# The Tsunami Early Warning at Stromboli Volcano

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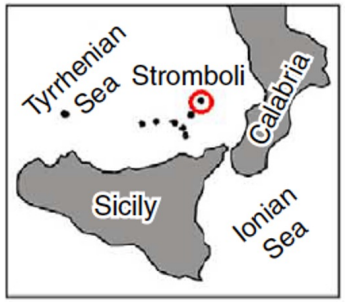
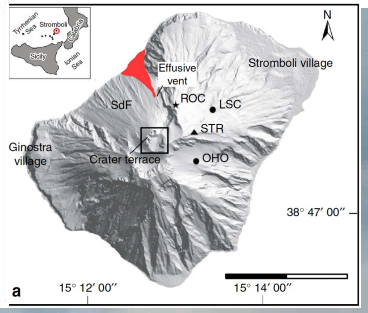
# Stromboli Volcano




1.2 km

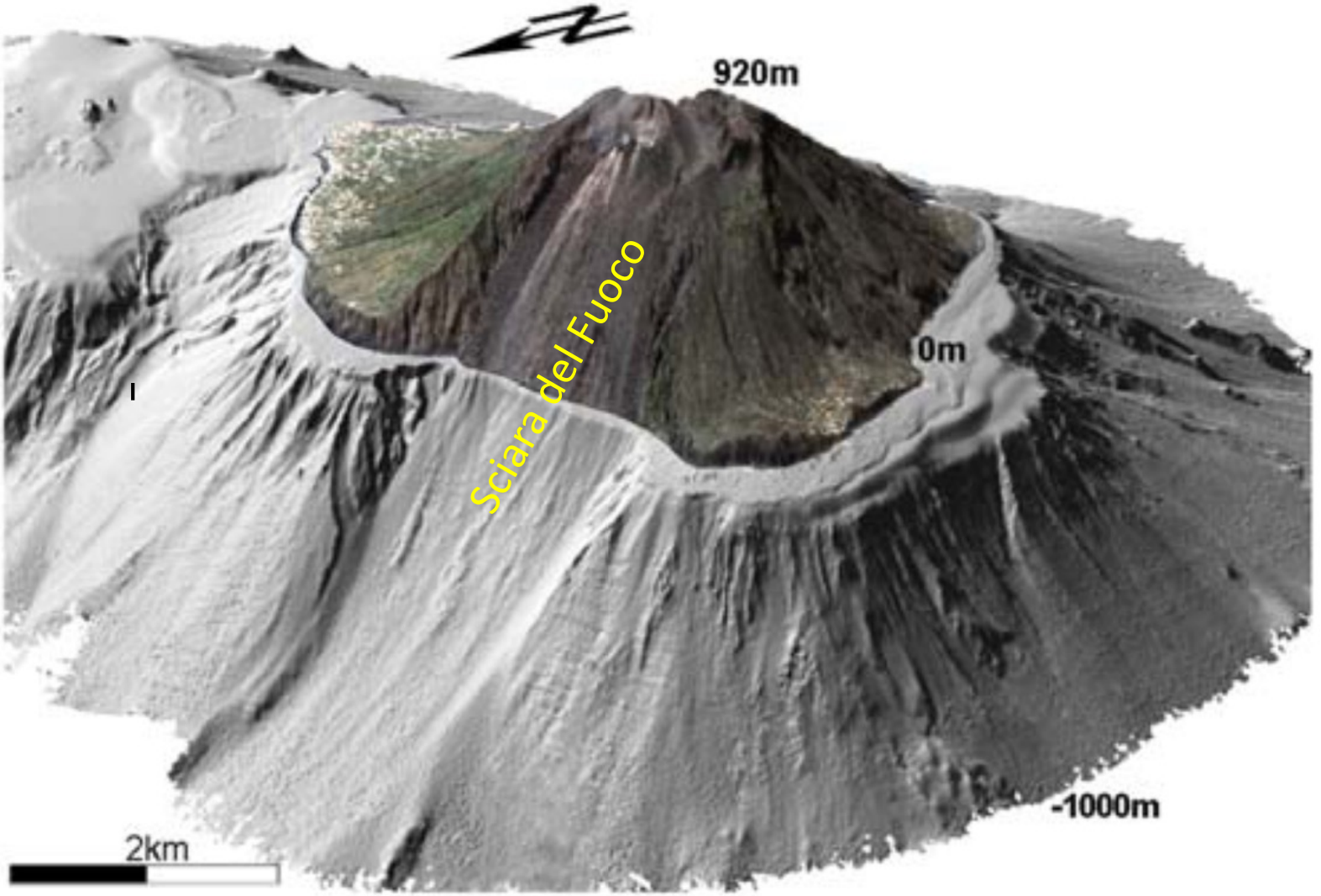
~2 km

«Sciara del Fuoco» (The Slope of Fire) is a ~35° unstable slope

# The Reason for TEWS: the 28 Dic. 2002 Tsunami

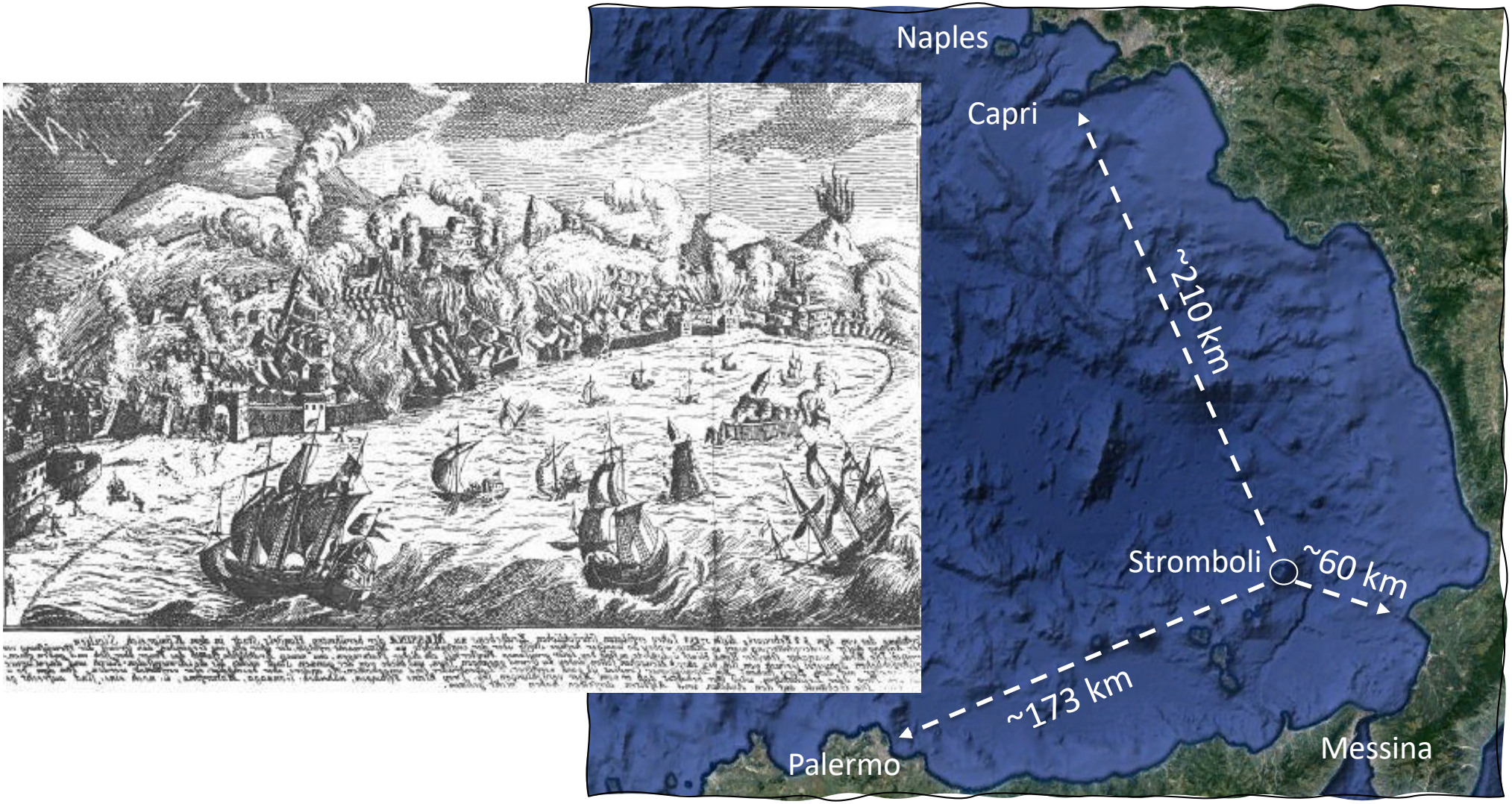

~10 $Mm^3$ of flank collapse generated a 10 m tsunami wave and ~200 m of inundation

# Potential Collapse of ~1000 $Mm^3$




Sector collapses occurred also during Roman age and involved volumes of $10^9$-$10^8$ $m^3$

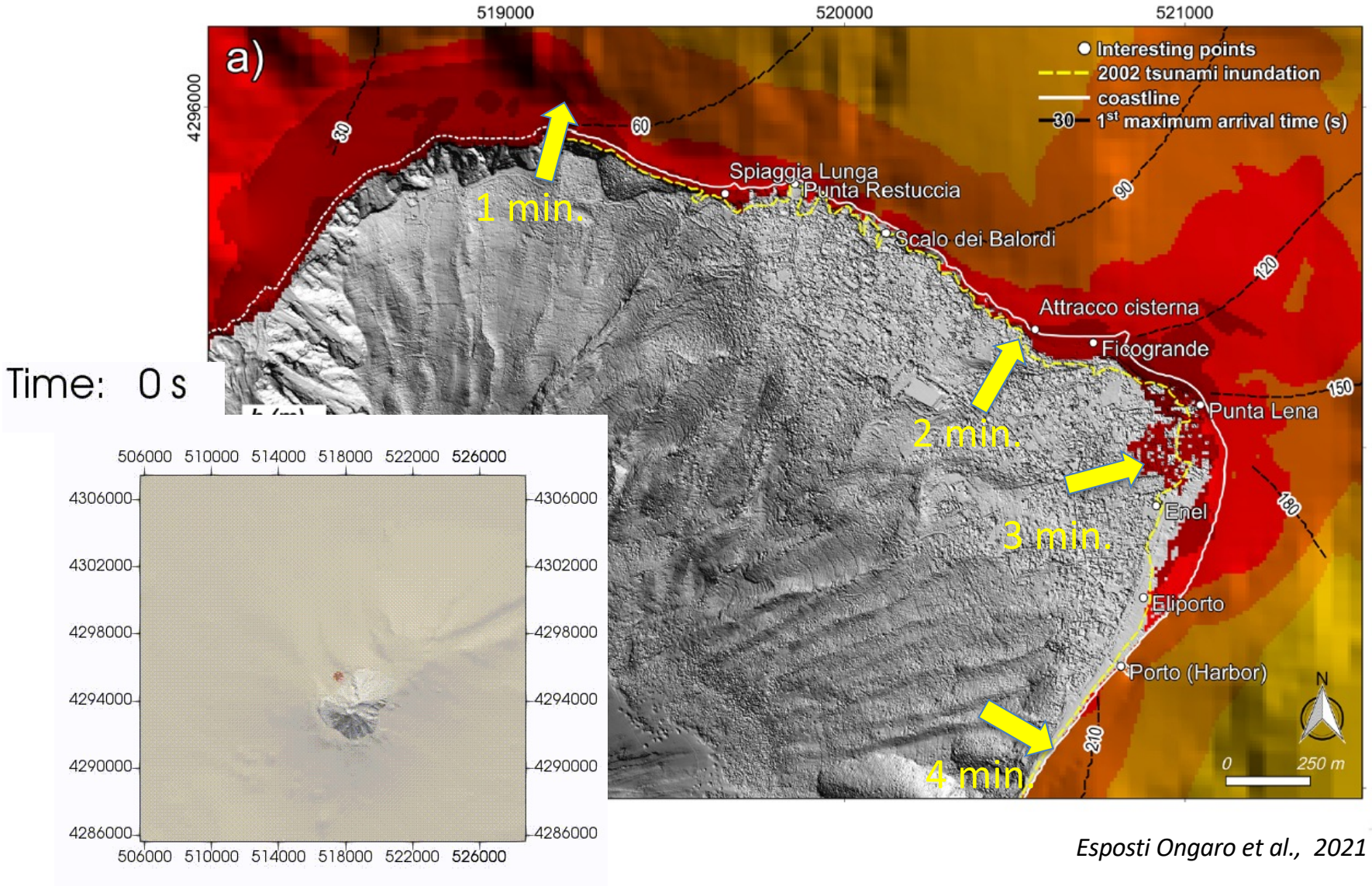
# Last partial Sector Collapse ~700 years ago




