Towards characterization of intrinsic and stratigraphic Q in VSP data with information measures

Siming Lv

Supervisor: Kris Innanen

Outline

- Introduction
- Initial Shannon entropy algorithm
  - ➢ Calculation strategy
  - ➢ Model tests & data analysis
- Conditional Shannon entropy algorithm
  - ➢ Calculation strategy
  - ➢ Model tests & data analysis
- Discussion
- Seven-well comparison
- Conclusion

1. **Stratigraphic filtering**:

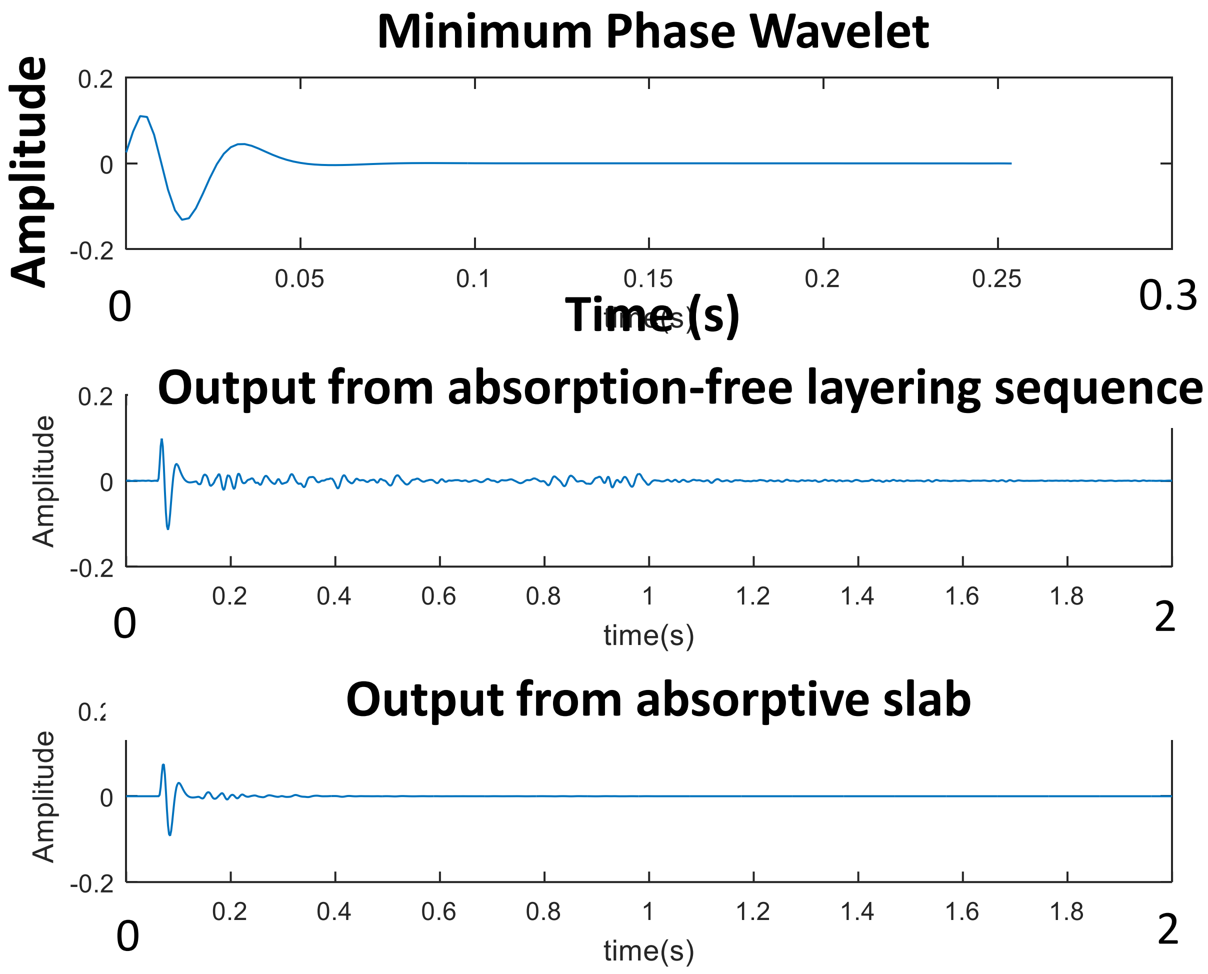
   interbed reverberations --> apparent amplitude attenuation

2. Stratigraphic filtering & absorption have **highly resembled effects**:

   ①decay and spread waveform;

   ②reduce the high-frequency content;

   ③append incoherent coda to the signal



3. $\left|\hat{T}(\omega,\tau)\right| = \exp(-R(\omega)\tau)$ (O'Doherty and Anstey, 1971)

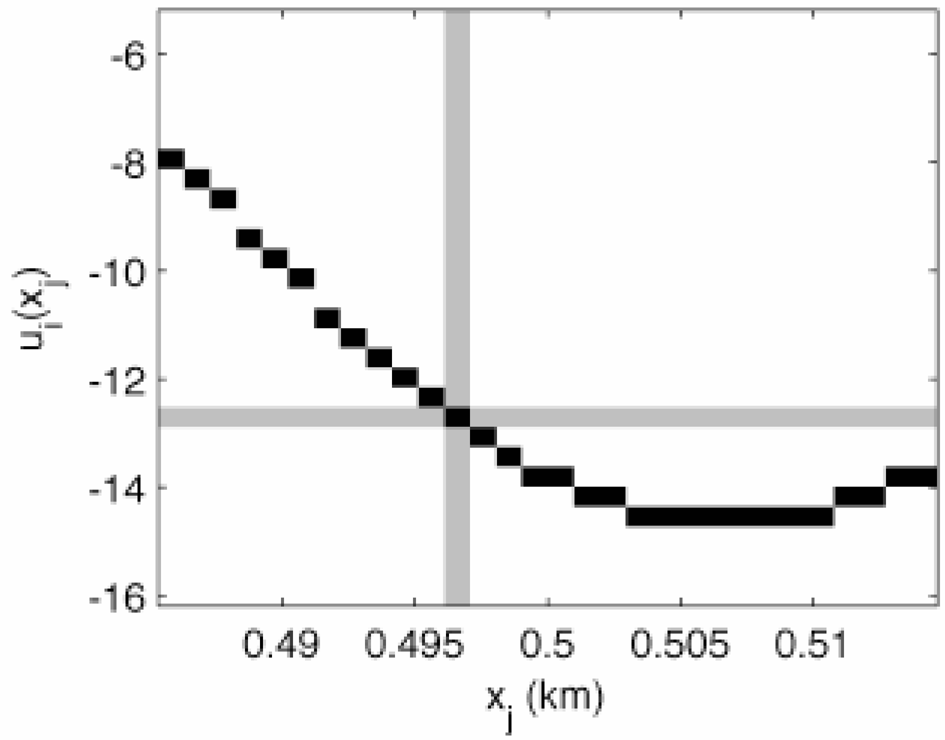
$Q_s(\omega) = \omega / 2R(\omega)$ (Banik et al., 1985)

$\left|\hat{T}(\omega,\tau)\right| = \exp(-\omega\tau / 2Q_d(\omega))$ (Aki and Richards, 1980)

4. **Heavy oil/Bitumen viscosity** is related to intrinsic Q (Vasheghani and Lines, 2009)

Calculation strategy

A snapshot of discrete VSP



1. **Shannon entropy**: measures the amount of information in an uncertain message using occurring probabilities of contents.

