The use of U-Net and Radon transforms for multiple attenuation

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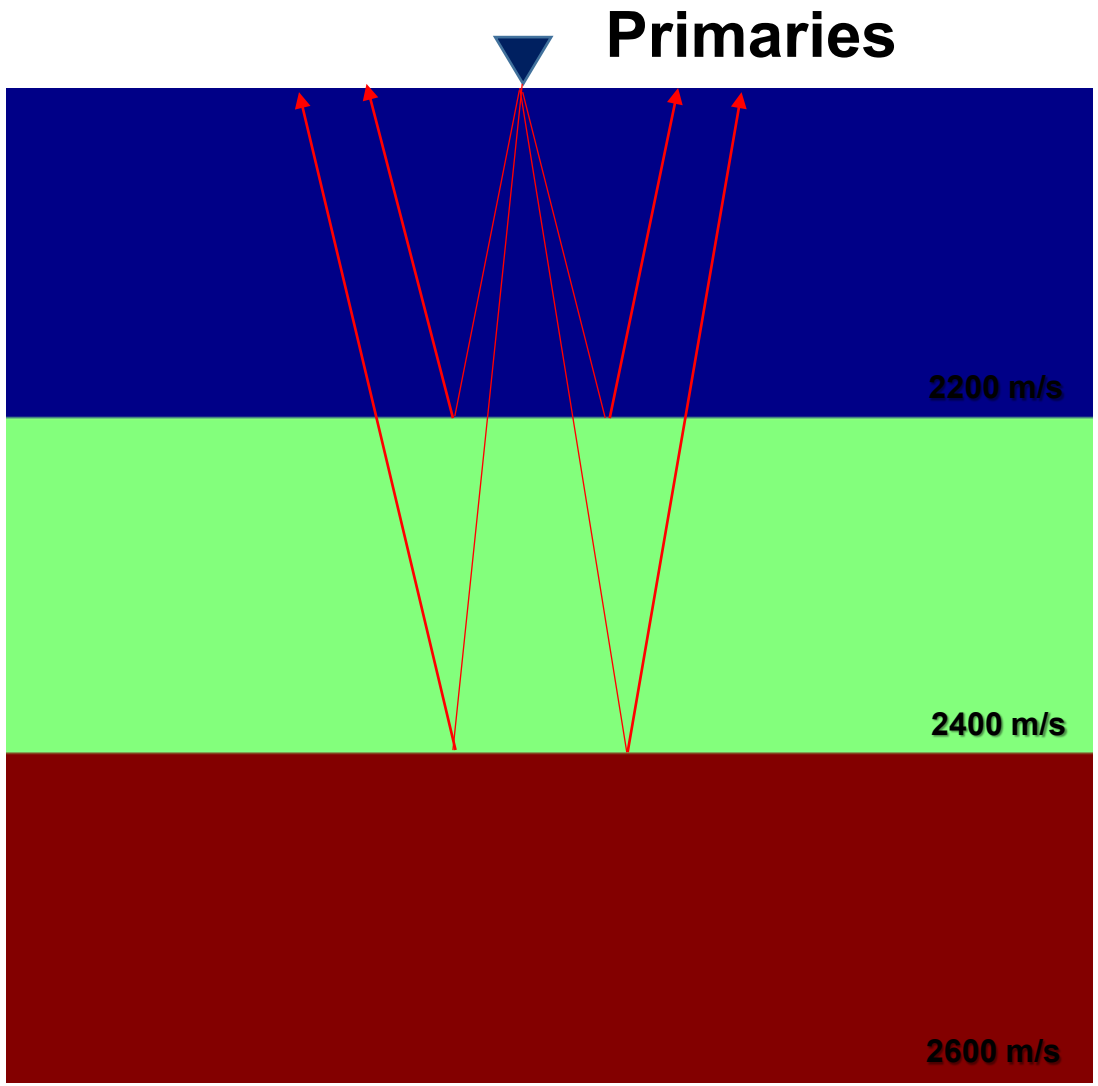
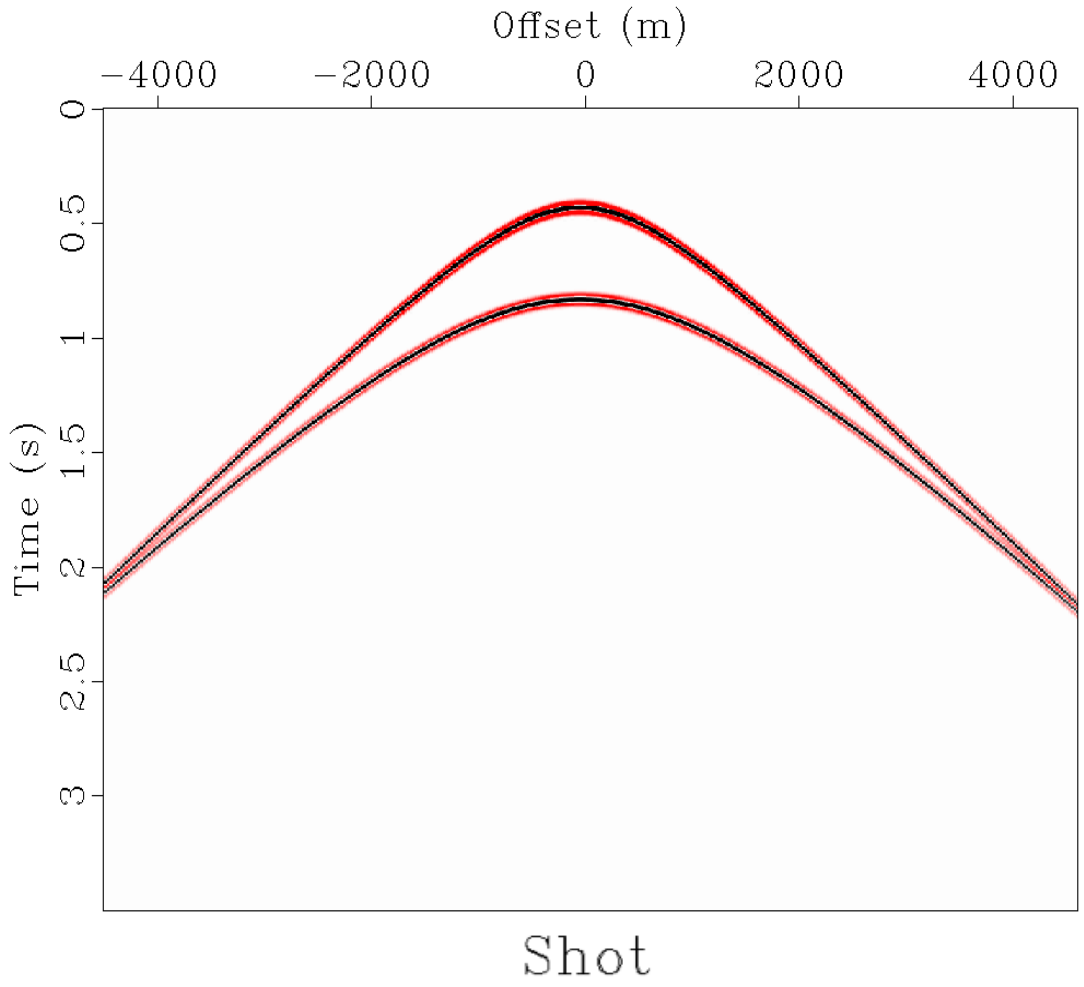
Outline

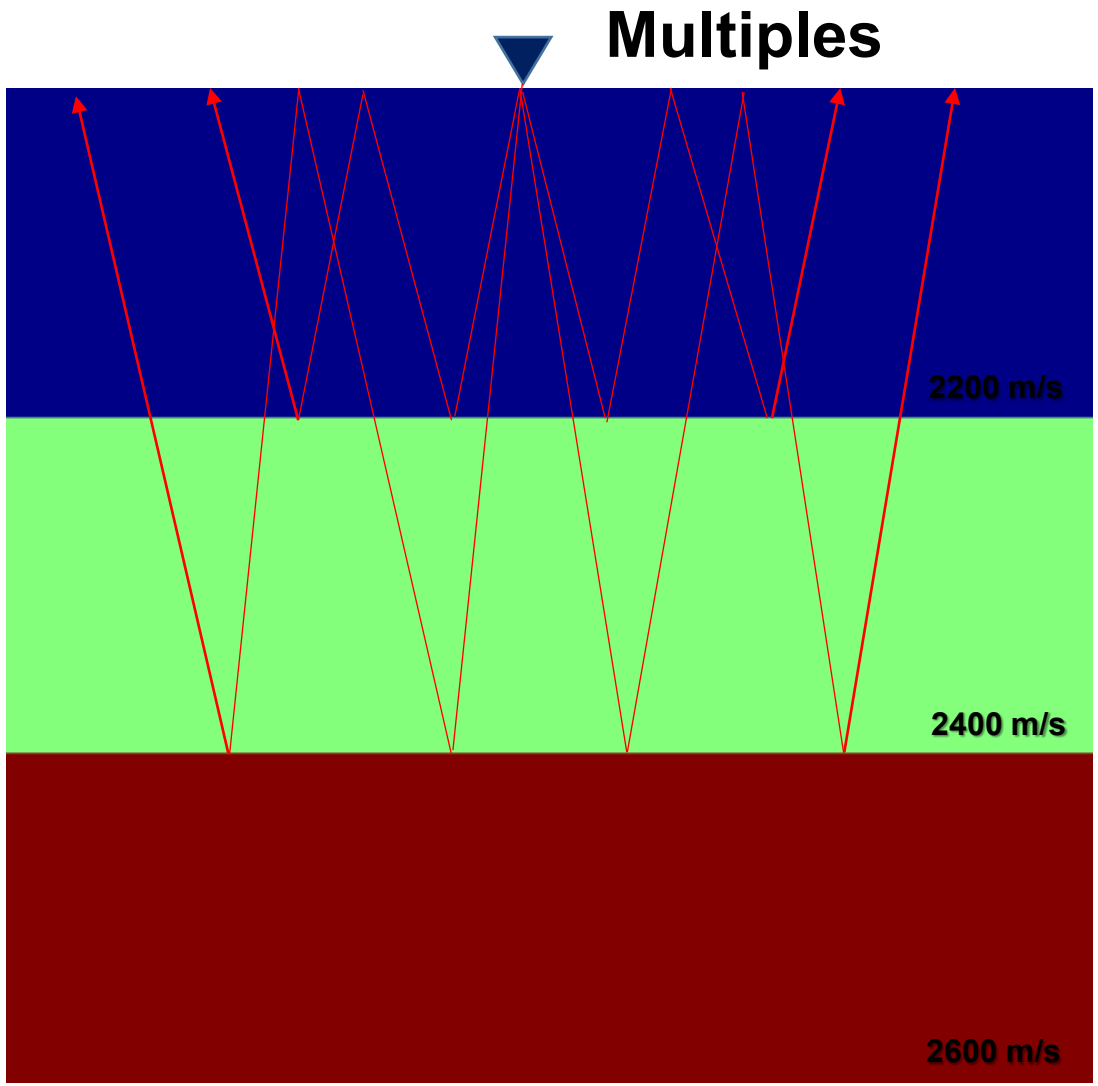
1. Theory
   - Radon Transform (RT)
   - U-Net
2. Methodology
3. Examples and Discussions
4. Conclusions and future work

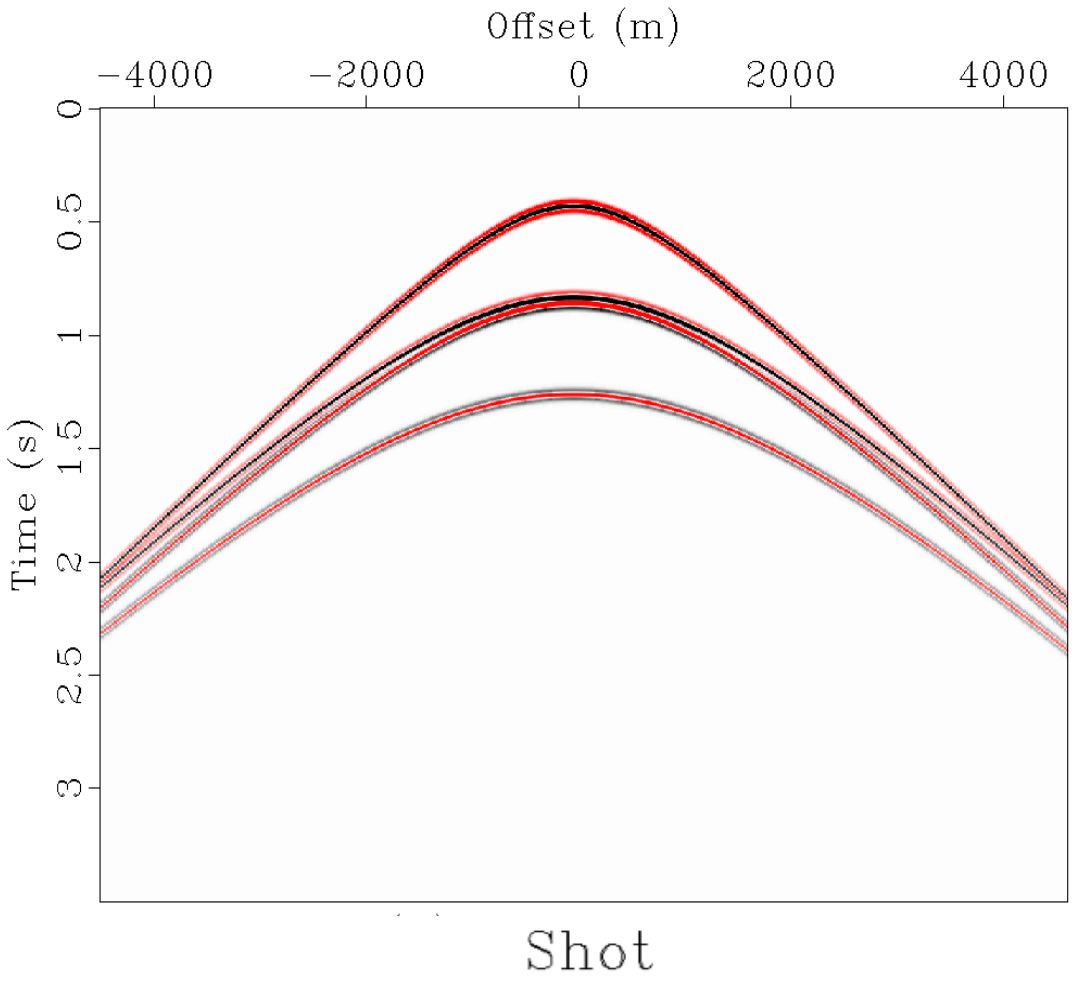
Seismic reflections: primaries





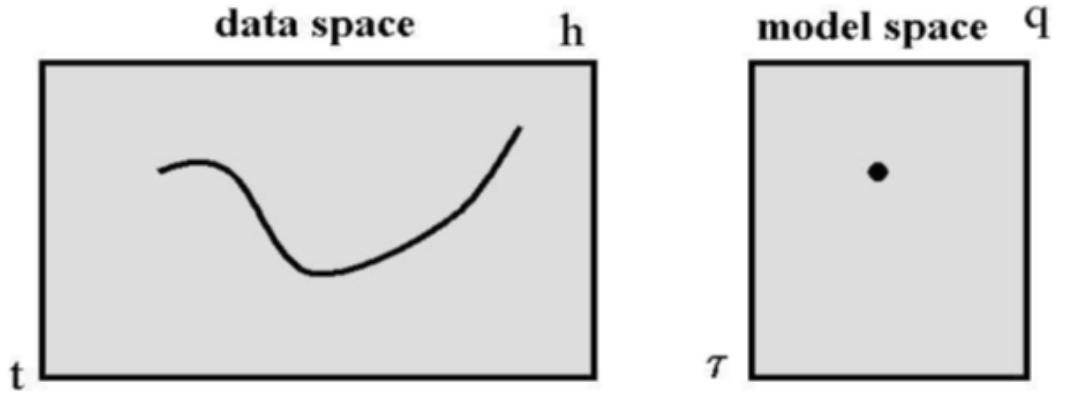
Primaries and multiples (coherent noise)





Radon Transform (RT)

- Mathematical tool that maps data (curve) into a transformed space (point)
- Application in seismic processing: it maps seismic gather events with line integrals that follow a certain type of curve (line, parabola, hyperbola)



