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Is 2D possible?

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ABSTRACT

One of the major concerns in the passive seismic imaging experiment as outlined in by Claerbout et al. (1988) is touched on by the title: *Why a big 2D array to record microseisms?* My question is: Will a linear array produce sufficient results? I answer this question in the affirmative with anecdotal and modeling evidence as well as note a recent success by seismologists from the University of British Columbia that suggests that the linear acquisition strategy can provide useful information about the subsurface.

INTRODUCTION

In the passive seismic imaging experiment as outlined in this volume (Artman, 2002), full coverage of plane waves arriving from all azimuths and with all incidence angles is necessary to fully illuminate the subsurface. Either case of absent ray parameter constituents or over-representation of a few can confound the correlation approach to passive imaging. In this event, beam-steering analysis such as that undertaken in Cole (1995) may yield useful information, but will not provide images of the subsurface. Also problematic could be energy arriving from perfectly perpendicular azimuths to the linear receiver spread. This energy would have infinite ray parameter values, and be indistinguishable from vertical waves arriving from the deep earth. To explore this issue, I will offer three arguments in favor of the feasibility of the linear strategy.

One of the convenient issues about exploring this question, is that we are able to find the answer along the way while making plans to accommodate larger dimensionality. We can decimate our data set to address this specific concern. This is precisely the strategy employed in the first case where the MDI[2] solar seismic data set is defined as a working model that we can decimate for the purposes of our concern. The second topic for discussion concerns the review of a patent application describing this acquisition strategy that claims informative results. Finally, seismologists at UBC have positive results inverting data collected with a linear array strategy across central Oregon. Through these three lines of evidence, I conclude that interpretable results are procurable from linear acquisition strategies.

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[2]The Michelson Doppler Imager, http://soi.stanford.edu/results/heliowhat.html

SOLAR DECIMATION

The solar data set can act as an excellent modeling exercise for testing our ideas about the passive imaging concept. The impulse response of the sun, while containing no reflective structure, is simple, not laterally variable, and the ambient noise is ubiquitous at all locations and azimuths. These characteristics make it a great laboratory if not a perfect model. The question it won't ever address however is: how long will our records need to be on earth?

