# Amplitudes: Reducing Acquisition Footprint for Prestack Migration Using Tsunami Imaging Suite

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## Introduction

Users of seismic data today are more interested in the amplitudes of the migrated data than ever before. The amplitudes of the output seismic gathers are used for distinguishing geologic and reservoir properties as well as for AVO analysis. The effective use of these technologies depends a great deal on the relative accuracy and stability of the amplitudes in the migrated gathers. Regardless of how careful we are in preserving the amplitudes within the migration algorithm, the acquisition geometry of the traces can distort the migrated amplitudes and render amplitude analysis very risky.

The acquisition pattern of 3D surveys can have a great effect on the resulting amplitudes, especially in land data-sets. In the ideal situation we would like each offset to be acquired on a regular grid, and for each cdp to contain all the offset ranges. This of course only happens in synthetic surveys. The distortion created by the acquisition geometry is called the acquisition footprint. It is the imprint left on the amplitudes by the irregular spacing of the acquired traces. In this article we discuss technology that significantly reduces the acquisition footprint as well as research we are doing to make further progress in this area.

## Two Problems Not Just One

There really are two dimensions to this problem. The first is that within an offset bin the traces are not acquired at a uniform density over the survey. This can be compounded by the common practice of merging surveys which have different acquisition geometries and possible overlap areas. The second problem is that the different offset bins usually have very different populations. The near offsets may have one tenth the number of traces in them as the middle offsets. This very large difference in trace population produces corresponding amplitude differences in the migrated gather. The small population offsets have weak amplitudes in the migrated gather; the large population offsets have high amplitudes in the migrated gather. Producing useful amplitudes from the migration requires addressing both of these issues.

Figure1 is a trace distribution map of the traces within a single offset bin. The blue areas show holes in the survey while the brighter white areas show high concentrations of traces in the acquisition. Figure2 is an offset histogram

