Estimation of phase and group velocities for the MASW survey using the 'slant stack generalized S-transform based' and 'phase shift' methods

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Outline

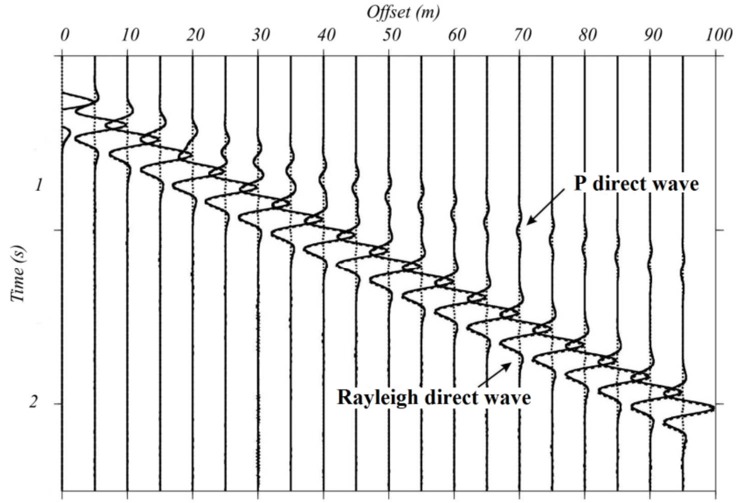
- Objective of this study
- MASW method
- The S transform and its generalized version
- Slant stack generalized S transform based
- Phase-Shift method
- Conclusion

Objective of this study

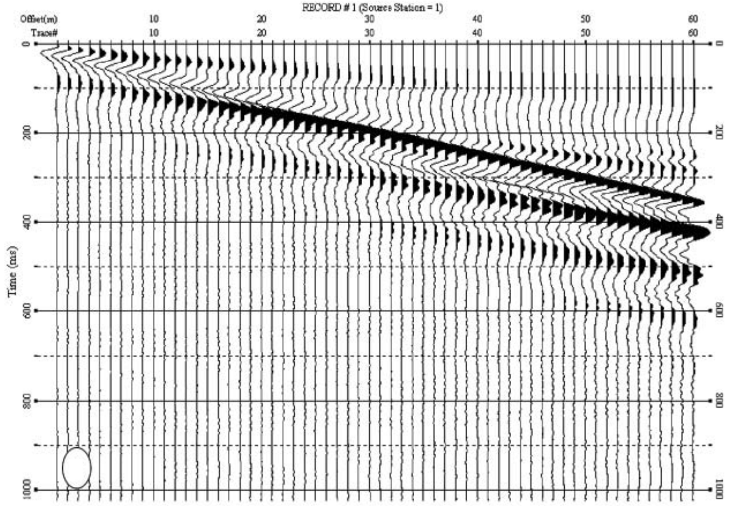
The Objective of this study is to expand a mathematical model to estimate group velocity and phase velocities of multi-modal ground-rolls for MASW survey.

MASW Method

Multi-channel Analysis of Surface Waves (MASW) is a method for estimating shear wave velocity based on dispersed Rayleigh waves.



(a)



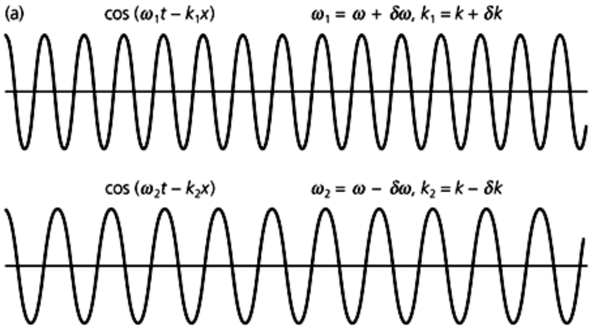
(b)

Luo et al., 2008
Gelis et al. 2005

Phase and Group Velocities

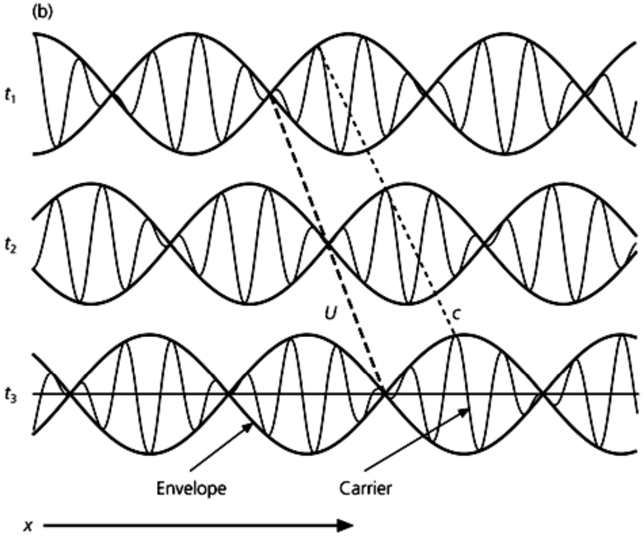
Phase velocity **is the velocity of each frequency component of dispersed surface wave which is defined as**

Vp= *f/ k.*



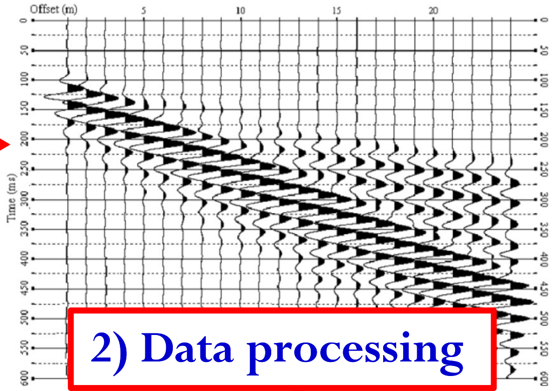
Group velocity ***is*** **the velocity of a wave pocket (envelope) of surface wave around frequency f which is defined as**

