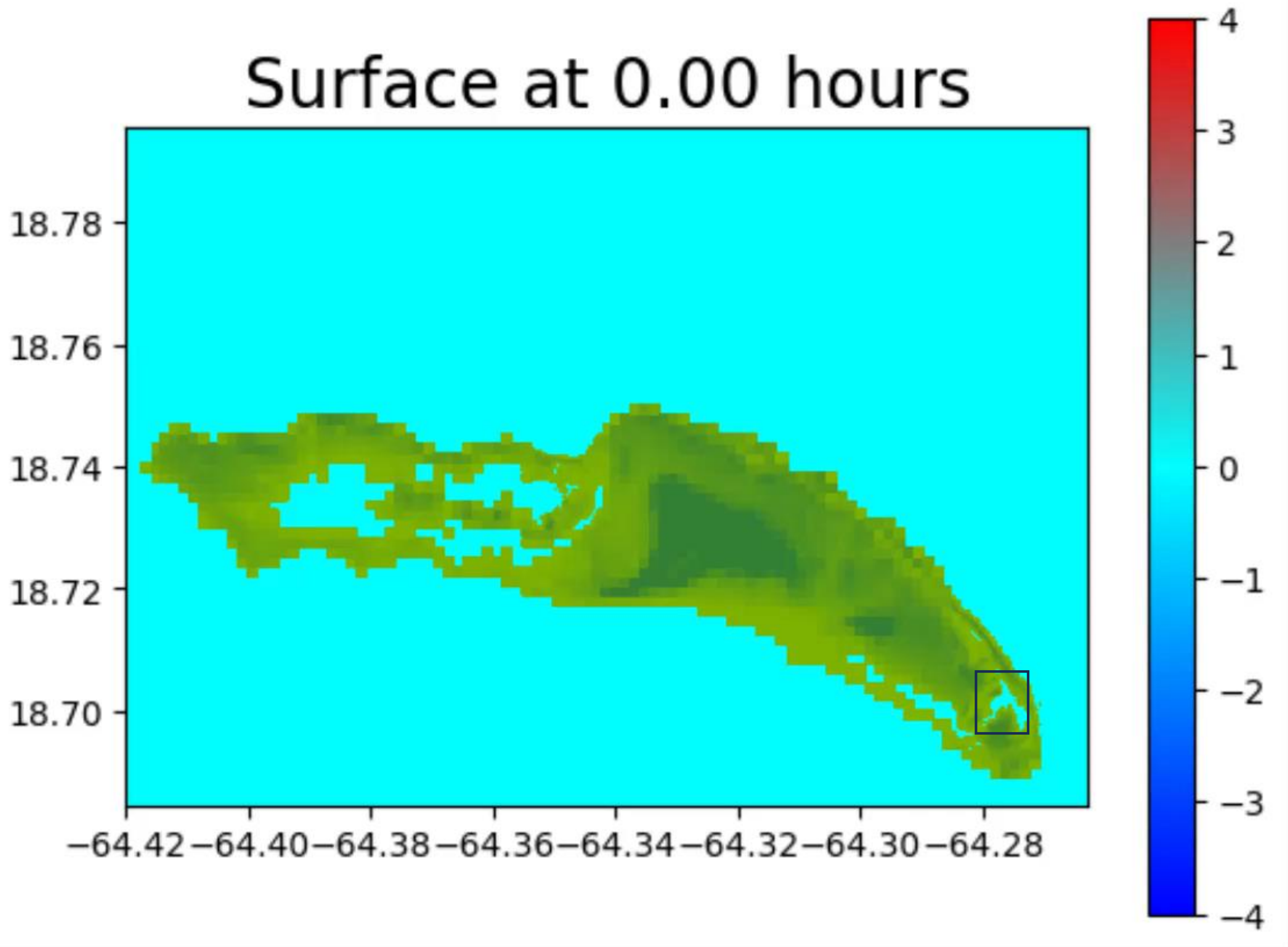
Estimation of Minimum Magnitude of Different Tsunamigenic Earthquake Sources from six centuries old boulder fields at Anegada (British Virgin Islands)

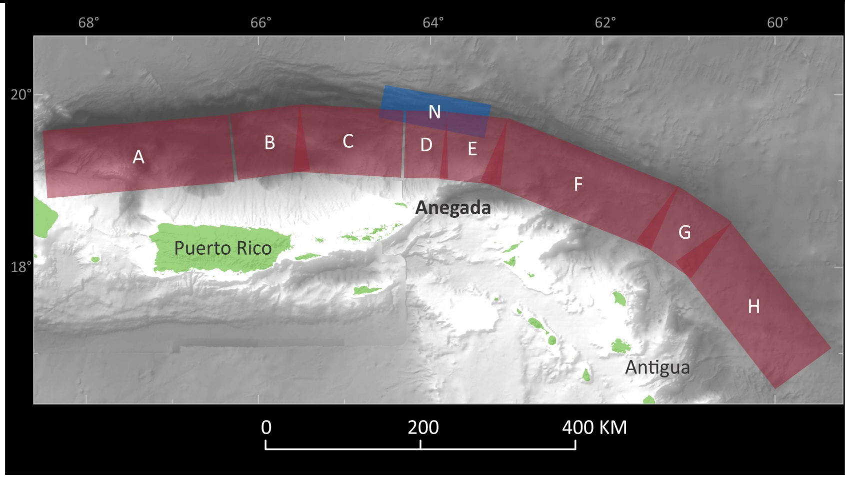
Hira Ashfaq Lodhi, Haider Hasan, Michaela Spiske, Brian Atwater, Yong Wei

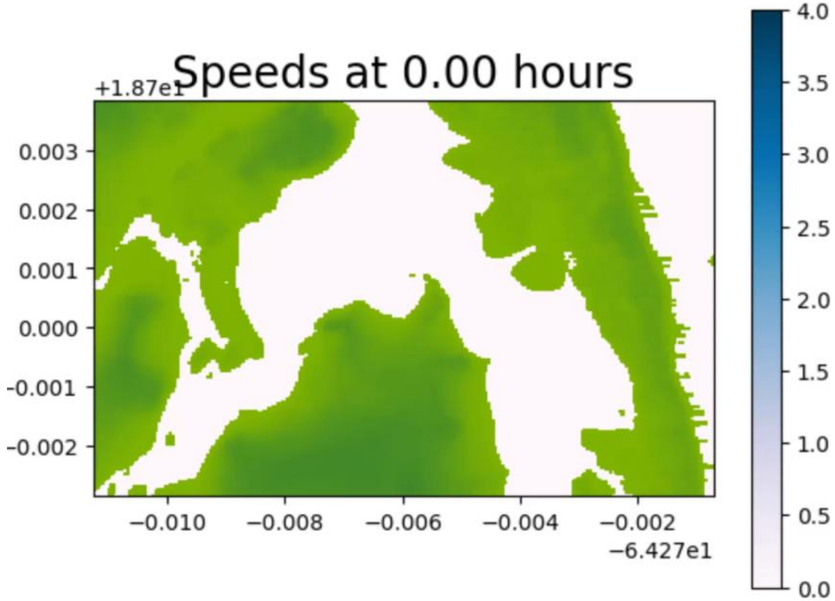
Outline

- Introduction
- Field evidence of over wash
- Setting
- Limestone boulder fields
- Tsunami Simulations
- Results based on Wet and Dry test and flow speed comparison
- Limitations

Inundation and Flow Speed







Introduction

- Tsunamis are unpreventable natural disasters.
- Tsunamis are capable of transporting sediments, including large boulders.
- Recent tsunamis of 2004, 2010 and 2011 have been known to move boulders along the coasts of different countries.
- Damaging potential of a tsunami is related to its hydraulic properties.
- Study of boulder transport by tsunami has a potential of improving hazard assessment along the coasts through out the world.

