

# Challenges and Strategies for Monitoring Induced Seismic Activity\*

Dario Baturan<sup>1</sup>, Wesley Greig<sup>2</sup>, and Neil Spriggs<sup>2</sup>

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<sup>1</sup>Seismology, Nanometrics, Kanata, Ontario, Canada ([dnk1006@dnk.com](mailto:dnk1006@dnk.com))

<sup>2</sup>Seismology, Nanometrics, Kanata, Ontario, Canada

## Abstract

In the past several years, injection induced seismicity has become an important issue. Though the phenomenon has been observed and documented for at least half a century, recent media attention and increased seismic activity in many regions have fueled public awareness and trepidation. As the public outcry builds, it is inevitable that stricter regulations governing the monitoring and protocols associated with induced seismicity will be introduced. Indeed more stringent regulations have already been established in Ohio within the past year. However what exact form these regulations will take remains unclear. It goes without saying that magnitude will play a central role in these policies, but where, if at all, will properties such as location, depth, b-value, and seismicity rate feature. All of these properties have some measure of subjectivity associated with data quality, processing methodology, and a priori knowledge that will inexorably be passed on to the regulations themselves. We address the challenges associated with implementing and meeting regulations that are effective and fair to both the public and the industry. How can we ensure that a seismic monitoring network meets the criteria set out by the regulations? How do we ensure that our attenuation model is giving an unbiased magnitude estimate? How do we incorporate the effect of complex local geology into event location algorithms? We discuss methods and monitoring strategies for industry to overcome these obstacles and to meet new regulations with minimal cost and effort. Finally, we investigate strategies to reduce the subjectivity of the regulations associated with the inherent uncertainty in earthquake properties.



# Challenges and Strategies for Monitoring Induced Seismic Activity

Designing and operating induced seismic monitoring  
networks to meet regulations

Dario Baturan, Wesley Greig, Neil Spriggs  
Presented at AAPG 2015

# Introduction

- Induced seismicity a well-known phenomenon
- Felt events are rare
- Following increased public awareness a number of regulations and protocols have been put in place to mitigate risk associated with induced seismicity
- Regulations to date have the following common points:
  - Characterize the risk of induced seismicity ahead of time
  - **Establish local seismic monitoring**
  - Develop a mitigation and response plan (modify operations)

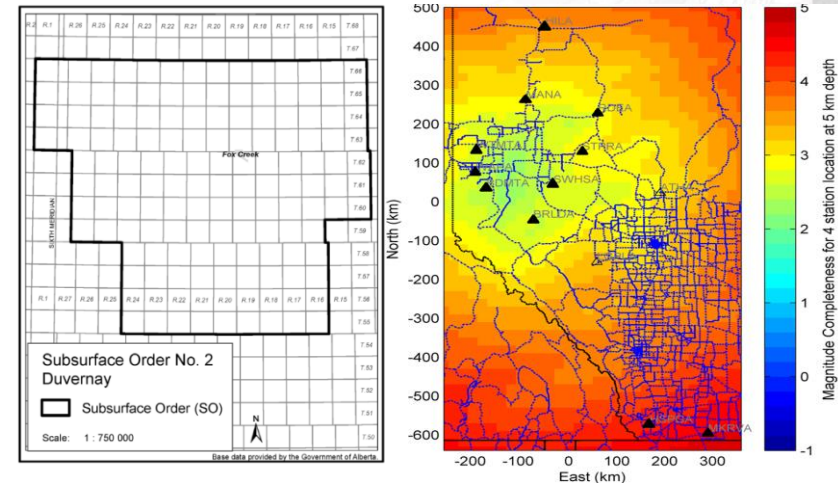
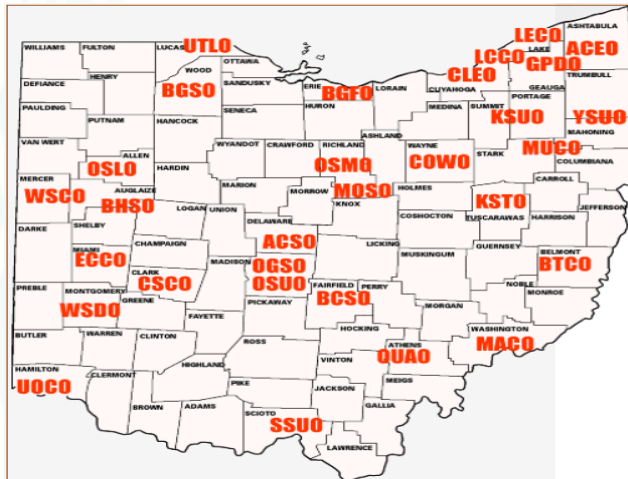
Some of the induced seismic monitoring network challenges:

<b>Network design</b>	How many stations are required to meet magnitude or location accuracy requirements at minimum cost?
<b>Monitoring protocol robustness</b>	When does a monitoring network not meet its mandate?
<b>Magnitude type</b>	What is the best magnitude scale to use in magnitude based traffic light protocols?
<b>Instrumentation</b>	Which instrument types have the most suitable dynamic range and response?

# Example Regulations – Key Points

## Alberta Energy Regulator – Subsurface Order # 2

- Continuous monitoring – 24/7 traffic light system
- Magnitude scale: Local (Richter) ML
- Yellow light: M2.0, Red light <4.0, Mc <M2.0
- Location uncertainty: better than 5 km
- Defines specific monitoring region
- AER has a 10-station backbone monitoring network



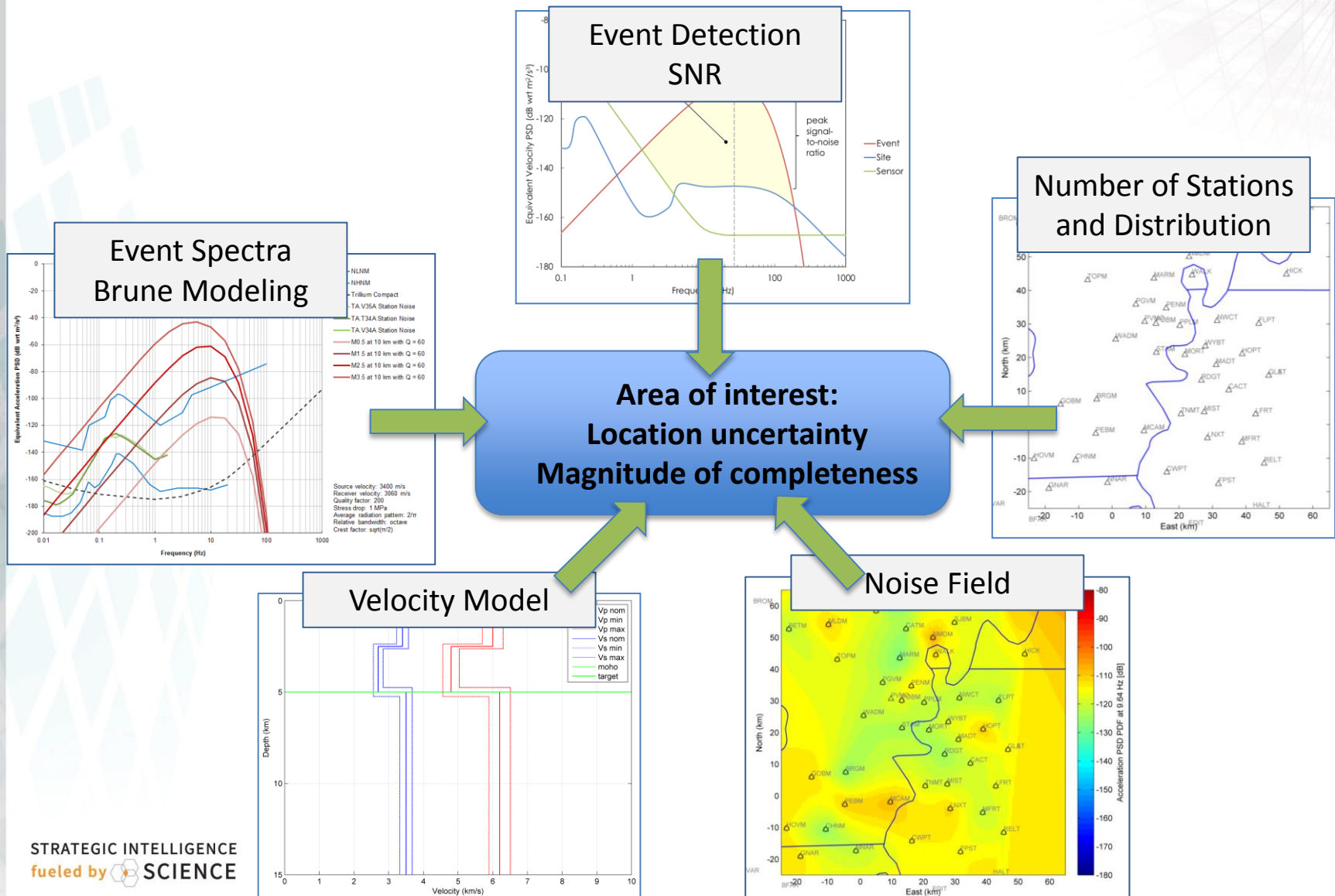
## Ohio Department of Natural Resources

- Applies to wells within 3 miles of a known fault or area of seismic activity with M>2.0
- Continuous monitoring – 24/7 system
- Stop operations if >M1.0 detected and investigate
- Location uncertainty: unspecified
- Backbone network in place – Ohio Seismic Network

