Viscoelastic full waveform inversion based on recurrent neural network

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Banff, AB

Outline

- (1) Introduction to neural network

(2) The recurrent neural network (RNN)

(3) Viscoelastic full waveform inversion based on RNN

(4) Inversion with various of objective functions

(5) Conclusions

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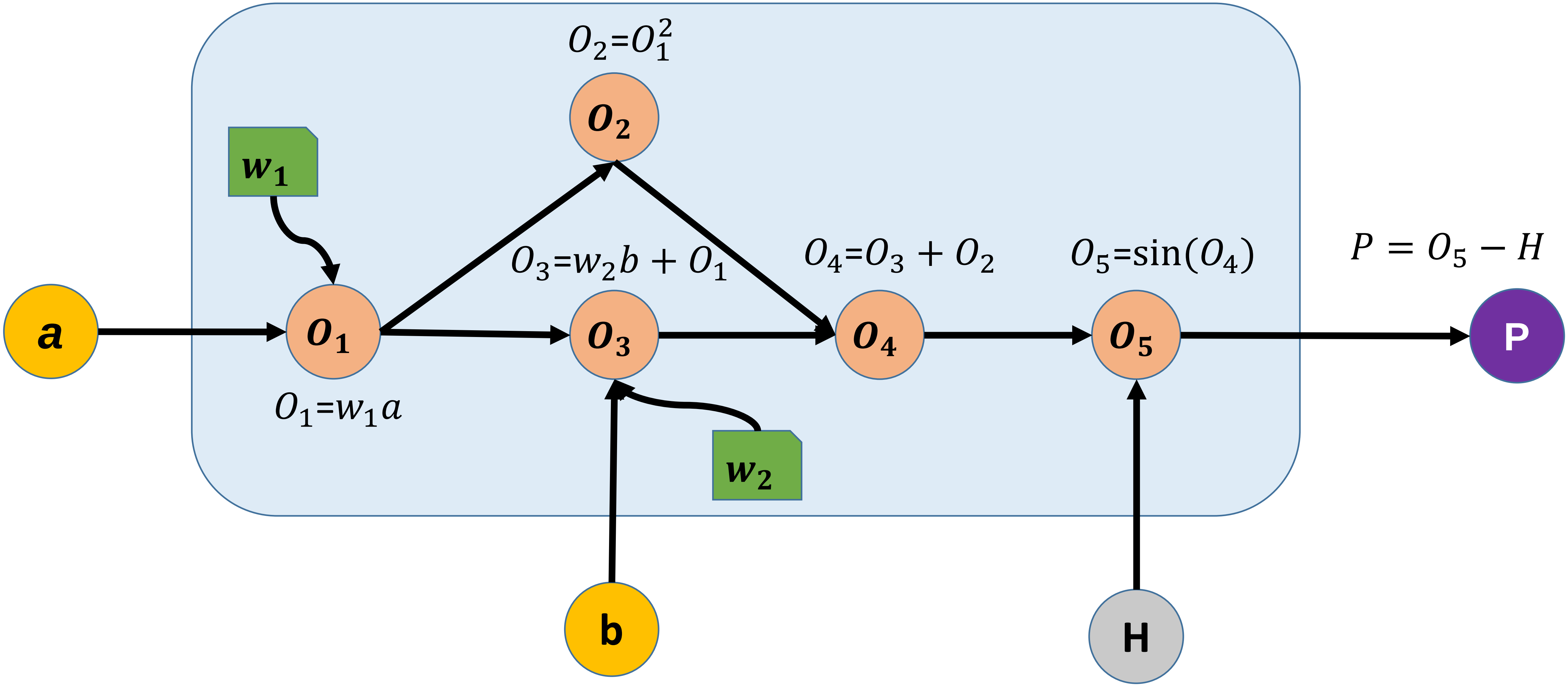
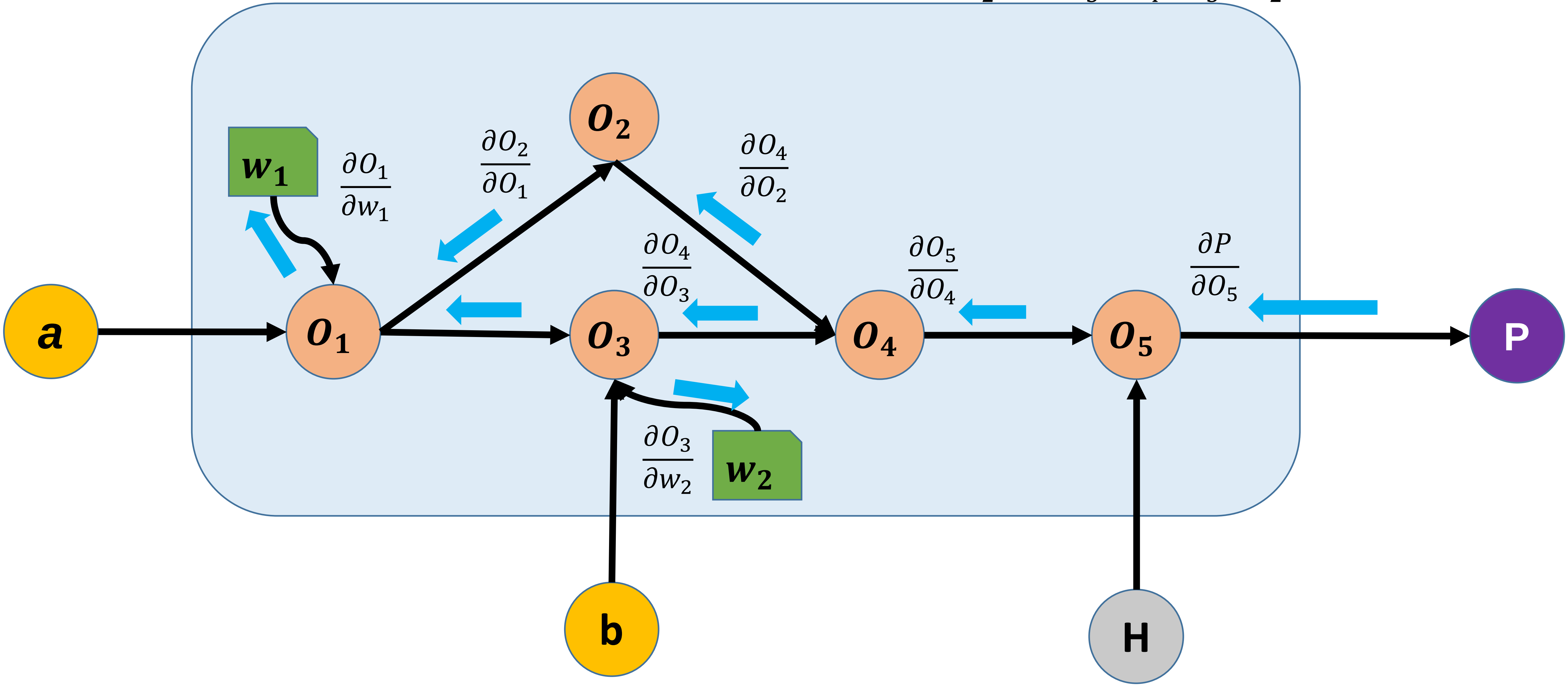
Part One: Introduction to neural network

Part one: Introduction to basic neural network



Part one: Introduction to basic neural network

$$\frac{\partial P}{\partial w_2} = \frac{\partial P}{\partial O_5}\frac{\partial O_5}{\partial O_4}\frac{\partial O_4}{\partial O_3}\frac{\partial O_3}{\partial w_2} = w_2 \cos(O_4)$$



