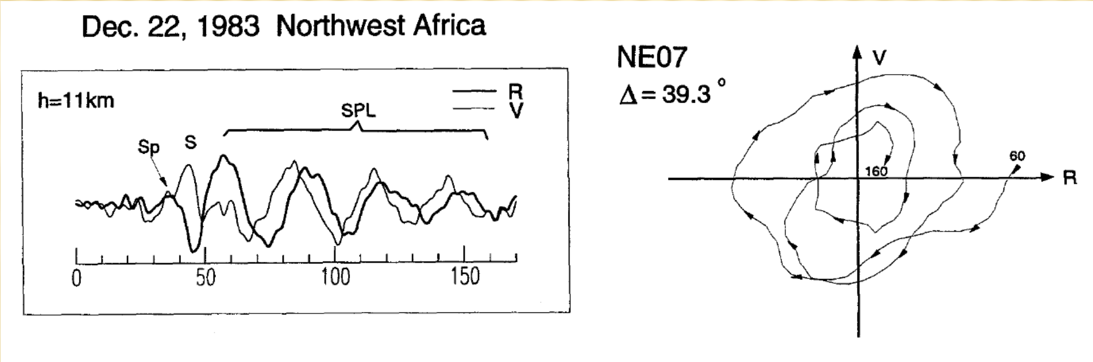
Teleseismic S enters crust, converts to P, which is trapped (supercritical), but when P reflects off Moho (total internal reflection) some converts to S and "leaks" out.

Pulliam et al., 2008 after Baag and Langston, 1985, after Chander et al., 1968, after Oliver, 1961.

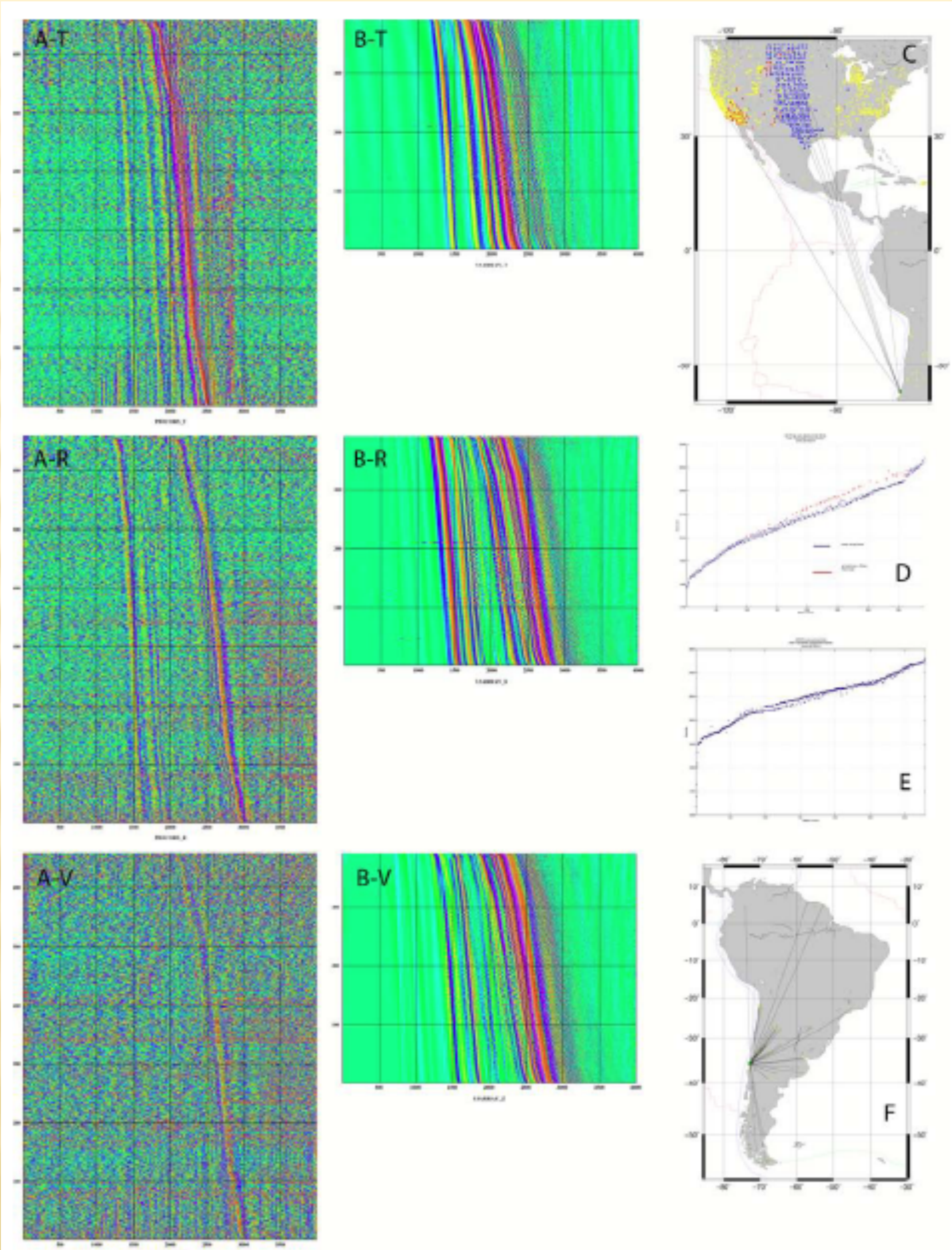
Particle motion of P_L
Prograde Elliptical.



Chander et al., 1968

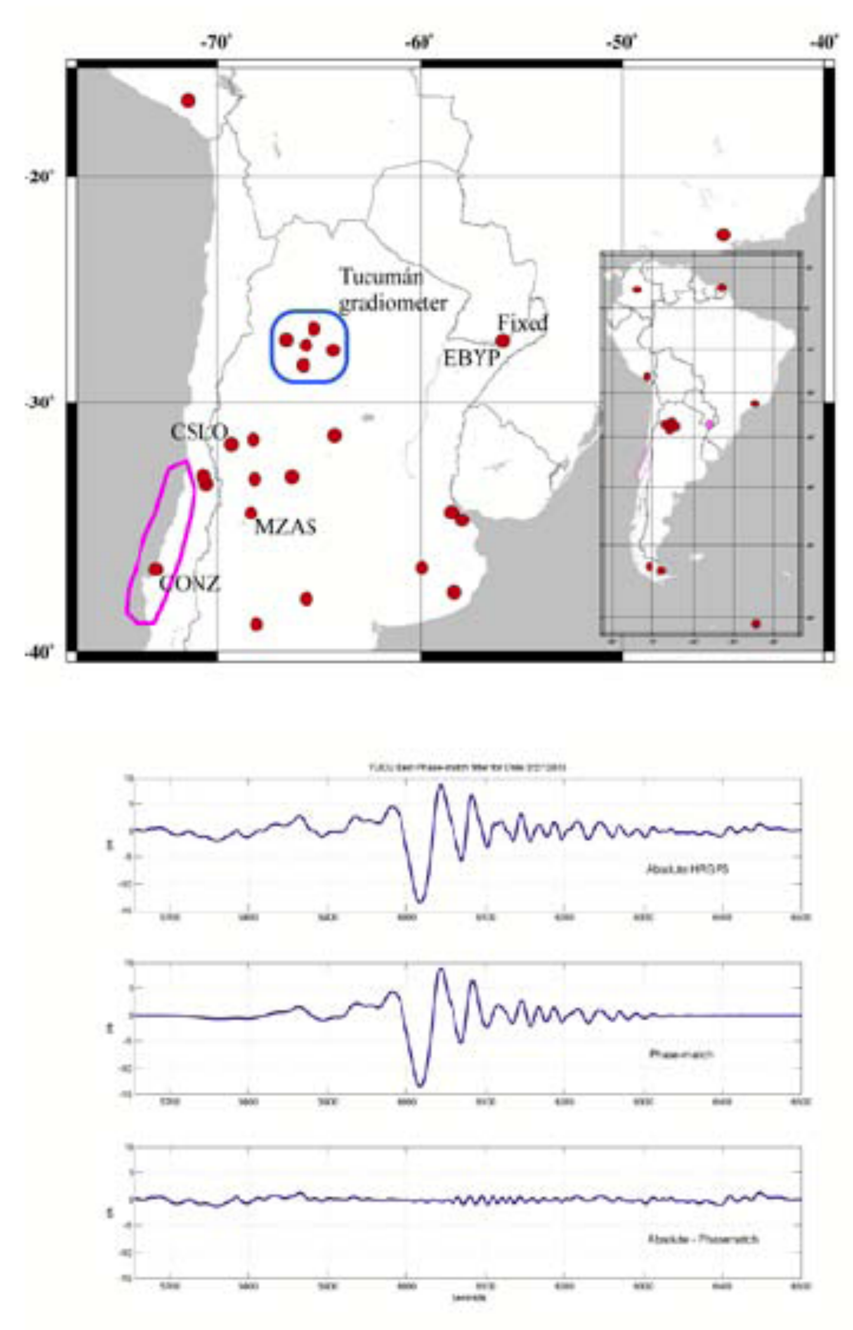


Zhang and Langston, 1996



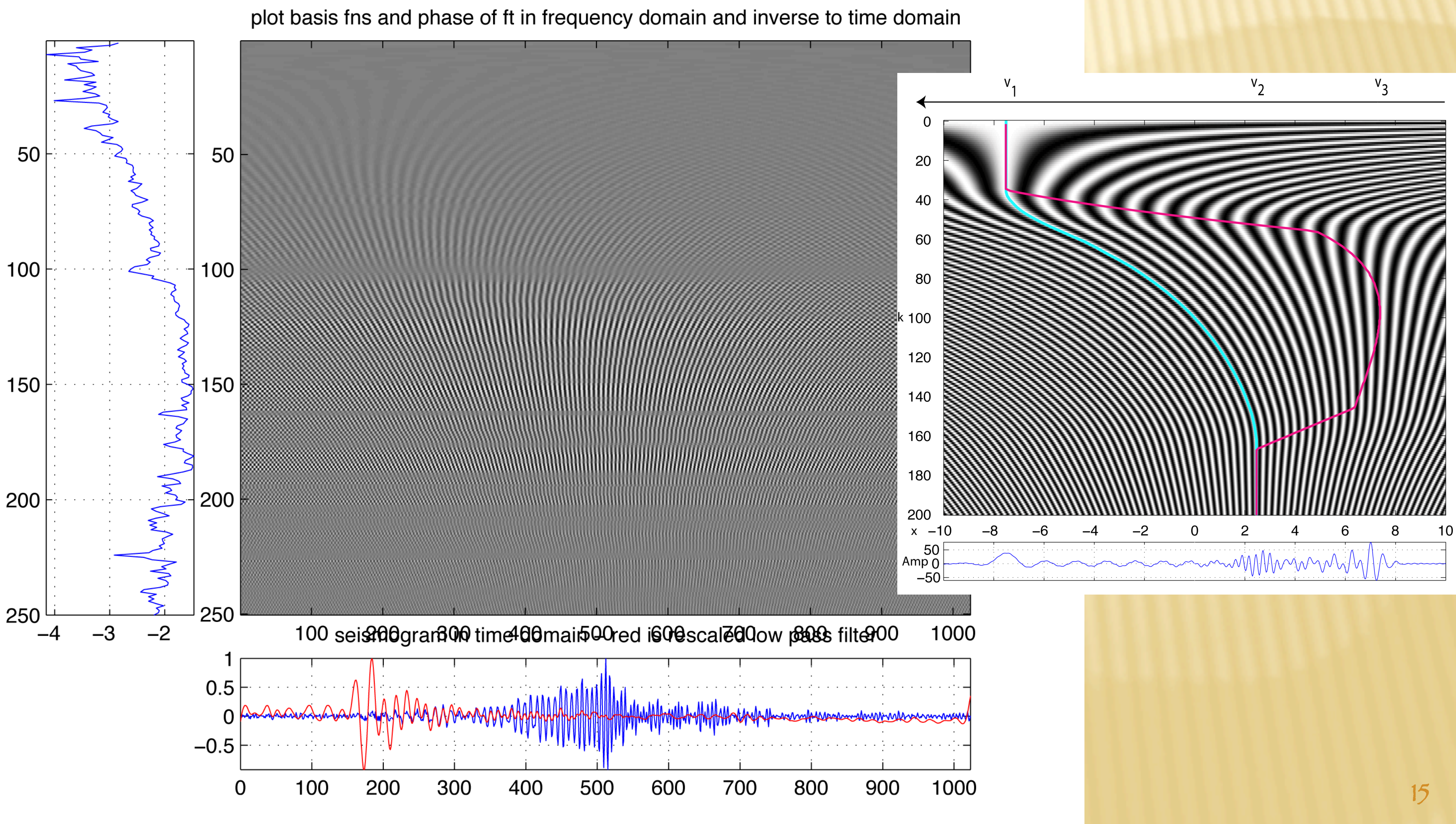
"Chatter" due to difference between crustal structure of Basin and Range (red slow), and Rocky mountains vs stable craton in eastern North America.