**How do we ensure seismic monitoring network will meet the criteria set out by the regulator?**



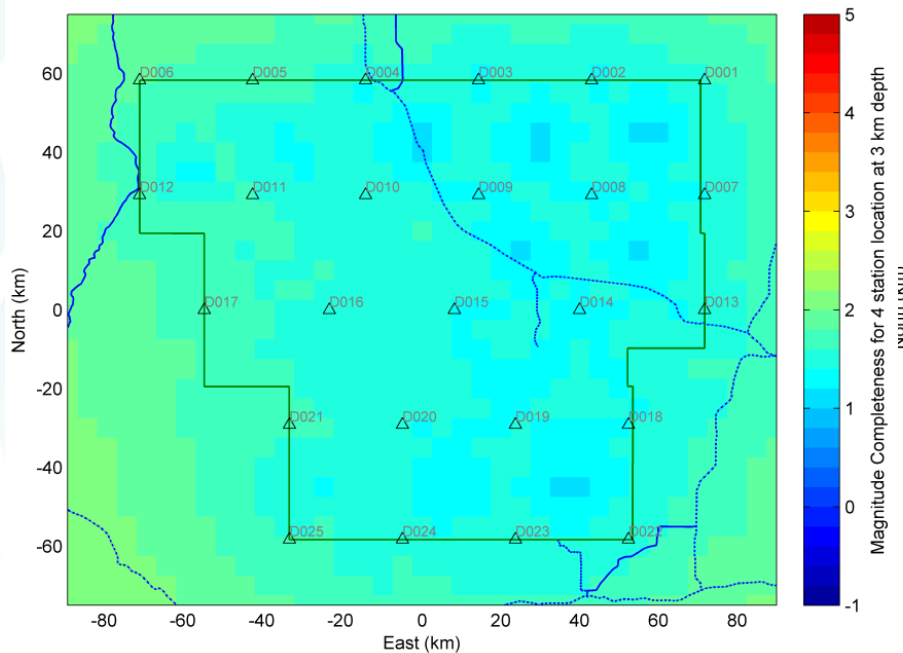
# Network Performance Modeling



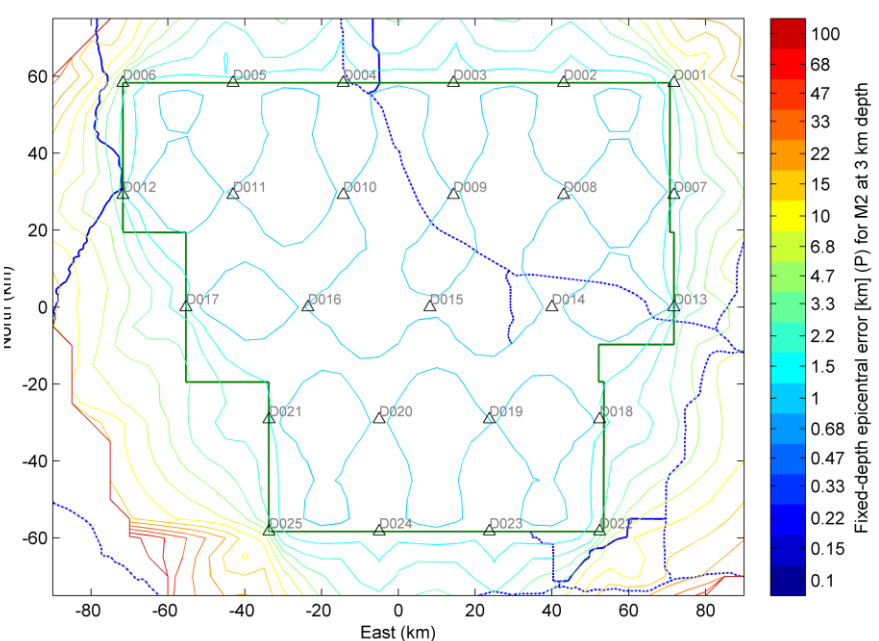
# Network Performance Modeling

- Example modeling results required to monitor 116 km by 170 km Duvernay region
  - 25 stations
  - Average  $M_c$  of  $\sim 1.8$
  - Epicentral location uncertainty  $\sim 1.5$  km
  - Average station spacing  $\sim 30$  km
- Idealized first pass station distribution diagrams:

**Magnitude of Completeness ( $M_c$ )**



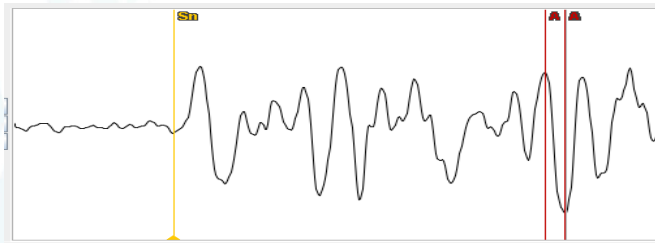
**Epicentral uncertainty (km)**



# Magnitude Scales

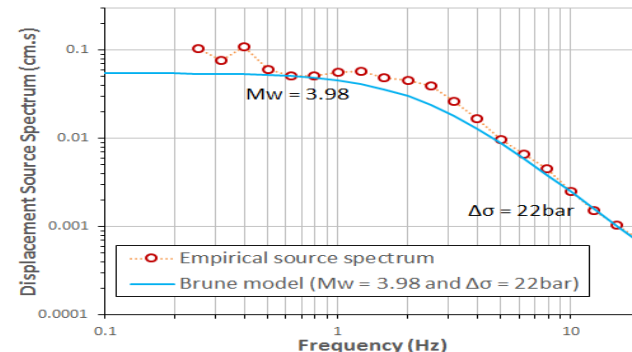
## Local (Richter) Magnitude Scale

- Based on the maximum measured amplitude scaled with distance
- Easy to compute
- Seismology standard
- Requires regional distance correction factors
- Site amplification can have significant effect



## Moment Magnitude Scale

- Based on the scalar moment and related to the physical properties of the earthquake:
- Computationally more expensive
- Microseismic monitoring standard
- Several computation methods
- Can account for radiation pattern

