# The effects of Non-linear cross-correlation function stacking on F-J dispersion curve extraction


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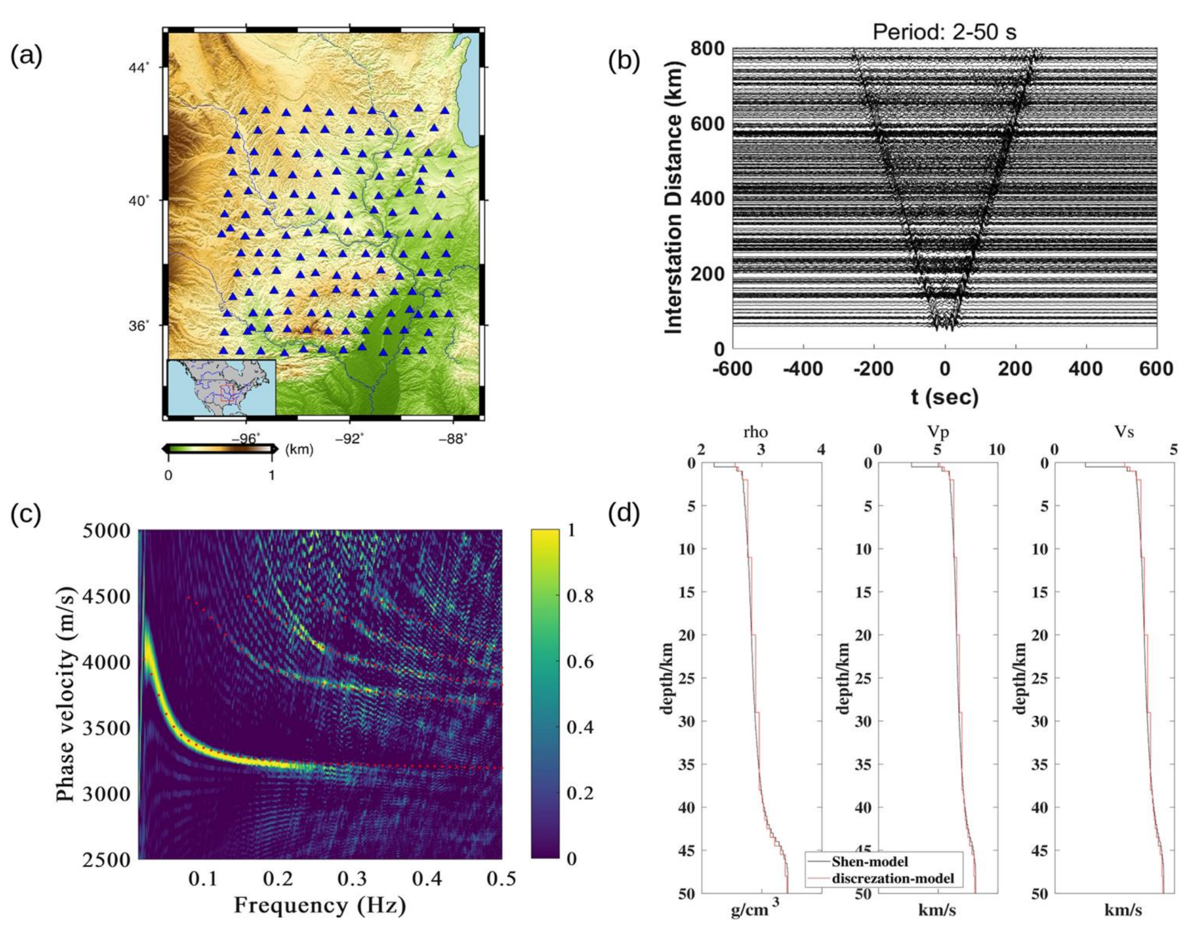
## I. Gist:

- *Multimodal* surface waves can be extracted using the frequency-Bessel transform *(F-J) method*, offering more constraints for inversion compared to traditional dispersion extraction techniques.
- The *stacking* of cross-correlation functions *(CCFs)* is a crucial step in the F-J method, currently employing the simplest linear stacking method. To enhance the signal-to-noise ratio (SNR) of CCFs, a series of *non-linear stacking* methods has been developed. However, their *suitability for F-J is uncertain* due to potential waveform alterations caused by some non-linear procedures.
- Therefore, this study compares the influences of three differently-designed non-linear stacking methods on F-J dispersion curve extraction.

