“We learn geology the morning after the earthquake.”

- Ralph Waldo Emerson

UNIVERSIDAD YACHAY TECH

ELTE EÖTVÖS LORÁND TUDOMÁNYEGYETEM

CRUSTAL STRUCTURE OF EASTERN BANGLADESH FROM AMBIENT SEISMIC NOISE

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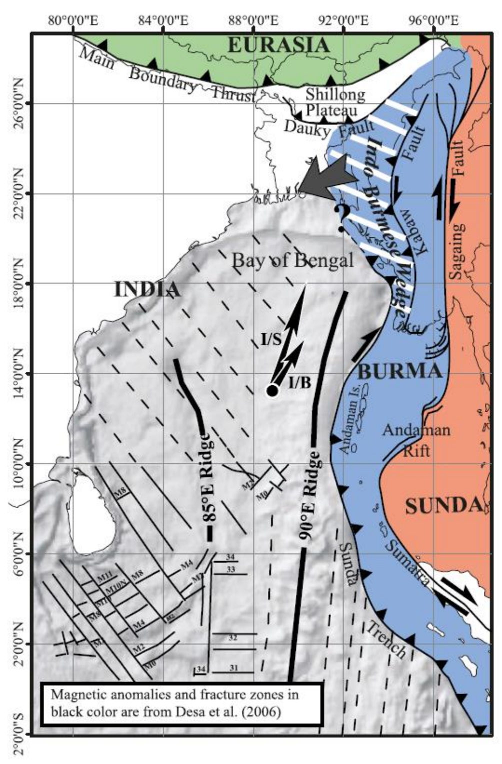
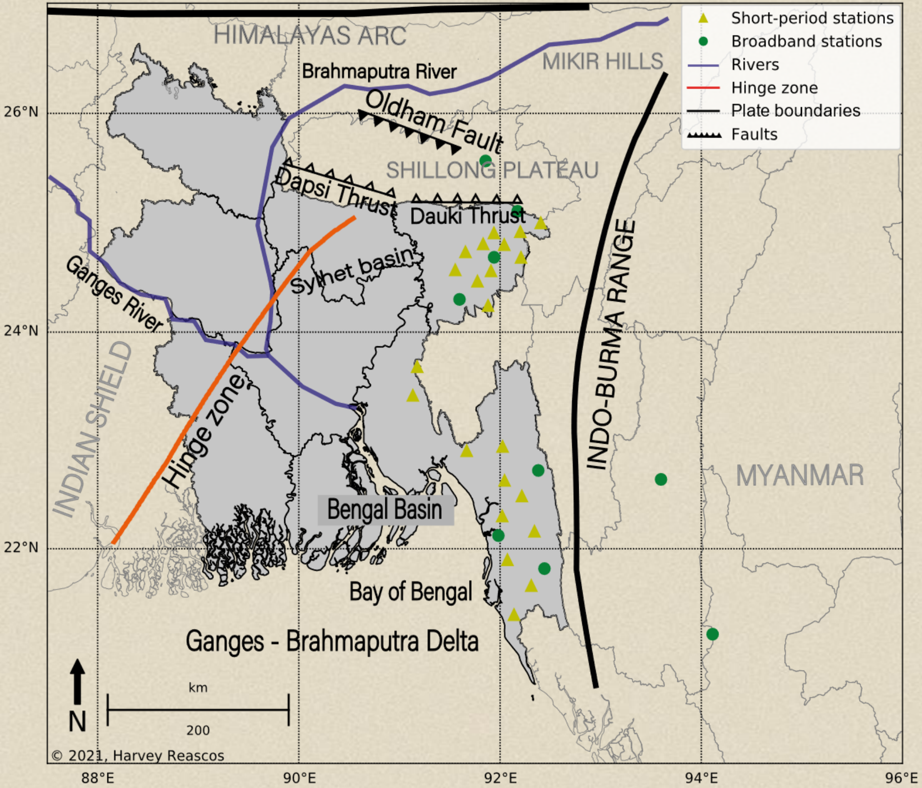
Budapest, 30th 2022

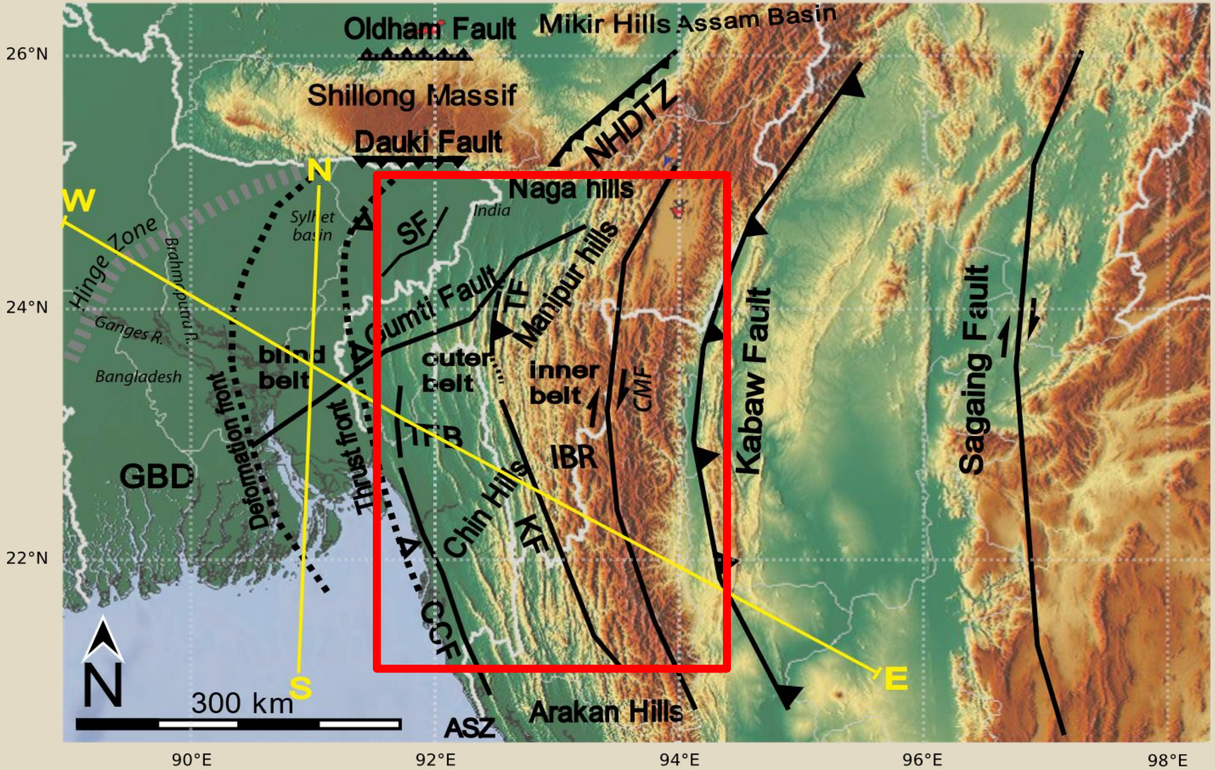
Bangladesh



(Maurin & Rangin, 2009)

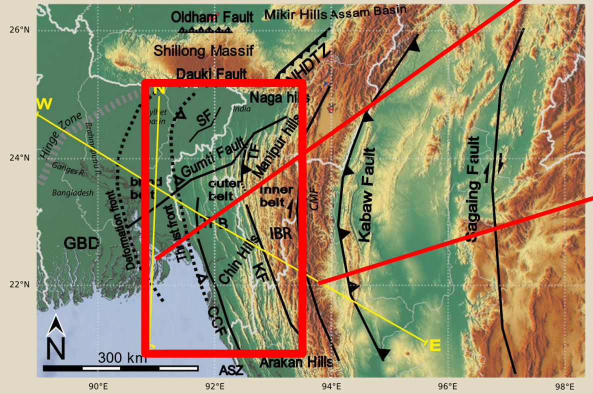


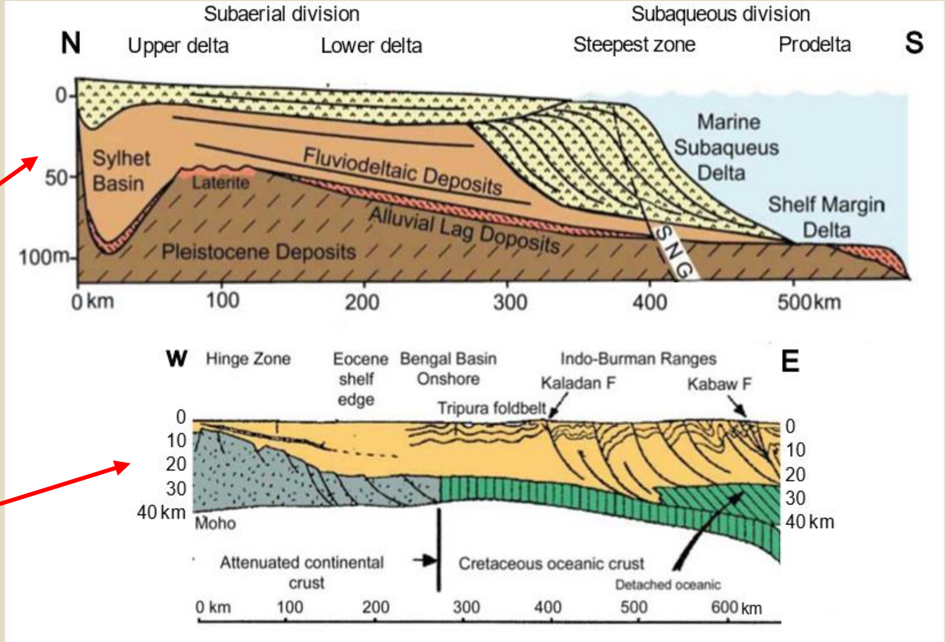
Indo-Burma Range (IBR)



Stratigraphy

- The Ganges-Brahmaputra Delta controls the stratigraphy of the region (Bandyopadhyay, 2019).
  - Subaqueous
  - Subaerial





(Bandyopadhyay, 2019).

