Understanding Unrest and Dynamic Triggering Processes on Sierra Negra, Galápagos Island

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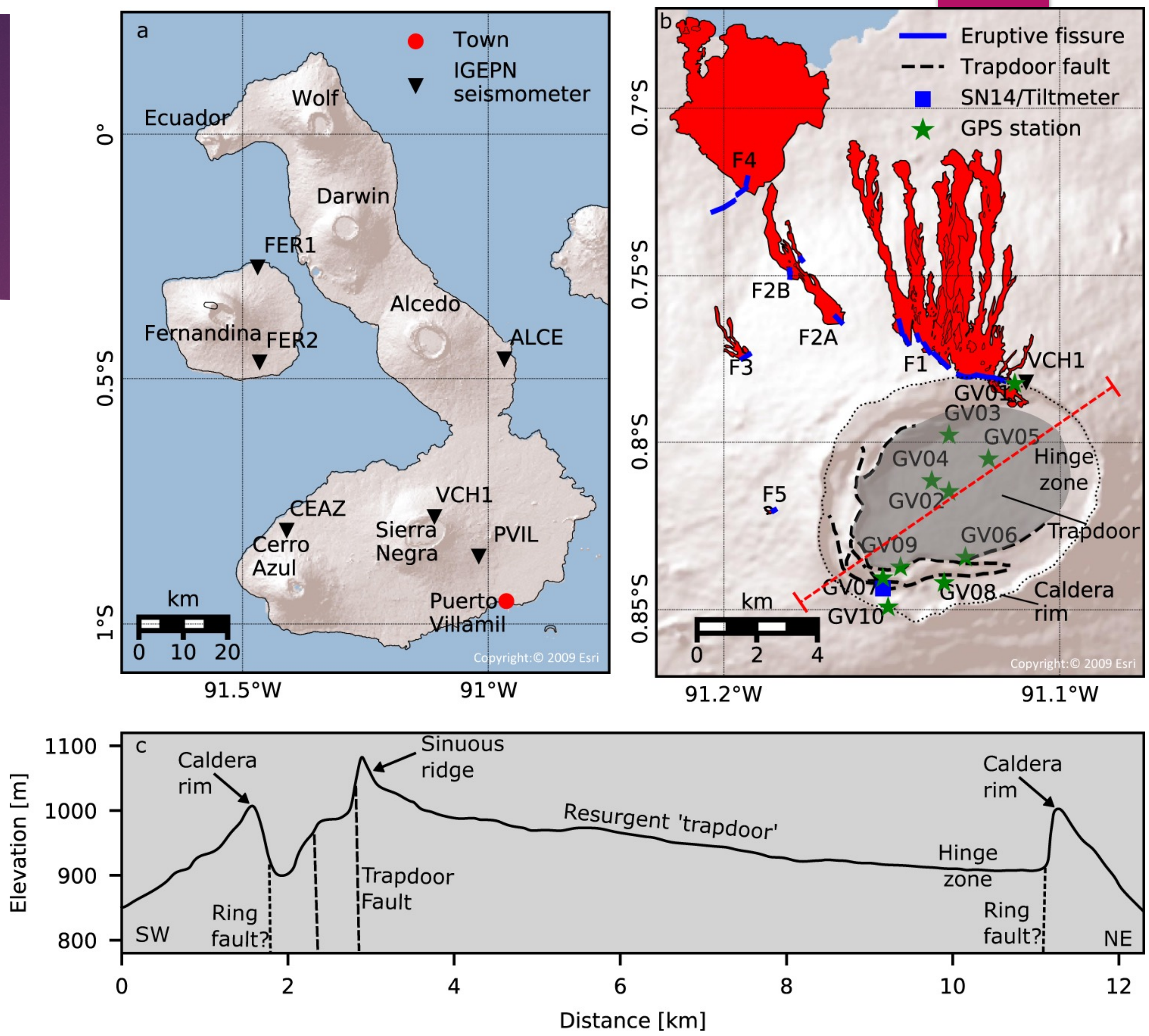
SUPPLEMENTARY MATERIAL

Introduction

- Dynamic triggering occurs when local seismicity activity has been induced by dynamic stress disturbances, originating from teleseismic earthquakes.
- Bell et al., 2021a proposes dynamic triggering on Sierra Negra.
- Sierra Negra is a basaltic shield volcano on Isabela Island and features a large elliptical summit caldera.

