Tsunami Generated by Volcanoes ad Hoc Team Report

Team :

Chair François Schindelé (France); Laura Kong (US, ITIC) ; Emily Lane (New-Zealand) ; Raphaël Paris (France); Maurizio Ripepe (Italy) ; Vasily Titov (US)

Secretariat : Rick Bailey (Unesco-IOC)

TGV activities

- MEETINGS
  The TGV team met 6 times by video-conference, from April 2022 to February 2023.

- SURVEY :
  The TGV team at his first meeting identified that to get as much information as possible related to the volcano observatories activities on tsunami monitoring and warning systems, on volcanic tsunami hazard assessment.
  The TGV ad hoc team decided to perform a survey.

- QUESTIONNAIRES
  A specific questionnaire would be prepared sent to a set of Volcano observatories and institutes in charge of volcano monitoring with identified contact people.

- VOLCANO OBSERVATORIES

Establishment of a list of Volcano observatories located close to sea or oceans with identified contact to send the questionnaire.

TGV Report

- 0 Introduction and background
- 1 Tsunami generated by volcanic activity
- 2 Numerical modeling of volcanic tsunamis
- 3 Volcanic tsunami hazard assessment (Stromboli)
- 4 Volcano monitoring requirements for tsunami warning (Stromboli)
- 5 Volcanic tsunami warning systems and SOPs (Stromboli, Anak Krakatau)
- 6 Recommendations

- Appendix 1 questionnaire and summary results/responses?
- Appendix 2 : list of tsunamigenic volcanoes

Message to Volcano observatories

- *A primary objective of the TGV Team is to make a list of the volcano observatories that monitor and warn of volcanoes that may generate tsunamis, including what type of networks and methods are using to do so*

- *The TGV Team has accordingly prepared a **specific questionnaire** on the issue.*

  We would very much appreciate if you could respond to the questionnaire and provide as much information or documents you can related to volcano tsunami monitoring and warning.

