CDSA: A New Seismological Data Center for the French Lesser Antilles

Mendy Bengoubou-Valerius,[1,2] Sara Bazin,[2] Didier Bertil,[3] François Beauducel,[2] and Alexis Bosson[2]

INTRODUCTION

The Lesser Antilles, in the eastern Caribbean, is prone to a large seismic hazard due to the subduction of the Atlantic lithosphere beneath the Caribbean plate, with a slow convergence rate of 2 cm/yr (Demets *et al.* 2000; Mann *et al.* 2002). The largest historical earthquake in the region, in 1843 between Guadeloupe and Antigua, had a magnitude estimate of 7.5 to 8 (Bernard and Lambert 1988), but historical seismicity covers too short a period of time (less than three and one-half centuries) to estimate the recurrence time of strong events or their plausible maximum magnitude. The latest destructive earthquake, Les Saintes in Guadeloupe in 2004, had a magnitude 6.3 (Institut de Physique du Globe de Paris 2004; Bertil *et al.* 2004).

To better understand the regional geodynamics and assess the related seismic hazard, we must improve our knowledge and our understanding of the area's present seismicity. Since the 1950s, several regional research institutes have monitored local seismicity. The Institut de Physique du Globe de Paris (IPGP) and Bureau de Recherches Géologiques et Minières (BRGM) have set up various seismological and accelerometric arrays to monitor the French islands of Guadeloupe and Martinique. As a consequence, several large datasets with very different formats and time spans exist, scattered among several sites. Providing a more integrated database for the seismicity of the Lesser Antilles arc was the primary motivation for creating the French Antilles Seismological Data Base (Centre de Données Sismologiques des Antilles, CDSA).

The aim of this paper is to introduce the newly created CDSA and to illustrate its capacity for improving our knowledge of the region's seismicity. In the first part of this study, we present the various arrays, waveform databases, and seismicity catalogs used by the CDSA. In the second part, we present and discuss new results provided by the CDSA database, particularly in terms of variations of seismic intensity along the arc, geometry of the subducting slab, and peak acceleration attenuation law.

1. Université des Antilles et de la Guyane
2. Institut de Physique du Globe de Paris
3. Bureau de Recherches Géologiques et Minières

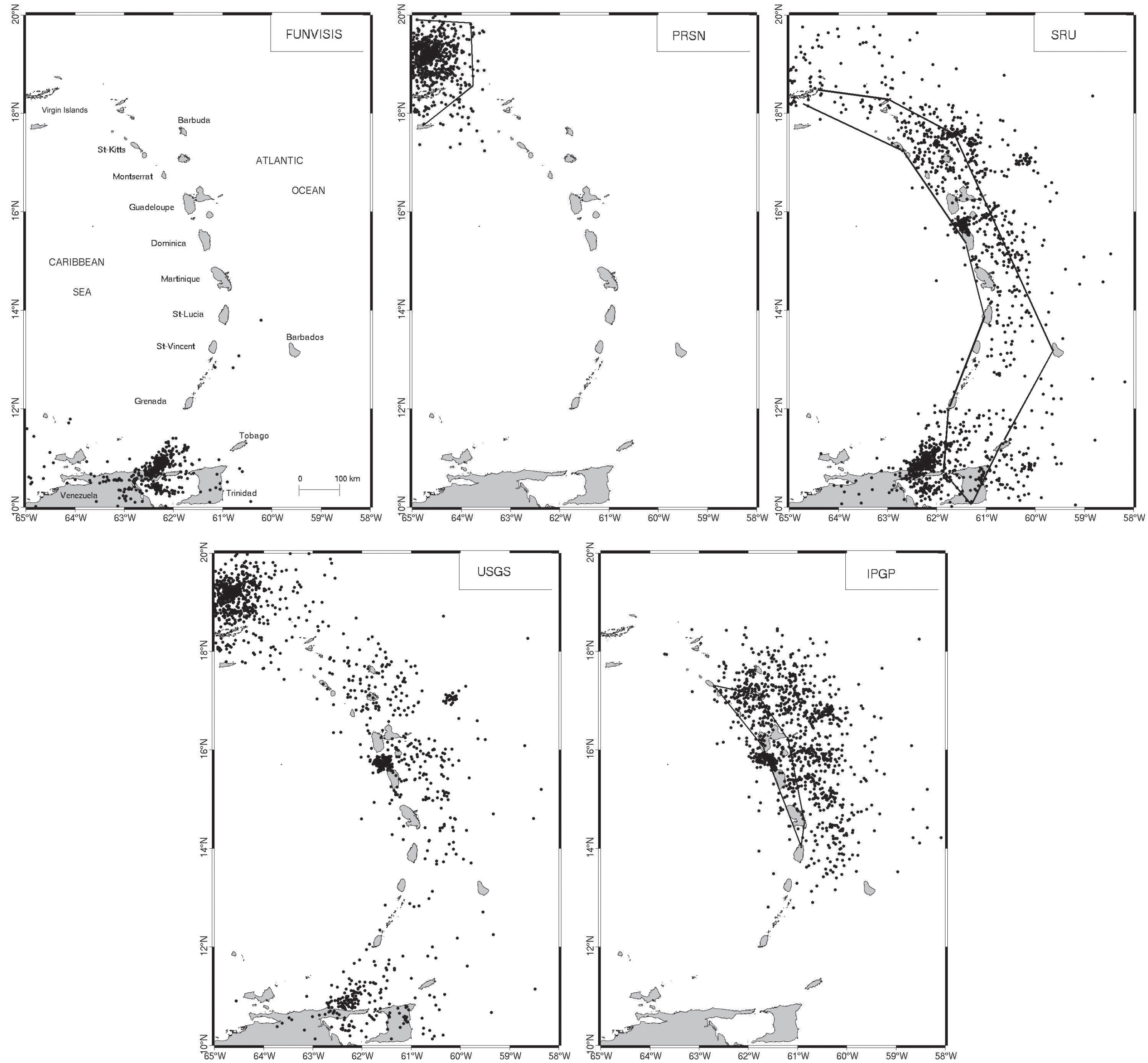
WEAK- AND STRONG-MOTION REGIONAL ARRAYS

The study area is located at the eastern border of the Caribbean plate between 10° and 20° N and 58° and 65° W. It is bounded to the north by the Puerto Rico trench and to the South by El Pilar fault in Venezuela, and it extends as far west as the Aves Rise. Therefore, it completely covers the Lesser Antilles volcanic arc, the Barbados accretionary prism and the subduction trench. This area spans 1,000 km north to south and 700 km east to west and is much wider than the area covered by the French monitoring network. So far, the French observatories of Guadeloupe and Martinique (OVSG and OVSM) have been able to locate seismic events only within a 300-km radius.

Five institutions (listed in table 1) publish regular seismic catalogs for the Lesser Antilles. Figure 1 presents examples of seismicity during a five-year period from these five catalogs. Each provides complementary information. The Puerto Rico Seismic Network (PRSN) is centered on the island of Puerto Rico, while the Fundacion Venezolana de Investigationes Sismologicas (FUNVISIS) is centered on Venezuela. IPGP

TABLE 1
Sources of Seismic Catalogs for the Lesser Antilles.

