ISTerre
Institut des Sciences de la Terre

IPGP
INSTITUT DE PHYSIQUE DU GLOBE DE PARIS

OBSERVATOIRES VOLCANOLOGIQUES ET SISMOLOGIQUES

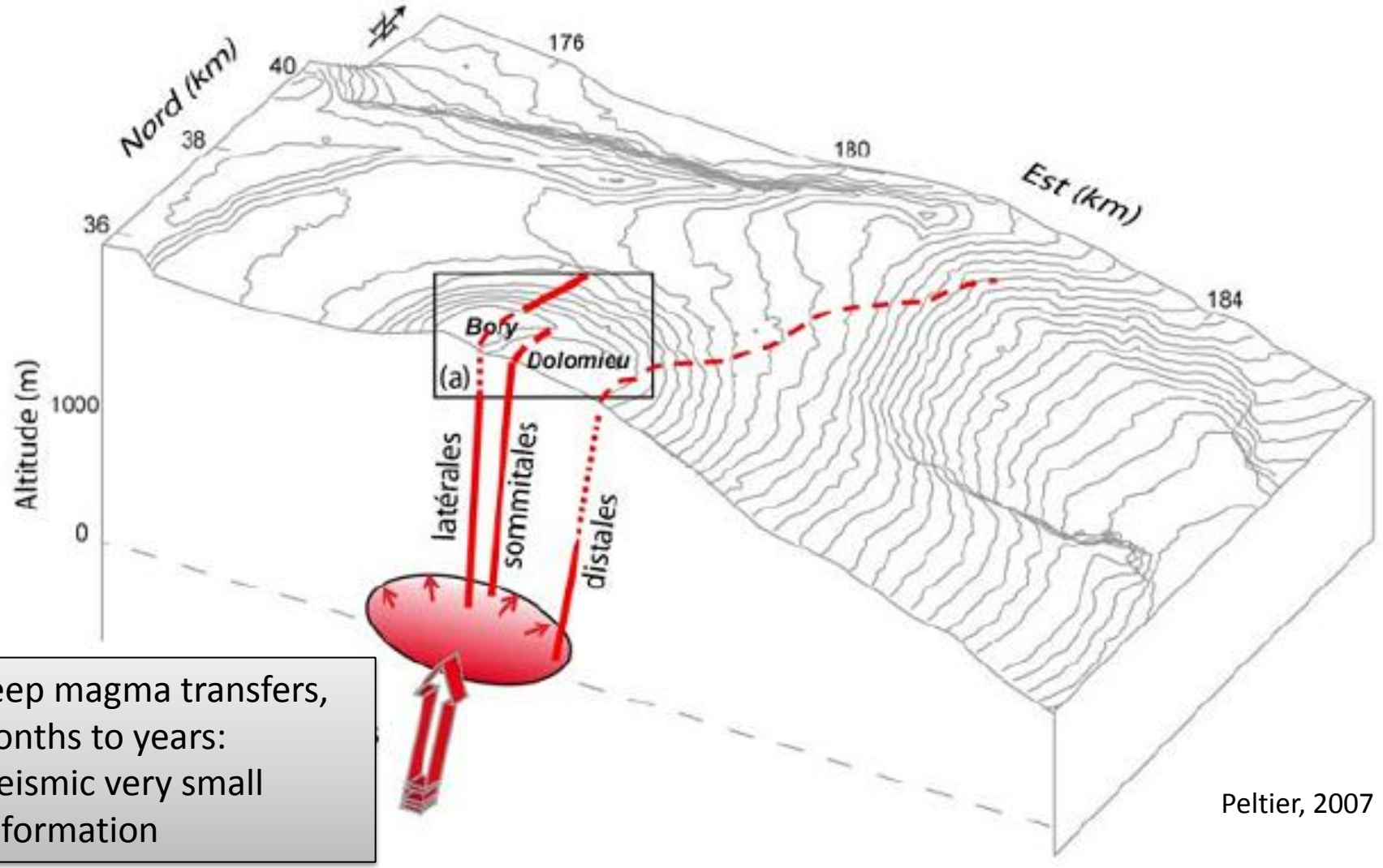
What can we learn about volcanoes using ambient seismic noise correlations?

Florent Brenguier, D. Rivet, A. Obermann, D. Clarke, M. Campillo, N. Shapiro, E. Larose

erc
Whisper Seismic ambient noise.
Towards continuous monitoring of the continuously changing Earth.

UnderVolc

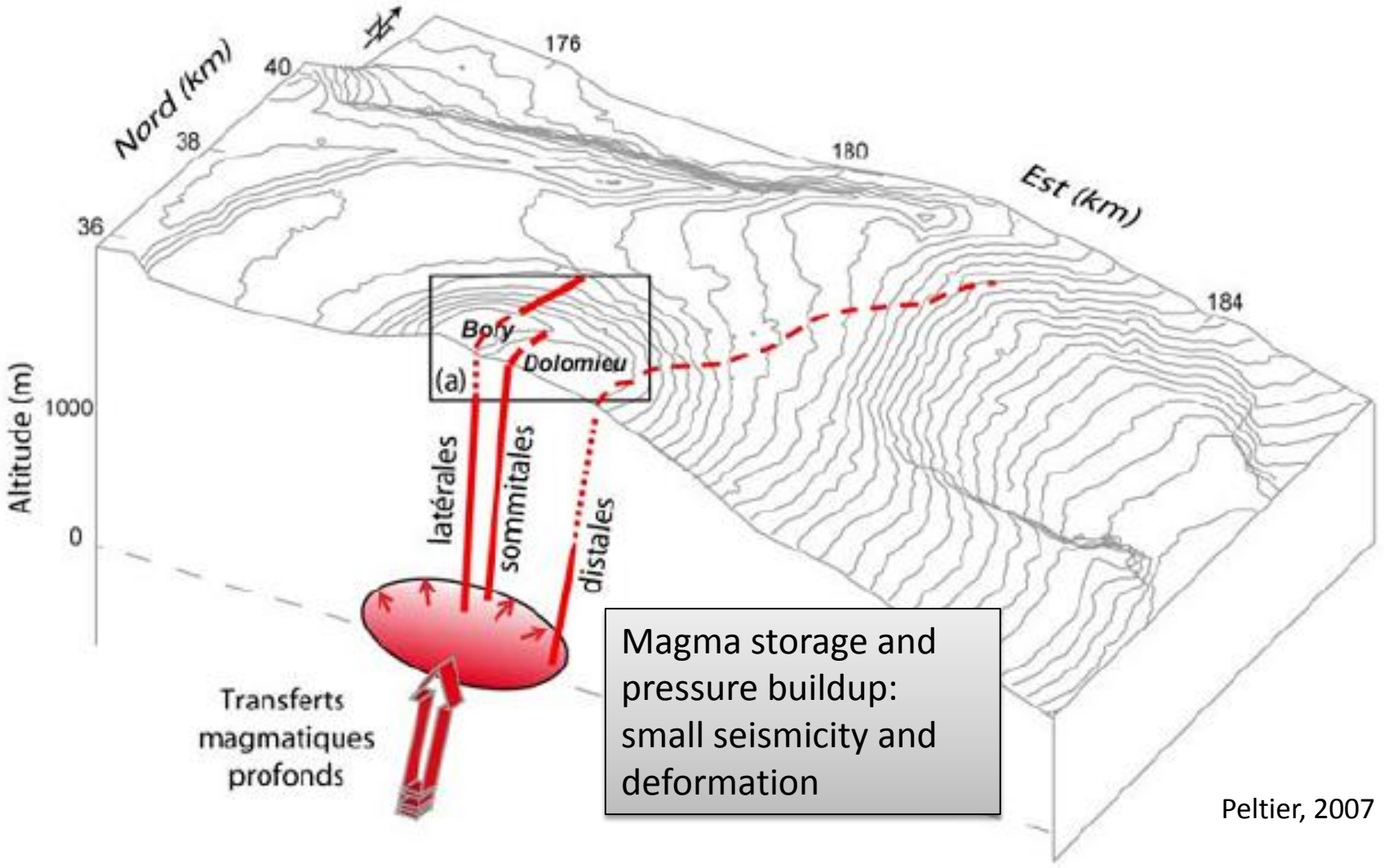
Volcanoes are among the most active parts of the Earth



Deep magma transfers, months to years: aseismic very small deformation

Peltier, 2007

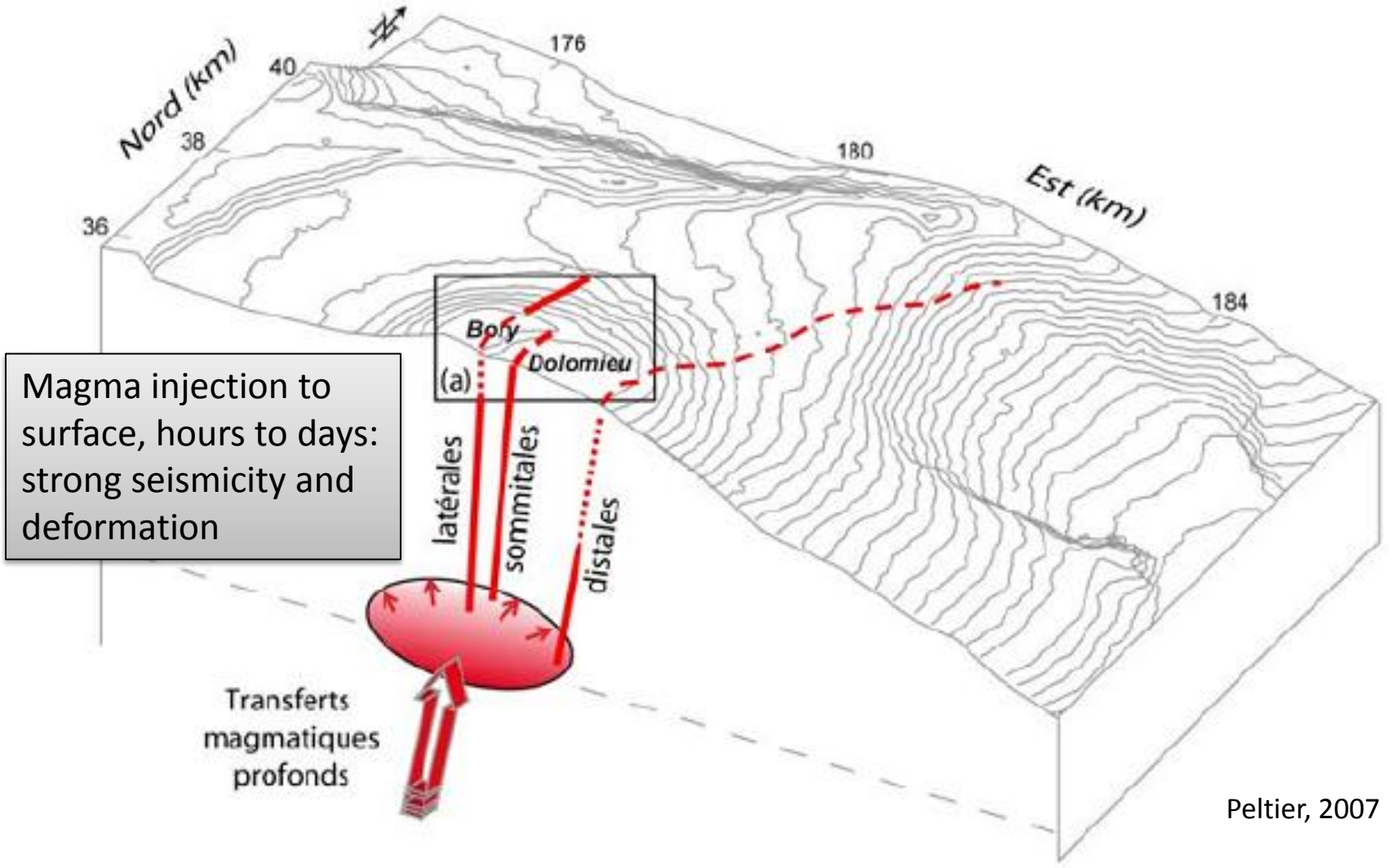
Volcanoes are among the most active parts of the Earth



Magma storage and pressure buildup: small seismicity and deformation

Peltier, 2007

Volcanoes are among the most active parts of the Earth



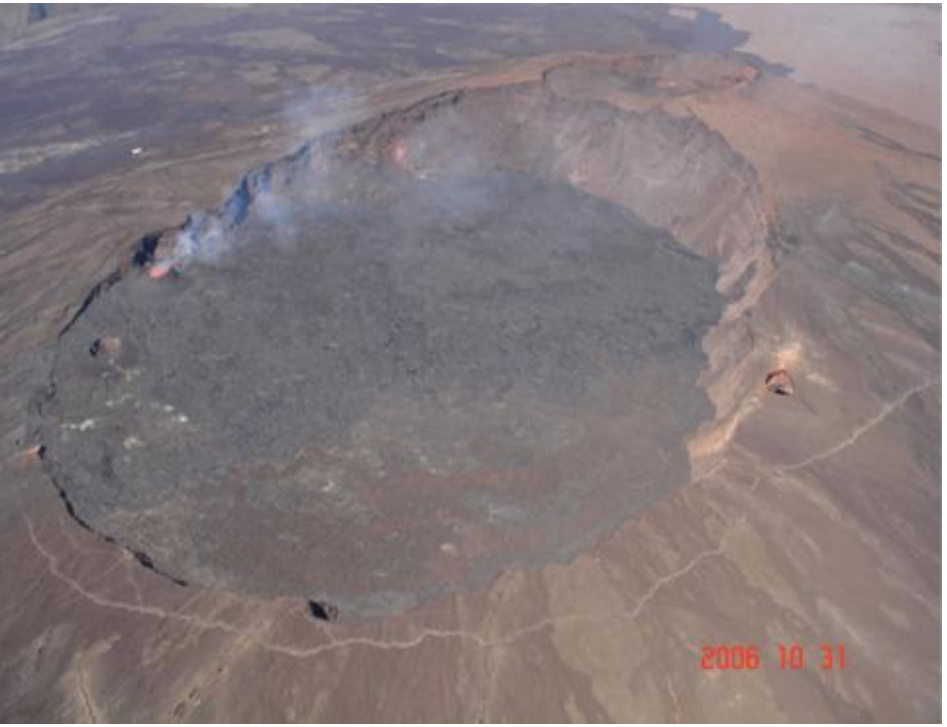
Magma injection to surface, hours to days: strong seismicity and deformation

Peltier, 2007

Magma eruption

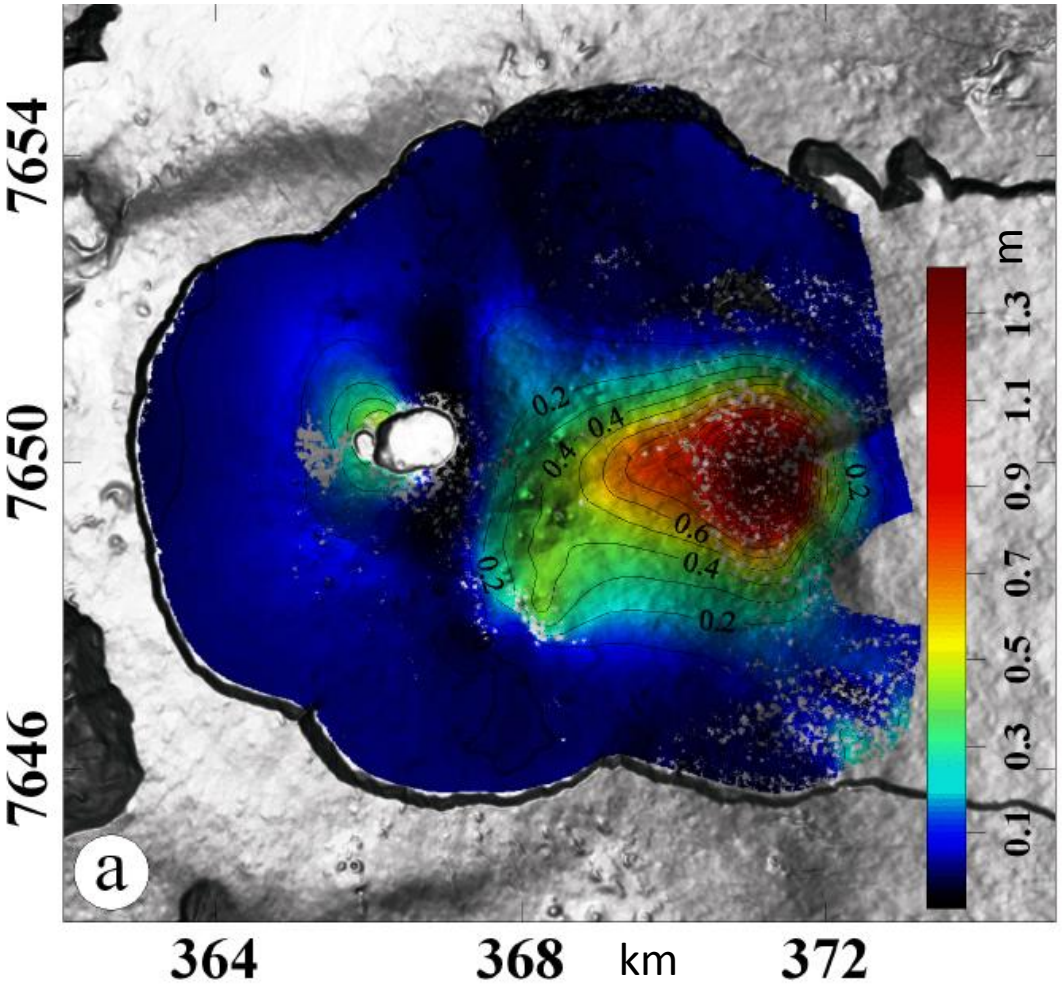
Piton de la Fournaise, Oct. 2010

Magma withdrawal may generate caldera collapse



Piton de la Fournaise, Before and after the April 2007 eruption and caledra collapse

