CARIBBEAN GEODYNAMIC RESEARCH STUDIES — AN INITIAL NOTE

P. Done
Department of Land Surveying
The University of the West Indies
St. Augustine
Republic of Trinidad & Tobago

Summary

The National Aeronautics and Space Administration (NASA) and the Jet Propulsion Laboratory (JPL) are mounting a programme of geodynamic research studies in the Caribbean. The Department of Land Surveying in the University of the West Indies is to participate in the Trinidad sector.

The general background to this important geodynamic programme is described, together with a discussion of the methodology.

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GEODYNAMICS: PLATE TECTONICS

Geodynamic studies are concerned with the forces and structural movements occuring within the Earth and with their effect on its outer crust. The basic theoretical framework is that of plate tectonics, which describes the solid outer 70—100 km or so of the Earth — the lithosphere — as being broken up into some 20 comparatively rigid blocks known as plates, as shown in figure 1. The concept of plate motion is a central feature of tectonic theory. Convection currents in the viscous mantle beneath the crust result in driving forces which cause the plates to move, mainly in the horizontal plane. At midocean ridges, the plates move away from one another, and the hot rising mantle material creates newly formed oceanic lithosphere. Where plates collide at oceanic margins, in so-called convergence zones, the dense oceanic crust of one plate may be "subducted" into the mantle, whilst the continental crust remains at the surface.

Although the motions are slow, the effects are very impressive. Steep mountain ranges, great earthquakes and significant volcanic activity tend to be associated with convergence zones, or plate boundaries where the plates are moving laterally with respect to each other — for example, as at the notorious San Andreas fault in California.

Estimates of the rates of such movement have historically been based on averages over long periods of time, essentially provided by major changes, occuring over hundreds or thousands of years, in geomagnetic patterns and anomalies. At present, comparatively little is known of variations in plate velocity over shorter periods. In many cases movements may be, for example, periodic, or episodic; tidal characteristics may also be exhibited. Velocities vary regionally and indeed locally; relative movements of up to 1 cm per month are believed to occur but they are usually not greater than 10 cm a year. Obviously geodynamic studies of such plate movements could be expected to lead to a greater understanding of linked phenomena such as earthquakes and volcanoes and, it may be hoped, to an enhanced prediction capability; the Mexican and Colombian tragedies of 1985 emphasise the desirability and importance of reliable forecasting techniques.

TERRESTRIAL MEASUREMENTS USING SPACE AND SATELLITE TECHNIQUES

The rationale behind tectonic monitoring is not the establishment of absolute coordinates but rather the detection of the small changes in relative position. For this purpose, modern geodetic techniques based on relative rather than absolute positioning are particularly well suited provided that adequate precision is attainable.

Geodetic baselines can now be measured to unprecedented precisions — to a few centimetres over several hundred kilometres — using two different techniques, Very Long Baseline Interferometry (VLBI) and Satellite Laser Ranging (SLR) [1, 2, 3, 4]. However, these two methods, despite the developments of somewhat more mobile units, cannot at present provide the basis for an economical measuring programme designed to provide observations suitable for plate

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tectonic or geodynamic studies. Such observations should be dense both in terms of both topographic and temp distribution. The availability of much more readily transportable, highly precise receivers based on the Global Positi ing System (GPS) has therefore transformed the position as regards the monitoring of tectonic plate movements; now becoming possible to make the necessarily large number of observations comparatively conveniently and exp tiously [5].

At present the GPS system is at the development and evaluation stage. Full deployment of the 18 satellite c stellation is expected by the end of this decade and all indications are that, although designed and operated primaril a navigational aid, it will be capable of yielding highly accurate positional accuracies for geodetic purposes. Two ma sources of systematic error in baseline measurement using this system are known to be uncertainties in the ep merides of the GPS satellite orbits and the effects of tropospheric water vapour on signal travel times. Assessment these separate effects is critically important; the NASA/JPL Geodynamics Programme [5, 6, 7] is concentrating on t aspect in its initial stages, with the aim of reducing the present strong dependence of baseline errors on baseline leng The aim in 1985 was to achieve subdecimeter performance three-dimensionally over distances up to 400 km. Sub quently, it is envisaged that vector accuracies at the 1—3 cm level should be attainable by 1989.

