



Earthquakes



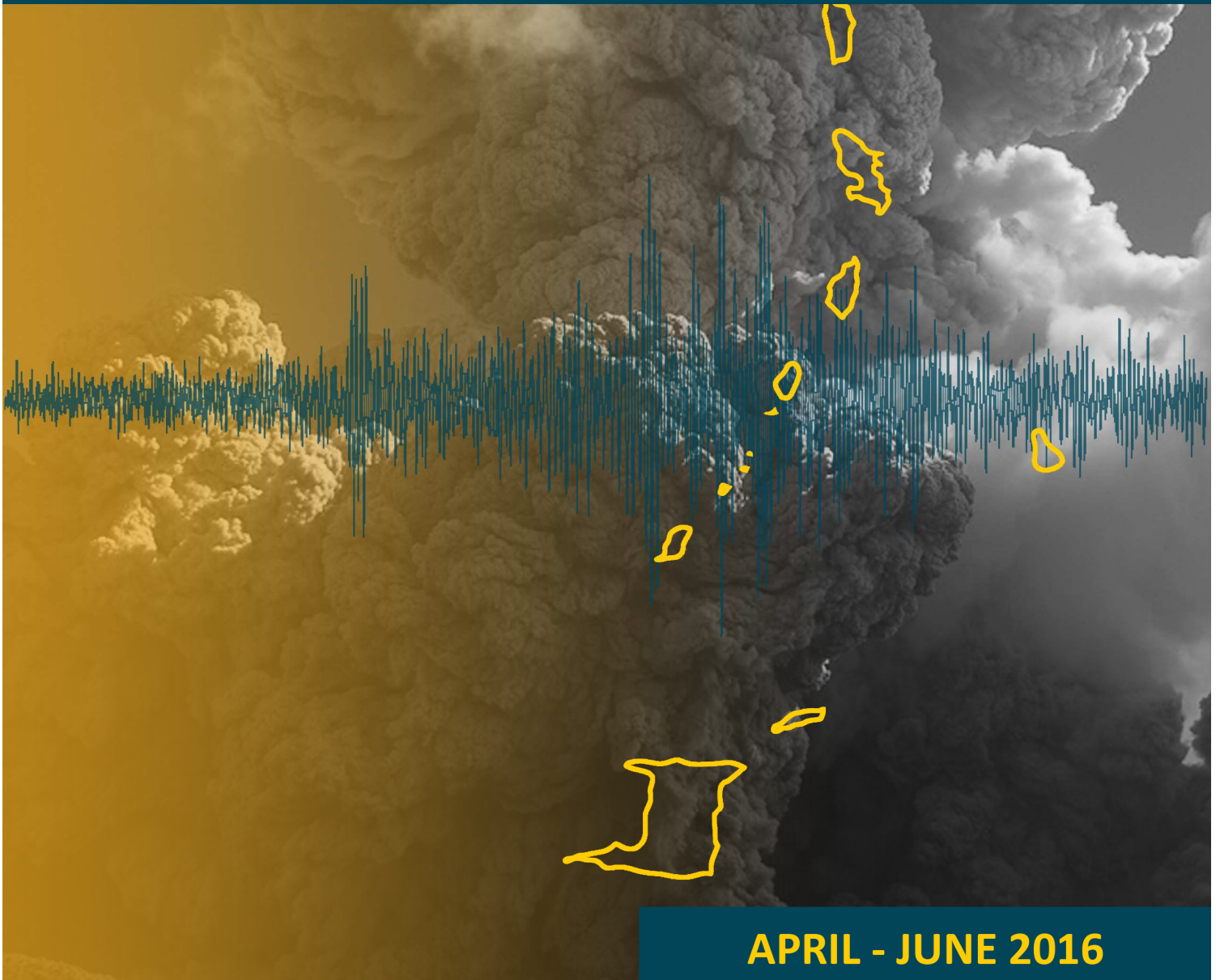
Volcanoes



Tsunamis



BULLETIN OF THE SEISMIC RESEARCH CENTRE THE UNIVERSITY OF THE WEST INDIES, ST. AUGUSTINE



APRIL - JUNE 2016

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Introduction

This bulletin reports on the activities at the Seismic Research Centre for the period April to June, 2016.

Data Acquisition and Processing

The Seismic Research Centre (SRC) operates more than 60 seismic stations as part of the Eastern Caribbean volcano and earthquake monitoring network (Fig. 1). There are nine subnets (Trinidad, Atlantic LNG, Dominica, Barbados, Grenada, St. Vincent, Saint Lucia, St. Kitts, Antigua) comprised of 35 stations in the legacy Soufrière System. The signals from each seismometer within a subnet are transmitted to the base computer and digitized by a 16-bit analogue to digital converter at 100 samples/sec. A triggering algorithm continuously searches the resulting time series from each station for possible earthquakes and, once preset triggering criteria are met (Soufrière System, 1988)¹, stores the "event" preceded by a selectable length of pre-triggering time record. There are also 33 digital stations where the signal from the sensors is digitised and time stamped on-site - 13 stations employ satellite (VSAT) transmission while the other 20 make use of the internet for data transmission.

