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Optical instruments for a combined seismic and geodetic borehole observatory

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Optical interferometry offers displacement sensing with the unusual combination of high sensitivity, linearity, and wide dynamic range, and it can be adapted to high temperature environments. We have applied interferometric technology to inertial seismic instruments and to optical fibers for strain measurements. When combining these methods into a single borehole package the result is a system that provides three components of observatory quality seismic recordings, two components of tilt, gravity, and vertical strain. The borehole package is entirely passive with the need for only optical fibers to connect the sensor sonde with surface electronics.

One of the sensors in the system is an optical fiber strainmeter, which consists of an optical fiber cable elastically stretched between two borehole anchor points separated by 100 m or more. The fiber's length is recorded optically, enabling sub-nanostrain detection of crustal deformations. A second sensor system uses laser interferometry to record the displacements of inertial mechanical suspensions – spring-mass for the vertical component and pendulums for the horizontal components – housed in a borehole sonde. The combined system is able to measure vertical and horizontal ground velocities, gravity, and tilt with sensitivities that compare favorably with any existing borehole system over time scales from 10 Hz to many days; because the downhole components are entirely passive, the instrument will have a long lifetime and could be made usable at high downhole temperatures. The simplicity and longevity of the metal and glass borehole sonde make it suitable for permanent cementation into a borehole to achieve good coupling and stability.

Several versions of the borehole inertial system have been deployed on land with excellent results, and a number of our optical fiber strainmeters have been deployed – both onshore and offshore. The combined system is currently under development.