(Trad, 2001)

$$m(q,\tau) = \int_{-\infty}^{+\infty} d[h, t = f_{t\leftarrow\tau}(\tau, q, h)]dh$$

RT model (curve parameter, zero-offset TWT)

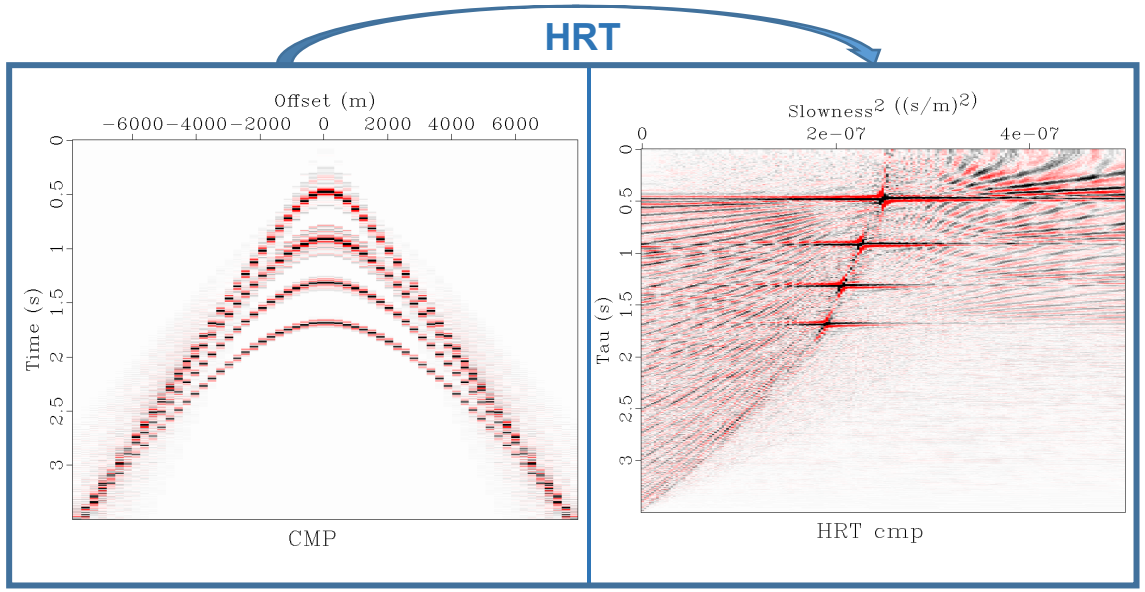
Input seismic gather (offset, TWT)

Integration path (curve)

Least squares solution to get high resolution (sparse) RT

- In practice the RT is calculated by inverting the forward operator:
  - Forward operator: $d(h,t) = \sum_{v} m(v, \tau = \sqrt{t^2 + h^2 q^2})$ OR $\boldsymbol{d = L\,m}$

- The most suitable solution can be found by minimizing the cost function using iterative re-weighted Least Squares (Thorson and Claerbout, 1985).



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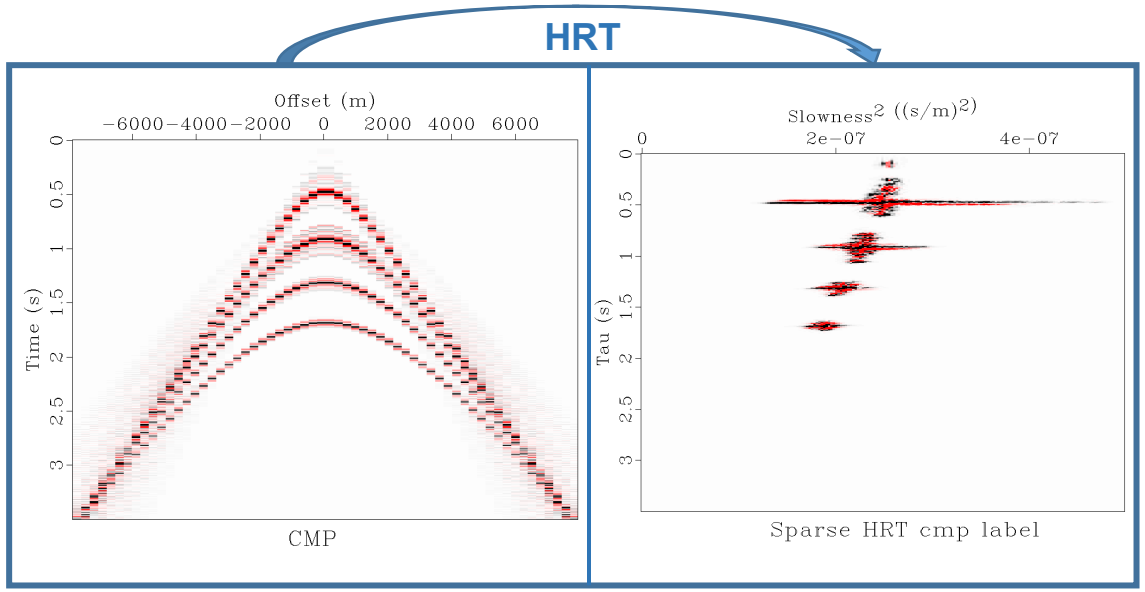
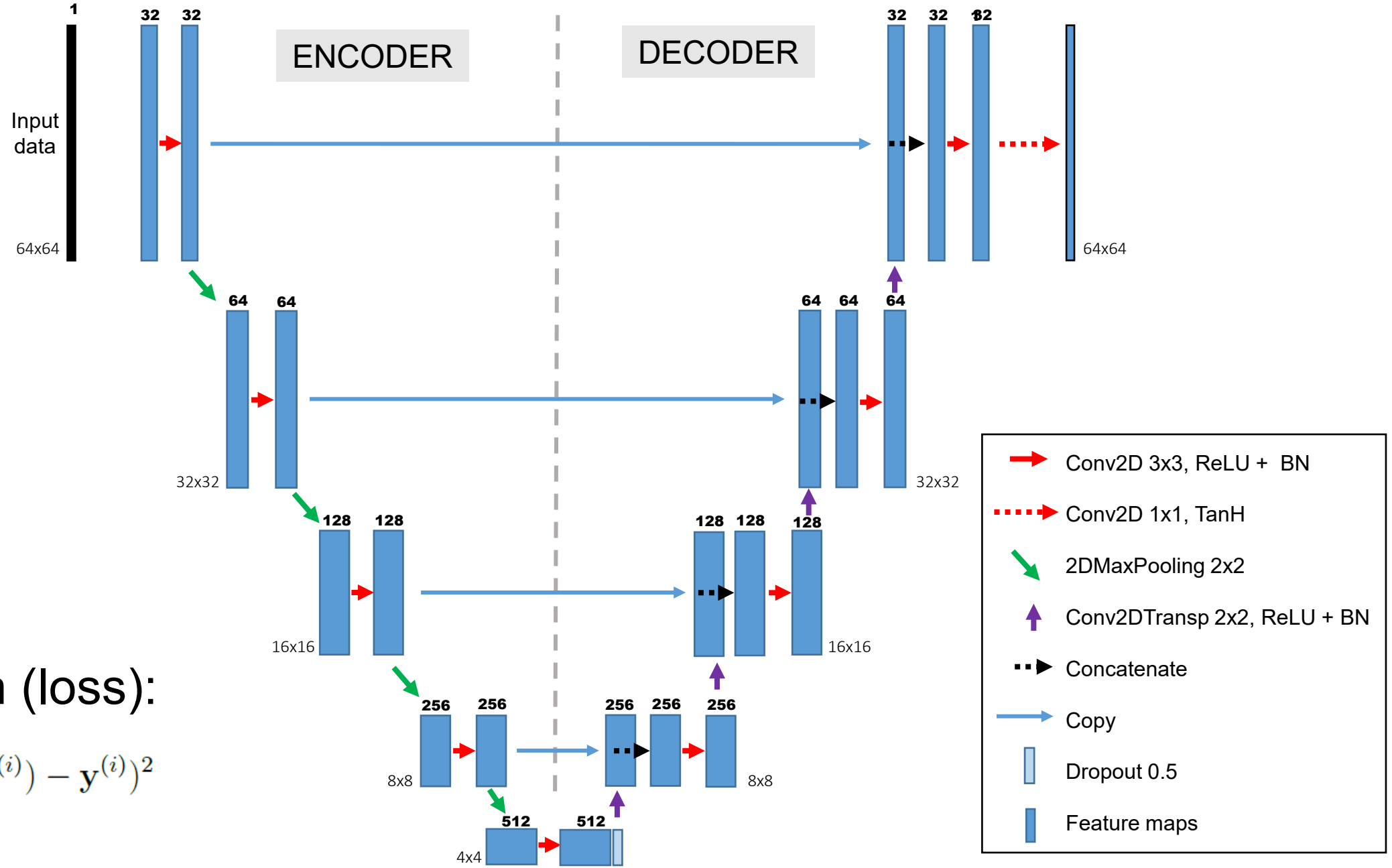


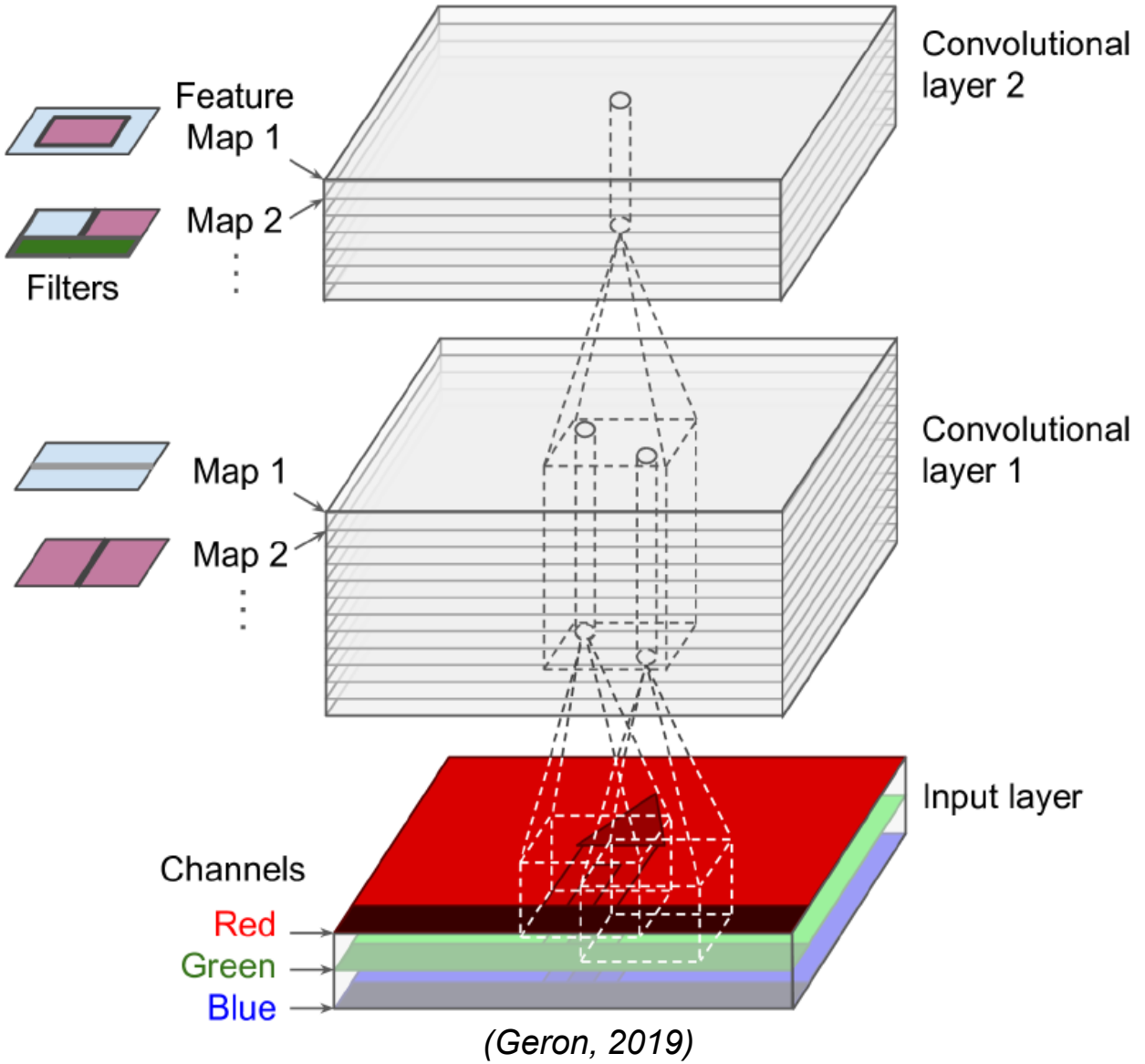
U-Net



Cost function (loss):

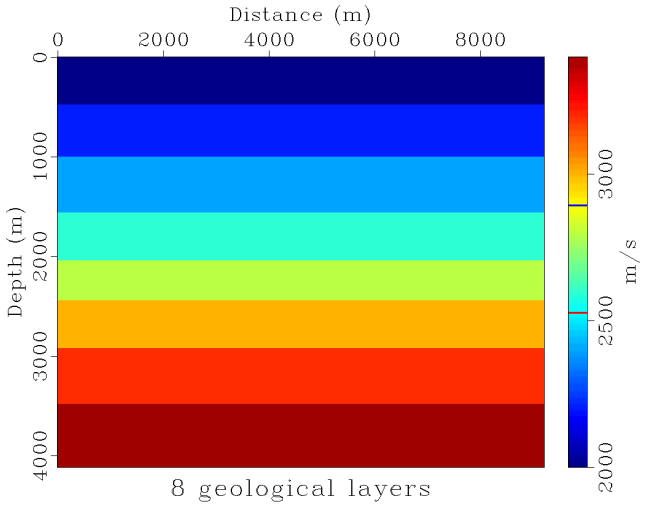
$$MSE = \frac{1}{n}\sum_{i=1}^{n}(\mathbf{x}^{(i)}) - \mathbf{y}^{(i)})^2$$

