Seismic Attributes - from Interactive Interpretation to Machine Learning

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Conditioning of Migrated, Stacked Data

Footprint Suppression

Data conditioning – Footprint suppression

After this section you should be able to:

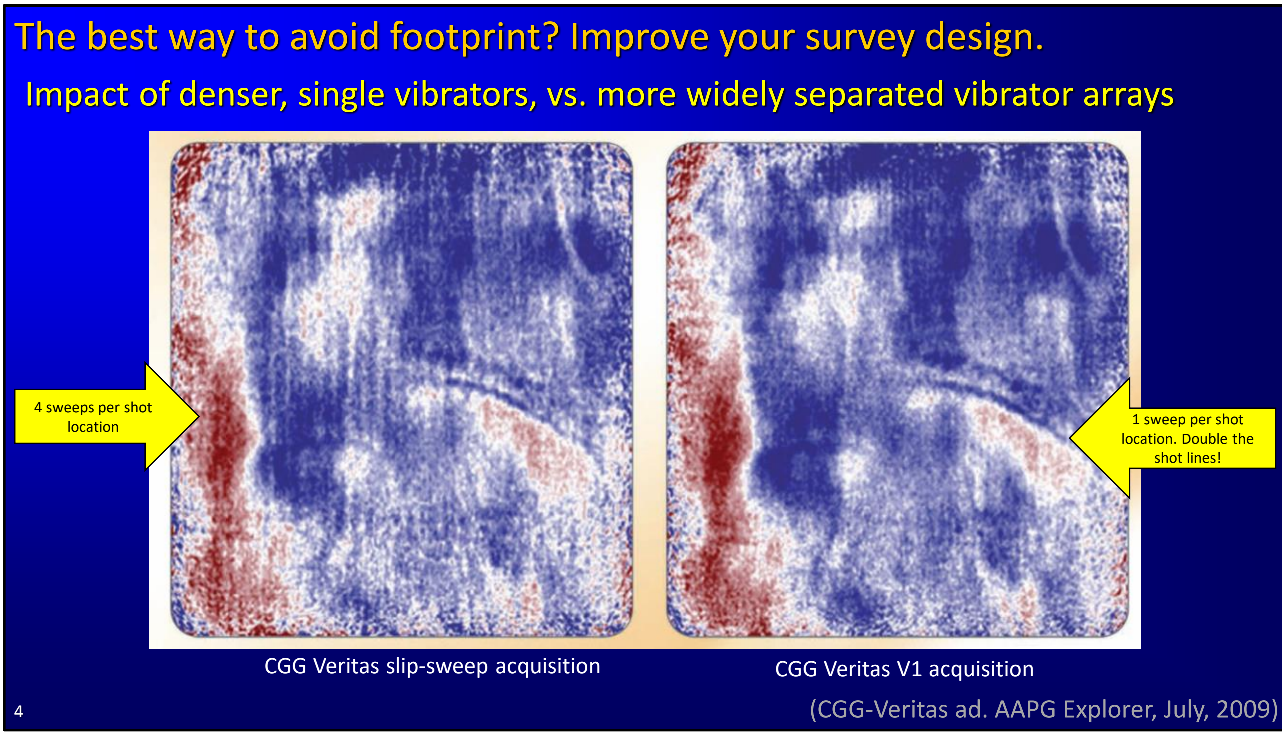
- Recognize the appearance of acquisition footprint and avoid interpreting it as signal
- Apply k_x-k_y and other filters to partially suppress periodic footprint

2

A list of learner objectives for the section on seismic data conditioning.

Causes of Acquisition Footprint

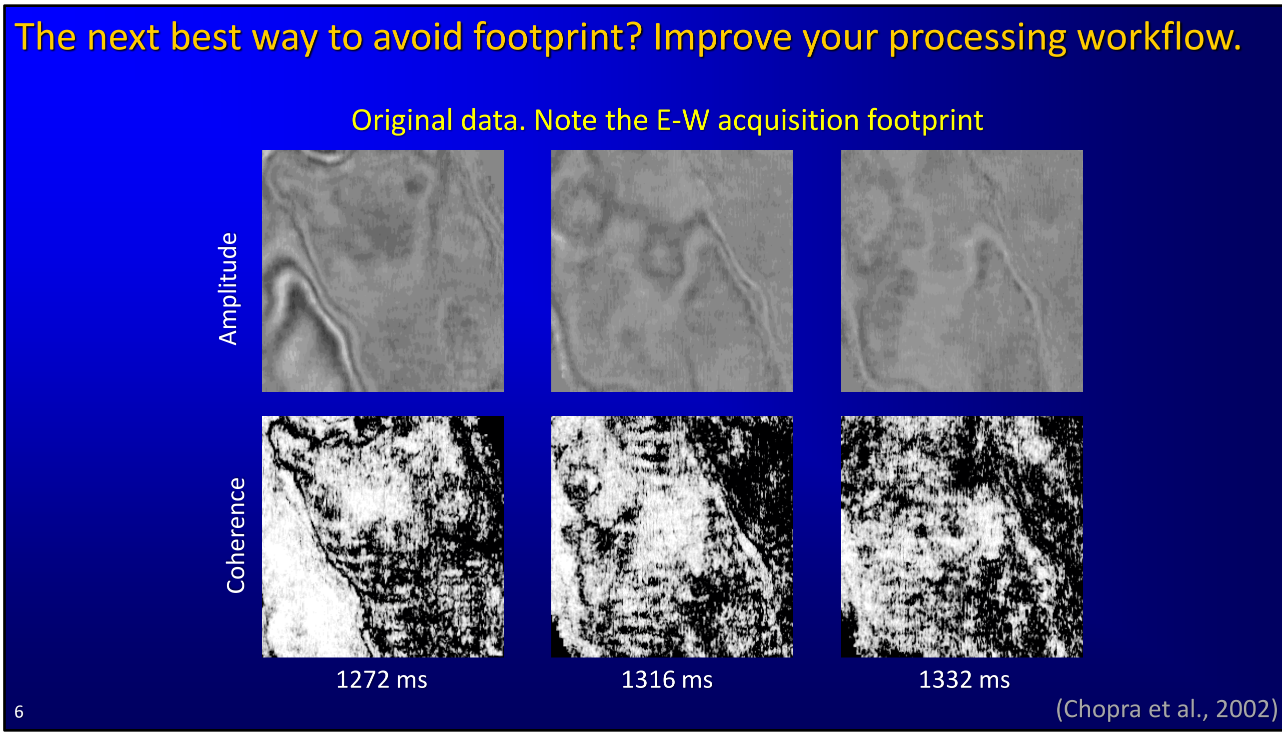
- Aliased backscattered noise, e.g. ground roll and low-velocity shallow diffractions
- Bin-to-bin variations in the distributions of offsets and azimuths that exacerbate AVO effects
- Obstacles causing deviations from the desired regular geometry
- Migration operator's attempt to image steep dips with short horizontal wavenumbers



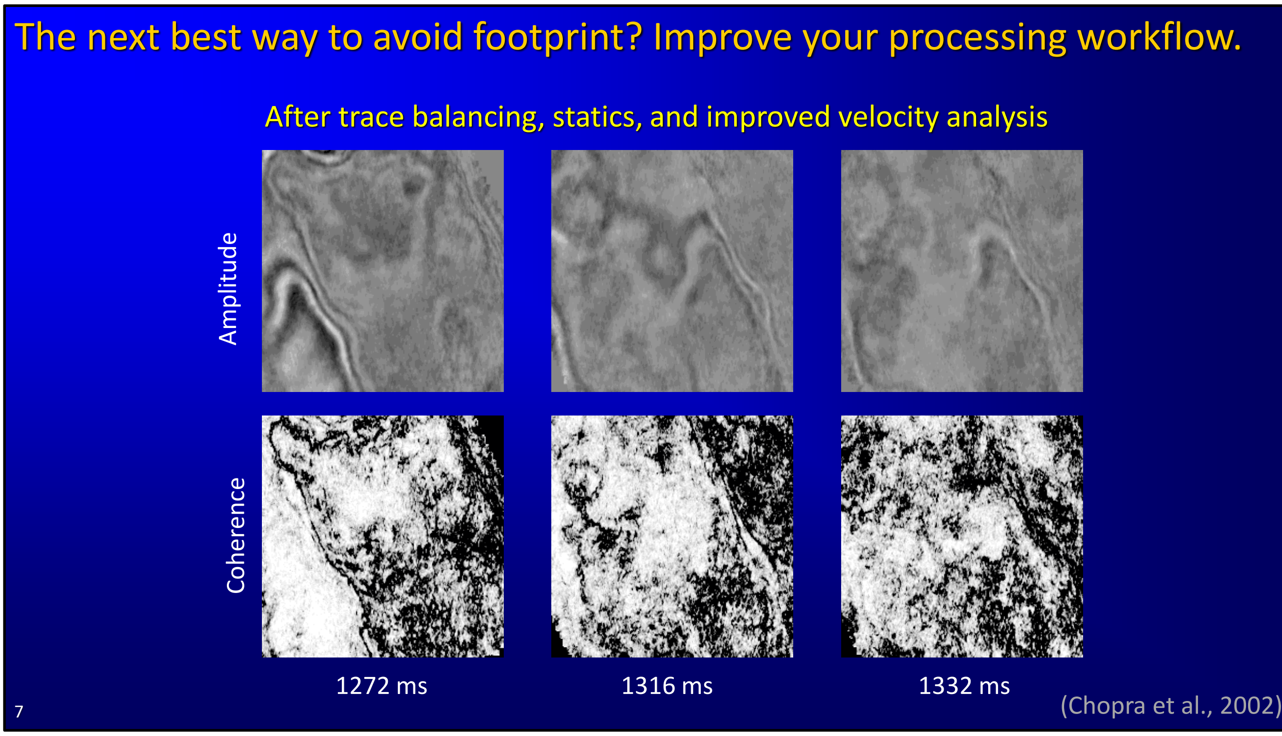
Recently, several seismic acquisition companies have designed workflows that replace conventional vibrator arrays generating vertically stacked data with denser acquisition using single sweep vibrators. With concomitant deployment of wide-azimuth, denser geophone arrays, considerable improvement in data quality can be achieved within the same time frame at the same cost. The reason for the improvement is that much of our noise is not random, but rather coherent. Leakage of ground roll, airwaves, and other coherent noise cannot be suppressed through vertical stacking. By adding additional shot points, we exploit the fact the differences in moveout between reflections and diffractions of interest vs. coherent noise. The result is a decrease in acquisition footprint (and because the decreased bin size) increased lateral resolution. (The above advertisement from CCG-Veritas can be found in the July 2009 AAPG Explorer, page 17).

