Anacoustic FWI and the problem of model type

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Motivations

- An open question is whether multiparameter FWI can become a practical technology for characterizing the reservoir.
- Attenuation is a key obstacle to extending FWI to fulfill this role:
  1. Failing to account for attenuative and dispersive effects can harm the accuracy with which we recover other parameters.
  2. Attenuation can be a parameter of interest in itself.

Anacoustic approximation

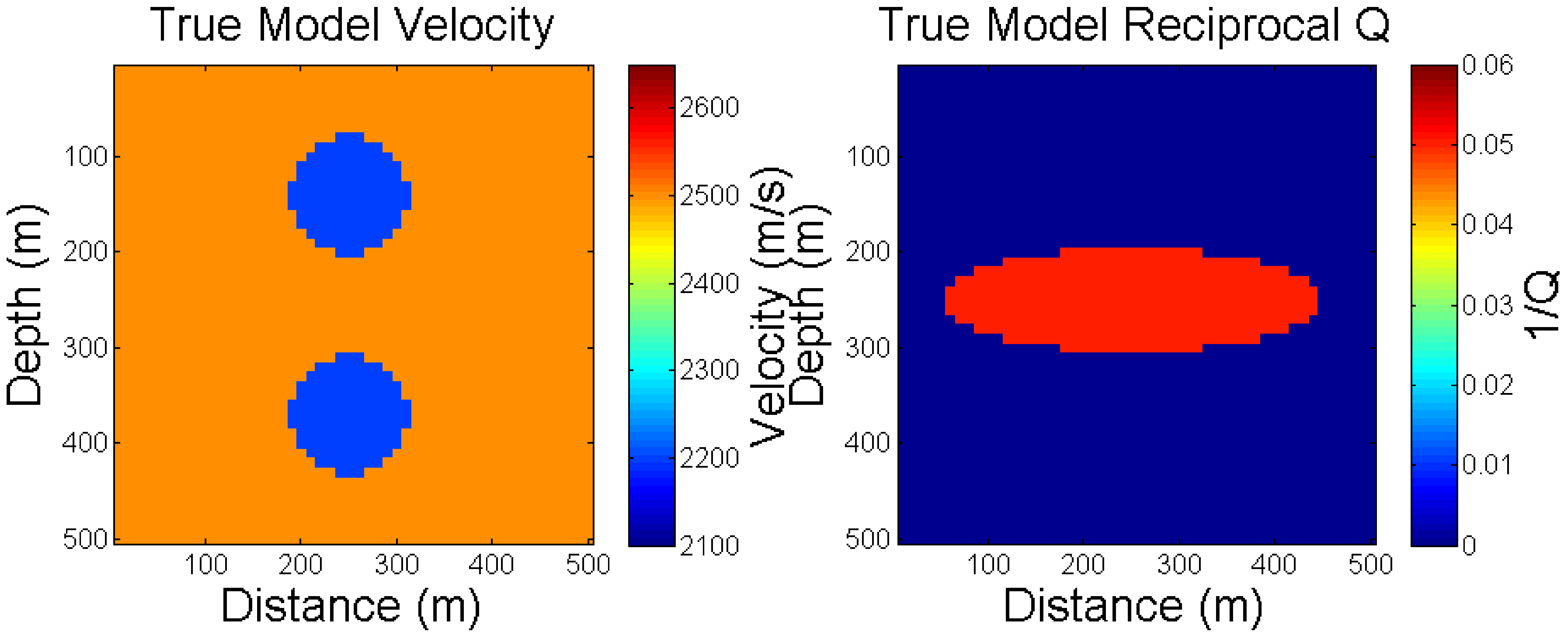
- Two parameters are considered, P-wave velocity V_P and quality factor Q_P.
- This approximation neglects the significant impacts that elasticity and anisotropy have on real data.
- The anacoustic approximation is not sufficient to generally model real data, but can be useful for
    1. special case environments e.g. zero offset VSP,
    2. guiding formulation of more complete (anelastic) FWI.

Full Waveform Inversion

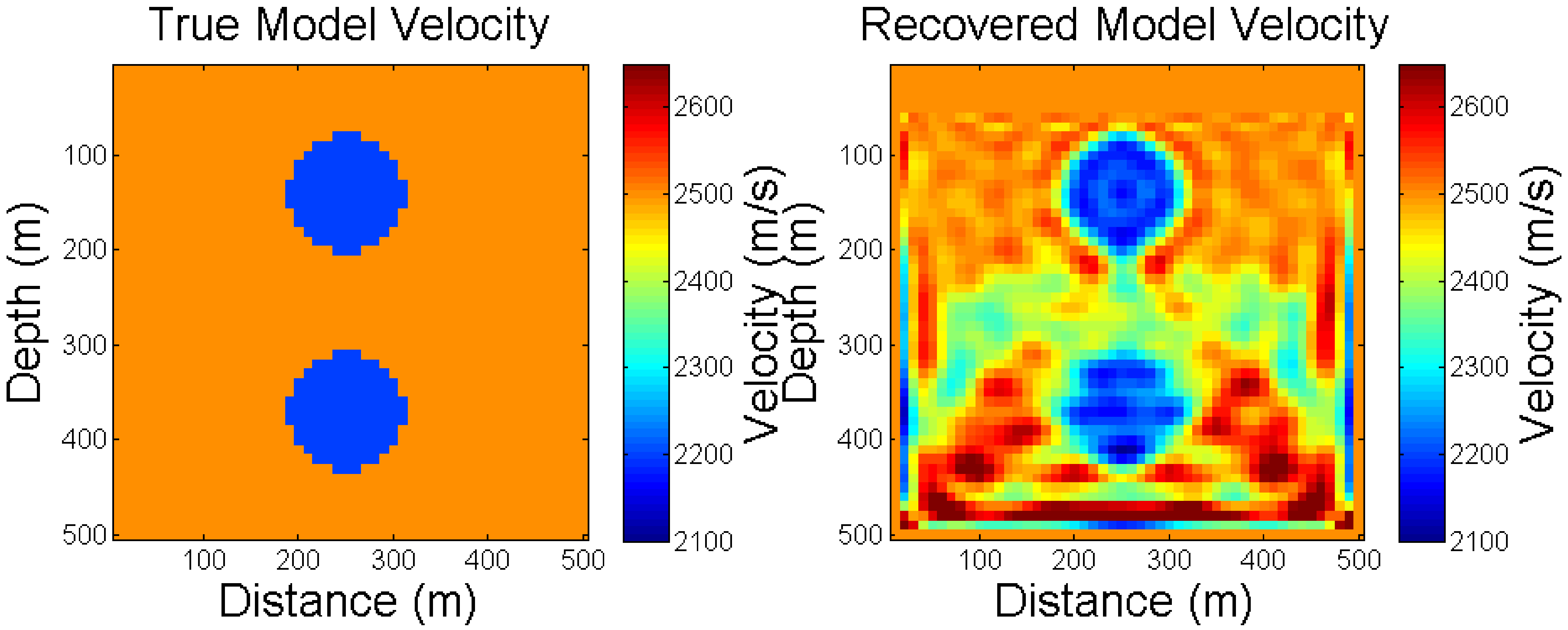
- FWI is an optimization problem which seeks to minimize an objective function.
- This objective function quantifies the discrepancy between measured data and synthetic data generated using the current model estimate.
- Ideally, the more similar the measured and synthetic data are, the closer the model estimate will be to the true subsurface.