Institution	Institution Code
Puerto Rico Seismic Network (PRSN)/ University of Puerto Rico http://redsismica.uprm.edu/	PRSN
Institut de Physique du Globe de Paris (IPGP) http://www.ipgp.jussieu.fr/	OVSG/OVSM
Seismic Research Unit (SRU)/ University of West Indies (UWI) http://www.uwiseismic.com/	SRU
Fundacion Venezolana de Investigationes Sismologicas (FUNVISIS) http://www.funvisis.gob.ve/	FUNVISIS
United State Geological Survey (USGS) http://earthquake.usgs.gov/	USGS

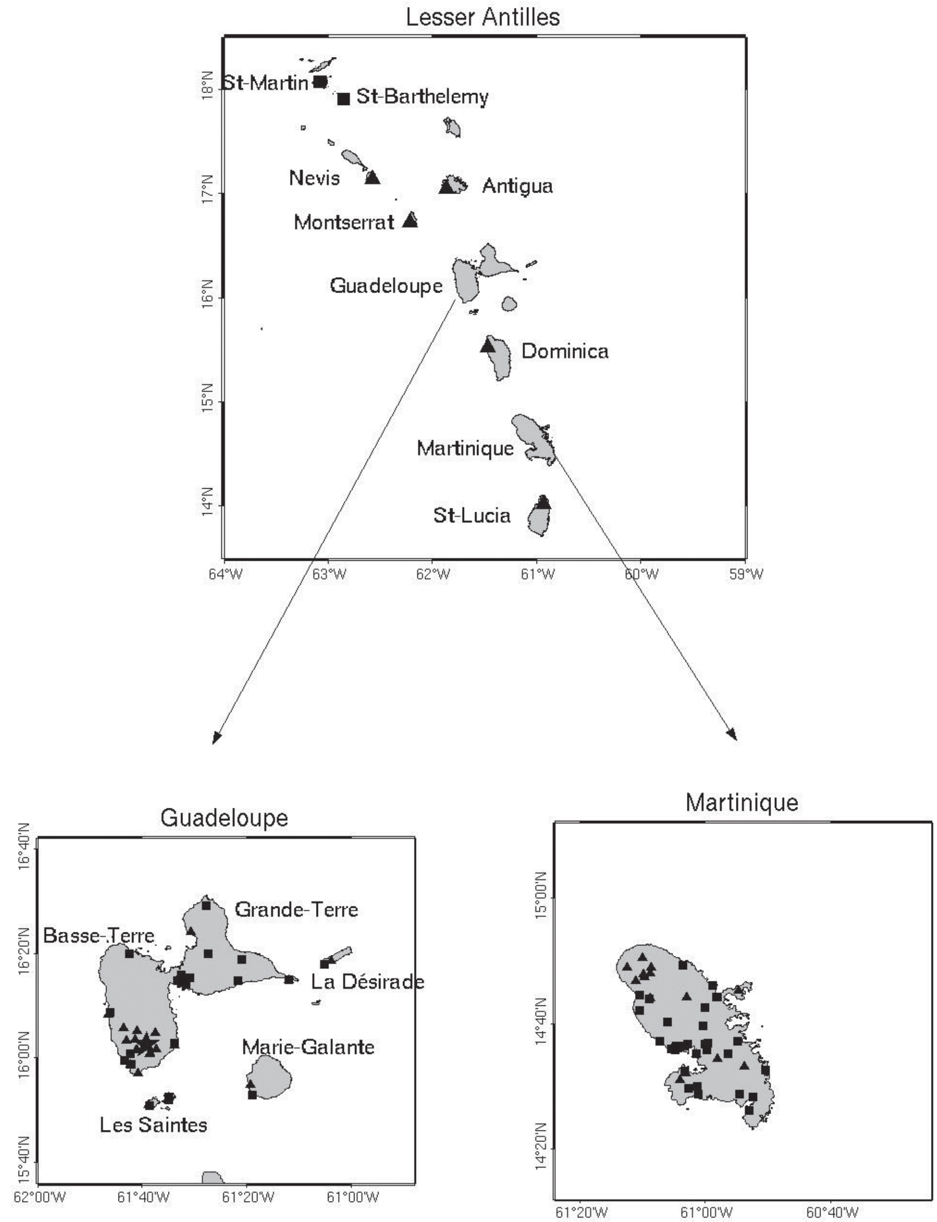


▲ **Figure 1.** Seismicity maps for magnitude > 2.7 from the five regional reports used by CDSA: PRSN, FUNVISIS, SRU, USGS, IPGP. The volcanic arc of the Lesser Antilles is located between the Caribbean Sea and the Atlantic Ocean, resulting from the subduction of the American plate under the Caribbean plate. The polygons show the area covered by each network by linking the outermost stations.

publishes a monthly synthesis from the OVSG and OVSM arrays, which cover the region between Antigua and St. Lucia. The Seismic Research Unit (SRU) array covers the whole arc, but its detection threshold is relatively high. The U.S. Geological Survey (USGS) provides a world seismicity catalog with a detection threshold of magnitude 4 in the Lesser Antilles.

The Eastern Caribbean region is known as a moderate-to-high seismic hazard area (Bernard and Lambert 1988; Tanner and Shedlock 2004). But until the mid-1990s, very little strong-motion data had been recorded. Until now, strong-motion data have not been included in attenuation models for the Lesser Antilles. Regional seismic hazard assessments are based on general attenuation models such as Youngs *et al.* (1997), Sadigh *et al.* (1997), or Ambraseys *et al.* (2005), which are not necessarily suitable for the local tectonic context. Local geology and topography in Martinique and Guadeloupe show large zones where strong amplification of surface ground motions are reported (Gagnepain-Beyneix *et al.* 1995; Castro *et al.* 2003; Lebrun *et al.* 2004).

BRGM installed its first strong-motion array in Guadeloupe in 1977, equipped with SMA-1 Kinemetrics analog instruments. Only one earthquake (16 March 1985, M_w =



▲ **Figure 2.** Station maps used by CDSA in Lesser Antilles, Guadeloupe, and Martinique. Squares indicate accelerometric stations, triangles indicate short-period seismometers, and the star shows the location of the broadband network of Soufriére volcano in Guadeloupe.

6.4 at epicentral distances of more 100 km) was recorded by these stations (Bernard and Lambert 1986). During the past 10 years, several digital accelerometric arrays have been established in the French West Indies. In 1994, BRGM installed the first digital accelerometric network to study site effects in urban areas. The Conseil Général Martinique has instrumented public buildings in Martinique since 1999. IPGP installed 27 permanent stations in Martinique and Guadeloupe from 2001 to 2005 as part of the French Permanent Accelerometric Array (Réseau Accélérométrique Permanent, RAP) and of CDSA. Two of those accelerometers have been installed in St. Martin and St. Barthélemy islands, which are French overseas collectivities or territories in the northern Lesser Antilles arc. Figure 2 shows the spatial distribution of stations, and table 2 describes the arrays. The RAP records are transmitted to the RAP central office (http://www-rap.obs.ujf-grenoble.fr) at the Laboratoire de Géophysique interne et tectonophysique (LGIT) at the Université Joseph Fourier (UJF) in Grenoble (France). All these strong-motion records, which are scattered among three institutions and in various numerical formats, are collected by CDSA.

CDSA DATA PROCESSING

The Centre de Données Sismologiques des Antilles (CDSA) was created to make available on request technical and scientific information about seismic activity in the Lesser Antilles. The Center involves three institutions: the Institut de Physique

TABLE 2
Sources of Seismic Data Used by CDSA. In total, for 2005 the CDSA used 120 stations including 42 short-period stations, 10 broadband stations, and 69 accelerometric stations.

Network Name	Owner institution	Operator	Installation date	Sensors	Station numbers in 2005	Objective
Seismic monitoring network of OVSG	IPGP	OVSG	1950	Short-period	25	Regional and volcanic seismicity survey around Guadeloupe
Broadband volcanic network of OVSG	IPGP	OVSG	2003	Broadband	5	Broadband surveyance of Soufrière Guadeloupe
Permanent accel-erometric network of Guadeloupe	RAP	OVSG	2002	Accelerometer	12	Ground motion observations and estimation of site effects
Accelerometric network of BRGM Guadeloupe	BRGM	BRGM	1994	Accelerometer	6	Site effects studies
CDSA accelerometric network	IPGP BRGM	OVSG	2005	Accelerometer	7	RAP network extension for ground motion observations
"Sismo des Ecoles" network of Guadeloupe	BRGM	BRGM	2003	Short-period	1	Project of seismometer installa-tion in public school
Broadband network of Bouillante Guadeloupe	BRGM	BRGM	2004	Broadband	5	Study the geothermal field of Bouillante
Seismic monitoring network of Martinique	IPGP	OVSM	1950	Short-period	16	Regional and volcanic seismicity survey around Martinique
Permanent accel-erometric network of Martinique	RAP	OVSM	2002	Accelerometer	8	Ground motion observations and site effects estimation
BRGM accelerometric network of Martinique	BRGM	BRGM	1994	Accelerometer	7	Site effects studies
Accelerometric net-work of Conseil Général Martinique	Conseil General Martinique	OVSM	1998	Accelerometer	29	Ground motion estimations in buildings of the Conseil Général

du Globe de Paris (IPGP), which is interested in fundamental research on seismic source and hazard; the Bureau de Recherches Géologiques et Minières (BRGM), which studies seismic hazard and risk; and the Université des Antilles et de la Guyane (UAG), which is involved in geological research in the Lesser Antilles.

