Earth Science Applications of Space Based Geodesy

DES-7355

Tu-Th 9:40-11:05

Seminar Room in 3892 Central Ave. (Long building)

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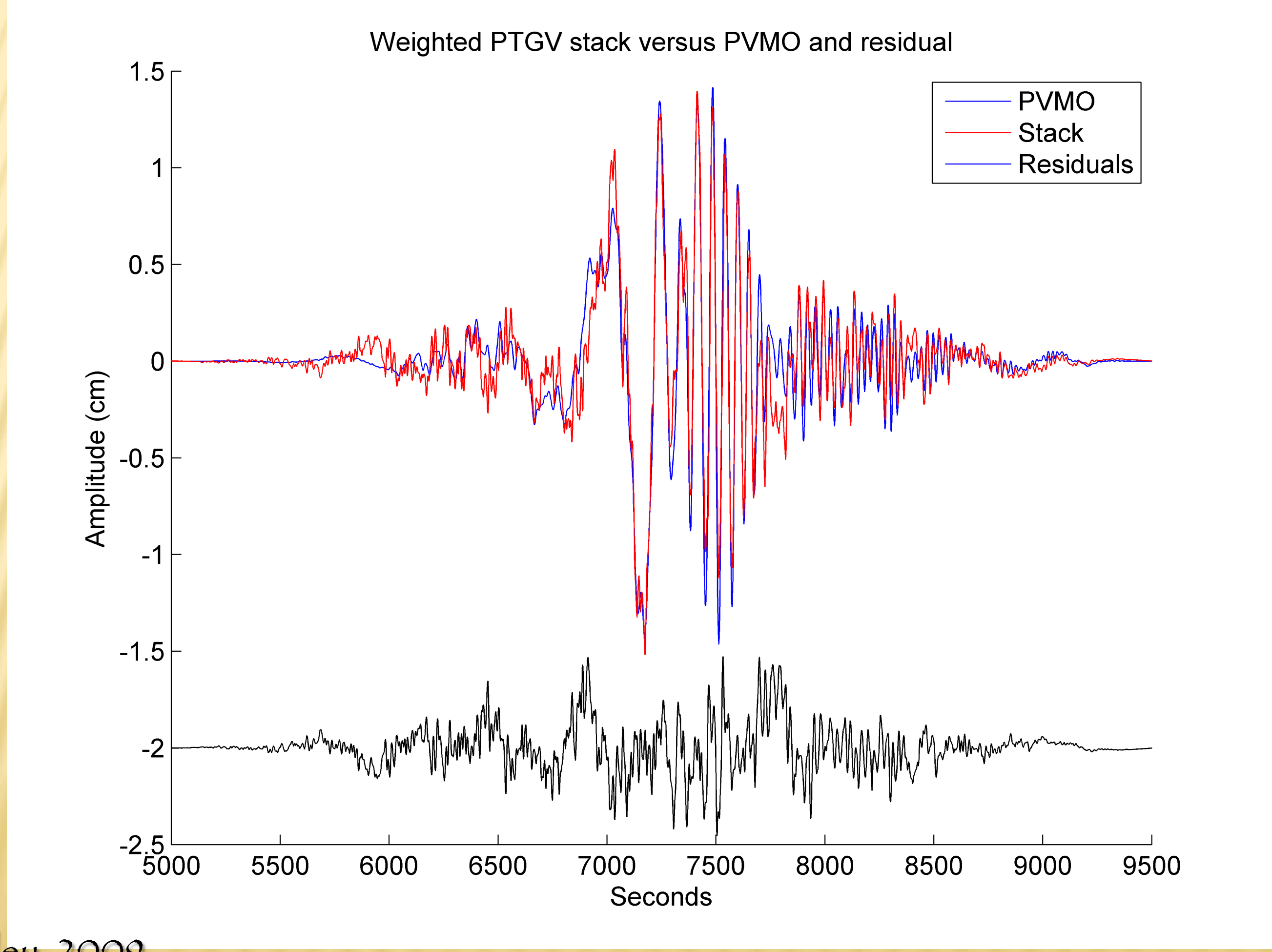
Office: 3892 Central Ave, Room 103
678-4929
Office Hours – Wed 14:00-16:00 or if I' m in my office.

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

Class 15

Kinematic GPS

GPS absolute displacement seismograms – Love wave of 2004 M9.0, Sumatra-Andaman earthquake in Portageville, AR.

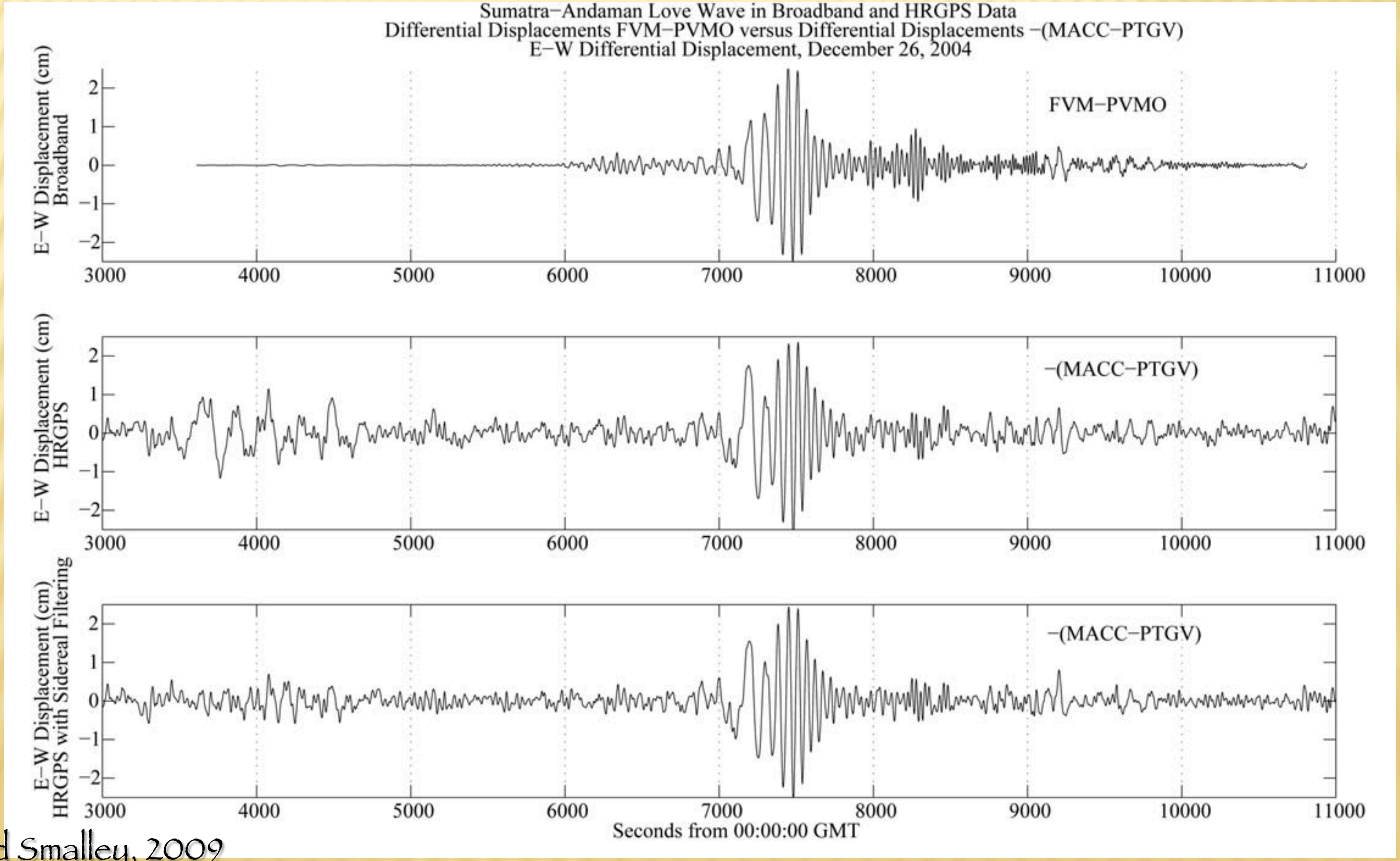


Davis and Smalley, 2009

Kinematic GPS

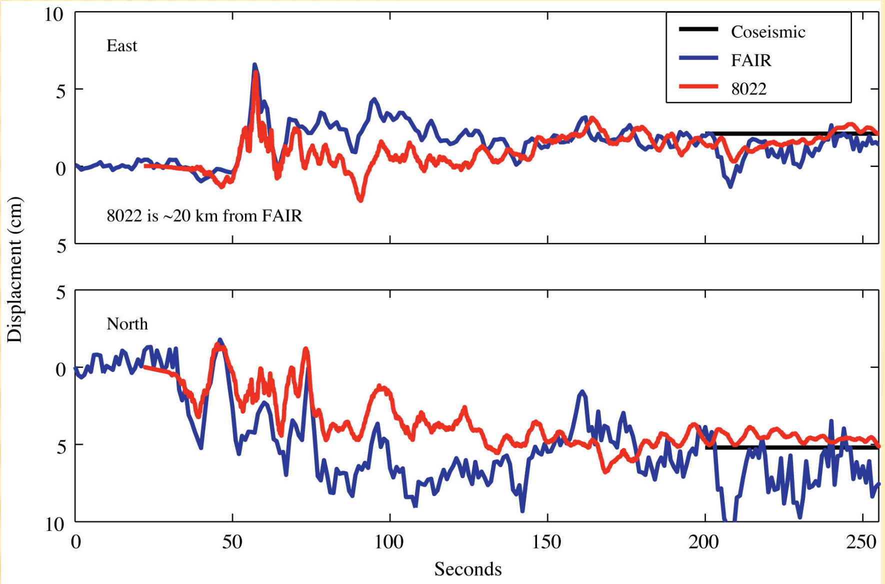
Differential – difference in position between two GPS antennas, one assumed "fixed". (PPP methods also exist, but are less precise)

$$D_{differential} = D_{kinematic} - D_{fixed}$$

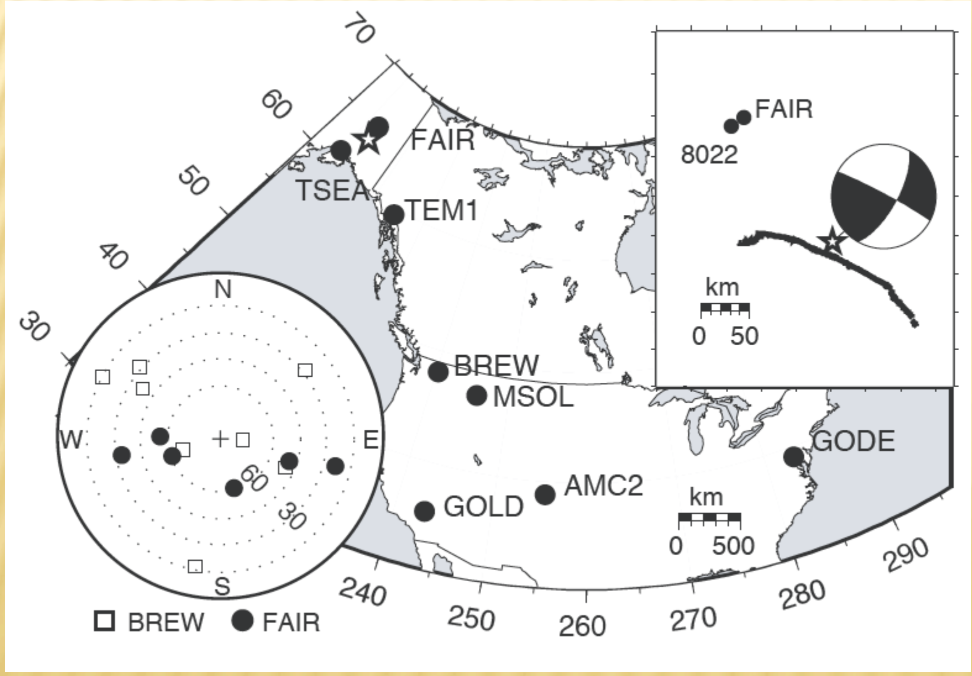


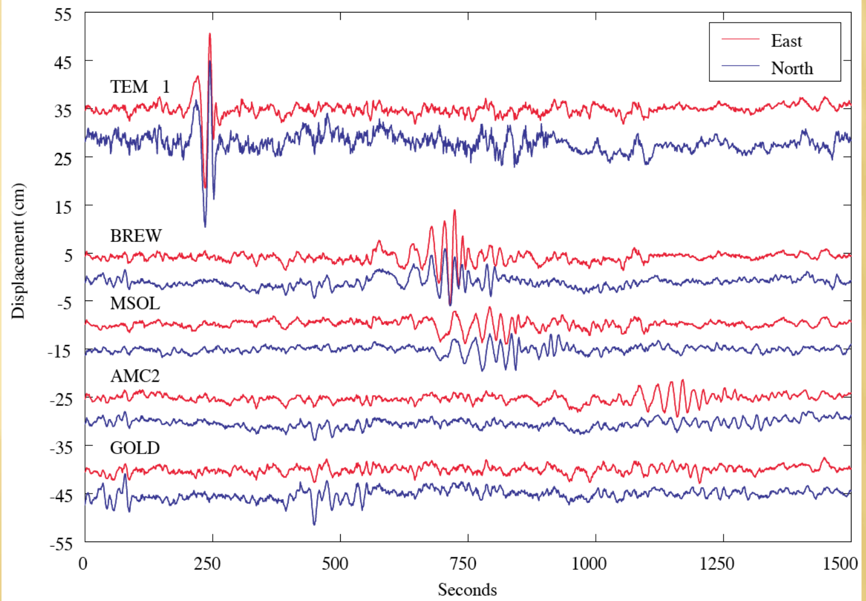
Davis and Smalley, 2009

How to get absolute displacements?



Most popular way to have one of the two sites outside the region with displacements (site is "fixed") – discovered GPS recorded surface waves at few thousand km.





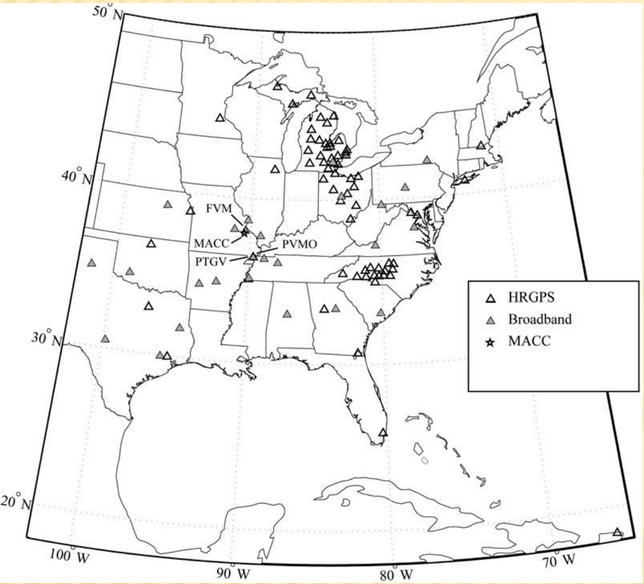
Larson et al, 2003

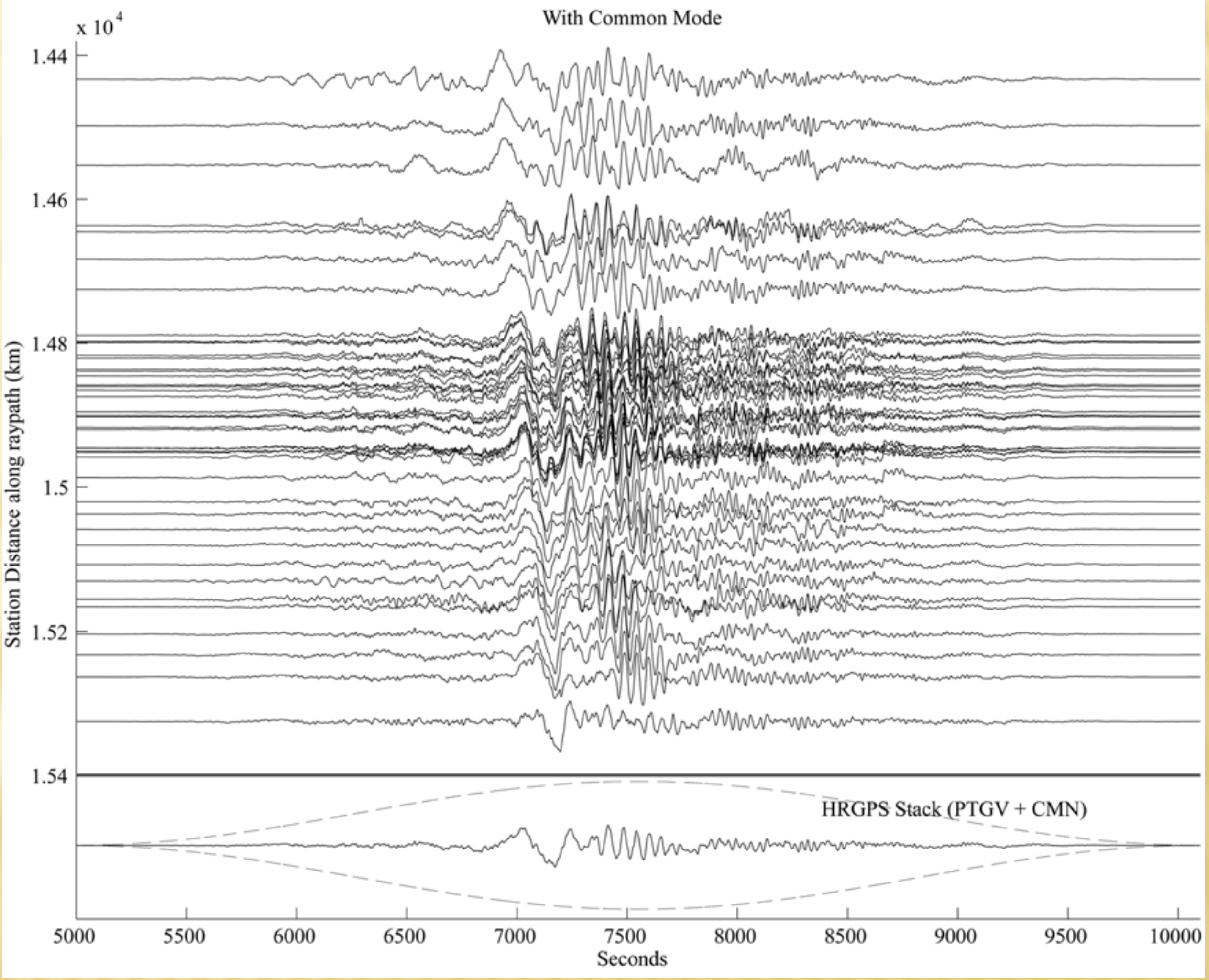
Does not work for surface waves from really big earthquakes with long duration surface wave trains

can't find "fixed" site.

(Fixed site has to be able to see common set satellites with kinematic site – since is differential.
The longer the baseline the fewer satellites are in common and the worse the overall location geometry.
The signal may be of longer duration than the time it takes for the waves to travel from the kinematic to the fixed site.)

Calculate differential displacement seismograms for large number sites in central North America – using "fixed" site in central North America.