  Your feedback will help guide us in developing best practice guidelines of how to warn communities at-risk of the threat from tsunamis generated by volcanic related sources.
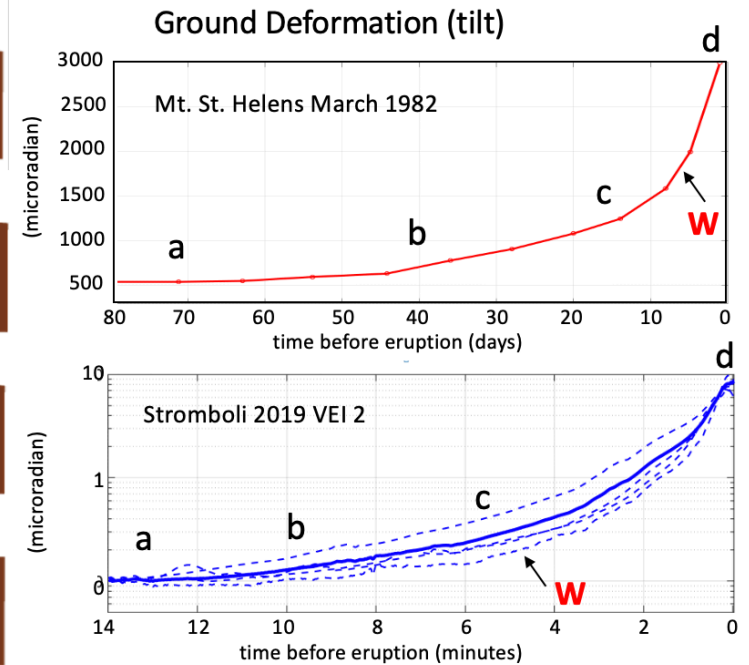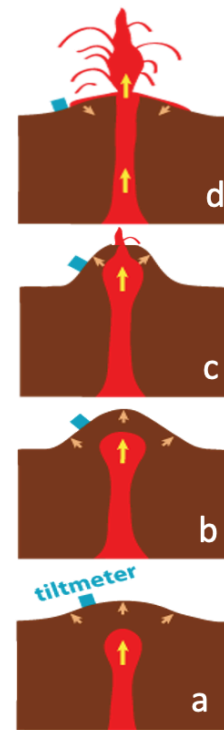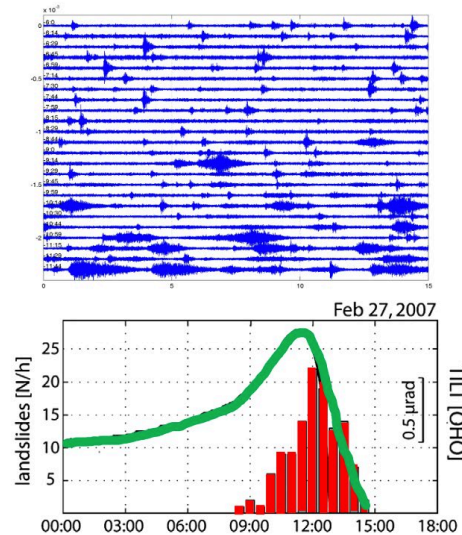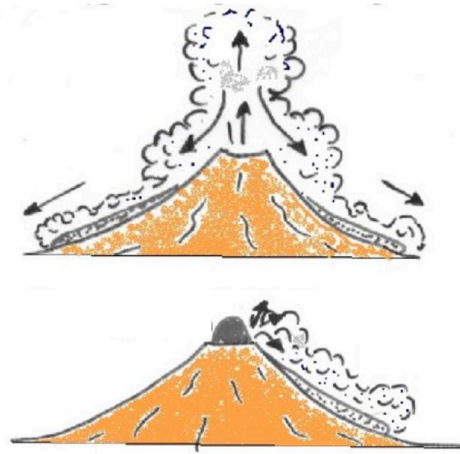
