Intergovernmental Oceanographic Commission

Workshop Report No. 291

Experts Meeting on Sources of Tsunamis in the Lesser Antilles

Fort-de-France, Martinique (France)
18–20 March 2019

UNESCO

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Executive Summary

The Intergovernmental Oceanographic Commission (IOC) of UNESCO supported a Group of Experts meeting on Lesser Antilles tsunami sources to better understand the uncertainties associated with the Lesser Antilles Trench and the nearby volcanic activity.

The 3-day experts meeting was held from 18 to 20 March 2019 on the French Lesser Antilles island of Martinique, France. The purpose of the experts meeting was to identify and quantify tsunami sources of both tectonic and volcanic origins, and related hazards and risks to support holistic risk management for the Lesser Antilles (preparedness, mitigation, response, and recovery).

Tsunamis from seismic and volcanic sources could have widespread impacts on the population health and economy of the Lesser Antilles. There are historical precedents for tsunamis generated by earthquakes associated with the Lesser Antilles Trench and volcanic activity. A very large tsunami associated with the Lesser Antilles Trench has the potential to cause widespread loss of life, damage and disruption to the region. Similarly, volcanic activity along the Lesser Antilles volcanic arc could potentially generate locally devastating tsunamis that would compound the volcanic crisis. The Lesser Antilles are made up of small islands with an increasing dependency on coastal-based tourism. Moreover, the population of these island nations and their infrastructure are concentrated in areas particularly prone to tsunami effects, low-lying coastal areas.

The meeting in Martinique aimed to focus on the uncertainties in tsunami hazard assessment for the Lesser Antilles and identify possible tsunami sources. The outcomes of the meeting can be used for Lesser Antilles hazard and risk assessment studies. The invited experts analysed credible tsunami sources, for which they identified the following groups of sources related to the subduction of North and South America plates beneath the Caribbean plate with potential to impact the Lesser Antilles:

1. Subduction Zone related sources consist of tsunami sources stemming from the interaction of North and South America plates with the Caribbean producing shallow thrust events capable of inducing near-field catastrophic tsunamis. Events in this category include sources tentatively similar to the 8 February 1843 earthquake (M7.5-8.0; Bernard and Lambert, 1988).

2. Island Arc Normal sources consist of crustal faults within the arc itself and thus not directly related to the subduction process. Tsunamigenic sources in this category are smaller events with smaller shallow rupture areas that are oriented perpendicular to the arc. An example of such a source is the M7.4 October 8, 1974 event that ruptured a normal fault oriented perpendicular to the arc between Antigua and Barbuda.

3. Island Arc Parallel sources consist of crustal faults within the arc itself and thus not related directly to the subduction process. Tsunamigenic sources in this category are smaller events with smaller shallow rupture areas that are oriented parallel to the arc. An example of such a source is the M6.3 November 21, 2004 earthquake along the Roseau fault between Guadeloupe and Dominica, an oblique fault oriented parallel to the arc axis.

4. Volcanic-induced sources consist of tsunamis generated by the explosive nature of volcanic islands either by volcanic eruption of underwater volcanoes, debris flows, or lateral collapse of volcanic islands. An example of such a source is the tsunami generated by debris flows at the volcano crisis of Mont Pelée in Saint Pierre, Martinique, on 4 May 1902.

1. BACKGROUND

The Lesser Antilles tectonic setting puts coastal residents at significant risk from local and regional tsunamigenic sources. In the central Lesser Antilles, the Caribbean plate converges with the North and South America plates at approximately 20 mm/yr. Convergence is less oblique in the central area of the arc than in the north, resulting in active island-arc tectonics and subduction processes.

This subduction zone is associated with a moderate to large seismic hazard. In the south, the lack of seismicity is sometimes interpreted as a seismic gap related to the anomalously thick and wide Barbados accretionary prism. In the past 500 years, two large thrust earthquakes have occurred in the central Lesser Antilles – one located east of Martinique (1839, M~7.5) and the other one east of Guadeloupe (1843). Although recent studies estimate the magnitude of the 1843 earthquake to be > 8.5, which is a magnitude with the potential to generate a tsunami, no significant tsunamis generated by the central Lesser Antilles subduction have been documented in recorded history. Since the region's historical seismicity spans less than 500 years, it can be challenging to determine recurrence rates as well as possible magnitudes for future earthquakes.

The Lesser Antilles volcanic arc is made of 12 Holocene active volcanoes in the 10 major islands of the younger arc. The active volcanoes are prone to flank collapses, which are potentially tsunamigenic. Tsunamis related to volcanic eruption or volcano flank collapse have been reported for several Lesser Antilles volcanoes (Mount Pelée, Montserrat, Kick'em Jenny, Soufrière–Saint Vincent).

A number of historical tsunamis have impacted the Lesser Antilles; however, limited wave information is available. Historical records indicate most of these tsunamis resulted in only small to moderate runups with limited damage. Some of the most significant runups are from the 18 November 1867 Virgin Islands earthquake and tsunami, which travelled along all the Lesser Antilles islands. Two transoceanic tsunamis have been reported in the Caribbean Sea. They were sourced from the 1 November 1755 Lisbon earthquake and the 31 March 1761 earthquake off of the Iberian coast. The 1755 event was observed in the whole of the Lesser Antilles with a runup of 6.4 m at the island of Saba, while the 1761 event is described only in Barbados. Transoceanic tsunamis related to Atlantic volcanic island (e.g. Canary Islands) collapses have also been hypothesized.

Date						Tsunami Cause						Tsunami Source Location				Tsunami Parameters					Tsunami Effects										Photos
																Max Water	Num. of	Magnitude		Tsu	Deaths		Injuries		Damage		Houses Destroyed		Houses Damaged		
Year	Mo	Dy	Hr	Mn	Sec	Val	Code	Earth-quake Mag	Vol-cano	Addl Tsu Info	Deposits	Country	Name	Latitude	Longitude	Height	Runups	Abe	Iida	Int	Num	De	Num	De	$Mill	De	Num	De	Num	De	
1690	4	16				4	1	8.0		*		ANTIGUA AND BARBUDA	ANTIGUA; SAINT KITTS AND NEVIS	17.500	-61.500		3														
1767	4	24	6			3	1	*		*		MARTINIQUE (FRENCH TERRITORY)	MARTINIQUE & BARBADOS	14.400	-61.000		2														
1795						3	1	*		*		TRINIDAD AND TOBAGO	PORT-OF-SPAIN	10.700	-61.700		1														
1802	3	19				2	1	*		*		ANTIGUA AND BARBUDA	ANTIGUA ISLAND & ST. CHRISTOPHER	17.200	-62.400		2														
1823	11	30				4	1	*		*		MARTINIQUE (FRENCH TERRITORY)	SAINT PIERRE	14.400	-61.000		1									1					
1824	9	13				-1	9	*		*		GUADELOUPE (FRENCH TERRITORY)	BASSE TERRE	16.700	-62.200		1														
1824	11	30				2	1	*		*		MARTINIQUE (FRENCH TERRITORY)	SAINT PIERRE	14.400	-61.000		1									1					
1825	9	21	1	45		2	1	*		*		TRINIDAD AND TOBAGO	PORT-OF-SPAIN	10.400	-61.300		1														
1831	12	3	23	40		1	1	*		*		TRINIDAD AND TOBAGO	TRINIDAD & ST. CHRISTOPHER	12.400	-61.500		2														
1843	2	8	14	50		4	1	8.3	Vol	*		GUADELOUPE (FRENCH TERRITORY)	POINTE-A-PITRE	16.500	-62.200	1.20	1		.30												
1843	2	17				1	6		Vol	*		GUADELOUPE (FRENCH TERRITORY)	MARIE-GALANTE ISLAND	15.933	-61.267		1														
1902	5	5				4	7		Vol	*	1	MARTINIQUE (FRENCH TERRITORY)	MOUNT PELEE	14.820	-61.170	5.00	1														
1902	5	7				4	6		Vol	*	1	SAINT VINCENT AND THE GRENADINES	SOUFRIERE VOLCANO	13.330	-61.180	1.00	3														
1902	5	8				2	6		Vol	*		MARTINIQUE (FRENCH TERRITORY)	MOUNT PELEE	14.820	-61.170		1														
1902	5	20				2	6		Vol	*		MARTINIQUE (FRENCH TERRITORY)	MOUNT PELEE	14.820	-61.170		4									1		1			
1902	6	6				2	0			*		MARTINIQUE (FRENCH TERRITORY)	FORT-DE-FRANCE	14.602	-61.065		1														
1902	7	8				2	0			*		MARTINIQUE (FRENCH TERRITORY)	MARTINIQUE	14.553	-61.009		1														
1902	8	30				4	6		Vol	*		MARTINIQUE (FRENCH TERRITORY)	MOUNT PELEE	14.820	-61.170	1.00	1														
1911	11	3				3	6		Vol	*		TRINIDAD AND TOBAGO	TRINIDAD	10.500	-61.200		1														
1939	7	24				2	6		Vol	*		GRENADA	KICK 'EM JENNY VOLCANO	12.300	-61.630	2.00	3														
1965	10	24				1	6		Vol	*		GRENADA	KICK 'EM JENNY VOLCANO	12.300	-61.630		0														
1968	9	20	6	9		2	1	6.2		*		VENEZUELA	CARUPANO	10.500	-62.600		1														
1969	12	25	21	32	27.3	4	1	7.2		*		GUADELOUPE (FRENCH TERRITORY)	GRAND BOURG	15.800	-59.700	.46	3		-3.30												
1985	3	16	14	54	.7	4	1	6.4		*		GUADELOUPE (FRENCH TERRITORY)	GUADELOUPE	17.013	-62.448	.12	1		-3.30												
1997	12	26	8			4	7		Vol	*		MONTSERRAT	WHITE RIVER VALLEY	16.720	-62.180	3.00	1														
1999	1	20				4	6		Vol	*	1	MONTSERRAT	SOUFRIERE HILLS VOLCANO	16.722	-62.180	2.00	3														
2003	7	12				4	6		Vol	*	3	MONTSERRAT	SOUFRIERE HILLS VOLCANO	16.722	-62.180	4.00	5									1					
2004	11	21	11	41	7.7	4	1	6.3		*	1	GUADELOUPE (FRENCH TERRITORY)	BASSE-TERRE, LES SAINTES	15.679	-61.706	.70	7														
2005	2	14	18	5	59.3	3	1	5.8		*		GUADELOUPE (FRENCH TERRITORY)	DOMINICA PASSAGE	15.775	-61.744		2														
2006	5	20	11	20		4	6		Vol	*		MONTSERRAT	SOUFRIERE HILLS VOLCANO	16.722	-62.180	1.00	4									1					
2007	11	29	19	0	20.4	1	1	7.4		*		MARTINIQUE (FRENCH TERRITORY)	MARTINIQUE	14.944	-61.274		0														
2018	8	21	21	31	46.0	2	1	7.3		*		VENEZUELA	SUCRE	10.855	-62.883		1														

Table 1. Tsunamis affecting the Lesser Antilles Island Arc obtained from the National Oceanic and Atmospheric Administration National Centers for Environmental Information (NCEI) database.

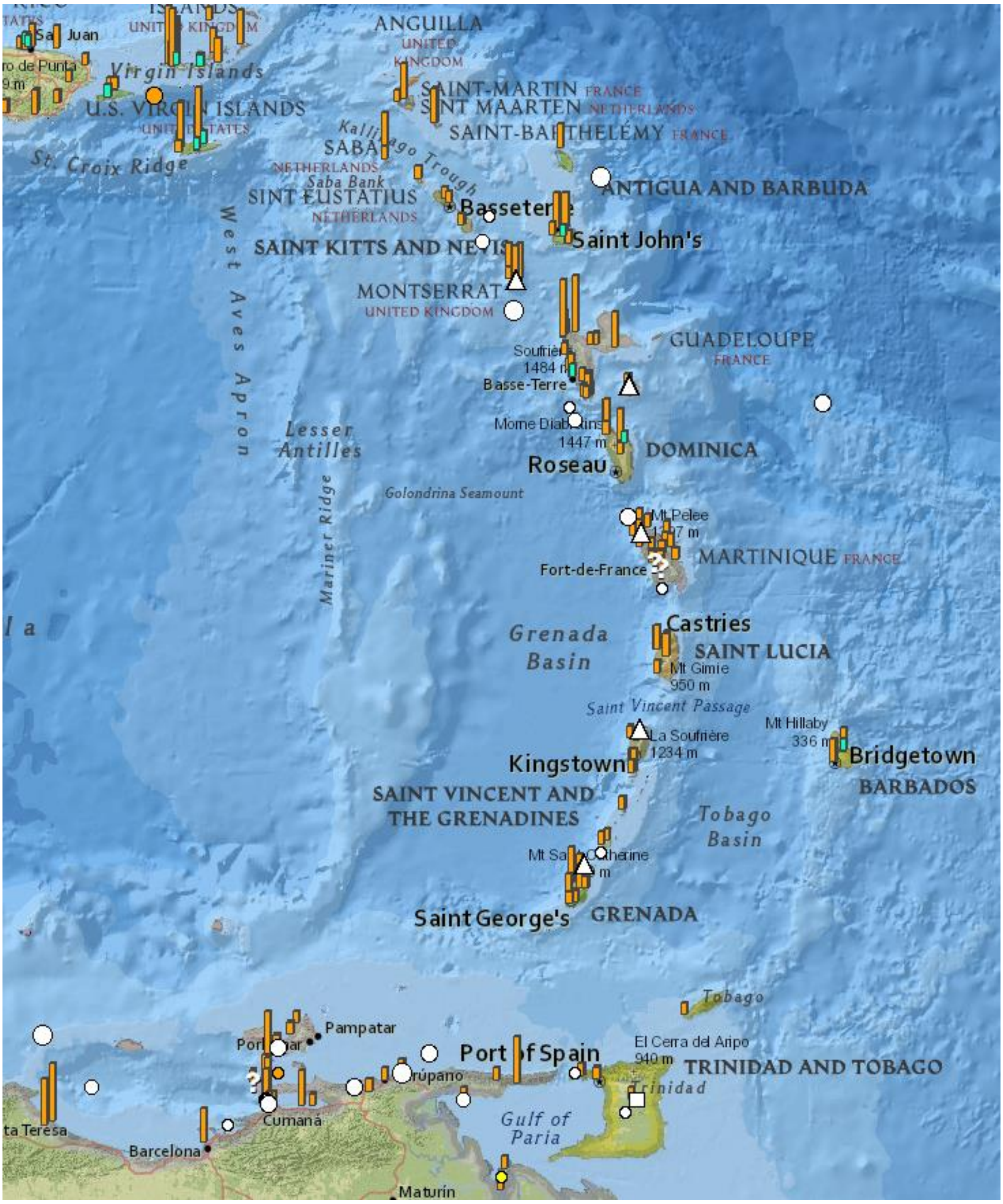

Figure 1. Map of the Lesser Antilles Arc showing significant historical tsunami sources. Tsunami sources include earthquakes (circles) and volcanoes (triangles). Observed tsunami runups are displayed as vertical bars. (NCEI database).

2. OBJECTIVE AND OUTCOMES

The objectives of the meeting were to identify and quantify credible tsunami sources in the Lesser Antilles that could significantly impact the local and regional area. The identified sources should be able to be used for tsunami modelling, evacuation mapping, planning and exercises.

As a minimum, the following outcomes were developed as results of the scientific experts meeting:

- Develop an IOC Technical Report summarizing the meeting and its findings;
- Provide recommendations for consideration by the CARIBE-EWS Working Groups and CARIBE-EWS Member States; and
- Suggest further research to support response and mitigation initiatives for affected CARIBE-EWS Member States.

3. MEETING TOPICS

The meeting included presentations of experts in the field and guided discussions in the following topics:

- Tectonics and seismicity of the Lesser Antilles,
- Historical seismic and tsunami records,
- Neotectonics of the Lesser Antilles,
- Paleotsunami studies,
- Near-field tsunami sources,
- Far-field tsunami sources,
- Tsunamigenic volcanic activity,
- Tsunamigenic submarine landslides,
- Tsunami modelling of tectonic, volcanic and landslide sources.

4. SUMMARIES OF INDIVIDUAL PRESENTATIONS

This section summarizes the contents of the presentations that relate to the focus of the meeting that were provided by the participating experts (see meeting agenda in Annex II for the order of presentations followed at the meeting).

4.1 OVERVIEW OF WG2 WORK FOR THE PAST 4 YEARS (by Silvia Chacón)

Working Group 2 (WG2) has performed surveys on the availability of tsunami evacuation maps and bathymetric data. Also a subgroup is exploring possibilities to perform a Probabilistic Tsunami Hazard Assessment (PTHA) for the Caribbean and Adjacent Regions.

WG2 created an interactive map with tectonic tsunami sources developed at Experts Meetings and used for Caribe Wave exercises. The map includes the seismic parameters of the sources and modelled maximum tsunami heights at deep ocean virtual gauges. The map is hosted by NCEI/NOAA and includes data from historic tsunamis. In addition, it has information on tide gauges both from the National Oceanic and Atmospheric Administration (NOAA) and the IOC Sea Level Station Monitoring Facility (SLSMF).

WG2 has supported four Experts Meetings:

- Tsunami Sources for Honduras, February 2016.
- Tsunami Sources for South Dominican Republic, May 2016.
- Tsunami Sources for Central America, June 2016.
- Group of Experts on Other Coastal Hazards, November 2018.

Subgroups of WG2 presented posters at AGU2015 and AGU2016, related to tsunami potential and modelling of tsunami sources in the region. Also, published two papers: *A Collaborative Effort Between Caribbean States for Tsunami Numerical Modeling: Case Study CaribeWave15* (https://doi.org/10.1007/s00024-017-1687-7) and *Nations Work Together to Size Up Caribbean Tsunami Hazards* (https://doi.org/10.1029/2018EO105609).

WG2 has set up a webpage at IOC Tsunami website summarizing the work and having availablethe related documents to download: http://www.ioc-tsunami.org/index.php?option=com_content&view=article&id=365&Itemid=336&lang=es

4.2 CARIBBEAN AND ADJACENT REGIONS TSUNAMI SOURCES AND MODELS WEBMAP (By Nicolas Arcos)

Since 2011, UNESCO's Intergovernmental Oceanographic Commission (IOC) Experts Meetings and Caribe Wave exercises have resulted in a variety of tsunami models of credible scenarios that would impact the Caribbean and adjacent regions. During the 12th session of the Intergovernmental Coordination Group for the Tsunami and other Coastal Hazards Warning System for the Caribbean and Adjacent Regions (ICG/CARIBE-EWS-XII) held in Puntarenas, Costa Rica, from 10 to 12 May 2017, a formal recommendation was adopted for Working Group 2 (Hazard Assessment) to compile the aforementioned tsunami scenarios with additional parameters such as tsunami energy plots and NOAA/NCEI historical tsunami data. In response to this recommendation, the Caribbean and Adjacent Regions Tsunami Sources and Models (CATSAM) map viewer was developed to identify potential tsunami sources. CATSAM is intended to provide modellers and hazard assessment professionals with an understanding of the UNESCO/IOC led tsunami modelling efforts, as well as how those efforts overlap with the Global Historical Tsunami Database developed and maintained by NOAA's National Centers for Environmental Information (NCEI) and co-located World Data Service (WDS) for Geophysics. The product is not meant to identify all tsunami sources in the region, just those identified by experts at UNESCO/IOC led meetings, as well as historically observed. Scenarios presented in CATSAM, as defined by several groups of experts on seismology, tsunamis and tsunami modelling.

CATSAM currently has 41 defined rupture planes as well as 23 associated vetted scenarios with offshore wave amplitudes. The scenarios were based on historical events and/or tectonic and geodetic data. Although some scenarios have a low probability of occurrence, they should be taken into account for preparedness purposes. The scenarios may include more than a single rupture plane; in this case, the planes are labelled (1, 2, 3 ...). Scenarios displaying the Moment Magnitude (M_w) at each plane correspond to that plane, not to the composite scenario. Other features available in CATSAM include historical tsunami information from the NOAA/NCEI/WDS global historical tsunami database, tide gauge and DART station information, and volcano locations.