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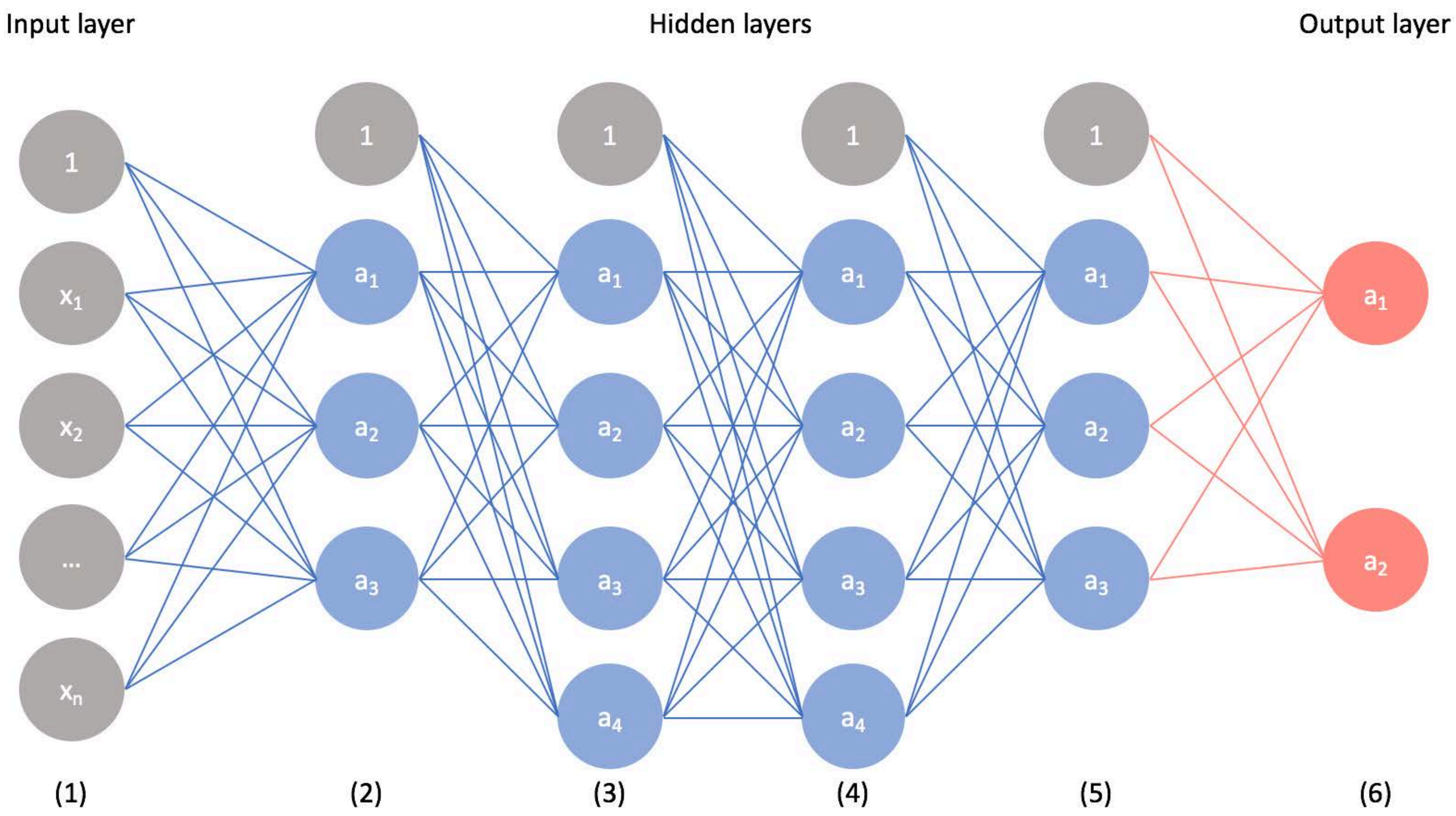
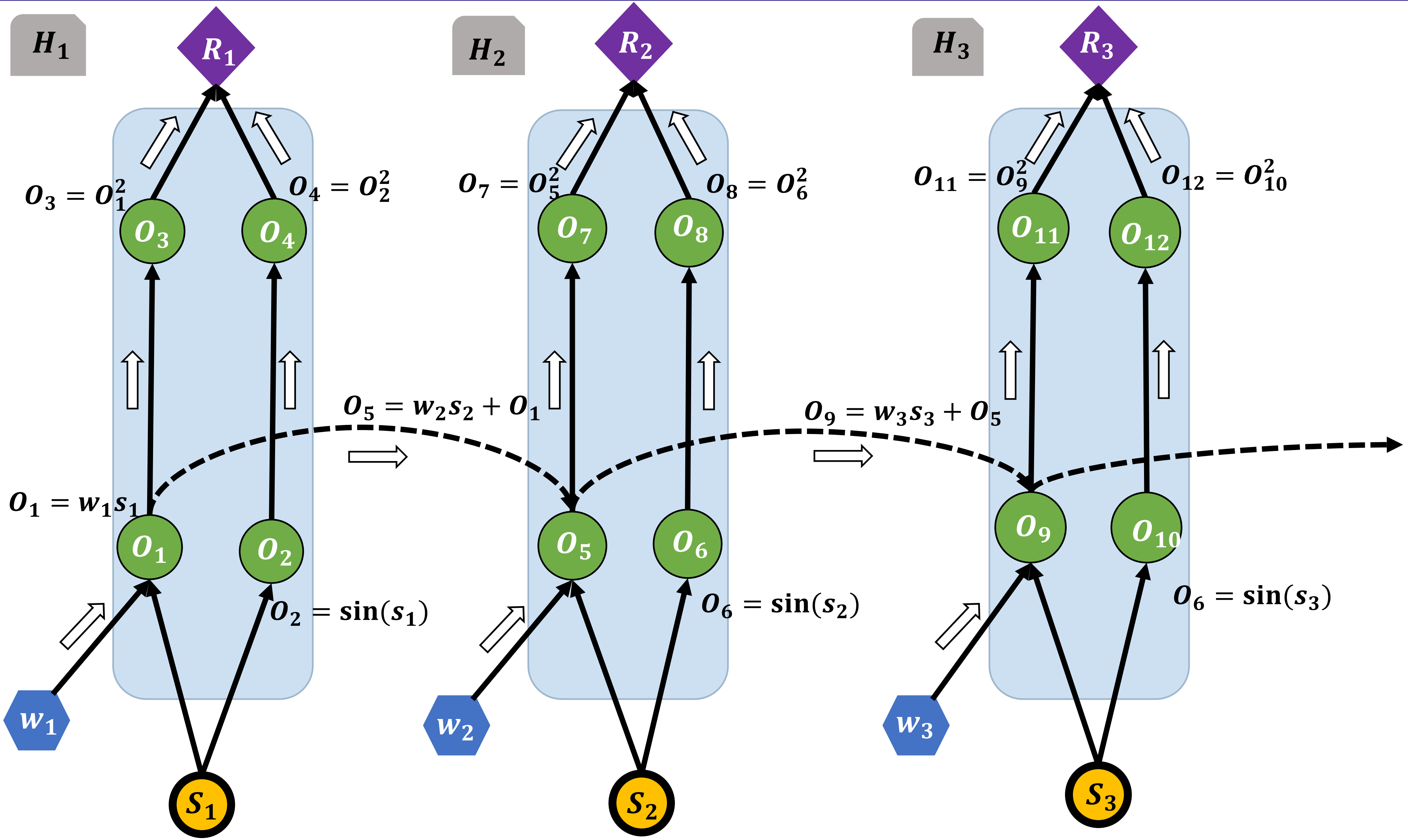


