Array-conditioned deconvolution of multiple-component teleseismic data with application to the Slave craton

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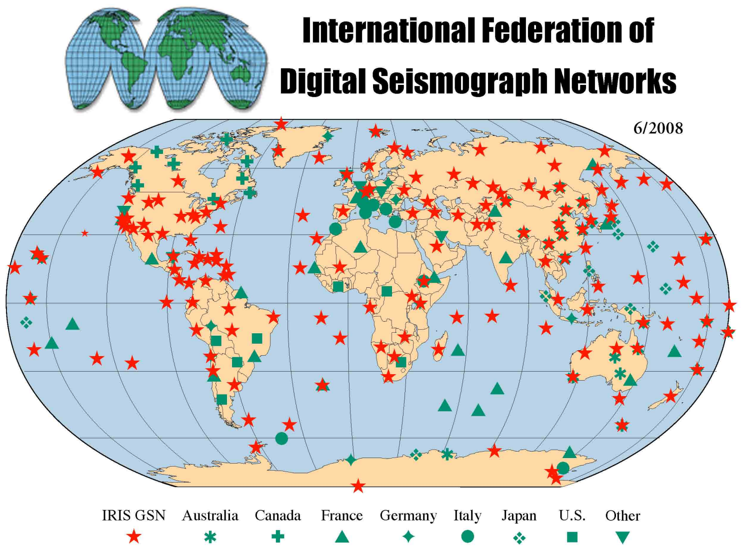
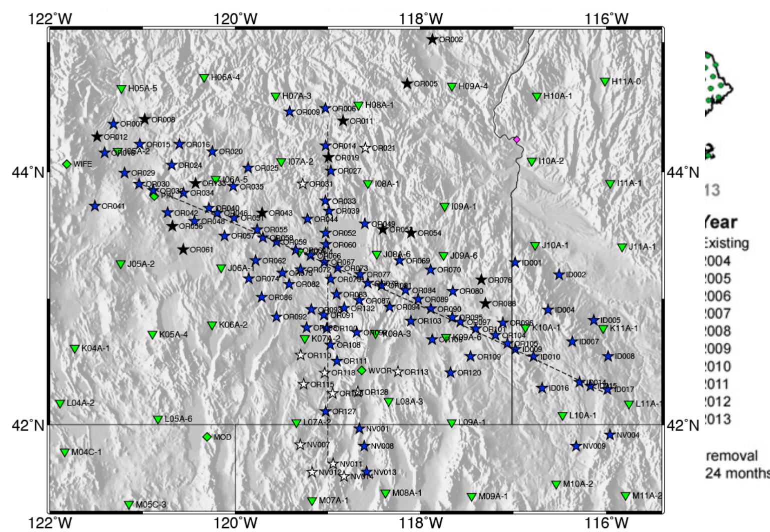
Summary

- Examine the applicability of an exploration-oriented, multichannel deconvolution technique to teleseismic data
- Synthetic experiments show the effectiveness of this method for noisy teleseismic recordings.
- Application to the Slave craton array data improves the data processing workflow and increases the number of usable earthquakes.
- An effective, automatic means for processing large amount of data- it does not require ad-hoc regularization; it is achieved naturally by using the noise present in the array data itself.

Motivation

From global seismic network to dense array experiments



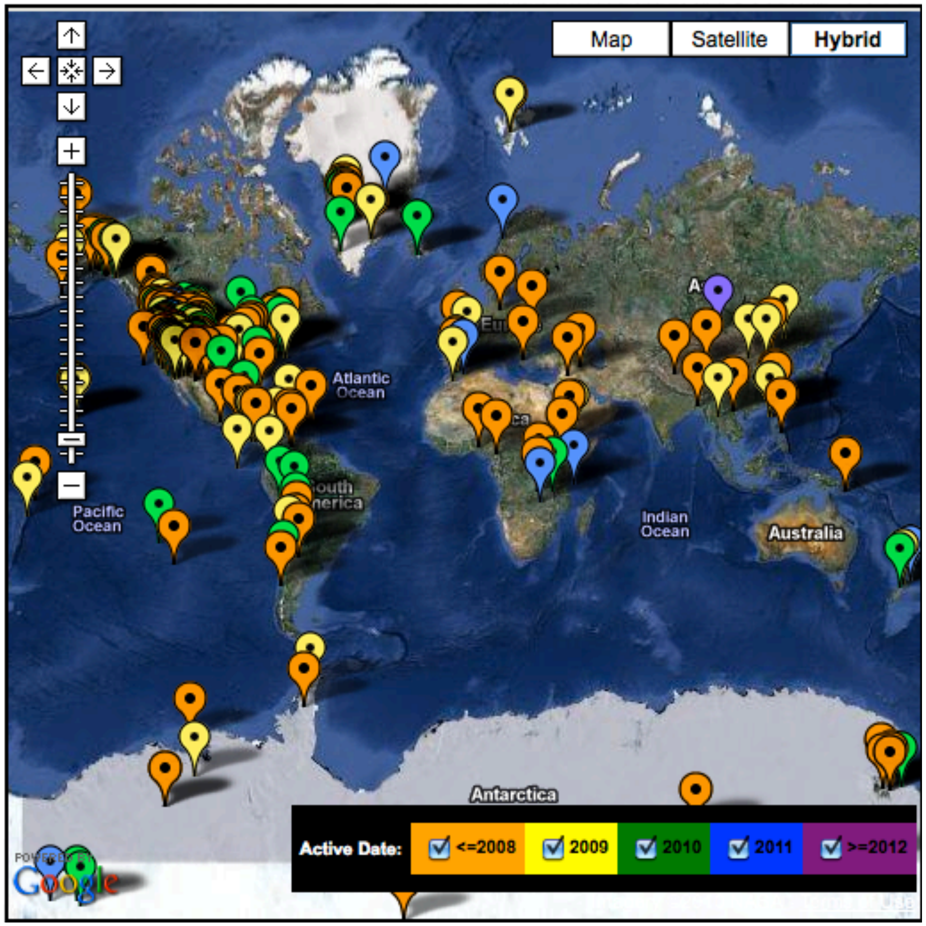


High Lava Plains (HLP) experiment

http://www.iris.edu/hq/programs/gsn/maps

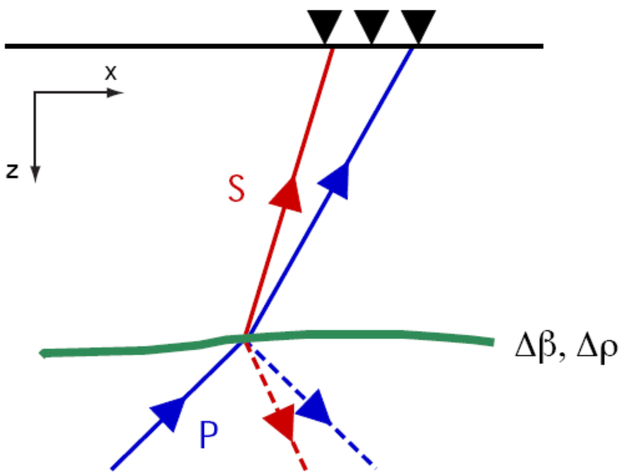
http://www.iris.edu/USArray/landowners/ta_install_map.html