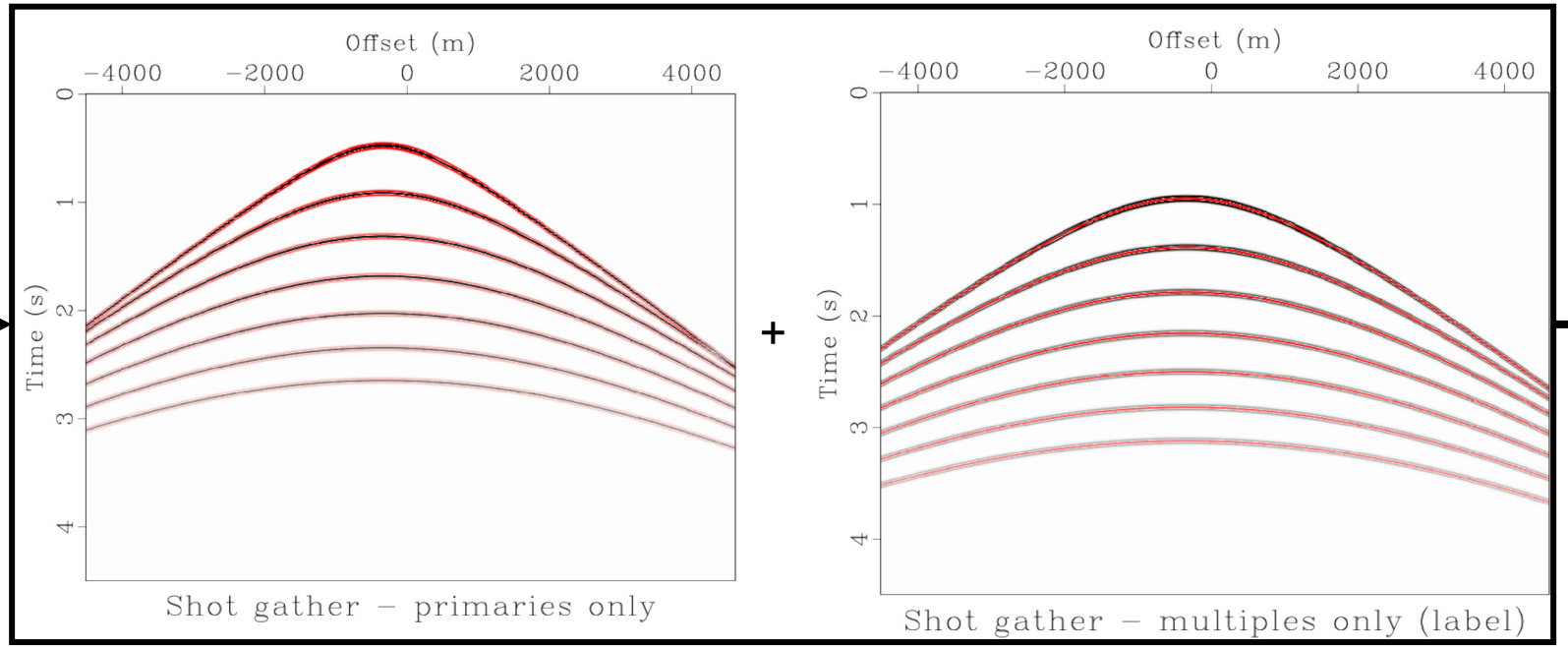
Convolutional Layers

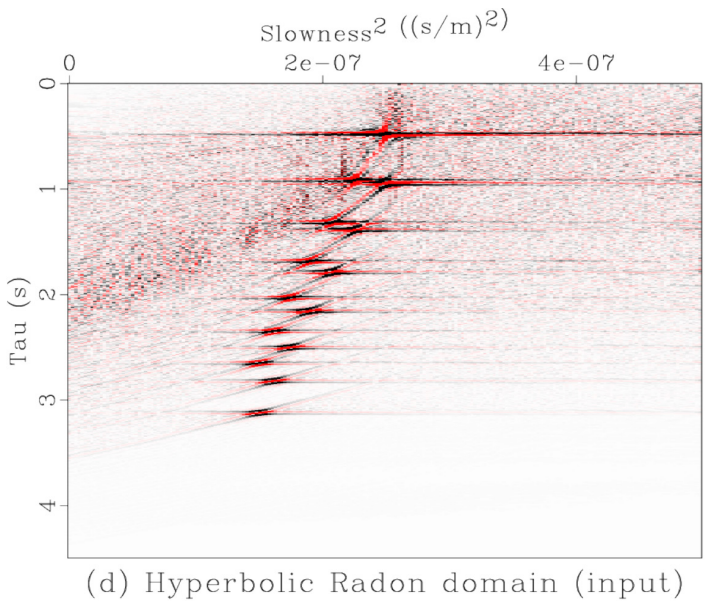


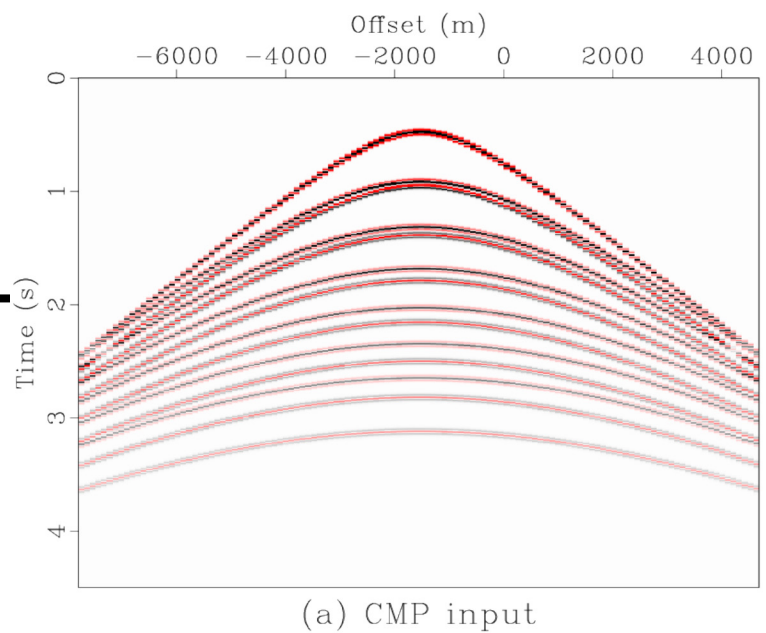
(Geron, 2019)

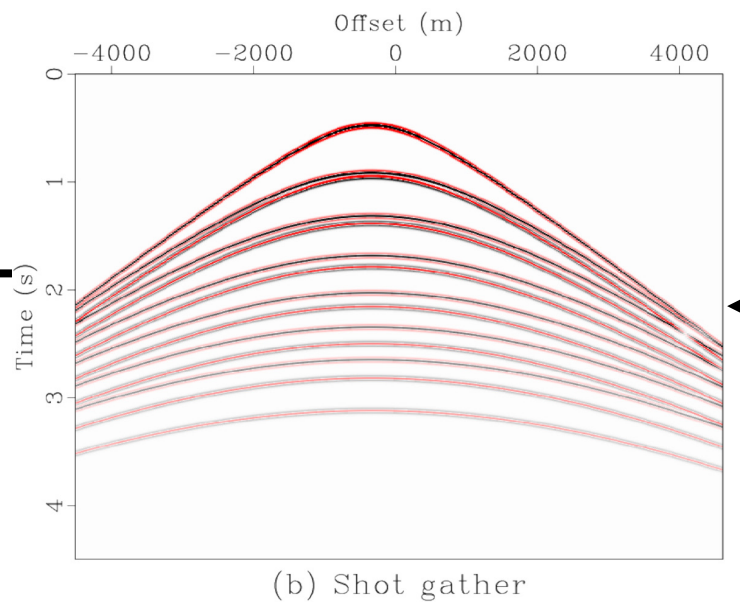
Workflow – Generating synthetic data: 8 geological layers case





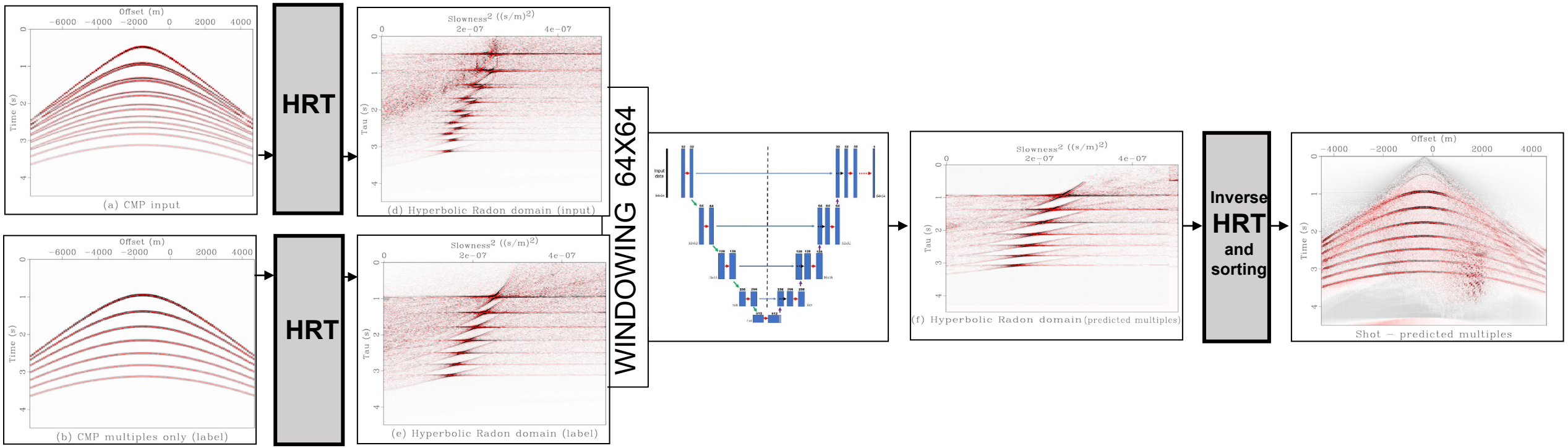






Workflow – predicting in HRT with U-Net (1 channel)

Input data

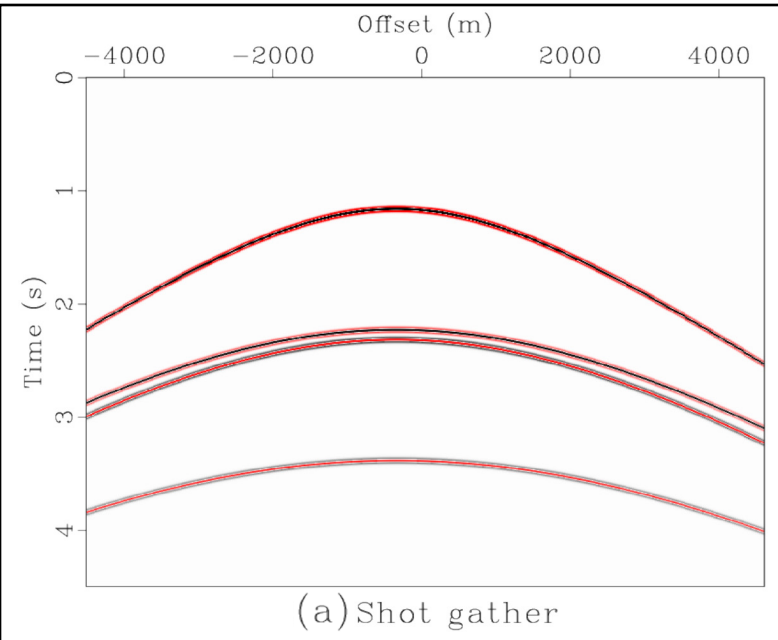


Input label

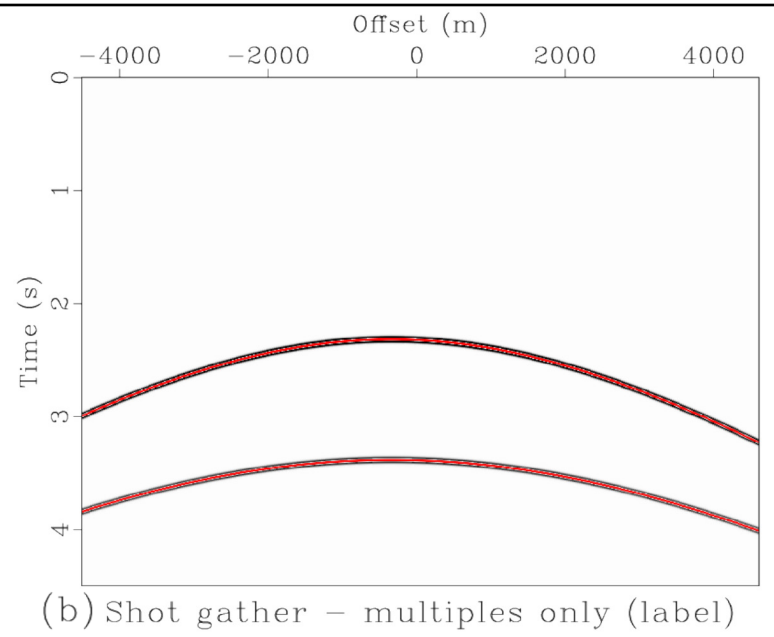
Test 1: inference

Train	Predict
3 geological layers	3 geological layers case
3 geological layers	5 geological layers case
3 geological layers	8 geological layers case
3 and 5 geological layers	8 geological layers case
3, 5, and 8 geological layers	8 geological layers case

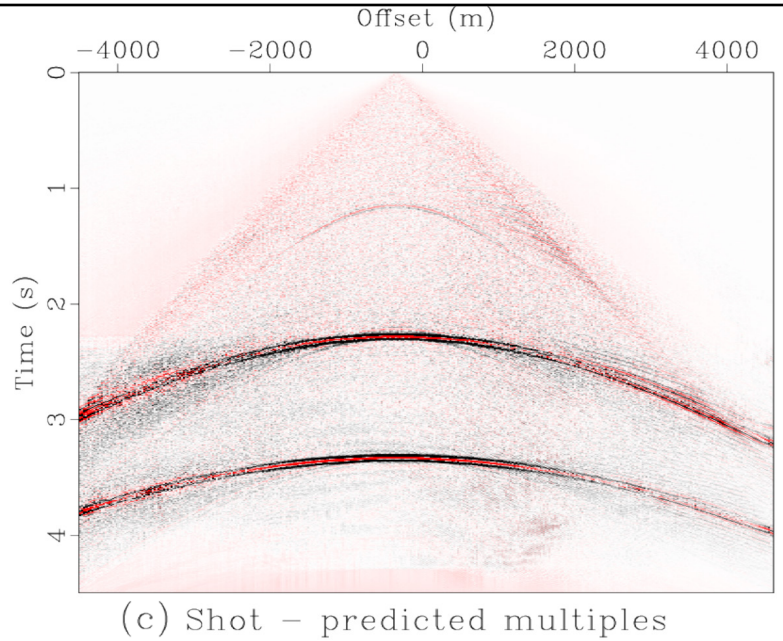
Train and predict for 3 geological layers



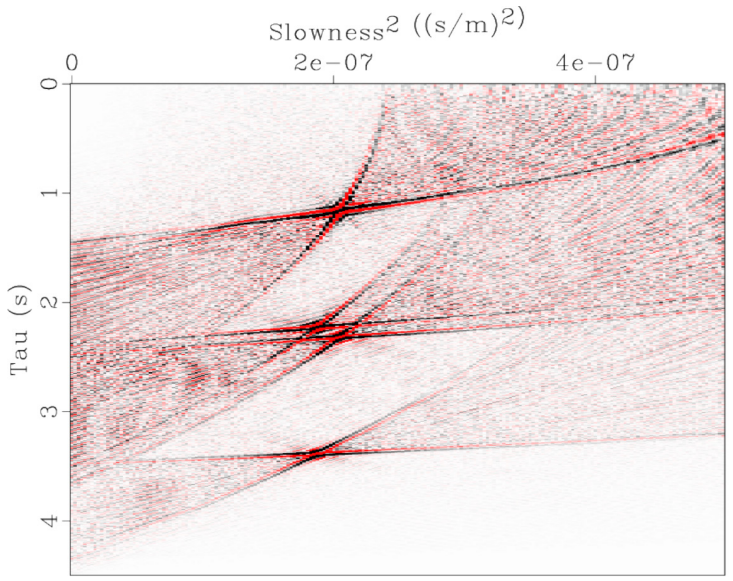
(a) Shot gather



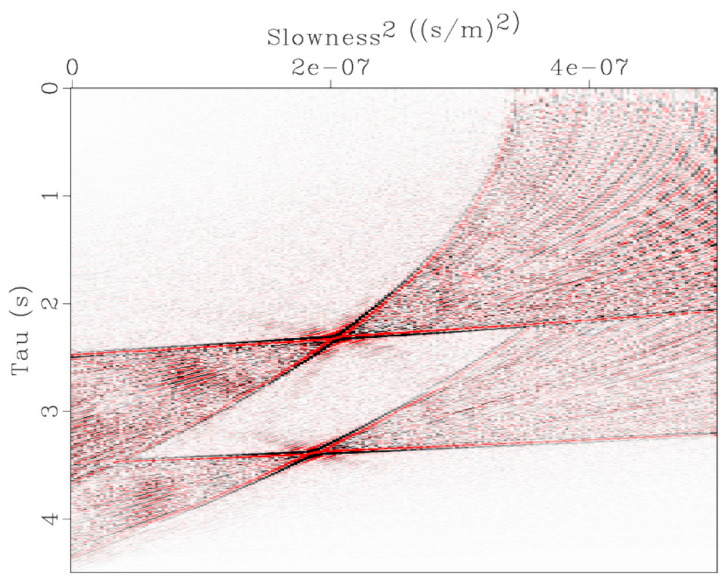
(b) Shot gather – multiples only (label)



