

Source identification of extreme event deposits in the Lesser Antilles using numerical modeling of tsunami wave propagation

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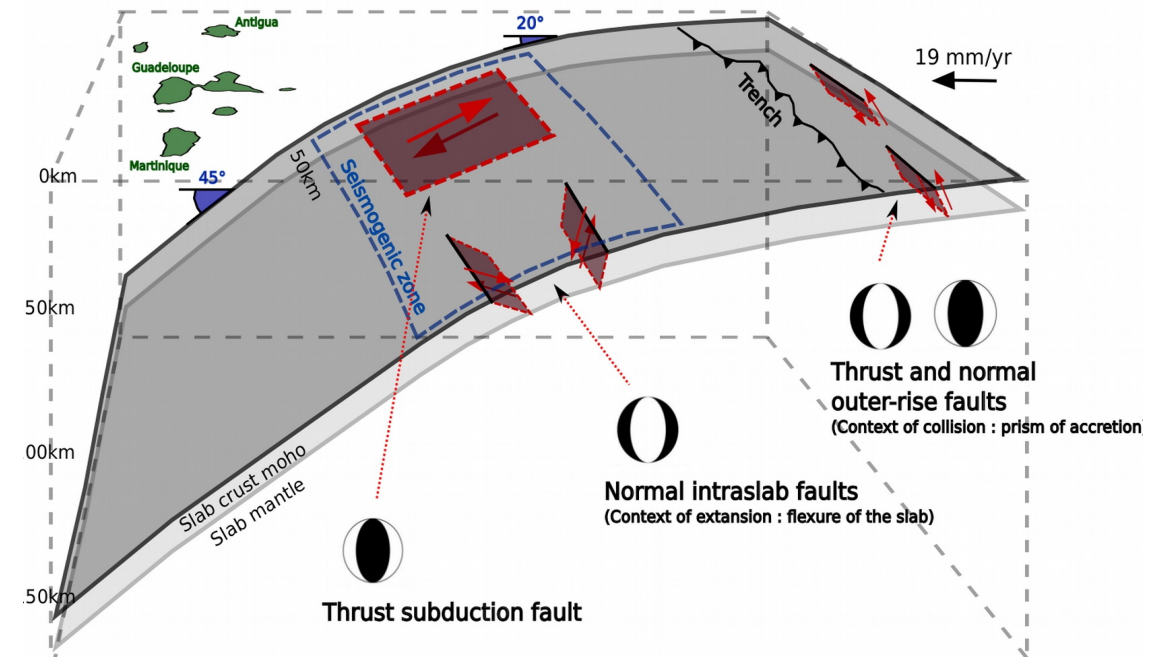
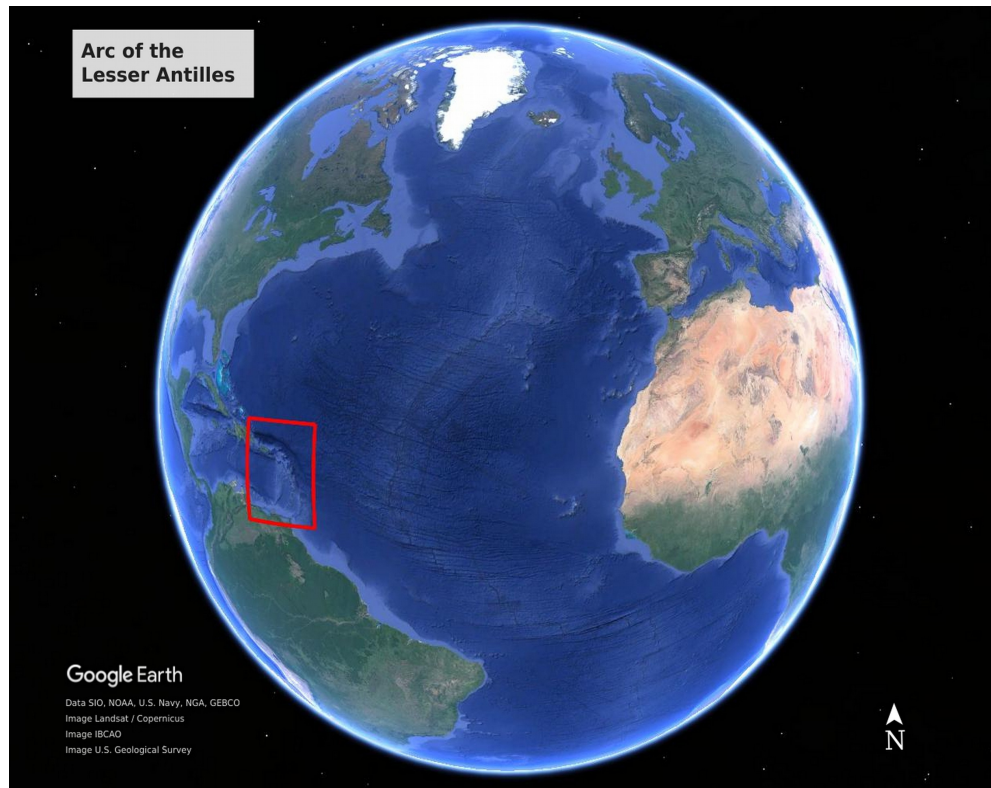
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- Introduction : CarQuakes project and the Lesser Antilles historical events
- The traces of a Middle Age tsunami in the Lesser Antilles
- The fault systems of the Lesser Antilles and choice of simulation sources
- Results of tsunami simulation
- Development of sediment transport model
- Conclusion

- **Carquakes Project** : Pluridisciplinary study of extreme event traces in the arc of the Lesser Antilles, aiming for a better understanding of the seismic cycle of the subduction zone and the evaluation of the seismic and tsunamigenic risks.

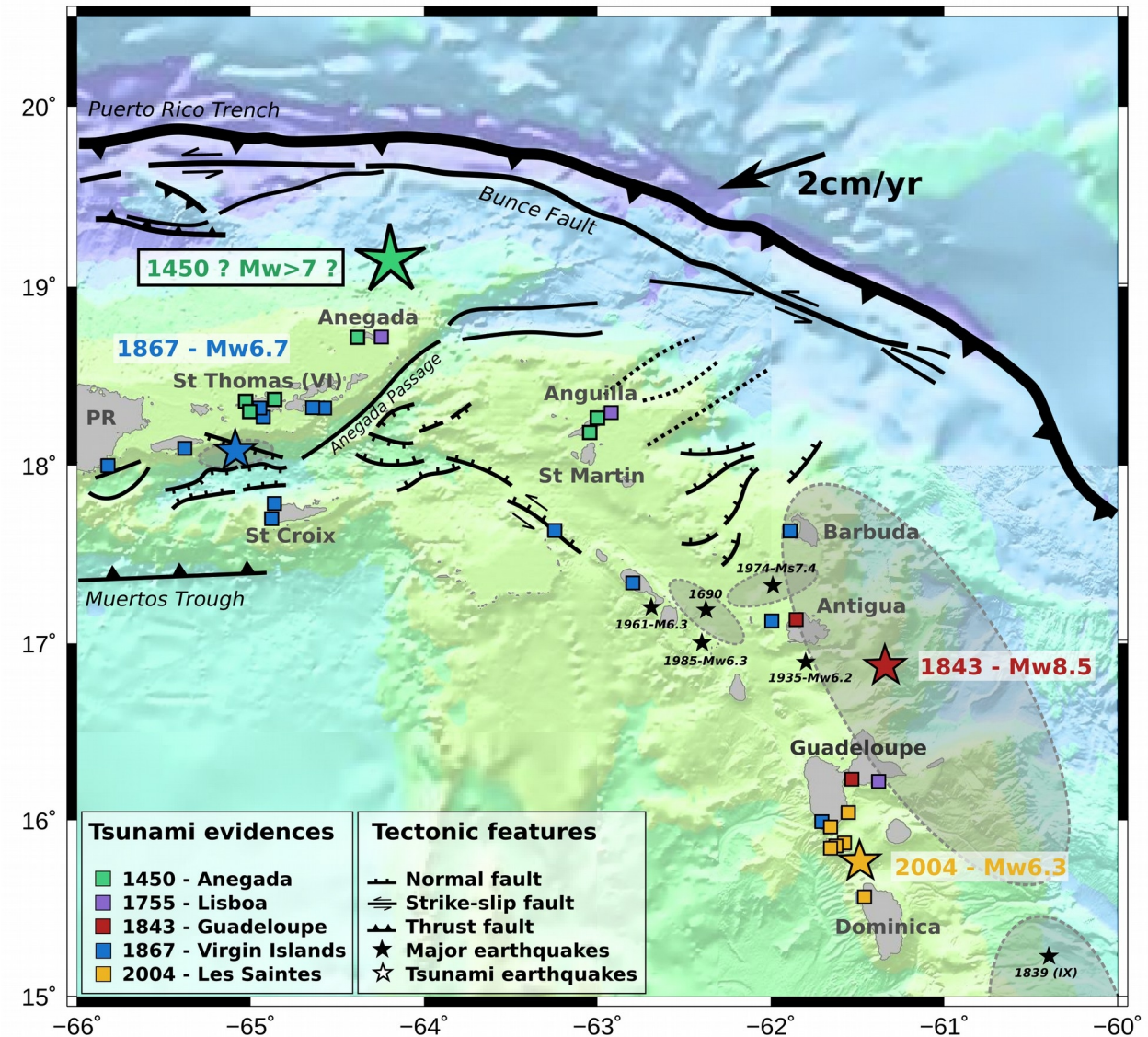


- Historical earthquakes and tsunami

Several $M_w > 7$ earthquakes (1839, 1843, 1867, 1969, 1974)

Tsunami earthquakes :

- 1755 : tsunami deposits associated to the Lisboa earthquake and tsunami ($\sim M8$)
- 1867 : 10m waves in St-Thomas, Virgin Islands ($M7.0$)
- 1843 : 1-2m run-up in Guadeloupe and Antigua ($M8.5$)
- 2004 : 1-2m waves in Les Saintes, Guadeloupe ($M6.3$)



- Three main area of the Lesser Antilles

Old earthquakes

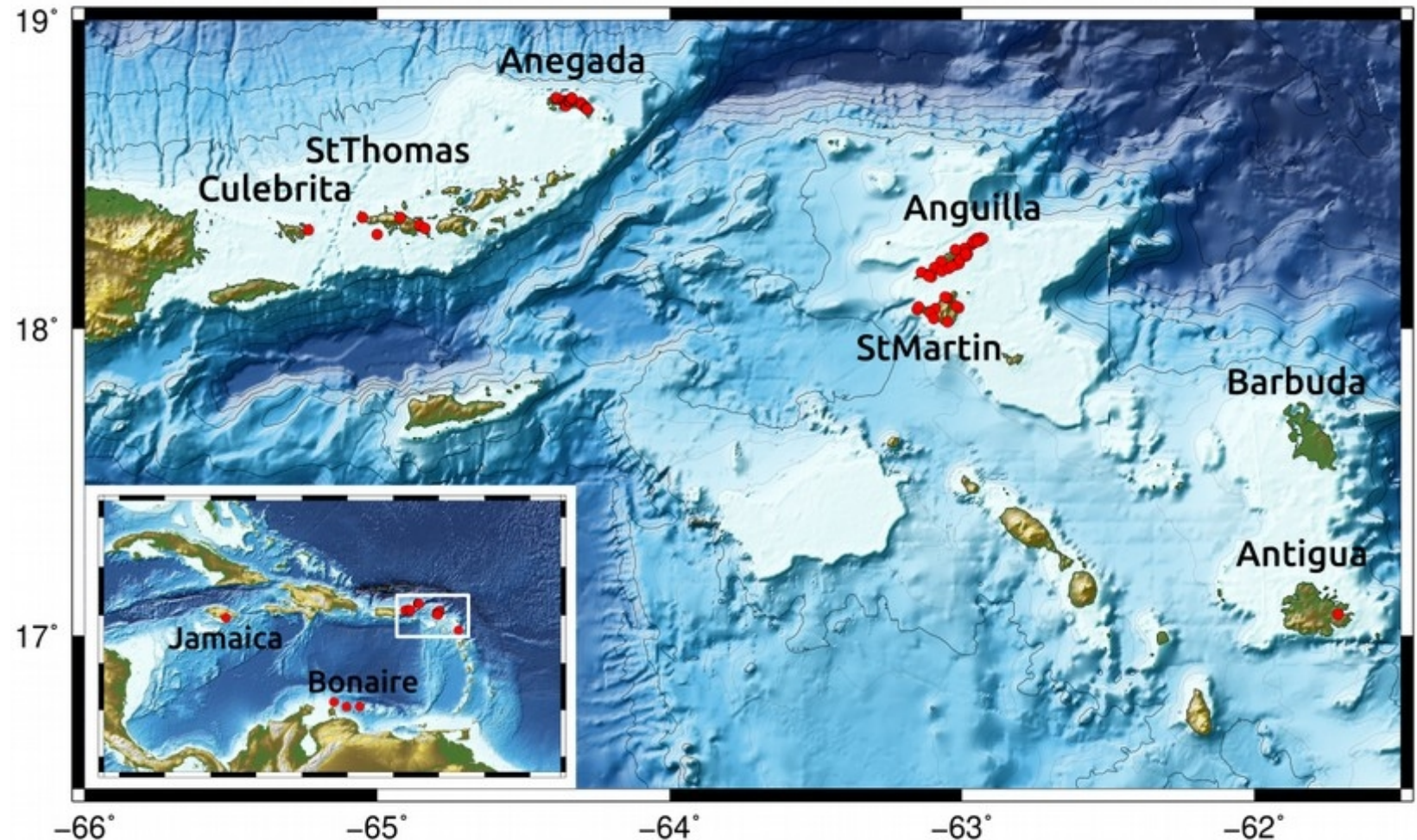
- No instrumental records
- Human testimonies or tsunami traces

Tsunami traces

- Deposits at the surface (boulders, clasts...)
- Deposits in sediment cores

Deposits dated from ~500yrs BP

- Anguilla and Scrub Islands
- Anegada Islands
- St-Thomas Island



- Anguilla – Scrub

A. SCHEFFERS et al. 2006 :

Boulders, clasts and sand deposits observed in Scrubb and Anguilla up to **12m** above the sea level.

Two samples dated from **~500 yrs BP**.

