Seismic velocity structure of the crust and mantle beneath northwestern Canada

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INTRODUCTION

Using cross-correlation to measure the travel-times of Rayleigh waves generated by 110 global earthquakes with magnitude >6.0 that occurred in 2004 and 2005, this research aims to map the variations of seismic velocity in the crust and mantle of NW Canada.

Having been subjected to various tectonic activities for the last four billion years, the present-day area of interest can be divided into three zones based on their ages, from east to west:

1. Older (4.0 - 2.6 Gya) Archean craton,
2. Younger (2.1 - 1.84 Gya) Proterozoic orogen,
3. Phanerozoic (1.7 - 0.6 Gya) sedimentary rocks that have been deformed through a series of extension, compression, and uplifting processes following their formation.

Thus, a deep understanding of this geologically diverse area would provide us with valuable information on how continents evolve over time.

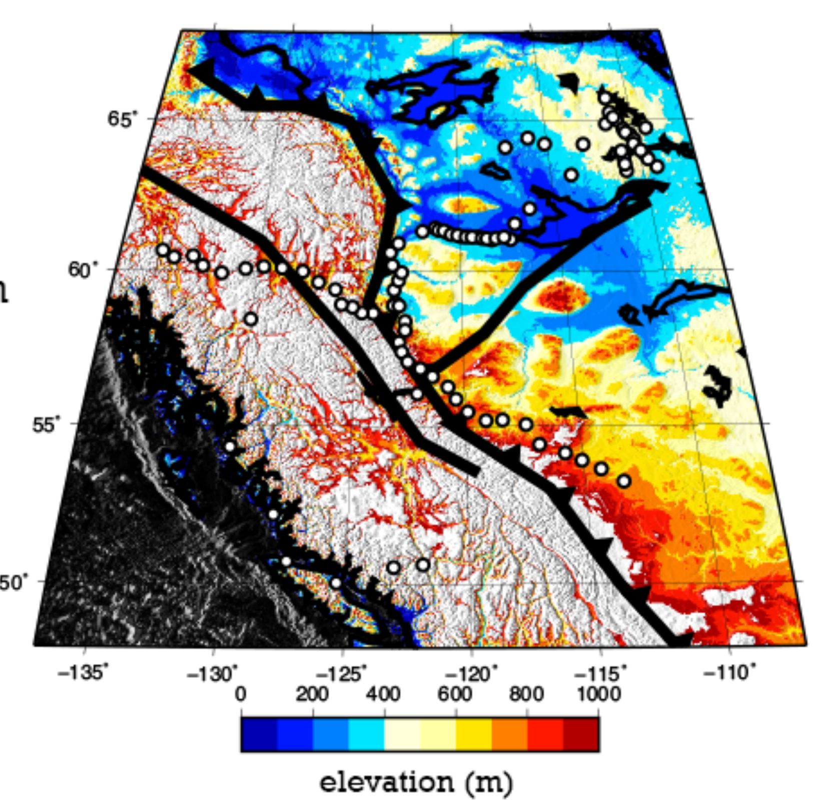


Figure 1. Topography map of study area. Blue indicates lower elevation, while red and white indicate higher elevation. Black lines represent Tintina fault (left) and Great Slave Lake shear zone (right). Jagged line represents Cordilleran deformation front. Station deployments are represented by white circles.

METHODS

1. Data collection from IRIS and CNDC archive

Obtain seismograms for 110 global earthquakes that occurred in 2004 and 2005 with magnitude >6.0. Each seismogram represents three hours of data since the occurrence of each earthquake.

