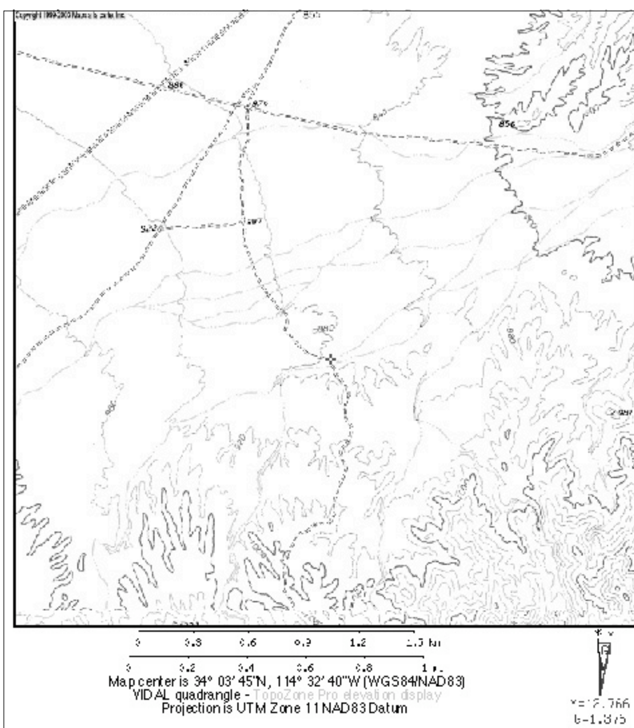
12.221 Field Geophysics

Instructors
Tom Herring, tah@mit.edu;
Brad Hager brad@chandler.mit.edu

Web: http://www-gpsg.mit.edu/~tah/12.221

CLASS 2: Introduction to GPS

Updates on Camp



Update on Camp Location

Camp will be at 34°03'45" N, 114° 32' 40" W

Map from topozone.com

Introduction to GPS

- Uses of GPS in this course
  - Hand held navigation. ($200)
  - Differential “kinematic” positioning for determining heights of gravity measurements (see later why)
  - Precise static positioning for ~1 mm positioning ($10,000)

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 ITRF2000 (Use Frame to denote realization)
- World Geodetic System WGS84 used by GPS control center (within a few meters of ITRF2000)
- However: Maps made well before this system and most US maps use North American Datum (NAD) 1927 (NAD27)
- 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.

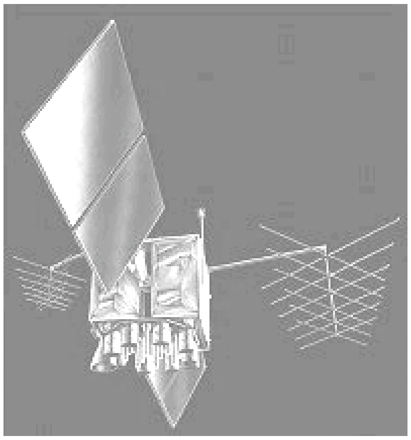
GPS Original Design

- 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 ~28)
  - 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)

Latest 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

$$V(t,\vec{x}) = V_o \sin[2\pi(ft - \vec{k}.\vec{x}) + \pi C(t)]$$

$C(t)$ is code of zeros and ones (binary).

