Seismic Site Characterization at Strong Motion Stations in Metro Vancouver

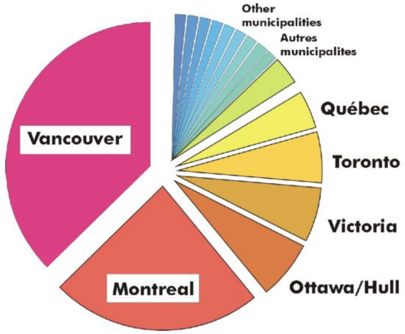
Jamal Assaf, Sheri Molnar, Hesham El Naggar, Aamna Sirohey

Institute for Catastrophic Loss Reduction

British Columbia Emergency Management BC

Western Engineering

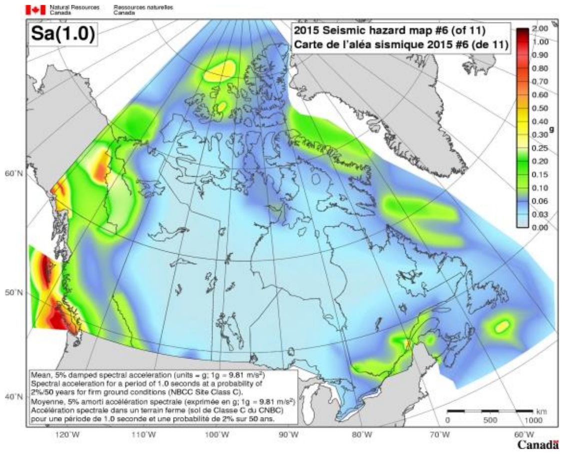
1- Earthquake Hazard and Risk in SW BC



Approximate seismic risk distribution in Canada (Adams et al 2002)

Southwestern British Columbia (SW BC), including GTA Vancouver, has the highest seismic risk in Canada

- Hazard is due to
  - 3 types of earthquakes
  - Sedimentary Georgia basin
- Over 2 million people in Metro Vancouver with critical infrastructure.



Seismic Hazard Map of the mean 5 % damped spectral acceleration (T =1.0 second) at a probability of 2% in 50 years for (site Class C) (Natural Resources Canada 2015)

- **What will the ground shaking be like in future earthquakes?**
- **Undergoing Microzonation project for Metro Vancouver**

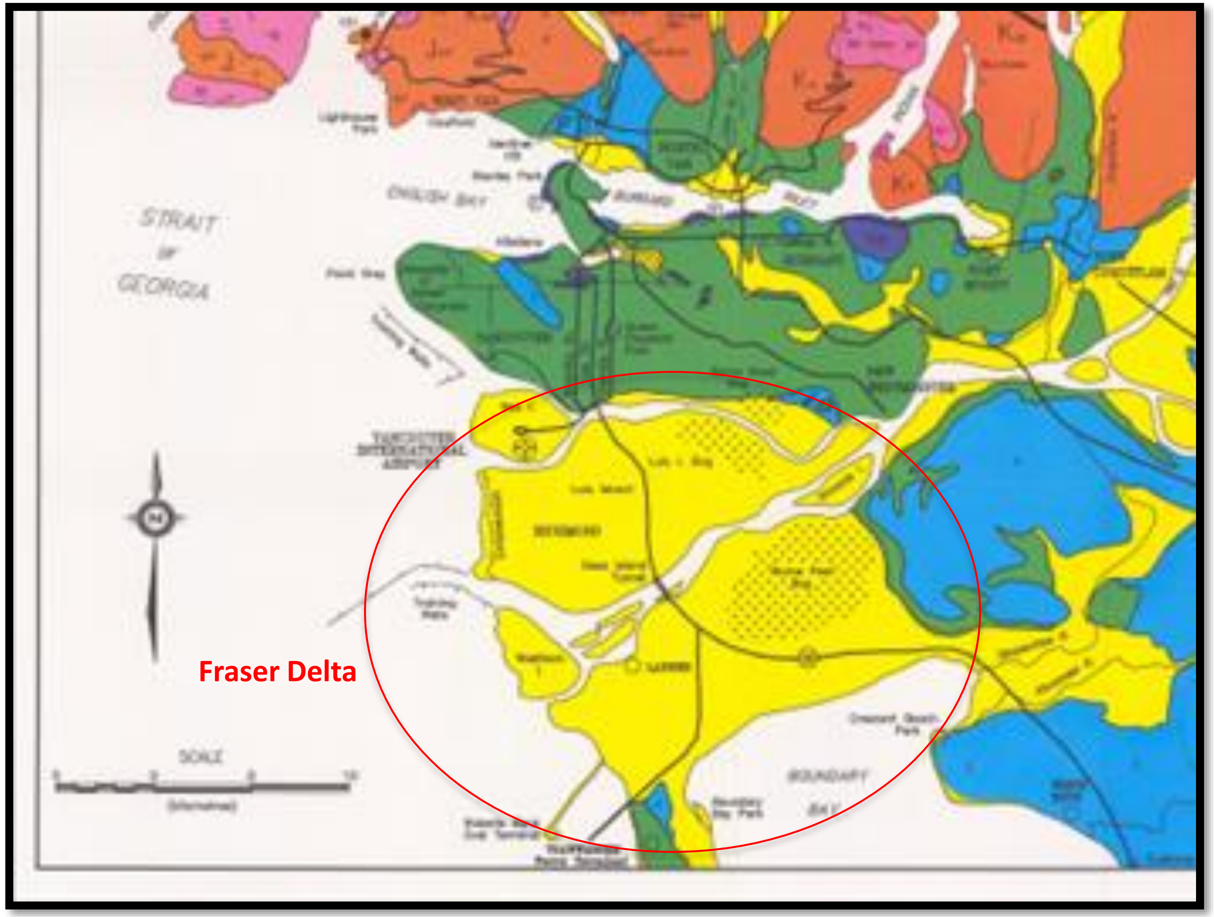
Greater Vancouver from googlemaps.com

2- Geology of Metro Vancouver

- The upper layer is young **soft Holocene** sediments mainly silts and sands up to 300 m thickness (Vs ~ 100 - 300 m/s).