Q model discrepancies

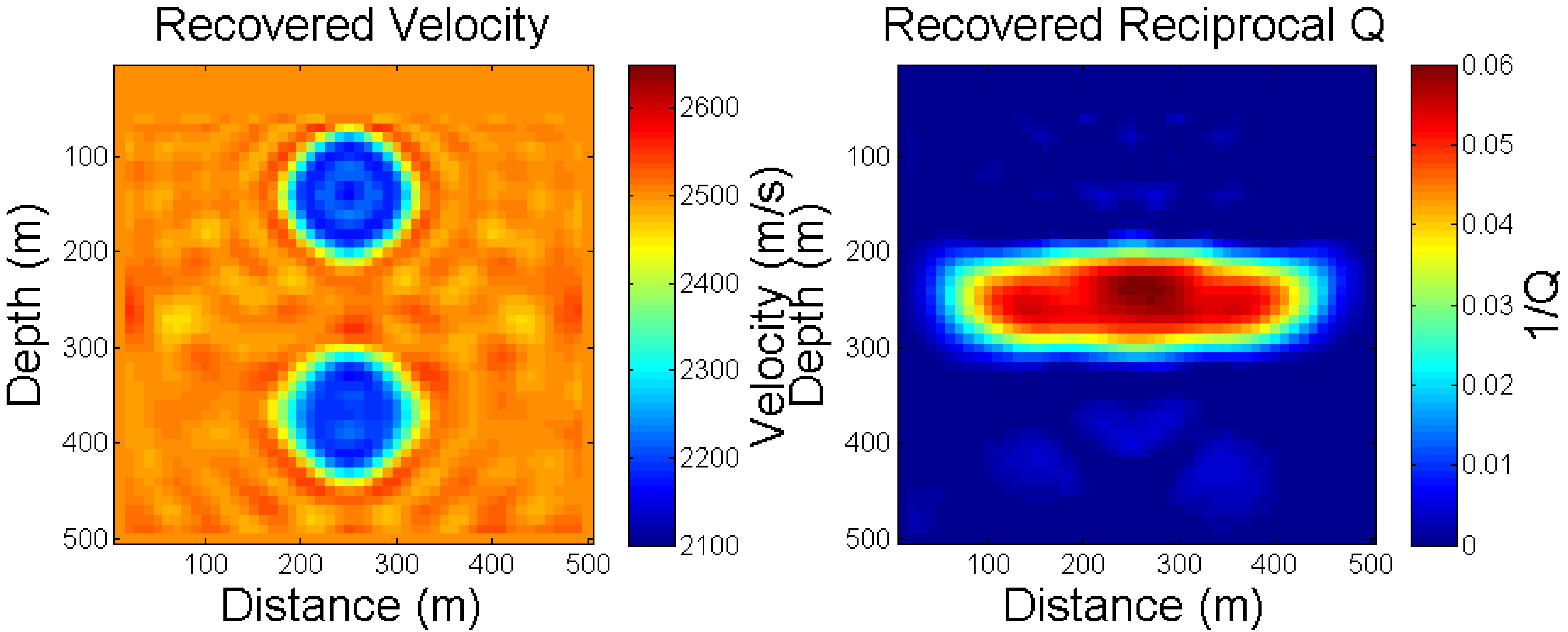
- A crucial assumption in FWI is that the physics which play a major role in creating the data are accurately reproduced in the synthetic modeling.


True Model Velocity
Depth (m)
100
200
300
400
500
Distance (m)
100
200
300
400
500
2600
2500
2400
2300
2200
2100
Velocity (m/s)
True Model Reciprocal Q
Depth (m)
100
200
300
400
500
Distance (m)
100
200
300
400
500
0.06
0.05
0.04
0.03
0.02
0.01
0
1/Q

Acoustic FWI



Anacoustic FWI



Q model discrepancies

- A crucial assumption in FWI is that the physics which play a major role in creating the data are accurately reproduced in the synthetic modeling.
- This assumption is questionable in the context of attenuation, where the prevalent nearly constant Q model is empirically based, and may not be applicable universally.
- It is important to know what impact an incorrect attenuation model will have on our anacoustic FWI.

KF nearly constant Q model type

- The most commonly assumed anacoustic model type is the empirical Kolsky-Futterman (KF) nearly constant Q model type.
- In the KF model, the wave equation is given by

$$\left[\frac{\omega^2}{c(\mathbf{r},\omega)^2} + \nabla^2\right] u(\mathbf{r},\omega) = f(\mathbf{r},\omega)$$

where ω is the frequency, u is the wave field, f is the source term, and

$$c(\mathbf{r},\omega) = c(\mathbf{r},\omega_0)\left[1 + \frac{1}{\pi Q(\mathbf{r})}\log\left(\frac{\omega}{\omega_0}\right) - \frac{i}{2Q(\mathbf{r})}\right] \quad ,$$

where ω_0 is a reference frequency.

SLS model type

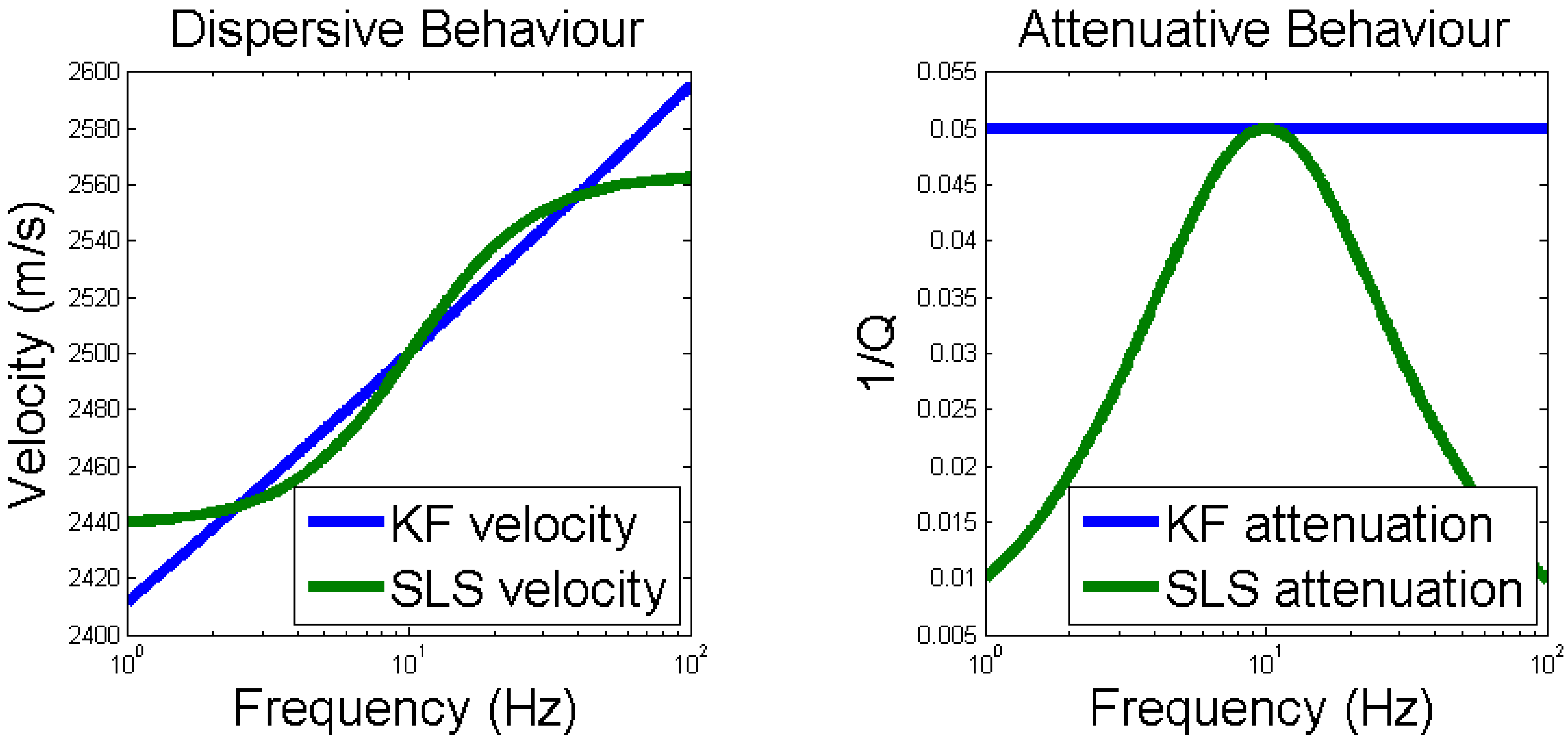
- Another anacoustic model type, which characterizes a number of possible attenuation mechanisms is the standard linear solid (SLS).
- In the SLS model type, *c* is given by

$$c(\mathbf{r},\omega) = c(\mathbf{r},\omega_0)\left[1 + \frac{(\omega\tau)^2}{Q(\mathbf{r},\omega)(1+(\omega\tau)^2)} - \frac{i}{2Q(\mathbf{r},\omega)}\right] \quad ,$$

$$Q(\omega) = \frac{1+\omega^2\tau_\epsilon\tau_\sigma}{\omega(\tau_\epsilon - \tau_\sigma)} \quad ,$$

and $\tau = \sqrt{\tau_\epsilon\tau_\sigma}$, where τ_ϵ and τ_σ are relaxation times.

