Improving deconvolution at low frequencies

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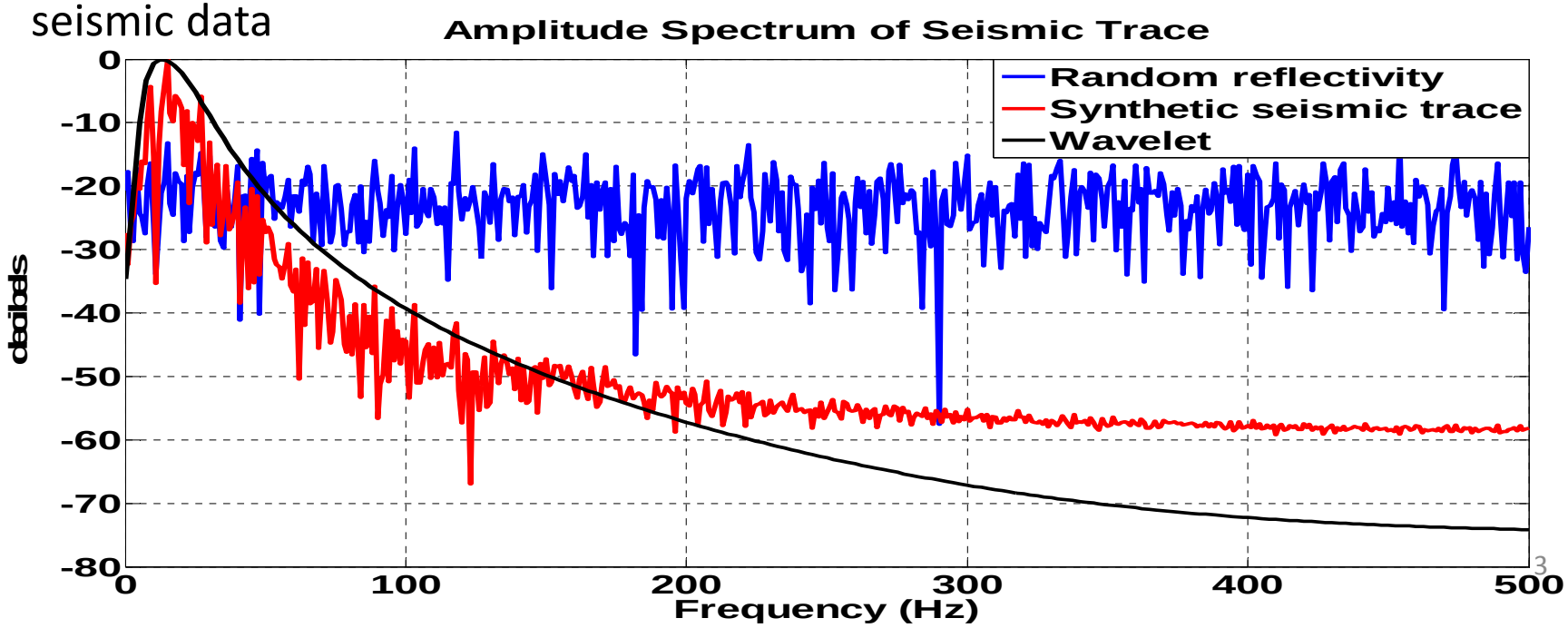
CREWES

Outline

- Introduction to Frequency domain deconvolution
- Various smoother types
- Minimum phase color operator
- Synthetic data processing and impedance inversion results
- Conclusion
- Acknowledgements

Frequency domain deconvolution

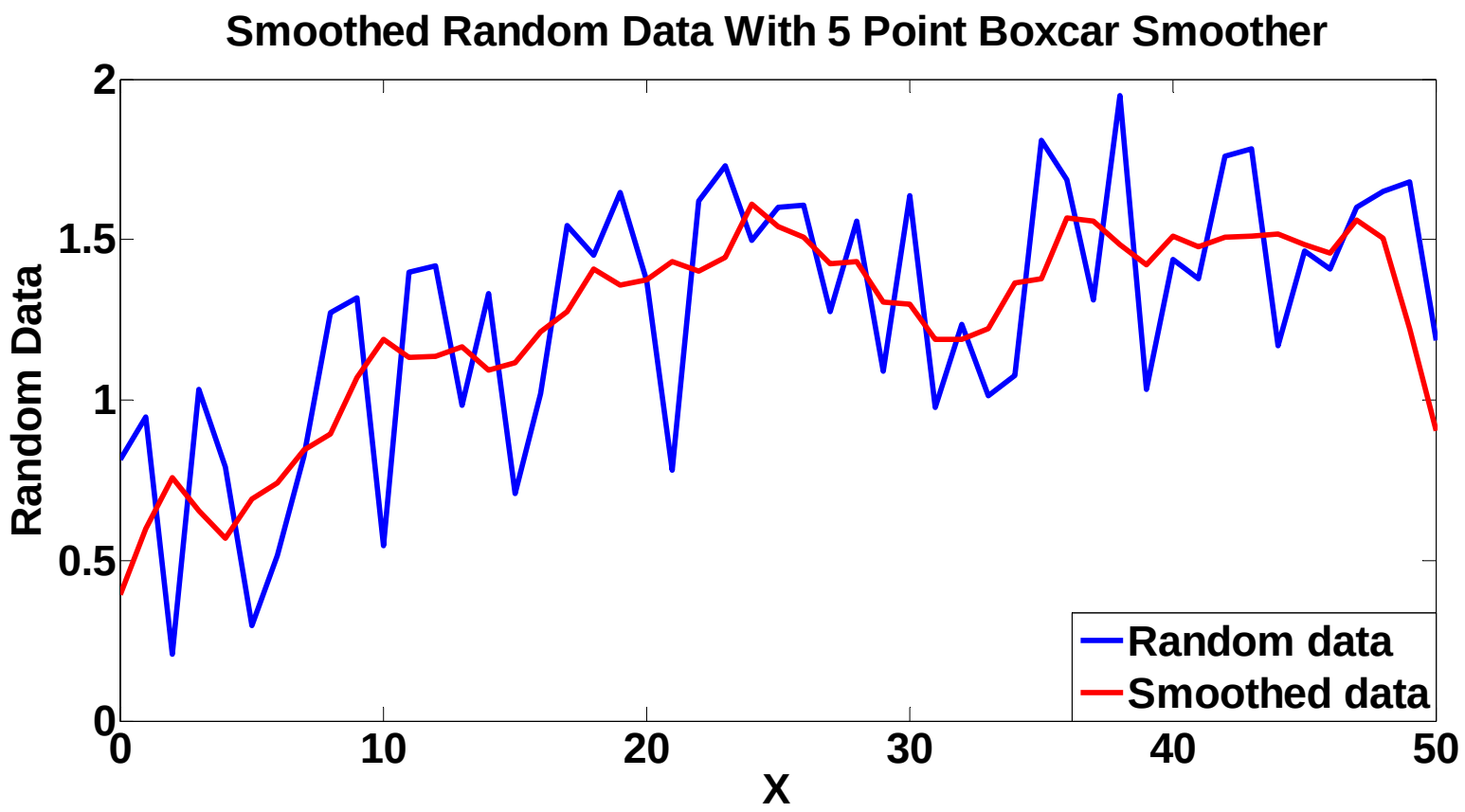
- The easiest deconvolution technique to conceptualize
- Four assumptions:
  - The wavelet should be minimum phase
  - The wavelet amplitude spectrum should be smooth
  - The wavelet should be stationary
  - The reflectivity should be random so it has a white amplitude spectrum
- The embedded wavelet can be estimate by smoothing the amplitude spectrum of seismic data



Smoothers for amplitude spectra

- Boxcar smoother (BS)

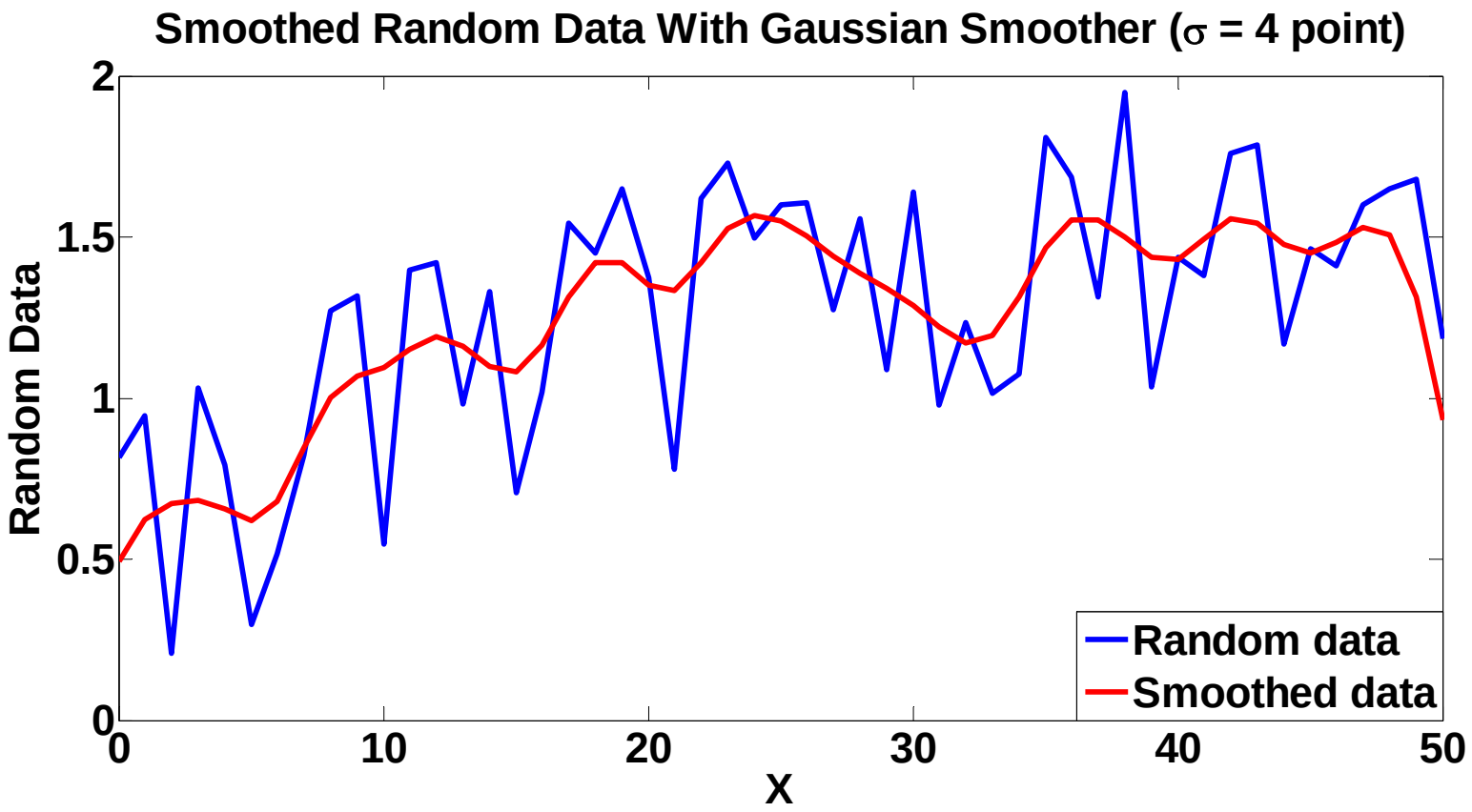
$$\bar{x}[i] = \frac{1}{2M+1} \sum_{j=-M}^{M} x[i+j]$$



Smoothers for amplitude spectra

- Gaussian smoother with constant σ (CGS)

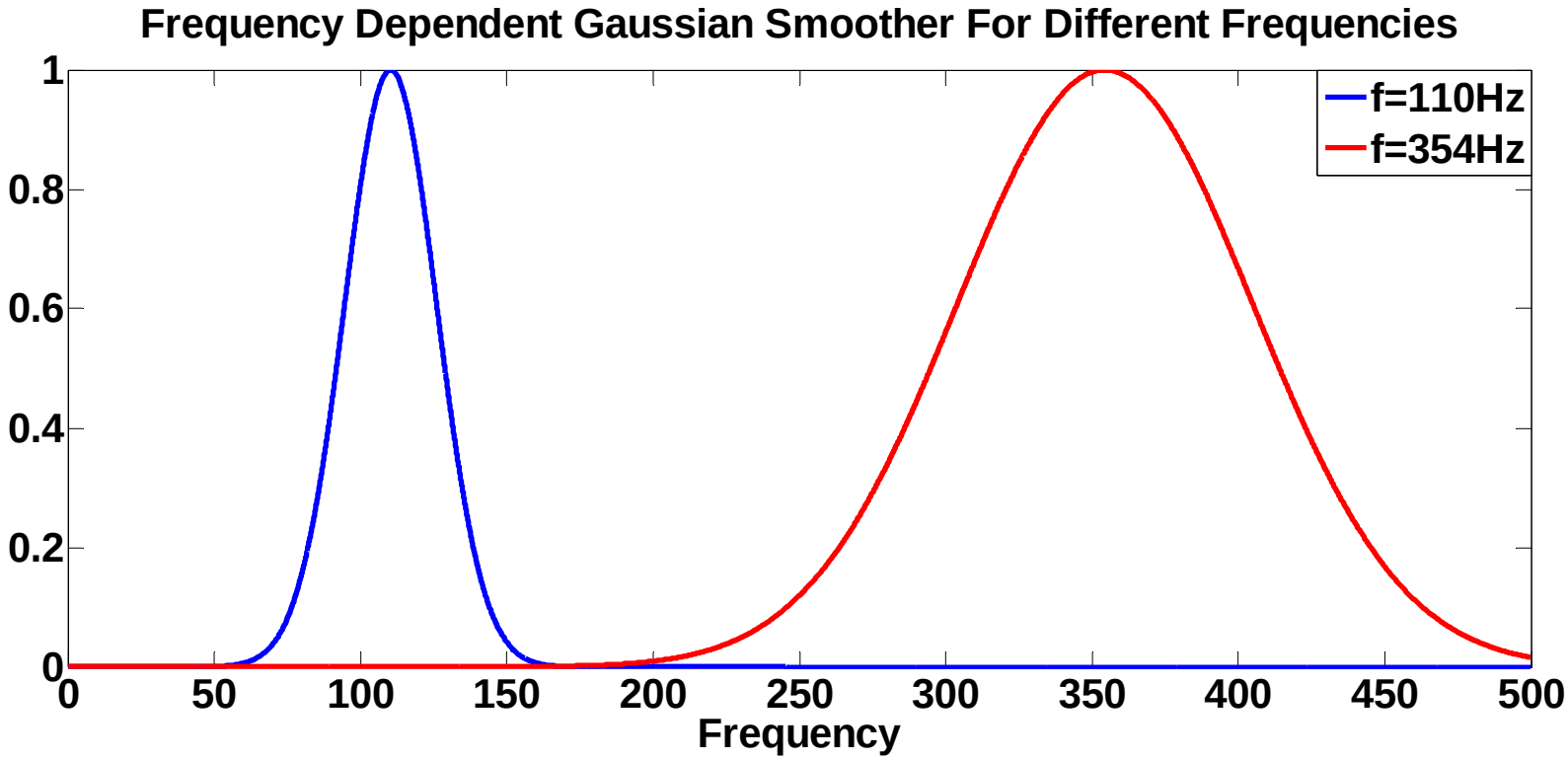
$$\bar{A}_j = \frac{\sum_k A_k g_{j-k}}{\sum_k g_k} \qquad g_k = e^{-(k\Delta f)^2/\sigma_f^2}$$