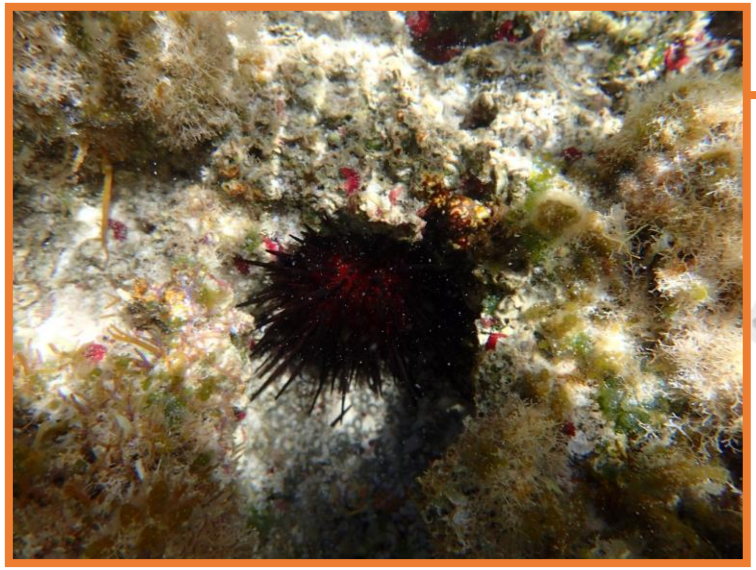
Imamura et al. 2008

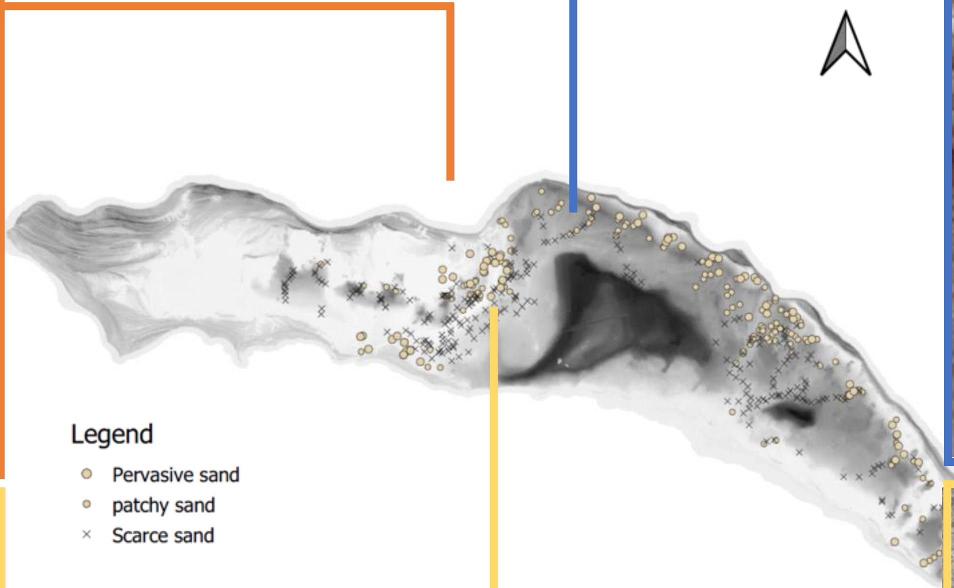
Liu et al. 2014

Suzuki et al. 2007

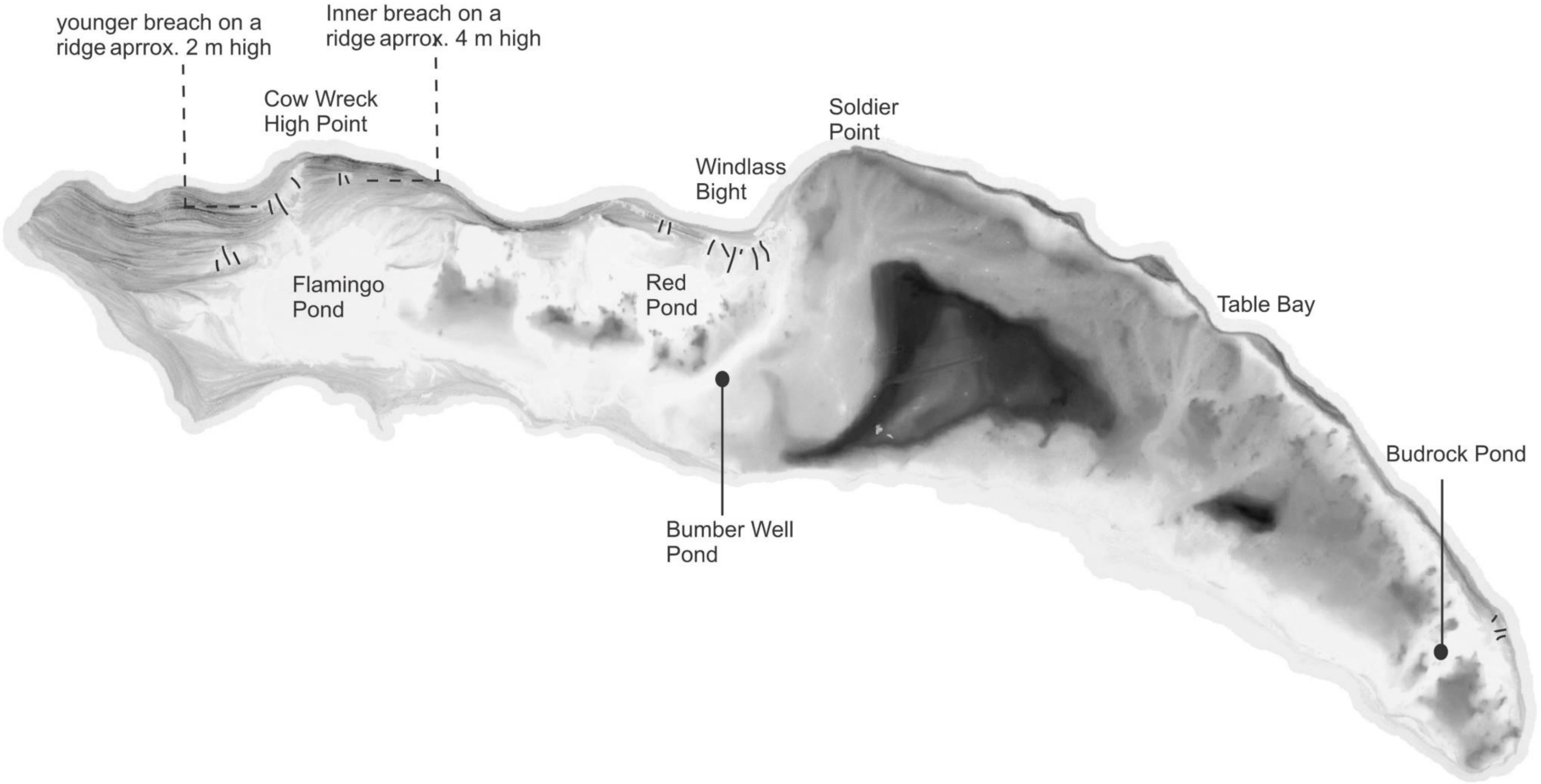
Spiske and Bahlburg et al. 2011

Field Evidence of over-wash at Anegada, sand and shell sheet

