



15th Munich Earth Skience School
ObsPy goes Downtown: Seismology in Cities

City Seismology

Heiner Igel



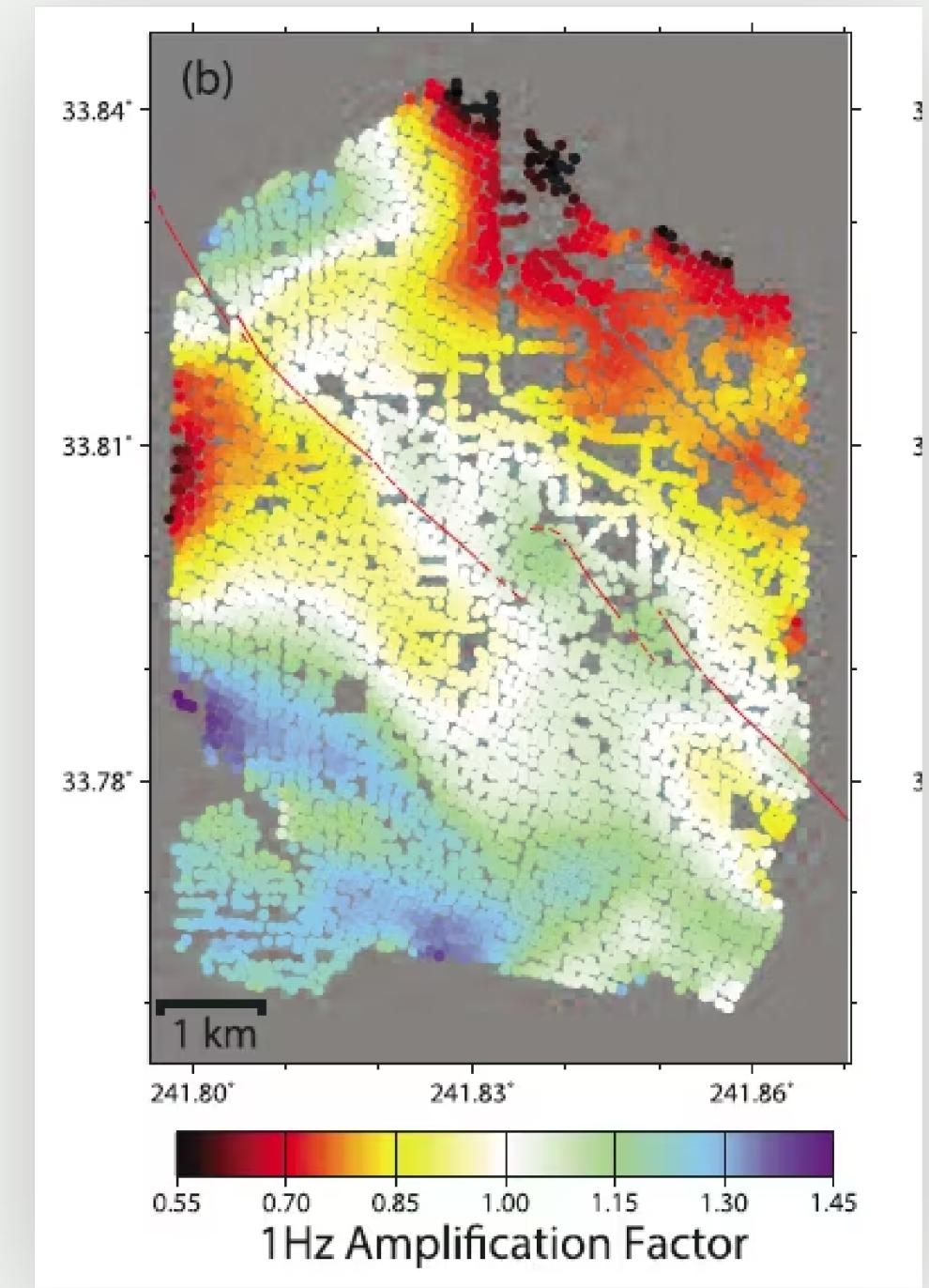
24 February 2025



Why?

Cities were **avoided** because of the high anthropogenic noise level, but

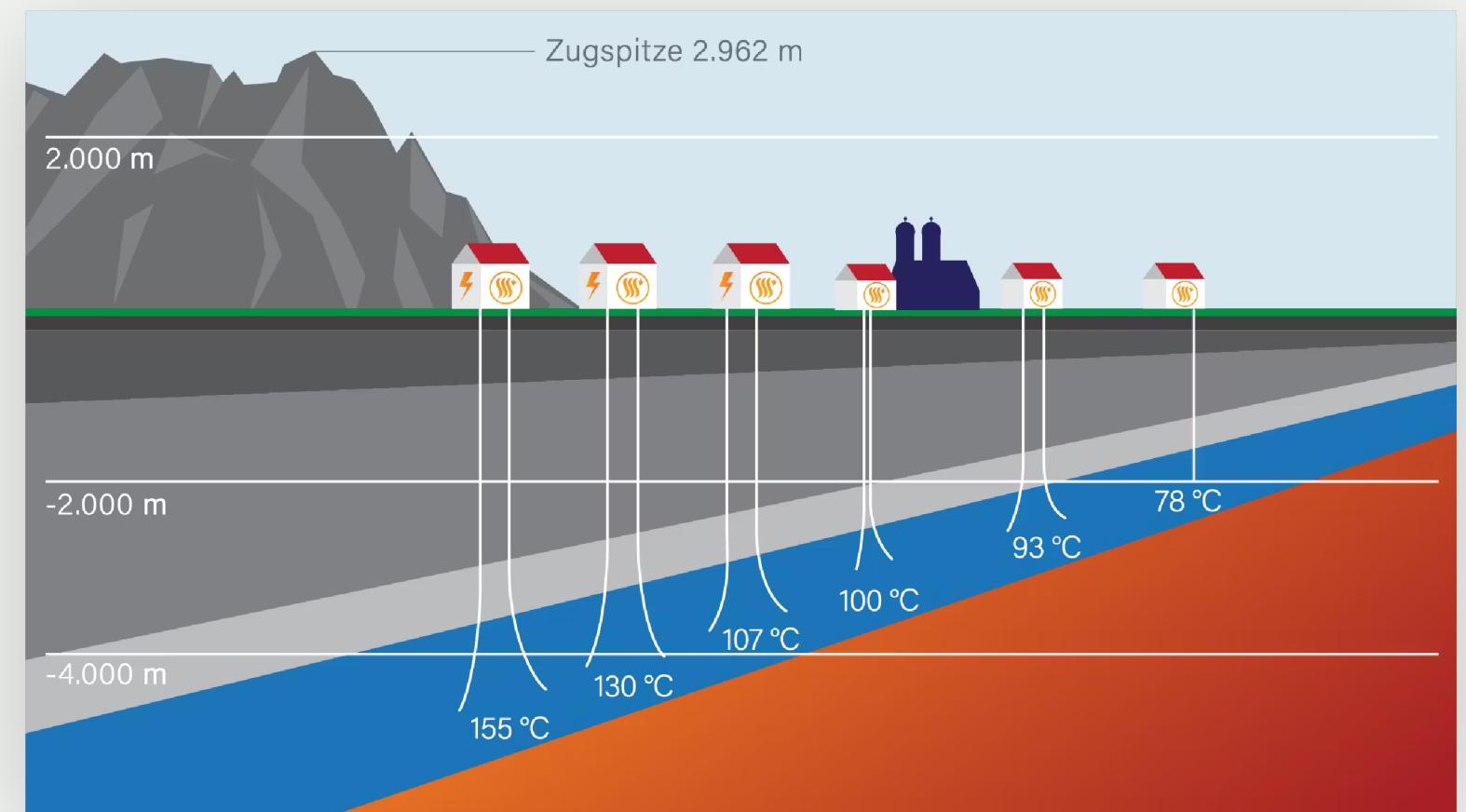
- Seismologists have learned to use **noise** as signal
- Elastic waves are great to **image** the subsurface
- Detailed knowledge of the **near surface structure** under cities is useful for many things (e.g. shaking hazard, soil-structure interaction)
- Velocity changes may help understanding **hydrological** processes
- Seismic **noise sources** may be well known, even continuous, which helps in using noise-based techniques
- May help understanding **climate-city-subsurface-societal interactions**



