12.221 Field Geophysics

Instructors
Brad Hager bhhager@mit.edu
Tom Herring, tah@mit.edu
Stephane Rondenay, rondenay@mit.edu

Web: http://geoweb.mit.edu/~tah/12.221

Lec 04: Introduction to GPS

Introduction to GPS

- Uses of GPS in this course
  - Hand held navigation. ($200)
  - Differential "kinematic" positioning for determining heights of gravity measurements and seismic locations.
  - Precise static positioning for ~1 mm positioning ($5-10K)

Coordinate Systems

- See discussion in IEEE paper
- We will need to deal with several coordinate systems and methods of expressing coordinates.
- System:
  - Origin at center of mass of Earth
  - Z-axis along average position of rotation axis (moves by 10 m during a year – call polar motion)
  - X-axis along Greenwich meridian (convention)
- Before space-based geodesy (mid-1970's), realizations of this system could differ by several hundred meters.
- Impact of this for us will be difference between North American Datum 1927 (NAD 27) (most paper maps use this system) and NAD83/World Geodetic System 1984 (WGS84) (used by GPS but with options for other systems)

Systems we need

- Modern GPS results are given in the "International Terrestrial Reference System". Latest *realization* is ITRF2005 (Use Frame to denote realization)
- World Geodetic System WGS84 used by GPS control center (within a few meters of ITRF2005)
- However: Maps made well before this system and most US maps use North American Datum (NAD) 1927 (NAD27) or NAD83 (which is very close to WGS84 and ITRF2005.
- NAD27 is approximately 200 m away from modern system

Types of coordinates

- Within a system, coordinates can be expressed in different ways:
  - Cartesian (XYZ – Computational easy)
  - Geocentric latitude, longitude and radius (spherical)
  - Geodetic latitude, longitude and height above ellipsoid (ellipsoidal coordinate system).
  - Universal Transverse Mercator (UTM) coordinates. Actually ellipsoidal map projection coordinates. These have units of distance compared to latitude and longitude which are angle measurements.
    - Coordinates expressed as Northing and Easting.
  - Digital Elevation Models (DEM) are often in UTM coordinates.

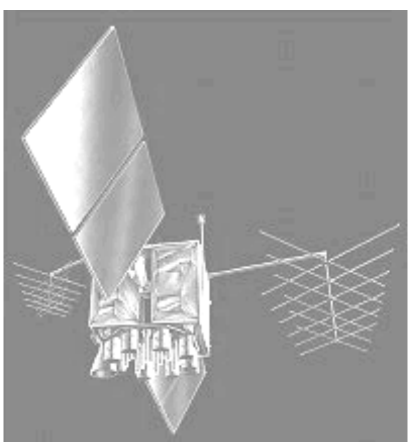
GPS Original Design

- Started development in the late 1960s as NAVY/USAF project to replace Doppler positioning system
- Aim: Real-time positioning to < 10 meters, capable of being used on fast moving vehicles.
- Limit civilian ("non-authorized") users to 100 meter positioning.

Design Characteristics of GPS

- Innovations:
  - Use multiple satellites (originally 21, now ~30-32)
  - All satellites transmit at same frequency
  - Signals encoded with unique “bi-phase, quadrature code” generated by pseudo-random sequence (designated by PRN, PR number): Spread-spectrum transmission.
  - Dual frequency band transmission:
    - L1 ~1.575 GHz, L2 ~1.227 GHz
    - Corresponding wavelengths are 190 mm and 244 mm
    - Dual frequency band transmission allows the dispersive delay of the ionosphere to be removed (10-100 m)

Block IIR Satellite



- Transmission array is made up of 12 helical antenna in two rings of 43.8 cm (8 antennas) and 16.2 cm (4 antennas) radii
- Total diameter is 87 cm
- Solar panels lead to large solar radiation pressure effects.
- Mass: 1,110 kg

Measurements

- Time difference between signal transmission from satellite and its arrival at ground station (called "pseudo-range", precise to 0.1–10 m)
- Carrier phase difference between transmitter and receiver (precise to a few millimeters) but initial values unknown (ie., measures change in range to satellites).
- In some case, the integer values of the initial phase ambiguities can be determined (bias fixing)
- All measurements relative to "clocks" in ground receiver and satellites (potentially poses problems).

Measurement Usage

- "Spread-spectrum" transmission: Multiple satellites can be measured at same time.
- Since measurements can be made at same time, ground receiver clock error can be determined (along with position).
- Signal

[redacted]

