Norwegian
Water Resources and
Energy Directorate

NVE

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Snow pillow measurements in Norway

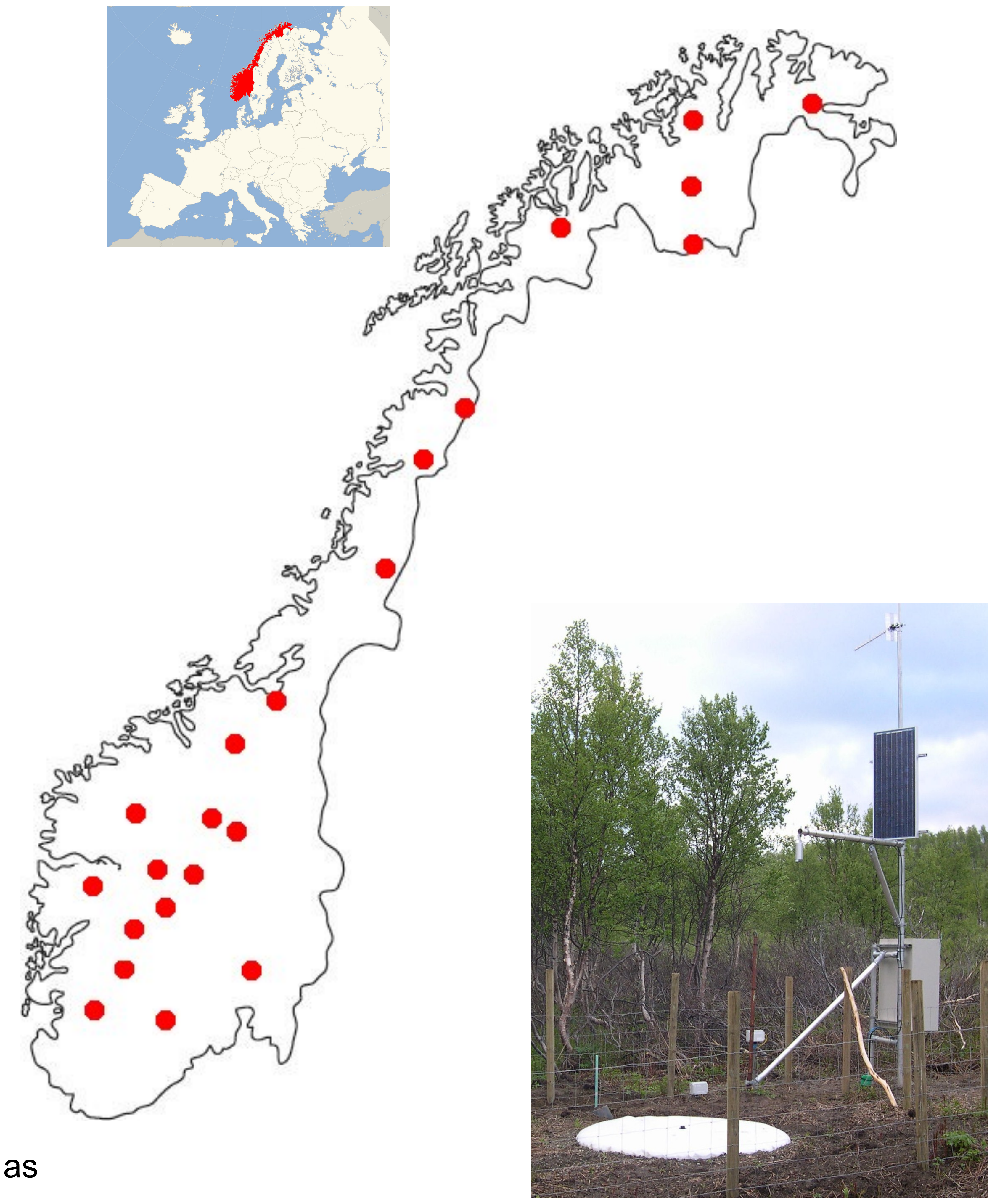
Snow pillows in Norway

As 50 % of annual precipitation falls as snow in Norway access to real time snow data is of great importance. Snow data is primarily used for hydropower planning (98.3 % of total energy production) and flood forecasting.

NVE has from 1967 built a network of 24 automatic snow pillow stations.

- Site altitudes 30-1200 meters a.s.l.
- Annual SWE_{max} 200-1700 mm
- Latitude 58°N – 79°N

NVE snow stations will have at least one 2.5 m^2 white PVC pillow filled with ethanol or glycol, with two pressure sensors and ultrasonic snow depth sensors. Data transfer is via cellular networks and the stations run on solar power.