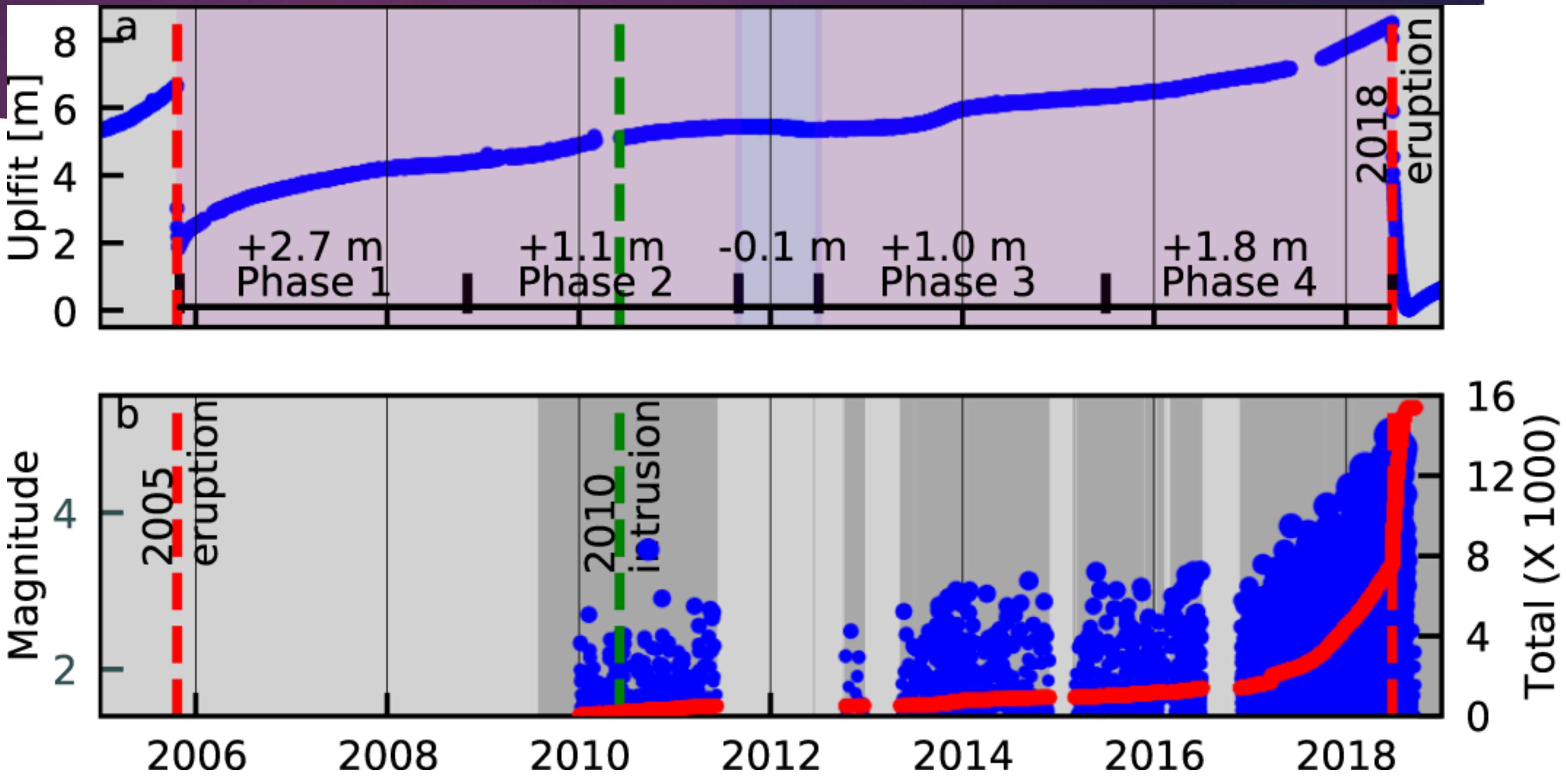
Introduction

- Sierra Negra is located on Isabela Island and has a trap-door fault system.
- It last erupted in 2018 and 2005.
- Image: Bell et al., 2021a



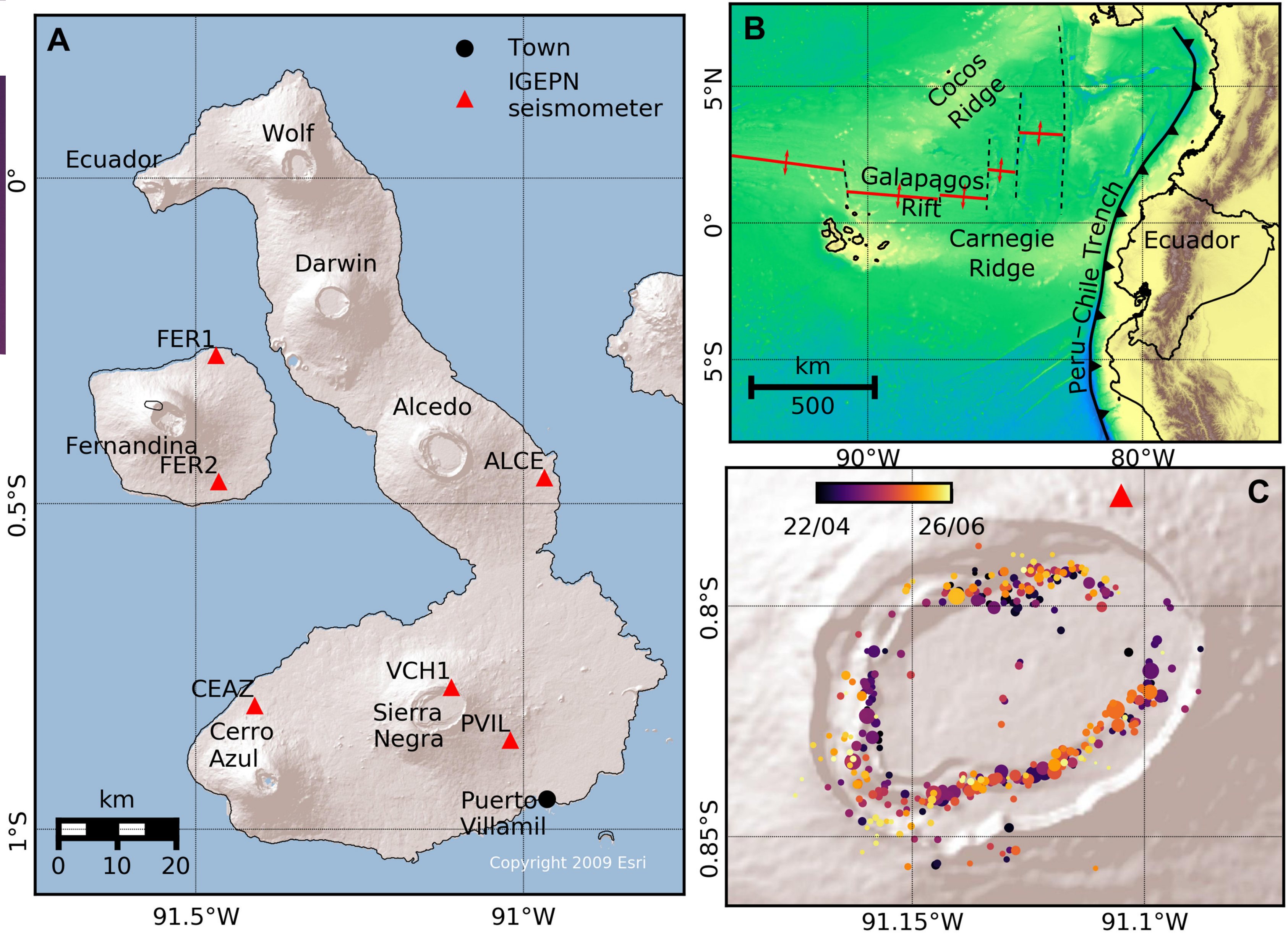
Introduction

- Sierra Negra experiences a pattern of pre-eruptive inflation, co-eruptive deflation, and post-eruptive inflation.
- Prior to its 2018 eruption, this inflation was divided into 4 key phases, corresponding to an increase in seismic activity.
- Image: Bell et al., 2021a