7. Influence of acquisition and processing on attributes

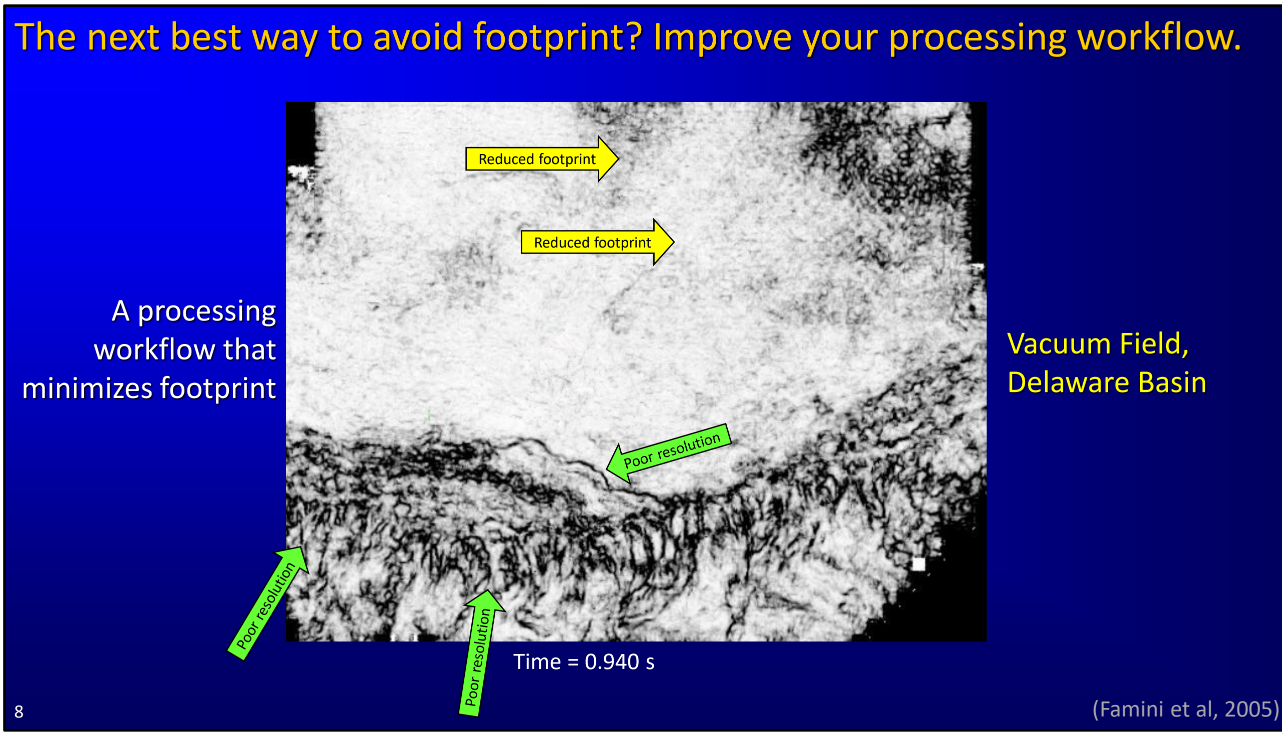
Reducing acquisition footprint
by reprocessing the original common shot gathers



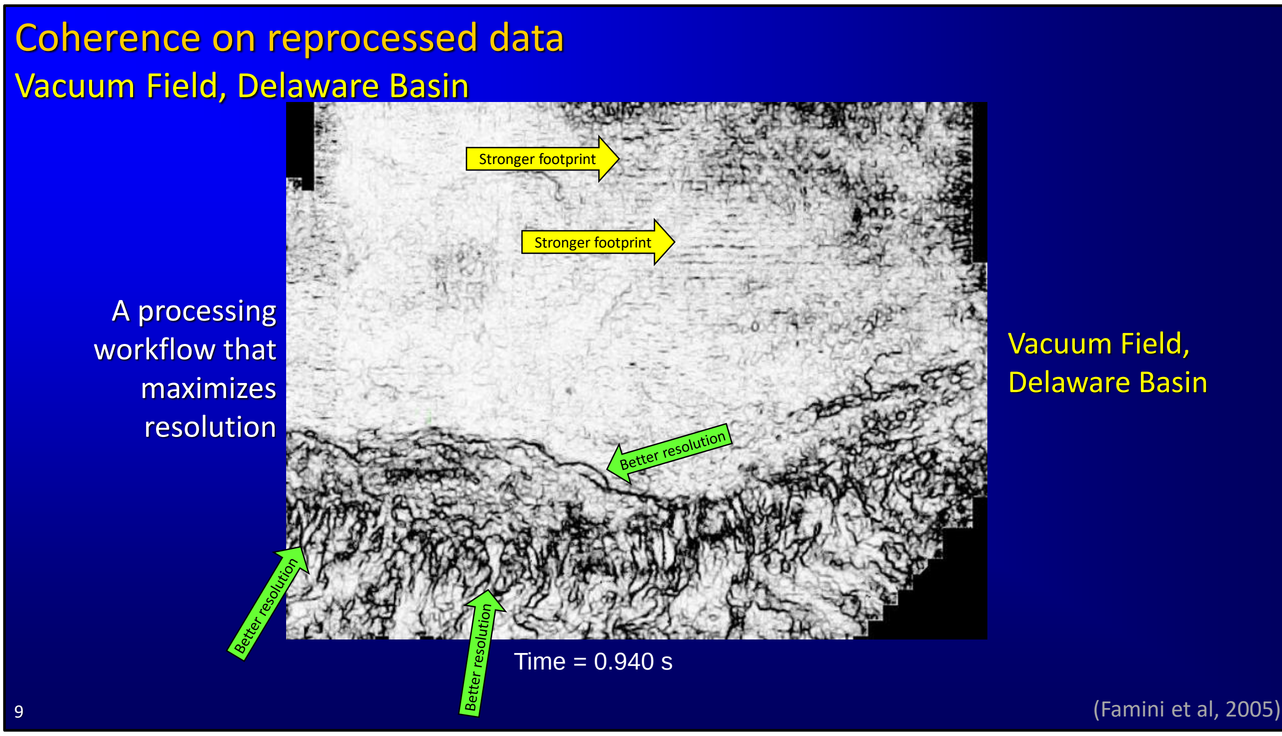
Time slices, at t = 1.272, 1.316, and 1.332 s, through (a) a seismic data volume and (b) the corresponding coherence volume. The acquisition footprint does not impede our ability to interpret the original seismic amplitude data, but it is exacerbated by the coherence calculation, in which we see wide east-west and narrow north-south artifacts. After Chopra (2002).



The same data slices as those shown in the previous figure, but displayed here after additional seismic processing (balancing, statics, and improved velocity analysis) to minimize the acquisition footprint. Although the impact on the original seismic data is minimal, we now are able to discern minor faults (indicated by gray arrows) and possible stratigraphic features (indicated by white arrows) that previously were masked by the acquisition footprint. After Chopra (2002).



Comparison of a time slice, at 1.0 s, through coherence volumes generated for a survey from the Delaware Basin, New Mexico, USA. The coherence slice from original processing. After Famini (2005).



Comparison of a time slice, at 1.0 s, through coherence volumes generated for a survey from the Delaware Basin, New Mexico, USA. Coherence slice after careful reprocessing to improve lateral resolution. Note the trade-off between increased acquisition footprint in the northeast corner, indicated by the yellow arrow, and improved resolution in the Brushy Canyon slump features indicated by the green arrow. Unfortunately, in this example improving the lateral resolution of the geologic features of interest also exacerbated the acquisition footprint. After Famini (2005).

Observations

• If the acquisition geometry follows a pattern, acquisition footprint will have periodic components

•The amplitude and location of these components will change with depth (and generally heal at greater depths)

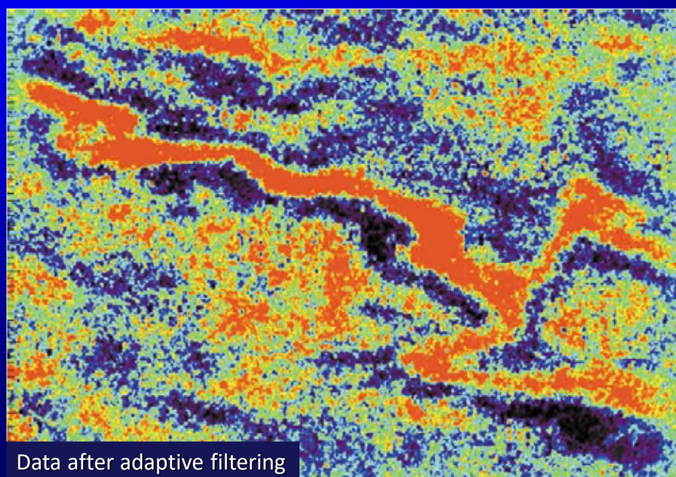
• If we know the acquisition program and processing workflow, we can predict what this pattern will be

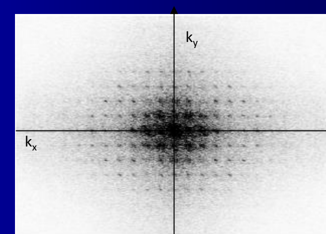
• Attributes exacerbate the impact of footprint

• Attributes may therefore serve as a means of characterizing footprint, allowing us to model it without knowing the details of acquisition and processing

k_x-k_y filters based on knowledge of the acquisition and processing

Land data, Algeria

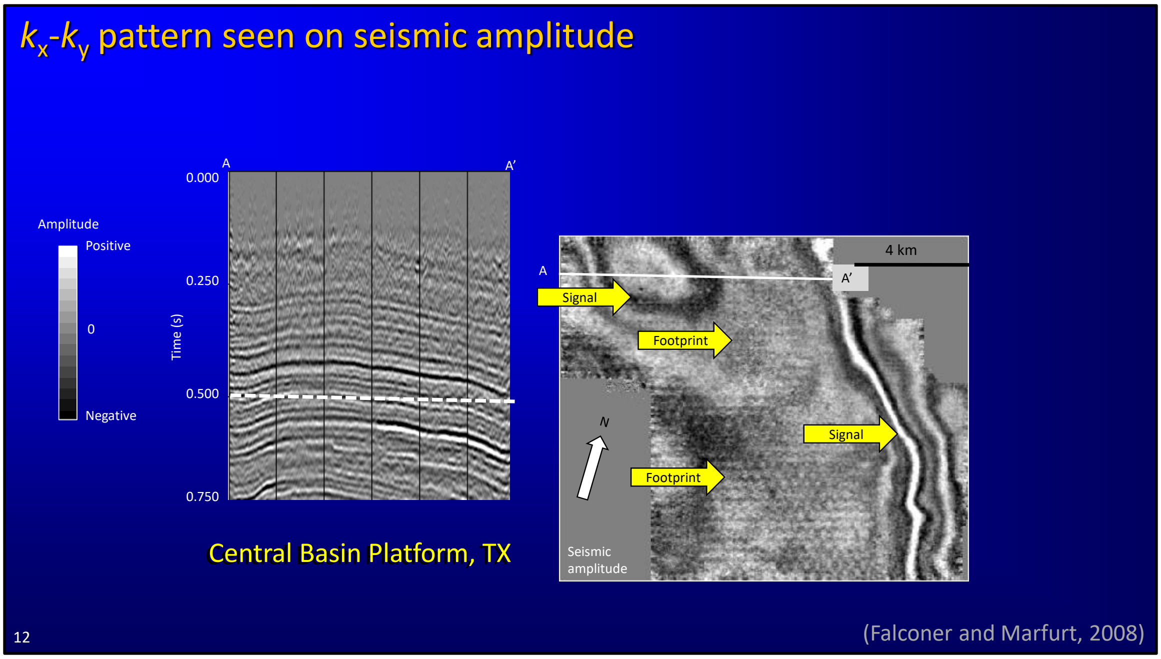




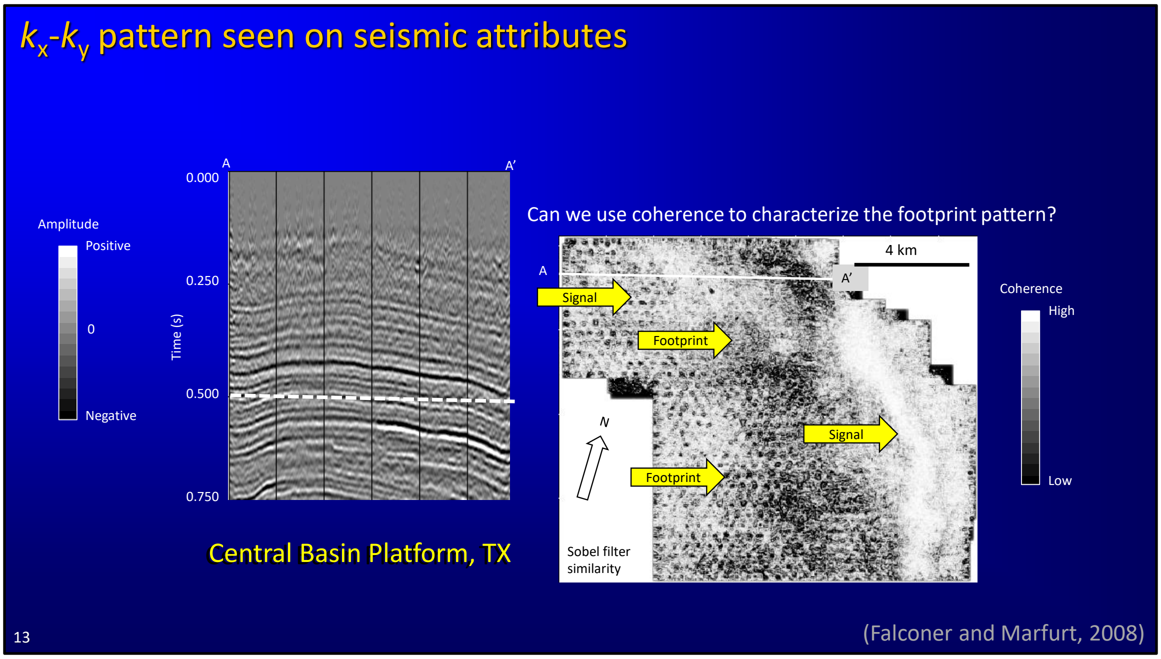
t = 3.2 s

(Drummond et al., 2001)