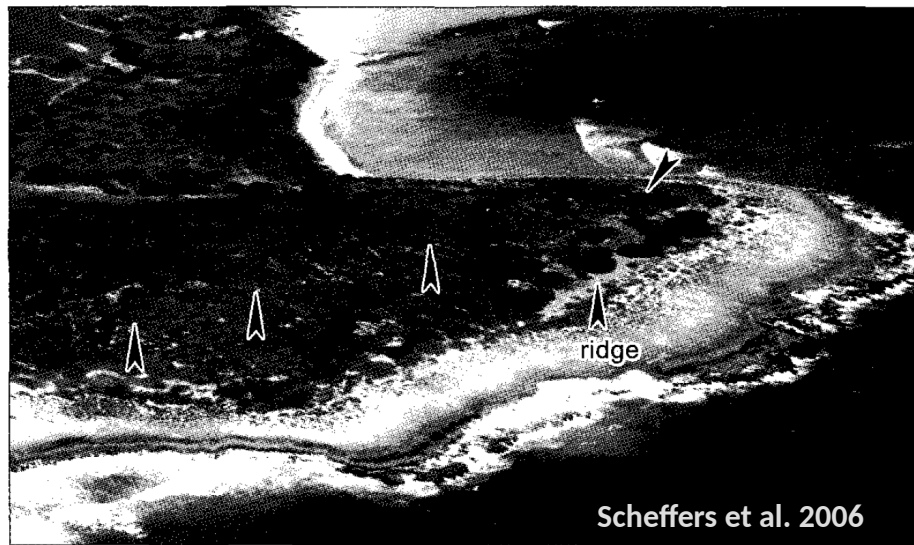
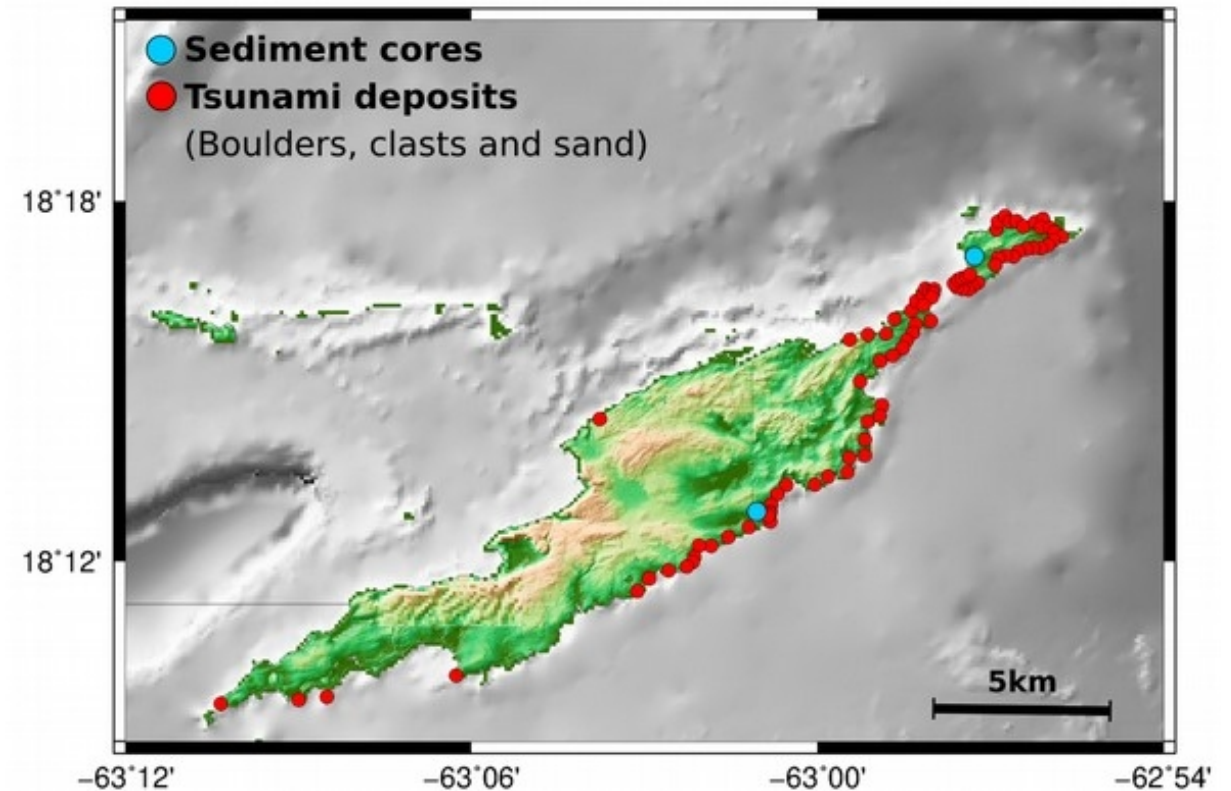


Figure 18. Headland south of Sandy Hill Bay with a debris ridge as well as large boulders in the vegetation at around +10–14 m asl.



Figure 14. Tsunami boulder fields at Abadam Hole on top of a terrace at about +12 m, separated from the cliff by a debris free belt.

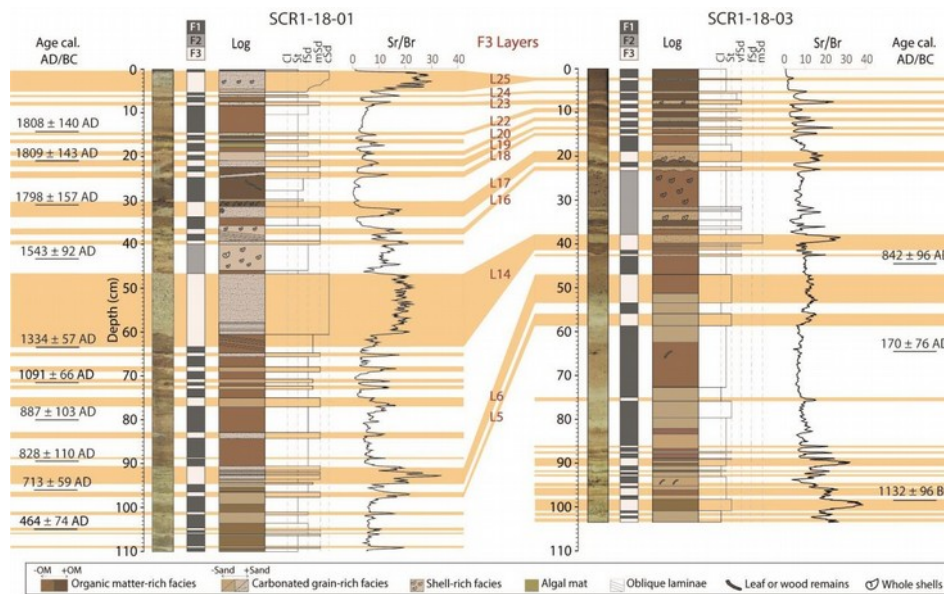


- Anguilla – Scrub

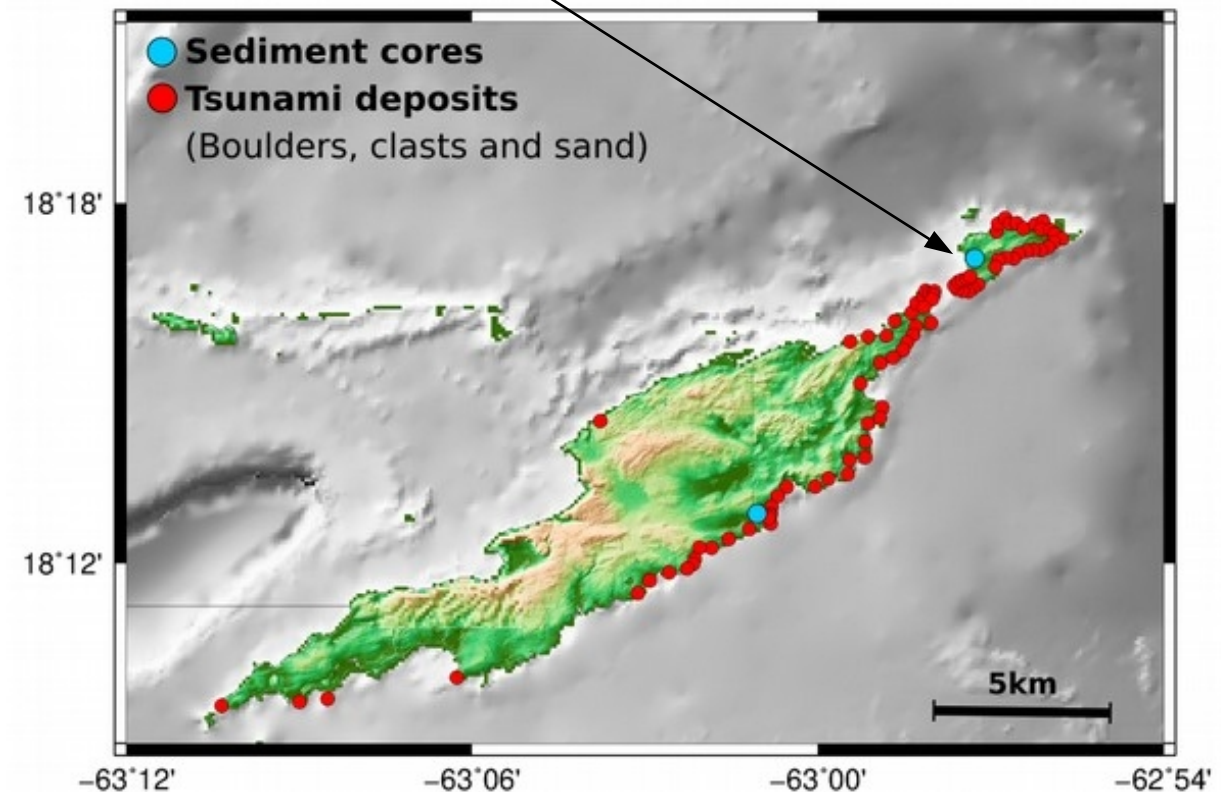
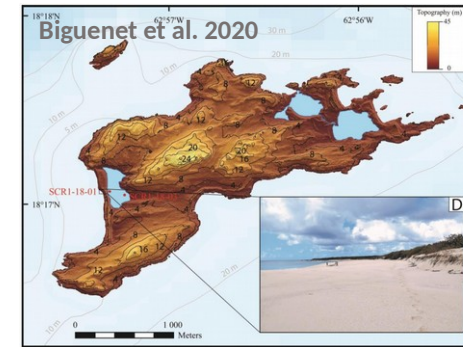
Biguenet et al 2020 :

5 sediments cores sampled in 2018 from a lagoon in Scrub and a pond in Anguilla.

Deposits dated from ~500yrs BP



Biguenet et al. 2020

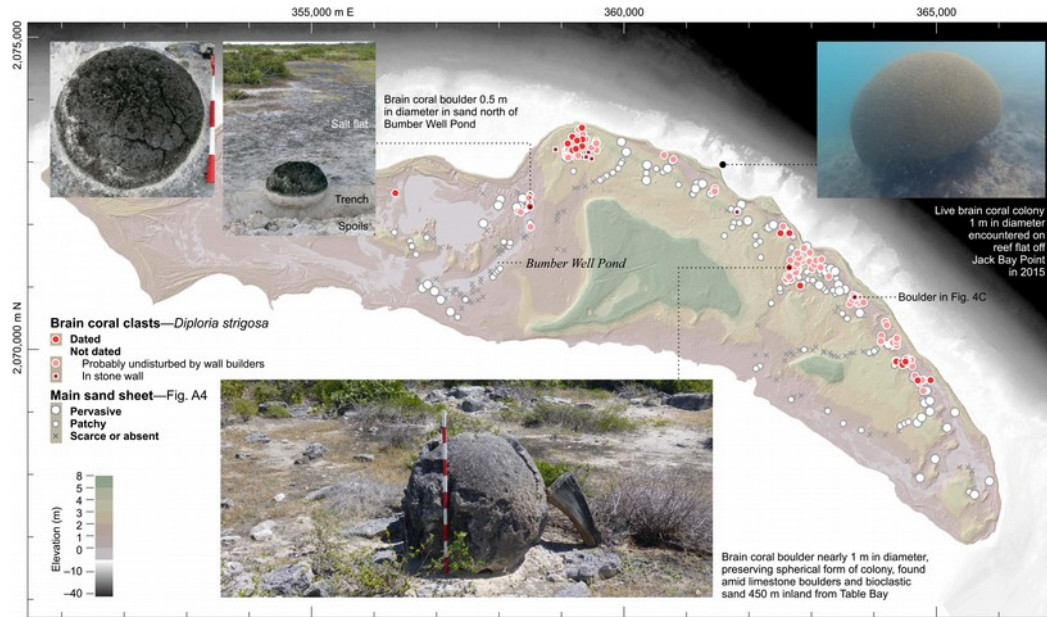


- Anegada Island

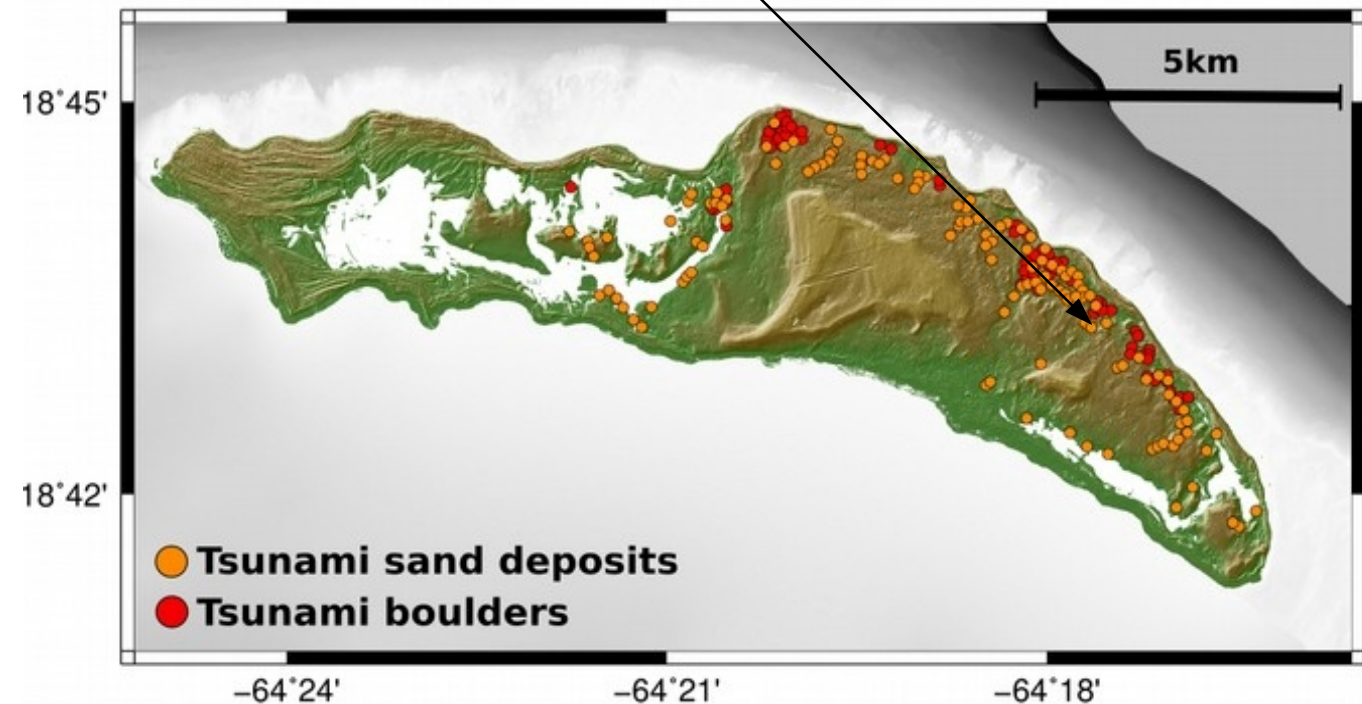
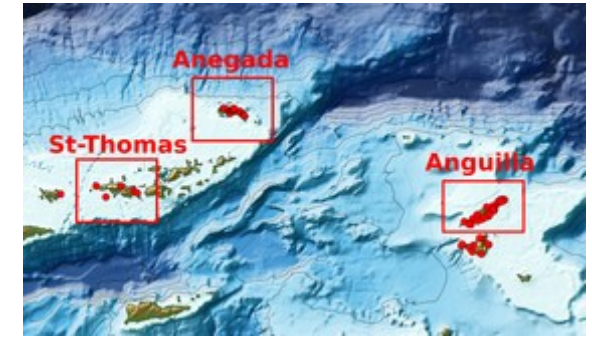
Atwater et al 2017 :

Boulders (~200), clasts and sand deposits observed in Anegada Island.

