Latest Developments in Very Broadband Seismometer Deployment Possibilities

Abstract

Broadband seismology has changed radically over the last 30 years, from researchers with a large seismological apparatus in their basement vaults to deploying a very broadband seismometer on an Antarctic ice sheet in the brief time it takes to shut off and restart a helicopter! The introduction of new instrumentation that is miniaturized and ruggedized reduces the logistics costs for deploying the lowest noise , very broadband sensors making new approaches affordable and possible. Could a researcher ever conceive of an experiment that could deploy the equivalent of an STS-1 in a temporary array? Broadband vendors continue to evolve and miniaturize traditional force feedback systems to enable researchers to create cost-effective early earthquake warning networks, continental scale rolling arrays, observe glacial seismics and record the ringing of the earth. The newest sensors can have the next logical step in integration from the digitizer to multiple instruments with combined dynamic ranges greater than 200dB. And the next iteration? Geodetic tilt? Atmospheric pressure? We discuss the latest developments that free researchers to deploy new arrays in even the harshest terrestrial conditions by reducing the limitations of the older systems and improving the noise performance, reliability and required logistics support while reducing the complexity.

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Drawbacks of Most Modern Broadband Seismometers

Primarily designed for deployments in temperature controlled vaults with dry, stable piers, a single and limiting use case!
There are probably 100's of VBB pier type instruments available for every well constructed pier…so how are the majority of these sensors installed?

- Cases and connectors made of corrodible materials
- Cases not robust enough to mitigate atmospheric pressure changes
- Cases not designed for pressures of immersion or for contact with other materials such as sand and soils
- Cases not designed with magnetic shielding
- Limited cold temperature tolerance
- Limited dynamic range (more than before but still not enough in EQ zones)
- Limited tilt tolerance
- Majority not deployable in smaller boreholes (<15mm diameter)
- Majority are not "smart" sensors, only analog outputs
- Most have poor electrical transient protection
- Most are designed and treated as a stand-alone instrument and not as a fully integrated part of a seismic station system
- Most can not report their own SOH, metadata, responses and identification
- Most have limited and inadequate vendor support

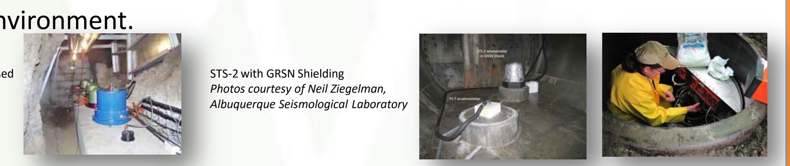
Discussion-Seismology applications and metrics evolved, the user community grew and researchers were awarded significant support in the science community through funding agencies. Instrumentation development has lagged and researchers have been improvising solutions that solved problems of higher noise floor, deploying instruments in a great range of conditions, in greater numbers and requiring less logistical support. Vendors are working on improving their designs for greater capability while reducing the majority costs of fielding and operating these systems in any terrestrial environment.

Temporary vaults using pier-type instruments, time consuming to buy the bits and build, vary in quality and rarely are waterproof

Trillium Horizon, an example of a **NEW** direct bury VBB Sensor, will work on a wet or flooded pier too!
Diameter 170 mm
Height 175 mm
Weight 9.5 kg

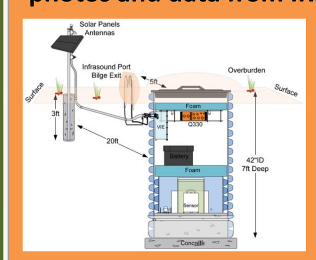
Blue cylinder is improvised pressure case for pier instrument

STS-2 with GRSN Shielding
Photos courtesy of Neil Ziegelman, Albuquerque Seismological Laboratory

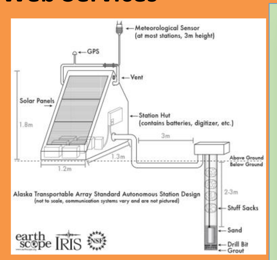


Posthole instruments using augured holes

US Array TA station evolution from left to right, all figures, photos and data from IRIS Web Services