2. "Message": time snapshots of 1D zero-offset VSP
   "Letter": displacement value ui

3. For m possible u_i, number of occurrences of each u_i in the snapshot: $W(u_i)$.
   Probability of its occurrence:

$$P(u_i) = \frac{W(u_i)}{\sum_{i=1}^{m} W(u_i)} \quad (i = 1, \dots, m)$$

Probability Distribution Function (PDF)

Calculation strategy

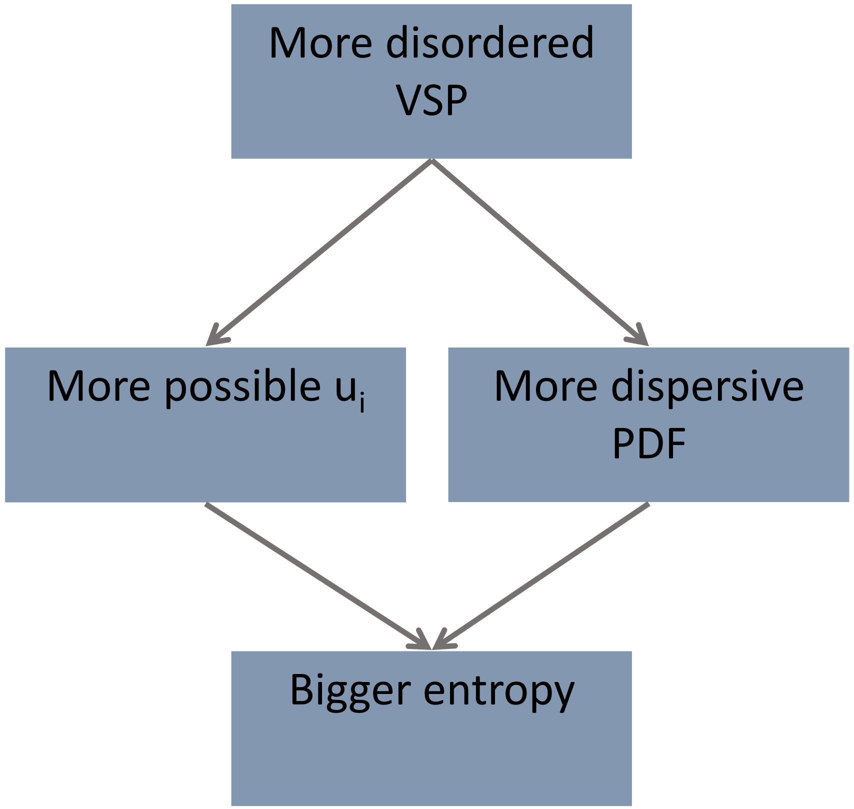
4. Shannon Entropy (H):
   Entropy of a single data point X_j :

$$H(X_j) = -\sum_{i=1}^{m} P(u_i)\log_2 P(u_i) \qquad \text{(bit)}$$

   Entropy of the whole snapshot:

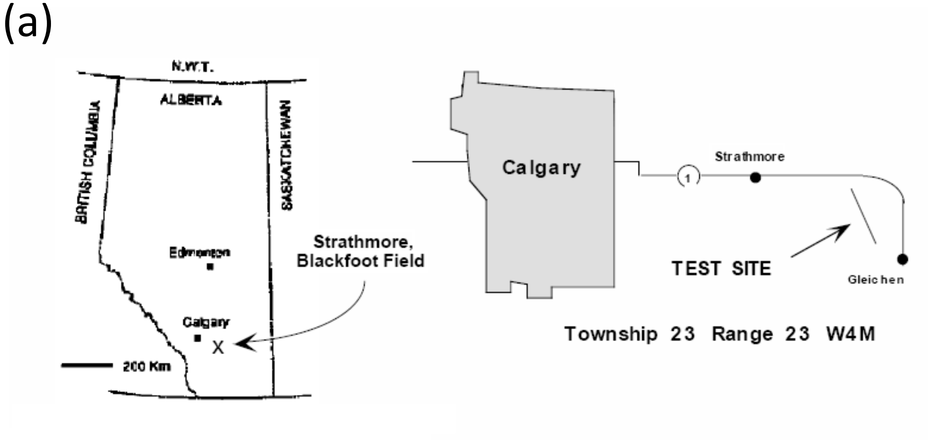
$$H = \sum_{j=1}^{N} H(X_j) \qquad (j = 1, \ldots, N) \quad \text{(bit)}$$

5. **Main strategy**: Investigate entropy change with time evolution.



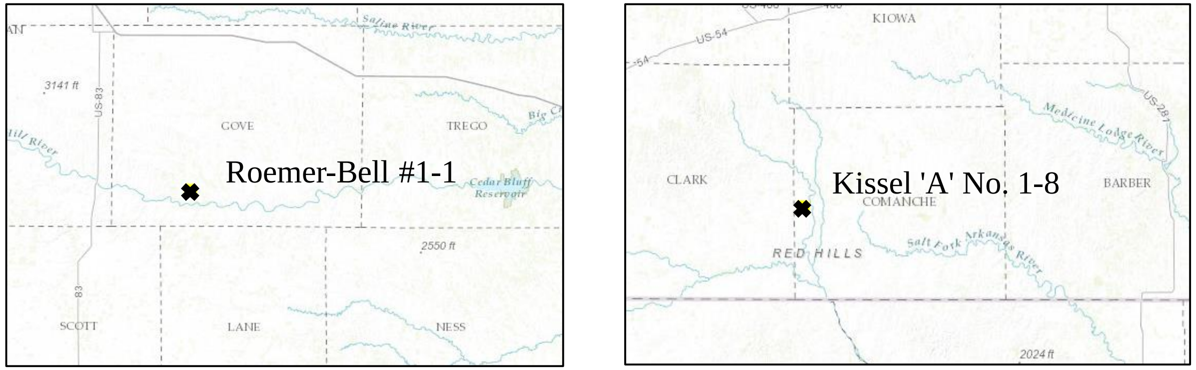
Well logs

(a)



(b)

(c)



(a) Two well logs from Blackfoot, Alberta: 1227 and 1409;