4.3 MISSING GREAT EARTHQUAKES (by Susan Hough)

Overwhelmingly, in the absence of documented tsunamis or geological evidence, magnitudes of historical earthquakes are constrained from shaking intensities estimated from archival accounts of damage and other effects. Due to several factors, including the unknowable stress drop (slip/rupture area) of historical earthquakes, magnitudes are highly uncertain. There is compelling evidence that the magnitudes of the largest earthquakes have been underestimated in general for events before 1900. The 1843 Lesser Antilles earthquake is an example of an event that might have been considerably larger (M>8.5) than the accepted catalogue magnitude. However, regardless of the mechanism and magnitude of this earthquake, it should not be taken as an archetype for future large earthquakes along this part of the Lesser Antilles subduction zone. Other credible sources, notably a shallow plate-interface event, would pose a much larger tsunami risk. In general, the historical catalogue for the Lesser Antilles is far too short to provide a reliable estimate of either the long-term rate, or maximum credible magnitude along any part of the zone.

4.4 CHALLENGES FROM ANCILLARY TSUNAMI SOURCES IN THE WAKE OF RECENT WORLDWIDE EVENTS (by Emile Okal)

Tsunami risk in the Lesser Antilles is impacted by significant volcanic activity at emerged sites (such as Montserrat) and submerged ones (such as Kick 'Em Jenny). In this context, the recent catastrophic tsunami at Krakatau, Indonesia, may offer valuable lessons in the Caribbean, since the Krakatau-Java geometry bears considerable similitude to the Montserrat-Guadeloupe one. We note that a remarkably precise scenario of the Krakatau disaster had been published by Giachetti et al. (2012), and similarly the 1997 and 2003 tsunamis at Montserrat have been modelled by Heinrich et al. (1998). We are thus in a situation where acceptable scenarios for volcanic tsunamis can be prepared in advance.

An additional risk comes from sources ancillary to large seismic events, namely landslides, which have played a major role in the generation of the 1867 Anegada Trough tsunami (Lopez et al., 2008; 2015), which had a catastrophic impact throughout the Lesser Antilles. This confirms a worldwide trend in recognizing landslides as major contributors to tsunami risk. Unfortunately, their triggering is a non-linear process in which the amplitude of the triggered phenomenon (the landslide) is not necessarily related to that of the trigger (the earthquake); in addition, triggered landslides can be significantly delayed with respect to their parent earthquake.

There also remains some doubt on the exact mechanism of generation of several historical tsunamis, in particular the 1842 Haiti event (for which crucial evidence may be available in the Turks and Caicos Islands), and the 1843 Antigua shock, whose impact was severe throughout the Lesser Antilles as an earthquake, but whose tsunami was deceptively low, suggesting that it may have represented an intraplate failure of the slab, similar to the 2009 Padang, Indonesia event.

Finally, proper mitigation of tsunami risk in the Lesser Antilles must include enhanced education of the populations at risk, as well as a reflection on some specific hazards, such as the ubiquitous presence in crowded harbours of large cruise ships which could become ballistic, and whose thousands of passengers are mostly unprepared to face a tsunami evacuation.

4.5 SEDIMENTARY AND EROSIONAL EVIDENCE OF HISTORICAL TSUNAMIS ON ANEGADA, BRITISH VIRGIN ISLANDS (by Michaela Spiske)

Anegada (British Virgin Islands) is a low-lying island (at maximum 8 m above sea level), located 120 km south of the Puerto Rico Trench. Sedimentary archives on Anegada document evidence of two tsunamis that affected the island. The younger event corresponds to the 1755 Lisbon tsunami. The older event occurred during pre-Columbian times (1200–1480 AD).

The pre-Columbian event inundated almost the entire island from north to south. Dune ridges were breached and large volumes of lagoonal, beach and dune sand were transported inland.

Sheets of mainly marine sand with conch and articulated Codakia shells cover the limestone platform and are found in the salt ponds. Large coral boulders were ripped off the coral reef and transported as far as 1.5 km on land. Slabs of the Pleistocene limestone platform were eroded from onshore point sources and scattered as elongate boulder fields. The best-fit earthquake scenario for this tsunami event is a thrust earthquake in the Puerto Rico trench with a magnitude of ~8.45.

The 1755 transatlantic Lisbon tsunami caused only minor inundation. The tsunami reused the breaches to inundate the salt ponds. A thin unit of marine sand was deposited. No boulders were moved.

4.6 UNEARTHING THE NORTHEAST CARIBBEAN'S EXTREME OVERWASH RECORD (by Zamara Fuentes)

A short historical record and a sparsity of large earthquake events limit our knowledge of hazards posed by fault systems in the northeast Caribbean. However, a record of deposited sediments in coastal lagoons provides evidence and helps fill the time-gap of event recurrence and intensity in the region. This presentation provides an update on detailed overwash studies at three coastal lagoons in St. Thomas (U.S. Virgin Islands), including results of additional fieldwork and lab analyses. Results show seven atypical overwash deposits recorded in three ponds that span a period of 5,000 years. Two deposits correlate with the A.D. 1867 tsunami originating in the Anegada Passage while another deposit correlates with an event in A.D. 1650–1800 possibly related to the A.D. 1755 Lisbon, Portugal, tsunami. Older deposits correlate with an A.D. 1200–1480 event previously recognized in Anegada (British Virgin Islands) that may be related to a tsunami originating in the Puerto Rico Trench. Furthermore, two deposits dated between 20 B.C. and A.D. 1150 and between 350 B.C. and A.D. 130, an older deposit between 1630 and 170 B.C. and a deposit older than 2900 B.C. appear to be associated with previously unrecognized events. Advances made during this study include: 1) recognition of a greater geographic impact of the A.D. 1650–1800 and A.D. 1200–1480 events from Anegada to St. Thomas; 2) description of a deposit related to the A.D. 1867 tsunami at two ponds; and 3) identification of four older events, extending the overwash record to about 3000 B.C.

4.7 TSUNAMIGENIC SOURCE SCENARIOS FOR MODELING TSUNAMI FLOODING FOR THE ISLAND OF MARTINIQUE (by Anne Lemoine)

In order to provide good estimation of potential tsunami impact affecting the island of Martinique, it is necessary to base high resolution simulation both on credible tsunamigenic source identification and accurate modelling strategy, taking into account local or regional datasets such as topo-bathymetry or heterogeneous soil friction. First, results of evaluation of potential tsunami impact on Martinique island, Lesser Antilles, were presented (Le Roy et al., 2017). Modelling strategy is based by calculating on regular mesh grids organized in the finest ranks thanks to a model that includes dispersive terms (Boussinesq equations solved). Heterogeneous soil friction according to land use is integrated for finest ranks. This methodology was validated for well-documented tsunamis, such as 2011 Tohoku or 1755 Lisbon events and was deployed for Martinique, integrating high-resolution bathymetry and land cover grids. The clue to evaluate potential flooding due to a tsunami in Martinique remains linked to an only partial knowledge of potential tsunamigenic sources. In order to determine credible tsunamigenic sources that could affect Martinique, we integrate tsunami and earthquake catalogues in our analysis: historical database of earthquakes and tsunamis (e.g. compilation of contemporary observations from 1551 and 1534 AD respectively in www.sisfrance.net/Antilles and tsunamis.brgm.fr) added to instrumental catalogues. Moreover, adding to the analysis of regional and local seismotectonic and seismogenic behaviour of active structures leads to the identification of 10 credible tsunamigenic sources that could potentially affect Martinique:

- Lesser Antilles subduction interface and forearc,
- Barbados area,
- Local crustal structures,
- North Venezuela,
- Marie-Galante graben,
- Muertos trough,
- Anegada passage,
- Puerto Rico Trench and
- Southwestern Iberia area.

For each source, a variability of scenarios is considered to take into account the fragmented knowledge of seismogenic behaviour and its variability. In parallel, 6 non-seismic sources were considered (dome or flank destabilization, lahar) including sources located in:

- Martinique,
- Saint Lucia,
- Dominica,
- Kick'em Jenny,
- La Palma, and
- Montserrat.

Considering large uncertainties associated with the behaviour of such sources, a parametric approach is applied that integrates a variability of hypothesis and sensitivity analysis.

Finally, tsunami modelling including inundation phase applied to Martinique coastal area (bathymetry resolution ~30 m) show a large variability of impacts depending on the one hand on the hypothesis of a seismic or non-seismic source, and on the other hand on particular exposure of receiving sites. Maximum sea surface elevation maps are compiled and shows the dominant effect of tsunamis induced by Lesser Antilles interplate earthquakes, especially at some sites along the eastern coast of Martinique. High-resolution (~6 m) tsunami modelling is in progress for a few coastal sites chosen among more exposed ones.

4.8 POSSIBLE SOURCES OF TSUNAMIS IN THE LESSER ANTILLES ARC: INSIGHTS FROM HIGH RESOLUTION GEOPHYSICAL MARINE DATA AND SEDIMENTS CORES (by Nathalie Feuillet)

The Lesser Antilles arc results from the subduction of the North and South American plates beneath the Caribbean plate at a rate of 2 cm/yr. Although this area is the site of multiple natural hazards, the seismic potential of this subduction zone remains poorly constrained. Any very large earthquakes that may have occurred were prior to modern times. Consequently, this subduction system has often been assumed to be aseismic. Since the occurrence of three M9-class worldwide earthquakes in recent years, many questions have arisen concerning the behaviour of megathrusts. We cannot exclude any subduction zone from producing such large events, and it becomes urgent to re-evaluate the seismic potential of the Lesser Antilles subduction zone. To address long-term earthquake recurrence by using the turbidite paleoseismology method, we collected 42 giant piston cores above the plate interface aboard the R/V *Pourquoi Pas?* in 2016 during the CASEIS cruise (doi 10.17600/16001800).

Petrophysical data including gamma density, P-wave velocity, magnetic susceptibility, resistivity, colour reflectivity, and colour imagery were acquired aboard on the 500 m of sediment cores we collected. Later analysis included XRF profiles, CT-scanning, microgranulometry, AMS, isotopic stratigraphy, and ^{14}C dating. We documented and established the chronology of several sedimentary facies including turbidites and homogeneities interbedded with hemipelagites and tephra in numerous cores. Chirp data shows that some events are correlated between multiple core sites over a large distance and may have been triggered by large earthquakes on the plate interface. Several cores offshore Guadeloupe show four alternations of several meters-thick turbitites (Tu) and/or homogeneities (Hm) and hemipelagites. Such Hm or Tu deposits have been documented elsewhere and may have been emplaced during megathrust events and tsunamis repeating at intervals of several tens of millennia. The ^{14}C dating on foraminifera indicates that the last event occurred 2500 years ago. In the framework of the ANR CARQUAKES project funded in 2018, we collected several sediment cores in March 2018 in shallow lagoons in Guadeloupe, Antigua, Barbuda, St. Barthelemy, St. Martin and Anguilla. The first analyses of the cores show that we sampled several sand layers much thicker than that deposited during the IRMA hurricane, which is the largest historical hurricane. This suggests that overwash events of larger magnitude (similar to the 1200–1400 AD event in Anegada), may have been triggered by tsunamis in this area.

The Lesser Antilles arc is also exposed to more local seismic events. On 21 November 2004, the Guadeloupe archipelago was struck by a magnitude 6.3 superficial and very damaging earthquake. To constrain the mechanisms of the recent deformation within the arc, several marine cruises were conducted since 1998 by IPGP (AGUADOMAR, MARTIREEF, GWADASEIS, BATHYSAINTES SUBSAINTES) and by other groups at Antilles University and IFREMER (KASHALLOW 1, 2, 3, ANTITHESIS). A lot of high-resolution data were acquired: Bathymetry, back-scatter images, Küllenberg cores, seismic reflection and chirp profiles. By combining them with onshore data, observations and measurements in the field, we have documented at several scales the active faulting between St. Lucia and Saba, the northernmost emerged volcano of the arc. We have shown that the Lesser Antilles arc is crosscut by two main fault sets: Arc-perpendicular graben in the outer arc and a large *en-échelon* system along the inner active arc. At plate scale, the arc-perpendicular fore arc graben and inner arc *en-echelon* system are connected, forming a sinistral horsetail, east of the tip of the left lateral Puerto Rico fault zone that takes up the trench parallel component of convergence between the North American and Caribbean plates, west of the Anegada passage. Considering the Caribbean North American Euler vector, the trench parallel component of shear increases northwestward with the curvature of the northern Caribbean plate edge, from 4 mm/yr. in Martinique to 17 mm/yr. in St. Martin, suggesting a total of a few millimetres per year across the entire fault system. Such rates are large enough that seismic hazard from shallow sources within the arc should be considered significant compared to that related to megathrust earthquakes along the plate interface. Upper plate active faults can be 30–50 km long and may be able to produce earthquakes with magnitudes larger than 6.5.

4.9 REVIEW OF RECENT ADVANCES IN THE SEISMO-TECTONICS OF THE CENTRAL LESSER ANTILLES (by Valérie Clouard)

Instrumental seismic data are a prerequisite to understand the regional context but a common catalogue was missing before 2010. The CDSA (Antilles Seismological Data Center) seismic common catalogue was built in 2013, covering an area from Puerto Rico Island to Venezuela. This catalogue can be found on-line at http://www.seismes-antilles.fr. It merges data from the International Seismological Centre (ISC) (PRSN, FUNVISIS, SRC) and from the French Volcano and Seismic Observatories from Martinique and Guadeloupe (OVS-IPGP). While the completeness magnitude is good around the islands, it falls to M=3 100 km from the island arc (Vorobieva et al., 2013). Joint inversion of (offshore) shots and local earthquakes leads to a 3-D view of the subduction slab down to 200 km-depth, and lateral variation of P-wave velocity enables to determine the potentially seismogenic zone at plate interface (Paulatto et al., 2017), which could extend down to 50 km-depth. In addition, several oceanographic campaigns have provided an image of the upper Caribbean plate structure, from the trench to the island arc (Kopp et al., 2011; Evain et al., 2013, Ruiz et al., 2013; Laigle et al, 2013a and b). The volcanic arc and the inner forearc would be built on the remnant of the Caribbean Plateau, the outer forearc would correspond to accreted oceanic plate, and between the backstop and the accretionary front is a thick accretionary prism. The backstop is shifted 25 km trenchward from the one derived from gravity data, implying a larger seismogenic zone. The décollement zone (or subduction channel) is clearly imaged over 75–100 km. Finally, recent studies using the new broad-band network deployed during the European Interreg TSUAREG project (Gonzalez, 2017; 2018) evidenced deep flat thrust and supraslab earthquakes as identified by Laigle et al. (2013b), thrust events concentrated only in two patches corresponding to the 1843 and 1839 rupture areas, and the slab depth beneath the volcanic arc, with a clear view of North and South America slab at respectively 125 km-depth and 80–100 km-depth.

4.10 TECTONICS OF THE SOUTHEASTERN CARIBBEAN (by John Weber)

The Southern Caribbean plate boundary is today a right-lateral transform boundary that takes up 20 mm/yr of shear with long strike-slip fault segments that right-step across pull-apart basins (Weber et al. 2001). Tanioka and Satake (1996) demonstrated how strike-slip faults that cut variable sea-floor bathymetry can generate tsunamis. From east to west, the principal transform faults are:

- the Central Range fault (CRF), Trinidad;
- the El Pilar fault (EPF), eastern and central Venezuela; and
- the Sebastian/La Victoria faults (SLVFs), western Venezuela.

The Gulf of Paria pull-apart basin connects the CRF and the eastern EPF (Flinch et al. 1999; Babb and Mann, 1999). GPS shows that the CRF and part of the EPF creep (Weber et al. 2020; Reinoza et al. 2015). Mendoza (2000) provides a nice study of the historic EPF earthquake. The CRF, eastern EPF, and Gulf of Para segment of the plate boundary thus has a low (CRF) to moderate (eastern EPF) tsunami potential. The Gulf of Cariaco is the step-over pull-apart basin (Schubert, 1985) connecting the documented seismogenic western EPF and eastern SLVFs (Perez et al. 2018). This PBZ segment should be considered as a credible tsunami source(s).

In addition to strike-slip faults, several significant active normal faults together take up ~3.5 mm/yr of motion (Weber et al. 2020) and either cut or have the potential to cut the seafloor in and around Tobago island, and should be considered as credible tsunami sources. These include:

- the Sub-Tobago terrane fault (Weber et al. 2015),
- Southern Tobago fault system (Morgan et al. 1988; Weber et al. 2015),
- North Tobago fault zone (unpublished 2d and 3d seismic mapping and data, Centrica Ltd.; Arkle et al., in prep.).

The tsunami potential of the subsea Kick ‘Em Jenny volcano north of St. Vincent at the southern end of the Lesser Antilles has been studied by Smith and Shepherd (1983), but this work likely needs updating.

Finally, the collapse of the Orinoco delta shelf-edge in the south-eastern Caribbean via growth faults, well-studied in Trinidad’s offshore Columbus Basin (e.g., Wood and Roberts, 2001) or transport via mass transport complexes, well-mapped in Pleistocene paleo-Orinoco deposits (Moscardelli et al. 2006, 2011), should be considered as credible tsunami sources.

4.11 MICROPLATE KINEMATICS AND INTERPLATE COUPLING IN THE CARIBBEAN FROM SPACE GEODETIC DATA (BY Eric Calais)

The geodetic results presented at the meeting are an update of the results published by Symithe et al. (2015) that benefit from more GPS sites and from longer observation times series, the latter acting to reduce the velocity uncertainties. We processed the entire campaign and continuous GPS data jointly in a consistent global reference frame. We then used the resulting velocity field as input to a kinematic model where surface velocities result from the rotation of rigid blocks bounded by locked faults accumulating interseismic strain, while allowing for partial locking along the Lesser Antilles, Puerto Rico, and Hispaniola subduction. We tested various block geometries, guided by previous regional kinematic models and geological information on active faults. Our findings refine a number of previously established results, in particular slip rates on the strike-slip faults systems bounding the Caribbean plate to the north and south. We refer to Symithe et al. (2015) for a detailed description of the methodology.

4.12 20TH-CENTURY STRAIN ACCUMULATION ALONG THE LESSER ANTILLES MEGATHRUST FROM CORAL MICROATOLL DATA (by Belle Philibosian)

Using the method of coral microatoll paleogeodesy developed in Sumatra, we examine 20th century vertical deformation on the islands of the northern Lesser Antilles and discuss the implications for strain accumulation on the megathrust. We collected cross sections from living microatolls at eight sites throughout the Antigua-Barbuda-Guadeloupe region, and observed coral morphology at three other sites including one on Anguilla Island. We derived a submergence or emergence rate at each site and removed the estimated 20th-century sea level rise (~1.1 mm/yr) to obtain tectonic deformation rates. We find a range of vertical deformation rates from +2 to -8 mm/yr, with a general trend of greater subsidence rates closer to the subduction front. The ~1 cm/yr spread in observed rates is an order of magnitude larger both than the expected maximum variability in 20th-century eustatic sea-level change across the region (Weil-Accardo et al., 2016), and than the slip rates on upper plate faults in the region (Feuillet et al., 2004; 2011; Leclerc et al., 2016). The only process capable of producing the observed magnitude and broad distribution deformation is locking variability on the subduction interface. Most of our data fit the expected deformation pattern of the down-dip edge of an interseismically locked patch on the megathrust: zero deformation near the volcanic arc increasing toward a small peak of uplift, then plunging subsidence nearer to the subduction front. Preliminary models suggest locking down to 50–60 km depth would be required to fit these data, with some variation both along strike and in time. Some data points are difficult to fit with megathrust coupling alone; these second-order variations in deformation rate are likely related to another process such as upper-plate faulting.

Our findings are in contrast to recent GPS-based models that suggest little or no strain accumulation anywhere along the Lesser Antilles megathrust. This discrepancy is potentially explained by the different time scales of measurement, as recent studies elsewhere have indicated that interseismic coupling patterns may vary on decadal time scales and that century-scale or longer records are required to accurately assess seismic potential (Meltzner et al., 2015). The accumulated strain we have detected will likely be released in future earthquakes, uplifting previously subsiding areas and potentially causing widespread damage from strong ground motion and tsunami waves. It should be noted, however, that our data (as well as the GPS data) do not constrain strain accumulation on the shallowest part of the subduction interface, which is also the most dangerous in terms of tsunami potential.

