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What ground tilt tells us about debris flow parameters

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Large mass movements cause the surface of the earth to deform, depending on the spatial distribution and magnitude of the mass movement and the response of the ground. In volcanology, tilt measurements are used to study earth surface displacement during volcanic processes such as dyke intrusions and magma chamber collapses. Broadband and long period seismometers also record tilt signals at periods of tens to hundreds of seconds, with the horizontal components being most sensitive to tilt. To obtain tilt from seismic recordings the signal from true ground motion and from apparent ground motion due to tilt have to be seperated. Nevertheless, seismometers have shown similar sensitivities as tiltmeters and are, depending on the type of tiltmeter and study site, less cumbersome to install. In this study, we explore the capability of tilt measurements from surface tiltmeters and broadband seismic sensors to determine debris flow parameters like mass, density and flow velocity. We focus on seismic broadband data recorded within a few meters of the Illgraben torrent in Switzerland. Illgraben's catchment is one of the most active mass wasting sites in the European Alps, producing several debris flows per year. Our seismic records show clear tilt signals from more than ten debris-flow events in 2018 and 2019, which we compare to data from large-scale laboratory experiments at the U.S. Geological Survey (USGS) debris-flow flume at which broadband seismometers and tiltmeters were installed for six 8-10 m^3 experiments in 2016.

To explain our observations, we present a model for the loading response of a layered elastic half-space to a moving surface load. This model can be used to invert our observed tilt signals for the surface load, i.e., the mass, density and/or geometry of the debris flow. To verify our model, we use nearby force plate and flow height measurements at both study sites. We discuss to what extent and under which assumptions, compared to force plate installations, the relatively simple and inexpensive tilt measurements can be used to determine debris flow parameters, which to date require sophisticated equipment.