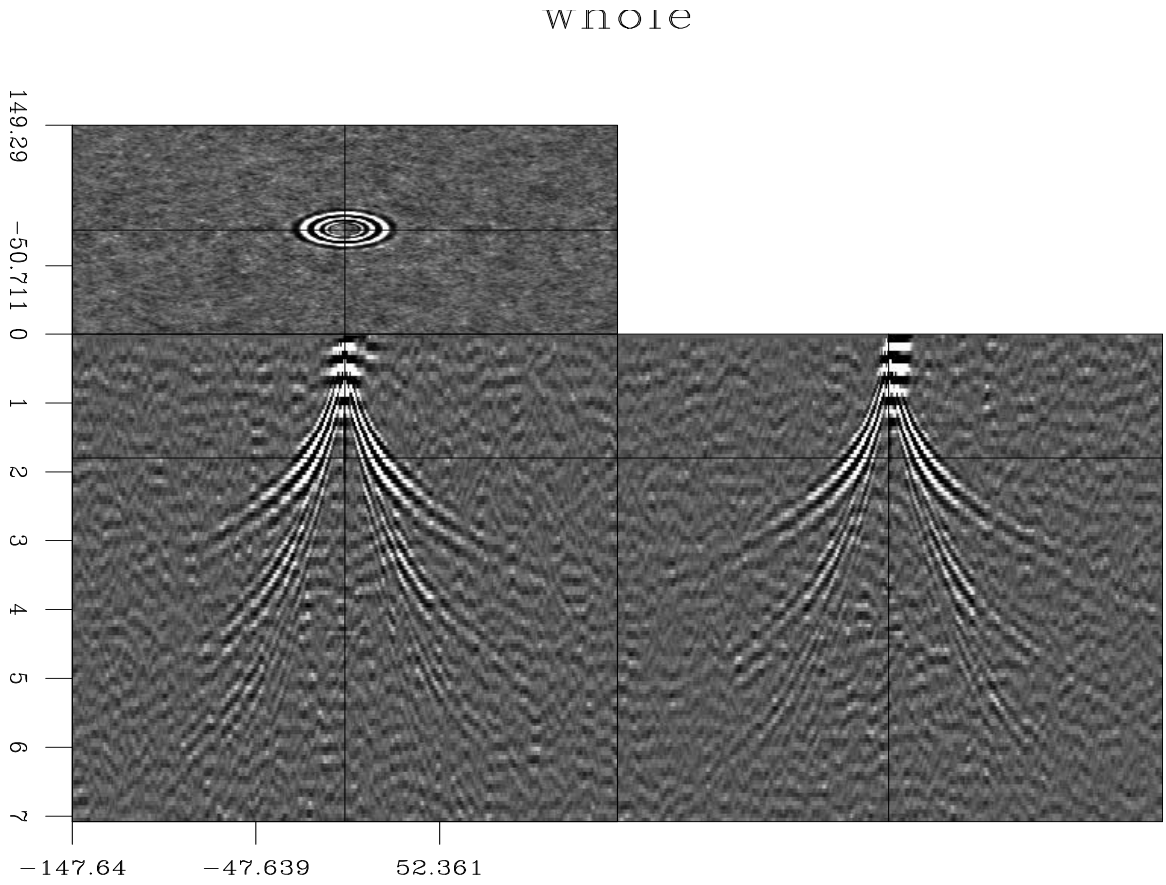

Figure 1: The entire data volume processed with the correlation methodology and stacked across offsets. From Rickett and Claerbout (1999) brad2-whole [ER]

While the dimensions of the full volume of the solar seismic data set are 256 x 256 x 256, it is easy to window smaller cubes out of the volume or simply take any one line of receivers. Figure 1, shown for reference, shows the impulse response of the sun as arrived at through the correlation processing of the entire solar data. Events are plunging waves, overturning and returning to the surface, of multiple order bounces within the survey area. Figure 2 is the result of a single line of receivers correlated with each other. While the quality of the image is definitely degraded, the plunging waves are readily interpretable (even the second order events if you really believe).

As an exercise for a well rounded argument, I also began decimating the data by various factors and comparing the result to images that were decimated by the same factor after being

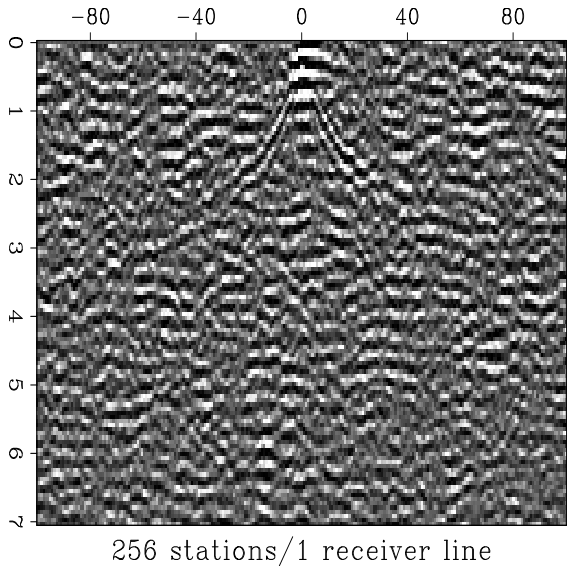

Figure 2: By using only one receiver line of the 256 available, the image quality is poor, but interpretable. Is this validation of the 2D experiment? brad2-2d [ER]

constructed with the entire data set. Since Figure 2 is very definitely of worse quality than one of the panels comprising Figure 1, I expected to see a steady degradation of the image quality from decimating the data space. Interestingly however, it seems that the 256 receiver square array seems to be quite oversampled. The third order body waves apparent in the Figure 1 are just disappearing in Figure 3 which is sub-sampled by 32x in the cross-line axis (only eight receiver lines across the entire cross-line direction!).

This result begs the question then: is the degradation in image quality a function of cross-line offset or number of receiver lines available to contribute information? As Figure 4 shows, the image quality is definitely degraded by using eight neighboring receiver lines as compared eight lines spanning the entire data volume. I believe this observation is due to the increase in the aperture of available information to sum into the result.

Now let's go back to considering the end case of only one line. Can adding one more receiver line significantly improve our image quality if chosen correctly? Figure 5 compares images created by processing two consecutive lines (on the left) with one created by line numbers 1 and 256 (on the right). Whereas the left panel is no more clear than Figure 2, the improvement in the right panel is dramatic.

