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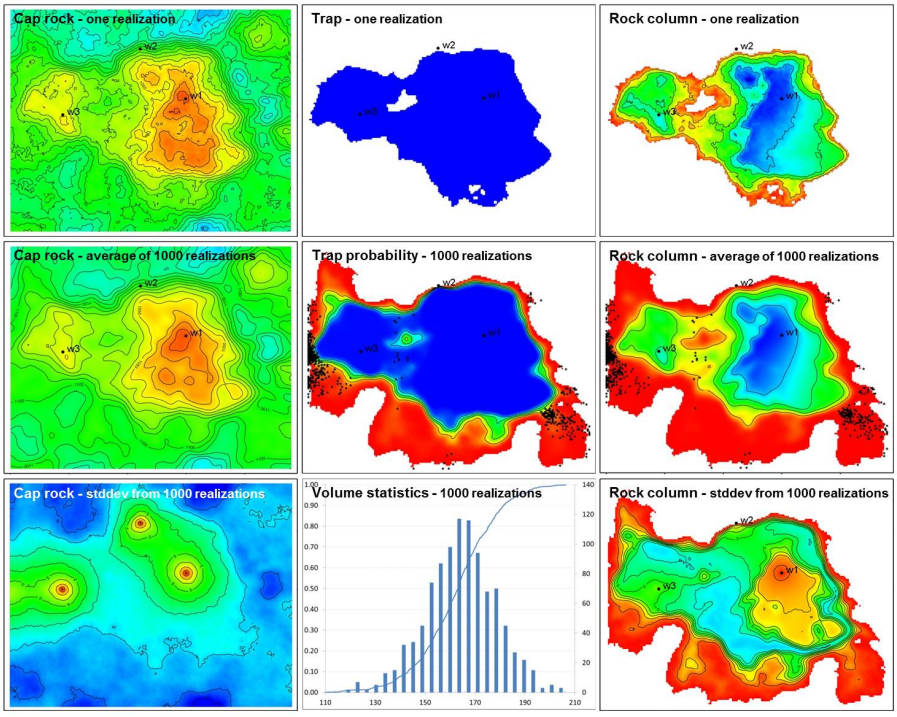
Note

Cohiba User Manual
Version 5.0



Note no SAND/04/2014

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Abstract

This user manual describes the functionality of the Cohiba surface modeling software.

The manual is prepared with numerous hypertext links suitable for viewing on a computer screen. Some parts of the manual documents technical or advanced topics. These are marked by the symbol in the right margin. The model file elements marked by this symbol should be modified with care.

The latest version of this manual is available at: www.nr.no/COHIBA.

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The front page figure is a collection of illustrations taken from Section 10.

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Contents

I Introduction 1

1 What is Cohiba? 2
- 1.1 Cohiba basic idea 2
- 1.2 Cohiba main features 3
- 1.3 Cohiba methodology 9
- 1.4 Cohiba input data 10
- 1.5 Quality control 11
- 1.6 Robust estimation of trends 12
- 1.7 Platforms and portability 12
- 1.8 The name 13

2 Terminology and concepts 14

II User manual 19

3 Getting started 20

4 Cohiba command line options 23
- 4.1 Specifying the random seed 23
- 4.2 Specifying number of realizations 23
- 4.3 Spill point detection 23

5 The Cohiba model file 25
- 5.1 Editing the Cohiba model file 27
- 5.2 Errors reading the Cohiba model file 27

6 Files and directories 29
- 6.1 File directory structure 29
- 6.2 Surface file formats 29
- 6.3 Well log file formats 29
- 6.4 Well points file format 30

7 The Cohiba output 33
- 7.1 Output maps 33

7.2 The log files . . . 33
7.3 Spill point files . . . 42
7.4 Well point files . . . 43
7.5 Well path files . . . 44
7.6 Well path cluster files . . . 45
7.7 Help point files . . . 47

8 Well data . . . 48
8.1 Using zone logs . . . 48
8.2 Using fault indicator logs . . . 48
8.3 Close well points . . . 49
8.4 Extracting well points from zone logs . . . 50
8.5 Horizontal wells . . . 56
8.6 Using well points outside lateral grid . . . 58

III Tutorials 63

9 Volume calculations . . . 64
9.1 Calculating the volumes . . . 66

10 Stochastic simulation example . . . 67
10.1 Acceptance criteria . . . 67
10.2 Results . . . 69

11 Multiple models . . . 75

12 Faults . . . 82

13 Free surfaces . . . 84
13.1 Linking free surfaces to other surfaces . . . 84

IV Reference manual 86

14 Cohiba model file elements . . . 87
14.1 `<project-settings>` (required) . . . 88
14.2 `<modelling-settings>` . . . 98
14.3 `<well-data>` . . . 110
14.4 `<surfaces>` (required) . . . 116
14.5 `<interval-models>` (required) . . . 125
14.6 `<volumes>` . . . 131

15 List of all elements **134**

16 Cohiba model file example **138**

16.1 Cohiba log file example 142

V Theory **151**

17 Prediction of surfaces **152**

17.1 Surfaces and intervals 152

17.2 Stochastic model for surfaces and intervals 152

17.3 Estimating the trend coefficients 154

17.4 Prediction of surfaces using kriging 159

17.5 Depth conversion 163

17.6 Gridding effects 166

18 Stochastic simulation **168**

18.1 Fast approximate simulation 169

18.2 Rejection sampling 170

19 Variogram examples **172**

20 Conditioning to zone logs **176**

20.1 Procedure for conditioning to zone logs 176

20.2 Clusters 180

VI Appendix **181**

A Release notes **182**

B Known issues **188**

References **189**

Index **194**

Part I
Introduction

1 What is Cohiba?

Cohiba is a computer program that provides a fast and accurate method for generating a set of deterministic surfaces using prediction, or a set of random realizations of the surfaces using stochastic simulation. Cohiba can use information from:

- Surface observations in wells (well points).
- Horizontal well paths with zone logs.
- Travel time maps.
- Interval velocity models.
- Geological interpretation of depositional thickness.
- Spill point depth.

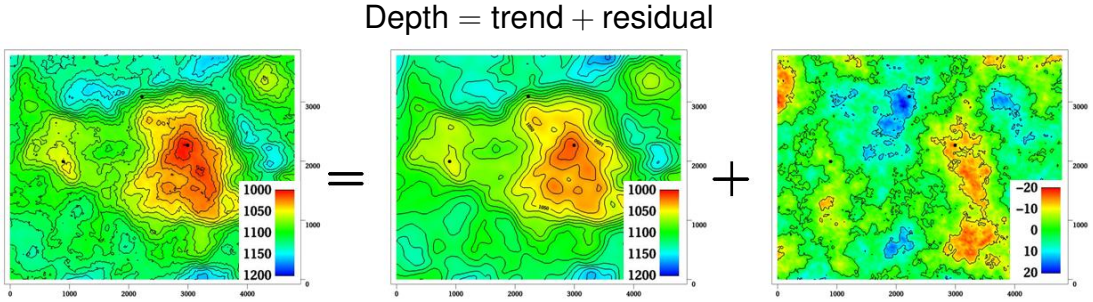
Cohiba uses the available data in a consistent manner to minimize the uncertainty. The accuracy is further improved by linking together all surfaces in a consistent multi-layered model.

Cohiba provides two ways of evaluating uncertainty:

- A local depth uncertainty at every surface location can be calculated.
- Stochastic (Monte Carlo) surface realizations can be generated. A set of these span the uncertainty range.

1.1 Cohiba basic idea

Surfaces are modeled as a sum of a *trend* and a *residual*. The trend captures the large scale shape of the surface and the residual captures (small) deviations between the trend and the unknown *true* surface. This is illustrated here:

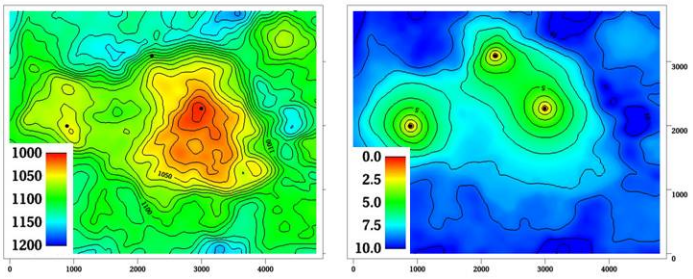


The trend can be a single known map or a linear combination of many known maps. The trend determines the main shape of the surface so the choice of trend maps is very important. The residual is usually small compared to the trend. The residual is specified by an residual uncertainty (standard deviation) and a spatial continuity determined by a variogram. The residual is in principle unknown and random.

Cohiba will adjust the specified trends to match well data. The remaining difference will be described by the residual. The residual will be irregular and random for stochastic simulation, just like the figure above. For deterministic surfaces, the residual surface is a smooth interpolation of the residuals at the wells. This is illustrated on page 17.

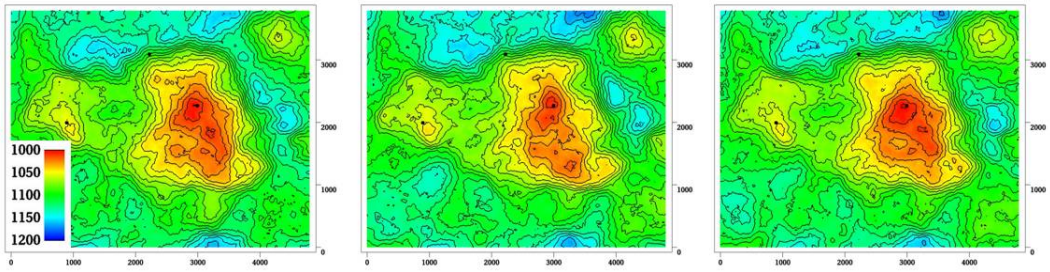
1.2 Cohiba main features

Deterministic surfaces. Cohiba finds the most likely surface given all available data. This is called prediction of surfaces and is typically used for well planning. The uncertainty (prediction error) can be calculated and displayed as a map. A predicted deterministic surface with corresponding prediction error is illustrated here:



Note how the uncertainty (prediction error) drops to zero at the three well points.

Stochastic surfaces. Cohiba can generate one or many stochastic realizations that are consistent with all available data. The stochastic realizations are generated using stochastic simulation. Stochastic simulation is sometimes called Monte Carlo simulation. Stochastic realizations are typically used for sensitivity, uncertainty and rock volume studies. Three stochastic simulations are illustrated here:



The average of a large set of stochastic simulations will coincide with a deterministic surface obtained using prediction. The standard deviation of the large set of stochastic simulations will coincide with the prediction error.

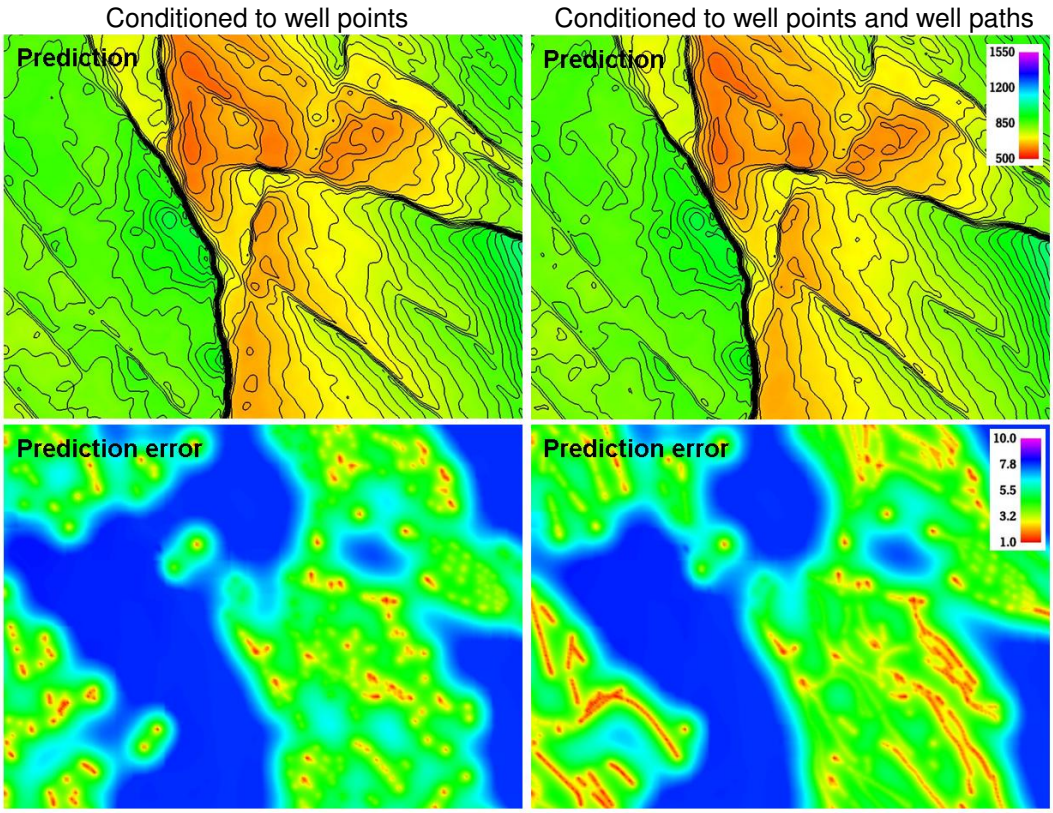
Stochastic simulated surfaces should look like the true surface. The details are of course not correct since they are unknown and random, but the irregularity should have the same geometric properties as the true surface.

It is impossible to see where the stochastic simulated surfaces are conditioned on well data provided the specified residual is consistent with the well data. That is, the specified residual has a realistic uncertainty. Cohiba provides an estimate of this.

It is common to say that the realizations from stochastic simulations are *equiprobable*. This is true in the sense that they all have probability zero! However, they are not equally likely. It is in principle possible to calculate how *likely* each simulated surface is. The most likely surface is the deterministic surface obtained using prediction. It is irrelevant how likely a simulated surface is. For practical purposes they can be treated as having identical statistical properties.

It is possible to add *acceptance criteria* to the simulated realizations. These are typically related to restrictions on the spill point of the surfaces. If the surface fail to meet the acceptance criteria, the realization is rejected, and new realizations are generated until the acceptance criteria is fulfilled.

Horizontal wells. Cohiba ensures that surfaces are correctly positioned according to zone logs in horizontal wells. Cohiba uses an advanced technique where surfaces are conditioned to inequality constraints along the well paths. This ensures correct location of surfaces and reduction in the surface uncertainty along the wells. Here is an example to show the effect of using information from well paths:

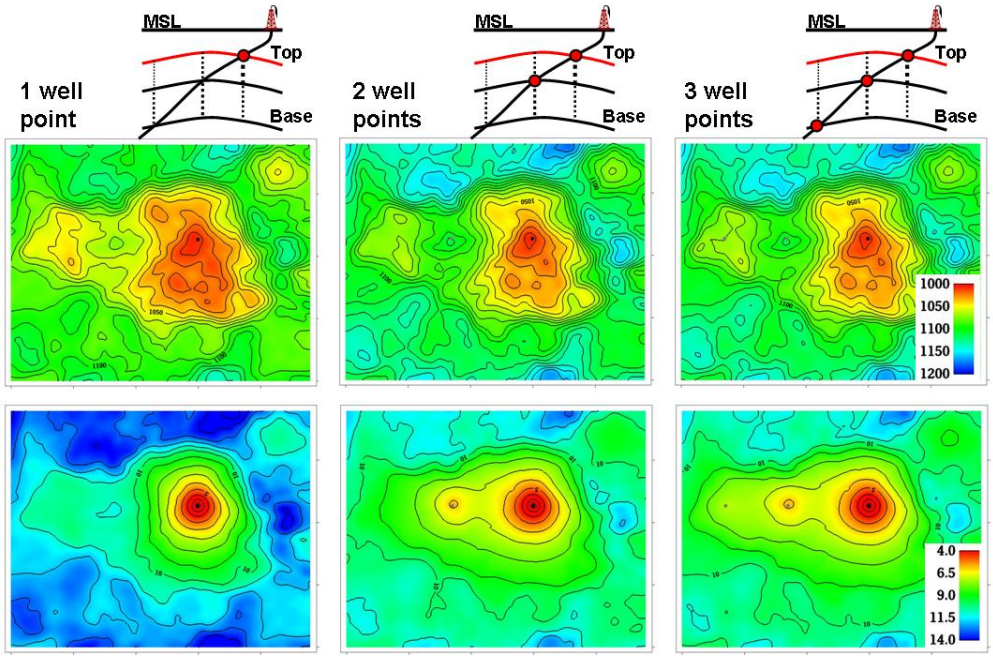


The two upper figures are the deterministic surfaces and the two lower figures are the corresponding prediction errors. The change in the deterministic surfaces are significant and the prediction errors has been significantly reduced along the well paths.

This approach works in complex situations with many surfaces and layers and will ensure correct results even when well paths follow very thin layers.

Multi layer models. Cohiba considers models for all surfaces (reflecting and non-reflecting) in a stratigraphic model *simultaneously*. This has two nice implications:

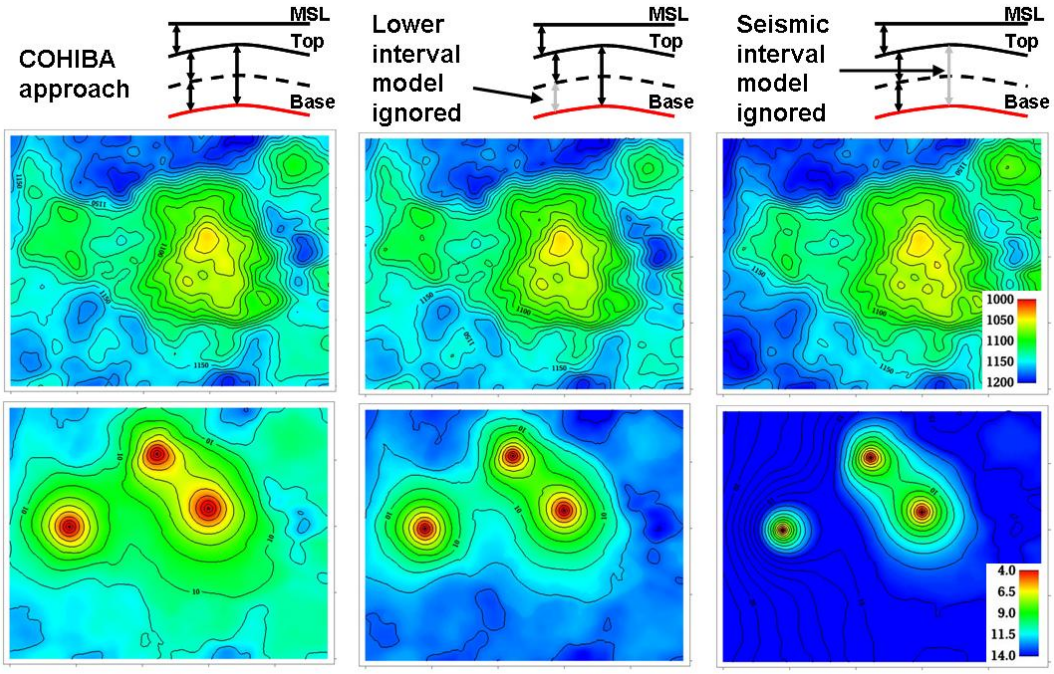
1. A particular surface is constrained by observations from surfaces above and below. This improves precision and reduces the uncertainty. The impact of observations below a surface is illustrated here:



   The illustration shows the top surface (and its prediction errors) from a model with three surfaces. This is the red surface in the schematic cross sections above the contoured maps. The three columns show how the deterministic (prediction) surface and prediction errors are modified as a deviated well is drilled into the two lower surfaces. The lateral location of the well points are easily seen on the prediction error maps. It is clearly seen that prediction errors are reduced by the observations of deeper surfaces.

2. Sufficient well data are well points and zone logs. Unobserved interval thicknesses in deviating or horizontal wells are not needed.

Ambiguous multi layer models. It is sometimes unclear when it is best to add layers from above or from below. This is solved by specifying multiple models and let Cohiba automatically combine the alternatives so that the precision is optimized. A typical example is a layered reservoir outlined by two accurate seismic reflectors. Cohiba solves this by automatically fitting the layers inside the envelope of seismic reflectors. This is illustrated here:



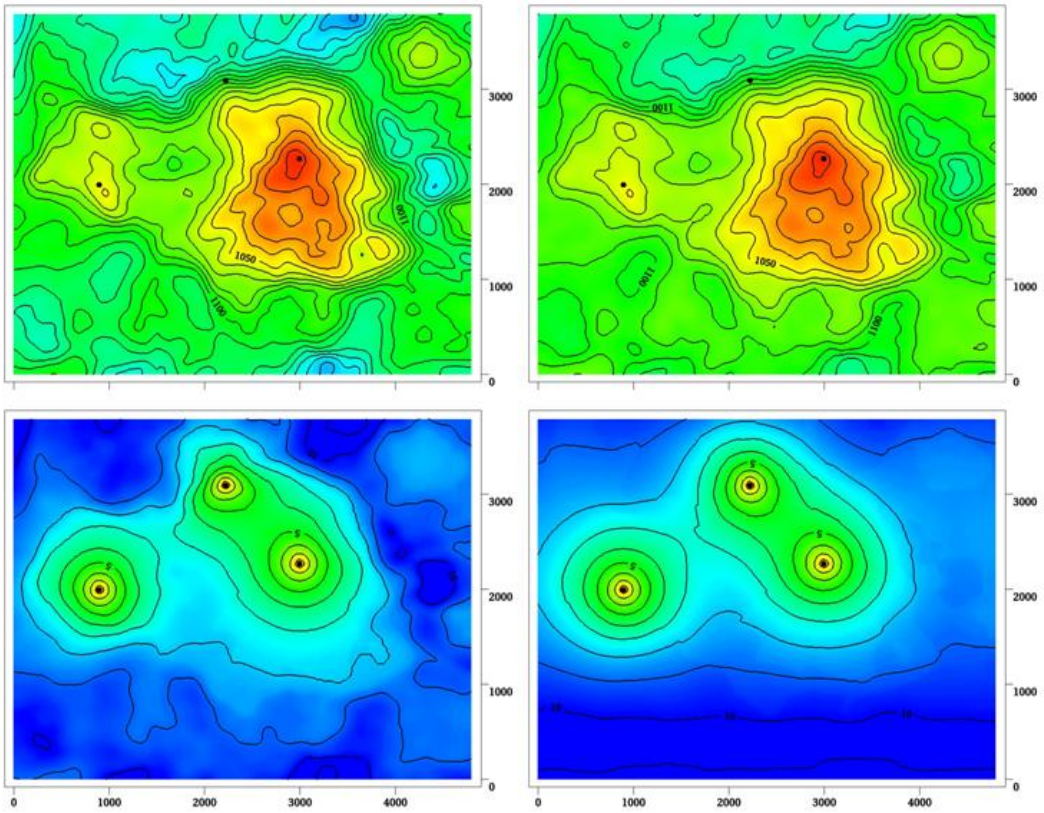
The illustration shows the base surface (and its prediction errors) from a model with three surfaces. This is the red surface in the schematic cross sections above the contoured maps. The top and base surfaces are seismic reflectors. The intermediate surface (dashed line) is not a seismic reflector. The left figures show how Cohiba handles this situation. The two figures in the middle show a typical solution where the model for the lowest layer is ignored. The figures to the right shows what happens if the information from the seismic travel times between the top and base surfaces is ignored.

Section 11 includes a discussion of multiple models.

Depth conversion. Seismic reflectors are described using interpreted travel time maps and an interval velocity model for each interval. The interval velocity model can be fitted to depth observations taking prior information and spatial correlation into account.

Example of two alternative depth conversion models:

$v(x, y) = a + b \cdot t(x, y)$ $v(x, y) = a + b \cdot y$

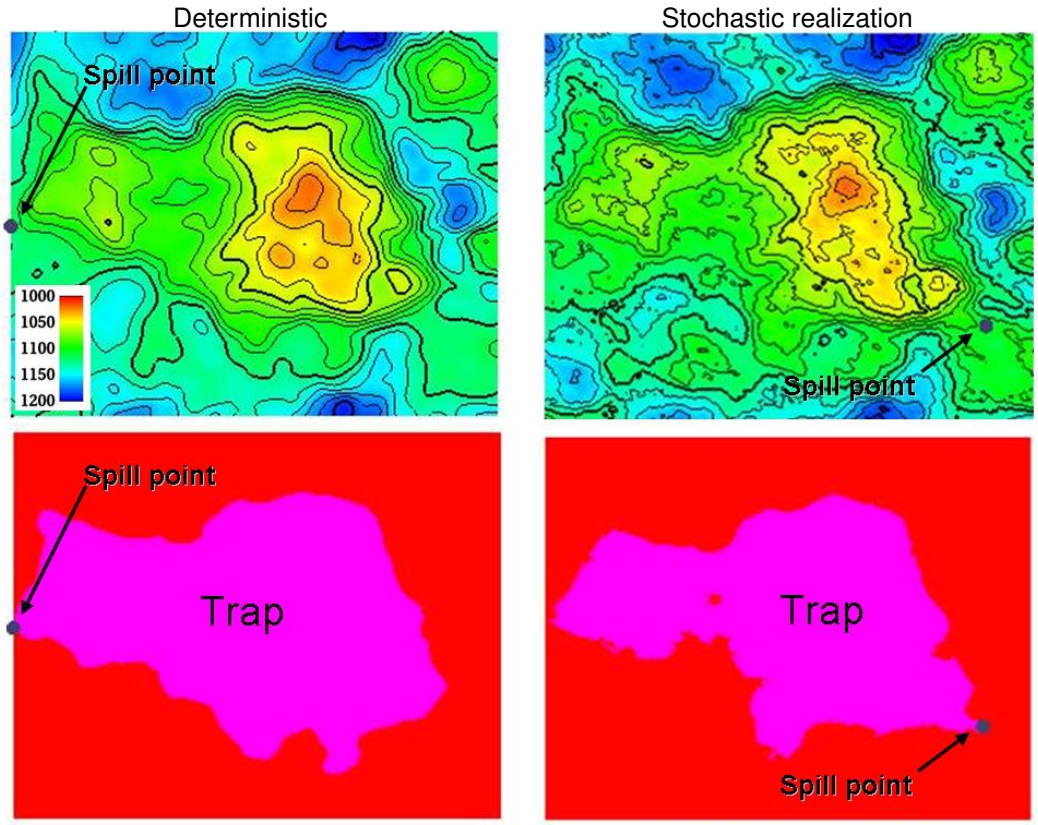


The left deterministic surface and prediction errors are obtained using an interval velocity that increase with the travel time, $t(x, y)$. The right figure shows a result using a north-south interval velocity trend (depend on the y-coordinate). Both interval velocity trends are fitted to the three well points.

Interval velocity maps. Interval velocities from e.g. stacking velocities can be used as the interval velocity model in the depth conversion.

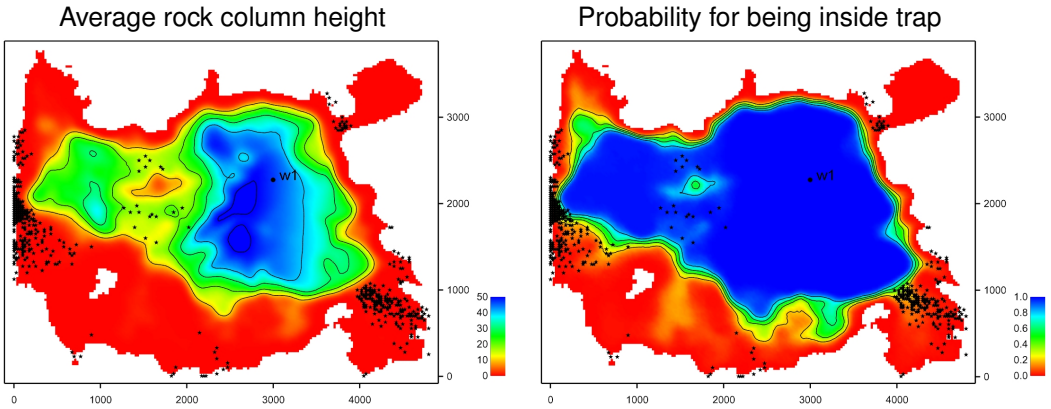
Isochores. Reservoir layers are typically described by smooth isochores or trends. Isochores are fitted to depth observations taking prior information and spatial correlation into account.

Spill point detection. Spill point and the corresponding trapped area can be found for any surface. Spill points can be detected in a single imported surface or on any surface generated by Cohiba. Here is an example of a spill point and the corresponding trap:



The spill point is detected and written to file (x-, y-, and z-coordinate). Also the trapped area can be written to an output grid file. Note that the spill point for the predicted and the simulated surfaces can be quite different.

Volume calculations. The gross rock volume between two surfaces and two hydrocarbon contacts can be calculated. The results are volumes and rock column maps. It is possible to ensure that the hydrocarbon contact is consistent with the spill point and that only trapped or connected volumes are considered. Average maps from multiple stochastic realizations are generated:



These maps are the average of 1000 realizations. The small black dots are the 1000 different spill points. For an extensive discussion of the possibilities see Section 10.

1.3 Cohiba methodology

Deterministic surfaces are obtained using *kriging* for prediction, and stochastic simulation (Monte Carlo) is used for creating alternative realizations. The conditioning data are the well data while seismic data and isochores can be included as trend maps. Kriging with trend maps fitted to well points are called *universal kriging* or *kriging with trends*. Cohiba also offers *Bayesian kriging* which is more robust when few well points are available. For more information on kriging and stochastic simulation see for instance the books by Isaaks and Srivastava (1989), Cressie (1993), Chilés and Delfiner (1999), and Lantuéjoul (2002).

Cohiba uses multiple linear regression (see e.g. Weisberg, 1985) to fit the trends to well points. Spatial correlations are taken into account so that the information from closely located well points are given less importance than well points scattered evenly in the area.

Different surfaces are *covariates* so cokriging is used if more than one surface is considered. The interval velocities are also correlated to the surfaces. Therefore surfaces and interval velocities are also covariates.

The residuals (differences between data and trends) are assumed to be *Gaussian random fields* allowing a fast and accurate Fast Fourier Transform (FFT) stochastic simulation technique. Experience has shown that the Gaussian assumption is reasonable as long as well points are consistent with trends for isochores and interval velocities.

The basic methods for handling several surfaces and intervals simultaneously were developed by Abrahamsen (1993). The extension to handling alternative ways of combining layers to obtain a surface was published by Abrahamsen (2005). The original idea on how to constrain the surfaces to zone logs along well paths was published by Abrahamsen and Benth (2001). Cohiba combines all these ideas into a consistent and robust framework for accurate surface prediction.

Spill point detection can be applied to any surface in the model or to a single imported surface. The algorithm is described in Abrahamsen et al. (2000). The algorithm requires a starting point known to belong to the trap.

Some theoretical details are supplied in Part V.

1.4 Cohiba input data

Depending on the situation, the user can choose to use the following input data:

Well points. Locations of intersections between well paths and surfaces.

- It is possible to specify an observation uncertainty at each well point.

Well paths with zone logs. Well points are extracted and surfaces will be adjusted according to the zone log information. This includes ensuring consistency with horizontal wells.

- It is possible to specify the vertical position uncertainty of the well path.

Travel time maps. These are interpreted travel time maps for seismic reflectors.

- Uncertainty in the interpreted travel time maps either as a constant value (say 4 ms) or as a map describing the interpretation in different areas.
- Variograms describing the spatial correlation of the uncertainty for each travel time map.

Interval velocity models:

- Interval velocity trend. Typical example is $v(x, y) = a + b \cdot t(x, y)$, where a and b are trend coefficients, and $t(x, y)$ is the seismic travel time at location (x, y). (Any linear function of maps can be used.)
- Interval velocity maps.
- Uncertainty in interval velocities either as a constant value or as a map.
- Variograms describing the spatial correlation of the uncertainty for each interval velocity.

Interval thickness models:

- Interval thickness trend. Any linear trends of coordinates and known maps are possible. For instance: $\Delta z(x, y) = a + b \cdot x + c \cdot y + d \cdot m(x, y)$, where a, b, c, and d are trend coefficients and $m(x, y)$ is any known map.
- Interval thickness trend using an isochore map: $\Delta z(x, y) = a \cdot m(x, y)$, where $m(x, y)$ is a user specified isochore map. Note that pinch outs are possible so $m(x, y)$ can be zero in large areas.
- Uncertainty in interval thickness either as a constant value or as a map.
- Variograms describing the spatial correlation of the uncertainty for each interval thickness.

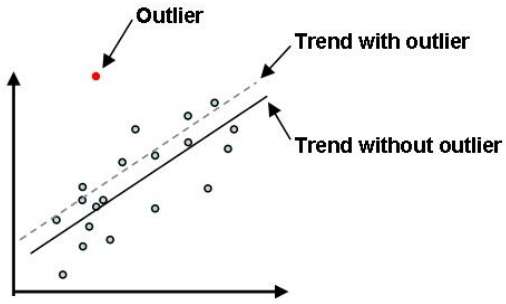
Ordering of surfaces. The surfaces in the model must be ordered according to their depth. This makes it possible to check if well observations are in correct order. Moreover, this ensures that erosion, on-lapping, and pinch outs, can be handled properly. Free surfaces (Section 13) do not have any ordering.

1.5 Quality control

Cohiba has methods for performing quality control of the input data. Conflicts and ambiguities in the data are handled automatically and reported, so that actions can be taken when necessary. Quality control includes:

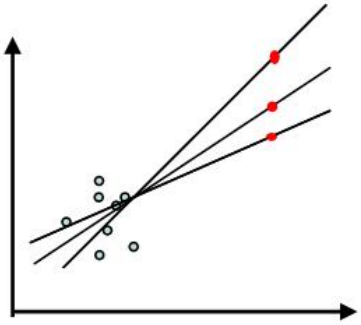
Model conflicts. Well points that are in conflict with the model are flagged. Well points are removed if the conflict may corrupt the results.

- Detection of *outliers*. These are well points that fit the model assumptions poorly. This can be caused by errors in the well data or by mismatch between well data and model assumptions. The red data in the following figure could be an outlier:



  Outliers will often have significant impact on the trends. See Section 17.3.4.1 for some details.

- Detection of *leverage points*. These are data that are potentially outliers but influence the model so strongly that they appear to fit nicely. The following picture shows how a leverage point (the red dot) will influence the regression line:



Conflicting observations. A common problem is that two or more observations are at the same location. There are two ways to handle this, depending on the situation:

1. If the data are identical (same well, same surface, same depth), the best approach is to collapse them to a single observation.
2. If the data have multiple values (different depth) they are retained but given a measurement error (uncertainty) determined by their difference.

Detected outliers, leverage points, and conflicts are flagged for inspection. In severe cases Cohiba removes data that otherwise would corrupt the surfaces.

1.6 Robust estimation of trends

The trends are fitted to well points using linear regression. Outliers and leverage points may corrupt the fitted trends. Therefore, severe outliers are removed prior to the fitting of the trend. This is done in an iterative way: First the trends are fitted using all well points and the mismatch between the trend and well points is analyzed. Then, the severe outliers are removed and the trends re-fitted to the remaining well points. This is repeated until there are no severe outliers left.

The iterative method of fitting the trends ensures a complete removal of inconsistent data so that trends becomes reasonable. Note that these data are also removed from the kriging step where the trends are locally fitted to the well points.

Well points removed from the estimation are flagged and reported. It is recommended to inspect the log files provided by Cohiba to check for errors and inconsistencies. The log files can be read into and analyzed in e.g. Excel. This is illustrated in Figure 1.1.

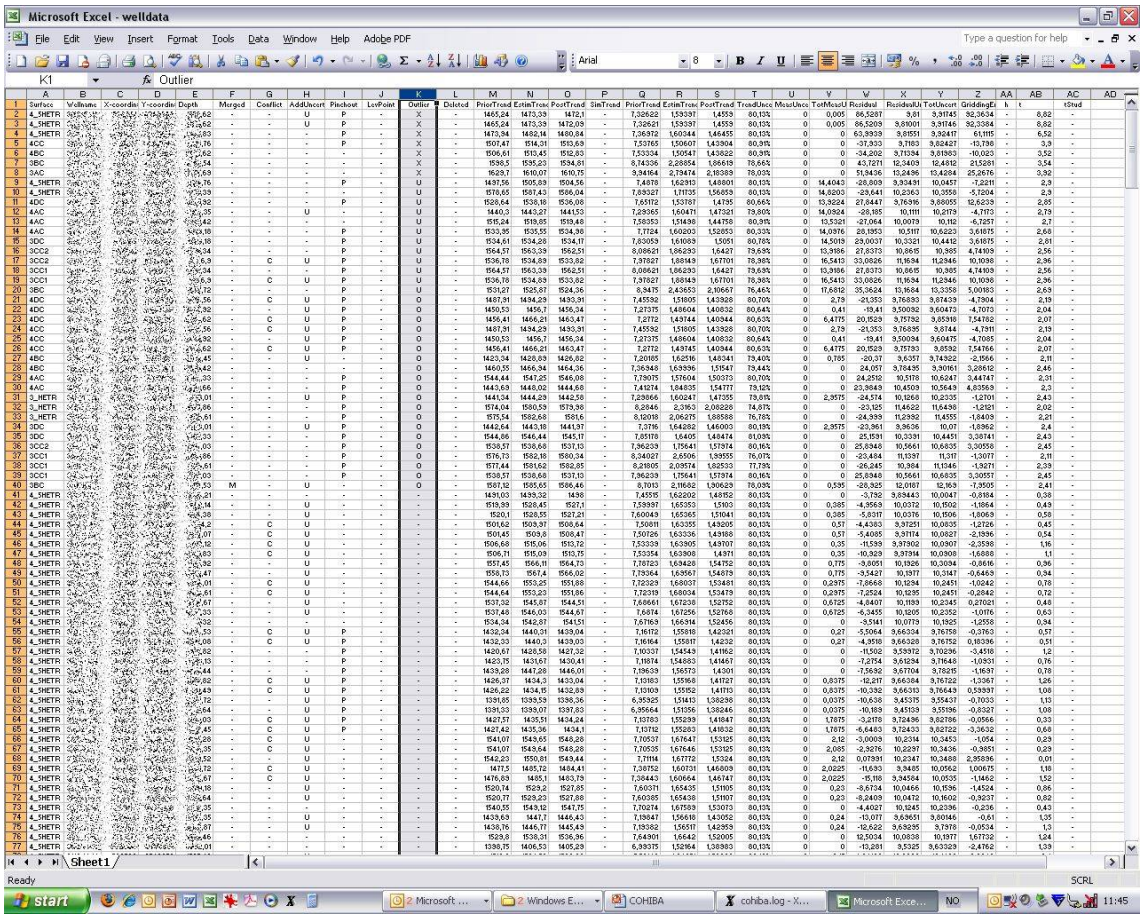


Figure 1.1. Log file for well points imported into Excel. Outlier status is reported in column K. The 7 first observations has been removed (row 2–8), the 12 next (row 9–20) are kept but a measurement error has been added, and another 20 well points (row 21–40) are marked as outliers.

1.7 Platforms and portability

Cohiba has been developed and tested on 64 bits Linux and Windows operating systems. 32 bits operating systems are not supported. Currently, we recommend Windows 7 and RedHat Enterprise Linux 5 or later, but Windows XP/Vista and any Linux distribution using kernel 2.6 or newer

should work.

In this manual, the directories use the slash: /. On Windows systems the slash must be replaced by a backslash: \.

1.8 The name

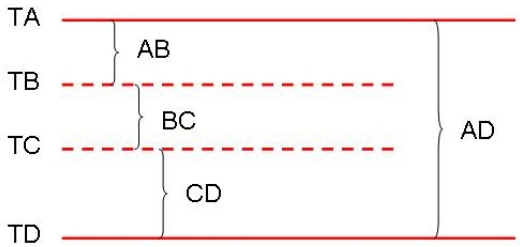
Cohiba is an acronym for **Co**rrelated **H**orizon **I**ntervals and **B**ayesian **A**nalysis. But more important it is a nice word that is easy to remember. It is also known to be a famous Cuban cigar. The previous versions of Cohiba were called HORIZON.

2 Terminology and concepts

This manual contains a lot of terminology. Some of these concepts, such as *interval*, are commonly used words but they have specific meaning in this document. This section tries to define exactly what is meant when certain words are used in this manual.

Surface. The surfaces in Cohiba are a set of depth surfaces in a specific depth order. The depth may coincide in pinch out situations. Every surface has a unique name used to identify the surface and data that belongs to it. A surface can be a *seismic reflector* with an associated travel time map. Surfaces can be *erosive* to surfaces below, and *on-lapped* by surfaces above.

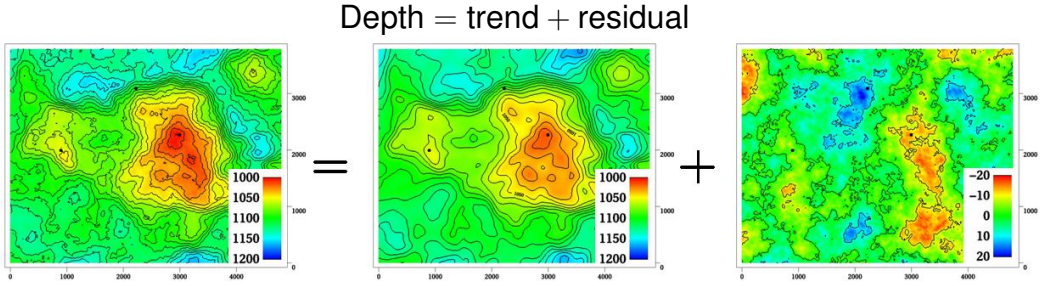
Interval. An interval in Cohiba has a top surface and a base surface. The top and base surfaces are two arbitrary surfaces but they must be in correct depth order (top above base). Any surface can be both a top surface and a base surface in several intervals. A common example is to have one interval spanning the whole reservoir and a set of smaller intervals spanning each individual reservoir zone. This is illustrated here:



The figure shows a schematic cross section of surfaces (`TA`, `TB`, `TC`, `TD`) and intervals (`AB`, `BC`, `CD`, `AD`). Note that surface `TA` is the top for intervals `AB` and `AD`, and surface `TD` is the base of intervals `AD` and `CD`.

Intervals are the most important building blocks in Cohiba. Surfaces are obtained by adding (or subtracting) the relevant intervals above (or below). The depth to any surface is the sum of interval thicknesses. The user must specify the depth sequence of the surfaces, the top and base surface for each interval, and how to build the interval thickness models. From this information, Cohiba automatically figures out how to assemble the intervals to obtain the surfaces in the best possible way.

Model. A model in Cohiba means a *stochastic model* for the intervals and the surfaces. The model is made up of two parts: The trend and the residual. Trends describe large scale behavior whereas the residual describes variations around the trend on a smaller lateral scale (typically less than 2000 m). This is illustrated by the following picture:



This trend is obtained from a seismic travel time map and a model for the interval velocity trend. The residual is a stochastic simulation of a possible realization of the mismatch between the trend and the real depth to the surface.

Given the model *and* the available data, Cohiba can predict or simulate the depth to surfaces.

Trend. The trend for a thickness can be constructed as a linear combination of known trend maps such as

$$\Delta z = a \cdot 1 + b \cdot x + c \cdot y + d \cdot m(x, y).$$

The three first trend maps, 1, x, and y, are simple, but the last trend map, $m(x, y)$, could for instance include a sedimentological interpretation of the depositional thickness. The values a, b, c, and d are called *trend coefficients*.

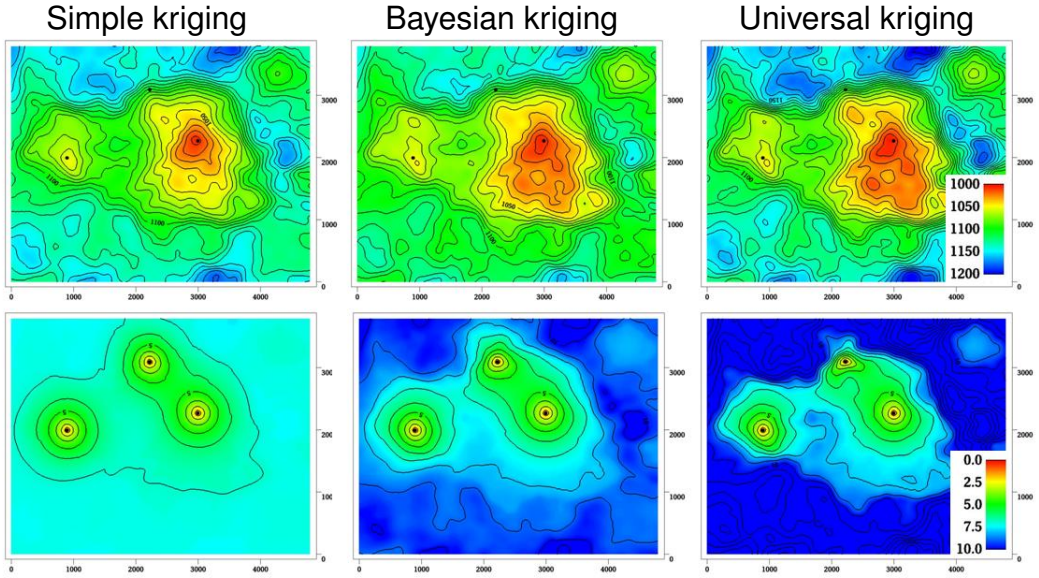
Similarly, interval velocity trends are used in combination with travel time maps for seismic depth conversion.

Cohiba supports any number of trend maps in the linear combination. But, most trends are quite simple and usually contains one or two trend maps.

Trend coefficients. The trend coefficients are assumed to have a Gaussian distribution. Cohiba offers three options of determining the values of the trend coefficients:

1. Cohiba can adjust the trend coefficients to the well points using linear regression[1]. This approach requires that there is enough well points. Otherwise, the estimation might fail or give very uncertain results. This option amounts to using *universal kriging*.
2. The user can specify the trend coefficients. This amounts to *simple kriging*. [2]
3. Cohiba can make a balance between a *prior specification* by the user and the estimates obtained from adapting the trend coefficients to data using linear regression. This is the recommended approach since it handles few (even zero) well points and will approach universal kriging if there is a lot of well points. This approach is called *Bayesian kriging*.

