Royal Netherlands
Meteorological Institute
Ministry of Infrastructure
and Water Management

Volcano Monitoring Updates Saba and St. Eustatius 2017 - 2023

E. de Zeeuw - van Dalfsen

De Bilt, 2023 | Technical report; TR 407

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Elske de Zeeuw - van Dalfsen

Updates sent by email to local governments
2017 - 2023

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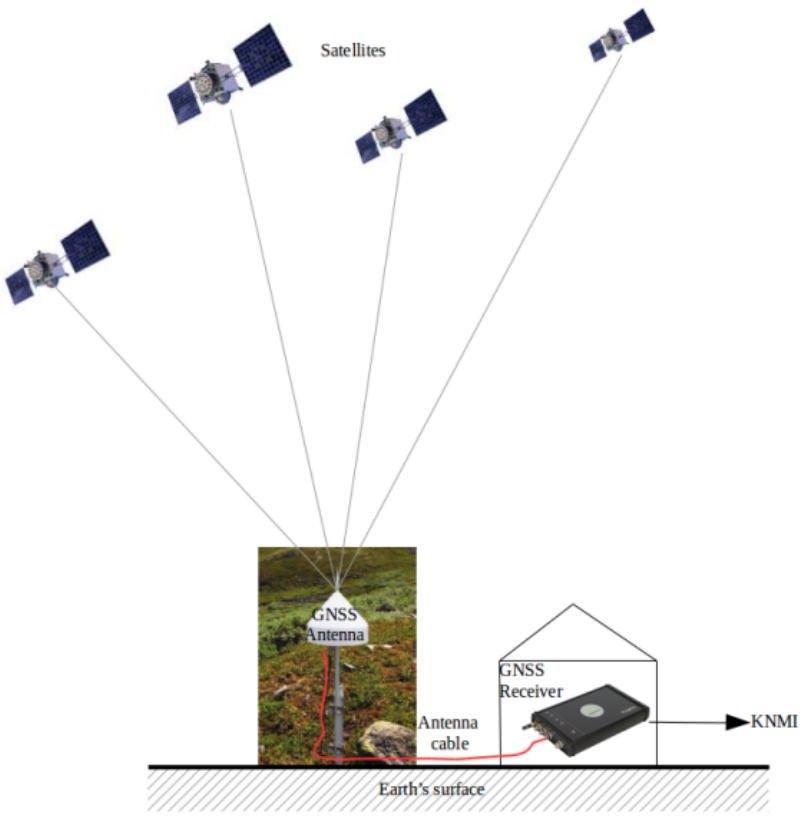
UPDATE 1 – Saba and St. Eustatius, GNSS instruments, 6 June 2017

Currently KNMI monitors the geological activity at the islands of Saba and St Eustatius with broadband seismometers. These register the ***shaking*** of the Earth. KNMI plans to expand this network with so-called “Global Navigation Satellite System” observations (GNSS). GNSS instruments monitor the ***movement*** of the Earth.

Multiple satellites orbit our planet. Signals from these satellites can be picked up at the surface using an antenna. From the antenna data is transmitted to the receiver. When the signal of several satellites is received at the same time, the precise location (latitude, longitude and altitude) of the antenna can be identified with centimeter precision. By installing a continuously operating antenna/receiver, the precise location of this point can be monitored through time.



To install the antenna at a permanent location, a so-called “monument” will be created. This basically means that the pole on which the antenna will be mounted is securely cemented into a hole drilled into rock. Data from these GNSS instruments will be sent automatically to KNMI for analysis. They can be used, on a regional scale, to study how the islands move due to plate tectonics (movements of the Earth’s crust), but also more locally to identify if the surface of the volcano remains stable. Together with the seismic data this will allow improved monitoring of the state of the volcano.

Aim is to install the first GNSS instruments (one at each island) in the last quarter of 2017.

UPDATE 2 – Saba, GNSS instruments and temperature logging of the hot spring, 6 November 2017

In the past months, KNMI purchased two Global Navigation Satellite System (GNSS) instruments, which will be dedicated to the observation of geophysical processes at Saba and St. Eustatius. The instruments are currently deployed and tested at KNMI. The data will be used, on a regional scale, to study how the islands move due to plate tectonics (movements of the Earth's crust), but also more locally to identify if the surface of the volcano remains stable. Together with the seismic data this will allow improved monitoring of the state of the volcano.

Due to the passing of Hurricanes Irma and Maria, the installation of the instruments is postponed till early 2018, when we will visit the island with a team of 3-5 people.

Attached is a letter asking permission from the local government to create the monument on which the antenna will be permanently installed (at St. Johns). We have also asked SATEL for their support in establishing facilities for data transmission.

KNMI plans to install a temperature logger at the hot spring opposite Green Island. This logger will measure and store the temperature of the hot spring several times per day for a period of at least 2 years. Monitoring of the temperature through time will give insight into the seasonal variations of the temperature as well as increases due to a change in volcanic activity.

UPDATE 2 – St. Eustatius, GNSS instruments, 6 November 2017

In the past months, KNMI purchased two Global Navigation Satellite System (GNSS) instruments, which will be dedicated to the observation of geophysical processes at Saba and St. Eustatius. The instruments are currently deployed and tested at KNMI. The data will be used, on a regional scale, to study how the islands move due to plate tectonics (movements of the Earth's crust), but also more locally to identify if the surface of the volcano remains stable. Together with the seismic data this will allow improved monitoring of the state of the volcano.

Due to the passing of Hurricanes Irma and Maria, the installation of the instruments is postponed till early 2018, when we will visit the island with a team of 3-5 people.

Attached is a letter asking permission from the local government to create the monument on which the antenna will be permanently installed (close to the EUTEL building just North of Kay Bay). We have also asked EUTEL for their support in establishing facilities for data transmission.

UPDATE 3 – Saba, March 2019

In January 2018 KNMI installed the first GNSS instrument at St Johns, followed by a second installation in February 2019 at the airport (Fig. 1). Both instruments are operating as expected and data is sent to KNMI automatically every hour. Data transmission is facilitated by SATEL .

Fig. 1 GNSS installation by St. Johns (left) and at the airport (right). The white part at the top is the antenna which receives the signals from satellites orbiting the Earth.

The instruments are subject to the harsh environmental conditions on the island and will have to be maintained every year to ensure their continued operation. KNMI will take charge of this task. The primary cause of marine corrosion in coastal areas is the chloride ions in the air from the evaporated sea salt in ocean spray, this is made worse by the high temperatures, which speed up the reaction time, corroding even stainless steel (Fig. 2).

Fig 2. Corroded stainless steel leveler after 1 year of exposure to the elements at St. John's (left). After maintenance the leveler looks almost new (right).

In January 2018 a temperature sensor was installed at the hot spring opposite Green Island. This sensor takes one measurement every 20 minutes and stores the data locally. The measurements will form a time series, which will give more detailed information about temperature changes of the hot spring, compared to the single temperature measurements taken so far.
The site was revisited in November 2018, when data were collected and new temperature probes were installed. In February 2019 we collected data once again and improved the installation.

Fig. 3 Temperature measurements of the hot spring opposite Green Island, in January 2018 (left), November 2018 (middle) and February 2019 (right). Temperature probes are buried in the ocean bed and covered with rocks to keep them in place. The data loggers are the small yellow cases mounted on the rock above the spring and housed in a black pelican case for additional protection from the elements in the most recent setup.

During every visit each seismometer is also visited and inspected for proper operations. Due to damage of one of the seismic dataloggers currently 3 seismometers are in operation at The Bottom, St. Johns, and Windwardside. The fourth seismometer will be reinstalled at the airport after repair (Fig. 4) as discussed with Maegan Hassell.

Fig. 4 The foreseen location for the fourth seismometer, underneath the stairs to the airport tower.

UPDATE 3 – St. Eustatius, March 2019

In January 2018 KNMI installed the first GNSS instrument at the White Hook EUTEL facility, followed by a second installation in January 2019 at the airport (Fig. 1). Both instruments are operating as expected and data are sent to KNMI automatically every hour. Data transmission is facilitated by continued support from EUTEL.

Fig. 1 GNSS installation by White Hook (left) and at the airport (right). The white part at the top is the antenna which receives the signals from satellites orbiting the Earth.

Fig 2. Corroded stainless steel leveler after 1 year of exposure to the elements at White Hook (left). After maintenance the leveler looks as good as new (right).

The instruments are subject to the harsh environmental conditions on the island and will have to be maintained every year to ensure their continued operation. KNMI will take charge of this task. The primary cause of marine corrosion in coastal areas is the chloride ions in the air from the evaporated sea salt in ocean spray, this is made worse by the high temperatures, which speed up the reaction time, even corroding stainless steel (Fig. 2).

During every visit each seismometer is visited and inspected for proper operations. The 3 current seismometers, at White Hook, the airport and at a private property, operate as expected.

A further expansion of the monitoring network is planned for 2020, in the Miriam C Schmidt botanical gardens. This setup would consist of a seismometer and a GNSS instrument which operate autonomously using solar panels and a satellite connection to transmit the data. The GNSS antenna would be placed on top of the boulder (Fig. 3), the GNSS receiver and seismometer would be placed in a vault which would be constructed and designed especially for this purpose and placed on the already existing concrete slab (Fig. 3). We are working with STENAPA to make this installation possible.

Fig. 3 Photos of the boulder on which the GNSS antenna, similar to the one at White Hook, would be placed (left) and the concrete slab which would house the vault for the GNSS receiver and seismometer (right).

UPDATE 4 – Saba, November 2019

Webpage

In the past months KNMI has developed a webpage dedicated to the volcanoes of St. Eustatius and Saba. You can find this webpage at: *http://www.knmidc.org/volcanoes/*. It contains information about the monitoring and setting of the volcanoes and the monitoring data can also be viewed. Please feel free to make suggestions for improvements!

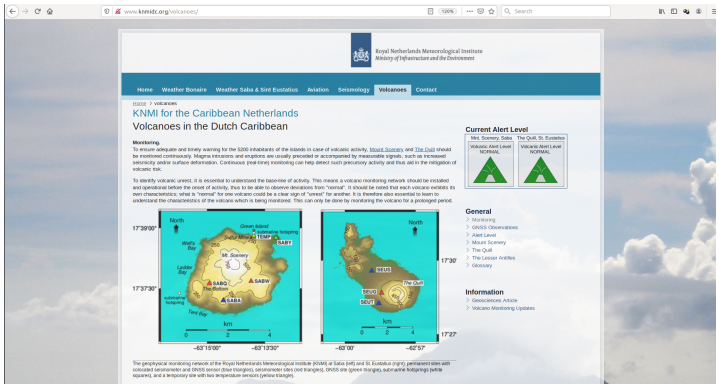


Figure 1. Screenshot of knmidc.org/volcanoes

Seismic data

KNMI is working on a system to automatically locate earthquakes in the Caribbean region, similar to the automatic earthquake detection in Groningen. In the meantime it would help us greatly if you could ask residents to fill in this form when they have felt an earthquake:
(https://www.knmi.nl/nederland-nu/seismologie/aardbevingen/melden).

Thanks to the continuous support of SATEL the three seismometers (called “SABA”, “SABQ” and “SABW”) are functioning well and produce data of good quality for the purpose of detecting earthquakes. As an example, a magnitude 6 earthquake north-west of Puerto Rico on September 24, 2019, around 03:23:40 UTC, was recorded by all stations with measured ground velocities up to 0.5 mm/s (see Figure 2).

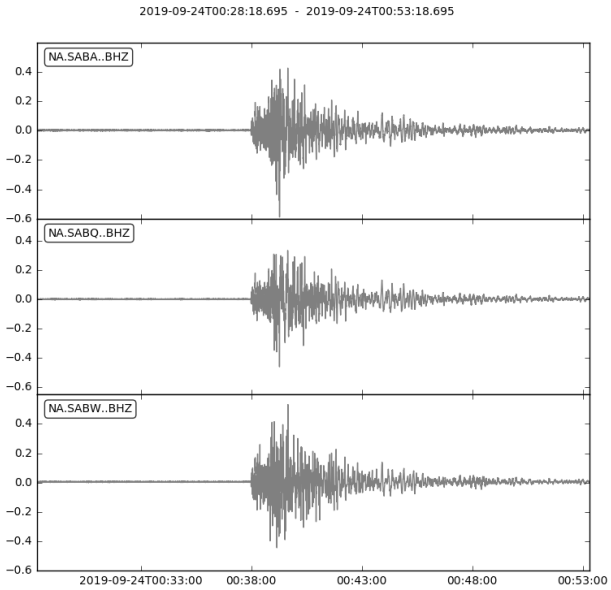
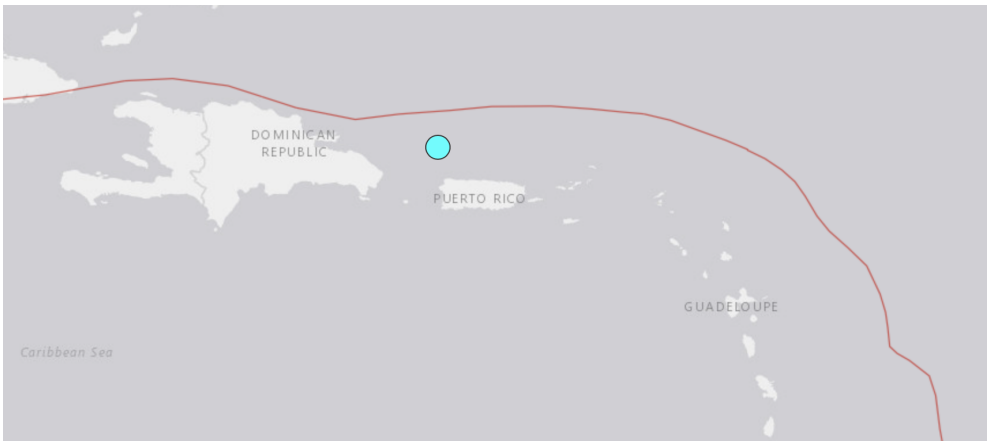


Figure 2: Seismic recordings of the vertical ground velocity in mm/s measured by seismic stations SABA, SABW and SABQ, due to an earthquake near Puerto Rico (source: USGS).



GNSS data

The two GNSS stations at St. Johns (called “SABA”) and at the airport (called “SABY”) have been functioning as expected. For each instrument we calculate the daily position very precisely. The result is plotted in a graph as a point, and by adding a new data point to the graph each day a time series is formed (see Figure 3). Station SABA has been operational since January 2018 and hence has a longer time series than station SABY, which became operational in February 2019.

Changes through time can be viewed in the time series for three components:

1) horizontal East-West, 2) horizontal North-South and 3) vertical Up-Down. Uncertainties for each point are a few mm for the East and North component and up to a few cm for the Up component. The data show a horizontal movement towards the NE for both stations. This movement is due to well-known plate tectonics whereby the North and South American plates subduct underneath the Caribbean Plate.

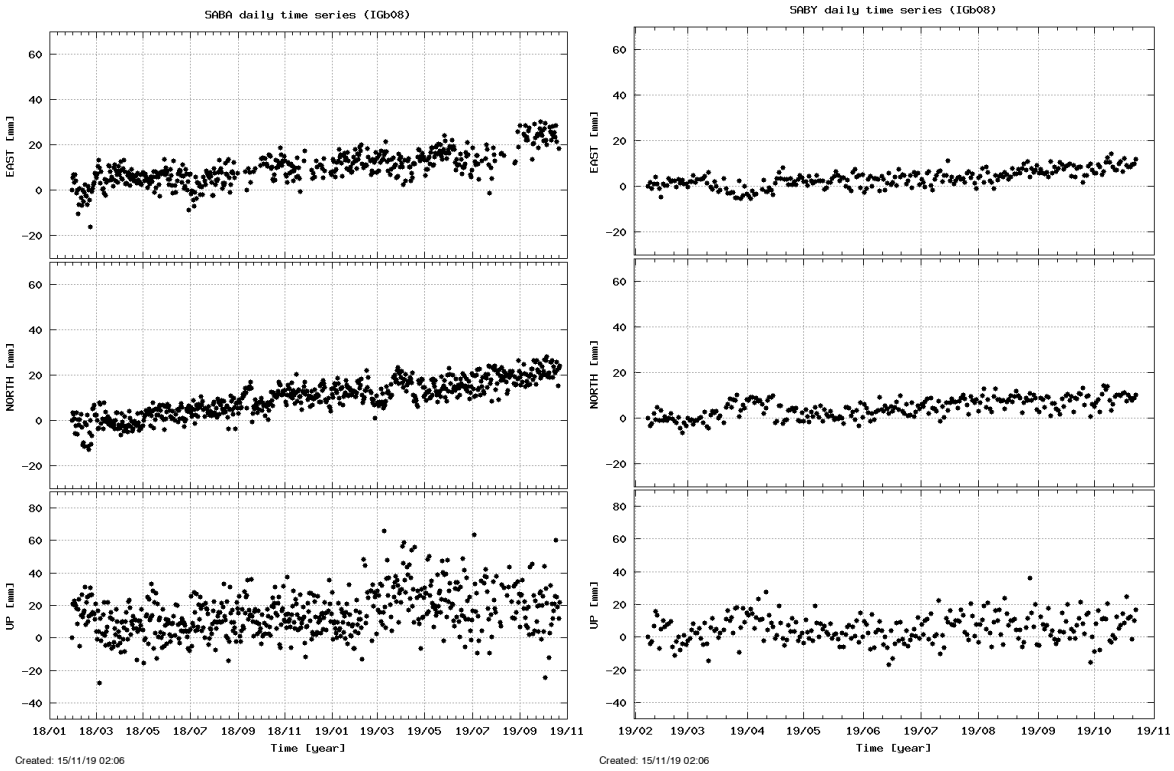


Figure 3: GNSS data from stations SABA and SABY.

Temperature data

Continuous temperature data were collected from the hotspring opposite Green Island in February 2019. Both temperature probes recorded data for 3 months, although 1 probe started to fail after the first month (See Figure 4). The maximum temperature of the hotspring is around 82 degrees Celsius. This temperature fluctuates due to heavy mixing with seawater. Analysis of these data together with pressure gauge data from the harbor of Saba suggest the temperature fluctuations correlate with the tides.

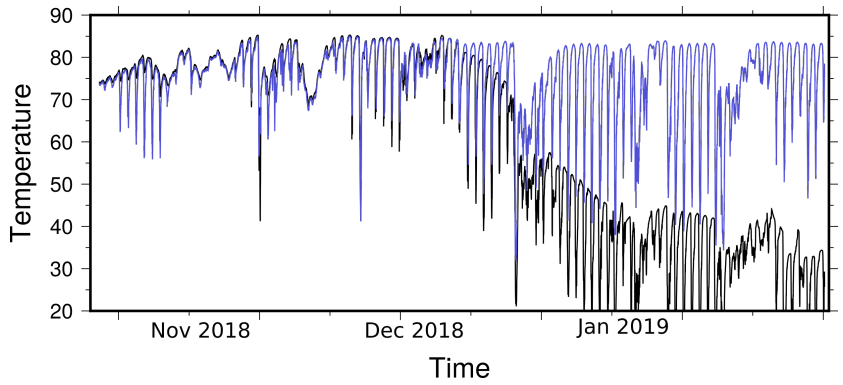
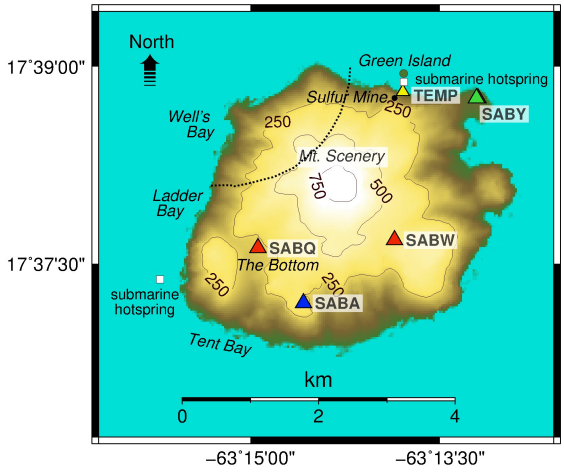


Figure 4: Recorded temperature (in degrees Celsius) at the hotspring opposite Green Island. Blue line depicts good data, black line shows compromised data quality with time due to failure of the temperature probe.

New site?

KNMI is looking for a good location for a third GNSS combined with a seismometer. We would like to request the help of the islanders in finding a suitable location.



This location should be:

1) In the NW section of the island (see Figure 5)
2) Have a sky view
3) Have solid ground, preferably rock
4) Accessible within 45 minutes on foot
5) Minimum 150 m from the sea
6) Minimum 150 m from a vertical cliff

Figure 5: Saba island. Dotted line marks the NW section of the island where the instrument should be located.

Anybody who has an idea for a location is encouraged to contact us via email.
When a team from KNMI visits Saba in January 2020 we can then check these options.
We hope to see you then!

UPDATE 4 – St. Eustatius, November 2019

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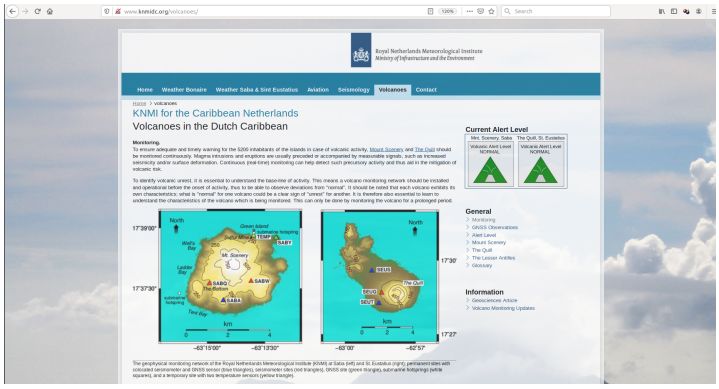

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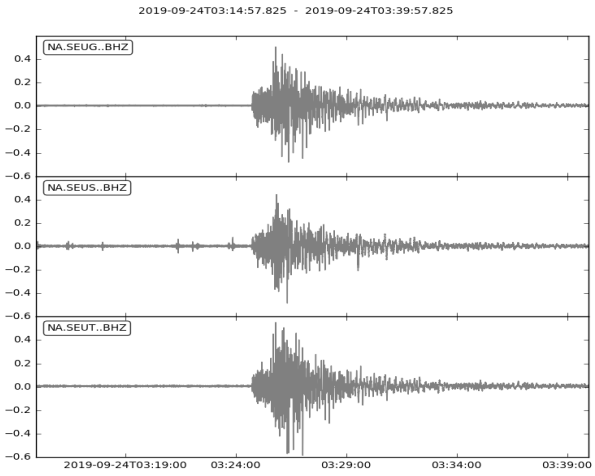
(https://www.knmi.nl/nederland-nu/seismologie/aardbevingen/melden).

Thanks to the continuous support of EUTEL, the airport management and George Works the three seismometers (called “SEUG”, “SEUS” and “SEUT”) are functioning well and produce data of good quality for the purpose of detecting earthquakes. As an example, a magnitude 6 earthquake north-west of Puerto Rico on September 24, 2019, around 03:23:40 UTC, was recorded by all stations with measured ground velocities up to 0.5 mm/s (see Figure 2).



