Bandwidth enhancement: Inverse Q filtering or time-varying Wiener deconvolution?

Mirko van der Baan
University of Alberta, Canada

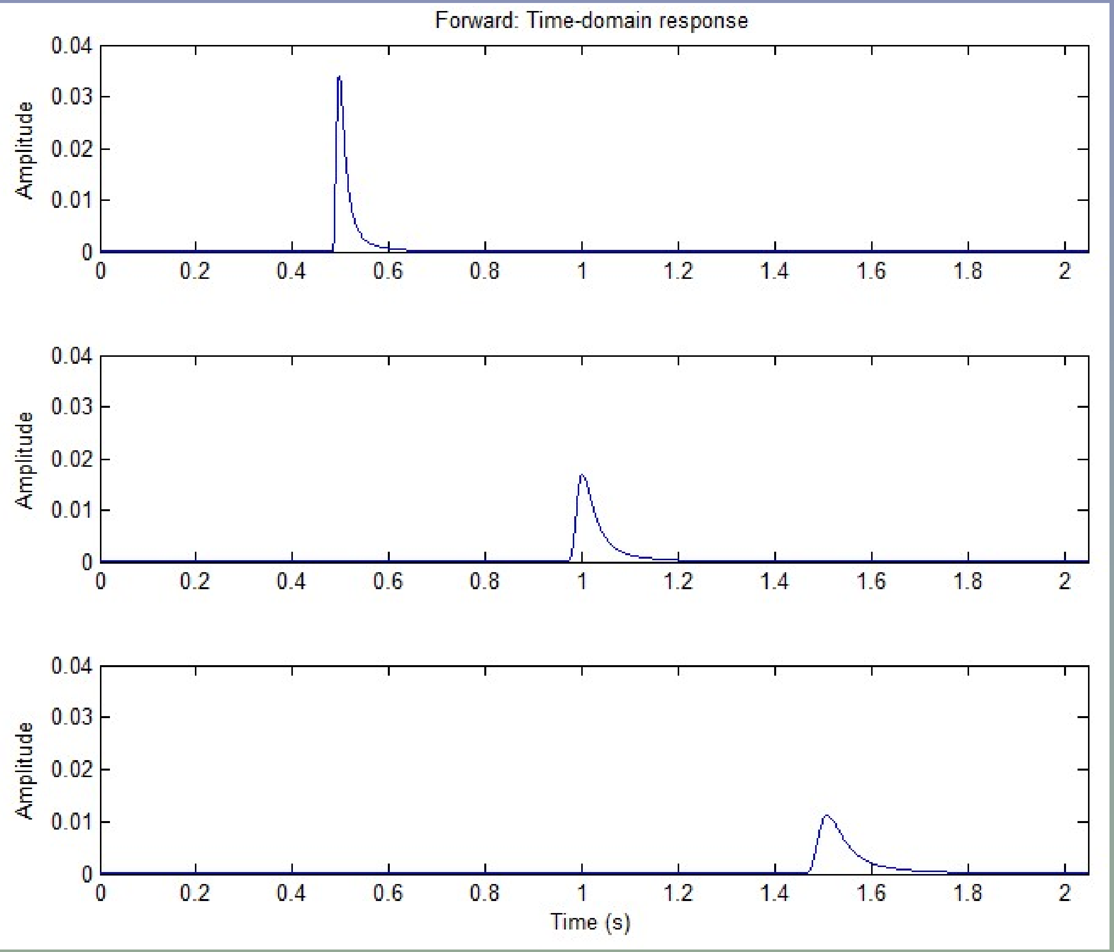
Inverse Q deconvolution

- Seismic data always suffer from
  - Attenuation ~ Freq-dependent amplitude decay
  - Dispersion ~ Freq-dependent velocities
- Required inverse Q corrections:
  - Amplitudes ~ regeneration of lost energy
  - Phase ~ make zero-phase

Attenuation and dispersion

- Forward propagation of Dirac (spike)

