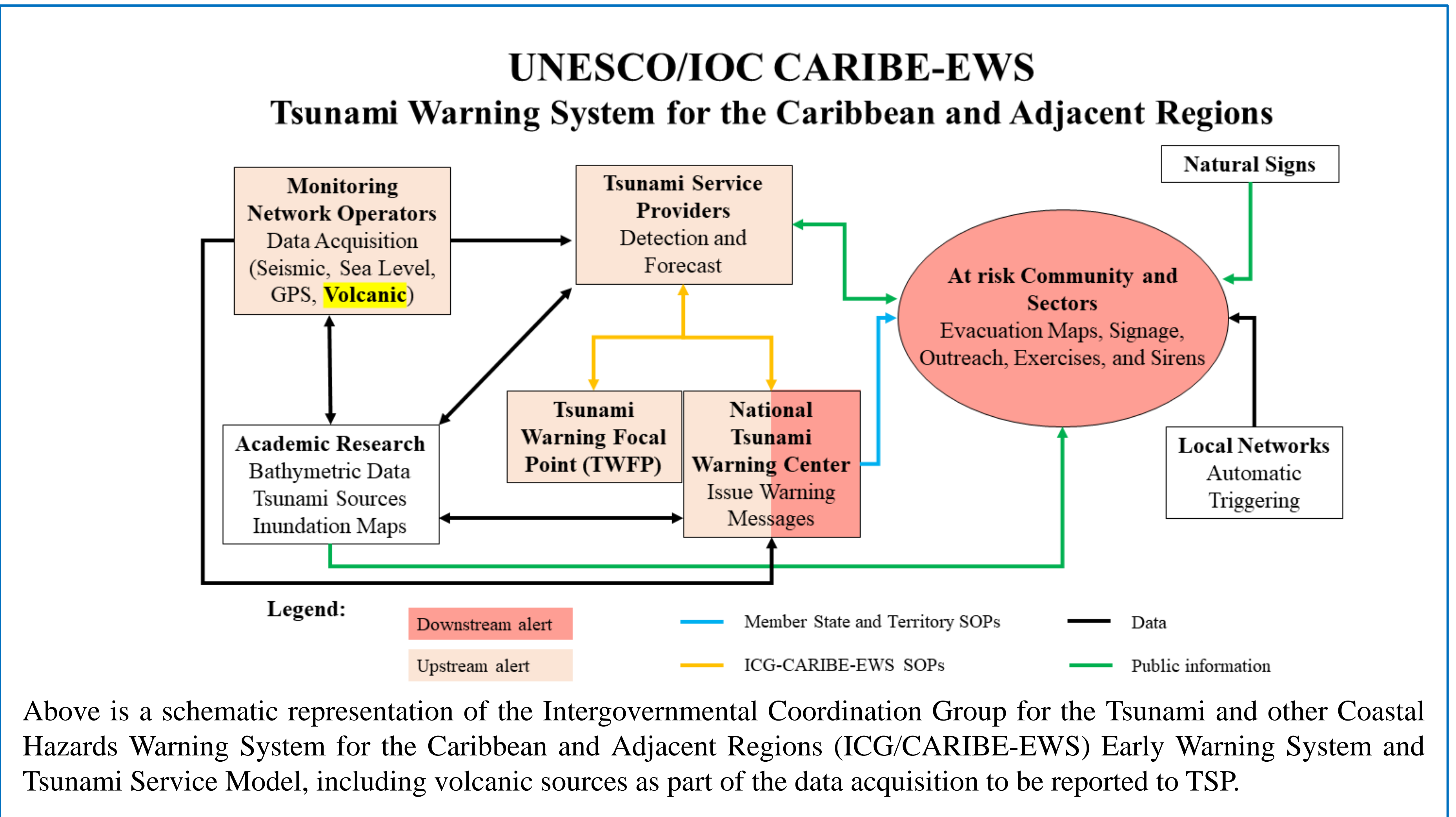


Christa von Hillebrandt-Andrade, Valerie Clouard, Jelis J. Sostre-Cortés, Elizabeth Vanacore, Bernardo Aliaga, Mike Angove, Nicolas Arcos, Silvia Chacón-Barrantes, Francisco Dourado, Octavio Gomez-Ramos, Erouscilla Joseph, Laura Kong, Lloyd Lynch, Charles McCreery, Dan McNamara, Raphael Paris, Lizzette Rodriguez, Roy Watlington