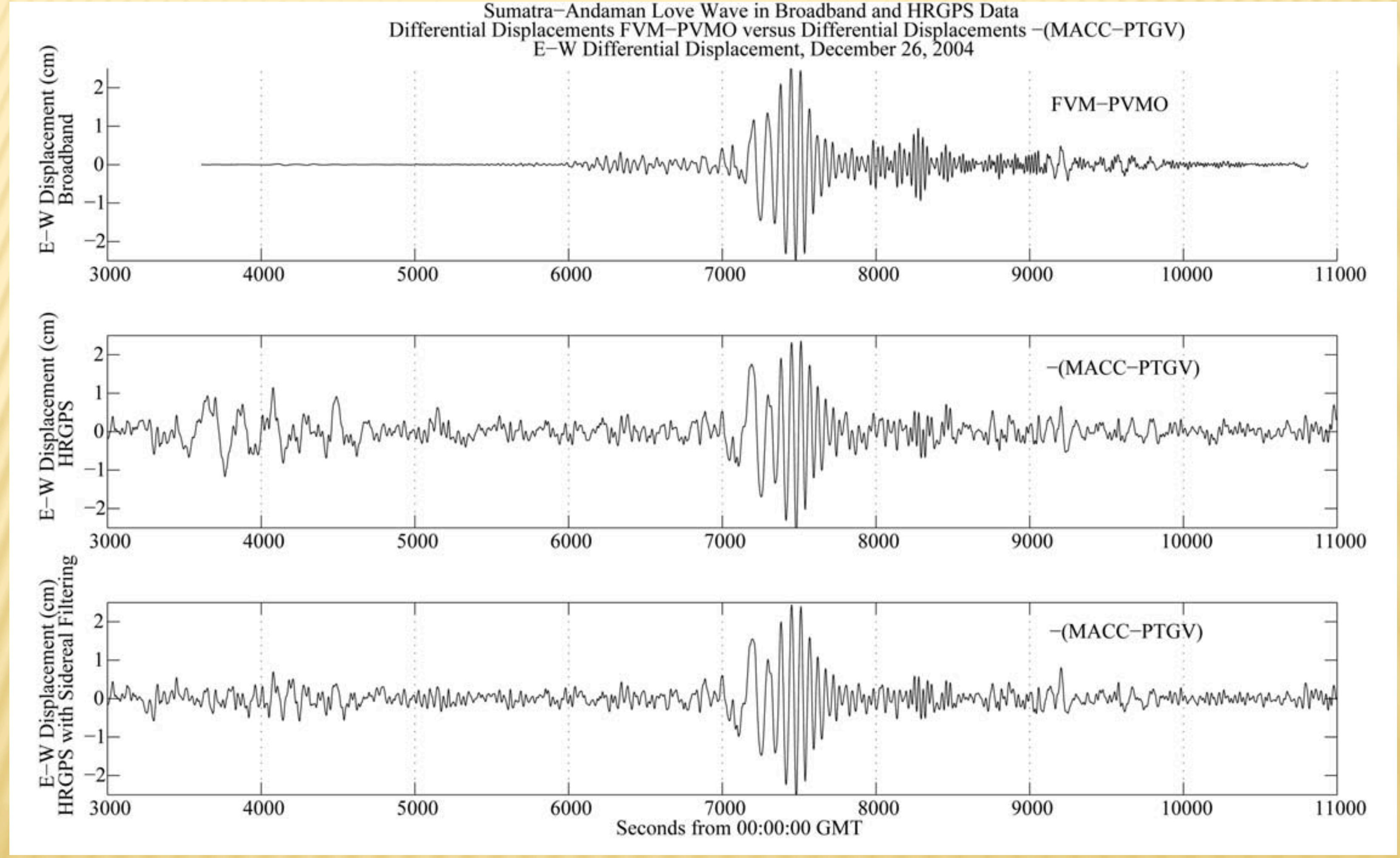


Difficult to tell (in this display) are not absolute seismograms.

(Bottom trace is sum.)

Davis and Smalley, 2009

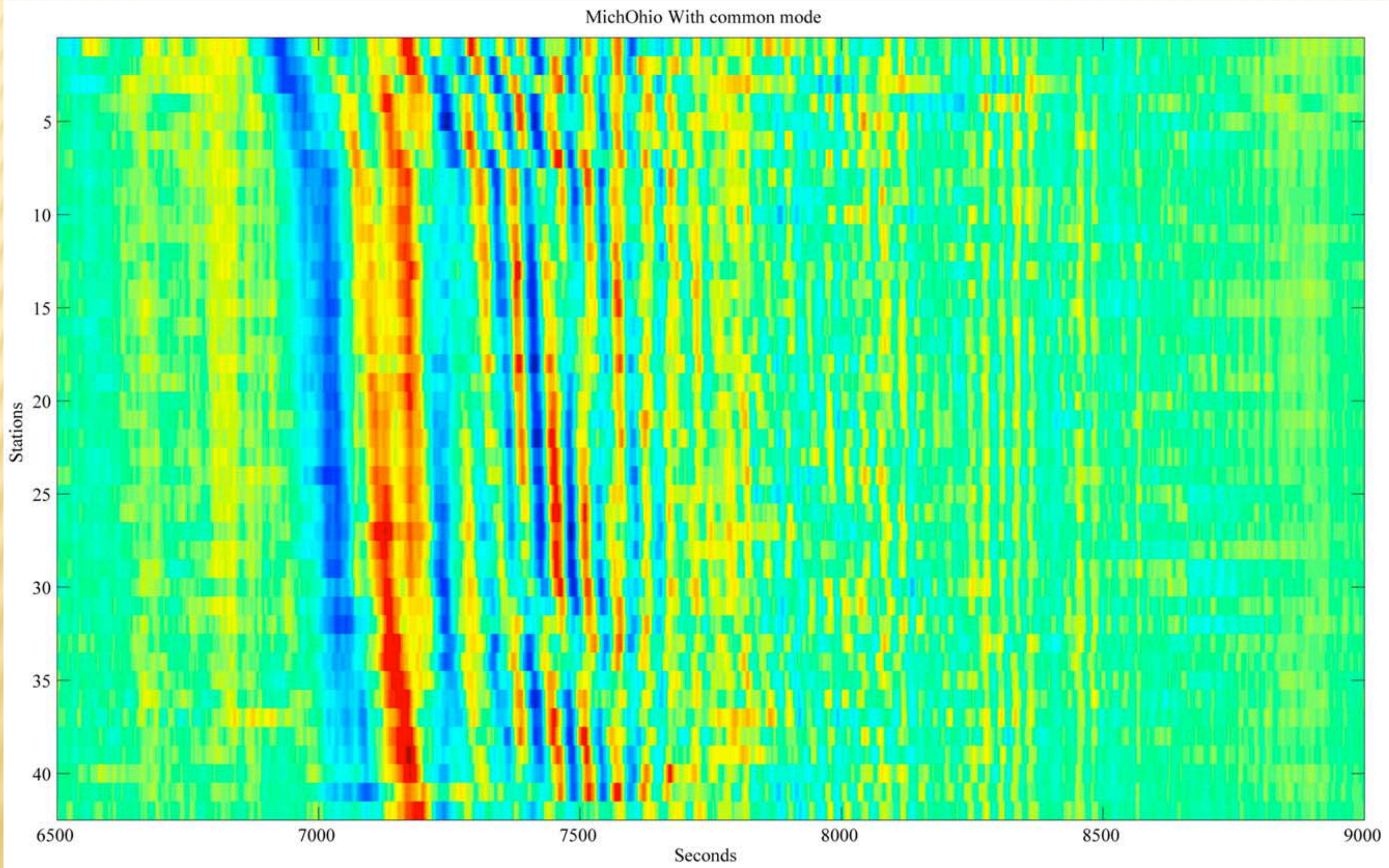
Note difference between middle and bottom traces – the bottom one has been sidereally filtered.



Davis and Smalley, 2009

Differential seismograms plotted as surface.

Now is does not quite look “right” (eg. - vertical lines, no “move-out”)

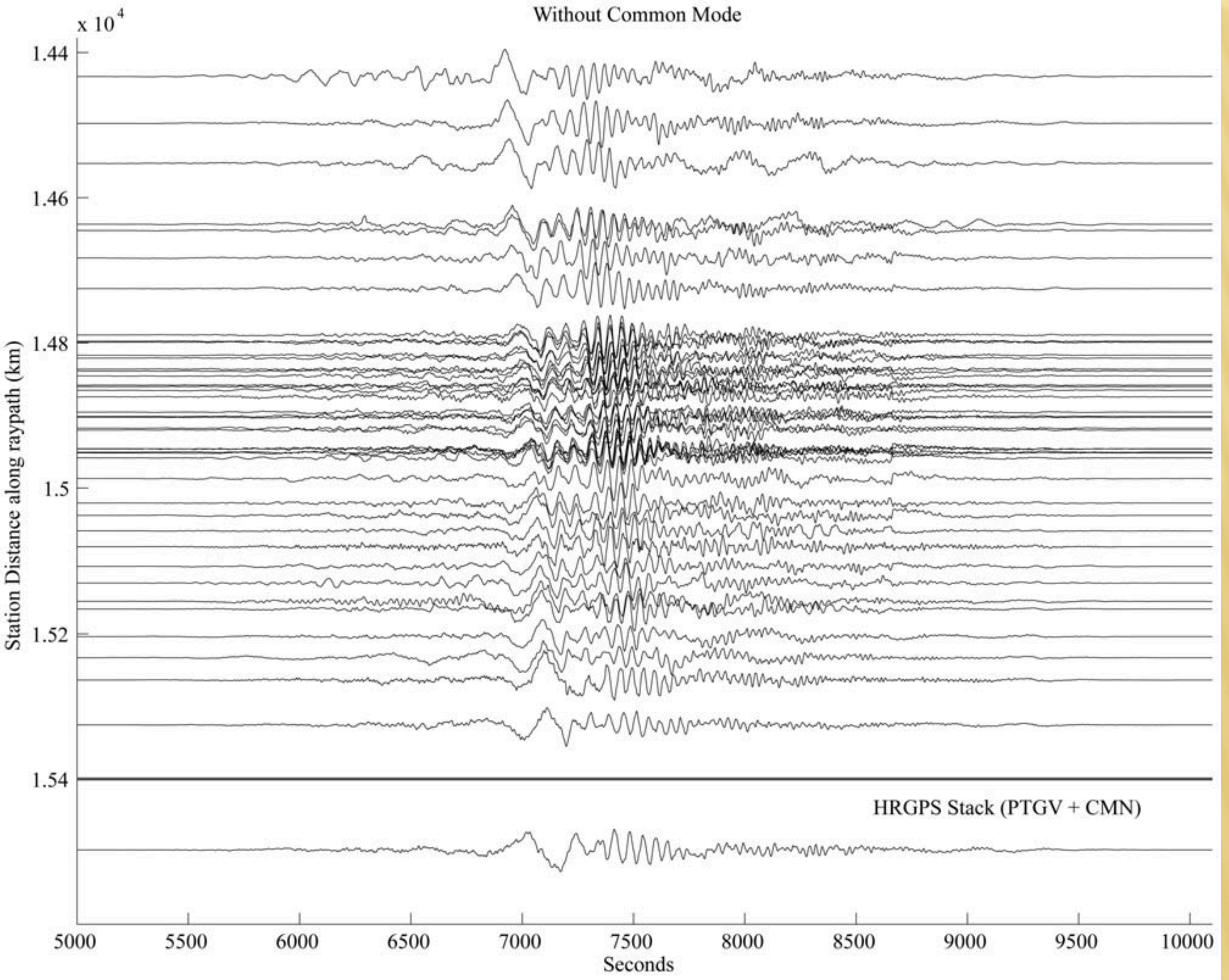


Davis and Smalley, 2009

Bottom trace is sum of differential seismograms (fixed-kinematic). This is an estimate of the absolute displacement of the "fixed" site – the kinematic sites "cancel" out.

$$\left\langle D_{fixed} \right\rangle = \sum_{n=1}^{m} \left(D_n - D_{fixed} \right)$$

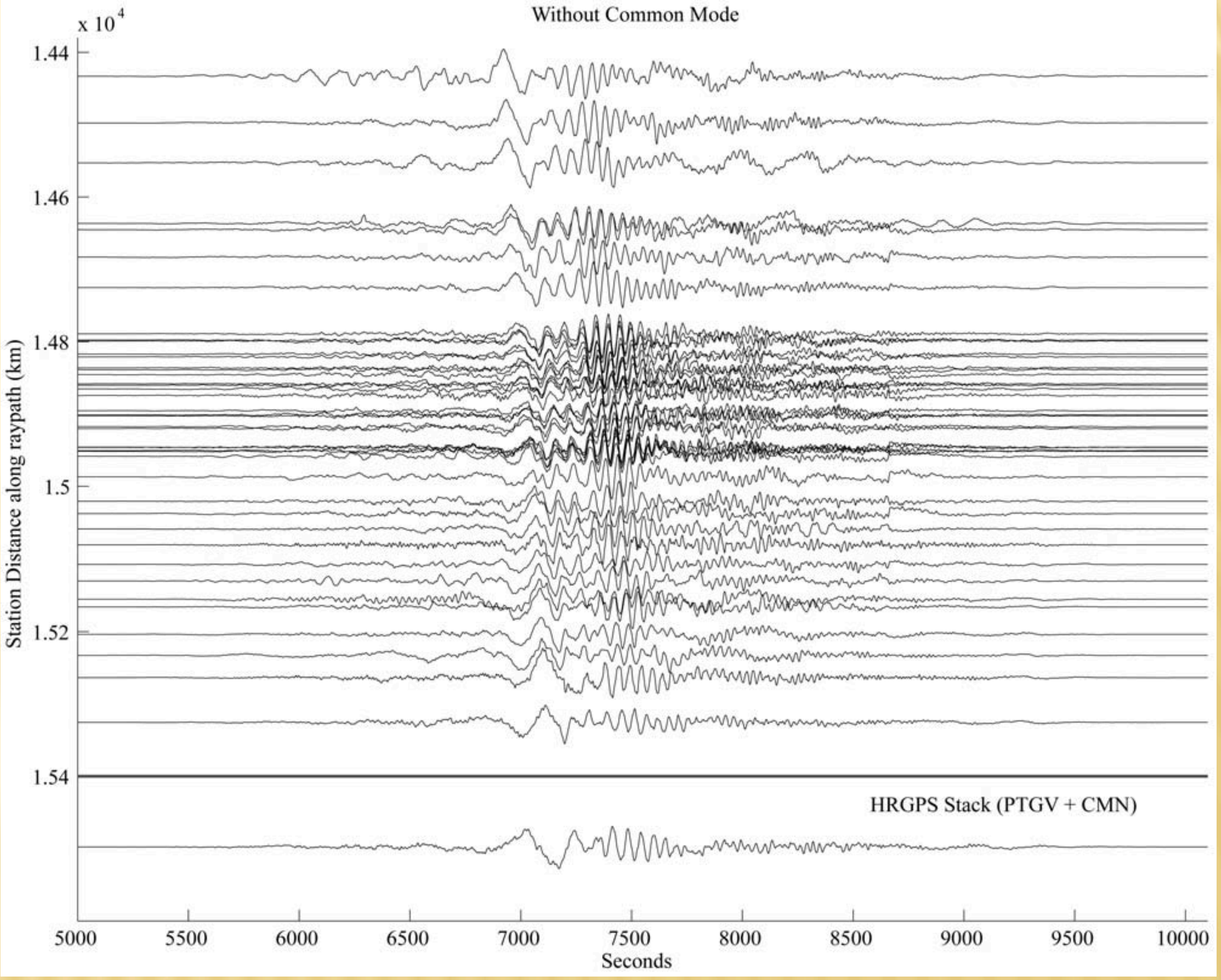
(Assume kinematic sites random with respect to one another)



Davis and Smalley, 2009

Subtracting the estimate of the absolute displacement time series of the fixed site (bottom trace) from the kinematic sites differential traces results in absolute displacement time series for the kinematic sites.

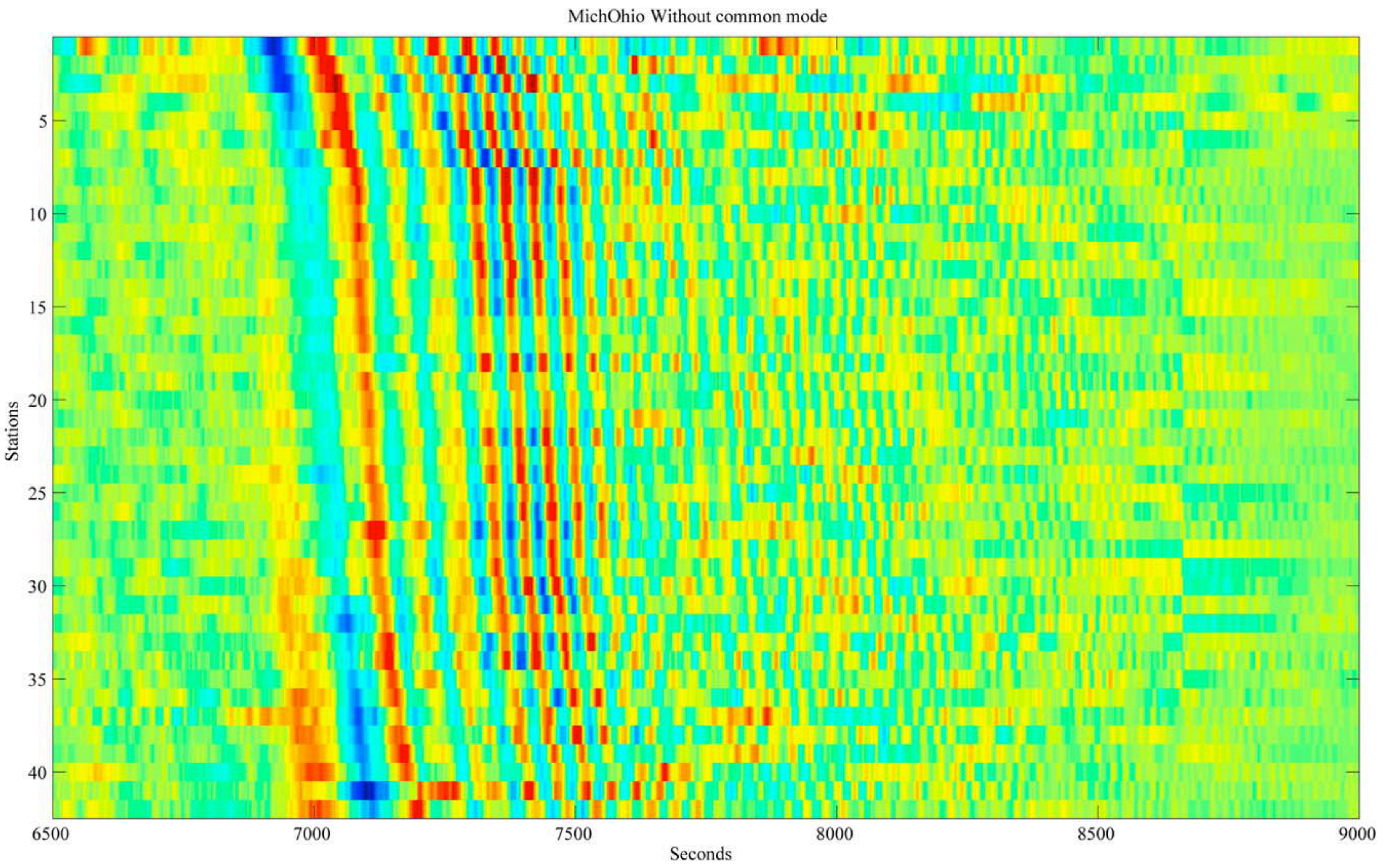
$$D_{kinematic} - \cancel{D_{fixed} + \langle D_{fixed} \rangle}$$



Davis and Smalley, 2009

Absolute seismograms plotted as surface.

