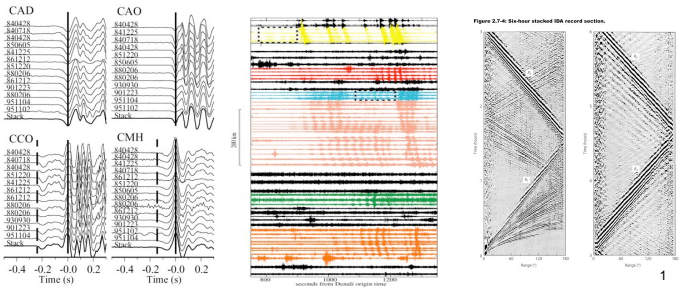
EAS 8803 - Obs. Seismology
Lec#11: Waveform Stacking

- Dr. Zhigang Peng, Spring 2011



Last Time

- Data management and basic data processing tools
- Systematic and random errors
- Waveform stacking
- Array analysis

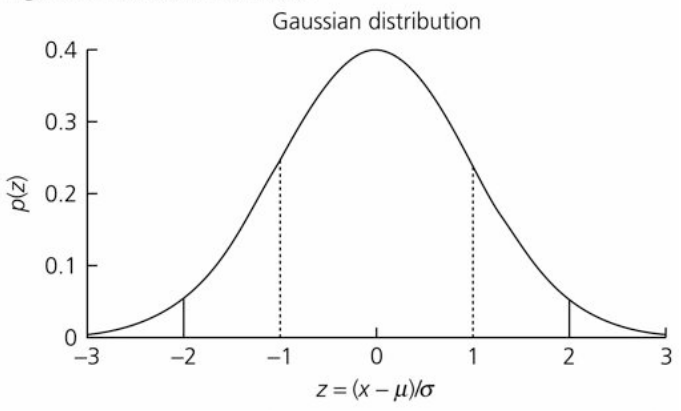
This Time

- Data management and basic data processing tools
- Systematic and random errors
- Waveform stacking
- Array analysis

Stacking

- Random errors
- Stacking examples

Figure 6.5-1: Gaussian distribution.



Stacking

$$\mu = \lim_{N\to\infty}\left[\frac{1}{N}\sum_{i=1}^{N} x_i\right]$$

$$\sigma^2 = \lim_{N\to\infty}\left[\frac{1}{N}\sum_{i=1}^{N} (x_i-\mu)^2\right]$$

$$\sigma_{\mu}^{\ 2} = \sigma^2 / N$$

•For stacking, the variance of the mean is $1/N$ times the variance of the individual measurements. Hence making N measurements reduces the standard deviation of the mean by $1/\sqrt{N}$

•This is the basic idea behind stacking, averaging multiple measurements of some quantity yields an estimate that a smaller uncertainty than the individual measurements.

Example of stacking

- Stacking in exploration geophysics
- Stacking to obtain reliable deep Earth structure
- Stacking to estimate seismic source properties

Figure 3.3-10: Cartoon geometry of a multichannel seismic reflection profile.