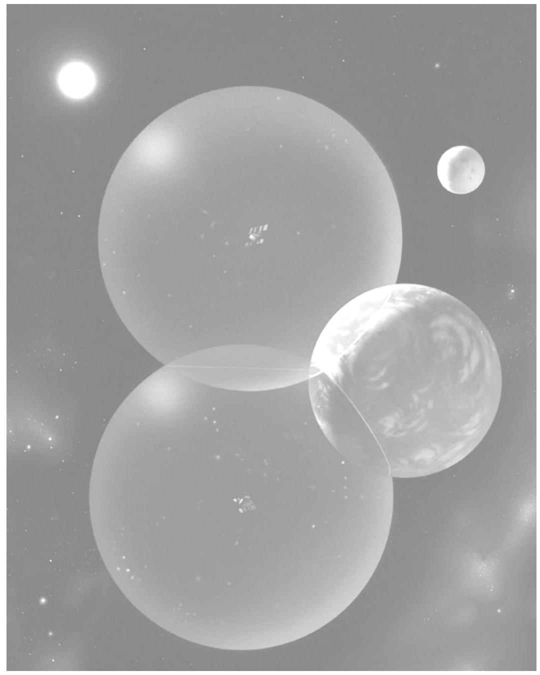
Varies discretely at 1.023 or 10.23 MHz

Measurement usage

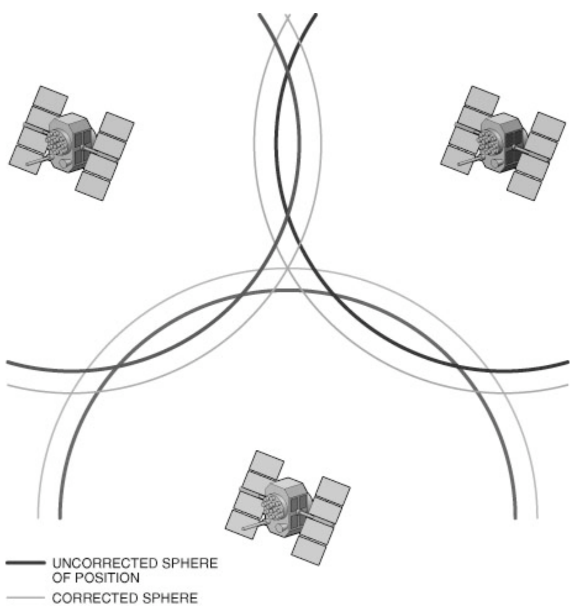
- Since the C(t) code changes the sign of the signal, satellite can be only be detected if the code is known (PRN code)
- Multiple satellites can be separated by "correlating" with different codes (only the correct code will produce a signal)
- The time delay of the code is the pseudo-range measurement.

Position Determination (perfect clocks)

- Three satellites are needed for 3-D position with perfect clocks.
- Two satellites are OK if height is known)



01/06/04



Position determination: with clock errors: 2-D case

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

Positioning

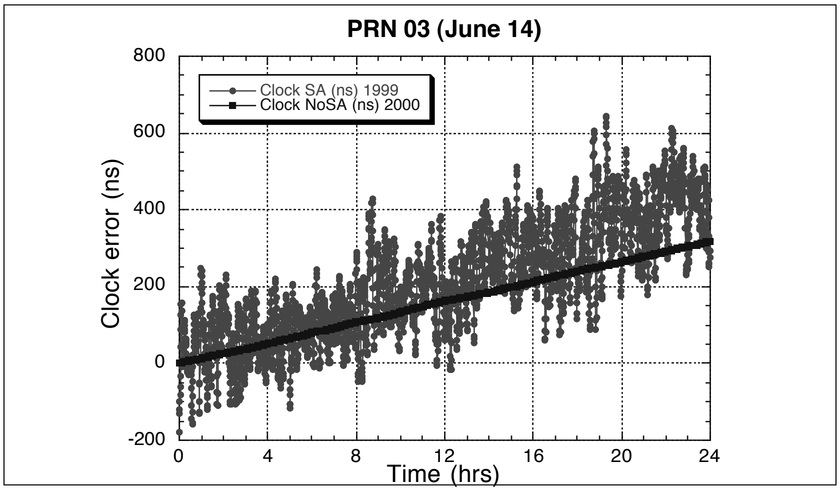
- For pseudo-range to be used for positioning the following quantities must known:
  - Errors in satellite clocks (use of Cesium clocks)
  - Positions of satellites
- This information is transmitted by satellite in "broadcast ephemeris". This information saved in receiver data file. We will use for in-field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

