Stanford Exploration Project, Report 105, September 5, 2000, pages 109–117

Short Note

3-D steering filters

Robert G. Clapp[1]

INTRODUCTION

In recent reports I introduced the concept of a steering filter (Clapp et al., 1997). Since then it has been used to regularize a wide variety of geophysical problems including interpolation (Crawley, 2000), multiple attenuation (Clapp and Brown, 2000, 1999), missing data problems (Clapp et al., 1997), migration (Prucha et al., 2000) , and tomography (Clapp and Biondi, 1998, 1999, 2000).

Each of these problems used a 2-D steering filter. Fomel (1999) introduced a method to construct a 3-D steering filter. Fomel formed a 3-D steering filter operator by first convolving two 2-D operators. To obtain a minimum-phase filter he performed spectral factorization for each dip component (p_x , p_y) pair in the data, significantly increasing the cost of constructing the operator. In order for the resulting filter to spread information over significant distances, a large number of filter coefficients must be used, increasing the cost of each iteration.

In this paper I present an alternative construction method. I show how a 3-D steering filter can be produced by cascading two 2-D steering filters. The cascaded approach does not provide as accurate a dip discrimination as that in Fomel's approach but it does not require the expensive spectral factorization, and the resulting filters are much smaller and less expensive to apply. I show how this method can accurately characterize a large range of dips and that it is accurate enough for a wide class of applications. In addition, I apply it to a simple synthetic missing data problem with very encouraging results.

METHODOLOGY

2-D steering filter

In 2-D we build our steering filters by creating a series of dip annihilation filters that that destroy a given slope p_{xz} in a $x - z$ plane. Further, we would like to control the bandwidth response of filters oriented at different slopes. We can achieve both these goals by constructing a triangle centered at the appropriate slope. Every grid cell center which the triangle passes

[1]**email:** bob@sep.stanford.edu

through is assigned a negative value proportional to the height of the triangle at that location,

$$f(\text{lag}) = -\frac{a\left(\frac{w}{2} - |\text{lag}| - p\right)}{\frac{w}{2}\sum_{\text{lag}} f(\text{lag})}, \tag{1}$$

where:

$f(\text{lag})$ is the filter coefficient at a given lag (for lags where $f(\text{lag}) < 0$)

a is the amplitude of the filter (ranging from 0 to 1)

w is the width of the triangle

p is the slope.

The wider the triangle base, the less *anisotropic* our smoothing filter becomes. By increasing or decreasing a, we can increase or decrease the *range* over which the smoothing filter operates.

3-D extension

A 3-D dip annihilation filter can be approximated by cascading two perpendicular 2-D filters, one oriented in the $x-z$ plane and the other oriented in the $y-z$ plane. We can write this new filter as

$$\mathbf{A_{3d}^{-1}} = \mathbf{A_x^{-1} A_y^{-1}}, \tag{2}$$

where $\mathbf{A_{3d}^{-1}}$ is our inverse 3-D steering filter operator, $\mathbf{A_x^{-1}}$ is an inverse steering filter oriented in the x-direction, and $\mathbf{A_y^{-1}}$ is an inverse y-direction steering filter.

The construction of two 2-D filters allows for a large degree of freedom in filter construction. The method can deal with a range of spatial dips with little variation in bandwidth response, Figure 1. In addition we can vary the *range* over which the smoother operates, both isotropically (Figure 2) and to some degree anisotropically (Figure 3).