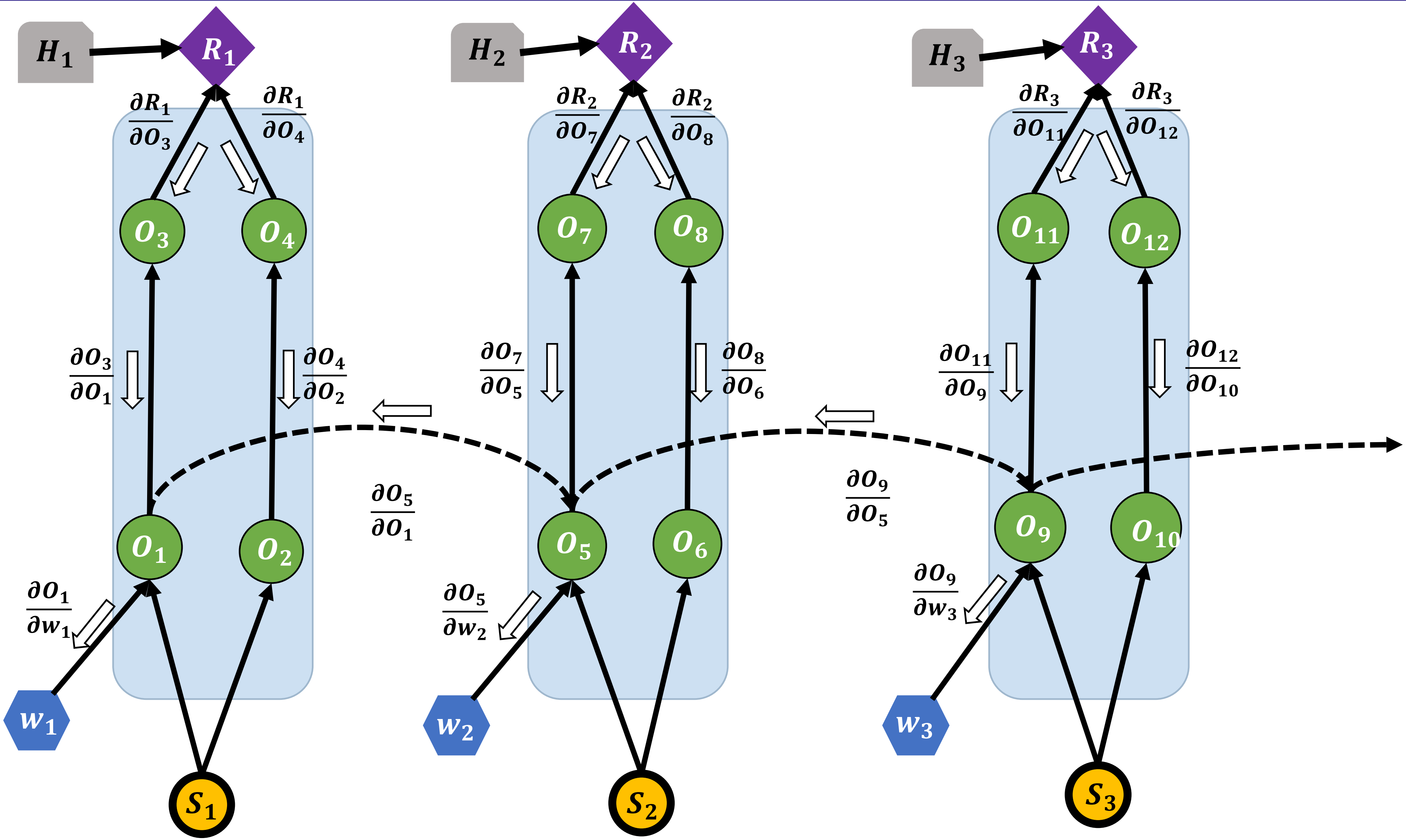
Fully connected network

Part TWO: The recurrent neural network

Part two: The recurrent neural network



Part two: The recurrent neural network



Part Three: Viscoelastic FWI based on RNN

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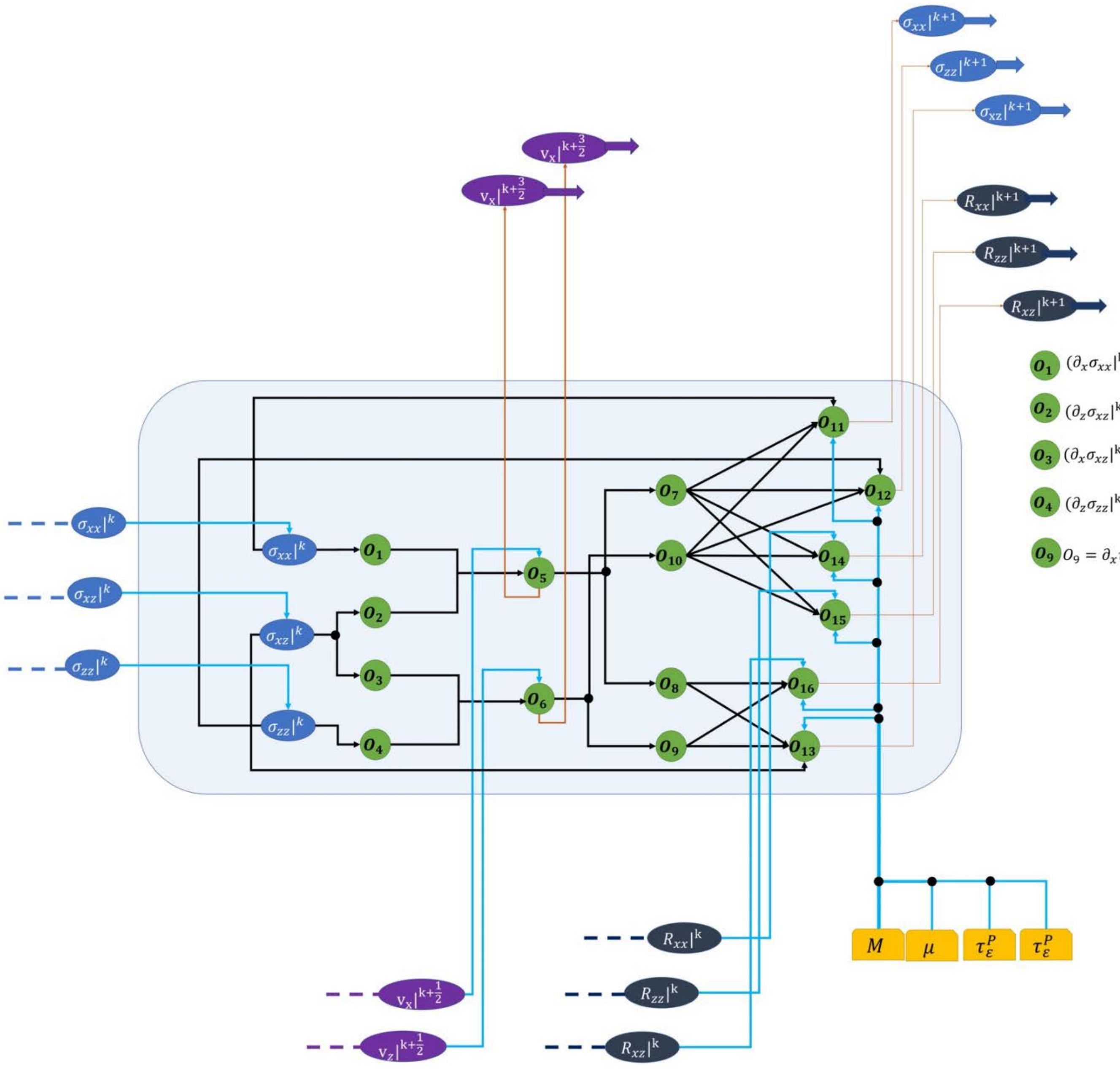
Viscoelastic wave equation

