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CENTRAL AND SOUTH AMERICA GPS GEODESY - CASA UNO

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Abstract. In January 1988, scientists from over 25 organizations in 13 countries and territories cooperated in the largest Global Positioning System (GPS) campaign in the world to date (Table 1). 43 GPS receivers collected approximately 590 station-days of data in American Samoa, Australia, Canada, Colombia, Costa Rica, Ecuador, New Zealand, Norway, Panama, Sweden, United States, West Germany, and Venezuela. The experiment was entitled CASA UNO, an acronym for Central and South America -- and uno is the Spanish word for one, designating first epoch measurements. The CASA UNO experiment was the first civilian effort implementing a global GPS satellite tracking network.

Scientific goals of the project include measurement of strain in the northern Andes, measurement of subduction rates for the Cocos and Nazca plates beneath Central and South America, and measurement of relative motion between the Caribbean plate and South America. A second set of measurements are planned in 1991 (CASA DOS), and should provide preliminary estimates of crustal deformation and plate motion rates in the region. The CASA series of experiments are intended to be carried out over at least one decade.

Introduction

Precise geodetic measurements with the Global Positioning System are now possible that allow determination of plate motion and crustal deformation rates within a short (several year) time span [e.g., Beutler et al., 1987; Tralli and Dixon, 1988; Dong and Bock, 1989]. High quality geodetic data can yield constraints on plate motion models, behavior at plate boundaries, and intraplate deformation. For example, measurements along a convergent plate boundary can elucidate the degree to which plate motion is episodic and associated with infrequent, large earthquakes, or steady state and aseismic. The degree of aseismic slip is particularly relevant to understanding "seismic gaps". The assumption of plate rigidity is a first-order approximation that encounters some exceptions in oceanic crust [Weissel et al., 1980; Stein and Okal, 1978] and numerous exceptions in weaker, more heterogeneous continental crust [Jordan, 1975; Dixon et al., 1985]. Strain may be spread continuously across a broad zone, or be confined to subparallel zones separated by more rigid microplates.

The CASA program is directed toward the following specific objectives [Kellogg et al., 1989]: 1) Obtain baseline measurements between several Pacific islands on the Cocos and Nazca plate and Colombia and Middle America that, when compared with future observations, will monitor subduction rates across the trenches and spreading rates across the Galapagos Rise; 2) Establish a survey network across the South Caribbean deformed belt that will demonstrate whether or not Caribbean crust is being subducted aseismically beneath the North Andes; 3) Obtain baseline measurements across the Romeral, Santa-Marta, and Bocono-East Andean fault systems that will eventually determine strain distribution across the North Andean continental margin; 4) Obtain elevation measurements to determine whether the northern Andes are still rising, as suggested by uplifted Pliocene-Quaternary terraces; 5) Co-locate Doppler and GPS to improve the frame tie between World Geodetic System (WGS) '72 and WGS '84 reference systems in this region.

The CASA Network and 1988 Measurements

The geometry of the CASA UNO GPS network is shown in Figure 1 [Kellogg et al., 1989]. All 25 sites are marked by concrete monuments and imbedded stainless steel markers surrounded by several reference markers. The geodetic agencies of Colombia, Costa Rica, Ecuador, Panama, and Venezuela are currently surveying the sites into their national first-order geodetic networks.

One of the most exciting results anticipated after the second GPS occupation of these sites is the first direct measurement of the convergence rates for rapidly subducting trenches. Colombia trench-crossing baselines were measured from Malpelo Island to Tumaco (390 km), Cali (570 km), Pasto (570 km), and Quito, Ecuador (580 km), and from Galapagos to Tumaco (1170 km). Convergence rates across the Middle America trench will be measured from Cocos Island to Liberia (540 km), Limon (620 km), and Farfan (870 km).

The 1988 measurements were divided into three five-day sessions [Neilan et al., 1989]. Receivers at Malpelo Island (Colombia), Panama, and Costa Rica remained fixed for all three sessions, as did all of the receivers at the tracking sites (see below). During the first session from January 18 to 22, 9 hour observations were made in Jerusalen (near Quito), Tumaco, Pasto, Mocoa, La Palma, and Cali, as well as at the fixed sites. In the second session from January 25 to 29, 7.5 hour observations were made at the fixed sites and at Galapagos, Jerusalen, Tumaco, Cali, Bogota, Villavicencio, and Bucaramanga. In the third session, February 1 to 5, 7.5 hour measurements were made at the fixed sites and Quito, Bogota, San Andres Island, Monteria, Cartagena, Bucaramanga, and Valledupar. The five Venezuelan sites were observed in four two-day and two three-day discontinuous 6 hour sessions.