Q = 30

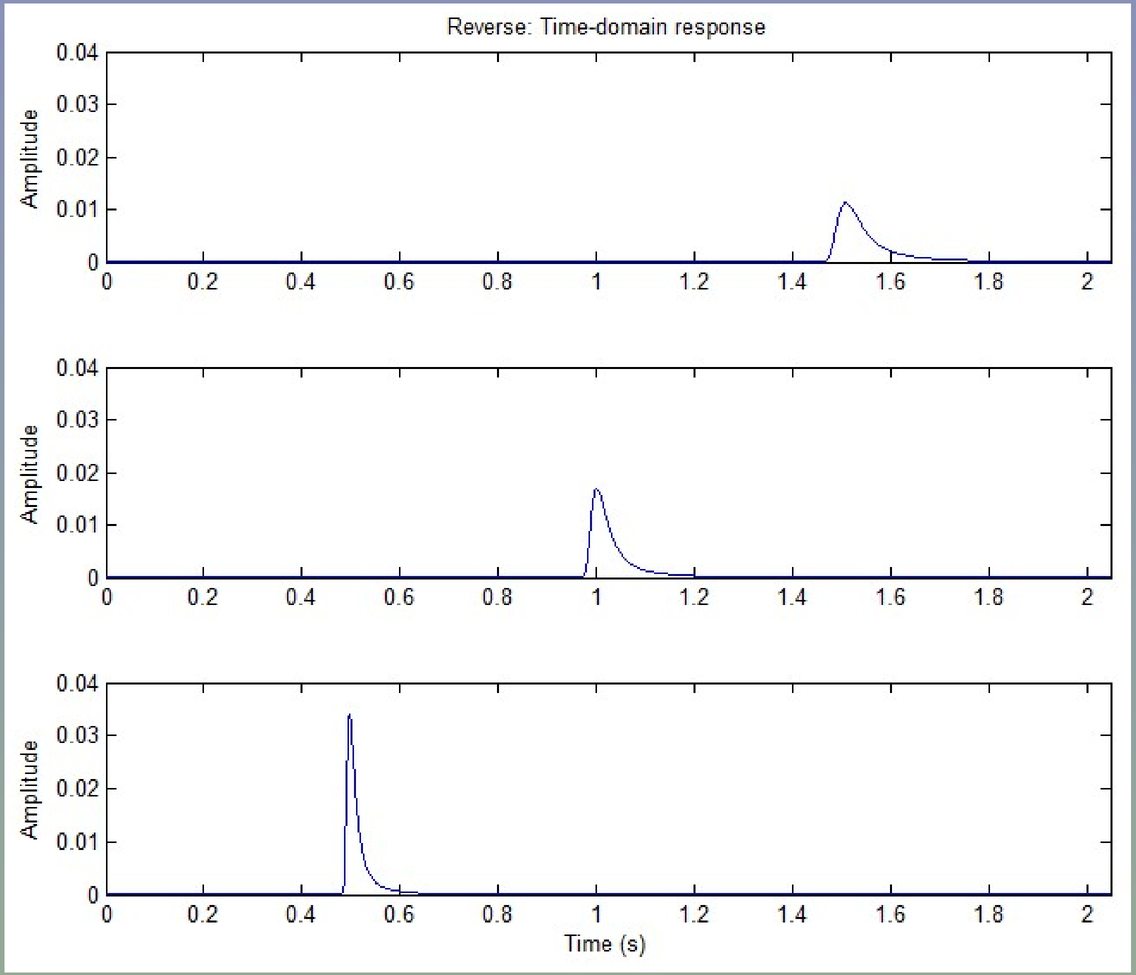


Time ↓

Desired inverse Q corrections

- Do reverse propagation of Dirac (spike)?

← Reversed Time



Q = 30

Inverse Q filtering

- Inverse Q filtering:
  - Replace time sign in any propagation module

- Process implemented via wavefield extrapolation (Hargreaves and Calvert, 1994)
  - Rationale: Migrate arrival to t=0
  - New implementation based on short-time Fourier transform (Van der Baan, Bliss 7, 2011)
    - Sliding window extracts signal
    - Amplitude (attenuation) and/or phase (dispersion) corrections feasible
    - STFT = Faster since less samples involved

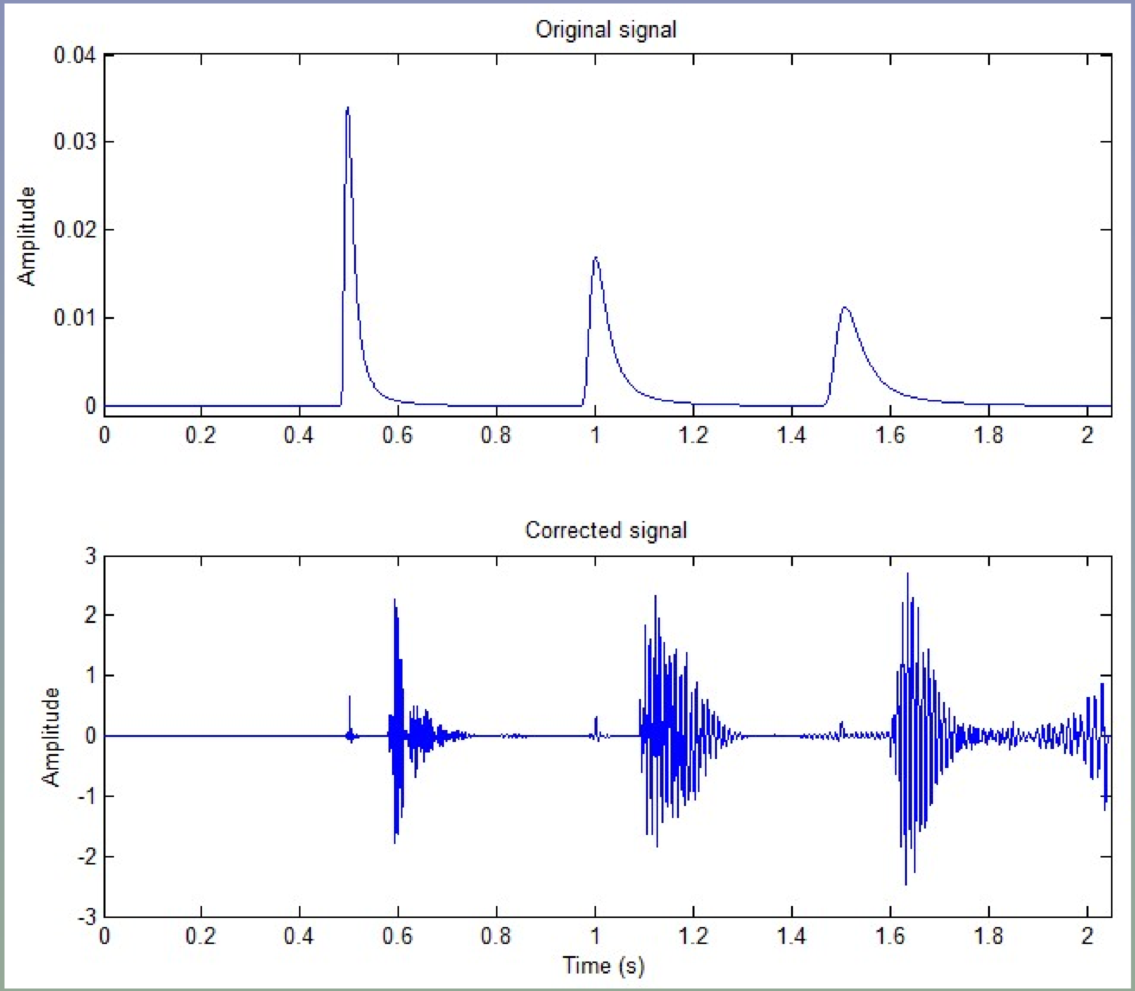
Inverse Q filtering

- Practicalities:
  - Forward propagation:
    - Attenuation and dispersion = inherently stable
  - Reversed propagation:
    - Attenuation corrections = unstable (regeneration of energy)
    - Dispersion corrections = inherently stable
    - General approach: include amplitude damping factor => limited energy amplification