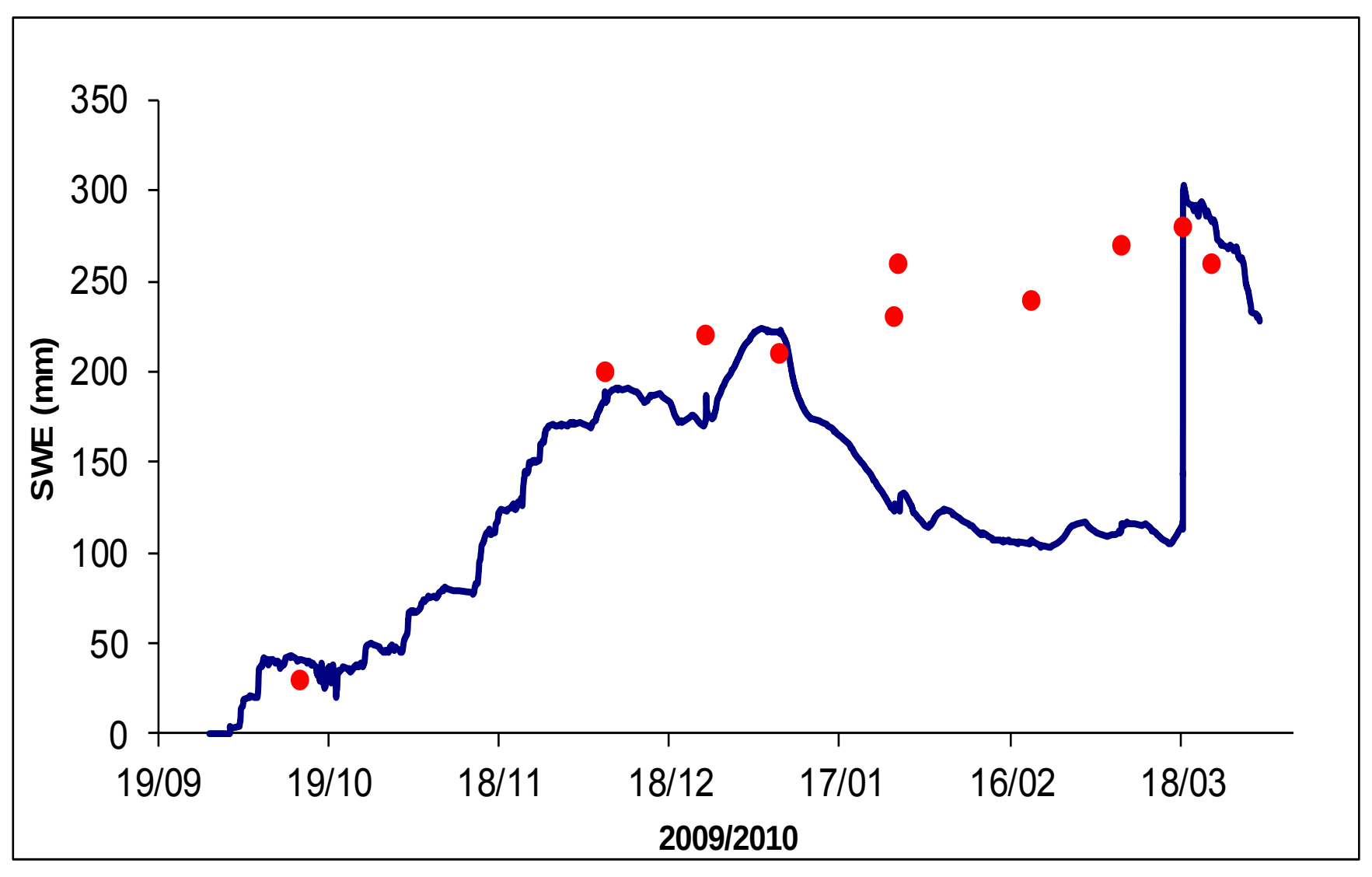
Bridging / pressure relief

Norwegian winter climate

- *Western part* - relatively mild winters, with rain on snow causing multiple crust layers in snow pack. Bridging problems almost every year.
- *East and Northern parts* - Stable, cold winter conditions. Precipitation only as snow at high altitudes. Snow pillows works generally well.
  Less stable at lower altitudes - bridging problems occasionally.