STUDY OBJECTIVES

- Study the shallow sediments and faults using tomography by applying for the first time ambient noise tomography in Bangladesh

- Interpret the phase velocity maps:

  - Crustal structure

  - Sediment layers

  - Depth of the basement rocks

  - Recognize faults

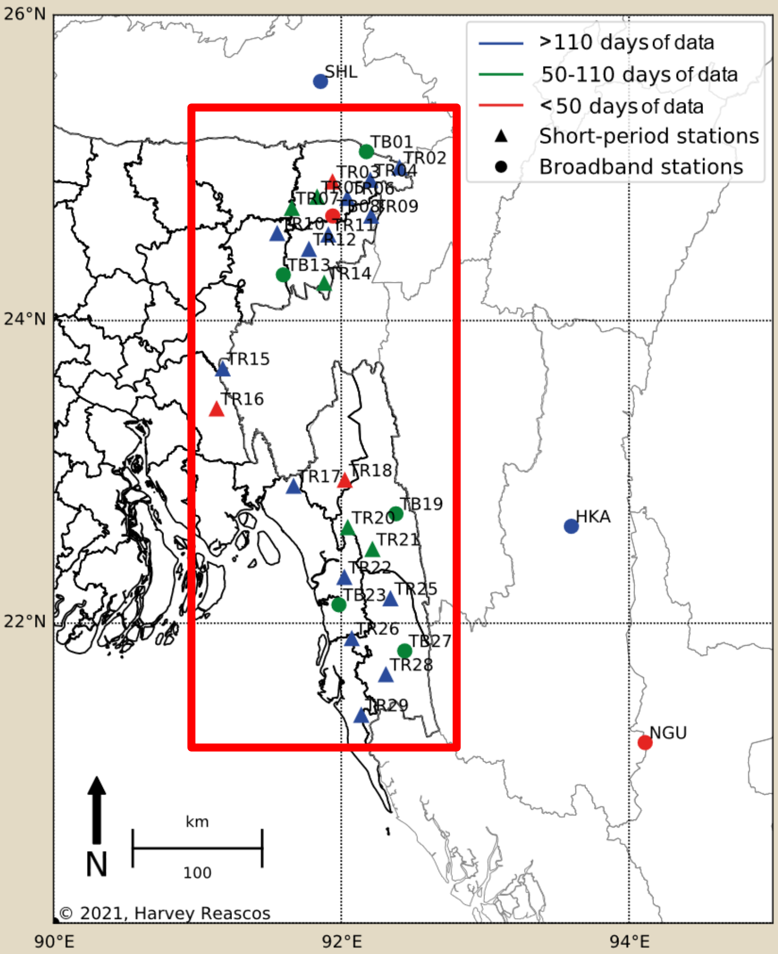
Data

Seismic Data:

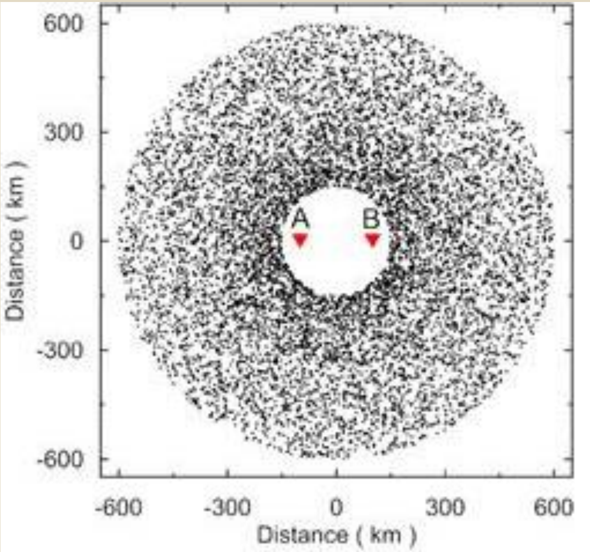
- Collected from the seismic network TREMBLE:
  - 22 short-period seismometers
  - 6 broadband seismometers
  - 3 extra broadband seismometers
- Data recorded from 2016 to the present.

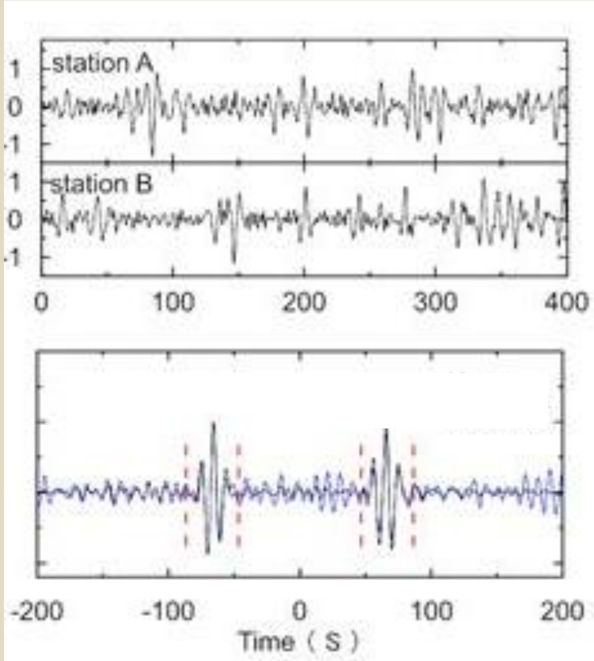
Current Data – Bangladesh:

- Six months of continuous data from January to June 2019



Ambient Noise Tomography



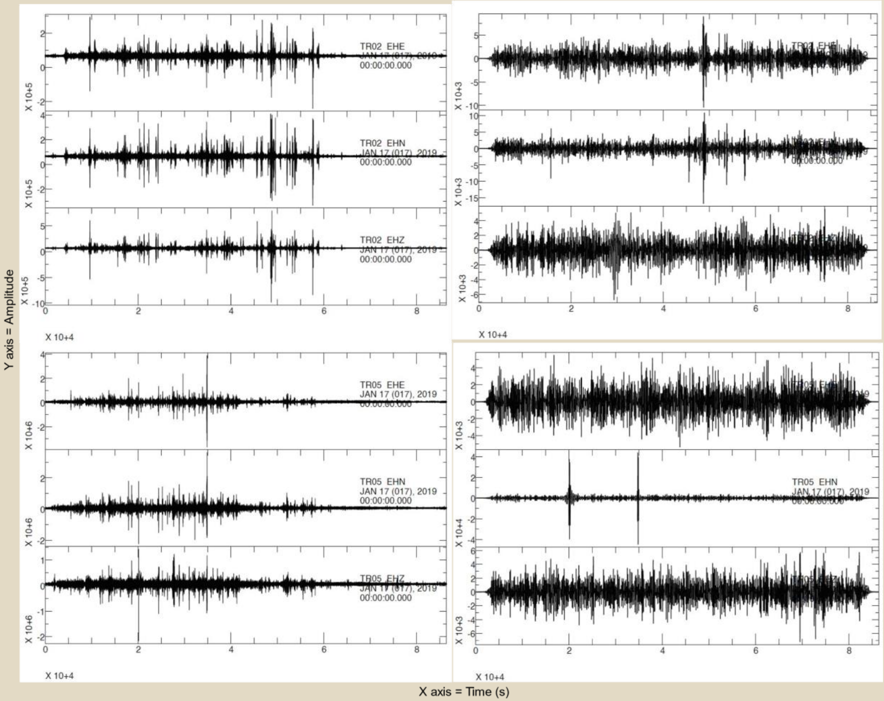


(Xie et al., 2020)

Methods

- Four steps to measure the phase velocity (Bensen et al., 2007):
  - Prepare the data
  - Compute a cross-correlation, n(n-1)/2 possible station pairs
  - The resulting waveform is an estimation of the Green’s Function.
  - Make an error analysis to select the acceptable measurements.
- MATLAB codes from GitHub written by Joshua Russell.

Processing Methods



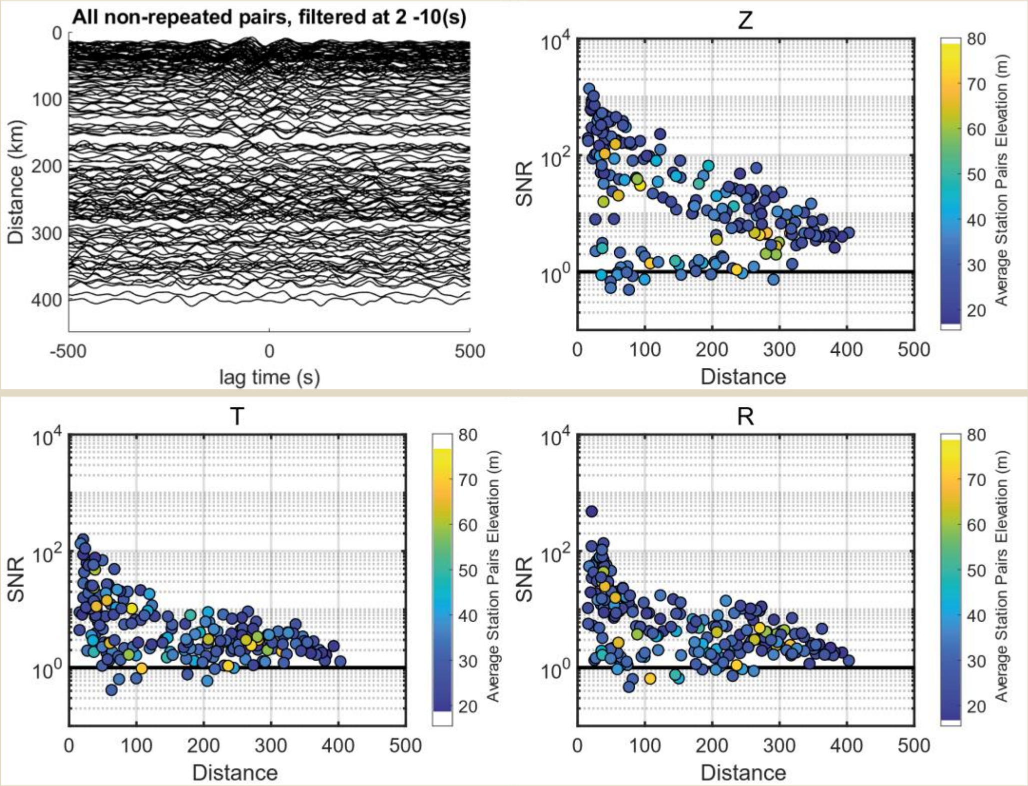
Preprocessing methods tested (Cupillard et al., 2011; Ekström et al., 2009; Shen et al., 2012):

It is important to remove non-stationary signals like earthquakes or spikes that could bias the correlation

- One-bit normalization
- Time-frequency normalization
- Basic prefilter
- Non-preprocessing

Phase Velocity Measurements

- Cross-spectrum and coherency
- Select the best signal to noise ratio (SNR) for ambient noise (it means in the frequency ~0.1Hz)
- Make measurements of phase velocity on Rayleigh Waves (e.g., Cupillard et al., 2011).

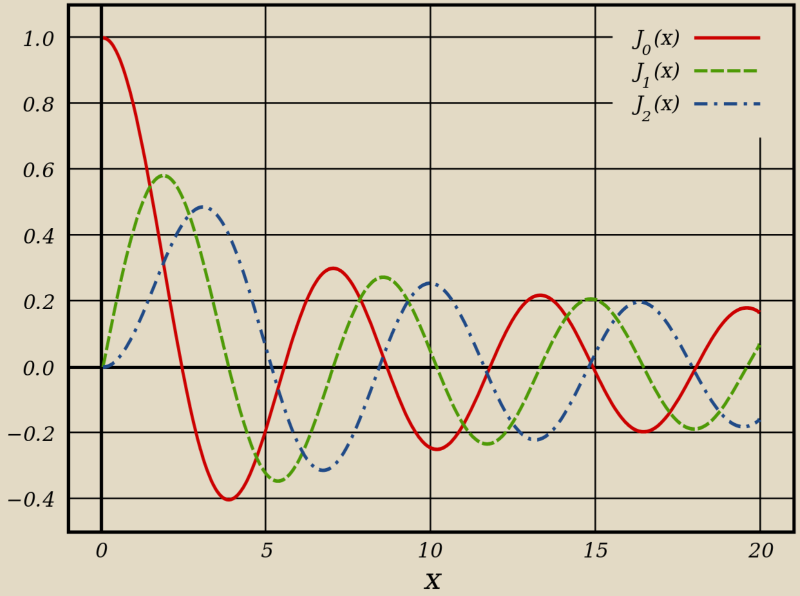


Phase Velocity Measurements

- The Bessel Function (J_0) describes the cross-correlation function in the frequency domain, the cross-spectrum (ρ)