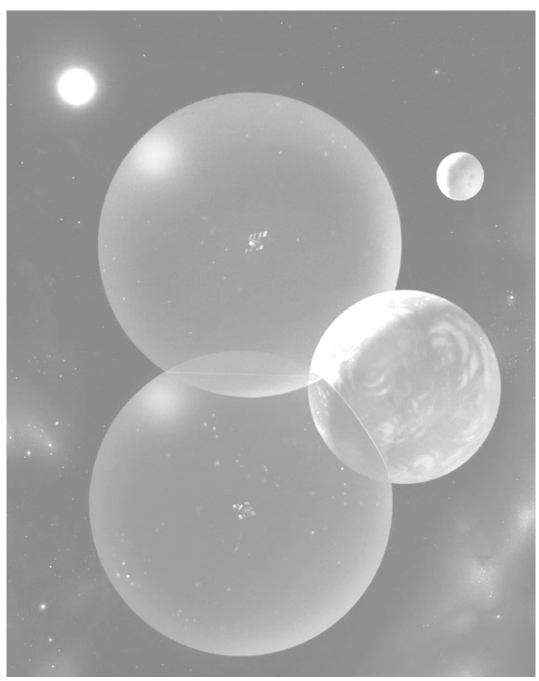
Measurement usage

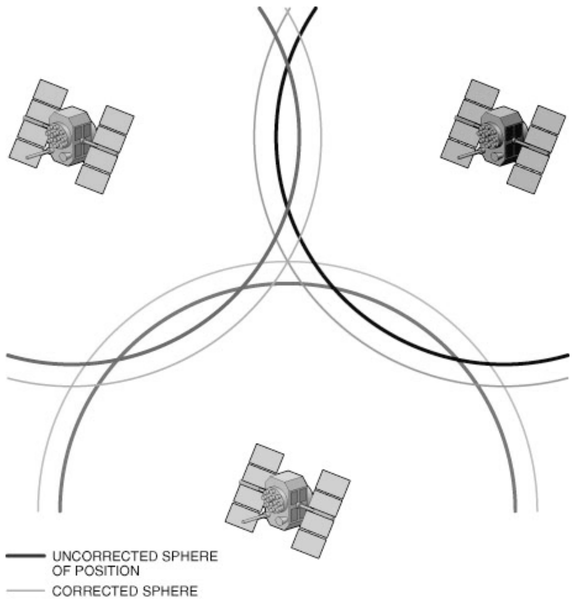
- Since the C(t) code changes the sign of the signal, satellite can be only be detected if the code is known (PRN code)
- Multiple satellites can be separated by “correlating” with different codes (only the correct code will produce a signal)
- The time delay of the code is the pseudo-range measurement.

Position Determination (perfect clocks)

• Three satellites are needed for 3-D position with perfect clocks.

• Two satellites are OK if height is known)





Position determination: with clock errors: 2-D case

- Receiver clock is fast in this case, so all pseudo-ranges are short

Positioning

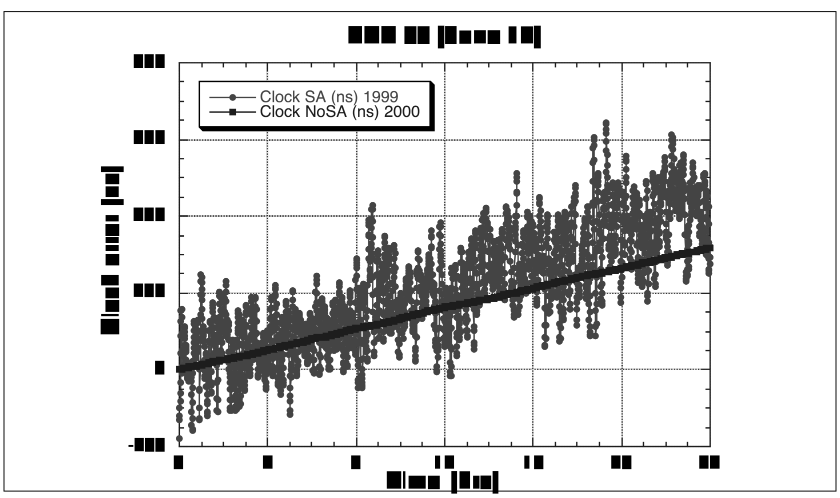
- For pseudo-range to be used for positioning the following quantities must known:
  - Errors in satellite clocks (use of Cesium or Rubidium clocks)
  - Positions of satellites
- This information is transmitted by satellite in "broadcast ephemeris". This information saved in receiver data file. We will use for in-field processing
- "Differential" positioning (DGPS) eliminates need for accurate satellite clock knowledge.

GPS Security systems

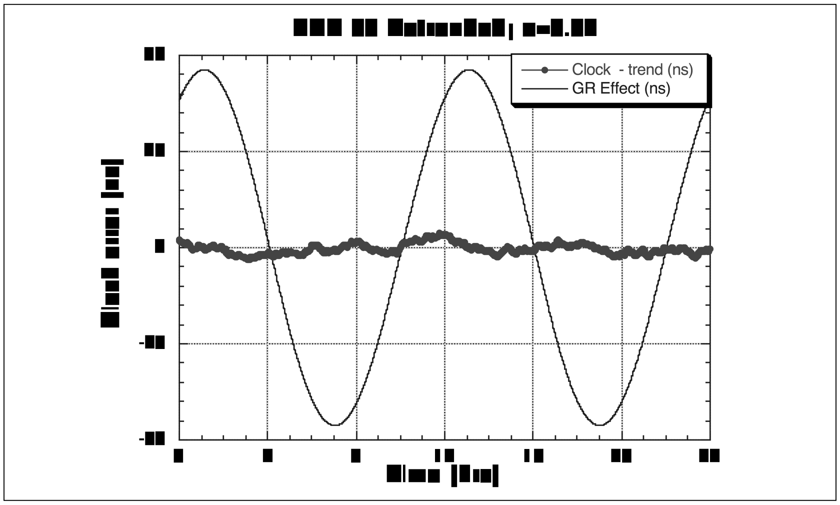
- Selective availability (SA) is no longer active but prior to 2000 “denied” civilian accuracy better than 100 m
  - Implemented by “dithering” (noising up) the satellite clock
  - Military receivers were able to undo the dithering
- Antispoofing (AS) active since 1992, adds additional encryption to P-code on L1 and L2.
- Makes civilian GPS receivers more expensive and more sensitive to radio interference
- Impact of AS and SA is small on differential GPS results

1 nanosecond (ns) = 30 cm

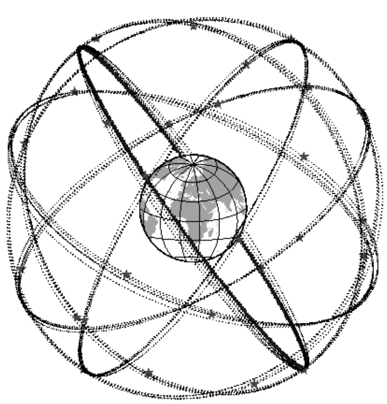
Effects of Selective Availability



Relativistic Effects: Sensitivity of GPS



Current constellation



- Relative sizes correct (inertial space view)
- “Fuzzy” lines not due to orbit perturbations, but due to satellites being in 6-planes at 55^o inclination.