Davis and Smalley



Phase match filtering to remove multipath.

How does phase match filtering work?



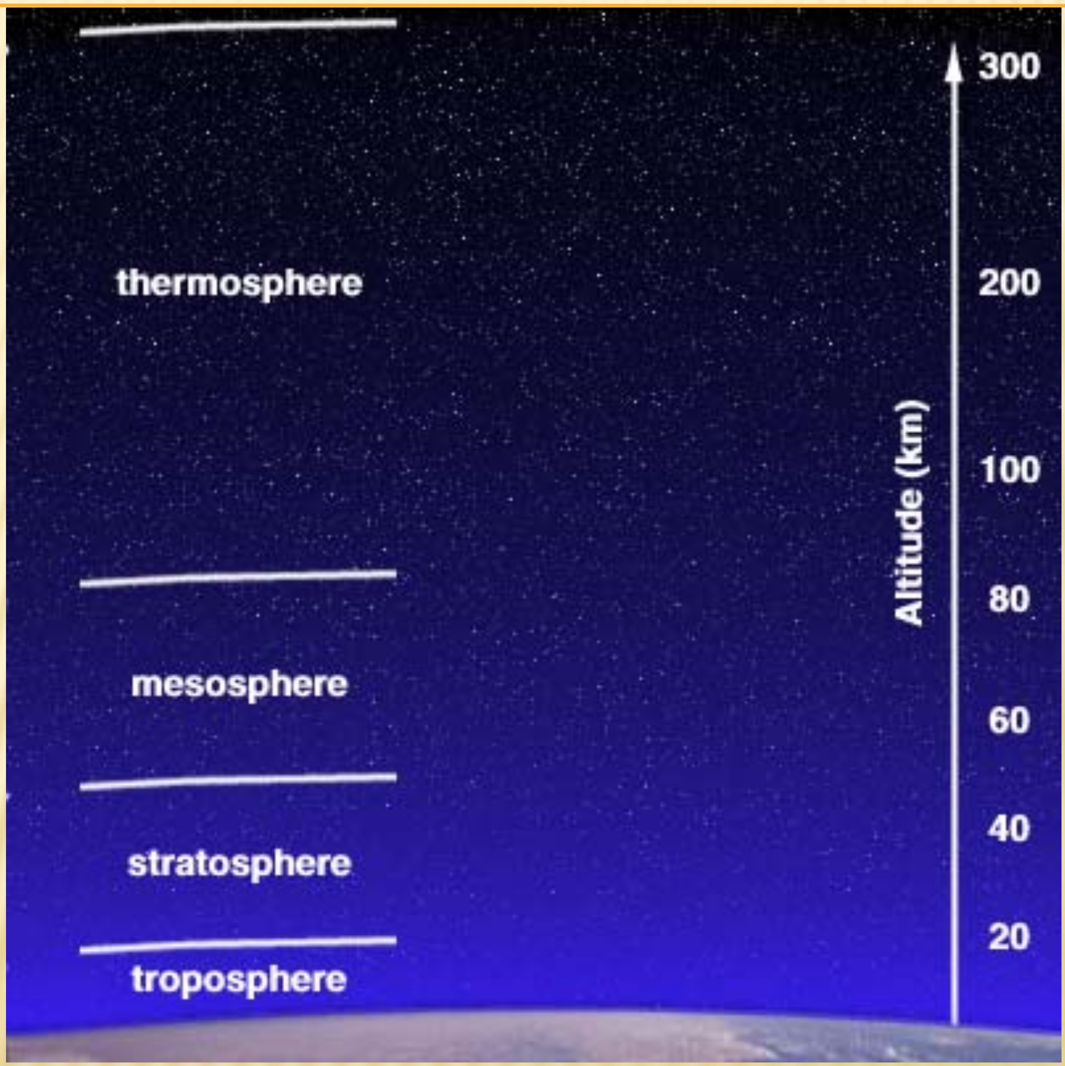
James is working on this for his thesis.

Further improvements to estimating HRGPS time series.
Additional applications (gradiometry).

Remote sensing with GPS.

Exploiting the noise in GPS data.

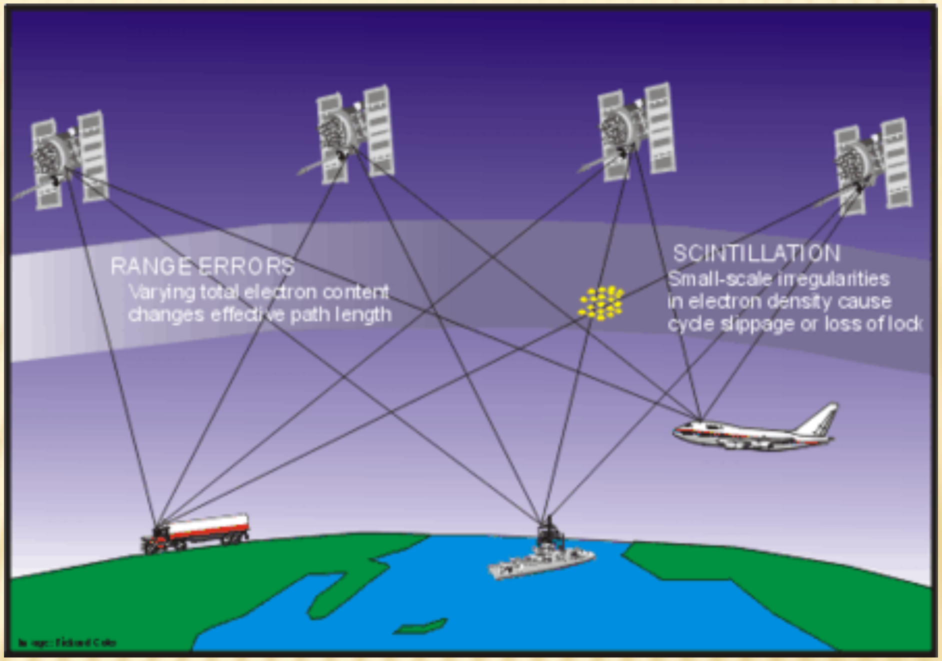
1500m



Ionosphere

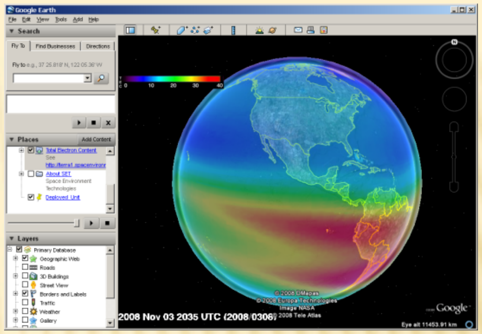
http://www-gpsg.mit.edu/~tah

Ionosphere Effects on GPS

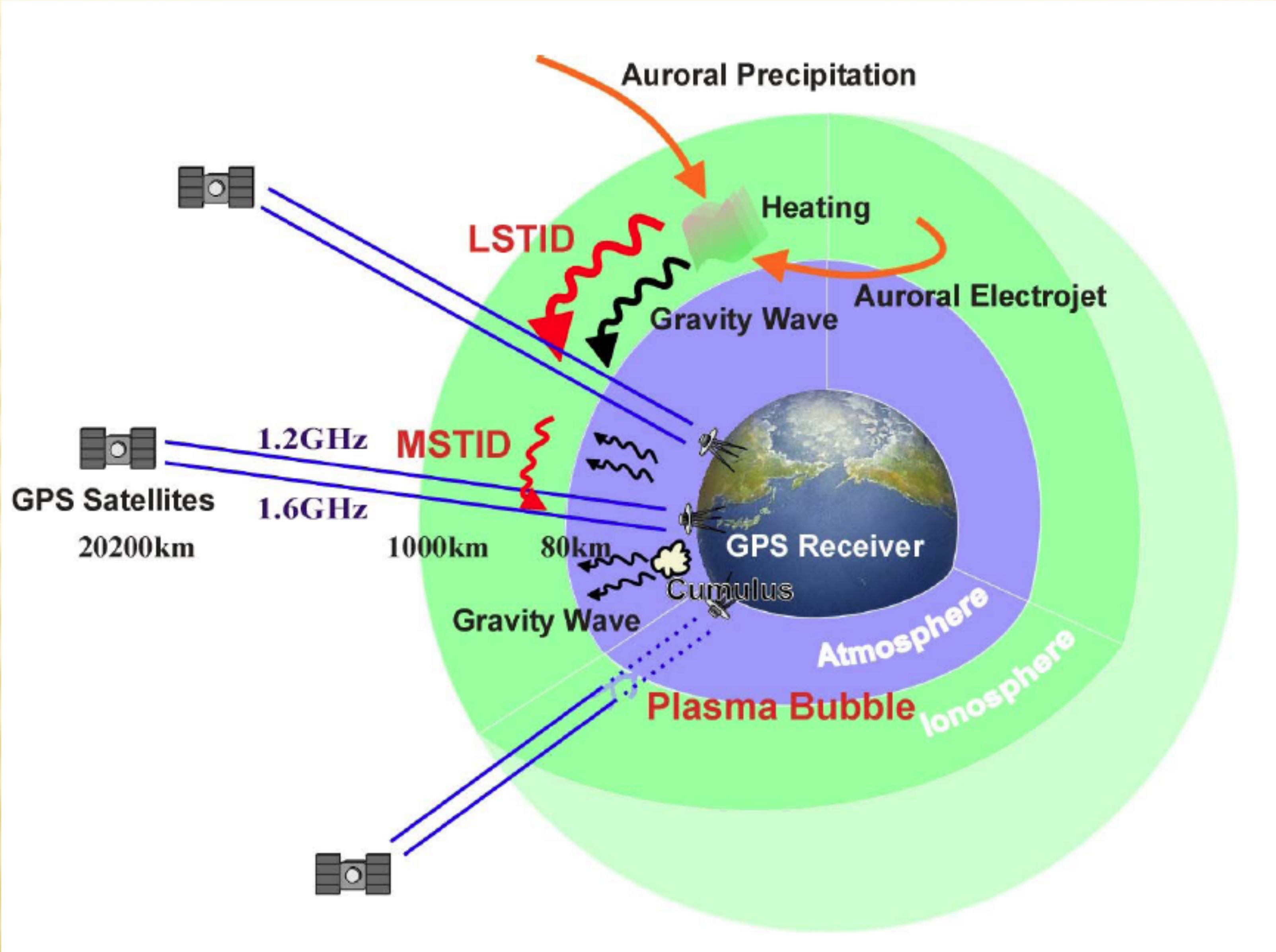


The ionosphere is defined as the region of the upper atmosphere where radio signal propagation is affected by charged particles.

