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Location of Stromboli volcano July 2019 paroxysm event based on long-range Infrasound detections in several IMS stations

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ABSTRACT

Stromboli is one of the most active volcanoes on Earth with a continuous explosive activity and persistent degassing since at least 3-7 AD (Rosi *et al*., 2000).

Being an open conduit volcano, its spectacular basaltic explosions interspersed by lava fountains occurring every ≈10 minutes (Ripepe *et al*., 2002) make it probably the world's best-know and best-monitored volcano.

On 3rd July 2019 at the 14:45:43 UTC a paroxysmal explosion occurred with an ash column that rose almost 5 km above the volcano.

This very strong explosive event was detected in several IMS infrasound stations, including IS42, located in the Azores islands in the middle of the North-Atlantic, at a distance of about 3,700 km.

We present the long-range infrasound detections that allowed us to locate the source based only in infrasound with an estimated error of less than 55 km from the ground truth event.

Keywords – Stromboli volcano, paroxysm, infrasound, IMS, IS42

1 INTRODUCTION

Rising from the Tyrrhenian Sea, north of Sicily (Italy), the Aeolian Archipelago (Italy), with an area of ≈115 km², consists of 7 islands among which is Stromboli with its active volcano.

In geological terms and as result of its tectonic setting this region is defined as a volcanic arc, characterized by active and dormant volcanoes and high levels of underwater volcanic activity (Figure 1).

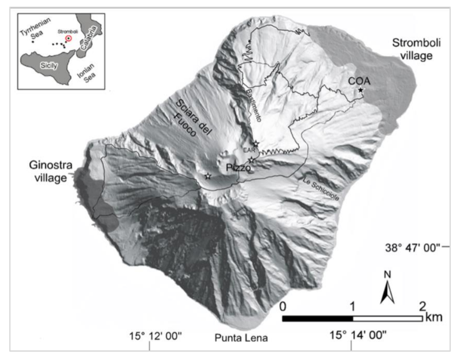


Figure 2 Stromboli Island with the town of Stromboli and Ginostra *(Rosi et al, 2013)*. COA – Advanced Operating Centre.

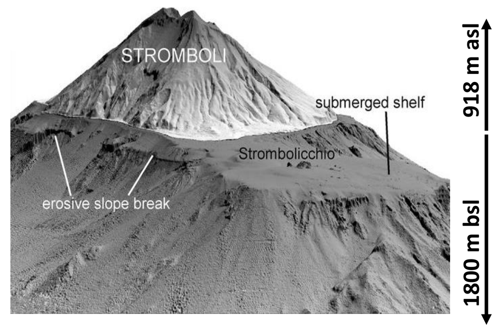


Figure 3 3D view of the submerged shelves flanking. *(Francalanci et al, 2013).*

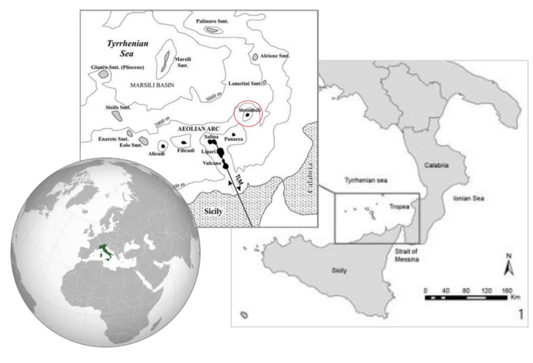


Figure 1 Aeolian Arc and seamounts with Stromboli Island location (red circle). TLM: Tindari-Letojanni-Malta tectonic line (*adapted* from Peccerillo, 2005).

Stromboli is the Aeolian archipelago northernmost island, with and area of aprox. 12.6km², hosting two small settled areas: Stromboli and Ginostra, in NE and SW respectively (Figure 2).

Stromboli is of one of the most active volcanoes on Earth with a continuous explosive activity and persistent degassing since at least 3-7 AD (Rosi *et al*, 2000).

It is a stratovolcano elongated along NE-SW and characterized by a cone-shaped structure, rising from ≈2700 m above seafloor with a subaerial peak of 918 m asl (Francalanci *et al*, 2013) (Figure 3).

With a variable number of active vents (7 to 9, Harris and Ripepe, 2007), the crater terrace, at the top of *Sciara del Fuoco*:(see Figure 2) is divided into three activity areas: the NE, Central and SW craters.