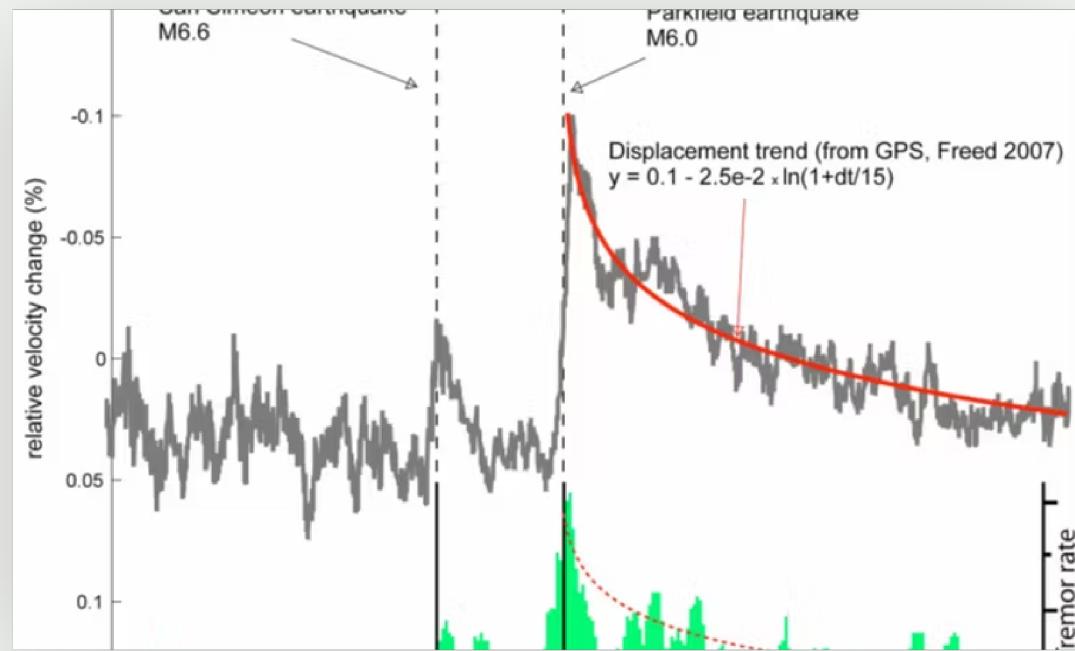
Bowden et al 2015

City Seismology

- **Anthropogenic Noise:** Vibrations from traffic, construction, industrial activities, and other human-related sources
- **Seismicity:** Even within urban areas, natural or induced seismic events occur, and their signals can be obscured or altered by the surrounding infrastructure.
- **Urban Infrastructure Response:** Studying how buildings, bridges, and other structures respond to both natural and man-made ground motion.
- **Dense Sensor Networks:** Deploying a network of seismometers throughout a city helps researchers capture high-resolution data, enabling them to distinguish between different signal sources.



The **methods** that make it possible



Interferometry ...

... enable us to extract tiny subsurface velocity changes ...

Lectures Mon



Distributed Acoustic Sensing

Strange data, but such a great spatial resolution, fibres everywhere!

Lectures Tue

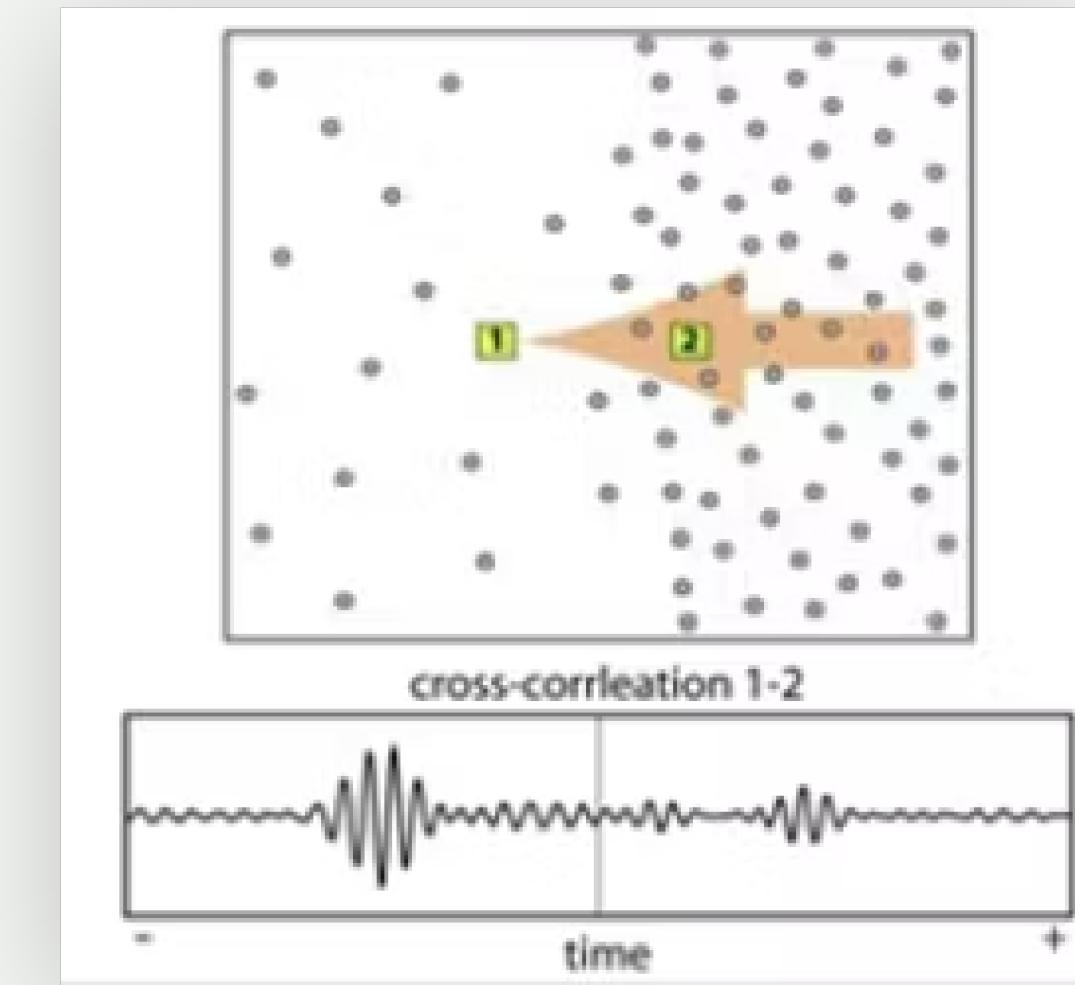
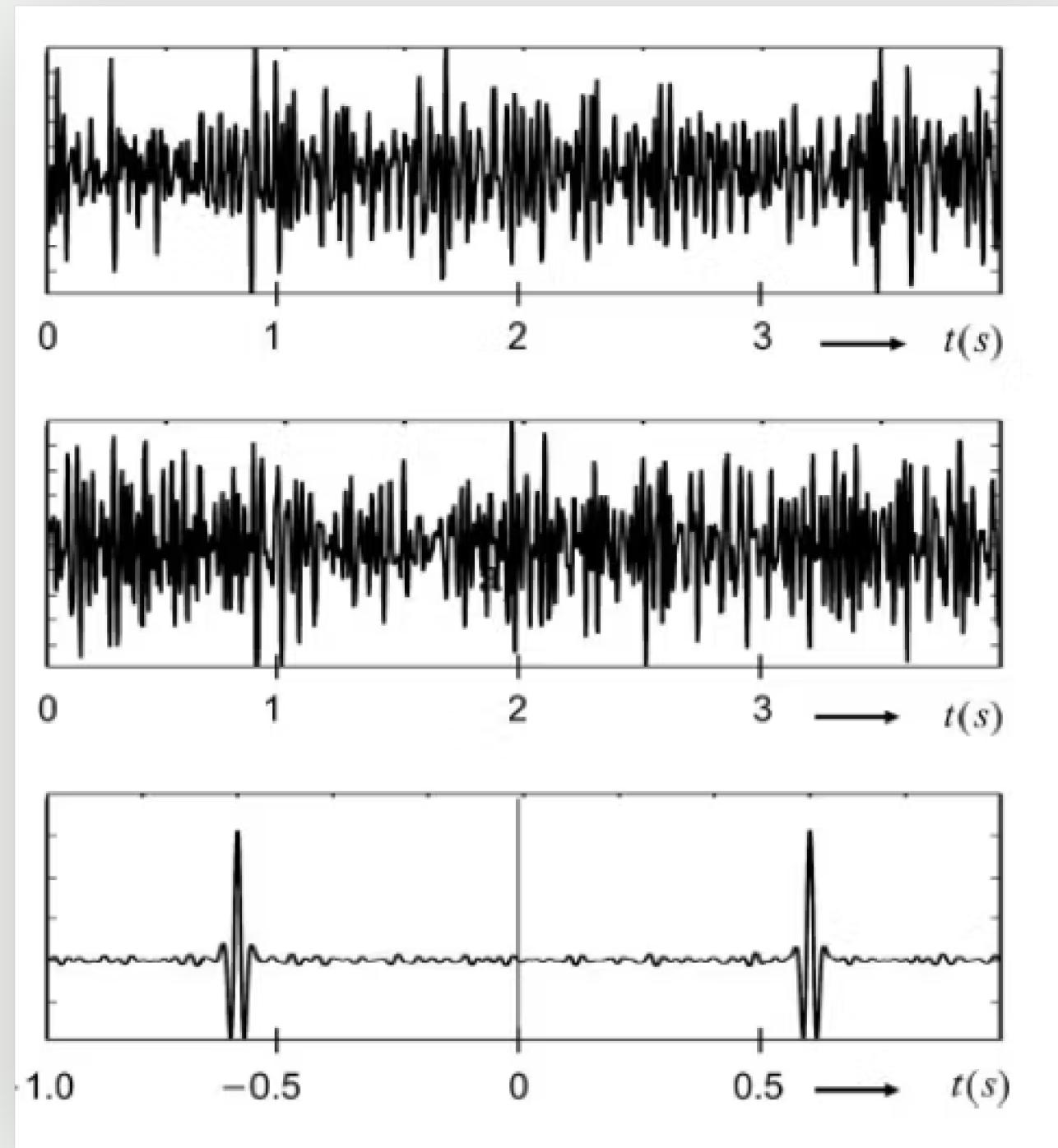