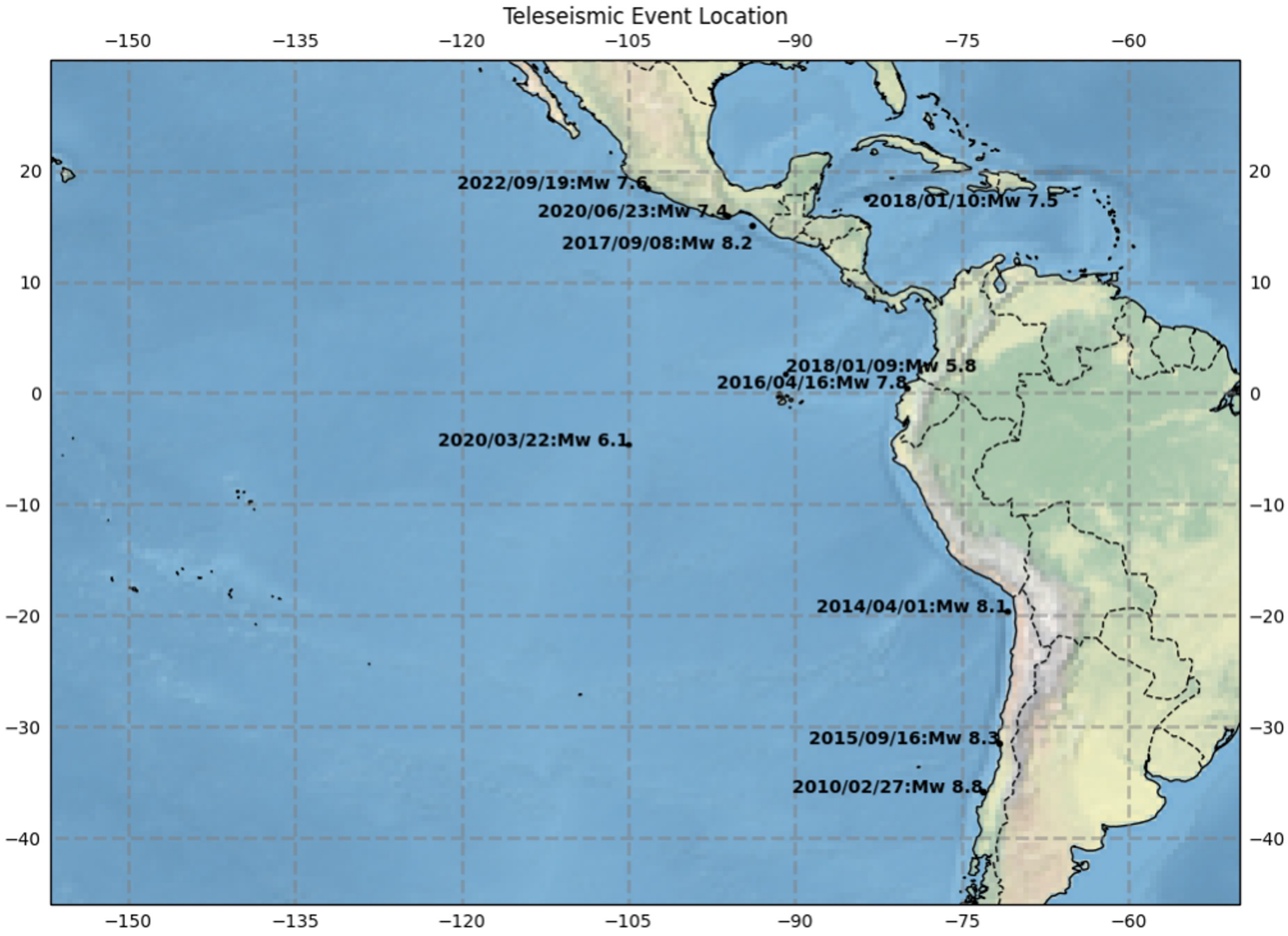
Introduction

- From January 2018 – December 2018 the IGUANA network covered the Sierra Negra caldera with seismometers.
- The IGUANA network located seismicity occurring along the trapdoor fault leading up to the 2018 eruption.
- Prior to 2018 and from January 2019 – December 2022 the only seismometer on Sierra Negra was located on the caldera wall (VCH1).
- Image: Bell et al., 2021b



