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Stromboli volcanic island as a source of tsunami hazard for the Tyrrhenian Sea

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Picture from https://www.instagram.com/p/Bze36RIC0Zr/

RATIONALE

- The volcanic dome of Stromboli is frequently affected by mass failures, induced by seismic shaking, magma intrusion or simply by gravitational load. Many of such events are reported in the catalogues, the last of which occurred in summer 2019.
- In December 2002, two relatively small (some millions m^3) landslides that took place with a time separation of few minutes generated tsunamis, causing relevant local effects.
- Through numerical modelling we explore the effects of tsunamis generated by slides detaching from the Sciara del Fuoco, in the NW sector of the Stromboli edifice, and covering a broad volume range (from 0.5 to 500 million m^3).
- This investigation aims at searching for correlations between representative quantities of landslides and ensuing tsunamis, able to provide insights on hazard management in the Aeolian Archipelago and in the Tyrrhenian Sea.

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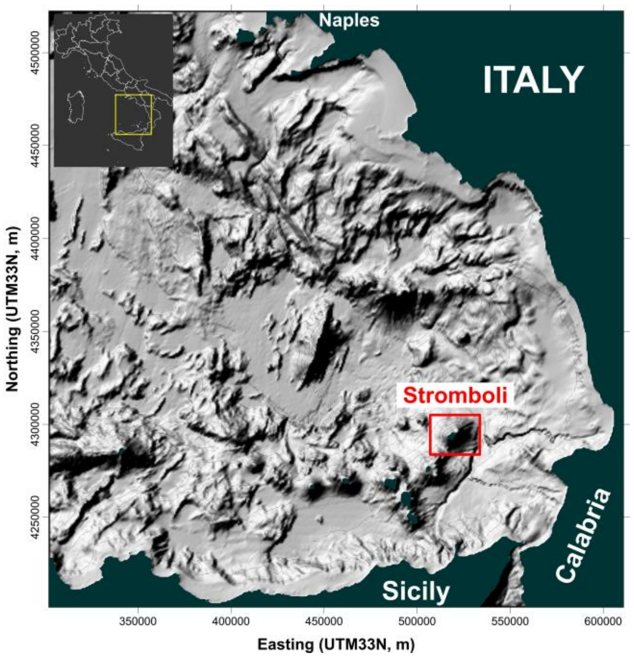
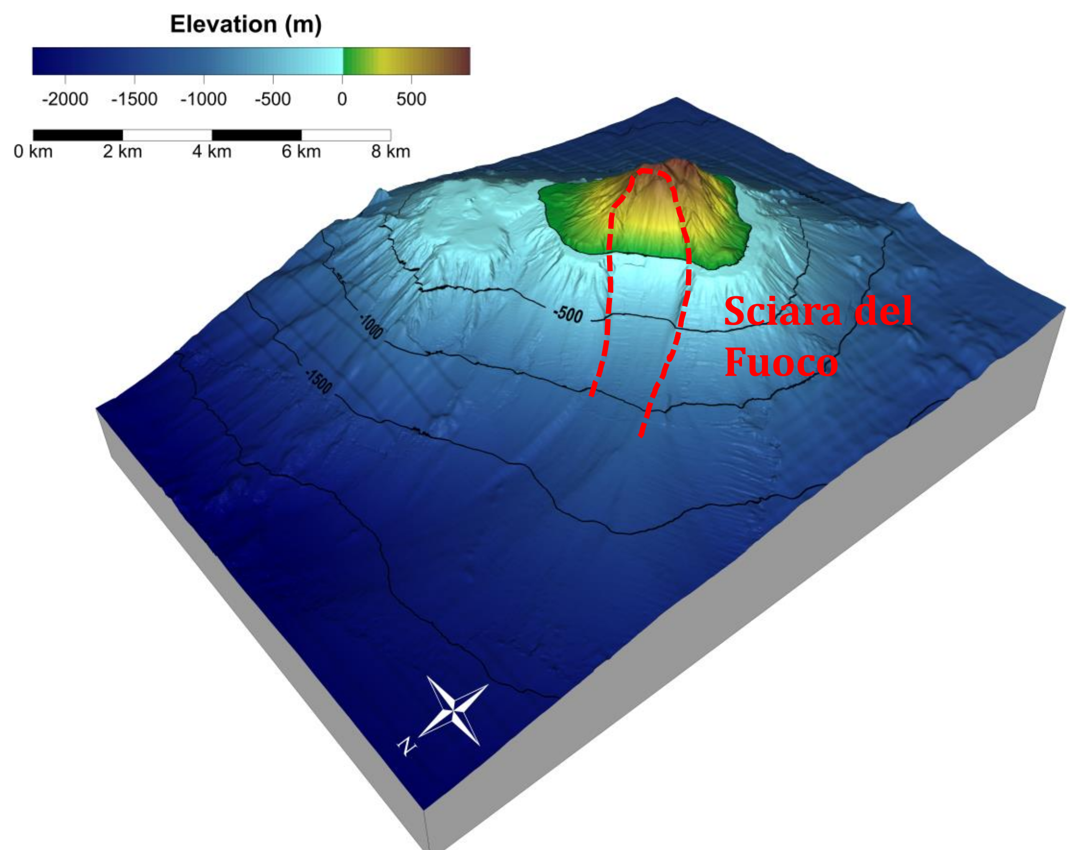
Stromboli Volcanic Setting