Vg= *df/ dk*

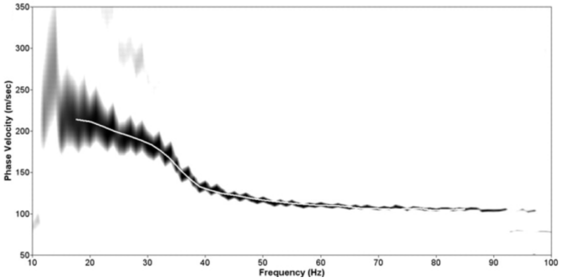


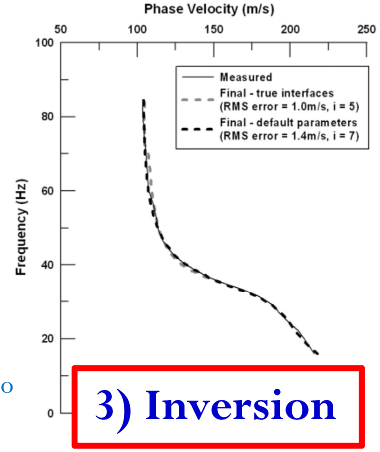
Three steps in MASW survey

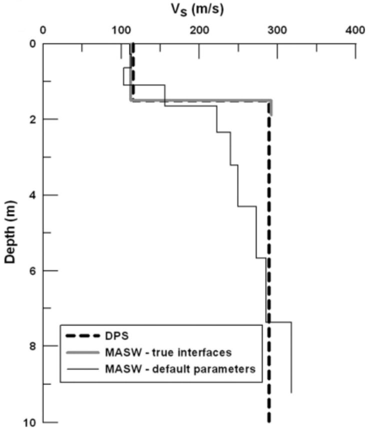
1) Data Acquisition



2) Data processing







3) Inversion

http://www.geovision.com/PDF/M_SASW.PDF

http://jeeg.geoscienceworld.org/content/vol13/issue2/images/large/eego

Time-Frequency Analysis

The S transform (Stockwell et al, 1996)

$$S[h(\tau)](t,f) = \int_{-\infty}^{+\infty} h(\tau)\left[\frac{|f|}{\sqrt{2\pi}} e^{-\frac{f^2(\tau-t)^2}{2}}\right] e^{-j2\pi f\tau} d\tau.$$

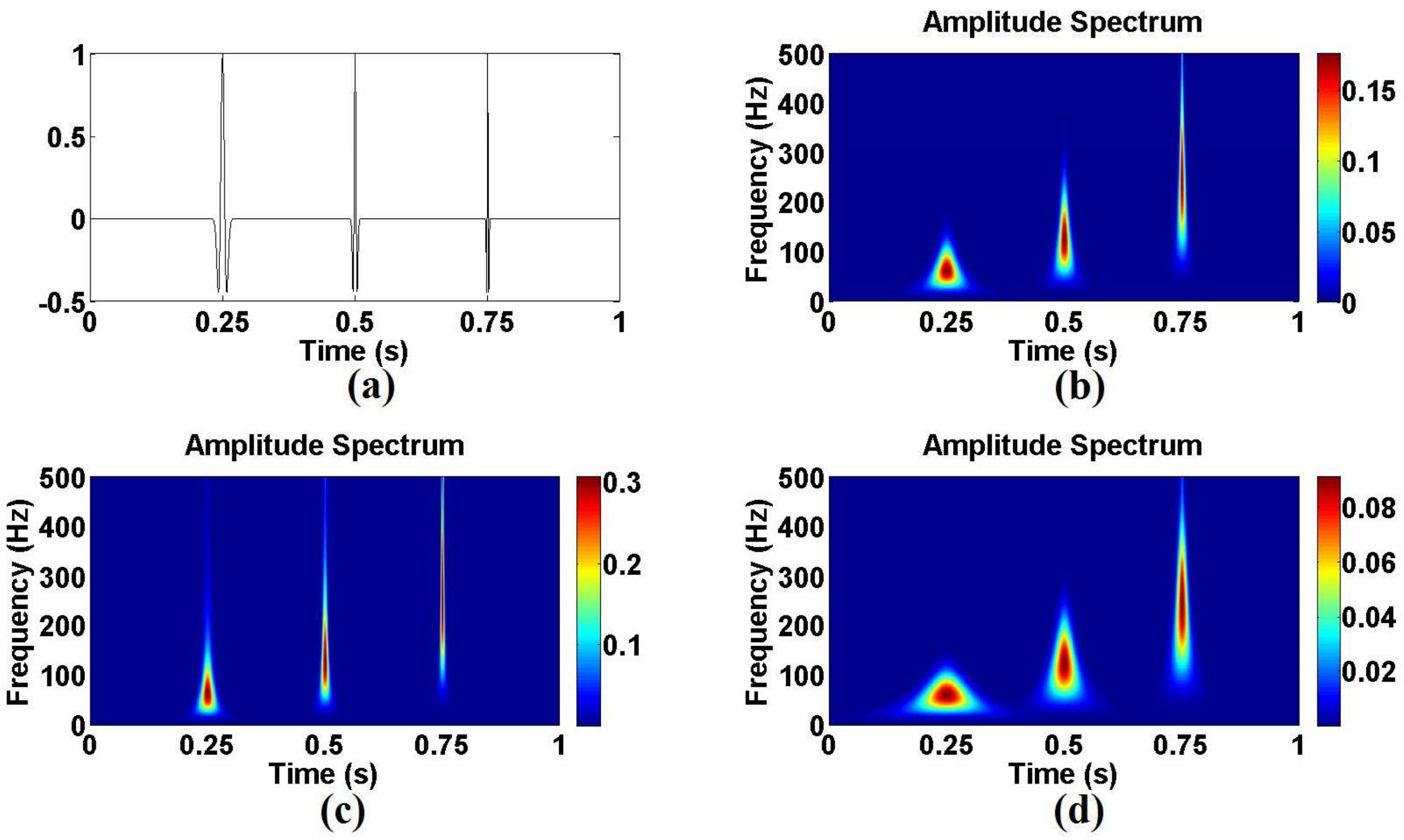
The generalized S transform (Pinnegar and Mansinha, 2003)

$$S_g[h(\tau)](t,f,\mathbf{p}) = \int_{-\infty}^{+\infty} h(\tau) w(\tau - t, f, \mathbf{p}) e^{-j2\pi f\tau} d\tau$$

A version of the generalized S transform is defined using a scaling factor ***σ,***

$$S_g[h(\tau)](t,f,\sigma) = \int_{-\infty}^{+\infty} h(\tau) \frac{|f|}{\sqrt{2\pi}\sigma} e^{-\frac{f^2(\tau-t)^2}{2\sigma^2}} e^{-j2\pi f\tau} d\tau$$

The Generalized S Transform



(a) (b)

(c) (d)

(a) a signal. (b), (c) and (d) the generalized S transforms of (a) for **σ**=1, 0.25 and 4 respectively.