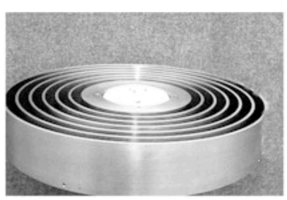
Types of parameters estimated in GPS analysis

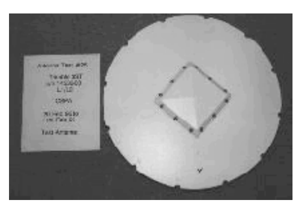
- GPS phase measurements at L1 and L2 from a global distribution of station used. Pseudo-range can be used but 100 times less accurate than phase.
- Giobal Analysis typically includes:
  - All site positions estimated
  - Atmospheric delay parameters estimated
  - “Real” bias parameters for each satellite global, integer values for regional site combinations (<500 km)
  - Orbital parameters for all satellites estimated (1-day orbits, 2-revolutions)
    - 6 Integration constants
    - 3 constant radiation parameters
    - 6 once-per-revolution radiation parameters
- Orbits need not be estimated when International GNSS Service (IGS) finals orbits are used (post-1996).

GPS Antennas (for precise positioning)

Nearly all antennas are patch antennas (conducting patch mounted in insulating ceramic).

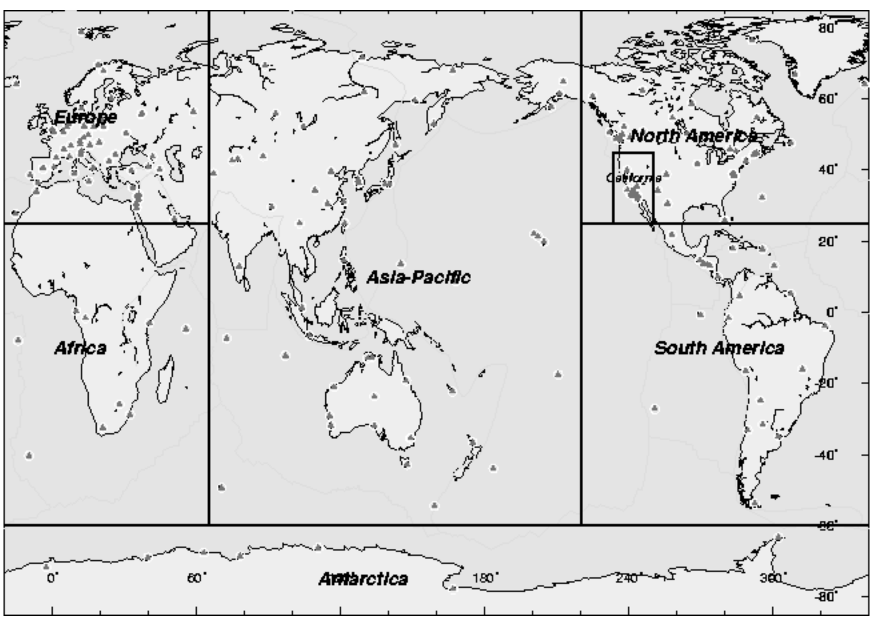
- Rings are called choke-rings (used to suppress multi-path)



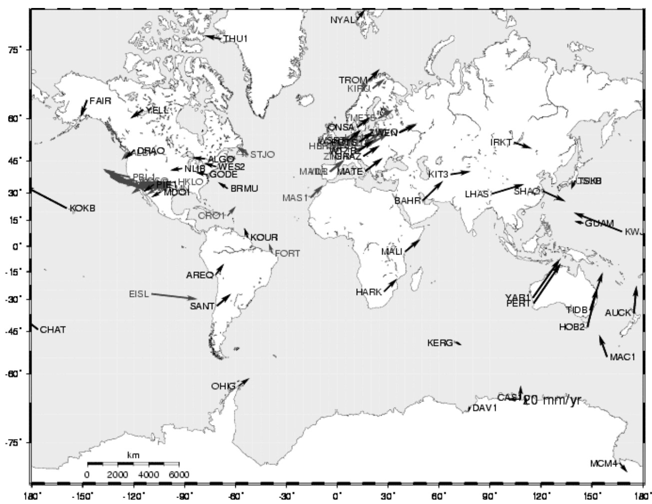


Styles of Monuments

Global IGS Network (~400 stations)



Typical global network



Black: Frame sites (define ITRF2000); Red other sites

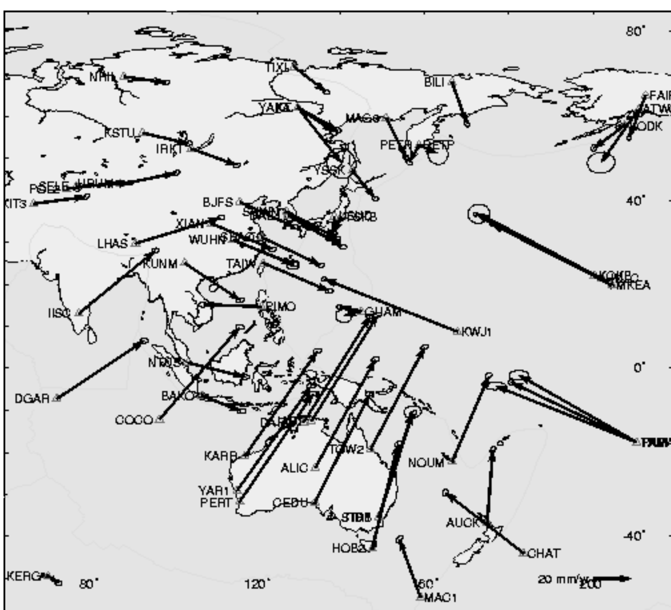
Example Results from GPS analyses

- Examples of time series for some sites
  - Tectonic motions in the Asian region
  - Motions in California (example in more detail later)
  - Time series of motions for some sites
  - Post seismic motion after 1999 Hector Mine earthquake

Tectonic Deformation Results

- “Fixed GPS” stations operate continuously and by determining their positions each day we can monitor their motions relative to a global coordinate system
- Temporary GPS sites can be deployed on well defined marks in the Earth and the motions of these sites can be monitored (campaign GPS)
- Our field camp sites will be temporary and we will measure “relative” to continuous Southern California Plate Boundary Observatory sites.
- http://pboweb.unavco.org/

