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Short Note

Upward continuation multiple suppression applied to the SEG multiples datasets

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INTRODUCTION

Two SEG multiple suppression workshop data sets were used as input to a multiple suppression algorithm based on upward continuation, originally formulated by Berryhill and Kim (1986). The recorded data are upward continued a distance equal to twice the water depth, with water velocity, in order to add a lag equal to the multiple period. A primary in the upward continued data should then line up with its first multiple in the original recorded data, a first order multiple in the upward continued data with a second order multiple in the original, and so on. The upward continued data and the original are cross-equalized using a scheme similar to Rickett (1997), and subtracted, leaving (hopefully) only primaries.

The first of the two data sets was recorded in deep water in the Gulf of Mexico, and shows individually identifiable multiples, but is complicated because there are multiple trains with different interfering periodicities. A shallow subsurface reflector brighter than the seafloor gives rise to a second set of multiple reflections. I find that both multiple trains can be removed simultaneously, but the large number of filter coefficients raises the danger that primaries will be predictable from the upward continued data.

The second data set was recorded in shallower water, off the coast of Western Australia, where a hard water bottom gives rise to short period, high amplitude multiples. These may present an intractable problem. At any rate, the results produced by this attempt at suppression are uninspiring to this point.

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IMPLEMENTATION

The multiple suppression algorithm applied here is that formulated by Berryhill (Berryhill and Kim, 1986). It is similar in principle to just shifting the data by a lag equal to one multiple period and subtracting, except that a more sophisticated operator is used. Kirchoff datuming is employed to model an additional bounce from the surface to the seafloor and back, so that the original primary and multiple energy, $P + M_1 + M_2 + ...$, emulates strictly multiples, $M_1' + M_2' + M_3' + ...$

The continuation velocity is known (water), though the seafloor does need to be picked. Here I pick one seafloor point, and do correlation in a sliding window around the seafloor. I then migrate the correlations with water velocity, pick the max in each trace as the seafloor, and calculate depth.

As a test, the correlations can be downward continued to the water bottom. Ideally they should wind up at zero time, but there is noticeable misfit in the deep water data, where there is strong seafloor topography, despite the initial migration, as shown in the top of Figure 1. I calculate a residual depth correction by estimating statics on the misfit, add it to the original depth estimate and downward continue again. The bottom of Figure 1 shows the correlations downward continued to the revised seafloor.

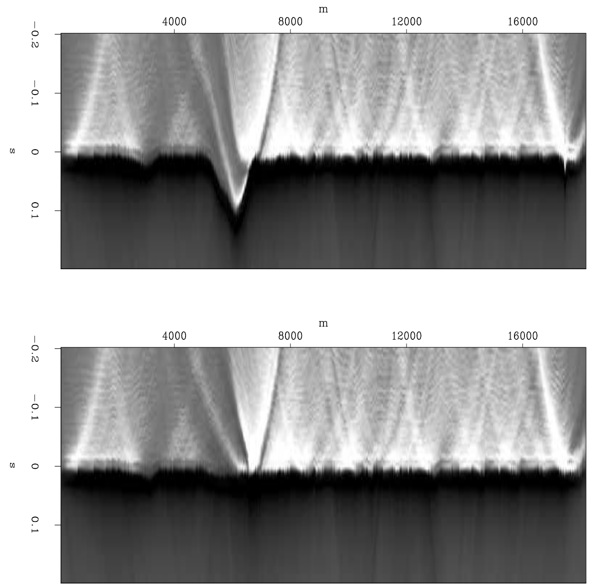

Figure 1: Downward continuing correlations to the calculated sea floor depth shows some depth error where there is large topography (top). Adding a residual depth term corrects the errors (bottom). sean2-deepBottom [ER]

Once the data are upward continued, the original and redatumed data are subtracted with the hope that

$$P + (M_1 - M_1') + (M_2 - M_2') + ... = P \tag{1}$$

where M_1 are the recorded first multiples and M_1' are first multiples modeled from primaries. In practice some fitting is necessary to make the newly modeled multiples look like the recorded multiples, and so the above turns into an optimization problem where

$$(P + M_1 + M_2 + ...) - a(M_1' + M_2' + M_3' + ...) \approx 0. \tag{2}$$

Ideally, the primaries P should not be predictable by the filter a, and will stay in the residual. This is like the cross-equalization of Rickett (1997). A basic problem is choosing the correct number of filter coefficients and the correct window size, a too-small number of coefficients relative to window size will not be able to predict the multiples, too many coefficients relative to window size will remove primaries along with multiples (Morley, 1982). I find that windows may be large in time (half or all of a trace), but that window width of more than a few traces hinders the suppression. An example is shown later in Figure 5.