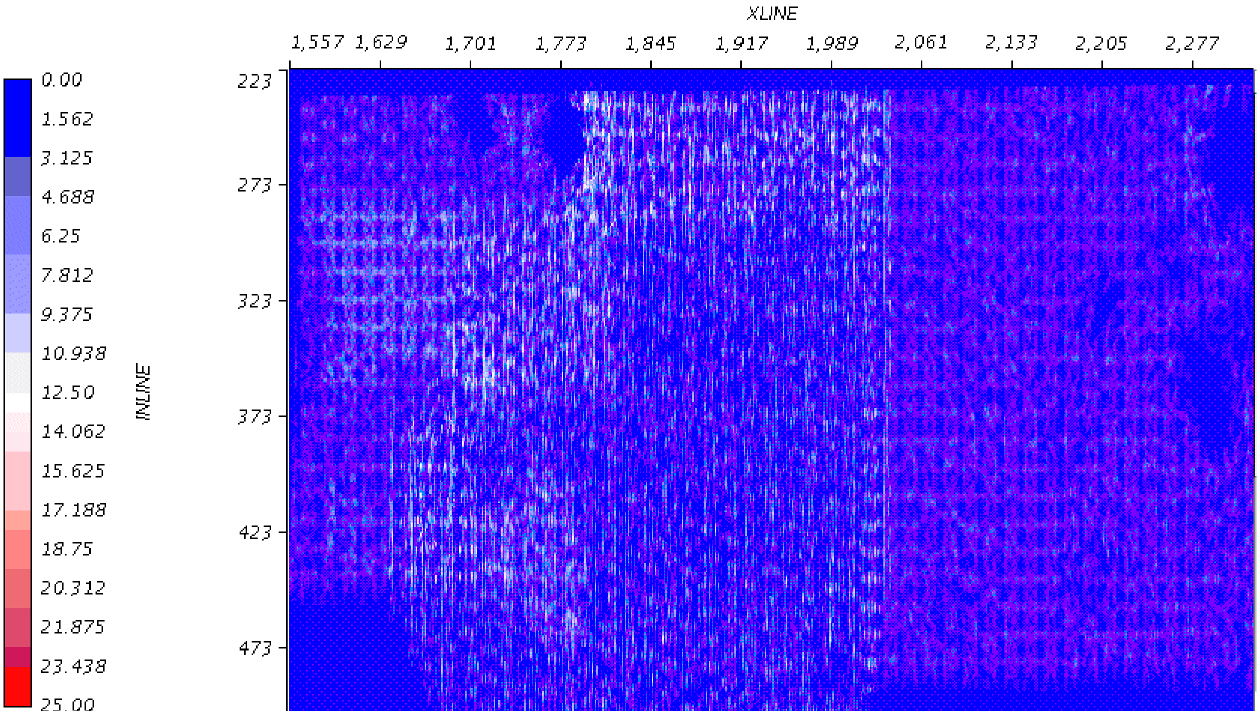

Figure 1: Map of input trace locations for offset range 3200 – 4000

showing a typical land survey offset population. We see very few traces in the near and far offsets, and large numbers of traces in the middle offsets. This type of distribution greatly distorts AVO analysis, since the amplitudes will certainly be distorted by virtue of the large variance in the number of traces within each offset bin.

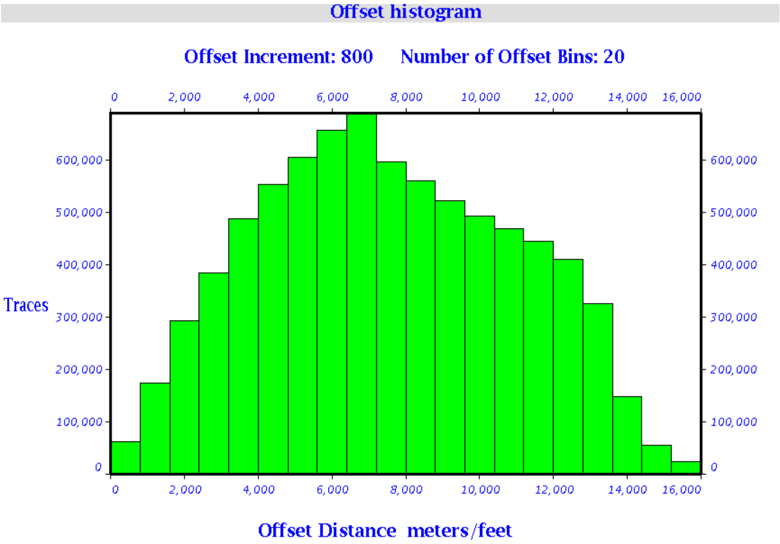

Figure 2: Offset histogram

## Compensating for Uneven Trace Distribution Within an Offset

The method described by Canning and Gardner (1) is generally effective at mitigating the problem of uneven trace distribution within an offset bin. We have implemented this method within the Tsunami Imaging Suite with some minor variations which increase the stability of the algorithm. In brief the method creates a set of weights that are applied to the input traces prior to migration. These weights are calculated by creating a set of polygons surrounding each trace within an offset plane, Figure3. The trace weights are created proportional to the area of the polygons. Roughly speaking, traces that are closer together receive lower weights and traces that are further apart get higher weights.

