High Temporal and Spatial Resolution of Crustal Deformation with GPS

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Objectives

GPS surveying has the potential to provide crustal deformation precursors for the prediction of large earthquakes and, in particular, to allow *frequent and dense* monitoring of coseismic and postseismic strain transients which would add to our fundamental understanding of the physics of the earthquake process. The goal of this research is to develop and evaluate the capability of surveying *spatially dense, small and medium-aperture, three-dimensional geodetic networks, in near real-time with several millimeter-level accuracy* using GPS in continuously operating ("strainmeter") and kinematic-type modes.

Investigations Undertaken and Data Collected

Imperial Fault Kinematic Survey

In May 1991, we surveyed a large portion of the Imperial College network across the northern part of the Imperial Fault near El Centro. This network has been surveyed since the early 1970's with very precise EDM instruments (first the Kern Mekometer and then the Kern Geomensor) [Mason, 1987]. The Geomensor measures distances with an accuracy of ± (0.1 mm + 0.1 ppm). The network consisted of approximately 300 stations at the time of the October 15, 1979 Imperial Valley earthquake, with stations about 800 meters apart at road intersections, about half of which lay in an 8x10.5 km block extending more than 6 km on either side of the surface break. In January-April 1991 the network was leveled by Imperial College using trigonometric leveling with a mean standard error of 1.8 mm. In addition, all fault crossing lines were re-surveyed with a Kern DM503 EDM indicating 55.7±11.5 mm of fault slip since 1987 [Mason et al., 1991].

The network is ideal for kinematic-type GPS surveying. The terrain is flat and there are very few obstructions which in most cases can be easily avoided. We deployed 4-5 Trimble 4000 SST receivers for four days (5-6, 8-9 May). Two receivers were used in kinematic mode while the remaining 2-3 receivers were deployed as base stations in static mode. To obtain redundancy we surveyed crossover points. Furthermore, the roving receivers moved from site to site synchronously. Typically, each kinematic site was surveyed for 10 minutes in order to average out multipath errors. Each roving team was able to survey about 10 points during two kinematic windows (five or more satellites) of 75 and 60 minute duration. We are currently comparing our results with the conventional horizontal and vertical measurements. [Mason et al. 1991].

Strainmeter-type Surveys near Parkfield

We surveyed the USGS Kennedy Ranch Alignment Array located 10 km southeast of Parkfield using kinematic GPS. On 11 November 1990, we observed the ten points of the 258 m long array with one hour of observations using three Trimble 4000 SST receivers. On 8-10 February 1991, we reobserved the array for one hour on each day using three Ashtech XII receivers. The data at the two end points of the array were collected at a 1 second sampling rate for the entire one hour period for all surveys. A roving receiver measured the intermediate points with repeated 3 minute occupations sampled at a 15 second sampling rate.

Permanent GPS Geodetic Array

The Permanent GPS Geodetic Array (PGGA) has been operated as a NASA pilot project since the spring of 1990 by Scripps Institution of Oceanography (SIO) and the Jet Propulsion Laboratory, with assistance from Caltech, MIT and UCLA. The objectives are to monitor crustal deformation continuously, in near real-time and with millimeter accuracy, using a fully automated and economically feasible system. The development and operations of the PGGA have been described by Bock and Shimada [1990], Bock et al. [1990], Bock [1991a,b] and Bock and Genrich [1991]. We are using the PGGA data to support our investigations of the spatial and temporal resolution of GPS.

Results Obtained

Implications for GPS Strainmeters and Kinematic GPS

We have reported on the results of the Kennedy Alignment Array Survey in Bock [1991], Bock and Genrich [1991], and Genrich and Bock [1991]. We reiterate our conclusions which provide guidelines for precise continuously monitoring and kinematic-type GPS surveys:
(1) Multipath effects interfering with the incoming radio signal will tend to average out over a period of several minutes. Therefore, to achieve one millimeter level precision with kinematic GPS a site should be occupied for about ten minutes. Several millimeter to one centimeter precision can be achieved with shorter occupations.
(2) In order to increase the resolution of millimeter-level position for a continuous GPS strainmeter, it is necessary to model the effect of multipath on the position components.
(3) Multipath effects can be modeled for GPS strainmeters to an rms of a millimeter or two at a resolution of about one minute.

