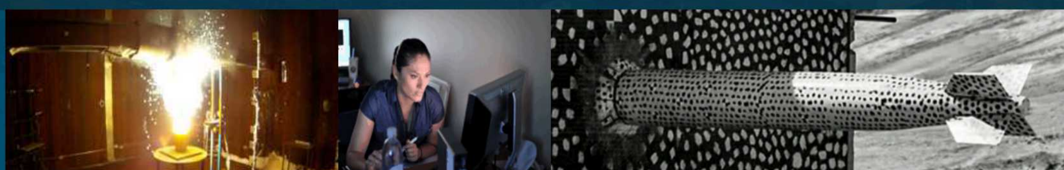
SAND2019-11276PE

Detection of Buried Machinery in Underground Tunnels Using Three-Dimensional Seismic Gradiometry: Proof of Concept

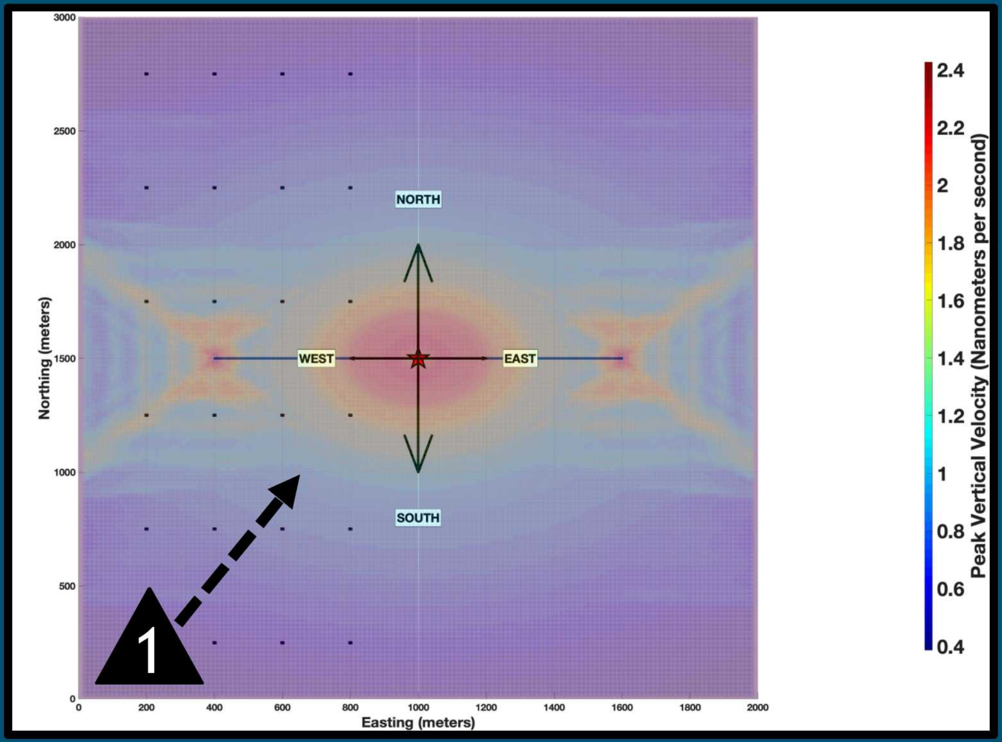


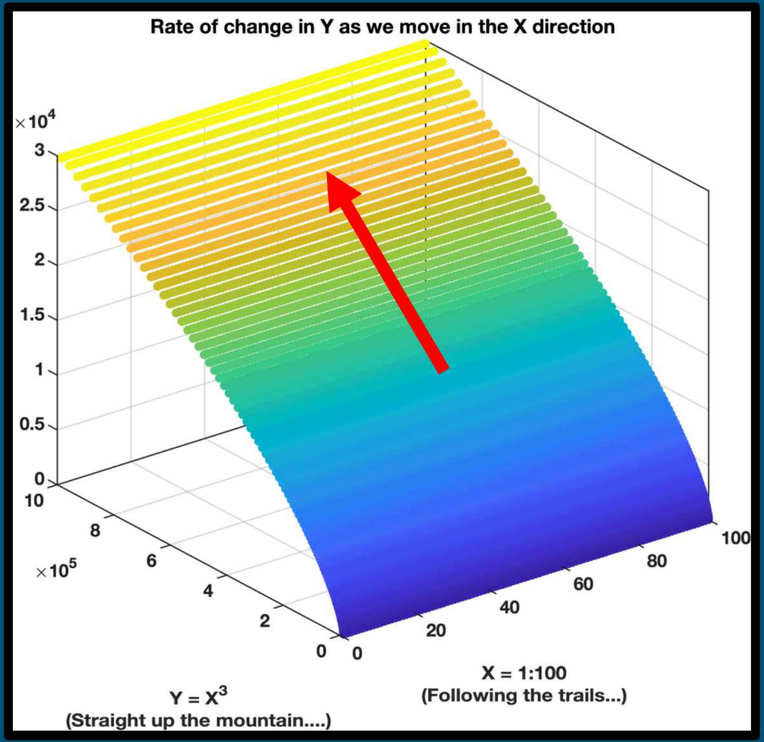
Charles Hoots, Richard Jensen, Leiph Preston, Christian Poppeliers

Sandia National Laboratories is a multimission laboratory managed and operated by National Technology & Engineering Solutions of Sandia, LLC, a wholly owned subsidiary of Honeywell International Inc., for the U.S. Department of Energy's National Nuclear Security Administration under contract DE-NA0003525.

