CHAPTER 1

Introduction

1.1 OVERVIEW

Averaging data that arise from identical or closely related physical experiments is a nearly universal method of improving signal and suppressing noise. A good example in seismic exploration is the vertical stack. A seismic source is activated several times at each shot point; the resulting reflection signals are then summed to produce the field record. The CDP method employs a horizontal stack: all traces with the same shot-to-receiver midpoint are combined.

Two sophisticated uses of data averaging in everyday seismic data processing are deconvolution and residual statics estimation. Deconvolution recognizes that the raw seismic record is blurred and ringy due to extended source duration, electronic recording filters, and subsurface reverberations. It attempts to estimate and remove these masking effects with temporal averaging. In contrast, we estimate residual static corrections through spatial averaging of apparent trace-to-trace time shifts. Each time shift is taken to be the sum of effects tied to the relative shot, receiver, and midpoint coordinates of the traces. This model is termed "surface-consistent" because the shot, receiver, and midpoint coordinates describe locations on the surface of the earth.

Spatially-consistent effects do appear in the deconvolution problem. For example, the same shot waveform is expected for all traces within a shot record. To improve estimates of this wavelet, the power spectra of traces in a common-shot record are sometimes averaged to estimate the power spectrum of the shot waveform. This assumes that all other filtering effects are uncorrelated between the traces and will cancel in the sum.

Experience with residual statics, which uses several averaging iterations covering many additional traces, prompted several workers to reject this assumption. (Morley, 1982; Pollet, Lowrie and Matthews, 1982; Morley and Claerbout, 1983; Sword, 1983.) Motivated by the improved data quality customarily obtained with surface-consistent processing for residual statics, they derived parallel ways to incorporate surface-consistent spatial averaging into deconvolution. These geophysicists first mapped the deconvolution problem into the residual statics framework by transformation into the log-frequency (quefrency) domain. Next, they decomposed the transformed data into surface-consistent components. Finally, they inverse-transformed selected components to produce corresponding time-domain estimates.

Morley and Claerbout also applied surface-consistent trace decomposition to marine data to improve prediction and suppression of reverberations within the water column. They reasoned that with a large velocity jump at the seafloor, a shallow water layer acts much like a low-velocity weathered layer – raypaths for primary subsurface reflections are nearly vertical at the surface. In this setting, a surface-consistent decomposition is equally a "seafloor-consistent" decomposition with filtering effects tied to the seafloor locations at which downgoing shot energy enters the seafloor and upcoming energy leaves the seafloor. This improved upon previous multiple prediction models by accommodating different reverberations at the shot and receiver locations.

A more powerful application of the surface-consistent model has been the suppression of pegleg multiple trains. The data are projected, using wave extrapolation, to a new recording surface coinciding with the seafloor where a surface-consistent adaptation of Noah's deconvolution (Claerbout, 1974; Riley, 1974) is applied to suppress water-path multiples. The deconvolved data are then extrapolated back to the sea surface to complete the process. The underlying ideas go back to Backus (1959). Prominent early work on seafloor-consistent methods includes Riley (1975), Estevez (1977), and Morley (1982).

Loewenthal, Lu, Roberson, and Sherwood (1974) gave another view of seafloor-consistent deconvolution, later applied to field data by Bernth and Sonneland (1983) and Berryhill and Kim (1986). In this approach, acoustic wave propagation in the water layer is used to add seafloor bounces to recorded seismic data in order to emulate multiple generation. Comparing the predicted multiples to the data, an adaptive subtraction process suppresses those events that match the multiple model. Seafloor-consistency is built into the process by specification of the seafloor topography from which acoustic energy is reflected.

1.2 DEVELOPMENT

In this thesis I tackle two difficulties that arise in surface-consistent applications of deconvolution, one algorithmic and one conceptual. Chapter 2 deals with the former, Chapter 3 with the latter.

The algorithmic problem is that log-frequency methods for surface-consistent decomposition are simple to understand and easy to use, but yield at best uncertain data quality. This is why the various log-frequency methods have to date been employed only infrequently and with limited success. The basic idea of spatial averaging is sound, it is the implementation that has gone wrong.

The conceptual problem is that the surface-consistent model lumps together filtering effects due to surface conditions such as recording filters with those due to near-surface conditions such as reverberation between the free surface and the water table. For marine data these independent effects separate both temporally and spatially as the seafloor depth increases or the seafloor topography roughens. In the applications described above, these effects are not properly separated and modeled. Either the surface effects are lumped into the seafloor reflector by specifying a different reflection character depending upon whether a shot or a receiver is above a given seafloor location, or the character of the seafloor is lumped into the surface effects by adaptive fitting of modeled data to the recorded data.

In Chapter 2, I develop a method for surface-consistent deconvolution that avoids the log-frequency transformation and treats the deconvolution problem in its conventional setting of time and space inverse-filtering. My deconvolution filters are computed as approximate solutions to a large, sparse, least-squares system. The problem turns out to be quite well-conditioned; useful solutions are obtained in a few iterations, with each iteration equivalent in cost to performing a single-trace deconvolution of the data.

In Chapter 3, I address a basic flaw in applying the surface-consistent model to the suppression of deep-water pegleg multiples. By separating shot and receiver effects, the surface-consistent model produces two descriptions of the seafloor: one when the source is above it and one when the receiver is above it. These filters are supposed to describe how waves are reflected from the seafloor; this is a physical response that is independent of the location or even existence of any equipment for seismic exploration. Recognizing this, I formulate a model of marine multiple suppression that is truly seafloor-consistent. In this new model, the seafloor is seen as a spatially varying reflection filter. I then adapt the nonlinear least-squares techniques earlier applied to surface-consistent prediction-error filtering to estimate these seafloor-consistent filters for a marine line from the Barents Sea. This results in a marked improvement in pegleg multiple suppression compared to both surface-consistent processing and conventional techniques for multiple removal.