Geological deposits indicate three partial flank collapse of ~200 x $10^6$ $m^3$ in 1300-1400 producing damages and victims in Gulf of Naples at 230 km from Stromboli

*Rosi et al.*, Sci Rep., 2018

# Tsunami Arrival Time

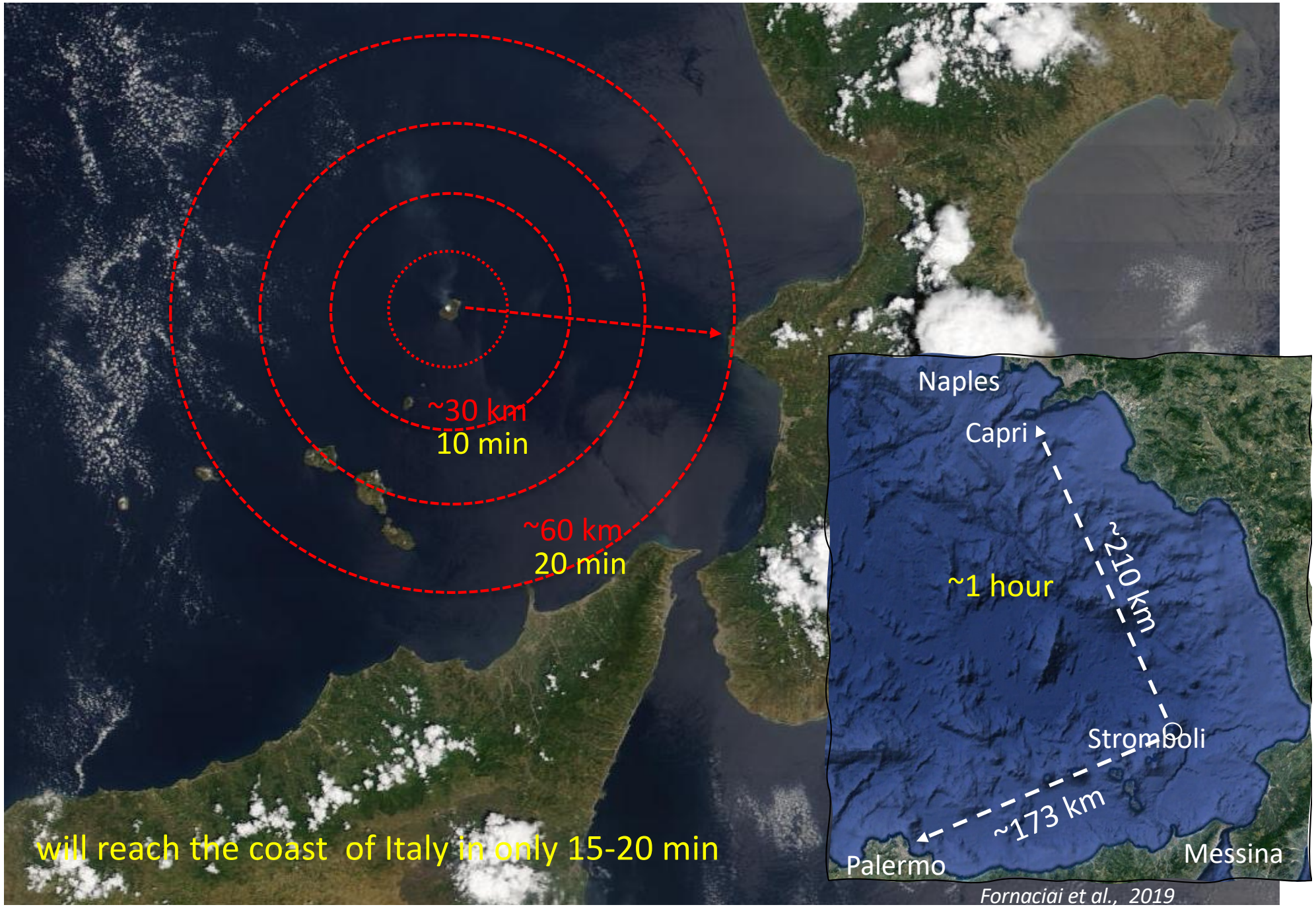



*Esposti Ongaro et al., 2021*

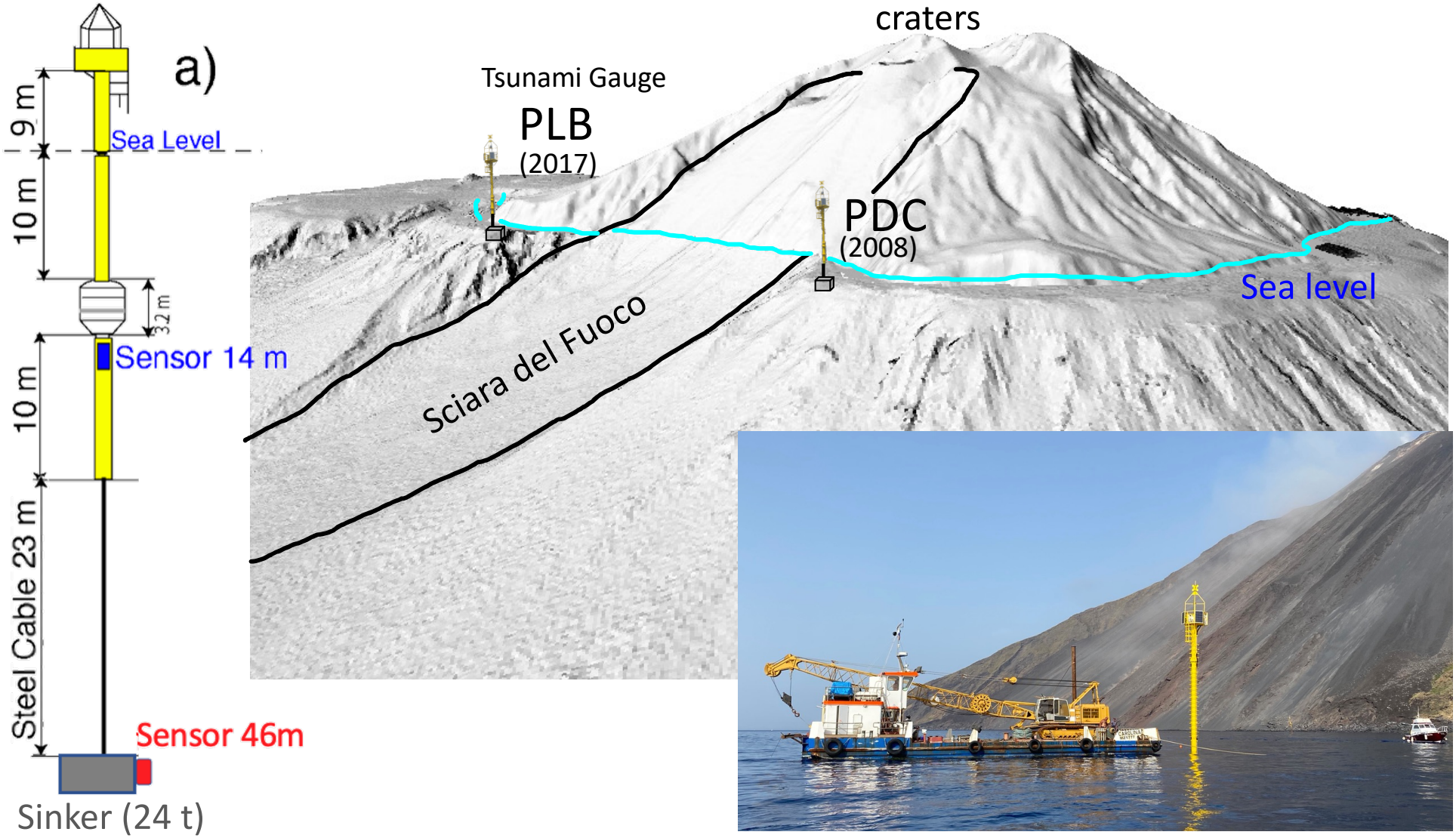
Tsunami would reach the coast of Stromboli in <~4 min

