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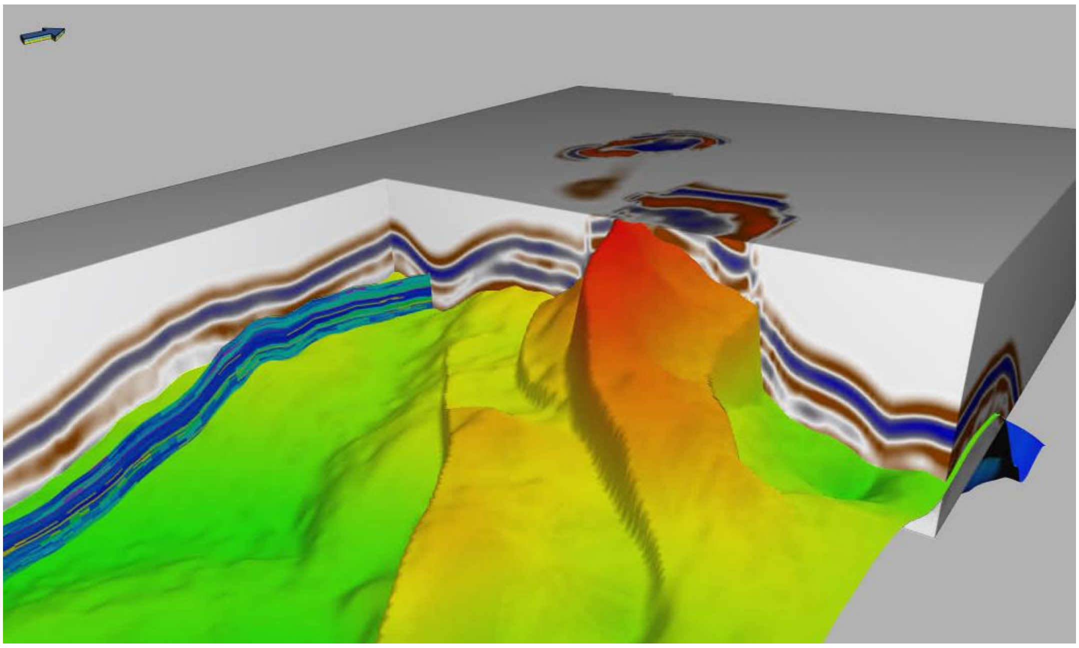
Note

Seismic Forward

User manual – version 4.3



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Abstract

This document describes Seismic Forward, a tool for generating synthetic seismic from elastic parameters Vp, Vs and density.

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Contents

1 Introduction

Seismic Forward is a tool for generating synthetic reflection seismic data from elastic parameters Vp, Vs and density. The elastic parameters are given in an Eclipse grid. The program is written in C++. The program takes as input argument a model file of XML format, described in Section 4. The main output is synthetic seismic data in SegY format and in a STORM grid (which can easily be imported to RMS). The seismic can be given in both time and depth, and seismic for various angles/offsets can be generated. Various output parameters can be selected and written on STORM or SegY format.

Release notes for recent versions are presented in Section 2. Section 3 gives a brief description of the theory and the implementation, and Section 4 gives a description of how to build a model file. Section 5 gives description of file formats and references respectively.

2 Release notes

2.1 Version 4.3

Reduce the number of grid cells with negative thicknesses when converting Eclipse grid to seismic grid.

A considerable amount of time has been spent reducing the number of grid cells with negative thicknesses. Given the flexibility enjoyed by Eclipse grids, it has proven very difficult to remove these negative thicknesses altogether. Important steps to improve the result:

A) Remove a division by zero bug that lead to “holes” in the generated seismic data
B) Fill values in edge cells that were formerly empty and that gave edge effects
C) Use the same Delaunay triangularization for all layers of the Eclipse grid. This can be turned off with using keyword <fixed-triangularization-of-eclipse-grid> (see Section 4.1.11)
D) When extracting layers from Eclipse grid, require active columns rather than active pillars
E) Use horizontal interpolation for the top and base surfaces of the Eclipse grid - use vertical interpolation when mapping the grid. Prior to version 4.3, horizontal interpolation was used for all layers. Vertical interpolation can be turned off for the grid mapping using keyword <vertical-interpolation-of-undefined-cells> (see Section 4.1.9) and horizontal interpolation can be activated using keyword <horizontal-interpolation-of-undefined-cells> (see section 4.1.10).

If negative thicknesses are encountered, the file negative_dz_points.rxat will be written to the output directory. The file format is Roxar Attribute Text and the file contains the location of negative thicknesses and attributes “Negative dz” and “Layer”. See Section 3.2 for details.

Wavelet export

The wavelet can be exported using keyword <wavelet> which is currently a part of element <output-parameters> (see Section 4.8.11).

Wavelet from file

When wavelet is read from file, the maximum amplitude (in absolute value) is now picked automatically as zero-time reference. The sample number for zero time specified in the wavelet file is over-run.

Wavelet length
The wavelet length is now estimated as the region where the amplitude is at least 0.001 of the maximum amplitude. The cut-off factor used to be 0.01 for wavelets read from file, but this gave noise in 4D data. For consistency, a Ricker wavelet has its length calculated the same way. For Ricker wavelets, the length was formerly defined to be 1000 / peak frequency. The wavelet length can also be given as input using the keyword <wavelet><length>.

White noise
Prior to version 4.3, white noise was added to reflection coefficients. Since this noise was convolved with the wavelet it was coloured. With this release noise added using the <white-noise> keyword adds noise to the synthetic seismic rather than to reflection coefficients. Specify <equal-noise-for-offsets> yes to have the same noise added to all offsets. To have noise added to reflection coefficients, the keyword <add-noise-to-refl-coef> can be used (see Section 4.5).

Grid padding
Prior to version 4.3, the grid was always padded with half a wavelet above the top and below the bottom. To get a different padding, the keyword <padding-factor-seismic-modelling> can be used. The original padding, which is default, is obtained with the factor 1.0

Log file
When running Seismic Forward, a log file is now generated. This file reports the model setup and parameter settings as well as statistics of both the elastic input parameters and output seismic data. In addition, run-time choices that are made are reported.

Test suite
To avoid introducing errors and breaking functionality, a test suite has been added to the Git repository. The test suite consists of a set of different forward modelling jobs with predefined answers. When running the test suite, output data are compared with the predefined answers. If there are mismatches, these are reported. See the Github README file for details on how to run the tests.

Moved keywords/commands
Keywords <max-threads> and <traces-in-memory> have been moved from top level <seismic-forward> to new element <project-settings>.

2.2 Version 4.2

This version was withdrawn prior to release.

2.3 Version 4.1

Offset seismic without stretch
Seismic according to offset but without NMO-stretch can be generated using the command in Section 4.6.4 <offset-without-stretch>. See section 3.5.3 for further details.

Parallelization
The resampling of depth surfaces and elastic parameters have been parallelized, as have the export of properties to SegY file. Properties include elastic properties as well as additional properties requested by the user.

Removal of negative thicknesses
Negative thicknesses can be automatically set to zero by using the command <remove-negative-delta-z> described in Section 4.1.8.

Resampling of parameters to SegY grid using interpolation
The vertical resampling of parameters into depth or time according to the SegY grid can now be performed by an interpolation rather than an index-based mapping. This is activated using the command <resampl-param-to-segy-with-interpol> described in Section 4.1.12. The lateral resampling is performed as earlier with centre point interpolation, see Sections 3.2 and 3.3.

2.4 Version 4.0

Seismic with NMO-stretch
The main new feature is the option to generate seismic with NMO-stretch – both for PP and PS data. The seismic is modelled for a set of specified offsets. Theory and relevant commands to include in the model file are given in Sections 3.5 and 4.6, respectively.

Data written to file sequentially
In order to save memory, the seismic traces are written to SegY files sequentially as calculated in the program. The option <memory-limit> is therefore removed. If seismic in Storm format is requested, the entire output grid will be stored in memory; hence seismic in Storm format may not be feasible for very large grids.

All pre-stack seismic on the same SegY file
When modelling seismic for more than one angle or offset and pre-stack seismic output is requested (Sections 4.8.15 to 4.8.18), all data are written to the same SegY file. This means that the names of the SegY files will not include any angle or offset numbering. The angle or offset of each specific seismic trace is given in the "trace header" of the SegY file (see Section 5.2). For seismic with NMO-stretch, output of the seismic time prior to NMO correction can be requested by the command < seismic-time-prenmo-segy> (see Figure 9 for example).

Only seismic stack on Storm grid
When modelling seismic for more than one angle or offset, only stacked seismic is available in Storm format. This means that for instance the commands <seismic-time> and <seismic-stack><time-storm> give identical output. If seismic for one specific angle or offset is requested on Storm format, the seismic modelling must be run with only this angle or offset. In previous versions, the default value for <seismic-time> and <seismic-depth> was 'yes', but in this version, default is 'no'.

Depth conversion and time shift performed differently
The seismic is now <u>only</u> modelled in time and is converted into depth and shifted in time afterwards if output seismic in depth or time shift is requested (it was modelled directly in depth in previous versions). This may give some small changes in the seismic compared to previous versions. Theory related to the depth conversion and time shift is given in Section 3.6.

Parallelization
The seismic modelling part of the code is parallelized. The speedup depends on the number of threads that are used in the parallelization. The tool uses all available threads unless the user specifies an upper limit (Section 4.9.2 <max-threads>). The performance is further dependent on the number of traces generated compared to the number of traces written, that is, if the

number of angles/offsets is large and only stacked seismic is written, a good performance can be expected. The resampling of depth and elastic parameters is not parallelized.

Large models/grids
Large models and/or seismic grids might give memory problems. In this case the number of traces that the tool can have in the memory at the time can be limited by the command <traces-in-memory>. However, this will not reduce the memory during regridding of surfaces and elastic parameters. For large models/grids, output of seismic in Storm format is not recommended.

Changed name of command from <depth> to <top-time>
The command for specifying the time value corresponding to the top reservoir in Section 4.7.5 has changed to <top-time>.

