VLP oscillations of Piton de la Fournaise

Insights into Caldera Collapses and Dike resonance

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Variety of seismo-volcanic signals

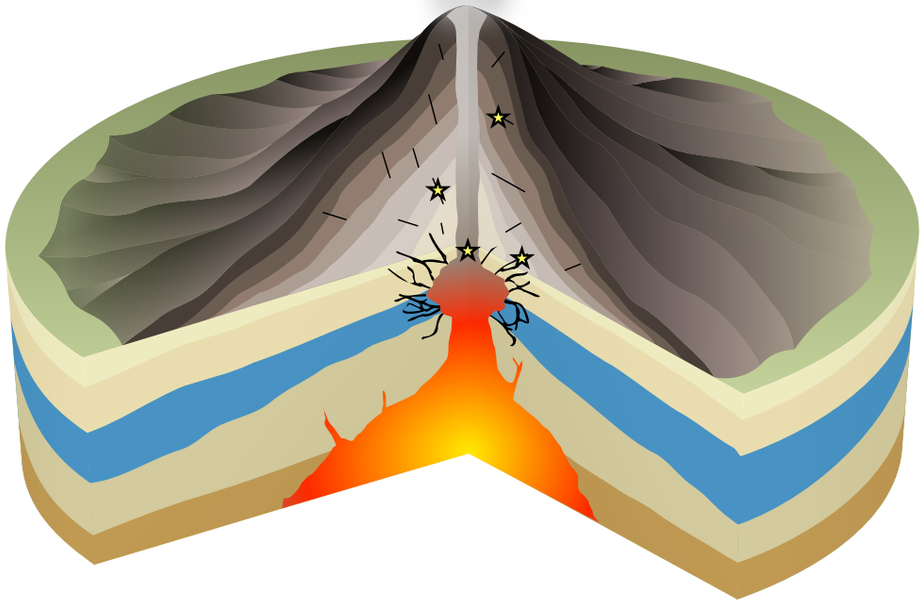
Diversity of volcanic sources

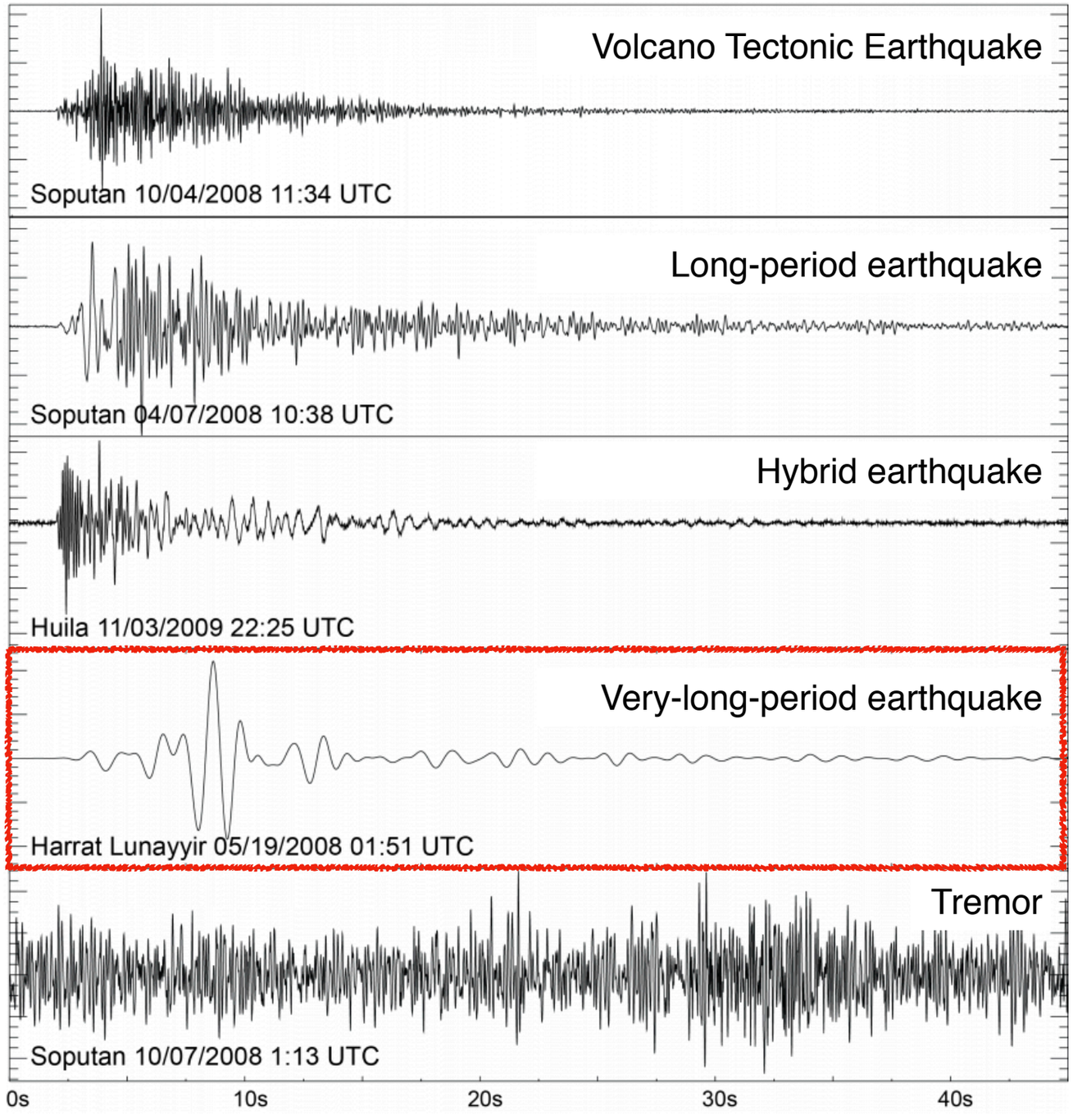
- Volcano Tectonic earthquakes:
  - *Brittle failures in the edifice*
  - *Link with magma transport ?*

- Long-Period / Very-long-period events:
  - *Resonating fluid-filled conduit ?*
  - *Moving fluid ?*
  - *Caldera collapse ?*

- Hybrid earthquakes:
  - *Brittle failures + conduit resonance ?*
  - *Brittle failures + path effect ?*

- Volcanic tremor:
  - *Long-lived resonating magma-filled conduit,*
  - *Flow-induced oscillations,*
  - *Bubble dynamics …*

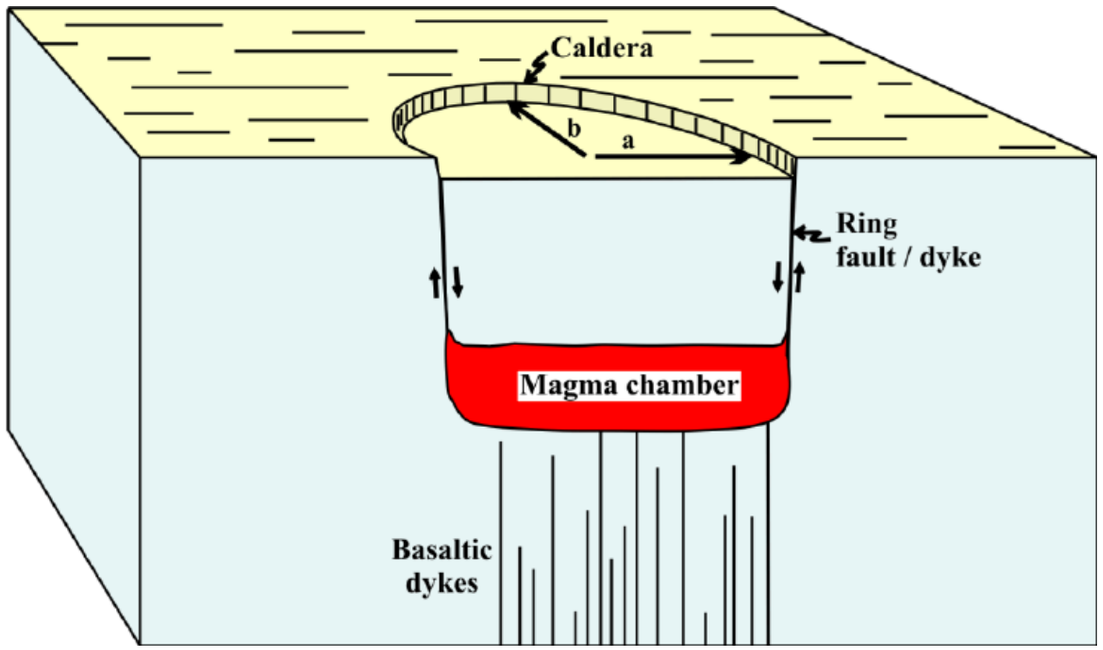




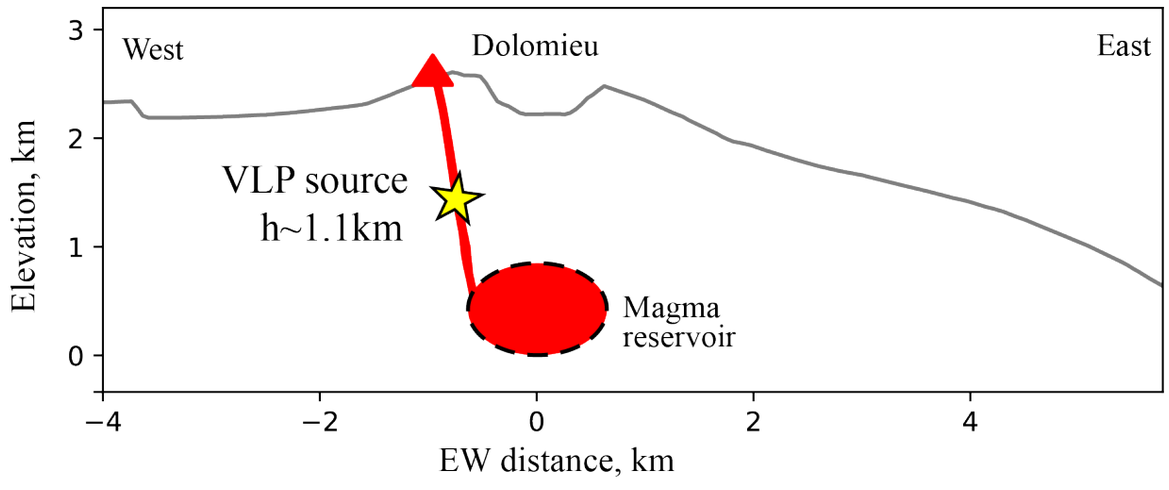
Zoback et al., 2013

Source mechanism of VLP signals ?

Caldera collapses



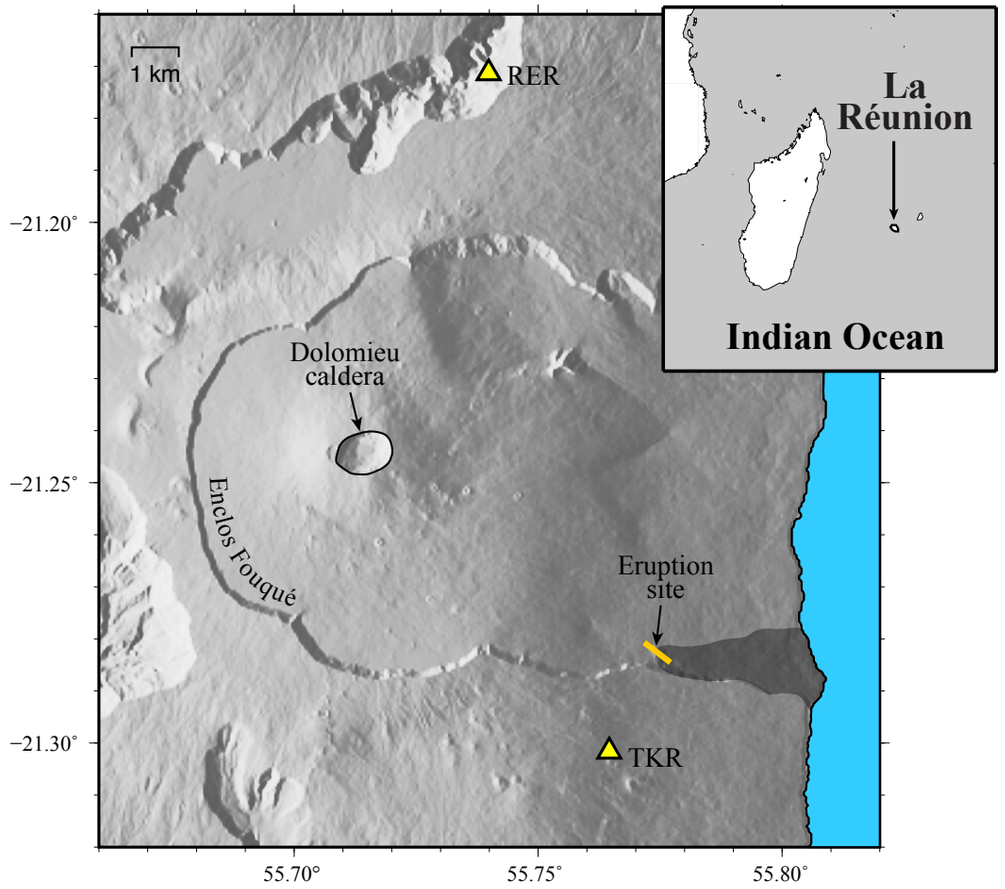
Conduit resonance



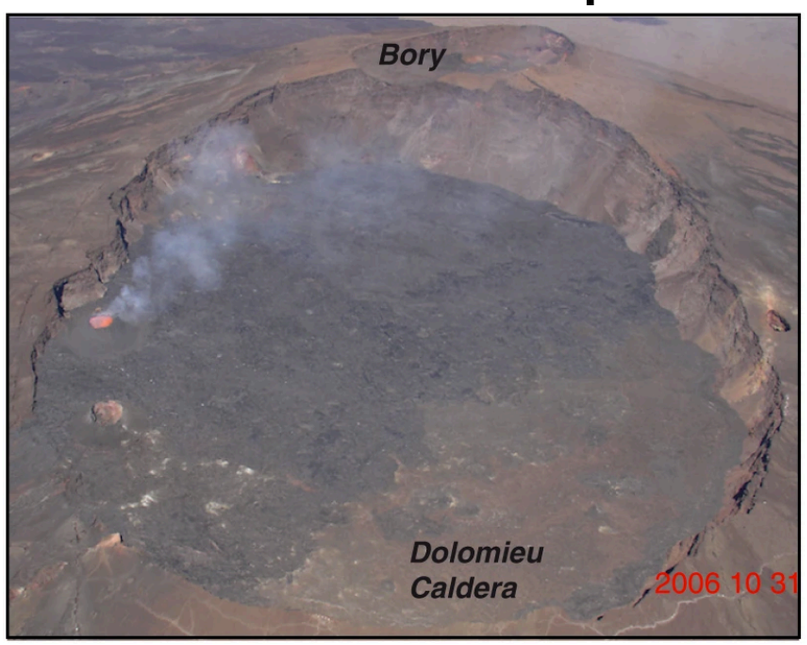
The 2007 collapse at Piton de la Fournaise volcano

