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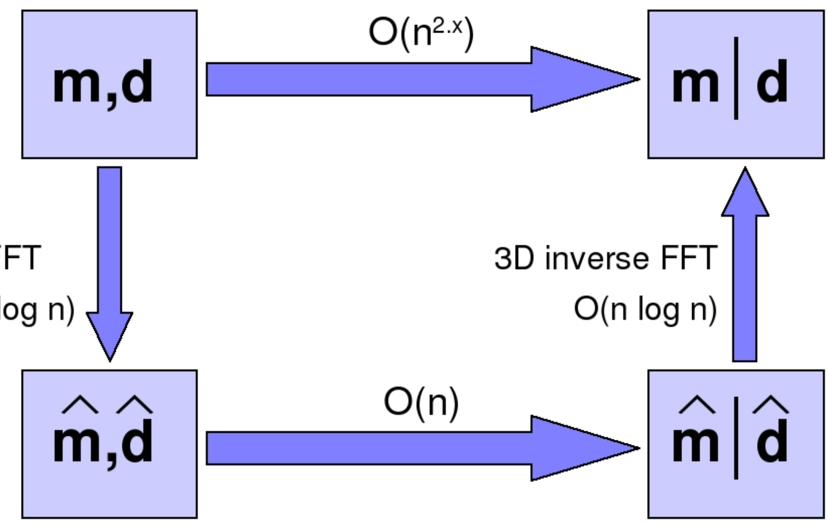
Note

CRAVA User Manual version 0.9.9



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Abstract

CRAVA is a simple inversion tool, particularly suited for quick generation of first pass inversions and facies probabilities for use in geological modeling. This manual describes the theory behind, the main implementation structure, and the actual use of this program.

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1 Model

1.1 Introduction

Seismic inversion has traditionally been treated as a deterministic problem. However, there are several uncertain aspects: There is noise in the seismic amplitude data, and the frequency resolution is limited. This means that neither high nor low frequencies can be resolved from the seismic amplitude data alone. Using a geostatistical approach to the problem of seismic inversion, the uncertainty may be treated in a consistent and robust way.

The CRAVA program uses the Bayesian linearised AVO inversion method of Buland et al. (2003) to take the uncertainty in seismic amplitude data into account. Since we only use amplitude data, we will from here on use the term seismic data for these. The seismic data are described using multi-normal distributions, and modelled as the seismic response of the earth model plus an error term. The earth model and error term are modelled as multi-normal distributions in which spatial coupling is imposed by correlation functions. Using a Bayesian setting, prior models for the earth and error terms are set up based on prior knowledge obtained from well logs, and the process of seismic inversion is reduced to that of finding a posterior distribution for the earth given the seismic data. The linearised relationship between the model parameters and the AVO data, makes it possible to obtain the posterior distribution analytically.

The posterior distribution for earth model parameters V_p (pressure-wave velocity), V_s (shear-wave velocity), and ρ (density), gives a laterally consistent seismic inversion. The lateral correlation follows the stratigraphy of the inversion interval by following the top and base of the inversion volume. As a consequence of the spatial coupling, the solution in each location depends on the solutions in all other locations. From the posterior distribution the best estimate of the model parameters and a corresponding uncertainty can be extracted. Moreover, since the distribution is normal, kriging can be used to match the well data, and the posterior covariance can be computed. This spreads full frequency information in an area around the wells. Full frequency realizations can be generated by sampling from the posterior distribution. A set of such realizations represents the uncertainty of the inversion.

1.2 AVO

Amplitude versus offset (AVO) inversion can be used to extract information about the elastic subsurface parameters from the angle dependency in the reflectivity, see e.g., Buland et al. (1996); Hampson and Russell (1990); Lörtzer and Berkhout (1993); Pan et al. (1994). In practice, and especially for 3-D surveys, linearised AVO inversion is attractive since it can be performed with use of moderate computer resources. Prior to a linearised AVO inversion, the seismic data must be processed to remove nonlinear relations between the model parameters and the seismic response. Important steps in the processing are the removal of the moveout, multiples, and the effects of geometrical spreading and absorption. The seismic data should be prestack migrated, such that dip related effects are removed. After prestack migration, it is reasonable to assume that each single bin-gather can be regarded as the response of a local 1-D earth model. The benefits of prestack migration before AVO analysis are discussed in Brown (1992); Buland and Landrø (2001); Mosher et al. (1996). It is further assumed that wave mode conversions, interbed multiples and anisotropy effects can be neglected after processing. Finally, the prestack gathers must be transformed from offsets to reflection angles.

1.3 Seismic model

The seismic response of an isotropic, elastic medium is completely described by the three material parameters $\{V_p(\mathbf{x},t), V_s(\mathbf{x},t), \rho(\mathbf{x},t)\}$, where the vector $\mathbf{x}$ gives the lateral position (x,y), and t is the vertical seismic travel time.

The weak contrast approximation by Aki and Richards (1980), relates the seismic reflection coefficients $c(\mathbf{x},t,\theta)$ to the elastic medium, and is a linearisation of the Zoeppritz equations. A continuous version of this approximation is given by Stolt and Weglein (1985):

$$\begin{aligned} c(\mathbf{x},t,\theta) = {} & a_{Vp}(\theta)\frac{\partial}{\partial t}\ln V_p(\mathbf{x},t) \\ & + a_{Vs}(\mathbf{x},t,\theta)\frac{\partial}{\partial t}\ln V_s(\mathbf{x},t) \\ & + a_{\rho}(\mathbf{x},t,\theta)\frac{\partial}{\partial t}\ln \rho(\mathbf{x},t), \end{aligned} \tag{1.1}$$

where θ is the PP reflection angle, and

$$\begin{aligned} a_{Vp}(\theta) &= \frac{1}{2}\left(1+\tan^2\theta\right), \\ a_{Vs}(\mathbf{x},t,\theta) &= -4\frac{V_s^2(\mathbf{x},t)}{V_p^2(\mathbf{x},t)}\sin^2\theta, \\ a_{\rho}(\mathbf{x},t,\theta) &= \frac{1}{2}\left(1-4\frac{V_s^2(\mathbf{x},t)}{V_p^2(\mathbf{x},t)}\sin^2\theta\right) \end{aligned} \tag{1.2}$$

for PP reflections, and

$$\begin{aligned} a_{Vp}(\theta) &= 0 \\ a_{Vs}(\mathbf{x},t,\theta) &= 2\frac{\sin\theta}{\cos\phi}\left(\frac{V_s^2(\mathbf{x},t)}{V_p^2(\mathbf{x},t)}\sin^2\theta-\frac{V_s(\mathbf{x},t)}{V_p(\mathbf{x},t)}\cos\theta\cos\phi\right), \\ a_{\rho}(\mathbf{x},t,\theta) &= \frac{\sin\theta}{\cos\phi}\left(-\frac{1}{2}+\frac{V_s^2(\mathbf{x},t)}{V_p^2(\mathbf{x},t)}\sin^2\theta+\frac{V_s(\mathbf{x},t)}{V_p(\mathbf{x},t)}\cos\theta\cos\phi\right), \end{aligned} \tag{1.3}$$

for PS reflections. Here, ϕ is the PS reflection angle, given by$\sin\phi = V_s/V_p\sin\theta$. These equations are linearised by replacing the ratio $V_s(\mathbf{x},t)/V_p(\mathbf{x},t)$ with a constant value $\bar{V}_p/\bar{V}_s$ when computing the coefficients.

The seismic data are represented by the convolutional model

$$d_{obs}(\mathbf{x},t,\theta) = \int w(\tau,\theta)\,c(\mathbf{x},t-\tau,\theta)\,d\tau + e(\mathbf{x},t,\theta), \tag{1.4}$$

where w is the wavelet, and e is an angle and location dependent error term. The part before the error term is the synthetic seismic. The wavelet can be angle dependent, but independent of the lateral position $\mathbf{x}$. The wavelet is assumed to be stationary within a limited target window.

The signal-to-noise ratio is defined as the ratio of the energy of the data to the energy of the noise in Equation 1.4, that is,

$$S/N = \left(\|w*c\|^2+\|e\|^2\right)/\|e\|^2, \tag{1.5}$$

where the operator * denotes the convolution. Since the error is independent of the synthetic seismic, the energy form the synthetic seismic and the noise can simply be added. Note that this is the definition of the S/N ratio we use here, another version does not include the noise energy in the enumerator.

1.3.1 Convolution with 3D wavelet

The seismic data can alternatively be represented as a convoution in three dimension

$$d_{obs}(\mathbf{x}, t, \theta) = \int w(\mathbf{x}, \tau, \theta)\, c(\mathbf{x} - \chi, t - \tau, \theta)\, d\chi d\tau + e(\mathbf{x}, t, \theta), \tag{1.6}$$

where w is a 3D wavelet. This wavelet is parametrized in the Fourier domain in terms of the spatial frequencies $\mathbf{k} = (k_x, k_y, k_z)$. For a more physical interpretation of the wavelet the parametrization is in spherical coordinates. For a point P this is given by

$$k_x = r\cos(\phi)\sin(\psi),\ k_y = r\sin(\phi)\sin(\psi),\ k_z = r\cos(\psi), \tag{1.7}$$

where r is the radial distance from origo to P, ϕ is the azimuth angle between the line from origo to P projected into the (k_x, k_y)-plane and the k_x-axis and ψ is the dip angle defined as the inclination angle between the line from origo to P and the upward pointing k_z-axis. ϕ varies between $0°$ and $360°$ while ψ varies between $0°$ and $90°$ implying that only upwards scattering reflections are considered, and not turning waves.

The model for the 3D wavelet is

$$\tilde{w}(r, \phi, \psi; \theta) = \alpha_1(\phi, \psi; \theta)\tilde{\alpha}_2(\frac{rV_0}{2\cos\theta}, \phi, \psi; \theta)\tilde{w}_0\left(\frac{rV_0}{2\cos\theta}; theta\right), \tag{1.8}$$

where the tilde denotes Fourier transform, $\tilde{w}_0(\omega; \theta)$ is the 1D pulse and functions $\tilde{\alpha}_1(\phi, \psi; \theta)$ and $\tilde{\alpha}_2(\omega, \phi, \psi; \theta) = \exp\{-\pi|\omega|H(\phi, \psi; \theta)\}$ are frequency independent and frequency dependent processing factors respectively, and the temporal frequency ω is given by $\omega = \frac{V_0 r}{2\cos\theta}$ where V_0 is the average velocity for the region of interest and $\cos\theta$ represents a stretch factor due to reflection angle.

1.4 Statistical model

The elastic parameters $V_p(\mathbf{x}, t)$, $V_s(\mathbf{x}, t)$, and $\rho(\mathbf{x}, t)$ are assumed to be log-normal random fields. This means that the distribution $\mathbf{m}(\mathbf{x}, t) = [\ln V_p(\mathbf{x}, t), \ln V_s(\mathbf{x}, t), \ln \rho(\mathbf{x}, t)]^T$ is multi-normal or multi-Gaussian, that is,

$$\mathbf{m}(\mathbf{x}, t) \sim \mathcal{N}\left(\boldsymbol{\mu}_m(\mathbf{x}, t), \boldsymbol{\Sigma}_m(\mathbf{x}_1, t_1; \mathbf{x}_2, t_2)\right), \tag{1.9}$$

where $\boldsymbol{\mu}_m(\mathbf{x}, t)$ are the expectations of $\mathbf{m}(\mathbf{x}, t)$ and $\boldsymbol{\Sigma}_m(\mathbf{x}_1, t_1; \mathbf{x}_2, t_2)$ gives the covariance structure. We assume that the covariance function is stationary and homogeneous (i.e., translationally invariant), and can be factorised as

$$\boldsymbol{\Sigma}_m(\mathbf{x}_1, t_1; \mathbf{x}_2, t_2) = \boldsymbol{\Sigma}_{0,m}\, \nu_m(\xi)\nu_m(\tau), \tag{1.10}$$

where $\nu_m(\xi)$ and $\nu_m(\tau)$ are correlation functions depending on the lateral and temporal distances $\xi = \|\mathbf{x}_2 - \mathbf{x}_1\|$ and $\tau = |t_2 - t_1|$, respectively, and $\boldsymbol{\Sigma}_{0,m}$ is a 3×3 covariance matrix having the variances of $\ln V_p$, $\ln V_s$ and $\ln \rho$ as diagonal elements and their covariances off the diagonal. Any valid covariance structures may be used.

If we let $\mathbf{m}$ and $\mathbf{d}_{obs}$ be discrete representations of $\mathbf{m}(\mathbf{x}, t)$ and $d_{obs}(\mathbf{x}, t, \theta)$ in a time interval, equation (1.4) may be written in matrix notation as

$$\begin{aligned} \mathbf{d}_{obs} &= \mathbf{WADm} + \mathbf{e} && (1.11) \\ &= \mathbf{Gm} + \mathbf{e} && (1.12) \end{aligned}$$

where $\mathbf{W}$ is the matrix representation of the wavelets, $\mathbf{A}$ is a matrix encompassing discrete representations of the coefficients a_{Vp}, a_{Vs}, and a_ρ, $\mathbf{D}$ is a differential matrix and $\mathbf{G} = \mathbf{WAD}$. The error matrix $\mathbf{e}$ is a time discretization of the error vector $\mathbf{e}(\mathbf{x},t) = [e(\mathbf{x},t,\theta_1),\ldots,e(\mathbf{x},t,\theta_{n_\theta})]^T$ and is assumed to be zero-mean coloured Gaussian noise, that is,

$$\mathbf{e}(\mathbf{x},t) \sim \mathcal{N}_{n_\theta}\left(\mathbf{0}, \boldsymbol{\Sigma}_e(\mathbf{x}_1,t_1;\mathbf{x}_2,t_2)\right). \tag{1.13}$$

The covariance of the error vector is

$$\boldsymbol{\Sigma}_e(\mathbf{x}_1,t_1;\mathbf{x}_2,t_2) = \boldsymbol{\Sigma}_{0,e}\, \nu_e(\xi)\nu_e(\tau), \tag{1.14}$$

where $\boldsymbol{\Sigma}_{0,e}$ is an $n_\theta \times n_\theta$ covariance matrix containing the noise variances for the different reflection angles on the diagonal, and the covariances between the angles off the diagonal. Furthermore, $\nu_e(\xi)$ and $\nu_e(\tau)$ are lateral and temporal correlation functions, similar to those given for $\mathbf{m}(\mathbf{x},t)$ in equation (1.10).

Since the relationship between the reflection coefficients and the elastic parameters given in equation (1.1) is linear, and the elastic parameters are assumed Gaussian distributed, the reflection coefficients become Gaussian. Moreover, since the convolution is a linear operation and we have assumed a Gaussian error model, the seismic data given in equation (1.4) are also Gaussian distributed.