4.13 VOLCANIC SOURCES OF TSUNAMIS: MECHANISMS, HISTORICAL EXAMPLES, AND IMPLICATION FOR TSUNAMI HAZARD IN THE LESSER ANTILLES (by Raphaël Paris)

Volcanic activity and volcano flank failures represent only 5% of the tsunamis recorded during the four last centuries. However, they are difficult to anticipate and their impact can be disastrous, as illustrated by the 1883 Krakatau tsunami. A review of historical examples shows that there is a variety of source mechanisms that can produce tsunamis around volcanoes (underwater explosion, caldera collapse, pyroclastic flow, debris flow, subaerial and submarine landslides, and earthquakes), thus resulting in a diversity of wave characteristics. The modelling strategies differ from one source to another, and several types of sources can be implied in a single eruption. Complex sources such as pyroclastic flows can be studied both through experimental and numerical simulations. In parallel to the progress required for better understanding the physics of volcanic tsunamis, there is an urgent need to integrate volcanic sources of tsunamis in tsunami hazard assessment, detection, and prevention, as illustrated by the December 2018 Anak Krakatau tsunami.

4.14 MODELING SUBMARINE LANDSLIDES IN THE PUERTO RICO–VIRGIN ISLANDS REGION (by Alberto López)

The availability of high-resolution multibeam bathymetry data of the sea-floor around the Puerto Rico–Virgin Islands region has been instrumental to identify the location and dimensions of large submarine landslides and the existence of fractures that would likely turn into future slide headscarps. Using a coupled 3D-2D tsunami numerical modelling approach has given insight into the possible effects that submarine landslides may develop in the future. The presentation demonstrates the methodology employed to manipulate current bathymetric data to simulate a hypothetical future slide and estimate the possible effects of such tsunamis in populated areas of the Puerto Rico metropolitan area, and compares the computed inundation extent with the tsunami evacuation zones obtained from seismic sources.

4.15 RECENT ADVANCES IN FTRT TSUNAMI SIMULATIONS AND LANDSLIDE GENERATED TSUNAMI MODELING (by Jorge Macías)

The objective of this presentation is twofold. On the one hand, to clearly quantify how much computing times have been reduced in recent years (from 2014 to 2018) in tsunami simulations. This is done by providing figures for the evolution of computing times in two examples in which our group, EDANYA of the University of Malaga, has worked. The first in the Mediterranean Sea as a joint work with the Italian National Institute of Geophysics and Volcanology (INGV) for its National Tsunami Early Warning System (TEWS). The challenge, in 2014, was to compute a well-defined problem in less than 6 minutes, something unthinkable at that time, when tens of hours were required for that particular problem. Nowadays, the same computation is performed in less than a minute in a cluster of 64 V100 nVIDIA graphics cards. The second example was in the whole Pacific Ocean. In both cases, the reduction in computing times exceeded expectations. A new era in Faster Than Real-Time (FTRT) Tsunami computations is here and TEWS around the world will benefit from these technological advances in the very near future.

On the other hand, we tried to summarize recent advances in the modelling of tsunamis generated by landslides, and to take a look at several models that the EDANYA Group has developed in recent years, visiting some real-world examples and some laboratory-based benchmarks. These models deal with solid rigid slides, granular slides, may or may not include dispersion and use shallow water approximations or multilayer approaches to include a richer vertical structure. At the same time, all these models are robust and efficient, implemented in multi-GPUs architectures in order to produce accurate and fast simulations.

5. IDENTIFICATION AND QUANTIFICATION OF TSUNAMI SOURCES CAPABLE OF AFFECTING THE LESSER ANTILLES

The tsunami threat to the Lesser Antilles can be divided into three main sources: earthquakes, volcano-related, and landslide processes (submarine and subaerial). The following sections describe the first two processes, as lack of time did not allow a proper discussion of landslide processes.

5.1 SEISMIC SOURCES

5.1.1 Evidence for the recommended sources

5.1.1.1 Seismic Activity

The Lesser Antilles volcanic arc lies along the eastern edge of the Caribbean plate. A convergence rate of approximately 2 cm/yr between the North American and Caribbean plate (DeMets et al., 2000; López-Venegas et al., 2006; DeMets et al., 2010) generates a long-term seismicity rate that is lower than the rates at more active plate boundaries such as subduction zones along Japan and parts of South America. It is important to stress that given the plate rate and the short historical record, it is very likely that historically observed seismicity does not reflect either the average long-term rate of activity or the maximum possible magnitude (Hough, 2013). Potential credible sources must therefore be identified to a large extent based on knowledge of fault structures. The entire Caribbean is moreover characterized by complex, and to some extent still poorly understood, tectonics, and therefore complex seismicity and seismic/tsunami hazard. Historically observed earthquakes reveal not only significant seismicity, with a well-defined Benioff zone extending to a depth of ~160 km, associated with the subduction zone itself, but also significant earthquakes with a range of focal mechanisms associated with other faults. Potential credible seismic tsunami sources can be defined based on the locations and extent of faulting, as inferred from several lines of evidence including bathymetry, seismicity, and observed focal mechanisms. As is the case along virtually every plate boundary, it is a challenge to proscribe segmentation boundaries across which ruptures are unlikely or unable to propagate. The 2011 Tohoku, Japan, earthquake demonstrated that dynamic earthquake ruptures will not necessarily respect segmentation and similitude laws identified by scientists. Nonetheless, the lateral as well as the depth extent of credible sources can be informed by the available data and an assumption of the maximum credible magnitude for the region.

5.1.1.2 Geodetic

Islands of the Lesser Antilles have been monitored with GPS for almost two decades, mainly for volcanic hazard. However, the inclusion of permanent GPS sites in recent years has been useful to estimate crustal deformation along the arc. Recent analysis of GPS data by Symithe et al. (2015) has provided the most updated velocity field for the Lesser Antilles, which has significantly improved compared to previous studies, allowing to draw important conclusions. In the current form, these studies do not require the existence of a distinct Northern Lesser Antilles block with slip partitioning in the northern Lesser Antilles and fast slipping strike-slip fault in the back-arc. On the contrary, GPS velocities are very consistent within the arc, excluding more that 2 mm/yr of deformation within the arc at the 95% confidence level.

In addition, the lack of current relative motion of the Lesser Antilles with respect to the Caribbean plate (less than ~1 mm/yr), including at the sites closest to the subduction interface such as Antigua in the north, La Désirade in the centre, or Barbados in the south, excludes a fully locked plate interface. Symithe et al. (2015) tested a number of plate locking models, starting with a fully locked interface from the trench down to a depth of 40 km, which they chose as the average depth of the 350°C isotherm in the absence of more information on the thermal structure of the subduction. On a more recent study, van Rijsingen et al. (2020) used GPS data and applied it to a Bayesian approach to conclude minimal coupling exist along the arc, and thus were able to rule out thrust mechanisms for the largest events in the region (1839 and 1843), and therefore, excludes the possibility that the plate interface is fully locked from the trench all the way down to 40 km depth. This fact is interesting because it presents conflicting evidence with the geologically and paleogeodetically derived data because bringing the locked interface to greater depths would only increase the misfit. Any locked region of significant lateral extent – for instance that of the assumed 1843 rupture – at greater depth would produce velocities with respect to the Caribbean plate that are not currently observed. The possibility remains that the plate interface is locked at shallow depth from the trench down to ~15 km, as the resolution of the GPS measurements is not sufficient to reliably estimate locking at such distances from the observation sites.

Therefore, results from GPS studies in the area can be used to conclude that any plate interface source located at depths greater than about 15 km violates either the GPS data or the notion that plate coupling can be used to estimate the extent area of future plate interface earthquakes, a notion that however appears to hold at most other subduction plate boundaries.

5.1.1.3 Geologic: Coral Microatoll Paleogeodetic Evidence

Based on coral microatoll records, each covering many decades within the time interval from the late 19th to early 21st century, Weil-Accardo et al. (2016) were able to determine vertical deformation rates in the northern Lesser Antilles forearc ranging from +2 to -8 mm/yr, with a general trend of greater subsidence rates closer to the subduction front. The only process capable of producing the observed magnitude and broad distribution deformation is locking variability on the subduction interface. Most of these data fit the expected deformation pattern of the down-dip edge of an interseismically locked patch on the megathrust: zero deformation near the volcanic arc increasing toward a small peak of uplift, then plunging subsidence nearer to the subduction front. Preliminary models suggest interface locking extending as far west as La Desirade Island and the eastern coasts of Antigua and Barbuda would be required to fit these data, which corresponds to depths of 50-60 km on the subduction interface. This accumulated strain will likely be released in future earthquakes.

While the recent GPS-based coupling models of Symithe et al. (2015) and van Rijsingen et al. (2020) suggest little or no strain accumulation, particularly below 15 km depth, anywhere along the Lesser Antilles megathrust during the last ~20 years, the coral data (which average deformation rates over many decades) suggest that significant strain accumulation occurred over the course of a century. These observations provide a basis for tsunami source models that include the domain of the plate interface below 15 km depth. Due to the distance between the islands and the subduction deformation front, the coral microatoll data (like the GPS data) unfortunately do not constrain strain accumulation on the shallowest part of the subduction interface, which is also the most dangerous in terms of tsunami potential. It should be noted that subduction interfaces that appear poorly coupled based on GPS data, such as along the coast of northern Peru, have still produced significant tsunamis, notably through so-called “tsunami earthquakes” (Nocquet et al., 2014).

5.1.1.4 Paleotsunami

The Lesser Antilles is a region with assumed long recurrence intervals for potential tsunamigenic earthquakes. However, historical observations reach back only to the 16th century (Lander et al., 2002) and thus do not cover even a single full earthquake cycle. Therefore, sedimentary sequences, both on- and offshore, are the only archives that provide evidence of ancient tsunamis beyond the limit of the historical record. The sedimentary archives may store direct or indirect evidence of earthquakes and tsunamis. Onshore tsunami deposits are direct indicators of large-scaled inundation. Indirect features of potential tsunamis include seismoturbidites and liquefaction, both linked to seismic shaking, as well as mass wasting deposits and submarine or subaerial scarps as evidence of large-scaled slides.

The sedimentary evidence of tsunamis in the Lesser Antilles is sparse in comparison to other coastlines worldwide. Atwater et al. (2017) documented fields of coral boulders on Anegada that were transported onshore by a tsunami in pre-Columbian times (1200–1480 AD). Fine-grained tsunami deposits in salt ponds underline that Anegada was almost entirely flooded from north to south. Deposits of the same age were also found on St. Thomas and Anguilla. Therefore, this pre-Columbian tsunami event had a significantly higher impact than any of the historically documented tsunamis (e.g. 1867).

Geological tsunami evidence of tsunamis in pre-Columbian times is rare on the other islands of the Lesser Antilles. Engel et al. (2016) give an overview of studies that presume to have found tsunami-related deposits. However, many of the listed deposits are dubious and their interpretation as tsunami deposits is questionable. A majority of the documented sediments may represent storm deposits. The interpretation of inundation deposits is not straightforward in regions that are affected both by tsunamis and storms. Severe storm events of the last decade have for example shown that large boulders can likewise be entrained and transported by storms. Coast-parallel coast-clast ridges were previously interpreted as tsunami deposits, but recent studies have proven that their fabric can only be created during storms when thousands of waves rush onshore and constantly move clasts (Morton et al., 2008; Spiske and Halley, 2014; Spiske, 2016).

In the future, more sedimentological studies are needed to decipher the tsunami history of the Lesser Antilles. The knowledge of sediment entrainment, transport and deposition during a tsunami has increased dramatically since the 2004 Indian Ocean and 2011 Tohoku tsunamis. Thus, previously described field sites in the Caribbean need to be revisited.

5.1.2 Definition of seismic sources

We define tsunamigenic seismic sources as simple rectangular fault ruptures where the four corners of each rupture plane indicate the orientation of the fault in space (strike, dip). Figure 2 shows the orientation in both map view (top) and obliquely (bottom) to better visualize the description of the fault parameters. Points A and D indicate the down-dip limit of the rupture plane, whereas points B and C are located up-dip or closer to the surface. As such, point A denotes the lower left corner of the fault plane and is found at the maximum depth the fault plane reaches between plates. Strike (φ) of the fault is along segment B–C, whereas the dip (δ) is the angle formed between a horizontal plane and the segment B–A at depth. In map view, segments B–A and C–D indicate an apparent width of the rupture plane (W_{ap}). Variables W and L are the true width and length of the fault rupture plane denoted by $W = W_{ap} / \cos \delta$ and L, respectively. The slip angle (λ) is shown on the oblique view and denotes the motion of the hanging wall with respect to the footwall. We follow this definition throughout the document with the aim of providing basic information to understand the sources that were defined and also provide the necessary information required to carry out any modeling attempt. The heading of Table 2 indicates the fault parameters used in the meeting to describe seismic sources.

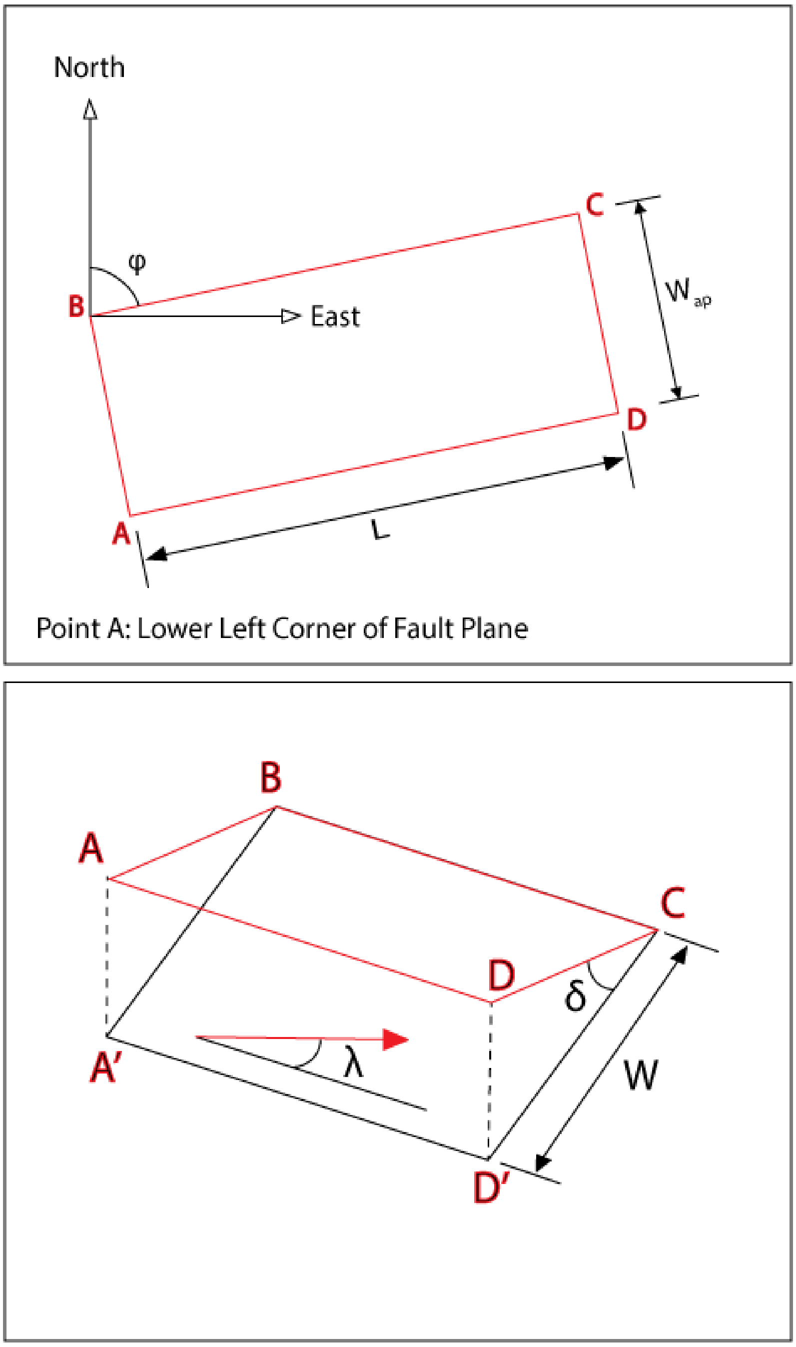

Figure 2. Adopted convention of source geometry. Map view and perspective view show fault plane rupture parameters; Fault source corners (A',B,C,D'), strike (φ), dip (δ), width (W), length (L), and slip direction (λ). Slip vector defined in the direction of slip angle λ lies on the dipping plane A'BCD'. Apparent width (W_{ap}) shows fault rupture width formed by plane ABCD in map view, which takes into consideration the dip of the fault. Segment BC is the updip fault length, while segment A'D' defines the downdip fault length.

5.1.2.1 Sub-fault segments

Based on the discussion of seismic sources, where an apparent discrepancy was observed between the geodetic results and the paleogeodetic and paleotsunami data, the group agreed to provide two sources for the same fault system. In this document we define a source based on the characteristics of the diagram shown in Figure 3. The full source has been defined in this document as a rupture having a total width of 200 km, starting from an approximate depth of 50 km at the downdip extent of the subduction interface, and reaching the initiation of the trench at the surface. This full domain has been divided into two segments:

- Segment A: Rupture area defined by the trench location on the seafloor down to approximately 15 km depth along the subduction interface (shown in yellow in Figure 3). This segment is also split into a shallower section dipping 8° down to a depth of 5 km, and a deeper one dipping 10° down to a depth of 15 km. This latter segment has been defined in this meeting as the source rupture plane. The total width of Segment A is approximately 100 km.

- Segment B: Rupture area with a width defined from the 15 km terminus of Segment A to a depth of 50 km. Segment B, shown in Figure 3 in red, has a continuous slope of 30 degrees.

5.1.2.2 Characteristics of Rupture Sources

The consensus reached at the meeting on the definition of multi-segment sources reconciles the different viewpoints expressed by the participants, given the limitations and suggestions of the presented available data. As it can be recalled from the summary of the presentations in the above section, the geologic and paleogeodetic data prefer a full source rupture, whereas the geodetic data suggests Segment A is the sole contributor to the rupture process and thus to any tsunami generation. In view of the presented discrepancies, the group agreed to adopt two possible sources for each interplate fault system.

- Full (Segments A & B) – complying with both paleogeodetic and geodetic data.

- Shallow (Segment A) – complies only with the geodetic data.

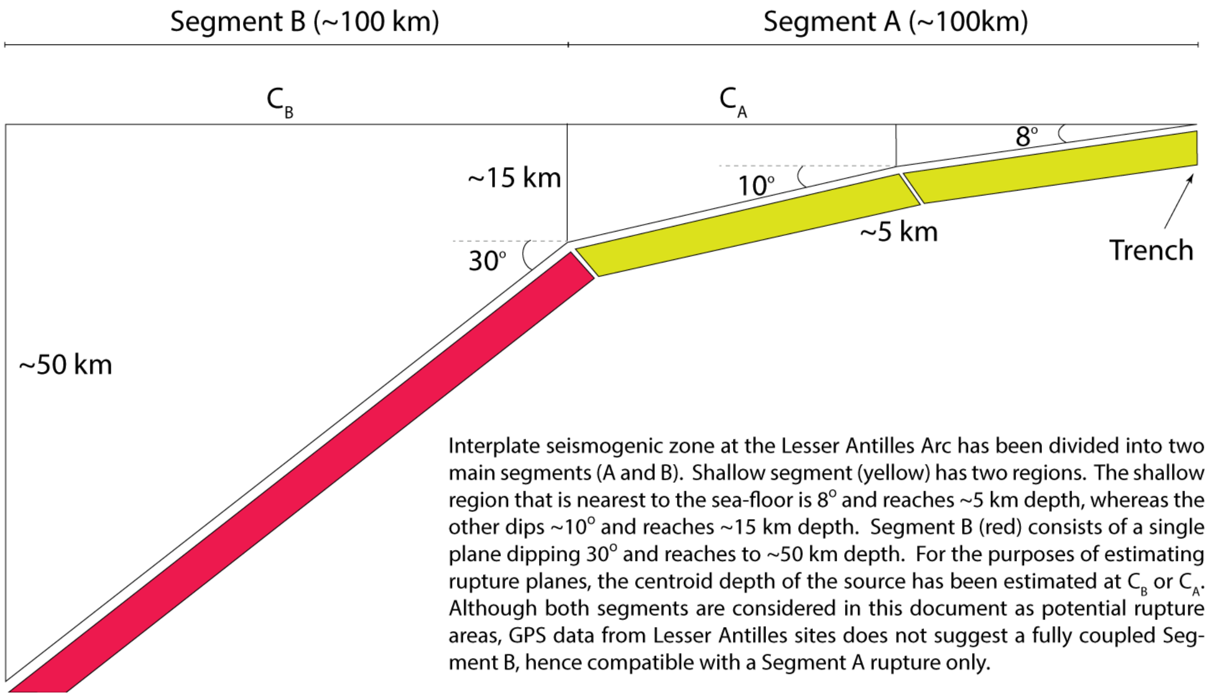

Figure 3. Cross-sectional view of subducting slab parametrization in the framework of the proposed tsunami sources for the interplate source category at the Lesser Antilles Trench. Experts have agreed to treat the subducting North America and South America slab as a two-segment slab with distinctive lengths and subduction angles and corresponding tsunami potential. Inset text provides a detailed description.