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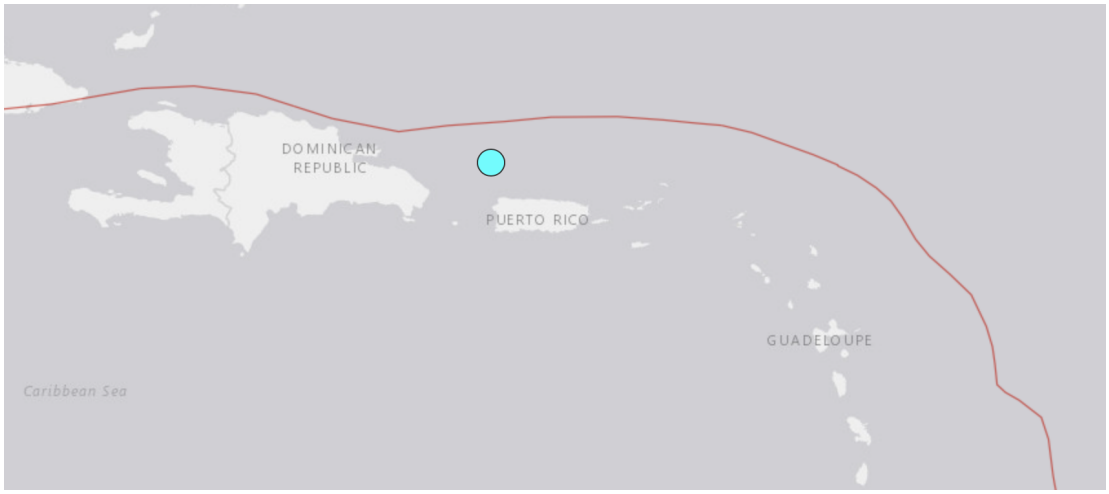


GNSS data

The two GNSS stations, at the EUTEL facility at dove road (called “SEUT”) and at the airport (called “SEUS”) have been functioning as expected. For each instrument we calculate the daily position very precisely. The result is plotted in a graph as a point, and by adding a new data point to the graph each day a time series is formed (see Figure 3). Station SEUT has been operational since January 2018 and hence has a longer time series than station SEUS, which became operational in February 2019.

Changes through time can be viewed in the time series for three components:

1) horizontal East-West, 2) horizontal North-South and 3) vertical Up-Down. Uncertainties for each point are a few mm for the East and North component and up to a few cm for the Up component. The data show a horizontal movement towards the NE for both stations. This movement is due to well-known plate tectonics whereby the North and South American plates subduct underneath the Caribbean Plate.

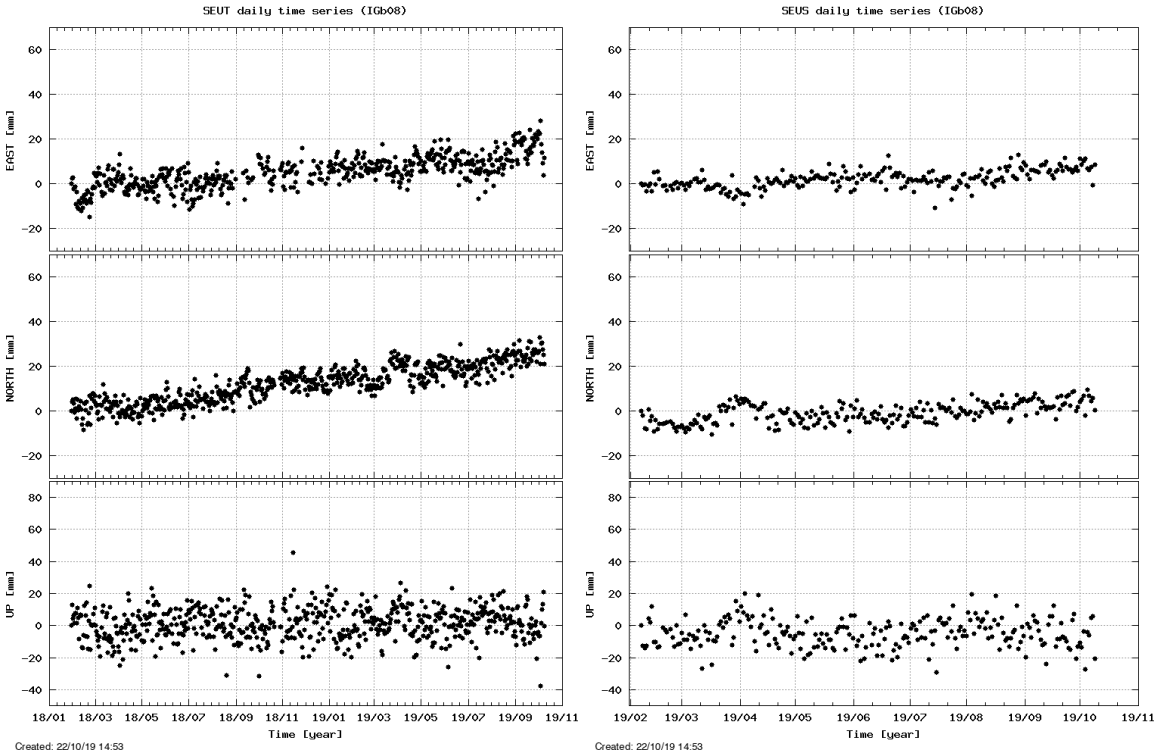


Figure 3: GNSS data from stations SEUT and SEUS.

A third GNSS installation is planned for 2020 at the Botanical gardens. Preparations for this installation are ongoing and will be finalized when a team from KNMI visits St. Eustatius in January 2020. We hope to see you then!

UPDATE 5 – Saba, January 2021

This update reports on the activities of KNMI in 2020 with respect to the volcanic/seismic monitoring network at Saba. The COVID-19 pandemic provides certain challenges considering our work, mainly related to travel restrictions and delayed delivery of new equipment. Regular observations of the data continued regardless throughout the year. The current monitoring network, and its extension planned for April 2021, is displayed in Fig. 1.

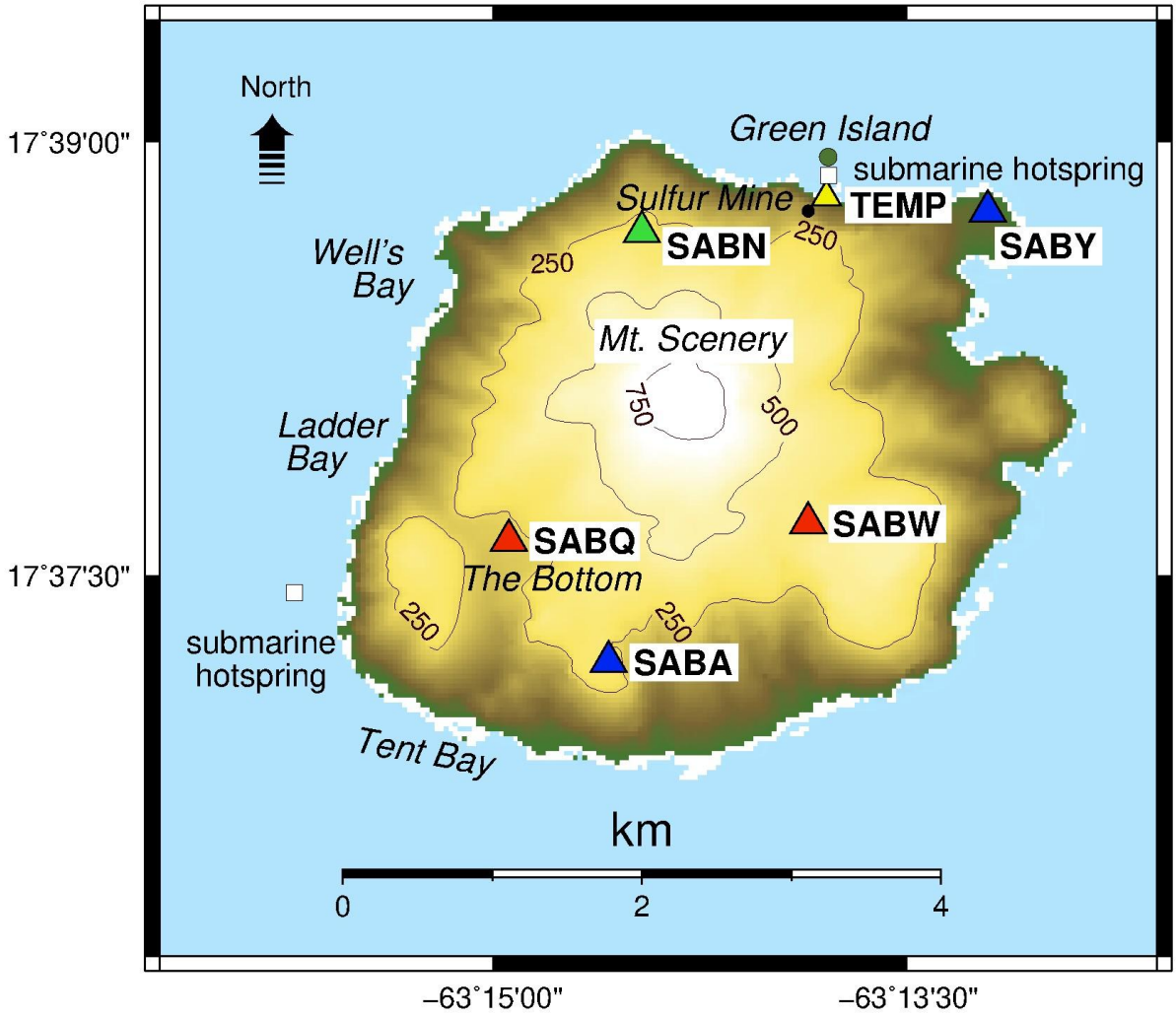


Fig. 1: Map showing the locations of current measurement sites on Saba with blue (GNSS/seismic stations) and red (seismic stations) triangles. In green the location of the proposed station at Grey Hill (planned installation April 2021).

Seismic data

Seismometers “SABY”, “SABW” and “SABA” are functioning well and produce data of good quality for the purpose of detecting earthquakes. Seismometer “SABQ” is currently out-of-order due to technical issues. Part of the equipment needs to be repaired by the manufacturer. Lightning protection is one of the most challenging issues in continuous data collection.

As an example of earthquake detection, on Dec 27, 2020, at 23:56:18 UTC (19:56:18 local time), a magnitude 4 earthquake took place at a depth of 6 km, about 27 km south-east of Saba. Our automatic monitoring system detected this event using the recordings from 3 seismometers at Saba, 3 seismometers on St. Eustatius and 1 on St. Maarten. The figures 2 and 3 show screenshots of the automatically determined earthquake parameters, as well as the recordings of the ground movement.

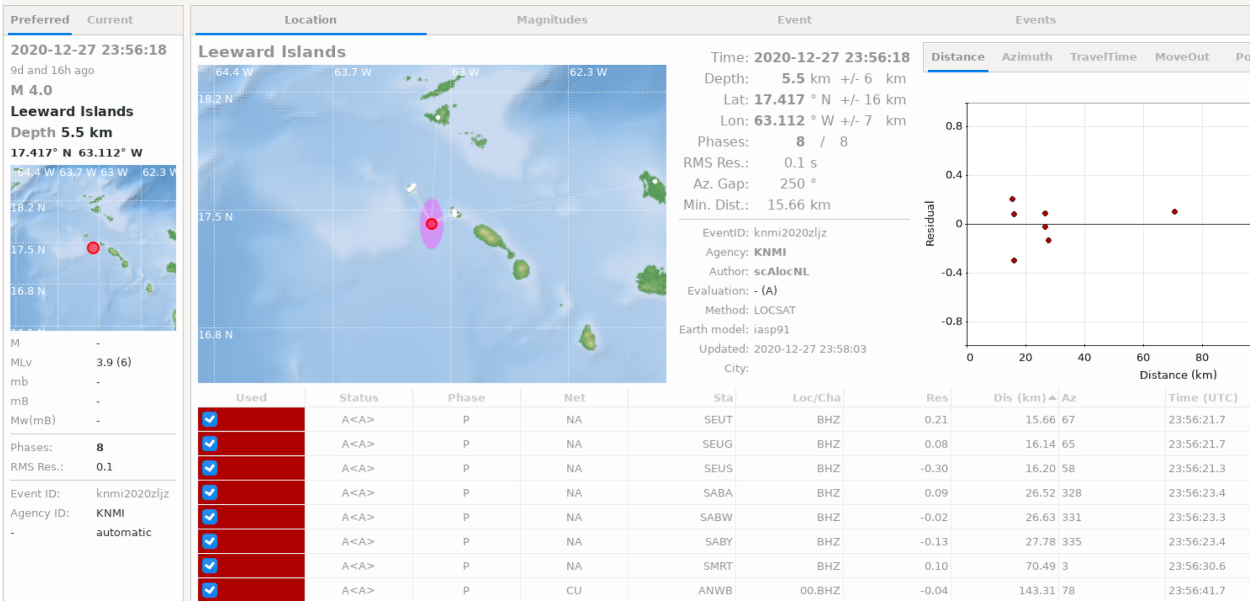


Fig. 2: Screenshot of the location of the earthquake at 27-12-2020 as derived by our automatic system from the seismometers at Saba , St. Eustatius and St. Maarten.

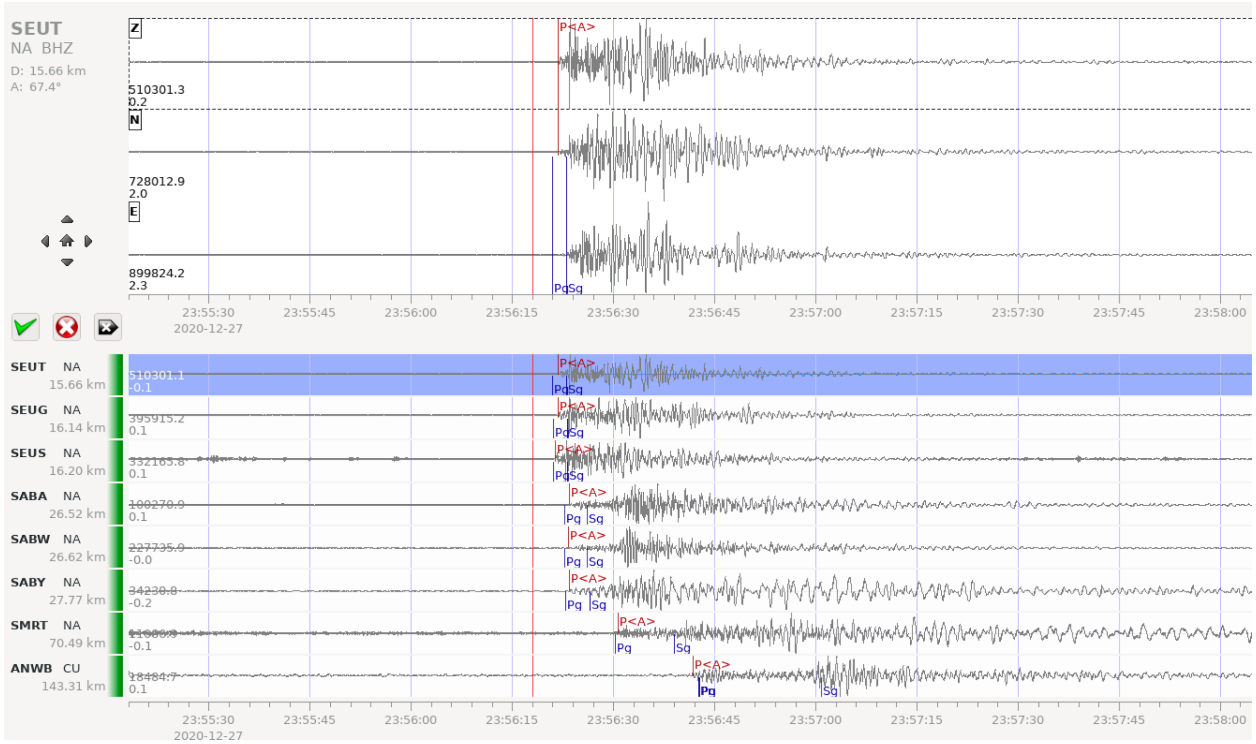


Fig. 3: Screenshot of the recorded seismic waveforms after the earthquake at 27-12-2020.

Don't forget that if you feel an earthquake it helps us if you fill out this form: https://www.knmi.nl/nederland-nu/seismologie/aardbevingen/melden

GNSS data

The two GNSS stations, at the SATEL facility at St. Johns (called "SABA") and at the airport (called "SABY") worked well most of 2020.

For each instrument we calculate the daily position very precisely. The result is plotted in a graph as a point, and by adding a new data point to the graph each day a time series is formed (Fig. 4). Station SABA has been operational since January 2018 and hence has a longer time series than station SABY, which became operational in February 2019.

Changes through time can be viewed in the time series for three components:
1) horizontal North-South, 2) horizontal East-West and 3) vertical Up-Down. Uncertainties for each point are, as expected, a few mm for the East and North component and up to a few cm for the Up component. The data show a horizontal movement towards the NE for both stations. This movement is due to well-known plate tectonics whereby the North and South American plates subduct underneath the Caribbean Plate. We can evaluate local deformation better by removing the plate tectonic signal from the data. Data corrected for the plate spreading signal are constant through time indicating no local deformation occurred. In most cases deformation of the flank of the volcano in the order of multiple centimeters to decimeters precedes a volcanic eruption. This will be best visible in the horizontal components of the data (North and East) as these have the highest accuracy.

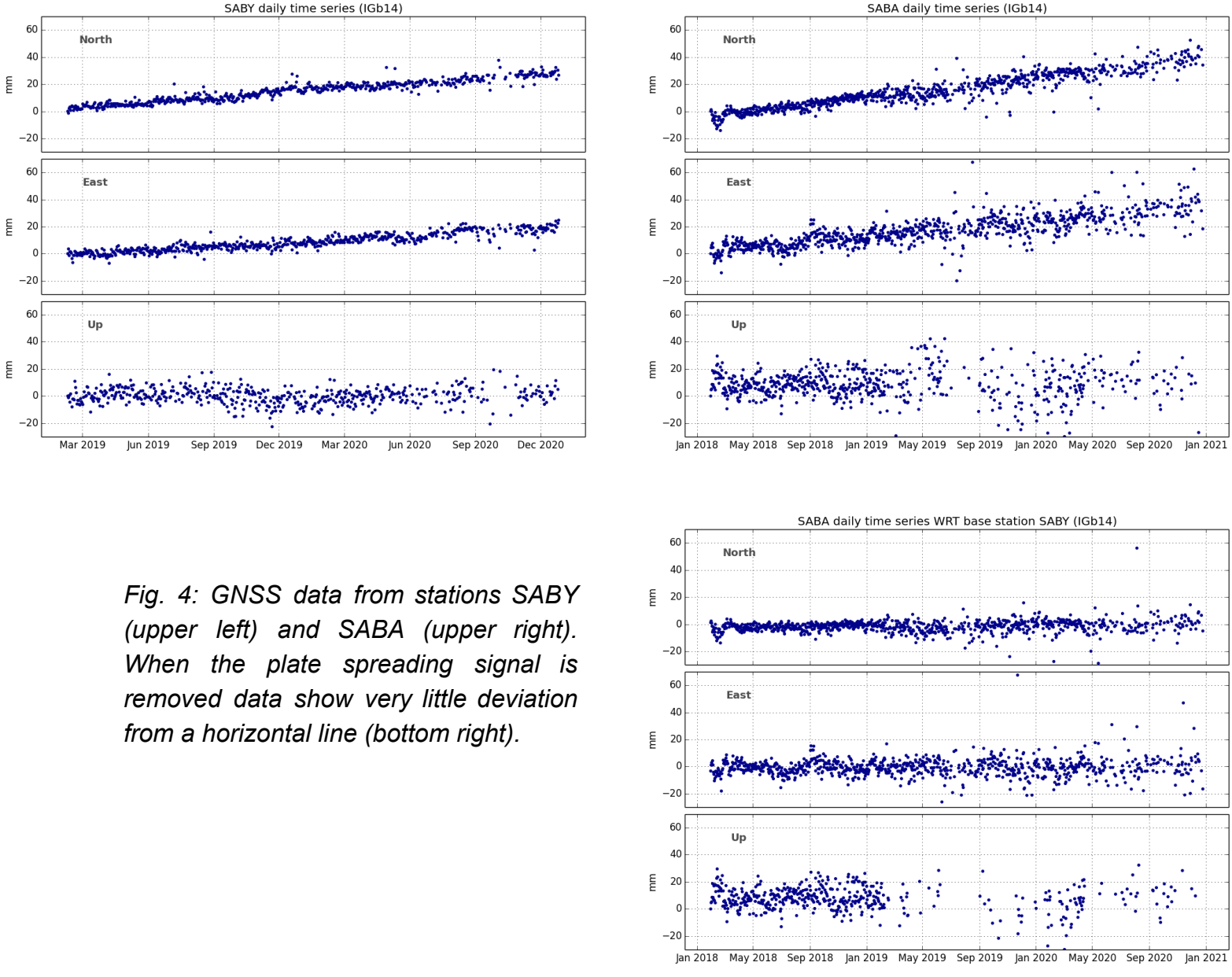


Fig. 4: GNSS data from stations SABY (upper left) and SABA (upper right). When the plate spreading signal is removed data show very little deviation from a horizontal line (bottom right).

Installation new site at Grey Hill

A new GNSS/seismic installation is planned for April 2021 at Grey Hill. All materials for this installation will be shipped to Saba in February 2021. This installation is innovative as it will be completely stand-alone. Satellite communication will be used to send the data to KNMI and solar panels/batteries will be used to power the site.

In October/November 2020 we tested the set-up at KNMI (Fig. 5). The GNSS/seismic station will consist of 1) a GNSS antenna mounted on a monument, 2) a concrete box housing the seismometer, 3) a VSAT dish needed to transmit the data, 4) two solar panels to power the equipment and 5) a cabinet housing all electronics.

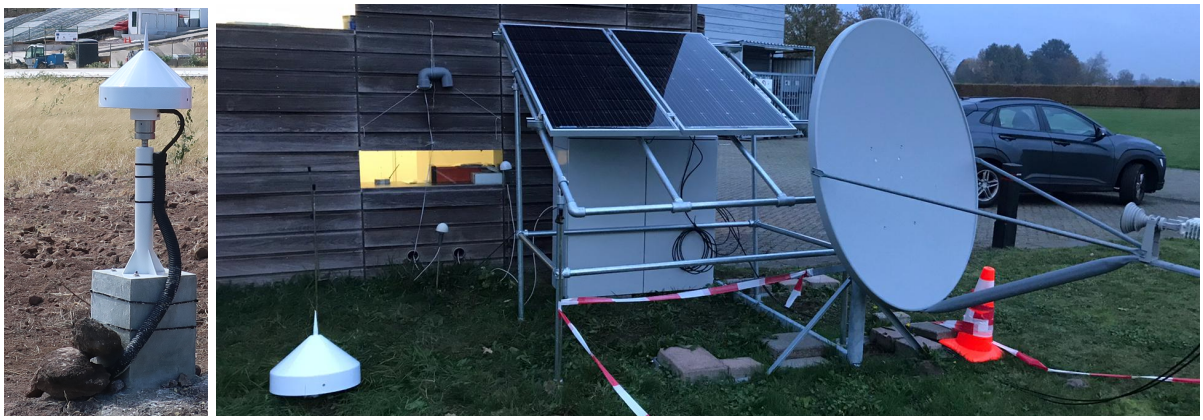


Fig.5: GNSS antenna mounted on a concrete monument (left). Concrete box for the seismometer not displayed. Test set-up at KNMI (right) showing VSAT dish, solar panels with cabinet underneath (5).