Frequency dependent smoother

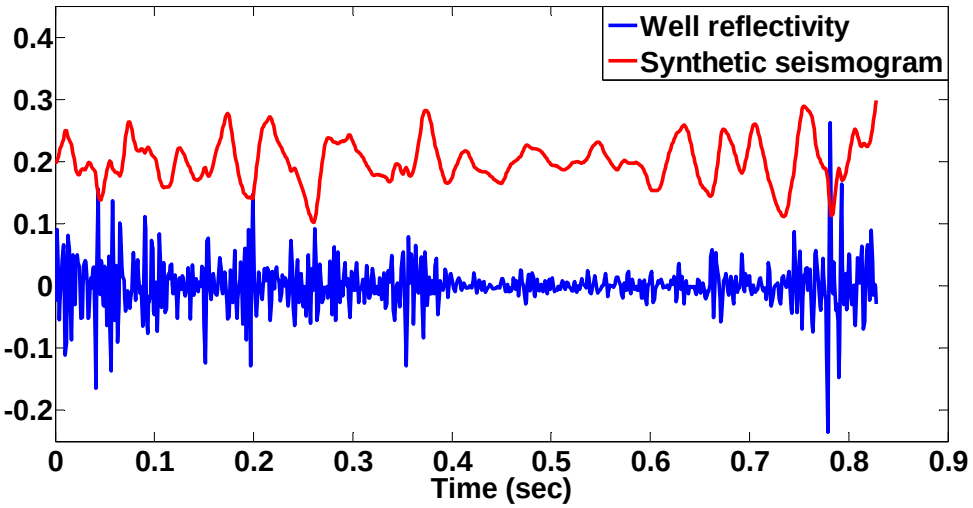
- Gaussian smoother with frequency dependent σ (FDGS)
  - lower frequencies require longer temporal windows.
  - Higher frequencies require small temporal windows.

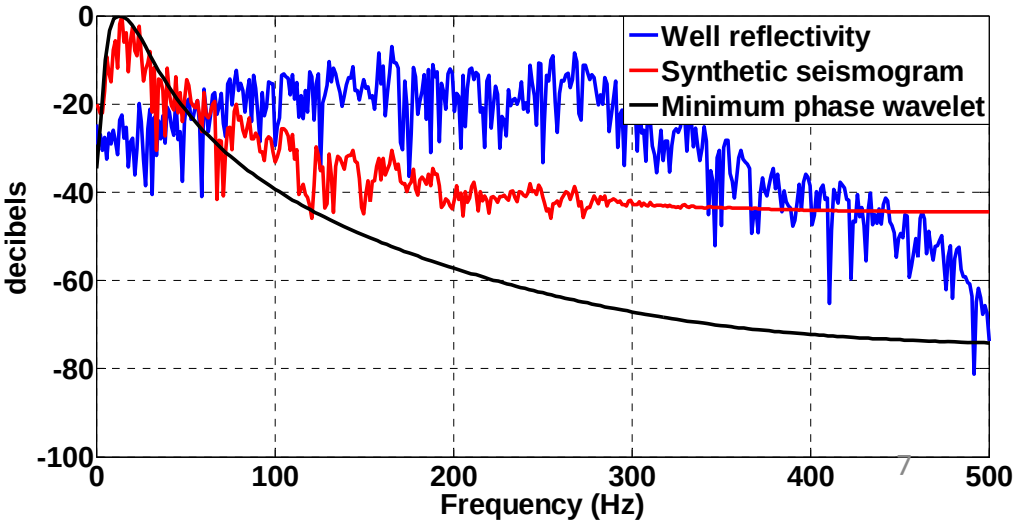
$$\sigma_f = \frac{f}{n} = \frac{k\Delta f}{n}$$



Deconvolution of zero-offset synthetic data

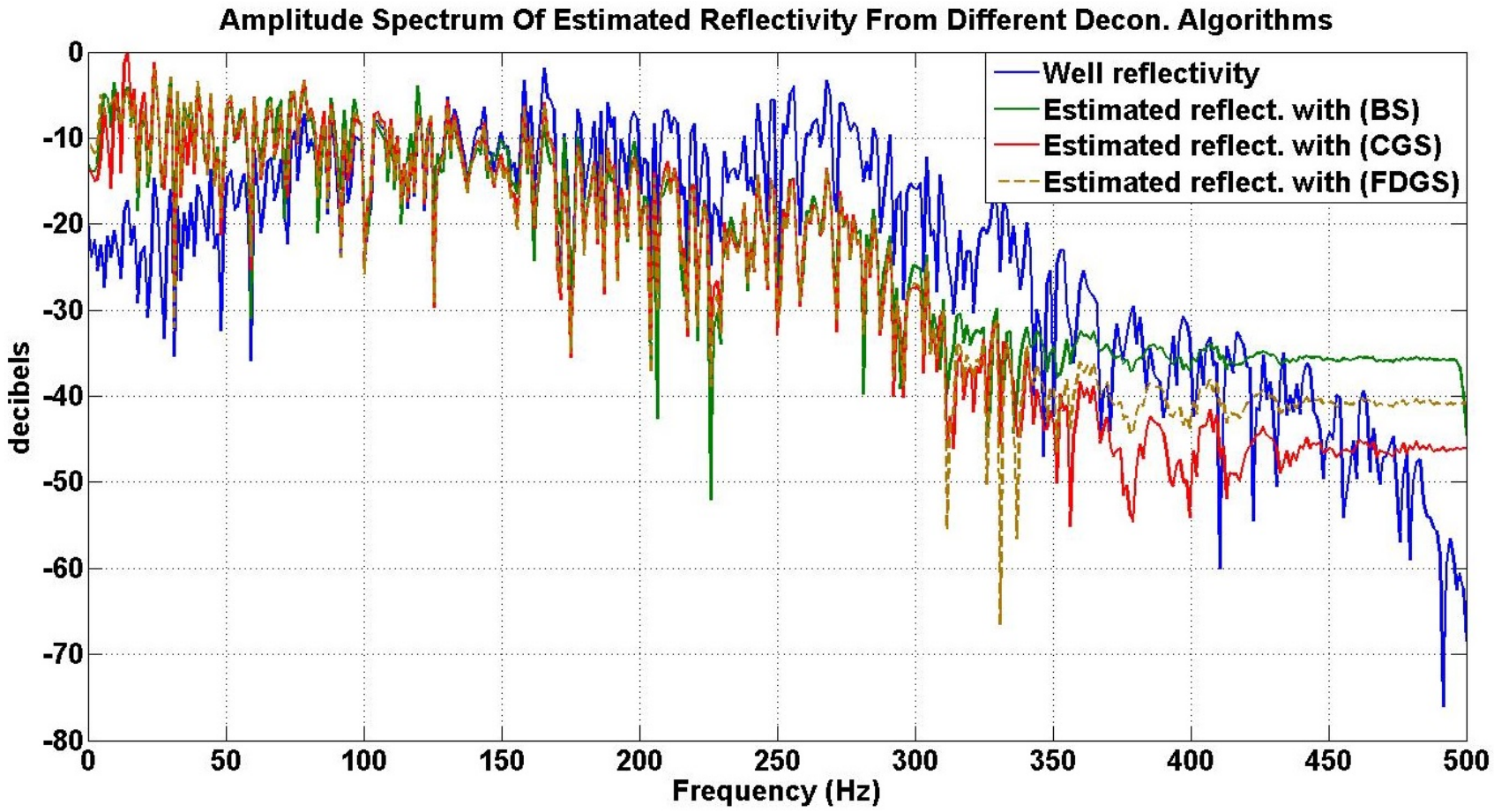
- Synthetic seismogram created by *seismo* in CREWES Matlab toolbox
- Husky Hussar well 12-27 reflectivity
- 15Hz minimum phase wavelet with one millisecond sample rate.
- Only the P-wave seismic data are used
- The multiple reflections are not considered





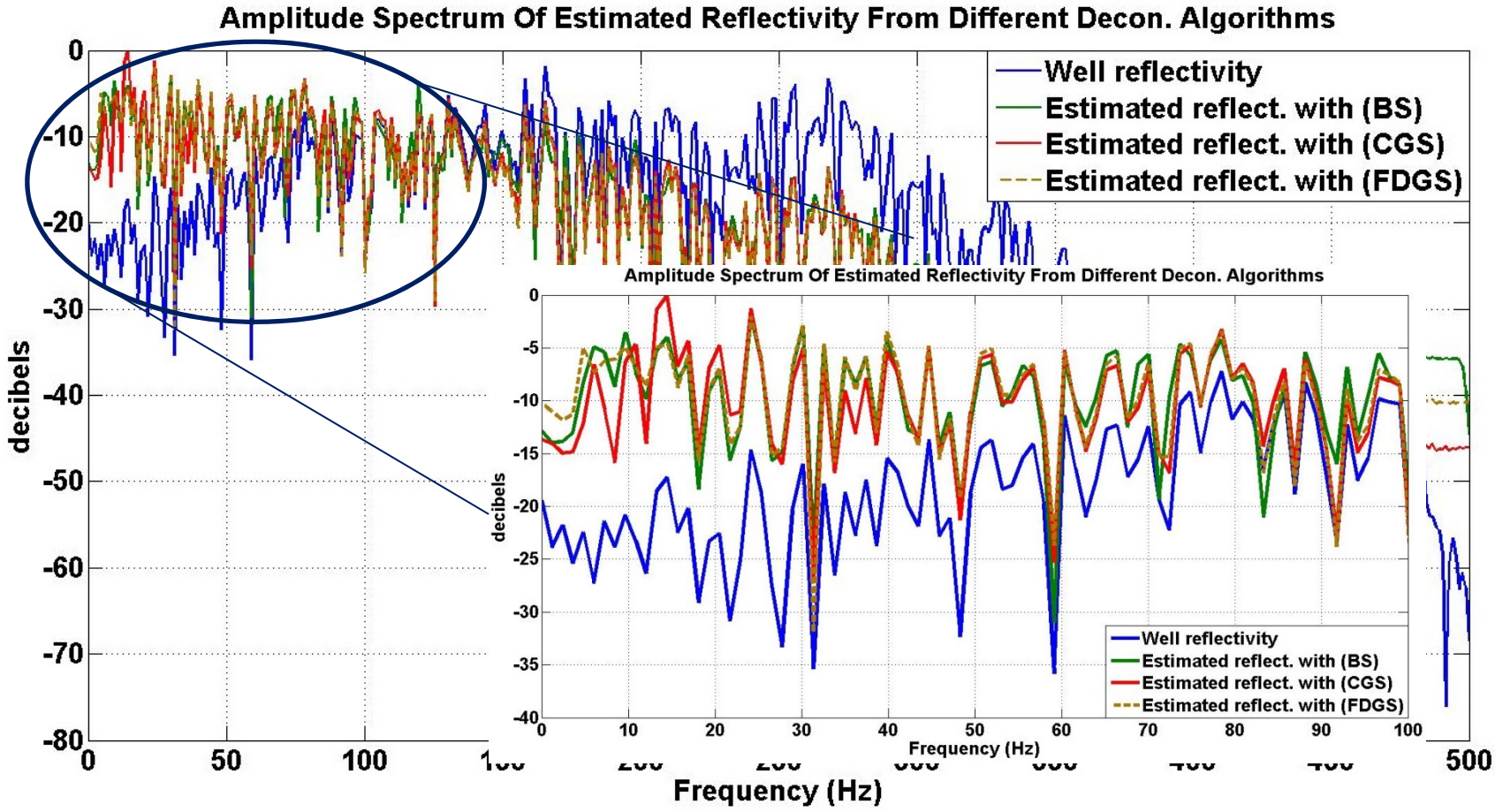
Deconvolution of zero-offset synthetic data

Amplitude spectra



Deconvolution of zero-offset synthetic data

Smoother choice makes little difference



Deconvolution Type	Decon with BS	Decon. with CGS	Decon. with FDGS
Max Correlation	0.5866	0.6347	0.5939

