On the subsurface monitoring capabilities of wavefield gradients: a case study from Mt. Zugspitze (German/Austrian Alps)

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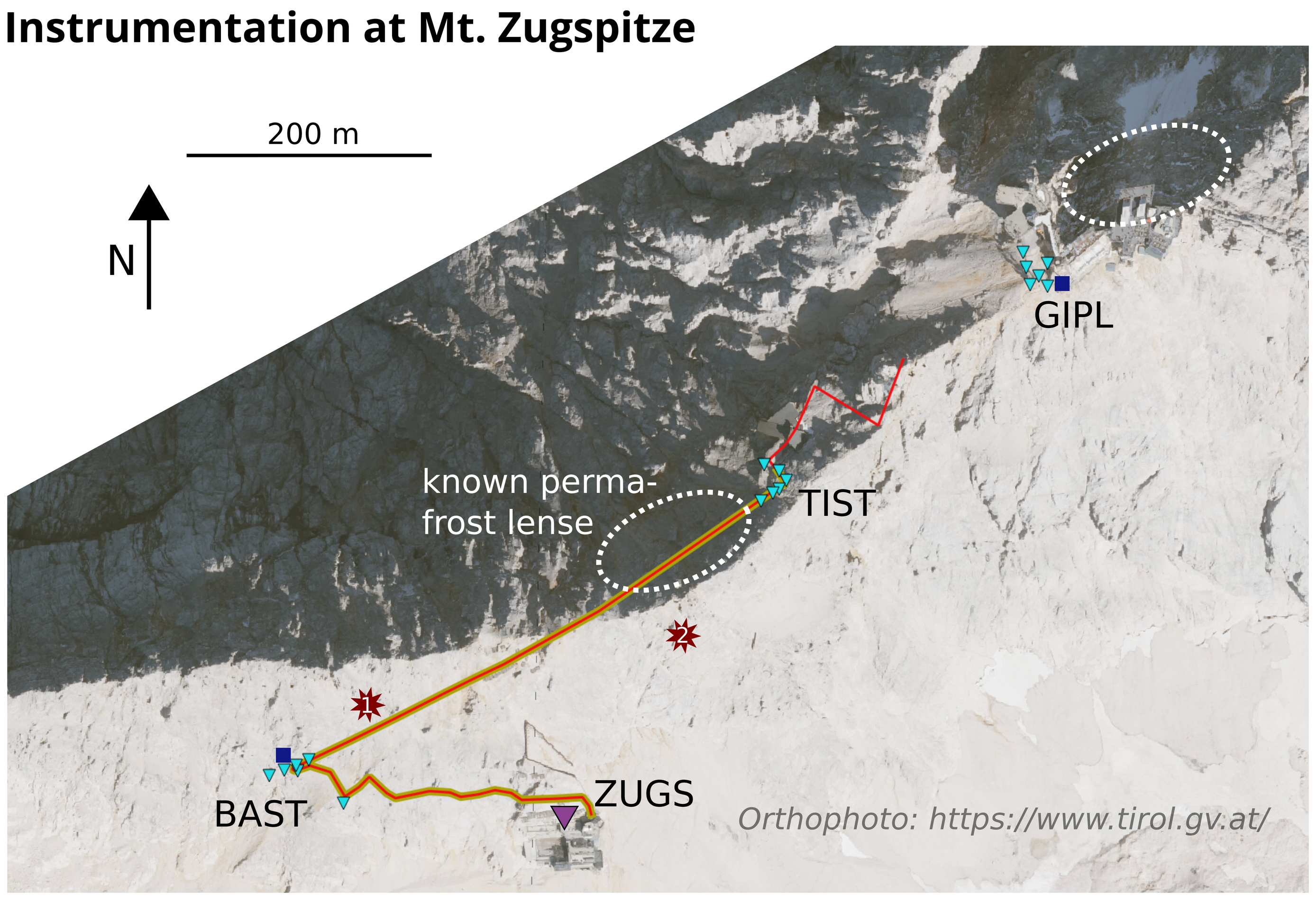
Abstract

Recent studies show that wavefield gradients, i.e. rotation and strain, provide novel insights into wave propagation. While rotations provide significant additional information on polarization properties, dynamic strain observations from distributed acoustic sensing (DAS) allow unprecedented spatial resolution. In addition, both rotation and strain observations exhibit increased sensitivity to near-receiver heterogeneities compared to the classical translational measurements. Incorporation of wavefield gradients is thus expected to advance the monitoring of subsurface changes towards a detailed spatio-temporal approach. Here, we present the first findings of an ongoing project dedicated to permafrost monitoring on Mt. Zugspitze (German/Austrian Alps), which includes strain and rotation sensing.