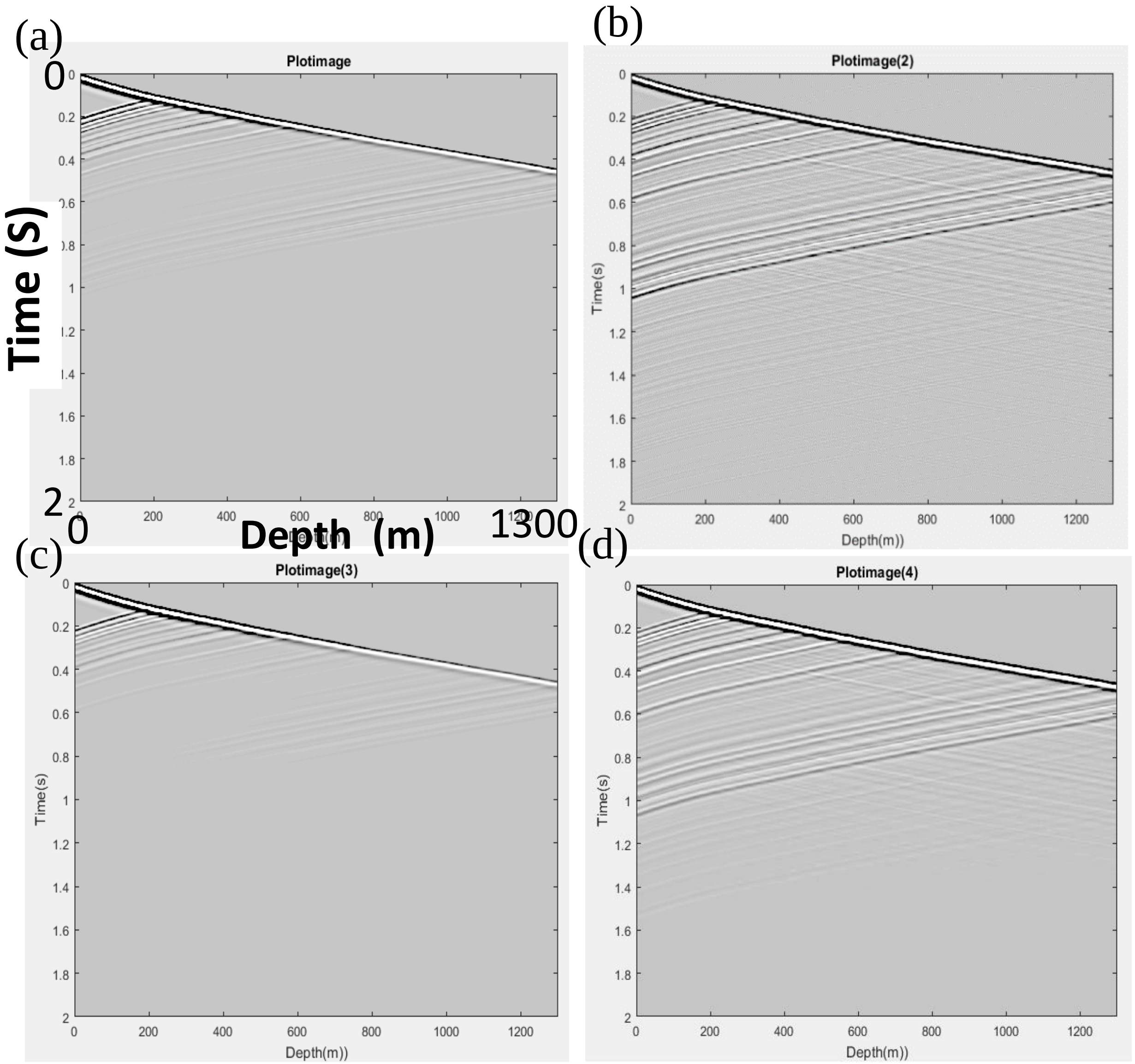
(b) Three well logs from near Hussar, Alberta: 12-27-025-21, 14-27-025-21 and 14-35-025-21;

(c) Two well logs from Gove and Comanche in Kansas, US: Roemer-Bell #1-1 and Kissel 'A' No. 1-8

Data analysis (Blackfoot 1227)

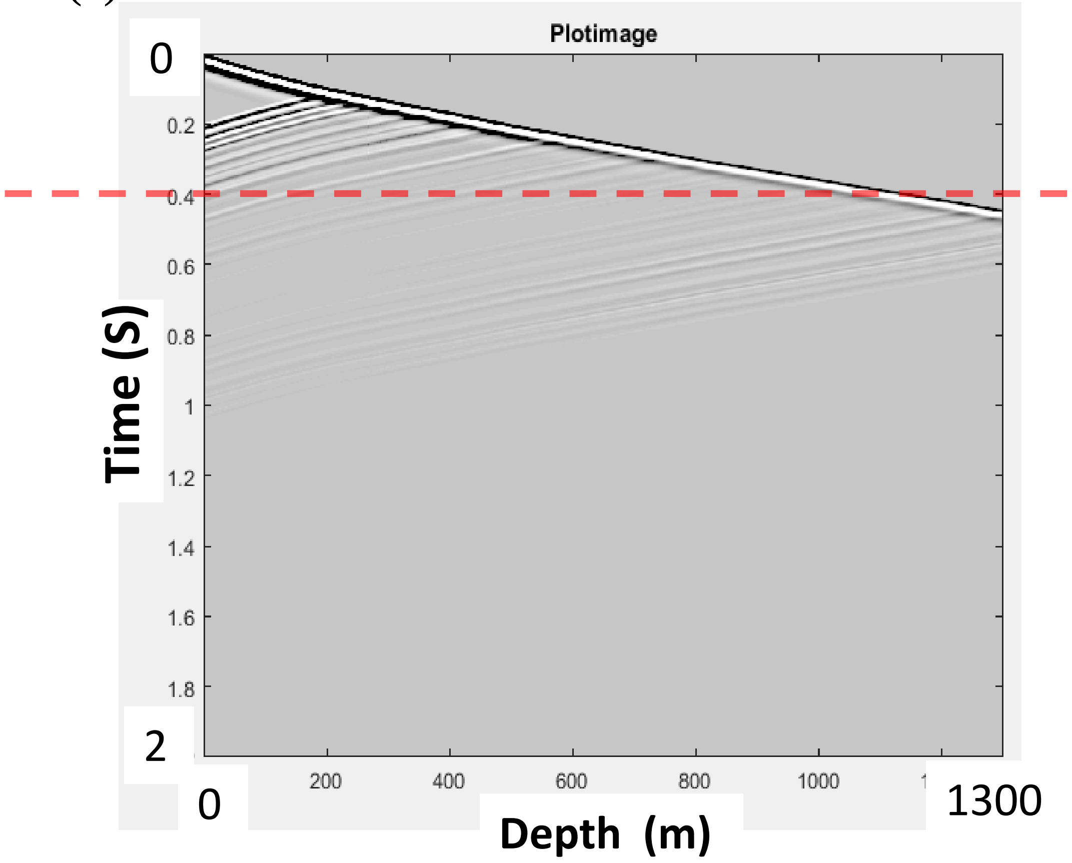
VSP data sets are built from intrinsic Q, P-velocity and density logs using a propagator matrix method (Margrave and Daley, 2014).

Q		Wavelet		Amplitude Bin Size
Min Q	Max Q	Type	Dominant F (Hz)	
20	220	Min Phase	30	0.001

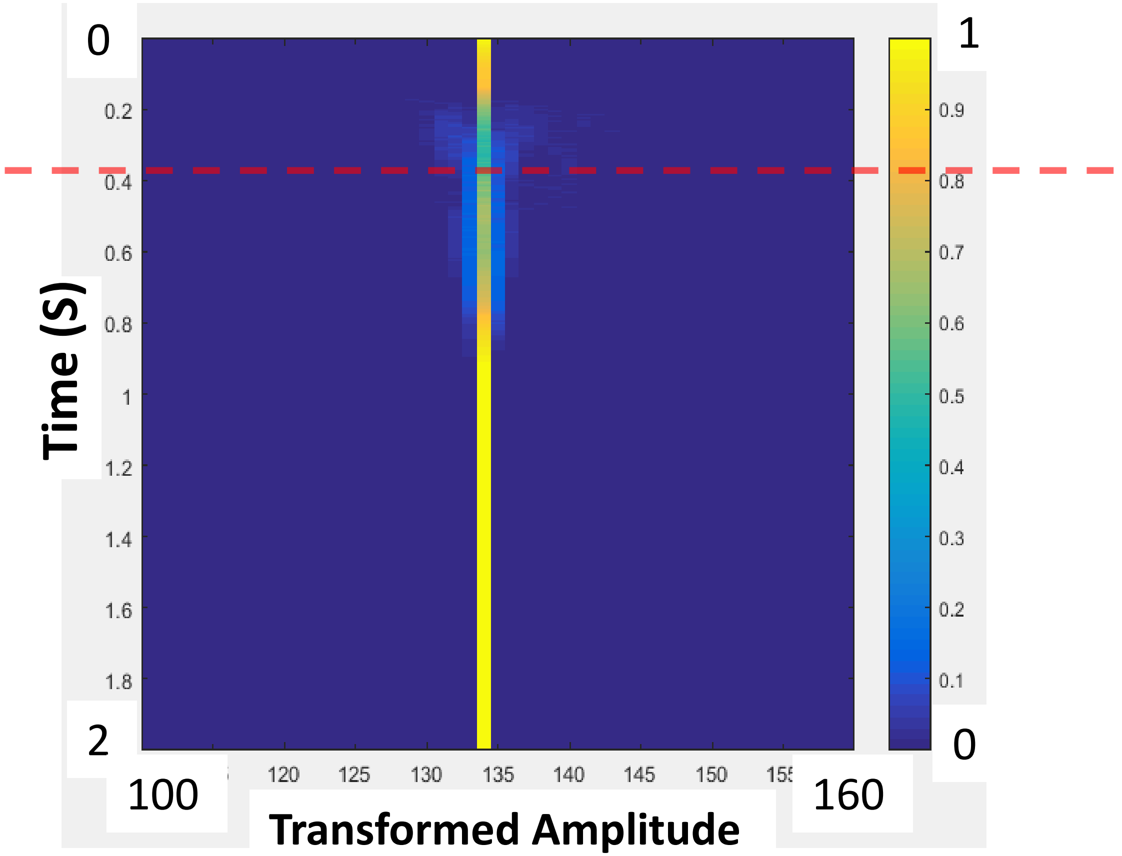


Data analysis (Blackfoot 1227)