There are 11 types of seismometers in use:

- 1Hz, vertical component, Sercel L4C seismometer
- 1Hz, vertical component, Integra LA100F seismometer
- 1Hz, single component, Kinematics SS-1 Ranger seismometer
- 1Hz, 3-component Sercel L4C-3D seismometer
- 1Hz 3-component Lennartz LE3D seismometer
- 5 seconds 3-component Lennartz LE3D seismometer
- 3-component Guralp CMG-3ESP-compact broadband seismometer
- 3-component Guralp CMG-40T broadband seismometer
- 3-component Guralp CMG-6T broadband seismometer
- 3-component Nanometrics Trillium 240 broadband seismometer
- 3-component Nanometrics Trillium 120 broadband seismometer

In addition, there are 4 types of accelerometers in use: Kinematics K2, Metrozet TSA-100S, Guralp CMG-5T and Nanometrics Titan.

In the Soufrière System data from each of the monitoring machines are routinely downloaded at the beginning of the working day or as often as necessary, depending on the level of activity, via telephone and internet, to computers at the TRN node. This is done in

¹ Seismic data acquisition system. For further information contact SRC

one of two ways: (i) operator-activated transfer or (ii) scheduled, software-activated transfer. The latter allows for the download of data during off-peak hours, so making it immediately available at the start of the working day. The SRC also operates an Earthworm system which acquires data from all stations (the Soufrière System stations as well as the digital stations) and facilitates data exchange with partner agencies. Data are analysed using software for picking phase arrival times using both SEISAN and WURSTMACHINE and routine hypocentral determination using WURSTMACHINE (WURSTMACHINE, 1988)².

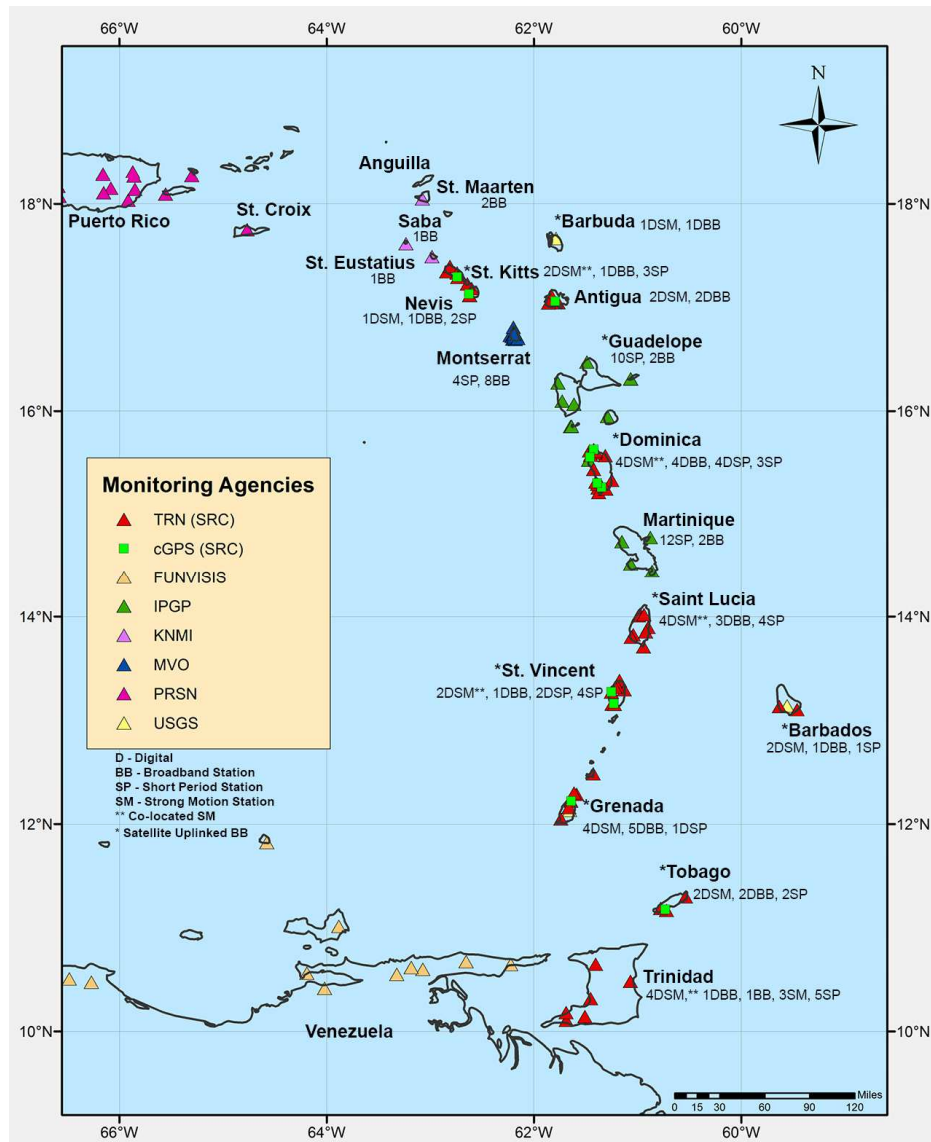


Fig. 1: Eastern Caribbean monitoring networks

² Seismic data processing system. For further information contact SRC.

While well-located, on-land, 3-station events receive special consideration; in general, events appearing in this bulletin were recorded at four or more stations. These were located and magnitudes (M_t) assigned using the following duration formula (Shepherd & Aspinall, 1983):

$$M_t = -0.705 + 2.073 \log_{10} \tau + 0.0018R$$

where τ is signal duration in seconds and R is hypocentral distance in km.