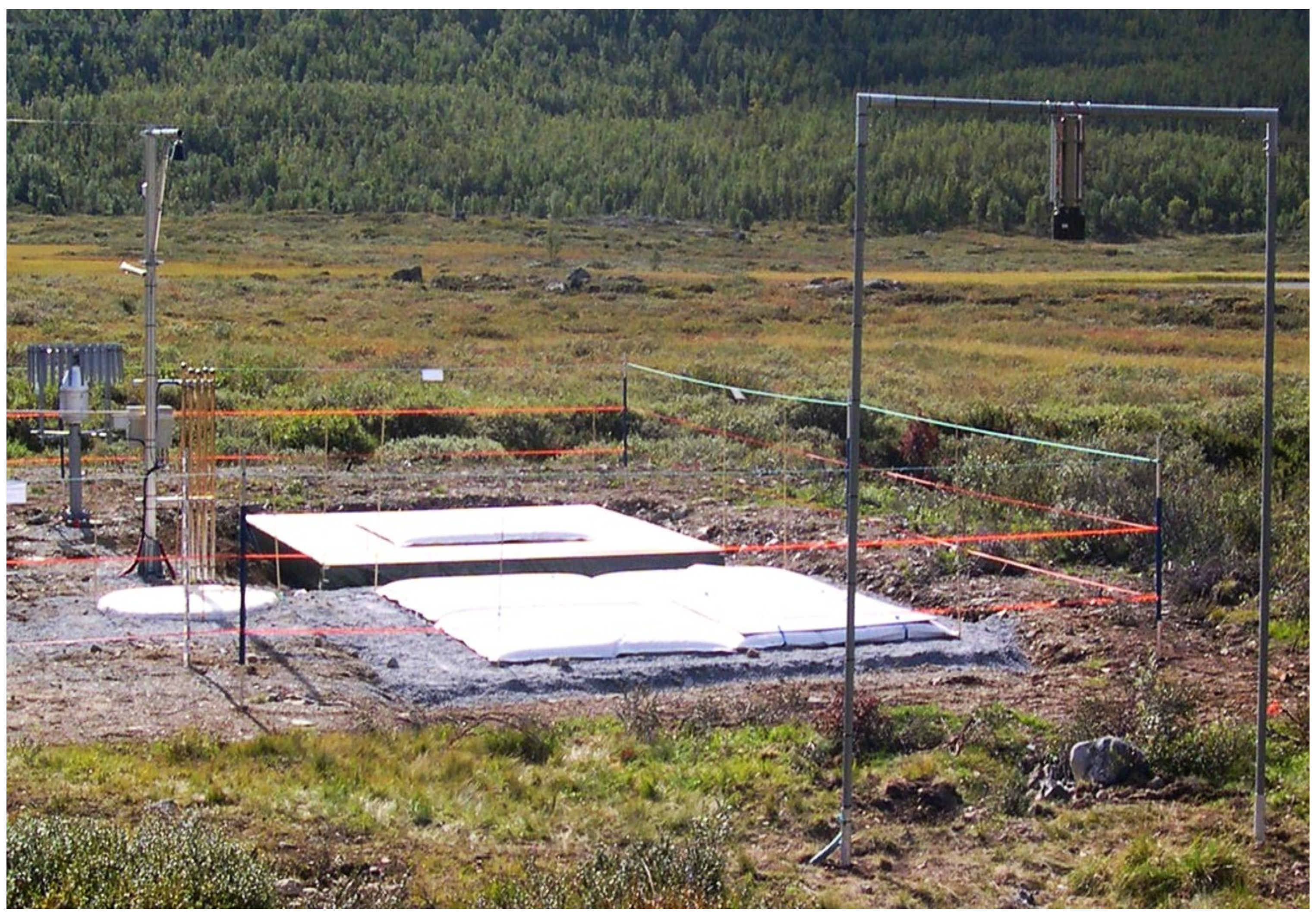
Snow brigde detection

- Unexpected decrease in SWE are assumed to be bridging effects.
  Snow on top of pillows were dug off and put back to break any snow bridges within the snow packs. SWE readings got back to expected levels, corresponding to manual measurements.
- One way of investigating bridging effects without changing the snow pack is to have a standard size snow pillow on top of a larger snow scale. This will be tested for the winter 2010/11.



Overcoming bridging problems

- By increasing size, the bridging errors are assumed to be reduced. Tests are being conducted using 4 squared pillows of all together 25 m^2 at two stations.
- The heat capacity and heat transfer properties of pillows change the natural thermodynamics. To mitigate this, a 25 m^2 wooden snow-scale with 0.5m air underneath is being tested at one station.
- On two sites hard tops of waterproof plywood are added to the flexible PVC pillows to avoid pressure relief from partly compressed areas on the pillows.
- … or replace pillows all together! In the 2010/2011 season passive gamma sensor is tested as an alternative to pillows. This sensor type is non-contact, do not measure pressure and hence will not be affected by bridging problems.



NVE has established a test site for snow gauging equipment (*Filefjell Snow Science Site*) with focus on bridging problems and gauging methodology comparison. The site is equipped with a full meteorological station, soil- and groundwater monitoring and radiometric measurements.

All of NVEs data are freely available to researchers, and we are eager to cooperate with other institutions.

An Experimental Investigation of Explosives and Snowpack Dynamic Response

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INTRODUCTION

Explosives are frequently used for avalanche control in public transportation corridors and within ski area boundaries. However, relatively little field research has been conducted to measure dynamic snowpack response parameters resulting from explosives use - specifically, the acceleration magnitudes within the snowpack, and the relationship between snowpack response to charge proximity, size, or repetitive charges at the same location. References (1), (2), (3).

Project Goals:

1) Develop a field-portable instrumentation suite capable of capturing snow dynamic response and air blast overpressure.
2) Measure the effect of blast range on snowpack response.
3) Measure the shock attenuation through the snow depth.
4) Measure the effect of explosive placement relative to the snow surface and explosive size.
5) Measure changes in snow pack response when subjected to repeated explosive shots at the same location.

Project Overview:

Six field experiments (11 detonations) were conducted at a site adjacent to the Bridger Bowl Ski Area during the 2010 winter. Snowpack dynamic responses were measured through the depth and at two ranges with various explosives and placements.