Largest collapse in ~300 years :

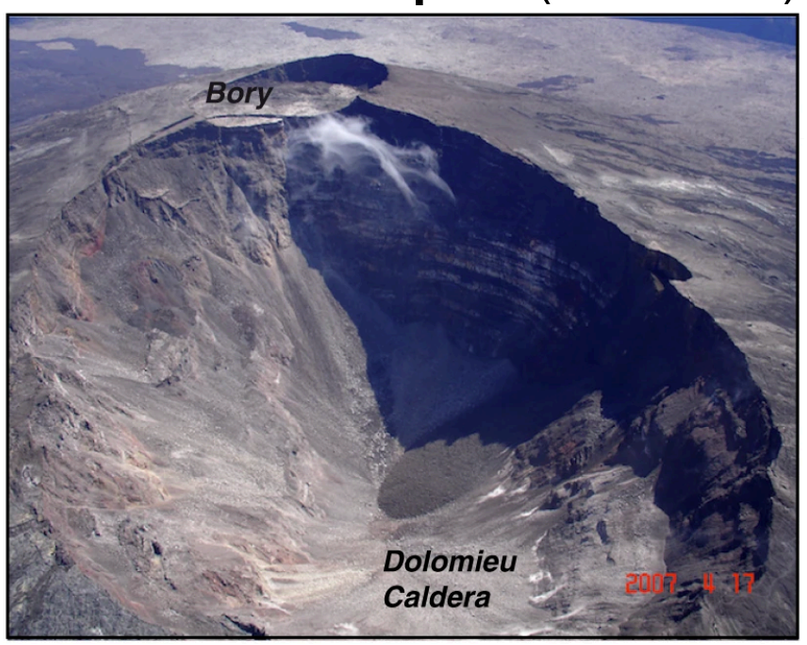
- Started with a low-elevation eruption
- Collapse started 3 days after the eruption onset
- Series of 48 repeating collapse events
- Resulted into a depression of 330 m in ~9 days



Before the collapse



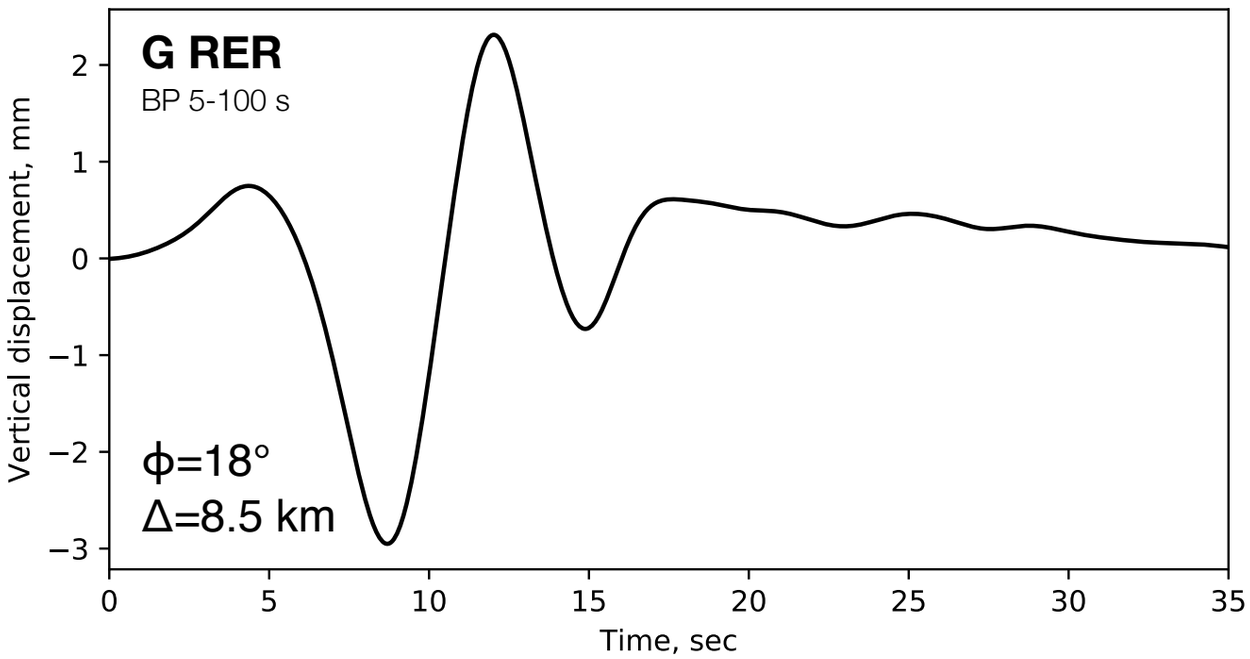
After the collapse (Δz>300m)

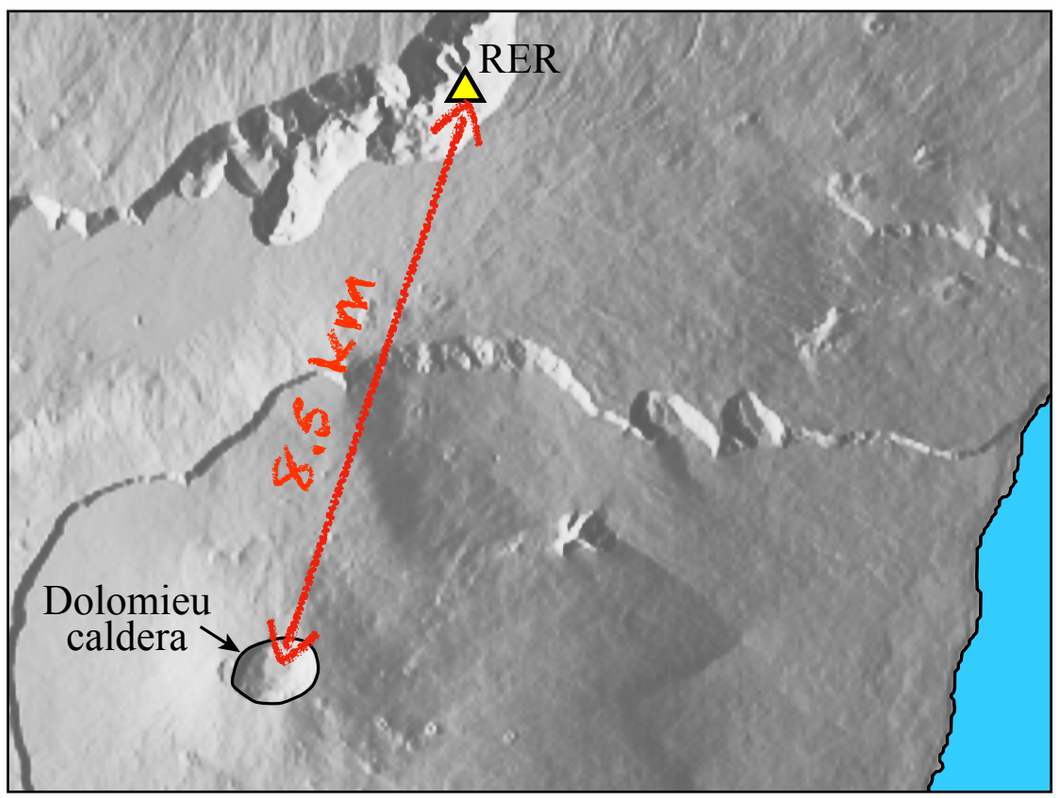


Fontaine et al. (2019), Duputel and Rivera (2019)

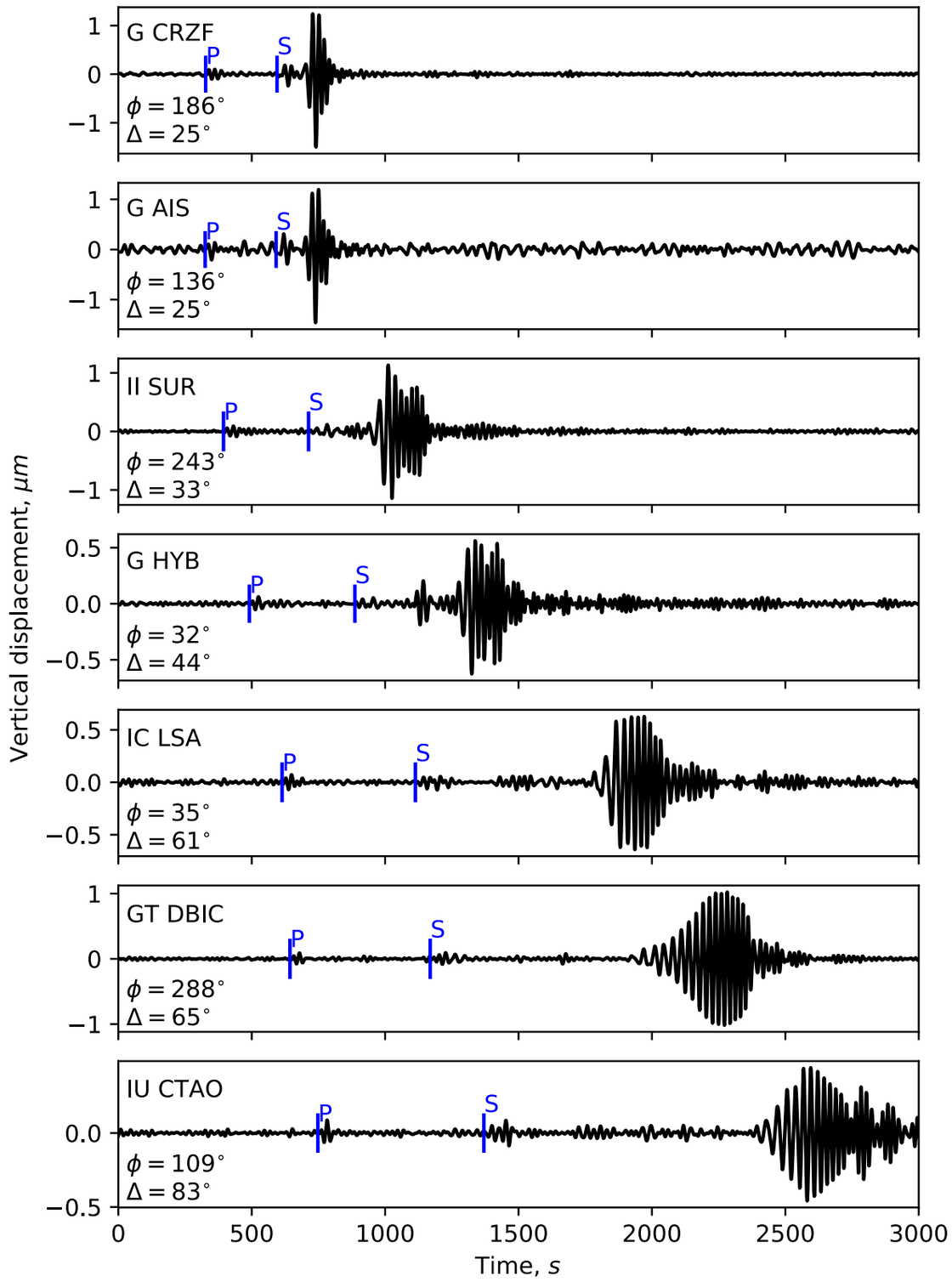
VLP signals during the first collapse event

GEOSCOPE station RER (5-100 s)



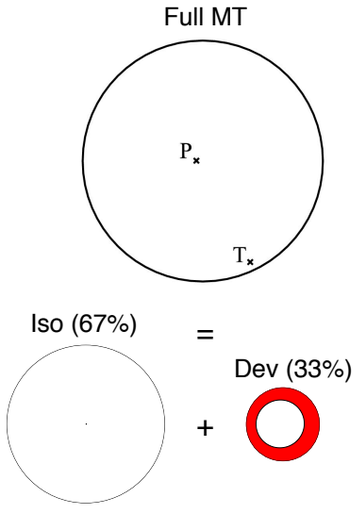


Teleseismic stations (20-50 s)