As mentioned in the previous article (Artman, 2002), only direct ray paths traveling in the same azimuth as the receiver line will record a ghost reflection. When considering the reflection from the free-surface, one can imagine that including larger offset in the perpendicular direction from a single line will allow ever more energy from the lost azimuths to be incorporated into the image. This will only work well in the case of a body with stationary characteristics for the extreme offsets described above. If heterogeneities exits within the offset range, constructive summation will not occur. Therefore, this may be of limited utility on earth, but might be advantageous perpendicular to strike.

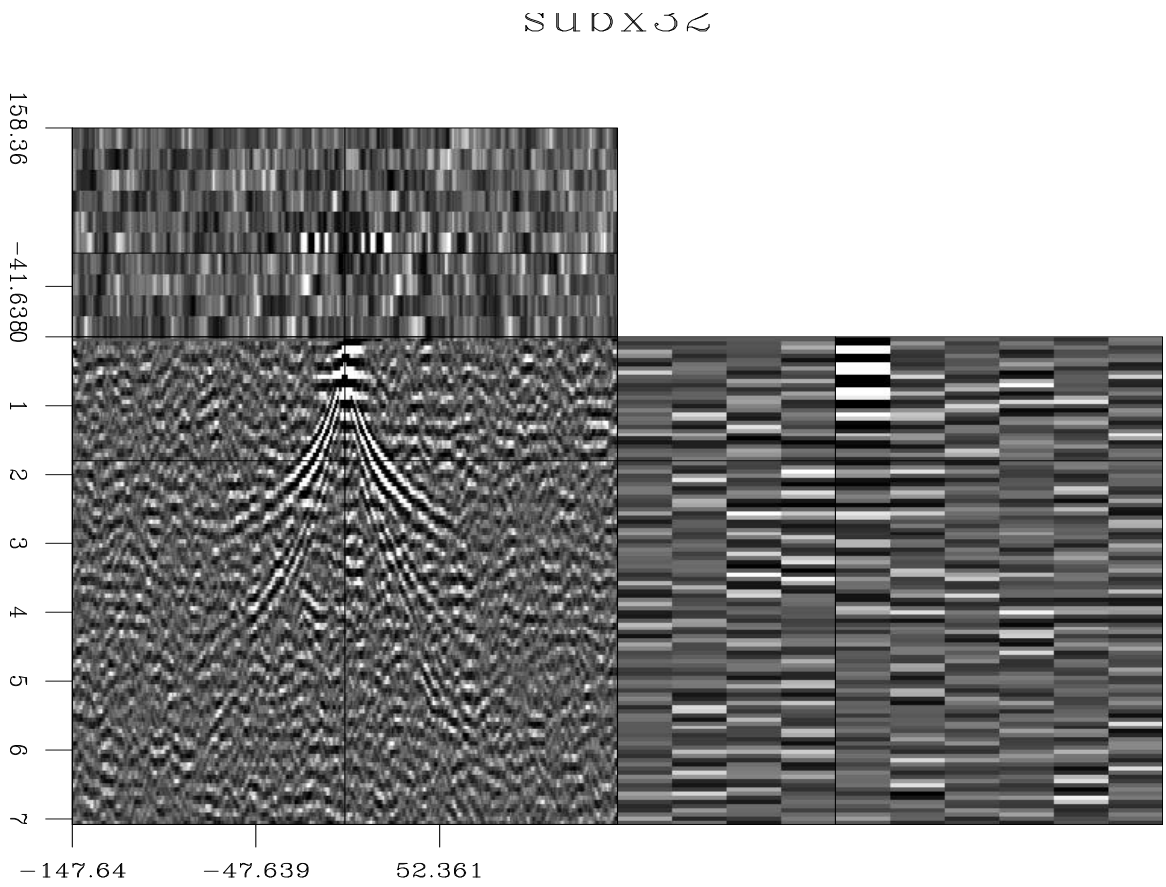

Figure 3: Taking only every 32nd receiver line of the available 256, the image manufactured from only 8 lines is not only interpretable, but arguable quite clear. brad2-subx32 [ER]