### Introduction

In the Caribbean, 14% of all probable and definite historical tsunamis are associated with volcanoes. However, the tsunami warning system that has been widely implemented was designed for tsunamis triggered by earthquakes. For this instance, when a magnitude above a threshold is recorded and from a certain location, action from the Tsunami Service Providers (TSP) is triggered. Earthquake generated tsunamis are different from volcanic tsunamis in terms of source, detection, warning messages and modelling. As such, with the current system it is very challenging to detect the triggering of tsunamis generated by volcanoes and to compute a tsunami propagation model in real time. Furthermore, recent volcano generated tsunamis, such as Hunga Tonga (2022) and Krakatau (2018), as well as volcanic activity in Kick'em Jenny (2015), Soufriere (2020-2021) and La Palma (2021) have highlighted the need to revise and modify the established warning systems, as well as improve monitoring systems to account for volcanic sources of tsunamis. Given the close proximity between the Caribbean countries and the threat volcanoes pose to them, this reinforces the need for the implementation of a coordinated response system within the region.



### Sample Threat Message

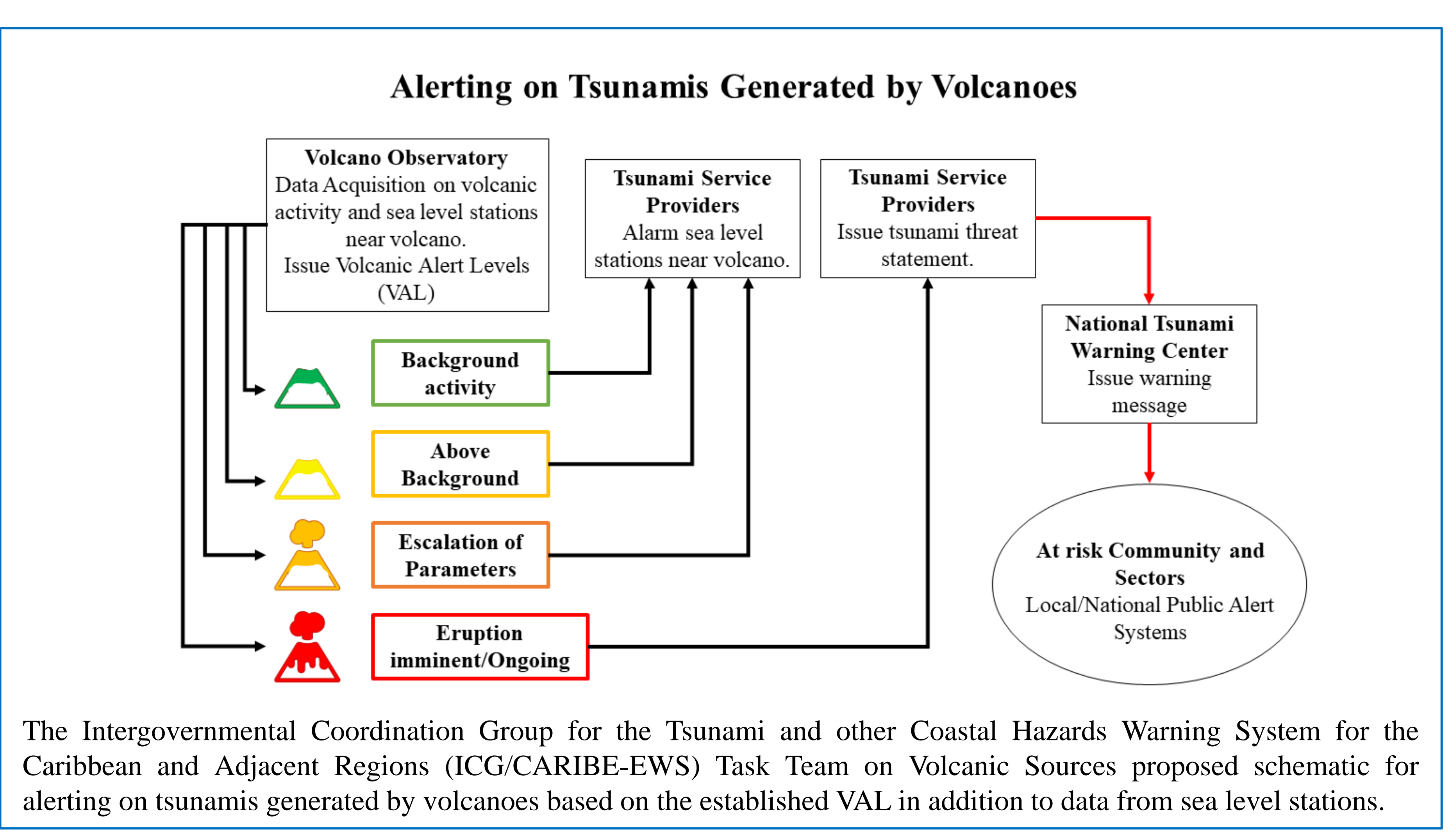
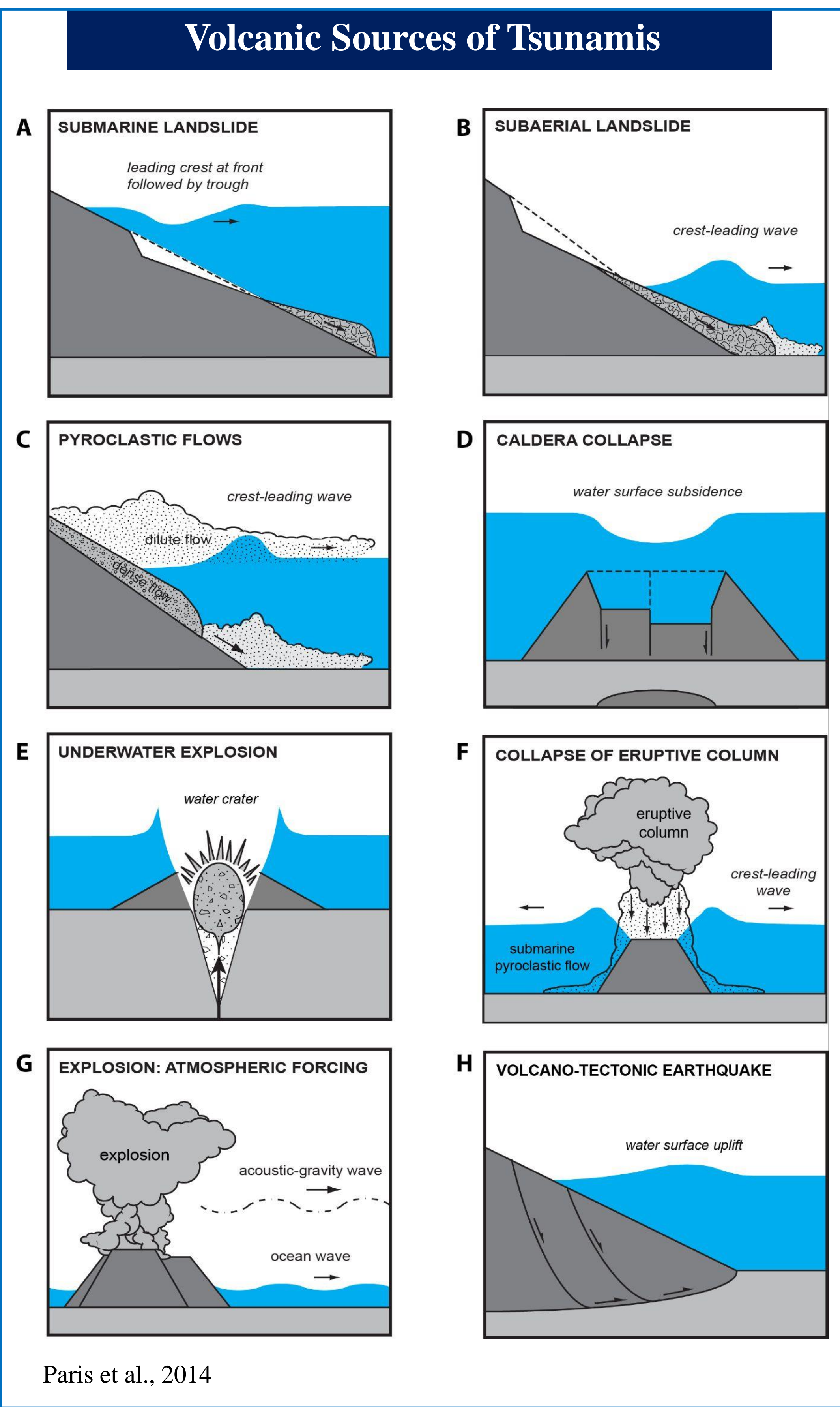
WECA41 PHEB 231407TSUCAX  
 ...TSUNAMI MESSAGE NUMBER 1...  
 NWS PACIFIC TSUNAMI WARNING CENTER HONOLULU HI1407 UTC THU MAR 23 2023  
 ...TSUNAMI THREAT MESSAGE...  
 \*\*\*\* NOTICE \*\*\*\* NOTICE \*\*\*\* NOTICE \*\*\*\* NOTICE \*\*\*\* NOTICE \*\*\*\*  
 THIS MESSAGE IS ISSUED FOR INFORMATION ONLY IN SUPPORT OF THE UNESCO/IOC TSUNAMI AND OTHER COASTAL HAZARDS WARNING SYSTEM FOR THE CARIBBEAN AND ADJACENT REGIONS AND IS MEANT FOR NATIONAL AUTHORITIES IN EACH COUNTRY OF THAT SYSTEM. NATIONAL AUTHORITIES WILL DETERMINE THE APPROPRIATE LEVEL OF ALERT FOR EACH COUNTRY AND MAY ISSUE ADDITIONAL OR MORE REFINED INFORMATION.  
 \*\*\*\* NOTICE \*\*\*\* NOTICE \*\*\*\* NOTICE \*\*\*\* NOTICE \*\*\*\* NOTICE \*\*\*\*  
