Supporting Information for "Hydrological effects on seismic-noise monitoring in karstic media"

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Contents of this file

Dataset S1

In this work we make use of 10 short- and broadband seismic stations from the Northeast Italy Seismic Network (OGS, 2016; Bragato et al., 2021) with the exception of the station ED06, which is part of the Collalto Seismic Network (OGS, 2012). During the first half of the measurement period five stations were running in triggering mode, thus half of the stations do not hold continuous recording before 2015. This limitation leads us to work with two datasets (as shown in Fig.1):

1. The 8-year dataset consists of 5 stations and comprises the complete recording time series 2011-2018. This dataset is used for estimating the complete time series of the seismic-velocity perturbations at network scale and analyze its depth sensitivity.

2. The 4-year dataset includes all 10 stations and its recording duration spans from 2015 to 2018. This dataset is employed to locate the lateral distribution of the seismic-velocity perturbations.

Processing S2

In both datasets we analyze the three components of the ambient-noise recordings. Data processing includes decimation from multiple sampling rates down to 5 Hz, and frequency filtering on the oceanic-microseism frequency band ($[0.1 - 1]$ Hz). Possible large seismic signals produced by local and regional seismicity are minimized with the use of spectral whitening and one-bit normalization on our frequency band of interest (Brenguier et al., 2008). We compute cross-correlations of the ambient-noise recordings between all station pairs on a basis of 1 hour-long windows with 30 minute overlap in order to improve the signal-to-noise ratio (Brenguier et al., 2014).

In order to study the time evolution of the relative-seismic-velocity perturbation we apply moving-window cross-spectral analysis (Poupinet et al., 1984; Clarke et al., 2011) to the ambient-noise cross-correlation codas. This technique requires a reference correlation gather, obtained by stacking all ambient-noise cross-correlations over the complete recording period (lapse time), and a monitor correlation-gather for every day by making stacks of limited duration. In order to identify an optimal duration for accurate monitoring of our datasets, we estimate the correlation coefficients between the reference correlation gather and multiple monitor gathers of different stack lengths. With this information we carry out a trade-off analysis between lapse-time resolution and stability in the seismic-signal reconstruction, and base our choice on the trend break of the correlation coefficients with respect to the multiple stack lengths: 30-day length appeared to be the optimal stack duration for our monitor correlation-gather. We use the surface-wave signal retrieved in the reference correlation gather to identify the different ballistic arrival-time between the respective station-pair locations. This arrival time allows us to distinguish the early spurious arrivals from the late physical arrivals (coda wavefield) of the reconstructed surface-wave signal. The coda wavefield is the basis of this monitoring analysis: it is caused by the scattering properties of the medium and is the part of the wavefield most sensitive to changes in the scattering medium (Snieder et al., 2008).

We select the first 56 s of scattering coda starting after the estimated ballistic arrival-time. We employ 6 s time windows with a 2 s shift (4 s overlap between consecutive windows), and measure time shifts and coherency coefficients. The coda-window relative time shift ${}^{\delta t}/{}_{t}$ is measured by linear robust regression of the time shifts δt from each window and from all station pairs jointly. Window sections with time-shift values larger than 0.5 s and/or coherency coefficients smaller than 0.5 are neglected during the regression. In order to estimate the relative seismic-velocity variation (${}^{\delta v}/{}_{v}$) at network scale, we assume the perturbation to be homogeneous throughout the study area; this leads to the linear relation with the relative time shifts: ${}^{\delta v}/{}_{v} = {}^{-\delta t}/{}_{t}$ (Poupinet et al., 1984).

The 30-day stack length required to produce stable correlated-coda results induces a lag in the lapse time of the $^{\delta v}/_{v}$ result. The same analysis with different stack-lengths shows that this lag is half the stack length (in the case of the result in Fig.2c, 15 days).

References

Bragato, P. L., Comelli, P., Saraò, A., Zuliani, D., Moratto, L., Poggi, V., ... Parolai, S. (2021, 03). The OGS–Northeastern Italy Seismic and Deformation Network: Current status and outlook. *Seismological Research Letters*, *XX*, 1-13. doi: 10.1785/0220200372

Brenguier, F., Campillo, M., Hadziioannou, C., Shapiro, N., Nadeau, R., & Larose, E. (2008). Postseismic relaxation along the San Andreas Fault at Parkfield from continuous seismological observations. *Science*, *321*(5895), 1478–1481. doi: 10.1126/science.1160943

Brenguier, F., Campillo, M., Takeda, T., Aoki, Y., Shapiro, N., Briand, X., ... Miyake, H. (2014). Mapping pressurized volcanic fluids from induced crustal seismic velocity drops. *Science*, *345*(6192), 80–82. doi: 10.1126/science.1254073

Clarke, D., Zaccarelli, L., Shapiro, N., & Brenguier, F. (2011). Assessment of resolution and accuracy of the moving window cross spectral technique for monitoring crustal temporal variations using ambient seismic noise. *Geophysical Journal International*, *186*(2), 867–882. doi: 10.1111/j.1365-246X.2011.05074.x

OGS. (2012). *Collalto Seismic Network - Rete Sismica di Collalto.* International Federation of Digital Seismograph Networks. Retrieved from `http://www.fdsn.org/doi/10.7914/SN/EV` doi: 10.7914/SN/EV

OGS. (2016). *Northeast Italy Seismic Network.* International Federation of Digital Seismograph Networks. Retrieved from `http://www.fdsn.org/doi/10.7914/SN/OX` doi: 10.7914/SN/OX

Poupinet, G., Ellsworth, W., & Frechet, J. (1984). Monitoring velocity variations in the crust using earthquake doublets: An application to the Calaveras Fault, California. *Journal of Geophysical Research: Solid Earth*, *89*(B7), 5719–5731. doi: 10.1029/JB089iB07p05719

Snieder, R., Van Wijk, K., Haney, M., & Calvert, R. (2008). Cancellation of spurious arrivals in Green's function extraction and the generalized optical theorem. *Physical Review E*, *78*(3), 036606. doi: 10.1103/PhysRevE.78.036606