~5000 people are exposed to the tsunami risk during summer time

# Tsunami Arrival Time



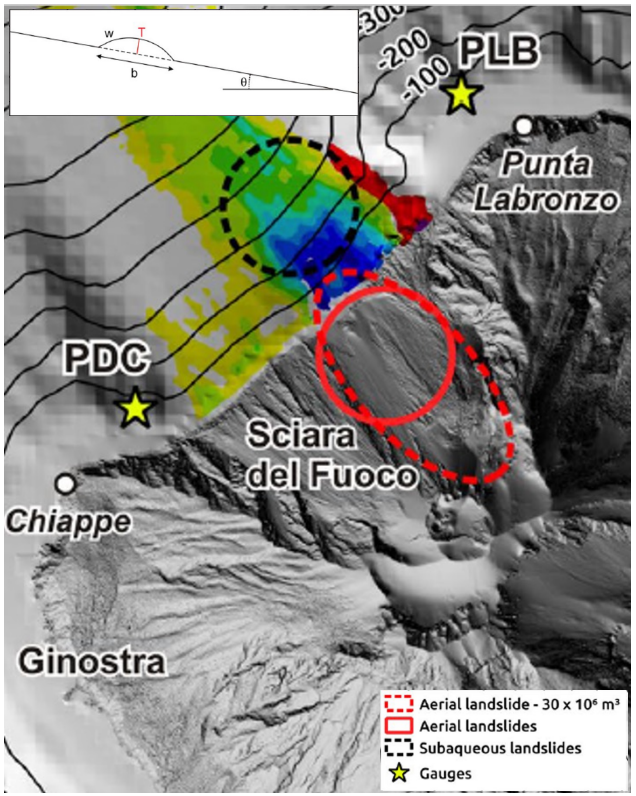
# The Tsunami Early-Warning System

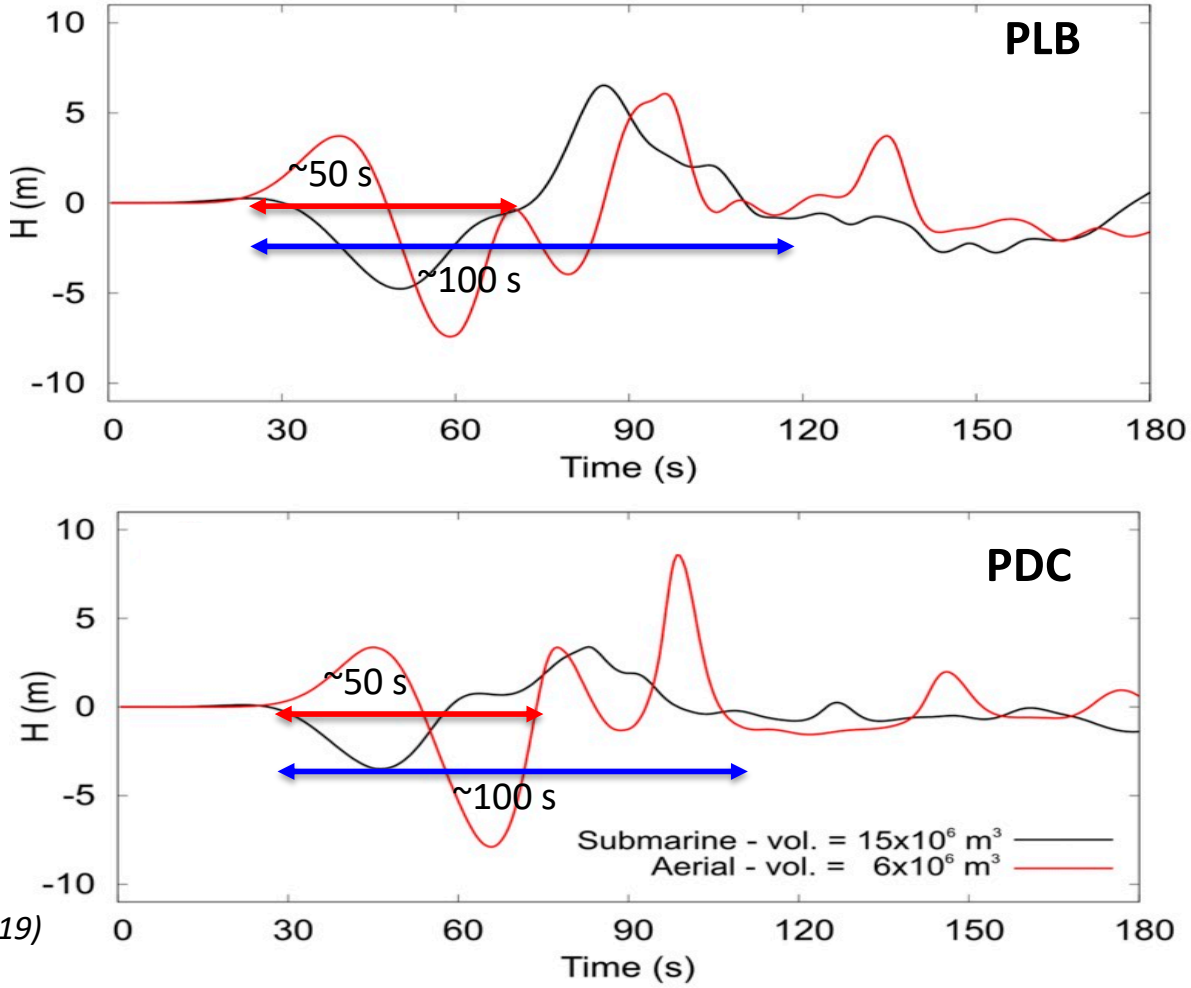



The system infrastructure is based on two elastic beacons

# Modelling tsunami in near-field: NHWAVE

**Submarine ($15 \times 10^6$ $m^3$) and Aerial ($6 \times 10^6$ $m^3$) collapse**



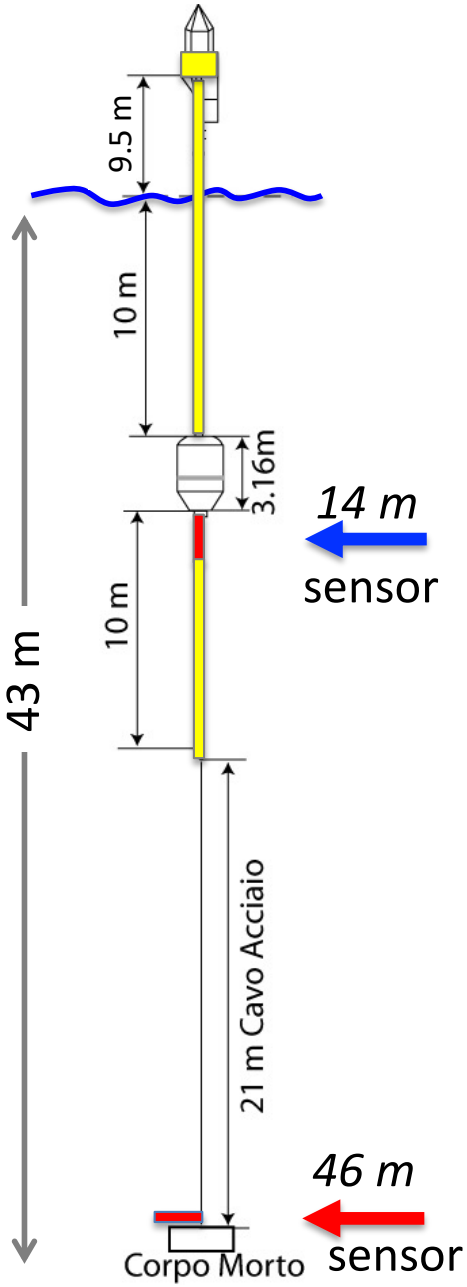




*(Fornaciai et al., 2019)*

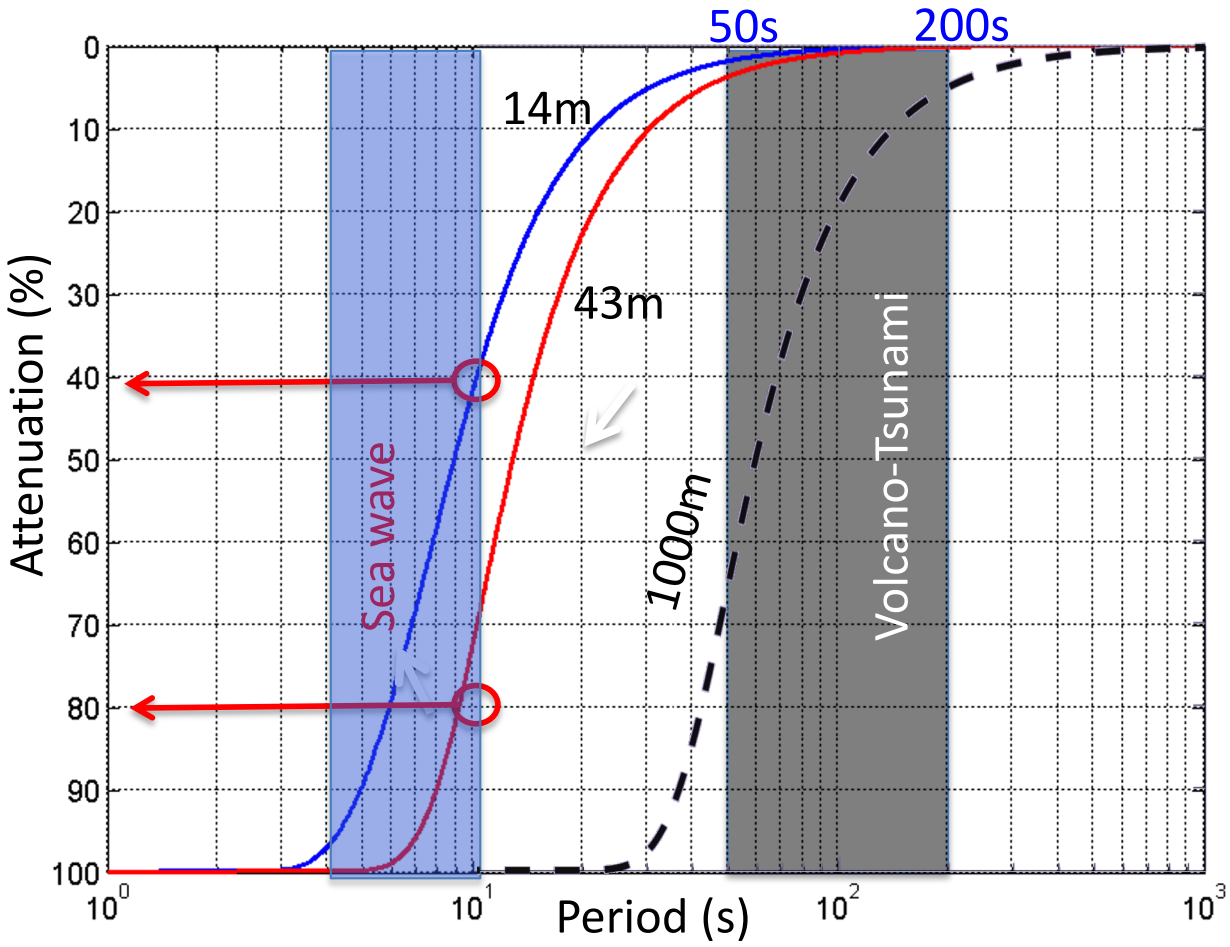
Periods of Tsunami range between 50 and 100 seconds