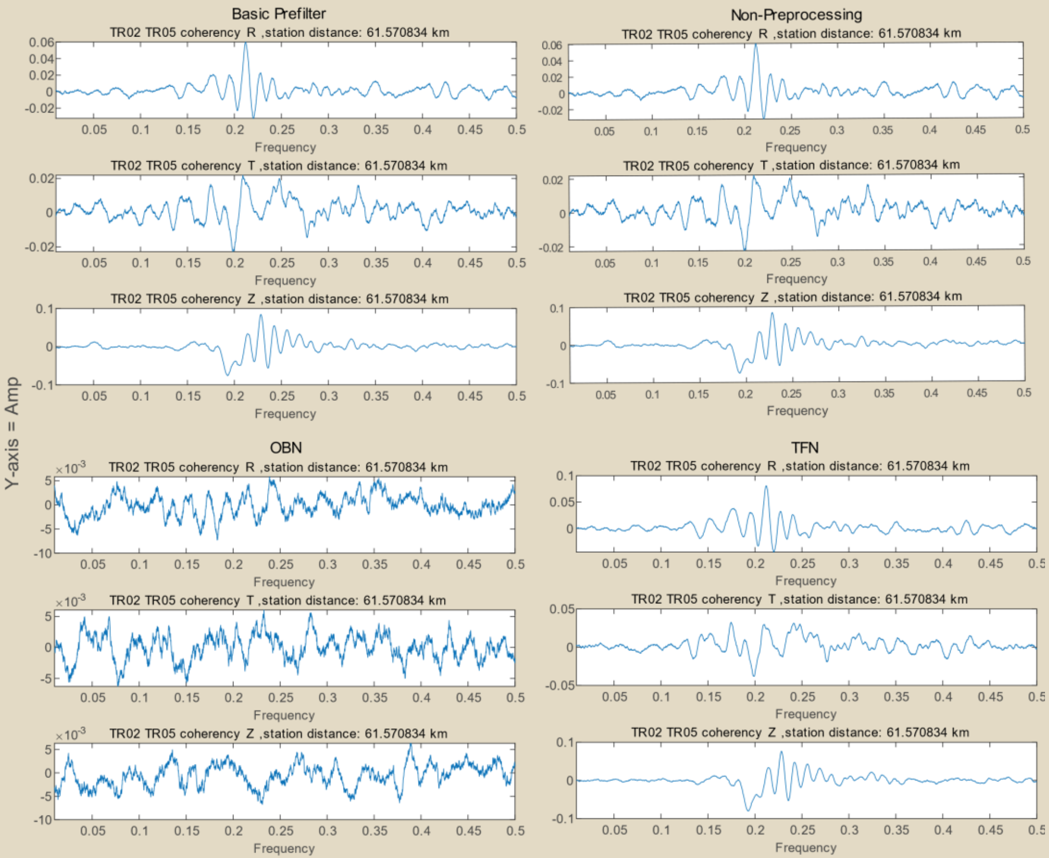
- Menke & Jin (2015) try to fit the Bessel function at all frequencies:

$$\rho(\omega, r) = AJ_0\left(\frac{\omega r}{c(\omega)}\right) with\ A = 1$$



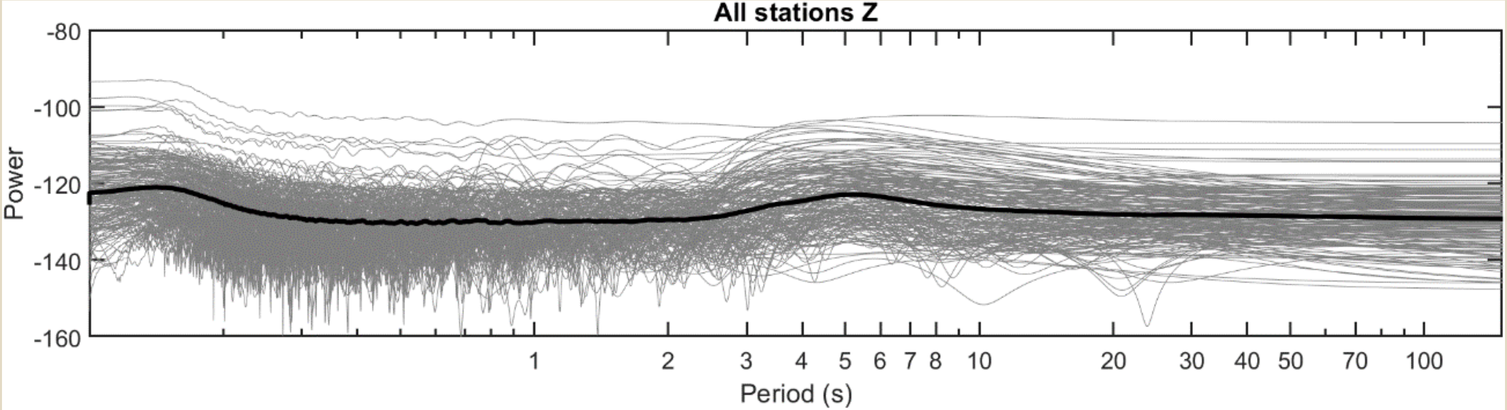
Comparison of preprocessing methods

- Calculate the cross-correlation of the 3h segment to get the coherency.



Power Spectral Density

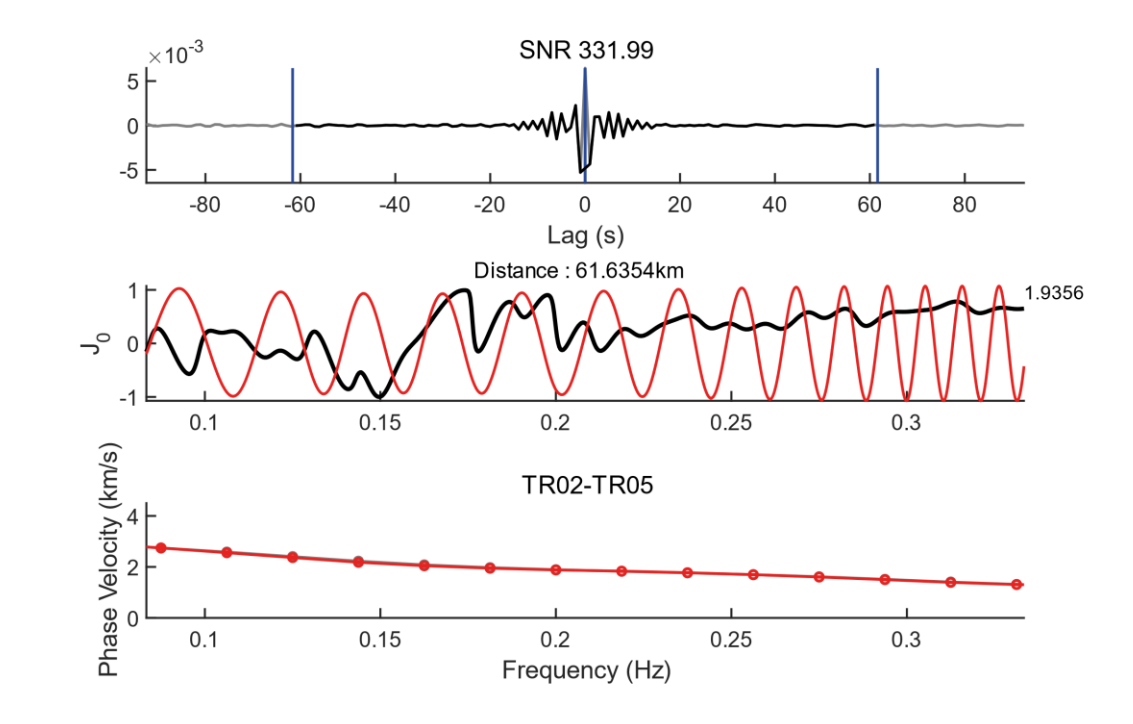
- Shallow values at most periods
- Slight jump in range 2 – 10 s



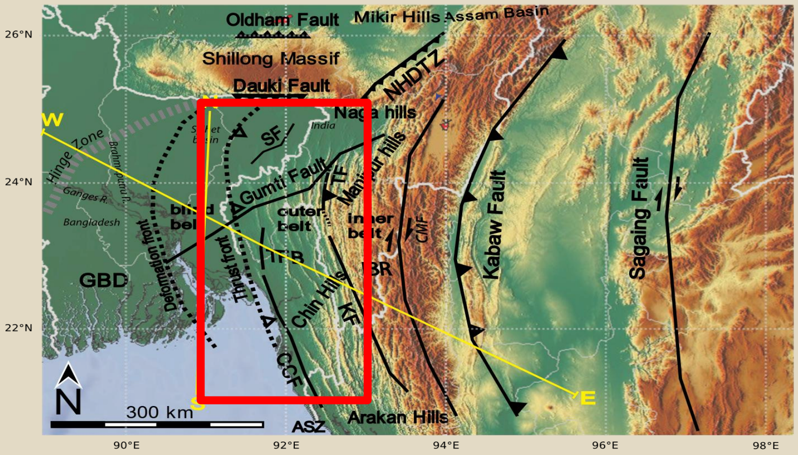
Phase velocity measurements and Bessel Function

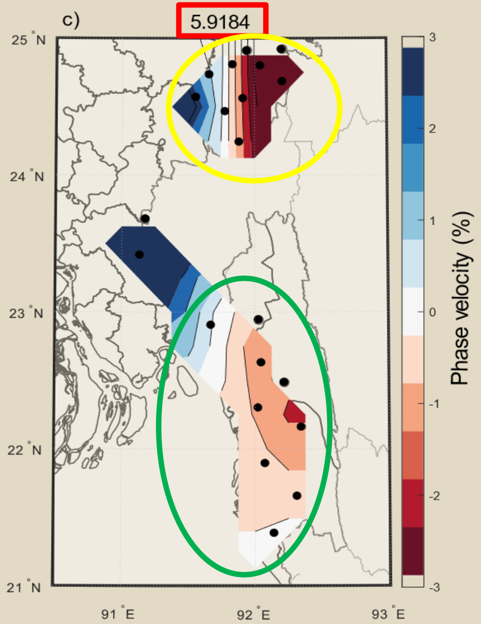
- Extract the phase velocity dispersion between all stations to fit the Bessel Function at J_0 to the real cross-spectrum

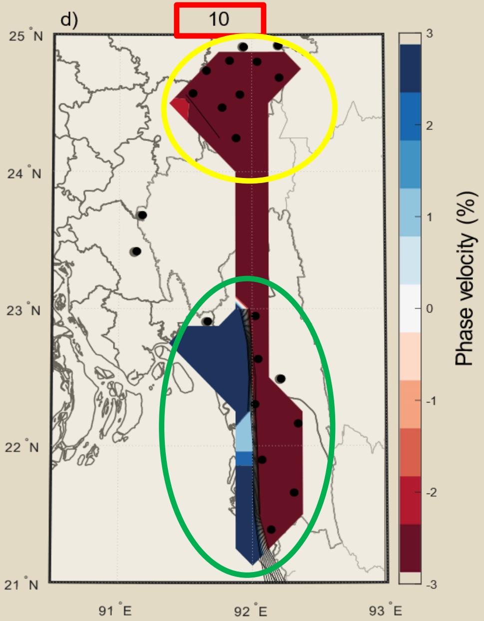
- Model from CRUST1.0



Phase velocity maps







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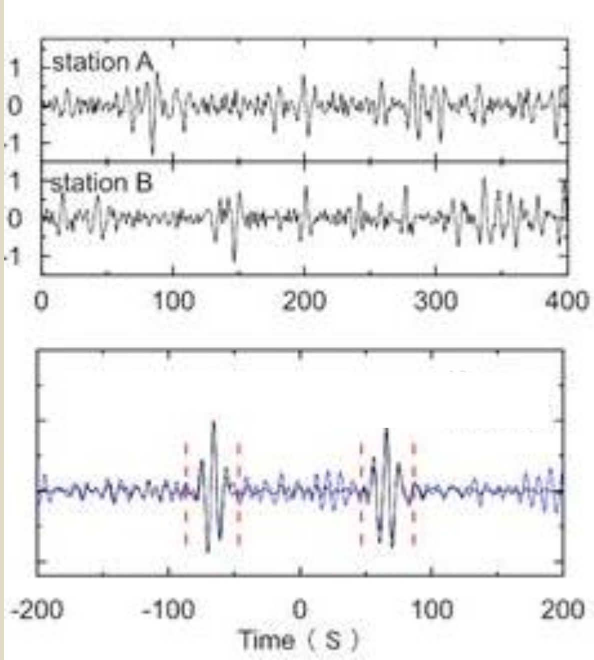
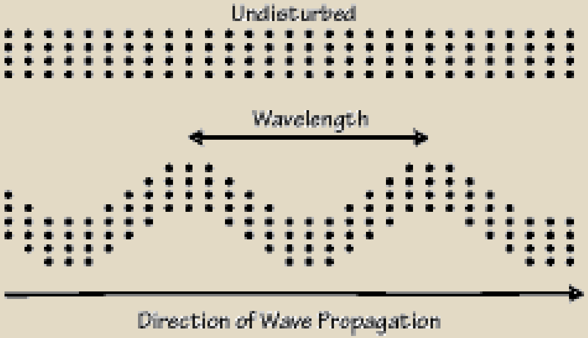
Cross-correlation formula

