

## CLAIMS

We claim:

- 5     1.     A method for separating effects of multiple seismic sources in simultaneous shooting acquisition, comprising:

obtaining blended seismic data recorded simultaneously in seismic streamers,  
acquired by activating approximately simultaneously two or more  
seismic sources towed at two or more positions in the vicinity of the  
10     seismic streamers;

for each activation of the two or more seismic sources,

calculating predicted blended seismic data as a product of a time delay-  
based blending matrix and deblended seismic data models;

calculating a residual difference between the blended seismic data and  
15     the predicted blended seismic data;

iteratively updating thea residual for an inversion solution of the  
deblended seismic data models for the activations of the two or  
more seismic sources, in which the iterative updating of the  
residual utilizes a sequence of overlapping temporal windows  
20     containing reflection events and utilizes normal moveout  
corrections based on largest reflection events in each temporal  
window; and

adding a final updated residual to a final updated deblended seismic data model  
result.

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2.     The method of claim 1, wherein the activating the two or more seismic sources approximately simultaneously comprises:

applying random time delays of -500 ms to +500 ms to timing of the activation  
of the two or more seismic sources.

3. The method of claim 2, wherein the two or more positions comprise positions at front and at rear, respectively, of the seismic streamers.
- 5 | 4. The method of claim 13, wherein the iteratively updating the residual comprises:
- selecting a set of  $N$  temporal windows, each containing reflection events, in the  
| blended seismic data recorded, starting with water bottom reflection and  
| proceeding downward;
- 10 | setting, at initial iterative step 0, deblended seismic data model results  $\mathbf{m}_{(0)}$  equal  
| to zero; and
- updating, at each iterative step  $i$ , from  $i = 1, 2, \dots, N$ , the residual  $\mathbf{r}_{(i)}$  for an  
| inversion solution of deblended seismic data model results  $\mathbf{m}_{(i)}$  at the  $i^{\text{th}}$   
| event in the selected set of  $N$  temporal windows.
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5. The method of claim 4, wherein the adding the final updated residual to the final  
| updated deblended seismic data model result comprises:
- adding, after the final iterative step, the final updated residual  $\mathbf{r}_{(N)}$  to the final  
| model result  $\mathbf{m}_{(N)}$ .
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6. The method of claim 4, wherein the updating, at each iterative step  $i$ , from  $i = 1, 2, \dots, N$ , the residual  $\mathbf{r}_{(i)}$  comprises:
- pseudo-deblending the residual  $\mathbf{r}_{(i-1)}$  for the two or more seismic sources,  
| generating pseudo-deblended CDP gathers as a product of the blended  
25 | seismic data multiplied by a conjugate transpose of the time delay-based  
| blending matrix;
- applying an NMO-correction to the pseudo-deblended CDP gathers;
- applying a filter to retrieve the coherent signals in the NMO-corrected CDP  
| gathers;

applying an inverse NMO correction to the retrieved signals;  
applying the random time delays to the inverse NMO-corrected signals;  
applying blending to the time-delayed signals; and  
subtracting the blended signals from the previous residual  $r_{(i-1)}$  to generate the  
5 new residual  $r_{(i)}$ .

7. The method of claim 6, wherein the applying a filter comprises applying a multi-dimensional median filter.

10 8. The method of claim 7, wherein the applying a multi-dimensional median filter further comprises:  
using a temporal window to limit the area where the multi-dimensional median filter is active.

15 9. The method of claim 6, wherein the applying a filter comprises applying a filter selected from the group consisting of frequency-wavenumber filters, Radon filters, and curvelet or wavelet domain filters.

20 10. The method of claim 1, wherein the iterative updating of the residual utilizes a static shift.

11. A system for separating effects of multiple seismic sources in simultaneous shooting acquisition, comprising:  
two or more seismic sources configured to be activated with random time delays  
25 of -500 ms to +500 ms to timing of the activation of the two or more seismic sources; and  
towed seismic streamers configured to simultaneously record blended seismic data in response to the activations of the two or more seismic sources,

configured to be towed at front and at rear, respectively, of the towed seismic streamers;

a programmable computer used to perform at least the following:

for each activation of the two or more seismic sources,

5        calculating predicted blended seismic data as a product of a time delay-  
         based blending matrix and deblended seismic data models;

calculating a residual difference between the blended seismic data and  
         the predicted blended seismic data;

10        updating ~~the~~iteratively a residual for an inversion solution of the  
         deblended seismic data models ~~for the activations of the two or~~  
         ~~more seismic sources,~~ in which the iterative updating of the  
         residual utilizes a sequence of overlapping temporal windows  
         containing reflection events and normal moveout corrections  
         based on largest reflection events in each temporal window; and

15        adding a final updated residual to a final updated deblended seismic data  
         model result.