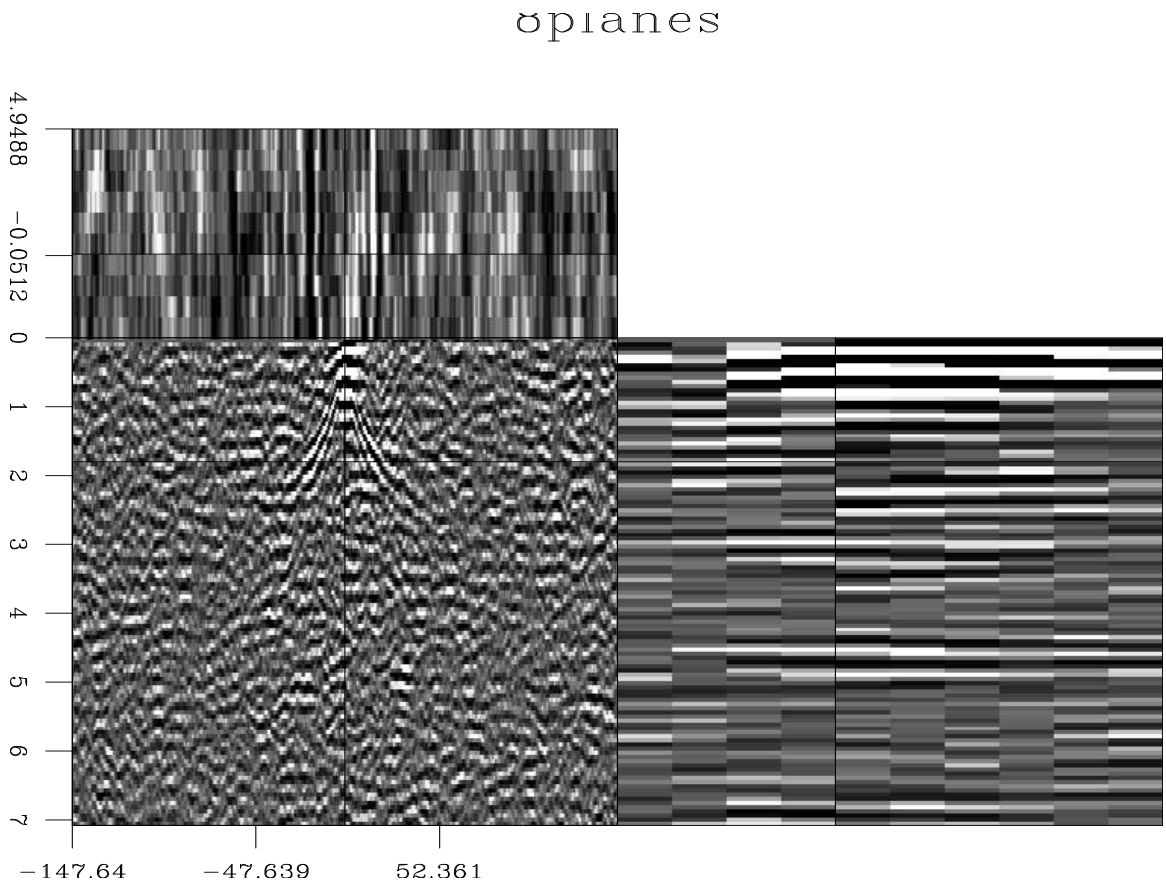

Figure 4: Utilizing the same number of (this time) contiguous planes of data as used in Figure 3, we are left with an image of degraded quality. brad2-8planes [ER]