~36 clasts and 16 brain corals dated from ~500yrs BP



Atwater et al. 2017

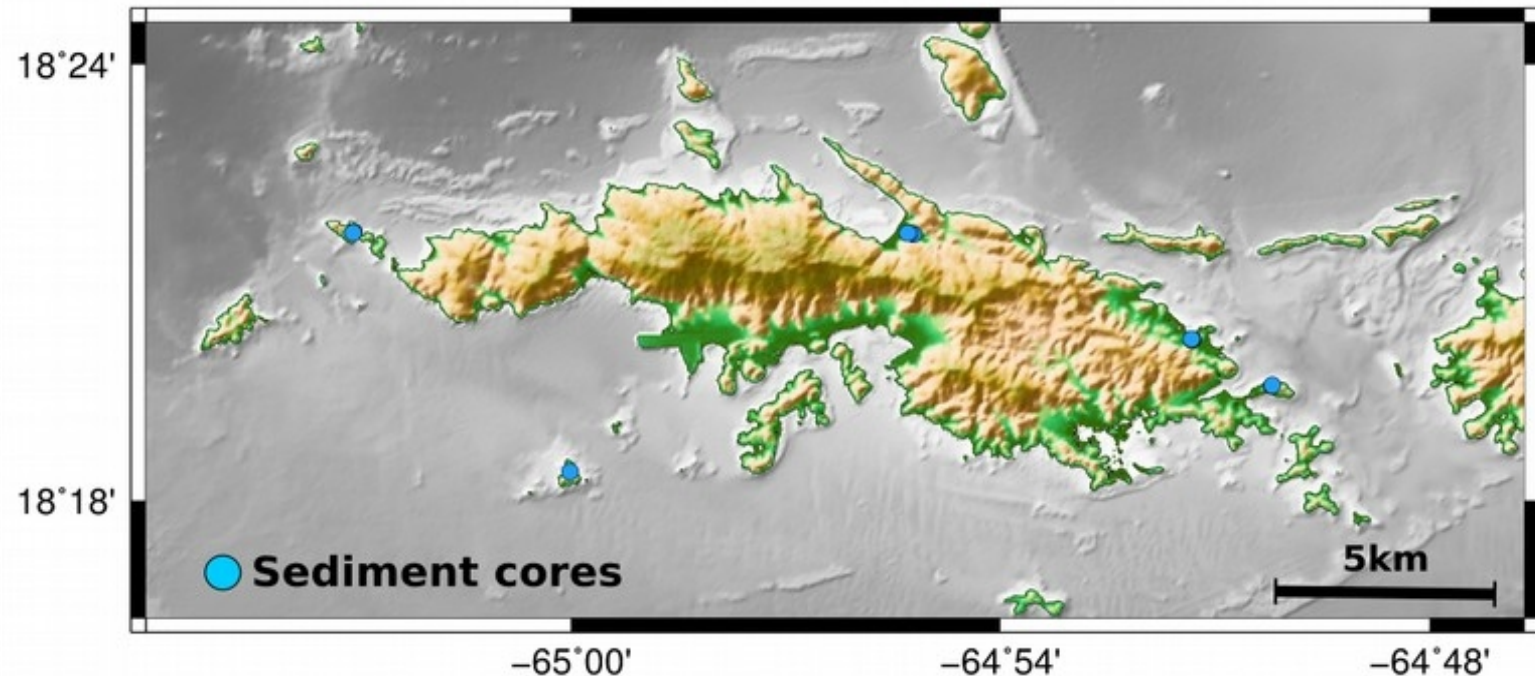
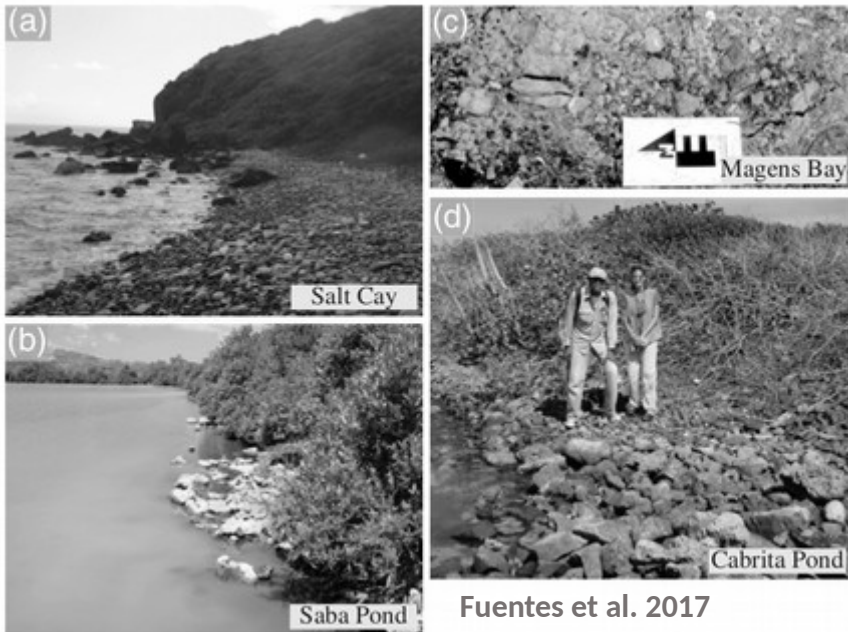
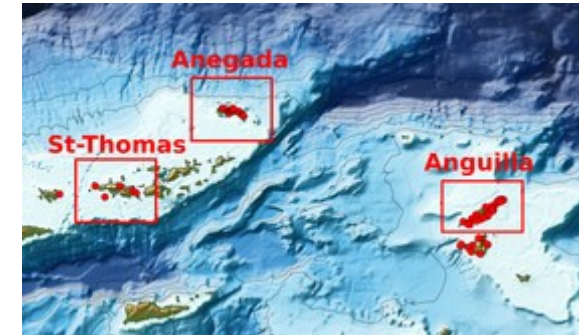
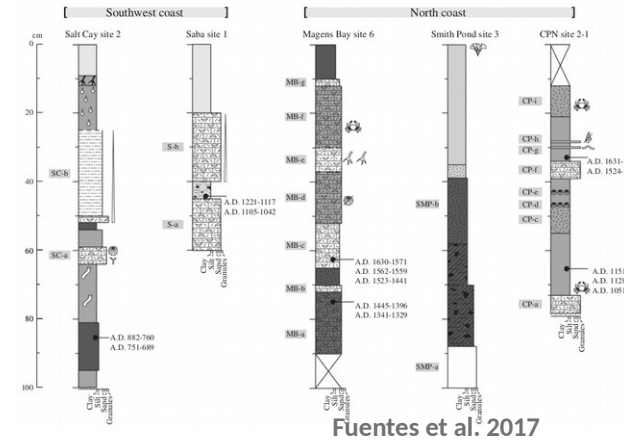


- St-Thomas (Virgin Islands)

Fuentes et al 2017 :

12 sediment cores sampled from 5 coastal ponds

Tsunami deposit dated from ~500yrs BP in the 5 locations

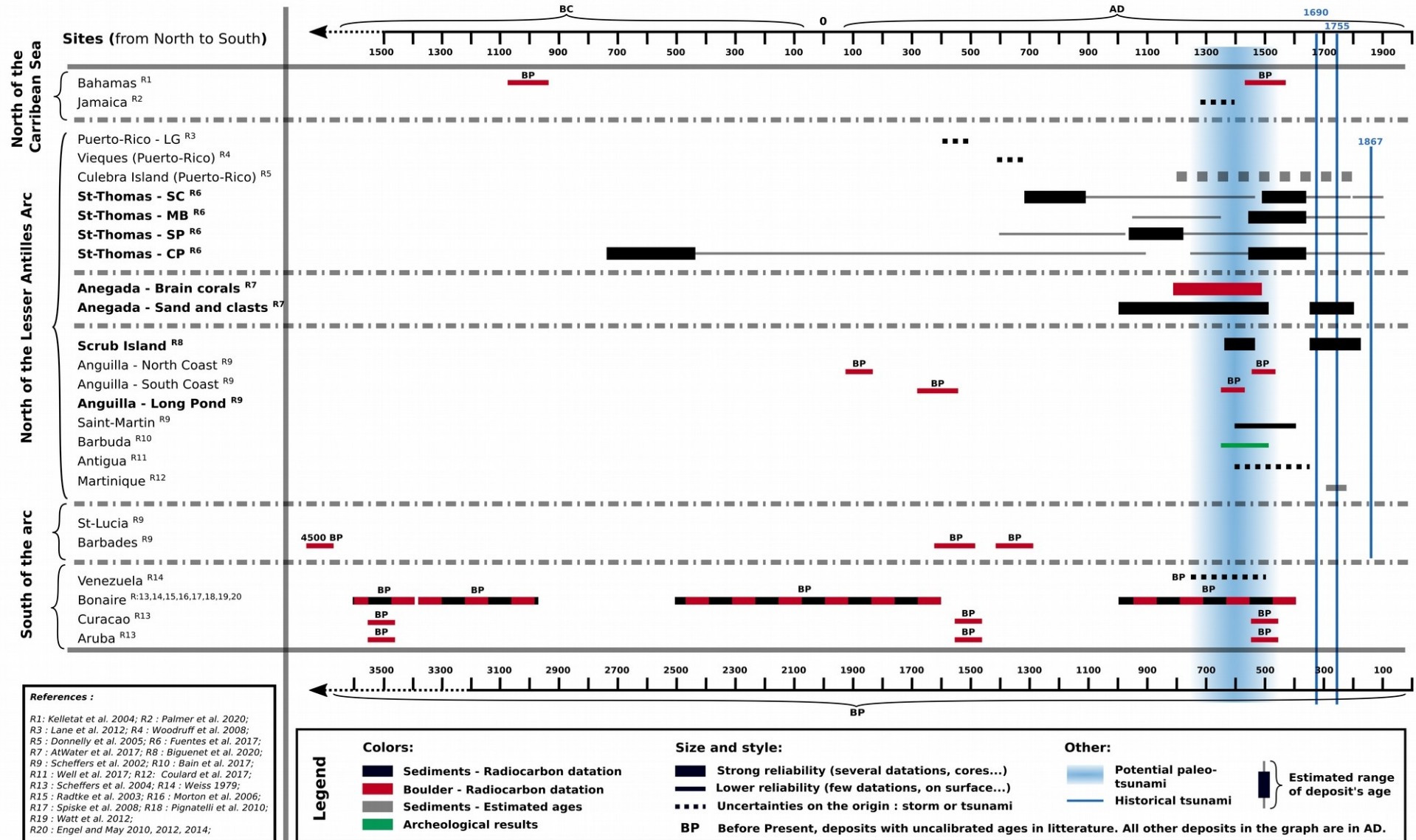


Datations :

- Anguilla and Scrub Islands : 1364 – 1469 yrs AD
- Anegada Islands : 1200 – 1480 yrs AD
- St-Thomas Island : 1200 – 1450 yrs AD

Tsunami simulation :

- One or several events ?
- Which fault systems ?



- Subduction contact

Subduction dip : 10°

Lateral segmentation :

- Anegada passage
- Barracuda ridge

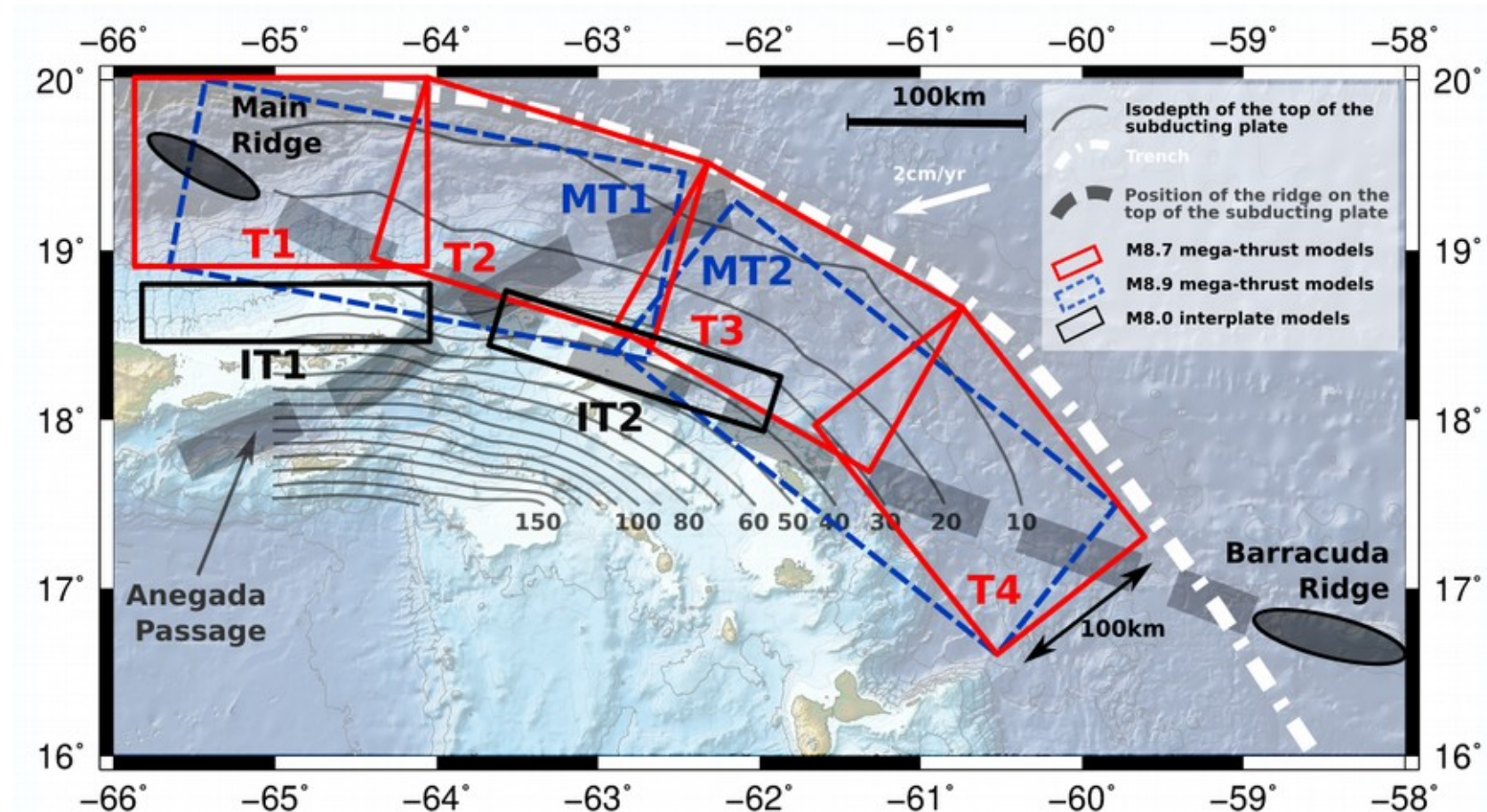
Depth segmentation :

- Seismogenic zone (0 to 50km)
- Subducted ridge

Mw8.7 thrust fault models (T1,T2,T3,T4)

Mw8.9 mega-thrust models (MT1, MT2)

Mw8.0 interplate 50km deep models (IT1,IT2)



Ref : Laurencin et al 2018 ; Pauletto et al. 2017 ; BieHick et al. 2019

- Intra-Arc fault systems**

Aneгада passage normal faults (F1, F2, F3, F4)

Trench perpendicular normal faults (F12, F13, F14, F15)

Trench parallel normal faults (F6, F7, F8, F9...)

