



Natural Resources
Canada

Ressources naturelles
Canada

Revised local- and regional-scale velocity and attenuation models for Canada for improved earthquake/explosion location, magnitude and yield estimates

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Goal: Improve magnitude consistency, yield estimates and event location accuracy in Canada: application to CTBT global seismic monitoring 2

Methods:

1. Lg amplitudes – regional magnitude consistency, yield estimates

- Seismic attenuation, magnitudes, yield estimates, ground shaking
- Inversion of Lg displacement amplitudes (events $M_N \geq 3$ from NEDB catalog) for regional crustal attenuation ($1/Q$) and frequency-dependent $Q(f)$
- >5,000 waveforms in eastern Canada; >3000 in Arctic regions

2. Travel times – event location accuracy

- RSTT tomographic inversion of NEDB- and ISC- validated events. P_n , P_g , S_n , L_g phases
- 37,261 arrivals from quakes; 1,670 from blasts, 106 from GT0 refraction explosions (Lithoprobe), 722 from GT0 mining rockbursts, 704 from GT5+ mining rockbursts



1. Regional crustal attenuation from Lg amplitudes $Lg-Q(f)$

Single frequency Q inversion

$$A_{ij}(f) = R_{ij}^{-\gamma} S_j(f) G_i(f) e^{-\pi f R_{ij} / Q \beta}$$

$$Q(f) = Q_0 (f/f_0)^\eta$$

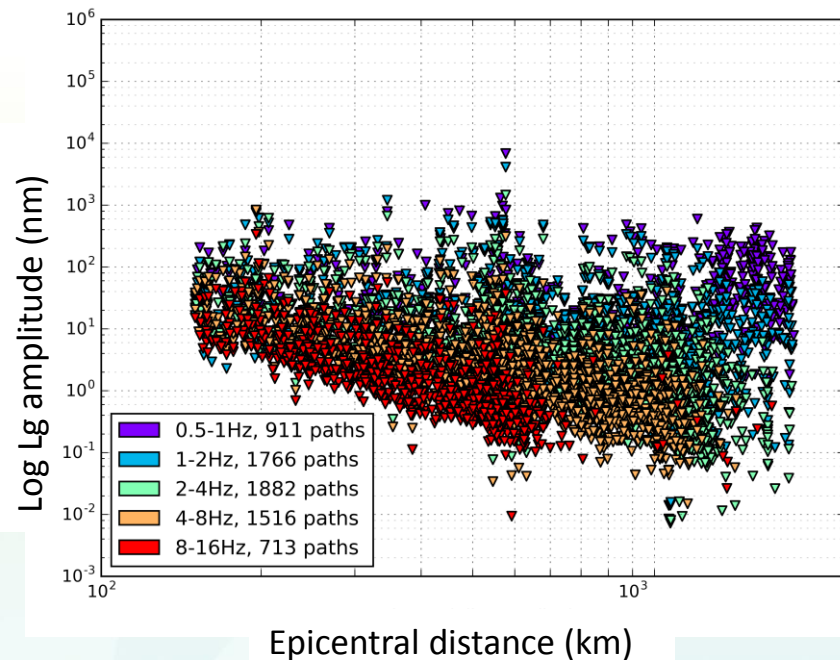
$$\gamma = 0.5$$

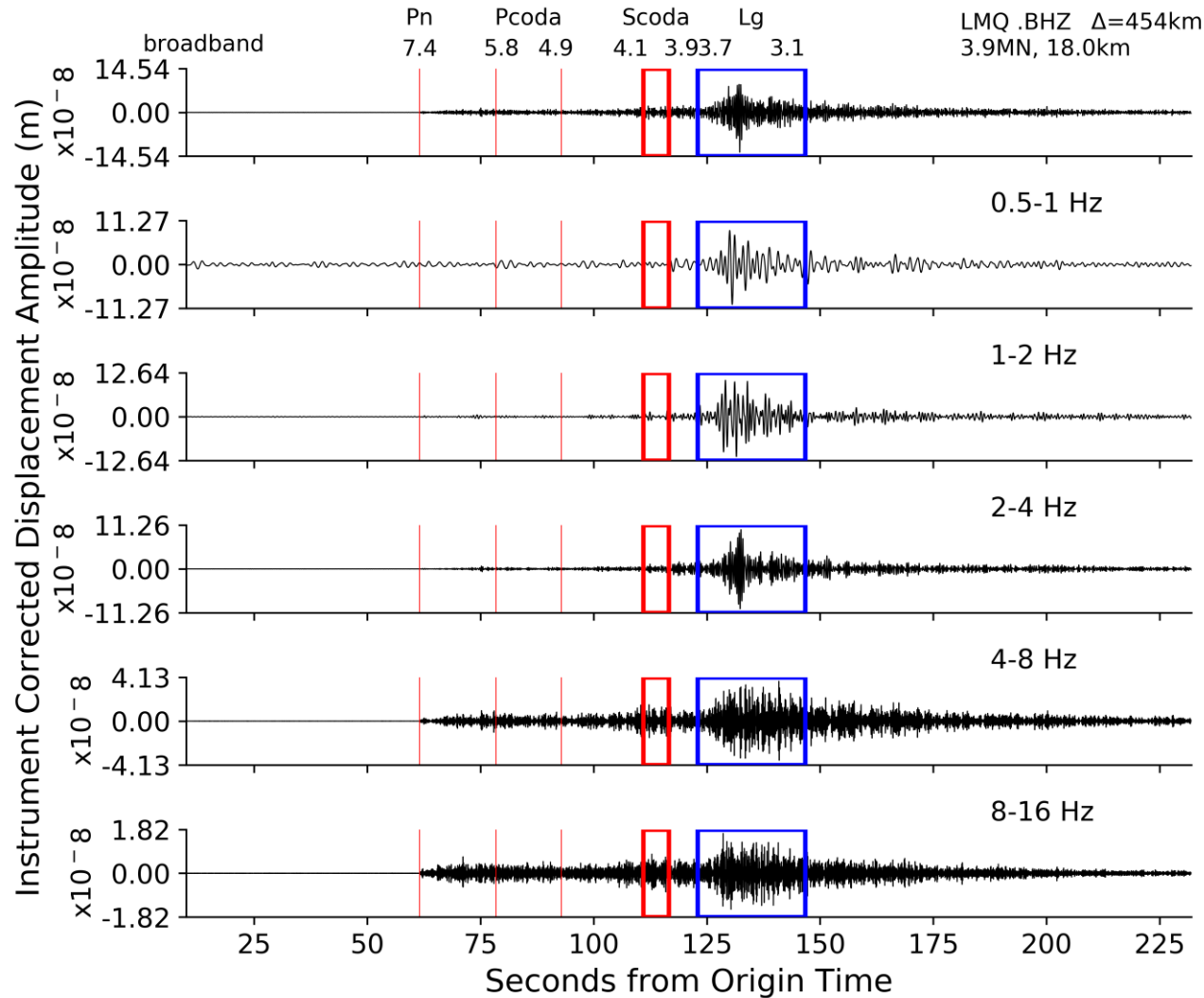
$$\beta = 3.6 \text{ km/s}$$

f_0 reference frequency

Q_0, Q at f_0

η assumed constant over all frequencies



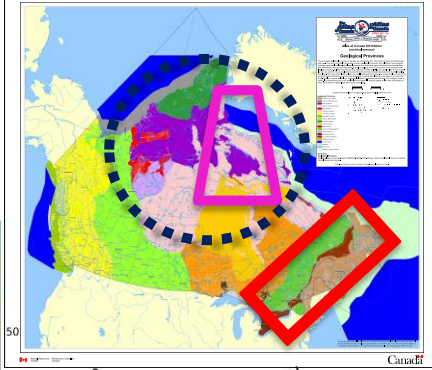
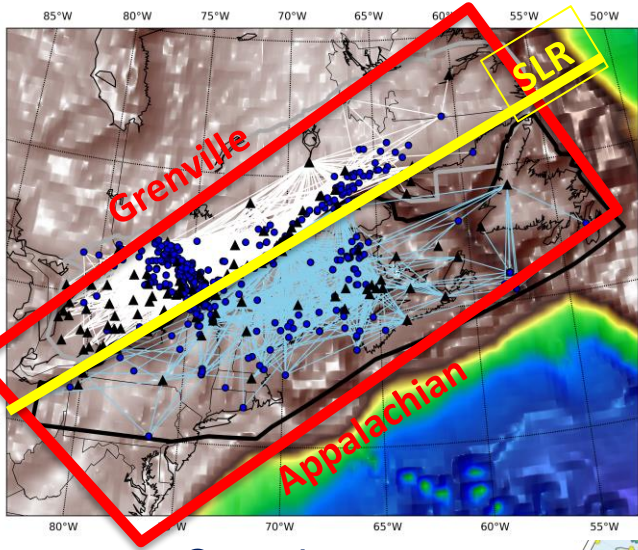


Grenville

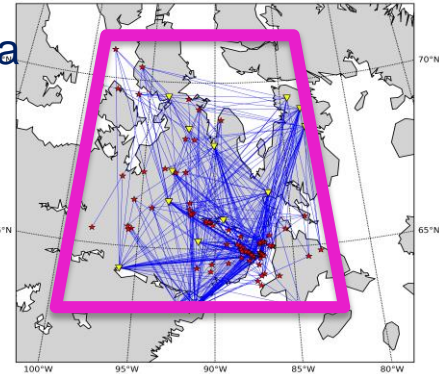
Earthquake & waveform selection criteria applied to **over 5000** regional seismograms.

