# Multiple suppression on land seismic data — case history

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## Summary

Multiple reflection problems not only exist in marine seismic data, but also in land seismic data. Due to distinct moveout differences between multiples and primary reflections in the land based seismic data, we present a processing strategy which combines stacking and *f-k* filtering for multiple suppression. Stacking with velocity from the primary partially attenuates multiple energy in the original seismic data and reduces computational costs. After determining the CMP ranges with residual multiples by constant velocity scan sections and stacked sections, application of *f-k* filtering to further suppress multiples in a selection of CMP gathers along the profile is cheap and robust. The results of field seismic data show that this strategy is very effective for multiple suppression in land seismic data. We expect this scheme may also be useful in other multiple attenuation methods.


## Introduction

Multiple reflections have been one of the most perplexing problems in seismic reflection exploration. Many different multiple attenuation methods have been developed since the 1980s. Weglein (1999) showed that these multiple attenuation methods may be classified into two major categories: (1) those that seek to exploit a feature or property that differentiates primary from multiple and (2) those that predict and then subtract multiples from seismic data. Until now, there is no multiple attenuation technique that works universally (Essenreiter et al, 2001). Therefore, it is important to choose a proper multiple suppression approach depending on the type of multiples in seismic data.

So far, most works discussed the multiple problems in marine seismic data due to strong multiples between sea bottom and sea surface. Literature concerning multiple suppression for land seismic data is limited. For marine seismic data, sea surface generates multiples in seismic acquisition. Due to relatively regular geometry, surface-related multiples are periodically present in marine seismic data, and they are relatively easy to be predicted and attenuated. In land seismic acquisition, although there is no subsurface media like sea surface and sea bottom, multiples can be generated at the surface by a strong reflection from a near surface consolidated formation. Irregular geometry patterns in land data acquisition often result in erroneous multiple prediction operators (Kelamis and Verschuur, 2000). Severe noise and statics problems in land seismic data also affect accurate multiple prediction. Thus, multiple elimination methods using multiple prediction and subtraction are not as effective in land data as in marine data. Filtering methods based on a property that differentiates primaries from multiples may be more proper for multiple suppression in land seismic data.

Among velocity filtering methods for multiple suppression, the *f-k* filtering method is very common and robust. In this paper, we follow the *f-k* filtering method described by Yilmaz (1987), Zhou and Greenhalgh (1994). Based on this scheme, we developed a practical processing strategy that is the combination of stacking and *f-k* filtering for multiple suppression in 2-D land seismic data. Multiples may be partially suppressed by stacking, while energy of the residual multiples may be removed by applying *f-k* filtering to NMO correction gathers. Our strategy not only suppresses the multiples efficiently, but also greatly preserves the primary amplitudes. The effectiveness of our strategy for suppressing multiples is demonstrated with a number of case studies involving processing 2-D land seismic data.

## Method

Coherent linear events in the *t-x* domain can be separated in the *f-k* domain by dip (Yilmaz, 1987). The certain types of unwanted energy will be removed from the original data by zeroing the *f-k* spectrum over a particular range of angles. The transformation of seismic data from the *t-x* domain to the *f-k* domain is achieved by the 2-D Fourier transform. The 2-D Fourier transform is able to separate events according to their dips in the *f-k* domain (Zhou and Greenhalgh, 1994). A linear event, $f(t,x)$, can be described by equation (1).

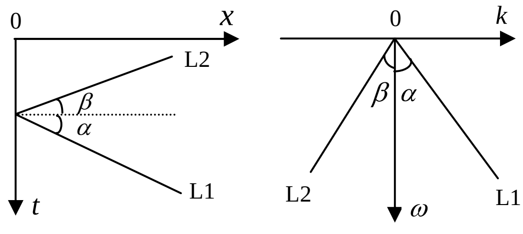
$$f(t,x) = s(t) * \delta(t - \tan(\alpha)x + b) \qquad (1)$$

Where the symbol "*" denotes convolution with respect to the variable $t$, time, $s(t)$ is seismic wavelet, $a$ is the angle between simulated linear event and the space axis, and the constant $b$ is the intercept of the event on the time axis. The 2-D Fourier transformed expression of equation (1) is given as

$$F(\omega,k) = S(\omega)e^{i\omega b}\delta(k - \omega\tan(\alpha)) \,. \qquad (2)$$

Where $S(\omega)$ is the Fourier transform of the time function $s(t)$ in equation (1), equation (2) shows that any linear event in the *t-x* domain can be transformed into another linear event in the *f-k* domain (Zhou and Greenhalgh, 1994).