Strong stress perturbations may trigger slope instability

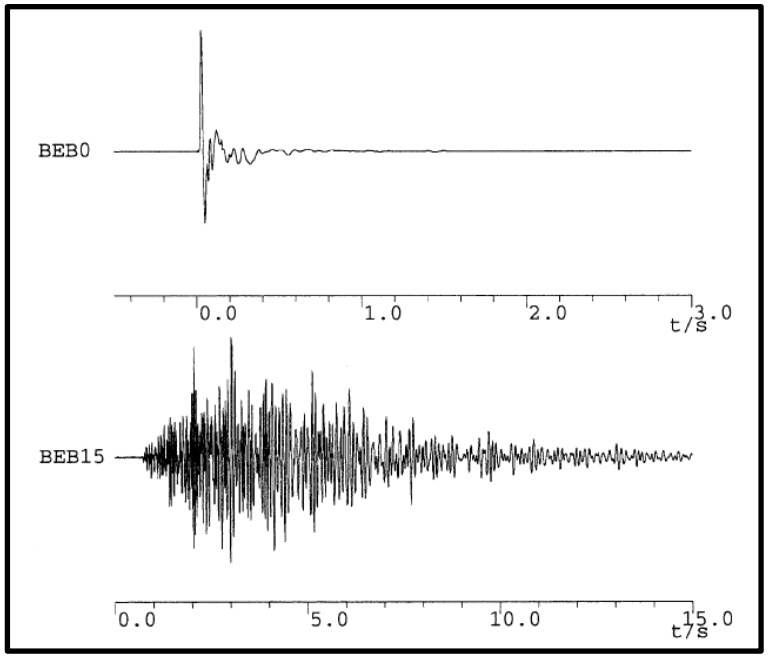


Courtesy of J.-L. Froger

Mt St Helens, 1982. Courtesy of Tom Casadevall

Picture insar

Volcanoes are strongly scattering medium



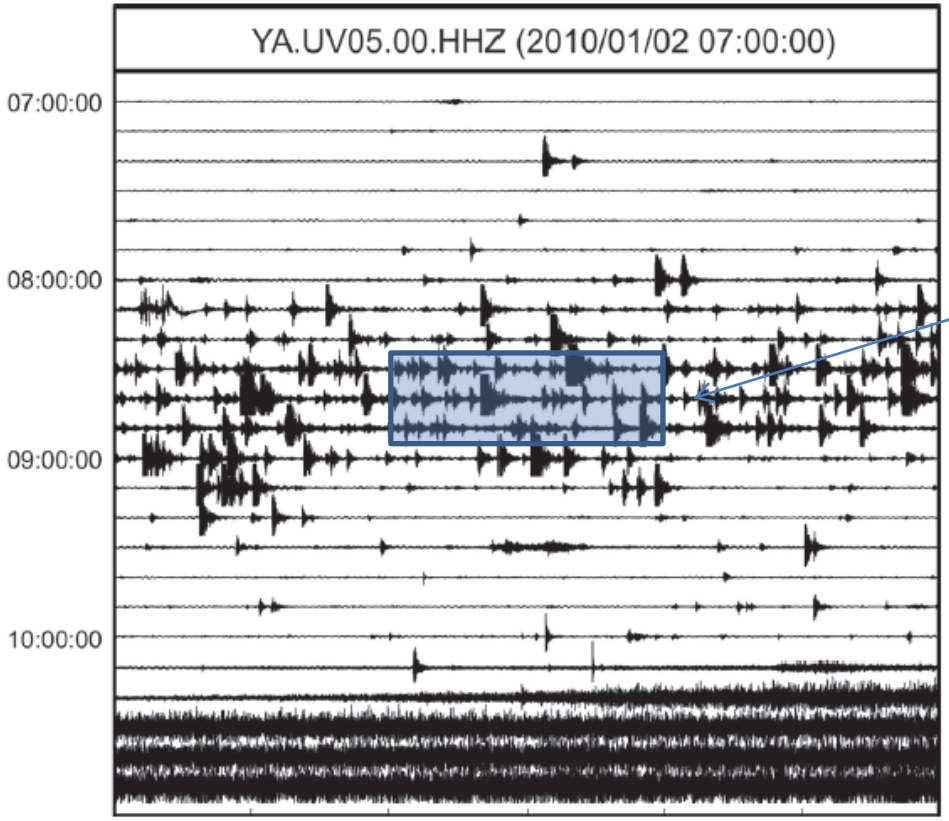
Very small mean free path

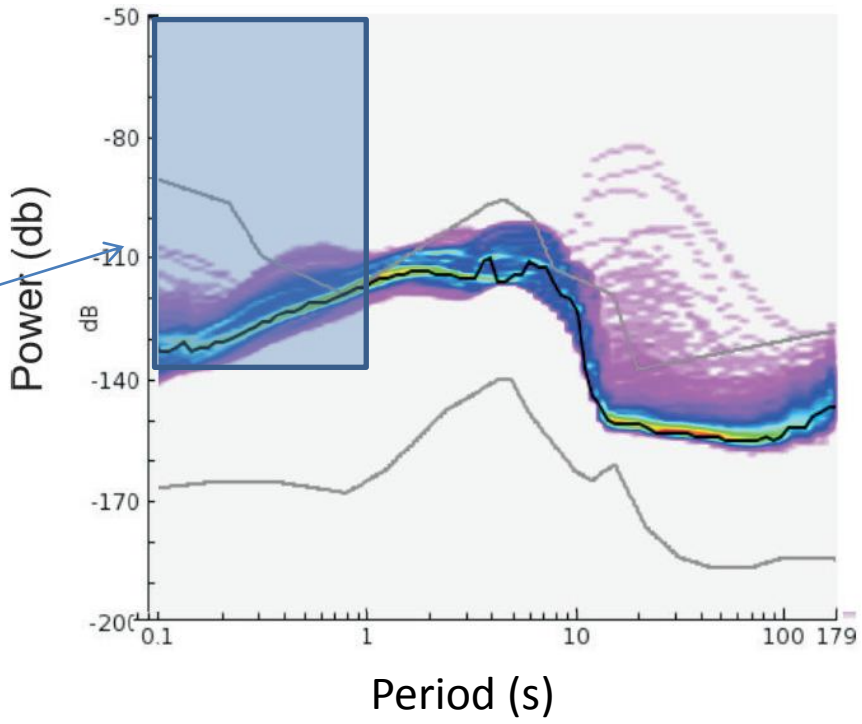
$$(\eta_s^{-1} \approx 100 \text{ m})$$

Wegler and Lühr, 2001

A variety of seismic signals on volcanoes!

Volcano-tectonic earthquakes

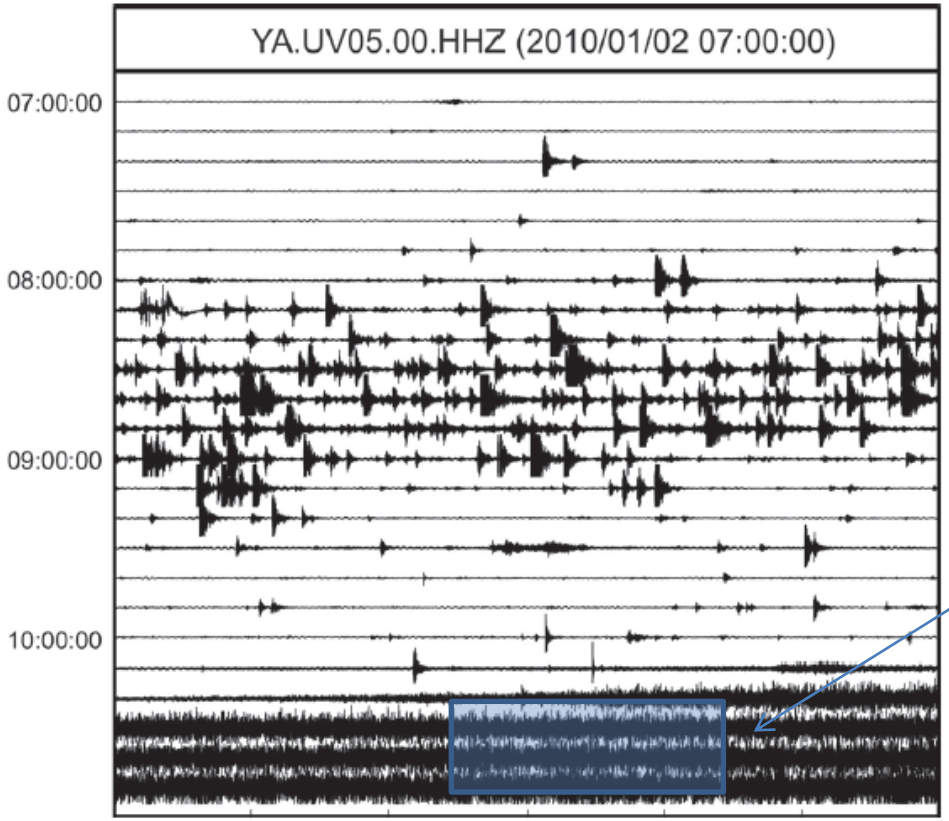


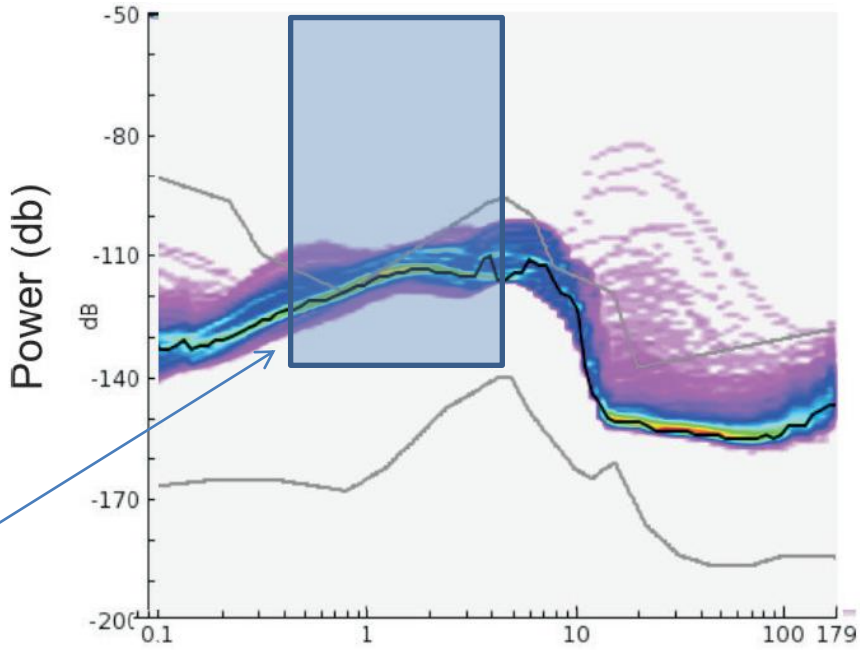


Brenguier et al. 2012

A variety of seismic signals on volcanoes!

Eruption tremor

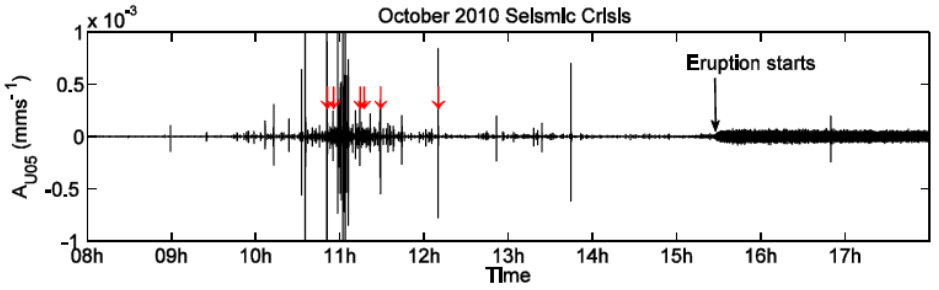


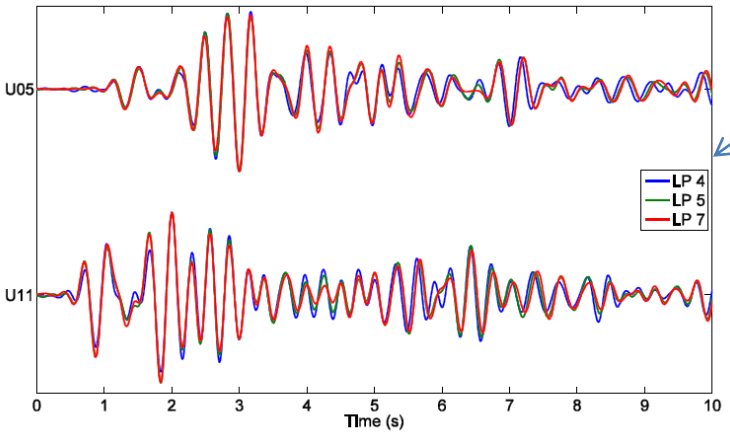


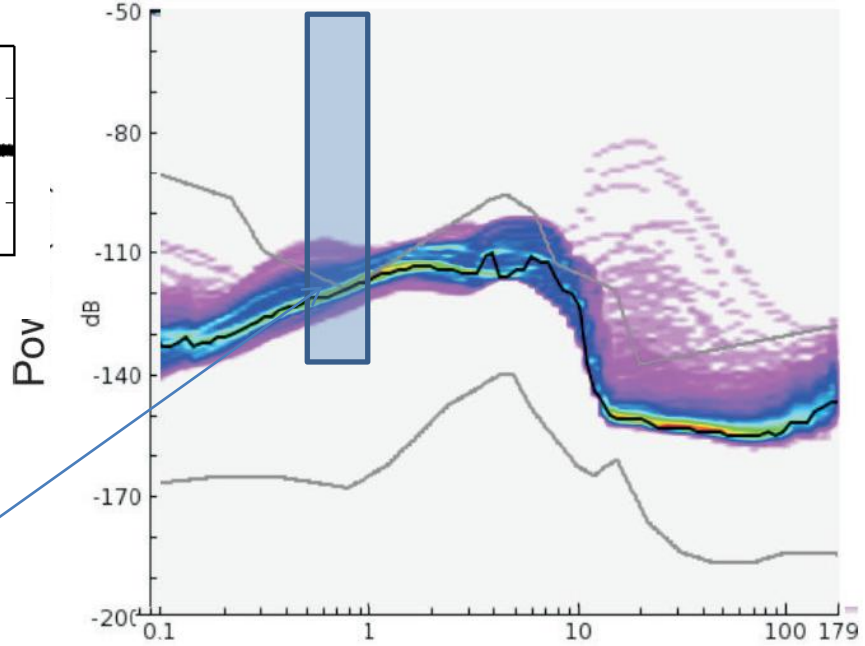
Brenguier et al. 2012

A variety of seismic signals on volcanoes!