Over 2500 remained from 287 events at 81 stations

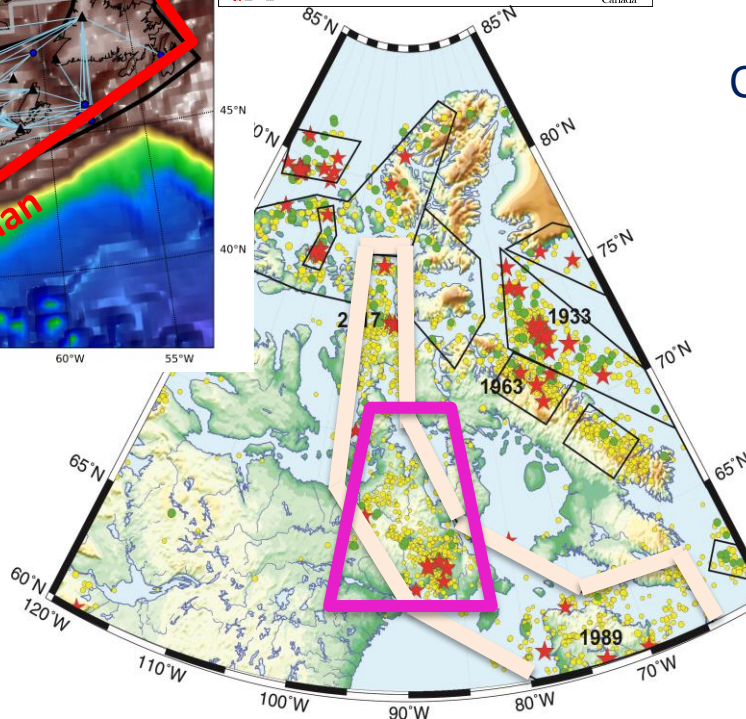
Lg datasets for regional $Q(f)$ –



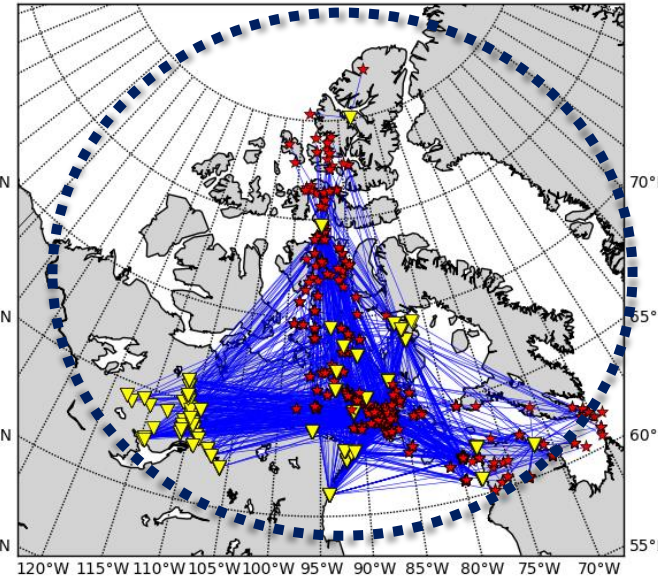
Boothia-Ungava Seismic Zone

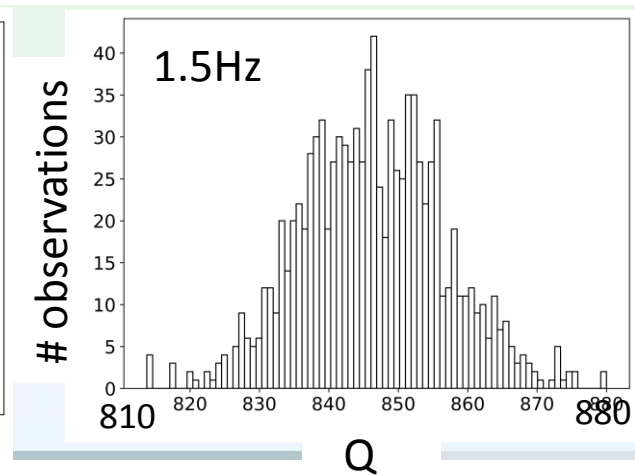
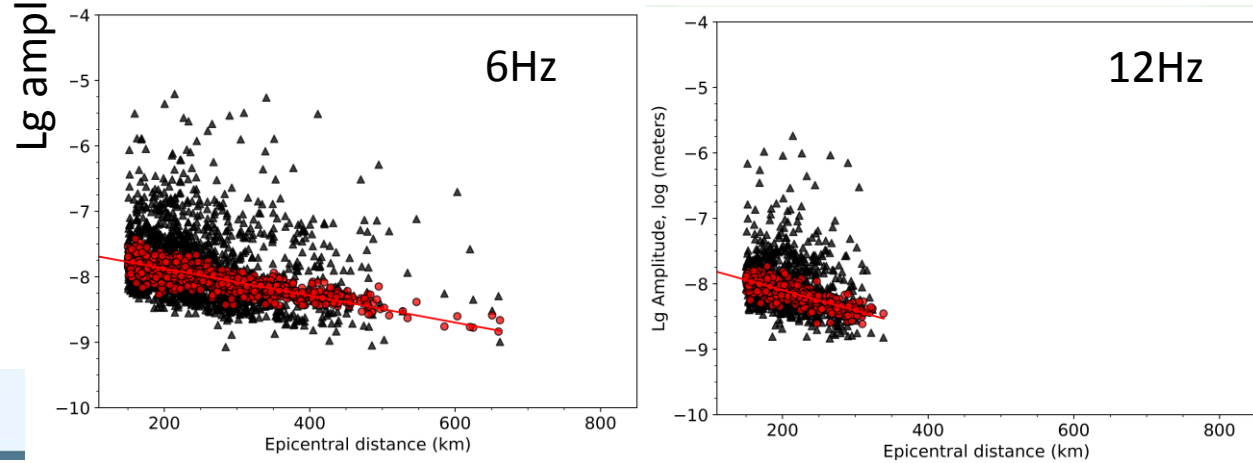
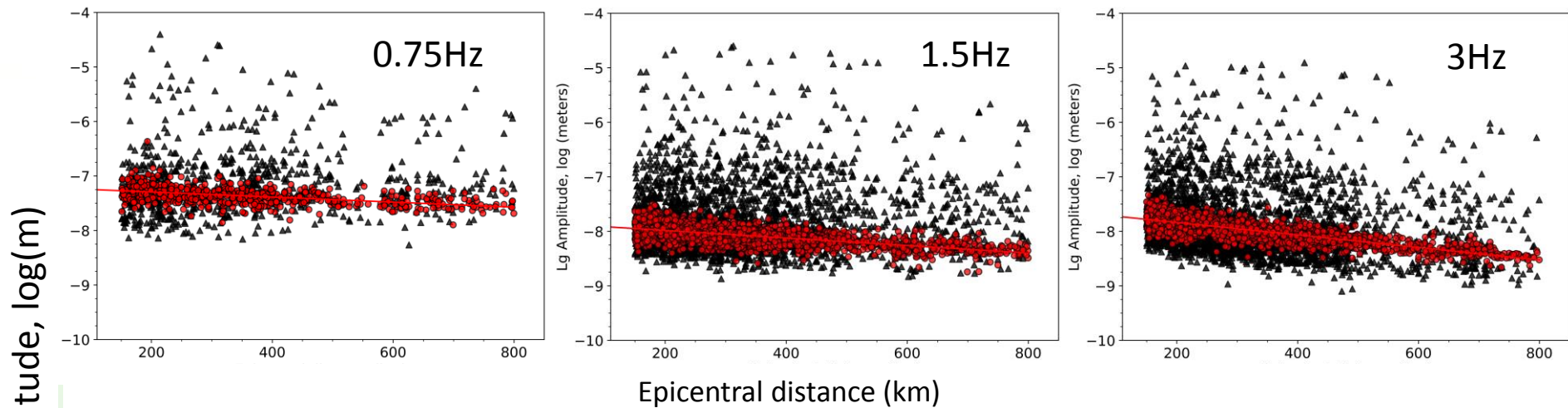


eastern Canada:
Grenville &
n. Appalachian
Provinces

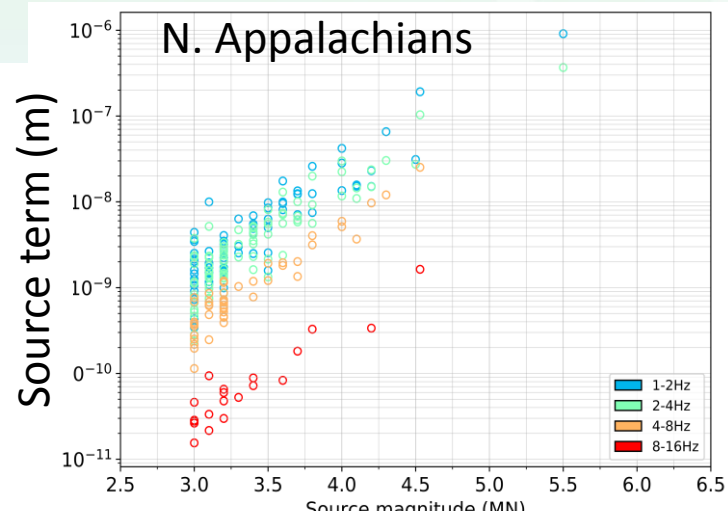
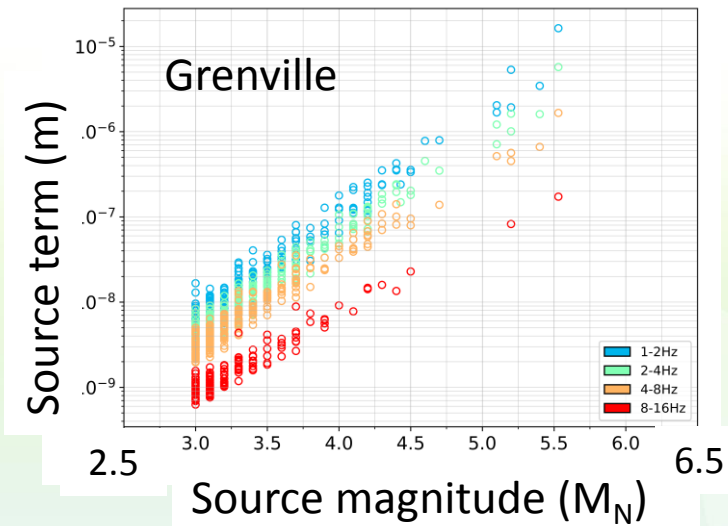