Instrumentation at Mt. Zugspitze



- ZUGS: permanent station (since 2006)
- Geophone/Trillium Compact stations: permafrost monitoring (since 2021)
- 6C Station: BlueSeis + Trillium Compact (July 2022 only)
- Fiber-optic cable for distributed acoustic sensing (periodically interrogated)
- Approximate location of avalanche triggering explosion

Transient signals

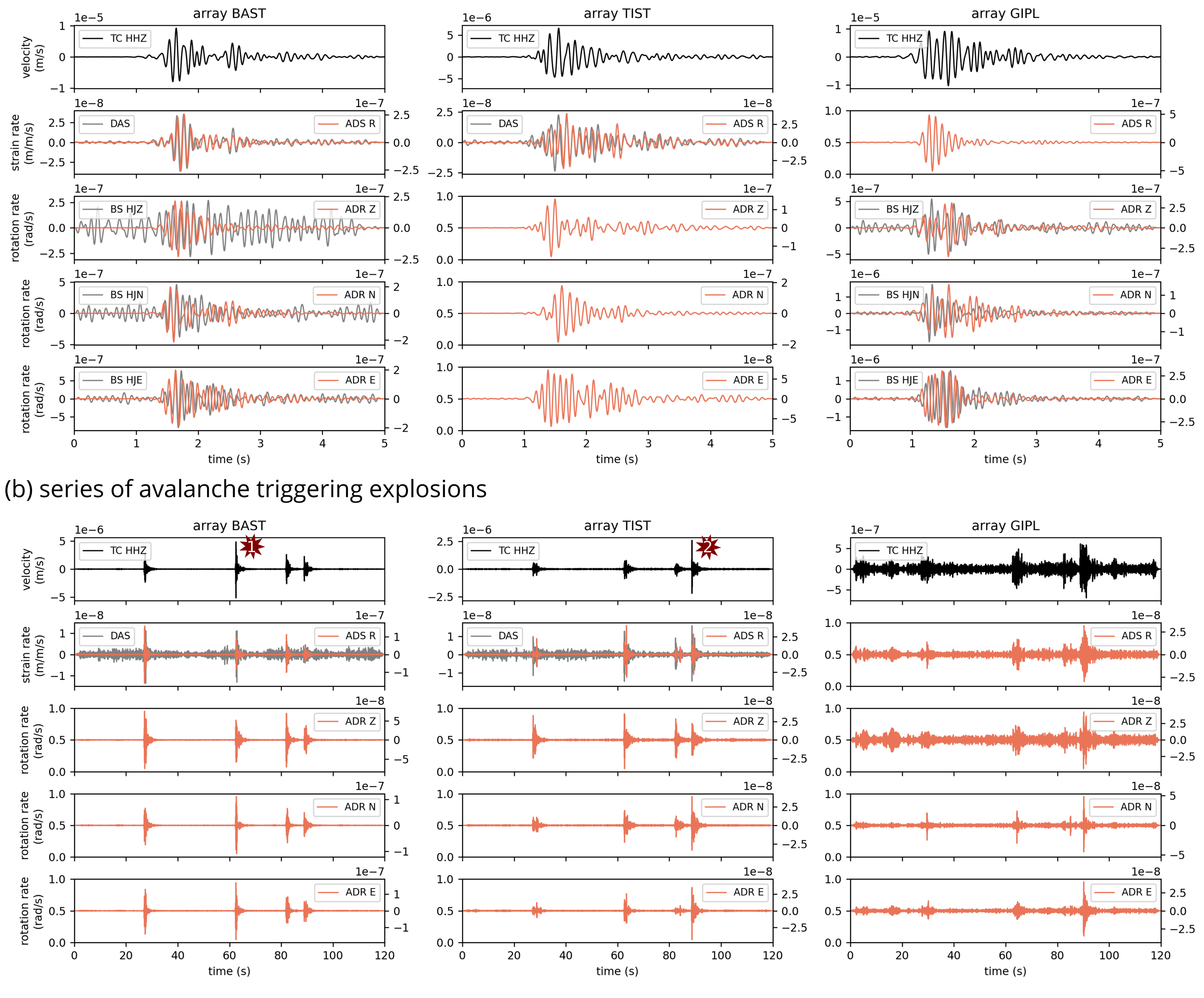


Fig. 1 Waveforms of ground velocity, strain rate and rotation rate for different signals. For strain and rotation, direct measurements are compared to array-derived time series. TC: Trillium Compact, BS: BlueSeis, ADS/R: array-derived strain/rotation.

