


Gone APE:
Spatiotemporal variations in shear-wave splitting during the 2018-19 Surrey, UK, earthquake sequence

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Summary

Shear-wave splitting measured for the 2018-19 earthquake sequence near Newdigate, Surrey, UK, yields fast polarisation measurements which differ by 90° despite the close proximity of the stations.

This result can be best explained by anisotropic poroelasticity, evidenced by the stress alignment of one set of measurements and temporal variations in the strength of anisotropy at both stations. This interpretation, however, requires significantly overpressured pore fluid South of the Newdigate fault!

Background

In April 2018, an earthquake sequence began near Newdigate, Surrey, UK. In July 2018 a network of monitoring stations was installed (Hicks et al., 2019). Between July 2018 and September 2019 the stations recorded 168 earthquakes, with a maximum magnitude of M_L 3.2.

By measuring shear-wave splitting for this dataset we aim to gain new constraints on the *in situ* stress field in Southern England where there is little existing stress data (Figure 1).

We also interpret new stress data for the Weald Basin from dual-calliper logs.

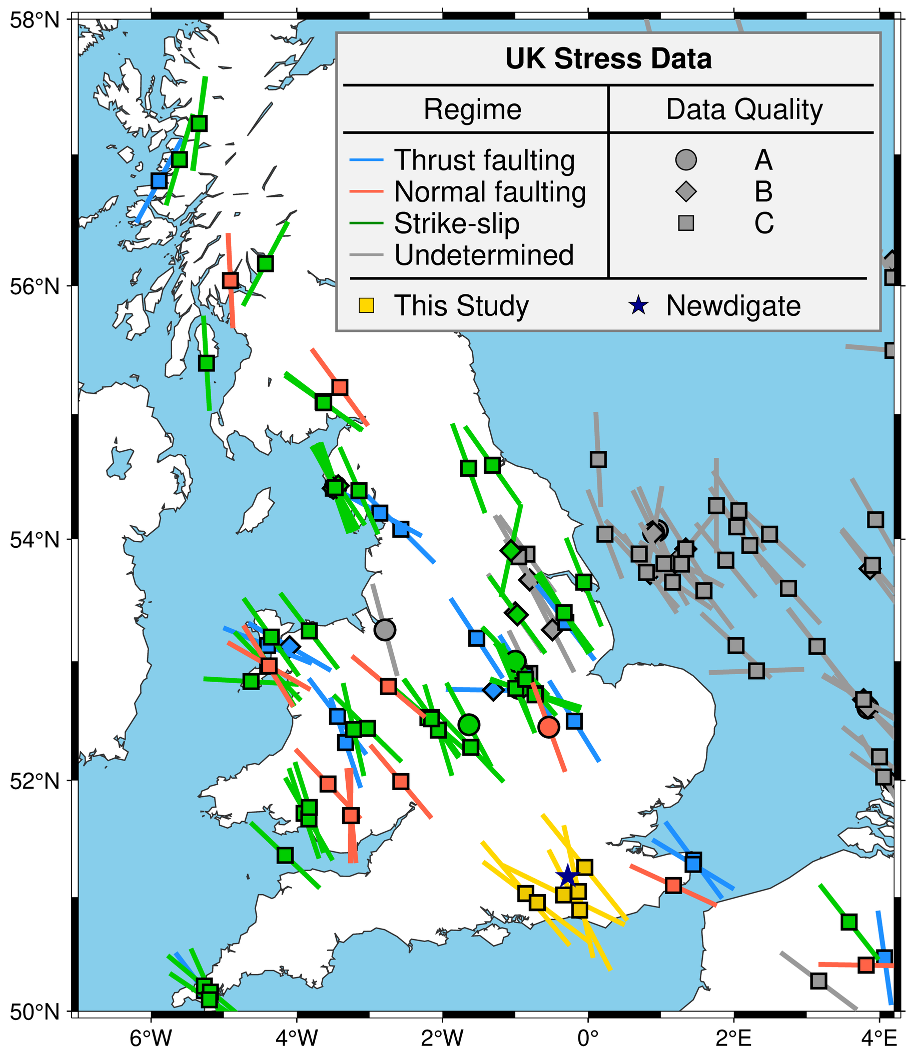

Figure 1. UK Stress data (Kingdon et al, 2022) and new stress data added for the Weald Basin.