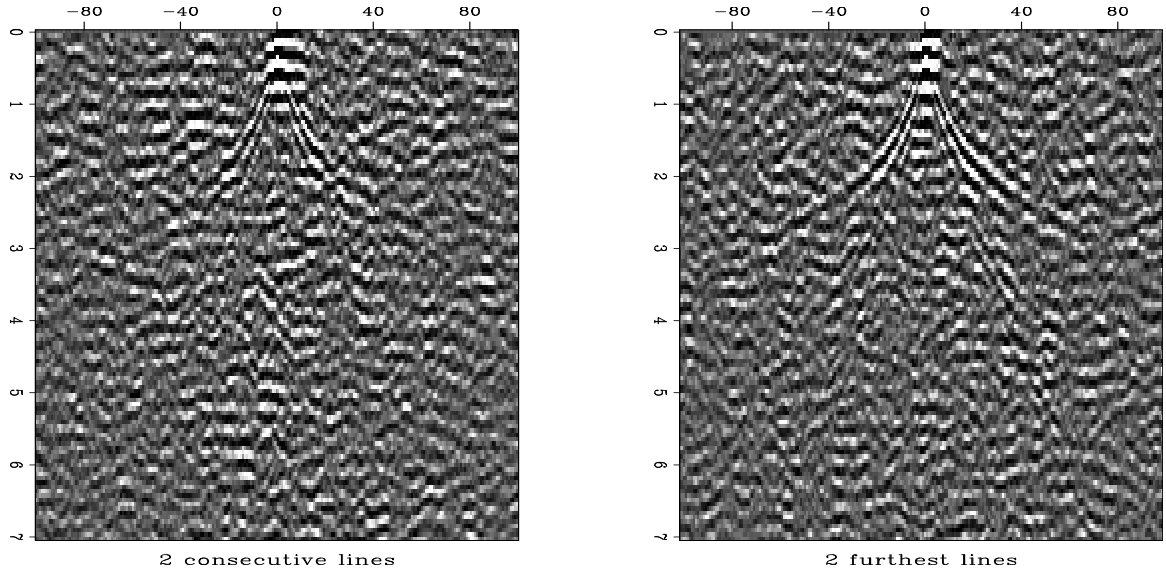

Figure 5: Surprisingly, two consecutive receiver lines does not produce as good an image as two lines spread across the length of the third axis of acquisition. brad2-compare [ER,M]

ANECDOTAL EVIDENCE

"My brother's friend from college works at a place that does it all the time."

The second line of evidence I have to present is only slightly more substantial that the quote above. While this time the U.S. patent office is involved, no results are available for inspection and one can assume a rosy bias on the effectiveness of anything submitted for patent. Nonetheless, in 1969 Charles Weller of Shell Oil Company filed for patent that describes a method of acquiring seismic data:

[s]eismic exploration is conducted with out using a seismic sound source by recording a plurality of relatively long stretches of ambient earth noise data at each of an array of seismic receiving stations...

The application covers the acquisition of data in any of several areal strategies on the surface of the earth. However, a linear array of six recording stations every 200 feet having returned*[m]eaningful alignment of events ... corresponding to known geologic boundaries ... obtained to beyond 5 seconds delay time*, involved a linear array of six recording stations every 200 feet. The application goes on to describe more specific issues relating to the successful acquisition and processing of the data set. The most interesting of these points is the first mention of an empirical understanding of just how long the records need to be. Weller makes the claim that approximately eight hours recording in the quiet Gulf coast region was 'satisfactory' for his images, and further that one to two hours was 'sufficient'.

OREGON

Michael Bostock showed results of the seismologic imaging effort at the University of British Columbia at an invited lecture given to the Stanford Geophysics Department on March 14, 2002. His group utilized a data set collected by John Nabalek of the University of Oregon. The 1993 data was collected with the IRIS-PASSCAL equipment and is freely available[3]. The array is 300 km long with 69 broadband seismometers every four km. Bostock inverts 31 earthquake event records across the array from many azimuths and teleseismic incidence angles to image crustal structure from the subducting oceanic crust into the volcanic back-arc basin across strike of the central Oregon Cascades region.

By inverting 31 earthquake events with dominate energies arriving with two second periods, his results have kilometer scale resolution. While the field equipment and experiment design limit the study to well below the resolution required for applications envisioned by this group, it does stand as a proof of concept for the linear experiment.

[3]http://www.iris.washington.edu/PASSCAL/data_reports/1996/96-004.pdf

CONCLUSION

Acknowledging that the sun model is not very earth-like (read: heterogeneous), it does offer us a convenient laboratory to test hypotheses against. In the consideration of whether areal acquisition strategies are mandatory for the success of passive imaging experiments, I find the imaging of the plunging waves from only one line of receivers a positive indication that they are not. Any layman understands that areal arrays will undoubtedly be better, but it will be useful to understand how effective a linear acquisition might be as this effort progresses.

Interestingly, it is possible to make step improvements in image quality by "squaring out" the acquisition geometry even with out filling in the volume with receiver stations. This implies that it is possible to do better than linear acquisition with out breaking the bank or one's back in the process. Undoubtedly the homogeneity of the sun's structure contributes to this result, however it is an important test to remember for future terrestrial projects.

Having made the effort to try this methodology with analog recording tapes and solid state electronics in 1968 with at least positive results, the Shell patent application stands as an enticing benchmark in the past that hints at the possibility of success. Finally, the images produced at the University of British Columbia utilizing a one dimensional array of receivers, while broadband and crustal scale, are fine examples of success in producing a 2D image with passive seismic data collection.

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