Ambient/gondola noise: 6C source (+velocity) tracking

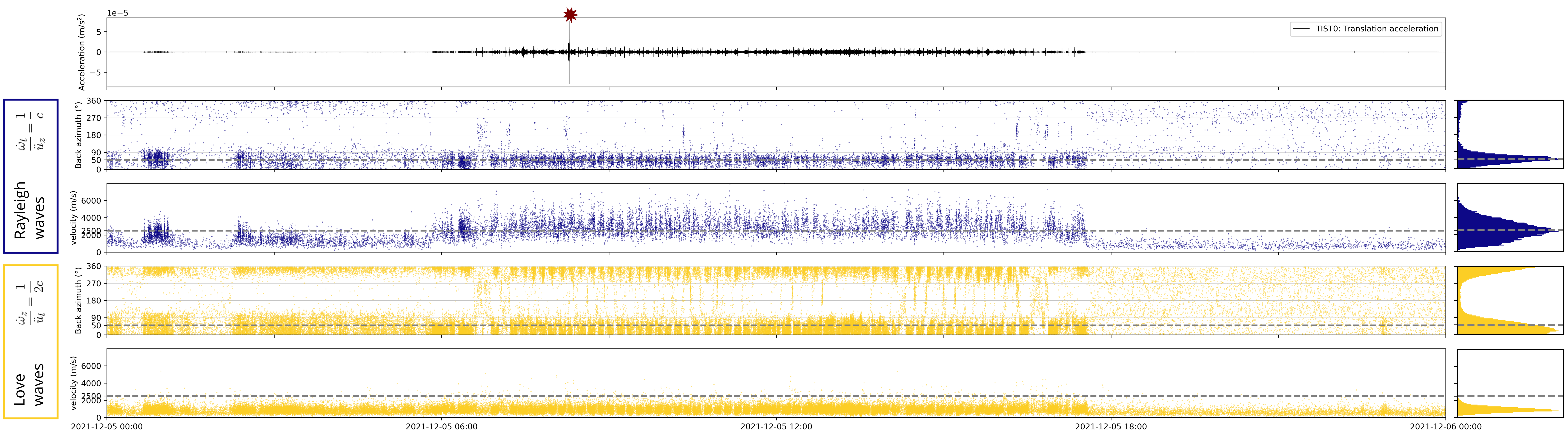


Fig. 2 Back azimuth tracking and velocity estimation using translation recordings and array-derived rotations at site TIST for a full day with typical site specific gondola noise. Back azimuths for Rayleigh waves are determined from the ratio of the two horizontal rotation components and for Love waves by maximizing the correlation coefficient between vertical rotation rate and transverse acceleration.