Temperature data hot spring

Continuous temperature data were collected from the hotspring opposite Green Island in January 2020 (Fig. 6). Measurements are taken every 20 minutes and stored locally. During summer the temperature variations are smaller than in winter which can be explained by the calmer sea conditions in summer. Analysis of the temperature data show a strong correlation between the temperature variations and the tides. The maximum spring temperature remains constant at ~82 degrees Celsius. During our next visit we will collect temperature data for 2020.

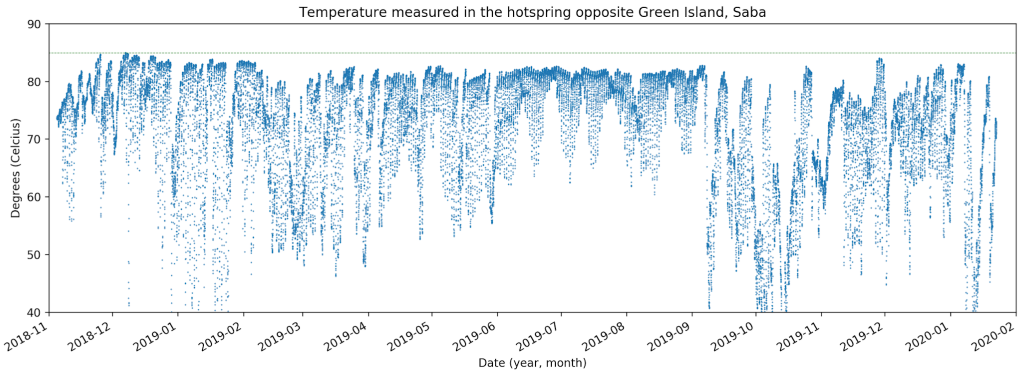


Fig. 6: Recorded temperature (in degrees Celsius) at the hotspring opposite Green Island.

Cracks Green Gut

In March 2020 a member of the public reported multiple cracks in the area of the Green Gut (Fig. 7). The crack along the wall was 60 cm deep and had warm moist air venting from it (T ~50 ℃). The Green Gut is an unstable area, however the warm air is unusual. It may be that compaction and rotting of waste causes heath to form. There is always the possibility that the volcano forms a vent, or already had it there in the past. If this would be the case the temperatures are still relatively low and there is no other evidence of volcanic origin yet (like sulfur or other mineral deposits). KNMI will bring a thermal camera to closely inspect the area during the next visit.

Fig. 7: Cracks at Green Gut March 2020

Dead vegetation on top of Mnt. Scenery

In March 2020 rangers of the SCF reported dead mountain mahogany trees in an area of ~10x10 m^2 close to the top of Mnt. Scenery (17.634617° -63.239450°). The area was investigated by a SCF team under guidance of KNMI for other signs of volcanic activity such as volcanic deposits (ash, sulfur), fumes and heath release. No such evidence was found, suggesting volcanic activity did not cause the trees to die. Photos and videos were captured for future reference by SCF. In January 2021 another photo and video survey was done (Fig. 7). The new images show clear regrowth of vegetation confirming that there is no volcanic activity in the area.

Fig. 7: Drone imagery captured by SCF showing the dead vegetation in March 2020 (left) and regrowth covering most of the patch in January 2021 (right).

Volcanic activity in the region

Currently several volcanoes in the Caribbean show increased levels of activity (see Fig. 8). This is not uncommon, for example in 1902 both Mt. Pelée, Martinique and La Soufrière, St. Vincent erupted. The Caribbean volcanoes are all formed by the same process: subduction at the plate boundary, but they do not share the same magma chamber, nor are they connected by long magma conduits. A volcanic eruption on one island can therefore not trigger an eruption on another island. For more information on the activity of other Caribbean volcanoes see:

- http://uwiseismic.com and http://nemo.gov.vc/nemo/index.php/home/welcome for Grenada, Grenadines, St. Vincent, St. Lucia, Dominica, St. Kitts and Nevis
- https://www.ipgp.fr/fr/ovsm/lobservatoire-volcanologique-sismologique-de-martinique-ovsm-ipgp for Martinique
- https://www.ipgp.fr/fr/ovsg/actualites-ovsg for Guadeloupe
- http://www.mvo.ms/ for Montserrat.

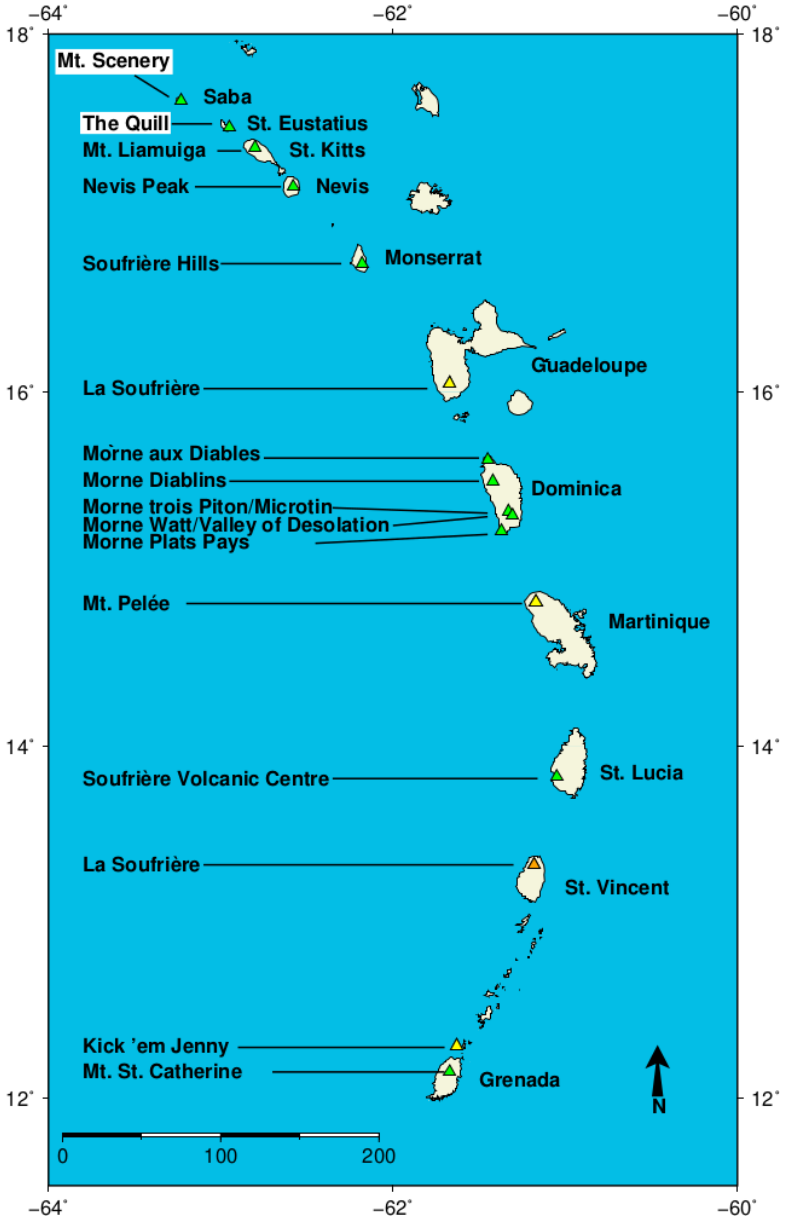
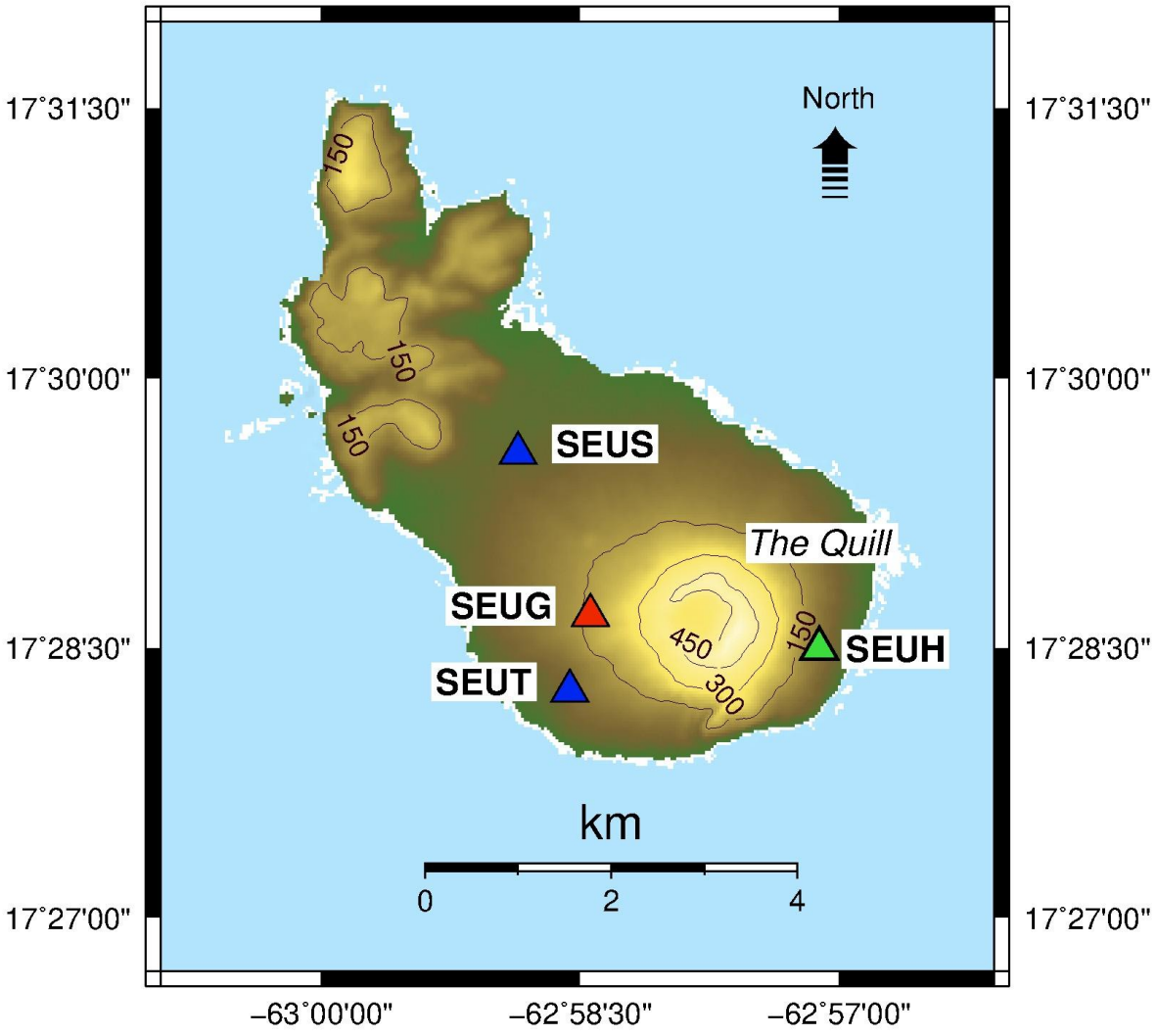


Fig. 8: The active arc of the Lesser Antilles showing the islands of Saba and St. Eustatius in the far north, as well as the other islands of the chain. The triangles depict the location of an active volcano, and their names are shown on the left. Mnt. Scenery and The Quill are highlighted. The color of the triangle depicts the state of the volcano as of 5 Jan 2021 whereby green=normal, yellow=advisory and orange=watch.

UPDATE 5 – St. Eustatius, January 2021

This update reports on the activities of KNMI in 2020 with respect to the volcanic/seismic monitoring network at St. Eustatius. The COVID-19 pandemic provides certain challenges considering our work, mainly related to travel restrictions and delayed delivery of new equipment. Regular observations of the data continued regardless throughout the year. The current monitoring network, and its extension planned for January 2021, is displayed in Fig. 1.



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Seismic data

All seismometers (called “SEUG”, “SEUS” and “SEUT”) are functioning well and produce data of good quality for the purpose of detecting earthquakes.
For example, on Dec 27, 2020, at 23:56:18 UTC (19:56:18 local time), a magnitude 4 earthquake took place at a depth of 6 km, about 16 km south-west of St. Eustatius. Our automatic monitoring system detected this event using the recordings from all 3 seismometers at St. Eustatius, 3 seismometers on Saba and 1 on St. Maarten. The figures 2 and 3 show screenshots of the automatically determined earthquake parameters, as well as the recordings of the ground movement.

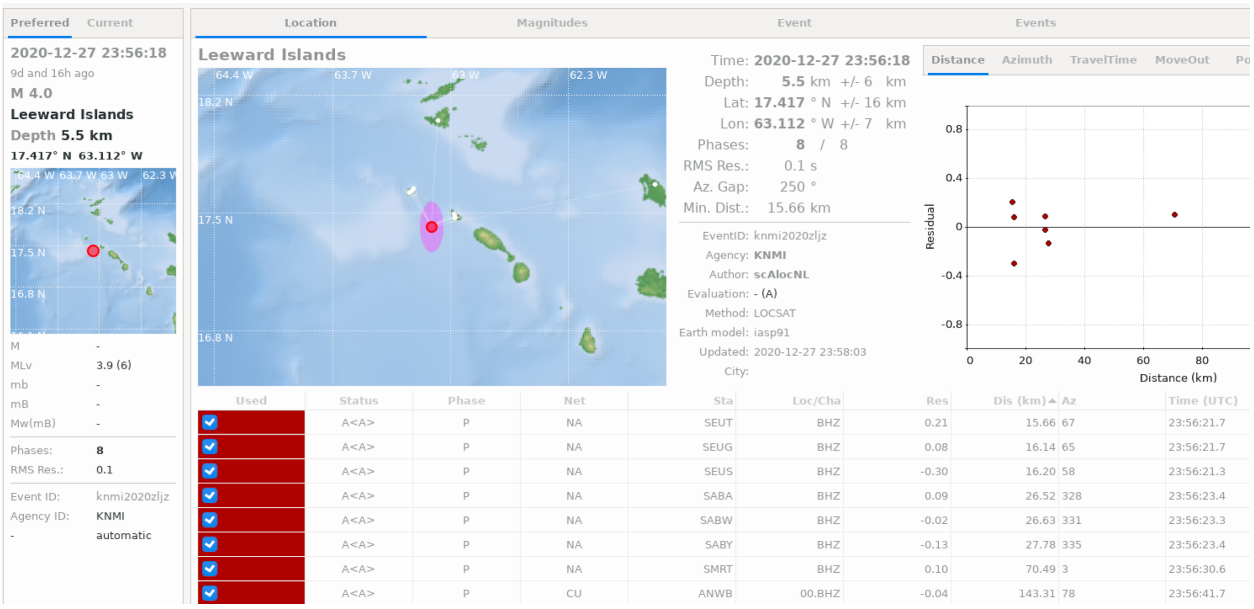


Fig. 2: Screenshot of the location of the earthquake at 27-12-2020 as derived by our automatic system from the seismometers at St. Eustatius, Saba and St. Maarten.

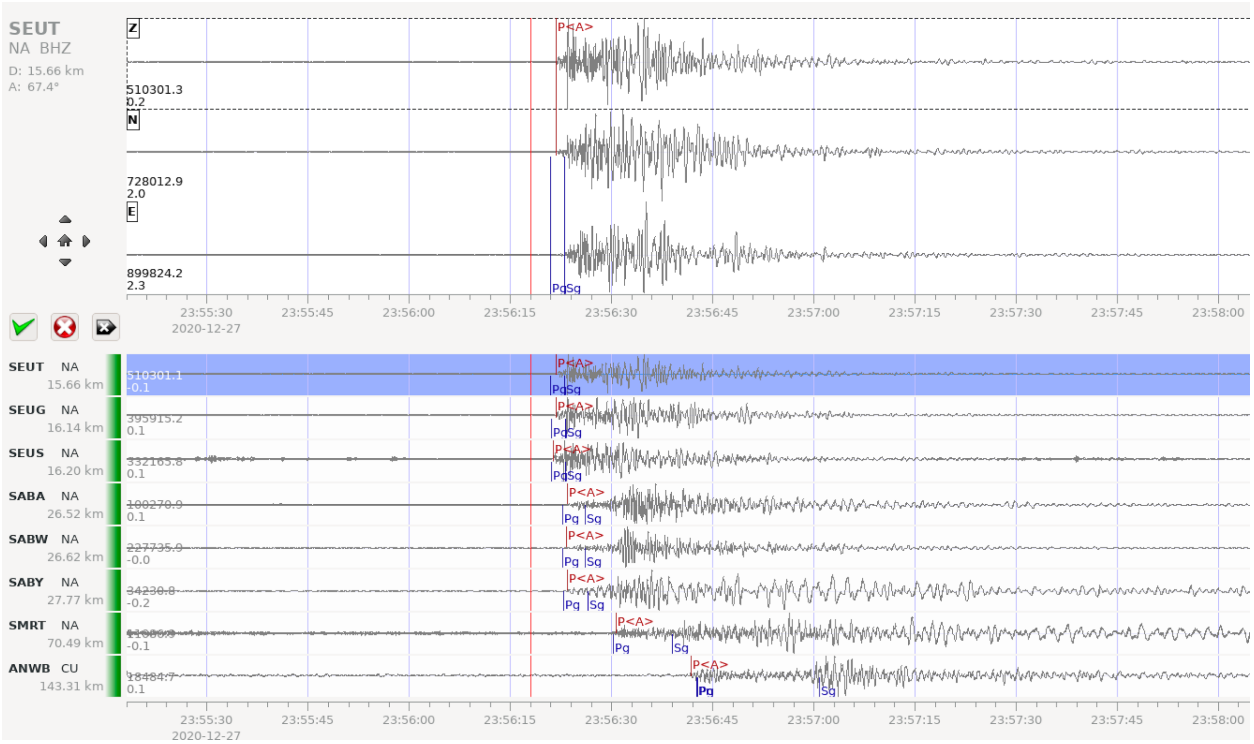


Fig. 3: Screenshot of the recorded seismic waveforms after the earthquake at 27-12-2020.

Don't forget that if you feel an earthquake it helps us if you fill out this form: https://www.knmi.nl/nederland-nu/seismologie/aardbevingen/melden

GNSS data

The two GNSS stations, at the EUTEL facility at dove road (called "SEUT") and at the airport (called "SEUS") worked well most of 2020. Unfortunately in October station SEUS was hit by lightning. Essential parts for the repair are on their way to St. Eustatius and repairs should take place in January 2021.

For each instrument we calculate the daily position very precisely. The result is plotted in a graph as a point, and by adding a new data point to the graph each day a time series is formed (Fig. 4). Station SEUT has been operational since January 2018 and hence has a longer time series than station SEUS, which became operational in February 2019.

Changes through time can be viewed in the time series for three components:
1) horizontal North-South, 2) horizontal East-West and 3) vertical Up-Down. Uncertainties for each point are, as expected, a few mm for the East and North component and up to a few cm for the Up component. The data show a horizontal movement towards the NE for both stations. This movement is due to well-known plate tectonics whereby the North and South American plates subduct underneath the Caribbean Plate. We can evaluate local deformation better by removing the plate tectonic signal from the data. Data corrected for the plate spreading signal are constant through time indicating no local deformation occurred. In most cases deformation of the flank of the volcano in the order of multiple centimeters to decimeters precedes a volcanic eruption. This will be best visible in the horizontal components of the data (North and East) as these have the highest accuracy.

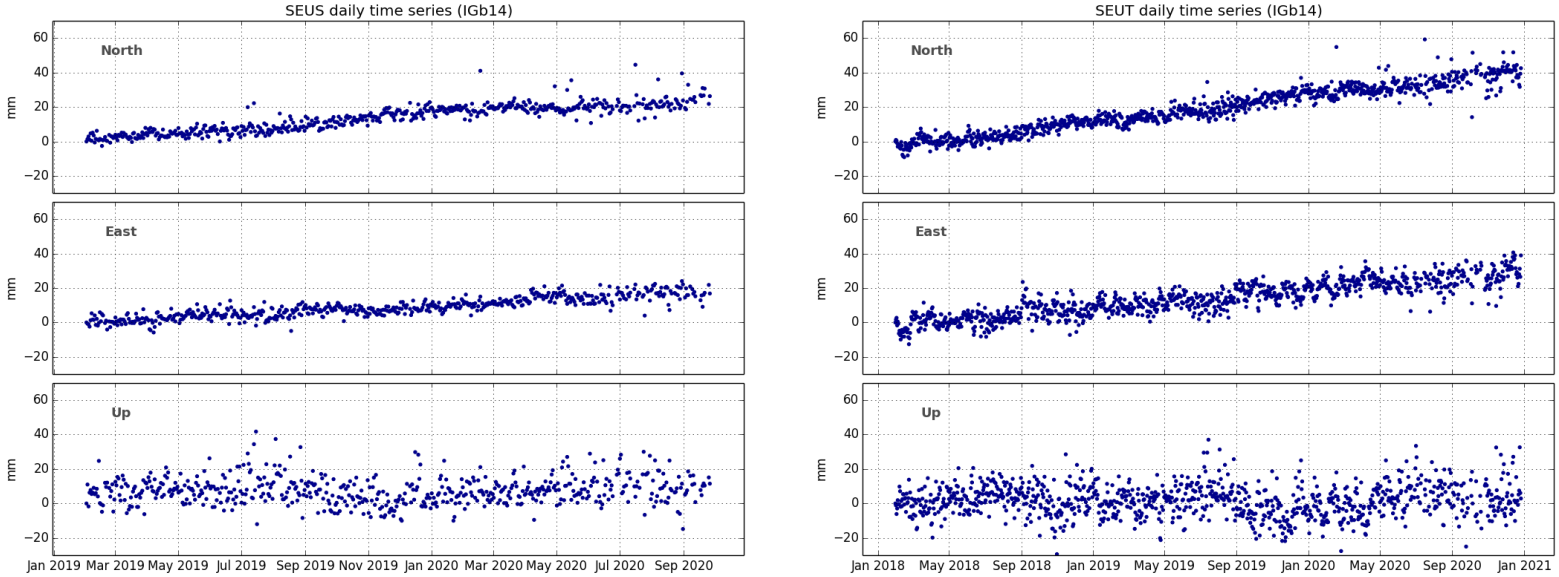
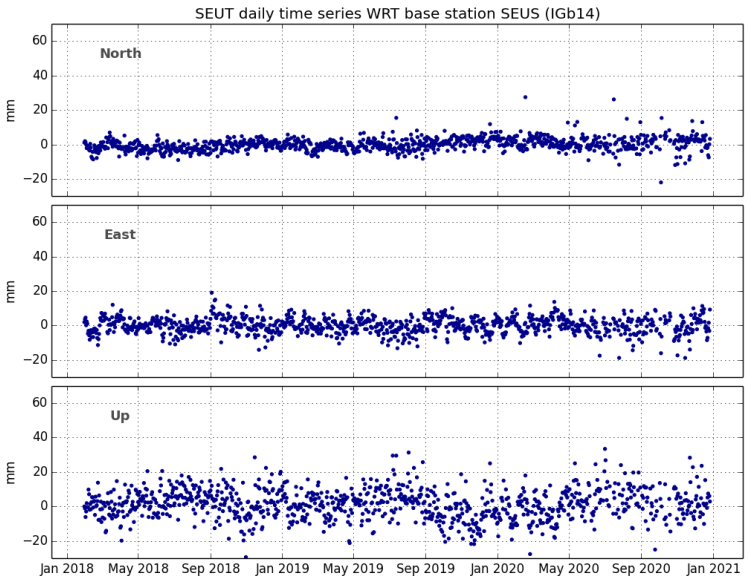


Fig. 4: GNSS data from stations SEUS (upper left) and SEUT (upper right). When the plate spreading signal is removed data show very little deviation from a horizontal line (bottom right).