- 0.9kg and 1.8kg charges of Pentolite cast boosters
  - Three locations with respect to the snow surface
  - 1m suspended, surface, and buried
- One test with 22.5kg ANFO on the surface

In each test, six dual-axis accelerometers were placed at various distances from the blast to capture the dynamic response of the snowpack. Shockwave over-pressure was recorded at one location using a pressure transducer placed just above the snow surface.

Figure 1. Test site near south gun mount at Bridger Bowl Ski Area for field experiments of the 2010 winter season. The slope was low angle, approx. 15-20 degrees, with west – southwest aspect. Old-growth timber surrounding the site provides a degree shelter from wind effects.

Figure 2. Left: 0.9kg Pentolite cast booster. This charge was used for several test configurations. Right: 0.9kg booster suspended 1m above the surface of the snowpack.

METHODS

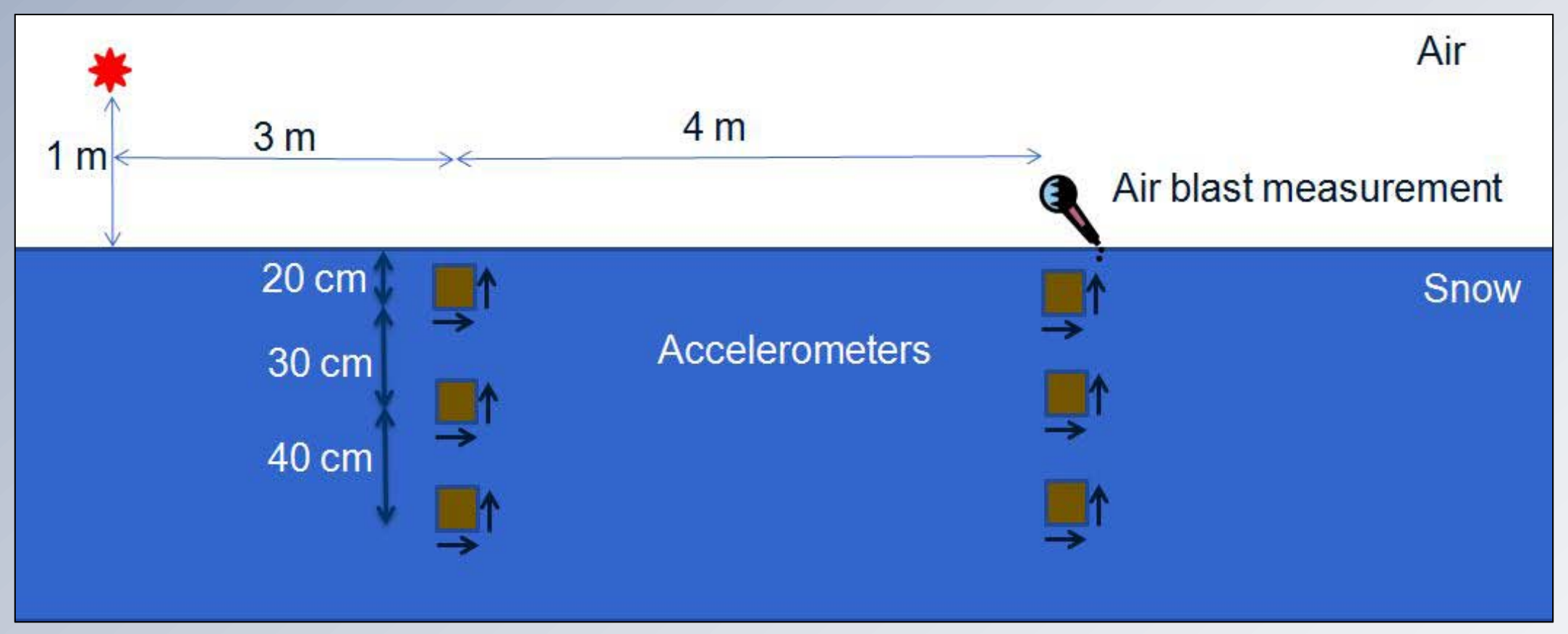

Figure 3 Test Site Layout. Configuration of sensors for experimental setup on 2/15/2010. Six dual-axis accelerometers placed throughout the depth of the snowpack, at 3m and at 7m from the blast site. A pressure transducer was placed at 7m in order to capture the over-pressure of the shockwave.