<top-time-constant>
When this command is used, the top point is found directly from the Eclipse grid. In previous versions the top point was found from the resampled top surface. This may give some shift in seismic time compared to previous versions.

Sorting of traces in SegY files
The traces in the SegY files has an inline sorting (for a given inline position, all xline positions follows successively). The inline and xline traces are sorted by increasing number, and when more than one angle or offset is requested (pre-stack seismic), all traces for a given inline/xline position are given successively.

Wavelet from file
Earlier versions of the tool have sometimes had problems with extracted wavelets (wavelet from file, section 4.3.2), giving seismic with strange or undefined values. The ‘ad hoc’ solution has been to add extra zeros at the start and end of the wavelet. This problem is now solved in version 4.0 and no extra zeros are needed.

N layers from file
The command <nlayers-from-file> is removed from this version. Windows for seismic output in time and depth can be specified with the commands in Section 4.7.9 <time-window> and 4.7.10 <depth-window>.

3 Theory

The output grid may cover the whole Eclipse grid, or a sub volume of the Eclipse grid.

First, we resample the depth of each layer in the Eclipse grid using Delaunay triangulation and store the values in a grid (see Section 3.2). By default, centre point interpolation is used for the triangulation, but corner point interpolation can also be used. Next, reflection coefficients are calculated layer by layer (see Section 3.1). For this, elastic parameters must be resampled (see Section 3.3). The elastic parameters are interpolated using Delaunay triangulation, with centre points in top and bottom of cells, in a way similar to the depth interpolation. The values are stored in a grid. In inactive cells where no values for elastic parameters exist, we use default values provided by the user. The user also must provide default values for use above and below the reservoir. Cells with thickness smaller than 0.1m, or another user defined limit, get the value from the cell above.

When the elastic parameters have been resampled, the two-way travel time (measured in ms) is calculated for each layer k:

$$\mathrm{twt(k)} \; = \; \mathrm{twt(k-1)} \; + \; 2000[\mathrm{z(k)} - \mathrm{z(k-1)}]/\mathrm{vp(k)}$$

Here z(k) is the depth in layer k. The values are stored in a grid.

Seismic data are calculated trace by trace using the convolution

$$\mathrm{seis}(t) = \sum_{k=0}^{n} c(k)\mathrm{Wavelet}[twt(k) - t] \qquad (1)$$

Here c(*k*) is the reflection at layer no *k*, and *Wavelet* is the wavelet specified either as an input file or as a Ricker wavelet with a user specified peak frequency (see Section 3.4). *twt(k)* is the two-way travel time at layer *k*.

White noise can be added to reflection coefficients or to the seismic signal. To add noise to the reflection coefficients, use the keyword <add-noise-to-refl-coef>. To add noise to the signal use keyword <white-noise>. Noise added to the reflection coefficients will be coloured by the wavelet.

3.1 Calculation of reflection coefficients

We use an Aki Richards type linearization of the Zoeppritz equations, given by Stolt and Weglein (1985). See also the Crava user documentation, Dahle et al (2011).

For PP seismic, angle θ and time t we have

$$c(t,\theta) = a_1 \frac{\Delta Vp}{\overline{Vp}} + a_2 \frac{\Delta Vs}{\overline{Vs}} + a_3 \frac{\Delta \rho}{\bar{\rho}} \qquad (2)$$

Here $\Delta Vp = Vp(t+) - Vp(t-)$, where $t+$ and $t-$ are on each side of a cell border, $\overline{Vp} = 0.5 * \big(Vp(t+) + Vp(t-)\big)$, and similar for *Vs* and ρ. The coefficients a_1, a_2, and a_3 are given by

$$a_1 = 0.5(1 + tan^2\theta)$$

$$a_2 = -4\left(\frac{\overline{Vs}}{\overline{Vp}}\right)^2 sin^2\theta$$

$$a_3 = 0.5(1 - a_2)$$

Here θ is the offset angle.

For PS seismic, we have

$$a_1 = 0$$

$$a_2 = 2\frac{\sin\theta}{\cos\varphi}\left(\left(\frac{\overline{Vs}}{\overline{Vp}}\right)^2 sin^2\theta - \frac{\overline{Vs}}{\overline{Vp}}\cos\theta\cos\varphi\right)$$

$$a_3 = \frac{\sin\theta}{cos\varphi}\left(-0.5 + \left(\frac{\overline{Vs}}{\overline{Vp}}\right)^2 sin^2\theta - \frac{\overline{Vs}}{\overline{Vp}}\cos\theta\cos\varphi\right)$$

Here, φ is the PS reflection angle, given by $\sin\varphi = Vs/Vp \cdot \sin\theta$.

3.2 Resampling of depth

Each layer in the Eclipse grid is resampled to a regular grid. The lateral grid resolution is the same as for the seismic data.

The default is to use centre point interpolation. The routine loops all eclipse cells, and for each cell (i, j), we collect centre point in top or bottom of cell (i, j) and the neighbour points (i + 1, j), (i + 1, j + 1) and (i, j + 1). The area defined by these four points is divided into two triangles by Delaunay decomposition in the xy-plane as shown in Figure 1.

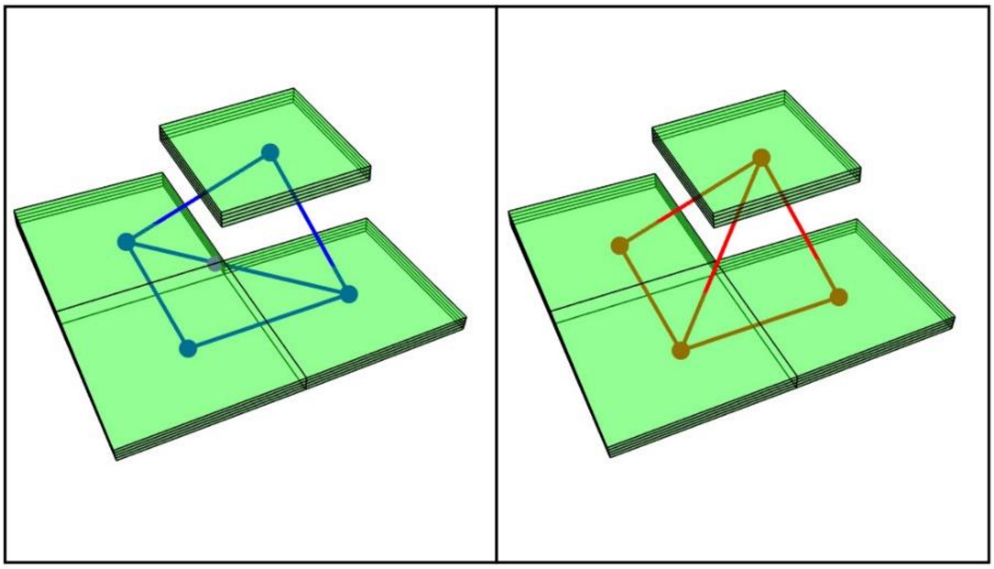

Figure 1: Illustration of Delaunay triangulation.

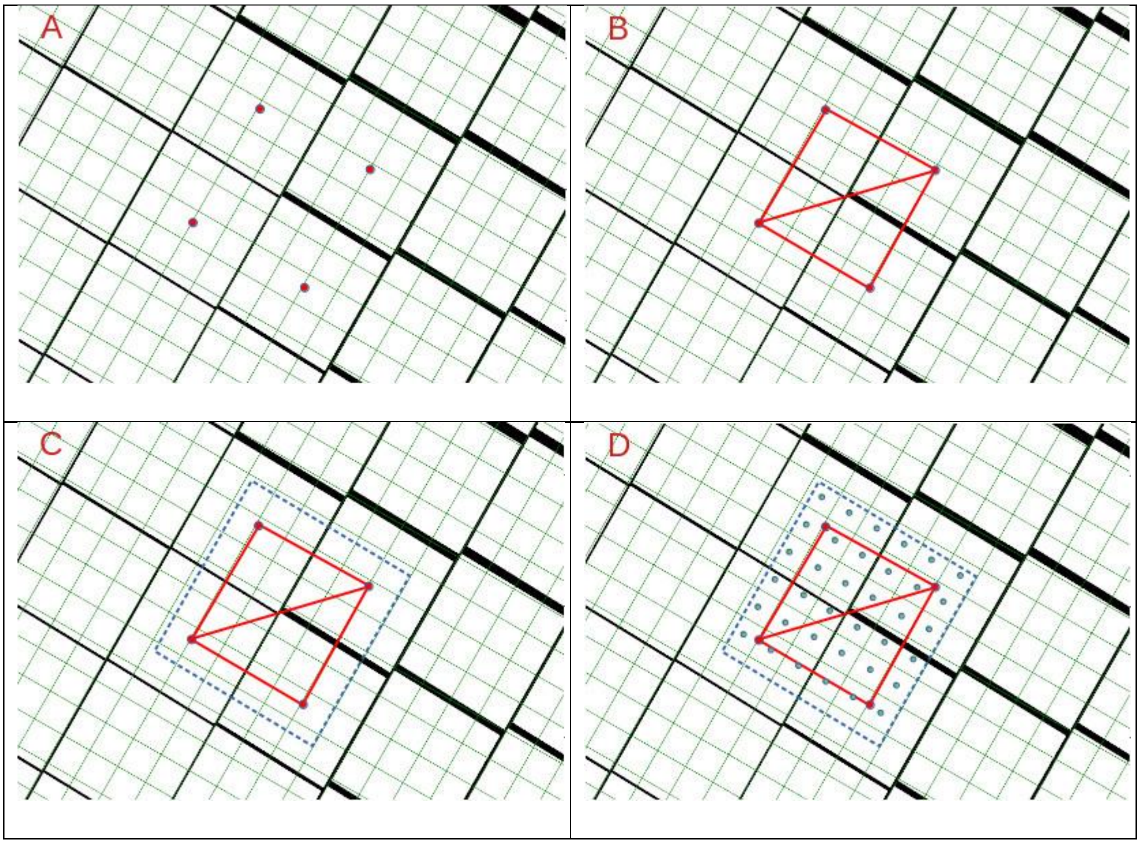

Figure 2: Resampling of depth. The resampled grid is shown as green, and the original Eclipse grid as black.