Ridge and Outer-Rise faults (OR1, R1, R2)

Fault parameters (Okada Model) :

Rupture depth : 0 to 15km (Moho ~ 20-25km)

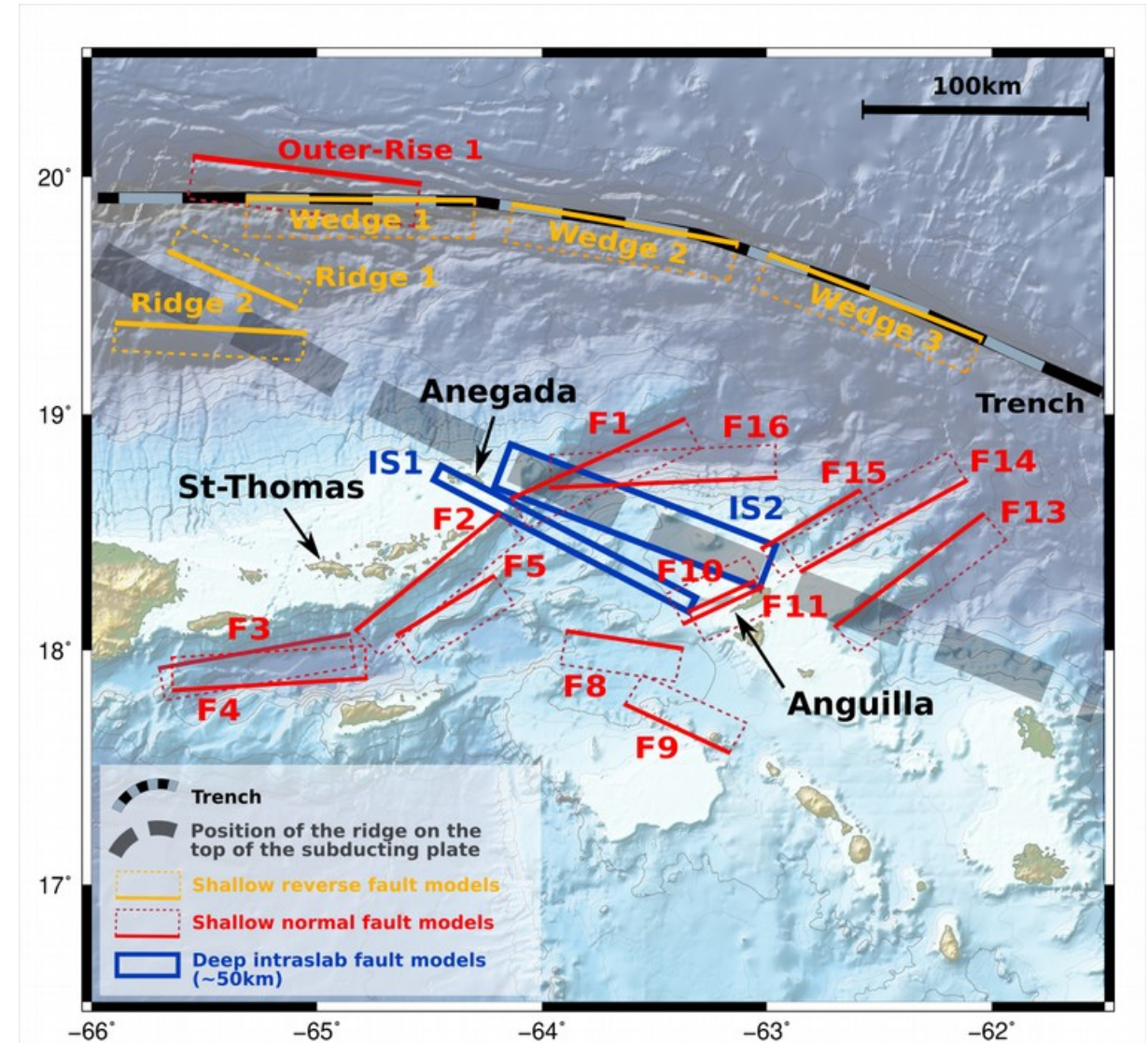
Angles : 45° dip; 90° rake

Lengths : 30km-100km and width : 20km - Slip : 2m

Magnitude : Mw7 to Mw7.5

- Other faults :**

Subduction wedge fault models (Wedge), Intraslab deep fault model linked to the subducted ridge (IS1, IS2)

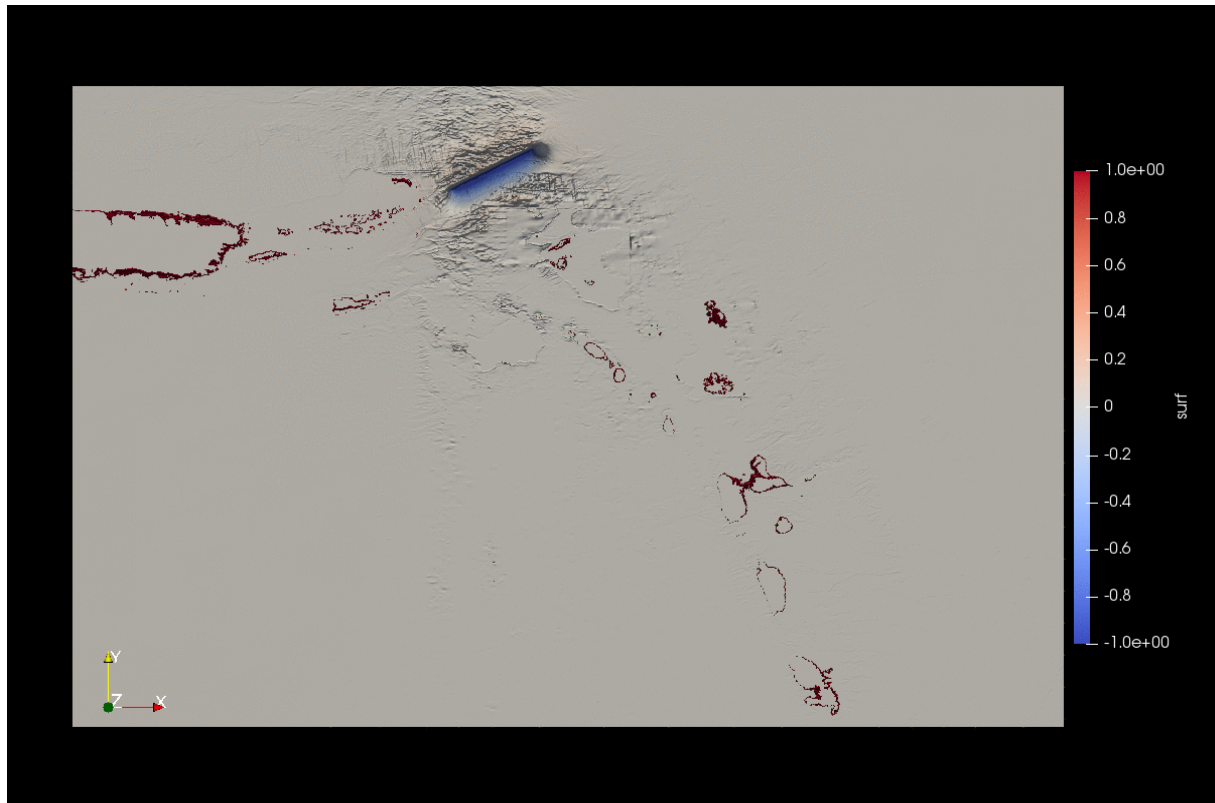


Ref : Feuillet et al. 2011; Laurencin et al. 2017; Pauletto et al. 2017; Santibanez et al 2019.

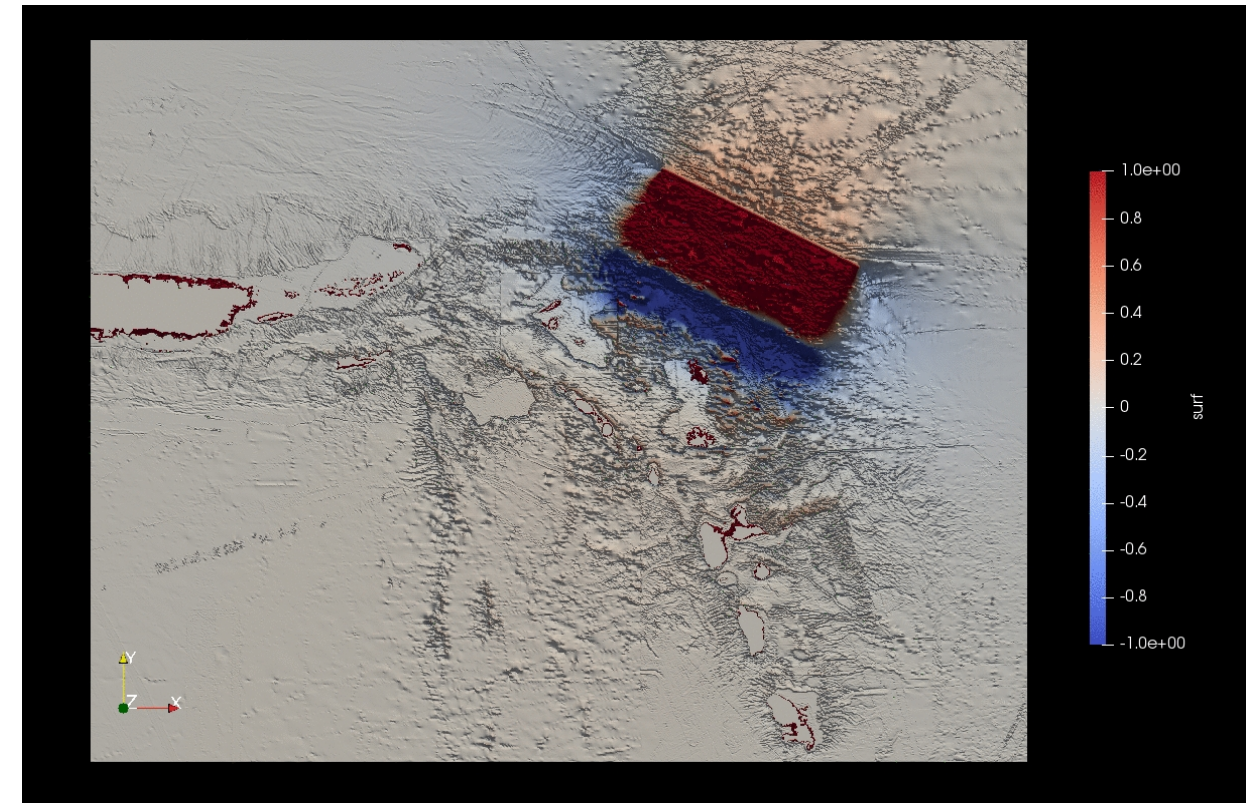
- **Simulations** : Okada model initial surface elevation, shallow water equations of wave propagation

Water elevation maps of 1h tsunami propagation in the Lesser Antilles :

Intra-arc fault model 1 : maximal water height of 1-2m

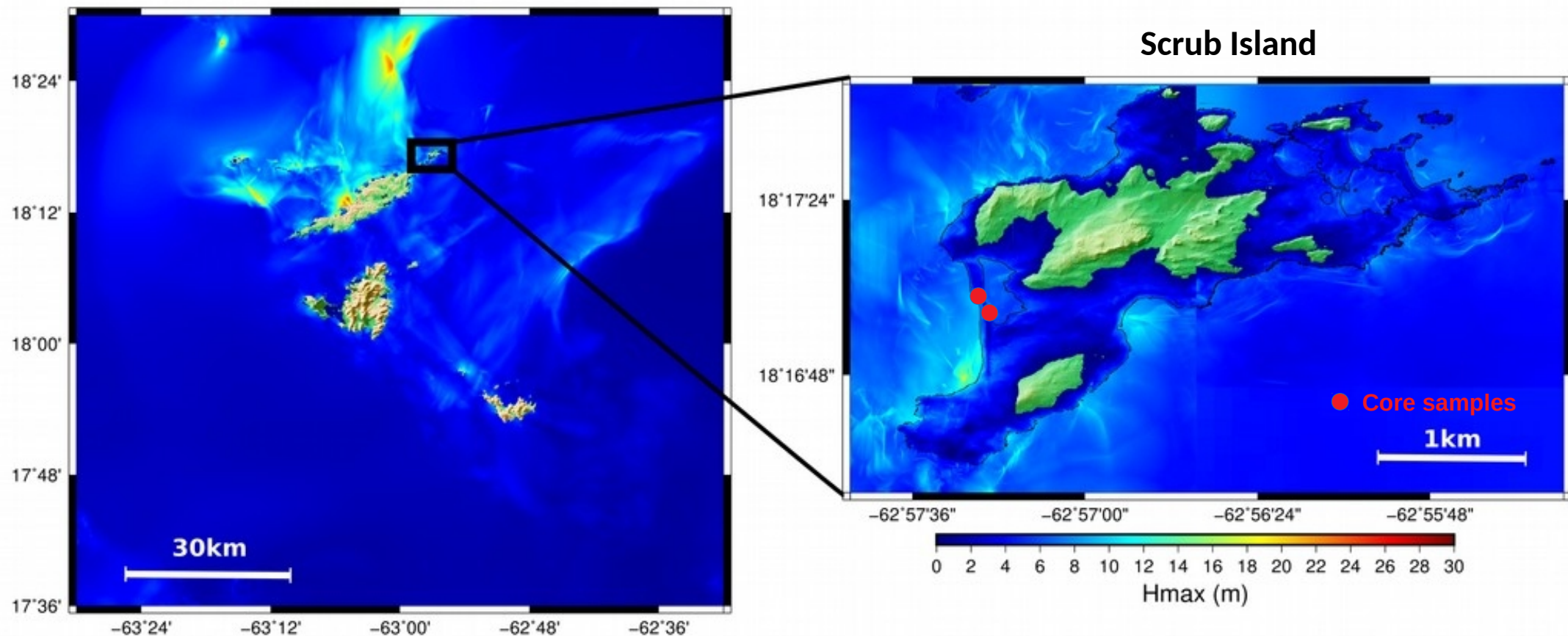


Mega-thrust fault model 3 : maximal water height of 20 m

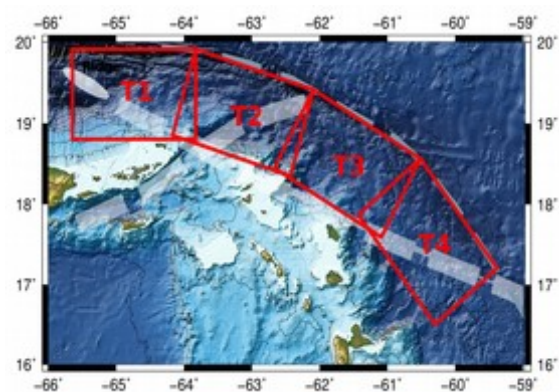
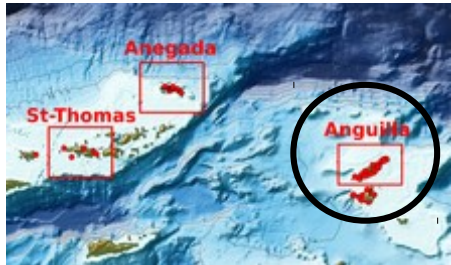
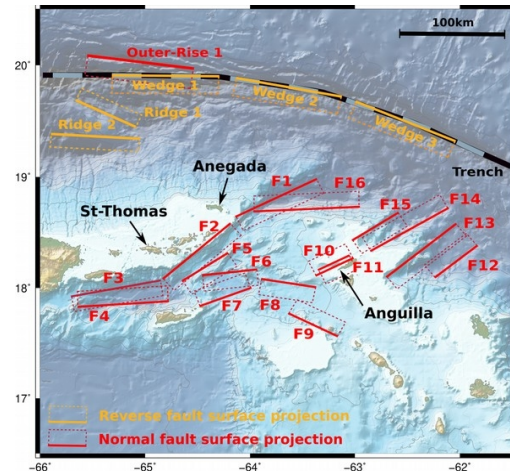