Multi-component seismology

Cool things to do when using a 6 DoF sensor like a seismic array

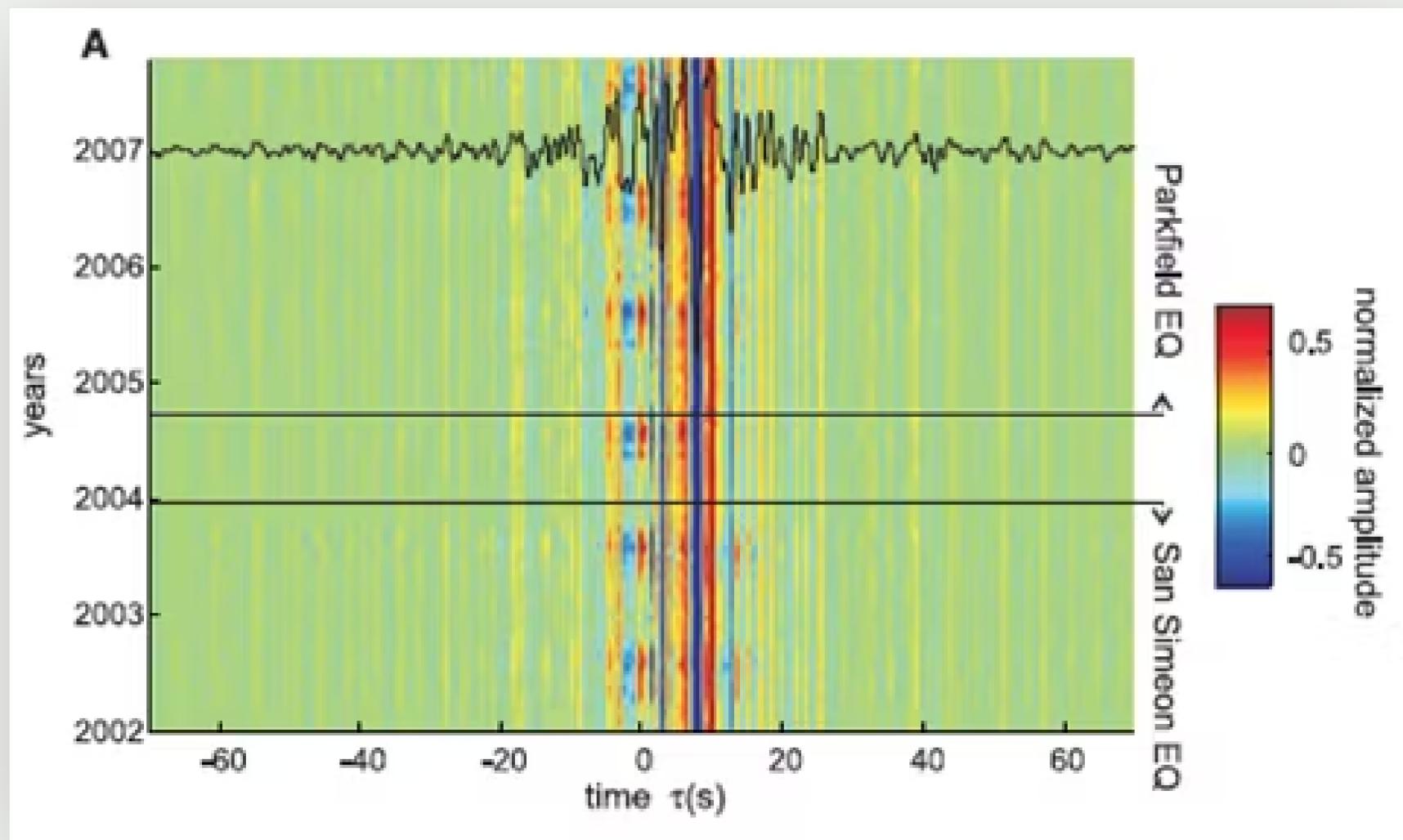
Lectures Tue and Thu

Interferometry

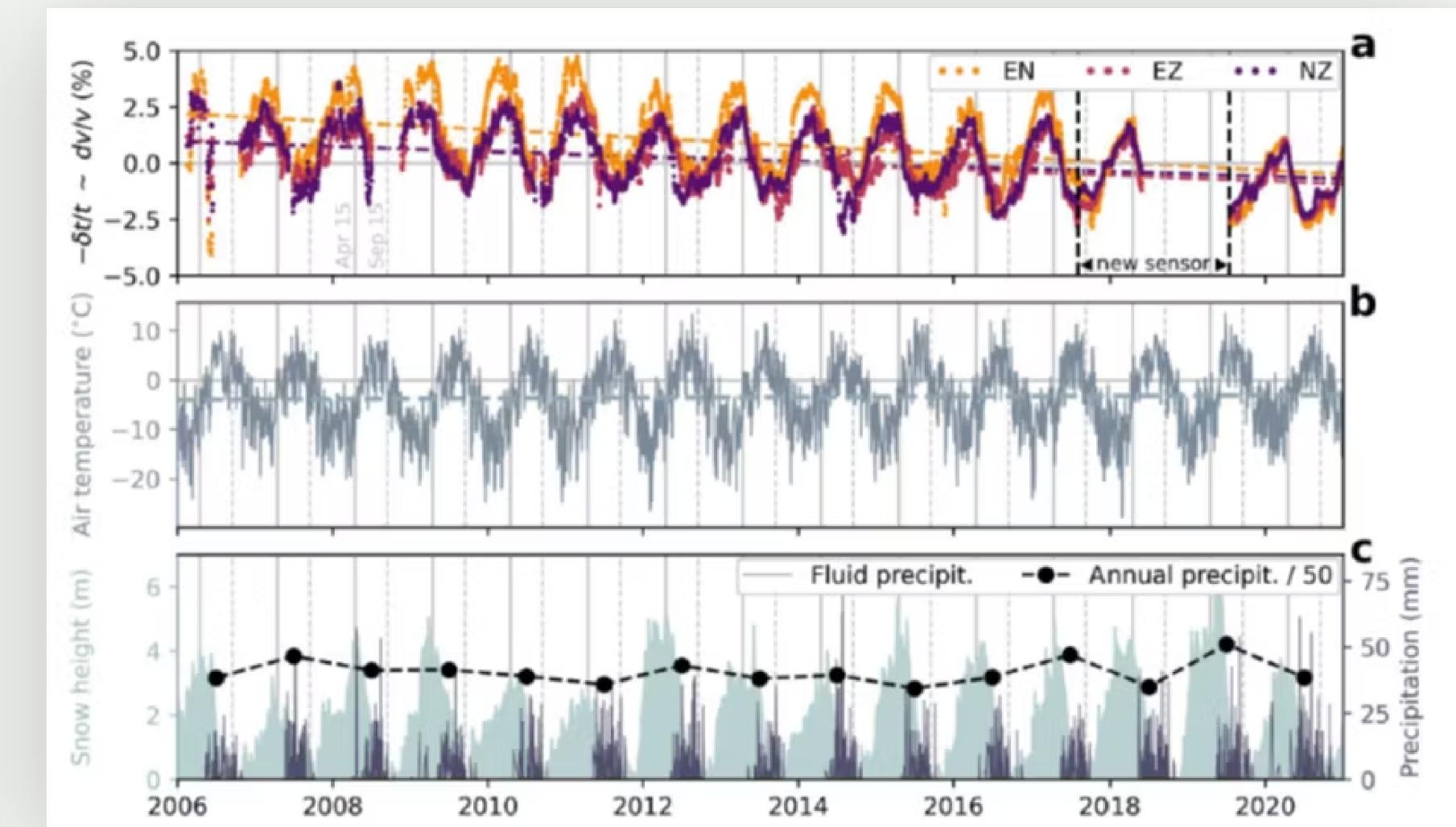


Wapenaar et al. 2010

Interferometry



Brenguier et al. 2008



Lindner et al. 2022

Distributed Acoustic Sensing

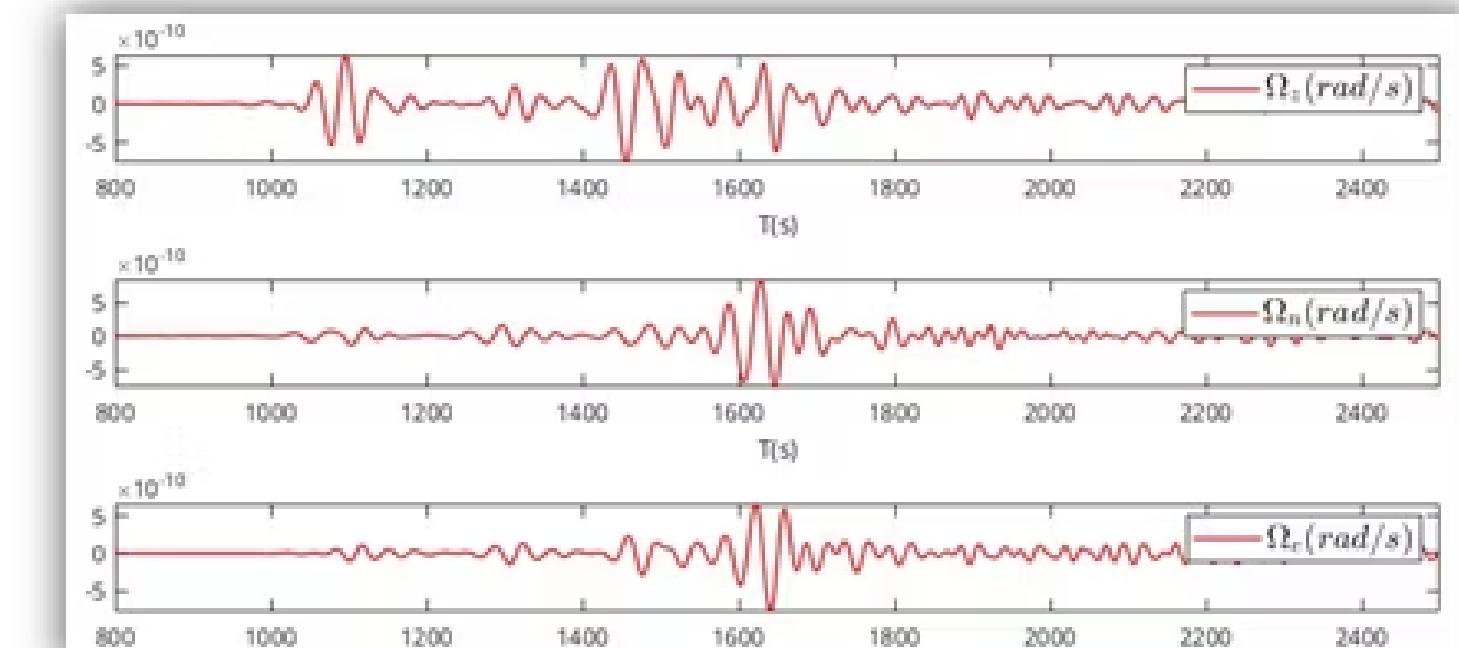
