May subsidence rate serve as proxy for site effects?

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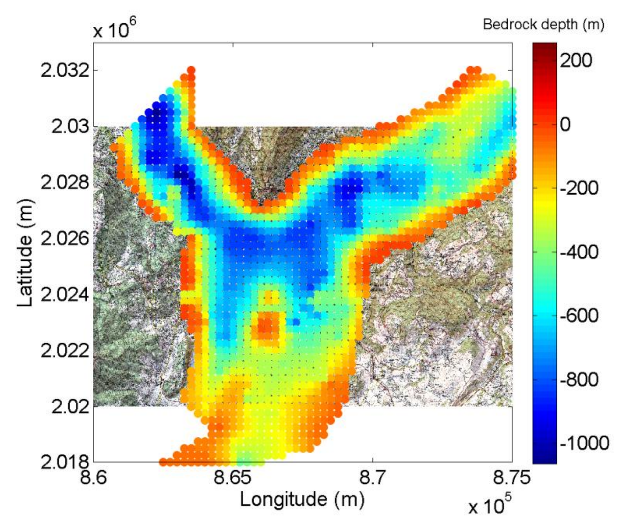
Introduction

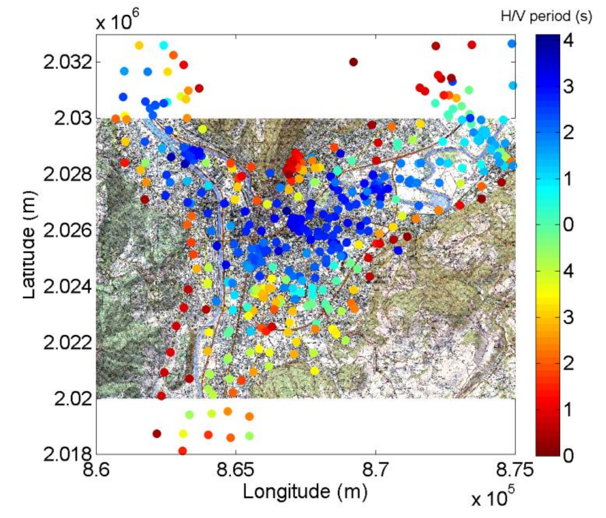
There is a growing interest to incorporate site effects in seismic hazard estimates (e.g. shaking maps, earthquake scenario, insurance models). The current practice is to use for site classification the average shear-wave velocity in the upper 30 meters (Vs30). Since site conditions are usually not known with the appropriate spatial coverage, a growing attention is paid to proxies. Recently, Wald and Allen (2007) proposed to use as a proxy for Vs30 the surface topography: a large slope is related to rock or stiff soil, while a small slope testify of soft soils. Cadet et al. (2008) proposed the use of resonance frequencies with or without information on the shallow shear-wave velocity as an alternative for site classification. Recent studies have shown the ability of InSAR Permanent Scatterer approach to densely map present-day ground motion in urban area with a millimetric precision for relative average annual displacement rate. Except anthropogenic causes (pumping, underground infrastructure), the long-term subsidence is caused by compaction of sediments due to increasing overburden. Since both resonance periods and subsidence rate increase with thickness and softness of soil, both data should be correlated. We test this simple idea on Grenoble city which is located in a valley filled with thick late quaternary deposits and for which all necessary data are available: SAR images, resonance frequencies, bedrock depth, shear-wave velocities, geotechnical and geological drillings, levelling data.