Results from Permanent GPS Geodetic Array

We have been estimating the position of the SIO-JPL-PFO triangle (Figure 1) daily since September 1991. We perform, at twenty-four intervals, a simultaneous weighted least squares adjustment of the station positions and improved satellites ephemerides using the PGGA data and data from a global set of tracking stations. As an example, the time series of positions of the JPL to Scripps baseline are shown in Figure 2, indicating an rms scatter of approximately 3 mm in the north, 6 mm in the east and 10 mm in the vertical. Considering the length of the PGGA baselines, we estimate that the daily orbits are precise at no worse than the 20-30 parts per billion level. We are investigating various approaches to improving the repeatability, particularly in the east and vertical components and performing tests at observation windows less than 24 hours. We also are examining the time series of a continuously operating GPS baseline from Piñon Flat Observatory to a site 14 km away [Happer, et. al., 1991]

We are also evaluating the precision of our satellite parameters based on overlapping orbital arcs. We are able to extrapolate several meter-level precise orbits twenty-four hours ahead of the time of collection. Although we typically perform solutions about 4-5 days after collection (primarily waiting for global tracking data that are downloaded by others), we now have all the components required to maintain a near-real time crustal motion monitoring array.

Our orbital ephemerides should be sufficiently precise to support most crustal deformation GPS surveys in California. Furthermore, our entire data base of orbital tracking data since April 1990, is on-line and accessible to investigators via anonymous ftp over Internet.

In Figure 3, we show the daily solutions of the Goldstone to JPL (Pasadena) baseline during the period of the Sierra Madre earthquake. We detect no significant deformation in the baseline (from a distance of 180 km) with a precision of several mm. This result agrees with horizontal and vertical displacements computed from earthquake dislocation models (D.C. Agnew, personal communication).

