Dip filtering and migration

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ABSTRACT

Dispersion effects are commonly seen in impulse responses of migration operators. These effects are due to the digitization in numerical solutions of wave propagating problems (Claerbout, 1985). Reducing the data sampling intervals can suppress them. Another approach is the use of dip-filtering. The paper will discuss the dip-filtering method. The dispersion effects can be reduced by incorporating the low-pass dip-filter into the migration operator, even when the sampling interval remains unchanged.

INTRODUCTION

The problem of frequency dispersion is strongly related to that of evanescent waves, because the dispersed high-frequency components are usually within the non-propagating (or evanescent) zone of seismic waves.

Low-pass dip-filtering can suppress the non-propagating (or evanescent) energy (Hale and Claerbout, 1983). The most commonly used dip-filtering is the pie-slice filtering in (ω, k_x, z) space (Claerbout, 1985), where ω and k_x are the Fourier duals of time t and horizontal distance x respectively. Applying the dip-filtering operator to (ω, k_x) representations of various migration schemes (usually called dispersion relations), we obtain different dip-filtered migration operators. These operators can then be transformed from space (ω, k_x) to space (t, x), or (ω, x), or (t, k_x) so that migration can be performed. These built-in dip-filter migration algorithms suppress the dispersion effects that arise during the wave field extrapolation.

DIP FILTERING

The low-pass dip filter can be represented as follows (Claerbout, 1985):

$$D(\omega,k_x) = \frac{\alpha}{\alpha + \frac{k_x^{\,2}}{-i\,\omega}}\ , \tag{1}$$

where α is the cutoff parameter, and the forward Fourier kernel is defined as $\exp(-i\,\omega t + ik_x\,x + ik_z\,z)$.

In order to determine α, let us suppose that the filter attenuates wave amplitudes by a factor of β ($\beta < 1$) at the boundary of propagating region $k_x\,v/\omega = 1$. That is,

$$\left|D(\omega,k_x)\right|_{k_x v/\omega=1} = \beta\ . \tag{2}$$

The cutoff parameter α of equation (1) can then be found as,

$$\alpha = \frac{\omega_0}{v^2\sqrt{(\frac{1}{\beta})^2 - 1}}\ , \tag{3}$$

where ω_0 is the dominant frequency of the seismic waves.

The low-pass dip-filtered output Q is related to the input P by

$$Q = D\ P\ . \tag{4}$$

MIGRATION WITH BUILT-IN DIP FILTERING

There are different kinds of migration equations, such as 15 degree in (t,x,z), 45 degree in (ω,x,x), and the linearly transformed wave equation (LITWEQ) migration (Li, 1984), etc. All of them can be given as the following general form,

$$M\ P = 0, \tag{5}$$

where P is wave field, and M is the (ω,k_x,z) representation of migration operator. For example, for the 15 degree migration method (Claerbout, 1985),

$$M = \frac{\partial}{\partial z} - \frac{ivk_x^{\,2}}{2\omega}\ . \tag{6}$$

Applying dip filter $D(\omega,k_x)$ to equation (5), we obtain the dip-filtered migration equation:

$$D\ M\ P \ = \ \left(1 + \frac{k_x}{-i\,\omega\alpha}\right)^{-1} M\ P \ = \ 0. \tag{7}$$

Transforming equation (7) back to the original coordinate system in which a migration algorithm is carried out, gives the desired dip-filtered migration equation. Some of the higher order derivative terms introduced by incorporating the low pass dip-filter into the migration equation need to be dropped before the new equation is implemented with finite differencing method.

Listed below are the low-pass dip-filtered migration equations for the 15 degree migration in the time-space domain (equation (8-1)), for the 15 degree migration in the frequency-space domain (equation (8-2)), for the 45 degree migration in the frequency-space domain (equation (8-3)), and for the LITWEQ (equation (8-4)):

$$\left[\frac{\partial^2}{\partial t\,\partial z} + \frac{v}{2}\frac{\partial^2}{\partial x^2} + \frac{1}{\alpha}\frac{\partial^3}{\partial z\,\partial x^2}\right] P \ = \ 0\ , \tag{8-1}$$