The differences between the three ways of specifying the coefficients and the corresponding kriging types are illustrated here:



1. The linear regression method minimizes the generalized least squares (GLS). This is similar to ordinary least squares but it takes into account the variation in precision of the well observations and their spatial clustering.
2. Simple kriging will ignore any uncertainty on the trend coefficients.

The upper row contains the surface depths and the lower row the corresponding prediction errors. There are two trend coefficients in this example that corresponds to surface depth and surface curvature respectively. There are only three well points in this example and that makes it difficult to estimate the coefficients accurately. In particular the trend coefficient determining the curvature is very uncertain. This is clearly seen on the prediction error for universal kriging. The opposite extreme is simple kriging where the trend coefficients are assumed to be known. Bayesian kriging is a balance between the two extremes. Universal kriging is unbiased and will perform better with more well points. Simple kriging will adapt locally to additional well points but the trend coefficients initial prior guess will not be modified by additional well points.

The user must specify a prior distribution for the trend coefficients. This amounts to specifying the prior mean values (expectation) and the prior standard deviation for each trend coefficient. The prior specifications are not used by the universal kriging approach. However, it is very important to always specify reasonable values for the prior mean values because these are used when evaluating depth uncertainties caused by travel time uncertainty and interval velocity uncertainty.

Trend map. The individual trend map(s) must be chosen by the user. This is where the geophysical and geological knowledge enters. Intelligent choice of trend maps will reduce the residual error and therefore improve precision. The individual trend maps can be a simple constant (say 200 meters) or complex maps related to geophysical measurements and geological interpretations.

Residual. The residual is added to the trend to capture the difference between the trend and reality. The residual is assumed to be a *Gaussian random field* with known properties that must be specified by the user. The properties include a variogram (spatial correlation function) (variogram) and an uncertainty (standard deviation). The variogram determines the continuity and smoothness of the residual whereas the uncertainty is a measure of how much we believe in our trend. The uncertainty can be specified by a single value or by a map.

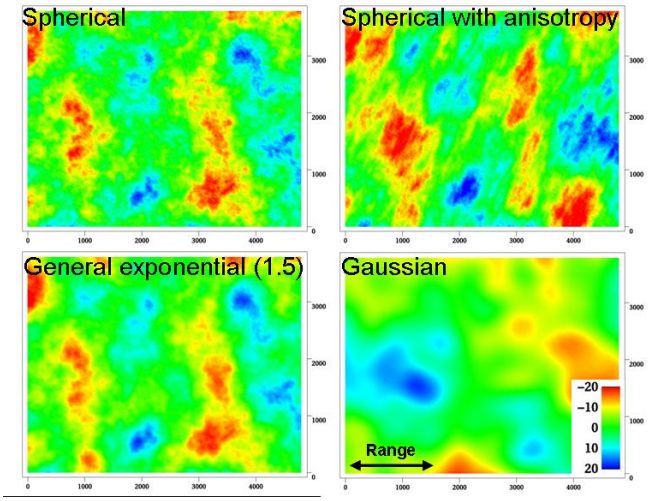
There are three types of residuals used by Cohiba:

1. For seismic reflectors, a *travel time residual* must be specified. This residual describes the interpretation error. Typical uncertainties are in the range 2–20 msec.

2. For a velocity interval, the *interval velocity residual* must be specified. Typical uncertainties are in the range 10–200 m/s.

3. For a thickness interval, the *thickness residual* must be specified. Typical uncertainties are 0–50 meters. (0 is used for pinch outs.)

Here is four examples of simulated residuals with different spatial smoothness:



Depth conversion. The top and base surfaces of some intervals can be seismic reflectors. Cohiba offers the possibility of specifying interval velocities models rather than interval thickness models. Cohiba will depth convert the travel times using the specified interval velocity model for these intervals. Any mixture of interval thickness and interval velocity models is possible.

An interval velocity trend can typically look like

$$v = a \cdot 1 + b \cdot t(x, y).$$

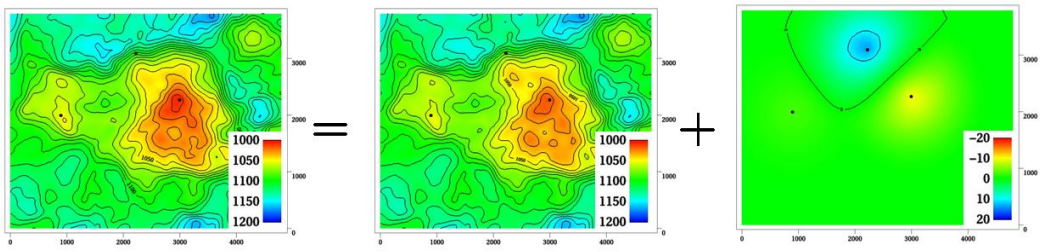
The thickness of the corresponding interval is obtained by multiplying the interval velocity by the travel times for that interval:

$$\Delta z = \Big(a \cdot 1 + b \cdot t(x, y)\Big) \cdot \Delta t(x, y).$$

Prediction. Prediction means to find the *most likely* set of surfaces given the model specifications *and* the data. This is a unique set of surfaces. It is common to call this deterministic surfaces.

A surface model is made of two parts, the trend and the residual. Prediction uses the fitted trend and the interpolated residuals at the well points. This is illustrated here:

Depth = trend + residual



Stochastic simulation. Stochastic simulation is a *stochastic* approach where trend coefficients and residuals are sampled from probability distributions to obtain a *realization*. The realization is *conditioned* to data, that is, the realizations are consistent with all the data. A realization is not unique—using a new random seed provides a new set of surfaces. The average of a large set of realizations will coincide with the deterministic surfaces obtained using prediction.

The stochastic simulation can be thought of as a two step procedure. First, the trend coefficients are drawn stochastically from their estimated distribution and multiplied with the trend maps to form the simulated trend. Then the residuals are drawn stochastically according to their spatially correlated distribution and added to the trends. Note that the uncertainty from the trends have a global impact whereas the uncertainty in the residual is more

local. During this process Cohiba ensures that the result is in correspondence with the well data.

Uncertainty. Uncertainty is a somewhat loose term. It can almost without exceptions be translated into *standard deviation* in this manual. All Cohiba input concerning uncertainty and measurement error are given as standard deviations. All output concerning uncertainty is also given as standard deviations.

Well data. There are two types of well data used by Cohiba: *Well points* and *well paths* with a *zone log*. Well points are the intersections between a well path and a surface. Well points can be imported directly from a file. Alternatively, well points can be extracted from a well path (well trajectory) using a zone log. Cohiba will detect all zone transitions and record a well point if the transition is associated with a surface. Cohiba can also ensure that the surfaces are located correctly according to the zone log. This is convenient for horizontal wells.

Part II
User manual

3 Getting started

Cohiba is started from the command line with the Cohiba model file as an argument:

```
> cohiba.exe model_file.xml
```

A Cohiba project consists of a Cohiba model file and a set of trend maps and well data. We start by running a very simple example, with a constant surface and one well point. We follow the steps:

1. Copy `cohiba.exe` to the current directory and create a subdirectory `00_test/`.
2. Create a file `model_file.xml` in `00_test/` using the following XML Cohiba model file:

```
<cohiba>
<project-settings>
  <project-directory>   00_test </project-directory>
  <input-directory-surfaces>  . </input-directory-surfaces>
  <input-directory-well-data> . </input-directory-well-data>
  <messages>
    <screen>
      <detail-level>
        <overall>             5 </overall>
      </detail-level>
    </screen>
  </messages>
  <output-grid>
    <format>         roxar text </format>
    <xstart>             448300 </xstart>
    <xlength>              1000 </xlength>
    <ystart>            6736000 </ystart>
    <ylength>              3000 </ylength>
    <xinc>                   50 </xinc>
    <yinc>                   50 </yinc>
  </output-grid>
</project-settings>

<modelling-settings>
  <mode>             prediction </mode>
  <kriging-method>     bayesian </kriging-method>
</modelling-settings>

<well-data>
  <well-points>
    <files>   wellpoints.cohiba </files>
  </well-points>
```

```
</well-data>

<surfaces>
  <surface>
    <name>                  top </name>
    <travel-time>
      <value>                 1 </value>
      <variogram>
        <type>        spherical </type>
        <range>             300 </range>
        <stddev>           0.01 </stddev>
      </variogram>
    </travel-time>
    <output>
      <depth>               yes </depth>
    </output>
  </surface>
</surfaces>

<interval-models>
  <interval>
    <top>                   MSL </top>
    <base>                  top </base>
    <interval-type>    velocity </interval-type>
    <trend>
      <coefficient-mean>      1 </coefficient-mean>
      <coefficient-stddev>  0.1 </coefficient-stddev>
      <value>              1000 </value>
    </trend>
    <variogram>
      <type>          spherical </type>
      <range>               500 </range>
      <stddev>                5 </stddev>
    </variogram>
  </interval>
</interval-models>
</cohiba>
```

---

3. Create the directory `00_test/input/` and create a file `wellpoints.cohiba` in `00_test/input/` with the following content:

```
top well 448800 6737500 1220 0.0
```

---

4. From the command line type: `cohiba.exe 00_test/model_file.xml`

Cohiba will start by reading the Cohiba model file, `model_file.xml`, and generate output and surfaces according to the specifications in the Cohiba model file. In this case, Cohiba is asked to make deterministic surface using Bayesian kriging on the surface `top` using the well point with coordinates $(448800, 6737500, 1220)$. Several directories are created under `0_test/output/`: `surfaces/`, `logfiles/`, and `wellpoints/`. The trend surface `dt_top.irap` and depth surface `d_top.irap` are written to the directory `surfaces/` using the ROXAR BINARY grid format. Log files are written under `logfiles/` and `wellpoints/` contains Cohiba well points files.

In Section 7 of the screen output you may find the following table:

```
Interval            Coef    PriorMean     PostMean PostMeanUpd     PriorStd      PostStd  PostStdUpd
-------------------------------------------------------------------------------------------------
MSL-to-top             1        1.000        1.217           -        0.100        0.011           -
```

This shows prior and posterior mean and standard deviations for the trend coefficient. The single data at 1220 m has moved the prior guess at 1000 m to 1217.3 m and the uncertainty has dropped from $0.1 \times 1000\,\mathrm{m} = 100\,\mathrm{m}$ to $0.011 \times 1000\,\mathrm{m} = 11.1\,\mathrm{m}$. This uncertainty should be compared to the residual uncertainties: $0.01\,\mathrm{s} \times 1000\,\mathrm{m/s} = 10\,\mathrm{m}$ (travel time) and $5\,\mathrm{m/s} \times 1\,\mathrm{s} = 5\,\mathrm{m}$ (interval velocity). Combining these gives a total uncertainty of $(10^2\,\mathrm{m}^2 + 5^2\,\mathrm{m}^2)^{1/2} = 11.2\,\mathrm{m}$. This is not a coincidence. A larger residual uncertainty would imply less impact from the well point and a larger posterior standard deviation.

4 Cohiba command line options

The normal way of running Cohiba is with a single Cohiba model file as the argument:

```
> cohiba.exe model_file.xml
```

The Cohiba model file can of course have any name.

4.1 Specifying the random seed

Cohiba offers a few ways of setting the random seed for stochastic simulation. One option is to use the `-s` option:

```
> cohiba.exe -s 123 model_file.xml
```

where `123` is the random seed. The random seed can also be specified in the random seed file (default is `seed.dat`) or in the Cohiba model file using the `<seed>` element.

4.2 Specifying number of realizations

Cohiba can generate a set of simulated realizations in one run. There are two options for specifying the number of realizations. It can be given in the command line using the `-n` option:

```
> cohiba.exe -n 100 model_file.xml
```

where `100` is the number of realizations. The number of realizations can also be specified in the Cohiba model file using the `<number-of-realizations>` element.

4.3 Spill point detection

Cohiba can find the spill point of a surface using `<spill-point>`. Cohiba also has a special mode where it reads a single surface and reports the spill point:

```
> cohiba.exe -g spillpointgrid.irap
```

The output will look like:

```
********************************************************************************
*****                                                                      *****
*****                      C O H I B A  -  4.2.0                           *****
*****                                                                      *****
*****                Copyright (c) 2006 by Norsk Regnesentral              *****
*****                                                                      *****
********************************************************************************

License expiration                          : Never
Licensed to                                 : Norsk Regnesentral/Statoil

Log written by                              : Unknown
Date and time                               : Wed Nov 20 11:39:28 2013
Host                                        : octane

********************************************************************************
```

```
*****     Section 17: Spill points                                              *****
*******************************************************************************

      Xstart       Ystart           XSpill       YSpill     ZSpill
-------------------------------------------------------------------
   333092.09   6434195.50        333092.09   6434195.50    1942.75
-------------------------------------------------------------------

*******************************************************************************
*****     Section 19: Timings summary                                           *****
*******************************************************************************

Section                                        CPU Time                Real Time
-------------------------------------------------------------------------------
Miscellaneous                             0.55   100.00 %        1.00   100.00 %
-------------------------------------------------------------------------------
Total                                     0.55   100.00 %        1.00   100.00 %

*******************************************************************************
*****     Section 20: Suggested tasks                                           *****
*******************************************************************************

No tasks suggested.

Total CPU  time used in COHIBA:     0.55
Total real time used in COHIBA:     1.00
```

The input file with an added prefix, `trap_`, is written to file. This file contains ones inside the trap and zeros outside the trap.

The format of the input grid-file is automatically detected. The output file has the same format as the input grid. The possible file formats are described in Section 6.2.

The following command line options are available:

Flag: `-g`
Description: Input grid file. Trigger the spill point detection algorithm for a single surface.
Argument: A string specifying the input grid's file name.
Default: No default.

Flag: `-x`
Description: Starting point x-coordinate for the spill point searching algorithm.
Argument: Real
Default: The x-coordinate where the surface has a minimum (highest point in surface).

Flag: `-y`
Description: Starting point y-coordinate for the spill point searching algorithm.
Argument: Real
Default: The y-coordinate where the surface has a minimum (highest point in surface).

Flag: `-m`
Description: Missing as wall flag. See Section 14.4.2.7.1.
Argument: `yes` / `no`.
Default: `yes`

5 The Cohiba model file

The Cohiba model file is a text file in XML (Extensible Markup Language) format. The basic XML syntax for one *element* is:

```
<name attribute = "attribute value">
 argument
</name>
```

where `name` is the name of the element and the `argument` is a value (string, number, etc.) or other elements. The attribute is omitted in most cases. Often `argument` contains further elements in a nested structure. The Cohiba model file is divided into six major elements:

1. `<project-settings>` ... `</project-settings>`
2. `<modelling-settings>` ... `</modelling-settings>`
3. `<well-data>` ... `</well-data>`
4. `<surfaces>` ... `</surfaces>`
5. `<interval-models>` ... `</interval-models>`
6. `<volumes>` ... `</volumes>`

There is a hierarchy of elements belonging to each of these six main elements. The sequence of the elements within a hierarchy is arbitrary[1] but it is recommended to stick to the suggested order to avoid confusion. Figure 5.1 show an example of the skeleton of a Cohiba model file.

Note that many of the elements can be repeated. E.g. there will be one `<surface>`...`</surface>` element for every depth surface considered in the model.

An extensive example of a Cohiba model file is given in Section 16.

A detailed description of each of these main elements and their sub-elements is provided in Section 14. Most elements are optional and default values are provided if the element is omitted.

1. An important exception is the order of surfaces. These *must* be specified in correct stratigraphic order (with the exception of free surfaces, cf. `<free-surface>`) to obtain correct ordering of the generated surfaces.

```
<cohiba>
    <project-settings>
       :
    </project-settings>
    <modelling-settings>
       :
    </modelling-settings>
    <well-data>
       :
    </well-data>
    <surfaces>
        <!-Surfaces MUST be listed in stratigraphic order ->
        <reference>
           :
        </reference>
        <surface>
           :
        </surface>
       :
    </surfaces>
    <interval-models>
        <interval>
           :
        </interval>
       :
    </interval-models>
    <volumes>
        <volume>
           :
        </volume>
       :
    </volumes>
</cohiba>
```

Figure 5.1. Skeleton of a Cohiba model file.

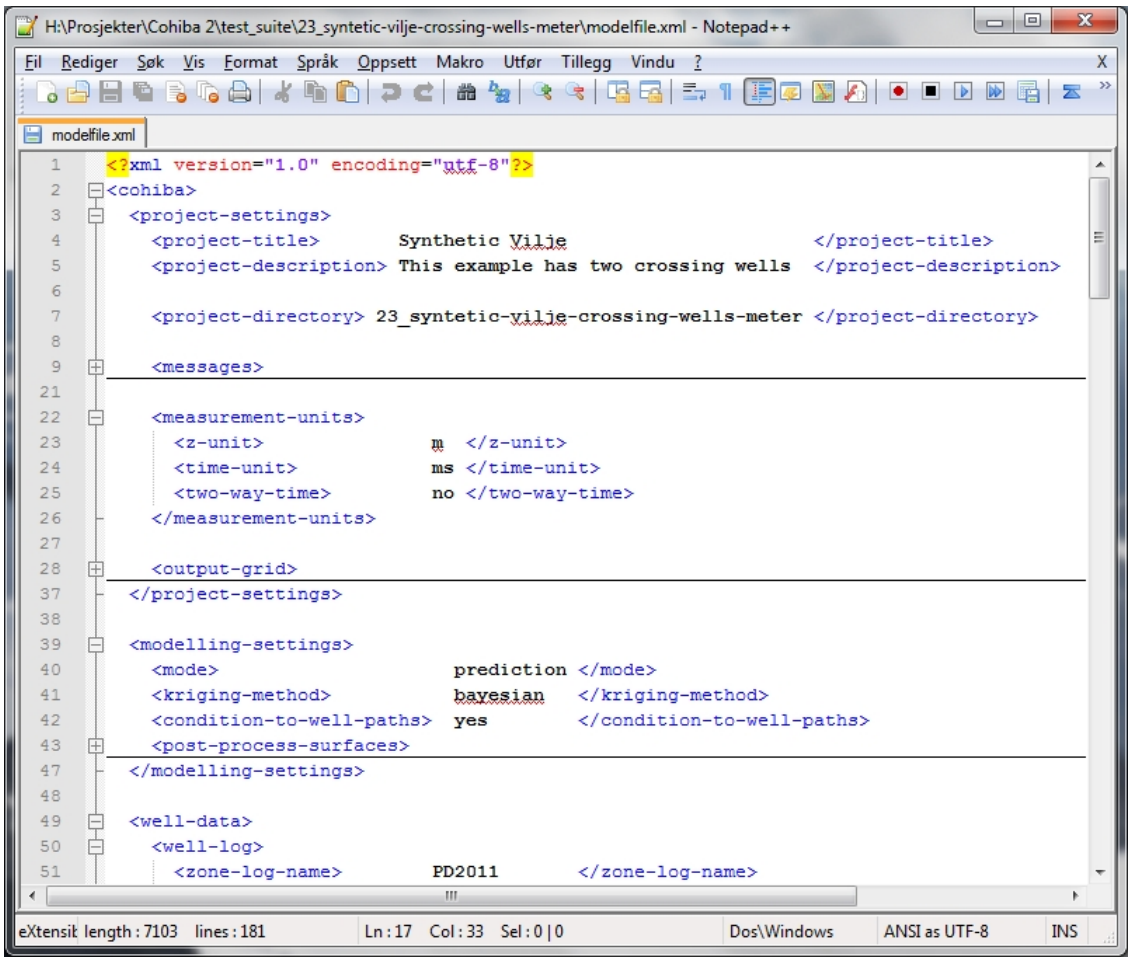


Figure 5.2. A Cohiba model visualized in the Notepad++ editor.

5.1 Editing the Cohiba model file

An XML file is a simple ASCII text file and almost any text editor (WordPad, Notepad, Word, Emacs,...) can edit the file. However, the structure of the XML file is easier to read in a more specialized XML editor. For instance the Microsoft XML Notepad 2007 or Notepad++ editors may be freely downloaded. The Notepad++ editor is illustrated in Figure 5.2.

5.2 Errors reading the Cohiba model file

When Cohiba reads the Cohiba model file it will detect most spelling and syntax errors.

If Cohiba encounters an error corrupting the structure of the XML syntax, then a message will be issued to screen and the Cohiba log file. The message can look like:

```
XML error: ln 287, col 1
while parsing 'benchmark/model_file.xml'.
Error reading end tag of <project-settings>: found </cohiba>

Fatal error: Could not read XML file
```

In this case, the final tag, `</project-settings>`, was forgotten.

If Cohiba finds an unknown element a message will be issued. It can look like:

```
Error: Unknown tag <variograms> encountered at line 274, column 7.
Select one of: <name>, <top>, <base>, <interval-type>, <trend>, <variogram>,
               <correlations> or <output>
Parsing error on line 264. Missing <variogram> entry under <interval>

Fatal error: Invalid model file.
```

In this case the <variogram> element has been misprinted as <variograms>. Note that Cohiba suggests the possible element names.

6 Files and directories

6.1 File directory structure

Cohiba reads a lot of information from files and writes results to numerous files. It is partly up to the user to organize the input files in a convenient way. Figure 6.1 shows an overview of the recommended directory structure and some files used by Cohiba. Note that the input file names are just examples and other names will be appropriate for a specific project.

The three top directories can be specified in the Cohiba model file using elements `<project-directory>`, `<input-directory>`, and `<output-directory>`. If a project directory has not been specified by the user, it defaults to the current working directory. The default output directory is `output/`.

By default, it is assumed that input surfaces are stored under `input/surfaces/` and well data under `input/welldata/` placed directly under the specified project directory. The default values for these sub-directories can be overridden using `<input-directory-surfaces>` and `<input-directory-well-data>`. For compatibility with earlier versions of Cohiba, the default values are set to "./" if `<input-directory>` has been specified.

Results are stored in the directories `surfaces/`, `logfiles/`, `spillpointdata/`, `wellpoints/`, `wellpaths/`, `clusters/`, and `helppoints/` under the specified output directory. Most output directories and most of the output files have fixed names and can not be modified by the user.

6.2 Surface file formats

The following surface file formats are supported:

ROXAR BINARY This is a binary file format that supports rotated grids. We recommend to use this format since it is the most flexible, memory efficient, cpu efficient and accurate of the supported formats.

ROXAR TEXT This is an ASCII file format that supports rotated grids.

STORM BINARY This is a binary file format that does not support rotated grids.

Constant Allows to define a constant surface value in the Cohiba model file.

See the IRAP RMS user guide, ROXAR ASA (2009), for information on the surface file formats.

The input file formats are automatically detected when reading from file. Undefined areas with missing codes are allowed and will be automatically detected. The format detection does not depend on the file extensions.

The output file format can be specified using `<format>`. The default is ROXAR BINARY. The file extensions are `.roxbin` for ROXAR BINARY, `.irap` for ROXAR TEXT and `.storm` for STORM BINARY. The rotation is specified using `<grid-azimuth>`.

6.3 Well log file formats

Well log files are used to import well paths (x-, y-, and z-coordinates) with corresponding zone logs and possible uncertainty logs.

Cohiba may import the following type of files containing well log data:

RMS WELL See the IRAP RMS user guide, ROXAR ASA (2009), for documentation.

LAS 2.0 The Log ASCII Standard file format is documented by www.cwls.org.

All files are specified using `<files>` under the `<well-log>` element. Cohiba detects the file formats automatically.

6.4 Well points file format

Well points can be imported using a simple ASCII text file format with one line for each observation. The file(s) are specified using the `<well-points>` element. The format is illustrated in Table 6.1. Each well point must contain the surface name, the well name, the x-, y-, and z-coordinate of the observation, and the vertical measurement error (standard deviation). The name of the surface must be identical to the string specified in the `<name>` element for the `<surface>`. The name of wells are used by Cohiba for consistency checks and reporting. Names can contain space if commas are used to separate all values.

Table 6.1. Definition of the Cohiba well points file format. The Cohiba well points file format use one line for each observation. The two first columns identify the observations by surface name and well name. The next three columns specify the well point coordinates in space, and the last column allows a measurement error (standard deviation) for the vertical position to be added. The ordering of the observations is arbitrary and has no effect on the generated surfaces. Lines beginning with a # are treated as comments. The entries can be separated by blanks, tabs or commas. Do not mix comma separated values and white space separated values in the same file.

White space separated (space and/or tabs):

```
#-------------------------------------------------------------
# Surface   Well    X-coord.    Y-coord.   Depth     Measur.
# name      name                                   error
#-------------------------------------------------------------
TopA        w1     535045.09  6742547.10  1255.12     0.00
TopB        w1     535045.09  6742511.36  1383.87     0.00
TopC        w1     535045.09  6742515.42  1400.23     0.00
#-------------------------------------------------------------
TopA        w2     532273.48  6737634.37  1194.15     1.00
TopB        w2     532223.72  6737667.37  1284.10     1.00
TopC        w2     532203.58  6737694.37  1301.15     2.00
#-------------------------------------------------------------
TopA        w3     536393.00  6736356.62  1155.23     0.50
TopB        w3     536194.01  6736389.87  1255.60     0.65
TopC        w3     536168.78  6736397.00  1300.75     2.98
#-------------------------------------------------------------
```

Comma separated:

```
#-------------------------------------------------------------------
# Surface    Well       X-coord.    Y-coord.   Depth     Measur.
# name       name                                         error
#-------------------------------------------------------------------
Top A,      well 1,     535045.09,  6742547.10,  1255.12, 0.00
Top B,      well 1,     535045.09,  6742511.36,  1383.87, 0.00
Top C,      well 1,     535045.09,  6742515.42,  1400.23, 0.00
#-------------------------------------------------------------------
Top A,      well 2,     532273.48,  6737634.37,  1194.15, 1.00
Top B,      well 2,     532223.72,  6737667.37,  1284.10, 1.00
Top C,      well 2,     532203.58,  6737694.37,  1301.15, 2.00
#-------------------------------------------------------------------
Top A,      well 3,     536393.00,  6736356.62,  1155.23, 0.50
Top B,      well 3,     536194.01,  6736389.87,  1255.60, 0.65
Top C,      well 3,     536168.78,  6736397.00,  1300.75, 2.98
#-------------------------------------------------------------------
```

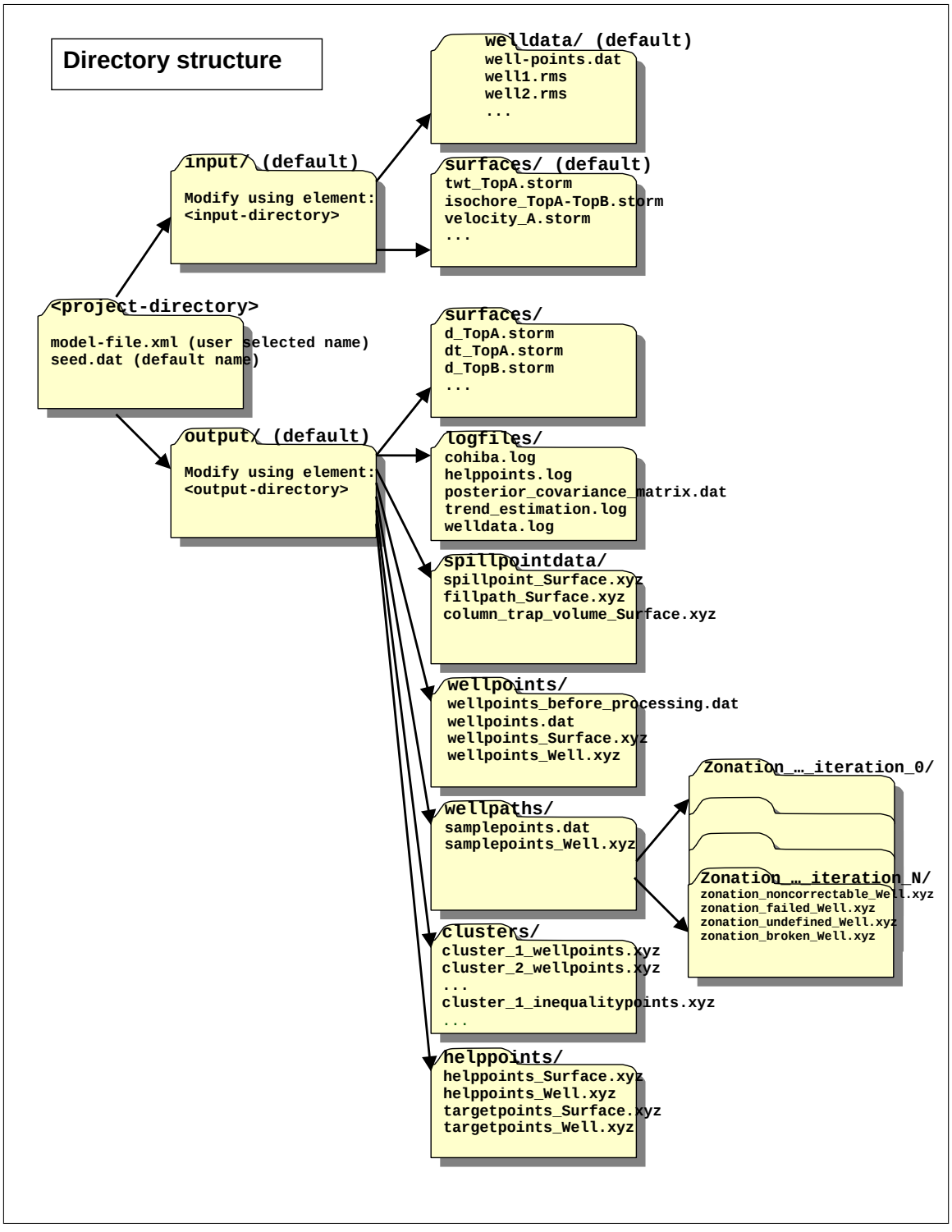


Figure 6.1. Recommended and default directory structure for Cohiba.

7 The Cohiba output

Cohiba stores results in the directories `surfaces/`, `logfiles/`, `spillpointdata/`, `wellpoints/`, `wellpaths/`, `clusters/`, and `helppoints/` under `output/` that is specified using the `<output-directory>` element. See Figure 6.1 for an overview. The default output directory is `output/`. These directories are automatically created if they are not already present.

The main result of Cohiba are the maps saved in `surfaces/`, but the log files in `logfiles/` also contain important information on the quality of the result. The outcome of the spill point detection algorithm is a set of trap surfaces under `surfaces/`, and spill points in `spillpointdata/`.

For convenience, the well data used for generating the surfaces are saved in formats convenient for visualization and quality control. The files are stored in the directories `wellpoints/`, `wellpaths/` `clusters/`, and `helppoints/`.

7.1 Output maps

All output maps are written to the `surfaces/` directory. The maps are named after the name of the surface, interval, or reservoir volume that they relate to. A prefix depending on the type of map and a possible trailing text in simulation mode is appended to the name. See Table 7.1 for a list of possible maps. Most maps are not generated by default.

Stochastic simulation of multiple realizations trigger the construction of average maps and empirical uncertainty (standard deviation) maps if output for the respective maps are requested. These maps are only made if `<number-of-realizations>` is more than one. These maps are updated for every finished realization. The average and uncertainty maps get the trailing texts `_mean` and `_stddev` in their file names. The average depth map will be similar to the predicted depth map if the number of realizations is large. If an `<acceptance-criteria>` apply, there might be a significant difference between the average depth maps and the predicted depth maps.

By default all simulated realizations are saved to file. A trailing text, `_nnnn`, where `nnnn` is the realization number, is added to the file name. This could look like:

```
d_TopA_0001.roxbin, d_TopA_0002.roxbin,..., d_TopA_9999.roxbin
trap_TopA_0001.roxbin, trap_TopA_0002.roxbin,..., trap_TopA_9999.roxbin
v_MSL-TopA_0001.roxbin, v_MSL-TopA_0002.roxbin,..., v_MSL-TopA_9999.roxbin
```

Additional digits will be added for realizations beyond realization number 9 999. The realization number is only added if `<number-of-realizations>` is more than one. Suppressing writing of individual realizations is possible using `<write-realization-maps>`.

7.2 The log files

The log files are written to the `logfiles/` directory under the user specified output directory. The log files can be used for quality control and inspection of Cohiba results.

7.2.1 The Cohiba log file

The Cohiba log file is specified in the `<logfile>` element described in Section 14.1.11.1. The default name is `cohiba.log`. An extensive example is given in Section 16.1.

Table 7.1. Output maps found in the surfaces/ directory. The only maps that are written by default are surface depths and rock columns. The latter require that a reservoir <volume> is defined.

Map (on/off element)	Prefix	Description
Output maps for surfaces:		
<depth>	d	Deterministic (prediction) or stochastic simulated depth to the surface dependent on the specified <mode>.
<depth-trend>	dt	Similar to <depth> but the residual is omitted.
<depth-error> (uncertainty)	de	Prediction error; Standard deviation at each point on the surface. No output in simulation mode.
<depth-trend-error> (uncertainty)	dte	Uncertainty caused by the uncertainty in trend coefficients. No output in simulation mode.
<depth-residual>	dr	Difference between <depth> and <depth-trend>.
<trap>	trap	The trap containing the starting point of the spill point calculation. The trap map is 1 if the grid node is inside the trap and 0 otherwise.
Output maps for intervals:		
<thickness>	t	Interval thickness computed as the difference between the two depth surfaces defining the interval (specified in <top> and <base> elements).
<thickness-trend>	tt	Interval thickness trend computed as the difference between the two depth surface trends defining the interval.
<thickness-residual>	tr	Interval thickness residual computed as the difference between <thickness> and <thickness-trend>.
<velocity>	v	Interval velocity computed as the difference between the two depth surfaces defining the interval divided by the corresponding travel time difference. Unrealistic velocities are removed by smoothing.
<velocity-trend>	vt	The posterior interval velocity trend.
Output maps for reservoir volumes:		
<column-map>	column	The rock column in a reservoir. See Section 9.1.

These are the sections in the Cohiba log file:

Section 1: Model settings
Reports the settings in the Cohiba model file. Detail level set by `<model-settings>`.

Section 2: Loading input data
Reports what data has been read from file and possible errors. Detail level set by `<data-loading>`.

Section 3: Pre-processing input data
Detail level set by `<pre-processing>`.

Section 4: The alternative ways to build each surface
Reports what intervals are used to build the surfaces. This includes all alternative models and their weights. See Figure 11.3 for an example of the output. Detail level set by `<surface-models>`.

Section 5: Processing well points
Reports redundant data and possible merging of duplicate well points. Reports potential conflicts and lists well points that have been removed or given additional uncertainty. Reports on pinch outs. Detail level set by `<well-points>`.

Section 6: Processing control points for eroded and onlapped surfaces
Reports possible control points that are needed to constrain eroded and on-lapping surfaces at observations of the eroding and on-lapped surfaces. Detail level set by `<extra-points>`.

Section 7: Sampling well trajectories and logs
Reports on processing of well paths with zone logs. Detail level set by `<well-paths>`.

Section 8: Trend coefficients based on well points
Reports the estimated values for the trend coefficients in the trends. Detail level set by `<trend-coefficients>`.

Section 9: Checking specified residual uncertainties
This is a way of checking that the specification of interval uncertainties are consistent with well points. The specified residual errors are compared to observed residual errors. This is done by extracting linear combinations[1] of the well points that correspond to observations of the true residual errors.

The specified residuals errors are classified as `OK`, `Low`, `High`, `Too low`, or `Too high`. Especially the two latter classifications is a sign of a wrongly specified residual uncertainty.

The identification of useful linear combinations can be time demanding so the element `<check-specified-residual-uncertainties>` can be used to omit the calculation.

Detail level set by `<residual-uncertainties>`.

Section 10: Identifying well point outliers and leverage points
Reports poor matches between well points and trend model. These are classified as outliers or leverage points. Detail level set by `<outliers>`.

1. It is not always possible to find such linear combinations and the number of linear combinations can be few making the estimates unreliable. The number of such linear combinations are reported. The element `<minimum-generalized-eigenvalue>` modifies a threshold used for selecting the linear combinations that correspond to the interval.

Section 11.x: Conditioning on well points along well paths
Reports errors. Usually caused by a trend model incompatible with the well points. Detail level set by `<well-point-conditioning>`.

Section 12.x: Finding help points for well path conditioning
Reports help points that will be used to ensure correct conditioning to zone logs. Detail level set by `<help-points>`.

Section 13.x: Trend coefficients based on well points and well paths
Reports the estimated values for the trend coefficients in the trends based on well points *and* well paths. Detail level set by `<trend-coefficients>`.

Section 14.x: Conditioning surfaces on all available points
Makes a final report on the quality of the surfaces. Detail level set by `<well-path-conditioning>`.

Section 15.x: Post process surfaces
Detail level set by `<post-processing>`.

Section 16.x: Checking zonation
Reports possible problems with conditioning surfaces to well paths. Detail level set by `<zonation-checking>`. This section is written to a separate file. See Section 7.2.8.

Section 17.x: Spill points
Detail level set by `<spill-points>`.

Section 18.x: Volume calculations
Detail level set by `<volume-calculations>`.

Section 19: Timings summary
Reports the amount of CPU time spent on different operations. Detail level set by `<timings>`.

Section 20: Suggested tasks
This is a task list of possible problems the user should look into. Detail level set by `<tasks>`.

Section 11 – 18 are repeated for every simulated realization. For simulation, the realization number, and a possible rejection sampling iteration, is added to the section number:

```
*****     Section 14.3.5: Conditioning surfaces on all available points
```

So 14 is the Section number, 3 is the realization number, and 5 is the iteration number. The iteration number is omitted if there are no rejection criteria.

The Cohiba log file is intended for catching problems during execution and for examining the main results. The output to screen is identical to the log file output provided the same detail levels have been specified. The log-file can be large. The task list is intended to give a quick way to identify possible problems. The task list is also written to `tasks.log`.

More detailed analysis are provided in the files `trend_estimation.log` and the `welldata.log`.

7.2.2 The `tasks.log` file

The `tasks.log` contains a task list of possible problems the user should look into. Detail level set by `<tasks>`.

7.2.3 The `volumes.csv` file

This `volumes.csv` is a comma separated file giving a list of calculated volumes. It is formatted for easy import into spreadsheets. The file contains volume from each `<reservoir-name>` and `<area-names>` which is specified in the modelfile. In case of simulation, the volumes from all realizations are listed. In addition, realization number and seed is included in each row. See Section 9 for more details.

7.2.4 The `simulation.log` file

This `simulation.log` contains a list of realization number and the random seed used to generate the realization. In case of rejection sampling the number of rejected samples is included in the list.

7.2.5 The `trend_estimation.log` file

The file `trend_estimation.log` contains an analysis of the trend coefficients in the trends. There is one line for each trend coefficient. The file is organized in columns described in Table 7.2. Missing or undefined entries are marked by an '–'.

The file is formatted for easy import into a spreadsheet See Section 7.2.10 and Section 7.2.11.

Use the `trend_estimation.log` file to inspect the quality of the trend coefficient estimates. Trend coefficients with low `UncertRed` might introduce too much uncertainty and could be removed if the t-value (`tEstim` or `tPost`) is small.

7.2.6 The `posterior_covariance_matrix.dat` file

The file `posterior_covariance_matrix.dat` contains the posterior covariance matrix between trend coefficients. The diagonal is the square of the posterior uncertainty `PostUncert` given in file `trend_estimation.log`. The sequence follows the sequence in `trend_estimation.log`.

7.2.7 The `zonation_after_conditioning_to_wellpoints.csv` file

The `zonation_after_conditioning_to_wellpoints.csv` is a comma separated version of the zonation summary given in Section 10 in the Cohiba log file. It is formatted for easy import into spreadsheets. See the Cohiba log file for explanation of codes.

7.2.8 The `zonation_after_conditioning_to_all_points.csv` file

The `zonation_after_conditioning_to_all_points.csv` is a comma separated version of the zonation summary given in Section 15 in the Cohiba log file. It is formatted for easy import into spreadsheets. See the Cohiba log file for explanation of codes.

7.2.9 The `welldata.log` file

The `welldata.log` file contains an analysis of the well points and how they fit to the surfaces. It also contains a summary of actions taken on well points. There is one line for each well point. See Table 7.3 for a detailed description of the columns.

The file is formatted for easy import into a spreadsheet. See Section 7.2.10 and Section 7.2.11 for a detailed description.

This file is important to study for a proper quality control of results.

7.2.9.1 Flags in `welldata.log`

The user should inspect for possible flags. This is an important quality control step that may detect serious errors in model and data.

Close well points in the same well and surface will be merged by Cohiba. Merged data are flagged

Table 7.2. The `trend_estimation.log` file. Description of columns. The formulas used are found in Table 17.2.

Tag	Description
`Interval`	Interval name.
`TopSurface`	Name of top surface.
`NumObs`	Number of observations in top surface.
`BaseSurface`	Name of base surface.
`NumObs`	Number of observations in base surface.
`Trend`	The interval often contains more than one trend coefficient. If there are 3 in this interval they will be labeled 1, 2, and 3. The numbering will follow the sequence of the `<trend>` elements.
`PriorMean`	Prior mean value for the trend coefficient. The value is specified by the `<coefficient-mean>` element.
`EstimMean`	Estimated mean value for the trend coefficient. This value is estimated using generalized least squares (GLS) which amounts to linear regression where the spatial correlation in the well data is accounted for. This value may fail to exist if there are too few data in some of the intervals. It is not calculated if simple kriging is specified.
`PostMean`	Posterior mean value for the trend coefficient. This value is estimated using a Bayesian approach which amounts to a weighting between the prior specification and the GLS estimate. Note that this estimate exist even if the GLS estimate fails to exist. It is not calculated unless Bayesian kriging is specified.
`PostMeanUpd`	Posterior mean value for the trend coefficient estimated using well points *and* information from the zone-logs along the well path.
`SimMean`	Simulated (Monte Carlo) value for the trend coefficient. The simulated values are drawn from the estimated distribution. For simple kriging it will be identical to the value specified in the `<coefficient-mean>` element unless the `<simulate-trend-uncertainty>` element is given the value `yes`. Only calculated in stochastic simulation mode.
`PriorUncert`	Prior standard deviation for the trend coefficient. The value is specified by the `<coefficient-stddev>` element.
`EstimUncert`	Estimated standard deviation for the trend coefficient. This value is estimated using generalized least squares (GLS). Not calculated if simple kriging is specified.
`PostUncert`	Posterior standard deviation for the trend coefficient. This value is estimated using a Bayesian approach. This value will always be less than `PriorUncert` and `EstimUncert`. Not calculated unless Bayesian kriging is specified.
`PostUncertUpd`	Posterior standard deviation for the trend coefficient estimated using well points *and* information from the zone-logs along the well path.
`UncertRed`	For universal kriging: (`PriorUncert` – `EstimUncert`)/`PriorUncert`. For Bayesian kriging: (`PriorUncert` – `PostUncert`)/`PriorUncert`. Uncertainty reduction in percent from the prior specification. Value is always in the range 0 – 100% for Bayesian kriging. For universal kriging negative values occur when the prior specification is more certain than the estimate. A small (or negative) value signals that well data has minor impact. Consider increasing the prior standard deviation of the trend coefficients if well data has minor impact. Consider using Bayesian kriging if a negative value occurs.
`tPrior`	`PriorMean/PriorUncert`.
`tEstim`	`EstimMean/EstimUncert`. A large t-value (> 2) shows that this is an important trend for explaining depth or interval velocity variations according to the well points. A small value (< 1) shows that the well points does not support the existence of such a trend. Consider removing it.
`tPost`	`PostMean/PostUncert`. See the comments on `tEstim`. Note that the conclusions using this t-value are less significant since these estimates can be heavily influenced by the a priori specifications.

Table 7.3. The `welldata.log` file. Description of columns. File contains one line for each well point. See Table 17.1 for exact formulas.

Col.	Tag	Value	Description
Data identification:			
A	`Surface`	Text	Name of surface.
B	`Wellname`	Text	Name of well.
C	`X-coordinate`	Real	UTM coordinate.
D	`Y-coordinate`	Real	UTM coordinate.
E	`Depth`	Real	Observed depth. From Cohiba well points file or transitions in zone logs.
Flags:			
F	`Merged`	`M`	Well point merged with other well point(s) from same well and surface.
G	`Conflict`	`C`	In potential conflict with other close well points in the same surface. (Slope > 10%)
H	`AddUncert`	`U`	Uncertainty added to well point because it is close to other well points. (Within grid cell distance)
I	`Pinchout`	`P`	Pinch out. Identical to well point from different surface. Deleted if squeezed between two surfaces.
J	`LevPoint`	`L`	Leverage point. Large impact on the trend estimation. Check input values!
K	`Outlier`	`O/U/S/E`	Data does not fit the trends properly. Check input values! `O` means that the data *could* be erroneous. `U` means that it is *likely* that data is erroneous so uncertainty has been added. `S` means that this data *surely* is erroneous and it is removed from estimation and interpolation. `E` is used for data that are extremely erroneous. These are removed one-by-one followed by a re-estimation of trends.
L	`Deleted`	`B/P/E/X/F/S/R`	The data has been excluded from *estimation* and *kriging*. There are seven reasons for deletion: `B` if well point is outside grid boundary. `P` if well point is a pinch out between other surfaces. `E` if the specified residual uncertainty (standard deviation) is zero. `X` if well point is a severe or extreme outlier. `F` if well point was close to a fault according to a fault indicator log. `S` if some surface or interval has a missing value at the well point. `R` if the well point is assigned to the reference surface.
Trend values:			
M	`PriorTrend`	Real	Depth trend using prior trend coefficients. (`-` if universal kriging mode.)
N	`EstimTrend`	Real	Depth trend using estimated (least squares) trend coefficients. (`-` if too few data or simple kriging.)
O	`PostTrend`	Real	Depth trend using posterior trend coefficients. (`-` unless Bayesian kriging mode.)
P	`SimTrend`	Real	Depth trend using simulated trend coefficients. (`-` unless stochastic simulation mode.)
Trend uncertainty (standard deviation):			
Q	`PriorTrendUncert`	Real	Prior depth trend uncertainty. (`-` if universal kriging mode.)
R	`EstimTrendUncert`	Real	Estimated depth trend uncertainty. (`-` if too few data or simple kriging.)
S	`PostTrendUncert`	Real	Posterior depth trend uncertainty. (`-` unless Bayesian kriging mode.)
T	`TrendUncertRed`	Real	Reduction (in %) between prior and posterior uncertainty. (`-` unless Bayesian kriging mode.)
Measurement error (standard deviation):			
U	`MeasUncert`	Real	Measurement error specified by the user.
V	`TotMeasUncert`	Real	Total measurement error including user specified and automatically added.
Residuals and uncertainties:			
X	`Residual`	Real	Difference between data and used trend.
Y	`ResidualUncert`	Real	Residual depth uncertainty (standard deviation).
Z	`TotUncert`	Real	Sum of trend uncertainty and residual uncertainty.
AA	`Mismatch`	Real	Mismatch between well point (data) and value interpolated from grid. Caused by gridding error *and* well point uncertainty.
Statistical measures for outliers:			
AB	`h`	Real	Number between 0 and 1. Value above $2 \times$ (`# of trend coefficients`)/(`# of data`) is classified as leverage point. (`-` if too few data.)
AC	`t`	Real	$t =$ |`Residual`|/`ResidualUncert`. Value above 1.96 (5 %) is flagged as 'O' in `Outlier`. Value above 2.58 (1 %) is flagged as error 'U' and `Residual`/2 is added as measurement error. Value above 3.09 (0.2 %) is classified as error 'X' and data is ignored in trend estimation and kriging interpolation. The exact limits are specified by `<t-value-outlier>`, `<t-value-severe-outlier>`, and `<t-value-error>`.
AD	`tStud`	Real	Same as `t` but takes into account `h`. Is used for outlier classification whenever `h` is available.

in the Merged column. This will usually not require any actions from the user but it is recommended to check why redundant well points are supplied.