Stromboli is a **volcanic island**, part of the Aeolian Archipelago, placed in the South-East Tyrrhenian Sea.

It is one of the most active volcanoes in the world and is **extensively studied and monitored**.

Its activity is characterized by **frequent explosive eruptions**, occasionally evolving into extreme events and **paroxysms**.



The main morphological feature of the volcanic edifice is the **large scar on the NW flank** of the dome, called **Sciara del Fuoco**.

It originated between 10 and 5 kyrs BP as the result of a collapse (the so-called **Holocene Landslide**) and represents the preferential site for erupted material discharge into the sea.

Tsunamis in the Aeolian Archipelago

Y	M	D	Rel.	Area	Source Type	Short Description
1879	2	4	1	Stromboli	Volcanic Activity	
1916	7	3	4	Aeolian Islands	Earthquake	Withdrawal/inundation at Stromboli
1919	5	22	4	Aeolian Islands	Volcanic Activity	Sea retreat/flooding at Stromboli
1926	8	17	2	Aeolian Islands	Earthquake	Anomalous sea retreat at Salina
1930	9	11	4	Aeolian Islands	Volcanic Activity	Strong sea retreat/flood at Stromboli
1944	8	20	4	Aeolian Islands	Volcanic Activity	Sea flooding. One house destroyed
1954	2	2	4	Aeolian Islands	Volcanic Activity	Slight tsunami at Stromboli
1988	4	20	4	Aeolian Islands	Gravitational Landslide	Small waves in Vulcano and Lipari
2002	12	30	4	Aeolian Islands	Volcanic Landslide	Heavy damage at Stromboli
2019	8	28	3	Stromboli	Volcanic Activity	30 cm runup in Ginostra

Mostly as a consequence of the Stromboli volcanic activity, the Aeolian Archipelago area has been repeatedly the scene of **tsunami events**. The catalogues report **10 tsunamis**, of different origin, that occurred in the last 150 years.

- Maramai A., Brizuela B., Graziani L. (2014) The Euro-Mediterranean Tsunami Catalogue, Annals of Geophysics, 57, 4, S0435. doi:10.4401/ag-6437
- National Geophysical Data Center / World Data Service: NCEI/WDS Global Historical Tsunami Database. doi:10.7289/V5PN93H7
- Tinti S., Maramai A., Graziani L. (2004) The new catalogue of the Italian tsunamis, Natural Hazards, 33, 439-465.

30 December 2002

Following a period of intense volcanic activity of Stromboli, on Dec 30th 2002 **two landslides** detached from the Sciara del Fuoco (the first submarine, the second subaerial), both with volume of some millions cubic meters. The post-tsunami observations reported **water elevations exceeding 10 m** *[Tinti et al., Bull. Vol., 2006a]*.