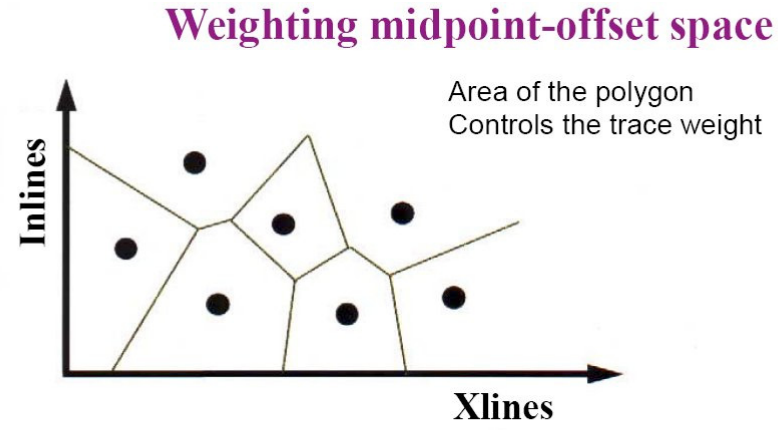

Figure 3: Polygons used to build weights

To demonstrate the method we created a synthetic dataset that has a constant velocity function throughout, in other words the V(z) function is uniform. The synthetic dataset contains a single flat event. If the traces in the synthetic dataset were created on a uniform grid, after migration, the flat event would have constant amplitude. However, we created the synthetic dataset with the trace distribution shown in Figure 1. Rather than a flat event with constant amplitude, the migration produced the result displayed in the time slice shown in Figure4. This time slice shows the acquisition footprint because when compared with Figure1, it is obvious that there is a significant correlation between the density of the traces and the amplitudes in the migrated event. This is what we would expect. We then created the input trace weights based on the polygon method, and reran the migration. Figure5 shows the result displayed in the time slice. We can see from this time slice that weighting of the input traces produces much more consistent amplitudes in the migrated event. This result is very typical of the results we see with the polygon weighting technique.

Over the years we have experimented with many attempts to scale the migrated traces after the migration based on counting the number of contributing samples to an output trace sample. These methods have all failed to produce desirable results. This is because while is it possible to measure the number of contributing samples to each output trace sample, it is not then possible to scale them correctly based on the measure count. The magnitude of the migrated amplitude is very non-linear. The migrated amplitude is affected by a great many factors such as the velocity model, the antialias filter, the time of the event, the dip of the event, and the signal to noise ratio. So it is not possible to create a single function based on the number of contributing input samples that will correctly scale the output samples. The only real solution is to scale the input trace amplitudes to compensate for their irregular density.

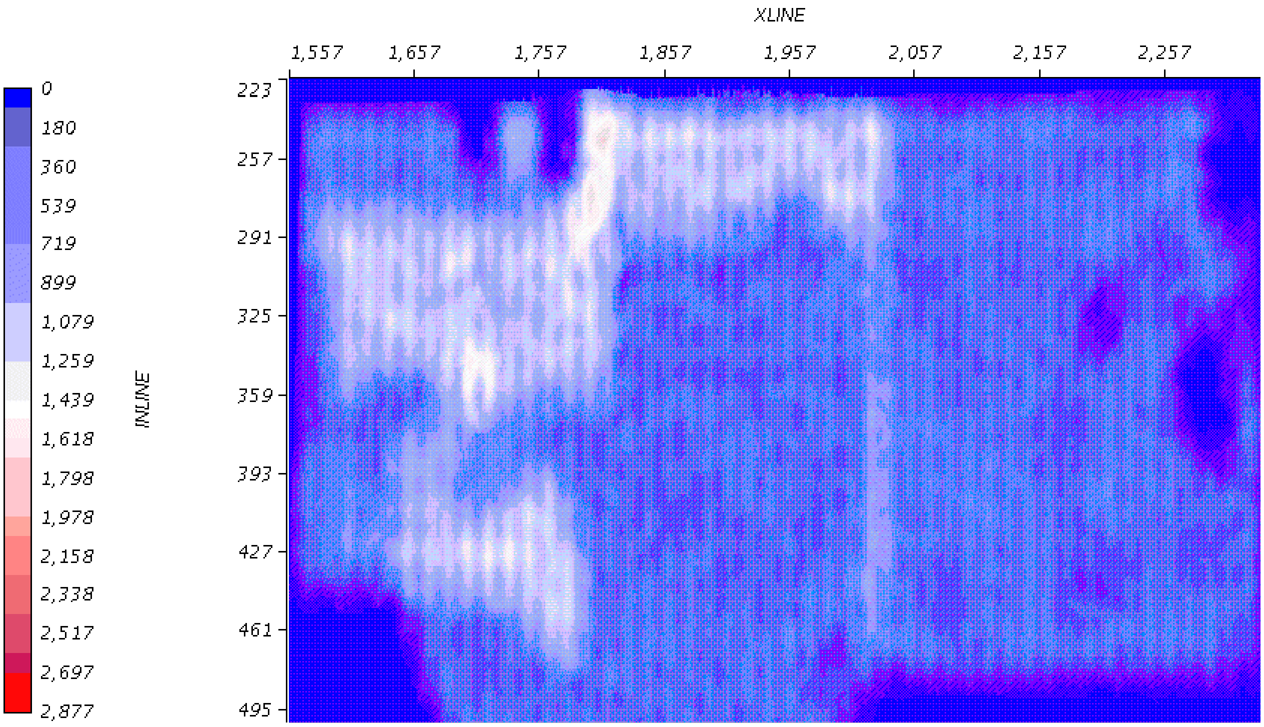

Figure 4: Time slice of migrated flat event showing acquisition footprint offset range 3200-4000