 ... TSUNAMI SOURCE EVENT PARAMETERS ...  
 -----  
 \* ORIGIN TIME 1352 UTC MAR 23 2023  
 \* COORDINATES 14.8 NORTH 61.2 WEST  
 \* LOCATION MOUNT PEELE VOLCANO... MARTINIQUE  
 \* EVALUATION ...  
 -----  
 \* THE OBSERVATORY FOR MOUNT PEELE VOLCANO ON MARTINIQUE REPORTS A FLANK COLLAPSE OF THE VOLCANO AROUND 1350 UTC WITH MATERIAL ENTERING THE SEA AROUND 1352 UTC ON THURSDAY MARCH 23 2023. \* A TSUNAMI HAS BEEN OBSERVED. \* BASED ON THIS INFORMATION... WIDESPREAD HAZARDOUS TSUNAMI WAVES ARE POSSIBLE. \* IT IS NOT POSSIBLE TO FORECAST TSUNAMI IMPACTS FROM THIS EVENT BUT THIS CENTER WILL CONTINUE TO MONITOR AND REPORT TSUNAMI OBSERVATIONS UNTIL IT APPEARS THE THREAT HAS PASSED  
 ... TSUNAMI THREAT FORECAST ...  
 -----  
 \* HAZARDOUS TSUNAMI WAVES FROM THIS EVENT ARE POSSIBLE WITHIN THE NEXT THREE HOURS ALONG SOME COASTS OF DOMINICA... MARTINIQUE... SAINT LUCIA... GUADELOUPE... SAINT VINCENT... MONTSERRAT... BARBADOS... SAINT KITTS... SINT EUSTATIUS... GRENADA... SABA... US VIRGIN IS... ANTIGUA... BARBUDA... SINT MAARTEN... ANGUILLA... TRINIDAD TOBAGO... BONAIRE... BR VIRGIN IS... PUERTO RICO... SAINT MARTIN... SAINT BARTHELEMY... DOMINICAN REP... VENEZUELA... ARUBA... CURACAO... HAITI... TURKS N CAICOS... BAHAMAS... CUBA... COLOMBIA... BERMUDA... PANAMA... CAYMAN ISLANDS AND JAMAICA  
 ... RECOMMENDED ACTIONS ...  
 -----  
 \* GOVERNMENT AGENCIES RESPONSIBLE FOR THREATENED COASTAL AREAS SHOULD TAKE ACTION TO INFORM AND INSTRUCT ANY COASTAL POPULATIONS AT RISK IN ACCORDANCE WITH THEIR OWN EVALUATION... PROCEDURES AND THE LEVEL OF THREAT. \* PERSONS LOCATED IN THREATENED COASTAL AREAS SHOULD STAY ALERT FOR INFORMATION AND FOLLOW INSTRUCTIONS FROM NATIONAL AND LOCAL AUTHORITIES  
 ... ESTIMATED TIMES OF ARRIVAL ...  
 -----  
 \* ESTIMATED TIMES OF ARRIVAL -ETA- OF THE INITIAL TSUNAMI WAVE FOR PLACES WITHIN THE REGION IDENTIFIED WITH A POTENTIAL TSUNAMI THREAT. ACTUAL ARRIVAL TIMES MAY DIFFER AND THE INITIAL WAVE MAY NOT BE THE LARGEST. A TSUNAMI IS A SERIES OF WAVES AND THE TIME BETWEEN WAVES CAN BE FIVE MINUTES TO ONE HOUR.