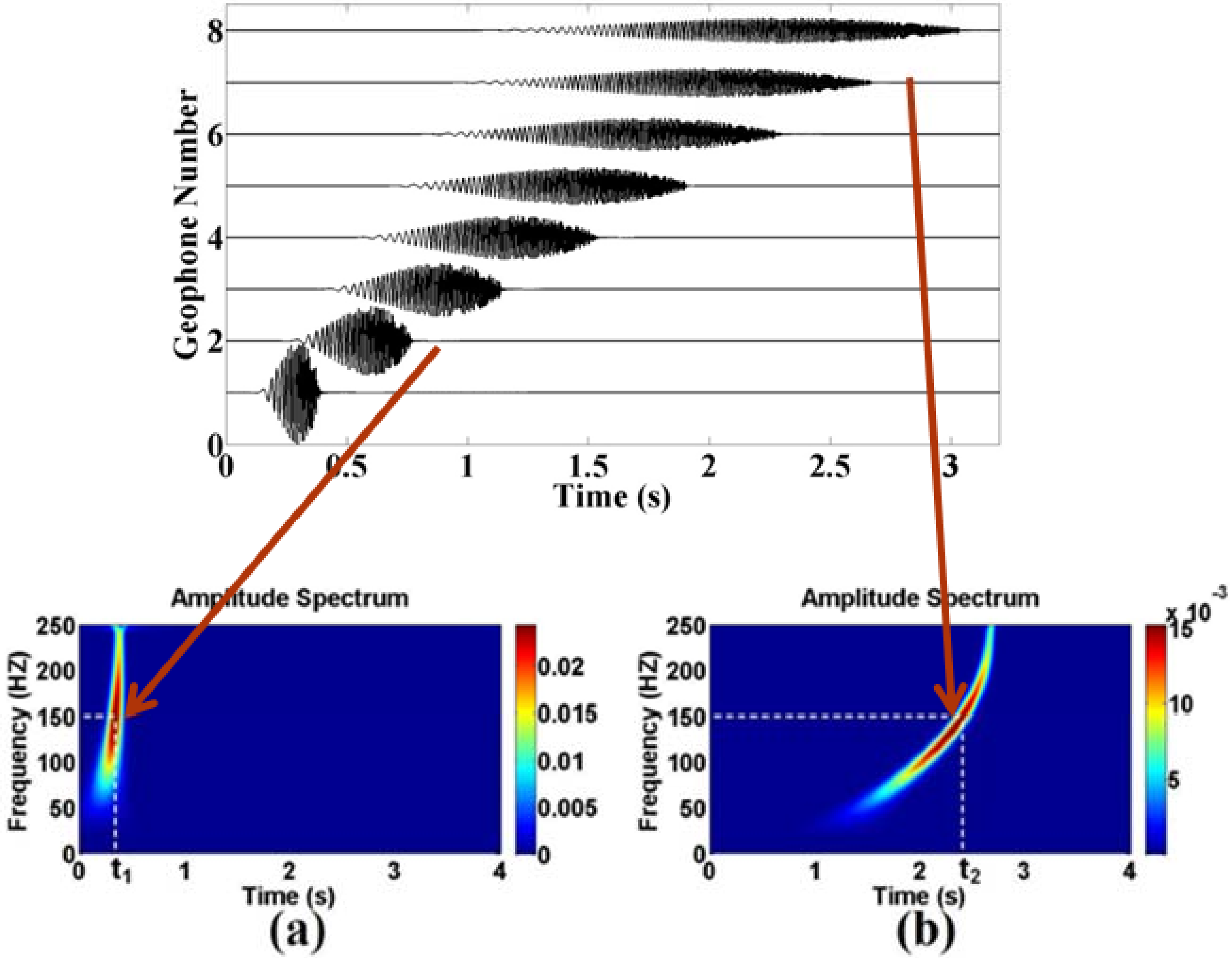
Estimation of group velocities

Assuming geometrical spreading correction has been applied on surface wave data, if h$_1$(τ) is the wavelet at station 1, the wavelet h$_2$(τ) recorded at station 2 can be expressed