FIELD DATA

Gulf Data Near Offset

Two near offset sections of a line from the Gulf of Mexico were used as inputs. The first has multiple trains with two periods; in addition to the water bottom, the bright reflector at about 2.3 seconds in the right half of the section produces its own multiples and peg legs (see Figure 2).

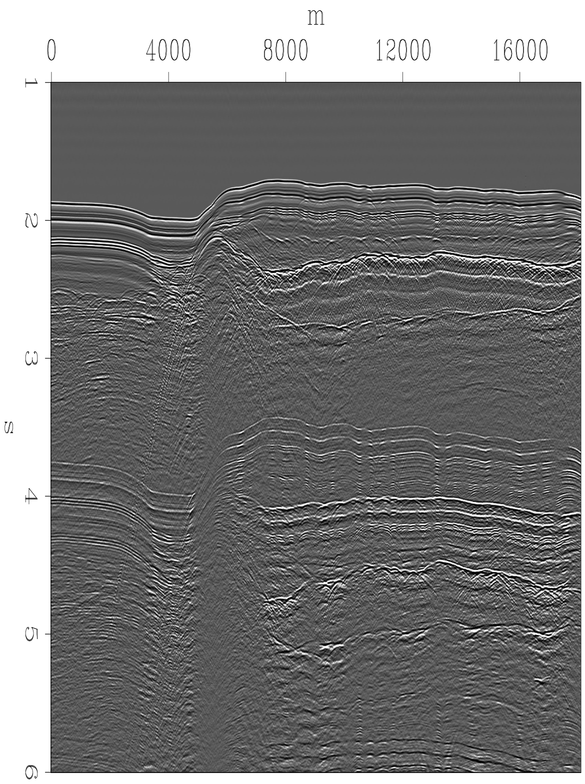

Figure 2: Time window of Gulf data near offset section. The sea floor at about 1.8 seconds and the bright reflector at 2.3 seconds generate separate multiple trains. sean2-deepInput [ER]

It is appealing to set up equation (2) to remove both lags at once, because the lags are superposed in the recorded data. For instance, the bright multiple at about 4.0 seconds is the first seafloor multiple of the 2.3 second reflector added to the first reflector multiple of the seafloor.

Filtering and subtracting gives the result shown in the right side of Figure 3, the left side shows the input. A good deep primary candidate in this data is the event near the left side of the section at about 6 seconds, dipping to the left.

The second near offset section has just the water bottom induced multiples and peglegs, but makes an interesting test for filtering because it has some visible deep primary energy. After picking the sea bottom, upward continuing, filtering, and subtracting, the multiples are largely suppressed and the primaries largely preserved. Figure 4 shows this section before and after multiple suppression. The large primary diffraction visible at the right side of the input at about 6 seconds is well preserved in the output.

The size of the filter and filter estimation window are important parameter choices. Here I use windows which are all or half the length of a trace, but generally only a single trace wide. Also, I use 100 or more filter coefficients to predict the multiples. For comparison, portions of results using smaller filters and wider windows are shown in Figure 5.

Multi Offset

This method seems able to suppress multiples fairly well, but the near offset sections do not provide enough deep primary energy to make a good test. To get an idea of the algorithm's behavior at larger offsets, some shot gathers were used as input. The technique is the same except that all offsets are used. Here I again use a separate filter for each trace. One possibility is a water bottom consistent filter estimation like that of Morley (1982), to help reduce the number of free filter coefficients, and reduce the possibility of predicting and removing primaries.

An input shot gather and output shot gather are shown in Figure 6. Here there are some deeper, high frequency events which are not obviously multiples. Some of these events do have zero offset times which indicate that they are most likely multiples, such as the event with a (projected) zero offset time of 4.1 seconds, 1.9 seconds after the primary at 2.2 seconds (water bottom time depth is 1.9 seconds). However, some are more likely to be primaries, such as the event with a zero offset time of about 4.6 seconds. Also interesting is that this method seems to do best at short offset, and might conceivably work well in conjunction with a method like the beam stack method of Holden (1996), which suppresses multiples well at far offsets, but not at near offset. The results are promising; a run on the full prestack data set will probably come later.