## II. F-J method:



*Work flow of F-J surface wave tomography* ***(Wang et al., 2019)***

(a) Array-based Ambient noise records

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(b) Cross-Correlation and ***stacking***

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(c) F-J transform (F-J spectrogram) and dispersion curve extraction

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(d) Subsurface 1D velocity structure inversion

## III. Stacking methods:

- ***Linear Stacking (LS)***:
  - Directly stacks ***all daylong CCFs***

$$CCF_{LS}(t)=\frac{1}{N}\sum_{j=1}^{N}C_{zz}^{j}(t)$$

- ***Phase-Weighted Stacking (PWS):***
  - Utilizes the phase of each time point in CCF to ***measure coherency as stacking weight***.

$$w(t)=\left|\frac{1}{N}\sum_{k=1}^{N}e^{i\phi_k(t)}\right|$$

$$CCF_{PWS}(t)=\frac{1}{N}\sum_{j=1}^{N}C_{zz}^{j}(t)\cdot w(t)^{v}$$

- ***Root-Mean-Square Ratio Selection Stacking (RMSS_SS):***
  - A ***time-domain SNR selective stacking*** method: select high SNR daylong CCFs based on RMS values within different period bands to stack.

$$CCF_{RMSS}(t)=\frac{1}{N^{*}}\sum_{j=1}^{N}C_{zz}^{j}(t_{pb})\cdot w^{j}(t_{pb})$$

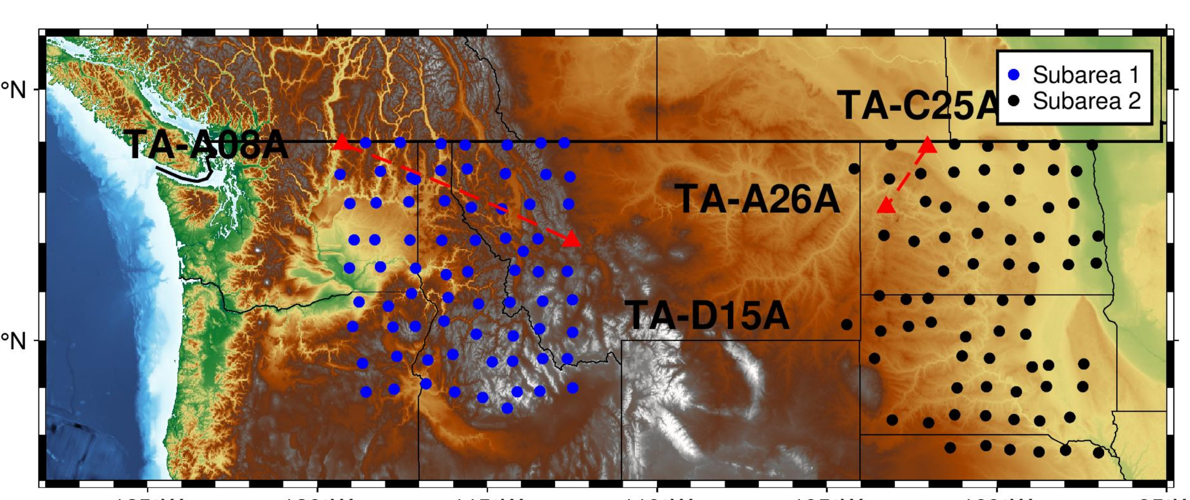
$$w^{j}(t_{pb})=\begin{cases}1, & Q^{j}\le G\\ 0, & Q^{j}>G\end{cases},\quad Q^{j}=\frac{RMS^{j}}{RMS^{N}}$$

- ***Frequency Domain Probability Selection Stacking (FPS):***
  - A ***frequency-domain probability selective*** stacking method: take daylong CCFs at each frequency point as sampling points to avoid stacking CCFs beyond standard deviation to improve the stacking CCFs.

$$CCF_{FPS}(f)=\frac{1}{N^{*}}\sum_{j=1}^{N}C_{zz}^{j}(f)\cdot w^{j}(f)$$

$$w^{j}(f)=\begin{cases}1, & C_{zz}^{j}(f)\le Var(C_{zz})\\ 0, & C_{zz}^{j}(f)>Var(C_{zz})\end{cases}$$