5.1.2.3 Sources

The group of experts suggest dividing the Lesser Antilles Arc into two sections: Northern and Southern. The division of the arc in these two provinces has been postulated in the past based on the differences of volcanic rock ages, petrographic affinities, angle of Benioff-Wadati profiles and arc morphology, among others. Based on GPS data, marine geophysical and geological surveys, the northern part of the arc appears to be more complex, with a wide variety of possible sources, whereas a single interplate source was suggested for the southern part.

- Northern Lesser Antilles Arc

This section of the arc features the abrupt change southward at the eastern terminus of the Puerto Rico Trench down to roughly latitude 15.5N. In this part of the arc, the experts identified three categories of sources.

A. Interplate sources

Sources in this category relate to the subduction of the North America plate beneath the Lesser Antilles forearc. Therefore, sources occur at the interface, as suggested by the two-segment model explained above and in Figure 3. Table 2 and Figure 4 show these sources, which from north to south are:

Northern Lesser Antilles 1 (NLA1): NLA1 has two sources. The first is denominated as NLAF1s, and features the shallow segment. Source NLAF1f features a source rupturing both segments (relate to Figure 3 for reference). Both segments have a fault length of 200 km and a slip angle of 50 degrees making it an oblique source, consistent with the relative plate motion direction in relation to the Lesser Antilles Trench direction. Using both segments yields a maximum M_w of 8.5.

Northern Lesser Antilles 2 (NLA2): NLA2 also has two sources. It is a similar source to NLA1 to the north but slightly less oblique (60 degrees slip angle). The 1843 event occurred in the domain of this source, although experts in the meeting did not feel confident concluding the source was due to an interplate mechanism. The source is also 200 km in length with a slightly larger wider segment A than NLA1. The total M_w for this event reaches 8.63 when both segments are combined and M_w =8.47 when only the shallower segment is considered.

Between Barracuda Ridge and Tiburon Rise (BRTR): This source is also segmented and follows the same fault length as in the two previous cases. The main difference with the other two sources is the full thrust mechanism (slip angle = 90degrees). Experts in the meeting considered this source could be controlled by the location of the two subducted ridges; the Barracuda Ridge to the north and the Tiburon Rise to the south. Studies such as Hayes et al.'s (2014) were used in the discussion to justify this source, as it has been argued that subducted ridges may play an important role in the mechanism of rupture initiation and suppression. Using both segments and the rest of the parameters in Table 1, BRTRf may rupture in a M_w 8.63 event, whereas using a single segment A source would yield a M_w =8.46.

Eastern Puerto Rico Trench – (EPRT): This source is adopted from a previous study addressing tsunami sources in the Puerto Rico – Virgin Islands region. The source has 3 lengthwise segments totalling 256 km fault length and features a full thrust mechanism. The justification for this event comes from the paleogeodesic and paleotsunami evidence of studies performed on the island of Anegada (Watt et al., 2011 Buckley et al., 2012; Atwater et al., 2017).

B. Normal Faults within the Arc

Extensive marine geological and geophysical surveys in the Lesser Antilles by various groups, in particular those from France, have generated a great wealth of data for the region, concluding with numerous faults within the forearc that run both parallel and perpendicular to the trench. The following sources have been identified and named based on the neighbouring islands. Tables 3 and 4 summarize source parameters for these arc-parallel and arc-normal crustal sources, respectively. Figure 5 shows the location and dimensions of these sources.

Arc-Parallel fault sources: Faults in this category demonstrate a predominant perpendicular orientation to the trench strike with a consistently normal mechanism. Due to the estimated fault dimensions, magnitudes for these sources are in the M_w ~7 range. The procedure to obtain these sources is as follows: first, a fault length is computed based on mapped faults on the bathymetry; from North to South, as shown on Figure 5 and in Table 3, these are:

- APANEG: Proposed source of the 18 November 1867 earthquake and tsunami (Barkan and ten Brink, 2010).
- APSMRT: Northeast of the island of St. Martin.
- APSABA: Northwest of Saba Island.
- APNEVIS: Fault between the islands of Nevis and Montserrat.
- APMONTS (1&2): Two segment fault source between Montserrat and Basse Terre of Guadeloupe. This source is based on the Bouillante-Montserrat Fault (Montserrat-Guadeloupe) mapped by Feuillet et al. (2001, 2002, 2004, 2010).
- APLESANT: Fault between the island of Les Saintes and Dominica, known as Roseau fault, described by Feuillet et al. (2011). Centroid, fault width, dip and rake were taken from Salichon et al. (2009).
- APDMNC: Fault between Dominica and Martinique. Dip and rake of the fault were obtained from events in this region available from the Global CMT catalog.
- APMRTQ: Fault between Martinique and St. Lucia with unknown dip direction. Two possible scenarios have been postulated for this fault, one that dips towards the Northwest, the other towards the Southeast.

Arc Normal fault sources: Faults in this category demonstrate an orientation predominantly normal to the trench strike with transtensional mechanisms. Normal faulting with some left-lateral motion is the predominant mechanism (6 out of 9 sources have an assigned rake of -75 degrees).

- ANANGN: NW-trending fault located Northeast of the island of Anguilla. This fault dips to the Southeast.
- ANANGS: Another normal fault located Northeast of Anguilla but with a longer fault length that dips towards the Northwest.
- ANSTBRTS: Normal fault offshore Northeast of the island of St. Barthélemy. Dip is towards the Southeast.
- ANBARBU: Short-length fault located north of the island of Barbuda.
- ANANTG: Long fault length dipping to the Northwest located Northeast of the island of Antigua. This fault dips towards the Northwest.
- ANMONTS: Normal fault dipping to the South-southeast and located east of the island of Montserrat.
- ANGTERR: Southeast-dipping fault Northeast of Grande Terre, Guadeloupe.

- ANDESI: Long fault length dipping North and located North of the island of La Désirade.
- ANMAGAL: Long fault length dipping towards North located North of the island of Marie Galante. This source is based on suggested fault parameters from Feuillet et al. (2004; 2011)
- ANDOM (N & S): Only faults in the list that do not follow a purely orthogonal direction to the trench axis. Faults striking East-Southeast and dipping Northeast.
- ANDOMN and ANDOMS are located east of the island of Dominica and both dip towards Northeast.

C. Atlantic faults:

Steeply dipping normal faults associated with aseismic oceanic ridges. These sources are based on marine geophysical studies by Pichot et al. (2012). Both sources in this category dip steeply towards the south, hence the small apparent width of the faults on Figure 4. Both have been assigned a rake of 90 degrees, suggesting pure thrust.

- Barracuda Ridge (BARR): Steeply-dipping (80 degrees) fault oriented towards East-Southeast along the axis of the Barracuda Ridge.
- Tiburon Rise (TIBR): Steeply-dipping (80 degrees) fault oriented towards East-Southeast along the axis of the Tiburon Rise.

- Southern Lesser Antilles Arc

A. Interplate source

Barbados (BARB): According to the experts, this source is a megathrust earthquake with questionable potential given that GPS studies have shown the island of Barbados has a similar velocity to the Caribbean plate, suggesting that the entire Southern Lesser Antilles arc moves along with the Caribbean plate, as opposed to the Northern Lesser Antilles that features distinctive deformation zones throughout the arc. It has been suggested that sediment input to the trench lubricates the subduction zone (Westbrook, 1975), thus resulting in a lower seismic hazard. However, since these arguments lack a proper validation, the experts decided to assign a single larger rupture source occupying the entire Southern Lesser Antilles subduction area. The same sub-segment approach was also applied to this source.

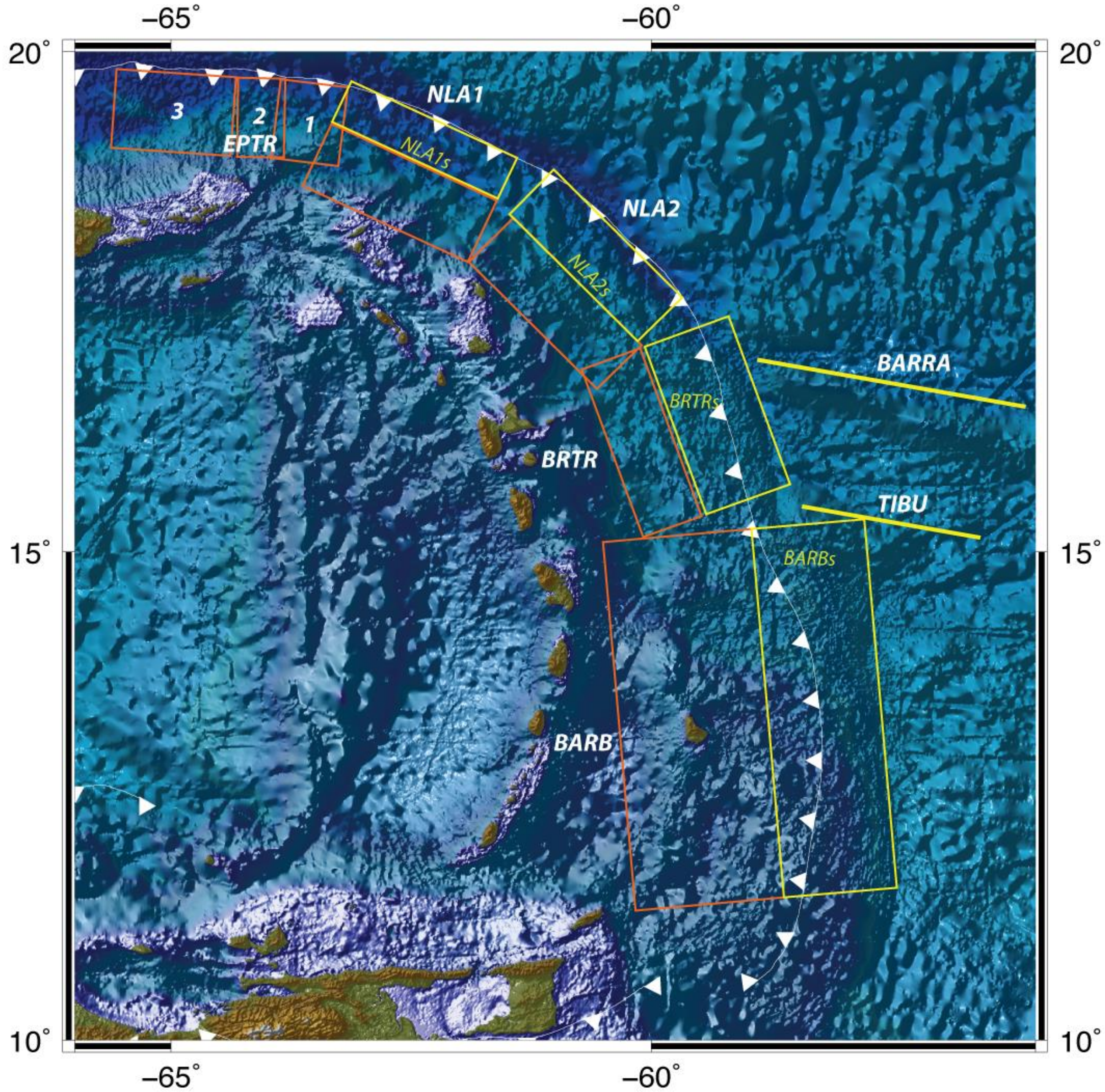

Figure 4: Interplate thrust fault and outer ridge sources considered during the experts meeting. A total of five thrust segments were considered, from north to south these are: EPTR, NLA1 and NLA2 – Northern Lesser Antilles 1 and 2, respectively; BRTR – a fault segment between the Barracuda and Tiburon ridges; and BARB – Southern Lesser Antilles segment under Barbados. Colour code of the segments (except for EPTR which is taken from a previous study) follow the characterization described in Figure 3 (two segment subduction interface where the updip section is shown in the yellow box, and the downdip segment in red). Two sources are identified: Full (suffix 'f' is added to the name of the source in Table 2) where both segments are considered, and Shallow (suffix 's') representing a source only rupturing the shallow portion of the thrust interface (yellow rectangles). Marine geological and geophysical studies have identified possible normal-fault sources along the Barracuda (BARRA) and Tiburon (TIBU) ridges.

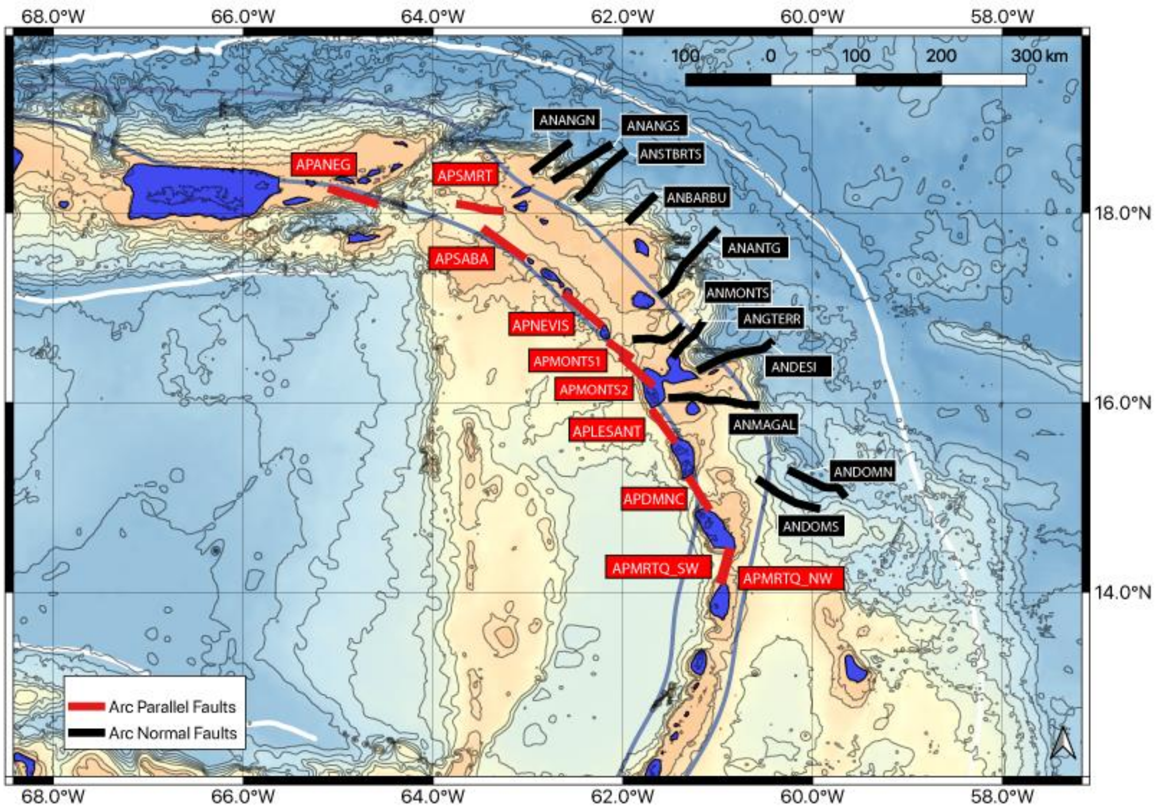

Figure 5. Tsunami sources within the forearc region. Black lines represent fault sources from predominantly normal faults oriented perpendicular to the arc direction (Arc Normal, Table 4). Red lines represent transtensional fault sources along the axis of the arc (Arc Parallel, Table 3). Both types of faults have been mapped by marine geophysical and geological surveys (Feuillet et al, 2001, 2002, 2010).

			Geometric Center			Fault Area		Fault Parameters					
Source #	**Name**	**Segm. #**	**Lon**	**Lat**	**Depth (km)**	**Length (km)**	**Width (km)**	**Strike (º)**	**Dip (º)**	**Rake (º)**	**Slip (m)**	**Seismic moment (N*m)**	**Magnitude (Mw)**
1	EPRT	1	-63.56	19.00	17	74	90	97	15	90	7.5	1.50E+21	**8.41**
		2	-64.06	19.04	17	51.6	90	91	15	90	7.5	1.04E+21	
		3	-64.97	19.08	17	130.7	90	94.4	15	90	7.5	2.65E+21	
2	NLA1f	1	-62.62	18.73	30	200	80	115	20	50	10	4.80E+21	**8.55**
		2	-62.38	19.22	20.5	200	40	115	8	50	15	3.60E+21	
3	NLA1s	1	-62.38	19.22	20.5	200	40	115	8	50	15	3.60E+21	**8.31**
4	NLA2f	1	-61.00	17.50	40	200	80	135	30	60	10	4.80E+21	**8.63**
		2	-60.58	17.98	15	200	70	135	8	60	15	6.30E+21	
5	NLA2s	1	-60.58	17.98	15	200	70	135	8	60	15	6.30E+21	**8.47**
6	BRTRf	1	-60.10	16.10	40	200	80	160	30	90	10	4.80E+21	**8.63**
		2	-59.31	16.38	13	200	100	160	8	90	10	6.00E+21	
7	BRTRs	1	-59.31	16.38	13	200	100	160	8	90	10	6.00E+21	**8.46**
8	BARBf	1	-59.56	13.28	38	420	170	175	10	90	10	2.14E+22	**9.05**
		2	-58.20	13.50	12	420	130	175	10	90	15	2.46E+22	
9	BARBs	1	-58.20	13.50	12	420	130	175	10	90	15	2.46E+22	**8.86**
10	BARRA	1	-57.50	16.70	7	300	15	100	80	90	3	4.05E+20	**7.67**
11	TIBU	1	-57.50	15.30	7	200	15	100	80	90	3	2.70E+20	**7.56**

Table 2. Interplate source parameters. Geometric centre reference refers to the central location of the fault rupture plane. Sources 2 – 9 have a shallow (s) and full (f) source determination to accommodate discrepancies in the seismogenic zone description based on available data. Estimates of Seismic Moment were based on the empirical relations of Wells and Coppersmith (1994).

Source #	Name	Segm. #	Lon	Lat	Depth (km)	Length (km)	Width (km)	Strike (º)	Dip (º)	Rake (º)	Slip (m)	Seismic moment (N*m)	Seismic moment (dyn-cm)	Magnitude (Mw)
12	APANEG	1	-65.00	18.17	15	50.00	25	135	45	-45	6.0	2.48E+20	2.48E+27	7.5
13	APSMART	1	-63.50	18.00	11.3	47.10	22	99	75	-75	1.5	5.13E+19	5.13E+26	7.1
14	APSABA	1	-63.21	17.71	11.3	52.37	22	306	75	-75	1.5	5.70E+19	5.70E+26	7.1
15	APNEVIS	1	-62.39	17.00	11.3	49.88	22	310	75	-75	1.5	5.43E+19	5.43E+26	7.1
16	APMONTS1	1	-62.07	16.60	7.3	25.60	15	304	75	-75	0.8	1.01E+19	1.01E+26	6.6
17	APMONTS2	2	-61.80	16.40	11.3	42.90	22	311	75	-75	1.4	4.36E+19	4.36E+26	7.0
18	APLESANT	1	-61.53	15.76	14	38.51	20	324	55	-90	1.3	3.30E+19	3.30E+26	6.9
19	APDMNC	1	-61.15	15.10	7.1	37.27	20	327	45	-75	1.3	3.20E+19	3.20E+26	6.9
20	APMRTQ_NW	1-NWdip	-60.93	14.26	9.9	31.42	20	195	80	-90	1.0	2.07E+19	2.07E+26	6.8
21	APMRTQ-SE	1-SEdip	-60.87	14.26	10	31.42	20	15	80	-90	1.0	2.07E+19	2.07E+26	6.8

Table 3. Arc-Parallel source parameters. Parameters follow same description as in Table 2.