MISSING DATA EXAMPLE

The missing data problem is probably the simplest to understand and interpret. Following the methodology of Claerbout (1999) we solve the problem in its preconditioned form using

$$\begin{aligned} \mathbf{d} &\approx \mathbf{J A^{-1} p} \\ \mathbf{0} &\approx \mathbf{I p}, \end{aligned} \tag{3}$$

where:

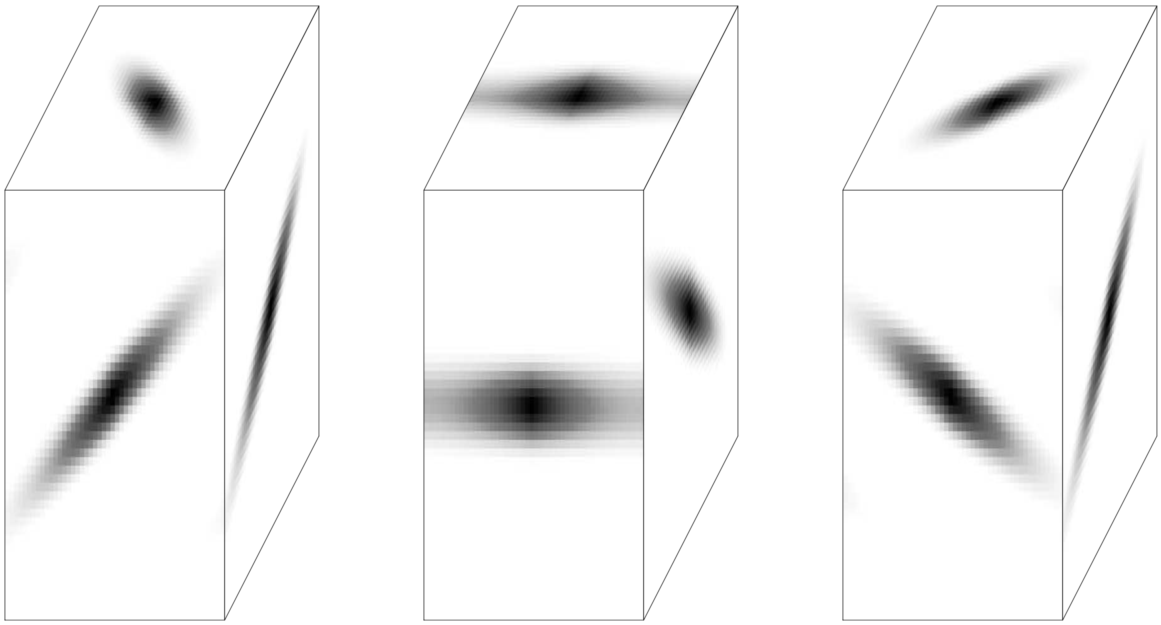

Figure 1: An example of filter behavior at different dip angles. Note how the bandwidth response is approximately the same in all panels. bob2-angles [ER]