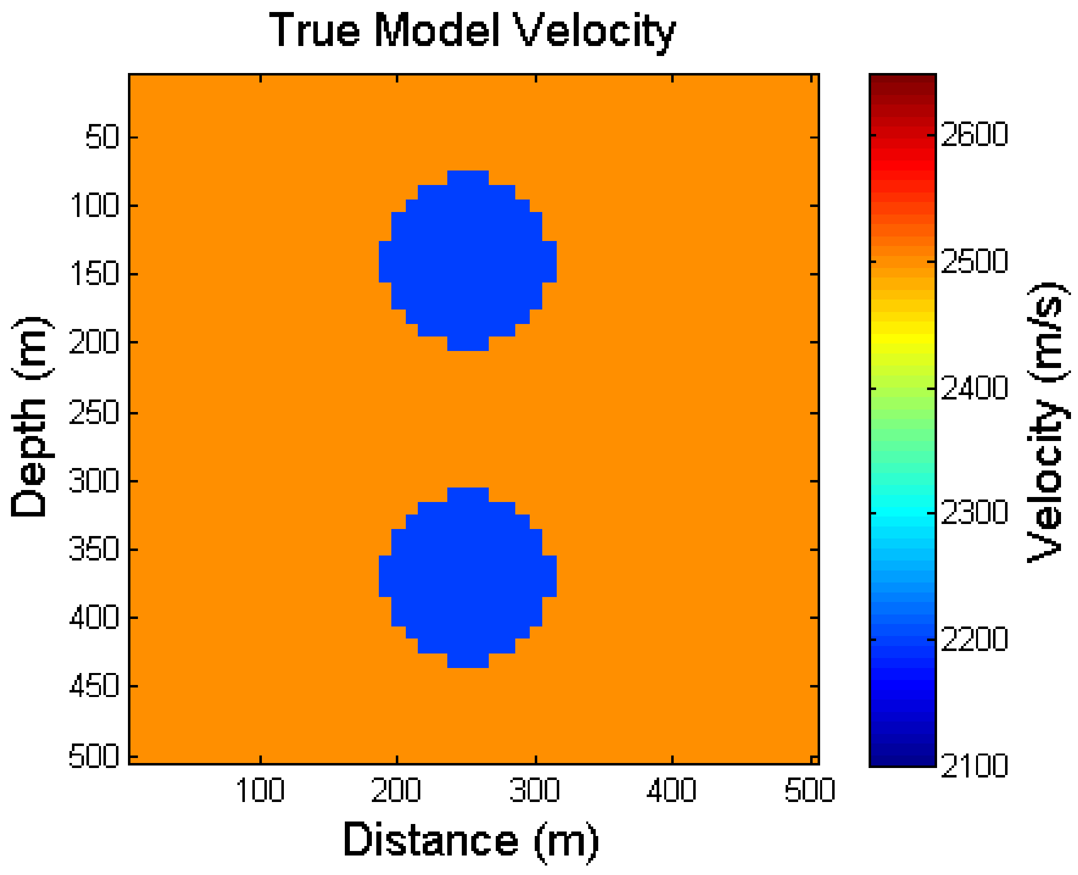
Comparison of KF and SLS model types



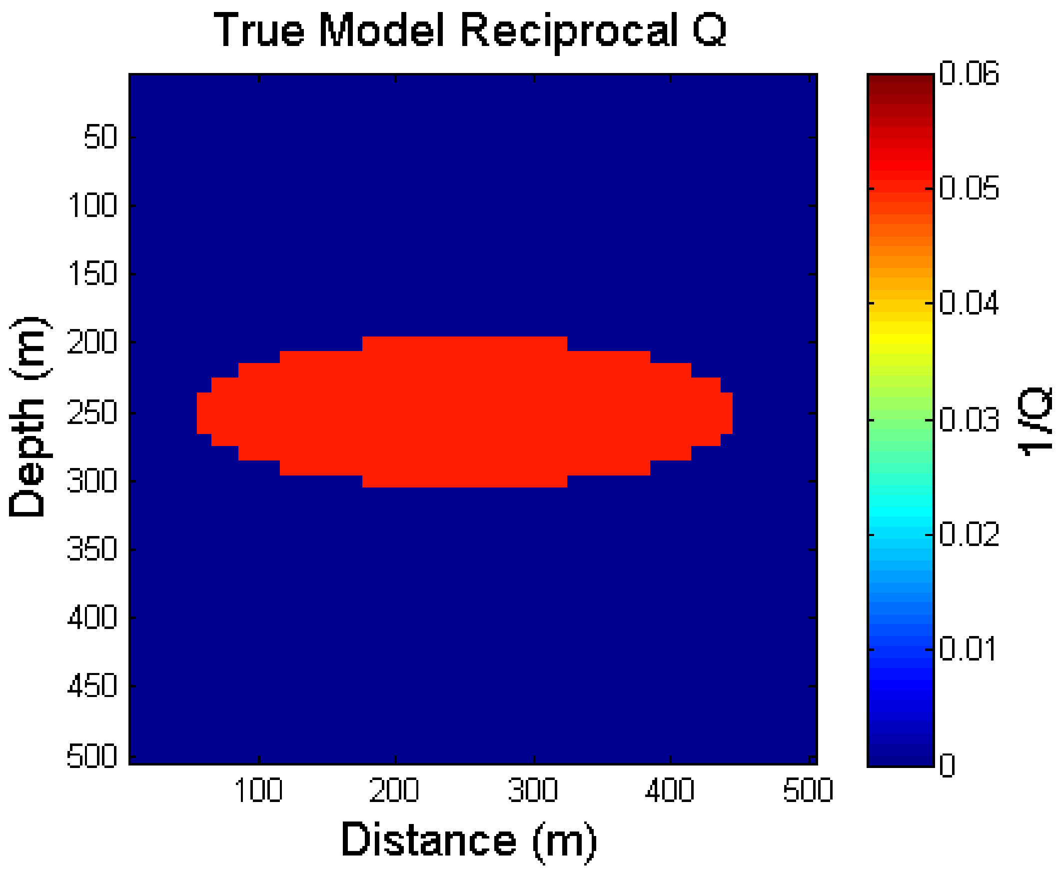
Q model discrepancies

- When using the wrong attenuation model type:
  1. Does attenuation compensation still occur?
  2. Does the recovered Q model have any relation to the true attenuation model?

KF Model

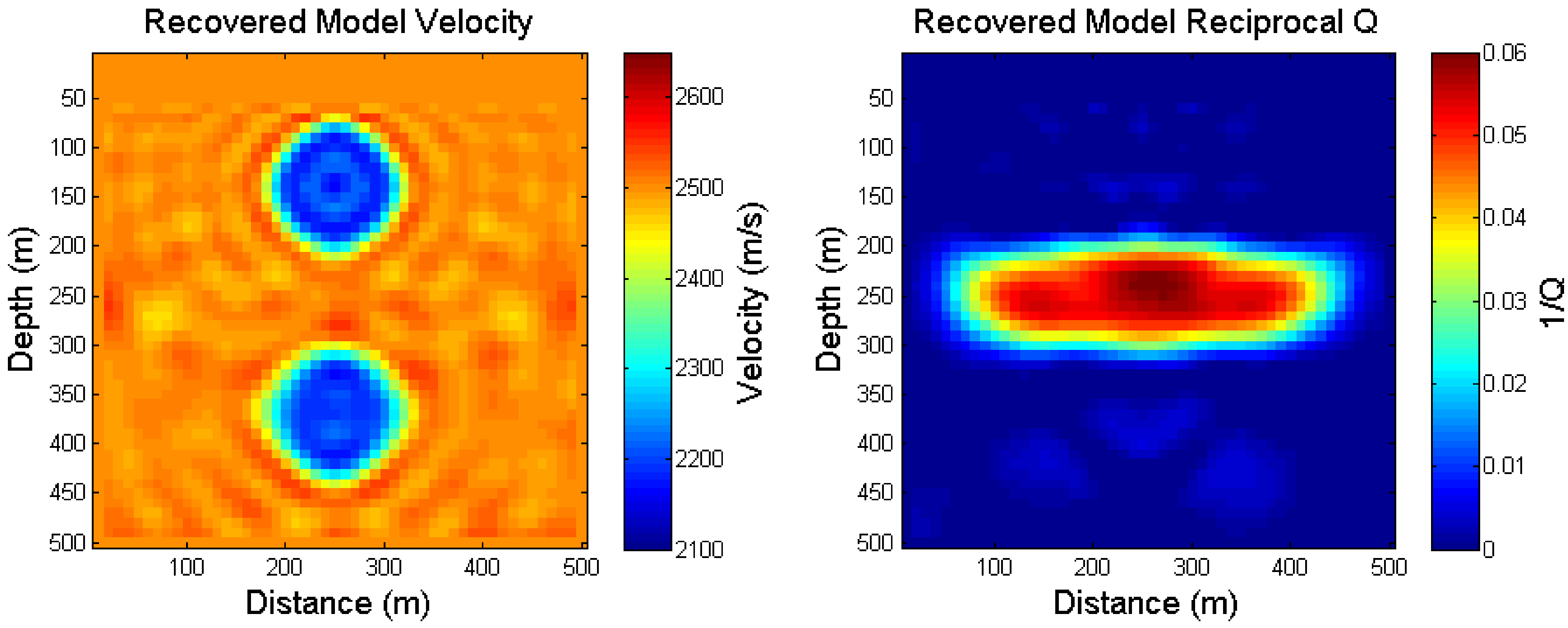


True Model Velocity
50
100
150
200
250
300
350
400
450
500
Depth (m)
100
200
300
400
500
Distance (m)
2600
2500
2400
2300
2200
2100
Velocity (m/s)

