Moment tensor solutions along the central Lesser Antilles using regional broadband stations

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A R T I C L E   I N F O

Article history:
Received 16 November 2016
Received in revised form 13 June 2017
Accepted 20 June 2017
Available online 22 June 2017

Keywords:
Moment tensor
Focal mechanism
Lesser Antilles
ISOSA
Subduction zone

A B S T R A C T

Using waveform data gathered from the seismological networks of the Lesser Antilles, we calculate 38 moment tensors for earthquakes with M ≥ 3, from 2013 to middle of 2015 by full waveform inversion. Nine of these moment tensor solutions are in good agreement with those previously reported by other institutions, it provides some guarantee for 29 new moment tensors for the central region of the Lesser Antilles. For earthquakes within the upper Caribbean lithosphere, our results evidence that extensional and strike-slip focal mechanisms are predominant, resulting from the intra-plate deformation produced by the subduction of the North America and South American Plates under the Caribbean Plate, whereas very few thrust events are observed. For deeper earthquakes (>90 km), our results compare well with older focal mechanisms from previous studies, showing normal oblique or strike slip faulting within the subducted slab. However, the inversion for most of the deeper events is less reliable (as documented, for example, by their larger condition numbers). We use the newly obtained moment magnitudes to estimate the scaling relationship with the local magnitudeMLv computed by the regional seismic network. The two magnitudes are consistent for earthquakes with magnitudes M > 4, with a slope close to unity. Further work is needed to precise the scaling relation for M ≤ 4.

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1. Introduction

The complex seismicity in the Lesser Antilles region is mostly related to the subduction of the North and South American plates beneath the Caribbean plate (Fig. 1). Regional earthquake catalogs (Bengoubou-Valérius et al., 2008; Massin et al., in prep.) show that the subduction process creates a 100–200 km wide deformation zone accompanied by shallow seismicity, from the trench to the Lesser Antilles Islands (where the active volcanic arc is located) and an intermediate depth seismicity along the slab observed down to 200 km. The instrumental seismicity indicates important lateral variations along the subduction zone, in particular in the central Lesser Antilles (between 16°N and 15°N, a >150 km wide region, where shallow seismicity is low and thrust earthquakes are rare (Fig. 1). Nevertheless the eastern Caribbean boundary has the classical characteristics of a subduction zone (e.g., Byrne et al., 1988). To the south of the Tiburon Ridge is located a thick accretionary prism, where turbidites from the Orinoco sediments are accreted (Westbrook, 1975; Westbrook et al., 1982; Pichot et al., 2012). In this area, a seismic gap has been identified and explained by a low coupling due to high sediment presence (Dorel, 1981; Wadge and Shepherd, 1984). The Tiburon Ridge is the northern limit of these sediments on the Atlantic seafloor (Brown and Westbrook, 1987). The area between the Tiburon Ridge and Barracuda Ridge represents the diffuse plate boundary zone between the South and the North America plates (Patrat et al., 2011). The Caribbean plate convergence with the American plates is stable since ca. 20 Myr (e.g., Bouysse and Westercamp, 1990; Meschede and Frisch, 1998; Pindell and Kennen, 2009), with a slow frontal to transitional convergence rate of ~2 cm/year (e.g., DeMets et al., 2000; Lopez et al., 2006; Symithe et al., 2015). Recent GPS data analysis indicates no relative motion of the Lesser Antilles islands with respect to the Caribbean plate, and the observed Caribbean plate active faults within the arc and the forearc only accumulate strain at a rate of less of 2 mm/yr (Symithe et al., 2015). A major issue in the region is the estimation of the seismic and tsunami potential of the subduction zone. Only few large historical earthquakes have occurred, the 1843 and the 1839 events (Fig. 1) being the largest ones (Bernard and Lambert, 1988; Feuillet et al., 2011; Hough, 2013). Based on regional reported intensities and damages, Bernard and Lambert (1988) proposed a magnitude between 7.5 and 8 and an interplate thrust event for the 1843 earthquake, while adding felt reports from North America leads to a magnitude >8.4 (Hough, 2013), with large uncertainties on its location. However, the lack of tsunami associated to the 1843 event is puzzling, whereas in the case of the 1839 earthquake, a small tsunami reported in Martinique (Clouard et al., 2017) is consistent
with a 7.5 thrust event as proposed by Bernard and Lambert (1988) and Feuillet et al. (2011).