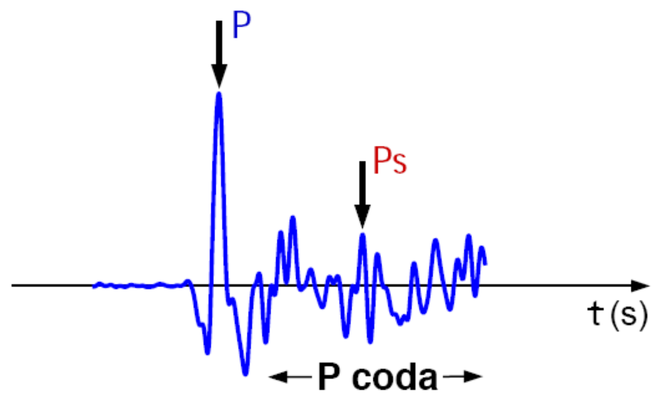
IRIS PASSCAL funded projects (2008-2012)



Receiver function imaging

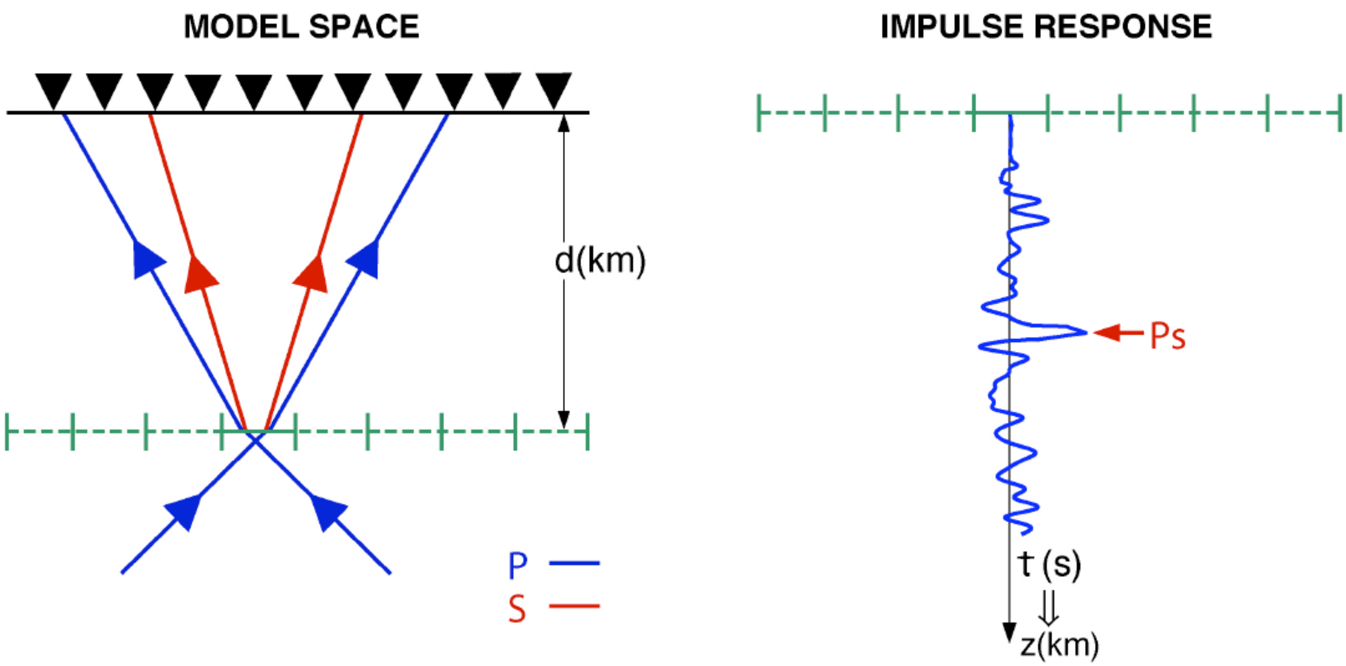
Body wave conversions





Rondenay 2009 Surv. Geophys.

Receiver function profile



Source normalization (deconvolution)

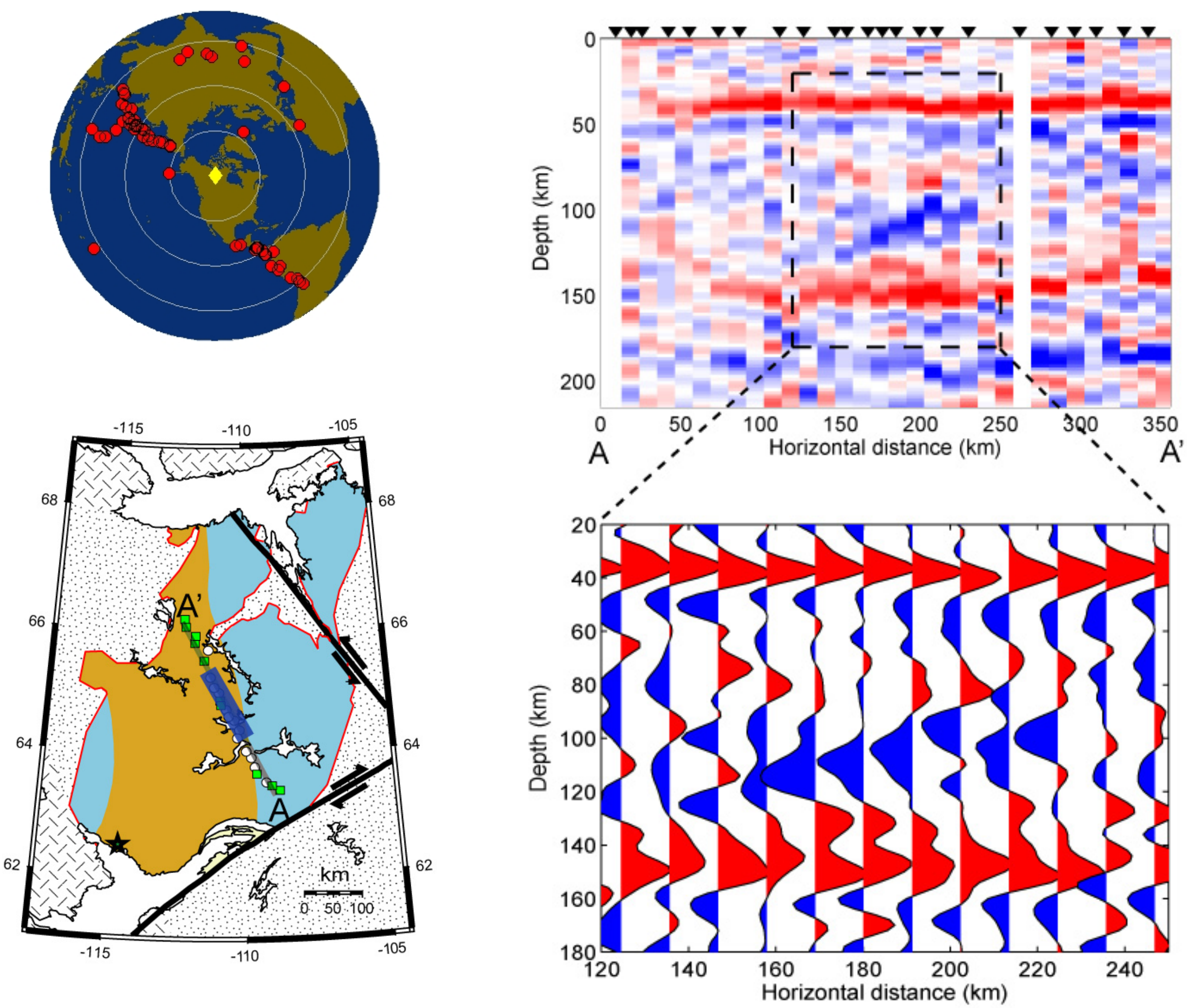
$$\hat{r}(\omega) = \frac{S(\omega)P^*(\omega)}{P(\omega)P^*(\omega) + \delta}$$