Available GPS instrumentation to be evaluated and compared consists of SERIES—X, MACROMETER and TI4100 receiver. It is intended to assess relative performance and field operability in conjunction with radiometers o a two year period, and to select the most appropriate satellite receiver system for full Caribbean deployment in 1987.

REDUCTION OF SYSTEMATIC ERROR

Reduction of orbital uncertainties is based upon the concept of a "super" control, or "fiducial" VLBI netwo This consists of the POLARIS stations of the National Geodetic Survey (NGS) which are resurveyed periodically VLBI (figure 2). GPS orbit uncertainties are reduced by carrying out simultaneous GPS observations at the kno (fiducial) points (figure 3). It is realised that for Caribbean use in particular the usefulness of the NGS network fiducial purposes would be considerably enhanced by provision of a further station in S. America [8], enabling t network physically to cover the area of interest, rather than a reliance having to be placed on extended extrapolation.

The water vapour effect can be corrected for by use of data from water vapour radiometers (WVR's); these are used derive the additional sky brightness along the quasar line of sight due to microwave emission from free water molecul and are reduced by algorithm [9]. New designs of WVR are expected to be so effective as to ensure that this error is longer dominant in the overall budget.

OBSERVATION STRATEGIES

Measurements connected with investigations of inter-plate and intra-plate kinematics should be capable of resolvi movements of the order of 1 cm/year [6]. The measurement frequency would depend on instrumental accuracy a the nature of the tectonic regime in the area concerned: it is considered that a measurement interval of two to fo months should normally suffice. Site selection is obviously important; for inter-plate movement studies this involves t unconditional positioning of the two ends of baseline on separate plates. This may not always be straightforward in a region in which boundaries are somewhat ill-determined or diffuse. In general, station establishment procedure is bas on a philosophy somewhat different from that in traditional land surveying: an ideal site for tectonic GPS measuremen should have low topographic relief and no visible evidence, or known history of, recent volcanic or tectonic activit Relatively flat areas of geologically old, sedimentary rocks are particularly desirable.

Inter-plate observation is the main type of geodynamic investigation, but it may be noted that there are othe aimed at quantification of post-seismic movements and seafloor spreading.

Post-seismic movements made after earthquakes are most valuable if instrument deployment can be effected withi a day or two of the event. The frequency of such measurements should then be of the order of hours.

A third type of procedure is necessitated by seafloor spreading activity. This phenomenon characteristically take place in areas some distance from continental land masses or islands. A seabed geodetic capability is required in thi context, with the concomitant harnessing of marine acoustic positioning techniques.

PROPOSED INVESTIGATIONS

The Caribbean area is tectonically very complex: figure 4 shows a map in which the figures are average velocities i cm/yr. It is believed that rates of plate motion are not particularly high, but the five plates in general interact in a variety of ways; subduction, convergence, lateral movement and spreading all occur. Obviously, most plate boundaries are located beneath the sea, and island sites take on added significance. The geographical size and compactness of the region is such that a relatively small number of GPS observation stations can yield significant data relevant to the study of crustal deformation, convergence, and general mantle rheology.

Over the next two or three years, a large number of baselines (indicated provisionally in figure 5) are to be observed so as to measure regional deformations:

(a) studies of the northern Caribbean plate boundary. Here the baselines are relatively short;
(b) observation of relatively long baselines across the major plate boundaries;
(c) baselines from Central America and Providencia and San Andreas to Cocos Island.

Provisional sites from which GPS observations are to be made are listed in the Annex.