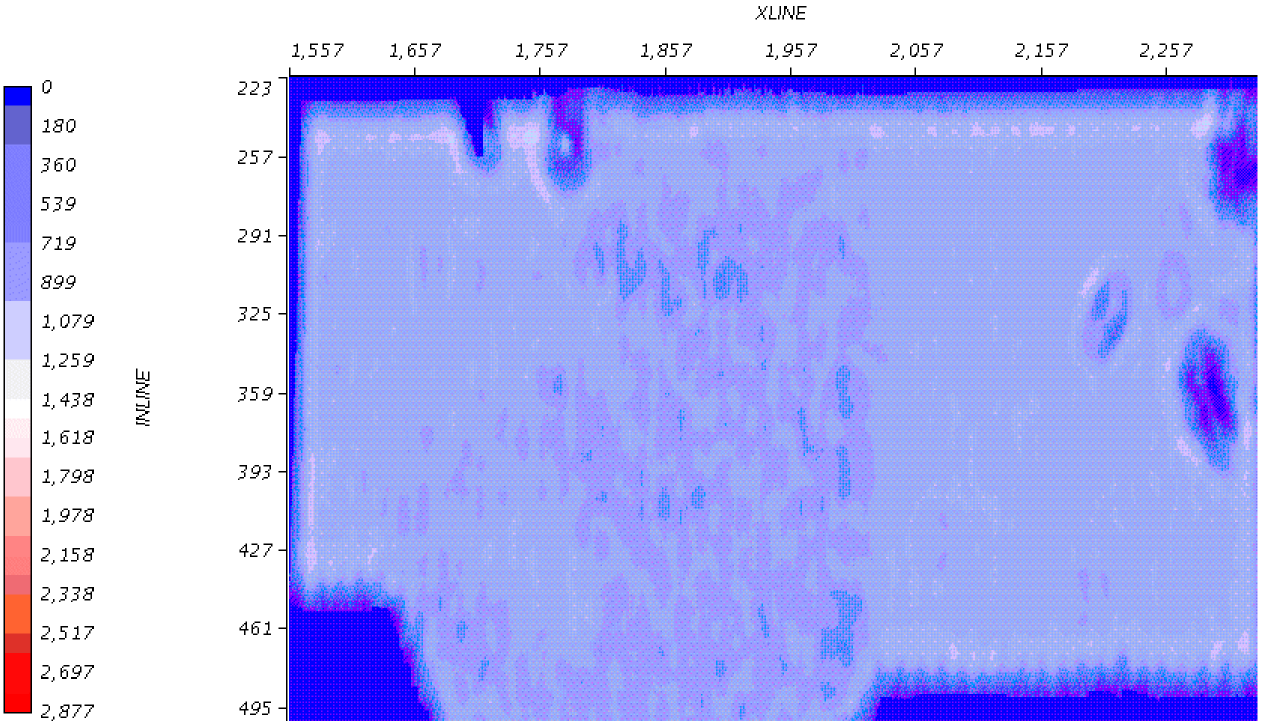

Figure 5: Time slice of migrated flat event using polygon weights offset range 3200-4000

## Compensating for Population Differences Between Offsets

As we see in the Figure2 histogram the population of traces within offset bins varies a great deal when offsets are chosen on a regular increment. The histogram shows the typical land distribution, where near and far offsets are under sampled compared to the middle offsets. This causes the amplitudes of the near and far offsets to be weak relative to the middle offsets. Figures 6–9 are made by migrating a flat synthetic event with the spatial distribution typical of Figure1, and the offset population shown in the trace histogram. The AVO signature of the event should be flat, however in Figure6 we see the usual amplitude distribution, where the near and far offsets are weak, because of the small number of traces within these offset bins. Figure7 shows the result of using the polygon weights that were discussed above. As we can see, while the polygon weights make for a more uniform spatial distribution within an offset plane, they do not compensate for the amplitude differences between offset bins.