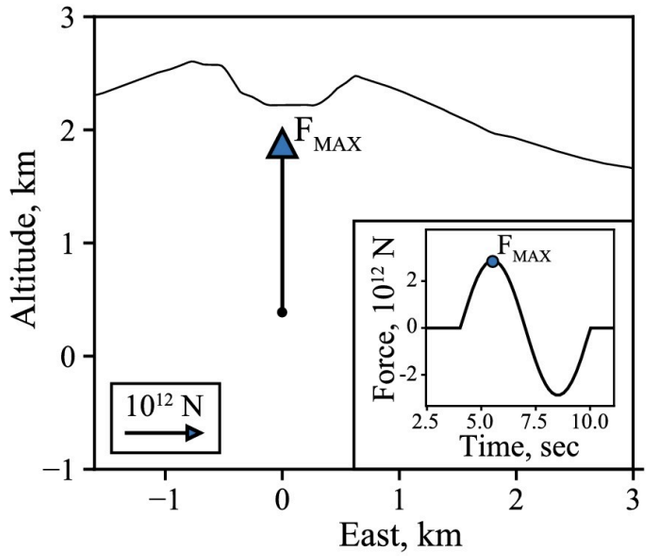
Source: Moment Tensor + Single Force

Moment tensor

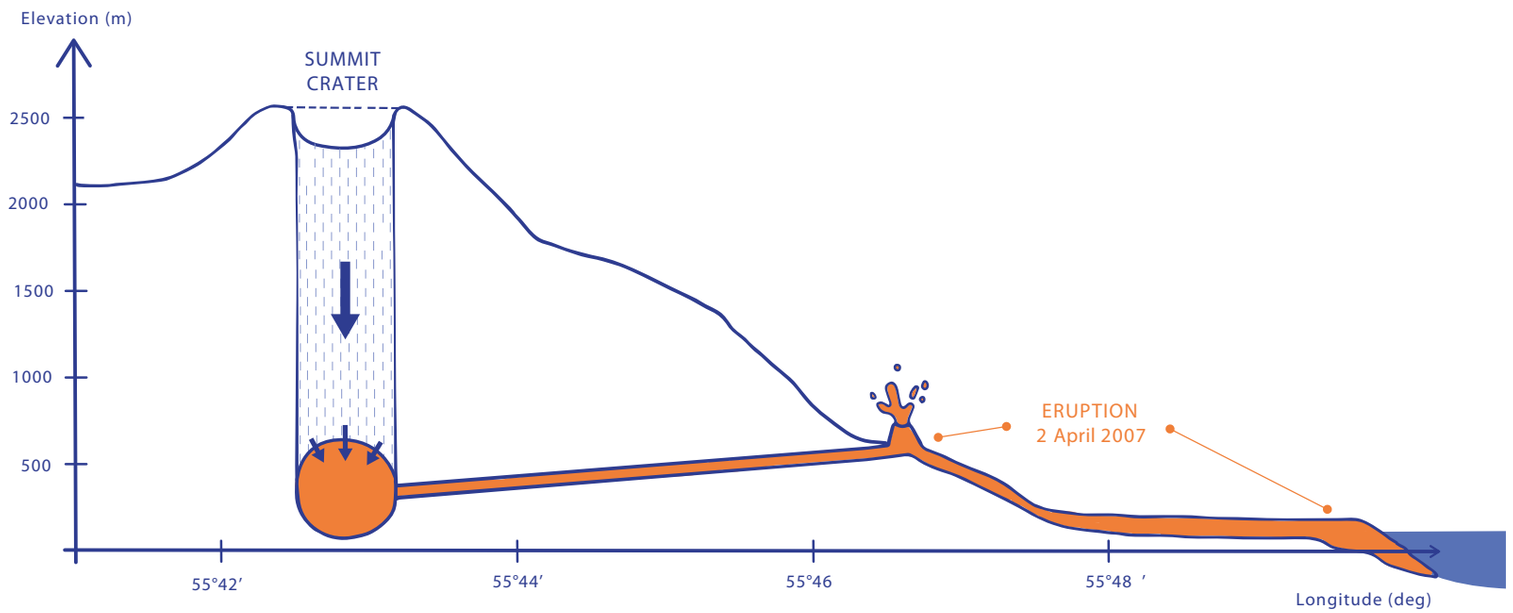


M_W=5.3 ; τ^{MT}=5 s ; t_h^{MT}=3 s
Centroid depth=2 km

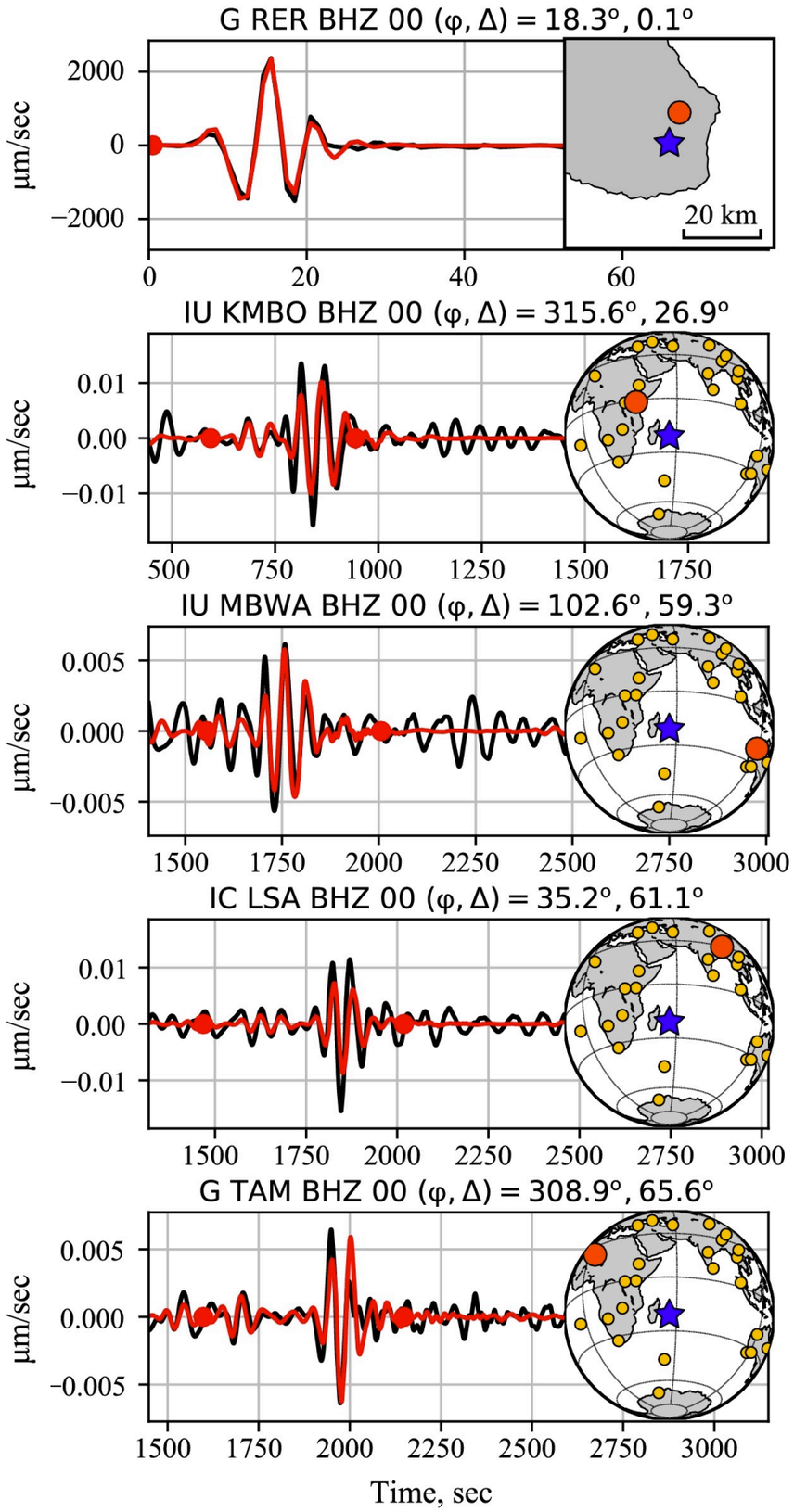
Single force



M_{CSF}=1.6x10^{13} kg.m ; τ^F=7 s ; t_h^F=3 s
Centroid depth=2 km



Duputel and Rivera (2019)



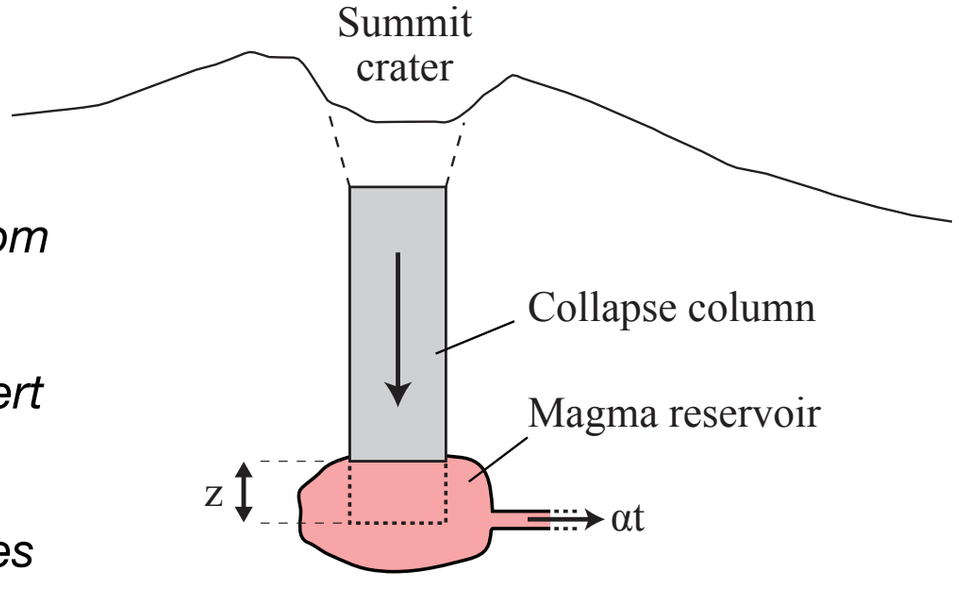
Collapsing piston

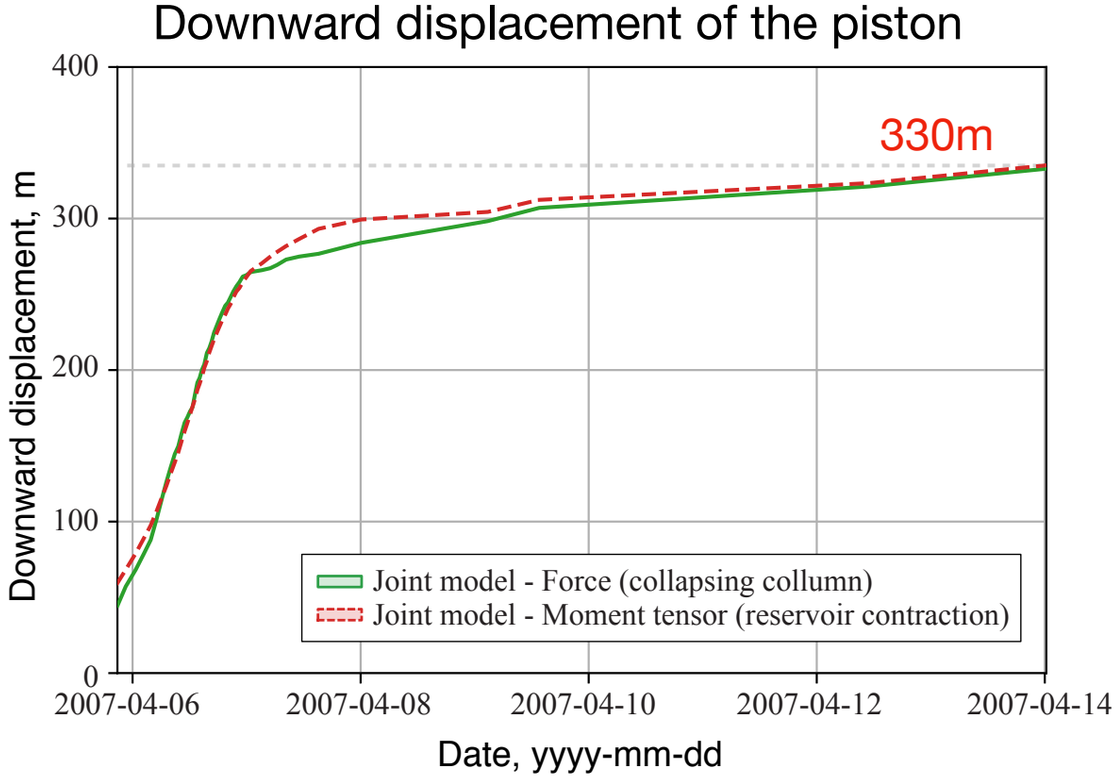
Displacement correlated to magma outflow

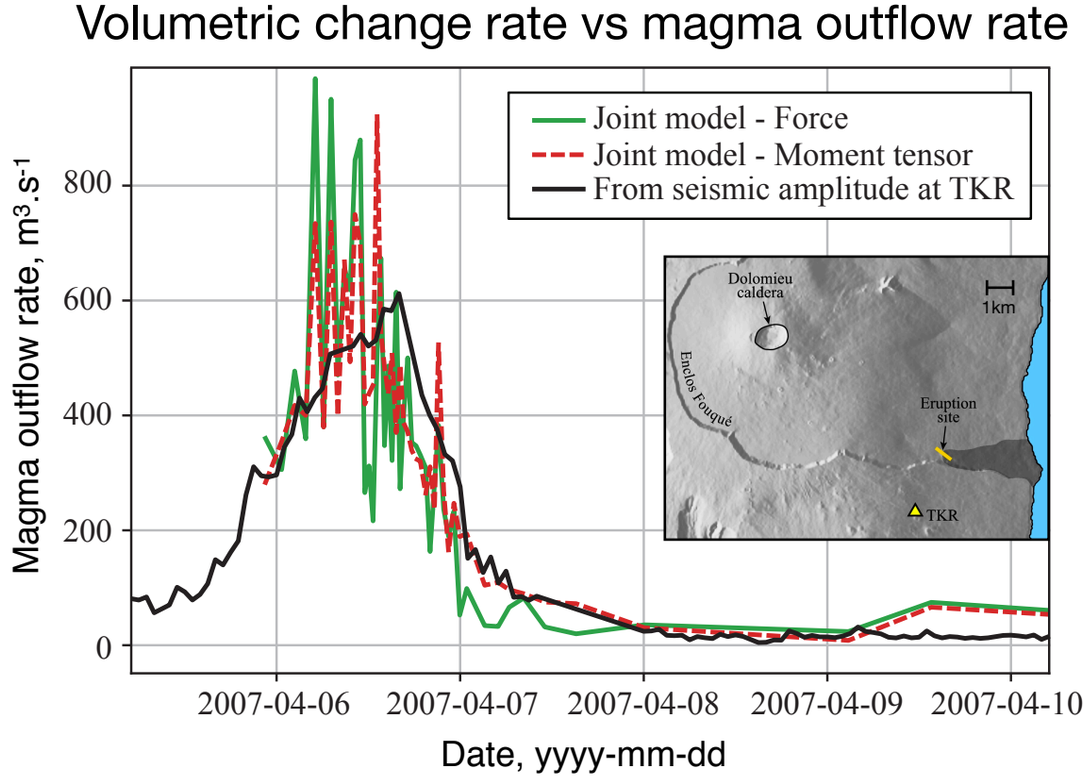
- *Piston displacement & Reservoir volumetric change derived from source model*

- *Lava extrusion rate derived from seismic amplitudes (from Hibert et al., 2015).*

- *Reservoir volumetric change consistent with lava extrusion rates derived from seismic amplitudes*