When two close well points are identified, Cohiba checks if there is a potential conflict, that is, the slope between the well points is more than 10 %. A potential conflict is flagged in the Conflict column. This typically happens if side tracks have been inconsistently adjusted. A potential conflict might be a serious error and should be checked by the user. An erroneous well point can be removed by adding it to the well point file specified in the <well-points-to-ignore> element.

Cohiba automatically adds a measurement error to all close well points to ensure numerical stability.[2] This is flagged in the AddUncert column. The amount of uncertainty added can be found by comparing the columns TotMeasUncert and MeasUncert. The added uncertainty depends on the mismatch between the potentially conflicting data and the difference in the merged data.

The LevPoint flag signals that a particular data point is a leverage point. A leverage point has a very strong influence on the trend coefficients in the trends so these data should be inspected to ensure that they are correct. Leverage points are less likely when there is a lot of data.

Mismatches and conflicts between the trend model and the well points are flagged in the Outlier column. If the data had a perfect Gaussian distribution, 5 % of the data would be classified as outliers. Outliers are classified in three levels: *Could* be an error, *likely* to be an error, and *surely* an error. Cohiba automatically adds a measurement error to the likely errors, and automatically removes those well points that are classified as surely an error. Cohiba handles all these situations automatically, *but* it is strongly recommended to look into the reasons for the errors.

The final flag in the Deleted column shows the well points that have been deleted prior to the trend estimation. There are three situations when well points are removed: Well points outside the grid boundary are not used, well points are a pinch out between other surfaces, and if the specified residual uncertainty (standard deviation) is zero at the well point location.

7.2.9.2 Trend values in welldata.log

The trend values—columns PriorTrend, EstimTrend PostTrend, and SimTrend — are obtained by evaluating the trends at the well point locations. Some of the trend values might be undefined depending on the <kriging-method> and the <mode> (prediction/simulation).

These values should be compared to the observed depth value in column Depth.

7.2.9.3 Trend uncertainty in welldata.log

These are given in columns PriorTrendUncert, EstimTrendUncert and PostTrendUncert. These values are obtained by evaluating the impact of the uncertainty in the trend coefficients at the well point locations. Some of these columns may be undefined depending on the <kriging-method> and the <mode> (prediction/simulation). All values are standard deviations.

For the Bayesian kriging mode the column TrendUncertRed is evaluated. It shows

$$(\texttt{PriorTrendUncert} - \texttt{PostTrendUncert})/\texttt{PriorTrendUncert}$$

in percent. The value will be between 0 % and 100 %. A small value indicates that well points has minor impact on the estimated trend in this location. Consider increasing the prior standard deviation of the trend coefficients if well data has minor impact on the trend at many locations.

7.2.9.4 Measurement error in welldata.log

Measurement error (uncertainty) is specified by using the last column in the Cohiba well points file. These uncertainties are reported in column MeasUncert. Cohiba adds additional measure-

2. A measurement error is only added if the well point has no initial measurement error.

ment error when well points are merged or if potential conflicts are detected. The resulting total uncertainty is reported in `TotMeasUncert`. These are reported as standard deviations.

To obtain the measurement error automatically added by Cohiba use the formula:

$$\sqrt{\texttt{TotMeasError}^2 - \texttt{MeasError}^2}.$$

(Variances add linearly.)

7.2.9.5 Residuals and uncertainties in `welldata.log`

The column `Residual` contains the difference between the observed depth (in `Depth` column) and the trend. The trend depends on the `<kriging-method>` and the `<mode>` (`prediction/simulation`) specified in the Cohiba model file.

The `ResidualUncert` column shows the model uncertainty obtained by aggregating the uncertainty in all intervals that are needed to obtain this surface. This include uncertainties in travel time, interval velocity, and interval thickness. All these uncertainties are specified in the `<variogram>` elements.

The `TotUncert` column contains the total uncertainties and is a combination of `ResidualUncert` and the uncertainty in the trend (i.e. `PostTrendUncert` with Bayesian kriging mode). Comparing the `TotUncert` column to the `ResidualUncert` column shows if it is the local residual uncertainty or the global trend uncertainty that dominates.

The `Mismatch` column shows the difference between the well point and the value obtained by using bilinear interpolation between the four nearest values in the grid. The mismatch is the sum of two factors:

1. A *gridding error* that is proportional to the `Residual` values. The gridding error can be large (several meters) if the residual is large. The gridding error is inevitable unless well points coincide with a grid corner location. See Figure 17.1 for an illustration.
2. Kriging is not a perfect interpolator when measurement uncertainties are present. Measurement uncertainties can be specified in the Cohiba well points file or the measurement uncertainties are automatically estimated from the resolution of the zone logs.

The gridding error is by default removed in the post processing unless there is a significant measurement error. The removal can be turned off using `<make-surfaces-interpolate-well-points>`.

7.2.9.6 Statistical measures for outliers in `welldata.log`

Leverage points are well points that influence the estimated trend values strongly. A corrupted leverage point might not be identified as an outlier because the estimates adapts to it. The column `h` contains the diagonal elements of what is called the hat matrix. This is a by-product of linear regression and can be used to identify leverage points. It is not available if the linear regression fails. See Section 17.3.4 for details.

The `t` column contains the t-value for each well point:

$$\texttt{t} = |\texttt{Residual}|/\texttt{ResidualUncert}.$$

The t-value is used for classifying outliers. Large values indicates that there is a severe mismatch between the well point and trend. Values above 1.96 are flagged as outliers, above 2.57 as uncertain, and values above 3.09 is classified as errors[3]. If the well points had a perfect Gaussian

3. These thresholds can be modified by the elements `<t-value-outlier>`, `<t-value-severe-outlier>`, and `<t-value-error>`.

distribution this would occur with a frequency of 5 %, 1 %, and 0.2 % respectively.

The `tStud` column is similar to `t` but includes a correction for leverage points. This makes it possible to identify leverage points as outliers even though the trend coefficients has adapted strongly to them.

7.2.10 Importing log files into Excel

Both `trend_estimation.log` and `welldata.log` are normal (ASCII) text files, but formatted for easy import into Excel. This is recommended since Excel offers many ways of sorting and color coding that simplifies the investigation. Also, the log files have many columns so using the `Hide/Unhide` column function is convenient.

To import the files into Excel follow these steps:

1. Start Excel.
2. Choose the appropriate file from the **File→Open...** menu. (Choose **Files of type: All Files (*.*)**).
3. A **Text Import Wizard** appears. Toggle on **Delimited** and choose **Next**.
4. Toggle on **Space** in the **Delimiters** section. Toggle on **Treat consecutive delimiters as one**. Then choose **Next**.
5. Choose **Advanced...**. In the new panel change the **Decimal separator** to '.' and press **OK**.
6. Press **Finish**.

7.2.11 Importing log files into OpenOffice/LibreOffice

To import the files into OpenOffice follow these steps:

1. Open an empty OpenOffice spreadsheet.
2. Choose the file from the **File→Open...** menu and set file type to **Text CSV (*.csv; *.txt;*.xls)**
3. In the appearing window, toggle **Separated by** and check the boxes for **Space** and **Merge delimiters**. Choose **OK**.

7.2.12 The `helppoints.log` file

Logs the help points used for conditioning on well paths with zone logs.

7.3 Spill point files

In addition to the trap output grids written to `surfaces/`, Cohiba generates a set of files for analyzing the trap(s). These files are written to the directory `spillpointdata/` under the output directory.

7.3.1 The `spillpoint_Surface.xyz` file

Contains the spill point coordinates (x-, y-, and z-coordinate) calculated for the surface `Surface`. In case of simulation, the spill point coordinates from all realizations are listed.

7.3.2 The `spillpoint_Surface.rmsinternal` file

Contains the spill points coordinates (x-, y-, and z-coordinate) calculated for the surface `Surface`, using the IRAP RMS internal points format. The file is an ASCII file with one line entry for each spill point. In addition to the x-, y-, and z-coordinates of the point a line also includes an attribute

with realization number. In case of simulation, the spill point coordinates from all realizations are listed.

7.3.3 The `fillpath_Surface.xyz` file

This is the set of points on surface `Surface` visited by the spill point detection algorithm before it terminates. The trail starts at the starting point and finish at some boundary point. Possible traps will be seen as clusters of points. This file is only generated when spill points are triggered from command line (see Section 4.3).

7.3.4 The `column_trap_volume_Surface.dat` file

This is a Table of cumulative volumes (left column) and trap volume (right column). This file is only generated when spill points are triggered from command line (see Section 4.3).

7.3.5 The `column_trap_volume_Surface.xyz` file

This is a Matlab script defining the cumulative volume trapped under `Surface`. This file is only generated when spill points are triggered from command line (see Section 4.3).

7.4 Well point files

These are saved in the `wellpoints/` directory under the specified output directory.

7.4.1 The `wellpoints_before_processing.dat` file

This file contains all the well points initially considered by Cohiba. The well points can be imported from multiple Cohiba well points files and from well paths containing zone logs. The well points specified in the files in the `<well-points-to-ignore>` element is removed from this list. X

7.4.2 The `wellpoints.dat` file

Cohiba merges duplicate data and removes unnecessary or corrupt data. The remaining data after this pre-process is written to the `wellpoints.dat` file using the Cohiba well points file format. This file can be used as input to Cohiba. Note however that it does not contain all information from well paths with zone logs; only the zone transitions are kept.

This file is an ASCII file that uses the Cohiba internal point format.

7.4.3 The `wellpoints_surface_Surface.xyz` and `excluded_wellpoints_surface_Surface.xyz` files

Contains well points for surface `Surface`. The first file contains well points from `wellpoints.dat` whereas the latter file containes the removed well points.

The files are ASCII files with x-, y-, and z-coordinates for each well point on separate lines.

7.4.4 The `wellpoints_zonelog_Well.xyz` and `excluded_wellpoints_zonelog_Well.xyz` files

Contains well points for `Well` extracted from zonelog transitions along the well paths. The first file contains well points from `wellpoints.dat` whereas the latter file containes the removed well points.

The files are ASCII files with x-, y-, and z-coordinates for each well point on separate lines.

7.4.5 The `wellpoints_pointfile_Well.xyz` and `excluded_wellpoints_pointfile_Well.xyz` files

Contains well points for `Well` read from Cohiba well points file(s). The first file contains well points from `wellpoints.dat` whereas the latter file contains the removed well points. Note that

the name of the well can be erroneous since well names from well point files are not used by Cohiba.

The files are ASCII files with x-, y-, and z-coordinates for each well point on separate lines.

7.4.6 The `wellpoints_Well.rmsinternal` files

Contains well points for `Well` using the IRAP RMS internal points format. These files are ASCII files with one line entry for each well point. In addition to the x-, y-, and z-coordinates of the point a line also includes a set of attributes. These attributes are the same as those given in `welldata.log` and described in Table 7.3 plus an attribute telling whether the point comes from a zone log or a point file.

7.5 Well path files

These files are saved in the `wellpaths/` directory under the specified output directory.

The wells are sampled at approximately twice the lateral grid spacing. Note that just a selection of these sample points are actually used in the conditioning. The selected sample points are those that are near or on the wrong side of surfaces after conditioning on the well points. All sample points are checked against the generated surfaces in the final quality control step.

7.5.1 The `samplepoints.dat` file

Contains all sample points along all wells. The file is an ASCII file with x-, y-, and z-coordinates and the zone code for each sample point.

7.5.2 The `samplepoints_Well.xyz` file

Contains the sample points for `Well`. The files are ASCII files with x-, y-, and z-coordinates for each sample point on separate lines.

7.5.3 The `special_samplepoints.xyz` file

Some sample points are included by default as they represent parts of the well path where it is especially important to have control. These are the points where the zone log starts and ends and the points where the zone changes from defined to undefined. The files are ASCII files with x-, y-, and z-coordinates for each sample point on separate lines

7.5.4 The `targetpoints_for_wellpaths_Well.xyz` file

Contains the target points for `Well`. The files are ASCII files with x-, y-, and z-coordinates for each sample point on separate lines.

7.5.5 The `zonation_Status_Well.xyz` status files

Sample points where the zone log is inconsistent with the calculated surfaces ar e written to a set of files. The sample points are written to separate files for each well and zonation status type. The status types and file naming conventions are found in Table 7.4.

These files contain the sample points for `Well`. Cohiba can iterate to minimize the number of sample points with broken zonation (use `<minimize-broken-zonation>`), and the files above are made after each iteration. To separate files made after the different iterations, the files are stored in folders `zonation_at_samplepoints_iteration_#iter/` where #iter is the number of iterations done to get rid of the broken zonation. The zonation status codes are used in the Cohiba log file.

The zonation is *non-correctable* if the sampled points are a part of a very thin zone or if the surface must be moved more that 3.09 standard deviations. (See `<t-value-error>`.)

Table 7.4. File naming convention for zonation status files.

File name	Zonation status
`zonation_noncorrectable_Well.xyz`	XY
`zonation_failed_Well.xyz`	N
`zonation_undefined_Well.xyz`	U
`zonation_broken_Well.xyz`	B

The *failed* and *broken* zonation refers to sample points where Cohiba is unable to get within the zonation correct. Broken zonation means that the zonation was correct when surfaces were only conditioned to well points.

7.5.6 The `samplepoints_Well.rmsinternal` file

This file contains information about sample points in `Well` when surfaces have been conditioned to well points only and *not* to help points. This information is used as a basis when help points are chosen.

The files are given in the IRAP RMS internal points format. This is an ASCII format where there is one line entry for each sample point. Each line contains the x-, y-, and z-coordinates of the point as well as a a set of attributes. The available attributes are listed in Table 7.5.

Similar status files are made after the conditioning on well paths. These files are stored in `zonation_at_samplepoints_iteration_0/` (see Section 7.5.5). The attributes in these files are described in Table 7.6.

When `<minimize-broken-zonation>` is turned on Cohiba may include additional help points in subsequent iterations to improve the conditioning to well paths. Status files for each iteration are stored in `zonation_at_samplepoints_iteration_#iter/`.

7.6 Well path cluster files

These files are saved in the `clusters/` directory under the specified output directory.

Each selected sample point will impose a constraint on a surface above or below. Usually, it is necessary to add constraints on the surface above and the surface below. So constraints, or inequalities, usually comes in pairs. The selected sample point and the associated constraint is called an inequality point for the surface.

The selected sample points and the inequality points are grouped into correlated clusters. Each cluster is handled separately when finding help points to replace the inequality points.

7.6.1 The `cluster_#_wellpoints.xyz` file

Contains the sample points belonging to cluster number #. The files are ASCII files with x-, y-, and z-coordinates for each well point on separate lines.

7.6.2 The `cluster_#_inequalitypoints.xyz` file

Contains the inequality points belonging to cluster number #. The files are ASCII files with x-, y-, and z-coordinates for each sample point on separate lines. Note that most of these coordinates are repeated twice; one constraint for the surface above and one constraint for the surface below a sample point.

Table 7.5. Sample point attributes in the `samplepoints_Well.rmsinternal` files used for choosing help points.

Attribute name	Type	Description
`Wellname`	`String`	Name of the well
`IsochoreThickness`	`Float`	Isochore thickness at sample point location.
`IsochoreTrendThickness`	`Float`	Isochore trend thick. at sample point location.
`DistanceToTopSurface`	`Float`	Distance to top surface from sample point.
`TopSurfaceStdDev`	`Float`	Top surface std.dev. at sample point location.
`TopSurfaceTValue`	`Float`	Top surface t-value at sample point location.
`TopSurfaceHelpPointNeeded`	`Bool`	Is help point needed for top surface?
`TopSurfaceHelpPointDeactivated`	`Bool`	Is help point deactivated for top surface?
`TopSurfaceHelpPointLost`	`Bool`	Could help point not be added to top surface?
`DistanceToBaseSurface`	`Float`	Distance to base surface from sample point.
`BaseSurfaceStdDev`	`Float`	Base surface std.dev. at sample point location.
`BaseSurfaceTValue`	`Float`	Base surface t-value at sample point location.
`BaseSurfaceHelpPointNeeded`	`Bool`	Is help point needed for base surface?
`BaseSurfaceHelpPointDeactivated`	`Bool`	Is help point deactivated for base surface?
`BaseSurfaceHelpPointLost`	`Bool`	Could help point not be added to base surface?
`NameOfTrueZone`	`String`	Zone name in well at sample point location.
`TrueZone`	`Discrete`	Zone number in well at sample point location.
`NameOfCalculatedZone`	`String`	Zone name in resulting surface model.
`CalculatedZone`	`Discrete`	Zone number in resulting surface model.
`Match`	`Bool`	Does zone in well and surface model match?

Table 7.6. Attributes in the `samplepoints_Well.rmsinternal` files after the conditioning on well paths. These files are stored in `zonation_at_samplepoints_iteration_#iter/`.

Attribute name	Type	Description
`Wellname`	`String`	Name of the well.
`IsochoreThickness`	`Float`	Isochore thickness at sample point location.
`IsochoreThicknessChange`	`Float`	Isochore trend thick. at sample point location.
`DistanceToTopSurface`	`Float`	Distance to top surface from sample point.
`ChangeInDistanceToTopSurface`	`Float`	Change in dist. to top surface from sample point.
`DistanceToBaseSurface`	`Float`	Distance to base surface from sample point.
`ChangeInDistanceToBaseSurface`	`Float`	Change in dist. to base surface from sample point.
`NameOfTrueZone`	`String`	Zone name in well at sample point location.
`TrueZone`	`Discrete`	Zone number in well at sample point location.
`NameOfCalculatedZone`	`String`	Zone name in resulting surface model.
`CalculatedZone`	`Discrete`	Zone number in resulting surface model.
`MatchText`	`String`	Match between true and calculated zones? (See Table 7.7.)
`MatchCode`	`Discrete`	Number representation of `MatchText`.
`FixText`	`String`	Was zonation fixed? (See Table 7.7.)
`FixCode`	`Discrete`	Number representation of `FixText`.

Table 7.7. The possible values for `MatchText` and `MatchCode`, and `FixText` and `FixCode`.

Text	Code	Description
`MatchText and MatchCode`		
U	-999	Zonation is undefined in either well of surface model.
Y	1	Zonation matches.
N	-1	Zonation does not match.
`FixText and FixCode`		
U	-999	Zonation is undefined in either well of surface model.
Y	1	Zonation was fixed by help points.
-	0	Zonation matched without help points.
N	-1	Zonation was not fixed. Unknown why.
X	-2	Zonation was not fixed because help points could not be used.
B	-3	Zonation was broken by introduction of help points.
F	-4	Zonation was broken but can be fixed by kriging iterations. Use `<minimize-broken-zonation>` to activate.

7.7 Help point files

These files are saved in the `helppoints/` directory under the specified output directory.

A help point is calculated for each inequality point. The help points are used to push or drag surfaces away from constraints imposed by the wells. Help points are only used when making deterministic surfaces.

The help points enters the kriging equations as ordinary well points but they have measurement errors. Help points belonging to the same cluster will have correlated measurement errors.

The help points are chosen so that the surfaces interpolate the target points; The target point is the expected location of the (deterministic) surface at the inequality point. The Data Augmentation Algorithm is used for calculating the target points.

7.7.1 The `helppoints_Surface.xyz` file

Contains the help points that belongs to surface `Surface`. The files are ASCII files with x-, y-, and z-coordinates for each inequality point on separate lines.

7.7.2 The `helppoints_Well.xyz` file

Contains the help points that belongs to `Well`. The files are ASCII files with x-, y-, and z-coordinates for each inequality point on separate lines.

7.7.3 The `targetpoints_Surface.xyz` file

Contains the target points that belongs to `Surface`. The files are ASCII files with x-, y-, and z-coordinates for each inequality point on separate lines.

7.7.4 The `targetpoints_Well.xyz` file

Contains the target points that belongs to `Well`. The files are ASCII files with x-, y-, and z-coordinates for each inequality point on separate lines.

8 Well data

There are two types of well data used by Cohiba: *Well points* and *well paths* with *(zone) logs*. Well points, which are sometimes called well picks or well markers, are the intersections between a well path and a surface. The well points can be extracted from well paths (well trajectory) using the zone log transitions or they can be imported directly from files.

The preferred approach is to use well paths with zone logs and let Cohiba detect zone transitions along the well path and record well points associated with surfaces in the model. If the wells are deviated or horizontal, Cohiba ensures that all surfaces are located correctly according to the well paths and their zone logs.

8.1 Using zone logs

The RMS WELL or LAS 2.0 formats are used for importing well paths with zone logs.

There is no generic relationship between the surfaces in the Cohiba model and the zones in the zone log. The link between surfaces and zones are made by specifying which zone a surface is directly on top of using the `<top-of-zone>` element. Non-unique zone names are discussed in Section 8.4.6.

A well file can contain a series of different logs so the particular zone log we want to use must be chosen using `<zone-log-name>`. Zone logs are numbers (non-negative integers) that must be linked to zone names. For RMS WELL files these numbers are linked to zone names in the file header:

```
GM2005a DISC 1 ABOVE 2 DRAUPNE 3 6BC 4 6AC 5 6AM 6 5CC 7 5CM 8 5BC
```

Here `GM2005a` is the zone log name, `DISC` specifies that the log is discrete, and the rest is the list of zone numbers and their associated zone names. The zone numbers must constitute a sequence of non-negative integers that increase by one.

The LAS 2.0 format does not include the zone names in the header so this must be supplied using `<zone-log-specification>`. This specification is very similar to the header in the RMS WELL files but it allows more general zone names.

Note that the zone name specification must be identical for all zone logs. Files with different zone name specification will be discarded. Also note that well names must be unique. If there are multiple files with identical well names an error is reported. This is to avoid reading the same data repeatedly.

8.2 Using fault indicator logs

Cohiba can not distinguish between a zone transition at a surface or a zone transition at a fault. In both cases, the transition will be interpreted as a zone top. This is not correct if the transition is at a fault.

To avoid this situation, we can add *fault indicator logs* to the existing well logs. These logs are discrete and consist of 0's and 1's. A 1 means that we are close to a fault and that Cohiba should ignore zone transitions.

The fault indicator log is properly specified in the header of the RMS WELL file as

```
FaultIndicator DISC 0 no 1 yes
```

where the structure is fixed except the label `FaultIndicator`. The fault indicator logs are specified using the `<fault-log-name>` in the `<well-log>` element.

8.3 Close well points

Two well points are considered laterally close if their separation in the x- and y-directions are smaller than the corresponding grid cell sizes. Since this closeness measure is linked to the grid resolution, fewer points will be considered close as the resolution increases. For two well points to be considered *close* they must also be close vertically. The vertical closeness, however, depends on whether the well points belong to the *same* or *different* surfaces.

If two or more well points are close they are likely to either carry *redundant* information or *conflicting* information. In both cases Cohiba has to modify the well points to avoid numerical instabilities. Depending on the situation, Cohiba will either delete well points, merge well points and/or add uncertainties to well points.

8.3.1 Identical well points

If two or more *identical* well points are observed only one is retained. By identical is meant, same well, same surface, same lateral coordinates (within one centimeter), and same z-coordinate (within one centimeter).

Identical well points occur if different well data files contains identical information or if a single file contains repeated information.

8.3.2 Close well points belonging to different surfaces — pinch outs

If two or more well points belong to different surfaces, they are considered close if they are laterally close and their separation in the z-direction is smaller than 1 centimeter.

This situation creates a *pinch out*. If three or more points are involved in a pinch out all but the uppermost and lower most well points become redundant and are deleted.

Well points that are part of a pinch out are flagged by a `P` in the `PinchOut` column of the `welldata.log` file. If the point has been deleted the `P` is given in the `Deleted` column instead.

8.3.3 Close well points belonging to the same surface

If two or more well points belong to the same surface, they are considered close if they are laterally close. They are considered *similar* if the slope between them are less than 10 %, that is, dz/dxy < 0.1. They are considered *potentially conflicting* if the slope is larger than 10 %. When two well points are involved in a potential conflict, these points, their lateral and vertical distance as well as their intermediate slope are logged to the main log file, again, provided the log level is sufficiently high. A point involved in a potential conflict is also indicated by a `C` in the `Conflict` column of the `welldata.log` file.

If the close well points come from the *same well*, the well points are *merged*. The merged observation gets the arithmetic average coordinates ($\bar{x}, \bar{y}$, and $\bar{z}$), and a new vertical uncertainty is estimated as $\sigma_z = \frac{1}{N-1}\sqrt{\sum_i^N (z_i - \bar{z})^2}$, where N is the number of merged well points.

This uncertainty is used for the merged well point. If this uncertainty is smaller than the individual well point uncertainties, then the smallest of the individual well point uncertainties is used instead. A well point that is a result of a merge is indicated by an `M` in the `Merged` column of the

welldata.log file. The coordinates of the removed points are only written to the main log file provided the log level is sufficiently high.

If the close well points come from *different wells*, the well points cannot be merged since it is impossible to dedicate the merged observation to one particular well. All well points are therefore kept, but an uncertainty equal to that estimated for merged well points is calculated for each pair. This uncertainty is used for one or both well points if it is larger than the uncertainties already assigned to each well point, else no action is taken.

When two well points are close it is important that both well points have a sufficiently high uncertainty; not only to reflect the actual uncertainty in the two well points, but also to ensure numerical stability.

A well point that has been given an increased uncertainty during the well point processing is flagged by a `U` in the `AddUncert` column of the welldata.log file.

8.3.4 Well points giving model error

If one or more residual uncertainties are set too low, one or more diagonal elements of the kriging matrix may become too small, possibly leading to numerical instabilities. If too small diagonal elements are found, Cohiba deletes the corresponding well points. This is shown by a `E` in the `Deleted` column of the welldata.log file.

To avoid this error, ensure that the relevant residual uncertainties are larger than zero at these well points.

8.3.5 Well points in undefined areas

Well points become redundant if at least one of the input surfaces (usually a time surface) has a undefined value in one of the four grid nodes around the observation. In such cases the well point has to be removed. To avoid such a removal, the surface with undefined values has to be interpolated or extrapolated so that the area near the well point becomes defined.

Well points removed because of undefined values are flagged by `S` in the `Deleted` column of the welldata.log file.

The region outside the output grid is also treated as undefined. In this case the well point is flagged by a `B`.

8.4 Extracting well points from zone logs

Consider the 5 zones: `above`, `A`, `B`, `C`, `D`, and refer to the surfaces (transition between zones) as `TA`, `TB`, `TC`, and `TD`. See Figure 8.1.

8.4.1 Simple zonation

If all zones have thicknesses larger than zero, it is straight forward to extract surfaces from zone transitions. The well passing through Figure 8.1, makes the zone transitions `above`→`A`, `A`→`B`, `B`→`C`, and `C`→`D`, and the corresponding well points belongs to surfaces `TA`, `TB`, `TC`, and `TD`. The direction of the transition is irrelevant for the assignment of surfaces. The transition `A`→`B` and `B`→`A` are both observations of surface `TB`.

The zone log values are typically defined at one feet intervals. Cohiba will extract a well point in the middle between the two log values at the transition. Also Cohiba will use a measurement error that is 1/4 the vertical difference between the two log values at the transition.

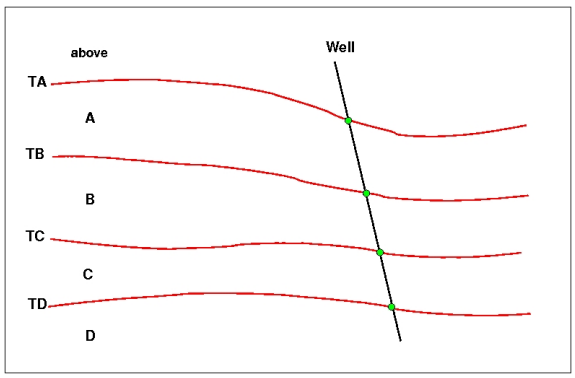


Figure 8.1. Transitions between a simple set of zones. The well points are given as green bullets.

8.4.2 Zones with pinch outs

If a zone has zero thickness in some area, it is said to have a *pinch out*. When a zone transition is made in a pinch out, two surfaces are observed.

In Figure 8.2, we have depicted a well crossing a set of zones where zone `B` has zero thickness in an area. The three zone-transitions reported in the zone log are `above`→`A`, `A`→`C`, and `C`→`D`. While the former and latter of these transitions refer to surfaces `TA` and `TD` respectively, the middle transition is really the joint transition `A`→`B`→`C`, and is consequently an observation of the two surfaces `TB` and `TC`.

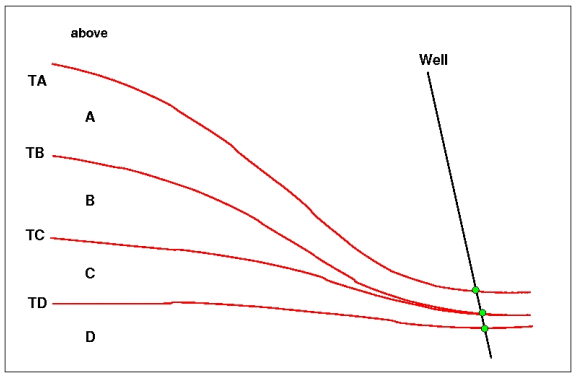


Figure 8.2. Zones with pinch out. The well points are given as green bullets.

A total of 12 different zone transitions may be observed between 5 zones. These are summarized in Table 8.1. Note that the table is symmetric in the "From" and "To" zones.

A well passing through a pinch out is a challenge as two well points get exactly the same coordinates. This may lead to numerical instabilities, requiring one of the observations to be removed. Cohiba is implemented to allow observations of different surfaces to coincide.

8.4.3 Erosive and on-lapped surfaces

If we encounter a zone transition of type `A`→`C`, it is not always true that this transition may be interpreted as the transition `A`→`B`→`C`. For this relation to hold, surface `TB` cannot be erosive. If `TB` *is* erosive, the transition `A`→`C` will be an observation of `TB` alone and *not* `TB` and `TC`.

A similar situation occur when there is a surface with on-lapping zones/surfaces. This surface is called *on-lapped*. The situation is almost identical to the situation with erosion except that erosive surfaces truncate surfaces below whereas on-lapped surfaces truncate surfaces above. Note that

Table 8.1. Surfaces observed for different zone-transitions.

From\To	A	B	C	D
A	—	TB	TB, TC	TB, TC, TD
B	TB	—	TC	TC, TD
C	TB, TC	TC	—	TD
D	TB, TC, TD	TC, TD	TD	—

Table 8.2. Surfaces observed for different zone-transitions if surface B is erosive.

From\To	A	B	C	D
A	—	TB	TB	TB
B	TB	—	TC	TC, TD
C	TB	TC	—	TD
D	TB	TC, TD	TD	—

a surface can be both erosive and on-lapped.

In Figure 8.3, we have illustrated a set of zones where the surface TB is erosive. The zone-transitions observed in the well, are above→A, A→B, B→C, and C→A. As argued above and illustrated in the figure, the latter of these transitions is an observation of surface TB only. Note how the erosiveness of surface TB, implies that one or more zones may be completely undefined (as opposed to being defined but with zero thickness).

Figure 8.4 illustrates the concept of an on-lapped surface. Surface TD is on-lapped by zones A, B, and C. As the on-lapped surface truncate from below, the zone transition B→D becomes an observation of surface TD only.

In Table 8.2, we have summarized the different zone-transitions that may be encountered with zones A, B, C, and D, where surface TB is erosive, and listed what surface-observation each transition corresponds to. The difference between this table and Table 8.1 is that, in all zone-transitions involving zone A, only surface TB is observed. This is a result of the erosion. The symmetry in the "From" and "To" zones is maintained, however.

Whether a surface is erosive and/or on-lapped or neither of these, is specified by the elements <erosive> and <onlapped>. When two or more surfaces are erosive, the upper surfaces erode the lower. In Cohiba, an erosive surface will erode an on-lapped surface.

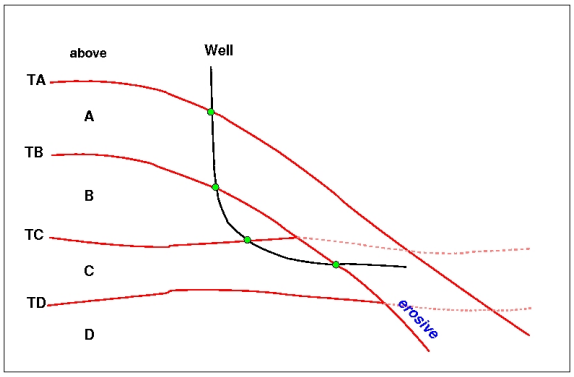


Figure 8.3. Zones where surface `TB` is erosive. The well points are given as green bullets.

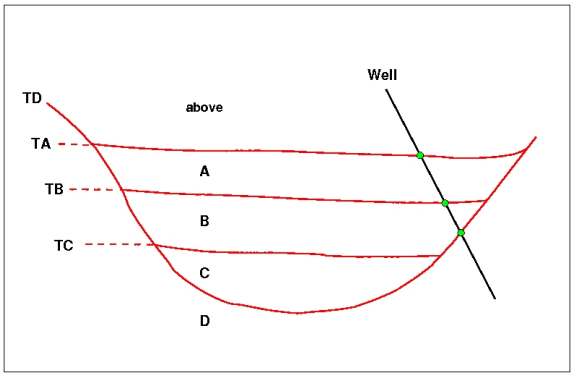


Figure 8.4. Zones where surface `TD` is on-lapped. The well points are given as green bullets.

8.4.4 Faults

A transition between zones can be caused by a fault rather than a surface. This situation is illustrated in Figure 8.5.

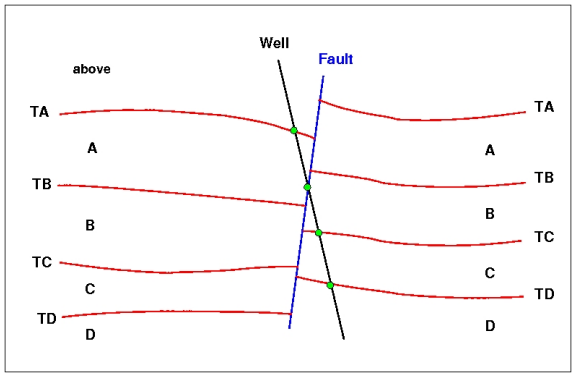


Figure 8.5. A set of faulted zones. The well points are given as green bullets.

Interpreting a zone transition caused by a fault as a well point will give erroneous results. The well shown in the figure enters from zone `A` into zone `B` via the fault. This zone transition is not an observation of `TB`.

It is impossible to distinguish a transition caused by a fault from an ordinary transition using a zone log alone. Therefore, some extra information must be supplied. This can be done by supplying *ignore points* using the element `<well-points-to-ignore>`. These are well points that should be excluded if found in the zone logs. An alternative is to specify a fault indicator log using the element `<fault-log-name>` in the element `<well-log>`.

8.4.5 Undefined sections

Many zone logs have sections that contains missing codes. If there are *short* undefined sections, Cohiba will just ignore the undefined section and use the two closest defined zone log values. A possible zone log transition will be detected and handled like any other zone log transition. This includes adding a measurement error that reflect the distance between the two closest zone log values.

Cohiba needs to know what is considered a short undefined section. This can be specified using the element `<threshold-for-removing-undefined-well-sections>`. The default value is one meter.

For long undefined sections, Cohiba will introduce special *inequality points* (see Section 20) at the edges of the undefined sections to ensure that surfaces are in the right position at these locations.

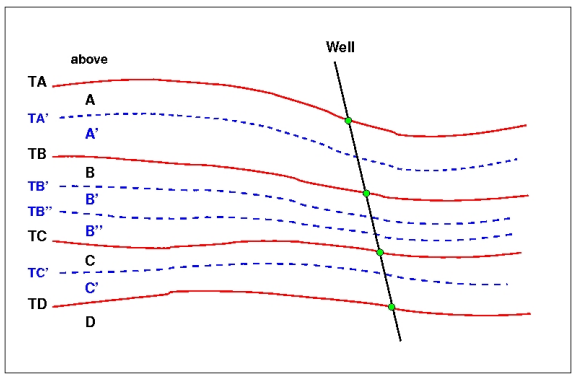


Figure 8.6. A simple set of zones with a zonation finer than the surface model. The well points are given as green bullets.

8.4.6 Non-unique zone names

A zone log must be expected to contain more zones than those included in the Cohiba model. In Figure 8.6, we have depicted this situation. The figure shows nine zones and surfaces, but only four of these surfaces are of interest; the red surfaces labeled `TA`, `TB`, `TC`, and `TD`.

To be able to extract the well points for these surfaces Cohiba needs to know the sequence of the surfaces and the name of the zones that are directly below the surface. The necessary specification is:

```
TA: A, A'
TB: B, B', B''
TC: C, C'
TD: D
```

The corresponding Cohiba model file specification use `<top-of-zone>` to associate a surface name as the top of the zones:

```
<surface>
    <name>                TA          </name>
    <top-of-zone>         A, A'       </top-of-zone>
    ...
</surface>
 <surface>
    <name>                TB          </name>
    <top-of-zone>         B, B', B''  </top-of-zone>
    ...
</surface>
 <surface>
    <name>                TC          </name>
    <top-of-zone>         C, C'       </top-of-zone>
    ...
</surface>
 <surface>
    <name>                TD          </name>
    <top-of-zone>         D           </top-of-zone>
```

```
    ...
</surface>
```

It is sufficient to specify only the first zone *if* zone numbers increase with increasing depth. So for surface TB, it is sufficient to write:

```
...
<surface>
    <name>                TB          </name>
    <top-of-zone>         B           </top-of-zone>
    ...
</surface>
...
```

This alternative may be used to minimize the probability of introducing errors like typing errors or zonation errors. It requires that zone names are listed in the well-header in the correct depth order. By correct depth order we mean a consecutive increasing sequence of non-negative integers.

Example: Valid zone log:

```
LOGNAME DISC 1 ABOVE 2 A  3 B  4 C  5 D
```

Example: Valid zone log:

```
LOGNAME DISC 1 ABOVE 2 A  3 A'  4 B  5 B'  6 B''  7 C  8 C'  9 D
```

Example: Valid zone log:

```
LOGNAME DISC 10 ABOVE 11 A  12 A'  13 B  14 B'  15 B"  16 C  17 C'  18 D
```

Example: Invalid zone log:

```
LOGNAME DISC 9 ABOVE 11 A  12 A'  13 B  14 B'  15 B"  16 C  17 C'  18 D
```

(The number 10 is missing.)

8.5 Horizontal wells

In parts of a well where the well runs parallel to a surface, the well points alone are not enough to guarantee surfaces consistent with the zone logs. This is illustrated in the left part of Figure 8.7, where the well is colored magenta in the region with incorrect zonation.

To avoid that surfaces cross the well path at incorrect locations, Cohiba select a series of constraints along the well path. In the right part of Figure 8.7, five additional constraints have been introduced. These force the surface TC to lie above the well path in accordance with the zone log. They do not, however, state explicitly where the surface TC is located.

Cohiba handles constraints from zone logs according to the method developed in Abrahamsen and Benth (2001). Without going into the technical details, the approach boils down to finding some additional help (well) points used in the kriging equations. The additional help points are

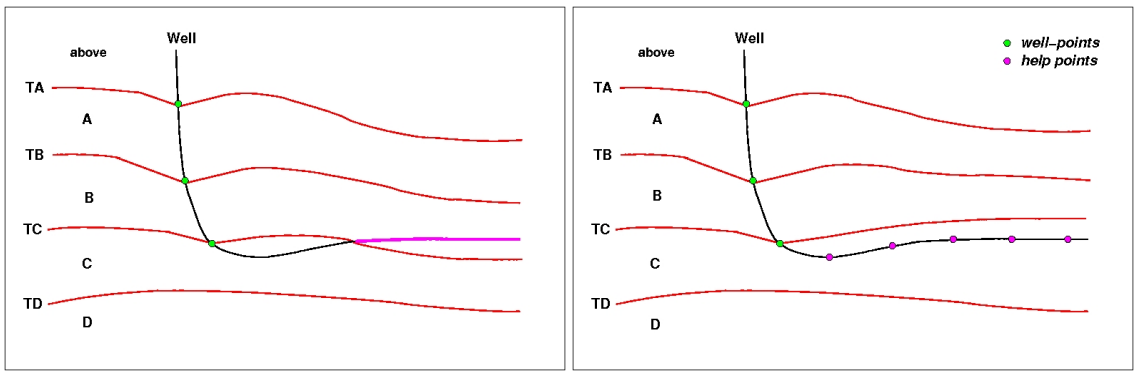


Figure 8.7. A horizontal well following a zone. In the left figure a part of the well (colored magenta) have ended up in the wrong zone after the surface-adjustment. In the right figure this problem has been corrected by the introduction of help points that ensures that the surface match the correct target depth.

chosen so that surfaces are consistent with the model assumptions for trends and residuals and all the well data, well points and zone log constraints.

For more details see Section 20 that discuss conditioning on zone logs.

8.5.1 Well path uncertainty

The vertical measurement error (standard deviation) of the well path can be specified using `<z-stddev-log-name>`. This must be a log of positive values. The measurement errors along the well paths are correlated. This is specified by a variogram using `<variogram>`. Figure 8.8 illustrates the measurement error and possible well paths.

General exponential variogram with $p = 1.75$ and range $= 1000$ m:

General exponential variogram with $p = 1.95$ and range $= 1000$ m:

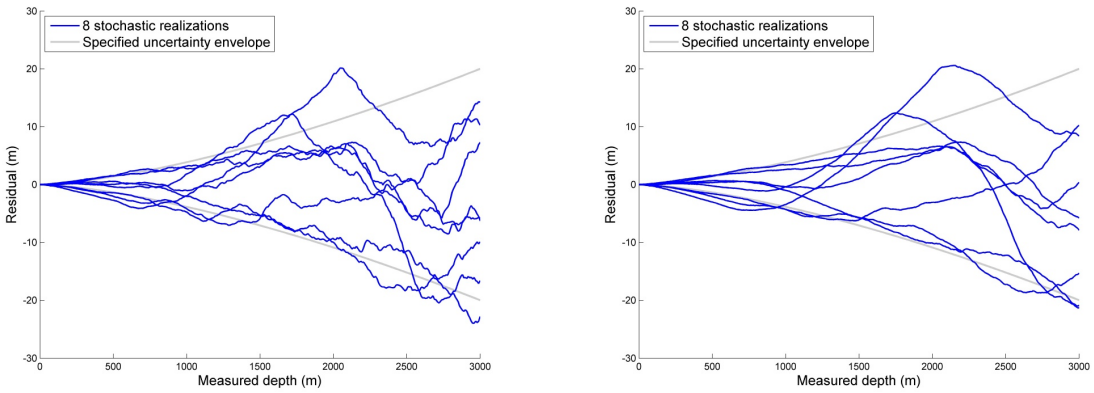
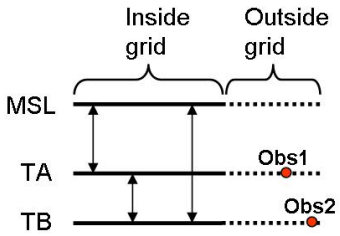


Figure 8.8. Vertical measurement error of the well paths as a function of measured depth (grey lines). The measurement error is specified as an uncertainty log using `<z-stddev-log-name>`. The blue lines are simulated realizations of the vertical measurement error.

8.6 Using well points outside lateral grid

Well points outside the grid definition can be added using the element <values-outside-grid> in the <well-data> element. At least one value will trigger the estimation of trend coefficients with this new point included in the estimation. Well points outside the lateral grid are not included in kriging. For each of these *outside grid well points* additional information must be provided. The number of <value> elements defines the minimum input required for other data types such as interval trend outside grid values, travel time outside grid values and standard deviation outside grid values. If no (X,Y) coordinates are provided, Cohiba will automatically generate large coordinates. If a well-name is omitted, Cohiba generates the name "outside-well".

Example: Given three surfaces: MSL, TA, and TB (both TA and TB are reflectors) and three intervals: MSL->TA, TA->TB and MSL->TB:

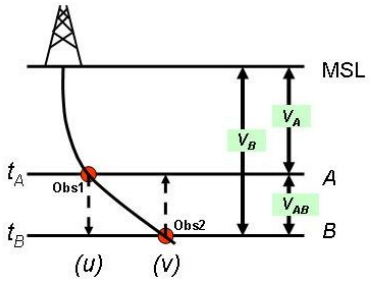


An outside grid well point (Obs1) at TA and an outside grid well point (Obs2) at TB require the following input:

Two values for travel time to TA
Two values for travel time residual standard deviation for TA
Two values for travel time to TB
Two values for travel time residual standard deviation for TB
Two values for interval velocity trend MSL->TA
Two values for interval velocity residual MSL->TA
Two values for interval velocity/isochore trend TA->TB
Two values for interval velocity/isochore residual TA->TB
Two values for interval velocity trend MSL->TB
Two values for interval velocity residual MSL->TB

This amounts to 20 values in total. If any of the values above are not entered, Cohiba will assume 0 as input, giving meaningless results. The required trend values must be taken at the same lateral location as the well point. This applies whether these extra well points originate from a vertical well or not. A consequence of this is that for a vertical well with one well point at both of two successive surfaces, the same values must be entered twice. Once for the first well point, and once for the second well point. Cohiba cannot assume that the well is vertical, and has no check for this.