Inv Q correction (attenuation + dispersion)

- Phase + unlimited amplitude correction: Unstable

Original



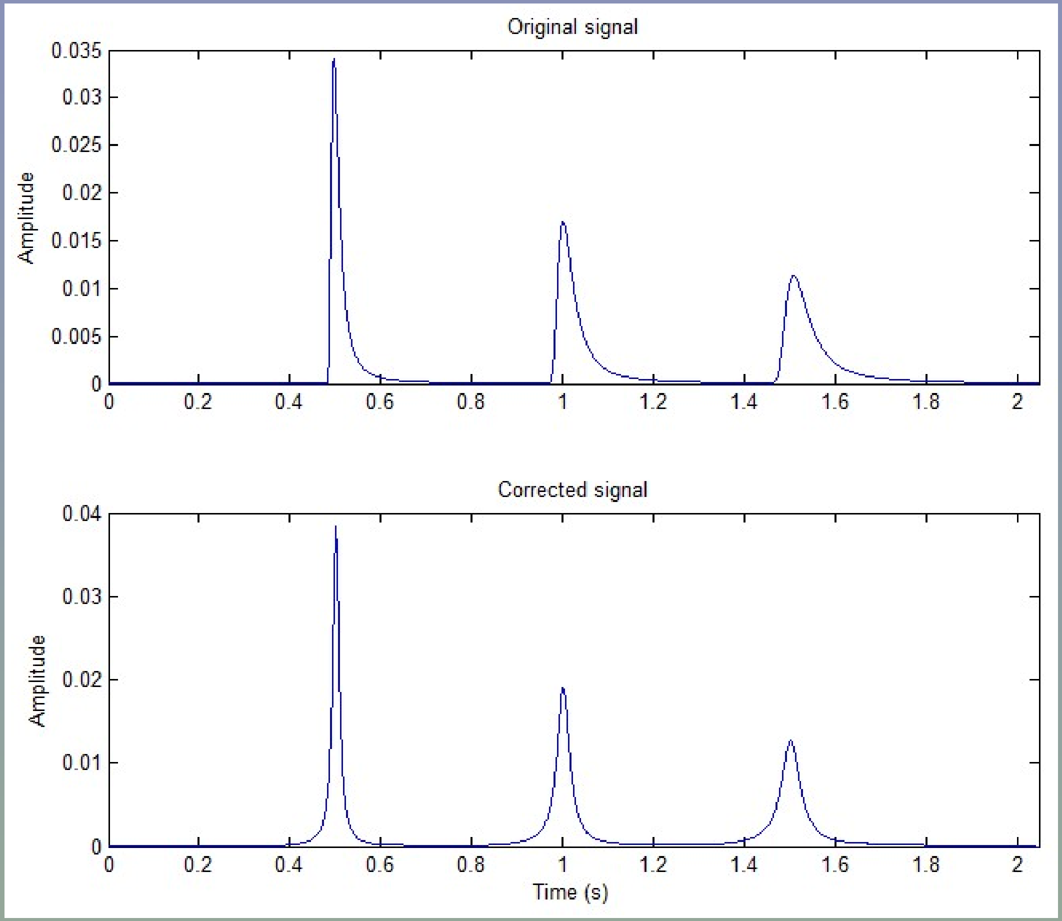
Max ampl multiplication factor = 1.e6

Amplitude + phase inverse Q

Inv Q correction (dispersion only)