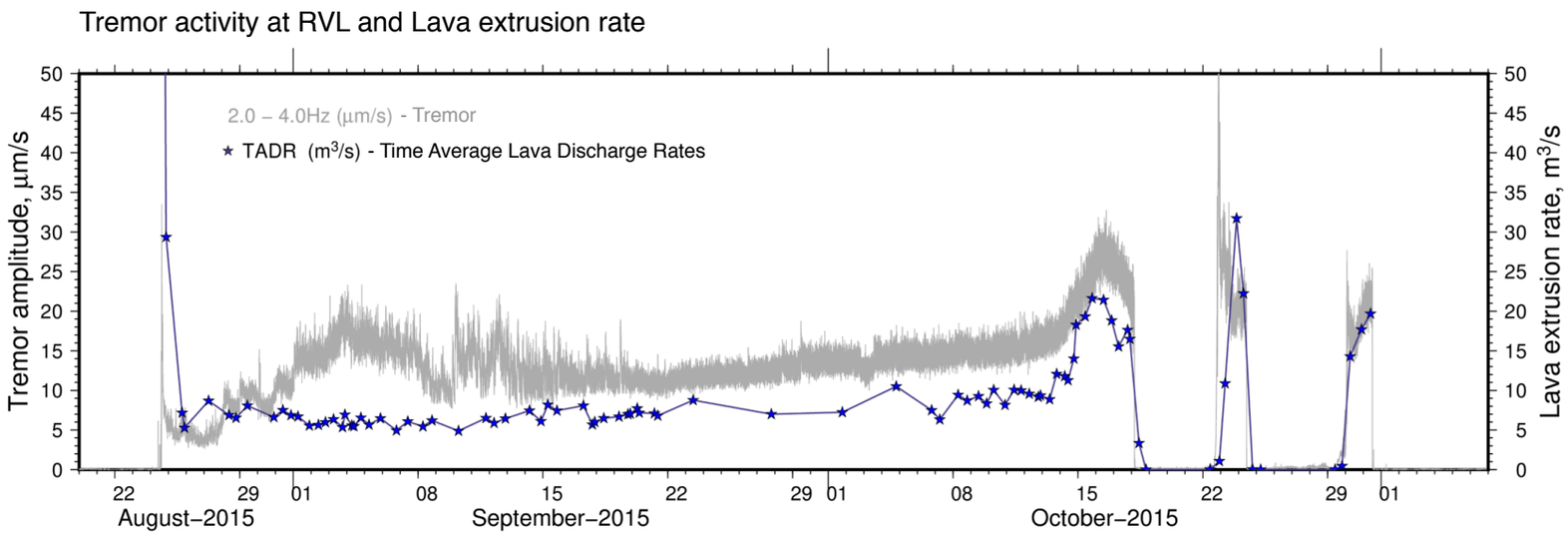


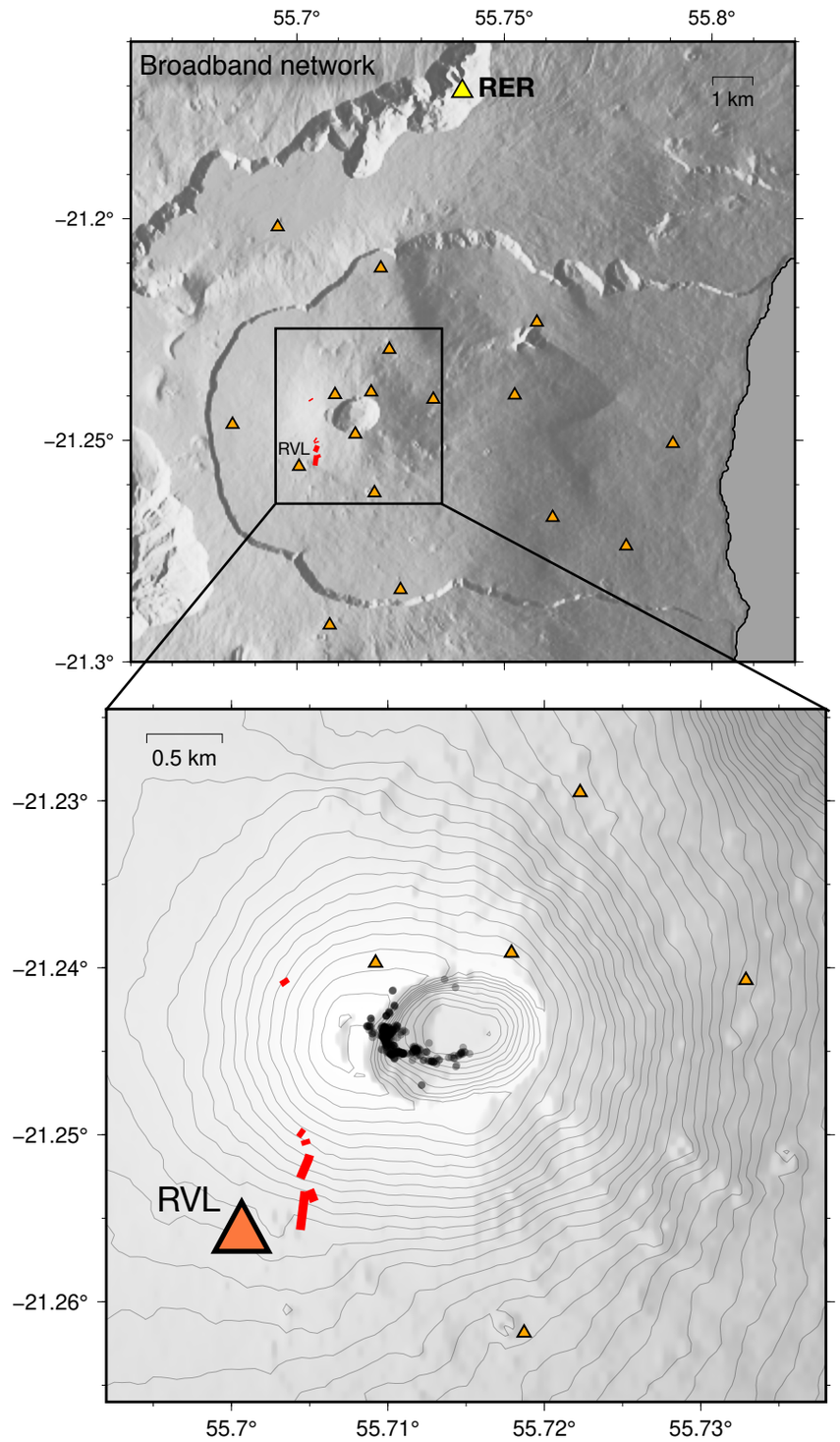
Duputel and Rivera (2019)

VLP signals during Aug. 2015 eruption at Piton de la Fournaise

August 2015 eruption :

- Pre-eruptive VT swarm lasting ~2 hours
- One single dike intersecting the central cone
- Duration ~ 2 months
- Two “rest” periods (Ø tremor, Ø emission)