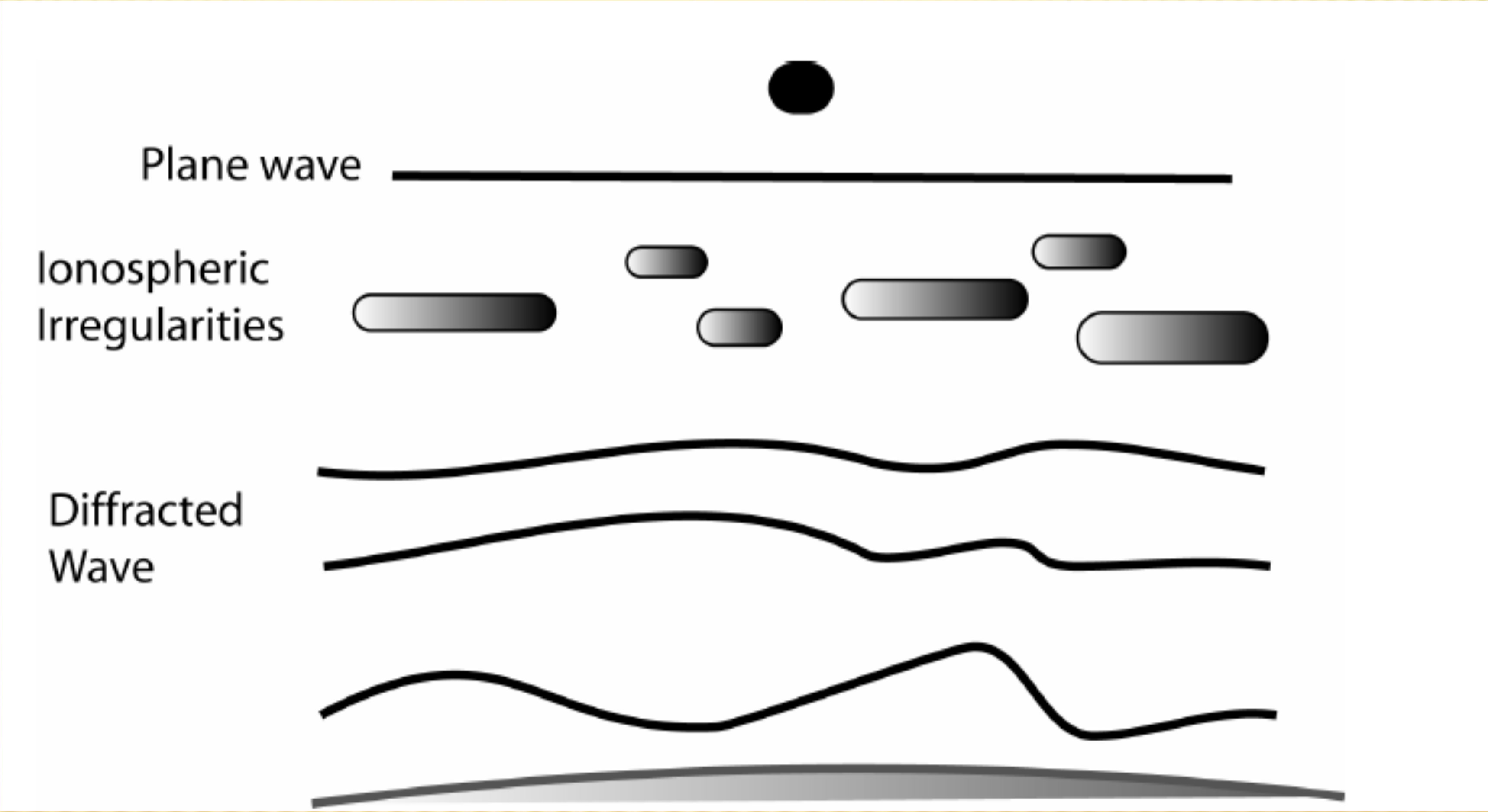
Ionospheric Effects…



- Space 'weather' can effect the speed of GPS signal, and thus the accuracy of the location estimate of the receivers
  - Solar flares, coronal holes, etc. producing strong geomagnetic storms
  - Measured in Total Electron Content (TEC) of the Ionosphere
    - See http://terra1.spacenvironment.net/%7Eionops/current_files/Google_TEC.kml
      - *Real time (10 min) TEC on Google Earth, Blue=good, Red = Bad*
- Degradation of GPS locations (more electrons = delay of signal)
  - Especially in the mid-latitudes – and can be highly variable
    - In severe cases, can prevent Satellite fix entirely
    - GPS receivers attempt to correct for effects
  - Can also use GPS error to measure Ionosphere (TEC)



Tsugawa, 2006



Dyrud et al., 2007

IONOSPHERIC DELAY

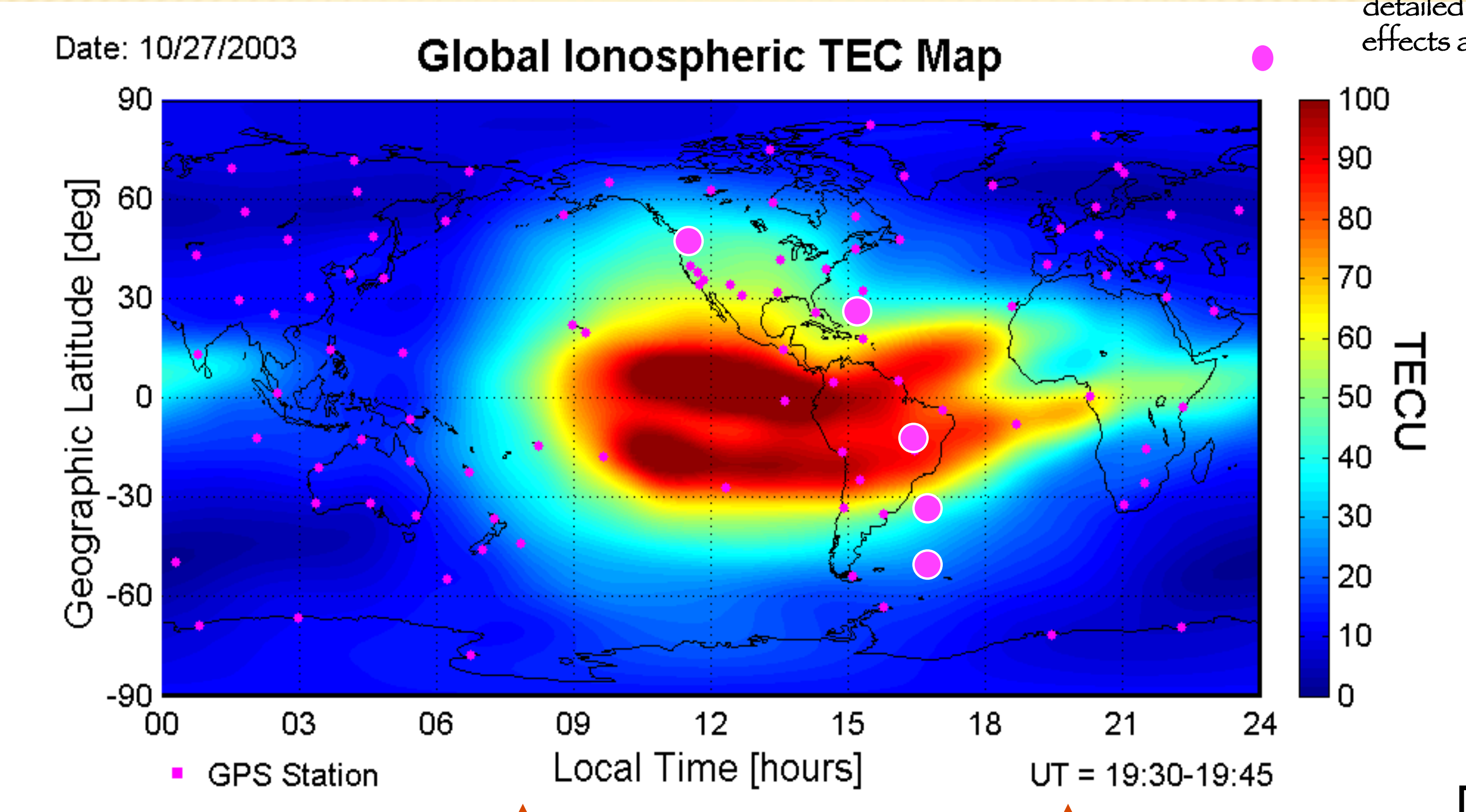
- Measured range given by $s = \int n \, ds$
  - n is the refractive index
  - ds is the path that the signal takes
- The path delay is given by
  - $\Delta_{ph}^{iono} = -(40.3/f^2) \int N_e \, ds_0 = -40.3/f^2 \, TEC$
  - $\Delta_{gr}^{iono} = (40.3/f^2) \int N_e \, ds_0 = 40.3/f^2 \, TEC$
    - Where $TEC = \int N_e \, ds_0$ is the total electron content

IONOSPHERIC DELAY

- Still need to know TEC
- Can either
  - Measure using observations
  - Estimate using models
- Note that with data on 2 frequencies, estimates of the unknowns can be made

LATITUDINAL VARIATION OF THE IONOSPHERE A CONCERN AT LOW AND MID LATITUDES

Locations where some detailed ionospheric effects are assessed



Dawn (ascending)

Dusk (descending)