2 METHODOLOGY

We analysed raw data for the period of the recorded eruptive activity in order to identify coherent infrasound signals detections on the selected back-azimuths (Figure 4; Table 1), using the *Progressive Multi-Channel Correlation Algorithm* - PMCC (Cansi, 1995).

For that we used the applications integrated in the NDC-in-a-Box, v. 4.0 package, supplied by the International Data Centre - IDC, and illustrated the back-azimuths with Google Earth® (Figure 5).

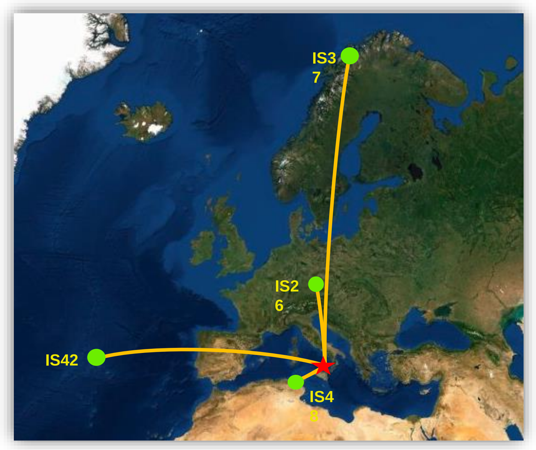


Figure 4 Source location , distance and back-azimuth to the nearest IMS stations (Goggle Earth®) .

Table 1 Name and source location.

Stromboli volcano		
Source location	38.789º N, 15.213º E	
Time period	3rd July 2019	
Stations	Source distance	Source Back-azimuth
I48TN	≈ 580 km	≈ 54°
I26DE	≈ 1 130 km	≈ 176°
I37NO	≈ 3 380 km	≈ 185°
I42PT	≈ 3 680 km	≈ 75°

Used software: Auto nms_client → DTKGPMCC → Geotool → Google Earth

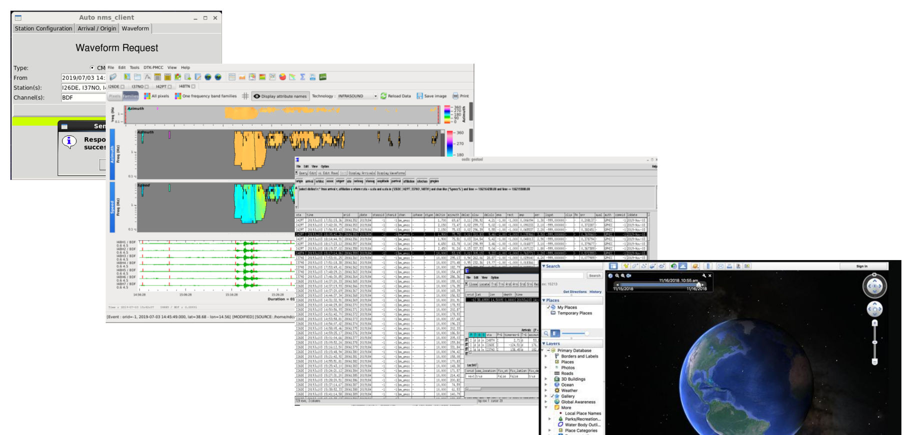


Figure 5 Sequence of steps and applications used.

The analysis was performed using the following steps and applications:

(1) Data retrieval through Auto nms_client;

(2) Interactive analysis with DTK-GPMCC (CEA/DASE);

(3) Event location in Geotool;

(4) Event Display using Goggle Earth®.

3 Local observations of the July 3rd Stromboli eruptive paroxysm event

Stromboli volcano eruptive behaviour is characterized by a persistent moderate explosive activity (7 to 17 events/hour with a 4-30s duration, ejection of pyroclasts and gas emission) interspersed by sporadic major explosions, lava flows or rare paroxysms.

The months leading up to the paroxysm event of July 3rd were of intense activity, which included the high-energy explosion and the extrusion of a lava flow event on June 25th.

At the 14:45:43 UTC, a very strong event occurred with two explosions, one from SW crater and the other from Central crater (Figure 6).