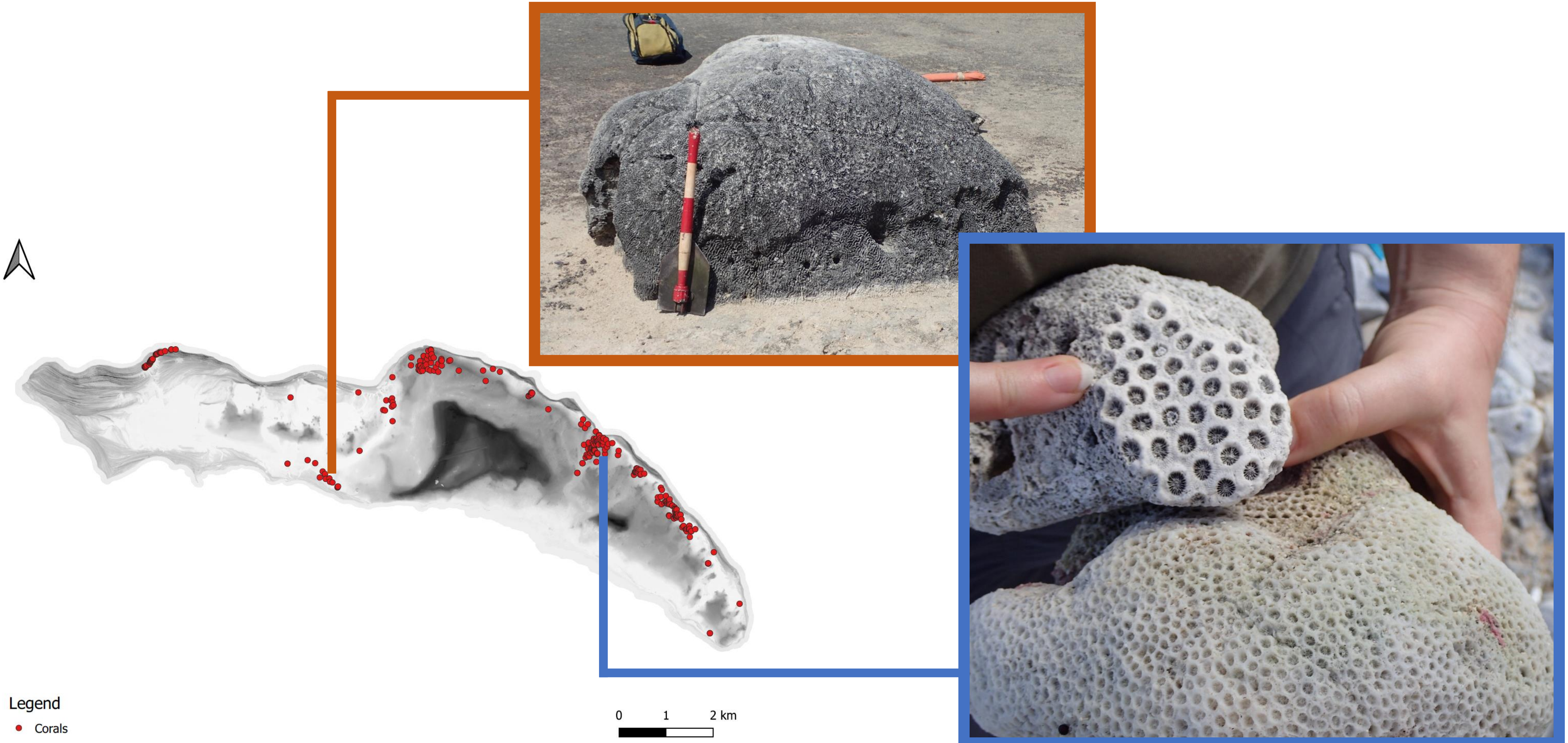




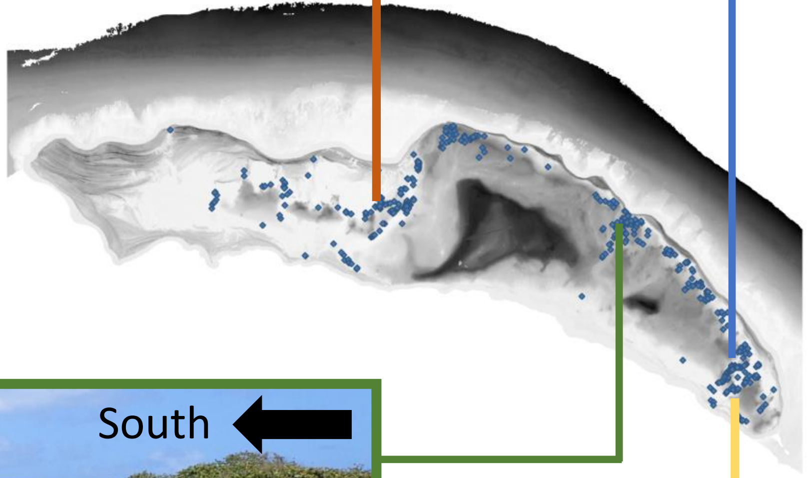
Field Evidence of over-wash at Anegada, breaches in beach ridges



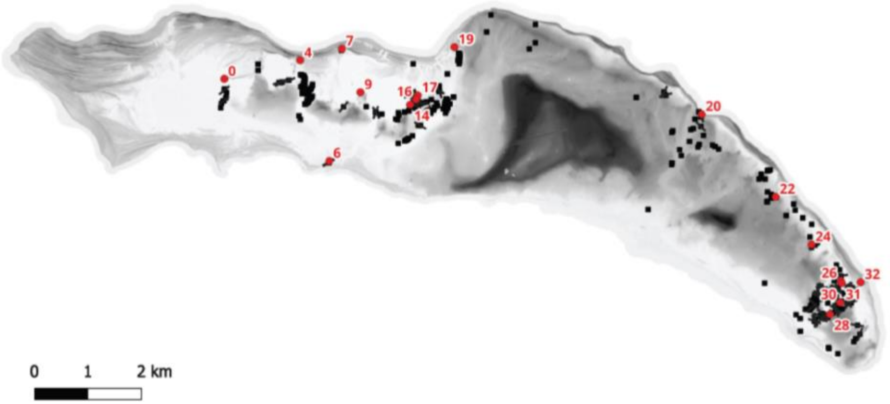
Field Evidence of over-wash at Anegada, coral boulders