3 Volcanic tsunami hazard assessment
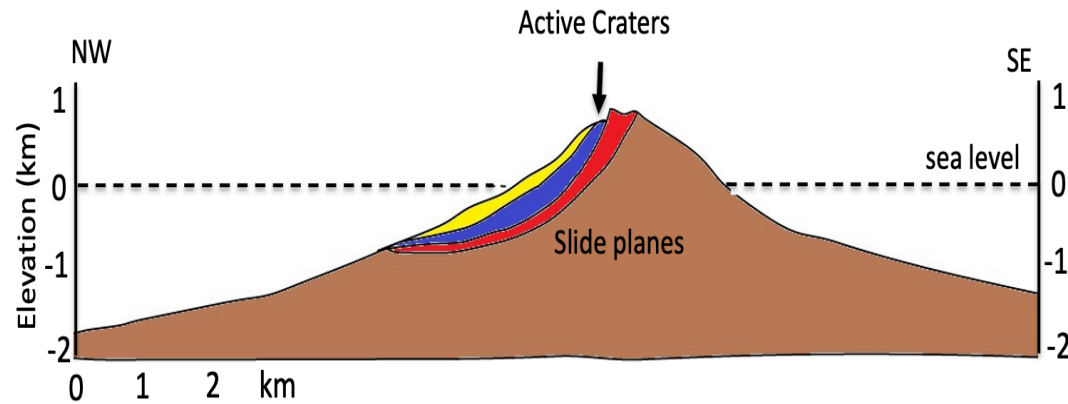
Position of the sliding planes of the 3 main collapses (from Tibaldi, 2001) of Vancori (in red), NeoStromboli (in blue) and Pizzo (in yellow).
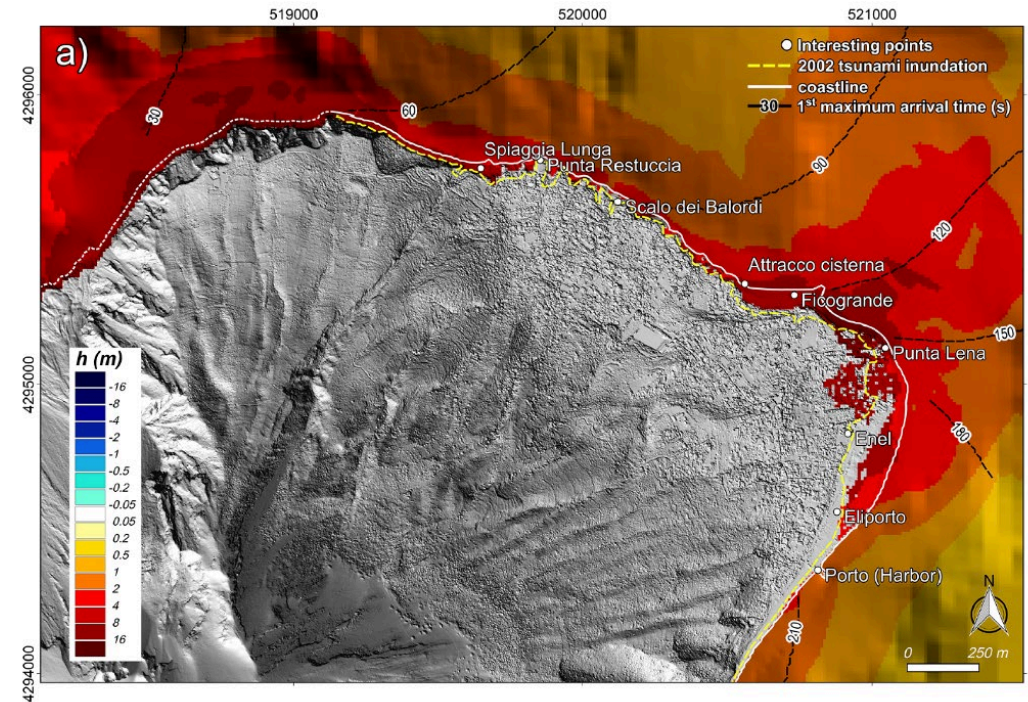
. Observed and simulated tsunami wave heights (December 2002) and runups on Stromboli