Results

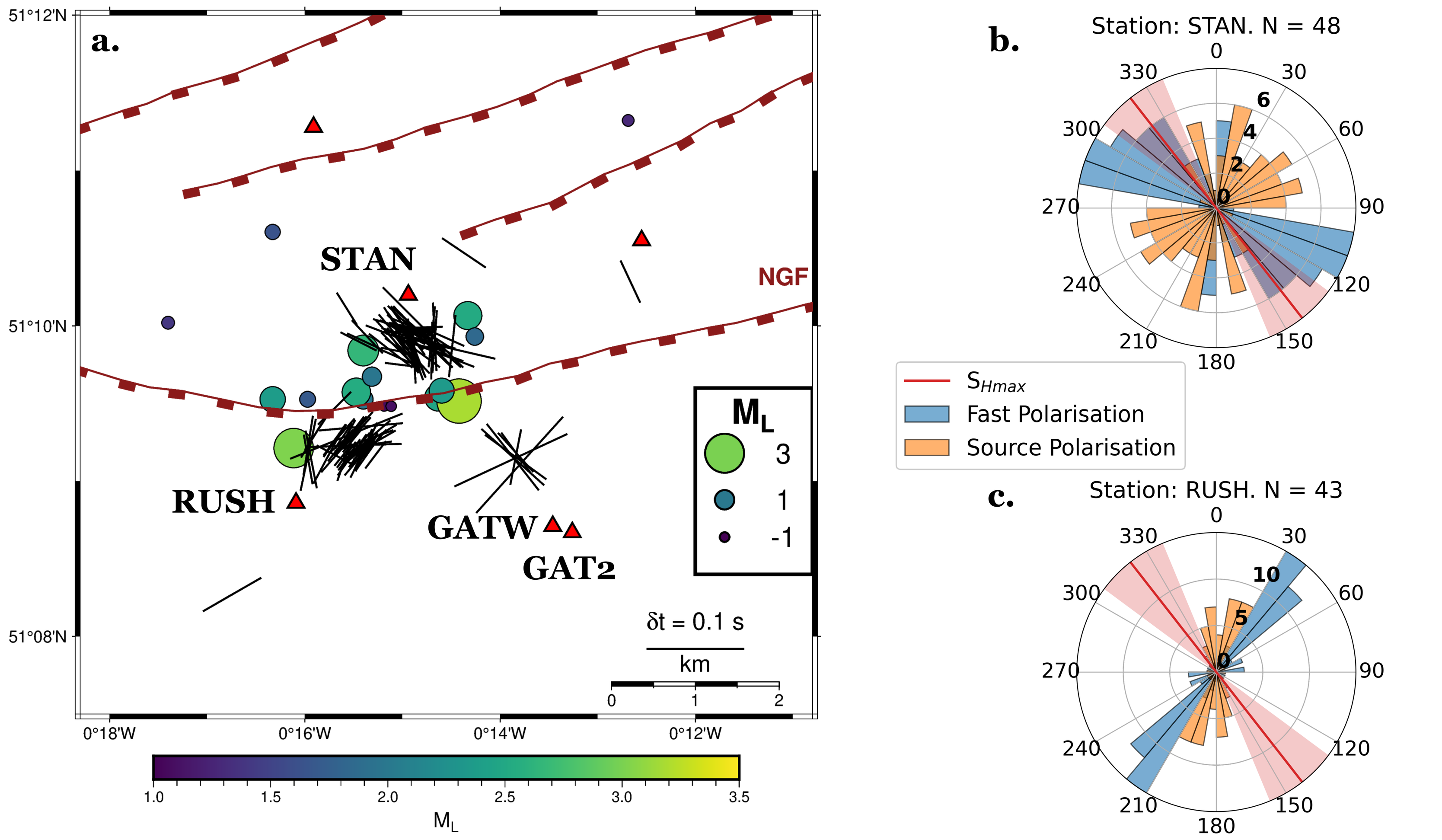

Figure 4. (a) Shear-wave splitting measured for the 2018-9 Newdigate earthquake sequence. Measurements plotted at source-receiver midpoint. Bar orientation corresponds to φ and length to δt. Rose histograms show φ and source polarisation measured at STAN (b) and RUSH (c) along with regional S_{Hmax} azimuth.

We make 118 "good" shear-wave splitting measurements following rounds of manual data quality inspection. Most measurements are made at two stations: STAN and RUSH, where the fast polarisation directions differ by approximately 90°. Examining these results leads to several questions:

What about the differences in source polarisation?