Installation new site botanical gardens

A new GNSS/seismic installation is planned for January 2021 at the Botanical gardens. All materials for this installation have been shipped to St. Eustatius. This installation is innovative as it will be completely stand-alone. Satellite communication will be used to send the data to KNMI and solar panels/batteries will be used to power the site.

In October/November 2020 we tested the set-up at KNMI (Fig. 5). The GNSS/seismic station will consist of 1) a GNSS antenna mounted on a monument, 2) a concrete box housing the seismometer, 3) a VSAT dish needed to transmit the data, 4) two solar panels to power the equipment and 5) a cabinet housing all electronics.

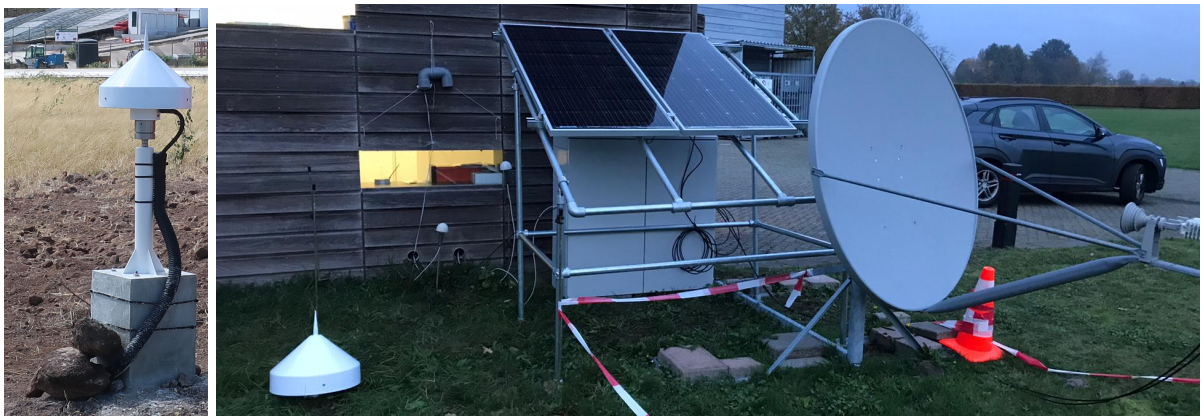


Fig.5: GNSS antenna mounted on a concrete monument (left). Concrete box for the seismometer not displayed. Test set-up at KNMI (right) showing VSAT dish, solar panels with cabinet underneath (5).

Volcanic activity in the region

Currently several volcanoes in the Caribbean show increased levels of activity (see Fig. 8). This is not uncommon, for example in 1902 both Mt. Pelée, Martinique and La Soufrière, St. Vincent erupted. The Caribbean volcanoes are all formed by the same process: subduction at the plate boundary, but they do not share the same magma chamber, nor are they connected by long magma conduits. A volcanic eruption on one island can therefore not trigger an eruption on another island. For more information on the activity of other Caribbean volcanoes see:

- http://uwiseismic.com and http://nemo.gov.vc/nemo/index.php/home/welcome for Grenada, Grenadines, St. Vincent, St. Lucia, Dominica, St. Kitts and Nevis
- https://www.ipgp.fr/fr/ovsm/lobservatoire-volcanologique-sismologique-de-martinique-ovsm-ipgp for Martinique

- https://www.ipgp.fr/fr/ovsg/actualites-ovsg for Guadeloupe
- http://www.mvo.ms/ for Montserrat.

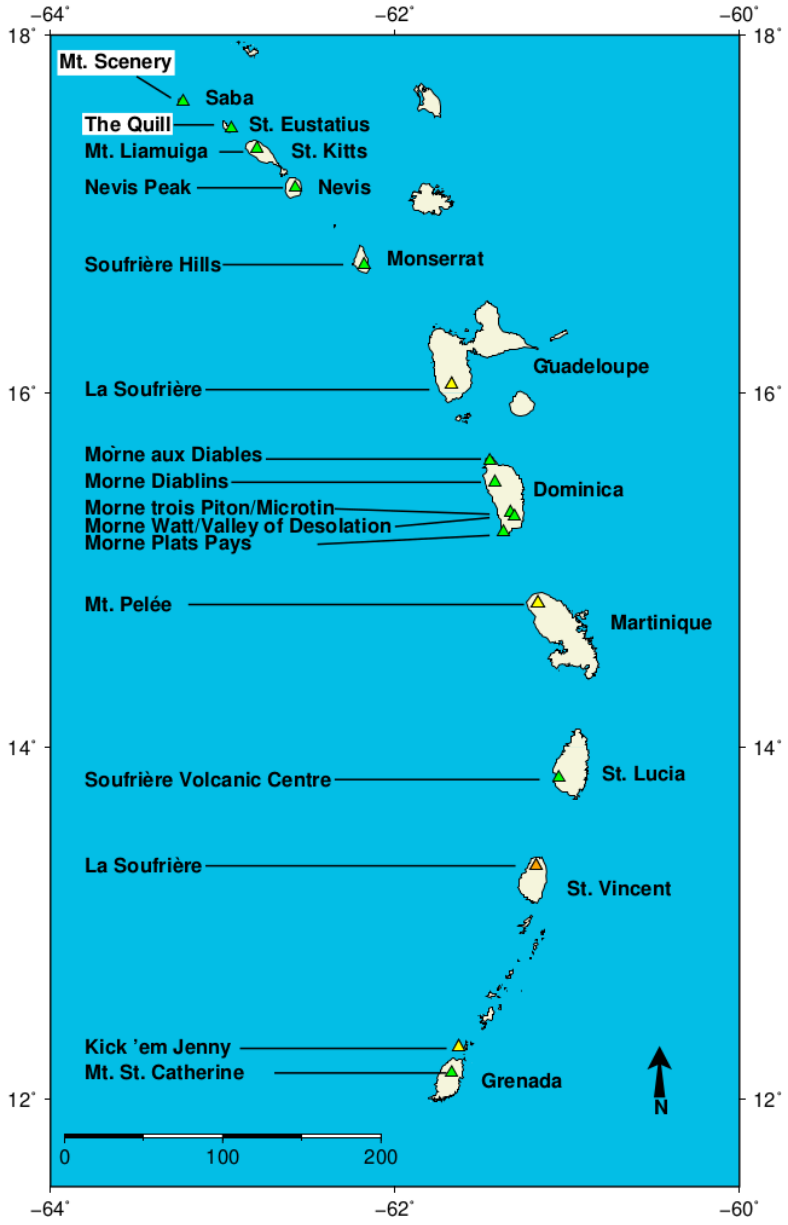


Fig. 8: The active arc of the Lesser Antilles showing the islands of Saba and St. Eustatius in the far north, as well as the other islands of the chain. The triangles depict the location of an active volcano, and their names are shown on the left. Mnt. Scenery and The Quill are highlighted. The color of the triangle depicts the state of the volcano as of 5 Jan 2021 whereby green=normal, yellow=advisory and orange=watch.

A team from KNMI will visit the island in January 2021 for the installation. We hope to meet you once we are out of quarantine!

UPDATE 6 – Saba, January 2022

This update reports on the activities of KNMI in 2021 with respect to the volcanic/seismic monitoring network at Saba. The COVID-19 pandemic provided an extra challenge considering our work, mainly related to travel and contact restrictions. Nevertheless we managed to build the new off-grid station at Grey Hill in April 2021 (called “SABN”) in cooperation with Korps mariniers. Also, regular observations of data at all stations continued throughout the year. The current monitoring network, and its extension planned for February 2022, is displayed in Fig. 1.

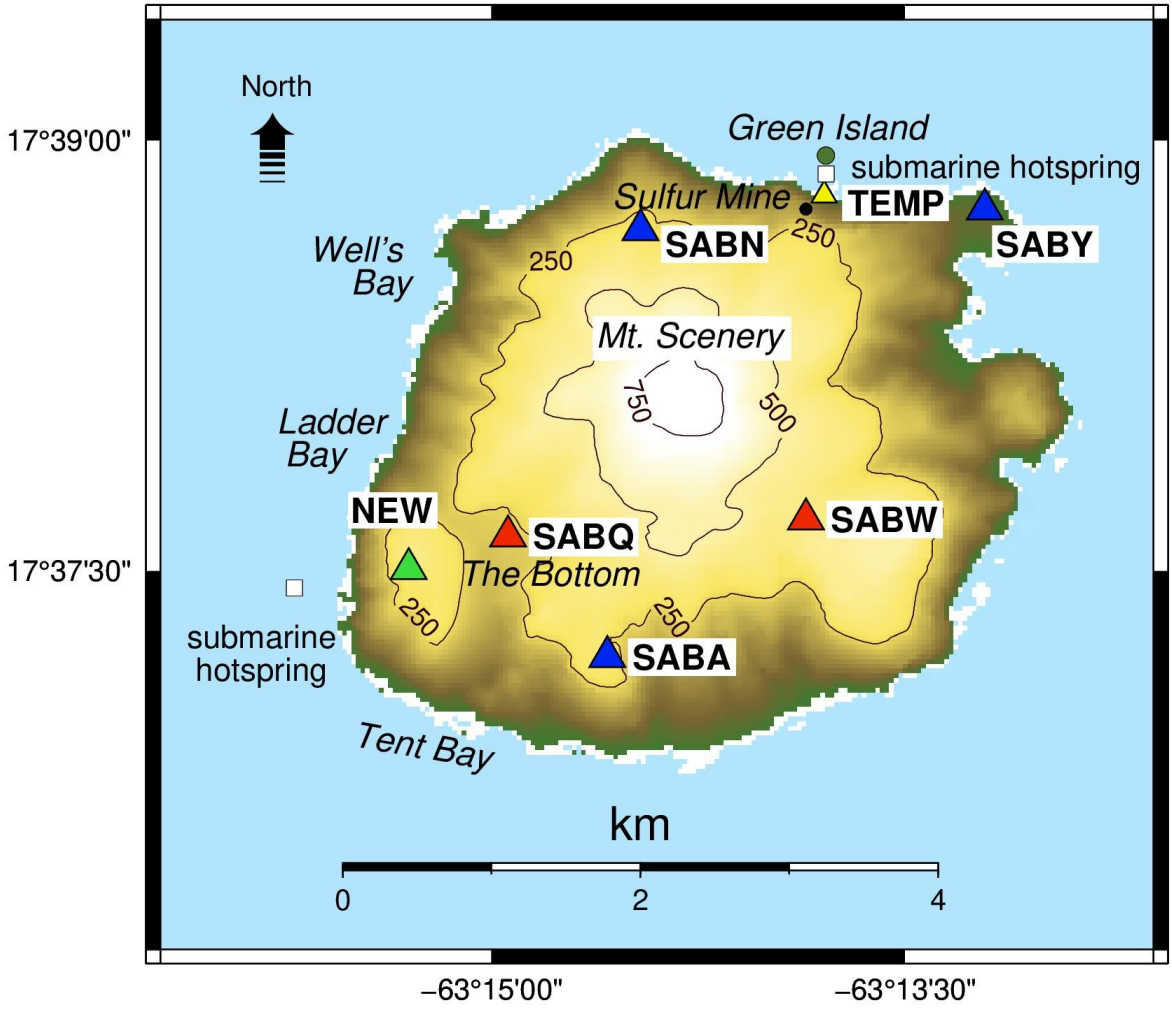


Fig. 1: Map showing the locations of current measurement sites on Saba with blue (GNSS/seismic stations) and red (seismic stations) triangles. Station SABN was built in April 2021. In green the location of the proposed GNSS station at the whale's tail (planned installation February 2022).

Installation Station SABN

In April 2021 a GNSS and seismometer were installed at Grey Hill with the courageous help of the Korps Mariniers (Fig. 2).

Fig. 2: Korps Mariniers helped to carry >2000 kg of materials up to Grey Hill.

The monitoring station “SABN” (Fig. 3) consists of a seismometer recording vibrations and a GNSS instrument measuring deformation. It is powered by solar panels and batteries. Data are sent 24/7 to KNMI using satellite communication.

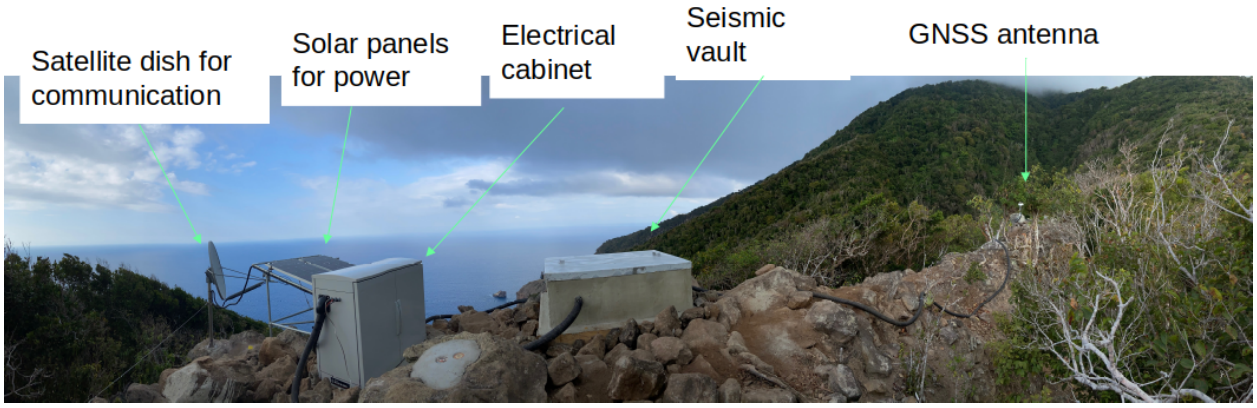


Fig. 3: The monitoring site “SABN” at Grey Hill.

Seismic data

Seismometer “SABQ” in The Bottom was repaired. All seismometers, including the new station “SABN”, are functioning well and produce data of good quality (Fig. 4). “SABA”, “SABQ”, “SABW” and “SABY” transmit data in near real-time to KNMI for the purpose of detecting earthquakes. Data from “SABN” are transmitted once a day by satellite.

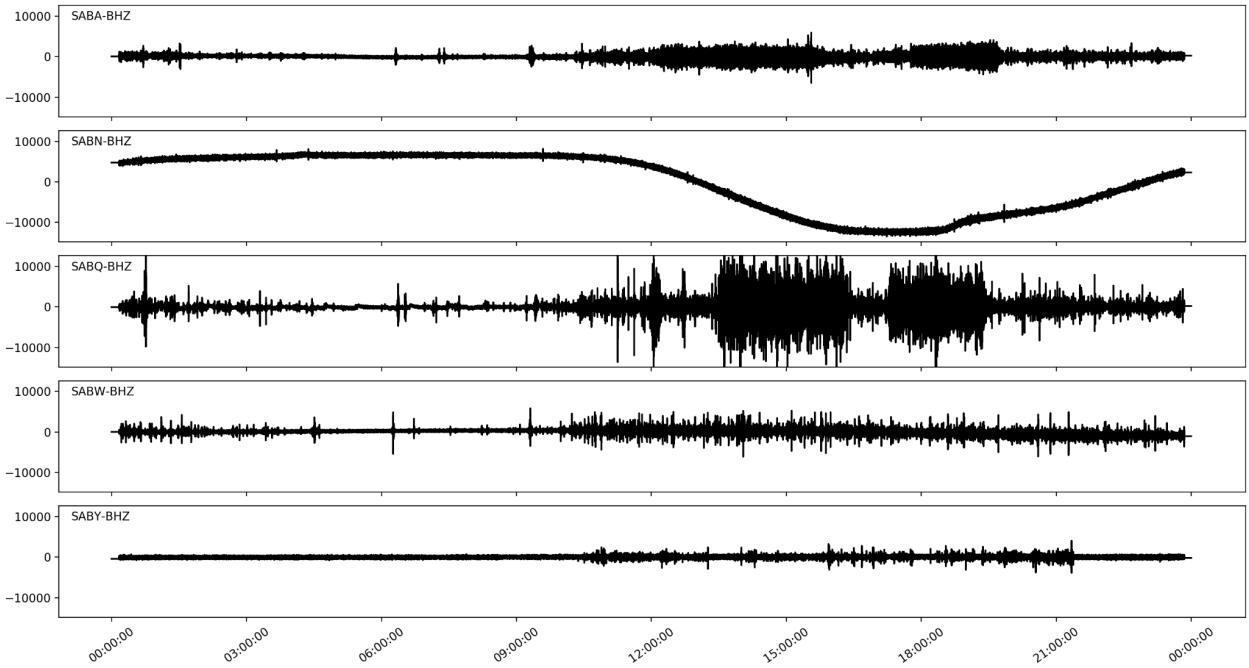


Fig. 4: Vertical ground motion recorded by the seismic stations at Saba on 01-09-2021. Notice the increase of human induced seismic noise during the day, except at SABN. Here, however, a daily variation is clearly visible due to temperature variation. This is suppressed at the other stations by temperature regulation (air conditioning). Both the human induced noise and temperature variation do not limit the functioning of the seismometer and the detection of earthquakes.

Live seismograms, with a delay of about 15 minutes, are available at our website: https://www.knmidc.org/seismology/. Please note that data from SABN are not displayed there because of the delay in data transfer. Furthermore, continuous data collection can be affected by communication problems, e.g. due to lightning damage or by power failure.

A new technique, called coincidence trigger, was implemented at KNMI to better detect small, local earthquakes, using data from all seismometers. Such automatic detections are manually reviewed by a seismologist. Fig. 5 shows an example of such an

earthquake detection and the manually reviewed earthquake location.

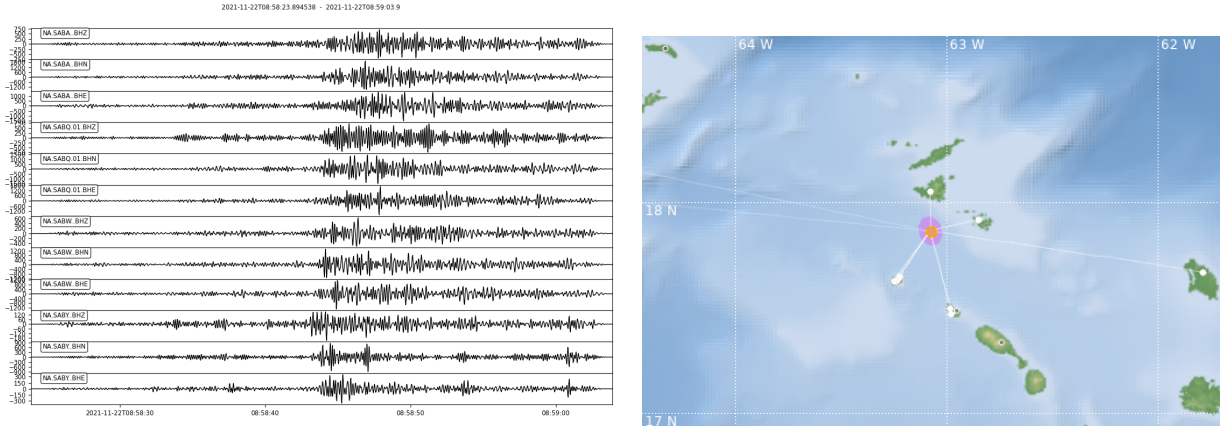


Fig. 5: Seismic recordings (left) from the seismometers at Saba of an automatically detected earthquake in between Saba and St. Maarten (right). The earthquake took place at 22-11-2021, 08:58:20 UTC, at a depth of 76 km and had a magnitude of 2.7.

You can help us to detect earthquakes by filling out the next form in case you have felt an earthquake: https://www.knmi.nl/nederland-nu/seismologie/aardbevingen/melden

GNSS data

The two regular GNSS stations, at the SATEL facility at St. Johns (called “SABA”) and at the airport (called “SABY”) worked well during 2021. The new off-grid remote site at Grey Hill (called “SABN”), installed in April 2021, also performed as expected since its installation. SABN transmits its data once a day via satellite communication to KNMI.

For each GNSS instrument on the island, a daily position is calculated very precisely and evaluated against external reference data by the KNMI. Each day, a new position is obtained and added to the timeseries as a new point. This creates a timeseries dating back to the instrument installation. The GNSS station SABA (at St. Johns) has been operating since January 2018. Station SABY (airport) became operational in February 2019. The recently installed station SABN (at Grey Hill) is operational from April 2021. Figure 6 shows the GNSS positioning time series from the year 2021.

With a long enough time series, trends in these components can be observed. The graphs in Figure 6 show a horizontal movement in the East and North direction for all stations. This effect is caused by the Earth’s tectonics. For Saba, the movement is attributed to the movement of the Caribbean Plate whereby the North and South American plates subduct underneath the Caribbean Plate.

To evaluate local deformations on the island, caused by e.g., slowly moving landslides or land deformation caused by geophysical processes, the plate tectonic signal is removed from the timeseries. Typically, deformations on the flank of a volcano preceding a volcanic eruption are in the order of multiple centimeters to decimeters, visible especially in the horizontal components. The bottom graphs in Figure 6 show the time series of SABA and SABN after removing the plate tectonic movement. They show very little deviation from a horizontal line. It thus indicates no significant deformation happening at the investigated sites.