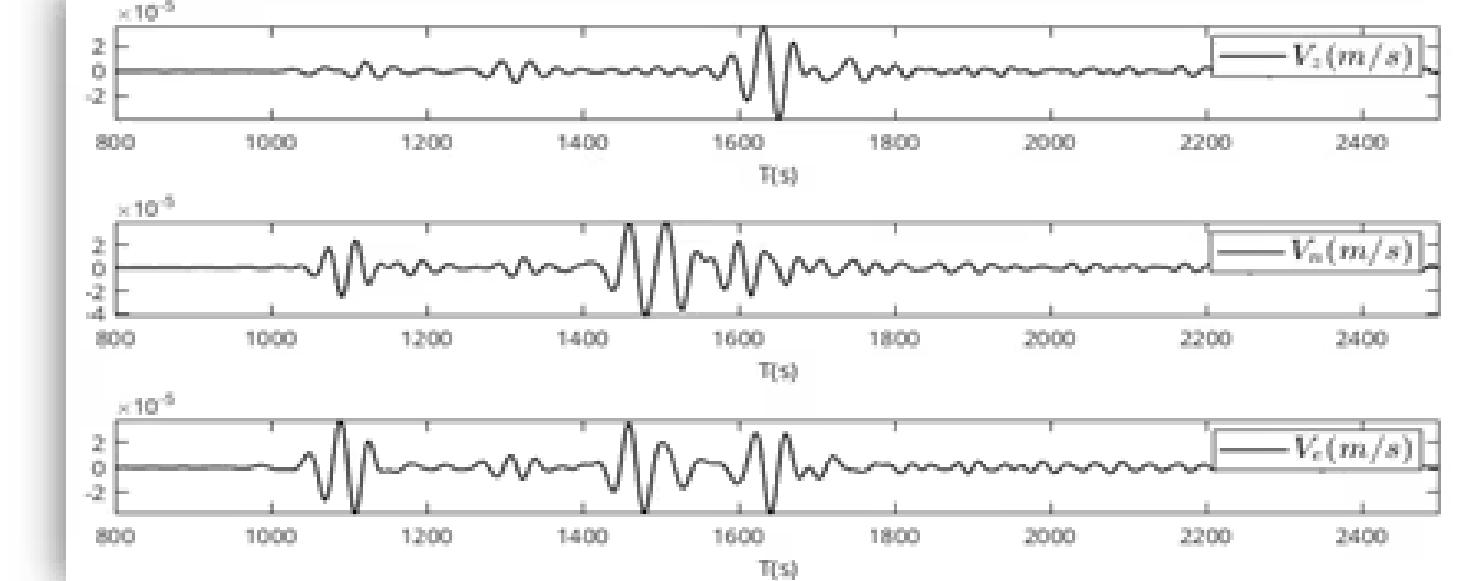


- Use **existing fibres** (lots)
- Difficult to precisely locate fibres in cities
- Uncertain **coupling**, errors in amplitude
- Single **scalar** component (longitudinal strain)
- Good for **phase** information (interferometry)
- (Surprisingly) high **sensitivity**
- Lots of data
- Requires **interrogator**
- Interrogators getting cheaper
- Is the **hype** justified?