Source #	Name	Segm. #	Lon	Lat	Depth (km)	Length (km)	Width (km)	Strike (°)	Dip (°)	Rake (°)	Slip (m)	Seismic moment (N*m)	Seismic moment (dyn-cm)	Magnitude (Mw)
22	ANANGN	1	-62.73	18.55	10.1	48.93	21	54	75	-90	1.4	4.75E+19	4.75E+26	7.1
23	ANANGS	1	-62.45	18.58	13.6	73.18	28	240	75	-90	1.7	1.15E+20	1.15E+27	7.3
24	ANSTBRTS	1	-62.2	18.38	13.6	74.17	28	43	75	-90	1.7	1.16E+20	1.16E+27	7.3
25	ANBARBU	1	-61.85	18.06	10	37.90	20	227	75	-90	1.3	3.25E+19	3.25E+26	6.9
26	ANANTG	1	-61.35	17.53	14.5	96.50	30	222	75	-90	2.0	1.91E+20	1.91E+27	7.5
27	ANMONTS	1	-61.59	16.71	12.1	57.15	25	80	75	-90	1.5	7.07E+19	7.07E+26	7.2
28	ANGTERR	1	-61.33	16.69	10.2	47.43	21	44	75	-90	1.4	4.60E+19	4.60E+26	7.0
29	ANDESI	1	-60.86	16.54	14.1	88.42	29	247	75	-90	1.9	1.61E+20	1.61E+27	7.4
30	ANMAGAL	1	-61.06	16.07	16	98.73	33	275	75	-90	2.0	2.15E+20	2.15E+27	7.5
31	ANDOMS	1	-60.25	15.03	13.6	74.06	28	303	75	-90	1.7	1.16E+20	1.16E+27	7.3
32	ANDOMN	1	-59.95	15.1	12.1	68.66	25	113	75	-90	1.7	9.63E+19	9.63E+26	7.3
	MGal1	1	-60.946	16.039	5	50	5	280	75	-90	1	8.25E+18	8.25E+25	6.5
	MGal2	1	-60.946	16.039	12	80	24	280	75	-90	2	1.27E+20	1.27E+27	7.3

Table 4. Arc-Normal source parameters. Parameters follow same description as in Table 2. Blue entries represent parameters from Feuillet et al. (2004) (MGal1) and Feuillet et al. (2011) (MGal2)

5.2 NON-SEISMIC SOURCES: VOLCANIC ERUPTIONS AND LANDSLIDES

Non-seismic sources of tsunamis include both subaerial and submarine landslides, and volcanic sources related to eruptive processes and volcano flank instability. Tsunami warning systems are structured primarily to deal with earthquake-generated tsunamis, and rely on automatic processing of earthquake location, wave detection (using tide gauges and buoys), numerical simulations of wave propagation and inundation, and communication networks to issue timely alarms. These systems are currently not suited to deal with non-seismic sources of tsunamis (Paris, 2015). In the NOAA/NCEI database, 11 volcanic tsunami events are listed for the Caribbean region since 1843. The Lesser Antilles are thus among the most frequently impacted areas in the world, even if historical volcanic tsunamis there were of moderate magnitude (max runup recorded <5 m). The Lesser Antilles are also exposed to tsunamis generated by landslides, as evidenced by numerous submarine landslide scars and recurrent mass-wasting deposits in the sedimentary record. According to the NOAA/NCEI database, co-seismic landslides were locally implied in the generation of waves during the 1692 (Jamaica), 1856 (Honduras), 1882 (Panama), 1918 (Puerto Rico) and 2010 (Haiti) earthquakes (e.g. López-Venegas et al., 2008, 2015; Hornbach et al., 2010). The 1979 local tsunami in Venezuela (Puerto Cumabero) was most probably generated by a landslide, which was not associated with any detectable earthquake. Landslides were also frequent in the geological history of volcanoes of the Lesser Antilles, with 47 main events during the last 1.2 million years and 15 during the last 12 thousand years (Boudon et al., 2007). Detailed record at the island scale reveals more frequent but less voluminous events in the northern part of the volcanic arc (e.g. >130 eruptive and mass-wasting events east of Montserrat in ~1 Ma: Coussens et al., 2016).

Indirect geological evidence of regional landslide-related tsunamis is presented by Lebas et al. (2011), Watt et al. (2012a, b) and Brunet et al. (2015). Brunet et al. (2015) observed at least three large-scaled subaerial flank collapse features on Martinique. The events occurred around 9, 32 and 127 thousand years ago and did certainly cause a large local or even regional tsunami. Lebas et al. (2011) detected seven mass wasting deposits (oldest, about 2.5 million year old) off Martinique which are potentially related to landslides that are much larger than any of the recent mass movements. Watt et al. (2012a, b) surveyed the sediments offshore Montserrat and found at least two mass wasting deposits (140 and 700 thousands years ago) that are related to flank collapses. They propose a recurrence interval of these events on the order of 10^3 to 10^4 years.

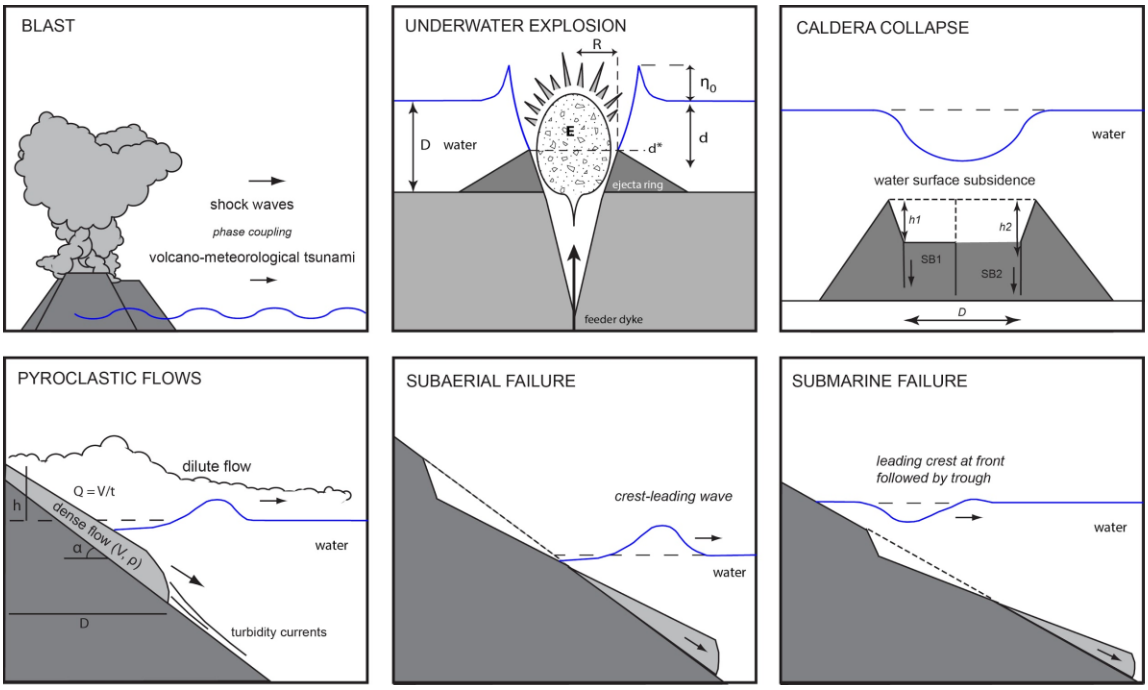

Figure 6. Non-seismic causes of tsunamis and some relevant parameters to consider for numerical simulations (modified from Paris et al., 2014).

YEAR	MONTH	DAY	COUNTRY	VOLCANO	LAT	LONG	CAUSE	WAVE HEIGHT
1902	5	5	MARTINIQUE (FRANCE)	MOUNT PELEE	14.82	-61.17	DEBRIS FLOW	≤ 4 m
1902	5	7	SAINT VINCENT - GRENADINES	SOUFRIÈRE	13.33	-61.18	PYROCLASTIC FLOW	≤ 1 m
1902	5	8	MARTINIQUE (FRANCE)	MOUNT PELEE	14.82	-61.17	PYROCLASTIC FLOW	
1902	5	20	MARTINIQUE (FRANCE)	MOUNT PELEE	14.82	-61.17	DEBRIS FLOW	
1902	8	30	MARTINIQUE (FRANCE)	MOUNT PELEE	14.82	-61.17	DEBRIS FLOW	≤ 1 m
1939	7	24	GRENADA	KICK 'EM JENNY	12.3	-61.63	EXPLOSION ?	≤ 2 m
1965	10	24	GRENADA	KICK 'EM JENNY	12.3	-61.63	EXPLOSION ?	
1997	12	26	MONTSERRAT	WHITE RIVER VALLEY	16.72	-62.18	PYROCLASTIC FLOW	≤ 3 m
1999	1	20	MONTSERRAT	SOUFRIÈRE HILLS	16.722	-62.18	PYROCLASTIC FLOW	≤ 2 m
2003	7	12	MONTSERRAT	SOUFRIÈRE HILLS	16.722	-62.18	PYROCLASTIC FLOW	≤ 4 m
2006	5	20	MONTSERRAT	SOUFRIÈRE HILLS	16.722	-62.18	PYROCLASTIC FLOW	≤ 1 m

Table 5. List of historical volcanic tsunamis that were observed in the Lesser Antilles since 1902 (modified from NCEI database: https:/www.ngdc.noaa.gov/hazard/tsu.shtml).

VOLCANO	COUNTRY	ISLAND	LAT	LONG	LAST ACTIVITY
Saba	Netherlands	Saba	17.63	-63.23	1640
The Quill	Netherlands	St Eustatius	17.478	-62,96	250
Liamuiga	St Kitts & Nevis	St Kitts	17.37	-62.8	160
Nevis	St Kitts & Nevis	Nevis	17.15	-62.58	unknown
Soufrière Hills	United Kingdom	Montserrat	16.72	-62.18	2013
Soufrière	France	Guadeloupe	16.04	-61.66	1977
Morne Watt	Dominica	Dominica	15.31	-61.31	1997
Morne Plat Pays	Dominica	Dominica	15.26	-61.34	1270
Mount Pelée	France	Martinique	14.81	-61.17	1932
Qualibou	St Lucia	St Lucia	13.83	-61.05	1766
Soufrière	St Vincent & Grenadines	St Vincent	13.33	-61.18	1979
Kick 'em Jenny	Grenada	submarine	12.30	-61.64	2017
St Catherine	Grenada	Grenada	12.15	-61.67	unknown

Table 6. List of active volcanoes of the Lesser Antilles (Smithsonian Institution Holocene volcano list available at http://volcano.si.edu/list_volcano_holocene.cfm).

The group of experts discussed different non-seismic sources of tsunamis to be considered in the Lesser Antilles and proposed the following scenarios as priorities for numerical simulations of non-seismic sources of tsunamis (Table 7).

- Scenario 1 is a submarine explosion located in the central crater of Kick'em Jenny submarine volcano (Grenada) at a water depth of 180 m. Sub-scenarios (1a, 1b, etc.) correspond to different energies of explosion that will directly influence the initial uplift of the water surface (water crater). Numerical simulations of tsunamis generated by underwater explosions generally use the empirical formula of Le Méhauté & Wang (1996) to estimate the initial surface displacement as a function of explosion energy (e.g. Ulvrova et al., 2016).

- Scenario 2 is a pyroclastic flow entering the sea at velocities up to 50 m/s, following a dome collapse at Montserrat Hills volcano, as occurred several times during the 1997–2006 period of intense activity (e.g. Heinrich et al., 1998; Calder et al., 1999; Herd et al., 2005; Le Friant et al., 2010). Scenario 1a is a pyroclastic flow in the Tar River valley (western flank of the volcano) with a volume flux of 16 million m³ over 2 minutes, corresponding to the 13 July 2003 paroxysm of incremental dome collapse (cf. simulations by Poisson & Pedreros, 2010). Scenario 1b is a 20 million m³ pyroclastic flow generated by a dome collapse and propagating in the White River Valley (southwestern flank), as observed on 26 December 1997 (cf. simulations by Heinrich et al., 1998). The pyroclastic flow scenarios that are proposed here represent benchmarking case-studies for advanced numerical simulations of such complex sources of tsunamis.

- Scenario 3 is a debris flow (lahars) flowing down the central crater of the Soufrière St. Vincent volcano to the western valleys. A local tsunami was observed at St. Pierre and Fort-de-France (Martinique), following a major lahar in the Rivière Blanche on 5 May 1902. Here we select the Soufrière St. Vincent because of: (a) its morphology (the central crater could act as a water reservoir and a breach in the rim would result in a lake outburst) and (b) short travel paths from the crater to the Caribbean Sea (<5 km). Two different volumes are proposed: 5 and 10 million m³. Expected impact is a local tsunami on the western coast of St. Vincent.

- Scenario 4 is a subaerial landslide on the southwestern flank of Morne Patate dome (southern Dominica Island), which was active about 500 years ago (Pelean-type eruption). The landslide has a volume of 0.3 km³, as proposed by Le Roy et al. (2017).

- Scenario 5 is a submarine landslide on the northwestern flank of Kick'em Jenny, with three sub-scenarios corresponding to three different volumes: 0.1 km³ (5a), 0.6 km³ (5b, as simulated by Harbitz et al., 2012, and Le Roy et al., 2017), and 1 km³ (5c, worst-case scenario).

- Scenario 6 is a massive collapse of the western flank of St. Vincent Island, affecting both the submarine and subaerial slopes. Such large-scale events are typical of the southern volcanoes of the Lesser Antilles (e.g. Boudon et al., 2007 and references therein). Based on the reconstructed volumes of these past collapses, we propose volumes ranging between 10 and 30 km³.

- Scenario 7 is a submarine landslide located approximately 25 km NNE of Barcelona city (Venezuela) on the carbonated shelf of the eastern Cariaco Basin. The Cariaco Basin is an east-west trending pull-apart basin at the boundary between the South-American and Caribbean plates. The landslide affects the southern talus of the basin and is directed northward (i.e. towards the Lesser Antilles). Three landslide volumes are proposed (1, 5, and 10 km³), although few data are available on the volume of past mass-wasting events in this basin. ten Brink et al. (2006) identified larger slides (up to 20 km³) in the Puerto Rico Trench.

- Scenario 8 is a submarine landslide on the slope of the Muertos Trough between the Dominican Republic and Puerto Rico. The landslide scar is located 75 km south of the epicentre of the 1984 San Pedro Basin earthquake, and it is directed southward. As for scenario 7, three sub-scenarios are defined based on the landslide volume (1, 5, and 10 km³).

- Scenario 9 is a submarine landslide in the Désirade Graben, east of Antigua and NE of Guadeloupe islands. The graben belongs to the northern part of the Barbados accretionary complex, and evidence of mass-wasting on its northern slope was recently provided by CASEIS marine cruise (PhD of Chloé Seibert). The landslide is thus directed southward, with three sub-scenarios (1, 5 and 10 km³).

SCENARIO	VOLCANO	LOCATION	LAT	LONG	CAUSE	REMARKS
1a	Kick'em Jenny	central crater	12.30	-61.64	underwater explosion	Explosion energy $E = 10^{13}$J
1b	Kick'em Jenny	central crater	12.30	-61.64	underwater explosion	Explosion energy $E = 10^{14}$J
1c	Kick'em Jenny	central crater	12.30	-61.64	underwater explosion	Explosion energy $E = 10^{15}$J
1d	Kick'em Jenny	central crater	12.30	-61.64	underwater explosion	Explosion energy $E = 10^{16}$J
2a	Montserrat Hills	eastern flank	16.71	-62.18	pyroclastic flow	Volume $V = 16 \times 10^6$ m³
2b	Montserrat Hills	southwestern flank	16.71	-62.18	pyroclastic flow	Volume $V = 20 \times 10^6$ m³
3a	Soufrière St Vincent	western flank	13.33	-61.18	debris flow	Volume $V = 5 \times 10^6$ m³
3b	Soufrière St Vincent	western flank	13.33	-61.18	debris flow	Volume $V = 10 \times 10^6$ m³
4	Dominica	Morne Patate SW	15.22	-61.36	subaerial landslide	Volume V = 0.3 km³
5a	Kick'em Jenny	northwestern flank	12.30	-61.64	submarine landslide	Volume V = 0.1 km³
5b	Kick'em Jenny	northwestern flank	12.30	-61.64	submarine landslide	Volume V = 0.6 km³
5c	Kick'em Jenny	northwestern flank	12.30	-61.64	submarine landslide	Volume V = 1 km³
6a	St Vincent	western flank	13.33	-61.18	massive flank collapse	Volume V = 10 km³
6b	St Vincent	western flank	13.33	-61.18	massive flank collapse	Volume V = 30 km³
7a	Cariaco Basin	northward	10.46	-64.78	submarine landslide	Volume V = 1 km³

SCENARIO	VOLCANO	LOCATION	LAT	LONG	CAUSE	REMARKS
7b	Cariaco Basin	northward	10.46	-64.78	submarine landslide	Volume V = 5 km^3
7c	Cariaco Basin	northward	10.46	-64.78	submarine landslide	Volume V = 10 km^3
8a	Muertos Trough	southward	17.55	-69.30	submarine landslide	Volume V = 1 km^3
8b	Muertos Trough	southward	17.55	-69.30	submarine landslide	Volume V = 5 km^3
8c	Muertos Trough	southward	17.55	-69.30	submarine landslide	Volume V = 10 km^3
9a	Desirade Graben	southward	17.25	-60.75	submarine landslide	Volume V = 1 km^3
9b	Desirade Graben	southward	17.25	-60.75	submarine landslide	Volume V = 5 km^3
9c	Desirade Graben	southward	17.25	-60.75	submarine landslide	Volume V = 10 km^3

Table 7. Selected scenarios of non-seismic sources of tsunamis in the Lesser Antilles

The different scenarios presented above embrace different source mechanisms (underwater explosions, pyroclastic flows, debris flows, volcanic and non-volcanic landslides, submarine and subaerial landslides). A large range of volumes is represented (from 5 million m^3 to 30 km^3). The spatial distribution of the selected tsunami sources and their directivity (e.g. direction of the flowing mass) was also considered in order to ensure a good representativity of the possible scenarios of tsunami wave propagation in the study area. Note that this list of scenarios represent a first step towards a more exhaustive list of credible scenarios. Other volcanoes such as Qualibou caldera (St. Lucia) or Liamuiga (St. Kitts) should be considered as potential sources of tsunamis in the case of a volcanic reactivation. The three scenarios of non-volcanic submarine landslides also represent three case-studies among many other possible sources of tsunami. In the future, this deterministic approach of non-seismic tsunami hazard in the Lesser Antilles could be replaced by a probabilistic approach integrating more scenarios and parameters.