The tsunami caused huge damages especially along the northern sector of the island, with the highest number of constructions *[Tinti et al., Bull. Vol., 2006a]*.

3 July and 28 August 2019

In summer 2019 a series of **strong explosions** occurred at Stromboli. The strongest (3rd July) ejected ballistics and generated a 5-km high eruptive column.

A **huge pyroclastic flow** from the Sciara del Fuoco travelled over the sea for some km.

The available tide gauges close to the source reported a **maximum 1 m** peak-to-peak water oscillation.

Picture from www.lifegate.it

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Numerical Modelling

LANDSLIDE MODEL (UBO-BLOCK)

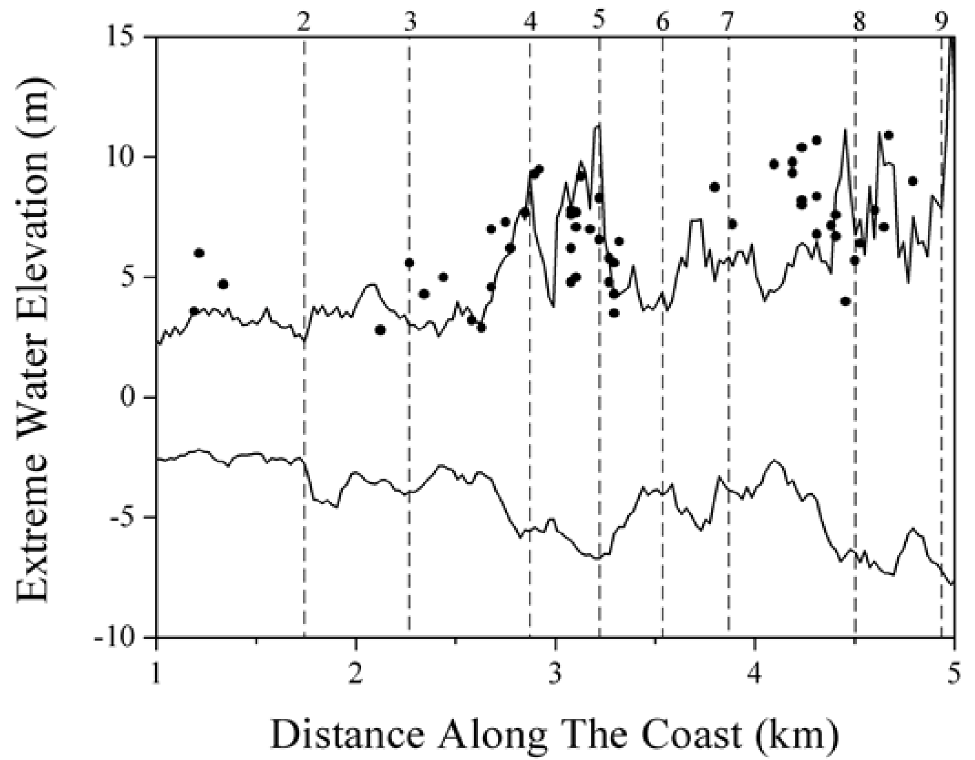
It is a **block-based approach**, accounting for mass shape changes, known to strongly influence tsunami generation.

The motion equations for each block's center of mass are solved by a finite difference technique *[Tinti et al., Nat. Haz., 1997]*.

TSUNAMI MODEL (UBO-TSUFD)

The **shallow-water equations** are solved through a finite difference method and a staggered-grids technique.

