

# Early warning signals before paroxysmal activity at Stromboli volcano, Italy

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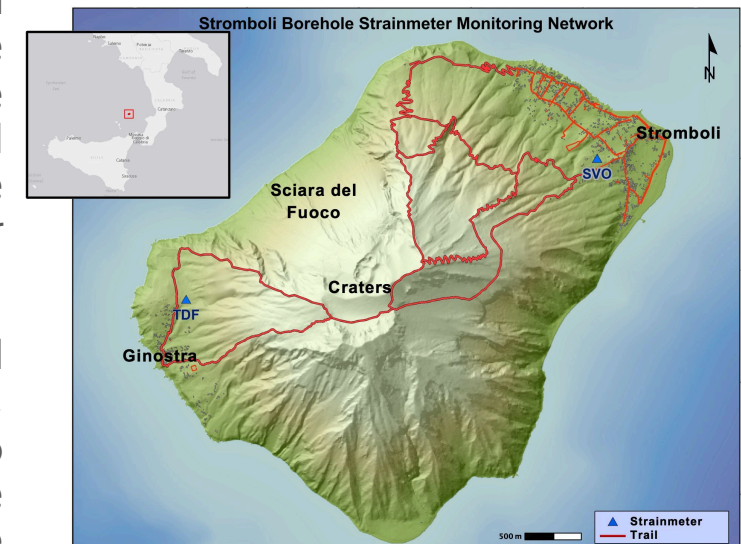
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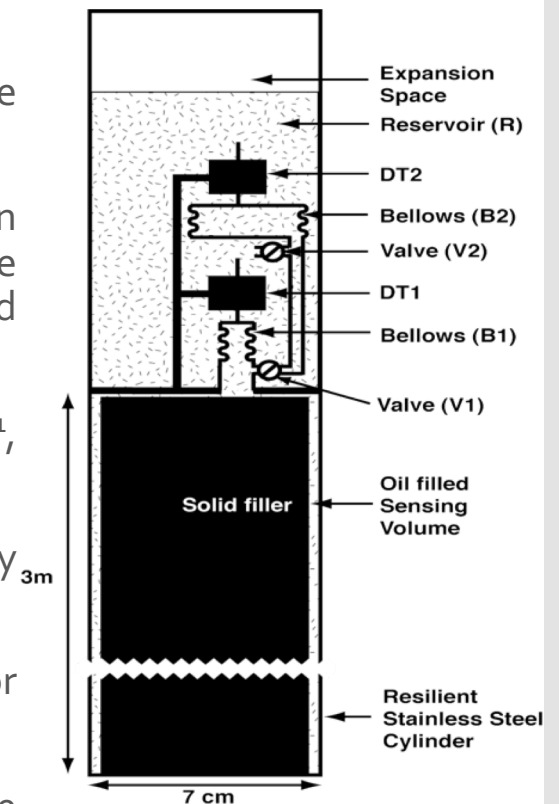
# Introduction

- Mt. Stromboli, an open-conduit volcano located in Aeolian Islands (Italy), produced vulcanian eruptions in 2003, 2007, 2014 and in July and August 2019, which were well recorded by the INGV monitoring network. In particular the three events occurred in 2007 and 2019 are studied by analyzing data recorded by Sacks-Evertson dilatometers, a special kind of borehole strainmeters capable of recording areal strain changes, which allow us to infer many details of source dynamics. These three events are clearly preceded by a slow strain buildup, starting several minutes before the paroxysms, which can be used in future for civil protection purposes.
- Eruptions consist of two or more pulses, with oscillations ranging from several seconds to some minutes, and lasting from several minutes to one hour after the explosions: the similitudes found among these three explosions are suggestive of the common source mechanism involved in their triggering process.
- In 2006 the monitoring network was complemented by the installation of two borehole strainmeters, instruments capable of recording the volcano behavior at low frequencies. Installation took place near the Ginostra village, in the western side of the island, and in the village of Stromboli.
- According to INGV Data Policy Principles, Creative Commons licenses are applied on recorded data.