Seismic Spatial Gradiometry Method: Summary

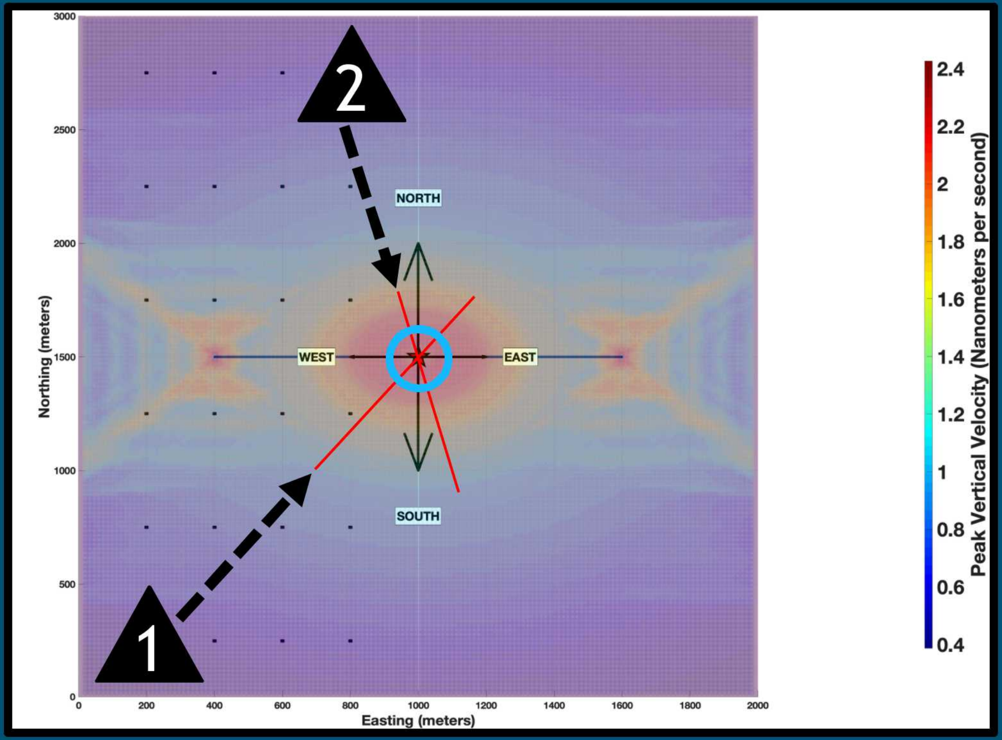
1. **Seismic gradiometry works by deriving the slope of the incoming wavefield to get a speed and directional vector of the wave at each array.**

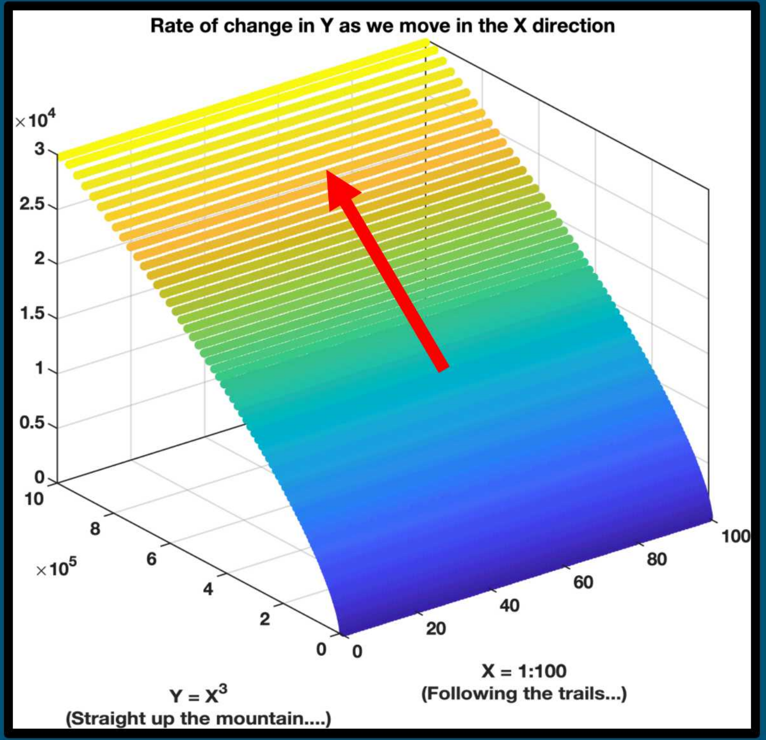




Seismic Spatial Gradiometry Method: Summary

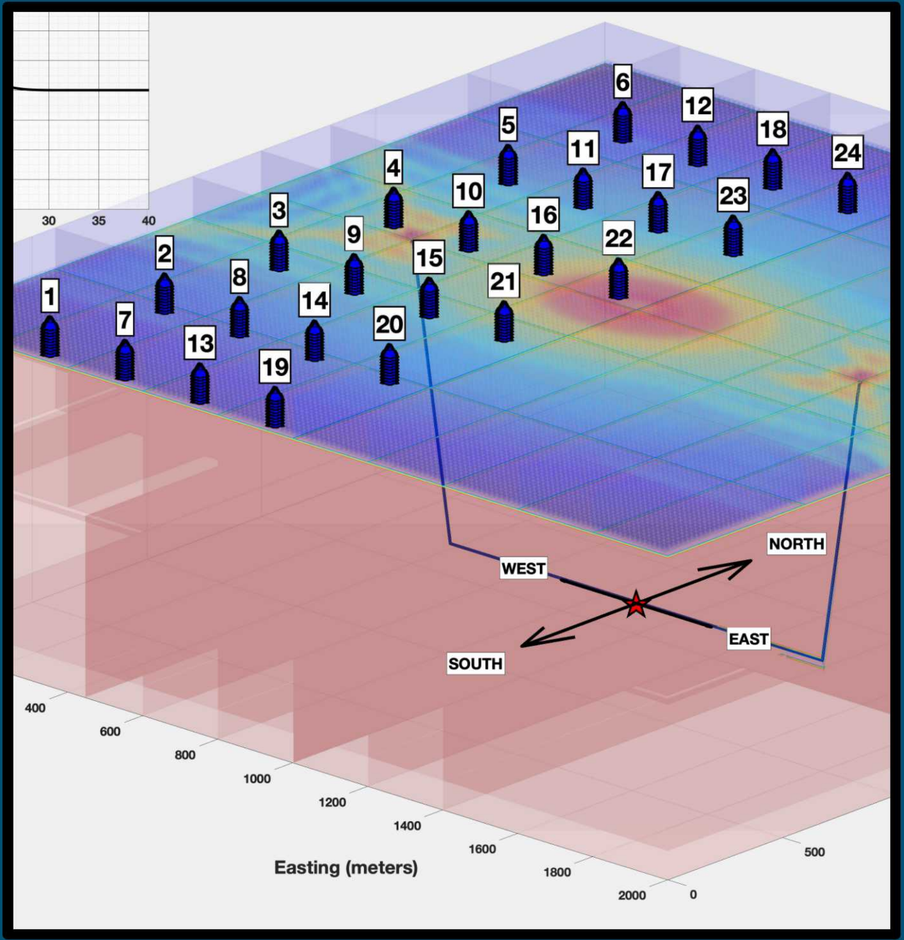
1. Seismic gradiometry works by deriving the slope of the incoming wavefield to get a speed and direction of the wave at each array.
2. We can use multiple arrays to see if and where these directional vectors intersect.