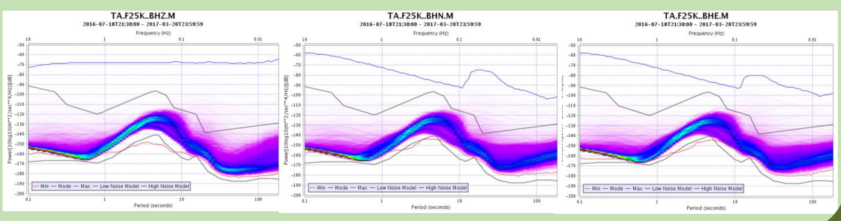
TA Vault based design used for first 8 years with pier style instruments, many stations had water damage



Alaska station design based on cased holes and ***posthole*** type sensors, this station design change lowered horizontal noise floors significantly in longer periods

An average TA AK Station…

TA Station F25K Christian River, AK, USA- Sensor T120PH

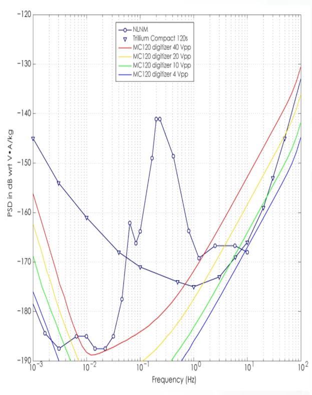


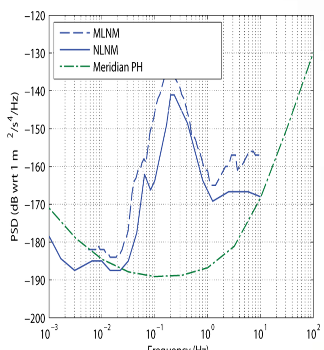
Examples of NEW integrated direct bury portable systems

Meridian based systems with integrated digitizers…if you still want all telemetry options and modern tilt tolerant broad and midband instruments in rugged containers sutiable for any terrestrial environment.

- Small size
- Rugged digitizer and cabling
- IP68, direct buriable
- Lightning and static discharge hardened
- Secure data, sealed data cartridge with industrial SD media
- Redundant data storage (data cartridge and downhole store)
- Self-aware metadata
- Response file generated on demand based on current configuration
- Allows for a unit tilt range of ±5° or ±10°(120PH) or ±2.5° or ±10° (Compact)
- Provides motorized automatic leveling and mass centering that can be remotely initiated(120PH)
- Leveling system that levels the internal seismometer to true vertical and horizontal orientation
- There is no mass lock
- Power required recording in autonomous mode 1.4W 120PH and .9W Compact

Compacts sensor and digitizer self noise





120PH self noise

Pressure vessel ideally suited to uncased or cased posthole installations

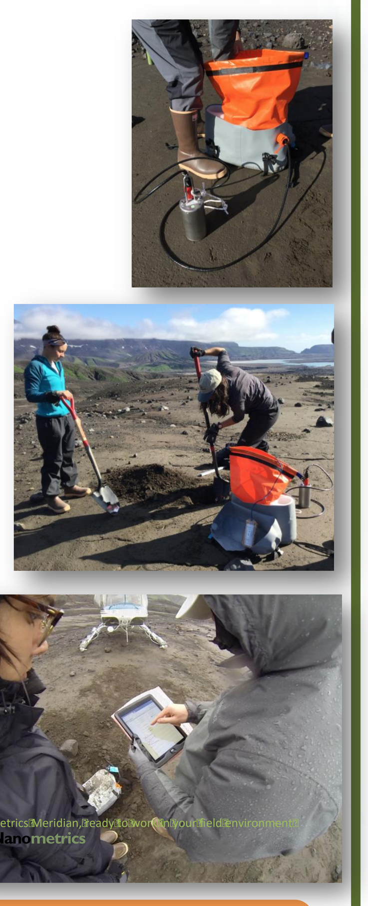
- Is made of stainless steel with a fully waterproof detachable cable entrance designed for continuous submersion.
- Posthole 120 is 143 mm (5.63 in.) outside diameter that allows for installations in narrow cased hole environments. Compact is 97mm (3.87 in.) outside diameter.
- Has a centered eyebolt in the end cap for attaching a lifting chain or strain relief cable
- The eyebolt has a load rating of 590 kg (1300 lb)

Exceptional performance that makes them ideal for teleseismic, regional, and local studies by providing:

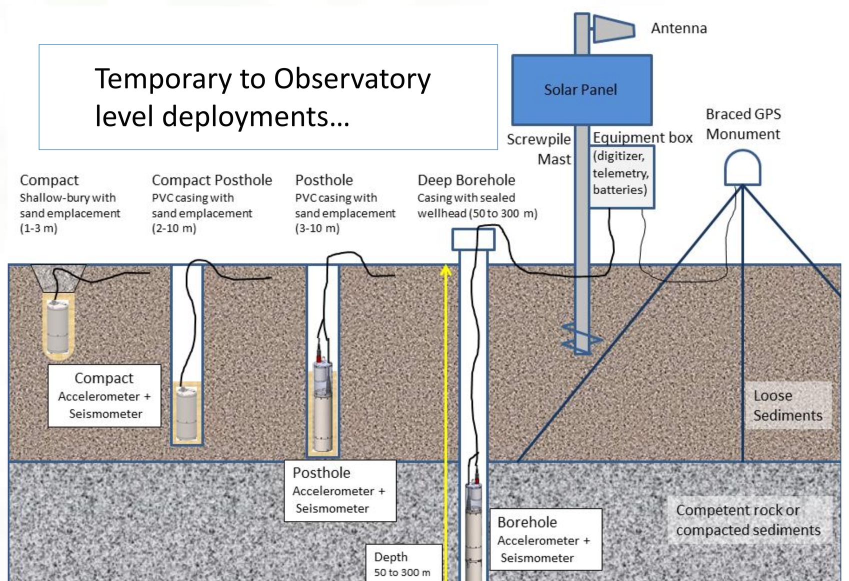
- An extended low frequency range useful out to beyond 1000 seconds (120PH)
- Low sensitivity to both tilt and temperature(120PH). Recentering is rarely required after the initial installation.
- The ability to resolve Peterson's new median-noise model (NLNM) down to a 200 second period(120PH)
- A wide dynamic range with a clip level of 16.6 mm/s up to 10 Hz and 0.17 g above 10 Hz(120PH)
- A symmetric triaxial arrangement of the sensing elements that ensures uniformity between vertical and horizontal outputs
- The ability to remotely select either the raw (UVW) or resulting horizontal-vertical (XYZ) outputs allows for the calibration of each axis separately.

Digitization, featuring:

- An intuitive Web interface accessible via Ethernet connection
- True 24-bit performance
- Dual sample rates of up to up to 2000 sps--only in streaming mode. 500sps maximum for continuous archiving mode
- Advanced bandpassed triggering
- Data retrieval via a removable SD™ card or local Ethernet in MiniSEED and SEGY file Formats
- Event peak ground motion statistics: acceleration, velocity, and displacement
- Acquisition and data management of high precision GPS data (BINEX)
- Comprehensive real-time communications options include SeedLink support
- Data latency as low as 1 second



New station options: Near-surface, posthole, borehole, icehole, snowhole!



The multi-use station design comprises power, telemetry, digitizer/data logger, seismic sensors and possibly other sensors such as high-rate GPS/GNSS instrumentation. Three options are considered for the site:

Near-surface: Direct-bury, typically to 1m, in an uncased hole, backfilled with sand. The 6-channel sensor is a Class-A accelerometer integrated with a compact 120s broadband seismometer in a compact posthole form factor.

Posthole: PVC or steel-cased hole 3-10m, backfilled partially with sand. The 6-channel sensor is a Class-A accelerometer integrated with an auto-levelling 120s or 360s broadband seismometer in a full posthole form factor.

Borehole: Steel-cased dry borehole drilled 50-300m. The 6-channel sensor is a Class-A accelerometer integrated with an auto-levelling 120s or 360s broadband borehole seismometer with a motorized holelock.

Sensor/digitizer integration benefits

The seismic signal digitizer is a key component of a integrated station, where specific advances are focused on delivering multiple data streams tailored for the different uses of the station data, as well as optimizing the cost and convenience of installation and operation.