For the time-discretized seismic data $\mathbf{d}_{obs}$, this gives us the multi-normal distribution

$$\mathbf{d}_{obs} \sim \mathcal{N}_{n_d}\left(\boldsymbol{\mu}_d, \boldsymbol{\Sigma}_d\right), \tag{1.15}$$

where

$$\boldsymbol{\mu}_d = \mathbf{G}\boldsymbol{\mu}_m, \tag{1.16}$$

$$\boldsymbol{\Sigma}_d = \mathbf{G}\boldsymbol{\Sigma}_m\mathbf{G}^T + \boldsymbol{\Sigma}_e. \tag{1.17}$$

where all vectors and matrices are time-discretized.

This means that the simultaneous distribution for $\mathbf{m}$ and $\mathbf{d}_{obs}$ is Gaussian, and that the distribution for $\mathbf{m}$ given $\mathbf{d}_{obs}$ can be obtained analytically using standard theory for Gaussian distributions:

$$\boldsymbol{\mu}_{m|d_{obs}} = \boldsymbol{\mu}_m + \boldsymbol{\Sigma}_m\mathbf{G}^T\boldsymbol{\Sigma}_d^{-1}(\mathbf{d}_{obs} - \boldsymbol{\mu}_d) \tag{1.18}$$

$$\boldsymbol{\Sigma}_{m|d_{obs}} = \boldsymbol{\Sigma}_m - \boldsymbol{\Sigma}_m\mathbf{G}^T\boldsymbol{\Sigma}_d^{-1}\mathbf{G}\boldsymbol{\Sigma}_m, \tag{1.19}$$

where $\boldsymbol{\mu}_d$ is the expected observation, that is, the seismic response of $\boldsymbol{\mu}_m$, and $\boldsymbol{\Sigma}_{d,m}$ is the covariance matrix between logarithmic parameters and observations. See Buland and Omre (2003) for a detailed description on how to compute these.

The computations given in equations (1.18) and (1.19) involves the inverse of $\boldsymbol{\Sigma}_d$. Given an inversion volume with n cells, this matrix has $n_\theta^2 n^2$ elements, and for any reasonably sized volumes, inverting this matrix is forbiddingly time consuming. However, the covariance function for a homogeneously correlated spatial variable is diagonalised by a 3D Fourier transform (Christakos (1992)), and in this domain the inversion problem can be solved independently for each frequency component. This reduces the complexity of the computations dramatically, and the calculation time becomes $\mathcal{O}(n \log n)$. This is illustrated in Figure 1.1. Details can be found in Buland et al. (2003)

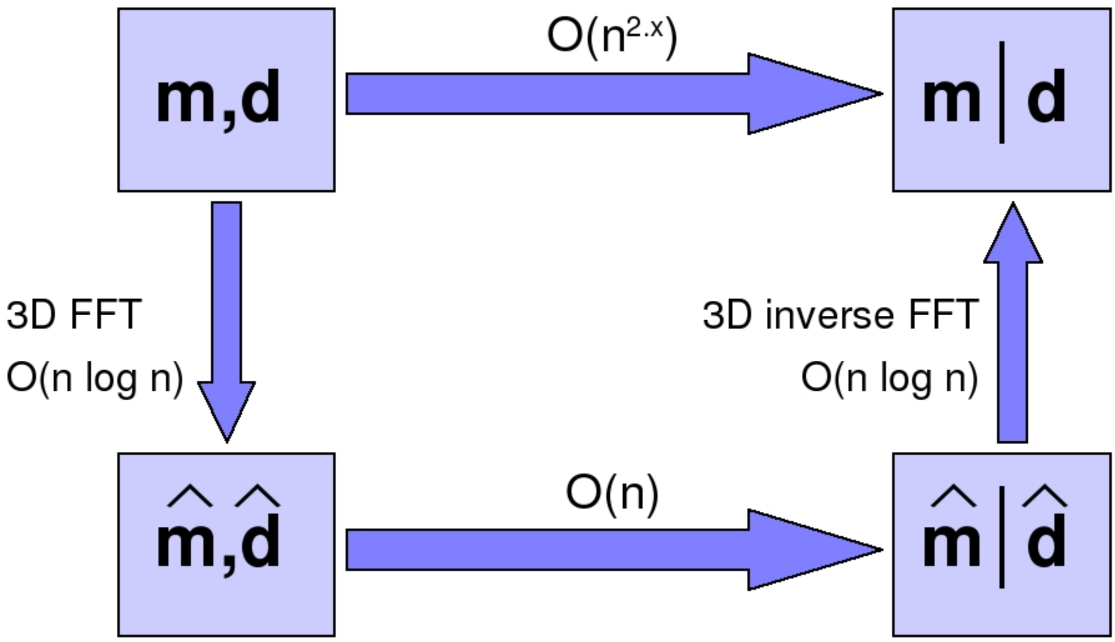

Figure 1.1. The problem is transformed to the Fourier domain, solved in this domain, and back-transformed to time domain. This reduces the problem from a $\mathcal{O}(n^{2.x})$ to a $\mathcal{O}(n \log n)$ process.

This seems to require that $\mathbf{d}$ is stationary, which would imply that the wavelet must be the same everywhere. However, we can divide out the wavelet from Equation 1.11 to obtain

$$\mathbf{d}' = \mathbf{ADm} + \mathbf{e}', \tag{1.20}$$

where $\mathbf{d}'$ is the data divided by the wavelet, and $\mathbf{e}'$ is the error divided by the wavelet. The details of how we do this division is given in Section 2.2.1. Note that we now assume that the noise after division, $\mathbf{e}'$ is stationary. Since we assume that a seismic response only depends on the reflections in that trace, this division can be done trace by trace. This assumption relies on a rather smooth seismic response, so the lateral variations in the wavelet should be smooth. We have chosen to restrict the local wavelet changes to only allow local temporal shift and amplitude scaling.

We can also work around the stationary noise assumption, and allow $\mathbf{e}'$ to vary laterally. This is done by utilizing the nature of a Bayesian solution, which always is a tradeoff between the prior and the posterior with noisefree data. By finding the posterior for a minimal noise, we can then interpolate between this solution and the prior to find an appropriate solution for the local noise level. When doing this, we ignore correlations between the adjusted area and other values, so we require constant noise level in each trace, since the conditional correlations inside a trace are much stronger than between traces. See Section 2.2.2 for details.

1.4.1 Facies probabilities

Facies probabilities are here found by first establishing the link between facies and inversion result, $p(f_i|\boldsymbol{\mu}_{m|d,i})$, where f_i is the facies at location i and $\boldsymbol{\mu}_{m|d,i}$ is the inversion result at the same location. The first step is to establish the link between the well logs $\mathbf{m}$ and the expectation given seismic observations $\boldsymbol{\mu}_{m|d_{obs}}$. We get this by combining Equation 1.12 and Equation 1.18:

$$\begin{aligned}
\boldsymbol{\mu}_{m|d_{obs}} &= \boldsymbol{\mu}_m + \boldsymbol{\Sigma}_m \mathbf{G}^T \boldsymbol{\Sigma}_d^{-1} (\mathbf{d}_{obs} - \boldsymbol{\mu}_d) \\
&= \boldsymbol{\mu}_m + \boldsymbol{\Sigma}_m \mathbf{G}^T \boldsymbol{\Sigma}_d^{-1} (\mathbf{Gm} + \mathbf{e} - \mathbf{G}\boldsymbol{\mu}_m) \\
&= \boldsymbol{\mu}_m + \mathbf{F}(\mathbf{m} - \boldsymbol{\mu}_m) + \mathbf{e}^*,
\end{aligned} \tag{1.21}$$

where

$$
\begin{aligned}
\mathbf{F} &= \boldsymbol{\Sigma}_m \mathbf{G}^T \boldsymbol{\Sigma}_d^{-1} \mathbf{G} && (1.22)\\
\mathbf{e}^* &\sim \mathrm{N}(0, \boldsymbol{\Sigma}_{e^*}) && (1.23)\\
\boldsymbol{\Sigma}_{e^*} &= \boldsymbol{\Sigma}_m \mathbf{G}^T \boldsymbol{\Sigma}_d^{-1} \boldsymbol{\Sigma}_e \boldsymbol{\Sigma}_d^{-1} \mathbf{G} \boldsymbol{\Sigma}_m. && (1.24)
\end{aligned}
$$

The operator $\mathbf{F}$ is used to filter the well logs and obtain the expected inversion values. For each facies, we then do a density estimation of $p(\boldsymbol{\mu}_{m|d_{obs}}|f)$ for each possible facies value f. This density estimation is done using a kernel smoothing approach, and by using the distribution of $\mathbf{e}^*$ as our kernel, we get an unbiased estimate of this distribution.

Finally we find the facies probability:

$$
p(f = j|\boldsymbol{\mu}_{m|d_{obs}}) = \frac{p(\boldsymbol{\mu}_{m|d_{obs}}|f = j)p(f = j)}{\sum_i p(\boldsymbol{\mu}_{m|d_{obs}}|f = i)p(f = i)}, \qquad (1.25)
$$

where $p(f = i)$ is the prior probability of facies i. This probability is then computed for each facies and each cell in the grid, with $\boldsymbol{\mu}_{m|d_{obs}}$ given by the inversion results.

2 Implementation

Whereas the general model was explained in Chapter 1 we explain a bit more of the actual implementation details here.

2.1 Using FFT for inversion

As previously stated, Equation 1.11 separates when transformed into the Fourier domain. After this transformation, the equation becomes

$$\tilde{\mathbf{d}}(\omega, \mathbf{k}) = \mathbf{G}(\omega)\tilde{\mathbf{m}}(\omega, \mathbf{k}) + \tilde{\mathbf{e}}(\omega, \mathbf{k})) \tag{2.1}$$

The ˜ denotes the 3D fourier transform, with temporal frequency ω, and lateral frequency vector $\mathbf{k} = (k_x, k_y)$. Due to the separation, we now have a set of n small equations, where n is the number of grid cells in the inversion volume. Everything is still normally distributed, so the solution to this equation follows the pattern from Equation 1.18 and Equation 1.19. We still must invert a data covariance matrix, but whereas this matrix had dimension $(n \cdot n_\theta)^2$ before the Fourier-transform, the matrix we must invert here is reduced to dimension n_θ^2, where n_θ is the number of angle stacks. Since the time for a matrix inversion is almost cubic in size, it is much faster to invert n of these small matrixes than the one large. After solving for $\tilde{\mathbf{m}}(\omega, \mathbf{k})$, we do the inverse transform of this to obtain the distribution for $\mathbf{m}$. The same does of course hold when we are using local wavelets that are divided out in advance, Equation 1.20. For full details, see Buland et al. (2003).

2.2 Local wavelet and noise

As shown, even though the use of FFT-transform requires stationarity, we are able to work around this. Wavelets can be made local since these can be divided out before solving the problem, and locally higher noise levels can be approximated by interpolating the low-noise solution and the prior distribution.

2.2.1 Dividing out the wavelet

A simple division of data by wavelet can easily be done in the Fourier domain, since the convolusion there is reduced to a multiplication, and the division can be done one frequency at a time. However, this is very unstable for frequencies where the wavelet is very weak or not present, so some stabilizing is needed.

In CRAVA this is done in two ways. First, we set an upper and lower cutoff frequency for the wavelet, default set to 5 and 55 Hz. Furthermore, for frequencies that fall below 10% of the average amplitude, we set the amplitude to 10% of average before doing the division.

2.2.2 Local noise

Local noise is implemented by first finding the solution using the minimum noise level, to fulfill the stationarity requirements of the FFT algorithm. We then interpolate the values for each locations between the prior and this minimum noise posterior. When doing this interpolation, we ignore correlation between locations. This is not a problem as long as the noise varies slowly and smoothly.

For each location $\mathbf{x}$ the adjusted estimate $\tilde{\boldsymbol{\mu}}_{m|d_{obs}}(\mathbf{x})$, is found from the inversion result $\boldsymbol{\mu}_{m|d_{obs}}(\mathbf{x})$

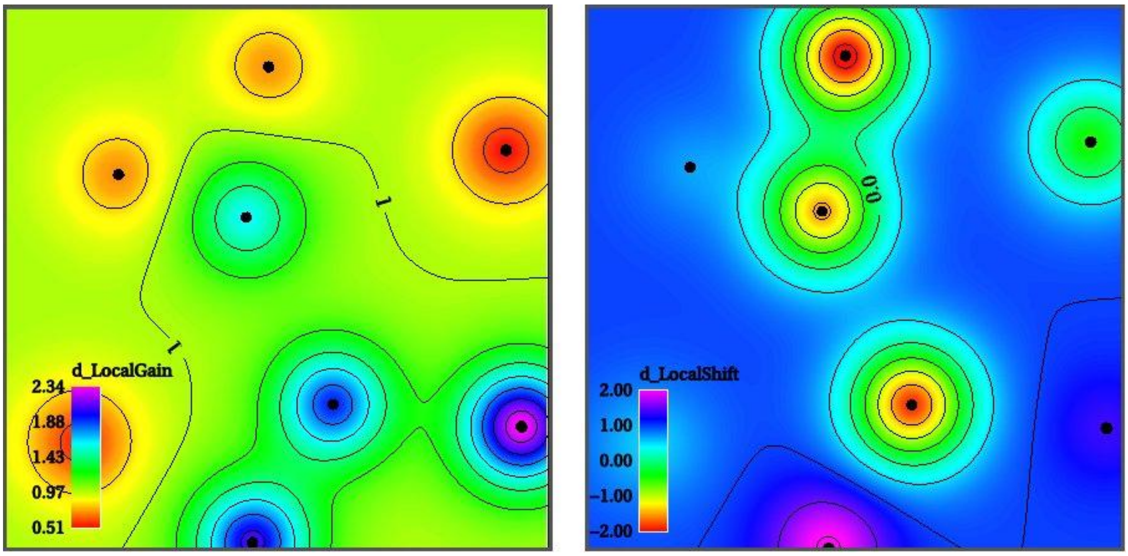

Figure 2.1. The local gain and shift maps involved when using local wavelets

by a linear relation,

$$\tilde{\boldsymbol{\mu}}_{m|d_{obs}}(\mathbf{x}) = \boldsymbol{\mu}_m(\mathbf{x}) + \mathbf{H_x}\left(\boldsymbol{\mu}_{m|d_{obs}}(\mathbf{x}) - \boldsymbol{\mu}_m(\mathbf{x})\right), \tag{2.2}$$

The matrix $\mathbf{H_x}$ is a shrinkage matrix, i.e. the adjusted estimate is always closer to the prior mean than the inversion result. The matrix $\mathbf{H_x}$ depends on the local error variance $\boldsymbol{\Sigma}_e^x$ and error variance used in the inversion $\boldsymbol{\Sigma}_e^0$.