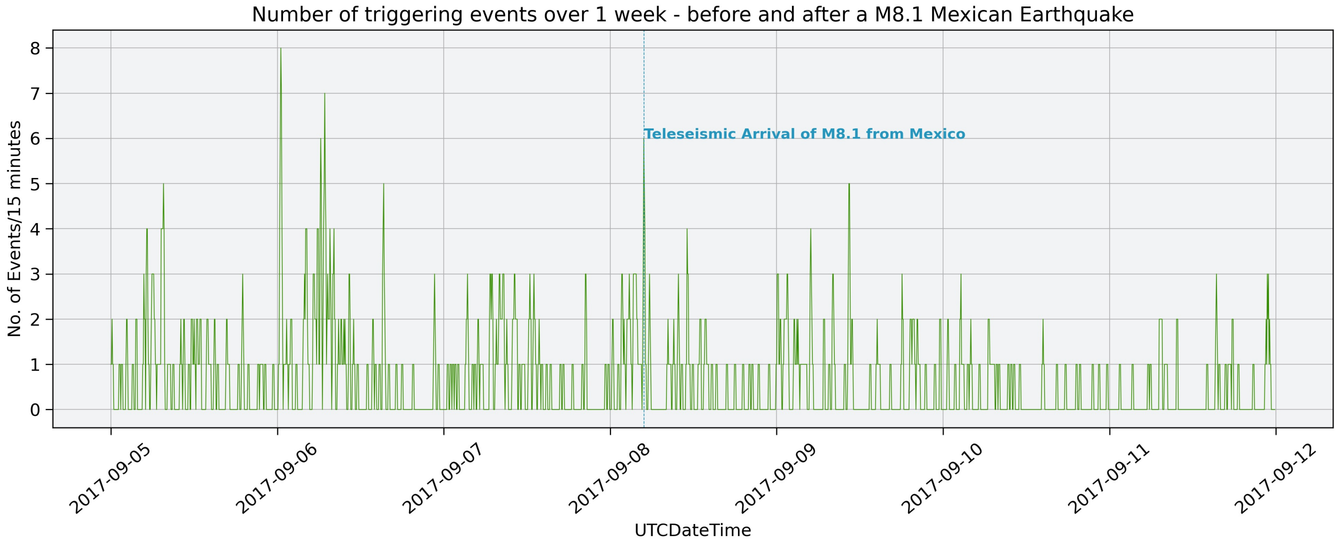
Introduction

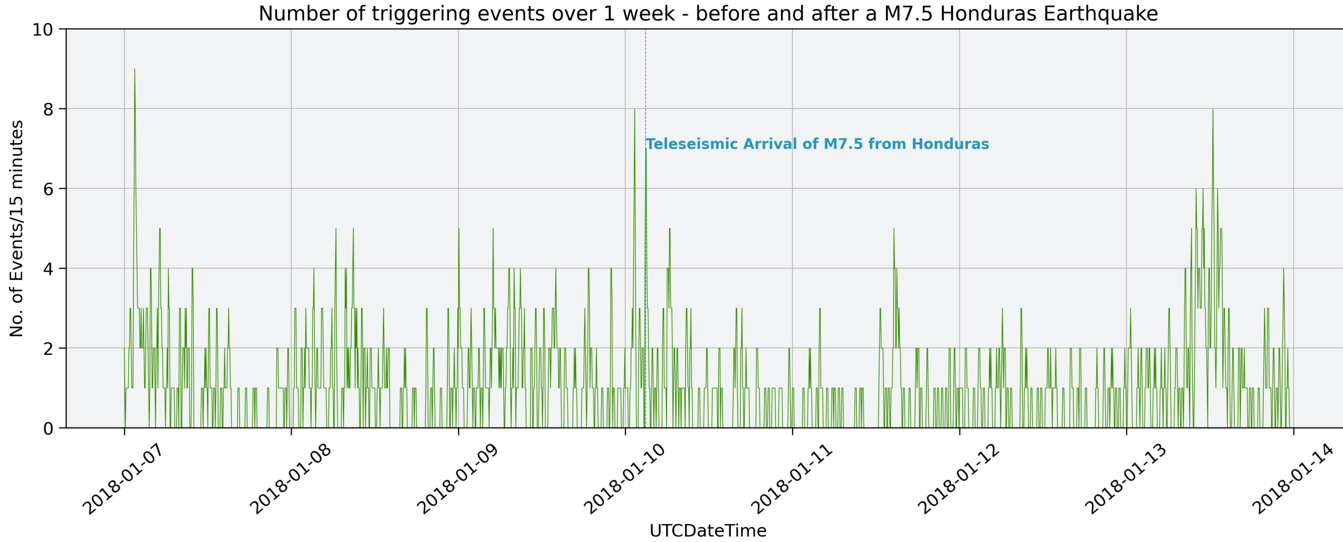
- Dynamic triggering is the process where local earthquakes are triggered by the dynamic stress perturbations associated with the arrival of transient seismic waves from distant earthquakes.



Event Statistics – Coincidental Seismicity or Not?

Method:
1. Divided each week into 15-minute increments.
2. Applied STA/LTA algorithm to each increment to calculate the number of detected events.





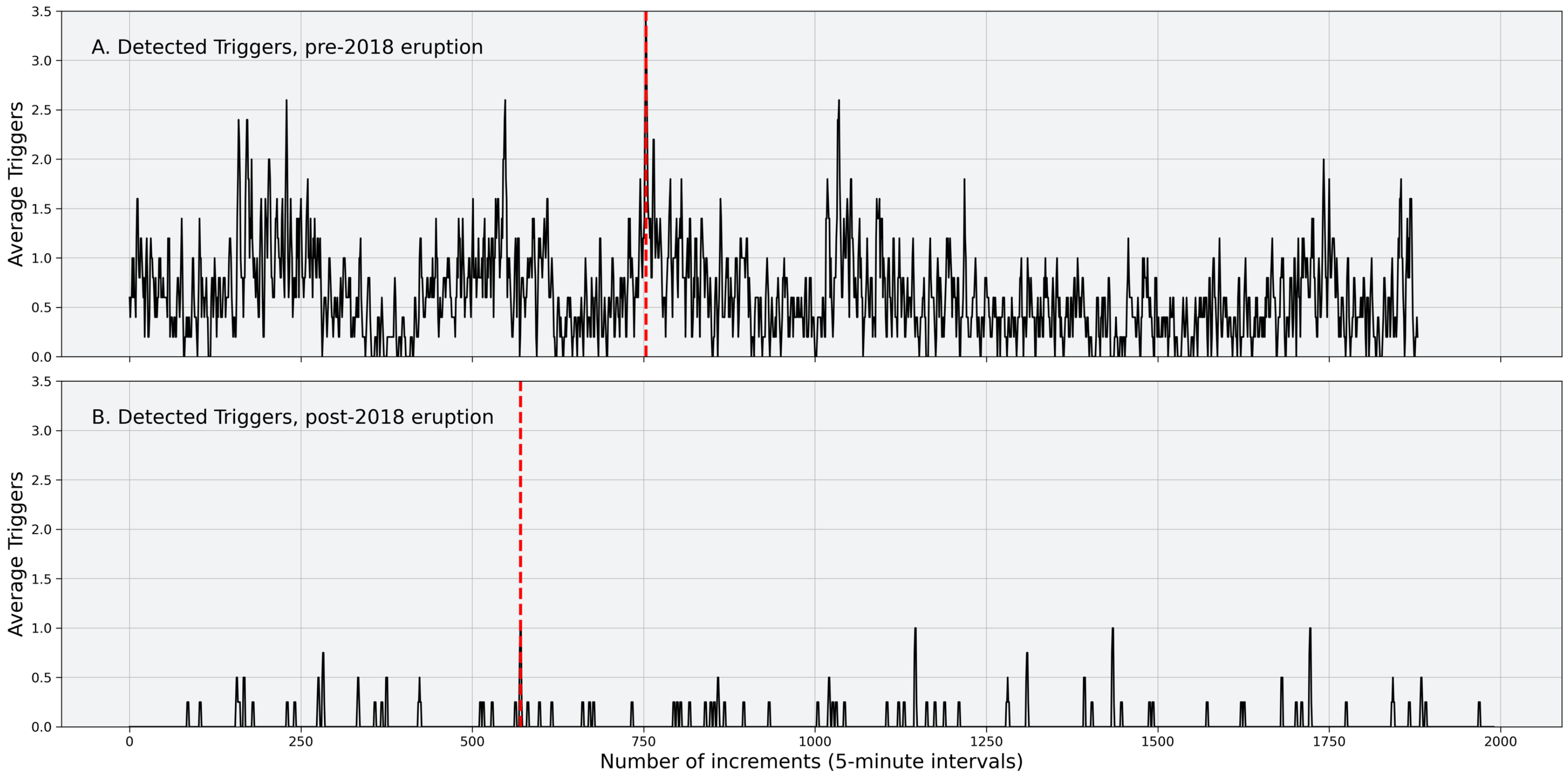
Event Statistics – Coincidental Seismicity or Not?

Stacking:

- 9 events (5 pre-2018 eruption, 4 post-eruption) were stacked to calculate the average number of detected events per 15-minute increment.

Method:

1. Locate the increment in which the teleseism arrival occurs.
2. Centre each week so that the teleseism time-increment occurs in the centre.
3. Stack each week and calculate the average number of detected events per time increment.