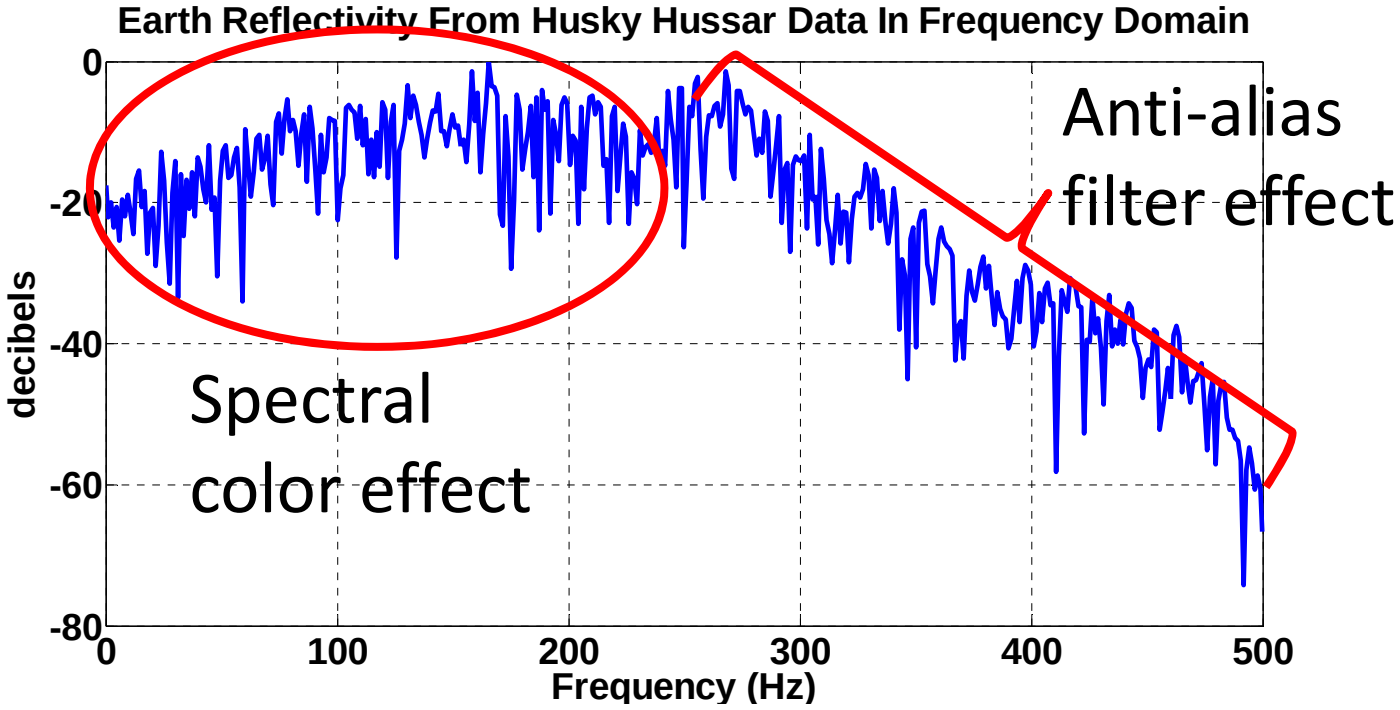
Where the problem is initiated!

✓The frequency domain deconvolution assumes that the amplitude spectrum of reflectivity should be white

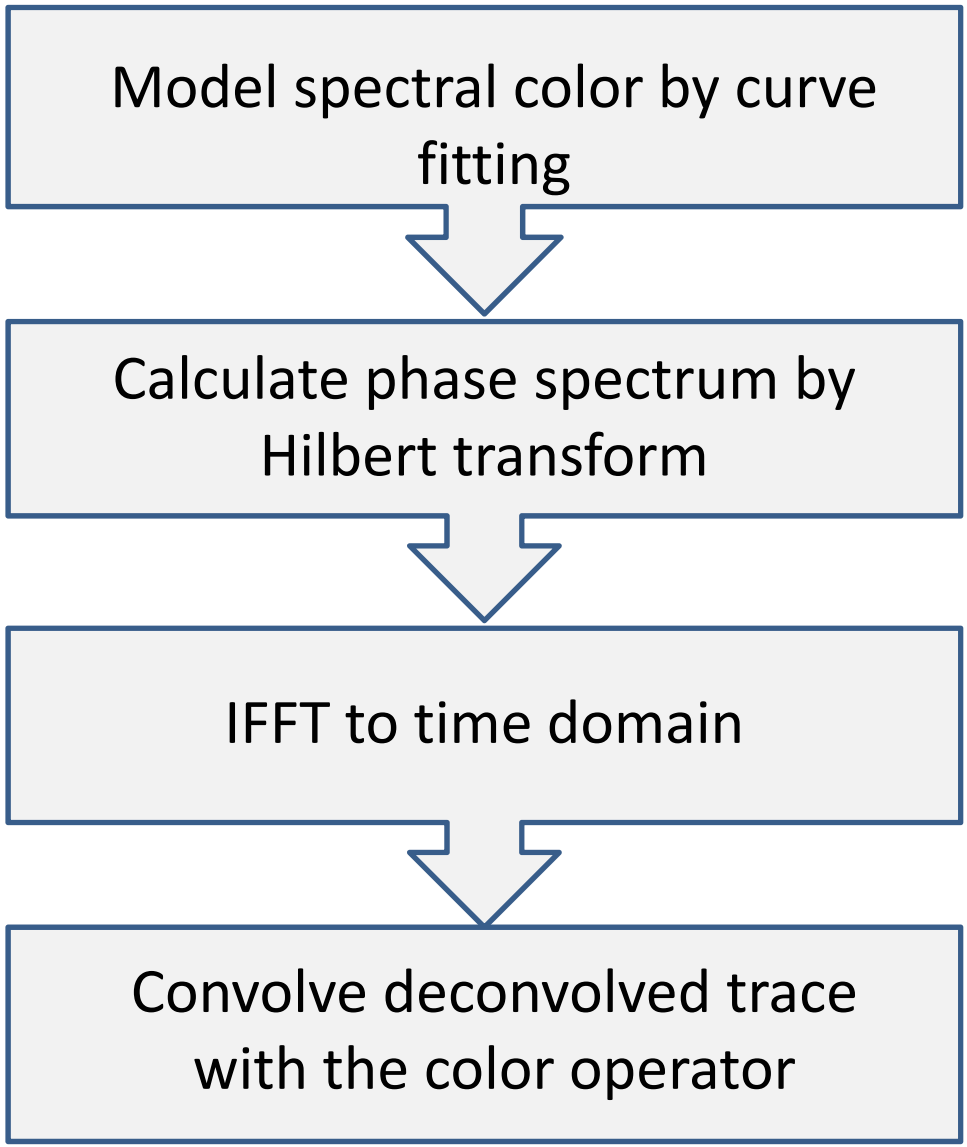
✓While the most reflectivities from wells all over the world do not have white spectra (Walden and Hosken, 1985).

Minimum phase color operator

- The color operator should depend only on the observed spectral shape of the reflectivity.
- The color operator should be minimum phase.
- Only the frequencies below than 250 (in this case) are interested.
- Color spectrum should be flat at high frequencies but show low-frequency roll off.