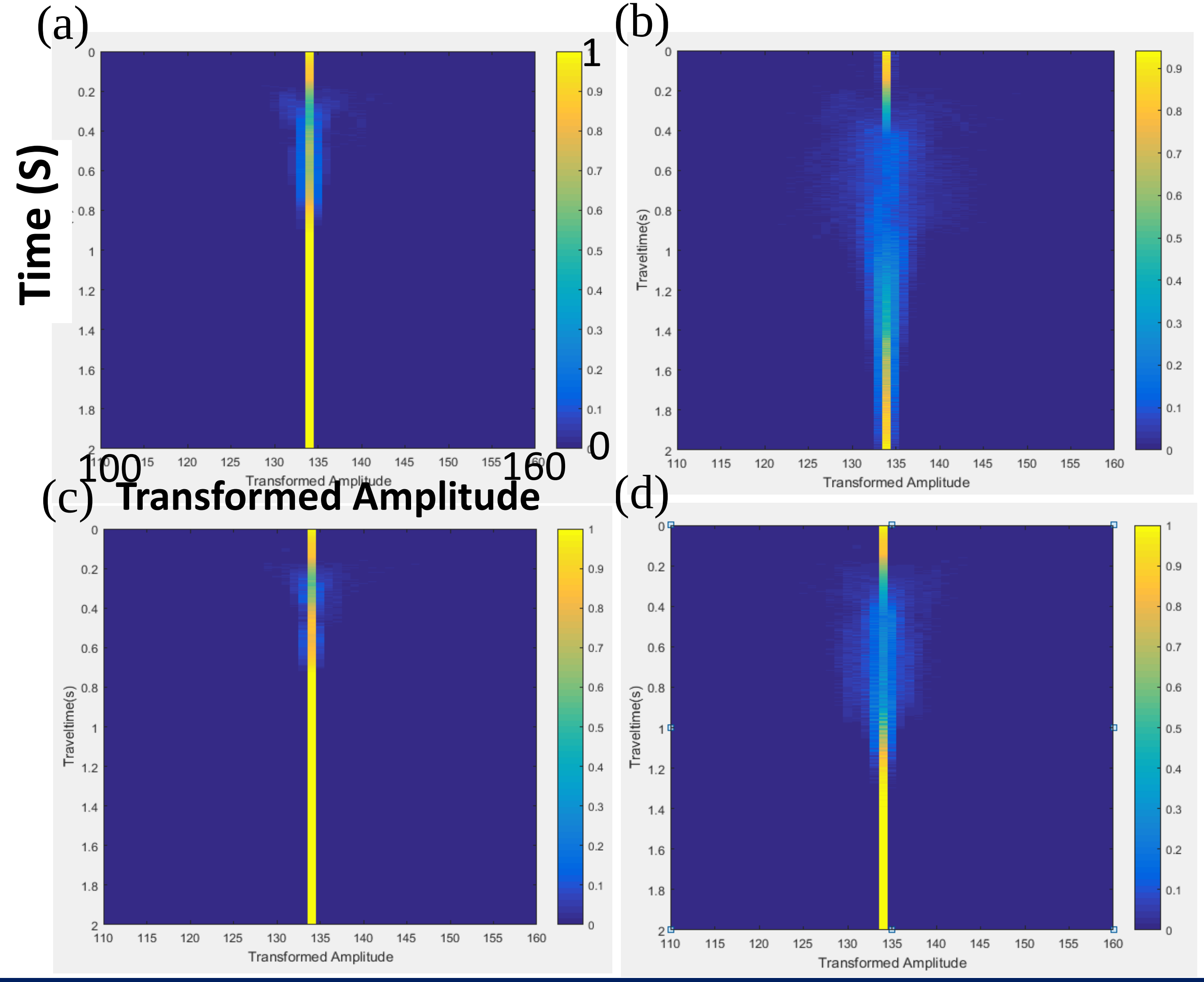
(a)



(a)

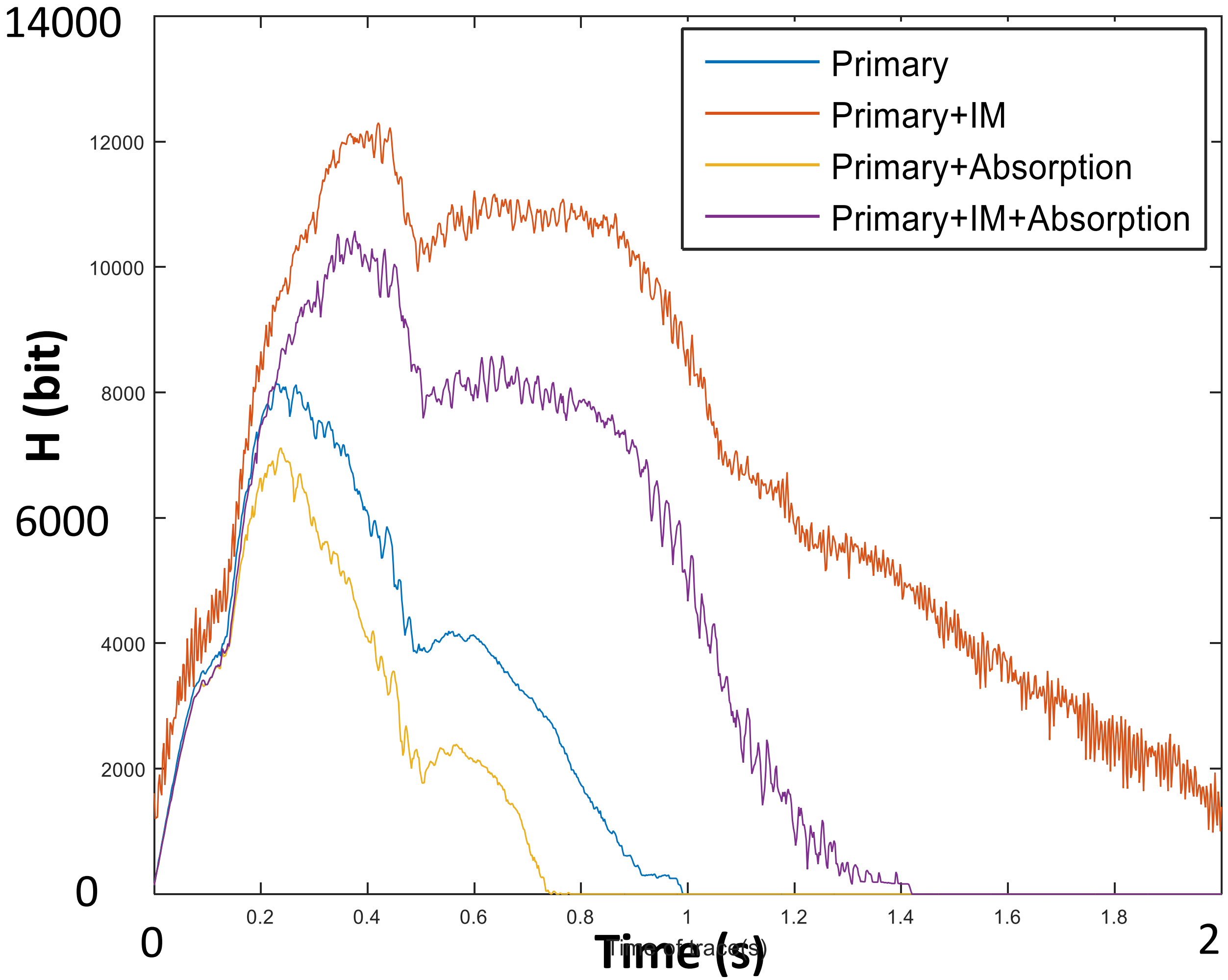


Data analysis (Blackfoot 1227)