Reports Published

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SOUTHERN CALIFORNIA
PERMANENT GPS GEODETIC ARRAY (PGGA)
BULLETIN

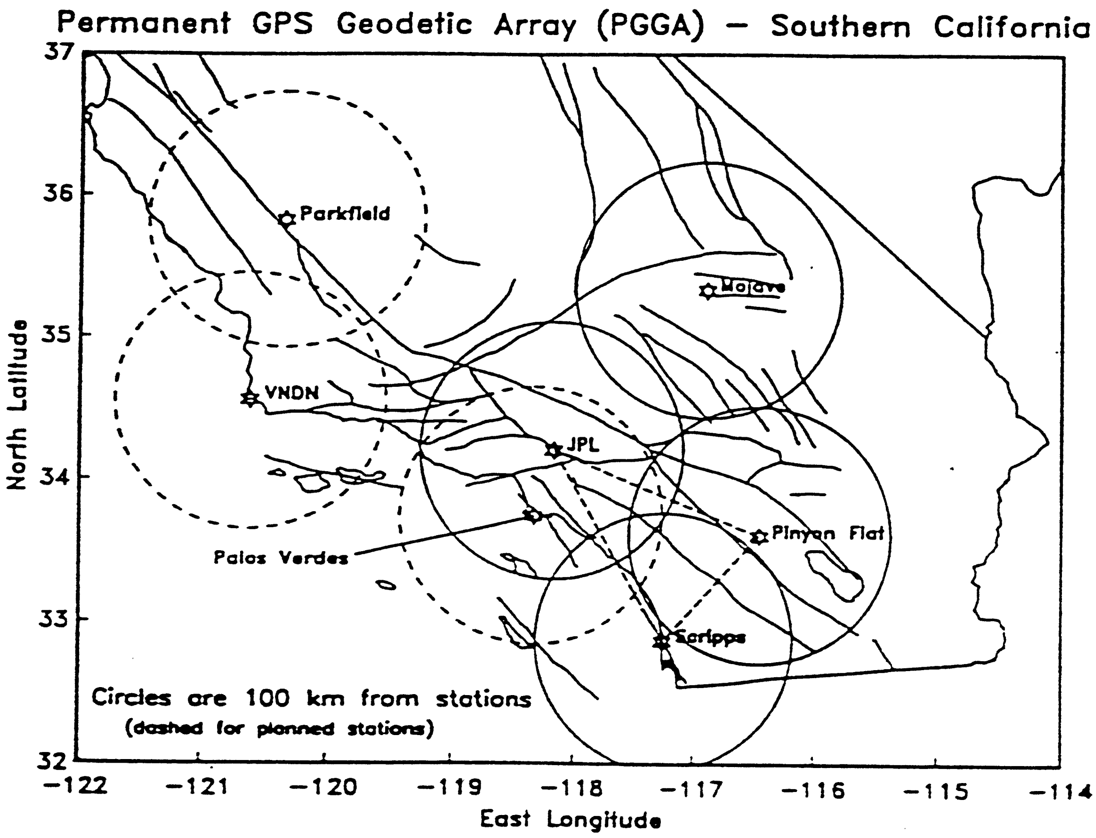

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Figure 1: Map of the Permanent GPS Geodetic Array (PGGA) in southern California taken from the cover page of the first issue of the PGGA bulletin. The sites at VNDN, Parkfield and Palos Verdes are expected to come on line in the first quarter of 1992.

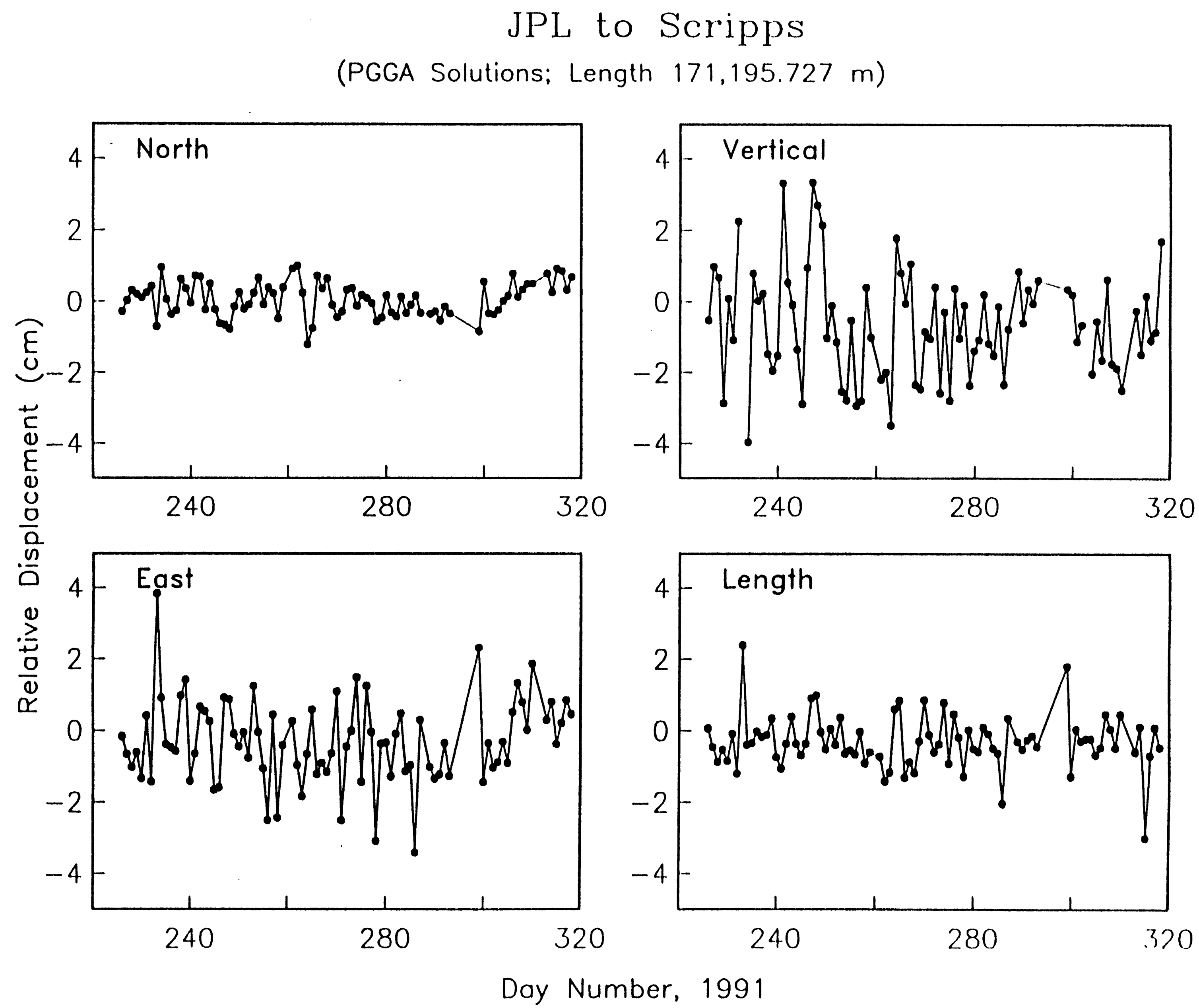

Figure 2: Daily PGGA solutions for the JPL to Scripps baseline for days 226-318.