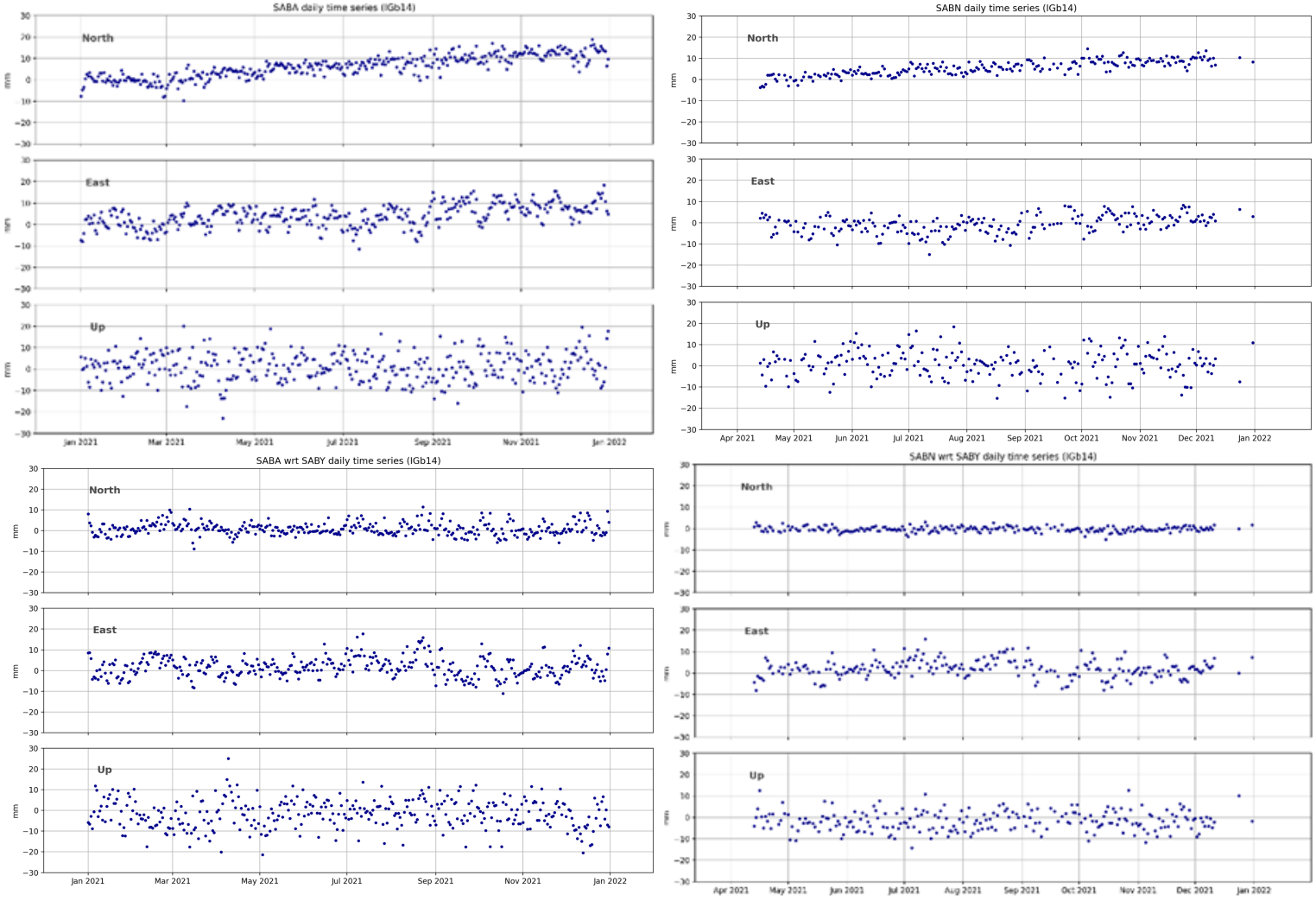


Fig. 6: GNSS data from stations SABA (upper left) and SABN (upper right) from 2021. When the plate movement signal is removed, the data shows very little deviation from a horizontal line (bottom graphs SABA and SABY).

Installation new site at Parish Hill

A new GNSS installation is planned for February 2022 at Parish Hill close to the Whale's Tail. This installation will not have a seismometer because it is relatively close to the operating seismometer located in the SATEL building in The Bottom. All materials for this installation arrived on Saba in January 2022. The new installation will be powered by solar panels/batteries.

Fig.7: Location of the new GNSS station close to the Whale's tail.

Temperature data hot spring

Every visit to the hot-spring opposite Green island we measure the temperature and install new data sensors. The maximum temperature of the spring is fairly constant at around 82 degrees Celsius. The hot spring environment is very harsh for the equipment. Chemical weathering (Fig. 8) resulted in the loss of both temperature sensors during 2021. Therefore we only have a few measurements during 2021. We replaced the sensors in October 2021 and hope to retrieve data in February 2022. To improve the robustness of the set-up we will use special tape to protect future temperature sensors. This tape is vulcanising and resistant to high temperatures and acidic environments.

Fig. 8: Chemical weathering of temperature sensor

Cracks Green Gut - Thermal images

In 2021 the Green Gut area was surveyed twice with the use of a thermal camera (Fig. 9). Most of the cracks observed in 2020 were covered with sand and rubble. The only remaining crack along the wall showed a maximum temperature of around 31 degrees celsius. Between April and October this feature was covered with vegetation. The hot air rising from this crack has no smell. It could be caused by the decomposition of underlying green waste or it could be a volcanic vent. If the latter, such a feature is completely normal and nothing to be concerned about. We will continue observations in this area.

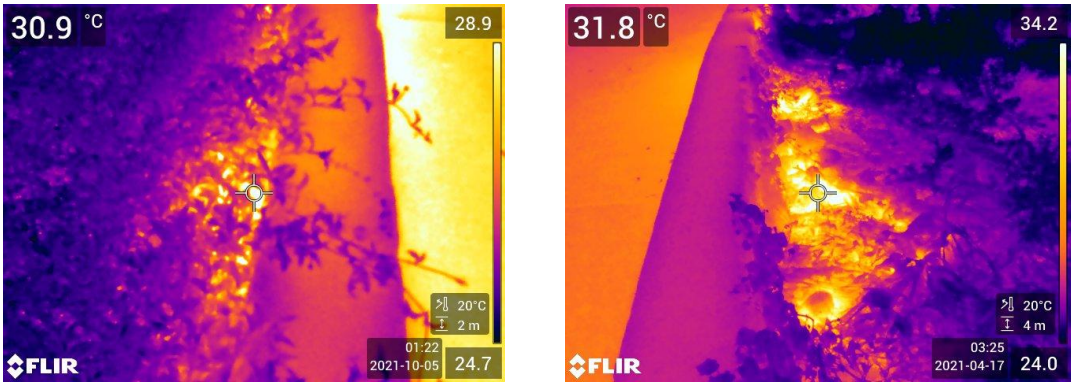


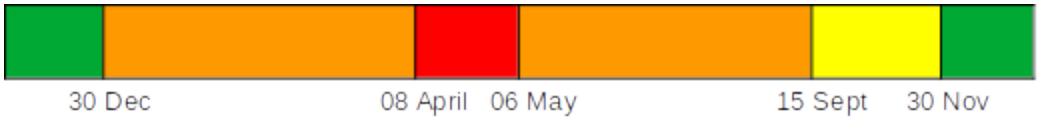
Fig. 9: Thermal camera images of the crack along the wall at the green gut measured in April 2021 (left) and October 2021 (right).

Volcanic activity in the region

In 2021 the Caribbean region experienced the explosive eruption of La Soufriere at St. Vincent. In December 2020 a dome (a mount built by fresh lava) was observed in the crater (Fig. 10). Over time this dome grew from a small black circular mount to a u-shaped mount filling the area between the crater rim and the vegetated old dome.

Fig. 10. Dome growth in the crater of St. Vincent between December 2020 and February 2021. Photos credit of UWISeismic.

On 30 December 2020 the alert level of the volcano (see table below) was raised to orange after the initial observation of the new dome. On 8 April 2021 seismic activity and gas output increased dramatically and the alert level was raised to red and evacuations started. From 9-22 April, 26 explosive eruptions occurred, with ash reaching 20 km altitude. On November 30, UWISeismic declared that the eruption was over.



Due to favorable wind conditions ash and volcanic gasses were mostly blown towards the ESE during the eruption so little was noticeable on Saba.

Currently three volcanoes in the Caribbean (Fig. 11) have a yellow alert level: Mount Pelée in Martinique, La Soufrière in Guadeloupe and Kick ‘em Jenny just North of Grenada. All other volcanoes have a green alert level.

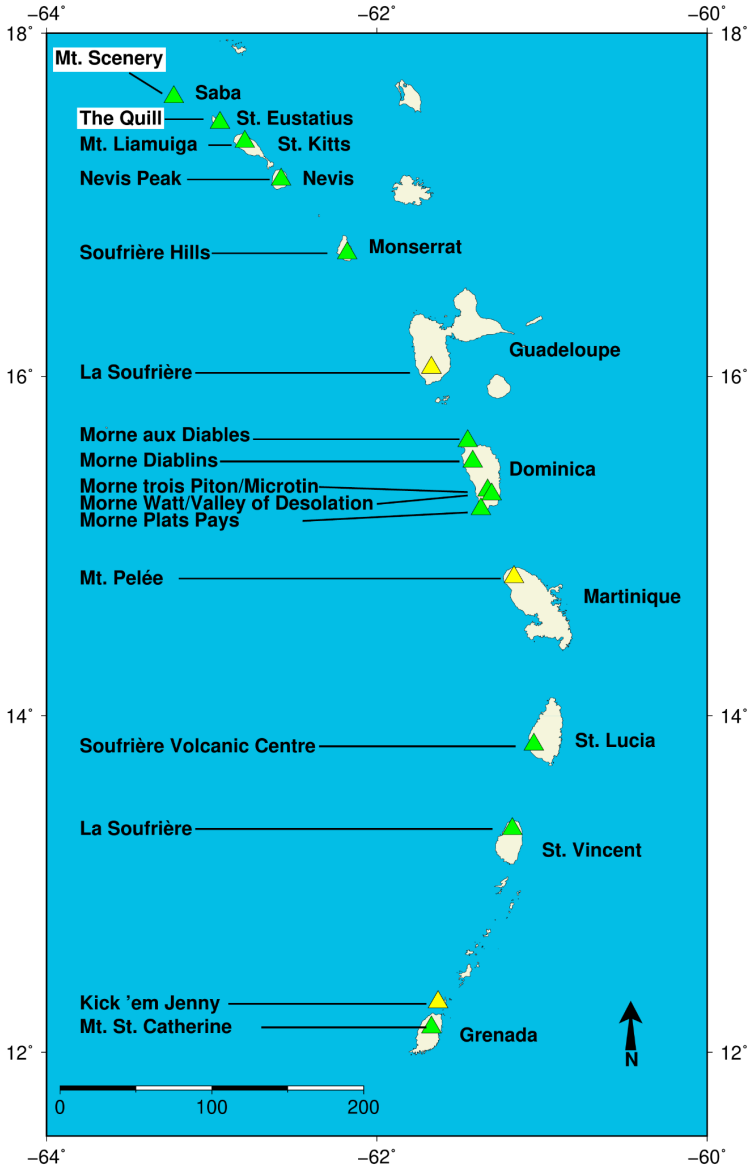


Fig. 11: The active arc of the Lesser Antilles showing the islands of Saba and St. Eustatius in the far north, as well as the other islands of the chain. The triangles depict the location of an active volcano, and their names are shown on the left.
Mnt. Scenery and The Quill are highlighted. The color of the triangle depicts the state of the volcano as of 26 Jan 2022 whereby green = normal and yellow = advisory.

For more information on the activity of other Caribbean volcanoes see:

- http://uwiseismic.com and http://nemo.gov.vc/nemo/index.php/home/welcome for Grenada, Grenadines, St. Vincent, St. Lucia, Dominica, St. Kitts and Nevis
- https://www.ipgp.fr/fr/ovsm/lobservatoire-volcanologique-sismologique-de-martinique-ovsm-ipgp for Martinique
- https://www.ipgp.fr/fr/ovsg/actualites-ovsg for Guadeloupe
- http://www.mvo.ms/ for Montserrat.

Volcanic gasses from other volcanoes reaching the Caribbean

Volcanic gasses can travel long distances and affect populations several thousand kilometers away from a volcano. The journey of the volcanic gasses can be observed with the use of satellites as is done by the Copernicus Atmosphere Monitoring Services (CAMS). For example, in October 2021, sulfate aerosols from the eruption of the Cumbre Vieja volcano in La Palma, Canary Islands, reached the Caribbean region (Fig. 12). These aerosols may cause itching of eyes, skin irritation or respiratory difficulties especially for younger children, the elderly or people with asthma. When affected it is advised to avoid strenuous activities and remain indoors with windows closed.

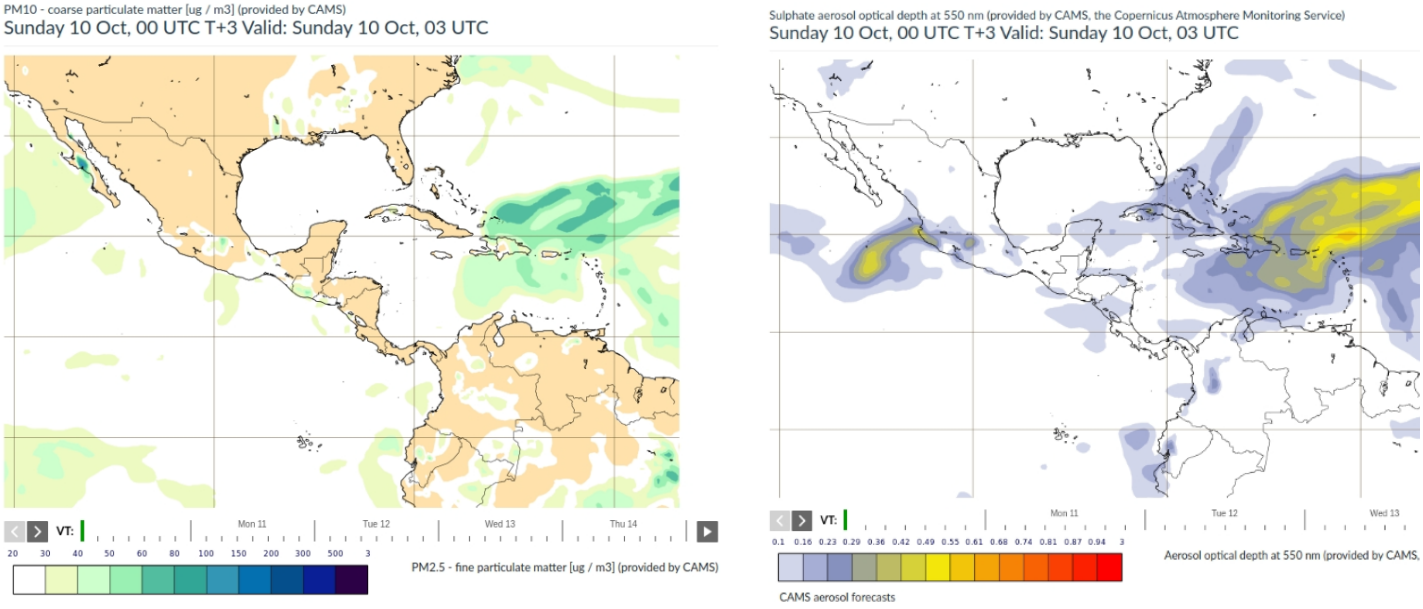


Fig. 12: Volcanic gasses reaching the Caribbean area on October 10th 2021. Dark green shows the highest concentration of particles in the air (left) and yellow/orange indicates high concentrations of sulfate aerosols (right).

"Volcano Monitoring Group" on Facebook

We created a Facebook group "Volcano Monitoring" (https://www.facebook.com/groups/1910967532268885). This is a place where we will share information and photos of our activity. We will also post information about seismic and volcanic activity in the region from sister organizations such as UWI-seismic and IPGP. At the same time the public can also share their observations concerning volcanic or seismic activity with us. We hope many interested people will join us in this group.

UPDATE 6 – St. Eustatius, March 2022

This update reports on the activities of KNMI in 2021 with respect to the volcanic/seismic monitoring network at St. Eustatius. The COVID-19 pandemic provided an extra challenge considering our work, mainly related to travel and contact restrictions. Nevertheless we managed to build the new off-grid station at the Miriam C. Schmidt Botanical garden in January 2021 (called “SEUH”). Also, regular observations of data at all stations continued throughout the year. The current monitoring network, and its extension planned for May 2022, is displayed in Fig. 1.

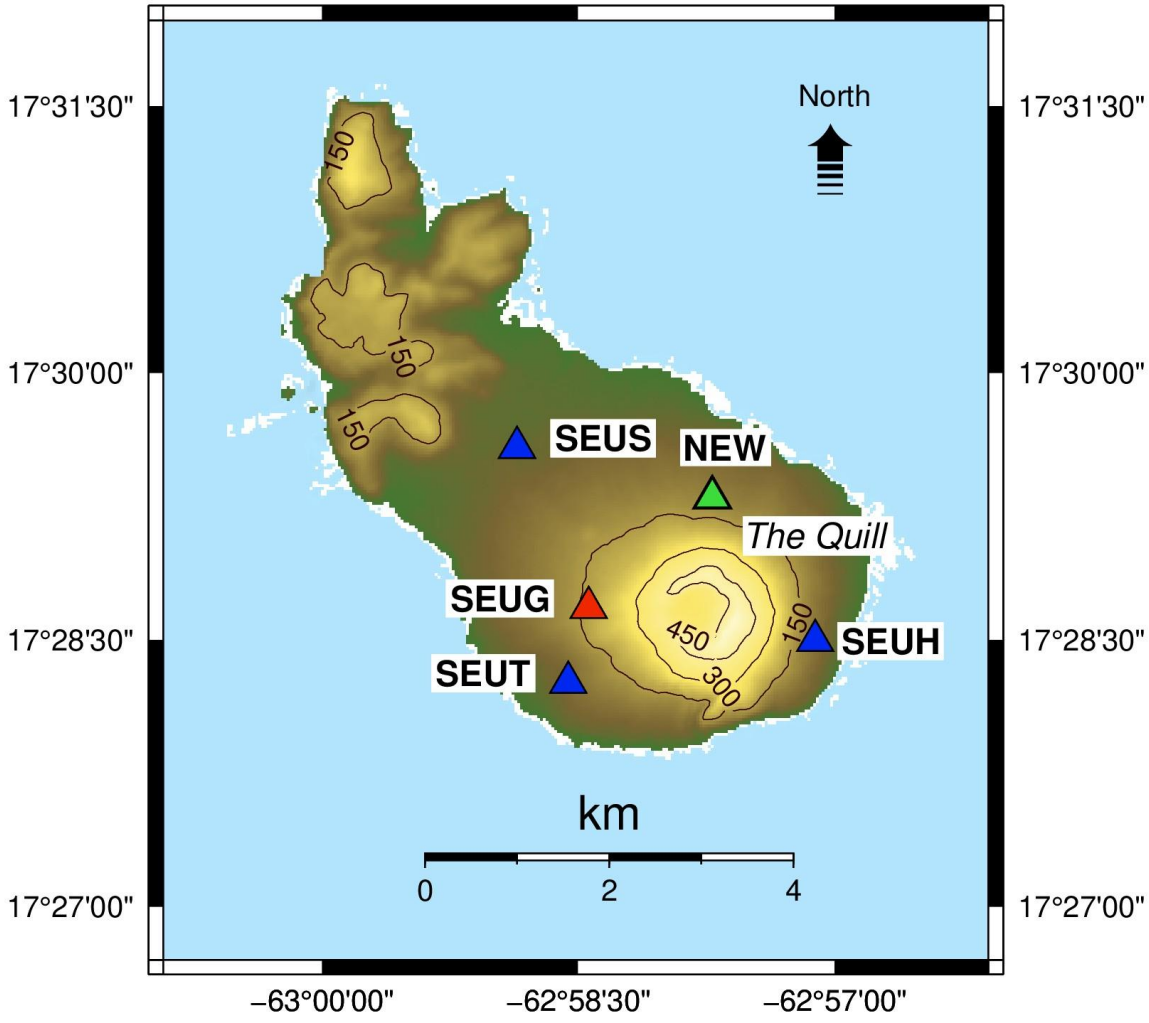


Fig. 1: Map showing the locations of current measurement sites on St. Eustatius with blue (GNSS/seismic stations) and red (seismic stations) triangles. Station SEUH was built in January 2021. In green the location of the proposed GNSS/seismic station at Bengalen (planned installation May 2022).

Installation Station SEUH

In January 2021 a GNSS and seismometer were installed at the Miriam C. Schmidt Botanical garden (Fig. 2).

Fig. 2: Drilling for the GNSS monument (left) and construction of the housing for the seismometer (right).

The monitoring station “SEUH” (Fig. 3) consists of a seismometer recording vibrations and a GNSS instrument measuring deformation. It is powered by solar panels and batteries. Data are sent 24/7 to KNMI using satellite communication.

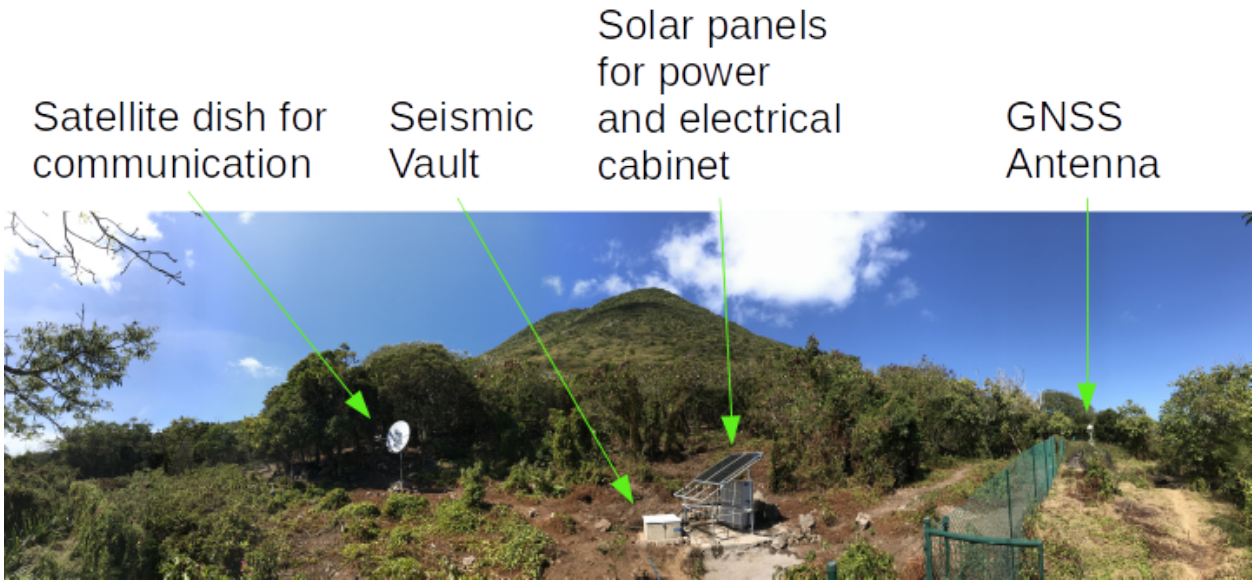


Fig. 3: The monitoring site “SEUH” at the Miriam C. Schmidt Botanical garden.

Seismic data

Seismometers at SEUH, SEUS and SEUT are functioning well and produce data of good quality (Fig. 4). Station SEUG, however, unfortunately stopped working on 10/09/2021 and is currently being repaired. SEUG, SEUS and SEUT are configured to transmit data in near real-time to KNMI for the purpose of detecting earthquakes. Data from SEUH are transmitted once a day by satellite.