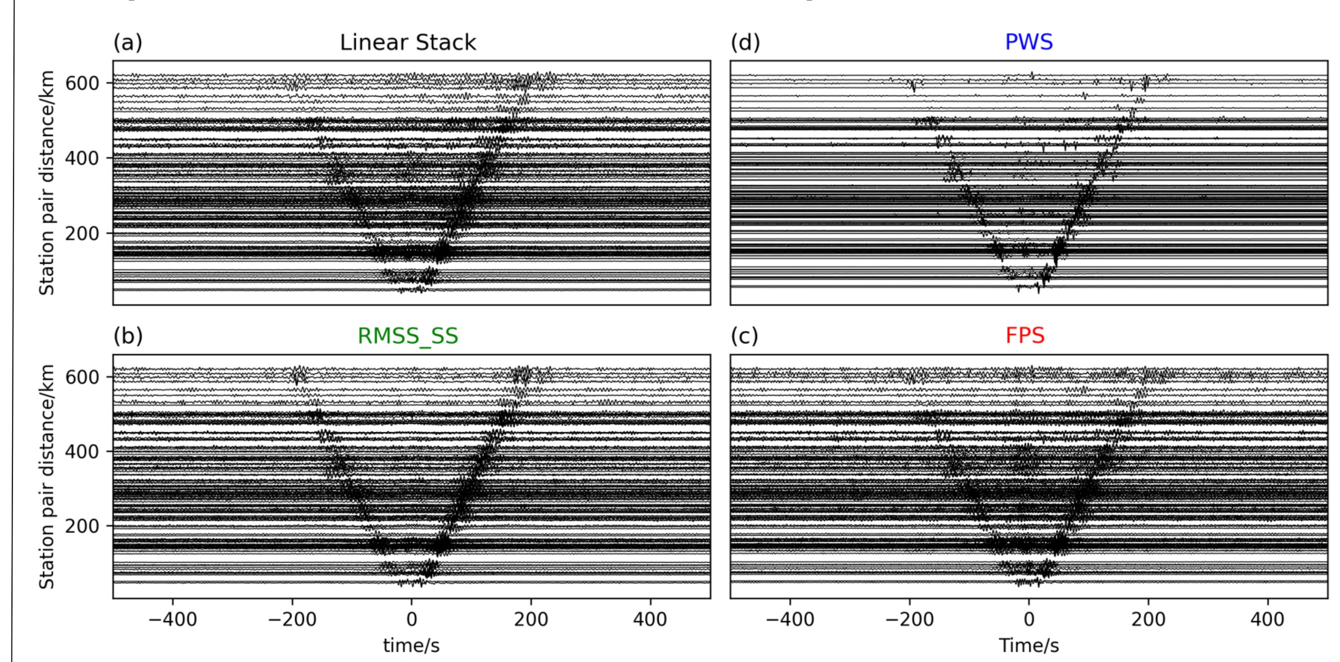
## IV. Realistic Data: USArray



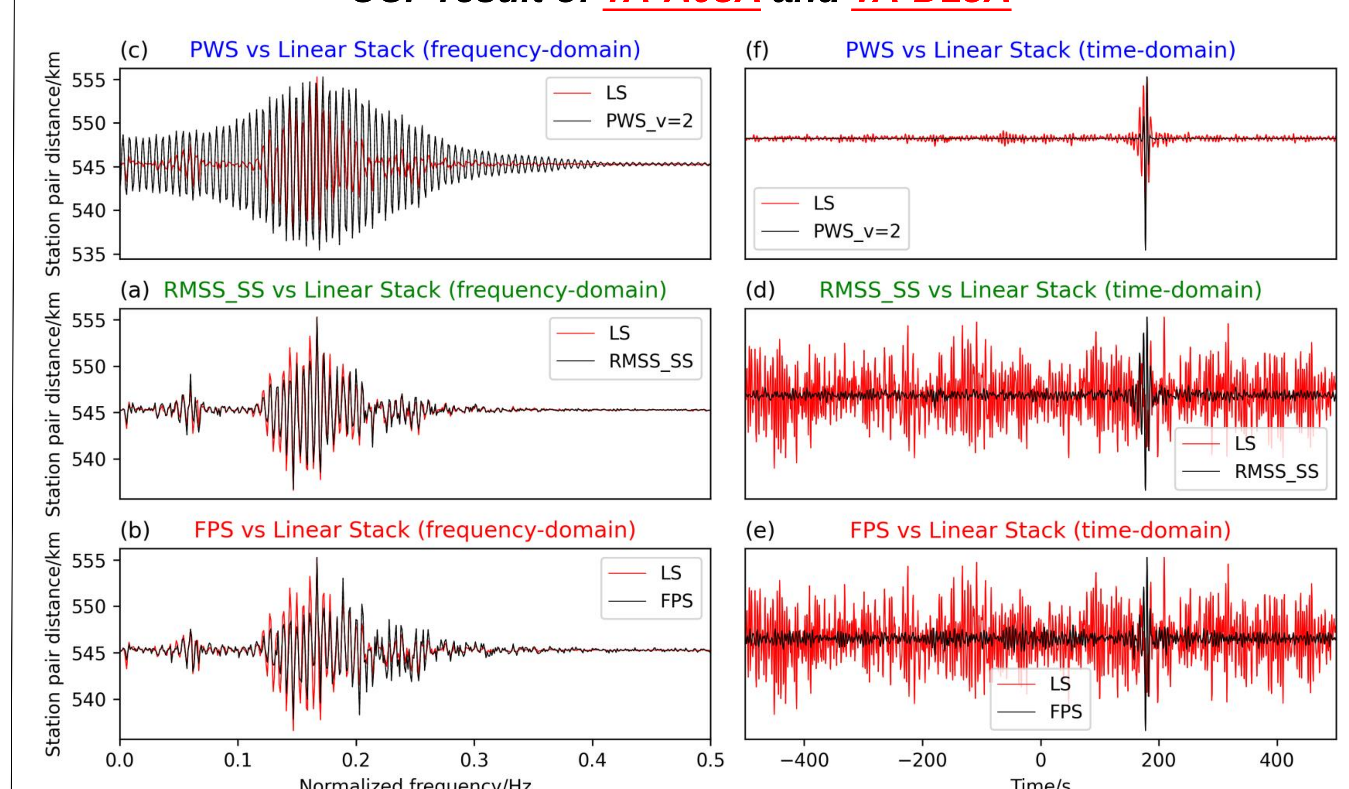

*Two array series used in this study: USArray, 150 days duration*