Due to the shear-wave window limitations, RUSH and STAN do not measure shear-wave splitting for all the same events. When we reduce the data to events where we have splitting at both RUSH and STAN, we see the source polarisations agree, and the difference in φ persists.

We also test the station alignments for teleseismic S arrivals, which shows that both RUSH and STAN are aligned correctly.

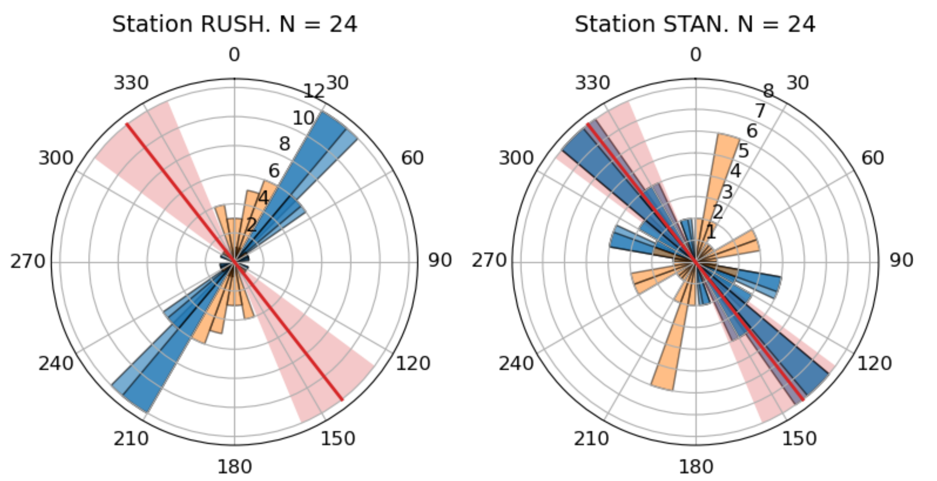

Figure 7. Rose histograms of shear-wave splitting measurements made at RUSH and STAN for the same earthquakes.

Shear-wave splitting

When a shear-waves propagates through an anisotropic medium it is split into, orthogonally polarised, **fast** and **slow** shear-waves which are separated by a delay time, δt.
We measure the polarisation, φ, of the **fast** shear-wave and the delay time, δt, between the **fast** and **slow** shear-waves.
Shear-wave splitting is measured for all 168 earthquakes in the Newdigate swarm using eigenvalue minimisation.