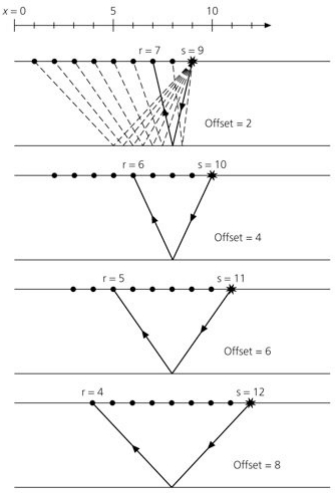
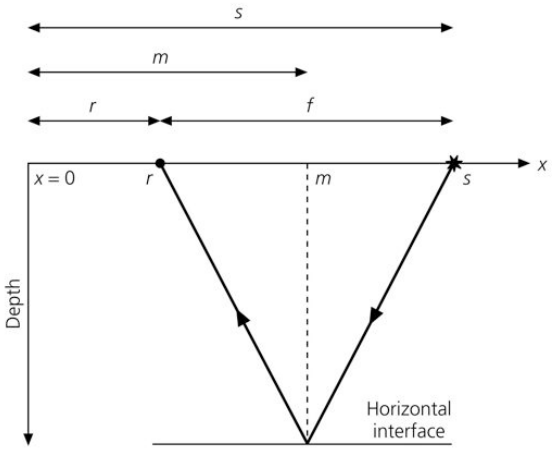
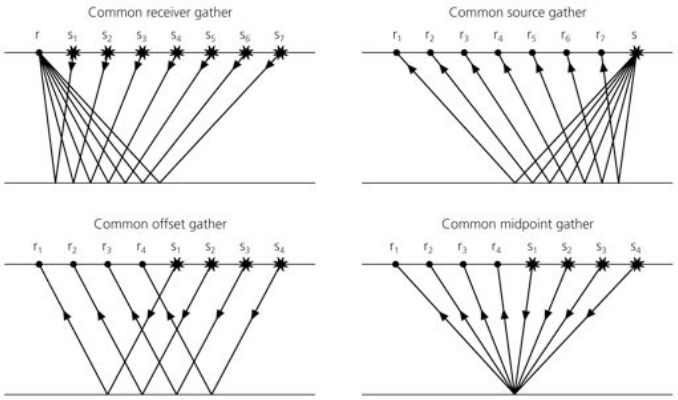


Figure 3.3-11: Relation between source, receiver, midpoint, and offset.



Stacking in exploration geophysics

Figure 3.3-13: Cartoon of the four different gather types.



NMO: a reflection whose variation in travel time with offset is the normal moveout

$$T(x) - t_0 = (x^2/\bar{V}^2 + t_0^2)^{1/2} .$$

A hyperbolic time shift lines up reflections with hyperbolic travel time curves (analogous to the reduced travel time plot).

Figure 3.3-15: Diagram of the normal moveout correction.

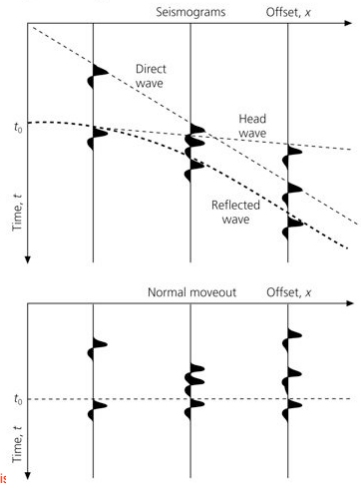


Figure 3.3-16: Cartoon of CMP stacking and velocity analysis.

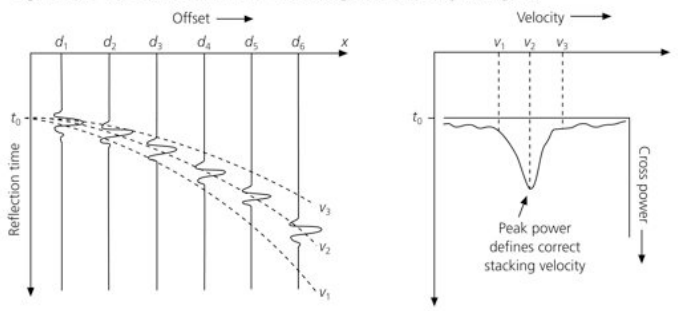


Figure 3.3-17: Example of CMP stacking and velocity analysis.

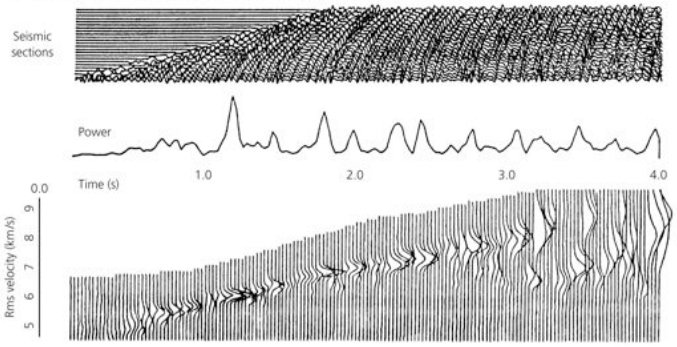


Figure 3.3-19: CMP stacking for flat and dipping layers.