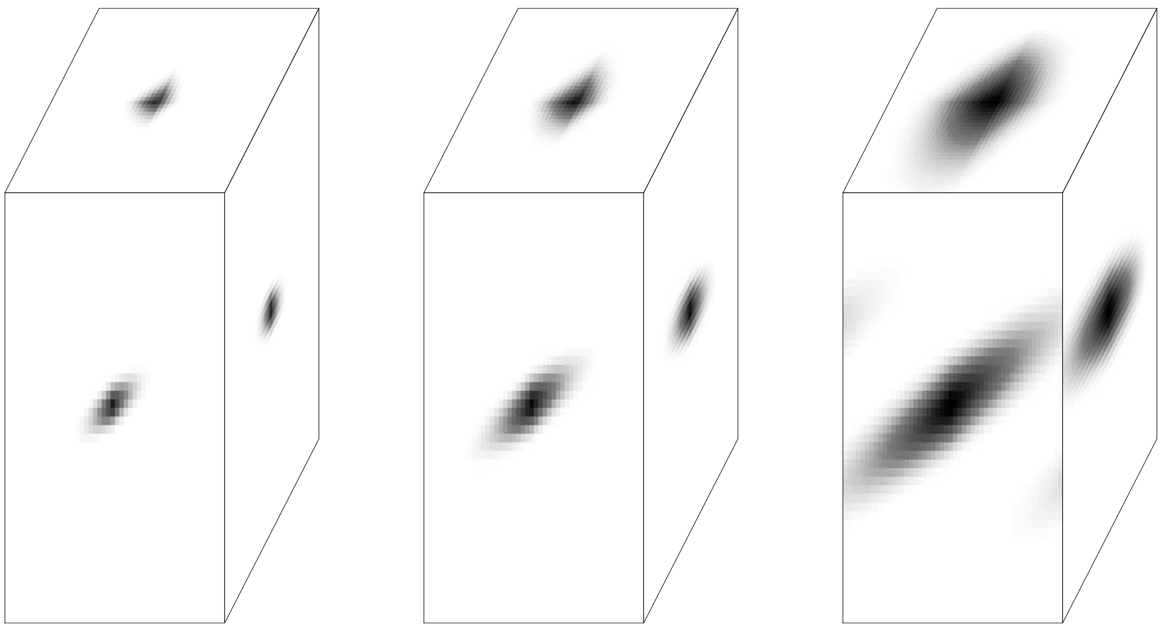

Figure 2: By changing what the non-zero lag coefficients sum to the area over which the filter acts can be drastically altered. bob2-iso [ER]

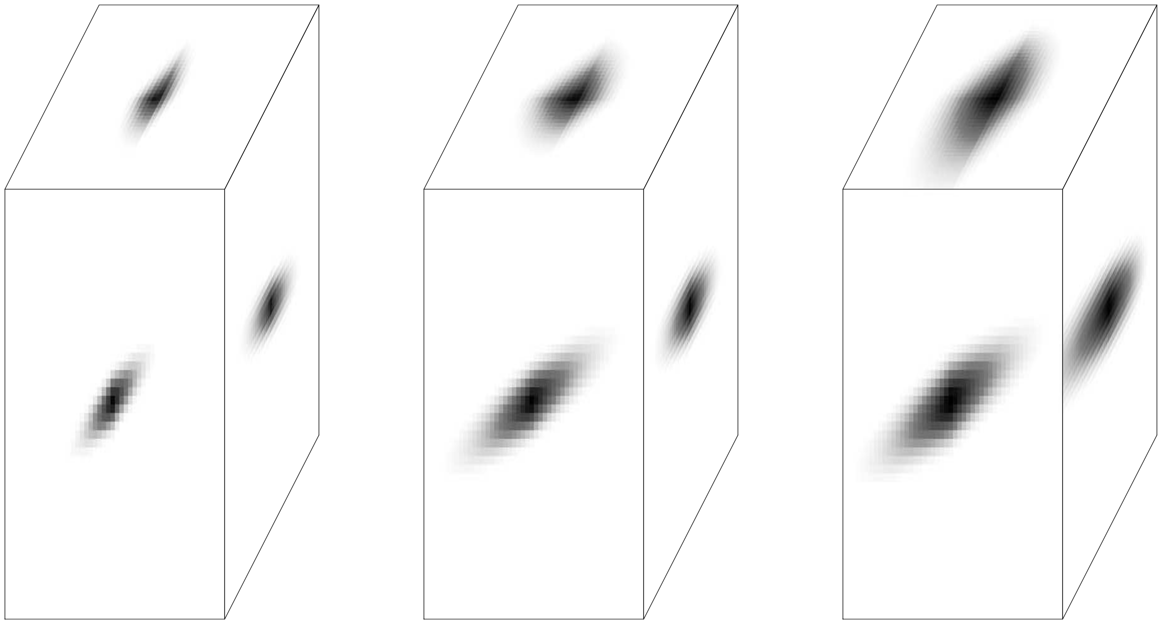

Figure 3: The cascading of two filters allows us to create a filter that acts over different range in the x and y direction. bob2-aniso [ER]

d is a binned version of our known points

J is the known data selector

$\mathbf{A^{-1}}$ is the preconditioning operator (in this case equation (2))

p is our preconditioned variable.