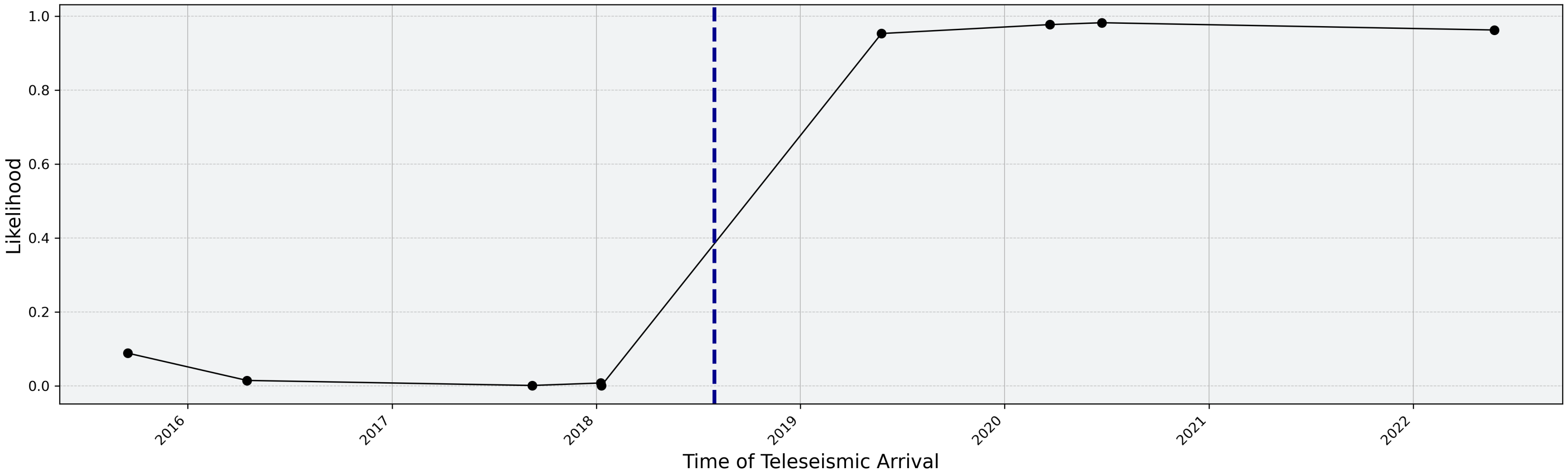


Event Statistics – Coincidental Seismicity or Not?

We now want to calculate the likelihood of coincidental seismicity occurring at the same time as dynamic triggering.

Method:

- Calculate the number of detected events that occur during the ‘target’ time increment.
- Shuffle the time increments and the number of events independently.
- Calculate the likelihood that the number of events that occur during the ‘target’ time increment occur at any other time increment.

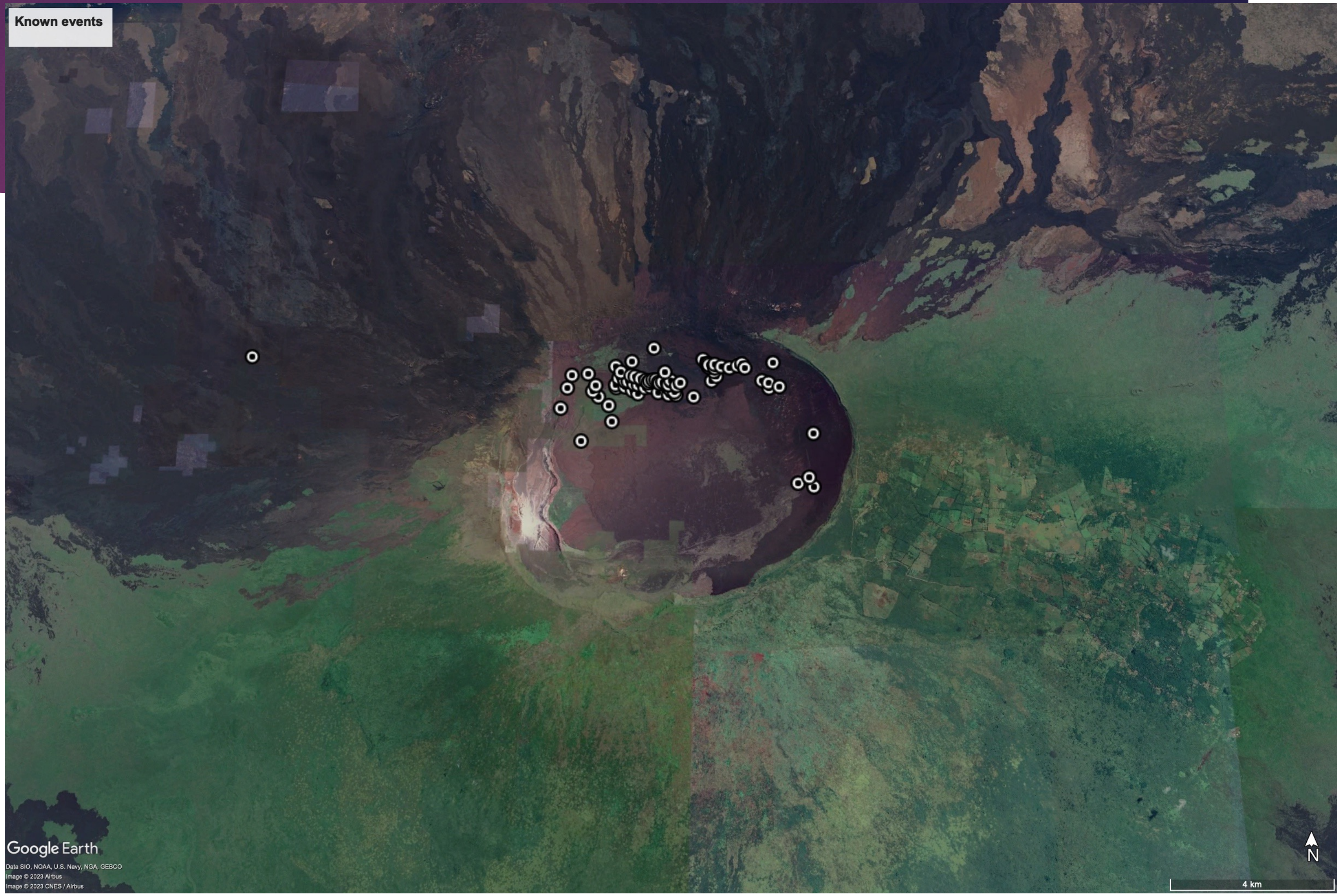


Event Location

Method:

1. Calculate the back-azimuth via rotation.
2. Calculate the distance via P-S wave delay time.
3. Calculate the latitude and longitude using the Haversine formula.

Utilise 79 known events (located when full seismic network was in operation) that were detected at VCH1 to test method.