- Middle layer **Pleistocene sediments** composed of ice compacted till and glaciomarine silts and sands (Vs ~ 500 m/s).

- The **Tertiary bedrock** underlying the Pleistocene layer consists of Miocene sandstone and shales with a depth range of 200 m to 1000 m (Vs >~1500 m/s) in Fraser Delta.



Geologic Map of GTA Vancouver (Armstrong 1980)

Silts & Sand

Till & Glaciomarine Silts

Tertiary bedrock

3- Site effects and Amplification in Vancouver

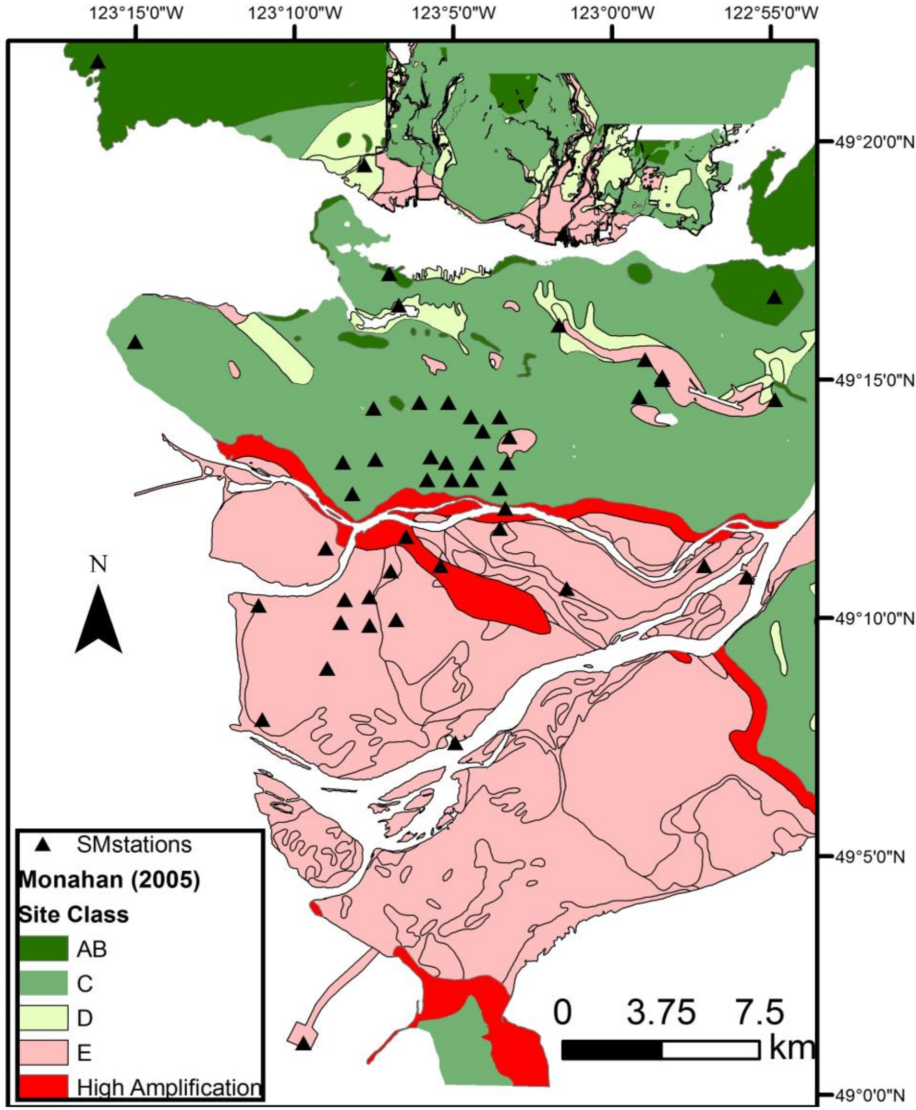
Site effect is the effect of local geology (stiffness and geometry) on the propagation of seismic waves.

- Previous earthquake records (1976 – 2001) demonstrated a maximum linear amplification of 8-11 near edge of delta relative to hard rock (Cassidy and Rogers, 2004).

- By developing Vs profiles, we will compute 1D theoretical site amplification across Metro Vancouver.

- The strong motion station network (BCSIMS) provide an opportunity to validate applicability of theoretical response, however, no detailed site characterization at strong motion stations currently exits.