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ANNEX. PROPOSED SITES FOR GPS OBSERVATIONS

	LATITUDE(N)	LONGITUDE(W)
Dominican Republic (3)		
1. Cabo Rojo	17°55′	71°39′
2. Santo Domingo, South Coast	18°30′	69°54′
3. Puerta Plata, North Coast	19°47′	70°35′
Haiti (4)		
1. Mole St. Nicolas	19°50′	73°20′
2. Cap Haitien	19°45′	72°10′
3. Isle de la Tortue	20°03′	72° 50′
4. Saint Marc	19°07′	72°42′
Puerto Rico (U.S.A.)	18°00′ to 18°30′	66°00′ to 67°00′

Grand Turk, Bahamas (U.K.)	21°27′	71°09′
Guantanamo Bay, Cuba	19°55′	75°10′
Jamaica (2)		
1. North Coast — Discovery Bay	18°24′	77°00′
2. South Coast — Portland Ridge	17°45′	77°09′
St. Croix (U.S.)	17°45′	64°45′
Cayman Island (U.K.)	19°20′	81°15′
Anegada Island (U.K.)	18°55′	64°10′
Swan Island (Honduras)	17°25′	83°55′
Ecuador (2)		
1. Quito	0°15′S	78°30′
2. Galapagos	0°50′S	89°30′
Costa Rica (2)		
1. Cocos Island	5°32′	87°03′
2. Limon	10°00′	83°02′
Colombia (4)		
1. Isla de Malpelo (Pacific)	3°59′	81°36′
2. Isla de Providencia (Caribbean)	13°20′	81°23′
3. Isla de San Andres (Caribbean)	12°33′	81°43′
4. Villavicencio	4°10′	73°40′
Guatemala		
Rubelsànto	16°00′	90°27′
Honduras (2)		
1. La Mesa/San Pedro Sula	15°30′	87°55′
2. Olanchita	15°30′	86°35′
Trinidad	10°10′	61°15′
Barbados	13°10′	59°30′
Venezuela (17)		
1. Aves Island	15°42′	63°38′
2. El Baul	7°00′	67°30′
3. Cuidad Bolivar	8°10′	63°30′
4. Maturin	9°45′	63°10′
5. Margarita	11°00′	63°55′
6. San Jose	10°00′	72°23′
7. Caripito	10°08′	63°05′