For the 1950–1978 period, Stein et al. (1982) determined 17 focal mechanisms in the Lesser Antilles and found only one thrust event near Antigua. Thus, they proposed that the central Lesser Antilles is largely decoupled and aseismic. A recent GPS study of the area arrives at a similar conclusion (Symithe et al., 2015). The instrumental seismicity since 1976 has registered only 6 earthquakes with magnitude >6 (Fig. 1) in the central part of the Lesser Antilles. Except the Martinique 2007 earthquake (M = 7.3) at intermediate depth, they are all shallow and too sparse to understand the strain partitioning of the area nor the state of coupling of the subduction.

The French Volcanological and Seismological Observatories in Guadeloupe and Martinique (OVS-IPGP), in addition with the Seismic Research Center (SRC-UWI) are the regional seismic network operators in charge of the Lesser Antilles seismicity monitoring. Since 1973, they routinely share their data and determine the hypocenters and local magnitudes of the earthquakes. During the four ultimate years, in order to improve the regional seismic monitoring and to contribute to the Caribbean Early Warning System, the OVS-IPGP and SRC-UWI have greatly increased their detection networks with the installation of several new high quality broadband stations (Anglade et al., 2015) along the Lesser Antilles arc. In addition, an effort has been done to produce a common regional catalog of the seismicity, named the CDSA catalog (Centre de Données Sismologiques des Antilles, http://www.seismes-antilles.fr), based on a compilation of all phases from the OVS-IPGP, the SRC-UWI and others seismic operators (Massin et al., in prep.). However, for a better understanding of the focal processes and their relationship with the tectonic environment, the style of faulting and moment tensors also need to be determined.

For earthquakes with M > 5, these parameters are routinely determined by international agencies by inversion of seismic waveform recorded in the far field (e.g., GCMT, Project http://www.globalcmt.org, IRIS catalog, http://ds.iris.edu, GEOSCOPE Observatory, http://geoscope.ipgp.fr, etc.). However, up to date, only 48 moment tensor solutions have been determined in our studied region since 1979 (Fig. 1), 12 of them in the last decade. Focal mechanisms can also be determined by other methods based on P polarities and S to P amplitude ratios (e.g., Buforn, 1994), but these methods need a good azimuthal coverage of the study area. In our study area, using P-wave polarities

![Fig. 1. Regional settings and GCMT focal mechanisms for earthquakes with M > 5, from 1950 to 2015 (Dziewonski et al., 1981). The convergent plate velocity comes from DeMets et al. (2000). The subsurface dimensions of 1839 and 1843 events are obtained from Wells and Coppersmith’s (1994) rupture area regression versus magnitude, with epicenter and magnitude of 8.3 for 1843 following Hough (2013) and epicenter and magnitude of 7.5 for 1839 following Bernard and Lambert (1988). The red dashed line is the deformation front of the accretionary prism. The black rectangle bounds the study area. The upper inset shows the location of the Eastern Caribbean. Bathymetry comes from ETOPO1 (Amante and Eakins, 2009). (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article.)](image-url)
Fig. 2. Map of the stations (triangles) used for determining the moment tensor solutions. The grey zone is the study area and detail of the Martinique Island is zoomed.

Fig. 3. Representation of a grid search for the 20140225 09:58:15.80 UTC earthquake. a) Vertical: in 10 trial source positions around the hypocenter (starting at the depth of 5 km, vertical step 3 km), and around the origin time in the range of ± 3 s (step of 0.45 s). b) Horizontal: at the previously determined depth of 14 km, the horizontal and vertical axis numbers are the source position numbers (with a step of 3 Km). The filling colors of the beach balls correspond to the double-couple percentage (DC scale on the upper right), the best-fitting solution (that of the largest correlation) is the red beach ball. This is a representative example, the real grid search differs on the “step” as mentioned in the text. (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article.)
recorded by a dense offshore temporary network, Ruiz et al. (2011) determined 22 focal mechanisms offshore Martinique and Dominica. They found a diffuse seismicity concentrated in the inner forearc, not related to any specific structure, mostly located near the base of the Caribbean crust and near the interface. However, due to insular configuration of the Lesser Antilles permanent seismic network and the fact that 95% of the seismicity is offshore, the seismic station distribution (Fig. 2) does not allow the use these methods.