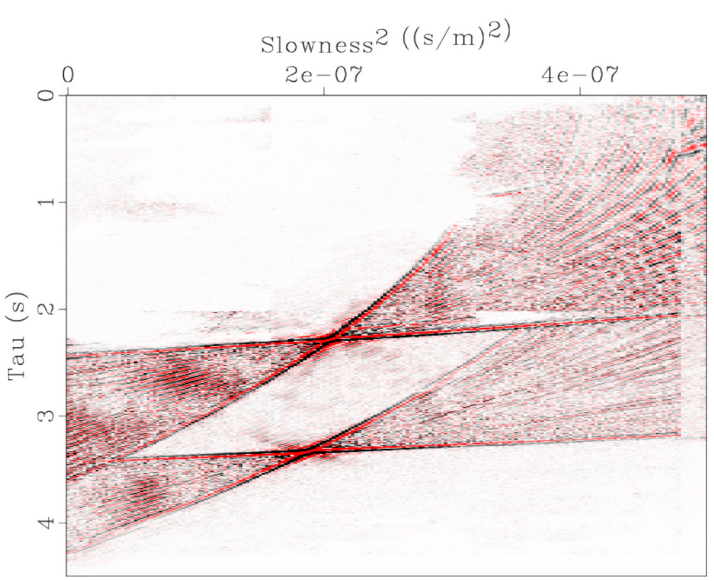
(c) Shot – predicted multiples



(d) Hyperbolic Radon domain (input)

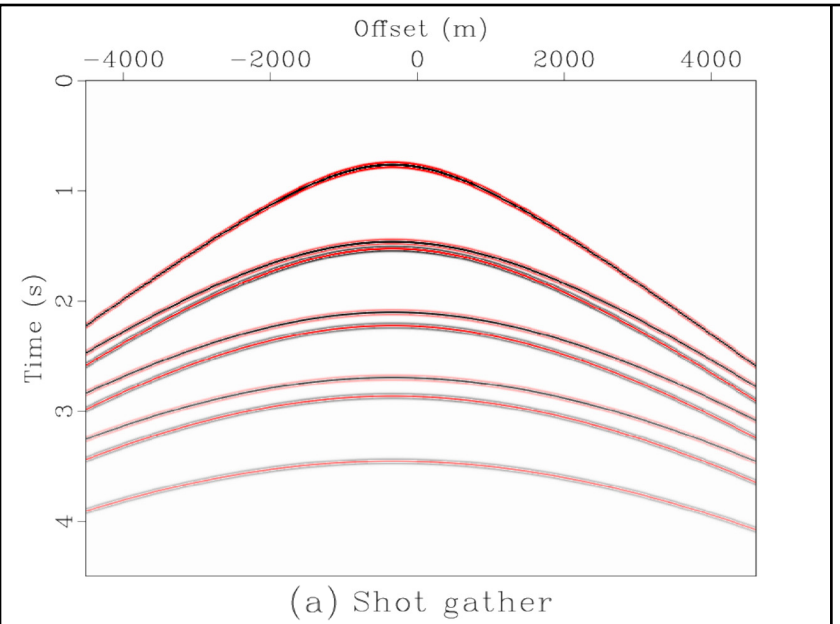


(e) Hyperbolic Radon domain (label)

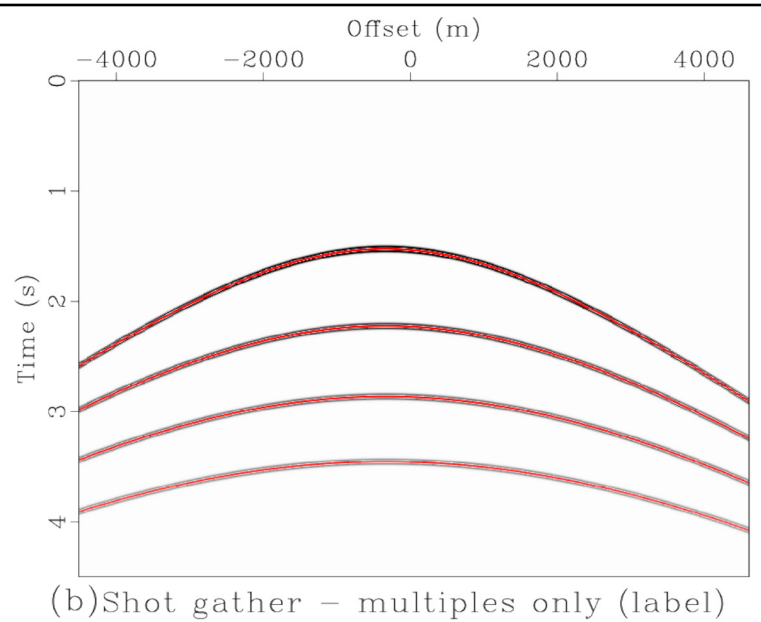


(f) Hyperbolic Radon domain (predicted multiples)

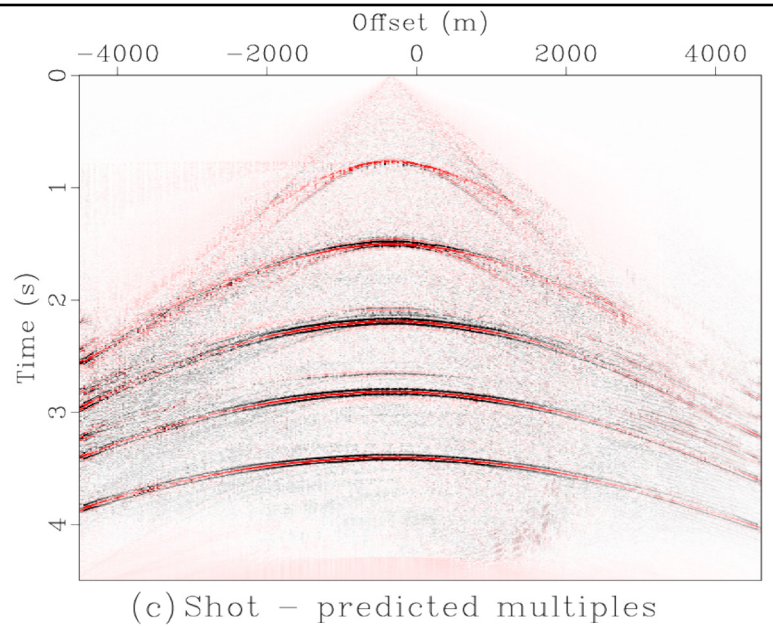
Train with 3, predict for 5 geological layers



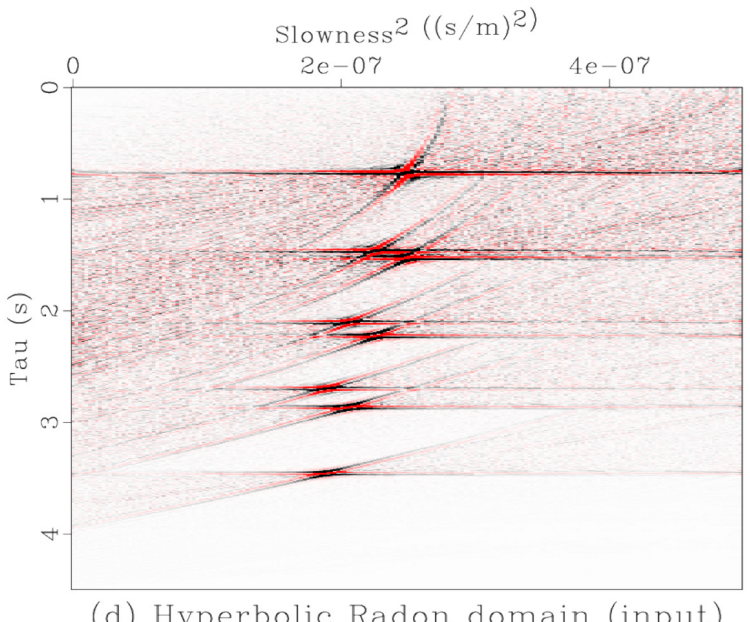
(a) Shot gather



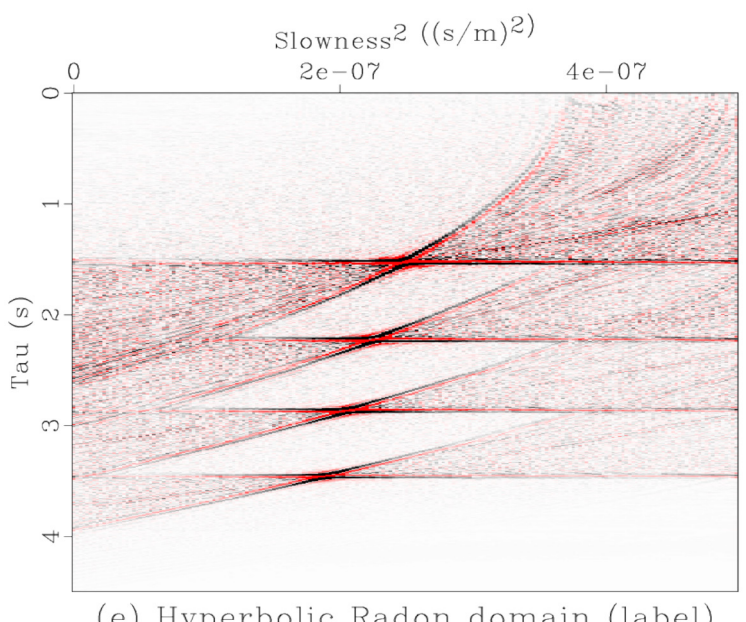
(b)Shot gather – multiples only (label)



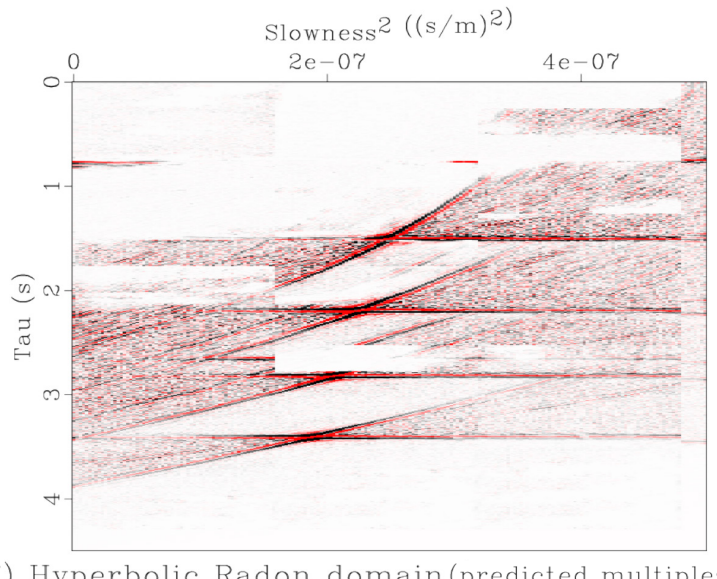
(c) Shot – predicted multiples



(d) Hyperbolic Radon domain (input)

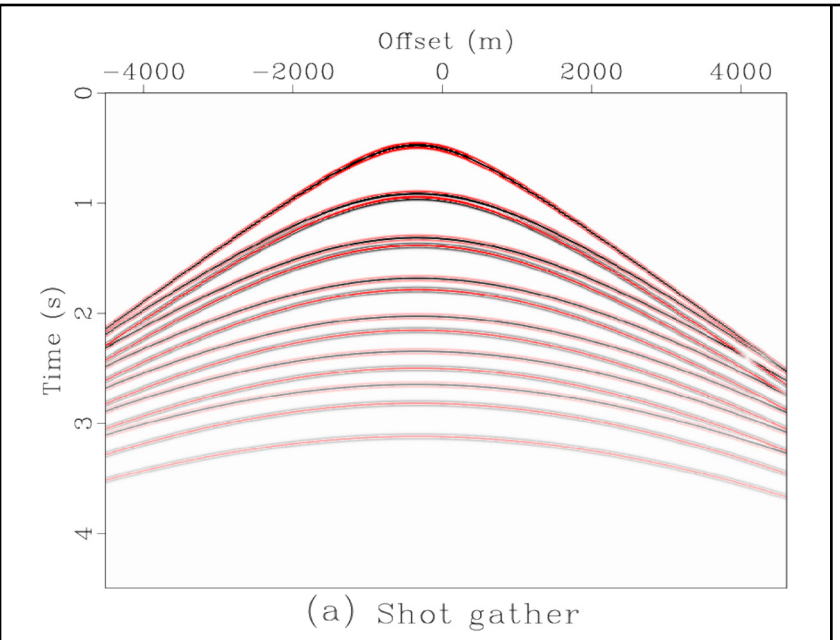


(e) Hyperbolic Radon domain (label)

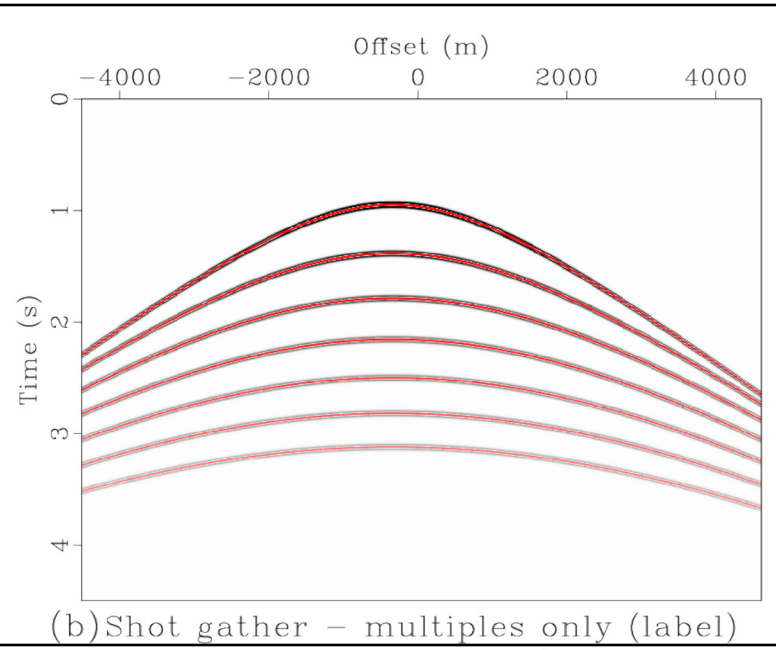


(f) Hyperbolic Radon domain (predicted multiples)

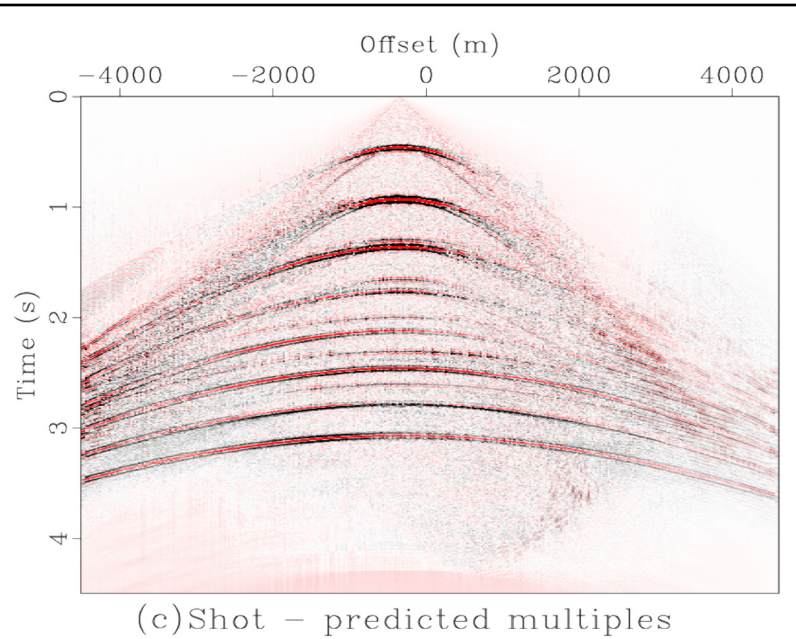
Train with 3, predict for 8 geological layers