The use of drum recording technology in the SRC dates back to 1953. Six stations are continuously displayed on two ink-pen, drum recorders, which continue to provide real-time visuals of activity in the near vicinity of the stations being displayed. Virtual drums, which consist of recorded signals from selected stations across the network, displayed on computer screens, are in operation and represent the future of continuous visual surveillance of activity in the area of responsibility.

Seismicity

Eastern Caribbean seismicity is usually concentrated to the east of a line from St. Kitts to Martinique, with hypocentres exhibiting a relatively well-defined subduction (Wadati-Benioff) zone. From the south of Martinique to Grenada there is a substantial reduction in the frequency of earthquakes. The Trinidad and Tobago area generates significant seismic activity, with the most active area being a narrow belt of seismicity beneath and to the north-east of the Paria peninsula of Venezuela. There is also significant activity in the Gulf of Paria. This Paria seismicity contains both shallow, <35 km, and intermediate depth, ≥ 35 km, earthquakes.

There were 1168 earthquakes recorded for the quarter, which is a 20% increase over that recorded in the previous quarter. Fig. 2a shows the daily and cumulative count of those events. Fig. 2b shows the 772 (66%) of those earthquakes, for which locations could be determined, plotted according to magnitude and depth ranges. The earthquakes generally lie in a relatively wide belt, which coincides with the location and curvature of the arc. The density of epicentres within this zone is variable. Details of origin time (UTC), geographic coordinates (latitude, longitude), depth and magnitude for each earthquake are listed in Appendix I.

There were 30 earthquakes of magnitude greater than or equal to 4.0 and 89 events lying within the magnitude range 3.5-3.9. The largest event for the period in the area of responsibility occurred, on 7th April, in the Gulf of Paria, near the south coast of the Paria peninsula, and was of magnitude 5.6. The six earthquakes reported felt were in the magnitude range 4.1-5.6, with highest reported Modified Mercalli Intensity IV; the distance of the biggest event from populated centres contributed to the relatively low associated intensity (Table 1).

The overall seismicity pattern for this period remains consistent with that being observed for the region in recent years. The area north of 15°N latitude output 575 (74%) of the events

located for the quarter, with 11% (85 events) within 12°N -15°N and the remaining 15% (112 earthquakes) south of 12°N.

The on-going elevated seismicity being seen in the area north of 15°N latitude, noted since 2011, now includes an earthquake of magnitude 6.4. Still, there continue to be significant magnitude deficits in the area, which can simply occur over time, or in the aftershock sequence of an earthquake of magnitude larger than the 6.4 of 19th March, 2016. The elevated activity being seen in the Les Saintes area, which “switched on” following the 2004/11/21, magnitude 6.0 earthquake, continued this quarter.

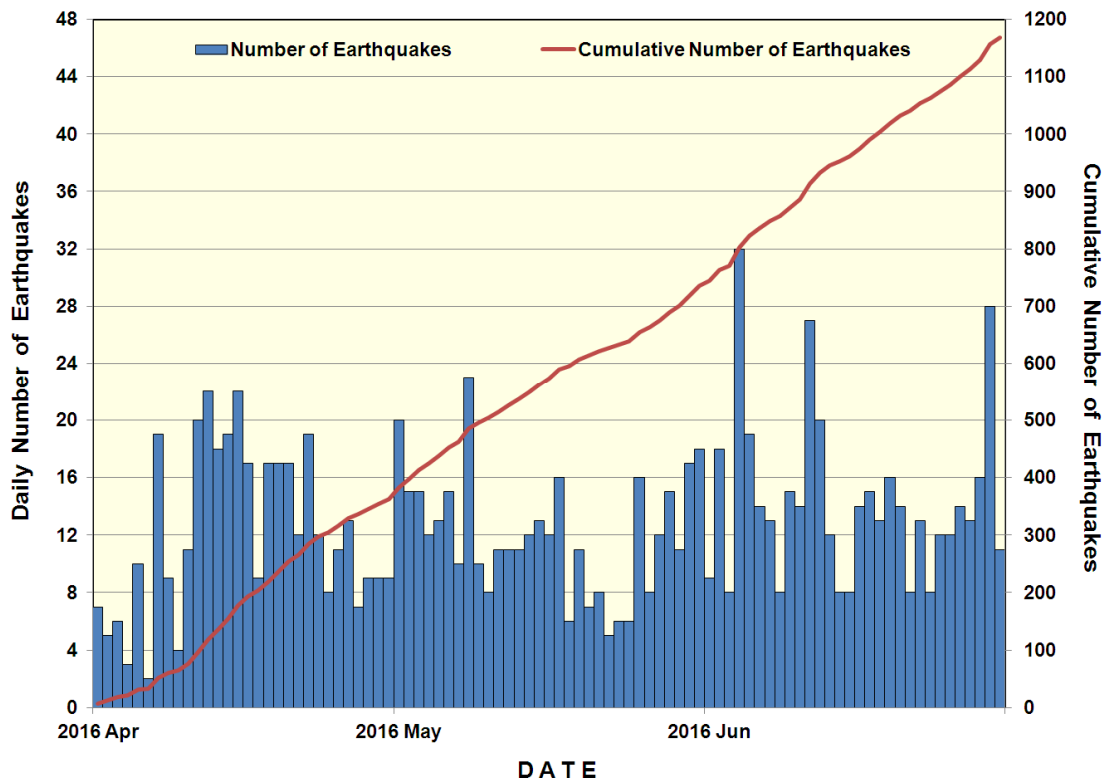


Fig. 2a: Daily and cumulative number of earthquakes during the period April – June 2016.