- **Simulations** : 23 grids from 450m resolution to 1m resolution

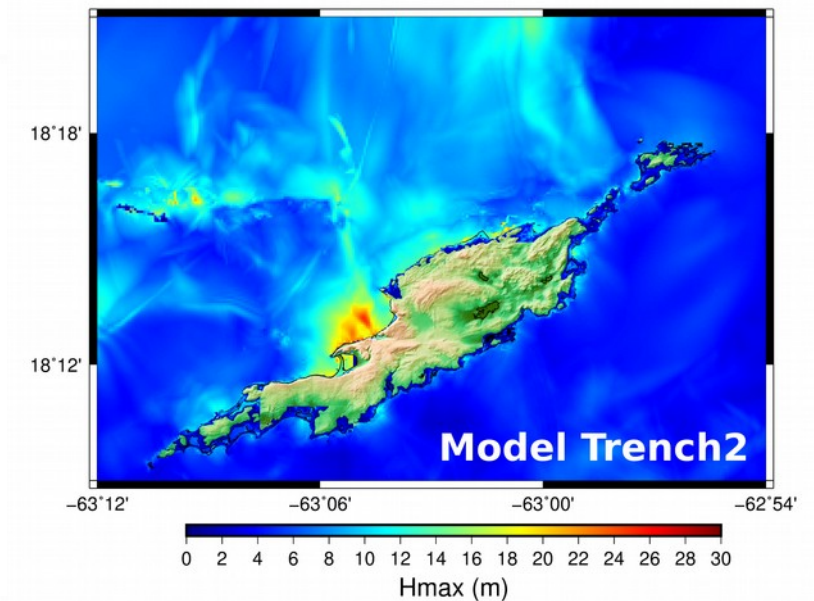
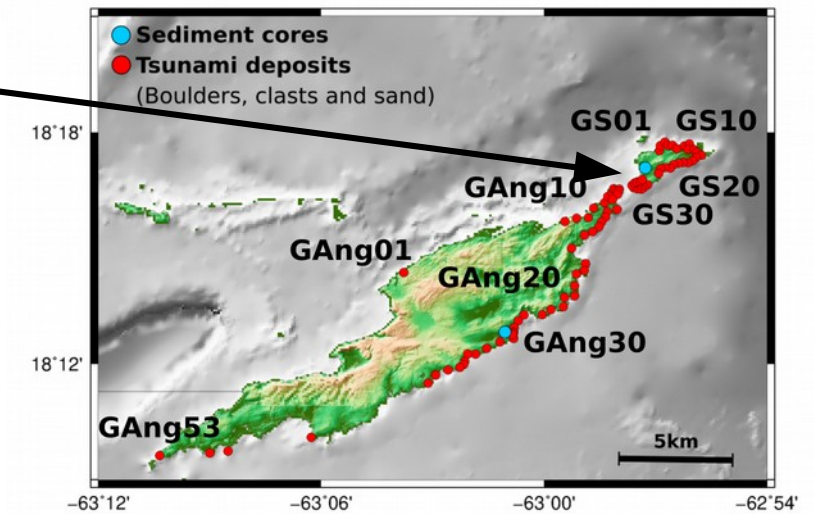
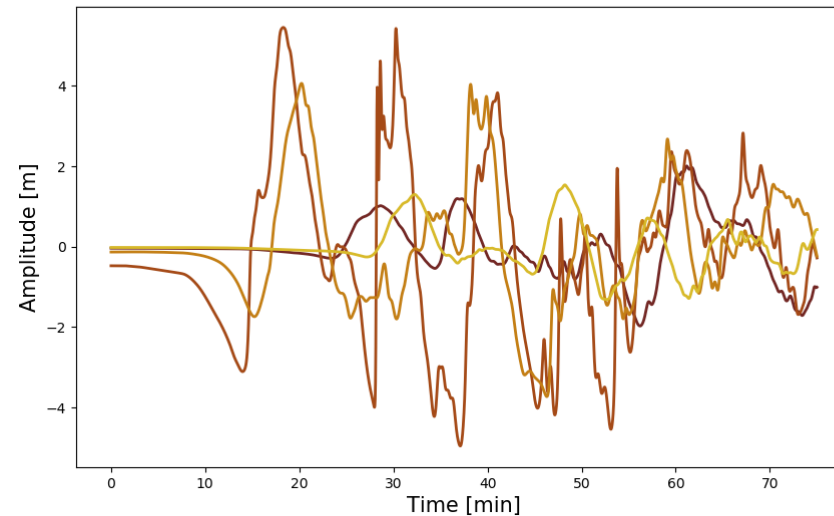
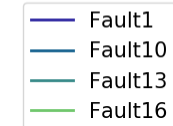
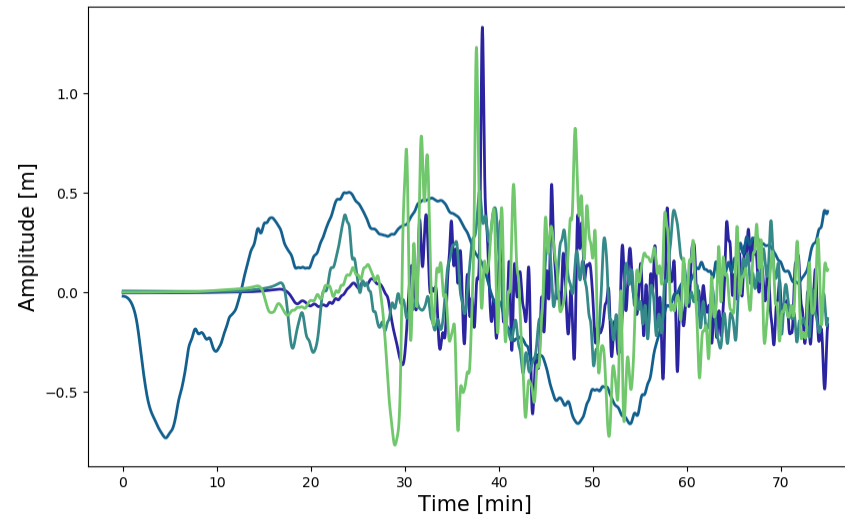
Results of the Mega-Thrust fault model 2 : 100m resolution grid and 1m resolution grid

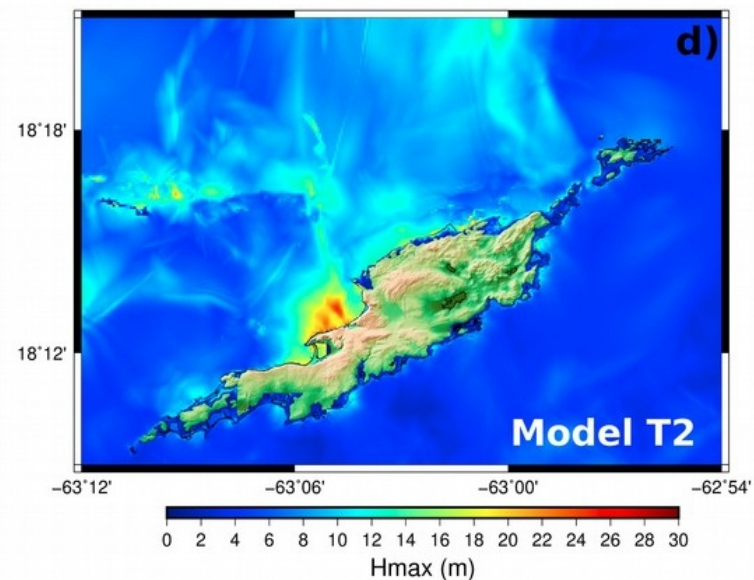
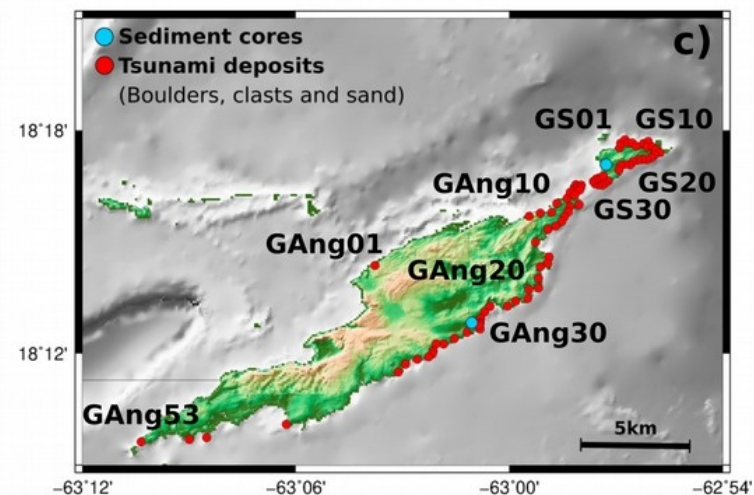
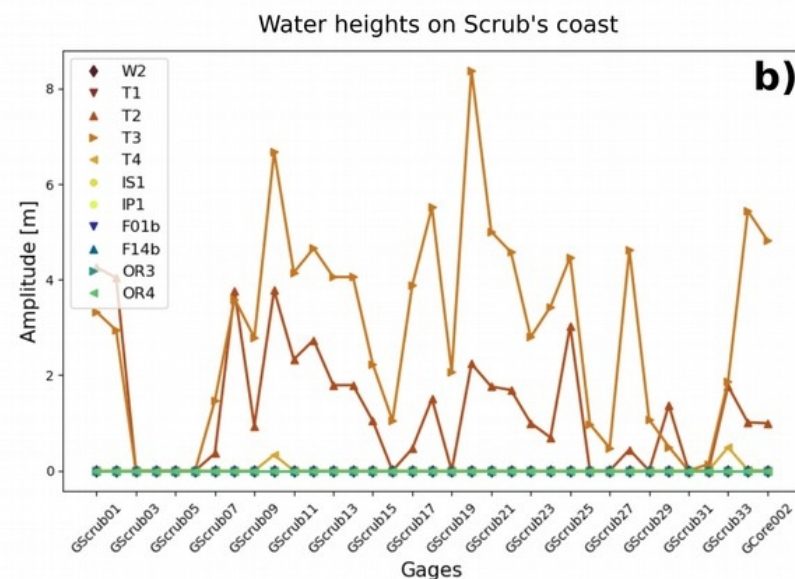
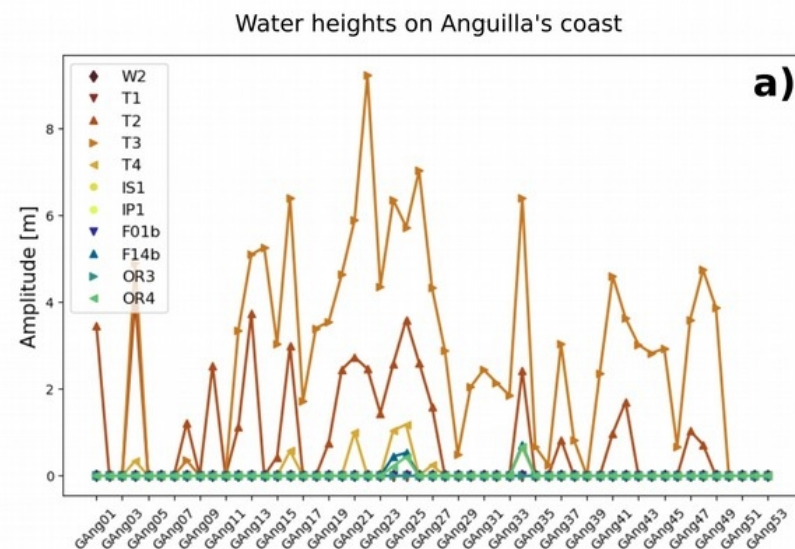
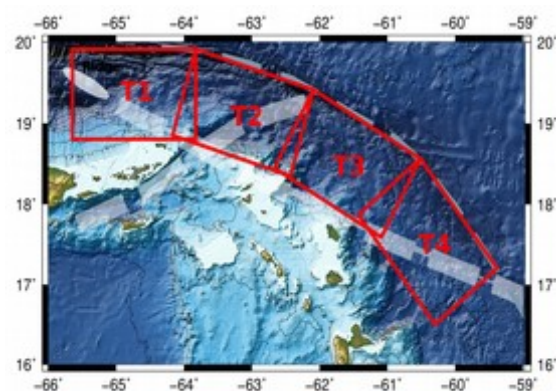
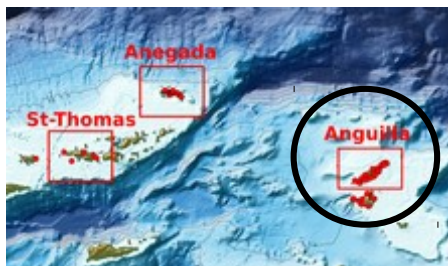
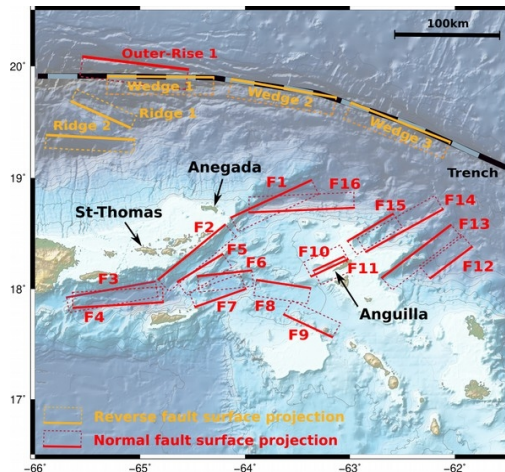