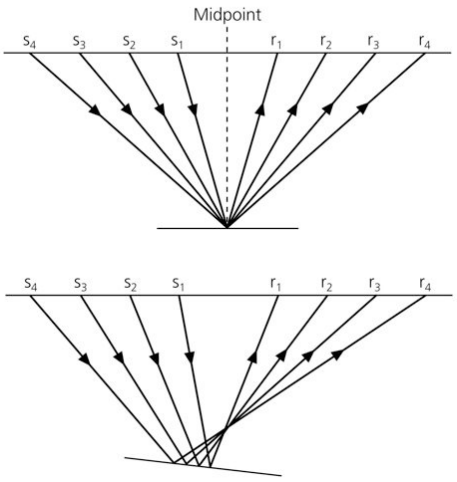


Figure 6.5-2: Results of drawing N samples from a Gaussian parent distribution.

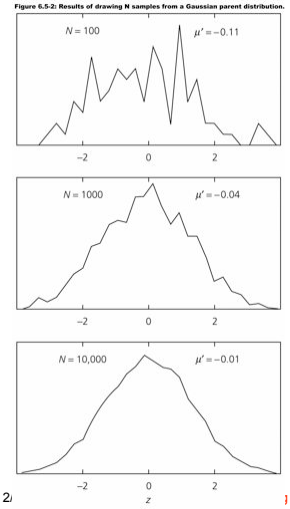


Figure 6.5-3: Example of stacking seismograms to enhance precursors to SS.

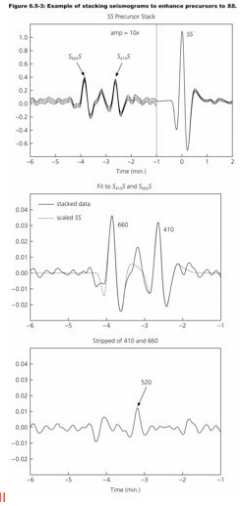


Figure 3.5-10: Ray paths for additional core phases.

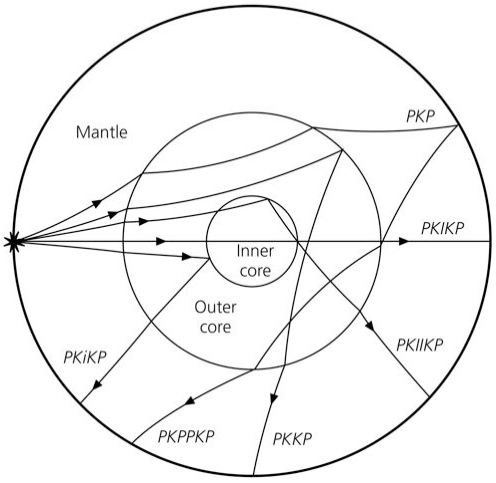
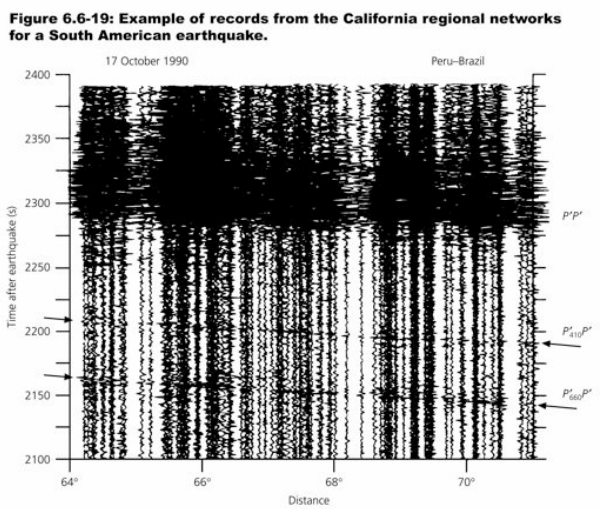
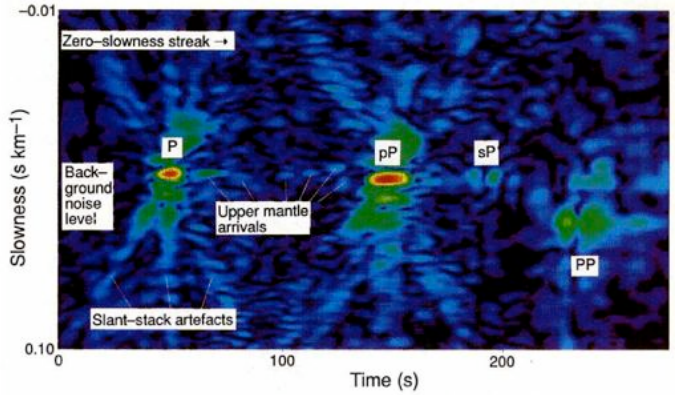
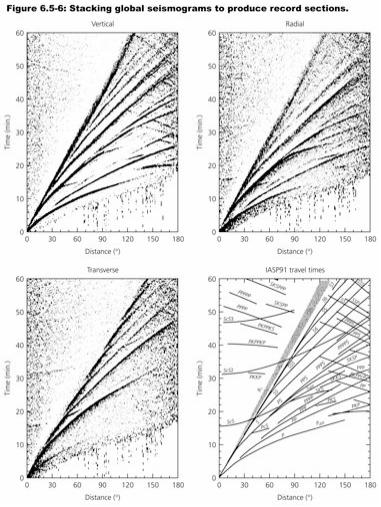