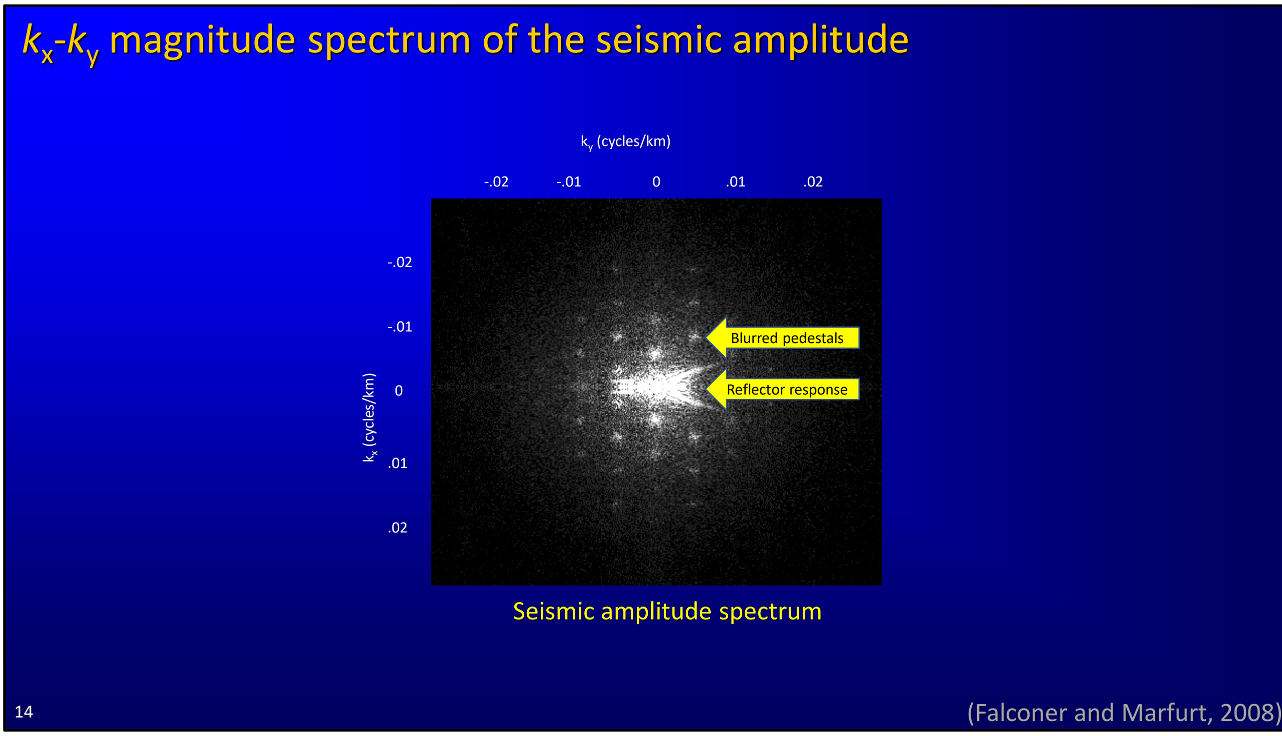
One of the first examples showing the advantage of k_x-k_y filtering of the migrated seismic data. The k_x-k_y pedestals were computed from knowledge of the source and receiver locations. Comparison of original data, data after k_x-k_y filter, and data after adaptive filtering. (After Drummond et al., 2001).



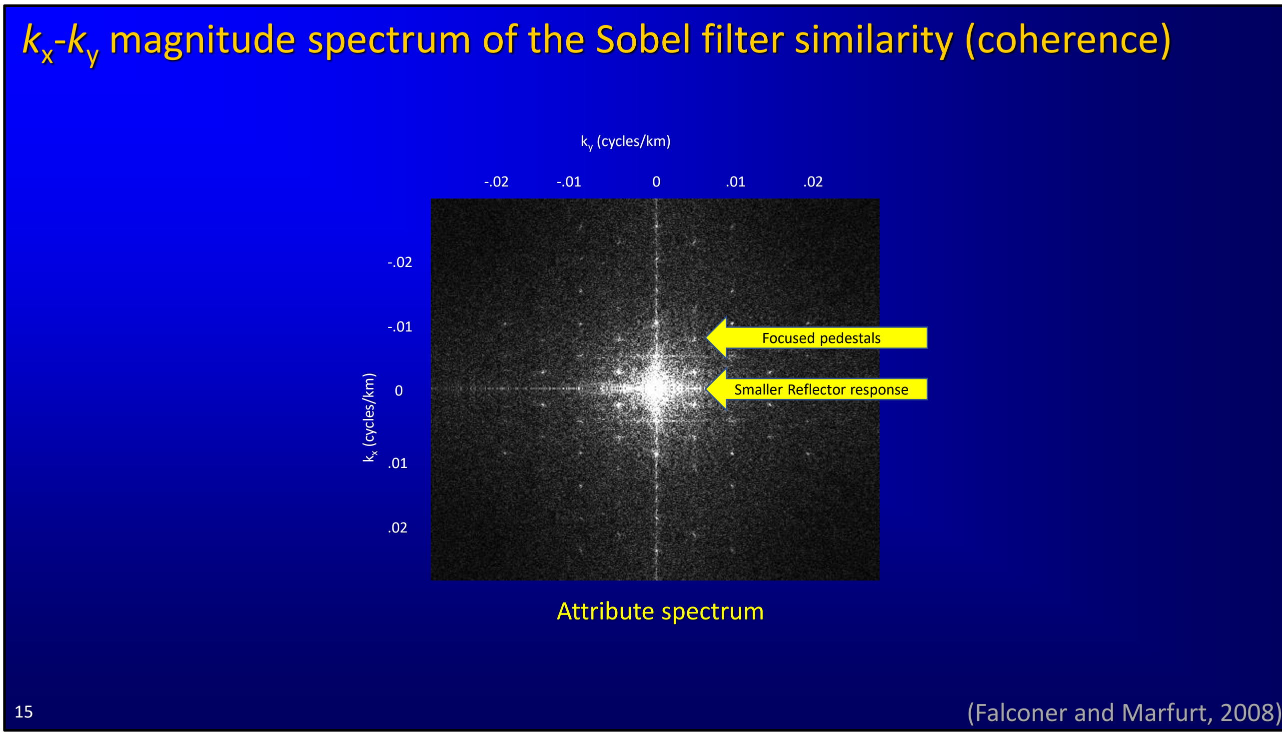
(Left) A vertical slice and (Right) time slice at t=0.5 s through a seismic amplitude volume acquired over the Central Basin Platform of west Texas, Note the strong periodic acquisition footprint that contaminates the data. Careful examination of the vertical slice shows that this footprint correlates to the steeply dipping artifacts cutting across the reflection events of interest. Without further access to the data, the two most likely causes are migration operator aliasing and/or aliased ground roll and shallow diffractions that have leaked through the processi



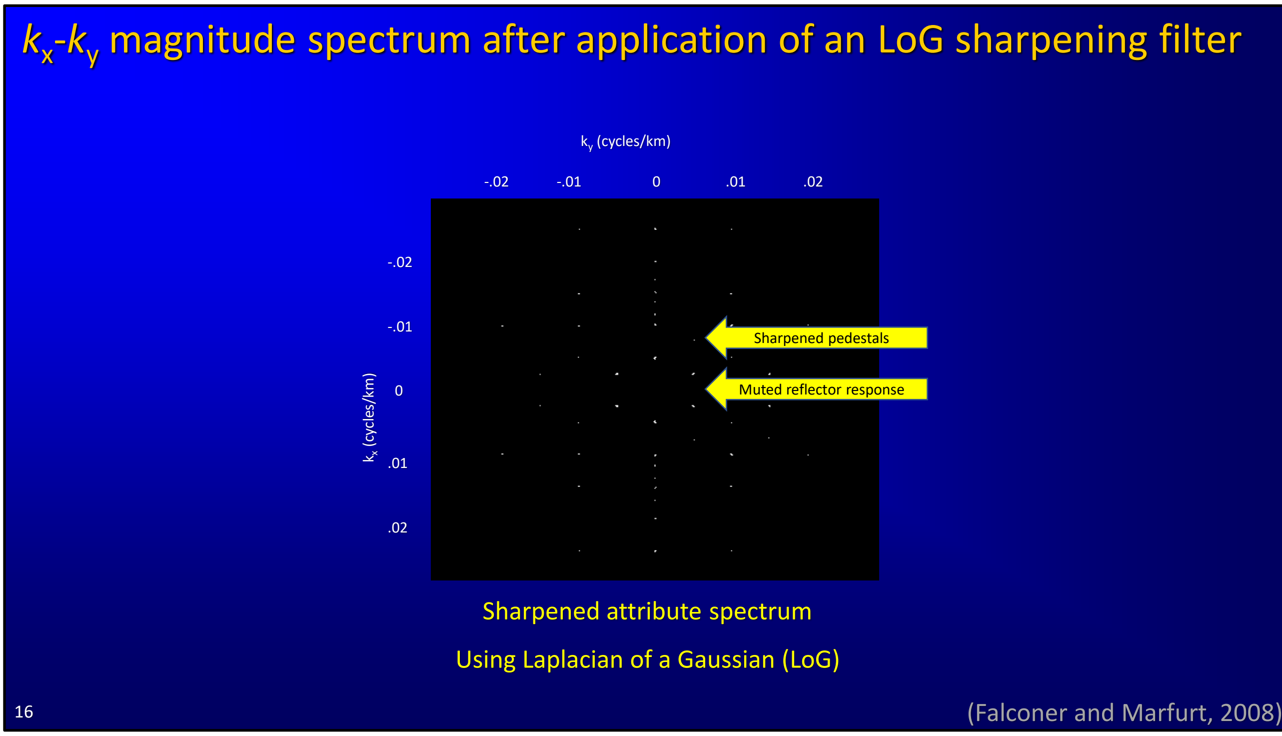
The same vertical section but now with a time slice at the same t=0.5 s level through the coherence (Sobel filter similarity) volume. Note the periodic pattern of the low coherence anomalies. Because coherence (and other attributes) are more sensitive to the footprint than the amplitude data, can we use it characterize the footprint pattern?



In the next three figures, I present a footprint suppression workflow that can often (but not always!) be successfully applied to migrated data. Since the data were acquired using orthogonal shot and receiver lines, the footprint also has an orthogonal pattern. This pattern is quite visible in the *k_x-k_y* magnitude spectrum of the seismic amplitude data.