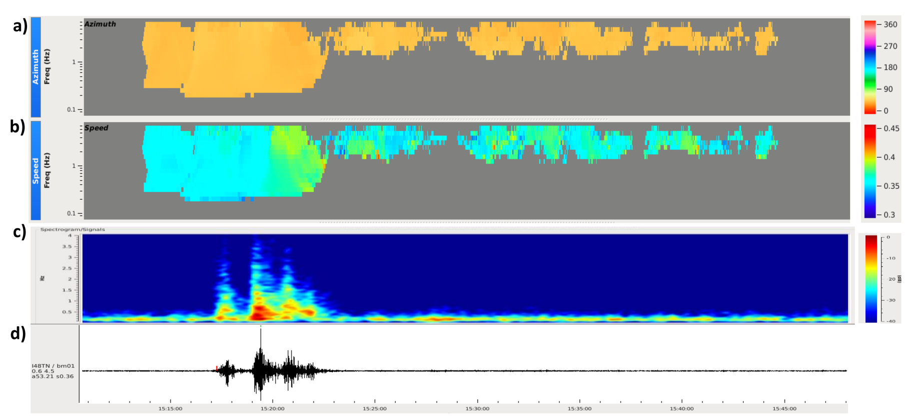
This paroxysmal event was accompanied by the formation of lava flows, followed by an intense emission of scoria and ash that affected the entire crater terrace and the western flank of the volcano. The fall of the pyroclasts cause fires on vegetation along the flank and reached distances of 400-500m from the coast (Figure 7).

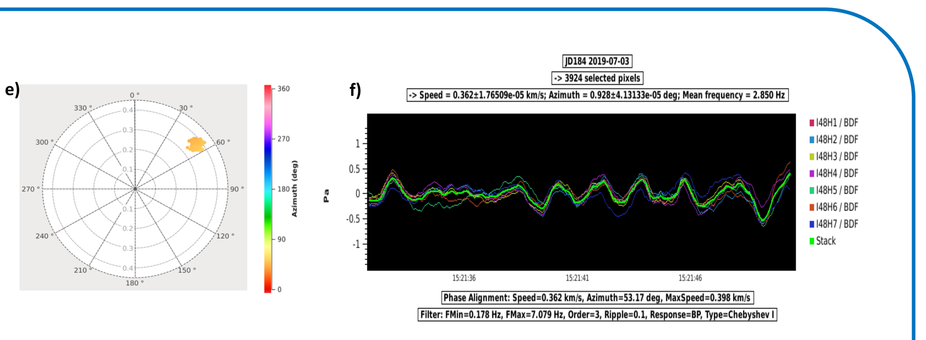
An ash plume rose to about 4-5 km high (a warning of possibly ash up to 10 km was issued by the VAAC Toulouse) and two pyroclastic flows moving through *Sciara del Fuoco* from where advanced out over the sea until about 1 km away from the coastline.

Figure 6 Strong explosion on the crater terrace on 14:45:43 UTC of July 3rd.

Figure 7 Fire on vegetation of the western flank caused by incandescent pyroclasts.