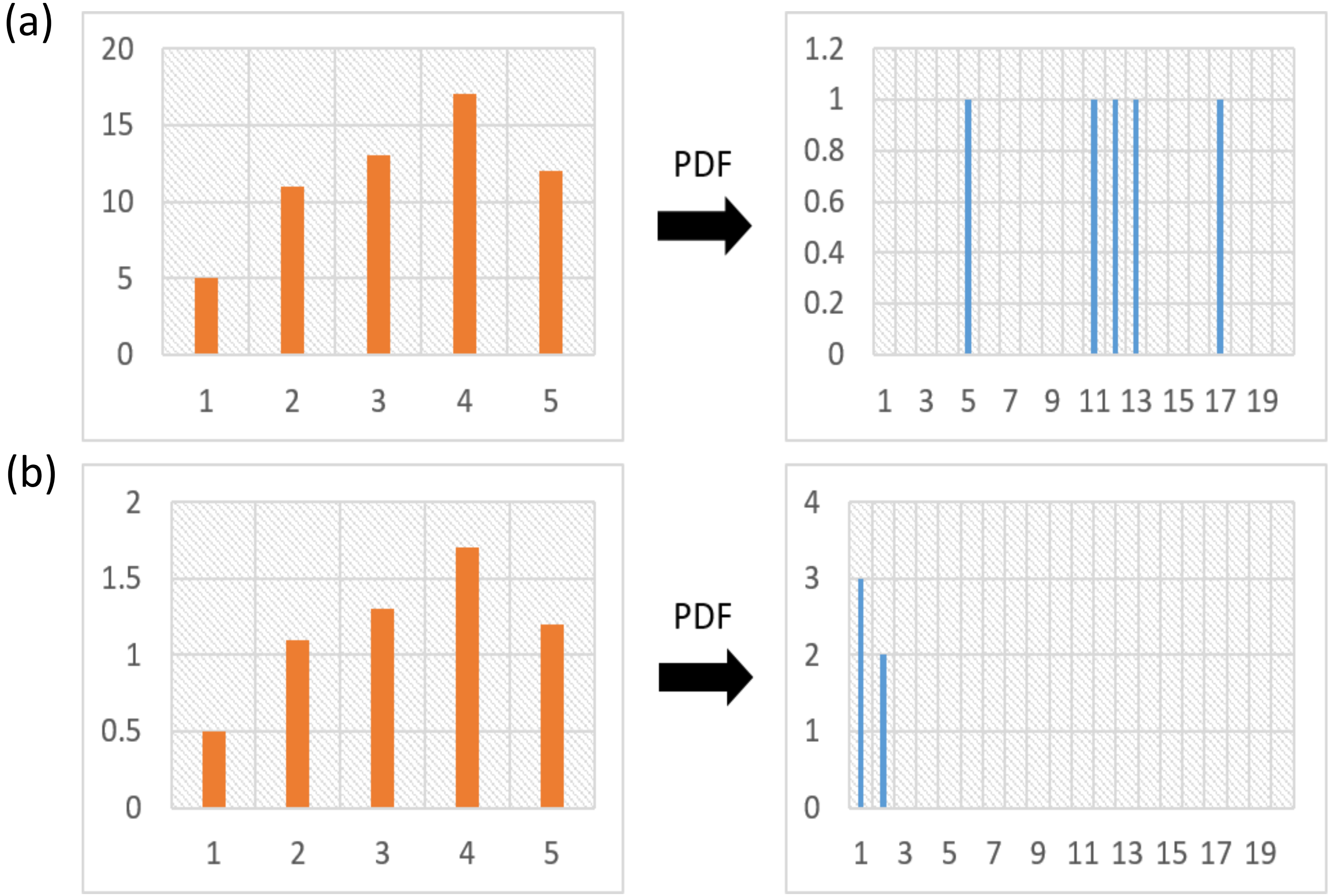
1. Complete localization represents zero state
2. PDFs with IMs: wider amplitude range, disperse effect in later arrival times;
3. PDFs with absorption: narrower amplitude range, disperse effect in earlier arrival times;
4. **IMs "scatter" wave; absorption "attenuates" wave**

Data analysis (Blackfoot 1227)



1. VSP data with IMs: higher peak H, latter peak time
2. VSP data without IMs: lower peak H, earlier peak time
3. VSP data with absorption: lower peak H, same peak time
4. **IMs** raise peak H **upward**; **intrinsic Q** draws peak H **downward**---act on H in the **opposite way**

Data analysis (Blackfoot 1227)

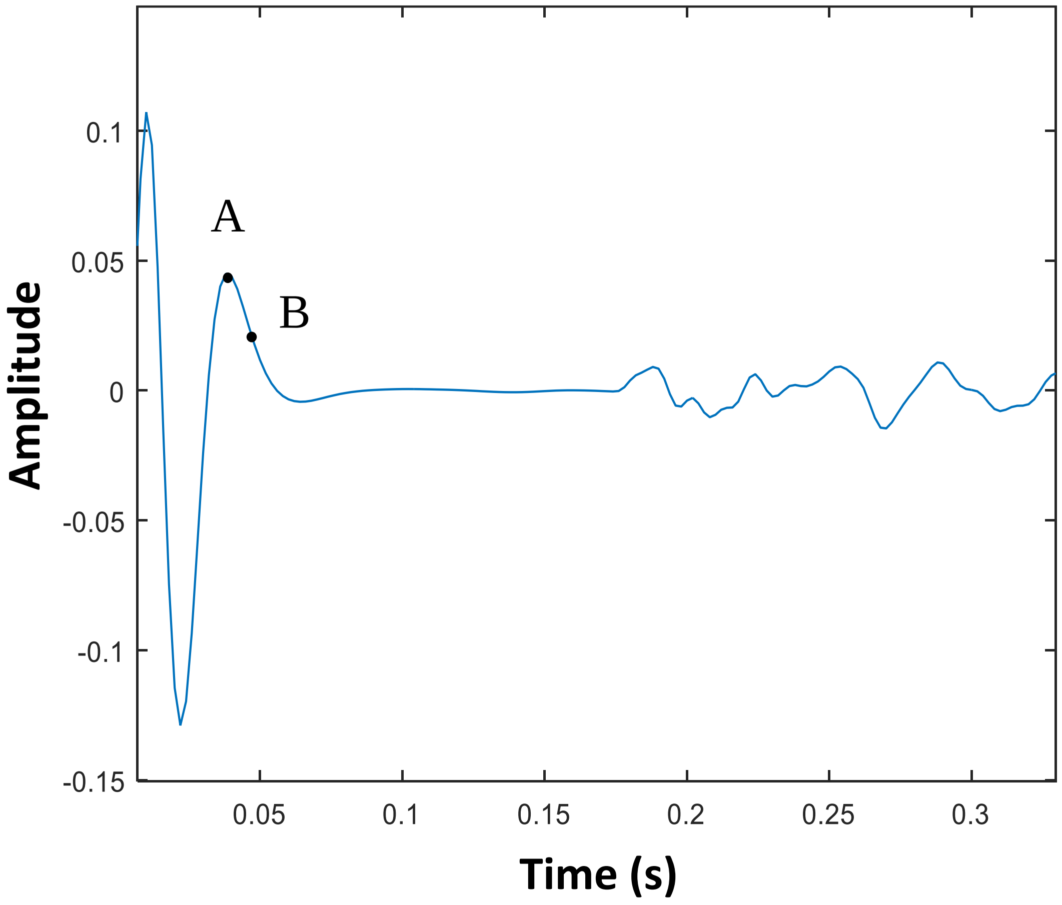


Why should attenuation lead to smaller entropy?