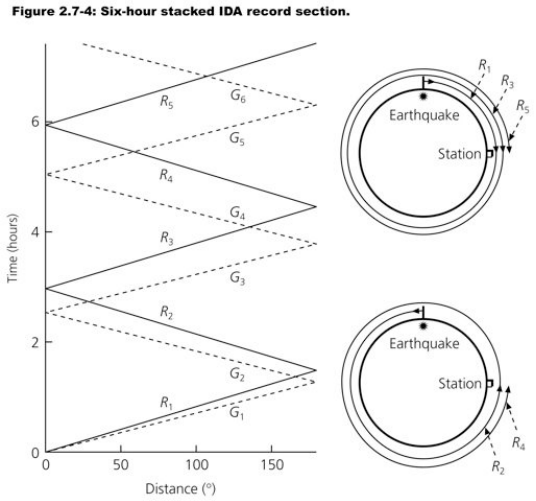
Figure 6.6-19: Example of records from the California regional networks for a South American earthquake.

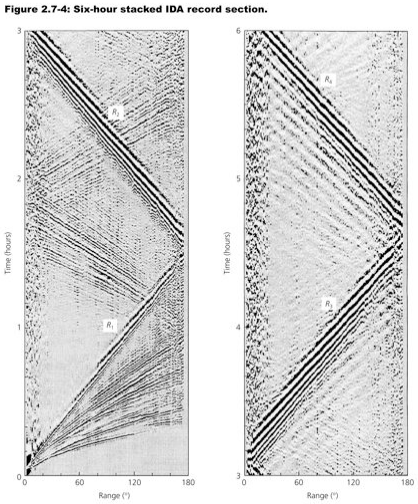


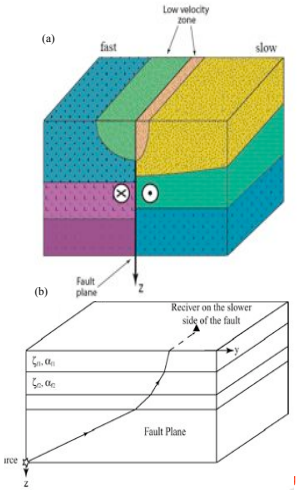


Slant stack of 3 April 1985 Bonin earthquake (Vidale and Benz, Nature, 1992)