LOCATION	REGION	COORDINATES	ETA(UTC)
ROSEAU	DOMINICA	15.3N 61.4W	1401 03/23
FORT DE FRANCE	MARTINIQUE	14.6N 61.1W	1403 03/23
CASTRIES	SAINT LUCIA	14.0N 61.0W	1403 03/23
BASSE TERRE	GUADELOUPE	16.0N 61.7W	1411 03/23
KINGSTOWN	SAINT VINCENT	13.1N 61.2W	1417 03/23
PLYMOUTH	MONTSERRAT	16.7N 62.2W	1423 03/23
BRIDGETOWN	BARBADOS	13.1N 59.6W	1432 03/23
BASSETERRE	SAINT KITTS	17.3N 62.7W	1435 03/23
SINT EUSTATIUS	SINT EUSTATIUS	17.5N 63.0W	1444 03/23
SAINT GEORGES	GRENADA	12.0N 61.8W	1444 03/23
SABA	SABA	17.6N 63.2W	1446 03/23
CHRISTIANSTED	US VIRGIN IS	17.7N 64.7W	1446 03/23
SAINT JOHNS	ANTIGUA	17.1N 61.9W	1500 03/23
PALMETTO POINT	BARBUDA	17.6N 61.9W	1502 03/23
SIMPSON BAAI	SINT MAARTEN	18.0N 63.1W	1503 03/23
THE VALLEY	ANGUILLA	18.3N 63.1W	1511 03/23
PIRATES BAY	TRINIDAD TOBAGO	11.3N 60.6W	1512 03/23
ONIMA	BONAIRE	12.3N 68.3W	1512 03/23
ANEGADA	BR VIRGIN IS	18.8N 64.3W	1515 03/23
SAN JUAN	PUERTO RICO	18.5N 66.1W	1516 03/23