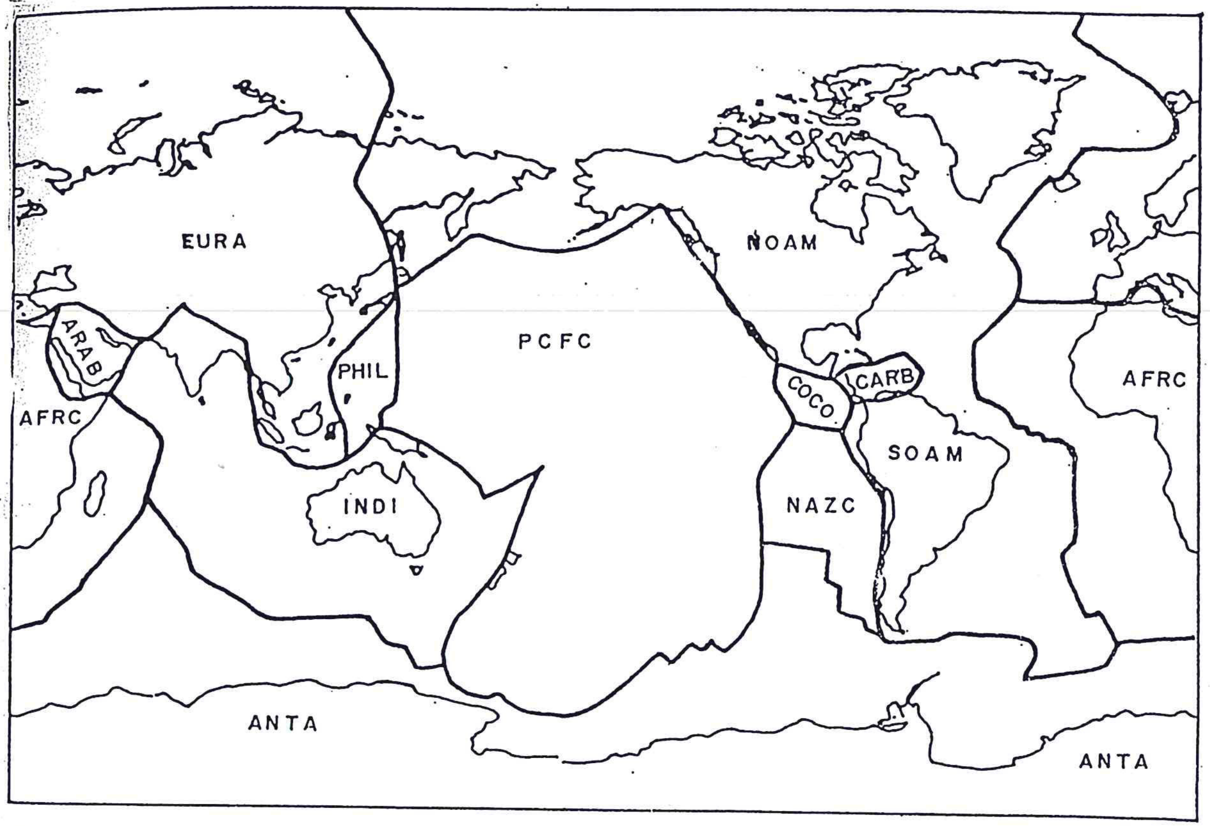

Fig. 1 MAJOR TECTONIC PLATES.