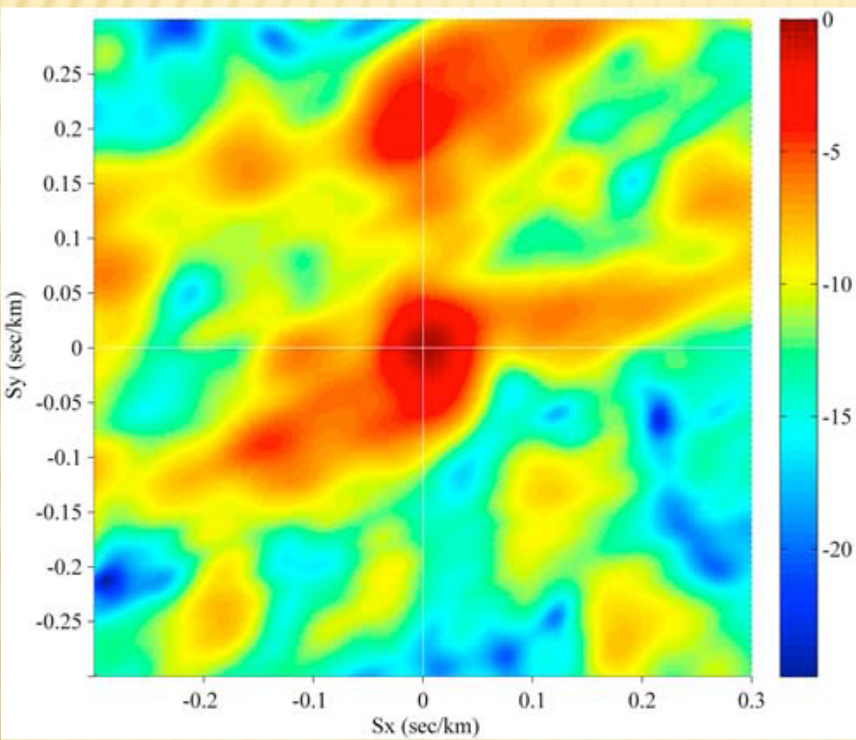
Now looks "right" ("move-out")

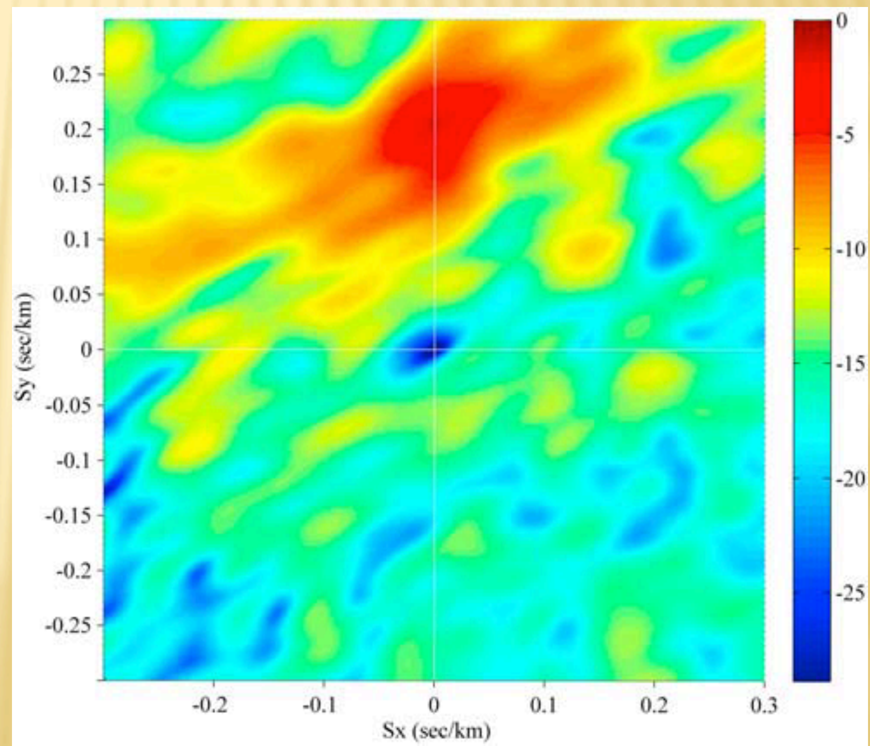


Davis and Smalley, 2009

Can also see by array processing (beam steering). Peaks show azimuth and slowness of plane waves crossing array. Peak in center (left) is infinite apparent velocity plane wave (everyone doing same thing at same time – the "fixed site"), the other peak is the surface wave.

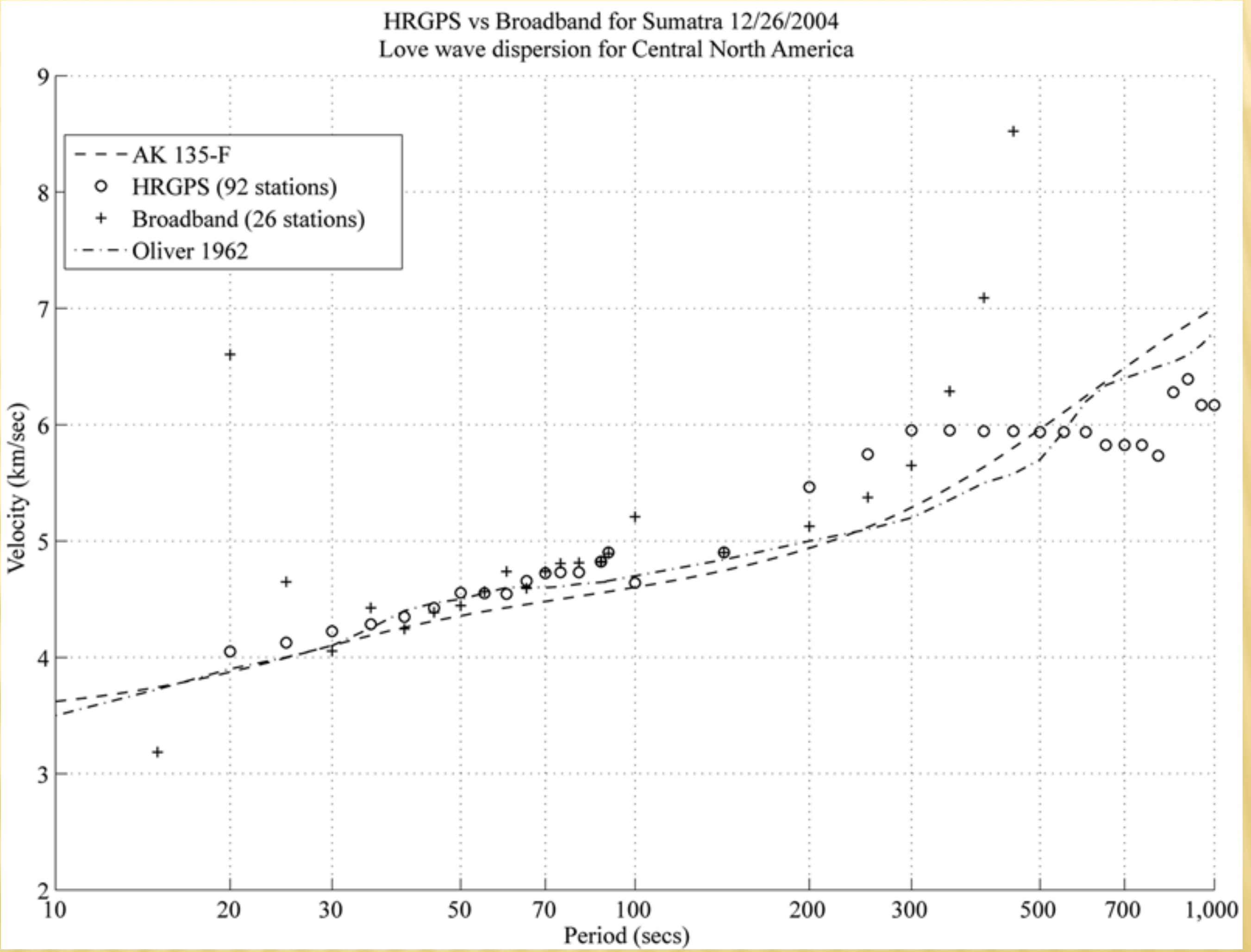
After removing fixed site can see just the surface wave.





Davis and Smalley, 2009

Now use beam steering to measure slowness at different periods and determine dispersion curve.



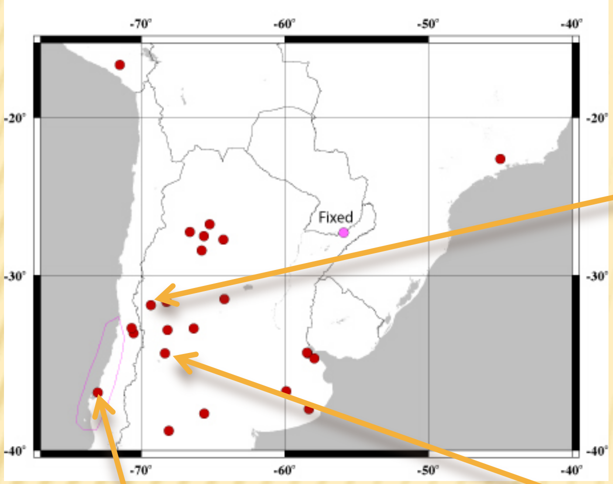
Davis and Smalley, 2009

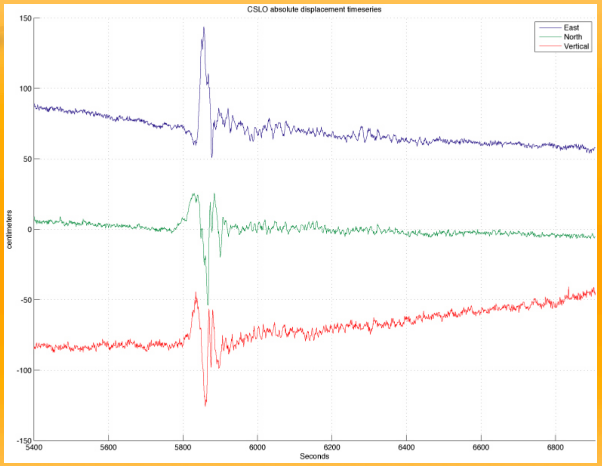
James is working on this for his thesis.

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

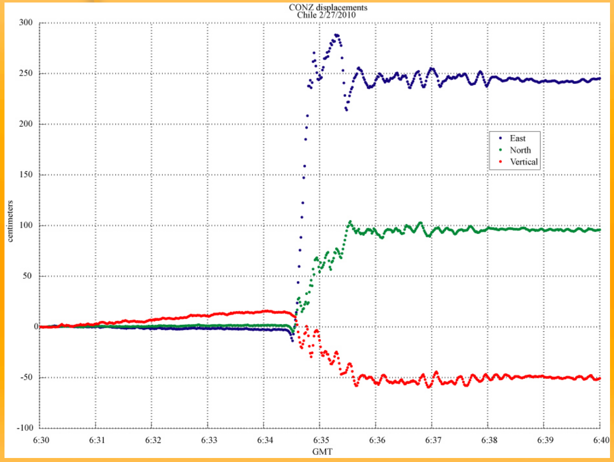
More Hi-Rate GPS from “LARGE” earthquake.

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

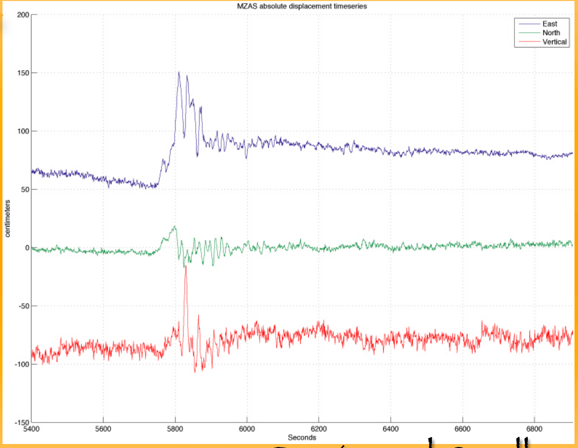




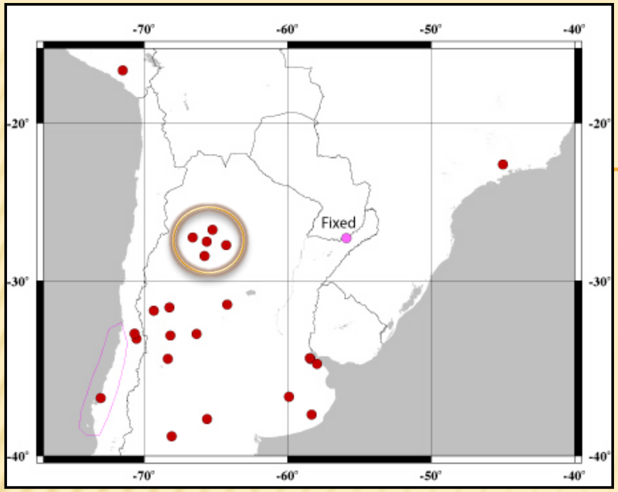
Near-Field, absolute displacement time series with static displacements.



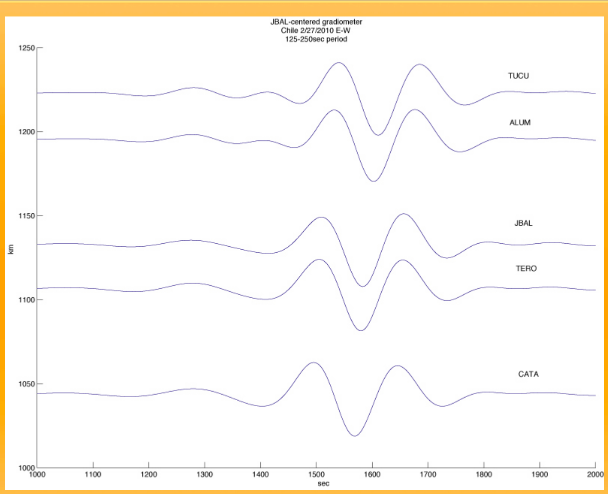
CONZ –absolute displacement coseismic time series



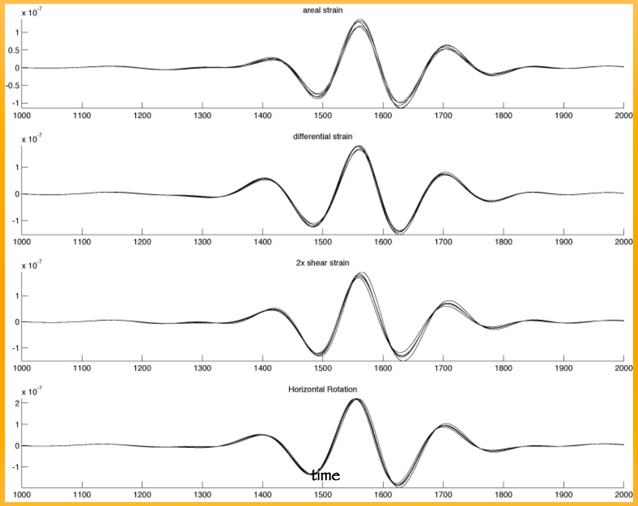
Davis and Smalley, 2009

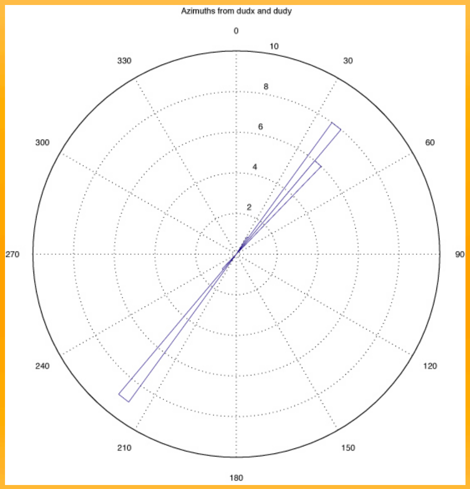


Absolute displacement, band passed (125-250 sec), phase matched filter for dispersion and gradiometry ("array" where wavelength>> spacing).

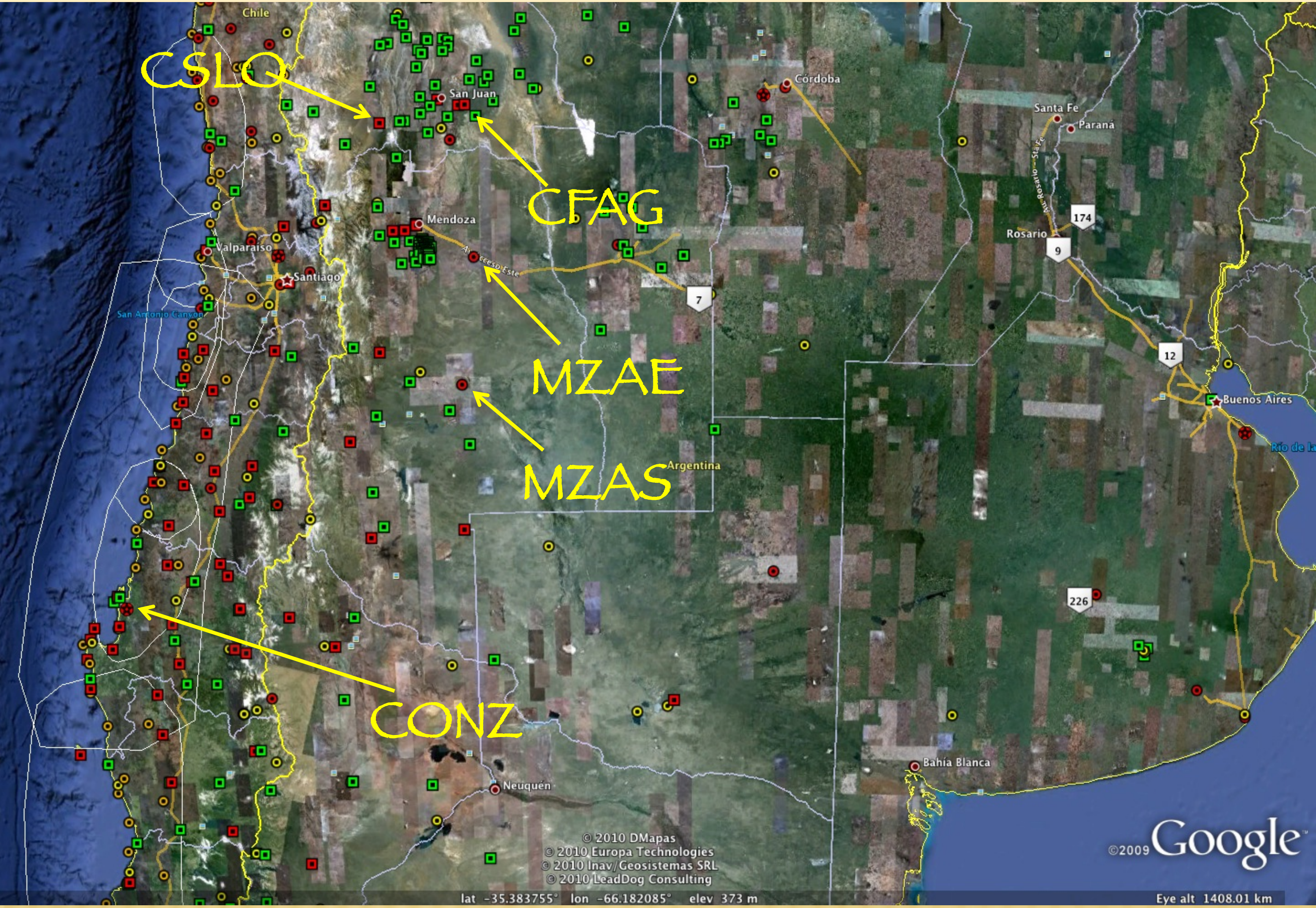


Gradiometry – dynamic strains, apparent velocity, azimuth.