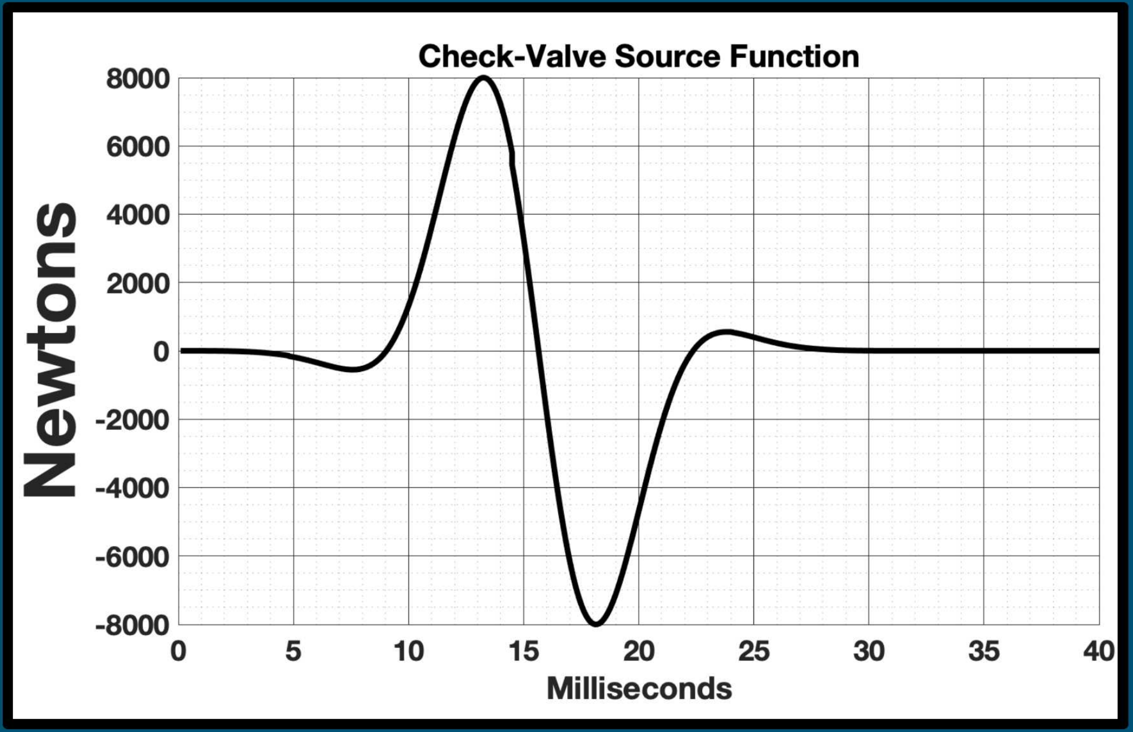
Experimental Design: Basic Model

1. Design a very basic seismic velocity model (P-wave) representative of hard rock velocities in the near surface U.S.A.
    1. A medium similar granite or gneiss (~5,0000 m/s).
2. Build a simple tunnel design through the model.
    1. 1m wide and 1m tall, that goes down to 100m depth at a 45˚.
    2. Then laterally traverses 1.0 km before coming back to the surface at a 45˚ angle. Tunnel is 1.3km long in total.



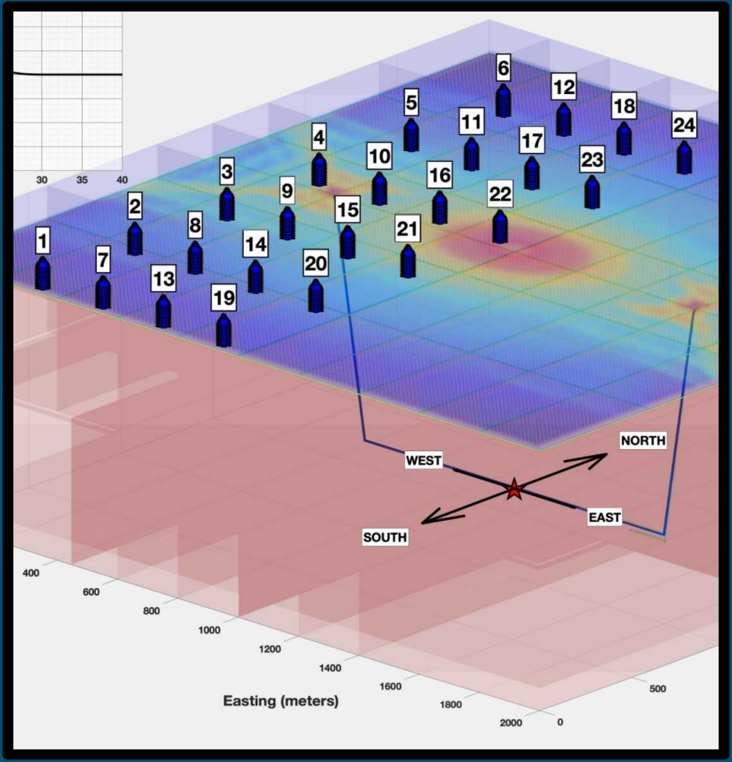
Experimental Design: Check Valve Source

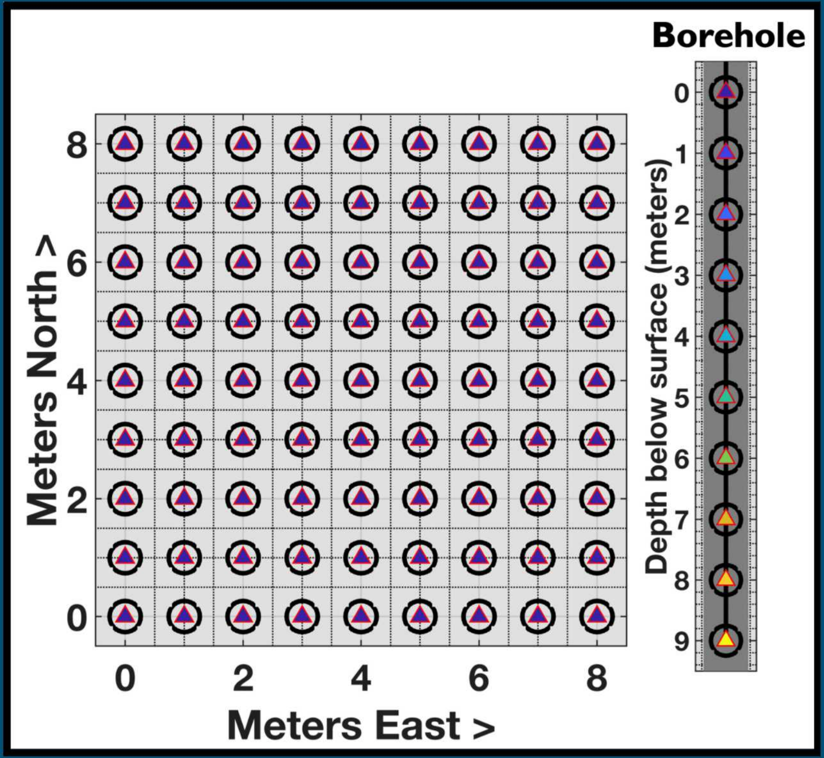
3. Simulate a man made source inside the tunnel.
    1. In the center of this tunnel, simulate a source that represents a 4-inch wide check valve lid shutting under the pressure of water over the course of ~20 milliseconds (50 Hz). A frequency just barely audible by humans.
        1. Aside: Check-valves are used in systems designed to pump water out of a flooding tunnel during and following their construction.
    2. With 100m of overhead water pressure on the valve (tunnel is 100m deep), a 4 inch valve can shut with the force of 8,000 Newtons.
        1. As an example, the average human exerts a constant 600 Newtons of force on the Earth at all times.
        2. So this is about equal to a baker's dozen people jumping all at once.