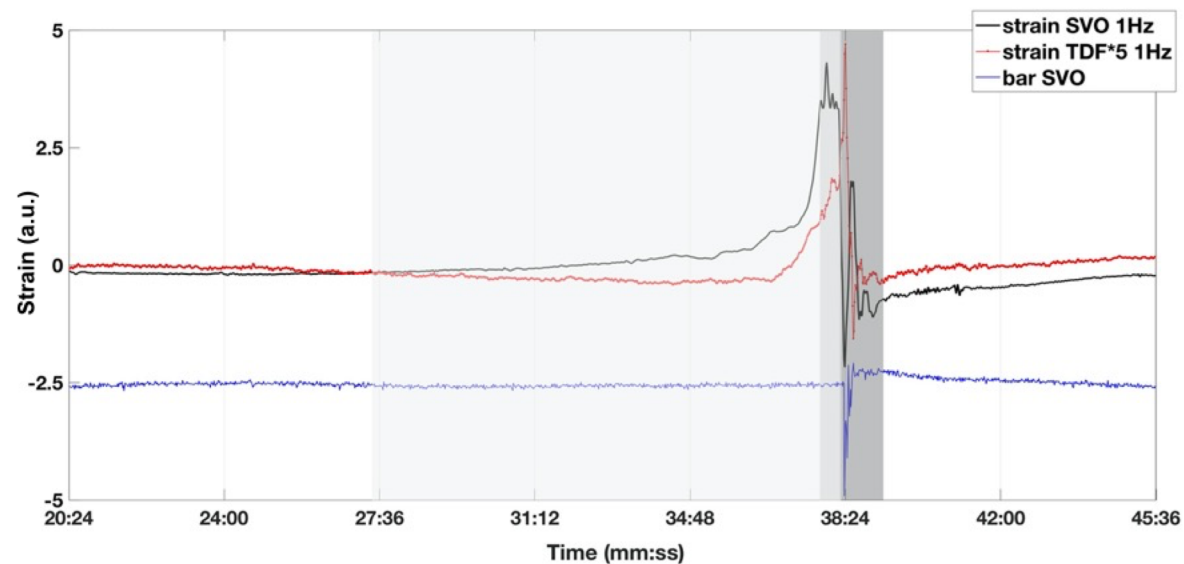
# Instruments

- Sacks-Evertson strainmeters are long stainless steel cylinders of about 7 cm in diameter and 4 m in length filled with degassed silicone oil, which provide two signal outputs, obtained by two different hydro-mechanical amplification systems: a bigger sensing volume is connected with a small bellow, whose length changes in proportion to the volume of oil entering or leaving it. The position of the top of the bellow is measured through a linear variable differential transformer (LVDT).
- Dynamic range of the instrument is about 140 dB.
- A second, less sensitive, bellows-displacement transducer-valve assembly is connected with the first one.
- The high-sensitivity output integrates the volumetric change in the strained reservoir. The low-sensitivity one is connected to the strained reservoir only when the instrument is sensing a rapid and strong strain change, thus measuring strain.
- Nominal resolution of Sacks-Evertson strainmeters is about  $10^{-11}$ , nominal dynamic range is  $10^{-11} - 10^{-3}$ .
- Low-frequency calibration of installed strainmeters is obtained by comparison with Earth tides (Hart et al., 1996).
- Once installed, the strainmeters are not adjustable nor recoverable.
- Borehole strainmeters installed near active volcanoes have provided significant information of eruptions and volcanoes dynamic.