4 Volcano monitoring requirements for tsunami warning

Collapse of the eruptive plume and/or crater rim/dome generates pyroclastic flows and rock avalanches along the steep volcano slope (from Francis, 1993).

Before explosive eruptions, upward magma migration progressively inflates the ground. This inflation can be used to deliver a warning days or minutes before eruption. Inflation at Mt. St. Helens (upper panel) started several days before the 19 March 1982 eruption. At Stromboli (lower panel), ground inflation is smaller but follows a regular pattern which is used to automatically issue alerts 4-5 minutes before violent explosive events (Ripepe et al., 2021).

# 4 Volcano monitoring requirements for tsunami warning
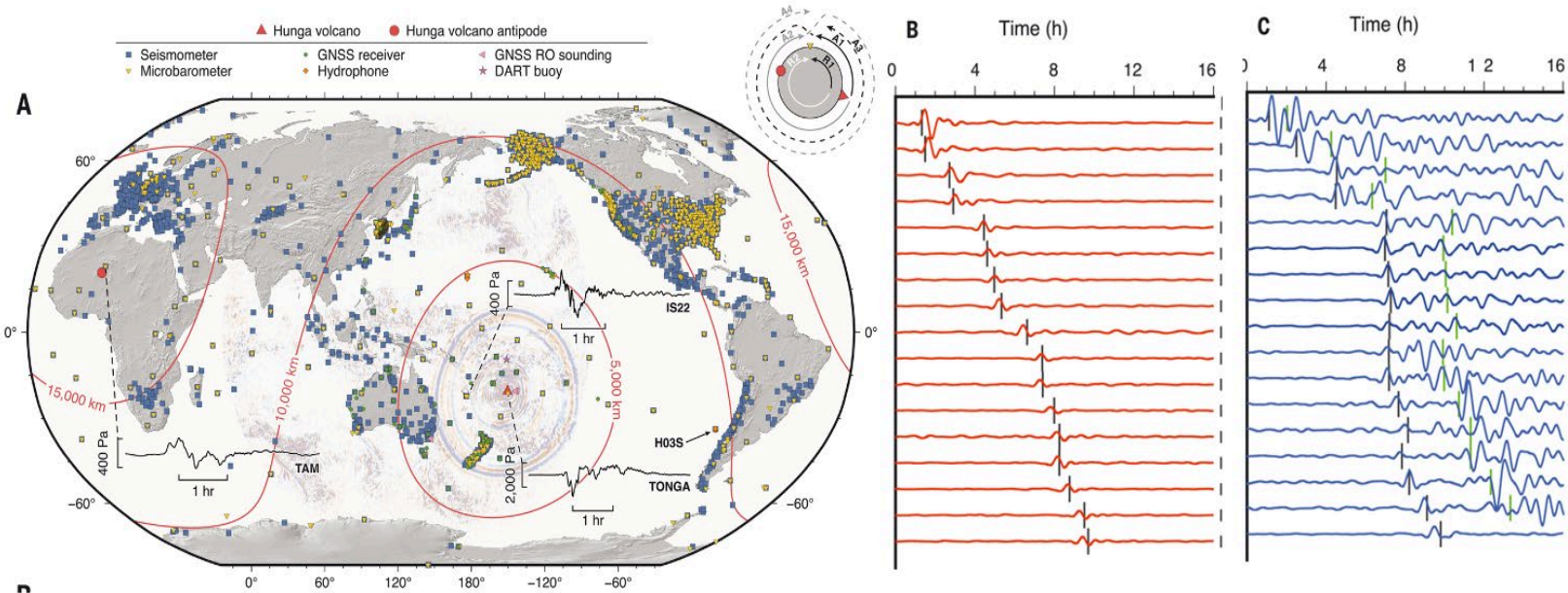
(A) Global distribution of recording geophysical sensors Background image is brightness temperature difference (Himawari-8) at 07:10 UTC on 15 January 2022. Selected 4-hour pressure waveforms are filtered from 10,000 to 100 s. Upper-right inset shows Hunga wave paths around Earth. (B) Observed barograms. (C) Observed ocean bottom pressure gauge waveform (Matoza et al., 2022; Kubota et al., 2022).