$$\left[\frac{\partial}{\partial}z - \frac{1}{i\,\omega\alpha}\,\frac{\partial^3}{\partial z\,\partial x^2} - \frac{v}{2i\,\omega}\,\frac{\partial^2}{\partial x^2}\right] P \ = \ 0\ , \tag{8-2}$$

$$\left[\frac{\partial}{\partial}z - \frac{\partial^3}{\partial z\,\partial x^2}\left(\frac{1}{i\,\alpha\omega} + \frac{v^2}{4\omega^2}\right) - \frac{v}{i\,2\omega}\,\frac{\partial^2}{\partial x^2}\right] P \ \equiv \ 0\ , \tag{8-3}$$

$$\left[\frac{\partial^2}{\partial x'^{\,2}} + \frac{2}{v}\,\frac{\partial^2}{\partial z'\,\partial t'} - \frac{2\sqrt{2}}{\alpha v^2}\,\frac{\partial^3}{\partial t'\,\partial x'^{\,2}}\right] P \ = \ 0\ . \tag{8-4}$$

The above equations can be implemented easily with finite difference method.

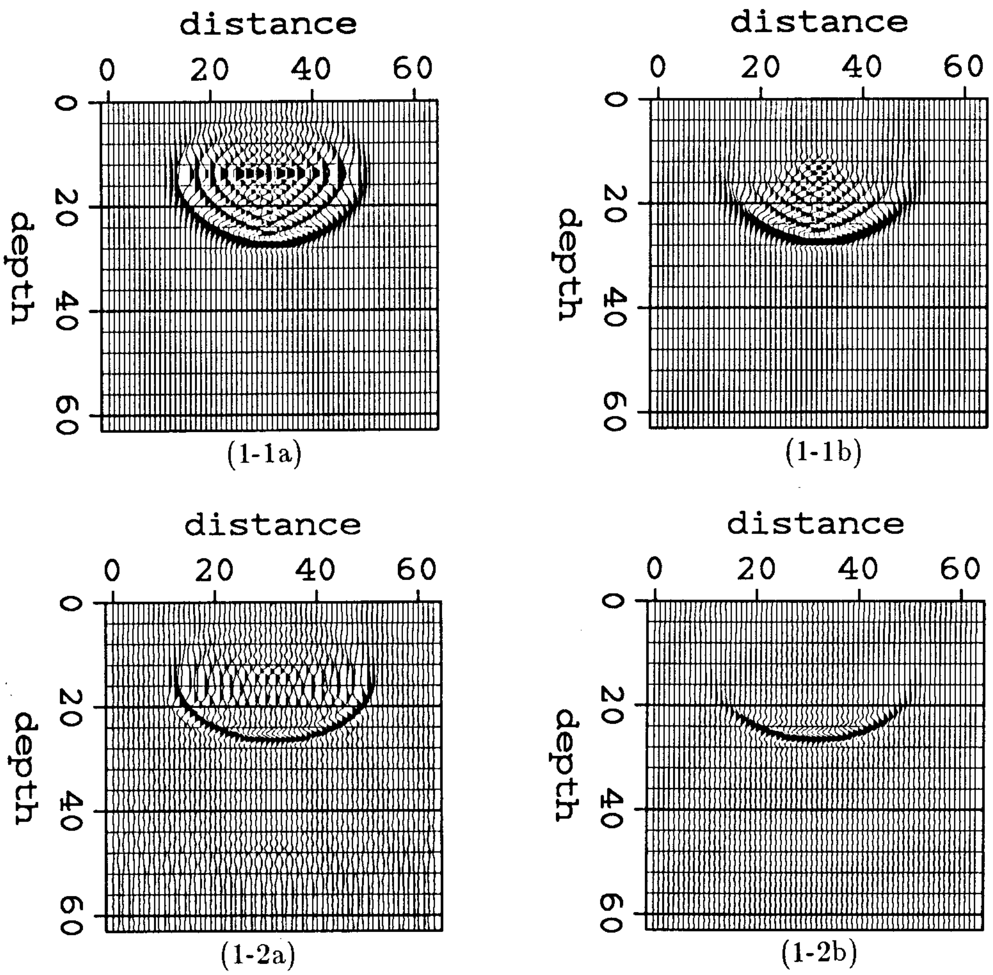


FIG. 1. Impulse responses of migration operators. (1-1a) 15 degree (t, x, z) without dip filter. (1-1b) 15 degree (t, x, z) with built-in low pass dip filter. (1-2a) 15 degree (ω, x, z) without dip filter. (1-2b) 15 degree (ω, x, z) with built-in low-pass dip filter.