6 DoF Seismology

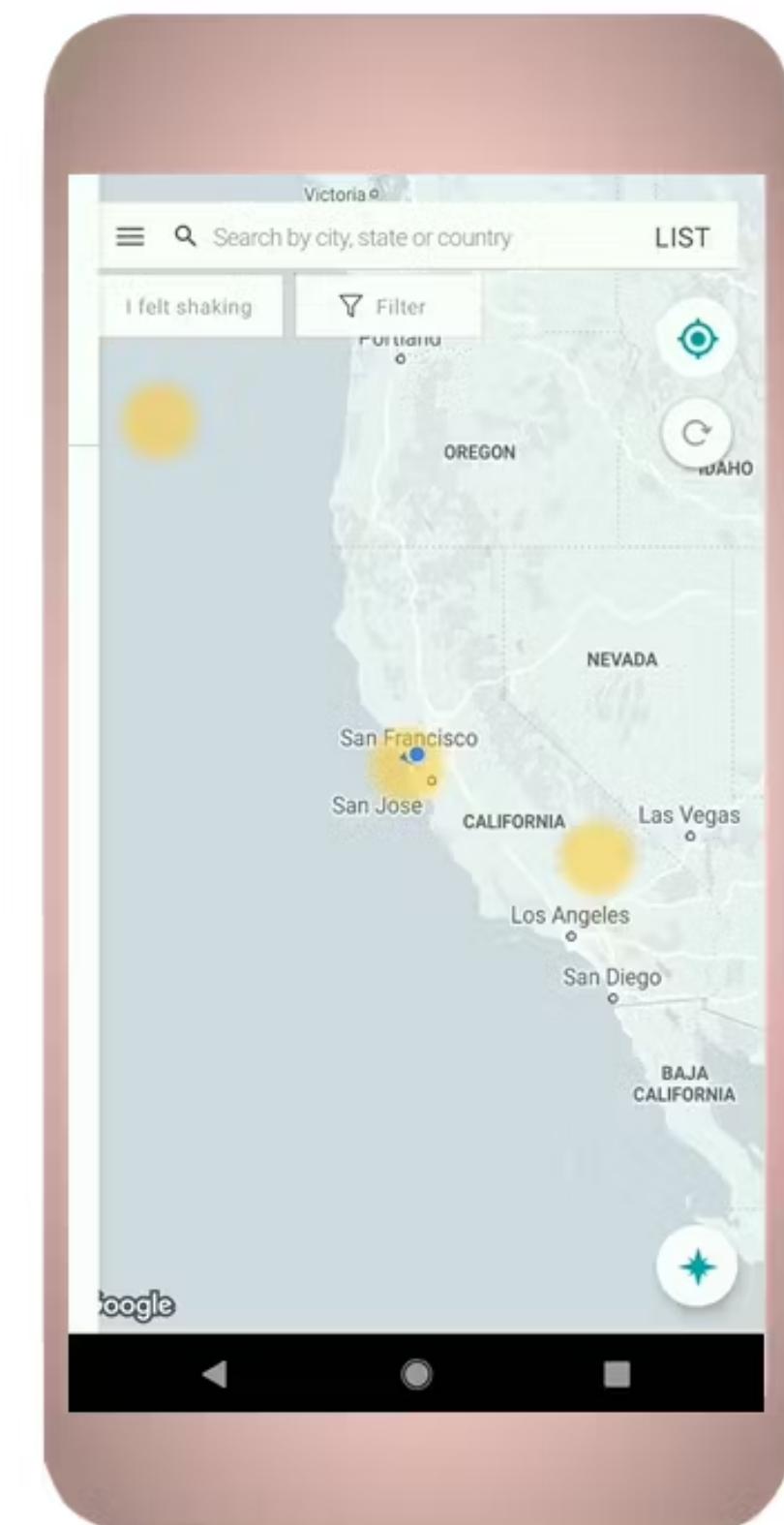
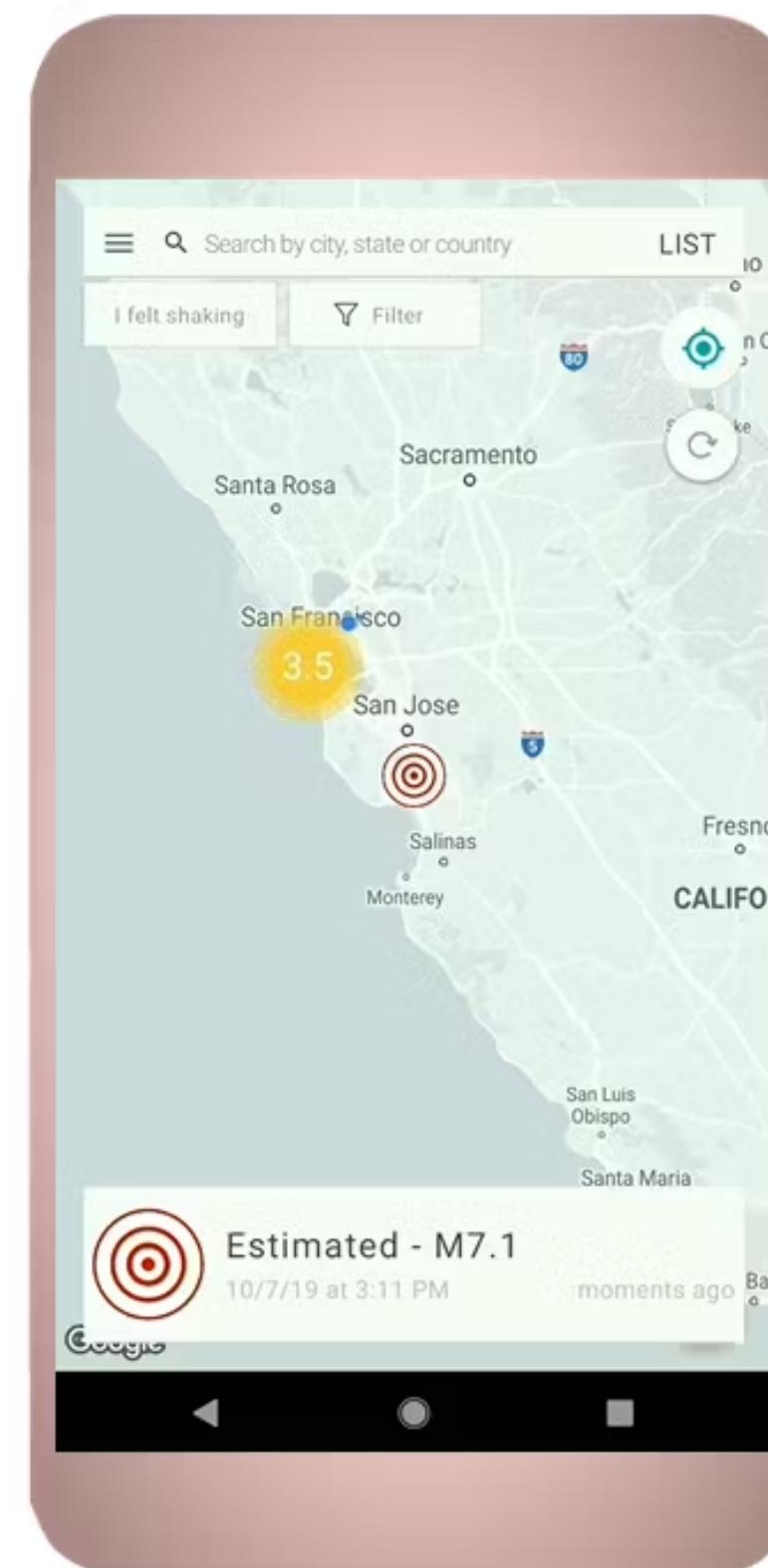
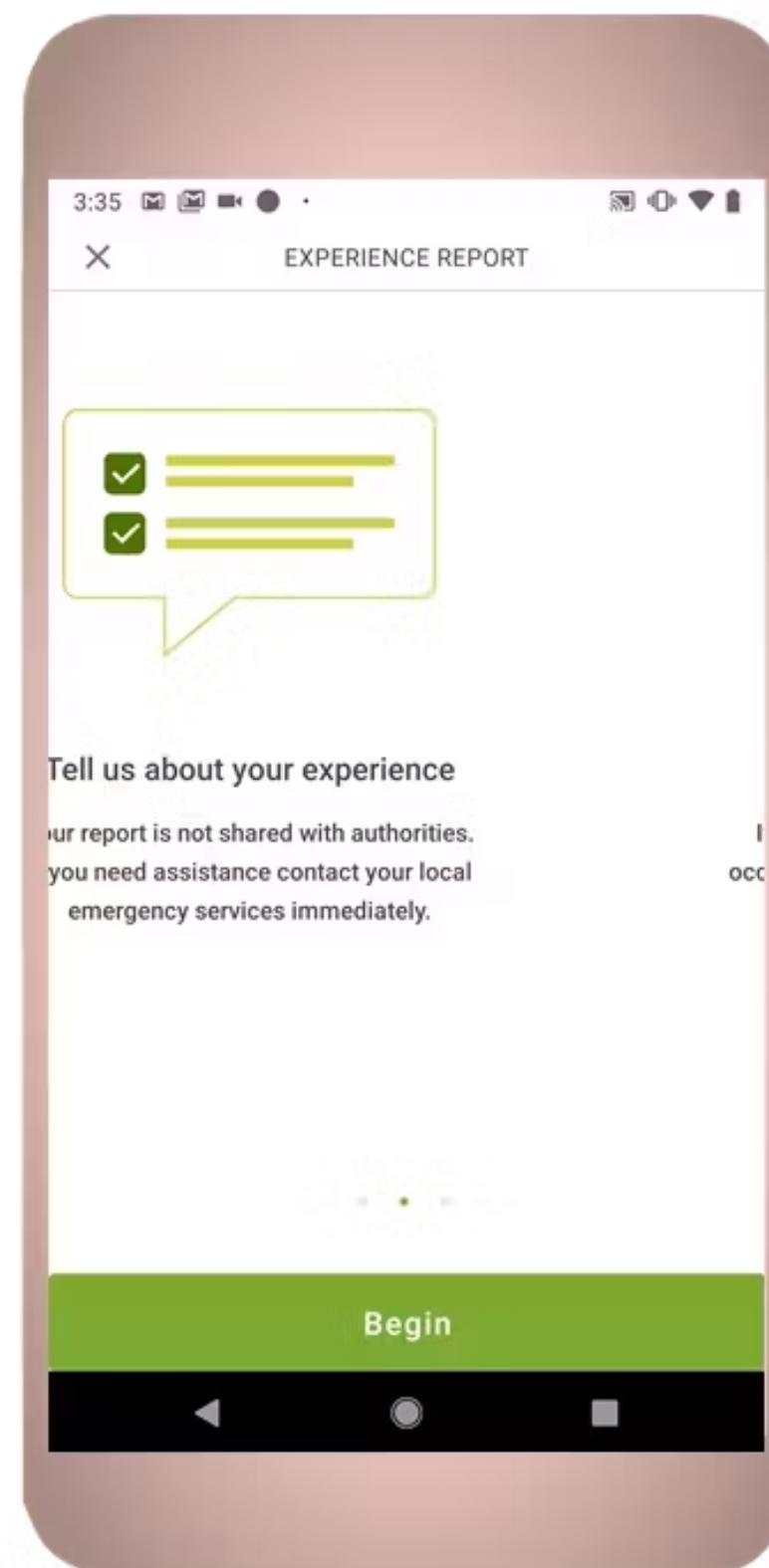
Translation

- Point measurements acts like an **array**
- Phase velocity information in amplitude ratio
- **Phase separation** P, S, Love, Rayleigh
- Backazimuth and incidence angle information
- Surface wave **dispersion**
- Azimuth dependent velocities → **anisotropy**
- **Portable** sensor not yet accurate enough
- Many application domains