To test the interpolation I used the 'qdome' dataset (Figure 4). I began by zeroing 95% of the original data (Figure 5) in vertical sections (somewhat simulating well logs). To obtain the p_{xz} and p_{yz} dip field I used the same methodology as Fomel (1999) estimating the dip field from the known data using a non-linear estimation scheme. Using the calculated dip field I then constructed $\mathbf{A_x}$ and $\mathbf{A_y}$ and iterated 50 times using fitting goals (4). Figure 6 shows the resulting interpolation. In general the 3-D steering filters did an excellent job recovering the original data. There is some lower frequency behavior around the fault boundaries but the fault position is still quite obvious.

CONCLUSIONS

I demonstrated how to construct a 3-D steering filter operator by cascading two 2-D steering filters. The method proved successful in characterizing a wide variety of dips and interpolating a sparse 3-D dataset.

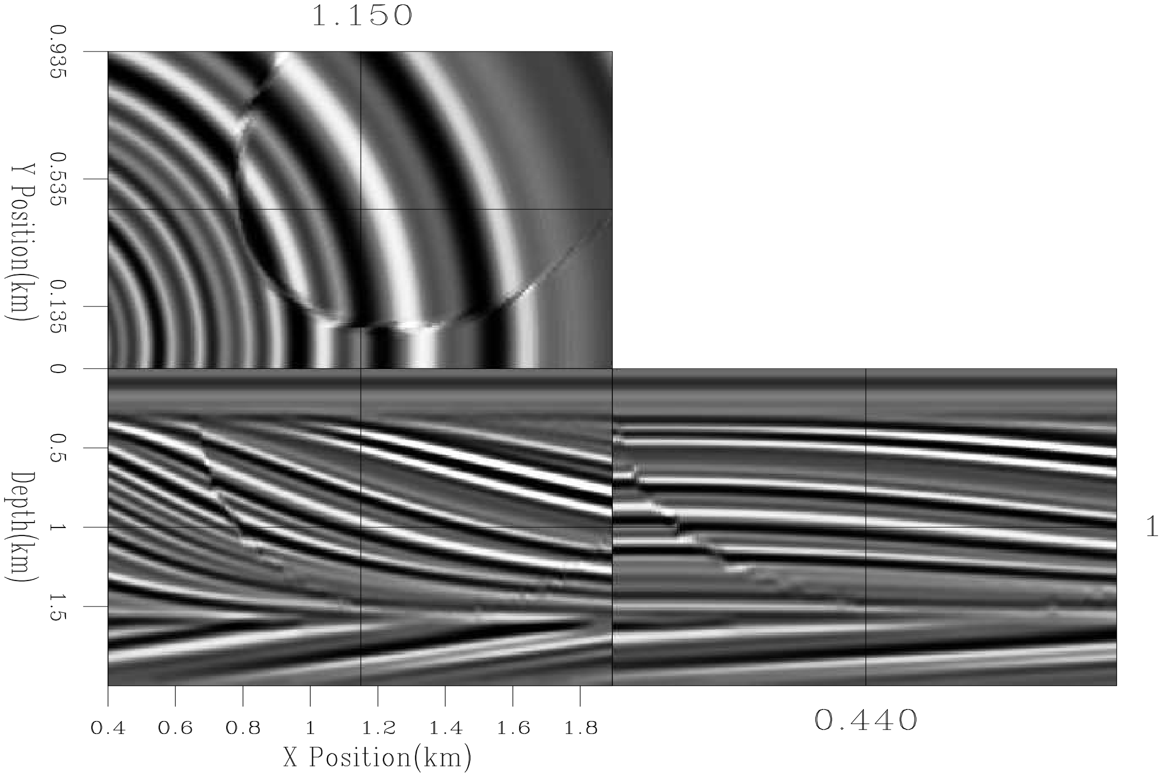

Figure 4: 3-D qdome model from Claerbout (1999). bob2-mod-orig [CR]

REFERENCES

Claerbout, J., 1999, Geophysical estimation by example: Environmental soundings image enhancement: Stanford Exploration Project, http://sepwww.stanford.edu/sep/prof/.