CDSA collects all available data from French West Indies arrays, centralizing them into a single database. The data processing consists of several steps:

- creating a unified seismic catalog;
- collecting all available signal records and seismic bulletins;
- calculating a new location; and
- presenting information about the strong motion and the felt seismicity.

Unified Seismic Catalog

CDSA has built a single reference catalog by merging the regional catalogs listed in table 1. A classification for different types of events has been defined: regional, volcanic, indeterminate, quarry blasts, and others (T and sonic waves). When several arrays provide different locations for the same event, the location of the closest array is kept and becomes the reference.

Data Collecting

The next step consists of collecting all available data: waveform records and phase data bulletins. Thanks to various cooperative agreements, the CDSA receives records collected by IPGP and BRGM in the French West Indies, as well as from accelerometric stations of the Conseil Général de Martinique. In table 2, we list the characteristics of the arrays. Figure 2 shows accelerometric, short-period, and broadband stations located in the Lesser Antilles. CDSA also gathers waveforms from one SRU station on St. Lucia (SLW) and from one Montserrat Volcanologic Observatory (MVO) station (MGH) on Montserrat. These waveform records and wave-arrival times are included in the database.

CDSA reduces the heterogeneity of the original recording formats to only two formats: IASPEI-SUDS and SAC. SUDS is used to visualize the data and pick the phase arrival times, because it was already used by the two observatories (OVSG and OVSM) that provide most of the data. SAC was also chosen because it is widely used, mainly for accelerometric data. All the waveforms related to phase picks are included in the database.

The data is validated by suppressing noisy records and by controlling time synchronization. An association process is used to identify each data file with a seismic event listed in the regional reference catalog. For events that are not referenced (teleseismic events, and regional events detected by too few stations to be located), the catalog is completed by adding the first arrival time detected for such events.

New Location

For each event with enough data (more than three stations and four phases), a new location is computed with the HYPOINVERSE-2000 program (Klein 2002) using velocity and ground-motion data. Earthquake focal depths can be as deep as 200 km in the subduction zone. Therefore the location process begins by determining a preliminary epicenter for a set of fixed depths between 0 and 200 km. The solution with the best root mean square (rms) is chosen as the trial hypocenter for definitive location. When epicentral distance for the closest station is greater than 200 km, the best fixed-depth solution is kept. Next, a seismologist manually validates each new location by keeping or rejecting the new solution. We don't keep the new solution if:

- no *S* wave is used for the location of a regional event;
- horizontal error is too large compared to D_{min}, the minimum distance at the closest station (for example, an error more than 15 km for D_{min} > 50 km); and
- D_{min} is more than 500 km.

A 1D velocity model determined by Dorel (1978) is used for the new location. It consists of a three-layer model with *P* velocities of, respectively, 3.5 km/s, 6.0 km/s, and 7.0 km/s, and a mantle velocity of 8.0 km/s. The thicknesses of the three layers are 3, 12, and 15 km. The *P*- to *S*-wave velocity ratio is taken to be 1.76.

Presently, CDSA calculates earthquake magnitude by using the duration form of Lee and Lahr (1975) for velocity records:

$$Md = 2 \log(T) + 0.0035 \times \mathrm{ED} - 0.87,$$

where *T* is the time lag in seconds between *P*-wave arrival time and the end of the *S* coda wave and ED is epicentral distance (km). This magnitude scale has been used by IPGP observatories OVSG and OVSM since their very first seismological bulletins. The correlation between *Md* (IPGP) and M_w or m_b (USGS) is plotted in figure 3. The *Md* magnitudes are shifted by 0.1 to 0.2 below the m_b values for magnitudes above 4.

The reference catalog is regularly updated with CDSA relocation results, except for distant events (greater than 200 km at the closest station). In the latter case, initial source parameters from the closest regional bulletin are kept as the best reference.

Strong Motion and Felt Seismicity

CDSA gathers strong-motion data provided by the French regional three-component accelerometric arrays. Hypocentral distance and peak ground acceleration (PGA) are computed for defining future attenuation laws. PGA is defined here as the maximum value of the two horizontal components for a given record. CDSA includes information about site conditions (rock, soil, or building). Site-effects evaluation is performed by Nakamura's technique (1989) based on the calculation of horizontal-to-vertical component spectral ratios (*H/V*) from ambient noise measurements (Douglas *et al.* 2006). When *H/V* measurements have been made on a station site, they are added to the database.

Information about the felt events is also stored. Observatories OVSG and OVSM list felt earthquakes in Guadeloupe and Martinique, respectively. On average, five to six earthquakes are felt locally every year. Moreover, CDSA collaborates with the French Central Seismology Office (BCSF; http://www.franceseisme.fr) for macroseismic investigation in the French West Indies. In particular, the CDSA team contributed to a BCSF macroseismic investigation that determined EMS98 intensities (European macroseismic scale) for each community of Guadeloupe after the 21 November 2004 Les Saintes earthquake (BCSF 2004).

Database

The CDSA database is managed by postgresSQL. The first dataset introduced in the database covers the period from January 2001 to May 2005. The CDSA seismic catalog provides a list of 11,860 events. Of these, 8,844 (75%) have signal or phase data detected by Guadeloupe and Martinique arrays. Among these, 4,967 (56%) have been relocated by CDSA, 503 (6%) are teleseismic events, and 3,374 (38%) do not have enough records for reliable hypocentral calculations. Accelerometric records exist for 2,260 events (26%).

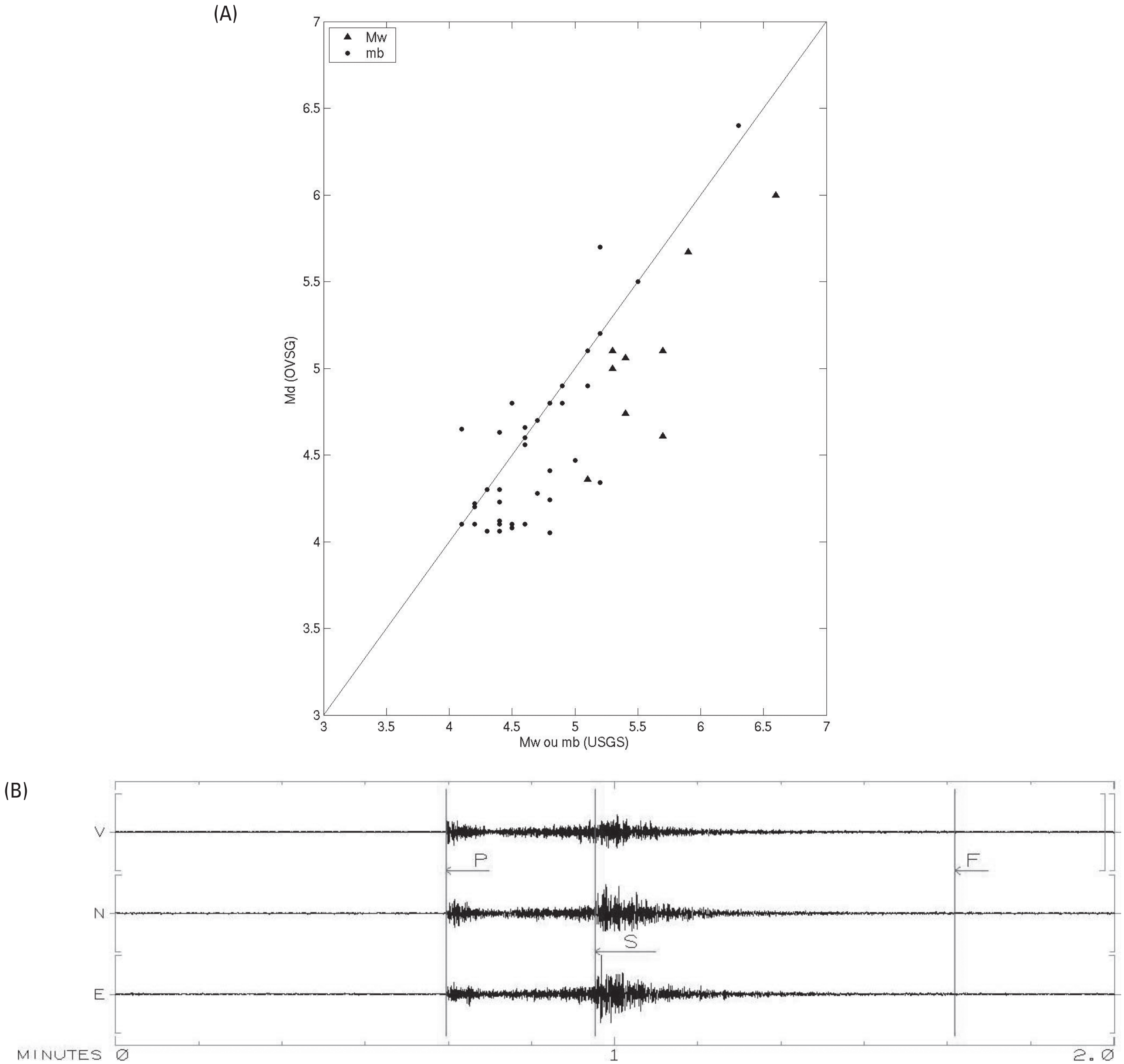
On average, 74% of CDSA locations have a horizontal error less than 5 km, and 78% have less than 10 km of vertical error. Due to errors in the velocity model, we expect that the actual errors are larger. Magnitude thresholds are evaluated from Gutenberg-Richter relations (Gutenberg and Richter 1954). We consider two categories of events: intraslabs (subduction earthquakes with depths > 50 km) and shallow events (depths < 30 km). For the second group, we have eliminated aftershocks of the 21 November 2004 event because the catalog is not complete for this seismic swarm. The magnitude threshold (*Md* = 2.7) is similar for the two types. The *b* values are quite close: *b* = 1.13 (intraslab) and *b* = 1.38 (shallow).