A year similar to the target launch year - 2014

Most of blue areas are not a concern for the Faraday rotation effect at L-band

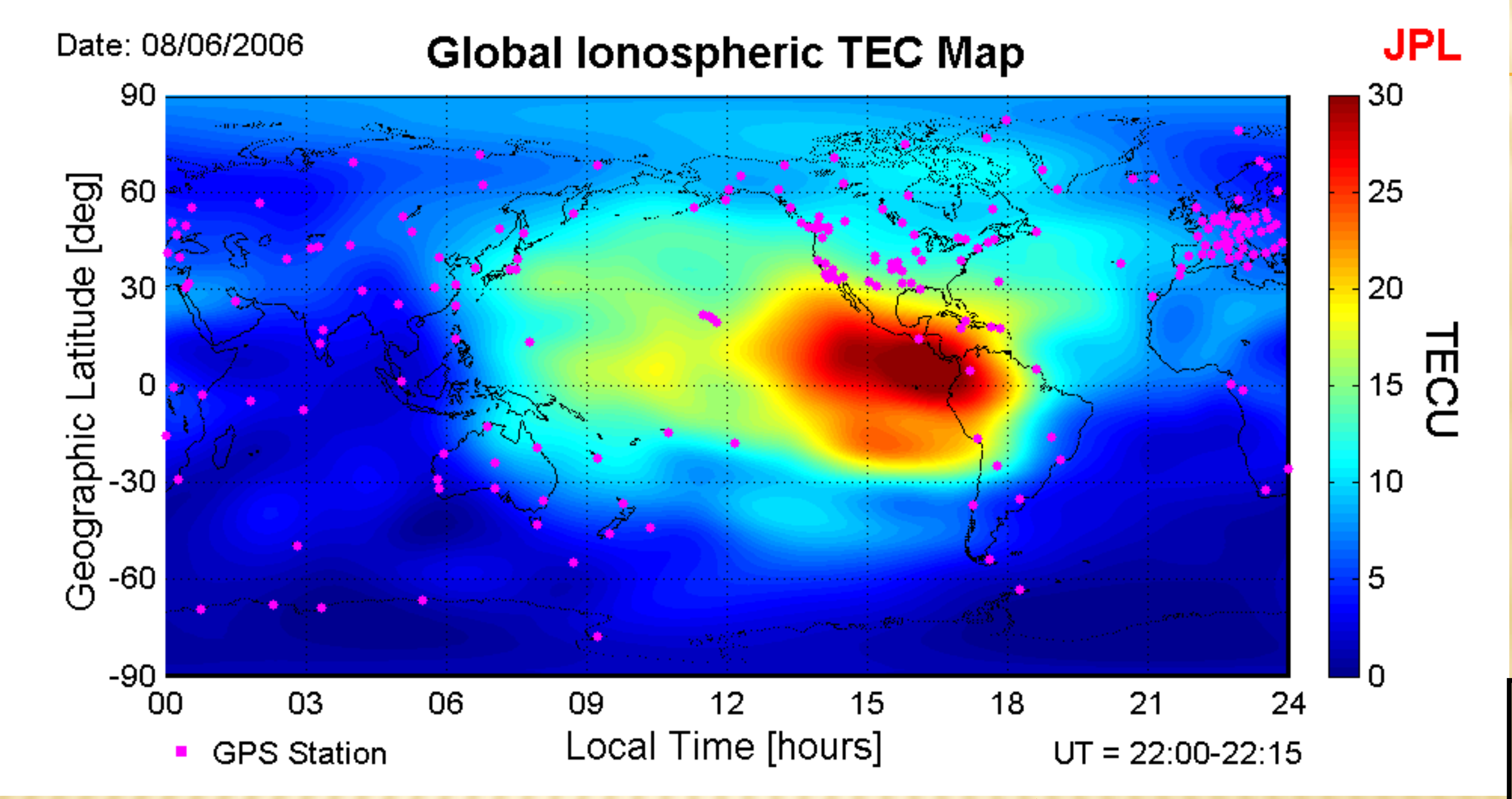
FREL

P

Suborbital & slant path (45°) are considered

Pi, 2006

TEC REDUCES SIGNIFICANTLY IN LOW SOLAR ACTIVITY YEARS

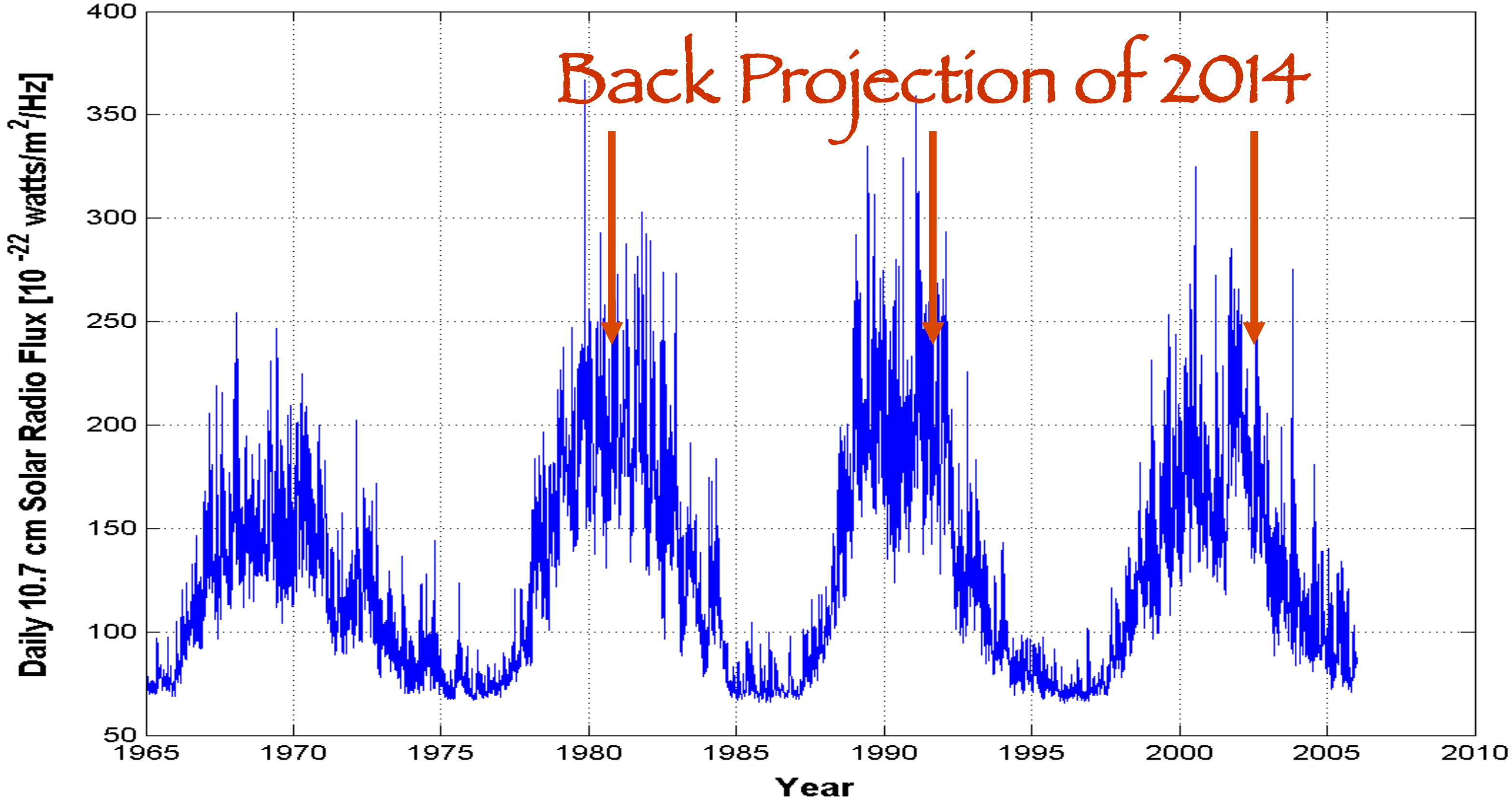


Suborbital & slant path (45°) are considered

In low solar activity years (e.g., 2006), ionospheric TEC can be a factor of 5 smaller than in high activity years, and the Faraday rotation effects on L-band SAR will be reduced to minimum.

Pi, 2006

THE SOLAR CYCLE PHASE OF THE TARGET LAUNCH YEAR

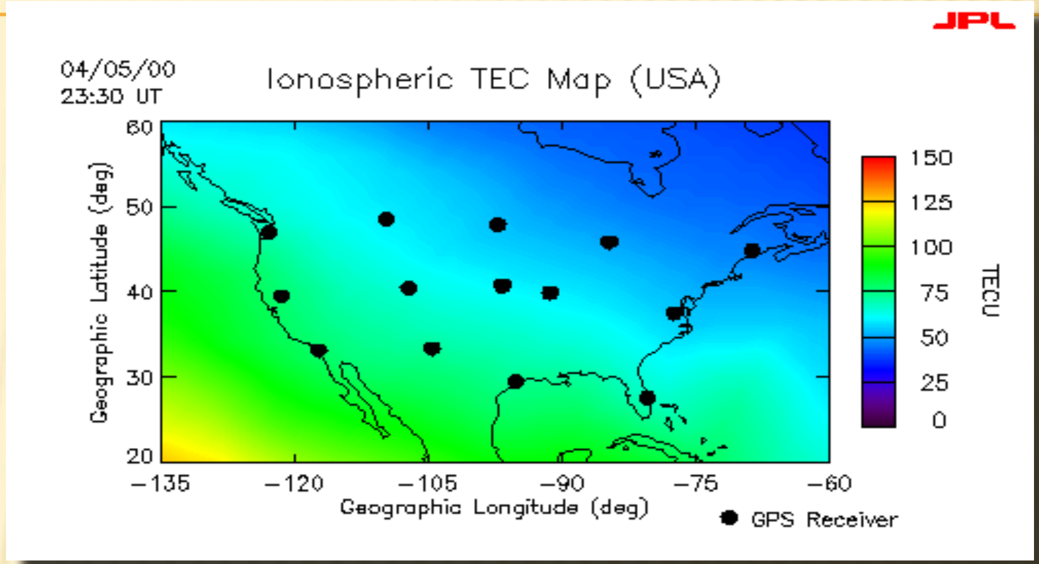


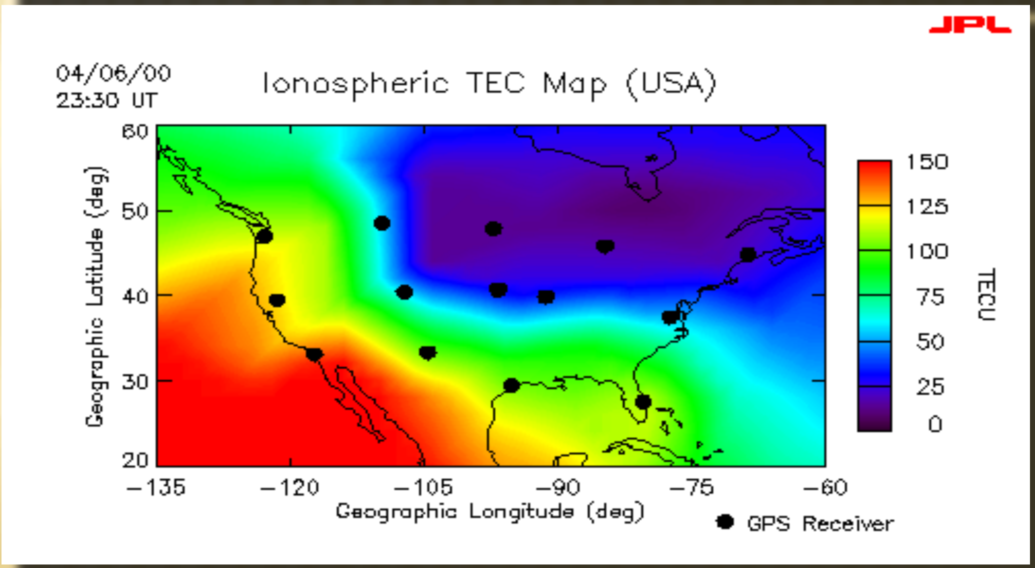
Sunspot Maximum	**1979**	**1990**	**2001**	**2012**	**2023**
Sunspot Minimum	**1985**	**1996**	**2007**	**2018**	**2029**

Pi, 2006

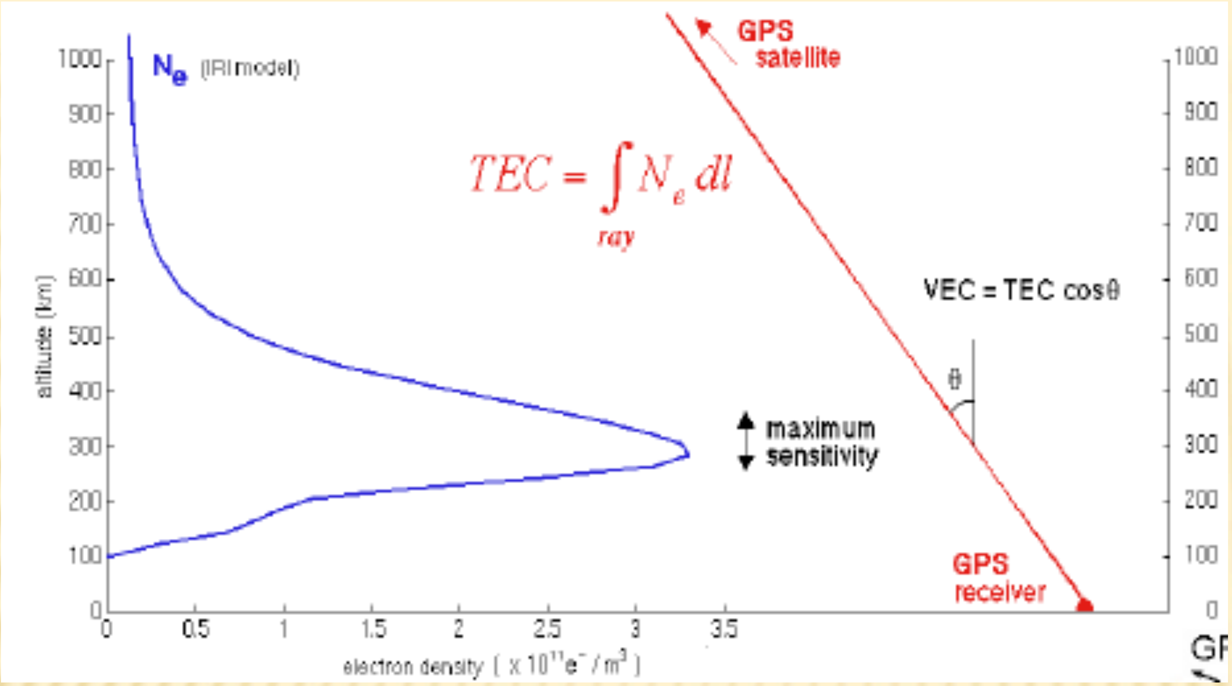
Ionospheric Spatial Structures during Storms