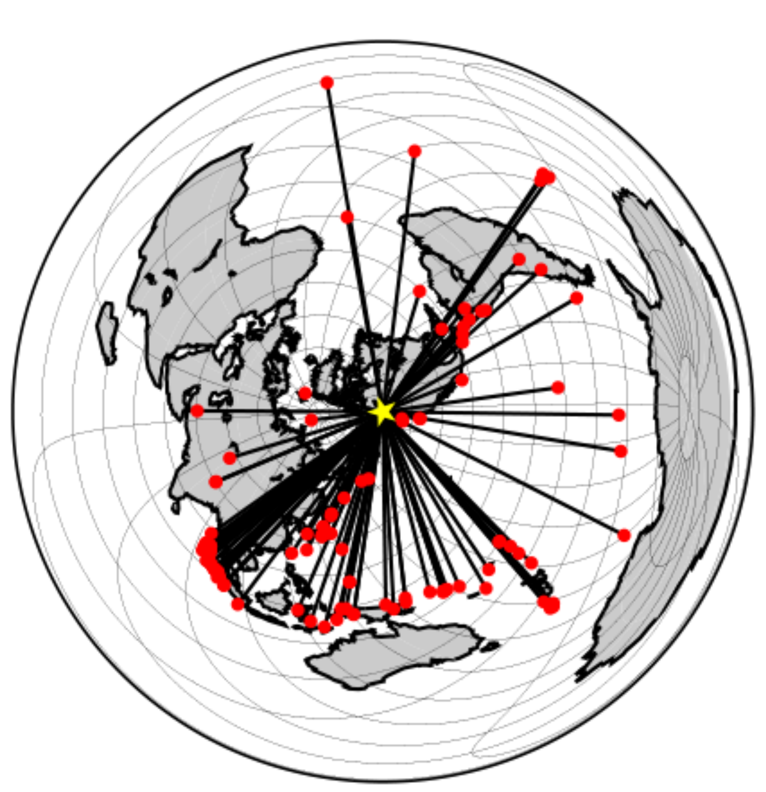


Figure 2. Distribution of global earthquakes used in this study. Map is centered on the study area, and black lines show the great-circle path from each earthquake to the study area.

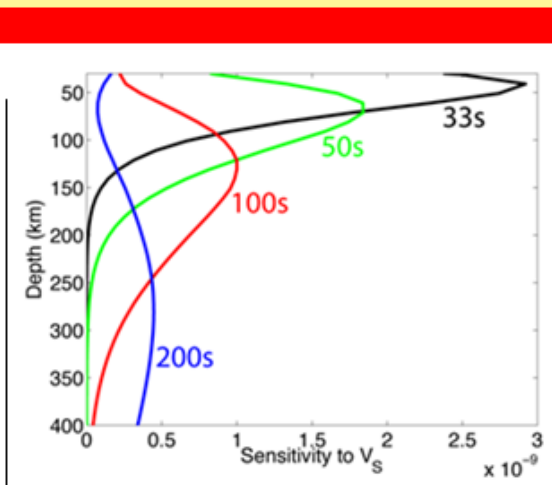


Figure 3. The colored curves describe the sensitivity of Rayleigh waves at four periods (33, 50, 100, and 200 s) to shear velocity in the mantle. By using measurements made at different periods, we are able to sample the mantle over a range of depths.

2. Two-station phase velocity approach

Identify station pairs located within 5° range of azimuth difference from a particular earthquake >> Cross-correlate the two surface-wave waveforms to determine the lag time between the wave's arrival at the first and second station. To obtain lag time as a function of frequency, the waveforms are pre-filtered in six different period bands >> result: 125,065 interstation lag times at each period.

3. Data selection

Remove lag times that correspond to unreasonably low or high propagation speeds, which eliminates 80,000 to 90,000 measurements at each period. The same interstation path may be represented by numerous measurements in this data set >> Calculate an average lag time for interstation paths with more than 10 lag time measurements and standard deviation of less than 0.6 >> Final data set of 600 - 1,100 observations at each period.