GPS Security systems

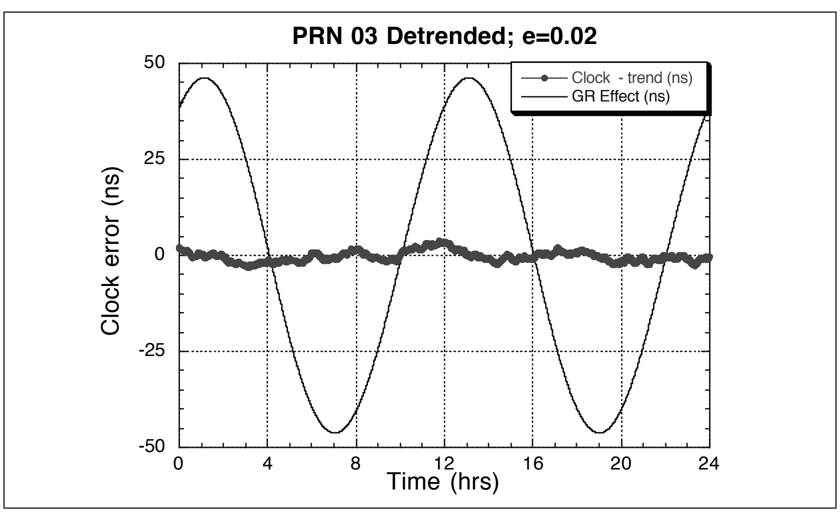
- Selective availability (SA) is no longer active but prior to 2000 "denied" civilian accuracy better than 100 m
  - Implemented by "dithering" (noising up) the satellite clock
  - Military receivers were able to undo the dithering
- Antispoofing (AS) active since 1992, adds additional encryption to 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

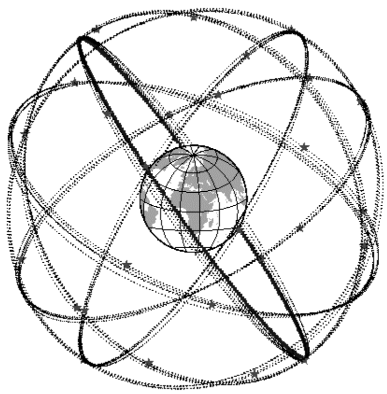
Effects of Selective Availability



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.

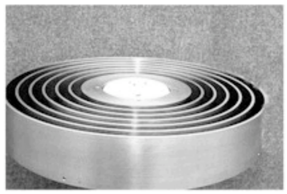
Types of parameters estimated in GPS analysis

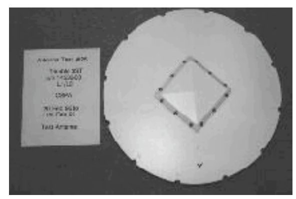
- GPS phase measurements at L1 and L2 from a global distribution of station used. Pseudo-range can be used but 100 times less accurate than phase.
- Giobal Analysis typically includes:
  - All site positions estimated
  - Atmospheric delay parameters estimated
  - “Real” bias parameters for each satellite 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
- For short site separation (<1000km): Orbits need not be estimated. Use International GPS Service (IGS)

GPS Antennas (for precise positioning)