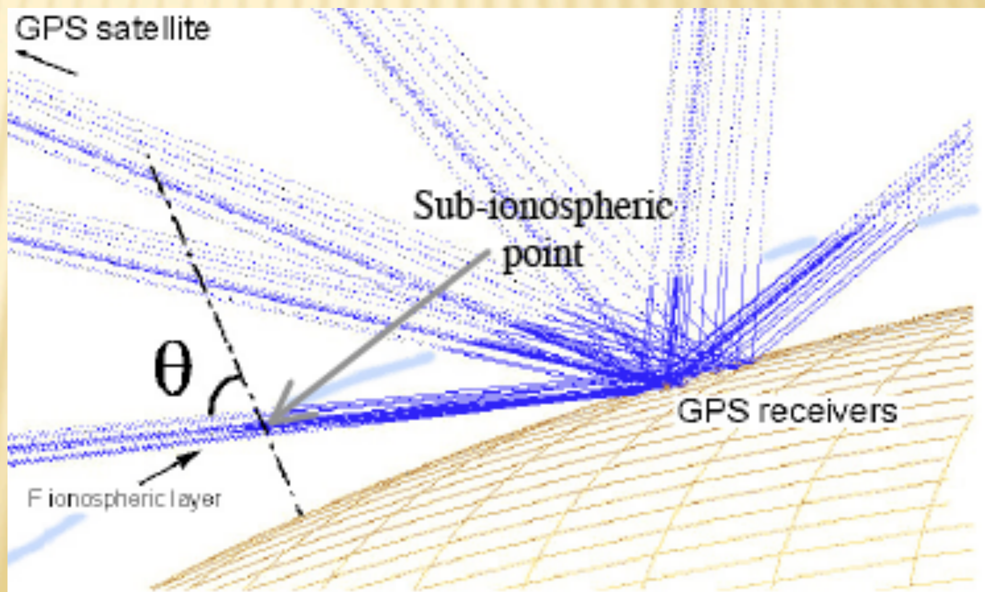
- Quiet ionosphere
  - Smooth
  - Small gradient
- Disturbed ionosphere
  - Large gradient
  - Curvature
  - Irregular structures
- Adjacent drop showing 50 TECU difference



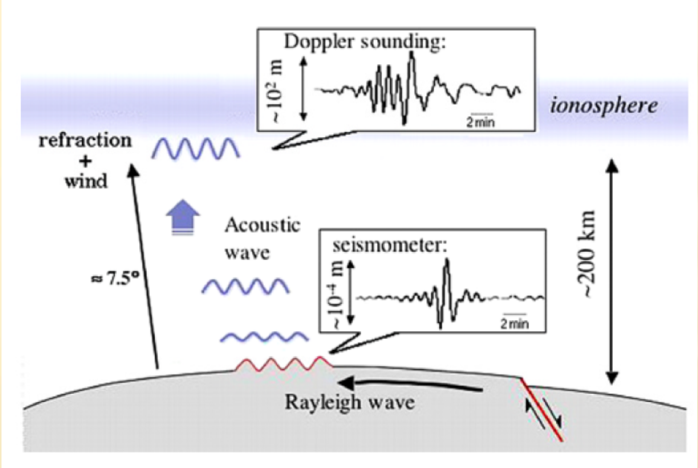


Pi, 2006

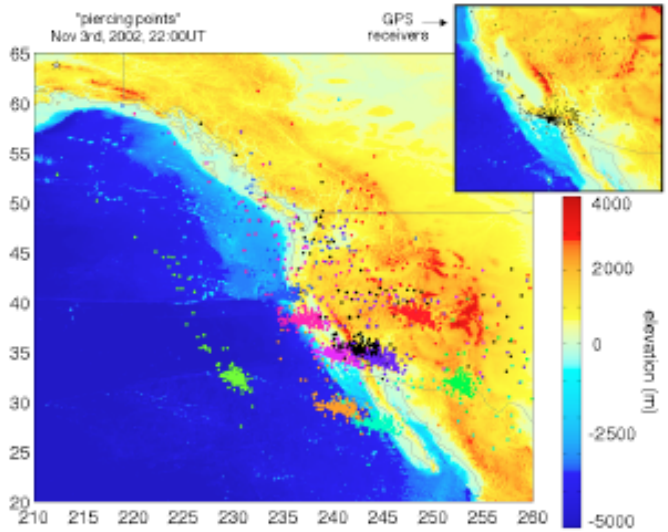




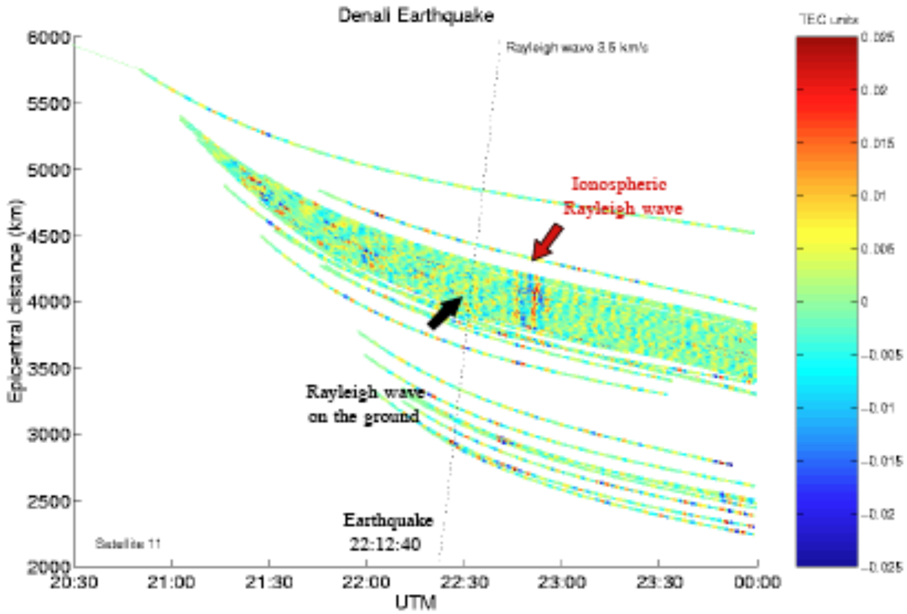
Ducic et al., 2003



- **Signal observed after Alaska Denali fault earthquake (M_s=7.9, Nov. 3 2002)**



Piercing points for ionospheric measurements from all receivers in California (SCIGN + IGS). Different satellites are shown with different colors. The black star shows the epicenter location for Denali earthquake.



Band-pass filtered TEC time series between 150 and 350 seconds from satellite 11, plotted as a function of time and distance to the epicenter. The black dashed line represent a typical Rayleigh wave on the ground.

Ducic et al., 2003

Ionosphere Delay

- Measured range given by $s = \int n \, ds$

  n : refractive index

  ds : signal path

- The path delay is given by
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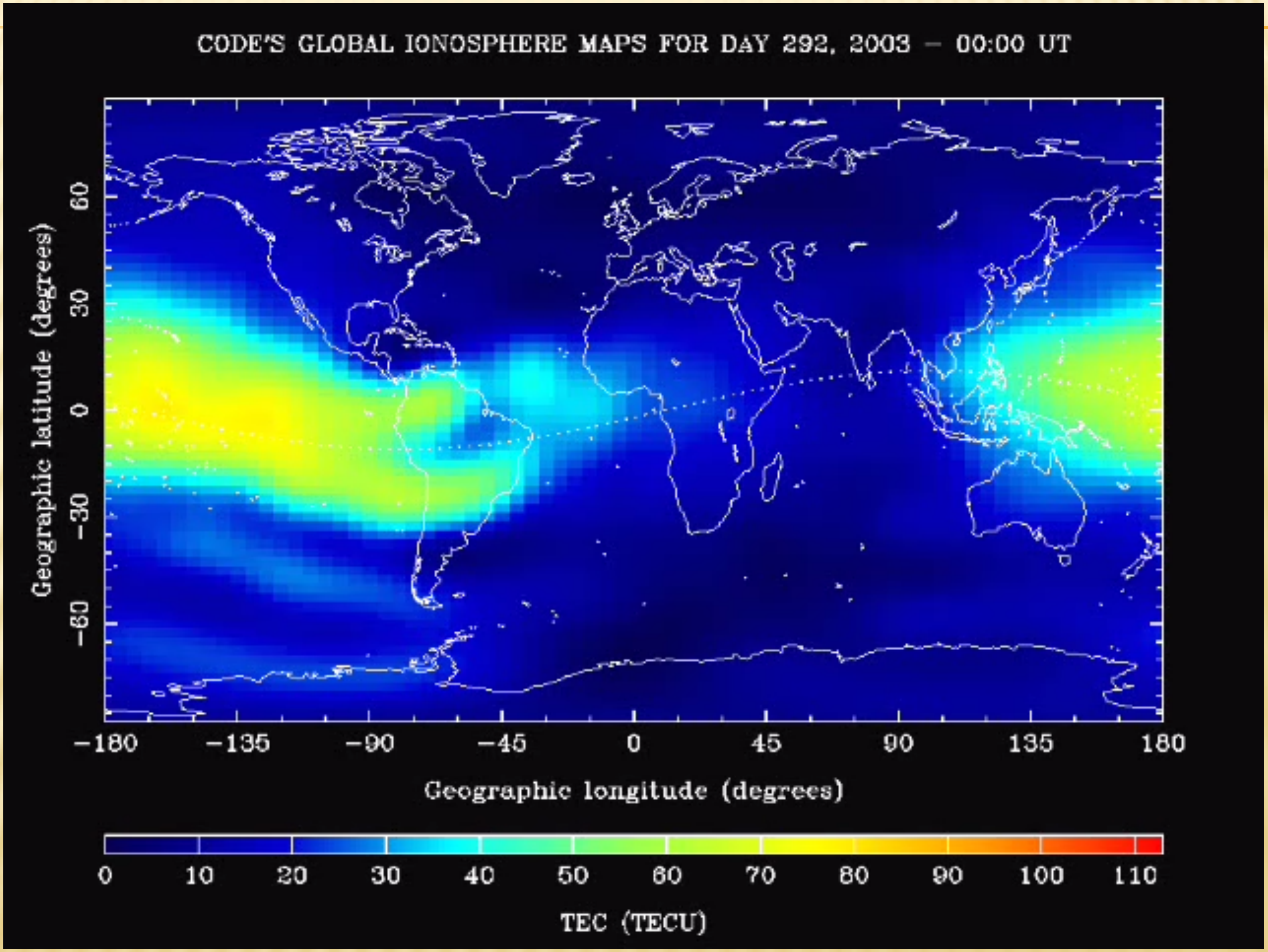
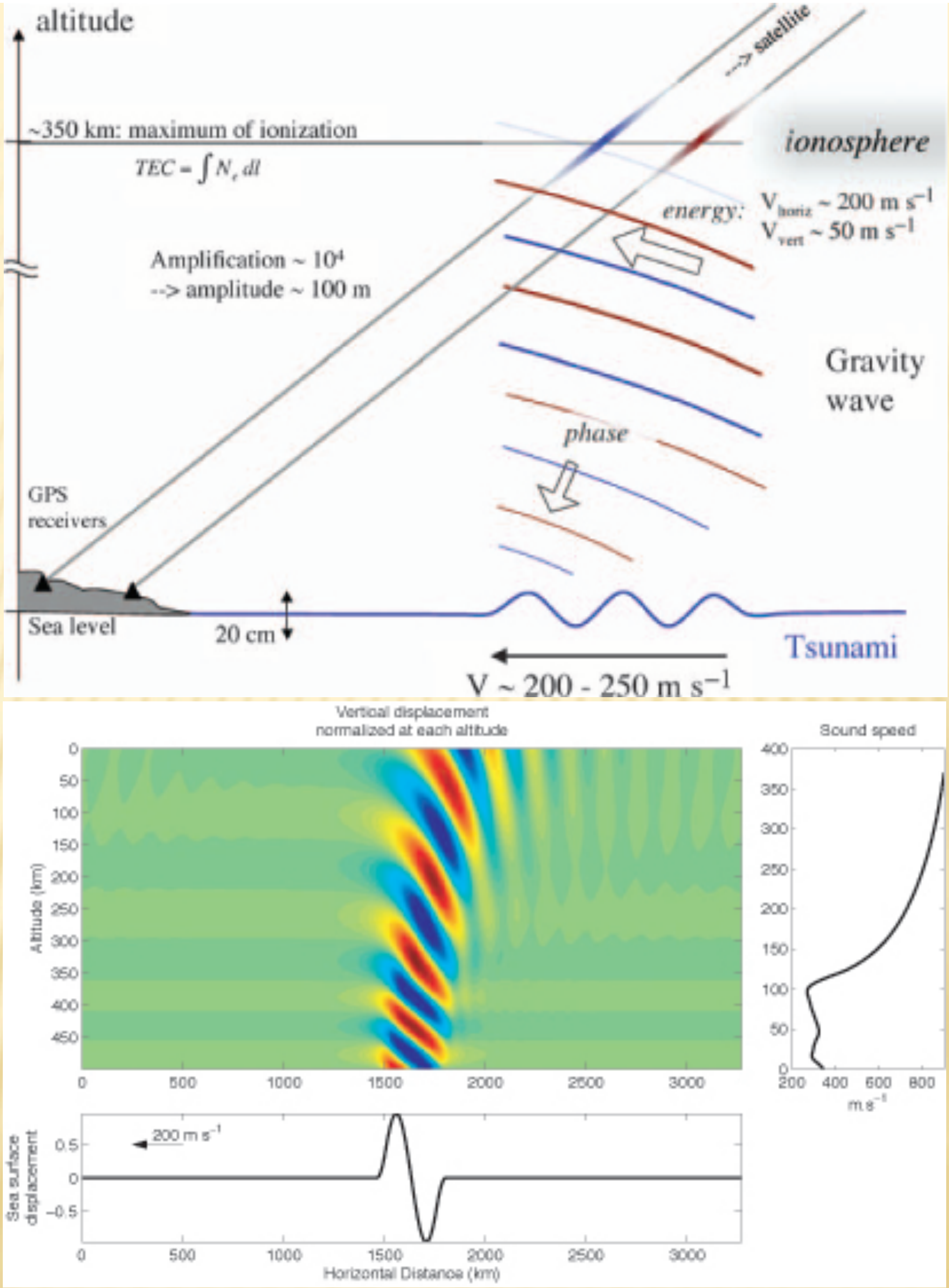
  - $\Delta_{gr}^{iono} = (40.3/f^2) \int N_e \, ds_0 = 40.3/f^2 \, TEC$