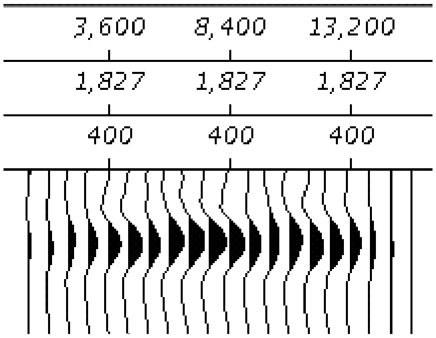

Figure 6: Migrated gather with no weights applied

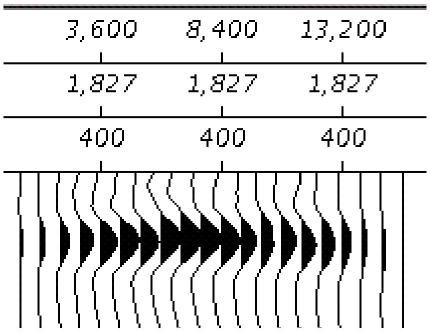

Figure 7: Migrated gather with weights applied

To compensate for the amplitudes between offset planes there are two solutions within Tsunami. The first is to optionally adjust the polygon weights such that they compensate for the different number of traces within each offset bin. After all the weights are built for all the offsets, we then go back and scale these weights such that the sum of the weights for each offset bin are normalized. This compensates for the amplitude weight *between* the offset bin. Figure8 shows the result of applying this technique. As we can see the gather now has a more uniform amplitude distribution. The trade off with this technique is that by raising the amplitude of noisy near offset traces, the stack section may show more high frequency noise. As with many geophysical processes the benefits must be weighed against the limitations.

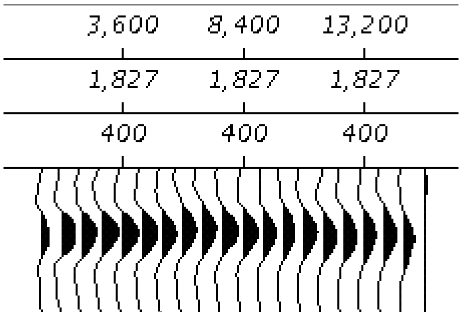

Figure 8: Migrated gather with weights applied and with weights normalized

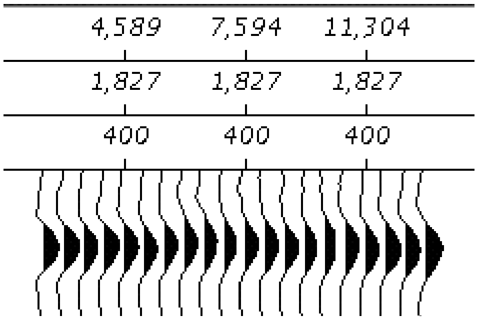

Figure 9: Migrated gather with balanced offset bins

The second method is to design the output offset increments such that each offset bin will have the same number of input traces in it. This of course means that the output offset bins will not have a uniform increment. Figure10 shows the offset values when the input traces are divided into twenty uniform offset bins. As expected the near and far offsets have larger increments between bins, while the middle offsets have smaller increments. This balancing of the number of input traces naturally balances the amplitudes on the output migrated gathers. As we can see from Figure9, the amplitudes of the event are now very uniform across the gather. In situations where this technique can be applied the best results can be achieved.