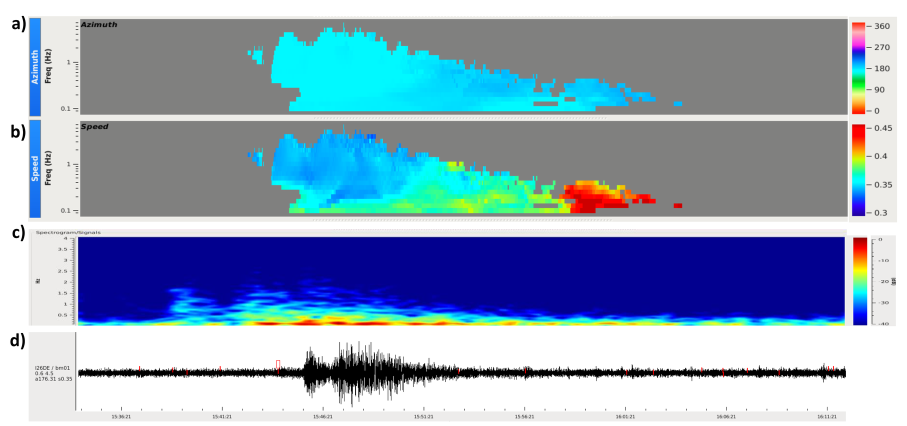
IMS IS48 GPMCC detections

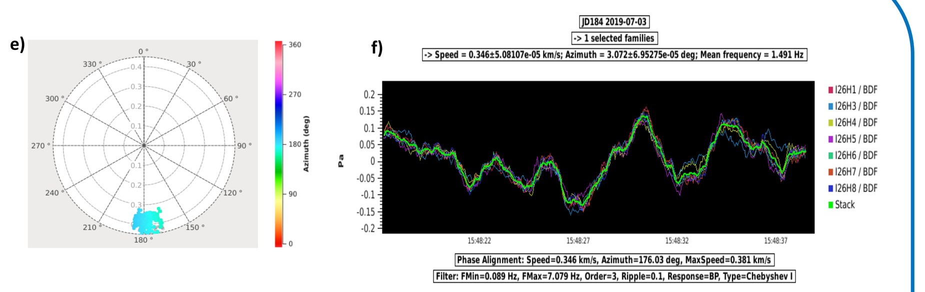




a) back-azimuth range from 46° to 58°; **b)** speed range between 0.330 to 0.450(Km/s); **c)** frequency between 0.275-3.5Hz; **d)** band-pass filtered beam (0.6-4.5 Hz); **e)** polar plot according to azimuth (polar angle) and trace velocity (polar radius), with a 53.11°, and 0.367 km/s speed (orange dots); **f)** Phase alignment (signal quality) of sensors and stack.

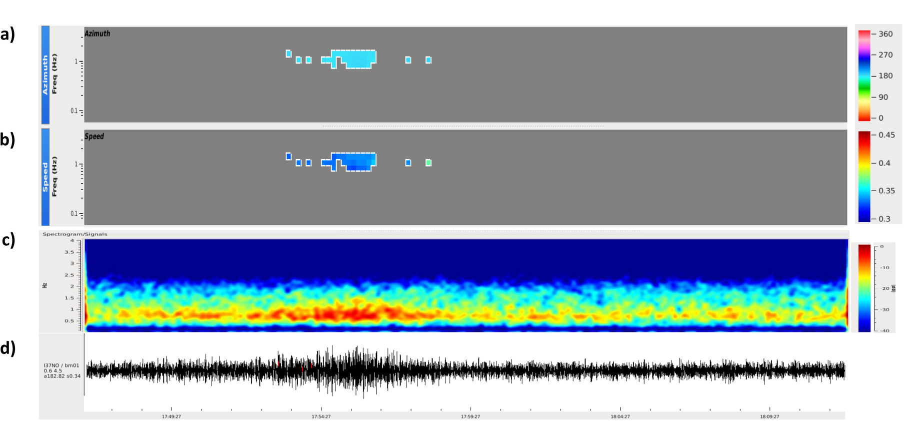
IMS IS26 GPMCC detections

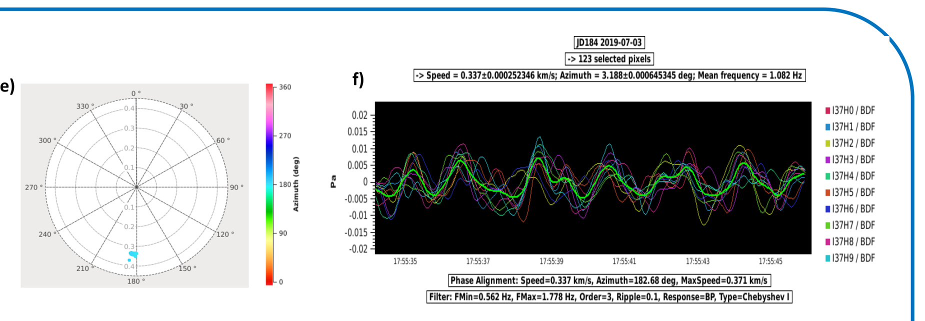




a) back-azimuth range from 172° to 180°; **b)** speed range between 0.350 to 0.450(Km/s); **c)** frequency between 0.5-1Hz; **d)** band-pass filtered beam (0.6-4.5Hz); **e)** polar plot according to azimuth (polar angle) and trace velocity (polar radius), with a 176.3°, and 0.352 km/s speed (blue dots); **f)** Phase alignment (signal quality) of sensors and stack.