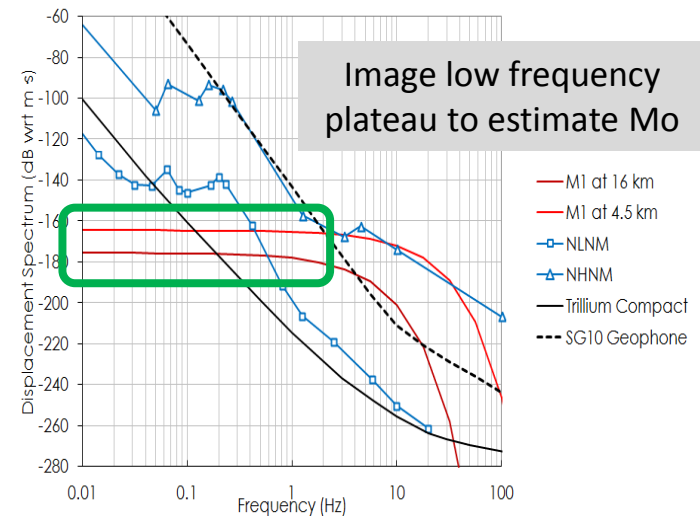
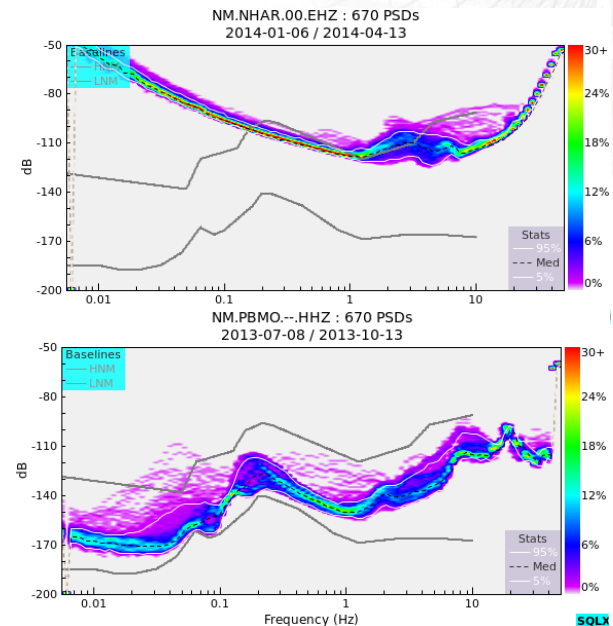
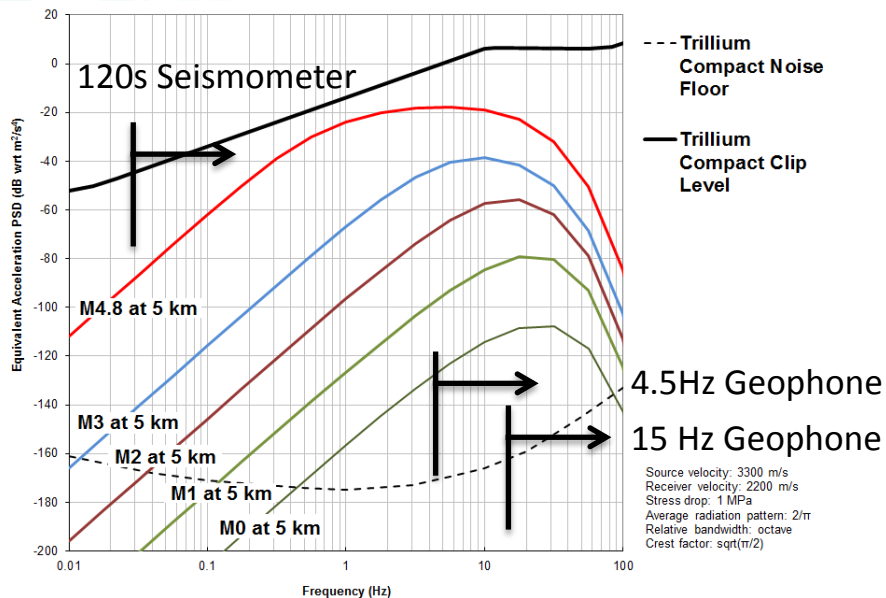


Earthquake (time)	NRCan $M_L$	USGS NEIC mb	Spectral Fitting $M_W$	PGC RMT $M_W$
23/01/2015 06:49:19	4.4	3.9	3.8	3.7

**Compute ALL >M3.0 red light threshold event magnitudes using RMT method**

# Instrumentation

- Induced seismicity
  - Epicentral distances ~2-30 km
  - Magnitude range ~ 0 to 4.5
  - Frequency range of interest ~ 1 to 30 Hz
- **Seismometers** have the right instrument response, clip level and noise floor to do the job
- More cost effective with fewer number of stations required
- Broadband 3-ch instruments enable Mw from RMTs