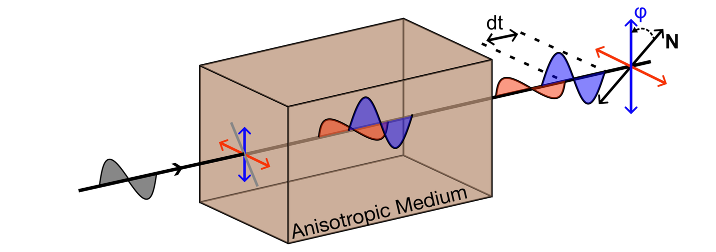

Figure 2. Schematic cartoon of shear-wave splitting

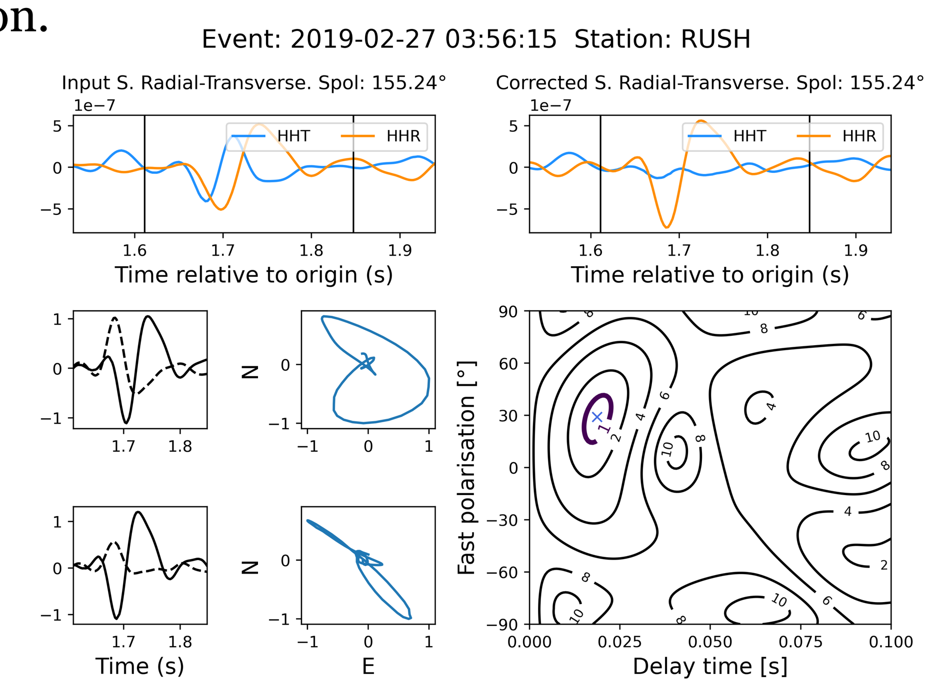

Figure 3. Example shear-wave splitting measurement made at RUSH. Input waveforms shown as radial-transverse components

References | Poster PDF

Anisotropic Poro-elasticity (APE)

Aligned fluid-filled fractures efficiently generate seismic anisotropy with a hexagonal symmetry. For differential horizontal stresses, where σ_1 and σ_3 are in the horizontal plane, these fractures will be sub-vertical and the mean fracture strike will be aligned with S_{Hmax} azimuth (Figure 5, Zatespin et al., 1997). The measured φ is parallel to fracture strike, allowing φ to be used as a proxy for S_{Hmax} azimuth. In the case of overpressured pore fluids φ can flip by 90° and is perpendicular to S_{Hmax} (Figure 6).

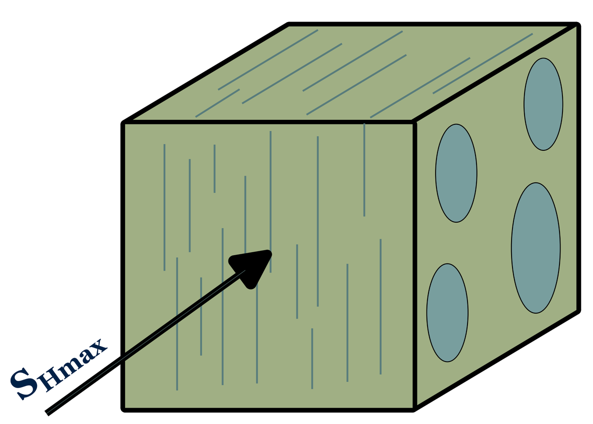

Figure 5. Schematic of APE model. Microcracks preferentially align with S_{Hmax}. Measured φ due to the cracks is parallel to S_{Hmax}.

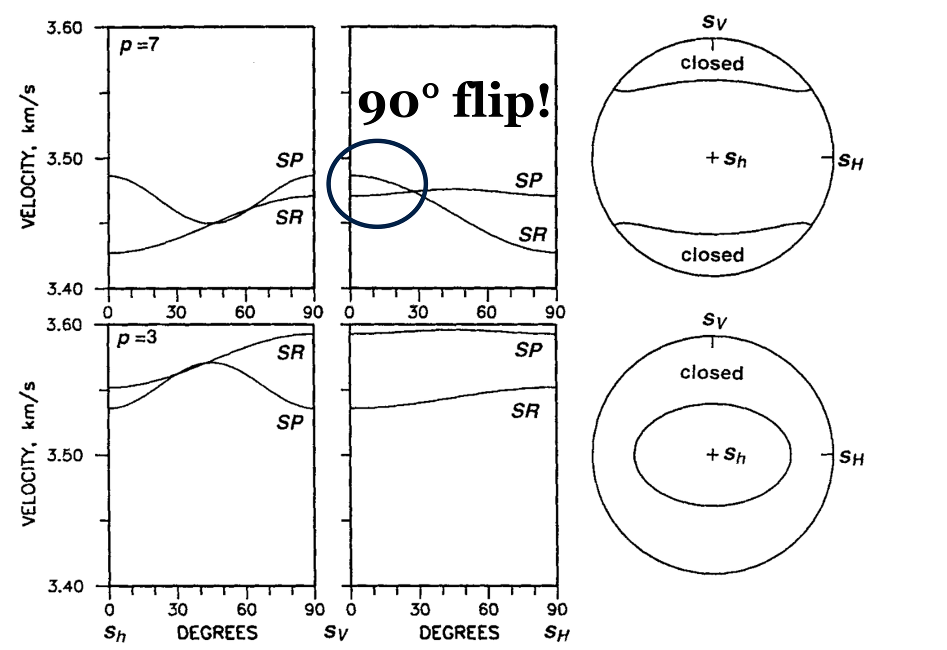

Figure 6. The APE model of Zatespin et al., (1997) for two overpressure cases. Here S_V = 12, S_{Hmax} = 6 and S_{Hmin} = 0. SR and SP are shear-waves polarised parallel and perpendicular to the plane of variation.