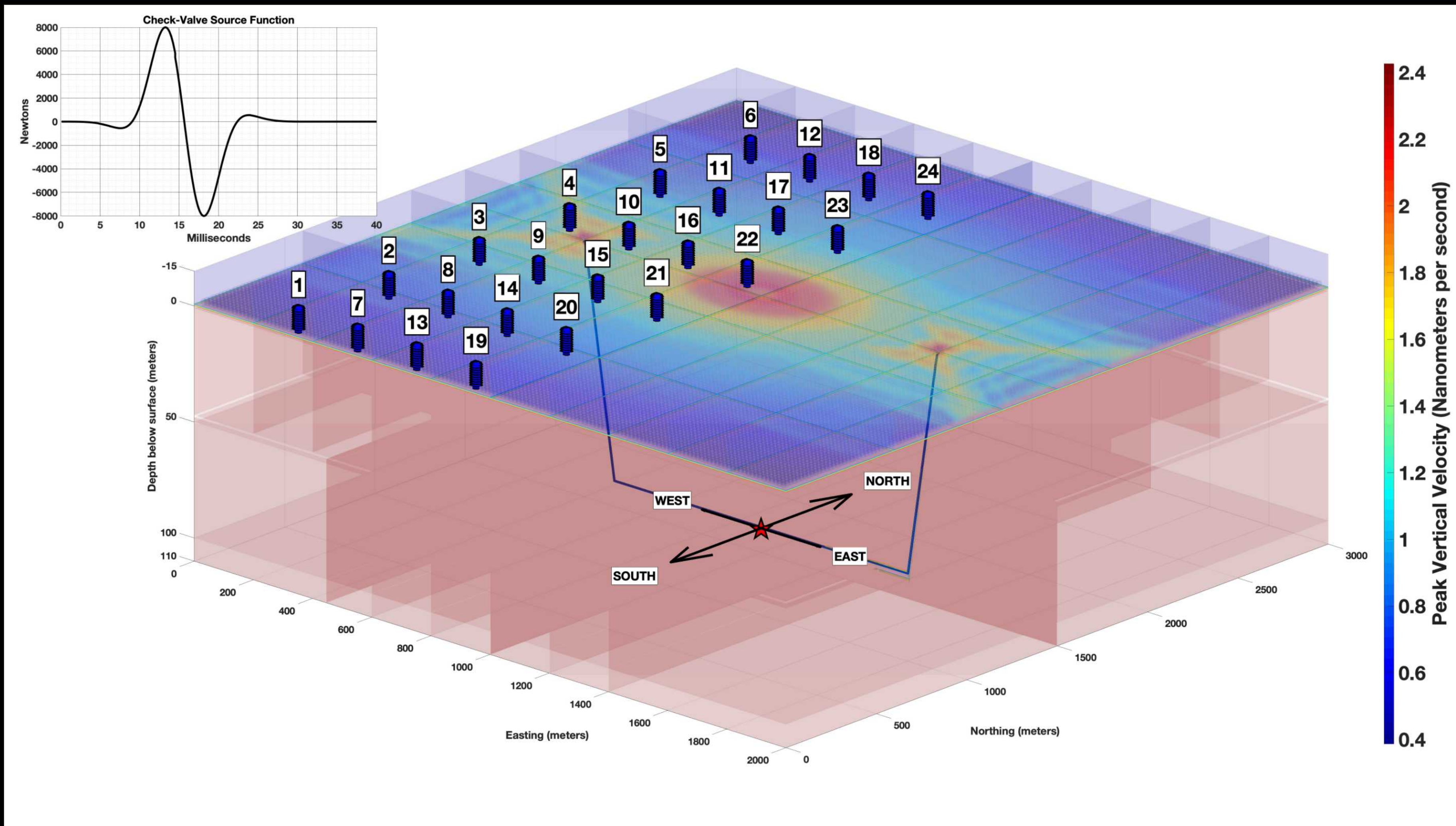
Experimental Design : Sub-Array Geometry

4. Populate area with a series of borehole seismic sub-arrays that we can later decimate to see how little data we can get away with using for locating the source.
    1. Each sub-array will be only 8-9 meters (~26 ft.) in diameter <u>and</u> depth.
        1. Generally speaking, this is an extremely small footprint for a seismic array.