Approximately 212 days of GPS data were collected with 16 TI-4100 receivers in the Northern Andes and Central America. Only two days of data were lost due to receiver failure. A D-series Water Vapor Radiometer (WVR) recorded data for three days at Tumaco. Two D-series WVR's in Liberia and Limon, Costa Rica and one R-series WVR in Panama collected data for 19 days during the experiment. An additional 378 days of GPS data were collected with 25 TI-4100 receivers and 2 new ROGUE receivers in Europe, North America, and the Pacific. GPS data recovery rates were better than 90% in Central and South America, and about 75% in the worldwide tracking network.

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TABLE 1. CASA UNO Participants

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Experiment Manager	
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Venezuelan Andes GPS Project	
Hermann Drewes, Christopher Reigber, K. Stuber, H. Tremel	Deutsches Geodatisches Forschungsinstitut, Munich, West Germany
O. Chourio	Direccion de Cartografia Nacional, Caracas, Venezuela
Heinz Henneberg, Melvin Hoyer	La Universidad del Zulia, Maracaibo, Venezuela
S. Rekkedal	Statens Kartverk, Honefoss, Norway
North Andes and Western Caribbean GPS Projects	
James N. Kellogg	Univ. of S. Carolina, Columbia, SC
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James Stowell	University NAVSTAR Consortium, Boulder, CO
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Orlando Nino, Sergio Camargo M., Benjamin Fernandez	Instituto Geografico Agustin Codazzi, Bogota, Colombia
Hugh N. Caddess	Inter-American Geodetic Survey, San Antonio, TX
Brian R. Tallman	Defense Mapping Agency HTC/GSGS, Washington, DC
Kenneth Barger,	Inter-American Geodetic Survey, Panama City, Panama,
Thomas Hughes,	San Jose, Costa Rica,
Leonard Leos,	Bogota, Colombia,
Vernon Perdue	Quito, Ecuador
Anibal Salazar, Jaime Mora V.	Instituto Geografico Militar, Quito, Ecuador
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Extended Fiducial Network / Equipment Support	
Bill Melbourne	Jet Propulsion Lab., Pasadena, CA
Gerald L. Mader	Nat. Geod. Survey, Rockville, MD
Robert Schutz	Center for Space Res., Austin, TX
Bob Russman	Defense Map. Agency, Wash., D.C.
William H. Prescott	U. S. Geological Survey, Menlo Park, CA,
George Williams	U.S.G.S., Reston, VA
John Hannah	Dept. Surveys and Land Information, New Zealand
Roger Merrell	Texas Highway Department, TX
Russell Crooks	FAA, American Samoa
Jim Clynch	Applied Research Laboratory, University of Texas, Austin, TX
Josef Popelar	EMR, Canada

The Global Tracking Network

One of the challenges of the CASA experiments is that many of the scientific goals require measurement of long (>100 km) and in some cases very long (>1000 km) baselines. GPS errors generally increase with increasing baseline length, and the main reason is uncertainties in the ephemerides of the GPS satellites at the time of observation. Typically, this effect is handled by making GPS observations at a few sites whose positions are well known by an independent technique such as very long baseline interferometry (e.g, Dixon et al., 1985). These "fiducial" sites then define the reference frame of the observations. In many previous GPS experiments, VLBI sites in the U.S. were adequate for this purpose, even for some experiments outside the continental U.S., for example, in the northern Caribbean (Dixon et al., 1990*a*) and the Gulf of California, Mexico (Dixon et al., 1990*b*). However, the accuracies of the satellite ephemerides based on a U.S.-only fiducial network degrade by the time the satellites are over South America.