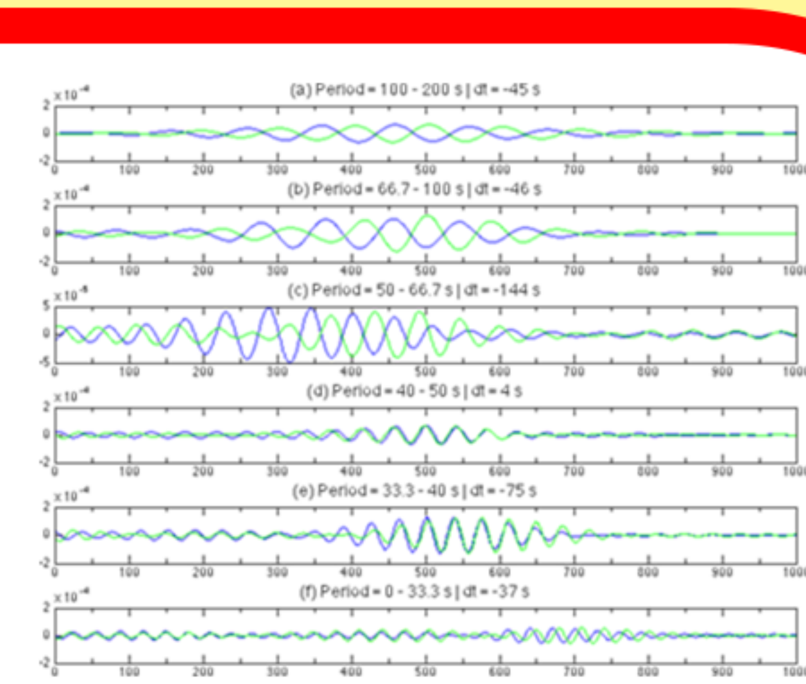


Figure 4. Cross-correlation of two waveforms for six different period filters between station XN-A09 (blue) and XN-A16 (green).

4. Matrix inversion

Divide study region into grids, each measuring 1° by 1°. The length of each Rayleigh wave path through each grid cell is determined. Matrix inversion is used to determine the wave velocity in each grid cell. This would give information about the variations in seismic velocity structure of the study region. Damping coefficient of $9*10^3$ is applied for smoothing purposes.

5. Checkerboard test

Check data distribution by creating a "synthetic" input matrix and comparing it with the results from matrix inversion.

RESULTS

Average velocity plotted at path midpoint

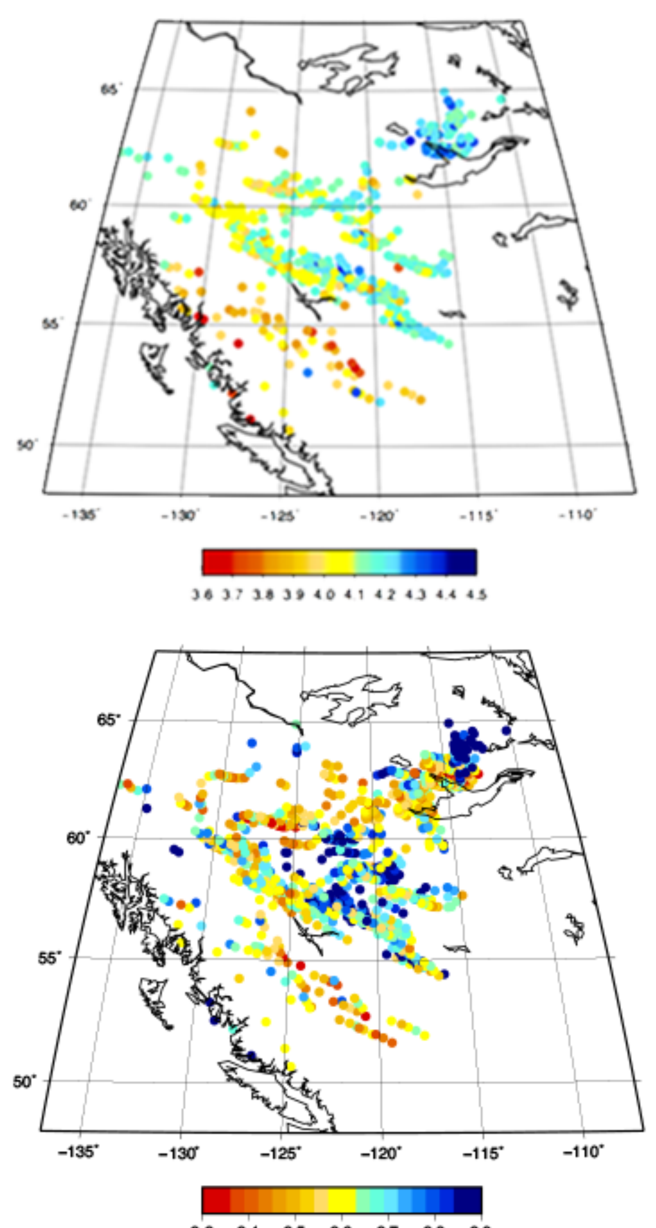


Figure 5. Average velocity of surface waves (km/s) calculated by dividing the lag time between two stations from interstation distance of each possible station pair plotted at the midpoint, for two different periods: (top) 200 s (bottom) 40 s. Both figures indicate lower-velocity western region and higher-velocity eastern region. The figures also indicate that shorter period waves generally travel in lower velocity compared to the longer ones.