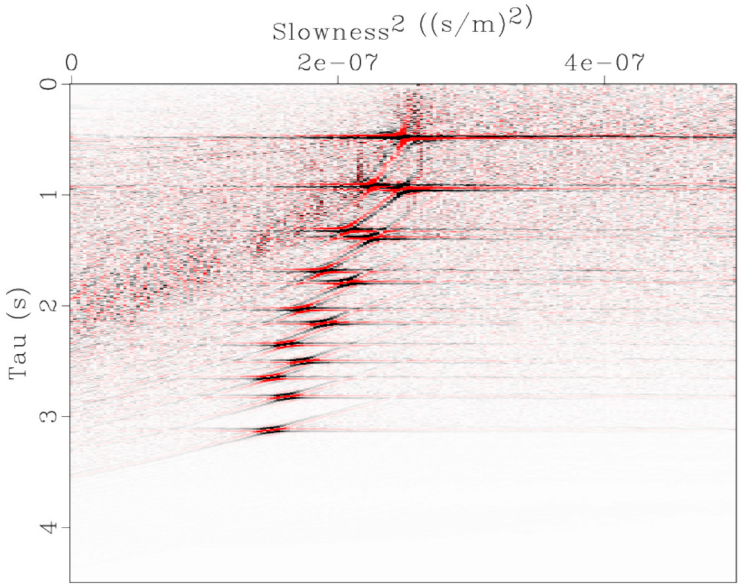
(a) Shot gather



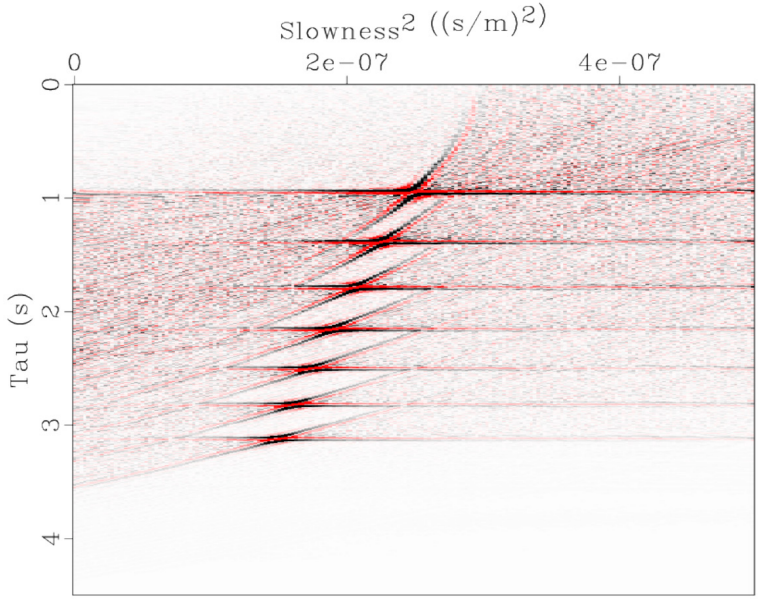
(b) Shot gather – multiples only (label)



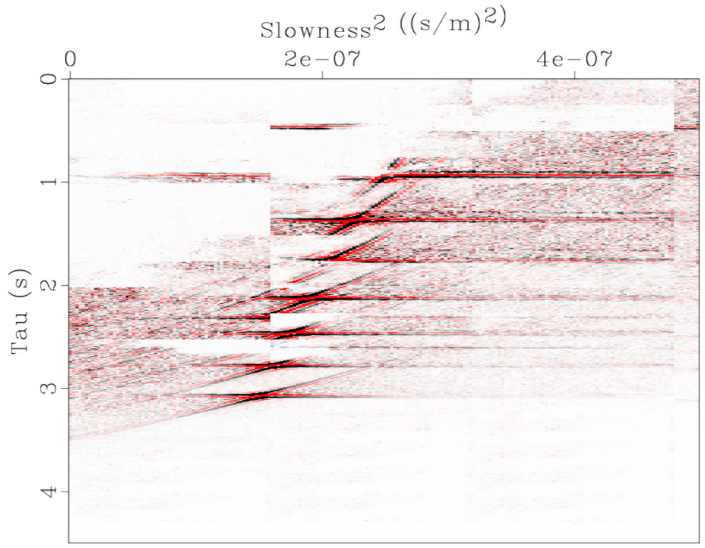
(c) Shot – predicted multiples



(d) Hyperbolic Radon domain (input)

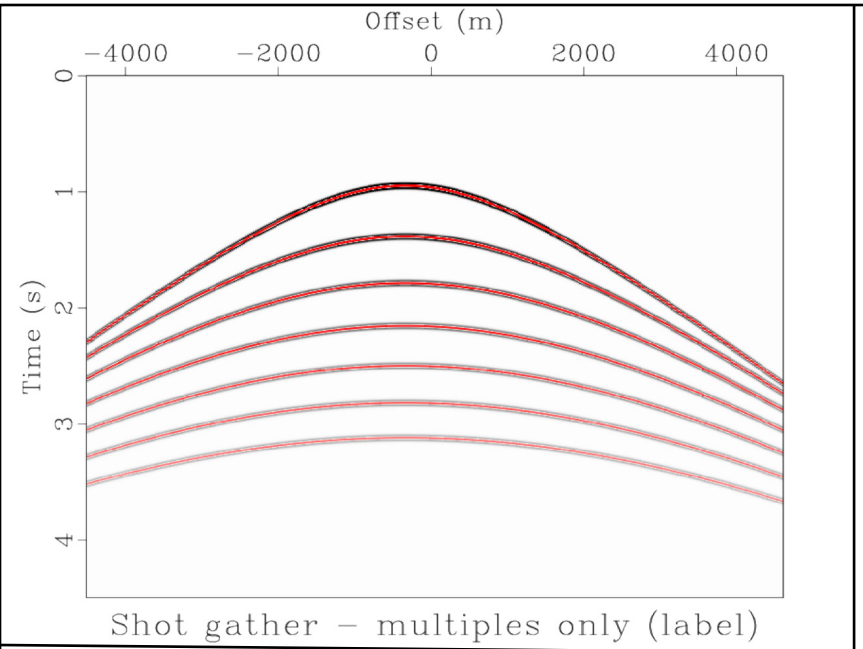


(e) Hyperbolic Radon domain (label)

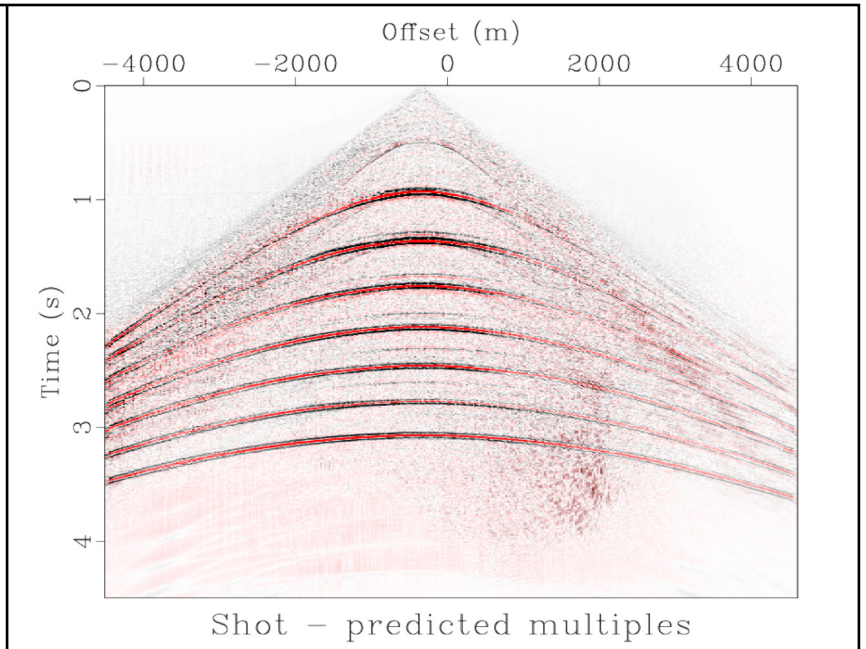


(f) Hyperbolic Radon domain (predicted multiples)

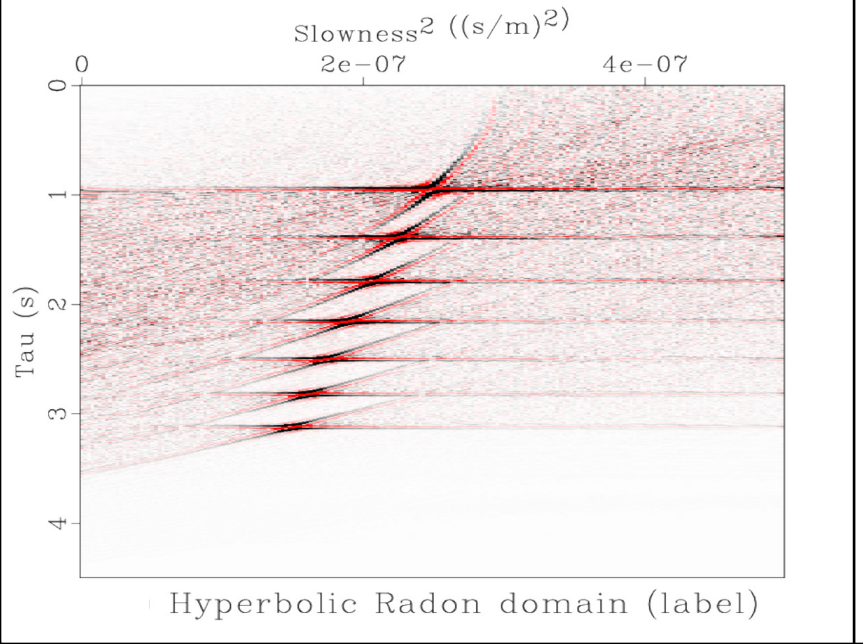
Train with 3 and 5, predict for 8 geological layers



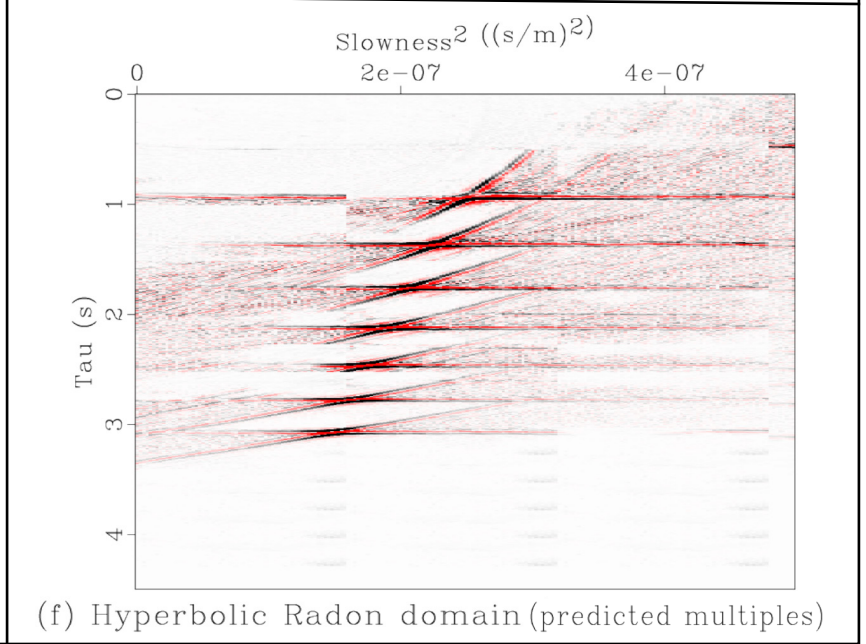
Shot gather – multiples only (label)



Shot – predicted multiples

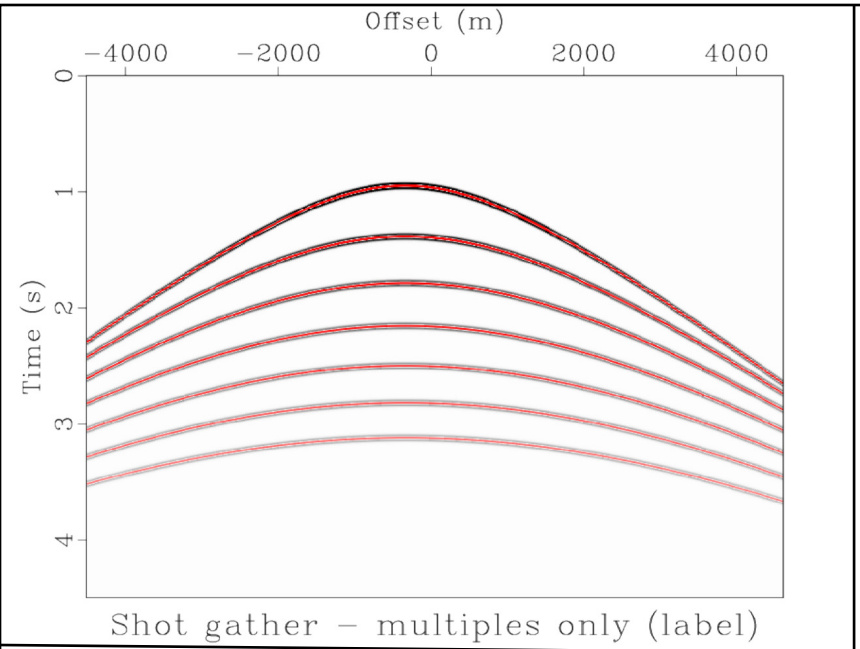


Hyperbolic Radon domain (label)

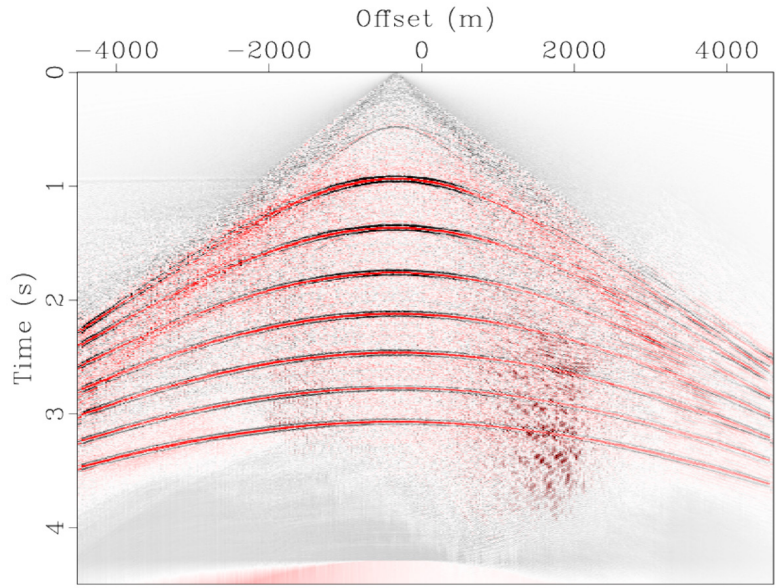


(f) Hyperbolic Radon domain (predicted multiples)

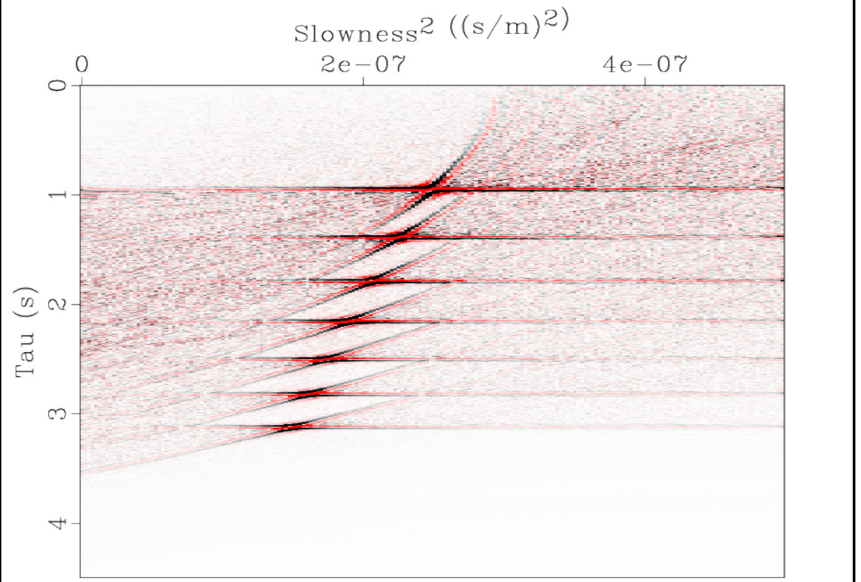
Train with 3, 5 and 8, predict for 8 geological layers