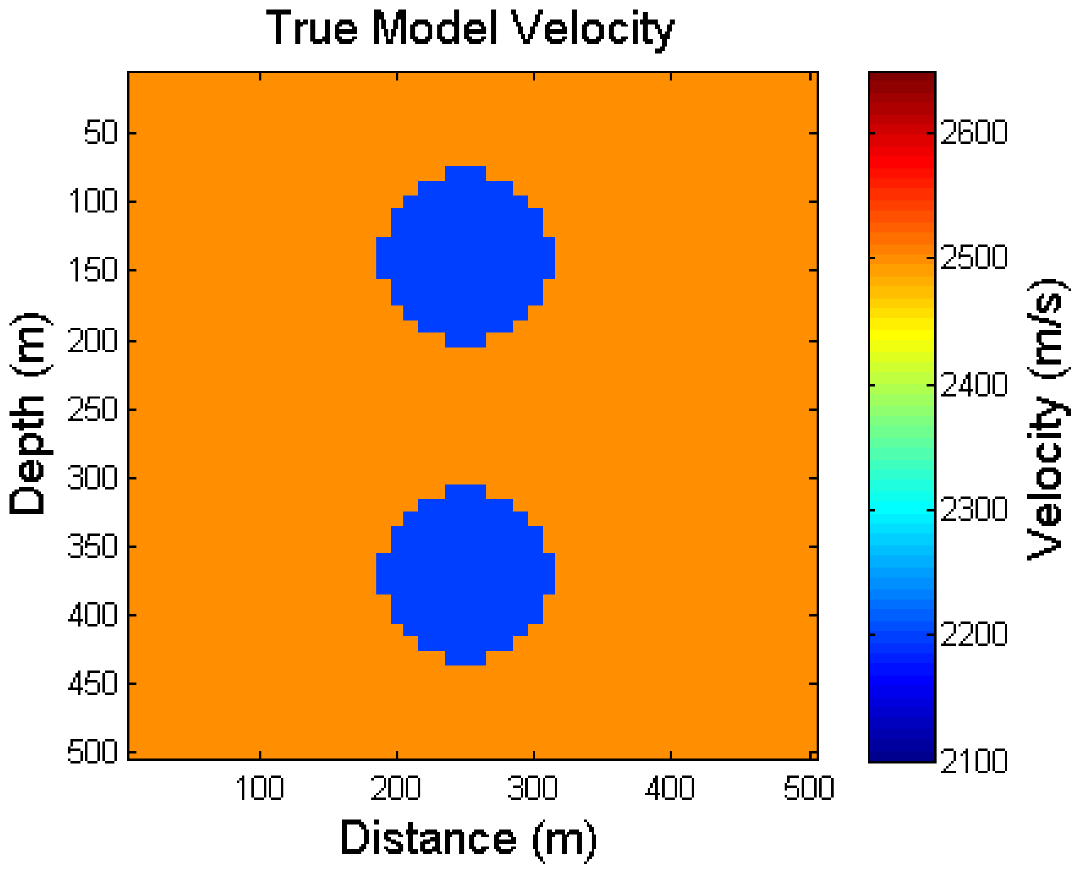


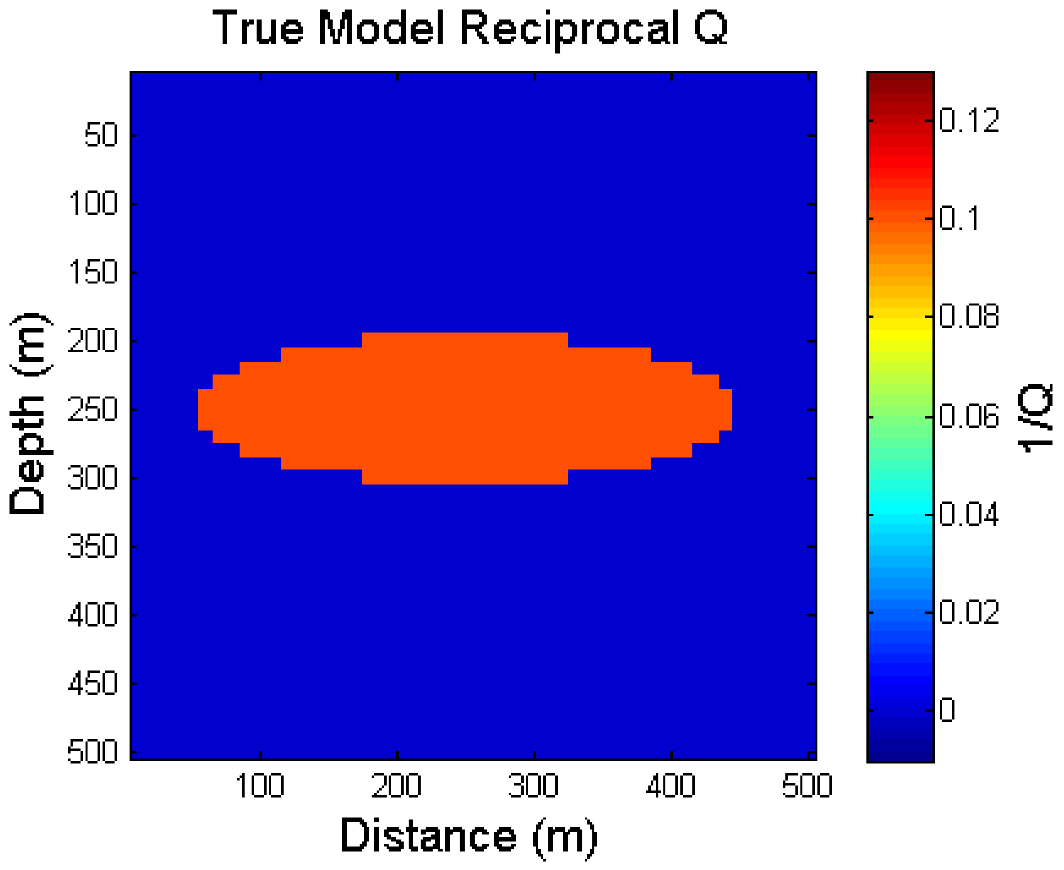
True Model Reciprocal Q
50
100
150
200
250
300
350
400
450
500
Depth (m)
100
200
300
400
500
Distance (m)
0.06
0.05
0.04
0.03
0.02
0.01
0
1/Q