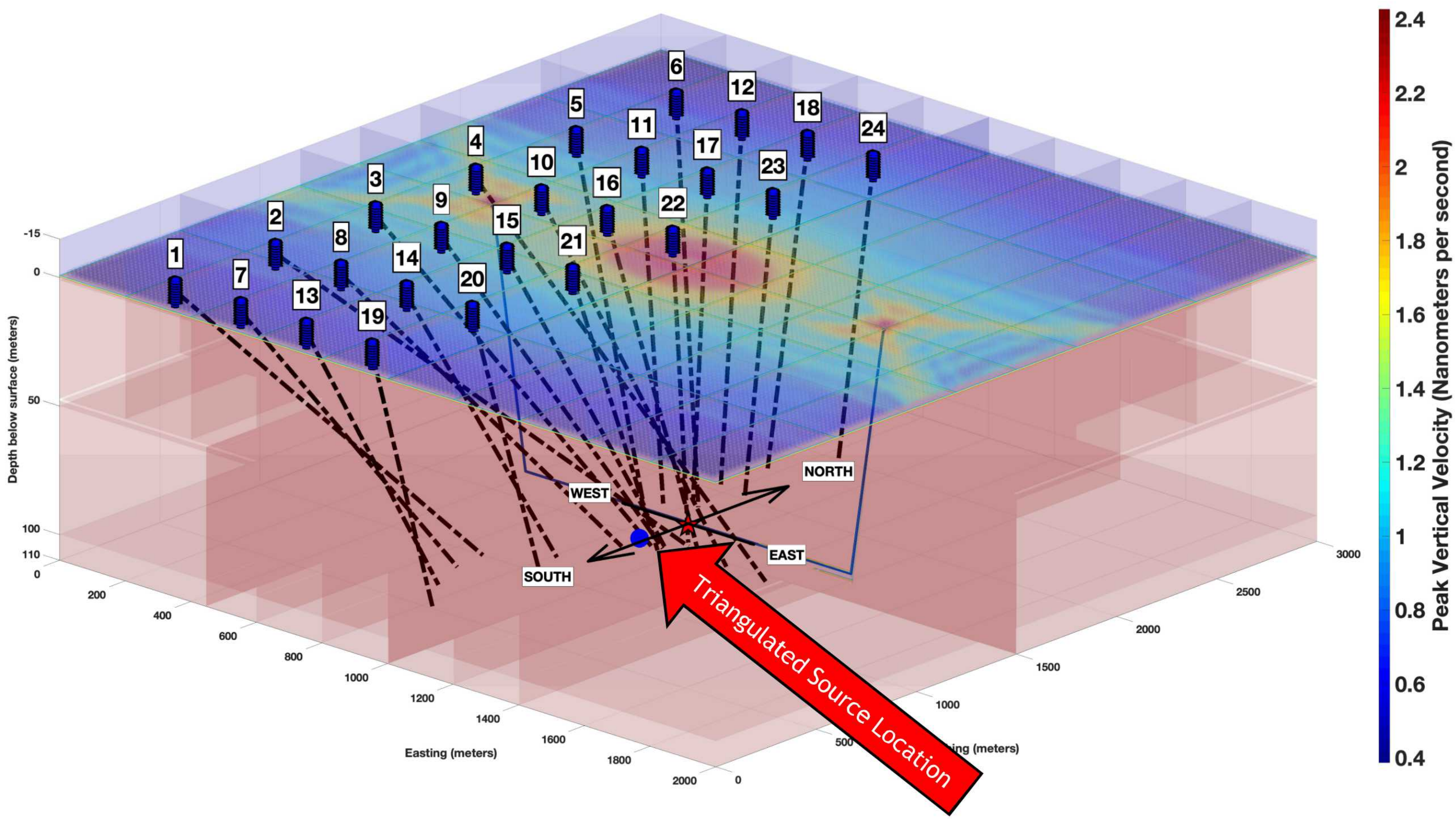




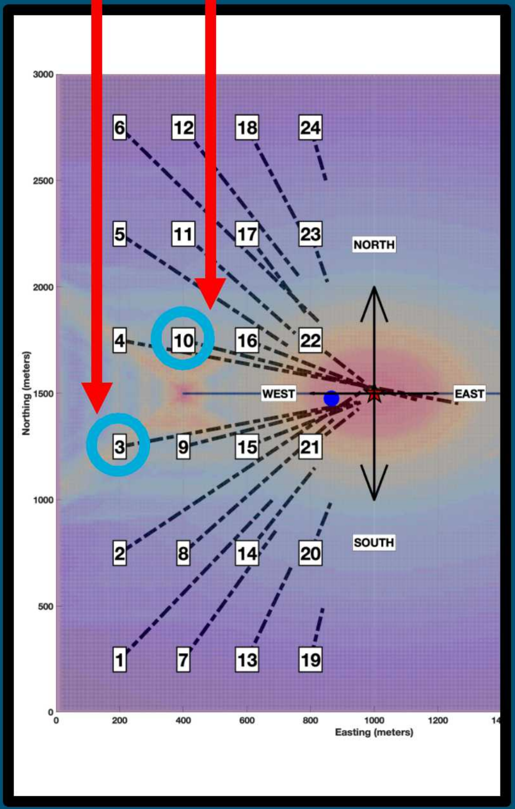
Generalized Model



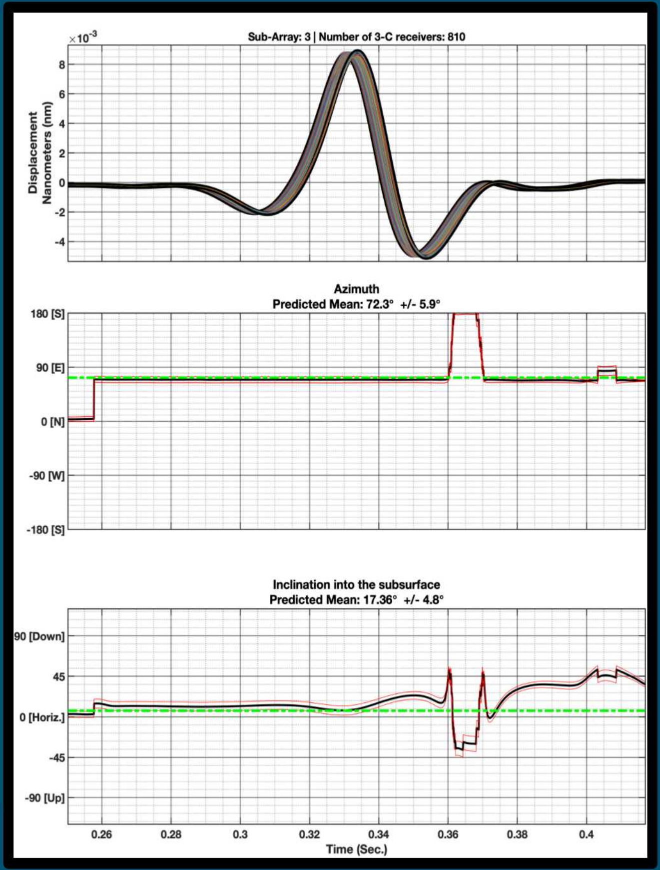
Perspective View



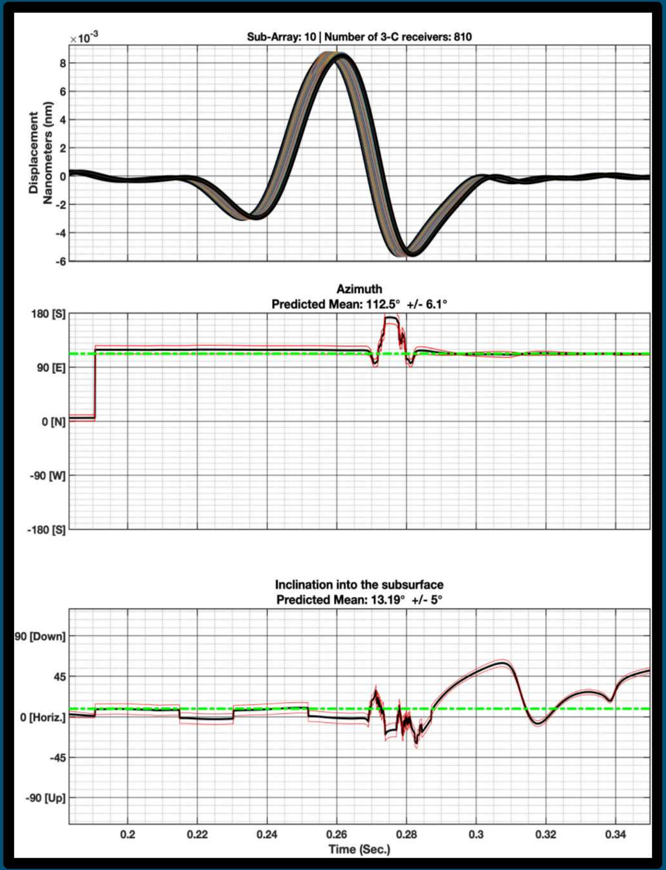
Analysis of results



Array 3



Array 10