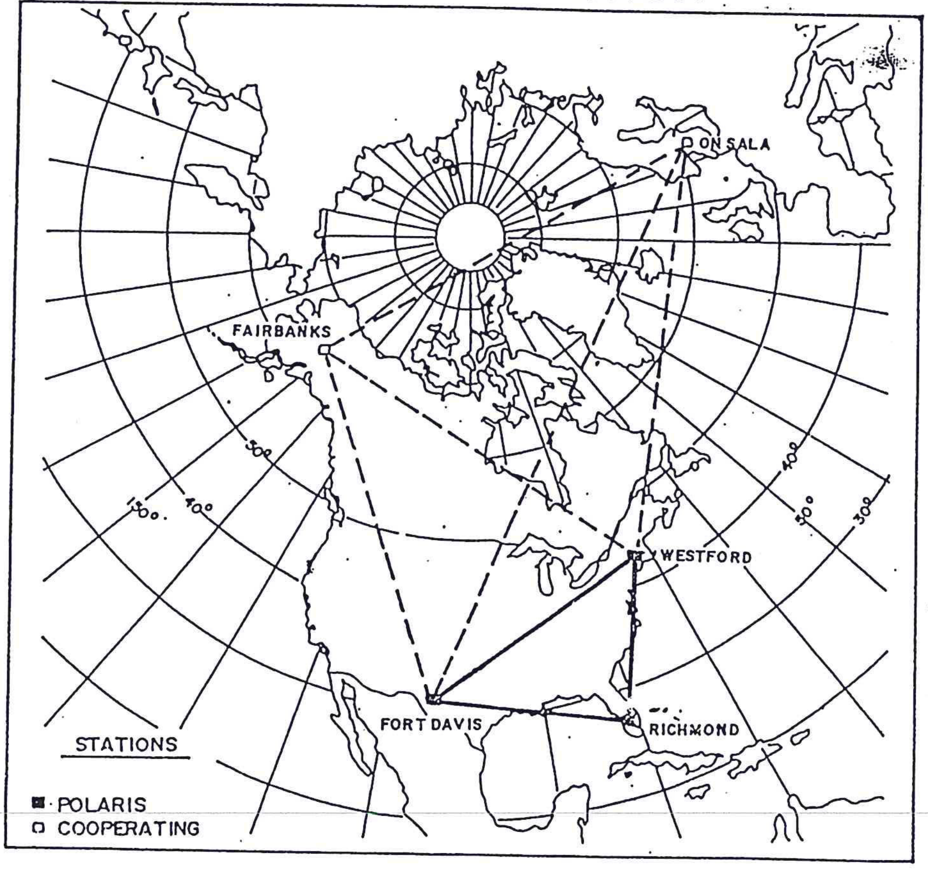

Figure 2. "POLARIS" V.L.B.I. STATIONS

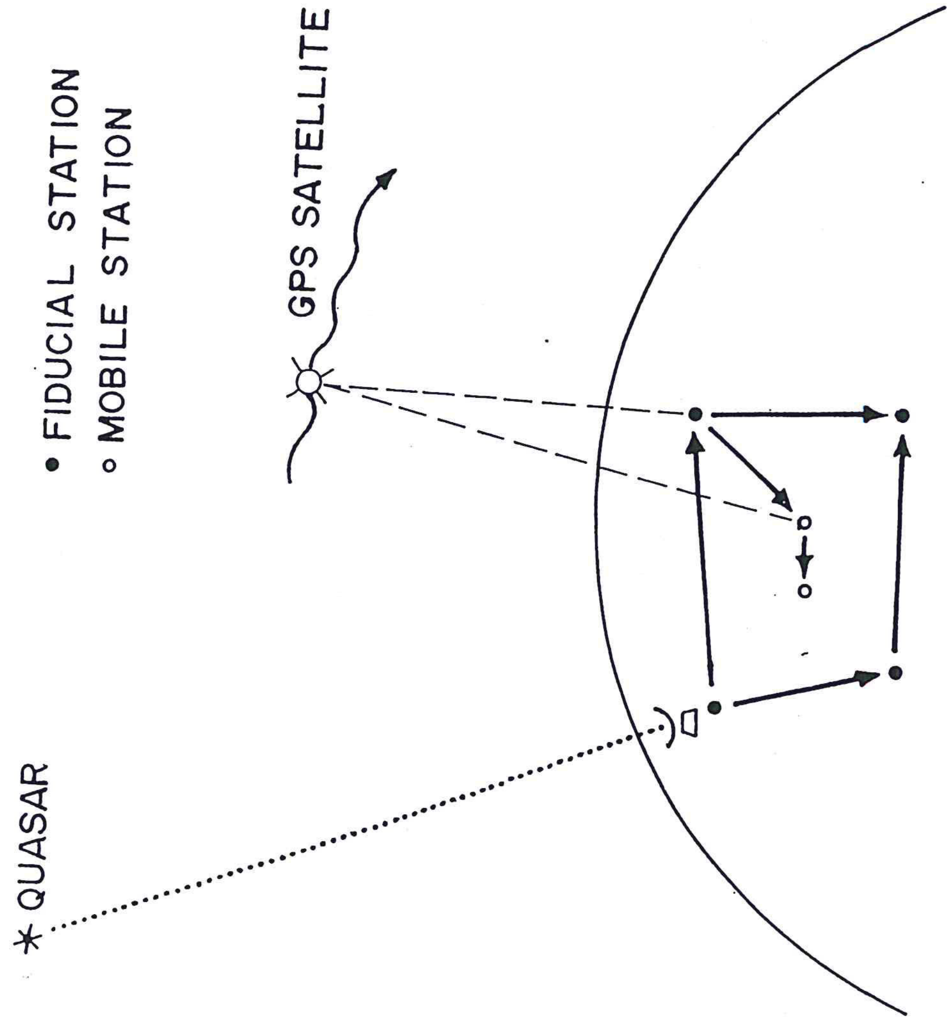

Figure 3. THE 'FIDUCIAL' CONCEPT