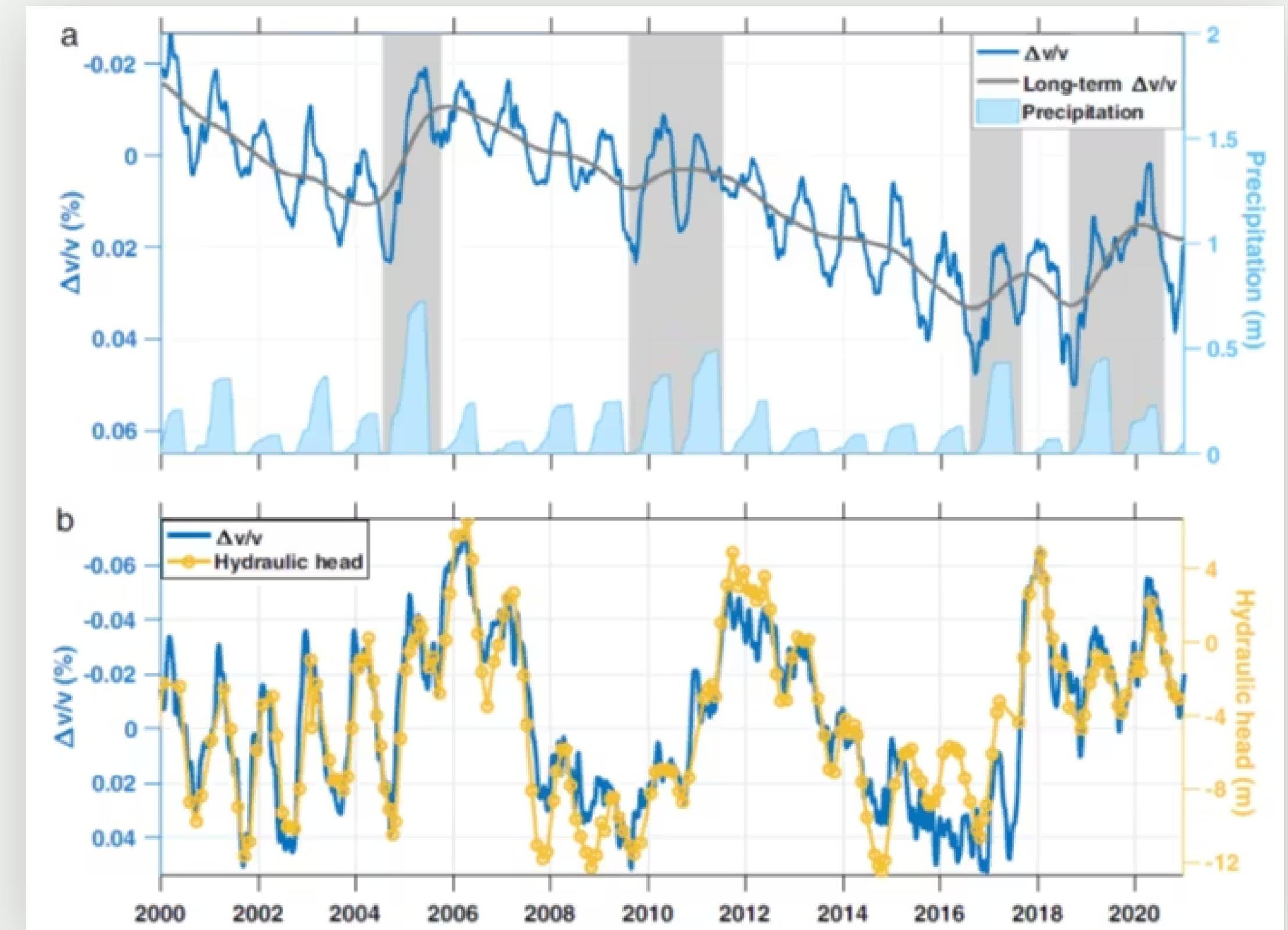
Rotation

Some Examples in City Environments



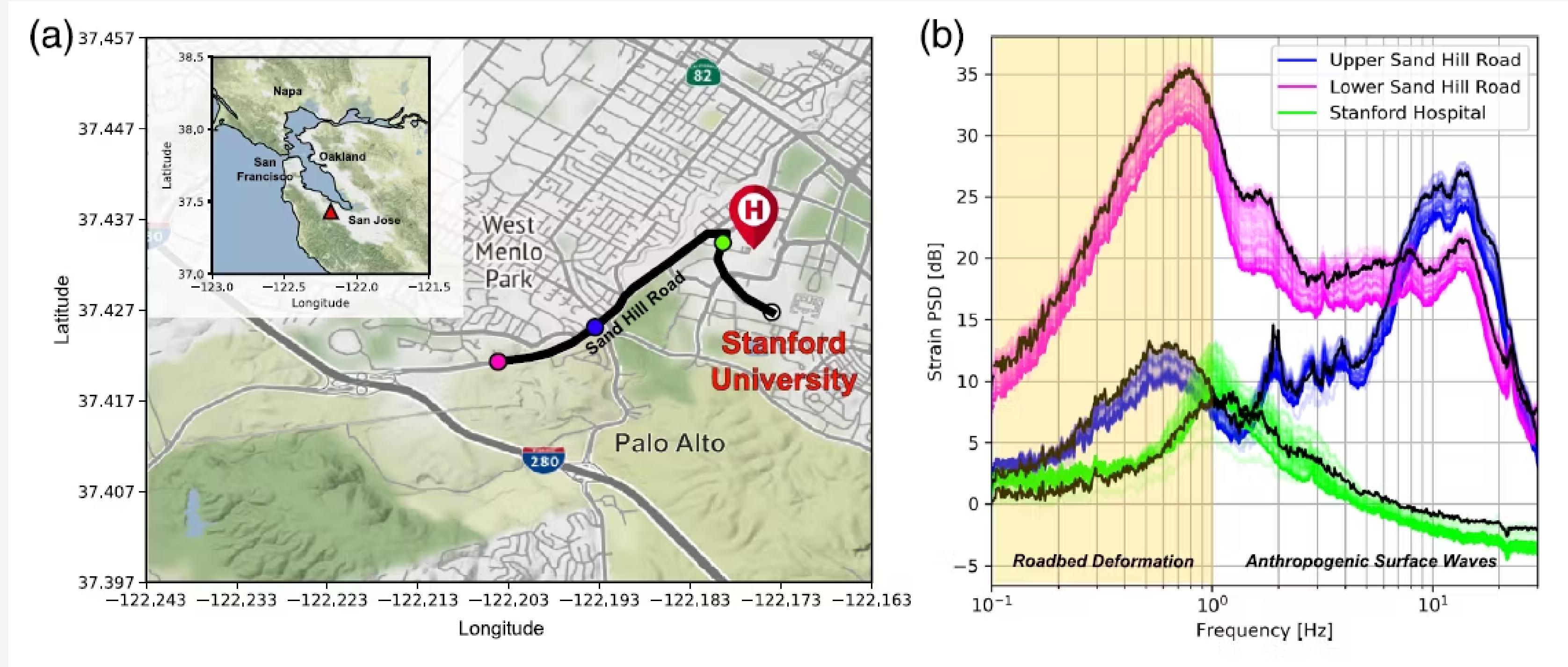
Hydrology

- Seismic noise observations in LA Basin
- $\Delta v/v$ from coda wave interferometry
- Excellent correlation with well head level (always like this?)
- 3D solution rather than single point information (wells)
- Connection with local climate
- Political boundaries visible through water regulations