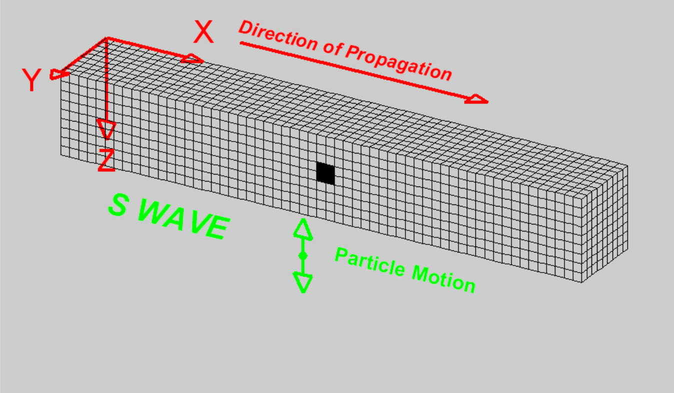
$$C_{AB}(t) = \sum p, p' \int A_p(\tau) B_{p'}(t+\tau) d\tau$$

Non-stationary signal
Same point-source
Cross-correlation between stations
Time



S-waves





1-8 km/s
Loose material < base Earth's mantle

CONCLUSIONS

1 Basic prefilter

Has better efficiency, coherency and SNR results than the other preprocessing methods

2 Z component

Has better correlation than horizontal components (R, T)

CONCLUSIONS

3 Frequency

We select a frequency range of [1/10 1/2] to retrieve the Green's Function, fit the Bessel function, and obtain the phase velocity measurements.

Set parameters 4

Although we set our parameters to high values we obtain Good results for tomography.

CONCLUSIONS

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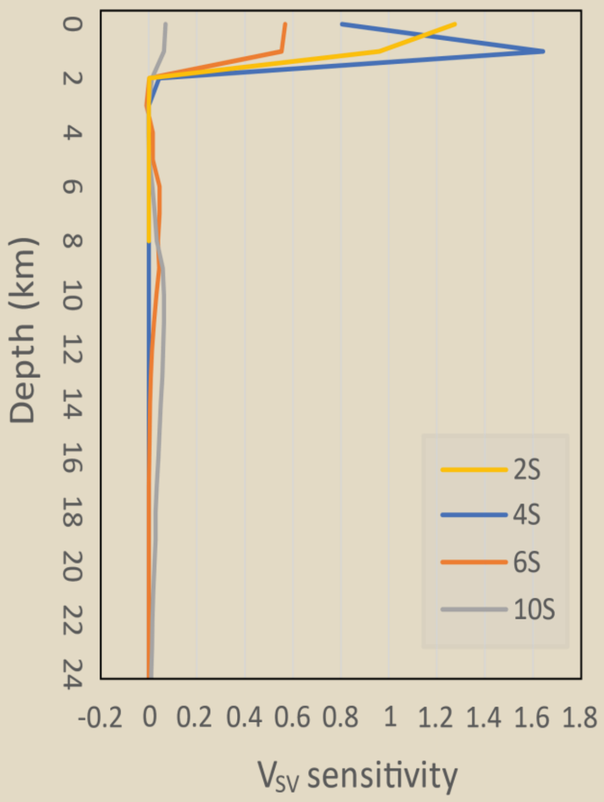
At shorter periods < 6s

The estimated phase speeds are ~3% faster in the northwestern part and ~3% slower in the northeastern region. The phase velocities are 3% slower to the west and 3% faster to the east in the southern region.

6

At 6 – 10 s periods

The phase speeds are 3% faster in the west part and 3% slower in east part in both north and south region with an exception in the northern region for 10 s period which presents 3% slower phase velocity in the majority of the area.


Depth (km)
0 2 4 6 8 10 12 14 16 18 20 22 24
-0.2 0 0.2 0.4 0.6 0.8 1 1.2 1.4 1.6 1.8
VSV sensitivity
2S
4S
6S
10S

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CONCLUSIONS

7

Risk and hazards

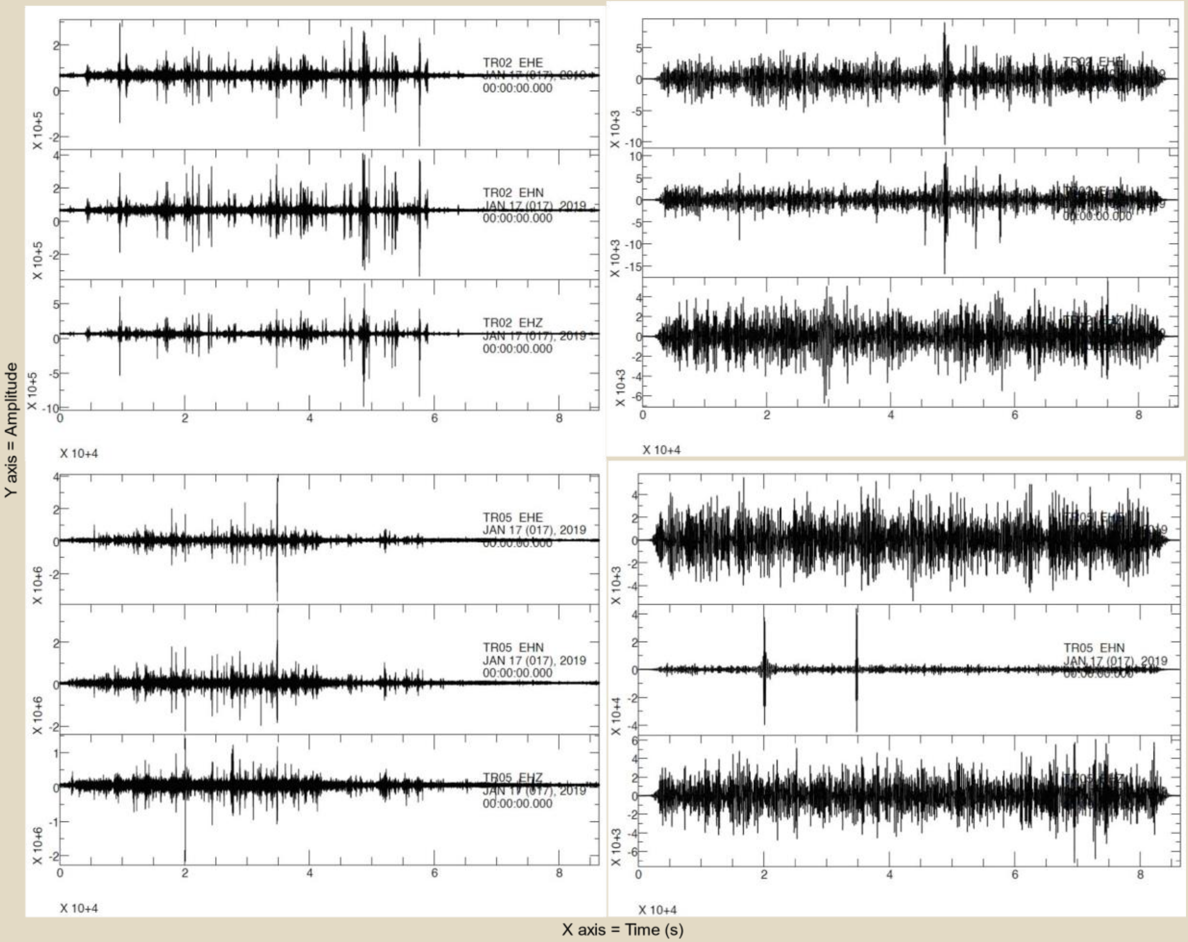
We might infer what zones could be more susceptible to risk and hazards in case of earthquakes of high magnitude. Secure the space identifying hazards, organize disaster supplies,

Future work

- We plan to continue improving these results.
  - It means adding more data for short-period stations and working with the broadband stations, increasing from six months to at least one year of data.
  - Testing different stacks for the data instead of just full-stack.
  - Try to fit better the Bessel Function, testing different phase velocity starting models, trying other filter options, adjustments, and normalizations.

Preparing Data

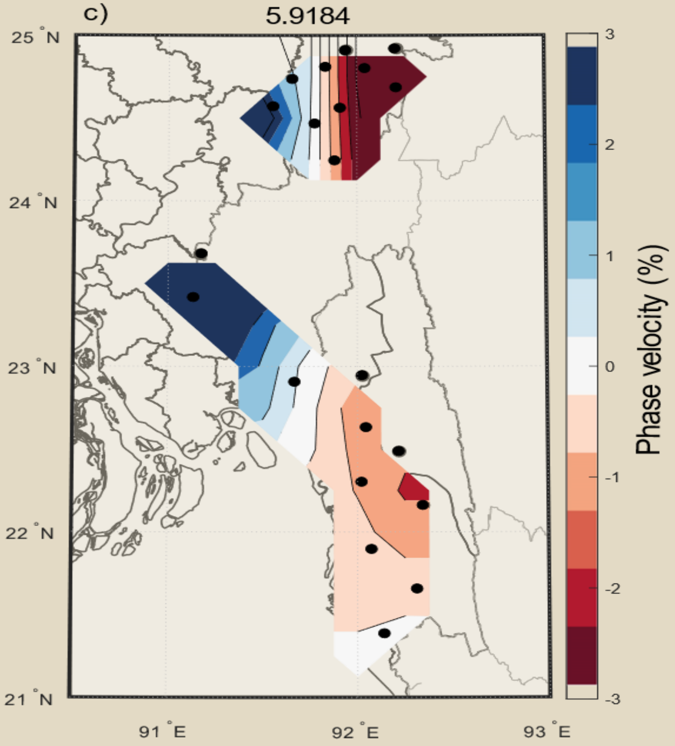
- 2702 days of data
- Short period stations: TR02 & TR05



Tomography

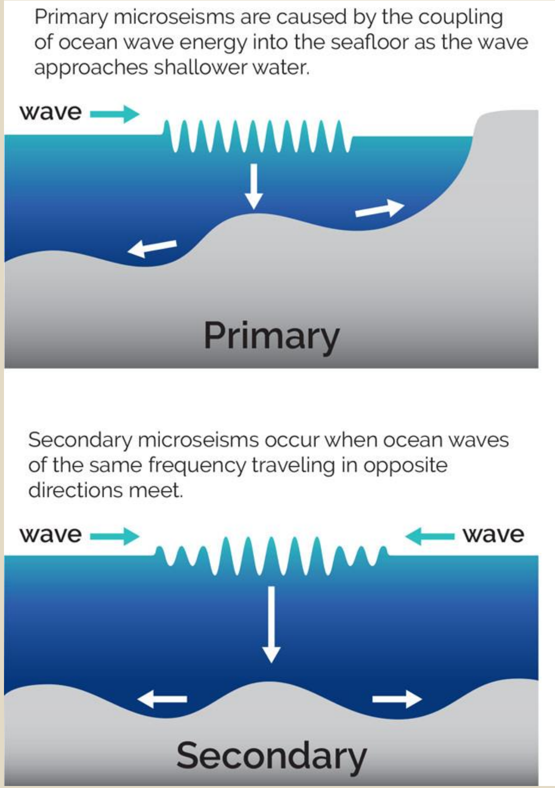
- It is a powerful technique to understand the plate-driving mechanism.