While, in general, the zone between Grenada and south of Martinique manifests low level seismicity, since 2008, persistent activity continues in the area east of Saint Lucia following a magnitude 4.7 earthquake on 2008/09/02; this quarter there were 11 events in the area, with the largest at magnitude 3.4. Also in the vicinity of Saint Lucia, near the northern tip, there has been an increased level of micro earthquakes; there were 12 in that area this quarter, with the largest at magnitude 3.3.

There were 15 earthquakes on/near land Trinidad in the magnitude range 2.7-3.9. There were no felt reports for these earthquakes.

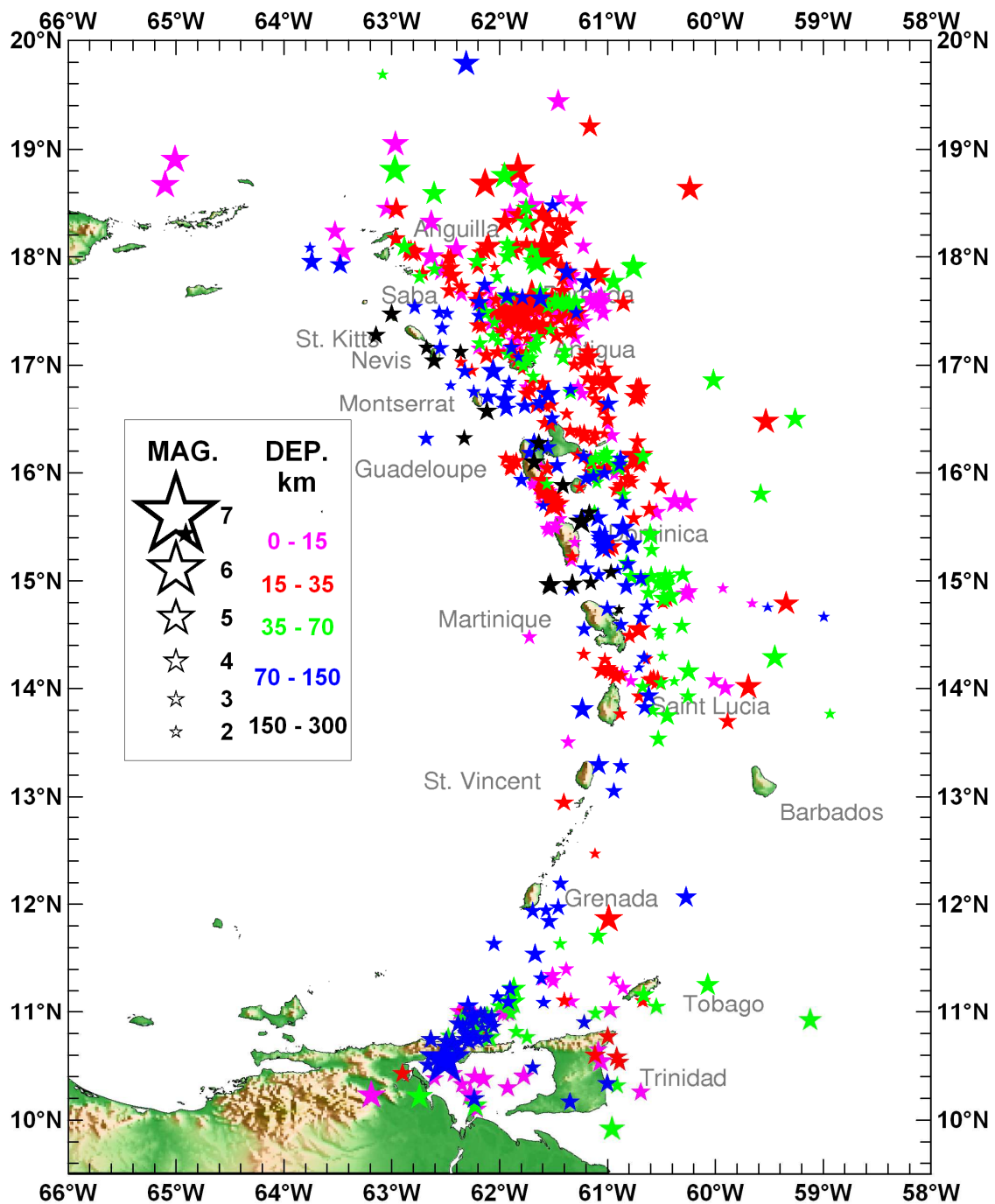


Fig. 2b: Eastern Caribbean epicentres during the period April – June 2016.

The zone marked out by the events seen in Fig. 3, which is a 3-D depiction of the earthquakes at depth, is called the Wadati-Benioff zone. It reveals the subduction of plate material that is taking place along the arc. Clearly evident is the depth distribution of the dense cluster of earthquakes north of Dominica.