The model allows for the computation of **land inundation** (moving boundary technique) and of local refinement via **grid nesting** *[Tinti and Tonini, NHESS, 2013].*

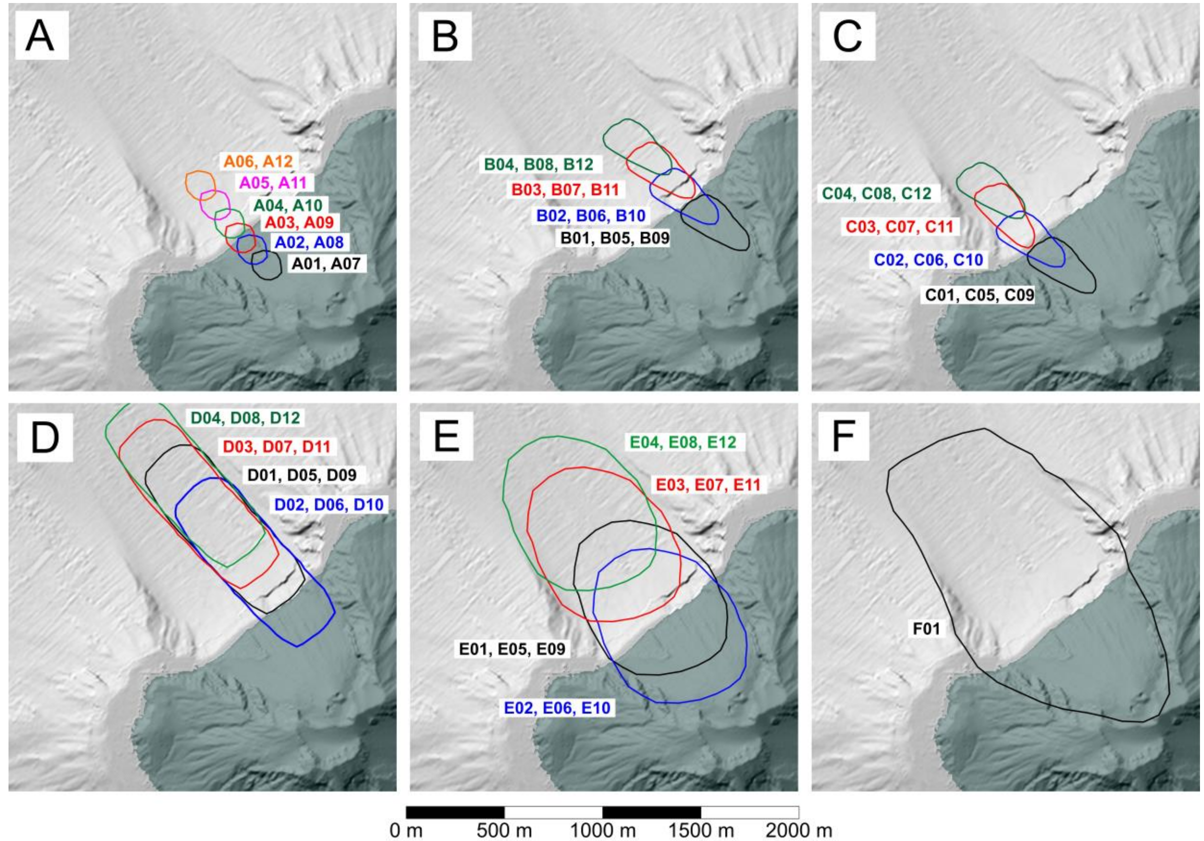


These models have been proven to provide satisfactory results when applied to real cases. More specifically, the simulations of the 2002 landslide-tsunamis match the observations (black dots in the plot) very well *[from Tinti et al., Bull. Vol., 2006].*

Landslide-Tsunami Scenarios

A **set of landslide scenarios** occurring along the Sciara del Fuoco slope has been designed, by varying shape, position, area, volume and thickness of the initial sliding mass (see Table below).

The respective sliding dynamics and ensuing tsunamis have been simulated through the models UBO-BLOCK and UBO-TSUFD.



Scenarios are coded from A to F with increasing volume (see Table on the right).

Scenarios B and C are based upon the **2002 second landslide** (subaerial).

Cases D are modifications of the **2002 first landslide** (submarine).

Case F is the reconstruction of the big **Holocene slide** generating the Sciara del Fuoco and is here considered as the upper limit.