NEW EPICENTRAL LOCATION FROM CDSA

The seismicity of the new CDSA catalog is presented in figure 4. Note that the seismic activity is not distributed homogeneously along the plate border, and two particular regions show a lack of seismicity:

- between the Virgin Islands and St. Kitts (area called Anegada passage), to the north; and
- between St. Lucia and Grenada, to the south.

The USGS seismicity map (figure 1) shows the same two regions, which suggests that the lack of seismicity is not an artifact related to array geometries. To better quantify this heterogeneous seismic activity, we identify three zones defined by latitude: zone A (14.8°–18°), zone B (13.1°–14.8°), and zone C (12°–13.1°). We also consider zone D to the north with a latitude range of 17.8–20° and a longitude range 62–64°W. There aren't enough events in each of these zones to make accurate estimates of the parameter *b* of a Gutenberg-Richter law, so we

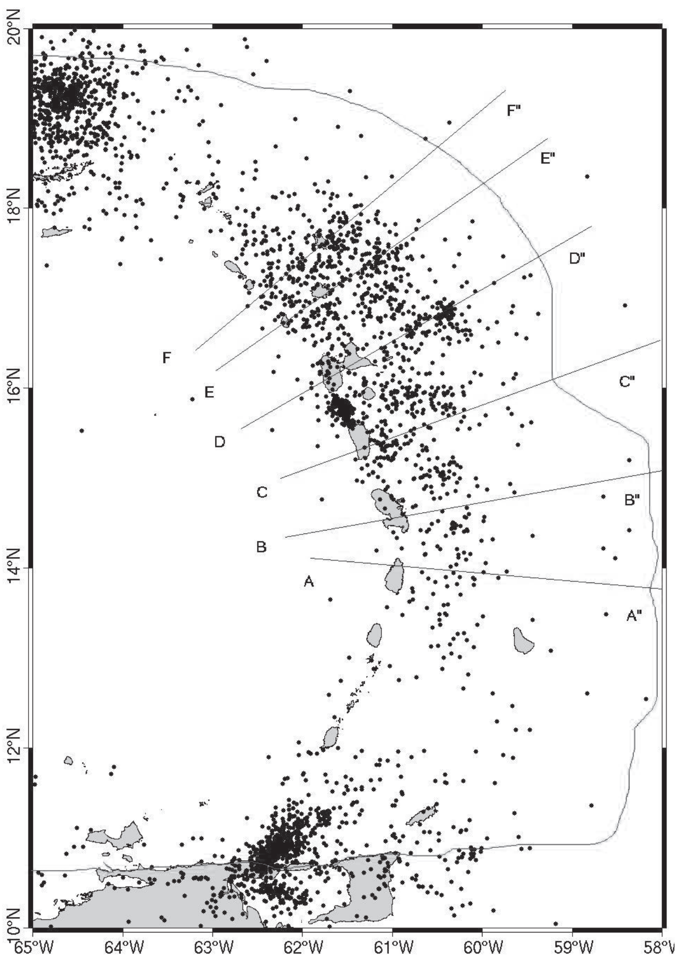


▲ **Figure 3.** (A) Comparison between *Md* (IPGP) used and M_w or m_b (USGS); (B) An example waveform where the *P* and *S* picks and the end of the *S* coda are shown.

followed a simpler approach. We calculate the number of events above magnitude 2.7 and magnitude 3 for the CDSA catalog and above magnitude 4 for the USGS catalog. The results are presented in table 3, together with the observed ratio between the number of small earthquakes (**M** > 2.7 or > 3) and large earthquakes (**M** > 4).

Ratios in zones C and D are twice smaller than in zone A for magnitude cutoff 2.7 and nearly equal for magnitude cutoff 3. Thus, to the first order, zones C and D have the same seismicity behavior as zone A (a factor of 2 might be due to random fluctuations for these small numbers). Zone B, however, shows small-to-large magnitude ratios much larger than does zone A (factor of 4 for magnitude cutoff 3). Therefore, the decrease of large magnitudes in zone B is most probably real, leading to higher *b* values. These results also show that the detection capabilities of the arrays in zones B, C, and D do not seem significantly different than in zone A for **M** > 2.7.

The lower seismic activity observed south of St. Lucia was first reported by Dorel (1981) and Wadge and Shepherd (1984). The authors explained this feature by a lower coupling between the two tectonic plates. Our results provide a finer image of the seismicity by identifying zone B as a low-seismicity area with



▲ **Figure 4.** Seismicity map for magnitude *Md* > 2.7 of CDSA complete catalog. Profiles AA″, BB″, CC″, DD″, EE″, and FF″ indicate the orientations of the cross-sections shown in figure 6. The continuous line represents the oceanic trench.

a lack of moderate earthquakes and zone C as an almost quiescent area. To the north, our study provides evidence for the relative seismic quiescence of area D, for which no explanation has yet been proposed.