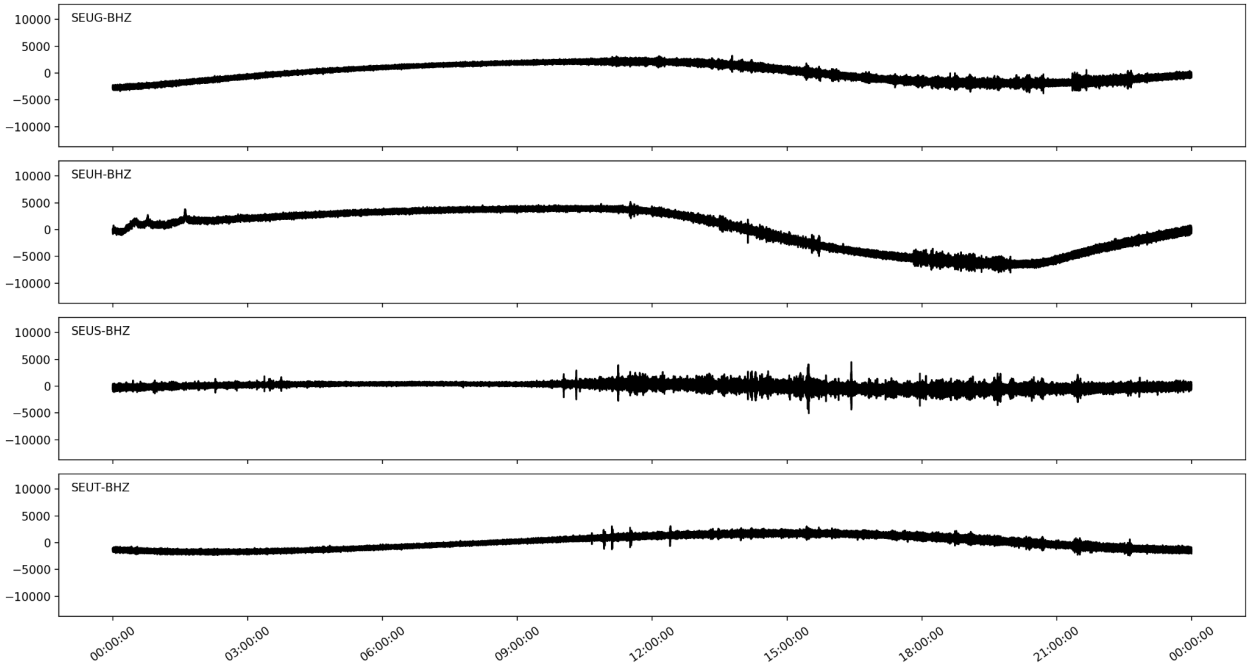


Fig. 4: Vertical ground motion recorded by the seismic stations at St. Eustatius on 01-09-2021. Notice the increase of human induced seismic noise during the day at SEUS due to its vicinity to traffic and offices. A daily variation, which is most likely due to temperature variation, is visible in SEUG and SEUH, and less pronounced in SEUT. Both the human induced noise and temperature variation do not limit the functioning of the seismometer and the detection of earthquakes.

Live seismograms, with a delay of about 15 minutes, are available at our website: https://www.knmidc.org/seismology/. Please note that data from SEUH are not displayed there because of the delay in data transfer. Furthermore, continuous data collection can be affected by communication problems, e.g. due to lightning damage or by power failure.

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are manually reviewed by a seismologist. Fig. 5 shows an example of such an earthquake detection and the manually reviewed earthquake location.

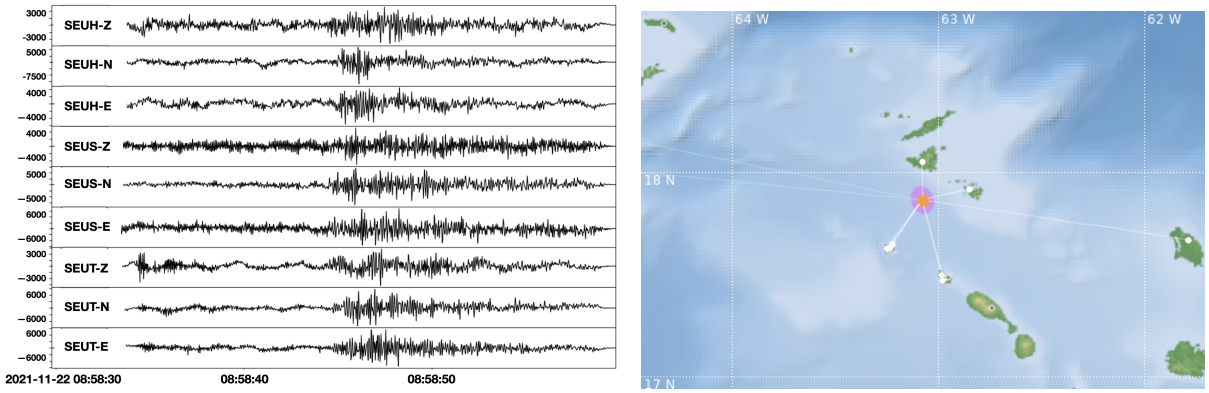


Fig. 5: Seismic recordings (left) from the seismometers at St. Eustatius of an automatically detected earthquake in between St. Eustatius and St. Maarten (right). The earthquake took place on 22-11-2021, 08:58:20 UTC, at a depth of 76 km and has a magnitude of 2.7.

You can help us to detect earthquakes by filling out the next form in case you have felt an earthquake: https://www.knmi.nl/nederland-nu/seismologie/aardbevingen/melden

GNSS data

The GNSS station at the EUTEL facility at White Wall (called “SEUT”) worked well during 2021. The GNSS antenna at the airport (called “SEUS”) sustained severe damage due to a lightning strike in september 2020. Power and internet connection to the site were recovered quickly but unfortunately the antenna was damaged beyond repair and was ultimately replaced in January 2021. The new off-grid remote site at the botanical garden (called “SEUH”), installed in January 2021, performed as expected. SEUH transmits its data via satellite communication to KNMI once a day.

For each GNSS instrument on the island, a daily position is calculated very precisely and evaluated against external reference data by the KNMI. Each day, a new position is obtained and added to the timeseries as a new point. This creates a timeseries dating back to the instrument installation. Figure 6 shows the GNSS positioning time series from the year 2021.

With a long enough time series, trends in these components can be observed. The graphs in Figure 6 show a horizontal movement in the East and North direction for all

stations. This effect is caused by the Earth's plate tectonics. For St. Eustatius, the movement is attributed to the movement of the Caribbean Plate whereby the North and South American plates subduct underneath the Caribbean Plate.

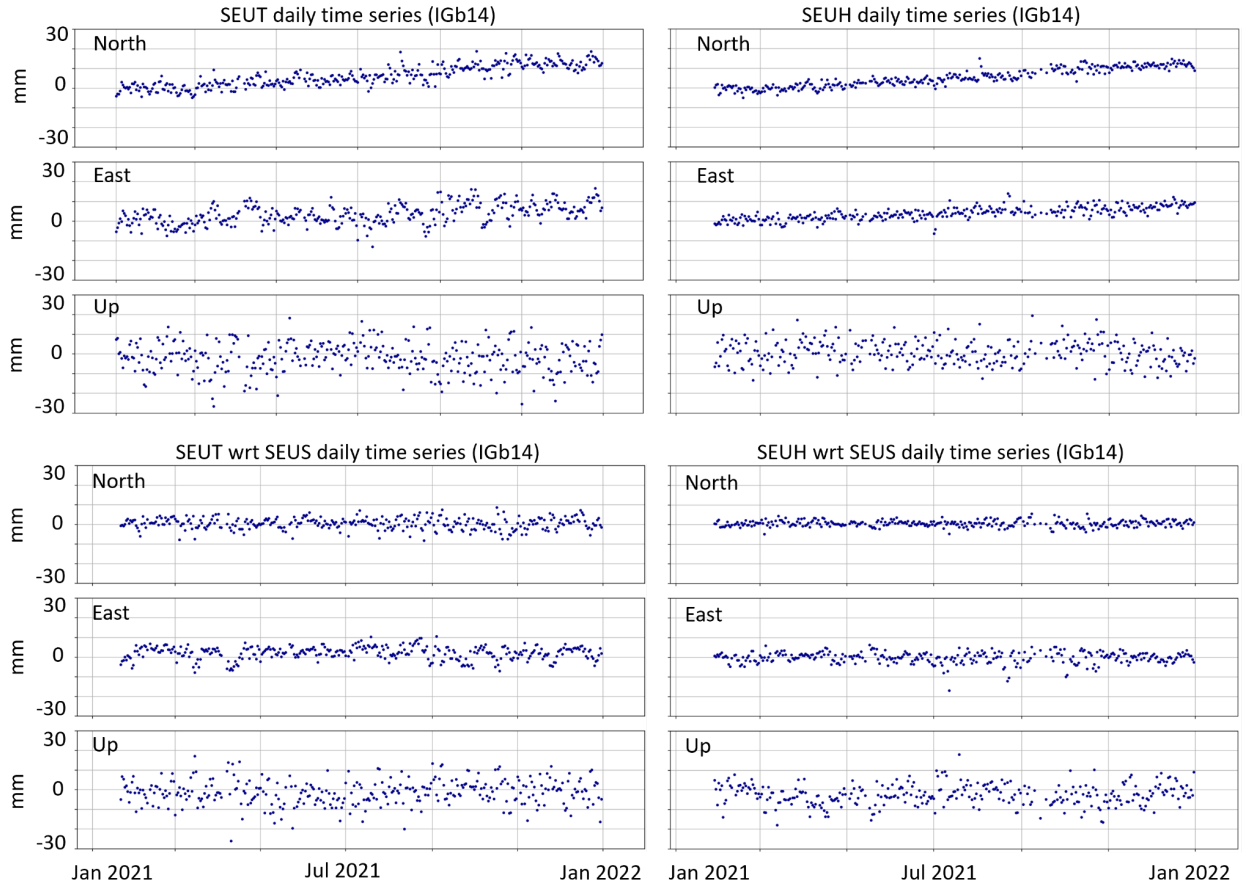


Fig. 6: GNSS data from stations SEUT (upper left) and SEUH (upper right) from 2021. When the plate movement signal is removed, the data shows very little deviation from a horizontal line (bottom graphs SEUT and SEUH).

To evaluate local deformations on the island, caused by e.g., slowly moving landslides or geophysical processes, the plate tectonic signal is removed from the timeseries. Typically, deformations on the flank of a volcano preceding a volcanic eruption are in the order of multiple centimeters to decimeters, visible especially in the horizontal components. The bottom graphs in Figure 6 show the time series of SEUT and SEUH after removing the plate tectonic movement. They show very little deviation from a horizontal line. This indicates no significant deformation happening at these sites.

Installation new site at Bengalen

A new GNSS/seismic installation is planned for May 2022 at Bengalen. This installation will consist of a GNSS antenna, seismometer, electrical cabinet and solar panels. A satellite dish is not needed for the data transmission as the location has cellular reception. All materials and equipment for this installation have been shipped to St. Eustatius.

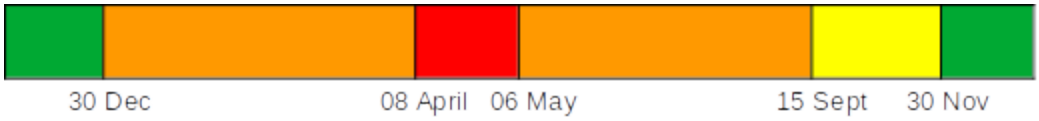
Fig.7: Location of the new GNSS & seismic monitoring site at Bengalen.

Volcanic activity in the region

In 2021 the Caribbean region experienced the explosive eruption of La Soufriere at St. Vincent. In December 2020 a dome (a mount built by fresh lava) was observed in the crater (Fig. 10). Over time this dome grew from a small black circular mount to a u-shaped mount filling the area between the crater rim and the vegetated old dome.

Fig. 10. Dome growth in the crater of St. Vincent between December 2020 and February 2021. Photos credit of UWISeismic.

On 30 December 2020 the alert level of the volcano (see table below) was raised to orange after the initial observation of the new dome. On 8 April 2021 seismic activity and gas output increased dramatically and the alert level was raised to red and evacuations started. From 9-22 April, 26 explosive eruptions occurred, with ash reaching 20 km altitude. On November 30, UWISeismic declared that the eruption was over.



Due to favorable wind conditions ash and volcanic gasses were mostly blown towards the ESE during the eruption so little was noticeable on Saba.

Currently three volcanoes in the Caribbean (Fig. 11) have a yellow alert level: Mount Pelée in Martinique, La Soufrière in Guadeloupe and Kick ‘em Jenny just North of Grenada. All other volcanoes have a green alert level.

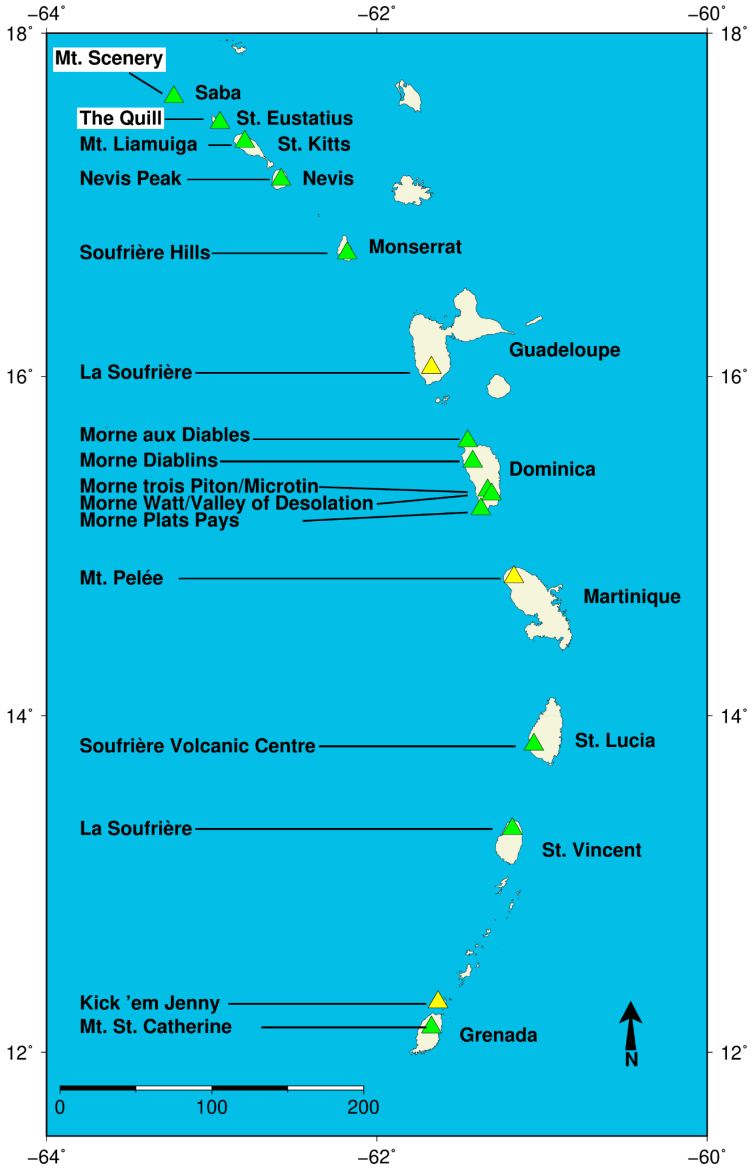


Fig. 11: The active arc of the Lesser Antilles showing the islands of Saba and St. Eustatius in the far north, as well as the other islands of the chain. The triangles depict the location of an active volcano, and their names are shown on the left.
Mnt. Scenery and The Quill are highlighted. The color of the triangle depicts the state of the volcano as of 26 Jan 2022 whereby green = normal and yellow = advisory.

For more information on the activity of other Caribbean volcanoes see:

- http://uwiseismic.com and http://nemo.gov.vc/nemo/index.php/home/welcome for Grenada, Grenadines, St. Vincent, St. Lucia, Dominica, St. Kitts and Nevis
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- https://www.ipgp.fr/fr/ovsg/actualites-ovsg for Guadeloupe
- http://www.mvo.ms/ for Montserrat.

Volcanic gasses from other volcanoes reaching the Caribbean

Volcanic gasses can travel long distances and affect populations several thousand kilometers away from a volcano. The journey of the volcanic gasses can be observed with the use of satellites as is done by the Copernicus Atmosphere Monitoring Services (CAMS). For example, in October 2021, sulfate aerosols from the eruption of the Cumbre Vieja volcano in La Palma, Canary Islands, reached the Caribbean region (Fig. 12). These aerosols may cause itching of eyes, skin irritation or respiratory difficulties especially for younger children, the elderly or people with asthma. When affected it is advised to avoid strenuous activities and remain indoors with windows closed.

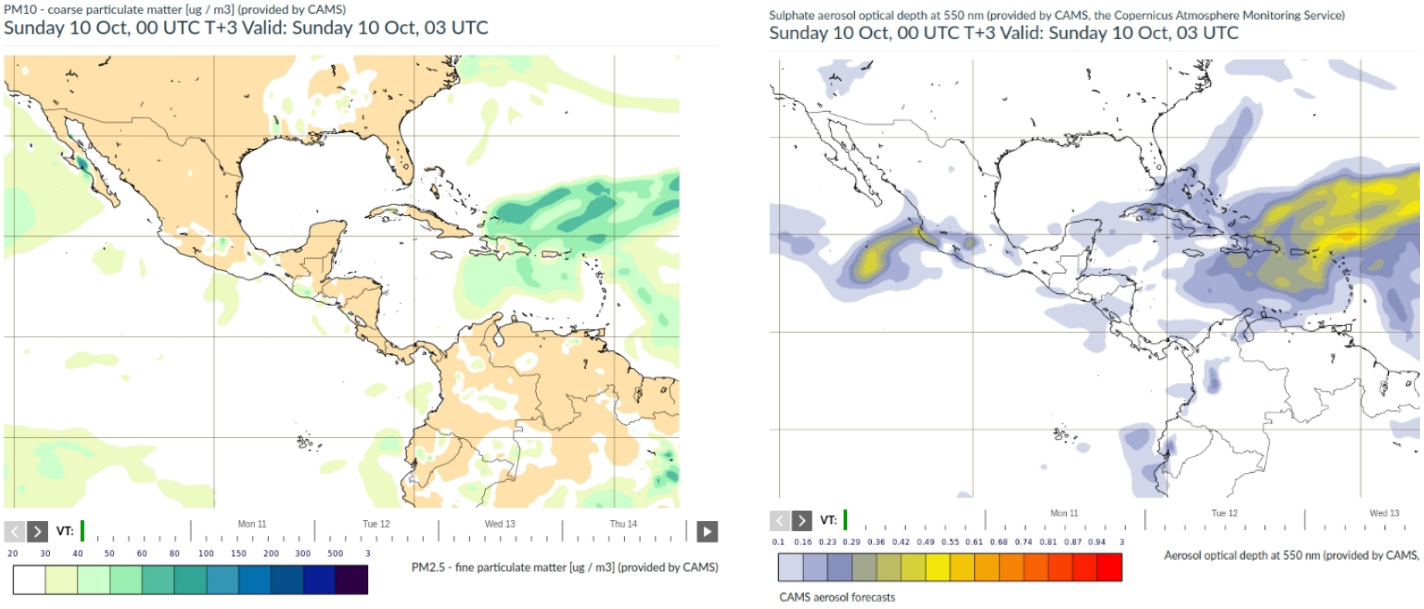

Fig. 12: Volcanic gasses reaching the Caribbean area on October 10th 2021. Dark green shows the highest concentration of particles in the air (left) and yellow/orange indicates high concentrations of sulfate aerosols (right).

"Volcano Monitoring Group" on Facebook

We created a Facebook group "Volcano Monitoring" (https://www.facebook.com/groups/1910967532268885). This is a place where we will share information and photos of our activity. We will also post information about seismic and volcanic activity in the region from sister organizations such as UWI-seismic and IPGP. At the same time the public can also share their observations concerning volcanic or seismic activity with us. We hope many interested people will join us in this group.

UPDATE 7 – Saba, April 2023

This update reports on the activities of KNMI in 2022 with respect to the volcanic/seismic monitoring network at Saba. In 2022 KNMI visited Saba in February and November. We built the new off-grid station at the Whale's tail (called "SABP") and installed four cost-effective GNSS units for a pilot study. Regular observations of data at all stations continued throughout the year. The current monitoring network is displayed in Fig. 1.

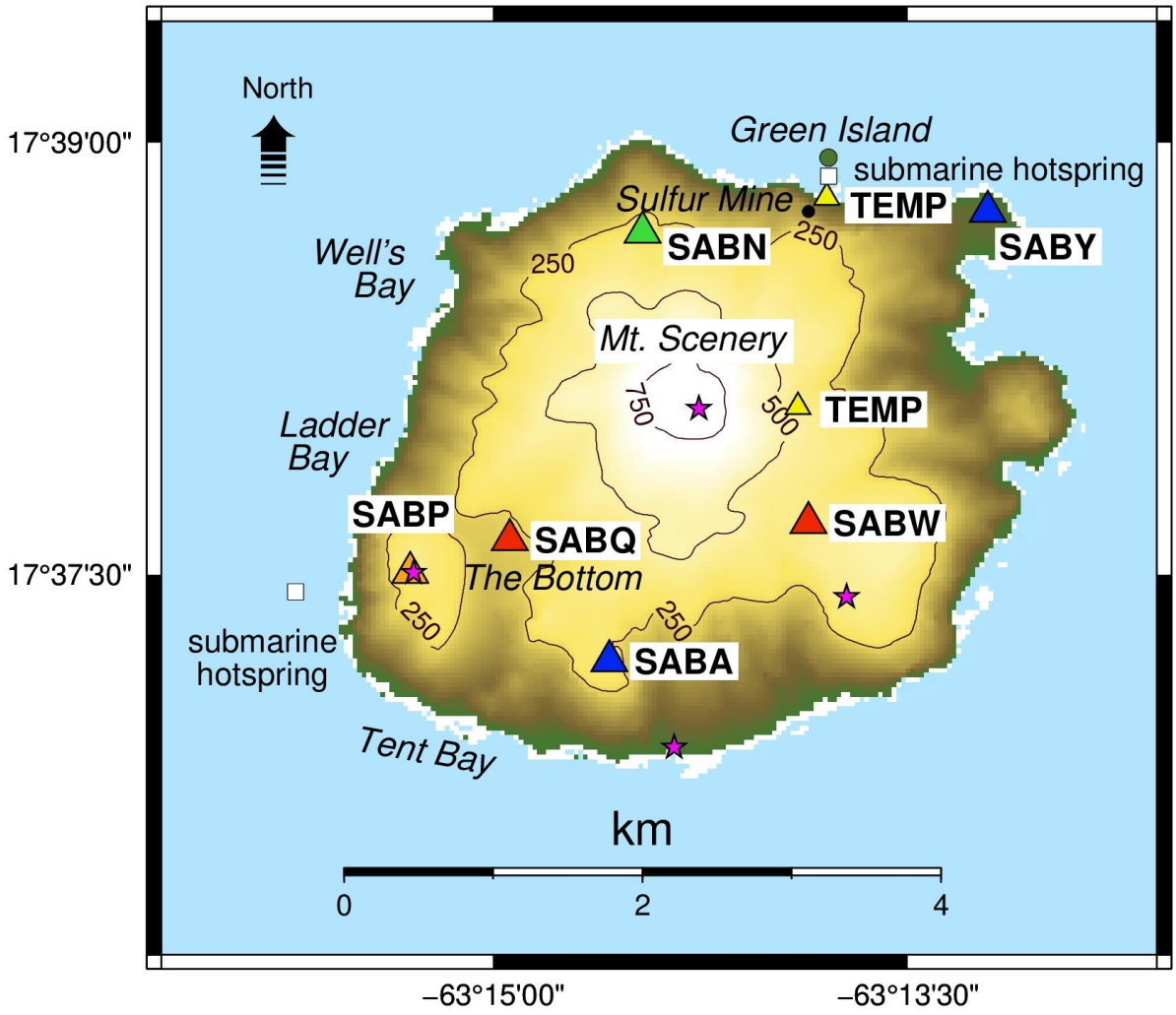

Fig. 1: Map showing the locations of current measurement sites on Saba with blue (GNSS/seismic stations) and red (seismic stations) triangles. The seismic and GNSS off-grid station is shown with a green triangle and the GNSS off-grid site with an orange triangle. Purple stars show the locations of the cost-effective units.