Slide	Volume (10^6 m^3)	Mean Thickness (m)	Max Velocity (m/s)
A	0.5 – 1.5	7.8 – 23.3	21.9 – 55.1
B	2.6 – 10.4	12.2 – 48.7	30.2 – 54.4
C	2.6 – 10.4	12.2 – 48.7	30.7 – 56.1
D	8.0 – 32.1	6.2 – 25.0	32.9 – 50.1
E	50.8 – 203.3	27.0 – 108.0	40.9 – 57.7
F	473.9	94.2	70.0

Total Tsunami Energy vs. Slide Potential Energy

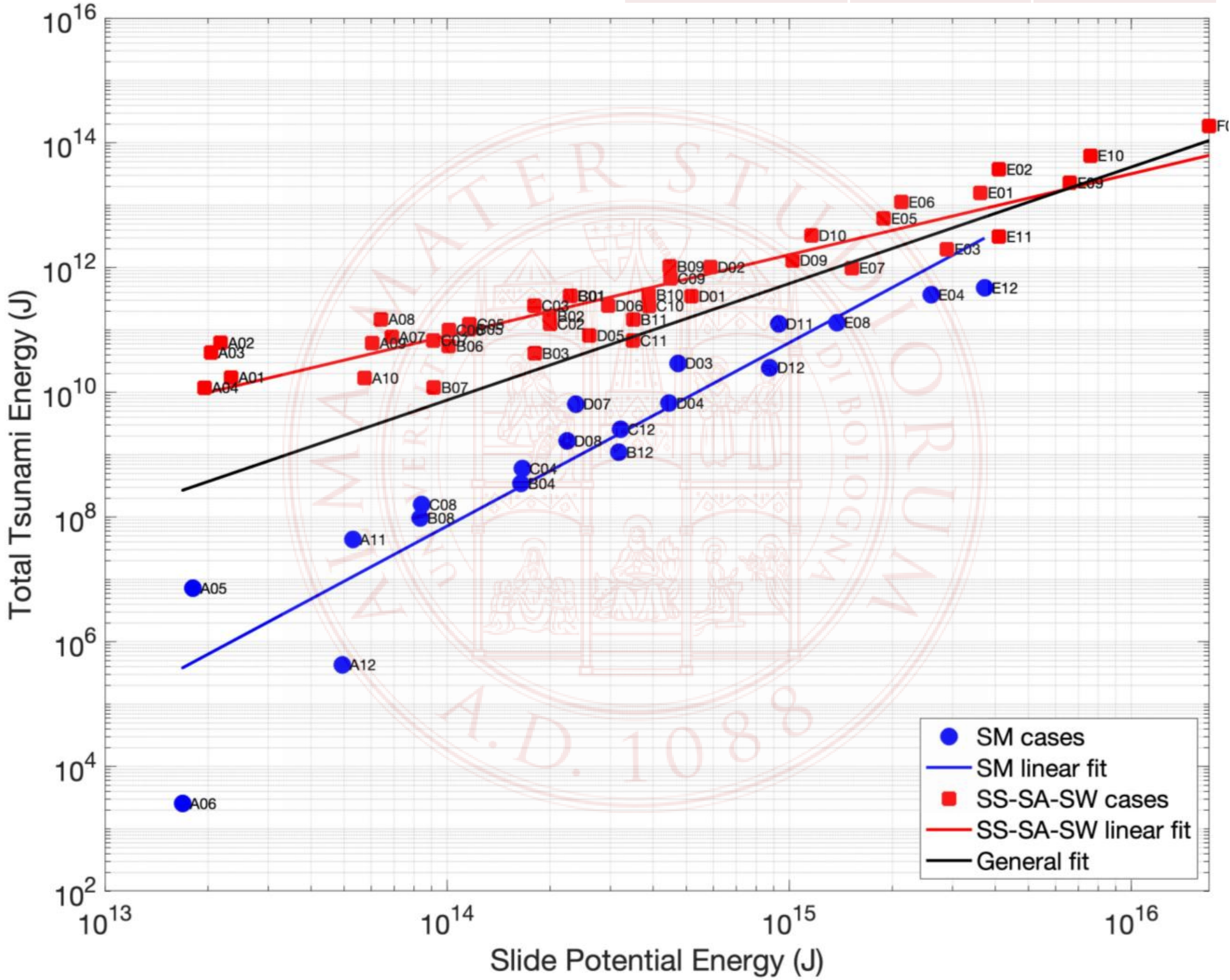
The correlation between the mass failures and the respectively generated tsunamis is here explored through the **POTENTIAL ENERGY** of the **slides** (**SPE**) and the **TOTAL ENERGY** of the tsunamis (**TTE**).