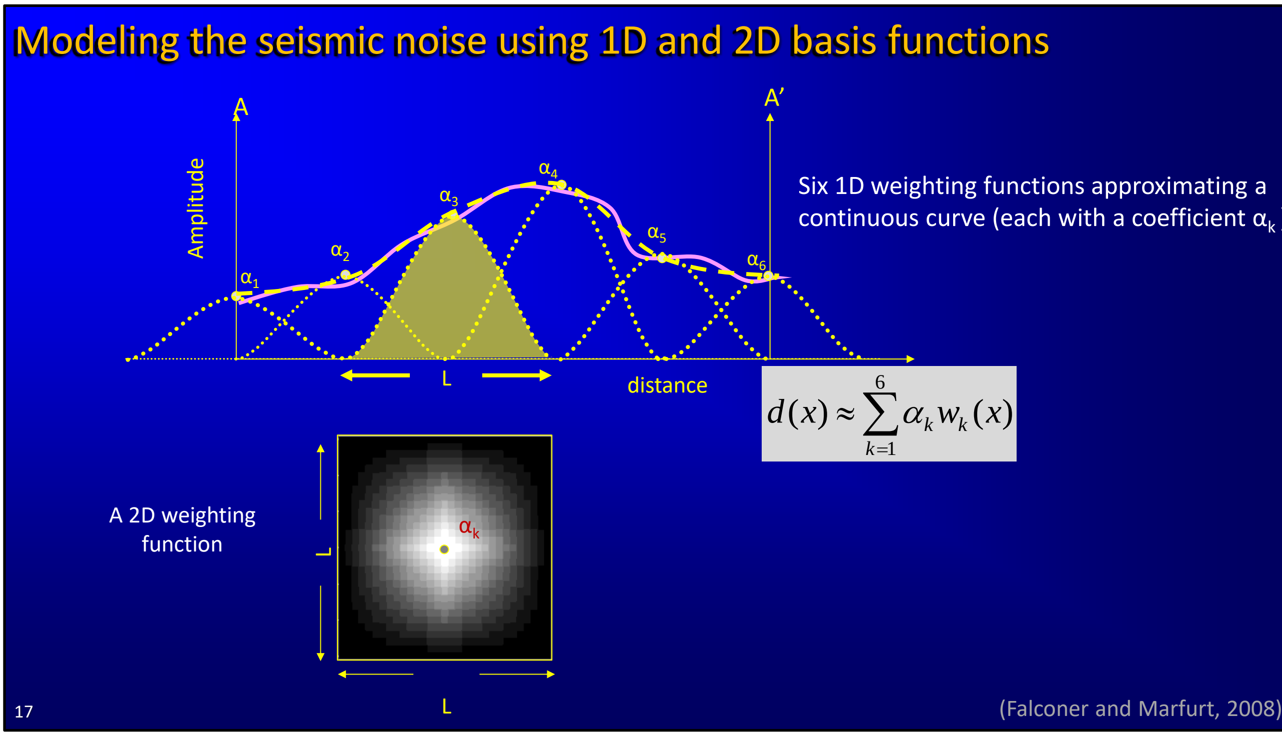


This periodic footprint pattern is exacerbated by the edge-sensitive attributes. The goal is to identify high magnitude k_x-k_y noise components. The most direct workflow is to construct a suite of notches based on these pedestals, apply it to the magnitude spectrum of the seismic amplitude data shown in the previous figure, and then reconstruct the data.

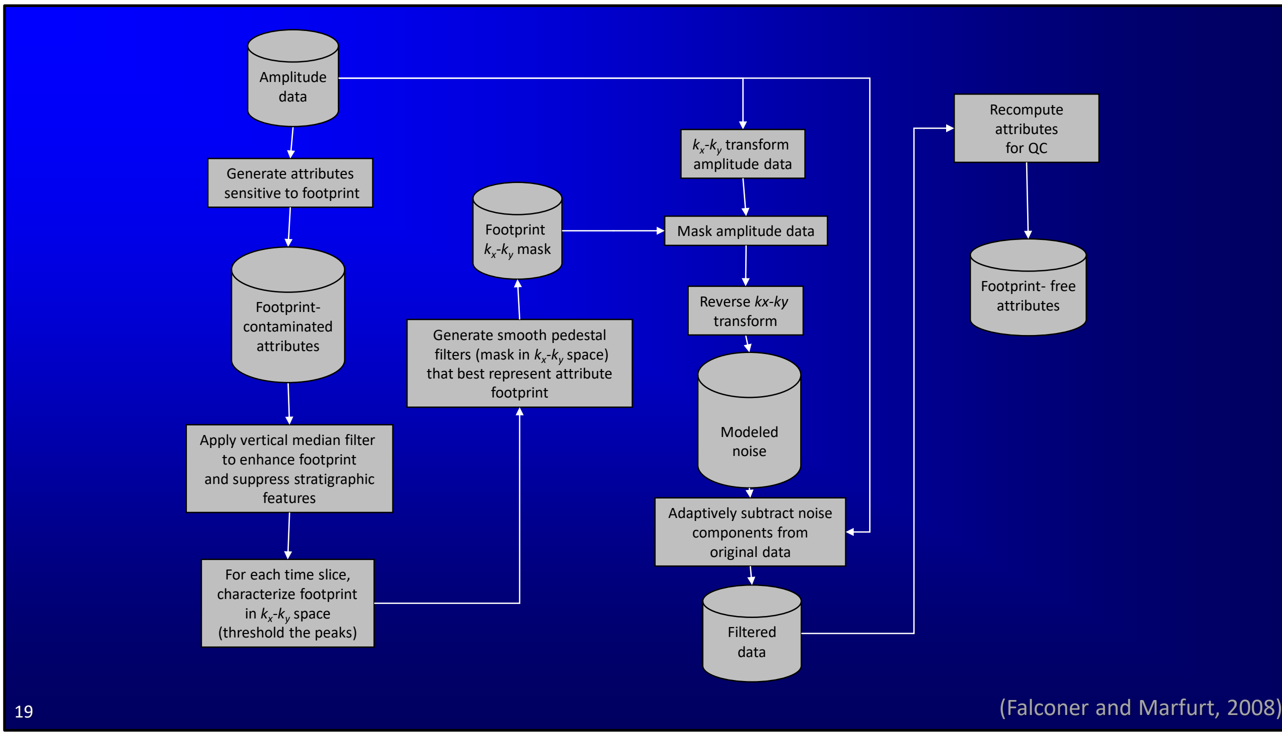


A pitfall in k_x-k_y filtering is that we may reject desired signal as well as undesired noise. For this reason, the noise characterization should be as focused as possible. By applying a Laplacian of a Gaussian filter to the previous image, we can sharpen the location of the footprint pedestals. Care must be taken near low wavenumber components about k_x=k_y=0. For example coherence anomalies associated with unconformities and other stratigraphic features that are nearly horizontal will give rise to low wavenumber anomalies. In this example, we have applied a simple mute to the lowest wavenumber components. The footprint at these components will therefore not be addressed.

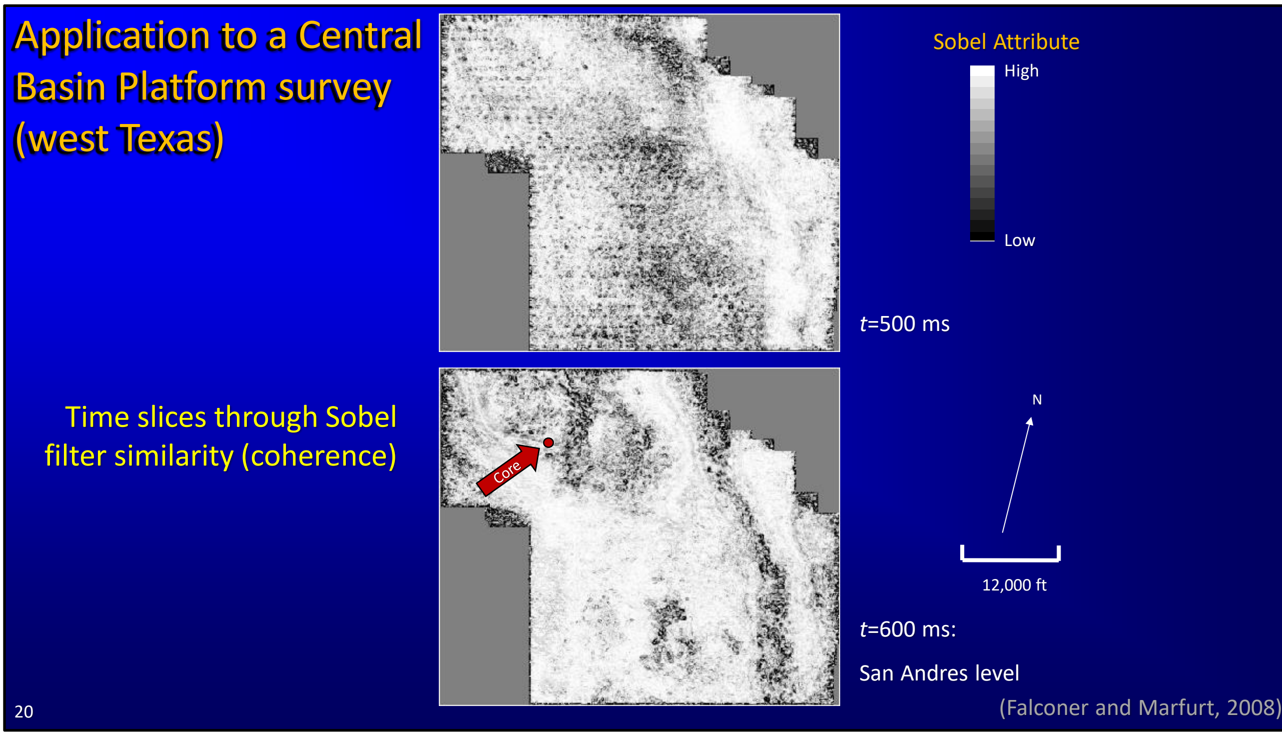
In the next steps, we will apply the picked pedestals to the original seismic amplitude k_x-k_y magnitude spectrum, reconstruct a model of the seismic amplitude noise, and adaptively subtract it from the the original x,y amplitude data.



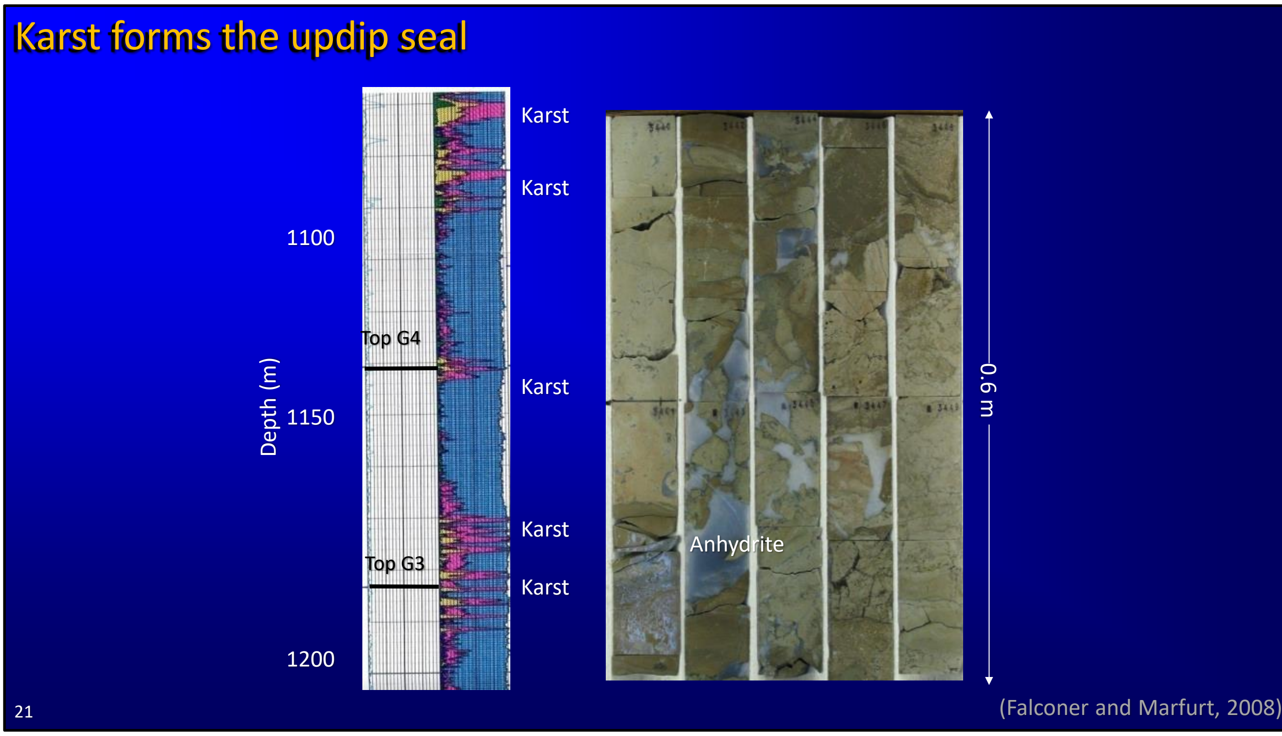
This image shows how one can represent a curved pink line by the linear combination of sixed (dotted yellow) raised cosine basis functions which add to give the dashed yellow line. The mathematical problem is then to estimate the six coefficients, alpha, that represent the hundreds of data measurements on the pink line. For footprint suppression, we will model the noise response using 2D Gaussian basis functions, as shown in the lower left of this figure.