01/09/08 12.221 IAP Lec 04 25

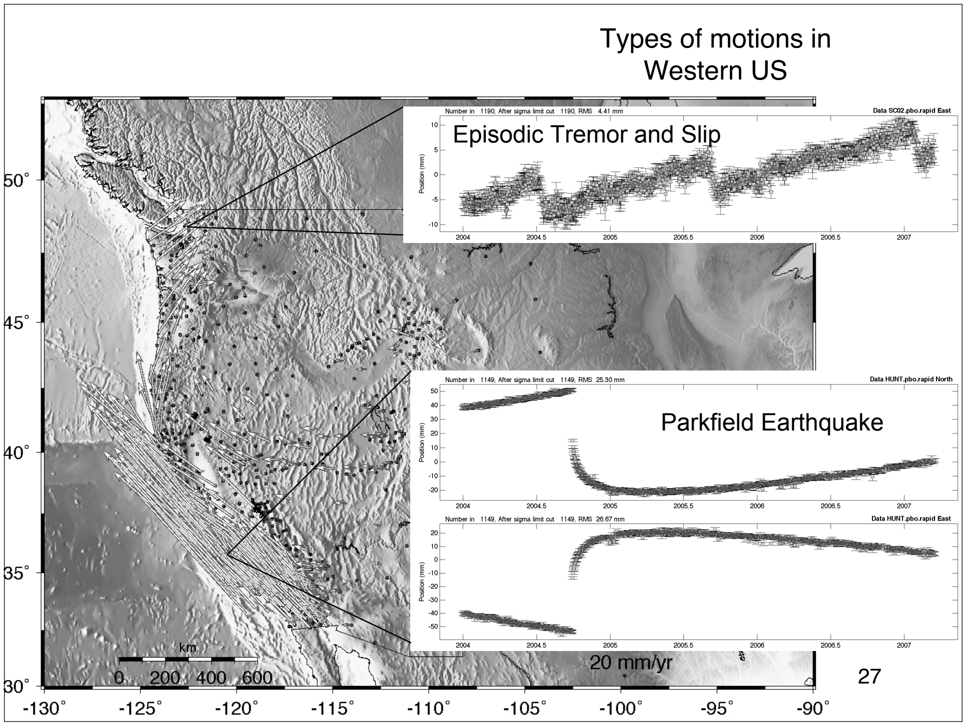


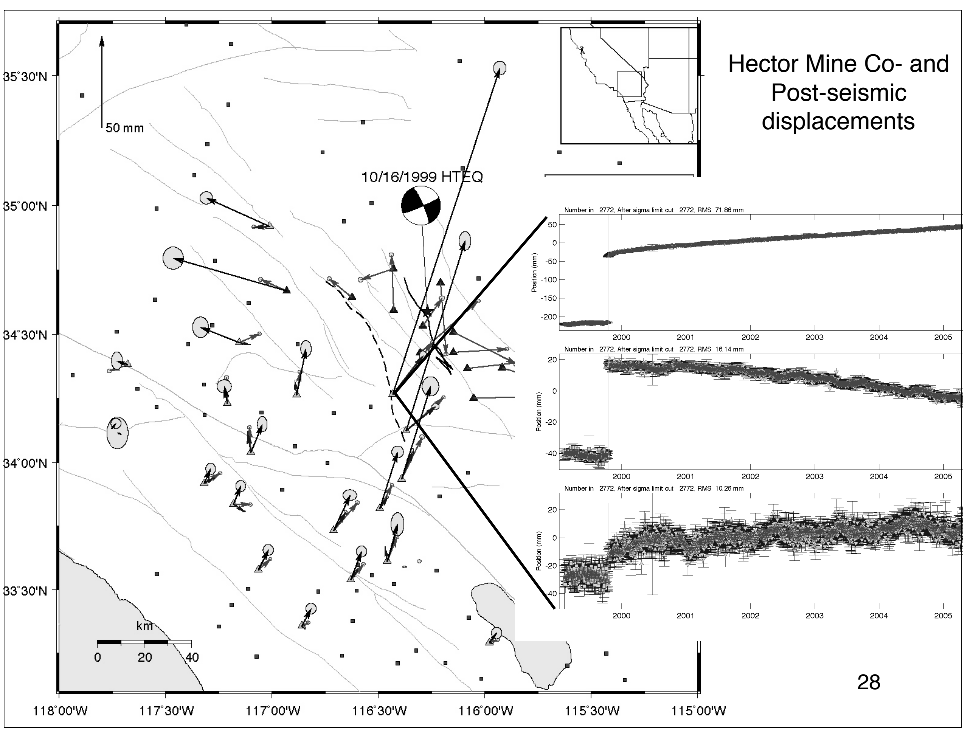
Example of motions measured in Pacific/Asia region

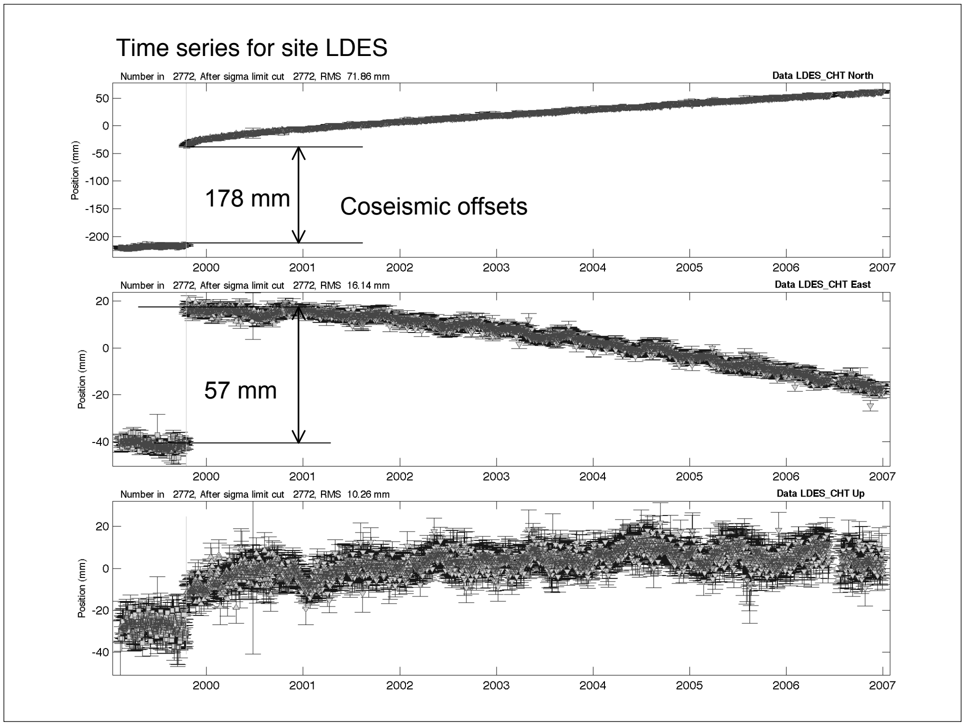
- Fastest motions are >100 mm/yr
- Note convergence near Japan