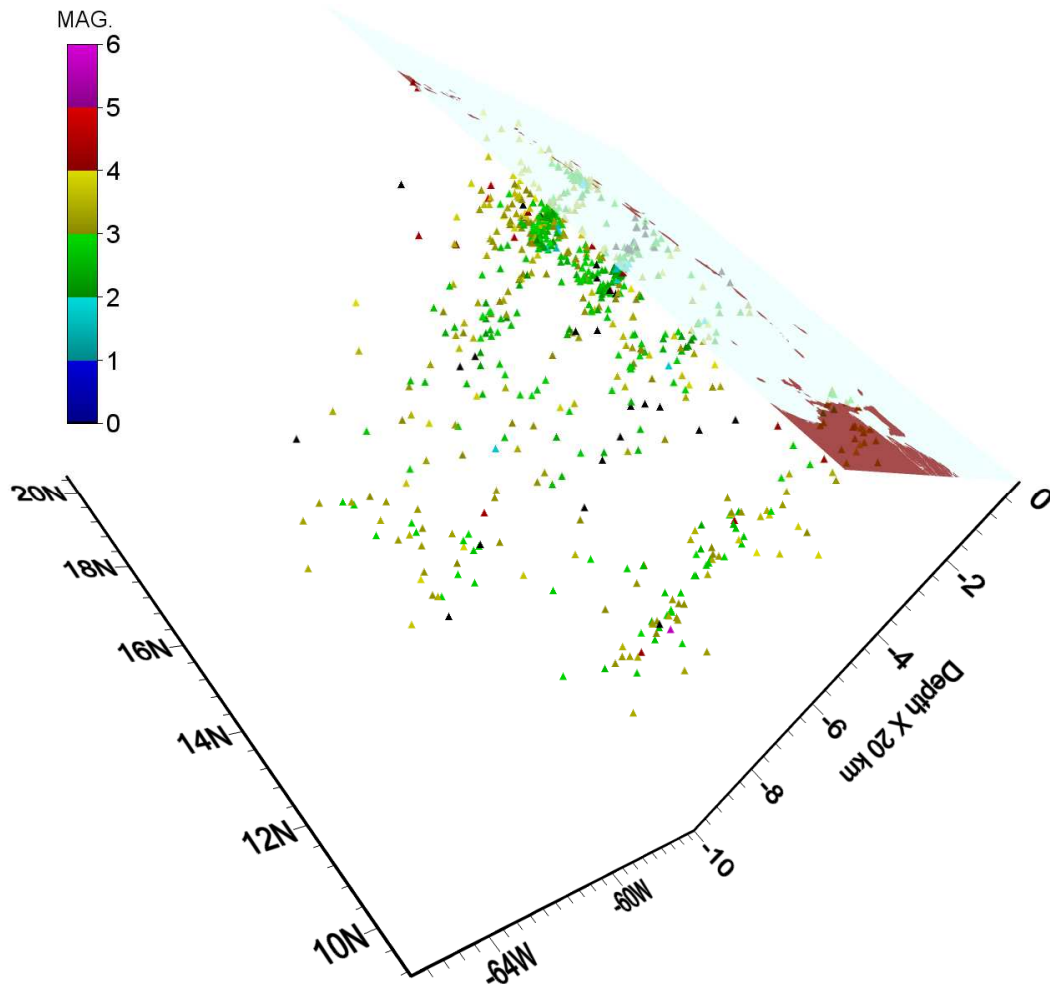


Fig. 3: Depth profile of earthquakes for the period April – June, 2016.

Table 1: Felt earthquakes for the period April - June 2016

DATE	TIME (UTC)	LAT. (°N)	LONG. (°W)	DEP. (km)	MAG. (Mt)	FELT REPORTS
2016/04/07	12:22:22.34	10.548	62.506	91	5.6	<p>Gulf of Paria, near south coast of Paria peninsula, Venezuela. Felt in Trinidad, Toabago, Grenada, St. Vincent and Saint Lucia.</p> <p>TRINIDAD MM INT: IV – Chaguaramas, Carenage, Diego Martin, Westmoorings, Maraval, Port of Spain, Champs Fleurs, Petit Valley, Morvant Belmont, San Juan, Barataria, Aranguez, Valsayn, Curepe, St. Augustine, Macoya, Tunapuna, Tacarigua, Trincity, Arima, Arouca, Lopinot, Toco, Cunupia, Chaguanas, Point Lisas III – Santa Cruz, Maracas Valley, Laventille, Cocorite, Maloney Gardens, D'Abadie, Sangre Grande, Charlieville, Chaguanas, Longdenville, Enterprise, Freeport, Couva, Gasparillo, Marabella, San Fernando, Tableland, Penal, Avocat, Princes Town, Point Fortin, Rio Claro, Biche, Tabaquite</p> <p>TOBAGO MM INT: III – Scarborough, Lambeau, Carnbee</p> <p>GRENADA MM INT: III – St. George's, Hope City, St. Paul's, St. Andrew's Carriocou, St. David's Mont Toute</p> <p>ST. VINCENT MM INT: III – Kingstown</p> <p>SAINT LUCIA MM INT: III - Castries</p>
2016/04/12	12:36:31.16	15.696	61.504	19	4.1	<p>North of Dominica. Felt in Dominica.</p> <p>DOMINICA MM INT: III – Picard</p>
2016/04/29	16:52:24.28	11.091	61.889	53	4.1	<p>North-west of Trinidad. Felt in Trinidad.</p> <p>TRINIDAD MM INT: IV – Port of Spain, Maracas, Chaguanas</p>
2016/05/08	13:48:03.69	17.593	61.701	247	5.1	<p>Near east coast of Barbuda. Felt in Antigua, St. Kitts, Montserrat and Guadeloupe.</p> <p>ANTIGUA MM INT: III – Jolly Harbour, St. John's Bellevue Estate</p> <p>ST. KITTS MM INT: III – Basseterre</p> <p>MONTserrat MM INT: III – Woodlands</p>