    - Where $TEC = \int N_e \, ds_0$ is the total electron content

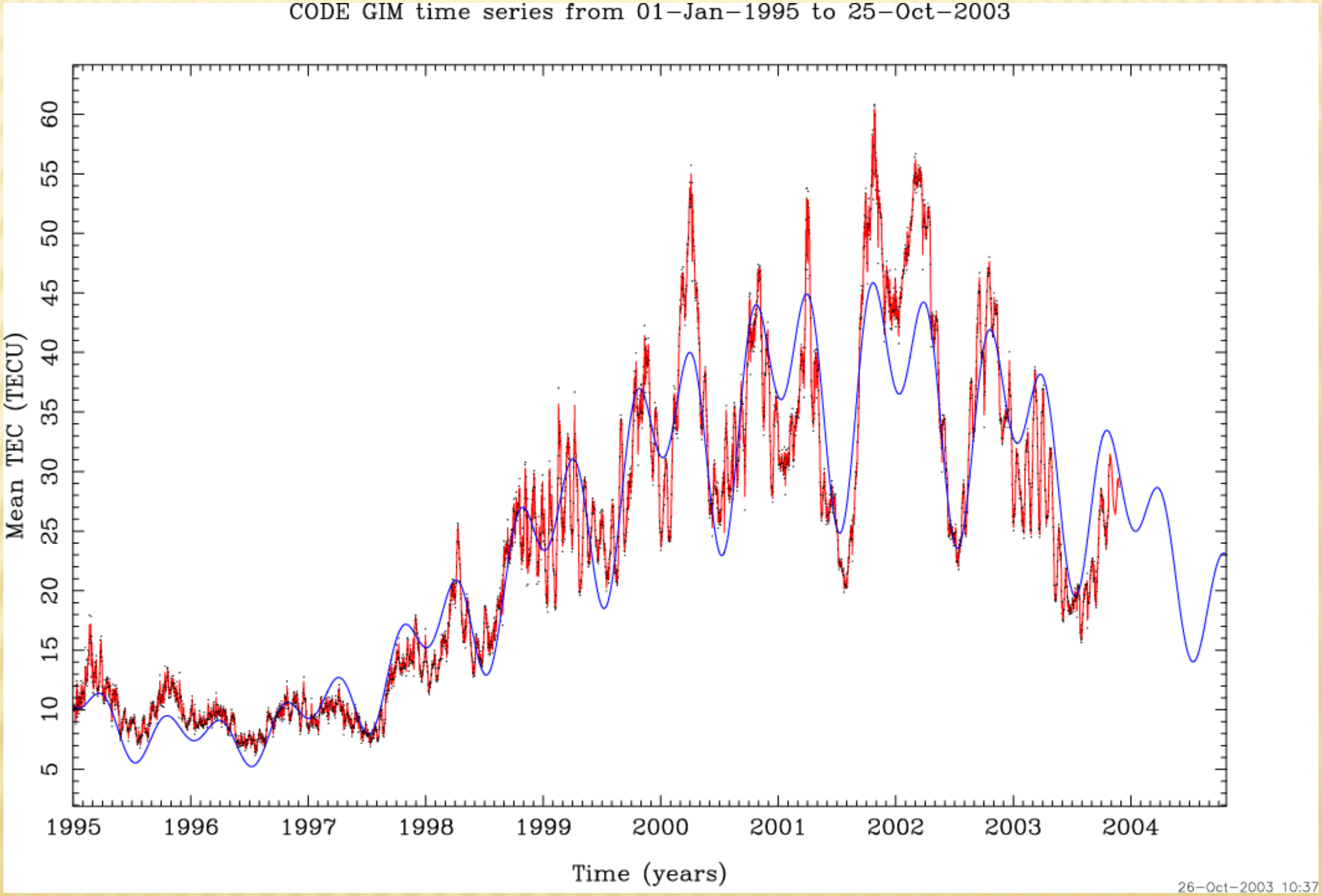
Ionosphere TEC





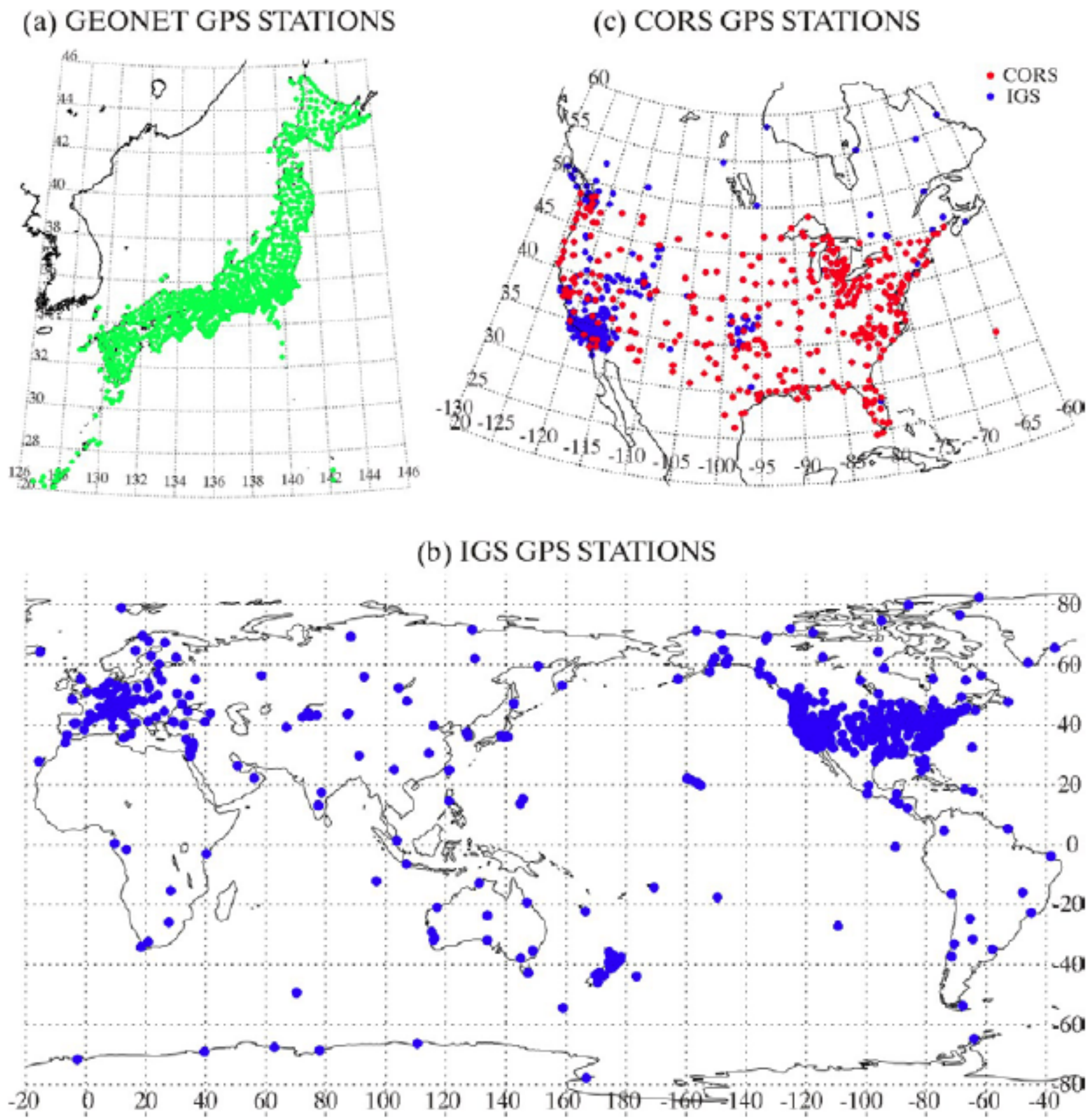
Artru et al., 2005

Ionosphere Variation

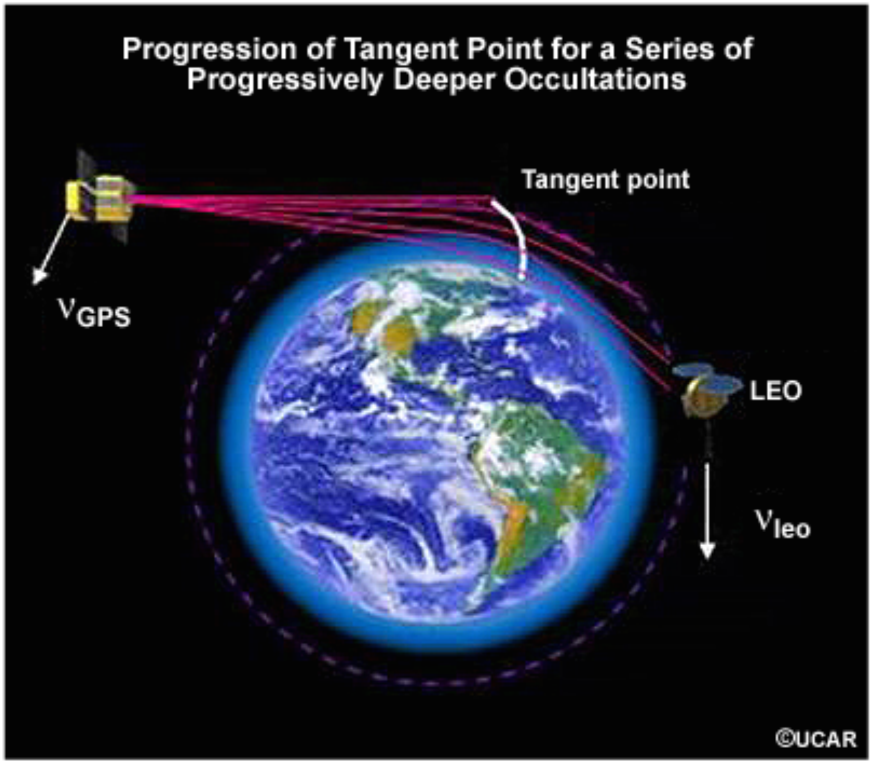


http://www.cx.unibe.ch/aiub/ionosphere.html

GPS Networks in the World

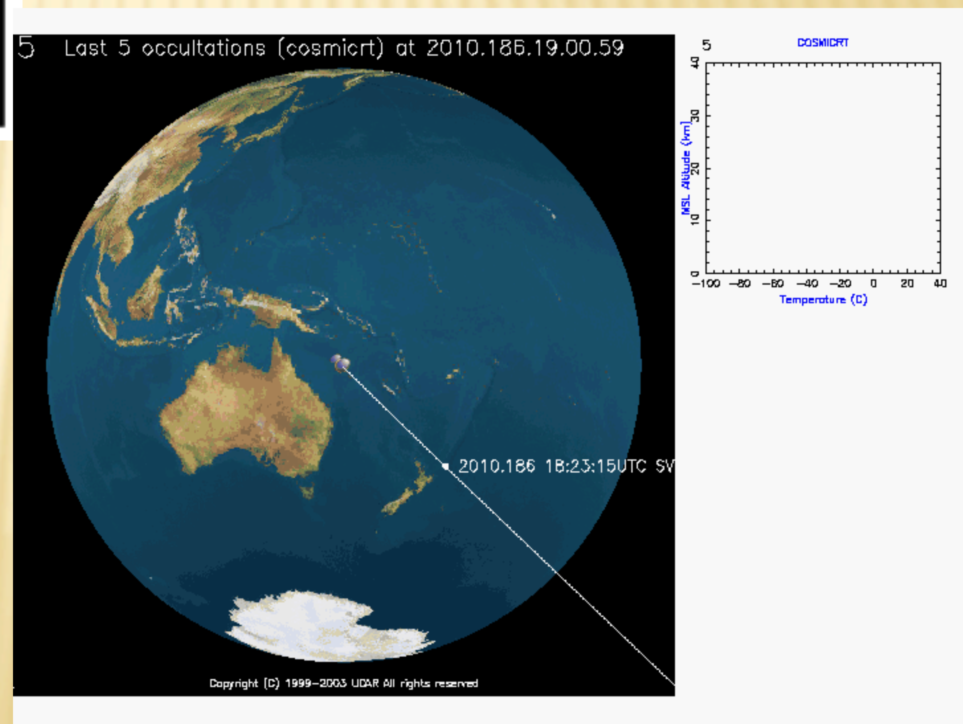


Tsugawa, 2006



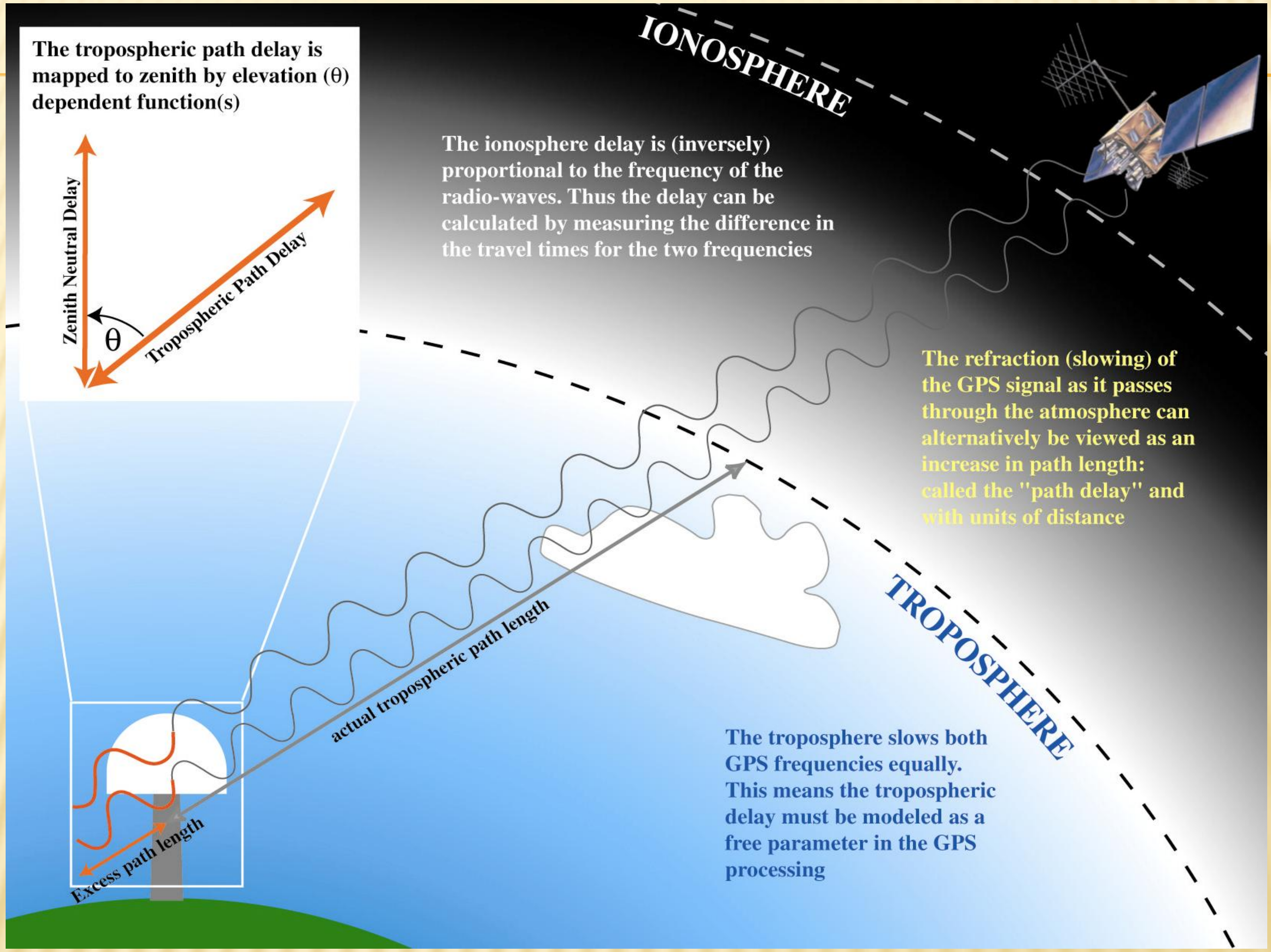
The LEO tracks the GPS phase
while the signal is occulted to determine the Doppler

The velocity of GPS relative to LEO must be estimated to ~0.2 mm/sec (20 ppb) to determine precise temperature profiles