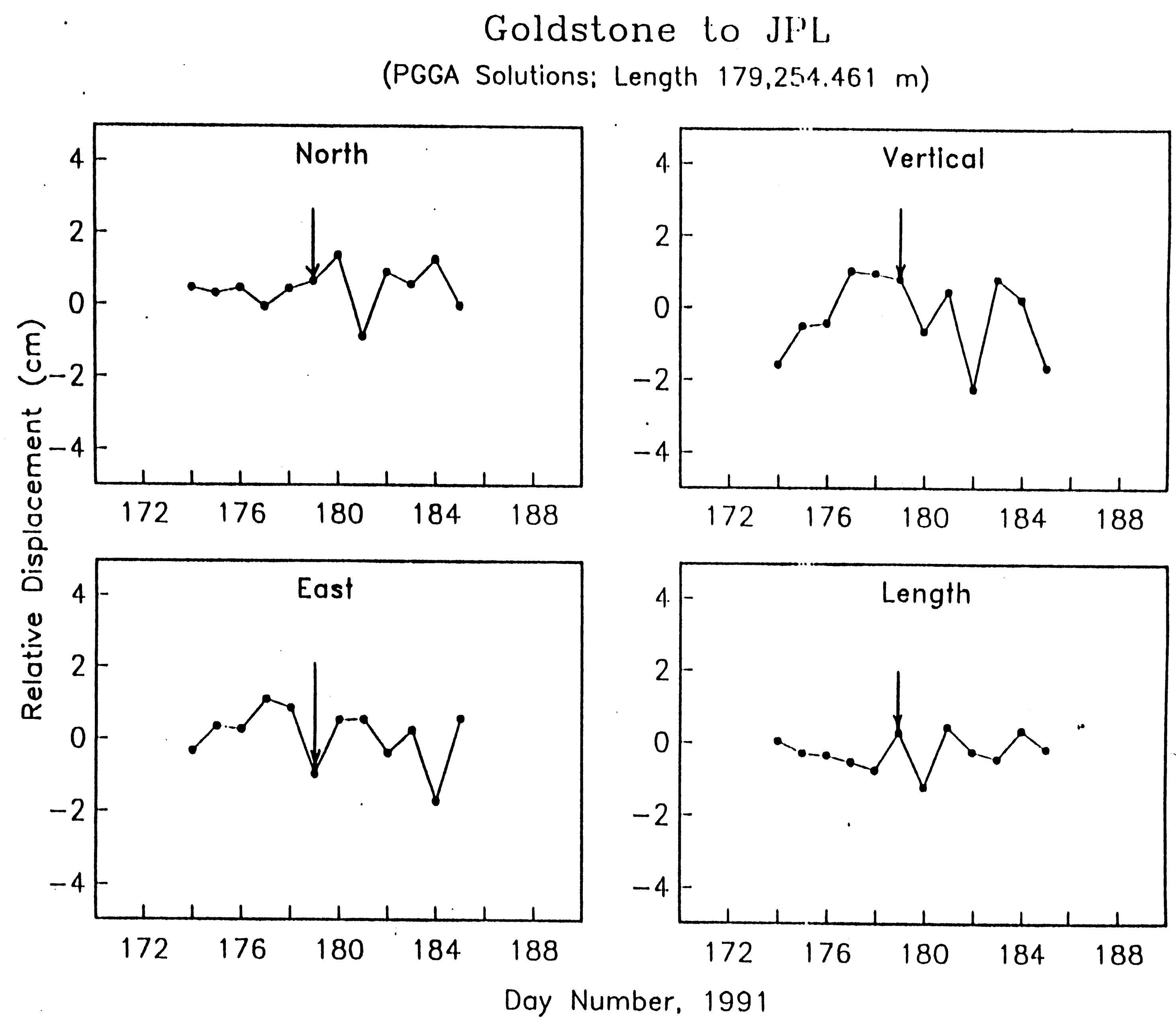

Figure 3: Daily PGGA solutions for the Goldstone to JPL baseline during the period of the Sierra Madre Earthquake (day 179). The vertical arrow indicates the first solution after the earthquake.