$$H_2(f) = e^{-\lambda(f)d} e^{-j2\pi k(f)d} H_1(f)$$

Assuming

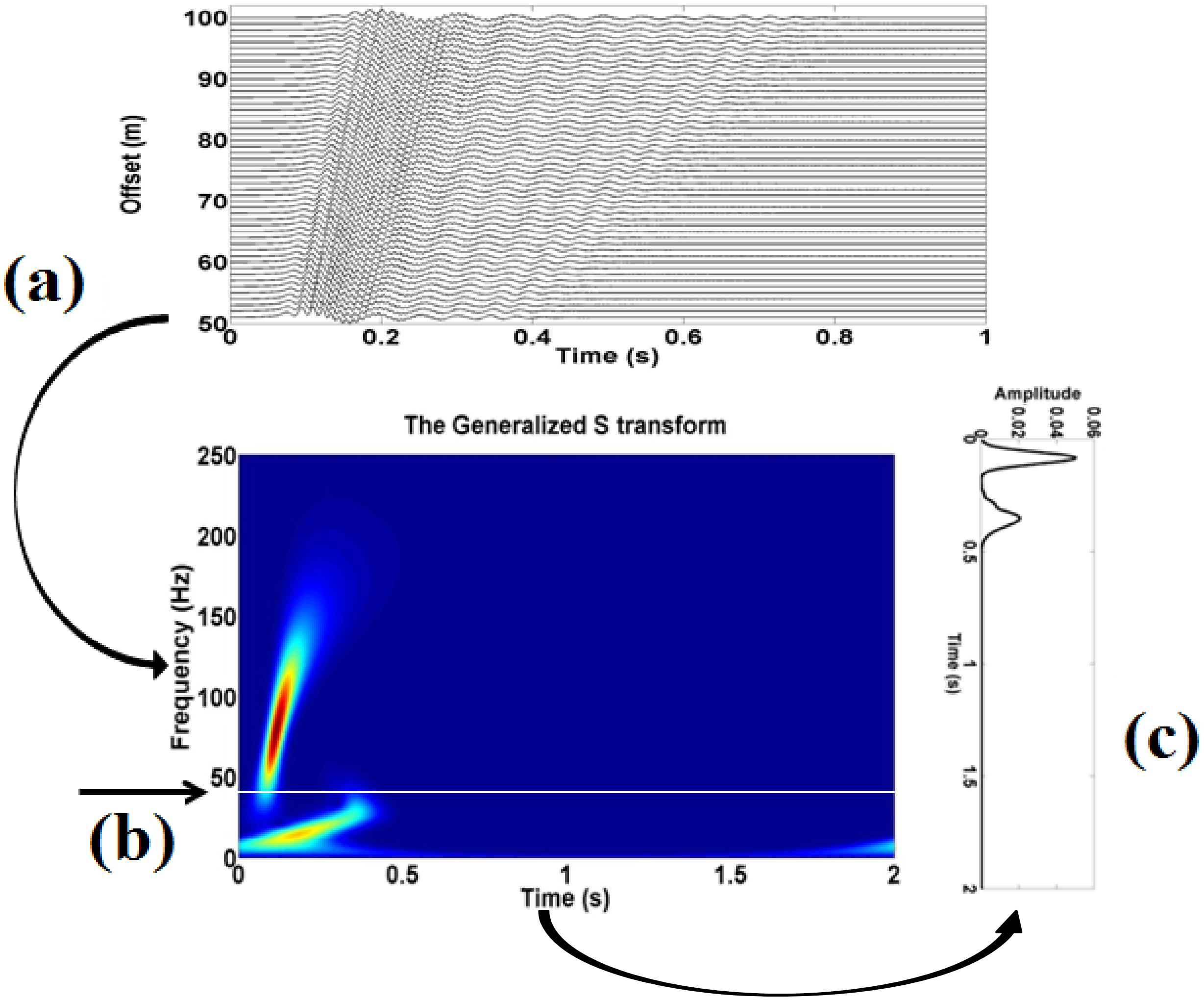
$$k(f+\alpha) = k(f) + \alpha k'(f) + O(\alpha^2),$$



