Insights on the long-term activity of Piton de la Fournaise Volcano from seismic velocity changes

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Abstract

We study Piton de la Fournaise (PdF) Volcano dynamics through the observation of continuous seismic velocity changes during the period 2009 to 2013. This velocity change time serie complements measures obtained before the Undervolc campain from 2000 to 2009 (Clarke et al 2011).

At short period (0.5-4s) we observe :

- Short-term velocity changes produced by the volcanic eruptions (e.g. October 2010 and December 2010).
- Short-term velocity changes produced by rainfalls.
- A long-term increase of the velocity is measured from 2007 to 2013 and is consistent with geodetic measurements.

At longer periods we observe velocity changes that do not correlate in time with PdF eruptive activity. Yet, distinctive episodes of velocity variations suggest changes in the elastic properties at lower depth.

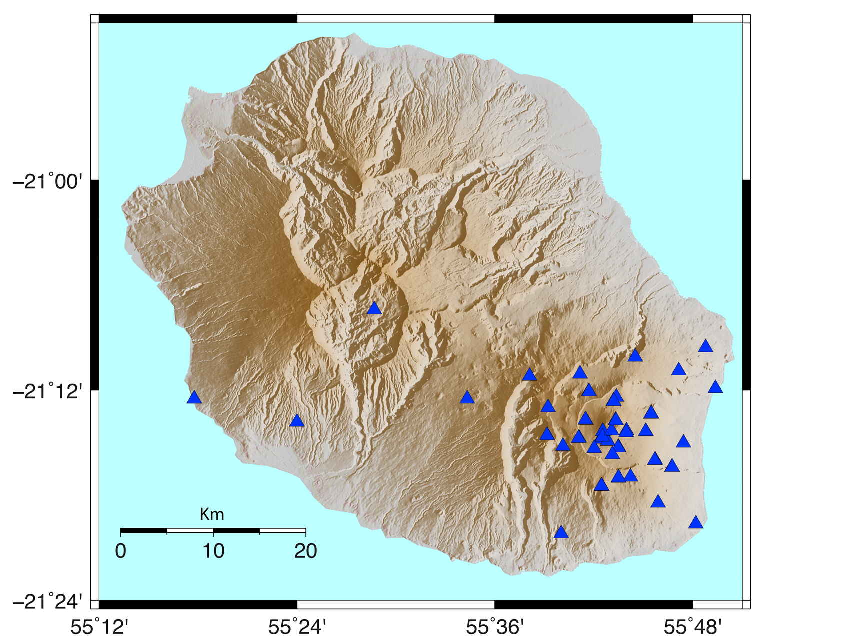


Figure 1. Map of La Reunion Island and the permanent broad-band seismic network mainly located on the Piton de la Fournaise volcano. 15 of the 36 stations were installed during the Undervolc campain.

1. Dataset and Methodology

- We compute cross-correlations of ambient seismic noise recorded at 36 broad-band stations (**Figure 1**) of the Undervolc and PdF Volcano Observatory networks.
- Velocity changes are estimated from the travel time delay measured on the coda of noise cross-correlations using the Doublet Method (**Figure 2**).
- Doublets method (e.g. Brenguier el al. 2008) measures apparent delays dt(t) within a series of short time overlapping windows at several distinct time t. These dt(t) are determined from the phase shift measurements in the frequency domain. The slope dt/t of the distribution of dt(t) measures reveals a change in the medium dv/v=-dt/t.
- We average relative velocity changes for all pairs of stations