Event Location

Distance:

$$\Delta = (t_s^{arr} - t_p^{arr}) \frac{v_p v_s}{v_p - v_s}$$

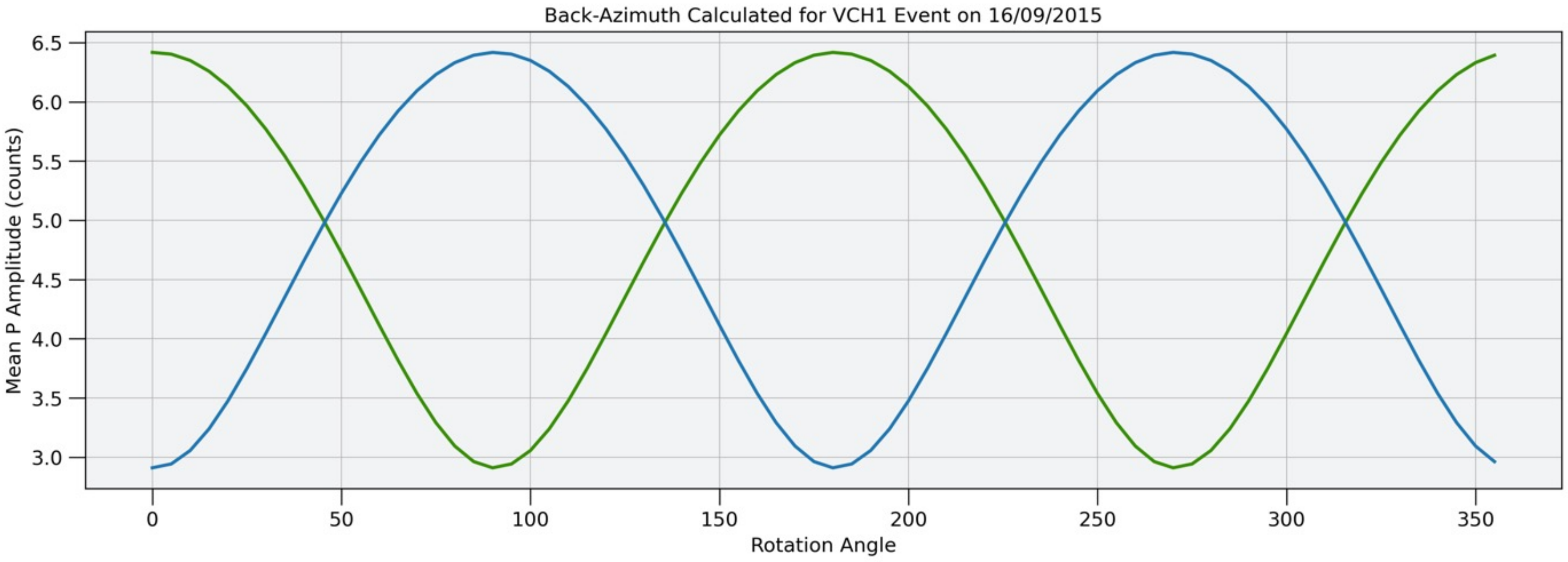
t_s^{arr} = S-wave arrival time

t_p^{arr} = P-wave arrival time

v_p = P-wave velocity (3.95km/s)

v_s = S-wave velocity (2.19km/s)

Back-Azimuth:
- Rotation north and east components until P-wave amplitude reaches a maximum value at any given rotation.



Event Location

- Calculating unknown latitude and longitude
- Great circle method? Cartesian coordinates?

Δ = Distance (km)

R_e = Radius of Earth (6371 km)

x_s = Latitude of station (VCH1)

y_s = Longitude of station (VCH1)

θ= Back-azimuth (radians)

$$x_1 = (0.5\times\pi - a)$$

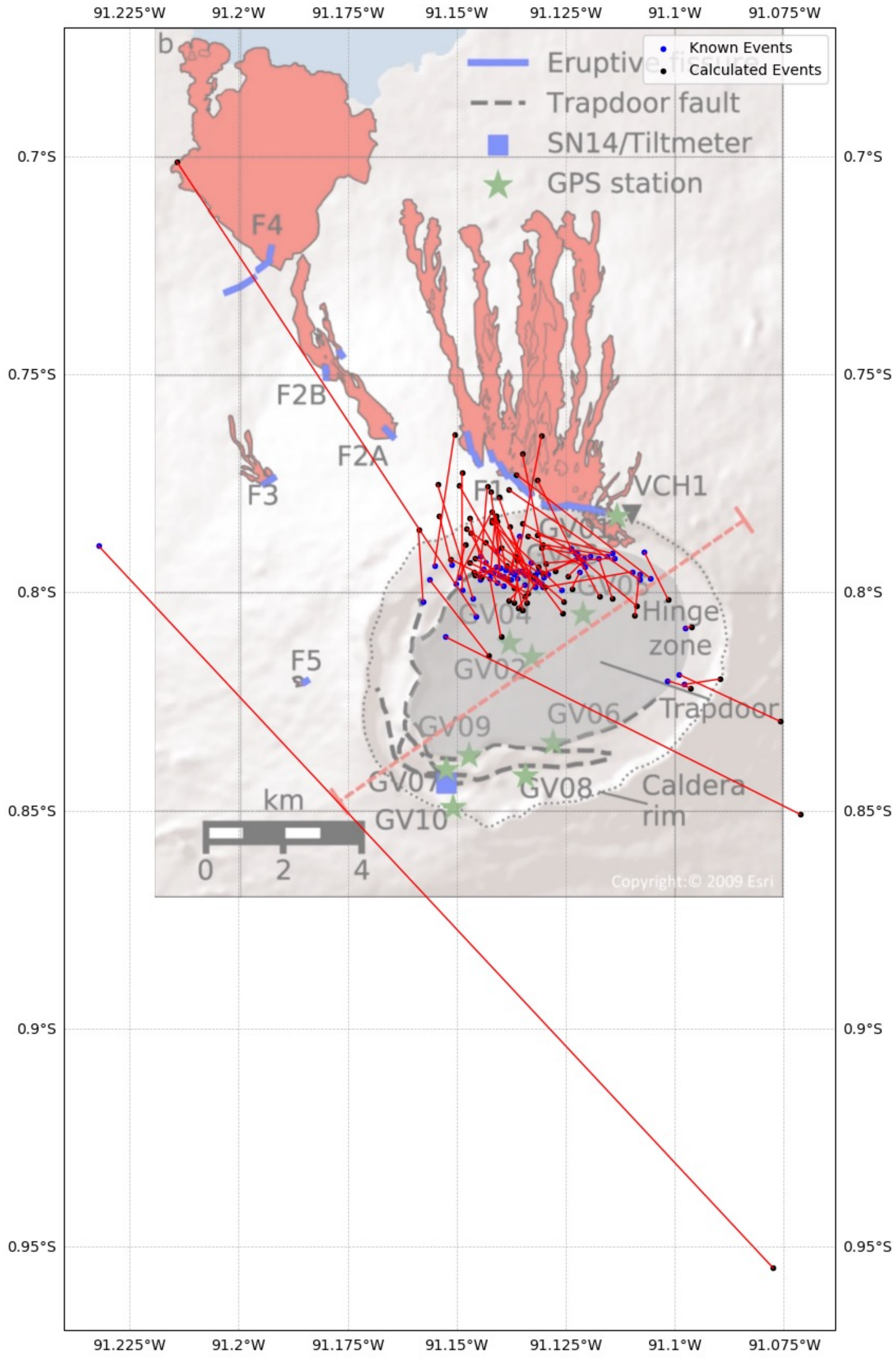
$$y_1 = \left(y_s + ASIN\left(\frac{SIN(b)\times SIN(\theta)}{SIN(a)}\right)\right)$$