Figures 1 and 2 compare the impulse responses of eight different migration operators. It is clear that the low-pass dip filter improves the results of migration very significantly. The filter greatly suppresses the dispersion effects present in Figures (1-1a), (1-2a), (2-1a) and (2-2a).

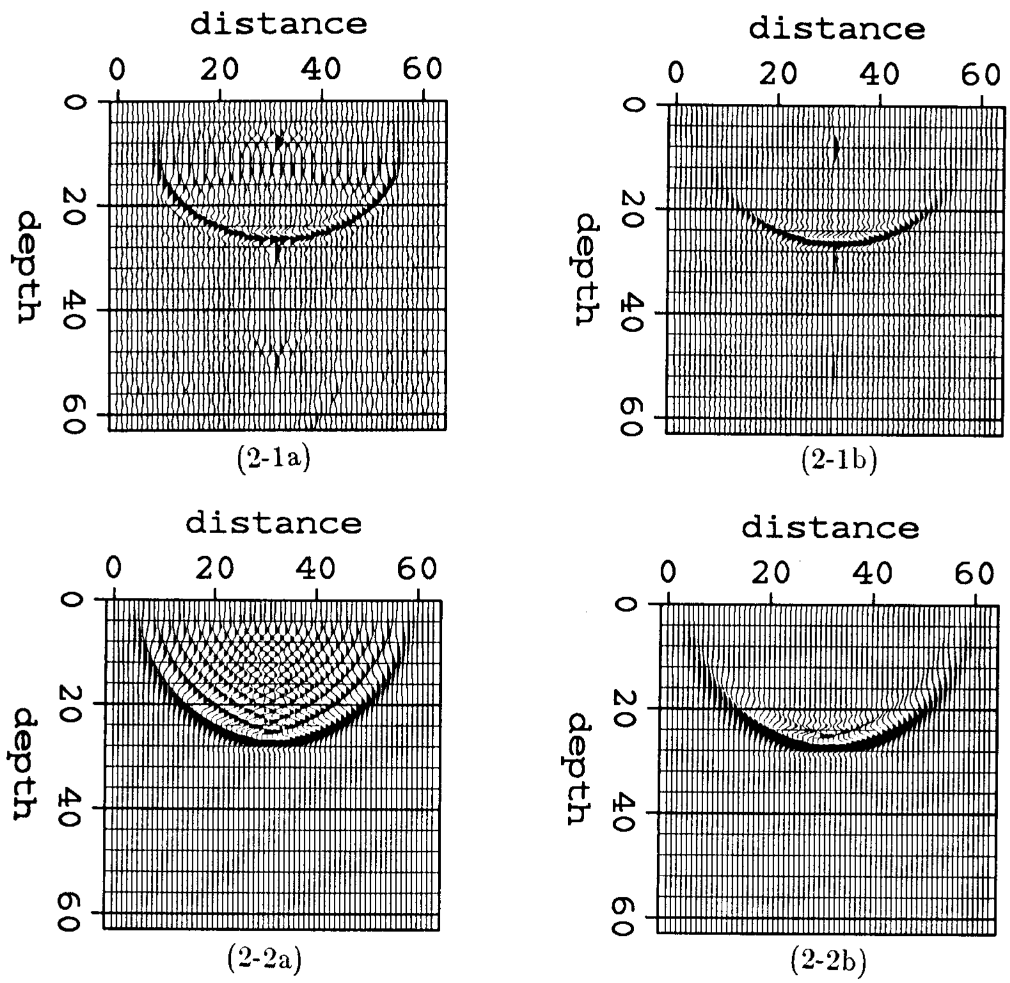