Aerial are more effective than submarine in generating tsunami

# The Tsunami Gauges




## Dispersion Model at 14 and 43 m depth

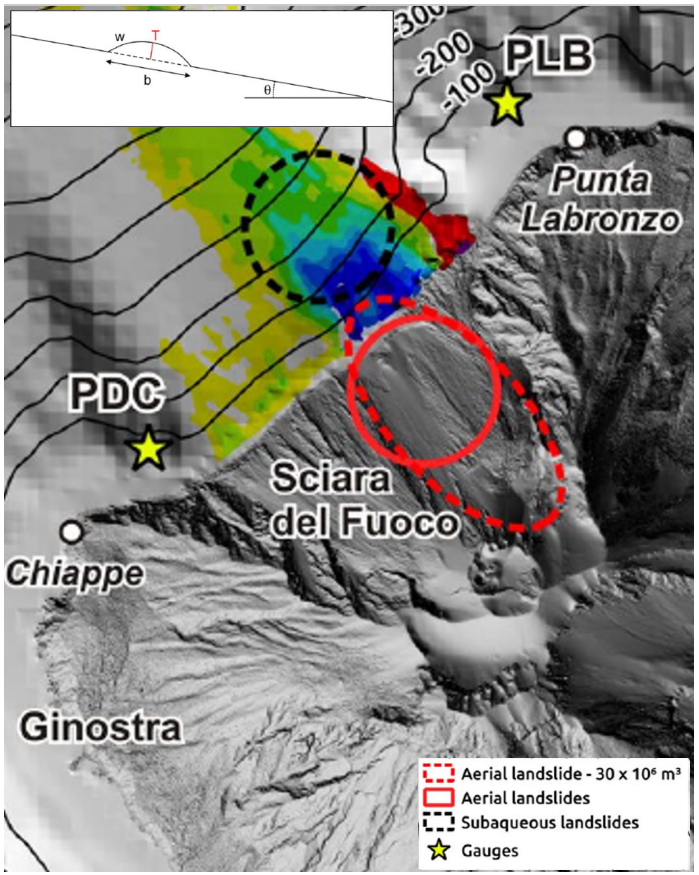


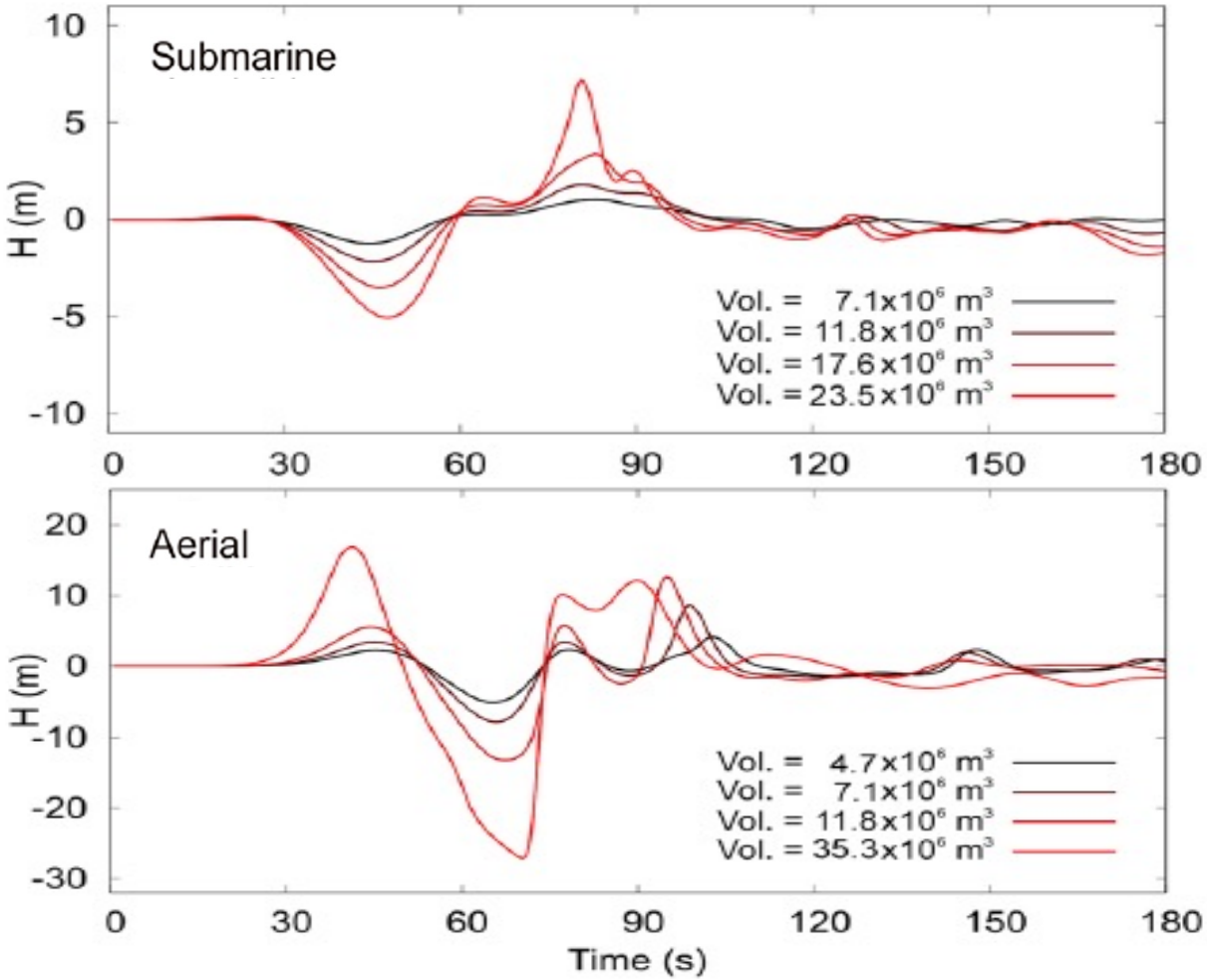

Sea effect is reduced >40% at 14 m and >80% at 43 m

Volcano Tsunami at 1000 m will be reduced by 5 to 65%

# Tsunami waveforms and Slide Volumes

**Submarine and aerial landslide with volumes between 4 and 35 Mm³**

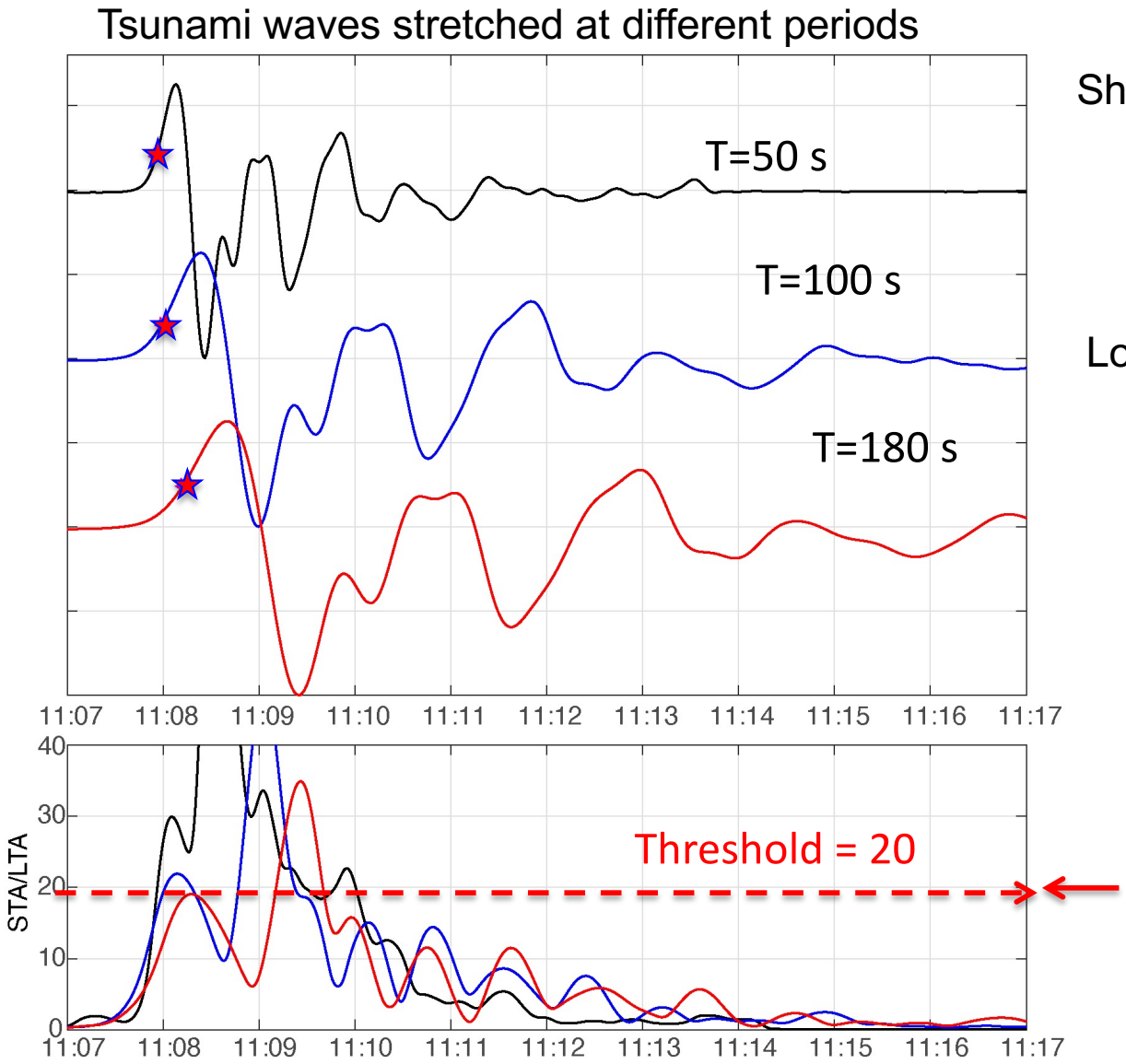



Tsunami waveforms do not change with volumes

We can use modelled waveform to «train» the detection algorithm

