THE DENSE GPS ARRAY IN SOUTHERN CALIFORNIA : A NEW TOOL FOR SEISMIC HAZARD ASSESSMENT

A. Donnellan
K. Hurst
J. Scheid
M. Watkins
F. Webb

Jet Propulsion Laboratory
4800 Oak Grove Drive
Pasadena, CA 91109

ABSTRACT

The Global Positioning System (GPS) has recently emerged as a powerful new technology for assessing earthquake hazard before earthquakes occur, and for assessing damage following moderate to large earthquakes. High precision dual frequency GPS receivers are used to measure small motions of the earth's crust. These motions, when measured over a number of sites in earthquake prone regions contribute to estimations of earthquake probabilities. GPS is also used to measure displacements following moderate to large earthquakes. Receivers can be mounted on engineered structures such as buildings and dams, to assess remotely whether these structures have been damaged from an earthquake. The Jet Propulsion Laboratory (JPL), and other institutions under the umbrella of the Southern California Earthquake Center (SCEC) are currently implementing a continuously operating dense GPS array in greater Los Angeles

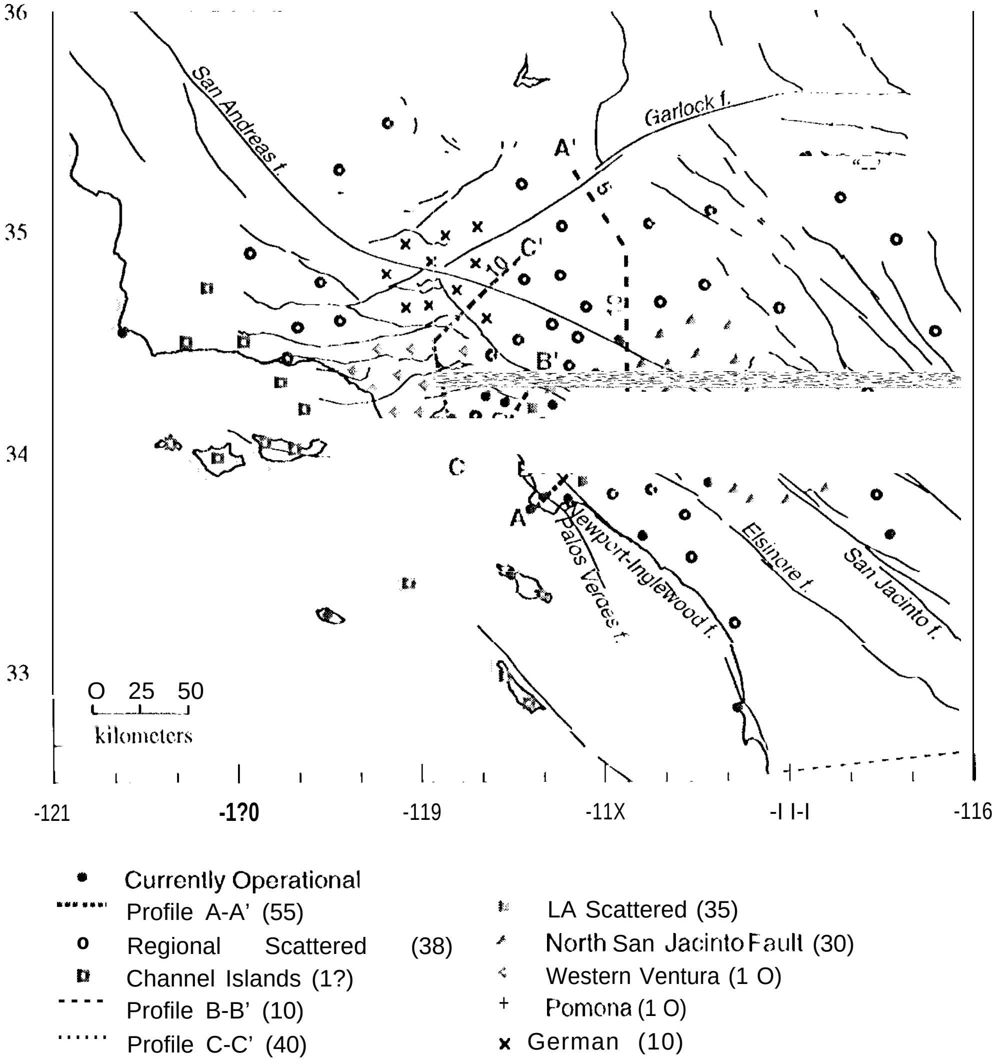

Figure 1. Map showing currently operational and planned stations of the Dense GPS Array for southern California. Profiles will sample fault systems that extend throughout greater Los Angeles. Scattered stations will monitor far-field and three-dimensional effects. Numbers in parentheses indicate number of stations.