The moment tensor determination by full waveform inversion has become a routine practice at many observatories due to the availability of high quality data (Havskov and Ottemöller, 2010). In this paper, we propose to use the newly upgraded Lesser Antilles seismic network to provide a complete moment-tensor catalog of low-magnitude earthquakes up to middle of 2015. Another innovation is that we complement the newly obtained moment tensor by their uncertainty estimate. The moment magnitudes (Mw) that we obtain are also compared with the commonly used local magnitudes MLv (measured on the vertical component). Preliminary tectonic implications of the results are discussed.

2. Data and method

2.1. Data selection

For this study, we use the CDSA catalog to identify earthquakes with M > 3.0, whose signal has been registered by at least 4 regional broad band 3-component seismic stations (Fig. 2 and the Electronic Supplement #1 summarize the most important features for each station). Within these data, we select two sets of earthquakes:

2.1.1. Set 1

It is selected for calibration purpose, and represents 9 regional earthquakes for which moment tensors were determined by international agencies.

2.1.2. Set 2

It is a set of 29 earthquakes, inside our study area and with good signal to noise ratio in the frequency band of the regional waveform inversion (typically below 0.1 Hz), for which the moment-tensor have not yet been calculated.

The velocity model for the waveform inversion is taken from Dorel (1978). This 1D model consists of three crustal layers with 3, 12, and 15 km of thicknesses and P velocities (Vp) of 3.5, 6.0, and 7.0 km/s.
respectively; the mantle model is represented by a half space of Vp 8.0 km/s. The Vp/Vs ratio for all the layers is 1.76. This model is routinely used for earthquake location by the OVS-IPGP network in the Lesser Antilles. Density values come from the relationship of Havskov et al. (2002). The stations with inconsistent results are removed from the inversion.

In order to select the optimum frequency band for filtering during the inversion, each component is initially evaluated in several frequency bands using the most updated version of SAC software (Goldstein, 1999). ISOLA codes (Sokos and Zahradník, 2008 and 2013) are used to calculate the Signal to Noise Ratio (SNR) of the events and to identify and remove the records spoiled by instrumental disturbances (Zahradník, and Plešinger, 2005 and 2010; Vackář et al., 2015). For each earthquake, at least 10 usable components and a SNR ≥ 2 in the frequency band used for the inversion are required.

The (deviatoric) moment tensors are calculated with ISOLA by full waveform inversion, using the least-squared method, while the centroid position and time are grid-searched. The spatial grid search is performed first vertically below epicenter in an interval around the hypocenter depth (with a step of 1 km), and in an interval of ~3 s around the origin time (step of 0.09 s) (Fig. 3a). The second grid search is usually performed in a horizontal plane with typical steps ranging from 2 to 4 km (Fig. 3b), fixing the reference depth from the first search. The best-fitting solution (Fig. 4) is characterized by the Variance Reduction percentage (VR), or correlation (where correlation squared equals VR), the Double-Couple percentage (DC) and the Condition Number (CN). CN serves for relative evaluation of the moment-tensor resolvability: the lower CN means the better resolvability (for exact definitions, see Krizova et al., 2013).

2.2. Calibrations results (Set 01)

In order to check the consistency of the inversion parameters to be used (e.g. instrumental calibration of the seismic stations, velocity...
between 0.01 and 0.06 Hz. This bandwidth is consistent with the filters suggested by Dreger (2002) for these magnitude values. The results are presented in Table 1.