Inversion results

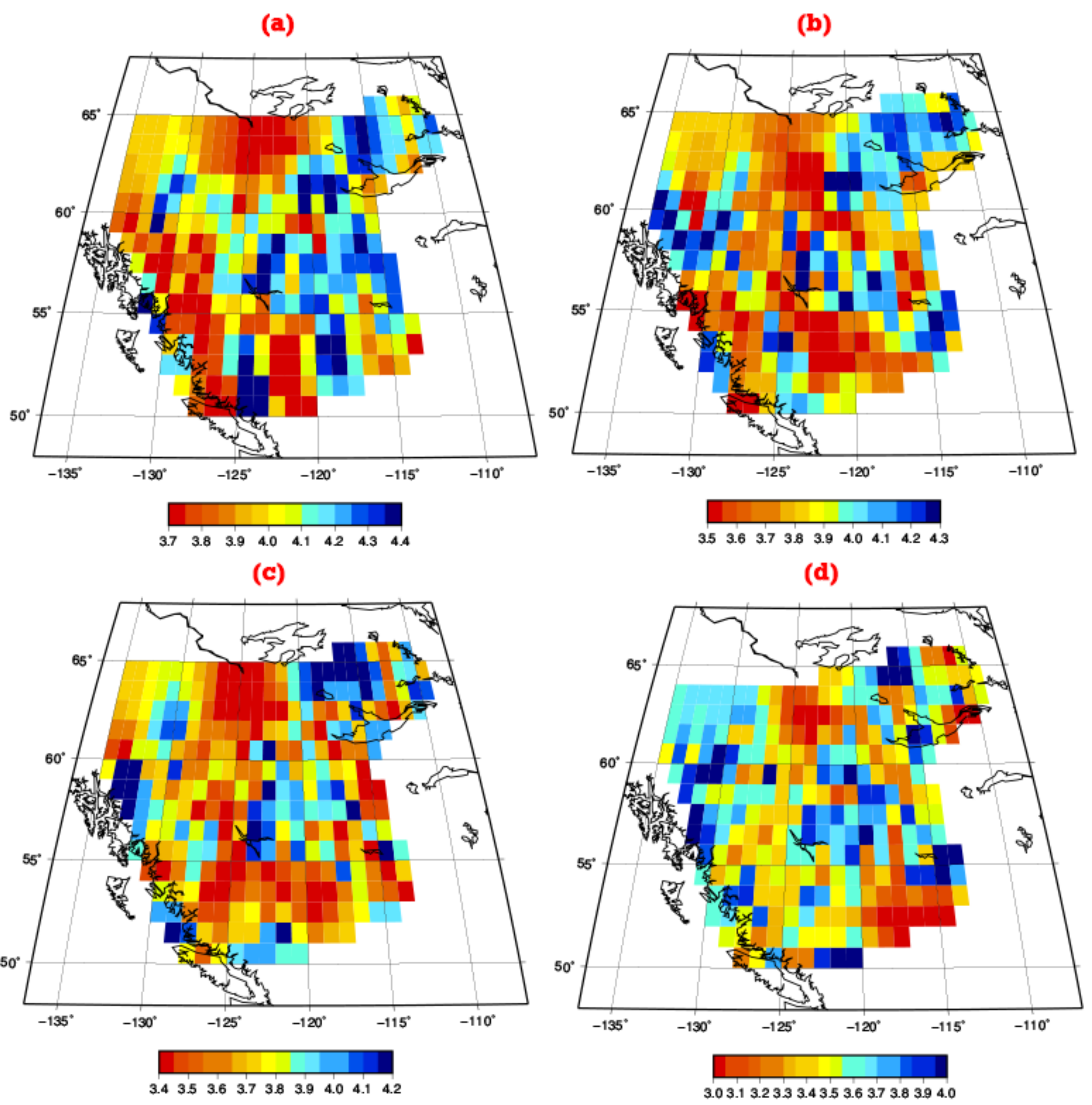


Figure 6. Matrix inversion results showing surface wave velocities (km/s) in grids measuring 1° by 1° for four different period filters: (a) 200 s (b) 66.7 s (c) 50 s (d) 33.3 s. These results indicate the same general trend as figure (5): lower velocity in the west and faster velocity in the east. These results also represent local anomalies due to distinctive tectonic setting of each region.