Canadian Arctic

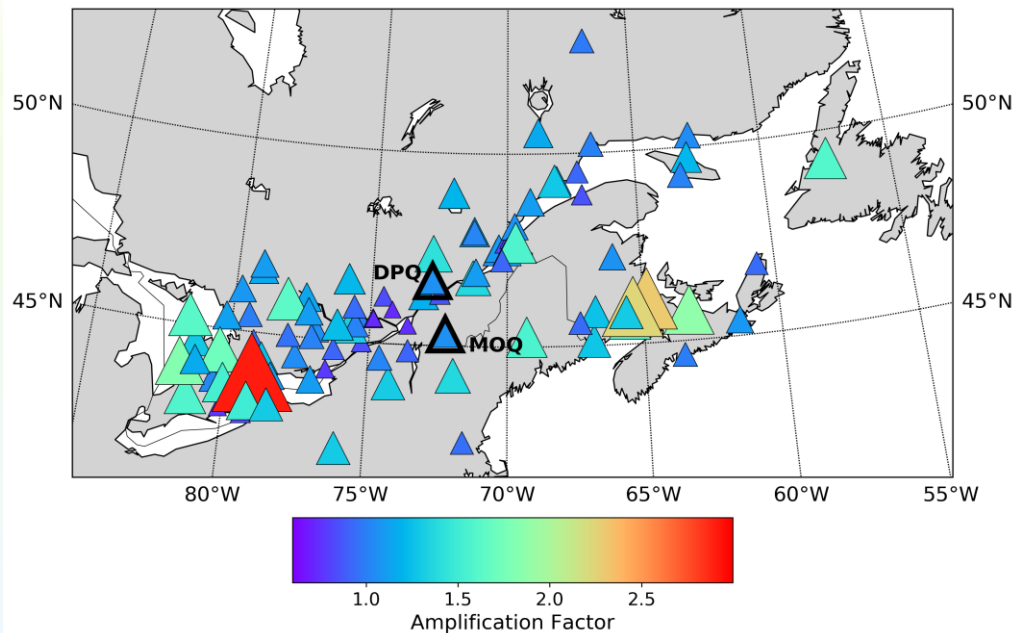




Grenville Province



Receiver terms

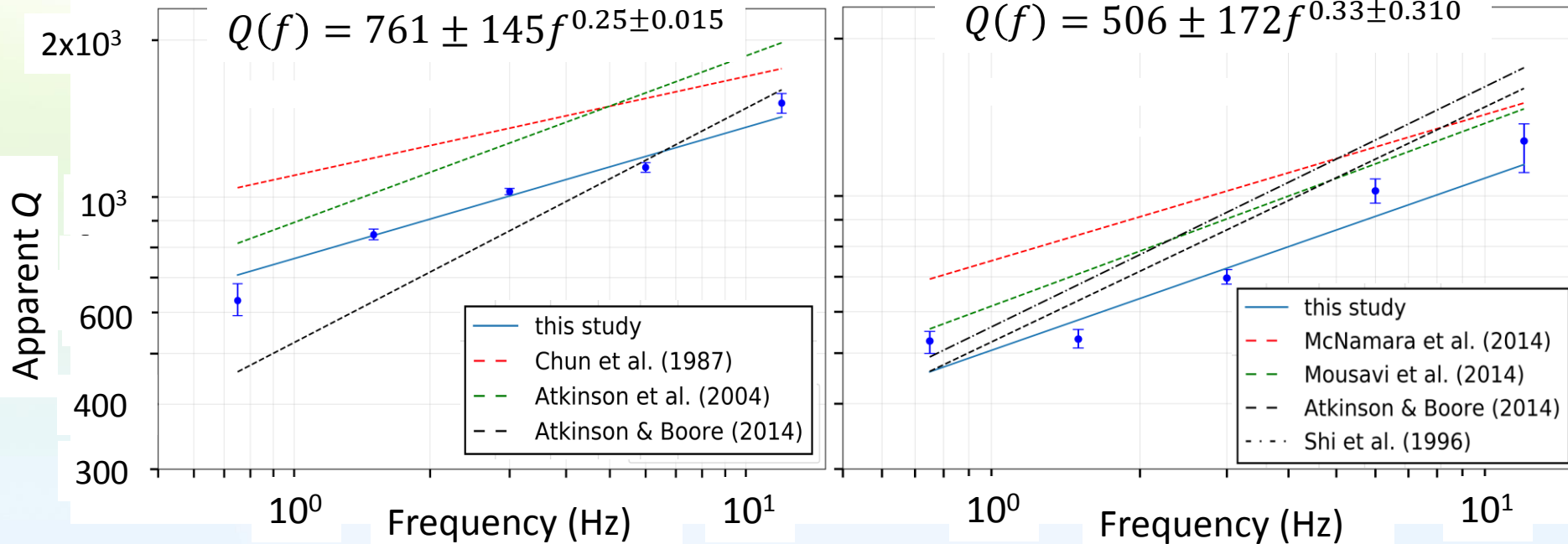


Perry et al., submitted to BSSA, 2019

Source terms

Department of Natural Resources, 2017

Apparent $Q(f)$ Grenville – N. Appalachians



Perry et al., submitted to BSSA, 2019

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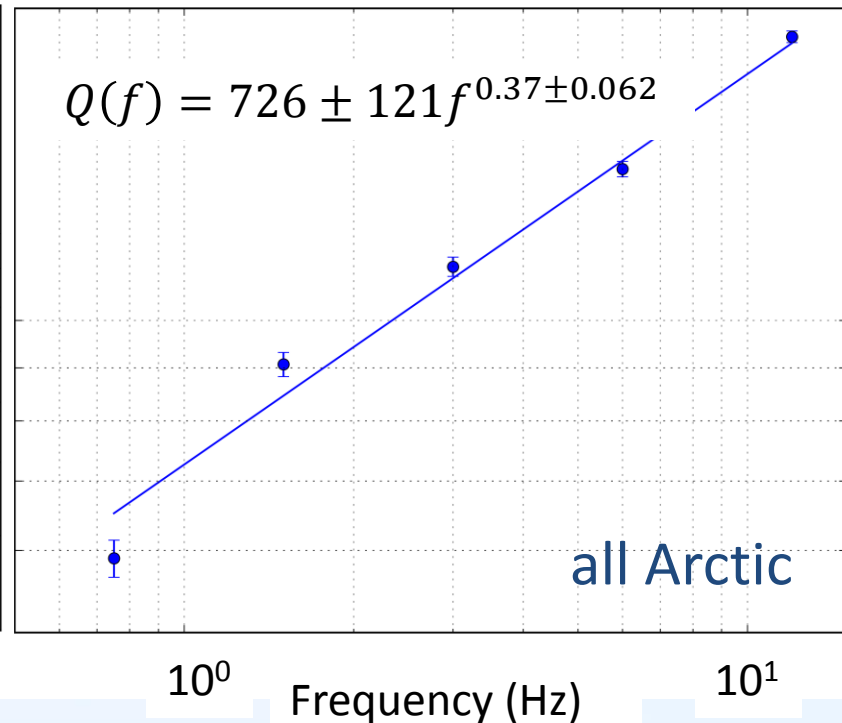
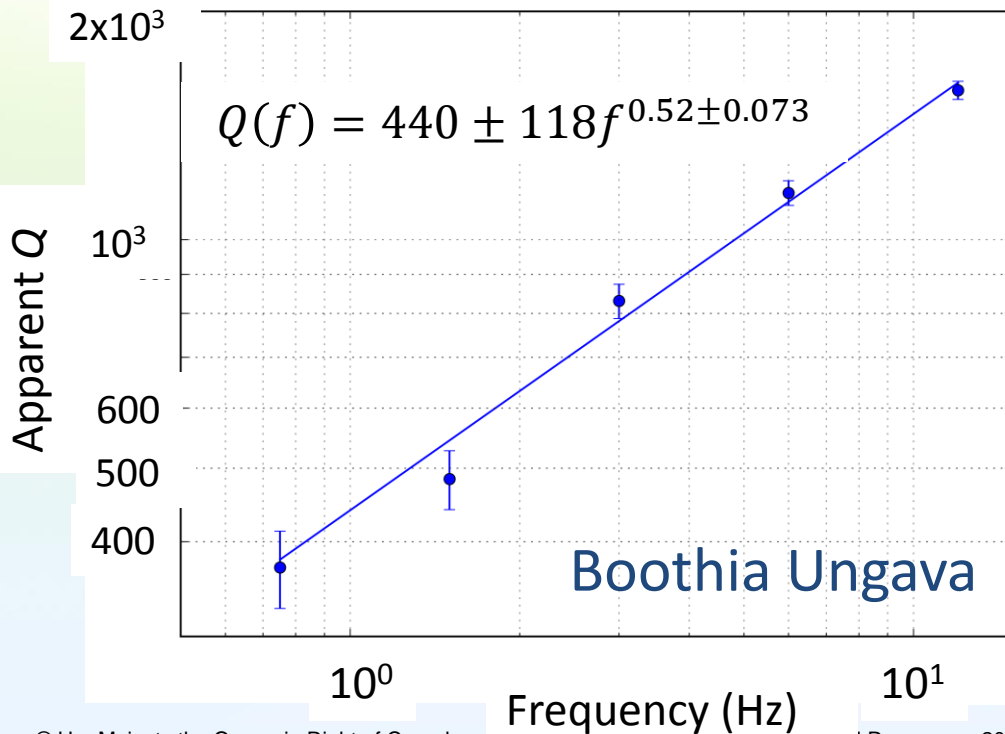
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SnT Conference, Vienna, June 24-28, 2019