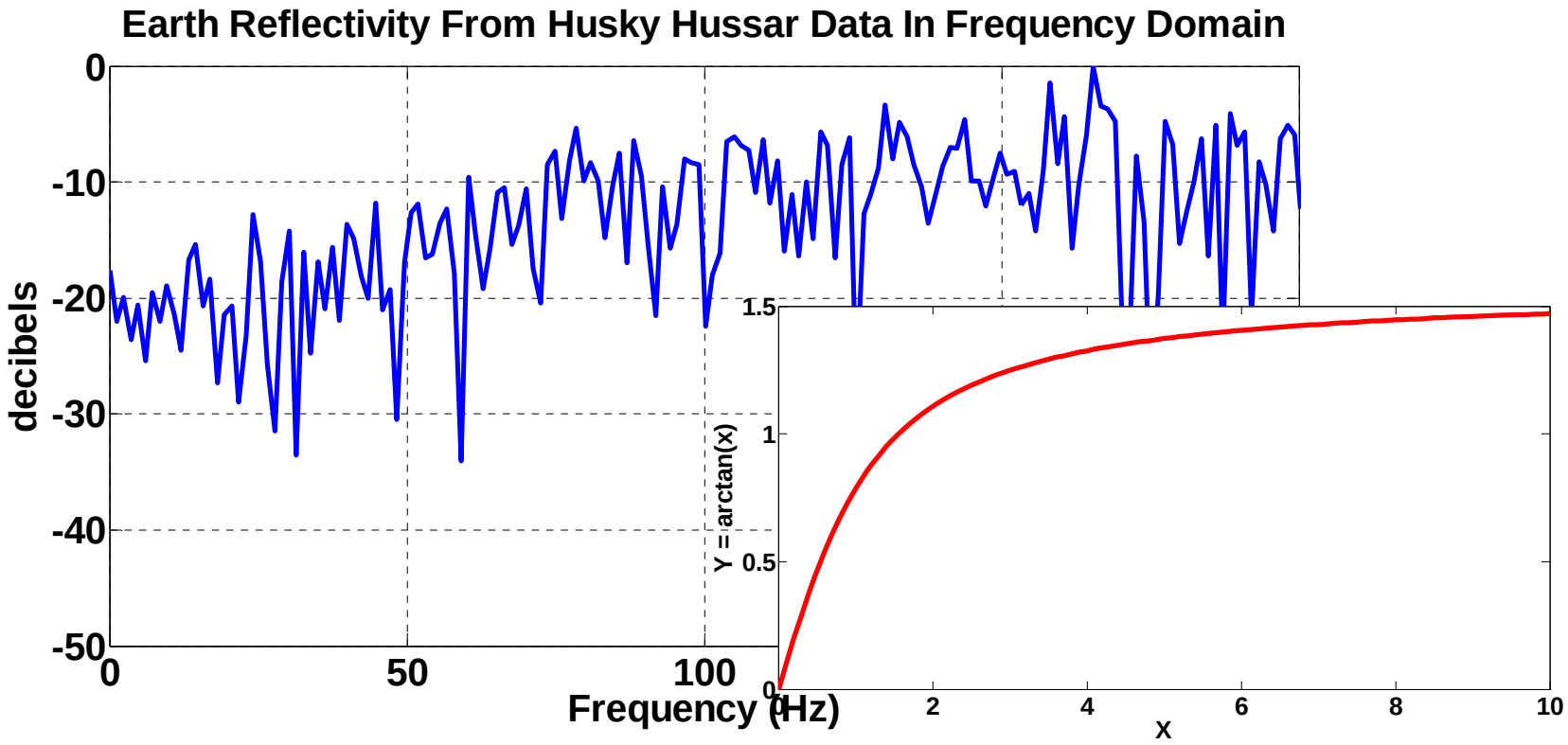


Minimum phase color operator



Minimum phase color operator

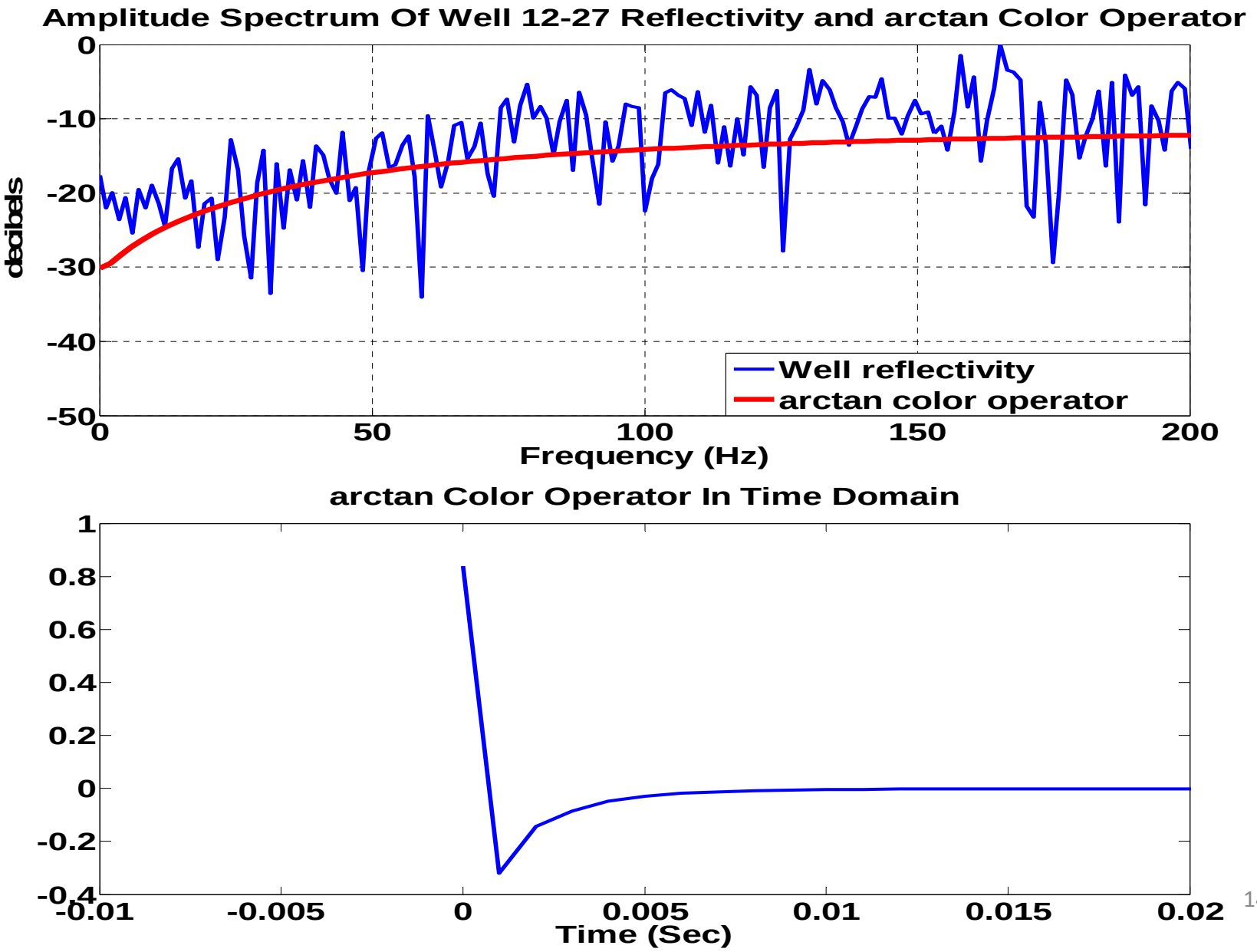
- **arctan color operator**



$$a + b\arctan(f) = R(f)$$

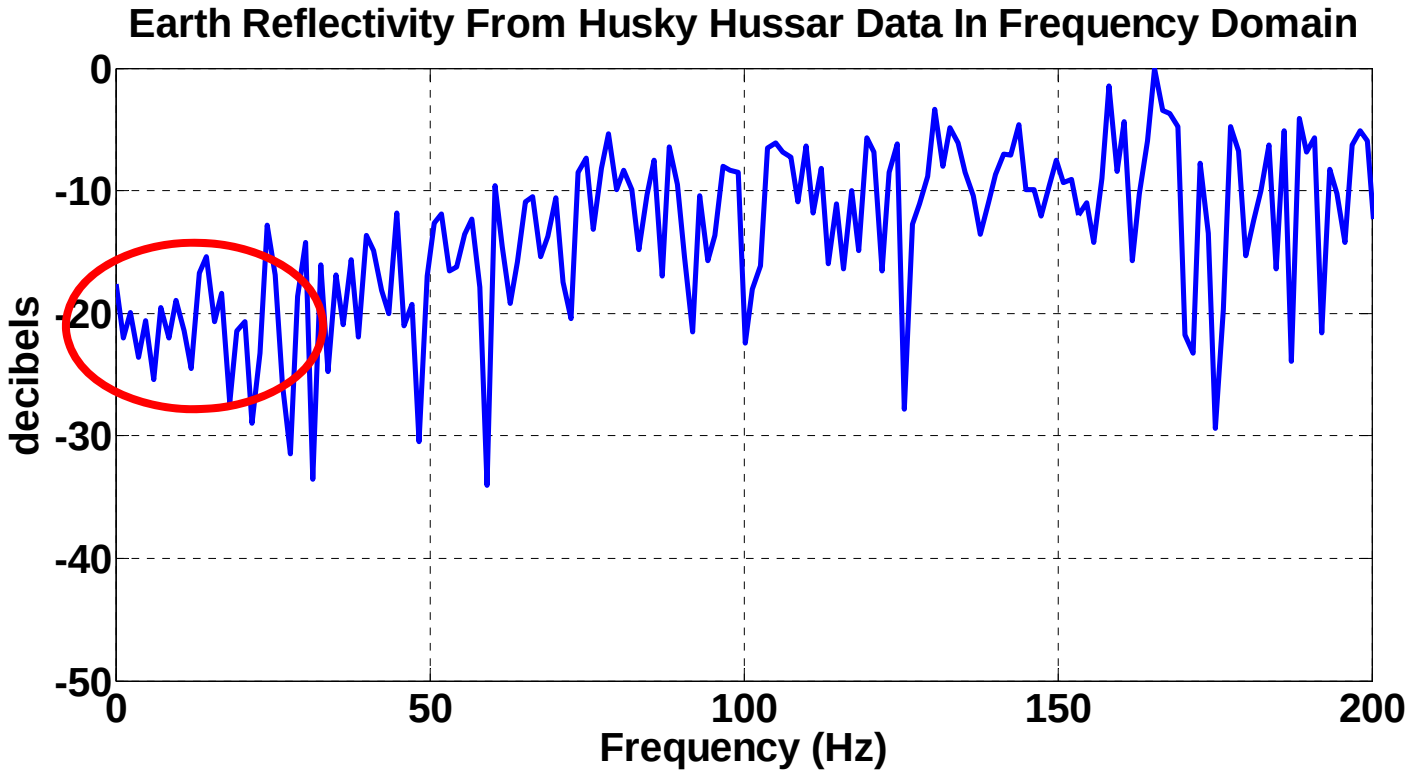
$$[1 \quad arctan(f)]_{n\times 2}\begin{bmatrix} a \\ b \end{bmatrix}_{2\times 1} = A\begin{bmatrix} a \\ b \end{bmatrix} = R_{n\times 1}$$