- Phase-only correction: Make zero phase = stable

Original



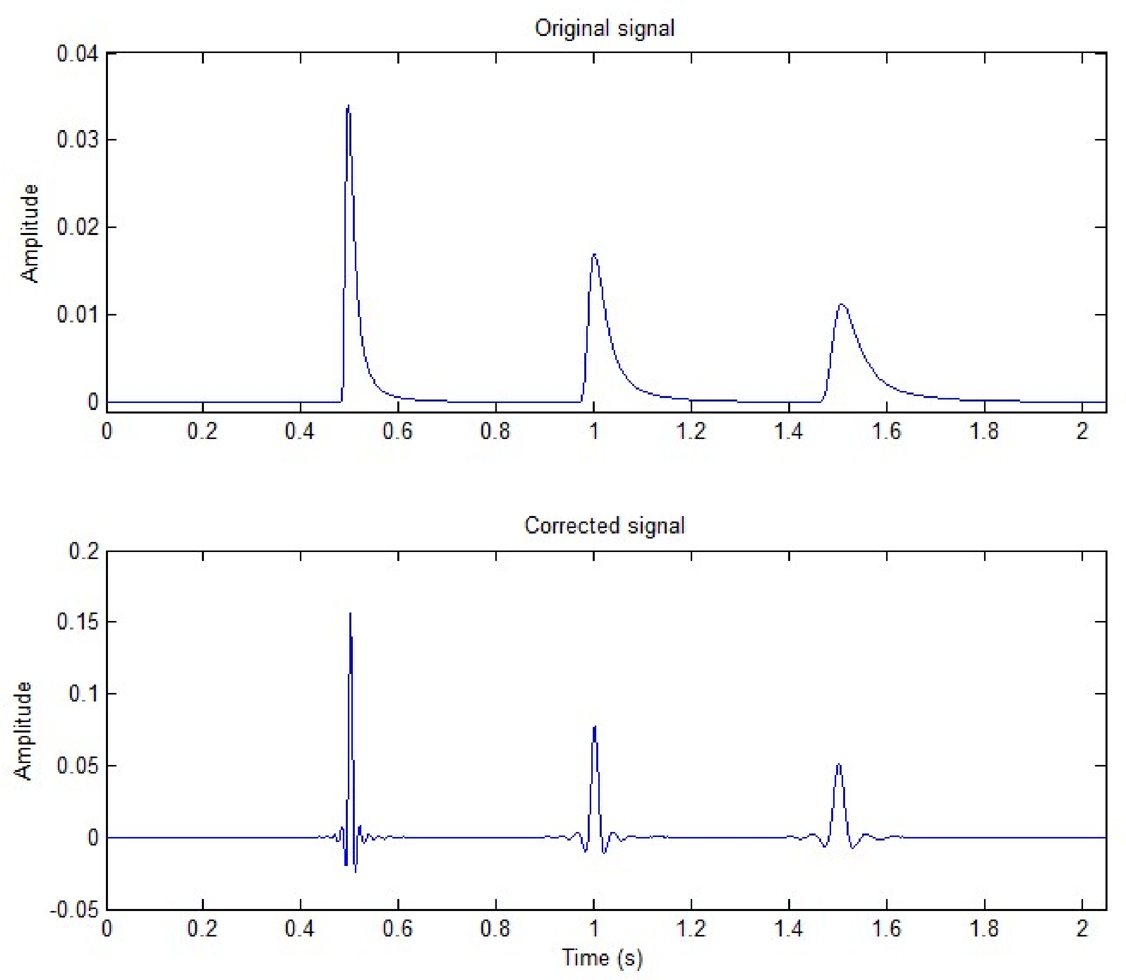
Max ampl multiplication factor = 1

Phase-only inverse Q

Inv Q correction (attenuation + dispersion)

- Phase + limited amplitude correction: Stable

Original



Max ampl multiplication factor = 100

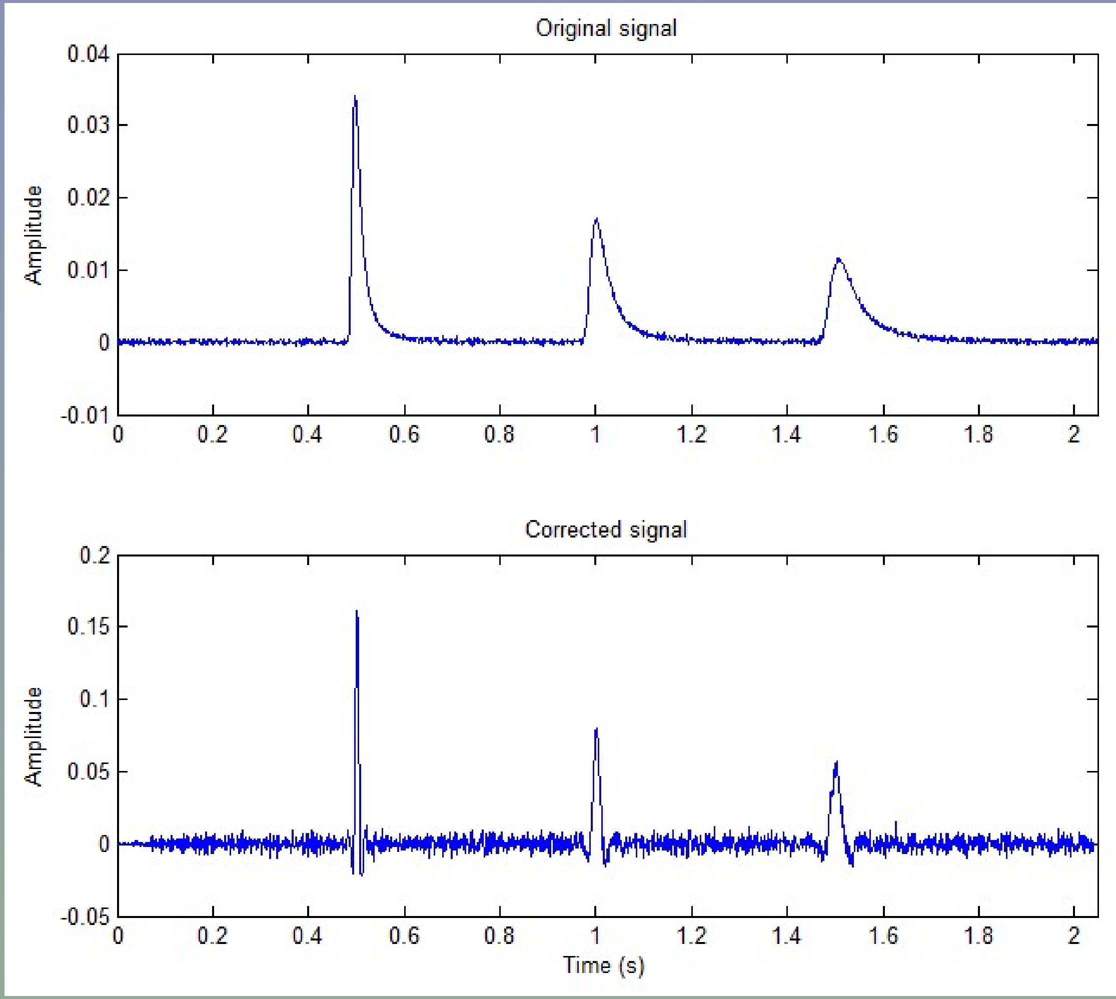
Constrained amplitude + phase inverse Q

Inv Q correction (attenuation + dispersion)