(a) and (b) the amplitude spectrum for traces 1 and 7 respectively

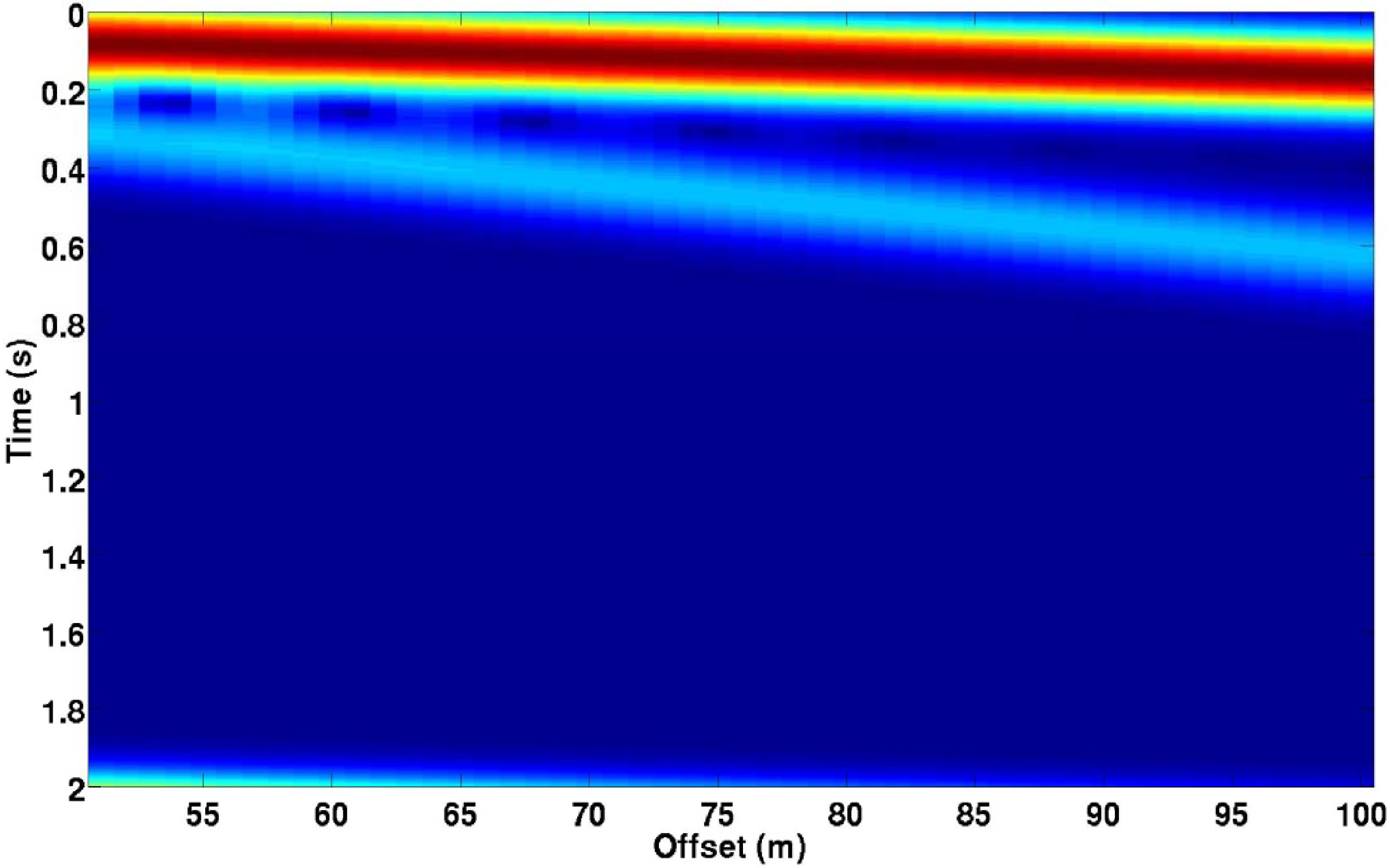
$$v_g = \frac{d}{\Delta t}$$

Slant Stack Generalized S transform Based



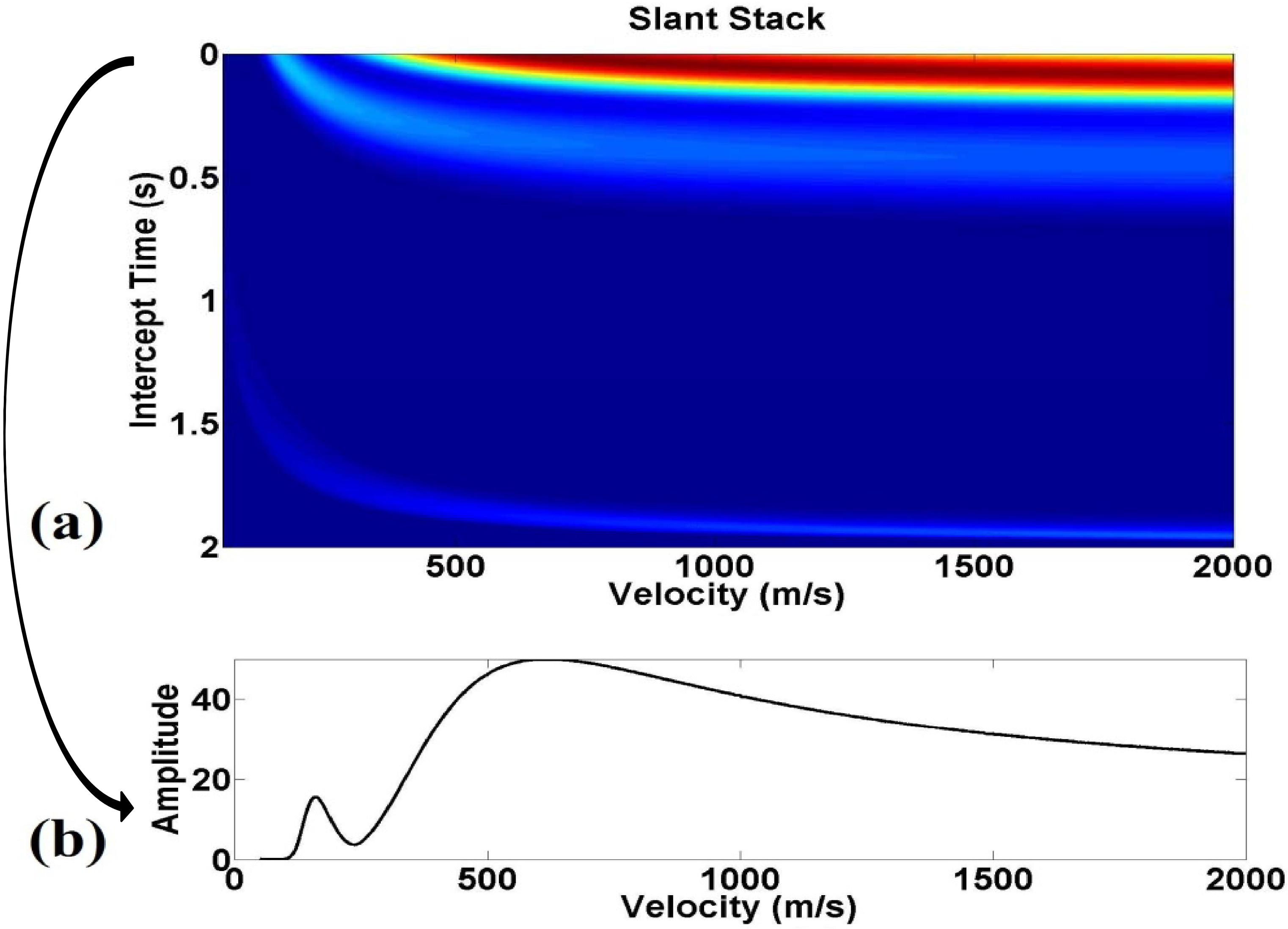
(a) A synthetic data containing a two modal ground roll. (b) The generalized S transform of the first trace in Figure 1. (c) Time representation of the generalized S transform at the single frequency 40Hz.