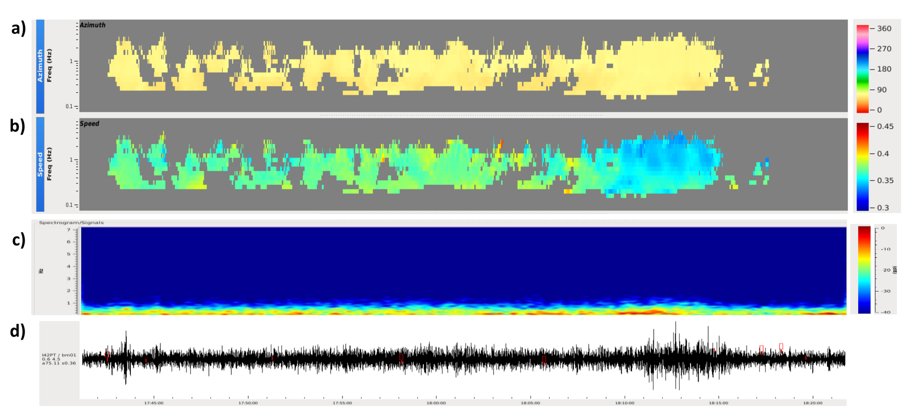
IMS IS37 GPMCC detections

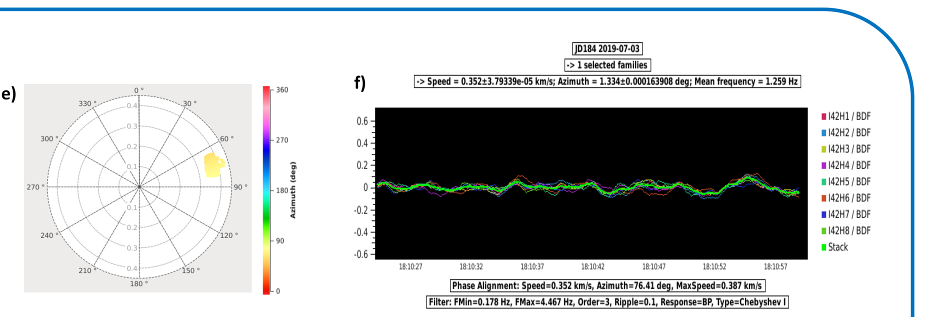




a) back-azimuth range from 179° to 185° 0.635-1.5Hz; **d)** band-pass filtered beam (0.6-4.5Hz); **e)** polar plot according to azimuth (polar angle) and trace velocity (polar radius), with a 185.4°, and 0.349 km/s speed (blue dots); **f)** Phase alignment (signal quality) of sensors and stack.

IMS IS42 GPMCC detections





a) back-azimuth range from 71° to 81°; **b)** speed range between 0.330 to 0.450 (Km/s); **c)** frequency between 0.275-3.5Hz; **d)** band-pass filtered beam (0.6-4.5Hz); **e)** polar plot according to azimuth (polar angle) and trace velocity (polar radius), with a 74.4°, and 0.352 km/s speed (yellow dots); **f)** Phase alignment (signal quality) of sensors and stack.

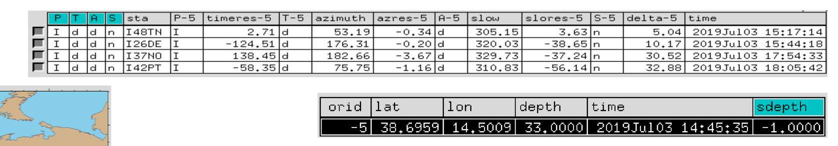
4 DATA RESULTS

GPMCC parameters results

Table 4 Resume table of infrasonic detection parameters.

Stromboli July 3rd paroxysm	Arrival time	Number of family detections	Number of pixels	Azimuth range (°)	Mean Azimuth (°)	Mean Frequency (Hz)	Mean Speed (km/s)	Max amplitude (Pa)
IS48	15:17:14	5	6322	46 - 58	53.1	1.97	0.367	1.87
IS26	15:44:18	1	2782	9 - 12	176.3	0.723	0.352	0.17
IS37	17:54:33	1	123	179 - 185	182.6	1.08	0.337	0.004
IS42	18:05:42	10	4423	71 - 81	76.4	1.07	0.352	0.12

Location result



P	T	A	S	sta	P-5	timeres-5	T-5	azimuth	azres-5	A-5	slow	slores-5	S-5	delta-5	time
I	d	d	n	I48TN	I	2.71	d	53.19	-0.34	d	305.15	3.63	n	5.04	2019Jul03 15:17:14
I	d	d	n	I26DE	I	-124.51	d	176.31	-0.20	d	320.03	-38.65	n	10.17	2019Jul03 15:44:18
I	d	d	n	I37NO	I	138.45	d	182.66	-3.67	d	329.73	-37.24	n	30.52	2019Jul03 17:54:33
I	d	d	n	I42PT	I	-58.35	d	75.75	-1.16	d	310.83	-56.14	n	32.88	2019Jul03 18:05:42

orid	lat	lon	depth	time	sdepth
-5	38.6959	14.5009	33.0000	2019Jul03 14:45:35	-1.0000

Figure 8 Geotool selected arrivals to obtaining a location.