$\text{Log}\,TTE = A\,\text{Log}\,SPE + B$		
Dataset	**A**	**B**
General	**1.87**	**-37.5**
SM	**2.94**	**-76.7**
SS-SA-SW	**1.30**	**-17.4**

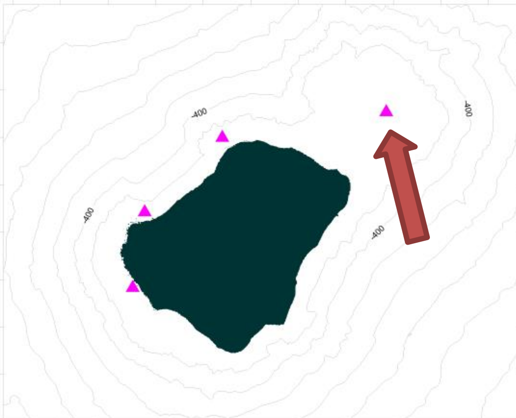
If energies are expressed in Joules and represented into a loglog plot, results of the **linear fit** are given in the Table on the right.

Two different behaviors are evident from the plot. Grouping the subaerial (SA), the submarine-subaerial (SS) and the shallow-water submarine (SW) cases, one obtains an **increase rate (coefficient A) in the regression law that is significantly lower than the respective increase rate** of the submarine (SM) cases.

Further, when potential energy is comparable, the SM cases are the least efficient **in transferring energy** to the water.



Maximum Tide Gauge Height vs. Slide Potential Energy



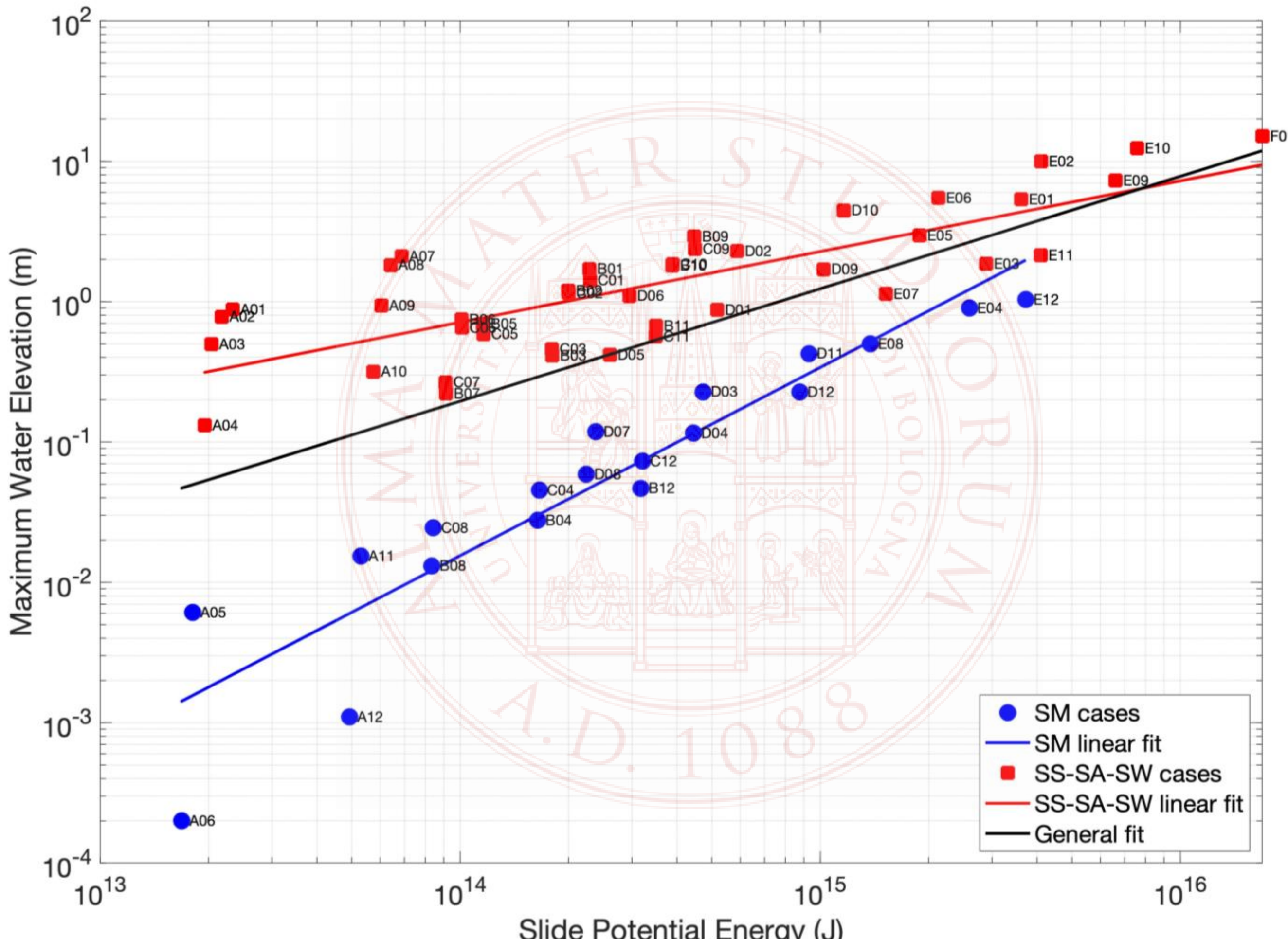
A similar correlation is investigated for the maximum tide gauge height (**MTGH**) computed in Strombolicchio, 2km NE of Stromboli, where a **permanent tide gauge** is installed.