Stacking of normalized traces

$$R(t) = R(h(t)) = F^{-1}\left[\sum_{k=1}^{N} \hat{r}(\omega) e^{i\omega \Delta T_{P_S}(p_k, h(t))}\right]$$

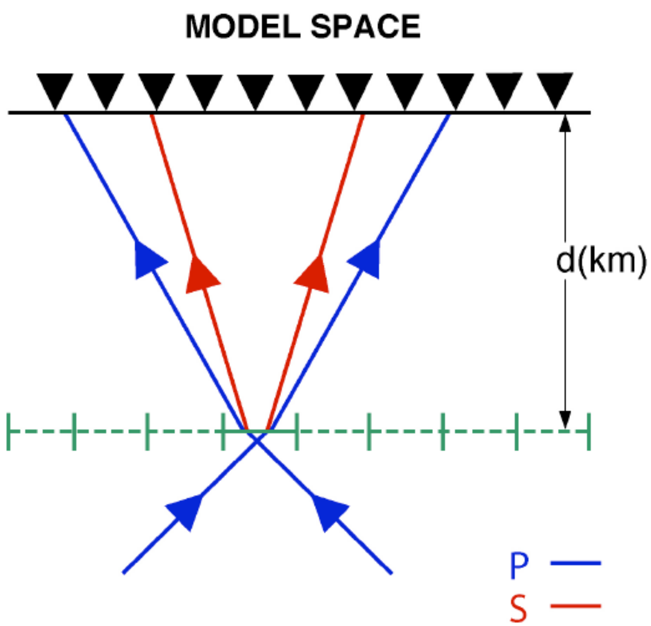
Rondenay 2009 Surv. Geophys.

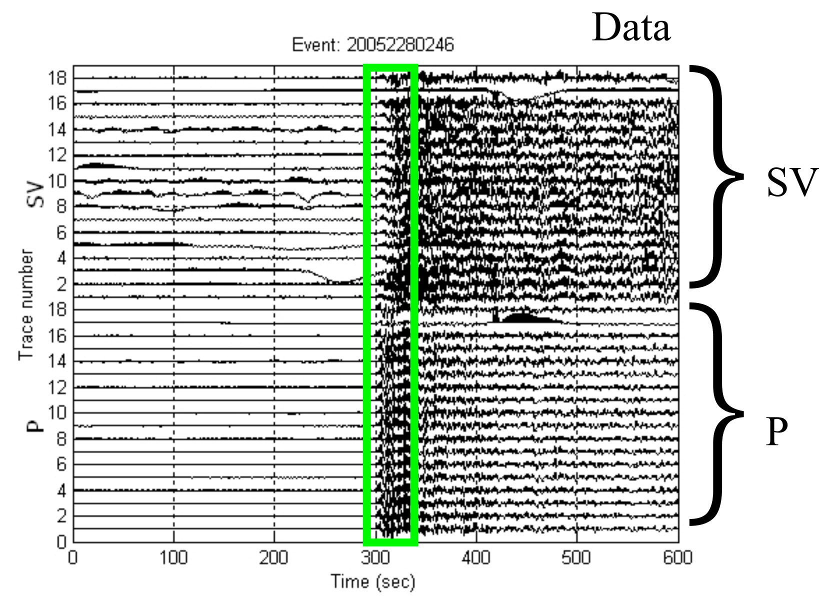
Receiver function profile: Slave craton

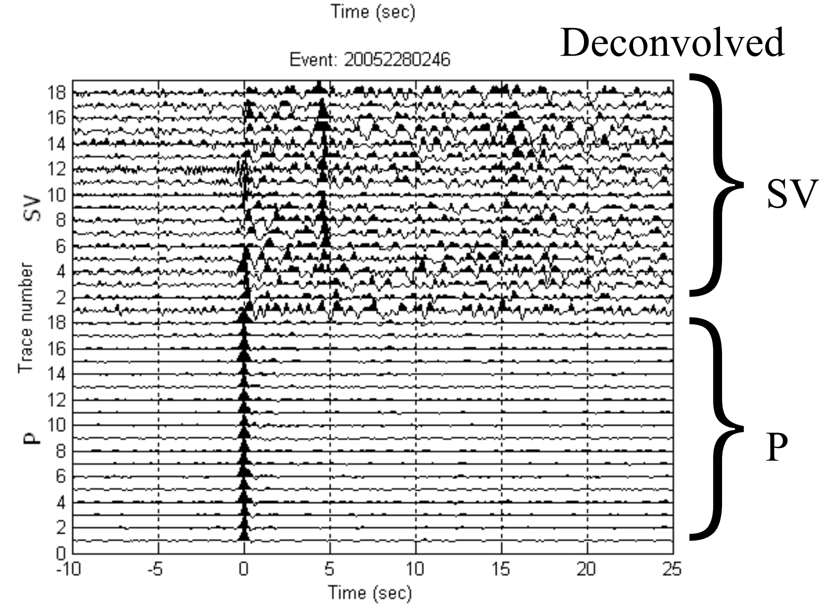


Chen, Rondenay et al. 2009 Science

Receiver function key step: Deconvolution







Source normalization (deconvolution)