# Detection Algorithm is based on STA/LTA ratio




Short Time Average

$$STA(t) = \frac{1}{M}\sum_{\tau=t-M}^{t}|x(t-\tau)|$$

Long Time Average

$$LTA(t) = \frac{1}{N}\sum_{\tau=t-N}^{t}|x(t-\tau)|$$

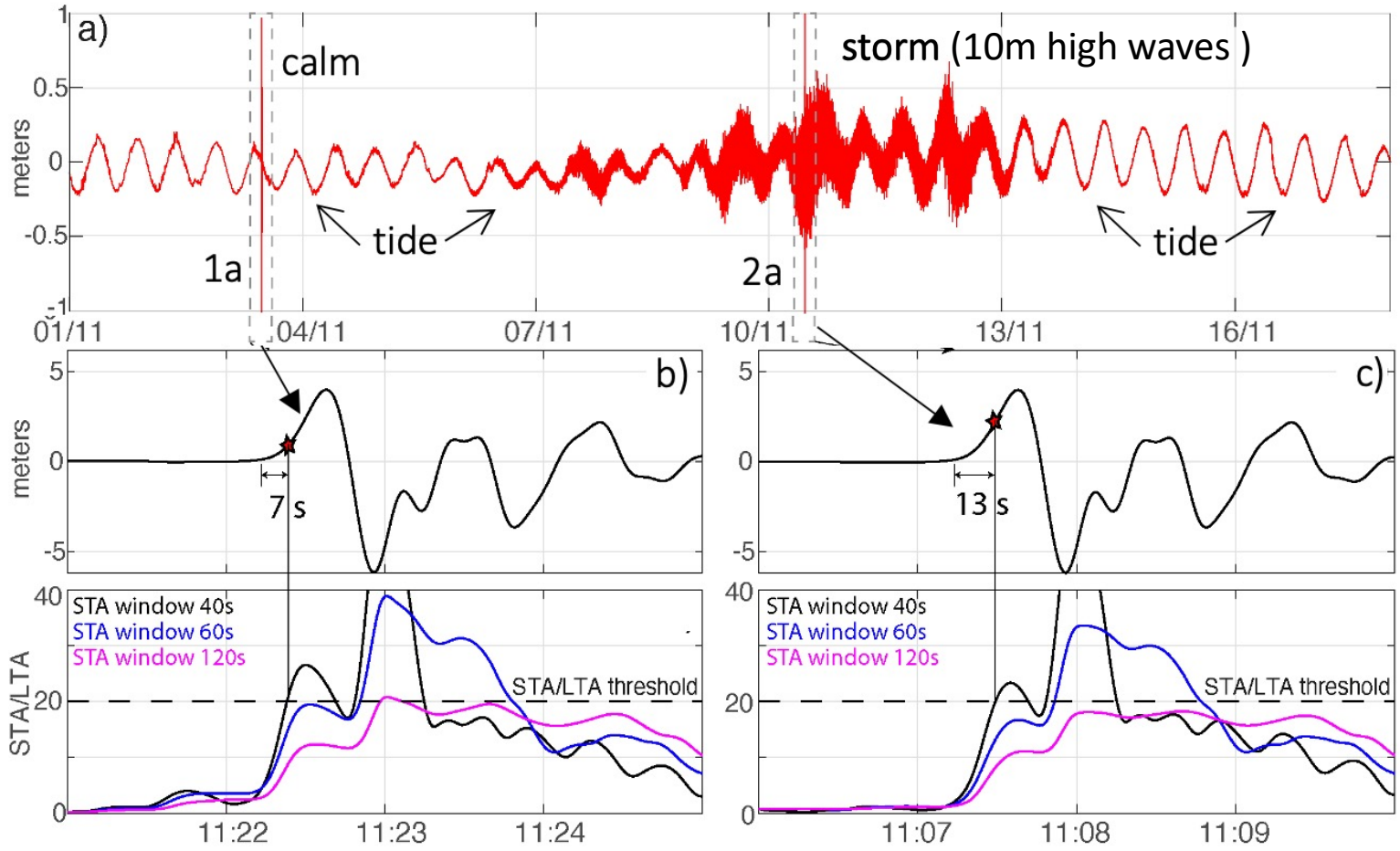
where: $M$=3600 s

$N$=40s

$$\frac{STA}{LTA} = 20$$

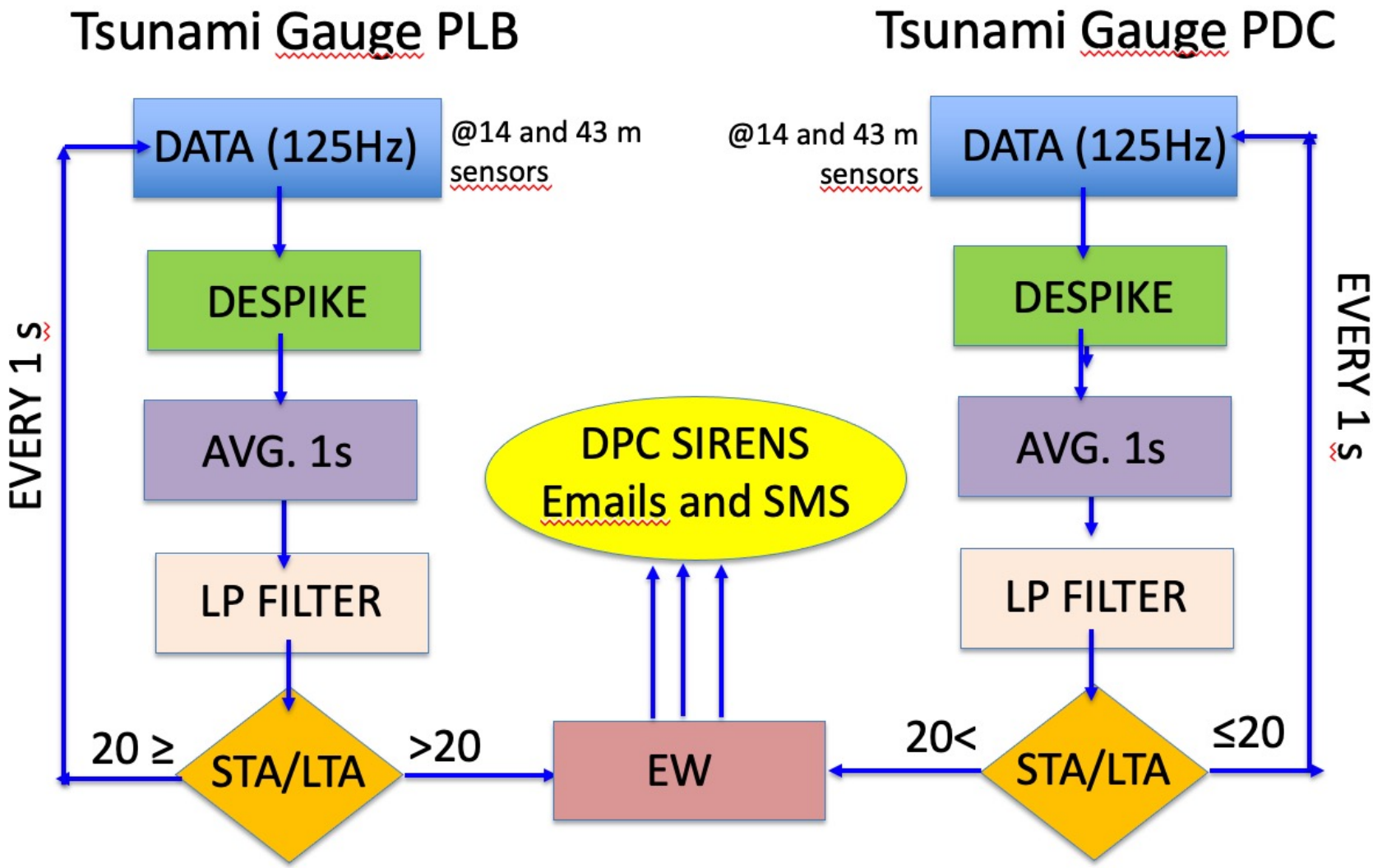
The STA/LTA >20 detects tsunami few seconds after the onset up to 180 s period

# Sensitivity of the STA/LTA ratio threshold



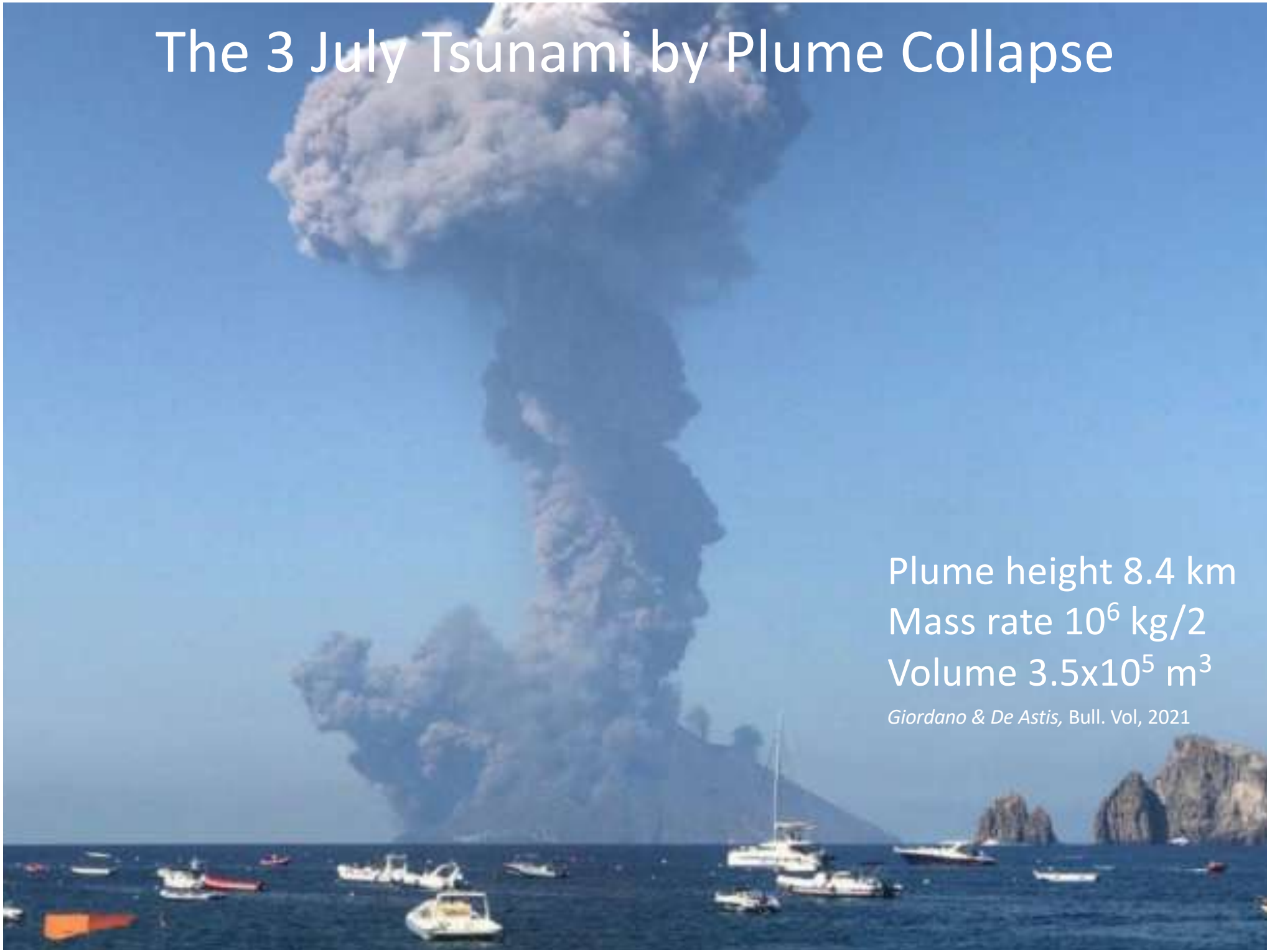

The STA/LTA >20 detects tsunami independently on sea conditions which introduces a detection delay of only 6 s