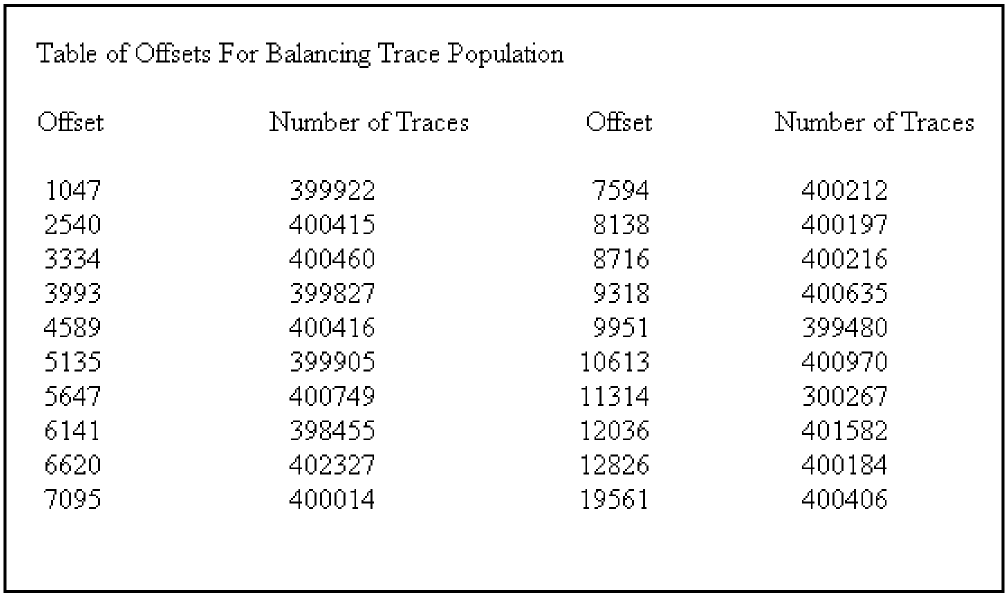

Table of Offsets For Balancing Trace Population

| Offset | Number of Traces | Offset | Number of Traces |
|---|---|---|---|
| 1047 | 399922 | 7594 | 400212 |
| 2540 | 400415 | 8138 | 400197 |
| 3334 | 400460 | 8716 | 400216 |
| 3993 | 399827 | 9318 | 400635 |
| 4589 | 400416 | 9951 | 399480 |
| 5135 | 399905 | 10613 | 400970 |
| 5647 | 400749 | 11314 | 300267 |
| 6141 | 398455 | 12036 | 401582 |
| 6620 | 402327 | 12826 | 400184 |
| 7095 | 400014 | 19561 | 400406 |

Figure 10: Table of offsets to created balanced offset bins

## Conclusions

We have shown that it is possible to compensate for amplitude variations caused by acquisition geometries by using a combination of techniques. It is possible to compensate for the spatial distribution of the traces within an offset bin by applying weights to the input traces that compensate for the trace density. It is possible to compensate for amplitude variations between offset bins by either adjusting the calculated weights to normalize the weights between offset bins, or by creating offset bins that have the same number of input traces in them. By using a combination of these methods the acquisition footprint can be greatly reduced.

In all cases the users should run a series of tests on target lines to confirm that the processes are producing the desired benefit. In some cases, where the distribution densities vary to the extreme, the results may not be as good as those shown in this article. It's also possible than when balancing the input trace population, that the nearest output offset will be increased more than desirable. This can happen when the near trace offsets are particularly under sampled. The Tsunami log will print the calculated offsets when it computes the irregular offset spacing. Tsunami also offers the option for the user to input a list of offsets which can be manually determined. In this way virtually any offset increment can be achieved.

## Limitations and Future Research

We are continuing to do research to mitigate the effects of acquisition geometry. The current polygon method takes only the trace location into account. So it is basically a first order solution. As we can see from Figures 4 and 5, it is achieving a significant improvement. However the method does not take into account the azimuth of the traces, the velocity model, or the time/depth of the event that is modeled. So while the current methods achieve a significant improvement in producing useful amplitudes, we think there is some room for improvement. We are in the process of completing research that will allow us to more accurately model the input trace weights. Using an inversion process, and the migration operator, it should be possible to more accurately adjust the input trace weights such that the image in Figure5 becomes even smoother. The weights will also be able to be slightly modified as a function of time/depth to model the changes in the impulse response as a function of time/depth. As we move deeper into the migrated section more mixing between the input traces takes place, and therefore the trace weights should be adjusted accordingly. We expect to have an update to this article in the first quarter that will demonstrate this new technology.

Reference

Reducing 3-D acquisition footprint for 3-D DMO and 3-D prestack migration
Anat Canning and Gerald Gardner,
Geophysics Vol 63, No 4, July-Aug 1998, pp 1178-1183