DATE	TIME (UTC)	LAT. (°N)	LONG. (°W)	DEP. (km)	MAG. (Mt)	FELT REPORTS
						GUADELOUPE MM INT: III –Les Abymes
2016/05/09	13:36:26.60	16.146	60.737	30	4.6	East of Guadeloupe. Felt in Guadeloupe and Dominica. GUADELOUPE MM INT: III – Sainte Anne DOMINICA MM INT: III – Mahaut
2016/06/09	03:38:31.17	11.862	60.989	25	4.2	North-west of Tobago. Felt in Grenada and St. Vincent. GRENADA MM INT: III – Mt. Rich St. Patrick ST. VINCENT MM INT: III - Mesopotamia

*UTC – Local Time + 4 hours MMI - Modified Mercalli Intensity

Volcanic Earthquakes detected during the period April – June 2016

Generally, the volcanic centres exhibited background seismic activity. Details of the activity at the Soufrière Hills Volcano may be found in releases from the Montserrat Volcano Observatory.

Volcanology

Dr. Erouscilla Joseph joined Dr. Giancarlo Tamburello of the University of Palermo (Italy), Ms Swetha Venugopal of Simon Fraser University (Canada), and Mr. Vincent Robert of OVSG (Guadeloupe, France) for fieldwork in the Valley of Desolation/Boiling Lake, Dominica from 17th - 20th May. The main objective of this field trip was to analyze the dominant volatile gas species (SO₂, H₂S, H₂O and CO₂) within the plumes emitted from the Boiling Lake and the Valley of Desolation fumarolic field. The gas composition of various hydrothermal features was measured using direct sample methods (MultiGAS, Giggenbach bottle sampling), while water samples were collected from other features for further analysis. Basaltic tephra samples were also collected to search for olivine-hosted melt inclusions, which are tiny blebs of primitive magma that contain the pre-eruptive volatile content. Combining these direct sampling methods, which analyze the composition of gases emitted at fumaroles and vents, with the pre-eruptive volatile contents of magma at depth, allows the computation of the volatile budget, which is the total volume of volatiles migrating through an arc and gases emitted into the atmosphere.

Ground Deformation

The SRC operates and maintains nine GPS receivers of the more than 40 receivers (maintained by other agencies) in the network utilised in its ground deformation work. During the reporting period, for a variety of reasons, we experienced challenges in our data download from several of the receivers. The DOMP receiver, located in Pennville, Dominica, has had a failure of internet connectivity. The aging Trimble NetRS DOMR receiver, located at the Ross University in Portsmouth, Dominica, failed in September of 2015 and requires replacement. Inadequate IT infrastructure at Bellevue Chopin, Dominica, means that the receiver installed there, BVCN, has been effectively decommissioned.

Data from the GPS STKN receiver at the NEMA office in Basseterre, St. Kitts cannot be downloaded via ftp because the IP address there is not static. Alternative methods of downloading the data, such as dynamic DNS or ftp push, are currently being explored. A summary of the stations in the SRC network is shown in Table 2.

Table 2: Status of Stations in SRC GPS Network

	Station	Status	Issues	Action Taken
1	ANTG	Active with data receipt	-	-
2	DOMI	Active with data receipt	-	-
3	SVGK	Active with data receipt	-	-
4	BATH	Active with data receipt	-	-
5	TSCA	Active with data receipt	-	-
6	SVGB	Active with data receipt	-	-
7	DOMP	Inactive, no data receipt	Public IP address down	Internet connectivity issue still unresolved.
8	DOMR	Inactive no data receipt	Not tracking any satellites	Visit to Dominica needed to replace receiver.
9	STKN	Inactive	No public IP address	Inter-agency IT discussions on the set up of DYN DNS system taking place.

Education and Outreach April – June 2016

The Education and Outreach (E&O) arm of the SRC provides the bridge between the science and societal application of improved knowledge and understanding of the geological hazards monitored by the SRC.

Student Outreach

An earthquake and volcano workshop was conducted with Grade 6 students at the International School, Port-of-Spain (ISPS). We also accepted an invitation from the Febeau Government Primary School (Trinidad) to participate in their career day (Plate 1). Mini workshops on earthquake science and safety were held with various classes throughout the day. No tours of the SRC were possible, during this quarter, due to the



Plate 1: E&O Research Assistant, Ms Alia Juman demonstrates a model of an erupting volcano for interested students of the Febeau Government Primary School, San Juan, Trinidad during their Careers Day.

shifting of operations to the new building. Tours will now have to be indefinitely postponed until a new area can be assigned for such sessions and a new tour route designed.

Science and Safety Sessions

Science and safety presentations on one of the following hazards: earthquakes, volcanoes, tsunamis, or sometimes on all three, are provided to private companies and other entities upon request. Participants in a course run by the Youth Training and Employment Partnership

Programme (YTEPP) were given an earthquake science and safety presentation at the YMCA headquarters, Port-of-Spain (Trinidad). The E&O team also presented a multi-hazard science and safety presentation to the Health and Safety section of the Venture Credit Union (Couva Branch, Trinidad).