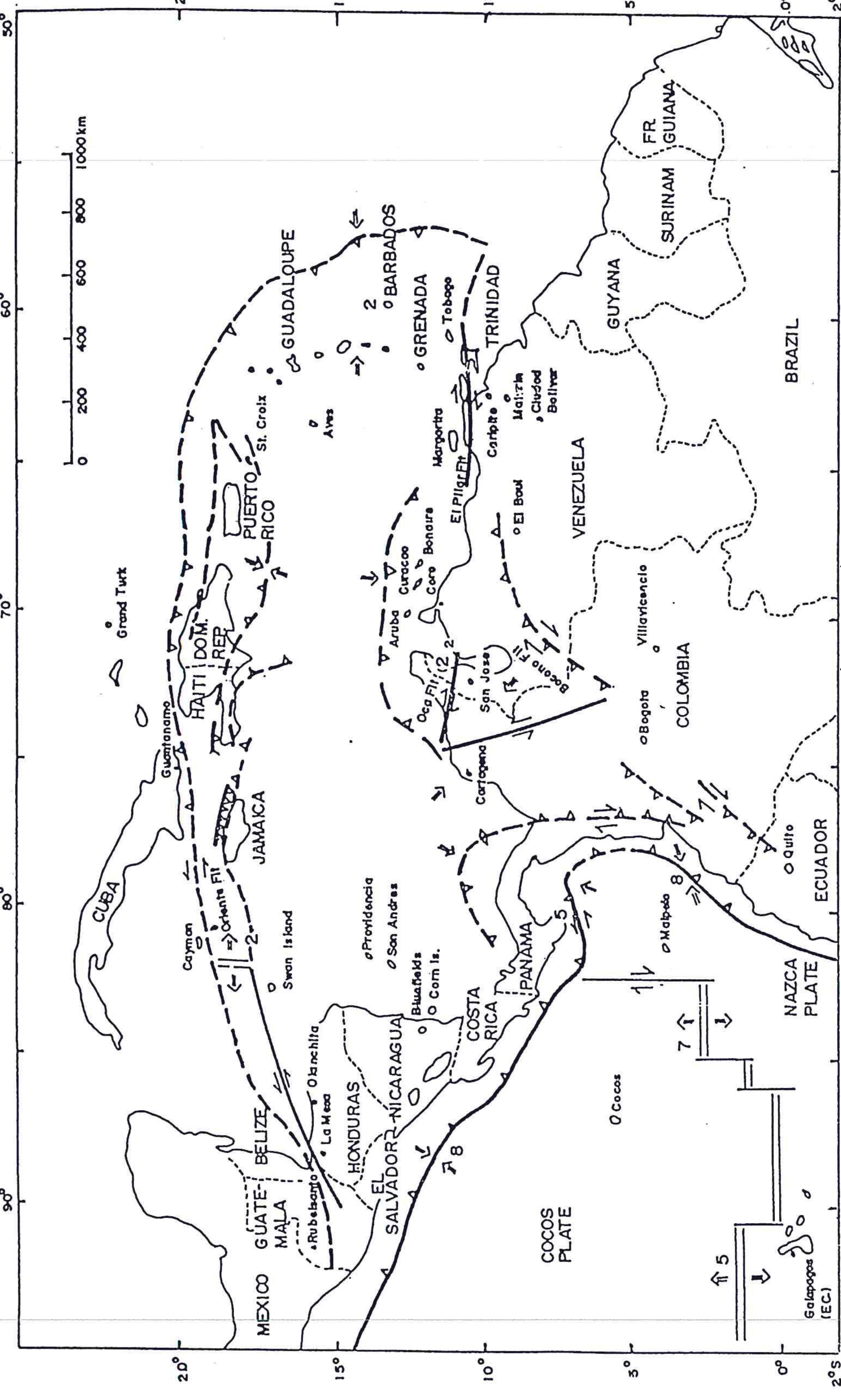

Figure 4. TECTONIC MAP OF THE CARRIBBEAN REGION
(Figures are average velocities in cm/year.)