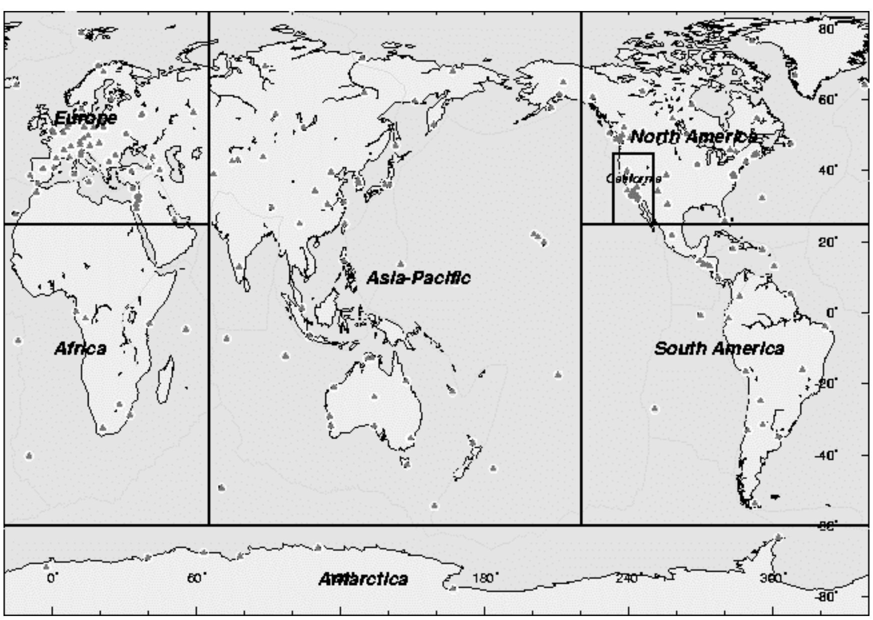
Nearly all antennas are patch antennas
(conducting patch mounted in insulating ceramic).

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

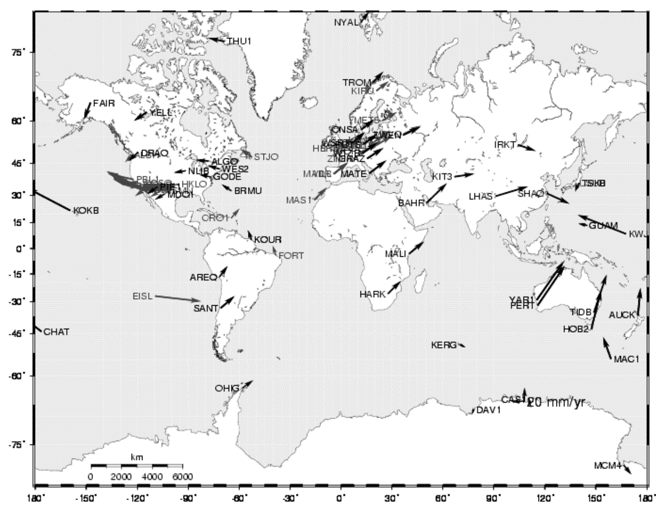




Global IGS Network (~250 stations)



Typical global network



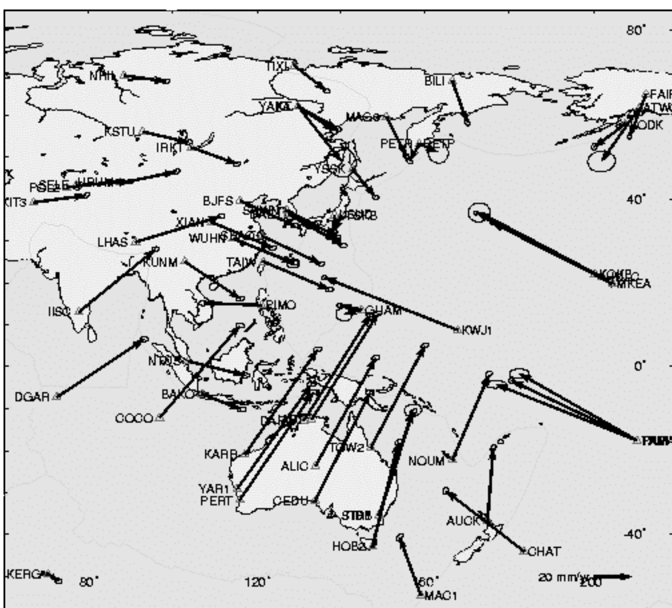
Black: Frame sites (define ITRF2000); Red other sites