Robertson et al. (1994)

$$
\begin{cases}
\dfrac{\partial v_x}{\partial t} = \dfrac{1}{\rho}\left(\dfrac{\partial \sigma_{xx}}{\partial x} + \dfrac{\partial \sigma_{xy}}{\partial y}\right) \\
\dfrac{\partial v_y}{\partial t} = \dfrac{1}{\rho}\left(\dfrac{\partial \sigma_{xy}}{\partial x} + \dfrac{\partial \sigma_{yy}}{\partial y}\right) \\
\dfrac{\partial \sigma_{xy}}{\partial t} = \mu\dfrac{\tau_\varepsilon^s}{\tau_\sigma}\left(\dfrac{\partial v_x}{\partial y} + \dfrac{\partial v_y}{\partial x}\right) + r_{xy} \\
\dfrac{\partial \sigma_{xx}}{\partial t} = \pi\dfrac{\tau_\varepsilon^p}{\tau_\sigma}\left(\dfrac{\partial v_x}{\partial x} + \dfrac{\partial v_y}{\partial y}\right) - 2\mu\dfrac{\tau_\varepsilon^s}{\tau_\sigma}\dfrac{\partial v_y}{\partial y} + r_{xx} \\
\dfrac{\partial \sigma_{yy}}{\partial t} = \pi\dfrac{\tau_\varepsilon^p}{\tau_\sigma}\left(\dfrac{\partial v_x}{\partial x} + \dfrac{\partial v_y}{\partial y}\right) - 2\mu\dfrac{\tau_\varepsilon^s}{\tau_\sigma}\dfrac{\partial v_x}{\partial x} + r_{yy} \\
\dfrac{\partial r_{xy}}{\partial t} = -\dfrac{1}{\tau_\sigma}\left(r_{xy} + \mu\left(\dfrac{\tau_\varepsilon^s}{\tau_\sigma} - 1\right)\left(\dfrac{\partial v_x}{\partial y} + \dfrac{\partial v_y}{\partial x}\right)\right) \\
\dfrac{\partial r_{xx}}{\partial t} = -\dfrac{1}{\tau_\sigma}\left(r_{xx} + \pi\left(\dfrac{\tau_\varepsilon^p}{\tau_\sigma} - 1\right)\left(\dfrac{\partial v_x}{\partial x} + \dfrac{\partial v_y}{\partial y}\right) - 2\mu\left(\dfrac{\tau_\varepsilon^s}{\tau_\sigma} - 1\right)\dfrac{\partial v_y}{\partial y}\right) \\
\dfrac{\partial r_{yy}}{\partial t} = -\dfrac{1}{\tau_\sigma}\left(r_{yy} + \pi\left(\dfrac{\tau_\varepsilon^p}{\tau_\sigma} - 1\right)\left(\dfrac{\partial v_x}{\partial x} + \dfrac{\partial v_y}{\partial y}\right) - 2\mu\left(\dfrac{\tau_\varepsilon^s}{\tau_\sigma} - 1\right)\dfrac{\partial v_x}{\partial x}\right)
\end{cases}
$$

Part three: Viscoelastic FWI based on RNN



O_1: $(\partial_x \sigma_{xx}|^{k})\Delta t/\rho$

O_2: $(\partial_z \sigma_{xz}|^{k})\Delta t/\rho$

O_3: $(\partial_x \sigma_{xz}|^{k})\Delta t/\rho$

O_4: $(\partial_z \sigma_{zz}|^{k})\Delta t/\rho$

O_5: $O_5 = v_x|^{k+\frac{1}{2}} = v_x|^{k-\frac{1}{2}} + \Delta t(O_1 + O_2)$

O_6: $O_6 = v_z|^{k+\frac{1}{2}} = v_z|^{k-\frac{1}{2}} + \Delta t(O_3 + O_4)$

O_7: $O_7 = \partial_x v_x|^{k+\frac{1}{2}}$

O_8: $O_8 = \partial_z v_x|^{k+\frac{1}{2}}$

O_9: $O_9 = \partial_x v_z|^{k+\frac{1}{2}}$

O_{10}: $O_{10} = \partial_z v_z|^{k+\frac{1}{2}}$

O_{11}: $O_{11} = \sigma_{xx}|^{k+1} = \sigma_{xx}|^{k} + \Delta t M\left(\frac{\tau_\varepsilon^p}{\tau_\sigma}\right)(O_7 + O_{10}) + (\Delta t)^2\mu\left(\frac{\tau_\varepsilon^s}{\tau_\sigma}\right)O_{10} + \Delta t R_{xx}|^{k+1}$

O_{12}: $O_{12} = \sigma_{zz}|^{k+1} = \sigma_{zz}|^{k} + \Delta t M\left(\frac{\tau_\varepsilon^p}{\tau_\sigma}\right)(O_7 + O_{10}) + (\Delta t)^2\mu\left(\frac{\tau_\varepsilon^s}{\tau_\sigma}\right)O_7 + \Delta t R_{zz}|^{k+1}$

O_{13}: $O_{13} = \sigma_{xz}|^{k+1} = \sigma_{xz}|^{k} + \Delta t M\left(\frac{\tau_\varepsilon^s}{\tau_\sigma}\right)(O_8 + O_9) + \Delta t R_{xz}|^{k+1}$

O_{14}: $O_{14} = R_{xx}|^{k+1} = R_{xx}|^{k} + \Delta t(\frac{1}{\tau_\sigma})(O_{14} + M\left(\frac{\tau_\varepsilon^p}{\tau_\sigma} - 1\right)(O_7 + O_{10}) - 2\mu\left(\frac{\tau_\varepsilon^s}{\tau_\sigma} - 1\right)O_{10})$

O_{15}: $O_{15} = R_{zz}|^{k+1} = R_{zz}|^{k} + \Delta t(\frac{1}{\tau_\sigma})(O_{14} + M\left(\frac{\tau_\varepsilon^p}{\tau_\sigma} - 1\right)(O_7 + O_{10}) - 2\mu\left(\frac{\tau_\varepsilon^s}{\tau_\sigma} - 1\right)O_7)$

O_{16}: $O_{16} = R_{xz}|^{k+1} = R_{xz}|^{k} + \Delta t(\frac{1}{\tau_\sigma})(O_{14} + \mu\left(\frac{\tau_\varepsilon^s}{\tau_\sigma} - 1\right)(O_8 + O_9))$

Velocity field

Stress field

Memory variable

Trainable parameters (M)