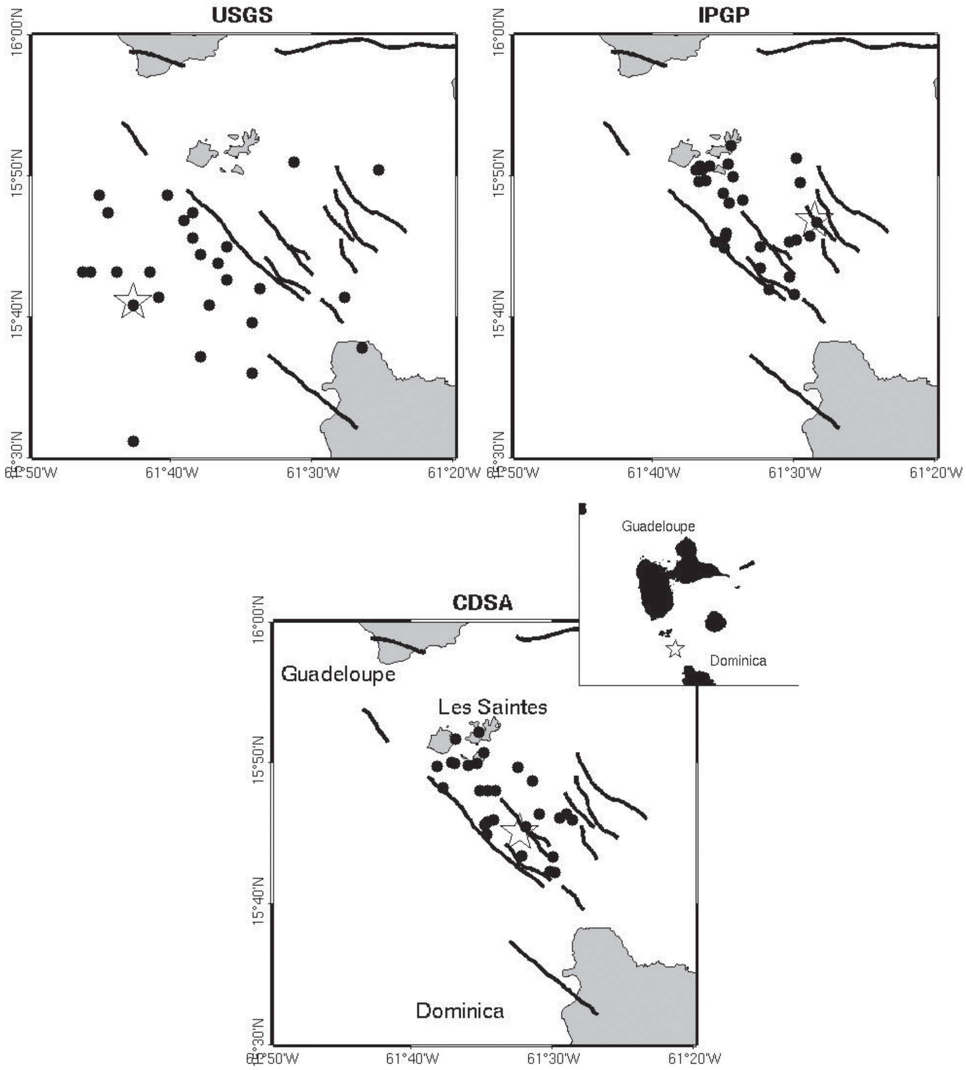
From CDSA data, we can study the relationship between shallow seismicity (between 0 and 50 km) and active faults. The cutoff depth is based on the observed seismicity distribution and is in agreement with Tichelaar and Ruff (1993), who observed that worldwide intraslab earthquakes nearly all occur at depths deeper than 50 km. The shallow seismicity presents the same heterogeneity as for the complete catalog within the same zones. The change from high seismic activity (zone A) to lower activity (B and C) coincides with changes in the active tectonic structures mapped by Feuillet *et al.* (2002) and the deepening of the Barbados accretionary wedge. Interestingly, the quiescent area coincides with the deepest part of the wedge. This correlation might be related to high pore pressure within the sediments, which allows stable aseismic creep or volumetric anelastic strain. We have no explanation at present for the seismicity change from zone A to zone D to the north.

At a more detailed scale, we clearly see the high seismicity of Marie-Galante graben, which is a major active tectonic structure southeast of Guadeloupe (figure 4). Two other dense clusters are visible: one between Guadeloupe and Dominica, which corresponds to the aftershocks of Les Saintes 2004 earthquake; and the other, northeast of Guadeloupe, which corresponds to a seismic swarm in 2001. The latter contains earthquakes of magnitude 3.3–4.8 that occurred between April and July 2001. Christeson *et al.* (2003) proposed that this cluster is located at the intersection of the subducted Barracuda Ridge with a backstop, forming a block of buoyant crust, accreted during the Late Miocene (Bangs *et al.* 2003). We note that the USGS National Earthquake Information Center (NEIC) location from this cluster is shifted by 40 km to the northeast with respect to the CDSA location. The latter appears more in agreement with this geodynamic interpretation.

The improvement of CDSA locations within zone A (close to Guadeloupe and Martinique) allows more detailed study of the area's seismicity. We observe that seismic swarms are more clustered than in the original catalogs. This can be illustrated by the case of Les Saintes 2004 sequence. The 21 November 2004 (M_w = 6.3) earthquake is the most recent destructive event to strike the French West Indies. This shallow earthquake, which occurred south of Les Saintes archipelago between Guadeloupe and Dominica, was followed by numerous aftershocks. We use these data to test CDSA locations and compare them with USGS and IPGP catalogs. Figure 5 shows the location of the mainshock and 28 main aftershocks with magnitudes greater than 4.0, as computed by the three arrays. The swarm detected by the USGS is scattered over 30 km and the mainshock is located 15 km westward. IPGP stations clipped on the mainshock, and only one *S* phase could be picked up on the short-period network. The mainshock is shifted toward the east in comparison to the aftershock swarm. CDSA included accelerometric stations

TABLE 3
Number of events above magnitudes 2.7 and 3 in the CDSA catalog and above magnitude 4 in the USGS catalog, and respective ratios between the two catalogs.

	CDSA (M > 2.7)	CDSA (M > 3)	USGS (M > 4)	CDSA/USGS (M > 2.7)	CDSA/USGS (M > 3)
A(14.8°–18°)	1,021	539	109	13.4	4.9
B(13.1°–14.8°)	106	68	4	26.5	17
C(12°–13.1°)	25	21	4	6.2	5.2
D(17.8°–20°)	98	92	21	4.7	4.4



▲ **Figure 5.** Position of the main shock (21/11/04, Les Saintes event) and the 28 largest aftershocks (with magnitude *Md* > 4) located by different regional networks: USGS, IPGP, and the new catalog. Regional faults of Feuillet (2000) are outlined.

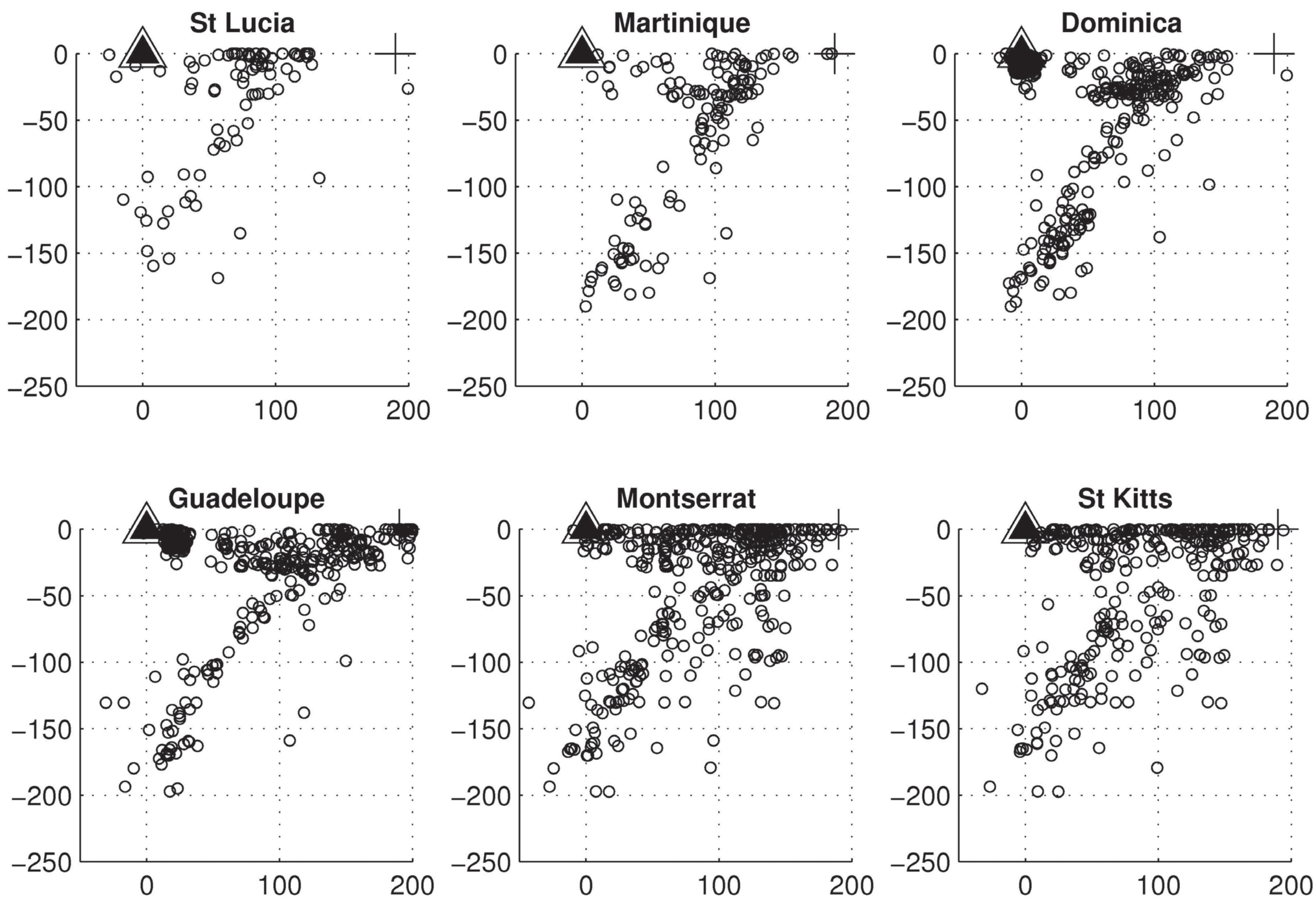
providing good *S* phases and obtained a location error of about 1 km for the mainshock. As a result, the CDSA swarm is less scattered than the others, and the mainshock epicenter is more accurately located within the swarm. The aftershocks are spread within a 25-km-long area, elongated in the NNW–SSE direction and fitting the fault systems mapped by Feuillet (2000).

