Department of Meteorology and Geophysics

Sub-daily seismic velocity changes as indicator for large vulnerable groundwater reservoirs

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Motivation and Research Context

As the number of droughts rise as a consequence of the climate change and **demands for water grow** due to population and industrial growth, the need for a broadly available and easily accessible water resources increases (Medal, 2018). **Shallow groundwater aquifers** fulfill this imperative need but their characteristics also impose concerns about potential pollution and contamination. Therefore a better **understanding of the vulnerability** of this water resource is necessary (Jang et al., 2017).

In this study we systematically investigate the **sub-daily** behavior of **seismic velocity changes** induced by fluctuations in air pressure. This analysis provides valuable insights into the interaction and connectivity of aquifers with the surface, allowing us to infer groundwater vulnerability.

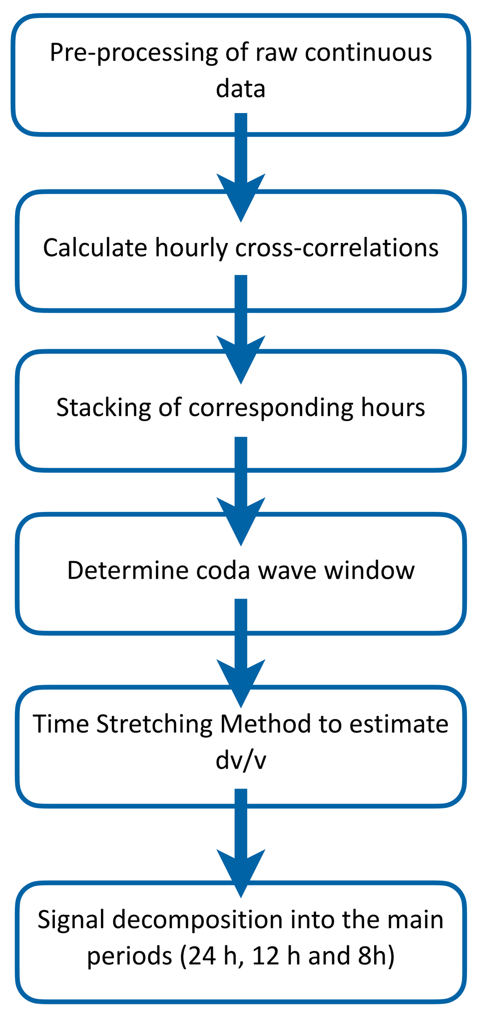
Hourly monitoring of dv/v using regional seismic networks

Goal: Inferring spatial variability of the semi-daily component of seismic velocity changes.

Challenge: Obtaining stable cross-correlations over long inter-station distances while being able to monitor daily and sub-daily behaviors of dv/v.

Solution: Stacking of the cross- correlations of corresponding hours (**Fig. 2**), assuming that the air pressure signal is stable and exhibits the same routine changes as the seismic velocity changes. This leads to 24 individual cross-correlations representing the average behavior of the particular hours. These served as basis for the measurement of the seismic velocity changes.

Data Processing Workflow:



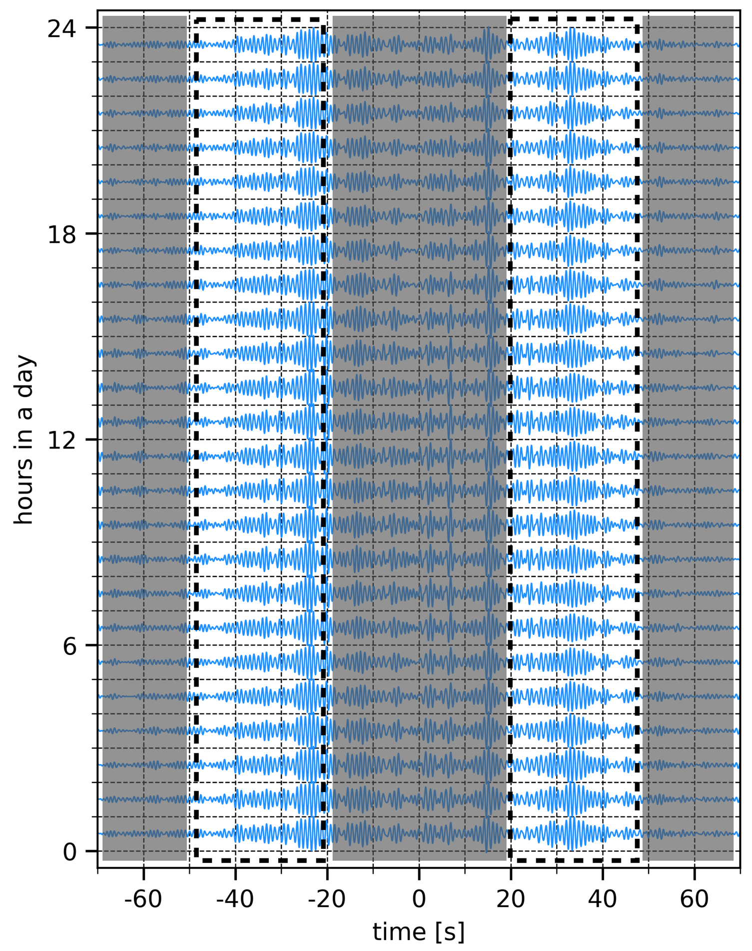


Fig. 2 Stacked cross-correlation for every hour for a station pair in northern Italy. Each trace represents the stack of all corresponding hour within the time period. The highlighted part represent the coda wave window.

Inferring daily and sub-daily dv/v

To analyze the dominant periodic behavior, we **decompose** the measured **seismic velocity changes** into multiple sinusoidal functions representing daily and sub-daily cycles.

While **S1** could have **multiple origins** (variation in the thermoelastic strain or thermal-induced self-noise) the **S2** is caused by changes in the **air pressure,** as other periodic environmental cycles cannot explain the observations.

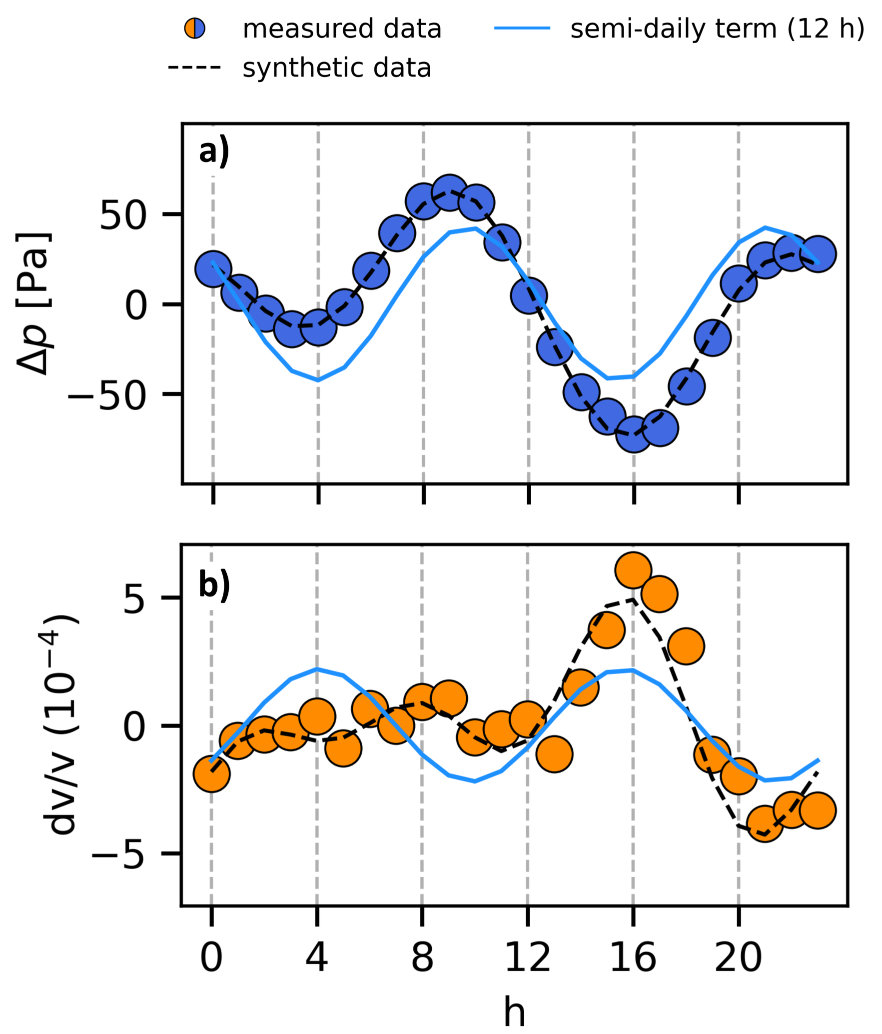


Fig. 2 Periodic patterns of a) air pressure, and b) seismic velocity changes (averaged over the study area in South and Central Europe). The dashed black line indicates the synthetic data from fitting sinusoidal functions using 24-hour, 12-hour and 8-hours periods. The blue line represents the fitted semi-daily component.