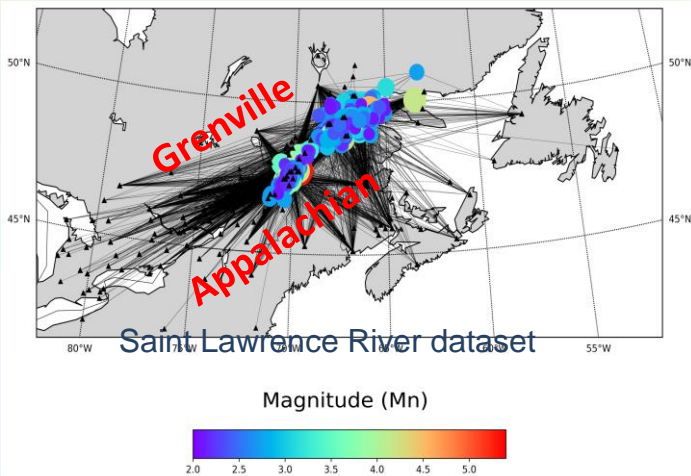


Apparent $Q(f)$ Arctic region

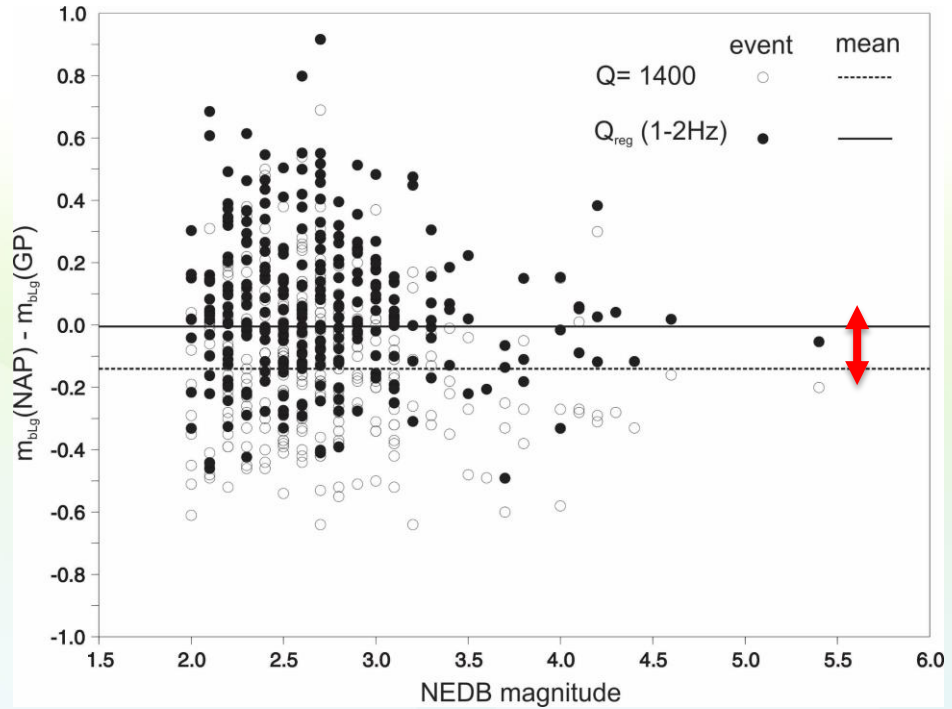


Recalculated mbLg magnitudes from regional $Q(f)$: Grenville– N. Appalachian Provinces, eastern Canada

Perry et al., submitted to BSSA, 2019



Minister of Natural Resources, 2017

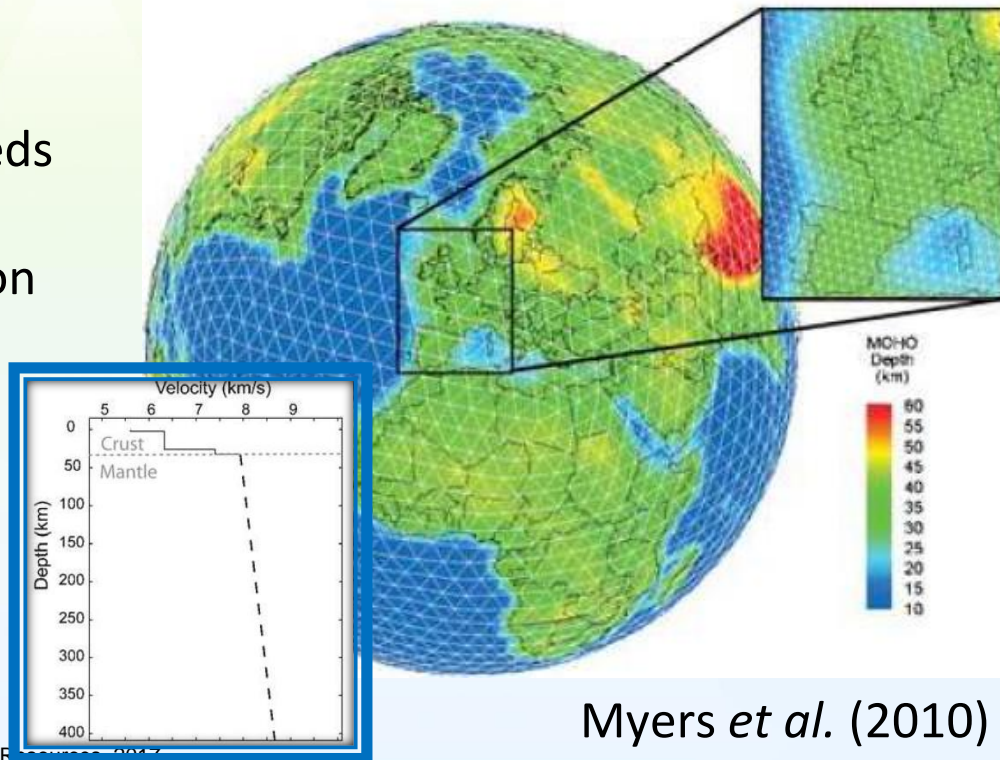


- 547 Saint Lawrence River earthquakes of $M_N \geq 2.0$, 2001-2017. All events had at least one Appalachian and Grenville station recording.
- 298 events with 3+ stations in each of Grenville/Appalachian



2. Local and regional travel times : RSTT Canada

- Wave speed is calibrated through tomography. Optimizes wave speeds such that $TT_{obs-pred}$ is minimized
- Velocity profiles at each tessellation grid are adjusted
- Structure defined by CRUST1.0
- Pg , Lg , Pn , Sn phases
- input: well located seismic events (natural and anthropogenic)



Myers *et al.* (2010)

Tomography overview

Multi-step: (rstt201404um starting model)

- (1) NEDB eqs, rockbursts, blasts, explosions (1980-)
- (2) New Bayesloc data (all phases)

LSQR inversion (Paige and Saunders, 1982).

- Regularization (optimized for new data)
 - Smoothing
 - Damping to previous iteration

Solve for:

- Upper mantle slowness (s)
- Upper mantle gradient (c^2)
 - $c = g*s + 1/r$
 - ($g = \text{gradient}$, $r = \text{radius}$)
 - Assumption: $c*h \ll 1$
- Pg/Lg crust (s_c)
(middle crust Pg/Lg)
- Crustal stack modifier
(of velocities) (α , β)

Myers *et al.* (2010);
M. Begnaud,
pers. comm.

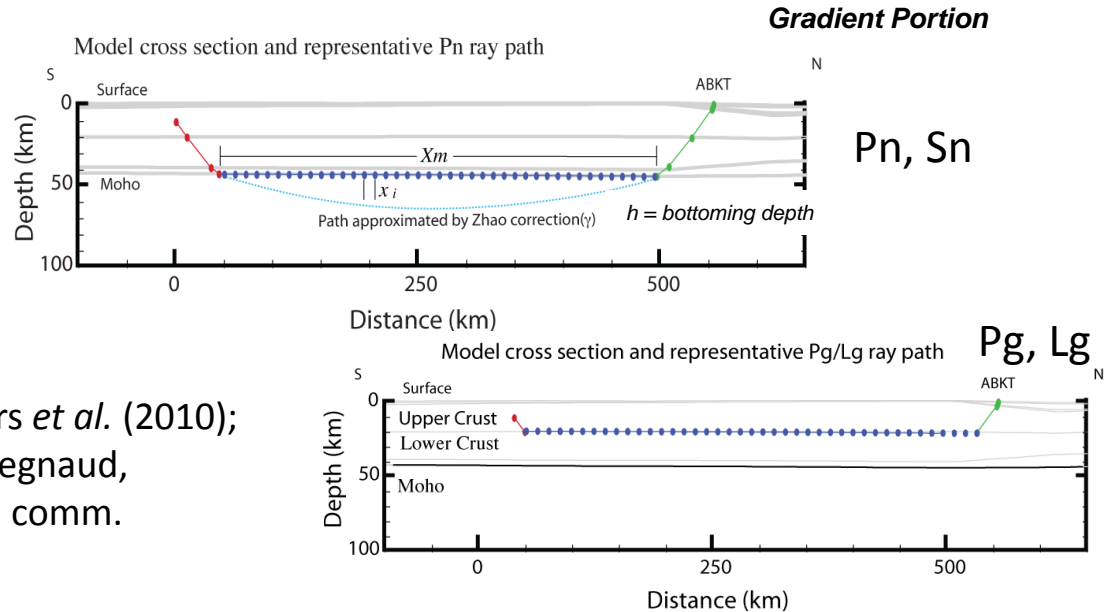
Mantle Phase

$$TT = \sum_{i=1}^N d_i s_i + a + b + g$$

Crustal Phase

$$T = \sum_{i=1}^N x_i s_i + a^u + b^u$$

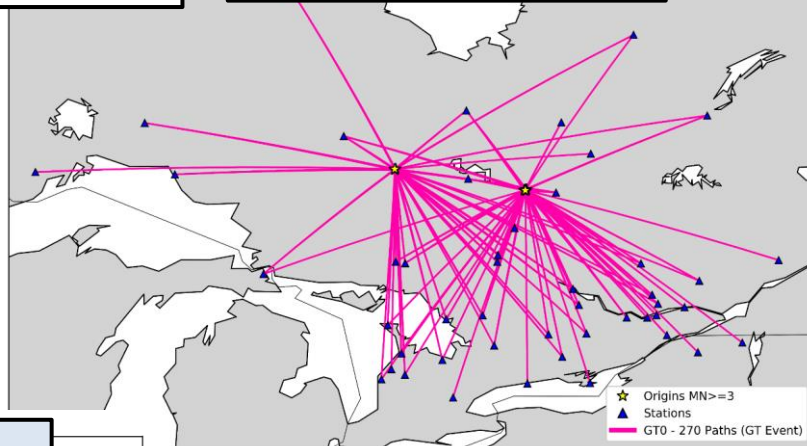
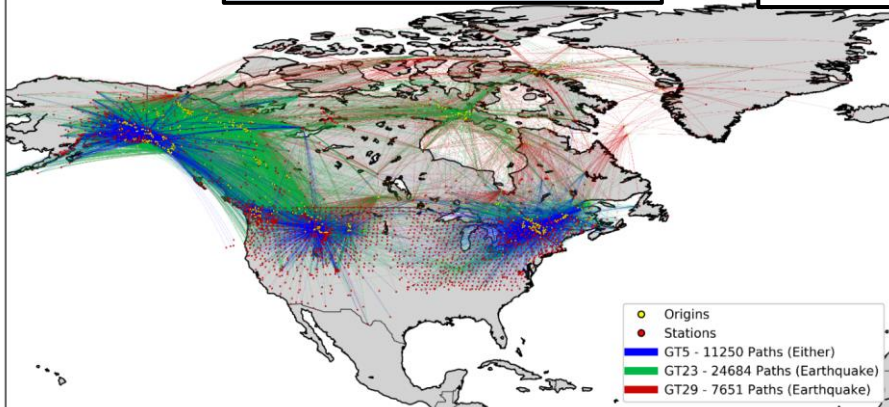
$$g = \frac{c^2 X_m^3}{24 V_0}$$