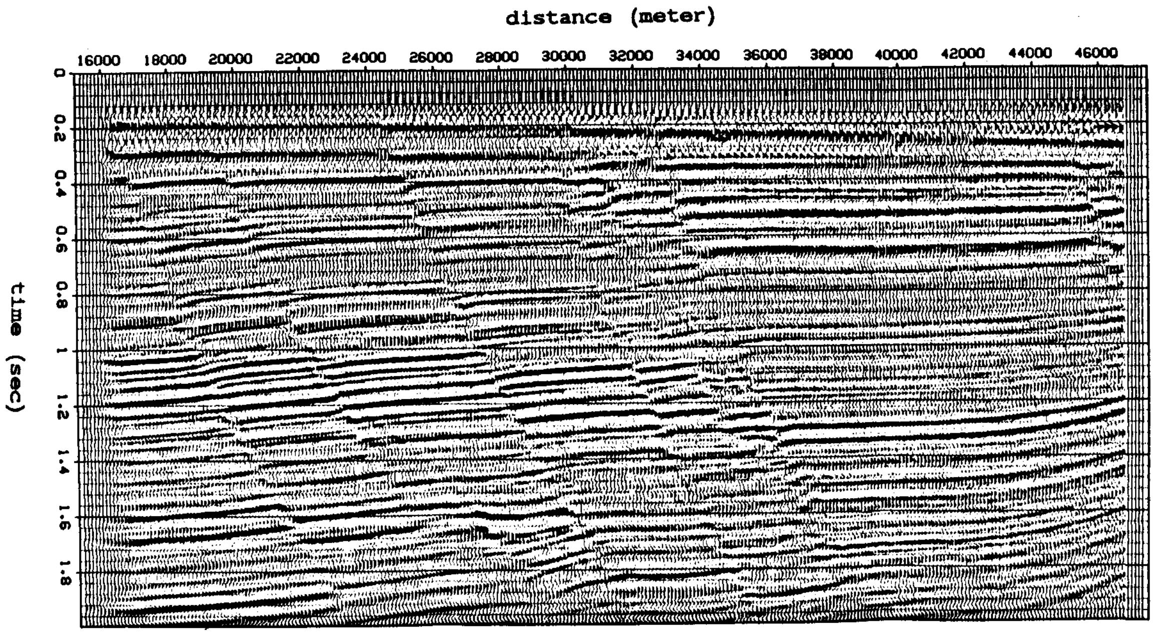
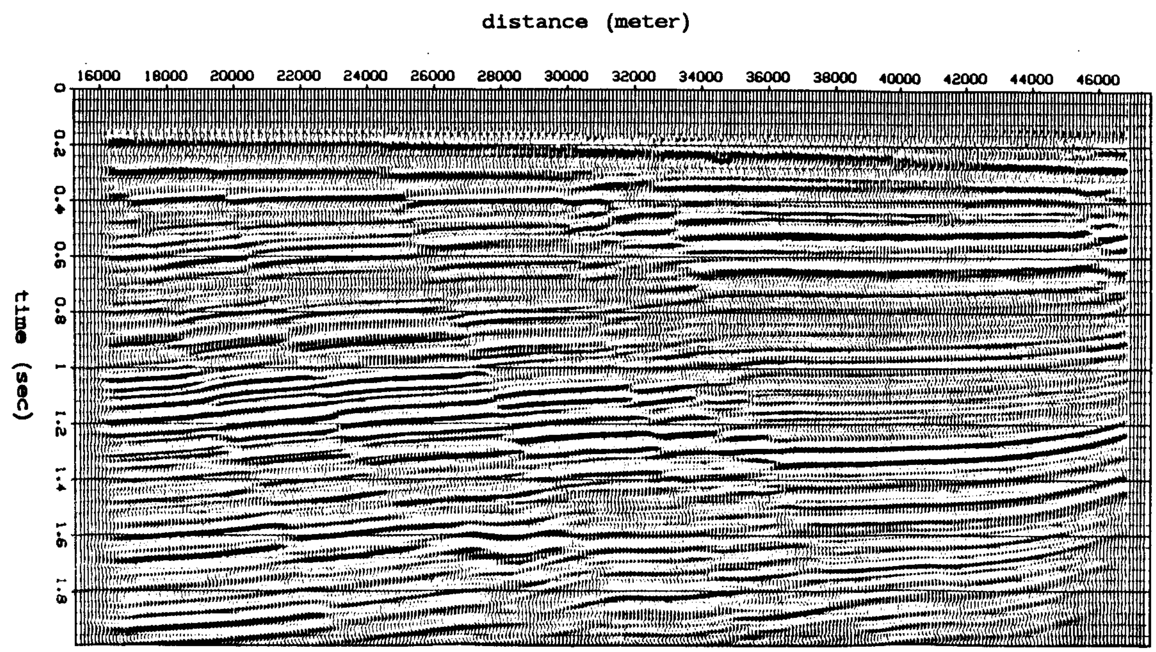


FIG. 2. Impulse responses of migration operators. (2-1a) 45 degree (ω, x, z) without dip filter. (2-1b) 45 degree (ω, x, z) with built-in low pass dip filter. (2-2a) LITWEQ (t', x', z') without dip filter. (2-2b) LITWEQ (t', x', z') with built-in low pass dip filter.