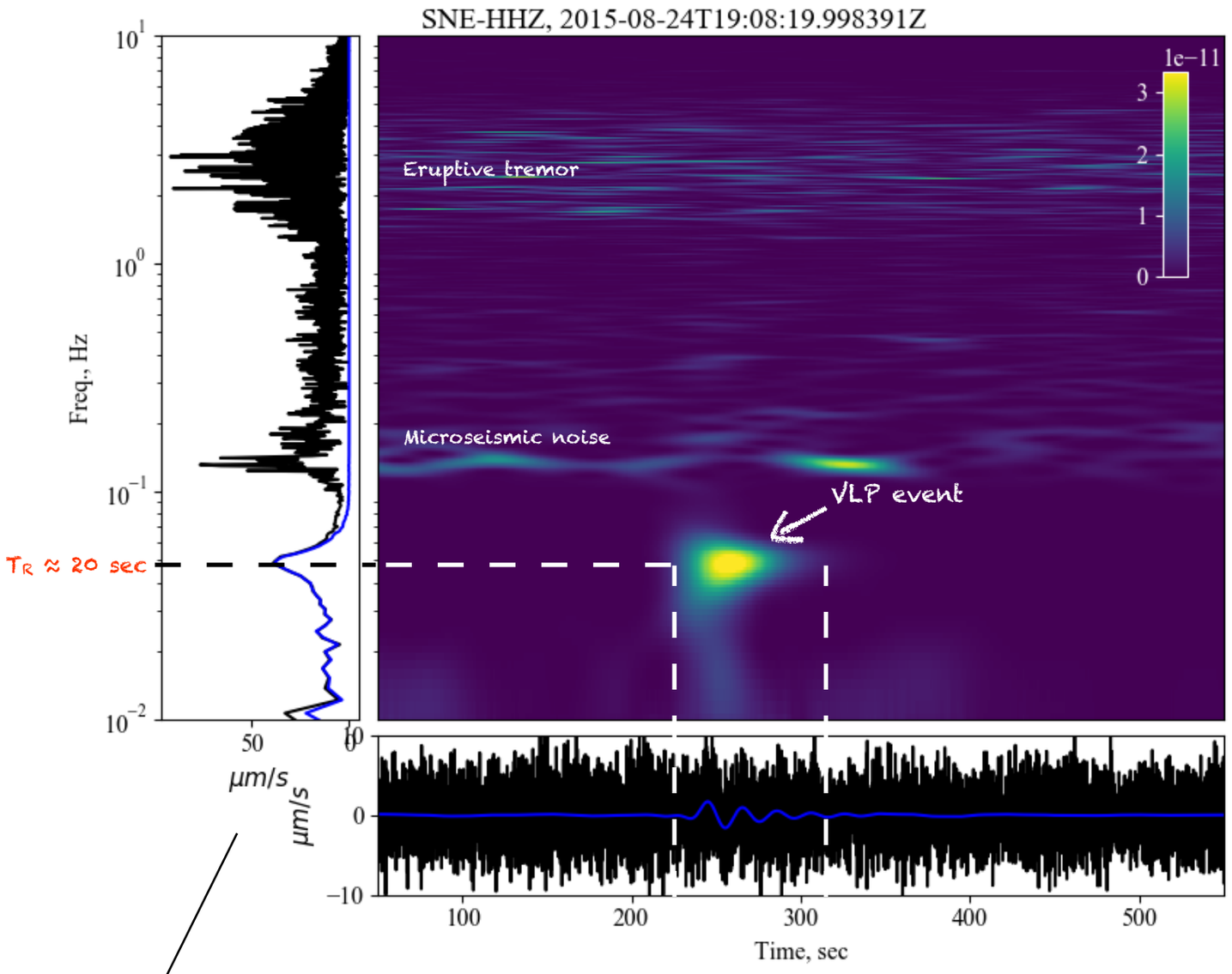


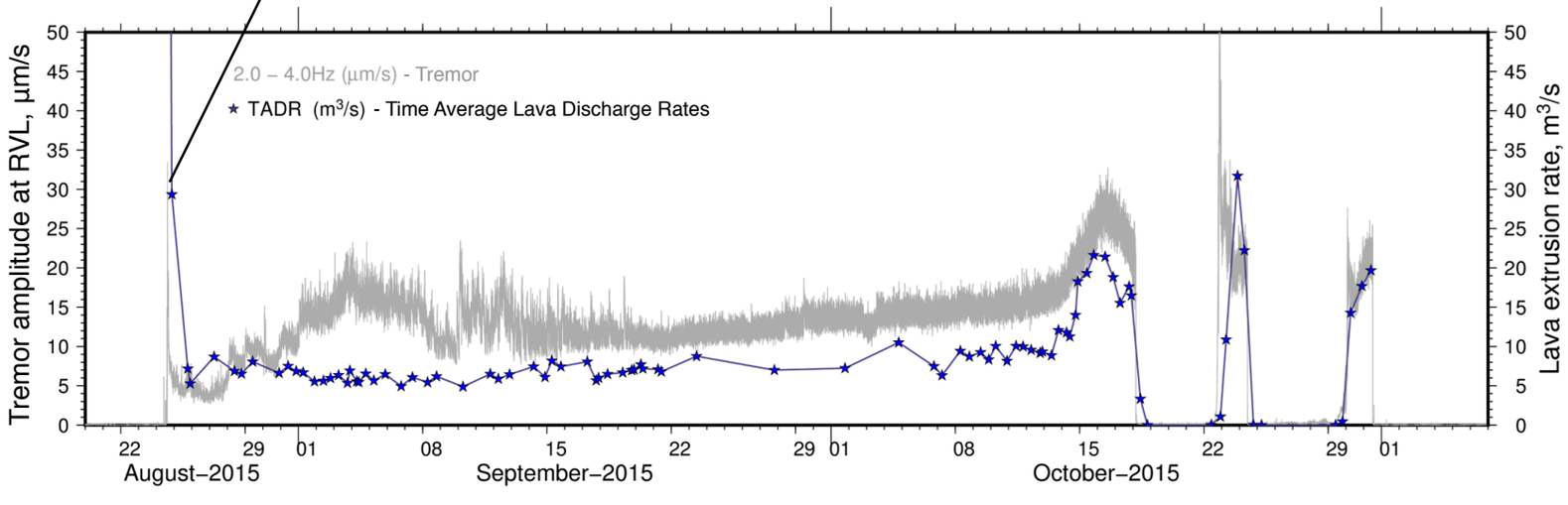
Red lines = eruptive fissures

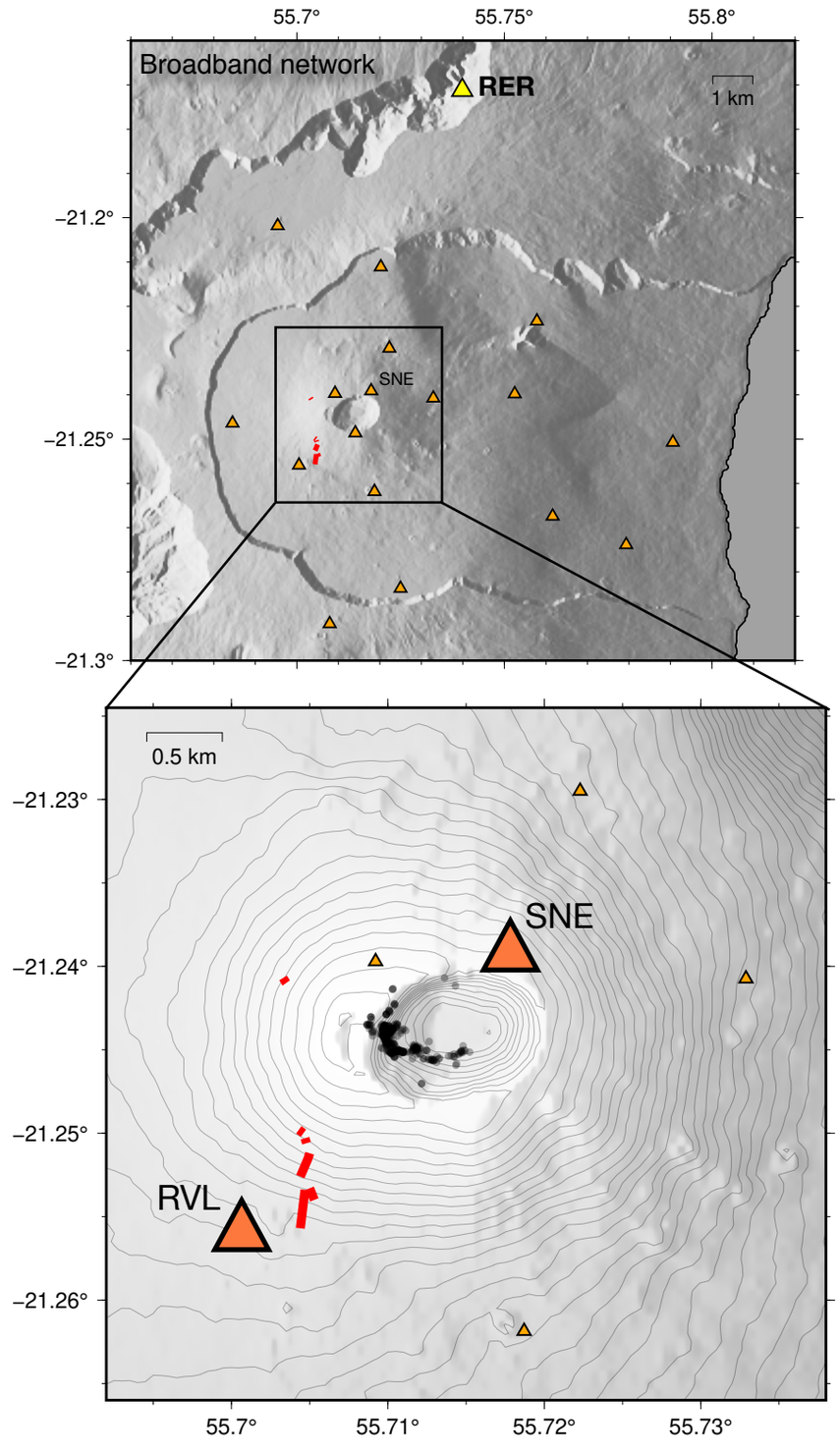
Black Circles = pre-eruptive VT swarm

Triangles = Broadband stations

VLP signals during Aug. 2015 eruption at Piton de la Fournaise







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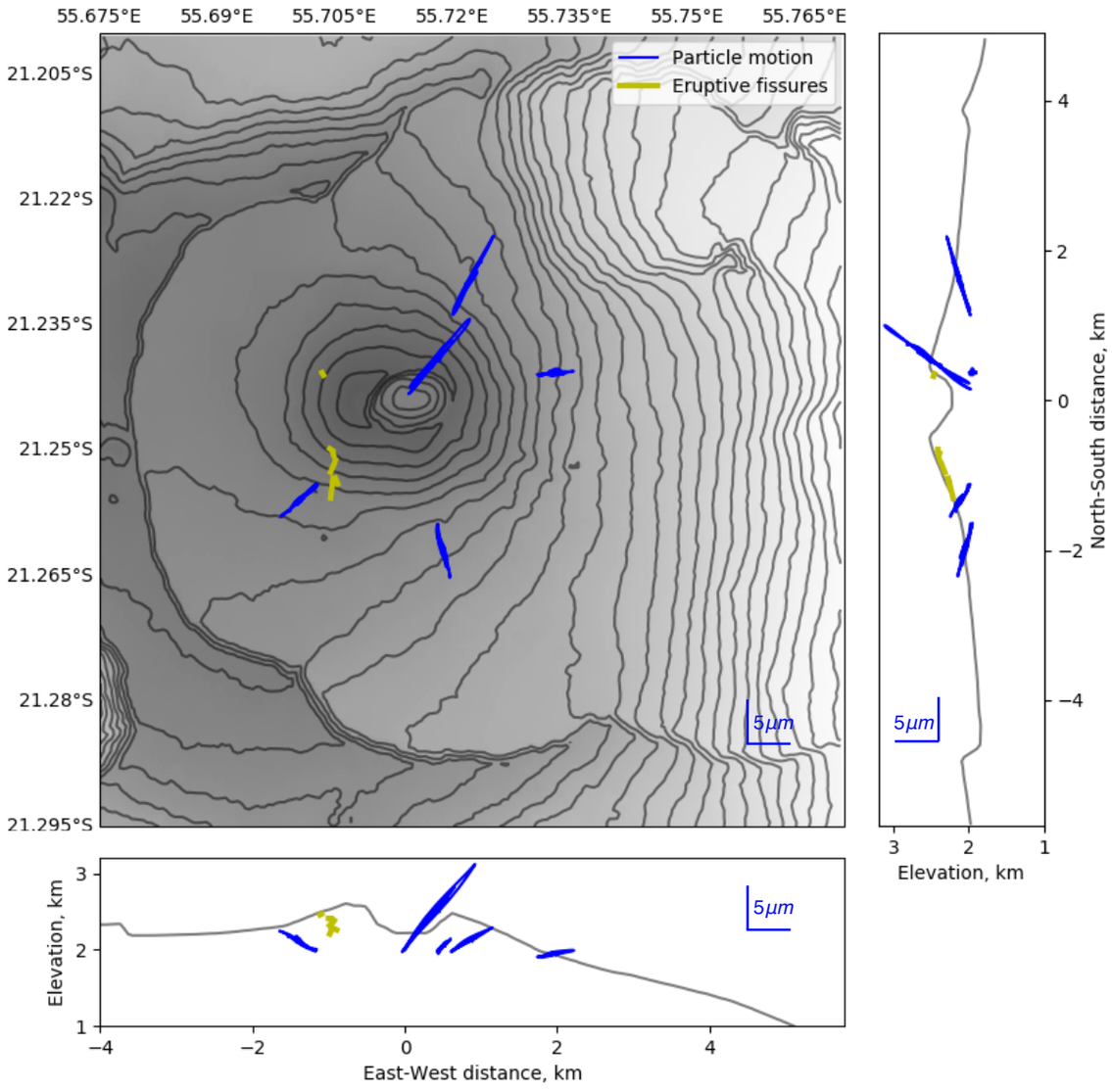
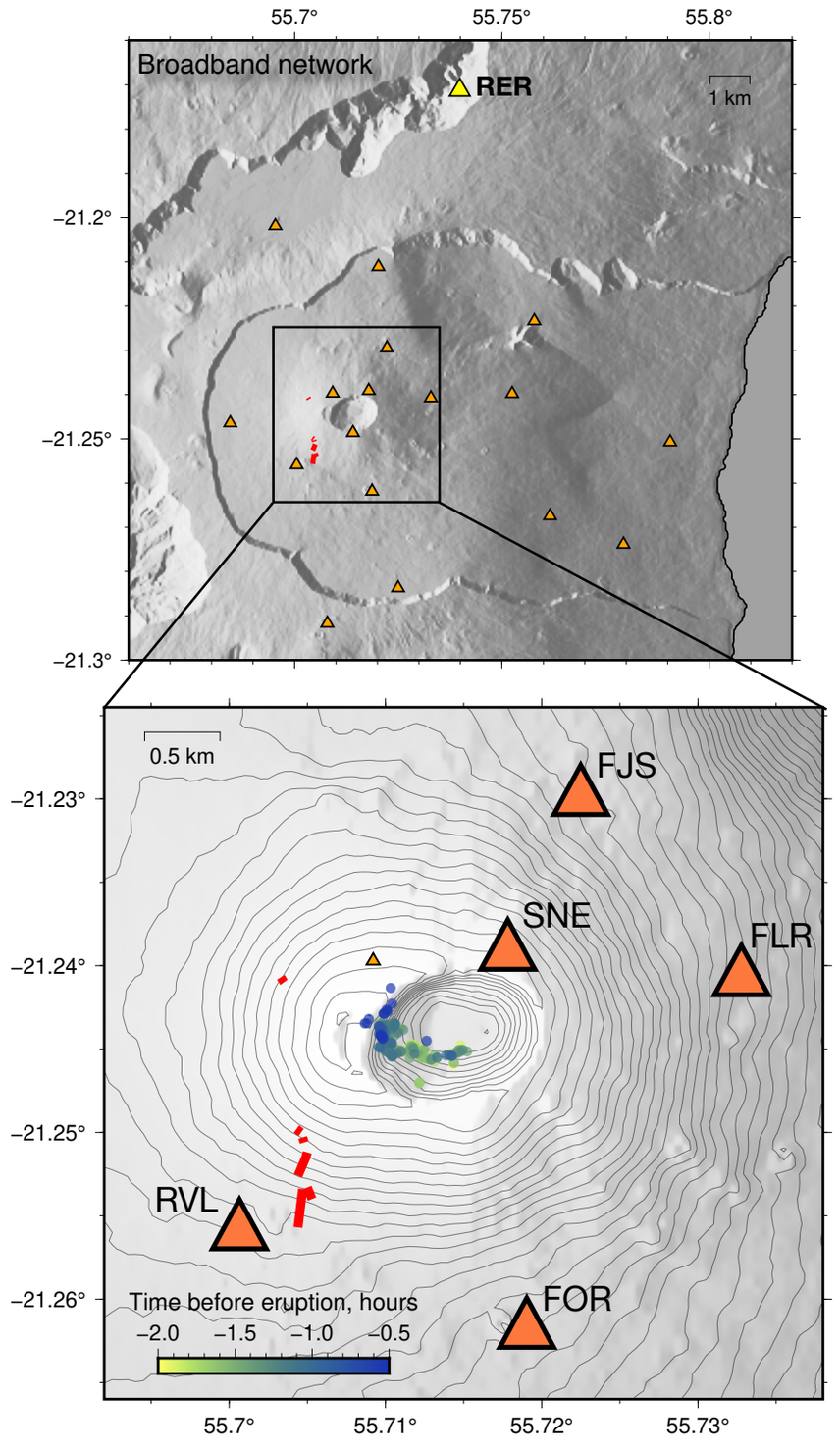
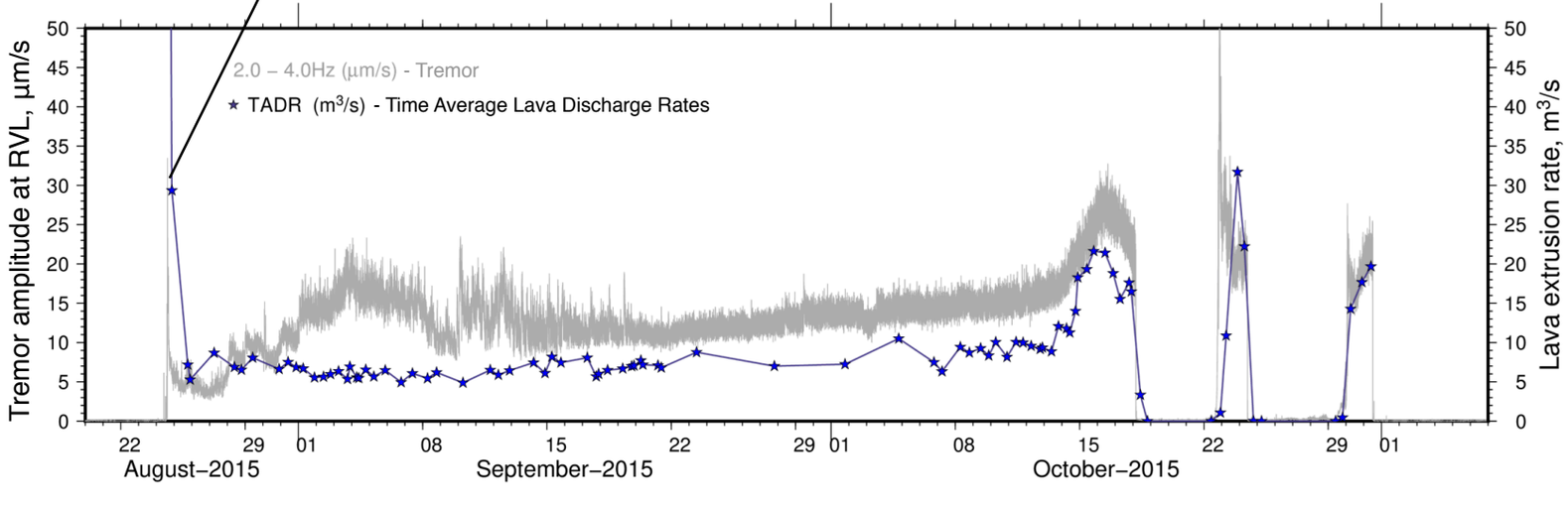
VLP signals during Aug. 2015 eruption at Piton de la Fournaise