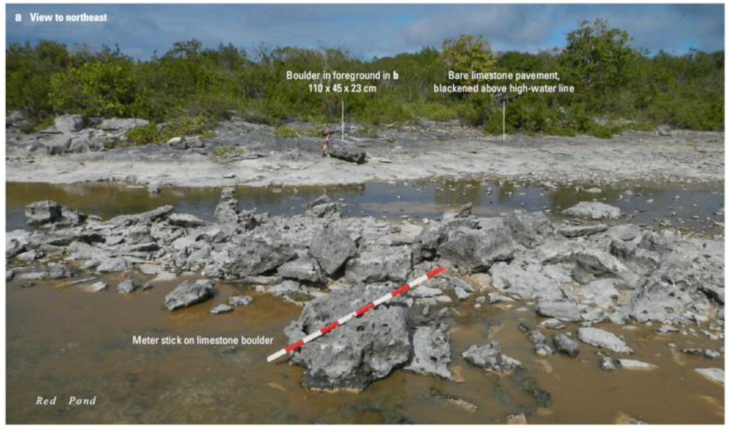


Field Evidence of over-wash at Anegada, Limestone Boulders

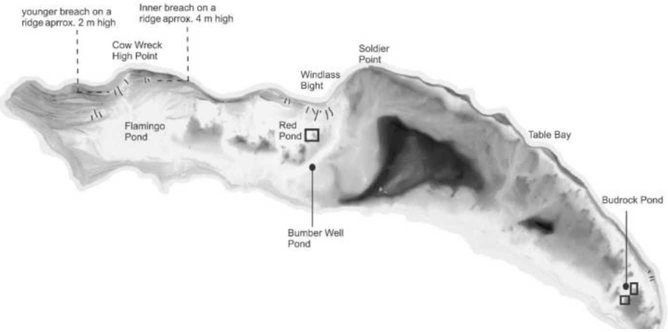


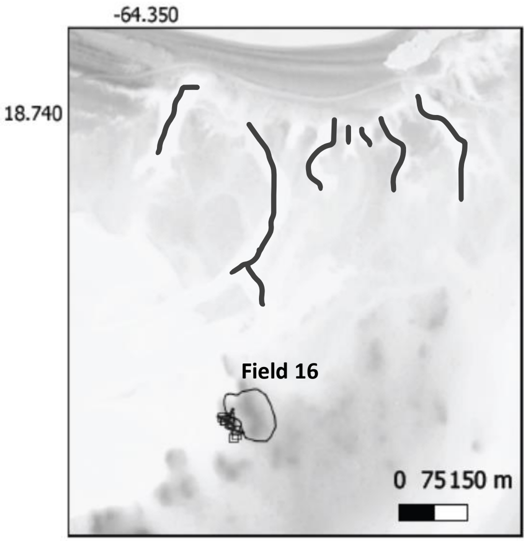
Limestone Boulder Fields

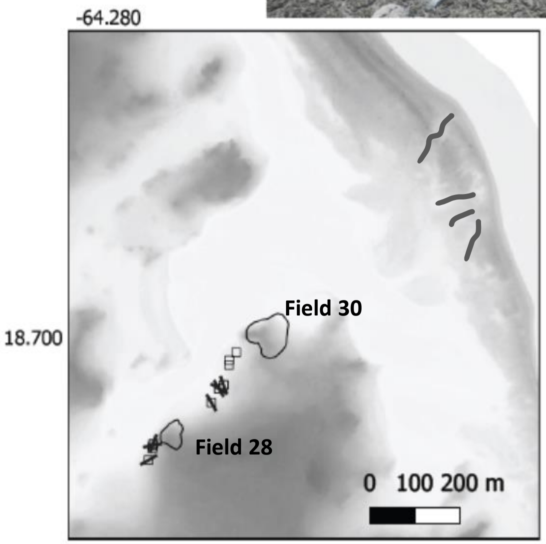


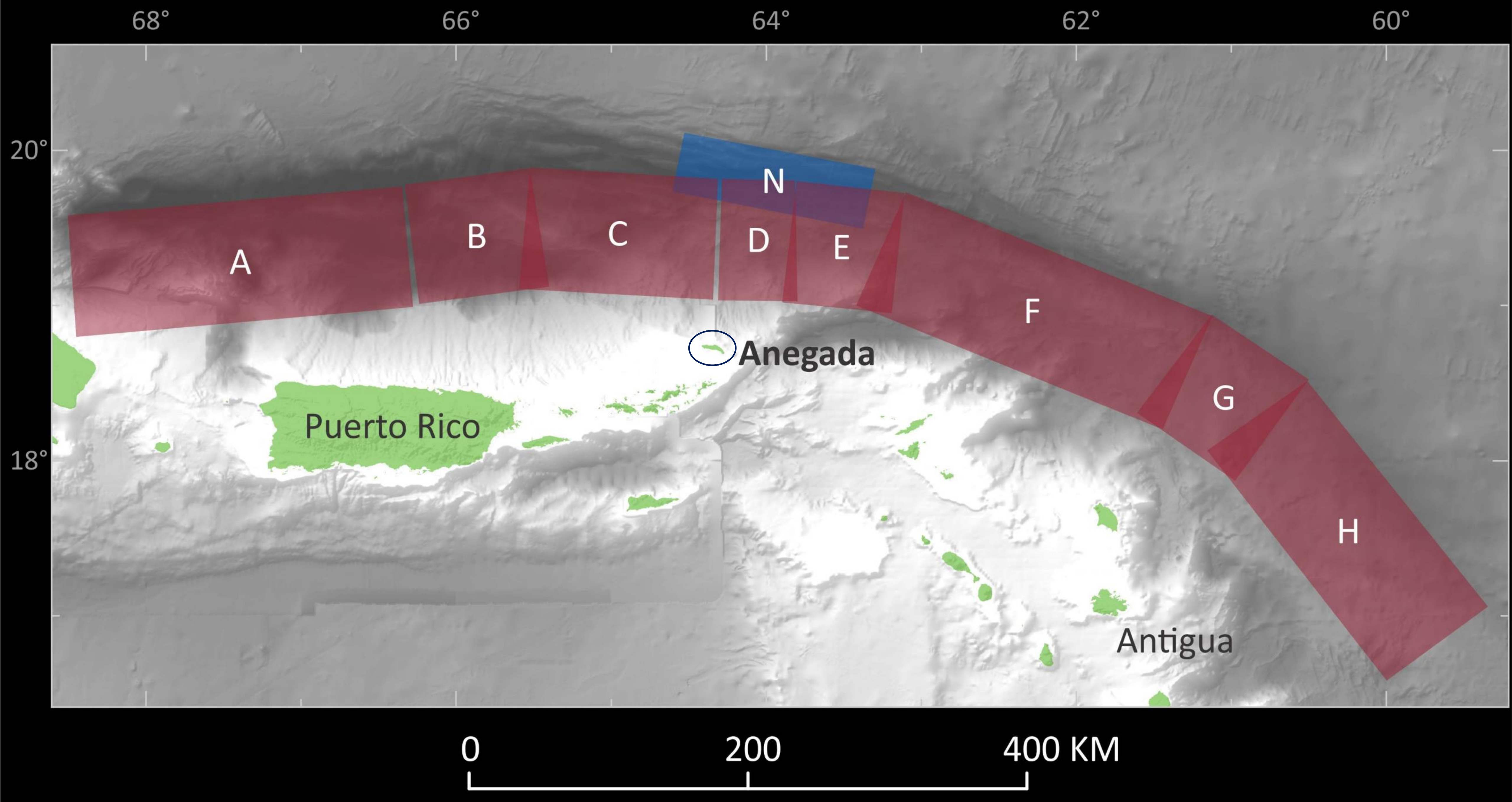


a View to southwest, near proximal end of field








68°
66°
64°
62°
60°
20°
18°
N
A
B
C
D
E
F
G
H
Anegada
Puerto Rico
Antigua
0
200
400 KM

Evaluation of Minimum Magnitude of Each Source

- Three tests for estimation of required minimum magnitude of tsunamigenic earthquake:

i. The wet and dry test (all limestone clasts).

ii. Island wide, flow speed test.

iii. Micro level, flow speed tests (Fields 16, 28 and 30).