arctan color operator



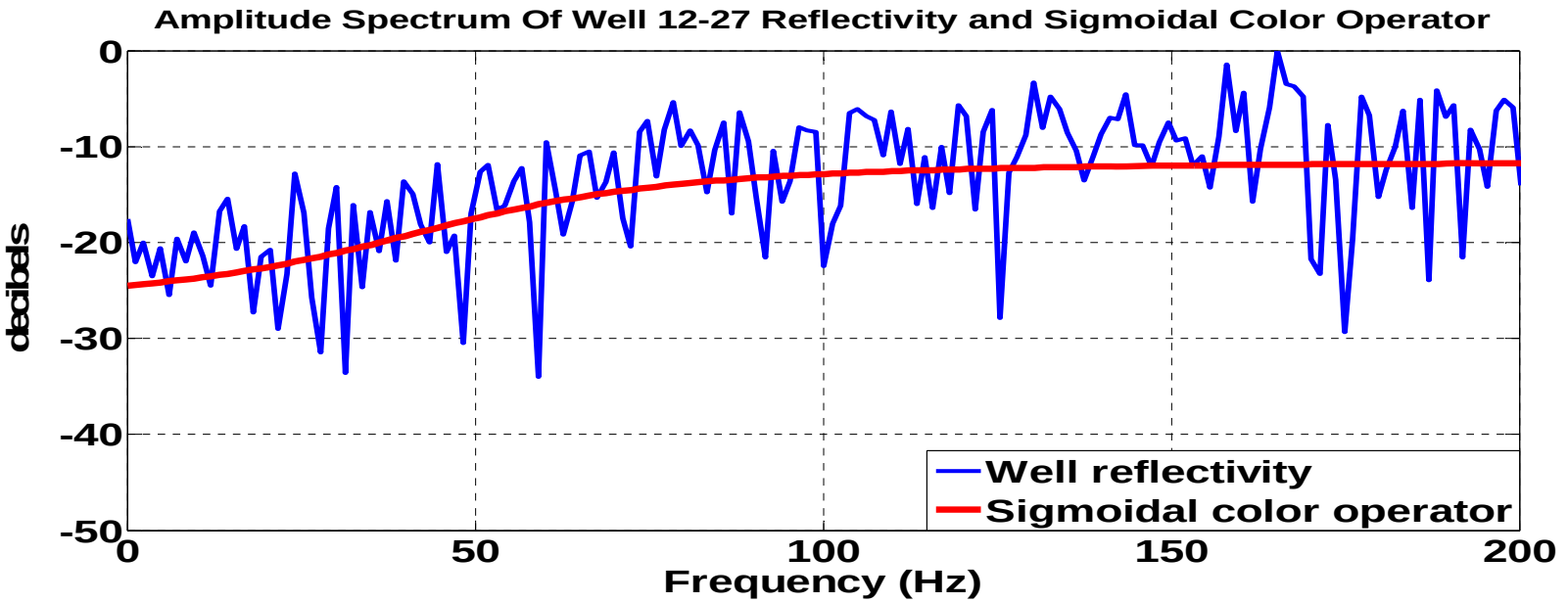
Minimum phase color operator

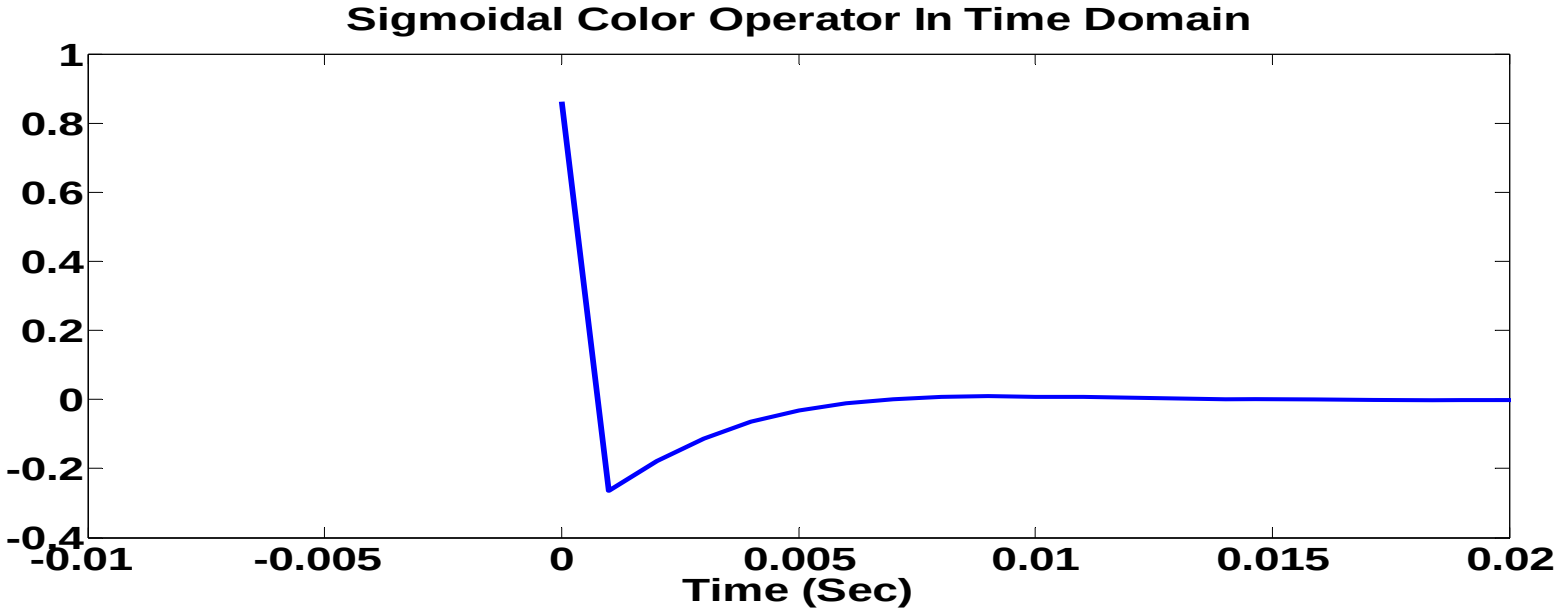
- **Sigmoidal color operator**



$$\frac{a+bs}{\sqrt{1+s^2}} = R(f) \qquad where:\ s = \frac{f-f_0}{f_0}$$

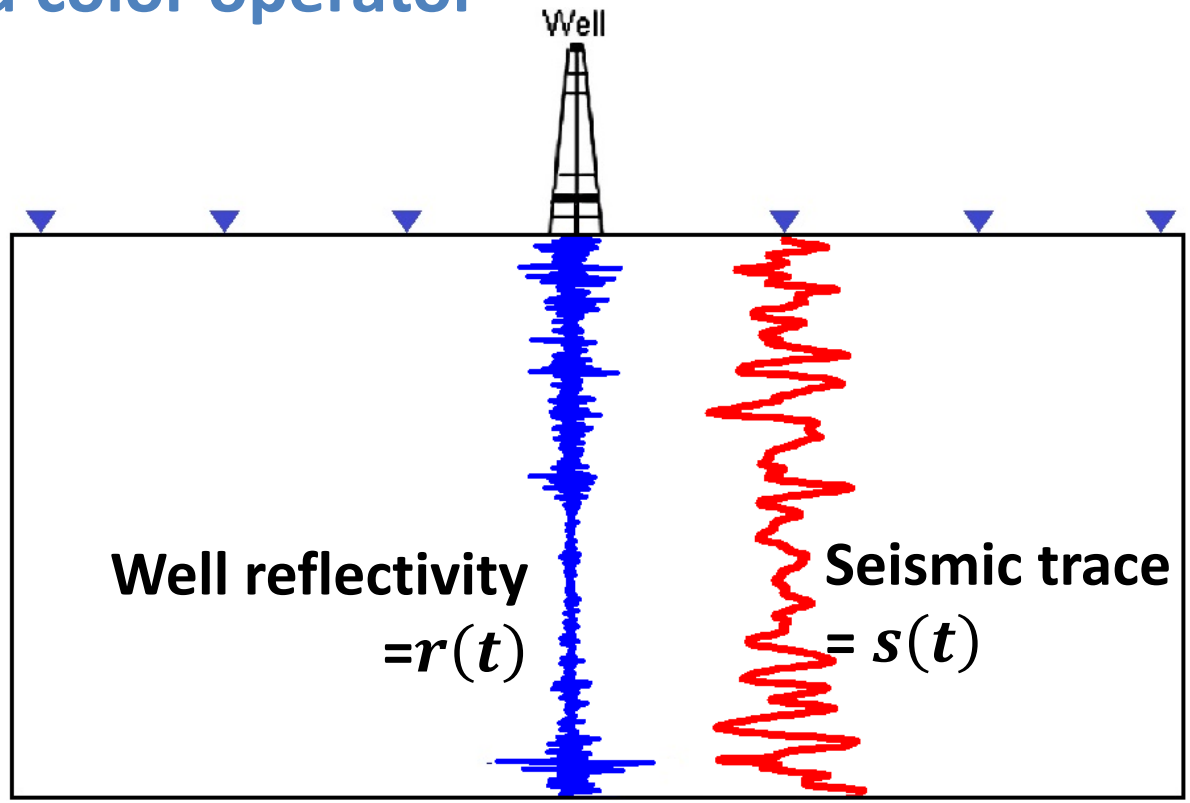
Sigmoidal color operator





Minimum phase color operator

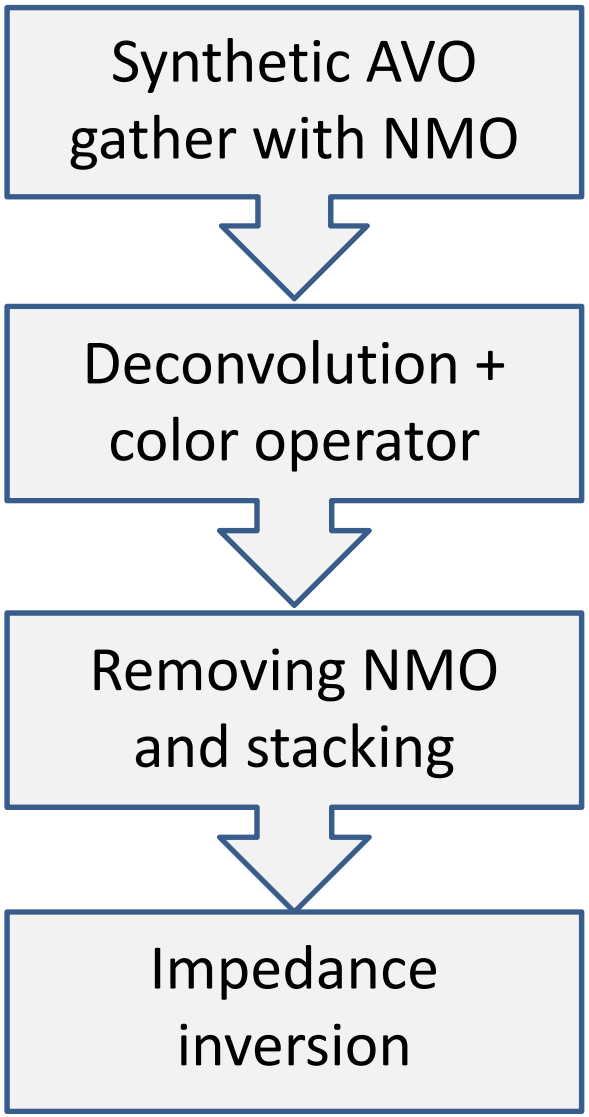
- **Forced color operator**



Color model $= \left|\frac{R(f)}{S_d(f)}\right| * b(f)$

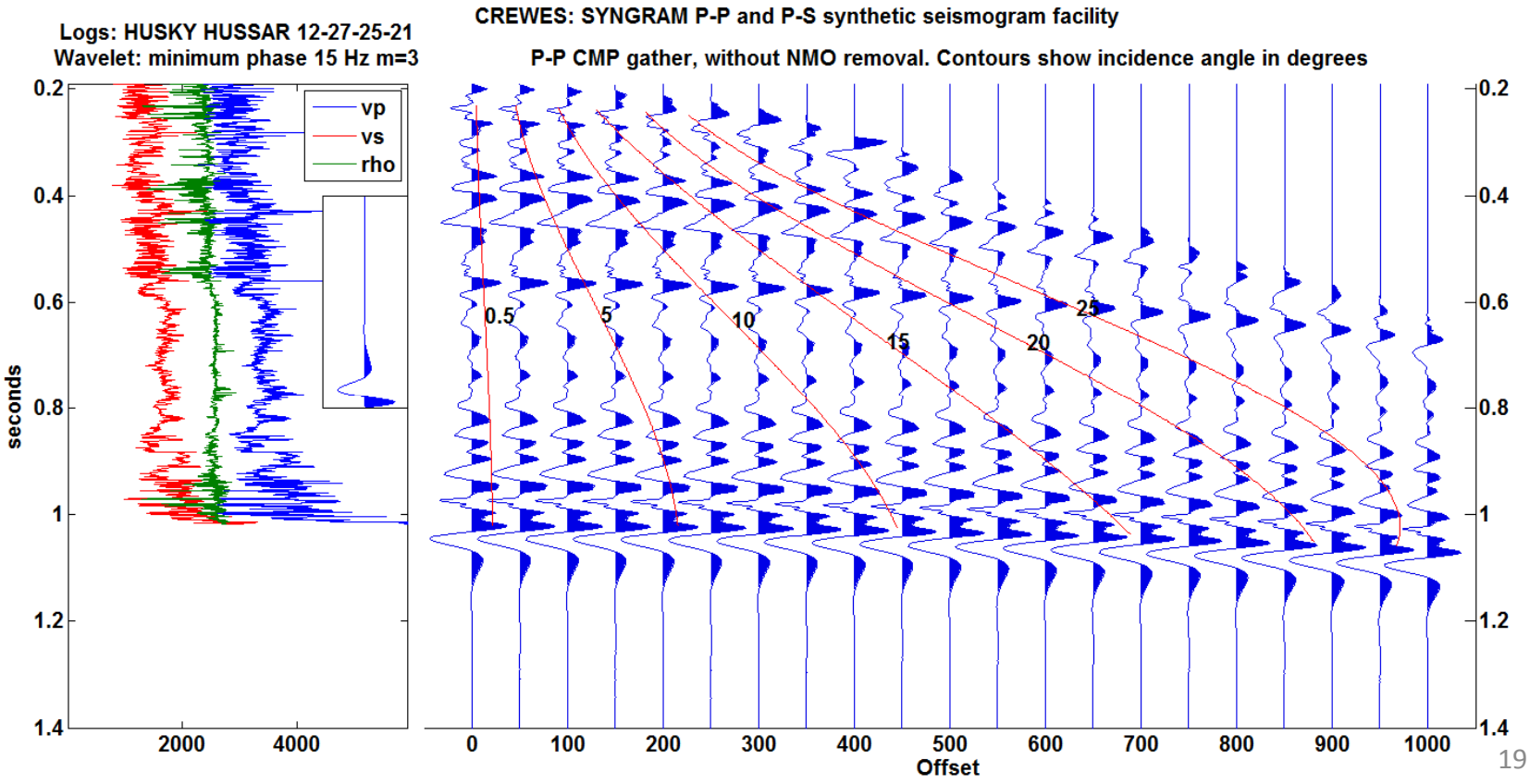
$S_d(f)$: Deconvolved Seismic trace
$b(f)$: Smoother

Processing synthetic AVO gather

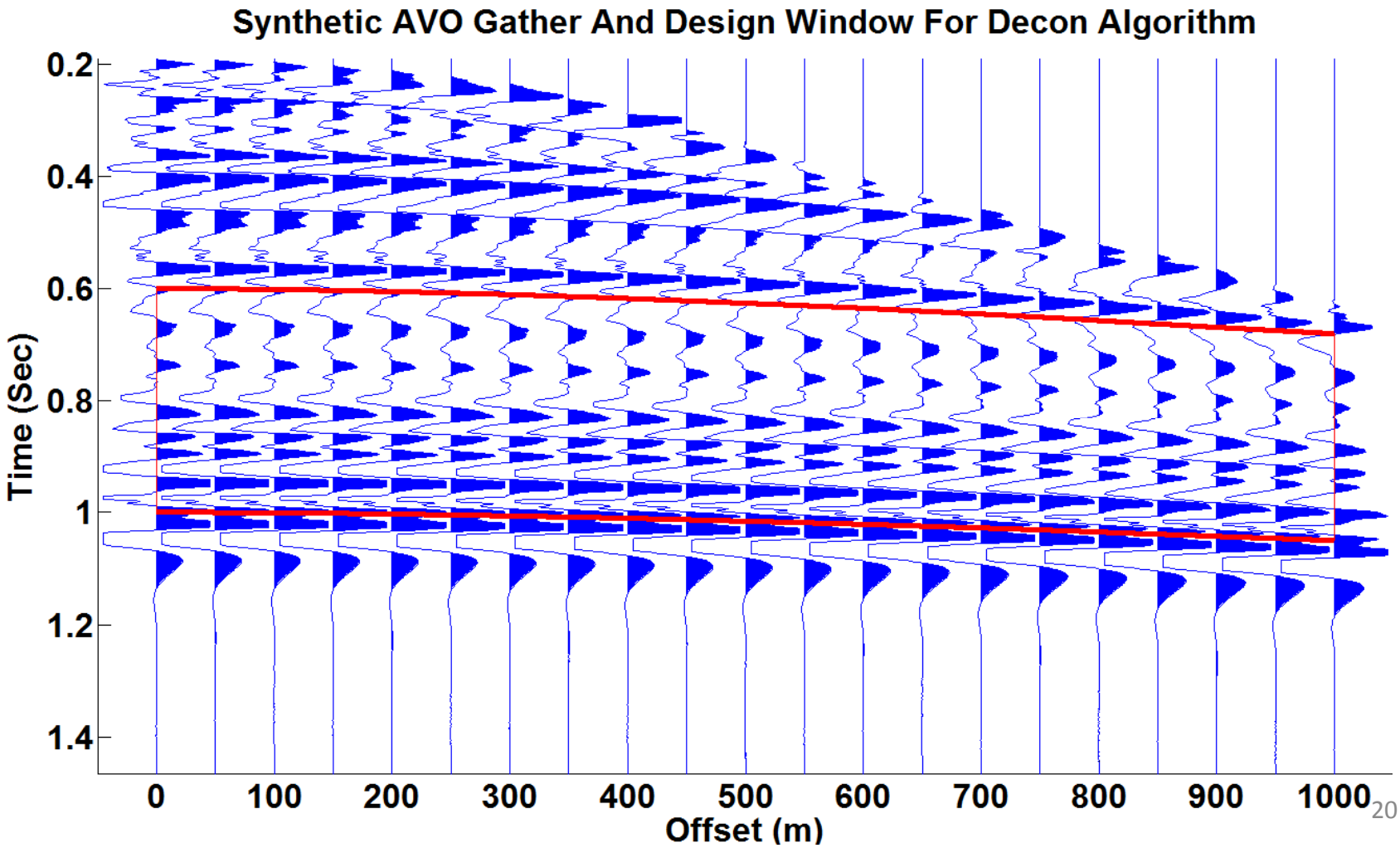


Processing synthetic AVO gather

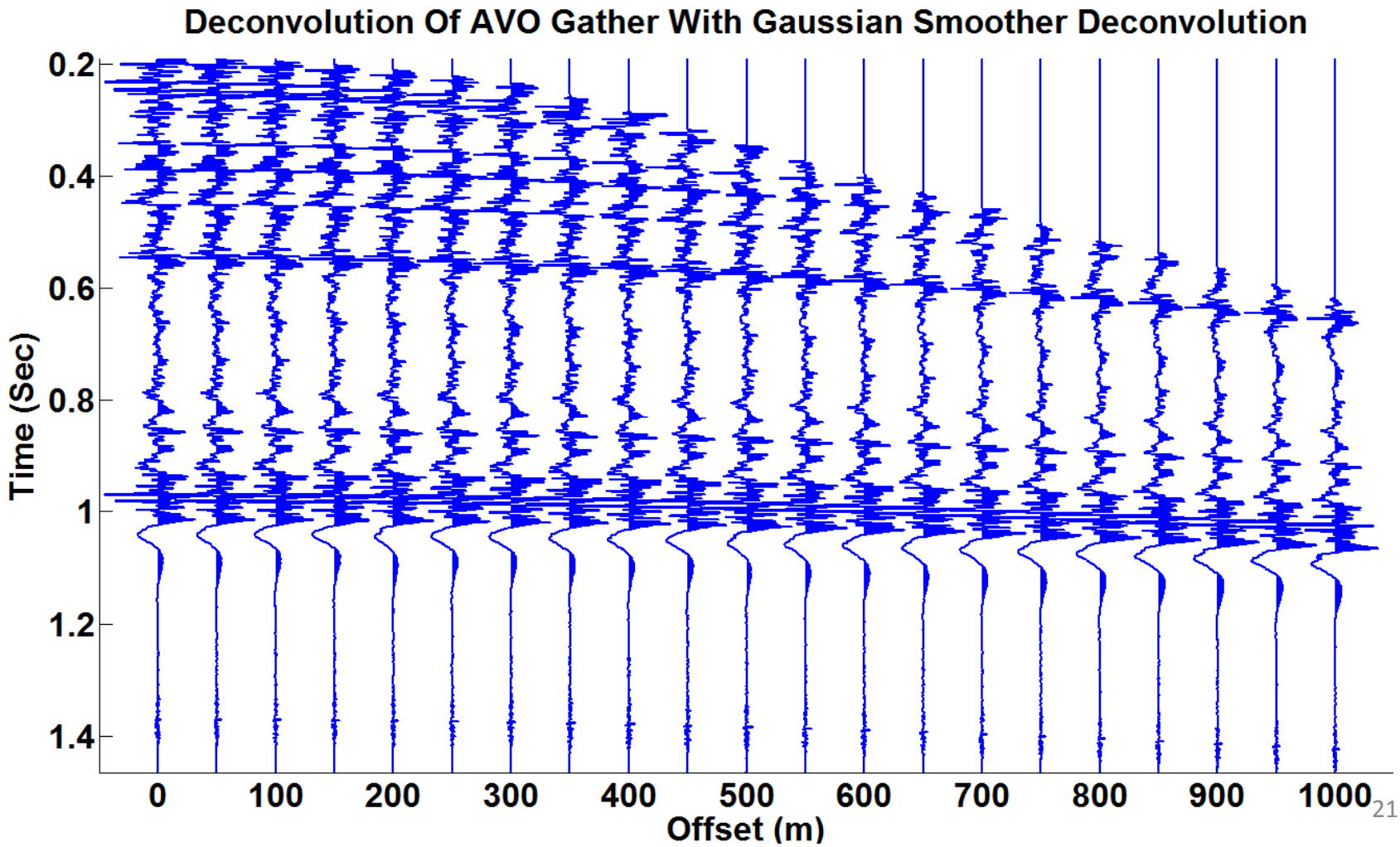
- Synthetic data created by *Syngram* in CREWES Matlab toolbox.
- Husky Hussar well 12-27 data have been used.
- 15Hz minimum phase wavelet with one millisecond sample rate.