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 Integrated Network (SCIGN)
- http://www.scign.org/

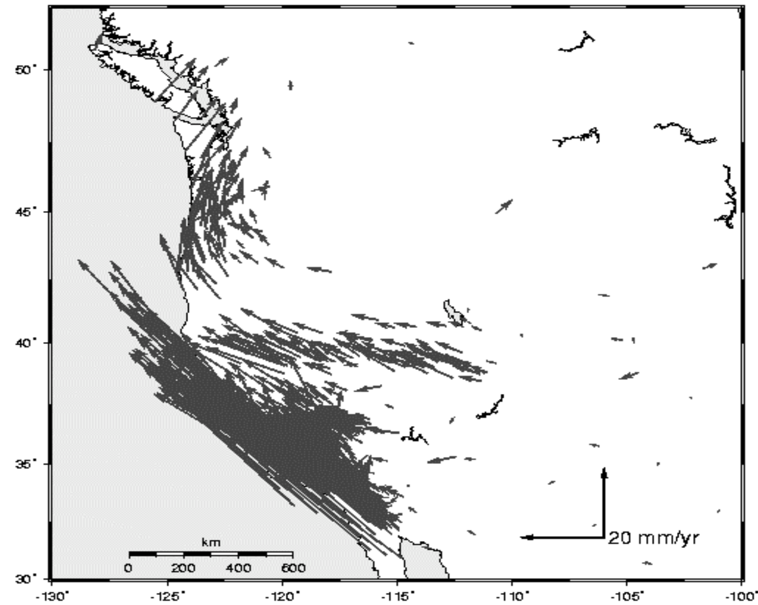


Example of motions measured in Pacific/Asia region

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

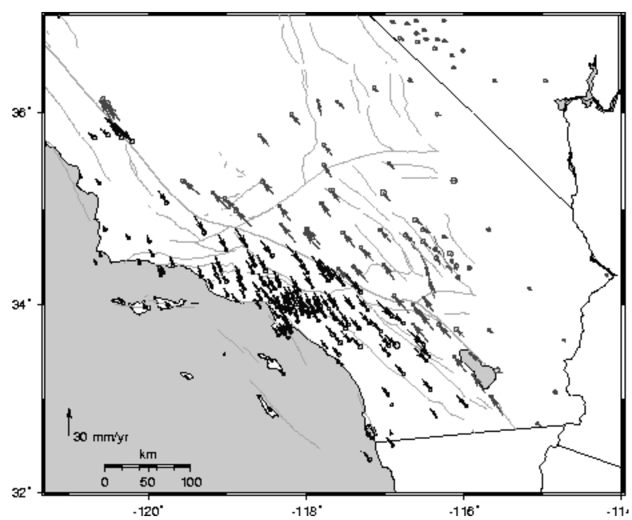
More at http://www-gpsg.mit.edu/~tah/MIT_IGS_AAC