## V. Results of Subarea 1

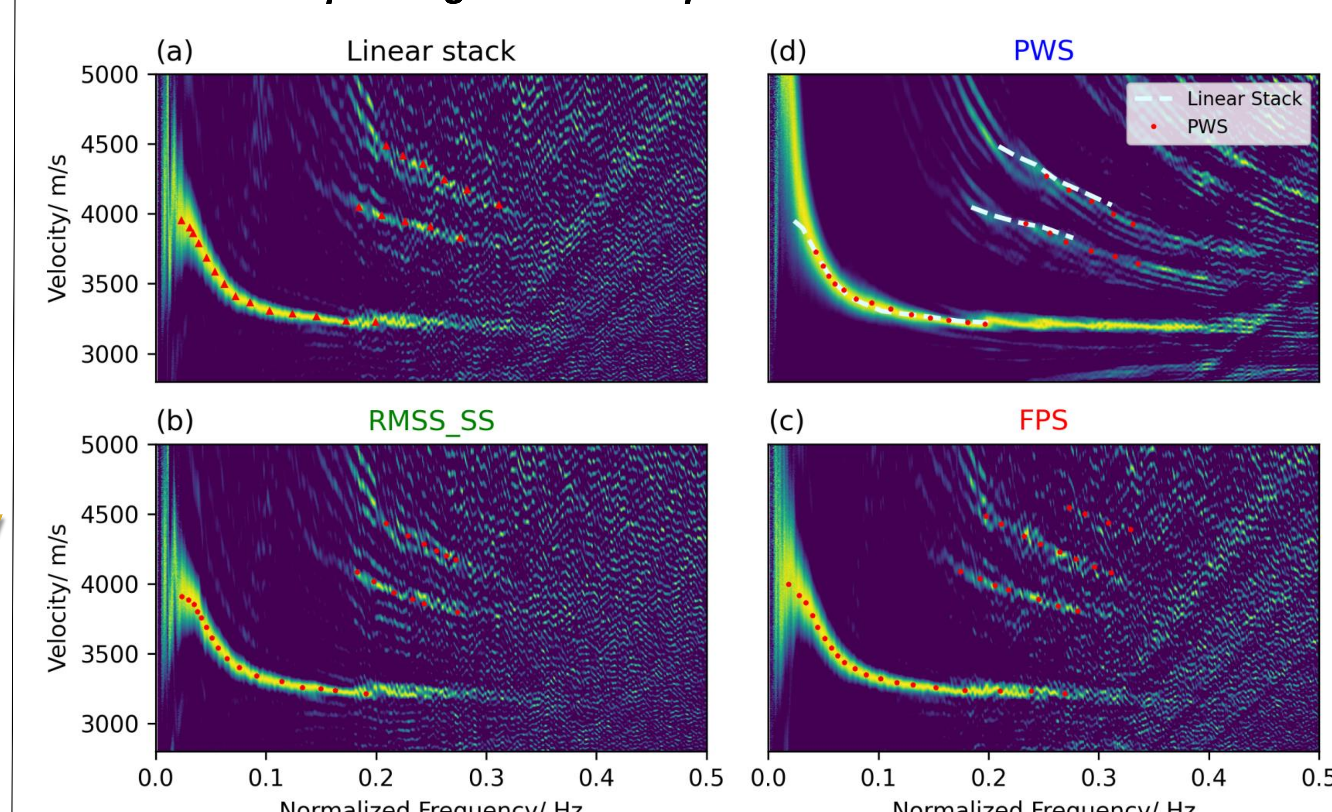
***Comparison of the stacked CCFs with respect to interstation distances***