Davis and Smalley, 2009


CSLO
CFAG
MZAE
MZAS
CONZ
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San Juan
Córdoba
Santa Fe
Paraná
Rosario
174
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12
Mendoza
Acceso Este
Valparaíso
Santiago
San Antonio Canyon
Buenos Aires
Río de la
Argentina
226
Bahía Blanca
Neuquén
© 2010 DMapas
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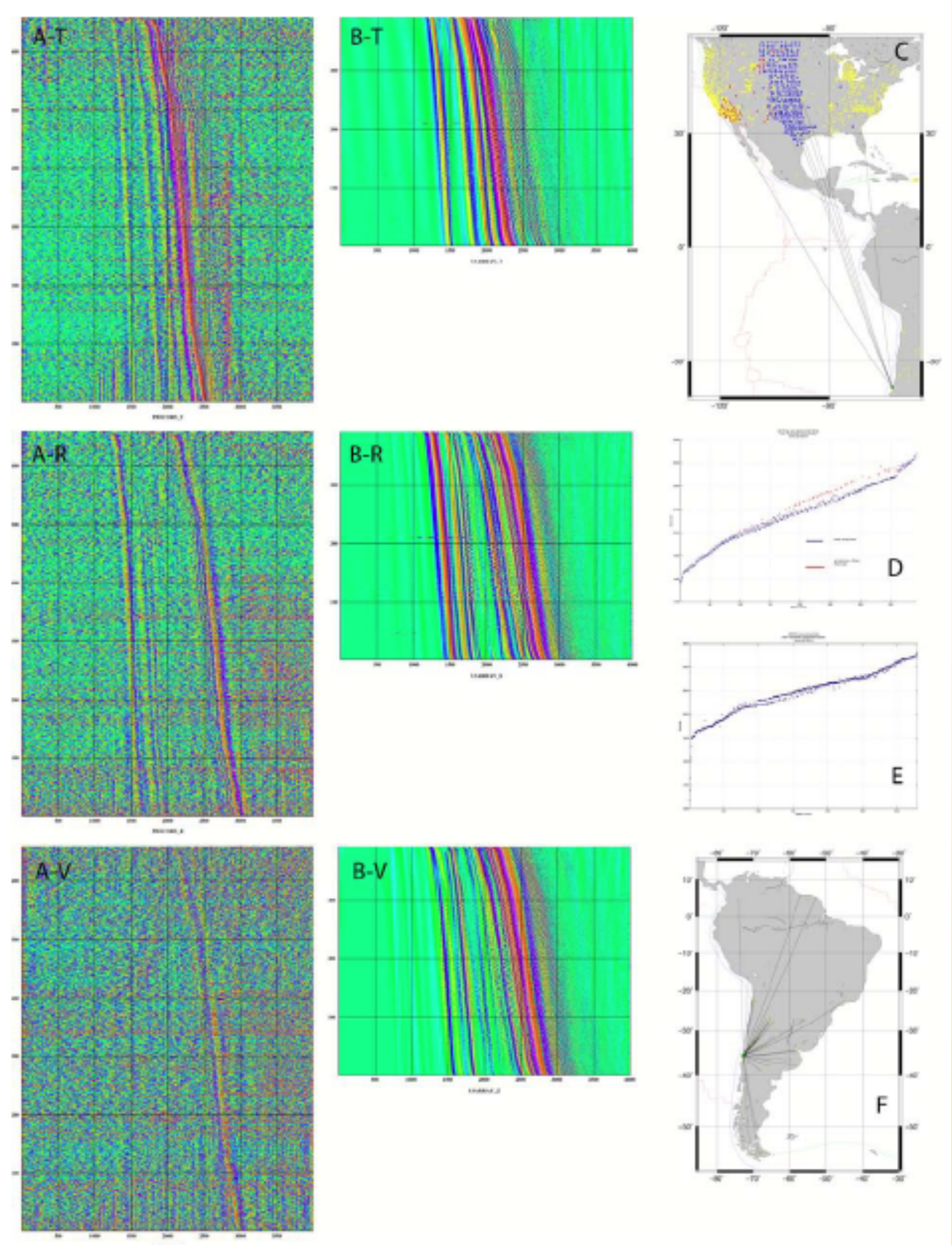
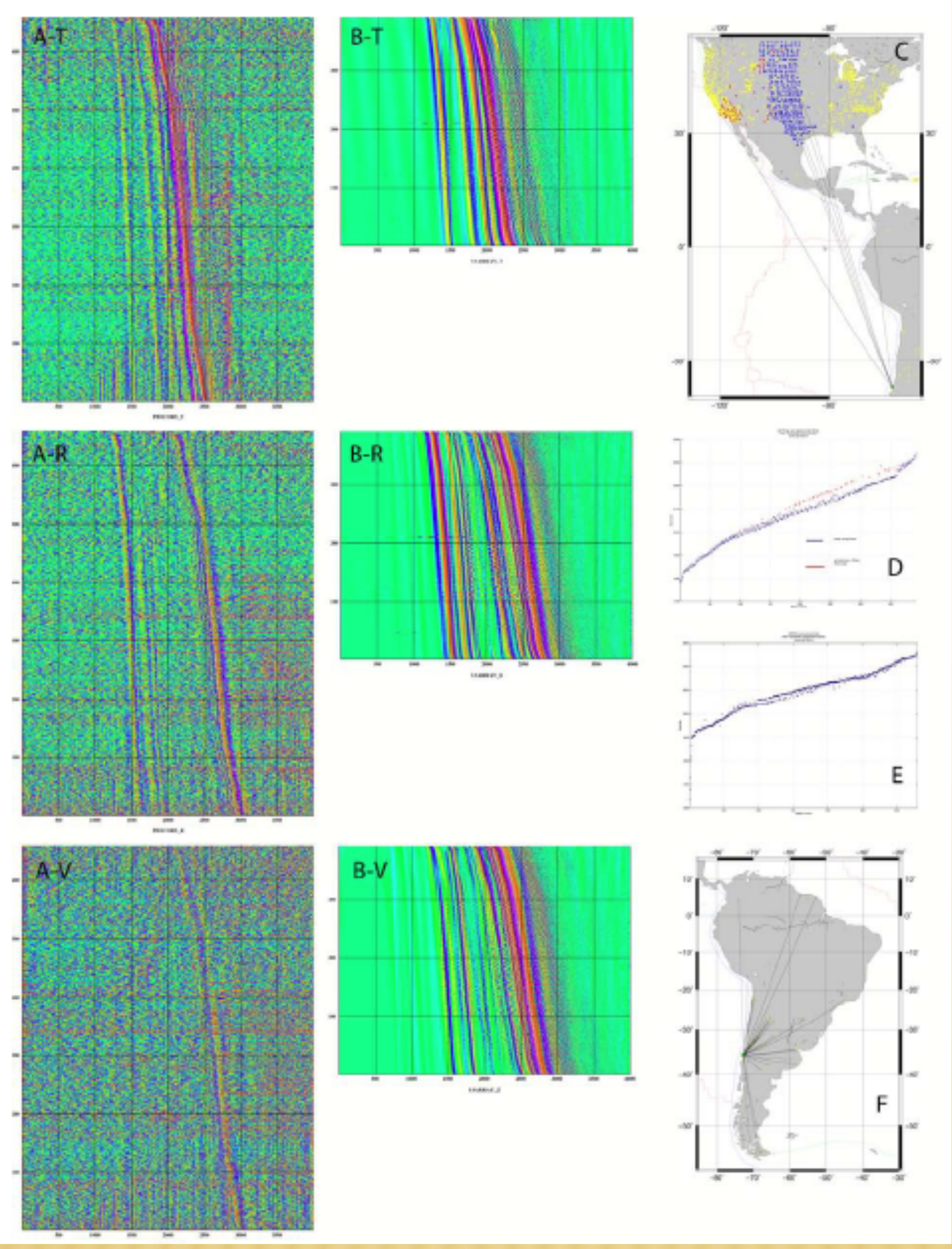
© 2010 Inav/Geosistemas SRL
© 2010 LeadDog Consulting
©2009 Google
lat -35.383755° lon -66.182085° elev 373 m
Eye alt 1408.01 km



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)

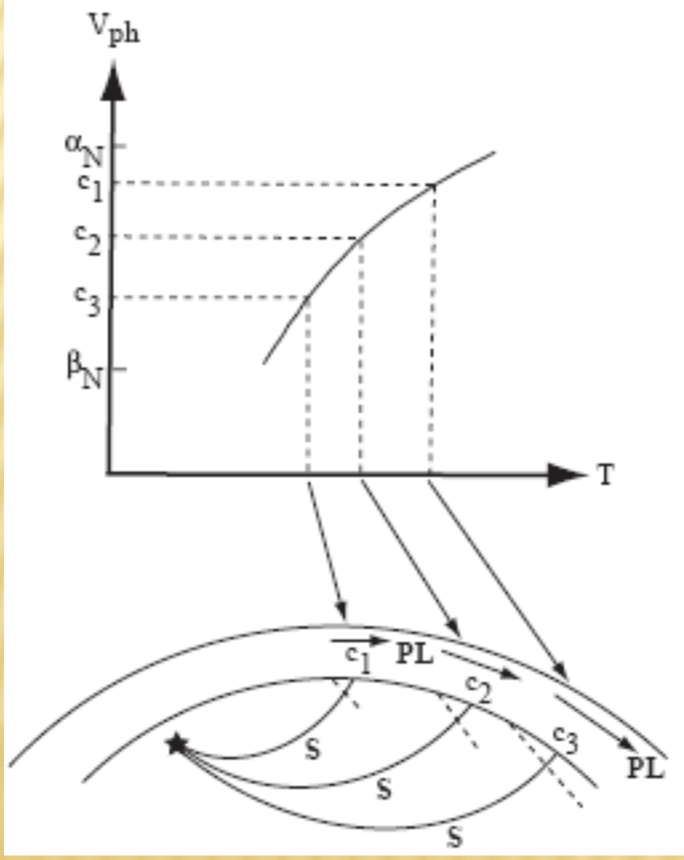
waves.

Davis and Smalley

What is Shear (or S) coupled P_L ?

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

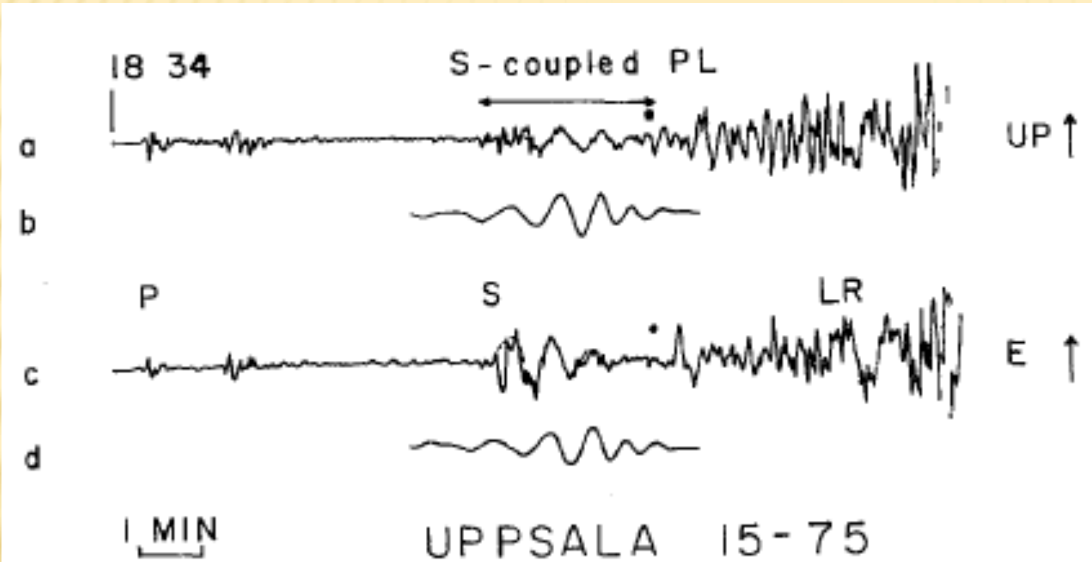
S apparent velocity same as P_L velocity.



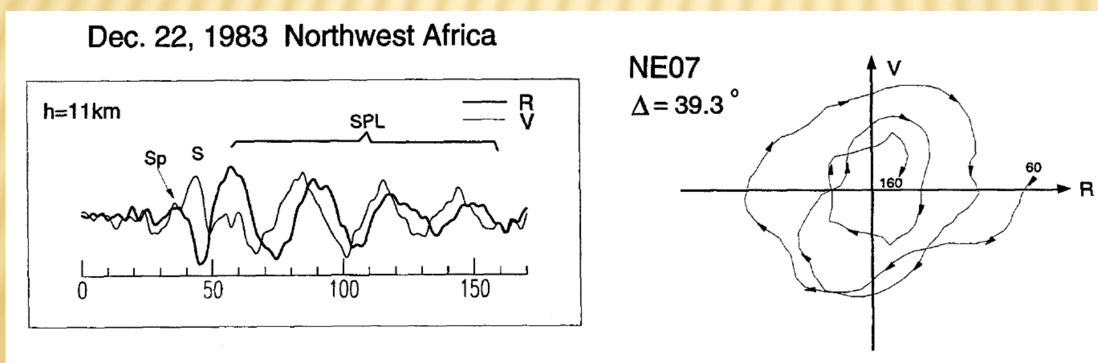
Teleseismic S enters crust, converts to P, which is trapped (supercritical), but when P reflects off Moho (total internal reflection) some converts to S and "leaks" out.

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

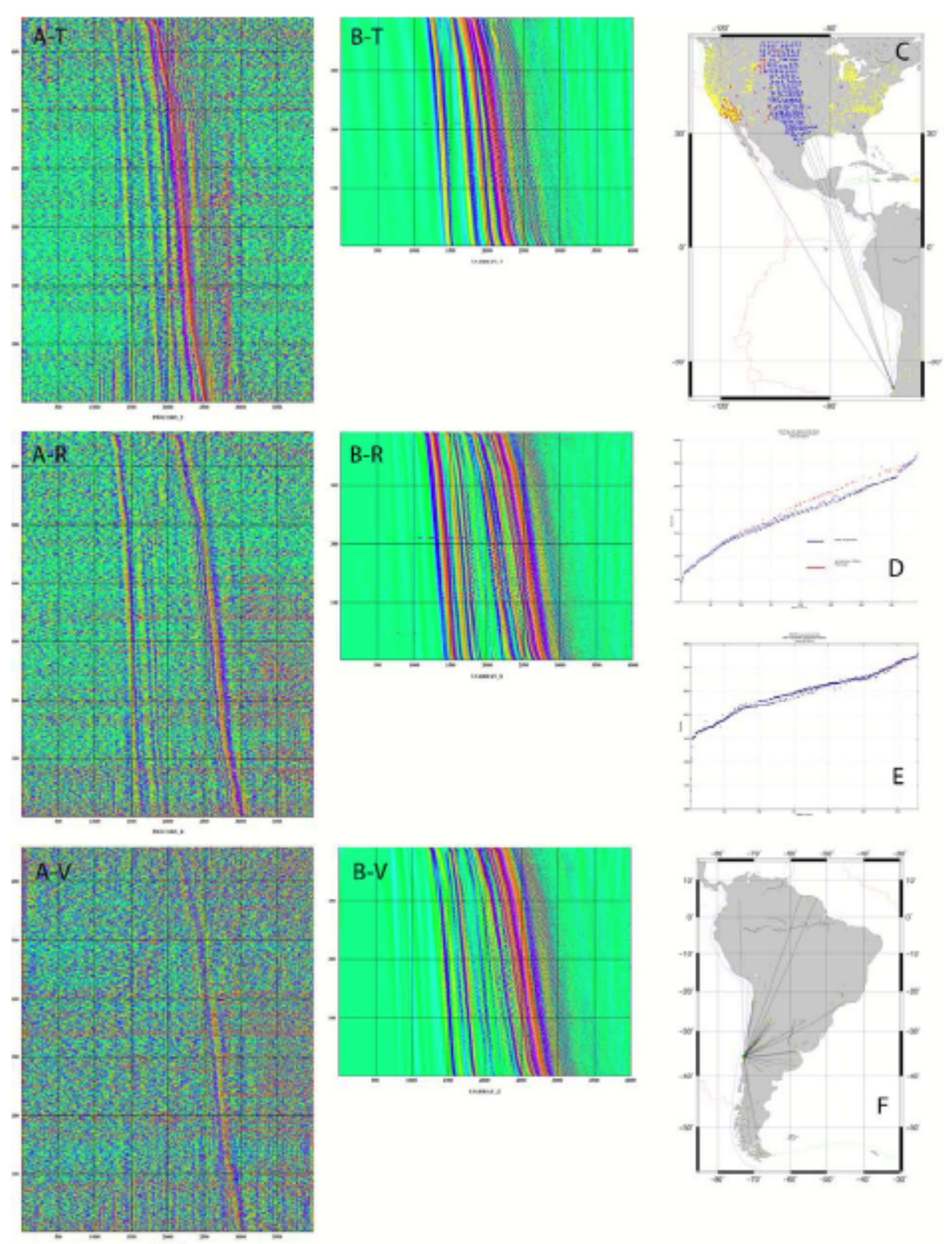
Particle motion of P_L
Prograde Elliptical.



Chander et al., 1968

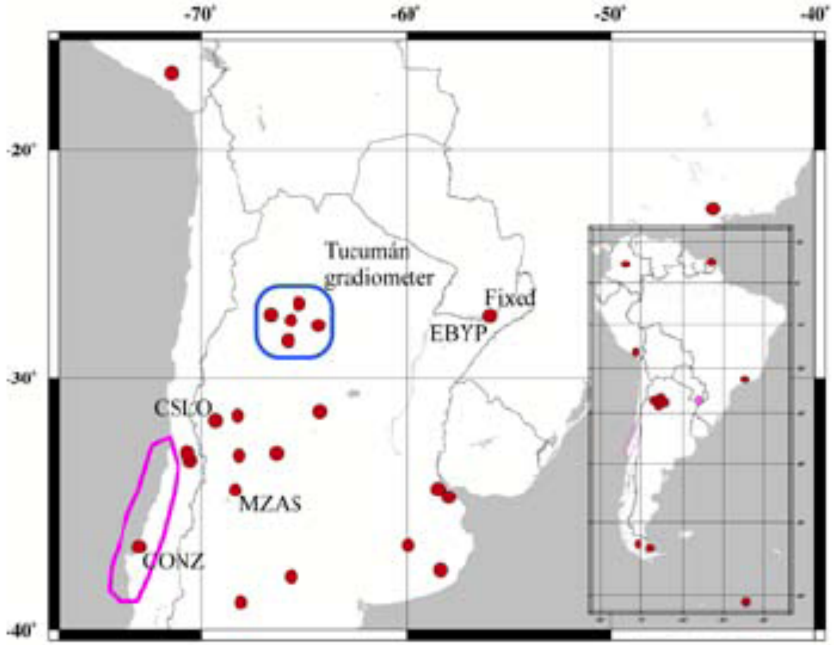


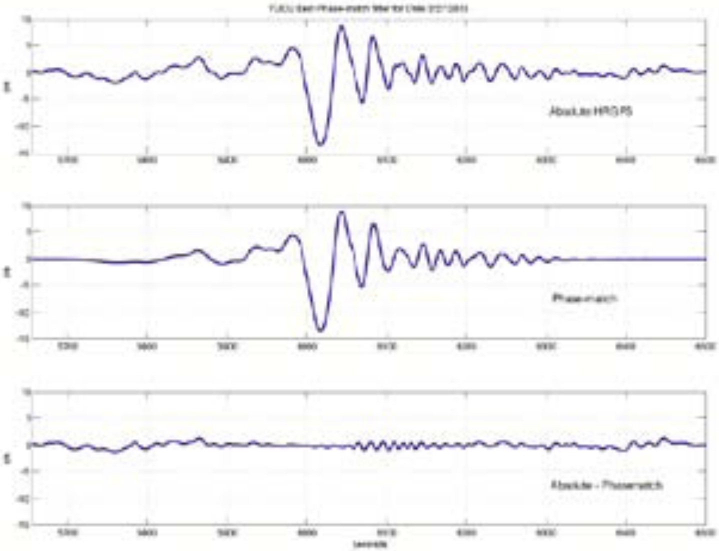
Zhang and Langston, 1996



“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.