Figure 3(a) is obtained by migrating a stacked section from the Gulf of Mexico by the 15 degree time-space domain migration without dip filtering. Some noise on the background of the section shown on Figure 3(a) is generated by the numerical dispersion effects of the operator. When the low-pass dip-filtered 15 degree time-space migration operator is applied to the same dataset, the noise is eliminated, as shown in Figure 3(b).



(a)



(b)

FIG. 3. Migrated sections of a seismic line from the Gulf of Mexico. (a) Migrated by 15 degree time-space migration. (b) Migrated by 15 degree time-space migration with built-in low pass dip filter.

There is a tradeoff between the suppression of dispersion and the preservation of large angle reflections. Figure 3(b) also shows this disadvantage: some dipping events were lost when the low-pass dip filter was applied. Therefore, one must choose carefully the cutoff parameter α, so as to suppress the dispersion effects to some extent yet still preserve most of the dipping events.

CONCLUSION

Introducing the low-pass dip filter into migration operator will suppress the numerical dispersion effects. This suppression is helpful in reducing the dispersion effects and hence improving the resolution of seismic sections.

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1985

	ЯНВАРЬ	ФЕВРАЛЬ	МАРТ
Пн.	7 14 21 28	4 11 18 25	4 11 18 25
Вт.	1 8 15 22 29	5 12 19 26	5 12 19 26
Ср.	2 9 16 23 30	6 13 20 27	6 13 20 27
Чт.	3 10 17 24 31	7 14 21 28	7 14 21 28
Пт.	4 11 18 25	1 8 15 22	1 8 15 22 29
Сб.	5 12 19 26	2 9 16 23	2 9 16 23 30
Вс.	6 13 20 27	3 10 17 24	3 10 17 24 31
	АПРЕЛЬ	МАЙ	ИЮНЬ
Пн.	1 8 15 22 29	6 13 20 27	3 10 17 24
Вт.	2 9 16 23 30	7 14 21 28	4 11 18 25
Ср.	3 10 17 24	1 8 15 22 29	5 12 19 26
Чт.	4 11 18 25	2 9 16 23 30	6 13 20 27
Пт.	5 12 19 26	3 10 17 24 31	7 14 21 28
Сб.	6 13 20 27	4 11 18 25	1 8 15 22 29
Вс.	7 14 21 28	5 12 19 26	2 9 16 23 30
	ИЮЛЬ	АВГУСТ	СЕНТЯБРЬ
Пн.	1 8 15 22 29	5 12 19 26	2 9 16 23 30
Вт.	2 9 16 23 30	6 13 20 27	3 10 17 24
Ср.	3 10 17 24 31	7 14 21 28	4 11 18 25
Чт.	4 11 18 25	1 8 15 22 29	5 12 19 26
Пт.	5 12 19 26	2 9 16 23 30	6 13 20 27
Сб.	6 13 20 27	3 10 17 24 31	7 14 21 28
Вс.	7 14 21 28	4 11 18 25	1 8 15 22 29
	ОКТЯБРЬ	НОЯБРЬ	ДЕКАБРЬ
Пн.	7 14 21 28	4 11 18 25	2 9 16 23 30
Вт.	1 8 15 22 29	5 12 19 26	3 10 17 24 31
Ср.	2 9 16 23 30	6 13 20 27	4 11 18 25
Чт.	3 10 17 24 31	7 14 21 28	5 12 19 26
Пт.	4 11 18 25	1 8 15 22 29	6 13 20 27
Сб.	5 12 19 26	2 9 16 23 30	7 14 21 28
Вс.	6 13 20 27	3 10 17 24	1 8 15 22 29

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