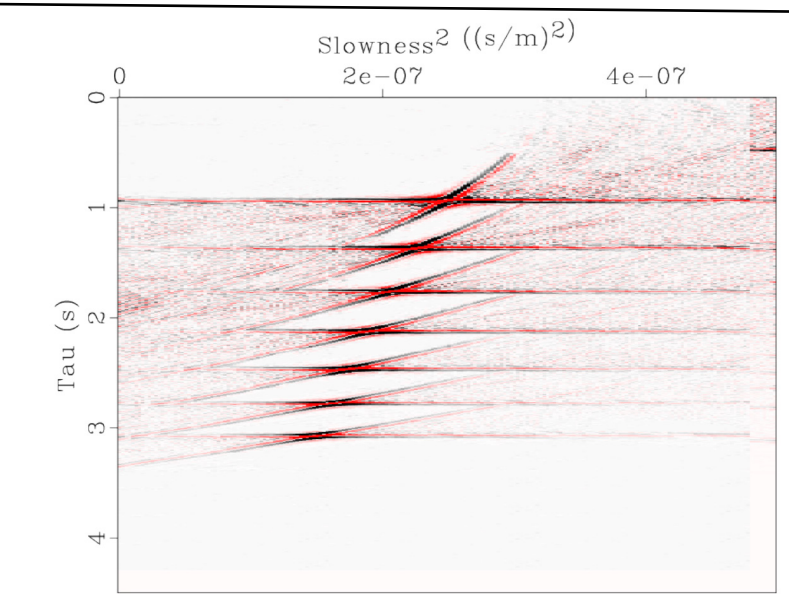
Shot gather – multiples only (label)



Shot – predicted multiples



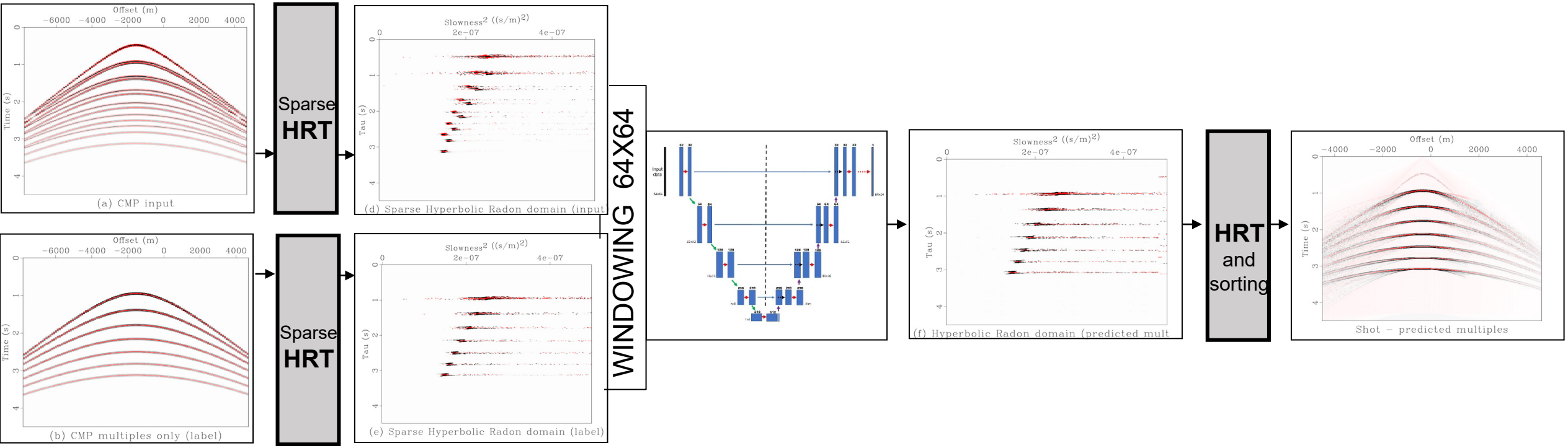
Hyperbolic Radon domain (label)



(f) Hyperbolic Radon domain (predicted multiples)

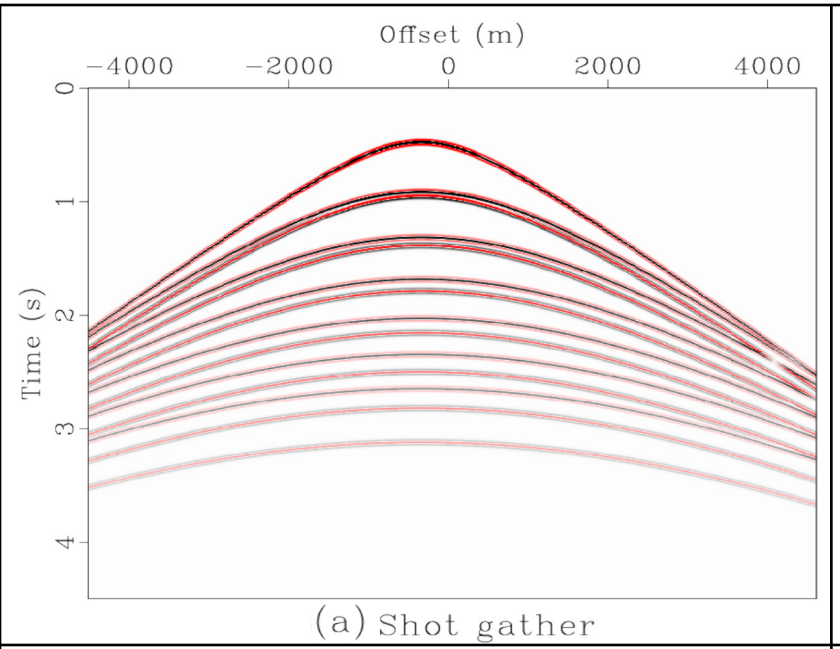
Test 2 – predicting the high resolution HRT with U-Net (1 channel)

Input data

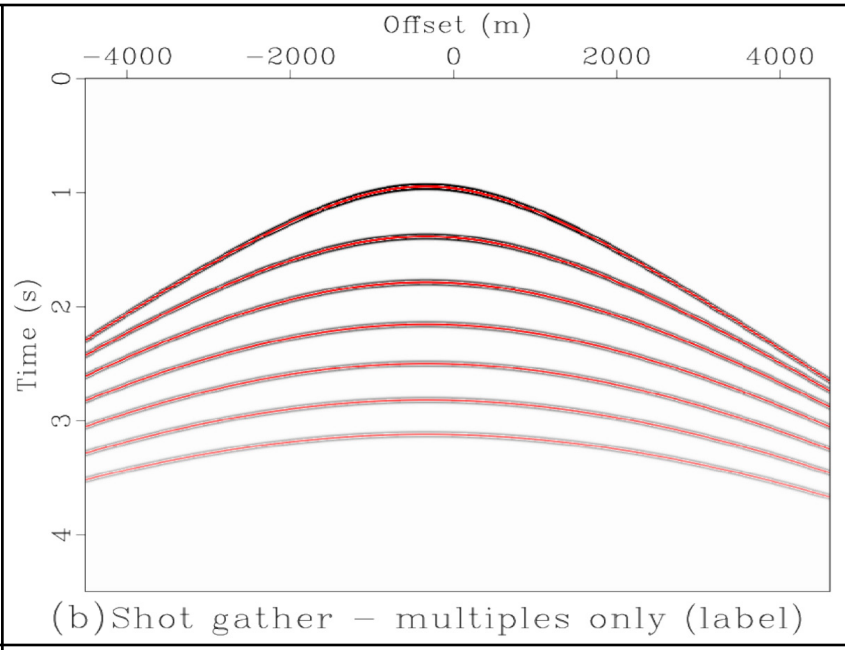


Input label

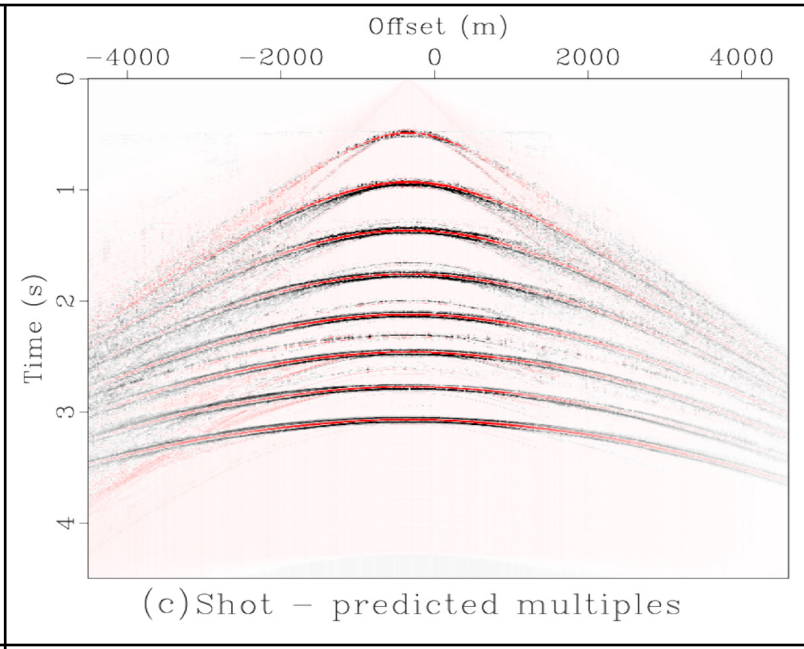
Train with 3 and 5, predict for 8 geological layers (both sparse HRT)



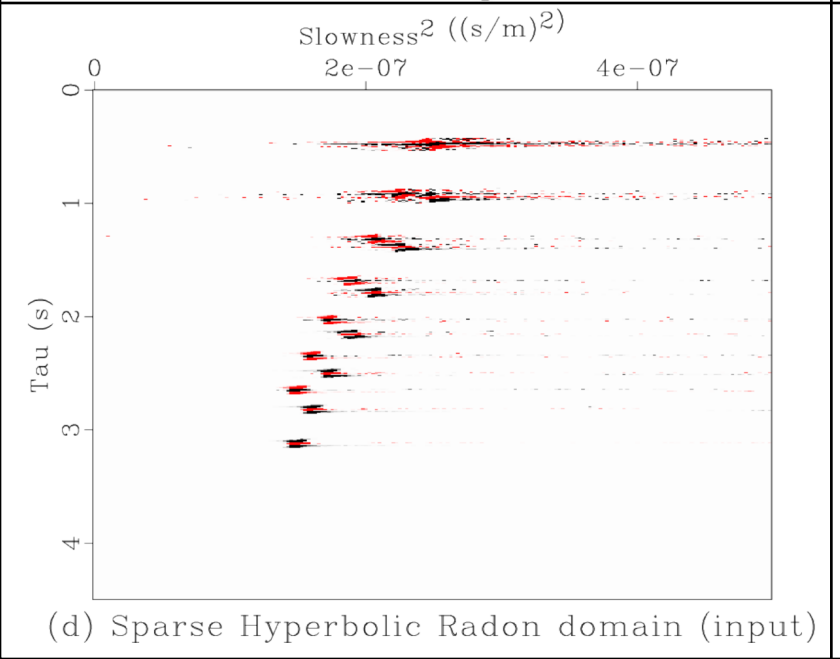
(a) Shot gather



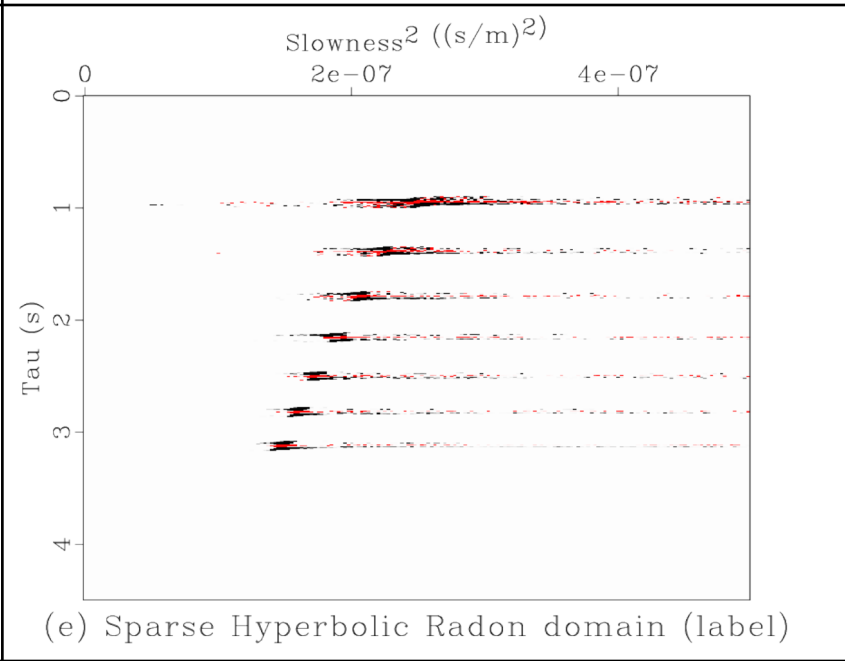
(b) Shot gather – multiples only (label)



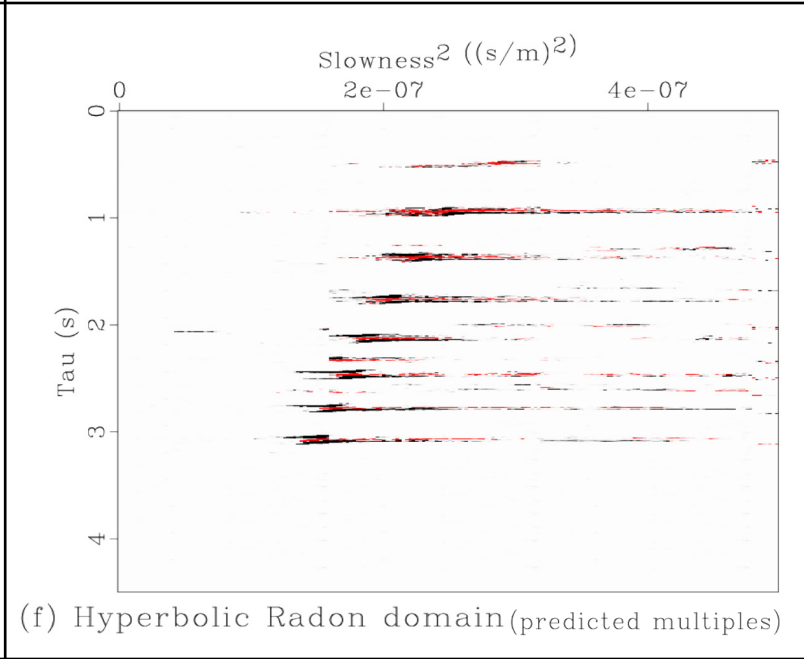
(c) Shot – predicted multiples



(d) Sparse Hyperbolic Radon domain (input)

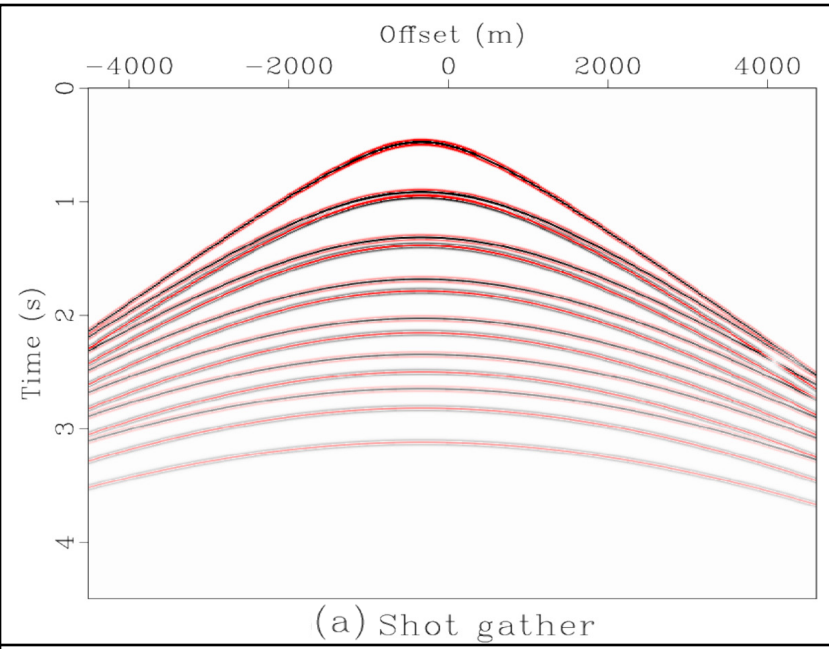


(e) Sparse Hyperbolic Radon domain (label)