Data points take on smaller values, many of which fall into identical bins to form a **relatively steep, concentrated PDF histogram**.

Concentrated PDF leads to smaller entropy.

Calculation strategy

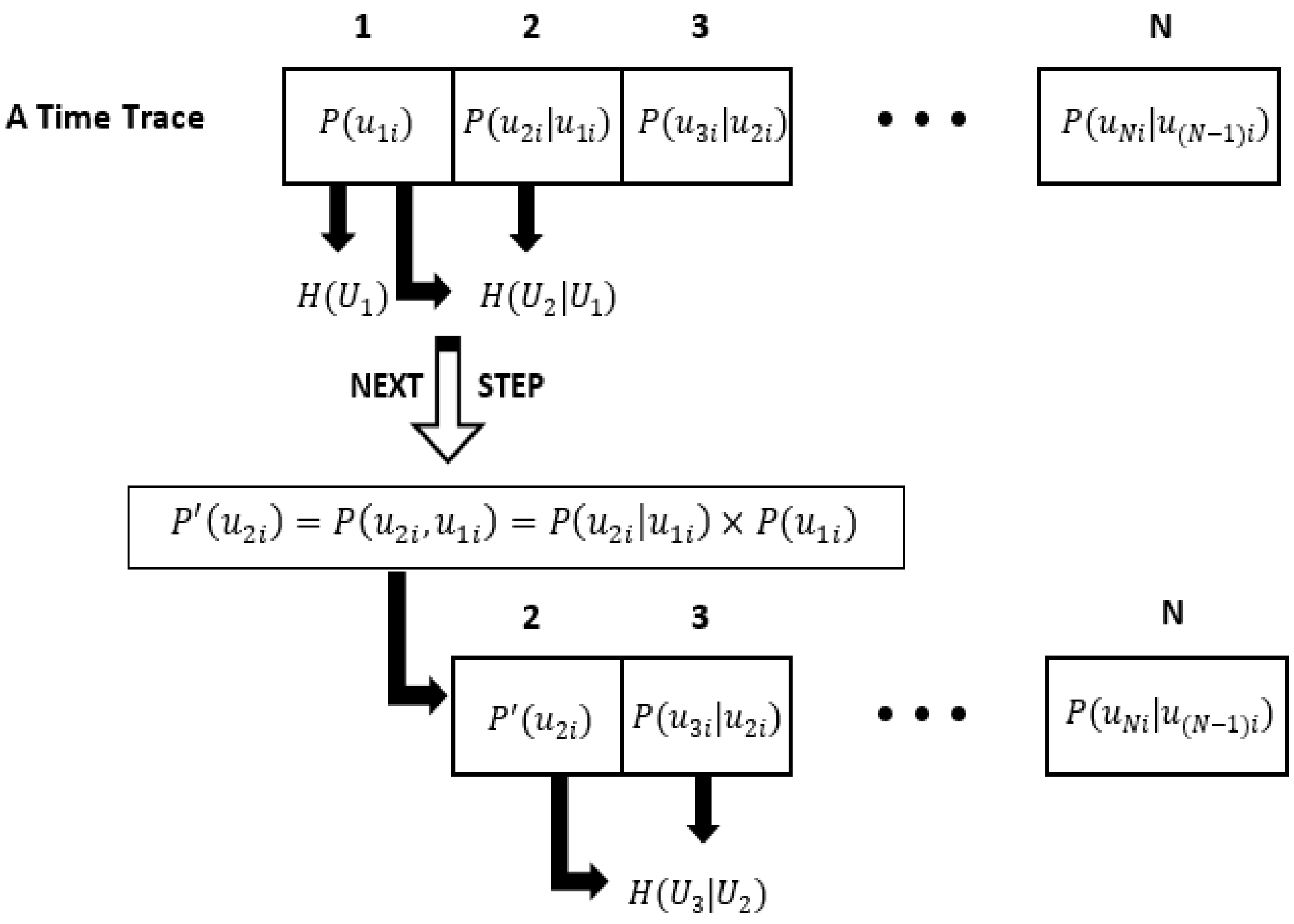


1. **Correlations of adjacent points** in wave field can be utilized;

2. Conditional probability: take u_0 as prerequisite and compute the conditional probability distribution of u_i following it in the whole data set:

$$P(u_i | u_{0j}) \qquad (i = 1, \dots, m; j = 1, \dots, m)$$

Calculation strategy



3. **Conditional Shannon entropy** for a single data point Y (in condition of leading point X amplitude being u_0):

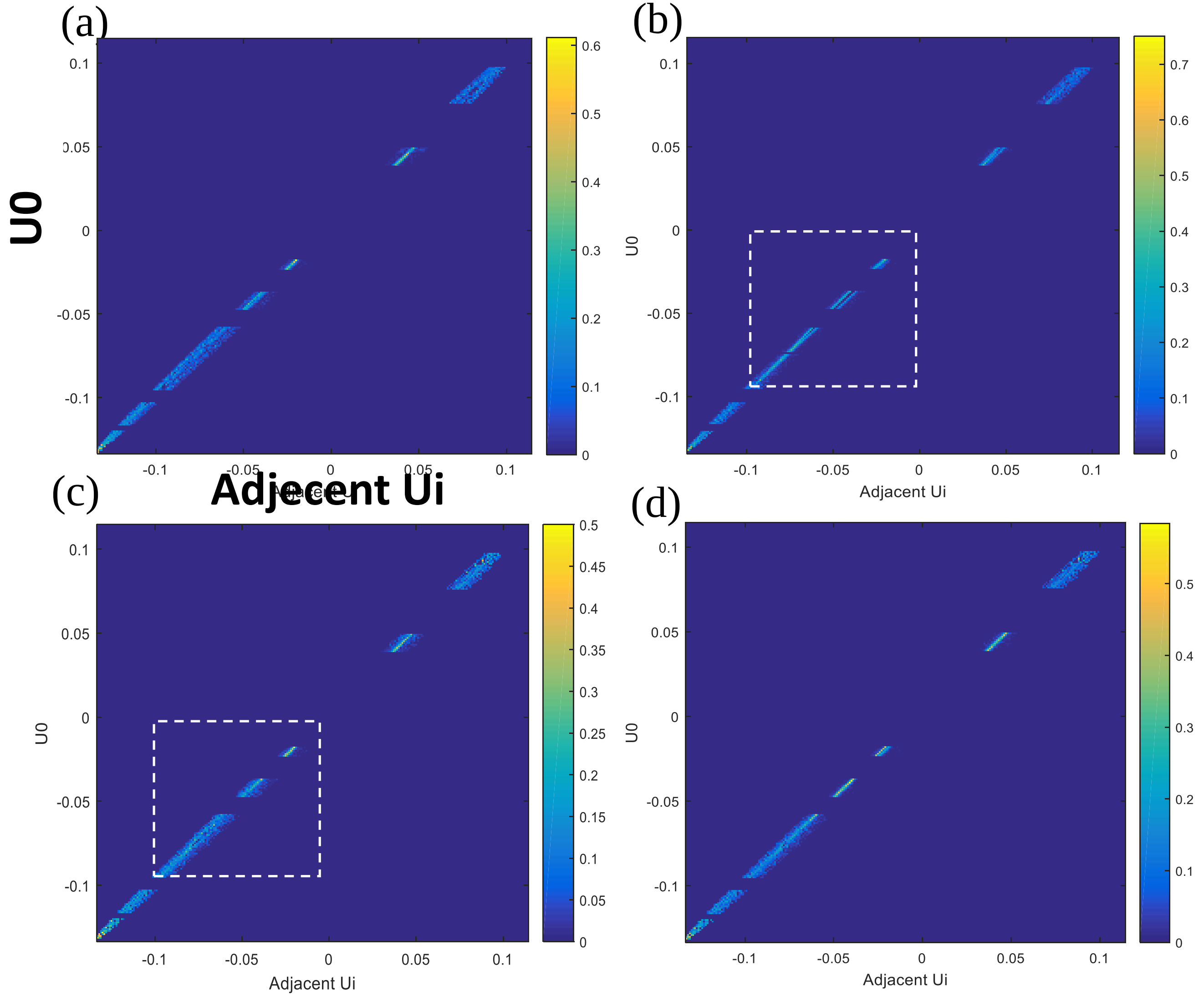
$$H(Y|X) = \sum_{u_{0j}} P(u_{0j}) H(Y|X = u_{0j})$$