- Inv Q amplitude corrections: Noise amplification

Original

Constrained amplitude + phase inverse Q



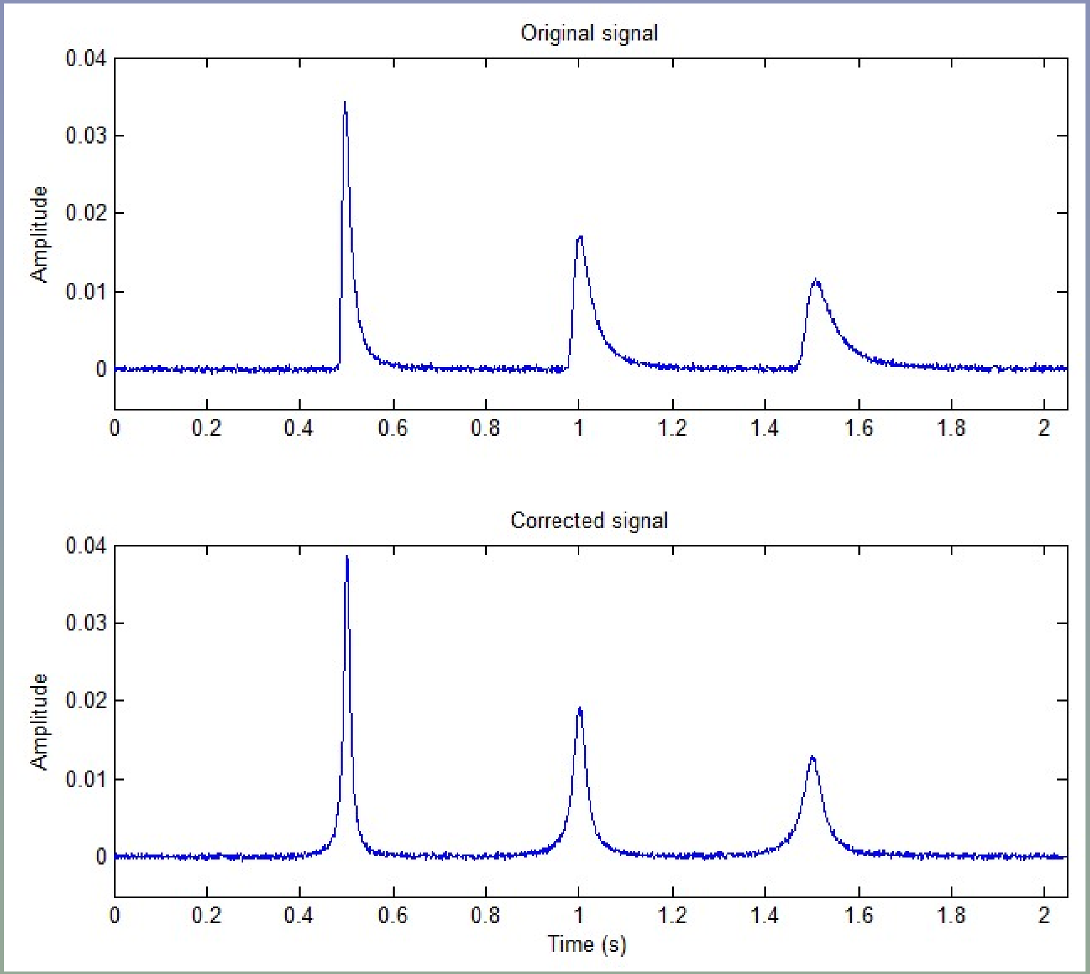
Max ampl multiplication factor = 20

Inv Q correction (dispersion)

- Inv Q phase corrections: No noise amplification

Original

Phase-only inverse Q



Max ampl multiplication factor = 1

Fundamental concerns

Inv Q amplitude corrections:

- Amplifies all frequencies
  - No wavelet bandwidth information
  - No natural balance resolution enhancement vs noise amplification
  - Bandpass filtering needed after corrections
- Requires Q factor
  - Likely nonstationary Q

Suggested combination

(1) Inverse Q filtering for dispersion corrections

- Unconditionally stable
- But does require Q (+/- 33-50%)

(2) Amplitude-only time-varying Wiener filtering

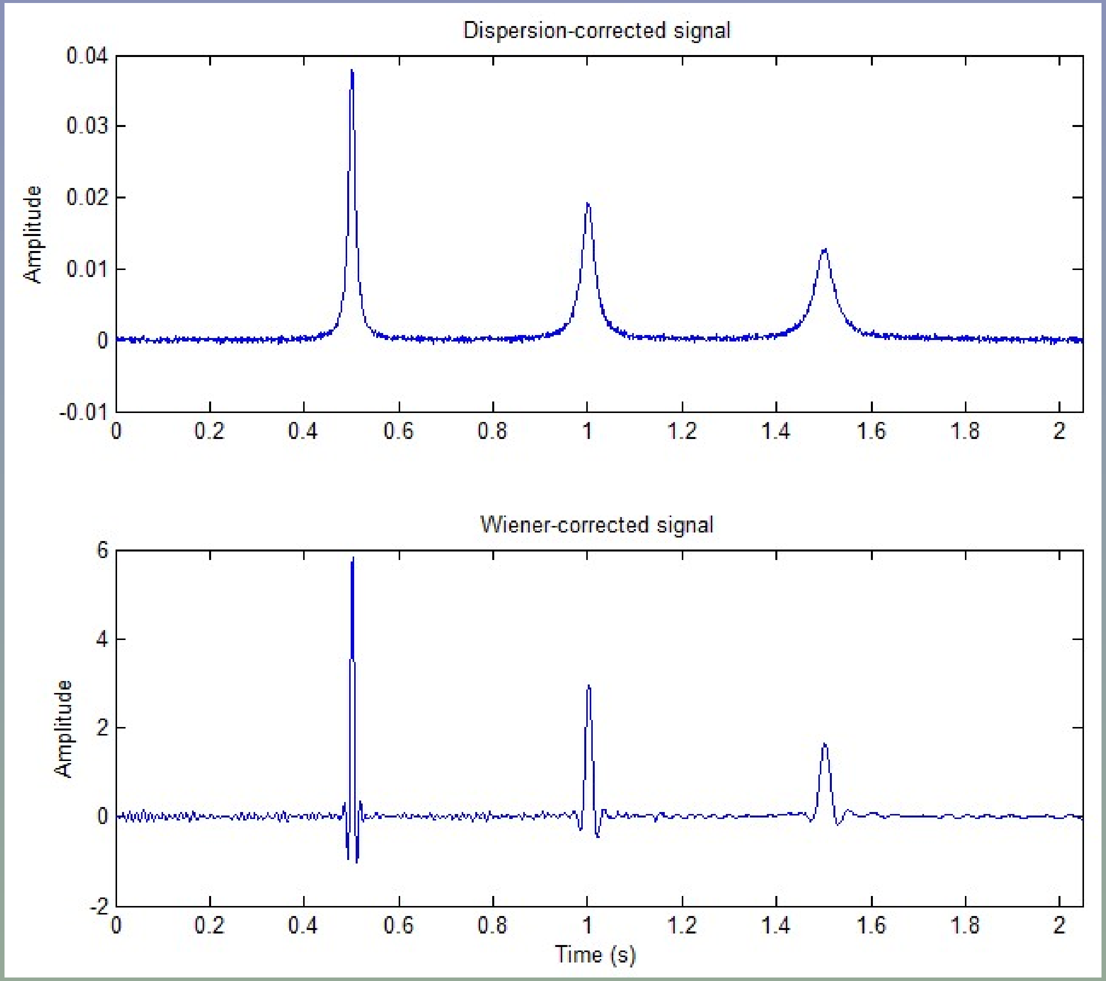
- Whitens data only within passband (= wavelet bandwidth)
- Inherent trade-off signal recovery and noise amplification
- Wavelet estimated via spectral averaging and sliding window