Australian Data Common Offset

The Australian data has very high-amplitude, short-period multiples. Using a sufficient number of filter coefficients to remove the multiples results in an output panel of noise. Because the seafloor multiples are so energetic, it may be unwise to treat them

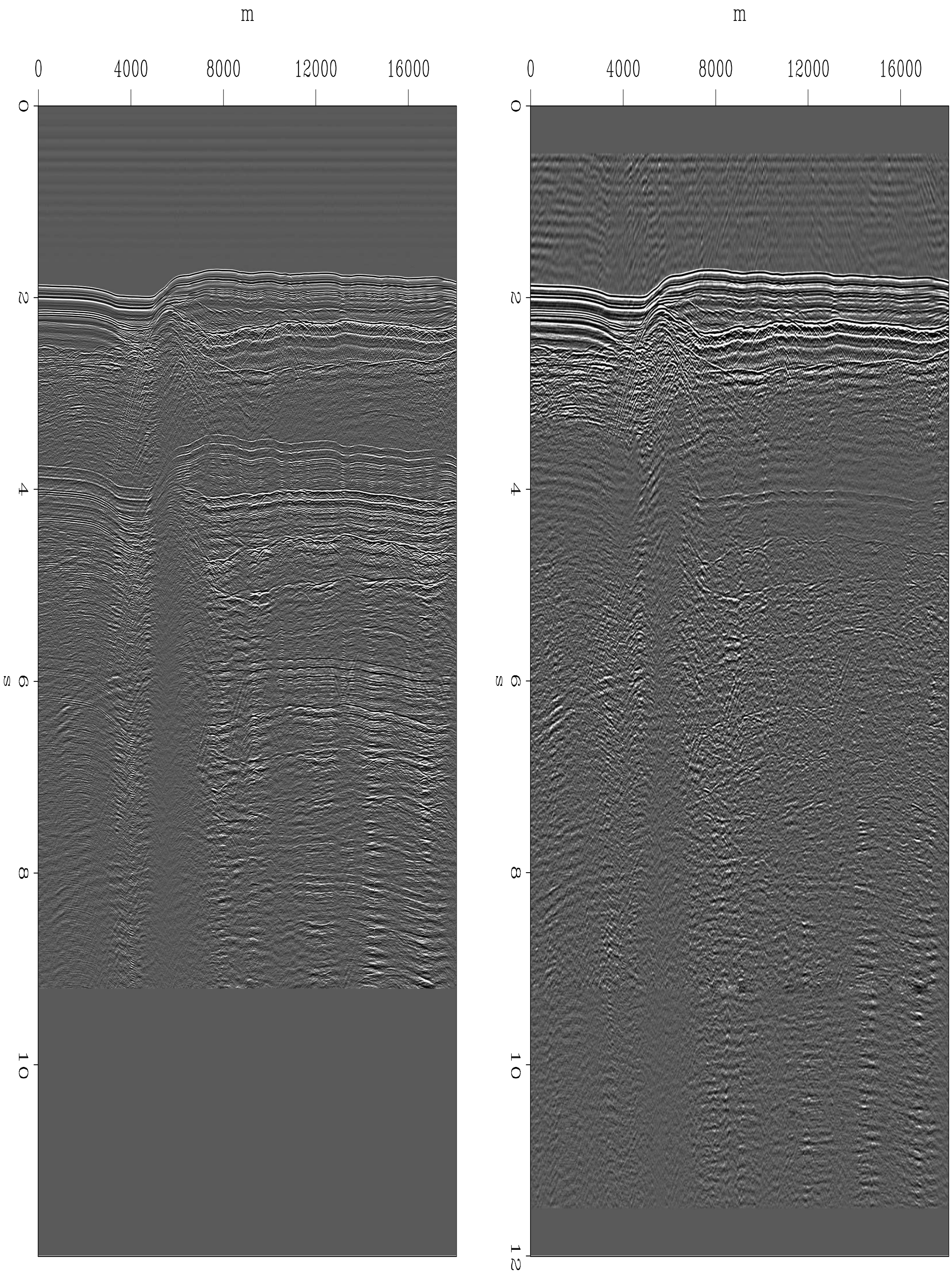

Figure 3: Input and output for first Gulf section. Left side shows input, right side shows data after multiple suppression. sean2-deepOut [ER]