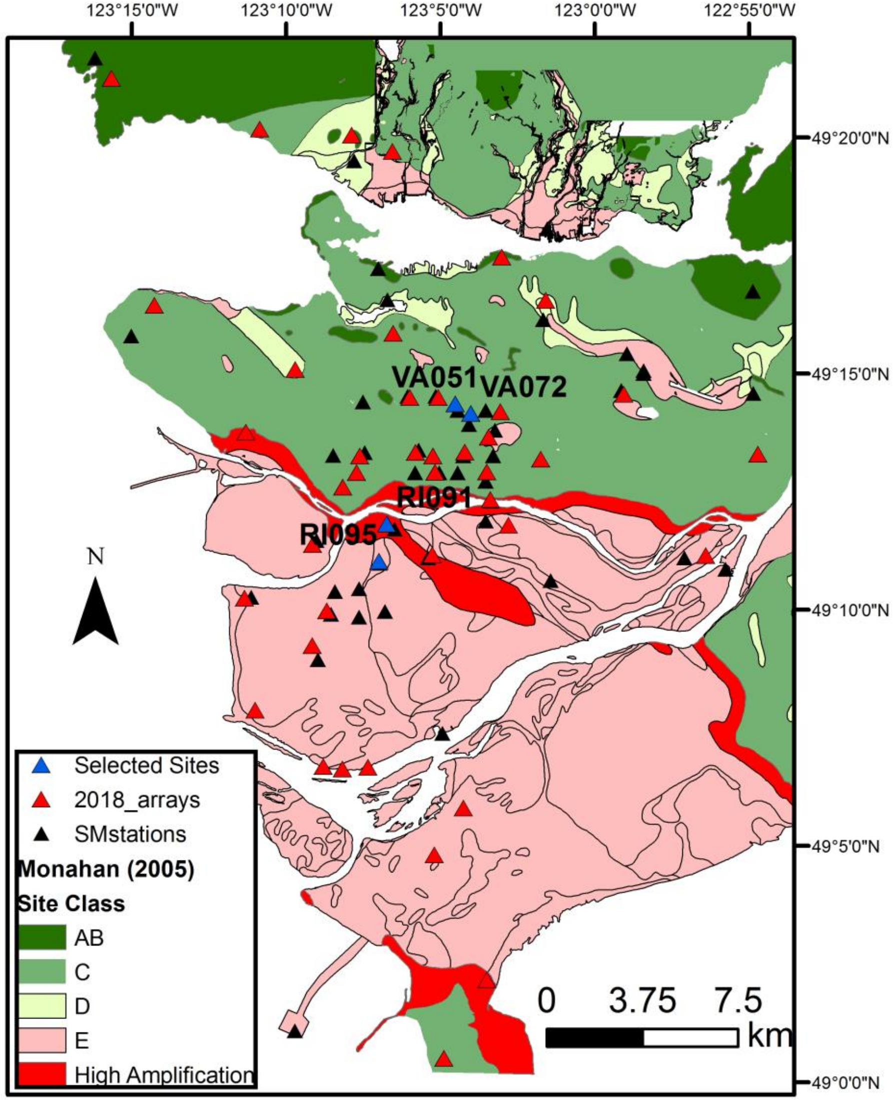
- The first goal of this study is to develop Vs profiles at strong motion stations.



Strong motion stations, base map current site class map (Taylor, 2006)

4- Field Campaign 2018

- Non-invasive surface wave measurements were conducted at 45 sites across Metro Vancouver (red triangles)
- Both active- and passive-source surface wave measurements were conducted at most sites.
- 20 of these sites are co-located with strong motion station (BCSIMS).
- 4 selected sites are chosen to show inversion methodology that will used to retrieve the Vs profile (blue triangles).

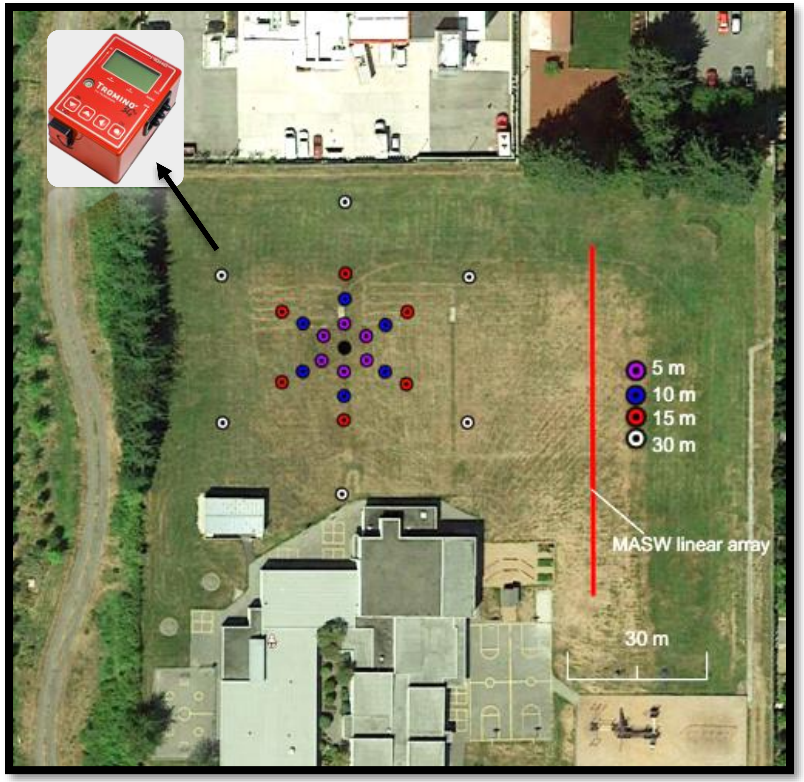


Array sites with strong motion stations, basemap current microzonation map (Taylor, 2006)

5- Subsurface characterization: Non-invasive methods

- Passive - source recording of ambient noise: Microtremor Array measurement (MAM), 7 circular Trominos® (3- components) record microtremors for at least 15 min.