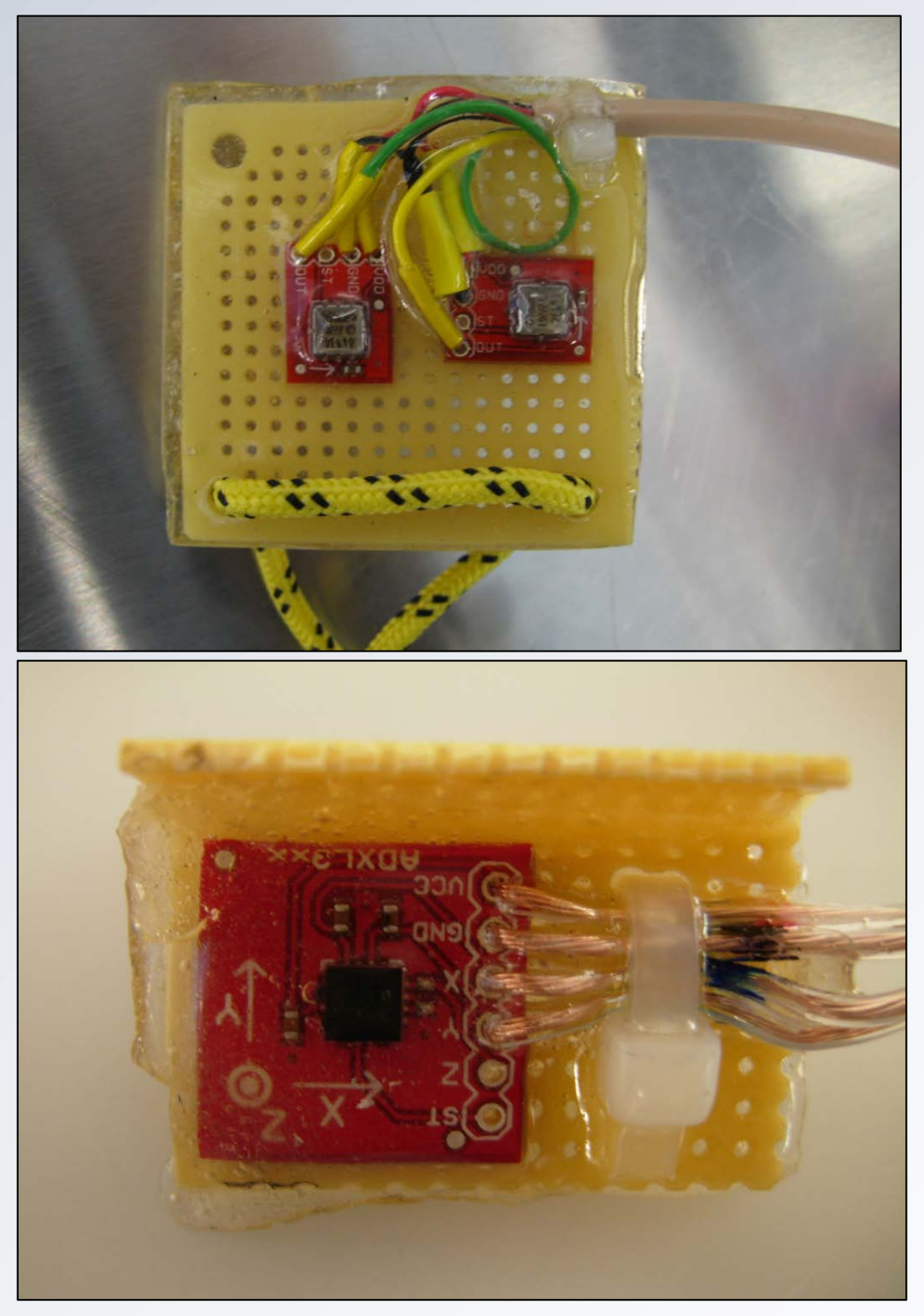

Figure 4. Acceleration Sensors. Top: Pair of Analog Devices ADXL193 ±250g single axis accelerometers mounted at 90° were placed closest to the blast. Lower : Analog Devices ADXL 321 ±18g dual axis accelerometers were placed at the farthest range from the blast.

Figure 5. Top: Larcor ± 34.4 kPa air overpressure sensor. Lower: Accelerometers placed through the depth of the snowpack. Pits were later backfilled with loose snow following placement.

Test Day	Explosive	Sensor Ranges	Snowpack Depth (cm)	Near surface sensors (cm)	Mid-depth sensors (cm)	Depth sensors (cm)
2/15/2010	0.9kg suspended 1m 1.8kg suspended 1m	3, 7m	120	23	53	91
2/27/2010	0.9kg suspended 1m	3, 7m	110	23	53	91
3/11/2010	0.9kg suspended 1m 0.9kg buried 40cm	2, 5m	80	22	50	75
3/23/2010	0.9kg suspended 1m 1.8kg suspended 1m	3, 7m	85	25	50	75
4/15/2010	0.9kg suspended 1m 0.9kg suspended 1m 0.9kg surface blast	3, 7m	125	30	55	105
4/29/2010	22.5kg ANFO surface	3, 7m*	60	10	30	55
	*Air pressure at 15m					

Figure 6. Test matrix for 2010 tests. In general, 3m and 7m were standard distances from blast for instrumentation placement. The effect of charge size was examined with detonation of a 0.9kg charge followed by the detonation of a 1.8kg charge.