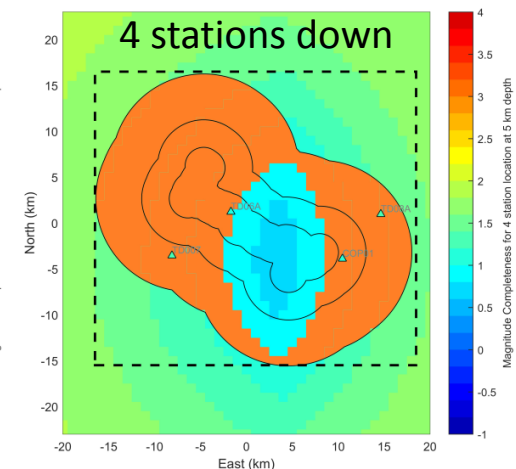
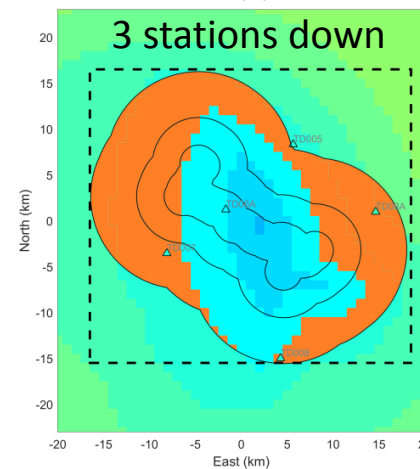
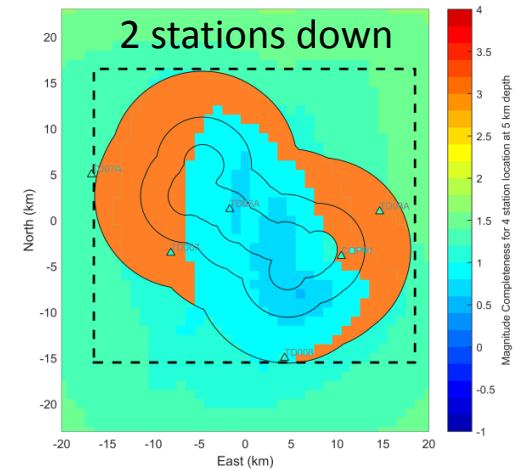
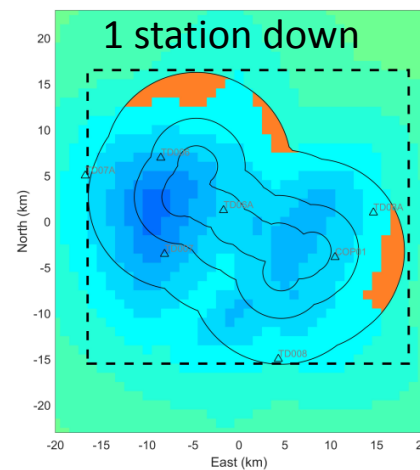
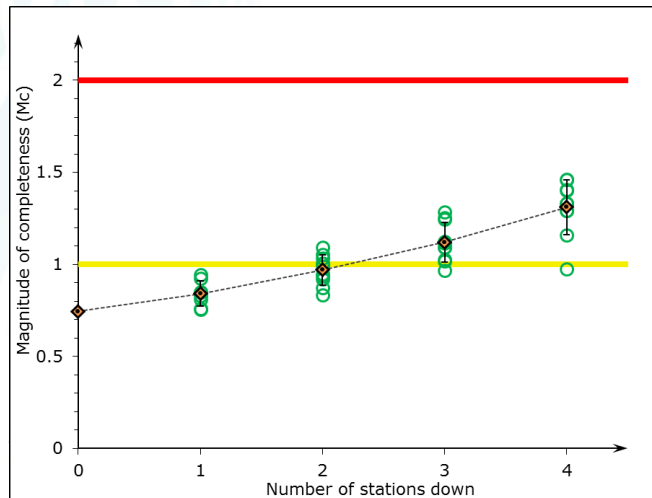