Installation Station SABP

In February 2022 a continuous GNSS was installed (Fig. 2) at the whale's tail with the courageous help of locals, organized by Lune Zijnen and Frank Granger, to carry all equipment and materials.

Fig. 2: Installation work at the Whale's Tail.

The monitoring station “SABP” (Fig. 3) consists of a GNSS instrument used to measure deformation. It is powered by solar panels and batteries. Data is sent 24/7 to KNMI using 3G mobile connection.

Fig. 3: The monitoring site “SABP” at The Whale’s Tail.

Installation cost-effective units

In February 2022 four cost-effective GNSS units were installed, as part of a pilot study, at the new harbor, on top of Mt. Scenery, at the Whale’s tail and in Windwardside.

Fig. 4 Cost-effective units installed on Saba: a) Windwardside, b) Mt. Scenery, c) Whale’s Tail, d) Harbor. Each unit consists of an antenna, solar panel for power, and box housing the receiver and electronics. Data is stored locally on a SD card.

The goal of the pilot study is to assess the quality of data from cost-effective GNSS units and their suitability for volcano monitoring. Cost-effective GNSS units are a lot cheaper than traditional GNSS stations but also less accurate. Initial results (Fig. 5) suggest data quality is comparable for daily positioning purposes and the units can thus be used to expand the existing monitoring network. Downside of the cost-effective units is that they are currently not connected to a network. Data is stored locally which is undesirable for volcano monitoring purposes. We will continue the pilot study in 2023 and consider upgrading the units with 3G/4G models for data transmission.

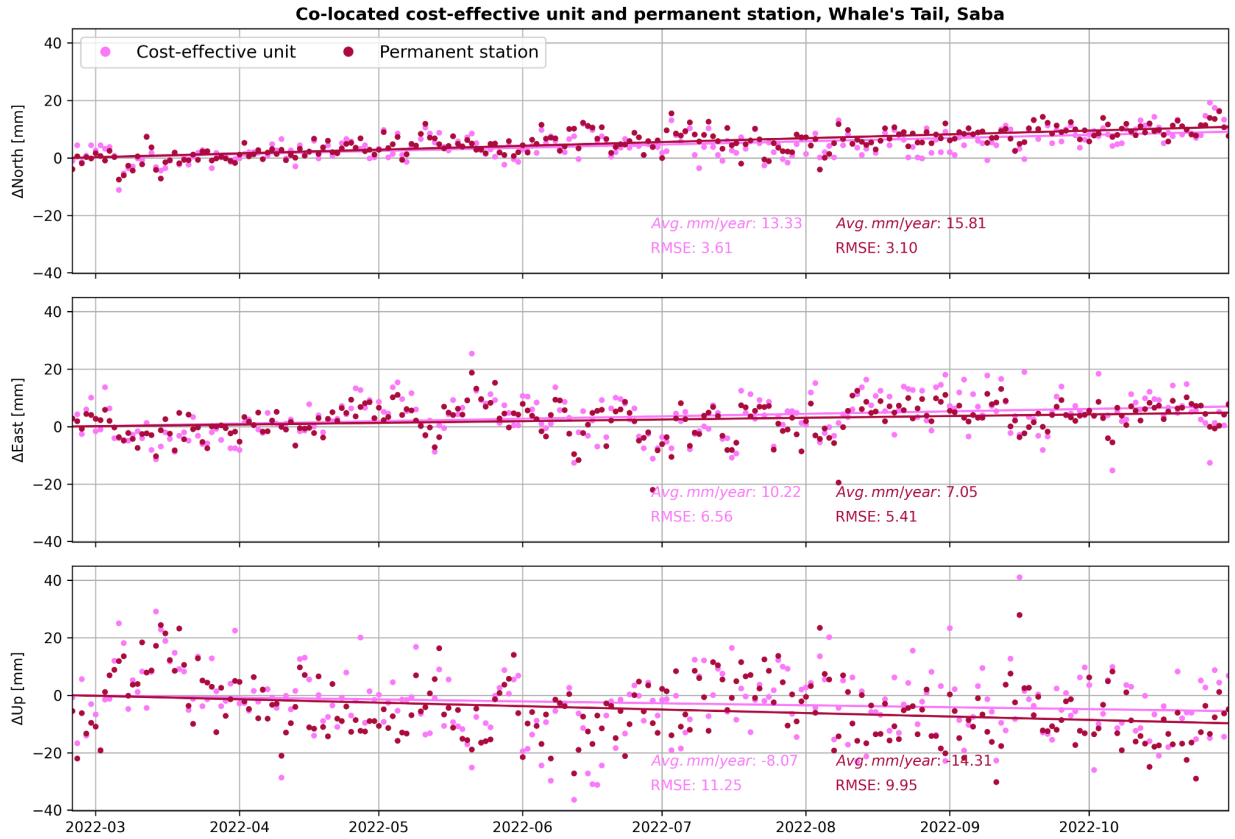

Fig. 5 Daily positioning results in North, East and Up direction of the cost-effective unit and the permanent GNSS at the Whale's Tail over a time span of 8 months. The movements to the North and East are caused by plate tectonics and are visible in data from both instruments. The error (RMSE) in the vertical (up) direction is also comparable.

Seismic data

The five seismometers on Saba are generally functioning well and produce data of good quality (fig. 5). However, sensor “SABY” needs some maintenance. Seismometers “SABA”, “SABQ”, “SABW” and “SABY” transmit data in near real-time to KNMI to ensure real-time monitoring of the seismicity. Seismometer “SABN” transmits data by satellite once a day. During winter, solar hours on Saba are too low to guarantee data transmission. We therefore plan to add an additional solar panel to the SABN site in 2023.

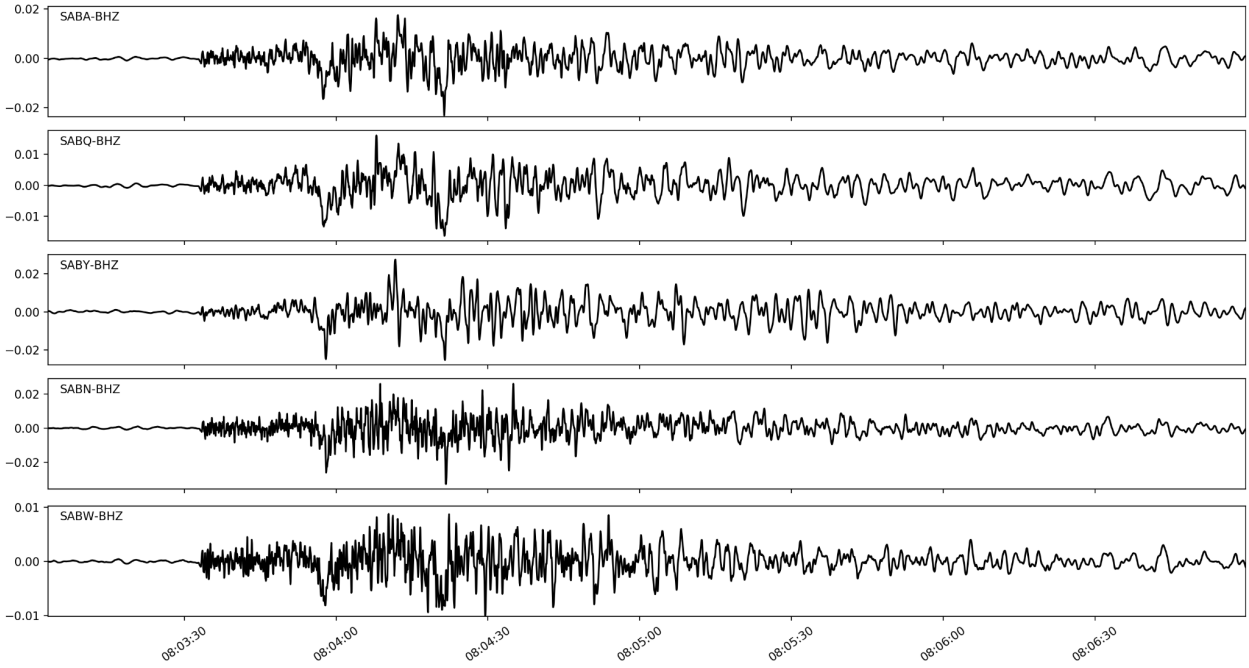

Fig. 5: Recordings of the vertical ground displacement (in millimeter) caused by the M5.5 earthquake at 15-02-2022 08:03 UTC. This earthquake took place at a depth of about 50 km, about 240 km ESE of Saba.

The five seismometers, together with those on St. Eustatius and St. Maarten, are capable of detecting earthquakes with magnitudes down to 1 within a region of 150 km around Saba. Our data fill the seismic monitoring gap around Saba that existed before the expansion of our monitoring network(Fig. 6). In 2022 KNMI detected and located 65 earthquakes around Saba within a distance of 150 km.

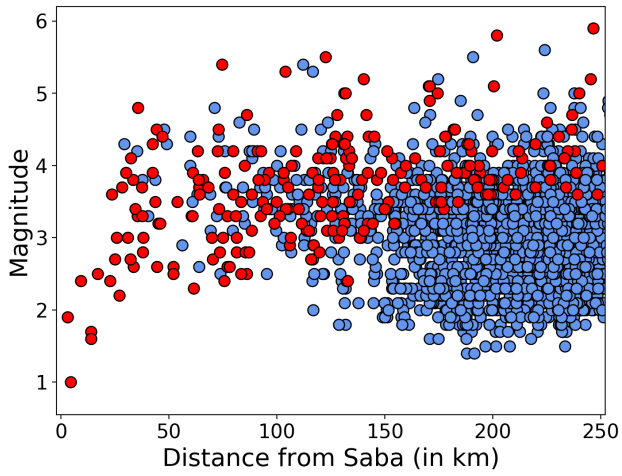

Fig. 6: Magnitude-distance distribution of earthquakes located by KNMI (red) and reported by USGS (blue) in 2017-2021.

Results of our seismic monitoring have been published in a special section of the Bulletin of the Seismological Society of America. on ‘’Caribbean Tectonics, Seismicity and Earthquake Hazards” (Sleeman et al., 2022). Our research shows that the majority of earthquakes near Saba take place West of Saba (Fig. 7) in the same region as the earthquake swarm of 1992.

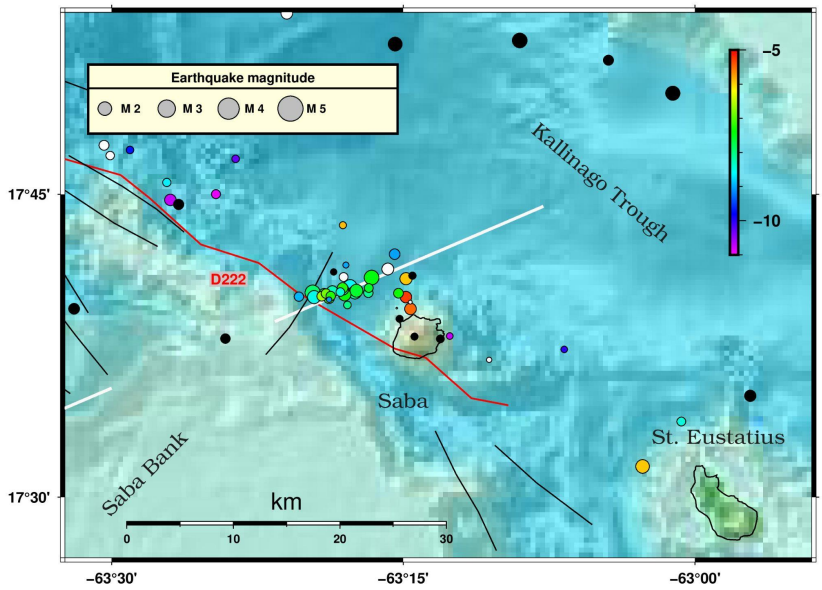

Fig. 7: Earthquake epicenters around Saba, presented by circles, coloured by depth and sized by magnitude. Most of the earthquakes located WNW of Saba align along a tectonic fault identified by Roobol and Smith (2004), at depths of around 8 km.

Live seismograms, with a delay of about 15 minutes, are available at our website: https://www.knmidc.org/seismology/. Please note that data from SABN is not displayed there because of the delay in data transfer. Furthermore, continuous data collection can be affected by communication problems, e.g. due to lightning damage or by power failure causing temporary unavailability.

You can help us to understand the significance of earthquakes in your region by filling out the next form in case you have felt an earthquake: https://www.knmi.nl/nederland-nu/seismologie/aardbevingen/melden

Sleeman, R., and E. de Zeeuw-van Dalfsen (2022). Bridging the Seismic Monitoring Gap around Saba, St. Eustatius, and St. Maarten in the Caribbean Netherlands: The NA Network, Bull. Seismol. Soc. Am. XX, 1–14, doi: 10.1785/ 0120220126

GNSS data

The three already operating GNSS stations, at the SATEL facility at St. Johns (called “SABA”), at the airport (called “SABY”) and at the remote site at Grey Hill (called “SABN”) worked well during 2022. The new off-grid remote site at the Whale’s Tail (called “SABP”), installed in February 2022, also performed as expected since its installation. SABN transmits its data once a day via satellite communication to KNMI.

For each GNSS instrument on the island, a daily position is calculated very precisely and evaluated against external reference data by the KNMI. Each day, a new position is obtained and added to the timeseries as a new point. This creates a timeseries dating back to the instrument installation. Figure 8 shows the GNSS positioning time series for the year 2022.

With a long enough time series, trends in horizontal (North and East) and vertical (Up) components can be observed. To evaluate local deformations on the island, caused by e.g., slowly moving landslides or land deformation due to geophysical processes, the plate tectonic signal is removed from the timeseries. Typically, deformations on the flank of a volcano preceding a volcanic eruption are in the order of multiple centimeters to decimeters, visible especially in the horizontal components. The graph in Figure 8 shows the time series of all permanent GNSS stations on Saba after removing the plate tectonic movement. They show very little deviation from a horizontal line. This indicates no significant deformation is happening at these sites.

Fig. 8: GNSS data from all permanent GNSS stations on Saba in 2022. The plate movement is removed from the signal. The data show very little deviation from a horizontal line.

Campaign GNSS survey

In comparison to continuous GNSS measurement, campaign GNSS surveys are conducted at fixed markers every 1-2 years. The goal of these measurements is to increase the spatial resolution of the ground deformation data to help identify potential centimeter scale changes and movements.

On Saba we identified 4 old GNSS campaign markers (Fig. 9) in Hells Gate, St. Johns, Wells Bay and The Level. The last time these markers were measured was in 2009. We plan to measure these, and two new markers in 2023.

Fig.9: The campaign gravity site Hells Gate. The marker that is measured is the tiny pin to the left of the handheld GPS.

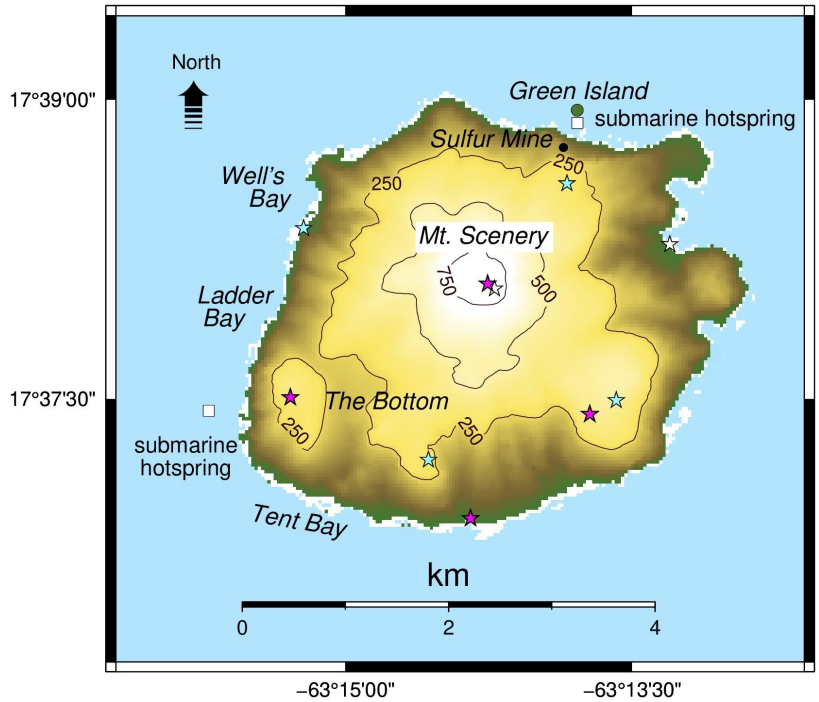

Fig. 10: Location of the old GNSS campaign markers indicated with cyan stars. Two possible new locations for campaign GNSS markers are shown with white stars. For comparison the locations of the cost-effective GNSS sites (purple stars) are also shown.

Temperature data hot spring

In February 2022 the temperature sensors at the hotspring were replaced with temperature sensors covered with chemically resistant tape. This protected the sensors well resulting in a good data set for 2022 (Fig. 11). The maximum temperature of the spring is fairly constant at around 84 degrees Celsius.

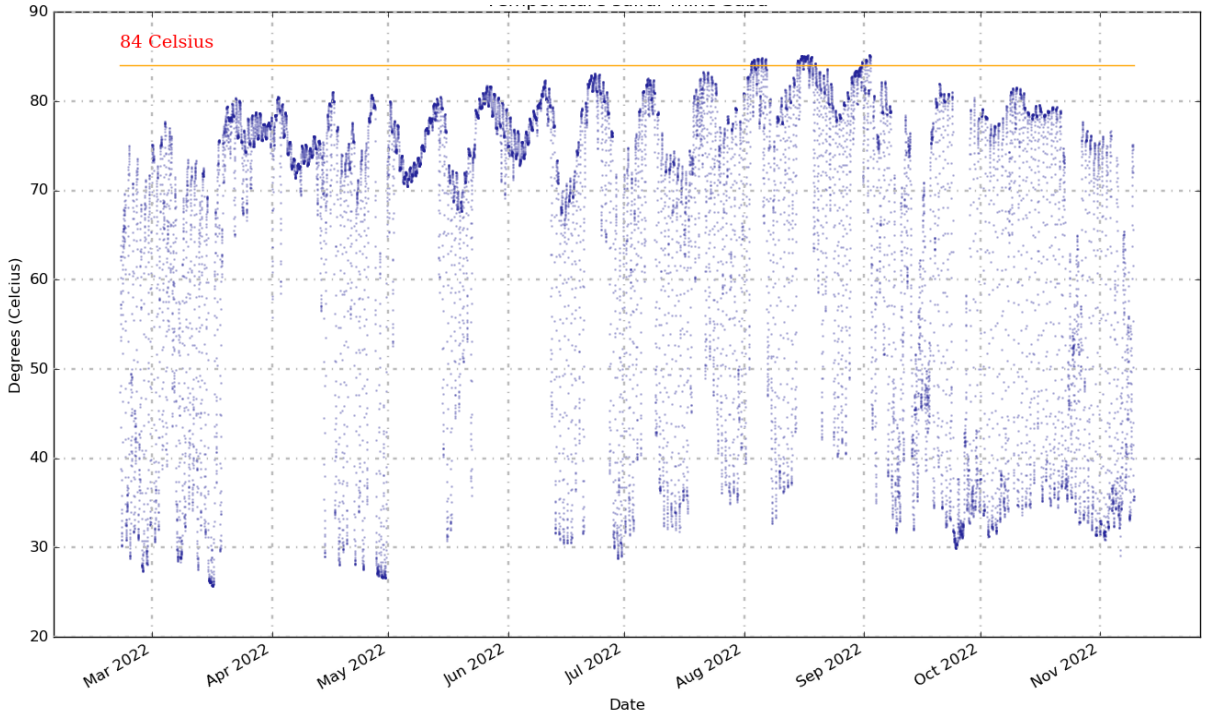

Fig. 11: Temperature data of the hotspring for 2022.

Cracks Green Gut - Thermal images

In 2022 the Green Gut area was surveyed twice with the use of a thermal camera (Fig. 12). The main crack along the wall showed a maximum temperature of around 36 degrees celsius. This temperature is slightly higher than the temperature of 31 degrees Celsius measured in 2021. Therefore we installed a temperature sensor in November 2022 (Fig. 13). A team from McGill University sampled the gas to establish its origin.

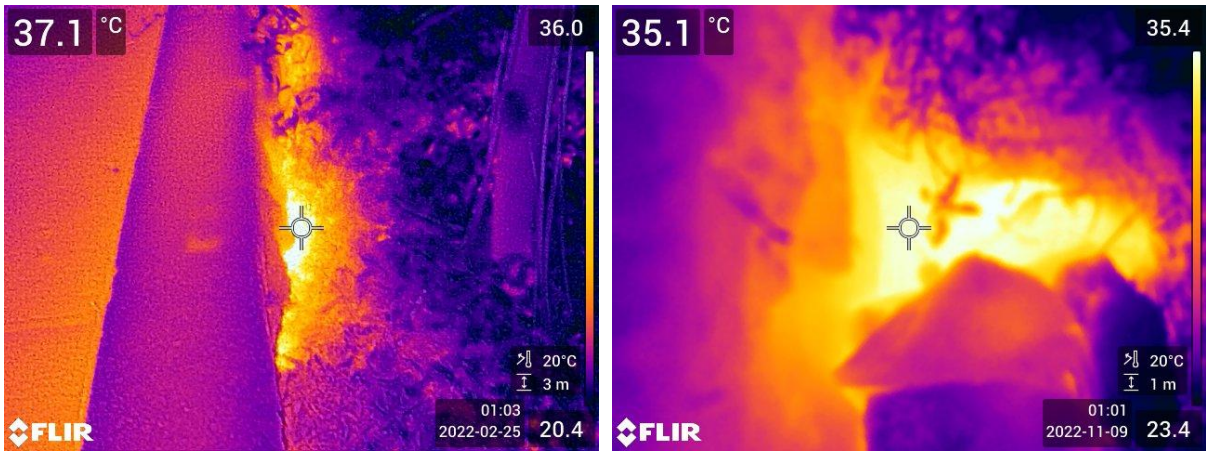

Fig. 12: Thermal camera images of the crack along the wall at the green gut measured in February 2022 (left) and November 2022 (right).

Fig. 13: Temperature sensor installed at the Green Gut. Data is stored locally and will be collected in 2023.

Volcanic activity in the region

Currently three volcanoes in the Caribbean (Fig. 14) have a yellow alert level: Mount Pelée in Martinique, La Soufrière in Guadeloupe and the underwater volcano Kick ‘em Jenny just North of Grenada. All other volcanoes have a green alert level.