Data

Bedrock map



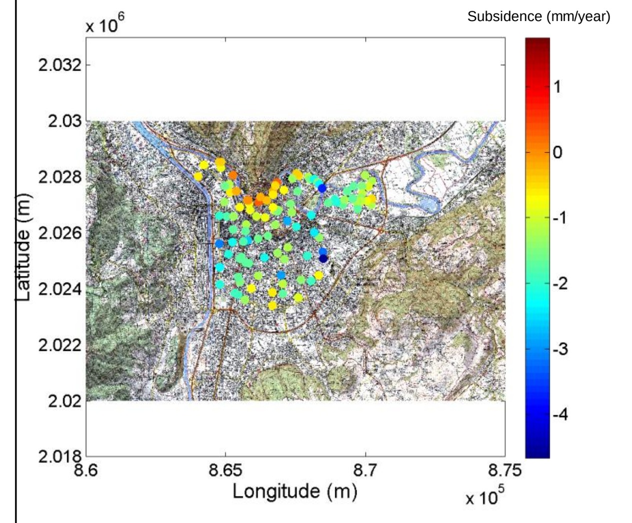
H/V peak periods



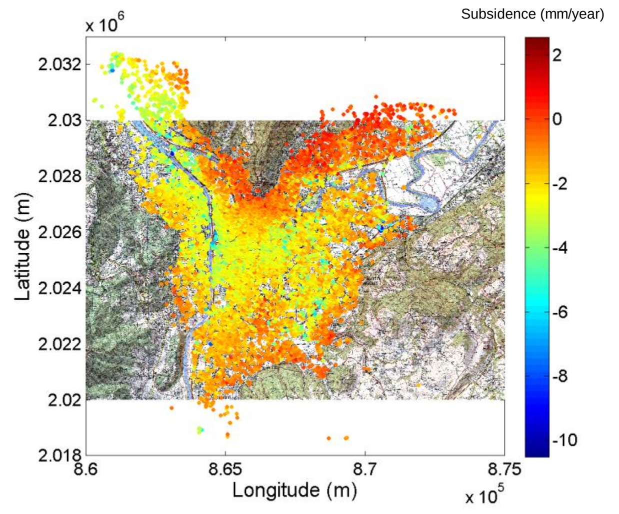
Sediment-to-bedrock depth map was obtained from the analysis of 419 gravimetric measurements performed in Grenoble area (Vallon, 1999).

H/V peak periods was obtained from the analysis of 579 ambient noise measurements acquired over the last 15 years through different ambient noise and seismological campaigns, by using velocimeters (Lennartz 5s, CMG40) and accelerometers amplified at low frequencies (Lebrun et al., 2001; Hobiger, 2006; Guéguen et al., 2007; Cornou et al, 2009).

Subsidence rate from levelling data



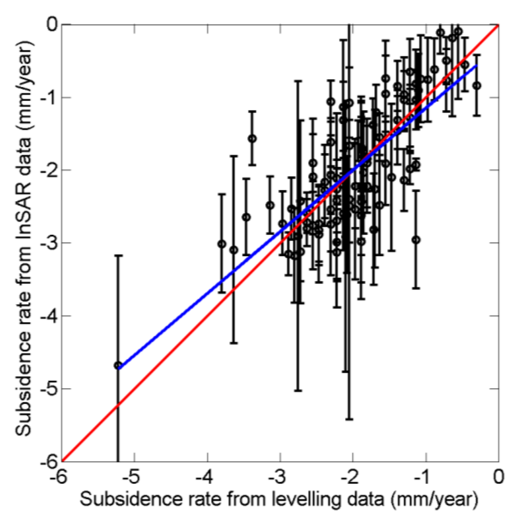
Subsidence rate from InSAR measurements



Subsidence rates from leveling data were obtained at 112 measurement sites. The reference site is located near the Bastille site.

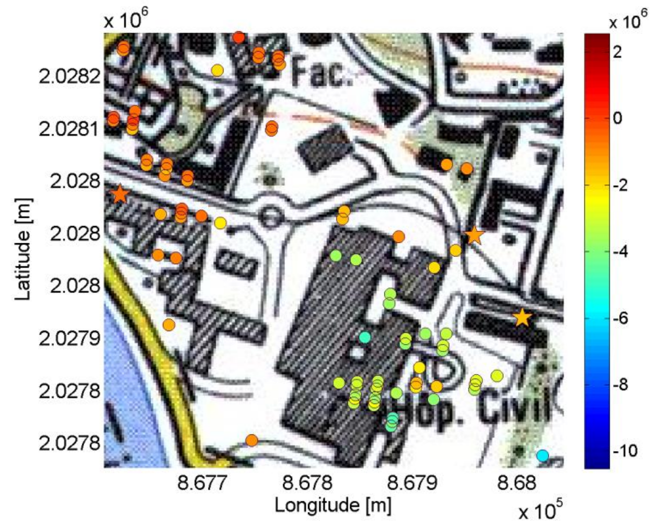
Subsidence rates from InSAR mesurements were estimated from the analysis of SAR images of the satellites ERS-1 and ERS-2 acquired in between 1992 and 2000. These data were processed by using the Permanent Scatterer approach (Colesanti, 2003) with a reference site located near the Bastille site and provided 19101 estimates of average vertical displacement with a precision of about 0.5 mm/year on average.