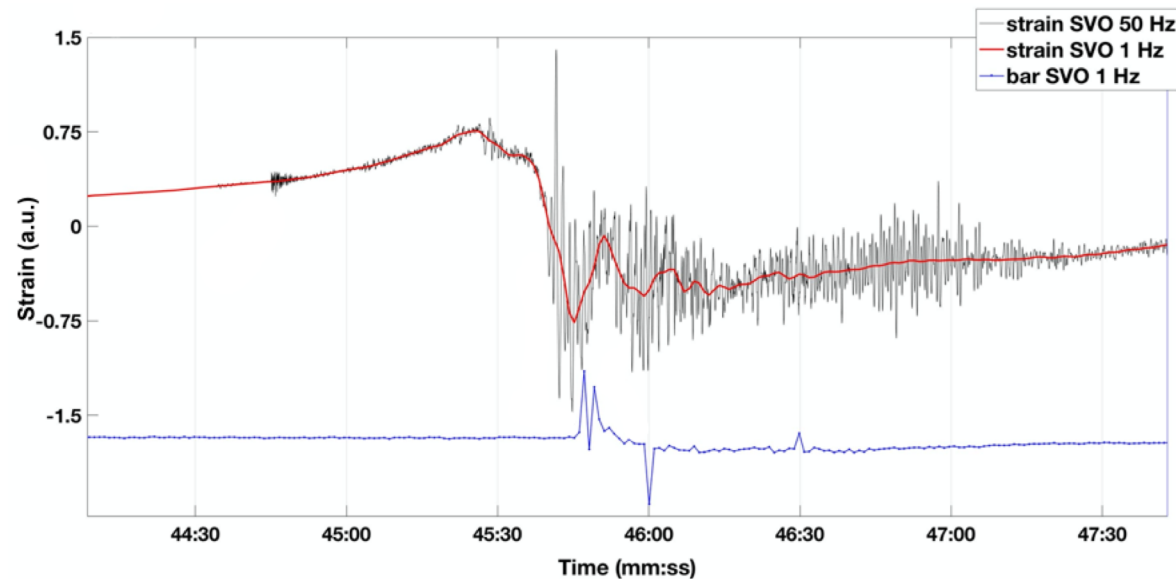
# Paroxysm Comparison Feb-Mar 2007

- An extensive activity phase of Mt. Stromboli, with a lava flow outpouring from the northern flank, started at 1:30 p.m. of February 27, 2007 and a small vulcanian explosion occurred on March 15, 2007.
- This activity produced an ash column reaching a height of 3-3,5 km above the craters.
- The paroxysmal activity lasted about 7 minutes.
- The dilatometer data show that the process of pressurization/depressurization of the conduit starts about 13 minutes before the explosion, as indicated by the microbarograph signals.