Each triangle defines a local surface, and all points inside a triangle get their z value from this surface. The decomposition can be made in two different ways. Prior to version 4.3, the decomposition was made such that the corner not common to the two triangles had a largest possible angle. To avoid negative thicknesses in the grid, it turns out that the decomposition must be the same for all layers of the Eclipse grid. By definition, the “blue” approach is therefore always taken.

Figure 2 A – D illustrates how the depth values of the Eclipse grid are mapped into a regular grid. The slightly faulted Eclipse grid is shown as a black mesh, while the regular grid to which it shall be mapped is shown as a green mesh. In A, the centre points of four adjacent Eclipse grid cells are high-lighted as red bullets. In B, the Delaunay decomposition/triangularization has been applied to these four centre points. A rectangle is created in the regular grid that covers these centre points as well as a neighbourhood around them. The neighbourhood is added to avoid edge effects. This rectangle is shown in C as a blue dashed line. All grid cells in the regular grid that have their centre points inside this rectangle are assigned a value from the Delaunay triangle it belongs to. This is shown in D.

Since grid cells outside the red rectangles are assigned depth values, most grid cells are assigned values from more than one quartet of Eclipse grid cells. This is corrected for at the end of the resampling by taking the average of the depth values that have been assigned to a given cell.

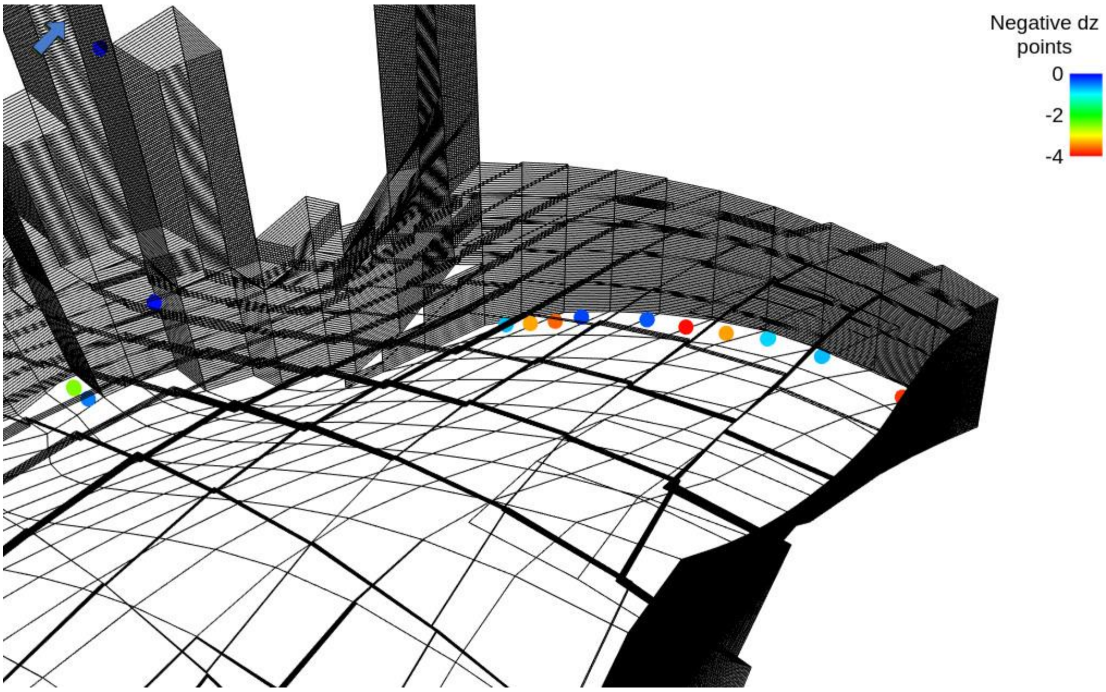

Figure 3: Visualization of places with negative thicknesses.

Alternatively, we can use corner point interpolation, and collect corners of each Eclipse cell. The area within these points is divided into two triangles, as described above. The corner point algorithm is not suitable if the grid contains reverse faults, which means that cells in different layers overlap each other. If the grid contains large cells which are not overlapping, corner point interpolation could be the best choice. At some point, a post-processing of layers at fault locations were implemented. This processing does not seem to improve the result and its geometrical intention is undocumented. It has therefore been turned off by default but can be activated with the keyword <cornerpt-interpolation-at-faults>.

After the resampling, some grid cells in the regular grid may remain empty. These are filled using vertical interpolation between the closest defined grid cell above and below. If all grid cells above or below are empty, the top and base surface of the Eclipse grid are used for interpolation. These surfaces are generated in the same way as the grid resampling and may themselves contain empty cells. Such empty cells are filled using horizontal interpolation. Starting with the "centre of mass" of the grid nodes in the resampled surface that have a value, empty grid nodes at increasing distance from this centre are filled. Each node is assigned the average of its neighbours. This procedure is iterated until all grid nodes have a value defined. All vertical interpolation can be omitted using the <vertical-interpolation-of-undefined-cells> keyword. By default, vertical interpolation is used.

For grids with complex faulting, some grid cells may end up with negative thicknesses. Such cells can have their thicknesses set to zero using the <remove-negative-delta-z> keyword. Negative thicknesses are written to the file negative_dz_points.rxat as points with attributes "Negative dz" and "Layer". The file format is *Roxar Attribute Text*. These points can be used to visualize where the negative thicknesses are located as illustrated in Figure 3.

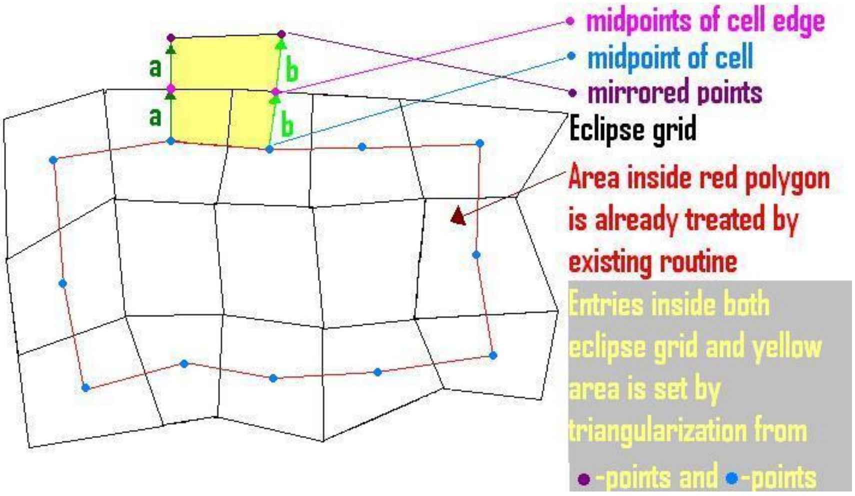

Figure 4: Treatment of edges when resampling elastic parameters.

3.3 Resampling of elastic parameters

This is done in a similar way as for the depth. To calculate reflections, values at both top and base of cells must be resampled. If a cell is inactive, default values for the parameters are used in triangularization. For inactive cells with thickness less than a given limit (default is 0.1 m), the value in the cell above is used.

Since we use centre of cells, an edge around the eclipse grid is not treated by this algorithm, see Figure 4. In this region, we use mirroring values to the outside of the eclipse grid, and then filling out unwritten values on the inside by triangulation. If a cell is inactive, default values for the parameters are used in the triangularization.

3.4 Wavelet

The wavelet can be read from file or specified parametrically as a Ricker wavelet. The ricker wavelet is given by the expression

$$\text{Wavelet}(t,a) = (1-2at^2)\exp\left(-at^2\right)$$

where $a = (\pi\nu)^2$ and ν is the peak frequency that must be specified by the user. The Ricker wavelet with a peak frequency of 25 Hz is shown in Figure 5.

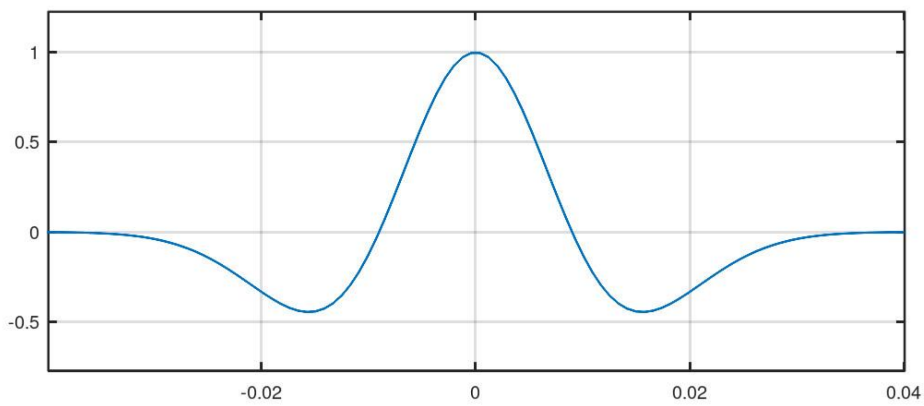

Figure 5: The Ricker wavelet with a peak frequency of 25 Hz.

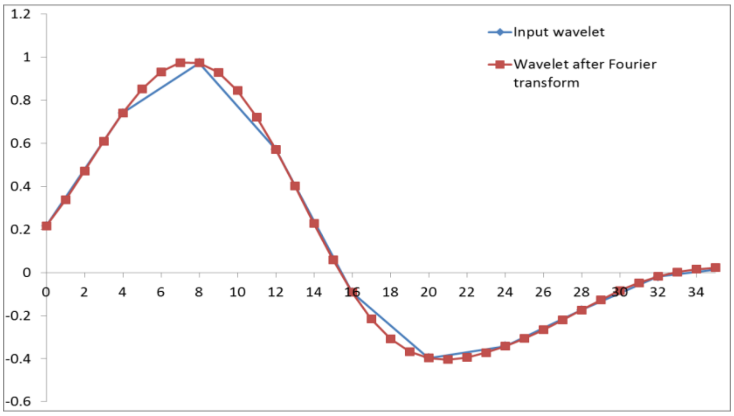

Figure 6: Smoothening of the wavelet.