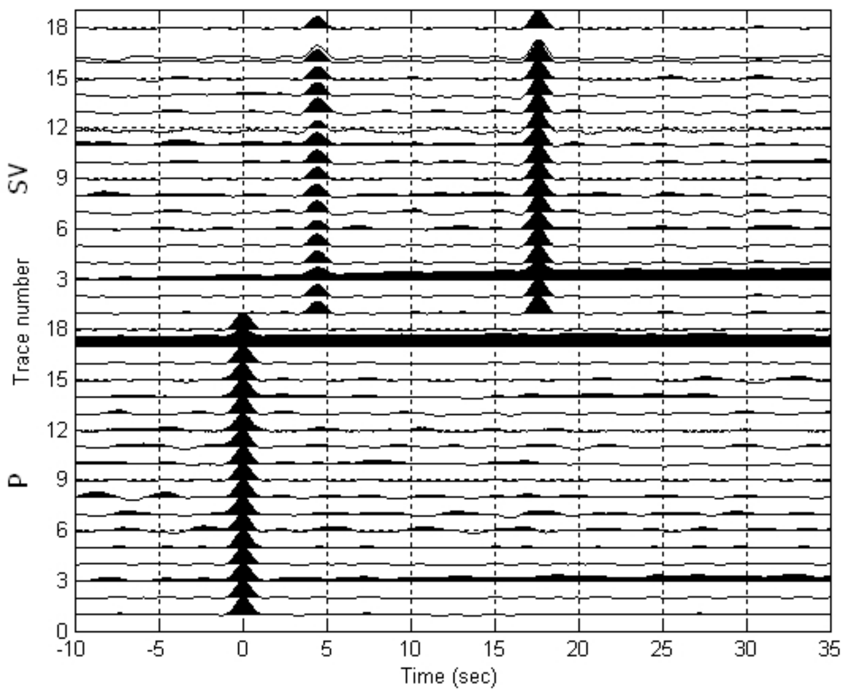
$$\hat{r}(\omega) = \frac{w^*(\omega)}{w(\omega)w^*(\omega) + \delta} d(\omega)$$

regularization

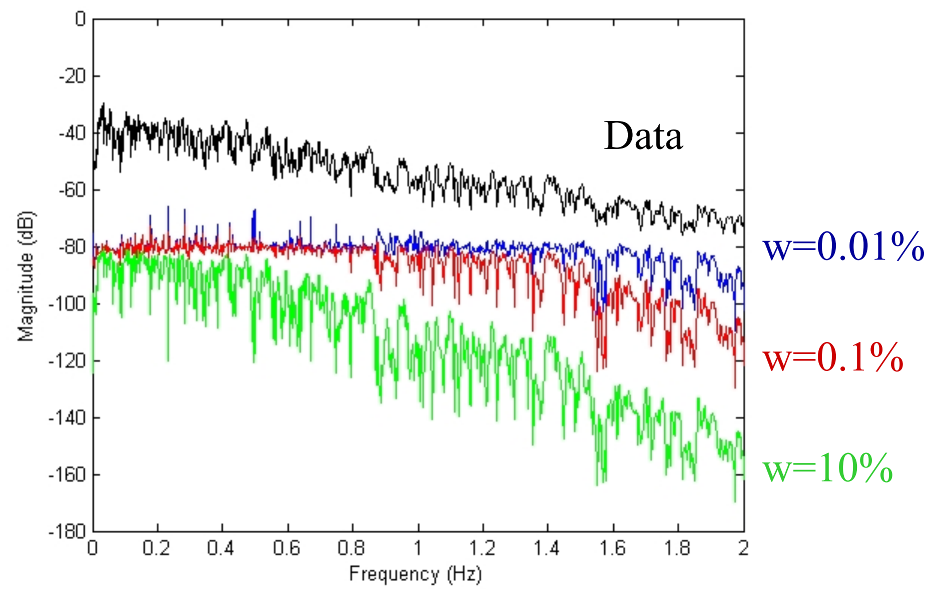
Waterlevel (Wiener) deconvolution

Deconvolved data

$\delta =$ [illegible]



Amplitude spectrum



Array-conditioned (multichannel) deconvolution

(Haldorsen, Miller & Walsh 1994; for vertical seismic profile)

Data model:

$$d_m(\omega) = w(\omega) + n_m(\omega).$$

To find a deconvolution filter such that

$$W(\omega) d_m(\omega) = 1.$$

The least-squares solution:

$$W(\omega) = \frac{\hat{w}^*(\omega)}{E_T(\omega)},$$

where

$$E_T(\omega) = \frac{1}{M} \sum_{m=1}^{M} |d_m(\omega)|^2.$$

Some rearrangements:

$$W(\omega) = \frac{\hat{w}^*(\omega)}{|\hat{w}(\omega)|^2} D(\omega), \quad \text{where} \quad D(\omega) = \frac{|\hat{w}(\omega)|^2}{E_T(\omega)}.$$

spiking decon filter   semblance

Semblance: data-adaptive filter that attenuates data at frequencies where signal-to-noise ratio is small

$$\rightarrow \quad W(\omega) = \frac{\hat{w}^*(\omega)}{|\hat{w}(\omega)|^2 + E_N(\omega)}. \qquad \text{cf.} \quad \hat{r}(\omega) = \frac{w^*(\omega)}{w(\omega) w^*(\omega) + \delta} d(\omega)$$