A detailed look at the region outside the reservoir is illustrated below.



Following the system given in the list above, when Obs1 is located at u and Obs2 is located at v Cohiba therefore require:

$t_A(u)$ and $t_A(v)$
$\sigma_{t_A}(u)$ and $\sigma_{t_A}(v)$
$t_B(u)$ and $t_B(v)$
$\sigma_{t_B}(u)$ and $\sigma_{t_B}(v)$
$V_A(u)$ and $V_A(v)$
$\sigma_{V_A}(u)$ and $\sigma_{V_A}(v)$
$V_{AB}(u)$ and $V_{AB}(v)$
$\sigma_{V_{AB}}(u)$ and $\sigma_{V_{AB}}(v)$
$V_B(u)$ and $V_B(v)$
$\sigma_{V_B}(u)$ and $\sigma_{V_B}(v)$

Omitting the model dependency of the V_B velocity model would ideally reduce the required input to:

$t_A(u)$ and $t_A(v)$
$\sigma_{t_A}(u)$ and $\sigma_{t_A}(v)$
$t_B(v)$
$\sigma_{t_B}(v)$
$V_A(u)$ and $V_A(v)$
$\sigma_{V_A}(u)$ and $\sigma_{V_A}(v)$
$V_{AB}(v)$
$\sigma_{V_{AB}}(v)$

However, Cohiba has not yet included the functionality of checking for *required data* only. At the time Cohiba reads the Cohiba model file part containing the data for one surface, the information on whether or not it is a coupled model with two or just one possible interval paths to each surface, is not available. Therefore, Cohiba demands that the data is given under the assumption of coupled models. Dummy values for $t_B(u)$ and $\sigma_{t_B}(u)$ must therefore be provided when specifying data for surface B.

The necessary information is provided hierarchically as follows. The `<values-outside-grid>` sections are highlighted in red:

```
<cohiba>
  <project-settings>
     ......
  </project-settings>
  <modelling-settings>
     ......
  </modelling-settings>
  <welldata>
```

```
    ......

  <values-outside-grid>
    <value well-name="outside-well" surface-name="TA" x="456000.0" y="6766000.0" stddev="0.1">
       1010
    </value>
    <value surface-name = "TB">
       1040
    </value>
  </values-outside-grid>
    ......
</welldata>
<surfaces>
   <!--Surfaces MUST be listed in stratigraphic order -->
   <reference>
     ......
   </reference>
   <surface>
     <name>   TA    </name>
     ......
      <travel-time>
       ......

       <values-outside-grid>
         <value>  1.01  </value>
         <value>  1.03  </value>
       </values-outside-grid>
       <variogram>
          ......

          <values-outside-grid>
            <value>  0.005  </value>
            <value>  0.005  </value>
          </values-outside-grid>
        </variogram>
     </travel-time>
         ......
   </surface>
    <surface>
     <name>   TB    </name>
     ......
      <travel-time>
       ......

       <values-outside-grid>
         <value>  1.11  </value>
         <value>  1.13  </value>
       </values-outside-grid>
       <variogram>
          ......

          <values-outside-grid>
            <value>  0.005  </value>
```

```
            <value>  0.005  </value>
          </values-outside-grid>
        </variogram>
         ......
     </travel-time>
        ......
   </surface>
</surfaces>

<interval-models>
   <interval>
      <name>    MSL-to-TA        </name>
       <trend>
          ....

          <values-outside-grid>
            <value>  2505  </value>
            <value>  2510  </value>
          </values-outside-grid>
          ....
        </trend>
        <variogram>
            ......

          <values-outside-grid>
            <value>  10.0  </value>
            <value>  15.0  </value>
          </values-outside-grid>
          .....
        </variogram>
      .....
   </interval>
   <interval>
      <name>    TA-to-TB        </name>
        <trend>
          ....

          <values-outside-grid>
            <value>  32  </value>
            <value>  33  </value>
          </values-outside-grid>
          ....
        </trend>
        <variogram>
          .......

          <values-outside-grid>
            <value>  4.0  </value>
            <value>  5.0  </value>
          </values-outside-grid>
          .......
        </variogram>
      .....
```

```
    </interval>
    <interval>
       <name>    MSL-to-TB        </name>
         <trend>
           ....

           <values-outside-grid>
             <value>  13  </value>
             <value>  14  </value>
           </values-outside-grid>
           ....
         </trend>
         <variogram>
              ......

           <values-outside-grid>
             <value>  12.0  </value>
             <value>  13.0  </value>
           </values-outside-grid>
           ......
         </variogram>
       .....
    </interval>
  </interval-models>
</cohiba>
```

Part III
Tutorials

9 Volume calculations

Cohiba can calculate the gross rock volume of reservoirs confined between surfaces and hydrocarbon contacts. Here is an example of a Cohiba model file specification for calculating the volumes in two reservoirs called `Brent Oil` and `Statfjord Oil`:

```
<volumes>
   <volume>
      <reservoir-name>      Brent Oil              </reservoir-name>
      <top-surface>         Top Brent              </top-surface>
      <base-surface>        Base Brent             </base-surface>
      <top-contact>         GOC Brent              </top-contact>
      <base-contact>        OWC Brent              </base-contact>
      <area-file>           brent-segments.irap    </area-file>
      <area-names>          0, Central Block,
                            2, East Block,
                            3, West Block          </area-names>
      <only-trapped-volume> yes                    </only-trapped-volume>
      <connected-volume>
         <xstart>           1234567.0              </xstart>
         <ystart>           1234567.0              </ystart>
      </connected-volume>
      <column-map>          yes                    </column-map>
   </volume>
   <volume>
      <reservoir-name>      Statfjord Oil          </reservoir-name>
      <top-surface>         Top Statfjord          </top-surface>
      <base-surface>        Base Statfjord         </base-surface>
      <top-contact>         GOC Statfjord          </top-contact>
      <base-contact>        OWC Statfjord          </base-contact>
      <area-file>           statjord-segments.irap </area-file>
      <area-names>          0, Central Block,
                            1, West Block          </area-names>
      <only-trapped-volume> no                     </only-trapped-volume>
      <remove-isolated-volumes-less-than> 1000000  </remove-isolated-volumes-less-than>
      <column-map>          yes                    </column-map>
   </volume>
</volumes>
```

The `<reservoir-name>` is used to identify the volume unit in output files. The surfaces are identified by their `<name>` in their `<surface>` specification. The `<top-surface>` and `<base-surface>` must belong to the stratigraphic framework of ordered surfaces and `<top-contact>` and `<base-contact>` must be free surfaces. The default for `<top-surface>` is the `<reference>` surface (MSL as default). At least one of `<base-surface>` and `<base-contact>` must be specified.

The <area-file> is an optional grid with integers called area numbers. The <area-file> is used to separate a reservoir into different areas such as fault blocks, license units or national territory. Volumes will be calculated for every non-negative area number present in the <area-file>. The optional <area-names> is used to associate names to the areas. If this option is used only integers that are associated with area names will be included in the volume calculations.

The volumes will be reported in a comma separated file volumes.csv that can be analyzed by Excel or other tools. The volumes.csv could look like:

```
          ,      ,     Brent Oil,   Brent Oil,   Brent Oil, Statfjord Oil, Statfjord Oil
Realization,  seed, Central Block,  East Block,  West Block, Central Block,    West Block
1,           12345,   12562962.10, 23205894.80, 23205894.03,   16562962.11,   17205894.34
2,           12346,    9792432.52, 20201481.70, 25105251.71,   14372851.31,   17504144.28
```

The first row contains <reservoir-name> and the second row contains <area-names>. There will be one row for each simulated realization. Each row contains the realization number, the random seed, and the volumes for that realization. Note that the random seed is incremented by one for each realization[1]. The volumes.csv is updated for every new simulated realization so aborting the execution will not destroy the information accumulated so far.

A map of column heights are calculated and saved to a grid file in surfaces/. A prefix, column_, is added to the <reservoir-name>. So a typical file name reads: column_Brent Oil.roxbin. These maps are by default written to file. The writing of these files can be turned off by <column-map>.

If the <only-trapped-volume> is put to yes, then the spill point for the <top-surface> must be calculated and possible volumes outside the trap will be discarded. This requires that <xstart> and <ystart> in <spill-point> are specified. The <connected-volume> element removes all volumes that are not in contact with the specified starting point, <xstart> and <ystart>. These coordinates could be the starting points, <xstart> and <ystart>, for the <spill-point> of <top-surface> or any other point known to be within the reservoir volume. The element <remove-isolated-volumes-less-than> does a similar job but it only removes connected volumes less than the specified threshold.

If there are different contacts in different sub-areas a separate <volume> specification must be made for each sub-area. The sub-area is selected by associating <area-names> to the area numbers in the <area-file> corresponding to the sub-area. Assume for instance that the Statfjord Central block has its own oil water contact:

```
<volume>
   <reservoir-name> Statfjord Central      </reservoir-name>
   <top-surface>    Top Statfjord          </top-surface>
   <base-surface>   Base Statfjord         </base-surface>
   <top-contact>    GOC Statfjord          </top-contact>
   <base-contact>   OWC Statfjord Central  </base-contact>
   <area-file>      statjord-segments.irap </area-file>
   <area-names>     0, Central Block       </area-names>
</volume>
```

In this case the surface OWC Statfjord Central is used as the oil water contact for the Central Block (area number 0).

1. This may look strange but two random seeds that only differ by one digit give just as different simulated realizations as any pair of random seeds.

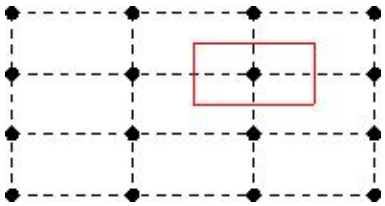


Figure 9.1. The volume within the red rectangle is assigned to the grid node in the center of the red rectangle.

9.1 Calculating the volumes

Cohiba represents depth surfaces on regular grids where the grid nodes are assigned depth values. Calculating volumes requires that the surfaces are defined between the grid nodes. The simplest extension is to extend the grid node value to the rectangle centered at the grid node, where the rectangle side lengths are identical to the distances between grid nodes. This is illustrated in Figure 9.1.

The rock column at a grid node is

$$\Delta z = \max\Big(0, \min\big(z_{\text{base}}, z_{\text{base contact}}\big) - \max\big(z_{\text{top}}, z_{\text{top contact}}\big)\Big). \tag{9.1}$$

This is the rock column reported in the `<column-map>`. The rock volume of the column is

$$V = x_{\text{inc}}\, y_{\text{inc}}\, \Delta z, \tag{9.2}$$

where the increments are the distances between grid nodes. The total volume belonging to an area is obtained by summation of the rock volume associated to each grid node belonging to the area. This is the default algorithm for calculating volumes used by Cohiba.

Cohiba also supplies a volume calculation based on bilinear interpolation of the surfaces instead of nearest neighbour interpolation. This is selected using `<volume-calculation-method>`. The two interpolation methods are compared in Figure 17.3. The two methods will give slightly different volumes since the interpolation algorithms are different. The numerical accuracy for the two methods are comparable. The algorithm for bilinear interpolation use algebraic expressions for the volume based on an analytical solution of the volume integral. The rock volume assigned to a grid node is the volume of the four nearest quadrants of the four adjacent cells. This is the volume in the colored rectangles seen in Figure 17.3(a). The rock column reported in the column map is

$$\Delta z = \frac{V}{x_{\text{inc}}\, y_{\text{inc}}}. \tag{9.3}$$

10 Stochastic simulation example

This section illustrates the use of stochastic simulation, rejection sampling, and volume distributions obtained from multiple realizations. The main purpose of the study is to calculate gross rock volume and the spatial distribution of the reservoir. The uncertainty in the volume and the uncertainty in spatial extent of the reservoir is calculated and visualized.

The model consists of the top and bottom surfaces of the reservoir and a horizontal oil water contact (OWC). The reservoir is assumed to be a filled structure so that the OWC is at the depth of the spill point of top reservoir. The gross rock volume above the OWC is calculated. Three wells are included sequentially to mimic an early appraisal situation. Spill points are only accepted if it is consistent with well observations. A large number of simulated realizations ensures that the uncertainties in the reservoir are captured in the calculated volume distributions. The top reservoir and the three wells are shown in Figure 10.1.

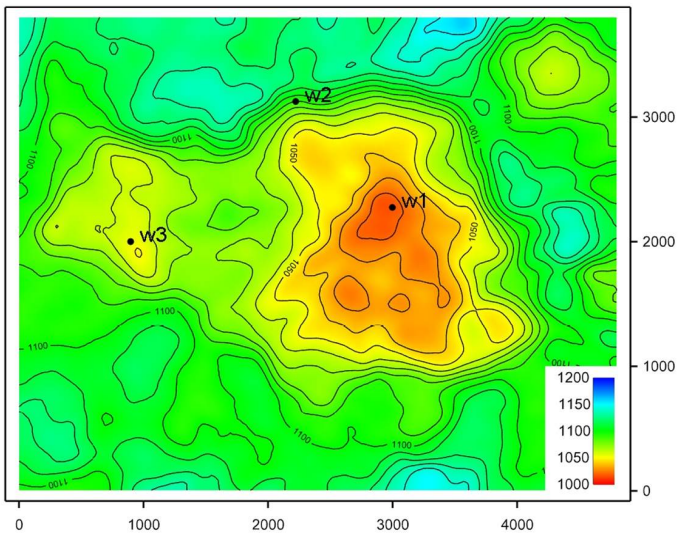


Figure 10.1. Map of top surface. The three wells are labeled `w1`, `w2` and `w3`.

10.1 Acceptance criteria

The volume of oil above the oil water contact (OWC) is the volume of interest. In this example we assume that the reservoir is a filled structure so that the OWC is located at the depth of the spill point. The OWC surface is conditioned to the spill point of the top surface using `<condition-to-spill-point-at-surface>`.

By including the three wells in Figure 10.2 sequentially, three different cases are defined. In the first case only the first well, w1, is included. This well crosses the bottom of the reservoir at a depth of 1063 meters. This well does not enter the water zone so the OWC must be below 1063 meters. In this case the spill point of the top reservoir, and thereof the depth of the OWC, is only accepted if it is below 1063 meters. This is specified by `<spill-point-below>`.

In the next case the second well, w2, is included. This well is an appraisal well drilled in the north

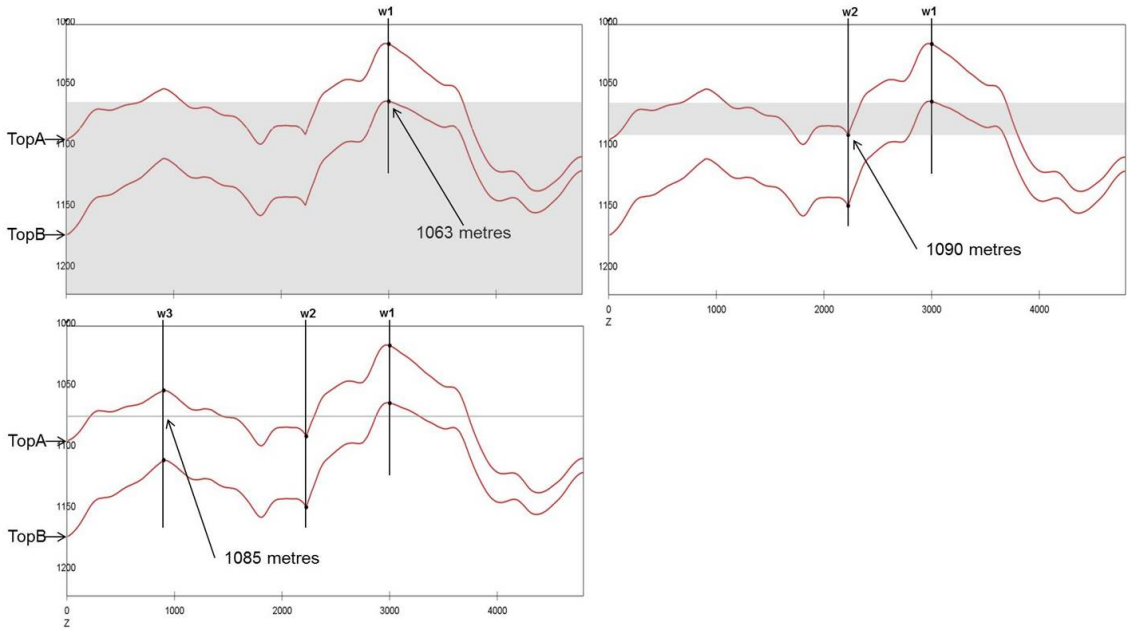


Figure 10.2. Fence diagram through the three wells. The grey areas indicate the acceptable depths for the spill points for the three cases.

flank of the main dome. The well crosses top reservoir at 1090 meters and enters the water zone without entering the oil zone. The second case therefore includes a new requirement that the spill point must be above 1090 meters. This is specified using `<spill-point-above>`.

The third well, w3, is included in the final case. This well crosses the OWC at 1085 meters. The acceptance criteria in the models above can therefore be replaced by a stricter criterion which requires that the spill point must be at 1085 meters depth. This is specified by the `<spill-point-at>`. It is however too restrictive to require the spill point to be at *exactly* this depth, hence an tolerance of 0.5 meters above and below is accepted. This is specified by `<spill-point-tolerance>`. The acceptance criteria for the three cases are summarized in Table 10.1 and illustrated by the fence diagrams in Figure 10.2.

Table 10.1. Acceptance criteria for the three cases.

	1 well	2 wells	3 wells
`<spill-point-below>`	1063 m	1063 m	1084.5 m
`<spill-point-above>`		1090 m	1085.5 m

In order for a realization to be accepted, the spill point depth must be within the specified acceptance criteria. If the spill point is not accepted, new samples are drawn until it is; hence giving one realization. The number of iterations is however limited by the `<maximum-rejection-rate>`. See Section 18.2 for details of rejection sampling.

The reservoir volume is calculated between top surface and base surface, and above the OWC. These three surfaces are specified using `<top-surface>`, `<base-surface>` and `<base-contact>`. See Section 9 for details regarding volume calculation. The volume in each realization is dependent on the simulated surfaces and the depth of the spill point.

In each of the three cases, 1000 realizations have been generated. The number of realizations is

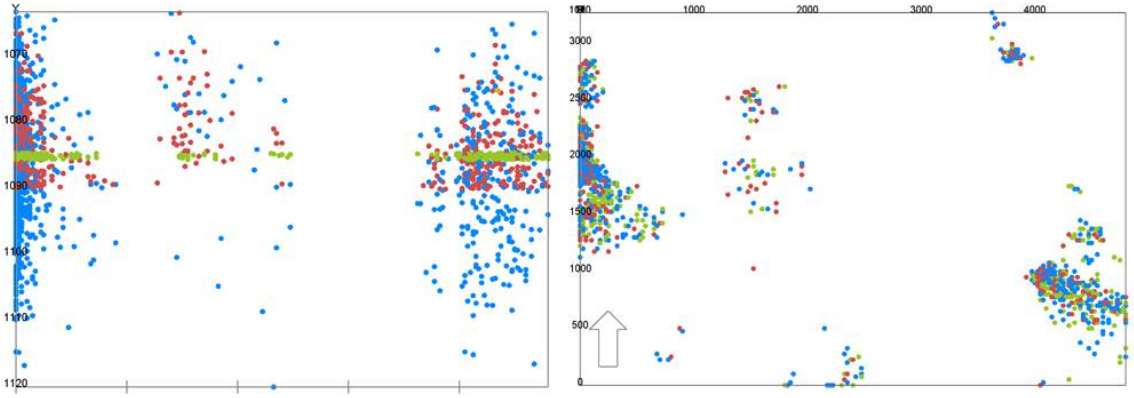


Figure 10.3. Spill points from 1000 realizations with 1, 2 and 3 wells. Left figure is a vertical cross section along the x-direction. The right figure is a top view. Blue spill points are constrained by 1 well, red spill points are constrained by 2 wells, and the green spill points are constrained by 3 wells.

specified using `<number-of-realizations>`. Average and standard deviation surfaces from all realizations are written to file.

Through this example the results from the stochastic simulations are compared to predictions (best estimate) results. Predictions of the surfaces are made using `<mode>` prediction.

10.2 Results

The rejection rates from the simulations are given in Table 10.2. The acceptance criteria for the case with all 3 wells are very strict, hence giving a rejection rate of 95 %. The number of samples to be drawn to get 1000 realizations is thus very high, which required a high `<maximum-rejection-rate>`.

Table 10.2. Rejection rate, average spill point depth in meters and average gross rock volume in million cubic meters based on 1000 simulated realizations. The uncertainties are standard deviations.

	Rejection rate	Average spill point depth	Average volume
1 well	2 %	1086.7 ± 10.4	183.4 ± 32.4
2 wells	54 %	1083.6 ± 4.8	163.9 ± 25.4
3 wells	95 %	1085.0 ± 0.3	162.6 ± 15.4

The spill points from all realizations are shown in Figure 10.3. From the right figure it can be seen that the most probable locations for spill are at the west and south-east in the map. The acceptance criteria has not affected the location of the spill points in the x-y plane, as spill points from all three cases seem to be represented in all clusters. The left figure shows that the the depth of the spill points are according to the acceptance criteria. The figure shows very clearly how the acceptance criteria is stricter in the model with 2 wells than with 1 well, and that only depths within an interval of a meter are accepted for the model with 3 wells.

The OWC is set to the spill point depth in each realization. The depth of the OWC will affect the volume in the reservoir, as the volume is only calculated above this contact. In addition, the uncertainties in the simulated surfaces will affect the volume. The calculated volumes from all three cases are summarized in Figure 10.4 and Figure 10.5. Figure 10.4 shows histogram of volume in bins of 8 million cubic meters in addition to cumulative distributions. In Figure 10.5 the minimum, maximum and mean plus/minus one standard deviation is illustrated in a bar plot. The figures show that the spread in volumes decreases as the acceptance criteria gets stricter and the num-

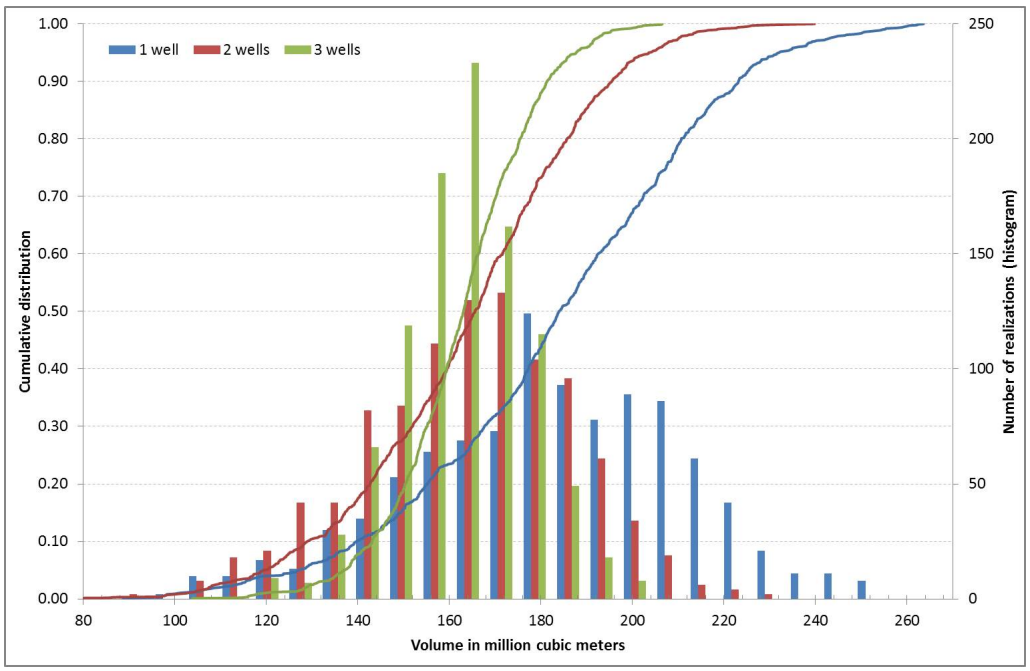


Figure 10.4. Histogram in bins of 8 million cubic meters and cumulative distribution of calculated volumes from 1000 realizations with 1, 2 and 3 wells.

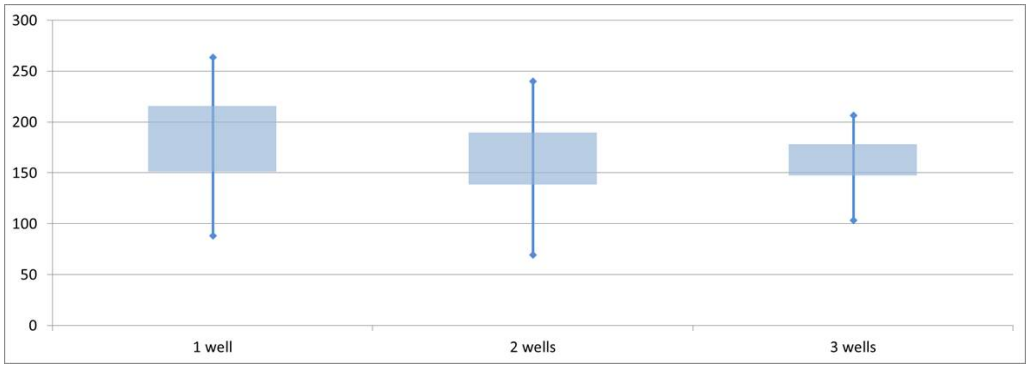


Figure 10.5. Box plot showing statistics of the calculated volumes from 1000 realizations in million cubic meters. The top and bottom of the vertical lines are the maximum and minimum volume. The top and bottom of the rectangle are the average volume plus and minus one standard deviation.

ber of wells in the model increases. The average volume is higher in the model with 1 well since there is no lower bound on the spill point and OWC. The average volumes of the models with 2 and 3 wells are in the same order, however the spread is less in the latter, which can be seen by the steeper cumulative curve in Figure 10.4. The standard deviation is also decreasing with stricter acceptance criteria as expected. The average spill point depth and volume with standard deviations are listed in Table 10.2.

Figure 10.6 shows the mean of the top surface for all three models. The relevant wells are included in the figures. It is not easy to spot much difference between the three cases based on these mean surfaces only. In the same figure the difference between the predicted depth and the mean surfaces are given. These are plotted on a scale where zero difference is white, where the predicted depth is deeper than the mean is red, and blue is the opposite case. In the model with 1 well the entire map is light blue. This indicates that the mean is somewhat deeper than the predicted depth. In

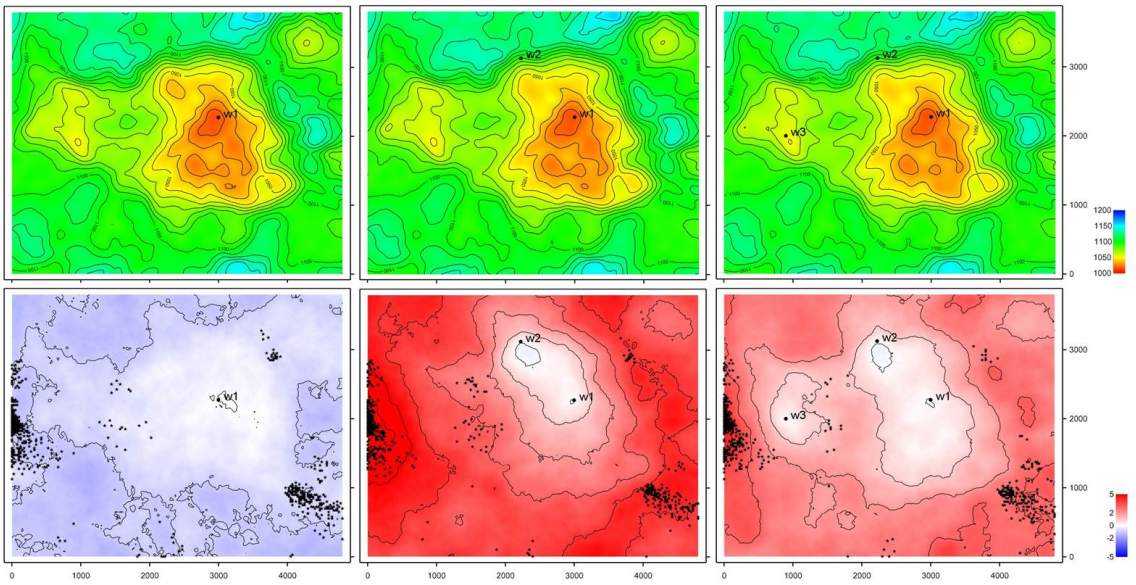


Figure 10.6. At the top are maps of mean surfaces of 1000 realizations with 1 well, 2 wells and 3 wells respectively. They use the same color legend as Figure 10.1. At the bottom are maps of predicted depths minus the mean surfaces. White color indicates no difference, red color shows that the predicted depths are deeper than the mean, and blue indicates the opposite. The relevant wells and spill points from cases with 1, 2 and 3 wells are included in the lower figures.

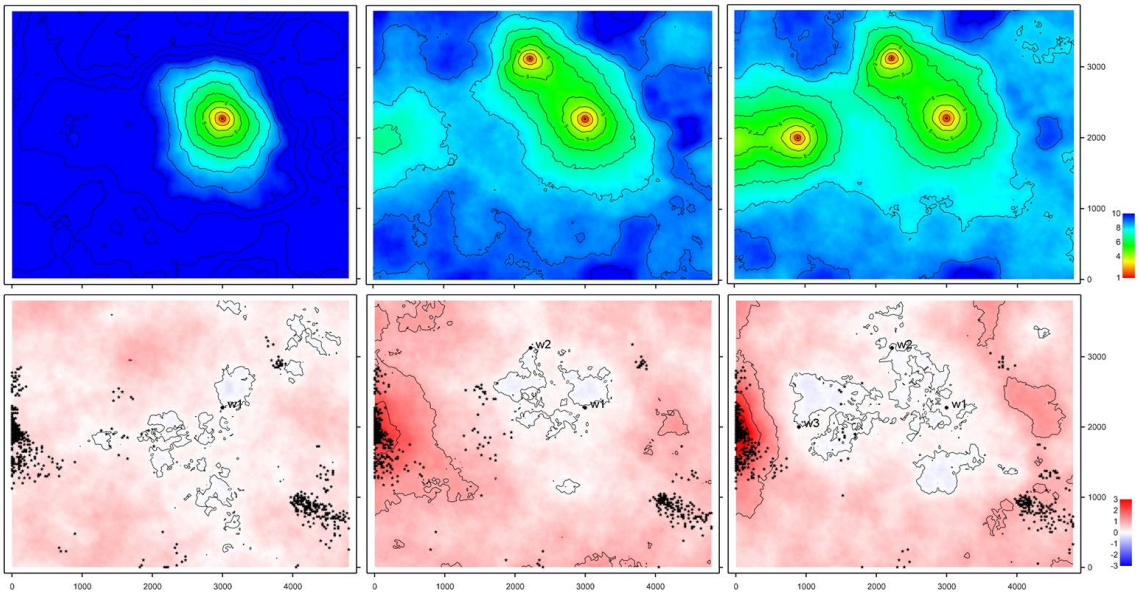


Figure 10.7. Empirical standard error maps of 1000 realizations with 1, 2 and 3 wells respectively on top. At the bottom are prediction errors minus standard deviation from the 1000 realizations with 1, 2 and 3 wells. White colour means no difference, red means that the depth error is higher than the stddev and blue is the opposite. The relevant wells and spill points from cases with 1, 2 and 3 wells are included in the lower figures.

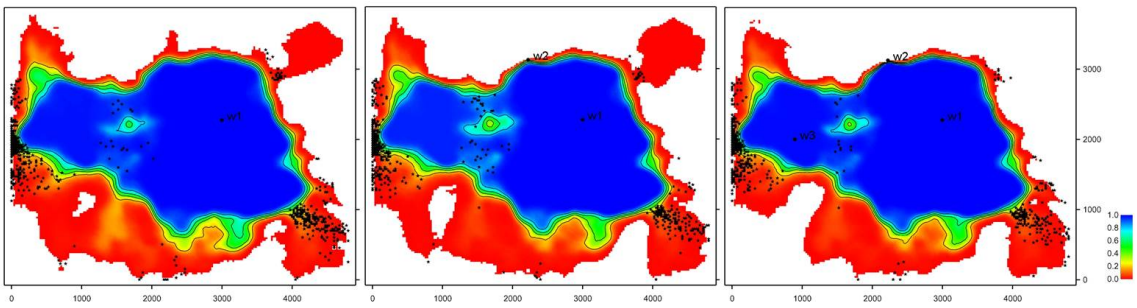


Figure 10.8. Map of probability for being inside the trap. This is the mean trap maps from 1000 realizations from case with 1, 2 and 3 wells respectively.

the models with 2 and 3 wells however, the mean surfaces are more shallow than the predictions. In these models the surfaces have been lifted, and especially at the locations of the spill. The model with 2 wells has the highest mean surface compared to the prediction. This model has also the most shallow average spill point depth, see Table 10.2. The spill point depth from the predictions are in the order 1092 meters, which is somewhat deeper than the averages from all three simulation models.

In Figure 10.7 the standard deviation of the top surface is shown for the three cases. The location of the wells are easily spotted in these figure as the standard deviation is zero at the wells. The standard deviation is compared to the depth error from prediction, and the differences are shown in the figure for all cases. If there were no rejected samples, the depth error should be approximately identical to the standard deviation of a large number of simulations. The difference between the depth error and standard deviation therefore gives an indication of the effect of the rejection sampling. Also here one can see a change related to the location of the spill in the models with 2 and 3 wells. The standard deviation is reduced compared to the depth error in the locations of the spill, especially at west of the map, as the acceptance criteria have limited the variability of the surfaces in these areas.

Figure 10.8 shows the probability for being inside the trap obtained from the average of trap maps from 1000 realizations. This map is written to file by using element `<trap>`. A trap map from one realization is one inside the trap and zero outside; hence the locations with one in the average map are inside the trap of all realizations. The figures show that there is a large variability in the area included in the volume calculation. Some traps have a large area, but about 70–80 % seem to be in the same order. Figure 10.9 includes column maps from the average of 1000 realizations at the top, and predictions at the bottom. These maps can give the volume directly by multiplying the value of each grid cell by the area of the grid cell, and can be written to file by using element `<column-map>`. The volume of the predicted models is in the order of 200 million cubic meters, which is larger than the average from the simulations. This is caused by a deeper spill point in the predicted top surface. This can to some extent be seen from Figure 10.9.

Figure 10.10 shows the standard deviation of the column maps in addition to the average of 1000 realizations. These figures show that the uncertainty in the area of the reservoir is reducing with increasing number of wells and stricter acceptance criteria, especially at west of the map.

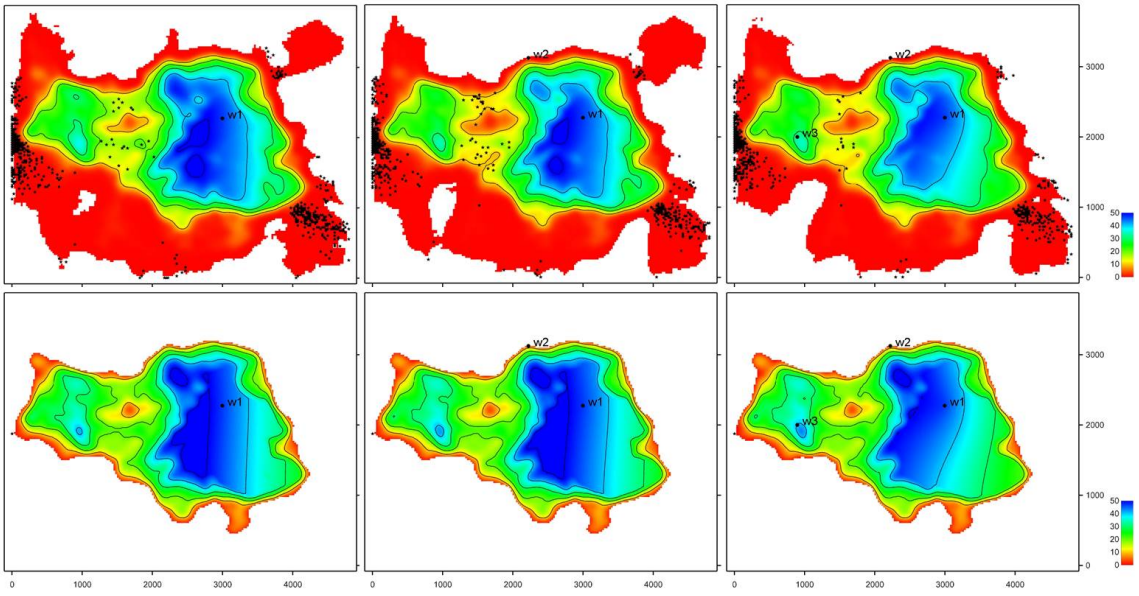


Figure 10.9. At the top; average column height map from case with 1, 2 and 3 wells respectively. At the bottom, the column height map from predictions with 1, 2 and 3 wells. The relevant wells and spill points are included.

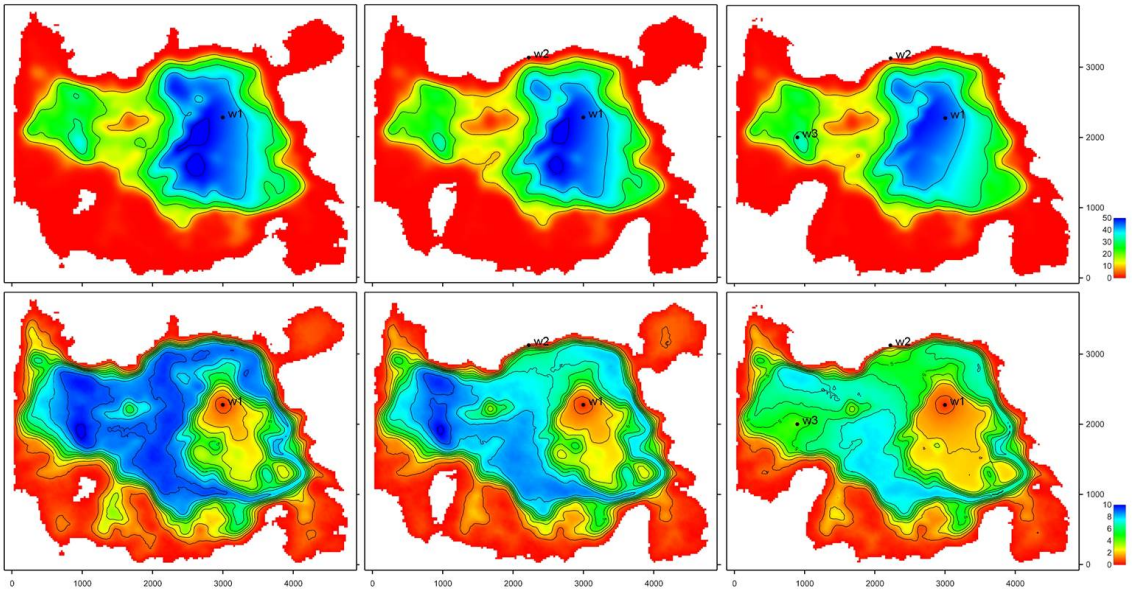


Figure 10.10. At the top; average column height map from model with 1, 2 and 3 wells respectively. At the bottom, standard deviation of column height map from model with 1, 2 and 3 wells respectively. The relevant wells are included.

10.2.1 Fast simulation versus ordinary simulation

Fast simulation is chosen using `fast-simulation` instead of the ordinary `simulation` in `<mode>`. The fast simulation is an approximation that ignores the complex spatial correlations close to well points. See Section 18.1 for details. The fast simulation particularly address the challenge of generating many stochastic realizations to obtain gross rock volume distributions. The assumption is that the approximations close to well points have little influence on the volumes. Figure 10.11 shows a comparison of volumes obtained using the ordinary simulation and the fast simulation. The stochastic realizations are obtained using the same seed. Rejection sampling on the spill points has not been used in this example. The histograms and in particular the cdf's are almost identical. This is confirmed by the numbers in Table 10.3. The differences between the curves and the numbers are smaller than the Monte Carlo noise, that is the random uncertainty introduced when using a finite number of stochastic realizations.

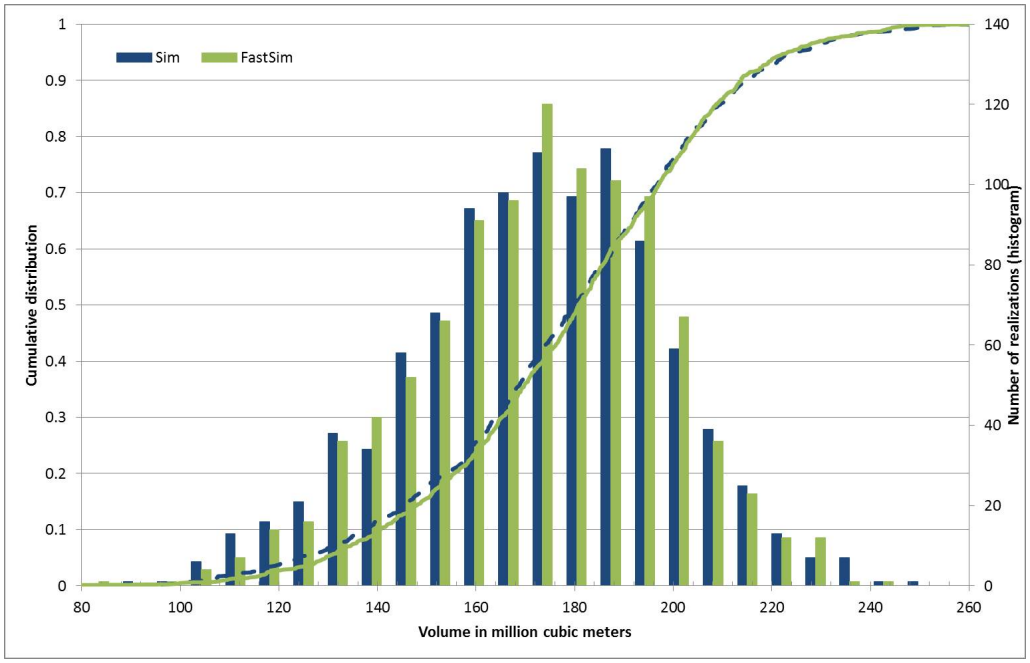


Figure 10.11. Gross rock volume distribution in million cubic meters from 1000 realizations using fast simulation and ordinary simulation.

Table 10.3. Gross rock volumes in million cubic meters from 1000 realizations using ordinary simulation and fast simulation.

	Ordinary simulation	Fast simulation
Average	178	179
Std.dev.	30	29
P10	137	141
P50	180	181
P90	215	214

11 Multiple models

Cohiba allows the user to specify several alternative ways of combining intervals to obtain a surface. This leads to multiple models that are combined into a unique solution for each surface. This is a unique feature for Cohiba.

Multiple models is a convenient way of squeezing surfaces between envelopes of well defined surfaces such as seismic reflectors. Intervals with large uncertainty are used for absorbing the inconsistencies between the models. Figure 11.1 shows an example.

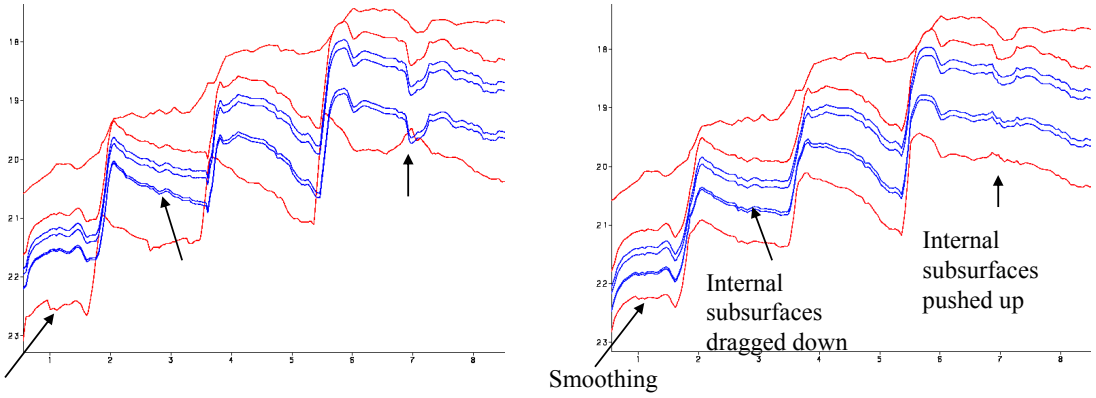


Figure 11.1. Cross section of two alternative ways of combining intervals. The red surfaces are seismic reflectors. The blue surfaces separates the internal zones that are assumed to have constant thickness. The figure to the left shows the surfaces when the internal zones are added to the seismic reflector above. The figure to the right shows the surfaces when Cohiba distributes the internal zones within the two seismic reflectors. We see that the result is a compromise between zones of constant thickness and the shape given by the two seismic reflectors. Note in particular that the seismic reflectors are also affected by the assumption that the zones have constant thickness.

11.0.2 Example from the Brent Group

Lets be specific and consider the Brent Group in the North Sea with its subdivision into the formations Broom, Rannoch, Etive, Ness and Tarbert. Assume that the top and base of Brent are good seismic reflectors. The crucial information is summarized in Table 11.1.

There are two ways of obtaining the depth to the surfaces below TopBrent. We can either add the isochores to TopBrent or we can find the depth to BaseBrent using depth conversion of the Brent group and add the isochores on top of BaseBrent.

