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Measuring the orientation of S_{Hmax} using ambient seismic noise

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Abstract Text:

The orientation of S_{Hmax}, the maximum horizontal compressive stress, is important for geodynamical modeling and understanding earthquake hazards, as well as in subsurface engineering applications such as fossil energy, geothermal energy, and CO_2 storage. The orientation of S_{Hmax} is important because it determines which pre-existing faults are optimally oriented for failure and the most likely orientations for new fractures. Fractures, and their orientations, are also strongly related to permeability. Currently, the two most common ways to estimate the orientation of S_{Hmax} are by making borehole measurements, or inverting earthquake focal mechanisms. Borehole measurements are expensive and most commonly used in hydrocarbon producing regions. Earthquake focal mechanism inversions can only be applied in areas with enough well recorded earthquakes by using focal mechanisms with sufficiently low uncertainties.

Here we present a new way to estimate the orientation of S_{Hmax} by using ambient seismic noise to measure stress-induced anisotropy in nonlinear elasticity. Using empirical Green's functions, we measure changes in seismic wave travel times between pairs of stations at a range of azimuths. For each station pair, we measure the difference in travel times from when the Earth is extended, to when the Earth compressed, due to solid-earth tides. This velocity difference, called nonlinear susceptibility, is due to the nonlinear elastic properties of the Earth's crust. We find that nonlinear susceptibility is stress-sensitive and its azimuthal dependence can be used to estimate the orientation of $S_{Hmax.}$ Our method has important advantages over existing methods; it is much less expensive than drilling a borehole, and can be applied in regions without active seismicity. It can also be applied at different length scales and measurements can be made temporally.

Plain-Language Summary:
Stress in Earth's subsurface is not the same in all directions. The directional dependence of stress determines how faults rupture and influences how fluids, such as water, oil, and gas, flow in the subsurface. Measuring the directional dependence of stress in the Earth's subsurface is difficult and expensive. It can be measured by drilling a well and making measurements in the well. It can also be measured by observing how earthquakes rupture. The

earthquake method requires a lot of high-quality measurements of seismic waves from a lot of earthquakes. We have discovered a new method to measure the directional dependence of stress. We measure how the velocity of seismic waves from background noise, traveling between two seismic stations, varies as the Earth is compressed and stretched by the gravitational pull of the sun and moon. This variation is related to the opening and closing of small cracks in rocks. We measure how these variations also vary by the orientation of the seismic stations. This variation is related to the directional dependence of the stress acting on small cracks in rocks. This method is inexpensive and can be applied nearly everywhere.

Session Selection:
T013. Geophysical constraints on crustal stress and structure in the age of machine learning

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Previously Published Material:
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