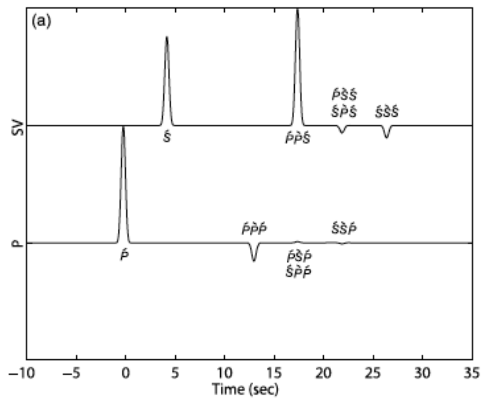
where

$$E_N(\omega) = \frac{1}{M} \sum_{m=1}^{M} |d_m(\omega) - w(\omega)|^2.$$

Chen et al. 2010 GJI

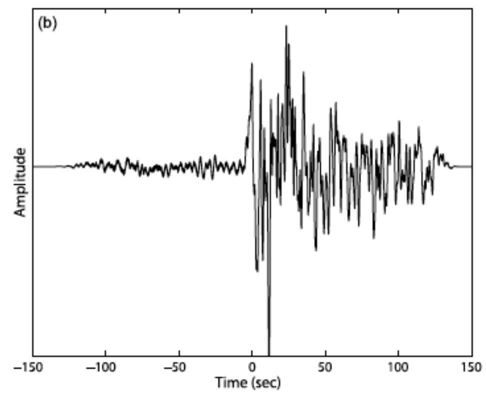
Making synthetics

Impulse response



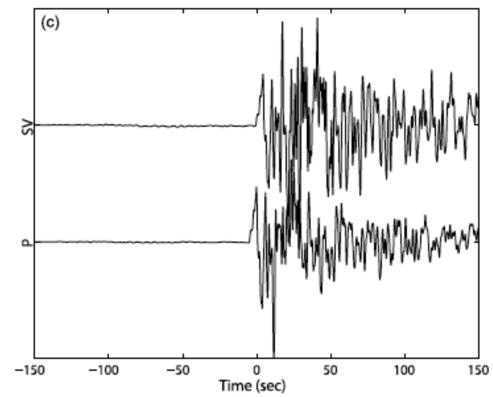
$*$

Source signature



$=$

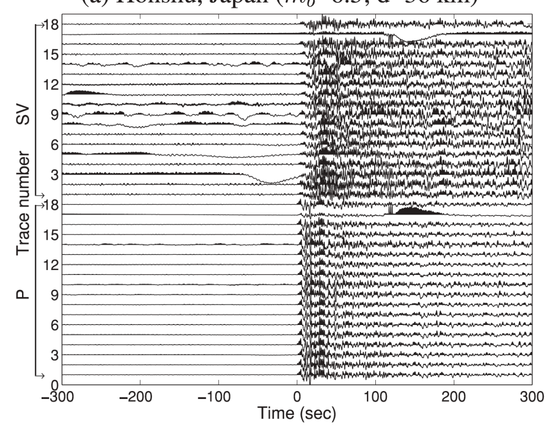
'noise-free' synthetics



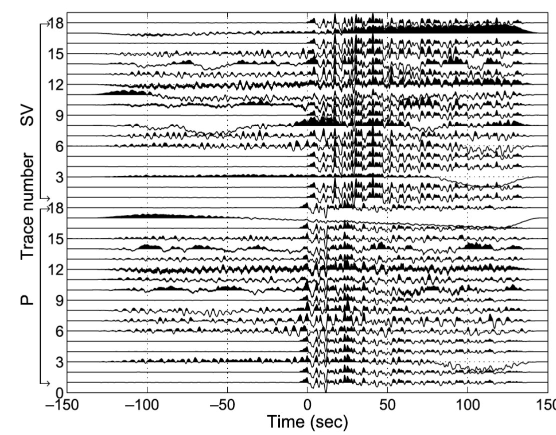
noise

$$d_p(t) = \hat{w}(t) \times g_p(t) + \lambda N_p(t)$$

(a) Honshu, Japan (m_b=6.5; d=36 km)



Teleseismic event



Complete synthetics

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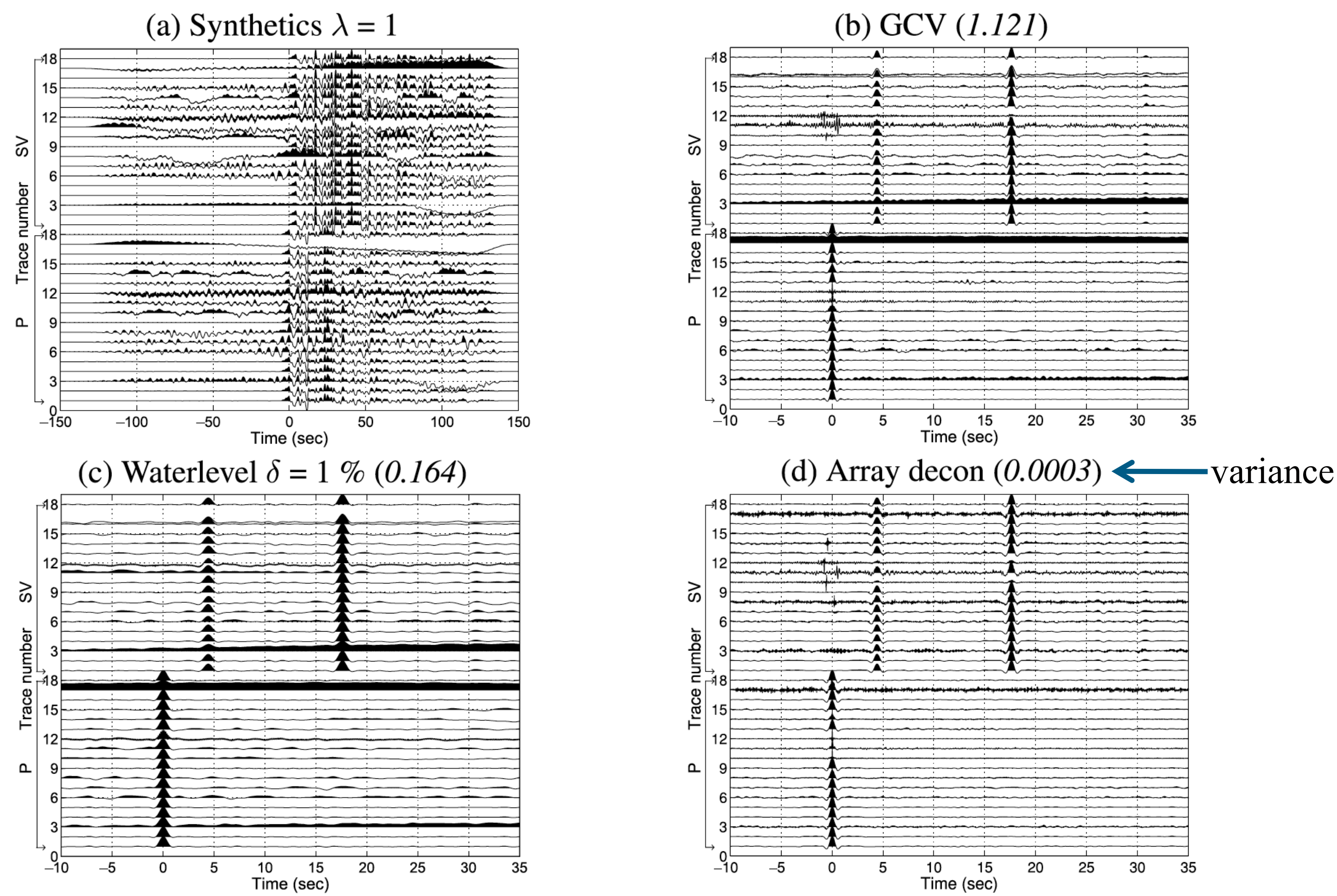
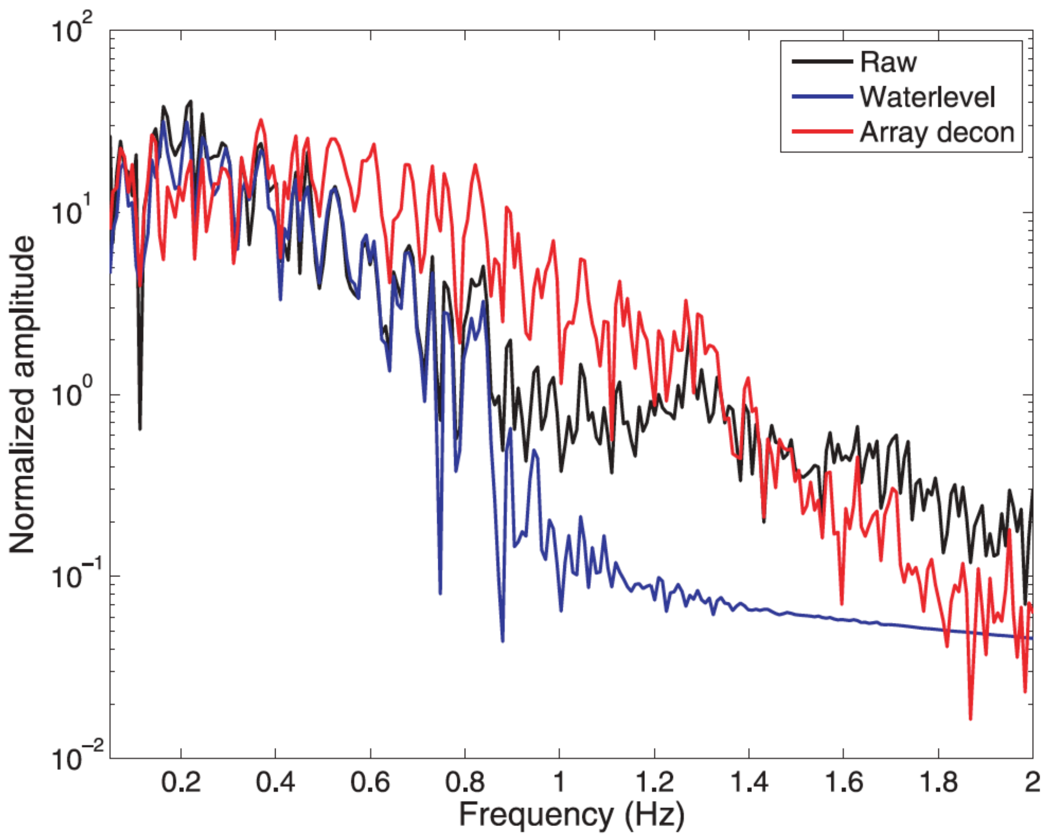
Synthetics experiments