If the wavelet is read from file, the file format must be Landmark ASCII Wavelet (see Section 5.4). Before calculating seismic data, the wavelet is smoothed. This is done by transforming the wavelet to the Fourier domain where the sampling density is increased. After the back-transform to time domain the sampling density has increased to approximately 1 ms. Because of this smoothening, synthetic seismic data will depend on the sampling density of the wavelet. The smoothening is depicted in Figure 6.

The maximum amplitude of the wavelet is identified automatically, and for wavelets read from file, the maximum location specified in the header is over-run. The wavelet length is set to be the part of the wavelet where the amplitude is at least 0.001 of the maximum amplitude.

3.5 NMO stretch

Normal moveout (NMO) is the effect the offset has on the arrival time of the reflection. The offset is the distance between a seismic source and a receiver; see Figure 7. Increasing offset gives an increasing delay in the arrival time of a reflection from a horizontal surface. A plot of arrival times versus offset has a hyperbolic shape. To adjust each event to its associated zero-offset arrival time, the seismic must be NMO corrected. NMO correction is basically a shift of the seismic in time. An effect of NMO is a stretching of the wavelet with increasing offset, referred to as NMO stretch. The NMO stretch is highest at far offsets and at early times, where the NMO correction is the most pronounced.

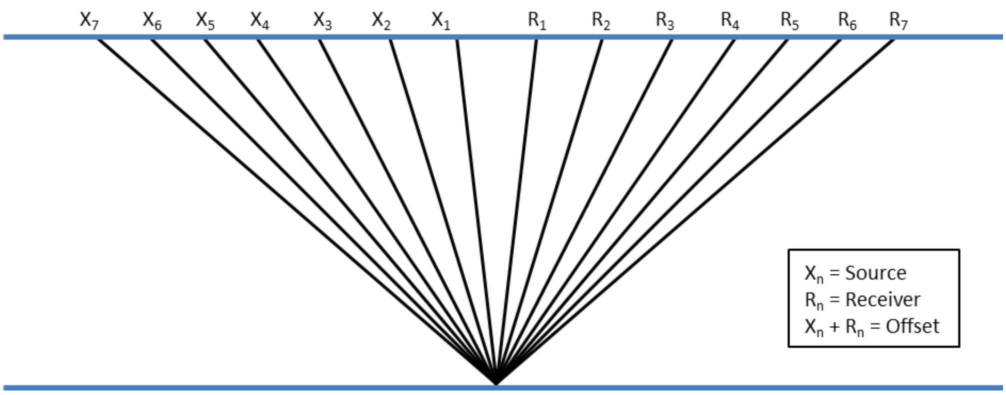

Figure 7: Path from source to receiver for seismic traces with various offsets.

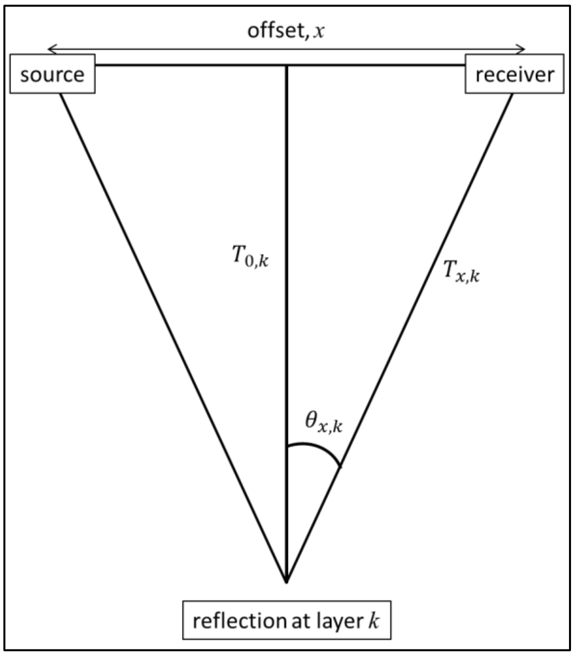

Figure 8: Geometry of a seismic reflection at layer *k*.

3.5.1 Generation of seismic data with NMO stretch

When generating seismic data with NMO stretch, the first step is to make root-mean-square velocities (RMS velocity) for all reflectors/layers including the sea floor. Interval velocity in the overburden must be estimated to get the RMS velocities in the reservoir. This is calculated from time and depth values for top reservoir plus user specified values for seabed (Section 4.6.1 <seafloor-depth> and 4.6.2 <velocity-water>). The RMS velocity at layer *k* is given as:

$$v_{rms,k} = \sqrt{\frac{\sum_{i=0}^{k} v_i^2 \Delta t_i}{T_{0,k}}} \;,$$

where v_i and Δt_i are the interval velocity and the interval two-way time (TWT) of layer *i* and $T_{0,k}$ is the TWT at zero offset down to layer *k*.

When the average velocities have been calculated, the TWTs down to each layer are calculated for every offset, see Figure 8. TWT to layer *k* for offset *x* is given as:

$$T_{x,k} = \sqrt{T_{0,k}^2 + \frac{x^2}{v_{rms,k}^2}} \;. \qquad (3)$$

The offset angle for each offset *x* and layer *k* is calculated as

$$\theta_{x,k} = \tan^{-1}\left(\frac{x}{v_{rms,k} \cdot T_{0,k}}\right).$$

The corresponding reflection coefficient at layer *k* for given offset *x*, $c(\theta_{x,k})$, is calculated according to Equation 2. The seismic trace at time *t* is calculated as:

$$\text{seis}(t) = \sum_{k=0}^{n} c(\theta_{x,k}) \text{Wavelet}[T_{x,k} - t]. \qquad (4)$$

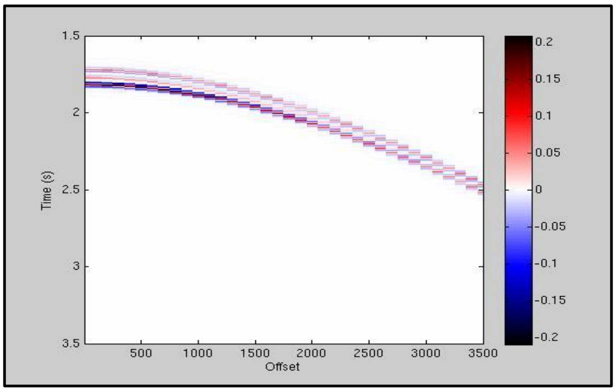

Figure 9: Example of seismic gather for offsets from 0 to 3500m.

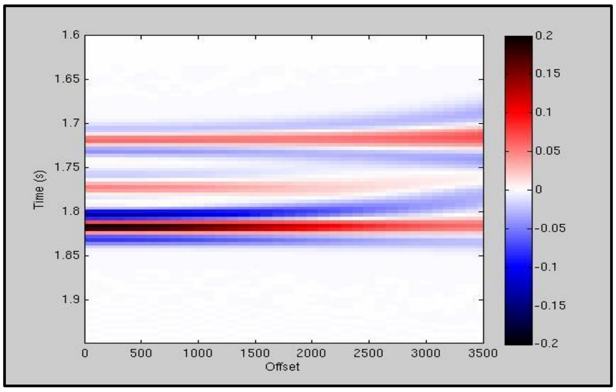

Figure 10: Example of seismic gather after NMO correction for offsets from 0 to 3500m.

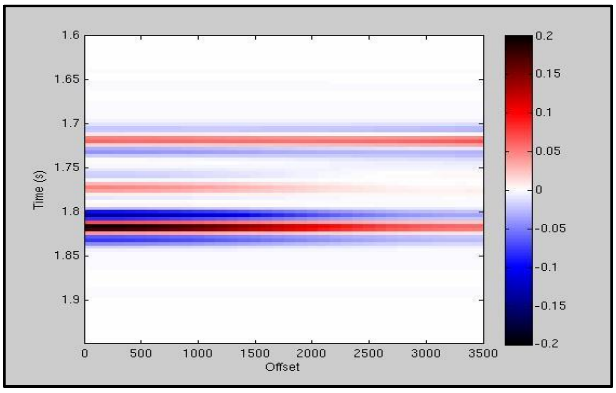

Figure 11: Example of seismic gather generated without NMO-stretch for offsets from 0 to 3500m.

3.5.2 NMO correction

The seismic data in Equation 4 are sampled regularly in time, $t = [t_0, t_0 + \Delta t, t_0 + 2\Delta t, \dots]$. For each time sample, t, the corresponding t_x is calculated according to Equation 3. To calculate t_x the RMS velocity is resampled according to t using linear interpolation. The generated seismic data are resampled into t_x with a cubic spline interpolation. These data are NMO corrected. See Figure 9 and Figure 10 for examples of seismic data before and after NMO correction. The NMO stretch is visible at far offsets in Figure 10. As a comparison, Figure 11 shows the same example of a seismic gather generated without NMO stretch.

3.5.3 Offset seismic without NMO stretch

Seismic data for various offsets can be generated without considering the increasing delay in the arrival time with offset, that is, without NMO-stretch. This is done by the same procedure as seismic with NMO stretch by letting offset $x = 0$ in Equation 3, giving $T_{x,k} = T_{0,k}$. Such seismic data are generated according to the zero-offset TWT, but with reflection angles corresponding to the geometry in Figure 8.

3.6 Depth conversion and time shifts

The seismic data are generated regularly in time $t = [t_0, t_0 + \Delta t, t_0 + 2\Delta t, \ldots]$ and resampled into t_x in case of seismic with NMO-stretch. Depth converted and time-shifted seismic is established from the generated seismic in time by interpolating the amplitudes into new grids in depth or time, respectively.