natural earthquakes

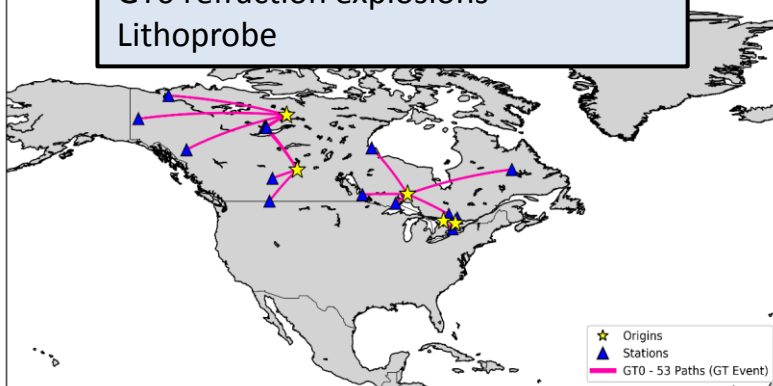
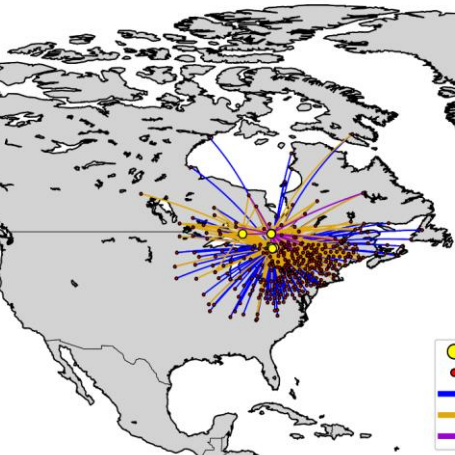
19800101-20190510

GT0 mining events

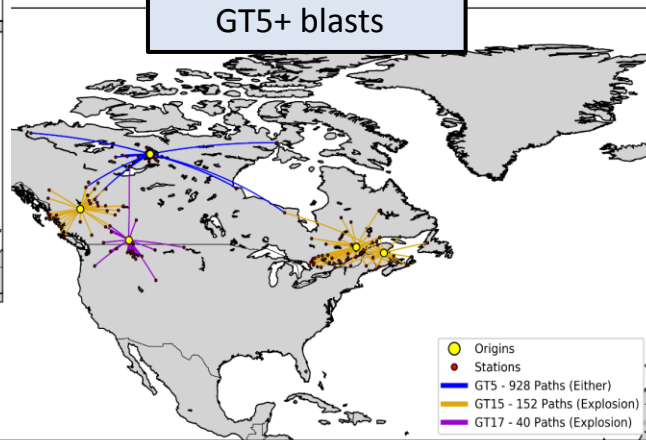


GT5+ mining events

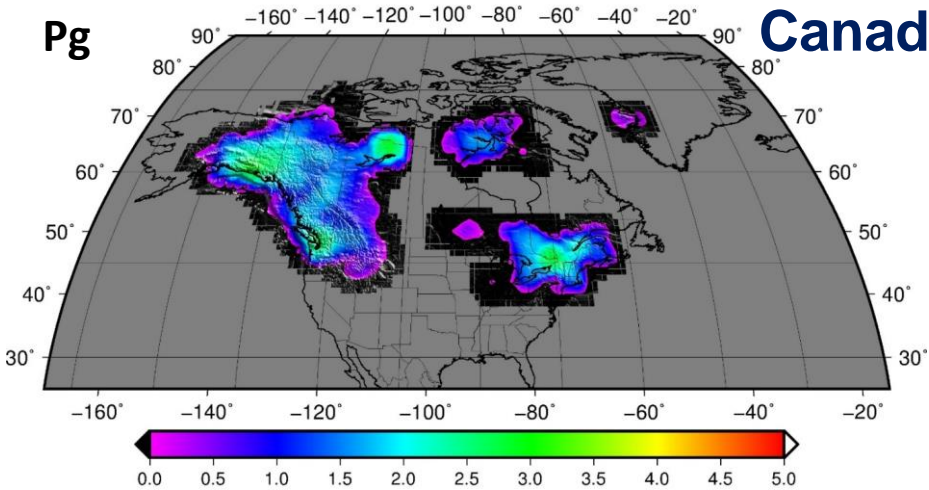
GT0 refraction explosions - Lithoprobe



GT5+ blasts

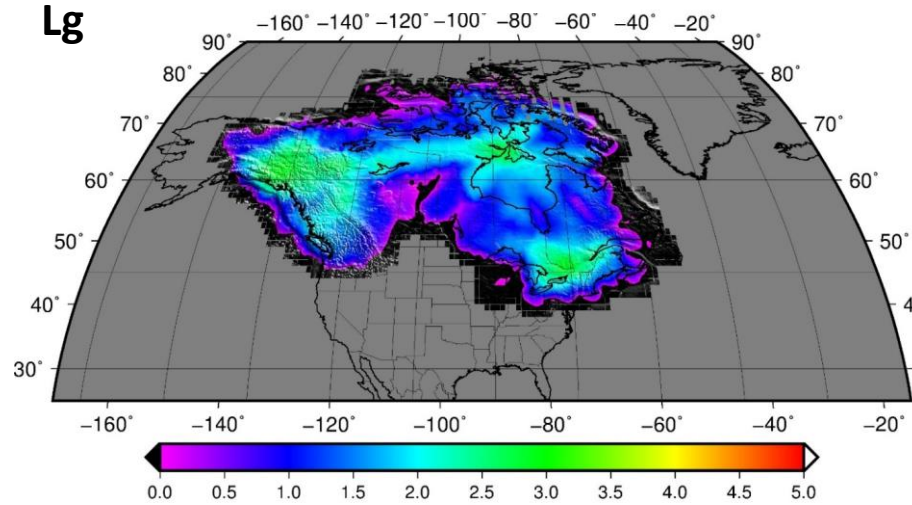


Pg **Canada Model**

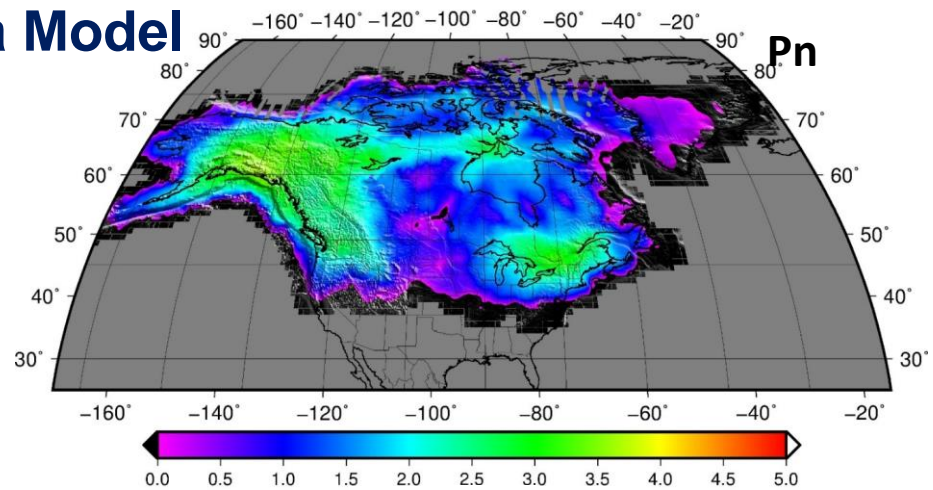


log10(hit count)