TV Wiener filtering after dispersion correction

- Time-varying Wiener : Little noise amplification

Phase-only inverse Q

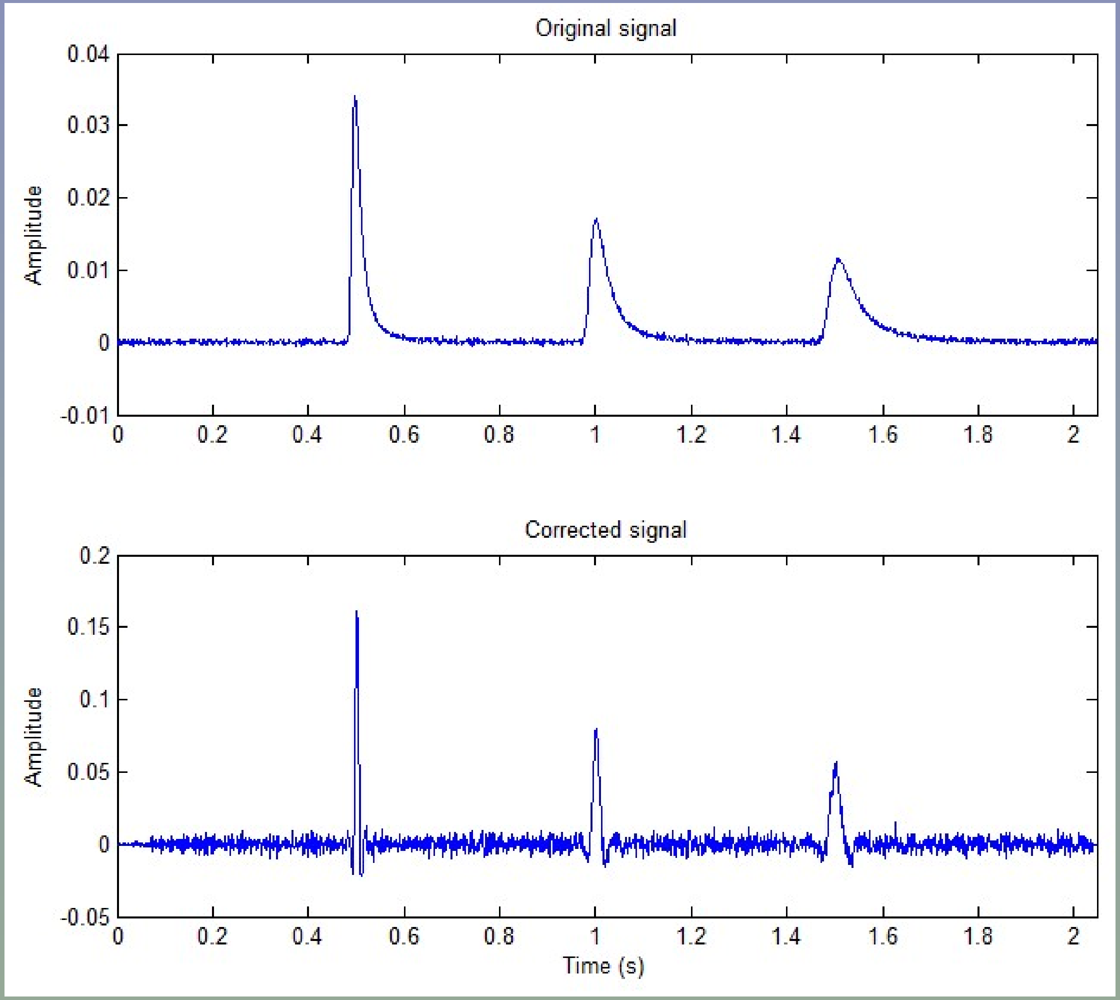
Time-varying Wiener



Inv Q correction (attenuation + dispersion)