$\text{Log } MTGH = A \text{ Log } SPE + B$		
Dataset	**A**	**B**
General	**0.80**	**-27.5**
SM	**1.34**	**-47.4**
SA-SS-SW	**0.50**	**-16.6**

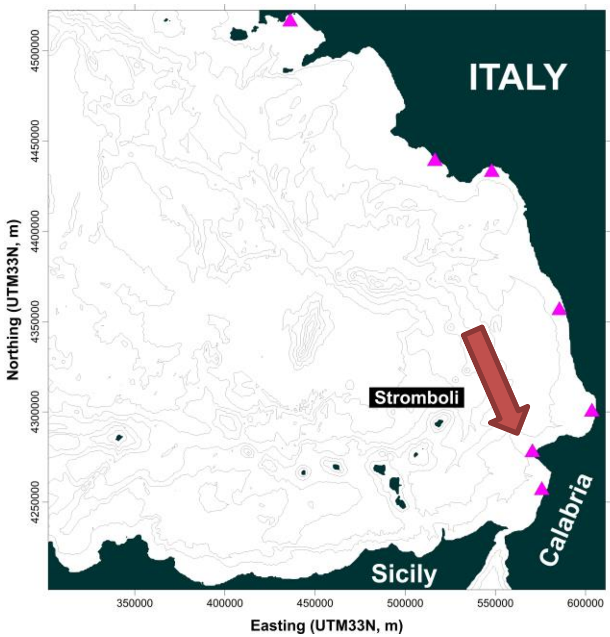
We observe that, like in the previous plot, the two groups of slide cases show **different behaviors**.

For the **SM** cases, the increase of water height (in m) with potential energy (in Joule) **is linear** (in the log scale): one order of magnitude growth in the slide potential energy entails about 4/3 orders of magnitude in the maximum water height.

For the **SA-SS-SW** cases, conversely, this is halved.