- Active-source recording: Multi-Channel Surface Wave Analysis (MASW) measurements. 24 4.5-Hz vertical-component geophones deployed in a linear array.



MAM

MASW

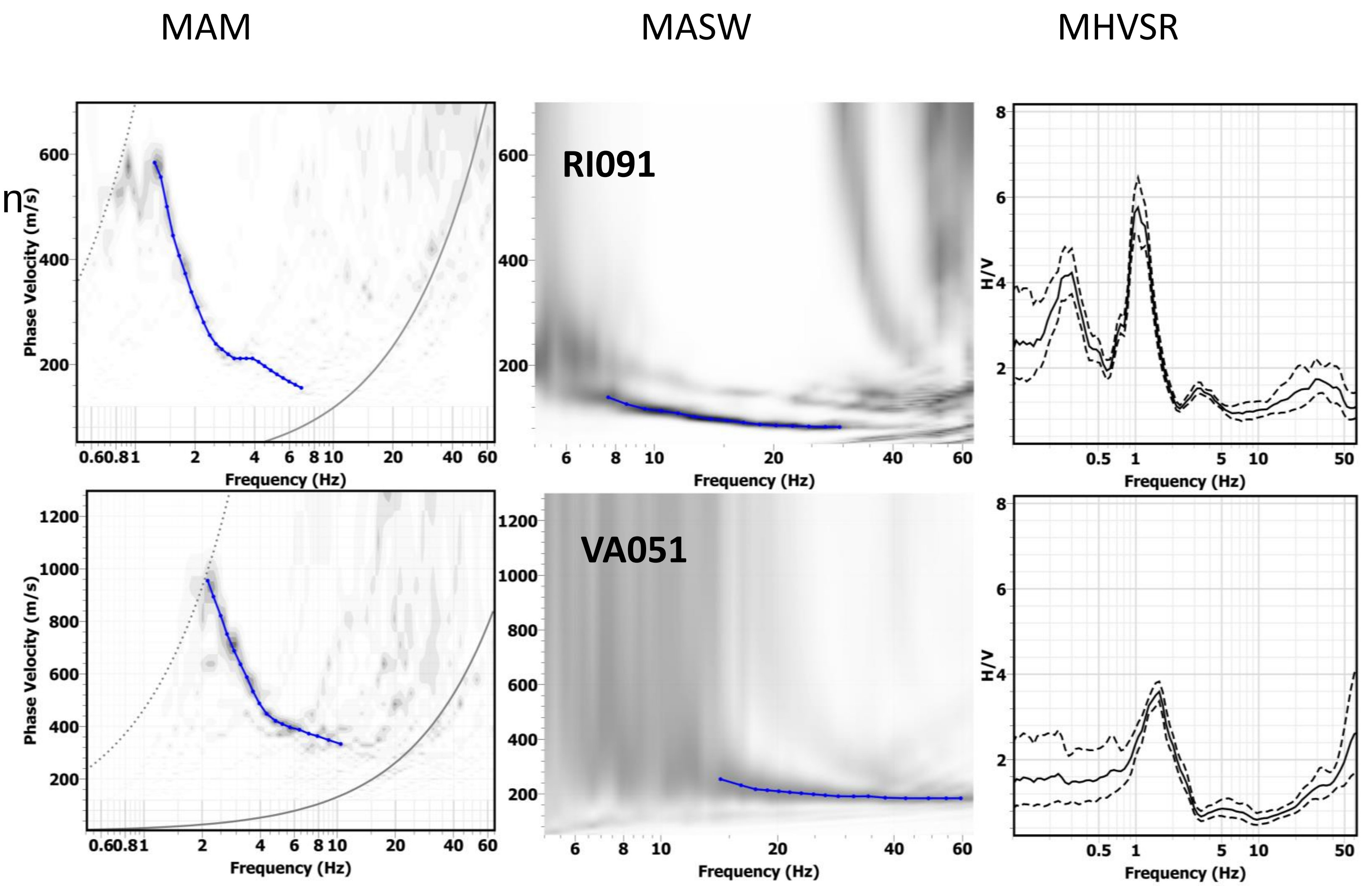
6- Processing

- The correlation between recordings allows extracting a Dispersion curve.
- A dispersion curve is a representation of change of phase velocity of Rayleigh wave with frequency or wavelength.

- MAM method gives dispersion estimates at low frequencies, as well as horizontal to vertical ratio (MHVSR)

- MASW method gives dispersion estimates at higher frequencies.

- The combination of both is to be used.