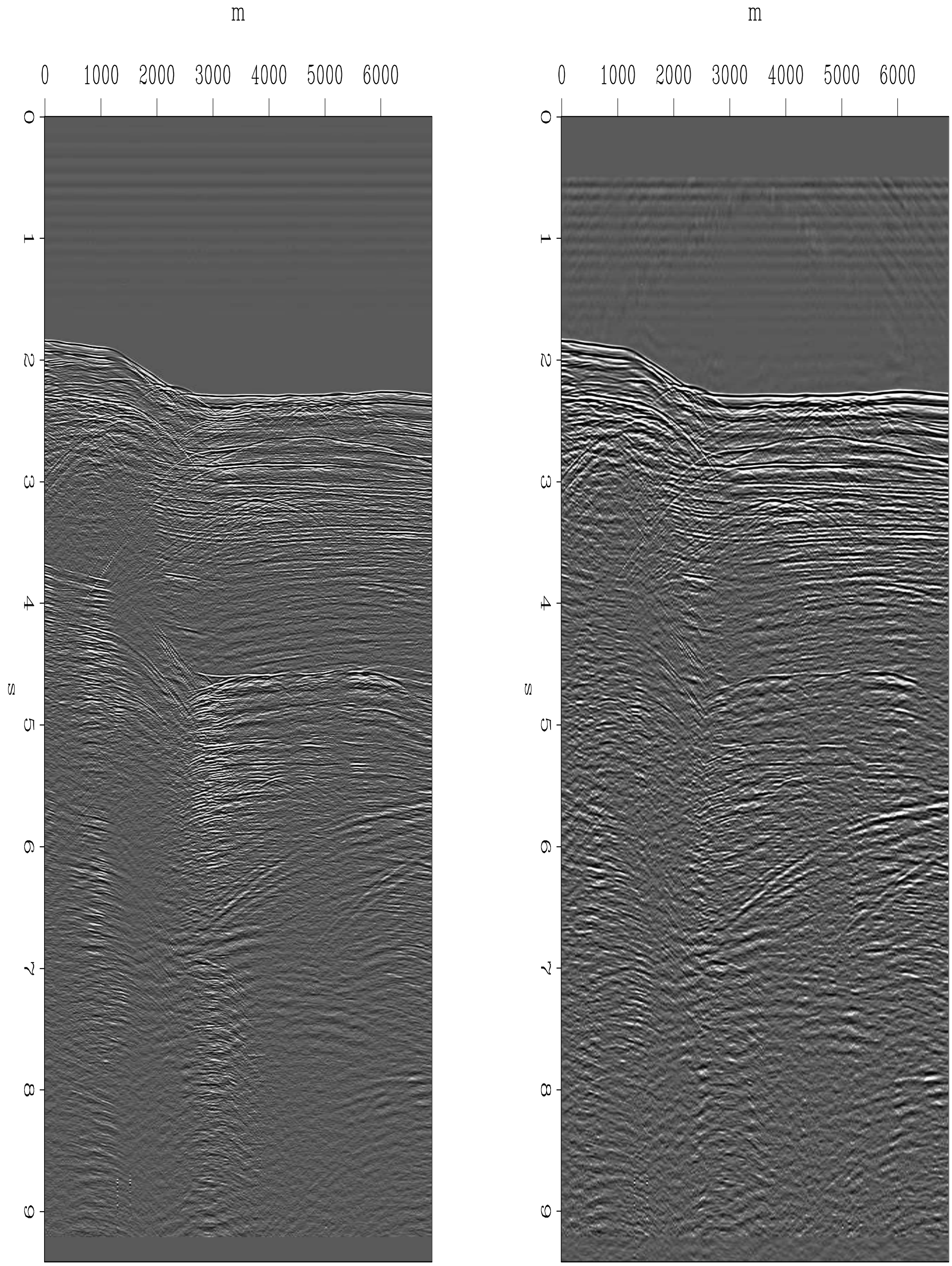

Figure 4: Input and output for second Gulf data section. Left side shows input, right side shows data after multiple suppression. $\boxed{\text{sean2-NM}}$ [ER]