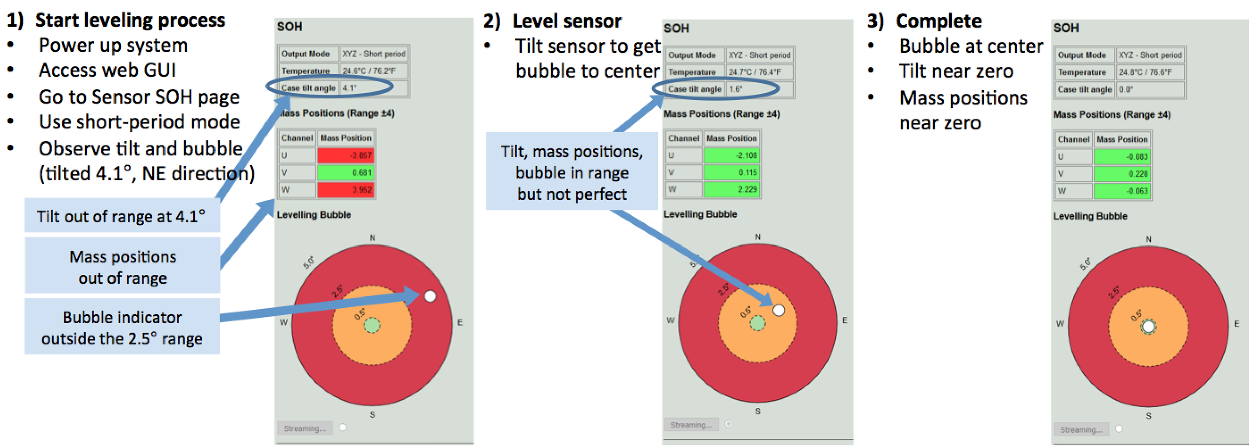
Installation and configuration:
Tight integration between the seismometer and digitizer can enable rapid, convenient installation and reduce errors.

- Use the seismometer's electronic leveling bubble displayed on digitizer web GUI while sensor is powered up

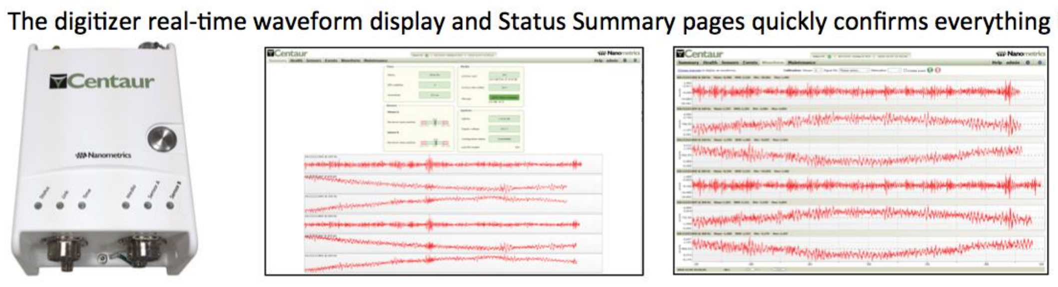
1) Start leveling process
- Power up system
- Access web GUI
- Go to Sensor SOH page
- Use short-period mode
- Observe tilt and bubble (tilted 4.1°, NE direction)

2) Level sensor
- Tilt sensor to get bubble to center

3) Complete
- Bubble at center
- Tilt near zero
- Mass positions near zero



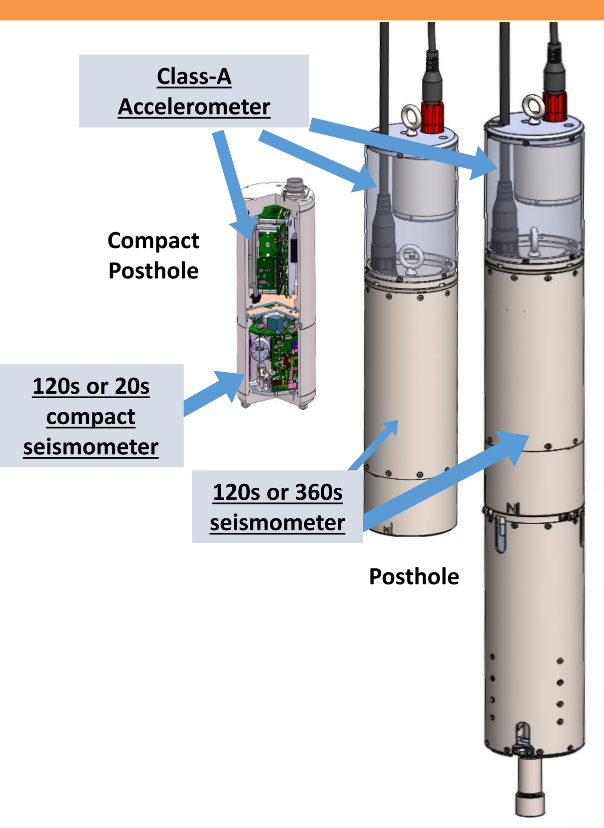
- The digitizer real-time waveform display and Status Summary pages quickly confirms everything is working