Comparison between InSAR and nivelling data

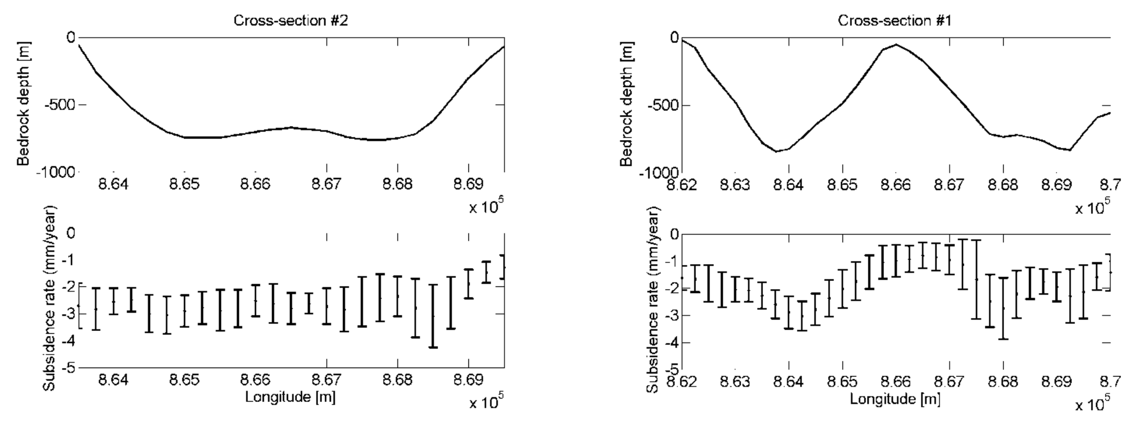


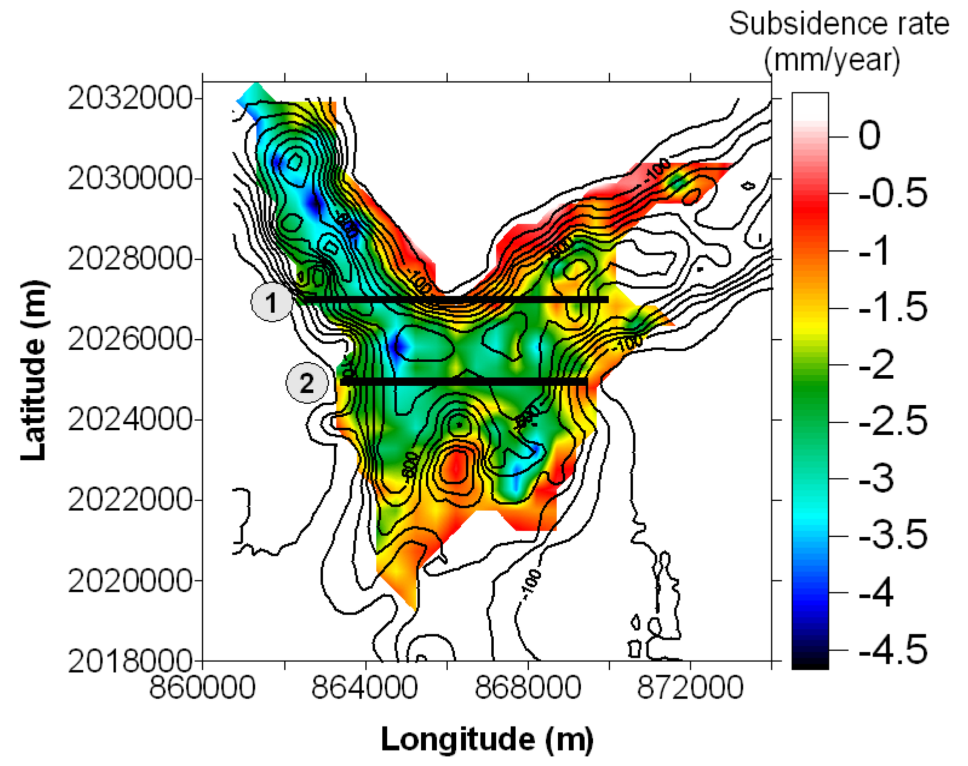
Comparison between subsidence rate derived from levelling and InSAR data is performed by averaging InSAR subsidence estimates in 200 m grid cells centred at levelling sites. Such size cells allow to account for most of the levelling data (100 over a total of 112 measurements) and a sufficient number of InSAR estimates (>5).