$$= -\sum_{u_{0j}} P(u_{0j}) \sum_{u_i} P(u_i|u_{0j}) \log P(u_i|u_{0j})$$

$$(i = 1, \dots, m; j = 1, \dots, m)$$

4. Use the work flow to get entropy of every snapshots

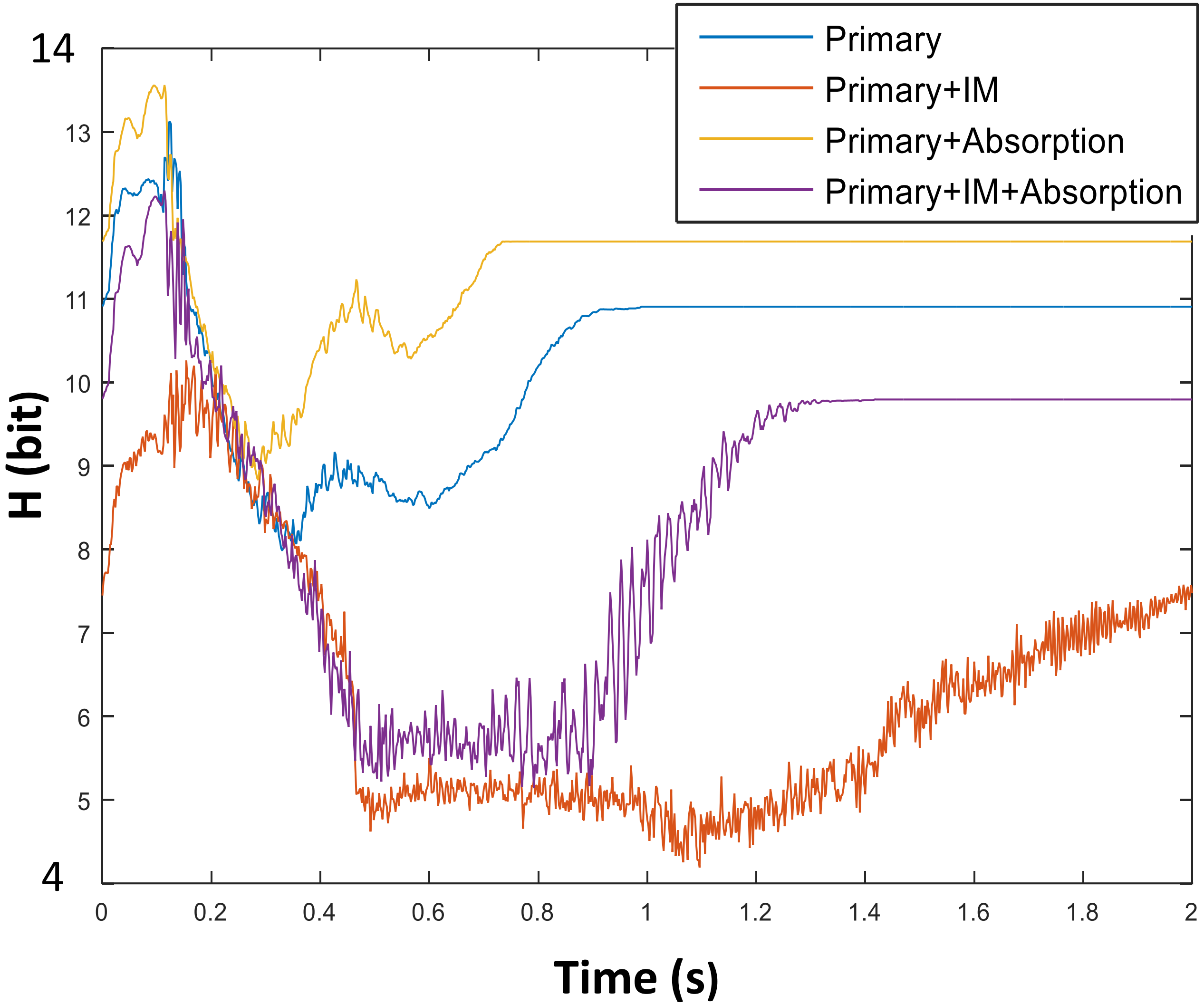
Data analysis (Blackfoot 1227)



Probabilities distribute along diagonals:
the amplitudes correlate strongly with its preceding value.

(several points around zero amplitude are muted for their vastly big values against others)

Data analysis (Blackfoot 1227)



1. VSP data with IMs: lower peak H
2. VSP data with absorption: higher peak H
3. **More waves = more restrictions to possible values**

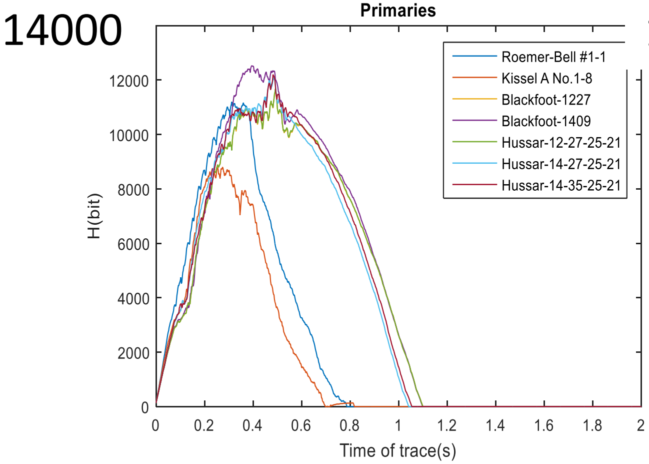
Discussion

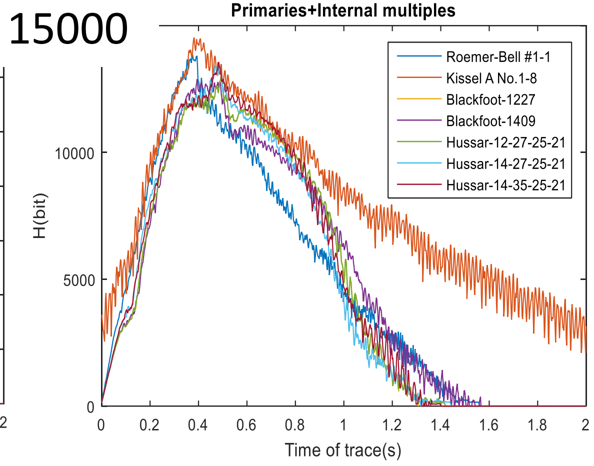
1. Innanen (2012): destroy the distinction of intrinsic &extrinsic Qs
   This research: rise rate of entropy might help distinguish intrinsic & extrinsic Qs