... POTENTIAL IMPACTS ...  
 -----  
 \* A TSUNAMI IS A SERIES OF WAVES. THE TIME BETWEEN WAVE CRESTS CAN VARY FROM 5 MINUTES TO AN HOUR. THE HAZARD MAY PERSIST FOR MANY HOURS OR LONGER AFTER THE INITIAL WAVE. \* IMPACTS CAN VARY SIGNIFICANTLY FROM ONE SECTION OF COAST TO THE NEXT DUE TO LOCAL BATHYMETRY AND THE SHAPE AND ELEVATION OF THE SHORELINE. \* IMPACTS CAN ALSO VARY DEPENDING UPON THE STATE OF THE TIDE AT THE TIME OF THE MAXIMUM TSUNAMI WAVES. \* PERSONS CAUGHT IN THE WATER OF A TSUNAMI MAY DROWN... BE CRUSHED BY DEBRIS IN THE WATER... OR BE SWEEPED OUT TO SEA  
 ... TSUNAMI OBSERVATIONS ...  
 -----  
 \* THE FOLLOWING ARE TSUNAMI WAVE OBSERVATIONS FROM COASTAL AND/OR DEEP-OCEAN SEA LEVEL GAUGES AT THE INDICATED LOCATIONS. THE MAXIMUM TSUNAMI HEIGHT IS MEASURED WITH RESPECT TO THE NORMAL TIDE LEVEL.  
 GAUGE TIME OF MAXIMUM WAVE COORDINATES MEASURE TSUNAMI PERIOD  
 GAUGE LOCATION LAT LON (UTC) HEIGHT (MIN)  
 -----  
 LE PRECHEUR MARTINI 14.8N 61.2W 1357 7.81M/25.6FT 16  
 -----  
 ... NEXT UPDATE AND ADDITIONAL INFORMATION ...  
 -----  
 \* THE NEXT MESSAGE WILL BE ISSUED IN ONE HOUR... OR SOONER IF THE SITUATION WARRANTS. \* FURTHER INFORMATION ABOUT THIS EVENT MAY BE FOUND AT WWW.TSUNAMI.GOV.