# Monitoring Protocol Robustness

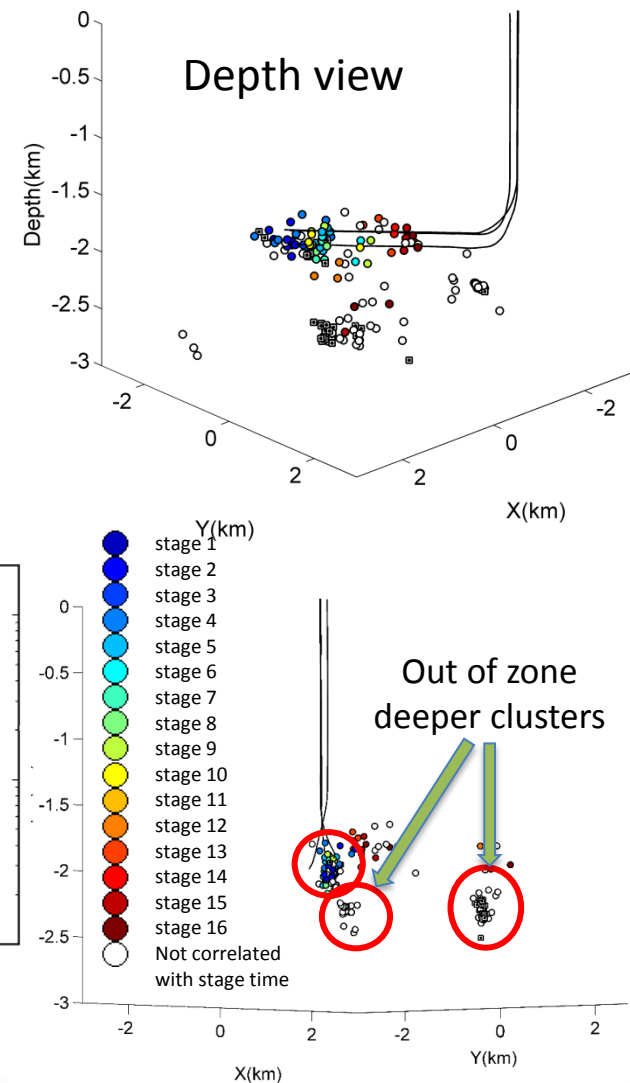
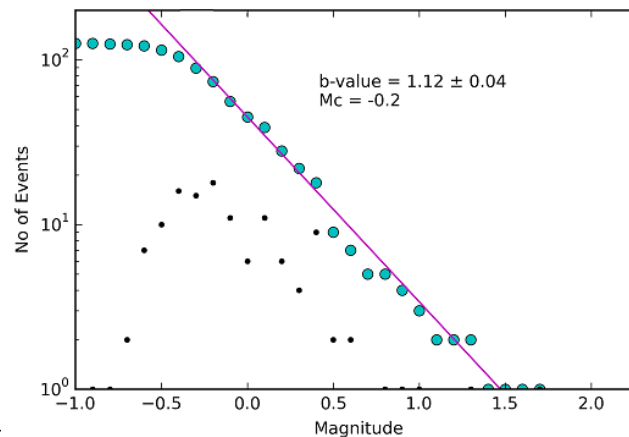
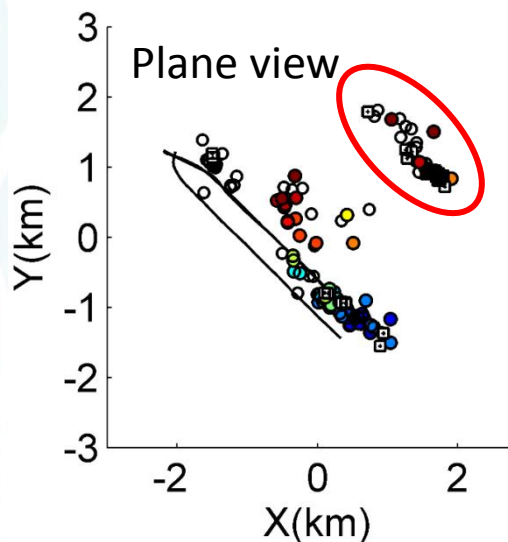
When does the network not meet its operating mandate?  
Does the monitoring protocol account for station data outages?

- Example network - Brazeau Dam, Alberta
- Brazeau network meets monitoring mandate with ~ 1 station down
- Model impact of each station on network performance
- Include redundancy in network design
- Incorporate pre-defined data outage alerts into the protocol



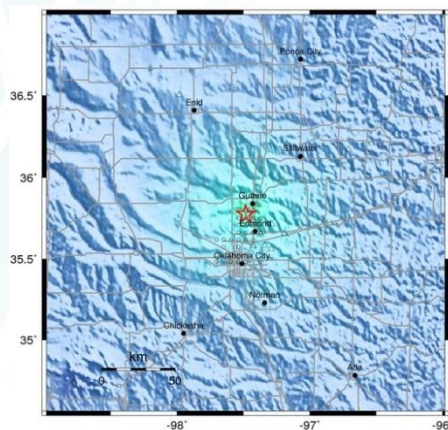
# Example Data Set

- 12-station induced seismic monitoring network
- 180 earthquakes recorded during and one week after the hydraulic fracture stimulation
- Magnitude range -0.9 to 1.3
- Three main clusters:
  - Two deeper clusters consistent with mapped faults
  - Third cluster within expected stimulated volume
- Multiple coupling mechanisms associated with different clusters (stress field changes vs. injection fluid)