Simple over lay no data exchange

Different data run parallel in cell

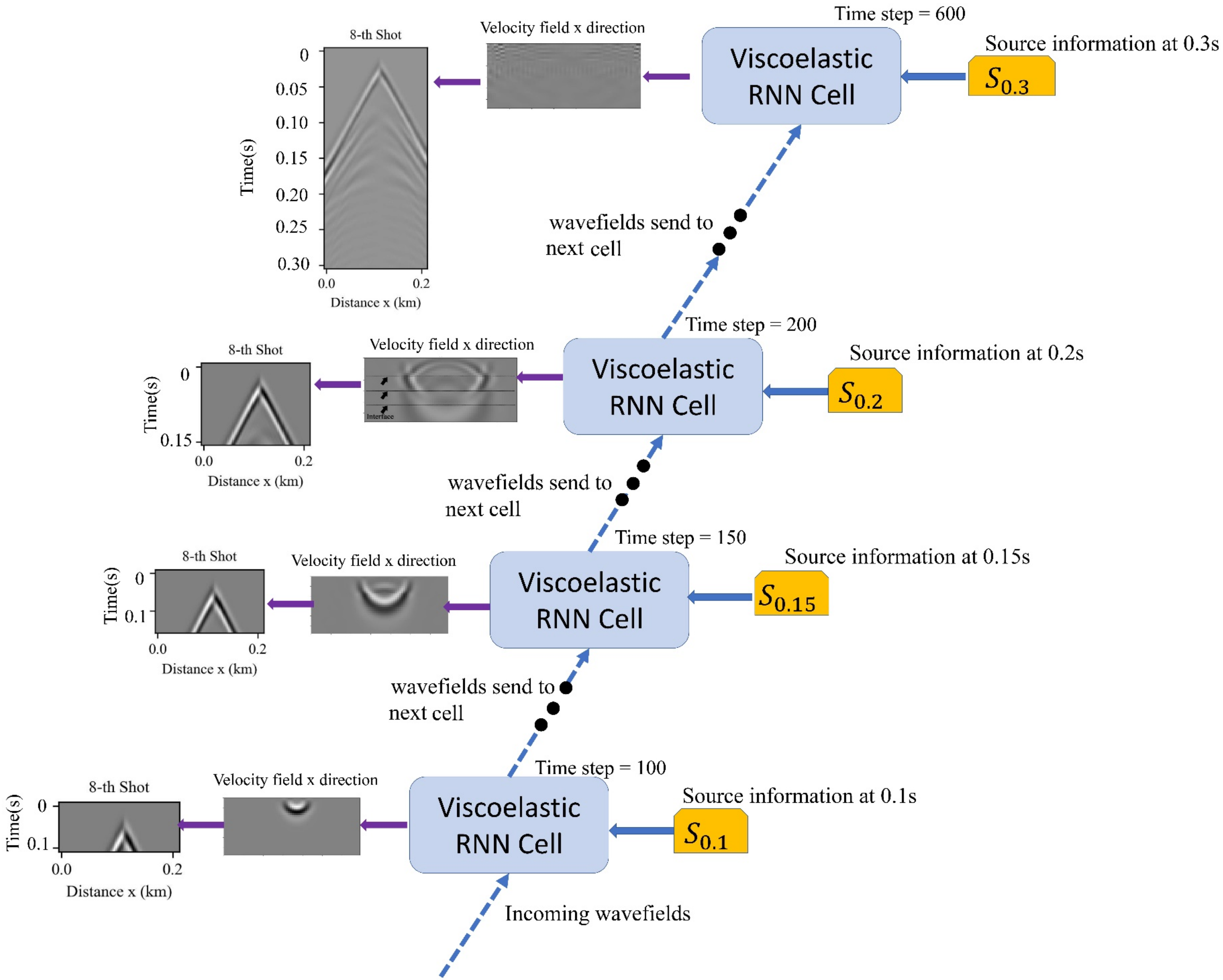
Data flow into cell

Send data to next cell

Data send into cell

Data send cell

Part three: Viscoelastic FWI based on RNN



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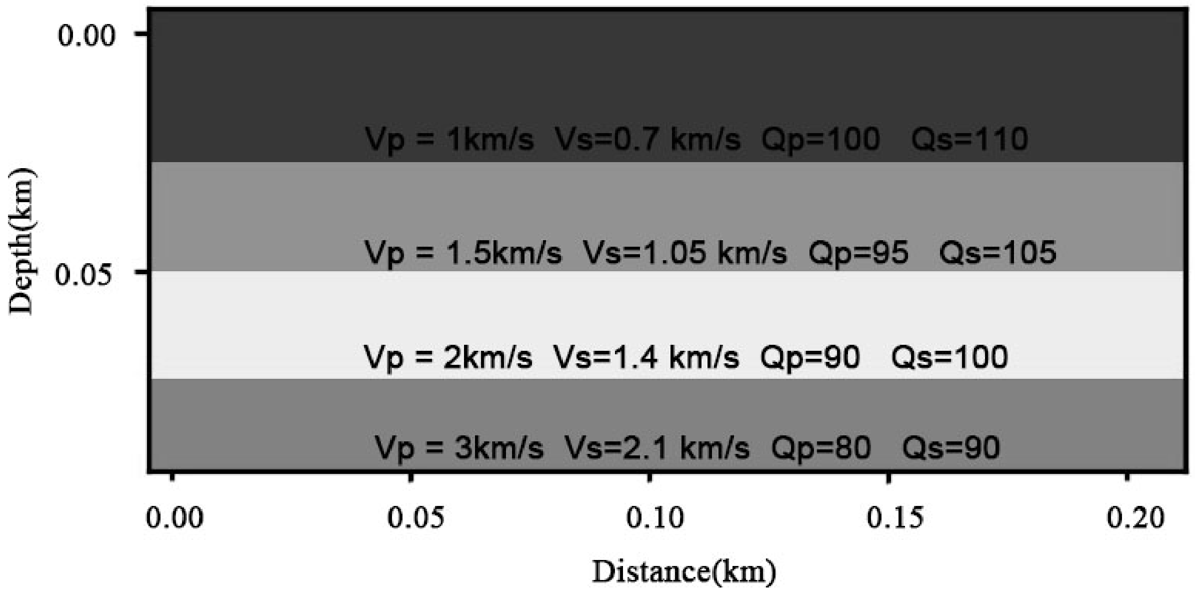

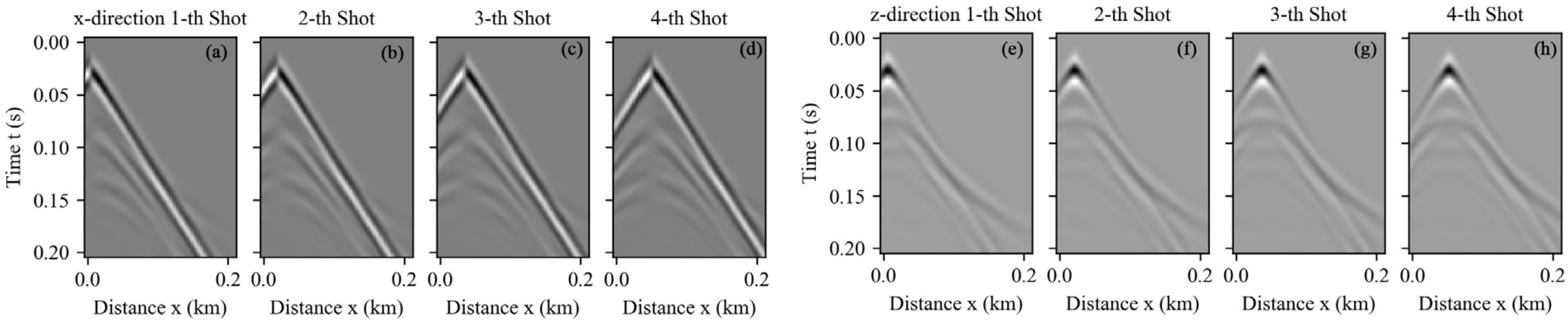

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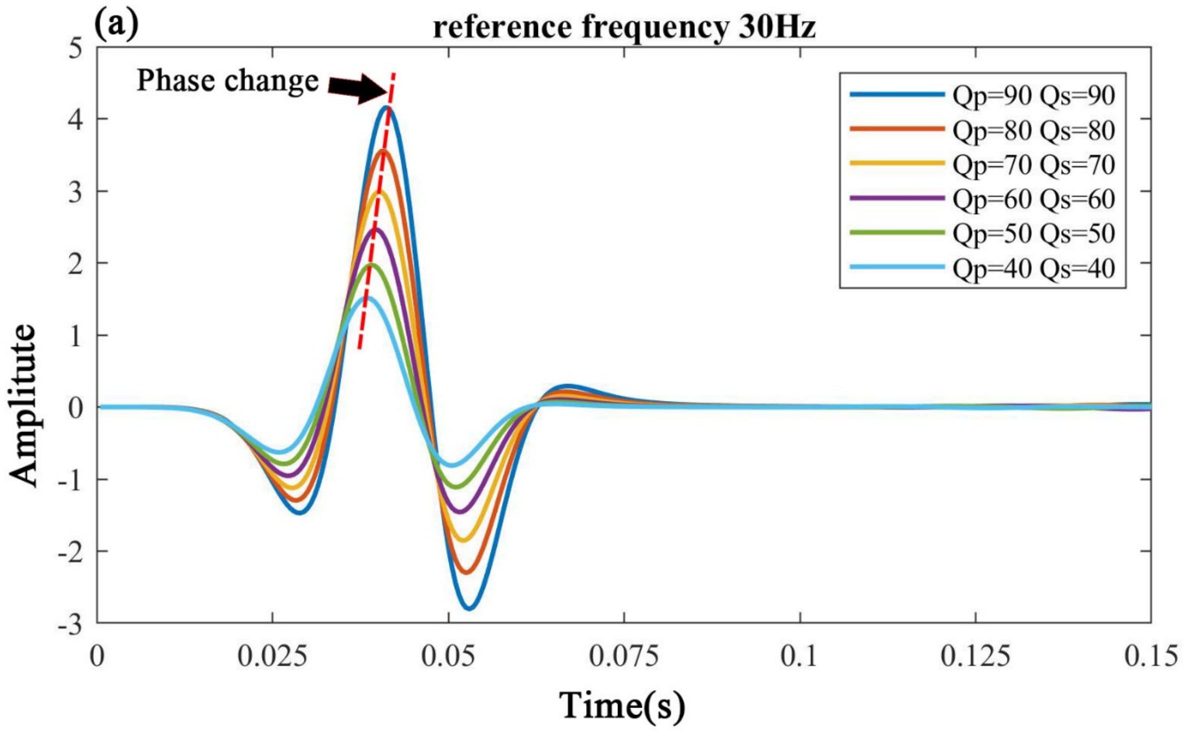