The mean departure from the Mw values of GCMT catalog is as small as 0.12. The differences are found more frequently for events far from our study area, where the scaling law for MLv as well as the crustal model (Dorel, 1978) and their corresponding attenuation values are less appropriate.

The approach proposed by Kagan (1991) describes the difference between two pure double-couple source models; the Kagan's angle (K-angle) is used to quantify the difference between each new focal mechanism and its corresponding GCMT solution. Our results show in general, relatively low Kagan's angle values, for most of the earthquakes (≤21°) and their mean value of 15°, which indicates a good agreement with GCMT. Such results with our first dataset of highest magnitude events, clearly indicates that the instrumental calibration and the velocity model used are relevant, and enables the process of weaker events.

3. New moment tensors solutions (Set 02)

Our full waveform inversion provides a set of 29 new moment tensor solutions for the Central Lesser Antilles (Fig. 6). Results are reported in Table 2 and in the following, each event is identified by the number that appears on this table. We now use again the Kagan’s angle but for a completely different purpose, to check the uncertainty of the moment tensor solutions as the deviation of each acceptable solution from the best-fitting one (Zahradník and Custodio, 2012). The K-angle values in Table 2 represents the mean of the deviation of all solutions (see example in the K-angle histogram, Fig. 7), and all of them are in acceptable range (Zahradník and Custodio, 2012). Overall, the solutions are characterized by adequate values of the variance reduction percentage (VR), the double-couple percentage (DC) and the condition number (CN).

For event most events (#11 to 14), in spite of the in general large NC and SNR, relatively large K-angle and CN values as well as low VR probably reflect the negative influence of the insular configuration of our network geometry. The 2 least resolved events are #17 and #28, which coincide with relatively large CN and small number of components (NC) used during the processing. Detailed results for all events are in the Electronic Supplement S2 as well as the waveform fit in the Electronic Supplement S3.

4. Discussion

4.1. Relationship between the focal mechanism and the source depth

The shallow seismicity accommodates the intra-Caribbean deformation by normal, normal-oblique or strike slip faulting in the forearc (Stein et al., 1982; Gagnepain-Beyneix et al., 1995). Among the 29 new moment tensors obtained, 18 occurred in the upper lithosphere at shallow depth (Fig. 6). To the north, events #5 and #24, at respectively 22 and 34 km-depth, are located on the southern wall of the NNE trending Antigua Valley (Fig. 8). Because of the geometry of this and other regional valleys, it has been proposed that they were normal fault-bounded grabens (Feuillet et al., 2002). The normal mechanisms we found confirm that and indicate that this trough is an active graben associated to normal faults down to crustal depths. #9 earthquake, located on the northern wall of Marie-Galante Graben (Fig. 8) coincides with previous normal earthquakes like 1992-08-03 and 2001-01-05 events (Fig. 5, and more information about previous earthquakes used for comparison in Electronic Supplement S4) and also indicates an active graben. #21 normal faulting earthquake is close and similar to the Mw = 6.2 2004 Les Saintes earthquake located on the major normal fault of the Roseau Graben extending from Les Saintes to Dominica (Bazin et al., 2010). It is located at the southern extremity of Roseau fault system, below the no longer active Roseau underwater volcano. #15 event is located at the top of the Arawak Valley, which, by analogy,
Table 2
New focal mechanisms derived in this study (Set 2).a