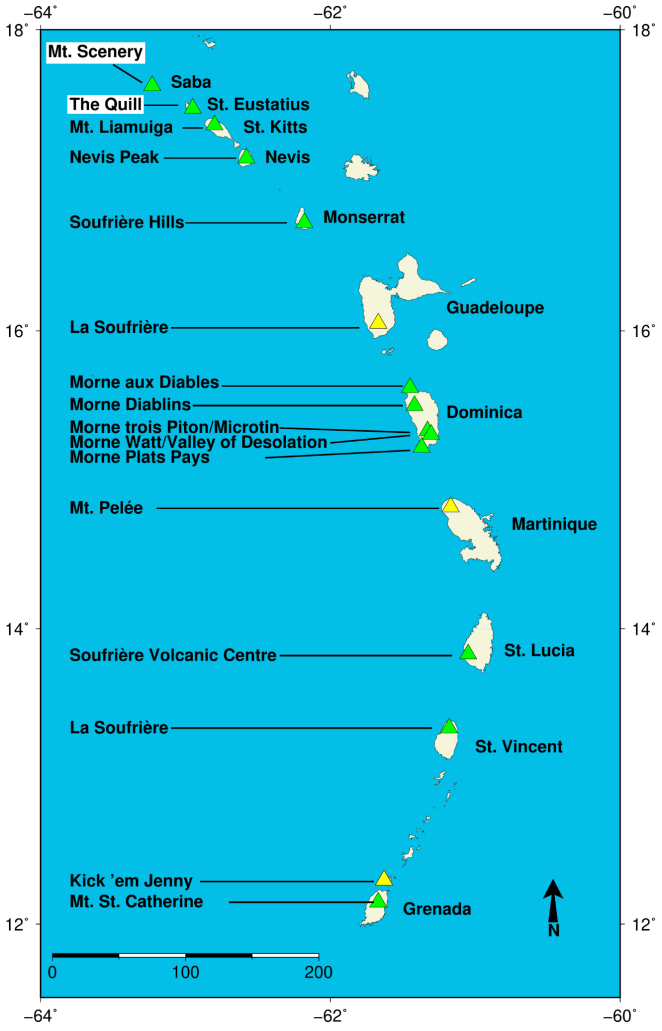

Fig. 14: The active arc of the Lesser Antilles showing the islands of Saba and St. Eustatius in the far north, as well as the other islands of the chain. The triangles depict the location of an active volcano, and their names are shown on the left.
Mnt. Scenery and The Quill are highlighted. The color of the triangles depicts the state of the volcanoes as of 19 April 2023 whereby green = normal and yellow = advisory.

For more information on the activity of other Caribbean volcanoes see:

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- https://www.ipgp.fr/observation/ovs/ovsg/ for Guadeloupe
- http://www.mvo.ms/ for Montserrat.

Filming on Saba

A crew from KRO-NCRV visited the island of Saba in February 2022 to interview KNMI and film for the program “Ruimteschip Aarde” (Fig. 15).
The program can be watched on-line: https://www.npostart.nl/ruimteschip-aarde/08-03-2023/KN_1731356

Fig. 15: Film crew from “Ruimteschip Aarde” at the building site of the new GNSS station SABP. For more info see: https://kro-ncrv.nl/programmas/ruimteschip-aarde/bodem.

“Volcano Monitoring Group” on Facebook

The Facebook group “Volcano Monitoring” now has 174 members (https://www.facebook.com/groups/191096753226885).
In 2022 we created 37 posts which were viewed by many members. The posts concerned earthquakes occurring in the region, the build of the new monitoring sites as well as information from UWI-seismic, our sister institute in Trinidad.

“PARATUS” project

In November 2022 the Horizon Europe-funded project PARATUS started. PARATUS aims at increasing the preparedness for multi-hazard disasters and reducing the risks and impact on society. The main goal is to develop an online Service Platform to evaluate risk scenarios during multi-hazard disasters. The Caribbean is one of the four case study areas of the project, focussing on Bonaire, St. Eustatius and Saba. KNMI is involved in the project as an expert on tropical storms, earthquakes, tsunamis and volcanic activity. For more info see: https://www.paratus-project.eu/about-draft/

UPDATE 7 – St. Eustatius, April 2023

This update reports on the activities of KNMI in 2022 with respect to the volcanic/seismic monitoring network at St. Eustatius. In 2022 KNMI visited St. Eustatius in May and November. We built the new off-grid station at Bengalen (called “SEUB”). Also, regular observations of data at all stations continued throughout the year. The current monitoring network is displayed in Figure 1.

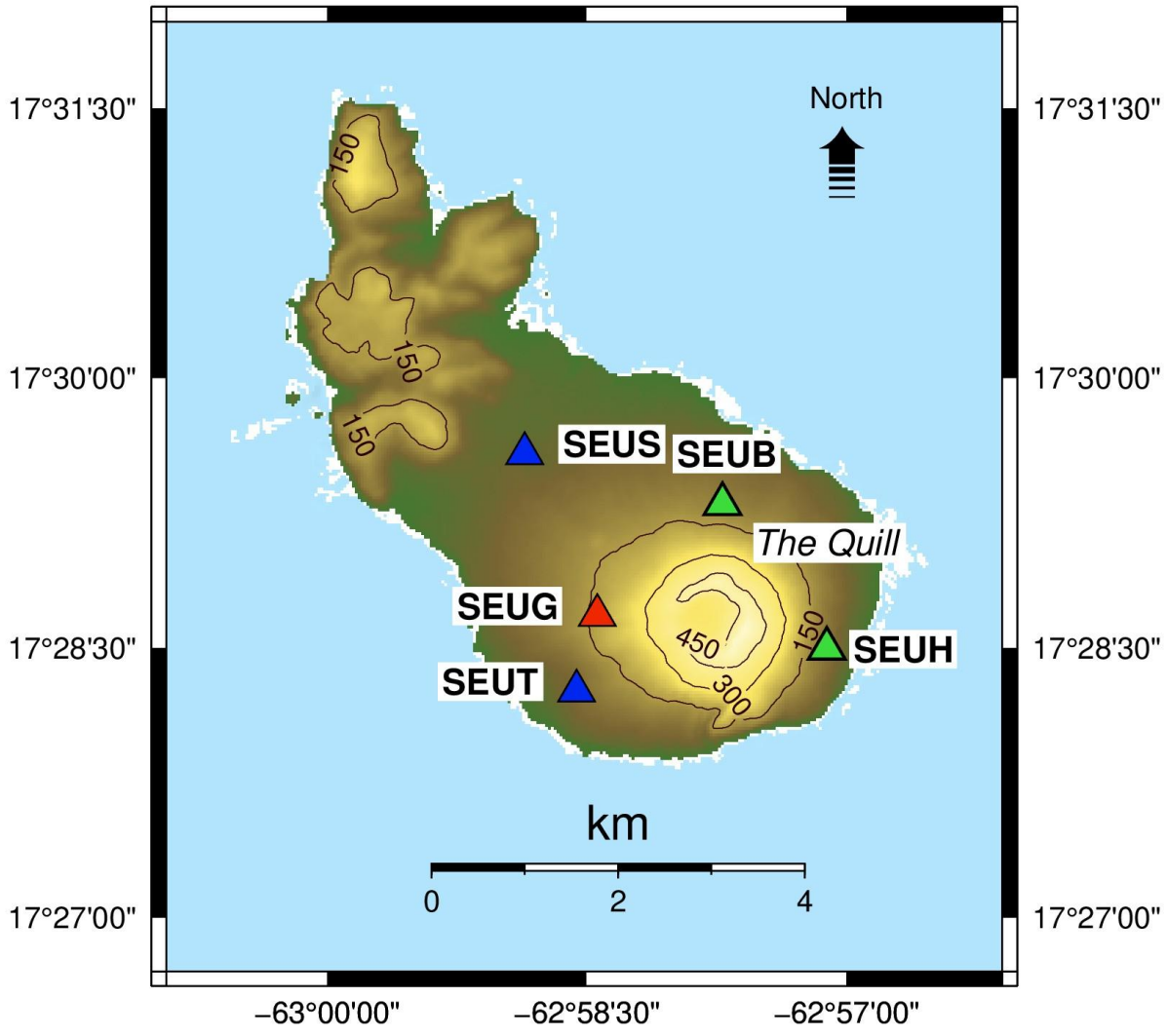

Fig. 1: Map showing the locations of current measurement sites on St. Eustatius with blue (GNSS/seismic stations) and red (seismic stations) triangles. GNSS/seismic stations that are self-sufficient are shown as green triangles.

Installation Station SEUB

In May 2022 a GNSS and a seismometer were installed at Bengalen (Fig. 2).

Fig. 2: Drilling for the GNSS monument (left) and construction of the housing for the seismometer (right).

The monitoring station “SEUB” (Fig. 3) consists of a seismometer recording ground vibrations and a GNSS instrument measuring deformation. It is powered by solar panels and batteries. Data are sent 24/7 to KNMI using 3G/4G mobile connection.

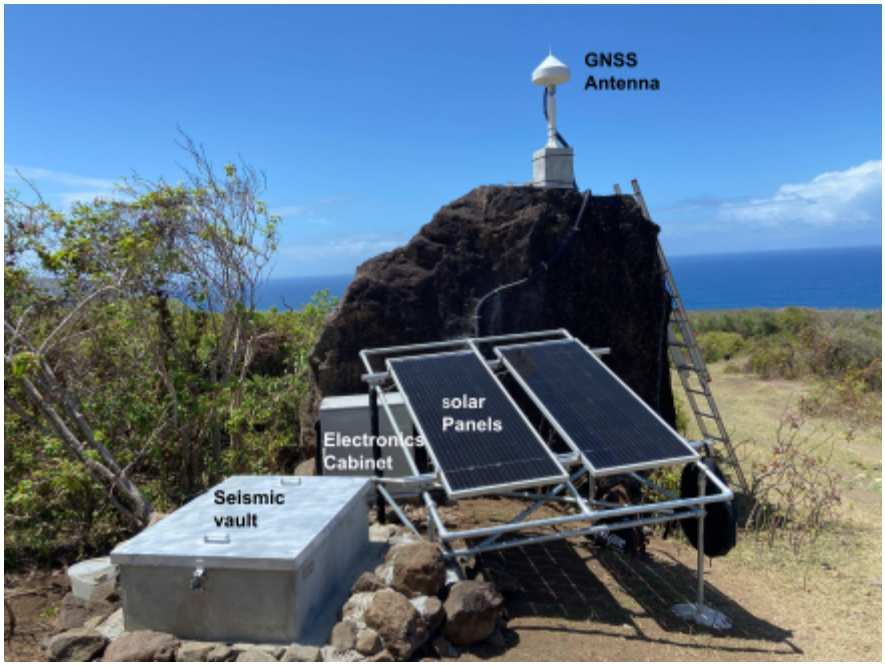

Fig. 3: The monitoring site “SEUB” at Bengalen.

Seismic data

The five seismometers on Saba are generally functioning well and produce data of good quality (Fig. 4). Station “SEUG” was successfully repaired and re-installed. “SEUG”, “SEUS” and “SEUT” are configured to transmit data in near real-time to KNMI to ensure real-time monitoring of the seismicity. Seismometer “SEUH” transmits data by satellite once a day. Also “SEUB” sends data to KNMI once a day, using 3G/4G.

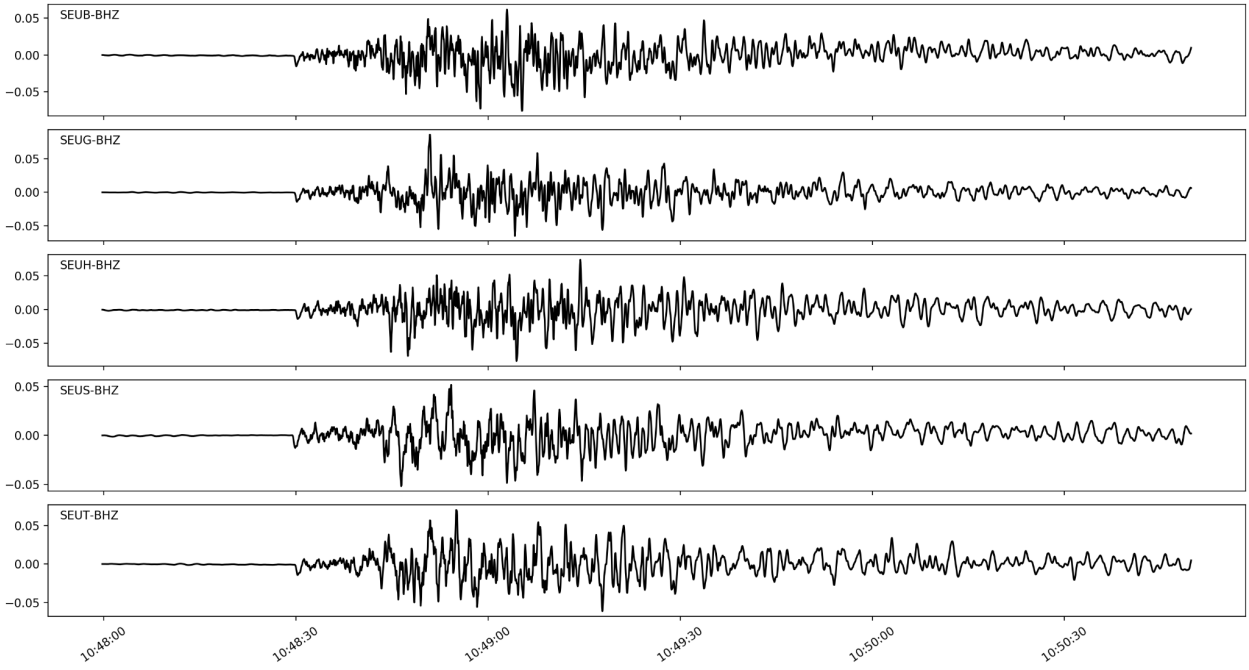

Fig. 4: Recordings of the vertical ground displacement (in millimeter) caused by the M5.1 earthquake at 17-06-2022 10:48:12 UTC. This earthquake took place at a depth of about 40 km, about 100 km N of St. Eustatius.

The five seismometers, together with those on Saba and St. Maarten, are capable of detecting earthquakes with magnitudes down to 1 within a region of 150 km around St. Eustatius. In 2022 KNMI detected and located 65 earthquakes around St. Eustatius within a distance of 150 km. Results of our seismic monitoring have been published in a special section of the Bulletin of the Seismological Society of America on ‘’Caribbean Tectonics, Seismicity and Earthquake Hazards” (Sleeman et al., 2022).

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GNSS data

The GNSS stations at the airport (called “SEUS”), the EUTEL facility at White Wall (called “SEUT”) and the botanical garden (called “SEUH”) worked well during 2022. The new off-grid station at Bengalen (called “SEUB”), installed in May 2022, performed as expected. SEUH transmits its data via satellite communication to KNMI once a day.

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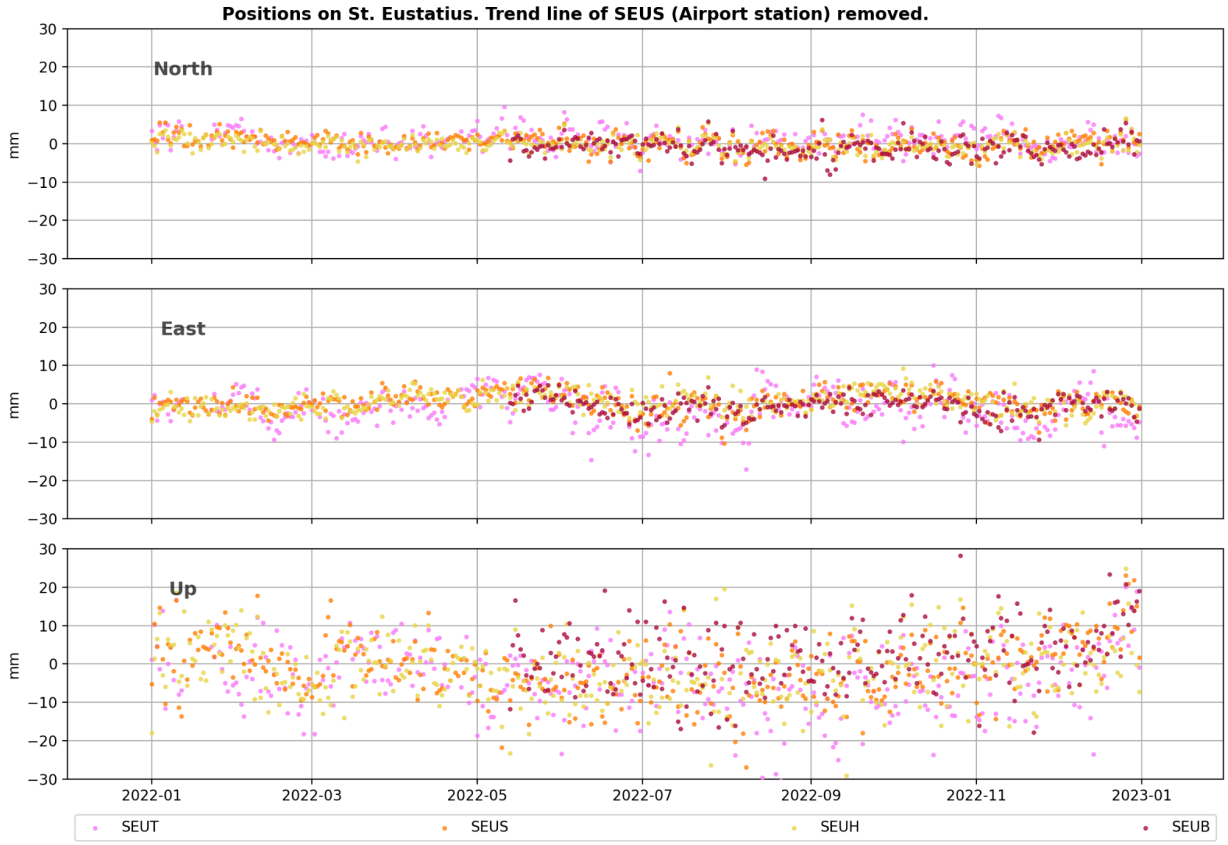
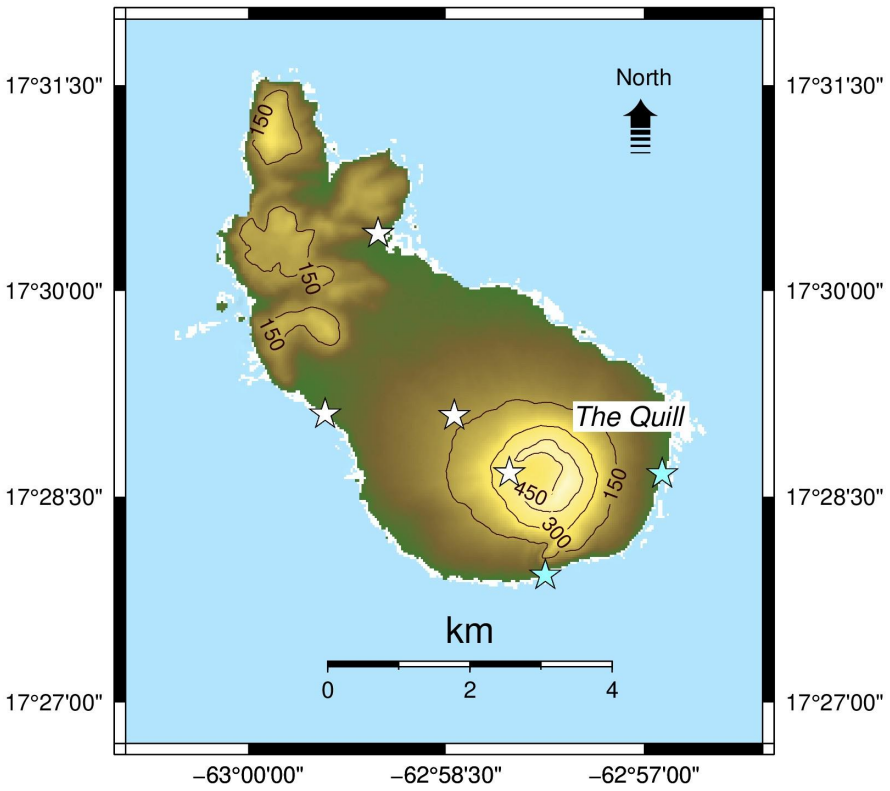


Fig. 5 GNSS data from all permanent GNSS stations on St. Eustatius in 2022. The plate movement is removed from the signal. The data show very little deviation from a horizontal line.

Campaign GNSS survey

In comparison to continuous GNSS measurement, campaign GNSS surveys are conducted at fixed markers every 1-2 years. The goal of these measurements is to increase the spatial resolution of the ground deformation data to help identify potential centimeter scale changes and movements.
On St. Eustatius we identified 2 old GNSS campaign markers (Fig. 6) at White Wall -Sugarloaf and between the botanical gardens and Golden Rock Resort. The last time these markers were measured was in 2009. We plan to measure these, and four new markers in 2023 (Fig. 7).

Fig. 6: The campaign gravity site Hells Gate. The marker that is measured is the tiny pin to the left of the handheld GPS.



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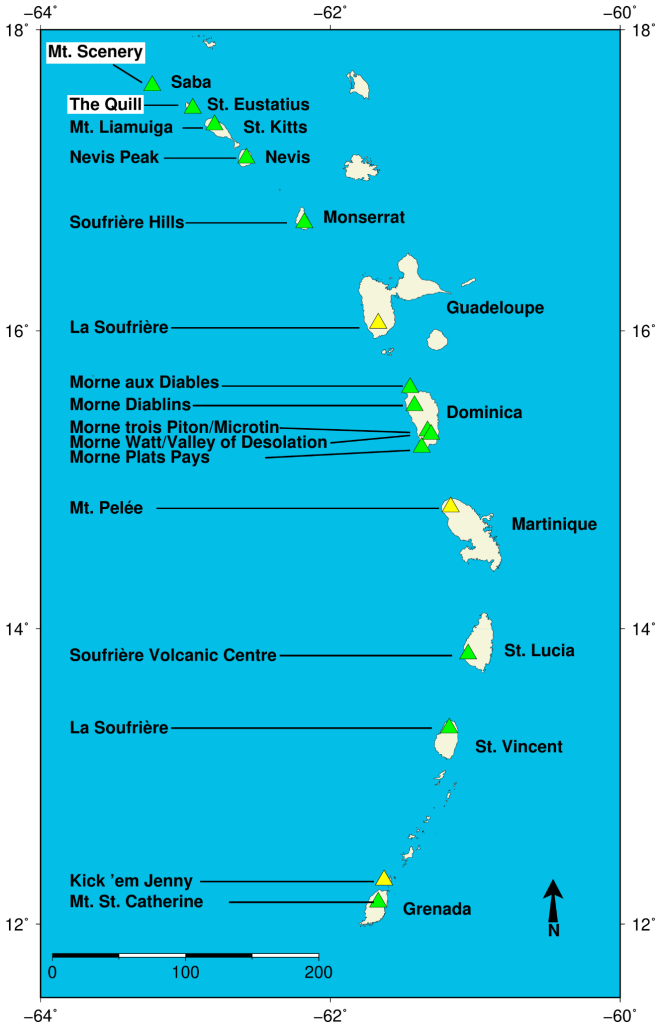

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Royal Netherlands Meteorological Institute

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