Comparison with global velocity models (Ekstrom, 2011)

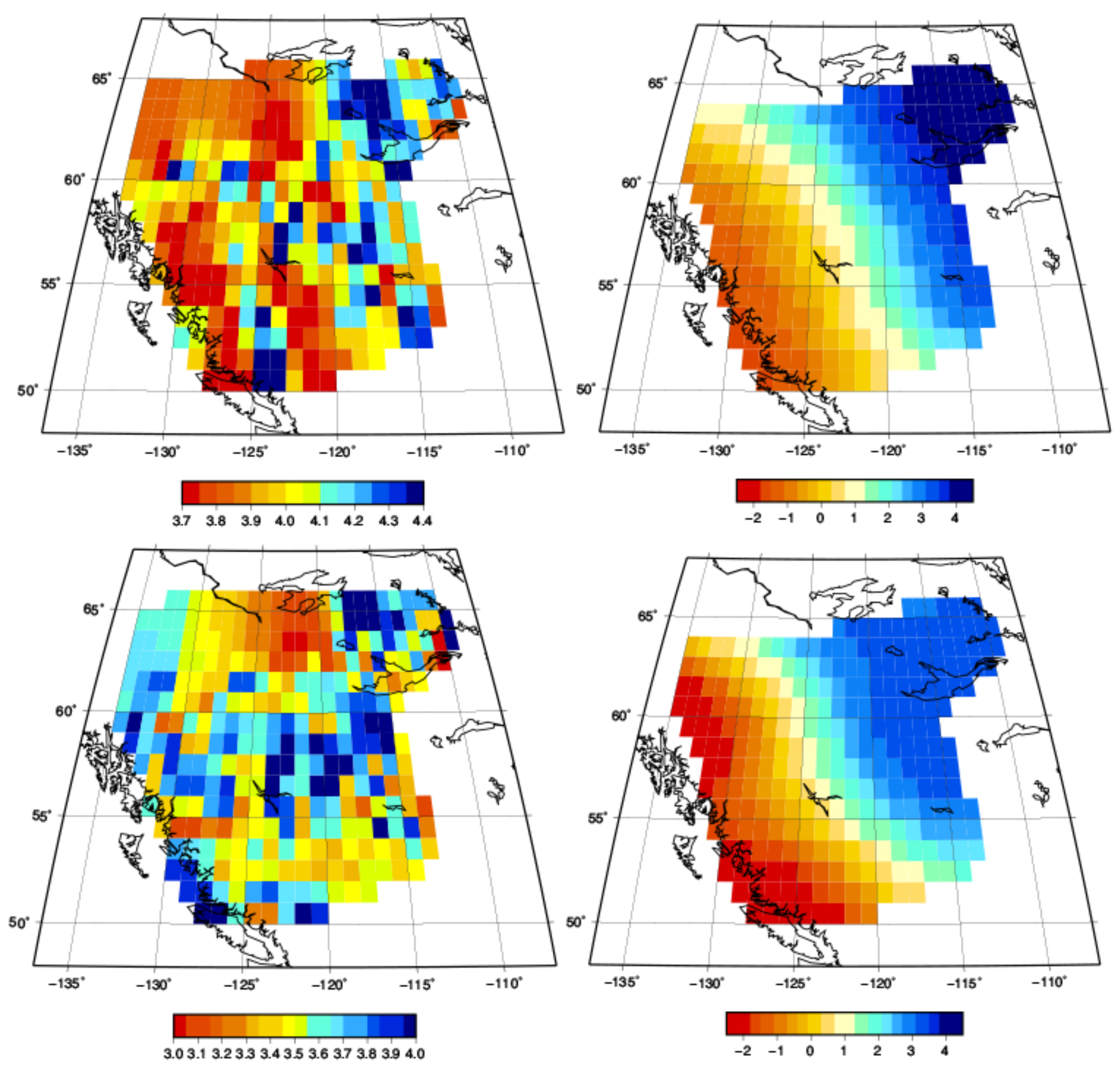
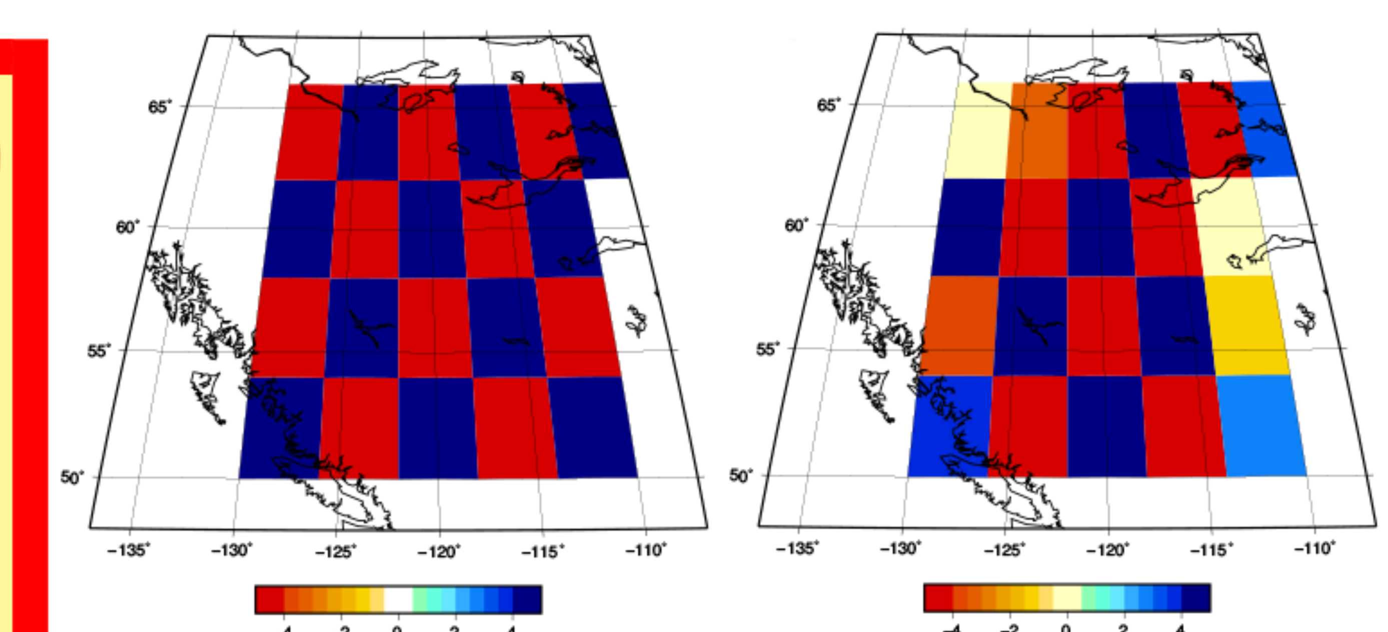