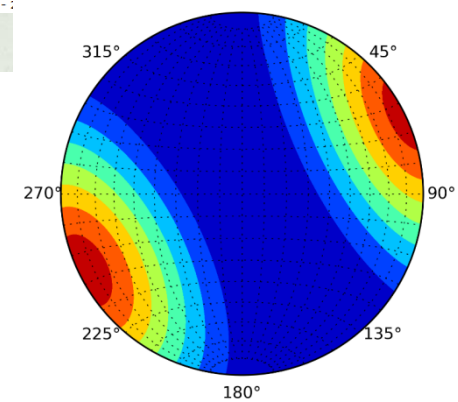
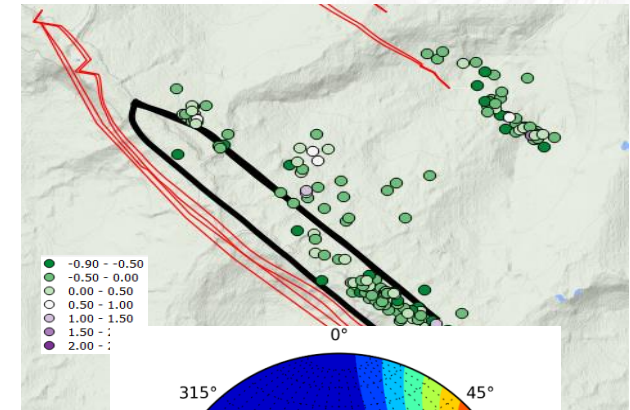
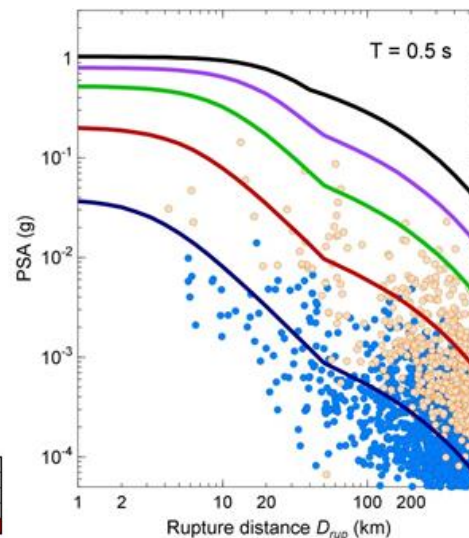


# Applications of Induced Seismic Data Sets

- Identify (delineate) new fault structures
- Refine maps of existing fault structures
- Perform local stress field inversion and estimate SHmax direction
- Get a better understanding of the fracture mechanics during hydraulic fracturing
- Assist in evaluating completions efficiency – investigate fluid pathways








PERCEIVED SHAKING	Not felt	Weak	Light	Moderate	Strong	Very strong	Severe	Violent	Extreme
POTENTIAL DAMAGE	none	none	none	Very light	Light	Moderate	Mod. Heavy	Heavy	Very Heavy
PEAK ACC (g)	<0.007	0.08	1.0	5.0	8.8	15	27	47	>83
PEAK VEL (cm/s)	<0.002	0.04	0.5	2.0	6.3	14	26	63	>126
INSTRUMENTAL INTENSITY	I	II-III	IV	V	VI	VII	VIII	IX	X



- Establish empirical local/regional attenuation relationships and site amplification maps
- Drive more accurate ground motion predictions (shake maps) and enable structural monitoring alerts – seismic hazard maps

# Summary

- Meet monitoring criteria out of the gate  Model network performance
- Report the most robust magnitude scale  Use RMT Mw for red lights
- Select appropriate instrumentation for the job  Seismometers
- Important to build robust monitoring protocols  Account for station outages
- Potential to use data to manage operations, monitor infrastructure and map fault structures in addition to risk management 
  - Manage operations
  - Monitor infrastructure
  - Map fault structures





# Nanometrics

STRATEGIC INTELLIGENCE  
fueled by  SCIENCE

## Thank You

Dario Baturan  
Director, Technical Operations  
[dariobaturan@nanometrics.ca](mailto:dariobaturan@nanometrics.ca)  
[www.nanometrics.ca](http://www.nanometrics.ca)