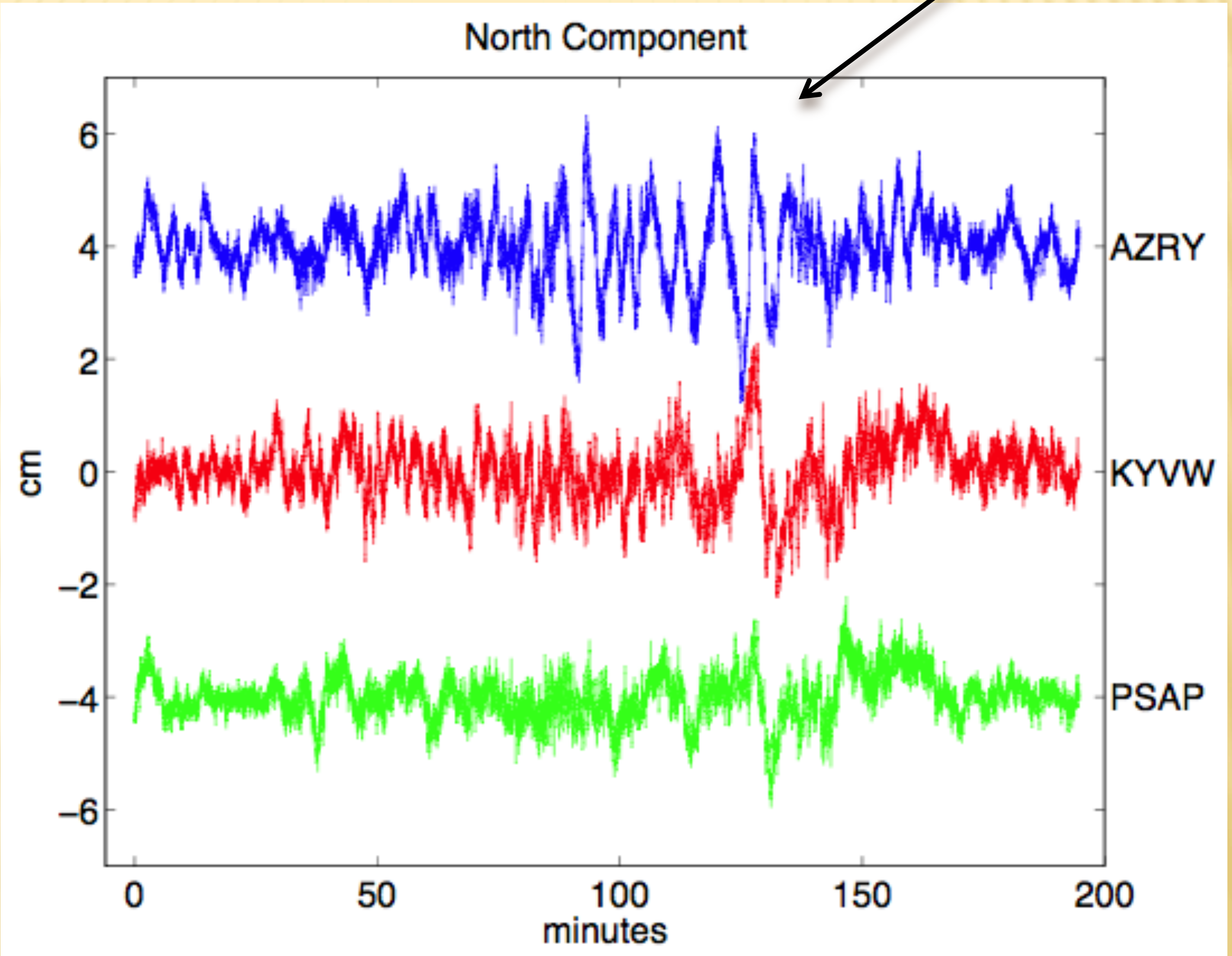
Further improvements to estimating HRGPS time series.
Additional applications (gradiometry).

Remote sensing with GPS.

Exploiting the noise in GPS data.

Multipath

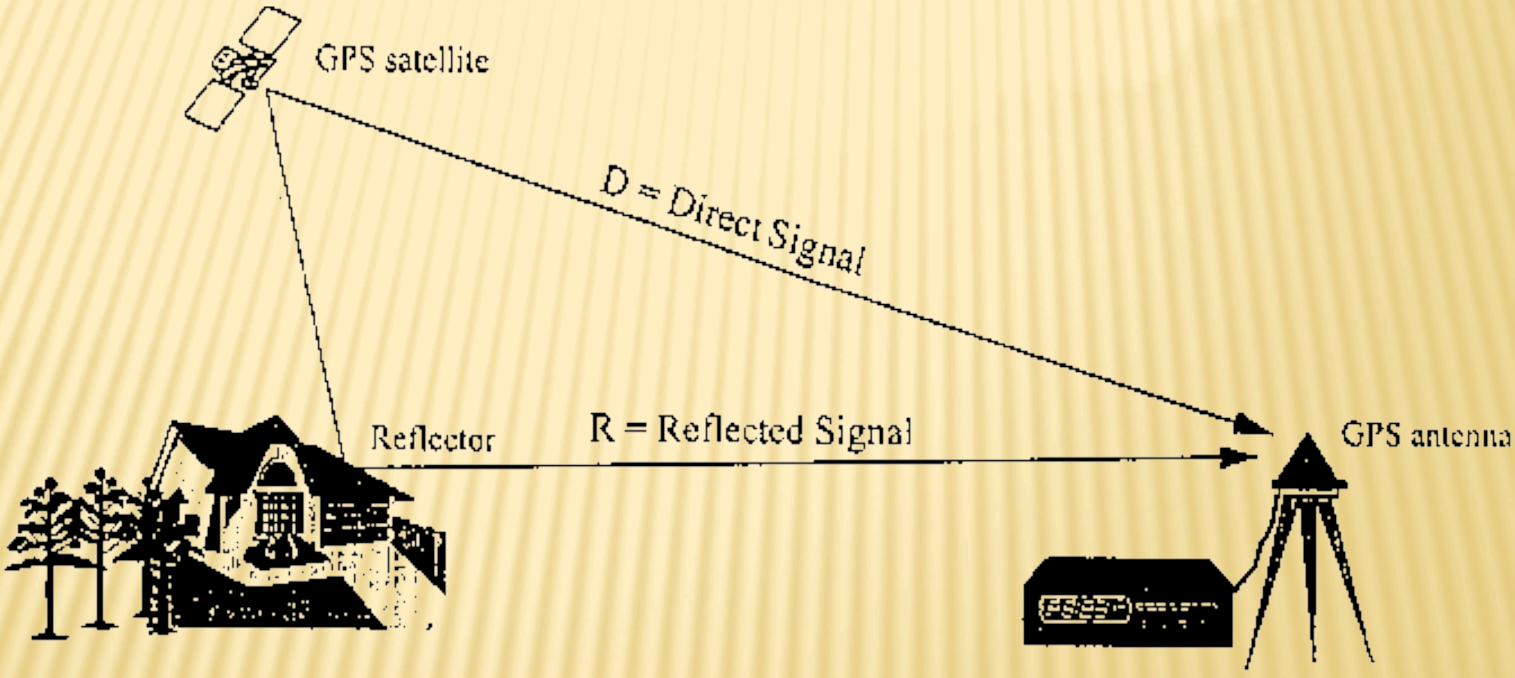
Multipath (reflected signals) is important (and doesn't difference out). Looks like earthquake?



If you are not a seismologist

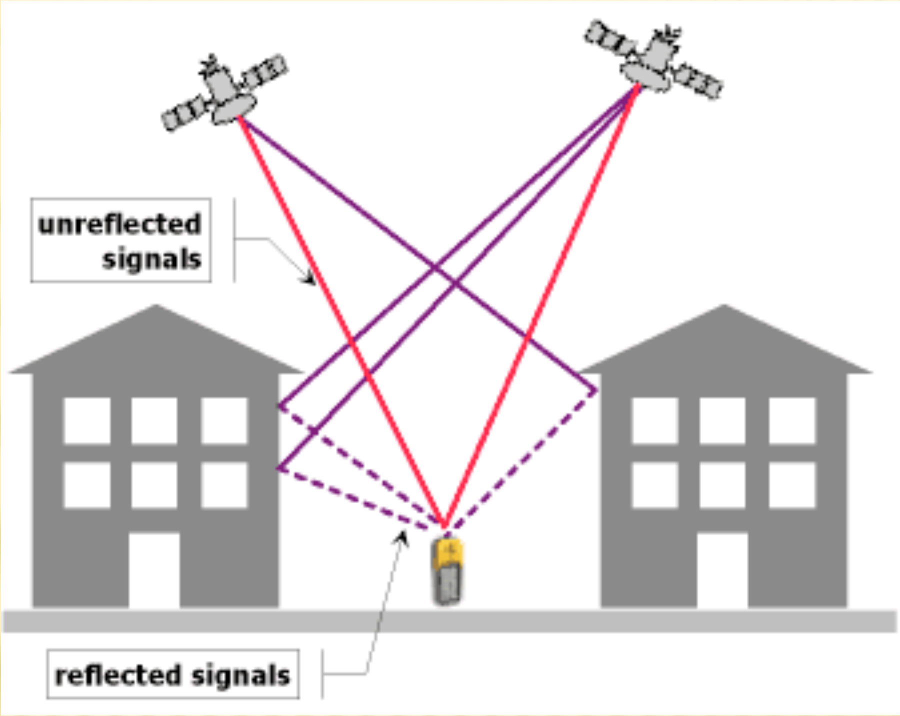
From Larson

Multipath Illustration



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

Multipath

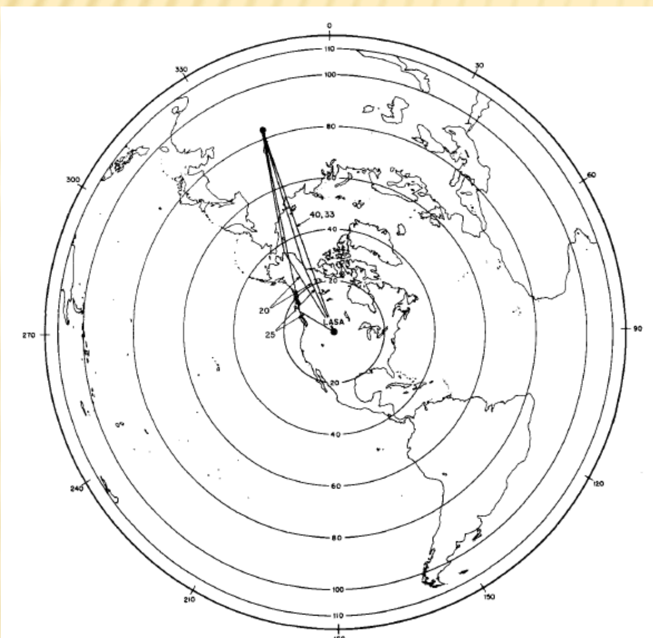


http://www.kowoma.de/en/gps/errors.htm

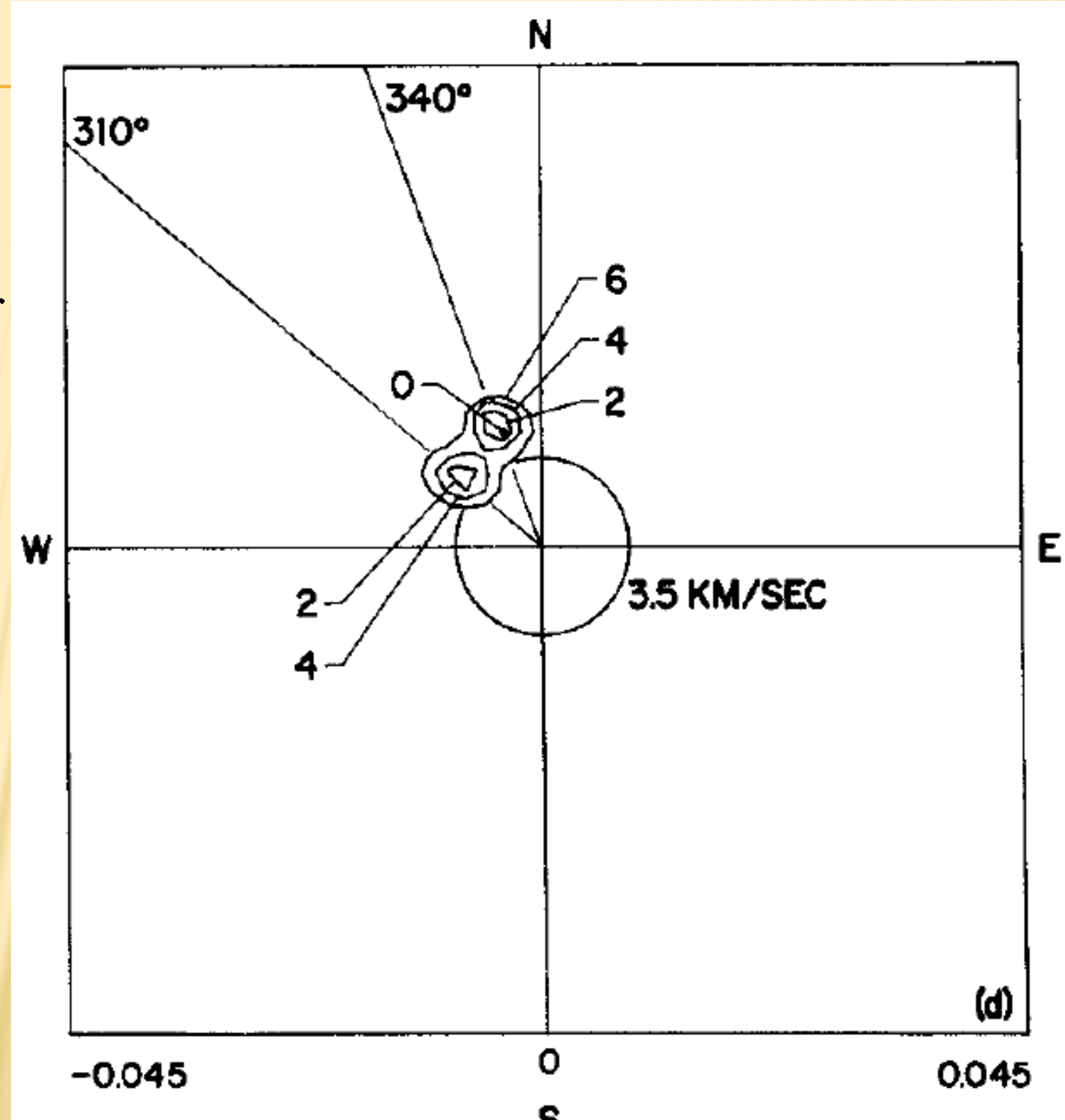
Multipath example

Seismic example – See two peaks in beamform.

(This is actually from synthetic test data, not actual seismic data. Simulating situation similar to below.)

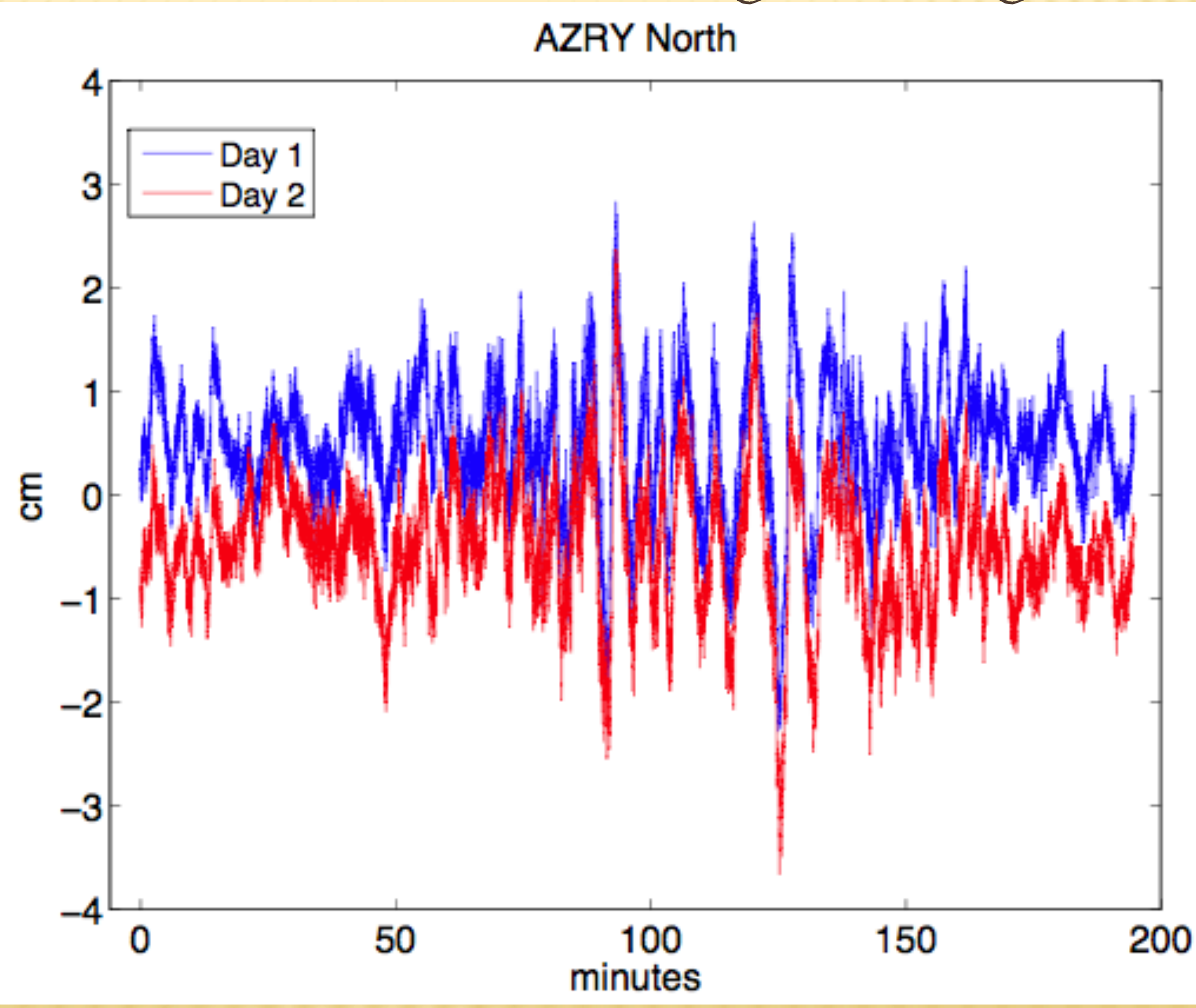


Multipath



Capon 1970

But look at day before or after – looks the same. Multipath looks same from day to day – due to orbits repeating (siderially), generating same reflections, day to day.