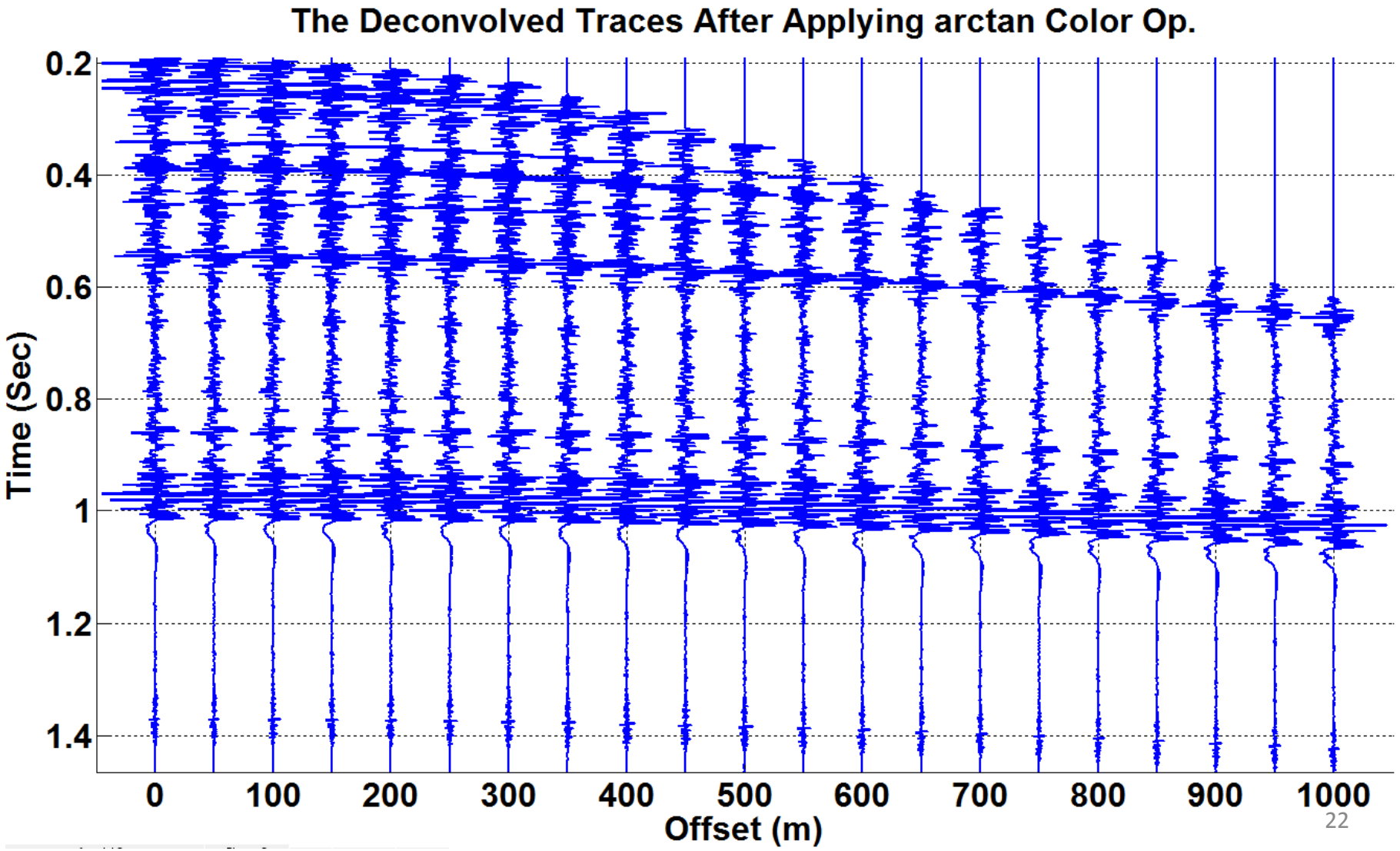
Designing window for decon algorithm



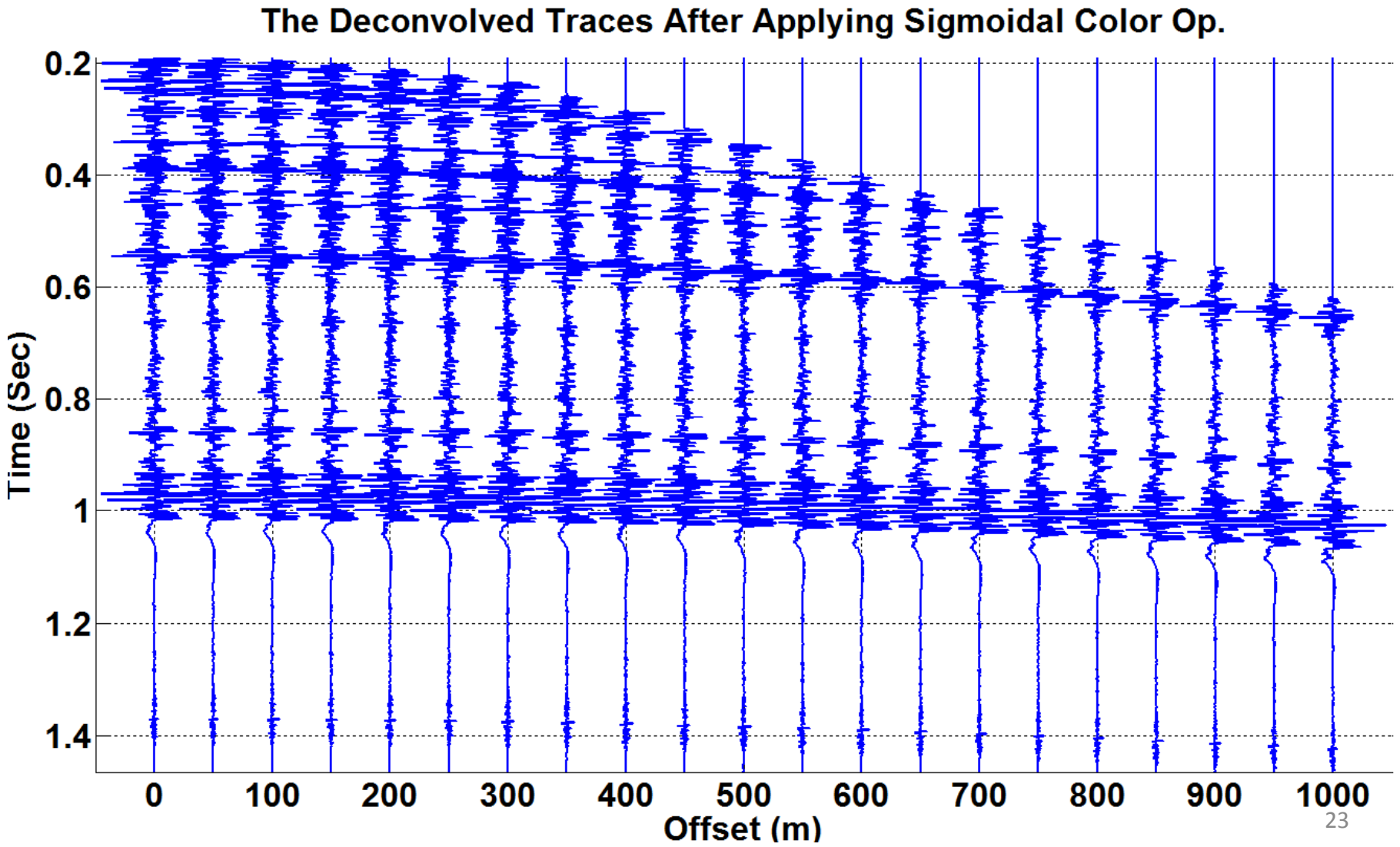
Deconvolution synthetic AVO gather with CGS



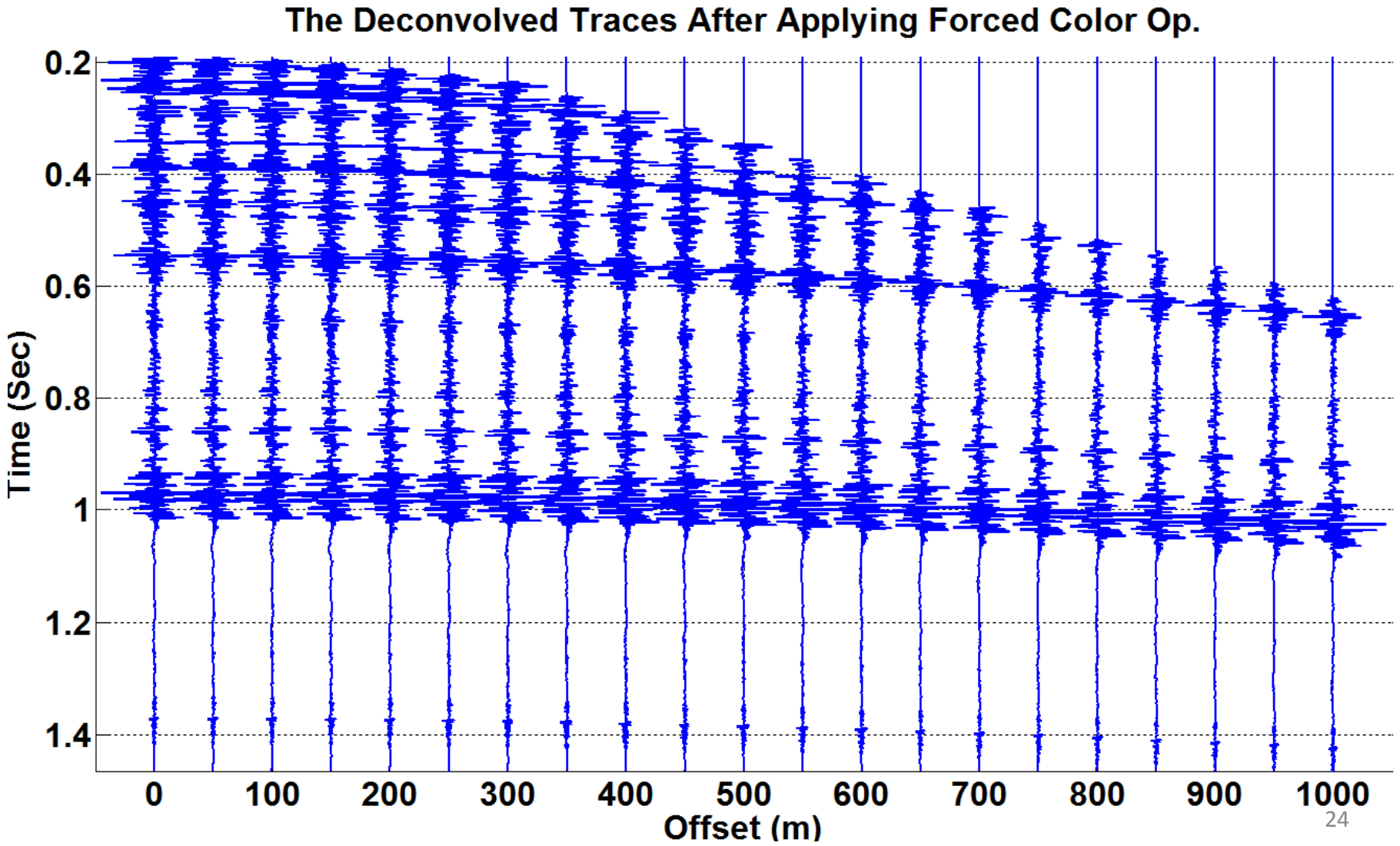
Applying arctan color operator to the deconvolved data



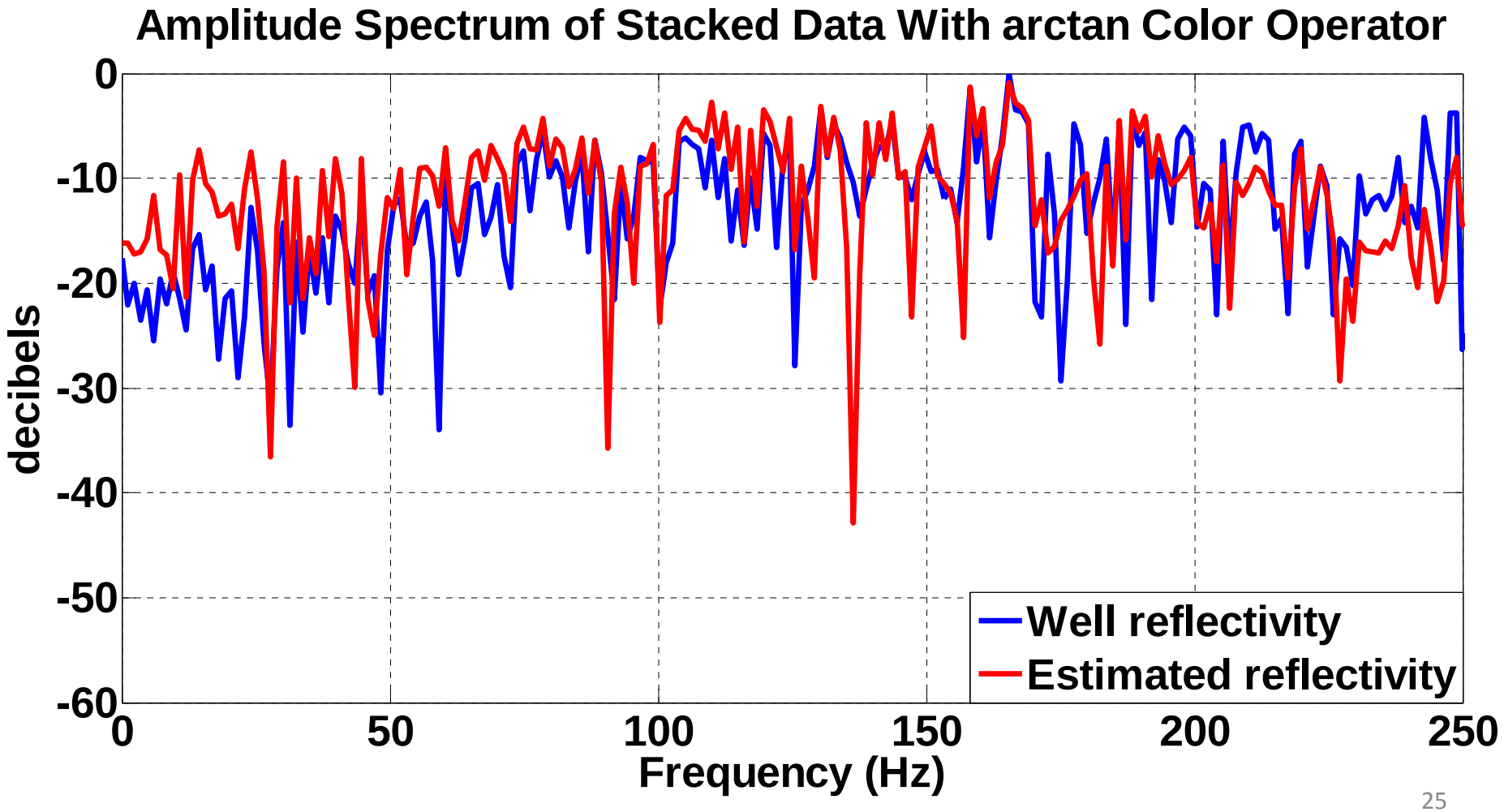
Applying Sigmoidal color operator to the deconvolved data