Red lines = eruptive fissures

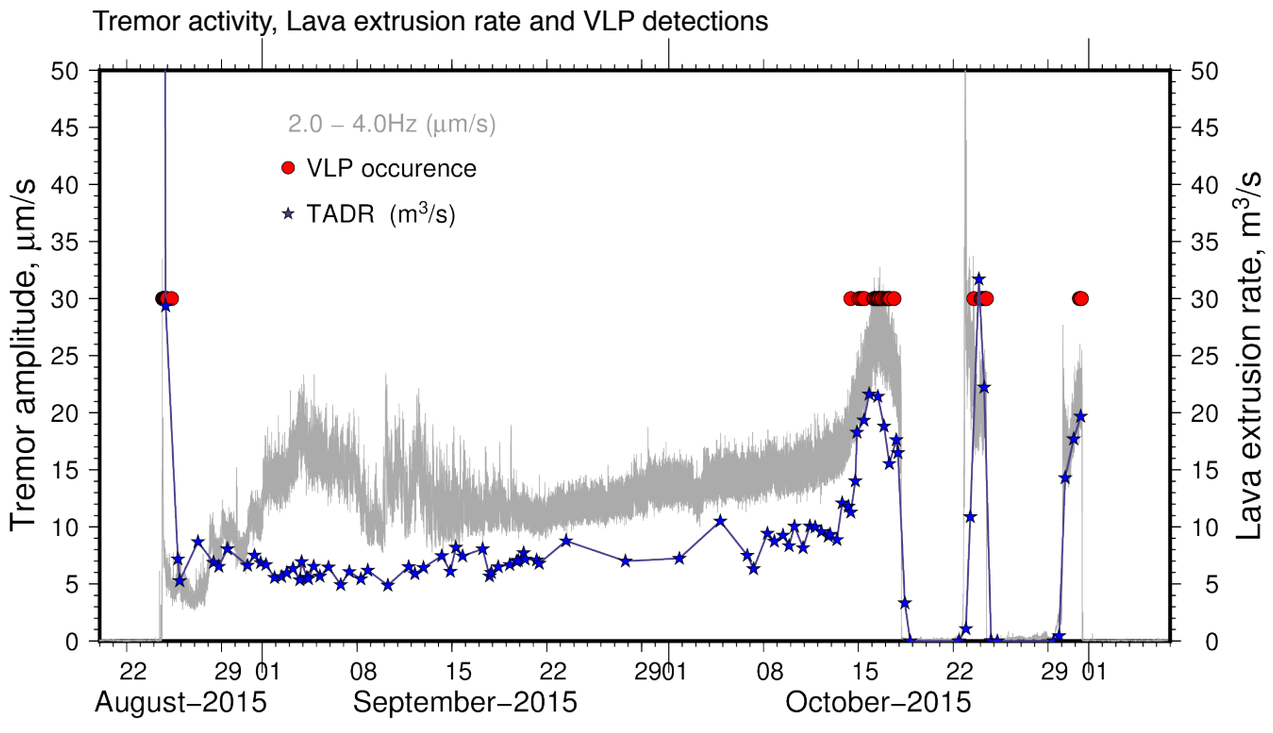
Circles = pre-eruptive VT swarm

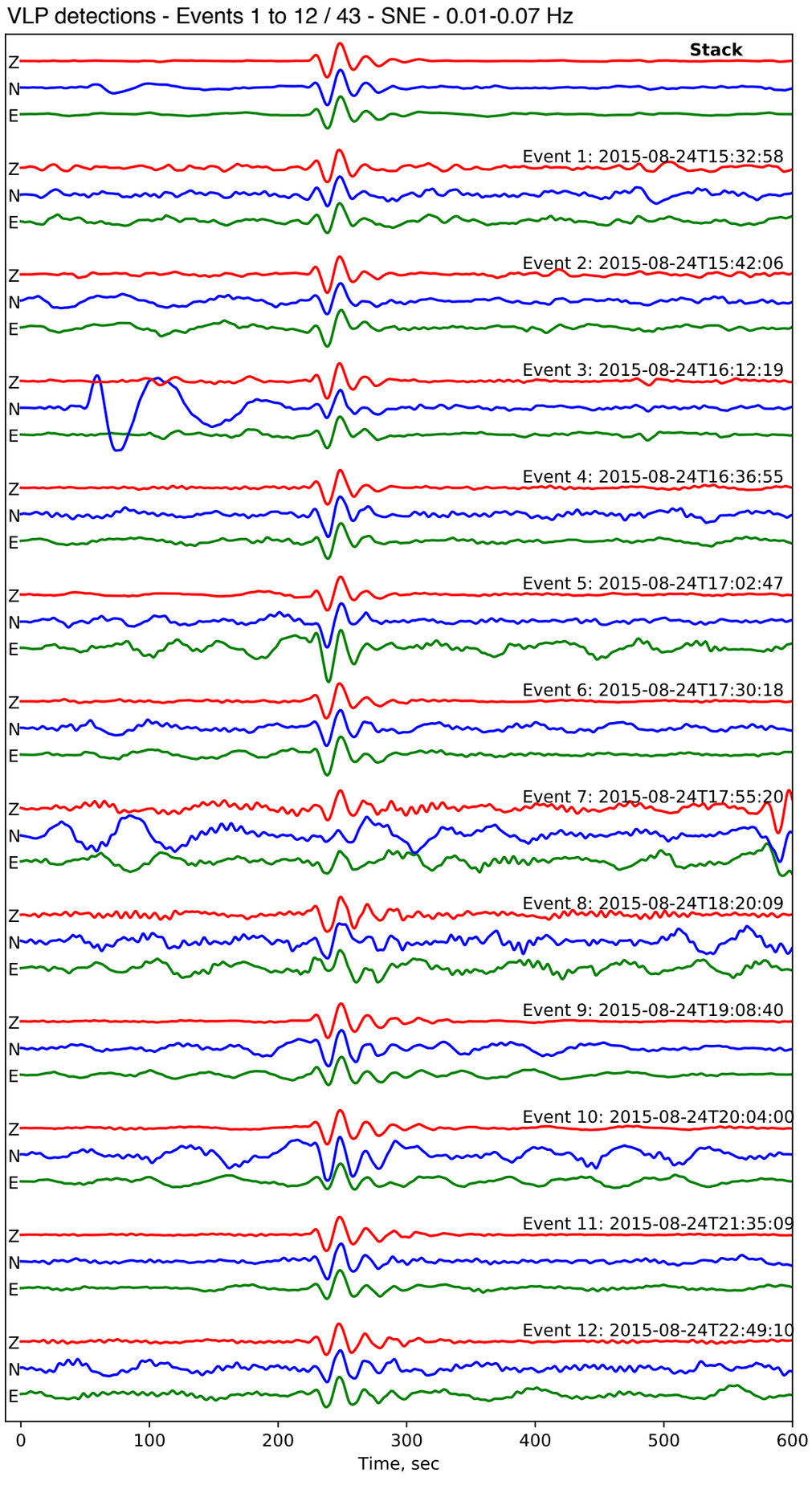
Triangles = Broadband stations

Searching for hidden VLP events

Template matching

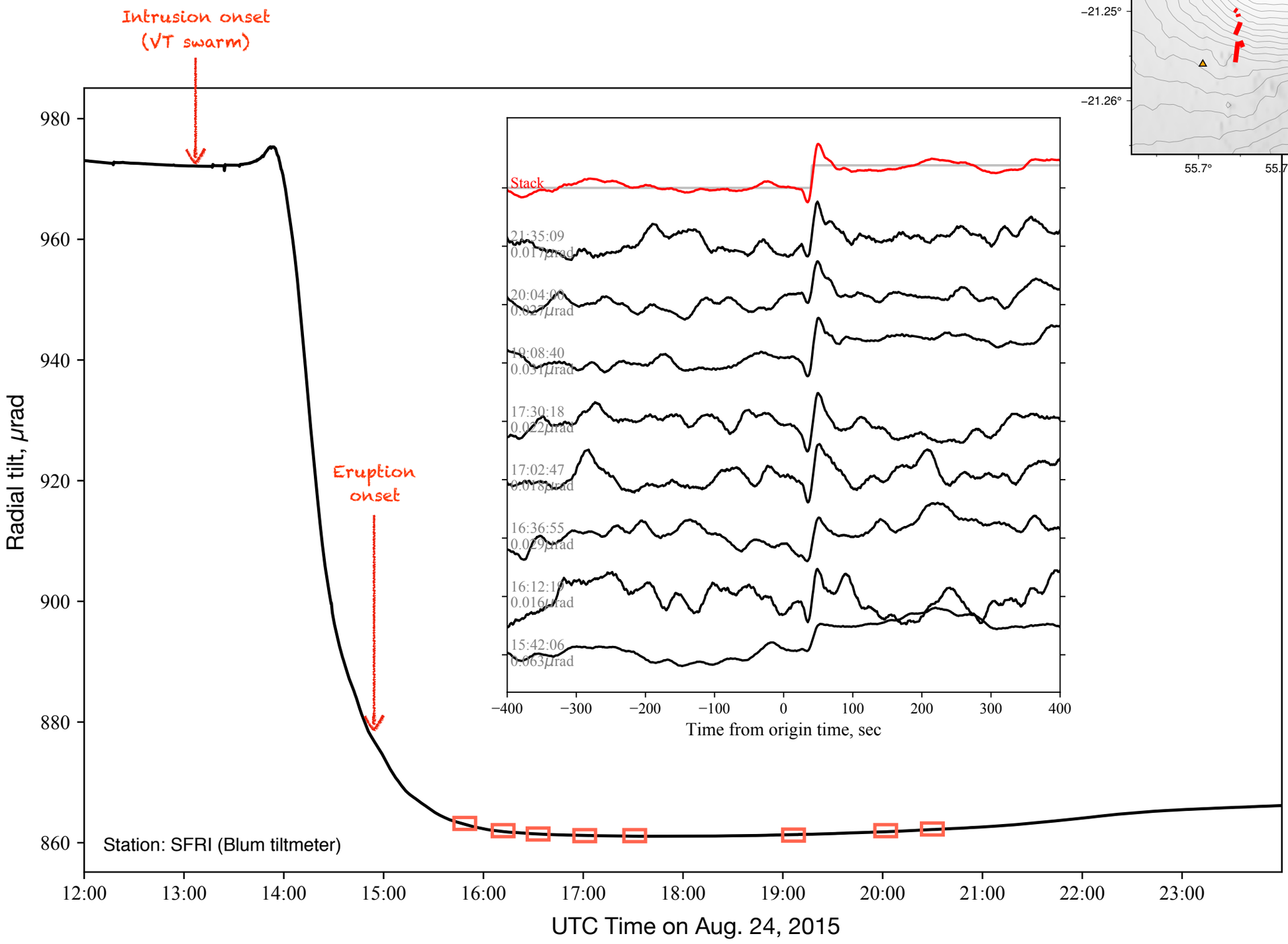
- Using visual detections as templates
- Manual screening to remove large teleseismic arrivals
- Bandpass filter 14-50 sec
- 43 detections ●
- VLP detected when the emission rate decreases

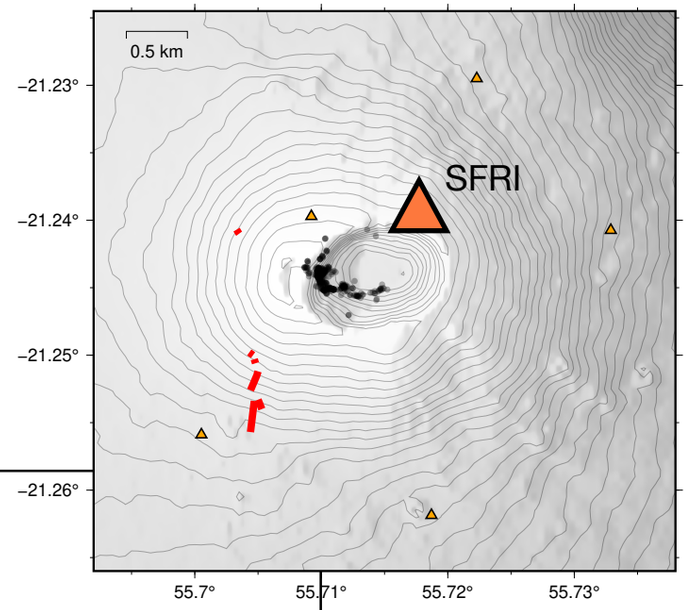




VLP signals on tiltmeters

Inflationary tilt steps

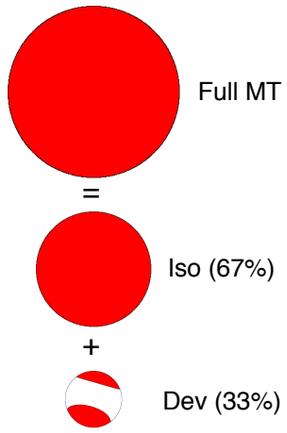


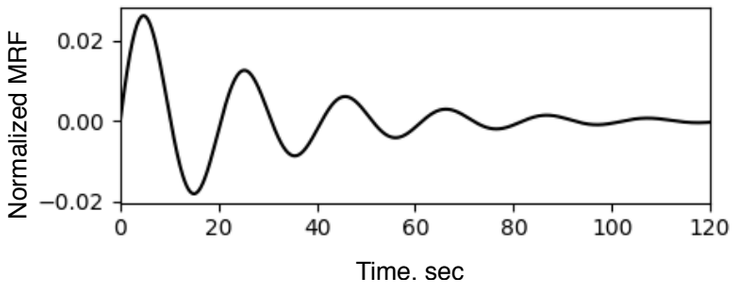


VLP source - CMT inversion

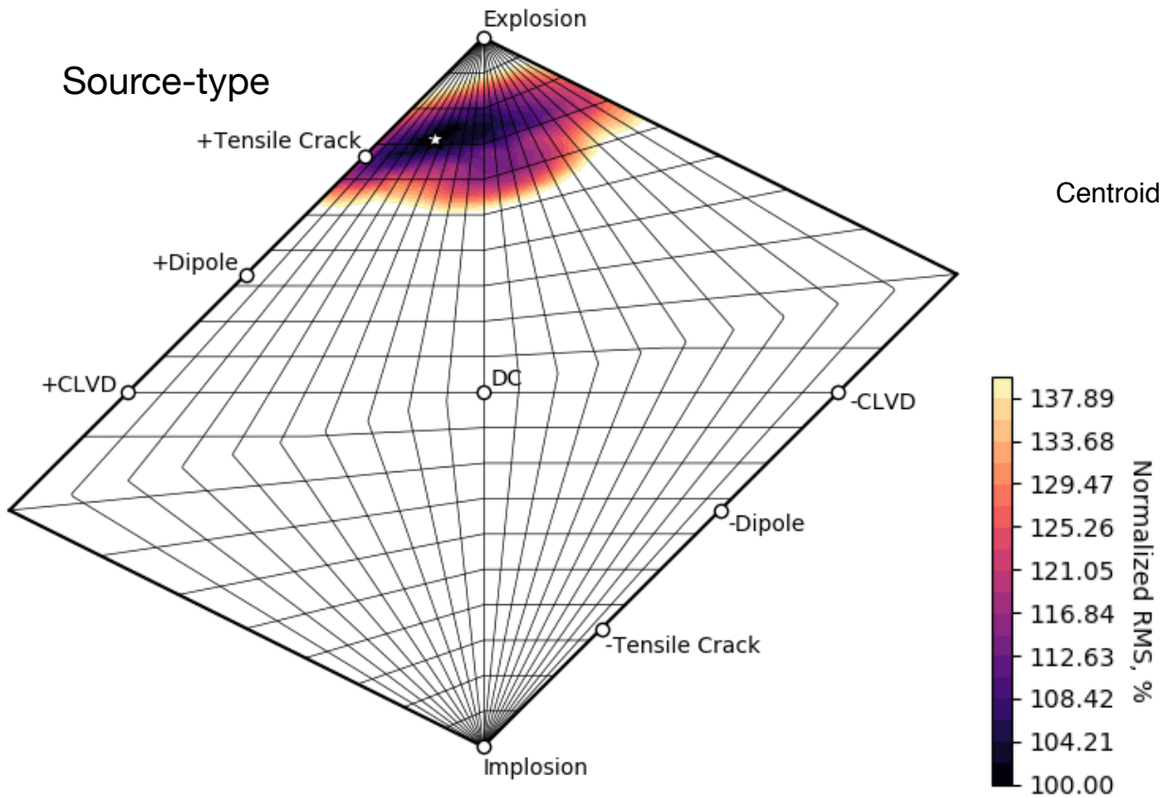
Inverted parameters:
MT components, lat, lon, dep, resonance period T_R, decay time τ.