From Larson

How multipath affects pseudorange estimation

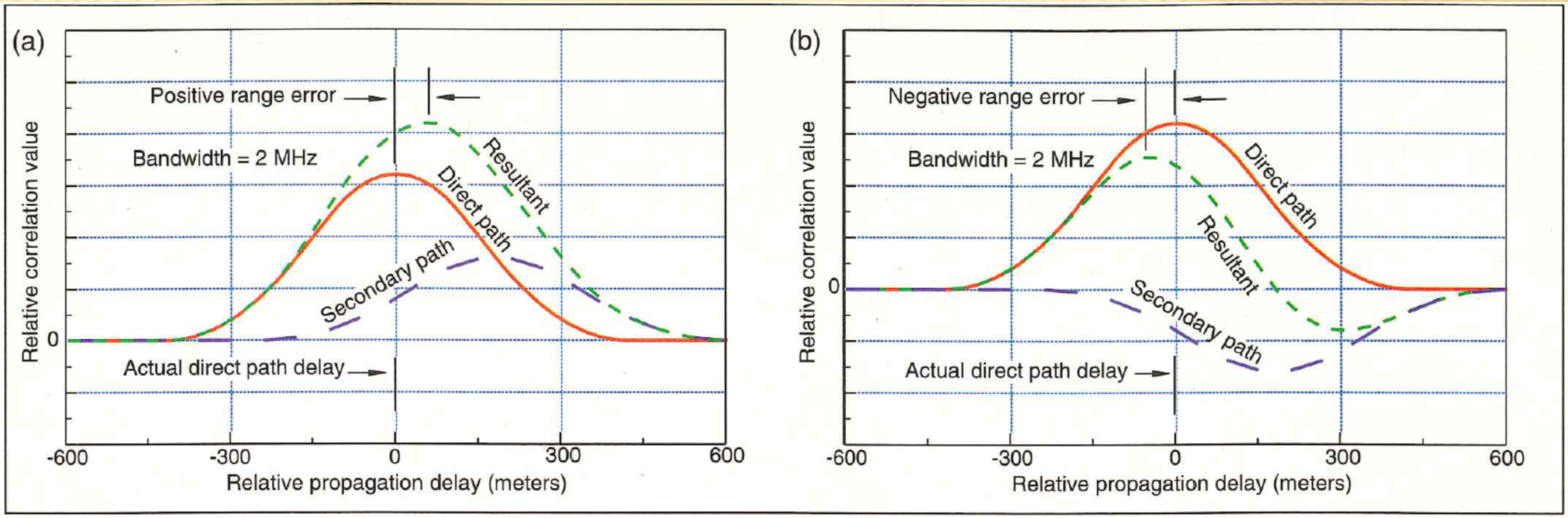
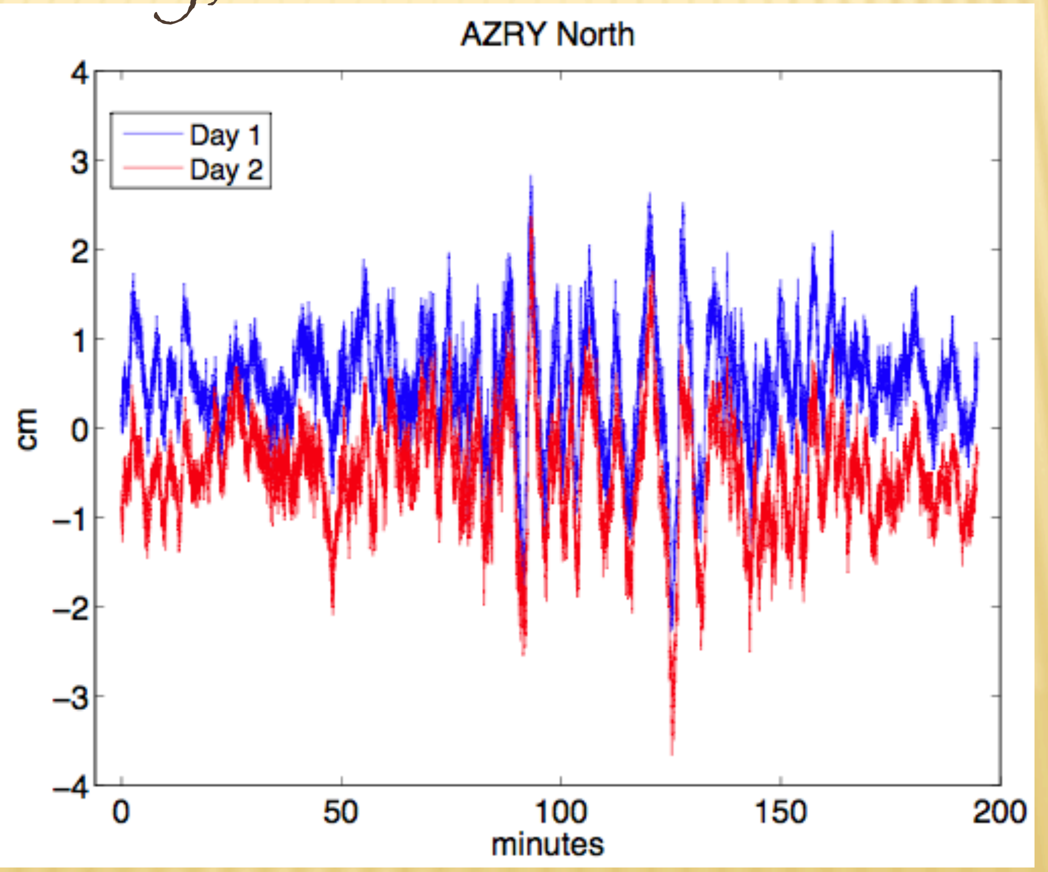


Figure 2. (a) Positive range error caused by an in-phase secondary signal path. The positive slope of the secondary path cross-correlation function shifts the peak of the direct path cross-correlation function to the right, as shown by the resultant curve. **(b)** Negative range error occurs when the secondary path is out of phase with the direct path.

GPS World, Innovation, Apr 97

So the trick is to calculate the GPS displacement time series from the day before or after and subtract from the day with the earthquake. Have to shift by the ~4 minutes due to the "almost" part of the 2x/day GPS orbit (2x per sidereal day, 4 min shorter than solar day).



From Larson

This is called Sidereal Filtering and it removes much of the multipath.

But it depends on the reflection environment remaining the same (no rain, snow, movement of nearby objects such as parked vehicles, etc.)

It also depends on getting the time shift right. Modification is to cross correlate between the two days to get a better time shift (each satellite's orbit is nominally 4 minutes short – but they vary individually, which effects the locations, etc.).

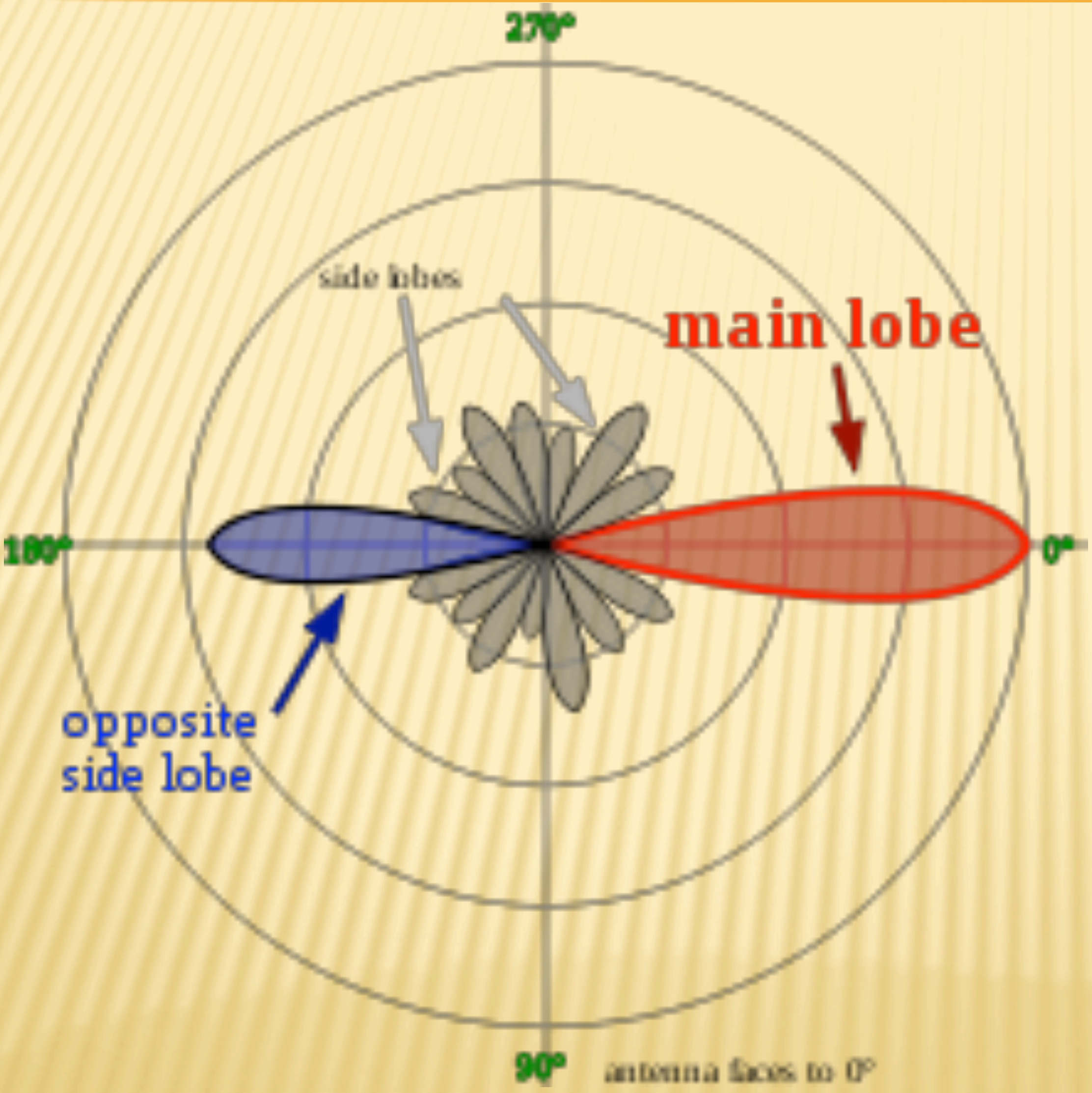
This is called "modified sidereal filtering"

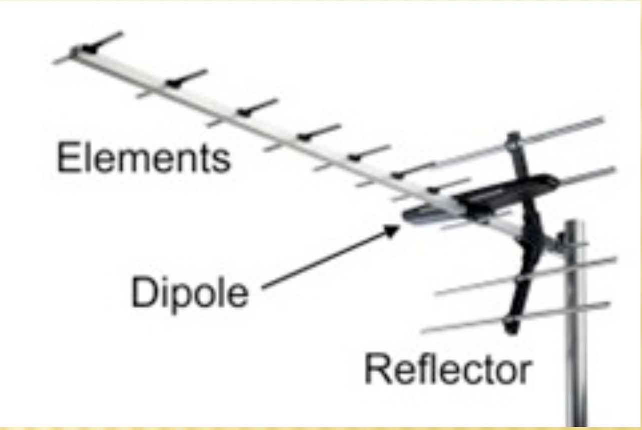
Sometimes done with average of a few days, but this low pass filters the sidereal filter time series.

Advantage – don't need a signal in the GPS data – can estimate multipath.

Multipath (approximately) stationary for a few days (when reflection environment stays same).

Multipath Mitigation through antenna design.

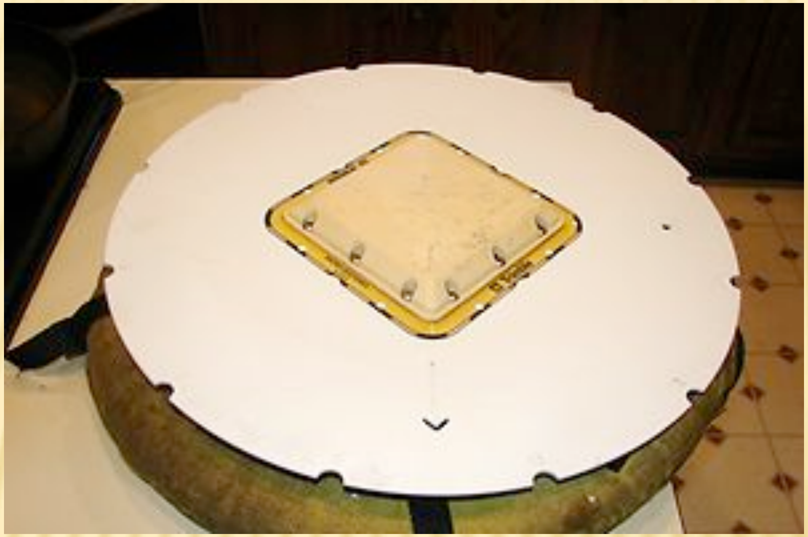




Directional response, receivers signals coming from direction of "main" lobe much better.

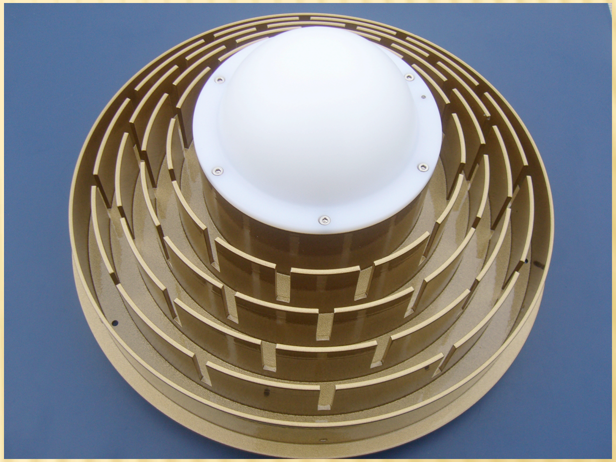
Radiation pattern from http://en.wikipedia.org/wiki/Antenna_%28radio%29

Multipath Mitigation through antenna design.



Multipath Mitigation through antenna design.

Choke ring antennas



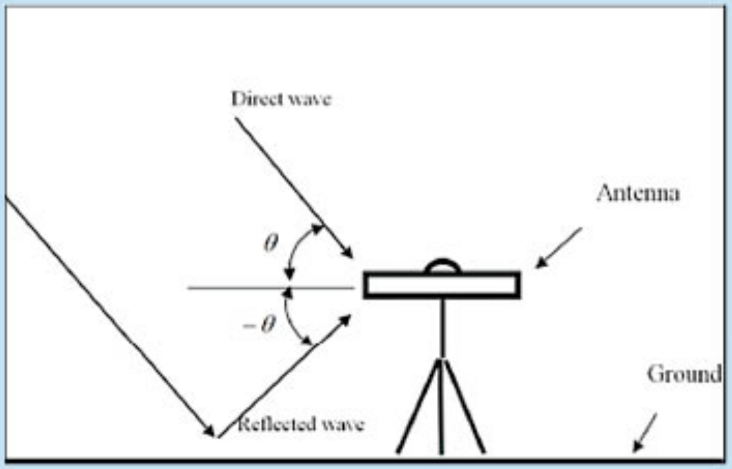
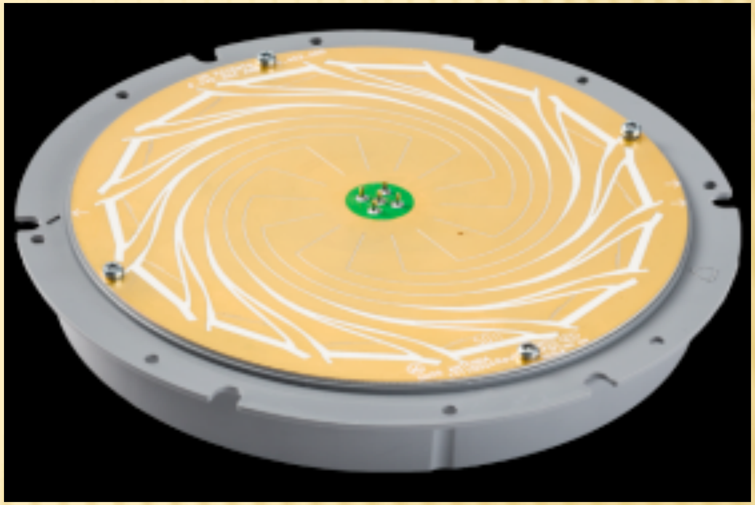
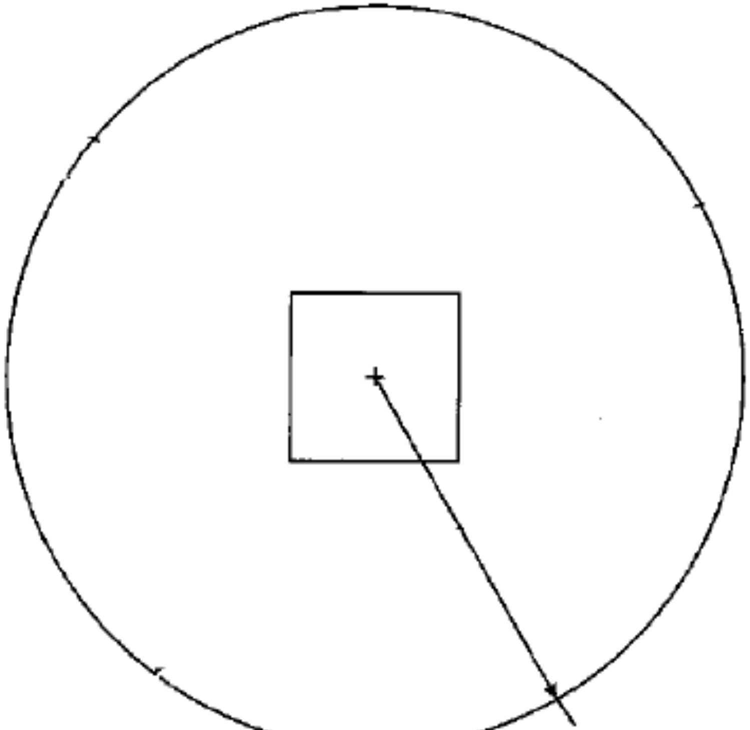


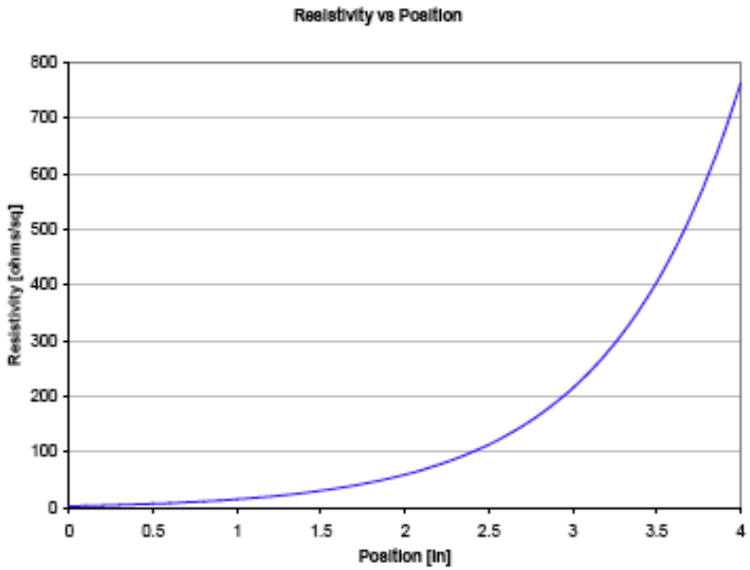
Figure 11. Direct and reflected signals orientation with respect to the antenna.

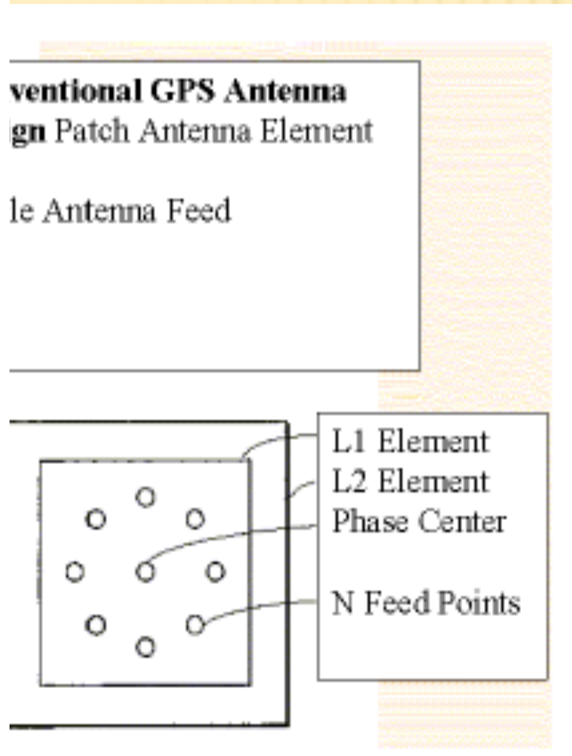
Multipath Mitigation through antenna design.



Some sort printed circuit board.

