

GPS-01

## **CONTINUOUS GPS MEASUREMENTS IN COLIMA, MEXICO, 1993-2001: IMPLICATIONS FOR THE KINEMATICS OF RIVERA PLATE SUBDUCTION**

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A better understanding of the mechanics of slip along the Rivera plate subduction interface requires observations throughout its seismic cycle. Annual measurements since 1995 in a 25-site GPS network in the states of Colima and Jalisco provide excellent spatial sampling of the coseismic and postseismic displacements associated with the Oct. 9, 1995  $M=8.0$  Colima-Jalisco earthquake (Hutton et al., 2001), but have limited temporal resolution and contain no information about motion prior to the earthquake. We present and discuss implications of new results from continuous GPS measurements collected by INEGI at two sites in the city of Colima during 2/1993-6/2001, including a unique estimate for the rate and direction of strain accumulation during the years prior to the Colima-Jalisco earthquake. Precise 3D coordinate time series determined using GIPSY software yield day-to-day coordinate scatter comparable to other continuously operating GPS receivers. In a North American reference frame, strain accumulated steadily toward the ENE at a rate of  $15\pm 4$  mm/yr from 2/93-10/95. Slip during the 1995 earthquake pointed in the opposite direction, implying that the principal locking zone prior to the earthquake became the principal zone of coseismic rupture. Post-seismic displacements are consistent with logarithmic decay, but are directed to the SSW, implying that most fault afterslip occurred southeast of the principal coseismic rupture zone. By mid-1997, the cumulative postseismic slip was two-thirds of the coseismic slip. Since mid-1997, the Colima GPS site has exhibited steady SSW-directed strain accumulation at a rate equal to only one-fifth that exhibited prior to the 1995 earthquake. We speculate that the slower rate results from a superposition of interseismic and postseismic processes that include relocking of parts of the subduction interface, deep afterslip, viscoelastic rebound in the lower crust and upper mantle, and a largely decayed poroelastic response.

GPS-02

## **CONTINUOUS GPS DATA IN GUERRERO AND OAXACA: A PRELIMINARY REPORT**

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Eight permanent stations in the states of Guerrero and Oaxaca have been operated by the Seismology Department at UNAM for a period of from 1-3 years. Although the velocities are not well constrained for the sites operating less than one year, we observe some interesting trends.

Data quality for these sites is good. Statistical analyses demonstrate that errors obtained for the estimates of position are within the acceptable range for GPS data. We observe deviations in daily position estimates from a yearly mean position of from 4-6 mm for the north component, 5-7 mm for the east component, and 9-13 mm for the vertical component.

Two inboard sites, IGUALA and YAUTEPEC are both located south of the deforming volcanic axis but show very different horizontal and vertical motions. The horizontal motion of Yautepec, with respect to stable North America, is less than the uncertainties and we therefore suggest that the motion of this site is not distinct from that of the North American plate. The direction of motion is rotated slightly counterclockwise from the expected direction. We also see rapid subsidence at this site, perhaps due to aquifer depletion which could account for the difference between the observed and expected directions. Iguala, with less than one year of data, exhibits velocities and directions of motion inconsistent with those expected. However, the short time series gives us little confidence in these data.

Four coastal sites, ACAPULCO, CAYACO, HUATULCO, and ZIHUATENEJO exhibit very similar motions despite the fact that these sites, with the exception of Cayaco, have operated for barely one year. The horizontal motions, with respect to a fixed North American plate, are in the direction predicted (approximately 33 degrees clockwise of north) but with only about 40% of the predicted plate rate. This verifies, to first order, the predicted degree of coupling between the North American and Cocos plates. The vertical motions may imply something about the existence of the Guerrero seismic gap. Acapulco and Cayaco, within the Guerrero gap are subsiding at 13.5mm/yr while just outside the gap, Zihuatenejo has a vertical motion equal to the uncertainties and therefore essentially no vertical motion. Further south and well away from the Guerrero gap, Huatulco is experiencing uplift of 11.3 mm/yr.

Longer time series will provide better estimates of both horizontal and vertical velocities as well as a continuous record of crustal deformation during this interseismic portion of the seismic cycle.