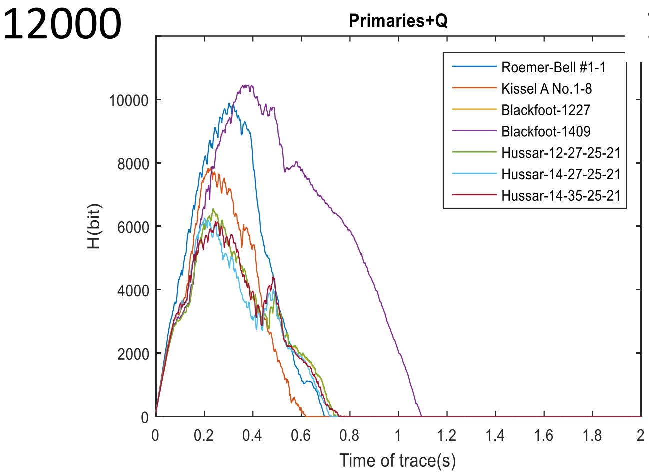
2. The entropy measurements from two algorithms have different reaction to extrinsic and intrinsic Q, but they are all reasonable according to analysis.

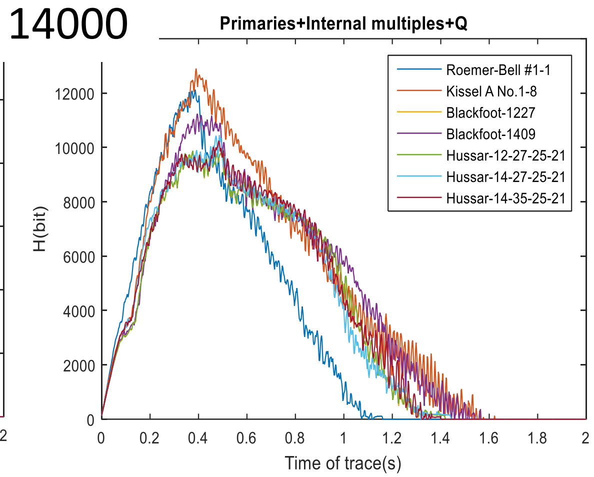
3. Initial entropy algorithm: finding possible amplitude values from unknown (small→big)
   Conditional entropy algorithm: eliminating impossible amplitude values from a known range (big→small)

Initial entropy

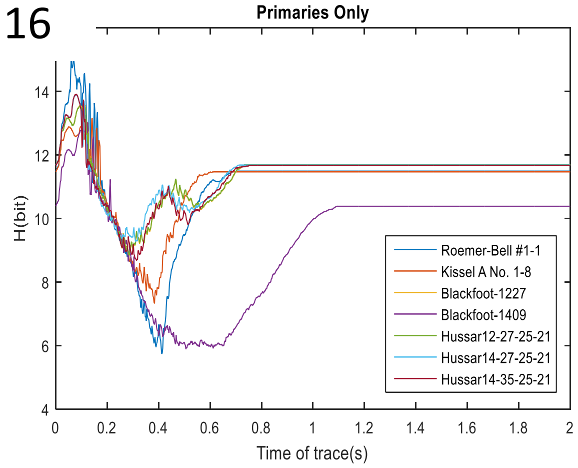


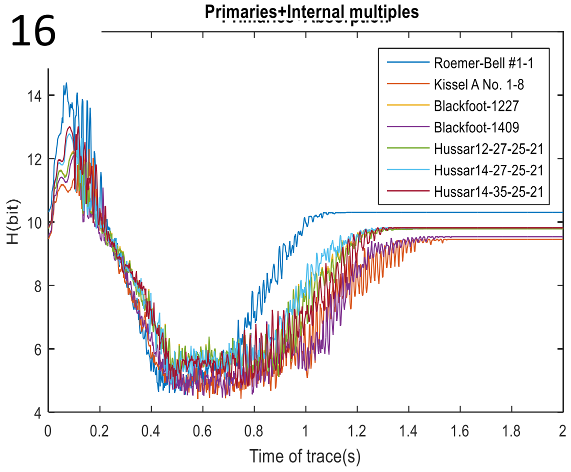


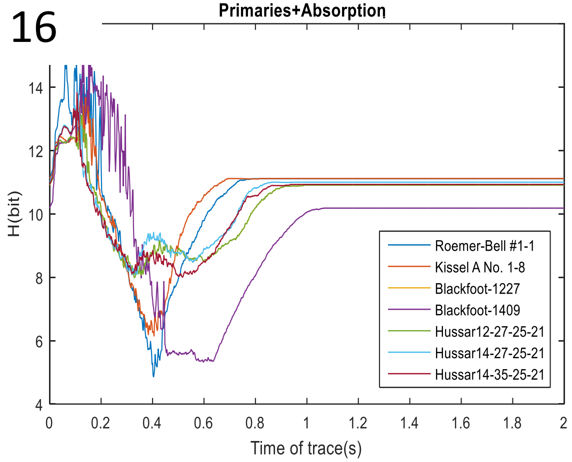


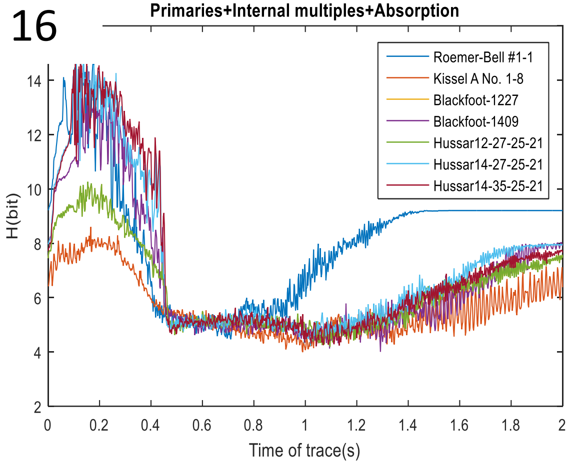


Conditional entropy









Conclusion

1. **Absorption**: transforms part of the wave energy into heats in an irreversible way
   Stratigraphic filtering (Internal Multiples): scatter energy to prevent them from completely transmitting through layers (leaving the overall energy intact)

2. **Shannon entropy** potentially serves as a **magnifier** that enhances these process differences, and translate them into a visible and measurable form;

3. Internal multiples and absorption always influence entropy variation in the **opposite way** in experiment.

References

Banik, N. C., L. Lerche, and R. T. Shuey. "Stratigraphic filtering, part I: Derivation of the O'Doherty-Anstey formula." *Geophysics* 50.12 (1985): 2768-2774.

Innanen, Kris. "Blurring the line between intrinsic and scattering attenuation by means of the Shannon entropy." CREWES Research Report 24 (2012).

Lines, Larry, R. Phillip Bording, and Fereidoon Vasheghani. "Viscosity Estimation Using Seismic Inversion." CREWES Research Report 25 (2013).

Margrave, Gary F., and P.F. Daley. "VSP modelling in 1D with Q and buried source." CREWES Research Report 26 (2014).

O'doherty, R. F., and N. A_ Anstey. "Reflections on amplitudes." Geophysical Prospecting 19.3 (1971): 430-458.

Thanks to:

Kris Innanen
CREWES sponsors
CREWES staffs and students

Questions?