Collaborations/Special Projects

Booth at Girl Guides *World Thinking Day* Event

During the period 13th-28th April, the National Emergency Management Organisation (NEMO), St. Vincent, in partnership with the SRC, Soufrière Monitoring Unit (SMU) and visiting scientists from the STREVA Project (Appendix II), commemorated the 37th anniversary of the 1979 La Soufrière eruption. The STREVA scientists were there conducting follow-up community workshops to share findings from their earlier research. This year's Volcano Awareness Week (VAW) campaign was extended for an additional week to accommodate the STREVA Project's community research showcases. Other VAW activities included the customary school workshops, an Ash Impact Workshop, a National Stakeholder Consultation, and the usually well subscribed Educational Field Tour of La Soufrière. A total of 20 school visits (8 Secondary and 12 Primary) were conducted from Monday 11th to Thursday 14th April. Each workshop included a short multimedia presentation, which was followed by an interactive activity and, time permitting, an evaluation. For the evaluation, informal questions were asked of primary school students, while secondary school students completed a timed quiz based on the material covered during the workshop.

The Educational Field Tour was carded for the final day of week one of the campaign. This year's tour was re-imagined in an attempt to better engage participating students.

Students competed in the “UWI SRC GeoSeekers’ La Soufrière Challenge” and were required to document their trip to the summit using photo collages of plant life and geology observed during the tour (Plate 2).



Plate 2: Winning Collage done by 4th Form students of the Georgetown Secondary School, St. Vincent for the first UWI-SRC Geoseekers Challenge that was conducted on the annual hike to La Soufrière volcano, during Volcano Awareness Week in St. Vincent and the Grenadines

UWI-SRC/STREVA personnel and local forestry officers served as guides for the tour, providing insights on the flora and geologic features seen along the trail. The competition also sought to increase the visibility of our Facebook platform among Vincentian youth (including participating students) by inviting the public to “like” competing schools’ photo collage submissions as part of the competition. The winning team received specially designed UWI-SRC “GeoSeekers” T-shirts (shown on the *right* being worn by staff members of the SRC). An original UWI-SRC “GeoSeekers” logo was conceptualized to potentially be used in future regional campaigns creating a platform for branded Earth science learning events and activities offered by the UWI-SRC.



The overarching objective of the campaign was met as targeted students and members of the public were exposed to information about the various hazards associated with their volcano and possible impacts in St. Vincent. After several years, the collaboration with NEMO and the SMU to provide logistical support in conducting this ESW campaign has proven reliable, though minor challenges persist.

Projects

The SRC is currently engaged in 11 projects, which are pursued within its routine work programme. Details of these projects are provided in Appendix II.

Trinidad & Tobago Microzonation Project (TTMP) – Principal Investigator Dr. Ilias Papadopoulos



Plate 3: Night time HVSR sampling in San Fernando accompanied by officers of the Trinidad and Tobago Police Service.

During this quarter, data collection continued in the second city, San Fernando. The field team worked on Single Site Measurement (SSM) during April; data were collected at night in areas with high levels of daytime, cultural noise. This is necessary because the technique being used in this analysis relies on data from natural sources, uncontaminated by artificial noise e.g. heavy traffic and machinery. Night time field work was done with the support of security details to promote the safety of the field team

(Plate 3). Single Site Measurements were completed in April. Microtremor Array Measurements (MAM), which is another phase of data acquisition, started in May and continued into June; this involves making recordings using an array of six instruments laid out in wide, open spaces e.g. parks, playing fields. Analyses of these data result in the production of shear wave velocity profiles of the subsurface lithology. These array measurements were done simultaneously in both Port of Spain and San Fernando.

The next city for investigation under the TTMP is Scarborough. Plans are progressing for the data acquisition exercise there.

Project: Disaster risk management in the Caribbean, support for the Seismic Research Centre, University of the West Indies; Government of New Zealand – Principal Investigators Dr. Erouscilla Joseph and Dr. Graham Ryan



Plate 4: Dr. Richard Robertson, SRC Director (right), Dr. Graham Ryan, volcanologist (left), meeting with Mr. Walton-France, Deputy Director, Global Development Division, New Zealand Foreign Affairs and Trade (Photo: Dr. Joan L. Latchman)

The Government of New Zealand is contributing to improving the monitoring of volcanoes and education and outreach to stakeholders in the Eastern Caribbean with a view to making the region more resilient to the impacts of volcanic eruptions. This is being done through collaboration with GNS Science, New Zealand. One aspect of this project seeks to develop SRC's capability to remotely and continuously monitor thermal areas at volcanoes (volcano-hydrothermal systems). One of the outputs of this objective consists of building and operating continuous monitoring stations at one volcano-hydrothermal system, and developing skills in the processing and interpretation of data from such stations.

During this quarter there was a change in administration of the Global Development Division, New Zealand Foreign Affairs and Trade and on 4th May, the new Deputy Director Mr. Dominic Walton-France visited the SRC (Plate 4) to gain first-hand knowledge of the region and the work being conducted under this project.

STREVA

The Strengthening Resilience in Volcanic Areas' (STREVA) research project is a collaborative project that aims to reduce the negative consequences of volcanic activity on communities and their assets. It works collaboratively across different scientific disciplines to improve our knowledge of volcanic hazard and risk, and to work with people who live with volcanic risk to develop ways to strengthen their resilience to future eruptions. Funded by the UK Natural Environment and Economic and Social Research Councils it is led by Professor Jenni Barclay of the University of East Anglia.