<table>
<thead>
<tr>
<th>Event #</th>
<th>Origin time yyyy:mm:dd hh:mm:ss.ss</th>
<th>Lat Lon depth (hypocent) centroid (centroid)</th>
<th>Min - max Δ (km)</th>
<th>MLv</th>
<th>Mw</th>
<th>Strike/Dip/rake NP1/NP2</th>
<th>Mon Ten</th>
<th>DC %</th>
<th>VR %</th>
<th>NC</th>
<th>SNR</th>
<th>K’</th>
<th>CN</th>
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<td>20130508 03:45:22.58</td>
<td>14.60-60.5712 (14.03-60.544)</td>
<td>44-98</td>
<td>3.8</td>
<td>3.6</td>
<td>277 19 21 167 83 108</td>
<td>57</td>
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<td>14.05-60.5812 (14.12-60.288)</td>
<td>53-255</td>
<td>3.6</td>
<td>3.5</td>
<td>224 64-157 124 69-27</td>
<td>94</td>
<td>65</td>
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<td>4</td>
<td>4</td>
<td>2.2</td>
<td></td>
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<tr>
<td>3</td>
<td>20131018 04:01:56.58</td>
<td>16.17-60.6841 (16.12-60.7352)</td>
<td>68-209</td>
<td>4.6</td>
<td>4.1</td>
<td>102 76-173 10 83-14</td>
<td>70</td>
<td>67</td>
<td>30</td>
<td>5</td>
<td>4</td>
<td>2.3</td>
<td></td>
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<tr>
<td>4</td>
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<td>15.01-60.4134 (15.05-60.4146)</td>
<td>91-147</td>
<td>4.4</td>
<td>3.9</td>
<td>150 26 74 348 66 98</td>
<td>75</td>
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<td>93-184</td>
<td>3.9</td>
<td>3.7</td>
<td>326 63-96 160 28-78</td>
<td>82</td>
<td>45</td>
<td>18</td>
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<td>4.4</td>
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<td>82</td>
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<td>4.2</td>
<td>3.6</td>
<td>235 44-127 102 57-60</td>
<td>68</td>
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<td>56-184</td>
<td>3.7</td>
<td>3.1</td>
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<td>4.9</td>
<td>291 18-154 176 82-73</td>
<td>100</td>
<td>67</td>
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<td>10</td>
<td>6</td>
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<td>4.8</td>
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<td>92</td>
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<td>4.9</td>
<td>5.1</td>
<td>287 3-176 193 90-85</td>
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<td>4.5</td>
<td>4.6</td>
<td>302 16-124 157 76-81</td>
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<td>15.38-60.7216 (15.36-60.6919)</td>
<td>87-147</td>
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<td>280 41-61 64 55-113</td>
<td>70</td>
<td>42</td>
<td>24</td>
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<td>3</td>
<td>2.1</td>
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No. Origin time yyyy:mm:dd hh:mm:ss.ss Lat Lon depth (hypocent) centroid (centroid) Min - max Δ (km) MLv Mw Strike/Dip/rake NP1/NP2 Foc Mec DC % VR % NC SNR K’ CN
16 20140617 12:25:44:13 15.73-61.21103 15.73-61.3295 111-154 3.6 3.7 64 47-175 330 86-43 88 40 12 2 8 4.8
18 20140717 04:42:58.41 14.97-60.5258 64-356 4.4 4.3.
than in other subduction zones. Tohoku, the seismogenic portion of the interface could extend deeper into the mantle wedge, above the subducting slab, and below the upper crust. This kind of event has been evidenced in the studied area by Laigle et al. (2013) and related to the bending of the Caribbean upper plate. The back-arc extension and the corresponding lithospheric boudinage of the Caribbean upper plate. The back-arc extension is a typical process of the West-directed subduction zones (Doglioni and Panza, 2015) due to the kinematics of the plates involved between 4.6 and 5.1. The vertical dip angle we found traduces the characteristic uplift and faulting of the upper plate over a subducting relief (Dominguez et al., 1998) and contribute to the uplift of the Barracuda Ridge observed since the Early Pleistocene related to the bending of the lithosphere prior subduction and to the North and South America plate motion (Pichot et al., 2012).

Events 11 to 14 are aftershocks of the M = 5.9, 16/05/2014 normal earthquake (in Table 1). They are located at the intersection of subducted Barracuda ridge with toe of the backstop (Fig. 8). The backstop is the forearc region significantly stronger than the region just trenchward of it (Byrne et al., 1993). In the Lesser Antilles case, the backstop geometry exhibits a contact with the accretionary wedge dipping trenchward (e.g., Westbrook, 1975) and it is the island arc crust that serves as backstop (Christeson et al., 2003). These 4 events are similar, at 5–7 km-depth, i.e. very shallow, with homogeneous magnitude between 4.6 and 5.1. The vertical dip angle we found traduces the characteristic uplift and faulting of the upper plate over a subducting relief (Dominguez et al., 1998) and contribute to the uplift of the Barracuda Ridge observed since the Early Pleistocene related to the bending of the lithosphere prior subduction and to the North and South America plate motion (Pichot et al., 2012).