Long-period earthquakes



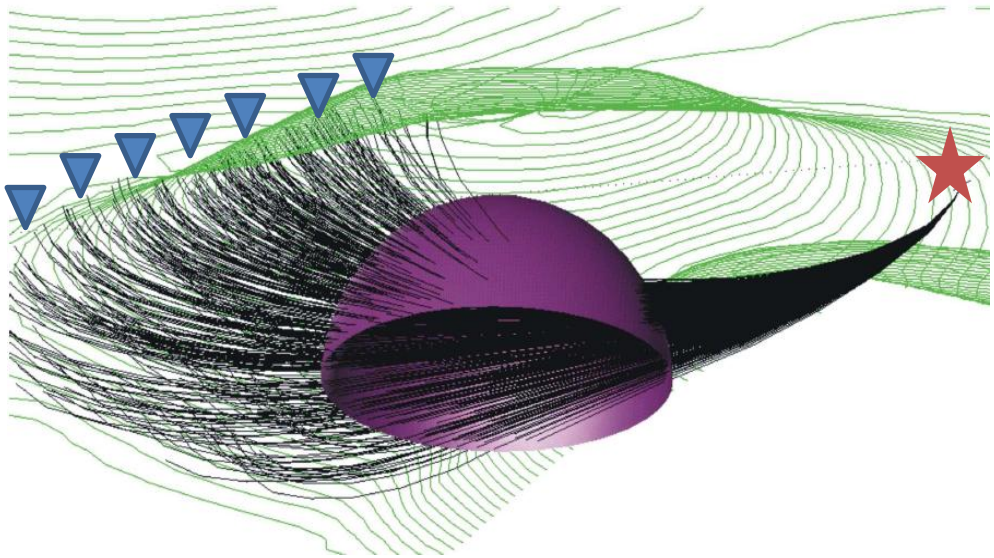




Zecevic et al. 2013

Our interest: Image and monitor volcanoes

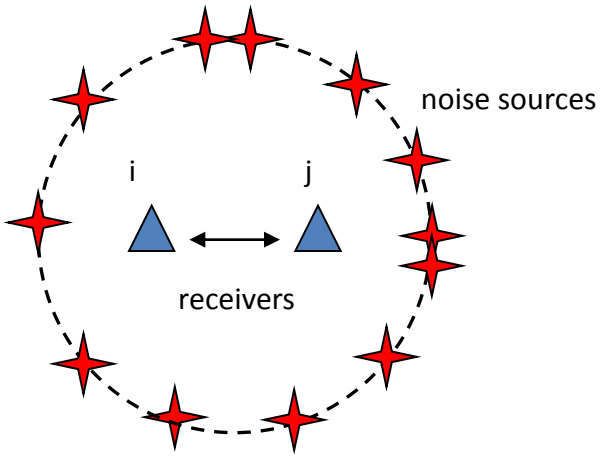
Seismic waves probe the rock mass at depth and their properties are affected by volcanic activity



Velocity contrasts in volcanoes are linked to:
- Contrasts between intrusive and effusive material

Changes of the volcano interiors affect:
- Seismic velocities
- Seismic intrinsic attenuation
- Scattering of seismic waves

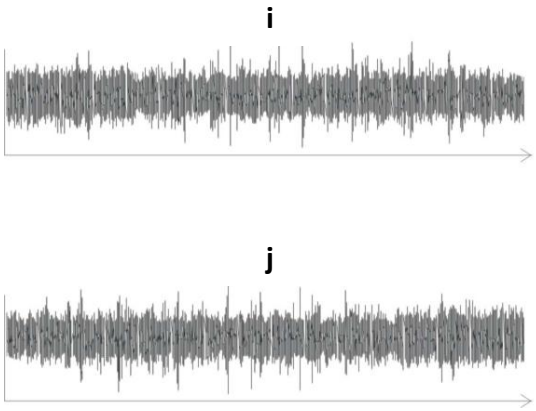
Extraction of Green's functions from correlations of seismic noise

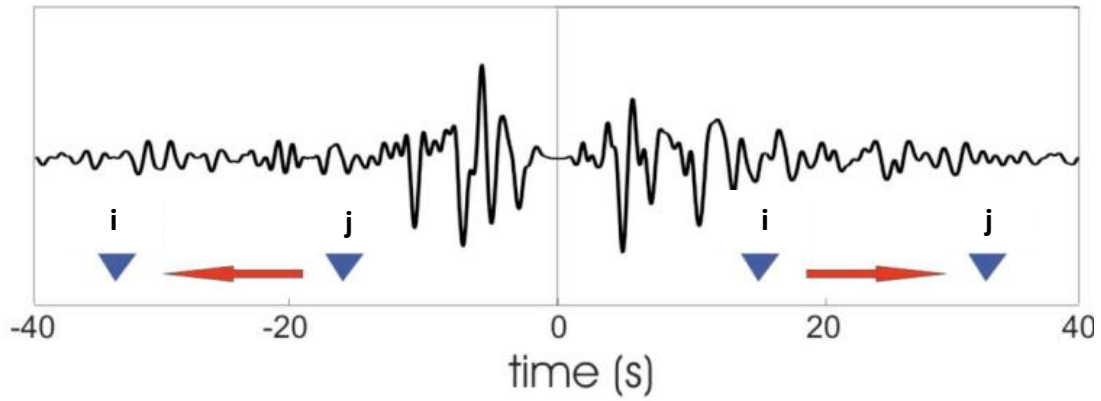


$$\frac{d}{d\tau} C(\tau, \vec{r}_A, \vec{r}_B) = \frac{-\sigma^2}{4\,a}(G_a(\tau, \vec{r}_A, \vec{r}_B) - G_a(-\tau, \vec{r}_A, \vec{r}_B))$$

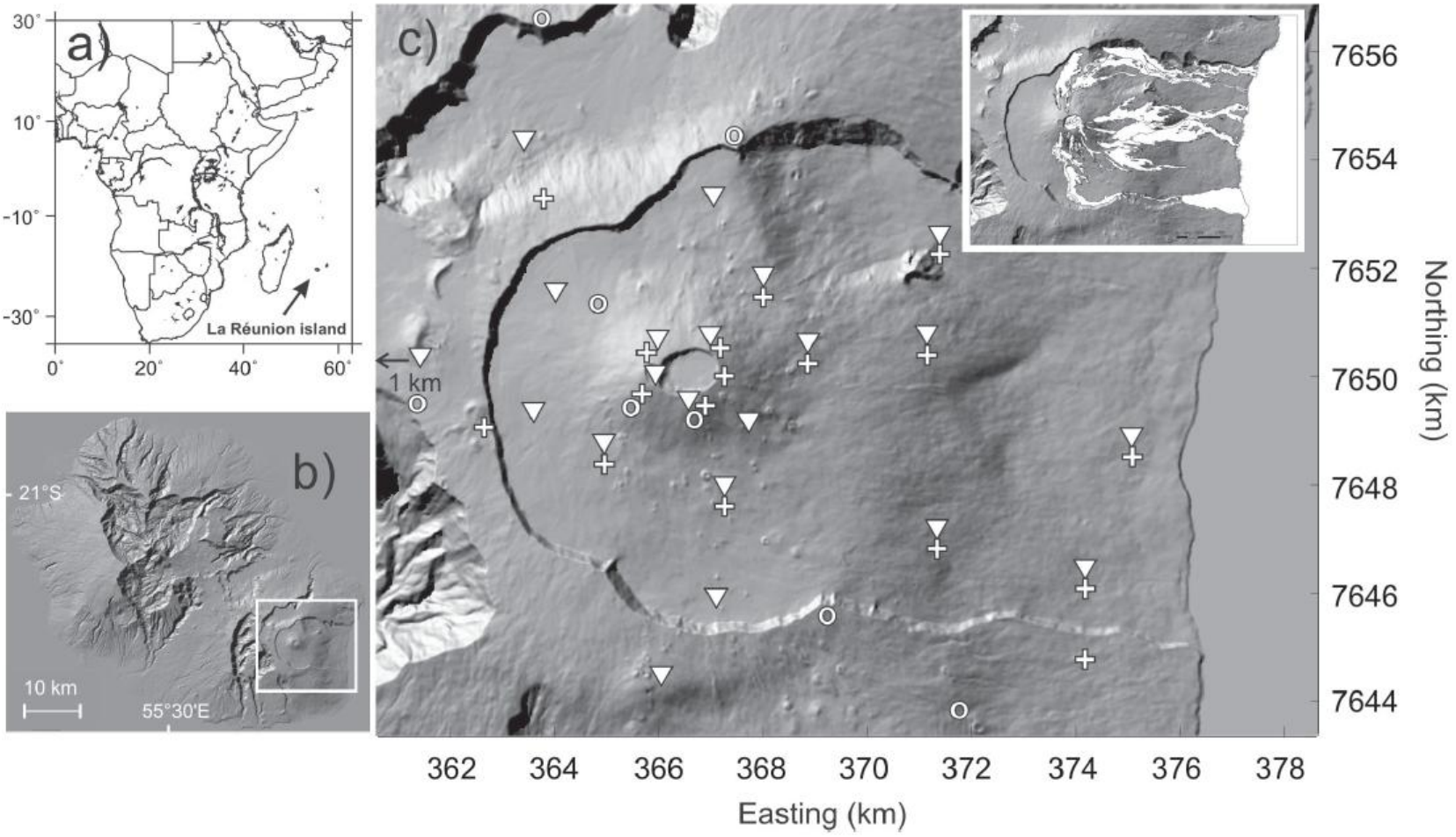
Campillo. 2006

$$G_{i,j} = \begin{pmatrix} Z_iZ_j & Z_iR_j & Z_iT_j \\ R_iZ_j & R_iR_j & R_iT_j \\ T_iZ_j & T_iR_j & T_iT_j \end{pmatrix}$$

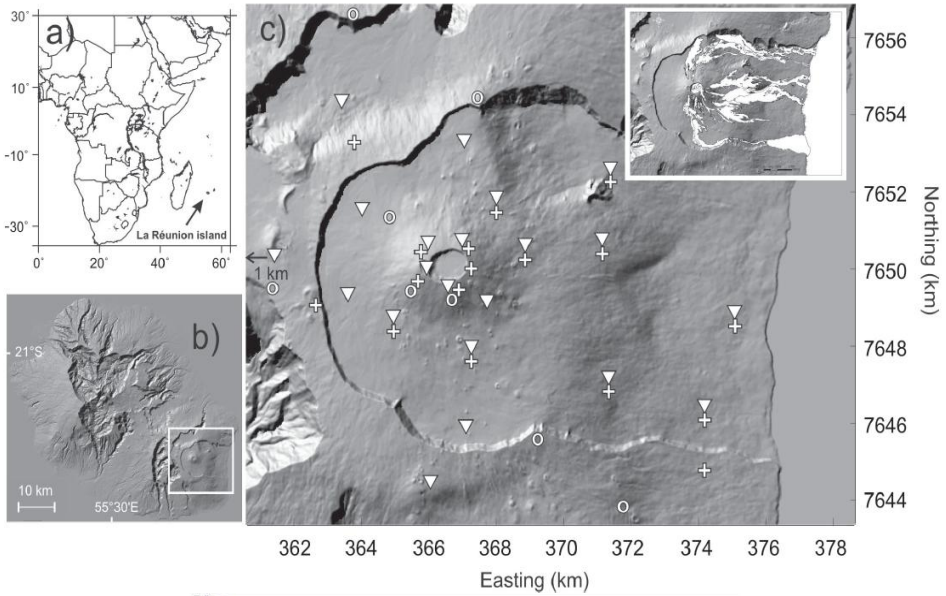


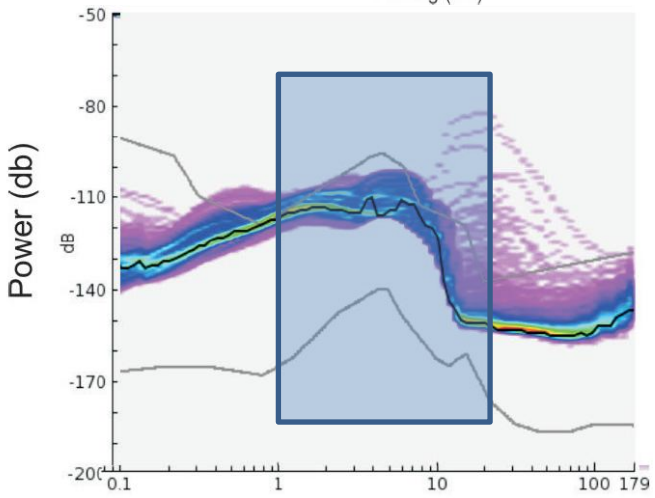


Piton de la Fournaise Volcano

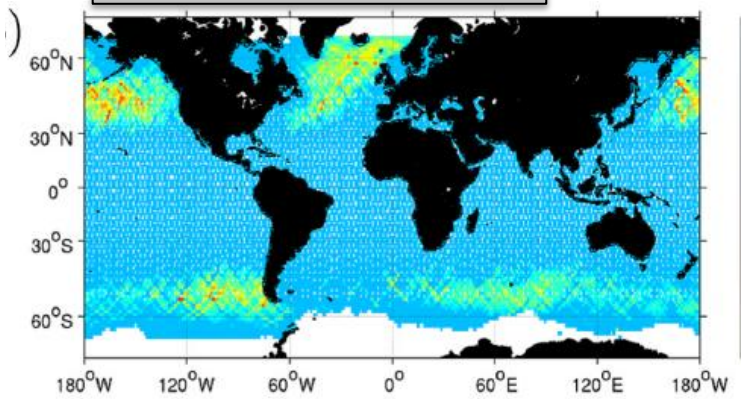


Ambient seismic noise sources properties at Piton de la Fournaise Volcano, La Réunion