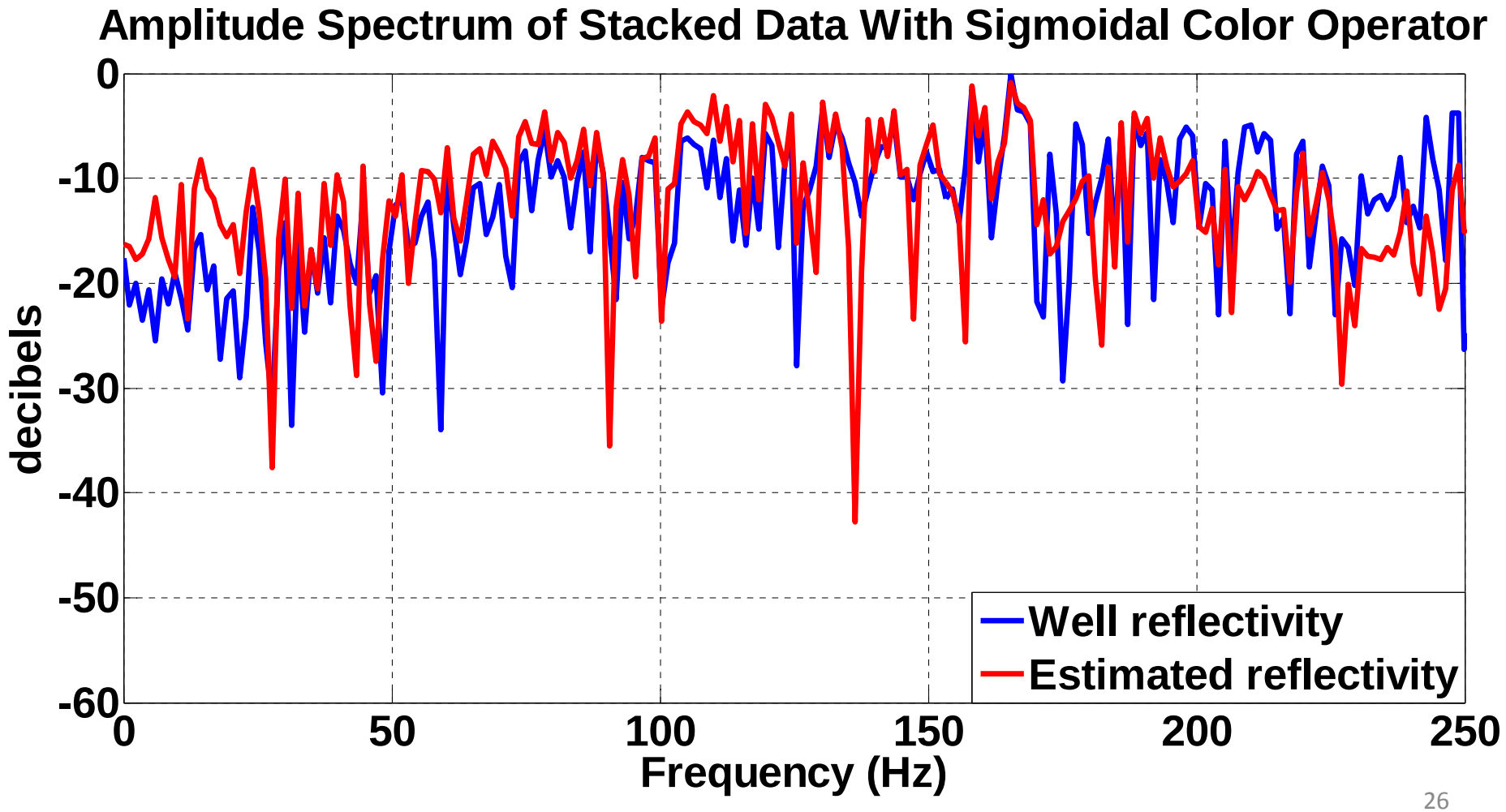
Applying Forced color operator to the deconvolved data



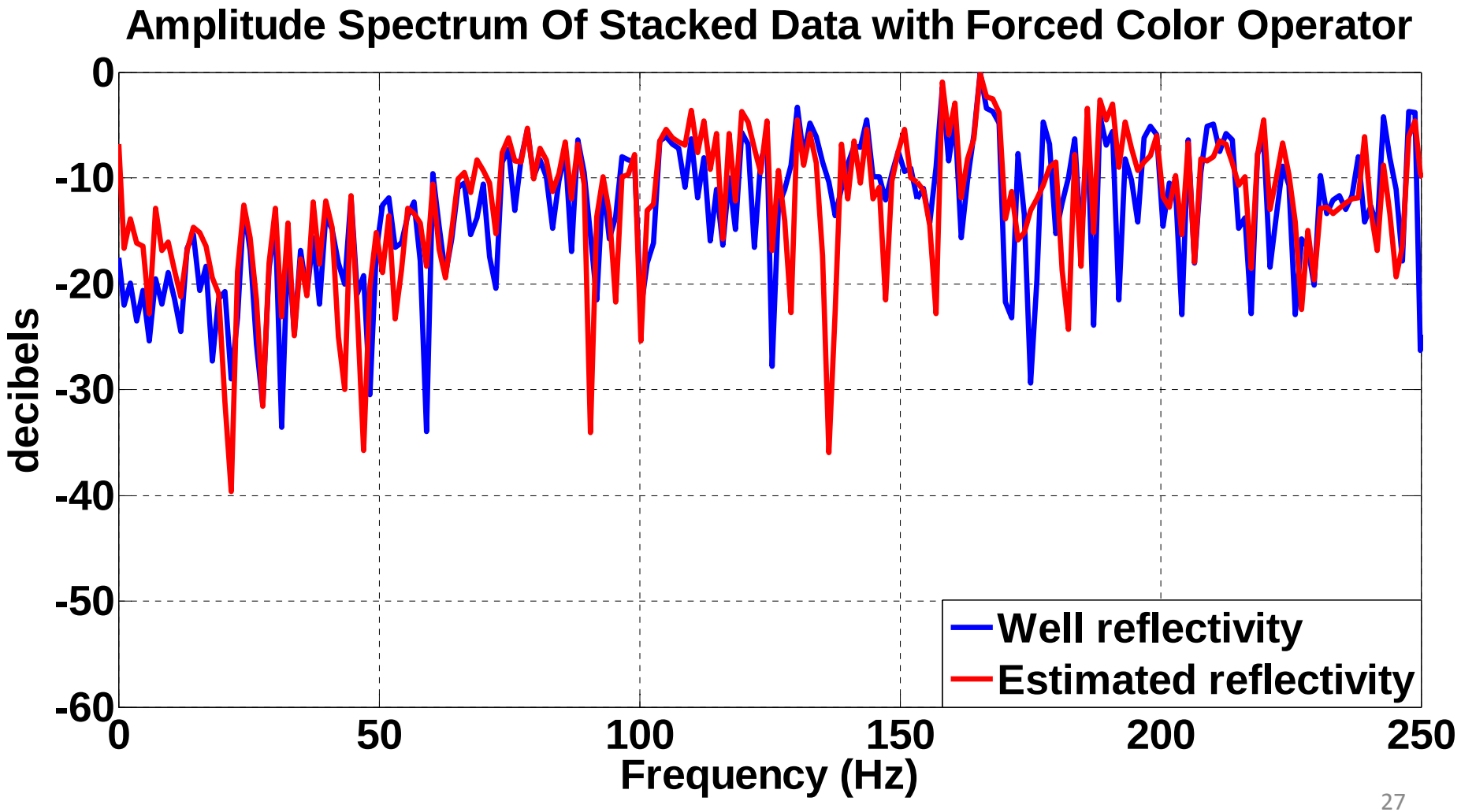
Amplitude spectrum of stacked data with arctan color operator



Amplitude spectrum of stacked data with Sigmoidal color operator



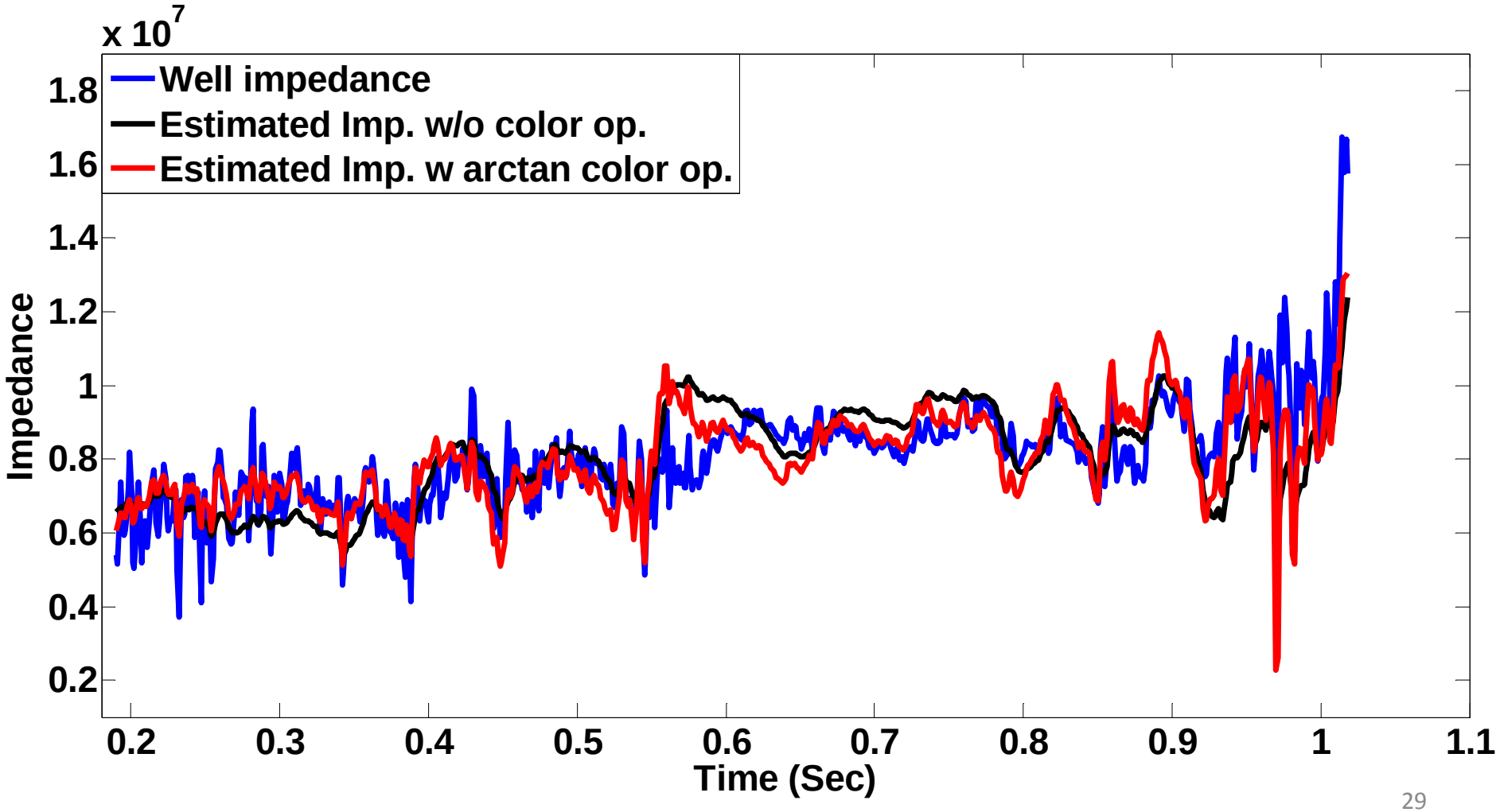
Amplitude spectrum of stacked data with Forced color operator



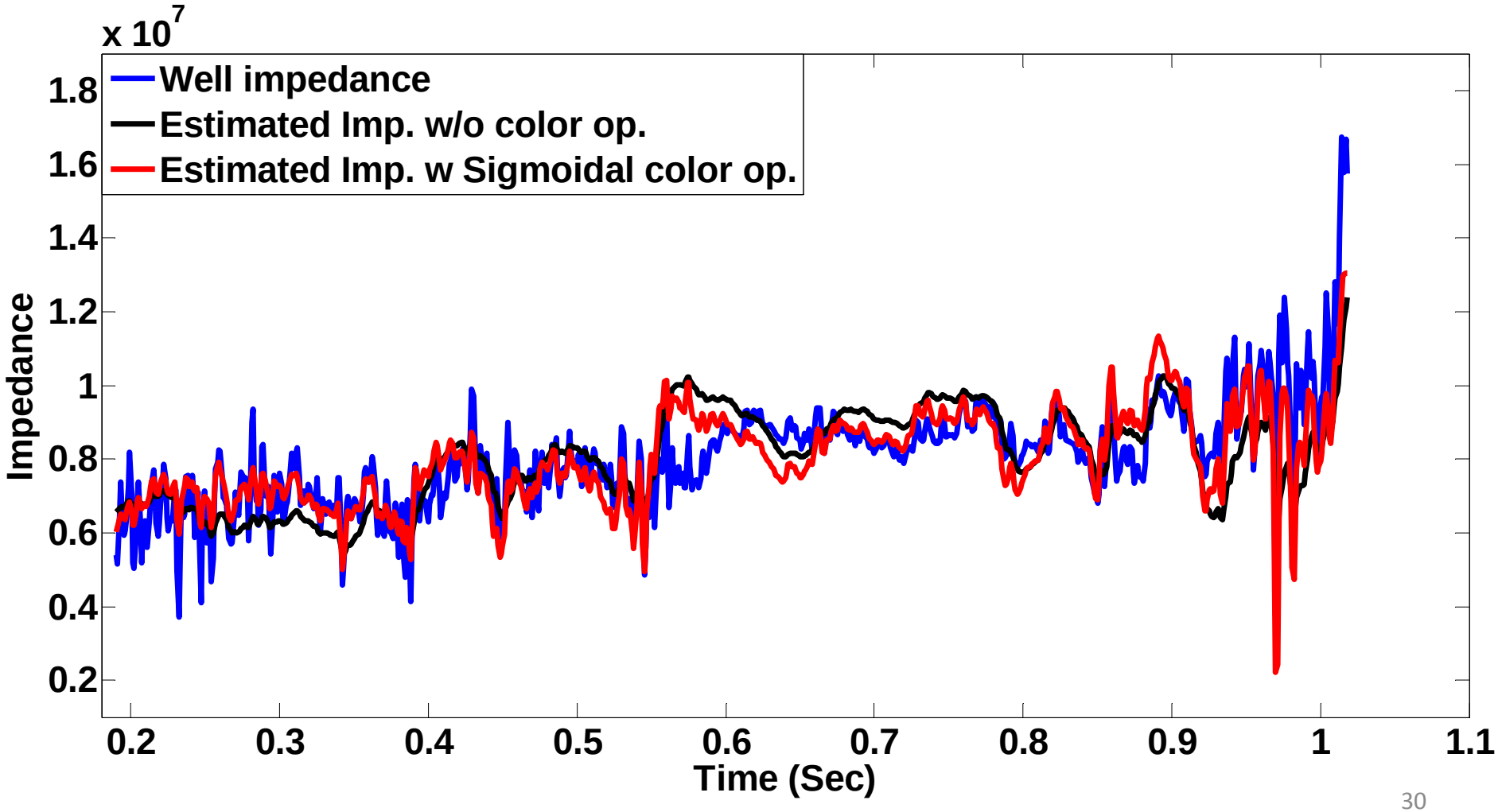
Impedance inversion

- ✓ **The acoustic impedance was calculated by *BLIMP* algorithm in CREWES Matlab toolbox (Ferguson and Margrave, 1996).**
- ✓ **The low cut-off frequency was selected 1Hz in BLIMP algorithm.**