GPS-03

## **DEFORMATION IN THE COLIMA-JALISCO REGION FROM MIXED-MODE GPS MEASUREMENTS: EVIDENCE FOR RE-LOCKING OF THE RIVERA PLATE SUBDUCTION INTERFACE**

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We report evidence for relocking of the shallow regions of the Rivera plate subduction interface following a 1.5-2 year period of postseismic adjustment following the  $M=8.0$ , Oct. 9, 1995 Colima-Jalisco earthquake. Annual and semi-continuous GPS measurements between March, 1998 and March of 2001 in a 25-site geodetic network spanning Colima and Jalisco yield site displacements are best fit by elastic half-space models that combine frictional relocking of the subduction interface above depths of 16 km with slow downdip afterslip beneath the coast at depths of 16-25 km. GPS coordinate time series for near-coastal sites display a gradual transition during 1997 from deformation that was dominated by postseismic fault afterslip to deformation dominated by strain accumulation. Modeling results also suggest that the southern Colima graben represents an important upper crustal discontinuity, with the only two geodetic sites SE of the graben exhibiting significantly different behavior than sites farther to the northwest.

Results from 3D finite element modeling of the Colima-Jalisco region and Rivera plate subduction zone allowing for realistic poroelastic and viscoelastic responses to the coseismic load and realistic crustal properties will also be described.

GPS-04

**OBSERVACIONES PRELIMINARES DE LA DEFORMACIÓN INTERSÍSMICA A LO LARGO DE LA COSTA DE GUERRERO USANDO DATOS DE GPS**

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Con el propósito de entender mejor los procesos de deformación intersísmica que ocurren en una zona de subducción, y el comportamiento en la interfase de dicha zona, se ha establecido en el estado de Guerrero, México, una red de monitoreo GPS. Ésta red esta compuesta actualmente de 21 estaciones temporales y 4 estaciones permanentes distribuidas a lo largo y ancho de la franja de deformación. Este proyecto involucra trabajo de investigadores y estudiantes de la UNAM así como investigadores de la Universidad de Colorado, en Boulder.

Desde 1992 a la fecha se han efectuado cuatro campañas GPS. Los datos adquiridos a partir de ellas así como los provenientes de una estación permanente que empezó a funcionar hace 4 años muestran la distribución temporal del desplazamiento intersísmico, además de la existencia de un evento lento en 1998. Hay evidencia preliminar que apunta hacia la subsistencia de un cambio del régimen sismotectónico en diferentes secciones de la zona conocida como “la brecha sísmica de Guerrero”.

Además de describir los aspectos temporales del desplazamiento intersísmico planeamos discutir los primeros resultados de modelación mostrando la extensión y la cantidad de acoplamiento en la falla de subducción.

GPS-05

**SILENT SLIP EVENT IN NW GUERRERO SEISMIC GAP, MEXICO**

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Aseismic slip events seem to be rather common than exceptional in subduction zones. Unfortunately episodic silent slips are normally overlooked by traditional geodetic surveys. Strain and tilt instrumentation or continuous GPS, gravity or tide gage observations are needed to reveal the duration and spatial development of episodic creep processes. Recent accurate and continuous GPS monitoring commenced detecting of slow events of this type with different amplitude and duration. For instance in Japan (Ozawa *et al.*, 2001) and Cascadia (Dragert *et al.*, 2001). Continuous GPS record at Cayaco located in the middle of the NW Guerrero seismic gap (CAYA GPS station has been operating since January 1997) shows a general long-term tendency of NE slow inland motion of the site, which is in agreement with a hypothesis

of the interseismically coupled plate interface in the gap. Nevertheless over a period of several months during early 1998 the CAYA GPS record revealed a static displacement of 2 mm east, 26 mm south and 16 mm up. A number of possible mechanisms generating this anomalous static displacement were examined. Those are: monument instability, gravitational slumping, groundwater variations, changes in GPS equipment and the reference frame, coseismic slip from background seismicity. All these factors were rejected with a high confidence as the source of the anomalous displacement signal at CAYA. Different interface slip models can simulate a surface deformation that fit the observed anomaly. One of the plausible models accounts this static crustal deformation for a result of slow transient slip on the lower boundary of the subduction seismogenic zone in Guerrero. Moment release estimates for this silent slip event is equivalent to the earthquake of Mw~6.5-6.8. This event does not have any clear relationship with previous large earthquakes on the Mexican subduction zone.