Lg

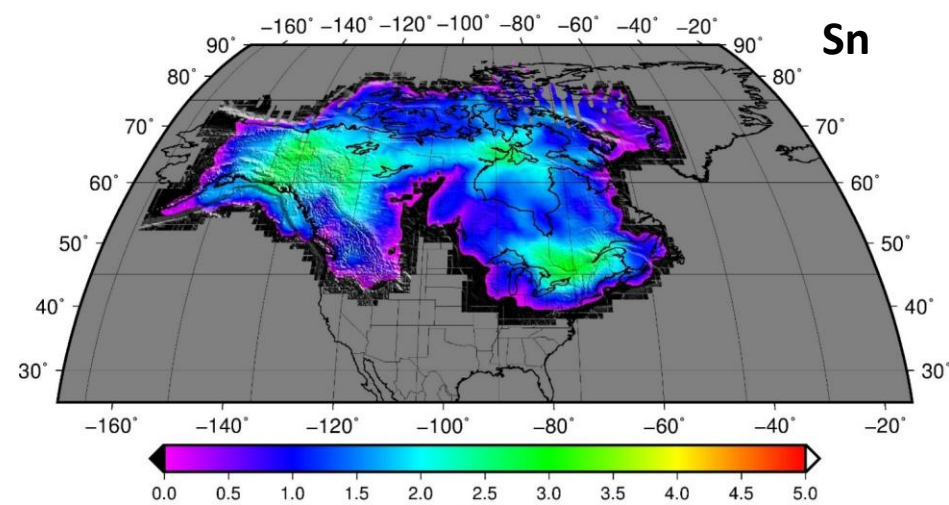


Pn

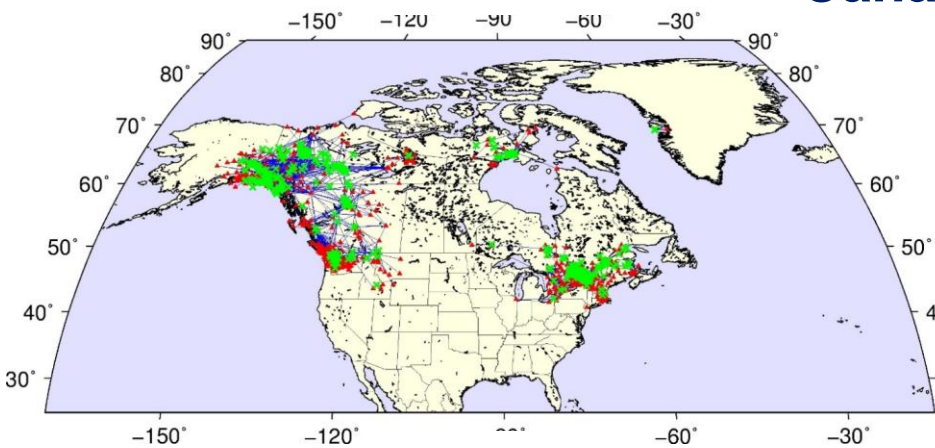


log10(hit count)

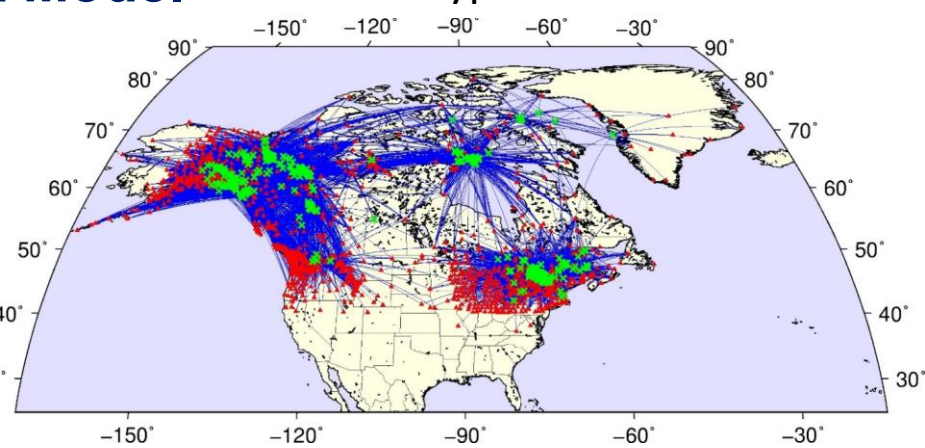
Sn



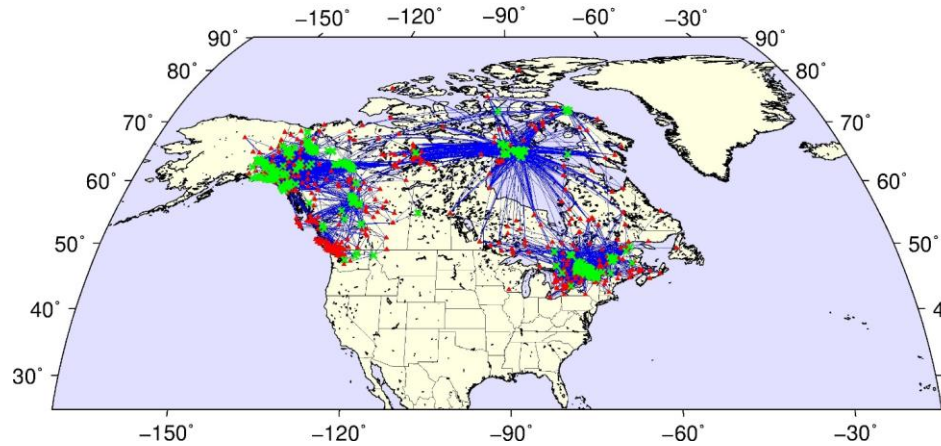
Pg raypaths



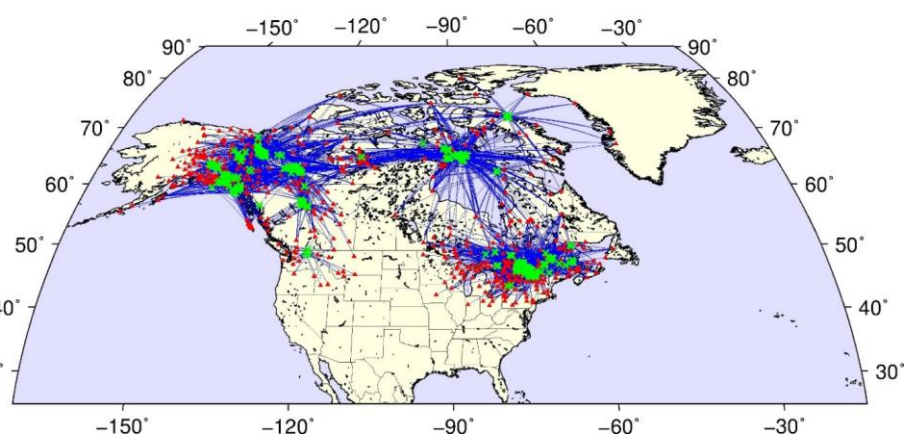
Canada Model



Pn raypaths



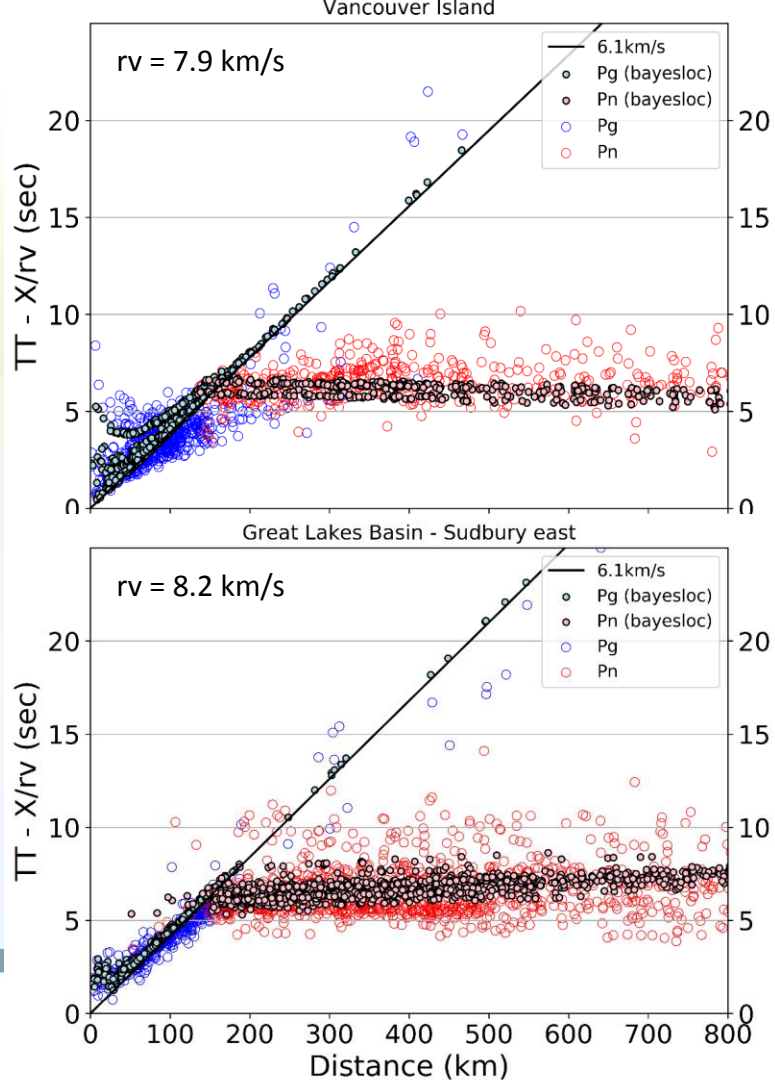
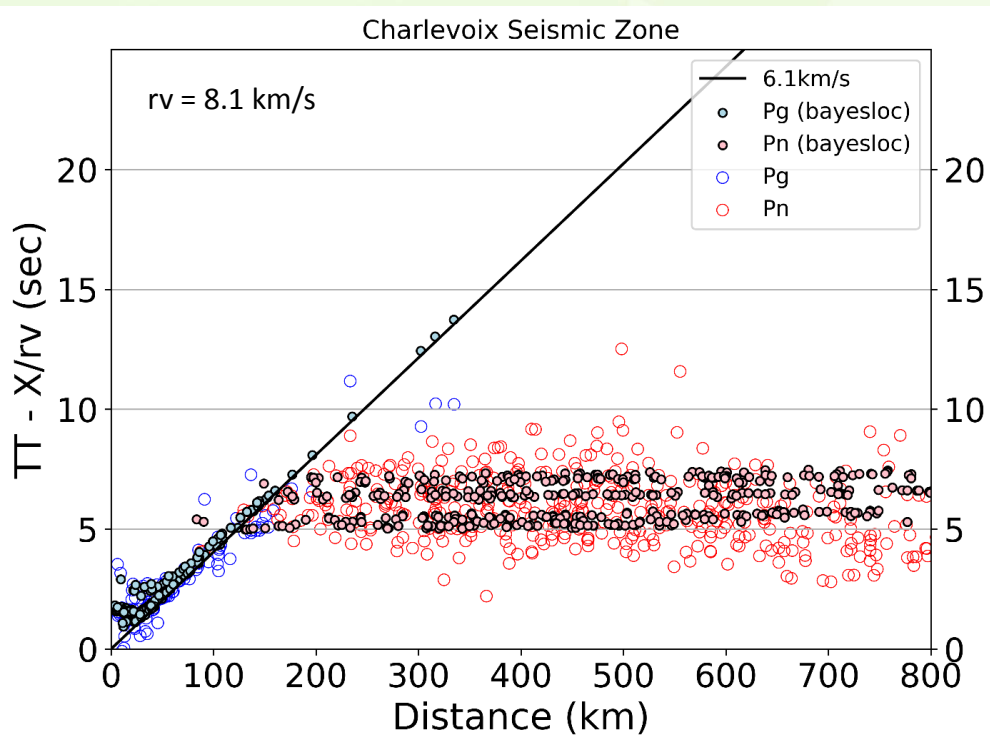
Lg raypaths