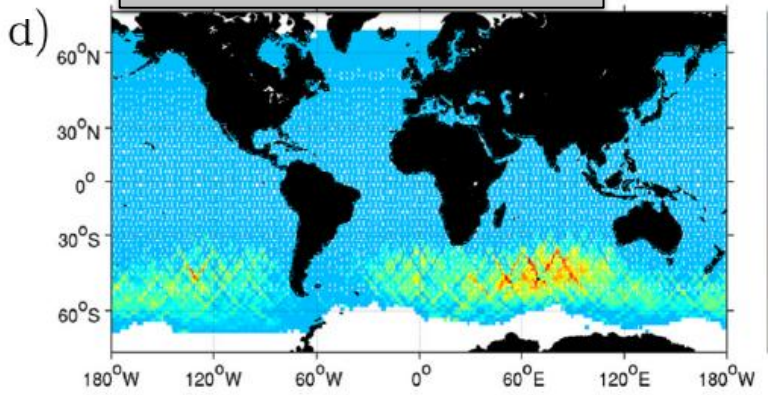




Wave height, winter

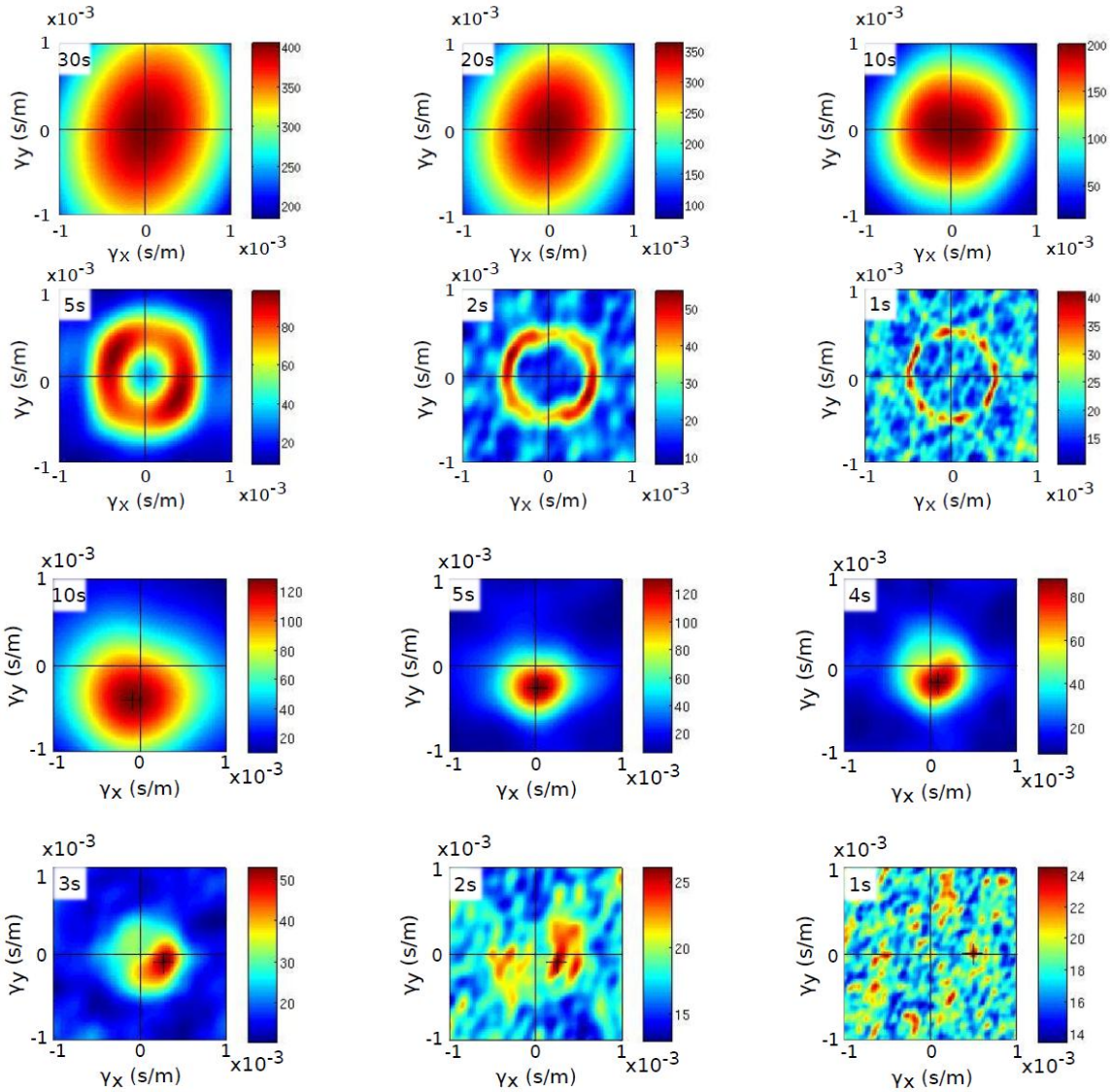


Wave height, summer



Stehly et al., 2006

Properties of seismic noise at PdF

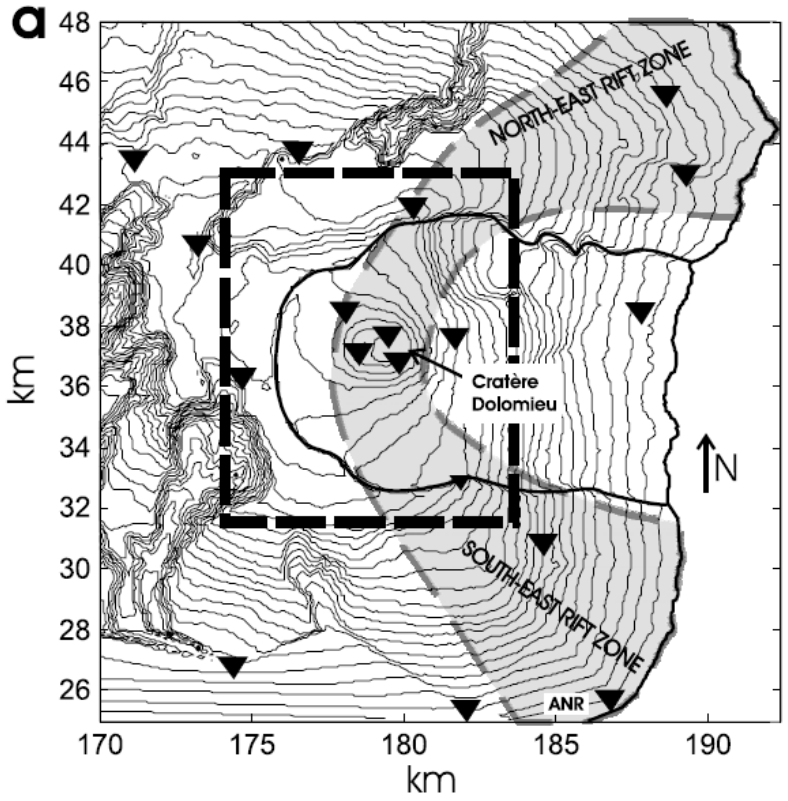


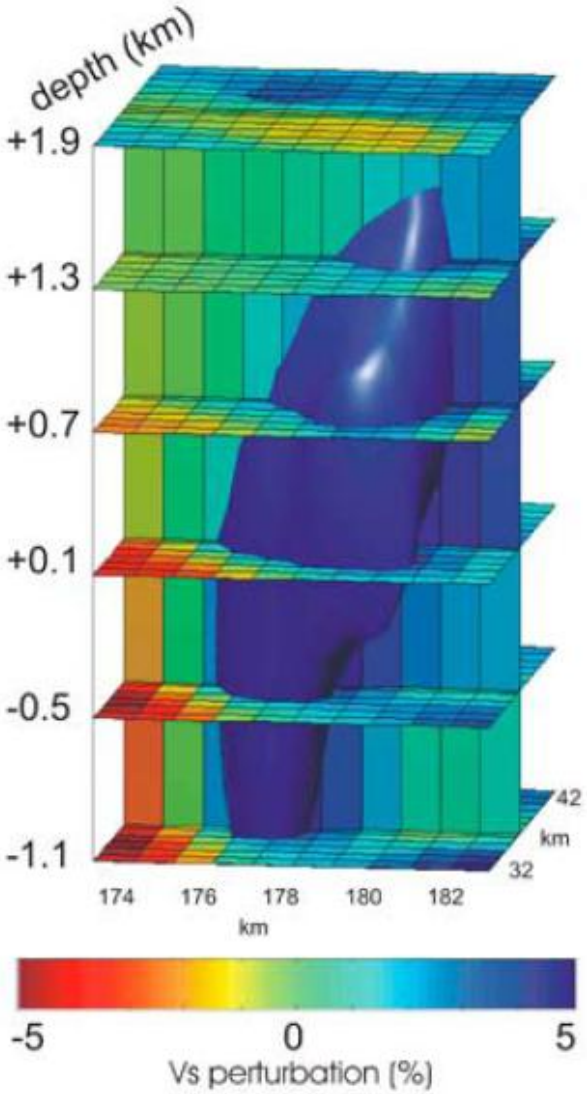
Theoretical array response

Beamforming of 1 day of noise, again, **scattering helps**

Tsang-Hin-Sun, 2012

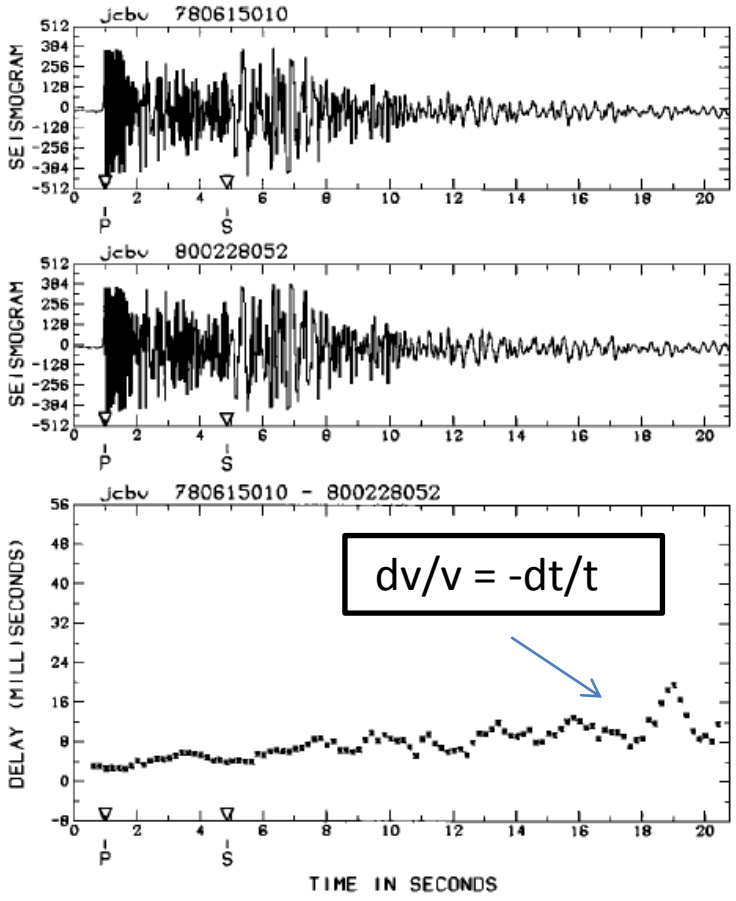
3D tomography using ambient noise



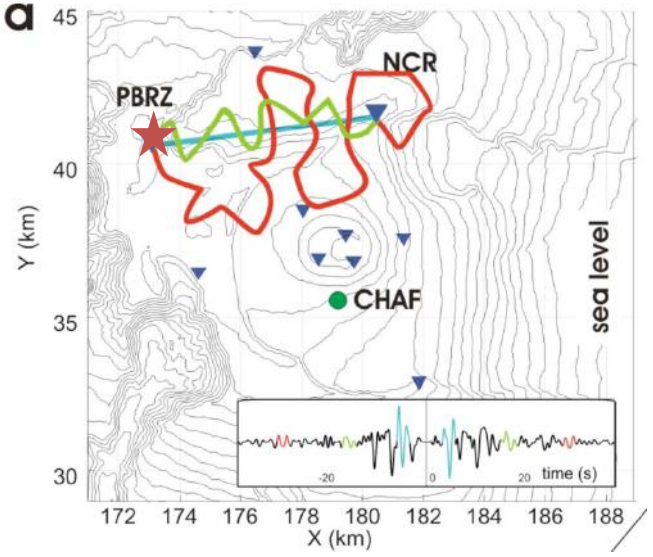


Brenguier et al., 2007

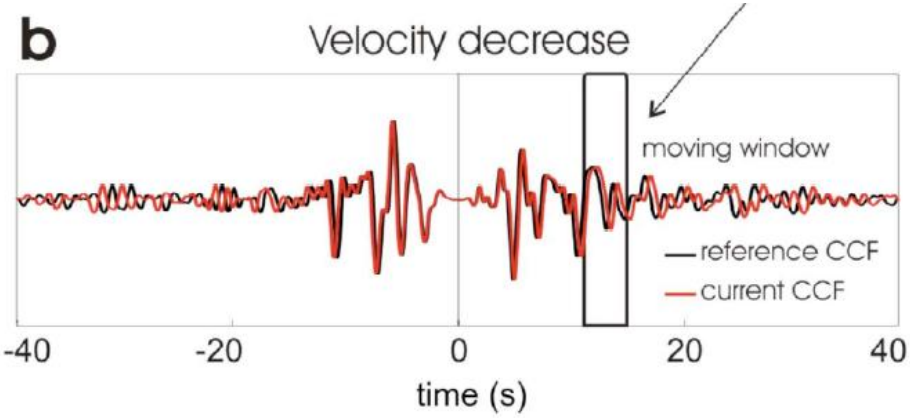
Measurements of seismic velocity changes: coda wave interferometry



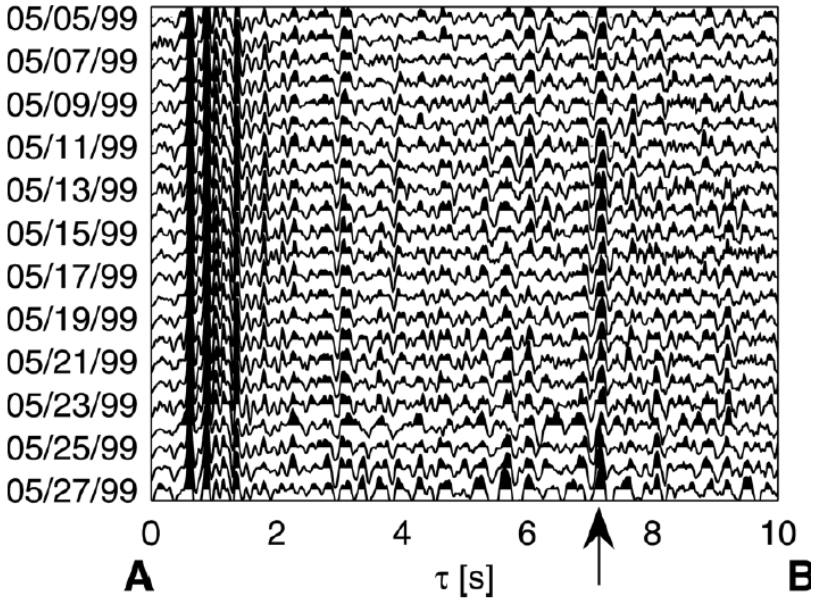
Poupinet et al., 1984

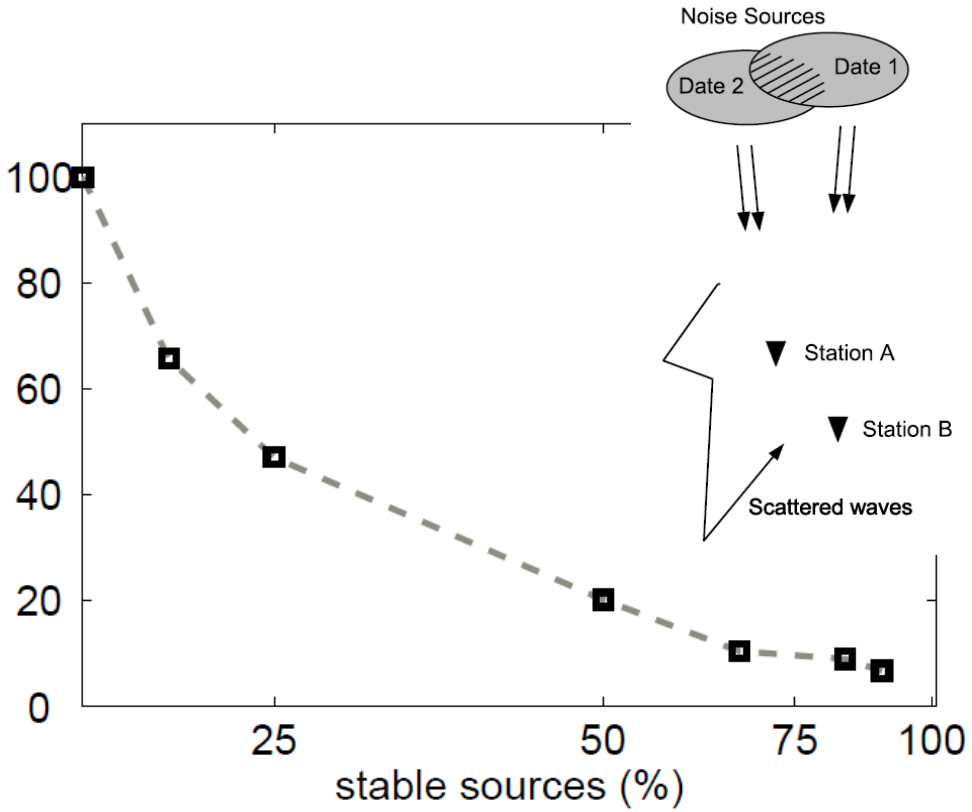


Δτ



May noise correlations be used for the reconstruction of virtual repeating seismic sources?