Slant Stack Generalized S transform Based



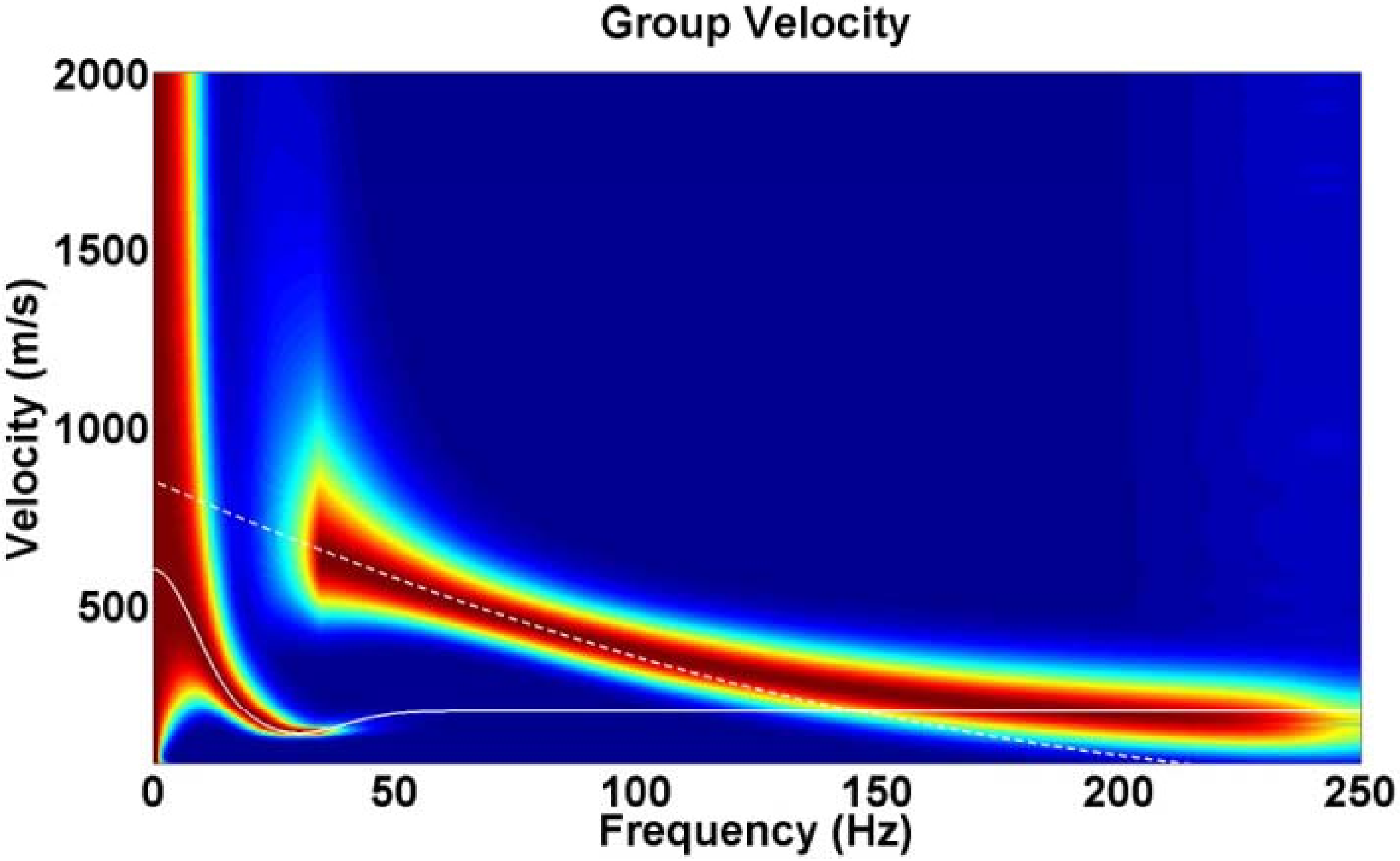
A pseudo-seismic record based of the generalized S transform of the traces of the record in Figure 1 at Frequency=40Hz.

Slant Stack Generalized S transform Based



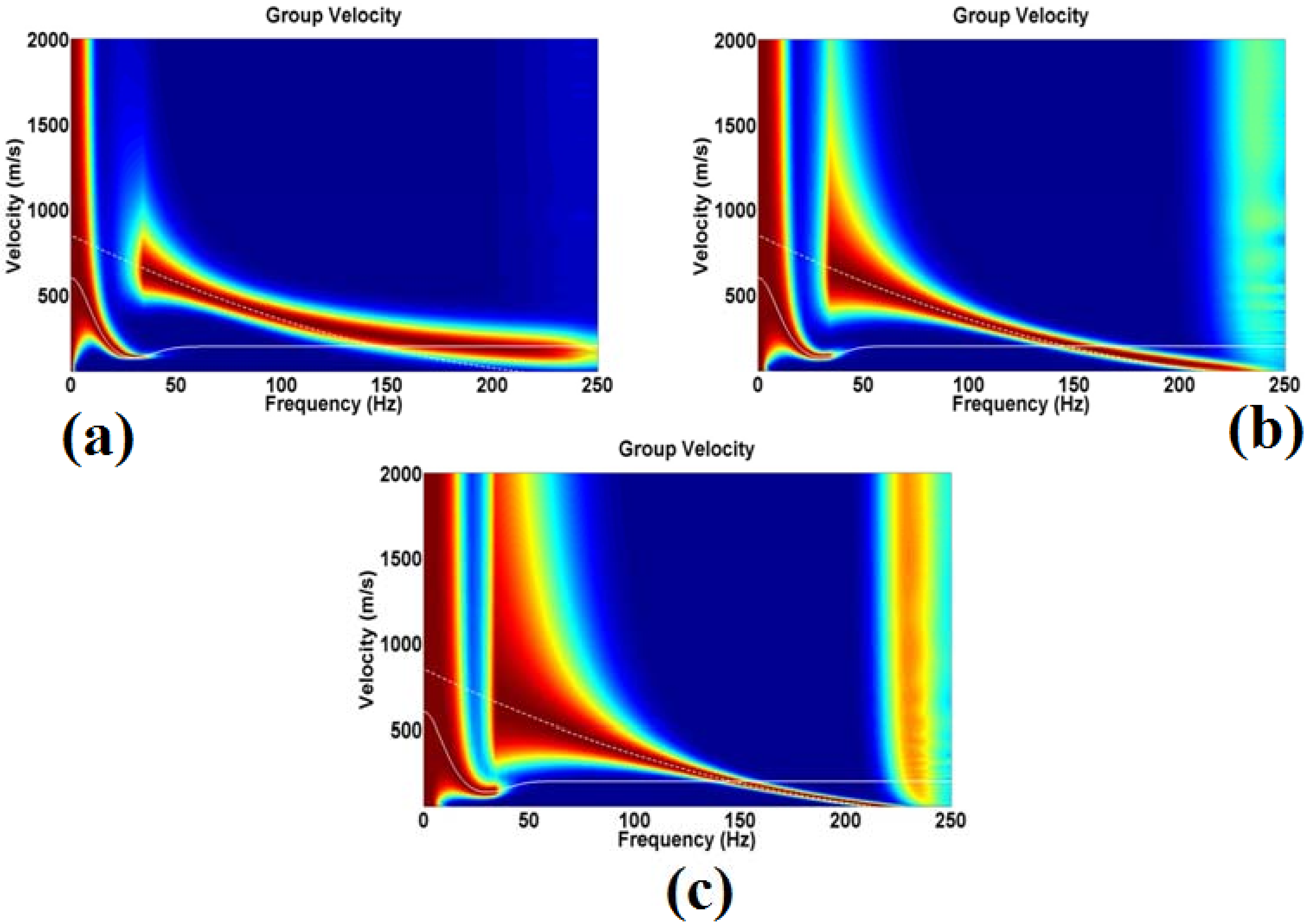
(a) The slant stack of the pseudo-record in Figure 7. (b) Single representation of the slant stack at intercept time T=0.