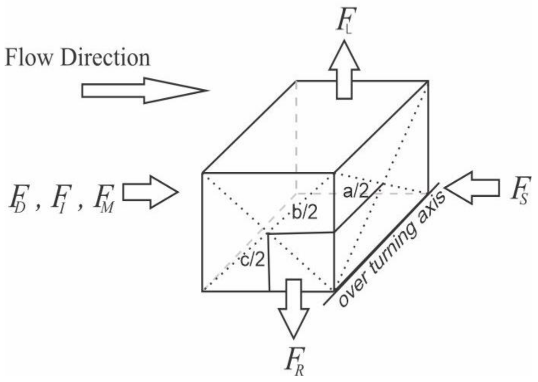
Normal Faulting Events

For Sliding mode of Transport (Lodhi et al., 2020).

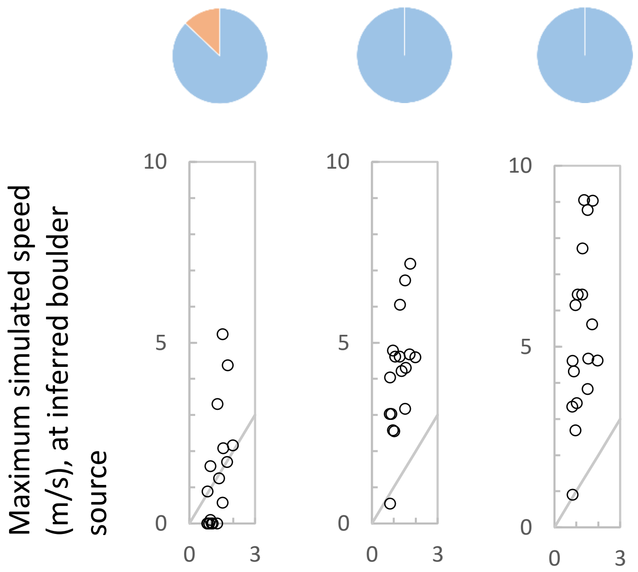
$$F_D + F_I + F_M \geq F_S$$

With Hydrodynamic Impact force

$$S_1 = \sqrt{\frac{2\mu_s gbc\left({}^{\rho_C}/_{\rho_W} - 1\right)}{cC_D + 2cC_I + \mu_S bC_L}}$$



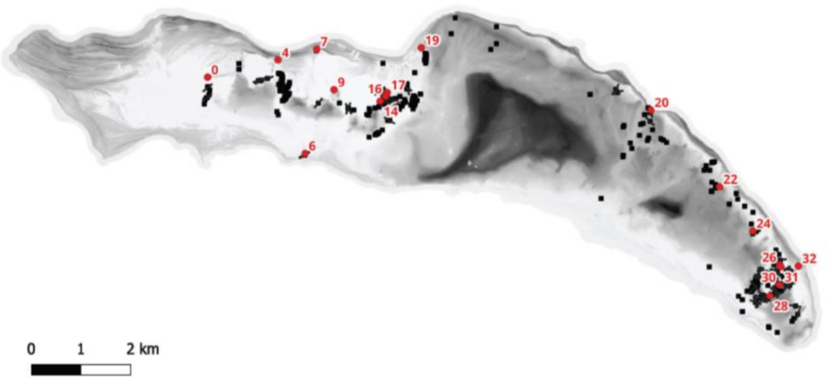
3.5	7.1	8.0	Uniform slip (m)
7.91	8.11	8.15	Earthquake size (Mw)



Percentage of 634 limestone boulders in simulated area of tsunami inundation

At diagonal line speed of tsunami simulation equals speed for initiating boulder transport

Minimum speed (m/s), from transport equation, for entraining largest boulder



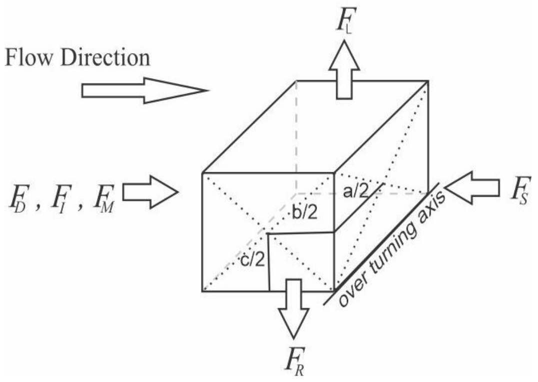
Thrust Faulting Events (CE)

For Sliding mode of Transport (Lodhi et al., 2020).

$$F_D + F_I + F_M \geq F_S$$

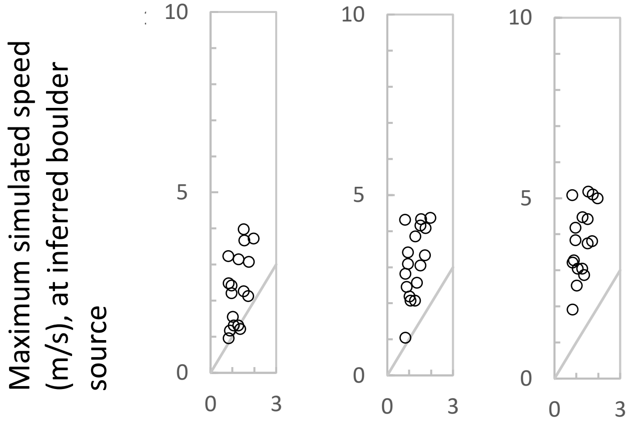
With Hydrodynamic Impact force

$$S_1 = \sqrt{\frac{2\mu_s g b c\left({\rho_C}/{\rho_W} - 1\right)}{cC_D + 2cC_I + \mu_s b C_L}}$$



4.2	5.2	6.3	Uniform slip (m)
8.35	8.42	8.47	Earthquake size (Mw)

Percentage of 634 limestone boulders in simulated area of tsunami inundation



At diagonal line speed of tsunami simulation equals speed for initiating boulder transport

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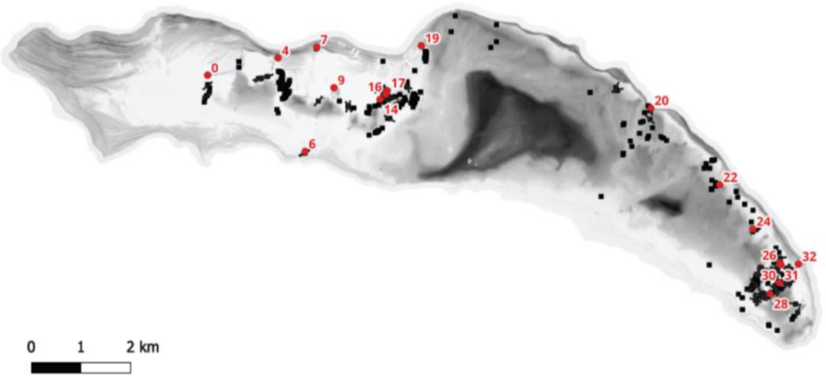


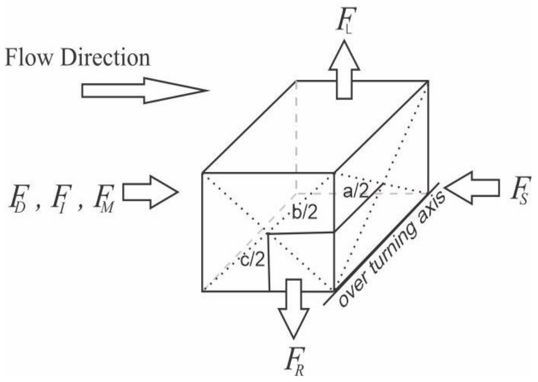
Thrust Faulting Events (CD)

For Sliding mode of Transport (Lodhi et al., 2020).