kilometers in size [2]. When the break occurs the surface of the earth can be displaced up to several meters. The Santa Susana Mountains, which are located just north of Northridge, grew nearly 50 centimeters during the earthquake [3]. in addition the surface of the earth was tilted locally. had the ground surface tilted slightly more the gravity flow of the Jenson Filtration Plant, located north of the epicenter, would have ceased to work. These ground displacements and tilts are easily measurable with GPS.

Traditionally GPS data have been collected by periodically setting up a GPS instrument in the field every 1-1 1/2 years. in 1991 four continuous GPS stations were implemented in southern California through a cooperative effort between several universities (UCSD, Caltech, UCLA, MIT); NASA Jet Propulsion Laboratory, and the US Geological Survey (USGS). These stations resulted in the first Permanent GPS Geodetic Array (PGGA) in southern California. The network provides an important framework for GPS data collection in southern California and provided valuable co- and postseismic data for both the Landers and Northridge earthquakes [4- 6].

Because GPS has proved to be a powerful tool for studying earthquakes, NASA and other agencies have committed funds to implement a continuously operating dense GPS array in greater Los Angeles. There are now over 35 continuously operating stations in southern California. Plans are to expand the network to 100 stations over the. next year, with the final network consisting of 250 stations (Figure 1). The total cost to implement the array is expected to be $10 million. NASA has committed significantly for station implementation over the next year, The USGS and National Science Foundation (NSF) have also contributed funds to the network. We are seeking additional funds from other sources. Not only will

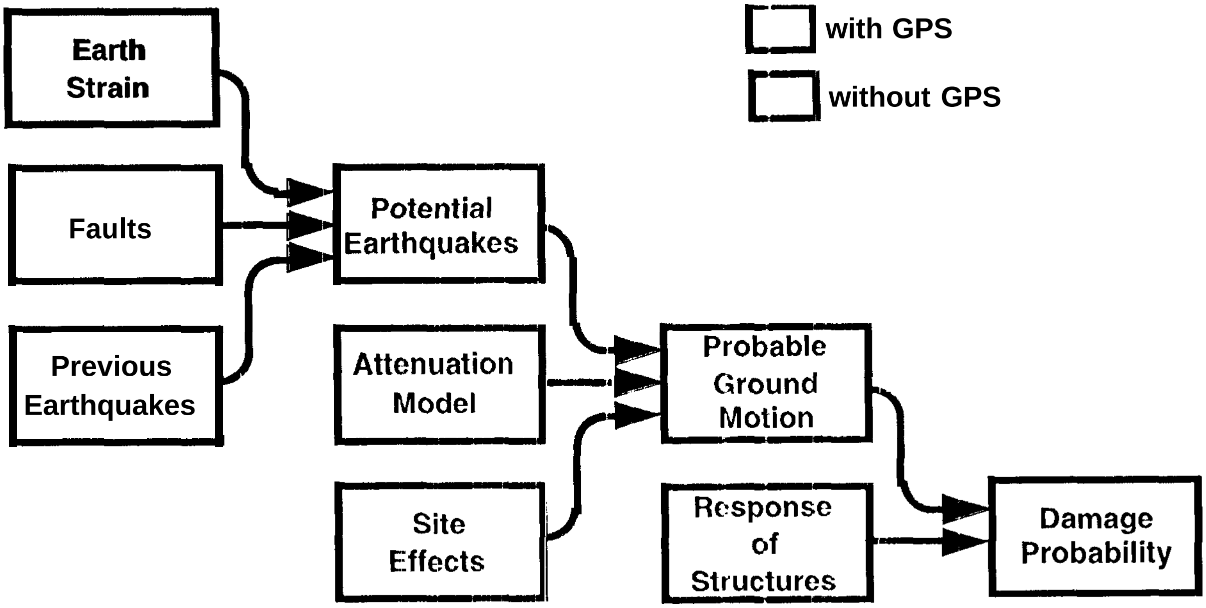

Figure 2. Earthquake risk diagram showing the contribution of GPS to earthquake hazard assessment.

seismic moment release, style and rates of faulting, frequency of earthquake recurrence, and seismic potential of thrust ramps. The GPS data will also be used to search for hidden thrust faults underlying greater Los Angeles.