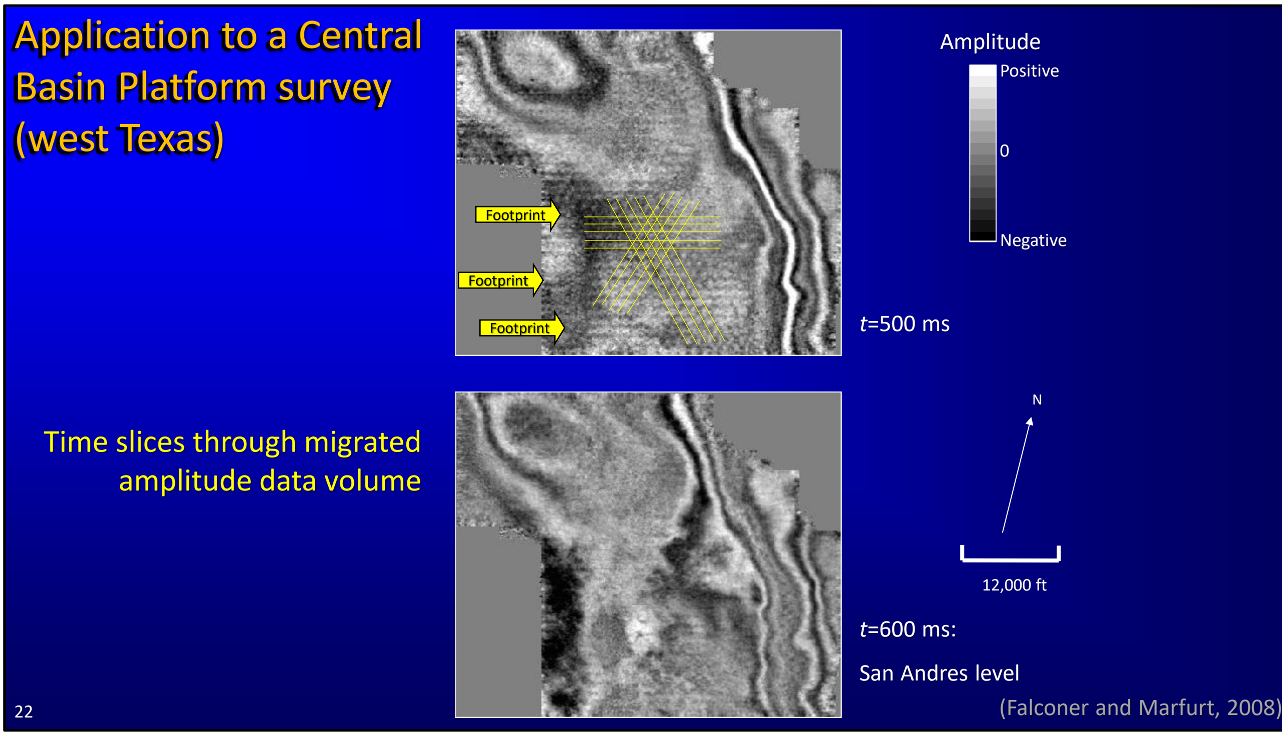
Here is the workflow. It looks complicated, but thus is the world of seismic processing.



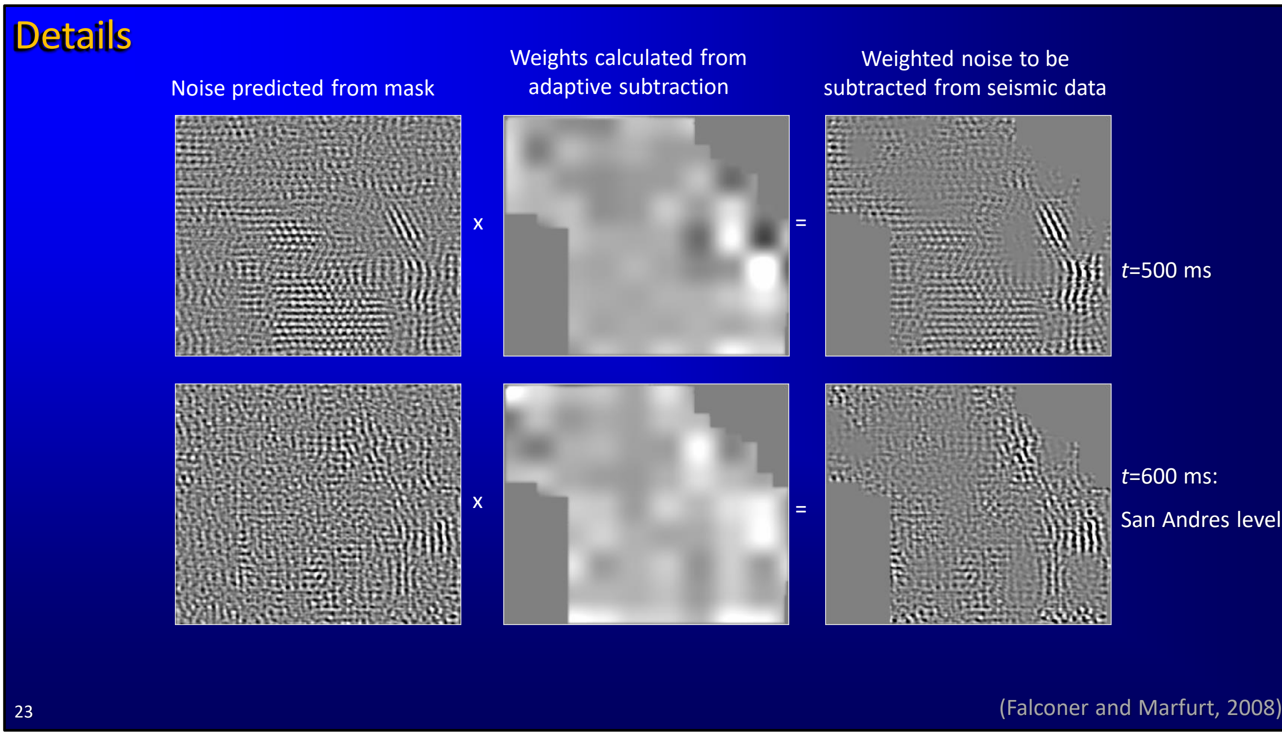
Images at *t*=500 and 600 ms. One of the targets is at the San Andres level. Footprint is strong at 500 ms, a little weaker at 600 ms, but strong enough to mask what we think are karst collapse features. The red dot shows the well location on the following slide.



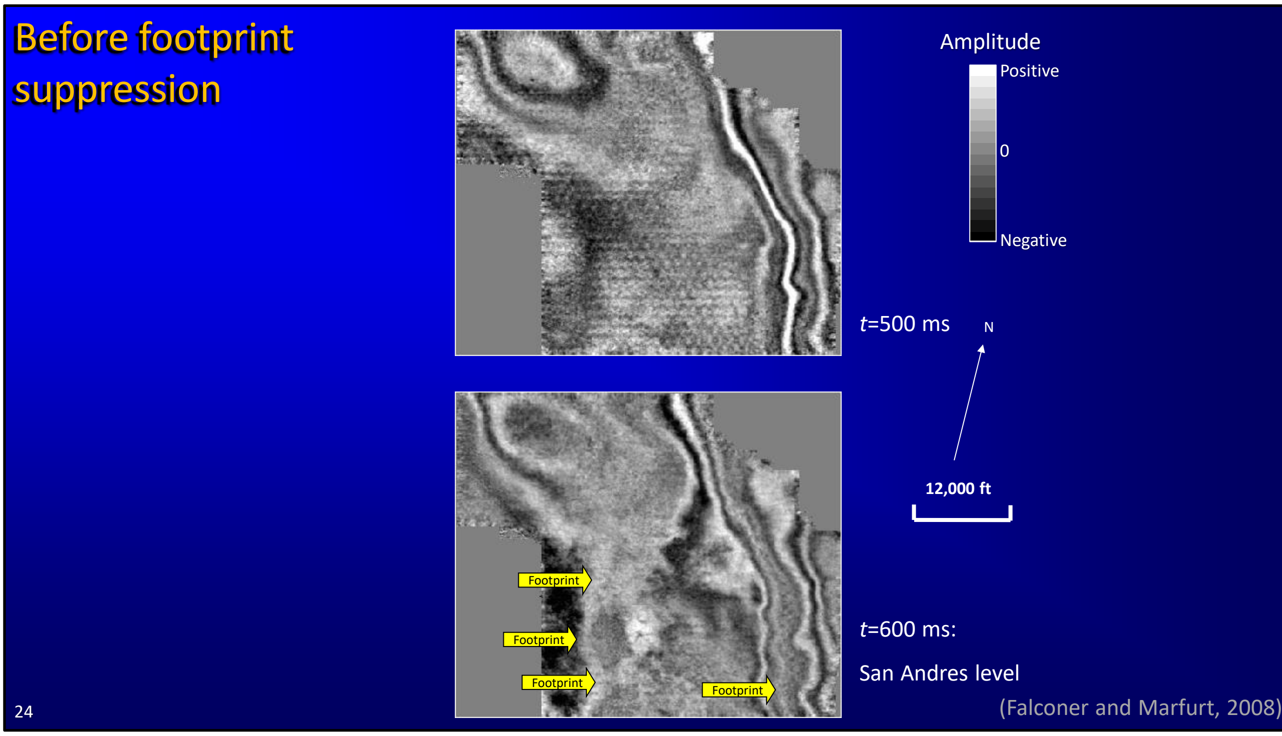
Note the anhydrite-filled karst seen in the well.