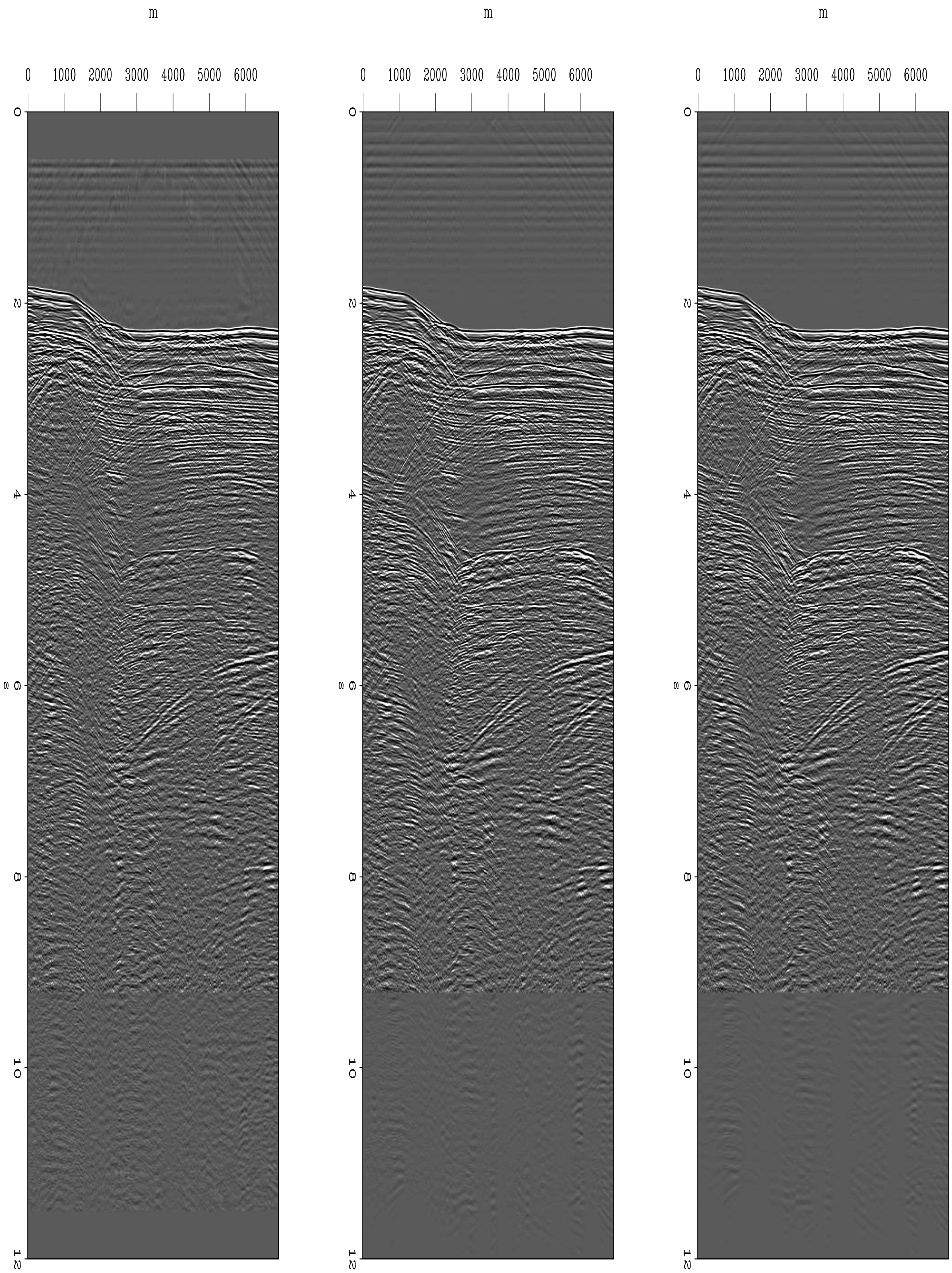

Figure 5: The left side shows the output for the second Gulf near offset section. The center shows output using shorter filter in time. The right shows output using wide filter estimation window. sean2-filtWindows [ER]