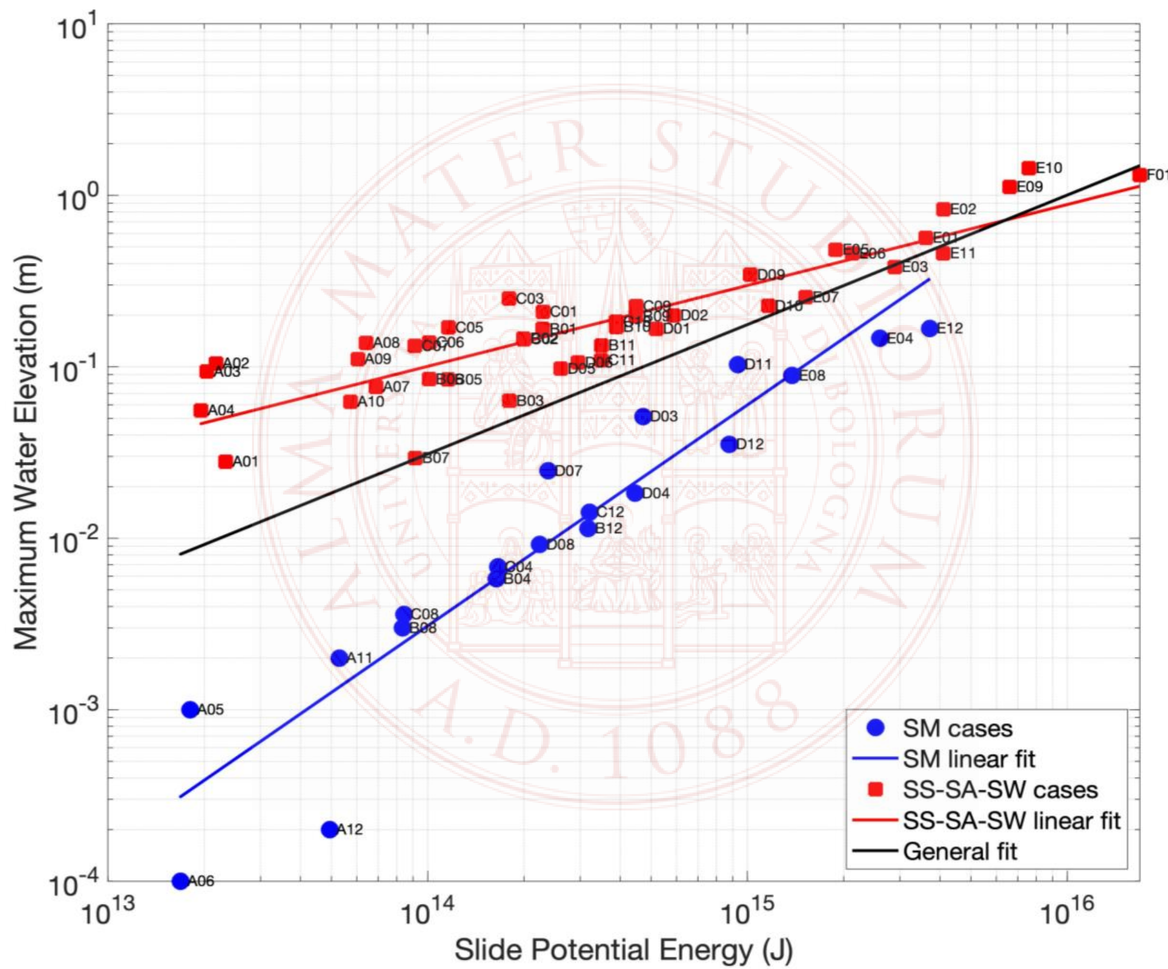


Maximum Tide Gauge Height vs. Slide Potential Energy



Enlarging the investigation to the **Tyrrhenian coasts**, the same approach is adopted also for a virtual **tide gauge** placed in **Capo Vaticano** (see the map on the left for location).

$\text{Log } MTGH = A \text{ Log } SPE + B$		
Dataset	**A**	**B**
General	**0.75**	**-27.8**
SM	**1.28**	**-47.3**
SA-SS-SW	**0.47**	**-17.5**



The same categorization of the tsunamigenic landslides results useful also for establishing a relationship between the maximum water height computed in a **more distant tide gauge** and the slide potential energy.

Remarkably, the coefficients of the linear fit are **very similar** to the previous ones.

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