Strike-slip mechanisms are sparse in the Caribbean upper lithosphere and we find only 4 shallow strike-slip events: #19 earthquake and its aftershock #20, 2 h later, #10 and #2. The lack of shallow events is another active graben. #26 earthquake is located at the northwestern limit of the Arawak basin, a deep forearc basin, with the buried southern part of the Karukera Spur (Evain et al., 2013). It can results from the subside of the Arawak basin or from the uplift of the Karukera Spur, as it is the case for its northern part. These normal faulting earthquakes may also be explained due to the back-arc extension and the corresponding lithospheric boudinage of the Caribbean upper plate. The back-arc extension is a typical process of the West-directed subduction zones (Doglioni and Panza, 2015) due to the kinematics of the plates involved as described Doglioni et al. (2007).

Table 2 (continued)

<table>
<thead>
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<th>No.</th>
<th>Origin time yyyy:mm:dd hh:mm:ss.sss</th>
<th>Lat Lon depth (hypocentrel) (centroid)</th>
<th>Min - max Δ (km)</th>
<th>MLv</th>
<th>Mw</th>
<th>StrikeDipslip NP1/NP2</th>
<th>Foc Mec</th>
<th>DC %</th>
<th>VR %</th>
<th>NC</th>
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<td>69–170</td>
<td>4.3</td>
<td>3.7</td>
<td>355 80–161 262 72–10</td>
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* Min - max Δ are hypocentral distance of the nearest and farthest station used for the inversion; NC is the number of components used; SNR the signal to noise ratio; K° is the mean Kagan angle of the family of the acceptable solutions and CN is the condition number. For the remaining symbols, see legend of Table 1.
strike-slip events in our studied area, in addition with geodetic analysis of Symithe et al. (2015) is another argument against the northern Lesser Antilles forearc bloc proposed by López et al. (2006). Respectively, strike-slip mechanism is the most common mechanism for intraslab earthquakes as seen with #3, 7, 16, 17, 22, 27, 28 and 29 strike slip events, at depth between 40 and 185 km (Fig. 6). Part of these earthquakes around 15° may be related not only to the subduction process but also to the relative displacements between the subducted Northern and Southern American plates. The 6 deeper earthquakes (depth > 90 km), in general, have relatively larger CN number and larger uncertainty (K-angle), but the resulting models have a comparable faulting type solutions than the older events from GCMT located in the same region and depth. For example: the pairs of events #16 and 2005-02-08 (Fig. 5) and #27 and 1996-09-24 have a normal oblique faulting and events #17 and 1982-01-08 have an strike slip faulting.

Finally, we find only one area where thrust faulting earthquakes occur, located eastward Martinique (events # 4 and # 18). These 2 events are located near the 1946-05-21 (Ms = 6.0) earthquake (Bernard and Lambert, 1988; Russo et al., 1992), the 1983-03-03 and 2008-02-06 (Mw = 5.3) earthquakes, and near several others thrust faulting earthquakes from Ruiz et al. (2011). This area also corresponds to the rupture area of 1839 earthquake. While our short time window database does not contain other thrust events, the rupture area of 1843 earthquake, from Desirade Island up to latitude 18°N is a second zone where thrust earthquakes have occurred (Fig. 8). Commonly, the major moment release at subduction zone occurs at the interface between the subducting plate and the overriding plate (e.g., Scholz, 1998). However, in the central Lesser Antilles, this coupled interface seems to be limited to the 2 areas that we identified, matching the subsurface rupture areas of the 2 large historical subduction earthquakes. Conversely, in the rest of the studied area, our results are consistent with the hypothesis that the central Lesser Antilles is decoupled as already proposed by Stein et al. (1982) and more recently by Symithe et al. (2015).