Cohiba will use both approaches and take a weighted average of the two results. These *model weights* are essentially proportional to the inverse of the squared uncertainty (the variance). It is possible to make a quick assessment of the uncertainty of the surfaces and thereby get a rough idea of what the model weights will be.

Table 11.1. The interpretation uncertainty of the travel times are 4 msec. and 8 msec. for TopBrent and BaseBrent respectively. The interval velocity uncertainty is 10 m/s for the interval down to TopBrent and the interval velocity uncertainty in Brent is 150 m/s. The isochore uncertainty of the individual formations are chosen to be 30 % of the thickness. All uncertainties are standard deviations.

		Time maps		Interval veloc.		Isochore	
Surface	Interval	typical	uncert.	typical	uncert.	typical	uncert.
		(msec. twt)		(m/s)	(m/s)	(m)	(m)
MSL		0	0				
	MSL-Brent			2200	10		
TopBrent		1900	4				
	Tarbert					30	9,0
TopNess							
	Ness					70	21,0
TopEtive							
	Etive			2500	150	30	9,0
TopRannoch							
	Rannoch					50	15,0
TopBroom							
	Broom					5	1,5
BaseBrent		2050	8				

Table 11.2. There are three alternative approaches for obtaining the depth to the surfaces below TopBrent: Adding isochores to TopBrent, adding isochores to BaseBrent, or the Cohiba approach combining both. The arrows indicate how the surfaces are obtained. Red arrows means depth conversion. The values in Table 11.1 were chosen so that the depth values are very similar for all approaches. The uncertainties however, differ significantly. The model weights chosen by Cohiba is seen in the Weight columns for each of the "Building from" approaches.

		Building from TopBrent				Building from BaseBrent				COHIBA		
Surface	Interval		Depth	uncert.	Weight		Depth	uncert.	Weight		Depth	uncert.
			(m)	(m)			(m)	(m)			(m)	(m)
MSL			0	0,0			0	0,0			0	0,0
	MSL-Brent											
TopBrent			2090	10,5			2090	10,5			2090	10,5
	Tarbert											
TopNess			2120	13,8	90,5 %		2123	32,9	9,5 %		2120	13,4
	Ness											
TopEtive			2190	25,1	49,7 %		2193	25,4	50,3 %		2191	18,9
	Etive											
TopRannoch			2220	26,7	42,2 %		2223	23,7	57,8 %		2221	18,7
	Rannoch											
TopBroom			2270	30,6	21,4 %		2273	18,4	78,6 %		2272	16,4
	Broom											
BaseBrent			2275	30,7	21,2 %		2278	18,3	78,8 %		2277	16,4

Table 11.3. Multiple models weights for the Brent example.

	Travel time uncert.	Velocity uncert.	Weight to BaseBrent	Weight to TopRannoch
Low uncertainty on BaseBrent	4 msec.	75 m/s	93.5 %	68.5 %
Base case	8 msec.	150 m/s	78.8 %	57.8 %
High uncertainty on BaseBrent	16 msec.	300 m/s	48.4 %	35.5 %

Adding all the formations gives the accumulated uncertainty of the Brent interval as:[1]

$$9^2\,\mathrm{m}^2 + 21^2\,\mathrm{m}^2 + 9^2\,\mathrm{m}^2 + 15^2\,\mathrm{m}^2 + 1.5^2\,\mathrm{m}^2 \approx 29^2\,\mathrm{m}^2.$$

The uncertainty of the thickness of the Brent interval using depth conversion is:[2]

$$\left(2500\,\mathrm{m/s} \times \tfrac{8\,\text{msec.}}{2000\,\text{msec./s}}\right)^2 + \left(150\,\mathrm{m/s} \times \tfrac{150\,\text{msec.}}{2000\,\text{msec./s}}\right)^2 = 10^2\,\mathrm{m}^2 + 11.25^2\,\mathrm{m}^2 \approx 15^2\,\mathrm{m}^2.$$

The first term is the contribution from the travel time uncertainty and the second term is the contribution from the interval velocity uncertainty. We see that using depth conversion gives a lower uncertainty (± 15 m) than using the isochore thicknesses (± 29 m) for BaseBrent. The model weights will be:

$$\frac{29^2}{29^2 + 15^2} = 0.79 \quad \text{and} \quad \frac{15^2}{29^2 + 15^2} = 0.21.$$

So the depth conversion approach will contribute 79 % to BaseBrent.

Table 11.2 shows a summary of the uncertainties and the model weights calculated by Cohiba. There are two important observations:

1. The Cohiba approach favor the approach with the smallest uncertainty. We can see a transition where deeper surfaces are more dependent on BaseBrent than the shallower ones.
2. The surface uncertainty obtained by the Cohiba approach is always smaller than the uncertainty using only one of the approaches. This is not a coincidence. Cohiba chooses the model weights so that the uncertainty is minimized.

Multiple models are indirectly specified by the user by specifying two (or more) interval models for one (or more) surfaces. Figure 11.2 shows how this is done for the Brent example.

Figure 11.3 shows how the multiple models and their weights are reported by Cohiba. The model weights are sampled at a few locations in the grid and will usually give different values for `Avg`, `Min`, and `Max`. In this simple example all surfaces and uncertainties are constant giving equal model weights in all grid nodes.

Model weights will *always* sum to one. This will be true for the reported average (`Avg`) value but not true for the reported `Min` and `Max` values. Note that model weights can be negative and even larger than 1 in some rare cases. This is caused by correlations between different models.

11.0.3 The model weights are sensitive to the uncertainty specifications

Since model weights depend on the inverse of the variances, they can change significantly if the uncertainty is changed by a relatively small amount.

Table 11.3 shows what happens to the model weights if we half or double the uncertainties. In the high uncertainty case, the seismic travel times for BaseBrent are no longer favored more than a simple stacking of isochores from TopBrent.

1. All specified uncertainties are assumed independent. Since the individual uncertainties are assumed independent we can simply add the variances (squared standard deviation) to obtain the total variance.
2. We must divide by 2000 msec./s since travel times are two-way-times in milliseconds.

```
<interval-models>
  <interval>
    <name> MSL-Brent  </name>
    <top>  MSL        </top>
    <base> TopBrent   </base>
    <interval-type> velocity </interval-type>
    ...
  </interval>

  <interval>
    <name> Brent      </name>
    <top>  TopBrent  </top>
    <base> BaseBrent </base>
    <interval-type> velocity </interval-type>
    ...
  </interval>

  <interval>
    <name> Broom      </name>
    <top>  TopBrent  </top>
    <base> TopRannoch </base>
    <interval-type> thickness </interval-type>
    ...
  </interval>

  <interval>
    <name> Rannoch      </name>
    <top>  TopRannoch   </top>
    <base> TopEtive     </base>
    <interval-type> thickness </interval-type>
    ...
  </interval>

  <interval>
    <name> Etive      </name>
    <top>  TopEtive   </top>
    <base> TopNess    </base>
    <interval-type> thickness </interval-type>
    ...
  </interval>

  <interval>
    <name> Ness       </name>
    <top>  TopNess    </top>
    <base> TopTarbert </base>
    <interval-type> thickness </interval-type>
  ...
  </interval>

  <interval>
    <name> Tarbert      </name>
    <top>  TopTarbert  </top>
    <base> BaseBrent </base>
    <interval-type> thickness </interval-type>
    ...
    </interval>
</interval-models>
```

Figure 11.2. BaseBrent and TopBrent enters the `<top>` and `<base>` elements twice. These double entries makes this a specification of multiple models. The crucial specifications are marked in dark red.

```
*************************************************************************************************
*****                  Section 4: The alternative ways to build each surface                  *****
*************************************************************************************************

               ModelWeights
Surface       Avg    Min    Max    Models
-------------------------------------------------
TopBrent    1.000  1.000  1.000    1: MSL → TopBrent
TopNess     0.905  0.905  0.905    1: MSL → TopBrent → TopNess
            0.095  0.095  0.095    2: MSL → TopBrent → BaseBrent → TopBroom → TopRannoch → TopEtive → TopNess
TopEtive    0.497  0.497  0.497    1: MSL → TopBrent → TopNess → TopEtive
            0.503  0.503  0.503    2: MSL → TopBrent → BaseBrent → TopBroom → TopRannoch → TopEtive
TopRannoch  0.422  0.422  0.422    1: MSL → TopBrent → TopNess → TopEtive → TopRannoch
            0.578  0.578  0.578    2: MSL → TopBrent → BaseBrent → TopBroom → TopRannoch
TopBroom    0.214  0.214  0.214    1: MSL → TopBrent → TopNess → TopEtive → TopRannoch → TopBroom
            0.786  0.786  0.786    2: MSL → TopBrent → BaseBrent → TopBroom
BaseBrent   0.212  0.212  0.212    1: MSL → TopBrent → TopNess → TopEtive → TopRannoch → TopBroom → BaseBrent
            0.788  0.788  0.788    2: MSL → TopBrent → BaseBrent
```

Figure 11.3. The report of the multiple models and their weights for the Brent case found in the Cohiba log file. The arrows indicate an interval.

```
                   ModelWeights
Surface          Avg    Min    Max    Models
-----------------------------------------------------------
...
Top_SN_9.3     0.136 -0.084  0.765    1: MSL → Top_Nordland → Top_Hordaland → Top_Balder → BCU → Top_SN_11.4 → Top_SN_11.3
                                                → Top_SN_11.2 → Top_SN_11.1 → Top_SN_10.4 → Top_SN_10.3
                                                → Top_SN_10.2 → Top_SN_10.1 → Top_SN_9.4 → Top_SN_9.3
               0.014 -0.045  0.079    2: MSL → Top_Nordland → Top_Hordaland → Top_Balder → BCU → Top_SN_11.4 → Top_SN_11.3
                                                → Top_SN_11.2 → Top_SN_11.1 → Top_SN_10.4 → Top_SN_10.3
                                                → Top_SN_10.2 → Top_SN_10.1 → Top_SN_9.3
               0.050 -0.023  0.141    3: MSL → Top_Nordland → Top_Hordaland → Top_Balder → BCU → Top_SN_11.4 → Top_SN_11.3
                                                → Top_SN_11.2 → Top_SN_11.1 → Top_SN_10.4 → Top_SN_10.1
                                                → Top_SN_9.4 → Top_SN_9.3
               0.016 -0.032  0.099    4: MSL → Top_Nordland → Top_Hordaland → Top_Balder → BCU → Top_SN_11.4 → Top_SN_11.3
                                                → Top_SN_11.2 → Top_SN_11.1 → Top_SN_10.4 → Top_SN_10.1
                                                → Top_SN_9.3
               0.266 -0.020  0.722    5: MSL → Top_Nordland → Top_Hordaland → Top_Balder → BCU → Top_SN_11.4 → Top_SN_10.4
                                                → Top_SN_10.3 → Top_SN_10.2 → Top_SN_10.1 → Top_SN_9.4
                                                → Top_SN_9.3
               0.058 -0.010  0.123    6: MSL → Top_Nordland → Top_Hordaland → Top_Balder → BCU → Top_SN_11.4 → Top_SN_10.4
                                                → Top_SN_10.3 → Top_SN_10.2 → Top_SN_10.1 → Top_SN_9.3
               0.249  0.022  0.613    7: MSL → Top_Nordland → Top_Hordaland → Top_Balder → BCU → Top_SN_11.4 → Top_SN_10.4
                                                → Top_SN_10.1 → Top_SN_9.4 → Top_SN_9.3
               0.212  0.002  0.857    8: MSL → Top_Nordland → Top_Hordaland → Top_Balder → BCU → Top_SN_11.4 → Top_SN_10.4
                                                → Top_SN_10.1 → Top_SN_9.3
```

Figure 11.4. The report of the multiple models and their weights found in Cohiba log file. The arrows indicate an interval.

11.0.4 Many multiple models and their weights

It is possible to specify many sets of multiple models including alternative zonation and alternative depth conversions. Cohiba will automatically sort out all possible ways of calculating the depth to any surface. This may include a lot of alternatives. Figure 11.4 shows a small piece of logging information taken from Cohiba log file. It shows the eight alternative models for the surface Top_SN_9.3. model weights

Note that the model weights are quite small for several of the alternatives and that they vary a lot in different areas. The deepest surfaces in this particular example can be reached in 128 different ways so the complexity can be significant.

Cohiba calculates the model weights by looking at the uncertainty of each model *and* the correlation between each model. Many models will have a lot of intervals in common. The common parts will make the alternative models correlated.

Cohiba may use a significant amount of CPU time calculating the model weights and the CPU time will increase with the number of alternative models. The calculation of the actual surfaces (stochastic or deterministic) is not sensitive to the number of alternative models.

11.0.5 Some words of advice

Multiple models are very convenient but they can obscure how surfaces are constructed since they combine several alternatives. It can therefore be difficult to understand why a surface gets its shape. A typical effect is that seismic reflectors are modified so that the features seen on the travel time maps are distorted. Figure 11.1 illustrates this quite clearly. The simple reason is that depth conversion is not accurate and alternative approaches to constructing the surface can strongly influence the surface shape. It is all a consequence of the user chosen uncertainties. Small travel time uncertainties and small interval velocity uncertainties will guaranty that features seen in travel time maps are preserved. But small uncertainties are not always realistic.

Be careful when using many small intervals

This may result in unrealistic small uncertainties since adding many small uncertainties result gives a smaller uncertainty than most realize. This is best illustrated by an example.

Let us consider a depth converted interval of 200 meters where the uncertainty is 20 meters. Now assume that there is a subdivision of this interval into equally thick zones. Further assume that the uncertainty of the thickness of each zone is 30 %. That is, if there is one zone, the uncertainty is 200 m $\times$ 30 % = 60 m. If there are two equally thick zones they have 100 m $\times$ 30 % = 30 m uncertainty, and if there are three equally thick zones they have uncertainty 66.6 m $\times$ 30 % = 20 m and so on. If the number of zones are N, the accumulated uncertainty for the whole interval becomes:

$$\mathrm{Var}\{\Delta Z\} = N \times (30\,\% \times 200\,\mathrm{m}/N)^2. \tag{11.1}$$

This uncertainty must be compared to 20 meters which is the uncertainty obtained using depth conversion. The uncertainty, $\sqrt{\mathrm{Var}\{\Delta Z\}}$, is plotted as a dark blue line in Figure 11.5 and the corresponding model weights given to the depth conversion alternative is plotted as the blue line.

We see that the model weights are 50 % when the accumulated uncertainty is approximately 20 meters. This is the point where it becomes less uncertain to use the subdivision rather than the depth converted interval.

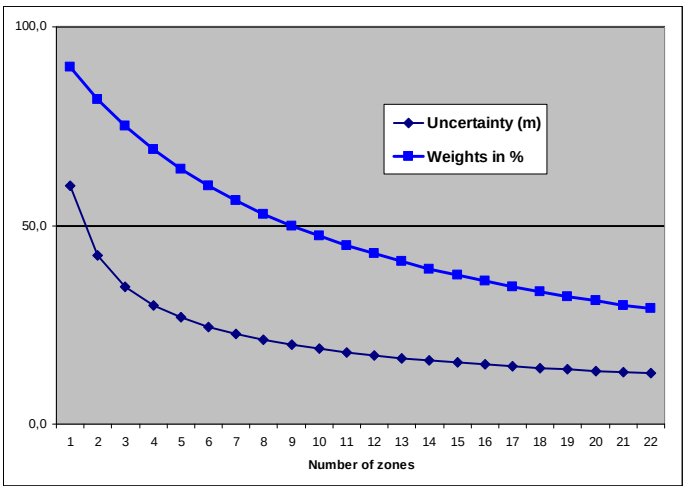


Figure 11.5. Model weights (blue line) as the number of subdivisions of the zone increase. The dark blue line is the accumulated uncertainty obtained using Eq. 11.1.

Small uncertainties are drowned by bigger uncertainties

Since accumulated uncertainties are obtained by summing the squares (the variances), small uncertainties are totally dominated by larger uncertainties. Here are a few examples:

$$10^2\,\mathrm{m}^2 + 1^2\,\mathrm{m}^2 \approx 10.05^2\,\mathrm{m}^2 \tag{11.2}$$

$$10^2\,\mathrm{m}^2 + 2^2\,\mathrm{m}^2 \approx 10.2^2\,\mathrm{m}^2 \tag{11.3}$$

$$10^2\,\mathrm{m}^2 + 5^2\,\mathrm{m}^2 \approx 11.2^2\,\mathrm{m}^2 \tag{11.4}$$

$$10^2\,\mathrm{m}^2 + 10^2\,\mathrm{m}^2 \approx 14.1^2\,\mathrm{m}^2. \tag{11.5}$$

Multiple models with no well data

It is quite common in large models that there are little or no well data for a few surfaces. This could give warnings like this:

```
WARNING: The average thickness between depth trend surfaces 'Top_SN_3.4' and 'Top_SN_3.3' is negative (-6.61).
        Probable cause: Conflict between multiple models for one or both surfaces.
```

12 Faults

Cohiba does not model faults directly. However, the underlying data used for describing faults, the travel time maps, are handled by Cohiba. So faulted seismic reflectors will give faulted surfaces[1]. The vertical component of the uncertainty of the fault position will depend on the travel time uncertainty and the interval velocity uncertainty. The vertical component of the uncertainty is close to the real uncertainty for low angle faults. The uncertainty will be underestimated for vertical and high angle faults.

Cohiba Version 2.0 and later version has introduced a new feature that ensure even better handling of faults. In previous versions, faults could open up even if the travel times showed that surfaces coincide along the fault. This had two causes:

1. Cohiba assumes that the uncertainties to the travel times from different surfaces are independent. This is normally a good approximation, but it is unrealistic when two seismic reflectors are very close or coinciding. So now Cohiba automatically adjust the travel time uncertainties so that close or coinciding seismic reflectors gets correlated (dependent) residuals. This is both realistic and gives zero uncertainty for the zero thickness between coinciding seismic reflectors along fault planes. This feature can be turned off using the element `<correlate-close-reflectors>`.

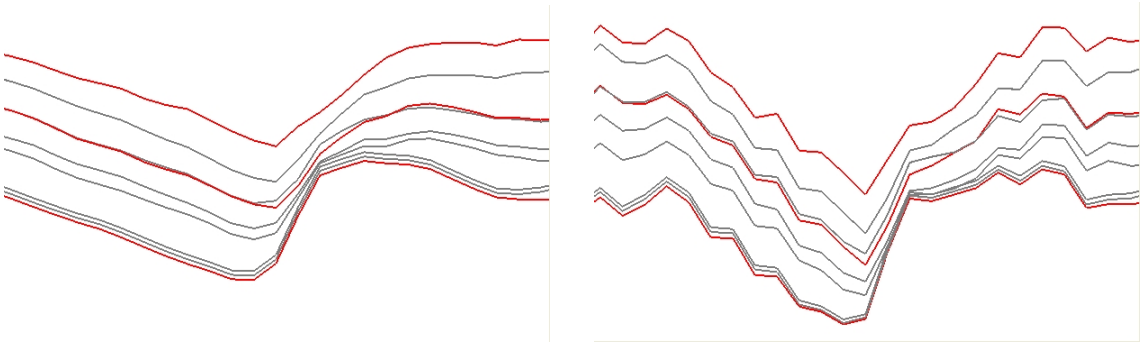
2. The zone thickness trends will in general disagree with the trends obtained from seismic depth conversion. This is solved by combining multiple models. If two seismic reflectors coincide, the thickness uncertainty between the seismic reflectors now becomes zero. This guarantees that the depth conversion alternative for the lower seismic reflector gets model weight 1 and other model alternatives get zero weight. However, the intermediate (non-reflecting) surfaces will not be perfectly squeezed in between the two coinciding seismic reflectors. This is solved if seismic reflectors behave as erosive surfaces *and* on-lapped surfaces. The seismic reflectors will then cut away any parts of the intermediate surfaces that are not in between the two seismic reflectors. This is now the default but it can be overruled by using the element `<treat-reflectors-as-eroding-and-onlapped>`.

   Note that this only affects the post processing of surfaces, not the extraction of well points. If a seismic reflector is eroding and/or on-lapped, then use the elements `<erosive>` and `<onlapped>`.

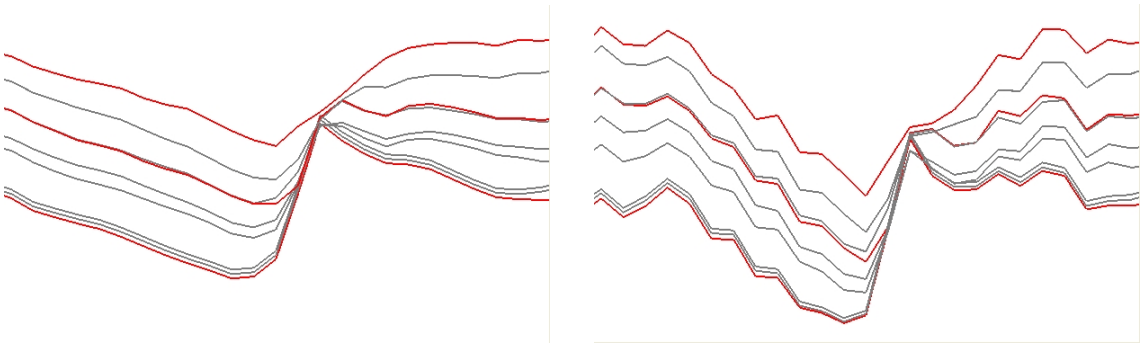
These features are illustrated in Figure 12.1.

1. Only normal faults can be represented by travel time maps so reverse faults must be approximated by vertical faults.

Original Cohiba model. Interval thickness models open the fault defined by the seismic reflectors:



Introducing correlated travel time uncertainty
(Turn off using element `<correlate-close-reflectors>`):



Introducing eroding and on-lapped seismic reflectors
(Turn off using element `<treat-reflectors-as-eroding-and-onlapped>`):

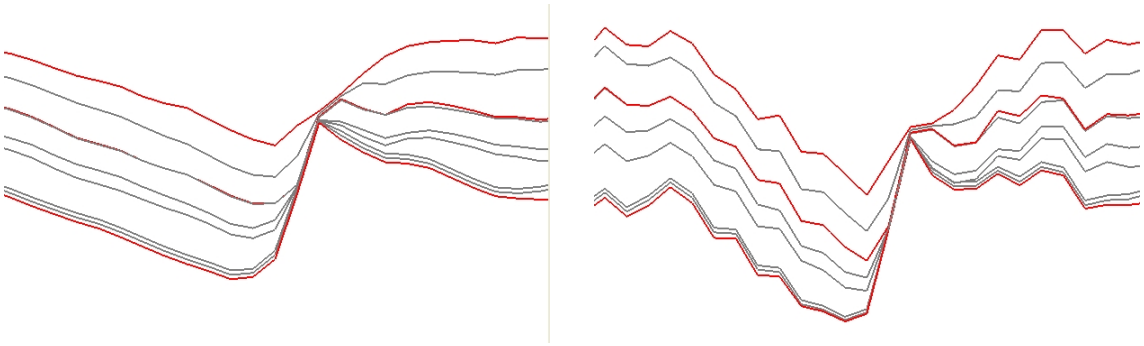


Figure 12.1. Cross section of a fault. Seismic reflectors are red. Deterministic (prediction) in the left column and one stochastic realization in the right column.

13 Free surfaces

A free surface is a surface that does not belong to the ordered sequence of surfaces that define the stratigraphy. A free surface may cut through other surfaces. Typical examples are hydrocarbon contacts and faults. A surface is specified as free using <free-surface>. Free surfaces are handled by Cohiba like any other surface except from situations where the correct ordering is needed. Free surfaces are listed after other surfaces.

Since a free surface has no particular order it can not erode other surfaces and it can not be onlapped. Erosion rules specified by <erosive> and <onlapped> are therefore ignored. A free surface will not be eroded by other surfaces and it will not lap onto other surfaces.

Since a free surface is not a boundary for a stratigraphic zone it is not meaningful to associate it with a <top-of-zone>. Therefore, zone logs can not be used to specify well points for free surfaces. Well points for free surfaces must be specified by well point files using <files> under <well-points>.

13.1 Linking free surfaces to other surfaces

Free surfaces can be linked to any surface using the <top> and <base> under <interval>. This can be utilized in various ways.

13.1.1 Control other surfaces using a flat spot

A flat spot is an almost horizontal gas-oil- or gas-water-contact that gives a strong seismic reflection. The seismic travel time to a flat spot will therefore have a very low uncertainty, say ± 1 msec.[1] It is possible to form velocity intervals between the flat spot and other reflecting surfaces. This might reduce the uncertainty in the other reflecting surfaces. Note that it is possible and meaningful to make velocity intervals that have negative thickness and negative interval travel times.

13.1.2 Control other surfaces using a hydrocarbon contact

A hydrocarbon contact is almost horizontal provided the fluids are in gravitational equilibrium. This can be used to calibrate depth measurements and correct for systematic measurement errors.

To be able to correct for systematic measurement errors in a well the errors in the well must be correlated. The standard deviation of the measurement errors are specified in the Cohiba well points files (Table 6.1). The *correlation* between the measurement errors are specified using <variogram> under <well-points>. The correlation between measurement errors is assumed to be zero between well points belonging to different wells.

It is also possible to specify a vertical measurement error on the well paths using <z-stddev-log-name>. The *correlation* along the well path is specified by <variogram> under <well-log>.

Note that the well point variogram is used for calculating the correlations between well points from free surfaces and well points extracted from zone logs.

1. The travel time uncertainty in areas outside the flat spot should be set to a high value, say 50 msec.

13.1.2.1 Linking hydrocarbon contacts to spill points

A free surface can be linked directly to the spill point of a different surface using `<condition-to-spill-point-at-surface>`. This is meant to be used for modeling a hydrocarbon for a filled structure. The `<name>` of the free surface can be used as the `<base-contact>` in volume calculations. This makes it possible to find the volume of a filled structure with an unknown spill point. This approach should be used in combination with `<only-trapped-volume>`. See Section 9.

Part IV
Reference manual

14 Cohiba model file elements

The Cohiba model file is an XML file and has the following structure:[1]

```
<cohiba>
    <project-settings>
       :
    </project-settings>
    <modelling-settings>
       :
    </modelling-settings>
    <well-data>
       :
    </well-data>
    <surfaces>
        <reference>
           :
        </reference>
        <surface>
           :
        </surface>
       :
    </surfaces>
    <interval-models>
        <interval>
           :
        </interval>
       :
    </interval-models>
    <volumes>
        <volume>
           :
        </volume>
       :
    </volumes>
</cohiba>
```

A complete list of all Cohiba model file elements is found in Section 15. All the elements are explained in detail in the following.

<cohiba> (required)

Description: Wrapper for all other elements of the Cohiba model file. This is called the root element in XML jargon.

Argument: The six main elements in the Cohiba model file.

Default: No default.

1. Any XML file should contain an initial line `<?xml version="1.0" encoding="UTF-8" ?>` to identify the XML version and the character encoding.

14.1 <project-settings> (required)

Description: General settings such as file name conventions, measurement units, and definition of project coordinate system.
Argument: Wrapper for elements.
Default: Empty string.

14.1.1 <project-title> (required)

Description: A Cohiba project title.
Argument: String.
Default: Empty string.

14.1.2 <project-description>

Description: Detailed description of the project.
Argument: String.
Default: Empty string.

14.1.3 <seed>

Description: Sets the random seed for the random number generator used in stochastic simulations. The argument is either a file name containing a random seed or a random seed. Any valid number is accepted as a random seed. The random seed file is located in the directory specified in <project-directory>. The default name of the random seed file is `seed.dat`. When running a stochastic simulation, a new random seed is always written to the random seed file at the end of the stochastic simulation. A new file will be created if it does not exist. The new seed is the old seed plus one.

It is also possible to set the random seed employing the option `-s` on the command line: `cohiba.exe -s 123 model_file.xml`.
See Section 4.1 for more details on the command line options. This will have precedence over random seeds specified in the Cohiba model file or the random seed file. If the random seed is unspecified and the random seed file does not exist, an automatic random seed will be generated based on the system clock.

Argument: File name or positive integer less than or equal to $2^{32} - 1 = 4\,294\,967\,295$. (C++ unsigned long int.)
Default: `seed.dat`
Example: Random seed:

```
<seed>     123   </seed>
```

Example: Specify a random seed file:

```
<seed>  myseed.dat  </seed>
```

14.1.4 <project-directory>

Description: A relative or absolute path to a Cohiba project. If a relative path is used, Cohiba must be executed from the directory the relative path refers to.
Argument: A valid path to a directory.
Default: Current directory (. in Linux).
Example: Relative path:

```
<project-directory>  my-cohiba-project/ </project-directory>
```

Example: Absolute path:

```
<project-directory>  /path/to/projects/my-cohiba-project/ </project-directory>
```

14.1.5 <input-directory>

Description: Relative or absolute path to all Cohiba input. The relative path is relative to the project directory.

Argument: A valid path to a directory

Default: input/

Example: Relative path:

```
<input-directory>  my-input/ </input-directory>
```

Example: Absolute path (can be to any location):

```
<input-directory>
   /path/to/projects/my-cohiba-project/my input/
</input-directory>
```

14.1.6 <input-directory-surfaces>

Description: Path to input surfaces. The path is relative to the input directory specified with <input-directory>.

Argument: A valid path to a directory

Default: surfaces/. If <input-directory> has been specified, the default is ./. See Section 6.1 for more information.

Example:

```
<input-directory-surfaces>   surfaces_50x50/   </input-directory-surfaces>
```

14.1.7 <input-directory-well-data>

Description: Path to well data input. The path is relative to the input directory specified with <input-directory>.

Argument: A valid path to a directory

Default: welldata/. If <input-directory> has been specified, the default is ./. See Section 6.1 for more information.

Example:

```
<input-directory-well-data>   wells/   </input-directory-well-data>
```

14.1.8 <output-directory>

Description: Relative or absolute path to the Cohiba output directories. The output directory has 8 subdirectories: surfaces/, logfiles/, spillpointdata/, wellpoints/, wellpaths/, clusters/, helppoints/ and wells/. All these directories are created if they do not exist prior to execution of Cohiba.

Argument: A valid path to a directory.

Default: output/.

Example: Relative path:

```
<output-directory>   my-output/   </output-directory>
```

Example: Absolute path:

```
<output-directory>
   /path/to/projects/my-cohiba-project/my-output/
</output-directory>
```

Example: Absolute path can be to any location:

```
<output-directory>   /path/to/my-output/   </output-directory>
```

14.1.9 <number-of-threads>

Description: Specifies the number of threads (parallel processes) that will be used when comput-

ing in parallel.[2] The possibilities are:

$$\begin{aligned} n > 0: &\quad \text{Number of threads} = \min(n, max) \\ n = 0: &\quad \text{Number of threads} = max \\ n < 0: &\quad \text{Number of threads} = \max\big(1, (max - |n|)\big), \end{aligned}$$

where *max* is the maximum number of threads available.

The usual maximum number of threads are 2 to 8 for laptops, 4 to 16 for desktops, and possibly a lot more for servers. We recommend to use the maximum number of threads on laptops and desktops. The actual number of threads used can be seen in the Cohiba log file as:

```
Threads in use                                  : 7 / 8
```

where, in this case, 7 threads out of a maximum of 8 threads have been used.

The kriging operations, estimation of residual uncertainty and the data loading is computed in parallel. The kriging computations usually take 90 – 95 % of the CPU time. Tests have shown that the efficiency of running the kriging operations in parallel depends on the problem. We have seen perfect scaling in some cases but not in all. CPUs made by Intel usually supports hyper-threading. Our experience is that the kriging calculations has no benefit from the additional hyper-threads.

Argument: Integer
Default: `0` (Use all available threads.)
Example: Use at most four threads (processors):

```
<number-of-threads>  4 </number-of-threads>
```

Example: Save one thread (processor) for other use:

```
<number-of-threads> -1 </number-of-threads>
```

14.1.10 `<prefix-for-log-files>`

Description: Specification of prefix for *all* log files.
Argument: String
Default: Empty string

14.1.11 `<messages>`

Description: Wrapper for elements specifying logging output levels to log file and screen. Available logging levels are:

0: No messages reported.
1: Errors reported.
2: Warnings reported.
3: Information messages reported. (Default)
4: Detailed information reported.
5: Very detailed information reported (mainly for debugging purposes).

The output information accumulate so that level 5 includes everything reported on level 4 an so on everything reported on level 4 and so on.

Argument: Elements specifying output to log file and screen.
Default: Void.

2. Cohiba uses the OpenMP API for parallelization.

14.1.11.1 `<logfile>`

Description: Wrapper for elements describing the output to the Cohiba log file. The log file is written to the `logfiles/` directory, under the output directory.
Argument: Elements specifying output to the Cohiba log file.
Default: Void.

14.1.11.1.1 `<name>`

Description: A string describing the name of the Cohiba log file.
Argument: String.
Default: `cohiba.log`

14.1.11.1.2 `<detail-level>`

Description: Wrapper for elements specifying the level of detail in the Cohiba log file. Each element can be set individually.
Argument: The elements corresponding to the different sections of the log file.
Default: Void.

14.1.11.1.2.1 `<overall>`

Description: Level of detail in output to log file. This level can be overruled within each output section mentioned below. See Section 7.2.1 for a brief explanation of each section.
Argument: 0 – 5
Default: 3

14.1.11.1.2.2 `<model-settings>`

Description: Level of detail in model settings output.
Section title: `Section 1: Model settings`
Argument: 0 – 5
Default: 3

14.1.11.1.2.3 `<data-loading>`

Description: Level of detail in reporting data loading.
Section title: `Section 2: Loading input data`
Argument: 0 – 5
Default: 3

14.1.11.1.2.4 `<pre-processing>`

Description: Level of detail in reporting pre-processing of input data.
Section title: `Section 3: Pre-processing input data`
Argument: 0 – 5
Default: 3

14.1.11.1.2.5 `<surface-models>`

Description: Level of detail in reporting of surface models and possible multiple models for surfaces. See Figure 11.2 for an example of the output. There is no output if this level is less than 3.

Section title: `Section 4: The alternative ways to build each surface`
Argument: 0 – 5
Default: 3

14.1.11.1.2.6 `<well-points>`

Description: Level of detail in reporting the processing of well points.
Section title: `Section 5: Processing well points`
Argument: 0 – 5
Default: 3

14.1.11.1.2.7 `<extra-points>`

Description: Level of detail in reporting the processing control points for eroded and on-lapping surfaces.
Section title: `Section 6: Processing control points for eroded and onlapped surfaces`
Argument: 0 – 5
Default: 3

14.1.11.1.2.8 `<well-paths>`

Description: Level of detail in reporting the processing of zone logs along well paths.
Section title: `Section 7: Sampling well trajectories and logs`
Argument: 0 – 5
Default: 3

14.1.11.1.2.9 `<trend-coefficients>`

Description: Level of detail in reporting trend coefficients.
Section title: `Section 8: Trend coefficients based on well points`
Section title: `Section 13.x: Trend coefficients based on well points and well paths`
Argument: 0 – 5
Default: 3

14.1.11.1.2.10 `<residual-uncertainties>`

Description: Level of detail in reporting match between specified and observed residual uncertainties.
Section title: `Section 9: Checking specified residual uncertainties`
Argument: 0 – 5
Default: 3

14.1.11.1.2.11 `<outliers>`

Description: Level of detail in reporting match between well points and trend models.
Section title: `Section 10: Identifying well point outliers and leverage points`
Argument: 0 – 5
Default: 3

14.1.11.1.2.12 `<well-point-conditioning>`

Description: Level of detail in reporting of errors in conditioning (kriging).

Section title: `Section 11.x: Conditioning on well points along well paths`
Argument: 0 – 5
Default: 3

14.1.11.1.2.13 `<help-points>`

Description: Level of detail in reporting of searching for help points sampled along the well paths.
Section title: `Section 12.x: Finding help points for well path conditioning`
Argument: 0 – 5
Default: 3

14.1.11.1.2.14 `<well-path-conditioning>`

Description: Level of detail in reporting of errors from well points sampled along well path.
Section title: `Section 14.x: Conditioning surfaces on all available points`
Argument: 0 – 5
Default: 3

14.1.11.1.2.15 `<post-processing>`

Description: Level of detail in report post processing. The post processing handles erosion, onlapping, pinch outs, and gridding errors.
Section title: `Section 15.x: Post process surfaces`
Argument: 0 – 5
Default: 3

14.1.11.1.2.16 `<zonation-checking>`

Description: Level of detail in report on checking zonation.
Section title: `Section 16.x: Checking zonation`
Argument: 0 – 5
Default: 3

14.1.11.1.2.17 `<spill-points>`

Description: Level of detail in report on spill point detection.
Section title: `Section 17.x: Spill points`
Argument: 0 – 5
Default: 3

14.1.11.1.2.18 `<volume-calculations>`

Description: Level of detail in report on volume calculations.
Section title: `Section 18.x: Volume calculations`
Argument: 0 – 5
Default: 3

14.1.11.1.2.19 `<timings>`

Description: Level of detail in report on CPU time usage.
Section title: `Section 19: Timings summary`
Argument: 0 – 5

Default: 3

14.1.11.1.2.20 `<tasks>`

Description: Level of detail in report on tasks.
Section title: `Section 20: Suggested tasks`
Argument: 0 – 5
Default: 3

14.1.11.2 `<screen>`

Description: Wrapper for elements describing the output to screen (monitor).
Argument: Elements specifying output to screen.
Default: Void.

14.1.11.2.1 `<detail-level>`

Description: Wrapper for elements specifying the level of detail in the output logging to screen. Each element can be set individually.
Argument: The elements corresponding to the different sections of logging.
Default: Void.

14.1.11.2.1.1 `<overall>`

Description: Level of detail in output to screen. This level can be overruled within each output section using the elements described for the logfile in Section 14.1.11.1.
Argument: 0 – 5
Default: 3

14.1.11.2.1.2 `<...>`

Description: Any of the elements `<model-settings>`, `<data-loading>`, `<pre-processing>`, `<surface-models>`, `<well-points>`, `<well-paths>`, `<trend-coefficients>`, `<residual-uncertainties>`, `<outliers>`, `<well-point-conditioning>`, `<help-points>`, `<well-path-conditioning>`, `<post-processing>`, `<zonation-checking>`, `<timings>`, or `<tasks>`.
Argument: 0 – 5
Default: 3

14.1.12 `<measurement-units>`

Description: Wrapper for specifying measurement units. See Table 14.1 for available units.
Argument: Elements for each unit type.
Default: Void.

14.1.12.1 `<z-unit>`

Description: Unit of depth. Meters or feet. Seismic velocity will be measured in feet per second if feet is chosen.
Argument: `m` / `ft`
Default: `m`

14.1.12.2 `<time-unit>`

Description: Unit of time. Seconds or milliseconds.

Table 14.1. Measurement units.

Property	Unit		Element
Lateral distance:	m	meter	
Vertical distance:	m ft	meter feet	`<z-unit>`

Travel time:
 	
(one-way or two-way)
	s
	ms
		second
		millisecond
			`<time-unit>`
			
			`<two-way-time>`

Seismic velocity:	m/s ft/s	meters per second feet per second[a]	`<z-unit>`

a. If vertical distance is measured in feet.

Argument: `s` / `ms`
Default: s

14.1.12.3 `<two-way-time>`

Description: A flag controlling whether the input time grids are given in two-way times (TWT) or not.
Argument: `yes` / `no`
Default: `no`

14.1.13 `<output-grid>` (required)

Description: Container for elements specifying grid dimensions and grid resolution for the output grids.[3] The dimensions can be read from a grid file using `<read-from-file>` or be specified using the elements `<xinc>`, `<xlength>`, `<yinc>`, and `<ylength>`. The number of grid nodes are calculated using

$$n_x = x_{\text{length}}/x_{\text{inc}} + 1 \qquad \text{and} \qquad n_y = y_{\text{length}}/y_{\text{inc}} + 1. \tag{14.1}$$

The rotation of the grids is specified using `<grid-azimuth>`. See Figure 14.1 for an overview.
Argument: Elements specifying the grid dimensions.
Default: No default.

14.1.13.1 `<format>`

Description: Output format. See Section 6.2 for possible file formats.
Argument: `roxar binary` / `roxar text` / `storm`
Default: `roxar binary`

14.1.13.2 `<read-from-file>`

Description: Use the specified grid file to define the dimension and resolution of the output grids. Valid arguments are any surface file in the input directory or a surface file with full path. The file format is either ROXAR BINARY, ROXAR TEXT or STORM BINARY. The file format is automatically detected.
Argument: Surface file name.
Default: No default.
Example: Reads grid definition from file `dS_IsochoreA.storm` in the default input directory.

3. Input grids can have different formats and dimensions.

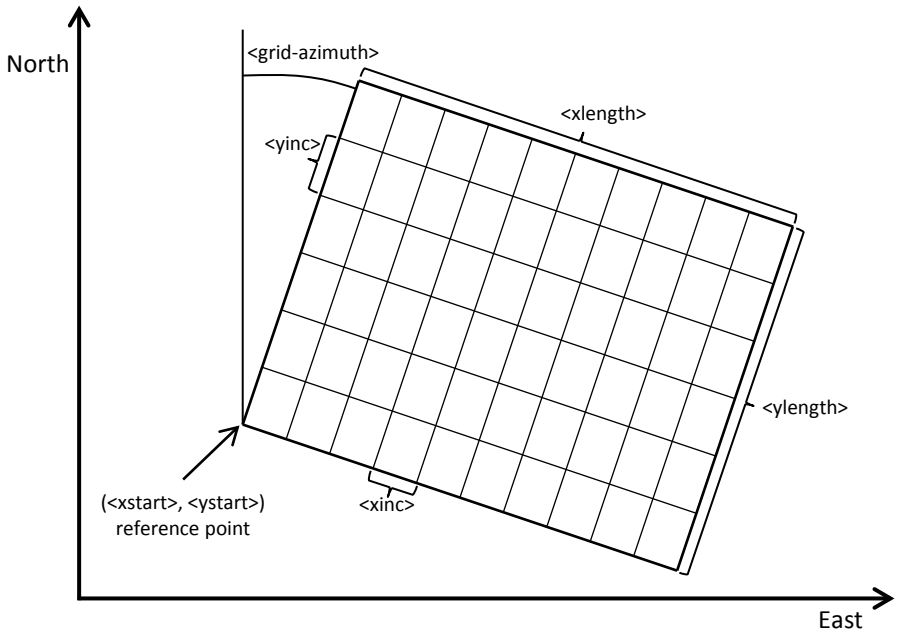


Figure 14.1. Overview of elements used to specify the output grid definition. Note that the surfaces are defined at the grid nodes (where the lines cross). Cohiba uses bilinear interpolation to approximate the surfaces inside the rectangles.

```
<output-grid>
  <format>           roxar text           </format>
  <read-from-file>   dS_IsochoreA.storm   </read-from-file>
</output-grid>
```

Note that file format of `dS_IsochoreA.storm` may differ from the specified output format. If the `<format>` element is omitted, the output format is set equal to that of `dS_IsochoreA.storm`.

14.1.13.3 `<xstart>`

Description: X-coordinate at reference point. (Typically the lower left corner of the grid.) See Figure 14.1.
Argument: Real.
Default: No default.

14.1.13.4 `<ystart>`

Description: Y-coordinate at reference point. (Typically the lower left corner of the grid.) See Figure 14.1.
Argument: Real.
Default: No default.

14.1.13.5 `<xinc>`

Description: X-increment. Size of grid cell in x-direction. See Figure 14.1.
Argument: Positive real.
Default: No default.

14.1.13.6 <yinc>

Description: Y-increment. Size of grid cell in y-direction. See Figure 14.1.
Argument: Positive real.
Default: No default.

14.1.13.7 <xlength>

Description: Length of grid in the x-direction. See Figure 14.1.
Argument: Positive real.
Default: No default.

14.1.13.8 <ylength>

Description: Length of grid in the y-direction. See Figure 14.1.
Argument: Positive real.
Default: No default.

14.1.13.9 <grid-azimuth>

Description: Azimuth angle for rotated grids. Angle is measured clockwise from north in degrees (360°). The center of the rotation is the reference point set by <xstart> and <ystart>. See Figure 14.1.

Note that this option only works for files using the ROXAR BINARY and ROXAR TEXT grid formats (see Section 6.2).

Argument: Float
Default: 0.0
Example: Grids rotated 15° clockwise from north:

```
<output-grid>
  <format>   roxar text </format>
  <xstart>          0.0 </xstart>
  <xlength>      5000.0 </xlength>
  <ystart>          0.0 </ystart>
  <ylength>     10000.0 </ylength>
  <xinc>          100.0 </xinc>
  <yinc>          100.0 </yinc>
  <grid-azimuth>   15.0 </grid-azimuth>
</output-grid>
```

14.2 <modelling-settings>

Description: Wrapper for elements determining the methods and algorithms used.
Argument: Elements specifying overall modeling settings.
Default: No default.

14.2.1 <mode>

Description: The default mode is `prediction`, that is, to generate a deterministic set of most likely surfaces using *kriging*.

If `simulation` or `fast-simulation` is chosen then <number-of-realizations> stochastic realizations are made using stochastic simulation. The `fast-simulation` mode is an approximation intended for efficient gross rock volume calculations. See Section 18.1 for technical details. Section 10.2.1 compares volume distributions obtained using `simulation` and `fast-simulation`. The CPU time for the initialization of the `fast-simulation` algorithm is long so this option should only be used for generating a set of realizations. We recommend to combine `fast-simulation` with reusing the model weights (see <model-weight-resolution>). The fast simulation is on the order of 3–5 times faster than the ordinary simulation.

`estimation` mode gives the possibility to run through the initial estimation of the trend coefficients without entering the more time consuming kriging steps in the prediction or stochastic simulation steps.

Argument: `prediction` / `simulation` / `fast-simulation` / `estimation`
Default: `prediction`

14.2.2 <kriging-method>

Description: The three available kriging methods to be used. *Simple kriging* assumes no uncertainty on the trend coefficients. *Universal Kriging* assumes the trend coefficients are unknown and fits them to well data. This method fails if there are too few well data. *Bayesian Kriging* assumes the trend coefficients are partly known (expectation and standard deviation specified) and adapts the trend coefficients to well data. This method is robust and works for any number of well data. If there is a lot of well data, Bayesian kriging will be very similar to universal kriging. Note that this will also affect stochastic simulation.
See Part V for more details.