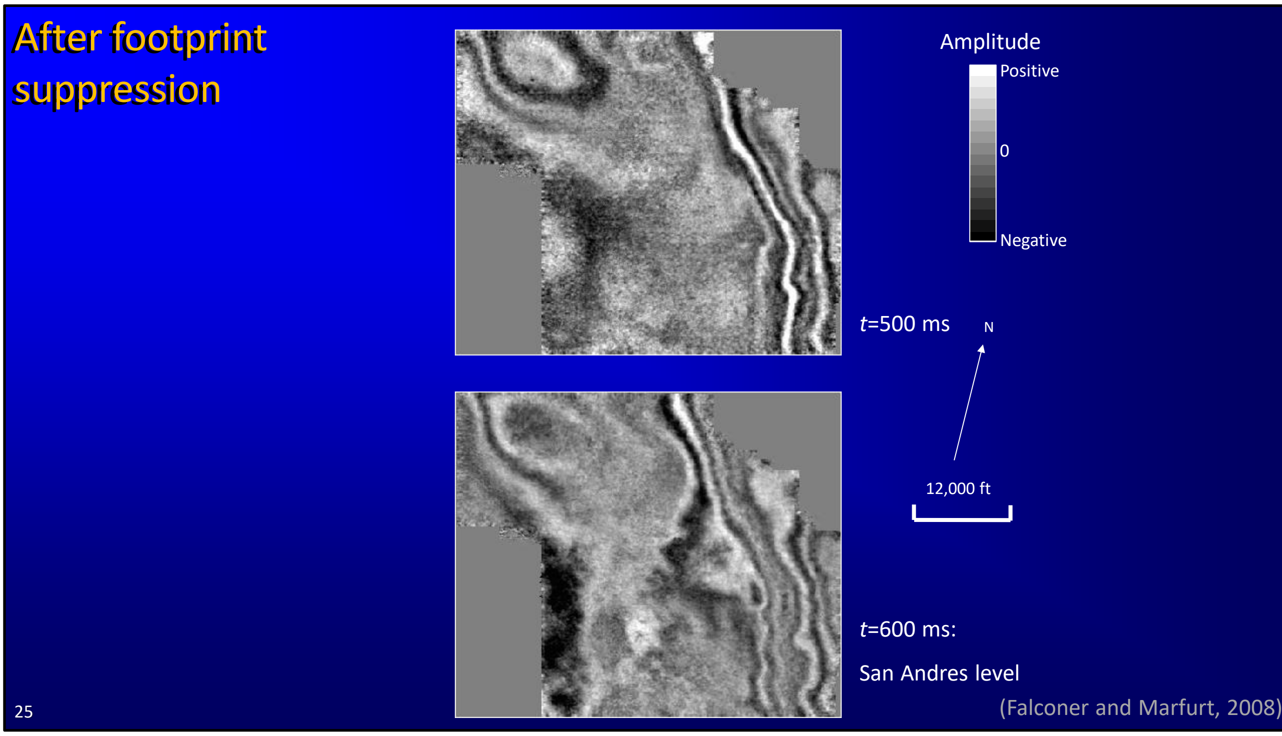
These time slices show footprint on the original amplitude data. One of the exploration targets is the San Andres level near *t*=600 ms, where we see strong footprint.



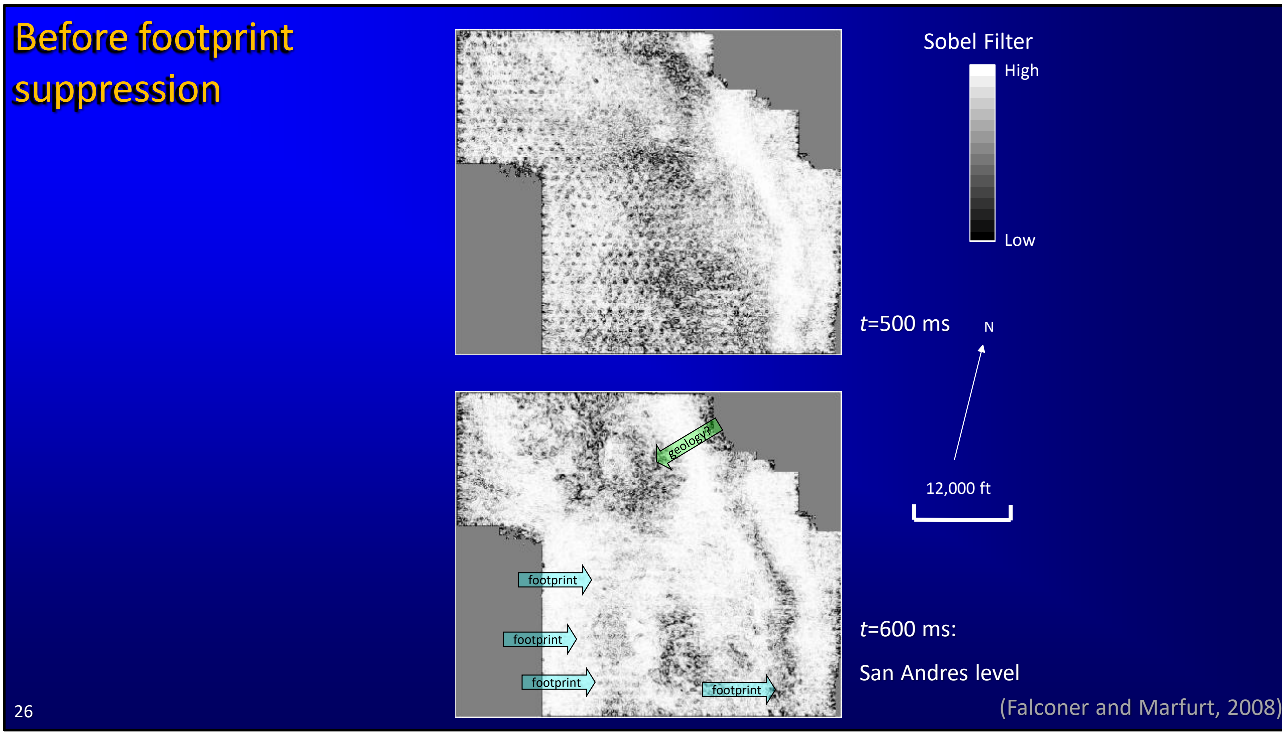
The top row of images at t=500 ms and the bottom row of images at t=600 ms shows on the left panels the noise predicted by applying the attribute-derived noise mask to kx-ky of the amplitude data and inverse transforming to x-y space to obtain a noise estimate. Note that noise is predicted even in the dead trace areas. The central panels show the weights applied to the predicted noise, while the right panels show the least-squares (adaptively) fit of the noise to the original amplitude data. This noise estimate will be simply subtracted from the original data.



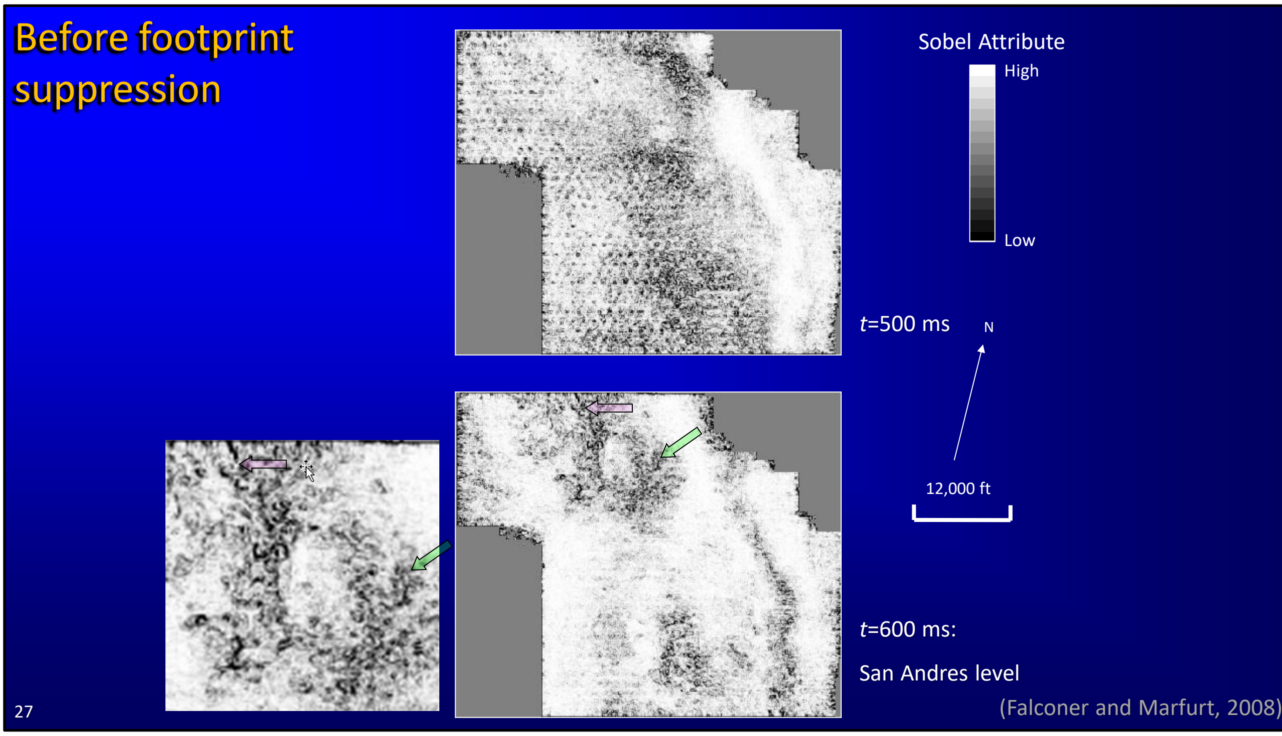
The two amplitude slices before footprint suppression.



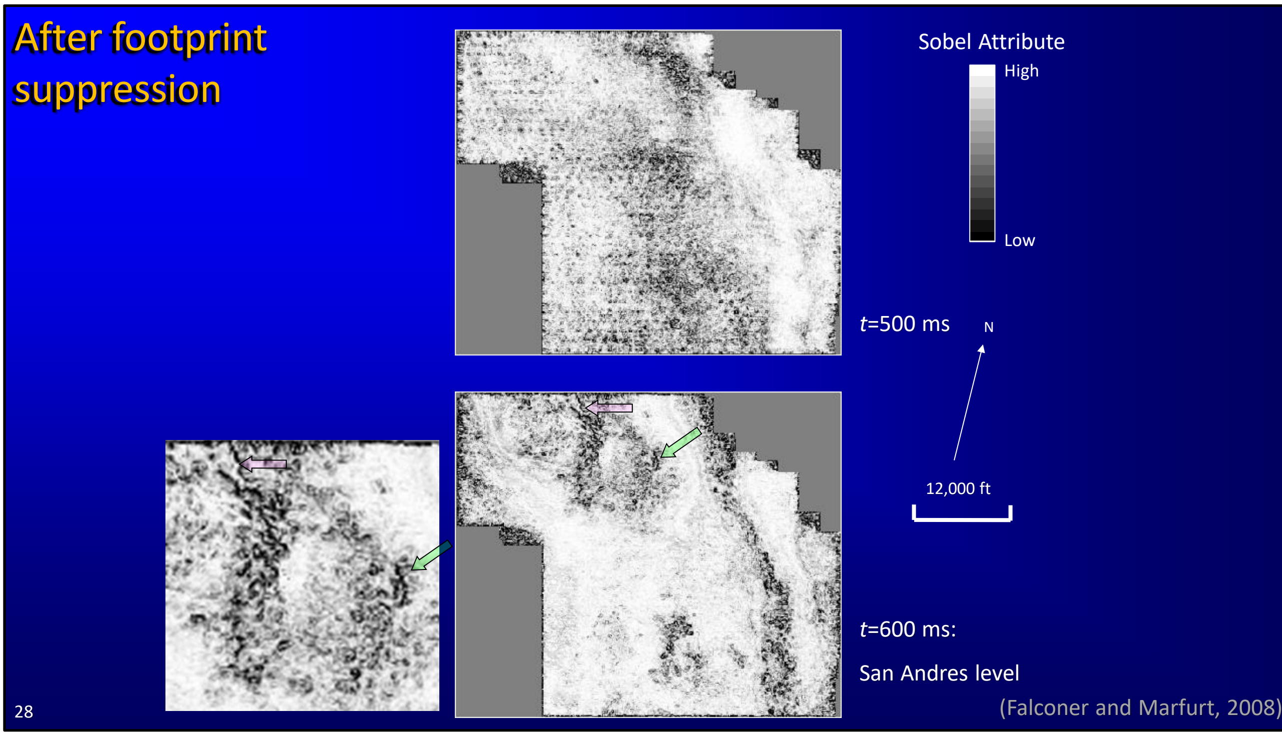
The same two amplitude slices after footprint suppression.