- Creates 2D-3D images from Earth's interior by combining information from many earthquakes (Murphy & Tjeerd, 2013).

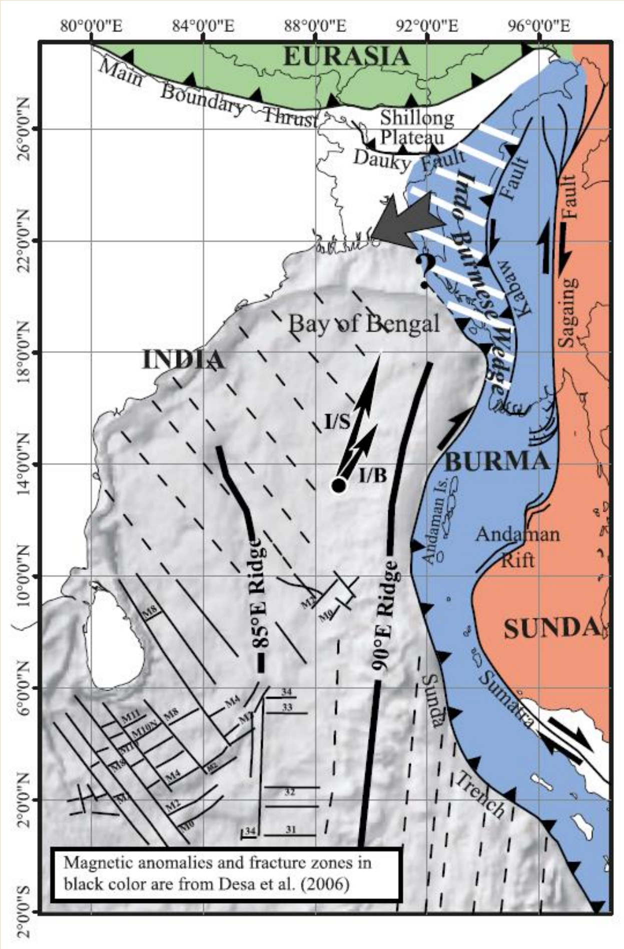


Ambient Seismic Noise

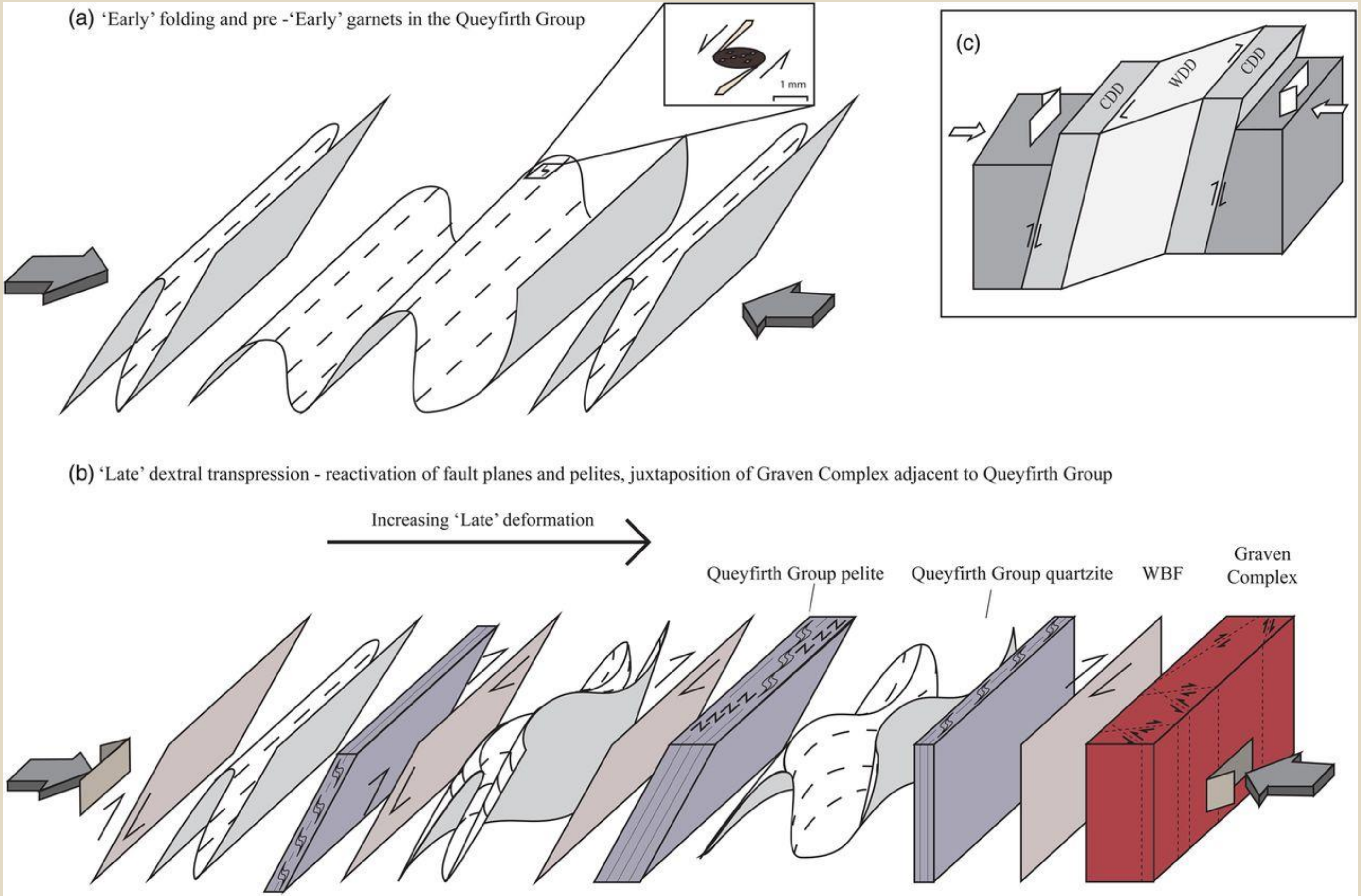
- Comprises various signals covering a huge range of frequencies (Yang & Ritzwoller, 2008).
- Broadband seismometer can record seismic noise: from milli Hz to tens of Hz (Schimmel et al., 2011).
- Short periods: 0.1 – 1 s
- Intermediate periods: 1 – 30 s
- Longer periods: 30 – 500 s (Schimmel et al., 2011).



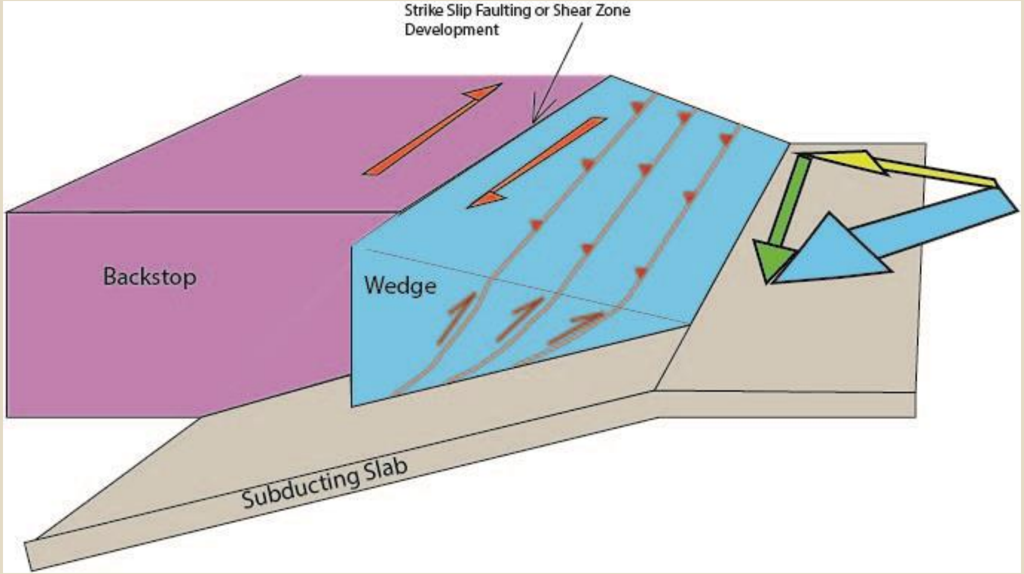
(Parkins, 2019)



(Maurin & Rangin, 2009)


(a) 'Early' folding and pre -'Early' garnets in the Queyfirth Group
1 mm
(c)
CDD
WDD
CDD
(b) 'Late' dextral transpression - reactivation of fault planes and pelites, juxtaposition of Graven Complex adjacent to Queyfirth Group
Increasing 'Late' deformation
Queyfirth Group pelite
Queyfirth Group quartzite
WBF
Graven Complex

Block diagram illustrating strain partitioning at an oblique convergent margin. The obliquity of plate convergence (blue arrows) induces stress components that are normal to the margin (yellow arrow) and parallel to the margin (green arrow). Elevated magnitudes of the arc parallel component induces horizontal translation (red arrows) between the wedge and the backstop.



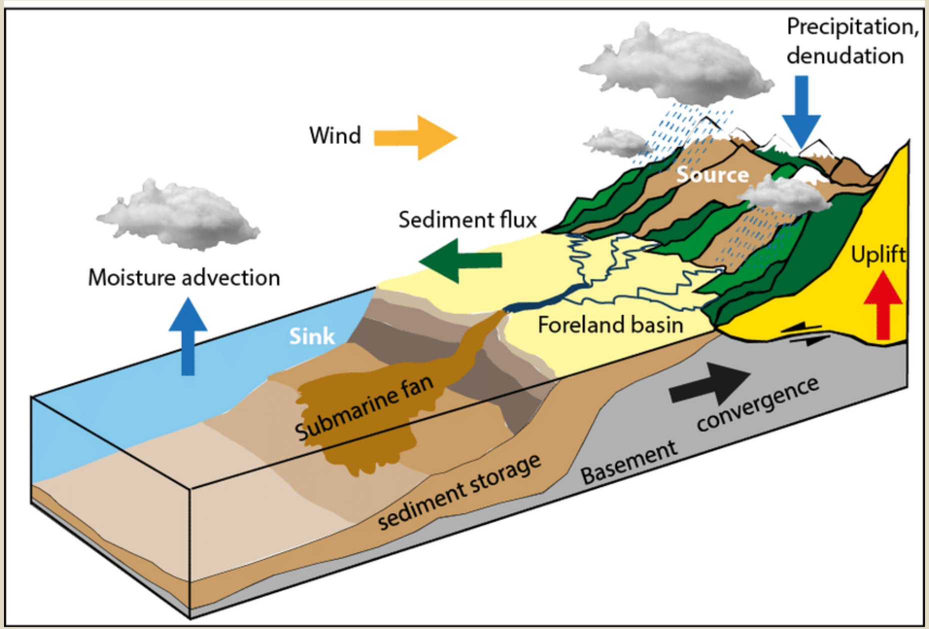
Preprocessing Methods

- OBN - Consists of retaining just signals (+1, -1) of each recorded sample.
- TFN – consists of filtering in narrow overlapping frequency bands within the target frequency ranges. Each narrow frequency band is treated separately and normalized to avoid strong signals at high or low frequencies. This normalization is achieved by dividing each band by its analytical time-domain envelope, producing a time series of unit amplitude.
- Basic prefilter – alters the seismic signals by removing the unwanted frequency signal from outside the range of our interest.