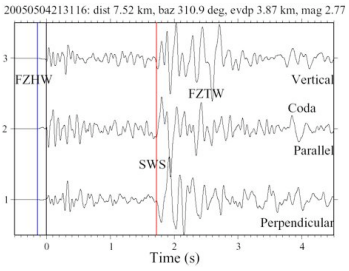




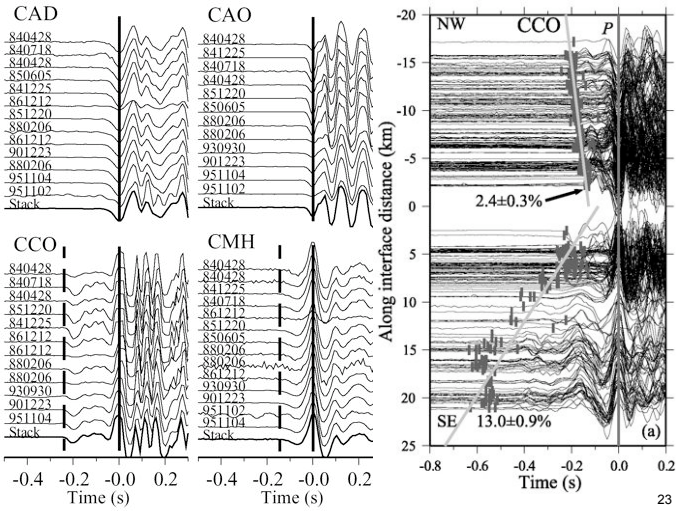




Fault zone head waves refract along bi-material interface and are recorded by stations on the slow side of the faults.



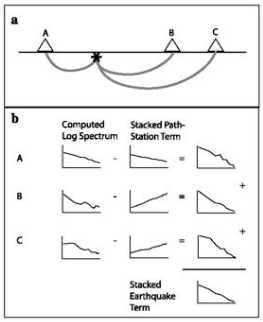
Zhao and Peng (GRL, 2008)

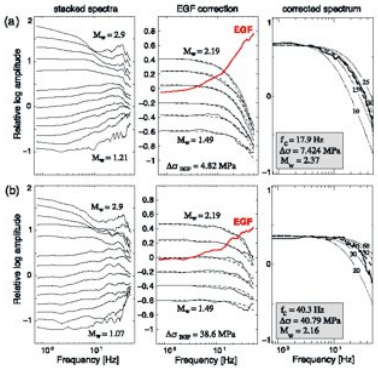


Stacking to obtain source properties

- Stacking is used to obtain reliable source properties (e.g., source time functions, source spectra, etc) under the following assumption:
  - Earthquake source is a common term for seismograms recorded at by multiple stations.
  - Hence stacking will help to enhance the source terms while suppressing other near-station effects.

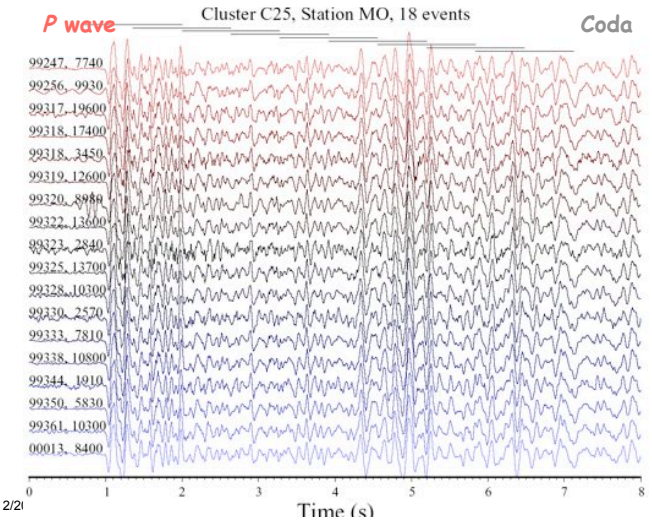
Stacking for reliable earthquake spectra



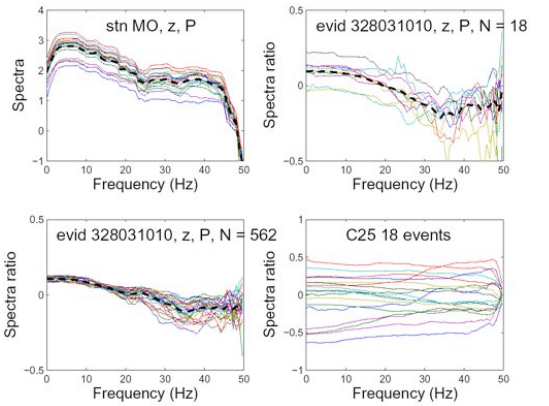


Prieto et al. (JGR, 2004)