Periodic seismic velocity changes induced by routine air pressure variations indicating shallow aquifer connectivity and vulnerability

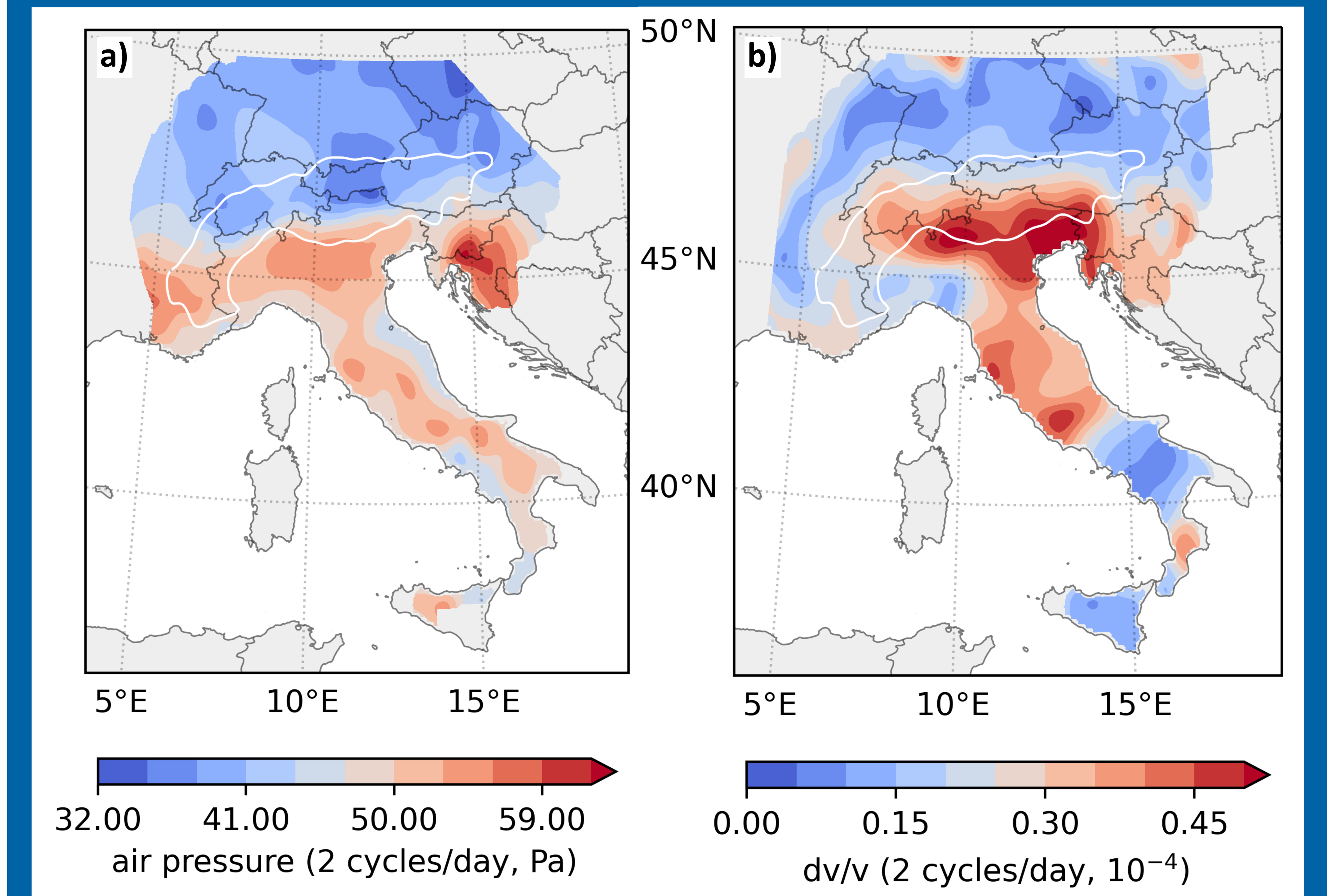


Fig. 1 Spatial distribution of the semi-diurnal amplitude of a) air pressure and b) seismic velocity change averaged over four years from 2016-2019. The white shape outline the Alpine Mountains. (Note: The amplitude of air pressure is de-meaned and does not represent the absolute value.)