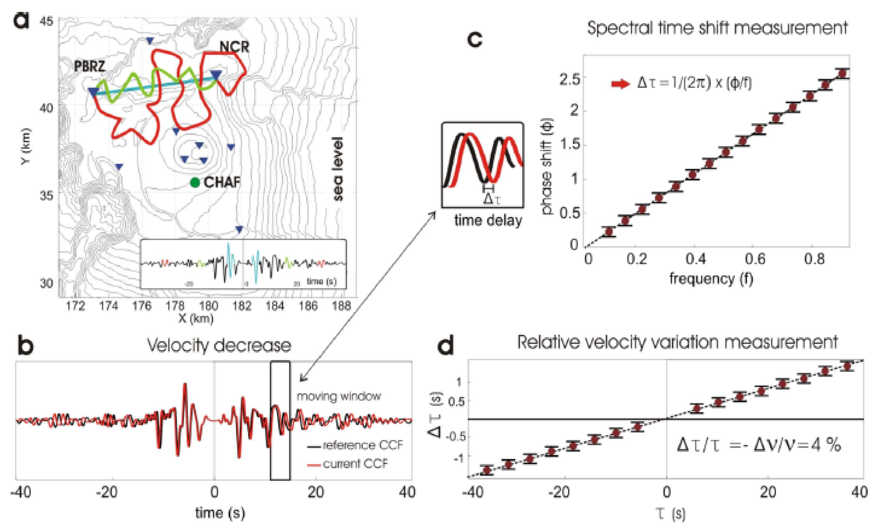


Figure 2. Example of velocity change measurments using the Doublet method on the coda of synthetic cross-correlations. (From Brenguier et al. 2008).

2. Global velocity increase from 2009 to 2012 and quality control

- Noise cross-correlations were computed between vertical components over 8-day windows that overlapped every day. We measure velocity changes from the cross-correlations in the 0.5 - 4 s period band.
- We check the quality of the relative velocity change measures looking at the average time shifts measured between the reference and current 8-day cross-correlations (using all receiver pairs). A well defined slope of the distribution of dt(t) gives a robust velocity change measure (e.g. Figure 3a, b and d).
- Short term velocity changes are often related to volcanic eruption (e.g. oct. 2010, jun., oct. and dec., 2011): a velocity decrease prior to the eruption followed by an increase during eruption (Brenguier et al. 2012, Obermann et al., Sens-Schoenfelder et al.).
- A long term velocity increase of about 0.2%/yr.