4 Volcano monitoring requirements for tsunami warning

Alert Level	Meaning
GREEN/NORMAL.	Background
YELLOW/ADVISORY	Above Background
ORANGE/WATCH	Escalation of Parameters
RED/ALERT	Eruption imminent/Ongoing

. **Color code representing the Volcano Alert levels (VAL)** used by many Volcano Observatories to issue alerts, which could be integrated in the Tsunami Warning Systems to actuate pre-warning procedures..

5 Volcanic Tsunami warning System : Stromboli (1/3)

Position of the two elastic beacons (PLB and PDC)
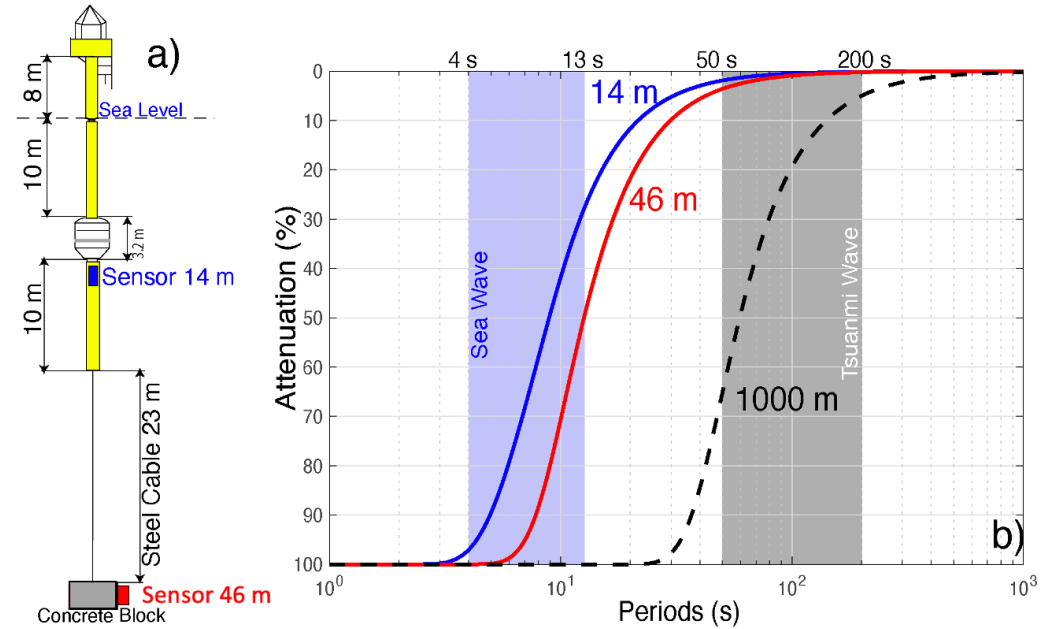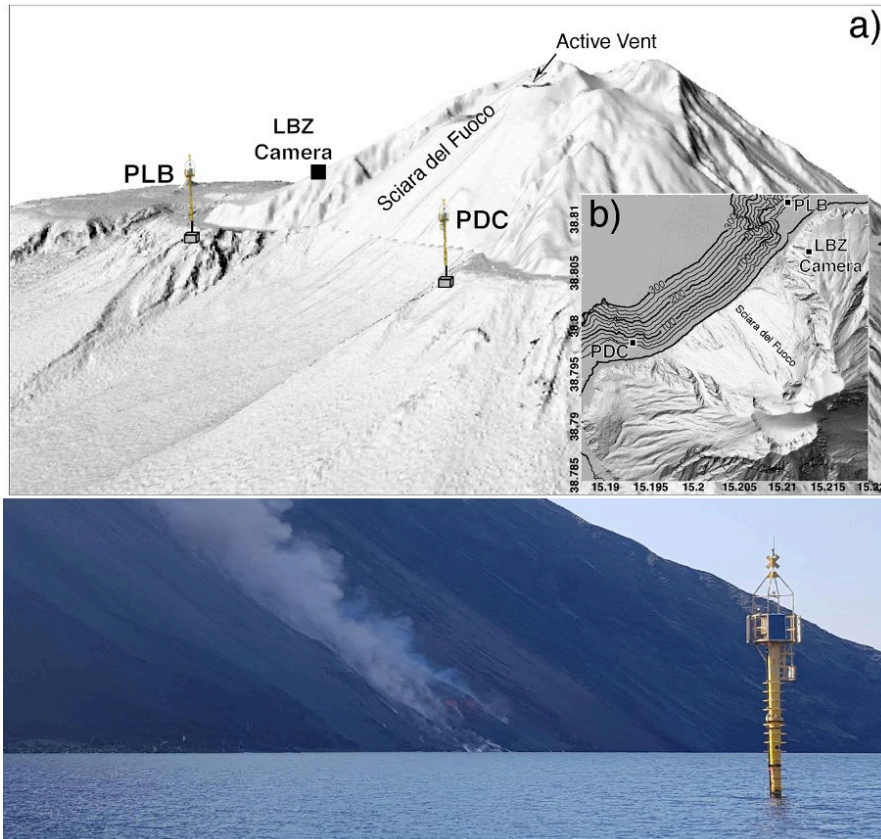
Schematic technical illustration of the main components of the elastic beacon
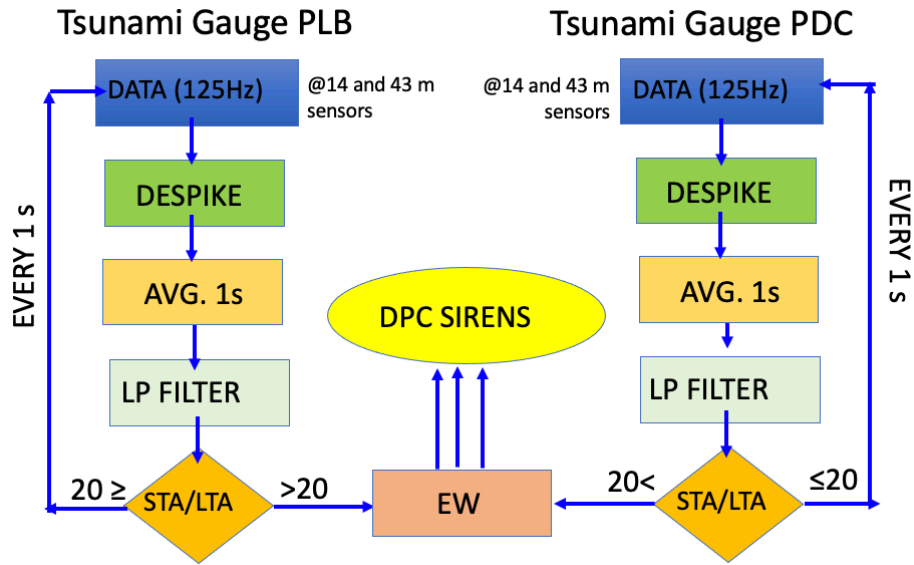
Chart flow of the automatic tsunami detection algorithm operating at Stromboli

Sequence of frames taken from the LBZ camera of the December 4, 2022, pyroclastic flow which moving downslope the Sciara del Fuoco

The tsunami generated by the impact of the pyroclastic density current occurred at Stromboli on December 4, 2022

. Tsunami signage at Stromboli indicating a) the limit of the Tsunami Hazard zone, b) the direction of the safer "Escape route" and c) the direction to waiting areas (from Bonilauri et al., 2021).