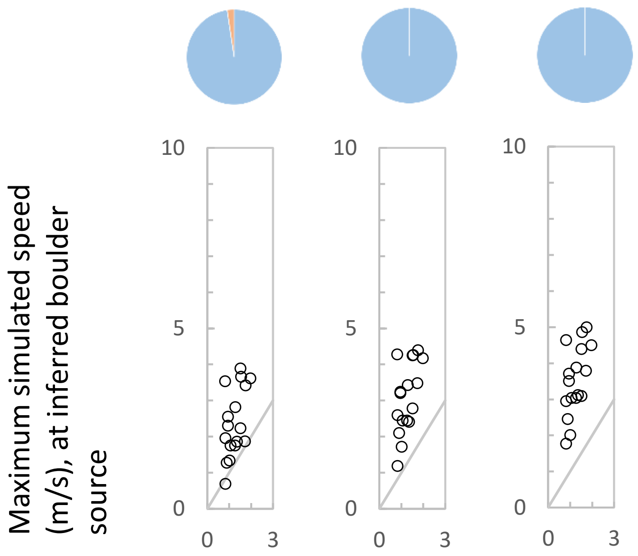
$$F_D + F_I + F_M \geq F_S$$

With Hydrodynamic Impact force

$$S_1 = \sqrt{\frac{2\mu_s gbc\left({}^{\rho_C}/_{\rho_W} - 1\right)}{cC_D + 2cC_I + \mu_s bC_L}}$$



5.2	6.3	7.0	Uniform slip (m)
8.32	8.37	8.40	Earthquake size (Mw)



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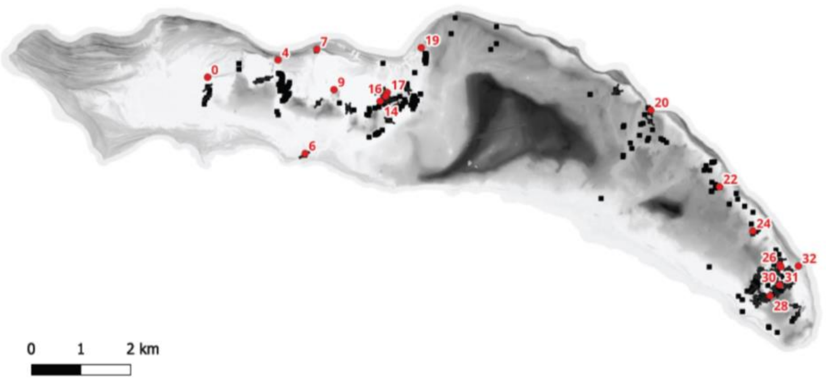


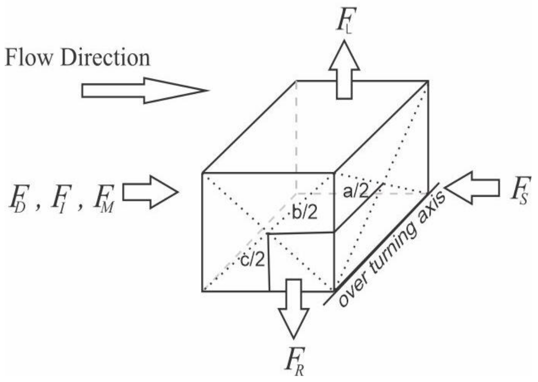
Thrust Faulting Events (CH)

For Sliding mode of Transport (Lodhi et al., 2020).

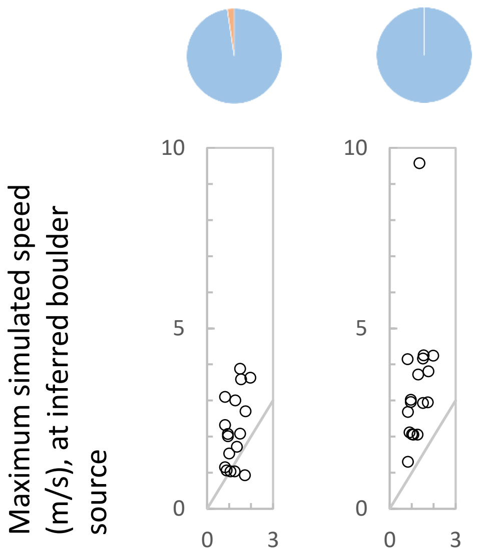
$$F_D + F_I + F_M \geq F_S$$

With Hydrodynamic Impact force

$$S_1 = \sqrt{\frac{2\mu_s gbc\left({}^{\rho_C}/_{\rho_W} - 1\right)}{cC_D + 2cC_I + \mu_S bC_L}}$$



Uniform slip (m)	4.2	5.2
Earthquake size (Mw)	8.67	8.73



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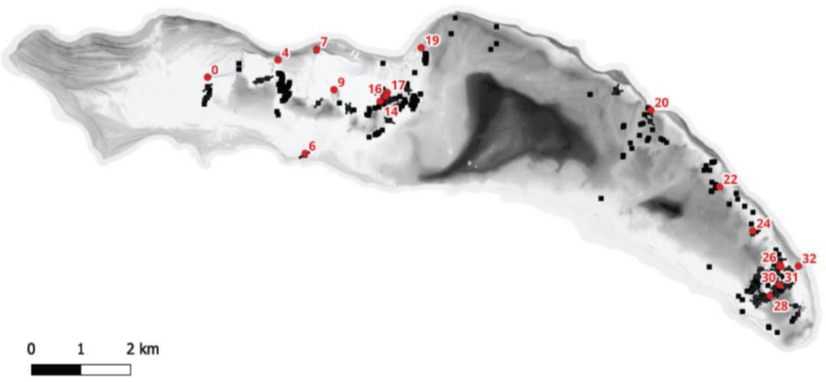
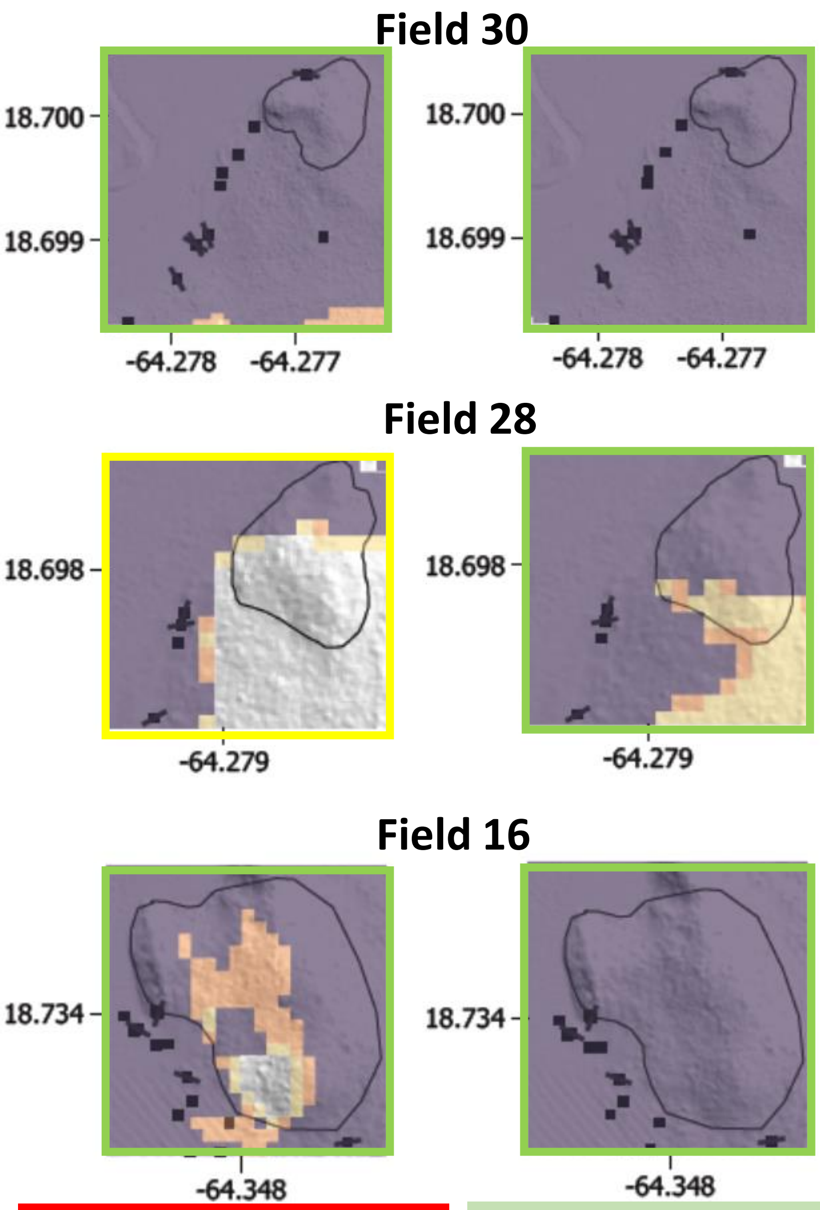
Minimum speed (m/s), from transport equation, for entraining largest boulder