Comparison shows that vertical displacements are - at first order - similar (figure on the left: the red curve stands for the 1:1 correlation while the blue curve indicates the regression curve). The large dispersion of InSAR estimates within cells is mainly caused by very local subsidence due to large size buildings (figure on the right: squares and stars stand for InSAR and levelling estimates, respectively) or local road infrastructures.



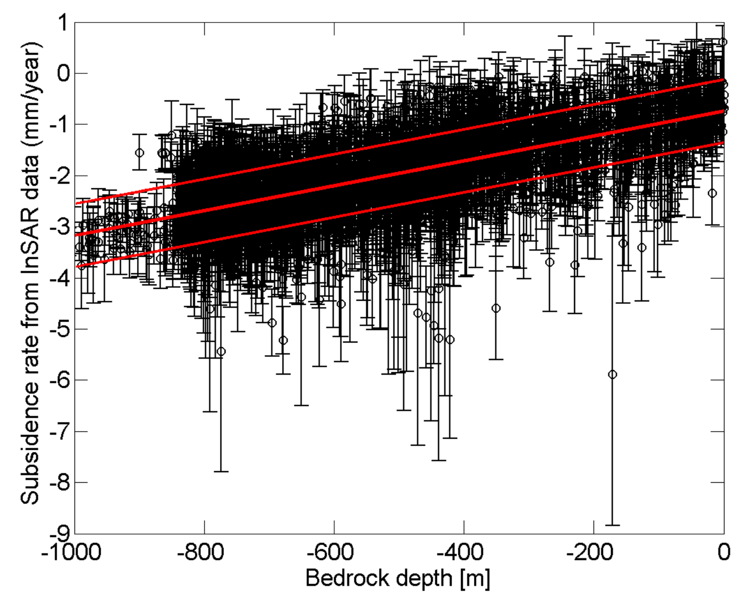
Comparison between InSAR and bedrock depth