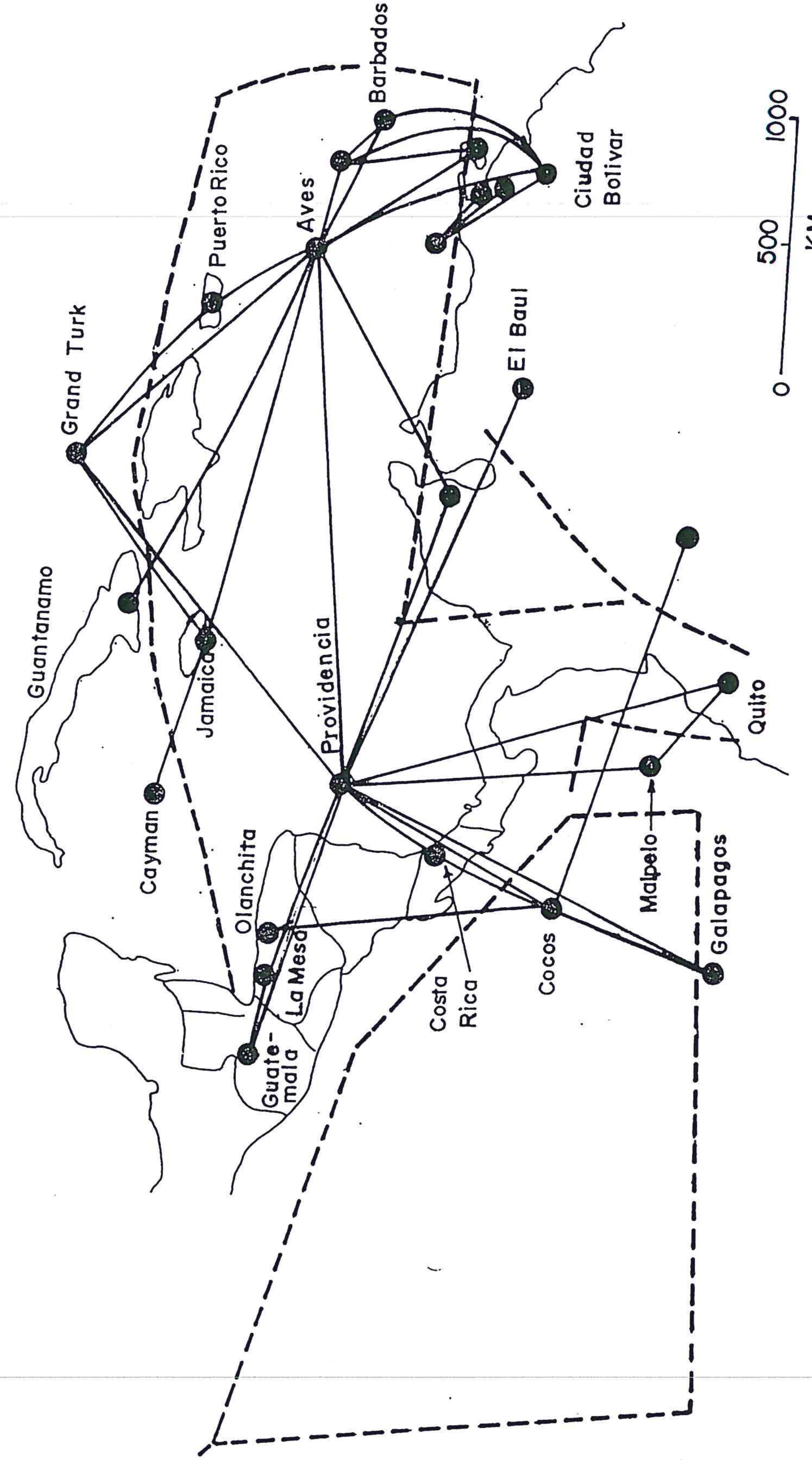

Figure 5 PROPOSED MAJOR CARRIBBEAN BASELINES.