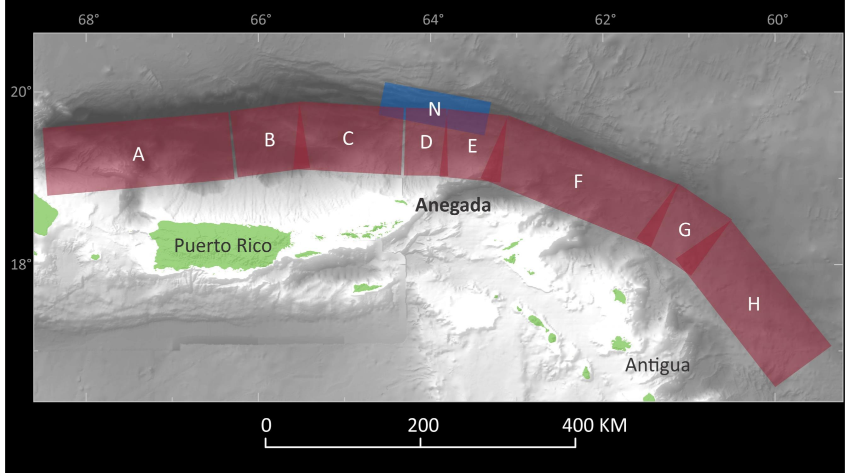
Micro-level Flow Speed Test (Normal Fault)

	a_ax_m	b_ax_m	c_ax_m	Predicted threshold flow speed_m/s	Min/Max of predicted threshold flow speed_m/s
	Boulder field 30				
1	0.40	0.30	0.20	**0.81**	0.81
2	1.20	0.40	0.15	0.93	1.40
3	0.70	0.50	0.30	1.04	
4	1.00	0.90	0.20	**1.40**	
5	0.50	0.40	0.05	0.93	
6	0.80	0.70	0.15	1.23	
7	0.70	0.40	0.15	0.93	
8	1.00	0.80	0.15	1.32	
	Boulder field 28				
1	0.50	0.30	0.10	0.81	0.74
2	0.60	0.35	0.10	0.87	0.93
3	0.50	0.40	0.10	**0.93**	
4	0.60	0.25	0.15	**0.74**	
	Boulder field 16				
1	0.60	0.50	0.15	1.04	0.66
2	0.50	0.40	0.05	0.93	1.14
3	0.60	0.45	0.18	0.99	
4	0.80	0.20	0.20	**0.66**	
5	0.67	0.45	0.15	0.99	
6	1.00	0.6	0.10	**1.14**	
7	1.10	0.45	0.23	0.99	
8	0.9	0.45	0.1	0.99	
9	0.45	0.35	0.25	0.87	



Slip 7.1m, 8.11 Mw

Slip 8m, 8.15 Mw



All move

Some move

None move

Micro-level Flow Speed Test (Thrust CE)

	a_ax_m	b_ax_m	c_ax_m	Predicted threshold flow speed_m/s	Min/Max of predicted threshold flow speed_m/s
	Boulder field 30				
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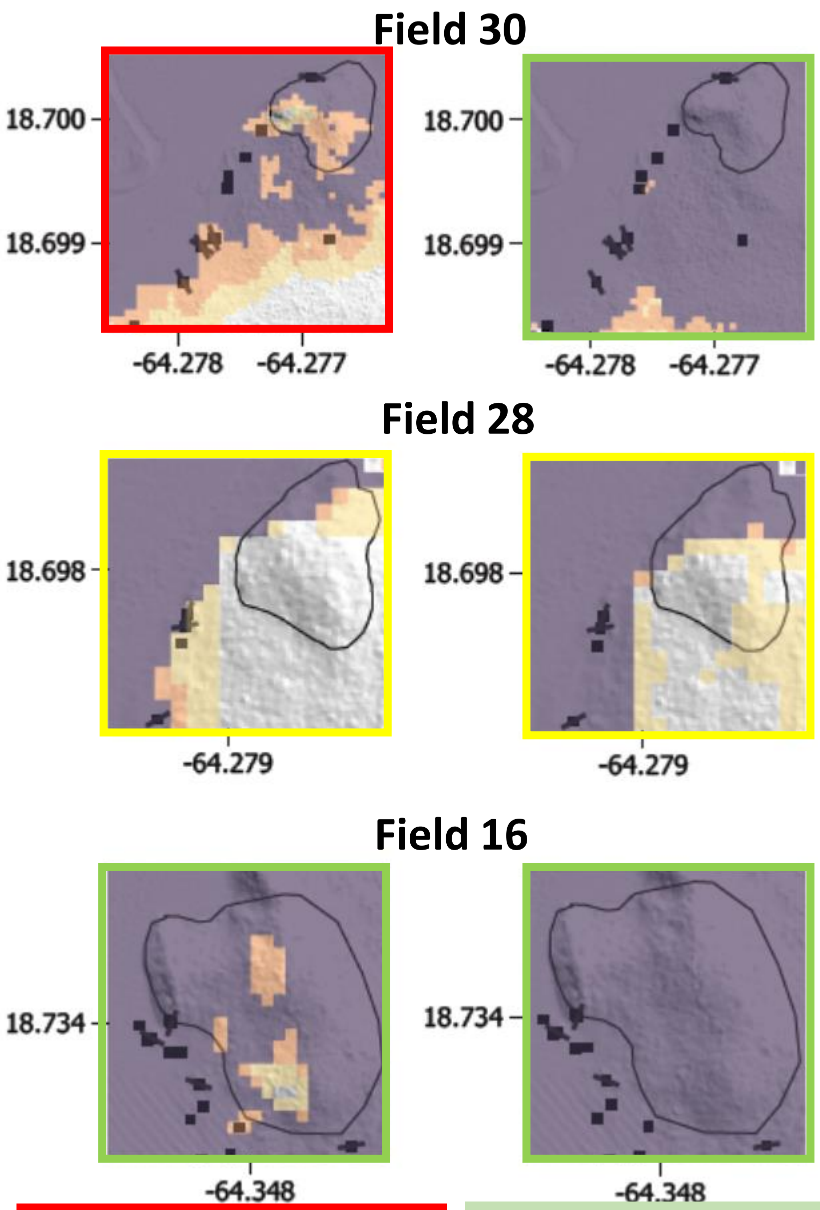