SPATIAL VARIABILITY OF BENIOFF PLANE DIP ANGLE

The Lesser Antilles subducting plate has quite a complex structure, as described by a few authors who have shown a variable dip angle of the slab along the arc (Dorel 1981; Girardin and Gaulon 1983; Wadge and Shepherd 1984; Girardin *et al.* 1991; Feuillet *et al.* 2002). However, their results significantly differ from each other. For instance, to the north of Antigua, Wadge and Shepherd (1984) find a 50 to 60° dip whereas Dorel (1981) finds 30°, and to the south near St. Vincent, Wadge and Shepherd (1984) find a 45 to 50° dip whereas Dorel (1981) finds 30°. This apparent contradiction results from the small number and/or the large location uncertainties of the events in the catalogs. Others studies have provided evidence for a kink affecting the whole slab at depth, related to a triple junction between the Caribbean and the separated North and South American plates (Wadge and Shepherd 1984).

To investigate the variation of dip angle along the arc inferred from the new CDSA locations, we present vertical cross-sections for six profiles perpendicular to the arc through several active volcanic islands. These are shown in figure 6. The sections are 150 km wide, and the seismicity associated with the subduction slab is clearly observed from 50 to 200 km.

There is no clear dip variation from north to south as a 50° dipping line globally fits the seismic clusters. This contradicts the results of Wadge and Shepherd (1984) because the contour of the mean position of the Benioff zone decreases in slope toward the north. However, for areas corresponding to profiles AA' and FF', the 50° dip angle value differs from the results of Dorel (1981) but agrees with the results of Wadge and



▲ **Figure 6.** Seismicity cross-sections (magnitude > 2.7) for six profiles perpendicular to the arc, through active volcanic islands (AA" to FF" shown in figure 4). The sections are 150 km wide. Triangles on the horizontal axis indicate the active volcanic front. Plus signs show the position of the negative gravity anomaly.

Shepherd (1984). All these results remain preliminary, because only five years of data could be relocated by CDSA.

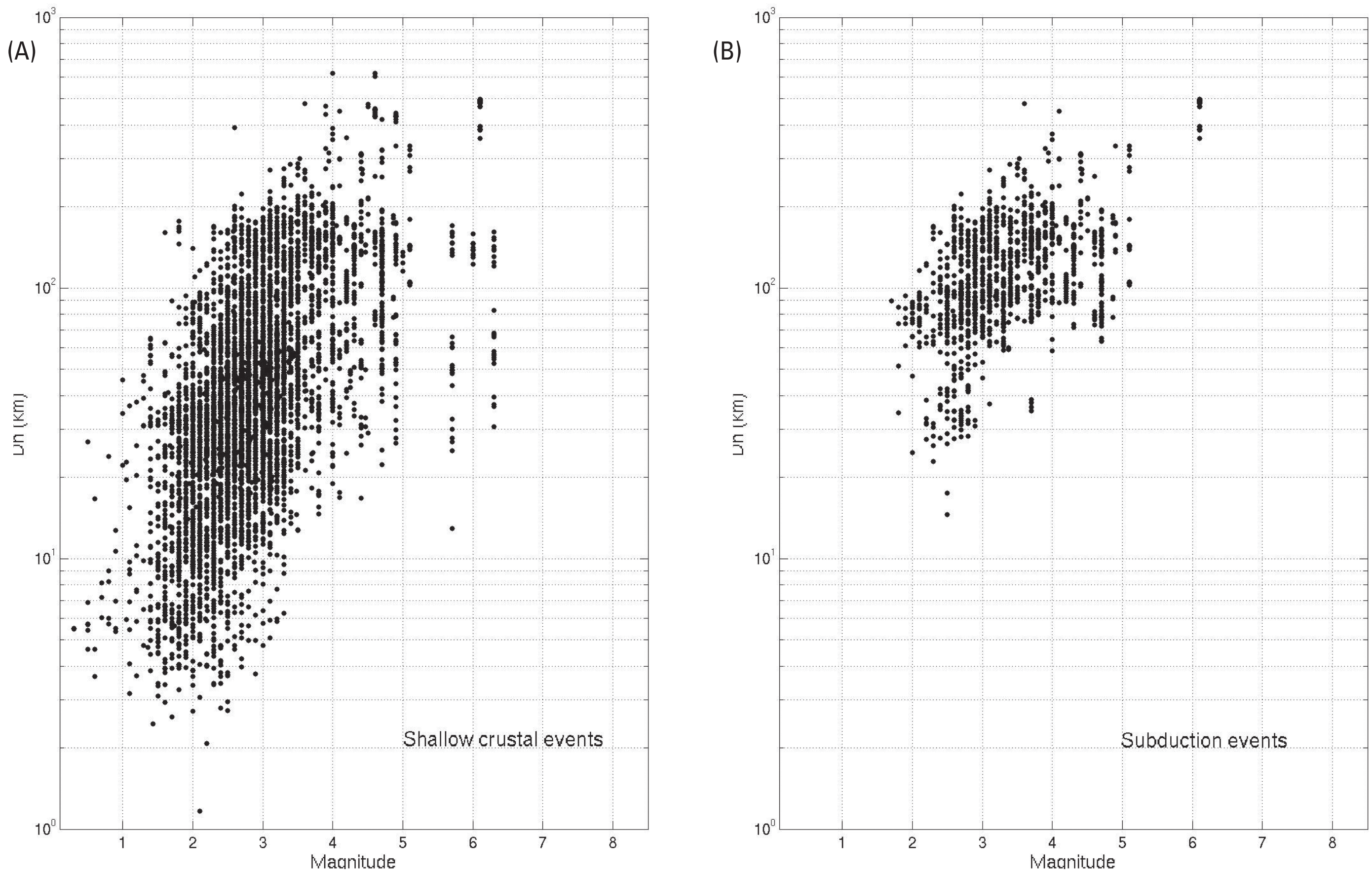
ATTENUATION LAWS

Here we distinguish shallow crustal earthquakes (< 50 km) from intraslab subduction earthquakes (occurring within the subducting oceanic plate). The CDSA has gathered enough data from 2,260 events to allow us to compute PGA values. PGA estimates vary between 0.1 mg and 200 mg for hypocentral distances from 5 to 500 km. Figure 7 shows the magnitude-distance distribution of the strong-motion dataset collected for analysis. A large portion of the data comes from shallow crustal earthquakes, a majority of them from Les Saintes aftershock area. Magnitudes range from 1 to 6 and hypocentral distances from 2 to 500 km (figure 7A). For subduction earthquakes (figure 7B), magnitude and distance ranges are much smaller (about 2–5 km for magnitude, 20–200 km for hypocentral distances).

