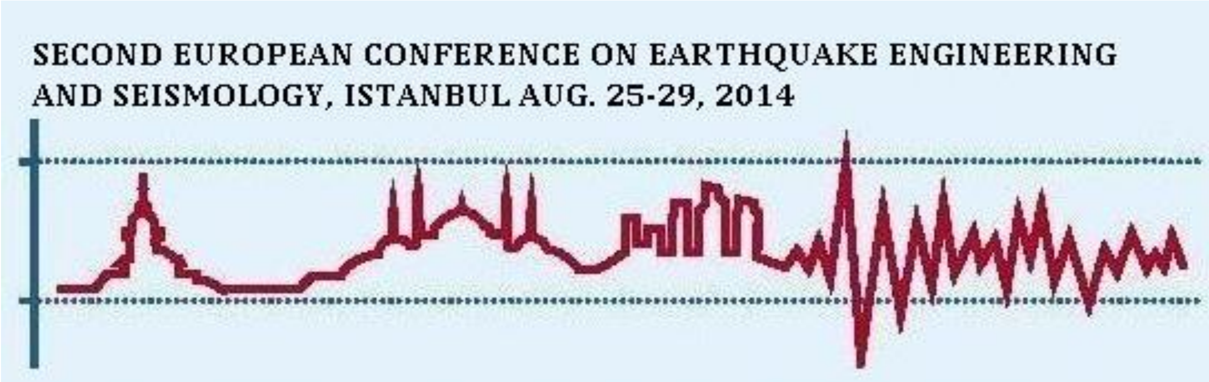

Seismic noise correlations to image changes in heterogeneous structures: Applications to volcano and fault zone monitoring

Anne OBERMANN[1], Thomas PLANES[2], Bérénice FROMENT[3], Eric LAROSE[4] and Michel CAMPILLO[5]

As seismic waves can penetrate to great depth, time-lapse seismic imaging (4D) provides a promising way to measure changes deep in the crust. General approaches of monitoring temporal changes include measuring changes in the travel time of direct P- and S-waves, and detecting changes in the coda waves (e.g. coda wave interferometry). To look for such changes, usually a highly repetitive source is required to minimize artifacts arising from changes in source location and mechanism. Repeating earthquakes and controlled sources are the most used sources so far in 4D studies. For monitoring purposes, however, repeating earthquakes are difficult to use because of the uncontrollable timing of the earthquakes and the uncertainty in source location. Controlled sources are probably the best way, but the high operating costs make it hard to use them routinely. Recent developments of new imaging techniques with ambient noise provide new possibilities for seismic monitoring. It has been shown that the cross-correlation function of a pair of recordings can be used to retrieve the Green's function between two receivers, as if one of the receivers behaves like an impulsive source (Weaver and Lobkis 2001). Campillo and Paul (2003) and Shapiro and Campillo (2004) showed that coherent surface waves can be extracted from earthquake coda waves and ambient noise correlations, opening the way to numerous applications in seismology. Since then, surface waves from ambient seismic noise correlations are widely used for high resolution imaging of the Earth's lithosphere (Ritzwoller et al. (2011) assort publications in this domain from all around the globe). However, surface waves are not sufficient to explore the deep structure of the Earth as they have limited depth resolution. Roux et al. (2005) have shown that P waves are also contained in the noise correlations and that they can be extracted at local scale and global scale (e.g. Ruigrok et al. 2011, Poli et al. 2012, Boué et al. 2013). In the last years, the feasibility to use noise cross-correlations to monitor continuous changes in medium properties within volcanoes and active fault zones was demonstrated (e.g. Sens-Schönfelder and Wegler (2006), Brenguier et al. 2008a,b).

The next challenge besides the monitoring is to assess the spatial repartition of the changes. Interestingly, the variation of the coda waveform depends on the position of the change relative to the sensors as well as on the time in the coda (Obermann et al. 2013a). We developed a novel inversion procedure (Planès et al. 2013), based on probabilistic approaches, to locate the medium changes in space with a high spatial resolution. The applications to volcano monitoring have shown that the location of future eruptions at Piton de la Fournaise volcano could be forecasted (Obermann et al. 2013b), as shown in Fig.1 for the 2010 October and December eruptions.
In a different application, profiting from the frequency dependent depth penetration of surface waves, stress changes due to the large Wenchuan earthquake could be observed below the epicenter (Obermann et al. 2014). In Fig 2. we show inversion results at different frequencies and dates.