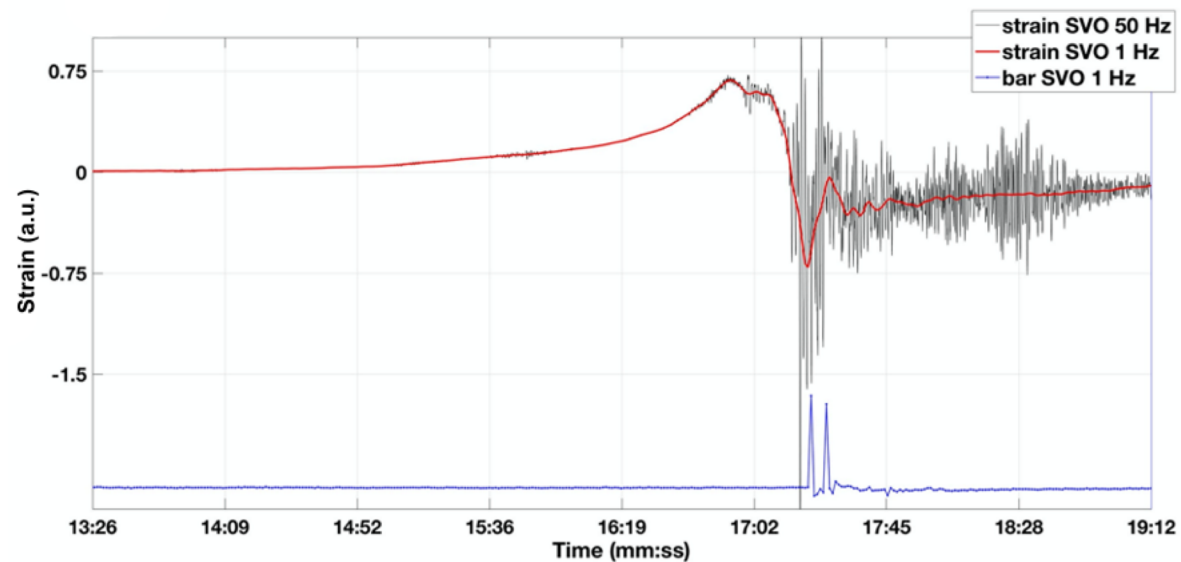
# Paroxysm Comparison Jul 2019

- During the period Dec 2018 – Jan 2019, the volcano had a phase of higher activity, followed by an activity level classified to “low to moderate”.
- Activity increased from June 2019, keeping a “moderate” level since June, 12<sup>th</sup> until the day before the eruption.
- This kind of behavior in volcanic dynamic has been very common in the past years.
- Almost one hour before the paroxysm a new vent appeared on the upper break in slope of the Sciara del Fuoco, a few 100 m northwest from the crater terrace: hot rocks broke off and, shortly after, a small lava flow started and slowly traveled downslope.



# Paroxysm Comparison Aug 2019

- This event produced an eruptive column which reached a height of 4 km above the crater summit.
- The strain recorded at SVO shows many features similar to the July 3 event.
- A very slow strain buildup is clearly visible several minutes before the explosion.
- The first two explosions were located in the central-southern crater area and a third, of lesser intensity, occurred twenty seconds later in the northern area.

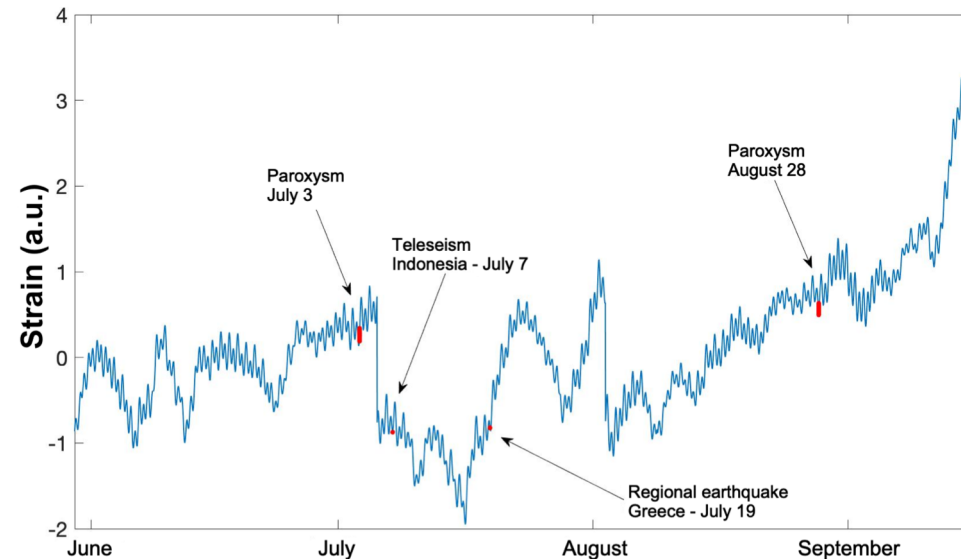


# Early Warning An Approach

- Following the two paroxysms occurred during the summer 2019, an initial early warning approach has been proposed.
- Early warning algorithms proposed in the past, used a filtered form of the input signal, which precluded a real-time trigger in recognizing the initial rise in strain for possible major or paroxysmal eruptions.
- Since the filtering window could influence the alert timing, authors propose a technique based on the change of the signal slope on non-filtered 1 sps data, proposing a possible real-time early warning system.
- Two different methodologies have been tested in respect to various thresholds, in order to find the earliest trigger while minimizing the number of false positive results.