Ma et al., 2022

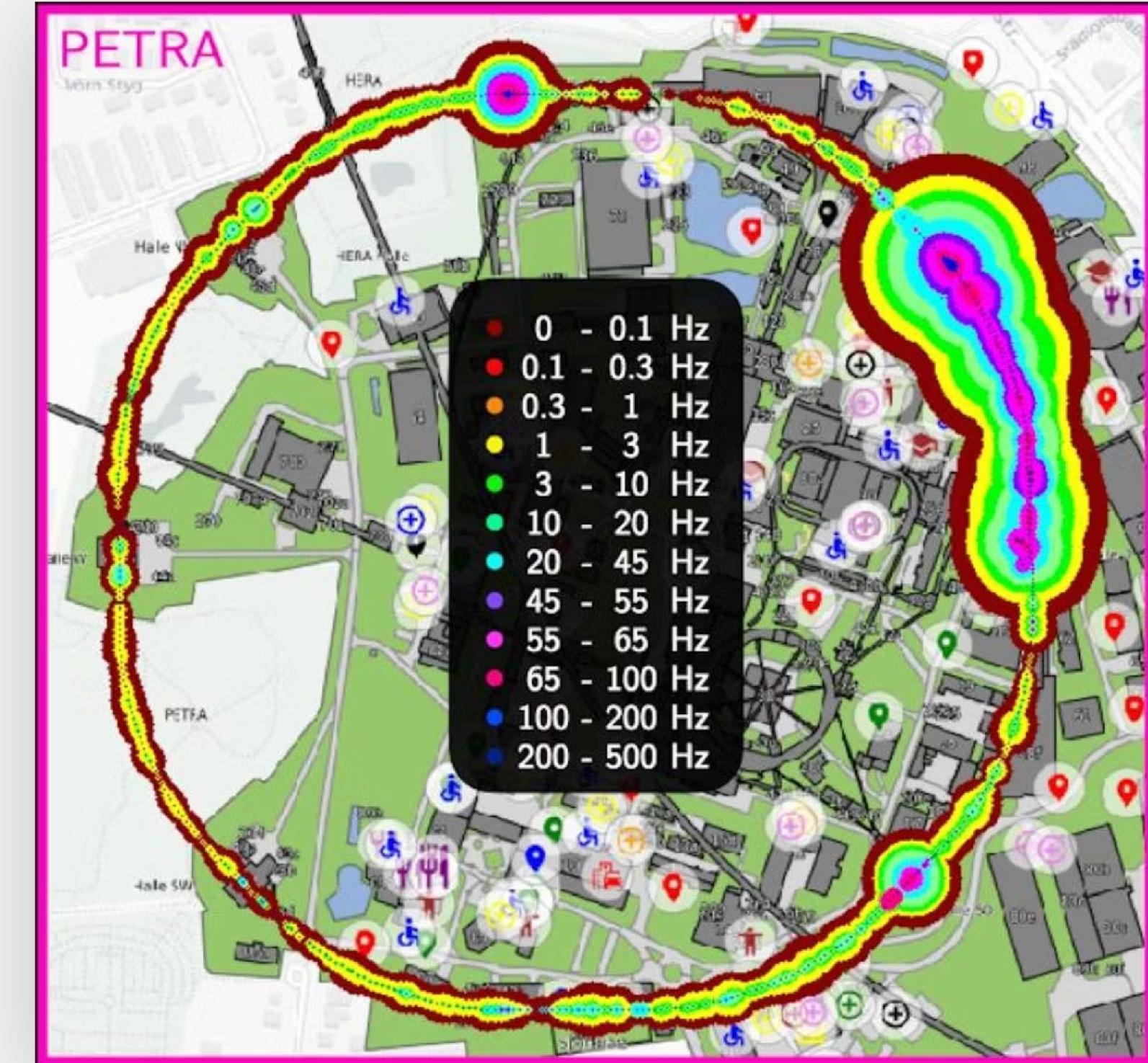
DAS in Cities



Lindsey et al. 2020

Swiftquakes

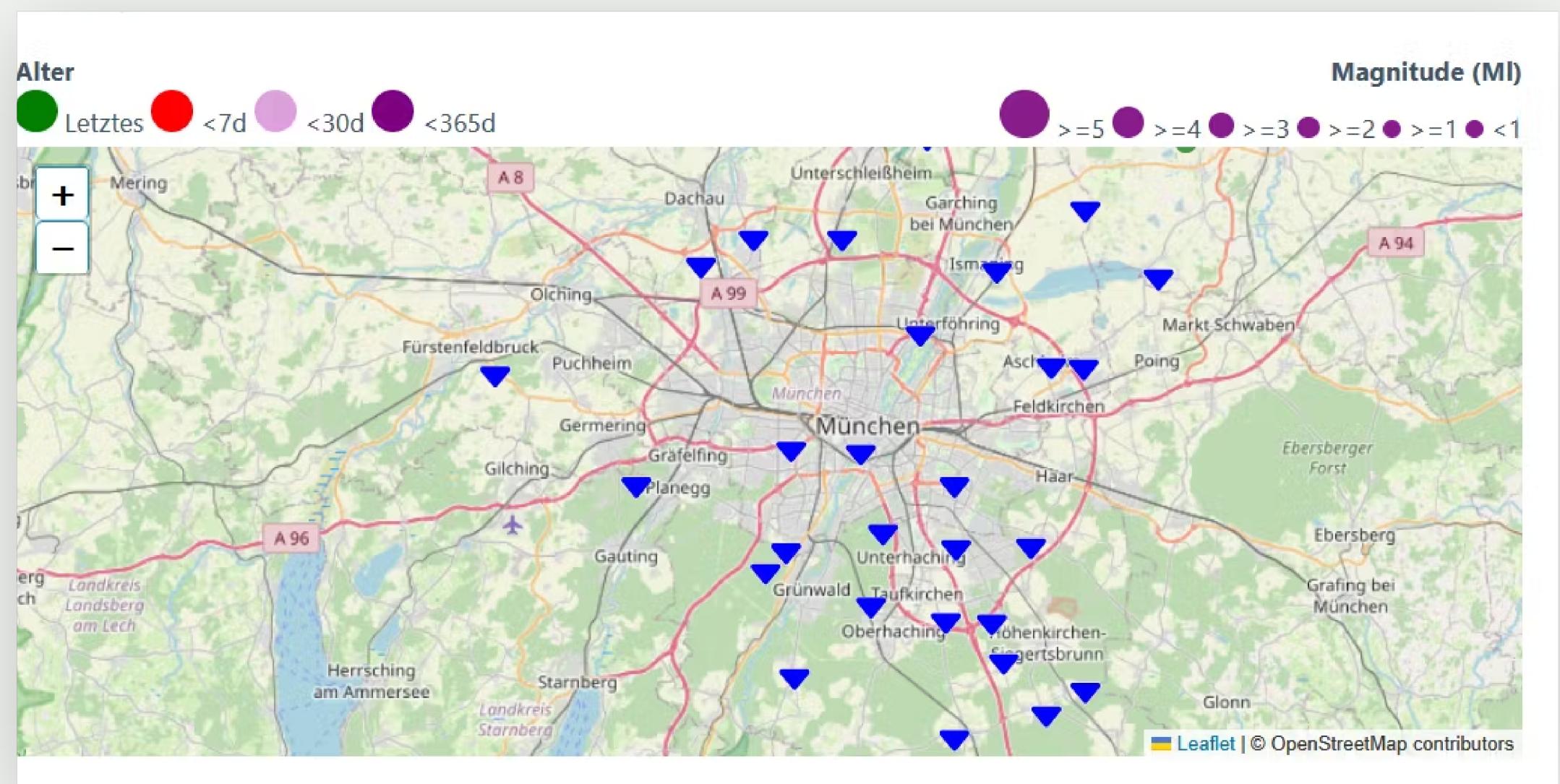
- Fibre-optic cable around DESY accelerator
- Taylor Swift Concert 1km away



Wave Project Hamburg

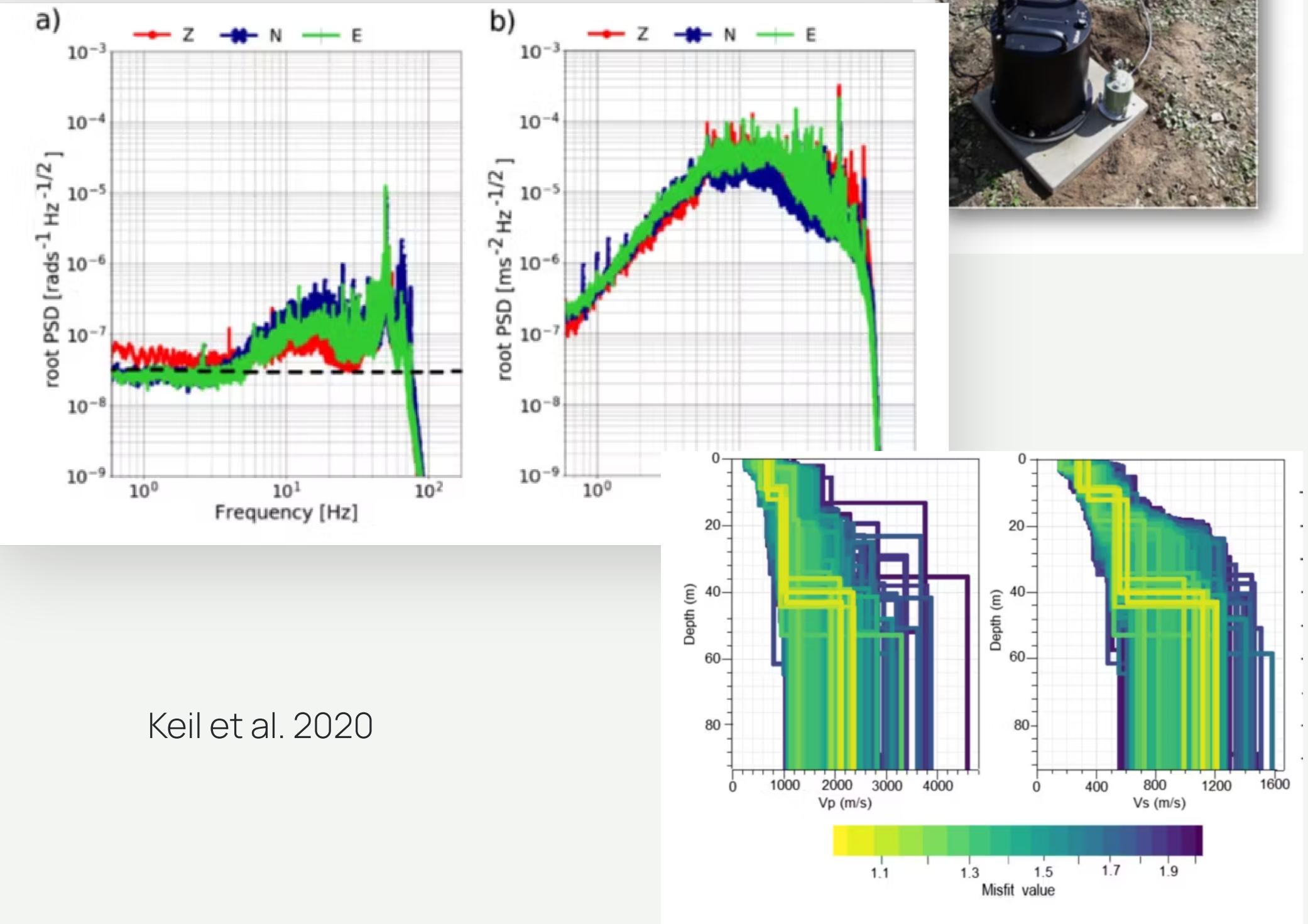
Cityquakes

- Geothermal projects in the city of Munich
- Recent densification of seismic network
- Seismicity in "erdbebendienst.de"
- Fake News?