To find the shrinkage matrix we first identify a matrix $\mathbf{G}_0$ which is such that it maps the local prior distribution to the local posterior distribution when it is observed with the noise Σ_e^0, i.e.

$$\mathbf{d}(\mathbf{x}) = \mathbf{G}_0\mathbf{m}(\mathbf{x}) + \mathbf{e}_0,$$

where $\mathbf{e}_0 \sim N\left(\mathbf{0}, \Sigma_e^0\right)$. The inversion of this expression is a linear relation

$$\boldsymbol{\mu}_{m|d_{obs}} = \boldsymbol{\mu}_m + \mathbf{P}(\Sigma_e^0)\left(\mathbf{d}_{obs} - \boldsymbol{\mu}_d\right) \tag{2.3}$$

where $\mathbf{P}(\Sigma_e^0) = \boldsymbol{\Sigma}_m\mathbf{G}_0^T\left(\mathbf{G}_0\boldsymbol{\Sigma}_m\mathbf{G_0}^T + \boldsymbol{\Sigma}_e^0\right)^{-1}$.

We then define the shrinkage matrix to be:

$$\mathbf{H_x}(\Sigma_e^{\mathbf{x}}, \Sigma_e^0) = \mathbf{P}(\Sigma_e^{\mathbf{x}})\mathbf{P}(\Sigma_e^0)^{-1}. \tag{2.4}$$

By this we mean that we remove the effect of the standard inversion and add the effect of the locally adapted inversion. The matrix $\mathbf{P}(\Sigma_e^0)$ is not invertible, but since the local noise always is larger than the noise in the inversion the product in expression 2.4 is always well defined.

2.3 Estimation of parameters

The estimation routines implemented in CRAVA are based on straightforward and commonly used techniques. This gives fast and robust estimation, although we may run into problems if the number of data points is too small, or the data quality is too low. The quality of an estimation result is never better than the quality of the data it is based on.

2.3.1 Estimating wavelet and noise

The wavelet estimation in CRAVA is based on White (1984). Wavelets are estimated at well locations, where we obtain the reflection coefficients from well logs. We then use the relation

$$\mathbf{d} = \mathbf{w} * \mathbf{c} + \mathbf{e} \tag{2.5}$$

where $\mathbf{d}$ is the seismic amplitude data, $\mathbf{w}$ is the wavelet, $\mathbf{c}$ the reflection coefficients, and $\mathbf{e}$ is the noise. We transform this to the Fourier domain, multiply with with the reflection coefficients, and take the expectation to get

$$d(\omega)\bar{c}(\omega) = w(\omega)|c(\omega)|^2 \tag{2.6}$$

Note that the convolution has disappeared, and the equation can be solved for each frequency ω. However, solving this directly in the frequency domain is unstable, so we need to do a frequency smoothing. This is done by transforming $d(\omega)\bar{c}(\omega)$ and $|c(\omega)|^2$ back to time domain, multiplying with a Papoulis taper, and transforming them back to the frequency domain. This is the same as applying a local smoothing in the frequency domain. After this, we divide out $w(\omega)$, and transform back to time domain.

We find the optimal vertical shift for each well. The global wavelet is then found by taking the arithmetic average of the zero-phase wavelets, weighted by the number of samples used from each well. The noise estimate is found by generating synthetic seismic using the averaged wavelet optimally shifted in each well, and subtracting this from the seismic data. The remaining part is assumed to be noise, and we measure the noise energy from this.

When using local wavelets, we find the optimal shift and/or scale of the global wavelet at each well location. Optimal here means minimizing the noise energy. We then use kriging to interpolate this between wells, with a shift of 0 and a scale of 1 as the mean level outside the well control area.

Local noise is estimated using the local noise energies from above. We always use local shift when estimating the noise, but only use local scale if it is used in the inversion. If local scale is used, the noise is divided by this. A noise scaling factor is then computed in each well, and kriged as above.

2.3.2 Estimating 3D wavelet

The expression for the 3D wavelet given in Equation 1.8 has only one unknown element, namely the 1D pulse $w_0(\omega)$. As for the 1D wavelet, the pulse is estimated from wells. Using reflection coefficients from well logs, time gradients estimated from seismic around wells and depth gradients computed from time gradients by using reference time surface and average velocity given by the user, a linear regression model can be set up for the seismic as

$$\mathbf{d} = \mathbf{K}\mathbf{w}_0 + \mathbf{e}. \tag{2.7}$$

The least squares estimate for $\mathbf{w}_0$ is

$$\widehat{w}_0 = (\mathbf{K}'\mathbf{K})^{-1}\mathbf{G}'\mathbf{d}. \tag{2.8}$$

2.3.3 Estimating correlations

We estimate correlations by first blocking the wells into the grid, and then do standard correlation estimation using

$$\mathrm{Cov}(X,Y) = \mathrm{E}(XY) - E(X)E(Y). \tag{2.9}$$

Since we model the covariance structure as separable, we have to collapse the full time dependent covariances between parameters into one parameter covariance matrix and a temporal correlation vector. This is done simply by using the covariances at time lag 0 as our covariance matrix, and averaging the remaining time correlation vectors for the parameters.

2.3.4 Estimating background model

As with the correlation estimation, the first step is to block the wells into the modeling grid. We then filter away everything above a cutoff frequency (default 6Hz) from the well logs. The next step is to take the average of all log data in each grid layer, giving a vertical trend. This trend is then smoothed using a moving average smoother, and finally filtered with the cutoff frequency.

We then use kriging of the well logs with this vertical trend as expectation to create the final background model.

2.3.5 Estimating optimal well location

The positioning uncertainty between well data and seismic data is often significant. To overcome this, the well may be moved to the location with maximum correlation between the seismic data and the reflection coefficients calculated from the well data. The relation between the seismic data and reflection coefficients is linear; so linear covariance is a good measure. The optimial well location is found by searching for the location with highest covariance in a lateral neighborhood around the original well location, where the well is allowed to be shifted vertically in each target position. The moving of wells is triggered by a command in the model file, and it is done prior to the estimation of wavelets, noise, correlations and background model.

2.4 Memory handling

The memory handling in CRAVA will primarily use memory to achieve speed. However, since the involved grids can be very large, we try to economize with the number of grids kept in memory. We also have a secondary option where we store more on disk, which will reduce memory use with a factor of at least 2 in realistic cases, but will also increase the running time by a factor of almost 3. We have both padded and unpadded grids. We count and check the number of padded grids used in detail, unpadded grids are only counted in memory computations. In the following, any mention of grid means padded, unpadded will be explcitly stated. Padded grids require s_p MB memory, unpadded s_u.

2.4.1 Grid allocation with all grids in memory

If the file option is not used, the grid memory allocation will go as follows:

1. Background grids for Vp, Vs and density, 3 grids.
2. If these are estimated, another 3 grids are allocated for estimation, but destroyed again before any other allocations.
3. Seismic grids, n_θ. If well optimisation is used, this will come before background grids.
4. Possibly prior facies probability grids, indicated by I_p, n_f unpadded grids.
5. Prior covariance, 6 grids.
6. If relative facies probabilities or local noise, a copy of background indicated by I_b, 3 grids.
7. **Peak:** At this stage, CRAVA reaches its first memory peak. Minimum memory use 10 grids, typical situation with three seismic grids and facies modelling requires 15 grids.
   Memory use: $P_1 = (9 + n_\theta + I_b * 3) * s_p + I_p * n_f * s_u$.
8. The posterior distribution is computed into the background and prior covariance grids, and seismic residuals are computed into the seismic grids. Thus, the inversion requires no extra grids. (But we needed a copy of the background for local noise or facies.)
9. After the inversion, the seismic grids are released, taking us off peak down to a base level:
   Memory use: $(9 + I_b * 3) * s_p + I_p * n_f * s_u$.
10. If simulation is used:

    a. Simulated grids are allocated, 3 grids.

b. If secondary parameters are used, indicated by I_s, a computation grid is allocated, 1 grid.

c. If kriging is used, indicated by I_k, 1 unpadded grid, not concurrent with computation grid.

11. **Peak:** New possible peak, since the number of grids now allocated may be larger than the released seismic grids.
Memory use: $P_2 = s_p * (12 + I_b * 3 + I_s) + (I_p * n_f + max(0, I_k - I_s)) * s_u$.

12. New release of grids, back to $s_p * (9 + I_b * 3) + I_p * 3 * s_u$.

13. If facies probabilities:

    a. 3D histograms of elastic parameters per facies are created, each of size 2MB, n_f special grids.

    b. Facies probability grids are created, including for undefined, $n_f + 1$ unpadded grids.

14. **Peak:** New possible peak, since the new memory allocated may be larger than the released seismic grids and/or the simulation+computation/kriging grids.
Memory use: $P_3 = (9 + I_b * 3) * s_p + (I_p * n_f + n_f + 1) * s_u + 2 * n_f$.

15. Can now release all grids related to facies probability, memory down to $s_p * 9$.

16. Eventual kriging of prediction allocates 1 unpadded grid.

17. Everything released.

The maximum memory use is thus the largest of the actual peaks. The maximum number of allocated padded grids will occur at either P_1 or P_2, whereas the largest number of other grids are allocated at P_3.

3 User guide

In this chapter, we describe how to build a CRAVA model file. The model file mainly follows the XML-format, but we also use the character '#' for commenting, meaning that the rest of the line after such a character is read as comment. XML/files are built with start- and endtags, encapsulating toher tags or values. All model files start with `<crava>`, and end with `<crava>`. An example of a model file is given in Appendix A.

3.1 Basic inversion

A primary ability for CRAVA is to run simple first-pass inversions. In this section, we describe how to build a model file for a simple inversion. We focus on how to get the key information into the program, whereas more detailed controls are discussed later, in Section 3.2. The key information elements for a CRAVA inversion run is:

- Seismic data.
- Wavelet.
- Signal/noise ratio.
- Inversion volume.
- Background model.
- Correlation structures.

Since CRAVA is designed to estimate any information that is not given, well data must also commonly be included.

3.1.1 Survey information

All information regarding the seismic data is gathered under the `<survey>` tag. This includes the file names for seismic data files, wavelet information and signal-to-noise ratio for each angle gather. As an example, it may look like this:

```
<crava>
<survey>
  <segy-start-time>  2500.0 </segy-start-time>
  <angle-gather>
    <offset-angle>     16.0 </offset-angle>
    <seismic-data>
      <file-name> ../input/seismic/Cube16.segy </file-name>
    </seismic-data>
  </angle-gather>
  <angle-gather>
    <offset-angle>     28.0 </offset-angle>
    <seismic-data>
      <file-name> ../input/seismic/Cube28.segy </file-name>
```

```
    </seismic-data>
  </angle-gather>
</survey>
</crava>
```

The seismic data can be on SegY-format, with a common offset time, given with <segy-start-time> if different from 0. The first value is used to represent the interval from start-time to start-time + time-step, so with a start-time of 100ms, and 4ms sampling, the first value is used in the grid cell covering the interval 100-104ms. Other file formats recognized by CRAVA is storm, Sgri and crava.

For each available angle, the rest of the information is gathered under an <angle-gather> tag, one for each offset. The actual angle is given by <offset-angle>.

3.1.1.1 Seismic data

The seismic data can be given as SegY-files. By default, CRAVA recognizes the Seisworks, Charisma and IESX formats, but you are also allowed to define your own format using the <segy-format> command. For information on how to use this, see <segy-format> in the reference manual chapter.

The name of the SegY file is given with <file-name>, as seen in Section 3.1.1. Naturally, seismic data is always required when running an inversion.

Other file formats recognized by CRAVA are storm, Sgri and crava.

3.1.1.2 Wavelet

To invert the seismic data, we need a wavelet for each angle. This wavelet can be read from file, using the <wavelet> and <file-name> commands like this:

```
  <angle-gather>
    <offset-angle>     16.0 </offset-angle>
    <seismic-data>
      <file-name> ../input/seismic/Cube16.segy </file-name>
    </seismic-data>
    <wavelet>
      <file-name> ../input/wavelets/wavelet16.txt </file-name>
    </wavelet>
  </angle-gather>
```

We can read wavelets on Swav and asc format.

If the <wavelet> command is not given, or given without <file-name>, the wavelet is estimated. See Section 2.3.1 for how this is done. If the wavelet is given on file, but unscaled, the command <scale> should be used if the scale is known, otherwise, the scale can be estimated by using the <estimate-scale> command. If none of these are specified, the wavelet will be used as it is on file.

3.1.1.3 Signal/noise ratio

This ratio is given with <signal-to-noise-ratio>. If this command is not given, the ratio is estimated. Note that we define the signal to noise ratio as the data variance divided by the error variance, where the data variance is model variance plus error variance.

3.1.2 Inversion volume

The volume used for inversion is given horizontally by a rectangle, and vertically bounded by a top and base surface. It is defined by the command <output-volume> under <project-settings>. Typically, it may look something like this:

```
<crava>
<project-settings>
  <output-volume>
    <utm-coordinates>
      <reference-point-x>  403050.0   </reference-point-x>
      <reference-point-y> 7211900.0   </reference-point-y>
      <length-x>              500.0   </length-x>
      <length-y>              500.0   </length-y>
      <angle>                  23.627 </angle>
      <sample-density-x>       50.0   </sample-density-x>
      <sample-density-y>       50.0   </sample-density-y>
    </utm-coordinates>

    <interval-two-surfaces>
      <top-surface>
        <time-file>     ../input/horizons/FlatTop_3100ms.storm </time-file>
      </top-surface>
      <base-surface>
        <time-file>    ../input/horizons/FlatBase_3600ms.storm </time-file>
      </base-surface>
      <number-of-layers> 125 </number-of-layers>
    </interval-two-surfaces>
  </output-volume>
</project-settings>
</crava>
```

3.1.2.1 Lateral extent

The lateral extent of the inversion volume is given under one of the the commands <area-from-surface>, <utm-coordinates>, or <inline-crossline-numbers>. The command <utm-coordinates> describes a rectangle, which may be rotated relative to the seismic data. It has the following parameters, which must all be specified:

- <reference-point-x> is the UTM x-coordinate of one corner of the area.
- <reference-point-x> is the UTM y-coordinate of the same corner.
- <length-x> is the extent of the area along the local x-axis.
- <length-y> is the extent of the area along the local y-axis.
- <angle> is the angle between the direction of the UTM x-axis and the local x-axis. Positive angles are counterclockwise.
- <sample-density-x> is the length of one grid cell along the local x-axis.
- <sample-density-y> is the length of one grid cell along the local y-axis.

Note that if the grid has the same rotation as the input SegY cubes with seismic data, output SegY cubes will have correct inlines and crosslines. Otherwise, these numbers are just counting from the initial corner. The command `<area-from-surface>` contains only one parameter, `<file-name>`, the name of a storm surface file defining the lateral extent of the inversion volume. The last way to define the inversion area is by the command `<inline-crossline-numbers>`. By this command, the following parameters can be used:

- `<il-start>` is the starting inline number.
- `<il-end>` is the ending inline number.
- `<xl-start>` is the starting crossline number.
- `<xl-end>` is the ending crossline number.
- `<il-step>` is the inline interval.
- `<xl-step>` is the crossline interval.

The parameters `<il-start>` and `<xl-start>` must be set if this command is used, the other parameters are optional. If they are not given, the numbers are taken from the Segy file containing the first seismic cube.

The area commands may be skipped altogether. The area will then be taken from the first input seismic data file, and defined as the smallest rectangle that covers all present traces.