Depth conversion:

The depths z_t corresponding to $t = [t_0, t_0 + \Delta t, t_0 + 2\Delta t, \ldots]$ are found through linear interpolation of the depth-to-TWT relationship established in the re-gridding of the model. This way the seismic data generated at t can also be associated with z_t.

To get seismic data regularly sampled in depth, data are interpolated into $z = [z_0, z_0 + \Delta z, z_0 + 2\Delta z, \ldots]$. This is done using cubic spline interpolation, provided the seismic is "sampled" according to z_t.

Seismic time shift:

The seismic is shifted in time basically using the same procedure as the depth conversion. The shifted times t_s corresponding to t are found through linear interpolation based on the relationship between TWT and shifted TWT at each layer of the reservoir. The seismic is regularly sampled into the shifted times using cubic spline interpolation, provided the seismic is "sampled" according to t_s.

4 Model file reference manual

This section describes how to build a model file for the Seismic Forward program. The model file uses the XML file structure. XML files are built with start and end tags, encapsulating other tags or values. All model files start with <seismic-forward> and end with </seismic-forward>.

In addition to the normal <!-- --> tags used to place comments in the file, the character '#' can also be used. All text following this character on the same line is considered a comment. Please note, that if this character is used XML file readers may treat the file as corrupt.

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

The following units are assumed throughout the XML model file:

Type	**Unit**
Depth and length	Meter - m
Time	Millisecond - ms
Velocity	Meter per second - m/s
Density	Kilogram per cubic metres - kg/m^3
Angles	Degrees

4.1 <elastic-param> (necessary)

Description: Contains Eclipse grid file name, default values and name of elastic parameters in file. Interpolation method for depth values can optionally be chosen here, and a limit for treating cells as zero thickness cells can be set.

Example:

```
<elastic-param>
  <eclipse-file> test_2006.grdecl </eclipse-file>
  <default-values>
    <vp-top>  3800 </vp-top>
    <vp-mid>  3400 </vp-mid>
    <vp-bot>  3800 </vp-bot>
    <vs-top>  1200 </vs-top>
    <vs-mid>  1900 </vs-mid>
    <vs-bot>  2100 </vs-bot>
    <rho-top> 2400 </rho-top>
    <rho-mid> 2400 </rho-mid>
    <rho-bot> 2400 </rho-bot>
  </default-values>
  <parameter-names>
    <vp>  VP_2006-07-01   </vp>
    <vs>  VS_2006-07-01   </vs>
    <rho> DENS_2006-07-01 </rho>
  </parameter-names>
</elastic-param>
```

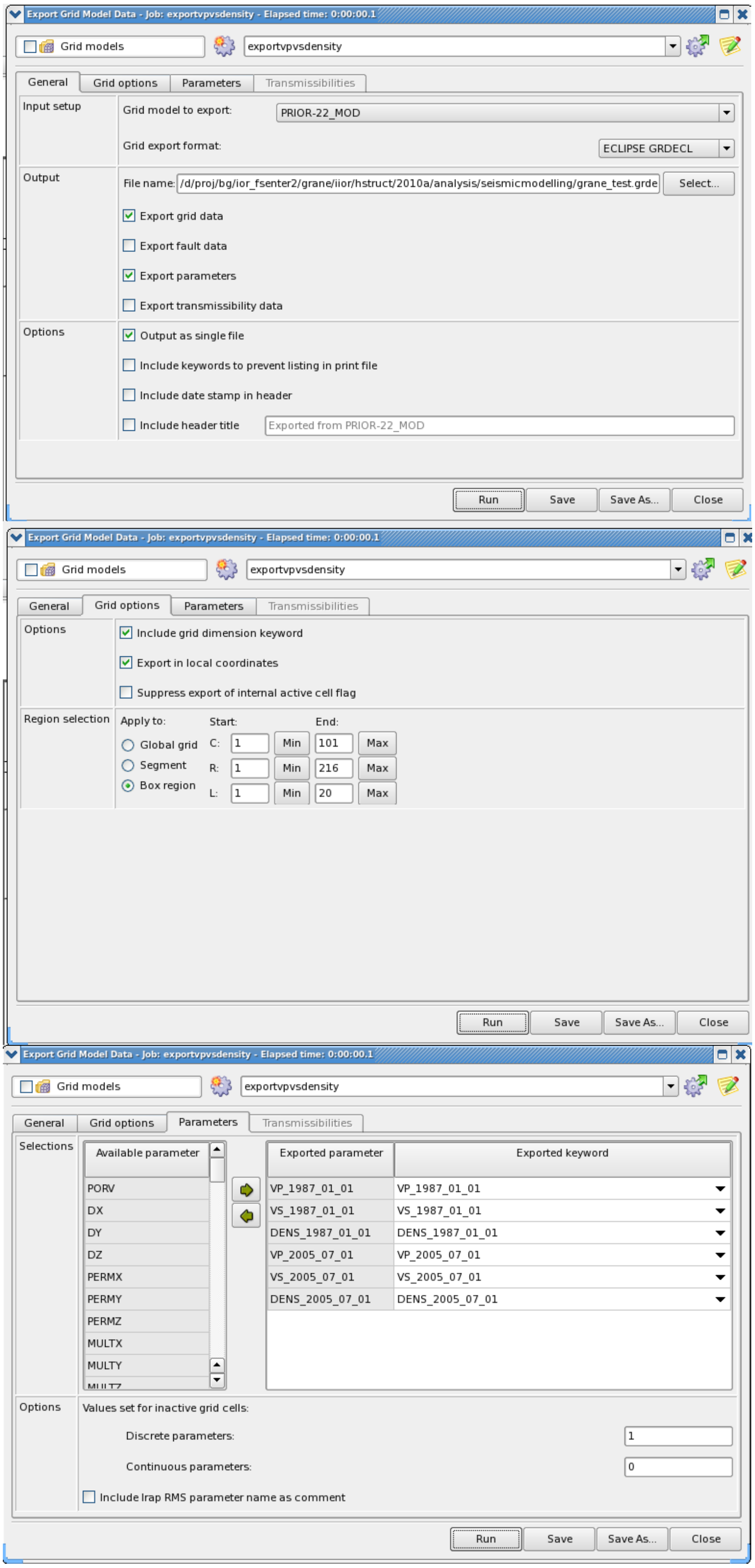

Figure 12: Export of Eclipse grids (grdecl file) from RMS.

4.1.1 <eclipse-file> (necessary)

Description: Name of Eclipse grid file containing elastic parameters. Figure 12 shows how to export an Eclipse grid from RMS.

Argument: File name.

4.1.2 <default-values> (necessary)

Description: Values of Vp, Vs, and rho over and under reservoir, and in missing cells within reservoir.

4.1.2.1 <vp-top> (necessary)

Description: Default value of vp above reservoir.

Argument: double

4.1.2.2 <vp-mid> (necessary)

Description: Default value of vp within reservoir. To be used at places with missing data.

Argument: double

4.1.2.3 <vp-bot> (necessary)

Description: Default value of vp below reservoir.

Argument: double

4.1.2.4 <vs-top> (necessary)

Description: Default value of vs above reservoir.

Argument: double

4.1.2.5 <vs-mid> (necessary)

Description: Default value of vs within reservoir. To be used at places with missing data.

Argument: double

4.1.2.6 <vs-bot> (necessary)

Description: Default value of vs below reservoir.

Argument: double

4.1.2.7 <rho-top> (necessary)

Description: Default value of density above reservoir.

Argument: double

4.1.2.8 <rho-mid> (necessary)

Description: Default value of density within reservoir. To be used at places with missing data.

Argument: double

4.1.2.9 <rho-bot> (necessary)
Description: Default value of density below reservoir.

Argument: double

4.1.3 <parameter-names> (necessary)
Description: Name of elastic parameters in Eclipse file

4.1.3.1 <vp> (necessary)
Description: Name of vp parameter in Eclipse file

Argument: String

4.1.3.2 <vs> (necessary)
Description: Name of vs parameter in Eclipse file

Argument: String

4.1.3.3 <rho> (necessary)
Description: Name of density parameter in Eclipse file

Argument: String

4.1.4 <extra-parameters>
Description: Name and default value of extra parameter. This command must be repeated for each extra parameter.

To write the extra parameters to time or depth segy files the commands <extra-parameters-time-segy> (Section 4.8.21) and/or <extra-parameters-depth-segy> (Section 4.8.22) under <output-parameters> must be given.

4.1.4.1 <name> (necessary)
Description: Name of extra parameter in Eclipse file

Argument: String

4.1.4.2 <default-value> (necessary)
Description: Default value of extra parameter

Argument: double

4.1.5 <cornerpt-interpolation-in-depth>
Description: Using corner-point interpolation instead of centre point interpolation when interpolating the depth of each layer in the Eclipse grid.

Argument: Yes or no, default is no.

4.1.6 <cornerpt-interpolation-at-faults>
Description: For corner-point interpolation, a post processing around faults can be activated using this keyword. This post-processing is not documented and currently not recommended.

Argument: Yes or no, default is no.

4.1.7 <zero-thickness-limit>

Description: If cell thickness is less than this limit, it should be treated as a zero-thickness cell, and get its value from the cell above. The value is in meters.

Argument: double, default is 0.1.

4.1.8 <remove-negative-delta-z>

Description: If cell thickness is negative, thickness is set to zero by using this keyword.

Argument: Yes or no, default is no.

4.1.9 <vertical-interpolation-of-undefined-cells>

Description: If cell thickness is undefined, it can be interpolated from the nearest defined cells above and below.

Argument: Yes or no, default is yes.

4.1.10 <horizontal-interpolation-of-undefined-cells>

Description: If cell thickness is undefined, it can be interpolated from the nearest defined cells in the same layer.

Argument: Yes or no, default is no.

4.1.11 <fixed-triangularization-of-eclipse-grid>

Description: Cells in the regular grid are interpolated from the Eclipse grid using Delaunay triangularization. This triangularization normally depends on the grid cell shape. However, unless the triangularization is chosen equal (fixed) for all cells having the same lateral position, negative thicknesses may be encountered. Using equal triangularization, on the other hand, may lead to rougher edges in faults etc.