Figure 1 schematically illustrates the separation of two linear events with different dips from the *t-x* domain to the *f-k* domain. Since the negative frequency part of the *f-k* spectrum of the function is the conjugate symmetry about the origin for the *f-k* spectrum of a real function, we only illustrate a positive-frequency *f-k* plane in Figure 1. The linear event $L_1$ in the *t-x* domain has positive values on the wavenumber axis in the *f-k* domain, while the linear event $L_2$ in the *t-x* domain is transformed into negative values of wavenumber in the *f-k* domain. Thus, based on the property of 2-D Fourier transform, we can design a filter in the *f-k* domain to remove the unwanted coherent linear events.




(a) (b)

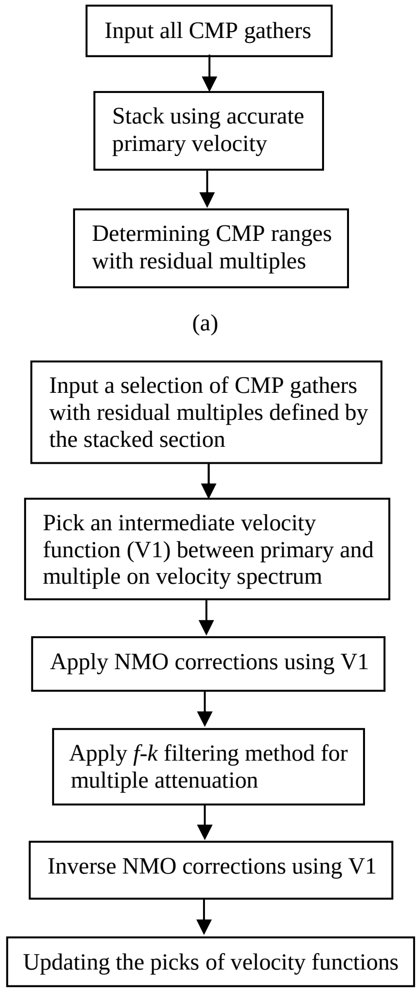
Figure 1: Schematic illustration of dipping events before and after 2-D Fourier transform. (a) Dipping events before 2-D Fourier transform; (b) Dipping events separated by 2-D Fourier transform.

Multiple suppression in the *f-k* domain is based on the fact that the primaries typically exhibit less moveout than do neighboring multiples (Yilmaz, 1987). In general, if we apply NMO correction to CMP gathers by using a velocity function greater than multiple velocity and less than primary velocity, multiples and primaries in the CMP domain will occur similar to the form exhibited in Figure 1 (a). The multiples are undercorrected, linear event $L_1$, and the primaries are overcorrected, linear event $L_2$. After 2-D Fourier transformation, the multiples will map to positive wave numbers in the *f-k* domain, while the primaries will occur in the negative wave number domain. Multiples may be removed by muting the positive wave number domain. Application of the inverse 2-D Fourier Transformation followed by an inverse NMO correction with the previously applied intermediate velocity function provides multiple free data. Our strategy for the multiple suppression in land data is seen in Figure 2.

**Field data and Multiple suppression**

**Field data**

The data are from a 2-D land survey area. A typical split-spread configuration with a 60-recording traces was used in each shot. All records are composed of 2500 samples with a 2.0-ms sample rate and record lengths of 5000 ms. Figure 3 shows a shot gather. The data are raw, except that the ground roll was attenuated. The signal-to-noise ratio observed on the shot gather below 1.0s is poor. The primary reflection masked by symbol P is from an igneous rock formation with a velocity of 2250 m/s, which generates surface multiple M. Unlike multiples in marine seismic data, only one order multiple appears on the shot gather around 1.2-1.3*s*. Its energy is very strong relative to the primaries around the multiples.




(b)

Figure 2: Schematic flow chart for multiple suppression. (a) shows the workflow of stacking for multiple suppression. (b) shows the workflow for multiple suppression by *f-k* filtering.

**Multiple suppression**

Since only part of the continuous CMP gathers contain multiples in this land seismic data, there is no need to remove multiples with prestack processing of each gather. According to the property of multiples in the land data, we proposed the strategy of the combination of stacking and the *f-k* filtering method for multiple suppression. Given

**Multiple suppression on land data**

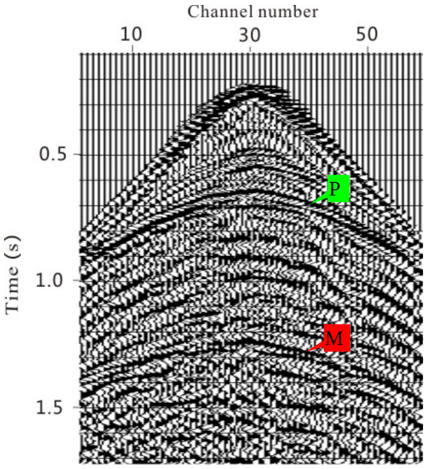



Figure 3: Field shot gather with one order multiple

accurate primary velocity, stacking all CMP gathers will suppress some multiples (Yilmaz, 1989; Foster and Mosher, 1992; Schoenberger, 1996). The *f-k* filtering method is applied only to those NMO corrected gathers with residual multiples that can not be removed by stacking. Based on the scheme above, our process for multiple suppression is as follows:

(a) Stack all CMP gathers with multiples and primaries using relatively accurate velocity function of primaries.
(b) Estimate the CMP ranges containing residual multiples on the stacked section. Choose the CMP gathers with multiples over a proper grid to generate velocity spectra and pick an intermediate velocity function $v_1$ such that $v_m<v_1<v_p$, where $v_m$ and $v_p$ are velocity functions associated with multiples and primaries, respectively.
(c) Perform normal moveout corrections to a selection of CMP gathers using the velocity function $v_1$ obtained in step (b). Thus, multiples and primaries will have different dips in the *t-x* domain.
(d) Apply the *f-k* filtering techniques to the NMO corrected CMP gathers and remove the multiples in the *f-k* domain. This step includes 2-D Fourier transform, zero the quadrant associated with the multiples and inverse 2-D Fourier transform.
(e) Perform inverse normal moveout corrections to the CMP gathers of the multiple attenuation using the velocity function $v_1$ as in step (b).
(f) Merge the CMP gathers attenuated multiples into other CMP gathers from the same line.
(g) Perform velocity analysis to update the picks for primary velocity functions.

## Results

Figure 4 shows a constant velocity stacked section using the primary $P_2$ velocity of 2250 m/s. Its shot records are from Line 1 in the in-line direction. Multiple reflections in Figure 4 are clearly visible and the CMP ranges containing multiples are 580-700. In order to illustrate the effect of the multiple suppression more clearly, some primary reflections are marked by an arrow with the symbol P and

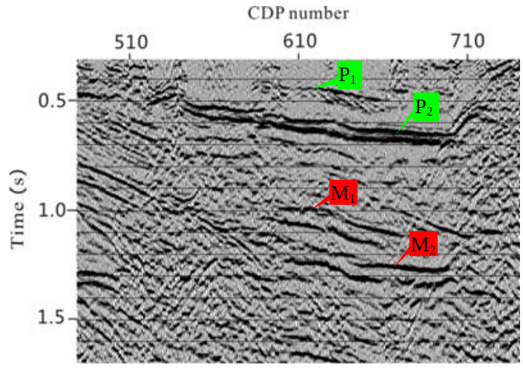



Figure 4: Constant velocity scan stacked section of Line 1, where the stacking velocity is 2250 m/s. Strong multiples are visible at 1.0-1.3*s*.

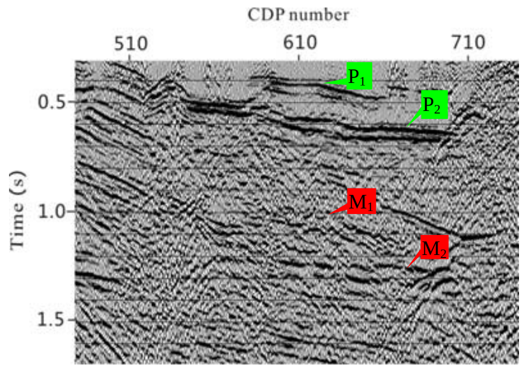



Figure 5: Stacked section using the primary velocity picked by velocity spectrum analysis. Most multiples are suppressed by stacking. Residual multiples only exhibit in CMP 650-700.

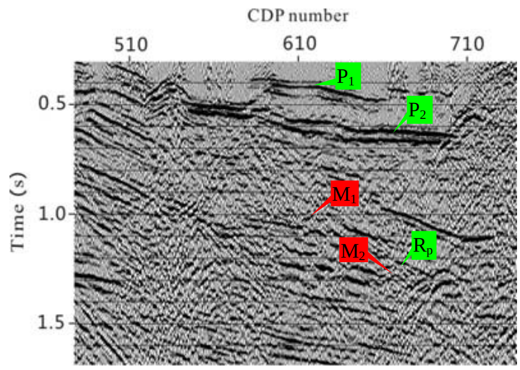



Figure 6: Stacked section after applying *f-k* filter. Multiples along the CMP 650-700 at 1.0-1.3*s* are suppressed well. The primary $R_P$ near the upper position of multiples is good recovery.