3.1.2.2 Top and bottom surfaces

The vertical extent is normally given by a top and a base surface in time, under the command `<interval-two-surfaces>`, as shown in Section 3.1.2. The file name for the top surface is given under command `<top-surface>`, `<time-file>`, and the base surface is given similarly under `<base-surface>`, `<time-file>`. The file format is binary storm or ASCII irap.

These surfaces also define the default lateral correlation direction for the elastic parameters, with the correlation being parallel to the top surface at the top, and base surface at the base. Between this, we create a top- and base-conform grid, so that the number of grid cells in each trace is constant, although the interval thickness may vary. This is shown in Figure 3.1. The inversion may be unstable if the resolution varies too much in different traces, so we recommend that no trace interval is larger than twice the shortest interval.

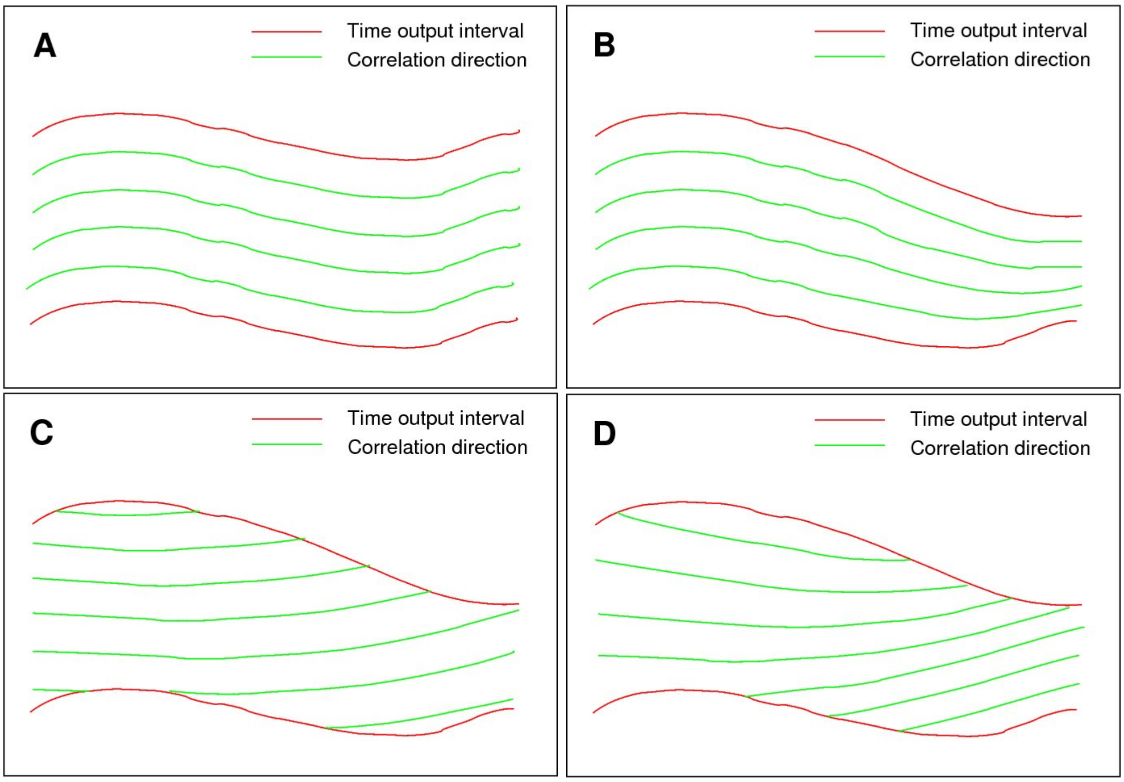

Figure 3.2. The layer structure of a (A) parallel top and base, (B) top- and base-conform compaction grid (C) Uniform correlation structure in a cut grid (D) Compactional correlation structure in a cut grid.

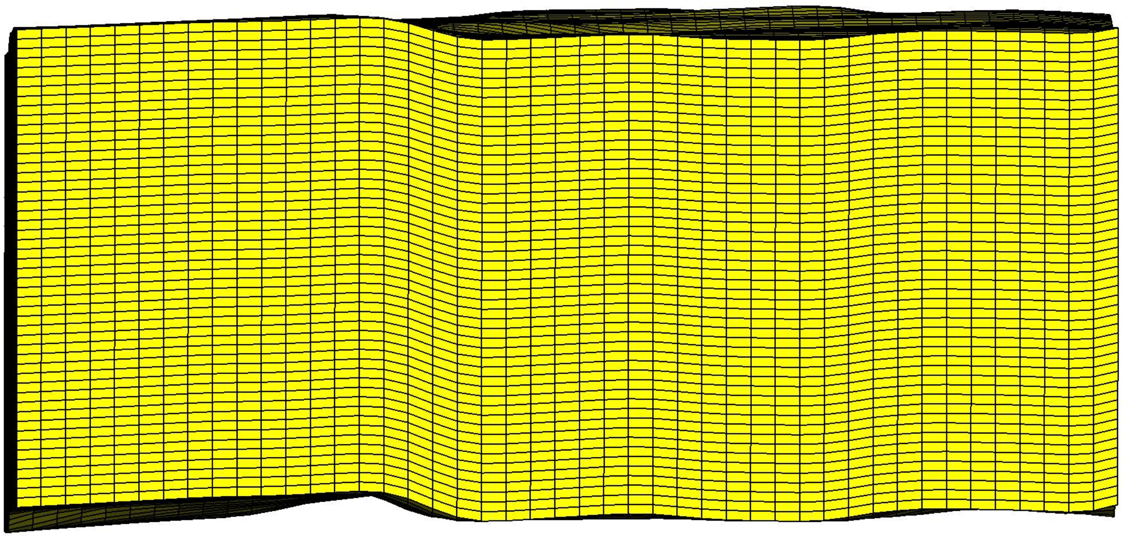

Figure 3.1. The layer structure of a top- and base-conform grid.

By specifying a correlation surface, the correlation direction can be independent of the interval surfaces, see Section 3.1.3.2. If this is done, there are no restrictions on the differences in interval thickness.

If only one surface is known, the command `<interval-one-surface>` can be used to invert an interval with top and base parallel to this surface. See Section 4.2.1.2 in the reference guide for more details. Note that depth conversion and correlation surfaces will not be available in this mode, so the lateral correlation will be parallel to this surface.

3.1.2.3 Depth conversion

The <output-volume> command is also where the depth conversion is specified, since this also constitutes a volume although in depth. Since the lateral area obviously is the same, the additional information for depth conversion is given under <interval-two-surfaces>. To do the depth conversion, one of the following must be given:

- Reference surface in depth (either top or base), and a velocity cube.
- Both top and base surface in depth. In this case, we assume constant velocity along each trace, computed from the time and depth surfaces.
- Both top and base surface in depth, and a velocity cube. In this case, we use the cube for relative velocity in a trace, and scale it to match the interval length.

Reference surfaces in depth are given with <depth-file> under <top-surface> and/or <base-surface>. The velocity cube can be read from a storm-file with the command <velocity-field>. Alternatively, the command <velocity-field-from-inversion> can be used to specify that Vp from inversion should be used for velocity. With depth conversion, the <interval-two-surfaces> command may look like this:

```
<interval-two-surfaces>
  <top-surface>
    <time-file>     ../input/horizons/FlatTop_3100ms.storm </time-file>
    <depth-file>    ../input/horizons/FlatTop_3100ms.storm </depth-file>
  </top-surface>
  <base-surface>
    <time-file>    ../input/horizons/FlatBase_3600ms.storm </time-file>
    <depth-file>   ../input/horizons/FlatBase_3800ms.storm </depth-file>
  </base-surface>
  <velocity-field>        ../input/velocity/velocity.storm </velocity-field>
  <number-of-layers>                                   125 </number-of-layers>
</interval-two-surfaces>
```

3.1.3 Prior model

Since seismic data only contain information about relative elastic parameters, the absolute level needs to be set with a background model. In a Bayesian inversion setting, the background model is the prior expectation. We also need the prior covariance, which is given by the covariance of the parameters, the lateral correlation and the temporal correlation, as described in Section 1.4. In the model file, all this is gathered under the <prior-model> command, which may look something like this:

```
<crava>
<prior-model>
  <background>
    <vp-file>
      ../../input/background/CravaBgVp.storm
    </vp-file>
    <vs-file>
      ../../input/background/CravaBgVs.storm
    </vs-file>
    <density-file>
      ../../input/background/CravaBgRho.storm
```

```
    </density-file>
  </background>
  <lateral-correlation>
    <variogram-type> genexp </variogram-type>
    <power>       1 </power>
    <angle>       0 </angle>
    <range>    2500 </range>
    <subrange> 2500 </subrange>
  </lateral-correlation>
</prior-model>
</crava>
```

3.1.3.1 Background model

The background model is given under the <background> command. It can be given from file, using <vp-file>, <vs-file> and <density-file>. These files should either be on Storm, crava, Sgri or SegY format. Alternatively, constant values can be used for background model, specified with <vp-constant>, <vs-constant> and <density-constant>. Any combinations of files and constants are also ok. If none of these are given, the background model will be estimated.

3.1.3.2 Covariances

As shown in Section 1.4 the prior covariance structure for the elastic parameters consists of three parts:

1. A 3x3 covariance matrix for pointwise covariance between the parameters. May be read from ascii file using the command <parameter-correlation>.
2. A temporal correlation vector, length equal to number of layers in grid, n_t. May be read from ascii file using the command <temporal-correlation>.
3. A lateral correlation structure. May be given as a variogram using the command <lateral-correlation>.

By default, the two first are estimated from well data, and the lateral correlation structure is set to a isotrope exponential variogram with range 1000. The reason for the latter choice is that this is hard to estimate, see Section 2.3.3 for details. The most common to override is the lateral correlation, where the variogram used for petrophysical modelling is a good choice.

3.1.4 Well data

Unless all information about wavelet, signal to noise and correlations are specified, well data are needed for estimation. Wells are given with the command <well-data>, and may look like this:

```
<crava>
<well-data>
  <log-names>
    <time>    TWT  </time>
    <dt>      DT   </dt>
    <dts>     DTS  </dts>
    <density> RHOB </density>
  </log-names>
  <well>
    <file-name> ../input/logs/ed6406_3-3_cut.rms    </file-name>
  </well>
```

```
  <well>
    <file-name> ../input/logs/ed6506_12-3_cut.rms   </file-name>
  </well>
  <well>
    <file-name> ../input/logs/ed6506_12-8_cut.rms   </file-name>
  </well>
  <well>
    <file-name> ../input/logs/ed6506_12-S4H_cut.rms </file-name>
  </well>
</well-data>
</crava>
```

There are two main elements here. The first is a well log interpretation, given by <log-names>, which tells CRAVA which headers to look for. The following logs are needed:

- Two way time log, specified with <time>.
- Vp log, either given by <vp> or <dt>. The latter is used for DT-logs.
- Vs log, either given by <vs> or <dts>. The latter is used for DTS-logs.
- Density log, given by <density>.

In addition, if facies probabilities are computed, a facies log is needed. This is specified with <facies>.

The wells are given with the command <file-name> under <well>, which is given once for each well. The reason for this is that additional information may be given for each well. Well files should be on RMS-format.

Each well may be moved to its optimal location using <optimize-location-to> under <well>, taking the arguments <angle> and <weight> allowing the user to assign different weights to the different angle gathers for each well. The maximum allowed offset and vertical shift for moving wells is specified in <maximum-offset> and <maximum-shift> under <well-data>, with default values of 250 m and 11 ms, respectively.

3.1.5 Output

Output is controlled under <io-settings> under <project-settings>. Here, you may set the output directory using <output-directory>, and a prefix for all output files using <file-output-prefix>. This prefix will be added to all output files.

Except for the log file which is placed directly under the output directory, all files output by crava are placed in sub-directories. These sub-directories are

```
output-directory / wells
                 / background
                 / wavelets
                 / seismic
                 / velocity
                 / correlations
                 / inversionresults
```

There are two main output formats: Grid output, controlled by <grid-output>, and well output controlled by <well-output>. The output section may look something like this:

```
<crava>
<project-settings>
  <io-settings>
    <file-output-prefix> CRAVA_ </file-output-prefix>
      <grid-output>
        <format>
          <segy> yes </segy>
        </format>
        <domain>
          <time>  yes </time>
          <depth> yes </depth>
        </domain>
        <elastic-parameters>
          <vp> yes </vp>
          <vs> yes </vs>
          <density> yes </density>
          <background> yes </background>
        </elastic-parameters>
      </grid-output>
      <well-output>
        <wells> yes </wells>
        <blocked-wells> yes </blocked-wells>
      </well-output>
  </io-settings>
</project-settings>
</crava>
```

3.1.5.1 Grid output

Different elastic parameters can be given as grid output. In addition, estimated background model may be written as grids. This is controlled by the `<elastic-parameters>` command under `<grid-output>`. See Section 4.2.3.4.3 for a full list of possible grids. If this command is not used, Vp, Vs and density will be written. Output of original and synthetic seismic data can be given by the `<seismic-data>` command. Other output grids are given by the command `<other-parameters>`kwindexother-parameters, for example correlations.

The grid format may be controlled using `<format>`. Here the yes/no parameters `<storm>`, `<segy>`, `<sgri>`, `<crava>` and `<ascii>` can be used to decide if grids should be written on storm- (RMS), segy-, Sgri-, crava- or ascii-format. You may choose several formats for one run; all grids will be written on all selected formats. Note that correlation grids make sense only in storm format. Default output format is storm. The crava format is a binary format only to be used with Crava. It can be read and written from CRAVA, and is useful if the output from a CRAVA run should be used as input to another CRAVA run because the format is fast to read.

By using the `<domain>` option, output may be written in time domain (`<time>`) or depth domain (`<depth>`, requires parameters set under `<output-volume>`, see Section 3.1.2.3), or both. Again, correlation grids only make sense in time domain, which is default.

3.1.5.2 Well output

Some versions of filtered elastic parameters (Vp, Vs and density) in wells can be generated by the `<well-output>` command. The logs written are

- Raw elastic logs.
- Elastic logs filtered to background frequency.
- Elastic logs filtered to seismic frequency.
- Elastic logs filtered with facies prediction filter (if available).
- Facies log (if available).

The wells can either be written with original sampling density, using <wells>, or matching the internal grid resolution, using <blocked-wells>.

3.1.6 Actions

The final information that is needed for a CRAVA run is what the run is supposed to do. This is controlled by <actions>. The <mode> keyword defines the purpose of this run. and should be set to "inversion" when doing inversion. Other options are "estimation", see Section 3.3 and "forward", see Section 3.5. When inversion is chosen, <inversion-settings> can be used to control basic aspects of the inversion. It may look something like this:

```
<crava>
<actions>
  <mode> inversion </mode>
  <inversion-settings>
    <prediction> yes </prediction>
    <simulation>
      <seed> 210471 </seed>
      <number-of-simulations> 10 </number-of-simulations>
    </simulation>
  </inversion-settings>
</actions>
</crava>
```

The command <prediction> can be used to turn predictions on or off. By default, the prediction will be generated. A number of full frequency stochastic realisations of the inversion by specifying <number-of-simulations> under <simulation>. The seed for the random generator can also be given here, with the <seed> command. Changing the seed will give a new set of realisations.