Argument: Yes or no, default is yes.

4.1.12 <resampl-param-to-segy-with-interpol>

Description: Vertically resample elastic or extra parameters into depth or time samples of SegY grid using interpolation rather than index mapping.

Argument: Yes or no, default is no.

4.2 <angle>

Description: Offset angle for seismic. Seismic cubes with offset angle ***theta-0***, ***theta-0 + dtheta***, ***theta-0 +*** 2****dtheta … theta-max***, will be generated. The command is optional, and if not given, only zero offset seismic is generated.

Example:

```
<angle>
   <theta-0>     0 </theta-0>
   <dtheta>      5 </dtheta>
```

```
  <theta-max> 30 </theta-max>
</angle>
```

4.2.1 <theta-0>
Description: Smallest offset angle.

Argument: double, default is 0.0.

4.2.2 <dtheta>
Description: Increment for offset angle.

Argument: double, default is 0.0.

4.2.3 <theta-max>
Description: Largest offset angle.

Argument: double, default is 0.0.

4.3 <wavelet> (necessary)
Description: Specifies which wavelet to use. One of the two commands <ricker> or <from-file> must be specified.

4.3.1 <ricker>
Description: The Ricker wavelet.

Example:

```
<wavelet>
 <ricker>
  <peak-frequency> 20 </peak-frequency>
 </ricker>
</wavelet>
```

4.3.1.1 <peak-frequency> (necessary)
Description: Peak frequency for Ricker wavelet

Argument: double

4.3.2 <from-file>
Description: Wavelet is specified in an input file.

Example:

```
<wavelet>
 <from-file>
  <format>    Landmark             </format>
  <file-name> wavelet_landmark.wvl </file-name>
 </from-file>
</wavelet>
```

4.3.2.1 <format> (necessary)
Description: Format of wavelet file. So far, only Landmark (Landmark ASCII Wavelet) is implemented. See Section 5.4 for description of Landmark ASCII Wavelet format.

Argument: Landmark

4.3.2.2 <file-name> (necessary)
Description: Filename of wavelet file. The Landmark ASCII Wavelet format is supported as wavelet input file (see Section 5.4).

Argument: String

4.3.3 <scale>
Description: Scaling factor for wavelet. An increase in impedance gives a positive peak.

Argument: double, default is 1.0.

4.3.4 <length>
Description: Specifies the wavelet length in ms.

Argument: double, default is undefined and the length is estimated.

4.4 <white-noise>
Description: This adds white noise to the generated seismic data. The white noise is sampled from a normal distribution with zero mean and a standard deviation as specified.

Example:

```
<white-noise>
 <equal-noise-for-offsets> yes    </equal-noise-for-offsets>
 <standard-deviation>      0.02   </standard-deviation>
 <seed>                    123456 </seed>
</white-noise>
```

4.4.1 <standard-deviation>
Description: Standard deviation to the white noise.

Argument: double, default is 1.0.

4.4.2 <seed>
Description: Seed number. If this command is not given, a random seed number will be used.

Argument: integer

4.4.3 <equal-noise-for-offsets>
Description: This lets you choose between unique noise for each offset or equal noise for all offsets.

Argument: Yes or no, default is no.

4.5 <add-noise-to-refl-coef>

Description: This adds white noise to *the reflection coefficients*. The white noise is sampled from a normal distribution with zero mean and a standard deviation as specified. This results in coloured noise in the seismic data, and the noise model is consistent with the model in Buland and Omre (2003).

Example:

```
<add-noise-to-refl-coef>
 <standard-deviation> 0.02   </standard-deviation>
 <seed>               123456 </seed>
</add-noise-to-refl-coef>
```

4.5.1 <standard-deviation>

Description: Standard deviation to the white noise.

Argument: double, default is 1.0.

4.5.2 <seed>

Description: Seed number. If this command is not given, a random seed number will be used.

Argument: integer

4.6 <nmo-stretch>

Description: When this command is specified, a seismic gather according to the specified offsets is generated for each position. The arrival time for each offset is modelled with hyperbolic NMO. The seismic is thereafter NMO-corrected to the associated zero-offset time, giving NMO-stretch in the modelled data. To perform NMO-correction, the seafloor depth and velocity in water is required. This command has priority over <angle> (Section 4.2), which means that if both <nmo-stretch> and <angle> are specified, <angle> is ignored.

Example:

```
<nmo-stretch>
 <seafloor-depth>  200 </seafloor-depth>
 <velocity-water> 1500 </velocity-water>
 <offset>
   <offset-0>      0 </offset-0>
   <doffset>      50 </doffset>
   <offset-max> 2000 </offset-max>
 </offset>
</nmo-stretch>
```

4.6.1 <seafloor-depth> (necessary)

Description: Depth of seafloor.

Argument: double

4.6.2 <velocity-water> (necessary)

Description: Velocity in water.

Argument: double

4.6.3 <offset>

Description: Offset for seismic. Seismic traces will be generated for offset ***offset-0***, ***offset-0 + doffset***, ***offset-0 +*** 2****doffset … offset-max***. The command is optional, and if not given, only zero offset seismic is generated.

4.6.3.1 <offset-0>

Description: Smallest offset.

Argument: double, default is 0.0.

4.6.3.2 <doffset>

Description: Increment for offset.

Argument: double, default is 0.0.

4.6.3.3 <offset-max>

Description: Largest offset.

Argument: double, default is 0.0.

4.6.4 <offset-without-stretch>

Description: If this command is specified, seismic data are generated according to offset and without NMO stretch. This means that the arrival time for each offset is assumed identical to zero-offset, and no NMO correction is applied. This option will give seismic similar, but not identical to the <angle> option since seismic is generated for constant offset gathers rather than constant angle gathers.

Argument: Yes or no, default is no.

4.7 <output-grid> (necessary)

Description: Specifies the dimensions of the resulting seismic grid and a possible window for output files.

The area used in the forward modelling can be defined in four different ways. If the default approach is not taken, the options have a prioritized order in case several are specified.

1) By default, the area is defined by the Eclipse grid, automatically calculated as the smallest rectangle covering the active cells in the Eclipse grid.

2) <area-from-segy>, where area is specified by a SegY file.

3) <area>, where a rectangle area can be specified.

4) <area-from-surface>, where area is specified by a Roxar text file.

The modelling interval is from top reservoir to bottom reservoir. In addition, there is a padding above and below the grid. By default, this padding is half a wavelet on both sides, but this can be adjusted with the <padding-factor-seismic-modelling> keyword. The time value corresponding to the top reservoir can be specified under <top-time>, and the cell size of the seismic grid can be specified under <cell-size>. For SegY output format, the segy indexes can be specified under <segy-indexes> and UTM precision under <utm-precision>. Output window in time or depth can be specified under <time-window> and <depth-window>.

Example:

```
<output-grid>
  <top-time>
     <top-time-constant> 1200 </top-time-constant>
   </top-time>
  <cell-size>
    <dx> 50 </dx>
    <dy> 50 </dy>
    <dz>  1 </dz>
    <dt>  4 </dt>
  </cell-size>
  <area-from-surface> top.irap </area-from-surface>
  <time-window>
    <top> 1000 </top>
    <bot> 2000 </bot>
  </time-window>
  <padding-factor-seismic-modelling> 1.0 </padding-factor-seismic-
modelling>
</output-grid>
```

4.7.1 <area-from-surface>

Description: A surface on Roxar text format is used to specify area. This command is not active if <area> or <area-from-segy> is given.

Argument: String with name of Roxar text surface file.

4.7.2 <area-from-segy>

Description: A segy file is used to specify area. Some standard SegY trace header formats are recognized, see Section 5.3. Other formats can be specified by the user, by using the key words <il0>, <xl0>, <utmxLoc>, and <utmyLoc>.

4.7.3 <padding-factor-seismic-modelling>

Description: The number of half-wavelets that are added above and below the grid as padding before the forward modelling. Useful when adding white noise, especially for larger offsets.

Argument: double. Default value is 1.0

4.7.3.1 <filename> (necessary)

Description: Name of segy file.

Argument: String with name of segy file.

4.7.3.2 <il0>

Description: Byte number for inline start in trace header in the given file.

Argument: integer

4.7.3.3 <xl0>
Description: Byte number for crossline start in trace header in the given file.

Argument: integer

4.7.3.4 <utmxLoc>
Description: Byte number for location of x coordinate in trace header in the given file.

Argument: integer

4.7.3.5 <utmyLoc>
Description: Byte number for location of y coordinate in trace header in the given file.

Argument: integer

4.7.4 <area>
Description: Defines the area of the seismic cube. See Figure 13 for an illustration of the parameters required. If specified, all parameters must be given. This command is not active if <area-from-segy> is given.

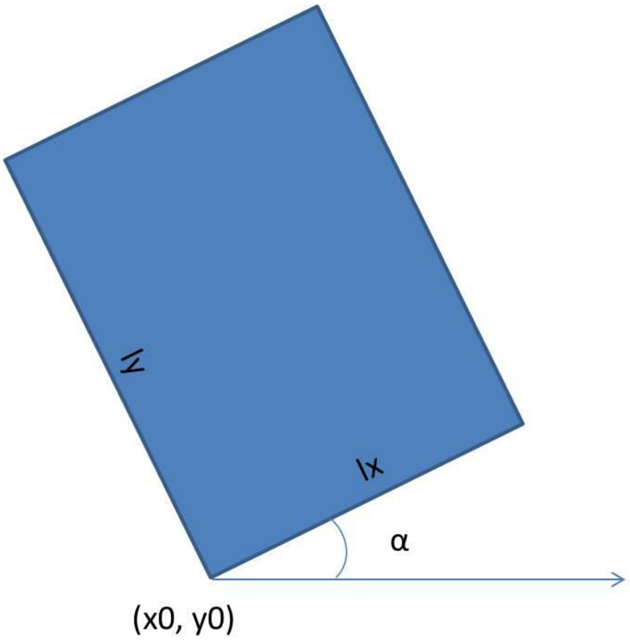

Figure 13: Illustration of area parameters.

