# Continuous GPS Network Operating Throughout Ecuador

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Recent devastating great earthquakes in Sumatra, Chile, and Japan show that scientists need to learn more about other less studied subduction zones that have also generated major earthquakes in the recent past. On the margin of northwest South America, offshore Ecuador and Colombia, the Nazca plate's rapid oblique subduction beneath the South American continent has produced a sequence of large earthquakes. A recently installed continuous GPS network is beginning to help scientists learn more about the geodynamic framework in Ecuador.

### *The Geodynamic Setting of the Region*

In 1906 the interface between the Nazca and South America plates ruptured in a single megathrust earthquake, generating a $M_w = 8.8$ earthquake over a 500-kilometer rupture length, similar to the great Chilean earthquake in 2010 (Figure 1). The same area ruptured again in three smaller episodes (1942, $M_w = 7.8$; 1958, $M_w = 7.7$; and 1979, $M_w = 8.2$), all adjacent to one another, with tsunamis reported for the 1906 and 1979 events [*Kanamori and McNally,* 1982]. All ruptures occurred north of the subducting Carnegie Ridge [*Kanamori and McNally,* 1982; *Beck and Ruff,* 1984], a 2-kilometer-high oceanic plateau formed by the Galápagos spreading center and hot spot, suggesting that the Carnegie Ridge behaves aseismically and may act as a barrier to rupture propagation.

Aside from producing subduction earthquakes, oblique subduction also induces permanent strain in the overriding plate, resulting in earthquakes at the surface [*Pennington,* 1981; *Nocquet et al.*, 2009]. Because of proximity to population centers, these earthquakes are potentially very destructive, even though magnitudes are usually less than those of subduction events. For interior Ecuador, four earthquakes with a modified Mercalli intensity of IX or greater have been recognized since the arrival of the Spanish conquistadors in the sixteenth century [*Beauval et al.*, 2010]. One of the most destructive earthquakes, with a modified Mercalli intensity of X, occurred in 1797, destroying Riobamba, a regional capital [*Egred,* 2000].

### *Ecuador's New National Continuous GPS Network*

GPS measurements with accuracy of a few millimeters can quantify displacements on the Earth's surface, revealing deformation processes preceding and subsequent to the occurrence of large earthquakes and/or volcanic eruptions. Continuous GPS (CGPS) measurements further enable scientists to catch time-varying displacements during and after earthquakes, slow slip events, and magmatic intrusions.

The government of Ecuador (population 14 million, area 250,000 square kilometers) recently increased funding for natural disaster mitigation for its citizens. A country-wide CGPS network of 70 permanent stations is in the final stages of installation. Funding for the equipment and its installation was provided to the Instituto Geofísico of the National Polytechnic University (IGEPN) in Quito by the National Secretary of Higher Education, Science, Technology and Innovation (Ecuador's equivalent of the U.S. National Science Foundation); the Secretary for Risk Management; the Environmental Ministry; a European Commission disaster preparedness project (DIPECHO); the Agence National de la Recherche (France); Géoazur (Nice, France); U.S. Southern Command; and the University of Miami and University of South Florida. IGEPN, which is in charge of Ecuador's seismic and volcano monitoring, maintains strong collaborations with the Institut de Recherche pour le Développement (IRD), Géoazur, Instituto Geográfico Militar-Ecuador, PetroEcuador, the Colombian Geological Survey, the U.S. Geological Survey (USGS), and the Strengthening Resilience in Volcanic Areas (STREVA) and