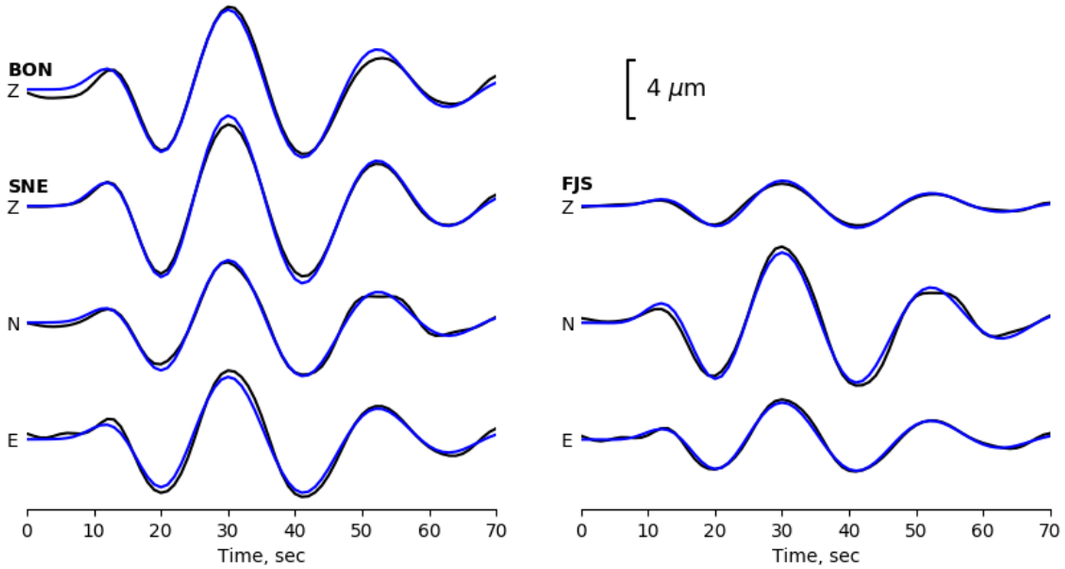
Damped oscillating moment-rate function:
$m(t) = \exp(-t/\tau)\ \sin(2\pi t/T_R)$

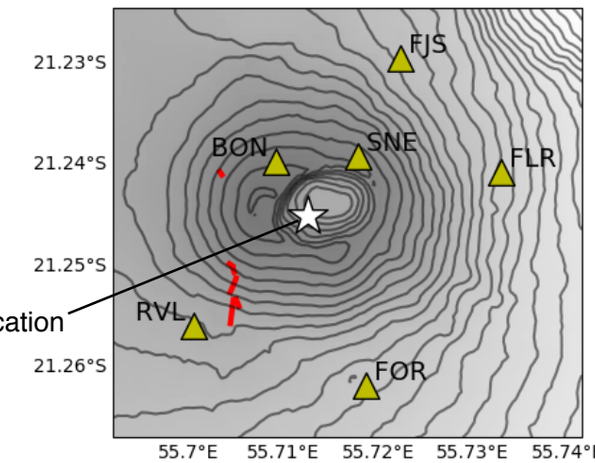




$M_W = 2.3$, $M_0 = 3.9E12$ N.m, Depth=1.2 km
$T_R = 20.5$ sec, τ = 28 sec



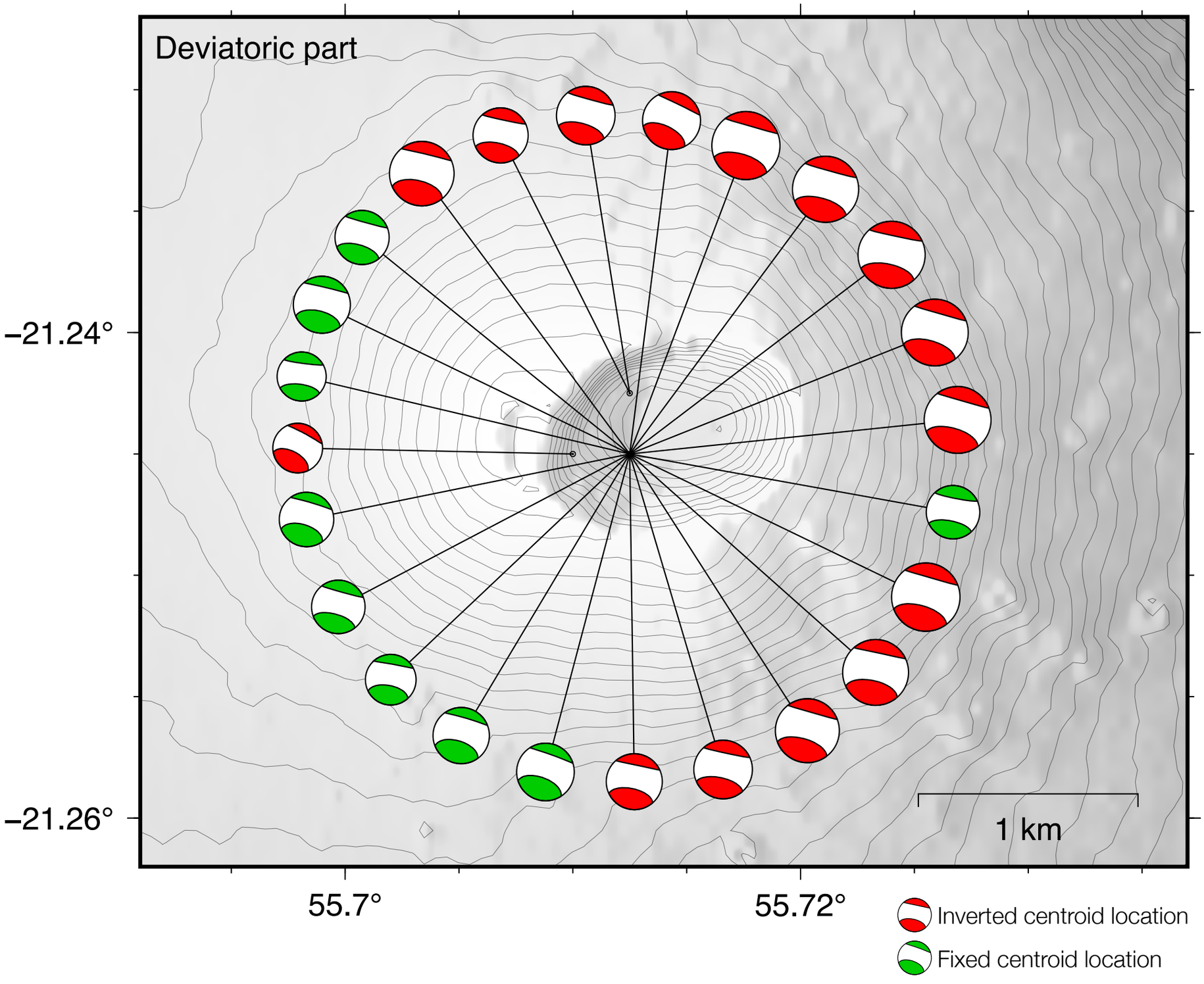




Black = observed waveforms
Blue = predictions

VLP source - CMT solutions from Aug. 24 to Oct 31, 2015

Persistent source mechanisms & locations



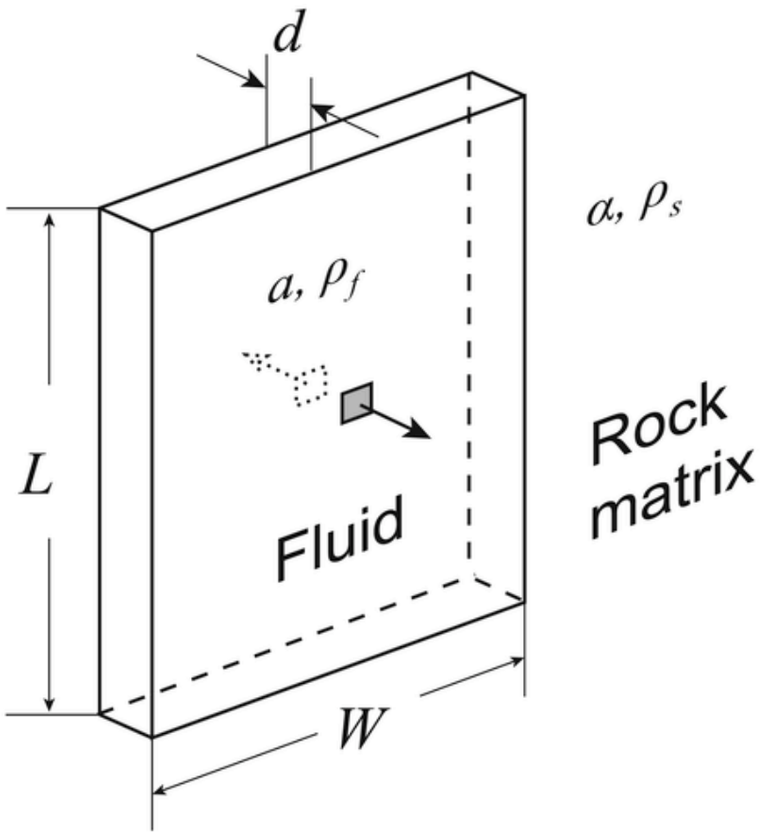
VLP source - CMT solutions from Aug. 24 to Oct 31, 2015

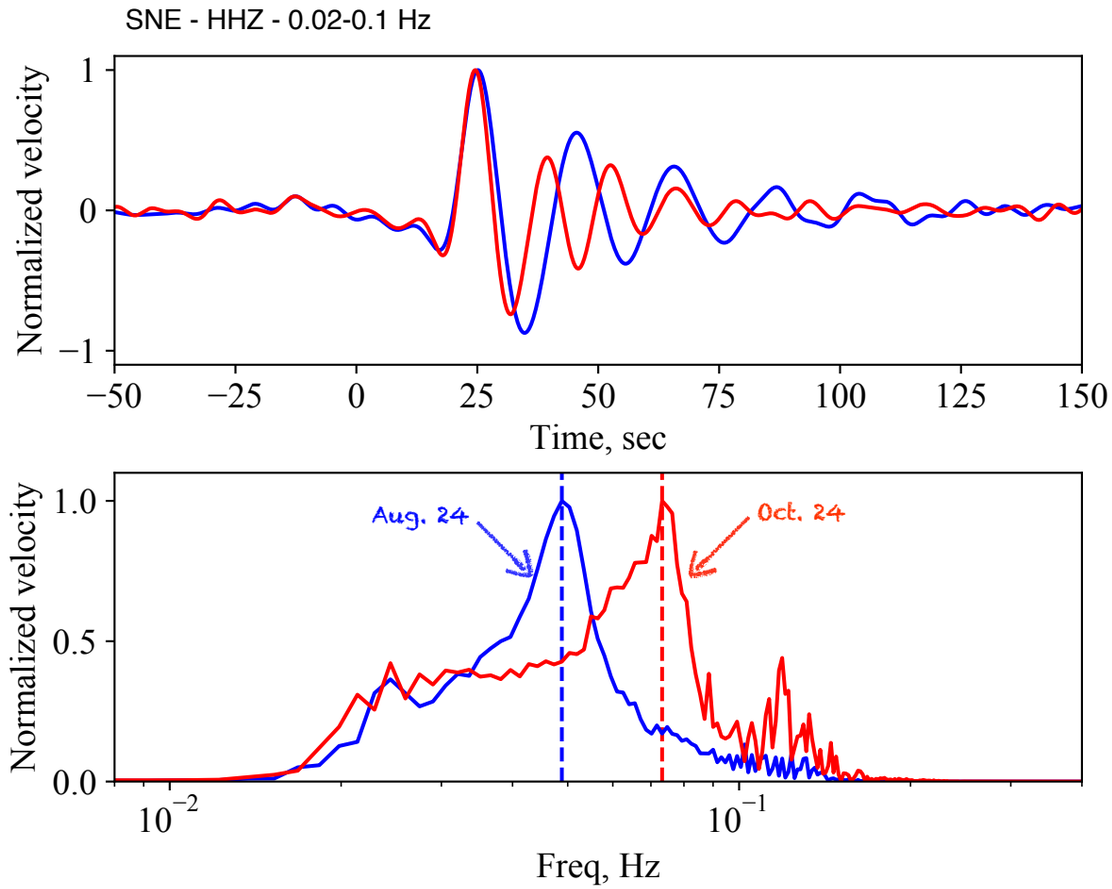
Decrease of the resonance period T_R

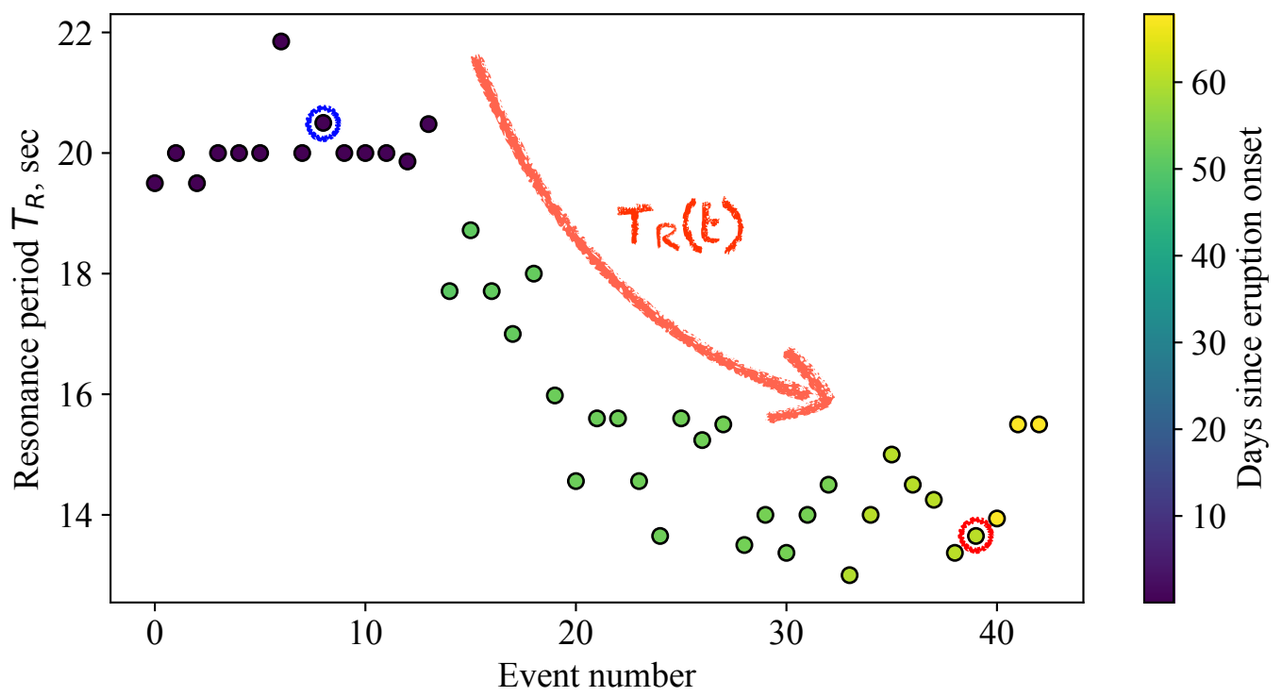
- T_R~20sec in August 2015
- T_R~12sec in October 2015

Rectangular fluid-filled crack
(Maeda and Kumagai, 2017)

- Decrease of the Dike width ?