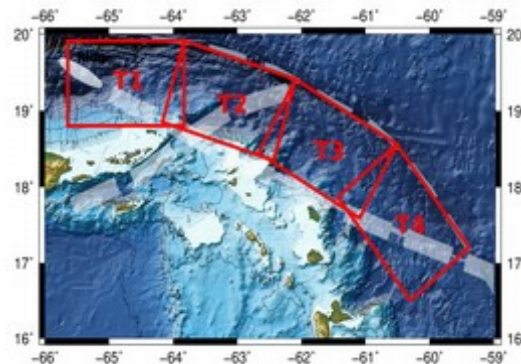
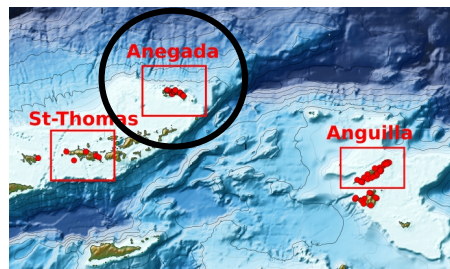
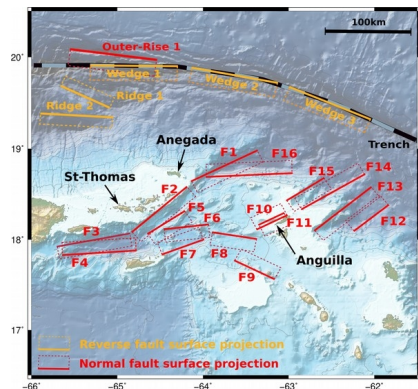
Simulation results : Anguilla



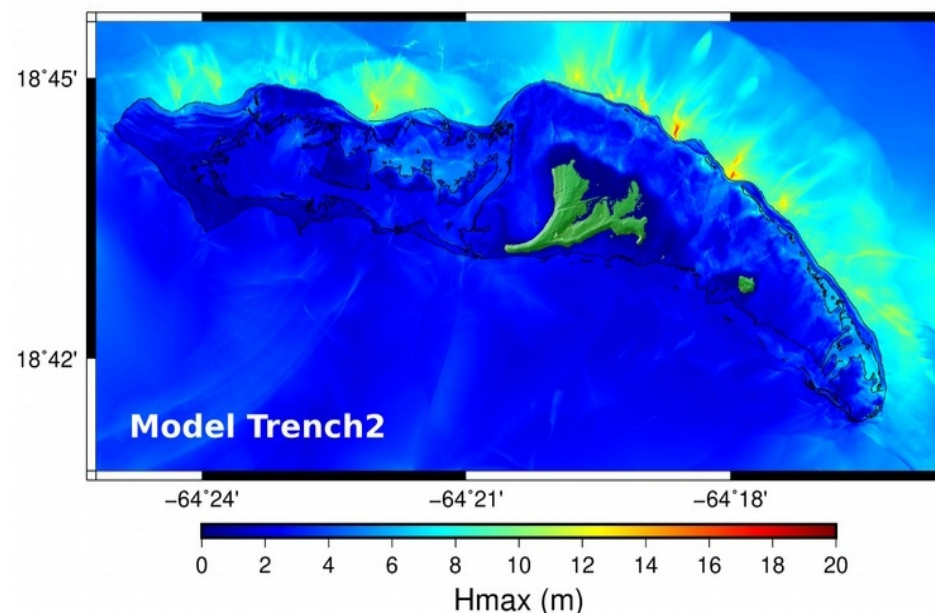
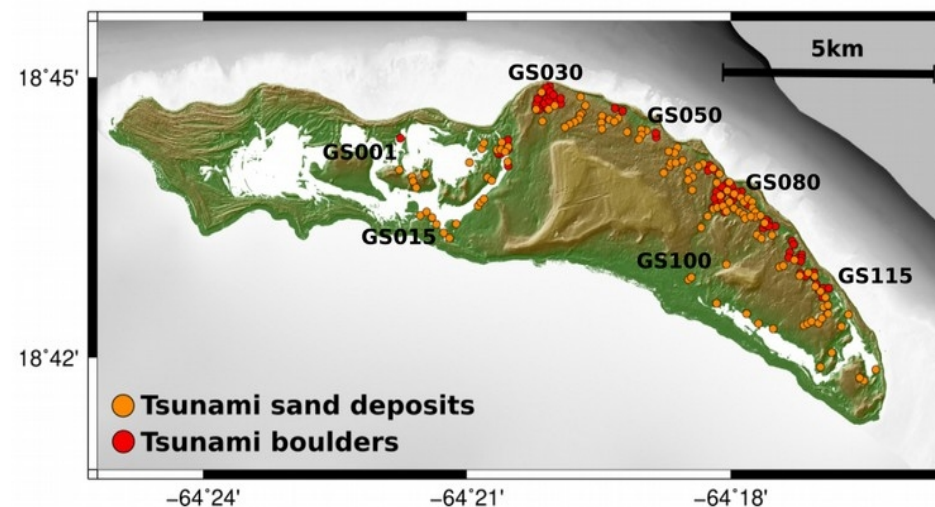
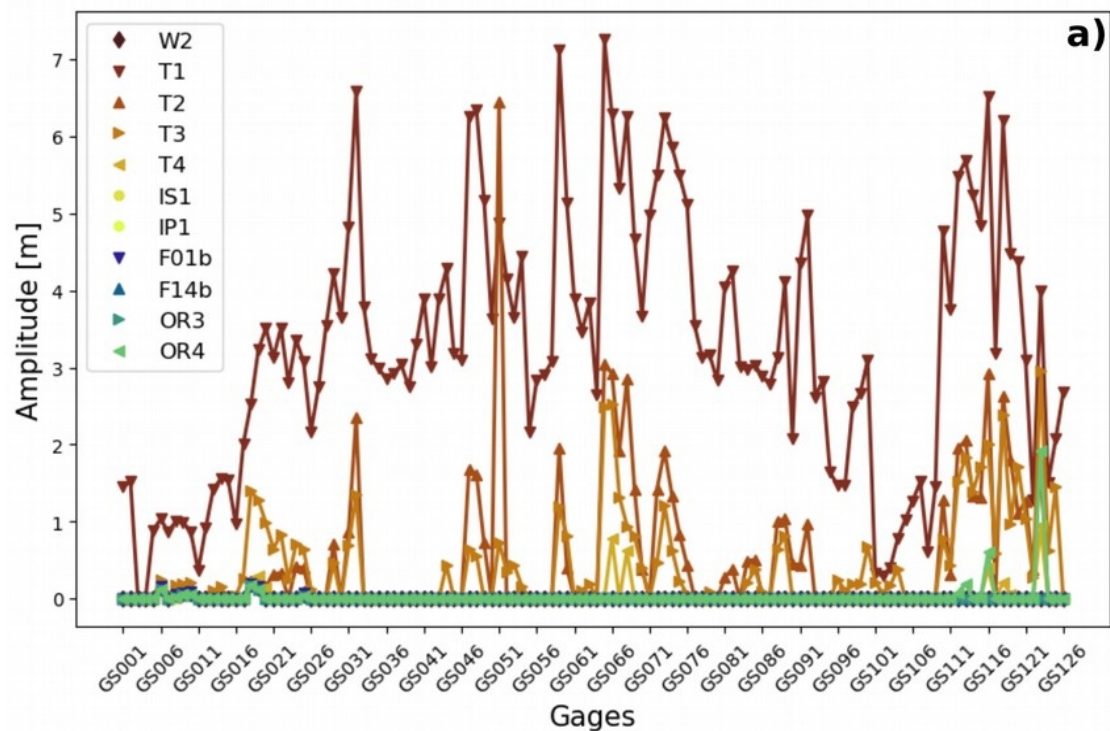
Gage record offshore Scrub Island

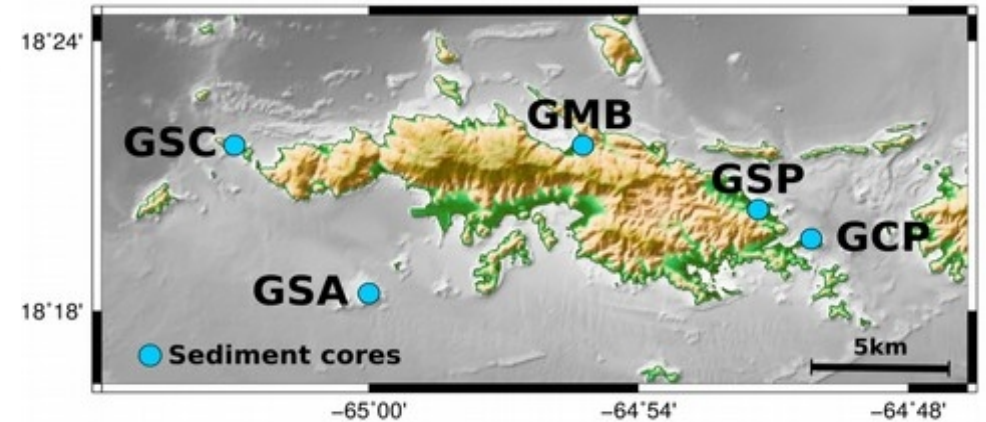
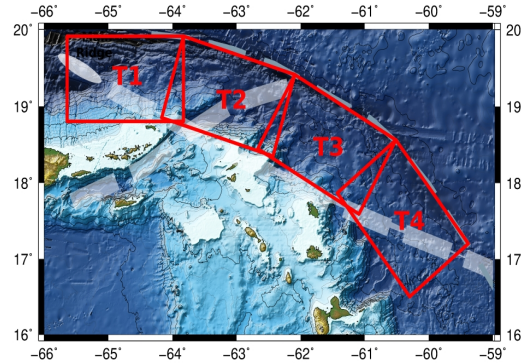
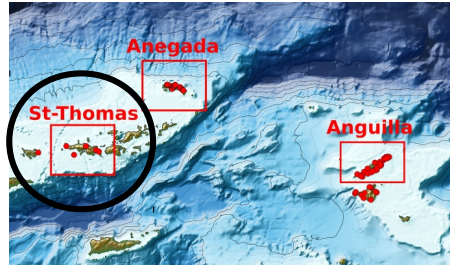
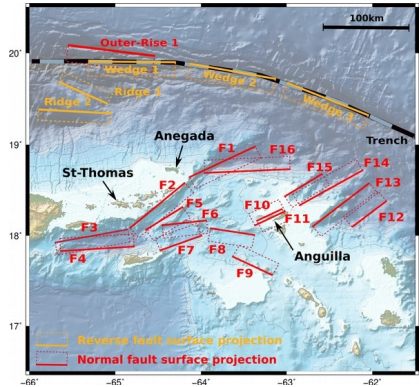




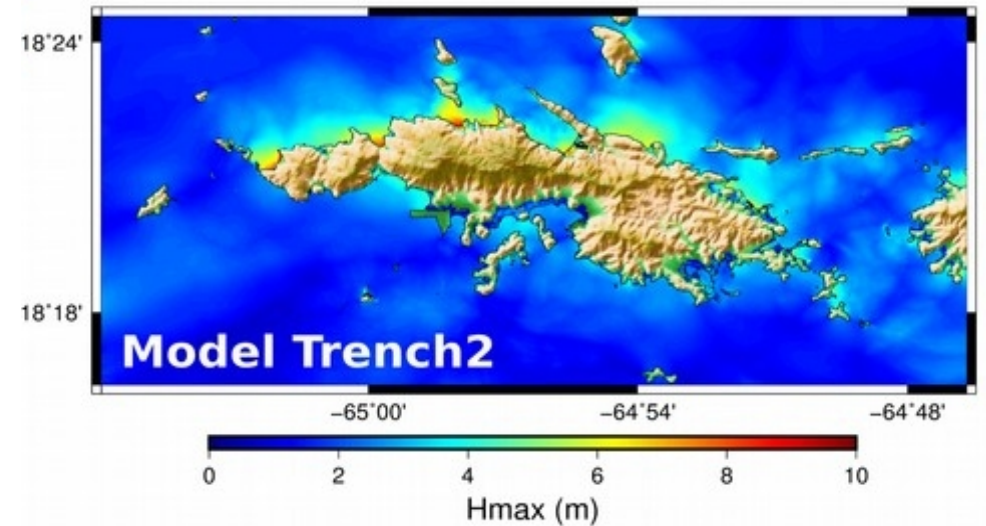
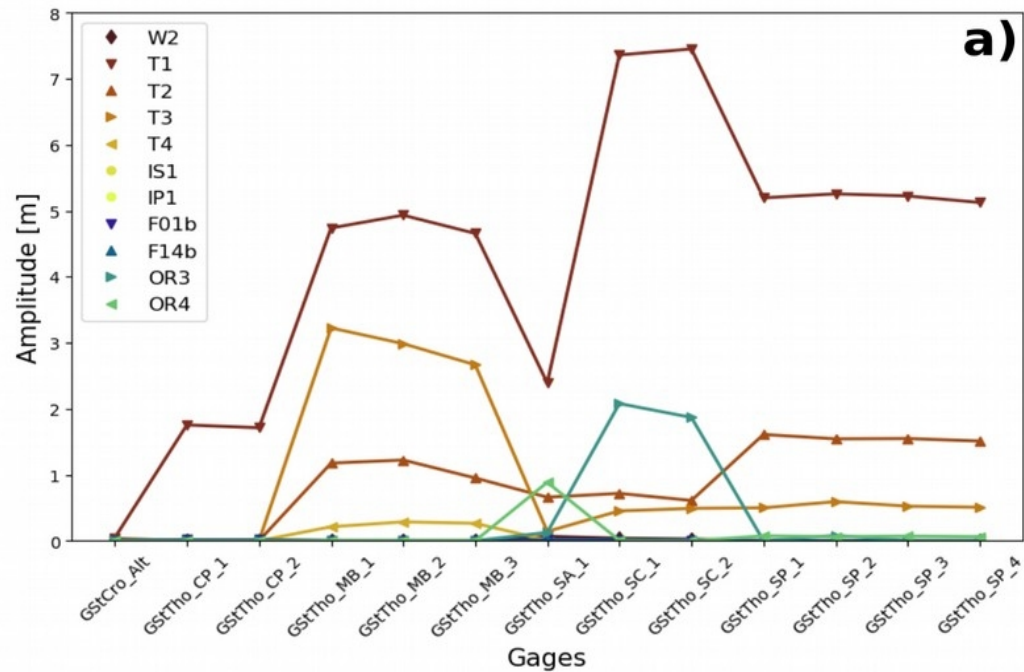