4.7.4.1 <x0> (necessary)
Description: x coordinate of lower left corner point, see Figure 13.

Argument: double

4.7.4.2 <y0> (necessary)
Description: y coordinate of lower left corner point, see Figure 13.

Argument: double

4.7.4.3 <lx> (necessary)

Description: Length of area in local x direction, se Figure 13.

Argument: double

4.7.4.4 <ly> (necessary)

Description: Length of area in local y direction, see Figure 13.

Argument: double

4.7.4.5 <angle> (necessary)

Description: Rotation angle of area, see Figure 13.

Argument: double

4.7.5 <top-time>

Description: Specifies time value corresponding to top of reservoir. When modelling seismic with the <nmo-stretch> option (Section 4.6), the top time value is used in calculation of rms-velocity down to top reservoir, and hence should be given a realistic value. This is also important when modelling seismic in depth.

4.7.5.1 <top-time-surface>

Description: Specifies a surface in time corresponding to top reservoir. The surface must be of type Roxar text. If the surface contains missing areas, the seismic will be missing (set to zero) in these areas.

Argument: String with name of Roxar text surface file.

4.7.5.2 <top-time-constant>

Description: Specifies a constant time value corresponding to top reservoir. The constant time corresponds to the top point of the Eclipse grid.

Argument: double, default value is 1000.0.

4.7.6 <cell-size>

Description: The cell size in the seismic grid is given here.

4.7.6.1 <dx>

Description: Cell size in x direction. If <area-from-segy> is given, dx is taken from segy file.

Argument: double, default value is 25m.

4.7.6.2 <dy>

Description: Cell size in y direction. If <area-from-segy> is given, dy is taken from segy file.

Argument: double, default value is 25m.

4.7.6.3 <dz>

Description: Cell size in vertical direction, for seismic in depth domain.

Argument: Double, default value is 4m.

4.7.6.4 <dt>

Description: Cell size in vertical direction, for seismic in time domain.

Argument: Double, size given in ms. Default value is 4ms.

4.7.7 <segy-indexes>

Description: Specifies the inline and crossline start point and the axis of the inline direction for grid output on SegY format. The command should not be used if <area-from-segy> is used, then the geometry is taken from the input segy file.

The inline and crossline directions are determined based on the geometry parameters specified under <area> and <cell-size>. By specifying <inline-direction> to “x” the inline and crossline directions are basically swopped.

Example:

```
<segy-indexes>
  <inline-start>     5 </inline-start>
  <xline-start>      5 </xline-start>
  <inline-direction> y </inline-direction>
</segy-indexes>
```

4.7.7.1 <inline-start>

Description: Location of inline start.

Argument: integer, default is 0.

4.7.7.2 <xline-start>

Description: Location of crossline start.

Argument: integer, default is 0.

4.7.7.3 <inline-direction>

Description: Axis of the inline direction. Legal arguments are x and y.

Argument: String, default is y.

4.7.7.4 <inline-step>

Description: Step size and direction for stepping along inline, where positive numbers mean positive inline direction and negative numbers mean negative inline direction.

Argument: Positive or negative integers, default is 1.

4.7.7.5 <xline-step>
Description: Step size and direction for stepping along crossline, where positive numbers mean positive inline direction and negative numbers mean negative inline direction.

Argument: Positive or negative integers, default is 1.

4.7.8 <utm-precision>
Description: Specifies the numerical precision of the UTM-coordinates in the header of the output segy file. *The precision is limited by the size of an integer (2^{31} - 1). If the precision exceeds this limit, i.e. if the number of significant digits exceeds ~10, a message will be given and no SegY file will be written.*

Argument: possible arguments are 0.0001, 0.001, 0.01, 0.1, 1, 10, 100, 1000 and 10000, default is 0.1.

4.7.9 <time-window>
Description: Specifies a time window for all output files in time.

4.7.9.1 <top>
Description: Specifies the top of the time window.

Argument: double

4.7.9.2 <bot>
Description: Specifies the bottom of the time window.

Argument: double

4.7.10 <depth-window>
Description: Specifies a depth window for all output files in depth.

4.7.10.1 <top>
Description: Specifies the top of the depth window.

Argument: double

4.7.10.2 <bot>
Description: Specifies the bottom of the depth window.

Argument: double

4.8 <output-parameters>
Description: Keyword to specify output variables from the program.

Example:

```
<output-parameters>
 <prefix>             parameters </prefix>
 <elastic-parameters> yes        </elastic-parameters>
 <reflections>        yes        </reflections>
```

```
</output-parameters>
```

4.8.1 <prefix>

Description: Name prefix of all output files.

Argument: String, default is empty string.

4.8.2 <suffix>

Description: Name suffix of all output files.

Argument: String, default is empty string.

4.8.3 <elastic-parameters>

Description: Writes resampled vp, vs, rho in Storm format to files "*prefix*+_vp_+*suffix* +.storm", "*prefix*+_vs_+*suffix*+.storm" and "*prefix*+_rho_+*suffix*+.storm". Depth is not correct; the output grid is a regular grid with the resampled values in each layer of the Eclipse grid.

Argument: Yes or no, default is no.

4.8.4 <reflections>

Description: Writes a cube with reflection coefficients at each layer of the Eclipse grid at the minimum specified angle or offset. The reflections are written in Storm format to file "*prefix*+_reflections_*theta_* +*suffix*+.storm" or "*prefix*+_reflections_*offset_* +*suffix*+.storm", where *theta* is the angle given under <theta-0> (Section 4.2.1) and *offset* is the offset given under <offset-0> (Section 4.6.3.1). If white noise is added to the reflections (Section 4.4), reflections with white noise are written to file "*prefix*+_reflections_noise_*theta_*+*suffix*+.storm" or "*prefix*+_reflections_noise_*offset_*+*suffix*+.storm".

Argument: Yes or no, default is no.

4.8.5 <zvalues>

Description: Writes depth values for each layer in the Eclipse grid in Storm format to file "*prefix*+_zgrid_+*suffix*+.storm".

Argument: Yes or no, default is no.

4.8.6 <twt>

Description: Writes two way travel time for zero offset in Storm format to file "*prefix*+_twt_+*suffix*+.storm".

Argument: Yes or no, default is no.

4.8.7 <vrms>

Description: Writes root-mean-square (RMS) velocity in Storm format to file "*prefix*+_vrms_+*suffix*+.storm".

Argument: Yes or no, default is no.

4.8.8 <twt-offset-segy>

Description: Writes two-way-time for each seismic gather for each offset (as specified in 4.6.3) in Segy format "*prefix*+_twt_offset_+*suffix*+.segy". The two-way-time will be written according to time-window if specified (4.7.9).

Argument: Yes or no, default is no.

4.8.9 <time-surfaces>

Description: Writes top and bottom of reservoir in time in Storm format to files "*prefix*+_toptime_+*suffix*+.storm" and "*prefix*+_bottime_+*suffix*+.storm".

Argument: Yes or no, default is no.

4.8.10 <depth-surfaces>

Description: Writes top and bottom of reservoir in depth in Storm format to files "*prefix*+_ topeclipse _+*suffix*+.storm" and "*prefix*+_ boteclipse _+*suffix*+.storm".

Argument: Yes or no, default is no.

4.8.11 <wavelet>

Description: Writes the wavelet to file in Landmark format. If a Ricker wavelet is used, the file name is "*prefix*_Wavelet_*x*Hz_as_used.txt", where *x* is the peak frequency. If the wavelet is read from file, the file name is "*prefix*_Wavelet_resampled_to_*x*ms.txt", where *x* is the sampling density.

Argument: Yes or no, default is no.

4.8.12 <seismic-time>

Description: Writes the seismic stack of all angles as specified under command <angle> in Section 4.2, or for seismic with nmo-stretch (Section 4.6) writes the seismic stack of all offsets as specified under command <offset> in Section 4.6.3. The seismic is written in Storm format to file "*prefix*+_seismic_time_stack_+*suffix*+.storm".

Argument: Yes or no, default is no.

4.8.13 <seismic-timeshift>

Description: Writes seismic shifted in time as a stack of all angles specified under command <angle> in Section 4.2, or for seismic with nmo-stretch (Section 4.6) a stack of all offsets as specified under command <offset> in Section 4.6.3. The parameter <timeshift-twt> (Section 4.10) must also be given. The seismic is written in Storm format to file "*prefix*+_seismic_timeshift_stack_+*suffix*+.storm".

Argument: Yes or no, default is no.

4.8.14 <seismic-depth>

Description: Writes the seismic in depth as a stack of all angles specified under command <angle> in Section 4.2, or for seismic with nmo-stretch (Section 4.6) a stack of all offsets as specified under command <offset> in Section 4.6.3. The seismic is written in Storm format to file "*prefix*+_seismic_depth_stack_+*suffix*+.storm".

Argument: Yes or no, default is no.

4.8.15 <seismic-time-segy>

Description: Writes seismic in time in SegY format to file "*prefix*+_seismic_time_+*suffix*+.segy". See Section 5.2 for description of the chosen SegY format. The entire angle or offset gather for each position is written.

Argument: Yes or no, default is no.

4.8.16 <seismic-timeshift-segy>

Description: Writes seismic shifted in time in SegY format to file "*prefix*+_seismic_timeshift_+*suffix*+.segy". See Section 5.2 for description of the chosen SegY format. The parameter <timeshift-twt> (Section 4.10) must also be given. The entire angle or offset gather for each position is written.

Argument: Yes or no, default is no.

4.8.17 <seismic-depth-segy>

Description: Writes seismic in depth in SegY format to file "*prefix*+_seismic_depth_+*suffix*+.segy". See Section 5.2 for description of the chosen SegY format. The entire angle or offset gather for each position is written.

Argument: Yes or no, default is no.

