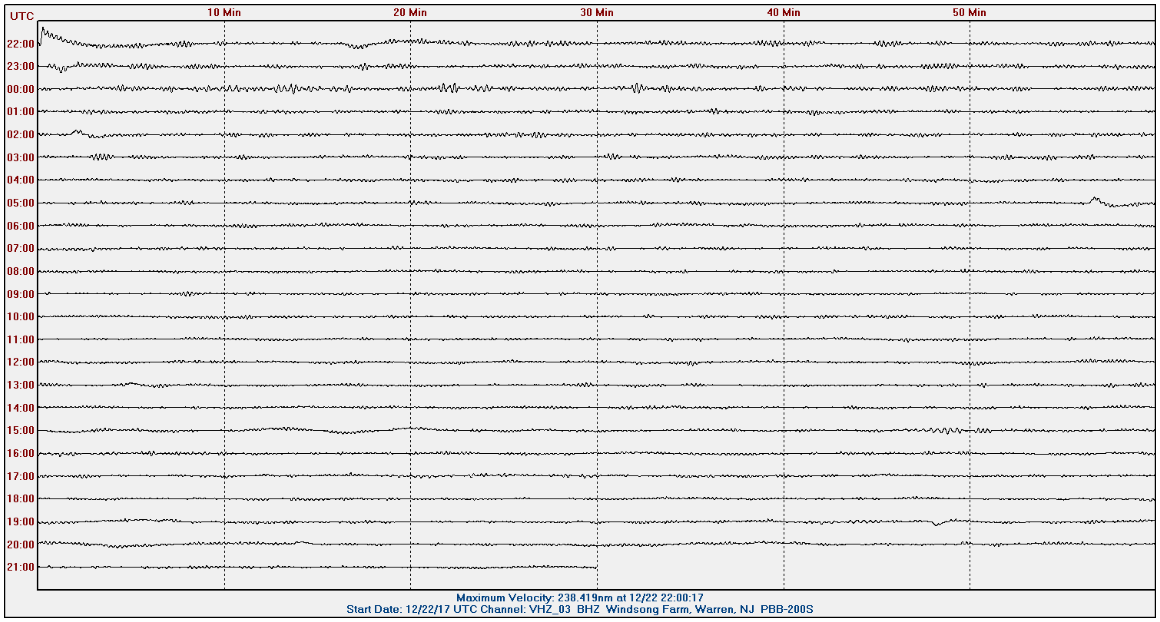
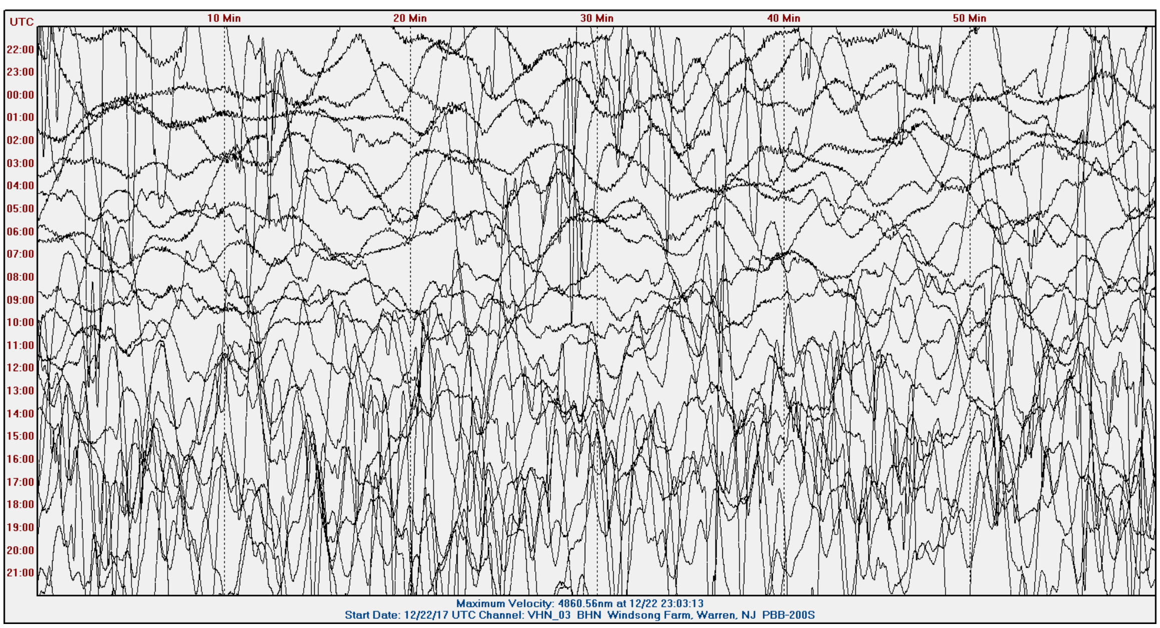
Why do I Prefer Vertical Seismometers?