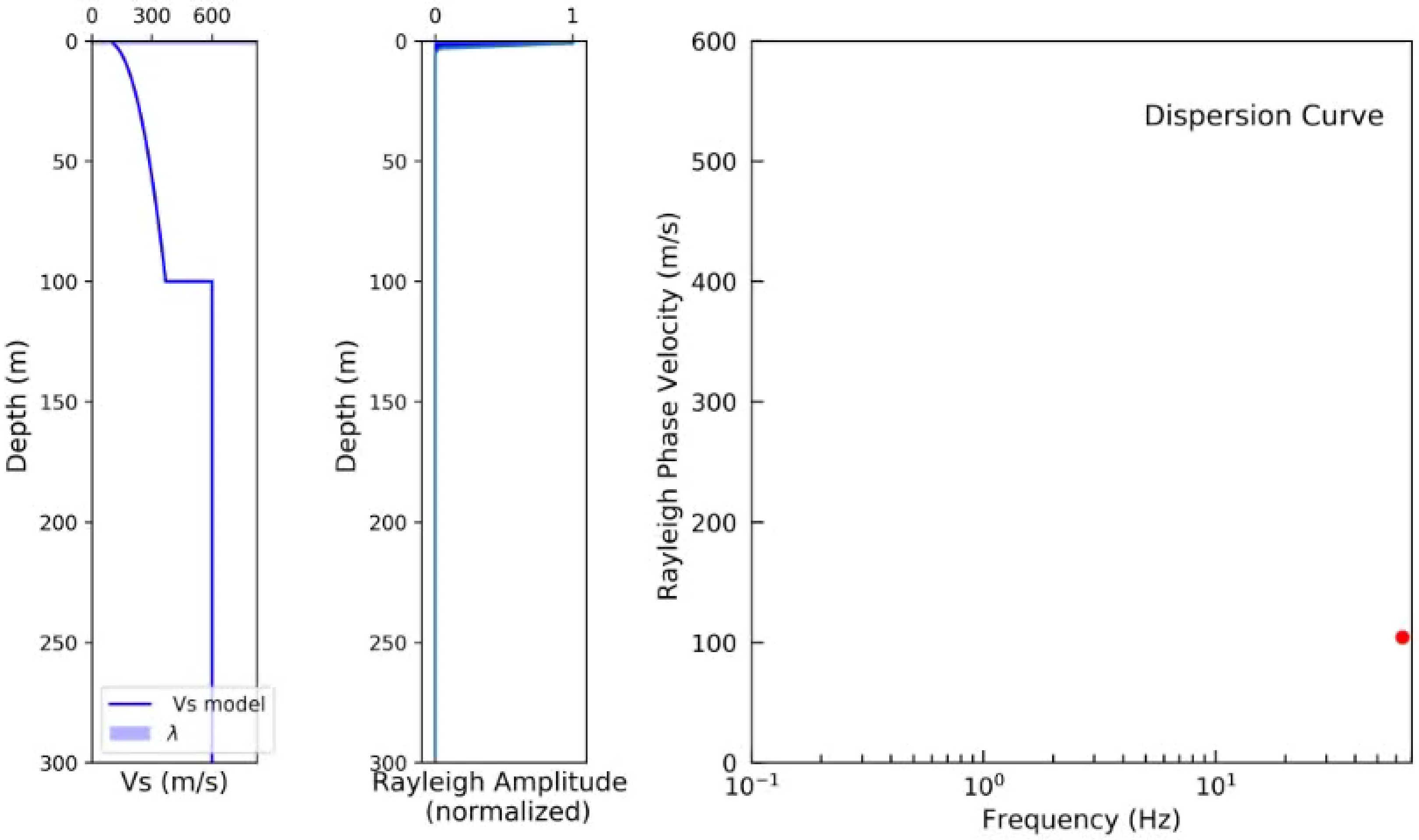


6- How is this dispersion curve related to Vs profile?

Two notes:

- Amplitude of Rayleigh waves (particle motion) is mainly confined to a depth of around 1 wavelength (λ).
- The phase velocity is proportional to relative amount of particle motion happening in each Vs layer.

This concept of geometric dispersion dictates the relation between Vs profile and surface wave measurements.



Forward dispersion curve from Vs profile.