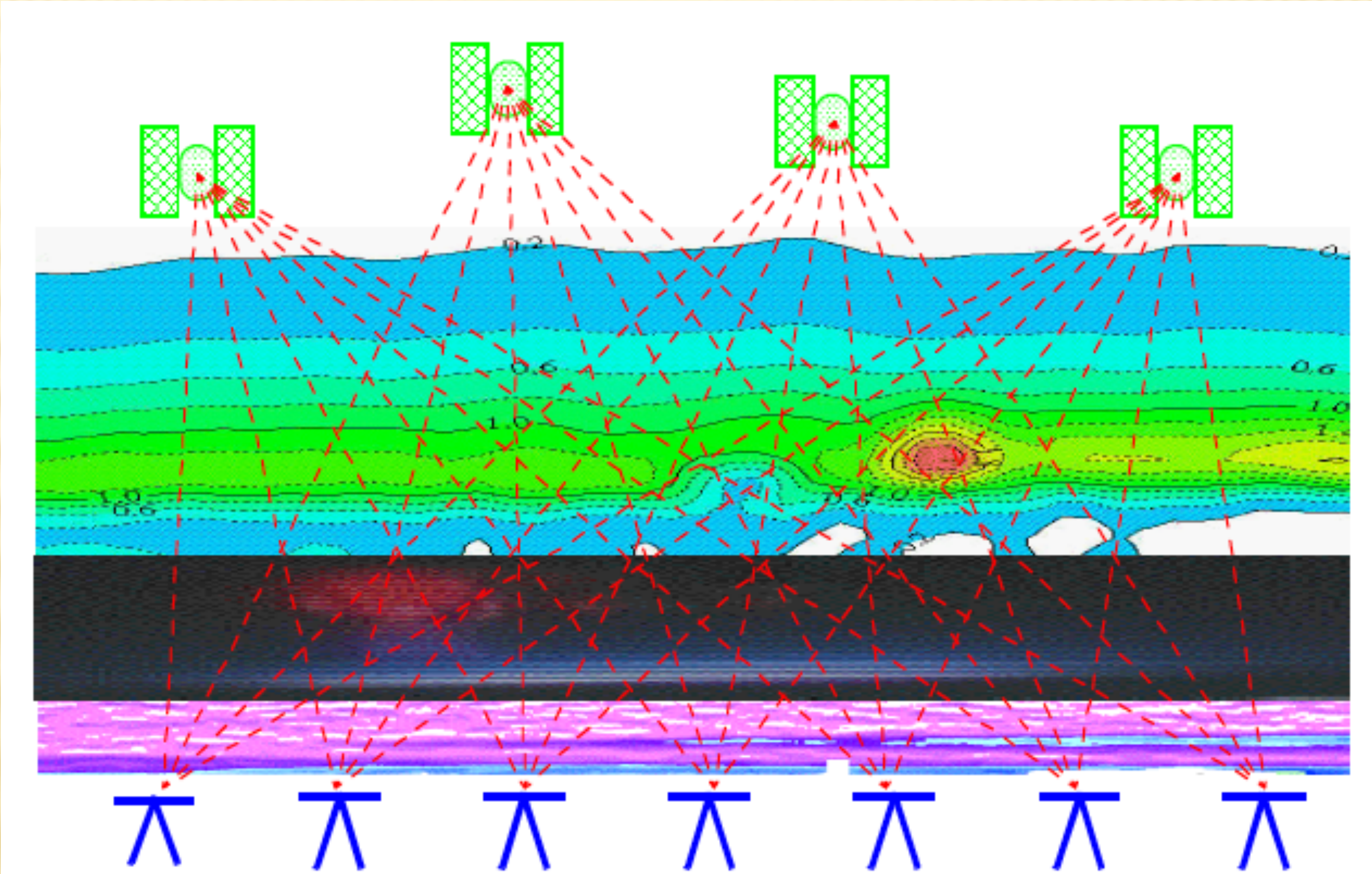


Rocken

Zenith Neutral Delay



- Tropospheric delays increase with decreasing elevation angle (more atmosphere to traverse)



Ware et al., 2000

TROPOSPHERIC DELAY

- Caused by the neutral atmosphere, which is a nondispersive medium (as far as GPS is concerned)
  - Troposphere extends up to 40 km
  - Effects carrier phase and code ranges the same
- Typically separate the effect into
  - Dry component
  - Wet component
- $\Delta^{Trop} = 10^{-6} S N_d^{Trop}\, ds + 10^{-6} S N_w^{Trop}\, ds$
  - Where N is the refractivity
  - ds is the path length