4.8.18 <seismic-time-prenmo-segy>

Description: Writes seismic in time in SegY format to file "*prefix*+_ seismic_time_ prenmo_+*suffix*+.segy". See Section 5.2 for description of the chosen SegY format. This command is only relevant for seismic with nmo-stretch (Section 4.6), and writes the entire offset gather for each position prior to nmo correction.

Argument: Yes or no, default is no.

4.8.19 <elastic-parameters-time-segy>

Description: Writes resampled vp, vs, rho in time in SegY format to files "*prefix*+_vp_time_+*suffix* +.segy", "*prefix*+_vs_time_+*suffix*+.segy" and "*prefix*+_rho_time_+*suffix*+.segy". See Section 5.2 for description of the chosen SegY format.

Argument: Yes or no, default is no.

4.8.20 <elastic-parameters-depth-segy>

Description: Writes resampled vp, vs, rho in depth in SegY format to files "*prefix*+_vp_depth_ +*suffix*+.segy", "*prefix*+_vs_depth_+*suffix*+.segy" and "*prefix*+_rho_depth_+*suffix*+.segy". See Section 5.2 for description of the chosen SegY format.

Argument: Yes or no, default is no.

4.8.21 <extra-parameters-time-segy>

Description: Writes the extra parameters from the Eclipse grid resampled in time in SegY format to files "*prefix*+_+*parameter-name*+_time_+*suffix*+.segy". See Section 5.2 for description of the chosen SegY format.

Argument: Yes or no, default is no.

4.8.22 <extra-parameters-depth-segy>

Description: Writes the extra parameters from the Eclipse grid resampled in depth in SegY format to files "*prefix*+_+*parameter-name*+_depth_+*suffix*+.segy". See Section 5.2 for description of the chosen SegY format.

Argument: Yes or no, default is no.

4.8.23 <seismic-stack>

Description: Writes the seismic stack of all angles as specified under command <angle> in Section 4.2, or for seismic with nmo-stretch (Section 4.6) writes the seismic stack of all offsets as specified under command <offset> in Section 4.6.3.

Example:

```
<seismic-stack>
  <time-storm>  yes </time-storm>
  <depth-storm> yes </depth-storm>
  <time-segy>   yes </time-segy>
  <depth-segy>  yes </depth-segy>
</seismic-stack>
```

4.8.23.1 <time-storm>

Description: Writes the seismic stack in time in Storm format to file "*prefix*+_seismic_time_stack_+*suffix*+.storm"

Argument: Yes or no, default is no.

4.8.23.2 <timeshift-storm>

Description: Writes the seismic stack shifted in time in Storm format to file "*prefix*+_seismic_timeshift_stack_+*suffix*+.storm". The parameter <timeshift-twt> (Section 4.10) must also be given.

Argument: Yes or no, default is no.

4.8.23.3 <depth-storm>

Description: Writes the seismic stack in depth in Storm format to file "*prefix*+_seismic_depth_stack_+*suffix*+.storm"

Argument: Yes or no, default is no.

4.8.23.4 <time-segy>

Description: Writes the seismic stack in time in SegY format to file "*prefix*+_seismic_time_stack_+*suffix*+.segy". See Section 5.2 for description of the chosen SegY format.

Argument: Yes or no, default is no.

4.8.23.5 <timeshift-segy>

Description: Writes the seismic stack shifted in time in SegY format to file "*prefix*+_seismic_timeshift_stack_+*suffix*+.segy". See Section 5.2 for description of the chosen SegY format. The parameter <timeshift-twt> (Section 4.10) must also be given.

Argument: Yes or no, default is no.

4.8.23.6 <depth-segy>

Description: Writes the seismic stack in depth in SegY format to file "*prefix*+_seismic_depth_stack_+*suffix*+.segy". See Section 5.2 for description of the chosen SegY format.

4.9 <project-settings>

Description: Keyword used for general settings.

Example:

```
<project-settings>
 <traces-in-mmeory> 200000  </traces-in-memory>
 <max-threads>           5  </max-threads>
</project-settings>
```

4.9.1 <traces-in-memory>

Description: Maximum number of seismic traces that can be held in memory simultaneously.

Argument: integer, default is 100 000.

4.9.2 <max-threads>

Description: Specifies the maximum number of threads that can be used by the program.

Argument: integer, default is maximum available threads.

4.10 <timeshift-twt>

Description: TWT used for time-shifted seismic is read from Storm file. This command has only effect if at least one of the output parameters <seismic-timeshift> (Section 4.8.13) or <seismic-timeshift-segy> (Section 4.8.16) is given.

Argument: File name.

4.11 <ps-seismic>

Description: Generate PS seismic instead of PP seismic.

Argument: Yes or no, default is no.

5 File formats

5.1 XML model file example

```
<seismic-forward>
  <elastic-param>
    <eclipse-file>  test_2006.grdecl  </eclipse-file>
    <default-values>
      <vp-top>                  3800  </vp-top>
      <vp-mid>                  3400  </vp-mid>
      <vp-bot>                  3800  </vp-bot>
      <vs-top>                  1200  </vs-top>
      <vs-mid>                  1900  </vs-mid>
      <vs-bot>                  2100  </vs-bot>
      <rho-top>                 2400  </rho-top>
      <rho-mid>                 2400  </rho-mid>
      <rho-bot>                 2400  </rho-bot>
    </default-values>
    <parameter-names>
      <vp>           VP_2006-07-01  </vp>
      <vs>           VS_2006-07-01  </vs>
      <rho>        DENS_2006-07-01  </rho>
    </parameter-names>
    <extra-parameters>
      <name>  SCO2diff_110912-090820  </name>
      <default-value>            0.0  </default-value>
    </extra-parameters>
  </elastic-param>

  <wavelet>
   <from-file>
    <format>    Landmark              </format>
    <file-name> wavelet_landmark.wvl  </file-name>
   </from-file>
  </wavelet>

  <white-noise>
   <standard-deviation>        0.02  </standard-deviation>
   <seed>                    123456  </seed>
  </white-noise>

  <nmo-stretch>
   <seafloor-depth>             200  </seafloor-depth>
   <velocity-water>            1500  </velocity-water>
   <offset>
     <offset-0>                   0  </offset-0>
     <doffset>                   50  </doffset>
     <offset-max>              2000  </offset-max>
   </offset>
  </nmo-stretch>

  <output-grid>
   <top-time>
     <top-time-constant>       1200  </top-time-constant>
   </top-time>
   <area>
    <x0>                     540000  </x0>
    <y0>                    6710000  </y0>
```

```
    <lx>                          4000  </lx>
    <ly>                         10000  </ly>
    <angle>                         45  </angle>
   </area>
   <cell-size>
    <dx>                            50  </dx>
    <dy>                            50  </dy>
    <dz>                             1  </dz>
    <dt>                             4  </dt>
   </cell-size>
   <segy-indexes>
     <inline-start>                  5  </inline-start>
     <xline-start>                   5  </xline-start>
     <inline-direction>              y  </inline-direction>
     <inline-step>                   1  </inline-step>
     <xline-step>                   -1  </xline-step>
   </segy-indexes>
  </output-grid>

  <output-parameters>
   <prefix>               parameters  </prefix>
   <suffix>                     grid  </suffix>
   <elastic-parameters>          yes  </ elastic-parameters>
   <reflections>                 yes  </reflections>
   <zvalues>                     yes  </zvalues>
   <twt>                         yes  </twt>
   <time-surface>                yes  </time-surface>
   <depth-surface>               yes  </depth-surface>
   <seismic-time-segy>           yes  </seismic-time-segy>
   <seismic-depth-segy>          yes  </seismic-depth-segy>
   <elastic-parameters-time-segy>yes  </elastic-parameters-time-segy>
   <elastic-parameters-depth-segy>yes </elastic-parameters-depth-…>
   <extra-parameters-time-segy>  yes  </extra-parameters-time-segy>
   <extra-parameters-depth-segy> yes  </extra-parameters-depth-segy>
   <seismic-stack>
     <time-storm>                yes  </time-storm>
     <depth-storm>               yes  </depth-storm>
     <time-segy>                 yes  </time-segy>
     <depth-segy>                yes  </depth-segy>
   </seismic-stack>
  </output-parameters>

</seismic-forward>
```

5.2 SegY header format for output

The following numbers are used in the trace header in SegY output files:

Variable	**Byte number**
Offset in meters or angle in degree	37
Start time/depth in seismic trace	109
X coordinate	181
Y coordinate	185
Inline number	189
Crossline number	193

5.3 SegY header formats for input

The following formats are recognized in input files (<area-from-segy>):

	Seisworks	**IESX**	**SIP**	**Charisma**	**SIPX**
Variable	Byte number	Byte number	Byte number	Byte number	Byte number
X coordinate	73	73	181	73	73
Y coordinate	77	77	185	77	77
Inline number	9	221	189	5	181
Crossline number	21	21	193	21	185

5.4 Landmark ASCII Wavelet input file

The Landmark ASCII Wavelet file has 4 headers before the wavelet sampling follows with one sample on each line.

1. Format
2. Number of samples
3. Sample number for zero time
4. Time sampling in *ms*

Example:

```
Landmark ASCII Wavelet
23
12
4
0
-1.84436E-05
-0.000220463
-0.001927747
-0.012221013
-0.055374287
-0.174860489
-0.36509521
-0.433627901
-0.077581906
0.620928647
1
0.620928647
-0.077581906
-0.433627901
-0.36509521
-0.174860489
-0.055374287
-0.012221013
-0.001927747
-0.000220463
-1.84436E-05
0
```

6 References

Buland, A. and Omre, H.(2003). Bayesian linearized AVO inversion. *Geophysics*, 68:185-198.

Dahle, P., Fjellvoll, B., Hauge, R., Kolbjørnsen, O., Syversveen, A.R., Ulvmoen, M. (2011) CRAVA User Manual version 0.9.9. NR Note SAND/03/2011.

Stolt, R.H. and Weglein, A.B. (1985). Migration and inversion of seismic data. *Geophysics*, 50:2458-2472.