### VONUT Sample Threat Message 1

...VONUT NUMBER 1...  
 ...THIS MESSAGE IS FOR THE CARIBBEWAVE23 EXERCISE ONLY...  
 ...VOLCANO OBSERVATORY NOTICE FOR TSUNAMI THREAT ...  
 ...VONUT...  
 (2) Issued: 20230323/1330Z  
 (3) Volcano: Pelée 360120  
 (4) Current Aviation Colour Code: Red  
 (5) Previous Aviation Colour Code : Orange  
 (6) Source: Volcanological and Seismological Observatory of Martinique (OVSM)  
 (7) Notice Number: 2023-01  
 (8) Volcano Location: 1448N6110W  
 (9) Area: Martinique Island, WI  
 (10) Summit Elevation: 4501 FT (1372 M)  
 (11) Volcanic Activity Summary: Increase in seismic activity, including tremors and several M>4 earthquakes at shallow depth, fissure openings, increase in fumarolic activity, important deformation of ca. 5 cm since the last 4 weeks on the southwestern flank.  
 (12) Sea sector of the impact (North, South, East, West) Most probably the south-western flank of Mount Pelee  
 (13) Name of the sea (Caribbean, Atlantic, Dominique Channel) Most probably the Caribbean Sea  
 (14) Closest tide gauges  
 prec: <https://www.ioc-sea-level-monitoring.org/station.php?code=prec>  
 ffr: <https://www.ioc-sea-level-monitoring.org/station.php?code=ffr>  
 lero: <https://www.ioc-sea-level-monitoring.org/station.php?code=lero>  
 rose: <https://www.ioc-sea-level-monitoring.org/station.php?code=rose>  
 stlu: <https://www.ioc-sea-level-monitoring.org/station.php?code=stlu>  
 ptmd: <https://www.ioc-sea-level-monitoring.org/station.php?code=ptmd>  
 mrlg: <https://www.ioc-sea-level-monitoring.org/station.php?code=mrlg>  
 (15) Remarks: The possibility of an eruption and a collapse from the south-western flank is high within the next hours or days.  
 (16) Contacts : Ms : Jordane CORBEAU tel: +596 696 60 34 85 fax: +596 596 55 80 80  
 Email: [directionovsm@services.cnrs.fr](mailto:directionovsm@services.cnrs.fr)  
 (17) Next Notice: A new VONUT will be issued if conditions change significantly.  
 Volcanic information can be found in: <http://www.ipgp.fr/en>