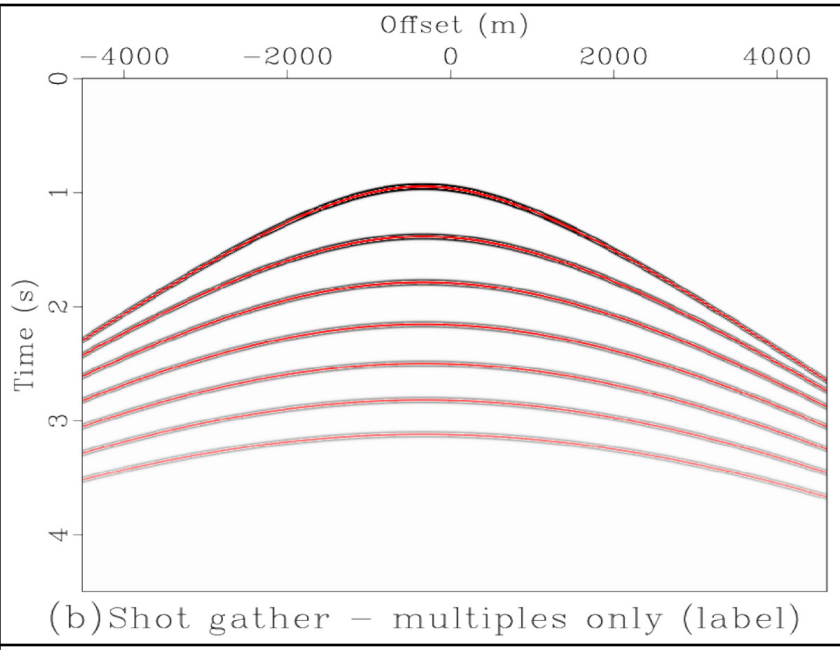


(f) Hyperbolic Radon domain (predicted multiples)

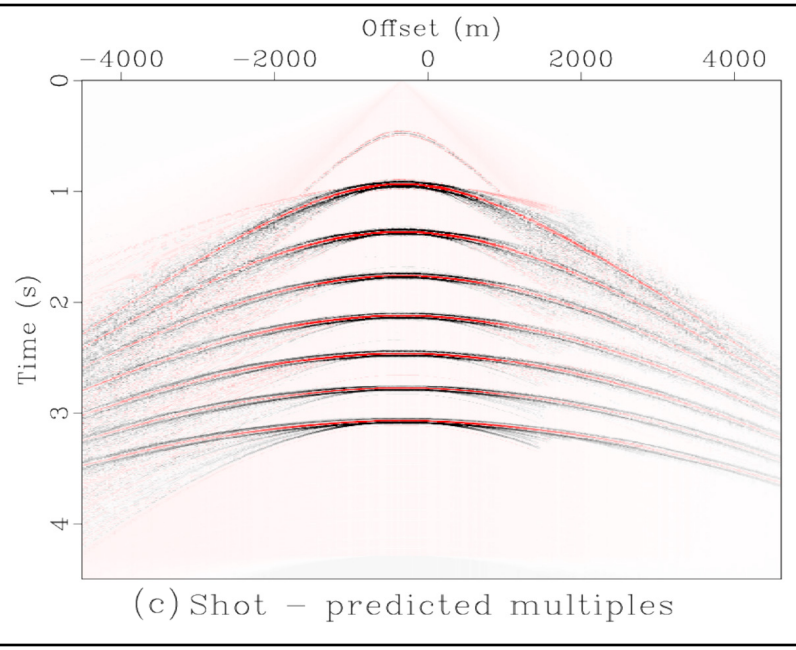
Train with 3, 5 and 8, predict for 8 geological layers (both sparse HRT)



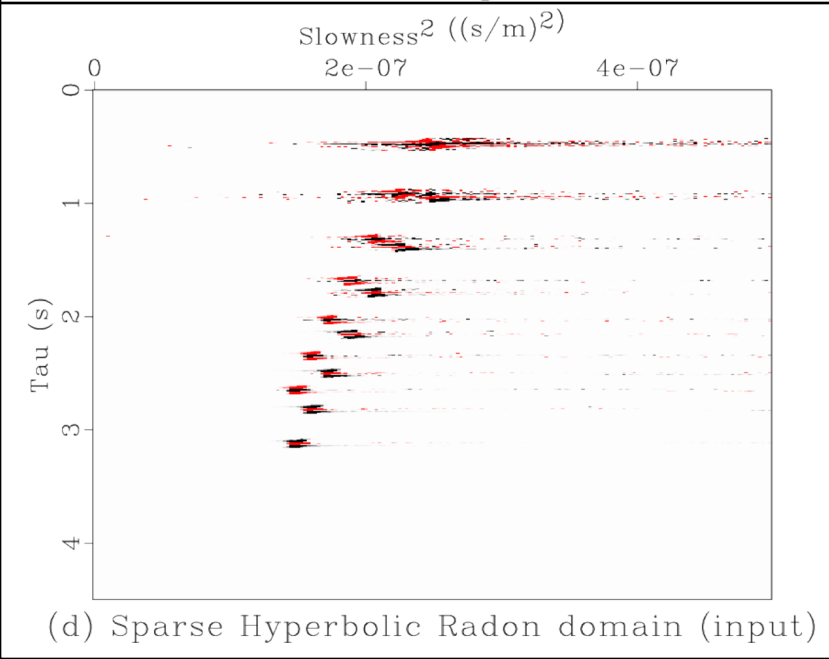
(a) Shot gather



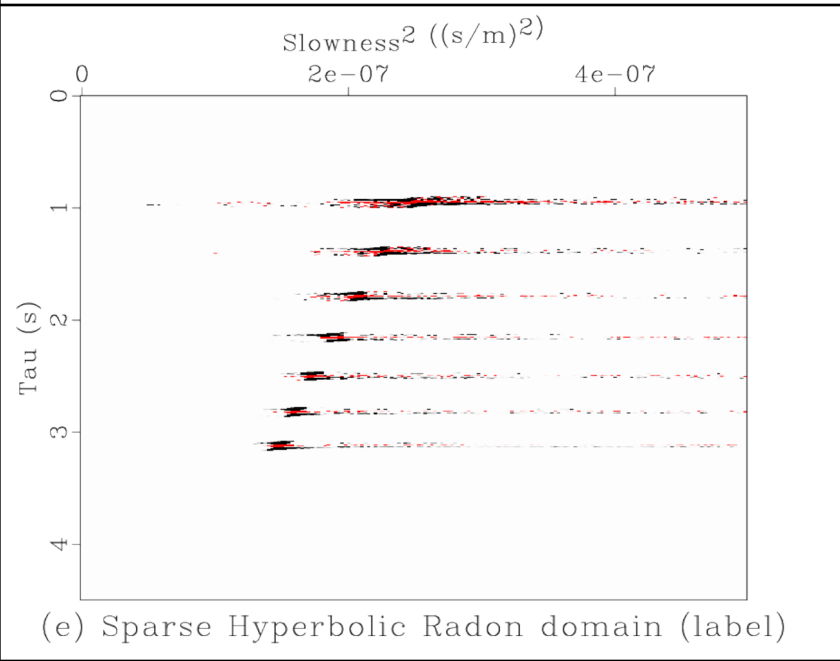
(b) Shot gather – multiples only (label)



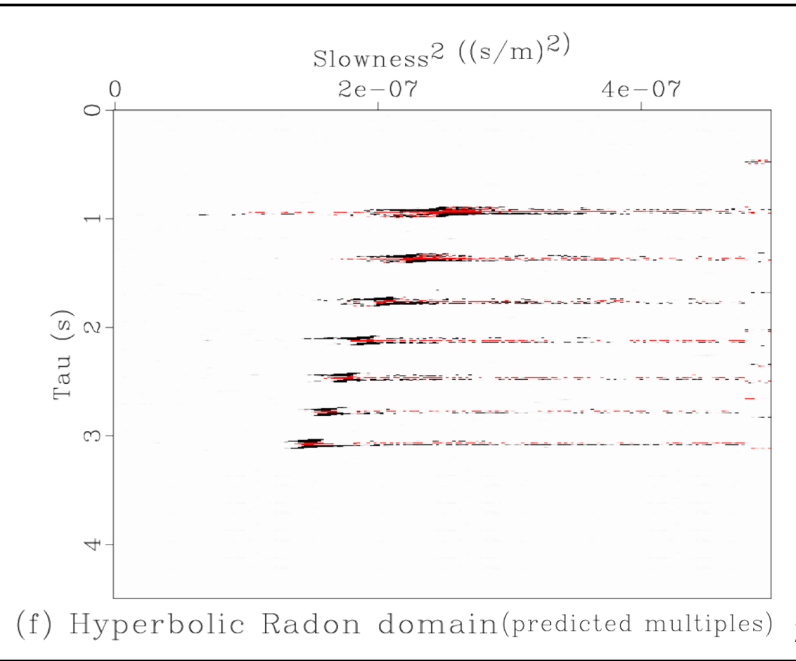
(c) Shot – predicted multiples



(d) Sparse Hyperbolic Radon domain (input)



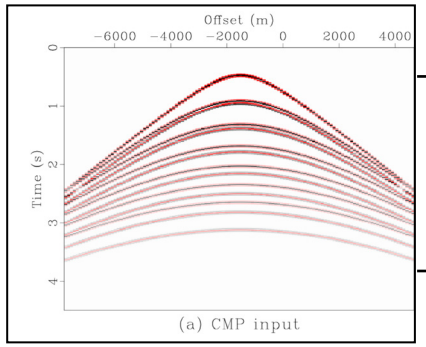
(e) Sparse Hyperbolic Radon domain (label)



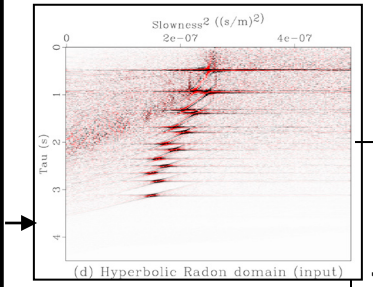
(f) Hyperbolic Radon domain(predicted multiples)

Test 3 – predicting the HRT with U-Net (2 channels: sparse and non-sparse)

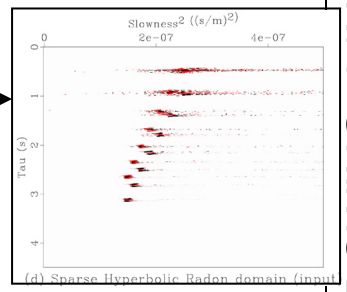
Input data



HRT

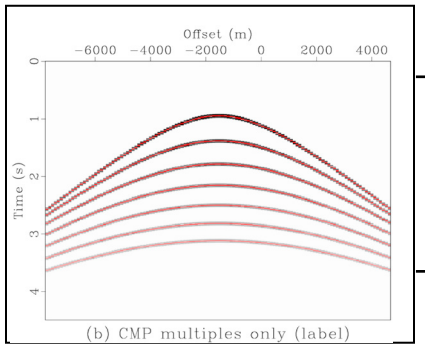


Sparse HRT

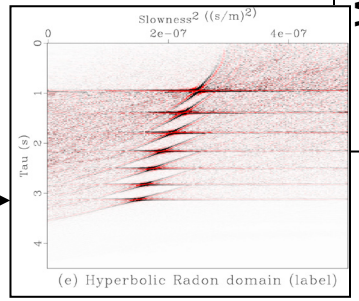


WINDOWING 64X64

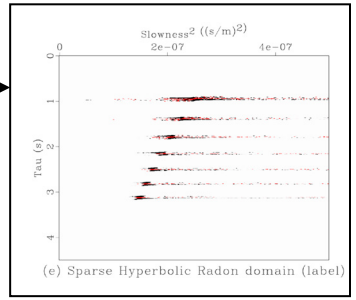
Input label

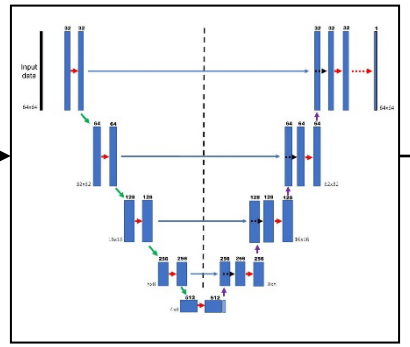


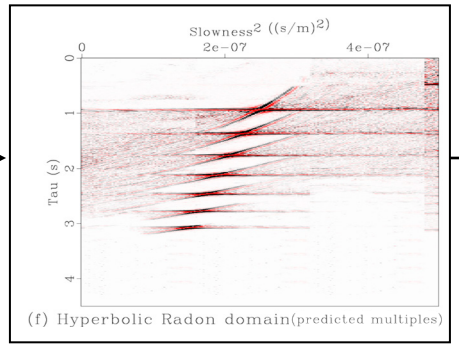
HRT



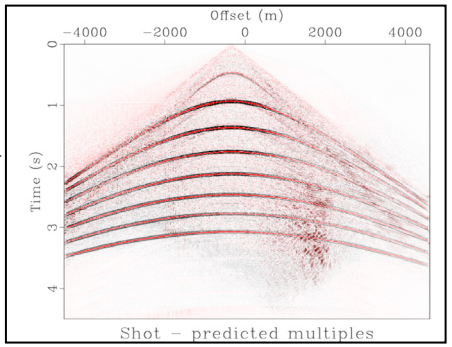
Sparse HRT



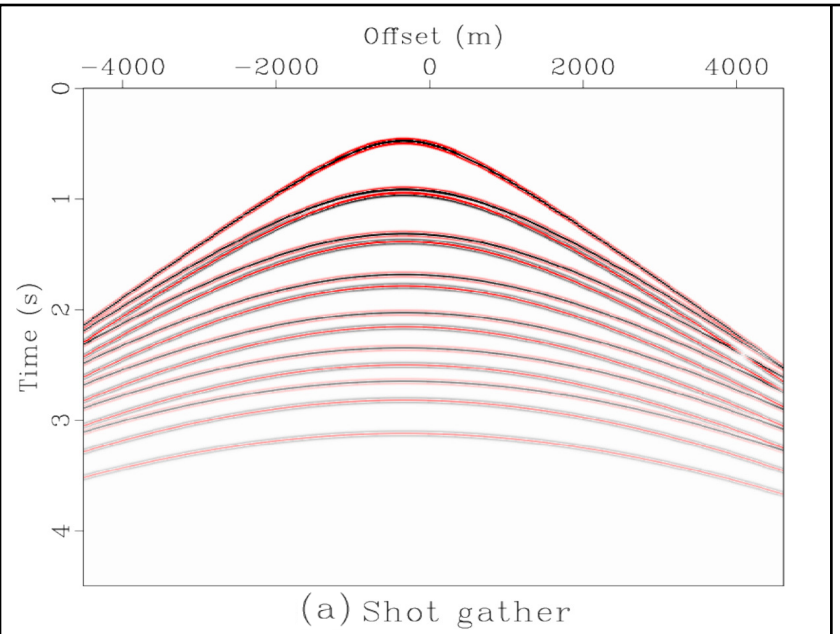




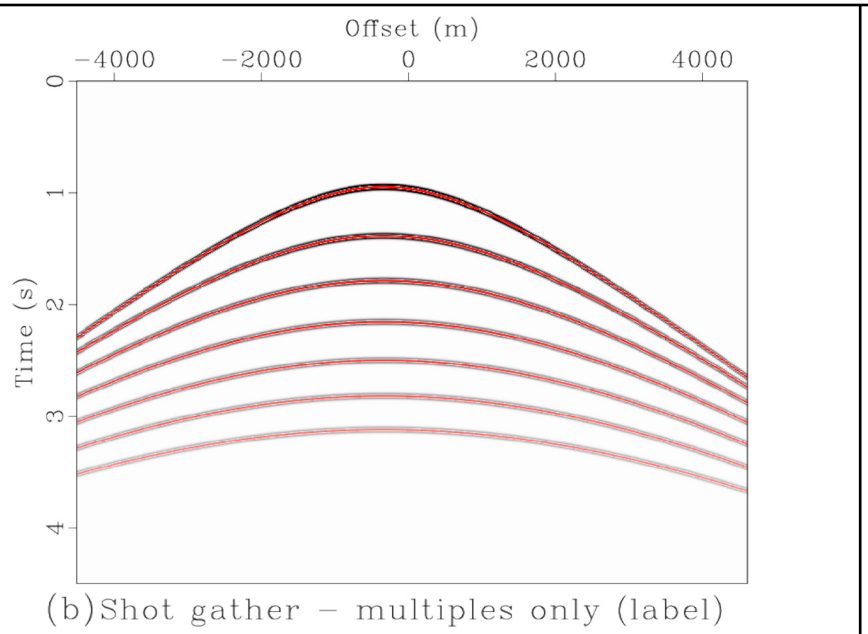
HRT and sorting



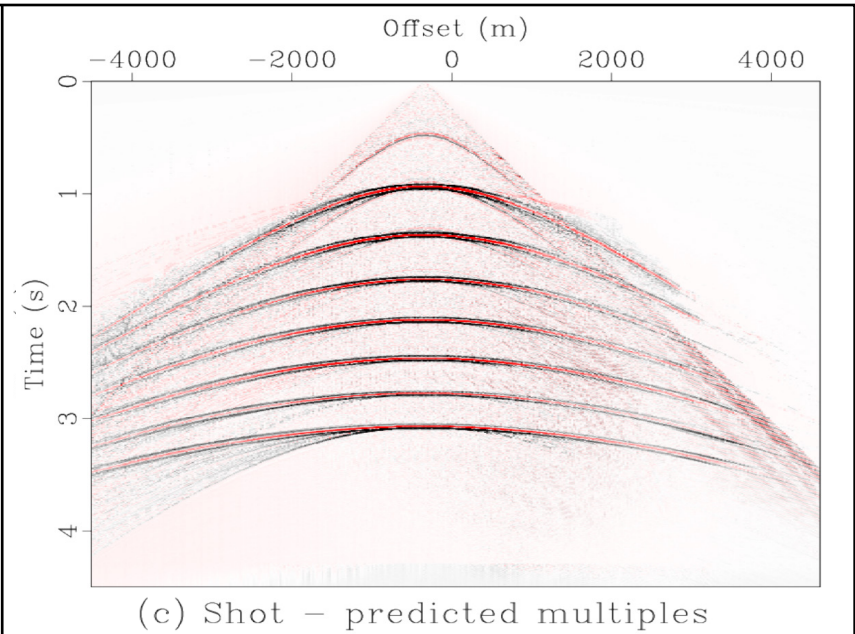
2 channels (label: sparse): train with 3, 5 and 8, predict for 8 geological layers