Can we explain this with anisotropic poroelasticity (APE)?

The APE model does predict 90° polarisation flips in the case of an overpressured pore fluid (Zatespin et al., 1997). Invoking APE, however, requires pore fluid pressures to be greater than S_{Hmax} (Figure 6) for the whole sequence!

Could this be fault-controlled anisotropy due to the Newdigate fault?

The Newdigate fault strikes East-West, which does not align with any measured splitting. Furthermore, when we look at the shear-wave splitting over time, we see temporal variations at both stations (Figure 8) which is best explained by APE.

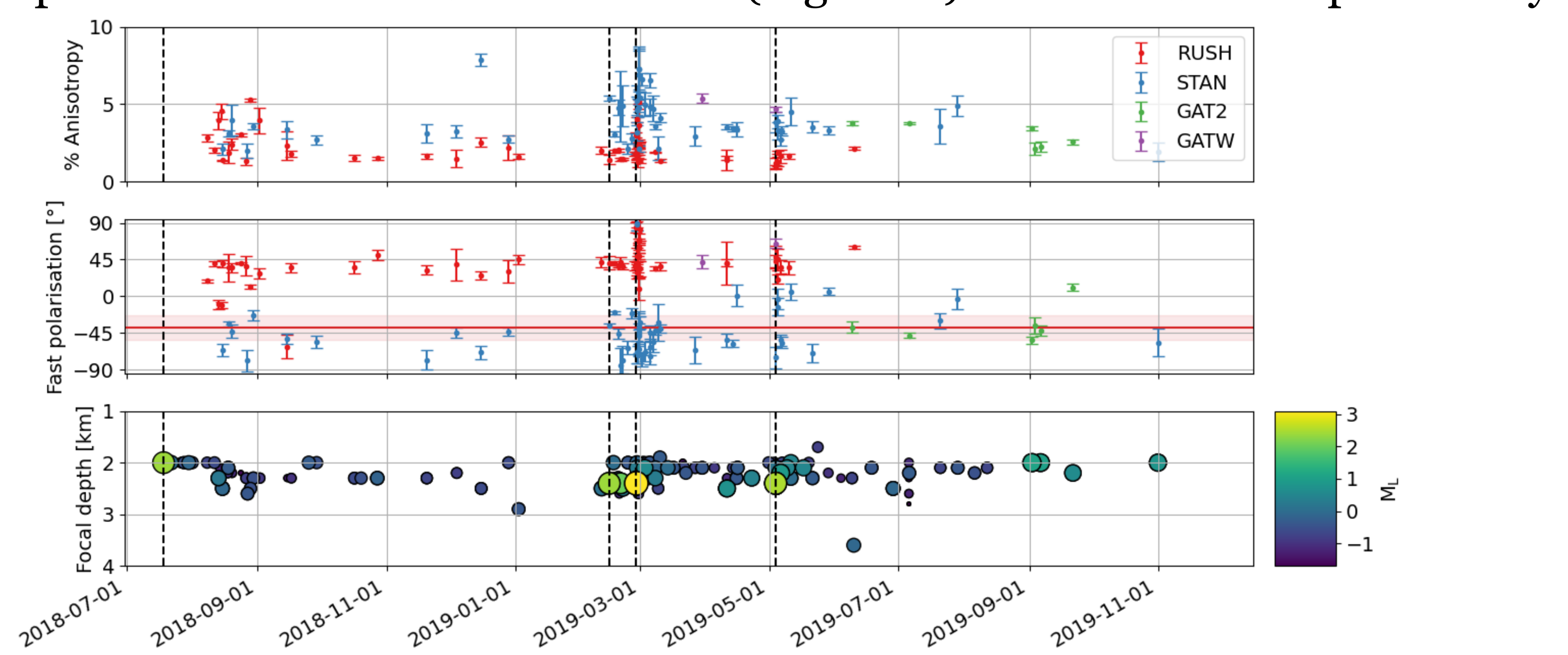

Figure 8. Shear-wave splitting measurements plotted over time. Bottom panel shows event depths and magnitudes reported by Hicks et al., (2019). Dashed lines show the main events in the swarm.