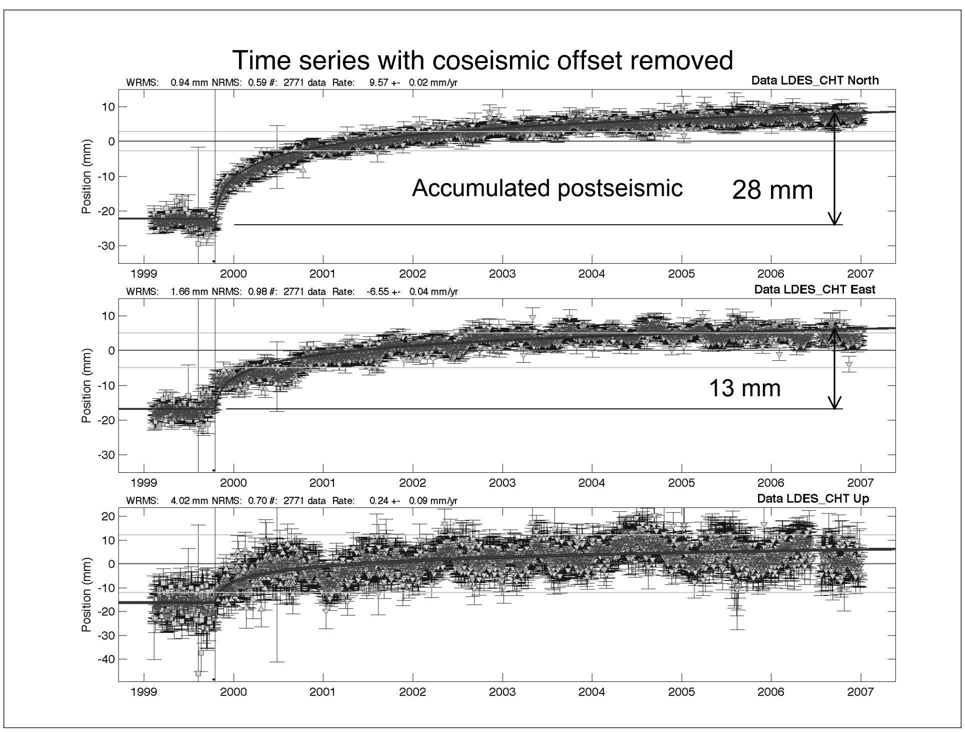
More at http://www-gpsg.mit.edu/~tah/MIT_IGS_AAC

01/09/08 12.221 IAP Lec 04 26

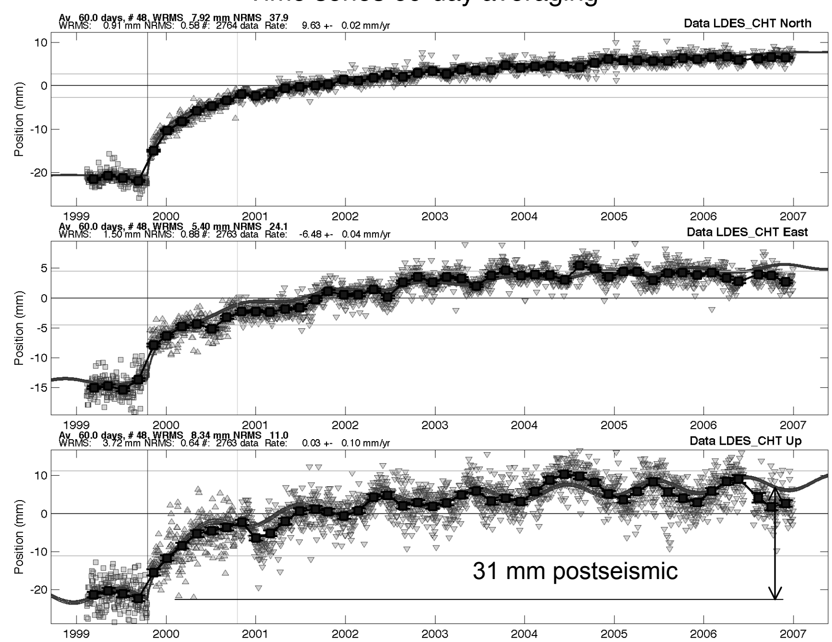

Types of motions in
Western US
Episodic Tremor and Slip
Parkfield Earthquake
20 mm/yr
27