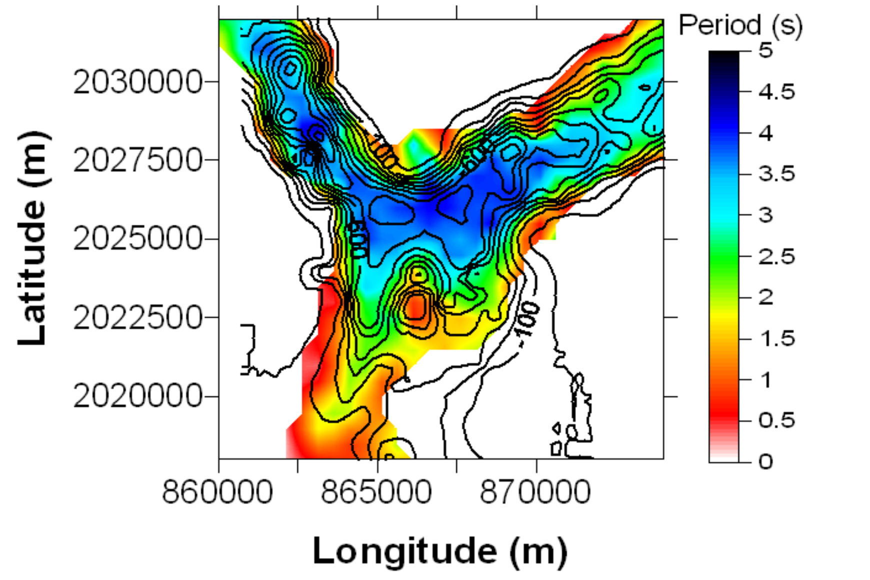


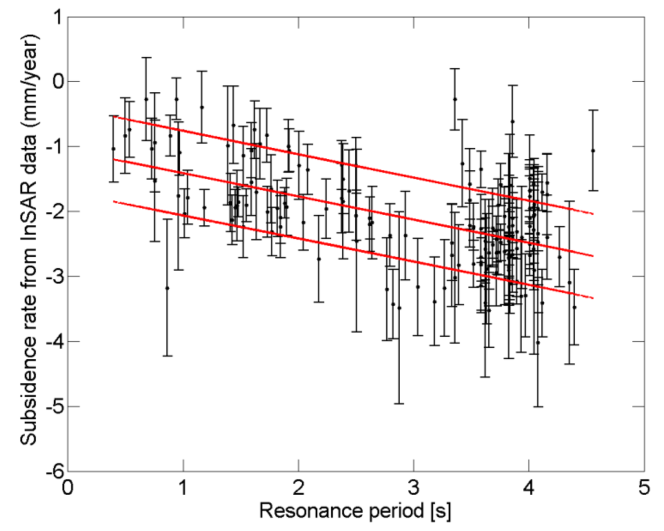
Bottom left figure displays a 500 m grid map of InSAR subsidence rates overlaid by the iso-contour lines of bedrock depth (in meters) while upper left figures show cross-sections of bedrock depth and subsidence rate:: higher is the bedrock depth, higher is the subsidence rate.

Subsidence rates averaged over 200 m grid cells as a function of bedrock depth exhibit a linear correlation (figure below, the red lines indicate the mean regression curve +/- standard deviation) .



Comparison between InSAR and HV



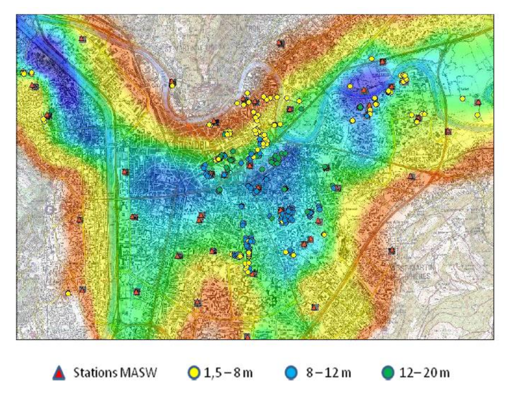


Left figure displays a 500 m grid map of H/V resonance periods overlaid by the iso-contour lines of bedrock depth (in meters) while right figure shows InSAR subsidence rates averaged over 200 m grid cells centred at the H/V site location. At first order, subsidence rate d is linearly correlated with the resonance period (T) through the following regression law :d (mm/an) = -0.36 T (s) -1

Conclusion

Results show that subsidence rates, ranging from 0 to -6 mm/year, are - at first order - linearly correlated with the resonance periods and the bedrock depth.

Given that no correlation was observed between subsidence rate and geology of surface layers (Tsuno et al., 2010) and the absence of large tectonic movements, it is very likely that the subsidence is mainly caused by compaction of the entire sedimentary column due to overloading of natural and anthropogenic origins (Prokopovich, 1986; Stramondo et al., 2008). This interpretation is supported by the spatial depth variation of the surficial fine-to-coarse deposits interface (Tsuno et al, 2010) that is similar to the spatial bedrock depth variation (left figure).



Fine-to-coarse material depth interface (Yellow: 1.5 to 8m, Blue: 8 to 12 m, green: 12 to 20 m) and map the bedrock depth (red: -100 m, blue: -1000 m).

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