Data Collection

- National Instruments NI-USB-9221 Instruments Data Acquisition System & notebook computer to record transducer signals
  - Labview v8.6 data collection rate was 5000 Hz
  - Sampling rate based on: 1)Nyquist theorem sampling rate considerations; 2)transient and relatively high-frequency acceleration signal components; 3)capture acoustic signals throughout the dynamic range of the air pressure sensor
- 7.2 amp-hour sealed 12 volt battery-powered sensors
- 30 m power cable to a junction box cabled to sensors
- Junction box directed 12-VDC to the microphone and also housed a 5 VDC voltage regulator for the accelerometers.
- 13 channels of data signals routed through the junction box and 30 m cable to data acquisition system

RESULTS

2/15/2010 Example Test Day

- Snow pit data recorded in the 120cm profile:
  - Rounds, ρ=273 kg/m³,down to 65cm below surface
  - Ice crust 65cm below surface
  - Depth hoar, ρ=223 kg/m³, below ice crust
- Two tests: 0.9kg explosive followed by 1.8kg explosive, both suspended 1m above the surface
  - Accelerometers placed at 20, 50 and 90cm depths (from top)
    - Two sets, at 3m and at 7m from charge
  - Air overpressure sensor placed 7m from explosives
- Vertical acceleration responses from first of two explosive charges are shown below in Figure 7

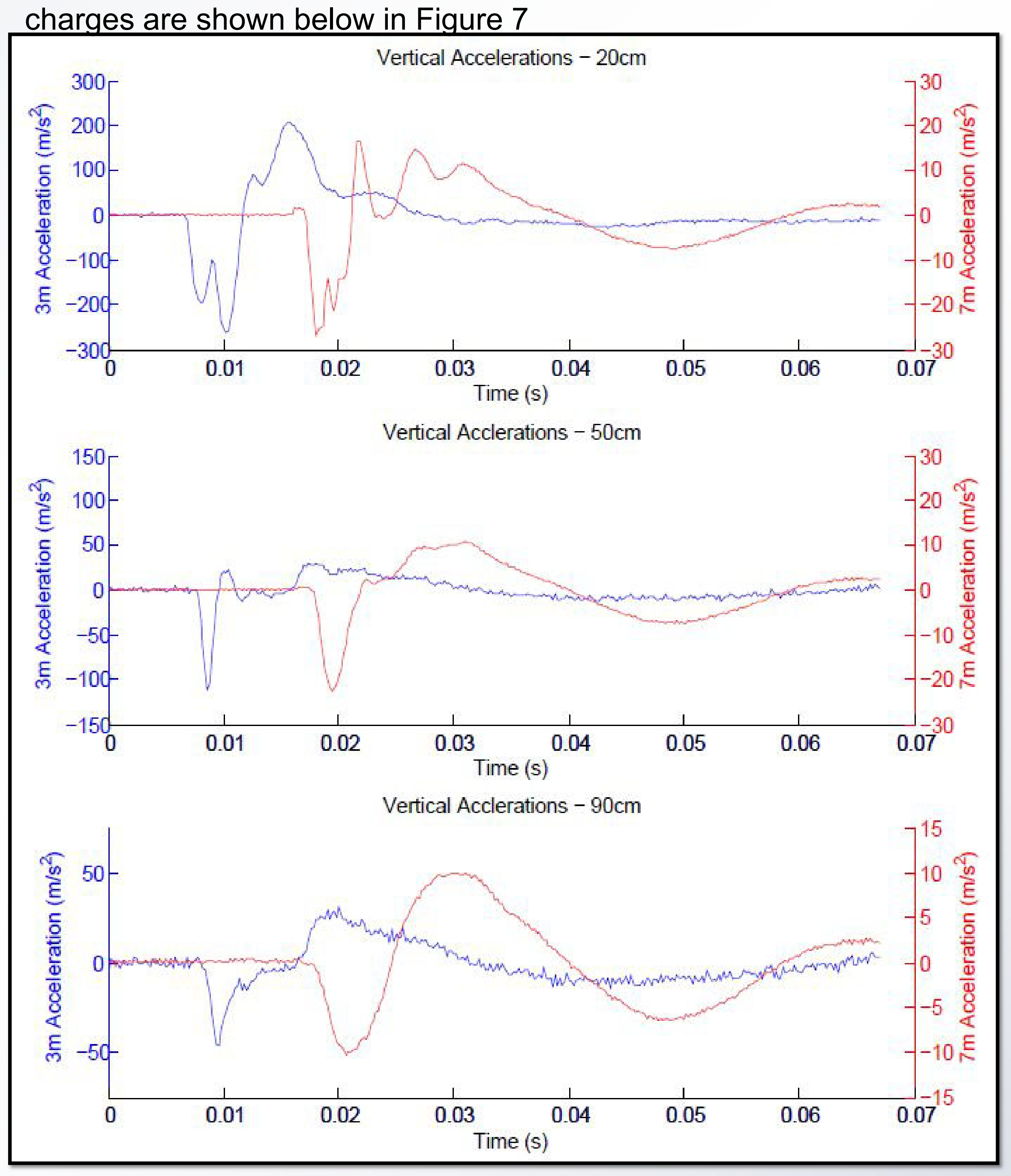

Figure 7. Vertical accelerometer time response.
- **Test data from a 1m suspended 0.9kg Pentolite cast booster, 2/15/2010**
- **Each graph for a specific depth in the snowpack**
  - **Red = measurements at 3m from the blast ; Blue = 7m from the blast (Note different scaling between red and blue axes)**
- **Time lag is evident, as a function of shockwave speed both vertically (through the depth) and horizontally**
- **Diminishing vertical acceleration with depth is evident, more pronounced near the blast than far from blast.**
  - **Indicates effectiveness of snowpack at dissipating the shockwave**
- **Snowpack oscillations indicate an elastic viscous response.**