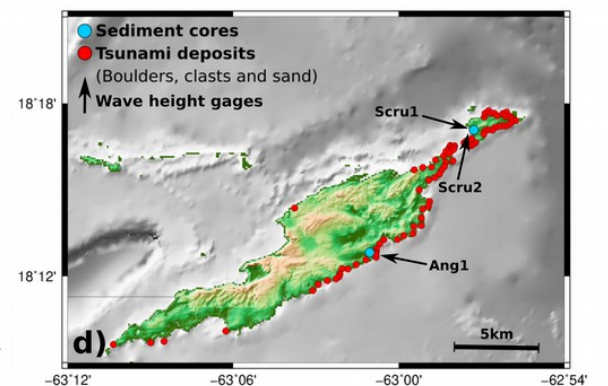
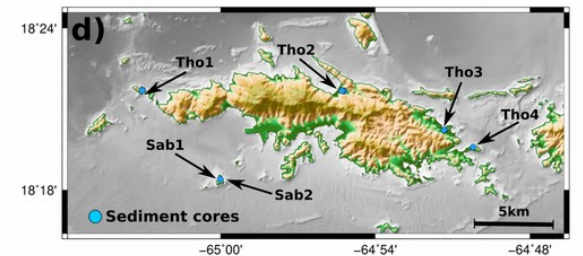
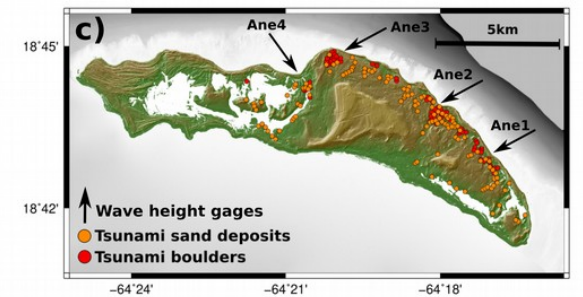
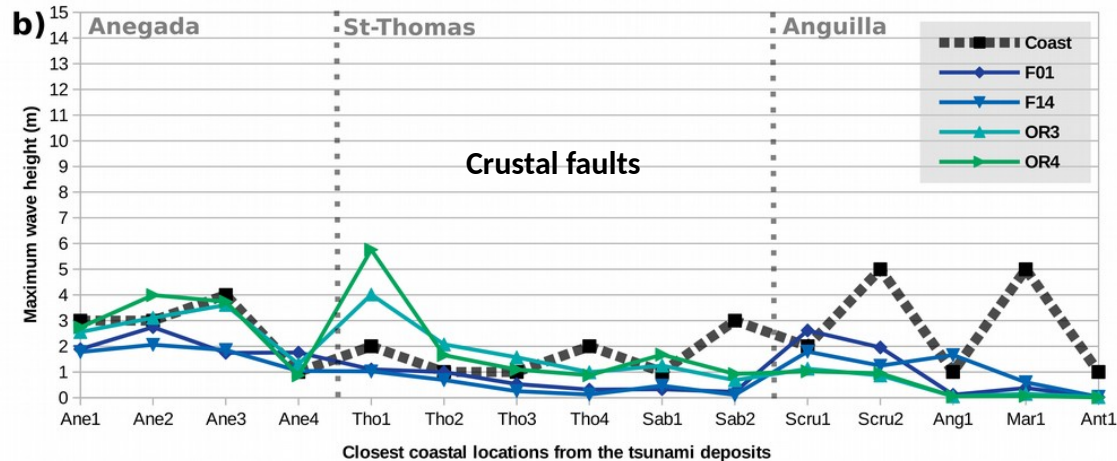
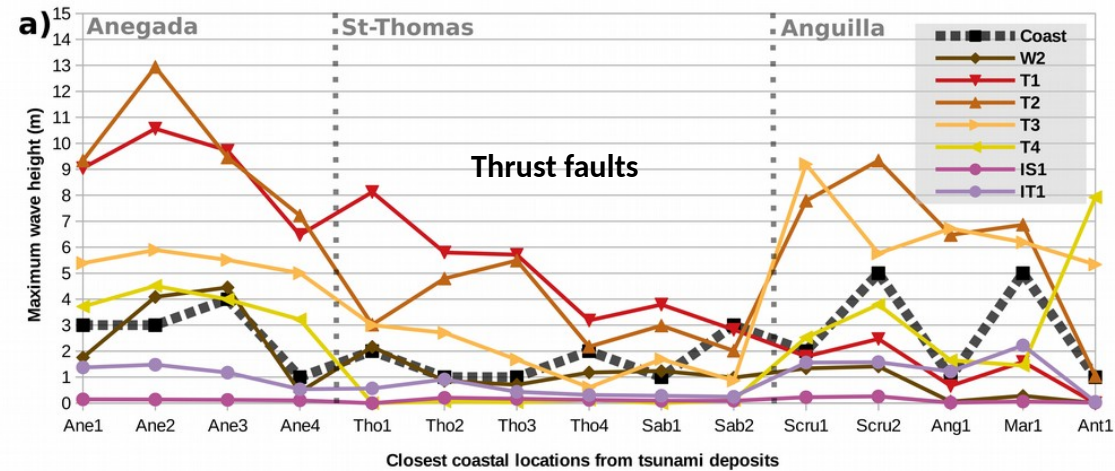
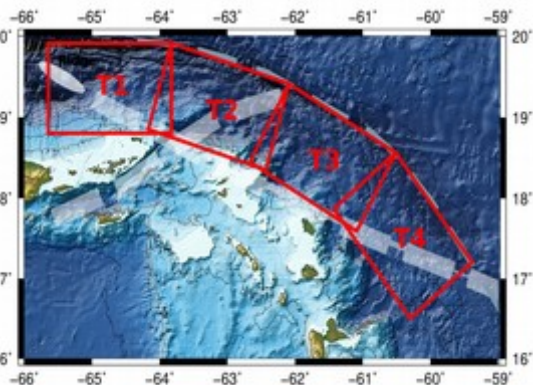
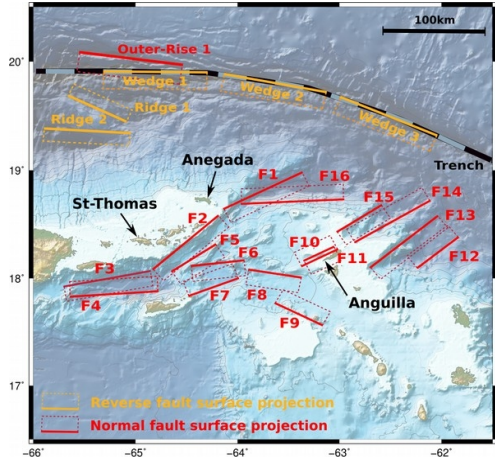
Water heights on Anegada's coast





Water heights on St-Thomas coasts

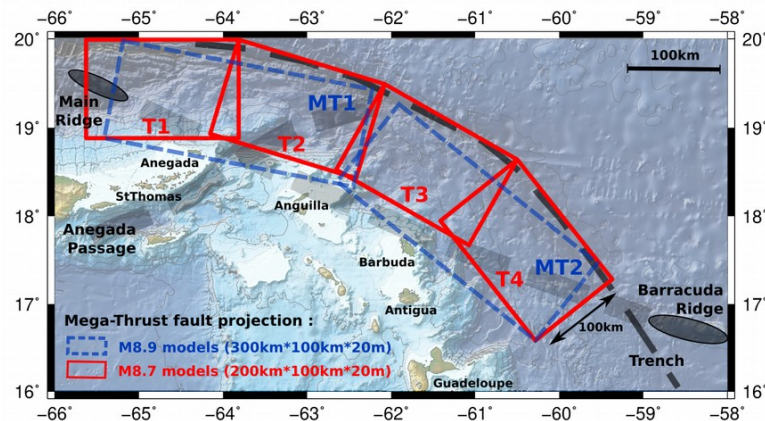
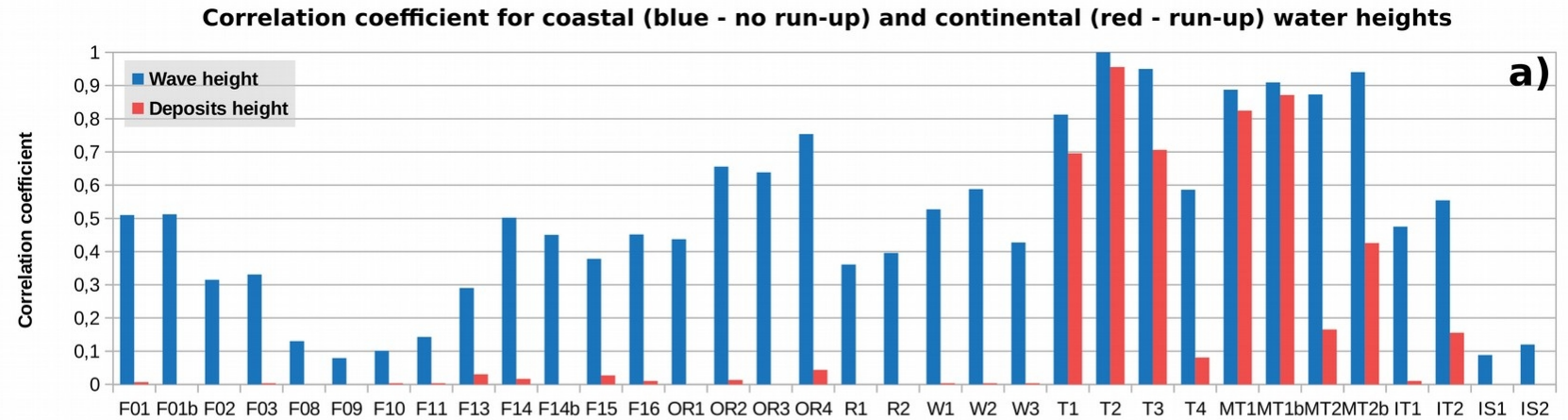
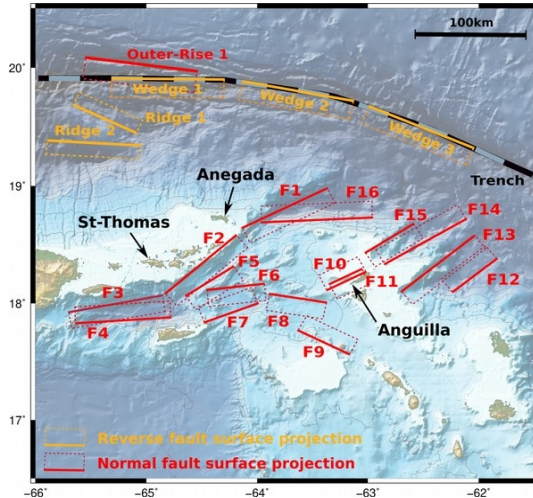




→ The wave heights generated by the **crustal fault** models are mainly **below** the coastal height threshold

→ Only some of the **subduction faults (T2, T3)** generate **waves higher** than the coastal height of the three islands

- Correlation coefficient between simulation results (**offshore water heights in blue** and **run-up in red**) and **observations** computed for each fault on the entire domain (all locations considered)



The best results are from the **subduction fault models** simulations.

All other sources generate amplitudes way too low to explain the presence of the deposits at all sites.

- Jamaica and Bonaire Islands tsunami deposits

Bonaire Island :

Boulder and deposits dated from
~500yrs BP

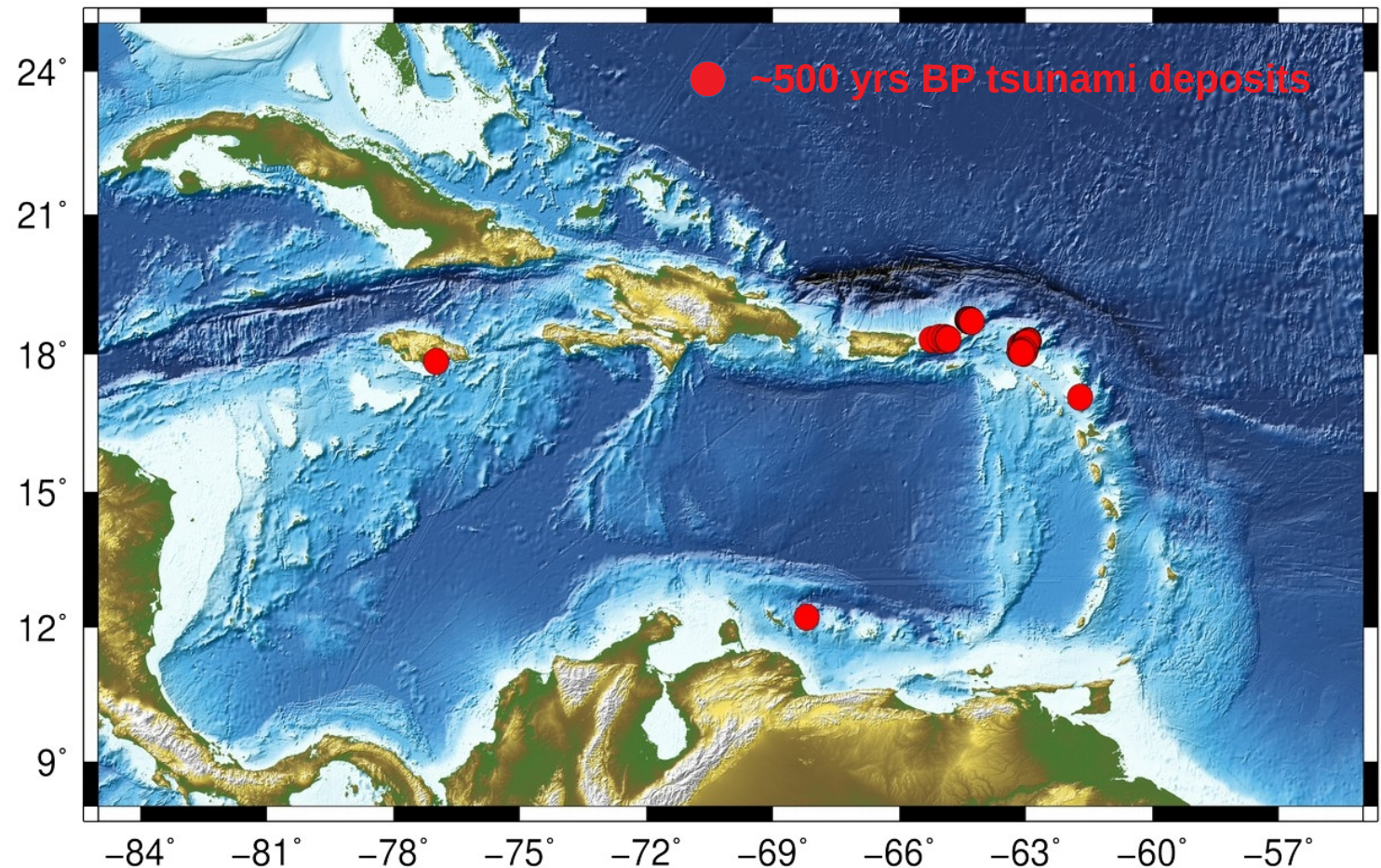
(Engel et al. 2010; Engel et al. 2016)