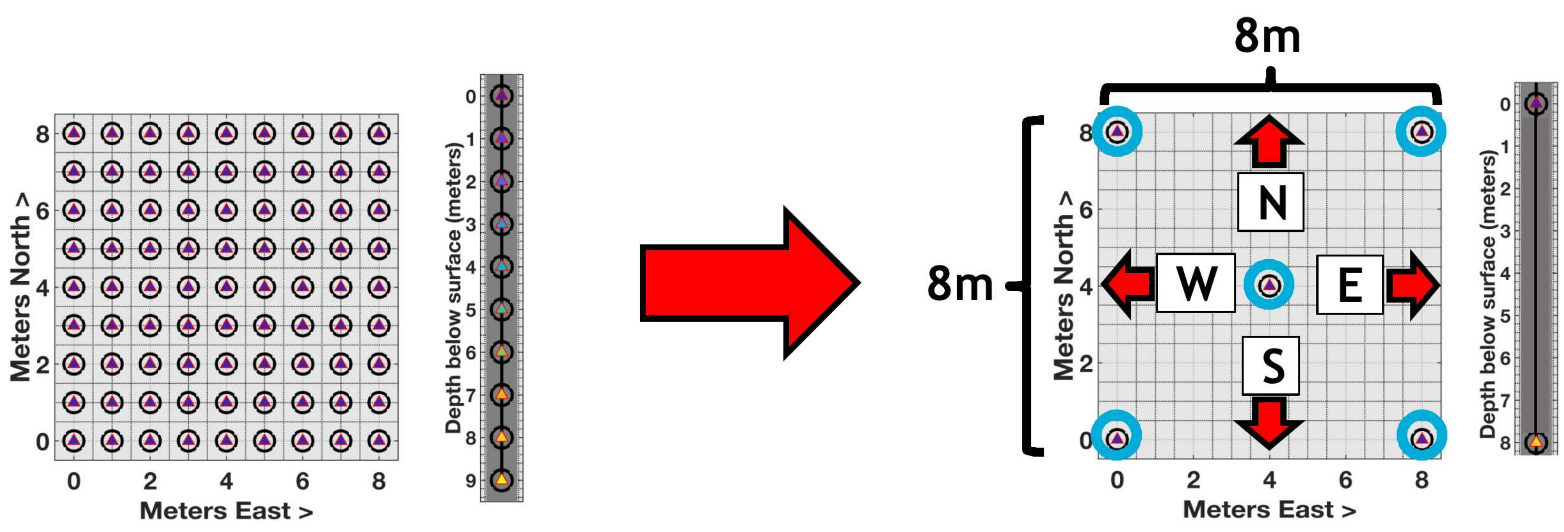


Stress testing the concept: From the ideal case to the more realistic (and cheaper) case.

Using only **THREE** sub-arrays and reducing the amount of receivers in each **99%**, can I still locate the source?