Group Velocity of the Record Based on Scaling factor σ=1.



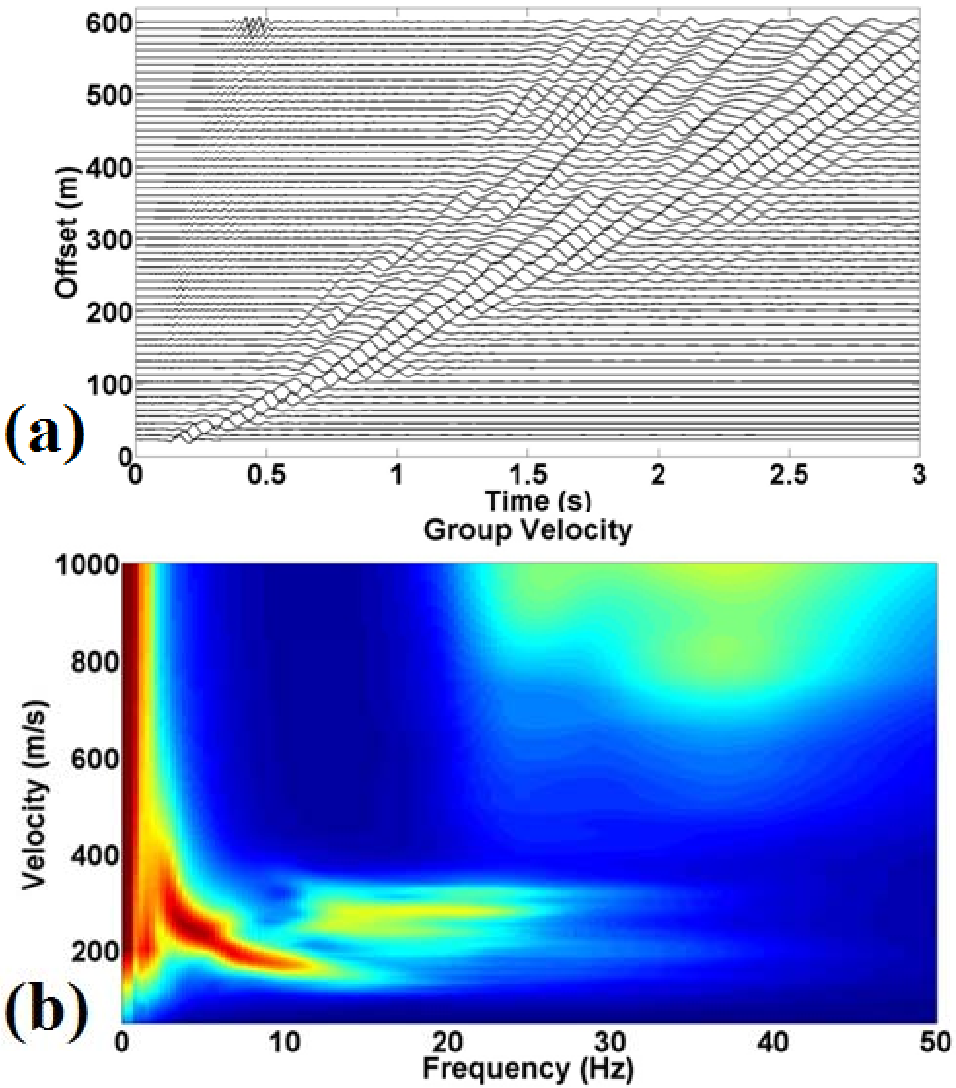
The estimated group velocity for the record in Figure 1 based on the scaling factor σ=1.The solid and dashed lines correspond to the theoretical values.

Group Velocity of the Record



(a), (b), and (c) the estimated group velocity for the record in Figure 1 based on the scaling factor σ=1, σ=5, and σ=20 respectively.

A Real Data Example



(a) A real data. (b) The estimated group velocity for the record based on the scaling factor σ=1.

Phase Shift (Park et al (1998))

Considering a seismic record in the offset-time domain u(t,x) contacting ground rolls, the Fourier transform for each trace is expressed