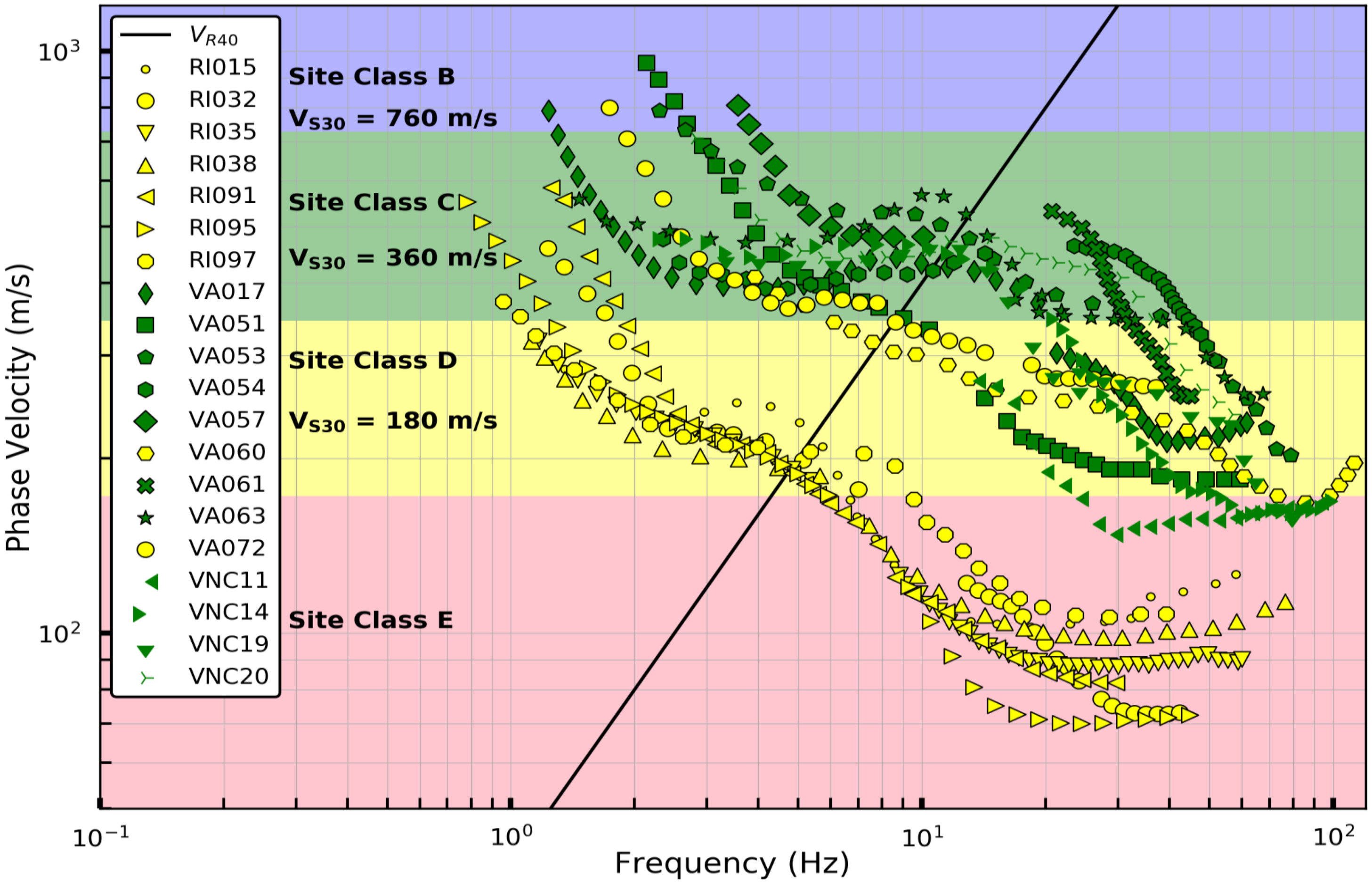
7- Dispersion curves

The following simplified equation (Martin and Diehl 2004) uses phase velocities corresponding to a 40-m wavelength Rayleigh wave, $V_{R[40]}$, to calculate Vs_{30} within 10 % error, where

$$Vs_{30} = 1.045\ V_{R[40]}\ .$$

Richmond Sites exhibit lower velocities, while Vancouver sites show higher velocities.

7 Richmond sites are Class D
2 Vancouver sites are Class C/D
11 Vancouver sites are Class C



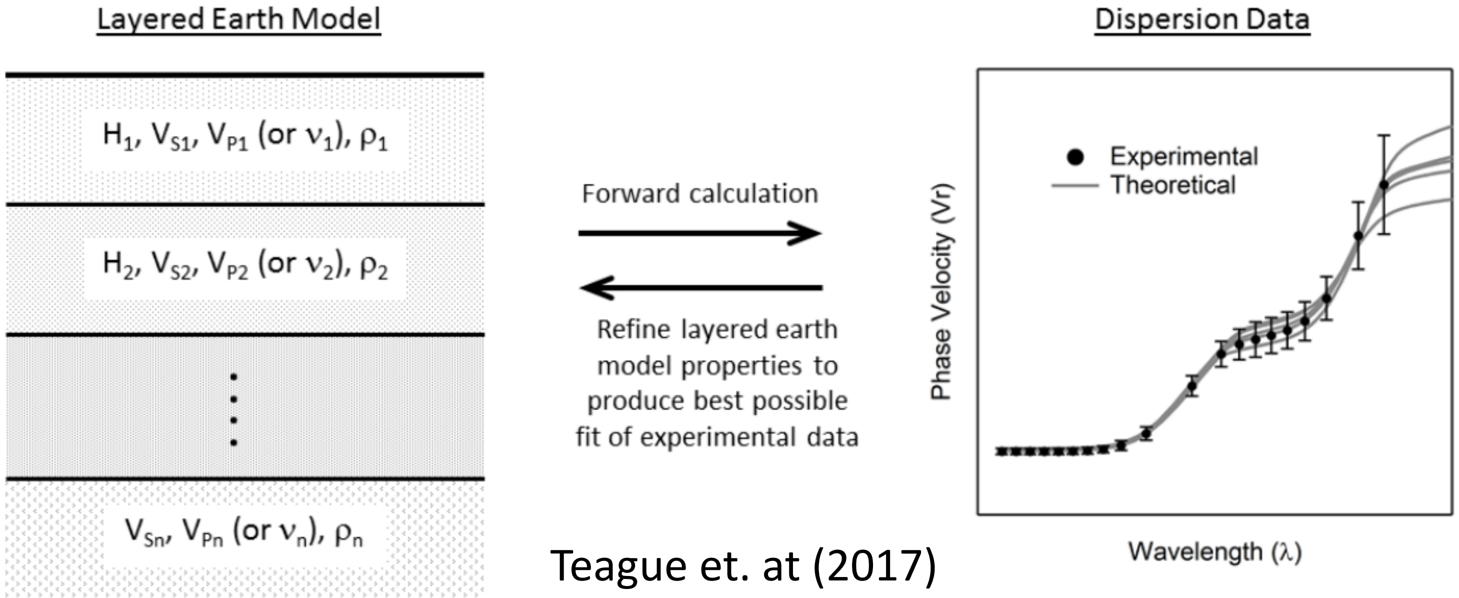
Dispersion Curves for all 20 sites co-located with strong motion stations (BCSIMS).