Geological features

- Sediments come from the Himalayas
  - High precipitation
  - Surface Run-off
  - Flooding

(MoDMER, 2015; Rabbel, 2006; Stoker et al., 1997)

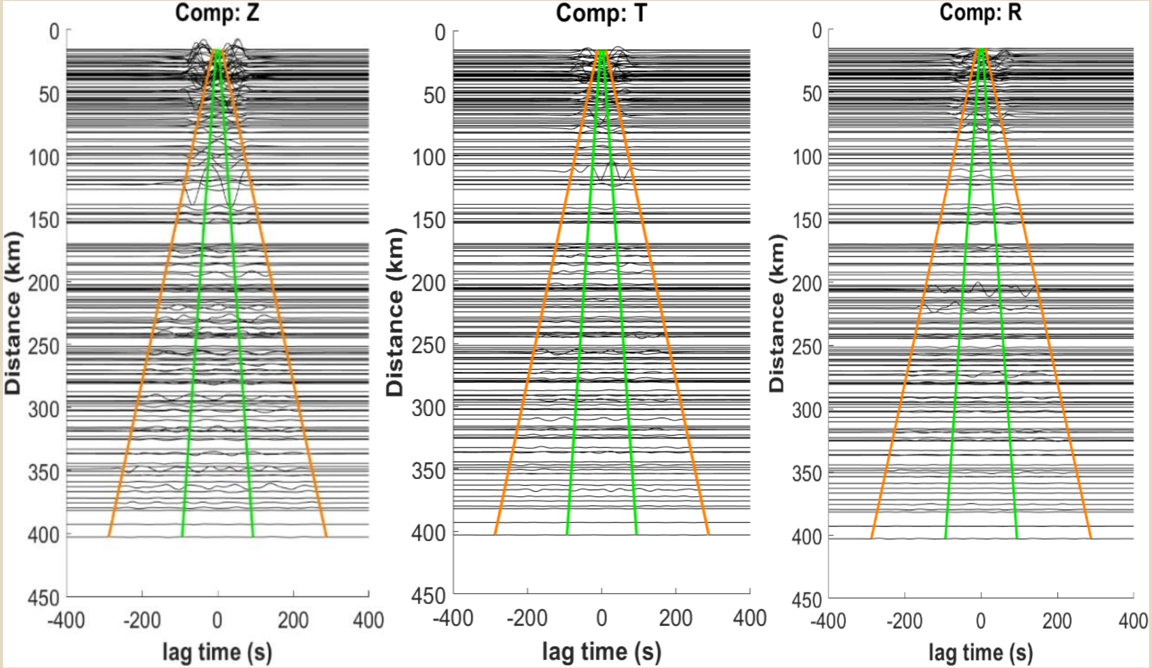


(Dey, 2016)

Phase velocity measurements and Bessel Function

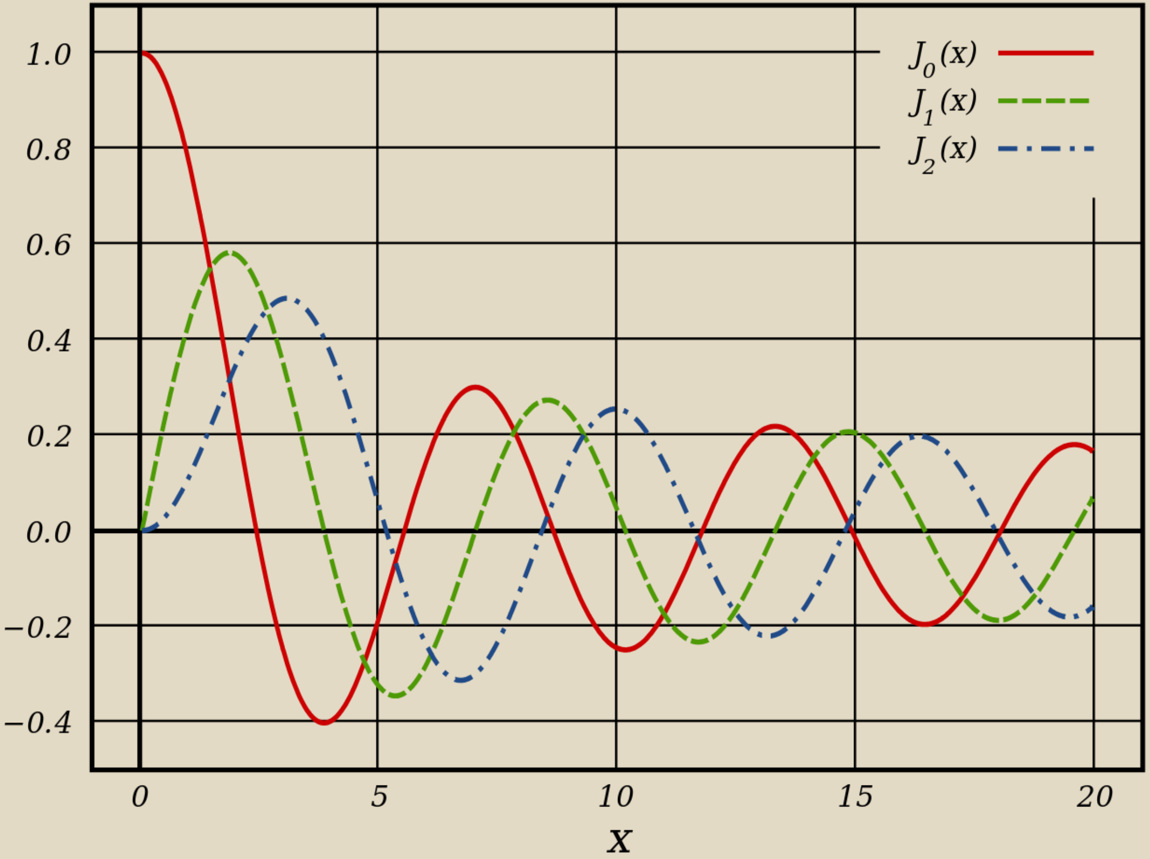
- Group velocity between 1.4 – 4.3 km/s

- Z-component has the better relationship by the amplitudes showed in both sides



Bessel function of the first kind, Jα(x), for integer orders α = 0, 1, 2

La Ecuación de Bessel aparece cuando se buscan soluciones a la ecuación de Laplace o a la ecuación de Helmholtz por el método de separación de variables en coordenadas cilíndricas o esféricas



SNR

Seismic noise. Noise is the undesirable part of seismic data that is not signal, and signal is what fits our conceptual model.

Multiple. A seismic event that experiences more than one reflection in the subsurface.

SNR. Signal-to-noise ratio – is a measure of strength of signal compared to noise, and it is a measure of seismic data quality.

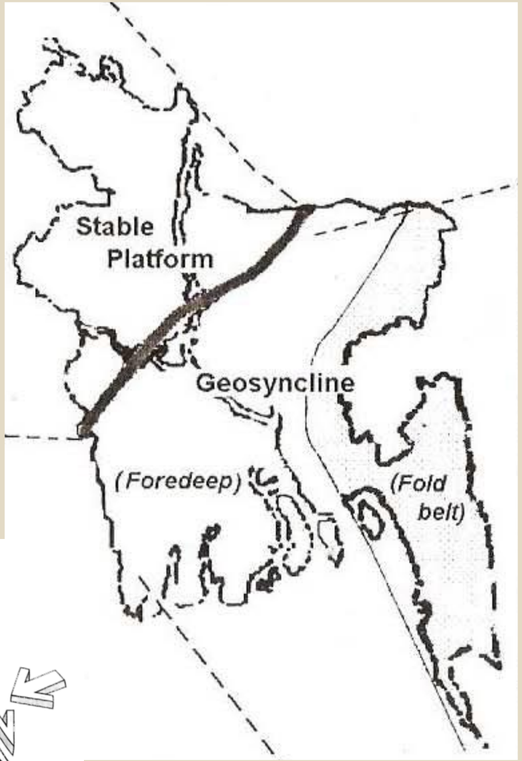
RMS velocity

The root-mean square (RMS) velocity is the value of the square root of the sum of the squares of the stacking velocity values divided by the number of values. The RMS velocity is that of a wave through sub-surface layers of different interval velocities along a specific ray path. RMS velocity is higher than the average velocity. RMS velocity is calculated using

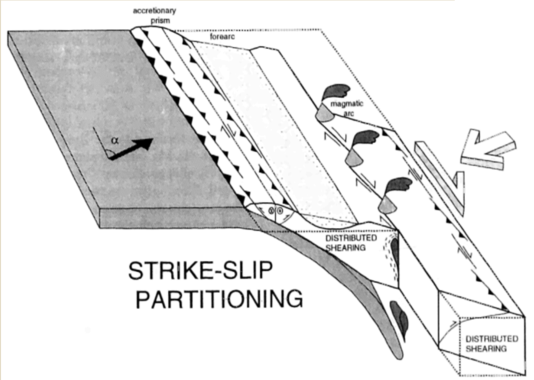
$$v_{\mathrm{RMS}} = \sqrt{\frac{\sum_{i=1}^{n} v_i^2 \triangle t_i}{\sum_{i=1}^{n} \triangle t_i}}$$

Large Scale Tectonics

- The convergence of the Indian Plate at the Indo-Burma Range (IBR) is highly oblique (Sarraz, 2015).
- The convergence occur by slip partitioning (Toda et al., 2016)
- Active Faults can host mild to great earthquakes.
- Divided into two tectonic units:
  - The Stable Precambrian
  - Geosynclinal basin



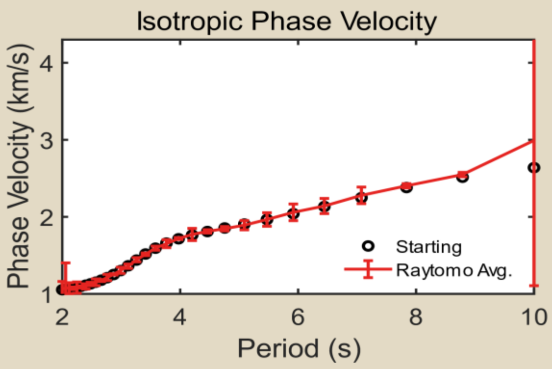
(e.g., Alam & Islam, 2009)

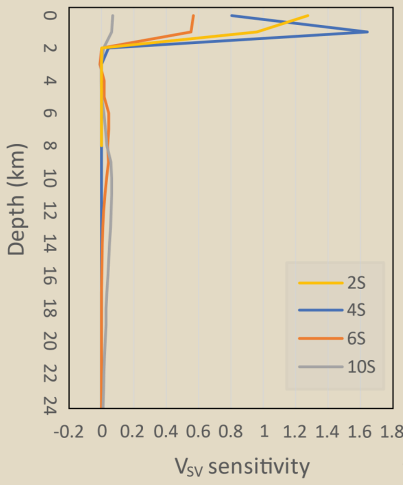


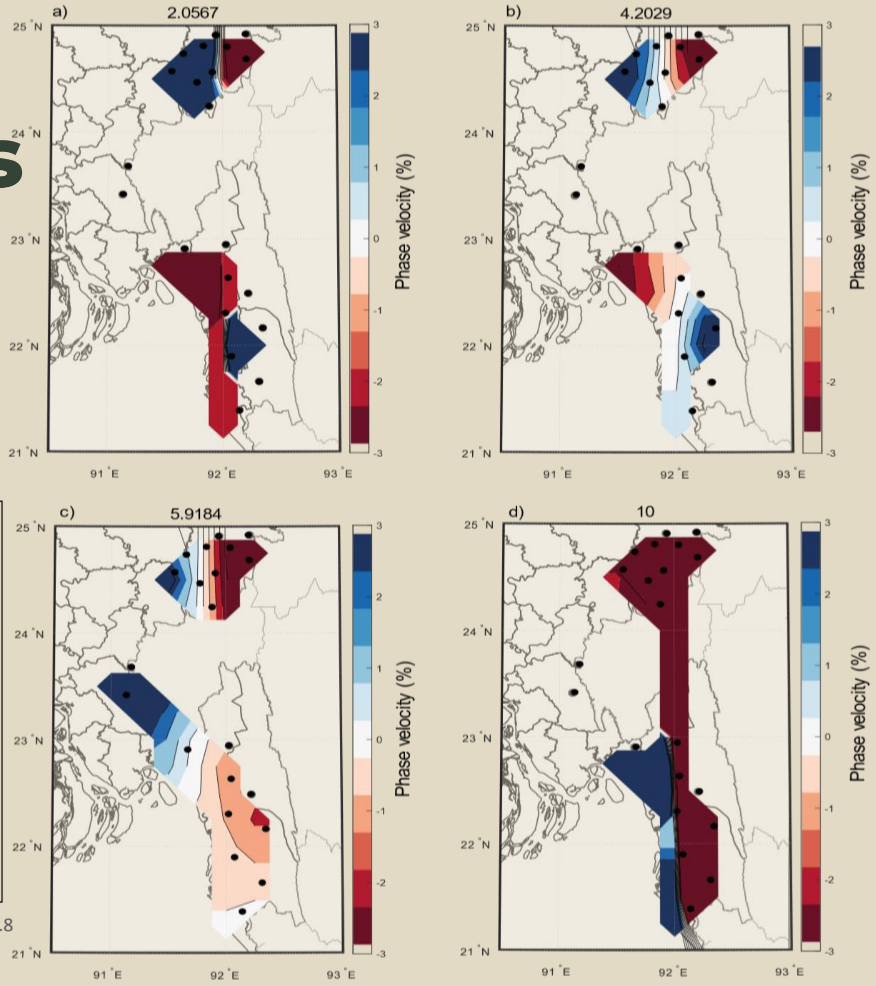
(Acocella, 2014)