Covariance analyses performed by Freymueller et al. [1986], Wu et al. [1988] and Freymueller and Golombek [1988] suggested a significant improvement in the accuracy of GPS orbits and CASA UNO baselines with the use of an extended tracking network. These predictions led to the implementation of a network (Figure 2) [Neilan et al., 1989] of GPS receivers at Black Birch Observatory, New Zealand; Pago Pago, American Samoa; Kokee Park, Hawaii; and at NASA's Deep Space Network (DSN) station in Canberra, Australia, to supplement existing tracking stations at Richmond, Florida; Westford, Massachusetts; Mojave, California; Yellowknife, Canada; Tromso, Norway; Onsala, Sweden; and Wettzell, West Germany. The impact of using various subsets of this tracking network as well as a global network on baseline repeatability in the CASA region was studied by Kornreich Wolf et al. [this issue] and Freymueller and Kellogg [this issue]. These results indicate significant advantages to the global tracking network approach, giving repeatability of about 5 mm plus two parts in 10^8 for horizontal components on baselines in the CASA region up to 1000 km in length.

Schutz et al. [this issue] use data from the extended global network to investigate the accuracy of the GPS satellite orbit estimates. They compare predicted versus observed orbits over 1 to 2 week periods, and demonstrate the existence of unmodelled forces affecting satellites in orbital planes that experience eclipses. By investigating GPS baseline repeatability and differences from VLBI or satellite laser ranging solutions with the extended global tracking network, Schutz et al. [this issue] suggest that precision and accuracy of the CASA UNO results are in the range 1-2 parts in 10^8 for horizontal components. Lichten [this issue] uses data from CASA UNO to show that orbit accuracies for the GPS satellites can be determined to significantly better than 1 meter, and suggests that with refinements in analytical techniques and models, orbit accuracies in the range 10-20 cm may be possible in the future.

Data Processing and Additional Results

Utilizing the STARPREP/GASP algorithm and DMA/NSWC precise satellite ephemerides and clock states, Malys and Jensen [this issue] obtained geodetic-quality point positions on a world-wide basis from GPS data collected over a period of a few hours. Geodetic point positioning is necessary for mapping control and the estimation of transformation parameters between a World Geodetic System (e.g., WGS 84) and a local or regional geodetic datum.

Using software developed at the University of Berne, Drewes et al. [1989] calculated a multistation solution for the