VLP source - CMT solutions from Aug. 24 to Oct 31, 2015

Decrease of the resonance period T_R

- T_R~20sec in August 2015
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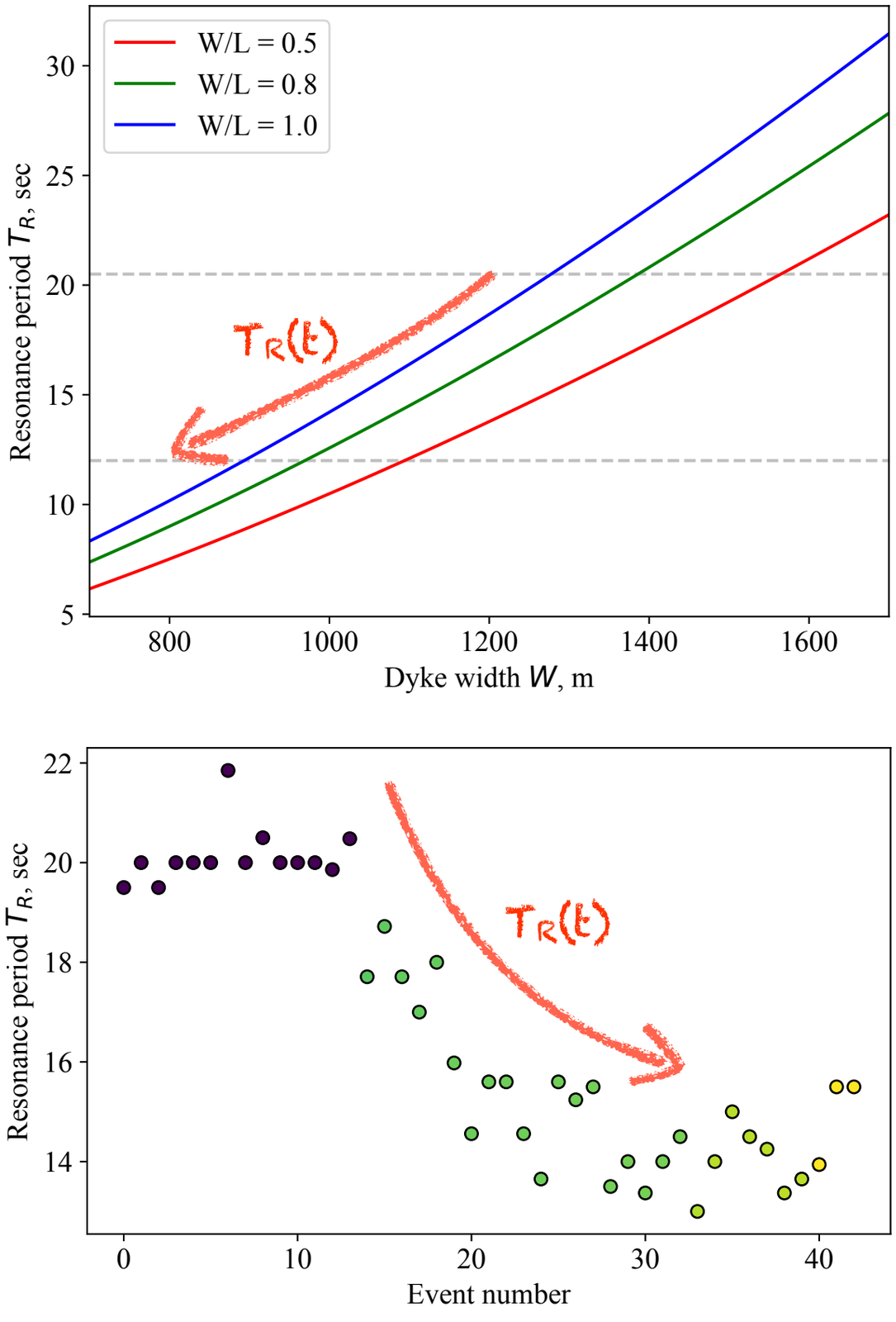
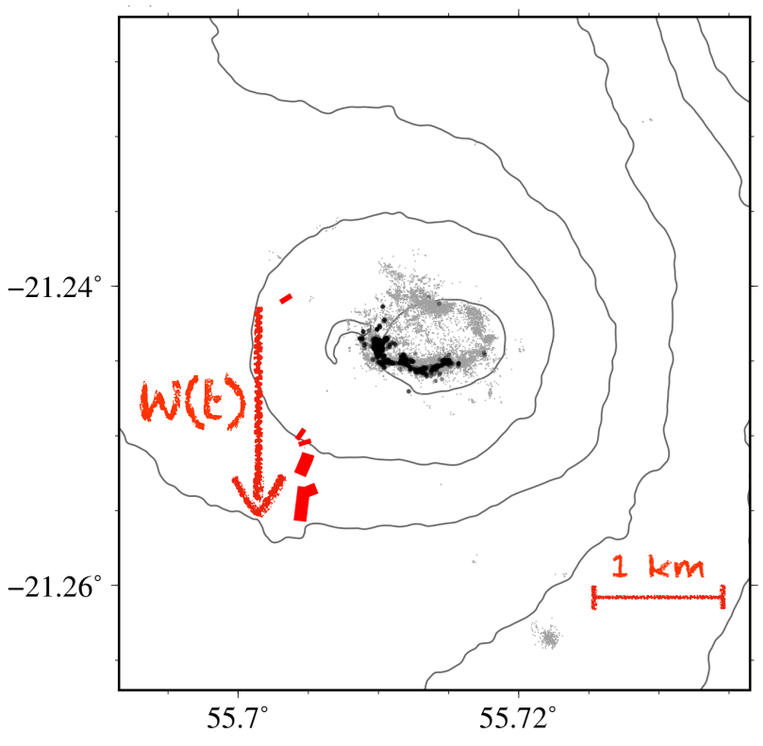
Rectangular fluid-filled crack
(Maeda and Kumagai, 2017)

- Decrease of the Dike width ?
- Consistent with field observations

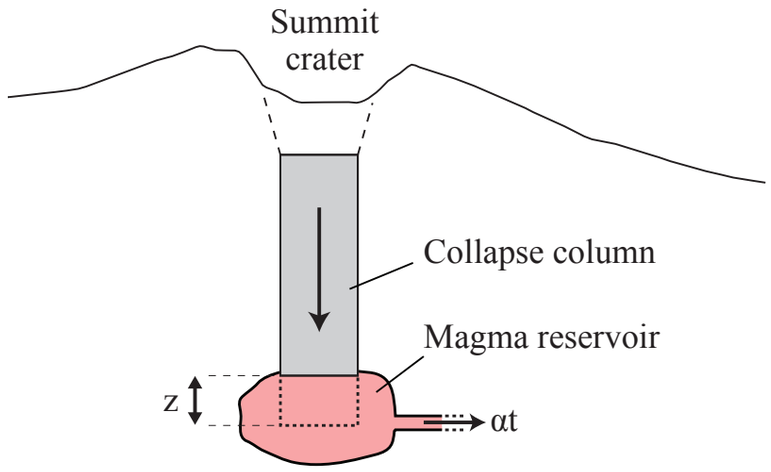




Conclusion

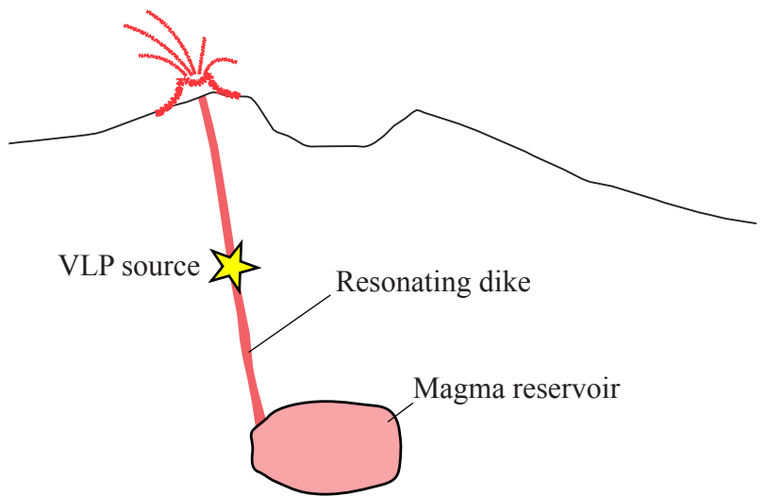
VLP signals - Caldera collapses

- Collapsing crack: reservoir contraction
- Vertical force: collapse of the piston



VLP signals - Dike resonance

- Resonating magmatic dike

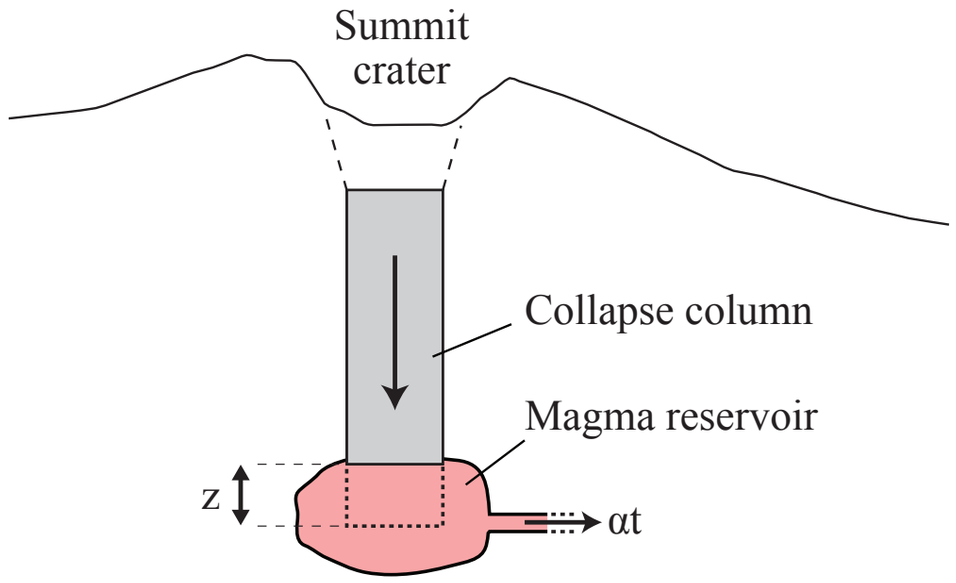


Thank you for your attention

Piston spring-block model

Simple model from Kumagai et al (2001):

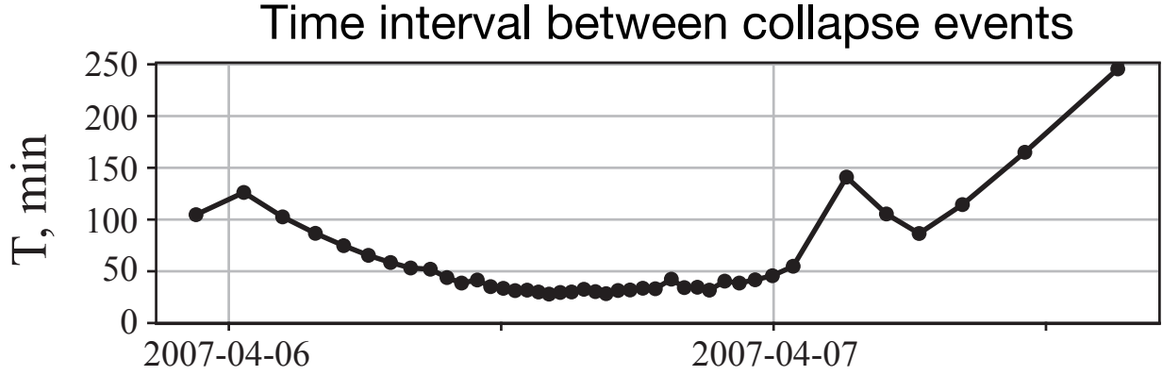
- *Weight of the collapsing piston balanced by*
  1. *Friction on the ring fault*
  2. *Pressure in the magma reservoir*

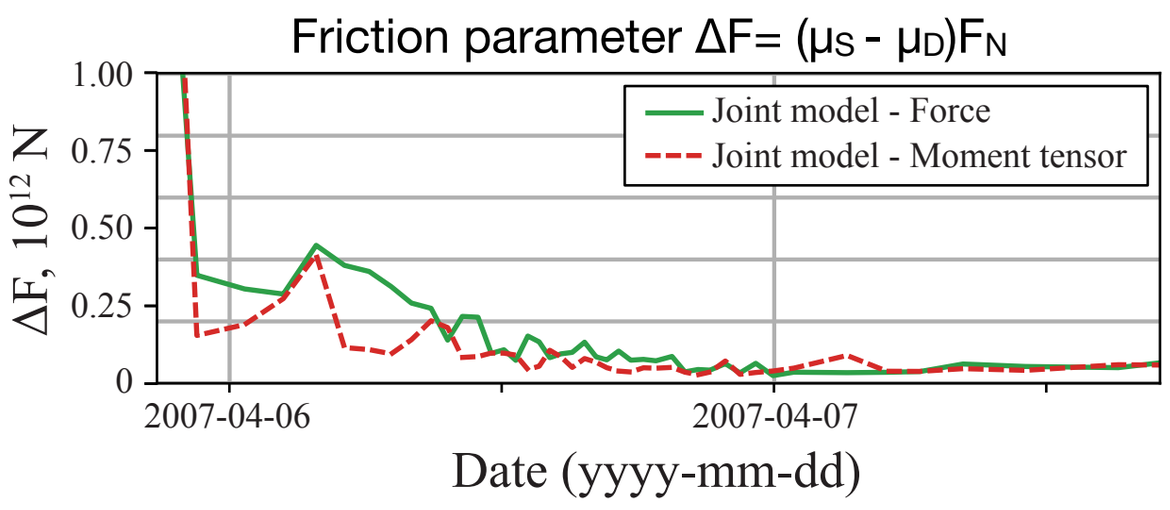


- *Events durations controlled by the geometry of the piston & properties of the magma reservoir.*
  - $\kappa = 10^8 - 10^{10}$ *Pa for durations of 6-14sec*

- *Time interval between collapses explained by changes of outflow rate and frictional resistance*
  - *Hydrothermal fluids ? (Michon et al., 2011)*
  - *Frictional melting ? (Han et al., 2019)*

Ring-shaped thermal anomaly (Urai et al., 2005)





Duputel and Rivera (EPSL, 2019)

VLP signals on tiltmeters

Example - Event 9 (2015-08-24 19:08:40 UTC)