4.2. The Mw versus MLv scaling

The local magnitude (MLv) is the Richter (1935) magnitude, derived from the maximum amplitude of the velocity signal on the vertical component and an attenuation law. MLv is computed routinely by the regional network operators (e.g., OVSMP-IPG and OSGV-IPG). To potentially improve their attenuation parameters and thus homogenize the catalog, we use our obtained moment magnitudes (Mw) to investigate their relationship with MLv. It is expected that the Mw – MLv scaling differs for stronger and weaker events. For example, Mw ≈ MLv for 4 < M < 6 (Kanamori, 1983) and Mw ~ 0.67MLv for M < 4 (Ottemöller and Havskov, 2003). Excluding events 1 and 4 from Table 1, which are too far from our study region, our data give (Fig. 9):

\[
M_w = 0.94 ML_v + 0.15 \quad \text{for} \quad 4 < M < 6
\]

\[
M_w = 0.53 ML_v + 1.53 \quad \text{for} \quad M > 4
\]

For M < 4, the latter relationship is less well constrained due to the considerable data scattering. More data are needed to precise the Mw-MLv relation for M < 4 and to make a comparison like Bindi et al. (2005) for the North of Italy, Scherbaum and Stoll (1983) for Germany, Zuniga et al. (1988) for Hawaii, etc. Nevertheless, for M > 4, the present data shows that MLv is a good proxy to Mw.

5. Conclusions

Using the records of the new broad band seismic network operating in the Lesser Antilles, a set of 38 moment tensor solutions for earthquakes with M ≥ 3 has been determined by full waveform inversion. Where other sources exist (like GCMT), our solutions compare well with them. The analysis of the new moment tensors for earthquakes in the Caribbean upper lithosphere indicates that normal, oblique and strike slip faulting are predominant, and reflects the intraplate deformations of the Caribbean plate from the subduction to the volcanic arc, in particular on the southern walls of most of the regional grabens. In our study area, only two thrust earthquakes located eastward of Martinique are present at depth between 40 and 90 km. This scarcity is consistent with GCMT catalog and may be explained, between others causes, by the hypothesis of the low coupling subduction in the central Lesser Antilles (e.g. Stein et al., 1982 and Symithe et al., 2015). However, two areas matching the subsurface rupture areas of the 2 large historical subduction earthquakes could define two patches of higher coupling. Intermediate depth earthquakes (deeper than 100 km) are located within the subducting slab and correspond to a normal oblique or strike slip faulting related to the subduction process. Nevertheless, in general, the largest uncertainties correspond to the inversion procedures of these deeper earthquakes. The comparison of our new Mw with the MLv is consistent with Kanamori (1983) results for M ≥ 4. However, for magnitudes < 4, the considerable data scatter requires more information to establish the Mw-MLv relation. The computation of Mw from spectral analysis (Edwards et al., 2010) could provide constrains on this law. This important problem requires further investigation.
before establishing a reliable magnitude scale for Lesser Antilles earthquakes.

Supplementary data to this article can be found online at http://dx.doi.org/10.1016/j.tecto.2017.06.024.

Acknowledgements

We are grateful to the team of the Volcanological and Seismological Observatory of Martinique (OVSM/IPGP) for all the work facilities and to IRIS and OVS-IPGP for the seismic records provided. We acknowledge

the constructive discussions with the IPGP Seismology team. We thank Mario Ruiz for sharing its Lesser Antilles focal mechanism database and Christine Deplus and Martin Patriat for sharing regional bathymetric data. Maps and Fig. 9 were done using the GMT software (Wessel et al., 2013). Comments from Editor-in-Chief Rob Govers helped to improve the manuscript and we also wish to thank two anonymous reviewers for their constructive remarks. This research was supported by the OVSM/IPGP, the European Interreg Caraïbe IV (31420) TSUAREG project, the CENAIS/CITMA (P211SCU-003) and the Czech Science Foundation grant GACR-14-04372S. This is an IPGP contribution #3849.
Fig. 9. Scaling of the moment magnitude Mw (from this study) with the local magnitude MLv: a) for 4 ≤ M ≤ 6 and b) 2.9 ≤ M ≤ 4.

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