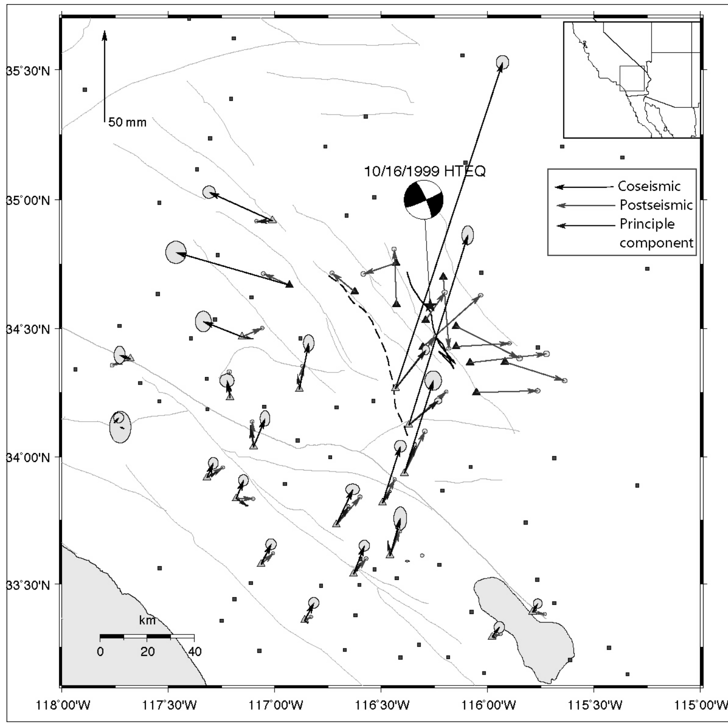

Hector Mine Co- and
Post-seismic
displacements
10/16/1999 HTEQ
50 mm
28


Time series for site LDES
Number in 2772, After sigma limit cut 2772, RMS 71.86 mm
Data LDES_CHT North
178 mm
Coseismic offsets
Number in 2772, After sigma limit cut 2772, RMS 16.14 mm
Data LDES_CHT East
57 mm
Number in 2772, After sigma limit cut 2772, RMS 10.26 mm
Data LDES_CHT Up
Position (mm)
2000 2001 2002 2003 2004 2005 2006 2007


Time series with coseismic offset removed
WRMS: 0.94 mm NRMS: 0.59 #: 2771 data Rate: 9.57 +- 0.02 mm/yr
Data LDES_CHT North
Accumulated postseismic
28 mm
WRMS: 1.66 mm NRMS: 0.98 #: 2771 data Rate: -6.55 +- 0.04 mm/yr
Data LDES_CHT East
13 mm
WRMS: 4.02 mm NRMS: 0.70 #: 2771 data Rate: 0.24 +- 0.09 mm/yr
Data LDES_CHT Up
Position (mm)
1999 2000 2001 2002 2003 2004 2005 2006 2007

Time series 60-day averaging



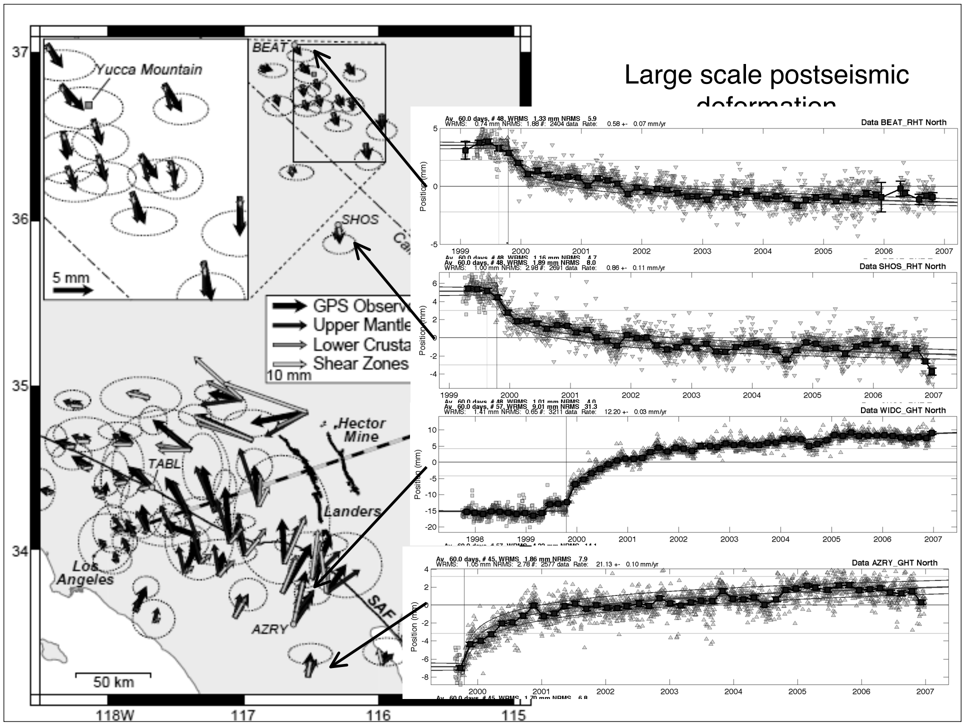


Analysis of postseismic signals

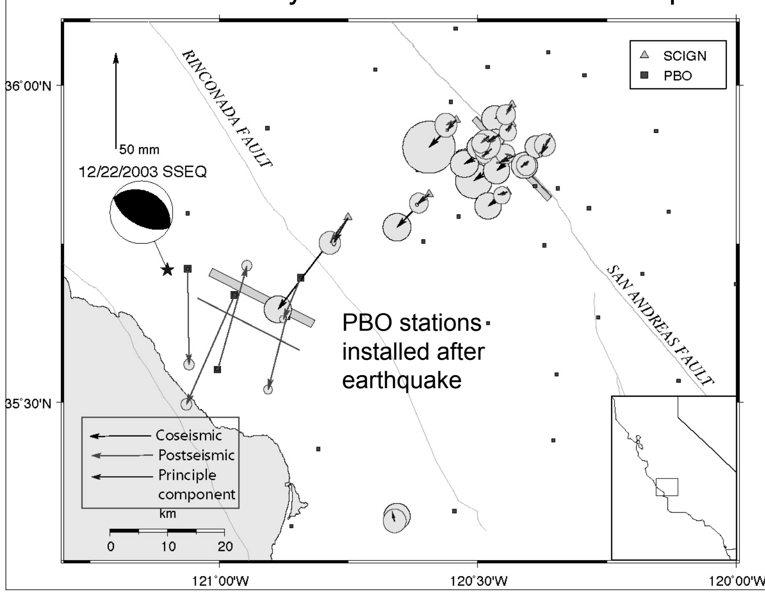
- One method of analysis for signals is principle component analysis
- Number of components related to number of processes acting during postseismic period