8- Inversion

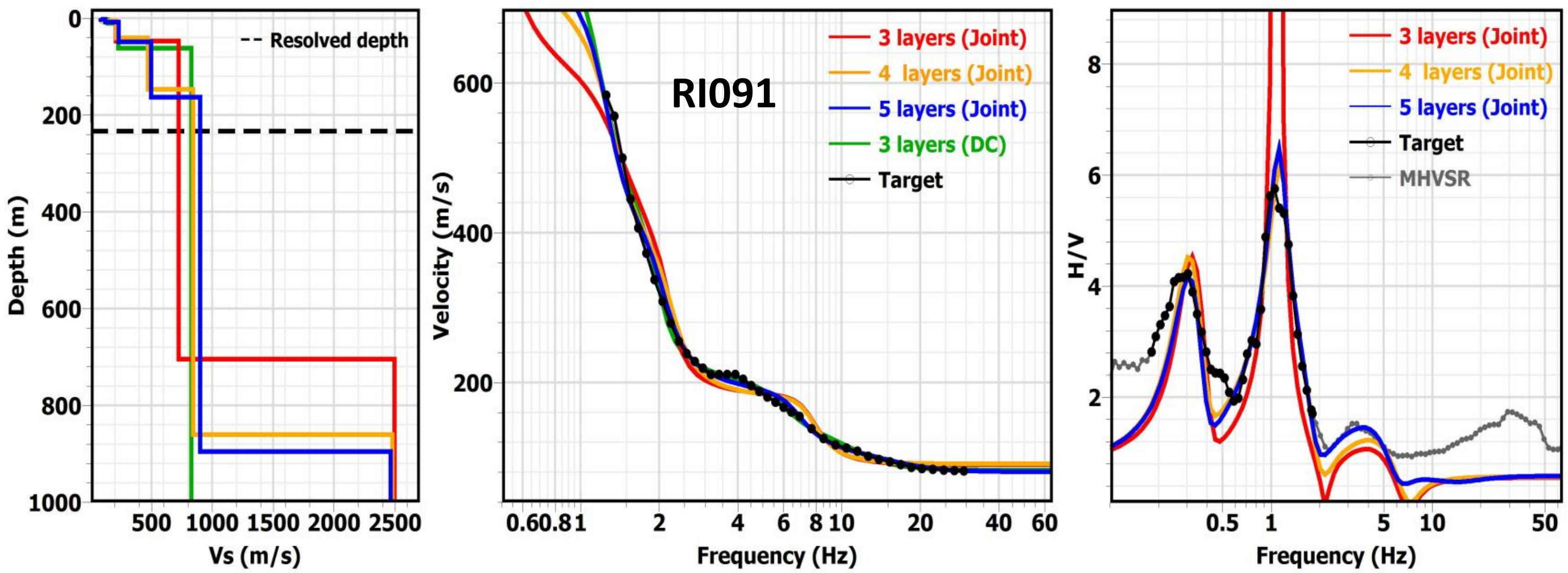
- Inversion tries to find a theoretical layered model (Vs profile) whose dispersion curve fits the experimental one.

- Joint Inversion is inverting both the dispersion curve and MHVSR, assuming that HVSR represents the Rayleigh wave ellipticity.

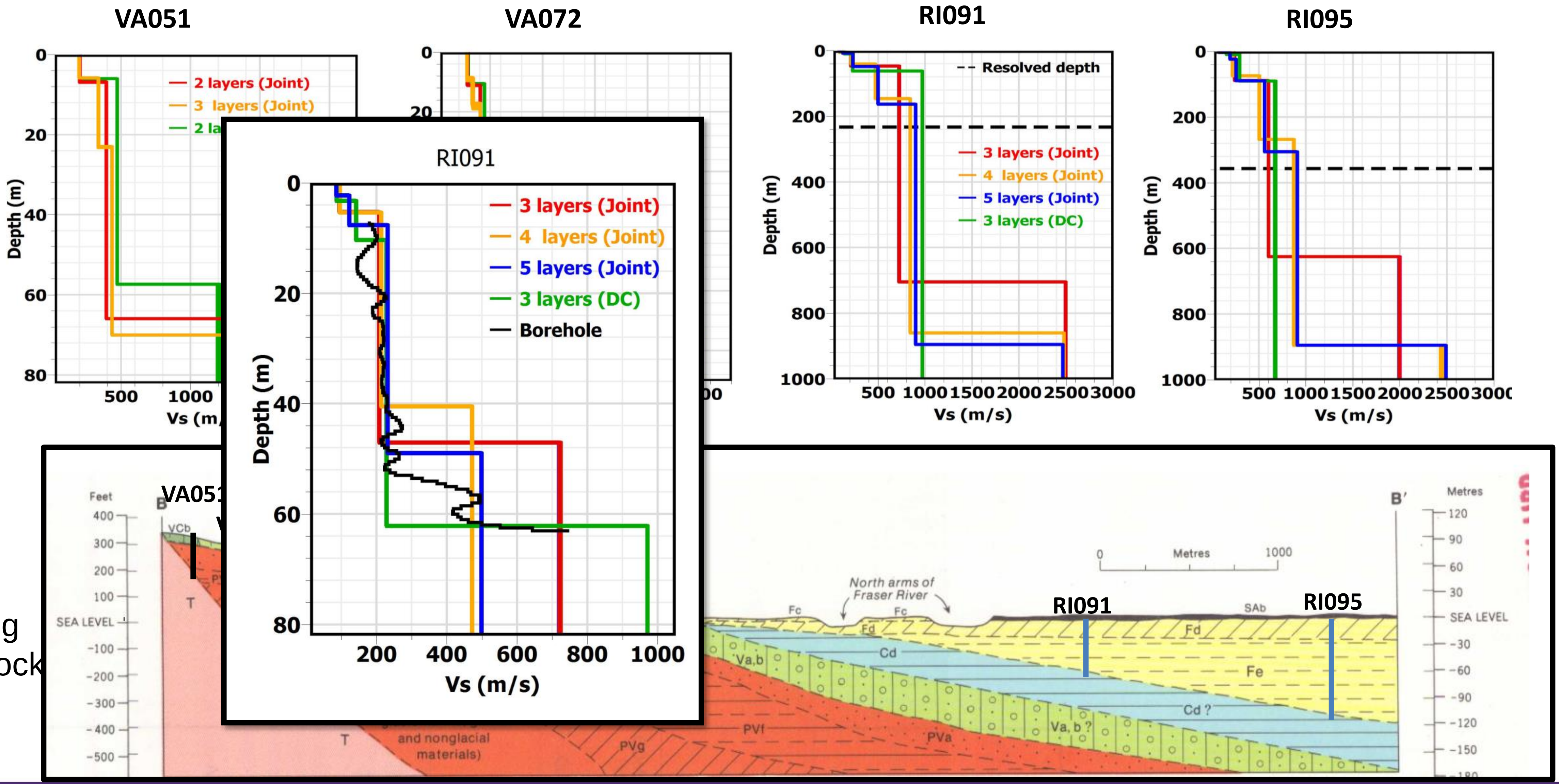
- We perform dispersion inversion (DC) and joint inversion (JT) using different layers to address non-uniquesness of the problem.