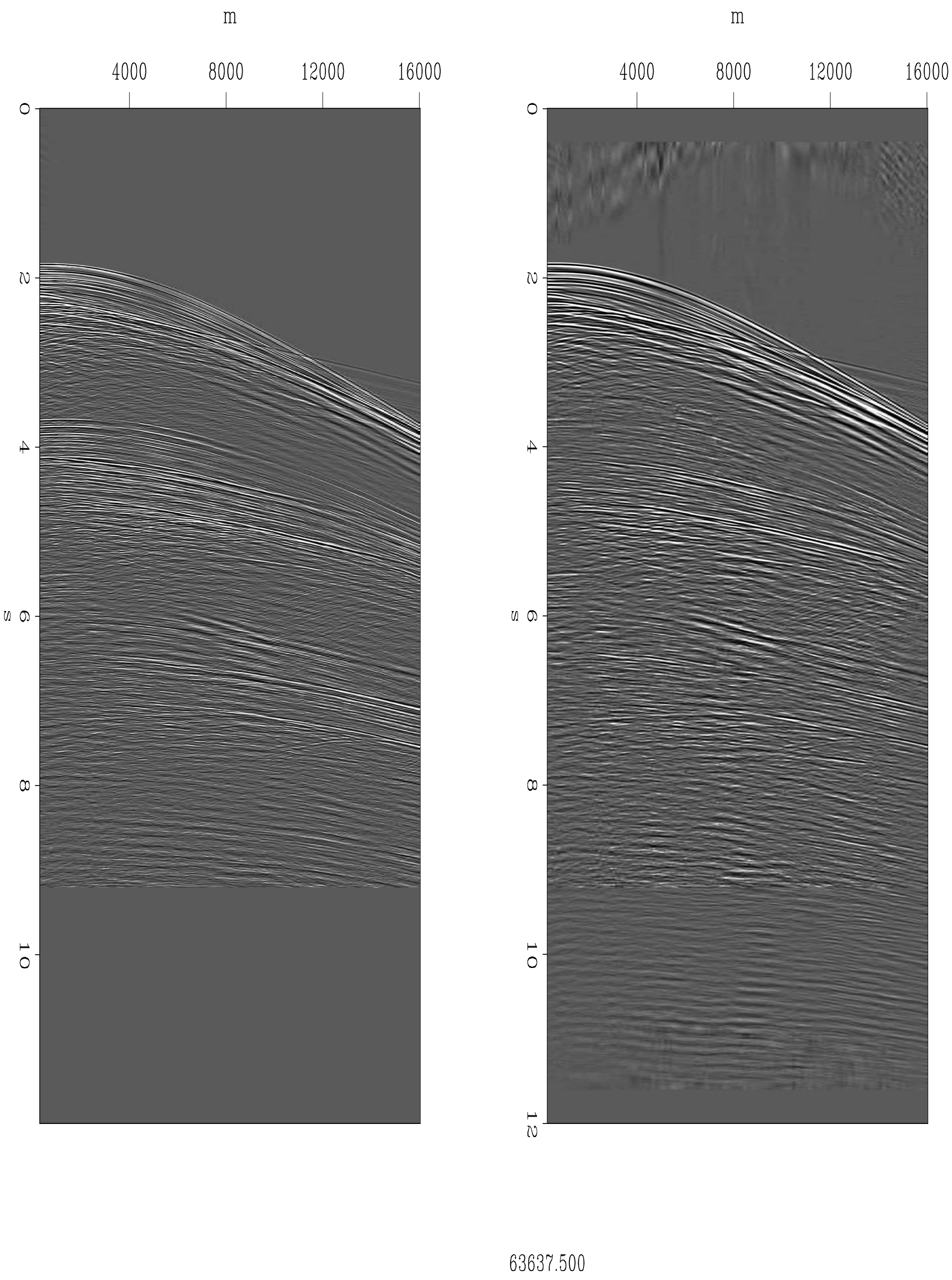

Figure 6: Original and multiple suppressed Gulf shot gathers. $\boxed{\text{sean2-DADOut}}$ [ER]

and the peglegs as the same problem. The input and output are shown in Figure 7. Suppression on the full prestack data might prove more interesting in this case; the output shown here is very incoherent, stacking in all offsets might reveal something.

CONCLUSION

The deep water data is a challenge for predictive methods like deconvolution or the upward continuation used here, because of its multiple periodicities. I find that both multiple trains can be removed together, but there are a large number of adjustable filter coefficients which raises the risk of removing primary energy as well as multiples. It should be interesting to see how moveout-based algorithms compare, because they do not have the problem of choosing a multiple period, though because some multiple paths spend more time below the seafloor, the normal problem of resolving differences in moveout may be more difficult.