- Inv Q amplitude corrections: Noise amplification

Original

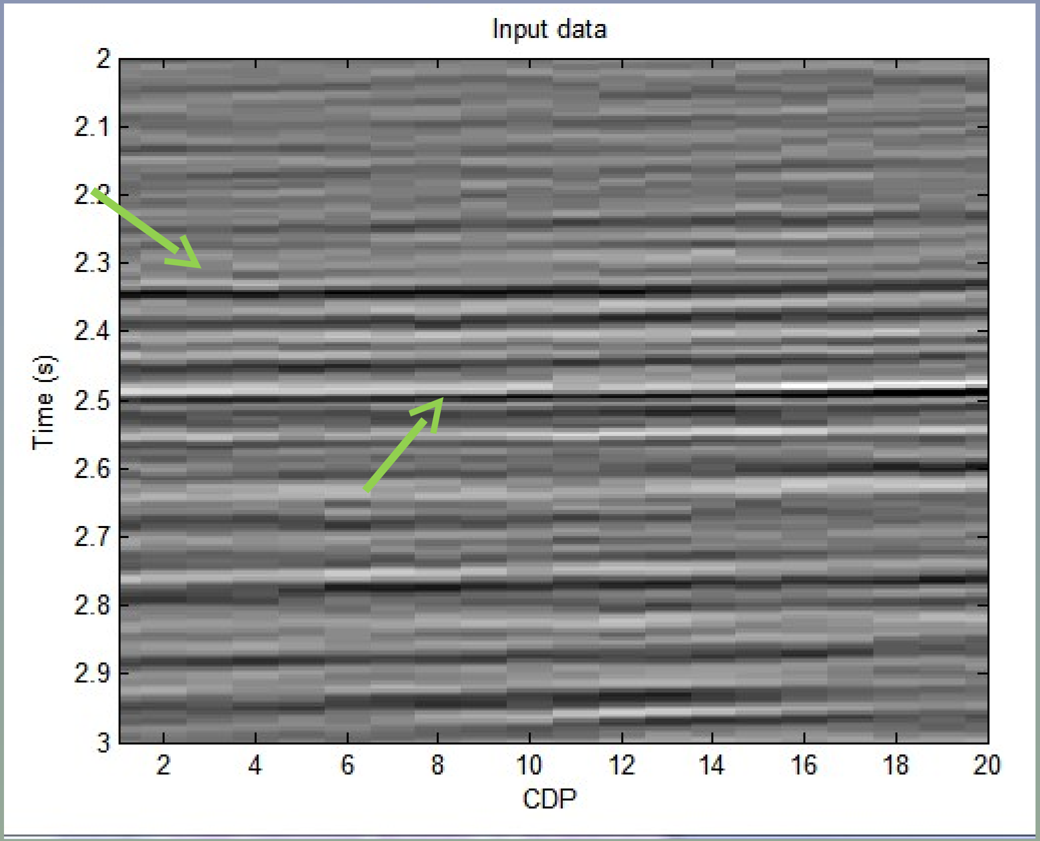


Max ampl multiplication factor = 20

Constrained amplitude + phase inverse Q

Real data example (zoom in)

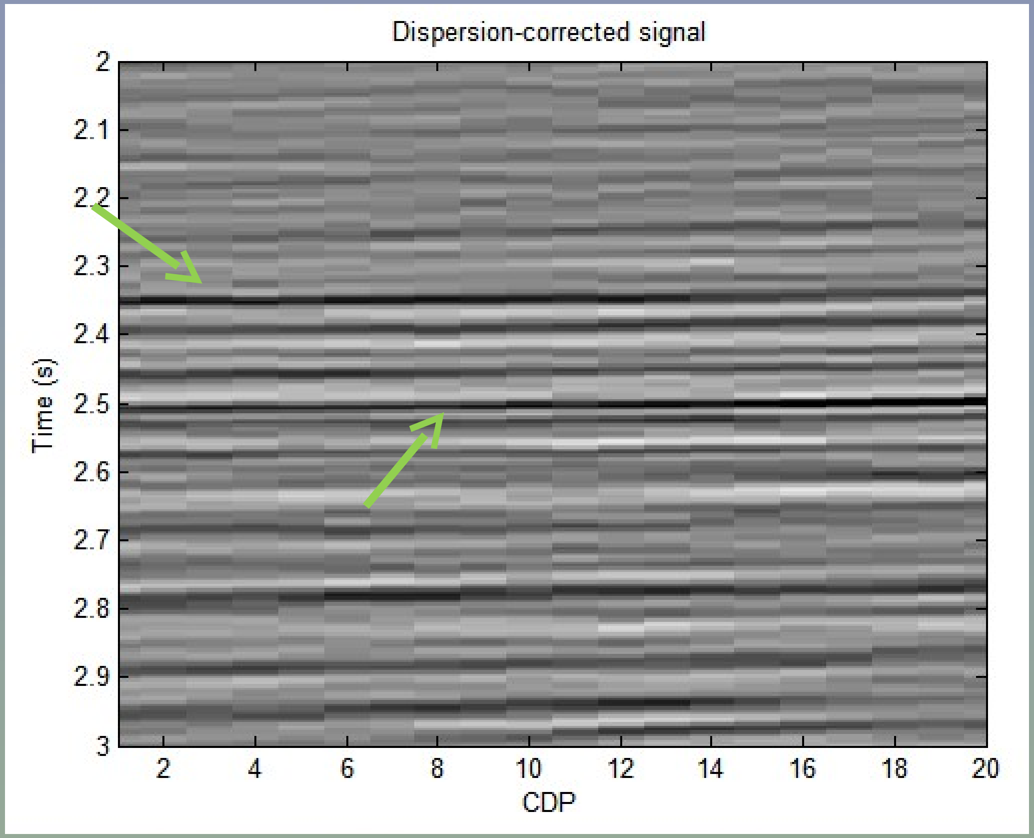
- Original:
  - Marine w known phase issues



Data courtesy:
Shell

Real data example (zoom in)

- Dispersion-corrected:
  - No noise enhancement
  - More zero-phase (symmetric waveforms)