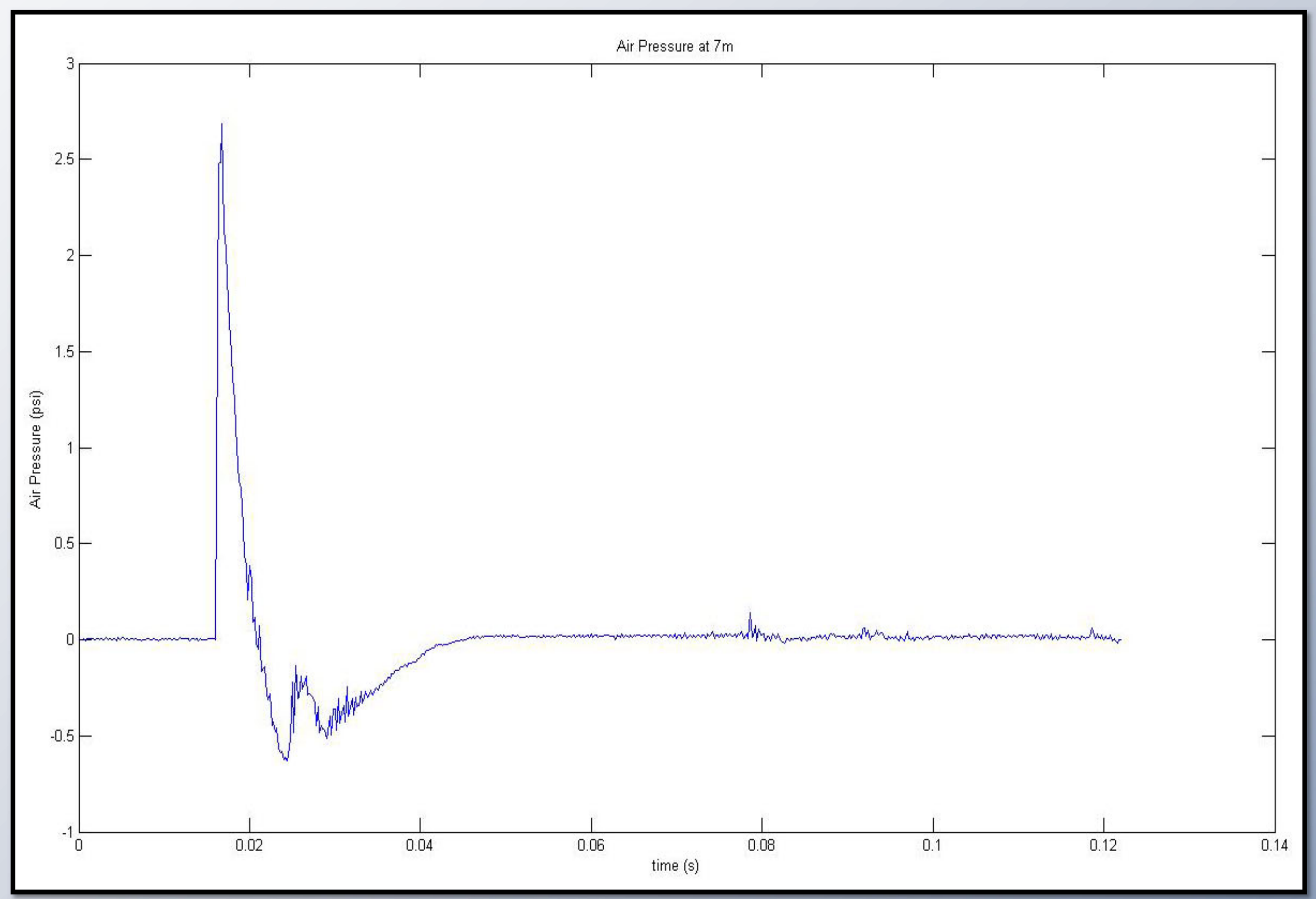

Figure 8. Air pressure time response.
- **Test data from a 1m suspended 0.9kg Pentolite cast booster, 2/15/2010**
- **Pressure transducer located 7m from the charge.**
- **Rapid pressure increase with shock front passage evident ; also the negative pressure phase after shock passage.**
- **The experimental peak pressure was near (approx. 15% higher)than a calculated theoretical value.**