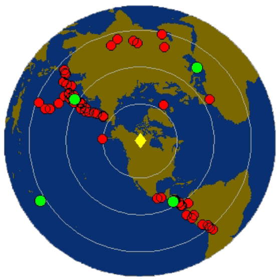
$$d_p(t) = \hat{w}(t) \times g_p(t) + \lambda N_p(t)$$

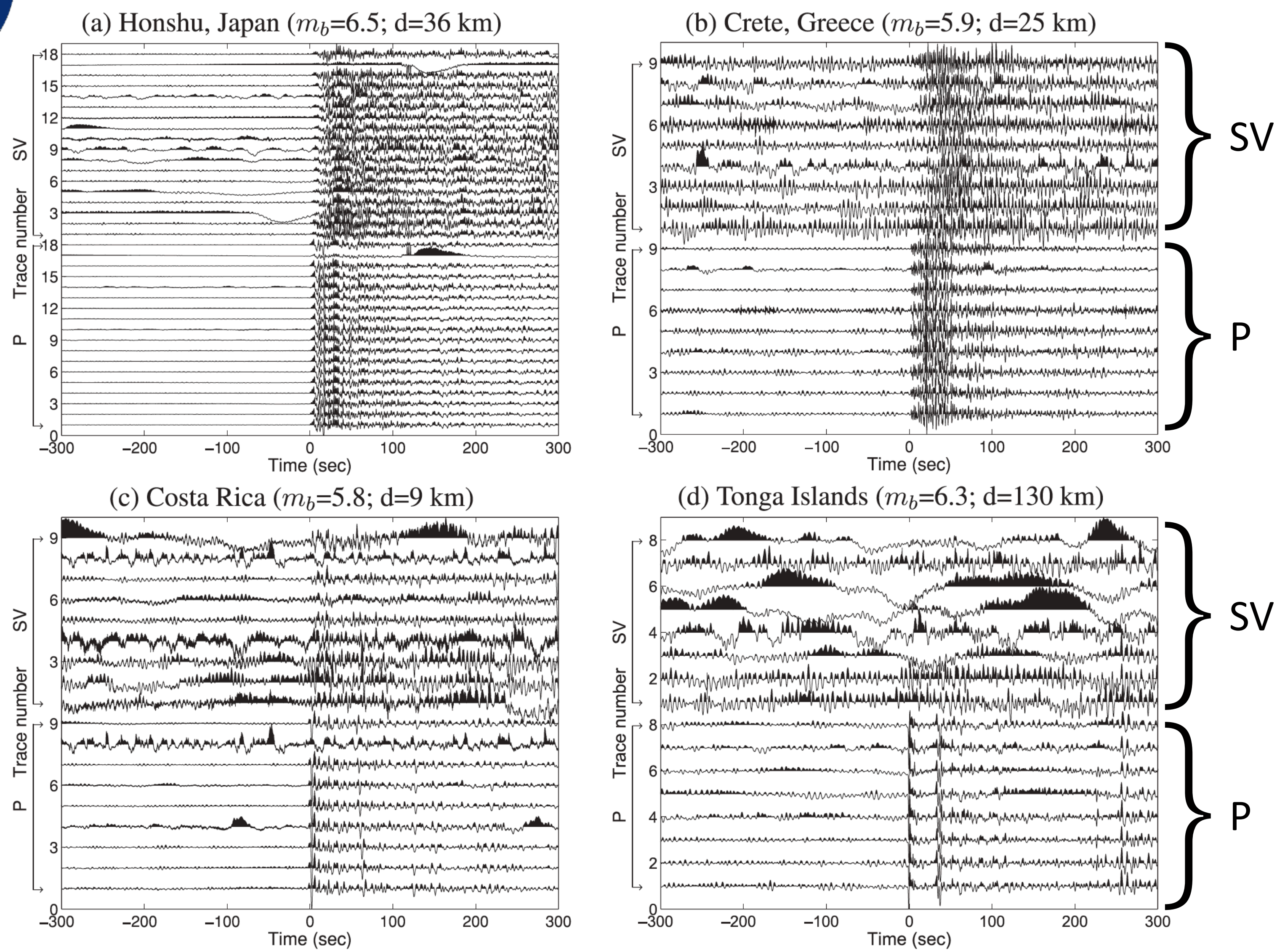


Spectra of deconvolved traces



Data examples

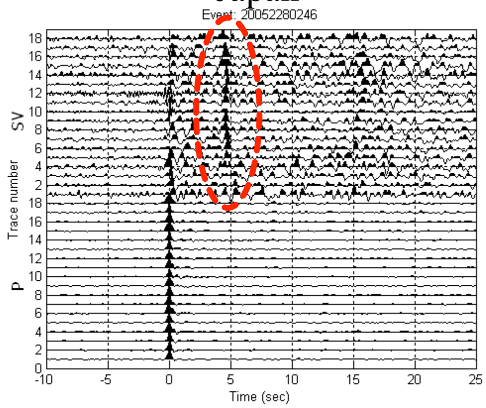




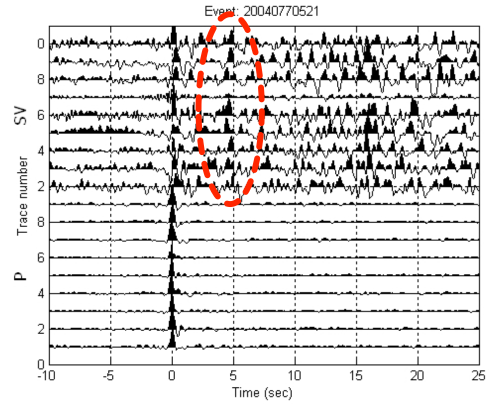
Deconvolved results

Array deconvolution

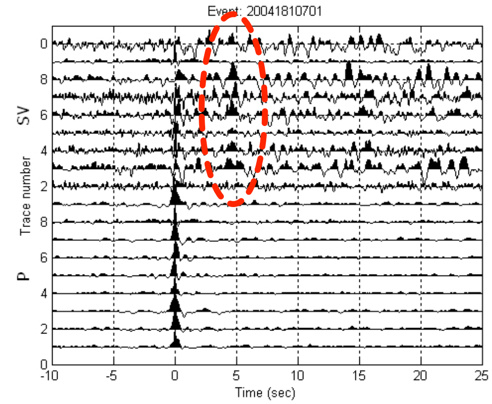
Japan



Greece

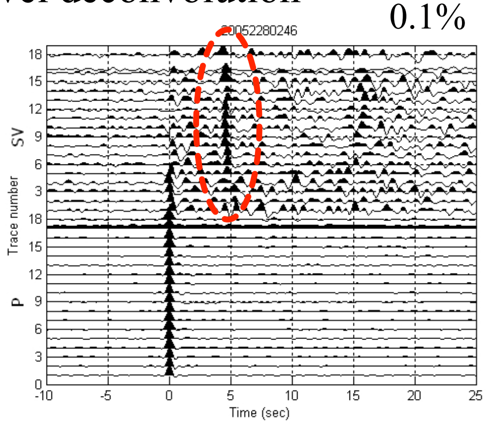


Costa Rica

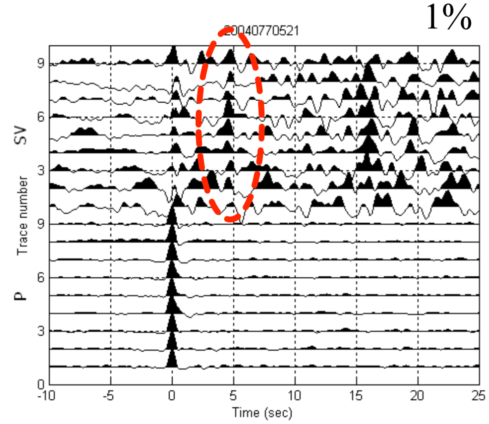


Waterlevel deconvolution