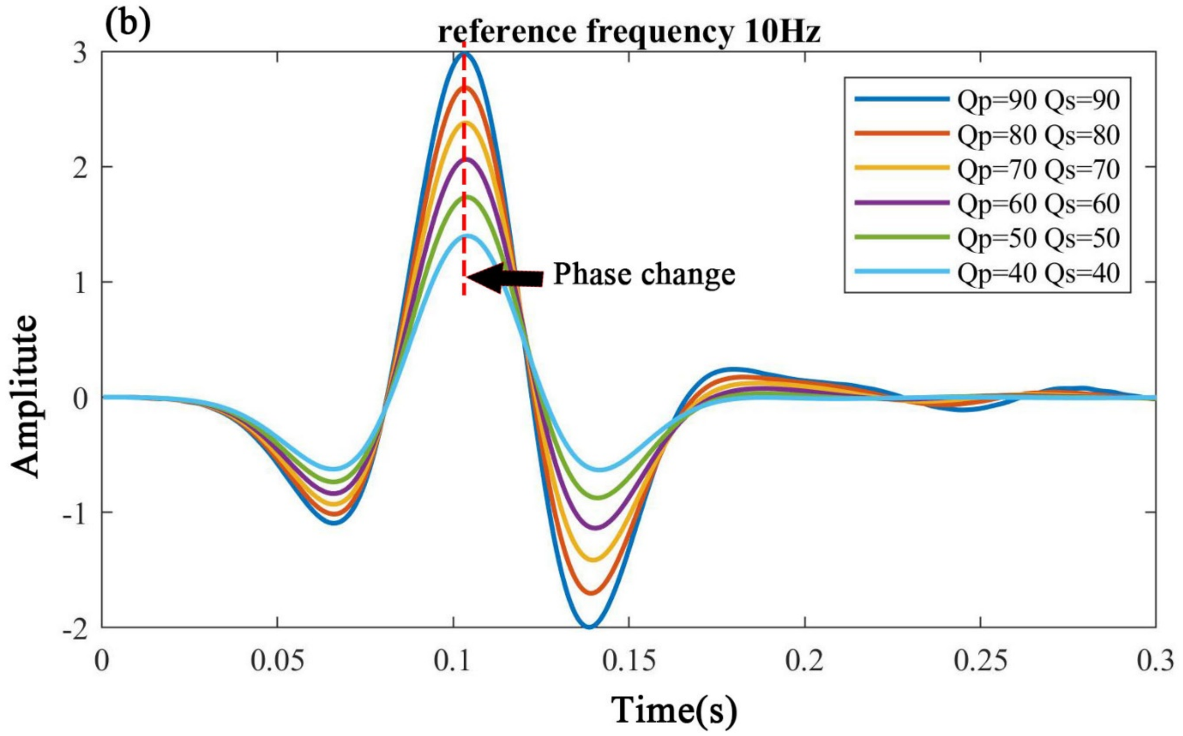

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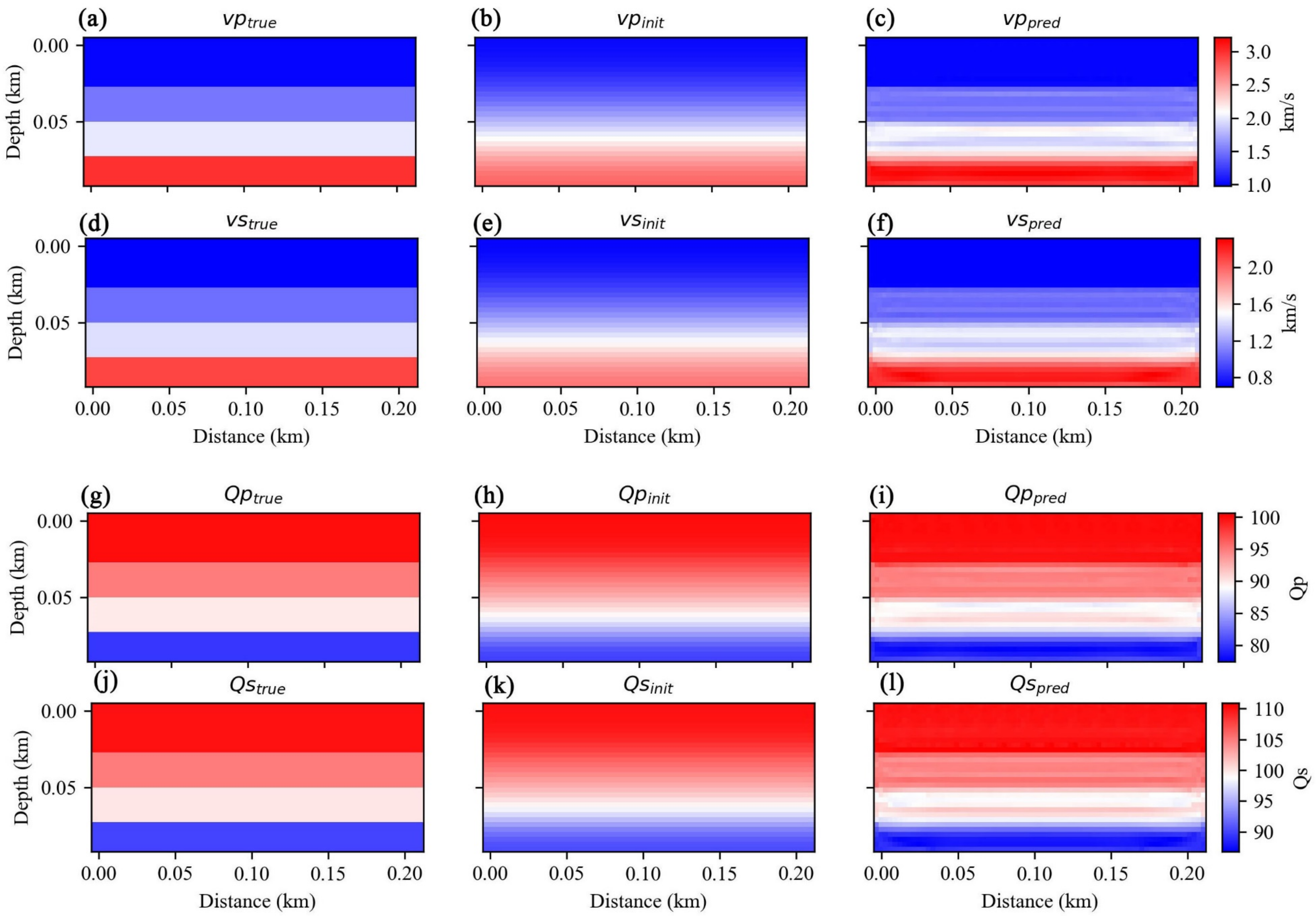