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ANNEX I

LIST OF PARTICIPANTS

Mr Bernardo ALIAGA ROSSEL
Programme Specialist, Tsunami Unit
Tsunami Coordination Unit
Intergovernmental Oceanographic
Commission of UNESCO
7, place de Fontenoy
75732 Paris Cedex 07
France
Tel: +33 1 456 803 17
Email: b.aliaga@unesco.org

Mr Nicolas ARCOS (remotely)
Natural Hazards Scientific Data Specialist
Geophysical Sciences
NOAA National Centers for
Environmental Information
325 Broadway
Boulder CO 80305
United States of America
Tel: +1 303 497 3158
Email: nicolas.arcos@noaa.gov

Mr Eric CALAIS
Ecole Normale Supérieure
45 Rue d'Ulm
75005 Paris CEDEX 05
France
Email: ecalais@geologie.ens.fr

Dr Silvia CHACON BARRANTES
Professor and Researcher
Sistema Nacional de Monitoreo de
Tsunamis (SINAMOT)
Universidad Nacional,
Campus Omar Dengo
Heredia Costa Rica
Tel: +506 830 966 90
Email: silviach@una.ac.cr

Ms Valérie CLOUARD
Directeur
Observatoire Volcanologique et
Sismologique de Martinique
Morne des Cadets
Fonds Saint-Denis
97250 French Antilles
Martinique, France
Tel: +596 784 144
Email: clouard@ipgp.fr

Dr Jordane CORBEAU
Observatoire Volcanologique et
Sismologique de Martinique
Morne des Cadets
Fonds Saint-Denis
97250 French Antilles
Martinique, France
Email: corbeau@ipgp.fr

Dr Nathalie FEUILLET
Institut de Physique du Globe de Paris
1, Rue Jussieu Case 89
75238 Paris CEDEX 05
France
Email: feuillet@ipgp.fr

PhD Zamara FUENTES
University of Puerto Rico
Mayaguez Campus
PO BOX 9000
Mayagüez PR 00681-9000
United States of America
Email: zamara.fuentes@gmail.com

PhD Susan E. HOUGH
U.S. Geological Survey/ Earthquake
Science Center
525 South Wilson Avenue
Pasadena CA 91106
United States of America
Email: hough@usgs.gov

Dr Anne LEMOINE
Direction Risques et Prévention
BRGM – French Geological Survey
3 avenue Claude-Guillemin
BP 36009
45060 Orléans CEDEX 2
France
Email: A.Lemoine@brgm.fr

Dr Jorge MACIAS (remotely)
Professor
EDANYA group
Universidad de Málaga
Facultad de Ciencias
Campus de Teatinos, s/n
29080 Málaga
Spain
Tel: +34 952 132 016
Email: jmacias@uma.es

Dr Alberto Manuel LOPEZ VENEGAS
Associate Professor
Department of Geology
University of Puert Rico - Mayaguez Campus
PO BOX 9000
Mayaguez PR 00681
United States of America
Tel: +1 787 8324 040 ext 2704
Email: alberto.lopez3@upr.edu

Prof. Emile OKAL
Department of Earth & Planetary Sciences
Geological Sciences
Northwestern University
Evanston, IL 60208 USA
United States of America
Tel: +1 847 491 3238
Fax: +1 847 491 8060
Email: emile@earth.northwestern.edu

Dr Raphaël PARIS
Observatoire de Physique du Globe de Clermont-Ferrand
Université Clermont-Auvergne
Laboratoire Magmas et Volcans
Campus Universitaire des Cézeaux
63178 Aubière
France
Email: Raphael.Paris@uca.fr

Ph.D. Belle PHILIBOSIAN
U.S. Geological Survey – Menlo Park Campus
345 Middlefield Rd.
Menlo Park CA 94025
United States of America
Email: bphilibosian@usgs.gov

Dr Michaela SPISKE
Universität Basel
Bernoullistrasse 32
CH-4056 Basel
Switzerland
Email: michaela.spiske@unibas.ch

Dr John C. WEBER
Grand Valley State University
The Seymour K. & Esther R. Padnos Hall of Science # 136
One Campus Drive
Allendale Michigan 49401-9403
United States of America
Email: WeberJ@GVSU.edu

Observers

Ms Sandrine CANO-LAURENT
Chef du Service Géomatique et Télégestion
DGAIE/Service Géomatique et Télégestion
Territorial Collectivity of Martinique
Rue Gaston Deferre CS 30137
97201 Fort de France CEDEX
Martinique, France
Tel: +596 696 231 403
Email: sandrine.cano-laurent@collectivitedemartinique.mq

Mr Grégory JABOL
Manager strategy major hazards
Direction risques majeurs
collectivite territoriale de Martinique
7 rue Gaston Defferre CTM
97200 Fort-de-France
Martinique, France
Tel: +596 696 391 316
Email: gregory.jabol@collectivitedemartinisue.mq

Dr Anne-Marie LEJEUNE
Head of the OVSM, Volcanologist
Observatoire Volcanologique et Sismologique de Martinique
Morne des Cadets
97250 Fonds Saint-Denis
French Antilles, Martinique
France
Tel: +596 (0) 696 80 02 53
Email: lejeune@ipgp.fr

Ms Aude NACHBAUR
DAT
BRGM – French Geological Survey
Lotissement Miramar, Pointe des Nègres
97200 Fort-de-France
Martinique, France
Email: a.nachbaur@brgm.fr

Ms Marie-Noëlle RAVEAU
Awareness and Preparedness Officer, Risk Manager
Safety and risk management unit
Territorial Collectivity of Martinique
Rue Gaston Deferre CS 30137
97201 Fort-de-France CEDEX
Martinique, France

Tel: +596 302204
Email: marie-noelle.raveau@cg972.fr

Mr Benoit VITTECOQ
Director
BRGM – French Geological Survey
Direction régionale de Martinique
Route Pointe des Nègres
4, lot. Miramar
97200 Fort-de-France
Martinique, France
Tel: +596696824839
Email: b.vittecoq@brgm.fr

Mr Jan WOERLEIN
Sciences Politiques
Sorbonne Université
27 rue Saint Guillaume
75337 Paris CEDEX 7
France
Email: jan.woerlein@sciencespo.fr

ANNEX II

MEETING AGENDA

Monday, 18 March 201

8:30	Registration
9:00	Welcome
9:15	Designation of Rapporteurs by source type: Seismic, volcanic, landslide
9:20	Goals and Objectives of the Experts Meeting: Alberto M. López
9:45	Historical seismicity and tsunami record of the region Susan Hough (20 min): “Missing Great Earthquakes” Franck Audemard (20 min): “Historical tsunamigenic earthquakes of northeastern Venezuela”

10:30 Coffee break

10:50	Case studies of recent tsunamis Emile Okal (20 min): "Challenges from ancillary tsunami sources in the wake of recent worldwide events”
11:10	Recent studies of tsunami-related work in the Caribbean Silvia Chacón (10 min): “Overview of WG2 work for the past 4 yrs” Michaela Spiske (15 min): “Sedimentary and erosional evidence of historical tsunamis on Anegada, British Virgin Islands” Zamara Fuentes (15 min): “Unearthing the northeast Caribbean’s extreme overwash record” Anne Lemoine (10 min): “Tsunamigenic source scenarios for modeling tsunami flooding for the island of Martinique”

12:20 Lunch break

14:00	CATSAM: Caribbean and Adjacent Regions Tsunami Sources and Models Webmap Nicolas Arcos (remote)(10 min)
14:15	Tsunami threat from Volcanic activity Raphaël Paris (20 min): “Volcanic sources of tsunamis: mechanisms, historical examples, and implication for tsunami hazard in the Lesser Antilles”
14:40	Tsunami threat from Submarine Landslide Alberto López (10 min): “Modeling Submarine landslides in the PRVI region”

15:00 Coffee break

15:15	Summaries of marine geophysical surveys Nathalie Feuillet (25? min): “Overview of Lesser Antilles marine cruises”

Tuesday, 19 March 2019

9:00 Recent advances in tsunami modeling and submarine landslide tsunami modeling:

Jorge Macías (20 min): “recent advances in ftrt tsunami simulations and landslide generated tsunami modeling”

9:30 Neotectonics of the Lesser Antilles: Brief summary of recent publications and findings

Eric Calais (20 min): “Microplate kinematics and interplate coupling in the Caribbean from space geodetic data"

Valerie Clouard (20 min): “Recent advance in central Lesser Antilles seismo-tectonic context”

10: 15 Coffee break

Belle Philibosian (20 min): "20th-century strain accumulation along the Lesser Antilles megathrust from coral microatoll data.”

John Weber (20 min): “Tectonics of the Southeastern Caribbean”

12:00 Lunch Break

14:00 Current sources of the Caribbean Region

Alberto López (10 min)

14:15-16:00 List and discuss potential sources for the Lesser Antilles

Alberto López - Discussion leader

18:30 Public Presentation at CDST (B. Aliaga, S. Chacón, V. Clouard, A. Lemoine, E. Okal, R. Paris)

Wednesday, 20 March 2019

9:00 -12:00 Discussion of sources: Definition of parameters and preliminary modeling (if possible)

a. Seismic: Emile Okal
b. Volcanic: Valerie Clouard and/or Raphaël Paris
c. Landslides: Alberto López

12:00 Lunch Break

14:00 Refine list and finalize source parameters: A. López + group

d. Seismic:
   i. Northern Arc
   ii. Southern Arc
e. Volcanoes
f. Landslides

Draft of report: Group

g. Subdivision of section tasks

Meeting closure

ANNEX III

LIST OF ACRONYMS

BRTR	Between Barracuda Ridge and Tiburon Rise
CATSAM	Caribbean and Adjacent Regions Tsunami Sources and Models
CRF	Central Range fault
EPF	El Pilar fault
FTRT	Faster Than Real-Time
FUNVISIS	Venezuelan Foundation of Seismological Research
ICG/CARIBE-EWS	Intergovernmental Coordination Group for the Tsunami and other Coastal Hazards Warning System for the Caribbean and Adjacent Regions
IFREMER	French Research Institute for Exploitation of the Sea
INGV	Italian National Institute of Geophysics and Volcanology
IOC	Intergovernmental Oceanographic Commission (of UNESCO)
IPGP	Institut de physique du Globe de Paris
ISC	International Seismological Centre
NCEI	National Centers for Environmental Information
NLA1	Northern Lesser Antilles 1
NLA2	Northern Lesser Antilles 2
NOAA	US National Oceanic and Atmospheric Administration
OVS-IPGP	French Volcano and Seismic Observatories from Martinique and Guadeloupe
PRSN	Puerto Rico Seismic Network
PTHA	Probabilistic Tsunami Hazard Assessment
SLSMF	IOC Sea Level Station Monitoring Facility
SLVFs	The Sebastian/La Victoria faults
TEWS	National Tsunami Early Warning System
UNESCO	United Nations Educational, Scientific and Cultural Organization
WDS	World Data Service
WG	Working Group

IOC Workshop Reports

The Scientific Workshops of the Intergovernmental Oceanographic Commission are sometimes jointly sponsored with other intergovernmental or non-governmental bodies. In most cases, IOC assures responsibility for printing, and copies may be requested from:

Intergovernmental Oceanographic Commission – UNESCO
1, rue Miollis, 75732 Paris Cedex 15, France

No.	Title	Languages
1	CCOP-IOC, 1974, Metallogenesis, Hydrocarbons and Tectonic Patterns in Eastern Asia (Report of the IDOE Workshop on); Bangkok, Thailand, 24-29 September 1973 UNDP (CCOP),	E (out of stock)
2	CICAR Ichthyoplankton Workshop, Mexico City, 16-27 July 1974 (UNESCO Technical Paper in Marine Sciences, No. 20).	E (out of stock) S (out of stock)
3	Report of the IOC/GFCM/ICSEM International Workshop on Marine Pollution in the Mediterranean; Monte Carlo, 9-14 September 1974.	E,F E (out of stock)
4	Report of the Workshop on the Phenomenon known as 'El Niño'; Guayaquil, Ecuador, 4-12 December 1974.	E (out of stock) S (out of stock)
5	IDOE International Workshop on Marine Geology and Geophysics of the Caribbean Region and its Resources; Kingston, Jamaica, 17-22 February 1975	E (out of stock) S
6	Report of the CCOP/SOPAC-IOC IDOE International Workshop on Geology, Mineral Resources and Geophysics of the South Pacific; Suva, Fiji, 1-6 September 1975.	E
7	Report of the Scientific Workshop to Initiate Planning for a Co-operative Investigation in the North and Central Western Indian Ocean, organized within the IDOE under the sponsorship of IOC/FAO (IOFC)/UNESCO/ EAC; Nairobi, Kenya, 25 March-2 April 1976.	E, F,S, R
8	Joint IOC/FAO (IPFC)/UNEP International Workshop on Marine Pollution in East Asian Waters; Penang, 7-13 April 1976	E (out of stock)
9	IOC/CMG/SCOR Second International Workshop on Marine Geoscience; Mauritius 9-13 August 1976.	E, F, S, R
10	IOC/WMO Second Workshop on Marine Pollution (Petroleum) Monitoring; Monaco, 14-18 June 1976	E, F E (out of stock) R
11	Report of the IOC/FAO/UNEP International Workshop on Marine Pollution in the Caribbean and Adjacent Regions; Port of Spain, Trinidad, 13-17 December 1976.	E, S (out of stock)
11 Suppl.	Collected contributions of invited lecturers and authors to the IOC/FAO/UNEP International Workshop on Marine Pollution in the Caribbean and Adjacent Regions; Port of Spain, Trinidad, 13-17 December 1976	E (out of stock), S
12	Report of the IOCARIBE Interdisciplinary Workshop on Scientific Programmes in Support of Fisheries Projects; Fort-de-France, Martinique, 28 November-2 December 1977.	E, F, S
13	Report of the IOCARIBE Workshop on Environmental Geology of the Caribbean Coastal Area; Port of Spain, Trinidad, 16-18 January 1978.	E, S
14	IOC/FAO/WHO/UNEP International Workshop on Marine Pollution in the Gulf of Guinea and Adjacent Areas; Abidjan, Côte d'Ivoire, 2-9 May 1978	E, F
15	CPPS/FAO/IOC/UNEP International Workshop on Marine Pollution in the South-East Pacific; Santiago de Chile, 6-10 November 1978.	E (out of stock)
16	Workshop on the Western Pacific, Tokyo, 19-20 February 1979.	E, F, R
17	Joint IOC/WMO Workshop on Oceanographic Products and the IGOSS Data Processing and Services System (IDPSS); Moscow, 9-11 April 1979.	E
17 suppl.	Papers submitted to the Joint IOC/WMO Seminar on Oceanographic Products and the IGOSS Data Processing and Services System; Moscow, 2-6 April 1979.	E
18	IOC/UNESCO Workshop on Syllabus for Training Marine Technicians; Miami, U.S.A., 22-26 May 1978 (UNESCO reports in marine sciences, No. 4 published by the Division of Marine Sciences, UNESCO).	E (out of stock), F, S (out of tock), R
19	IOC Workshop on Marine Science Syllabus for Secondary Schools; Llantwit Major, Wales, U.K., 5-9 June 1978 (UNESCO reports in marine sciences, No. 5, published by the Division of Marine Sciences, UNESCO).	E (out of stock), S, R, Ar
20	Second CCOP-IOC Workshop on IDOE Studies of East Asia Tectonics and Resources; Bandung, Indonesia, 17-21 October 1978	E
21	Second IDOE Symposium on Turbulence in the Ocean; Liège, Belgium, 7-18 May 1979.	E, F, S, R
22	Third IOC/WMO Workshop on Marine Pollution Monitoring; New Delhi, 11-15 February 1980.	E, F, S, R
23	WESTPAC Workshop on the Marine Geology and Geophysics of the North-West Pacific; Tokyo, 27-31 March 1980.	E, R
24	WESTPAC Workshop on Coastal Transport of Pollutants; Tokyo, Japan, 27-31 March 1980.	E (out of stock)
25	Workshop on the Inter-calibration of Sampling Procedures of the IOC/ WMO UNEP Pilot Project on Monitoring Background Levels of Selected Pollutants in Open-Ocean Waters; Bermuda, 11-26 January 1980.	E (Superseded by IOC Technical Series No.22)
26	IOC Workshop on Coastal Area Management in the Caribbean Region; Mexico City, 24 September- 5 October 1979.	E, S
27	CCOP/SOPAC-IOC Second International Workshop on Geology, Mineral Resources and Geophysics of the South Pacific; Nouméa, New Caledonia, 9-15 October 1980.	E
28	FAO/IOC Workshop on the effects of environmental variation on the survival of larval pelagic fishes. Lima, 20 April-5 May 1980.	E
29	WESTPAC Workshop on Marine Biological Methodology; Tokyo, 9-14 February 1981.	E
30	International Workshop on Marine Pollution in the South-West Atlantic; Montevideo, 10-14 November 1980.	E (out of stock) S
31	Third International Workshop on Marine Geoscience; Heidelberg, 19-24 July 1982.	E, F, S
32	UNU/IOC/UNESCO Workshop on International Co-operation in the Development of Marine Science and the Transfer of Technology in the context of the New Ocean Regime; Paris, France, 27 September-1 October 1982.	E, F, S
32 Suppl.	Papers submitted to the UNU/IOC/ UNESCO Workshop on International Co-operation in the Development of Marine Science and the Transfer of Technology in the Context of the New Ocean Regime; Paris, France, 27 September-1 October 1982.	E
33	Workshop on the IREP Component of the IOC Programme on Ocean Science in Relation to Living Resources (OSLR); Halifax, 26-30 September 1963.	E
34	IOC Workshop on Regional Co-operation in Marine Science in the Central Eastern Atlantic (Western Africa); Tenerife, 12-17 December 1963.	E, F, S
35	CCOP/SOPAC-IOC-UNU Workshop on Basic Geo-scientific Marine Research Required for Assessment of Minerals and Hydrocarbons in the South Pacific; Suva, Fiji, 3-7 October 1983.	E
36	IOC/FAO Workshop on the Improved Uses of Research Vessels; Lisbon, Portugal, 28 May-2 June 1984.	E
36 Suppl.	Papers submitted to the IOC/FAO Workshop on the Improved Uses of Research Vessels; Lisbon, 28 May-2 June 1984	E
37	IOC/UNESCO Workshop on Regional Co-operation in Marine Science in the Central Indian Ocean and Adjacent Seas and Gulfs; Colombo, 8-13 July 1985.	E
38	IOC/ROPME/UNEP Symposium on Fate and Fluxes of Oil Pollutants in the Kuwait Action Plan Region; Basrah, Iraq, 8-12 January 1984.	E
39	CCOP (SOPAC)-IOC-IFREMER-ORSTOM Workshop on the Uses of Submersibles and Remotely Operated Vehicles in the South Pacific; Suva, Fiji, 24-29 September 1985.	E
40	IOC Workshop on the Technical Aspects of Tsunami Analysis, Prediction and Communications; Sidney, B.C., Canada, 29-31 July 1985.	E
40 Suppl.	First International Tsunami Workshop on Tsunami Analysis, Prediction and Communications, Submitted Papers; Sidney, B.C., Canada, 29 July-1 August 1985.	E
41	First Workshop of Participants in the Joint FAO/IOC/WHO/IAEA/UNEP Project on Monitoring of Pollution in the Marine Environment of the West and Central African Region (WACAF/2); Dakar, Senegal, 28 October-1 November 1985.	E
43	IOC Workshop on the Results of MEDALPEX and Future Oceanographic Programmes in the Western Mediterranean; Venice, Italy, 23-25 October 1985.	E
44	IOC-FAO Workshop on Recruitment in Tropical Coastal Demersal Communities; Ciudad del Carmen, Campeche, Mexico, 21-25 April 1986.	E (out of stock) S
44 Suppl.	IOC-FAO Workshop on Recruitment in Tropical Coastal Demersal Communities, Submitted Papers; Ciudad del Carmen, Campeche, Mexico, 21-25 April 1986.	E
45	IOCARIBE Workshop on Physical Oceanography and Climate; Cartagena, Colombia, 19-22 August 1986.	E
46	Reunión de Trabajo para Desarrollo del Programa "Ciencia Oceánica en Relación a los Recursos No Vivos en la Región del Atlántico Sud-occidental"; Porto Alegre, Brasil, 7-11 de abril de 1986.	S
47	IOC Symposium on Marine Science in the Western Pacific: The Indo-Pacific Convergence; Townsville, 1-6 December 1966	E
48	IOCARIBE Mini-Symposium for the Regional Development of the IOC-UN (OETB) Programme on 'Ocean Science in Relation to Non-Living Resources (OSNLR)'; Havana, Cuba, 4-7 December 1986.	E, S
49	AGU-IOC-WMO-CPPS Chapman Conference: An International Symposium on 'El Niño'; Guayaquil, Ecuador, 27-31 October 1986.	E
50	CCALR-IOC Scientific Seminar on Antarctic Ocean Variability and its Influence on Marine Living Resources, particularly Krill (organized in collaboration with SCAR and SCOR); Paris, France, 2-6 June 1987.	E
51	CCOP/SOPAC-IOC Workshop on Coastal Processes in the South Pacific Island Nations; Lae, Papua-New Guinea, 1-8 October 1987.	E
52	SCOR-IOC-UNESCO Symposium on Vertical Motion in the Equatorial Upper Ocean and its Effects upon Living Resources and the Atmosphere; Paris, France, 6-10 May 1985.	E
53	IOC Workshop on the Biological Effects of Pollutants; Oslo, 11-29 August 1986.	E
54	Workshop on Sea-Level Measurements in Hostile Conditions; Bidston, UK, 28-31 March 1988.	E
55	IBCCA Workshop on Data Sources and Compilation, Boulder, Colorado, 18-19 July 1988.	E
56	IOC-FAO Workshop on Recruitment of Penaeid Prawns in the Indo-West Pacific Region (PREP); Cleveland, Australia, 24-30 July 1988.	E
57	IOC Workshop on International Co-operation in the Study of Red Tides and Ocean Blooms; Takamatsu, Japan, 16-17 November 1987.	E
58	International Workshop on the Technical Aspects of the Tsunami Warning System; Novosibirsk, USSR, 4-5 August 1989.	E
58 Suppl.	Second International Workshop on the Technical Aspects of Tsunami Warning Systems, Tsunami Analysis, Preparedness,	E