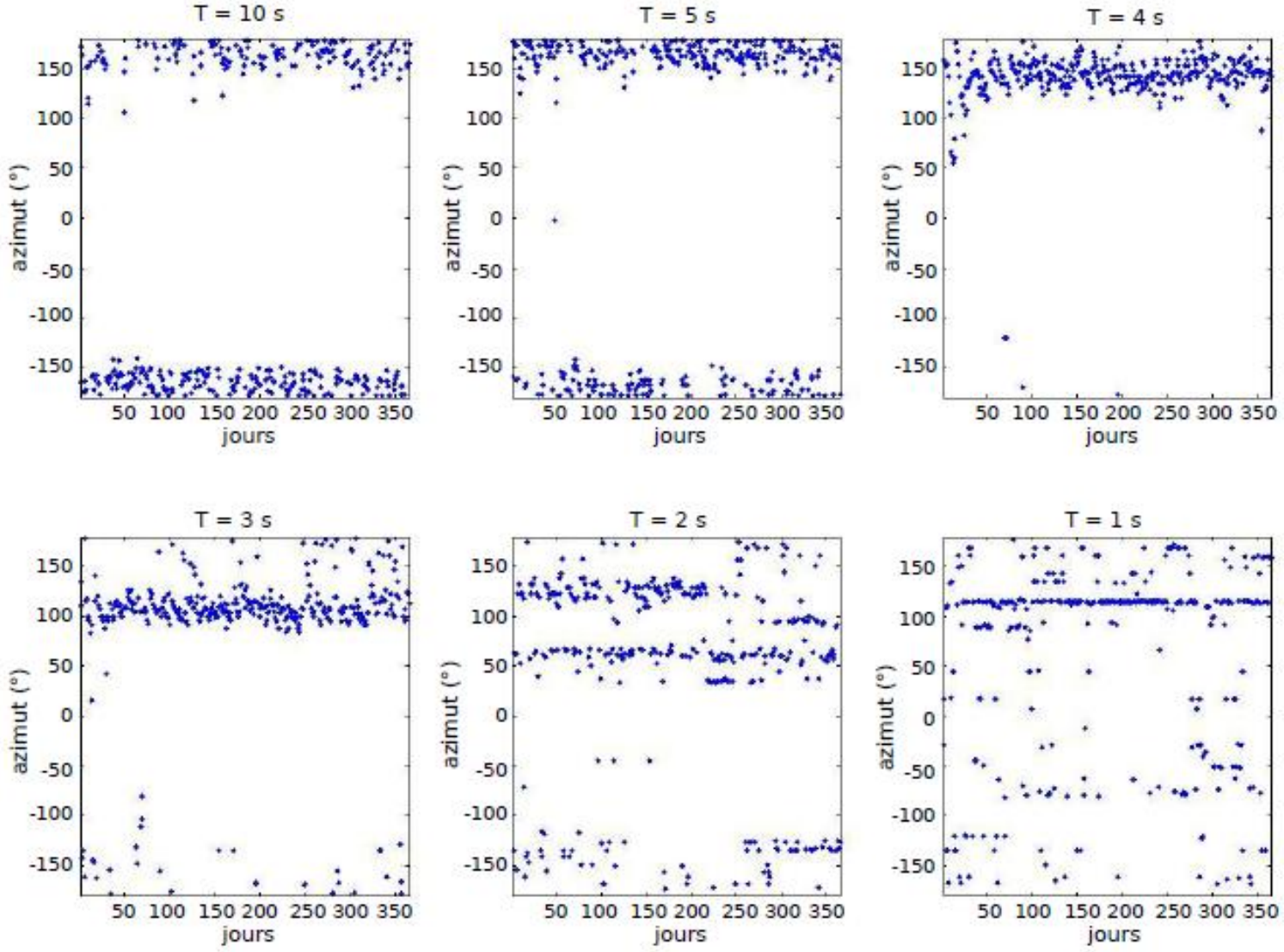




Sens-Schönfelder and Wegler, 2006

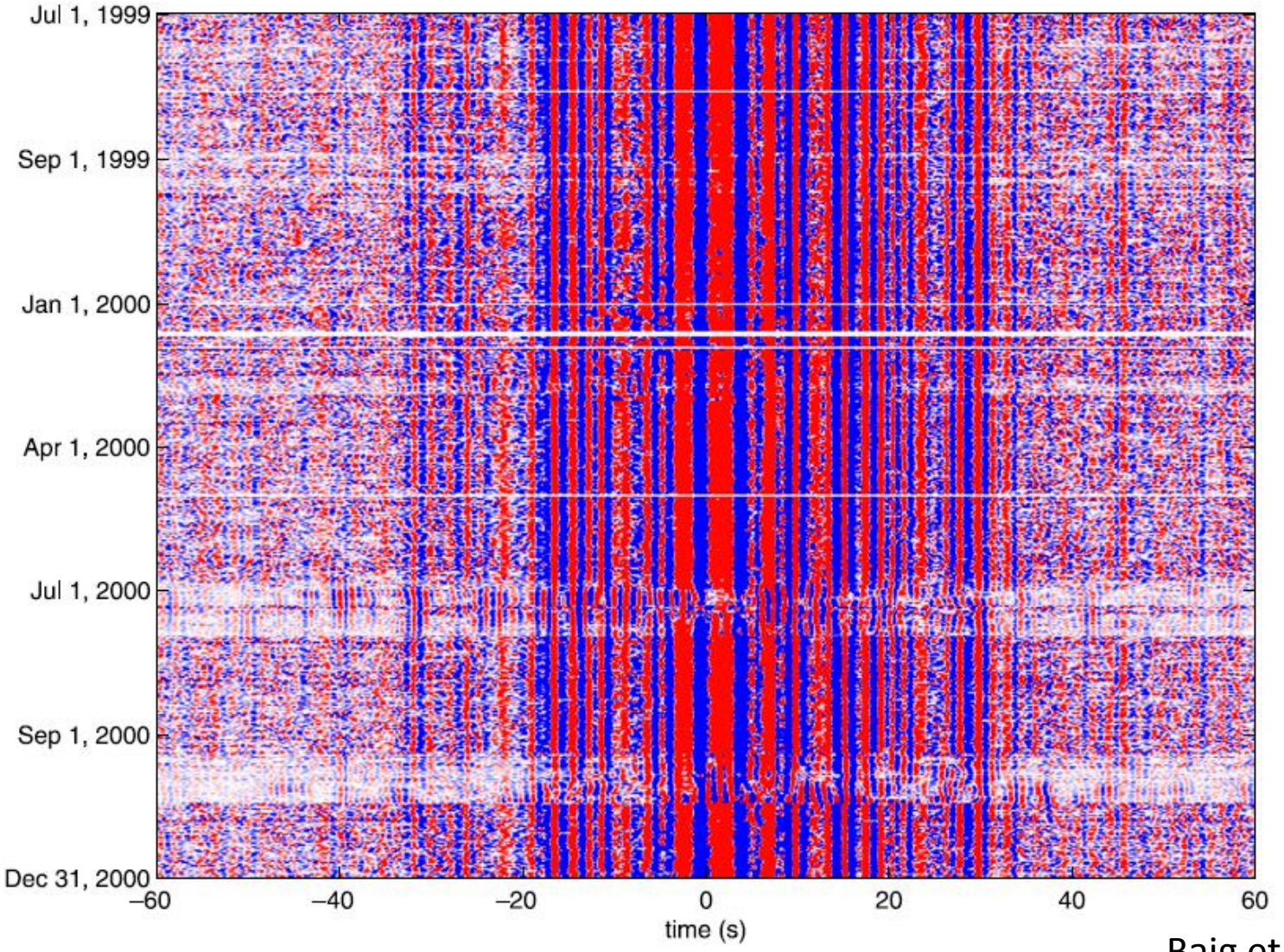
Hadziioannou et al. 2009

Temporal evolution of seismic noise azimuth at PdF



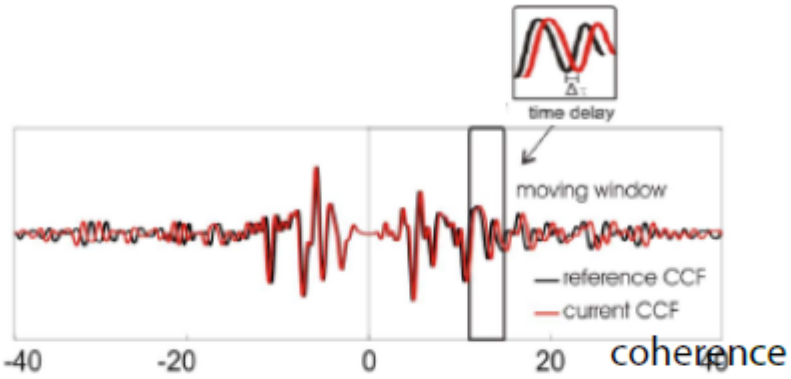
Tsang-Hin-Sun, 2012

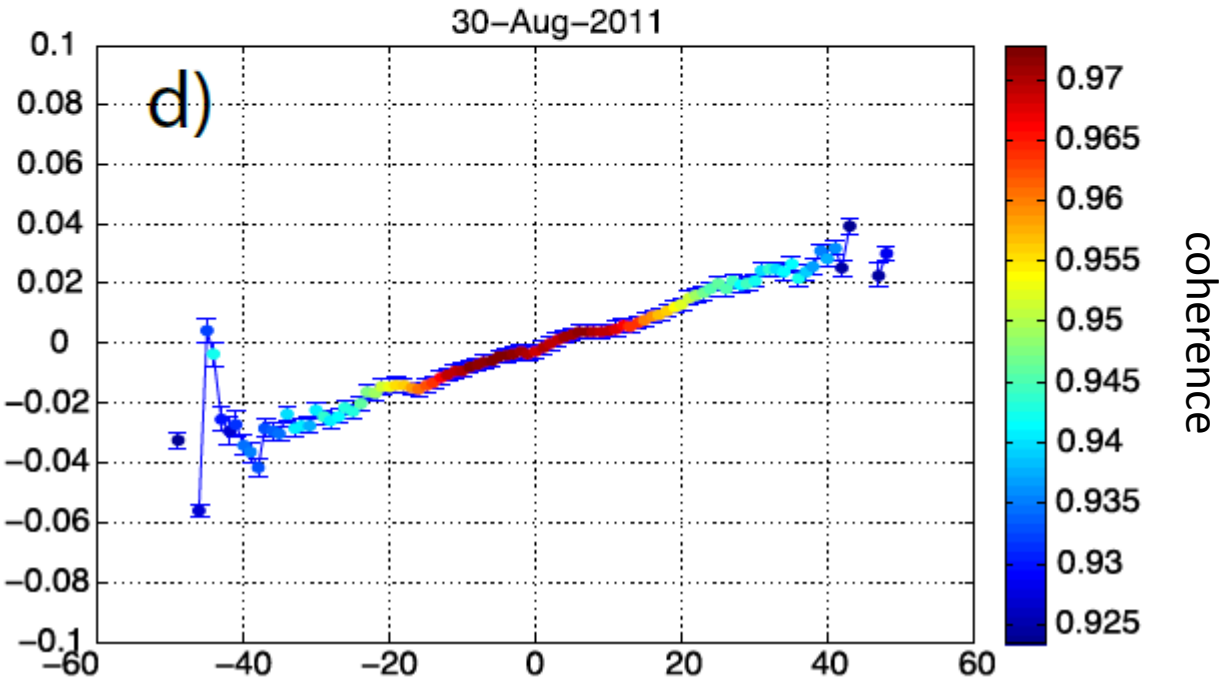
Measurements of velocity changes from the coda of noise correlations at PdF Volcano



Baig et al., 2009

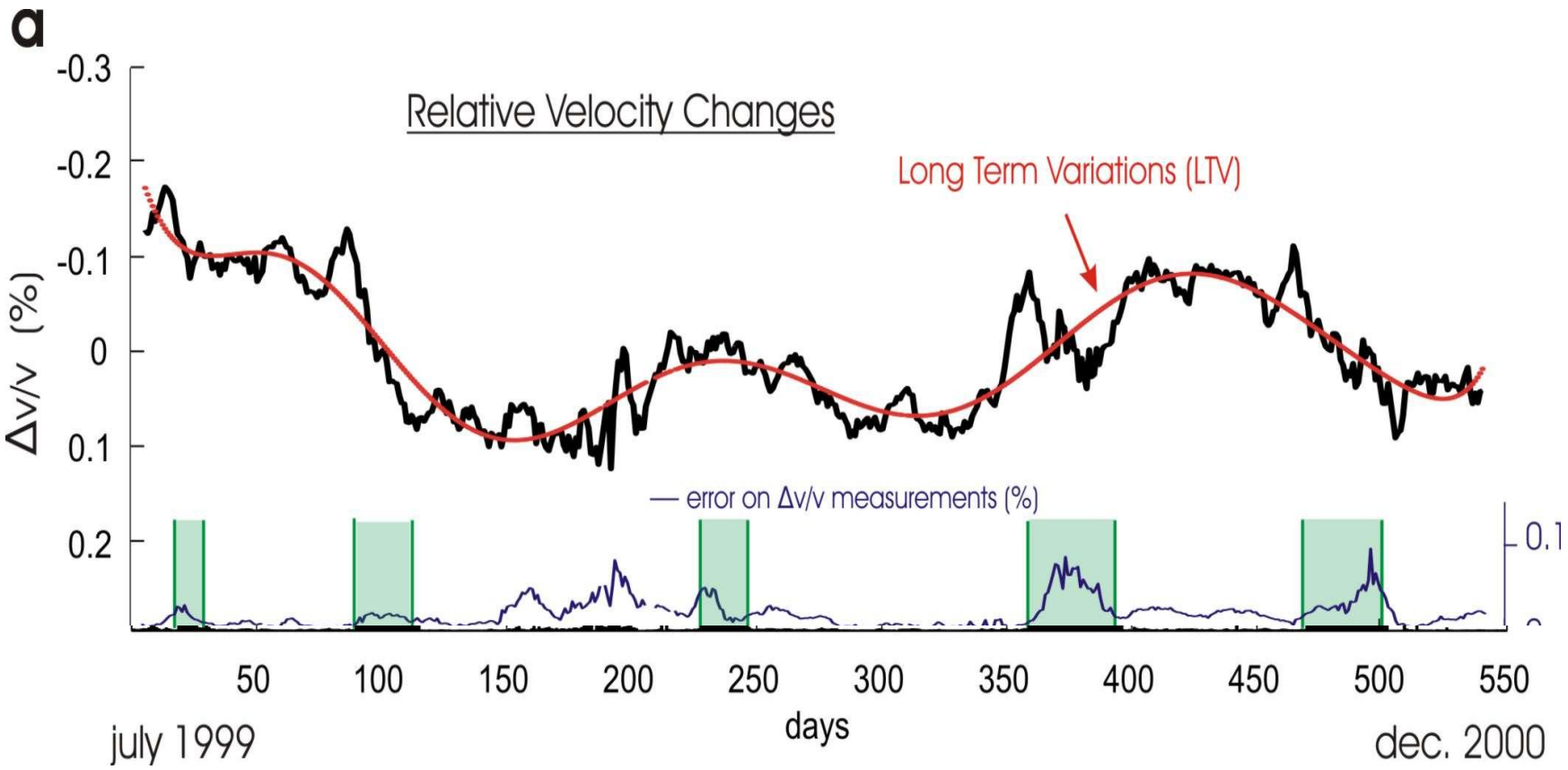
Measurements of velocity changes from the coda of noise correlations at PdF Volcano