Mechanism behind the dv/v change

The effect behind the velocity change is connected to an interplay between compressible air trapped within the capillary fringe (zone above the water table, where water is held due to capillary forces) and fluctuations in air pressure (Turk, 1975). The actual velocity change happens due to changes in water content (saturation) in this zone. The effect is displayed in **Fig. 4** and **Fig. 5.**

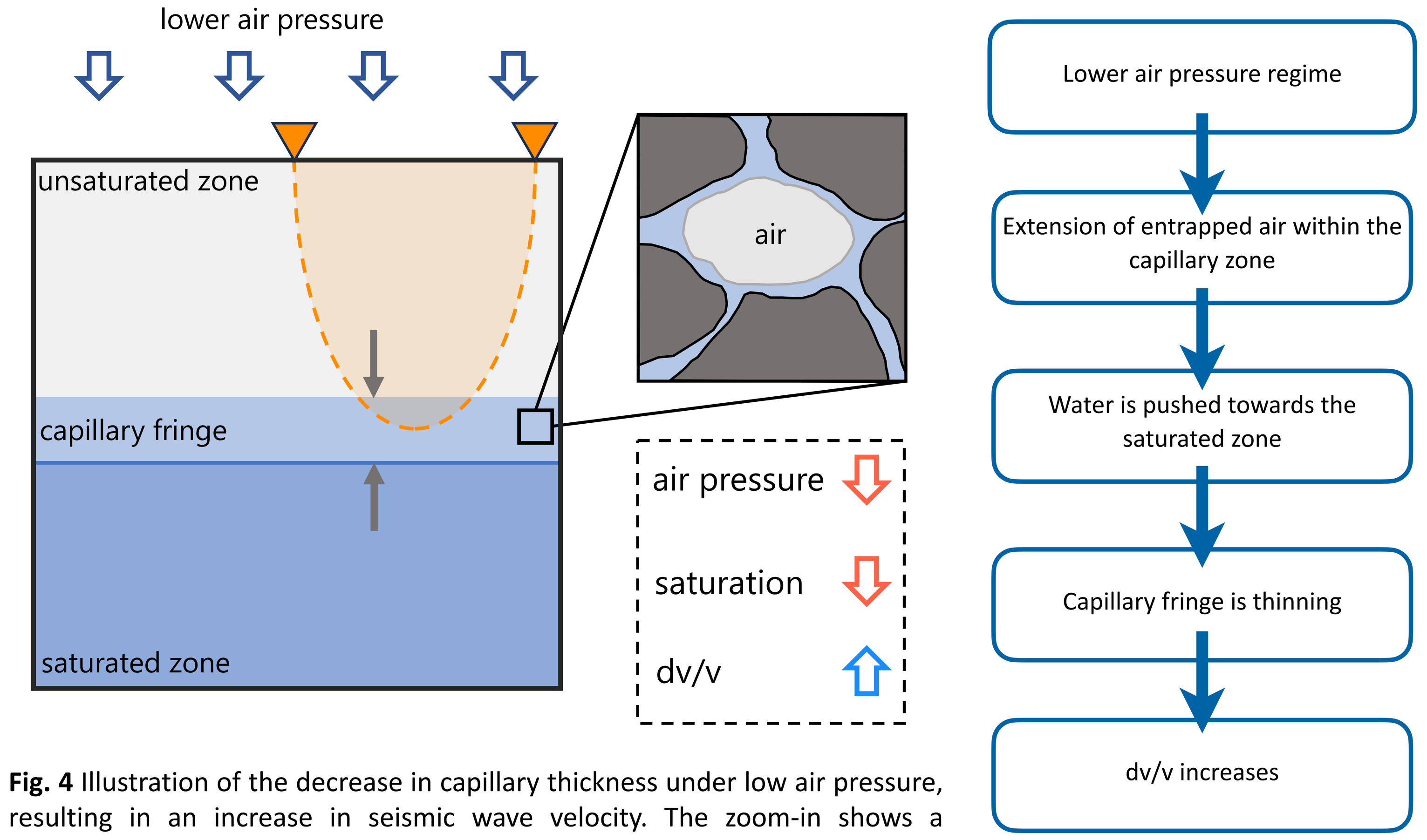


Fig. 4 Illustration of the decrease in capillary thickness under low air pressure, resulting in an increase in seismic wave velocity. The zoom-in shows a representation of entrapped air in a low pressure regime (modified after Fabbri et al. 2019). The orange shaded area is a simplistic represent the parts sampled by the waves.