3.2 Advanced inversion options

Although CRAVA is mainly intended as a simple and fast inversion tool, there are still some options to control the inversion, and using more sophisticated approaches. Most of these are covered here, see also Section 4.2.4 for details about <advanced-settings>.

3.2.1 Non-stationary wavelet and noise

Although the FFT-algorithm which is at the core of CRAVA requires stationarity, this does not mean that the entire inversion has to be stationary, as discussed in Section 2.2. We allow lateral variations in wavelet amplitude, wavelet shift and signal to noise ratio.

Unlike the basic level, where parameters that were not specified automatically got estimated, use of local wavelets or noise must be explicitly triggered. For wavelets, this is done with the <local-wavelet> command under <wavelet>. There are four possible commands under <local-wavelet>:

1. <shift-file> gives a file name for a map giving the local shifts. The file must be on storm format.

2. <estimate-shift> will estimate a local shift map when set to "yes".

3. <scale-file> gives a file name for a map giving the local scale. The file must be on storm format.

4. <estimate-scale> will estimate a local scale map when set to "yes".

Naturally, the shift can not be both given and estimated, the same holds for scale. Note that you may choose to use only shifts, omitting both scale keywords, or use only scale.

The local noise is triggered similarly, by using one of these two commands under <angle-gather>:

1. <local-noise-scaled> gives a file with the local scaling of the signal to noise ratio, on storm format.

2. <estimate-local-noise> estimates the local scaling of the signal to noise ratio if set to "yes".

3.2.2 PS-seismic and reflection approximations

By default, CRAVA assumes that the input seismic data are PP, but PS data can also be used. For both cases, we use linearized Aki-Richards, see Equation 1.1. The type of seismic data is indicated by using the <type> command under<seismic-data>. Here, <type> should be either "pp" or "ps". Note that PS data must also be aligned in PP-travel time, as no such alignment is done internally by CRAVA.

Instead of using the default reflection approximation, the user may supply the parameters to compute the reflections. We always assume that for a given angle and seismic type, the reflections can be computed from the equation

$$
\begin{aligned}
c(\mathbf{x},t,\theta) = {} & a_{Vp}(\theta)\frac{\partial}{\partial t}\ln V_p(\mathbf{x},t) \\
& + a_{Vs}(\mathbf{x},t,\theta)\frac{\partial}{\partial t}\ln V_s(\mathbf{x},t) \\
& + a_{\rho}(\mathbf{x},t,\theta)\frac{\partial}{\partial t}\ln \rho(\mathbf{x},t).
\end{aligned} \tag{3.1}
$$

The coefficients a_{Vp}, a_{Vs} and a_ρ can be read from file, using the <reflection-matrix> command under <advanced-settings>. This file should have one line for each seismic data file, and each line should have the three coefficients for one set of seismic input data. The order of the lines should be the same as the order of the seismic data in the <survey> command.

3.2.3 Well quality checks

Well logs are often faulty, and CRAVA has some safety mechanisms to detect this. The primary mechanism is to detect extreme values, and set these missing. The default upper and lower bounds are shown in Table 3.1. These can be overridden using the command <allowed-parameter-values> under <well-data>. Here, <minimum-vp>, <minimum-vs>, <minimum-density> and the corresponding maximum values can be given.

Some logs may stay within reasonable values, but have too much or too little variation, also indicating that something is wrong. For each log, the variance of the logarithm of the log minus the background is computed, and if it is outside reasonable bounds, this triggers an error. The default bounds are shown in Table 3.2. These can also be overridden with <allowed-parameter-values>, using <minimum-variance-vp> and so on.

	Min	Max
Vp	1300	7000
Vs	200	4200
Density	1.4	3.3

Table 3.1. Default intervals for valid log values.

	Min	Max
Var(ln(Vp))	$5 * 10^{-4}$	$250 * 10^{-4}$
Var(ln(Vs))	$10 * 10^{-4}$	$500 * 10^{-4}$
Var(ln(Density))	$2 * 10^{-4}$	$100 * 10^{-4}$

Table 3.2. Default intervals for valid log variances.

3.2.4 Generate synthetic seismic from inversion data

It is possible to generate synthetic seismic by a forward modeling with the Vp, Vs and density resulting from the inversion. This is done by the command <synthetic> under <seismic-data> under <grid-output>, <io-settings>, in command <project-settings>.

3.3 Estimation

As mentioned, CRAVA can estimate many of the needed parameters. There are several commands that control the estimation behavior for wavelets, noise and background model. Note that the correlations will always be estimated as explained in Section 2.3 from all available well logs, and do not have any further controls.

3.3.1 Estimation mode

If you only want to do the estimation, in order to check the quality of the estimates, you can use "estimate" in the <mode> command. Using this, CRAVA will perform the initial model building tasks and estimate needed information, but terminate once all information needed for inversion is estimated. When running in estimation mode, you can also control the main estimation aspects using the <estimation-settings> command. This allows you to control which of the main estimation tasks should be carried out, setting yes or no for <estimate-correlations>, <estimate-wavelet-or-noise> or <estimate-background>. Parameters with a "no" will not be estimated unless needed for other estimations. Note that in estimation mode, all estimated parameters are written to file, regardless of output settings.

3.3.2 Wavelet and noise estimation

Wavelets and noise are estimated together. These parameters will only be estimated from wells that are vertical or close to vertical, since this allows comparing synthetic seismic from well logs with one or a couple of traces, and thus reduces alignment issues. The angle limit can be controlled by the <maximum-deviation-angle> command under <well-data>. In addition, wells can be excluded individually, by setting <use-for-wavelet-estimation> to "no" under <well>.

By default, the wavelet and noise are estimated in the region between the top and bottom surface for the inversion area. This may be further limited using the <wavelet-estimation-interval> command under <survey>, where a separate set of restricting surfaces are given with <top-surface-file> and <base-surface-file>. Since these are under <wavelet>, they can be different for each angle.

Some wavelet estimation options are also found under <advanced-settings> under <project-settings>. These are

- <wavelet-tapering-length> which controls the length of the wavelet (in ms).
- <minimum-relative-wavelet-amplitude> which finds the wavelet length, by setting the cut-off size for edge peaks relative to center peak.
- <maximum-wavelet-shift> which controls how far the wavelet can be shifted locally, see Section 2.3.1.

3.3.3 Background model estimation

The background model is estimated as a low frequency vertical trend. The trend is given in relative depth in the inversion volume, so the trend value along the top and bottom surface is constant. At well locations, the trend is kriged to the well logs. By default, all wells are used background model estimation, but can be excluded by using <use-for-background-trend> under <well> for individual wells.

The background estimation can be controlled by some commands under <background>. These are:

- <velocity-field> takes an external velocity field, typically from migration, and uses as Vp background, kriged to low frequency Vp well logs.
- <lateral-correlation> gives a variogram for the kriging. Larger ranges extends well data further away from wells.
- <high-cut> allows specification of a maximum frequency for the background model.

3.4 Facies prediction

An important feature in CRAVA is the ability to create facies probabilities. This requires that <mode> is set to "inversion", and is triggered by the <facies-probabilities> command under <inversion-settings>. The value given here should be either "absolute" or "relative", corresponding to probability computations based on absolute or relative inverted parameters. If the distribution for elastic parameters for each facies is constant over the inversion volume, using absolute values is more stable. However, if there are trends in the elastic parameters, the relative values are more robust.

The facies probabilities are computed based on the inversion results and a distribution for inversion values given facies computed from filtered well logs, where the filter is defined by the inversion. See Section 1.4.1. Probability cubes will be computed for all facies seen in wells, and an additional undefined probability cube is also generated, indicating areas where the inversion values are too far away from well data to make reliable predictions.

Except from the trigger in <inversion-settings>, all parameters related to facies probabilities are given under <facies-probabilities> under <prior-model>. Here is an example:

```
<crava>
<prior-model>
  <facies-probabilities>
    <facies-estimation-interval>
      <top-surface-file>  ../input/horizons/facies_top.storm  </top-surface-file>
      <base-surface-file> ../input/horizons/facies_base.storm </base-surface-file>
    </facies-estimation-interval>
    <prior-facies-probabilities>
      <facies>
```

```
        <name>        sand </name>
        <probability> 0.4  </probability>
      </facies>
      <facies>
        <name>        shale </name>
        <probability> 0.6   </probability>
      </facies>
    </prior-facies-probabilities>
  </facies-probabilities>
</prior-model>
</crava>
```

The volume to use for facies probability computation can be controlled with <facies-estimation-interval>, similar to estimation interval for wavelets. Parallel to the wavelet case, wells may also be excluded using the <use-for-facies-probabilities> command under <well>.

3.4.1 Prior probabilities

In order to get reliable probabilities, we need good prior probabilities. By default, CRAVA computes the average fraction of each facies in the relevant interval of the wells. This can be overridden using the <prior-facies-probabilities> command, which allows specification of these. Note that probabilities must be given for each facies. Probabilities can either be given globally, with <probability>, or as a full 3D trend, using <probability-cube>. The latter takes a file name as argument; this should be a storm-file that covers the inversion volume.

3.5 Forward modelling

A minor functionality in CRAVA is that it can do forward modelling, showing what seismic response the program would expect from a given set of elastic parameters. This is triggered by using "forward" as <mode>. In this mode, we generate synthetic seismic data from the given background cubes. A file for forward modelling looks like this:

```
<crava>
<actions>
  <mode> forward </mode>
</actions>

<survey>
  <angle-gather>
    <offset-angle>  0 </offset-angle>
    <wavelet>
      <file-name> ../input/wavelets/ricker.txt      </file-name>
    </wavelet>
  </angle-gather>

  <angle-gather>
    <offset-angle> 10 </offset-angle>
    <wavelet>
      <file-name> ../input/wavelets/rickershift.txt </file-name>
    </wavelet>
  </angle-gather>
</survey>
```

```
<prior-model>
  <earth-model>
    <vp-file>      ../input/background/Vp.storm  </vp-file>
    <vs-file>      ../input/background/Vs.storm  </vs-file>
    <density-file> ../input/background/Rho.storm </density-file>
  </earth-model>
</prior-model>

<project-settings>
  <output-volume>
    <utm-coordinates>
      <reference-point-x>  400000.0 </reference-point-x>
      <reference-point-y> 7227500.0 </reference-point-y>
      <length-x>             2500.0 </length-x>
      <length-y>             2500.0 </length-y>
      <angle>                   0.0 </angle>
      <sample-density-x>      250.0 </sample-density-x>
      <sample-density-y>      250.0 </sample-density-y>
    </utm-coordinates>

    <interval-two-surfaces>
      <top-surface>
        <time-file> ../input/horizons/top.irap  </time-file>
      </top-surface>
      <base-surface>
        <time-file> ../input/horizons/base.irap </time-file>
      </base-surface>
      <number-of-layers>                   250 </number-of-layers>
    </interval-two-surfaces>
  </output-volume>

  <io-settings>
    <file-output-prefix> CRAVA_ </file-output-prefix>
      <grid-output>
        <format>
          <segy> yes </segy>
        </format>
      </grid-output>
  </io-settings>

</project-settings>
</crava>
```

Note that no seismic files are given under <survey>, as these are now computed. No wells are used, since nothing can be estimated here. We need the angles to generate seismic data for, the corresponding wavelets, the elastic parameters (given as earth model), and the volume. Instead of using one of the commands defining volume, the volume can be taken from Vp. The output format can be controlled using <io-settings>, as can input- and output-directory. Other input will be ignored.

4 CRAVA model file reference manual

The numbering shows the command grouping. A command with no subnumbering expects a value to be given, otherwise, it is only a grouping of other commands.

File names are currently given with a path relative to the directory settings in <project-settings>-<io-settings>-<input/output/top-directory>. If these are not given, the path will always be relative to the working directory.

All commands are optional, unless otherwise stated. A necessary command under an optional is only necessary if the optional is given.

4.1 `<actions>` (necessary)

Description: Controls the main purpose of the run.
Argument: Elements specifying the main purpose
Default:

4.1.1 `<mode>` (necessary)

Description: Inversion: Invert seismic input data to elastic parameters and/or facies probabilities. Needs seismic data and volume, all other missing data will be estimated. Forward: Create seismic response from background model. Not able to estimate anything. Estimation: Checks input data and performs estimation of lacking information for inversion, but stops before inversion.
Argument: 'inversion', 'forward' or 'estimation'
Default:

4.1.2 `<inversion-settings>`

Description: Controls aspects of the inversion. Only valid with the `<mode>` 'inversion' above.
Argument: Elements controlling the inversion
Default:

4.1.2.1 `<prediction>`

Description: Controls whether predicted elastic parameters will be generated.
Argument: 'yes' or 'no'
Default:

4.1.2.2 `<simulation>`

Description: Controls aspects of the simulation of elastic parameters.
Argument: Elements controlling the simulation of elastic parameters
Default:

4.1.2.2.1 `<seed>`

Description: A number used to initialize the random generator. Running a model file with a given seed will give the same simulation results each time.
Argument: Integer

Default: 0.0

4.1.2.2.2 `<seed-file>`

Description: Alternative to `<seed>`. This is an ASCII file containing a number. At the termination of the run, the file will be overwritten with a seed generated by the random generator. Thus, a model file using this will generate different simulation results on sequential runs.
Argument: ASCII file containing a number
Default:

4.1.2.2.3 `<number-of-simulations>`

Description: Integer value giving the number of stochastic realizations to generate.
Argument: Integer
Default: 0

4.1.2.3 `<kriging-to-wells>`

Description: Should the realizations be kriged to well data?
Argument: 'yes' or 'no'
Default: 'yes' if not the `<simulation>` command is used.