Rhayleigh wave phase velocity maps

- Kernels calculated from the CRUST1.0 model at the location 24.5° latitude and 91.5° longitude
- The range of phase velocity varies from -3 to 3%

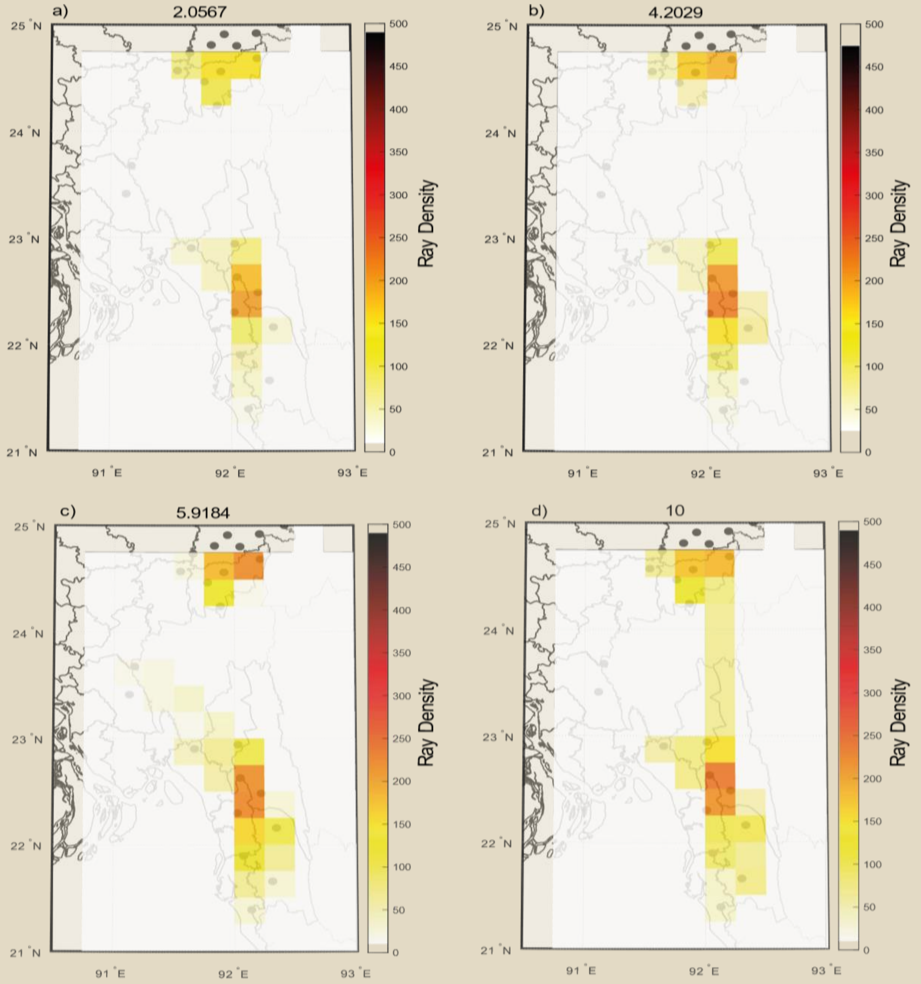






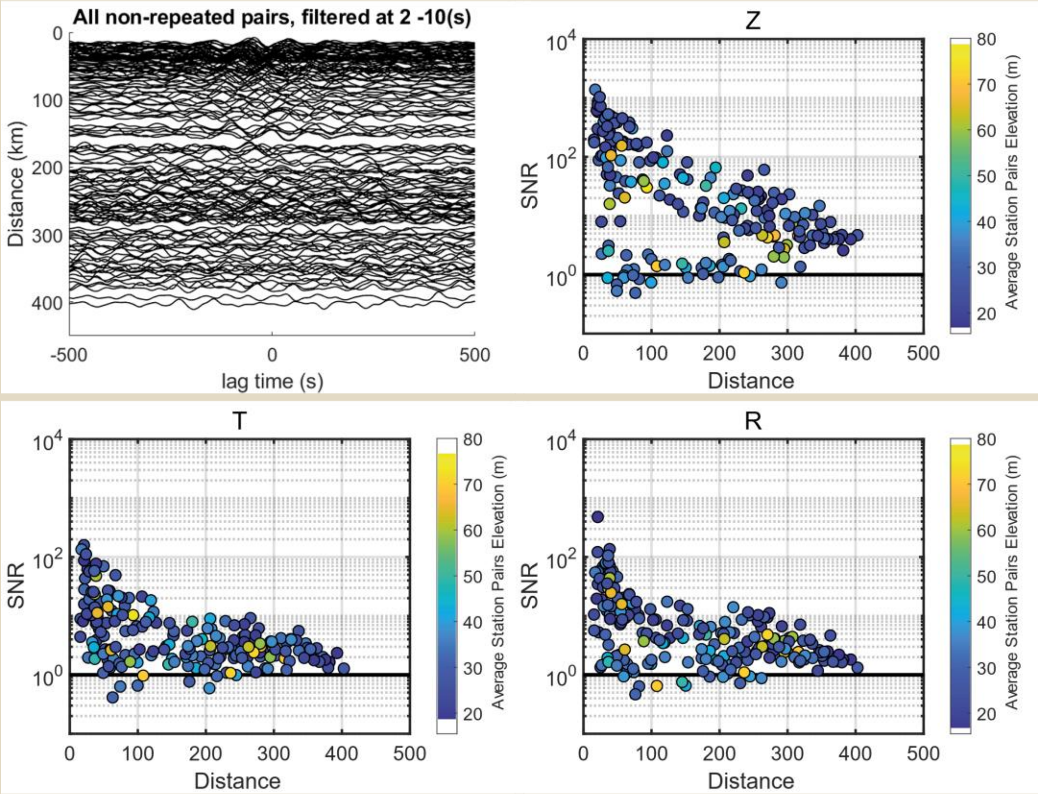
Rhayleigh wave phase velocity maps

- Phase velocity measurements to generate a ray density map at different periods



Cross-spectra & SNR

- Short-period stations
- Z-component has better SNR vs. distance relationship than R and T.



Phase Velocity Measurements

- After the phase velocity has been found, the amplitude is calculated by (Menke & Jin, 2015) :

$$A = \frac{[\rho^{pre}(c, A = 1)]^T \rho^{obs}}{[\rho^{pre}(c, A = 1)]^T [\rho^{obs}(c, A = 1)]}$$

- Reorder the observed cross-spectrum and unknown phase velocity as vectors, ***m*** = *[c, A]* (Menke & Jin, 2015)

- Typical least-squares equation is: ***Gm***= ρ

- To linearize the equation by the deviation of the initial model:

$$\boldsymbol{G}\Delta\boldsymbol{m} = \Delta\rho$$

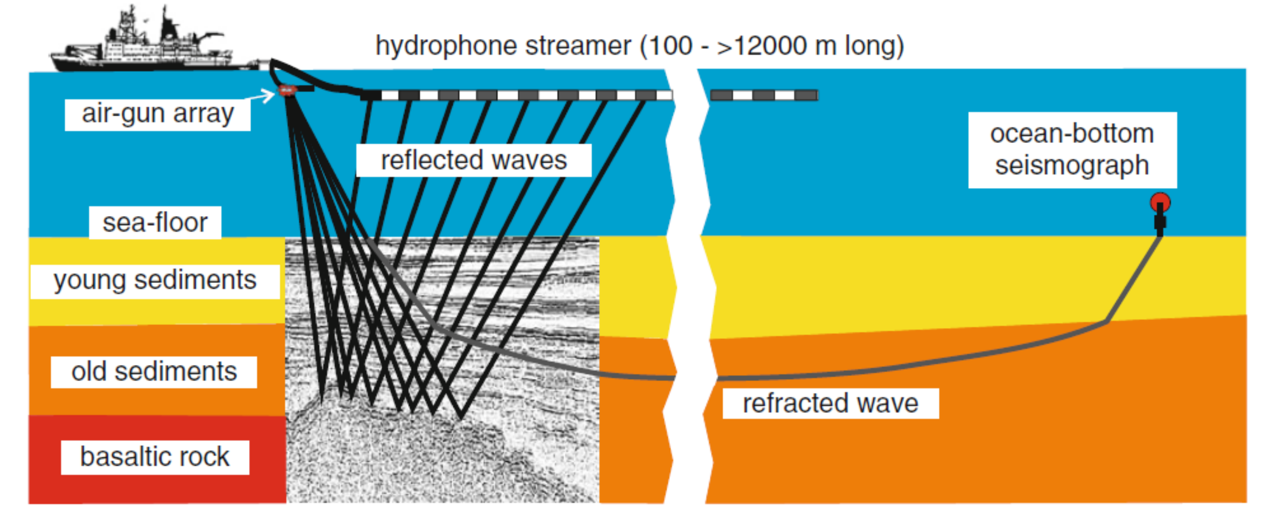
- $\boldsymbol{G}$ contains:
    - Restrictions on the phase velocity curve's derivatives
    - Smoothness of the phase velocity curve

(Menke & Jin, 2015)

Seismic Methods

- Seismic methods to obtain good surface and crustal structure models (Artemieva & Meissner, 2012; Rabbel, 2006; Stoker et al., 1997).