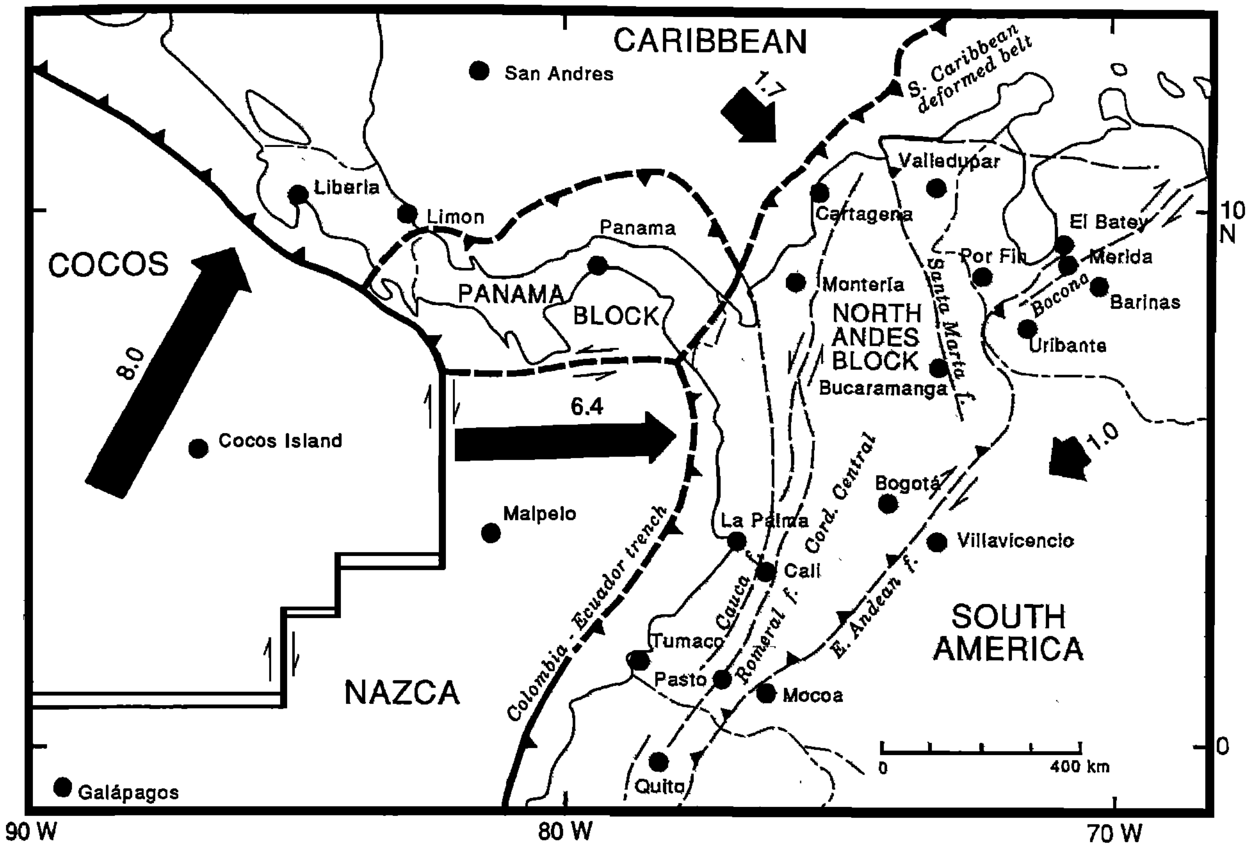

Fig. 1. CASA UNO Site Locations of the first GPS network in the North Andes and Central America [Kellogg et al., 1989]. Present-day plate motions (bold arrows) relative to the North Andean block (Cocos plate motion relative to Caribbean) showing average slip rates (cm/yr) during the last 5 to 10 m.y. after Minster and Jordan [1978]. GPS sites are noted by black circles.

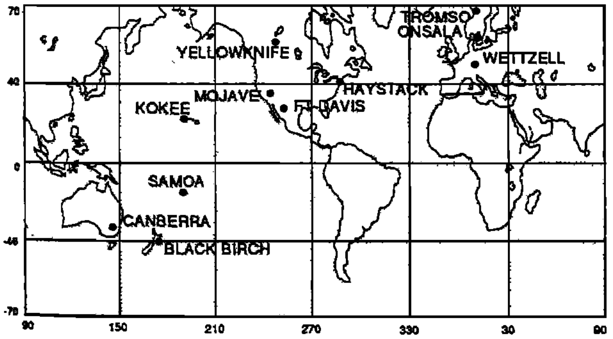

Fig. 2. Extended fiducial network for 1988 CASA UNO campaign [Neilan et al., 1989].

Venezuelan network. After final cycle slip analysis and ambiguity resolution, they report formal errors at the cm level or better for baselines of up to 250 km in length.

Kellogg et al. [this issue] report initial results from a number of baselines in the northern Andes, and use day-to-day repeatability coupled with geophysical estimates of rates across specific tectonic boundaries to predict the likelihood of detecting significant change in the first repeat experiment, CASA DOS, currently scheduled for 1991.

One of the major error sources for GPS baseline estimates, and probably the dominant error source for short to medium length (several 10's to several hundred km) baselines is uncertainty in the correction for the variable wet tropospheric path delay. Most of the CASA sites did not have water vapor radiometers, which can provide independent calibration of the wet path delay. Dixon and Kornreich Wolf [this issue] review several methods for correcting this error, and demonstrate that stochastic estimation techniques provide very good results in the absence of independent calibration. Thus, lack of WVR's at most of the CASA sites should not degrade the results to any significant degree if this analytical approach is employed.

Lindquister et al. [this issue] investigate the effects of single day and multi day arc strategies on baseline precision and accuracy. Their assessment is based on daily repeatability (a measure of precision) and comparison to VLBI (a measure of accuracy) of GPS results for the Mojave-Owens Valley (245 km) and Mojave-Hat Creek (729 km) baselines. For the horizontal components of these baselines, repeatability is in the range 2-4 mm, while agreement with VLBI is at the centimeter level, using either constrained single-day or multi-day arc solutions.

The enormous size of the CASA UNO data set means that highly automated data processing techniques are desirable. For GPS, loss of "lock" on the carrier phase signal and resulting cycle slips has been a troublesome aspect of data processing, requiring time consuming analyst intervention. Blewitt [this issue] describes an algorithm for automated detection and correction of carrier phase cycle slips. The algorithm can be employed when both carrier phase and P-code pseudorange data are recorded, as they were with the TI-4100 receivers used in the CASA UNO experiment, and achieved a 99% success rate on a tested subset of the CASA UNO data.

The second CASA campaign (CASA DOS) is scheduled for January 1991. The enthusiasm shown by the twenty-five cooperating organizations from Latin America, North America, Europe, and the Pacific ensures continued international support for GPS geodesy in this tectonically active part of the world.

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