Fm=35Hz
Nshot = 7
Receiver: top
Tmax = 0.3s

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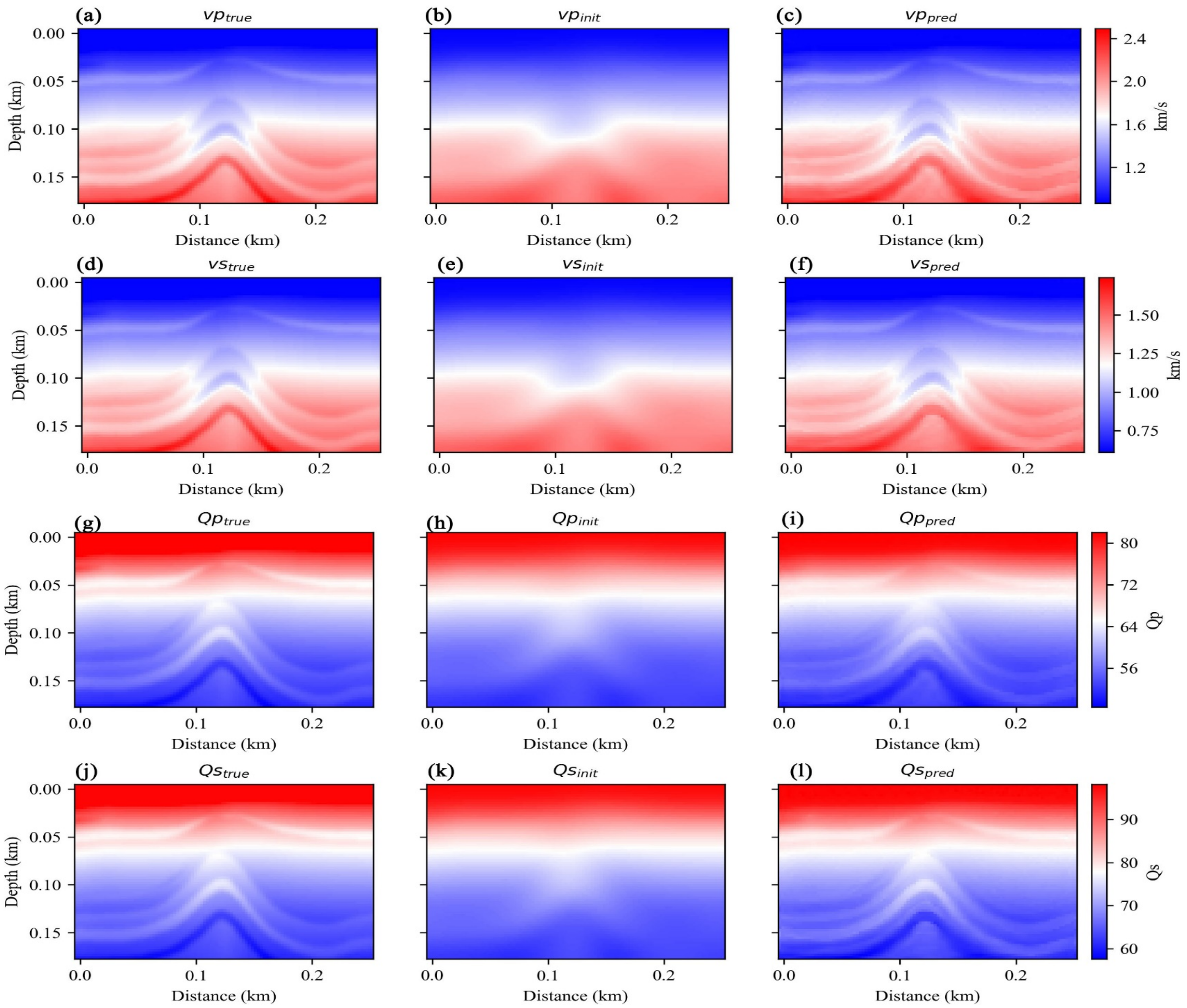


Fm=35Hz
Nshot = 7
Receiver: top
Tmax = 0.3s

Part four: Viscoelastic FWI based on RNN with different objective functions

The loss function for l_1 is:

$$loss_{l_1} = |x - y|$$

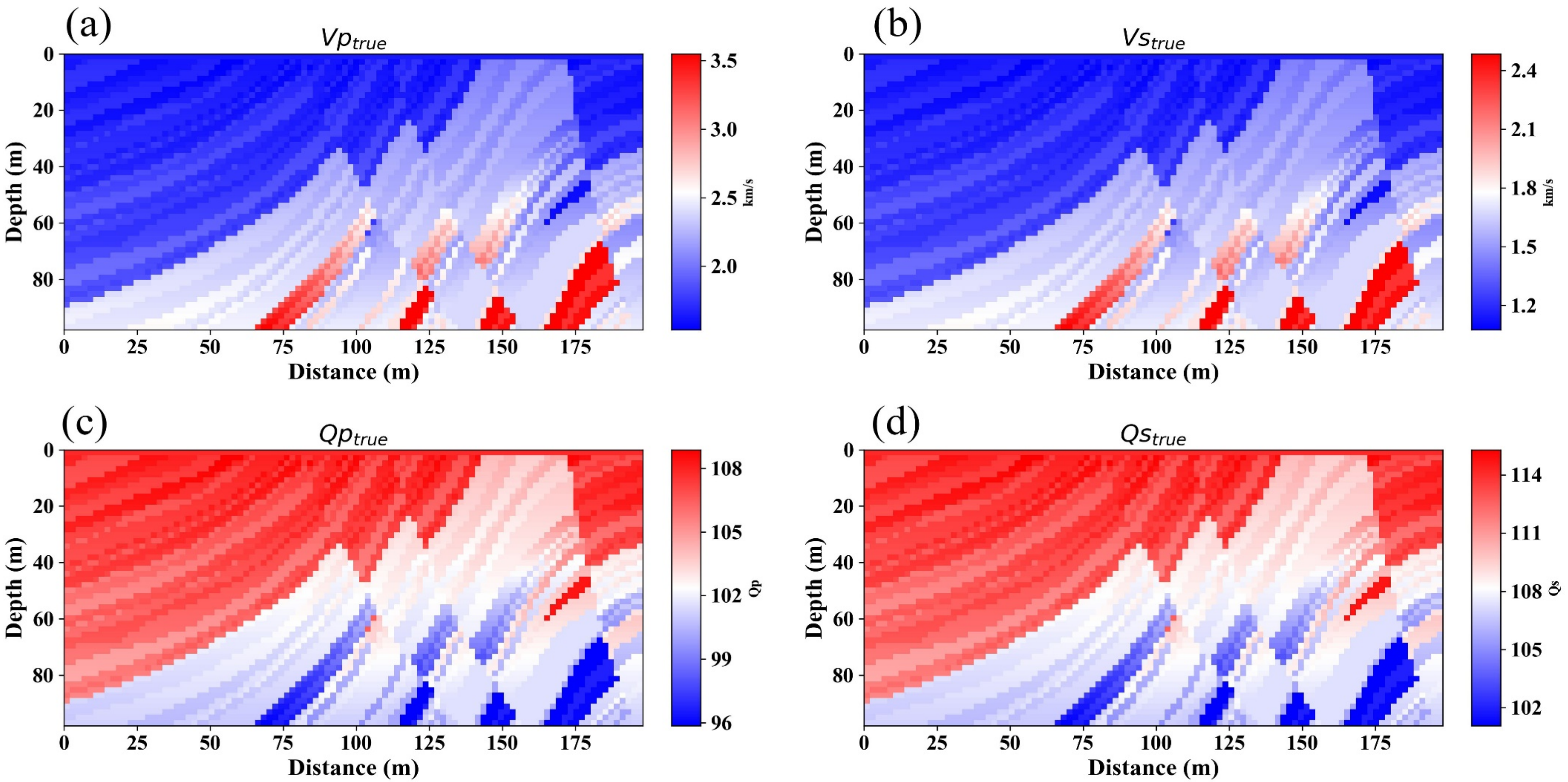
The loss function for l_2 is:

$$loss_{l_2} = \frac{1}{2}(x - y)^2$$

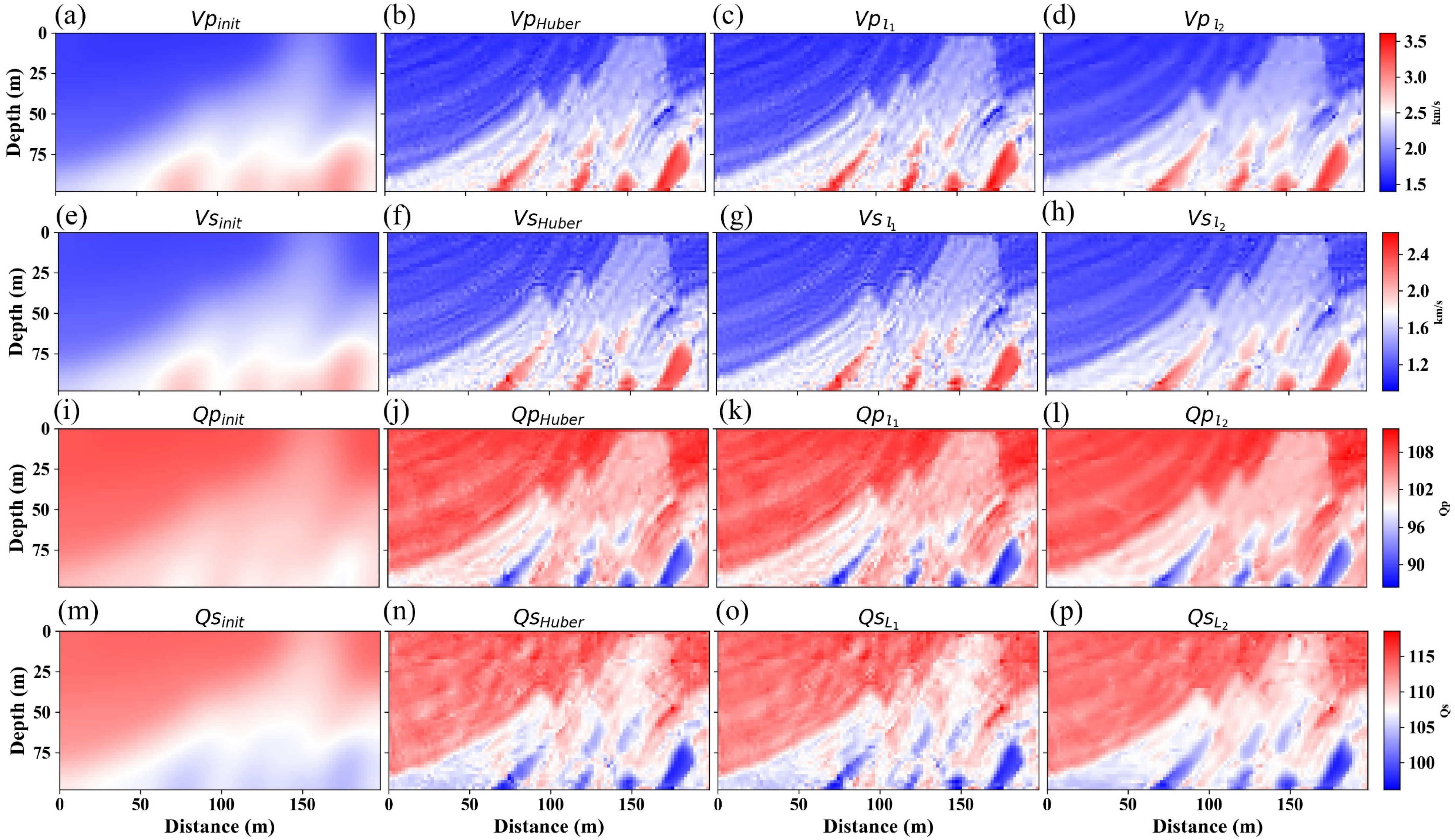
The loss function for Huber function is:

$$loss_{Huber} = \begin{cases} 0.5(x - y)^2, if|x - y| < 1 \\ |x - y| - 0.5, otherwise \end{cases}$$

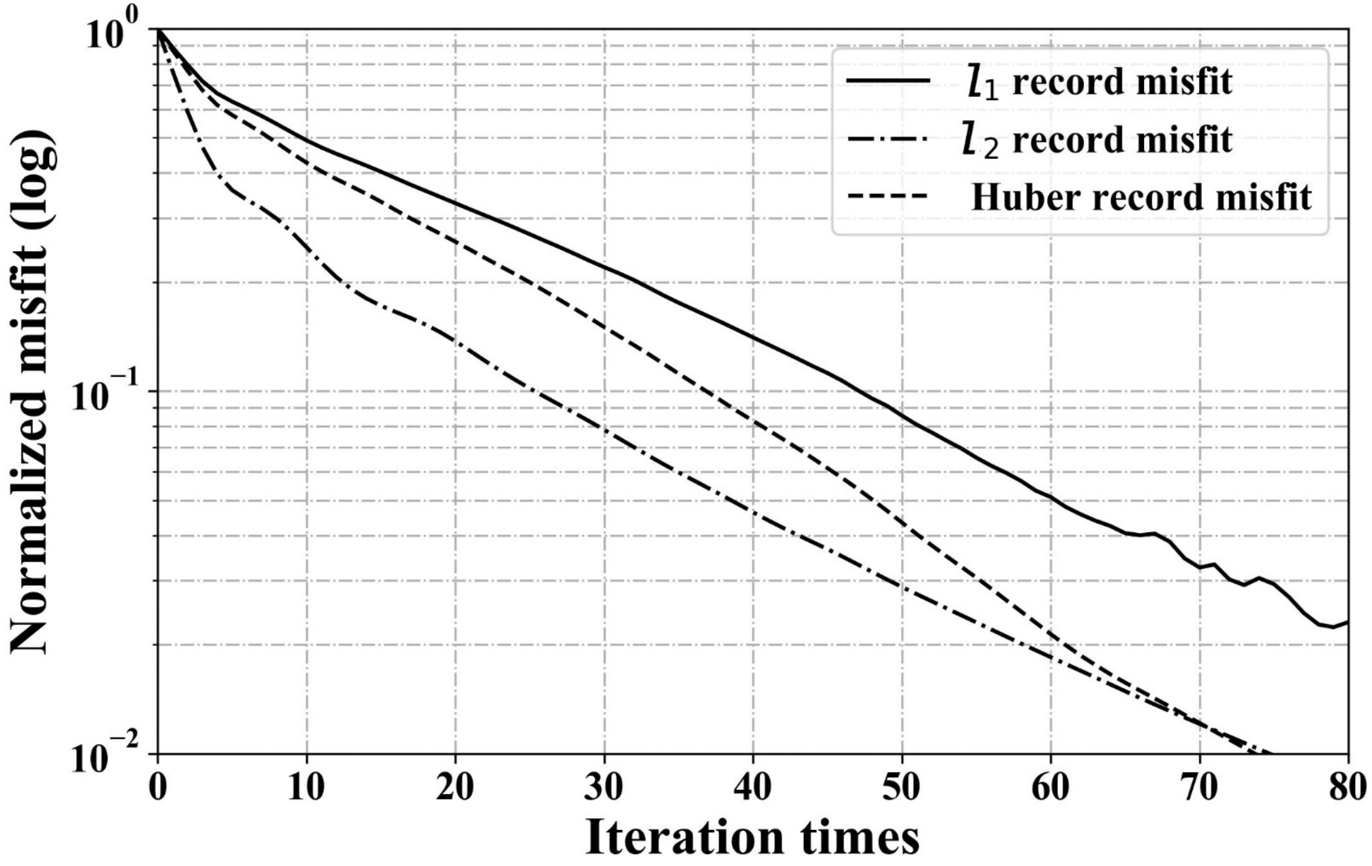
Part four: Viscoelastic FWI



Part four: Viscoelastic FWI



Viscoelastic RNN FWI with different objective functions



Shot records data residual

Conclusions

- **Viscoelastic RNN FWI can give promising inversion results**
- **RNN is a powerful tool for seismic inversion problem**
- **The use of different misfits help improve inversion results**

Acknowledgements

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THANK YOU