KF FWI Result

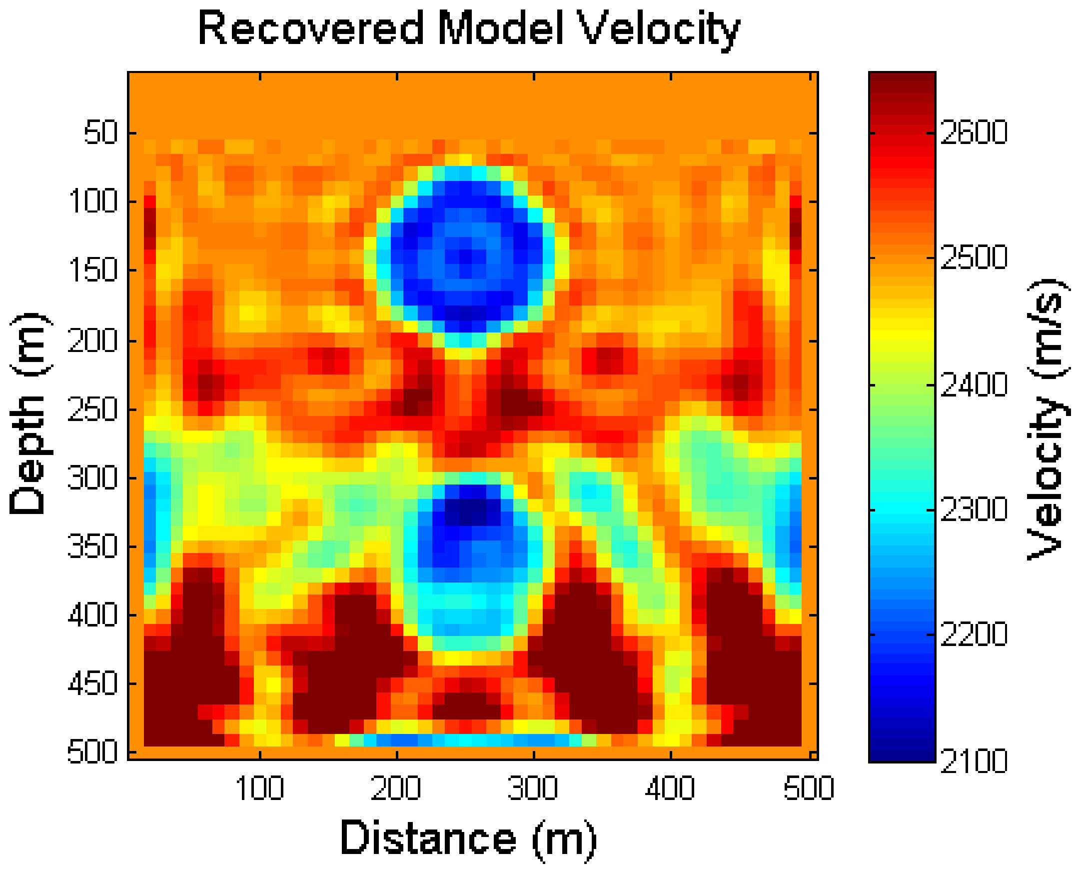


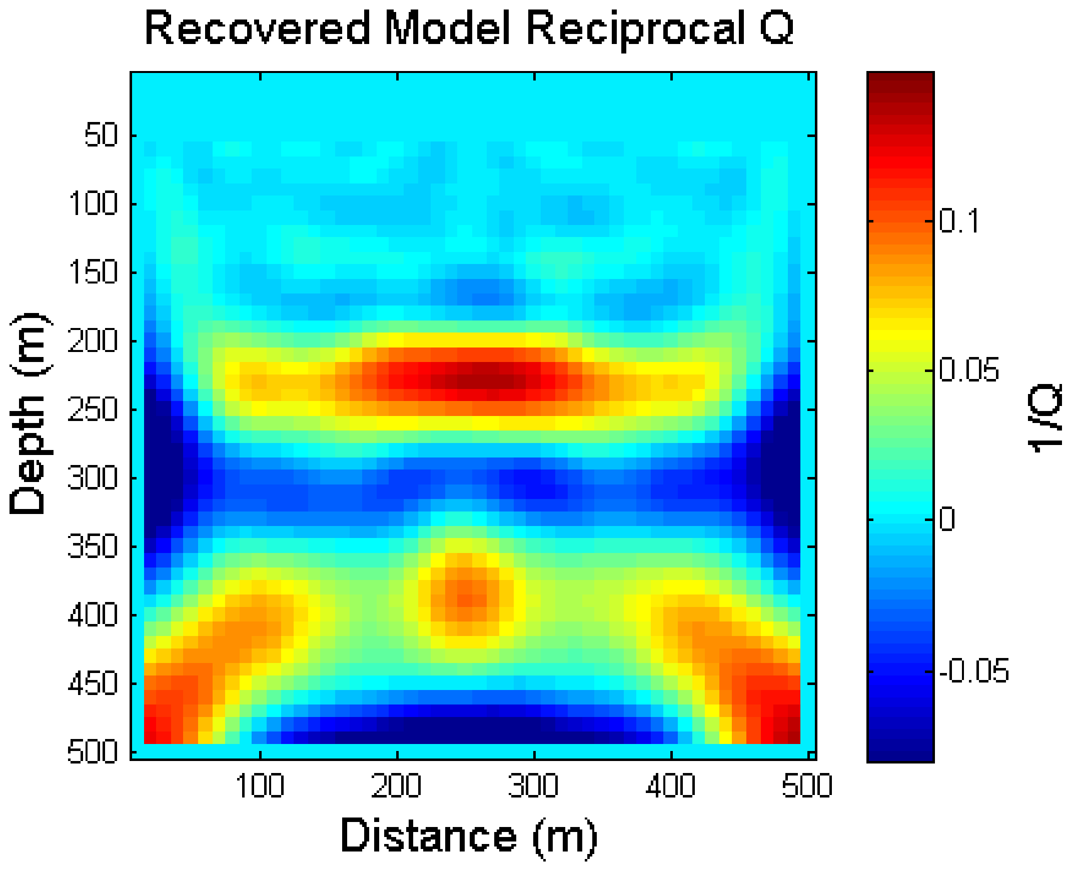
SLS Anacoustic Model, 15Hz





SLS Attenuation Example

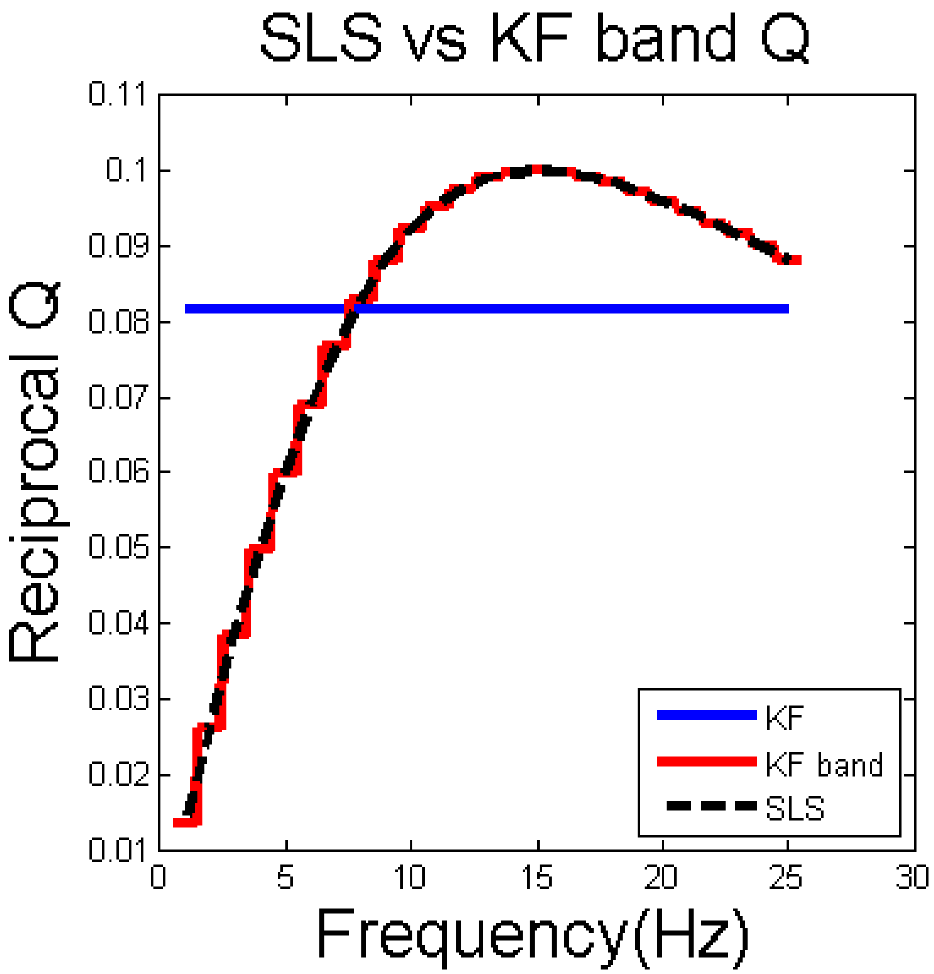


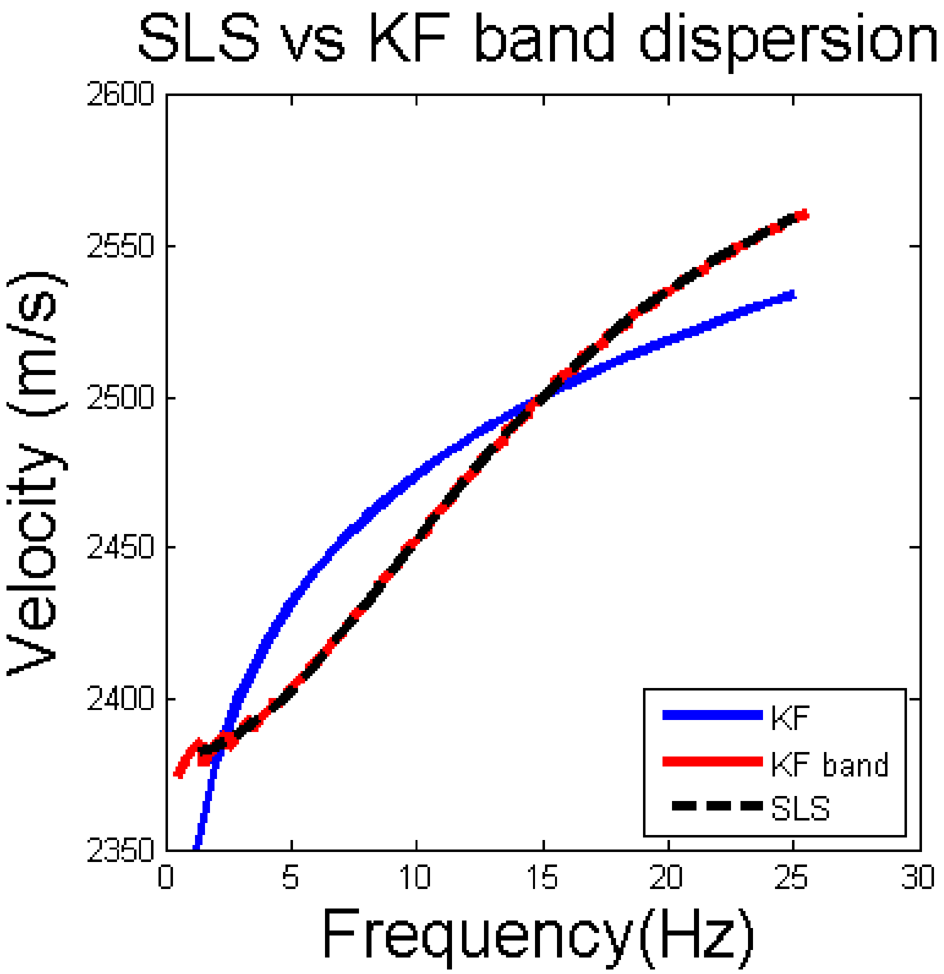


Approximating an Unknown Model

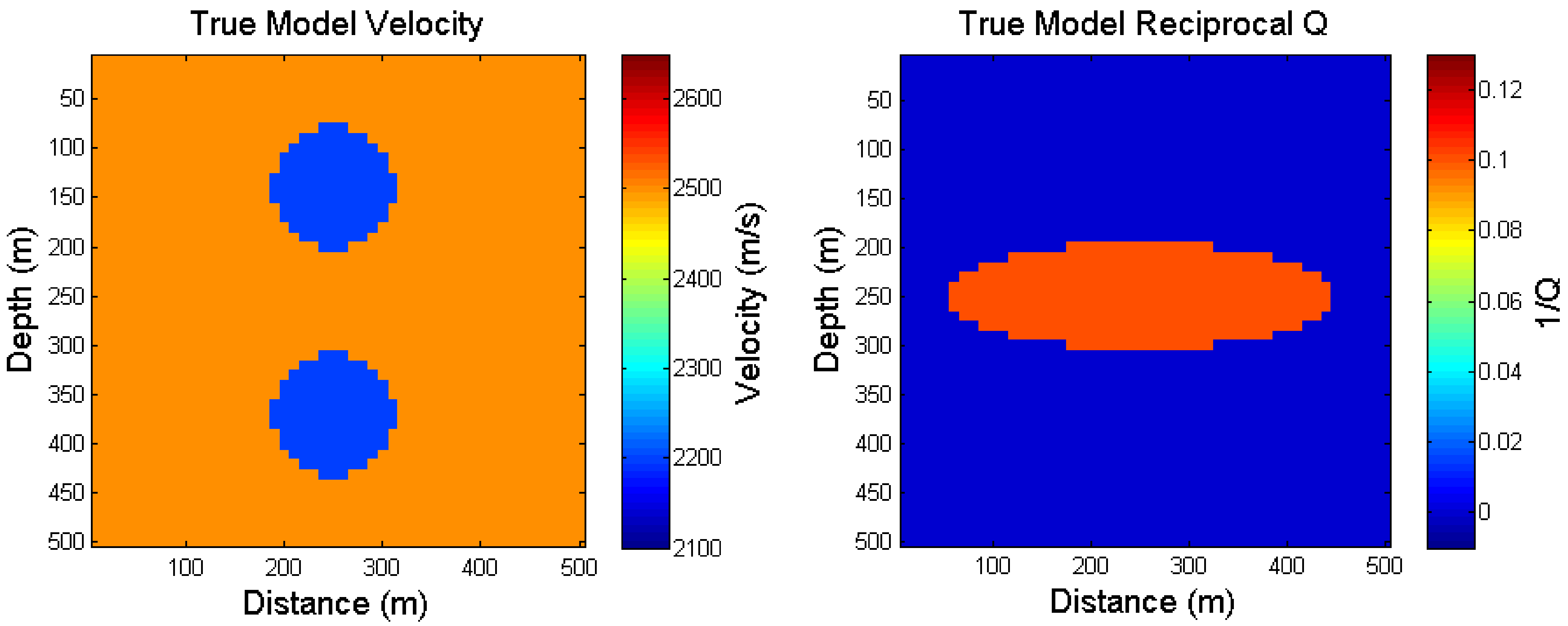
- FWI results when applying an incorrect attenuation model can have serious problems.
- Better results may be obtained if the attenuation and dispersion are allowed to more freely vary to better match the observed physics.
- This can be achieved to some extent by requiring a constant Q and V_P only over a small frequency band, and letting the Q and V_P in each band vary independently.