[1] Dr., SED/ETH, Zurich, Switzerland, anne.obermann@sed.ethz.ch
[2] Dr., Colorado School of Mines, Golden, USA, planest@mines.edu
[3] Dr., MIT, Boston, USA, fromentb@mit.edu
[4] Dr., ISTerre, Grenoble, France, eric.larose@ujf-grenoble.fr
[5] Prof. Dr., ISTerre, Grenoble, France, michel.campillo@ujf-grenoble.fr

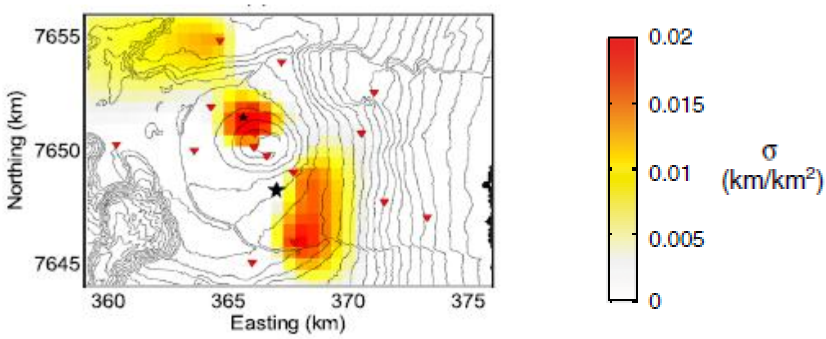

Fig 1: Scattering cross-section density map of Piton de la Fournaise volcano, La Réunion Island, indicating the structural changes (large sigma value) that occurred due to the 2010 October eruption (large star) and the 2010 December eruption (small star). For the inversion data from 15 broadband stations were used (red triangles) (Obermann et al. 2014).

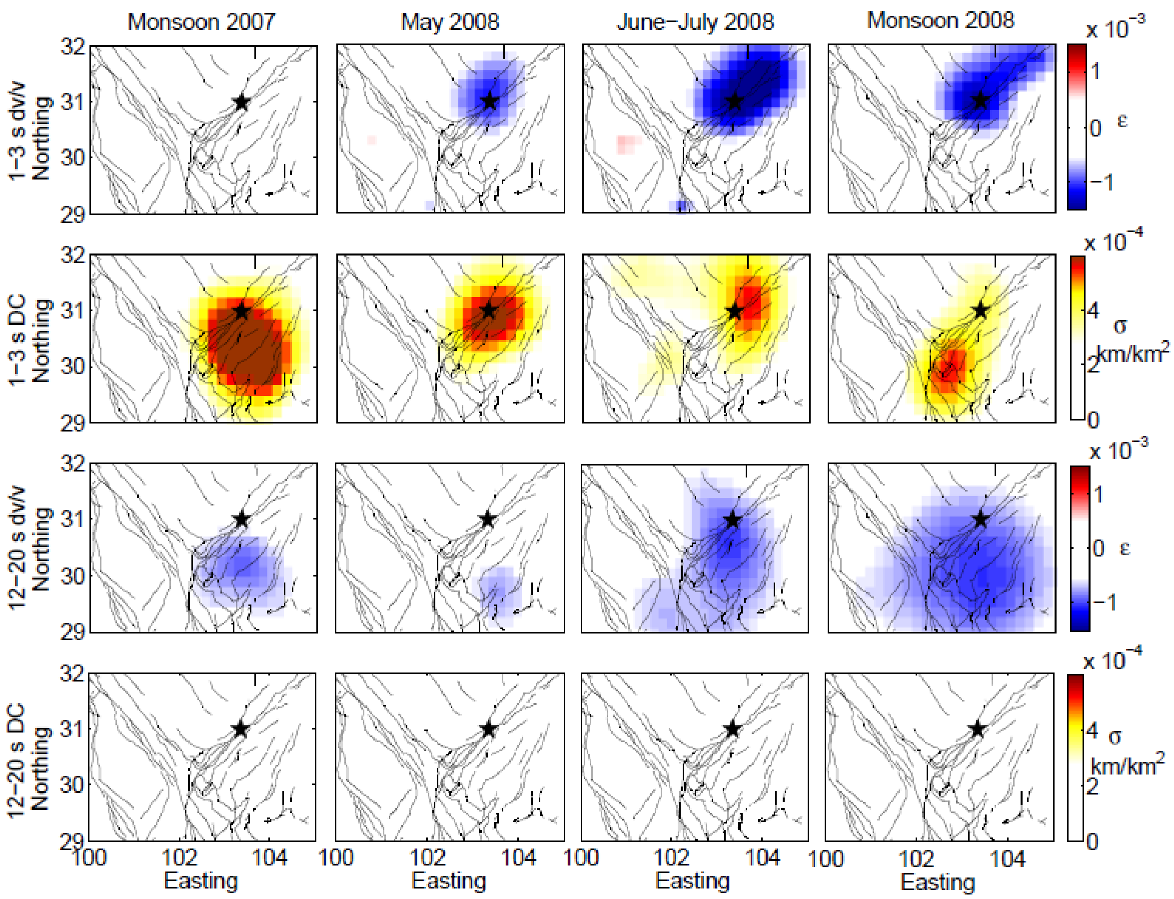

Fig 2.: Least squares inversion of the relative velocity changes (epsilon) and the decoherence values (DC) in the 1-3 s and in the 12-20 s period band. In the columns we show the results for the monsoon period in Aug-Sept 2007, the Mw 7.9 Wenchuan earthquake in May 2008, the aftershock period (June-July 2008) and the monsoon period in Aug-Sept. 2008 (Obermann et al. 2014).

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