$$a = ACOS\big(COS(b)\times COS(0.5\times\pi - x_s) + SIN(0.5\times\pi - x_s)\times SIN(b)\times COS(\theta)\big)$$

$$b = \left(\frac{\Delta}{R_e}\right)$$

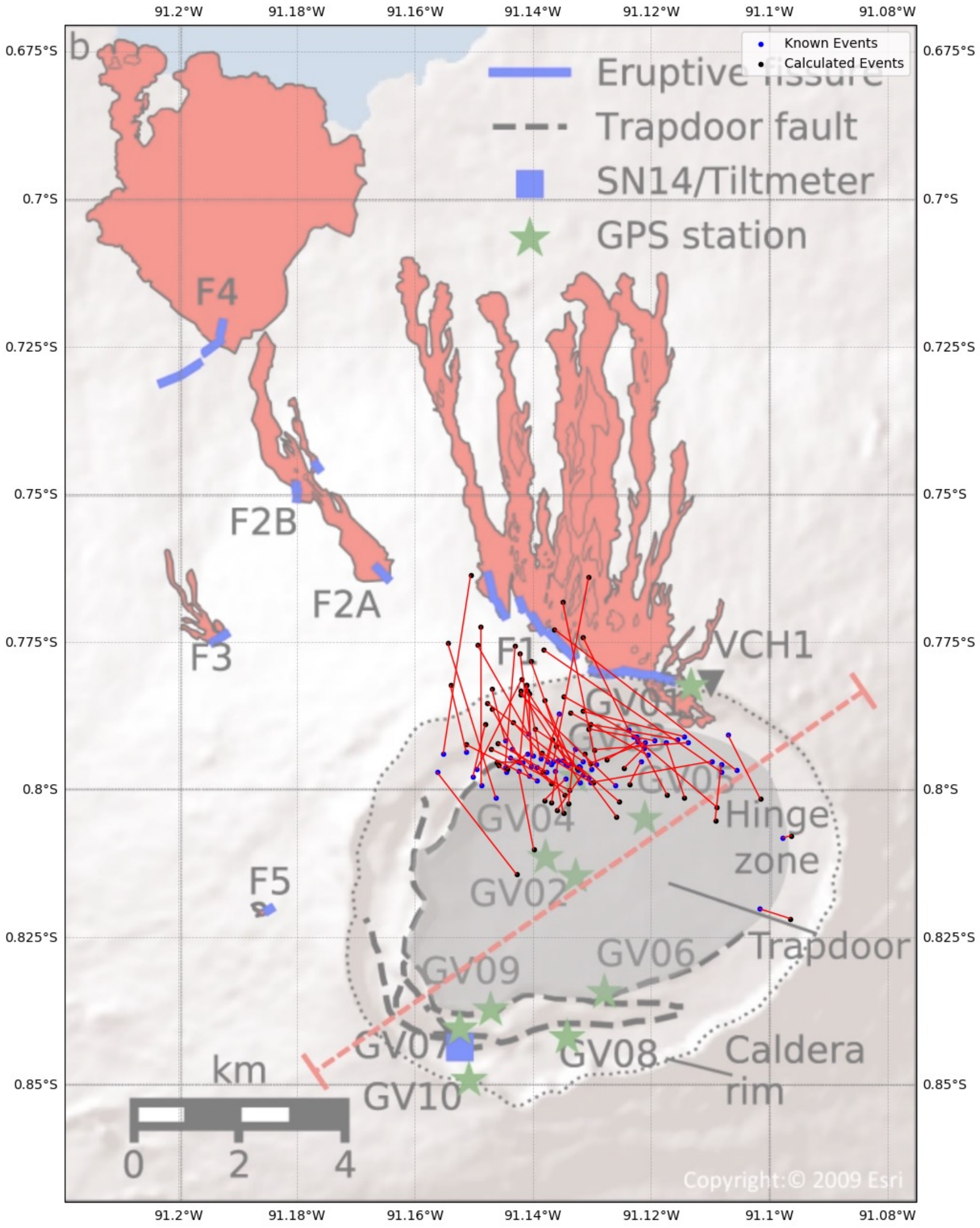
Event Location

- Haversine formula.
- Average distance discrepancy: 2078m.