Post-earthquake Analysis

When an earthquake occurs the earth's crust deforms significantly. After an earthquake data from the GPS network will be immediately retrieved and analyzed. Motions of the stations will be used to assess the areas of greatest ground motion and deformation. These data can be used in conjunction with data from strong ground motion instruments to indicate the regions where the greatest damage was likely to have occurred.

The GPS data can also be used to determined the faulting mechanism. The location of potential aftershocks can be assessed better once the location and orientation of the fault has been determined. The location and orientation of the fault can also be used to evaluate whether other large earthquakes may be triggered on nearby faults. After an earthquake occurs the ground continues to deform rapidly. The network will be used to monitor post-earthquake ground motions to evaluate whether nearby faults are being loaded, which would increase the likelihood of an earthquake on the nearby fault. The post-earthquake motions will also help scientists understand the complete earthquake cycle, earthquake mechanics, and the rheologic properties of the earth's crust.

GPS stations located on engineered structures can be used to remotely assess whether these structures have been damaged in the earthquake. Geophysical models can be used to estimate the distribution of ground motion across the entire region. If a GPS antenna is mounted on a building and dots not show the expected motion it is likely that the building has been deformed or damaged. The GPS receivers can also be used to monitor the movement of bridges and dams. The dense GPS network can serve as a framework in which lower cost receivers can be implemented.

As the ground deforms in response to an earthquake it may also tilt. These tilts can be measured with the GPS network. If