Argument: `simple` / `bayesian` / `universal`
Default: `bayesian`

14.2.3 <number-of-realizations>

Description: Number of realizations for <mode> `simulation` or `fast-simulation`.
Argument: Positive integer
Default: 1

14.2.4 <write-realization-maps>

Description: Turns on or off the writing of maps to file for individual simulated realizations. See Table 7.1 for a list of possible maps. Average and standard deviation maps are not affected. Choosing `no` may save a lot of disc space.

The realization numbers are added to the standard file names:

```
d_TopA_0001.roxbin, d_TopA_0002.roxbin,...
```

```
trap_TopA_0001.roxbin, trap_TopA_0002.roxbin,...
v_MSL-TopA_0001.roxbin, v_MSL-TopA_0002.roxbin,...
```

Additional digits will be added for realizations beyond realization number 9 999.

This option has no consequence for `prediction` <mode>.

Argument: `yes` / `no`
Default: `yes`

14.2.5 <write-all-logfiles>

Description: This option makes it possible to suppress writing of log-files for well points, average statistics, trend estimation and help points. It is primarily intended to avoid writing a lot of files when generating multiple realizations when using simulation and fast simulation <mode>.

Argument: `yes` / `no`
Default: `yes`

14.2.6 <condition-to-well-paths>

Description: Starts an algorithm that attempts to move surfaces so that they are in correspondence with the zone logs. The algorithm will sample the zone log and generate a lot of additional well points used in deterministic surfaces or stochastic simulation of surfaces. If speed is critical set the value to `no`.

Argument: `yes` / `no`
Default: `yes`

14.2.7 <simulate-trend-uncertainty>

Description: This flag has only effect in stochastic simulation mode and if simple kriging has been specified. If `yes` is specified, the trend coefficients will be drawn from the prior specification. This option can be used to specify exactly the standard deviation on the trend coefficients used during simulation.

Argument: `yes` / `no`
Default: `no`

14.2.8 <check-specified-residual-uncertainties>

Description: Turns on or off the estimation of residual uncertainty. This can be a time consuming calculation and is not necessary when the specified residual uncertainties are considered correct. This calculation is done in parallel if Cohiba uses more than one thread. See <number-of-threads> for details.

Argument: `yes` / `no`
Default: `yes`

14.2.9 <minimize-broken-zonation>

Description: Cohiba selects and use a set of sample points along the well trajectories to constrain the surfaces. See Section 20 for details. In certain cases, the selected sample points are insufficient to ensure that all sample points along the well paths are consistent with the surfaces. In particular, some of the selected sample points may cause some non-selected sample points to become inconsistent. These are called *broken sample points*. The number of broken sample points are reported in Section 15 in the Cohiba log file. Choosing `Yes` tells Cohiba to add the broken sample points to the selected sample points and repeat the process of conditioning surfaces to the well data. Note that each iteration will

increase the execution time significantly. The maximum number of iterations is set by <maximum-iterations-to-avoid-broken-zonation>.

Argument: yes / no
Default: no

14.2.10 <pre-process-surfaces>

Description: Wrapper for elements controlling pre-processing of surfaces.
Argument: Elements controlling pre-processing.
Default: Void.

14.2.10.1 <make-time-surfaces-consistent>

Description: When turned on (yes), Cohiba makes seismic reflectors consistent by letting the upper travel times erode the deeper travel times.

Warning: Note that this *must not* be used if air interpretations are present.

Argument: yes / no
Default: no

14.2.10.2 <smoothing-factor-velocity-trends>

Description: Sometimes the input velocity trend maps contains large fluctuations or irregularities. Smoothing the maps on input will in such situations give more realistic velocity trends by filtering out high frequencies. This factor decides how much smoothing is performed. 0 means no smoothing, leaving the input map unchanged. 1 means full smoothing giving a constant (the mean). If input maps show a low-frequent behaviour, even quite high values of the smoothing factor will keep the maps unchanged. After the smoothing, a check is performed to decide if smoothing makes a significant impact.[4] If the impact is small the smoothing is dropped.

Argument: Real between 0 and 1.
Default: 0.5

14.2.11 <post-process-surfaces>

Description: Wrapper for elements controlling post-processing of surfaces. This includes truncating surfaces due to erosion and on-lapping, pinch outs and removal of gridding errors.
Argument: Elements controlling pre-processing.
Default: Void.

14.2.11.1 <erode-and-onlap>

Description: Choosing no overrides all input flags related to <erosive> and <onlapped> surfaces. Default is to truncate all surfaces by the erosive and on-lapped surfaces.

This has no effect on free surfaces since they can not erode or be on-lapped.

Argument: yes / no

---

4. This is done as follows:
a) Make the smoothed trend: $\bar{v}(x, y)$.
b) Find the residual: $r(x, y) = v(x, y) - \bar{v}(x, y)$.
c) Find minimum and maximum residual: $r_{\text{min}} = \min r(x, y)$ and $r_{\text{max}} = r(x, y)$.
d) Find the smoothed velocities at these two locations: $\bar{v}_{\text{min}}$ and and $\bar{v}_{\text{max}}$.
e) Find the span of values: $\bar{v}_{\text{span}} = \max \bar{v}(x, y) - \bar{v}(x, y)$.
f) Calculate $t_{\text{min}} = |r_{\text{min}}/\bar{v}_{\text{min}}|$ and $t_{\text{max}} = |r_{\text{max}}/\bar{v}_{\text{max}}|$.
g) Calculate $u_{\text{min}} = |r_{\text{min}}/\bar{v}_{\text{span}}|$ and $u_{\text{max}} = |r_{\text{max}}/\bar{v}_{\text{span}}|$.
The smoothed trend is used if $t > 0.01$ and $u > 0.1$. The t's and the u's measure if the smoothing makes a noticeable change relative to the value of trend and relative to the range of values in the trend respectively.

Default: `yes`

14.2.11.2 <treat-reflectors-as-eroding-and-onlapped>

Description: Will ensure that seismic reflectors truncate other surfaces. See Figure 12.1 for an example. This will only affect the post processing and not the extraction of well points from zone logs. If <erode-and-onlap> is set to `no`, this has no effect. The individual elements <erosive> and <onlapped> for each seismic reflector will be overruled by this setting.

This has no effect on free surfaces since they can not erode or be on-lapped.

Argument: `yes` / `no`
Default: `yes`

14.2.11.3 <make-average-of-crossing-surfaces>

Description: Post-process surfaces to produce a sequence of stratigraphically correct surfaces. Negative thickness will be removed and replaced by a zero thickness interval — a pinch out. This algorithm does not take into account well observations. The default is to remove all negative thicknesses.

Argument: `yes` / `no`
Default: `yes`

14.2.11.4 <make-surfaces-interpolate-well-points>

Description: Kriging is a perfect interpolator but the gridding of the surfaces introduce a smoothing of the bulls eye at the well point. By choosing `yes` this gridding error at the well points is removed. (See Section 17.6.)
This is done by adjusting the four grid values closest to a well point to ensure perfect bilinear interpolation. Since different well points may share common grid values all modifications are treated simultaneously. The algorithm minimizes the sum of all adjustments.

The removal of the gridding errors for well points are treated simultaneously with the removal of gridding errors along well paths.
See <allow-small-surface-adjustment-at-sample-points>.

The gridding error at a well point is only removed if a few conditions are met:

- The well point is not an outlier.
- The well point uncertainty is less than 1 meter (default). The default value can be modified using <maximum-stddev-for-well-points-interpolation>.
- The residual, observation minus trend, is less than the value specified by <maximum-residual-for-well-points-interpolation>. (Default is 999 meters.) This gives a possibility to avoid some rare occasions that gives large spikes in the surfaces.
- If two well points are close, the surface can get spikes caused by a steep gradient between the well points. The maximum allowed gradient can be set using <maximum-gradient-for-surface-adjustment>. (Default is 100.)

Argument: `yes` / `no`
Default: `yes`

14.2.11.5 <allow-small-surface-adjustment-at-sample-points>

Description: Removes gridding errors along well paths. The gridding errors has the same cause and is removed in the same way as gridding errors for well points. See <make-surfaces-interpolate-well-points> for details. The adjustment of surfaces to re-

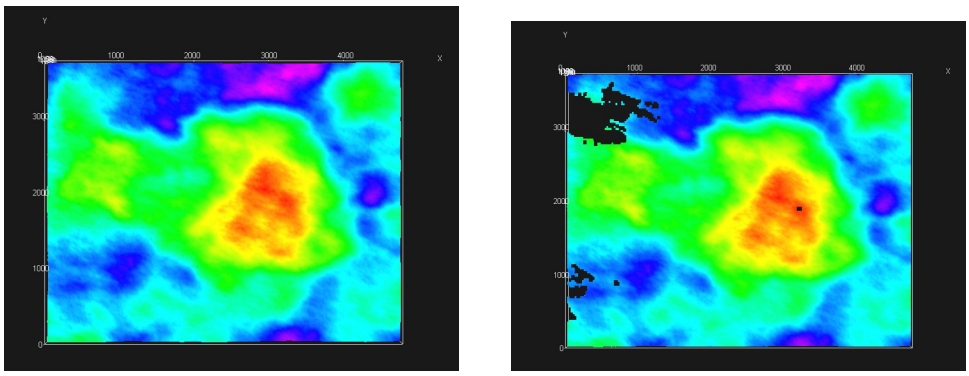


Figure 14.2. Original surface to the left (default). To the right is <set-eroded-nodes-to-undefined> set to yes.

move the gridding errors for well paths are consistent with the removal of gridding errors for well points. The value set by <maximum-gradient-for-surface-adjustment> affects the removal of gridding errors at sample points and well points.

The gridding error at a sample point is only removed if one of these conditions are met:

1. If a sample point is less than 1 meter (default) on the *wrong* side of a surface. The default value can be modified using <maximum-residual-for-adjustment-at-sample-points>.

2. If a sample point is *closer* than 0.5 meter (default) to the surface. The default value can be modified using <minimum-distance-from-surface-to-sample-points>.

The surface grid nodes are modified such that the surface becomes exactly 0.5 meter (default) away from the well path at the sample points. This distance is modified by <minimum-distance-from-surface-to-sample-points>.

Argument: yes / no
Default: yes

14.2.11.6 <set-eroded-nodes-to-undefined>

Description: Eroded areas is set to undefined if value is yes. If <erode-and-onlap> is set to no, this has no effect. See Figure 14.2.
Argument: yes / no
Default: no

14.2.11.7 <smoothing-factor-calculated-velocities>

Description: Interval velocities are calculated as $v = \Delta z/\Delta t$. This might give unrealistic results for very short travel times, Δt. Unrealistic velocities are replaced by a smoothing process if <smoothing-factor-calculated-velocities> is set to a positive value. This means that the high frequencies in the calculated velocity maps are filtered out. Low value gives little smoothing with 0.0 leaving the velocities unchanged, while higher values gives much smoothing, with 1.0 leaving a constant velocity (the mean). A suggested value if smoothing is desired is 0.5.
Argument: Real between 0 and 1
Default: 0.0

14.2.12 <advanced-settings>

Description: Wrapper for elements controlling algorithms. Don't touch it if you don't mean it.
Argument: Elements controlling algorithms.
Default: Void.

14.2.12.1 <maximum-rejection-rate>

Description: This is the maximum rejection rate for rejection sampling during stochastic simulation. The default, 0.9, gives at worst a 90 % rejection rate. The simulation is aborted if Cohiba estimates that the rejection rate is larger than the maximum rejection rate. To get the specified <number-of-realizations>, the <acceptance-criteria> must be relaxed or the maximum rejection rate must be increased. See Section 18.2 for more details.
Argument: Float in [0,1].
Default: 0.9

14.2.12.2 <model-weight-resolution>

Description: This option makes it possible to calculate model weights (Section 11) once and to save them for later use when running multiple realizations. This may reduce CPU times. It is also possible to calculate the model weights on a coarser grid in order to save memory.

Choosing 0 (default) means that model weights are calculated at full resolution and must be recalculated for every realization.
Choosing 1 means that model weights are calculated at full resolution and that they will be saved and reused if multiple realizations are generated.
Choosing any $n > 1$ means that the weights are calculated at every n^{th} grid node in each direction. Model weights in between the calculated weights are obtained by bilinear interpolation. Model weights will be saved and reused if multiple realizations are generated.

If $n > 0$ and the <number-of-realizations> is more than 1 in any simulation <mode>, then model weights will be saved for later use. The memory usage is proportional to $1/n^2$. We recommend to use $n > 1$ when there is many alternative models. Choosing a large n will reduce the spatial accuracy of the model weights.

We recommend to use 5 for fast simulation. We recommend to use the default for prediction and ordinary simulation since the gain in speed normally is small.
Argument: Non-negative integer.
Default: 0

14.2.12.3 <maximum-stddev-for-well-points-interpolation>

Description: Gridding errors at a well point is removed if the uncertainty (standard deviation) is less than this value. Has only effect if <make-surfaces-interpolate-well-points> is yes.
Argument: Positive real (meters)
Default: 1.0

14.2.12.4 <maximum-residual-for-well-points-interpolation>

Description: Gridding errors at a well point is removed if the residual is less than this value. The value can be set to a smaller value (say 10) to avoid spikes in the surfaces. Has only effect if <make-surfaces-interpolate-well-points> is yes.
Argument: Positive real (meters)
Default: 999.0

14.2.12.5 <maximum-gradient-for-surface-adjustment>

Description: Gridding errors at a well point or sample point is removed if the gradient between the point and another point is less than this value. The value can be set to a smaller value (say 10) to avoid spikes in the surfaces. Has only effect if <make-surfaces-interpolate-well-points> or <allow-small-surface-adjustment-at-sample-points> are yes.

Argument: Positive real

Default: 100.0

14.2.12.6 <maximum-residual-for-adjustment-at-sample-points>

Description: Gridding errors at a sample point is removed if the sample point is less than 1 meter (default) on the *wrong* side of a surface. Increasing this value will increase the number of grid nodes that are modified. It has only effect if <allow-small-surface-adjustment-at-sample-points> is yes.

Argument: Positive real (meter)

Default: 1.0

14.2.12.7 <minimum-distance-from-surface-to-sample-points>

Description: The distance between a well path and a surface will never be smaller than this value. Also gridding errors at a sample point is removed if the sample point is closer to a surface than 0.5 meters (default). Increasing this value will increase the number of grid nodes that are modified. It has only effect if <allow-small-surface-adjustment-at-sample-points> is yes.

Argument: Positive real (meter)

Default: 0.5

14.2.12.8 <allow-sample-points-near-faults>

Description: Allow sample points also where the fault indicator log indicates a fault.

Argument: yes / no

Default: no

14.2.12.9 <solver-for-weights>

Description: Specifies the method used for solving the linear equation system that gives the model weights. The conjugate gradient method is significantly faster than the Cholesky decomposition if there are many model weights. The two methods can give slightly different results since the linear equation system can be (very) rank deficient.

Argument: conjugate-gradient / cholesky

Default: conjugate-gradient

14.2.12.10 <maximum-iterations-to-avoid-broken-zonation>

Description: This option has only an effect if <minimize-broken-zonation> is set to yes. Choosing an integer $N > 1$ allows Cohiba to repeat the kriging N times. At each new iteration broken sample points from the previous iteration is added to the selected sample points. Note that each iteration will increase the execution time significantly. Setting <minimize-broken-zonation> to no is equivalent to selecting 1.

Argument: Positive integer

Default: 3

14.2.12.11 <correlate-close-reflectors>

Description: Cohiba assumes that all residuals are uncorrelated. This assumption fails for seismic reflectors that are near or coinciding. Then the uncertainty in the two time residuals are highly correlated. Turning this flag on makes Cohiba automatically modify the correlation between travel time residuals. See an example in Figure 12.1.

The correlations are increased towards 1 when seismic reflectors are closer than $\sigma_{t_1} + \sigma_{t_2}$, that is, the sum of the standard deviations of the two travel time residuals. The correlation is set to $\rho = \max\big(0, [1 - \frac{|\Delta t|}{\sigma_{t_1}+\sigma_{t_2}}]\big)$. So correlations becomes 1 if $\Delta t = 0$.

This option does not affect reflectors that are free surfaces (see <free-surface>).

Argument: yes / no
Default: yes

14.2.12.12 <max-obs-direct-estim-trend-coef>

Description: When the number of well points is smaller than this threshold, the posterior trend coefficients and covariance matrix are calculated using Eq. 17.21a and Eq. 17.21b. If the number of well points is larger than this, expressions Eq. 17.22a and Eq. 17.22b are used. This only applies when <kriging-method> is bayesian. See Section 17.3.2 for details.

Argument: Positive integer.
Default: 200

14.2.12.13 <max-obs-GLS-approx-trend-coef>

Description: When the number of well points is more than this threshold the non-zero covariances are ignored when estimating trend coefficients. This amounts to replacing the GLS estimates (Eq. 17.18a and Eq. 17.18b) by the WLS estimates (Eq. 17.19a and Eq. 17.19b). The WLS approximation can handle a lot of well points. This applies when <kriging-method> is universal or bayesian. See Section 17.3.1 for details.

Argument: Positive integer.
Default: 2000

14.2.12.14 <max-obs-GLS-approx-extreme-outliers>

Description: When trend coefficients are calculated, extremely erroneous well points (see <t-value-extreme-error>) are removed one at a time, and after each removal updated trend coefficients are calculated. To save time, we estimate the trend coefficients using the WLS approximation when there are more than 1000 well points available and remove as many extreme outliers as possible. When no more outliers are found, we recalculate trend coefficients using the GLS approximation (if there are less than 2000 well points available) and continue removing extreme outliers, and severe outliers as usual. The element <max-obs-GLS-approx-extreme-outliers> gives maximum number of well points that can be available in a calculation before the WLS approximation is used to remove extreme outliers.

Argument: Positive integer
Default: 1000

14.2.12.15 <max-obs-update-trend-coef-using-well-paths>

Description: The trend coefficients are not adjusted to fit horizontal well paths *if* the number of well points are more than this value. This saves a lot of CPU time. The idea is that the trend coefficients are estimated with sufficient accuracy when the number of well points exceed this limit.

Argument: Positive integer
Default: `200`

14.2.12.16 `<threshold-for-trace-clustering>`

Description: The constraints from each well path are grouped in correlated clusters. This element specifies the threshold for the correlations. Specifying a low correlation means that all constraints are probably grouped into one cluster. Specifying a high value means that constraints must be strongly correlated to be grouped. Ideally all constraints should be handled simultaneously, but small clusters are important to obtain fast performance.
Argument: Real between 0 and 1.
Default: `0.3`

14.2.12.17 `<threshold-for-cluster-merging>`

Description: The correlated clusters are merged if any pair of constraints have a correlation larger than this threshold. A small value will cause all clusters to be merged. A large value will avoid any merging of clusters. Some merging is needed if well paths are near.
Argument: Real between 0 and 1.
Default: `0.5`

14.2.12.18 `<threshold-for-removing-undefined-well-sections>`

Description: Maximum length of zone log section with undefined values (missing code). Cohiba will extract a well point in the middle of the undefined section and add a measurement error that is 1/4 the vertical length of the undefined section. Cohiba will ignore the zone transition if the undefined section is longer than this threshold. Short undefined sections is produced by some databases.
Argument: Positive real. Length unit in meters.
Default: `1.0`

14.2.12.19 `<threshold-for-help-point-deactivation>`

Description: Cohiba keeps those *selected sample points* (see page 177) that impose the strongest restrictions on the surfaces and deactivate those that are highly correlated to the strongest restrictions. Choosing 1 means that no target points will be deactivated while choosing a low value (< 0.5) means that many selected sample points will be deactivated. Note however that deactivated sample points might be used in later iterations if `<minimize-broken-zonation>` is set to `yes` (Default). Choosing a small value will reduce the number of selected sample points and thereby reduce the CPU time.
Argument: Real in [0, 1].
Default: `0.95`

14.2.12.20 `<minimum-isochore-thickness>`

Description: Cohiba will not use help points along well paths for zones thinner than this threshold.
Argument: Positive real. Length unit in meters.
Default: `0.1`

14.2.12.21 `<threshold-for-mild-error>`

Description: Cohiba will classify a mismatch between a well path and a surface according to this threshold. Only affects reporting.
Argument: Positive real. Length unit in meters.
Default: `1.0`

14.2.12.22 `<t-value-outlier>`

Description: Threshold for flagging well point as outlier. 5 % of the well points will be classified as outliers if they follow a Gaussian distribution.
Argument: Positive real.
Default: `1.95996` (see e.g. Wikipedia).

14.2.12.23 `<t-value-severe-outlier>`

Description: Threshold for flagging well point as uncertain. A measurement error will be added. 1 % of the well points will be classified as uncertain if they follow a Gaussian distribution.
Argument: Positive real.
Default: `2.57583` (see e.g. Wikipedia).

14.2.12.24 `<t-value-error>`

Description: Threshold for flagging well point and well path constraint as erroneous. Well point or well path constraint will be removed. 0.2 % of the observations will be classified as erroneous if they follow a Gaussian distribution.
Argument: Positive real.
Default: `3.09023` (see e.g. Wikipedia).

14.2.12.25 `<t-value-extreme-error>`

Description: Threshold for flagging well point and well path constraint as extremely erroneous. Only the most extreme well point will be removed and the trends re-fitted. The procedure will be iterated until all extreme errors have been removed. 0.01 % of the observations will be classified as extremely erroneous if they follow a Gaussian distribution.
Argument: Positive real.
Default: `3.8906` (see e.g. Wikipedia).

14.2.12.26 `<t-value-prediction-first-point>`

Description: A sample point is close to a surface if it is closer than `<t-value-prediction-first-point>` times the prediction error. A close sample point gives a constraint (inequality point) used when conditioning to zone logs. See Step 3 on page 177 for more details.
Argument: Positive real.
Default: `0.8`

14.2.12.27 `<t-value-prediction-second-point>`

Description: A close sample point and its associated inequality point might cause the neighboring surface to violate the sample point. Therefore, inequality points usually come in pairs. See Step 3 on page 177 for more details. If the sample point is closer to the second surface than `<t-value-prediction-second-point>` times the prediction error this inequality is also used.
Argument: Positive real.
Default: `2.5`

14.2.12.28 `<t-value-simulation-first-point>`

Description: The same as `<t-value-prediction-first-point>` but used in stochastic simulation mode. A higher default value is chosen since there is a higher risk of ending up on the wrong side when simulating.
Argument: Positive real.
Default: `2.0`

14.2.12.29 <t-value-simulation-second-point>

Description: The same as <t-value-prediction-second-point> but used in stochastic simulation mode.

Argument: Positive real.

Default: 2.5

14.2.12.30 <maximum-generalized-eigenvalue-for-inequality-points>

Description: When calculating the help points, the inverse of the matrix $(C^{i|e} - \Sigma^i)$ goes into the formulas. This matrix is not always positive definite so a method to modify the sample covariance matrix is needed. This can be done by truncating some eigenvalues. The specified number gives this truncation limit such that of the eigenvalues are above this limit.

Argument: Real value close to, but less than 1.0

Default: 0.9

14.2.12.31 <maximum-dxy-for-identical-well-points>

Description: If two well points on the same surface are close enough, they will be treated as equal. This keyword is used to change the largest lateral distance two well points can have before they are treated as different well points.

Argument: Positive real (distance in meter).

Default: 5.0

14.2.12.32 <maximum-dz-for-identical-well-points>

Description: If two well points on the same surface are close enough, they will be treated as equal. This keyword is used to change the largest vertical distance two well points can have before they are treated as different well points.

Argument: Positive real (distance in meter).

Default: 0.5

14.2.12.33 <maximum-slope-before-possible-conflict>

Description: Two close well points that belong to the same surface but different wells cannot be merged. Instead uncertainty is added. If the slope between the well points (calculated as dxy/dz) are too large, the points are flagged as possibly in conflict. This keyword can be used to alter the sensitivity.

Argument: Positive real

Default: 0.1

14.2.12.34 <minimum-stddev-close-well-points>

Description: If there are two well points belonging to the same surface within a grid-cell distance they are required to have a minimum uncertainty. This keyword can be used to change this minimum uncertainty.

Argument: Positive real (standard deviations in meters)

Default: 0.01

14.2.12.35 <threshold-for-conditioning-in-neighbourhood>

Description: Controls the use of neighborhoods in the kriging algorithm. If the number of well points is larger than this number, kriging is performed in overlapping rectangular subsets. This algorithm runs fast and gives a good approximation. If there appears rectangular patches in the output grids, consider increasing this number.

Argument: Positive integer.

Default: `100`

14.2.12.36 `<preprocess-range-factor-for-neighbourhood>`

Description: Determines data neighborhood size as the fraction of the range in the pre-processing step. The well points in the neighborhood is used to find the prediction and prediction error at the sample points along the well paths. See the second step in Section 20.1 for some explanation.

Argument: Positive real.

Default: `1.5`

14.2.12.37 `<minimum-range-factor-for-neighbourhood>`

Description: Minimum data neighborhood size as the fraction of the range.

Argument: Positive real.

Default: `1.0`

14.2.12.38 `<maximum-range-factor-for-neighbourhood>`

Description: Maximum data neighborhood size as the fraction of the range.

Argument: Positive real.

Default: `2.0`

14.2.12.39 `<target-number-of-data-in-neighbourhood>`

Description: If the number of well points within the rectangle determined by `<minimum-range-factor-for-neighbourhood>` is less than this number, the rectangular neighborhood will be expanded until this number is obtained. However, the rectangle will never exceed the size given by `<maximum-range-factor-for-neighbourhood>`. Note that the default value, `0`, means that the rectangular neighborhood always remains at the size determined by `<minimum-range-factor-for-neighbourhood>`.

Argument: Non-negative integer.

Default: `0`

14.2.12.40 `<minimum-generalized-eigenvalue>`

Description: This is a threshold that determines how many linear combinations of well points that are used when estimating the residual uncertainties. A large value (close to 1) will reject most linear combinations unless they perfectly match the corresponding interval thickness. A small value (close to 0) will include almost all linear combinations and the estimates will approach the overall estimate that blends all intervals.

Argument: Real in [0,1].

Default: `0.5`

14.2.12.41 `<volume-calculation-method>`

Description: Calculating volumes require that the surface is defined between grid nodes. Two interpolation techniques are supplied. We recommend the default because the `bilinear` option has not been rigorously tested. See Section 9.1 for details.

Argument: `nearest-neighbor` / `bilinear`

Default: `nearest-neighbor`

14.3 <well-data>

Description: Wrapper for <well-log>, <well-points>, <values-outside-grid> and <well-points-to-ignore> elements.

Argument: Any number of <well-log>, <well-points>, and <well-points-to-ignore> elements

Default: No default.

Example: See Section 14.3.5 for a complete example.

14.3.1 <well-log>

Description: A wrapper for elements describing zone logs and fault indicator logs.

Argument: Elements specifying the zone log or fault indicator log along well paths.

Default: No default.

14.3.1.1 <zone-log-specification>

Description: The zone log specification is a set of integers (non-negative in consecutive order) and associated zone names separated by commas. See Section 8.1 for more details. This specification is necessary when reading LAS 2.0 files. It is not needed for RMS WELL files since they include the zone log specification in the header. For LAS 2.0 files the zone name can include any ASCII character (including space) except for commas. The zone name can not include spaces if used with RMS WELL files. Note that files with a different zone name specification will be discarded.

Argument: A comma separated list.

Default: Empty string.

Example: Reading two LAS 2.0 files and one RMS WELL file:

```
<well-log>
    <zone-log-specification>
         1, ABOVE, 2, DRAUPNE, 3, 6BC, 4, 6AC, 5, 6AM, 6, 5CC, 7, 5CM, 8, 5BC
    </zone-log-specification>
    <zone-log-name> GM2005a                </zone-log-name>
    <files>         w1.las, w2.las, w3.rms  </files>
</well-log>
```

14.3.1.2 <zone-log-specification-file>

Description: See <zone-log-specification> for details. This element has the same purpose as <zone-log-specification> but the zone log specification is read from an ASCII file rather than from the Cohiba model file. In the ASCII file there is one line entry for each zone, and this entry consists of a comma separated zone number and zone name.

Argument: A string.

Default: Empty string.

Example: Reading two LAS 2.0 files and one RMS WELL file:

```
<well-log>
    <zone-log-specification-file>
           zone-log-specification.txt
    </zone-log-specification-file>
    <zone-log-name> GM2005a                </zone-log-name>
    <files>         w1.las, w2.las, w3.rms  </files>
</well-log>
```

The specification file which is placed in the same directory as the well data may look like:

```
0, Nordaland Gr
1, Hordaland Gr
2, Zone TOP CHALK
```

14.3.1.3 <zone-log-name>

Description: Zone log identifier. A file may contain several zone logs and this element is used to select the correct one. Currently, only one zone log can be specified.

Argument: A string.

Default: Empty string.

Example: `<zone-log-name> GM2005a </zone-log-name>`

Example: `<zone-log-name> ZonesSnorre </zone-log-name>`

14.3.1.4 <fault-log-name>

Description: Specifies the name of the fault indicator log. A 1 in the fault indicator log means that it is near a fault and a 0 means that it is far away from a fault.

Argument: A string.

Default: Empty string.

Example: `<fault-log-name> FaultIndicator </fault-log-name>`

14.3.1.5 <z-stddev-log-name>

Description: Specifies the name of the log describing the *vertical* positioning error of the well path. The uncertainty is the standard deviation. The units are determined by <z-unit>. If the uncertainty log in a well is missing the uncertainty is assumed to be zero. The positioning error is by default correlated. The default correlation can be modified using <variogram-distance> and <variogram>.

Argument: A string.

Default: Empty string.

Example: `<z-stddev-log-name> VerticalUncertainty </z-stddev-log-name>`

14.3.1.6 <files>

Description: The well path files to be imported. This element may be repeated in order to import different files in different locations (directories). Multiple files are separated by a comma. The file formats are detected automatically. See Section 8 for available file formats.

The well names must be unique. Two files with identical well names will cause an error.

Argument: Any valid path relative to <input-directory>. Wild cards (*) are supported.

Default: Empty string.

Example: One file:

```
<files> wells/31-2_K-11H.w </files>
```

Example: Three files:

```
<files> wells/W1.rms, wells/W2.rms, wells/W3.las </files>
```

Example: All files in directory:

```
<files> wells/* </files>
```

14.3.1.7 <tops-as-mean-values>

Description: Cohiba supports two methods for extracting the well points from the zone log:

1. The mean value of the position of the two points in the zone transition. This is the default and is selected with argument yes. A measurement error (standard deviation) equal to $|z1 - z2|/4$ is added to the well point. The typical logging distance is one foot which is

approximately 30 cm. The standard deviation will then be approximately 7.5 cm.

2. The last (along the well path) point in the zone transition. This is selected with argument `no`.

The method chosen affects *all* files imported in `<files>`.

Argument: `yes` / `no`
Default: `yes`

14.3.1.8 `<first-log-entry-as-top>`

Description: In the LAS 2.0 well format, the first zone top is often given by a zone log transition from -999 to 0 as seawater is not treated as a zone. Choosing `yes` will ensure that such transition will be recorded as a zone top.

Argument: `yes` / `no`
Default: `no`

14.3.1.9 `<variogram-distance>`

Description: Specifying the distance calculation used by the variogram(s) specifying the spatial continuity of the vertical positioning error of the well path.

Let A and B be two points on the well-path. The `along-length` distance means that the correlation between A and B is computed as $\rho(r_{\text{MD}}/R_{\text{MD}})$, where ρ is the correlation function specified by `<variogram>`, r_{MD} is the measured depth at B minus the measured depth at A, and R_{MD} is the variogram range.

The correlation for the `euclidean` distance is $\rho(r_{xyz}/R_{xyz})$, where ρ is the correlation function specified by `<variogram>`, r_{xyz} is the spatial (euclidean) distance between A and B, and R_{xyz} is the variogram range.

For the `zonal` distance, the correlation between A and B is computed as the product $\rho_z(r_z/R_z)\,\rho_{xy}(r_{xy}/R_{xy})$, where ρ_z and ρ_{xy} are correlation functions specified by `<variogram>`, r_z is the vertical distance, r_{xy} is the lateral spatial distance, R_z is the vertical range, and R_{xy} is the lateral range. It is possible to specify two different variograms by repeating `<variogram>` twice, one for the vertical and one for the lateral direction.

Argument: `along-length`, `euclidean`, or `zonal`.
Default: `along-length`

14.3.1.10 `<variogram>`

Description: Wrapper for elements specifying an *optional* variogram for the vertical measurement error in well paths. This variogram is shared by all the wells in `<files>` that contain the uncertainty log specified by `<z-stddev-log-name>`. If this variogram is omitted, a default variogram model will be used.

This element can be repeated twice if we specify `<variogram-distance>` to be `zonal`. In this case, the first variogram defines the vertical correlation, ρ_z, and the second variogram defines the lateral correlation, ρ_{xy}.

Argument: Elements `<type>`, `<range>`, and `<power>`.
Default: See elements `<type>`, `<range>`, and `<power>`.

14.3.1.10.1 `<type>`

Description: The type of variogram.
Argument: The variograms in Table 14.2.

Default: `generalized exponential`

14.3.1.10.2 <range>

Description: The variogram range.
Argument: Non-negative real.
Default: `2000.0`

14.3.1.10.3 <power>

Description: The variogram power, p. Only used for the variograms `generalized exponential` and `rational quadratic` (see Table 14.2).
Argument: Non-negative real. Can not exceed 2.0 for `generalized exponential`.
Default: `1.8`

14.3.2 <well-points>

Description: Wrapper for elements specifying well points. The <well-points> element can be used to add additional well points to the well points extracted from zone logs.

If measurement errors are present in the well point files, then it is possible to specify a correlation between the measurement errors in a well by using <variogram-distance> and <variogram>.
Argument: Elements <files>, <variogram-distance>, and <variogram>.
Default: No default.

14.3.2.1 <files>

Description: Specification of the Cohiba well points file (s) to be imported. This element can be repeated in order to import files in different locations. See Table 6.1 on page 31 for details on the file format. Repeating files by accident will not affect the final result since repeated well points are merged.
Argument: Any valid path relative to <input-directory>. Wild cards (*) are supported.
Default: Empty string.
Example: `<files> mywellpoints/* </files>`

14.3.2.2 <variogram-distance>

Description: Specifying the distance calculation used by the variogram(s) specifying the correlation between measurement errors in a well.

Let A and B be two well points belonging to the same well. The correlation for the `euclidean` distance is $\rho(r_{xyz}/R_{xyz})$, where ρ is the correlation function specified by <variogram>, r_{xyz} is the spatial (euclidean) distance between A and B, and R_{xyz} is the variogram range.

For the `zonal` distance, the correlation between A and B is computed as the product $\rho_z(r_z/R_z)\,\rho_{xy}(r_{xy}/R_{xy})$, where ρ_z and ρ_{xy} are correlation functions specified by <variogram>, r_z is the vertical distance, r_{xy} is the lateral spatial distance, R_z is the vertical range, and R_{xy} is the lateral range. It is possible to specify two different variograms by repeating <variogram> twice, one for the vertical and one for the lateral direction.
Argument: `euclidean` or `zonal`.
Default: `euclidean`

14.3.2.3 <variogram>

Description: Wrapper for elements specifying a correlation between measurement errors in well points from the same well. This will only have effect if there are non-zero measurement errors specified in the well point files. If this element is omitted it assumed that measurement errors in a well are uncorrelated. That is equivalent to a `white noise` variogram type. Measurement errors in different wells are assumed uncorrelated.

This element can be repeated twice if we specify <variogram-distance> to be `zonal`. In this case, the first variogram defines the vertical correlation, ρ_z, and the second variogram defines the lateral correlation, ρ_{xy}.

If we condition to free surfaces (see <free-surface>), then this variogram is used to find correlations between measurement errors between well points on the free surface and well points extracted from zone logs.

This variogram is shared by all the well points in <files>.

Argument: Elements <type>, <range>, and <power>.

Default: No default. Uncorrelated if this element is omitted.

14.3.2.3.1 <type>

Description: The type of variogram.

Argument: The variograms in Table 14.2.

Default: `generalized exponential`

14.3.2.3.2 <range>

Description: The variogram range.

Argument: Non-negative real.

Default: `2000.0`

14.3.2.3.3 <power>

Description: The variogram power, p. Only used for the variograms `generalized exponential` and `rational quadratic` (see Table 14.2).

Argument: Non-negative real. Can not exceed 2.0 for `generalized exponential`.

Default: `1.8`

14.3.3 <well-points-to-ignore>

Description: Wrapper for <files> elements that specify well points that should be discarded.

Argument: <files> elements.

Default: Empty string.

14.3.3.1 <files>

Description: The well points that should be excluded if found in the zone logs. This element can be repeated in order to import different files in different locations. See Table 6.1 on page 31 for details on file format.

Any valid path relative to <input-directory>. Wild cards (*) are supported.

Default: Empty string.

Example:
```
<files> ignorepoints/* </files>
```

14.3.4 <values-outside-grid>

Description: Wrapper for <value> elements which specify the depth coordinate of the well point outside the grid. Each <value> element defines one well point.
Argument: <value> elements.
Default: Empty.

14.3.4.1 <value well-name="" surface-name="" x="" y="" stddev="">

Description: A depth value associated to the <well-data> element.
Attribute: **well-name** The name of the well associated to this observation.
Attribute value: String
Attribute default: "outside-well"
Attribute: **surface-name** The name of the surface associated to this observation.
Attribute value: String.
Attribute default: Empty string.
Attribute: **x** The X coordinate
Attribute value: Real
Attribute default: Largest machine real
Attribute: **y** The Y coordinate
Attribute value: Real
Attribute default: Largest machine real
Attribute: **stddev** The standard deviation
Attribute value: Real
Attribute default: 0.0
Argument: Real.
Default: No default.
Example: `<value surface-name = top> 1105.01 </value>`

14.3.5 Example of <well-data> specification

```
<well-data>
   <well-log>
      <zone-log-name>       GM2005a                    </zone-log-name>
      <z-stddev-log-name>   VerticalUncertainty        </z-stddev-log-name>
      <tops-as-mean-values> yes                        </tops-as-mean-values>
      <files>               ../welldata/*.roxbin       </files>
   </well-log>
   <well-points>
      <files>               ../welldata/new_markers.dat </files>
   </well-points>
</well-data>
```

14.4 <surfaces> (required)

Description: Wrapper for <reference> and <surface> elements in stratigraphic order. Free surfaces (see <free-surface>) can be in arbitrary order. A valid model must contain at least one surface different from the reference surface. The surfaces must be defined in a common rectangular output grid specified in the <output-grid> element.

Argument: A <reference> element and <surface> elements in correct depth order.

Default: No default.

14.4.1 <reference>

Description: Wrapper for elements specifying the reference surface. This is typically MSL (mean sea level). There can only be one <reference> element. Cohiba assumes that depth values and travel time values increase with increasing depth. Reference depth and travel time values can be negative.

Note that there will always exist a datum (horizontal plane) that defines zero depth. The reference surface, well points, and the output surfaces are defined relative to this datum. The datum is often MSL but any horizontal plane can be used.

Argument: Elements specifying the reference surface.

Default: A flat surface at zero depth having zero travel times. (See default values below)

14.4.1.1 <name>

Description: Name of reference surface.

Argument: String.

Default: MSL

Example:
```
<name> Mean Sea Level </name>
```

14.4.1.2 <depth>

reference surface

Description: Depth at the reference surface (relative to the global datum).

Argument: A real number or a grid file.

Default: 0.0

14.4.1.3 <travel-time>

Description: Seismic travel time at the reference surface.

Argument: A real number or a grid file.

Default: 0.0

14.4.2 <surface> (required)

Description: Wrapper for elements specifying a single surface. This element is repeated for every surface (except the reference) in the model. Important: The surface elements must be in stratigraphic order.

Argument: Elements specifying the surface.

Default: No default.

14.4.2.1 <name> (required)

Description: A *unique* name for the surface. The name is used for identifying data in the Cohiba well points file and for identifying top and base of an <interval> and a <volume>. All output surface files concerning this surface will include this name.

Argument: String.

Default: No default.
Example: `<name> Top Brent </name>`

14.4.2.2 `<top-of-zone>`

Description: This defines a mapping of zone log transition to the surface. If zone numbers increase with increasing depth, it is sufficient to specify the first zone name after *this surface*. Otherwise, all zone names below this surface and above the next surface must be specified. For details see Section 8.4.6.

This element has no use if the surface is a `<free-surface>`.
Argument: A sequence of zone names separated by a comma.
Default: Empty if no zone log is specified, otherwise it is required.
Example: `<top-of-zone> A', B', C' </top-of-zone>`
Example: `<top-of-zone> A' </top-of-zone>`

14.4.2.3 `<erosive>`

Description: A flag controlling whether the surface is erosive or not. This affects the extraction of well points from zone logs *and* post processing. Erosiveness in the post processing for all surfaces may be turned off using the element `<erode-and-onlap>`.

A `<free-surface>` can not be erosive so this element has no effect for free surfaces.
Argument: `yes` / `no`
Default: `no`

14.4.2.4 `<onlapped>`

Description: A flag controlling whether this surface is going to be on-lapped by surfaces above. An on-lapped surface can be eroded by a surface above. This affects the extraction of well points from zone logs *and* post processing. To override the post processing for all surfaces use the element `<erode-and-onlap>`.

A `<free-surface>` can not be on-lapped so this element has no effect for free surfaces.
Argument: `yes` / `no`
Default: `yes`

14.4.2.5 `<free-surface>`

Description: A flag controlling whether this surface is free or not. A surface is considered free if it is not part of the stratigraphy, typically, a fault or a hydrocarbon contact. See Section 13 for more details. This flag affects the extraction of well points from zone logs since a free surface is not associated to any zone. So `<top-of-zone>` have no meaning for a free surface. Well points belonging to a free surface must therefore be specified using `<well-points>`. All surfaces (ordinary and free) are conditioned to all well points, including well points on free surfaces. Free surfaces can be connected to other surfaces through intervals, and they can also be reflectors. Free surfaces are reported after the set of stratigraphically ordered surfaces, following the order in which they appear in the Cohiba model file.

Travel time residuals for free surfaces are never assumed to be correlated to other travel time residuals so that `<correlate-close-reflectors>` will not affect free surfaces.

Free surfaces can not erode and they can not be on-lapped. Free surfaces are not eroded by other surfaces and they will not lap onto other surfaces.

Argument: `yes / no`
Default: `no`

14.4.2.6 `<travel-time>`

Description: Specification of the grid containing the travel times for the seismic reflector. If this element is used, this surface automatically becomes a seismic reflector.
Argument: Elements specifying the travel time.
Default: No default.

14.4.2.6.1 `<value>`

Description: The travel time values.
Argument: File name or constant. See Section 6.2 for possible file formats.
Default: `0.0`.

14.4.2.6.2 `<values-outside-grid >`

Description: Wrapper for `<value>` elements which specify the travel time values. Each `<value>` element is in one-to-one correspondence with one well point outside the grid in `<values-outside-grid>` of `<well-data>`.
Argument: `<value>` elements.
Default: One `<value>` with value 0.0 for each `<value>` given in `<values-outside-grid>` from `<well-data>`.

14.4.2.6.2.1 `<value>`

Description: A travel time value for a well point outside the grid.
Argument: Real.
Default: No default.
Example: `<value> 0.1 </value>`

14.4.2.6.3 `<variogram>`

Description: Wrapper for elements specifying the travel time residual. The residual models the interpretation uncertainty in the travel time. It is specified by the standard deviation and the variogram (spatial correlation function). Typical values for the standard deviation is 4 – 20 msec. two-way time.
The available variograms are found in Table 14.2.
Argument: Elements specifying the travel time uncertainty.
Default: Default values for child elements.

14.4.2.6.3.1 `<type>`

Description: The type of variogram.
Argument: The variograms in Table 14.2.
Default: `spherical`

14.4.2.6.3.2 `<range>`

Description: The variogram range parallel to the azimuth direction. (North-south direction by default)

Table 14.2. Supported variogram types in Cohiba. Variograms, $\gamma(x)$, are closely linked to correlation functions, $\rho(x)$ by the simple relation $\gamma(x) = 1 - \rho(x)$. Here $x = r/R$ where r is the distance and R is the <range>. See Section 19 for some illustrations of simulated realizations. See e.g. Section 4 in Abrahamsen (1997) for mathematical details on the correlation functions.

<type>	**Correlation function**
constant	$\rho(x) = 1$
white noise	$\rho(x) = 1$ if $x = 0$, 0 otherwise
exponential	$\rho(x) = \exp(-3\,x)$
gaussian	$\rho(x) = \exp(-3\,x^2)$
generalized exponential	$\rho(x) = \exp(-3\,x^p), \quad 0 < p \leq 2$
spherical2	$\rho(x) = 1 - \frac{2}{\pi}(x\sqrt{1-x^2} + \arcsin x)$ if $x < 1$, 0 otherwise
spherical	$\rho(x) = 1 - \frac{3}{2}x + \frac{1}{2}x^3$ if $x < 1$, 0 otherwise
spherical5	$\rho(x) = 1 - \frac{15}{8}x + \frac{5}{4}x^3 - \frac{3}{8}x^5$ if $x < 1$, 0 otherwise
rational quadratic[a]	$\rho(x) = 1/(1 + \text{scale} \times x^2)^p, \quad p > 0$
damped sine	$\rho(x) = \sin \pi x / \pi x$

a. The scale is chosen such that $\rho(1) = 0.05$, that is, the correlation is 5 % at the correlation length.

Argument: Non-negative real.
Default: 1000.0

14.4.2.6.3.3 <subrange>

Description: The variogram subrange. Variogram range perpendicular to the azimuth direction. (East-west direction by default.)
Argument: Non-negative real.
Default: Value of range.