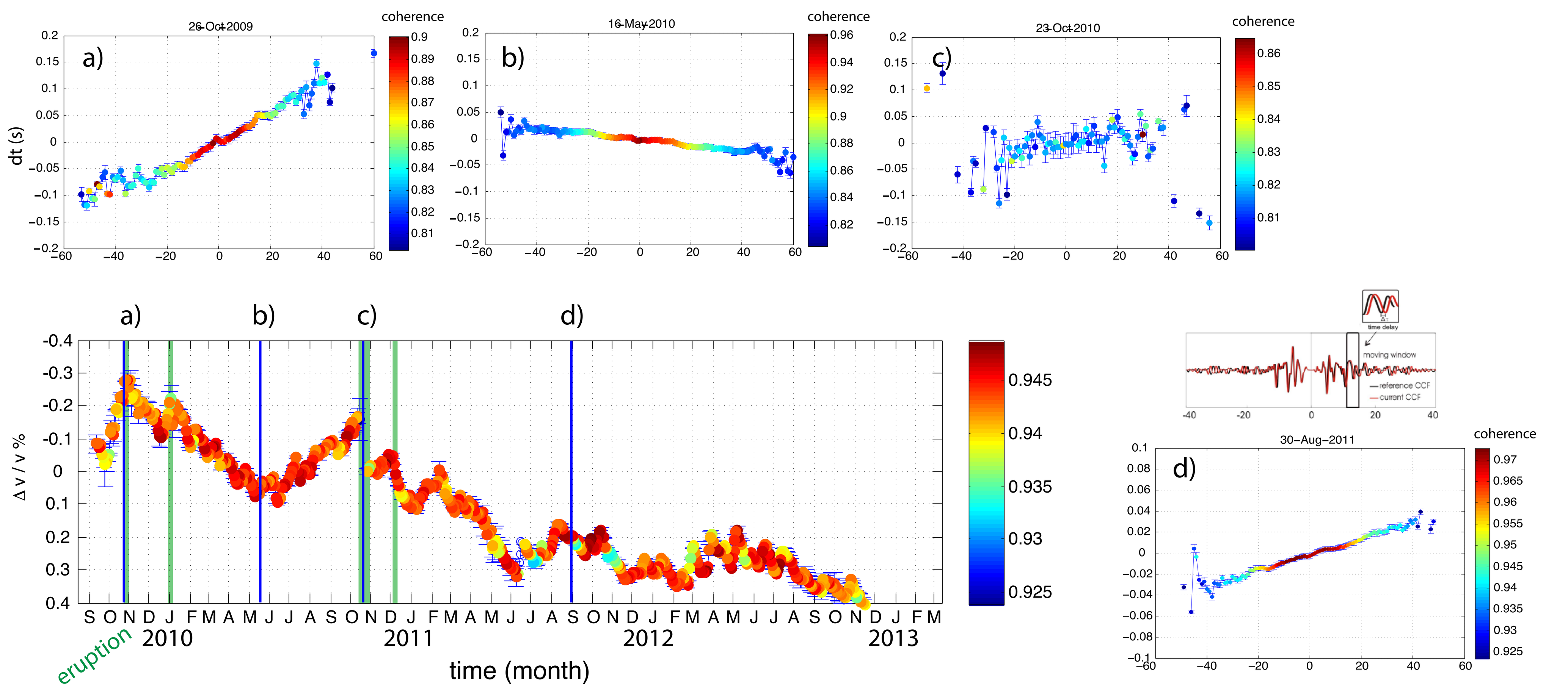


Figure 3. The large central figure shows relative velocity changes in the 0.5 - 4s period band. Green bands indicate volcanic eruptions. Figures a,b,c and d are time shift distributions of the Doublet measures for given dates using all station pairs.

3. PdF long term dynamic from more than 12 years of noise records

- From the complete seismic velocity change time serie (2000 to 2013) we observe the long-term dynamic of Piton de la Fournaise volcano (Figure 5).
- From 2000 to the last great eruption in April 2007, there is a long term velocity decrease of about 0.07 %/yr. After the eruption of April 2007 the average velocity of the volcano increase at a faster rate 0.2%/yr.
- We compare the evolution of seismic velocity with geodetic measures. We are interested in particular to volumetric changes, which are more likely to produce velocity decreases. Baseline changes between pair of stations located around the volcano crater (continuous lines Fig. 4) indicate that since April 2007 eruption the volcano inter-eruption dynamic changes from inflation to deflation. For long distance baselines (dashed lines Fig. 4), we observe a similar behavior after April 2007 eruption with a global baseline shortening between stations.
- At relatively short period (0.5 - 4s) velocity changes well capture the volcanic eruptions as well as the long term evolution of the volcanic dome.

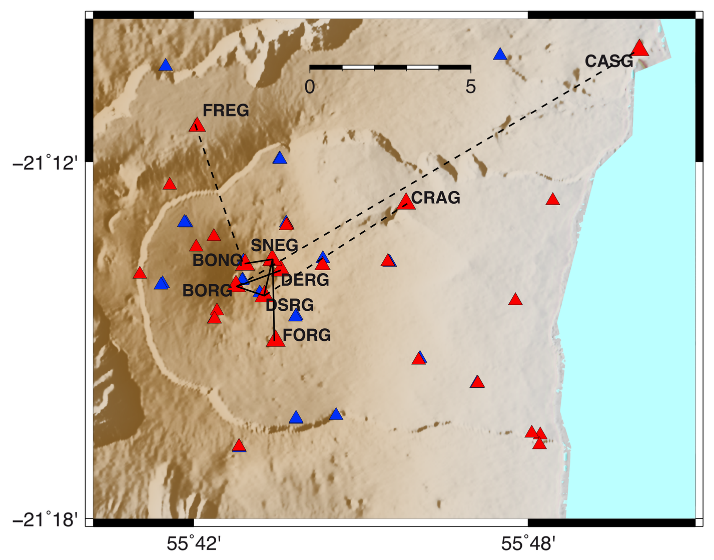


Figure 4. Map of the Piton de la Fournaise Volcano and the GPS permanent network (red triangles). Larger triangles indicate the positions used in the baseline change measures. Blue triangles indicate seismic stations.