# Early Warning Strain rate

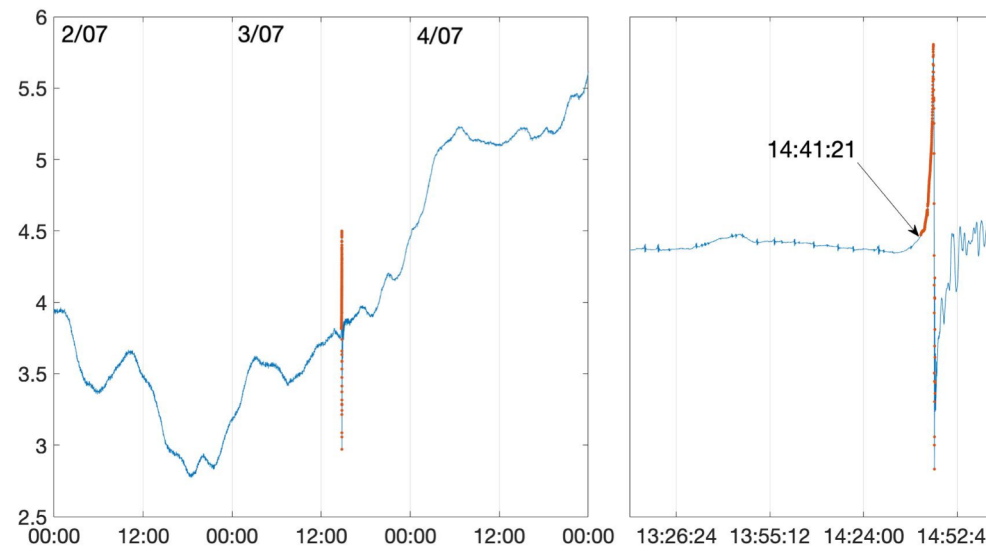
- The first method uses a strain-rate approach.
- A 40 seconds long window slides over the signal as data are recorded by the datalogger: the mean value of the derivative of the window is compared with the same value calculated during the previous step. A 97.5% overlap (39s) is considered.
- Such a difference is compared with a threshold, wisely chosen.
- With this configuration, the algorithm was capable of correctly trigger both 2019 paroxysms, three minutes before the summit onset of the eruptions.
- The method still triggers teleseisms and regional earthquakes: in order to avoid the false positive results a possible solution could be a real-time interrogation of seismic databases.





# Early Warning Strain Fit

- The second method fits data with a previously recorded model.
- This method allows to obtain an anticipated trigger when a paroxysmal eruption is going to occur, amounting to about four minutes before the eruption onset.
- Also in this case, however, false positive alarms are triggered, mostly due to spurious signals, teleseisms and regional earthquakes.



# Data Policy

- According to INGV Data Policy Principles (found at <https://data.ingv.it/docs/>), the Creative Commons licenses are applied.
- The type of license depends on the intellectual property to the data creation:
  - o Raw or basic data
  - 1 Data products
  - 2 Data products resulting from scientific investigations
  - 3 Integrated data products

# Conclusions

- Mt. Stromboli, an active open-conduit volcano, has extensively monitored in the last years.
- Since 2006 a network of borehole dilatometers is installed near it, allowing to analyze volcanic dynamics at low frequencies.
- SVO dilatometer recorded the Feb-Mar 2007 paroxysmal sequence, as well as the two paroxysmal explosions occurred in July and August 2019.
- A comparison of explosions shows a similar behavior, which is suggestive of a common source mechanism.
- A preliminary early-warning approach for paroxysmal eruptions is proposed.
- Data are available through Creative Commons license as raw product (o-type).