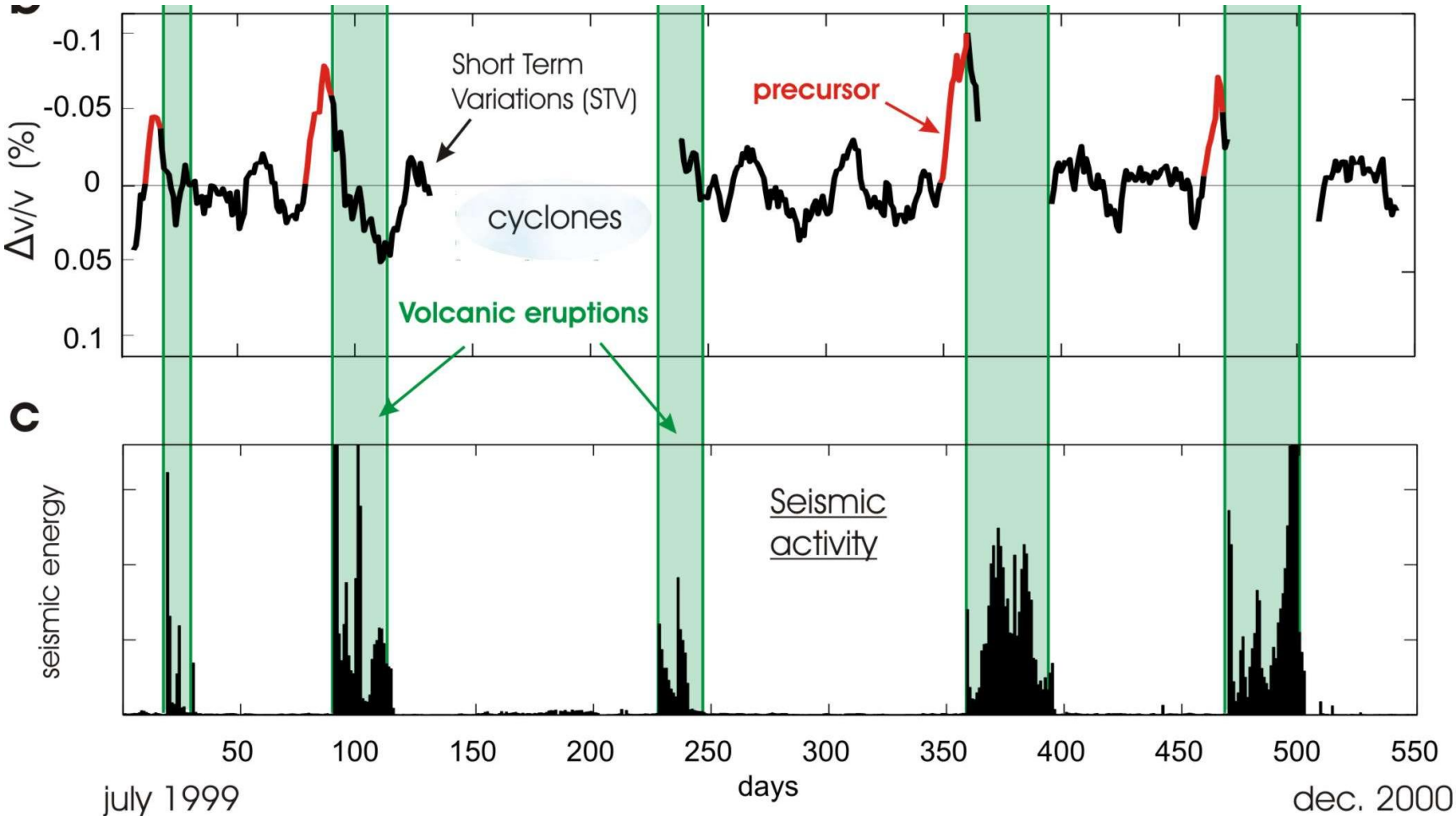
$dv/v=-dt/t$

Velocity change measurements at PdF volcano



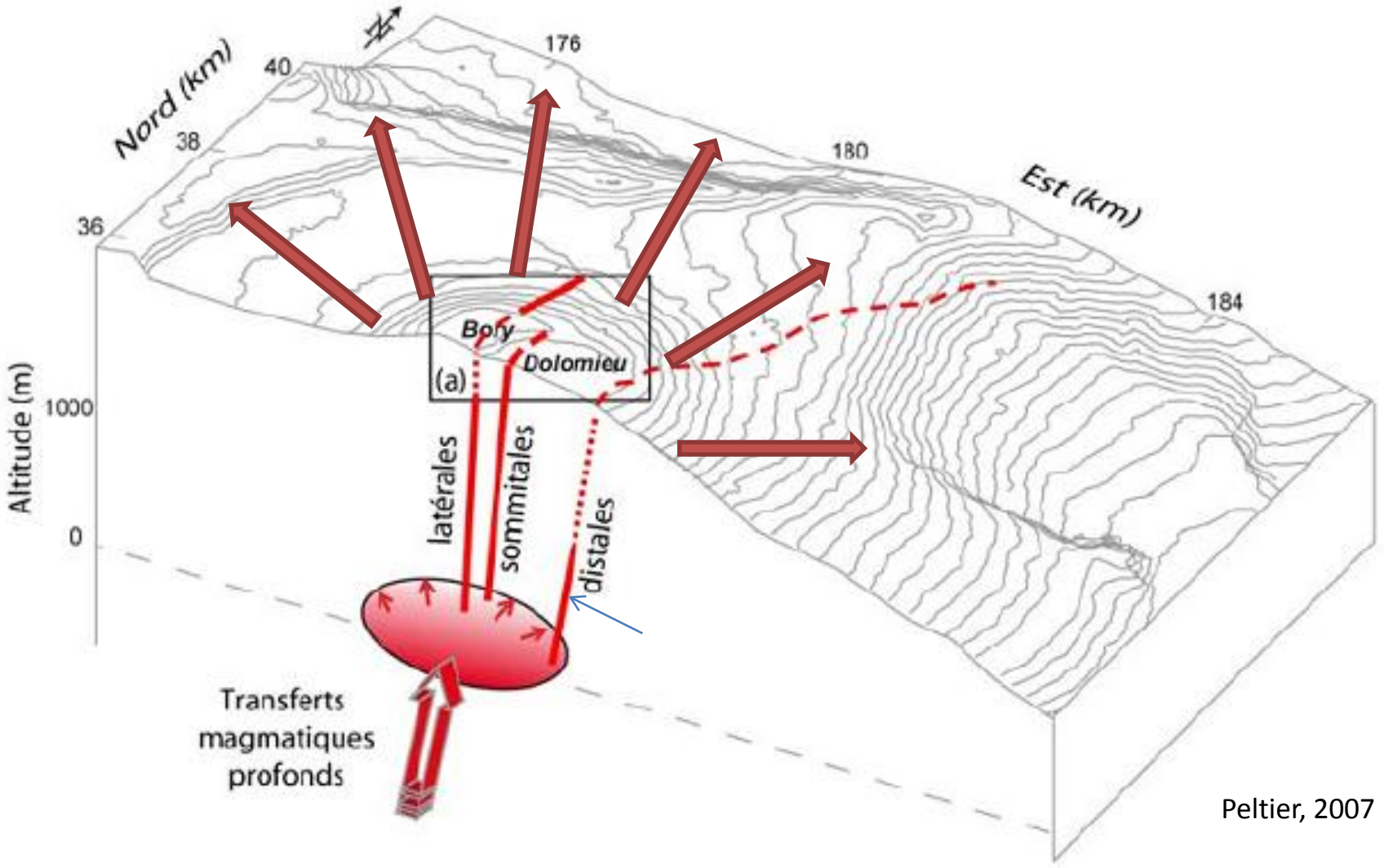
Brenguier et al., 2008

Velocity change measurements at PdF volcano



Brenguier et al. 2008

Stress build-up within the reservoir "dilates" the edifice



Peltier, 2007

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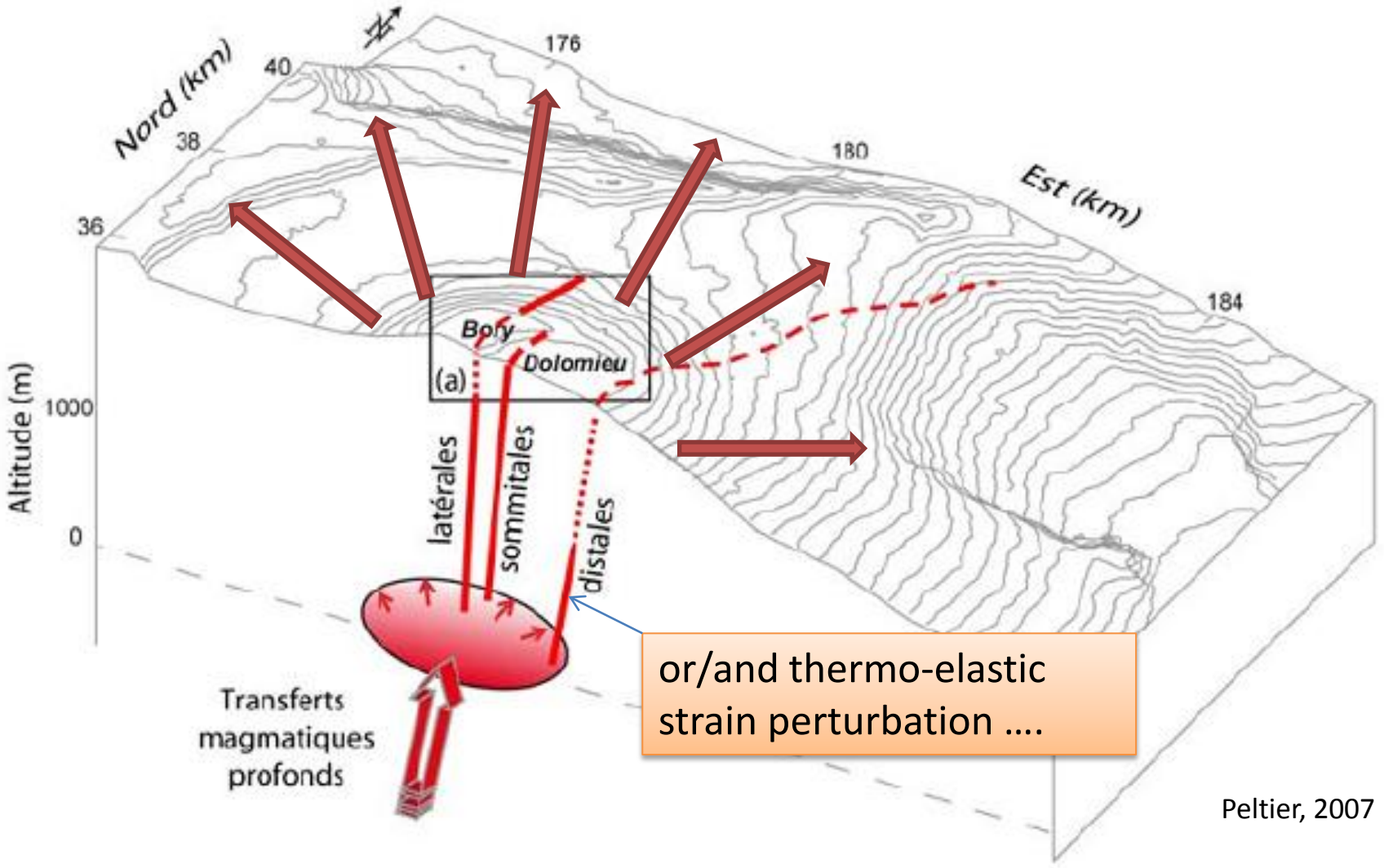
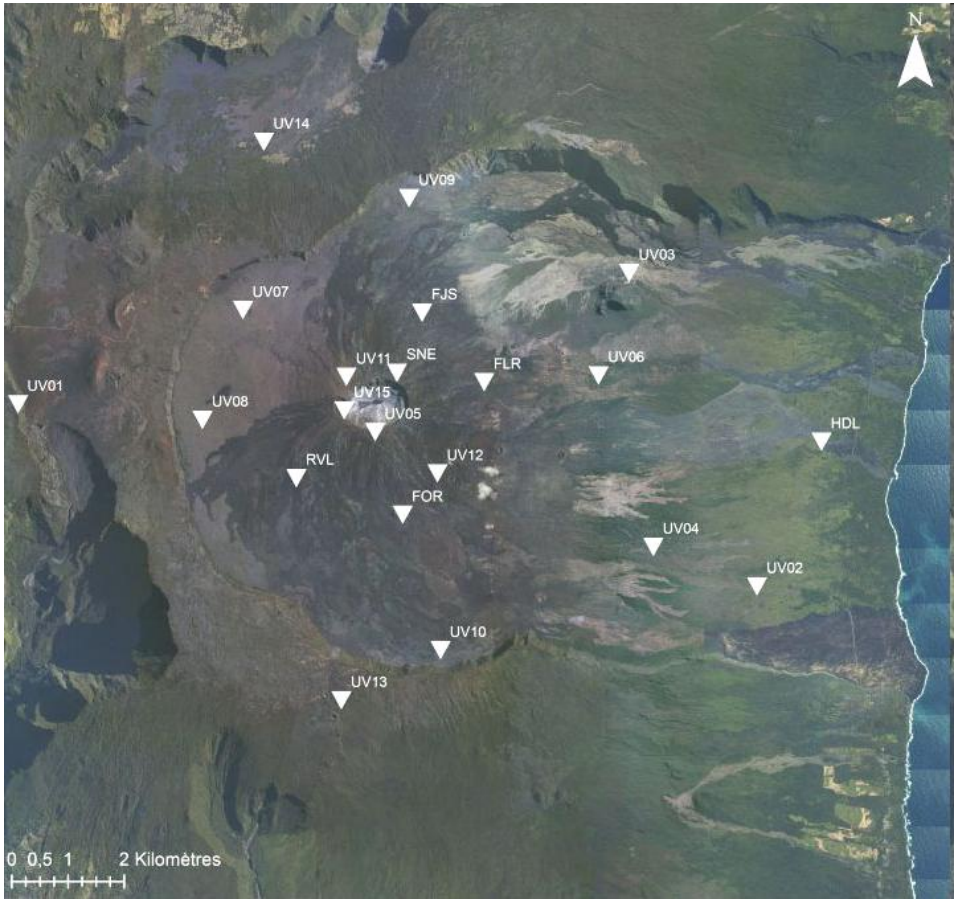


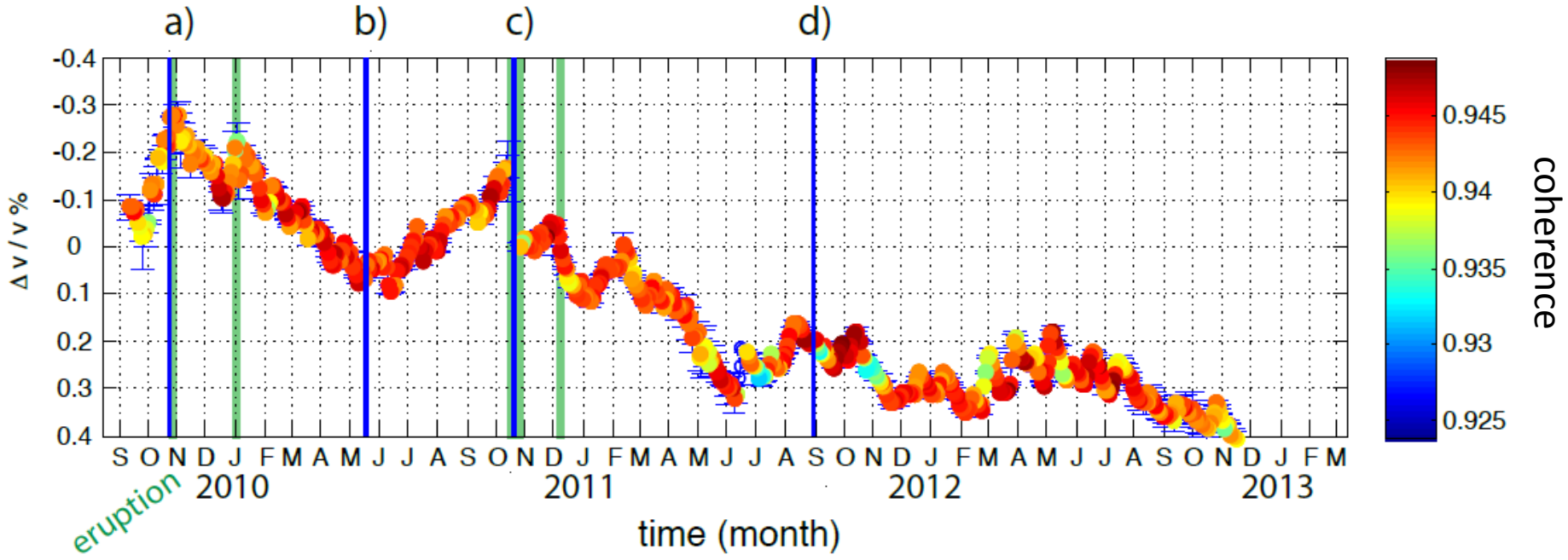
Peltier, 2007

Improving microseism noise records: UnderVolc project broad-band stations

UnderVolc

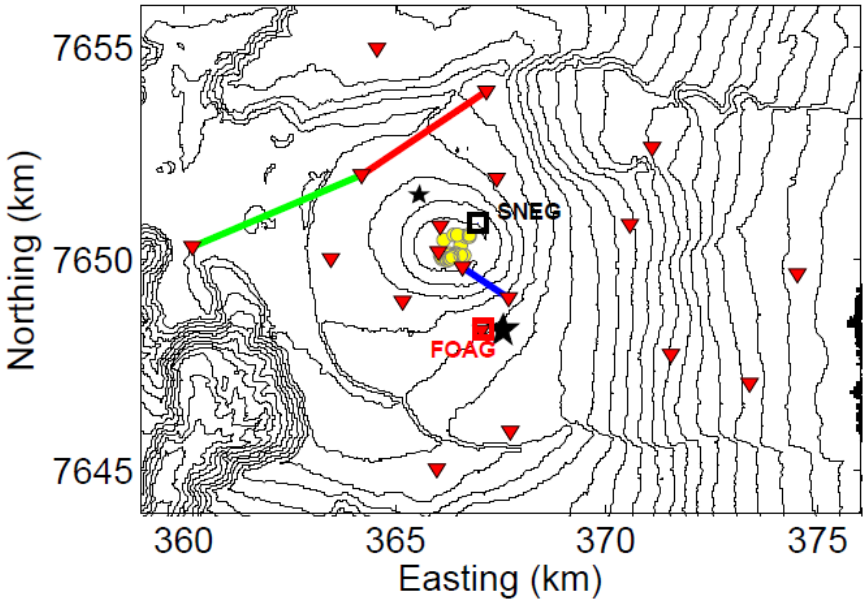


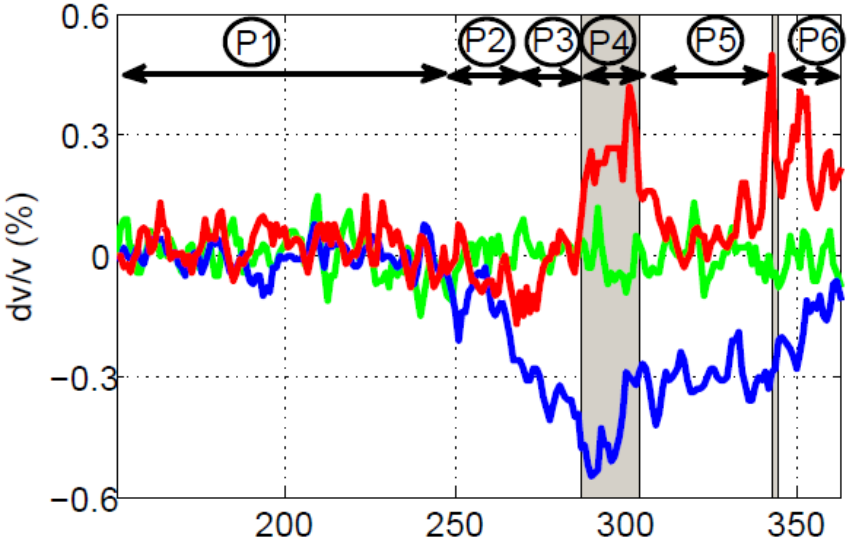
Recent velocity change measurements at PdF volcano



Rivet al al. 2013

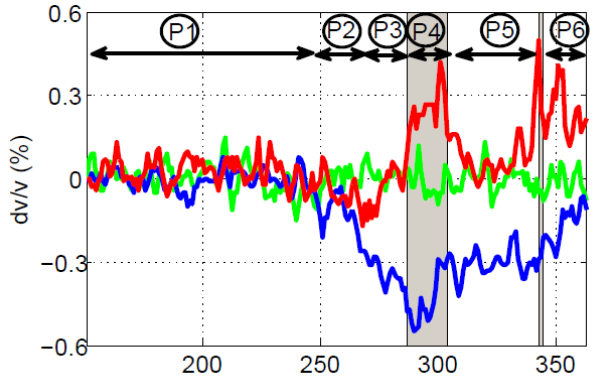
Localization of pre-eruptive seismic velocity changes (1)

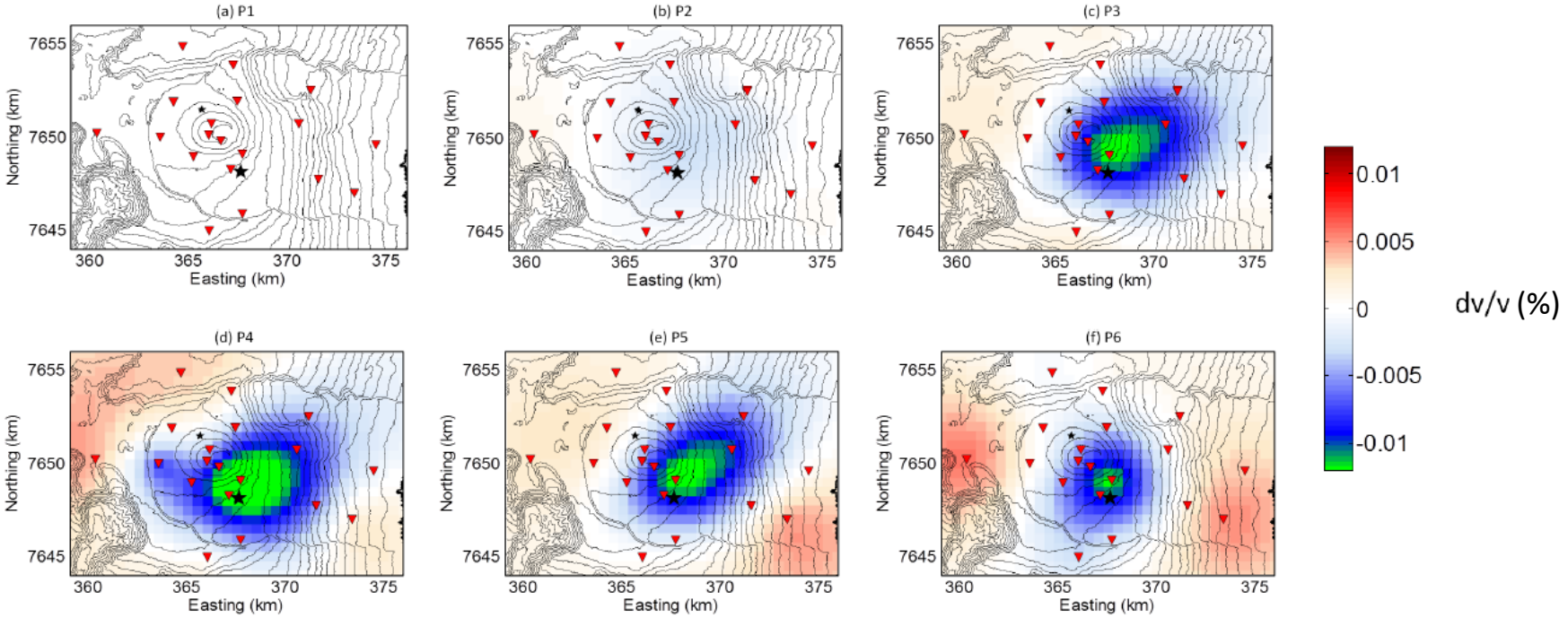




Obermann et al. 2013

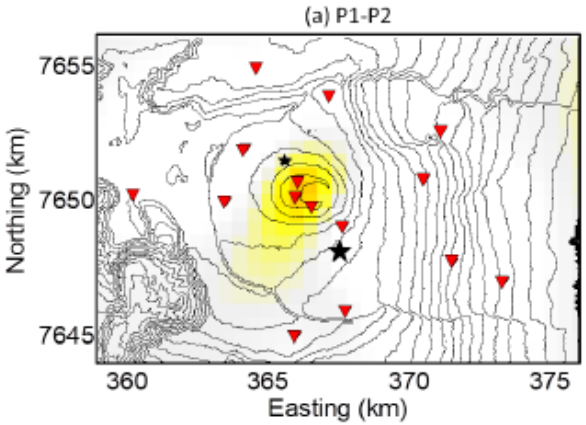
Localization of pre-eruptive seismic velocity changes (2)