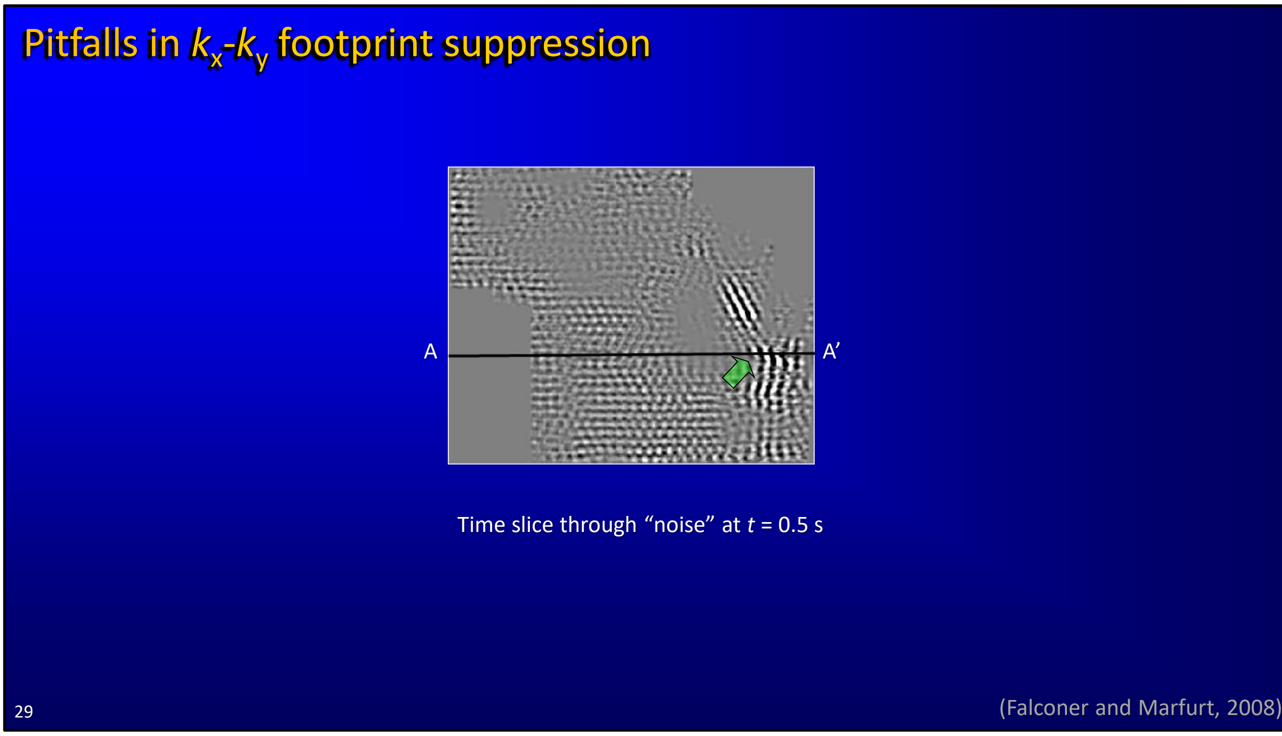
The two attribute slices computed from the seismic amplitude data before footprint suppression.



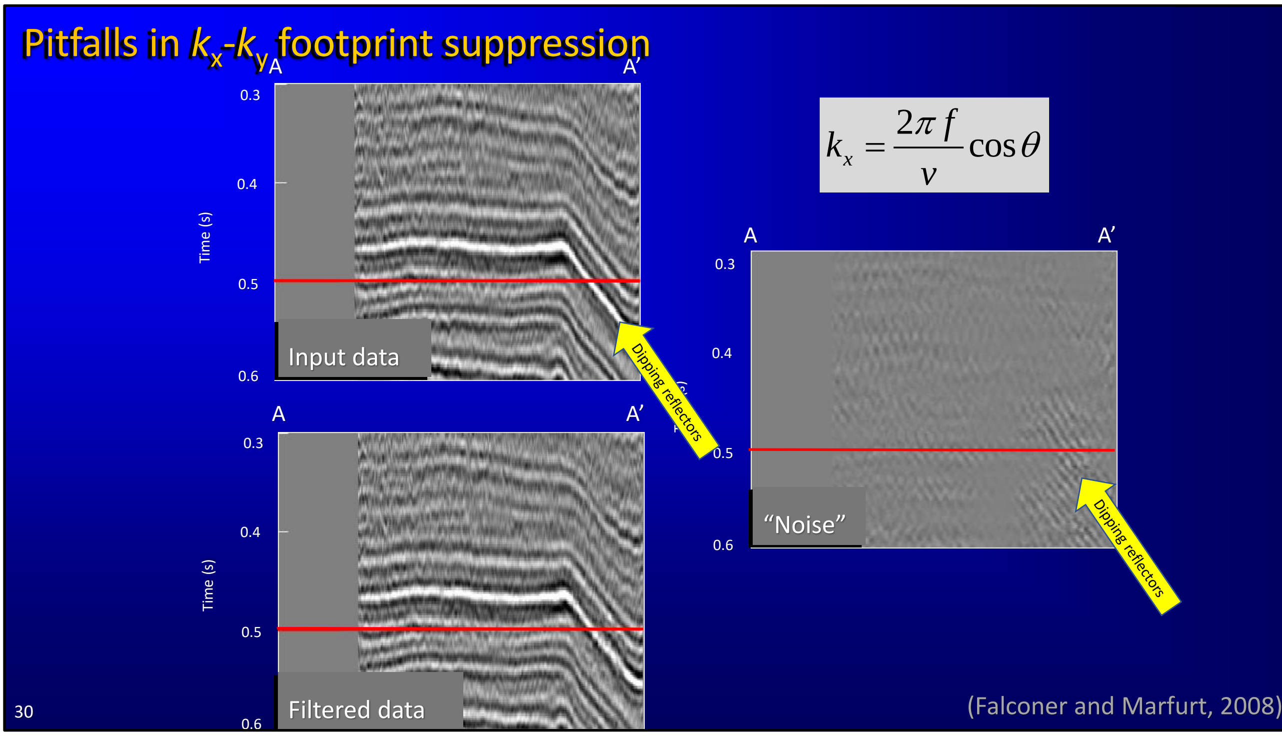
The two attribute slices computed from the seismic amplitude data before footprint suppression. The insert on the left shows the target karsted area. What is karst and what is footprint?



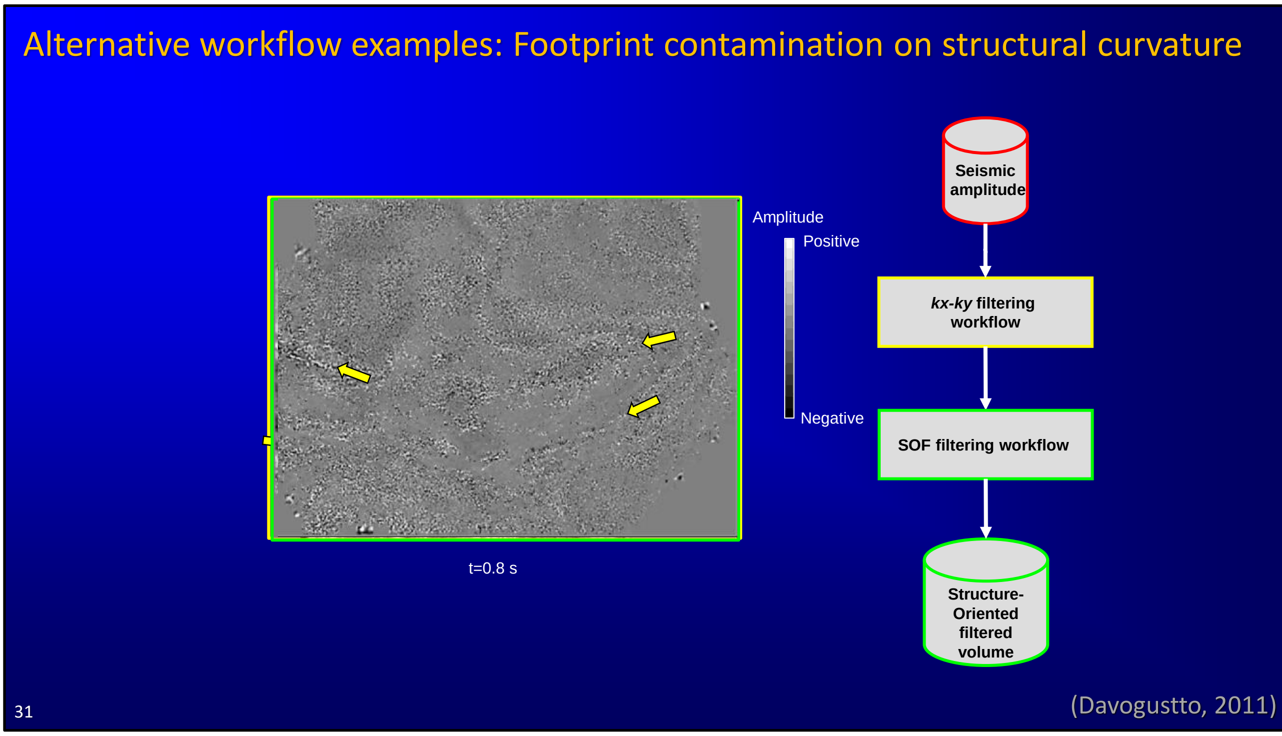
The two attribute slices computed from the seismic amplitude data after footprint suppression. The insert on the left appears more geological. While we can not assure that there is no footprint remaining in these images, we are confident that at least the periodic components of noise have been removed.



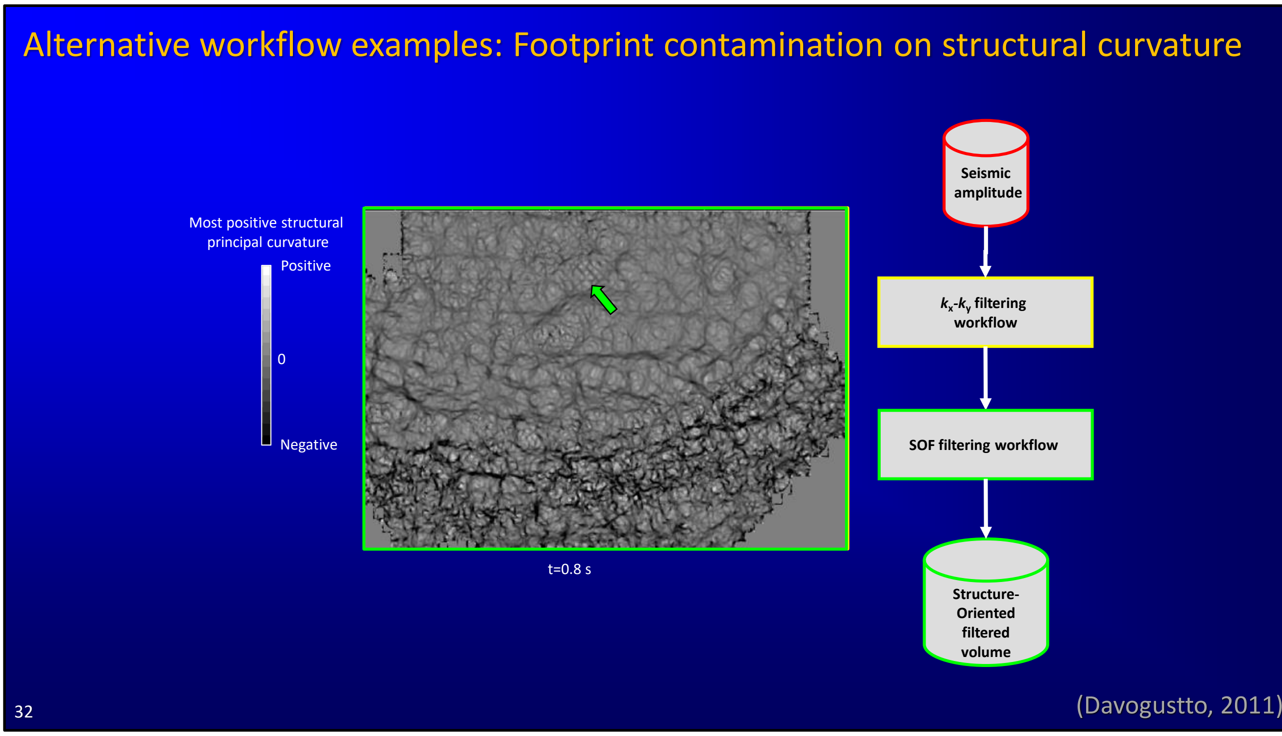
A pitfall arises when we have steep dip. In this image, the green arrow indicates signal associated with steep dips going into the Midland Basin.