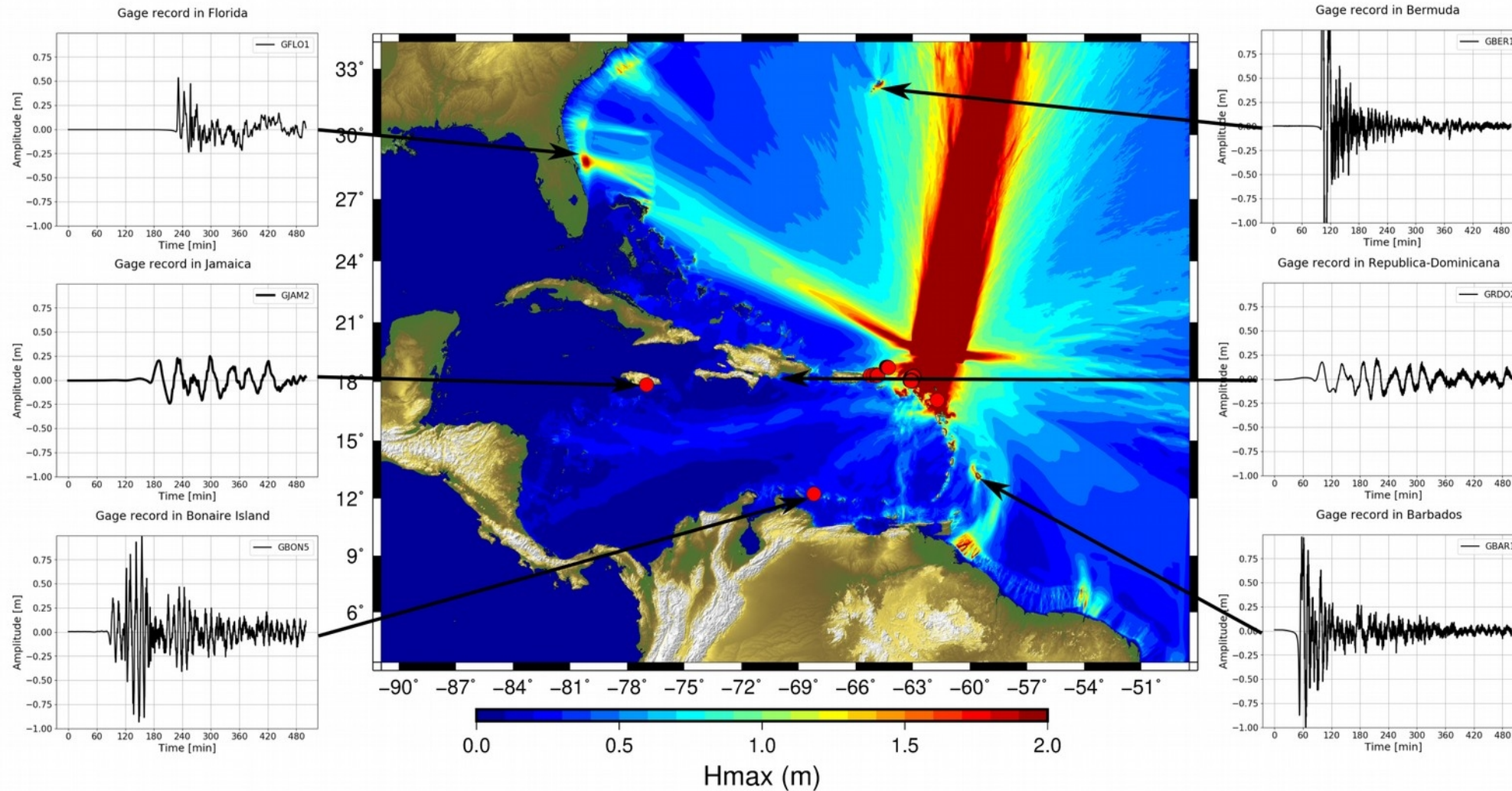
Jamaica :

Deposit dated from ~500yrs BP in a
sediment core sampled from a coastal
pond.

(Palmer et al. 2020)

**Could those deposits be generated by a
same event coming from the Lesser
Antilles ?**





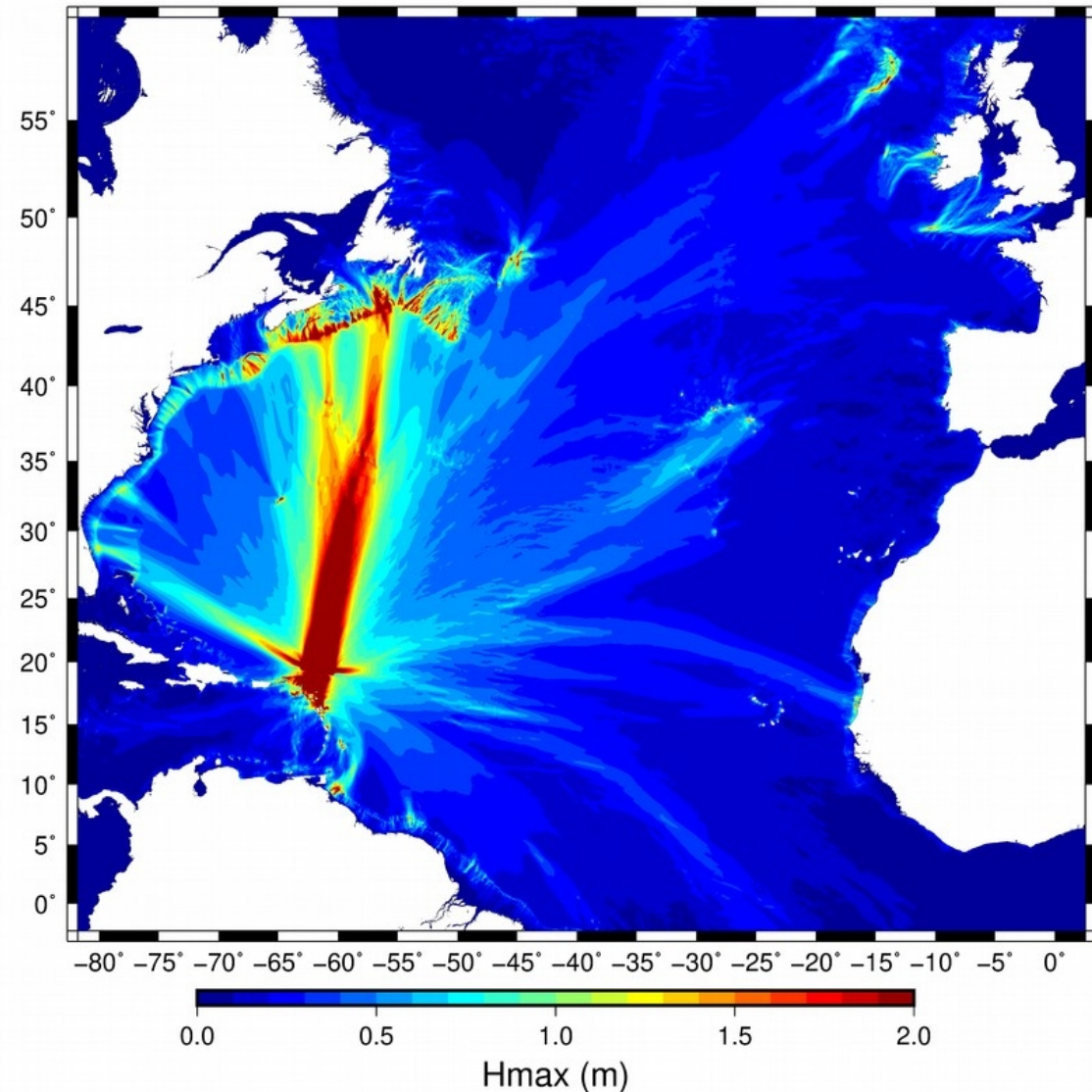
The biggest source model does not generate more than **1m in Bonaire** and **0.5m in Jamaica**. It seems unlikely that the “middle age” tsunami deposits on those 2 islands are related to the same Antilles tsunami event.

Farfield impact of an Antilles tsunami

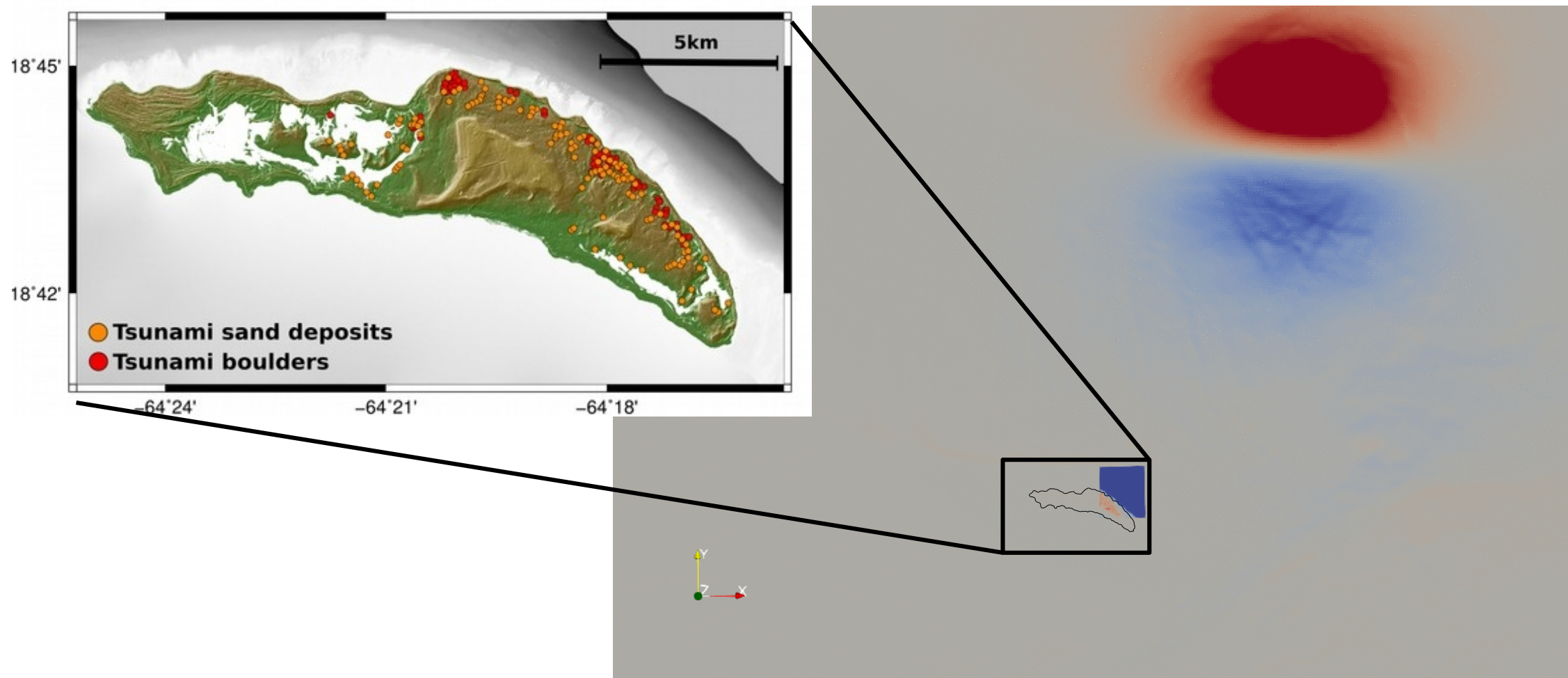
→ Important wave amplitudes along the American coasts

→ Sites with **wave amplification**

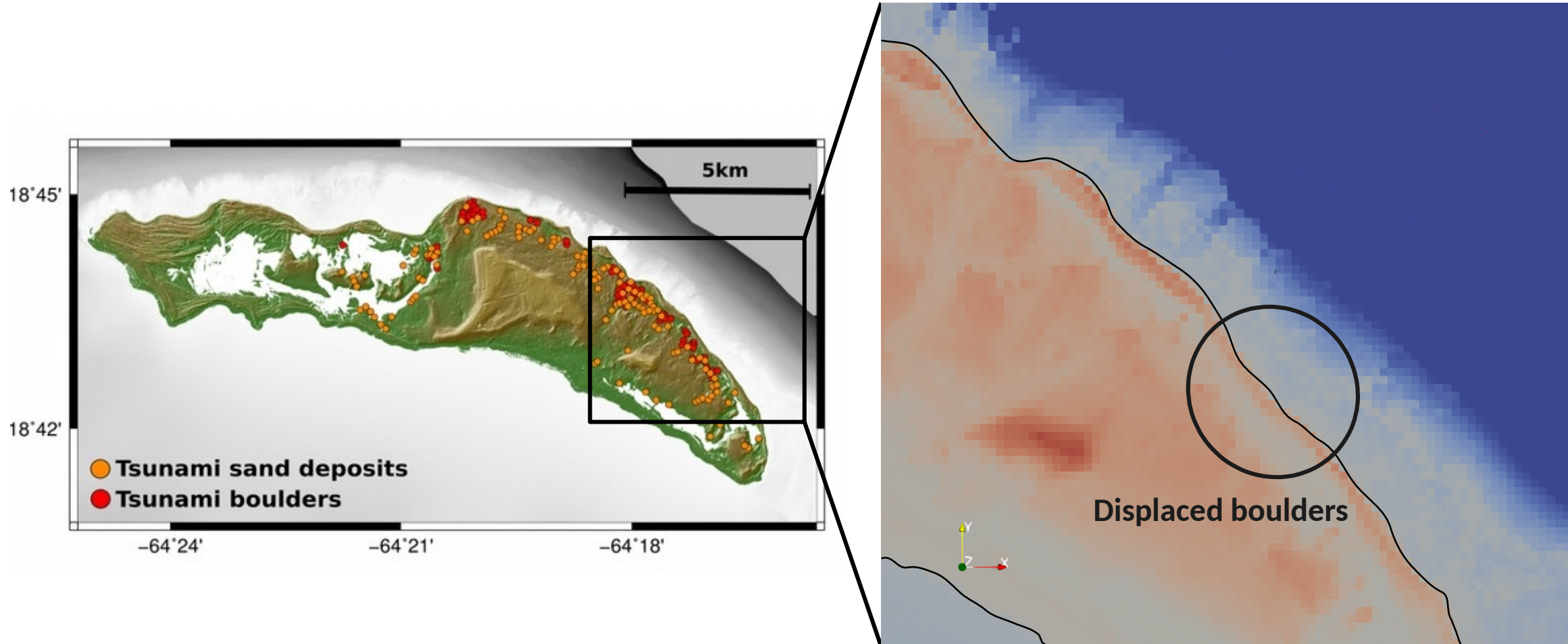
→ Similarly to the tsunami of 1755 Lisbon earthquake that affected the Antilles coasts, could a Lesser Antilles earthquake generate a **transatlantic tsunami on European coasts** ?



- Exemple of a sediment transport model in development



- Exemple of a sediment transport model in development



- Among 35 fault models tested, only one **Mw>8 mega-thrust earthquake** generates a tsunami high enough to explain the presence of deposits in all studied sites.
- The hypothesis of **several tsunamis and storms** occurring during this middle age period should not be excluded. However each of those different events should still be **exceptional** to explain the observations of the different sites.
- The occurrence of mega-thrust earthquake on this subduction interface is debated due to its apparent **low coupling**. However, discovery of important turbidites deposits on deep forearc basins of the arc with recurrence time of several thousand years could be an indication of the **very long seismic cycle of the subduction interface**. It could justify **the occurrence of a major subduction earthquake 500 yrs ago**.

→ Future sediment sampling campaign

New sediment cores from the arc and potentially more tsunami deposits to better constrain the fault models

→ Far field data

Exploring the possible existence of tsunami deposits in farfield sites from tsunami generated in the Antilles (American coasts, Bahamas...)

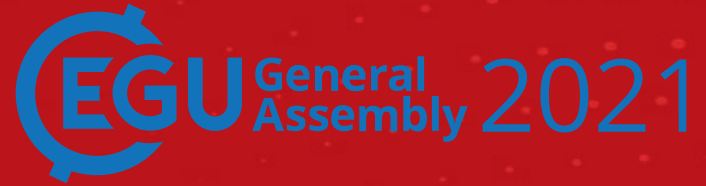
Studying the impact of major tsunami scenario on the American and European coasts

→ Development of sediment transport models

Calibration of the code ongoing.

It will be a complementary tool for the identification of the tsunami sources.

It could help in the discrimination of an earthquake and hurricane source.



Thank you for your attention