32

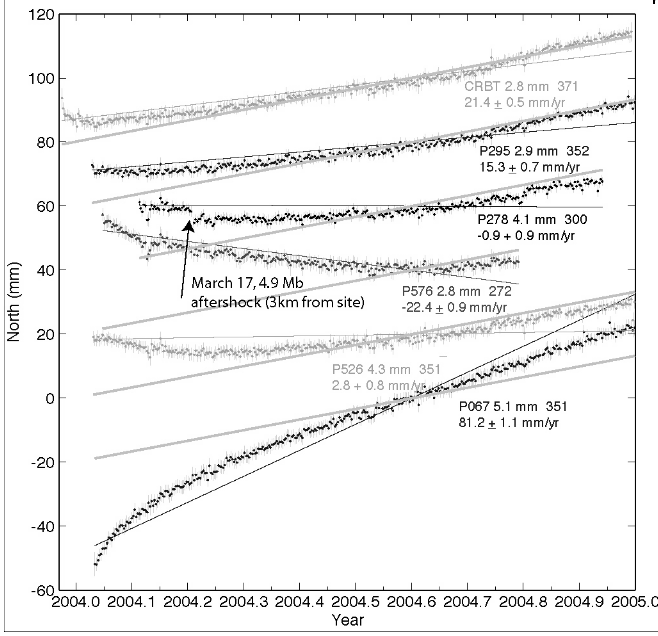
Large scale postseismic deformation



Analysis for San Simeon Earthquake



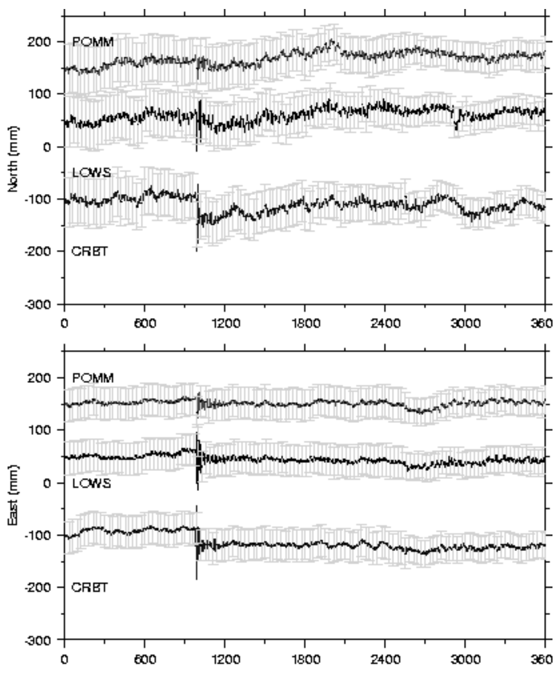
34



Time series of North motion of sites near San Simeon

Grey lines show motion expected for this part of California

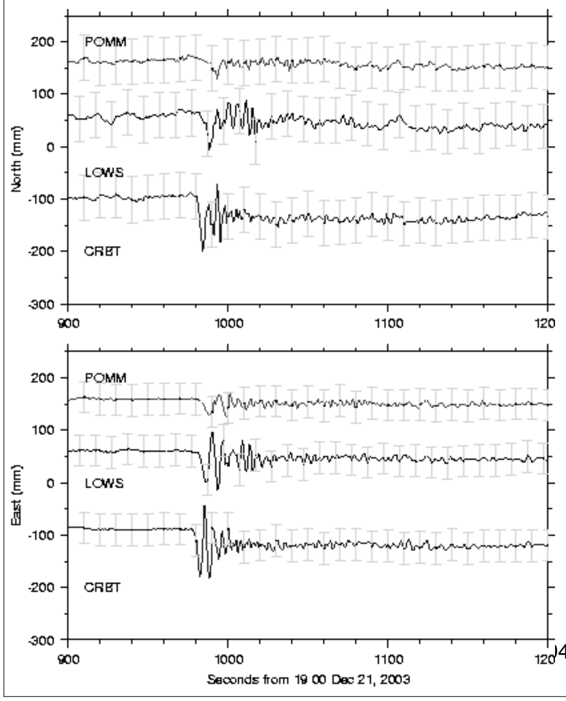
35



Arrival of surface waves from San Simeon Earthquake (1-Hz)

GPS stations around Parkfield operate at 1-Hz sampling rates, which allows us to study surface wave arrivals from nearby and large magnitude earthquakes

36



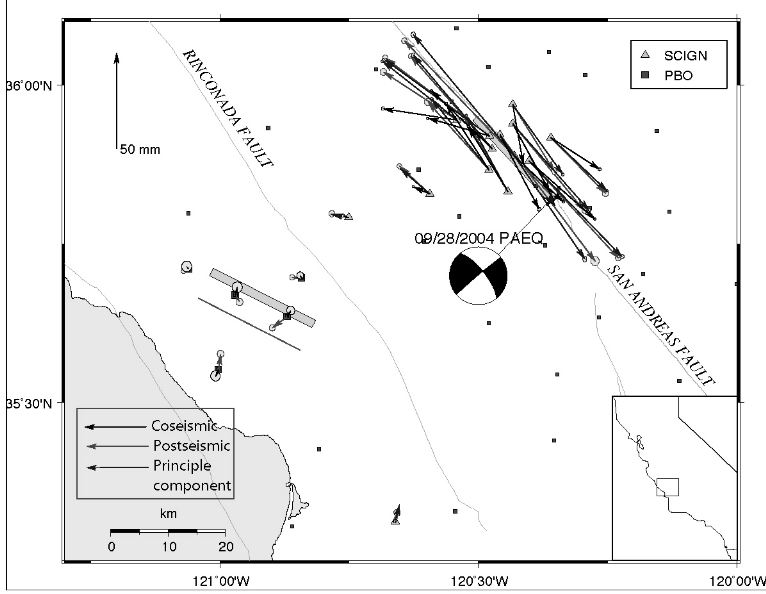
Time zoom of arrivals

In addition to the surface waves, the static co-seismic offset can also be seen here.

Real time high rate GPS data useful for surveying and engineering communities.