Detail in Western United States



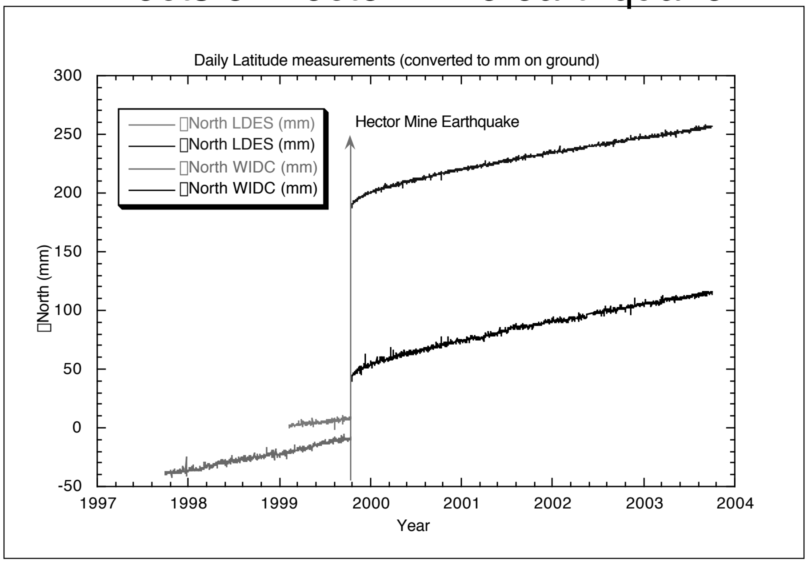
California Detail

- Continuous site results from SCIGN
- Red vectors relative to NA; Blue relative to Pacific Plate
- In 100 years, fastest points move 5 m

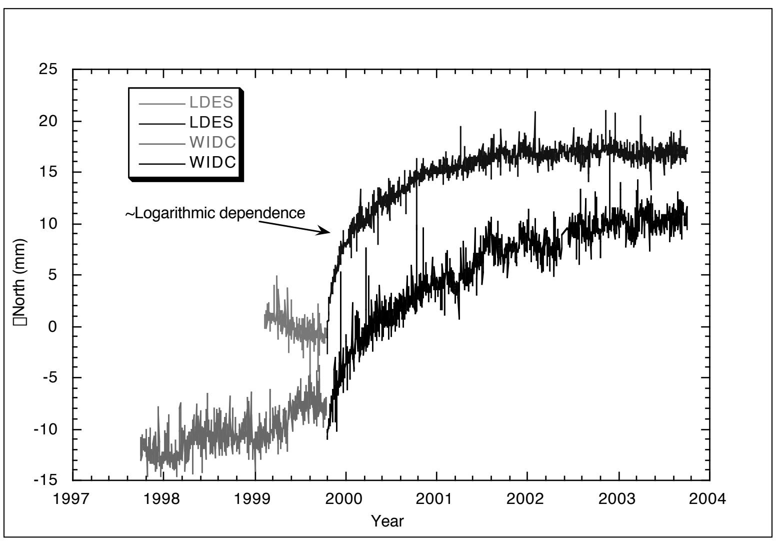


http://www-gpsg.mit.edu/~tah/SCIGN_MIT/SCIGN_96_0309_Results.html

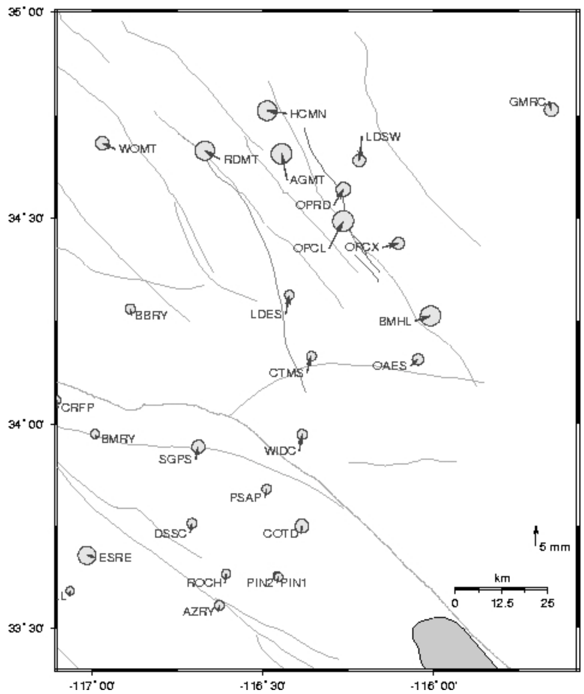
Effects of Hector Mine earthquake



Removed 12.6 mm/yr+coseismic offset



Estimates of logarithmic coefficients



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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.
  - Manuals for GAMIT/GLOBK will be a field camp for reading.