The STREVA team has been working for many years in St Vincent and the Grenadines, in collaboration with NEMO and the SRC. For Volcano Awareness Week in St. Vincent



Plate 5: (STREVA team front row, left to right) **Lara Mani, Dr. Anna Hicks, Prof. Jenni Barclay (Principal Investigators, Dr. Victoria Sword-Daniels, Peter Simmonds, and (back row right) Dr. Paul Cole** (SRC and SMU team back row, left to right) **Clevon Ash, Winston Carl Phillips, Dr. Richard Robertson, and Omari Graham.**

during April, the SRC and the STREVA project team partnered to execute a series of activities whose main intention was to feed back major research findings to various stakeholders in St. Vincent. The activities included community outreach activities in communities located on the east and west flank of La Soufrière volcano. These community activities included the showing of new films featuring community members, execution of a scenario and development of personal preparedness plan. In addition, a national stakeholders meeting and ash impacts workshop was held and the STREVA team assisted with the annual educational tour to

La Soufrière that is undertaken as part of Volcano Awareness Week.

Current Research

Routine Research

SRC staff members are engaged in several research projects aimed at developing understanding of the processes influencing the seismic and volcanic activity in the Eastern Caribbean. Following are the topics currently being pursued:

Geochemical and isotopic characterization of geothermal systems in the Lesser Antilles, and its use as a tool for monitoring changes in volcanic activity – the use of long-term geochemical surveillance of volcanic-hydrothermal systems can provide useful information of the changes in chemistry of geothermal reservoirs that may be indicative of changes in magmatic input. Geothermal monitoring also allows study of the evolution of these geothermal systems over time. - **Dr. Erouscilla P. Joseph**

Radon monitoring in earthquake forecasting for Tobago - South-west Tobago is being used as the test zone. The project seeks to explore the utility of radon as a seismic monitoring tool. – **Dr. Joan L. Latchman and Dr. Erouscilla P. Joseph**

Magnitude output imbalance as a diagnostic tool in earthquake forecasting – **Dr. Joan L. Latchman**

Improved well-targeting for Caribbean geothermal exploitation: An improved seismic velocity geothermometer – **Dr. Graham Ryan**

Student Research

Dynamics of Geothermal Systems in the Eastern Caribbean – modelling of the geophysical conditions of the Boiling Lake, Dominica to better understand the phenomena of its unusual activity, and study the general response of geothermal systems to deep magmatic input – Ph.D. project, **Deborah Robertson; Supervisor Dr. Erouscilla P. Joseph.**

Deciphering the genesis of Soufrière magmas St. Vincent – Ph.D. project, **Michal Camejo; Supervisor Dr. Richard Robertson**

Development, testing, and application of a low-cost technology sulphur dioxide monitor as a tool for use in a volcanic emissions monitoring network. – M.Phil. project, **Viveka Jackson; Supervisor Dr. Erouscilla P. Joseph**

Assessment of the communication protocols used in Volcanic Emergency Management in the Eastern Caribbean. – M.Phil. project, **Omari Graham; Supervisor Dr. Richard Robertson**

Modelling the Montserrat geothermal system – M.Phil. project, **Racine Basant**, Supervisor **Dr. Graham A. Ryan**

Tomographically constrained Montserrat reservoir model using AUTOUGH2 - Development of a numerical two phase flow model of the Montserrat geothermal system with a novel use of seismic tomography data to provide model boundary conditions – Honorary Research fellow project, **Elliot Jiwani-Brown**, Supervisor **Dr. Graham A. Ryan**

Departmental Seminars

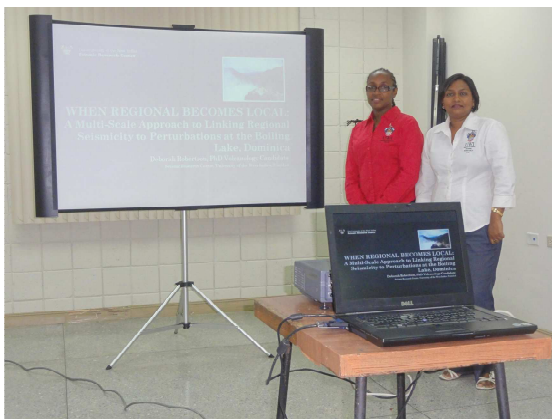


Plate 6: Ms Deborah Robertson with her supervisor, Dr. Erouscilla Joseph, following her presentation on the Boiling Lake.

The first seminars to be held in the new SRC facility took place in late June. The designated Server Room is being used as the interim venue for such meetings until the operations meant for this area are transferred from the old building.

On 22nd June, Ms Deborah Robertson (Plate 6) gave a presentation on *When Regional Becomes Local: A Multi-scale Approach to Linking Regional Seismicity to Perturbations at the Boiling Lake, Dominica*, in which she showed the techniques being employed to find possible explanations for the episodes of rapid lake level changes over very short time scales.

Also on 22nd June, Dr. Papadopoulos held a seminar on Earthquake Loss Estimation in the Caribbean (Plate 7). The seminar



Plate 7: Dr. Papadopoulos providing insights on his work on Earthquake Loss Estimation in the Caribbean.

provided insights gained from his work under the “Disaster Vulnerability and Risk Assessment Modelling Jamaica and the Greater Caribbean Basin Project”, for which he recorded Microtremor Array data to define the geology of Kingston, Jamaica. The results were then used as input to CaribEviz, an earthquake hazard assessment software package, to calculate the possible loss from an earthquake in the vicinity of Kingston. The same presentation was also given during the APPET 2016 conference.