# Tsunami Early-Warning Flow Chart




Alert is issued when The STA/LTA >20 at both gauges

# The 3 July Tsunami by Plume Collapse



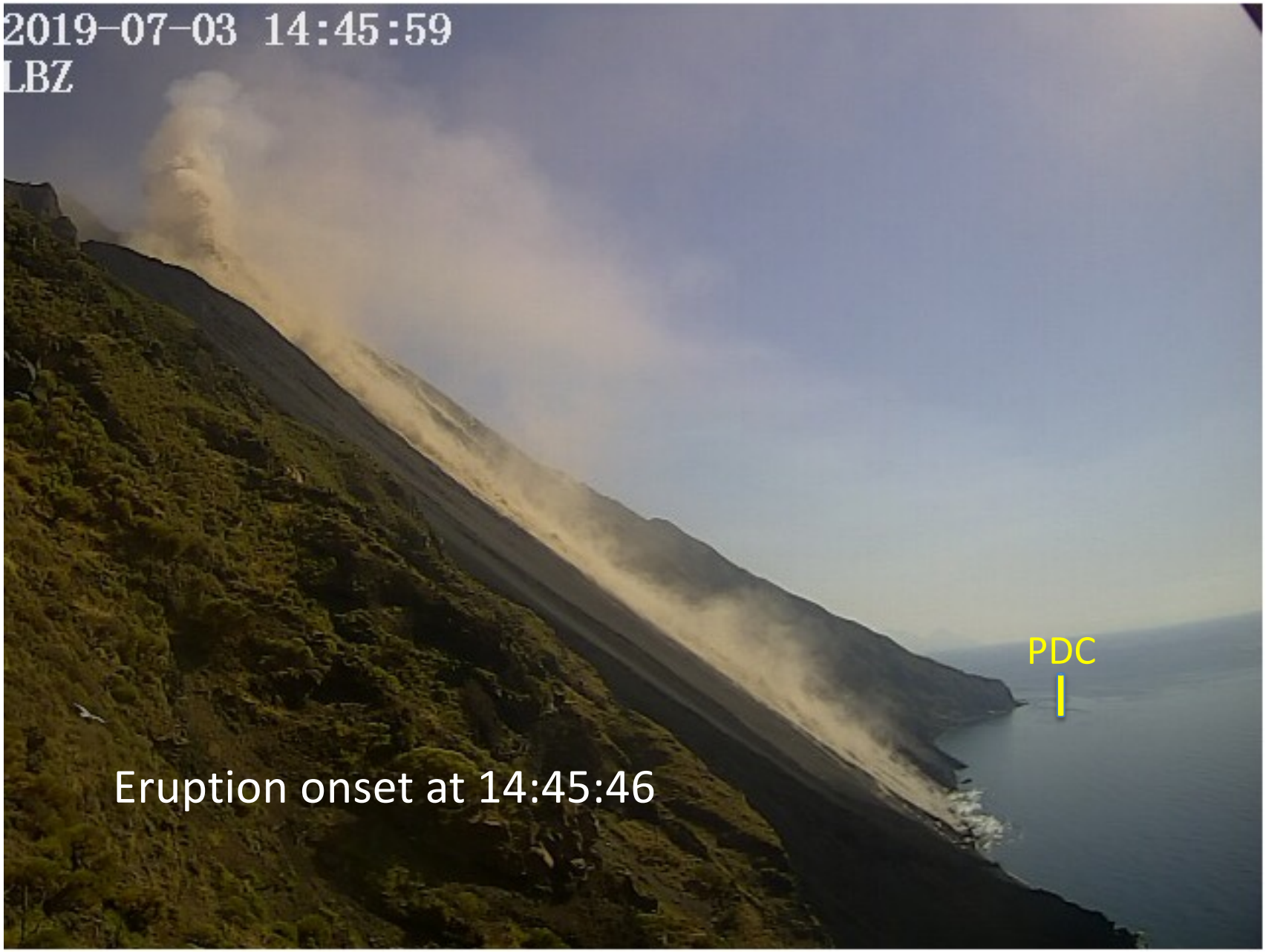
Plume height 8.4 km

Mass rate $10^6$ kg/2

Volume $3.5 \times 10^5$ $m^3$

*Giordano & De Astis,* Bull. Vol, 2021

# The 3 July, 2019 Explosive Eruption (Paroxysm)



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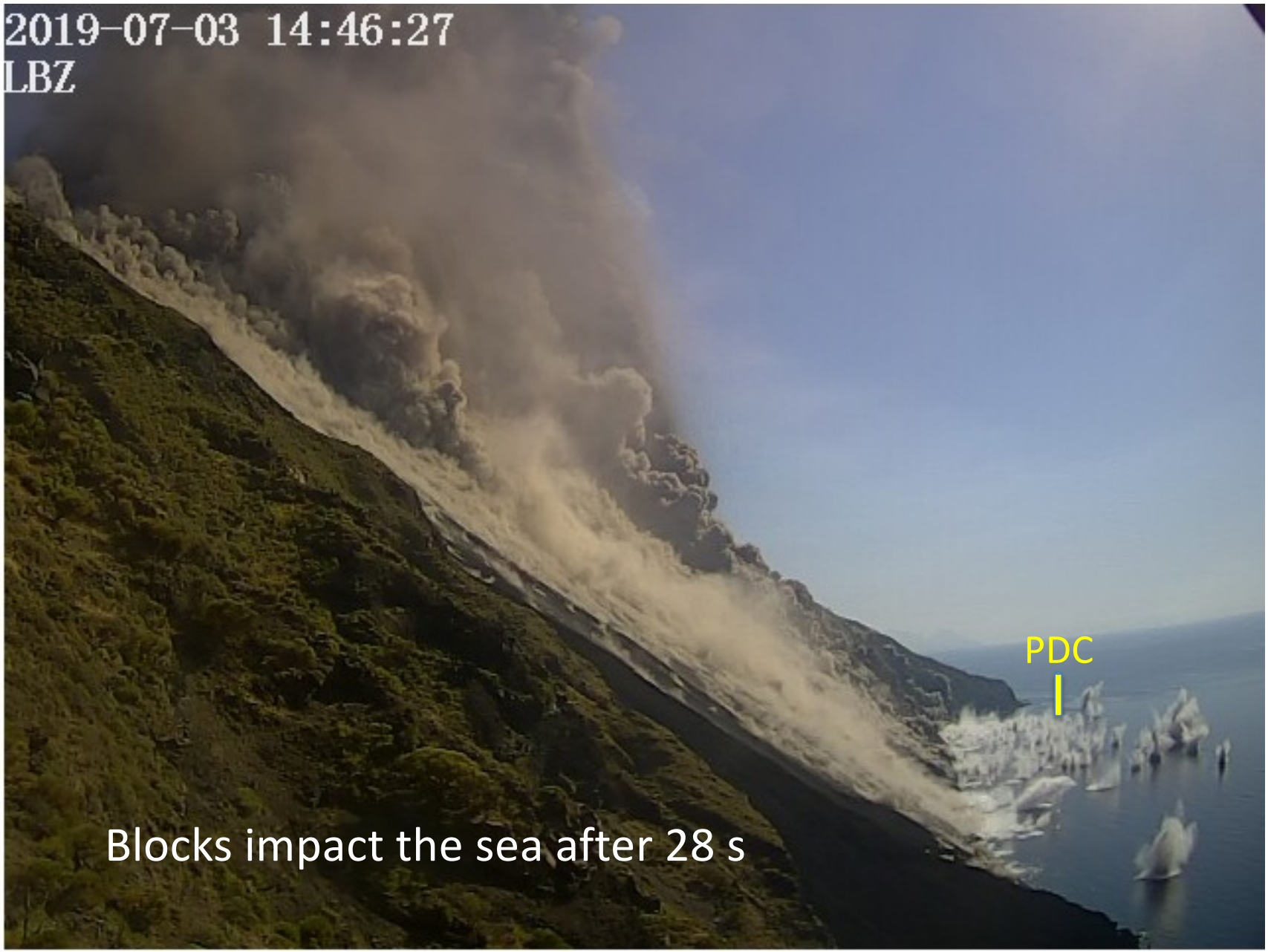

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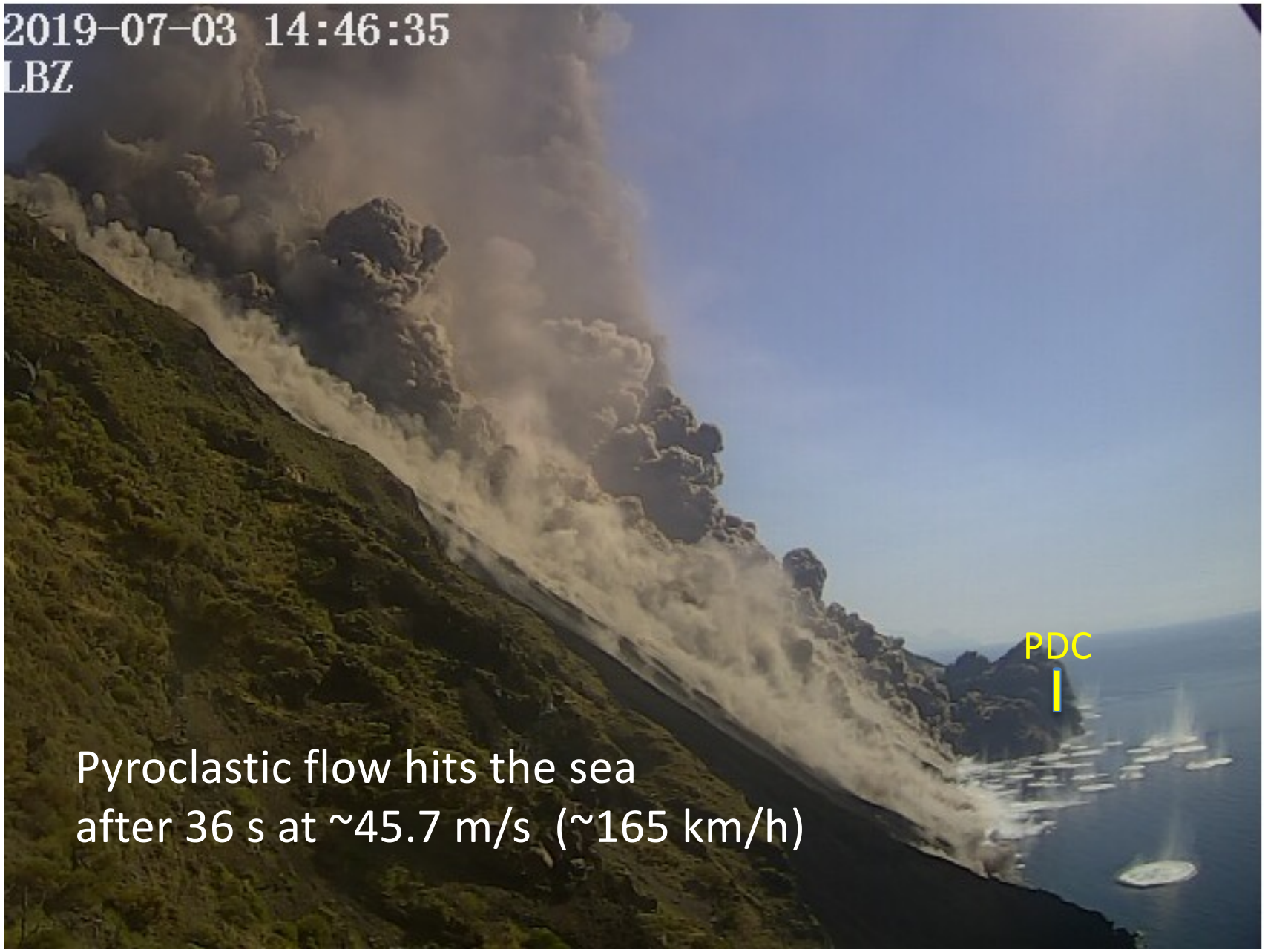