14.4.2.6.3.4 <azimuth>

Description: The variogram azimuth. Angle is measured clockwise from north. Units are degrees (full circle is 360°). Any input angle is possible but a warning is issued if angle is outside $[-360°, 360°]$.
Argument: Real.
Default: 0.0

14.4.2.6.3.5 <stddev>

Description: The standard deviation (square root of sill) .
Argument: Standard deviation as a constant or a grid file name, or elements <relative> and <minimum>. See Section 6.2 for possible file formats.
Default: 1.0
Example: Constant standard deviation:

```
<stddev> 0.001 </stddev>
```

Example: Standard deviation given by a surface grid file:

```
<stddev> dT_TopA.storm </stddev>
```

Example: Relative standard deviation:

```
<stddev>
```

```
    <relative>  0.10 </relative>
    <minimum>   1.00 </minimum>
</stddev>
```

14.4.2.6.3.5.1 <relative>

Description: The standard deviation relative to the travel time specified in <value>.
Argument: Positive real.
Default: 0.1

14.4.2.6.3.5.2 <minimum>

Description: Minimum standard deviation. This has only effect if <relative> has been used.
Argument: Positive real.
Default: 0.0

14.4.2.6.3.6 <power>

Description: The variogram power, p. Only used for the variograms generalized exponential and rational quadratic.
Argument: Non-negative real. Can not exceed 2.0 for generalized exponential.
Default: 1.0

14.4.2.6.3.7 <values-outside-grid>

Description: Wrapper for <value> elements which specify the travel time residual values. Each <value> element is in one-to-one correspondence with one well point outside the grid in <values-outside-grid> of <well-data>.
Argument: <value> elements.
Default: One <value> with value 0.0 for each <value> given in <values-outside-grid> from <well-data>.

14.4.2.6.3.7.1 <value>

Description: A travel time residual value at the well point outside the grid.
Argument: Real.
Default: No default.
Example: <value> 0.001 </value>

14.4.2.7 <spill-point>

Description: This element triggers the detection of the spill point of the surface. The corresponding trapped area can be written to a map using <trap>.

Wrapper for elements <missing-as-wall>, <xstart> and <ystart> that controls the search for the spill point and the corresponding trap. The starting point for the search algorithm can be anywhere inside the trap. It is recommended to choose a starting point that is known to belong to the trap such as a discovery well or a producing well. If the starting point is outside a trap the algorithm will fail. If the algorithm fails, the output trap map will contain zeros and the file spillpoint_Surface.xyz with spill point coordinates will contain missing codes (-9999.0).

Note that a depth surface can contain multiple traps. Only the trap containing the starting

point will be found.

The spill point is calculated after post processing of the surfaces.

Argument: Elements specifying starting point and how to interpret missing codes.

Default: Void

14.4.2.7.1 `<missing-as-wall>`

Description: Determines how the spill point search algorithm handles missing codes in the surface maps. The missing codes can either be considered as a wall or as a sink. If missing codes act as a wall (`yes`), the trap can not spill into areas with missing codes and the spill point search stops when the map boundary is found. If the missing codes are considered as a sink (`no`), the spill point search algorithm stops when it encounters the map boundary or grid nodes with missing codes that are in contact with the map boundary.

Argument: `yes` / `no`

Default: `no`

14.4.2.7.2 `<xstart>`

Description: Starting point x-coordinate for the spill point searching algorithm. The starting point for the search algorithm can be anywhere inside the trap. It is recommended to choose a starting point that is known to belong to the trap such as a discovery well or a producing well.

Argument: Real

Default: No default.

14.4.2.7.3 `<ystart>`

Description: Starting point y-coordinate for the spill point searching algorithm. The starting point for the search algorithm can be anywhere inside the trap. It is recommended to choose a starting point that is known to belong to the trap such as a discovery well or a producing well.

Argument: Real

Default: No default.

14.4.2.8 `<acceptance-criteria>`

Description: Wrapper for elements specifying acceptance criteria used for rejection sampling in stochastic simulation. The acceptance criteria only apply when simulating surfaces. It is possible to have several acceptance criteria for each surface.

If the rejection criteria are strict, a large number of simulated realizations might be necessary to obtain a single accepted realization. All surfaces will be discarded if one acceptance criterion fails. If the acceptance criteria is very strict the `<maximum-rejection-rate>` must be increased.

The acceptance criteria are checked after post processing of the surfaces.

Argument: Elements describing acceptance criteria.

Default: Void

14.4.2.8.1 `<spill-point-above>`

Description: The surface is accepted if the spill point is above a constant or above the specified surface at the spill point coordinates. The surface can be specified as any of the surfaces specified in <surfaces> or it can be read from a file. This criteria requires that <xstart> and <ystart> in <spill-point> are specified.

Argument: Constant, surface <name>, or a file name. See Section 6.2 for possible file formats.

Default: Void

14.4.2.8.2 <spill-point-below>

Description: The surface is accepted if the spill point is below a constant or below the specified surface at the spill point coordinates. The surface can be specified as any of the surfaces specified in <surfaces> or it can be read from a file. This criteria requires that <xstart> and <ystart> in <spill-point> are specified.

Argument: Constant, surface <name>, or a file name. See Section 6.2 for possible file formats.

Default: Void

14.4.2.8.3 <spill-point-at>

Description: The surface is accepted if the spill point is at a constant or at the specified surface at the spill point coordinate. The surface can be specified as any of the surfaces specified in <surfaces> or it can be read from a file. This criteria requires that <xstart> and <ystart> in <spill-point> are specified.

This is a strict criterion so by default a plus minus one meter tolerance is assumed. This tolerance can be modified by <spill-point-tolerance>.

Argument: Constant, surface <name>, or a file name. See Section 6.2 for possible file formats.

Default: Void

14.4.2.8.4 <spill-point-tolerance>

Description: The tolerance for accepting criterion <spill-point-at>. This tolerance applies on both sides so 1 meter means that the spill point will be accepted within a two meter depth window. If this value becomes too small then it is highly unlikely to obtain a simulated realization that will be accepted. So there is a trade off between speed and precision.

Argument: Positive real.

Default: 1.0 (meter)

14.4.2.8.5 <trap-larger-than>

Description: The surface is accepted if the trap is larger than the specified area in square meters. This criteria requires that <xstart> and <ystart> in <spill-point> are specified.

Argument: Positive real.

Default: 1.0 (meter^2)

14.4.2.9 <condition-to-spill-point-at-surface>

Description: The surface is translated vertically so that its depth matches the depth of the specified surface at the specified surface' spill point. This makes it possible to use this translated surface as the <base-contact> for a filled structure in a <volume> calculation.

This element can only be used for a <free-surface>. This criteria requires that <xstart> and

<ystart> in <spill-point> for the specified surface are specified.

We recommend that this surface do not have any well points, and do not link to other surfaces since the translation to fit the spill point will not take into account well points nor the relations to other surfaces.

Argument: Surface <name>.
Default: Void

14.4.2.10 <output>

Description: Wrapper for elements specifying if a particular type of output grid is written to file.
Argument: Elements for each grid type.
Default: Void

14.4.2.10.1 <depth>

Description: The output depth surface.
Argument: yes / no.
Default: yes

14.4.2.10.2 <depth-error>

Description: The output depth prediction error surface. Note that turning this on will increase the CPU time significantly.
Argument: yes / no.
Default: no

14.4.2.10.3 <depth-trend>

Description: The output depth trend surface.
Argument: yes / no.
Default: no

14.4.2.10.4 <depth-trend-error>

Description: The output depth trend error surface.
Argument: yes / no.
Default: no

14.4.2.10.5 <depth-residual>

Description: The output depth residual surface.
Argument: yes / no.
Default: no

14.4.2.10.6 <trap>

Description: The output trap surface associated to a spill point. This criteria requires that <xstart> and <ystart> in <spill-point> are specified.
Argument: yes / no.
Default: no

14.4.3 Example of <surface> specification

```
<surface>
   <name>                  TopA           </name>
   <top-of-zone>           IsochoreA      </top-of-zone>
   <erosive>               yes            </erosive>
   <onlapped>              no             </onlapped>
   <spill-point>
      <missing-as-wall>    yes            </missing-as-wall>
      <xstart>              342292.0      </xstart>
      <ystart>             4263452.0      </ystart>
   </spill-point>
   <output>
      <depth>              yes            </depth>
      <depth-trend>        yes            </depth-trend>
      <depth-error>        yes            </depth-error>
      <depth-trend-error>  yes            </depth-trend-error>
      <depth-residual>     yes            </depth-residual>
      <trap>               yes            </trap>
   </output>
   <travel-time>
      <value>              T_TopA.roxbin  </value>
      <variogram>
         <type>            spherical      </type>
         <range>           1000           </range>
         <subrange>        2000           </subrange>
         <azimuth>           45           </azimuth>
         <stddev>          dT_TopA.roxbin </stddev>
      </variogram>
   </travel-time>
   </surface>
```

14.5 <interval-models> (required)

Description: Wrapper for <interval> elements. Each <interval> element links two arbitrary surfaces by describing the thickness or the interval velocity (depth conversion) between them. The intervals usually link two adjacent surfaces but it is possible to link surfaces having several surfaces (and intervals) between them. A single surface can be top and base in several intervals so that there are multiple ways of obtaining the depth to a surface.

Argument: <interval> elements.

Default: No default.

14.5.1 <interval> (required)

Description: Wrapper for elements describing the interval. There are two types of intervals: Thickness intervals and velocity intervals. The latter is used to describe the interval velocity between two seismic reflectors. This element is repeated for each interval model between two surfaces.

Argument: Elements describing the interval.

Default: No default.

14.5.1.1 <name>

Description: An interval name. All output concerning this interval will use this name.

Argument: String.

Default: A string made from the names of the top and base of the interval: `TopSurfaceName-to-BaseSurfaceName`.

14.5.1.2 <top> (required)

Description: The surface defining the top of the interval. Top and base surfaces must be different.

Argument: An existing surface name.

Default: No default.

14.5.1.3 <base> (required)

Description: The surface defining the base of the interval. Top and base surfaces must be different.

Argument: An existing surface name.

Default: No default.

14.5.1.4 <interval-type> (required)

Description: For thickness intervals, the trends describe the thickness, and for velocity intervals, the trends describe interval velocity. Velocity intervals require that the top and base surfaces of the interval are seismic reflectors.

Argument: `thickness / velocity`.

Default: No default.

14.5.1.5 <trend>

Description: Wrapper for a single interval thickness/velocity trend map and interval trend coefficient. An interval (thickness or velocity) may contain a sum of several interval trend maps so this element may be repeated any number of times.

Argument: Elements describing a interval trend map and its interval trend coefficient.

Default: Void.

Example: A coefficient with mean 1.07 and uncertainty (standard deviation) 0.05:

```
<trend>
  <coefficient-mean>   1.07                </coefficient-mean>
```

```
  <coefficient-stddev> 0.05                </coefficient-stddev>
  <value>              S_IsochoreB.storm   </value>
</trend>
```

Example: A 15 % uncertainty on the coefficient with default value 1.0:

```
<trend>
  <relative-stddev>    0.15                </relative-stddev>
  <value>              S_IsochoreB.storm   </value>
</trend>
```

14.5.1.5.1 <coefficient-mean>

Description: Prior mean value (expectation) of interval trend coefficient. The interval trend coefficient is multiplied by the value specified in element <value> below to obtain the interval thickness/velocity trend. When possible, we recommend to drop this element and thereby use the default value of 1.

Argument: Real.

Default: 1.0

14.5.1.5.2 <coefficient-stddev>

Description: Prior uncertainty (standard deviation) of interval trend coefficient. When possible, we recommend to drop this element and use <relative-stddev> instead. Do not use this element in combination with <relative-stddev>.

Argument: Non-negative real.

Default: 0.0

14.5.1.5.3 <relative-stddev>

Description: Prior relative uncertainty (standard deviation) of interval trend coefficient. Do not use this element in combination with <coefficient-stddev>.

Argument: Non-negative real.

Default: 0.1 (This means a 10 % uncertainty)

14.5.1.5.4 <value>

Description: A interval trend map (grid) or a constant. This map is multiplied by its corresponding interval trend coefficient.

Argument: File name or constant. See Section 6.2 for possible file formats.

Default: 1.0

14.5.1.5.5 <values-outside-grid>

Description: Wrapper for <value> elements which specify the trend values. Each <value> element is in one-to-one correspondence with one well point outside the grid in <values-outside-grid> of <well-data>.

Argument: <value> elements.

Default: One <value> with value 0.0 for each <value> given in <values-outside-grid> from <well-data>.

14.5.1.5.5.1 `<value>`

Description: A trend value associated to the well point outside the grid.
Argument: Real.
Default: No default.
Example: `<value> 1105.01 </value>`

14.5.1.6 `<correlations>`

Description: Correlations between interval trend coefficients.
Argument: A sequence of arguments `<cp-q>`, where p and q (p different from q) refers to the order of the trend coefficients within this `<interval>` element. Make sure that the values entered define a proper correlation matrix, that is, a symmetric positive definite (SPD) matrix.
Default: `0.0`; no correlations.
Example: Correlation matrix for 3 trend coefficients:

```
<correlations>
  <c1-2> 0.01  </c1-2>
  <c1-3> 0.03  </c1-3>
  <c2-3> 0.002 </c2-3>
</correlations>
```

14.5.1.6.1 `<cp-q>`

Description: Prior correlations between trend coefficients p and q. The numbering is according to the order of appearance in the list of trends, starting at 1. Indices exceeding the maximum number of trends will be ignored.
Argument: Real between -1 and 1.
Default: `0.0`

14.5.1.7 `<variogram>` **(required)**

Description: Wrapper for elements specifying the interval uncertainty, that is, interval thickness residual or interval velocity residual. The residual is the *unknown* difference between the true interval thickness/velocity and interval thickness/velocity trend. It is specified by the variogram (spatial correlation function) and the standard deviation.
Argument: Elements specifying the interval thickness or interval velocity residual.
Default: No default.

14.5.1.7.1 `<type>`

Description: The type of interval residual variogram.
Argument: The variograms in Table 14.2.
Default: `spherical`

14.5.1.7.2 `<range>`

Description: The interval residual variogram range parallel to the azimuth direction. (North-south direction by default)
Argument: Non-negative real.
Default: `1000.0`

14.5.1.7.3 `<subrange>`

Description: The interval residual variogram subrange. Variogram range perpendicular to the azimuth direction. (East-west direction by default.)
Argument: Non-negative real.
Default: Value of range.

14.5.1.7.4 <azimuth>

Description: The interval residual variogram azimuth. Angle is measured clockwise from north. Units are degrees (full circle is $360°$). Any input angle is possible but a warning is issued if angle is outside $[-360°, 360°]$.
Argument: Real.
Default: `0.0`

14.5.1.7.5 <stddev>

Description: The interval residual standard deviation (square root of sill) .
Argument: Standard deviation as a constant or a grid file name, or elements `<relative>` and `<minimum>`. See Section 6.2 for possible file formats.
Default: `1.0`
Example: Constant standard deviation:

```
<stddev> 0.001 </stddev>
```

Example: Standard deviation given by a surface grid file:

```
<stddev> dZ_IntervalAB.storm </stddev>
```

Example: Relative standard deviation:

```
<stddev>
   <relative>  0.10 </relative>
   <minimum>   1.00 </minimum>
</stddev>
```

14.5.1.7.5.1 <relative>

Description: The standard deviation relative to the thicknesses or interval velocities specified in the interval `<trend>`.
Argument: Positive real.
Default: `0.1`

14.5.1.7.5.2 <minimum>

Description: Minimum standard deviation. This has only effect if `<relative>` has been used.
Argument: Positive real.
Default: `0.0`

14.5.1.7.6 <power>

Description: The interval residual variogram power, p. Only used for the variograms `generalized exponential` and `rational quadratic` (see Table 14.2).
Argument: Non-negative real. Can not exceed 2.0 for `generalized exponential`.
Default: `1.0`

14.5.1.7.7 <values-outside-grid>

Description: Wrapper for <value> elements which specify the interval thickness/velocity residual values. Each <value> element is in one-to-one correspondence with one well point outside the grid in <values-outside-grid> of <well-data>.

Argument: <value> elements.

Default: One <value> with value 0.0 for each <value> given in <values-outside-grid> from <well-data>.

14.5.1.7.7.1 <value>

Description: A interval thickness/velocity residual value at the well point outside the grid.

Argument: Real.

Default: No default.

Example: <value> 0.001 </value>

14.5.1.8 <output>

Description: Wrapper for elements specifying if a map (grid) should be written to file.

Argument: Elements for each map.

Default: Void

14.5.1.8.1 <thickness>

Description: The thickness of the interval, i.e., the difference between top and base depth surfaces.

Argument: yes / no.

Default: no.

14.5.1.8.2 <thickness-trend>

Description: The thickness trend of the interval, i.e., the difference between the top trend and the base trend surfaces.

Argument: yes / no.

Default: no.

14.5.1.8.3 <thickness-residual>

Description: The difference between the thickness and the thickness trend of the interval.

Argument: yes / no.

Default: no.

14.5.1.8.4 <velocity>

Description: The output interval velocity, i.e., the interval thickness divided by the time difference.

Argument: yes / no.

Default: no.

14.5.1.8.5 <velocity-trend>

Description: The posterior interval velocity trend.

Argument: yes / no.

Default: no.

14.5.2 Example of <interval> specification

```
<interval>
   <name>                  MSL-to-TopA          </name>
   <top>                   MSL                  </top>
   <base>                  TopA                 </base>
   <interval-type>         velocity             </interval-type>
   <trend>
      <coefficient-mean>   2500                 </coefficient-mean>
      <coefficient-stddev>  200                 </coefficient-stddev>
      <value>                 1                 </value>
   </trend>
   <trend>
      <coefficient-mean>   25.0                 </coefficient-mean>
      <coefficient-stddev> 12.5                 </coefficient-stddev>
      <value>              v-overburden.roxbin  </value>
   </trend>
   <correlations>
      <c1-2>               0.9                  </c1-2>
   </correlations>
   <variogram>
      <type>               spherical            </type>
      <range>              1000                 </range>
      <subrange>           2000                 </subrange>
      <azimuth>              45                 </azimuth>
      <stddev>
         <relative>        0.05                 </relative>
      </stddev>
   </variogram>
   <output>
      <thickness>          yes                  </thickness>
      <thickness-trend>    yes                  </thickness-trend>
      <velocity>           yes                  </velocity>
   </output>
</interval>
```

14.6 <volumes>

Description: Wrapper for elements describing the gross rock volume of one or more reservoirs. See Section 9 for details and an example.

Argument: <volume> elements.

Default: No default.

14.6.1 <volume>

Description: Wrapper for elements describing the surfaces outlining one reservoir unit. There is an option for assigning the volume to different areas (segment, license, political boundary, etc.) using <area-names>.

Argument: Elements describing the volume of a reservoir unit.

Default: No default.

14.6.1.1 <reservoir-name>

Description: The name of the reservoir unit. This name is required. This name is used for reporting to `volumes.csv`.

Argument: String

Default: No default.

Example: `<reservoir-name> Upper Brent </reservoir-name>`

14.6.1.2 <top-surface>

Description: The name of the top surface of a reservoir, usually the base of the reservoir caprock.

Argument: Surface <name>.

Default: The name of the <reference> surface.

14.6.1.3 <base-surface>

Description: The name of the base surface of a reservoir. Note that either this surface or the <base-contact> must be specified.

Argument: Surface <name>.

Default: No default.

14.6.1.4 <top-contact>

Description: The name of the top hydrocarbon contact of a reservoir. This is usually the gas-oil-contact. This surface must be a free surface (Section 13).

Argument: Surface <name>.

Default: No default.

14.6.1.5 <base-contact>

Description: The name of the base contact of a reservoir. This hydrocarbon contact is usually the oil-water-, gas-water- or gas-oil-contact. This surface must be a free surface (Section 13). Note that either this surface or the <base-surface> must be specified.

Argument: Surface <name>.

Default: No default.

14.6.1.6 <area-file>

Description: File with a unique integer (area number) for every area (segment, license, political boundary, etc.) of interest. The area numbers are represented as floats $(-1.0, 0.0, 1.0, 2.0, \ldots)$. Volumes will be recorded separately for every non-negative area number presented in the grid. Areas with negative area numbers are ignored. Areas are by default named by the area

number. Other names can be supplied using <area-names>.

Argument: File name. See Section 6.2 for possible file formats.

Default: No default.

14.6.1.7 <area-names>

Description: Used to associate the area numbers in the <area-file> by names. If <area-names> is used then only area numbers that are associated with area names will be included in the volume calculations.

Argument: Comma separated list with alternating area number and area name.

Default: No default.

Example:

```
<area-names>
    0, Central Block, 2, East Block, 3, West Block
<area-names>
```

14.6.1.8 <only-trapped-volume>

Description: If yes, then the spill point for the <top-surface> will be calculated and possible volumes outside the trap will be discarded. This option requires that <xstart> and <ystart> in <spill-point> are specified.

This option should be used in combination with <condition-to-spill-point-at-surface> for <base-contact>. This ensures that the base contact is consistent with the spill point depth.

In some situations the trap might be split into disconnected volumes by the <base-surface>. The disconnected volumes can be removed using <connected-volume>.

Argument: yes / no

Default: no

14.6.1.9 <remove-isolated-volumes-less-than>

Description: Small pockets of rock volume is removed from the rock column map before the volumes are calculated.

Nothing is removed if the minimum volume is zero.

Argument: Minimum volume in cubic meters.

Default: 1000000 (One million cubic meters.)

14.6.1.10 <connected-volume>

Description: Only a single connected volume in the rock column map is kept. The connected volume must include the coordinates specified by <xstart> and <ystart>.

Argument: The coordinates to a point inside the connected volume.

Default: No default.

Example:

```
<connected-volume>
    <xstart>  314680.00 </xstart>
    <ystart> 7348210.00 </ystart>
</connected-volume>
```

14.6.1.10.1 <xstart>

Description: X-coordinate to a point inside the connected volume. This could typically be the start-

ing point, <xstart>, of the <spill-point> algorithm.

Argument: Real

Default: No default.

14.6.1.10.2 <ystart>

Description: Y-coordinate to a point inside the connected volume. This could typically be the starting point, <ystart>, of the <spill-point> algorithm.

Argument: Real

Default: No default.

14.6.1.11 <column-map>

Description: If yes, then a map of the rock column height of the reservoir is written to a grid file in surfaces/.

Argument: yes / no

Default: yes

15 List of all elements

<cohiba> *(required)*
<project-settings> *(required)*
· <project-title> *(required)*
· <project-description>
· <seed>
· <project-directory>
· <input-directory>
· <input-directory-surfaces>
· <input-directory-well-data>
· <output-directory>
· <number-of-threads>
· <prefix-for-log-files>
· <messages>
· · <logfile>
· · · <name>
· · · <detail-level>
· · · · <overall>
· · · · <model-settings>
· · · · <data-loading>
· · · · <pre-processing>
· · · · <surface-models>
· · · · <well-points>
· · · · <extra-points>
· · · · <well-paths>
· · · · <trend-coefficients>
· · · · <residual-uncertainties>
· · · · <outliers>
· · · · <well-point-conditioning>
· · · · <help-points>
· · · · <well-path-conditioning>
· · · · <post-processing>
· · · · <zonation-checking>
· · · · <spill-points>
· · · · <volume-calculations>
· · · · <timings>
· · · · <tasks>
· · <screen>
· · · <detail-level>
· · · · <overall>
· <measurement-units>
· · <z-unit>
· · <time-unit>
· · <two-way-time>
· <output-grid> *(required)*
· · <format>
· · <read-from-file>
· · <xstart>
· · <ystart>
· · <xinc>
· · <yinc>
· · <xlength>
· · <ylength>
· · <grid-azimuth>
<modelling-settings>

<mode>
<kriging-method>
<number-of-realizations>
<write-realization-maps>
<write-all-logfiles>
<condition-to-well-paths>
<simulate-trend-uncertainty>
<check-specified-residual-uncertainties>
<minimize-broken-zonation>
<pre-process-surfaces>
  <make-time-surfaces-consistent>
  <smoothing-factor-velocity-trends>
<post-process-surfaces>
  <erode-and-onlap>
  <treat-reflectors-as-eroding-and-onlapped>
  <make-average-of-crossing-surfaces>
  <make-surfaces-interpolate-well-points>
  <allow-small-surface-adjustment-at-sample-points>
  <set-eroded-nodes-to-undefined>
  <smoothing-factor-calculated-velocities>
<advanced-settings>
  <maximum-rejection-rate>
  <model-weight-resolution>
  <maximum-stddev-for-well-points-interpolation>
  <maximum-residual-for-well-points-interpolation>
  <maximum-gradient-for-surface-adjustment>
  <maximum-residual-for-adjustment-at-sample-points>
  <minimum-distance-from-surface-to-sample-points>
  <allow-sample-points-near-faults>
  <solver-for-weights>
  <maximum-iterations-to-avoid-broken-zonation>
  <correlate-close-reflectors>
  <max-obs-direct-estim-trend-coef>
  <max-obs-GLS-approx-trend-coef>
  <max-obs-GLS-approx-extreme-outliers>
  <max-obs-update-trend-coef-using-well-paths>
  <threshold-for-trace-clustering>
  <threshold-for-cluster-merging>
  <threshold-for-removing-undefined-well-sections>
  <threshold-for-help-point-deactivation>
  <minimum-isochore-thickness>
  <threshold-for-mild-error>
  <t-value-outlier>
  <t-value-severe-outlier>
  <t-value-error>
  <t-value-extreme-error>
  <t-value-prediction-first-point>
  <t-value-prediction-second-point>
  <t-value-simulation-first-point>
  <t-value-simulation-second-point>
  <maximum-generalized-eigenvalue-for-inequality-points>
  <maximum-dxy-for-identical-well-points>
  <maximum-dz-for-identical-well-points>
  <maximum-slope-before-possible-conflict>
  <minimum-stddev-close-well-points>
  <threshold-for-conditioning-in-neighbourhood>
  <preprocess-range-factor-for-neighbourhood>
  <minimum-range-factor-for-neighbourhood>
  <maximum-range-factor-for-neighbourhood>
  <target-number-of-data-in-neighbourhood>
  <minimum-generalized-eigenvalue>
  <volume-calculation-method>

```
<well-data>
·   <well-log>
·   ·   <zone-log-specification>
·   ·   <zone-log-specification-file>
·   ·   <zone-log-name>
·   ·   <fault-log-name>
·   ·   <z-stddev-log-name>
·   ·   <files>
·   ·   <tops-as-mean-values>
·   ·   <first-log-entry-as-top>
·   ·   <variogram-distance>
·   ·   <variogram>
·   ·   ·   <type>
·   ·   ·   <range>
·   ·   ·   <power>
·   <well-points>
·   ·   <files>
·   ·   <variogram-distance>
·   ·   <variogram>
·   ·   ·   <type>
·   ·   ·   <range>
·   ·   ·   <power>
·   <well-points-to-ignore>
·   ·   <files>
·   <values-outside-grid>
·   ·   <value well-name="""" surface-name="""" x="""" y="""" stddev="""">
<surfaces> (required)
·   <reference>
·   ·   <name>
·   ·   <depth>
·   ·   <travel-time>
·   <surface> (required)
·   ·   <name> (required)
·   ·   <top-of-zone>
·   ·   <erosive>
·   ·   <onlapped>
·   ·   <free-surface>
·   ·   <travel-time>
·   ·   ·   <value>
·   ·   ·   <values-outside-grid>
·   ·   ·   ·   <value>
·   ·   ·   <variogram>
·   ·   ·   ·   <type>
·   ·   ·   ·   <range>
·   ·   ·   ·   <subrange>
·   ·   ·   ·   <azimuth>
·   ·   ·   ·   <stddev>
·   ·   ·   ·   ·   <relative>
·   ·   ·   ·   ·   <minimum>
·   ·   ·   ·   <power>
·   ·   ·   ·   <values-outside-grid>
·   ·   ·   ·   ·   <value>
·   ·   <spill-point>
·   ·   ·   <missing-as-wall>
·   ·   ·   <xstart>
·   ·   ·   <ystart>
·   ·   <acceptance-criteria>
·   ·   ·   <spill-point-above>
·   ·   ·   <spill-point-below>
·   ·   ·   <spill-point-at>
·   ·   ·   <spill-point-tolerance>
·   ·   ·   <trap-larger-than>
```

```
·   ·   <condition-to-spill-point-at-surface>
·   ·   <output>
·   ·   ·   <depth>
·   ·   ·   <depth-error>
·   ·   ·   <depth-trend>
·   ·   ·   <depth-trend-error>
·   ·   ·   <depth-residual>
·   ·   ·   <trap>
<interval-models> (required)
·   <interval> (required)
·   ·   <name>
·   ·   <top> (required)
·   ·   <base> (required)
·   ·   <interval-type> (required)
·   ·   <trend>
·   ·   ·   <coefficient-mean>
·   ·   ·   <coefficient-stddev>
·   ·   ·   <relative-stddev>
·   ·   ·   <value>
·   ·   ·   <values-outside-grid>
·   ·   ·   ·   <value>
·   ·   <correlations>
·   ·   ·   <cp-q>
·   ·   <variogram> (required)
·   ·   ·   <type>
·   ·   ·   <range>
·   ·   ·   <subrange>
·   ·   ·   <azimuth>
·   ·   ·   <stddev>
·   ·   ·   ·   <relative>
·   ·   ·   ·   <minimum>
·   ·   ·   <power>
·   ·   ·   <values-outside-grid>
·   ·   ·   ·   <value>
·   ·   <output>
·   ·   ·   <thickness>
·   ·   ·   <thickness-trend>
·   ·   ·   <thickness-residual>
·   ·   ·   <velocity>
·   ·   ·   <velocity-trend>
<volumes>
·   <volume>
·   ·   <reservoir-name>
·   ·   <top-surface>
·   ·   <base-surface>
·   ·   <top-contact>
·   ·   <base-contact>
·   ·   <area-file>
·   ·   <area-names>
·   ·   <only-trapped-volume>
·   ·   <remove-isolated-volumes-less-than>
·   ·   <connected-volume>
·   ·   ·   <xstart>
·   ·   ·   <ystart>
·   ·   <column-map>
```

16 Cohiba model file example

See Section 16.1 for the Cohiba log file generated from this example.

```
<?xml version="1.0" encoding="utf-8"?>
<cohiba>
  <project-settings>
    <project-title>       Synthetic Vilje                      </project-title>
    <project-description> This example has two crossing wells  </project-description>

    <project-directory> 23_syntetic-vilje-crossing-wells-meter </project-directory>

    <messages>
      <logfile>
        <detail-level>
          <overall> 4 </overall>
        </detail-level>
      </logfile>
      <screen>
        <detail-level>
          <overall> 4 </overall>
        </detail-level>
      </screen>
    </messages>

    <measurement-units>
      <z-unit>               m  </z-unit>
      <time-unit>            ms </time-unit>
      <two-way-time>         no </two-way-time>
    </measurement-units>

    <output-grid>
      <xstart>              0.0 </xstart>
      <ystart>              0.0 </ystart>
      <xlength>          4800.0 </xlength>
      <ylength>          3800.0 </ylength>
      <xinc>               50.0 </xinc>
      <yinc>               50.0 </yinc>
      <format>      roxar text  </format>
    </output-grid>
  </project-settings>

  <modelling-settings>
    <mode>                     prediction </mode>
    <kriging-method>           bayesian   </kriging-method>
    <condition-to-well-paths>  yes        </condition-to-well-paths>
    <post-process-surfaces>
      <make-surfaces-interpolate-well-points> no </make-surfaces-interpolate-well-points>
      <allow-small-surface-adjustment-at-sample-points> no </allow-small-surface-adjustment-at-sample-points>
```

```
    </post-process-surfaces>
  </modelling-settings>

  <well-data>
    <well-log>
      <zone-log-name>        PD2011       </zone-log-name>
      <files>                w1.rmswell   </files>
      <files>                w4.rmswell   </files>
    </well-log>
    <well-points>
      <files>       synthetic_markers.dat </files>
    </well-points>
  </well-data>

  <surfaces>
<!--Surfaces must be listed in stratigraphic order -->
    <reference>
      <name>                 MSL               </name>
      <depth>                0                 </depth>
    </reference>

    <surface>
      <name>                 TopA              </name>
      <erosive>              no                </erosive>
      <onlapped>             no                </onlapped>
      <top-of-zone>          A                 </top-of-zone>
      <output>
        <depth>              yes               </depth>
        <depth-trend>        yes               </depth-trend>
        <depth-error>        yes               </depth-error>
        <depth-trend-error>  yes               </depth-trend-error>
        <depth-residual>     yes               </depth-residual>
      </output>
      <travel-time>
        <value>              T_TopA.storm      </value>
        <variogram>
          <type>             spherical         </type>
          <range>            1000              </range>
          <subrange>         2000              </subrange>
          <azimuth>          20.00             </azimuth>
          <stddev>           2.0               </stddev>
        </variogram>
      </travel-time>
    </surface>

    <surface>
      <name>                 TopB              </name>
      <erosive>              no                </erosive>
      <onlapped>             no                </onlapped>
      <top-of-zone>          B                 </top-of-zone>
      <output>
        <depth>              yes               </depth>
        <depth-trend>        yes               </depth-trend>
```

```
      <depth-error>         yes                 </depth-error>
      <depth-trend-error>   yes                 </depth-trend-error>
      <depth-residual>      yes                 </depth-residual>
    </output>
  </surface>

  <surface>
    <name>                  TopC                </name>
    <erosive>               no                  </erosive>
    <onlapped>              no                  </onlapped>
    <top-of-zone>           C                   </top-of-zone>
    <output>
      <depth>               yes                 </depth>
      <depth-trend>         yes                 </depth-trend>
      <depth-error>         yes                 </depth-error>
      <depth-trend-error>   yes                 </depth-trend-error>
      <depth-residual>      yes                 </depth-residual>
    </output>
  </surface>
</surfaces>

<interval-models>
  <interval>
    <name>                  MSL-to-TopA         </name>
    <top>                   MSL                 </top>
    <base>                  TopA                </base>
    <interval-type>         velocity            </interval-type>
    <trend>
      <coefficient-mean>    1.00                </coefficient-mean>
      <coefficient-stddev>  0.08                </coefficient-stddev>
      <value>               2500                </value>
    </trend>
    <trend>
      <relative-stddev>     0.50                </relative-stddev>
      <value>               Vcorr.storm         </value>
    </trend>
    <variogram>
      <type>                spherical           </type>
      <range>               1000                </range>
      <subrange>            2000                </subrange>
      <azimuth>             20.00               </azimuth>
      <stddev>              10.00               </stddev>
    </variogram>
  </interval>

  <interval>
    <name>                  TopA-to-TopB        </name>
    <top>                   TopA                </top>
    <base>                  TopB                </base>
    <interval-type>         thickness           </interval-type>
    <trend>
      <relative-stddev>     0.2                 </relative-stddev>
      <value>               S_IsochoreA.storm   </value>
```

```
      </trend>
      <variogram>
        <type>               spherical          </type>
        <range>              1000               </range>
        <subrange>           2000               </subrange>
        <azimuth>            20.00              </azimuth>
        <stddev>             10.00              </stddev>
      </variogram>
    </interval>

    <interval>
      <name>                 TopB-to-TopC       </name>
      <top>                  TopB               </top>
      <base>                 TopC               </base>
      <interval-type>        thickness          </interval-type>
      <trend>
        <relative-stddev>    0.2                </relative-stddev>
        <value>              S_IsochoreB.storm  </value>
      </trend>
      <variogram>
        <type>               spherical          </type>
        <range>              1000               </range>
        <subrange>           2000               </subrange>
        <azimuth>            20.00              </azimuth>
        <stddev>              9.00              </stddev>
      </variogram>
    </interval>
  </interval-models>
</cohiba>
```