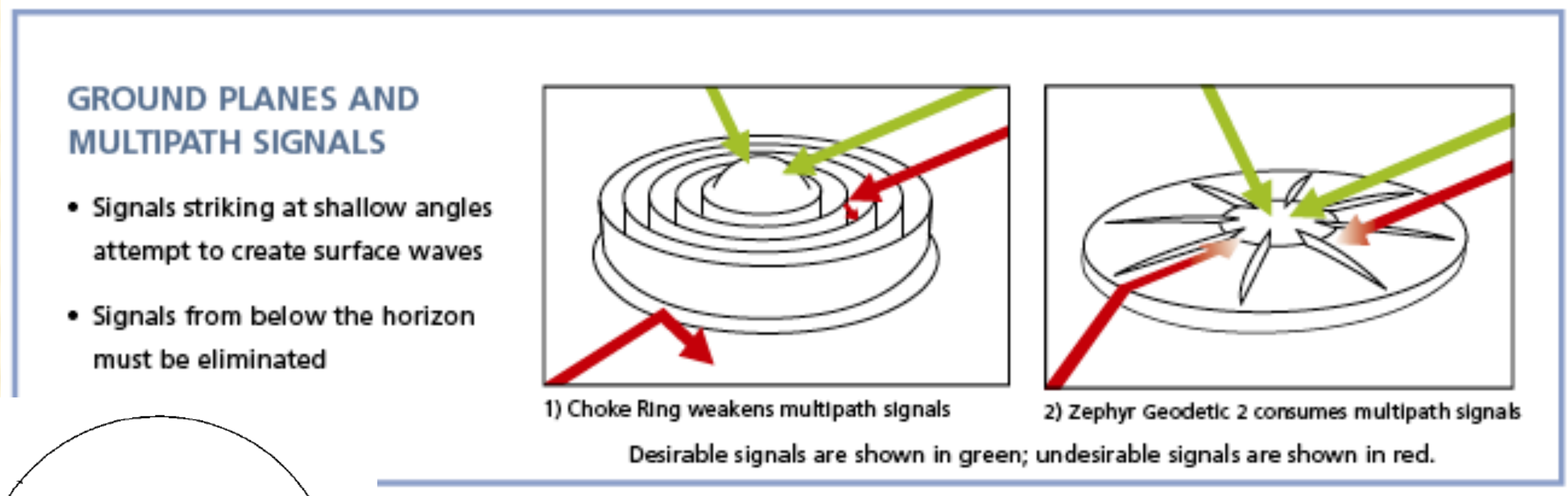


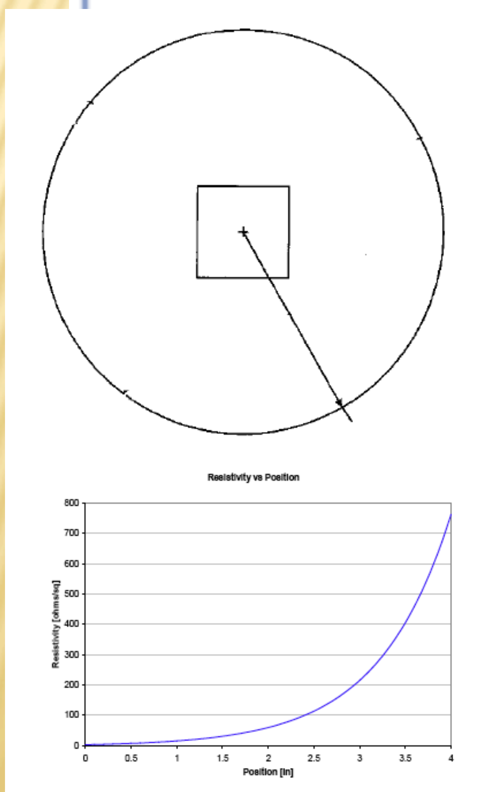

Resistivity vs Position
Resistivity [ohms/sq]
800
700
600
500
400
300
200
100
0
0
0.5
1
1.5
2
2.5
3
3.5
4
Position [in]


ventional GPS Antenna
gn Patch Antenna Element
le Antenna Feed
L1 Element
L2 Element
Phase Center
N Feed Points


consumes multipath signals
are shown in red.

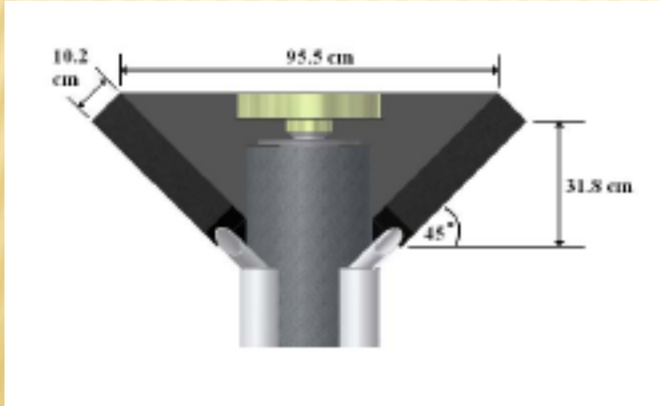
Multipath Mitigation through antenna design.





Resistive ground plane.

Multipath Mitigation through antenna design.

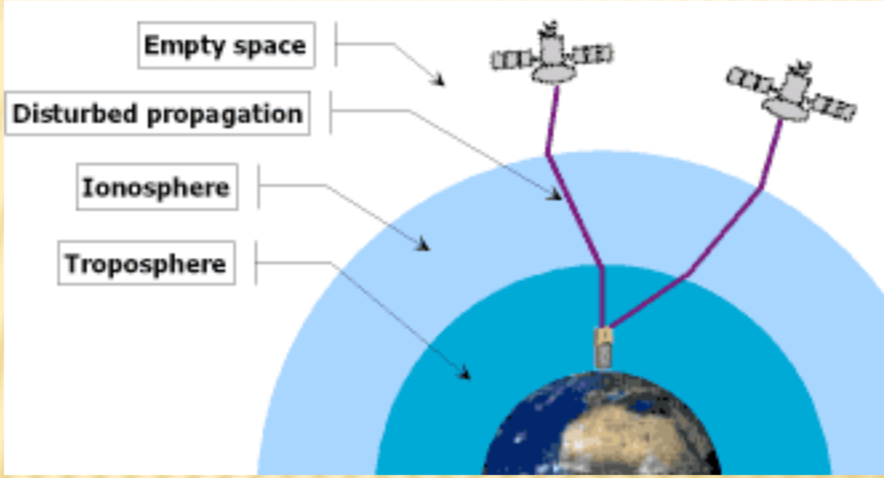


Add microwave absorbers

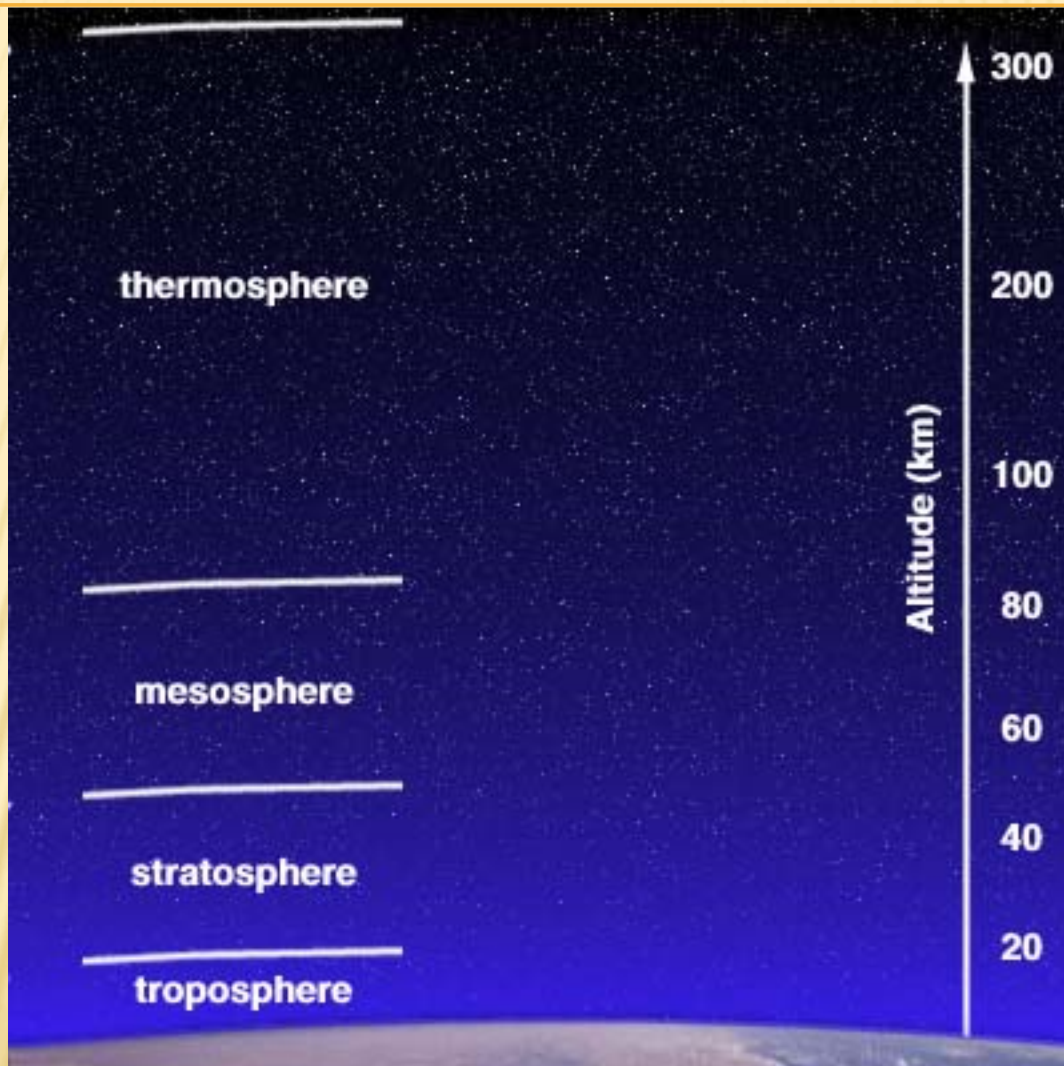
Multipath Mitigation through antenna design.

The porcupine antenna!?

Atmospheric effects



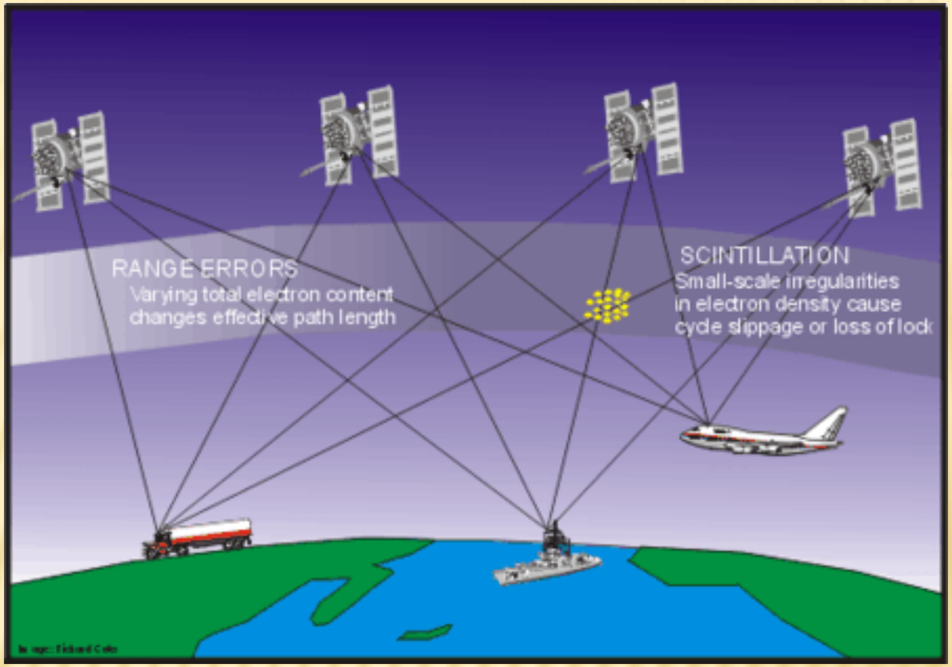
1500m



Ionosphere

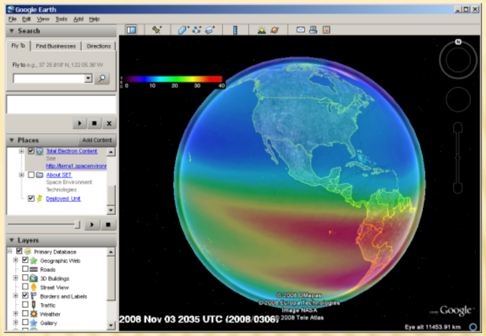
http://www-gpsg.mit.edu/~tah

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

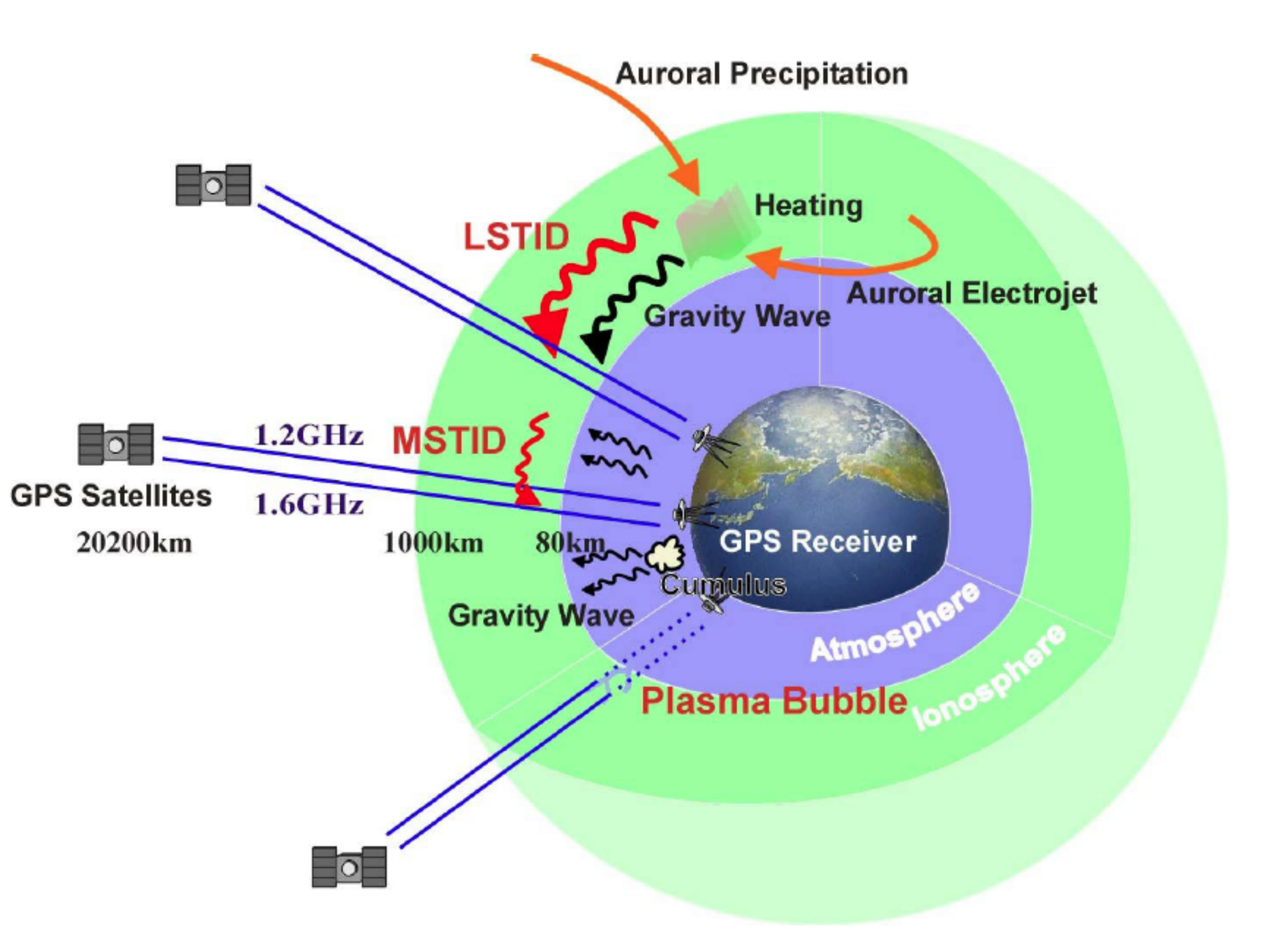
  Solar flares, coronal holes, etc. producing strong geomagnetic storms

  - Measured in Total Electron Content (TEC) of the Ionosphere

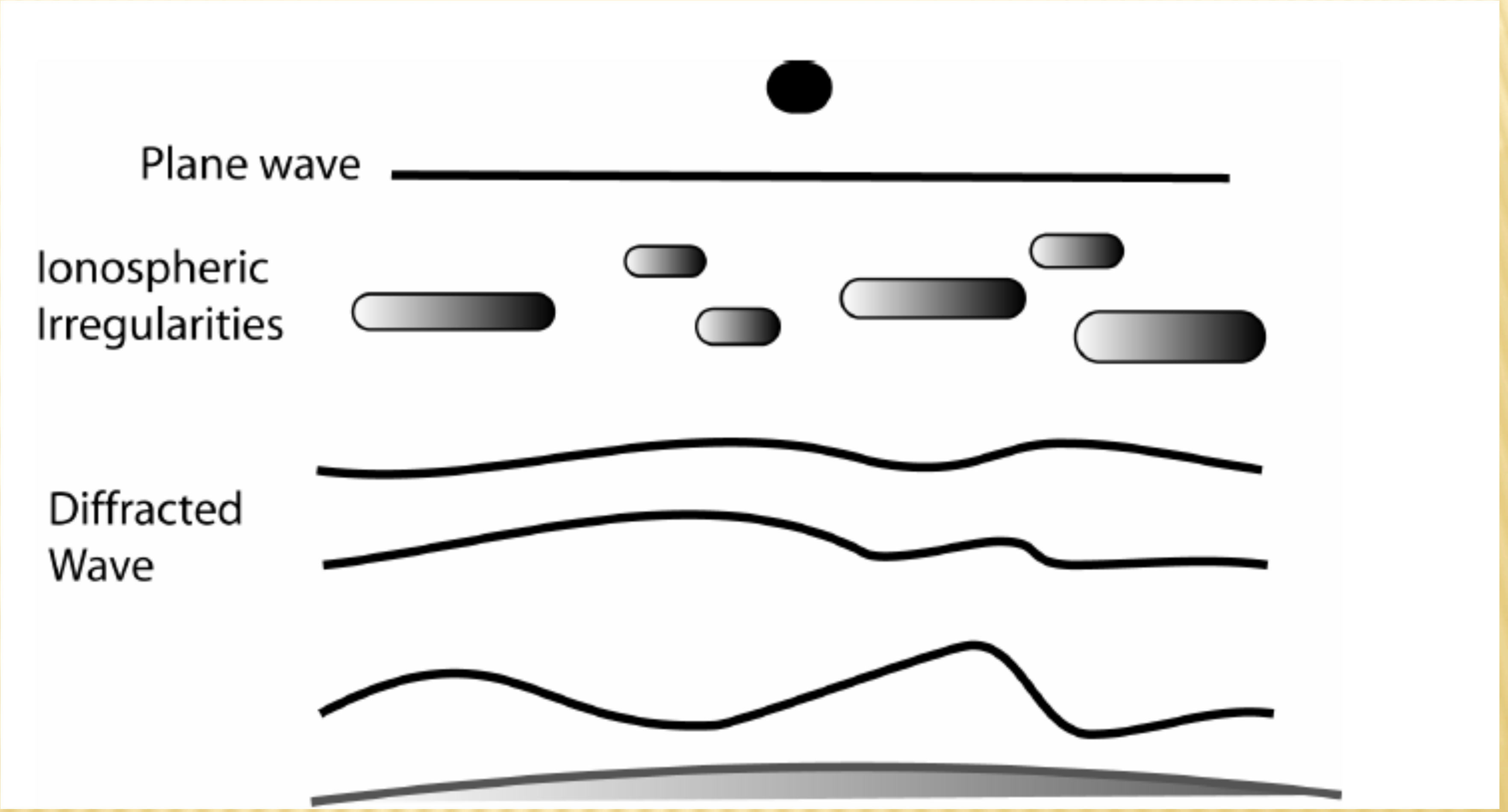
  See http://terra1.spacenvironment.net/%7Eionops/current_files/Google_TEC.kml