Teague et. at (2017)



9- Inversion results with geology



Cross section (Armstrong and Hickock ,1979)

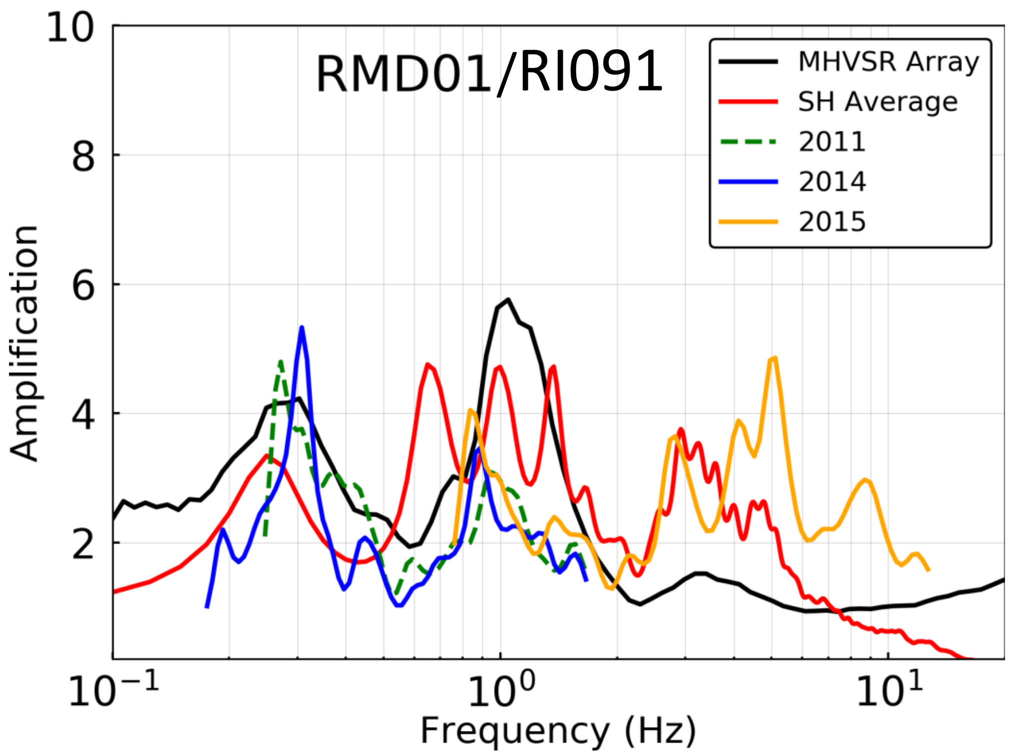
10- Application

- Using these velocity profiles, we compute the linear-elastic transfer function (1D SH Haskel, 1960).

- SH is the average of transfer functions of different Vs models.

- Comparison between SH, EHVSR, MHVSR will give insights into the applicability of 1D theoretical solution with empirical amplification.

- The effect of variability in Vs profiles on site transfer function should be included!



11- Conclusions and future work

- Non-invasive surface wave techniques, in urban settings like Metro Vancouver, provide adequate characterization of subsurface conditions in time-effective manner.
- Basic site characterization (Vs_{30}, f_0) was done using active- and passive-source measurements near 20 strong motion stations.
- The developed Vs profiles for Richmond and Vancouver sites are in line with geologic settings and comparable to invasive techniques.
- Developing Vs profiles for all 20 sites using (joint) inversion of dispersion curves and MHVSR shall be achieved.
- Validation of non-invasive techniques with co-located invasive measurements (deep boreholes) is to be targeted the next field campaign in July, 2019.
- These Vs profiles have applications in GMPEs development, site-specific hazard assessments.

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Thank you

Questions ??

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