Figure 7. Matrix inversion results showing surface wave velocities (km/s) in grids measuring 1° by 1° for two different period filters: (top-left) 100 s; (bottom-left) 40 s. Both results are compared with global velocity models (color expresses % in velocity deviation from PREM) from a previous study for the same area and periods: (top-right) 100 s; (bottom-right) 40 s. Our results confirm the west-to-east velocity transition from lower to higher velocity, as well as provide higher-resolution velocity variations of the region.



Checkerboard test result

Figure 8. Checkerboard test (color scale is based on % in velocity pertubation) for 40 s-period waves. (left) input checkerboard matrix (right) output "recovered" matrix. The test indicates uneven data distribution. More data are obtained for the middle part of study region, indicated by the outcome grids for some of western and eastern parts that are only partially "recovered" and do not perfectly match the color of input checkerboard pattern. Each grid has a dimension of 4° by 4°.

CONCLUSIONS & FUTURE WORK

CONCLUSIONS

>> The two-station surface (Rayleigh) wave velocity approach used in this research agrees with the result found in previous studies: lower velocity in the west and higher velocity in the east. The line along which the veleciy difference occurs marks the transition between the younger, tectonically active orogen in the west and the older, more stable craton in the east.

>> Local velocity anomalies in certain regions that differ from previous studies are most likely due to uneven distribution of data points, as indicated by the checkerboard test.

FUTURE WORK

This method can be employed to map seismic velocity of the crust and upper mantle in other regions. Future projects would benefit from data obtained from stations that are distributed evenly throughout area of interest. The author is currently doing similar analysis on the Antarctic region using data from global earthquakes that occurred in 2010 to 2012 with magnitude >6.0.

ACKNOWLEDGMENTS

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