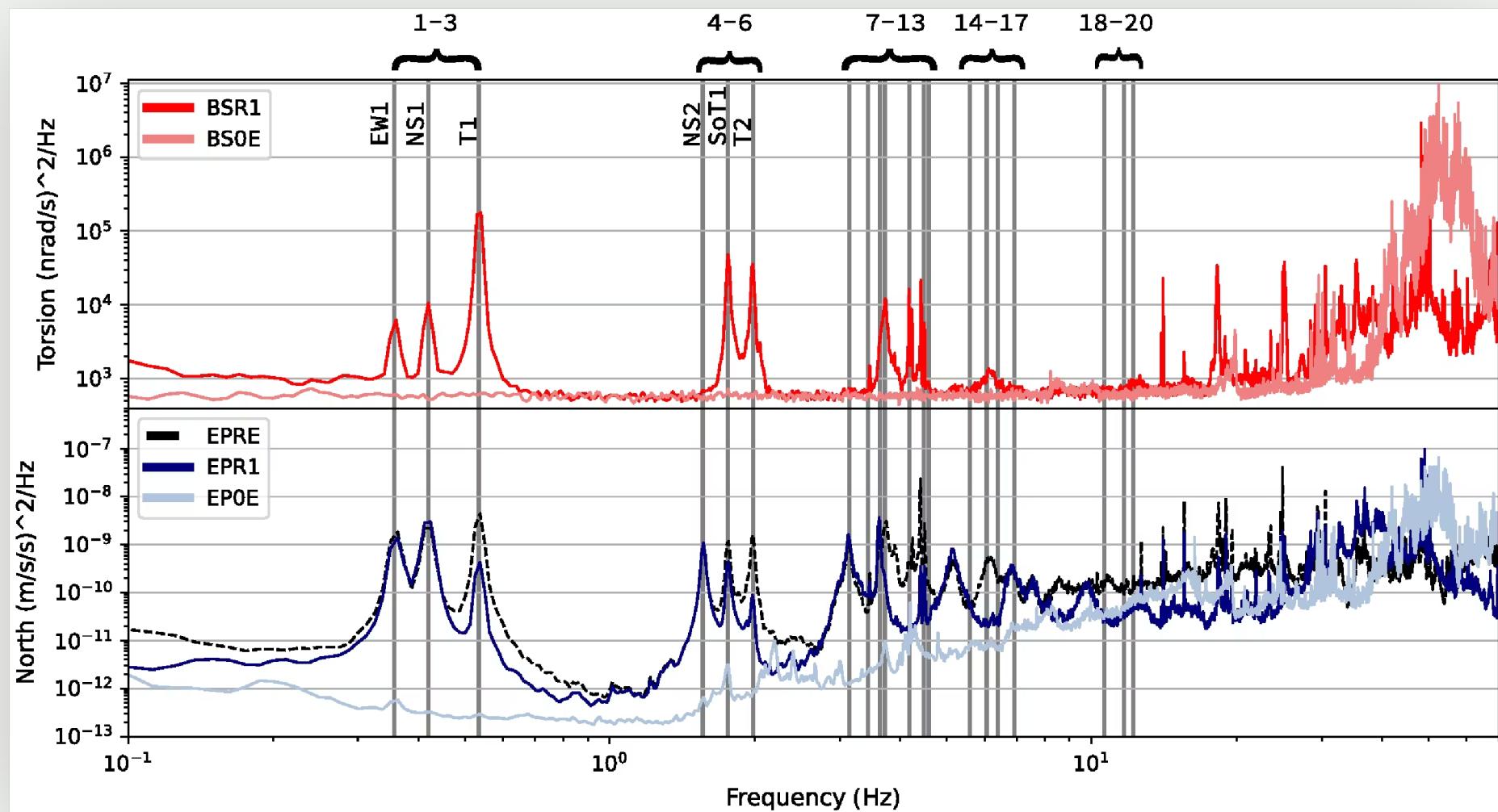


6 DoF in Cities

- Point measurements like arrays
- Surface wave dispersion
- 1D velocity inversion
- Site effect estimation

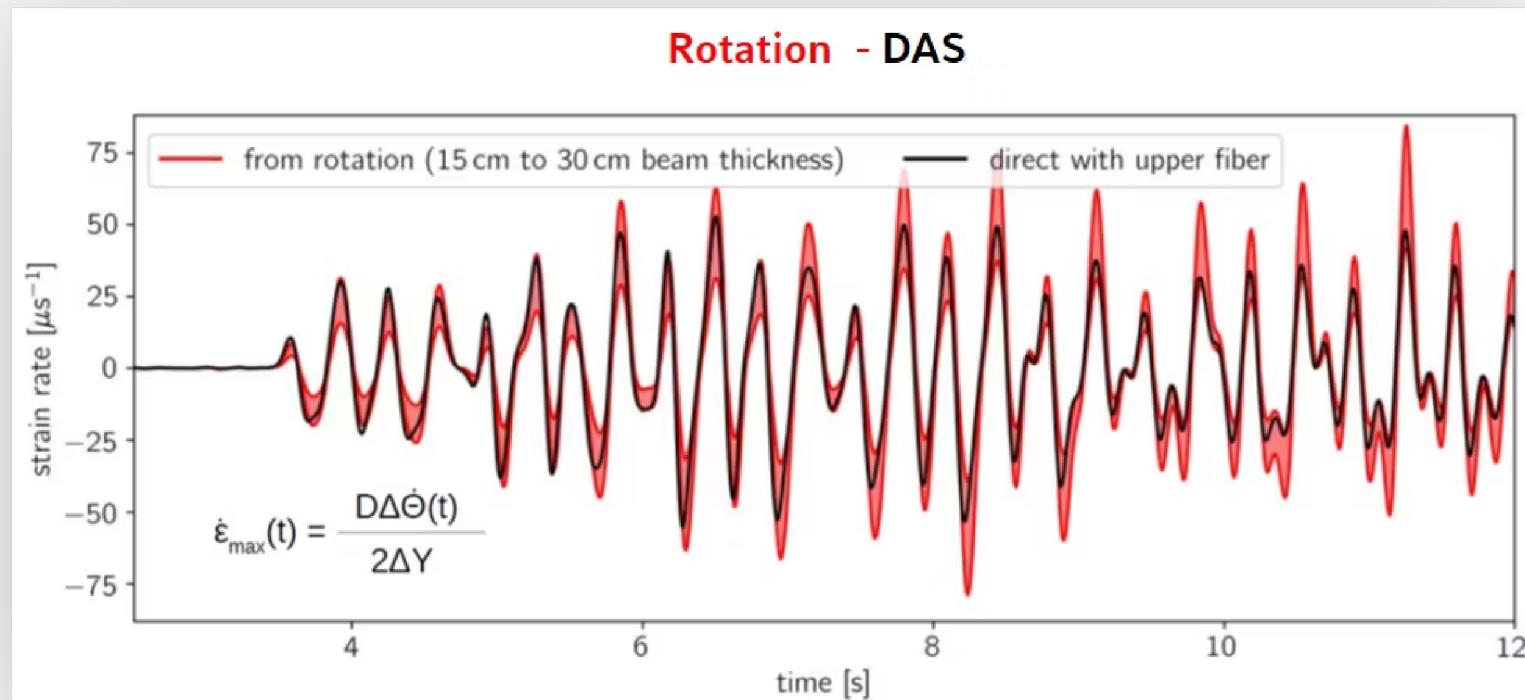


Structure vibrations



Rossi et al. 2023

Structure vibrations



Bernauer, Dhabu and co-workers

Questions

1. What are the **challenges** if we observe ground motions in cities?
2. What **instrumentation** should we use and for what purpose?
3. Are there real **science** problems to be solved or are there only **methodological** challenges?
4. Would it allow us to connect to **social** sciences? Does it make sense?
5. Are there **legal** problems if we measure noise in cities (privacy)?

Enjoy the workshop!!!





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