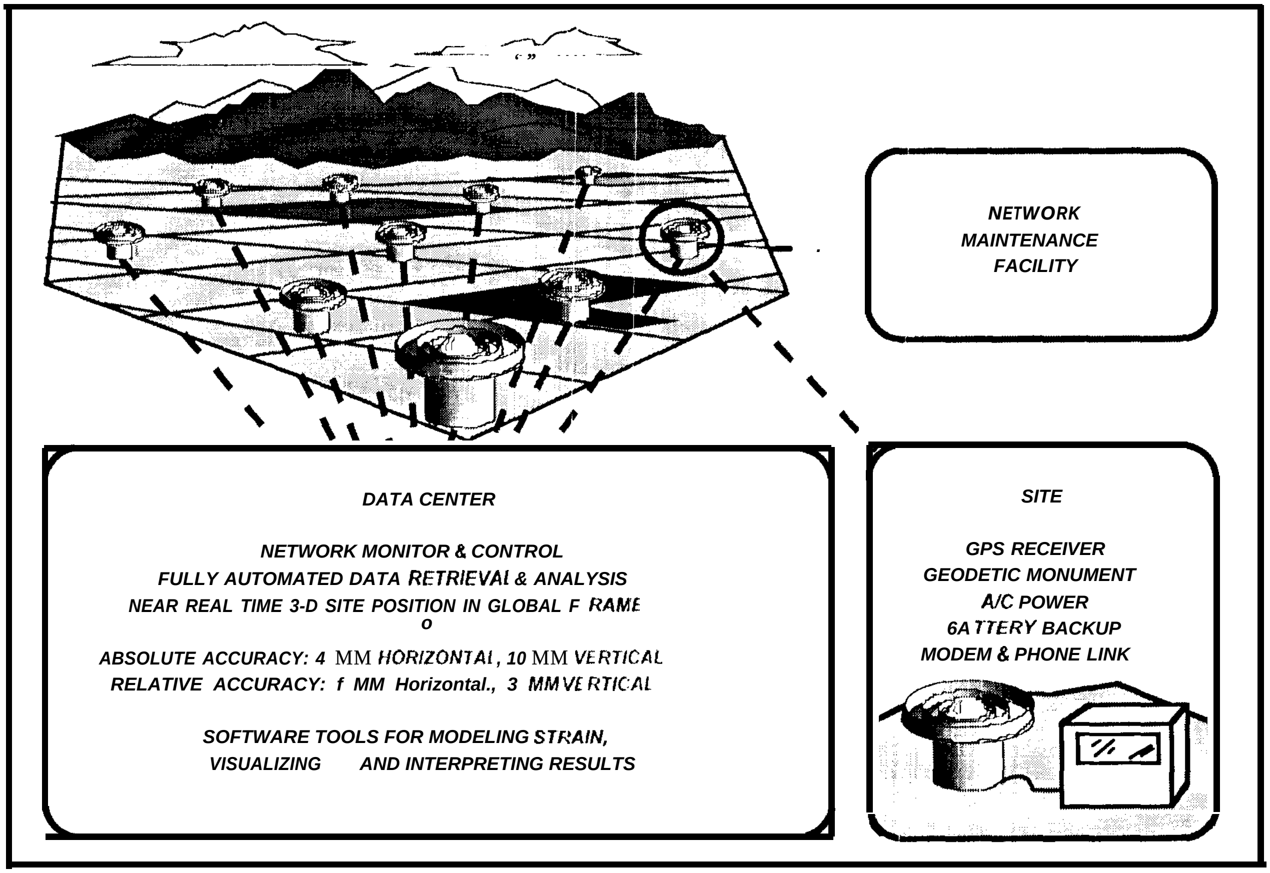

Figure 3. Elements of the dense GPS array. Each site contains a GPS antenna, receiver, and communications device such as a modem or phone link. The data are downloaded and processed daily at a central analysis center. Data and solutions are archived.

or water lines will not flow properly. Again, the health of the lines can be assessed remotely with the GPS network.

ELEMENTS OF THE NETWORK

The GPS array will consist of 250 GPS stations, each equipped with a stable monument, antenna, receiver, power, and communication device (Figure 3). The monument must be very stable and well coupled to the ground because we are measuring such small motions. Sturdy buildings or specially designed ground mounts serve as stable monuments.

DATA ANALYSIS AND PRODUCTS

The GPS data will be relayed to a data archiving center located at JPL on a daily basis. A backup center will be located at the Scripps institution of Oceanography in San Diego. Data will be downloaded more frequently should an earthquake occur. After the data are verified and archived they will be processed at both Scripps and JPL.

At JPL the data will be analyzed with the GIPSY/OASIS II software package [8], which was developed at JPL. The software employs a square root information filter and can produce decimeter level GPS satellite orbits as well as site positions accurate to a few millimeters. We will use orbits produced at JPL to compute the station positions in the GPS array. After the network has operated for a sufficient length of time (about 1 year) we will also produce velocity maps and

1 hour	10 mm
1 day	3 mm
1 week	1 mm

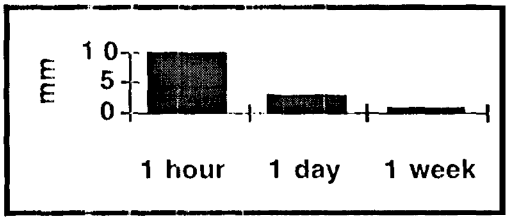

Figure 4. Expected accuracy for solutions calculated 1 hour, 1 day, and 1 week after data collection.

strain **maps.** These **will** be **publicly** available via anonymous FTP and the World Wide Web. Current information about the network and links to other participating institutions can be found on the World Wide Web at http://milhouse.jpl.nasa.gov/.

JPL has developed efficient schemes for analyzing the data. Within one hour after data collection, solutions will be obtained that achieve an accuracy of about 10 mm (Figure 4). The quality of the solutions is related to the quality of the orbits of the GPS satellites. JPL produces quick estimates of the satellite orbits. These orbits are improved with time, hence the precision of the station position solutions also improves with time, such that one week after data collection 1 mm station position accuracy can be obtained. The high precision results are necessary to estimate inter-earthquake station velocities, which may be on the order of just a few mm/yr. Therefore, there is no urgency in producing these solutions immediately. Following a large earthquake, however, it is important to rapidly produce solutions. Station motions can be several centimeters to a few meters after a large earthquake, thus 10 mm accuracy is sufficient immediately following an earthquake.

NETWORK MANAGEMENT

Several institutions are active in continuous GPS studies in southe from the dense GPS away will be available on the Internet via anonymous FTP and the World Wide Web.

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