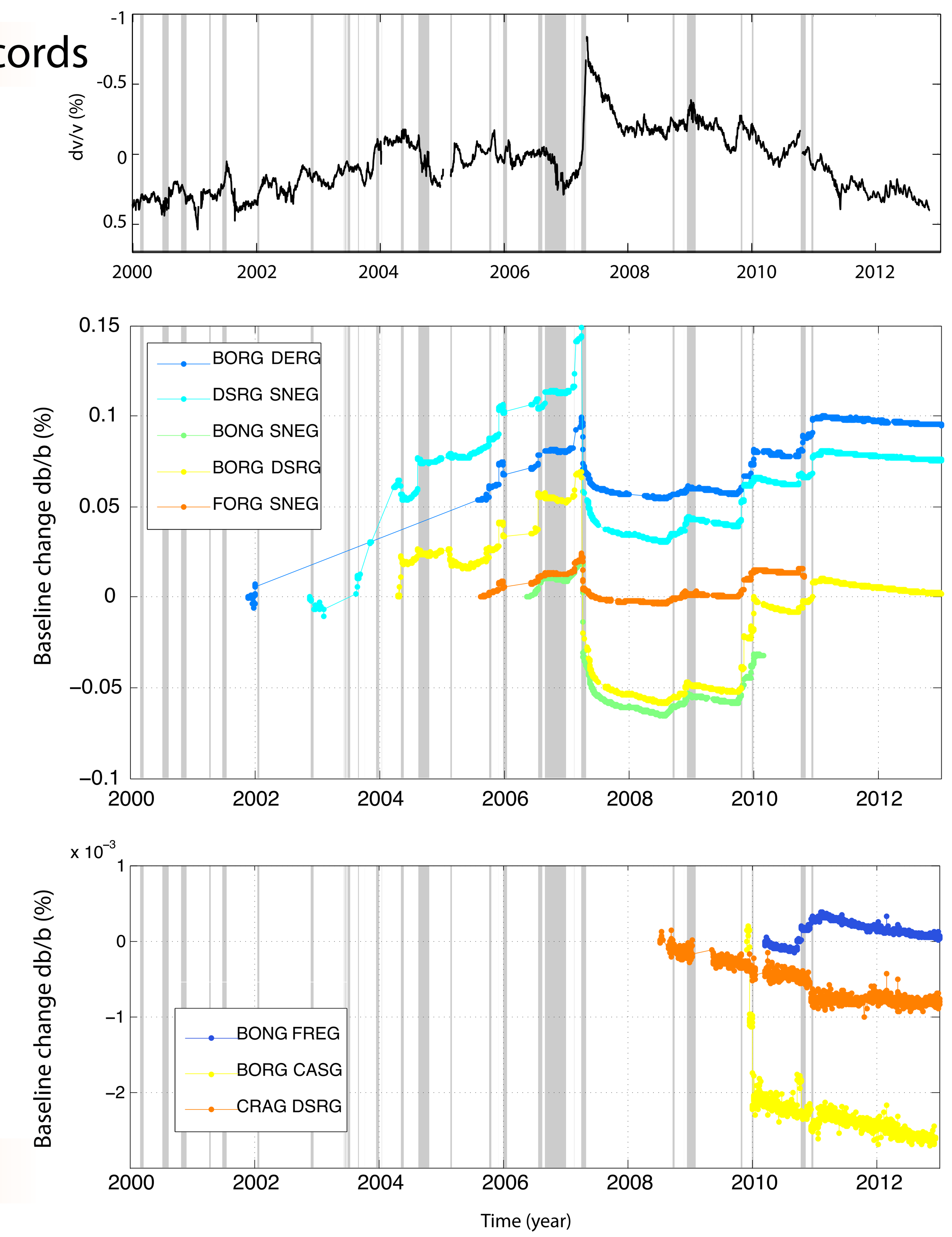


Figure 5 (right). Upper figure, seismic velocity changes from 2000 to 2013 observed in the 0.5 to 4s period band. The gray bands indicate volcanic eruptions. The largest eruption occured in April 2007. Middle figure, baseline change for 5 station pairs around the volcano crater (continuous lines in Figure 4). For each pair the reference baseline *b* is the first measure availlable. Lower figure, same as the middle one but for longer distance between GPS stations pairs (dashed lines in Figure 4).