Volcano monitoring SOP for tsunami pre-alert

Color code representing the Volcano Alert levels (VAL) used by many Volcano Observatories to issue alerts.

Alert levels are usually defined by volcano observatories and represent the "official" communication of volcano status by scientists to civil protection authorities

Alert Level	Meaning
GREEN/NORMAL.	Background
YELLOW/ADVISORY	Above Background
ORANGE/WATCH	Escalation of Parameters
RED/ALERT	Eruption imminent/Ongoing

Following a similar strategy to that used by the ICAO for the ash dispersal in the atmosphere, the Volcano Tsunami Alert Notification (VOTAN) levels should indicate:

a) two levels of pre-eruption volcanic activities ; a significant unusual and/or increasing volcanic activity (YELLOW) or a larger increasing activity (ORANGE) which could presage a volcanic eruption.

b) ongoing volcanic eruption (RED); description of the eruption including whether flank instability or a large plume is occurring.

c) volcanic eruption cessation (GREEN).

Such monitoring system don't provide any information about :
- **Estimated day and arrival time of tsunami waves**
- **Tsunami Threat level**

Stromboli Operating Procedure – using sea level records

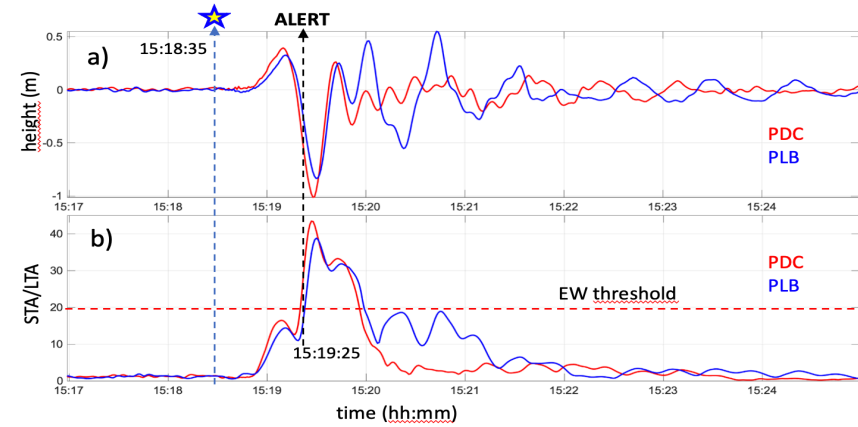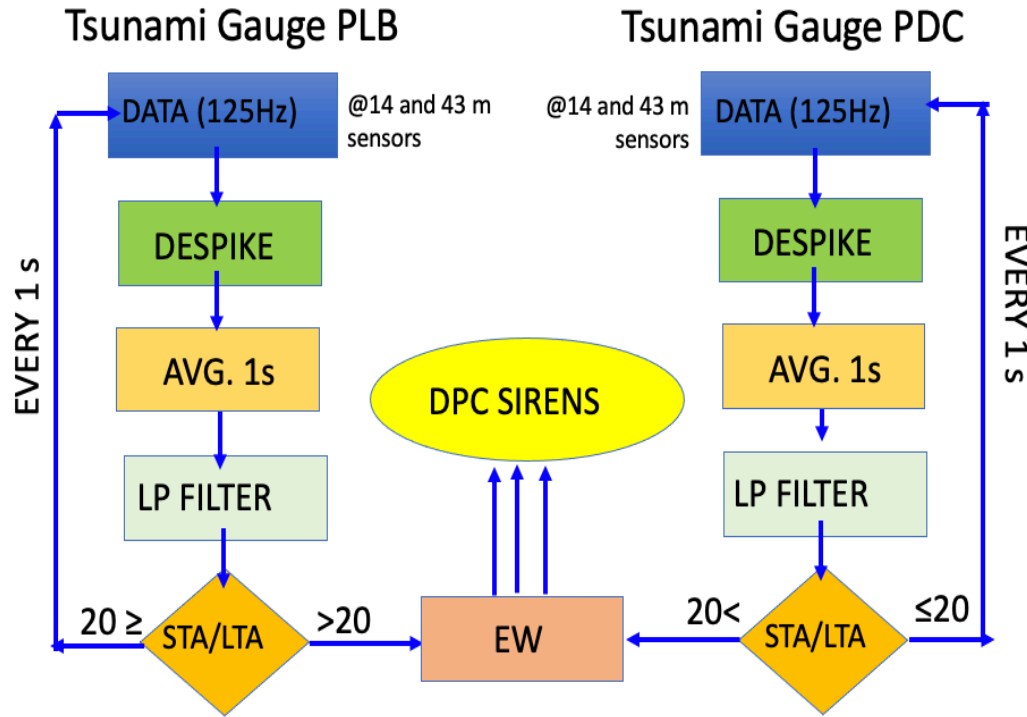The Automatic Alert detection and tsunami generated by the impact of the pyroclastic density current occurred at Stromboli on December 4, 2022