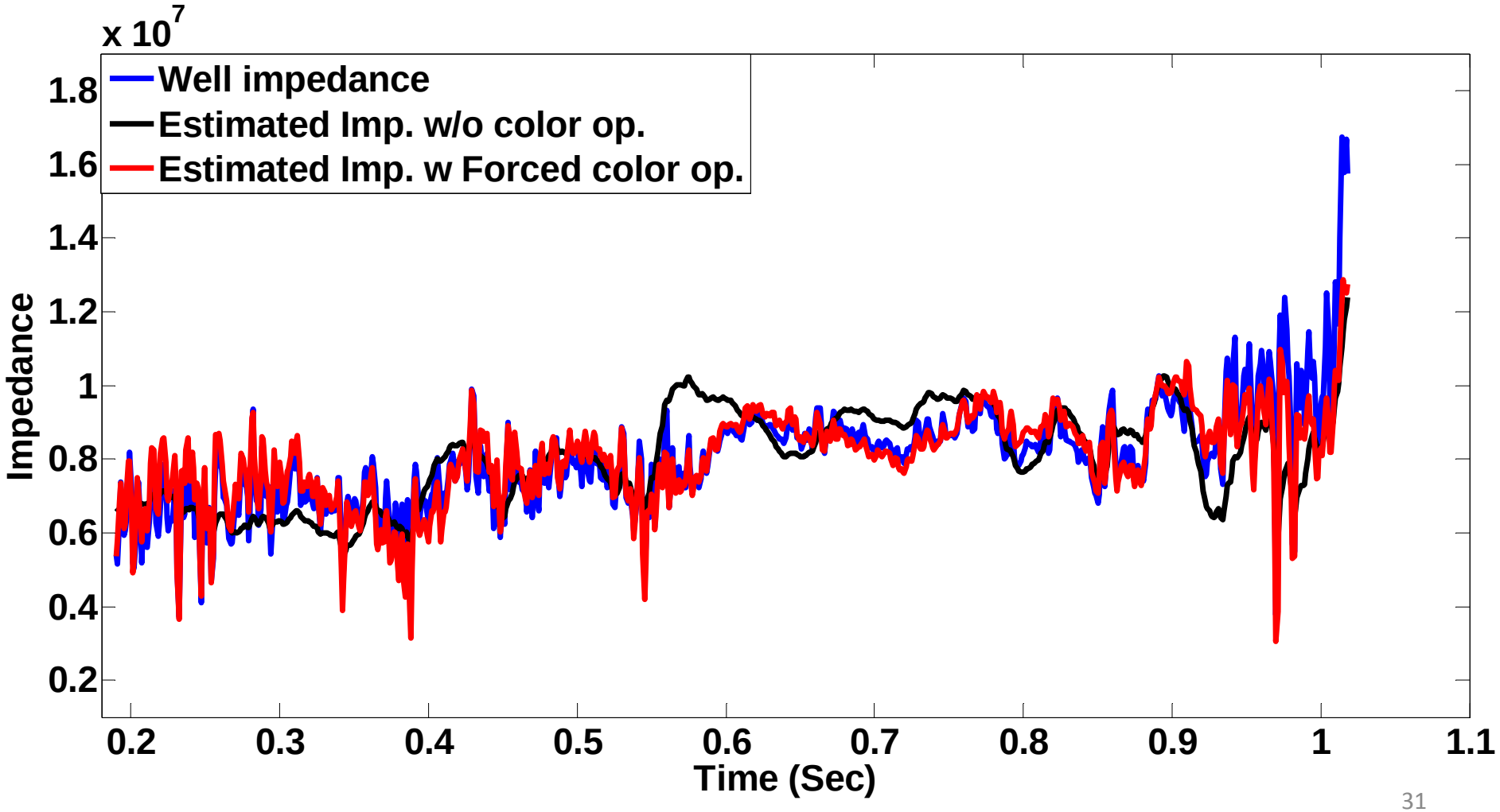
Impedance inversion
arctan color operator



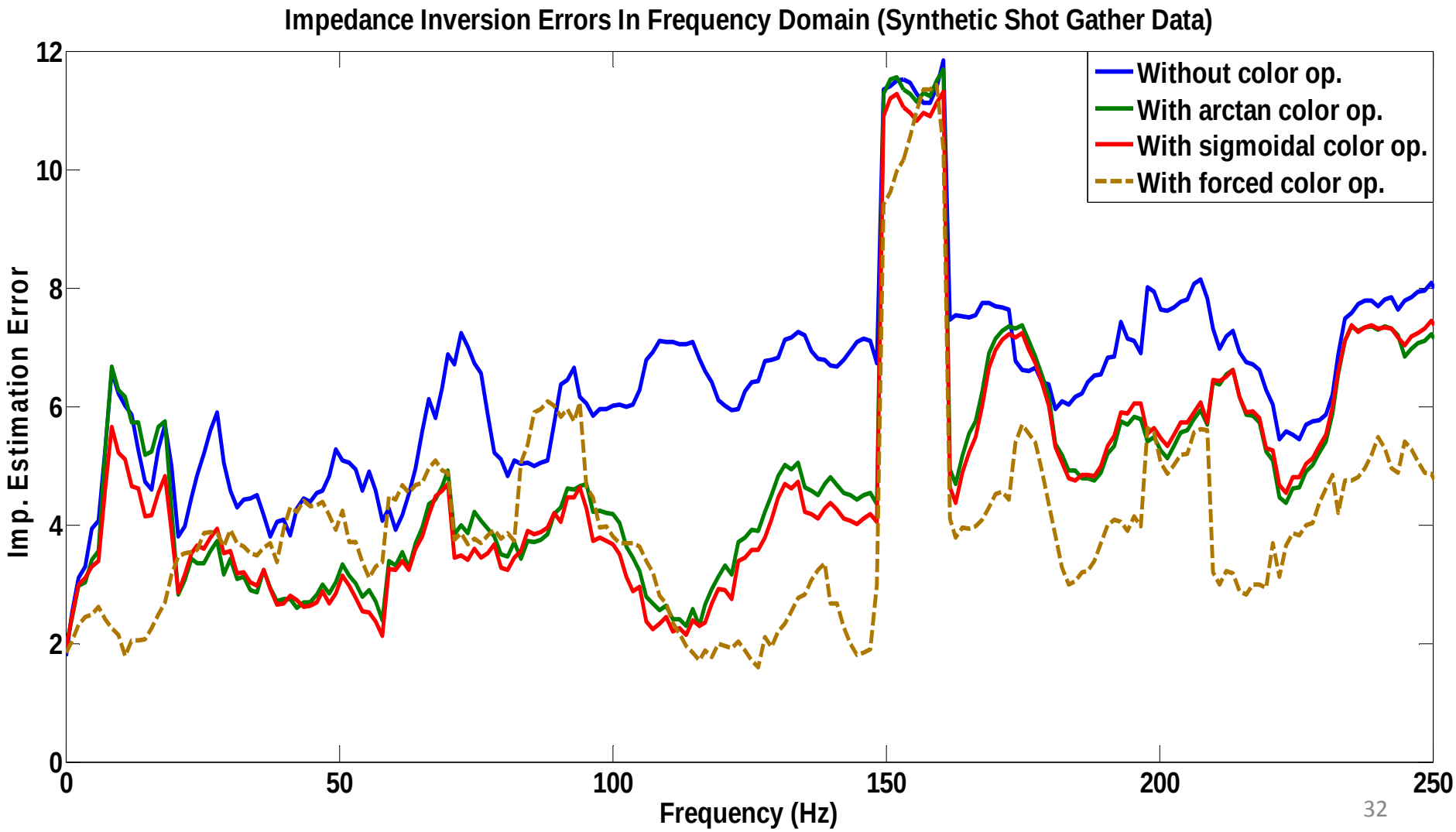
Impedance inversion sigmoidal color operator



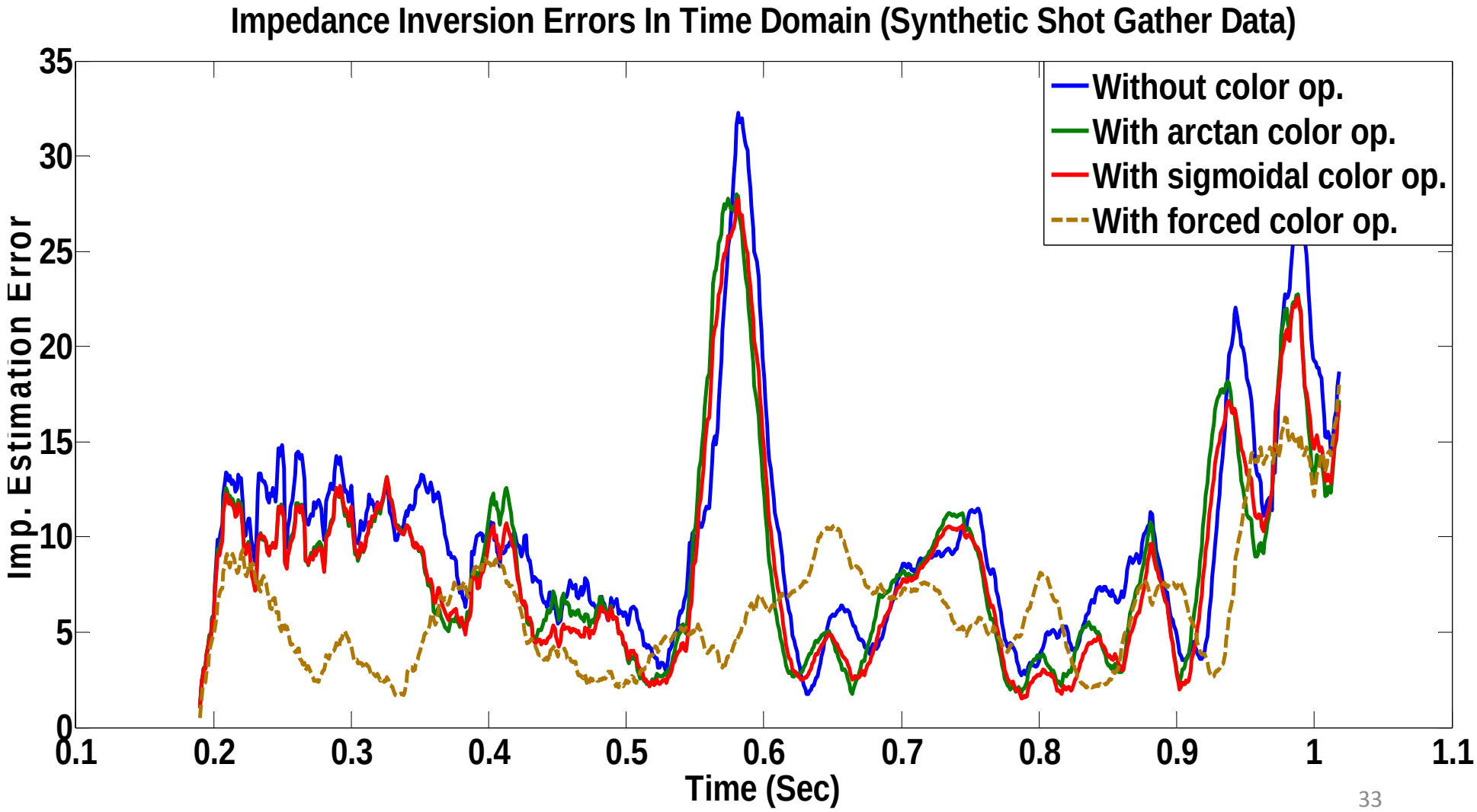
Impedance inversion forced color operator



Impedance estimation errors in frequency domain



Impedance estimation errors in time domain



Conclusion

- Deconvolution can be affected by choosing different smoothers but the differences are minor.
- A deconvolved trace shaped to a white spectrum can be corrected by applying a color operator right after deconvolution.
- The result of impedance inversion is greatly improved after applying color correction because this affects the low frequencies.
- Any color correction is better than no color correction.

Acknowledgment

- All CREWES sponsors
- All the students and staff in CREWES
- NSERC through CRD grant 379744-08


THANKS!