12.    The system of claim 11, wherein the iteratively updating ~~the~~a residual  
comprises:

20        selecting a set of  $N$  temporal windows, each containing reflection events, in the  
         blended seismic recorded data, starting with water bottom reflection and  
         proceeding downward;

         setting, at initial iterative step 0, deblended seismic data model results  $\mathbf{m}_{(0)}$  equal  
         to zero; and

25        updating, at each iterative step  $i$ , from  $i = 1, 2, \dots, N$ , the residual  $r_{(i)}$  for an  
         inversion solution of deblended seismic data model results  $\mathbf{m}_{(i)}$  at the  $i^{\text{th}}$   
         temporal window in the selected set of  $N$  temporal windows.

13. The system of claim 12, wherein the updating, at each iterative step  $i$ , from  $i = 1$ , 2, ...,  $N$ , the residual  $\mathbf{r}_{(i)}$  comprises:

pseudo-deblending the residual  $\mathbf{r}_{(i-1)}$  for the two or more seismic sources,  
generating pseudo-deblended CDP gathers as a product of the blended seismic data multiplied by a conjugate transpose of the time delay-based blending matrix;

applying an NMO-correction to the pseudo-deblended CDP gathers;

applying a multi-dimensional median filter to retrieve the coherent signals in the NMO-corrected CDP gathers;

applying an inverse NMO correction to the retrieved signals;

applying the random time delays to the inverse NMO-corrected signals;

applying blending to the time-delayed signals; and

subtracting the blended signals from the previous residual  $\mathbf{r}_{(i-1)}$  to generate the new residual  $\mathbf{r}_{(i)}$ .

14. At least one computer readable medium with a computer program stored thereon, the program having logic operable to cause at least one programmable computer to perform a method comprising:

obtaining blended seismic data recorded simultaneously in seismic streamers,  
acquired by activating approximately simultaneously two or more seismic sources towed at two or more positions in the vicinity of the seismic streamers;

for each activation of the two or more seismic sources,

calculating predicted blended seismic data as a product of a time delay-based blending matrix and deblended seismic data models;

calculating a residual difference between the blended seismic data and the predicted blended seismic data;

~~iteratively updating the residual for an inversion solution of the deblended seismic data models for the activations of the two or more seismic~~

sources, in which the iterative updating of the residual utilizes a sequence of overlapping temporal windows containing reflection events and utilizes normal moveout corrections based on largest reflection events in each temporal window; and  
5 | adding a final updated residual to a final updated deblended seismic data model result.

15. The medium of claim 14, wherein the activating the two or more seismic sources approximately simultaneously comprises:  
10 | applying random time delays of -500 ms to +500 ms to timing of the activation of the two or more seismic sources.

16. The medium of claim 15, wherein the two or more positions comprise positions at front and at rear, respectively, of the towed seismic streamers.

15 | 17. The medium of claim ~~14~~15, wherein the iteratively updating the residual comprises:

selecting a set of  $N$  temporal windows, each containing reflection events, in the seismic recorded data, starting with water bottom reflection and  
20 | proceeding downward;  
setting, at initial iterative step 0, deblended seismic data model results  $\mathbf{m}_{(0)}$  equal to zero; and  
updating, at each iterative step  $i$ , from  $i = 1, 2, \dots, N$ , the residual  $\mathbf{r}_{(i)}$  for an inversion solution of deblended seismic data model results  $\mathbf{m}_{(i)}$  at the  $i^{\text{th}}$   
25 | temporal window in the selected set of  $N$  temporal windows.

18. The medium of claim 17, wherein the adding the final updated residual to the final updated model result comprises:

adding, after the final iterative step, the final updated residual  $\mathbf{r}_{(N)}$  to the final model result  $\mathbf{m}_{(N)}$ .

19. The medium of claim 17, wherein the updating, at each iterative step  $i$ , from  $i =$   
5 1, 2, ..., N, the residual  $\mathbf{r}_{(i)}$  comprises:

pseudo-deblending the residual  $\mathbf{r}_{(i-1)}$  for the two or more seismic sources,  
generating pseudo-deblended CDP gathers as a product of the blended  
seismic data multiplied by a conjugate transpose of the time delay-based  
blending matrix;

10 applying an NMO-correction to the pseudo-deblended CDP gathers;  
applying a multi-dimensional median filter to retrieve the coherent signals in the  
NMO-corrected CDP gathers;  
applying an inverse NMO correction to the retrieved signals;  
applying the random time delays to the inverse NMO-corrected signals;  
15 applying blending to the time-delayed signals; and  
subtracting the blended signals from the previous residual  $\mathbf{r}_{(i-1)}$  to generate the  
new residual  $\mathbf{r}_{(i)}$ .

20. The medium of claim 19, wherein the applying a multi-dimensional median  
20 filter further comprises:

using a temporal window to limit the area where the multi-dimensional median  
filter is active.