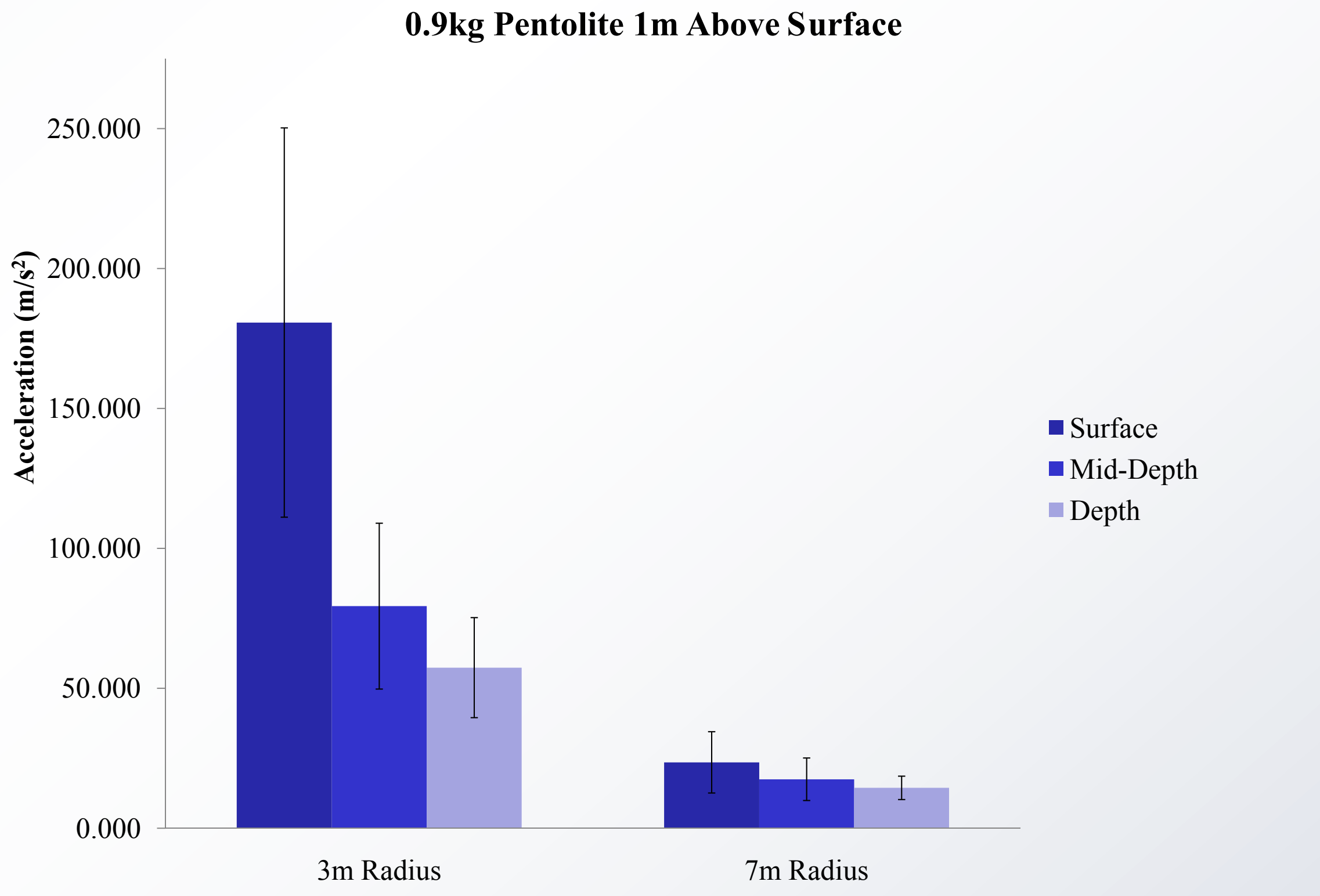

Figure 9. Peak acceleration magnitudes at 3m and 7m and through the depth of the snowpack.
- **Values averaged from all 0.9kg suspended charges surface, mid-depth, and depth for all 2010 tests.**
  - **Error bars indicate 1 standard deviation.**
- **The snow response is greatly diminished with both increasing depth and distance from the charge.**
- **The decreasing acceleration through the depth is more apparent at 3m when compared to 7m.**
- **At 3m: Mid-depth and depth accelerations were 44.8% and 19.9% of the surface acceleration, respectively.**
- **At 7m: Mid-depth and depth accelerations were 76.2% and 67.1% of the surface acceleration, respectively**

CONCLUSIONS

A method for measuring the dynamic response of snow due to an explosive charge was designed, built and field tested in 2010

- Vertical and radial accelerations due to the explosive blast were recorded at 6 locations within the snowpack for each test
- Air overpressure was measured before, during and after explosive shockwave passage

Observed data trends:

- Snowpack exhibits dynamic response (after wave passes)
- Dramatic decrease in acceleration with range and depth
- Air blast produced much higher snowpack response than surface or buried shots
- Buried charge in moist snow did not have widespread effect (beyond crater) when compared to air blast
- Snowpack conditions complicate comparisons:
  - Snow response not linear with shot size
  - Doubling charge did not double response
  - Wet snow lower response, but less attenuation
  - Repeated charge reduced response at close range

Future work planned includes

- Further investigation into explosive effectiveness related to variations in snowpack condition, charge location and charge magnitude
- Field validation of a numerical approach that is under development
- Extend the test methodology to include measurements during an explosives-induced avalanche release

REFERENCES

(1) Abromeit, D., 2010, "Inbounds incidents & fatalities 2008/9", *Avalanche Review*, vol 28, no 23, pp 26

(2) Gubler, H., 1977, "Artificial Release of Avalanches by Explosives," *Journal of Glaciology*, v 19, n 81, pp 419-429

(3) Ueland, J., 1992, "Effects of Explosives on the Mountain Snowpack", *1992 International Snow Science Workshop*, Breckenridge, CO

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