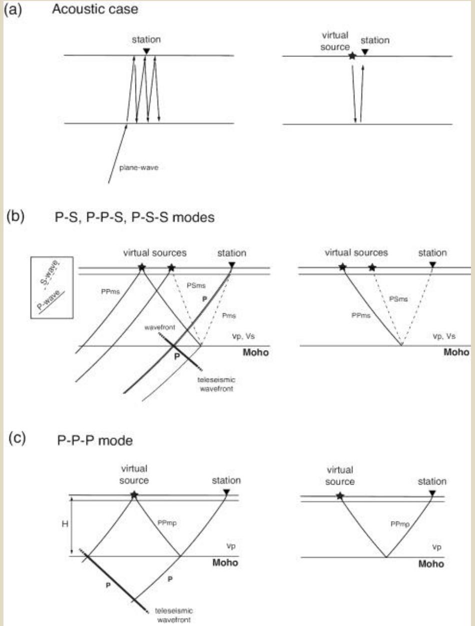
- Active sources (Mooney, 2015)
  - Seismic refraction
  - Seismic reflection



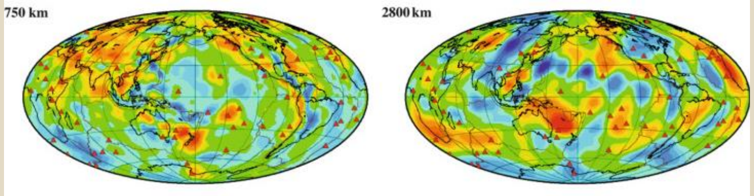
(Hübscher, C., & Gohl, K. (2016)

Seismic Methods

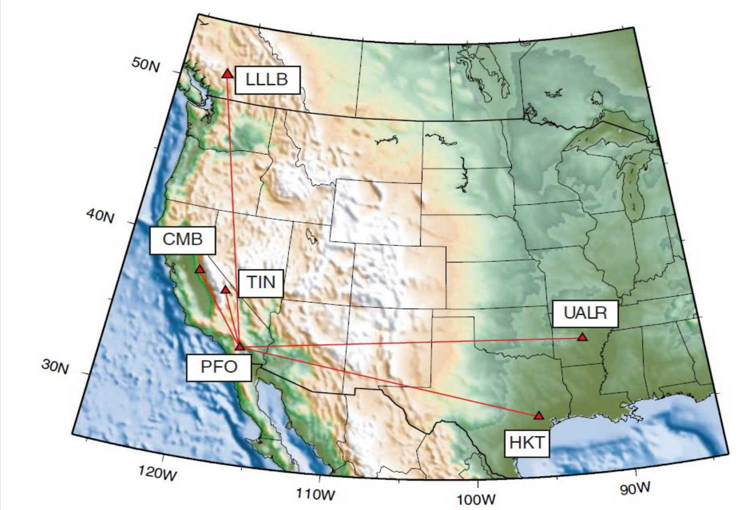
- Passive sources (Mooney, 2015)
    - Seismic tomography
    - Seismic receiver functions
    - Seismic ambient noise inversion



(Condie, 2016)



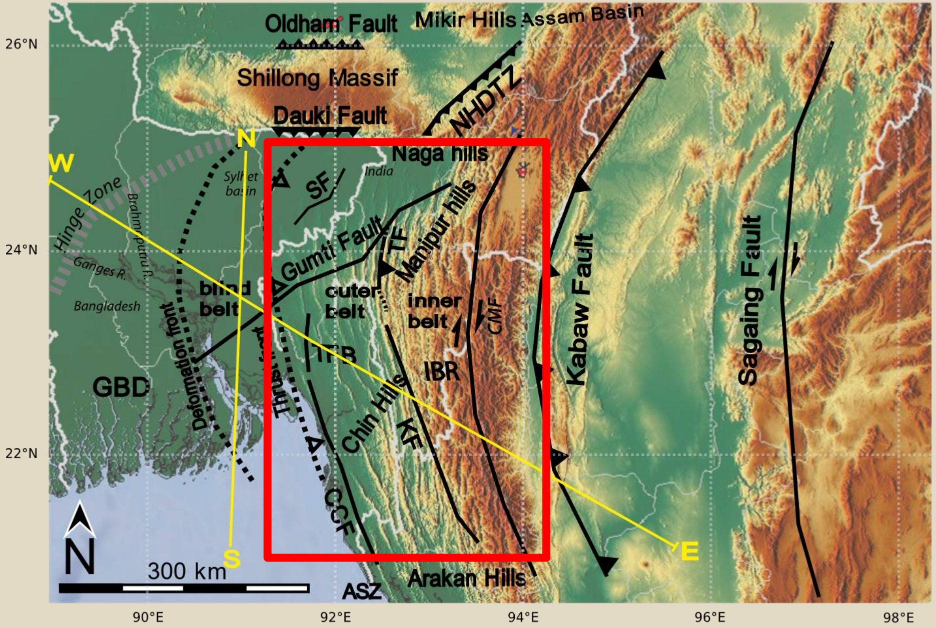
(Hübscher, C., & Gohl, K. (2016)

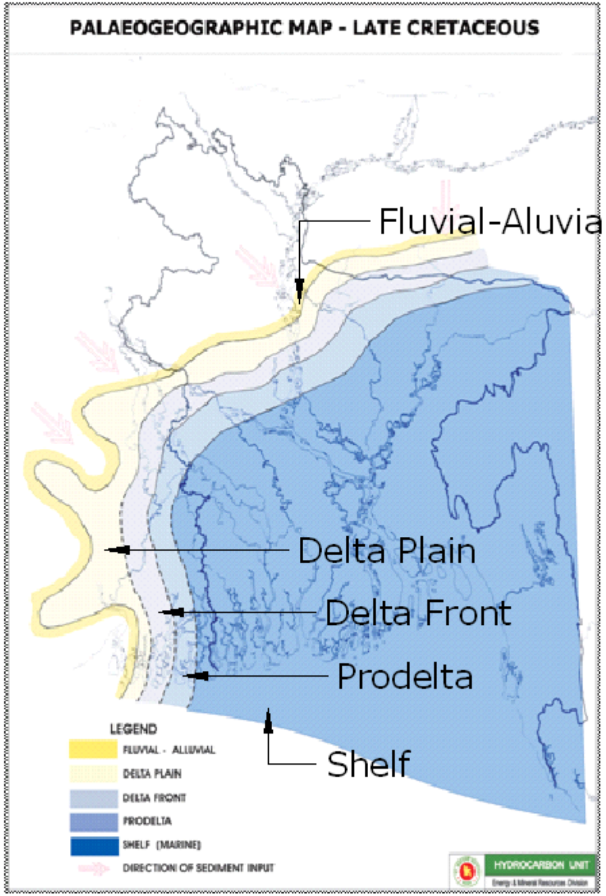


(Bensen, 2007)

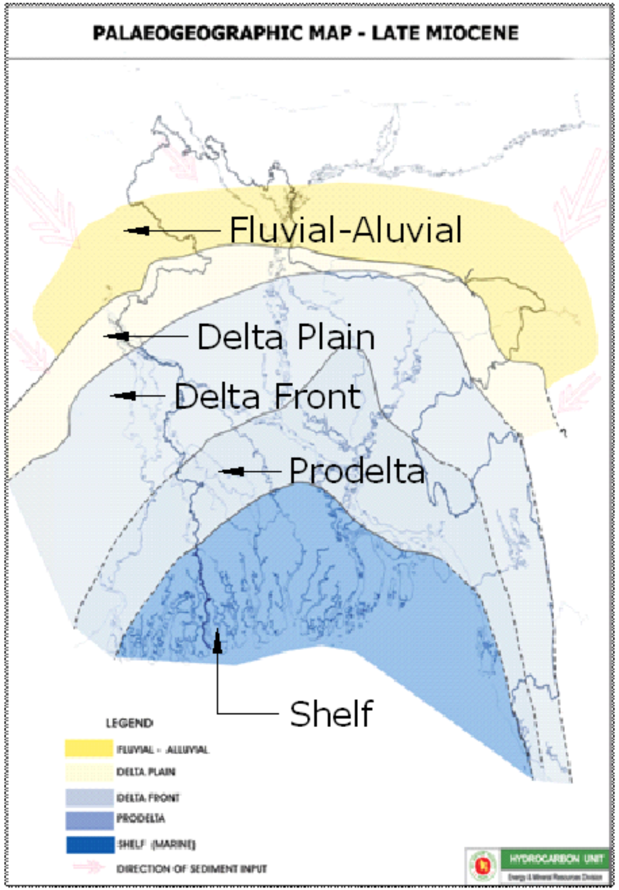
Indo-Burma Range (IBR)

- Convergence rate is ~13 – 17 mm/y
- Décollement depth between 3,1 – 3,4 km (Betka et al., 2018).





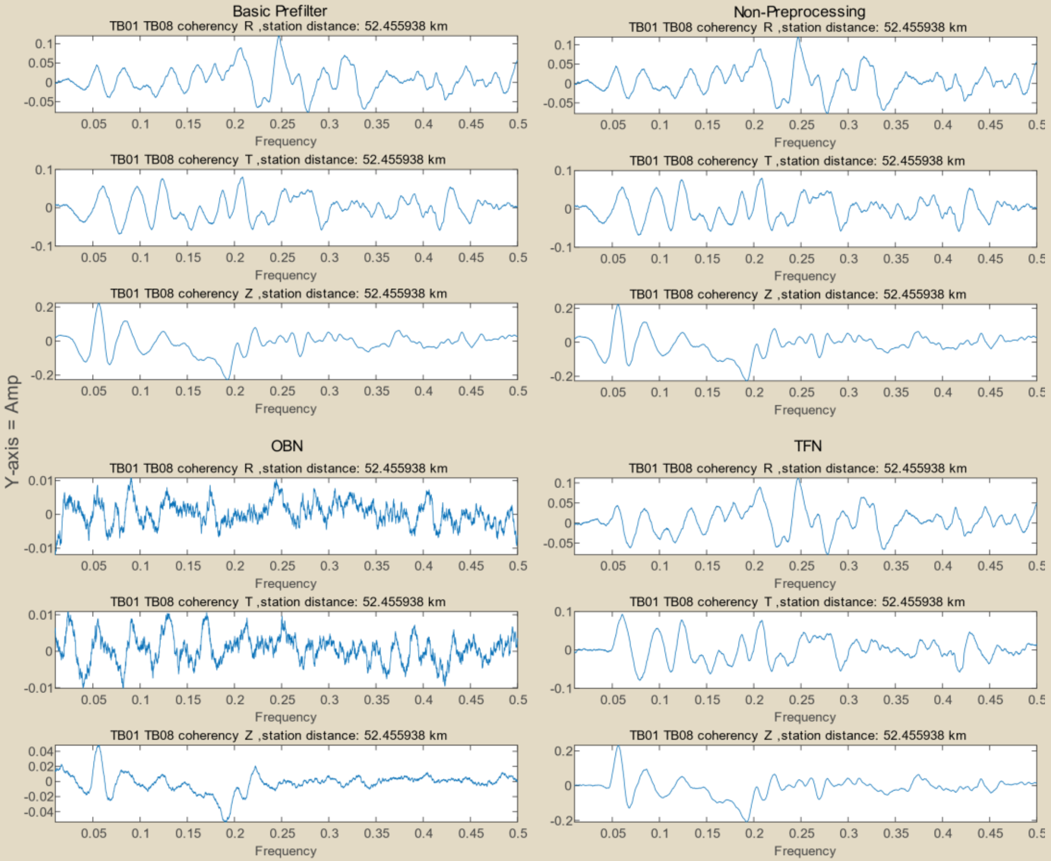
PALAEOGEOGRAPHIC MAP - LATE CRETACEOUS
Fluvial-Aluvial
Delta Plain
Delta Front
Prodelta
Shelf
LEGEND
FLUVIAL - ALLUVIAL
DELTA PLAIN
DELTA FRONT
PRODELTA
SHELF (MARINE)
DIRECTION OF SEDIMENT INPUT
HYDROCARBON UNIT



PALAEOGEOGRAPHIC MAP - LATE MIOCENE
Fluvial-Aluvial
Delta Plain
Delta Front
Prodelta
Shelf
LEGEND
FLUVIAL - ALLUVIAL
DELTA PLAIN
DELTA FRONT
PRODELTA
SHELF (MARINE)
DIRECTION OF SEDIMENT INPUT
HYDROCARBON UNIT

Comparison of preprocessing methods

- Calculate the cross-correlation of the 3h segment to get the coherency.
- 398 samples of coherency for short period stations
- 30 samples of coherency for broadband stations



Cross-spectra & SNR

- Broadband stations
- Z-component has better SNR vs. distance relationship than R and T
- Relative small amount of data available