The shallow water data poses a stubborn problem, because the multiples are so bright and closely spaced. Some energy does make it out of the suppression algorithm, but it is not coherent.

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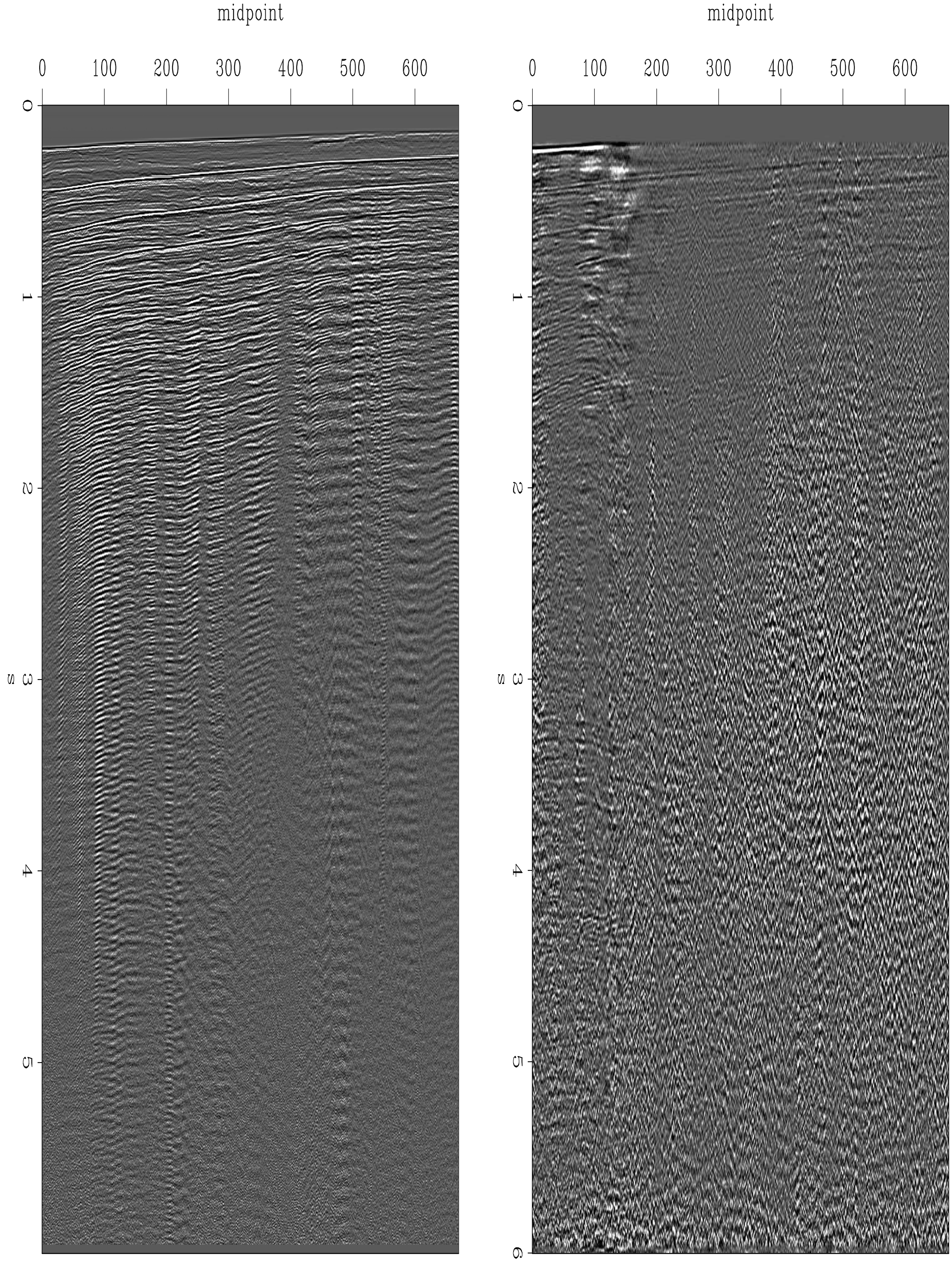

Figure 7: Near offset section from Australian data set, before and after multiple suppression. sean2-BHP [ER]