Clapp, R. G., and Biondi, B. L., 1998, Regularizing time tomography with steering filters: SEP–**97**, 137–146.

Clapp, R. G., and Biondi, B., 1999, Preconditioning tau tomography with geologic constraints: SEP–**100**, 35–50.

Clapp, R. G., and Biondi, B. L., 2000, Tau tomography with steering filters: 2-D field data example: SEP–**103**, 1–19.

Clapp, R. G., and Brown, M., 1999, Applying sep's latest tricks to the multiple suppression problem: SEP–**102**, 91–100.

Clapp, R. G., and Brown, M., 2000, $(t-x)$ domain, pattern-based multiple separation: SEP–**103**, 201–210.

Clapp, R. G., Fomel, S., and Claerbout, J., 1997, Solution steering with space-variant filters: SEP–**95**, 27–42.

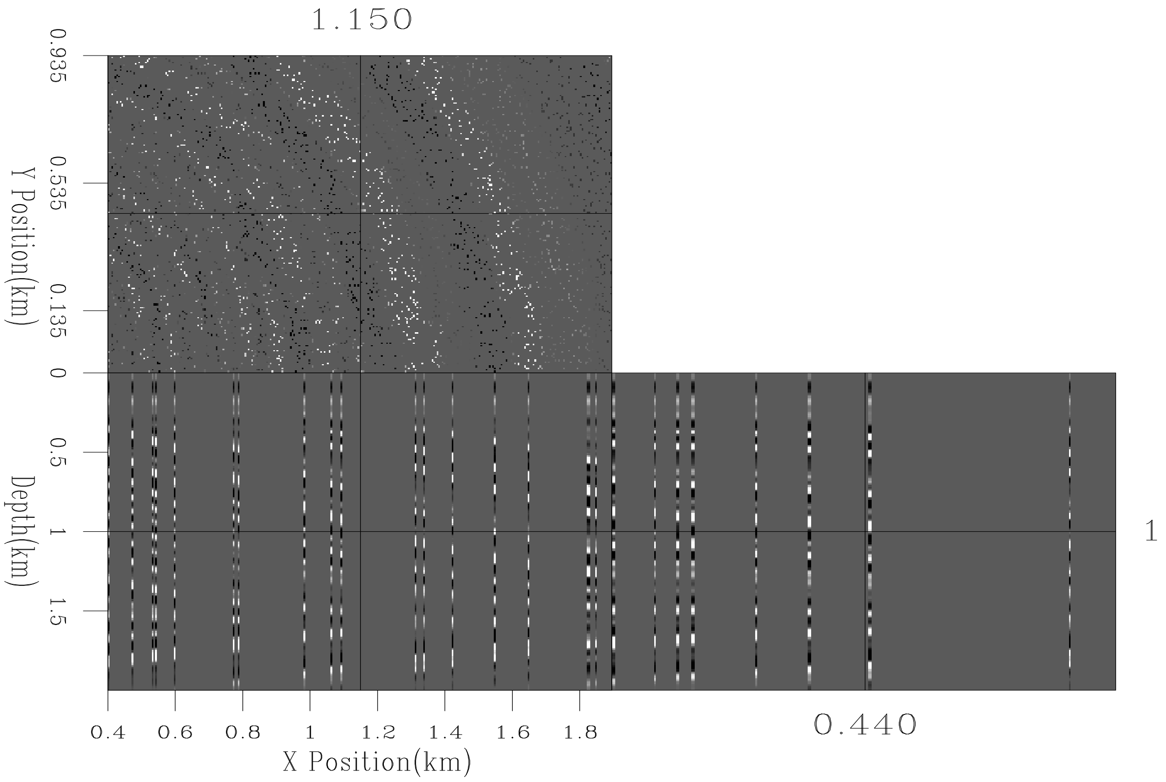

Figure 5: Decimated qdome model. 95% of the original traces (Figure 4) have been thrown away. bob2-mod-in [CR,M]