Chart flow of the automatic tsunami detection algorithm operating at Stromboli

The Stromboli Automatic Alert System based on tsunami waves detection would automatically send an alert in about 20s after the onset of the waves that activates the sirens at Stromboli and other islands as the South Eastern coasts of Tyrrhenean sea.

Non SOP Stromboli

- In case of a tsunami detection by the TEWS (Figure 19) the Department of Italian Civil Protection (DPC) has defined in cooperation with the Sicily Regional Civil Protection, the Lipari Municipality and the monitoring centers of INGV and University of Florence (LGS) national PROCEDURE for non-conventional tsunami. Given the short alert time (<4 minutes), the TEWS will send the alert before tsunami wave will be fully developed (generally within the first 20 s from the onset). this gives no time to run models to estimate the possible effects on the nearby coast. Therefore, in spite of the amplitude of the tsunami wave, once received the notification from the TEWS, the DPC will automatically activate for three minutes the acoustic alert (sirens) at Stromboli and Ginostra villages, Panarea and Lipari island, and in the control room of the Harbour Office of Milazzo (see Figure 15) with a continuous monotone sound. Besides, emails and SMS messages will be automatically sent to a list of previously selected Authorities with the following text: "Tsunami wave in progress at Stromboli".

- The early-warning message is thus automatically delivered to control room for the Emergency of i) the National Civil Protection, ii) the Sicily Regional Civil Protection, iii) the Lipary Municipality, and iv) the Prefecture of Messina. In coordination and cooperation with the National Department of Civil Protection the in-charge Authorities will keep the contact with i) the Mayor's delegates for the islands of Stromboli, Vulcano, Panarea, Alicudi, and Filicudi; ii) the municipalities along the Sicily and Calabria coast, iii) the operating structures present on the territory (e.g. Police, Firefighters, Forestry Corps, etc.) and iv) the voluntary structures of Civil Protection present on the different islands with the aim to inform people, apply the safety procedure at local level, and regulate the navigation and the docking of boats.

- Once the tsunami risk is declared over, the Lipari Municipality, with the support of the Regional Department of Civil Protection, will evaluate the opportunity to inform with a message the population of Stromboli, Ginostra, and Panarea by using the same acoustic alert system in "voice" mode. The Department of Civil Protection, will monitor the possible effects of the tsunami along the coasts, and in agreement with the Sicilian Region, it will evaluate the activation of the emergency national civil protection plan.

SOP and NTWC

- The TEWS implemented at Stromboli is the first early warning system developed to automatically deliver an alert in case of a tsunami generated by volcanic activity (Lacanna & Ripepe, 2020).

- At the moment operating outside the standard procedure developed for earthquake-generated tsunami.

- On August 2022 the University of Florence (LGS) and the National Institute of Geophysics and Volcanology (INGV), in the framework of the operational monitoring activities for the National Department of Civil Protection (DPC), signed a Cooperation Agreement to integrate the TEWS of Stromboli within the activities the national Tsunami Alert Center (CAT) of the INGV.