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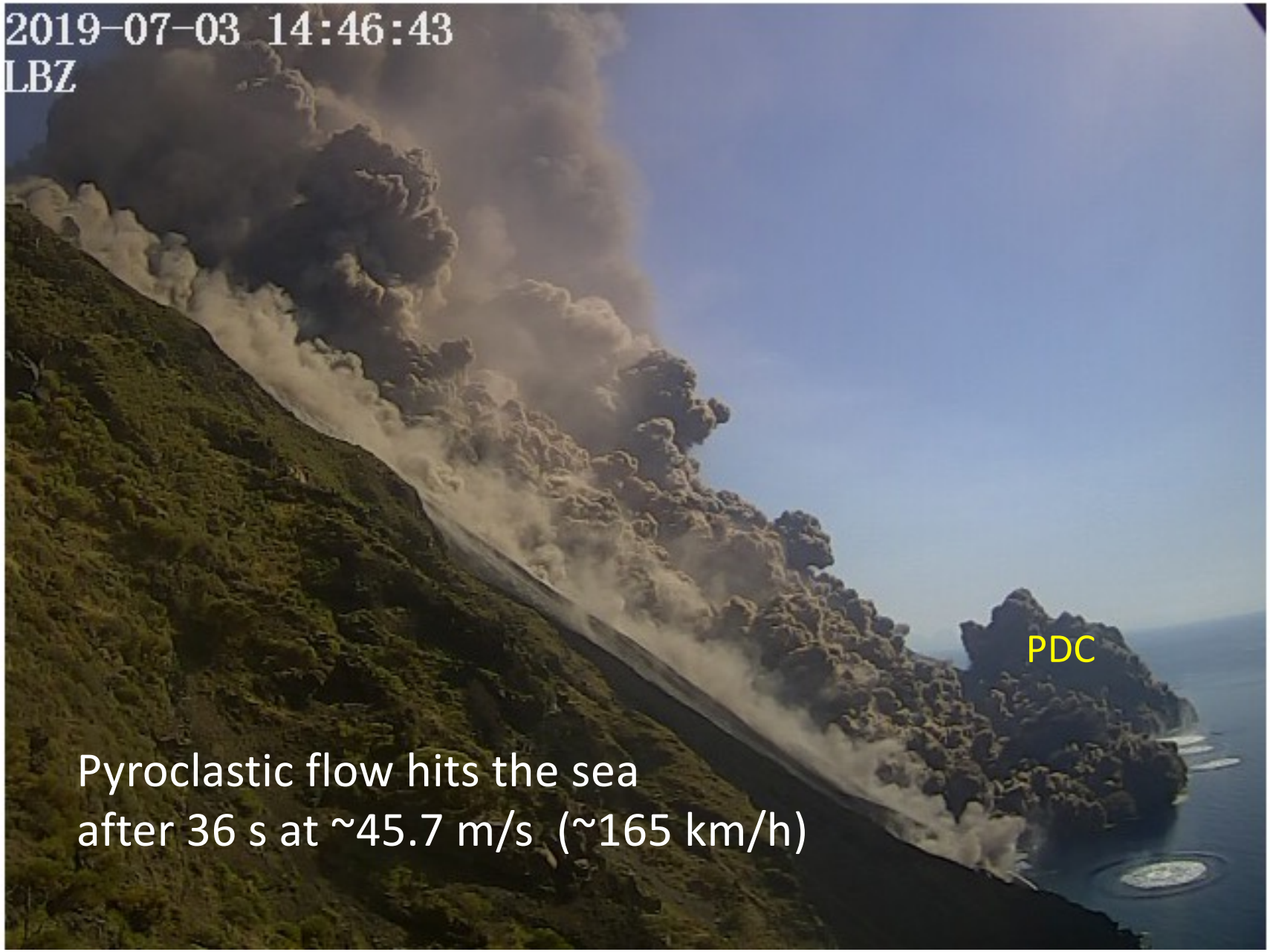

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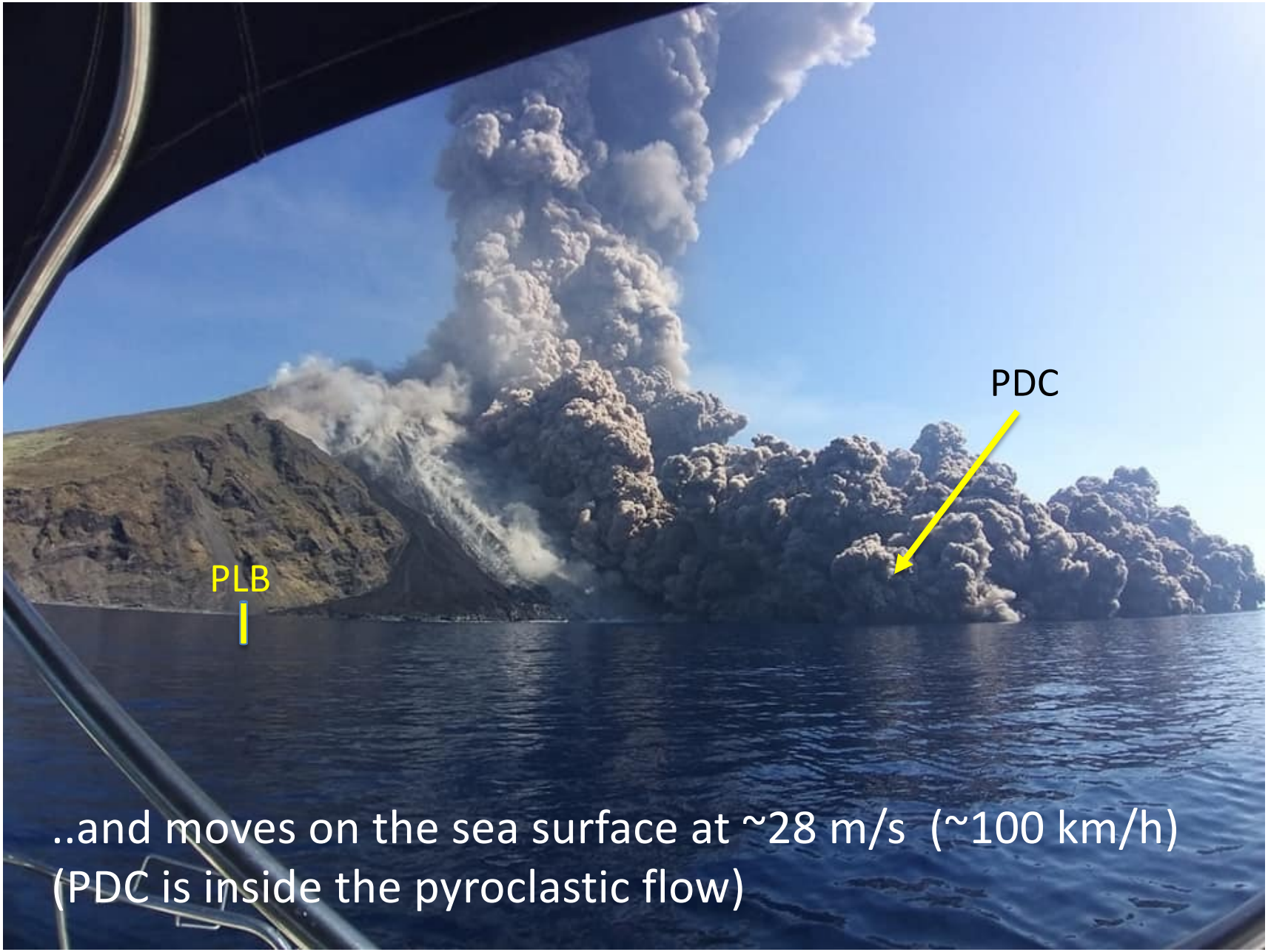
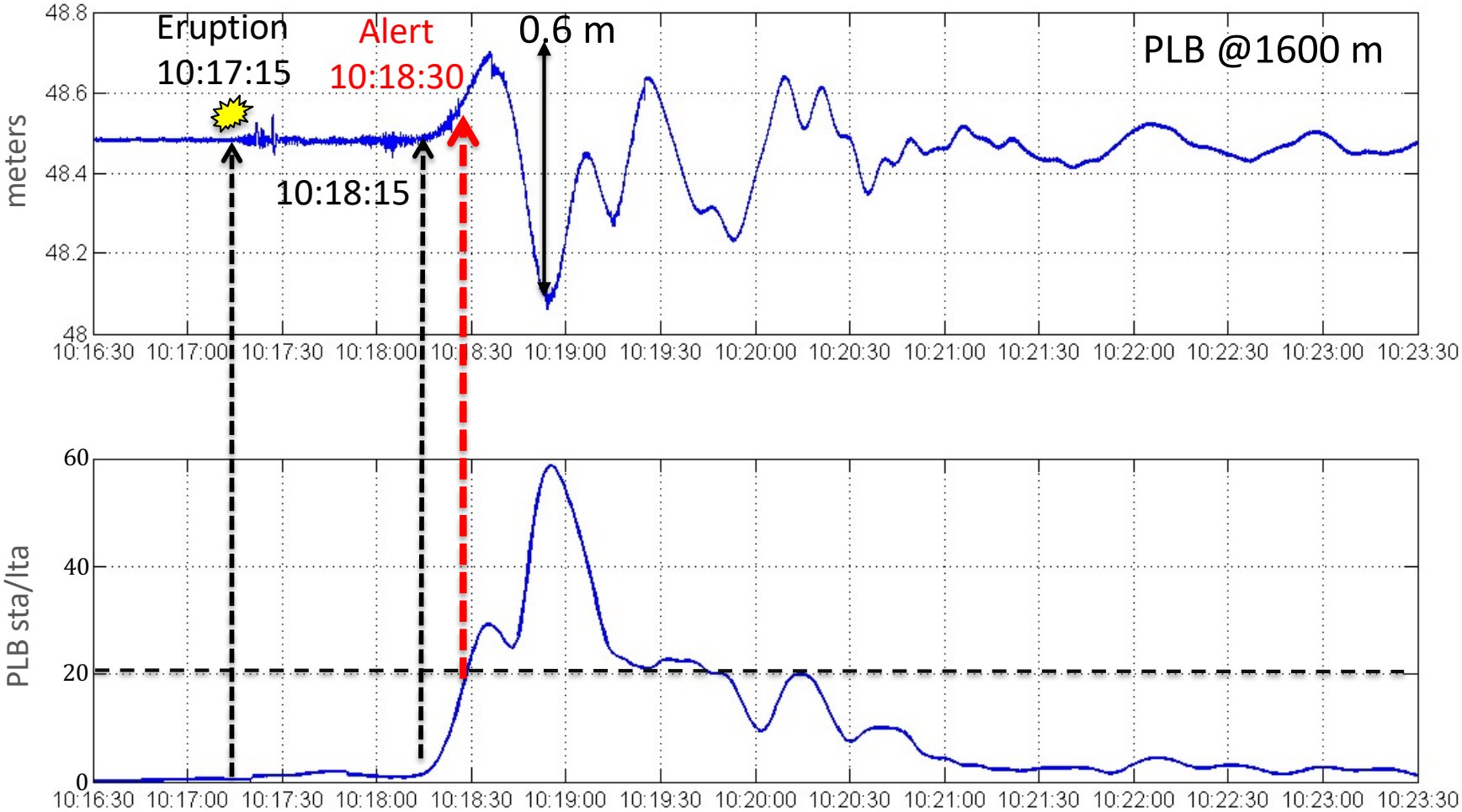