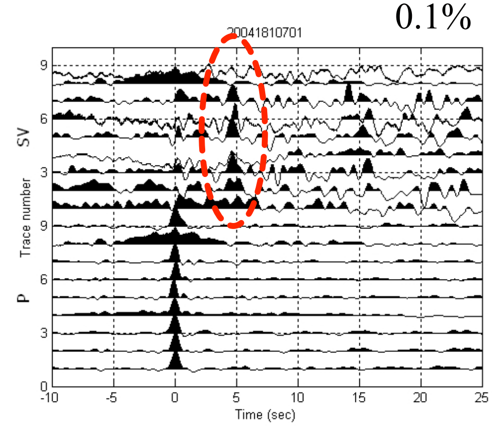
0.1%



1%

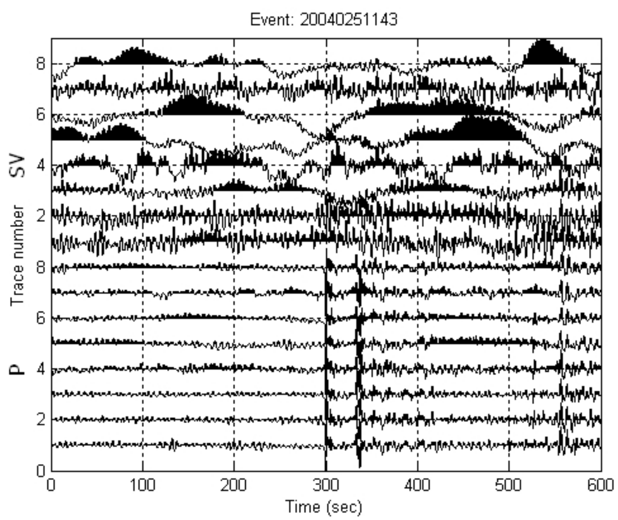


0.1%

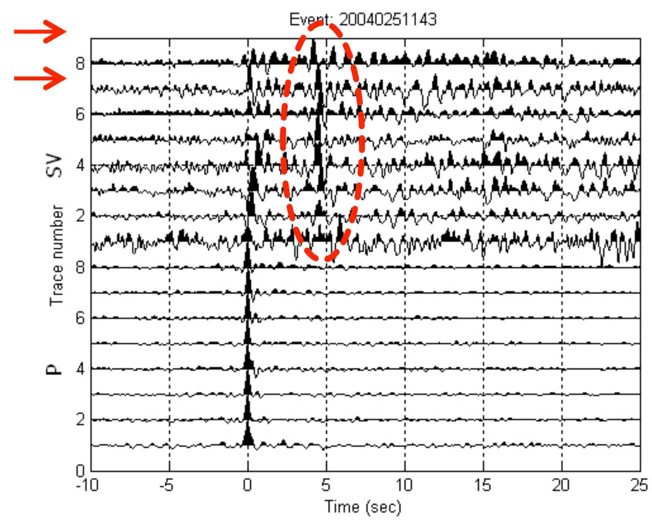


Deconvolved results

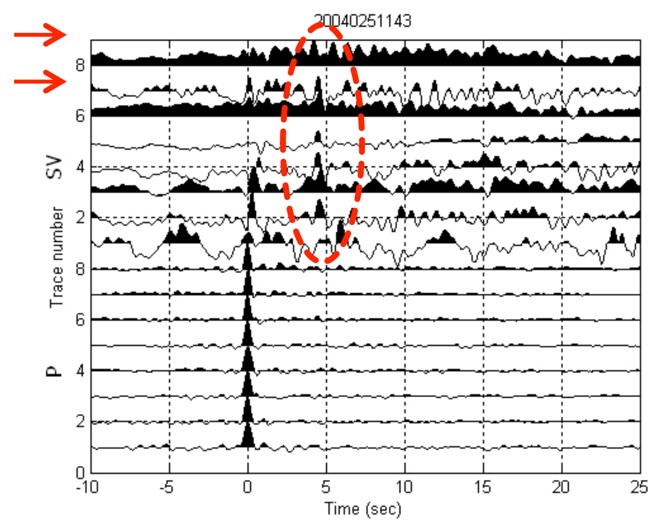
Tonga



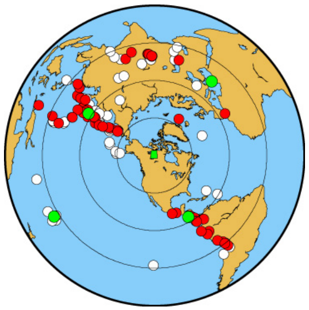
Array decon

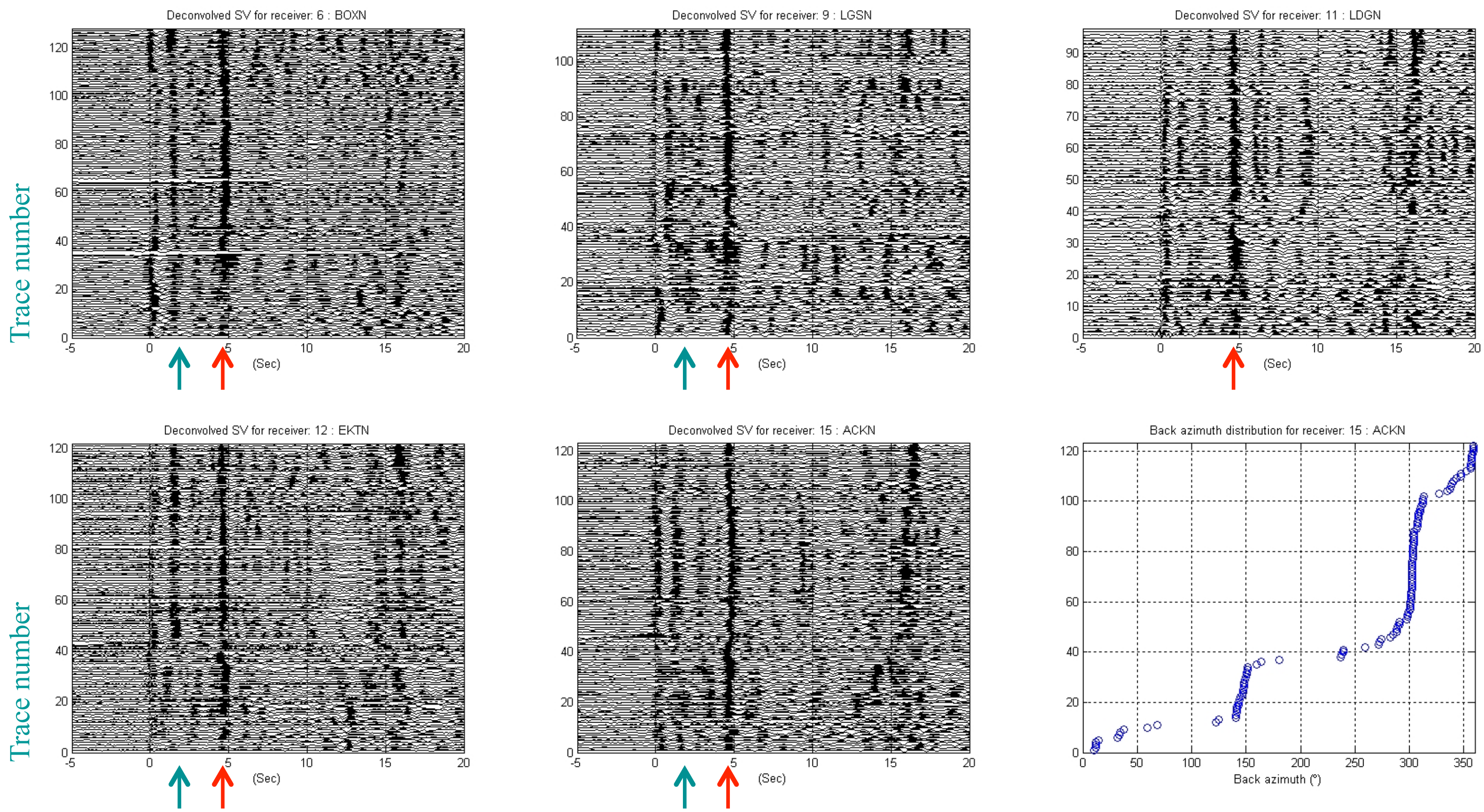


Waterlevel decon (0.01%)

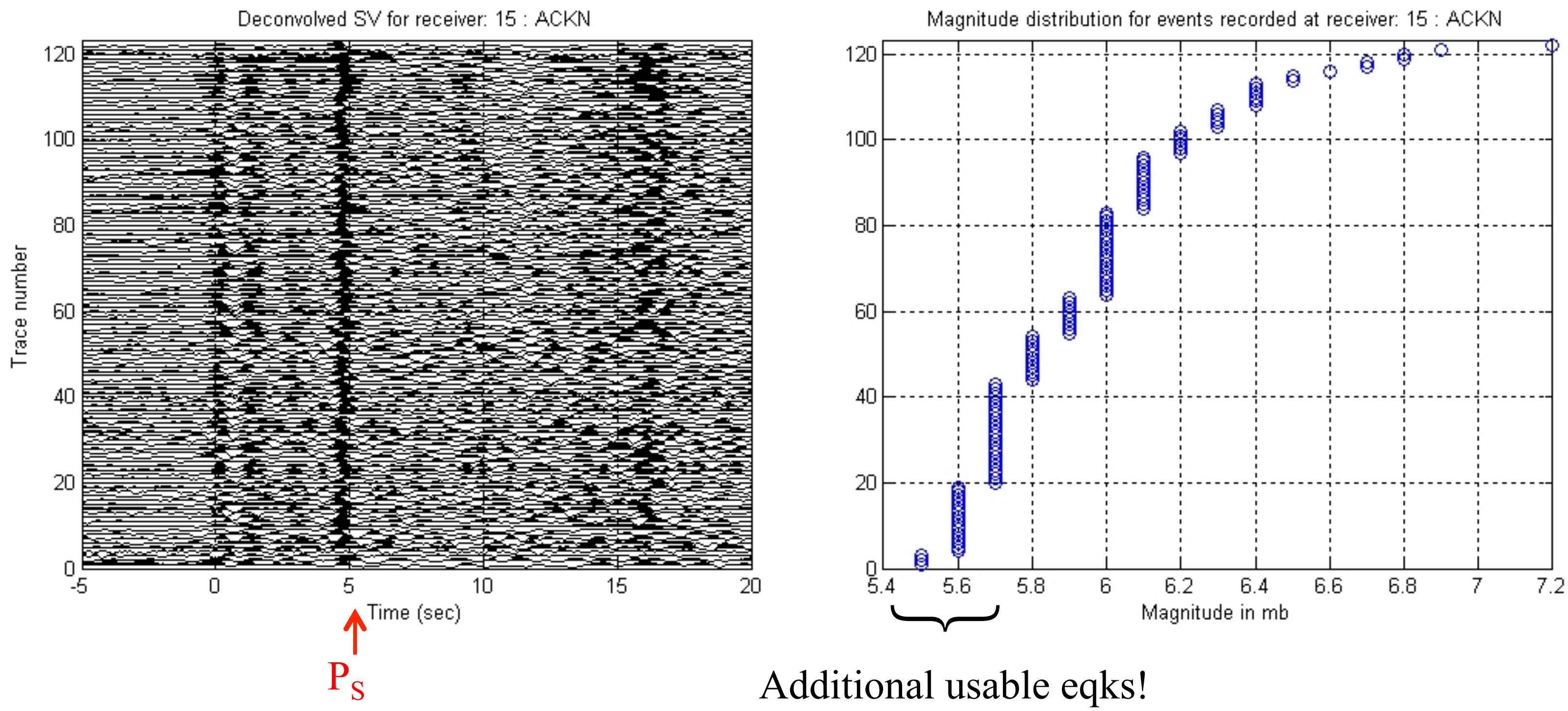


Deconvolved SV data (w.r.t. backazimuth)





Deconvolved SV data (w.r.t. magnitude)



Additional usable eqks!

Conclusions

- Array deconvolution technique constructs an inverse filter that automatically determines and subsequently attenuates the noise from data.
- This technique improves the efficiency and effectiveness of receiver function calculation and data preprocessing workflow.
- Helps to detect small-scale crustal heterogeneities beneath each receiver.
- Suitable for processing large amounts of data, e.g., those from USArray; and for smaller earthquakes.

Chen et al., GJI 182, 2010.