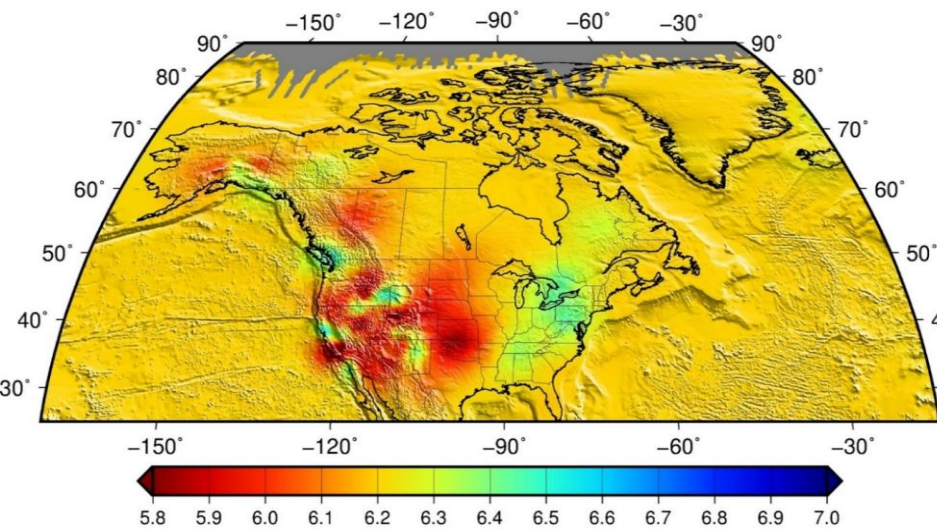


Sn raypaths

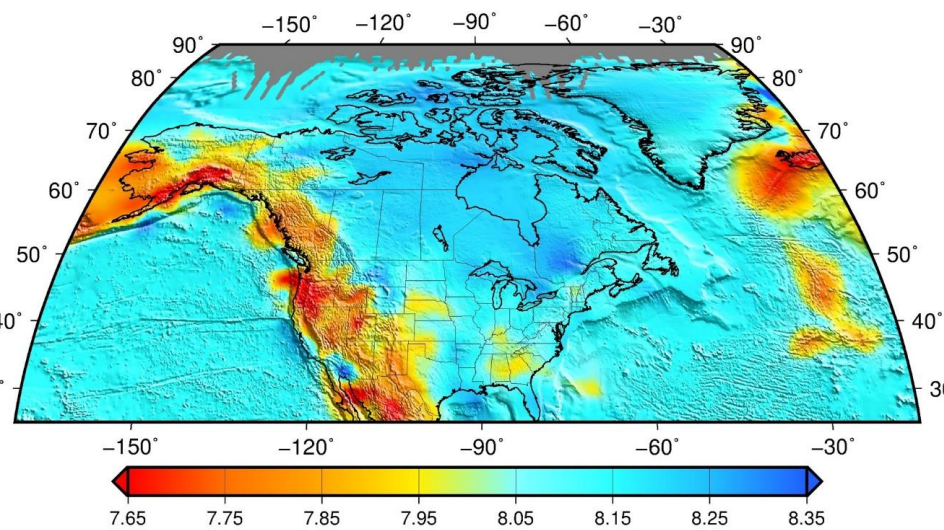
BayesLoc performance:

Accuracy and consistency of bulletin data is improved through Bayesloc multiple event locator [Myers *et al.*, 2007, 2009]

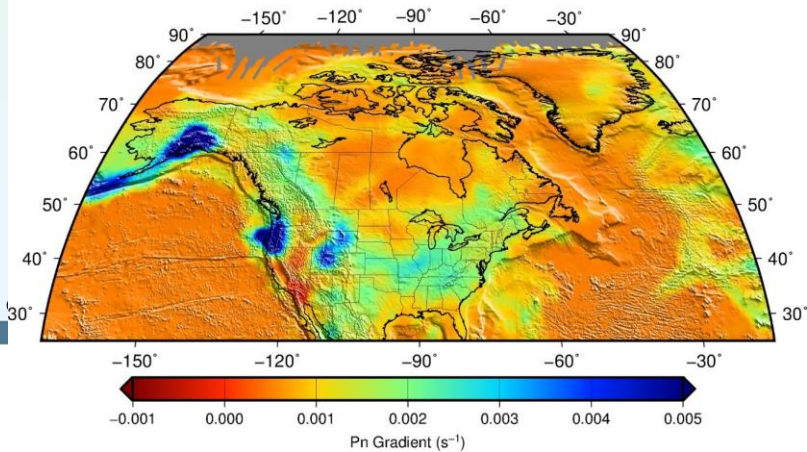




Pg crustal velocity (km/s)

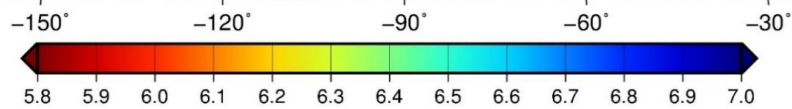
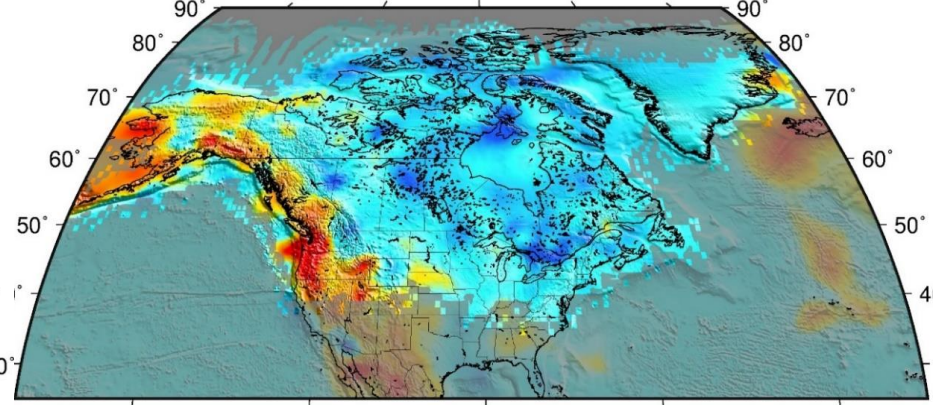
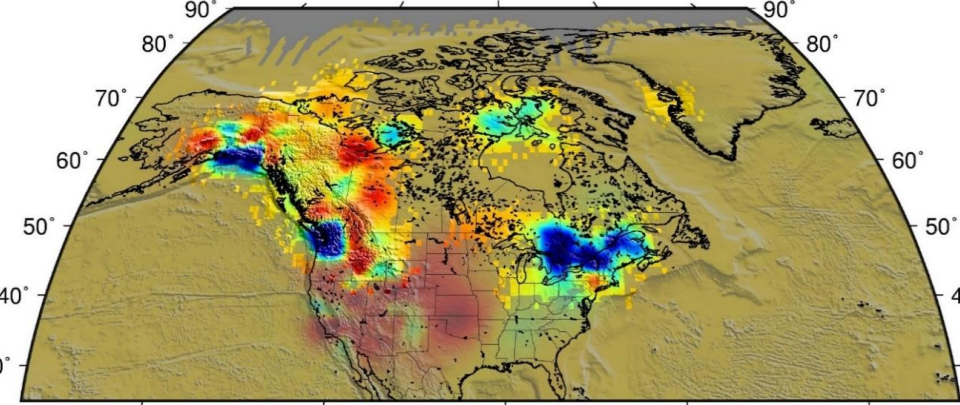


Pn velocity (km/s)

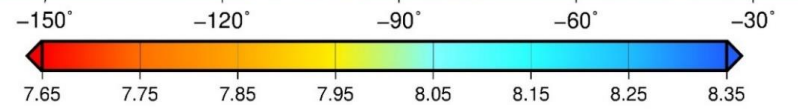


Pn Gradient (s^{-1})

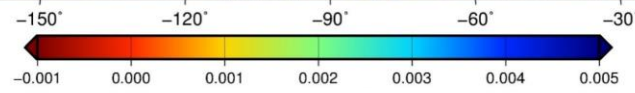
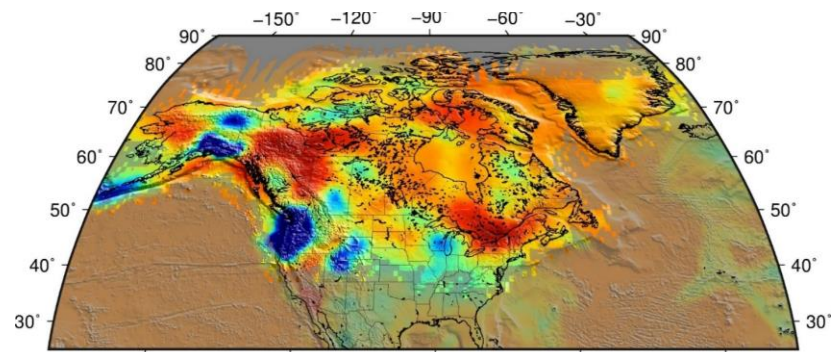
Starting *P* Model



Pg crustal velocity (km/s)