Approximating an Unknown Model

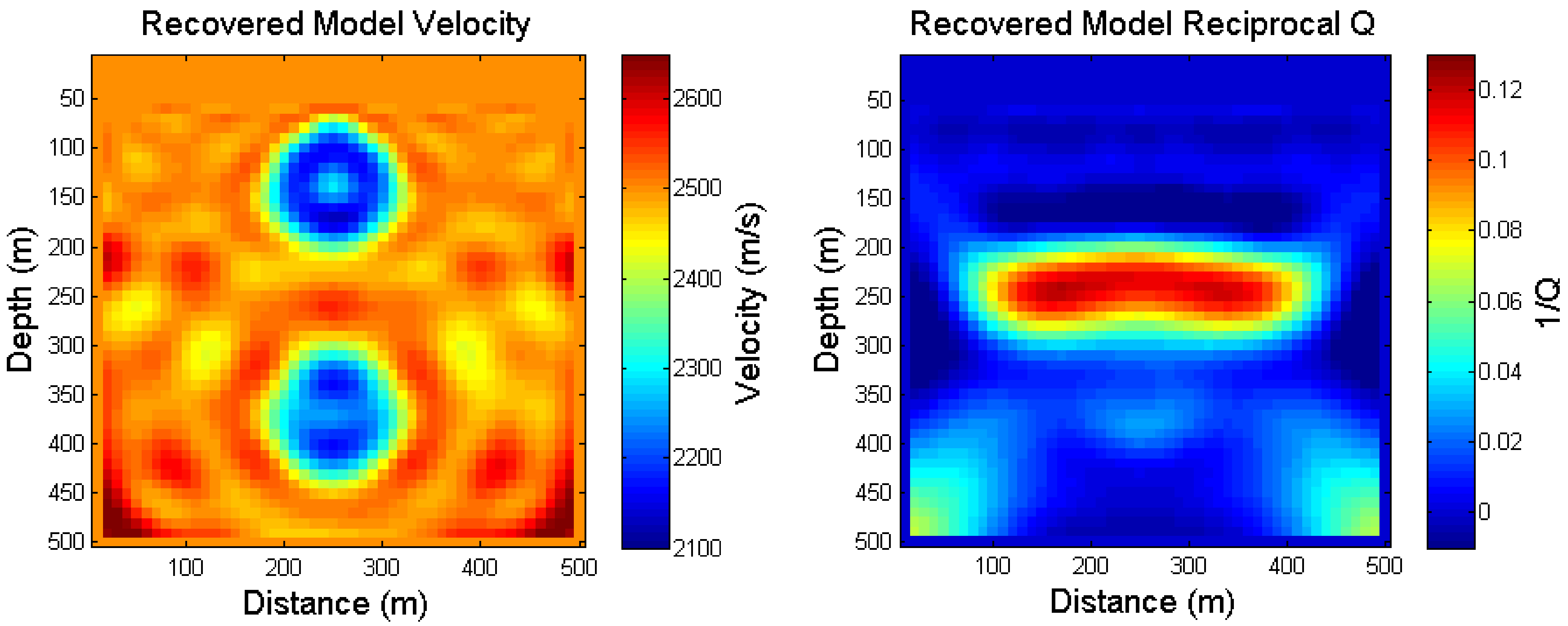




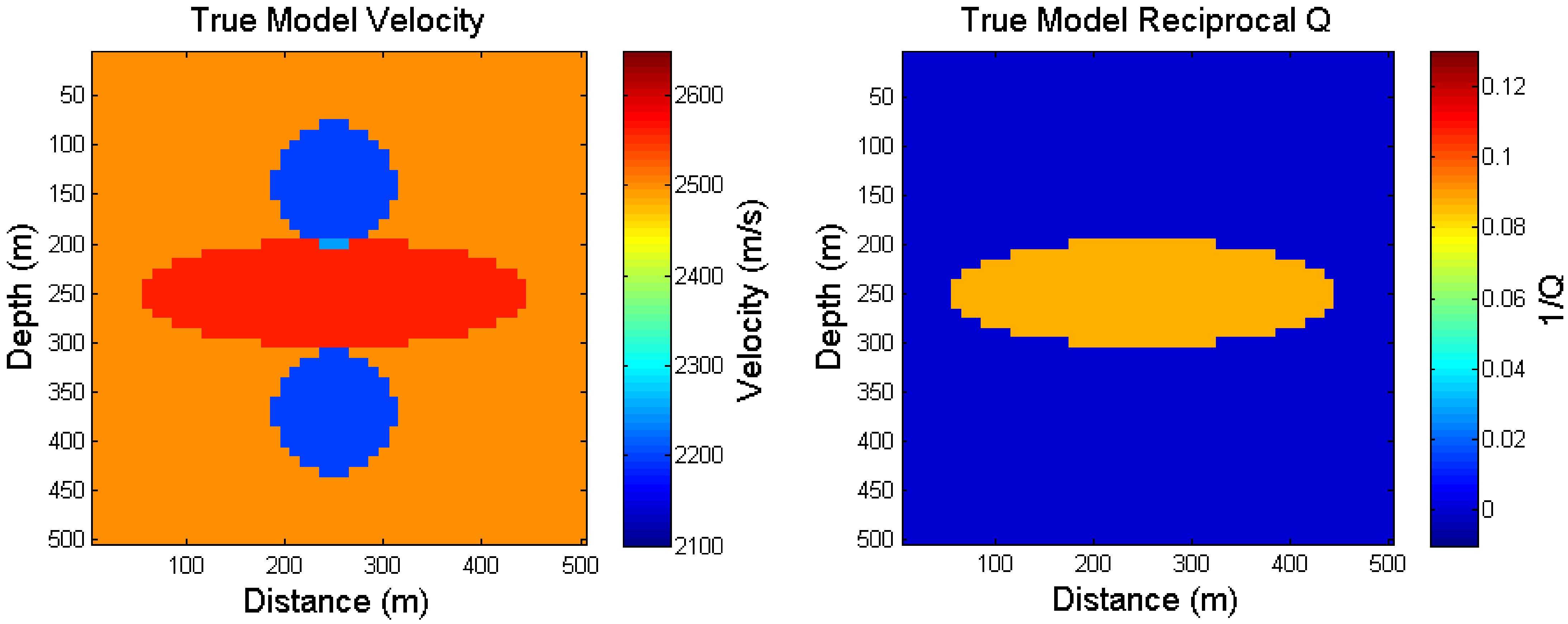
SLS Anacoustic Model, 15Hz



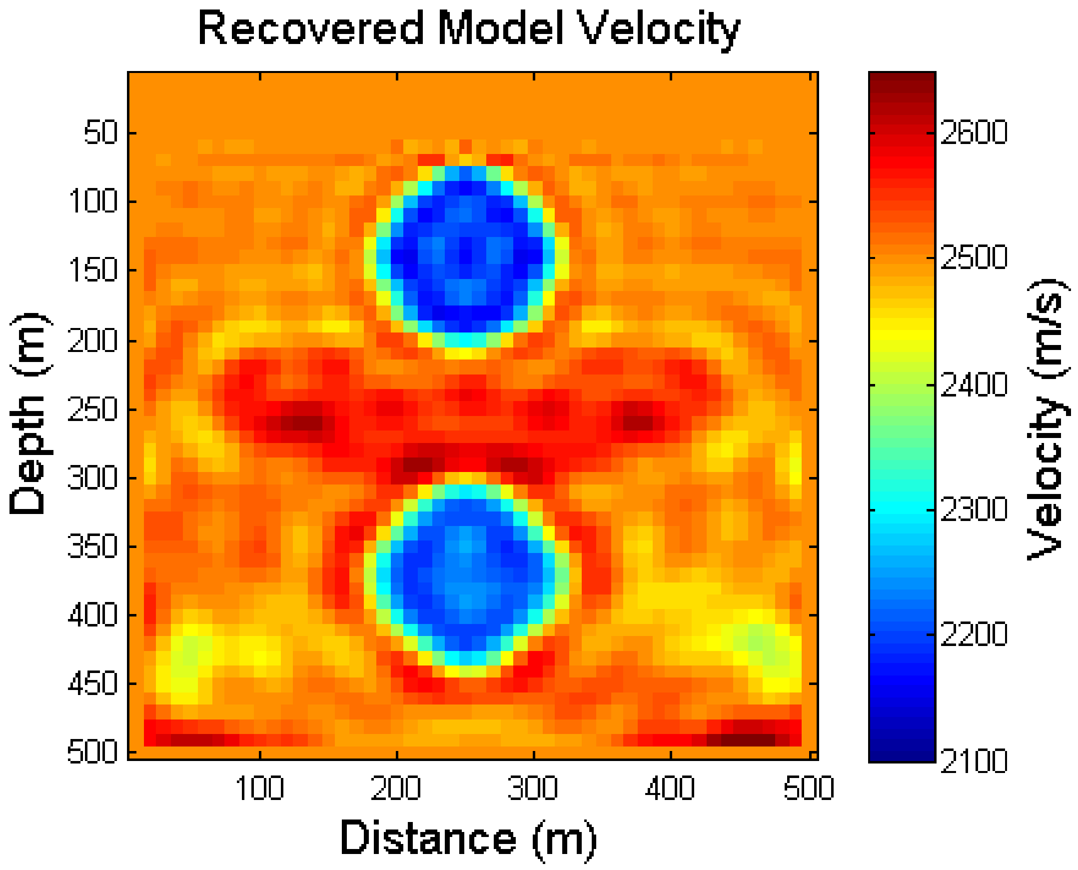
SLS Attenuation Example, Q(ω), 15Hz

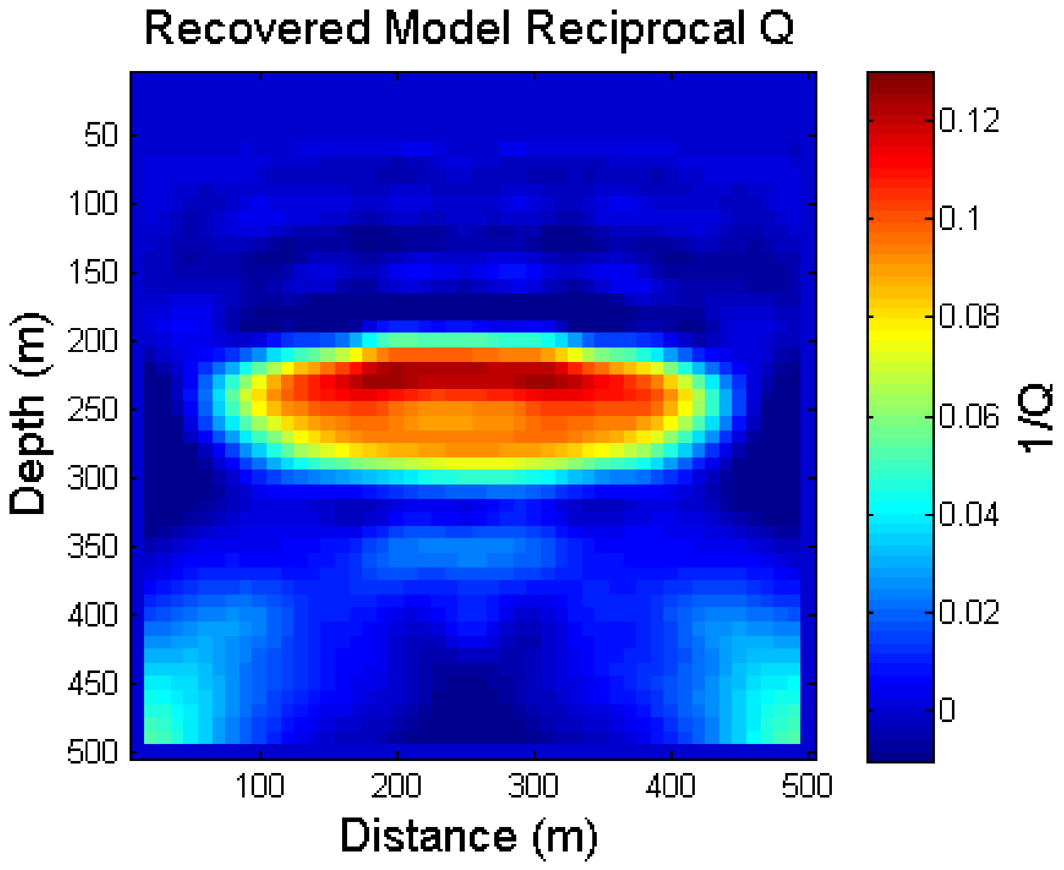


SLS Anacoustic Model, 25Hz

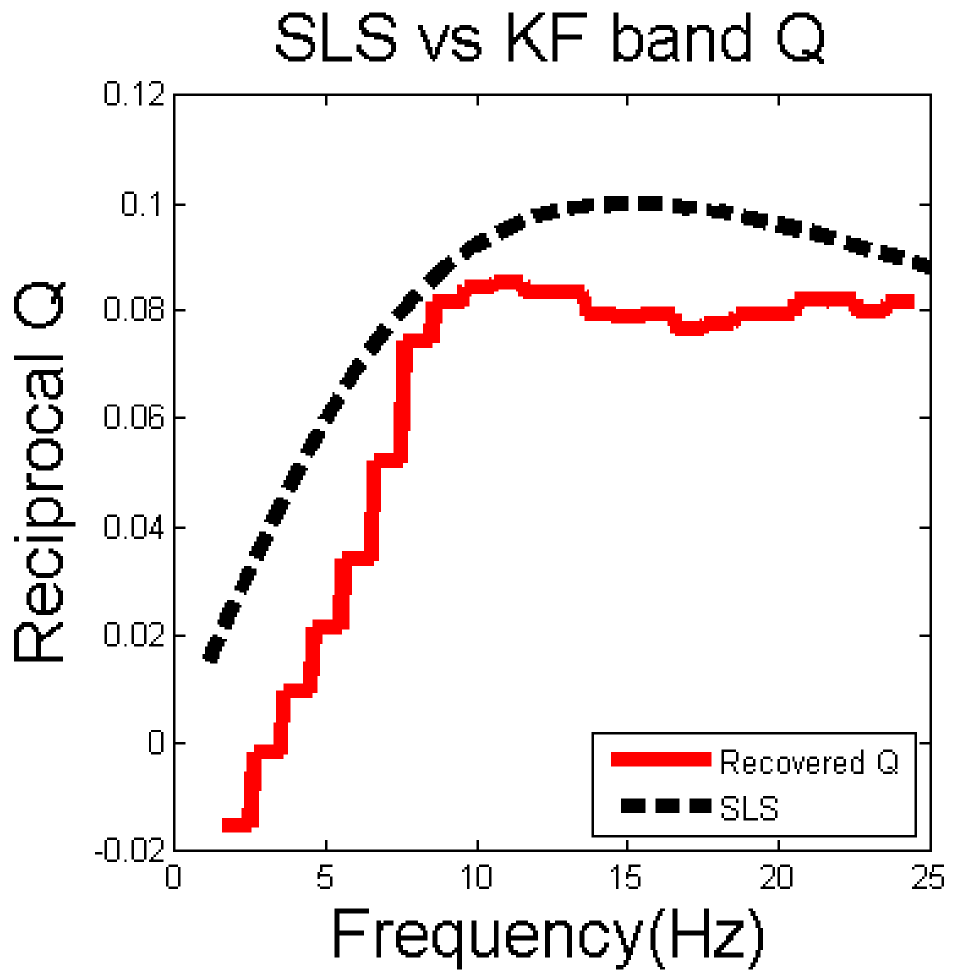


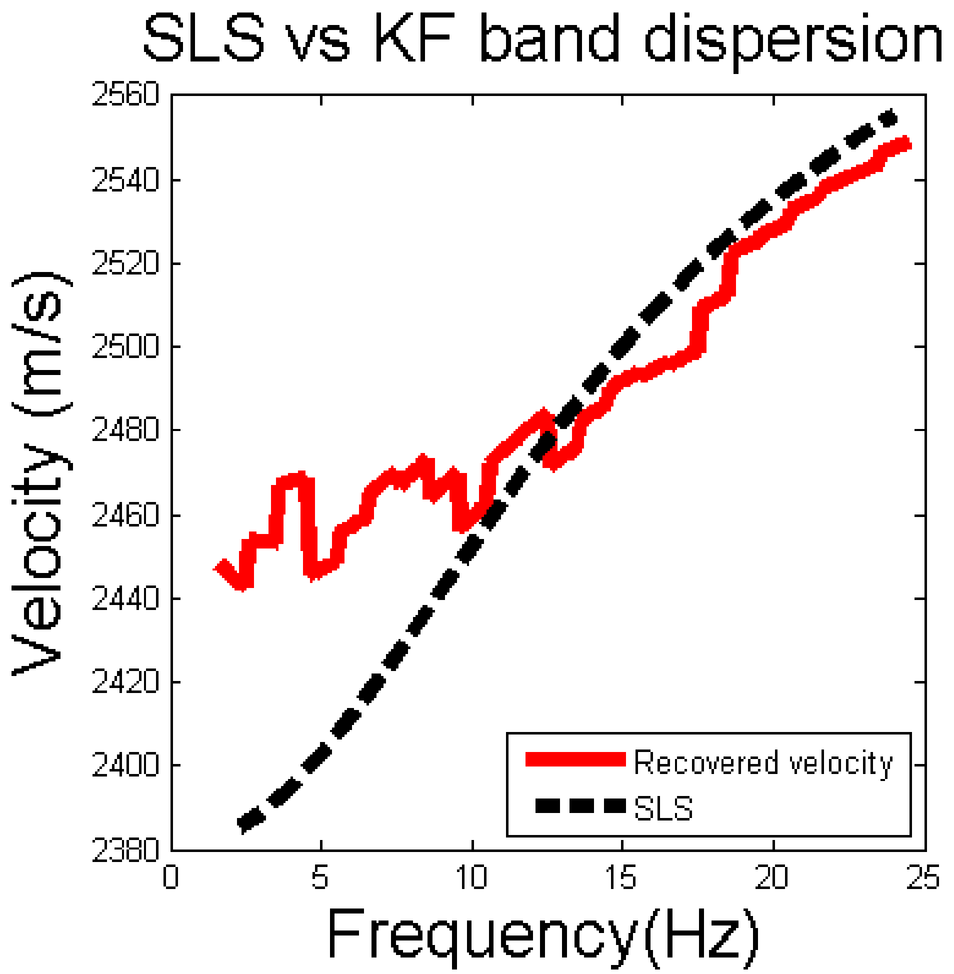
SLS Attenuation Example, Q(ω), 25Hz





Attenuation-Dispersion Comparison





Conclusions

- Attenuation does not generally conform to any one existing model type.
- Assuming incorrect attenuation physics can be a significant problem in anacoustic FWI.
- Flexible strategies can be adopted to cope with uncertainty in the attenuation mechanism.

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