4 Short term velocity changes and rainfall

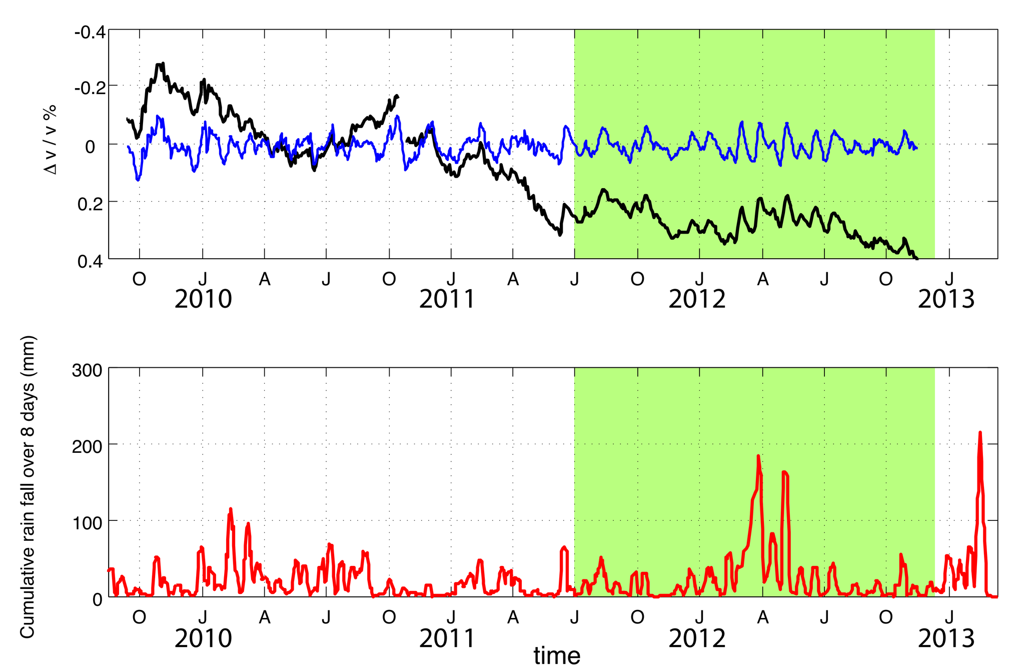


Figure 6. top, velocity changes measured in the 0.5-4 s period band (black line) and the high pass filter to 100 days velocity changes. Below, cumulative rainfalls on a 8-day moving windows.

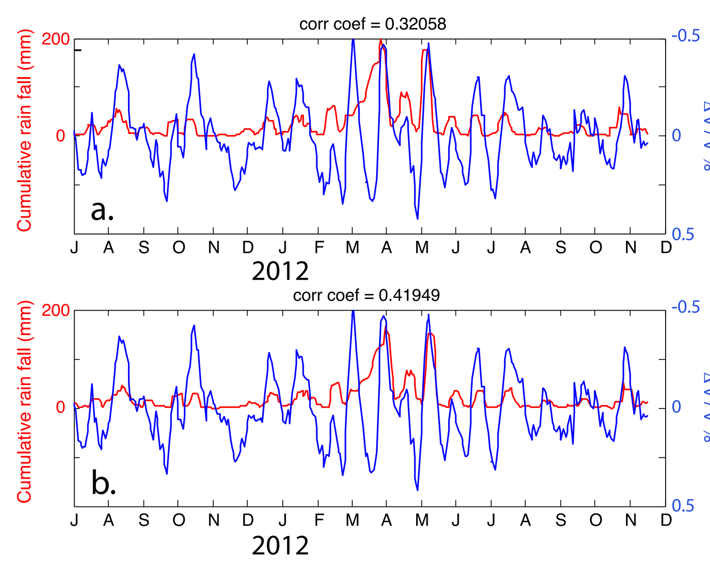
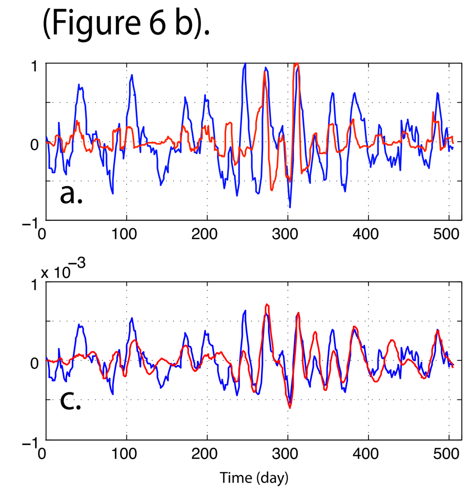


Figure 7. a. high pass velocity changes (blue curve) and 8-day cumulative rainfalls (red curve). b. rainfall variation is shifted of 4 days to maximaze the correlation coefficient. This indicates that there is a delay between rainfalls and velocity changes.