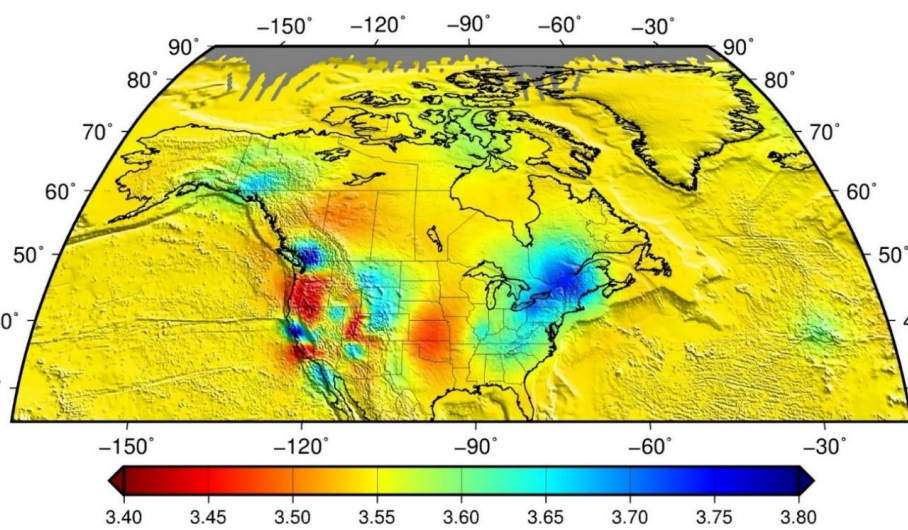


Pn velocity (km/s)

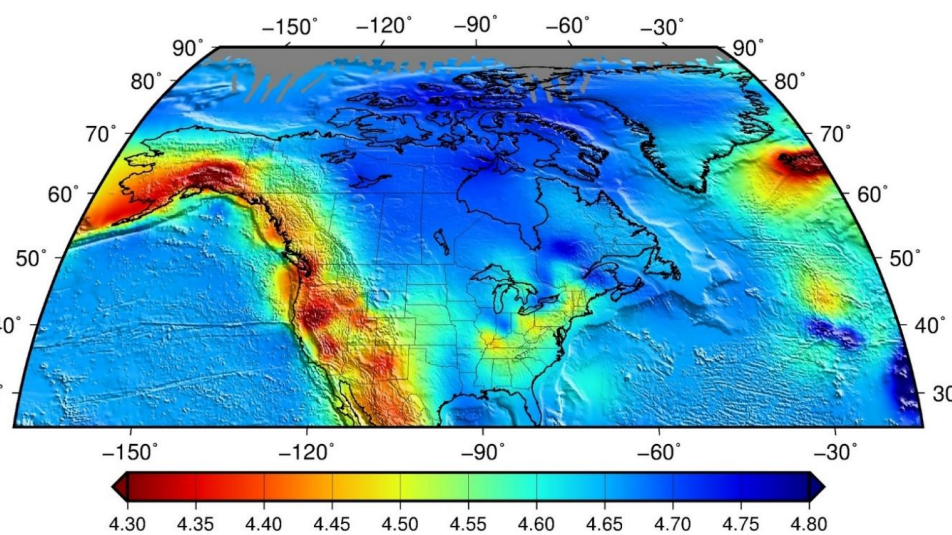


Pn Gradient (s⁻¹)

4 iterations *P* Model

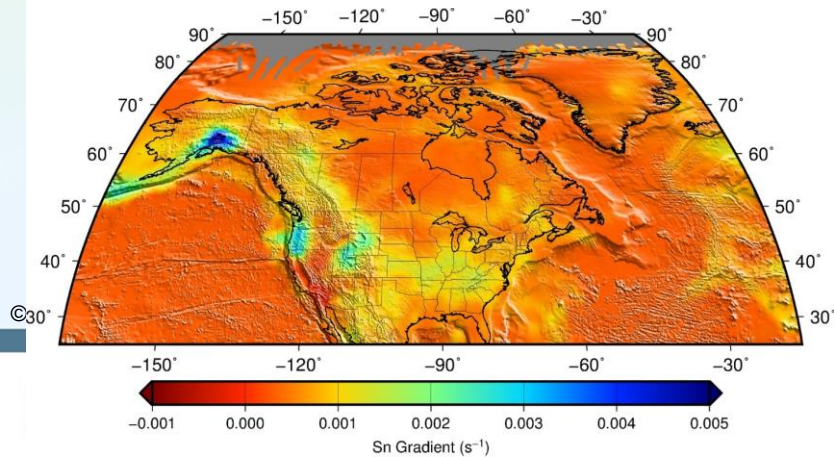


Lg crustal velocity (km/s)

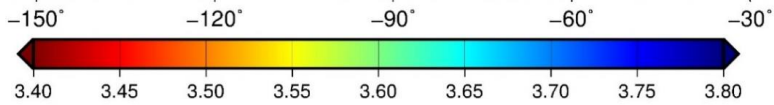
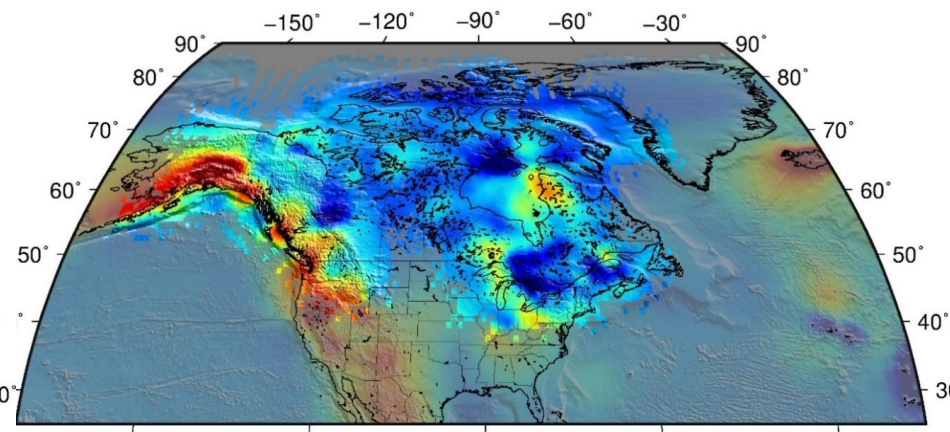
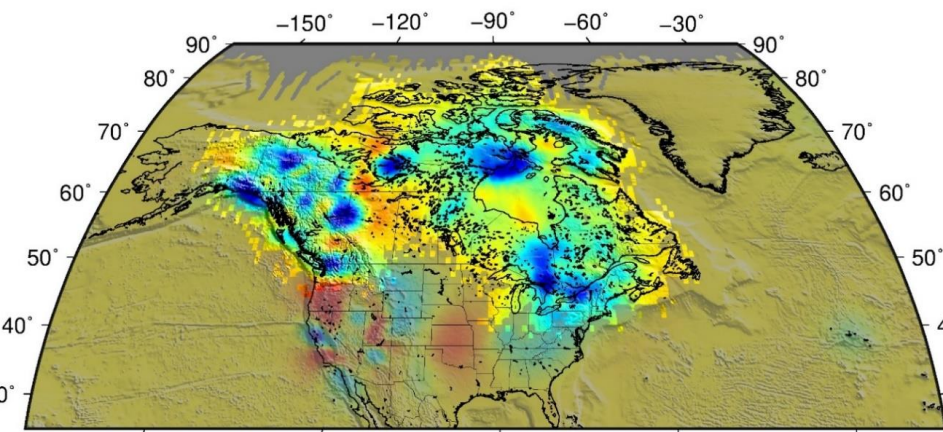


Sn velocity (km/s)

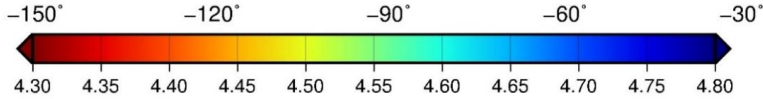
Starting S Model



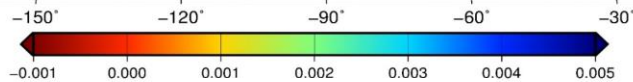
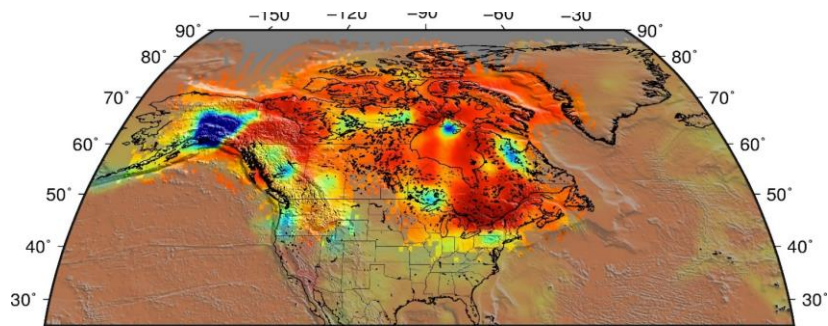
Sn Gradient (s⁻¹)



Lg crustal velocity (km/s)



Sn velocity (km/s)



Sn Gradient (s⁻¹)

5 iterations S Model

P and *S* travel time residuals for RSTT Canada

- Reduction in local and regional travel time residuals by combining Canadian dataset with existing RSTT North America

starting model:

Pg: 1.478 s

Pn: 1.422 s

Lg: 3.543 s

Sn: 2.365 s

final model:

Pg: 1.026 s (4 iterations)

Pn: 1.184 s (4 iterations)

Lg: 1.769 s (5 iterations)

Sn: 1.289 s (5 iterations)



Conclusions

- Regionally-appropriate $Q(f)$ relations should be applied in magnitude calculations to ensure consistency across provinces and accuracy of seismic catalogs. Benchmark for raypaths traversing multiple regions.
- Incorporation of NEDB Canadian catalog into RSTT North America reduces travel time residuals of all local and regional phases Pg , Lg , Pn , Sn by 17-50%. Lg residuals show greatest improvement with 50% reduction

Next steps

- Assessment of event location accuracy with RSTT Canada using independent validation dataset
- Development of a unified tomographic attenuation model for North America including Canadian datasets and established regional $Q(f)$ relations for validation.

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