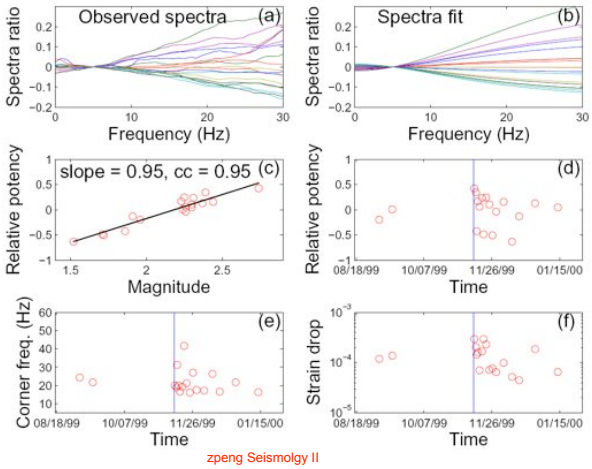
Allmann and Shearer (JGR, 2007)



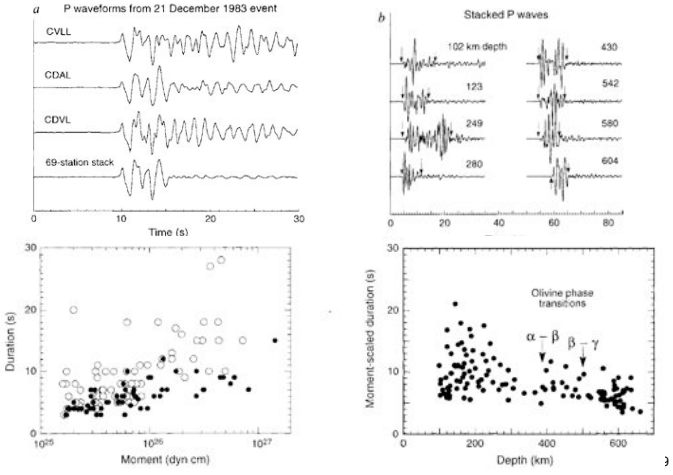
Two-step stacking procedure [Vidale et al., 1994] to isolate source and site spectra



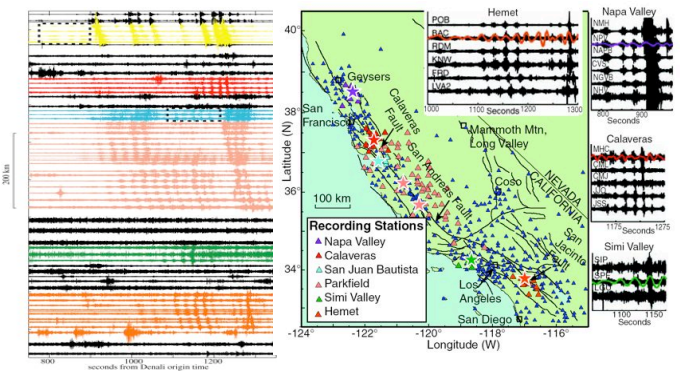
Assuming an average strain drop of 10^-4



Stacking for source time function (Vidale and Houston, Nature, 1993)



Triggered tremors at California



Gomberg et al. (Science, 2008)

Example of stacking using SAC

- The easiest way is to use the command "addf" in SAC:
  - SAC> r wf1.sac
  - SAC> addf wf2.sac
  - SAC> …
  - SAC> div 10
  - SAC> w stack.sac
  - # Note: the data has to be the same length
- Another way is to use my own command: sacStack

sacStack

- usage: sacStack [-E(t(0-9,-5(b),-3(o),-2(a))|vel)] [-N] [-Q] [-Rt1/t2] [-Sbaz/p] -Ooutput_file (sac_traces in the argument list or from the stdin)
  - -E: align with a time mark or with an apparent velocity (b)
  - -N: normalize (off)
  - -Q: square traces before stacking (off)
  - -R: time window t1 and t2
  - -S: set baz and user0 (p) in head
- Example:
  - sacStack –Et-3 –R0/20 –Ostack.sac wf*.sac

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- Data management and basic data processing tools
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- Waveform stacking
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Next Time

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