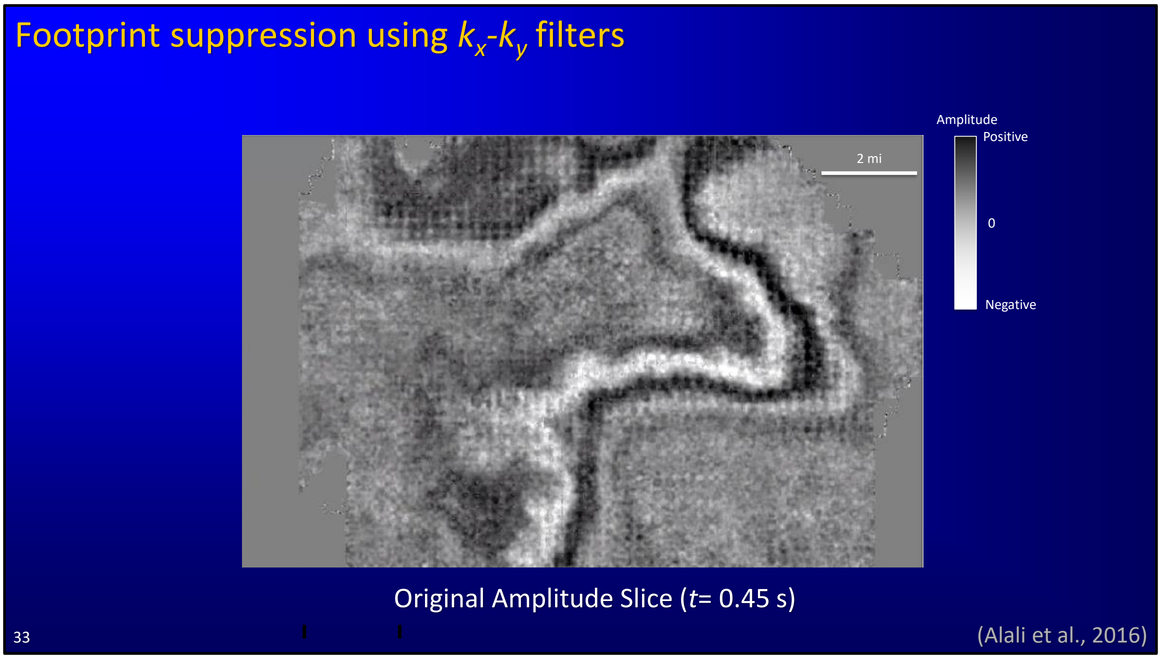
Further inspection shows removal of steeply dipping migration artifacts, but also part of the steeply dipping reflectors. The kx-ky components of the steeply dipping reflectors overlaps with the kx-ky components of the noise and has been removed! Applying such a filter on flattened volumes would be a potential workaround.



One can cascade filters. Here, Davogustto has followed kx-ky filtering with structure-oriented filtering.



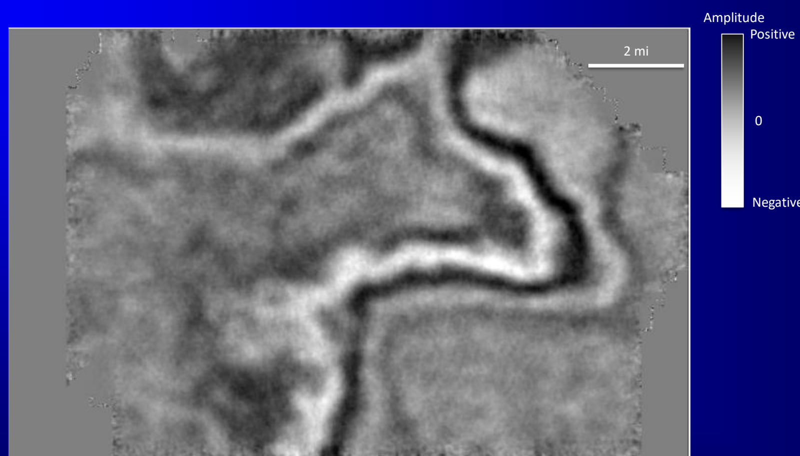
While not perfect, the resulting curvature images now lack much of the east-west and north-south artifacts seen on the original data. The NW-SW trending artifacts (green arrow) are still suspicious.



(a) Time slice at t = 0.450 s through a seismic data volume acquired over Vacuum Field, NM, USA in the late 1990s. This part of the Delaware Basin has multiple objectives, with the shallow Yates horizon strongly contaminated by north-south and east-west acquisition footprint. The footprint heals with depth but still contaminates impedance and other attributes necessary for quantitative interpretation. (b) Corresponding time slice through the coherence volume. Coherence exacerbates the footprint, thereby making it a noise characterization tool. (c) Because it has little to do with the reflectivity, footprint varies slowly in the vertical direction, with the major change healing with depth due to an increase in fold and a decrease in sensitivity to velocities. If the lateral variation in the overburden velocity is smooth, the pattern persists but is slowly warped.

These patterns allow one to “enhance” the footprint artifacts by applying a ±100 ms median filter to the coherence volume. Seismic data courtesy of Marathon Oil Co.. After Figure 1 of Alali et al. (2016). Used by permission.

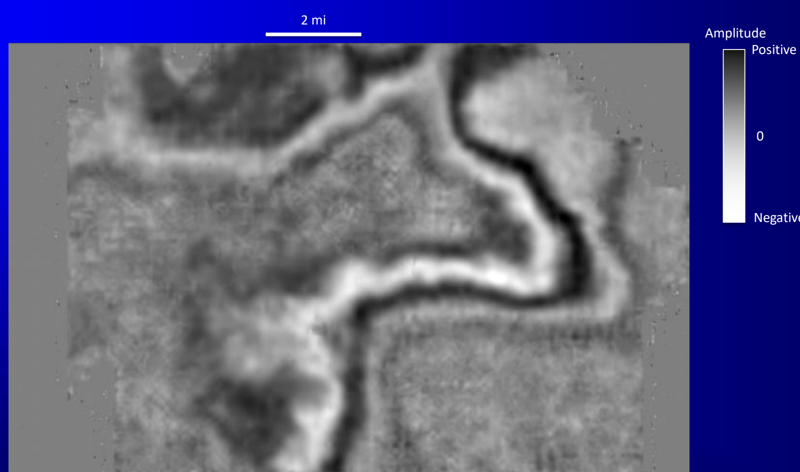
Footprint suppression using k_x-k_y filters



Amplitude Slice after Footprint Suppression (t= 0.45 s)

(Alali et al., 2016)

Footprint suppression using 2D CWTs

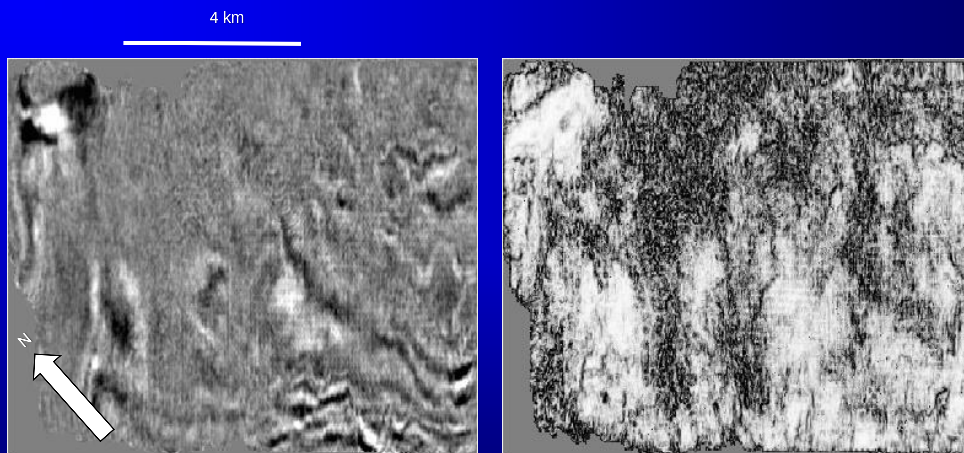


Amplitude Slice after Footprint Suppression (t= 0.45 s)

40

(Alali et al., 2016)

Footprint suppression using 2D CWTs
(Chicontepec Basin)



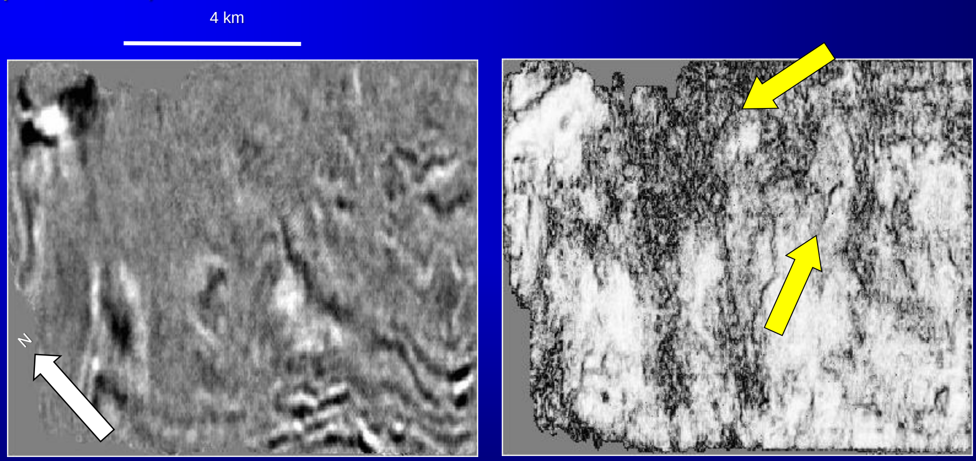
Before footprint suppression using x-y wavelet transforms

41

(Cvetkovic et al., 2008)

In this example Cvetkovic et al. (2007) applied 2D x-y wavelet transforms to the data. This 2D transform is basically a space-variant kx-ky transform.

Footprint suppression using 2D CWTs
(Chicontepec Basin)



After footprint suppression

42

(Cvetkovic et al., 2008)

High amplitude noise components were muted and the data reconstruction, resulting in very nice lineament preservation.

Post Migration Poststack Data Conditioning

In Summary:

- Periodic acquisition programs often generate periodic acquisition footprint. For reasonably flat overburden, the periodic pattern can be attenuated through k_x-k_y filtering
- The 2D CWT can adapt to footprint that changes pattern due to the velocity overburden or due to different acquisition patterns seen in merged surveys,
- Dense acquisition is the best way to avoid acquisition footprint. For wide azimuth land acquisition, increasing the number of traces per km^2 by a factor of four does not increase the cost of acquisition by four
- 5D interpolation is a partial solution to footprint prior to impedance inversion; however, edges in the data are often smeared

43

Summary comments on post-migration data conditioning of post-stack data