The Les Saintes islands earthquake (2004/11/21, M_w = 6.3) is the event for which we have the largest amount of accelerometric data. PGA distribution with distance is represented in figure 8 and table 4. The event was recorded by 46 stations at distances between 30 and 150 km. An illustration of site effects is presented in the seismograms of figure 9. For the mainshock, one compares the records at Ste. Rose (soil site) and Le Moule (rock site), both at 70 km from the epicenter, which provides a peak amplitude ratio of 2.

Unfortunately, there was no accelerometric station at Les Saintes Islands, near the activated fault. Therefore, the peak accelerations at these islands could only be estimated by interpolating the trend of its attenuation at a shorter distance. We estimate a PGA of 200–300 mg or larger, which is consistent with the EMS98 intensity VIII reported by BCSF on these islands (BCSF 2005).

In figure 8, we compare the acceleration data with the predicted acceleration using two attenuation laws computed for shallow crustal earthquakes (Sadigh *et al.* 1997; Chang *et al.* 2001). The Sadigh *et al.* (1997) model for rock sites is applicable to earthquakes with moment magnitudes of 4 to 8+ and distances up to 100 km. The Chang *et al.* (2001) model is valid for magnitudes of about 4 to 7 and for distances of about 5 to 250 km. The PGA prediction is rather good for Guadeloupe records at less than 100 km, but clearly overestimates the PGA observed in Martinique at about 150 km by a factor of 2 to 3.



▲ **Figure 7.** Magnitude-distance distributions of peak ground-motion data used in this study. (A) shallow crustal earthquakes; (B) subduction zone earthquakes.

There presently are not enough magnitude 6 or larger earthquakes in the database to reliably constrain parameters for a new attenuation law.

CONCLUSIONS

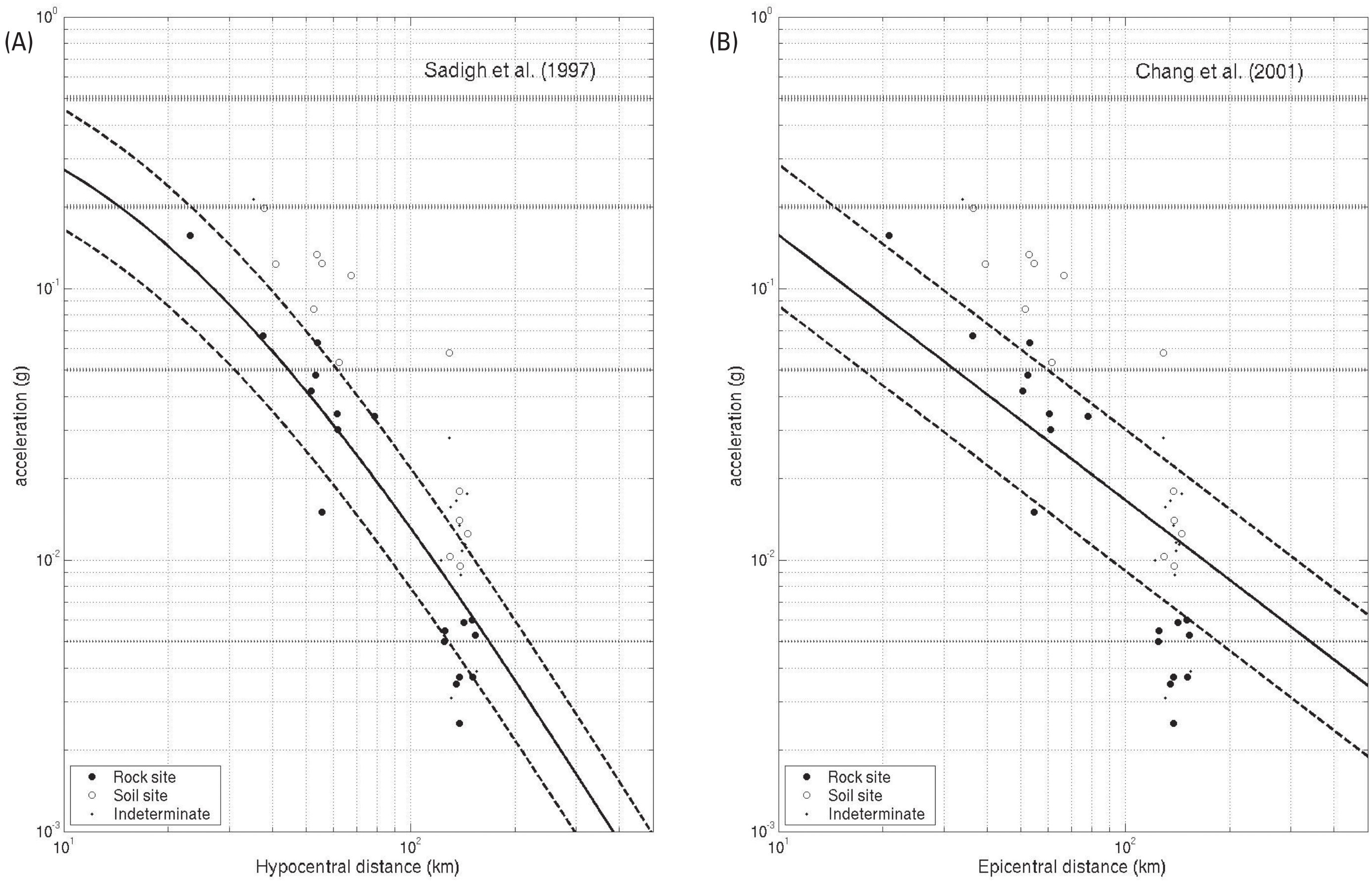
The Lesser Antilles arc is prone to a large seismic hazard. The geodynamic context is relatively complex, the historical seismicity covers too-short a period of time (less than 3.5 centuries) to estimate the recurrence time of strong events, and seismicity associated with shallow active faults near the islands is not well-understood. Although several regional institutions produce catalogs of seismicity, the information remains partial. Under such conditions, the seismic hazard assessment is still relatively approximate and needs to be improved, which motivated the creation of the French Antilles Seismological Data Base, CDSA.

The purpose of CDSA is to collect and merge the data existing in the French Antilles. CDSA generates a new seismicity catalog that is as complete as possible. The five years of seismicity presently analyzed allow us to compare seismic activity on the whole arc and to see clearer evidence for variations in the seismicity level along the arc. The magnitude threshold is 2.7, and even lower near the islands of Guadeloupe and Martinique. We have been able to confirm a progressive increase of seismic activity from south to north between Martinique and Antigua and identify two presently quiescent zones, near St. Kitts to the north and Grenada to the south.