Because horizontal long-period instruments are super-sensitive to ground tilt variation.

This is a recording of vertical ground velocity, at about 410 nm/s and 1 hour per line.
The instrument's velocity response is relatively flat down to 0.0083Hz (120 seconds).



This is the same instrument's horizontal North-South channel with identical sensitivity.



Although I have a relatively quiet site, ground tilting obliterates the horizontal motions from distant quakes unless they are quite large.

The vertical channel recorded above can easily display ground-motion velocity peaks of 100 nm/s from the surface waves of distant quakes. Since surface waves have frequencies in the general vicinity of 0.3 radians per second, equivalent to an oscillation period of 20.9 seconds, a ±100 nm/s ground oscillation at that frequency implies a peak acceleration of
$100 * 0.3 = \pm 30$ nm/s^2 or slightly over 3 nano-g's.

To understand the sensitivity to tilting, that same acceleration of ±3 nano-g's in an horizontal direction, will be created by ground-tilting of ±3 nano-radians. This is equivalent to the tilt represented by a deflection equaling ±the thickness of a typical sheet of paper at a distance of 25 km. As an example of one source of such tilting, when my well pump runs to fill its pressure tank, even though it is located 30m from my seismometer and is 90m deep in basalt bedrock, as water is withdrawn, the ground tilting it causes at the seismometer is easily seen on the horizontal channels. Varying atmospheric pressure from passing weather systems or from wind will also cause such ground tilting, as can the effect of wind acting on the house or on nearby trees.

Then why aren't long-period verticals used everywhere by amateurs? Because they are hard to make. Building a vertical seismometer which is that sensitive is equivalent to making a scale capable of recording fluctuations of 0.3 microgram in a 100 g weight, and then recording, perhaps, 100 such measurements per second.

The problem centers around the device that supports the test mass while observing its apparent weight variations from ground acceleration. You can't weigh it with a balance, because both the balance weights and the mass are acted upon identically by the ground acceleration, so there will be no net effect. Common designs for verticals use a spring to support and weigh the mass. However, the strength, i.e. the modulus of elasticity, of spring materials varies with temperature. A typical spring material which we have used varies in strength by an amount which is equivalent to 240 000 nano-g's per °C, making it extremely difficult to detect our 3 nano-g variation in any real world environment. Using a magnet to support the mass is even worse, as typical magnet materials vary in strength by amounts approximating a million nano-g's per °C.

The key to solving the problem is to make use of an electronic feedback system to measure the ground acceleration forces in a way that doesn't respond very much to changes in the characteristics of the mechanism which is supporting the mass. One good design adds a coil-magnet assembly to a spring-supported mass, which allows a varying vertical force to be applied to it by an electronic feedback circuit. As the mass begins to move from its rest position in response to ground motion, a sensitive electronic position sensor, one typically based on capacitance variations, detects the change and produces a signal voltage. That signal is then greatly amplified and applied to the coil, so as to almost completely oppose the ground acceleration force and thus maintain the mass very near its rest position. The current in the coil thus becomes an accurate measure of the acceleration seen by the mass, which current, in effect, can then be integrated to provide an output signal representing the vertical ground velocity. Although this may sound rather complicated, it works well.

If the feedback circuit's frequency response curve is properly shaped and the temperature changes of the spring are made to be very slow by means of good thermal insulation, the feedback loop can continually correct for temperature variations without excessively disturbing the instrument's output.

Most modern long-period seismometers use some version of this design.

Brett Nordgren
10 October, 2018

A much more detailed discussion by Prof. Erhard Wielandt may be found at http://gfzpublic.gfz-potsdam.de/pubman/item/escidoc:4019:6/component/escidoc:4020/Chapter_5_rev1.pdf beginning on page 20.