Velocity change monitoring: direct and coda waves

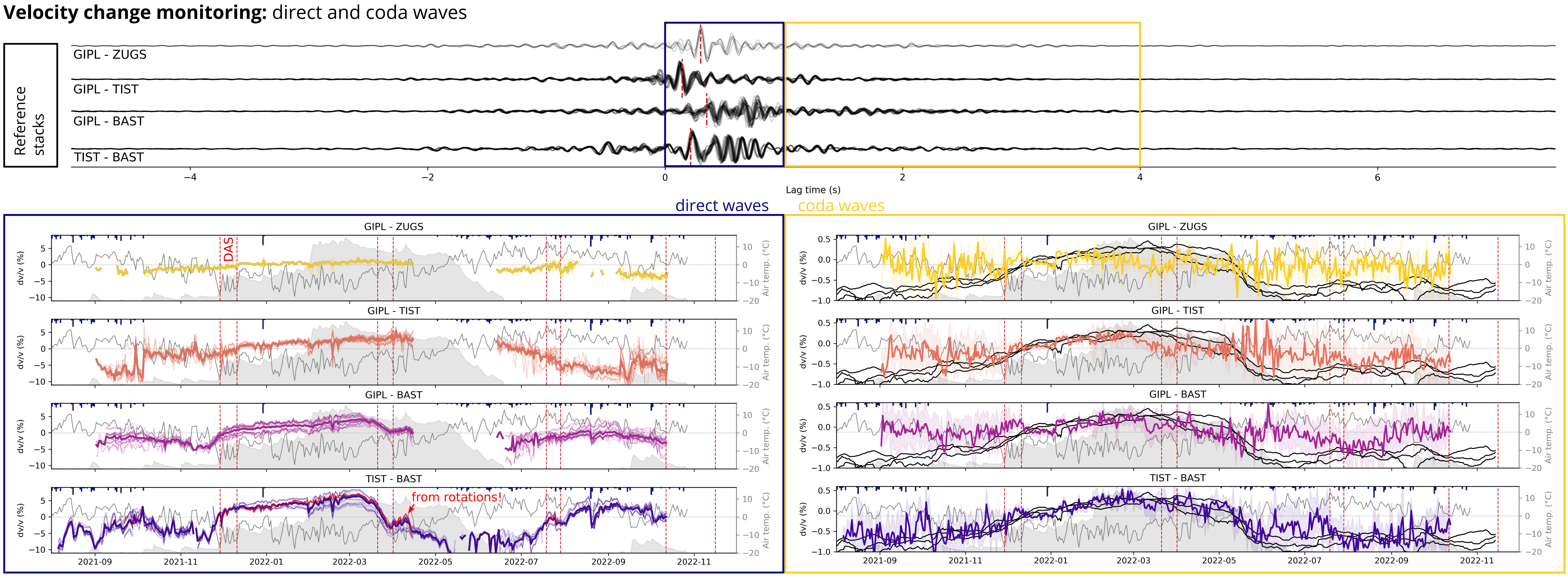
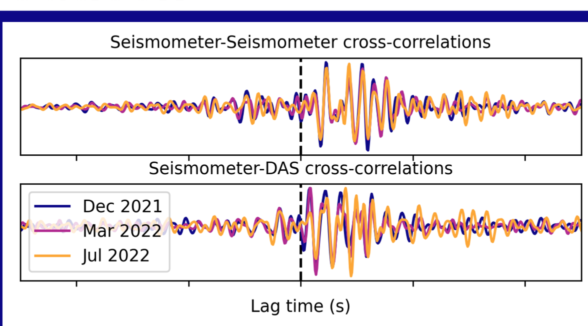


Fig. 3 Velocity change monitoring (colored lines) using direct (left panel) and coda (right panel) waves. For direct waves, we use the wavelet cross-spectrum method, for coda waves the moving-window cross-spectral technique. Each subplot also shows the air temperature (gray line), snow cover (gray shading) and fluid precipitation (blue bars). For coda waves, also the ZUGS single-station results (Lindner et al., GRL, 2021) are shown (black lines).

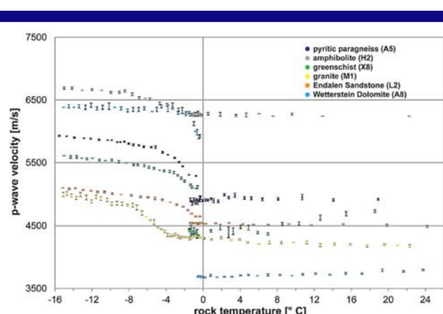
Conclusions

Array-derived waveforms appear robust (e.g. compare well with DAS recordings) and reveal a stationary source of Rayleigh waves (excitation through gondolas). Velocity changes obtained from the direct waves' rotational motions (TT component) agree with those from translational motions (ZZ component). Both direct and coda waves reveal similar velocity changes (though differences are evident) and are most prominent between sites TIST and BAST, where a known permafrost body is located.

Outlook



- Monitoring with DAS to get fine spatial resolution?
- Do wavefield gradients help to detect/monitor velocity changes?



Possible to infer rock temperature?

Draebing & Krautblatter, The Cryosphere, 2012

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