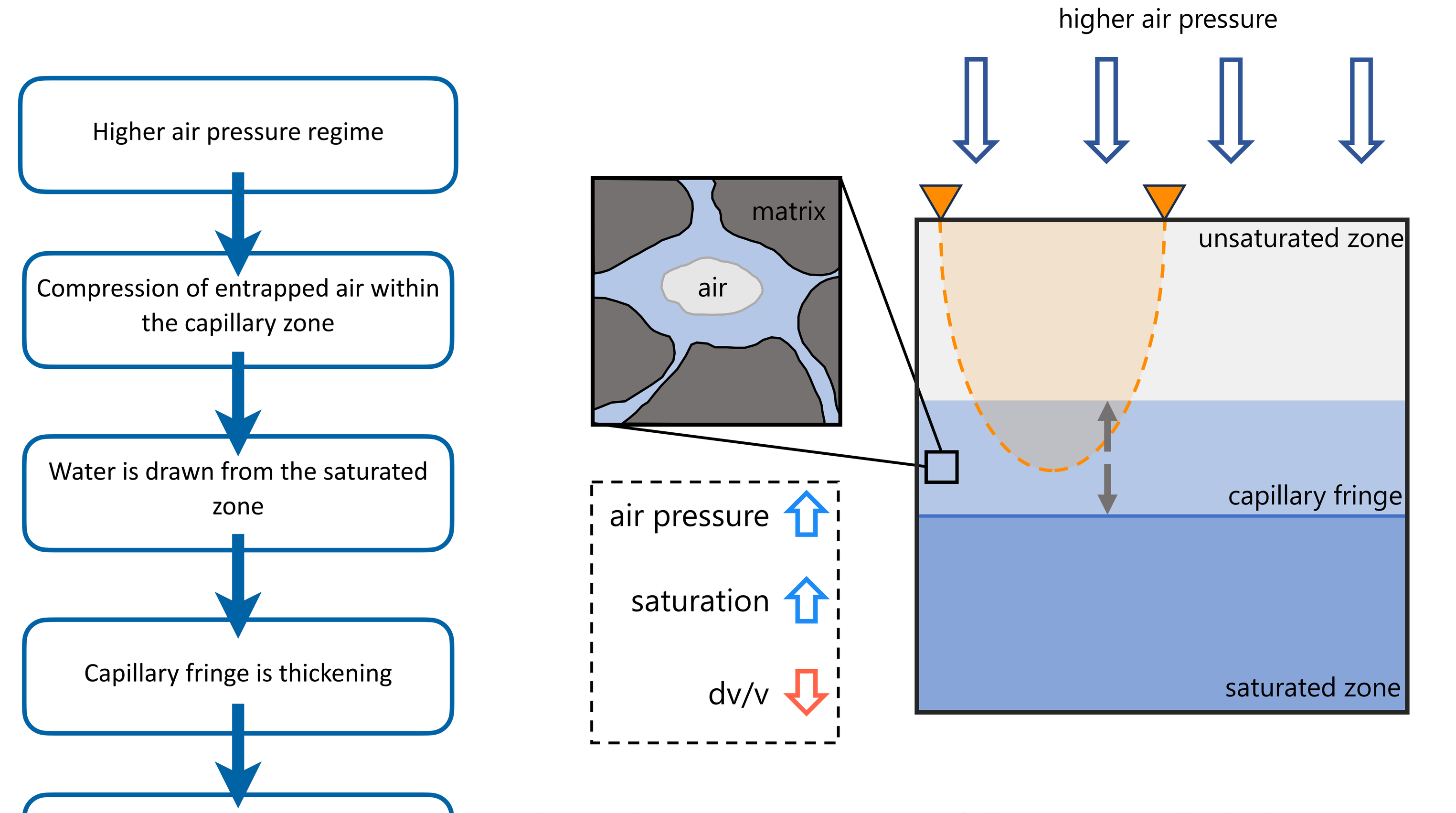


Fig. 5 Schematic representation of the process under high air pressure, where the capillary fringe becomes thicker with a lowered water table. The entrapped air (zoom-in) is compressed freeing up space for water (modified after Fabbri et al. 2019). The orange shaded area is a simplistic represent the parts sampled by the waves.

Take home messages

(1) Inferring daily and sub-daily trends in seismic velocity is feasible by adapting the classical coda-wave interferometry approach.
(2) Using regional seismic network can significantly improve our understanding of the near surface zone, in particular changes related to vulnerability of shallow water reservoirs.
(3) More local investigations, serving as calibrations, could lead to a set of complementary methods to point-wise hydrological borehole measurements broaden the understanding of water resources.

References

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