### Proposed Actions

- Volcano Observatories issue warning messages of potential or ongoing eruptions to Tsunami Service Providers.
- Tsunami Service Providers then monitor tide gauge data and issue tsunami threat message to National Tsunami Warning Center if a pre-defined threshold is reached.
- Work to increase the sea level station network, specially near active volcanoes.
- Include volcanic sources in CARIBE WAVE exercises.
- Aspire for communities prone to tsunami risk to become Tsunami Ready for an effective tsunami response.

### Future Work

The procedures mentioned here are essential for the development of updated tsunami warning systems that account for volcanic sources. More work and research is still yet to be done to implement the necessary revisions for these imperative systems. Such as advancing volcano scenario modeling and tsunami forecasting, as well as expanding observations, including seismic and geodetic.

### VONUT Sample Threat Message 2

...VONUT NUMBER 2...  
 ...THIS MESSAGE IS FOR THE CARIBBEWAVE23 EXERCISE ONLY...  
 ...VOLCANO OBSERVATORY NOTICE FOR TSUNAMI THREAT ...  
 ...VONUT...  
 (1) ... VOLCANO OBSERVATORY NOTICE FOR TSUNAMI THREAT - VONUT  
 (2) Issued: 20230323/1355Z  
 (3) Volcano: Pelée 360120  
 (4) Current Aviation Colour Code: Red  
 (5) Previous Aviation Colour Code : Red  
 (6) Source: Volcanological and Seismological Observatory of Martinique (OVSM)  
 (7) Notice Number: 2023-02  
 (8) Volcano Location: 1448N6110W  
 (9) Area: Martinique Island, WI  
 (10) Summit Elevation: 4501 FT (1372 M)  
 (11) Volcanic Activity Summary: A new eruption began at 1350Z. Huge dome collapse confirmed by visual information at SW Pelee volcano at 1350Z and reached the sea at 1352Z.  
 (12) Sea sector of the impact (North, South, East, West) South-west of the volcano  
 (13) Name of the sea (Caribbean, Atlantic, Dominique Channel) Caribbean Sea  
 (14) Closest tide gauges  
 prec: <https://www.ioc-sea-level-monitoring.org/station.php?code=prec>  
 ffr: <https://www.ioc-sea-level-monitoring.org/station.php?code=ffr>  
 lero: <https://www.ioc-sea-level-monitoring.org/station.php?code=lero>  
 rose: <https://www.ioc-sea-level-monitoring.org/station.php?code=rose>  
 stlu: <https://www.ioc-sea-level-monitoring.org/station.php?code=stlu>  
 ptmd: <https://www.ioc-sea-level-monitoring.org/station.php?code=ptmd>  
 mrlg: <https://www.ioc-sea-level-monitoring.org/station.php?code=mrlg>  
 (15) Remarks: Part of our network is unavailable. Prêcheur tide gauge might be damaged.  
 (16) Contacts : Ms : Jordane CORBEAU tel: +596 696 60 34 85 fax: +596 596 55 80 80  
 Email: [directionovsm@services.cnrs.fr](mailto:directionovsm@services.cnrs.fr)  
 (17) Next Notice: A new VONUT will be issued if conditions change significantly.  
 Volcanic information can be found in: <http://www.ipgp.fr/en>

### Acknowledgements

We would like to recognize the support of the ICG CARIBE EWS Task Team on Volcanic Sources, as well as the ad hoc working group of Tonga Sea Level Disturbances in the Caribbean and Adjacent regions.