4.1.2.4 `<facies-probabilities>`

Description: Should facies probabilities be estimated?
Argument: 'yes' or 'no'
Default: 'no'

4.1.3 `<estimation-settings>`

Description: Controls what will be estimated. Only valid with the `<mode>` 'estimation'. Note that these commands can only turn off estimations - a parameter that is given will not be estimated even if it says so here.
Argument: Elements controlling what to estimate
Default:

4.1.3.1 `<estimate-background>`

Description: If 'no', background will not be estimated unless needed for other estimation.
Argument: 'yes' or 'no'
Default: 'yes'

4.1.3.2 `<estimate-correlations>`

Description: If 'no', correlations will not be estimated unless needed for other estimation.
Argument: 'yes' or 'no'
Default: 'yes'

4.1.3.3 `<estimate-wavelet-or-noise>`

Description: If 'no', wavelets and/or noise will not be estimated unless needed for other estimation.
Argument: 'yes' or 'no'
Default: 'yes'

4.2 <project-settings> (necessary)

Description: Controls inversion volume, output and advanced program settings.
Argument: Elements controlling inversion volume, output and advanced program settings
Default:

4.2.1 <output-volume> (necessary)

Description: Defines the core inversion volume. All grid output will be given in this volume.
Argument: Elements defining the core inversion volume.
Default:

4.2.1.1 <interval-two-surfaces>

Description: One way to give the top and bottom limitations. Must be used if output in depth domain is desired. This or <interval-one-surface> must be given.
Argument:
Default:

4.2.1.1.1 <top-surface> (necessary)

Description: File name(s) for top surface file(s).
Argument: Elements controlling the top surface
Default:

4.2.1.1.1.1 <time-file>

Description: File name for storm grid file giving top surface in time. This or <time-value> must be given.
Argument: File name
Default:

4.2.1.1.1.2 <time-value>

Description: Value giving the top time for the inversion interval. This or <time-file> must be given.
Argument: Value
Default:

4.2.1.1.1.3 <depth-file>

Description: File name for storm grid file giving top surface in depth.
Argument: File name
Default:

4.2.1.1.2 <base-surface> (necessary)

Description: File name(s) for base surface file(s).
Argument: Elements controlling the base surface
Default:

4.2.1.1.2.1 <time-file>

Description: File name for storm grid file giving base surface in time. This or <time-value> must be given.
Argument: File name
Default:

4.2.1.1.2.2 <time-value>

Description: Value giving the base time for the inversion interval. This or <time-file> must be given.
Argument: Value
Default:

4.2.1.1.2.3 <depth-file>

Description: File name for storm grid file giving base surface in depth.
Argument: File name
Default:

4.2.1.1.3 <number-of-layers>

Description: Integer value giving how many layers to use between top and base surface.
Argument: Integer
Default:

4.2.1.1.4 <velocity-field>

Description: File name for storm grid file. Gives more detailed depth conversion information. Without this, constant velocity per trace is used. If only one depth surface is given, this is used to compute the other. Otherwise, the depth interval will always match both surfaces, but the velocity field is scaled and used for internal depth computations. Can not be used with <velocity-field-from-inversion>.
Argument: File name
Default:

4.2.1.1.5 <velocity-field-from-inversion>

Description: If given, velocity field from inversion is used for depth conversion. See <velocity-field> for details on how this is done. Can not be used with <velocity-field>.
Argument: 'yes' or 'no'
Default:

4.2.1.2 <interval-one-surface>

Description: Using this command gives parallel top and base of inversion interval. This or <interval-two-surfaces> must be given.
Argument: Elements for parallel top and base inversion interval
Default:

4.2.1.2.1 <reference-surface>

Description: File name for storm surface file. The top and base surfaces for the inversion interval will be parallel to this.

Argument: File name
Default:

4.2.1.2.2 `<shift-to-interval-top>`

Description: Value giving the distance from reference surface to top surface. This value is added to the reference surface to create the top surface.
Argument: Value
Default:

4.2.1.2.3 `<thickness>`

Description: Value giving the thickness of the inversion interval. This value is added to the top surface to create the base surface.
Argument: Value
Default:

4.2.1.2.4 `<sample-density>`

Description: Value giving the thickness of a layer in the inversion interval. The thickness should be divisible by this value.
Argument: Value
Default:

4.2.1.3 `<area-from-surface>`

Description: Inverson area can be defined by a surface. Then the name of the surface is given in this command. Other ways to define inversion area are by the commands `<utm-coordinates>` or `<inline-crossline-numbers>`. If none of these commands are used, the area is defined by the first seismic data file, or from Vp if we do forward modeling.
Argument:
Default:

4.2.1.3.1 `<file-name>`

Description:
Argument: Name of file
Default:

4.2.1.4 `<utm-coordinates>`

Description: Describe area by UTM coordinates.
Argument:
Default:

4.2.1.4.1 `<reference-point-x>`

Description: Value giving the x-coordinate of a corner of the area.
Argument: Value
Default:

4.2.1.4.2 `<reference-point-y>`

Description: Value giving the y-coordinate of a corner of the area.
Argument: Value
Default:

4.2.1.4.3 <length-x>

Description: Value giving the area length along the rotated x-axis.
Argument: Value
Default:

4.2.1.4.4 <length-y>

Description: Value giving the area length along the rotated y-axis.
Argument: Value
Default:

4.2.1.4.5 <sample-density-x>

Description: Cell size along the rotated x-axis.
Argument: Integer
Default:

4.2.1.4.6 <sample-density-y>

Description: Cell size along the rotated y-axis.
Argument: Integer
Default:

4.2.1.4.7 <angle>

Description: Orientation of the azimuth.
Argument:
Default:

4.2.1.5 <inline-crossline-numbers>

Description: Describe area by inline and crossline numbers. il-start and xl-start must be given if this command is used, the other variables are optional. The numbers which are not specified are taken from the SegY file containing seismic data. The command is only working if seismic data are given on SegY format.
Argument:
Default:

4.2.1.5.1 <il-start>

Description: Start value for inline.
Argument:
Default:

4.2.1.5.2 <il-end>

Description: End value for inline.
Argument:

Default:

4.2.1.5.3 `<xl-start>`

Description: Start value for crossline.
Argument:
Default:

4.2.1.5.4 `<xl-end>`

Description: End value for crossline.
Argument:
Default:

4.2.1.5.5 `<il-step>`

Description: Step value for inline.
Argument:
Default:

4.2.1.5.6 `<xl-step>`

Description: Step value for crossline.
Argument:
Default:

4.2.2 `<time-to-depth-mapping-for-3d-wavelet>`

Description: Defines the mapping between pseudo-depth and local time in the target area for 3D wavelet.
Argument: Reference depth, velocity and time surface for mapping
Default:

4.2.2.1 `<reference-depth>`

Description: Holds the z-value for the reference depth for target area
Argument: Depth in meter
Default:

4.2.2.2 `<average-velocity>`

Description: Holds the average velocity in the target area
Argument: Velocity in meter/second
Default:

4.2.2.3 `<reference-time-surface>`

Description: Filename for the time surface corresponding to the reference depth.
Argument: File name
Default:

4.2.3 `<io-settings>`

Description: Holds commands that deal with what output to give and where, and where to find input.
Argument: Elements controlling output and input

Default:

4.2.3.1 `<top-directory>`

Description: Directory name giving the working directory for the model file. Must end with directory separator.
Argument: Directory name
Default:

4.2.3.2 `<input-directory>`

Description: Directory name, relative to `<top-directory>`, for root directory for input files. Must end with directory separator.
Argument: Directory name
Default:

4.2.3.3 `<output-directory>`

Description: Directory name, relative to `<top-directory>`, for root directory for output files. Must end with directory separator.
Argument: Directory name
Default:

4.2.3.4 `<grid-output>`

Description: All commands related to output given as grids are gathered here.
Argument: Elements controlling output given as grids
Default:

4.2.3.4.1 `<domain>`

Description: Commands specifying which domain output should be in.
Argument: Elements controlling the output domain
Default:

4.2.3.4.1.1 `<depth>`

Description: Should output come in depth domain? Requires information under `<interval-two-surfaces>`.
Argument: 'yes' or 'no'
Default: 'no'

4.2.3.4.1.2 `<time>`

Description: Should output come in time domain?
Argument: 'yes' or 'no'
Default: 'yes'

4.2.3.4.2 `<format>`

Description: Control of the format of output grids.
Argument: Elements controlling the format of output grids
Default:

4.2.3.4.2.1 `<segy-format>`

Description: Information about the segy format. By default CRAVA recognizes SeisWorks, IESX, SIP and Charisma.
Argument: Elements containing information about the segy format.
Default:

4.2.3.4.2.1.1 `<standard-format>`

Description: Giving the starting format for modifications.
Argument: 'seisworks', 'iesx', 'charisma' or 'SIP'
Default: 'seisworks'

4.2.3.4.2.1.2 `<location-x>`

Description: The byte location for the x-coordinate in the trace header.
Argument: Integer
Default:

4.2.3.4.2.1.3 `<location-y>`

Description: The byte location for the y-coordinate in the trace header.
Argument: Integer
Default:

4.2.3.4.2.1.4 `<location-il>`

Description: The byte location for the inline in the trace header.
Argument: Integer
Default:

4.2.3.4.2.1.5 `<location-xl>`

Description: The byte location for the crossline in the trace header.
Argument: Integer
Default:

4.2.3.4.2.1.6 `<bypass-coordinate-scaling>`

Description: Indicates whether coordinate scaling information should be used.
Argument: 'yes' or 'no'
Default:

4.2.3.4.2.1.7 `<location-scaling-coefficient>`

Description:
Argument: Integer
Default:

4.2.3.4.2.2 `<segy>`

Description: Should grid output come as segy?
Argument: 'yes' or 'no'
Default:

4.2.3.4.2.3 <storm>

Description: Should grid output come as storm?
Argument: 'yes' or 'no'
Default: 'yes' if <format> command is not given.

4.2.3.4.2.4 <crava>

Description: Should grid output come in crava binary format?
Argument: 'yes' or 'no'
Default:

4.2.3.4.2.5 <sgri>

Description: Should grid output come as storm sgri?
Argument: 'yes' or 'no'
Default:

4.2.3.4.2.6 <ascii>

Description: Should grid output come as storm ascii?
Argument: 'yes' or 'no'
Default:

4.2.3.4.3 <elastic-parameters>

Description: Controls which elastic grid parameters to output. All are 'yes' or 'no'.
Argument: Elements controlling which elastic parameters to output
Default: If this command is not given, vp, vs and density are written.

4.2.3.4.3.1 <vp>

Description:
Argument: 'yes' or 'no'
Default:

4.2.3.4.3.2 <vs>

Description:
Argument: 'yes' or 'no'
Default:

4.2.3.4.3.3 <density>

Description:
Argument: 'yes' or 'no'
Default:

4.2.3.4.3.4 <lame-lambda>

Description:
Argument: 'yes' or 'no'
Default:

4.2.3.4.3.5 `<lame-mu>`

Description:
Argument: ’yes’ or ’no’
Default:

4.2.3.4.3.6 `<poisson-ratio>`

Description:
Argument: ’yes’ or ’no’
Default:

4.2.3.4.3.7 `<ai>`

Description:
Argument: ’yes’ or ’no’
Default:

4.2.3.4.3.8 `<si>`

Description:
Argument: ’yes’ or ’no’
Default:

4.2.3.4.3.9 `<vp-vs-ratio>`

Description:
Argument: ’yes’ or ’no’
Default:

4.2.3.4.3.10 `<murho>`

Description:
Argument: ’yes’ or ’no’
Default:

4.2.3.4.3.11 `<lambdarho>`

Description:
Argument: ’yes’ or ’no’
Default:

4.2.3.4.3.12 `<background>`

Description:
Argument: ’yes’ or ’no’
Default:

4.2.3.4.3.13 `<background-trend>`

Description:
Argument: ’yes’ or ’no’
Default:

4.2.3.4.4 <seismic-data>

Description: Controls which seismic data parameters to output. All are 'yes' or 'no'.
Argument: Elements controlling which seismic data to output
Default:

4.2.3.4.4.1 <original>

Description: Write original seismic data to file.
Argument: 'yes' or 'no'
Default:

4.2.3.4.4.2 <synthetic>

Description: Generate synthetic seismic from the inverted data.
Argument: 'yes' or 'no'
Default:

4.2.3.4.4.3 <residuals>

Description:
Argument: 'yes' or 'no'
Default:

4.2.3.4.5 <other-parameters>

Description: Controls which other parameters to output. All are 'yes' or 'no'.
Argument: Elements controlling which other to output
Default:

4.2.3.4.5.1 <facies-probabilities>

Description: Write facies probabilities to file.
Argument: 'yes' or 'no'
Default: 'yes' if facies estimation is requested and <facies-probabilities-with-undef> is not specified

4.2.3.4.5.2 <facies-probabilities-with-undef>

Description: Write facies probabilities with undefined value to file.
Argument: 'yes' or 'no'
Default: 'no'

4.2.3.4.5.3 <time-to-depth-velocity>

Description: Write time-to-depth velocity to file.
Argument: 'yes' or 'no'
Default:

4.2.3.4.5.4 <extra-grids>

Description: Temporary, will be replaced. Currently triggers writing of

- Estimated background files in extended versions (go above and below inversion volume).
- Estimated background files in standard volume.

Argument: 'yes' or 'no'
Default:

4.2.3.4.5.5 `<correlations>`

Description: These are the posterior correlations between vp, vs and density after inversion.
Argument: 'yes' or 'no'
Default:

4.2.3.5 `<well-output>`

Description: Collects all output that can be given in well format. Wells contain logs for vp, vs and density, each of these in four versions: Raw, filtered to background frequency, filtered to seismic frequency and seismic resolution. In addition, the facies log is written if found.
Argument: Elements collecting output given in well format
Default:

4.2.3.5.1 `<format>`

Description: Controls well formats used for output. Default is RMS.
Argument: Elements controlling the formats used for output
Default:

4.2.3.5.1.1 `<rms>`

Description: Controls if wells are written on RMS format.
Argument: 'yes' or 'no'
Default:

4.2.3.5.1.2 `<norsar>`

Description: Controls if wells are written on NORSAR format.
Argument: 'yes' or 'no'
Default:

4.2.3.5.2 `<wells>`

Description: Writes wells following original sampling density.
Argument: 'yes' or 'no'
Default:

4.2.3.5.3 `<blocked-wells>`

Description: Writes wells sampled to internal grid resolution.
Argument: 'yes' or 'no'
Default:

4.2.3.5.4 `<blocked-logs>`

Description: Not currently active.
Argument:
Default:

4.2.3.6 `<wavelet-output>`

Description: Collects all output that can be given for wavelets.
Argument: Elements controlling wavelet output
Default:

4.2.3.6.1 `<format>`

Description: Controls wavelet formats used for output. Default is JASON.
Argument: Elements controlling the formats used for output
Default:

4.2.3.6.1.1 `<jason>`

Description: Controls if wavelets are written on JASON form, being 'wlt' format.
Argument: 'yes' or 'no'
Default: 'yes'

4.2.3.6.1.2 `<norsar>`

Description: Controls if wavelets are written on NORSAR form, being 'swav' format.
Argument: 'yes' or 'no'
Default: 'no'

4.2.3.6.2 `<well-wavelets>`

Description: Writes estimated wavelets for each well used for wavelet estimation.
Argument: 'yes' or 'no'
Default: 'no'

4.2.3.6.3 `<global-wavelets>`

Description: Writes global wavelets for each seismic angle.
Argument: 'yes' or 'no'
Default: 'no'

4.2.3.6.4 `<local-wavelets>`

Description: Writes estimated local wavelet shift and scale surfaces. Can only be written when `<local-wavelet>` is requested.
Argument: 'yes' or 'no'
Default:

4.2.3.7 `<other-output>`

Description: Controls output that is neither standard grid nor well.
Argument: Elements controlling output
Default:

4.2.3.7.1 <extra-surfaces>

Description: Temporary, will be replaced. Currently writes:

- Top and base surface for constant thickness interval used for log filtering and facies probabilities.
- Top and base surface for extended inversion interval computed from correlation surface.
- Top and base surface for background estimation interval (larger than inversion interval).