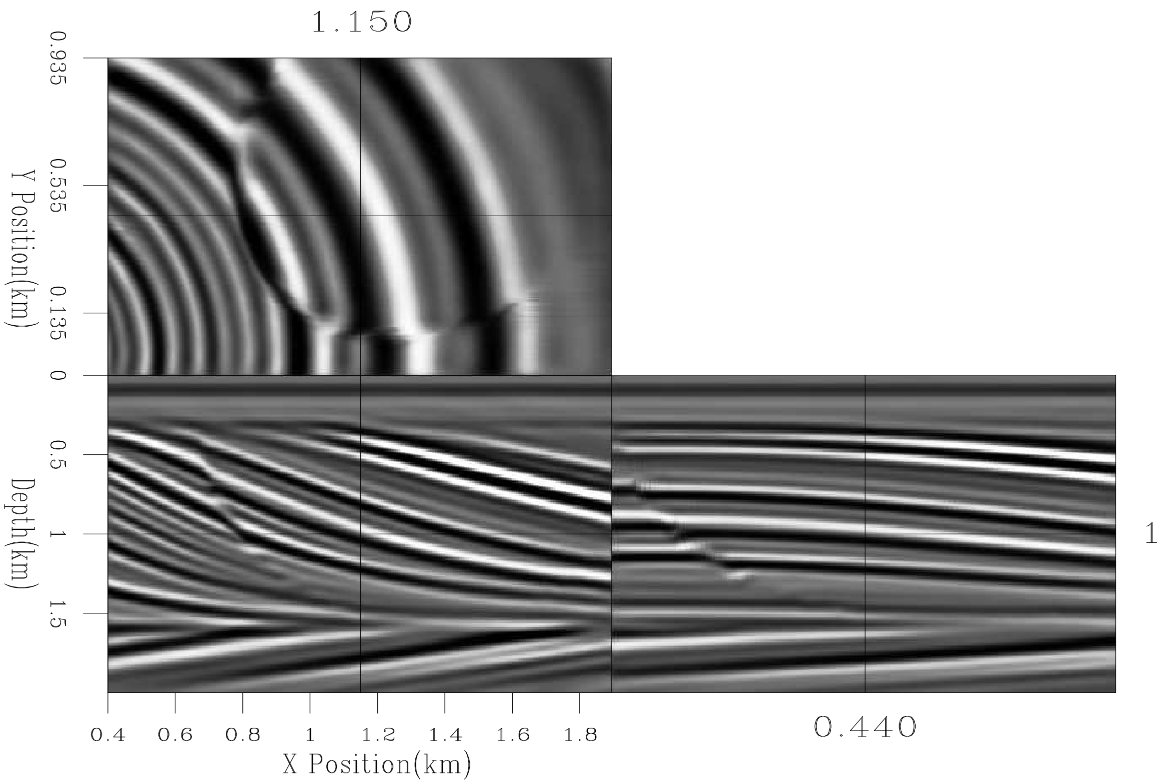

Figure 6: Interpolated qdome model starting from the data in Figure 5. Note how it is a little lower frequency than Figure 4 but otherwise a near perfect interpolation result. bob2-mod-out [CR,M]

Crawley, S., 2000, Seismic trace interpolation with nonstationary prediction-error filters: SEP–**104**.

Fomel, S., 1999, Plane wave prediction in 3-D: SEP–**102**, 101–110.

Prucha, M. L., Clapp, R. G., and Biondi, B., 2000, Seismic image regularization in the reflection angle domain: SEP–**103**, 109–119.