## Multiple suppression on land data

the multiple reflections corresponding to their primary reflections are marked by the arrow with symbol M. The reflections of the primary $P_1$ and $P_2$ are both from an igneous rock which generates multiple $M_1$ and $M_2$, respectively. Since the multiple $M_2$ has similar velocity as the primary $P_2$, the stacked energy of the multiple $M_2$ is very strong in the constant velocity stacked section. Multiple reflections shown in Figure 4 form the dominant signal at 1.0-1.3*s*.

Figure 5 shows the stacked section of Line 1. All CMP gathers were stacked by using relatively accurate primary velocity picked by semblance analysis starting at 1750 m/s, where the primary velocity is 3000 m/s around the multiple $M_2$. Comparing with Figure 4, the multiple $M_1$ and $M_2$ originally in the CMP 580-650 have disappeared almost completely in Figure 5, while the multiple $M_2$ in the CMP 650-700 were not attenuated by stacking. According to our strategy, we attenuate the targeted multiple using *f-k* filtering method rather than all multiples in the raw data**.**

Figure 6 shows the stacked section after applying the *f-k* filtering method to CMP 650-700 gathers. In comparison to Figure 5, it is obvious that there is significant attenuation of the multiples and good recovery of the primaries around the position of removed multiples. The primary $R_p$ masked by the multiples in Figure 5 is visible in Figure 6.

The difference is again large enough to exhibit in the cross-line direction. Figure 7 shows the stacked section in the cross-line direction by using relatively accurate primary velocity. Its shot records are from Line 2 in the 2-D land area. The primary is also marked by an arrow with the symbol $P_3$ and one order multiple is marked by the arrow with symbol $M_3$. The reflections of the primary $P_3$ are also from an igneous body. The strong multiple reflections generated on this igneous rock formation are clearly visible between CMP 140-230 and 1.3-1.9*s*. In contrast to the multiple $M_2$ shown in Figure 5, the energy of the residual multiple $M_3$ is relatively stronger and the multiple $M_3$ in the time domain shows a dipper angle.

Figure 8 shows the stacked section corresponding to Figure 7, where multiple $M_3$ are well suppressed by applying the *f-k* filtering to the selected CMP gathers with multiples. As multiples were removed some primary reflections masked by the multiple $M_3$ have good recovery. The stacked section in Figure 8 is easier to interpret.

### Conclusions

We have described the strategy that enables us to successfully suppress multiples for land seismic data. We also demonstrate the effectiveness of the processing strategy with field data examples. Stacking can suppress part of multiples. It not only reduces the cost of computing, but also greatly preserves the amplitudes of primaries. To remove the residual multiples in the stacked section, the *f-k* filtering method based on NMO correction gathers is simple and robust. As long as the picks of the velocity function between primaries and multiples on the velocity spectrum and the defining of the reject zone in the *f-k* domain are relatively accurate, the residual multiples will be greatly attenuated by the *f-k* filtering. In addition, the evaluation of multiples is important in the multiple attenuation processing. It is not enough to identify the multiples from primaries only by stacked sections. We also rely on velocity spectrum, constant velocity scan stacked sections to distinguish multiples from original data.


### Acknowledgements

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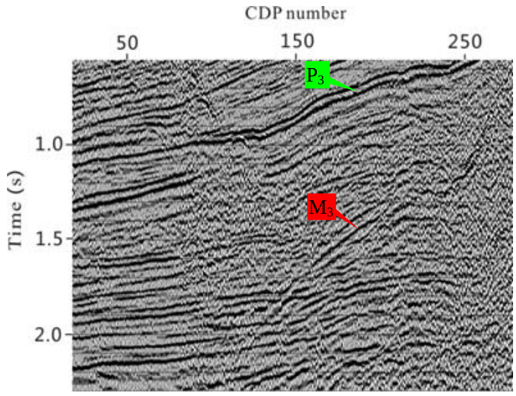


Figure 7: Stacked section of Line 2 in the cross-line direction. Two slant multiples are visible between CMP 140-230 and 1.3-1.9*s*.

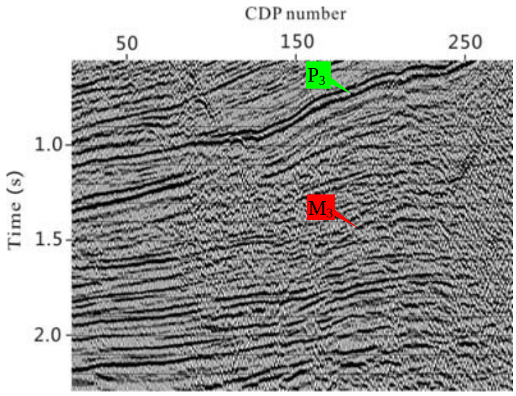


Figure 8: Stacked section corresponding to Figure 7. Multiples are eliminated well by applying *f-k* filter to CMP 140-230 gathers.

**EDITED REFERENCES**

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