***CCF result of TA-A08A and TA-D15A***

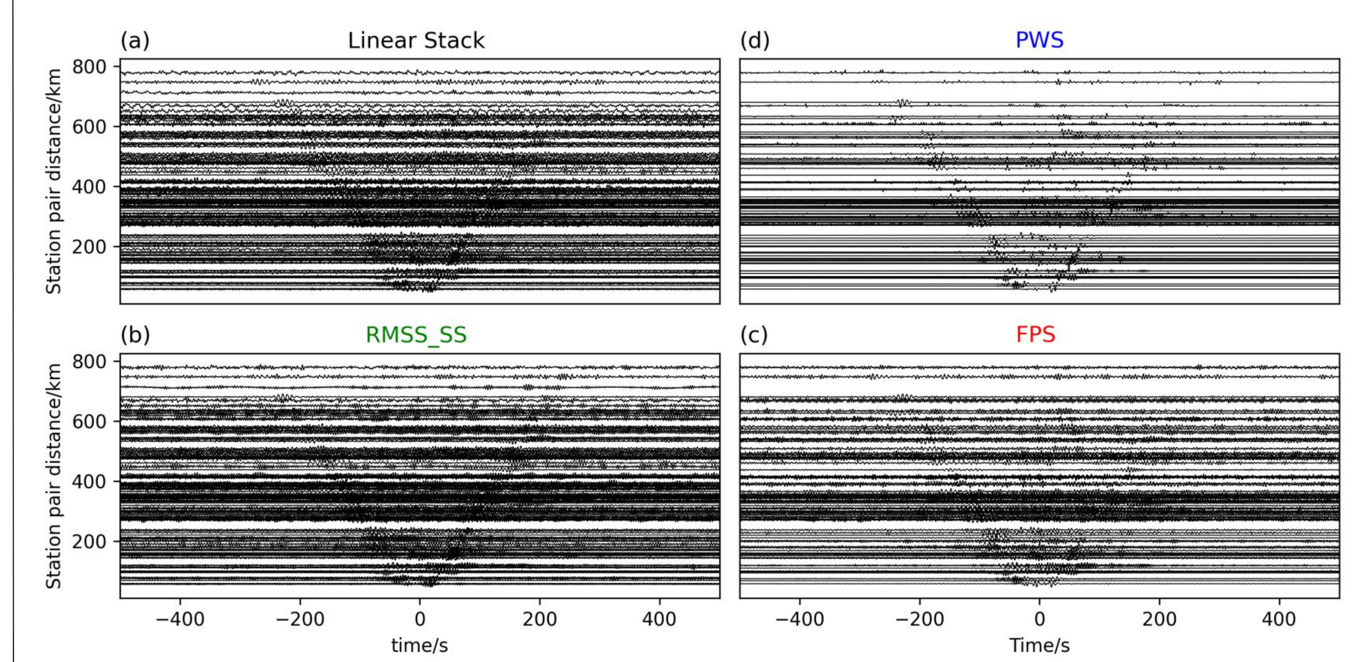



***F-J spectrogram and dispersion curve extracted***

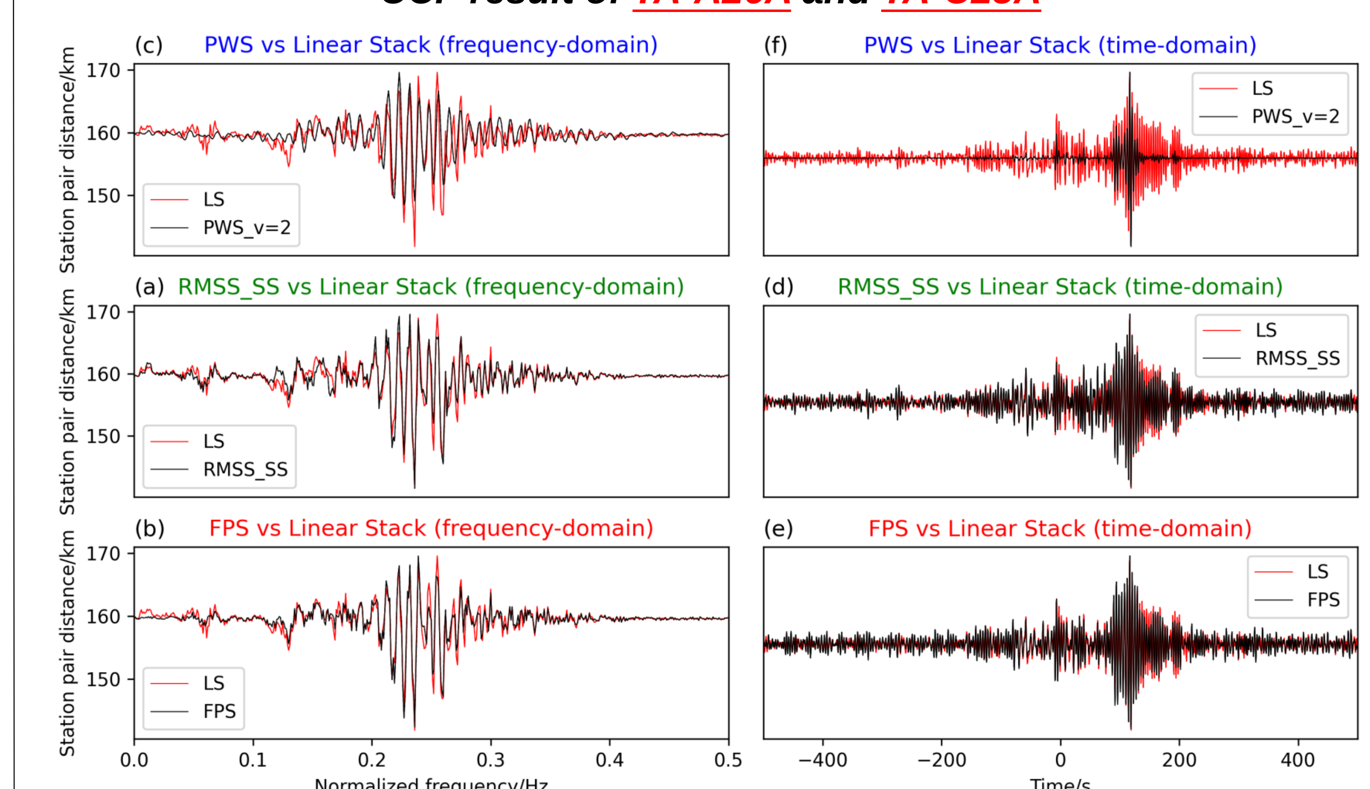



## VI. Results of Subarea 2

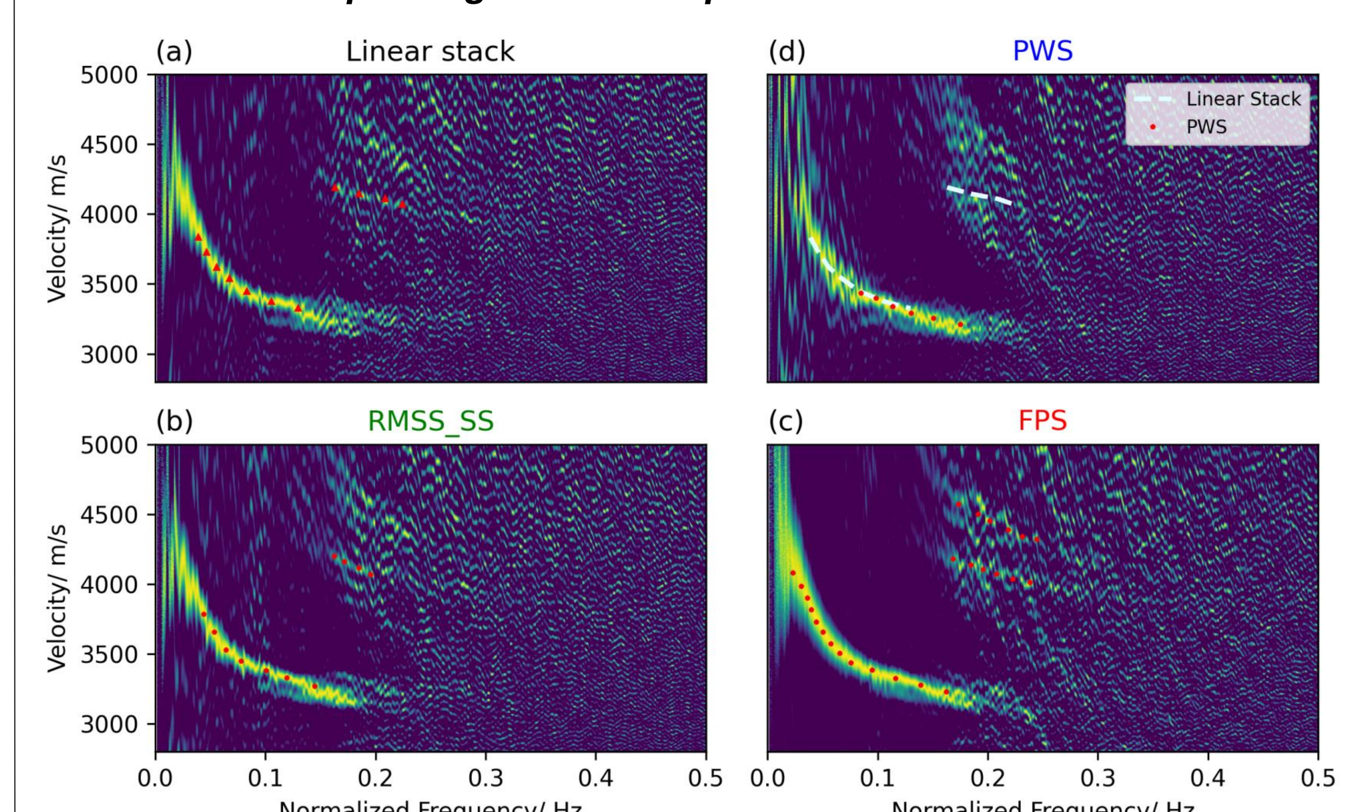
***Comparison of the stacked CCFs with respect to interstation distances***




***CCF result of TA-A26A and TA-C25A***




***F-J spectrogram and dispersion curve extracted***




## IV. Summary:

- **PWS** significantly ***improves the SNR of CCFs***, while dramatically **damages the F-J spectrogram quality**.
- **RMSS** has a mild influence on both CCFs and F-J spectrogram, which ***can remove some strait artifacts***.
- **FPS** has a slight improvement on CCFs' SNR, while ***enhancing the resolution and continuity of multimode***.