No.	Title	Languages
	Observation and Instrumentation. Submitted Papers; Novosibirsk, USSR, 4-5 August 1989.	
59	IOC-UNEP Regional Workshop to Review Priorities for Marine Pollution Monitoring Research, Control and Abatement in the Wider Caribbean; San José, Costa Rica, 24-30 August 1989.	E, F, S
60	IOC Workshop to Define IOCARIBE-TRODERP proposals; Caracas, Venezuela, 12-16 September 1989.	E
61	Second IOC Workshop on the Biological Effects of Pollutants; Bermuda, 10 September-2 October 1988.	E
62	Second Workshop of Participants in the Joint FAO-IOC-WHO-IAEA-UNEP Project on Monitoring of Pollution in the Marine Environment of the West and Central African Region; Accra, Ghana, 13-17 June 1988.	E
63	IOC/WESTPAC Workshop on Co-operative Study of the Continental Shelf Circulation in the Western Pacific; Bangkok, Thailand, 31 October-3 November 1989.	E
64	Second IOC-FAO Workshop on Recruitment of Penaeid Prawns in the Indo-West Pacific Region (PREP); Phuket, Thailand, 25-31 September 1989.	E
65	Second IOC Workshop on Sardine/Anchovy Recruitment Project (SARP) in the Southwest Atlantic; Montevideo, Uruguay, 21-23 August 1989.	E
66	IOC ad hoc Expert Consultation on Sardine/ Anchovy Recruitment Programme; La Jolla, California, U.S.A., 1989	E
67	Interdisciplinary Seminar on Research Problems in the IOCARIBE Region; Caracas, Venezuela, 28 November-1 December 1989.	E (out of stock)
68	International Workshop on Marine Acoustics; Beijing, China, 26-30 March 1990.	E
69	IOC-SCAR Workshop on Sea-Level Measurements in the Antarctica; Leningrad, USSR, 28-31 May 1990.	E
69 Suppl.	IOC-SCAR Workshop on Sea-Level Measurements in the Antarctica; Submitted Papers; Leningrad, USSR, 28-31 May 1990.	E
70	IOC-SAREC-UNEP-FAO-IAEA-WHO Workshop on Regional Aspects of Marine Pollution; Mauritius, 29 October - 9 November 1990.	E
71	IOC-FAO Workshop on the Identification of Penaeid Prawn Larvae and Postlarvae; Cleveland, Australia, 23-28 September 1990.	E
72	IOC/WESTPAC Scientific Steering Group Meeting on Co-Operative Study of the Continental Shelf Circulation in the Western Pacific; Kuala Lumpur; Malaysia, 9-11 October 1990.	E
73	Expert Consultation for the IOC Programme on Coastal Ocean Advanced Science and Technology Study; Liège, Belgium, 11-13 May 1991.	E
74	IOC-UNEP Review Meeting on Oceanographic Processes of Transport and Distribution of Pollutants in the Sea; Zagreb, Yugoslavia, 15-18 May 1989.	E
75	IOC-SCOR Workshop on Global Ocean Ecosystem Dynamics; Solomons, Maryland, U.S.A., 29 April-2 May 1991.	E
76	IOC/WESTPAC Scientific Symposium on Marine Science and Management of Marine Areas of the Western Pacific; Penang, Malaysia, 2-6 December 1991.	E
77	IOC-SAREC-KMFRI Regional Workshop on Causes and Consequences of Sea-Level Changes on the Western Indian Ocean Coasts and Islands; Mombasa, Kenya, 24-28 June 1991.	E
78	IOC-CEC-ICES-WMO-ICSU Ocean Climate Data Workshop Goddard Space Flight Center; Greenbelt, Maryland, U.S.A., 18-21 February 1992.	E
79	IOC/WESTPAC Workshop on River Inputs of Nutrients to the Marine Environment in the WESTPAC Region; Penang, Malaysia, 26-29 November 1991.	E
80	IOC-SCOR Workshop on Programme Development for Harmful Algae Blooms; Newport, U.S.A. 2-3 November 1991.	E
81	Joint IAPSO-IOC Workshop on Sea Level Measurements and Quality Control; Paris, France, 12-13 October 1992.	E
82	BORDOMER 92: International Convention on Rational Use of Coastal Zones. A Preparatory Meeting for the Organization of an International Conference on Coastal Change; Bordeaux, France, 30 September-2 October 1992.	E
83	IOC Workshop on Donor Collaboration in the Development of Marine Scientific Research Capabilities in the Western Indian Ocean Region; Brussels, Belgium, 12-13 October 1992.	E
84	Workshop on Atlantic Ocean Climate Variability; Moscow, Russian Federation, 13-17 July 1992	E
85	IOC Workshop on Coastal Oceanography in Relation to Integrated Coastal Zone Management; Kona, Hawaii, 1-5 June 1992.	E
86	International Workshop on the Black Sea; Varna, Bulgaria, 30 September – 4 October 1991	E
87	Taller de trabajo sobre efectos biológicos del fenómeno «El Niño» en ecosistemas costeros del Pacífico Sudeste; Santa Cruz, Galápagos, Ecuador, 5-14 de octubre de 1989.	S only (summary in E, F, S)
88	IOC-CEC-ICSU-ICES Regional Workshop for Member States of Eastern and Northern Europe (GODAR Project); Obninsk, Russia, 17-20 May 1993.	E
89	IOC-ICSEM Workshop on Ocean Sciences in Non-Living Resources; Perpignan, France, 15-20 October 1990.	E
90	IOC Seminar on Integrated Coastal Management; New Orleans, U.S.A., 17-18 July 1993.	E
91	Hydroblack'91 CTD Intercalibration Workshop; Woods Hole, U.S.A., 1-10 December 1991.	E
92	Réunion de travail IOCEA-OSNLR sur le Projet « Budgets sédimentaires le long de la côte occidentale d'Afrique » Abidjan, côte d'Ivoire, 26-28 juin 1991.	E
93	IOC-UNEP Workshop on Impacts of Sea-Level Rise due to Global Warming. Dhaka, Bangladesh, 16-19 November 1992.	E
94	BMTC-IOC-POLARMAR International Workshop on Training Requirements in the Field of Eutrophication in Semi-enclosed Seas and Harmful Algal Blooms, Bremerhaven, Germany, 29 September-3 October 1992.	E
95	SAREC-IOC Workshop on Donor Collaboration in the Development of Marine Scientific Research Capabilities in the Western Indian Ocean Region; Brussels, Belgium, 23-25 November 1993.	E
96	IOC-UNEP-WMO-SAREC Planning Workshop on an Integrated Approach to Coastal Erosion, Sea Level Changes and their Impacts; Zanzibar, United Republic of Tanzania, 17-21 January 1994.	E
96 Suppl.	IOC-UNEP-WMO-SAREC Planning Workshop on an Integrated Approach to Coastal Erosion, Sea Level Changes and their Impacts; Submitted Papers 1. Coastal Erosion; Zanzibar, United Republic of Tanzania 17-21 January 1994.	E
96 Suppl	IOC-UNEP-WMO-SAREC Planning Workshop on an Integrated Approach to Coastal Erosion, Sea Level Changes and their Impacts; Submitted Papers 2. Sea Level; Zanzibar, United Republic of Tanzania 17-21 January 1994.	E
97	IOC Workshop on Small Island Oceanography in Relation to Sustainable Economic Development and Coastal Area Management of Small Island Development States; Fort-de-France, Martinique, 8-10 November, 1993.	E
98	CoMSBlack '92A Physical and Chemical Intercalibration Workshop; Erdemli, Turkey, 15-29 January 1993.	E
99	IOC-SAREC Field Study Exercise on Nutrients in Tropical Marine Waters; Mombasa, Kenya, 5-15 April 1994.	E
100	IOC-SOA-NOAA Regional Workshop for Member States of the Western Pacific - GODAR-II (Global Oceanographic Data Archeology and Rescue Project); Tianjin, China, 8-11 March 1994.	E
101	IOC Regional Science Planning Workshop on Harmful Algal Blooms; Montevideo, Uruguay, 15-17 June 1994.	E
102	First IOC Workshop on Coastal Ocean Advanced Science and Technology Study (COASTS); Liège, Belgium, 5-9 May 1994.	E
103	IOC Workshop on GIS Applications in the Coastal Zone Management of Small Island Developing States; Barbados, 20-22 April 1994.	E
104	Workshop on Integrated Coastal Management; Dartmouth, Canada, 19-20 September 1994.	E
105	BORDOMER 95: Conference on Coastal Change; Bordeaux, France, 6-10 February 1995.	E
105 Suppl.	Conference on Coastal Change: Proceedings; Bordeaux, France, 6-10 February 1995	E
106	IOC/WESTPAC Workshop on the Paleographic Map; Bali, Indonesia, 20-21 October 1994.	E
107	IOC-ICSU-NIO-NOAA Regional Workshop for Member States of the Indian Ocean - GODAR-III; Dona Paula, Goa, India, 6-9 December 1994.	E
108	UNESCO-IHP-IOC-IAEA Workshop on Sea-Level Rise and the Multidisciplinary Studies of Environmental Processes in the Caspian Sea Region; Paris, France, 9-12 May 1995.	E
108 Suppl.	UNESCO-IHP-IOC-IAEA Workshop on Sea-Level Rise and the Multidisciplinary Studies of Environmental Processes in the Caspian Sea Region; Submitted Papers; Paris, France, 9-12 May 1995.	E
109	First IOC-UNEP CEPPOL Symposium; San José, Costa Rica, 14-15 April 1993.	E
110	IOC-ICSU-CEC regional Workshop for Member States of the Mediterranean - GODAR-IV (Global Oceanographic Data Archeology and Rescue Project) Foundation for International Studies, University of Malta, Valletta, Malta, 25-28 April 1995.	E
111	Chapman Conference on the Circulation of the Intra-Americas Sea; La Parguera, Puerto Rico, 22-26 January 1995.	E
112	IOC-IAEA-UNEP Group of Experts on Standards and Reference Materials (GESREM) Workshop; Miami, U.S.A., 7-8 December 1993.	E
113	IOC Regional Workshop on Marine Debris and Waste Management in the Gulf of Guinea; Lagos, Nigeria, 14-16 December 1994.	E
114	International Workshop on Integrated Coastal Zone Management (ICZM) Karachi, Pakistan; 10-14 October 1994.	E
115	IOC/GLOSS-IAPSO Workshop on Sea Level Variability and Southern Ocean Dynamics; Bordeaux, France, 31 January 1995	E
116	IOC/WESTPAC International Scientific Symposium on Sustainability of Marine Environment: Review of the WESTPAC Programme, with Particular Reference to ICAM, Bali, Indonesia, 22-26 November 1994.	E
117	Joint IOC-CIDA-Sida (SAREC) Workshop on the Benefits of Improved Relationships between International Development Agencies, the IOC and other Multilateral Inter-governmental Organizations in the Delivery of Ocean, Marine Affairs and Fisheries Programmes; Sidney B.C., Canada, 26-28 September 1995.	E
118	IOC-UNEP-NOAA-Sea Grant Fourth Caribbean Marine Debris Workshop; La Romana, Santo Domingo, 21-24 August 1995.	E
119	IOC Workshop on Ocean Colour Data Requirements and Utilization; Sydney B.C., Canada, 21-22 September 1995.	E
120	International Training Workshop on Integrated Coastal Management; Tampa, Florida, U.S.A., 15-17 July 1995.	E
121	Atelier régional IOC-CERESCOR sur la gestion intégrée des zones littorales (ICAM), Conakry, Guinée, 18–22 décembre 1995	F
122	IOC-EU-BSH-NOAA-(WDC-A) International Workshop on Oceanographic Biological and Chemical Data Management, Hamburg, Germany, 20-23 May 1996	E
123	Second IOC Regional Science Planning Workshop on Harmful Algal Blooms in South America; Mar del Plata, Argentina, 30 October–1 November 1995.	E, S
124	GLOBEC-IOC-SAHFOS-MBA Workshop on the Analysis of Time Series with Particular Reference to the Continuous Plankton Recorder Survey; Plymouth, U.K.,4-7 May 1993.	E
125	Atelier sous-régional de la COI sur les ressources marines vivantes du Golfe de Guinée ; Cotonou, Bénin, 1-4 juillet 1996.	E

No.	Title	Languages
126	IOC-UNEP-PERSGA-ACOPS-IUCN Workshop on Oceanographic Input to Integrated Coastal Zone Management in the Red Sea and Gulf of Aden. Jeddah, Saudi Arabia, 8 October 1995.	E
127	IOC Regional Workshop for Member States of the Caribbean and South America GODAR-V (Global Oceanographic Data Archeology and Rescue Project); Cartagena de Indias, Colombia, 8-11 October 1996.	E
128	Atelier IOC-Banque Mondiale-Sida/SAREC-ONE sur la Gestion Intégrée des Zones Côtières ; Nosy Bé, Madagascar, 14-18 octobre 1996.	E
129	Gas and Fluids in Marine Sediments, Amsterdam, the Netherlands; 27-29 January 1997.	E
130	Atelier régional de la COI sur l'océanographie côtière et la gestion de la zone côtière ;Moroni, RFI des Comores, 16-19 décembre 1996.	E
131	GOOS Coastal Module Planning Workshop; Miami, USA, 24-28 February 1997	E
132	Third IOC-FANSA Workshop; Punta-Arenas, Chile, 28-30 July 1997	S/E
133	Joint IOC-CIESM Training Workshop on Sea-level Observations and Analysis for the Countries of the Mediterranean and Black Seas; Birkenhead, U.K., 16-27 June 1997.	E
134	IOC/WESTPAC-CCOP Workshop on Paleogeographic Mapping (Holocene Optimum); Shanghai, China, 27-29 May 1997.	E
135	Regional Workshop on Integrated Coastal Zone Management; Chabahar, Iran; February 1996.	E
136	IOC Regional Workshop for Member States of Western Africa (GODAR-VI); Accra, Ghana, 22-25 April 1997.	E
137	GOOS Planning Workshop for Living Marine Resources, Dartmouth, USA; 1-5 March 1996.	E
138	Gestión de Sistemas Oceanográficos del Pacífico Oriental; Concepción, Chile, 9-16 de abril de 1996.	S
139	Sistemas Oceanográficos del Atlántico Sudoccidental, Taller, TEMA;Furg, Rio Grande, Brasil, 3-11 de noviembre de 1997	S
140	IOC Workshop on GOOS Capacity Building for the Mediterranean Region; Valletta, Malta, 26-29 November 1997.	E
141	IOC/WESTPAC Workshop on Co-operative Study in the Gulf of Thailand: A Science Plan; Bangkok, Thailand, 25-28 February 1997.	E
142	Pelagic Biogeography ICoPB II. Proceedings of the 2nd International Conference. Final Report of SCOR/IOC Working Group 93; Noordwijkerhout, The Netherlands, 9-14 July 1995.	E
143	Geosphere-biosphere coupling: Carbonate Mud Mounds and Cold Water Reefs; Gent, Belgium, 7–11 February 1998.	E
144	IOC-SOPAC Workshop Report on Pacific Regional Global Ocean Observing Systems; Suva, Fiji, 13-17 February 1998.	E
145	IOC-Black Sea Regional Committee Workshop: 'Black Sea Fluxes' Istanbul, Turkey, 10-12 June 1997.	E
146	Taller Internacional sobre Formación de Capacidades para el Manejo de las Costas y los Océanos en le Gran Caribe, La Habana, – Cuba, 7–10 de Julio de 1998 / International Workshop on Management Capacity-Building for Coasts and Oceans in the Wider Caribbean, Havana, Cuba, 7–10 July 1998	S/E
147	IOC-SOA International Training Workshop on the Intregration of Marine Sciences into the Process of Integrated Coastal Management, Dalian, China, 19-24 May 1997.	E
148	IOC/WESTPAC International Scientific Symposium – Role of Ocean Sciences for Sustainable Development Okinawa, Japan, 2-7 February 1998.	E
149	Workshops on Marine Debris & Waste Management in the Gulf of Guinea, 1995-97.	E
150	Primera Sesión del Grupo de Trabajo COI sobre Algas Nocivas en el Caribe y Regiones Adyacentes (IOCARIBE-ANCA)/First Meeting of the IOC Working Group on Harmful Algae in the Caribbean and Adjacent Region (IOCARIBE-ANCA), 29 June – 1 July 1998, Havana, Cuba.	S/E ***(electronic copy only)***
151	Taller Pluridisciplinario TEMA sobre Redes del Gran Caribe en Gestión Integrada de Áreas Costeras Cartagena de Indias, Colombia, 7-12 de septiembre de 1998.	S
152	Workshop on Data for Sustainable Integrated Coastal Management (SICOM) Maputo, Mozambique, 18-22 July 1998	E
153	IOC/WESTPAC-Sida (SAREC) Workshop on Atmospheric Inputs of Pollutants to the Marine Environment Qingdao, China, 24-26 June 1998	E
154	IOC-Sida-Flanders-SFRI Workshop on Ocean Data Management in the IOCINCWIO Region (ODINEA project) Capetown, South Africa, 30 November-11 December 1998.	E
155	Science of the Mediterranean Sea and its applications UNESCO, Paris 29-31 July 1997	E
156	IOC-LUC-KMFRI Workshop on RECOSCIX-WIO in the Year 2000 and Beyond, Mombasa, Kenya, 12-16 April 1999	E
157	'98 IOC-KMI International Workshop on Integrated Coastal Management (ICM), Seoul, Republic of Korea 16-18 April 1998	E
158	The IOCARIBE Users and the Global Ocean Observing System (GOOS) Capacity Building Workshop, San José, Costa Rica, 22-24 April 1999	E
159	Oceanic Fronts and Related Phenomena (Konstantin Fedorov Memorial Symposium) – Proceedings, Pushkin, Russian Federation, 18-22 May 1998	E
160	Under preparation	
161	Under preparation	
162	Workshop report on the Transports and Linkages of the Intra-americas Sea (IAS), Cozumel, Mexico, 1-5 November 1997	E
163	Under preparation	
164	IOC-Sida-Flanders-MCM Third Workshop on Ocean Data Management in the IOCINCWIO Region (ODINEA Project), Cape Town, South Africa, 29 November – 11 December 1999	E
165	An African Conference on Sustainable Integrated Management; Proceedings of the Workshops. An Integrated Approach, (PACSICOM), Maputo, Mozambique, 18 –25 July 1998	E, F
166	IOC-SOA International Workshop on Coastal Megacities: Challenges of Growing Urbanization of the World's Coastal Areas; Hangzhou, P.R. China, 27 –30 September 1999	E
167	IOC-Flanders First ODINAFRICA-II Planning Workshop, Dakar, Senegal, 2-4 May 2000	E
168	Geological Processes on European Continental Margins; International Conference and Eight Post-cruise Meeting of the Training-Through-Research Programme, Granada, Spain, 31 January – 3 February 2000	E
169	International Conference on the International Oceanographic Data & Information Exchange in the Western Pacific (IODE-WESTPAC) 1999, ICIWP '99, Langkawi, Malaysia, 1-4 November 1999	E ***(electronic copy only)***
170	IOCARIBE-GODAR-I Cartagenas, Colombia, February 2000	***under preparation***
171	Ocean Circulation Science derived from the Atlantic, Indian and Arctic Sea Level Networks, Toulouse, France, 10-11 May 1999	E
172	(*Under preparation*)	
173	The Benefits of the Implementation of the GOOS in the Mediterranean Region, Rabat, Morocco, 1-3 November 1999	E, F
174	IOC-SOPAC Regional Workshop on Coastal Global Ocean Observing System (GOOS) for the Pacific Region, Apia, Samoa, 16-17 August 2000	E
175	Geological Processes on Deep-water European Margins, Moscow-Mozhenka, 28 Jan.-2 Feb. 2001	E
176	MedGLOSS Workshop and Coordination Meeting for the Pilot Monitoring Network System of Systematic Sea Level Measurements in the Mediterranean and Black Seas, Haifa, Israel, 15-17 May 2000	E
177	*(Under preparation)*	
178	*(Under preparation)*	
179	*(Under preparation)*	
180	Abstracts of Presentations at Workshops during the 7th session of the IOC Group of Experts on the Global Sea Level Observing System (GLOSS), Honolulu, USA, 23-27 April 2001	E
181	*(Under preparation)*	
182	*(Under preparation)*	
183	Geosphere/Biosphere/Hydrosphere Coupling Process, Fluid Escape Structures and Tectonics at Continental Margins and Ocean Ridges, International Conference & Tenth Post-cruise Meeting of the Training-through-Research Programme, Aveiro, Portugal, 30 January-2 February 2002	E
184	*(Under preparation)*	
185	*(Under preparation)*	
186	*(Under preparation)*	
186	*(Under preparation)*	
187	Geological and Biological Processes at deep-sea European Margins and Oceanic Basins, Bologna, Italy, 2–6 February 2003	E
188	Proceedings of 'The Ocean Colour Data' Symposium, Brussels, Belgium, 25-27 November 2002	E
189	Workshop for the Formulation of a Draft Project on Integrated Coastal Management (ICM) in Latin America and the Caribbean (LAC), Cartagena, Colombia, 23–25 October 2003 Taller de Formulación de un Anteproyecto de Manejo Costero Integrado (MCI) en América Latina y el Caribe (ALC), Cartagena, Colombia, 23–25 de Octubre de 2003	E F ***(electronic copy only)***
190	First ODINCARSA Planning Workshop for Caribbean Islands, Christchurch, Barbados, 15–18 December 2003	E ***(electronic copy only)***
191	North Atlantic and Labrador Sea Margin Architecture and Sedimentary Processes — International Conference and Twelfth Post-cruise Meeting of the Training-through-research Programme, Copenhagen, Denmark, 29–31 January 2004	E
192	Regional Workshop on Coral Reefs Monitoring and Management in the ROPME Sea Area, Iran I.R., 14–17 December 2003	E ***(under preparation)***
193	Workshop on New Technical Developments in Sea and Land Level Observing Systems, Paris, France, 14–16 October 2003	E ***(electronic copy only)***
194	IOC/ROPME Planning Meeting for the Ocean Data and Information Network for the Central Indian Ocean Region	***(under preparation)***
195	Workshop on Indicators of Stress in the Marine Benthos, Torregrande-Oristano, Italy, 8–9 October 2004	E
196	International Coordination Meeting for the Development of a Tsunami Warning and Mitigation System for the Indian Ocean within a Global Framework, Paris, France, 3–8 March 2005	E
197	Geosphere-Biosphere Coupling Processes: The TTR Interdisciplinary Approach Towards Studies of the European and North African Margins; International Conference and Post-cruise Meeting of the Training-Through-Research Programme, Morocco, 2-5 February 2005	E
198	Second International Coordination Meeting for the Development of a Tsunami Warning and Mitigation System for the Indian Ocean, Grand Baie, Mauritius, 14–16 April 2005	E
199	International Conference for the Establishment of a Tsunami and Coastal Hazards Warning System for the Caribbean and Adjacent Regions, Mexico, 1–3 June 2005	E
200	Lagoons and Coastal Wetlands in the Global Change Context: Impacts and Management Issues — Proceedings of the International Conference, Venice, 26–28 April 2004 (*ICAM Dossier N° 3)*	E
201	Geological processes on deep-water European margins - International Conference and 15th Anniversary Post-cruise Meeting of the Training-Through-Research Programme, Moscow/Zvenigorod, Russian Federation, 29 January–4 February 2006	E
202	Proceedings of 'Ocean Biodiversity Informatics': an international conference on marine biodiversity data management Hamburg, Germany, 29 November–1 December 2004	E
203	IOC-Flanders Planning Workshop for the formulation of a regional Pilot Project on Integrated Coastal Area Management in Latin America, Cartagena de Indias, Colombia, 16–18 January 2007	*E* ***(electronic copy only)***
204	Geo-marine Research along European Continental Margins, International Conference and Post-cruise Meeting of the Training-through-research Programme, Bremen, Germany, 29 January–1 February 2007	E
205	IODE/ICAM Workshop on the development of the Caribbean marine atlas (CMA), United Nations House, Bridgetown, Barbados, 8–10 October 2007	E ***(electronic copy only)***
206	IODE/JCOMM Forum on Oceanographic Data Management and Exchange Standards, Ostend, Belgium, 21–25 January 2008	*(Under preparation)*
207	SCOR/IODE Workshop on Data Publishing, Ostend, Belgium, 17–18 June 2008	*(Under preparation)*