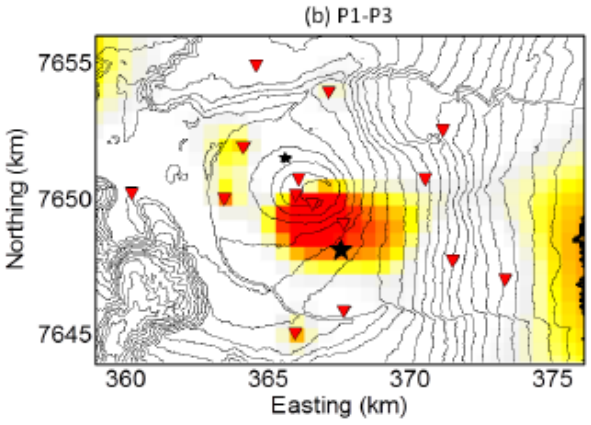


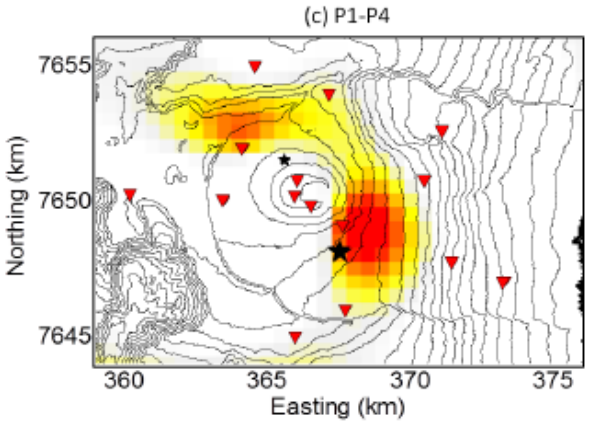


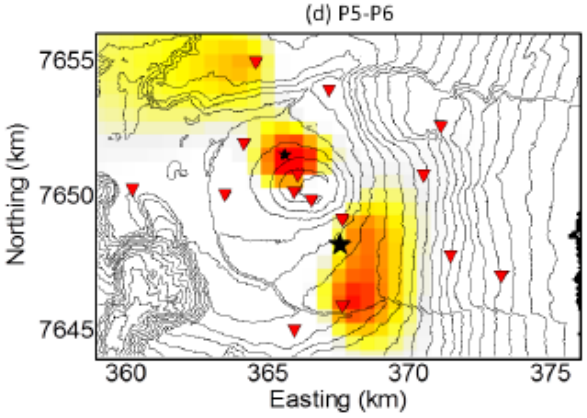
Obermann et al. 2013

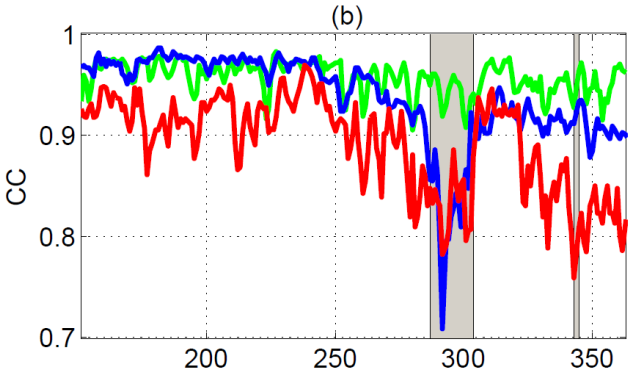
Localization of pre-eruptive seismic velocity changes (3)

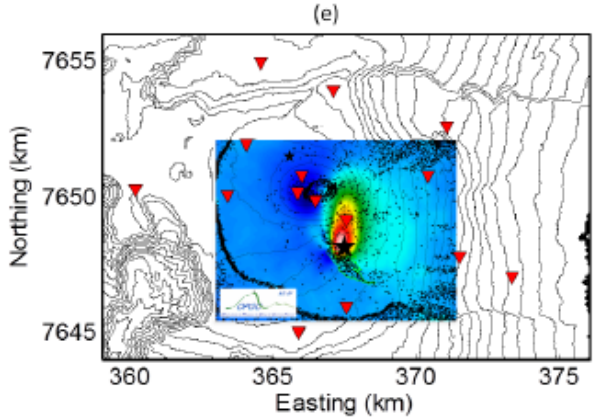






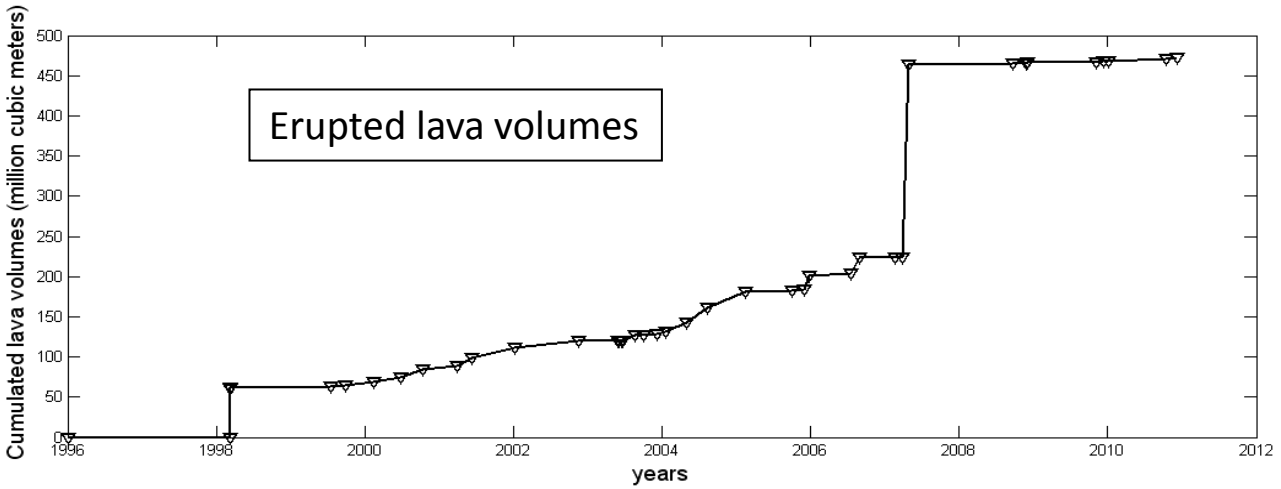


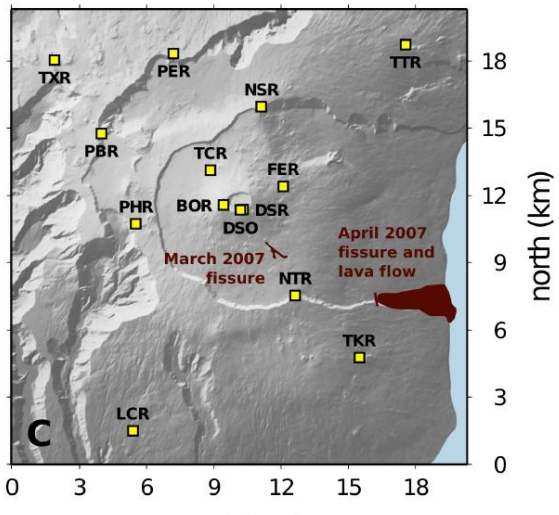


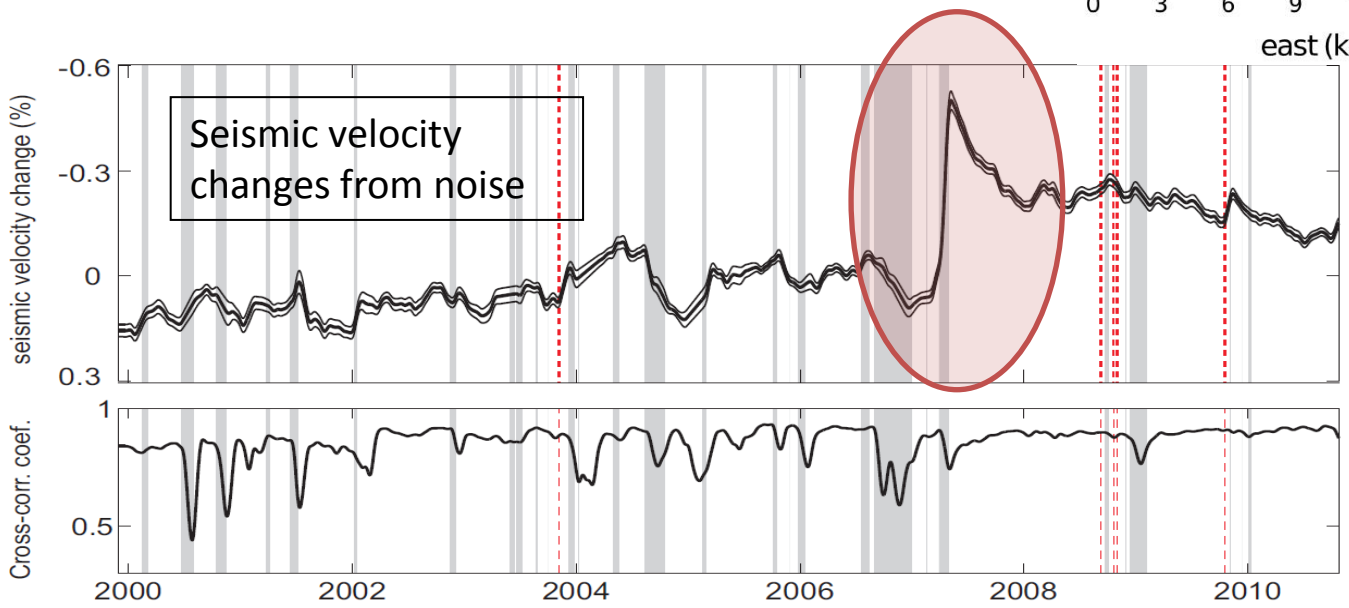


Larose et al., 2010, Obermann et al. 2013

The case of the April 2007 eruption



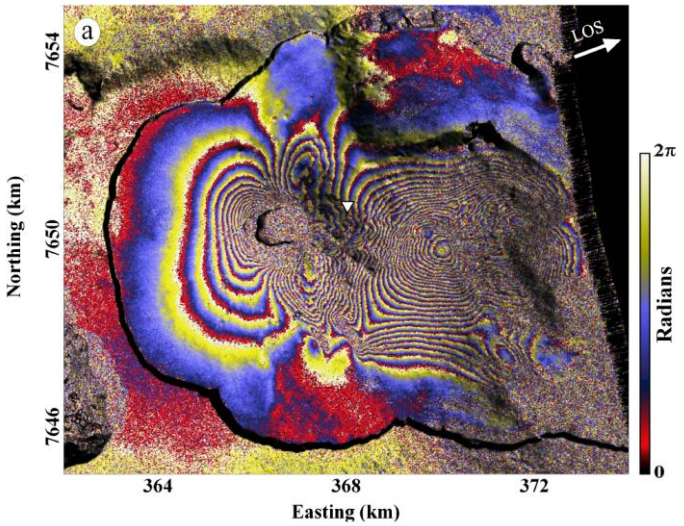


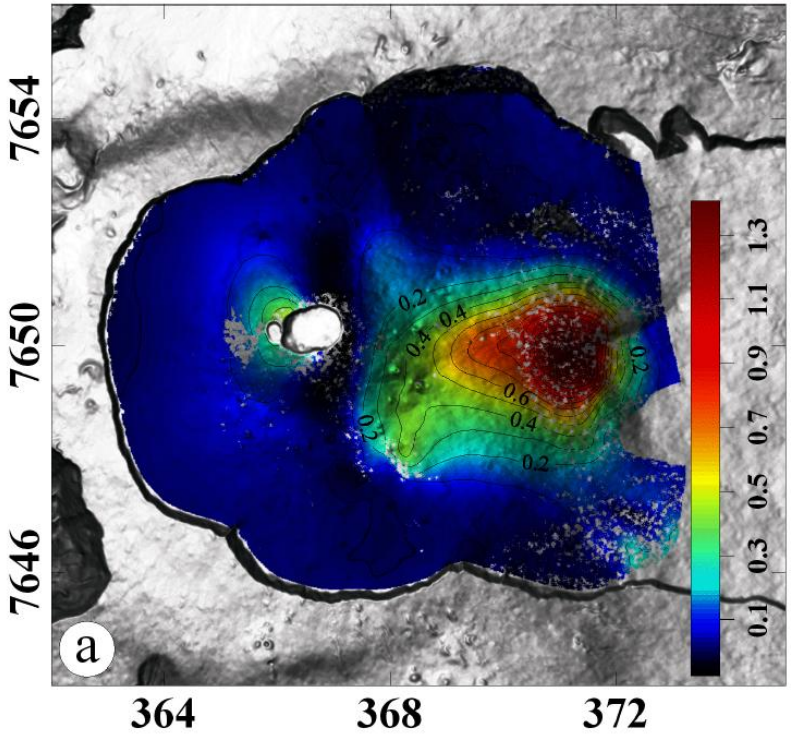


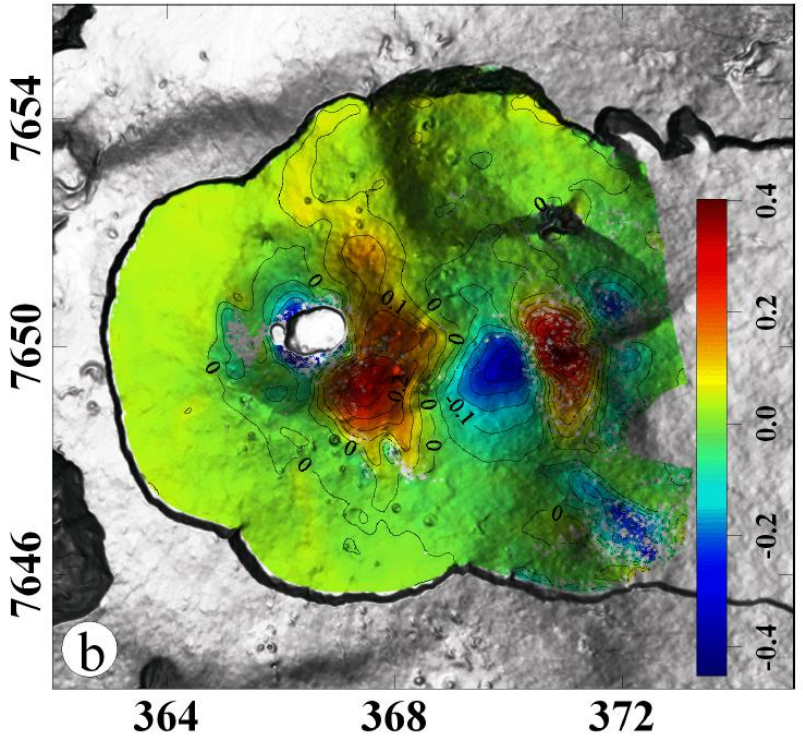
Clarke et al., 2013

Deformation from InSAR

- Widespread eastward flank movement (1.4 m max)
- Volumetric deformation as strong as 10^-4
- PB : no temporal resolution : When the movement initiated?