TROPOSPHERIC DELAY

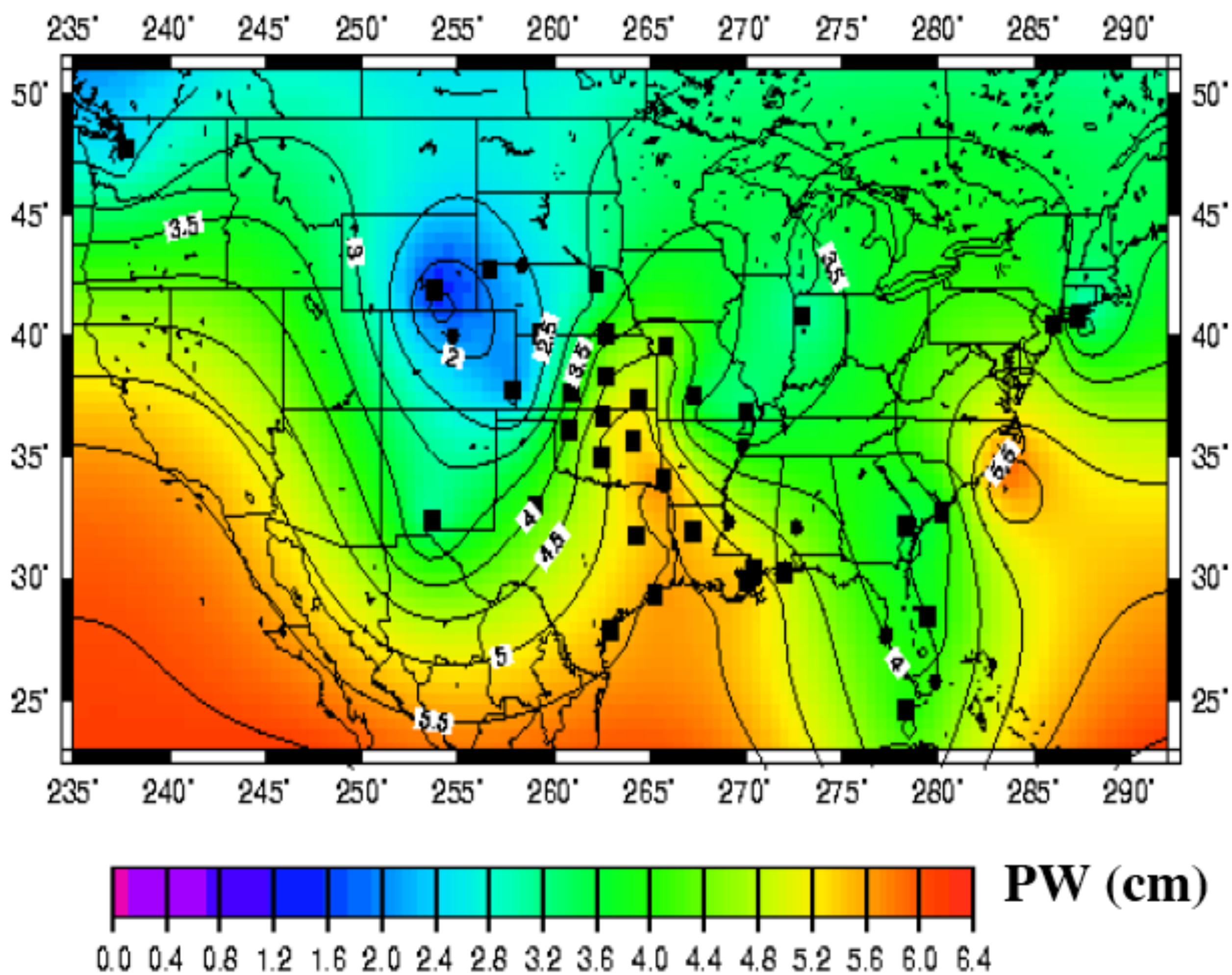
- Dry component contributes 90% of the error
  - Easily modeled
- Wet component contributes 10% of the error
  - Difficult to model because you need to know the amount of water vapor along the entire path

TROPOSPHERIC DELAY

- There are many models which estimate the wet component of the tropospheric delay
  - Hopfield Model
  - Modified Hopfield Model
  - Saastamoinen Model
  - Lanyi Model
  - NMF (Niell)
  - Many, many more

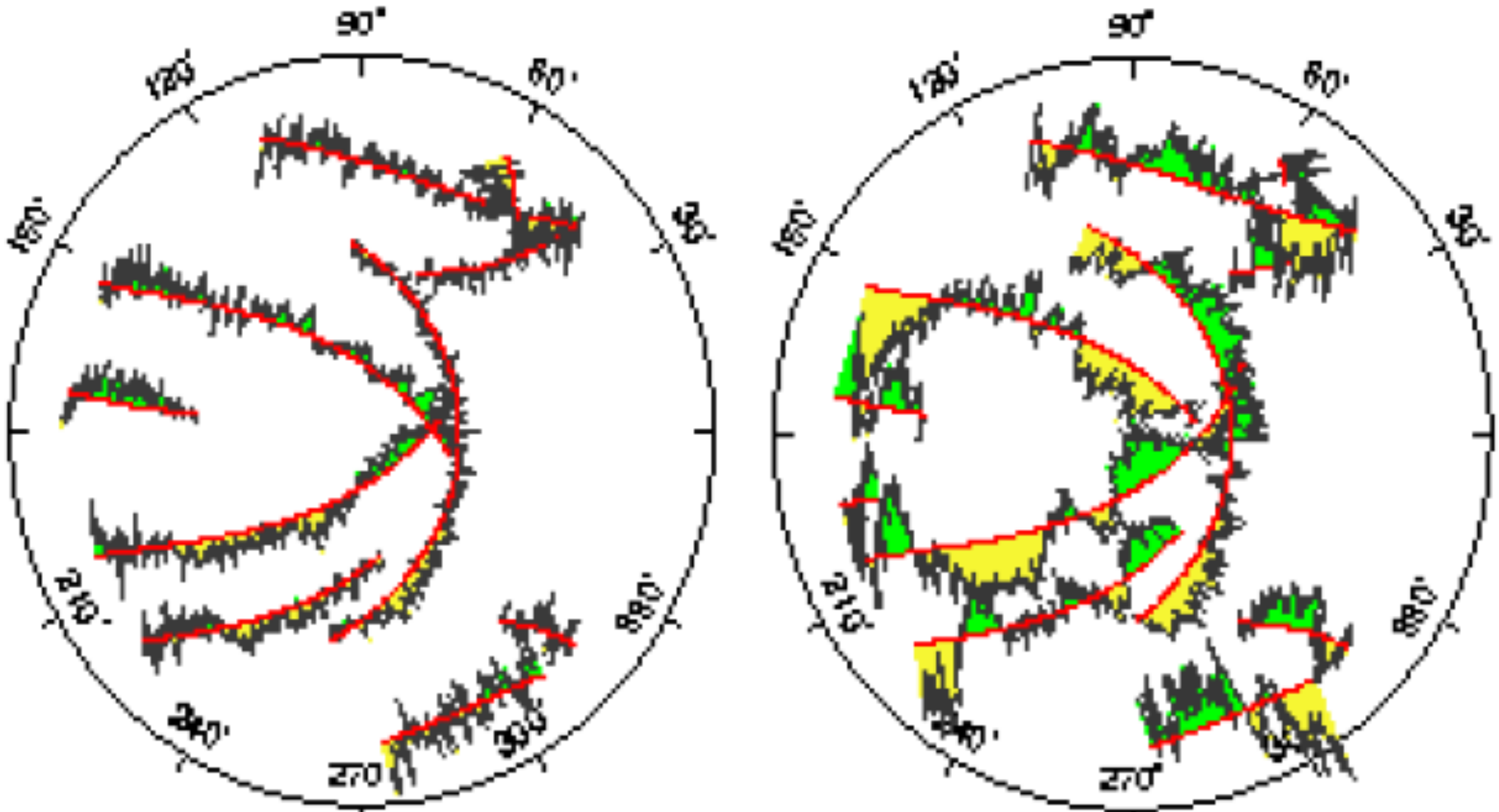
Real-Time GPS Sensing of Precipitable Water (PW)

9/4/99 21:00 UT



Ware et al., 2000

Atmospheric Slant Delays



Calm, 5.7 mm rms

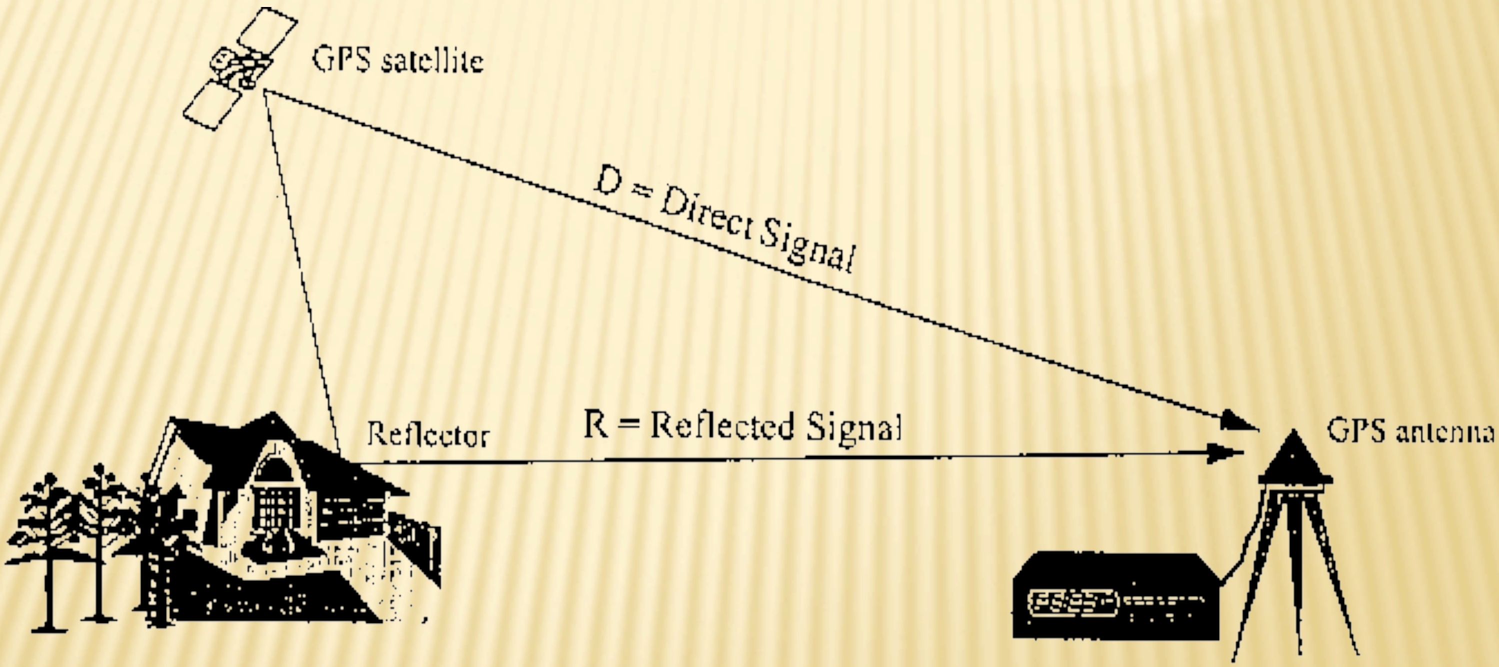
Typhoon, 11.1 mm rms

Ware et al., 2000

MULTIPATH ERRORS

- GPS assumes that the signal travels directly from the satellite to the receiver
- Multipath results from signal reflecting off of surface before entering the receiver
  - Adds additional (erroneous) path length to the signal
- Difficult to remove; best to avoid

Multipath Illustration



From http://www.gmat.unsw.edu.au/snap/gps/gps_survey/chap6/6212.htm

Eric Calais' GAMIT overview