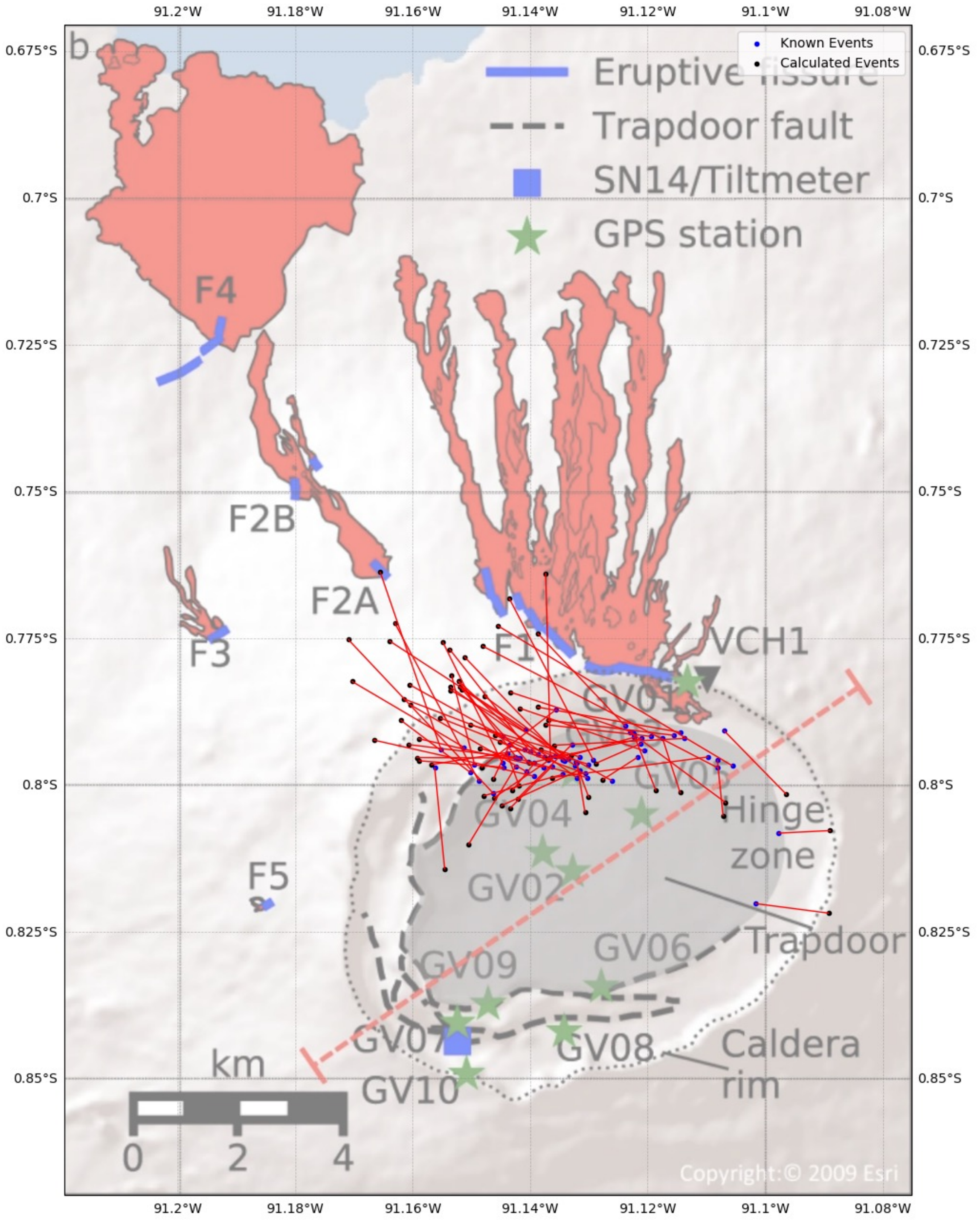
Event Location

- Haversine formula.
- Removal of events with a P-S wave delay time > 1s.
- Average distance discrepancy: 1465m.



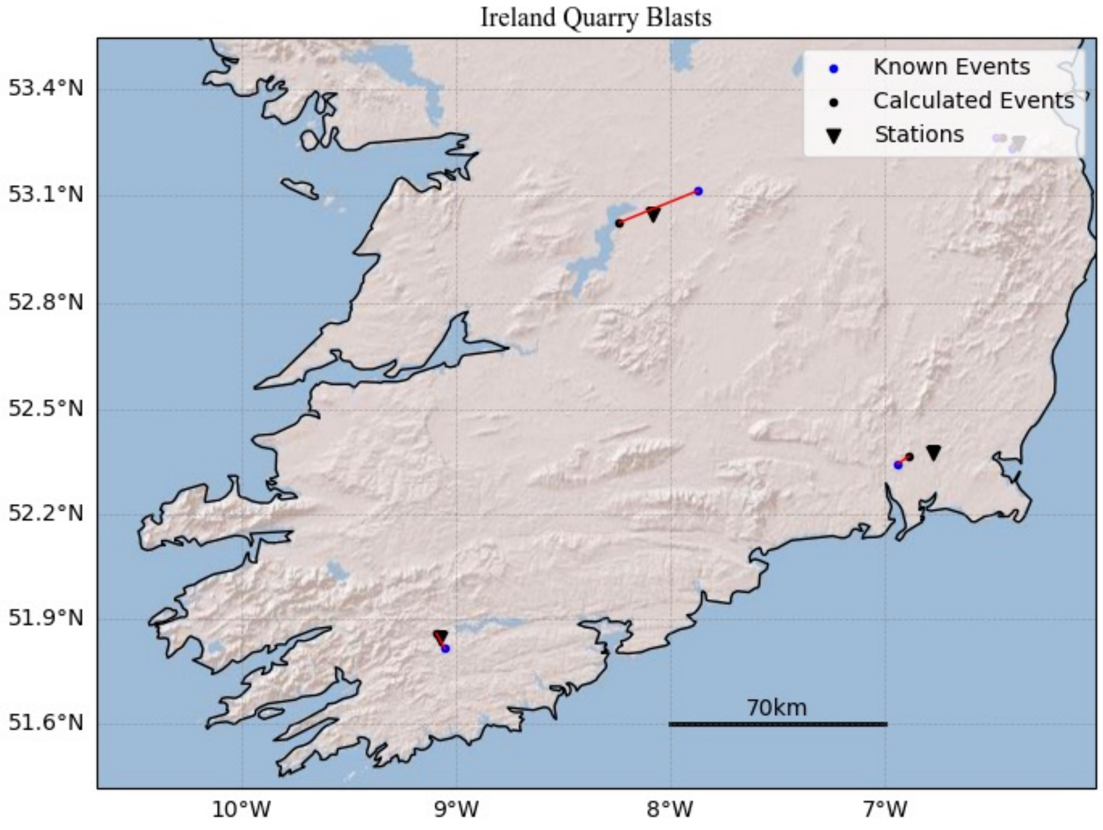
Event Location

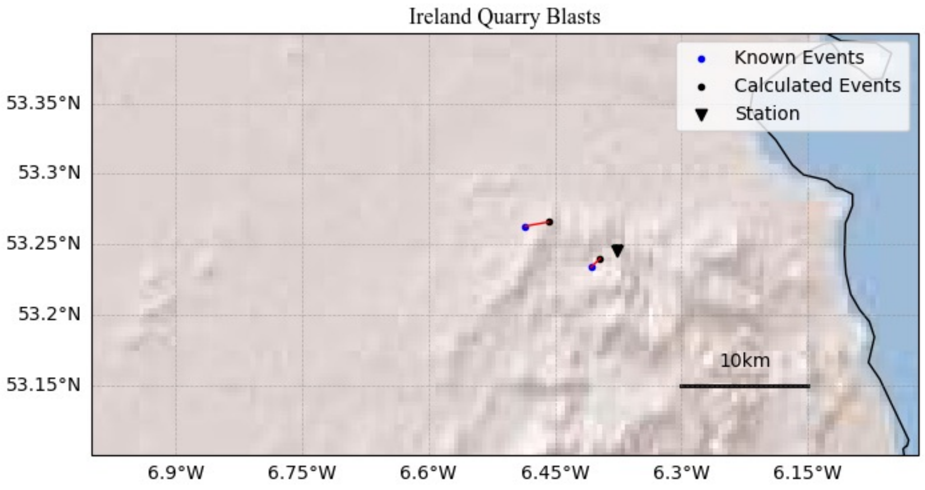
- Cartesian formula.
- Removal of events with a P-S wave delay time > 1s.
- Average distance discrepancy: 2075m.



Event Location

- Applying to Ireland quarry blasts.
- Majority have P-S wave delay time > 1s.





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