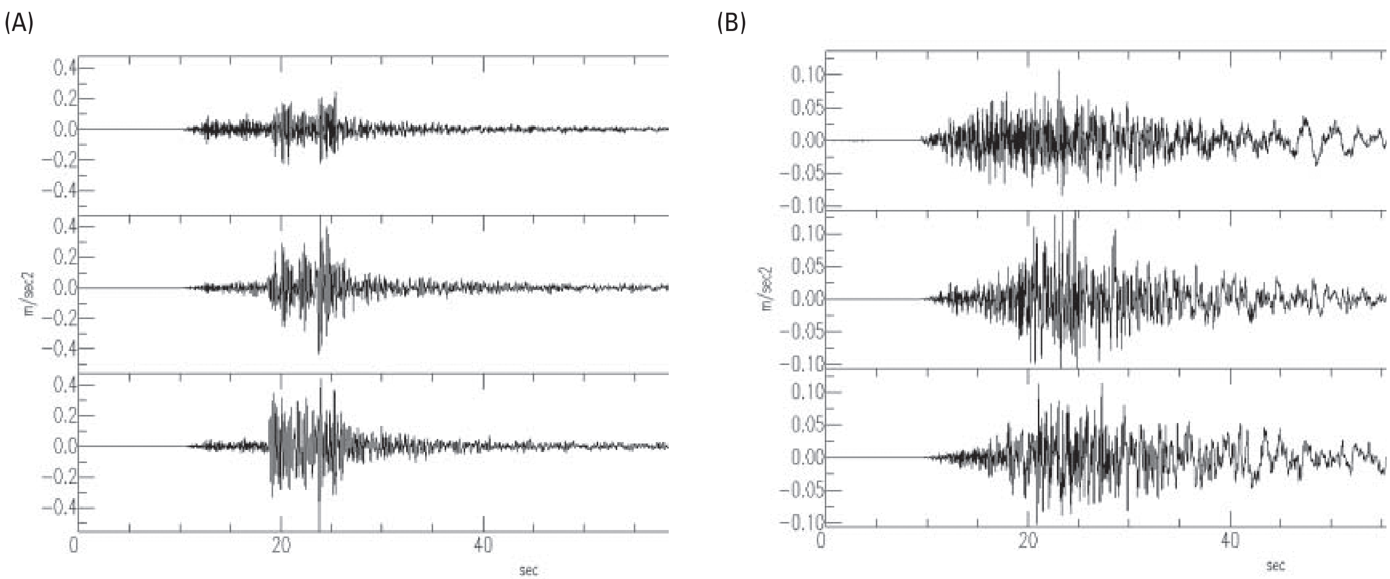
In the central part of the arc (17.5°N–13.5°N), the CDSA catalog improves our knowledge of the subduction zone and of the shallow seismicity because its hypocenter locations have smaller uncertainties than the original catalogs. It better defines the slab structure and dip angle: the latter seems constant between St. Lucia and St. Kitts, with a mean value of 50°. Moreover, the CDSA catalog better constrains the relationship between tectonic structures and seismicity, such as a backstop near Guadeloupe, and offshore active faults around Guadeloupe and Martinique, in particular for the 2004 Les Saintes seismic crisis. Including accelerometric data in CDSA has reduced location errors, but azimuth coverage is not improved: the problem of island–arc alignment remains. Only ocean-bottom instruments could improve this drawback. For this purpose, IPGP installed ocean bottom seismometerin 2006.

High-quality digital accelerometric data are recent in the Lesser Antilles, and there is not yet any attenuation relationship adapted for the Lesser Antilles. Preliminary results from the CDSA compilation show that standard attenuation laws overestimate peak accelerations at large distances by a factor of 2 to 3.

In conclusion, the newly created CDSA will improve regional hazard assessment and bring valuable input to applied and fundamental research, in particular through its accessibil-



▲ **Figure 8.** Comparison between PGA for the mainshock (Les Saintes, 21/11/04, M_w 6.3) and the predicted values using two attenuation equations (Sadigh *et al.* 1997; Chang *et al.* 2001). The solid line indicates the predicted PGA, the broken lines indicate the standard error of the equation. Horizontal lines indicate empirical limits for degree of perception based on Feuillard (1984): from bottom to top, the earthquake is felt by few people, the earthquake is felt by a large majority of people, the earthquake can cause important damages, the earthquake can cause general panic.



▲ **Figure 9.** Comparison between records from two stations at the same distance (70 km) from the epicenter (21/11/04) with different site conditions: (A) SROA (soil site) and (B) MOLA (rock site).

TABLE 4
Strong motions recorded by accelerometric stations in the French West Indies for the mainshock (Les Saintes, 21/11/04). Site conditions are indicated R for rock, S for soil, NA for indeterminate; the number indicates the type of classification: (1) for H/V measurements, (2) for geological determination (Douglas *et al.* 2005).

Stations	Code	Networks	Type	Hypocentral distance (km)	PGA (g)
Grand-Bourg-Marie-Galante	GBGA	RAP-IPGP	R (1)	32.4	0.157
Houelmont-Gourbeyre	GHMA	BRGM-GUA	R (1)	35.0	0.213
Préfecture-Basse-Terre	PRFA	RAP-IPGP	R (1)	37.1	0.067
Belfont-Saint-Claude	GJYA	BRGM-GUA	R (1)	37.9	0.198
Aérodrome de Baillif	ABFA	RAP-IPGP	S (1)	40.1	0.123
Ecole de Pigeon-Bouillante	PIGA	RAP-IPGP	R (1)	53.3	0.048
Institut-Pasteur-Abymes	IPTA	RAP-IPGP	R (1)	55.9	0.042
Fengarol Pointe-à-Pitre	GFEA	BRGM-GUA	S (1)	56.6	0.084
Lauricisque Pointe-à-Pitre	GLAA	BRGM-GUA	S (1)	57.6	0.133
Antéa-Abymes	GBRA	BRGM-GUA	R (1)	58.3	0.063
Aéroport Glide fond	GGFA	BRGM-GUA	R (2)	59.5	0.015
Aéroport Glide surface	GGSA	BRGM-GUA	S (1)	59.5	0.124
Morne à l'Eau	MESA	RAP-IPGP	S (1)	67.3	0.053
Le Moule	MOLA	RAP-IPGP	R (1)	68.0	0.030
St-François	SFGA	RAP-IPGP	R (1)	68.9	0.034
Sainte-Rose	SROA	RAP-IPGP	S (1)	69.1	0.112
Anse-Bertrand	BERA	RAP-IPGP	R (1)	83.5	0.034
Observatoire Morne des Cadets	CGOB	CG-MAR	R (1)	121.9	0.010
Piscine Carbet	CGCA	CG-MAR	R (1)	124.1	0.005
Sainte Marie	MASM	RAP-IPGP	R (1)	126.4	0.006
Collège Saint-Just Trinité	CGTR	CG-MAR	S (1)	130.0	0.028
Mairie-Trinité	MTRA	BRGM-MAR	S (1)	130.1	0.058
Hôpital Trinité	MATR	RAP-IPGP	S (1)	130.3	0.010
Centre Thermal Absalon	CGAS	CG-MAR	S (1)	130.4	0.003
Réservoir Deux Terres	CGDT	CG-MAR	S (1)	131.0	0.016
Météo Desaix	MAME	RAP-IPGP	R (1)	134.9	0.006
Collège Saint Joseph	CGSJ	CG-MAR	S (1)	135.7	0.017
Exotarium-Fort-de-France	MEXA	BRGM-MAR	S (1)	137.7	0.018
Immeuble Concorde DDST	CGCO	CG-MAR	R (1)	137.8	0.003
Archives Départementales Haut	CGAH	CG-MAR	R (1)	137.9	0.013
Archives Départementales Bas	CGAS	CG-MAR	S (1)	137.9	0.004
Théâtre-Fort-de-France	MTHA	BRGM-MAR	S (1)	138.1	0.014
Dillon-Fort-de-France	MDIA	BRGM-MAR	S (1)	138.6	0.010
Centre culturel Atrium	CGAT	CG-MAR	S (1)	138.8	0.009
Collège Petit Manoir Lamentin	CGPB	CG-MAR	S (1)	140.6	0.011
Collège Place d'Armes	CGPA	CG-MAR	S (1)	140.8	0.012
Zone Aéro-Militaire	MAZM	RAP-IPGP	R (2)	142.3	0.006
Collège du François	CGFR	CG-MAR	NA	144.2	0.011
Barrage de la Manzo Haut	CGMH	CG-MAR	NA	146.1	0.018
Barrage de la Manzo Bas	CGMB	CG-MAR	NA	146.2	0.013
Diamant	MADI	RAP-IPGP	R (2)	150.8	0.004
Marin	MAMA	RAP-IPGP	R (1)	150.8	0.006
Collège Diamant	CGDI	CG-MAR	R (1)	153.3	0.005
Collège Vauclin	CGVA	CG-MAR	S (1)	155.6	0.004

ity on the Internet (http://www.seismes-antilles.fr). Presently, CDSA focuses on data collected by the French arrays, but it would be a great opportunity to set up a cooperative data exchange among different Caribbean countries and institutes involved in assessing the seismic hazard of this region.

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Observatoire Volcanologique et Sismologique de la Guadeloupe
Le Houelmont, 97113 Gourbeyre Guadeloupe (FWI)
mendy@ovsg.univ-ag.fr
(M.B.-V.)