No.	Title	Languages
208	JCOMM Technical Workshop on Wave Measurements from Buoys, New York, USA, 2–3 October 2008 (IOC-WMO publication)	*(Under preparation)*
209	Collaboration between IOC and OBIS towards the Long-term Management Archival and Accessibility of Ocean Biogeographic Data, Ostend, Belgium, 24–26 November 2008	*(Under preparation)*
210	Ocean Carbon Observations from Ships of Opportunity and Repeat Hydrographic Sections (IOCCP Reports, 1), Paris, France, 13–15 January 2003	E ***(electronic copy only)***
211	Ocean Surface pCO_2 Data Integration and Database Development (IOCCP Reports, 2), Tsukuba, Japan, 14–17 January 2004	E ***(electronic copy only)***
212	International Ocean Carbon Stakeholders' Meeting, Paris, France, 6–7 December 2004	E ***(electronic copy only)***
213	International Repeat Hydrography and Carbon Workshop (IOCCP Reports, 4), Shonan Village, Japan, 14–16 November 2005	E ***(electronic copy only)***
214	Initial Atlantic Ocean Carbon Synthesis Meeting (IOCCP Reports, 5), Laugavatn, Iceland, 28–30 June 2006	E ***(electronic copy only)***
215	Surface Ocean Variability and Vulnerability Workshop (IOCCP Reports, 7), Paris, France, 11–14 April 2007	E ***(electronic copy only)***
216	Surface Ocean CO2 Atlas Project (SOCAT) 2nd Technical Meeting Report (IOCCP Reports, 9), Paris, France, 16–17 June 2008	E ***(electronic copy only)***
217	Changing Times: An International Ocean Biogeochemical Time-Series Workshop (IOCCP Reports, 11), La Jolla, California, USA, 5–7 November 2008	E ***(electronic copy only)***
218	Second Joint GOSUD/SAMOS Workshop, Seattle, Washington, USA, 10–12 June 2008	E ***(electronic copy only)***
219	International Conference on Marine Data management and Information Systems (IMDIS), Athens, Greece, 31 March–2 April 2008	E
220	Geo-marine Research on the Mediterranean and European-Atlantic Margins. International Conference and TTR-17 Post-cruise Meeting of the Training-through-research Programme, Granada, Spain, 2–5 February 2009	E ***(electronic copy only)***
221	Surface Ocean CO_2 Atlas Project Pacific Regional Workshop, Tsukuba, Japan, 18-20 March, 2009 (IOCCP Report Number 12)	E ***(electronic copy only)***
222	Surface Ocean CO_2 Atlas Project Atlantic and Southern Oceans Regional Meeting, Norwich, UK, 25-26 June, 2009 (IOCCP Report Number 13)	E ***(electronic copy only)***
223	Advisory Workshop on enhancing forecasting capabilities for North Indian Ocean Storm Surges, Indian Institute of Technology (IIT), New Delhi, India, 14–17 July 2009	E ***(electronic copy only)***
224	2009 International Nutrients Scale System (INSS) Workshop Report, Paris, France, 10–12 February 2009	E ***(electronic copy only)***
225	Reunión subregional de planificación de ODINCARSA (Red de Datos e Información Oceanográficos para las Regiones del Caribe y América del Sur)/ ODINCARSA (Ocean Data and Information Network for the Caribbean and South America region) Latin America sub-regional Planning Meeting, Universidad Autónoma de Baja California (UABC), Ensenada (México), 7-10 December 2009. 2010	E/S ***(electronic copy only)***
226	OBIS (Ocean Biogeographic Information System) Strategy and Work plan Meeting, IOC Project Office for IODE, Oostende, Belgium, 18–20 November 2009	E ***(electronic copy only)***
227	ODINAFRICA-IV Project Steering Committee, First Session, Ostend, Belgium, 20–22 January 2010. 2010	E ***(electronic copy only)***
228	First IODE Workshop on Quality Control of Chemical Oceanographic Data Collections, Ostend, Belgium, 8–11 February 2010. 2010	E ***(electronic copy only)***
229	Surface Ocean CO_2 Atlas Project Equatorial Pacific, North Pacific, and Indian Ocean Regional Workshop, Tokyo, Japan, 8–11 February 2010. 2010 (IOCCP Report Number 18)	E ***(electronic copy only)***
230	SCOR/IODE/MBLWHOI Library Workshop on Data Publication, Paris, France, 2 April 2010	E ***(electronic copy only)***
231	First ODINAFRICA Coastal and Marine Atlases Planning Meeting, Ostend, Belgium, 12–14 October 2009	E ***(electronic copy only)***
232	Eleventh International Workshop on Wave Hindcasting and Forecasting and Second Coastal Hazard Symposium, Halifax, Canada, 18–23 October 2009	E ***(electronic copy only)***
233	2010 Meeting of the Joint IODE-JCOMM Steering Group on the Global Temperature-Salinity Profile Programme Ostend, Belgium, 5–7 May 2010	E ***(electronic copy only)***
234	Southern and Indian Surface Ocean CO_2 Atlas (SOCAT) Workshop, CSIRO Marine Laboratories, Hobart, Tasmania 16-18 June 2010	E ***(electronic copy only)***
235	The Caribbean Marine Atlas (CMA) Review and Planning Workshop and Saint Lucia National Coastal Atlas Stakeholder Event, Bay Gardens Inn, Rodney Bay, Saint Lucia, 2–6 August 2010	E ***(electronic copy only)***
236	First Session of the IODE Steering Group for the IODE OceanDataPortal (SG-ODP-I), 20–22 September 2010, Ostend, Belgium	E ***(electronic copy only)***
237.	Ad hoc meeting of the IODE Steering Group for OBIS, Ostend, Belgium 18-19 November 2010	E ***(electronic copy only)***
238.	Implementing Adaptation to Climate Change in Western and Eastern Africa, Nairobi, Kenya, 3-5 November 2010	E ***(electronic copy only)***
239.	2nd Advisory Workshop on enhancing forecasting capabilities for North Indian Ocean Storm Surges, 11-15 February 2011, New Delhi, India	E ***(electronic copy only)***
240.	Ocean Biogeographic Information System (OBIS) Infrastructure Meeting, INCOIS, Hyderabad, India, 2–4 March 2011.	E ***(electronic copy only)***
241.	Best Practice on Tsunami and Coastal Hazards Community Preparedness and Readiness in Central America and the Caribbean, 11–13 August 2008, Panama City, Panama	E ***(electronic copy only)***
242.	Integrated Coastal Area Management (ICAM) Training Workshop for the English Speaking Caribbean States, 16–18 March 2011, Bridgetown, Barbados	E ***(electronic copy only)***
243.	Implementing Adaptation to Climate Change in Western and Eastern Africa: Targeting the Adaptation Fund. Nairobi, Kenya, 3–5 November 2010	*cancelled*
244.	SCOR/IODE/MBLWHOI Library Workshop on Data Publication, 4th Session, British Oceanographic Data Centre, Liverpool, United Kingdom, 3-4 November 2011	E ***(electronic copy only)***
245.	Surface Ocean CO2 Data-to-Flux Workshop, UNESCO, Paris, 12-14 September 2011	*cancelled*
246.	NEAMTIC/ICAM Workshop on Coastal Management Approaches for Sea-Level Related Hazards, Paris, UNESCO, 5–7 December 2011	E ***(electronic copy only)***
247.	Technical Workshop on the IODE OceanDataPortal, IOC Project Office for IODE, Ostend, Belgium, 27-29 February 2012	E ***(electronic copy only)***
248.	Inter-sessional working group for updating the IOC Strategic Plan for Oceanographic Data and Information Exchange (2012-2015), Ostend, Belgium, 1-2 March 2012	E ***(electronic copy only)***
249.	Operational Oceanography of IOC (for Group II Member States), 20–22 March 2012 Paris, UNESCO (Advisory Workshop)	E ***(electronic copy only)***
250.	Advisory Workshop on The Future of IOC towards next ten years and its Implications for Member States, Varna, Bulgaria, 19 March 2012	E ***(electronic copy only)***
251	Second Technical Meeting of Ocean Biogeographic Information System (OBIS), Ostend, Belgium, 21–22 June 2012	E ***(electronic copy only)***
252.	SCOR/IODE/MBLWHOI Library Workshop on Data Publication, 5th Session, Woods Hole Oceanographic Institution, Woods Hole, USA, 9-10 October 2012	E ***(electronic copy only)***
253.	Second IODE Workshop on Quality Control of Chemical and Biological Oceanographic Data Collections, 22-24 October 2012, IOC Project Office for IODE, Ostend, Belgium	E ***(electronic copy only)***
254.	Consultation on Scientific and Technical Aspects of Sustained Ocean Observations and Services, 5th March, 2013, Rio de Janeiro, Brazil	E ***(electronic copy only)***
255.	Earthquake and tsunami hazard in Northern Haiti: Historical events and potential sources (Meeting of experts)	E ***(electronic copy only)***
256	Sexto Taller Regional de Planificación Científica sobre Floraciones de Algas Nocivas en Sudamérica, Guayaquil, Ecuador, 22-24 Octubre 2003	S ***(electronic copy only)***
257	*(Under preparation)*	
258	*(Under preparation)*	
259	Noveno Taller Regional-COI de Planificación Científica sobre Florecimientos de Algas Nocivas en Sudamérica, 11-13 enero 2011, Puerto Varas, Chile	S ***(electronic copy only)*** *(Summary in E)*
260	*Caribbean Marine Atlas Review and Planning Meeting, Miami, USA, 10-13 December 2013*	
261	Indo-Pacific Ocean Forum on "Charting the Future of Sustained Ocean Observations and Services", Bangkok, Thailand, 25-28 Nov. 2013	E ***(electronic copy only)***
262	*First Planning Workshop For The Ocean Data And Information Network For The Westpac Region (ODINWESTPAC), Tianjin, China, 4-7 March 2014*	
263	*International Coastal Atlas Network Workshop 6: Expanding Participation in Coastal Web Atlas Development and Use, 16–17 June 2013, University of Victoria, British Columbia, Canada*	
264	9th WESTPAC International Scientific Symposium, Research Directors' Forum: A Healthy and Safe Ocean for Prosperity in the Indo-Pacific region, Nha Trang, Viet Nam, 22 April 2014	E ***(electronic copy only)***
265	Electoral Group 1 Consultation on the Future of the IOC, Utrecht, The Netherlands, 26–27 May 2014	E ***(electronic copy only)***
266	IOC-UNESCO-ISESCO workshop on Improving Tsunami Warning and Emergency Response in the North-Eastern Atlantic, Mediterranean and connected seas Rabat, 23-24 September 2014	A/E/F ***(electronic copy only)***
267	Proceedings of the First IOCAFRICA Ocean Forecasting workshop for the Western Indian Ocean region, Nairobi, Kenya, 11–15 August 2014	E ***(electronic copy only)***
268	Proceedings of the African Summer School on Application of Ocean Data and Modelling Products, Ghana, Kenya, April–September 2014	E ***(electronic copy only)***
269.	*Forum on Sustained Ocean Observations and Services in IOC Group V (Africa and Arab countries)*	E
270.	*Second China-Africa Forum on Marine Science and Technology, 9-10 April 2015, Nairobi, Kenya*	*Under preparation*
271.	WESTPAC Workshop on Research and Monitoring of the Ecological Impacts of Ocean Acidification on Coral Reef Ecosystems. Phuket, Thailand, 19–21 January 2015	E ***(electronic copy only)***
272.	Second IOCAFRICA Planning Meeting for the Second International Indian Ocean Expedition (IIOE-2), 6-8 October 2015, Catembe, Mozambique	E ***(electronic copy only)***
273.	Initiative de LOANGO : Atelier de la sous-région sur l'érosion côtière en Afrique centrale, Loango, République du Congo, 6–10 octobre 2008	F
274.	First Session of the Advisory Group for the Ocean Data and Information Network for the WESTPAC Region (ODINWESTPAC), Tianjin, China, 27-28 January 2016	E
275.	Scientific meeting of experts for coordinated scenario analysis of future tsunami events and hazard mitigation schemes for the South China Sea region, Xiamen, China, 16–18 November 2015	E
276.	Sources of Tsunamis in the Caribbean with Possibility to Impact the Southern Coast of the Dominican Republic, Santo Domingo, Dominican Republic, 6–7 May 2016	E & S
277.	VI IOC Regional Science Planning Workshop on Harmful Algae in the Caribbean and Adjacent Regions, Santo Domingo, Dominican Republic, 26-30 October 2015 / COI – VI Taller Regional de Planificación Científica sobre Algas Nocivas en el Caribe y Regiones Adyacentes, Santo Domingo, República Dominicana, 26-30 Octubre 2015	E/S
278.	Tsunami Hazard in Central America: Historical Events and Potential Sources. Meeting of Experts, San José, Costa Rica, 23-24 June 2016	E
279.	2nd International Conference on Marine/Maritime Spatial Planning, 15-17 March 2017, UNESCO, Paris	E
280.	Information Meeting on North-Eastern Atlantic, the Mediterranean and Connected Seas Tsunami Early Warning and Mitigation System (NEAMTWS) and NEAMWave 17 Tsunami Exercise: Summary Recommendations, Tunis, Tunisia, 13-14 September 2017	E/F/Ar
281.	Workshop on Sea-Level Measurements in Hostile Conditions, Moscow, Russian Federation, 13–15 March 2018	E/R
282.	IODE/OBIS-Event-Data workshop on animal tagging and tracking, Ostend, Belgium, 23–26 April 2018	E
283.	Sixth International XBT Science Workshop, Ostend, Belgium, 18–20 April 2018	E
284.	Sargassum and Oil Spills Monitoring Pilot Project for the Caribbean and Adjacent Regions Workshop, Mexico DF, Mexico, 2–4 May 2018	E
285	Drafting Workshop for the development of a training and Repository Portal for the Caribbean Large Marine Ecosystem	E

No.	Title	Languages
286.	Preparing for the Next Tsunami: Reducing Losses and Damages in the Coastal Western Mediterranean Areas: Summary Recommendations, Rabat, Morocco, 15-16 November 2018	E/F/Ar
287	Workshop on Sea level Data Archaeology, UNESCO, Paris, 10–12 March 2020	E
288	Workshop on data sharing between UN agencies as a contribution to the UN decade of ocean science for sustainable development, Online meeting, 20 April 2020, 14:00-16:30	E
289	Expert meeting on Tsunami sources, hazards, risk and uncertainties associated with the Tonga-Kermadec Subduction Zone. Wellington, New Zealand. 29 October – 3 November 2018.	E
290	International data sharing workshop for non-UN IGOs, Global and Regional organizations and projects, NGOs and private sector, Online meeting, 12 October 2020.	E
291	Experts Meeting on Sources of Tsunamis in the Lesser Antilles. Fort-de-France, Martinique (France), 18–20 March 2019	E