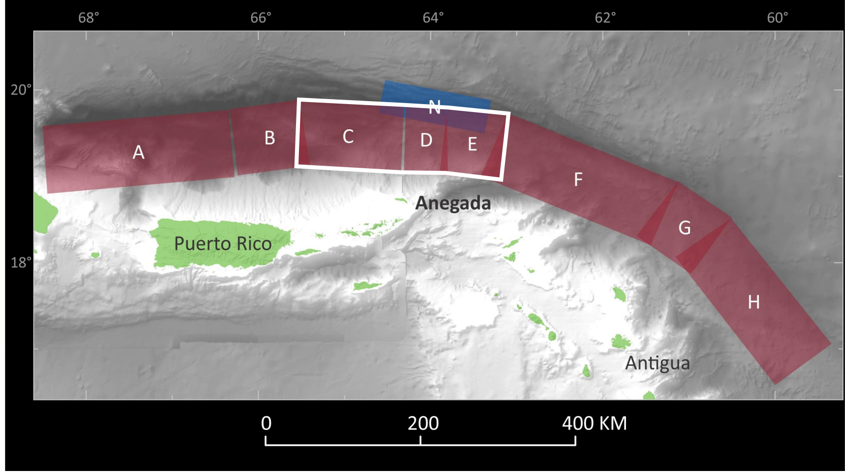

All move

Some move

None move

Slip 5.2m, 8.42 Mw

Slip 6.3m, 8.47 Mw

Micro-level Flow Speed Test (Thrust CD)

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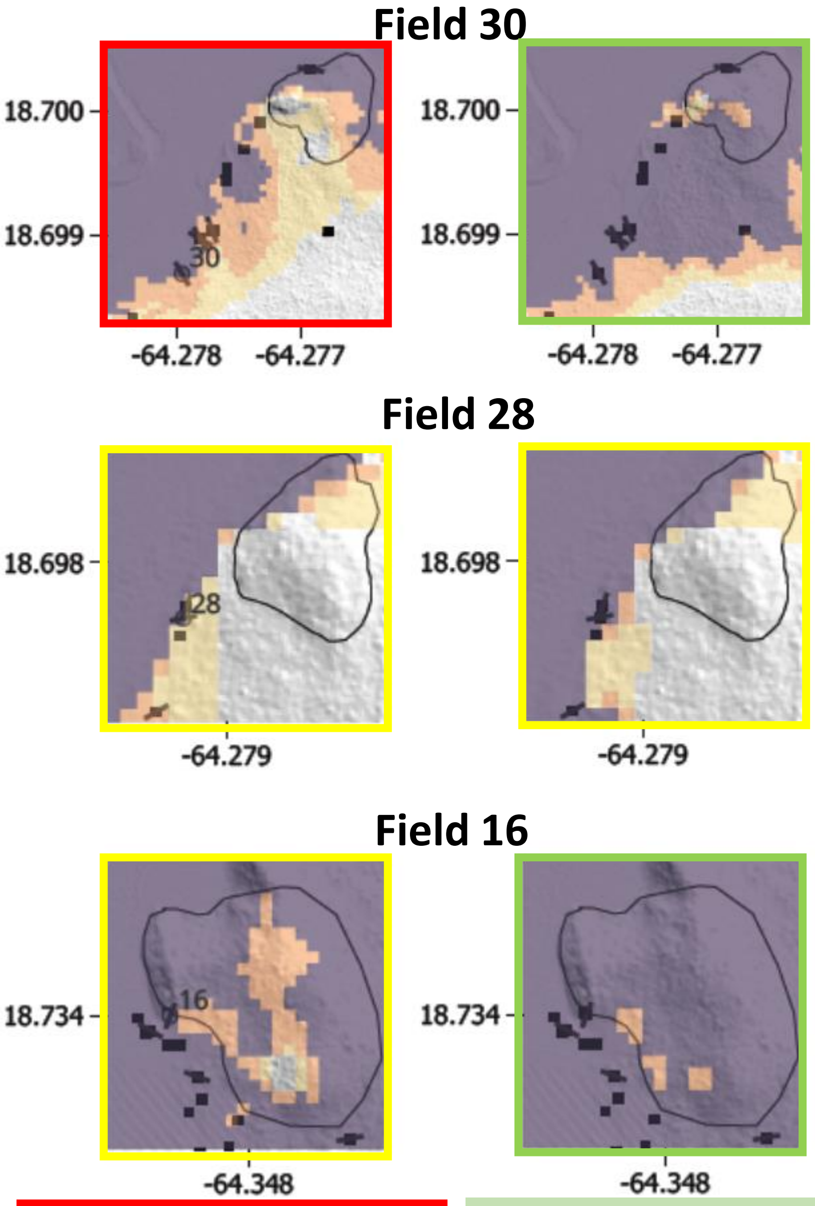

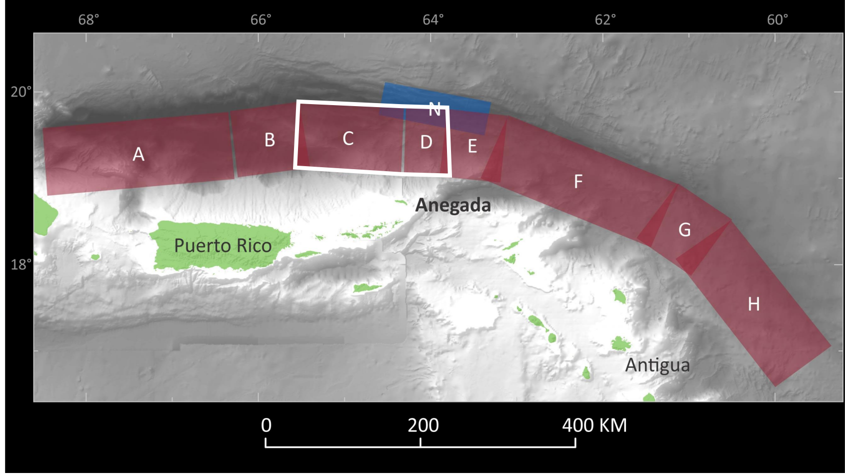

All move

Some move

None move

Slip 6.3m, 8.37 Mw

Slip 7m, 8.40 Mw

Results

- Failure of Trans-Atlantic tsunamis.
- Normal fault generates the records for an event of 8.15 Mw whereas any of the thrust events requires at least a 8.4 Mw event.
- For thrust events, most sensitive fault segments are due north of island.
- The results show relative insensitivity towards rupturing of segments east or west of the island.

Limitations of the Study

- Fake quakes.
- Uniform slip distribution.
- Quiver plots.
- Concrete Topography.
- Transportation limited to a single scenario.

Thank you