- Since January 2011 no eruption happened. During a quiet period, from july 2011 to december 2012, we investigate the origine of short-term velociy changes. We compare rainfalls with short term velocity changes.
- First we high pass filter the velocity variations to consider only variations shorter than 100 days (Figure 6).
- We observe that rain episodes are almost systematicaly followed by a velocity drop (Figure 7 a).
- We observe a delay of 4 days between the rainfall and velocity changes (Figure 6 b).



- We compute the transfer function between the rainfalls and the velocity changes (Figure 7).

Figure 7. a. 100 days high pass filter of both rainfall (red) and velocity changes (bleu). b. Transfer function from filtered rainfalls (input) to velocity changes (output).

5. Long period velocity changes

- We measure seismic velocity changes at longer period between 4 and 10s (Figure 9). At these periods coda waves sample deepter the crust and allow to observe changes below the volcanic cone.
- The dynamic of the variations are quite different from the one observed at shorter period (Figure 3). Velocity changes are not correlated with volcanic eruptions. The largest velocity drop occured from february to march 2010.

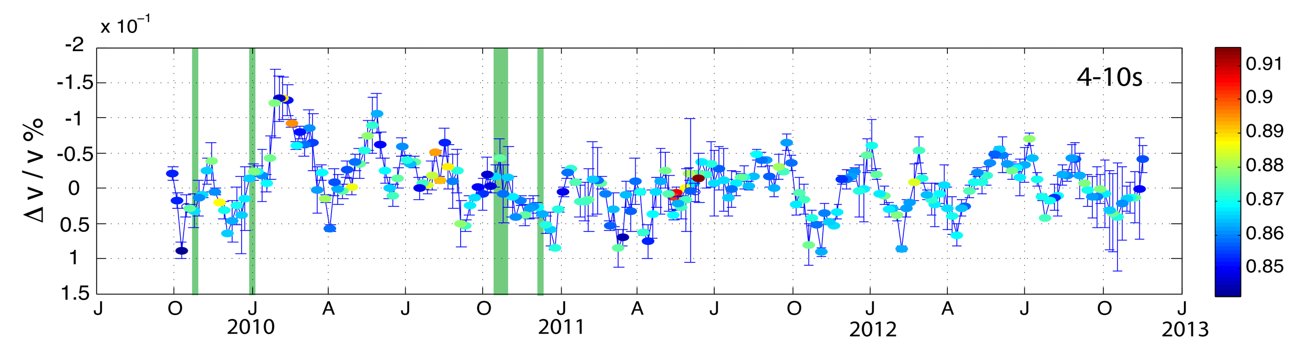


Figure 9. Seismic velocity changes measured in the 4-10s period band. Green bands indicate volcanic eruptions.

Conclusions

- 13 years time serie of seismic velocity changes shows the long term dynamic of the volcano. Both GPS measures and velocity changes indicate a deflation since the end of 2007.
- Short term variations are related to the volcano eruptive activity but also are related to the hydrostatic loading during rail fall.
- Velocity changes at longer period are sensitive to deeper variations of the elastic properties. This meseasure should be performed during the «active» period of the volcano to extract valuable information on the magma chamber.

Clarke. , D. The measurement of temporal seismic velocity variations on Piton de la Fournaise volcano, La Réunion, from cross-correlations of ambient seismic noise. PhD thesis, IPGP, 2011.

Brenguier, F. , N. M. Shapiro, M. Campillo, V. Ferrazzini, Z. Duputel, O. Coutant, and A. Nercessian. Towards forecasting volcanic eruptions using seismic noise. Nature Geoscience, 1(2) :126–130, 2008b.

Brenguier, F., Kowalski, P., Staudacher, T., et al. First Results from the UnderVolc High Resolution Seismic and GPS Network Deployed on Piton de la Fournaise Volcano. Seismological Research Letters 83: 97-102, 2012

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