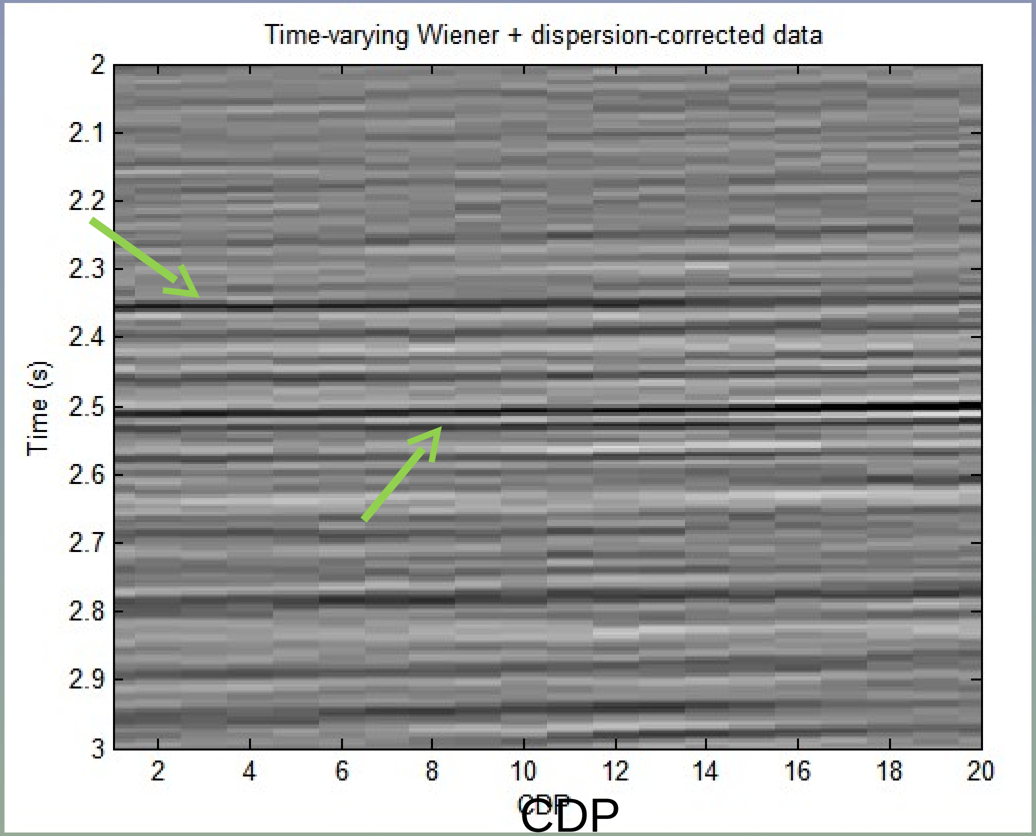


Data courtesy:
Shell

Q = 150

Real data example (zoom in)

- Dispersion + Wiener:
  - No noise enhancement
  - Bandwidth improvement => Higher resolution



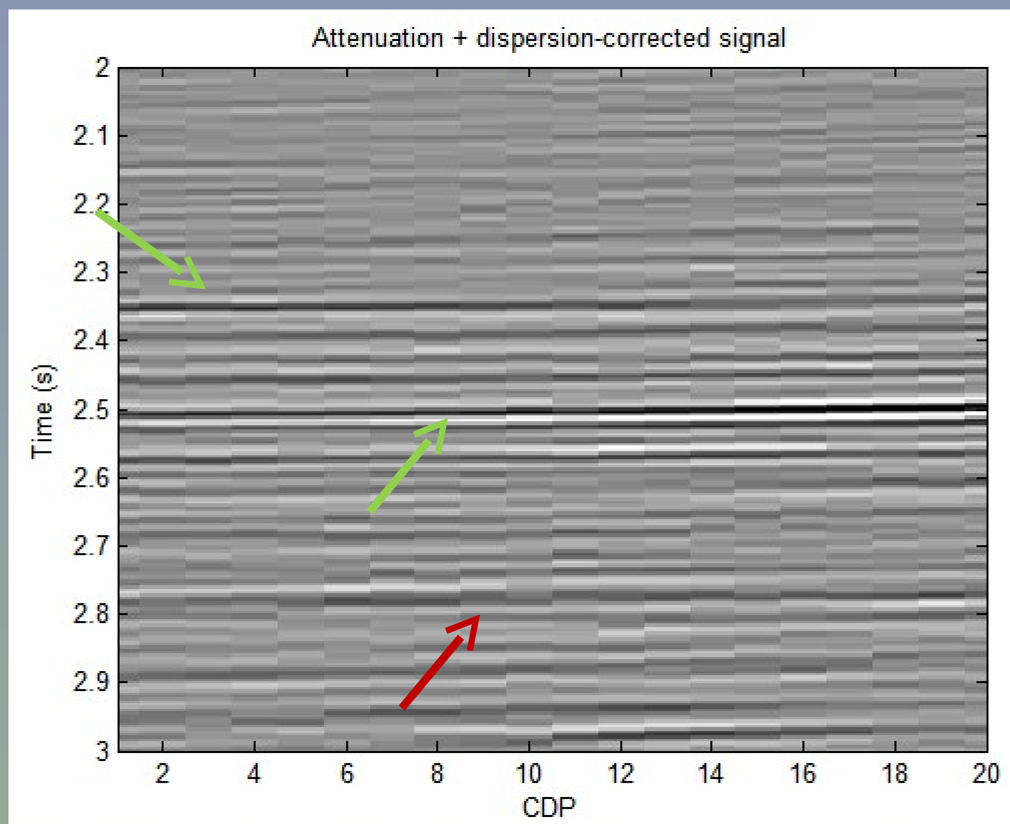
CDP

Data courtesy: Shell

Q = 150

Real data example (zoom in)

- Ampl + phase inv Q:
  - Best resolution enhancement of few reflectors
  - But strong noise enhancement elsewhere



Data courtesy: Shell

Max ampl multiplication factor = 5.

Q = 150

Conclusions

- Inverse Q filtering:
  - Replace time sign in any propagation module
  - Forward propagation:
    - Attenuation and dispersion = inherently stable
  - Reversed propagation:
    - Attenuation corrections = unstable (recreation of energy)
    - Dispersion corrections = inherently stable

Conclusions

- Alternative:
  - Combine phase-only inverse Q filtering + time-varying Wiener filtering
  - Phase-only inverse Q filtering:
    - Corrects for dispersion (= inherently stable)
  - Nonstationary Wiener filtering
    - Whitens data only within passband (= wavelet bandwidth)
    - Natural balance resolution enhancement vs noise amplification

Acknowledgments

Shell: For permission to show the data

BLind Identification of Seismic Signals (BLISS) is supported by