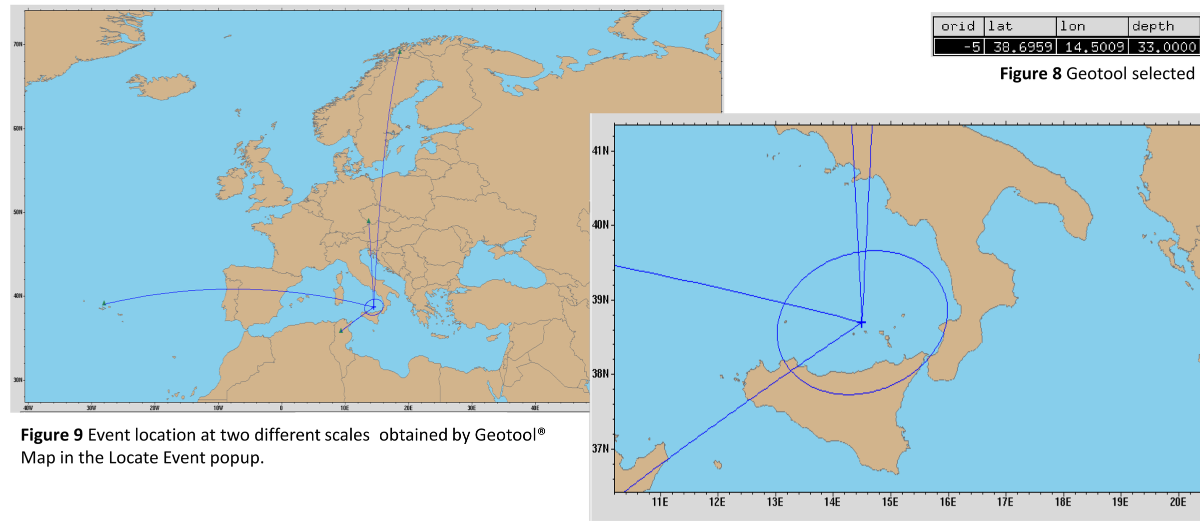


Figure 9 Event location at two different scales obtained by Geotool® Map in the Locate Event popup.

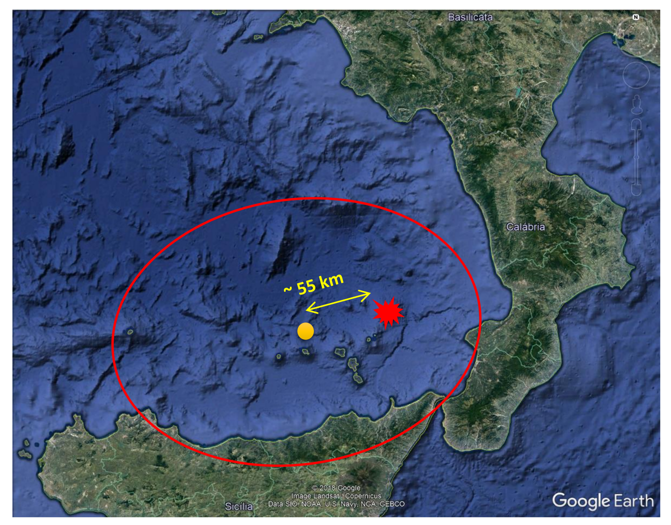


Figure 10 Infrasound data based event location ≈55km WSW of the ground truth source and its uncertainty ellipse (Google Earth®).

Using only data from the IMS infrasound stations and processing the selected signal arrivals with Geotool (Figure 8), we were able to locate the event, about 55 km WSW from its ground truth source (Figure 9, 10).

5 CONCLUSIONS

- The results obtained for this paroxysmal event confirm that IMS infrasound stations are able to detect and locate long-range explosive volcanic eruptions, as enhanced by the collaborative work carried out by IVAR and LGS on the behalf of the ARISE2 Project, by detecting explosive volcanic eruptions based on IMS stations at distances between 580 and 3,680 km from the source;
- Additionally, it was possible to determine a source location based only in infrasound data, with the ground truth event located inside its uncertainty ellipse;
- The final results are in agreement with the IDC-CTBTO bulletins.

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