-64 boreholes
-Each one is 9m deep

-5 boreholes
-Each one is 8m deep

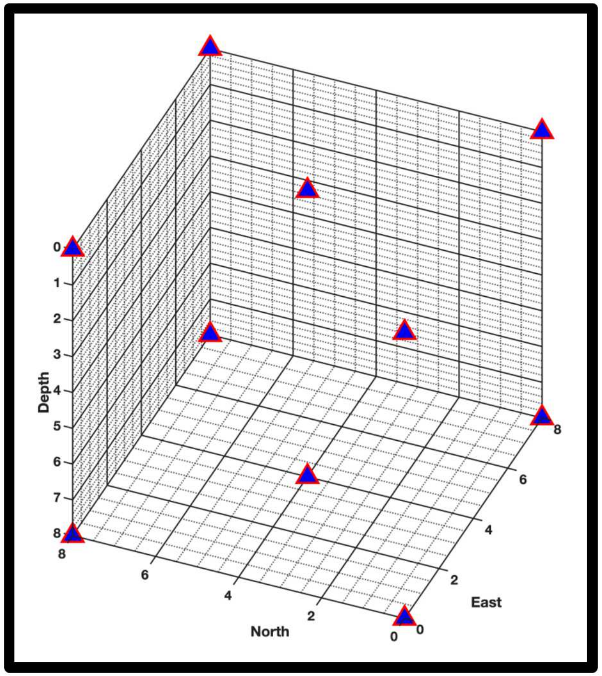


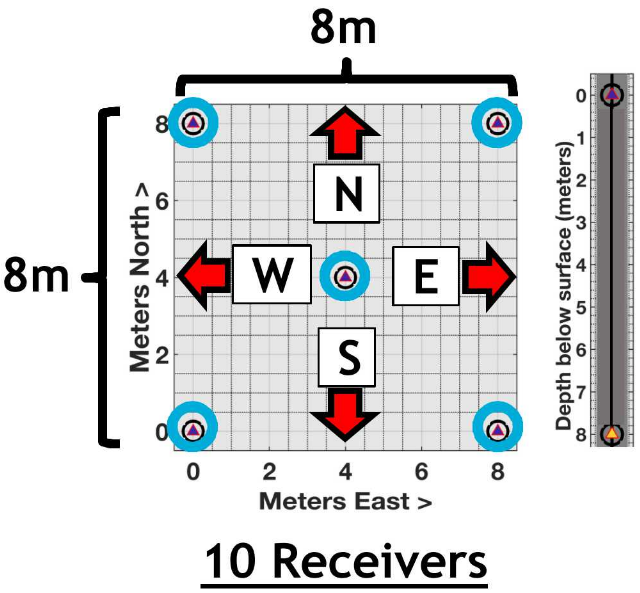
810 Receivers

10 Receivers
(99% reduction)

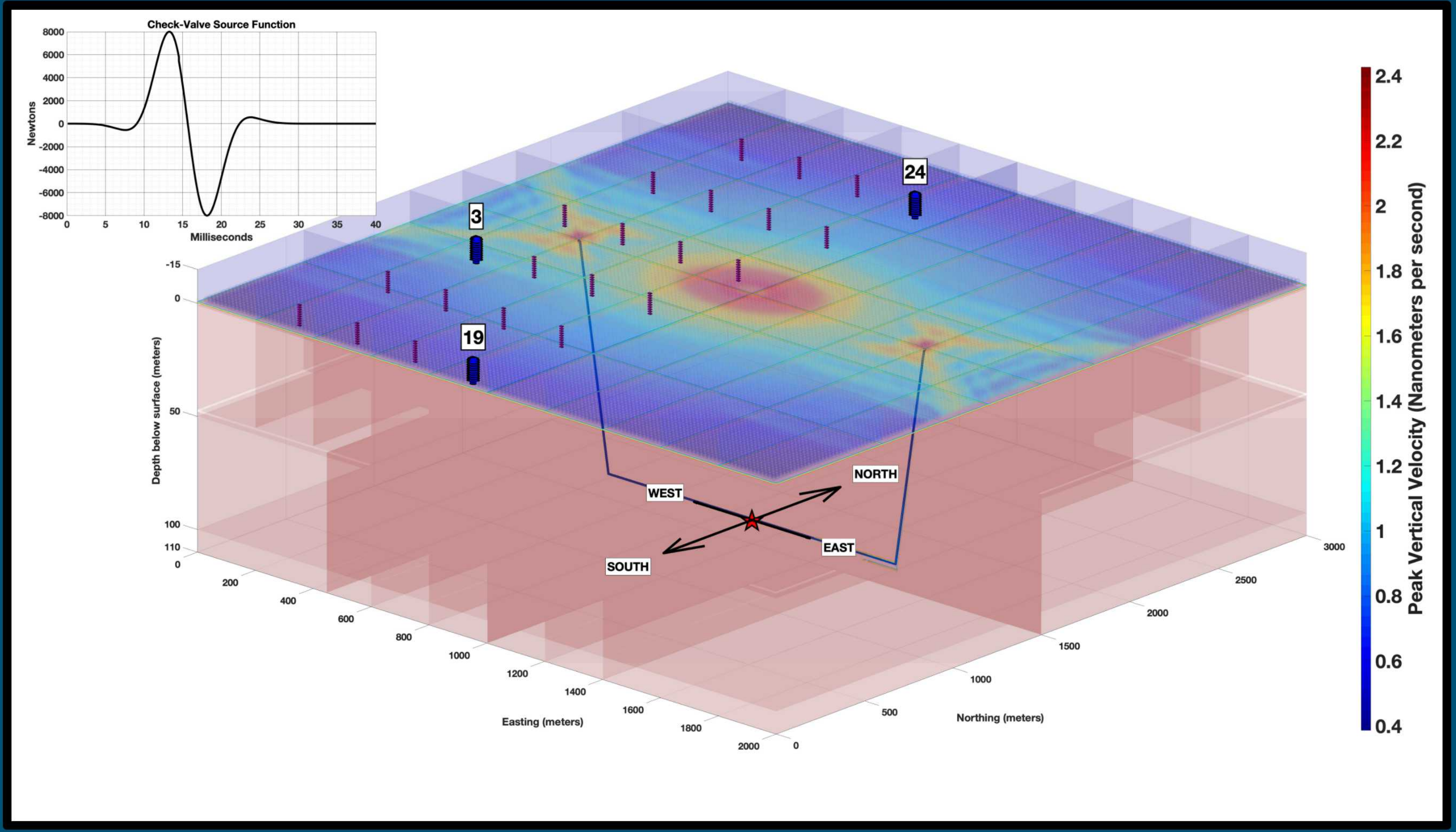
Stress testing the concept: From the ideal case to the more realistic (and cheaper) case.

Using only **THREE** sub-arrays and reducing the amount of receivers in each **99%**, can I still locate the source?



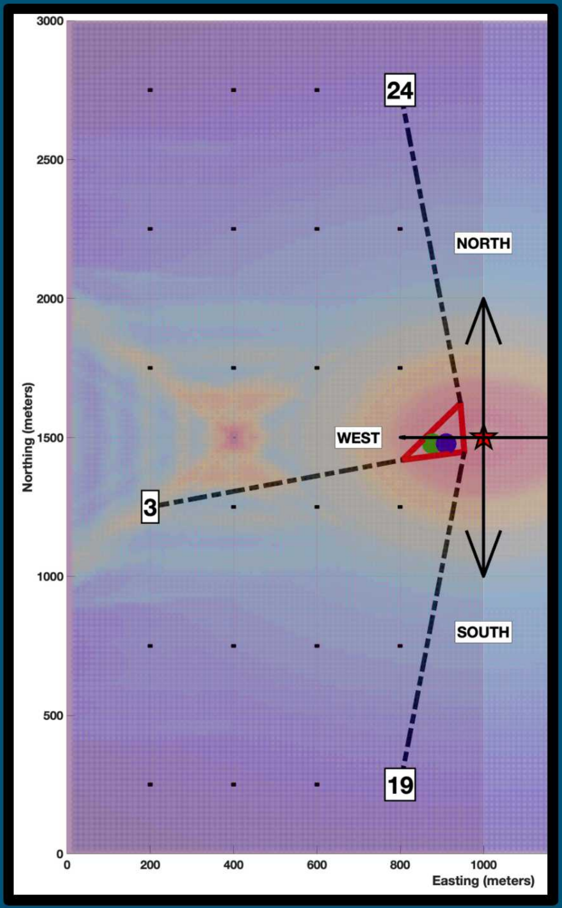


A Simpler Array Design....