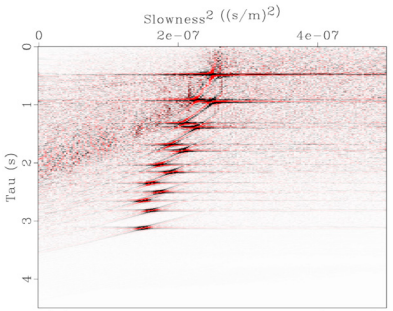
(a) Shot gather



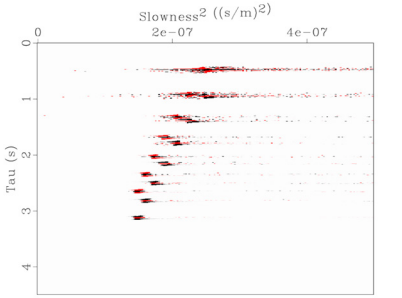
(b) Shot gather – multiples only (label)



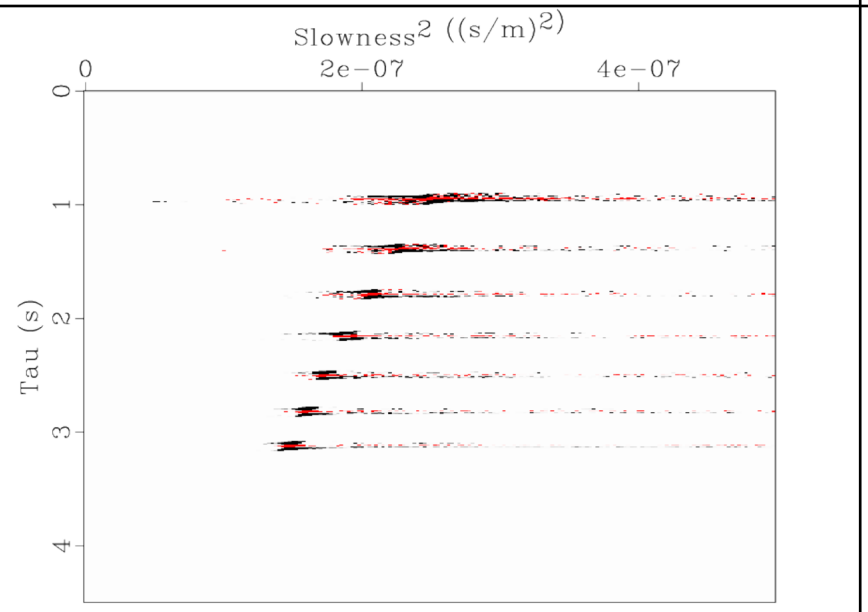
(c) Shot – predicted multiples



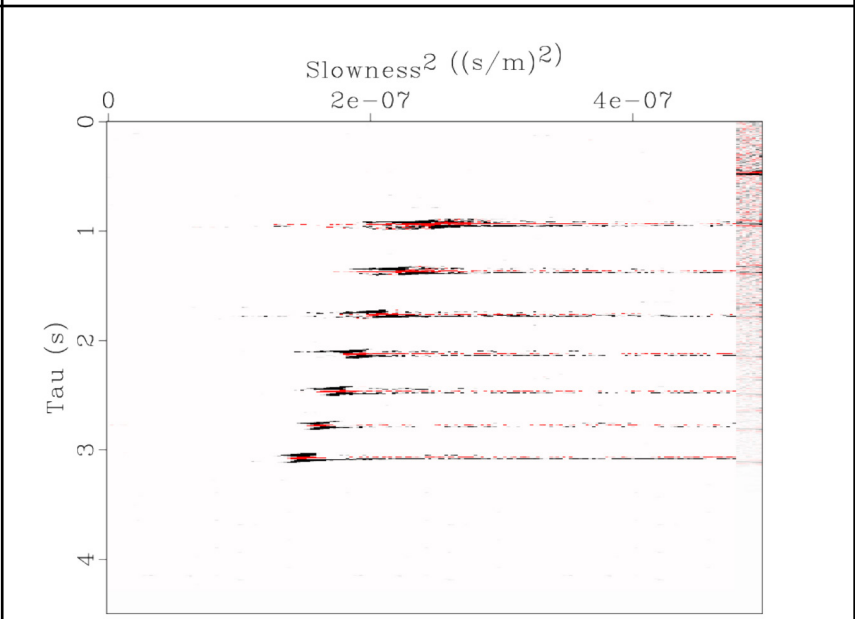
(d) Hyperbolic Radon domain (input)



(d) Sparse Hyperbolic Radon domain (input)

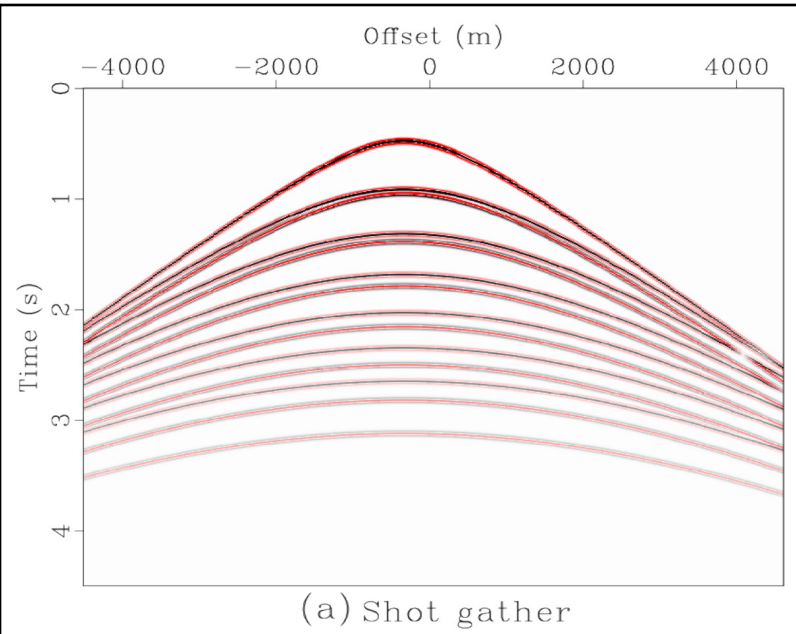


(e) Sparse Hyperbolic Radon domain (label)

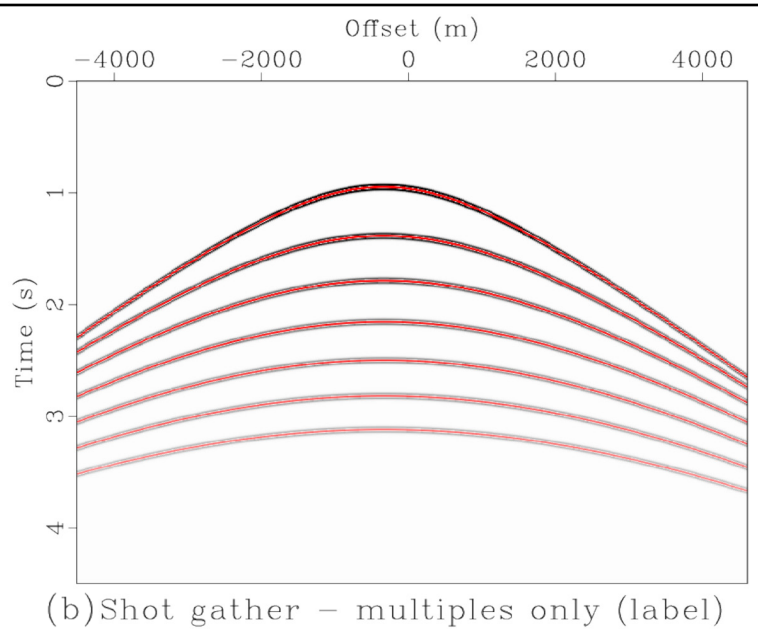


(f) Hyperbolic Radon domain (predicted multiples)

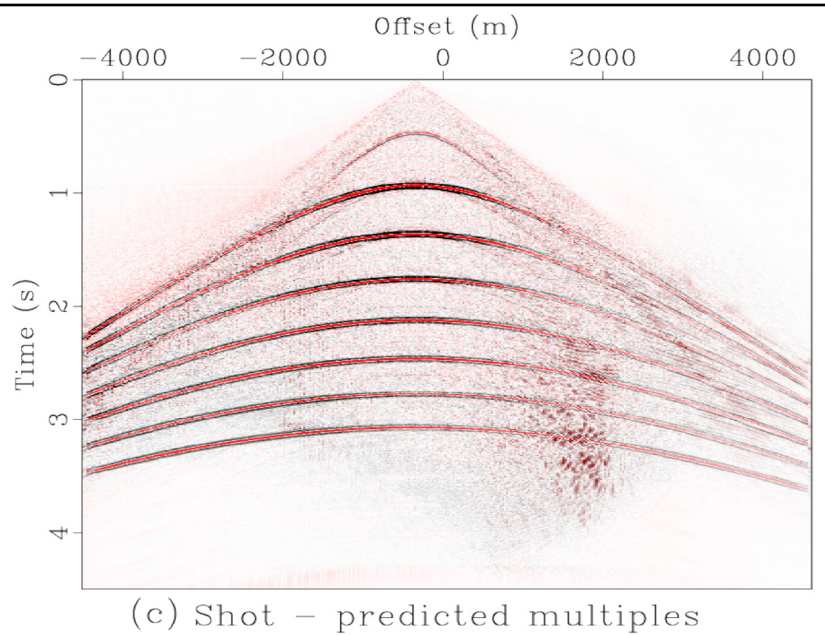
2 channels (label: non-sparse): train with 3, 5 and 8, predict for 8 geological layers



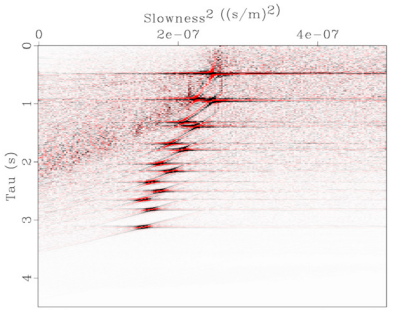
(a) Shot gather



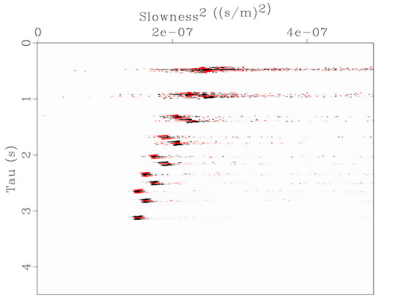
(b) Shot gather – multiples only (label)



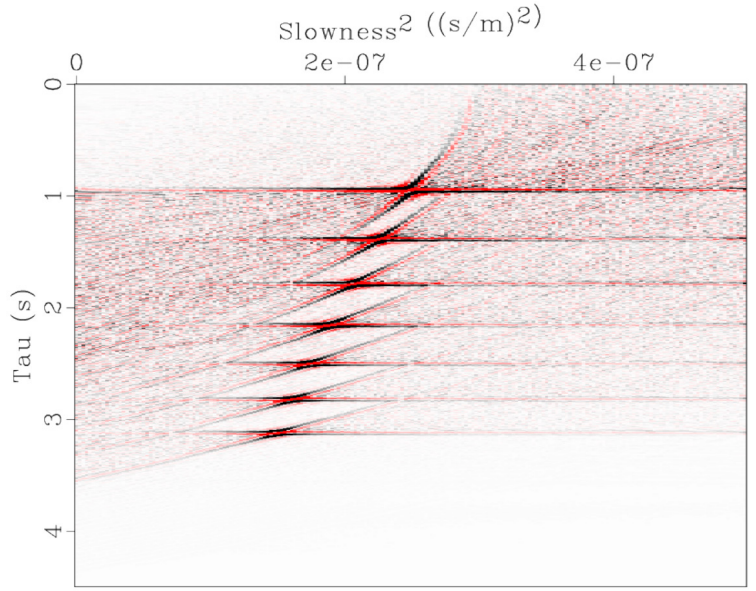
(c) Shot – predicted multiples



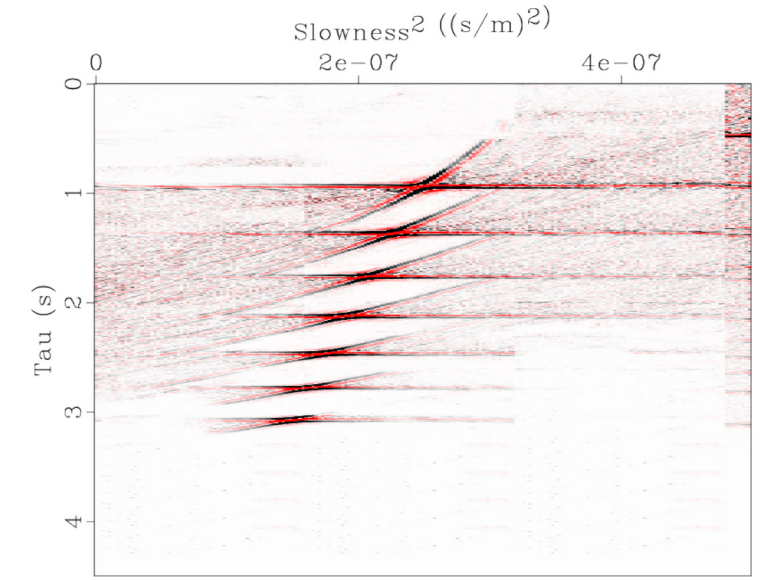
(d) Hyperbolic Radon domain (input)



(d) Sparse Hyperbolic Radon domain (input)



(e) Hyperbolic Radon domain (label)



(f) Hyperbolic Radon domain (predicted multiples)

Conclusions and Future Work

- HRT is an important tool to separate multiple and primary;
- The U-Net can be used to separate the primaries and multiples in the Radon space and therefore predict multiples;
- Training with two channels using non-sparse labels resulted on better multiple prediction;
- Artifacts generated by the transform are difficult to predict at inference time, decreasing the generalization power.

- Future work:
  - ➢ Test with more complex geologic models;
  - ➢ Train with more channels using different features: parabolic Radon transform;
  - ➢ Address windowing issue.

Thank you!

- CREWES industrial sponsors,
- NSERC (Natural Science and Engineering Research Council of Canada).