  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

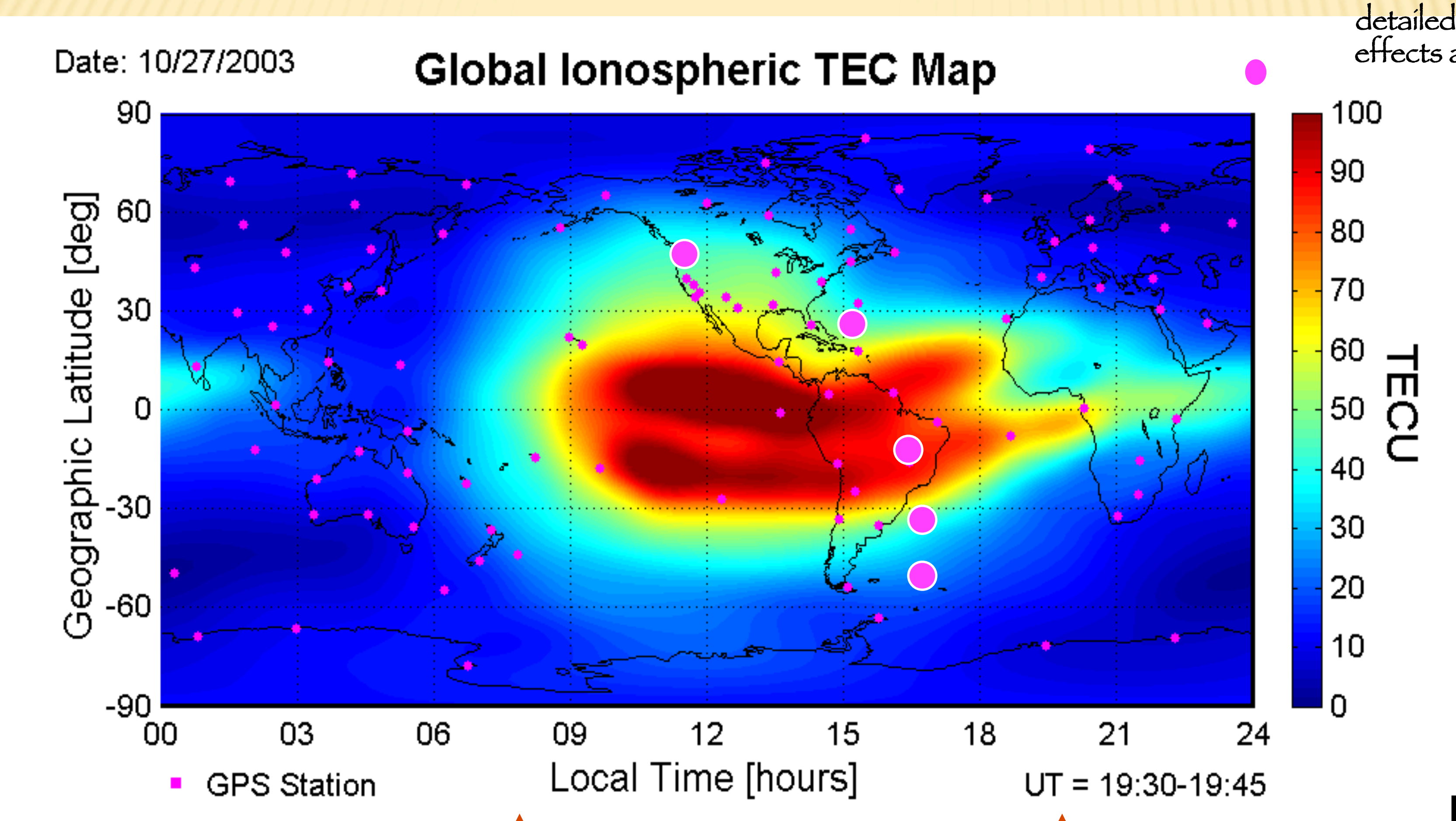
- Measured range given by $s = \int n \, ds$
  - n is the refractive index
  - ds is the path that the signal takes
- The path delay is given by
  - $\Delta_{ph}^{iono} = -(40.3/f^2) \int N_e \, ds_0 = -40.3/f^2 \, TEC$
  - $\Delta_{gr}^{iono} = (40.3/f^2) \int N_e \, ds_0 = 40.3/f^2 \, TEC$
    - Where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



FRE

L

P

Dawn (ascending)

Dusk (descending)

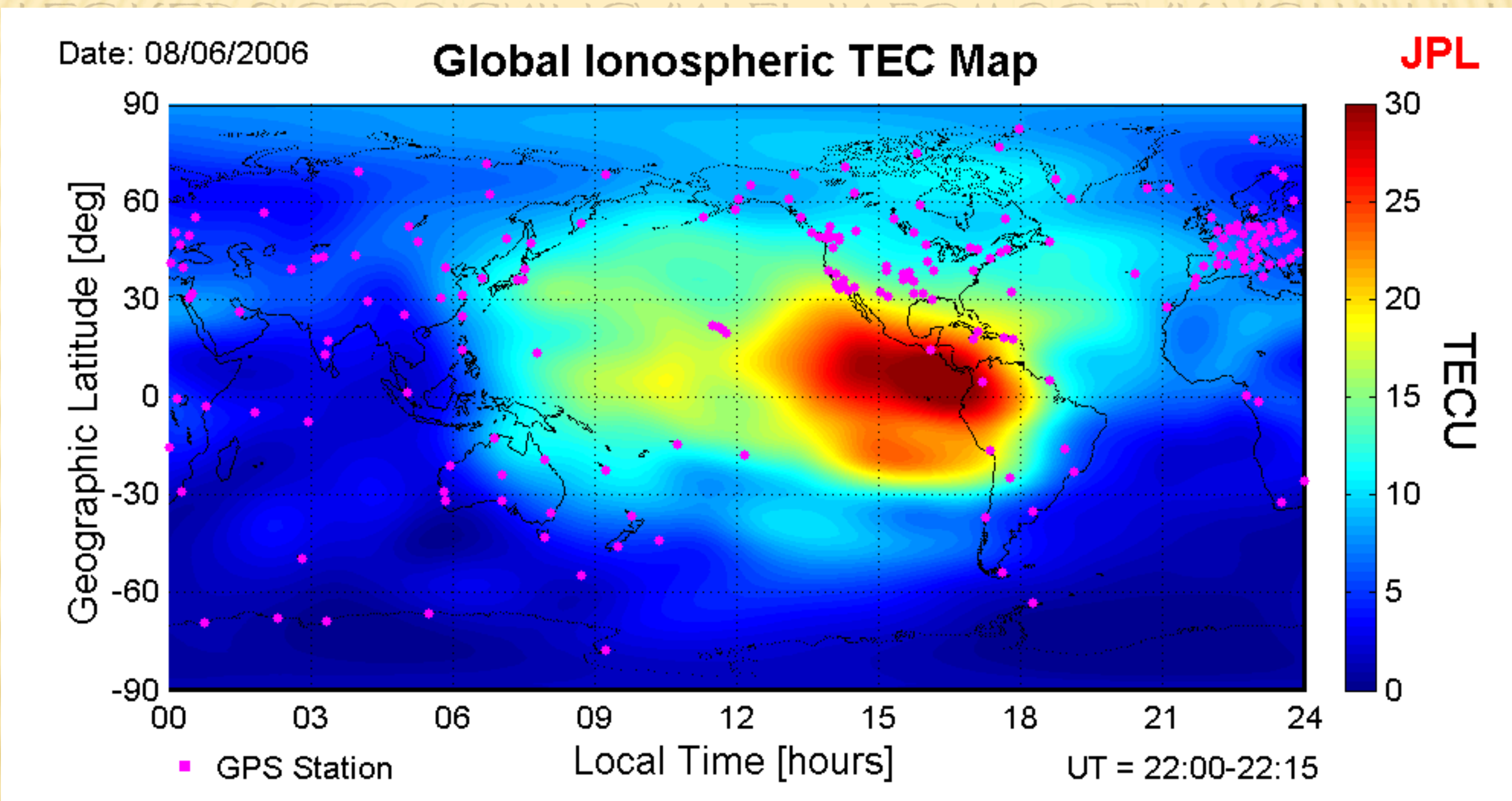
A year similar to the target launch year - 2014

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

Suborbital & slant path (45°) are considered

Pi, 2006

TEC REDUCES SIGNIFICANTLY IN LOW SOLAR ACTIVITY YEARS



L

FRE

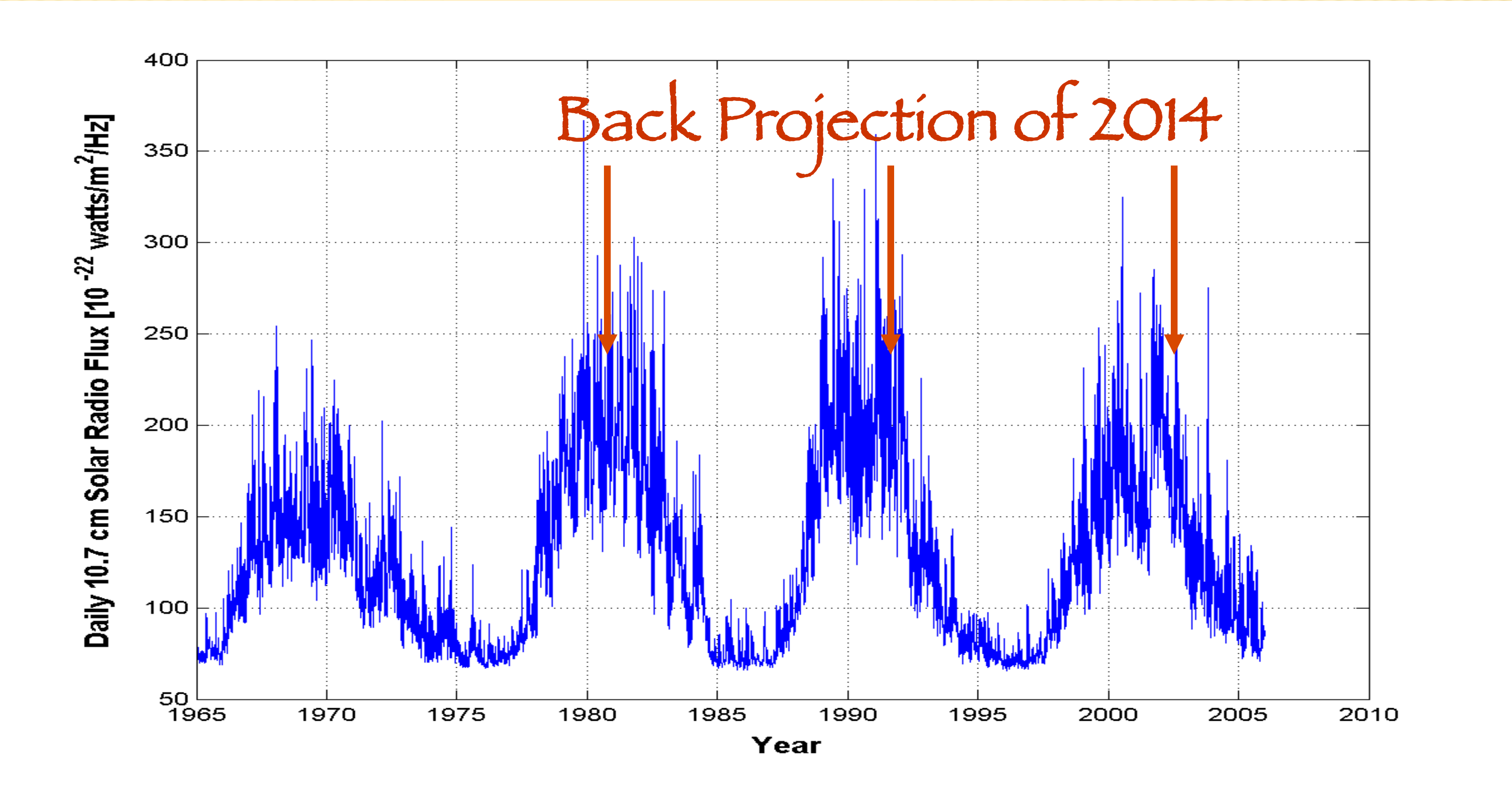
P

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

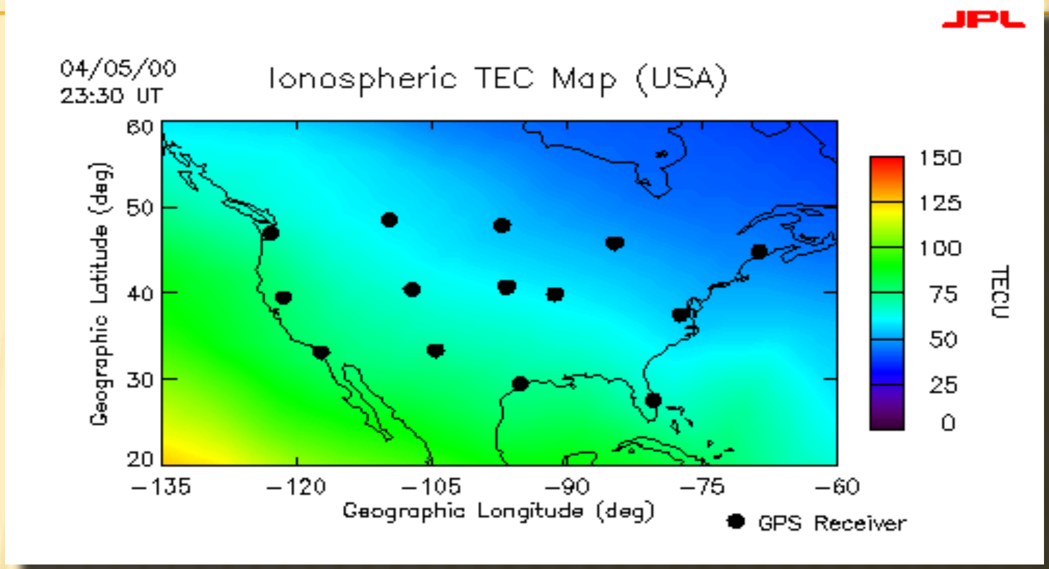


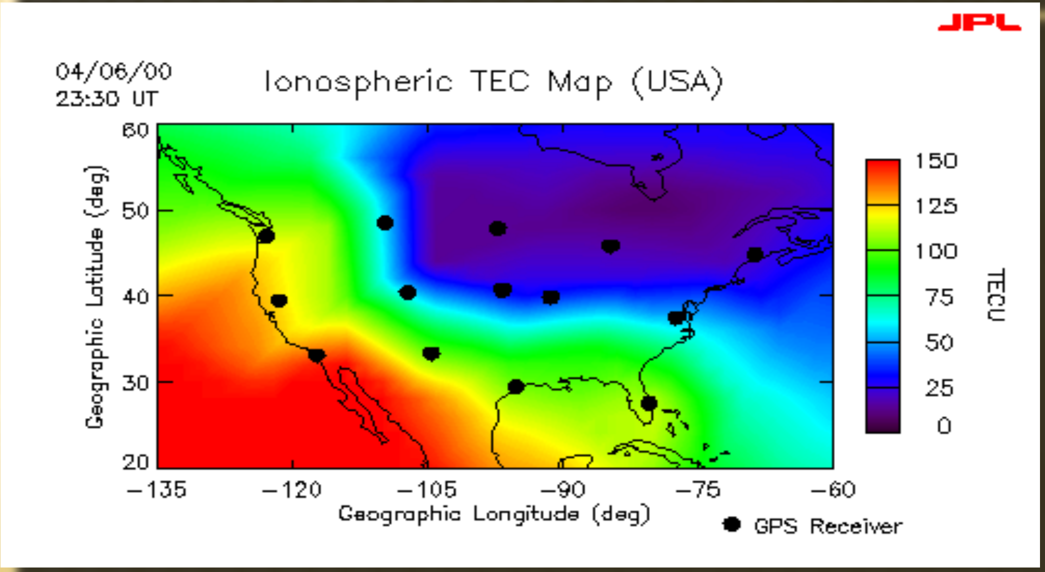
Sunspot Maximum	1979	1990	2001	2012	2023
Sunspot Minimum	1985	1996	2007	2018	2029

Pi, 2006

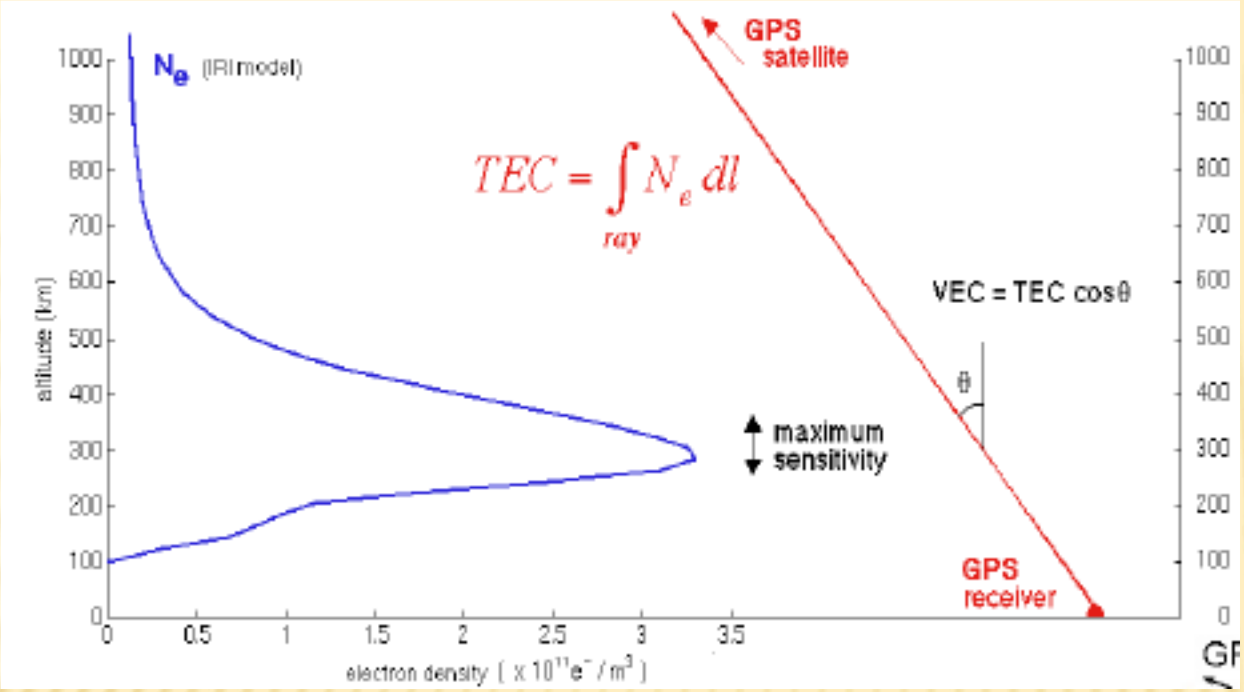
Ionospheric Spatial Structures during Storms

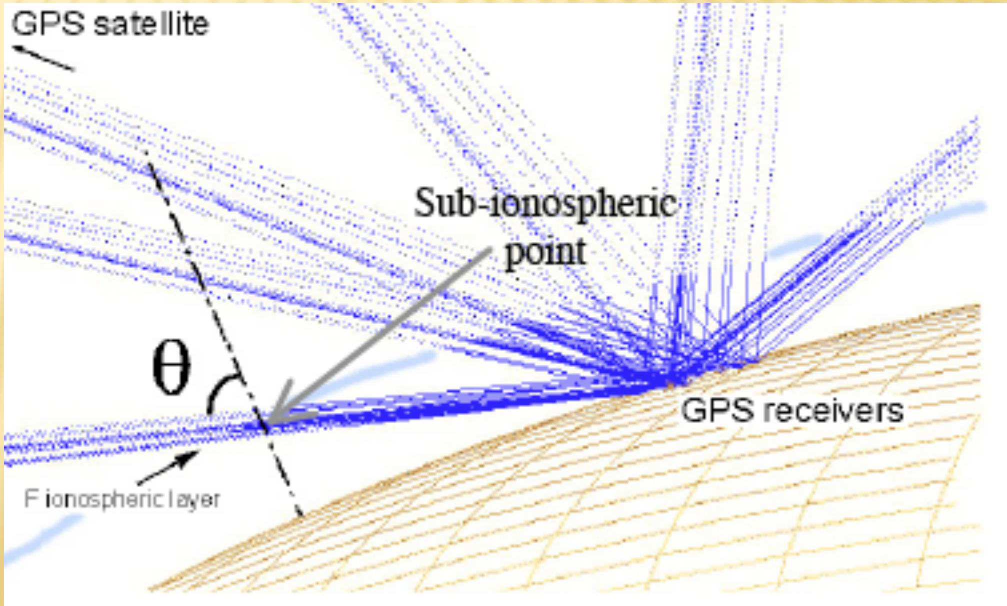
- Quiet ionosphere
  - Smooth
  - Small gradient
- Disturbed ionosphere
  - Large gradient
  - Curvature
  - Irregular structures
- Adjacent drop showing 50 TECU difference





Pi, 2006





Ducic et al., 2003