37

Parkfield Earthquake

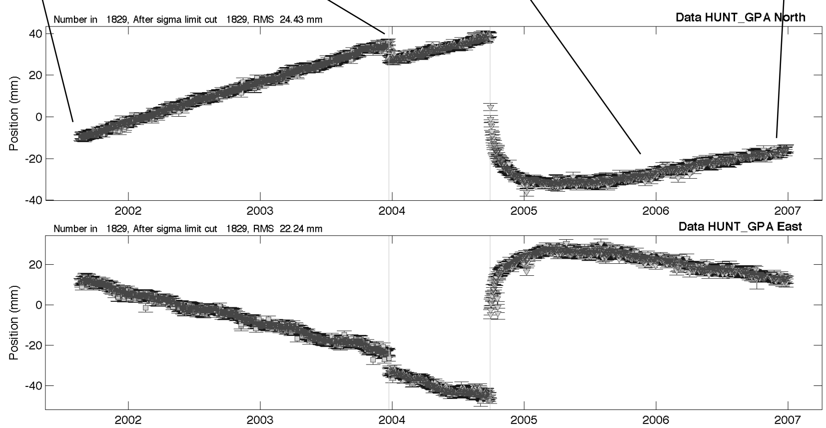


38

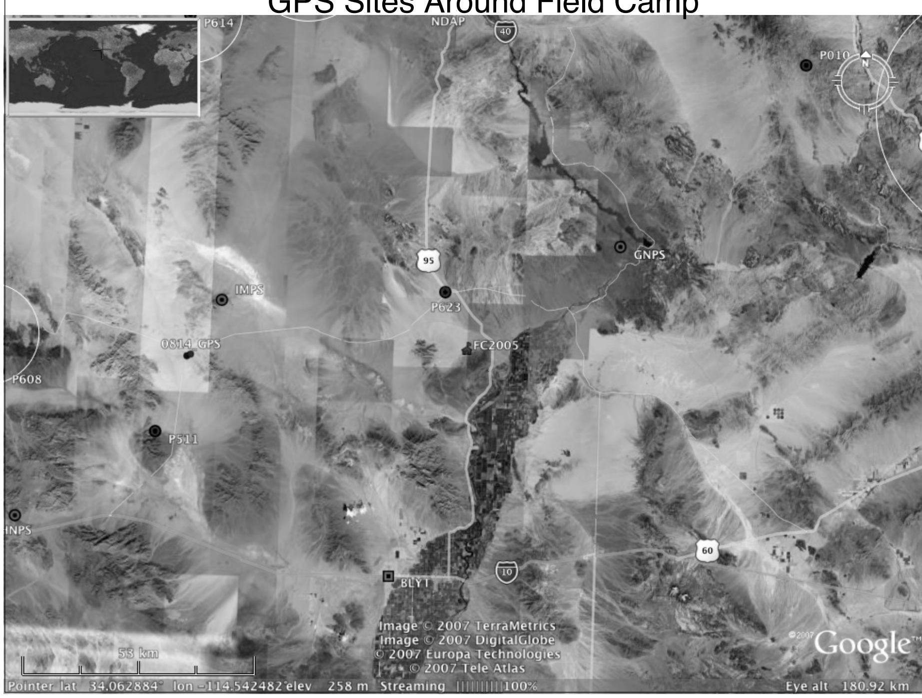
Full North/East Time series for Parkfield site

Pre-Earthquake
North 19.1±0.1 mm/yr
East -15.2±0.3 mm/yr

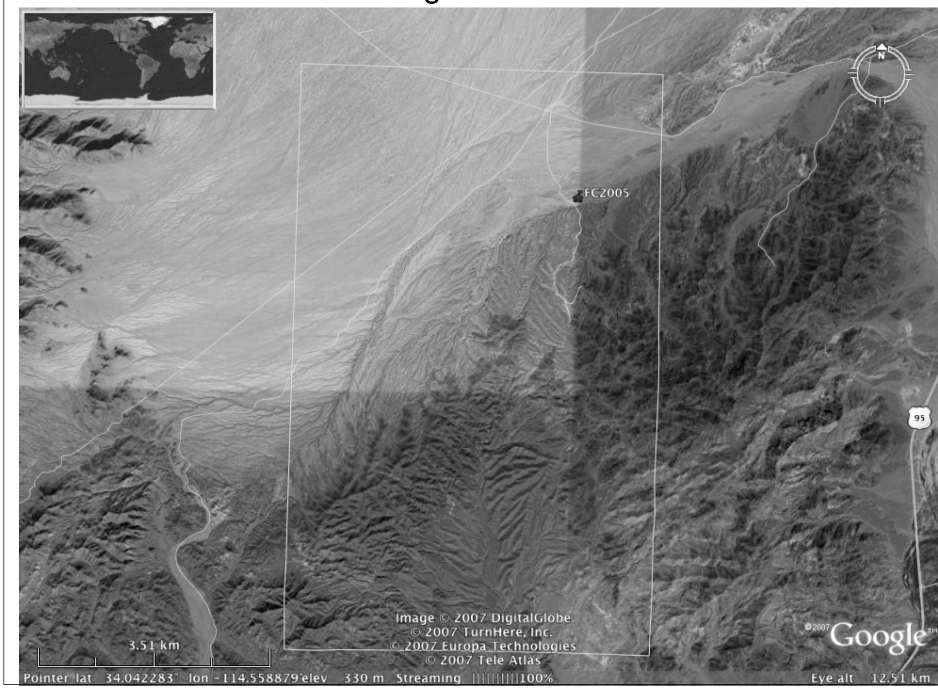
2006-2007 Velocities
North 10.5±0.3 mm/yr
East -10.0±0.5 mm/yr



GPS Sites Around Field Camp



Regional view



12.221 Uses of GPS

- In the course we will use different GPS analysis packages:
  - Hand-held receivers: These have the software built in and you just need to select correct options.
  - TRACK: Kinematic GPS processing in the field (time series of station positions)
  - GAMIT: Full static GPS positioning (run on campus)
  - GLOBK: Used to tie our GPS results into the rest of California.