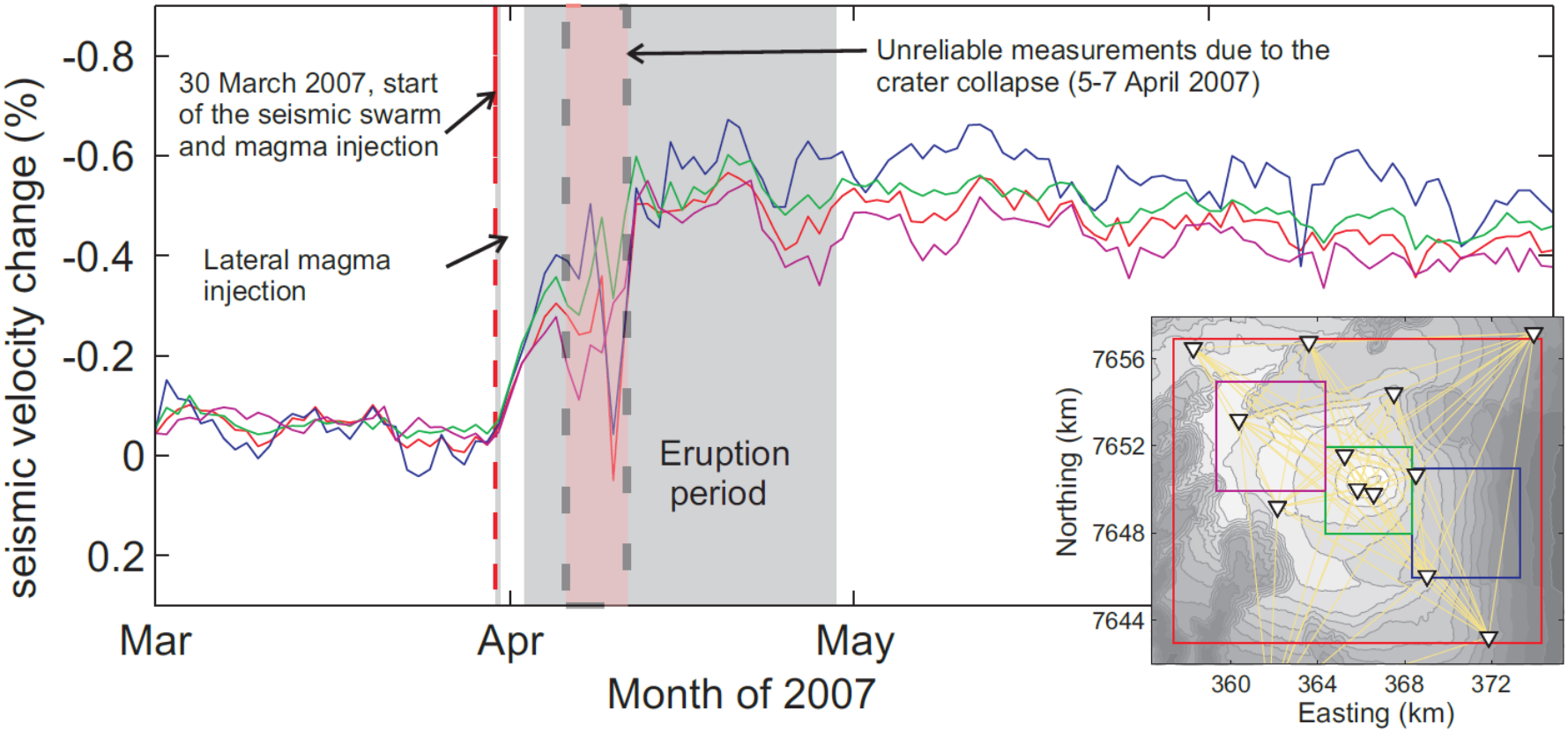




Courtesy of J.L. Froger

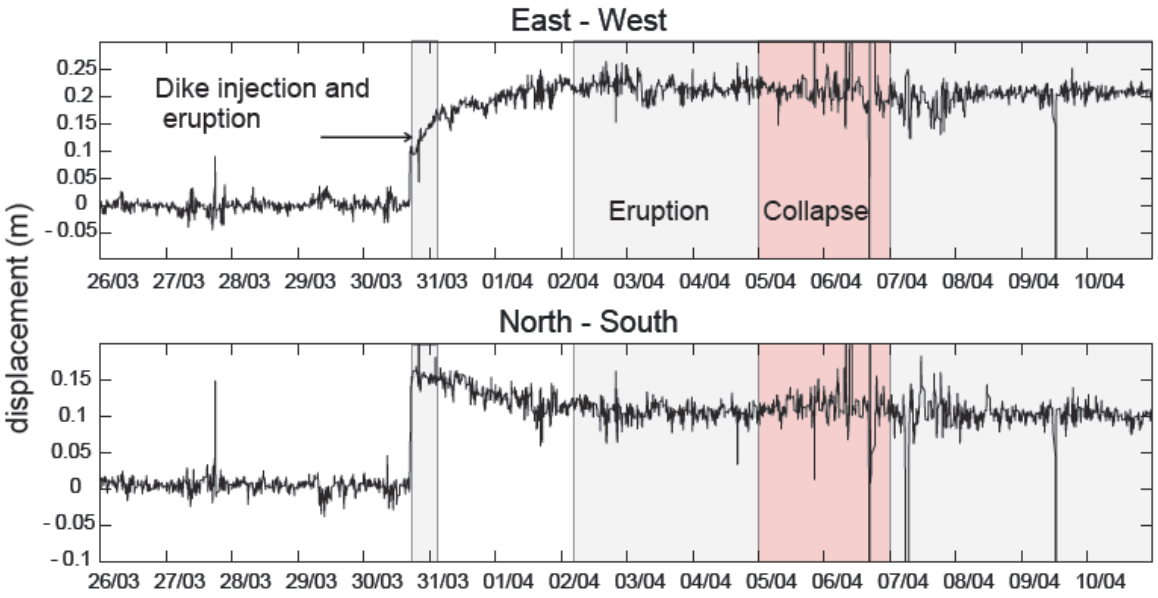
Short-term velocity variations

- Large velocity drop starts on March 30
- Seems to localize on the eastern part of the volcano
- Velocity drop lasts about 15 days



GPS measurements

• An eastern flank movement starts on March 30



Courtesy of A. Peltier

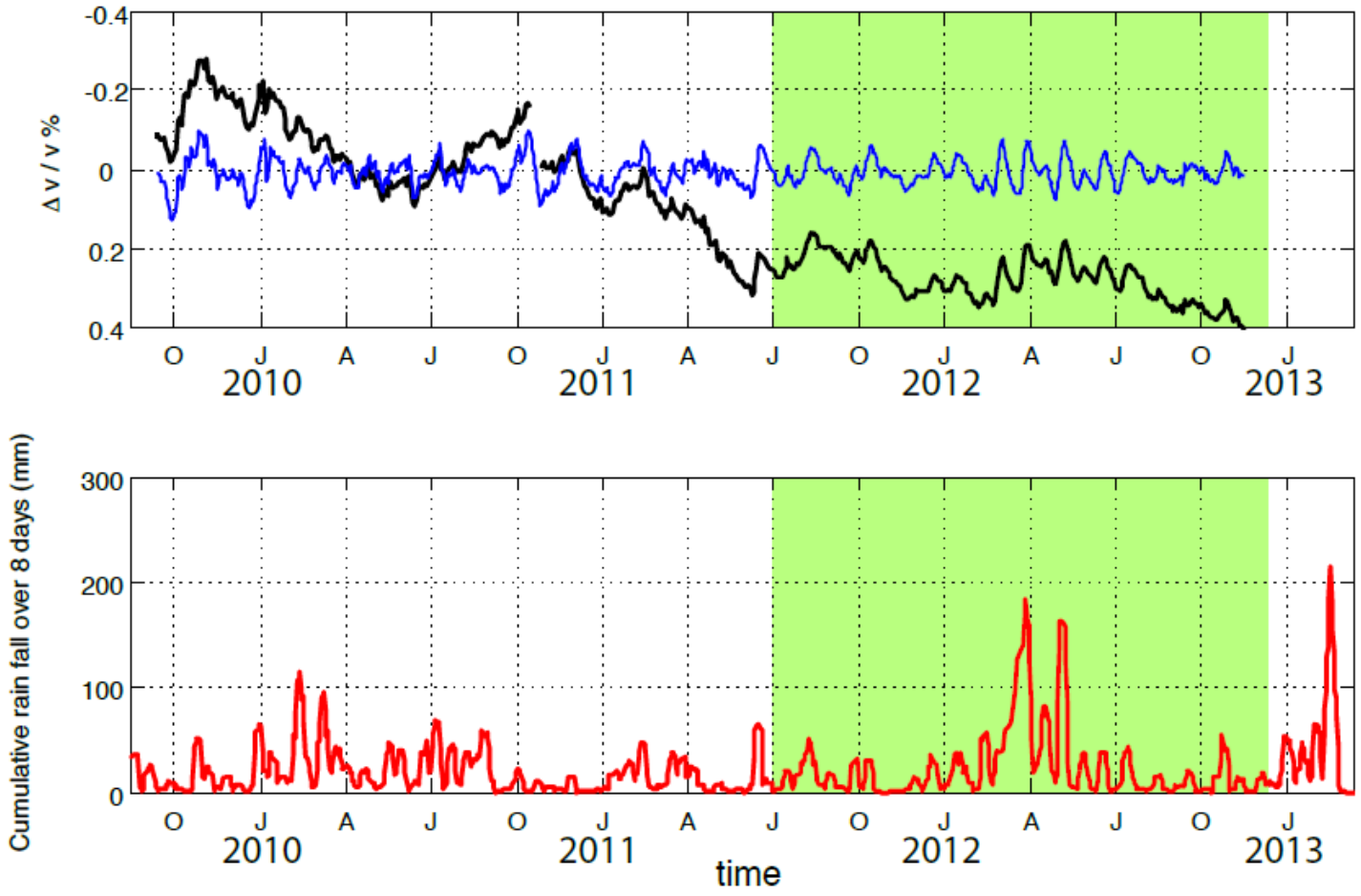
CONCLUSIONS:

• A large eastern flank movement occurred during the March-April volcanic episode

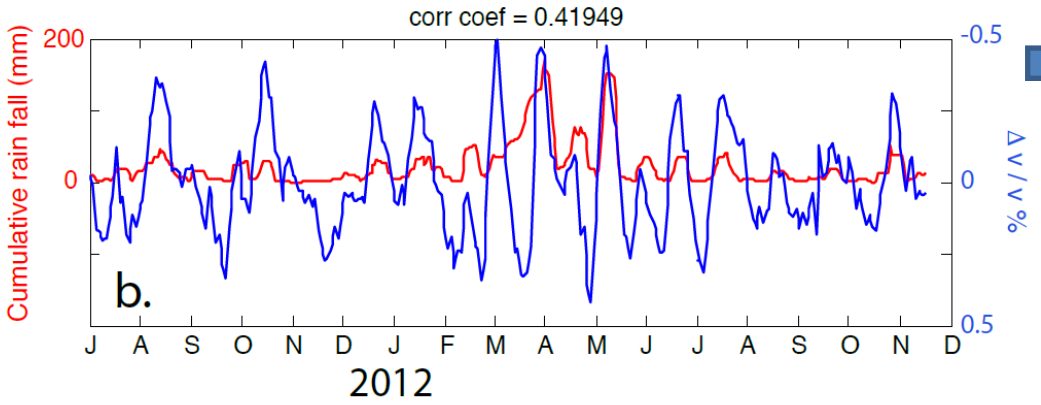
• GPS measurements as well as seismic velocity changes indicate that this movement started at the time of the March 30 magma injection and eruption

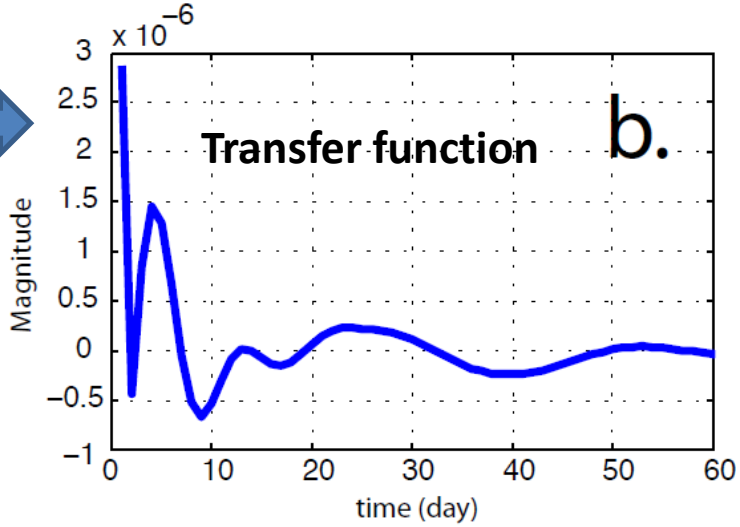
• Might thus probably have been triggered by the increase of horizontal stress due to the March 30 eruption and may have favored the horizontal migration of magma and the large April 2007 eruption.

Prospect: effect of non-volcanic perturbations on velocity change measurements (tides, air pressure change, rainfall, T°)

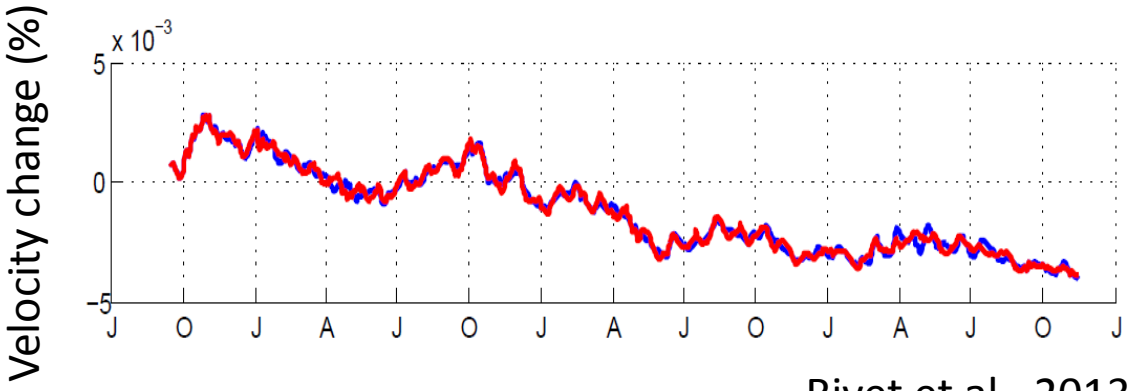


Effect of rainfall on velocity change measurements





Subtraction of rain-induced velocity change



Rivet et al., 2013

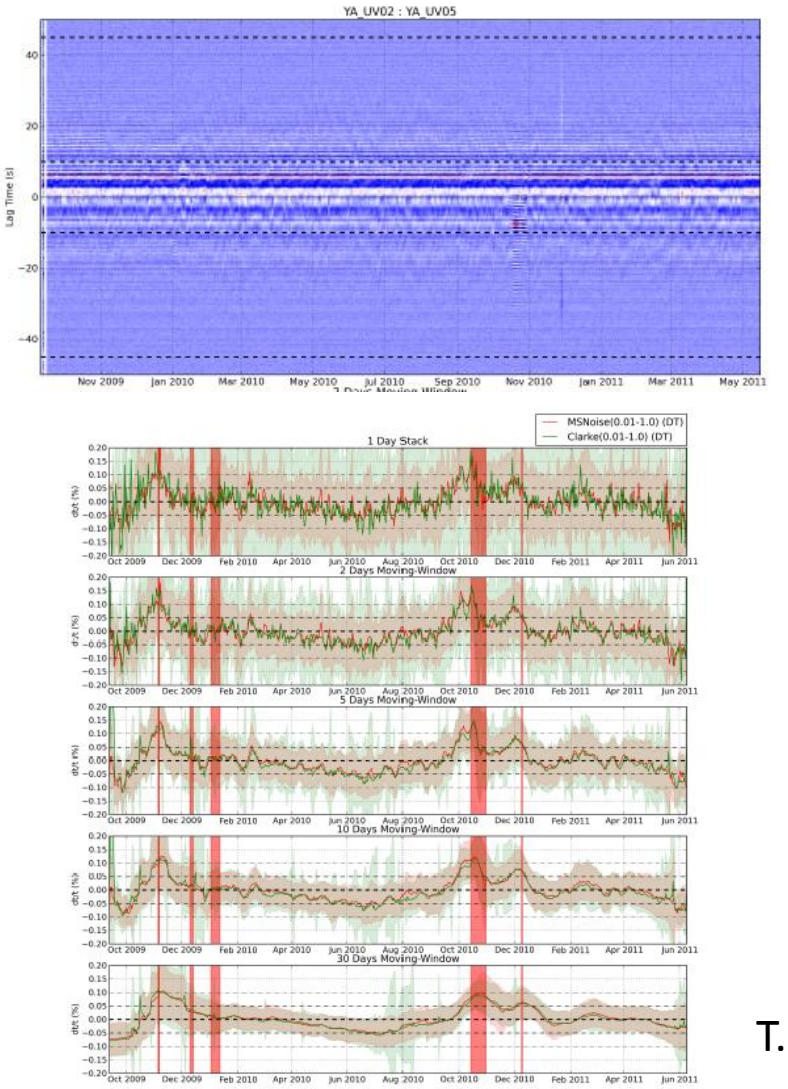
Conclusions

- Continuous monitoring of seismic velocities using ambient seismic noise allows a resolution of **less than 0.01 % ,~ a stress detection threshold of ~1 kPa, and a temporal resolution of less than 1 day.**

- On volcanoes, such monitoring allows to capture eruption **precursory** velocity changes and markers for **flank movements**

- Such a precise observations are sensitive to many phenomena acting on the rock mass (**rainfall, tides, thermo-elastic strain, barometric pressure change**, …). These must be known precisely in order to extract the **volcanic contribution** to the observed velocity changes

Providing an operational tool for real-time noise-based monitoring (MSNoise)



- Written in Python (no requirement for Matlab)
- Automatic processing of real-time data and archives
- Ideally suited for volcano monitoring

T. Lecocq et al., 2013


Thanks for your attention !