GPS-06

**FAULT PROPERTIES AND SEISMIC HAZARD IN THE GUERRERO GAP**

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Geodetic data from the Guerrero gap include level lines, campaign and continuous GPS, long-baseline tilt and tide gauge measurements. These data indicate that the subduction interface is currently locked between the Guerrero coast and the mid-America trench, and that transient motion in 1998 resulted from an aseismic slip event on the subduction interface. The aseismic slip event propagated along strike of the subduction interface, slightly down-dip of the locked portion of the fault. The anomalous slip behavior was similar to two other aseismic slip events seen in Japan [Ozawa *et al.*, 2001] and Cascadia [Dragert *et al.*, 2001]. Modeling of time-dependent friction on faults suggests that aseismic slip events can occur without generating seismic rupture if fault frictional properties are velocity strengthening (i.e., friction increases with increasing slip velocity). This would imply that the portion of the subduction interface that slipped in 1998 will not generate large seismic ruptures in the future. However, the strong locking of the subduction interface up-dip of the slip event, and background seismicity in the locked zone up to magnitude M~5, indicate that friction is velocity-weakening seaward of the coast. Hence, future large earthquakes can be expected on the seaward portion of the subduction interface in the Guerrero gap. The current strain accumulation could generate an event with moment magnitude Mw greater than or equal to 8.0.

GPS-07

**DETERMINACIÓN DE ZONAS DE PELIGRO POR  
INESTABILIDAD DE TALUD EN EL CERRO  
CHIQUEHUIE, DELEGACIÓN GUSTAVO A.  
MADERO, D.F., MEDIANTE TÉCNICAS DE GPS**

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Los habitantes de la colonia La Pastora, ubicada en la ladera poniente del Cerro del Chiquihuite al norte de la Cd. de México, han sido afectados por deslaves de tierra, así como algunos desprendimientos de rocas durante los últimos 3 años. En Abril del 2000 se instalaron 12 puntos de control en la ladera norte del cerro y una estación de referencia en la cima con el fin de dar un seguimiento periodico y cuantificar posibles movimientos diferenciales de la zona de piedemonte. A la fecha se han realizado más de 13 campañas en las que se emplearon técnicas de GPS diferencial para obtener la posición relativa de los puntos de control respecto a la estación de referencia. Con el análisis de las series de tiempo obtenidas es posible caracterizar las zonas de peligro y detectar los lugares más susceptibles a sufrir nuevos deslizamientos. Actualmente es posible observar variaciones de más de 10 cm en algunos de los sitios de medición. Esto sugiere un movimiento diferencial o reacomodo de la zona de piedemonte, posiblemente relacionado con el sistema de fallas reconocido localmente.

GPS-08 CARTEL

**INTERCOMPARACIÓN DE DIFERENTES MÉTODOS  
DE SOLUCIÓN Y SU APLICACIÓN EN EL  
MONITOREO DE DEFORMACIÓN SUPERFICIAL  
EN VOLCANES ACTIVOS MEDIANTE GPS**

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La actividad reciente del volcán Popocatepetl ha modificado sensiblemente la calidad de vida de las poblaciones cercanas. A partir de 1994 se ha integrado una red de 9 estaciones GPS de operación continua con el objetivo de caracterizar la deformación del aparato volcánico y conocer mejor los procesos magmáticos que operan en su interior. Actualmente existe un retraso de 15 a 20 días en la obtención de una solución utilizando posicionamiento mediante órbitas precisas, el cual es necesario para obtener la mejor precisión posible. Por otra parte la solución utilizando órbitas predichas tiene un retraso de aproximadamente 12 horas, lo cual es aún insuficiente para poder realizar un pronóstico a corto plazo. En este trabajo se analiza la comparación en la variación de líneas de base obtenidas a partir de la solución basada en técnicas diferenciales con el de una solución utilizando órbitas precisas. El objetivo que se busca es el de validar metodologías que permitan soluciones más rápidas para poder caracterizar tendencias en la deformación superficial de estructuras volcánicas en intervalos de unas cuantas horas y con un tiempo de respuesta de unos cuantos minutos. El análisis se realizó en dos estaciones de la red DefNet que opera el Laboratorio de Cartografía Digital (<http://cardi.igeofcu.unam.mx>) instaladas en el volcán Popocatepetl con una serie de tiempo de 90 días y utilizando únicamente observaciones de una sola frecuencia (L1). Los resultados muestran una tendencia similar en la línea base, haciendo factible su utilización para la obtención de un elemento útil en la toma de decisiones para las autoridades de protección civil.