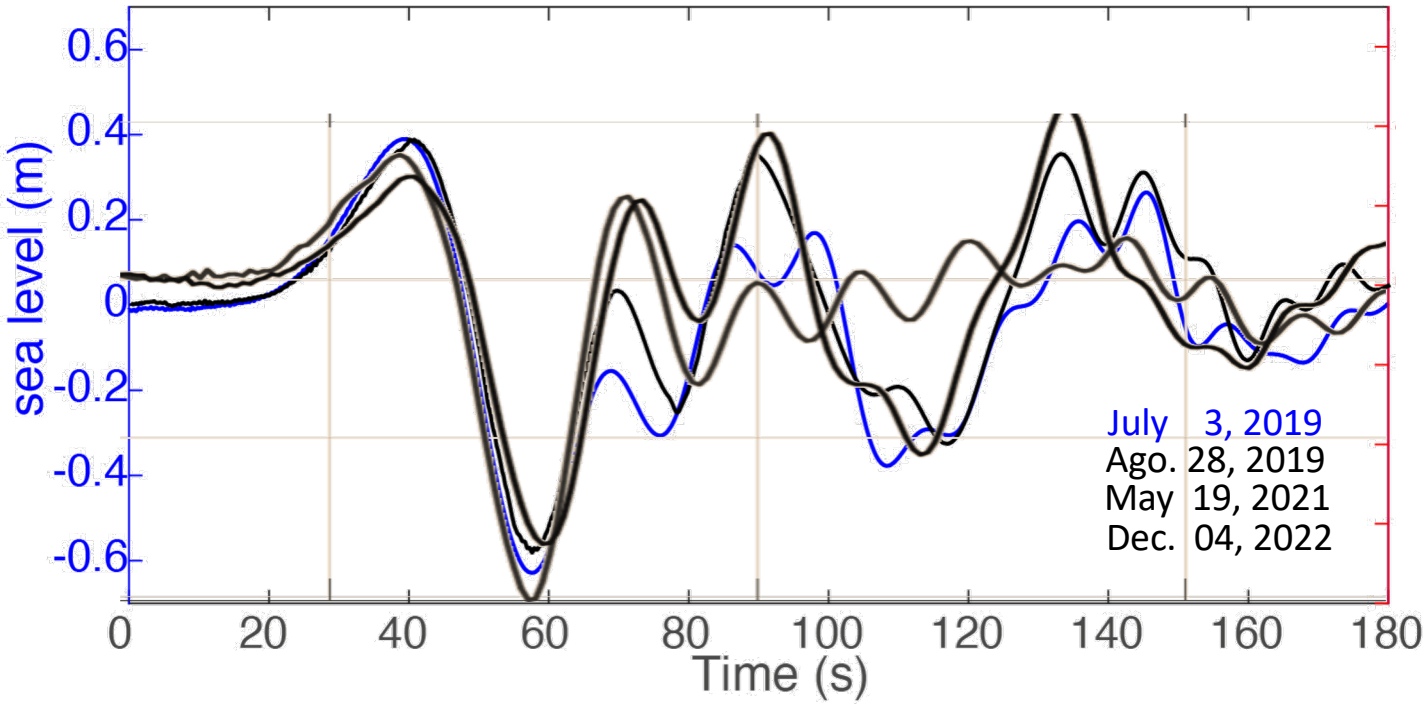
# Reaction Time of the EW tsunami




Tsunami was recorded 60 seconds after the explosive eruption

Alert issued 15 secondi after the onset and 75 s after the explosion

# Stability of the Tsunami waveforms




Tens of Tsunamis of 4-150 cm with different source location and dynamics have been recorded in the last 4 years)

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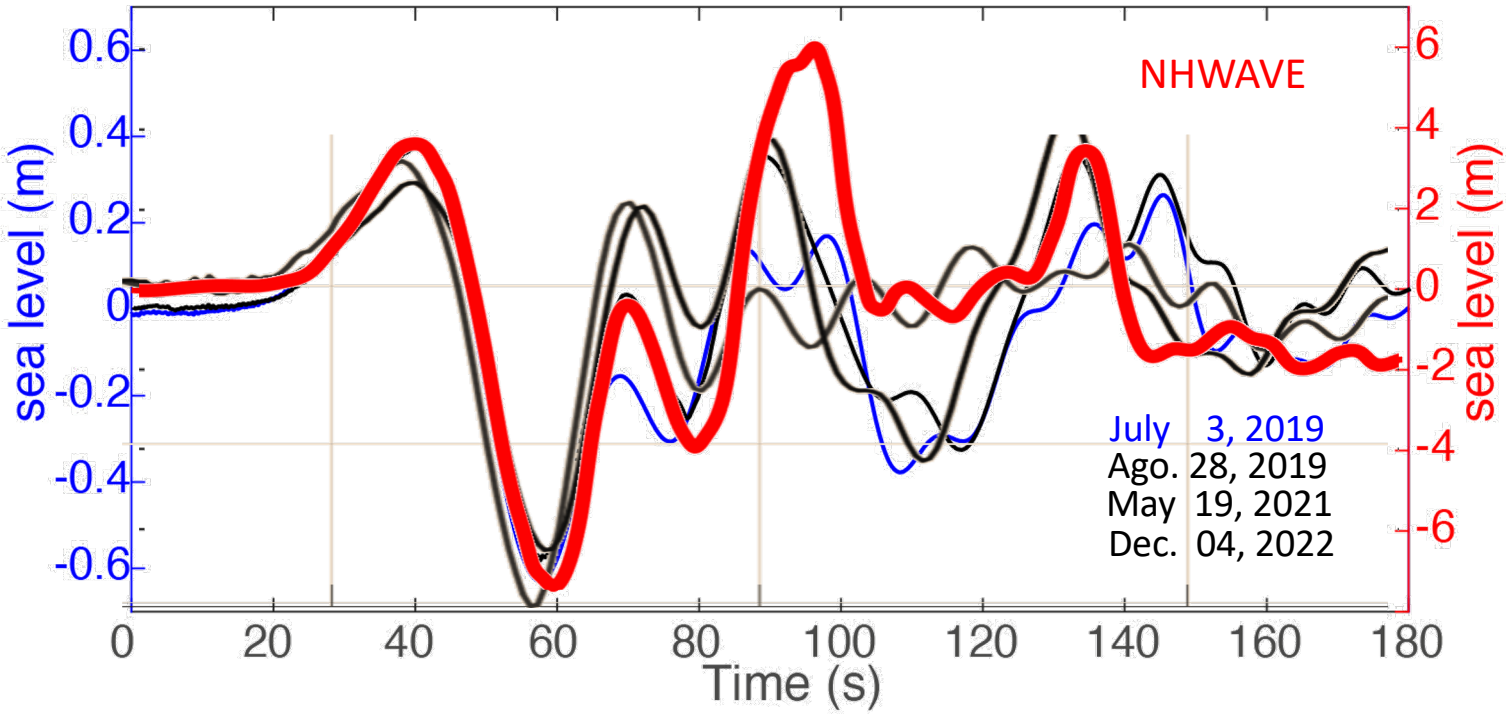
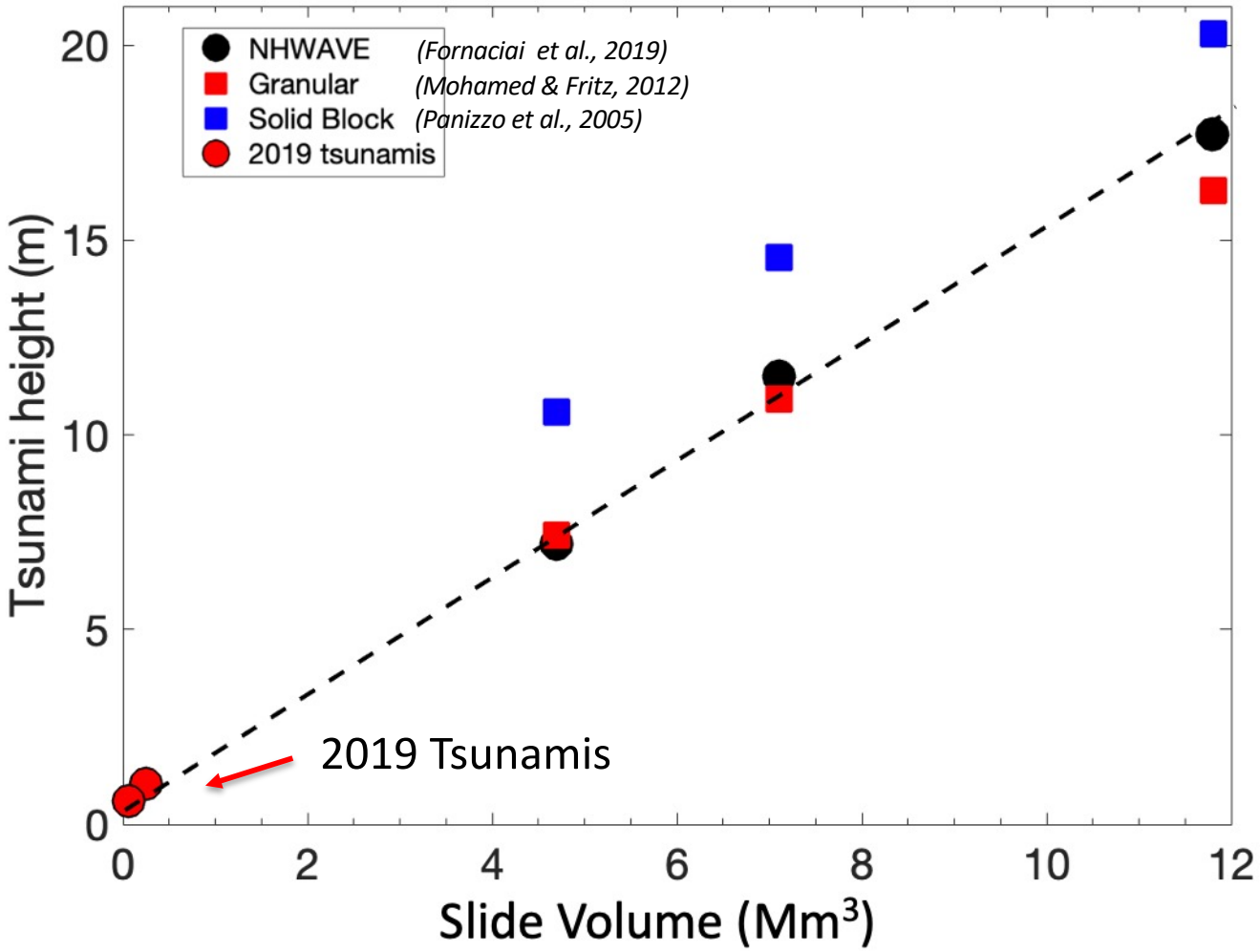



Similar Waveform of Tsunami calculated with NHWAVE for a landslide and in spite of the ~2 order amplitude difference and different source parameters

# Tsunami height and slide volume correlation




Numerical (black dots) and Empirical (Block and Granular) modells shows a Linear correlation between Tsunami height and slide volume

Inundation scenario can be calculated «a-priori»

# Conclusion and/or Suggestions:

- Volcano generate tsunami with periods (50-200 s) shorter than earthquake

1. Tsunami gauges deployed in deep water (>300 m) will be no-sensitive.
2. The record of volcano-tsunami, requires at least 1 Hz sampling rate

- Tsunami Source is generally close to populated area (<10 min)

1. Alert should be issued automatically with no human supervision
2. Detection algorithm should ‘react’ as prompt as possibly (within seconds)

- Tsunami Waveforms for the same Volcano are Stable

1. Numerical waveforms can be used to ‘train’ the detection algorithm
2. Linear relationship between volume and amplitude can be found
3. A-priori inundation scenarios should be used to estimate possible impact in real-time