Argument: 'yes' or 'no'
Default:

4.2.3.7.2 <prior-correlations>

Description: Write prior correlation files.
Argument: 'yes' or 'no'
Default:

4.2.3.7.3 <background-trend-1d>

Description: Write the background trend as 1D curve.
Argument: 'yes' or 'no'
Default:

4.2.3.7.4 <local-noise>

Description: Writes estimated local noise surface. Can only be written when <local-noise-scaled> or <estimate-local-noise> is requested.
Argument: 'yes' or 'no'
Default:

4.2.3.7.5 <rock-physics-distributions>

Description: Writes rock physics distribution per facies, in a vp, vs, and density STORM-grid. Only available when facies probabilities are computed.
Argument: 'yes' or 'no'
Default: 'no'

4.2.3.8 <file-output-prefix>

Description: Common prefix added to all files written in the run. Identifies the run.
Argument: String
Default:

4.2.3.9 <log-level>

Description:
Argument: String. Possible values are error, warning, low, medium, high.
Default: Low

4.2.4 <advanced-settings>

Description: A collection of different commands that control advanced aspects of the program control.
Argument: Commands controlling advanced aspects of the program control
Default:

4.2.4.1 `<fft-grid-padding>`

Description: Controls the padding size, can be used to optimize memory or improve visual results. Padding should be at least one range laterally, and a wavelet length vertically to avoid edge effects.

Argument: Elements controlling the padding size

Default:

4.2.4.1.1 `<x-fraction>`

Description: Value telling how large the padding in the x-direction should be relative to the x-length.

Argument: Value

Default: 0.0

4.2.4.1.2 `<y-fraction>`

Description: Value telling how large the padding in the x-direction should be relative to the y-length.

Argument: Value

Default: 0.0

4.2.4.1.3 `<z-fraction>`

Description: Value telling how large the padding in the x-direction should be relative to the thickness.

Argument: Value

Default: 0.0

4.2.4.2 `<use-intermediate-disk-storage>`

Description: When running under windows with less physical memory than the program requires, this activates a built-in smart-swap. It is more efficient to use this smart-swapping than the built-in windows paging system. Linux/unix swap is so efficient that this option has little effect there. If you run Crava on a machine that you share with other users, it can be wise ut use this if you know that Crava will need most of the memory.

Argument: 'yes' or 'no'

Default:

4.2.4.3 `<maximum-relative-thickness-difference>`

Description: Value giving the limit of how small the minimum interval thickness can be relative to maximum. If this gets too low, the transformation to stationarity for the FFT-algorithm gives strange results.

Argument: Value

Default: Default is 0.5, which is ok. Slightly smaller seems to work as well.

4.2.4.4 `<frequency-band>`

Description: This command controls the frequency band of the inversion, so high and/or low frequencies can be filtered away. This ought to be done by the wavelet, but can be done here.

Argument: Elements controlling the frequency band of the inversion

Default:

4.2.4.4.1 <low-cut>

Description: Value setting the minimum frequency affected by the inversion.
Argument: Value
Default: 5.0

4.2.4.4.2 <high-cut>

Description: Value setting the maximum frequency affected by the inversion.
Argument: Value
Default: 55.0

4.2.4.5 <energy-threshold>

Description: If the energy in a trace falls below this threshold relative to the average, the trace is interpolated from neighbors.
Argument: Value
Default: 0.0

4.2.4.6 <wavelet-tapering-length>

Description: Value giving the length of the wavelet to be estimated in ms.
Argument: Value
Default: 200.0

4.2.4.7 <minimum-relative-wavelet-amplitude>

Description: Value giving the ratio between the smallest relevant amplitude and the largest amplitude of peaks on an estimated wavelet. Edge peaks below this ratio are removed.
Argument: Value
Default: 0.05

4.2.4.8 <maximum-wavelet-shift>

Description: Value controlling how much the wavelet is allowed to be shifted when doing estimation of wavelet or noise.
Argument: Value
Default: 11.0

4.2.4.9 <white-noise-component>

Description: In order to stabilize the inversion, we need to interpret some of the noise as white. This value controls the fraction.
Argument: Value between 0 and 1.
Default: 0.1

4.2.4.10 <reflection-matrix>

Description: The file should be a 3 by number of seismic data cubes ascii matrix. The first column is the factor used for vp for each cube setting (angle and ps/pp) when computing the reflection coefficients. The second and third are for vs and density.
Argument: File name
Default: Linearized Aki-Richards.

4.2.4.11 <kriging-data-limit>

Description: Integer value giving the limit for the amount of well data used to krige each point. A high value gives a smoother and more exact field, but takes more time.
Argument: Integer
Default: 250

4.2.4.12 <debug-level>

Description: Gives debug messages and output. Not intended for use except on request by NR.
Argument: Integer value 0, 1 or 2.
Default: 0

4.2.4.13 <smooth-kriged-parameters>

Description: Tells whether we should smooth borders between kriging blocks or not.
Argument: yes or no
Default: no

4.3 <survey> (necessary)

Description: All information about the seismic data is collected here.
Argument: Elements containing information about the seismic data
Default:

4.3.1 <angular-correlation>

Description: 1D variogram. Gives the noise correlation between survey angles.
Argument: 1D variogram
Default:

4.3.2 <segy-start-time>

Description: Global start time for segy cubes. This is used if no individual time is given for a segy-cube.
Argument: Value
Default:

4.3.3 <angle-gather> (necessary)

Description: Repeatable command, one for each seismic data cube.
Argument: Elements containing information about the different seismic data cubes
Default:

4.3.3.1 <offset-angle> (necessary)

Description: This is the angle for the seismic data cube.
Argument: Value
Default:

4.3.3.2 <seismic-data> (necessary)

Description: Information about the seismic data cube.
Argument: Elements containing information about the seismic data cube
Default:

4.3.3.2.1 <file-name> (necessary)

Description: File name for the seismic data cube. This can be a segy file, a storm binary file, a Sgri file or a crava binary file. The file type will be automatically detected.
Argument: File name
Default:

4.3.3.2.2 `<start-time>`

Description: Value giving the start time for this segy file.
Argument: Value
Default:

4.3.3.2.3 `<segy-format>`

Description: Information about the segy format. By default, CRAVA recognizes SeisWorks, IESX, SIP and Charisma.
Argument: Elements containing information about the segy format
Default:

4.3.3.2.3.1 `<standard-format>`

Description: Giving the starting format for modifications.
Argument: 'seisworks', 'iesx', 'charisma' or 'SIP'
Default: 'seisworks'

4.3.3.2.3.2 `<location-x>`

Description: The byte location for the x-coordinate in the trace header.
Argument: Integer
Default:

4.3.3.2.3.3 `<location-y>`

Description: The byte location for the y-coordinate in the trace header.
Argument: Integer
Default:

4.3.3.2.3.4 `<location-il>`

Description: The byte location for the inline in the trace header.
Argument: Integer
Default:

4.3.3.2.3.5 `<location-xl>`

Description: The byte location for the crossline in the trace header.
Argument: Integer
Default:

4.3.3.2.3.6 `<bypass-coordinate-scaling>`

Description: Indicates whether coordinate scaling information should be used.
Argument: 'yes' or 'no'

Default:

4.3.3.2.3.7 `<location-scaling-coefficient>`

Description:
Argument: Integer
Default:

4.3.3.2.4 `<type>`

Description: Indicating the type of seismic data. Note that if both pp and ps cubes are used, these must be aligned.
Argument: 'pp' or 'ps'
Default: 'pp'

4.3.3.3 `<wavelet>`

Description: Information about the wavelet for this angle and seismic type. If not given, the wavelet will be estimated.
Argument: Elements containing information about the wavelet and seismic type
Default:

4.3.3.3.1 `<file-name>`

Description: File name for wavelet file. If not given, wavelet is estimated.
Argument: File name
Default:

4.3.3.3.2 `<scale>`

Description: Wavelet read from file is multiplied by this. Has no meaning when wavelet is estimated.
Argument: Value
Default:

4.3.3.3.3 `<estimate-scale>`

Description: Should global scale be estimated?
Argument: 'yes' or 'no'
Default:

4.3.3.3.4 `<local-wavelet>`

Description: The amplitude and shift of the wavelet may be modified locally by 2D fields for shift and scale values. This is handled here.
Argument: Elements modifying the amplitude and shift of the wavelet
Default:

4.3.3.3.4.1 `<shift-file>`

Description: File name for storm surface file giving the local shift for the wavelet. Not allowed when wavelet is estimated.
Argument: File name

Default:

4.3.3.3.4.2 <scale-file>

Description: File name for storm surface file giving local scale for the wavelet. Not allowed when wavelet is estimated.
Argument: File name
Default:

4.3.3.3.4.3 <estimate-shift>

Description: Should a local shift be estimated? Not allowed with <shift-file>, but can be used both with given and estimated wavelet.
Argument: 'yes' or 'no'
Default:

4.3.3.3.4.4 <estimate-scale>

Description: Should a local scale be estimated? Not allowed with <scale-file>, but can be used both with given and estimated wavelet.
Argument: 'yes' or 'no'
Default:

4.3.3.4 <wavelet-3d>

Description: Information about the 3D-wavelet for this angle and seismic type. If not given, a 1D-wavelet is assumed.
Argument: Elements containing information about the 3D-wavelet
Default:

4.3.3.4.1 <file-name>

Description: File name for the 1D-wavelet file. This 1D-wavelet will define the 3D-wavelet in combination with the filter given in <processing-factor-file-name>. If not given, the 1D-wavelet is estimated.
Argument: File name
Default:

4.3.3.4.2 <processing-factor-file-name>

Description: File name for 3D-wavelet damping factor filter file. The 3D-wavelet is defined by the 1D-wavelet and the filter. The 1D-wavelet is either given in <file-name4> or estimated. In either case this filter file must be given.
Argument: File name for the amplitude scalings in the wavenumber filter.
Default:

4.3.3.4.3 <propagation-factor-file-name>

Description: File name for 3D-wavelet correction filter filter file. This is used to set up the noise model for the 3D-wavelet.
Argument: File name for the correction factors in the wavenumber filter.
Default:

4.3.3.4.4 `<stretch-factor>`

Description: Stretch factor for 3D-wavelet. The pulse is stretch with this factor.
Argument: Value > 0.0
Default: 1.0

4.3.3.4.5 `<estimation-range-x-direction>`

Description: Range for area around the well in x-direction where data are used in 3D wavelet estimation.
Argument: Value >= 0.0
Default: 0.0

4.3.3.4.6 `<estimation-range-y-direction>`

Description: Range for area around the well in y-direction where data are used in 3D wavelet estimation.
Argument: Value >= 0.0
Default: 0.0

4.3.3.5 `<match-energies>`

Description: If 'yes', signal to noise ratio and wavelet scaling will be set to match model values with empirical values. Not a common estimator.
Argument: 'yes' or 'no'
Default:

4.3.3.6 `<signal-to-noise-ratio>`

Description: Value for the signal to noise value. If not given, this will be estimated.
Argument: Value
Default:

4.3.3.7 `<local-noise-scaled>`

Description: Name of file with local noise.
Argument: File name
Default:

4.3.3.8 `<estimate-local-noise>`

Description: Can not say 'yes' here if `<local-noise-scaled>` is given.
Argument: 'yes' or 'no'
Default:

4.3.4 `<wavelet-estimation-interval>`

Description: Controls the time interval used for wavelet estimation by a top and base surface.
Argument: Elements controlling the time interval used for wavelet estimation
Default: By default, estimation is done from all available seismic and well data.

4.3.4.1 `<top-surface-file>`

Description: File name for storm surface file giving the top of the time interval used for wavelet estimation.
Argument: File name
Default:

4.3.4.2 <base-surface-file>

Description: File name for storm surface file giving the base of the time interval used for wavelet estimation.
Argument: File name
Default:

4.4 <well-data>

Description: All information about the well data is collected here.
Argument: Elements containing information about the well data
Default:

4.4.1 <log-names>

Description: CRAVA needs to find the time, vp, vs, density and possibly facies logs. The name of these logs in the well files are given here.
Argument: Name of logs
Default:

4.4.1.1 <time>

Description: Name of the TWT log
Argument: String
Default:

4.4.1.2 <vp>

Description: Name of the vp log. May not be given if <dt> is given.
Argument: String
Default:

4.4.1.3 <dt>

Description: Name of the inverse vp log. May not be given if <vp> is given.
Argument: String
Default:

4.4.1.4 <vs>

Description: Name of the vs log. May not be given if <dts> is given.
Argument: String
Default:

4.4.1.5 <dts>

Description: Name of the inverse vs log. May not be given if <vs> is given.
Argument: String
Default:

4.4.1.6 <density>

Description: Name of the density log.
Argument: String
Default:

4.4.1.7 `<facies>`

Description: Name of the facies log.
Argument: String
Default:

4.4.2 `<well>`

Description: Repeatable command, one for each well. Contains information about the wells.
Argument: Elements containing information about the wells
Default:

4.4.2.1 `<file-name>`

Description: File name for a well file. RMS or Norsar format.
Argument: File name
Default:

4.4.2.2 `<use-for-wavelet-estimation>`

Description: Should this well be used for wavelet estimation?
Argument: 'yes' or 'no'
Default:

4.4.2.3 `<use-for-background-trend>`

Description: Should this well be used for background trend estimation?
Argument: 'yes' or 'no'
Default:

4.4.2.4 `<use-for-facies-probabilities>`

Description: Should this well be used for facies probability estimation?
Argument: 'yes' or 'no'
Default:

4.4.2.5 `<synthetic-vs-log>`

Description: Is the Vs log in this well synthetic? Will be detected from Vp correlation if not specified here.
Argument: 'yes' or 'no'
Default:

4.4.2.6 `<filter-elastic-logs>`

Description: Should we multi-parameter-filter the elastic logs in this well after the inversion?
Argument: 'yes' or 'no'
Default:

4.4.2.7 `<optimize-position>`

Description: Repeatable command, one for each offset angle used for estimating optimized well location for this well.
Argument: Elements controlling optimization of well location
Default:

4.4.2.7.1 `<angle>`

Description: Offset angle used for estimating optimized well location
Argument: Value
Default:

4.4.2.7.2 `<weight>`

Description: Weight of the offset angle given in `<angle>`
Argument: Value
Default: 1

4.4.3 `<high-cut-seismic-resolution>`

Description: This frequency is used to filter wells down to seismic resolution. Only used to generate output logs for QC.
Argument: Value
Default:

4.4.4 `<allowed-parameter-values>`

Description: Sometimes there are faulty values in well logs. Here, trigger values for error detection can be controlled. These fall in two categories: Actual log values that are wrong, or logs that have extremely low or high variance when the background model is subtracted.
Argument: Elements controlling trigger values for error detection
Default:

4.4.4.1 `<minimum-vp>`

Description: Value for the smallest legal vp value.
Argument: Value
Default: 1300 m/s

4.4.4.2 `<maximum-vp>`

Description: Value for the largest legal vp value.
Argument: Value
Default: 7000 m/s

4.4.4.3 `<minimum-vs>`

Description: Value for the smallest legal vs value.
Argument: Value
Default: 200 m/s

4.4.4.4 `<maximum-vs>`

Description: Value for the largest legal vs value.
Argument: Value
Default: 4200 m/s

4.4.4.5 `<minimum-density>`

Description: Value for the smallest legal density value.
Argument: Value
Default: 1.4 g/cm^3

4.4.4.6 `<maximum-density>`

Description: Value for the largest legal density value.
Argument: Value
Default: 3.3 g/cm^3

4.4.4.7 `<minimum-variance-vp>`

Description: Value for the smallest legal variance in the vp log after the background is subtracted and logarithm is taken.
Argument: Value
Default: 0.0005

4.4.4.8 `<maximum-variance-vp>`

Description: Value for the largest legal variance in the vp log after the background is subtracted and logarithm is taken.
Argument: Value
Default: 0.0250

4.4.4.9 `<minimum-variance-vs>`

Description: Value for the smallest legal variance in the vs log after the background is subtracted and logarithm is taken.
Argument: Value
Default: 0.0010

4.4.4.10 `<maximum-variance-vs>`

Description: Value for the largest legal variance in the vs log after the background is subtracted and logarithm is taken.
Argument: Value
Default: 0.0500

4.4.4.11 `<minimum-variance-density>`

Description: Value for the smallest legal variance in the density log after the background is subtracted and logarithm is taken.
Argument: Value
Default: 0.0002

4.4.4.12 `<maximum-variance-density>`

Description: Value for the largest legal variance in the density log after the background is subtracted and logarithm is taken.
Argument: Value
Default: 0.0100

4.4.4.13 `<minimum-vp-vs-ratio>`

Description: Value for the smallest Vp/Vs-ratio regarded as likely.
Argument: Value
Default: 1.4

4.4.4.14 `<maximum-vp-vs-ratio>`

Description: Value for the largest Vp/Vs-ratio regarded as likely.
Argument: Value

Default: 3.0

4.4.5 <maximum-deviation-angle>

Description: Value for the maximum deviation angle of a well before it is excluded from estimation based on vertical wells (such as wavelet and signal to noise).
Argument: Value
Default: 15

4.4.6 <maximum-rank-correlation>

Description: If the correlation between vp and vs logs exceed this value, the vs log is considered to be synthetic, and not counted as additional data in estimation.
Argument: Value close to, but less than 1.
Default: 0.99

4.4.7 <maximum-merge-distance>

Description: Value giving the minimum distance in time between well log entries before they are merged to one observation.
Argument: Value
Default: 0.01

4.4.8 <maximum-offset>

Description: Value giving the maximum allowed offset for moving wells in meters.
Argument: Value
Default: 250

4.4.9 <maximum-shift>

Description: Value giving the maximum allowed vertical shift for moving wells.
Argument: Value
Default: 11.0

4.4.10 <well-move-data-interval>

Description: Defines an interval for estimation of facies probability given elastic parameters.
Argument: Elements defining estimation interval
Default: Everywhere facies and elastic logs are present.

4.4.10.1 <top-surface-file>

Description: File name for storm surface file giving the top of the estimation interval.
Argument: File name
Default:

4.4.10.2 <base-surface-file>

Description: File name for storm surface file giving the base of the estimation interval.
Argument: File name
Default:

4.5 <prior-model>

Description: This command defines the prior model for elastic parameters and possibly also facies.
Argument: Elements defining prior models for elastic parameters and facies

Default:

4.5.1 `<background>`

Description: Contains information about the background model or how to estimate it. Note that either all parameters must be given, or all must be estimated.
Argument: Elements containing information about the background model
Default:

4.5.1.1 `<vp-file>`

Description: File name for storm, segy, Sgri or crava grid file, giving background vp. Can not be given together with `<vp-constant>`.
Argument: File name
Default:

4.5.1.2 `<vs-file>`

Description: File name for storm, segy, Sgri or crava grid file, giving background vs. Can not be given together with `<vs-constant>`.
Argument: File name
Default:

4.5.1.3 `<density-file>`

Description: File name for storm, segy, Sgri or crava grid file, giving background density. Can not be given together with `<density-constant>`.
Argument: File name
Default:

4.5.1.4 `<vp-constant>`

Description: Value, used for constant vp background. Can not be given together with `<vp-file>`.
Argument: Value
Default:

4.5.1.5 `<vs-constant>`

Description: Value, used for constant vs background. Can not be given together with `<vs-file>`.
Argument: Value
Default:

4.5.1.6 `<density-constant>`

Description: Value, used for constant density background. Can not be given together with `<density-file>`.
Argument: Value
Default:

4.5.1.7 `<velocity-field>`

Description: File name for storm grid file giving a velocity field used as base for vp in background estimation. Can not be used if the background parameters are given.
Argument: File name
Default:

4.5.1.8 <lateral-correlation>

Description: 2D variogram for the lateral correlation in the elastic parameters in the estimated background model, used for kriging of wells. Can not be used if the background parameters are given.
Argument: 2D variogram
Default:

4.5.1.9 <high-cut-background-modelling>

Description: Value giving the maximum frequency in the estimated background model. Can not be used if the background parameters are given.
Argument: Value
Default:

4.5.2 <earth-model>

Description: Contains inverted seismic data used for forward modeling.
Argument: Vp, vs and rho used for forward modeling.
Default:

4.5.2.1 <vp-file>

Description: File name for storm, segy, Sgri or crava grid file, giving vp.
Argument: File name
Default:

4.5.2.2 <vs-file>

Description: File name for storm, segy, Sgri or crava grid file, giving vs.
Argument: File name
Default:

4.5.2.3 <density-file>

Description: File name for storm, segy, Sgri or crava grid file, giving density.
Argument: File name
Default:

4.5.3 <local-wavelet>

Description: Contains prior information for local wavelet modeling.
Argument: Elements containing prior information for local wavelet estimation.
Default:

4.5.3.1 <lateral-correlation>

Description: 2D variogram for the lateral correlation in local wavelet modeling.
Argument: 2D variogram
Default:

4.5.4 <lateral-correlation>

Description: 2D variogram for the lateral correlation in the elastic parameters.
Argument: 2D variogram
Default:

4.5.5 <temporal-correlation>

Description: File name for the temporal correlation file.
Argument: File name
Default:

4.5.6 <parameter-correlation>

Description: File name for the parameter correlation file.
Argument: File name
Default:

4.5.7 <correlation-direction>

Description: File name for the storm surface file giving the correlation direction for the inversion.
Argument: File name
Default:

4.5.8 <facies-probabilities>

Description: Commands controlling the generating of facies probabilities.
Argument: Elements controlling facies probabilities
Default:

4.5.8.1 <use-vs>

Description: Decides whether V_s information is used when computing facies probabilities.
Argument: 'yes' or 'no'.
Default: 'yes'.

4.5.8.2 <use-prediction>

Description: Decides whether sampled inversion logs are used when computing facies probabilities. If not, filtered logs are used.
Argument: 'yes' or 'no'.
Default: 'no'.

4.5.8.3 <use-absolute-elastic-parameters>

Description: Decides whether facies probabilities are generated based on absolute elastic parameters or elastic parameters minus trend (background model).
Argument: 'yes' or 'no'
Default: 'no'

4.5.8.4 <estimation-interval>

Description: Defines an interval for estimation of facies probability given elastic parameters.
Argument: Elements defining estimation interval
Default: Everywhere facies and elastic logs are present.

4.5.8.4.1 <top-surface-file>

Description: File name for storm surface file giving the top of the estimation interval.
Argument: File name
Default:

4.5.8.4.2 <base-surface-file>

Description: File name for storm surface file giving the base of the estimation interval.
Argument: File name
Default:

4.5.8.5 `<prior-probabilities>`

Description: Prior facies probabilities are given for all facies. Priors can be given as constant numbers or storm cubes. If this command is not given, prior distribution is estimated from wells.
Argument: Elements controlling facies probabilities
Default:

4.5.8.5.1 `<facies>`

Description: Repeatable command, one for each facies. All facies present in well logs must be given.
Argument: Elements containing information about the facies
Default:

4.5.8.5.1.1 `<name>`

Description: Name of facies.
Argument: Facies name
Default:

4.5.8.5.1.2 `<probability>`

Description: Probability for the facies given above. Either this command or `<probability-cube>` is given, same for all facies.
Argument: Real numbers between 0 and 1. Numbers for all facies must sum to one.
Default:

4.5.8.5.1.3 `<probability-cube>`

Description: File name for file containing prior facies probability for facies with name given above. Either this command or `<probability>` is given, same for all facies.
Argument: File name
Default:

4.5.8.6 `<uncertainty-level>`

Description: Value defining how large the undefined probability will be when facies probabilities are computed. This value is scaled and used as likelihood for undefined when facies probabilities are computed.
Argument: Value
Default: 0.01

4.6 `<variogram-keyword>`

Description: Variograms are given on the following form
Argument:
Default:

4.6.1 `<variogram-type>`

Description: Either 'genexp' or 'spherical' for general exponential or spherical variogram.
Argument:
Default:

4.6.2 `<angle>`

Description: Value for the azimuth direction.
Argument:
Default:

4.6.3 `<range>`

Description: Value for the range in the azimuth direction.
Argument:
Default:

4.6.4 `<subrange>`

Description: Value for the range normal to the azimuth direction.
Argument:
Default:

4.6.5 `<power>`

Description: Value between 1 and 2 for the power of the general exponential variogram. Not allowed for spherical variogram.
Argument:
Default:

All angles are given as mathematical angles in degrees.

A Sample CRAVA model file

```
<crava>
<actions>
  <mode> inversion </mode>
  <inversion-settings>
    <prediction> yes </prediction>
    <kriging-to-wells> yes </kriging-to-wells>
  </inversion-settings>
</actions>


<survey>
  <angular-correlation>
    <variogram-type> genexp </variogram-type>
    <range> 10 </range>
    <power> 1 </power>
  </angular-correlation>
  <segy-start-time> 2500 </segy-start-time>
  <angle-gather>
    <offset-angle> 16 </offset-angle>
    <seismic-data>
      <file-name> ../../5_two_cubes_four_wells_pred_nokrig/input/seismic/Cube16.segy </file-name>
    </seismic-data>
    <wavelet>
      <file-name>
        ../../5_two_cubes_four_wells_pred_nokrig/input/wavelets/CRAVA_Wavelet_Scaled_16.0_deg.asc
      </file-name>
    </wavelet>
    <signal-to-noise-ratio> 4 </signal-to-noise-ratio>
  </angle-gather>
  <angle-gather>
    <offset-angle> 28 </offset-angle>
    <seismic-data>
      <file-name> ../../5_two_cubes_four_wells_pred_nokrig/input/seismic/Cube28.segy </file-name>
    </seismic-data>
    <wavelet>
      <file-name>
        ../../5_two_cubes_four_wells_pred_nokrig/input/wavelets/CRAVA_Wavelet_Scaled_28.0_deg.asc
      </file-name>
    </wavelet>
    <signal-to-noise-ratio> 3 </signal-to-noise-ratio>
  </angle-gather>
</survey>

<well-data>
  <log-names>
    <time>    TWT  </time>
    <dt>      DT   </dt>
    <dts>     DTS  </dts>
```

```
    <density> RHOB </density>
  </log-names>
  <well>
    <file-name> ../../5_two_cubes_four_wells_pred_nokrig/input/logs/ed6406_3-3_cut.rms    </file-name>
  </well>
  <well>
    <file-name> ../../5_two_cubes_four_wells_pred_nokrig/input/logs/ed6506_12-3_cut.rms   </file-name>
  </well>
  <well>
    <file-name> ../../5_two_cubes_four_wells_pred_nokrig/input/logs/ed6506_12-8_cut.rms   </file-name>
  </well>
  <well>
    <file-name> ../../5_two_cubes_four_wells_pred_nokrig/input/logs/ed6506_12-S4H_cut.rms </file-name>
  </well>
</well-data>

<prior-model>
  <background>
    <vp-file>
      ../../5_two_cubes_four_wells_pred_nokrig/input/background/CRAVA_BG_Vp.storm
    </vp-file>
    <vs-file>
      ../../5_two_cubes_four_wells_pred_nokrig/input/background/CRAVA_BG_Vs.storm
    </vs-file>
    <density-file>
      ../../5_two_cubes_four_wells_pred_nokrig/input/background/CRAVA_BG_Rho.storm
    </density-file>
  </background>
  <lateral-correlation>
    <variogram-type> genexp </variogram-type>
    <range> 1000 </range>
    <subrange> 500 </subrange>
    <angle> 70 </angle>
    <power> 1  </power>
  </lateral-correlation>
</prior-model>

<project-settings>
  <output-volume>
    <utm-coordinates>
      <reference-point-x>  398500 </reference-point-x>
      <reference-point-y> 7210300 </reference-point-y>
      <length-x> 4500 </length-x>
      <length-y> 4500 </length-y>
      <angle> 23.627 </angle>
      <sample-density-x> 50 </sample-density-x>
      <sample-density-y> 50 </sample-density-y>
    </utm-coordinates>
    <interval-two-surfaces>
      <top-surface>
        <time-file>
          ../../5_two_cubes_four_wells_pred_nokrig/input/horizons/TopTime_avg3100ms.storm
        </time-file>
```

```
      </top-surface>
      <base-surface>
        <time-file>
          ../../5_two_cubes_four_wells_pred_nokrig/input/horizons/BaseTime_avg3600ms.storm
        </time-file>
      </base-surface>
      <number-of-layers>
        125
      </number-of-layers>
    </interval-two-surfaces>
  </output-volume>
  <io-settings>
    <file-output-prefix> CRAVA_ </file-output-prefix>
    <grid-output>
      <format>
        <ascii> yes </ascii>
      </format>
      <domain>
        <time>  yes </time>
        <depth> no </depth>
      </domain>
      <elastic-parameters>
        <vp> yes </vp>
        <vs> yes </vs>
        <density> yes </density>
        <background> no </background>
      </elastic-parameters>
    </grid-output>
    <well-output>
      <wells> no </wells>
      <blocked-wells> no </blocked-wells>
    </well-output>
    <other-output>
      <wavelets>            no </wavelets>
      <prior-correlations>  no </prior-correlations>
      <background-trend-1d> no </background-trend-1d>
    </other-output>
  </io-settings>
  <advanced-settings>
    <fft-grid-padding>
      <x-fraction> 0.200001 </x-fraction>
      <y-fraction> 0.200001 </y-fraction>
      <z-fraction> 1.000000 </z-fraction>
    </fft-grid-padding>
    <white-noise-component>
      0.1
    </white-noise-component>
  </advanced-settings>
</project-settings>
</crava>
```

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