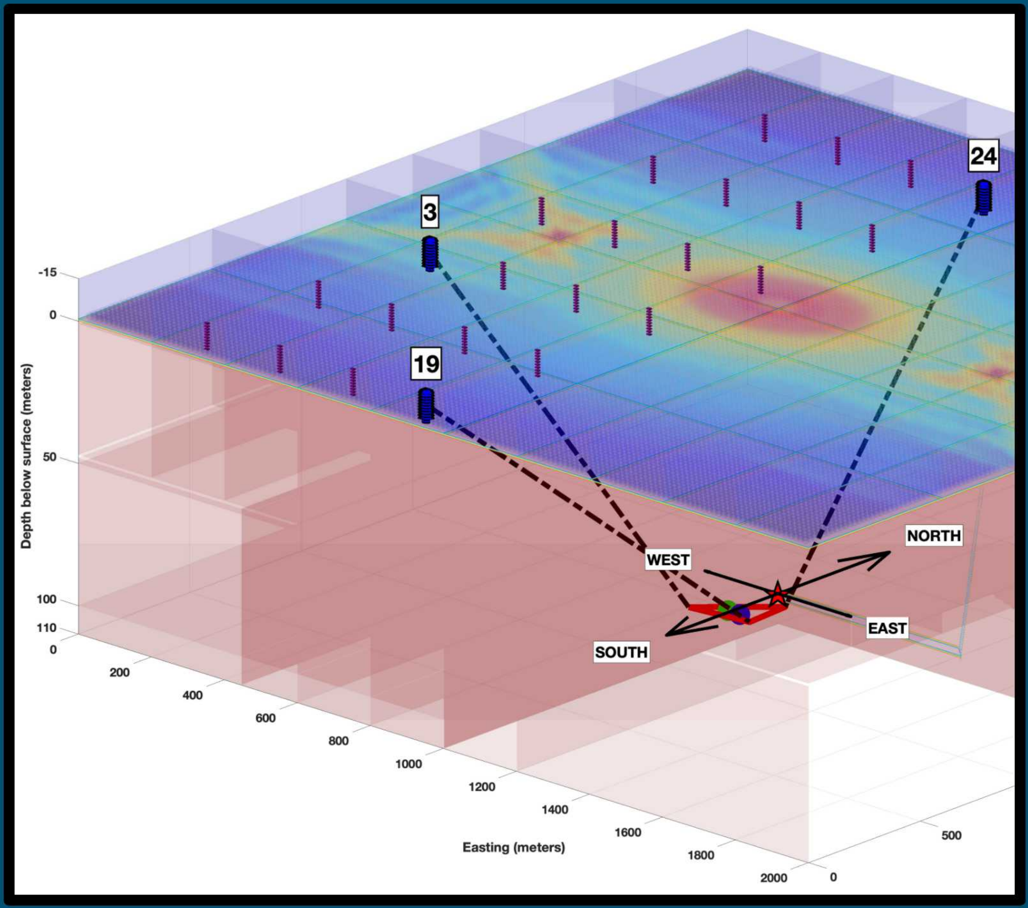


Results: It worked!

Top Down View

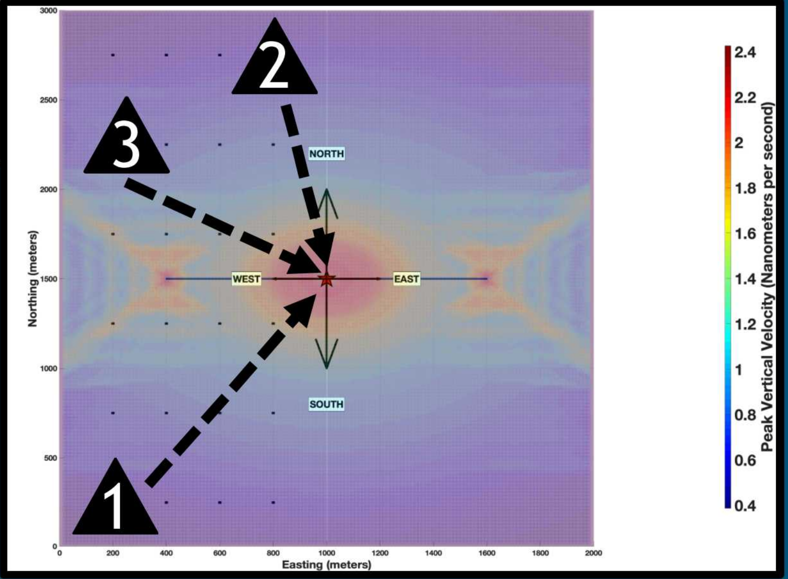


Perspective View



Concluding Remarks

1. **Concerning using seismic spatial gradiometry for locating man made sources in the subsurface (e.g. tunnels):**
    1. **This proof of concept successfully demonstrates the viability of the technique for locating man made sources in the subsurface. In this case, a small and long tunnel with a check valve pump system.**
    2. **The solution (locating the source) is highly sensitive to array design more than array data volume.**
        1. Spatial variety (depth and azimuth) and diameter for a given array can be more important than the volume of data in in any given sub-array.
    3. **Each of these sub-arrays calculate the source location independent of each other.**
        1. For this reason, the intersection of predicted locations from multiple sub-arrays spread over kilometers could provide a operational capability to locate tunnels as they are being made.
        2. Such a capability could be integrated into a well designed passive telemetric seismic network that continuously locates and reports the intersection of located subsurface signals.
    4. **This can also be implemented in 2D:**
        1. **Surface arrays will yield a map location (no depth)**
        2. **A much simpler (and quicker/cheaper) deployment.**



End

1. **Concerning using seismic spatial gradiometry for locating man made sources in the subsurface (e.g. tunnels):**

    1. **This proof of concept successfully demonstrates the viability of the technique for locating man made sources in the subsurface. In this case, a small and long tunnel with a check valve pump system.**

    2. **The solution (locating the source) is highly sensitive to array design more than array data volume.**
        1. Spatial variety (depth and azimuth) and diameter for a given array can be more important than the volume of data in in any given sub-array.

    3. **Each of these sub-arrays calculate the source location independent of each other.**
        1. For this reason, the intersection of predicted locations from multiple sub-arrays spread over kilometers could provide a operational capability to locate tunnels as they are being made.
        2. Such a capability could be integrated into a well designed passive telemetric seismic network that continuously locates and reports the intersection of located subsurface signals.

    4. **This can also be implemented in 2D:**
        1. **Surface arrays will yield a map location (no depth)**
        2. **A much simpler (and quicker/cheaper) deployment.**

End.

Questions?

Acknowledgement:
We are thankful for the support of the **National Geospatial-Intelligence Agency** who funded this effort.