Examples of NEW integrated Earthquake Early Warning systems

Cascadias are the combination of proven high-performance strong motion and weak motion seismic sensors into a single integrated modular unit that can be installed as a single instrument. Cascadia provides several advantages for installation as well as improved performance.

Several options can be considered, incorporating a variety of physical form-factors, seismometer technology, and accelerometer signal range selections.



Form-factors:
- Compact posthole 97mm(3.8") diameter
- Auto-leveling full Posthole 143mm(5.75") diameter
- Observatory-class Borehole 143mm(5.75") diameter

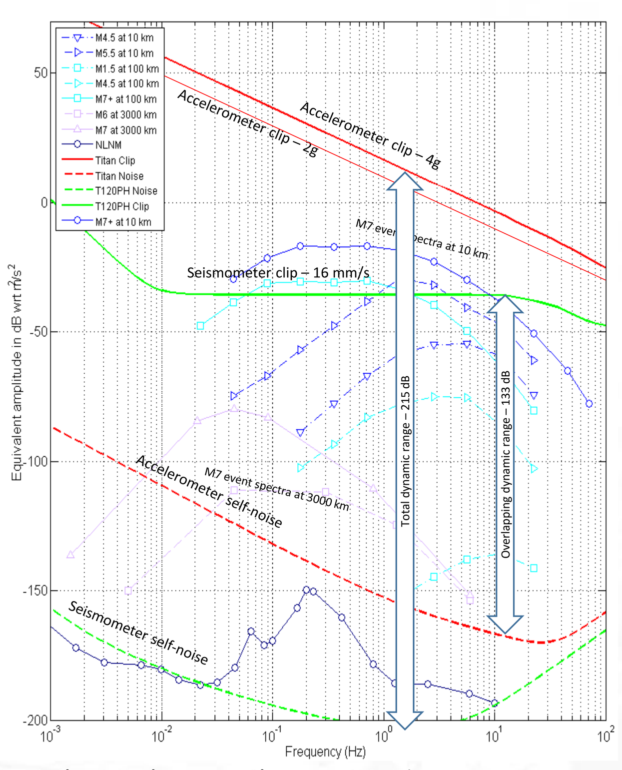
Seismometer technology:
- Compact Broadband - 120s (in compact form-factor)
- Compact 10° tilt-range - 20s (in compact form-factor)
- Observatory-class – 120s (in full posthole or borehole)
- GSN-class – 360s (in full posthole or borehole)

Accelerometer range:
- Dynamic selection of signal range: ±4g, ± 2g, ± 1g, ± ½g, ± ¼g

Site and installation improvements
- Two sensors managed as one
- Bore or dig one hole, whether shallow or deep borehole
- Manage one cable (compact form-factor)
- Level and align once
- Electronic leveling bubble on digitizer GUI
  - Easily manipulate the compact posthole in a dark hole
  - Check vertical orientation of sensor at any time remotely
  - Observe verticality of borehole casing during installation

Performance and operational improvements
- Always on-scale: local large magnitude as well as very weak signals recorded with the high combined dynamic range of the two sensors
- All six channels precisely aligned
- Surface noise (cultural, temperature, tilt) reduced, even with shallow burial

Graphical view of combined sensor dynamic range, showing maximum recordable signals (clip level), minimum discernable signals (self-noise floor), typical earthquake spectra at various magnitudes and distances, the Peterson New Low Noise Model, and the overlapping and total dynamic ranges. One example is shown: a Titan 4g accelerometer combined with a Trillium 120 Posthole. Other options can be considered, e.g.: GSN-class 360s seismometers, configuring the accelerometer to 2g and for high density arrays at a lower cost a Titan 4g combined with a Trillium Compact 120 second PH.



4g Class A Accelerometer + Observatory 120s Seismometer