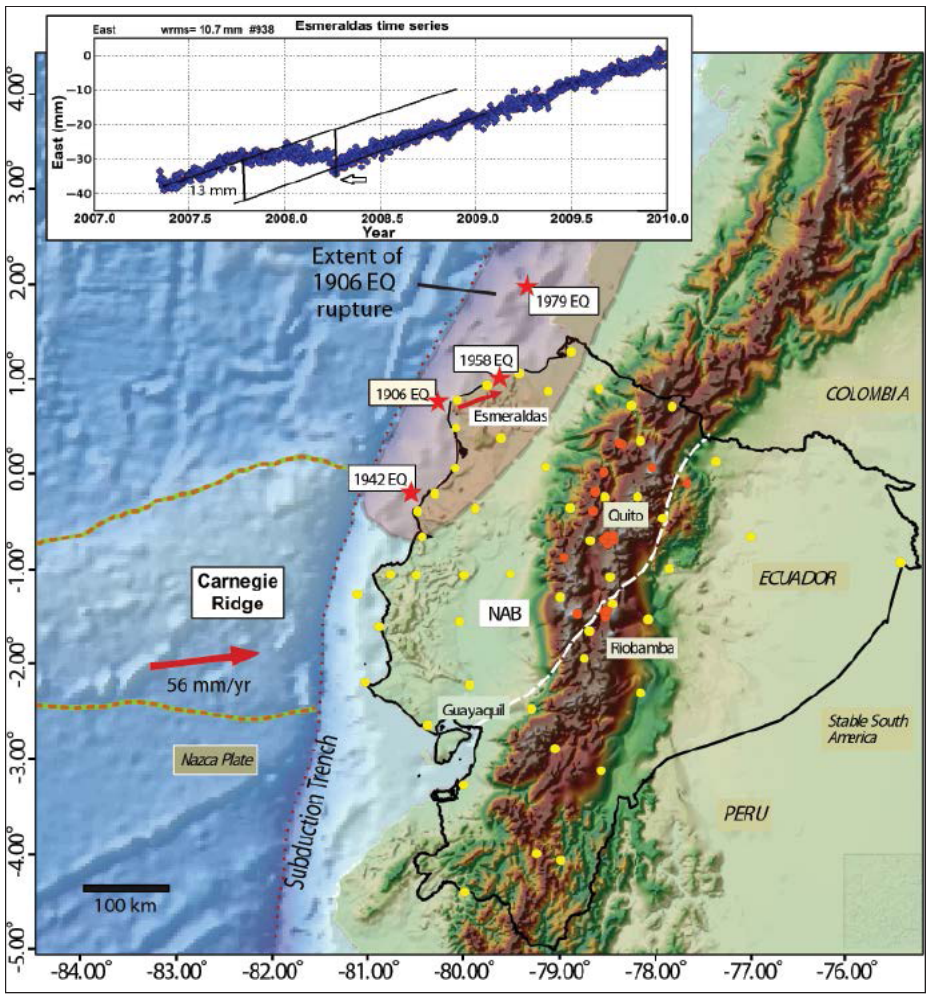


*Fig. 1. Map of the northwestern margin of South America, the North Andean Block (NAB) boundary in Ecuador (delimited by the dashed white line), the hypocenters of the major subduction earthquakes (EQ) that have occurred in the past 100 years (red stars), and the 2-kilometer-high Carnegie Ridge, which lies astride the Nazca plate and the subduction trench. The inset displays a plot of the Esmeraldas CGPS time series with the slow slip event of 2008 occurring over 4 months (indicated by the box), with a maximum horizontal displacement of 13 millimeters to the west (represented by the arrow). Yellow dots are continuous GPS (CGPS) stations for monitoring tectonics; orange dots are CGPS stations for monitoring volcanics. The convergence rate of the Nazca plate toward South America is 56 millimeters per year (large red arrow), with a vector of N83°E [*Kendrick et al., *2003]. The small red arrow at Esmeraldas represents the station's velocity of 19 millimeters per year in a N70°E direction with respect to stable South America.*

Volcanic Unrest in Europe and Latin America (VUELCO) projects. IGEPN is also deploying 60 permanent broadband seismometers and 80 accelerometers.

The data from these new networks complement existing short-period seismic and sparse GPS instrumentation. Before the installation of these networks, only campaign GPS sites, such as the Central and South America GPS Geodesy project in the 1990s [*Kellogg et al.,* 1989; *Trenkamp et al.,* 2002], had existed; now there are permanent geodetic baselines. CGPS networks also monitor 11 volcanoes, including the now-erupting Tungurahua and others with elevated hazard.

With the help of IRD, a data center was set up within IGEPN where CGPS data are processed using GAMIT/GLOBK, a comprehensive GPS analysis software [*Herring et al.,* 2010].

### *First Slow Slip Event Registered*

Over the past decade, episodic slow slip events along subduction zones have been documented. Understanding of their role in the seismic cycle budget, while not well constrained, is improving as a result of the combination of CGPS and seismic observations. The first CGPS site along Ecuador's coast was installed in 2007 at Esmeraldas. The station velocity is 19 millimeters per year in a N70° direction with respect to stable South America.

The first slow slip event registered by the Esmeraldas CGPS occurred in mid-2008 along Ecuador's subduction zone, landward of the 1906 megathrust epicenter. The slow slip event lasted approximately 4 months and involved a 13-millimeter horizontal displacement westward, the direction opposite to the interseismic velocity (Figure 1, inset). In addition, in 2010 a slow slip event synchronous to a seismic swarm was recorded by several CGPS stations around the La Plata Island seismic nest, near the subduction interface [*Vallée et al.,* 2013].

### *Objectives of the CGPS Network*

Both tectonic and volcanic investigations and monitoring are being addressed. Data derived from the national CGPS network are being applied to obtain a better image of interplate coupling along the subduction zone interface by modeling CGPS station velocities, to record episodic slow slip events along the coastal margin and determine how these events play a role in the regional seismic cycle, and to process high-rate data from CGPS stations along the coastal margin in real time to rapidly determine slip and rupture lengths for subduction earthquakes of magnitude > 7.

The network data will also be used to model the kinematics of the North Andean Block, an escape tectonic microplate, which is delimited by a strike-slip fault system that permits movement to the northeast (i.e., the free face) [*Pennington,* 1981; *Egbue and Kellogg,* 2010] and which concentrates deformation between the subducting margin and the South American craton, and the associated faults that delimit the North Andean Block. In addition, researchers plan to combine CGPS, tiltmeter, seismic, and gas data to estimate depths and volume changes of magma storage zones and rates of magma ascent during volcanic unrest and to share CGPS data within the Continuously Operating Caribbean Observational Network (COCONet) project (see *Eos*, *93*(9), 89–90, doi:10.1029/2012EO090001). Together, these studies should help scientists better understand both seismic and volcanic hazards in Ecuador.

### *Acknowledgments*

We thank Mike Lisowski (USGS) and Mark Murray (New Mexico Institute of Mining and Technology) for help with instrumentation and processing, IGEPN colleagues, the Andes du Nord (ADN)-Géoazur project, Pete LaFemina (Penn State) for DEFNODE instruction, UNAVCO, and the Escuela Politécnica Nacional and Secretaría Nacional de Educación Superior, Ciencia, Tecnología e Innovación (SENESCYT) for support.

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