$$U(x,\omega) = \int u(x,t)e^{-i\omega t}\,dt.$$

The equation above could be rewritten as

$$U(x,\omega) = P(x,\omega)A(x,\omega)$$

Phase spectrum

Amplitude spectrum

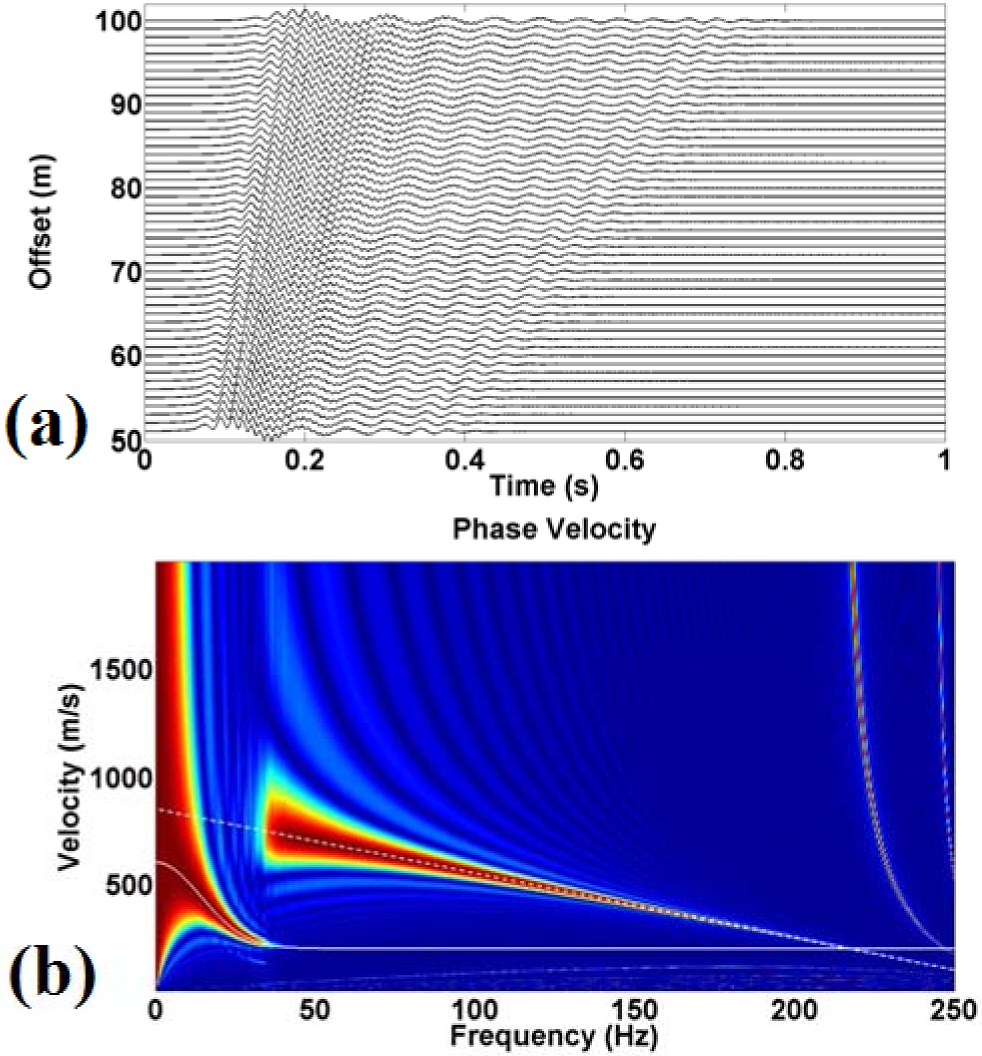
Phase Shift

Applying the operator $e^{i2\pi fx/v_p}$ where v_p is a phase velocity to the following integral

$$V\left(f, v_p\right) = \int \frac{U(x,\omega)}{|U(x,\omega)|} e^{i2\pi fx/v_p} dx = \int P(x,\omega) e^{i2\pi fx/v_p} dx,$$

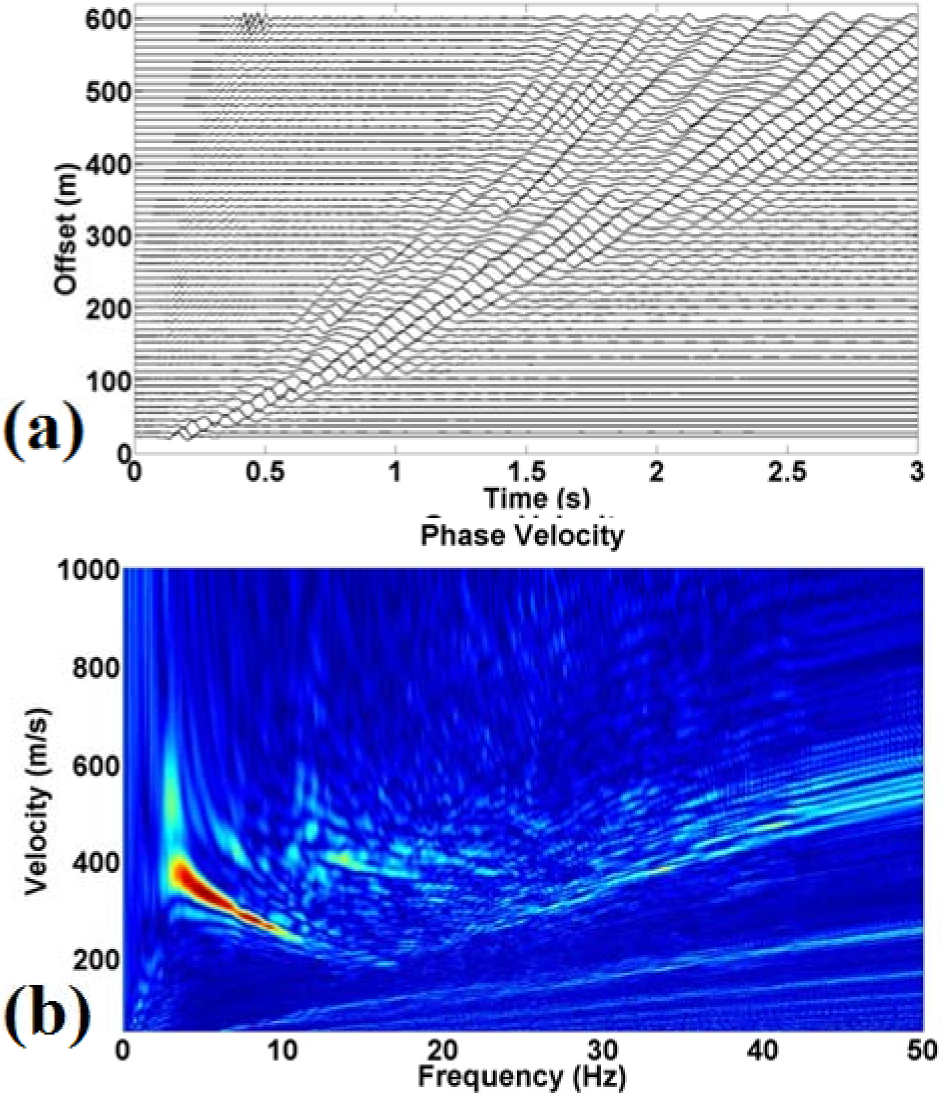
we obtain a two dimensional image of the phase velocities versus frequencies (Park et al., 1998). It is clear that at those frequencies where v_p is equal to the phase velocities of the signal, the integral will have a maximum.

A Synthetic Data Example



(a) A synthetic data composed of two modal ground roll. (b) The estimated phase velocity.

A Real Data Example



(a) A real data composed of two modal ground roll. (b) The estimated phase velocity.

Conclusion

Slant Stack S-transform based is a flexible method to estimate group velocity of ground-roll.

The resolution of the group velocity is manipulated by a scaling factor. As smaller scaling factor should be chosen for the low frequency ground roll. However, for higher frequencies, a larger scaling factor should be chosen. Therefore, there is a trade of between the resolution of low and high frequency ground roll. Based on our imperial observations, for the ranges of the frequencies that we deal with in the MASW survey (3-100Hz), scaling factors from 1 to 5 are recommended.

Phase-shift method is a very fast and high resolution technique for estimation of phase velocity.

Acknowledgements

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