16.1 Cohiba log file example

The following Cohiba log file was generating using the Cohiba model file in Section 16.

```
*************************************************************************************************
*****                                                                                       *****
*****                                C O H I B A  -  5.0.1beta                              *****
*****                                                                                       *****
*****                        Copyright (c) 2006 by Norsk Regnesentral                       *****
*****                                                                                       *****
*************************************************************************************************

License expiration                          : Never
Licensed to                                 : Norsk Regnesentral

Log written by                              : Unknown
Date and time                               : Wed Apr 23 11:54:39 2014
Host                                        : octane
Threads in use                              : 8 / 8

*************************************************************************************************
*****     Section 1: Model settings                                                         *****
*************************************************************************************************

Model file                                  : 23_syntetic-vilje-crossing-wells-meter/modelfile.xml

Project title                               : Synthetic Vilje
Project description                         : This example has two crossing wells

Project directory                           : /opt/project/Cohiba/trunk/test_suite/23_syntetic-vilje-crossing-wells-me
Input directory for surfaces                : input/surfaces
Input directory for well data               : input/welldata
Output directory                            : output

Modelling mode                              : prediction
Conditioning method                         : Bayesian kriging
Condition to well paths                     : yes
Check specified residual uncertainties      : yes
Iterate to minimize amount of broken zonation  : no

Pre-process surfaces:
   Make time surfaces consistent            : no
   Smooth velocity trends if needed         : yes
Post-process surfaces:
   Treat reflectors as eroding and onlapped    : yes
   Set eroded nodes to undefined            : no
   Truncate against erosive/onlapped surfaces  : yes
   Make average of crossing surfaces        : yes
   Make surfaces interpolate well points    : no
   Allow small surface adj. at sample points   : no

Well logs:
   Zone log name                            : PD2011
   File names                               : w1.rmswell; w4.rmswell
   Interpret first log entry as zone top    : no
   Find zone tops as mean values            : yes

Well points:
   File names                               : synthetic_markers.dat

Output grid:
   format                                   : roxar text
```

```
   xstart  (rot. point)                        :        0.00
   ystart  (rot. point)                        :        0.00
   azimuth                                     :        0.00
   xinc                                        :       50.00
   yinc                                        :       50.00
   nx                                          :          97
   ny                                          :          77

Measurement types:
   Depth                                       : True vertical depth (TVD)
   Time                                        : One-way time (OWT)

Measurement units:
   Depth                                       : m
   Time                                        : ms
   Velocity                                    : m/s

Reference surface:
   Name                                        : MSL
   Depth                                       : 0.00
   Time                                        : 0.00


Surface     TREND [ TravelTime  ]  VARIO [ Type        Range  Subr  Power  Azimuth      StdDev]
-------------------------------------------------------------------------------------------------
MSL                       0.0000                -        -     -      -        -           -
TopA                T_TopA.storm           spherical    1000  2000     -     20.00      2.0000

Surface     ATTRIB [ Erosive  Onlapped  Reflector  FreeSurface  TopOfZones
-------------------------------------------------------------------------
MSL                  no       no        yes        no           -
TopA                 no       no        yes        no           A
TopB                 no       no        no         no           B
TopC                 no       no        no         no           C

Surface     OUTPUT [ Depth  Error  Trend  TrendError  Residual  Trap]
-------------------------------------------------------------------
MSL                  yes    no     no     no          no        no
TopA                 yes    yes    yes    yes         yes       no
TopB                 yes    yes    yes    yes         yes       no
TopC                 yes    yes    yes    yes         yes       no

Interval       TREND [   Mean   Std.dev             Value]  VARIO [ Type        Range  Subr  Power  Azimuth      StdDev]
-------------------------------------------------------------------------------------------------------------------------
MSL-to-TopA            1.0000    0.0800           2500.00           spherical    1000  2000     -     20.00     10.0000
MSL-to-TopA            1.0000    0.5000  Vcorr.storm                spherical    1000  2000     -     20.00     10.0000
TopA-to-TopB           1.0000    0.2000  S_IsochoreA.storm          spherical    1000  2000     -     20.00     10.0000
TopB-to-TopC           1.0000    0.2000  S_IsochoreB.storm          spherical    1000  2000     -     20.00      9.0000

Interval       OUTPUT [ Thickness  ThicknessTrend  Residual  Velocity  VelocityTrend ]  IntervalTop  IntervalBase   Inter
-------------------------------------------------------------------------------------------------------------------------
MSL-to-TopA             no         no              no        no        no               MSL          TopA           veloc
TopA-to-TopB            no         no              no        no        no               TopA         TopB           thick
TopB-to-TopC            no         no              no        no        no               TopB         TopC           thick

*************************************************************************************************
*****     Section 2: Loading input data                                                     *****
*************************************************************************************************

Well paths are resampled to 5.0m intervals. (This does not affect the well point extraction)

The specification for zone log 'PD2011' is taken from the well 'w1'
```

```
Well points are extracted between the following groups of zones:

ZoneTop    Erosive/Onlapped      ZoneNum  SubZones
---------------------------------------------------------
MSL             0 / 0               0     ( Above )
TopA            0 / 0               1     ( A )
TopB            0 / 0               2     ( B )
TopC            0 / 0               3     ( C )


                                                                                  Zones
Wellname                 MD           X           Y        Z   StdDev  FaultInd  Upper/Lower  ZoneTop  Surface
-------------------------------------------------------------------------------------------------------------
w4                   288.31     2602.50     1840.00  1039.18     0.06      0        0 / 1        1     TopA
w4                  1033.36     3347.50     1840.00  1045.00     0.00      0        1 / 2        2     TopB
w4                  1038.36     3352.50     1840.00  1045.00     0.00      0        1 / 2        2     TopB
w4                  1188.36     3502.50     1840.00  1044.99     0.00      0        0 / 1        1     TopA

w4                  : Number of zone tops :     4
w4                  : Well path entries   :   244/   271   (after initial resampling/in original zone log)


                                                                                  Zones
Wellname                 MD           X           Y        Z   StdDev  FaultInd  Upper/Lower  ZoneTop  Surface
-------------------------------------------------------------------------------------------------------------
w1                   170.52     3001.00     2272.50  1015.81     0.40      0        0 / 1        1     TopA
w1                   847.68     3001.00     1597.50  1042.15     0.08      0        1 / 2        2     TopB
w1                  1145.79     3001.00     1300.00  1061.00     0.00      0        2 / 3        3     TopC
w1                  1195.80     3001.00     1250.00  1062.00     0.00      0        2 / 3        3     TopC
w1                  1378.32     3001.00     1067.50  1059.95     0.02      0        1 / 2        2     TopB
w1                  1458.33     3001.00      987.50  1058.99     0.00      0        0 / 1        1     TopA

w1                  : Number of zone tops :     6
w1                  : Well path entries   :   289/   293   (after initial resampling/in original zone log)


Valid wells                                 :        2
     1 : w1
     2 : w4

Number of zone tops found in logs           :       10

Number of well path points taken from logs  :      533

Well points read from file  /opt/project/Cohiba/trunk/test_suite/23_syntetic-vilje-crossing-wells-meter/input/welldata/sy

Well points added                       :    6
Duplicate well points                   :    0 (the larger uncertainty is kept)
Total number of well points             :   16

Finished loading well point files.

Wells added from point file(s)              :        2
     3 : w2
     4 : w3

Well points read from zone logs/wellpoint files (before processing in COHIBA):

#Surface              Wellname                    X            Y            Z    StdDev
#-----------------------------------------------------------------------------------------
TopA                  w1                    3001.00      2272.50      1015.81      0.40
```

```
TopB                w1                  3001.00      1597.50      1042.15      0.08
TopC                w1                  3001.00      1300.00      1061.00      0.00
TopC                w1                  3001.00      1250.00      1062.00      0.00
TopB                w1                  3001.00      1067.50      1059.95      0.02
TopA                w1                  3001.00       987.50      1058.99      0.00
TopA                w4                  2602.50      1840.00      1039.18      0.06
TopB                w4                  3347.50      1840.00      1045.00      0.00
TopB                w4                  3352.50      1840.00      1045.00      0.00
TopA                w4                  3502.50      1840.00      1044.99      0.00
TopA                w2                   900.00      2001.00      1052.50      0.00
TopB                w2                   900.00      2001.00      1072.63      0.00
TopC                w2                   900.00      2001.00      1109.46      0.00
TopA                w3                  2225.00      3101.00      1085.21      0.00
TopB                w3                  2225.00      3101.00      1115.44      0.00
TopC                w3                  2225.00      3101.00      1143.62      0.00


                                          TimeMapNodes                          TimeStdDevMapNodes
Surface                                Defined          Undefined                Defined          Undefined
-------------------------------------------------------------------------------------------------------------
TopA                            7469 (100.00%)        0 (  0.00%)         7469 (100.00%)        0 (  0.00%)

                                        IntervalTrendMapNodes                   IntervalStdDevMapNodes
Interval              Trend          Defined          Undefined                Defined          Undefined
-------------------------------------------------------------------------------------------------------------
MSL-to-TopA               1     7469 (100.00%)        0 (  0.00%)         7469 (100.00%)        0 (  0.00%)
MSL-to-TopA               2     7469 (100.00%)        0 (  0.00%)         7469 (100.00%)        0 (  0.00%)
TopA-to-TopB              1     7469 (100.00%)        0 (  0.00%)         7469 (100.00%)        0 (  0.00%)
TopB-to-TopC              1     7469 (100.00%)        0 (  0.00%)         7469 (100.00%)        0 (  0.00%)

                                             TimeMap                                TimeStdDevMap
Surface                            Avg      Std      Min      Max            Avg      Std      Min      Max
-------------------------------------------------------------------------------------------------------------
TopA                            447.71     9.78   422.24   471.19           2.00     0.00     2.00     2.00

                                          IntervalTrendMap                       IntervalStdDevMap
Interval              Trend        Avg      Std      Min      Max            Avg      Std      Min      Max
-------------------------------------------------------------------------------------------------------------
MSL-to-TopA               1    2500.00     0.00  2500.00  2500.00          10.00     0.00    10.00    10.00
MSL-to-TopA               2       0.07     9.78   -25.39    23.56          10.00     0.00    10.00    10.00
TopA-to-TopB              1      17.06     7.03     5.00    29.12          10.00     0.00    10.00    10.00
TopB-to-TopC              1      23.09    10.55     5.00    41.17           9.00     0.00     9.00     9.00

Memory usage for grids
----------------------
Memory needed to hold all input grids      ( 11) :     0.6MB
Memory needed to hold all output grids     ( 15) :     0.9MB
Total memory usage needed for grids              :     1.5MB

*****************************************************************************************************
*****     Section 3: Pre-processing input data                                                  *****
*****************************************************************************************************

Converting time grid and time stddev grid for surface MSL into seconds.
Converting time grid and time stddev grid for surface TopA into seconds.

Time surfaces are assumed consistent. (Truncations not requested by user.)

Time surfaces residuals are assumed consistent. Truncations not requested by user.

Difference between input velocity trend and filtered velocity trends:
```

```
Interval          Trend       Minimum    Maximum    Average     StdDev     Smooth
-------------------------------------------------------------------------------
MSL-to-TopA           1         0.000      0.000      0.000      0.000         no
MSL-to-TopA           2        -0.794      0.863      0.002      0.156         no

*****************************************************************************************************
*****     Section 4: The alternative ways to build each surface                                     *****
*****************************************************************************************************

                  ModelWeights
Surface     Avg    Std    Min    Max    Models
-----------------------------------------------------
TopA      1.000  0.000  1.000  1.000    1: MSL -> TopA
TopB      1.000  0.000  1.000  1.000    1: MSL -> TopA -> TopB
TopC      1.000  0.000  1.000  1.000    1: MSL -> TopA -> TopB -> TopC

                    DepthUncertainty(StdDev)
Surface          Avg        Std        Min        Max    Models
-------------------------------------------------------------------------
TopA           6.728      0.080      6.528      6.896    1: MSL -> TopA
TopB          12.053      0.044     11.942     12.147    1: MSL -> TopA -> TopB
TopC          15.042      0.035     14.954     15.118    1: MSL -> TopA -> TopB -> TopC

*****************************************************************************************************
*****     Section 5: Processing well points                                                         *****
*****************************************************************************************************

Identifying and merging points belonging to the same surface and same well.

Maximum x-distance for merging well points  :  50.0000         (x-length of grid cell)
Maximum y-distance for merging well points  :  50.0000         (y-length of grid cell)

Merge  Point Surface         Wellname               X            Y          Z      OldStd  NewStd
-------------------------------------------------------------------------------------------------------------
    1  Old   TopB            w4               3352.50      1840.00    1045.00        0.00
    1  Old   TopB            w4               3347.50      1840.00    1045.00        0.00
    1  New   TopB            w4               3350.00      1840.00    1045.00                0.00

Number of well point merges                 :        1
Number of well points deleted (in merge)    :        1

Number of well points before processing     :       16
Well points available for conditioning      :       15

Surfaces                WellPoints
-----------------------------------
TopA                             6
TopB                             5
TopC                             4
-----------------------------------
Total                           15

*****************************************************************************************************
*****     Section 6: Processing control points for eroded and onlapped surfaces                 *****
*****************************************************************************************************

Nothing to do here when there are no extra points available.

*****************************************************************************************************
*****     Section 7: Sampling well trajectories and logs                                            *****
*****************************************************************************************************
```

```
Resampling well paths at 10.0m intervals.
w1                  : Well path entries   (after/before)              (   145/   289)
w4                  : Well path entries   (after/before)              (   128/   244)

Number of well path points taken from logs                   :      533
Number of dense-sampled well path points after resampling    :      273

Removing well path points outside output grid boundaries.

All well path points are inside the output grid.

Removing well path points associated with undefined surface/interval values.

No well path points are associated with undefined surface/interval values.

Resampling well paths at 100.0m intervals.
w1                  : Well path entries   (after/before)              (    16/   145)
w4                  : Well path entries   (after/before)              (    14/   128)

Number of dense-sampled well path points before resampling   :      273
Number of coarse-sampled path points after resampling        :       30

Removing well path points close to faults.

No well path points are marked as close to a fault.

Removing well path points lying closer than 50.0m to another well path point (in same zone).

Number of coarse-sampled well path points before filtering   :       30
Number of coarse-sampled well path points after filtering    :       29

Finding well path points lying closer than 50.0m to a well point. (No action taken.)

All well path points are sufficiently distant to existing well points.

*************************************************************************************************
*****     Section 8: Trend coefficients based on well points                                 *****
*************************************************************************************************

Computing a-posteriori coefficients using exact formulas.

                                                 Trend coefficients
Interval            Coef   PriorMean    PriorStd    PostMean     PostStd PostMeanUpd  PostStdUpd
-------------------------------------------------------------------------------------------------
MSL-to-TopA            1       1.000       0.080       0.972       0.003           -           -
MSL-to-TopA            2       1.000       0.500       1.020       0.426           -           -
TopA-to-TopB           1       1.000       0.200       1.025       0.163           -           -
TopB-to-TopC           1       1.000       0.200       1.043       0.142           -           -


*************************************************************************************************
*****     Section 9: Checking specified residual uncertainties                               *****
*************************************************************************************************

 0%       20%       40%       60%       80%       100%
 |    |    |    |    |    |    |    |    |    |    |
 ^^^^^^^^^^^^^^^^^^^^^^^^^^^^^^^^^^^^^^^^^^^^^^^^^^^^

Total number of well points      : 15
Number of well points available  : 15

                Specified/Obs    95% AcceptanceRange     NumberOf    Specified
```

```
Interval          Uncertainty    LowerLimit UpperLimit   WellPoints  Uncertainty
-------------------------------------------------------------------------------
MSL-to-TopA             -             -         -           -              -
TopA-to-TopB        1.444         0.624     2.453           5             OK
TopB-to-TopC        5.210         0.566     3.729           3       Too high
-------------------------------------------------------------------------------
Overall             1.528         0.739     1.548          15           High

Consider reducing the prior residual uncertainty for interval 'TopB-to-TopC

*******************************************************************************************************
*****     Section 10: Identifying well point outliers and leverage points                     *****
*******************************************************************************************************

No leverage points found.

No outliers found.

Surface           WellPoints         Bias    rmsResidual
-----------------------------------------------------
TopA                       6         0.18           5.05
TopB                       5         0.57           9.98
TopC                       4        -0.07          12.30

*******************************************************************************************************
*****     Section 11: Conditioning on well points along well paths                            *****
*******************************************************************************************************

In the preprocessing for conditioning to well-paths:  1.71% of the grid nodes will be active.

 0%       20%       40%       60%       80%       100%
 |    |    |    |    |    |    |    |    |    |    |
 ^^^^^^^^^^^^^^^^^^^^^^^^^^^^^^^^^^^^^^^^^^^^^^^^^^^^

w1                 : Well path points in wrong zone/total number of points         2/    16
w4                 : Well path points in wrong zone/total number of points         2/    13

Summary            : Well path points in wrong zone/total number of points         4/    29

*******************************************************************************************************
*****     Section 12: Finding help points for well path conditioning                          *****
*******************************************************************************************************

The distribution of cluster sizes (number of help points in each cluster) :

  Size     Count  Frequency
---------------------------
  0- 5         2      0.667
  5-10         0      0.000
 10-15         1      0.333
 15-20         0      0.000
 20-25         0      0.000
 25-30         0      0.000
 30-35         0      0.000
 35-40         0      0.000
 40-45         0      0.000
 45-50         0      0.000
 50+           0      0.000

Largest cluster has 14 help points and 9 well points

Number of help-point clusters :        3
```

```
Calculating optimal location of help points

 0%       20%       40%       60%       80%       100%
 |    |    |    |    |    |    |    |    |    |    |
 ^^^^^^^^^^^^^^^^^^^^^^^^^^^^^^^^^^^^^^^^^^^^^^^^^^^^

Number of well points                                :       15
Number of help points added                          :       18
Total number of points available for conditioning    :       33

*****************************************************************************************************
*****     Section 13: Trend coefficients based on well points and well paths                    *****
*****************************************************************************************************

                                                 Trend coefficients
Interval            Coef   PriorMean    PriorStd    PostMean     PostStd PostMeanUpd  PostStdUpd
-----------------------------------------------------------------------------------------------------
MSL-to-TopA            1       1.000       0.080       0.972       0.003       0.972       0.003
MSL-to-TopA            2       1.000       0.500       1.020       0.426       1.020       0.426
TopA-to-TopB           1       1.000       0.200       1.025       0.163       1.067       0.160
TopB-to-TopC           1       1.000       0.200       1.043       0.142       1.043       0.142


*****************************************************************************************************
*****     Section 14: Conditioning surfaces on all available points                             *****
*****************************************************************************************************

 0%       20%       40%       60%       80%       100%
 |    |    |    |    |    |    |    |    |    |    |
 ^^^^^^^^^^^^^^^^^^^^^^^^^^^^^^^^^^^^^^^^^^^^^^^^^^^^

*****************************************************************************************************
*****     Section 15: Post process surfaces                                                     *****
*****************************************************************************************************

Treating reflectors as erosive and onlapped surfaces.

No erosion truncations performed.

No onlap truncations performed.

The tables below summarises the number of nodes truncated from
either above (erosion) or below (onlapping):

TruncatingSurface       Erosive   Onlapped  Reflector  MovedNodes
-----------------------------------------------------------------
TopA                        no         no        yes           0

*****************************************************************************************************
*****     Section 16: Checking zonation                                                         *****
*****************************************************************************************************

Final zonation status at well path points                      <1.0m  >1.0m  Total
-------------------------------------------------------------------------------
Number of well path points with unchanged zonation      (-) :                  25
Number of well path points with zonation corrected      (Y) :                   4
Number of well path points for which correction failed  (N) :       0      0      0
Number of well path points with broken zonation         (B) :       0      0      0
Number of well path points with fixable broken zonation (F) :       0      0      0
Number of well path points with noncorrectable zonation (X) :       0      0      0
Number of well path points with undefined zonation      (U) :                   0
-------------------------------------------------------------------------------
```

```
Total number of well path points                          :                  29

Final zonation status for wells:
-------------------------------------------------------------------------
Number of wells with correct zonation after preprocessing :      0
Number of wells with zonation corrected by conditioning   :      2
Number of wells with correct zonation                     :             2
Number of wells with incorrect zonation  < 1.0m           :      0
Number of wells with incorrect zonation  > 1.0m           :      0
Number of wells with undefined zonation                   :      0
Number of wells with zonation problems                    :             0
-------------------------------------------------------------------------
Total number of wells                                     :             2

The table below summarizes the amount of crossing depth trend surfaces (negative trend isochores) if any:

Top        Base        MinThickness MaxThickness AvgThickness   NegValues
-------------------------------------------------------------------------
TopA       TopB               5.336       31.070       18.203      0.000%
TopB       TopC               5.215       42.947       24.081      0.000%

*************************************************************************************************
*****     Section 17: Spill points                                                          *****
*************************************************************************************************

No spill point detection has been requested.

*************************************************************************************************
*****     Section 18: Volume calculations                                                   *****
*************************************************************************************************

No volume calculation has been requested.

*************************************************************************************************
*****     Section 19: Timings summary                                                       *****
*************************************************************************************************

Section                                        CPU Time              Real Time
-------------------------------------------------------------------------------
Loading input data                      0.07     3.04 %        0.00     0.00 %
Regridding input data                   0.01     0.43 %        0.00     0.00 %
Predicting surfaces along well paths    0.03     1.30 %        0.00     0.00 %
Finding help point probability dist.    1.84    80.00 %        2.00   100.00 %
Predicting surfaces                     0.16     6.96 %        0.00     0.00 %
Post-processing                         0.01     0.43 %        0.00     0.00 %
Writing files                           0.12     5.22 %        0.00     0.00 %
Miscellaneous                           0.06     2.61 %        0.00     0.00 %
-------------------------------------------------------------------------------
Total                                   2.30   100.00 %        2.00   100.00 %

*************************************************************************************************
*****     Section 20: Suggested tasks                                                       *****
*************************************************************************************************

 1. A change of specified residual uncertainty has been suggested. See residual uncertainty section.

Total CPU  time used in COHIBA:     2.30
Total real time used in COHIBA:     2.00
```

Part V
Theory

17 Prediction of surfaces

17.1 Surfaces and intervals

The basic assumption made by Cohiba is that any depth surface is obtained by adding intervals specified by <interval> elements. So the fundamental building blocks are the intervals. The link between surfaces and intervals is made by the <top> and <base> elements that associate the top and base surfaces of an interval. Cohiba will automatically assemble the necessary intervals to obtain any surface. Cohiba is very flexible when it comes to combining intervals to obtain surfaces. An illustration is shown on page 14 and an extensive example is given in Section 11. Any combination of surfaces and intervals is possible as long as three requirements are fulfilled:

1. One of the intervals must have <reference> as <top>.
2. Surface <top> must be above surface <base> if none of the surfaces are free surfaces (Section 13).
3. The specification can not be cyclical. That means that a surface can not be obtained by adding an interval that has itself as <top>.

These three requirements guarantees a consistent specification that links any surface to the <reference> surface by adding (or subtracting) intervals.

Cohiba requires a strict ordering of surfaces entering the stratigraphic framework. The ordering is the order the <surface> elements appear in the Cohiba model file. The ordering is used for several purposes:

- Obtain correct truncation caused by <erosive> and <onlapped> properties.
- Correct interpretation of zone logs.
- Automatic change of sign when an interval contributes with a negative thickness to a surface. This happens when intervals are added on top of deeper surfaces.

The strict ordering does not apply to surfaces that are specified as free surfaces (Section 13).

The intervals have no specific order and any surface can be the <top> and <base> of several intervals.

17.2 Stochastic model for surfaces and intervals

The number of intervals defined in the model is denoted I and the number of surfaces are denoted L. There might be more intervals than surfaces so $I \geq L$. To simplify the notation we introduce the set of all intervals that contribute to surface l by $\mathcal{I}^l$. The depth to surface l is obtained by adding[1] the thicknesses of all intervals, i, that belongs to the set $\mathcal{I}^l$:

$$Z^l(\mathbf{x}) = z^{\text{ref.}}(\mathbf{x}) + \sum_{i \in \mathcal{I}^l} \Delta Z_i(\mathbf{x}), \qquad \mathbf{x} \in \mathbb{R}^2. \tag{17.1}$$

The reference surface, $z^{\text{ref.}}(\mathbf{x})$, is usually MSL but can be replaced by an arbitrary reference surface using <reference>. In the following we will assume that $z^{\text{ref.}}(\mathbf{x}) = 0$ to simplify the notation.

1. Or subtracting if intervals are added on top of deeper surfaces. We omit this to simplify the notation in this section. Cohiba will of course take proper care of possible negative signs.

The thickness of interval i is modeled as

$$\Delta Z_i(\mathbf{x}) = \Delta m_i(\mathbf{x}) + \Delta \epsilon_i(\mathbf{x}), \tag{17.2}$$

where $\Delta m_i(\mathbf{x})$ is the *interval thickness trend* and $\Delta \epsilon_i(\mathbf{x})$ is the *interval thickness residual*. The interval thickness residual is modeled as a zero mean *Gaussian random field* (Abrahamsen, 1997) specified by the correlation function, $\rho(h)$, and the standard deviation, $\sigma_i(\mathbf{x})$, so that

$$\mathrm{E}\{\Delta \epsilon_i(\mathbf{x})\} = 0, \tag{17.3a}$$

$$\mathrm{Var}\{\Delta \epsilon_i(\mathbf{x})\} = \sigma_i^2(\mathbf{x}), \tag{17.3b}$$

$$\mathrm{Cov}\{\Delta \epsilon_i(\mathbf{x}), \Delta \epsilon_j(\mathbf{y})\} = \delta_{ij}\, \sigma_i(\mathbf{x})\, \sigma_j(\mathbf{y})\, \rho(\|\mathbf{x} - \mathbf{y}\|). \tag{17.3c}$$

Interval thickness residuals from different intervals are assumed independent. This is obtained by the Kronecker delta[2] in Eq. 17.3c. The stochastic properties of the Gaussian random field is specified by the `<variogram>` element.

The interval thickness trend for interval i, is a linear combinations of P_i known trend maps, $f_{i,p}(\mathbf{x})$:

$$\Delta m_i(\mathbf{x}) = \sum_{p=1}^{P_i} \beta_{i,p}\, f_{i,p}(\mathbf{x}). \tag{17.4}$$

These trend maps are typically constants, isochore maps, or any map used to model the thickness of interval i. The specification of the known trend maps is done by repeated use of the `<value>` in the wrapper element `<trend>`. To simplify, we organize the P_i known trend maps for interval i as a vector $\mathbf{f}_i{}'(\mathbf{x}) = [f_{i,1}(\mathbf{x}), \ldots, f_{i,P_i}(\mathbf{x})]$ so that

$$\Delta m_i(\mathbf{x}) = \mathbf{f}_i{}'(\mathbf{x}) \cdot \boldsymbol{\beta}_i. \tag{17.5}$$

Using this notation we can write the depth to a surface as

$$Z^l(\mathbf{x}) = m^l(\mathbf{x}) + \epsilon^l(\mathbf{x}), \tag{17.6}$$

where

$$m^l(\mathbf{x}) = \sum_{i \in \mathcal{J}^l} \mathbf{f}_i{}'(\mathbf{x}) \cdot \boldsymbol{\beta}_i \tag{17.7}$$

$$\epsilon^l(\mathbf{x}) = \sum_{i \in \mathcal{J}^l} \Delta \epsilon_i(\mathbf{x}). \tag{17.8}$$

These are called the *depth trend* and the *depth residual* respectively. The depth residual is a sum of Gaussian random fields and is therefore also a Gaussian random field.

To further simplify the notation, consider all trend maps and corresponding trend coefficients for all I intervals organized as two vectors:

$$\mathbf{f}(\mathbf{x}) = \begin{bmatrix} \mathbf{f}_1(\mathbf{x}) \\ \vdots \\ \mathbf{f}_I(\mathbf{x}) \end{bmatrix}, \qquad \boldsymbol{\beta} = \begin{bmatrix} \boldsymbol{\beta}_1 \\ \vdots \\ \boldsymbol{\beta}_I \end{bmatrix}. \tag{17.9}$$

These vectors contain all the trend maps and all the trend coefficients belonging to all the I intervals so the size of these vectors are $P = \sum_{i=1}^{I} P_i$.

2. Kronecker delta: $\delta_{ii} = 1$ and $\delta_{ij} = 0$ for $i \neq j$.

We can now write Eq. 17.6 as

$$Z^l(\mathbf{x}) = \mathbf{f}^{l\prime}(\mathbf{x}) \cdot \boldsymbol{\beta} + \epsilon^l(\mathbf{x}), \tag{17.10}$$

where trend maps in $\mathbf{f}_i(\mathbf{x})$ are replaced by zeros when they belong to intervals that does *not* contribute to surface l. That is, $\mathbf{f}_i(\mathbf{x}) = \mathbf{0}$ in $\mathbf{f}^l$ if $i \notin \mathcal{I}^l$.

17.3 Estimating the trend coefficients

All the well points from all the L surfaces can be organized in a column vector:

$$\mathbf{Z} = \begin{bmatrix} \mathbf{Z}^1 \\ \vdots \\ \mathbf{Z}^L \end{bmatrix}, \tag{17.11}$$

where $\mathbf{Z}^{l\prime} = [Z^l(\mathbf{x}_1^l), \ldots, Z^l(\mathbf{x}_{N^l}^l)]$ is a column vector of the N^l well points of surface l. So $\mathbf{Z}$ is a vector of all $N = \sum_{l=1}^{L} N^l$ well points at all the L surfaces.

Similarly we can organize all the P trend map values at the N well points as a $N \times P$ dimensional *design matrix*[3]

$$\mathbf{F} = \begin{bmatrix} \mathbf{F}^1 \\ \vdots \\ \mathbf{F}^L \end{bmatrix}, \tag{17.12}$$

that is build up by $N^l \times P$ dimensional sub-matrices for each surface:

$$\mathbf{F}^l = \begin{bmatrix} \mathbf{f}^{l\prime}(\mathbf{x}_1^l) \\ \vdots \\ \mathbf{f}^{l\prime}(\mathbf{x}_{N^l}^l) \end{bmatrix}. \tag{17.13}$$

Using this notation we can write Eq. 17.10 for all the observed depths as

$$\mathbf{Z} = \mathbf{F}\boldsymbol{\beta} + \boldsymbol{\epsilon}, \tag{17.14}$$

where the residual vector, $\boldsymbol{\epsilon}$, is organized in the same sequence as the well points vector, $\mathbf{Z}$. Eq. 17.14 is recognized as a standard linear regression problem for the trend coefficients $\boldsymbol{\beta}$ with correlated residuals.

17.3.1 Linear regression

The standard estimate for the coefficients, $\boldsymbol{\beta}$, in a linear regression model such as Eq. 17.14 can be found in any textbook on (multiple) linear regression as the ordinary least squares (OLS) solution:

$$\widehat{\boldsymbol{\beta}}_{\text{OLS}} = \left(\mathbf{F}'\,\mathbf{F}\right)^{-1}\mathbf{F}'\,\mathbf{Z} \tag{17.15a}$$

$$\widehat{\boldsymbol{\Sigma}}_{\text{OLS}} = \sigma^2\left(\mathbf{F}'\,\mathbf{F}\right)^{-1}, \tag{17.15b}$$

where $\text{Var}\{\epsilon_i\} = \sigma^2$ is assumed constant and independent for *all* well points. This is not a reasonable assumption in this case since well points are highly correlated.

3. In statistics the design matrix is often denoted by the symbol $\mathbf{X}$. We use $\mathbf{F}$ and here to avoid confusion with the coordinates $\mathbf{x}$.

According to equations Eq. 17.3c and Eq. 17.8 the covariance between two well points are

$$\begin{aligned}\mathrm{Cov}\{Z^l(\mathbf{x}), Z^k(\mathbf{y})\} &= \mathrm{Cov}\{\epsilon^l(\mathbf{x}), \epsilon^k(\mathbf{y})\} \\ &= \mathrm{Cov}\left\{\sum_{i\in\mathcal{J}^l}\Delta\epsilon_i(\mathbf{x}), \sum_{j\in\mathcal{J}^k}\Delta\epsilon_j(\mathbf{y})\right\} \\ &= \sum_{i\in\mathcal{J}^l\cap\mathcal{J}^k}\mathrm{Cov}\{\Delta\epsilon_i(\mathbf{x}), \Delta\epsilon_i(\mathbf{y})\} \\ &= \sum_{i\in\mathcal{J}^l\cap\mathcal{J}^k}\sigma_i(\mathbf{x})\,\sigma_i(\mathbf{y})\,\rho(\|\mathbf{x}-\mathbf{y}\|).\end{aligned} \tag{17.16}$$

The double sum is removed by using the assumption that interval residuals from different intervals are independent; see the Kronecker delta in Eq. 17.3c. The significance of Eq. 17.16 is that it gives a simple recipe for calculating the covariance between two surface depths at two arbitrary well points. We see that the correlation between the surface depths at different well points is caused by spatial correlation and that surfaces have residuals in common.

The covariances between depths at all well points can be organized in a covariance matrix called the *kriging matrix*:

$$\mathbf{K} = \mathrm{Var}\{\mathbf{Z}\}\,. \tag{17.17}$$

It is possible to show (Mardia et al., 1979, p. 172) that the best linear unbiased estimator (BLUE) for the coefficients is the *generalized least squares* (GLS) estimator:

$$\widehat{\boldsymbol{\beta}}_{\mathrm{GLS}} = \left(\mathbf{F}'\,\mathbf{K}^{-1}\mathbf{F}\right)^{-1}\mathbf{F}'\,\mathbf{K}^{-1}\mathbf{Z} \tag{17.18a}$$

$$\widehat{\boldsymbol{\Sigma}}_{\mathrm{GLS}} = \left(\mathbf{F}'\,\mathbf{K}^{-1}\mathbf{F}\right)^{-1}. \tag{17.18b}$$

The correlations between the depths at different well points and the local varying variance, $\sigma_i(\mathbf{x})$, at different well points will influence the estimate through the kriging matrix. Note that the ordinary least squares estimate is retrieved if well points are independent and the variance is the same at all well points, that is, $\mathbf{K} = \sigma^2\mathbf{I}$.

If the number of well points, N, is very large, Cohiba uses a weighted least squares (WLS) estimate:

$$\widehat{\boldsymbol{\beta}}_{\mathrm{WLS}} = \left(\mathbf{F}'\,\mathbf{D}^{-1}\mathbf{F}\right)^{-1}\mathbf{F}'\,\mathbf{D}^{-1}\mathbf{Z} \tag{17.19a}$$

$$\widehat{\boldsymbol{\Sigma}}_{\mathrm{WLS}} = \left(\mathbf{F}'\,\mathbf{D}^{-1}\mathbf{F}\right)^{-1}, \tag{17.19b}$$

where $\mathbf{D} = \mathrm{Diag}\{\mathbf{K}\}$. This amounts to ignoring the correlation between well points. This approximation is necessary to avoid using too much CPU and RAM. The number of well points where Cohiba switches from GLS to WLS can be changed by `<max-obs-GLS-approx-trend-coef>`. The default is $N = 2000$.

17.3.2 Bayesian estimation

Ordinary, weighted and generalized least squares methods requires that $N > P$ *and* that all columns of $\mathbf{F}$ are non-parallel so that $\mathrm{rank}(\mathbf{F}) = P$. If the columns of $\mathbf{F}$ are near parallel or linear combinations of the columns are near parallel a problem called *collinearity* occurs (Weisberg, 1985, p. 196). This is a serious problem since the estimates of the coefficients become unreliable and the estimation variance becomes very large. Collinearity occurs when the data is unable to distinguish the contribution from the different trend maps, $f_{i,p}(\mathbf{x})$. This is usually caused by too

few well points, clustering of wells, unobserved surfaces due to pinch outs or too many coefficients in the trend model. Simplifying the thickness trends by removing some of the trend maps is one solution, but usually the chosen trend maps have a particular purpose. So Cohiba supports an alternative way of handling collinearity. This is done by specifying the coefficient values using `<coefficient-mean>` and `<coefficient-stddev>`. These numbers are the prior means and the prior standard deviations in the prior P-dimensional multinormal distribution for the coefficient values

$$\boldsymbol{\beta} \sim N_P(\boldsymbol{\beta}_0, \boldsymbol{\Sigma}_0). \tag{17.20}$$

The diagonal elements of $\boldsymbol{\Sigma}_0$ are specified using `<coefficient-stddev>` and some of the off-diagonals can be set to non-zero by using `<correlations>`.

The Bayesian estimate for the posterior expectations and covariances are

$$\widehat{\boldsymbol{\beta}}_{\text{Bayes}} = \boldsymbol{\beta}_0 + \boldsymbol{\Sigma}_0 \mathbf{F}'\left(\mathbf{K} + \mathbf{F}\,\boldsymbol{\Sigma}_0\,\mathbf{F}'\right)^{-1}(\mathbf{Z} - \mathbf{F}\,\boldsymbol{\beta}_0) \tag{17.21a}$$

$$\widehat{\boldsymbol{\Sigma}}_{\text{Bayes}} = \boldsymbol{\Sigma}_0 - \boldsymbol{\Sigma}_0 \mathbf{F}'\left(\mathbf{K} + \mathbf{F}\,\boldsymbol{\Sigma}_0\,\mathbf{F}'\right)^{-1}\mathbf{F}\,\boldsymbol{\Sigma}_0. \tag{17.21b}$$

This estimate is robust for any N, including $N = 0$. In that case the prior guess, $\boldsymbol{\beta}_0$, is returned. If the prior uncertainty vanishes, $\boldsymbol{\Sigma}_0 \to \mathbf{0}$, then the prior guess, $\boldsymbol{\beta}_0$, is also returned. It is also possible to fix one or more coefficients by specifying zero prior uncertainty and use the well points for estimating the rest. It can also be shown, on reasonable assumptions, that if $\boldsymbol{\Sigma}_0 \to \boldsymbol{\infty}$ then we obtain the GLS estimate (Omre and Halvorsen, 1989).

Eq. 17.21a and Eq. 17.21b includes an inversion of the $N \times N$ matrix $(\mathbf{K} + \mathbf{F}\,\boldsymbol{\Sigma}_0\,\mathbf{F}')$. This is CPU and RAM demanding so alternative expressions are used when N is large:

$$\widehat{\boldsymbol{\beta}}_{\text{Bayes}} = \widehat{\boldsymbol{\Sigma}}_{\text{Bayes}}\left(\boldsymbol{\Sigma}_0^{-1}\boldsymbol{\beta}_0 + \widehat{\boldsymbol{\Sigma}}_{\text{xLS}}^{-1}\,\widehat{\boldsymbol{\beta}}_{\text{xLS}}\right) \tag{17.22a}$$

$$\widehat{\boldsymbol{\Sigma}}_{\text{Bayes}} = \left(\boldsymbol{\Sigma}_0^{-1} + \widehat{\boldsymbol{\Sigma}}_{\text{xLS}}^{-1}\right)^{-1}. \tag{17.22b}$$

These expressions are algebraically identically to Eq. 17.21a and Eq. 17.21b provided $\text{rank}(\mathbf{F}) = \text{rank}(\boldsymbol{\Sigma}_0) = P$ and $N > P$.

Cohiba uses the robust formulas Eq. 17.21a and Eq. 17.21b when the number of data, N, is few[4]. Otherwise Eq. 17.22a and Eq. 17.22b are used.

The estimates $\widehat{\boldsymbol{\Sigma}}_{\text{xLS}}$ and $\widehat{\boldsymbol{\beta}}_{\text{xLS}}$ are GLS estimates for moderate number of data, N, and WLS estimates for large N. The number of data where Cohiba switches from GLS to WLS can be changed by `<max-obs-GLS-approx-trend-coef>`.

Cohiba will automatically switch to Bayesian estimation using Eq. 17.21a and Eq. 17.21b if $\text{rank}(\mathbf{F}) < P$ even though the user has chosen `universal` for the `<kriging-method>`. This is necessary since the GLS and WLS estimates fail to exist if $\text{rank}(\mathbf{F}) < P$.

17.3.3 Trend and trend uncertainty

The estimated depth trend is

$$\widehat{m}^l(\mathbf{x}) = \mathbf{f}^{l\prime}(\mathbf{x}) \cdot \widehat{\boldsymbol{\beta}}, \tag{17.23}$$

where the estimates, $\widehat{\boldsymbol{\beta}}$, depends on the estimation methods. This map can be written to file using element `<depth-trend>`.

The estimation method is chosen using the element `<kriging-method>` in the Cohiba model file. Choosing `universal` amounts to using the GLS estimate, $\widehat{\boldsymbol{\beta}}_{\text{GLS}}$ (Eq. 17.18a) and choosing `bayesian`

4. This number is set in the Cohiba model file using the element `<max-obs-direct-estim-trend-coef>`. The current default is 200

amounts to using $\widehat{\boldsymbol{\beta}}_{\text{Bayes}}$ (Eq. 17.21a or Eq. 17.22a). Choosing `simple` amounts to skipping estimation and use the prior guess $\boldsymbol{\beta}_0$ (Eq. 17.20).

The depth trend uncertainty (depth trend error) is given by

$$\widehat{\sigma}^l(\mathbf{x}) = \sqrt{{\sigma^l}^2(\mathbf{x}) + \mathbf{f}^{l\prime}(\mathbf{x})\widehat{\boldsymbol{\Sigma}}\,\mathbf{f}^l(\mathbf{x})}, \tag{17.24}$$

where the covariance estimate, $\widehat{\boldsymbol{\Sigma}}$, depends on the estimation methods. This map can be written to file using the element `<depth-trend-error>`. The surface residual variance, ${\sigma^l}^2(\mathbf{x})$, is given by (compare Eq. 17.16)

$$\begin{aligned} {\sigma^l}^2(\mathbf{x}) &= \text{Var}\{\epsilon^l(\mathbf{x})\} = \sum_{i\in\mathcal{I}^l} \text{Var}\{\Delta\epsilon_i(\mathbf{x})\} \\ &= \sum_{i\in\mathcal{I}^l} \sigma_i^2(\mathbf{x}). \end{aligned} \tag{17.25}$$

The estimation method is chosen by `<kriging-method>`; see discussion above. Choosing `simple` means that $\widehat{\boldsymbol{\Sigma}} = \mathbf{0}$.

Eq. 17.24 ignores the local adaption to well points. The first part is the contribution from the residuals. The second part is the contribution from the uncertainty in the estimates of the coefficients. For simple kriging the last term vanishes since the coefficients are assumed to be known.

17.3.4 Quality control of the trend estimation

The quality control consist of two main objectives: Removing corrupted well points and checking that the trend coefficient estimates are reliable.

17.3.4.1 Outliers and leverage points

Outliers (Weisberg, 1985, pp. 114–118) are well points that match the trends poorly. This might be an indication that the well points are corrupted. Consider all trend estimates at the well points and organize them in an N dimensional vector similar to $\mathbf{Z}$. They are obtained by

$$\widehat{\mathbf{m}} = \mathbf{F}\,\widehat{\boldsymbol{\beta}}. \tag{17.26}$$

Denote $\mathbf{Z}_n, \widehat{\mathbf{m}}_n$ etc. as the values belonging to well point n.

Outliers are identified by calculating a t-value for every well point

$$\mathbf{t}_n = \frac{|\mathbf{z}_n - \widehat{\mathbf{m}}_n|}{\sqrt{\mathbf{K}_{nn}}}, \qquad \text{for } n = 1, \ldots, N, \tag{17.27}$$

with the classification rules:[5]

$$\text{If} \quad \mathbf{t}_n \geq \begin{cases} 1.95996 & \text{then } n \text{ is an outlier (5\%).} & \text{Action: Flag for inspection.} \\ 2.57583 & \text{then } n \text{ might be an error (1\%).} & \text{Action: Add uncertainty.} \\ 3.09023 & \text{then } n \text{ is an error. (0.2\%).} & \text{Action: Delete.} \end{cases} \tag{17.28}$$

The uncertainty added to a well point classified as a possible error is $\sigma = |\mathbf{z}_n - \widehat{\mathbf{m}}_n|/2$.

The thresholds can be changed using `<t-value-outlier>`, `<t-value-severe-outlier>`, and `<t-value-error>`.

Leverage points are well points that influence the estimated trend coefficients strongly. A corrupted leverage point might not be identified as an outlier because the trend coefficient estimates adapts to the well point.

5. Percentages are the fraction of data classified if $\mathbf{t}_n$ has a normal distribution. This is a good approximation if $N \gg P$.

Using Eq. 17.18a gives

$$\widehat{\mathbf{m}} = \mathbf{F}\,\widehat{\boldsymbol{\beta}}_{\text{GLS}} = \mathbf{H}\,\mathbf{Z}, \tag{17.29}$$

where the so-called hat matrix[6], $\mathbf{H}$, is

$$\mathbf{H} = \mathbf{F}\big(\mathbf{F}'\,\mathbf{K}^{-1}\mathbf{F}\big)^{-1}\mathbf{F}'\,\mathbf{K}^{-1}. \tag{17.30}$$

Consider

$$\mathbf{h}_n = \frac{\partial\,\widehat{\mathbf{m}}_n}{\partial \mathbf{Z}_n} = \mathbf{H}_{nn} \qquad \big(h_n \in [0,1]\big). \tag{17.31}$$

Large $\mathbf{h}_n$ values indicates that the observed depth value, $\mathbf{Z}_n$, at well point n, has large influence on the estimated trend, $\widehat{\mathbf{m}}_n$, at that well point. Note that this analysis is only possible when $\text{rank}(\mathbf{F}) = P$ so that $\mathbf{H}$ exist. This often fails.

A well point n is classified as a leverage point using the following classification rule:

$$\text{If} \quad \mathbf{h}_n \geq 2 \cdot P/N \quad \text{then } n \text{ is a leverage point.} \quad \text{Action: Flag for inspection.} \tag{17.32}$$

Leverage points are seldom classified as outliers using Eq. 17.27 since the estimate is highly influenced by the well points depth value. An alternative is to use the Studentized residuals (Weisberg, 1985, pp. 113-116):

$$\mathbf{t}_n^{\text{Student}} = \frac{|\mathbf{z}(\mathbf{x}_n) - \widehat{\mathbf{m}}_n|}{\sqrt{\mathbf{K}_{nn}}\sqrt{1-\mathbf{h}_n}}, \tag{17.33}$$

which will identify outliers that are leverage points using the criteria in Eq. 17.28. Cohiba uses $\mathbf{t}_n^{\text{Student}}$ rather than $\mathbf{t}_n$ for classifying outliers when $\mathbf{t}_n^{\text{Student}}$ is available, that is, when $\text{rank}(\mathbf{F}) = P$.

The `welldata.log` file contains one row for each well point. It is the most important source of information for analyzing the consistency between well points and trends. All columns in `welldata.log` are described in Table 7.3 The formulas used for the calculating the values in `welldata.log` are listed in Table 17.1.

17.3.4.2 Checking the trend coefficient estimates

The trend coeficients, $\boldsymbol{\beta}$, are distributed according to the the prior guess, $N(\boldsymbol{\beta}_0, \boldsymbol{\Sigma}_0)$, the least squares estimates (GLS or WLS), $N(\widehat{\boldsymbol{\beta}}_{\text{xLS}}, \widehat{\boldsymbol{\Sigma}}_{\text{xLS}})$, or the posterior estimate, $N(\widehat{\boldsymbol{\beta}}_{\text{Bayes}}, \widehat{\boldsymbol{\Sigma}}_{\text{Bayes}})$. Interesting checks are to compare prior versus xLS and Bayesian estimates for both expectation and standard error. Check if

$$\boldsymbol{\Sigma}_{0,pp} > \widehat{\boldsymbol{\Sigma}}_{\text{xLS},pp}. \tag{17.34}$$

Violation of this means that the prior distribution carry more information than the well points. This is not a healthy sign if there is a lot of data. However, this situation is common when there is little data supporting the estimation of a particular trend coefficient.

The following inequality is always satisfied:

$$\widehat{\boldsymbol{\Sigma}}_{\text{Bayes},pp} \leq \begin{cases} \boldsymbol{\Sigma}_{0,pp} \\ \widehat{\boldsymbol{\Sigma}}_{\text{xLS},pp}. \end{cases} \tag{17.35}$$

Note that $\widehat{\boldsymbol{\Sigma}}_{\text{xLS}}$ fails to exist if the least squares problem has a non-unique solution, that is, $\text{rank}(\mathbf{F}) < P$.

6. The name, hat matrix, comes from the observation that $\mathbf{H}$ puts the hat on $\mathbf{Z}$. According to Eq. 17.26: $\widehat{\mathbf{m}} = \mathbf{H}\,\mathbf{Z}$.

Table 17.1. Formulas used in `welldata.log` for well point n. See Table 7.3 for description of all columns in `welldata.log`.

Column name	Value	Comment
`PriorTrend`	$m_0^{l_n}(\mathbf{x}_n) = \mathbf{f}^{l_n\,\prime}(\mathbf{x}_n) \cdot \boldsymbol{\beta}_0$	Prior guess on trend.
`EstimTrend`	$\widehat{m}_{\text{xLS}}^{l_n}(\mathbf{x}_n) = \mathbf{f}^{l_n\,\prime}(\mathbf{x}_n) \cdot \widehat{\boldsymbol{\beta}}_{\text{xLS}}$	Only relevant for universal and Bayesian kriging.
`PostTrend`	$\widehat{m}_{\text{Bayes}}^{l_n}(\mathbf{x}_n) = \mathbf{f}^{l_n\,\prime}(\mathbf{x}_n) \cdot \widehat{\boldsymbol{\beta}}_{\text{Bayes}}$	Only relevant for Bayesian kriging.
`SimTrend`	$m^{l_n,s}(\mathbf{x}_n) = \mathbf{f}^{l_n\,\prime}(\mathbf{x}_n) \cdot \boldsymbol{\beta}^s$	Simulated trend.
`PriorTrendUncert`	$\sigma_0^{l_n}(\mathbf{x}_n) = \sqrt{\mathbf{f}^{l_n\,\prime}(\mathbf{x}_n)\boldsymbol{\Sigma}_0\,\mathbf{f}^{l_n}(\mathbf{x}_n)}$	Prior guess on uncertainty.
`EstimTrendUncert`	$\widehat{\sigma}_{\text{xLS}}^{l_n}(\mathbf{x}_n) = \sqrt{\mathbf{f}^{l_n\,\prime}(\mathbf{x}_n)\widehat{\boldsymbol{\Sigma}}_{\text{xLS}}\,\mathbf{f}^{l_n}(\mathbf{x}_n)}$	Only relevant for universal and Bayesian kriging.
`PostTrendUncert`	$\widehat{\sigma}_{\text{Bayes}}^{l_n}(\mathbf{x}_n) = \sqrt{\mathbf{f}^{l_n\,\prime}(\mathbf{x}_n)\widehat{\boldsymbol{\Sigma}}_{\text{Bayes}}\,\mathbf{f}^{l_n}(\mathbf{x}_n)}$	Only relevant for Bayesian kriging.
`TrendUncertRed`	$100 \cdot \frac{\sigma_0(\mathbf{x}_n) - \widehat{\sigma}_{\text{Bayes}}(\mathbf{x}_n)}{\widehat{\sigma}_{\text{Bayes}}(\mathbf{x}_n)}$	Only relevant for Bayesian kriging.
`MeasUncert`	$\sigma_{\text{meas}}^{l_n}(\mathbf{x}_n)$.	User specified measurement uncertainty. (Usually zero.)
`TotMeasUncert`	$\sqrt{{\sigma^{l_n}}_{\text{meas}}^{2}(\mathbf{x}_n) + {\sigma^{l_n}}_{\text{aut.add.}}^{2}(\mathbf{x}_n)}$	User specified + automatically added uncertainty.
`Residual`	$z^{l_n}(\mathbf{x}_n) - \widehat{m}^{l_n}(\mathbf{x}_n)$.	Data − estimated trend.
`ResidualUncert`	$\sigma^{l_n}(\mathbf{x}_n) = \sqrt{\mathbf{K}_{nn}}$, see Eq. 17.25.	Specified residual uncertainty.
`TotUncert`	$\widehat{\sigma}^{l_n}(\mathbf{x}_n)$, see Eq. 17.24	Residual uncertainty + trend uncertainty.
`Mismatch`	$z^{l_n}(\mathbf{x}_n) - z_{\text{interp.}}^{l_n}(\mathbf{x}_n)$	$z_{l_n\,\text{interp.}}(\mathbf{x}_n)$ is the bilinear interpolation of the four closest values in grid.
`h`	$\mathbf{h}_n = \mathbf{H}_{nn}$	Used to detect leverage points.
`t`	$\mathbf{t}_n$, see Eq. 17.27.	Used to detect outliers.
`tStud`	$\mathbf{t}_n^{\text{Student}}$, see Eq. 17.33.	Used to detect outliers when avaialable.

Too many trend coefficients compared to the number of data gives inaccurate estimates. A simple t-statistic is again efficient:

$$t_p = \widehat{\beta}_p / \sqrt{\widehat{\boldsymbol{\Sigma}}_{pp}}. \tag{17.36}$$

Finding $t_p < 2$ is a *possible* sign of a trend not supported by the well data.

The `trend_estimation.log` has one row for each trend coefficient. The six first columns identify the coefficient (interval, surfaces, number of well points etc.). The next columns are described in Table 17.2.

17.4 Prediction of surfaces using kriging

Cohiba uses kriging for interpolation and extrapolation between well points.

The user choose the kriging method by selecting `universal`, `bayesian`, or `simple` in the element `<kriging-method>` in the Cohiba model file. The predicted depth for all these three choices is

Table 17.2. Formulas used in `trend_estimation.log` for trend coefficient p. See Table 7.2 for description of all columns in `trend_estimation.log`.

Column name	Value	Comment
`PriorMean`	$\boldsymbol{\beta}_{0p}$	Prior guess on coefficient. (User specified.)
`EstimMean`	$\widehat{\boldsymbol{\beta}}_{\text{xLS},p}$	Estimated coefficient (least squares). This might fail to exist if there are to few data.
`PostMean`	$\widehat{\boldsymbol{\beta}}_{\text{Bayes},p}$	Posterior mean. This value is calculated if `<kriging-method>` is `bayesian` *or* least squares estimation fails.
`PostMeanUpd`	$\widehat{\boldsymbol{\beta}}_{\text{Bayes},p}$	Posterior mean including zone log information.
`SimMean`	$\boldsymbol{\beta}_p^s$	Simulated value. The value is drawn for estimated or posterior distribution depending on `<kriging-method>`.
`PriorUncert`	$\sqrt{\boldsymbol{\Sigma}_{0,pp}}$	Prior standard deviation.
`EstimUncert`	$\sqrt{\widehat{\boldsymbol{\Sigma}}_{\text{xLS},pp}}$	Estimation standard deviation.
`PostUncert`	$\sqrt{\widehat{\boldsymbol{\Sigma}}_{\text{Bayes},pp}}$	Posterior standard deviation.
`PostUncertUpd`	$\sqrt{\widehat{\boldsymbol{\Sigma}}_{\text{Bayes},pp}}$	Posterior standard deviation including zone log information.
`UncertRed`	$100\frac{\sqrt{\widehat{\boldsymbol{\Sigma}}_{\text{Bayes},pp}}-\sqrt{\boldsymbol{\Sigma}_{0,pp}}}{\sqrt{\boldsymbol{\Sigma}_{0,pp}}}$	Uncertainty reduction in percent.
`tPrior`	$\boldsymbol{\beta}_{0p}/\sqrt{\boldsymbol{\Sigma}_{0,pp}}$	t-statistic for prior guess.
`tEstim`	$\widehat{\boldsymbol{\beta}}_{\text{xLS},p}/\sqrt{\widehat{\boldsymbol{\Sigma}}_{\text{xLS},pp}}$	t-statistic for estimated coefficient.
`tPost`	$\widehat{\boldsymbol{\beta}}_{\text{Bayes},p}/\sqrt{\widehat{\boldsymbol{\Sigma}}_{\text{Bayes},pp}}$	t-statistic for posterior estimate.

given by the so-called kriging predictor:

$$Z^{*l}(\mathbf{x}) = \widehat{m}^l(\mathbf{x}) + \mathbf{k}^{l\prime}(\mathbf{x})\,\mathbf{K}^{-1}\big(\mathbf{Z} - \widehat{\mathbf{m}}\big), \tag{17.37}$$

where the N covariances

$$\mathbf{k}^{l\prime}(\mathbf{x}) = \mathrm{Cov}\big\{Z^l(\mathbf{x}), \mathbf{Z}\big\} \tag{17.38}$$

are calculated using Eq. 17.16 and $\widehat{m}^l(\mathbf{x})$ is the estimated depth trend given by Eq. 17.23. So the difference between the three available kriging methods is the choice of trend estimation.

Note that the kriging predictor consists of the estimated trend and the predicted residual:

$$\epsilon^{*l}(\mathbf{x}) = Z^{*l}(\mathbf{x}) - \widehat{m}^l(\mathbf{x}) = \mathbf{k}^{l\prime}(\mathbf{x})\,\mathbf{K}^{-1}\big(\mathbf{Z} - \widehat{\mathbf{m}}\big). \tag{17.39}$$

Estimating the trend is fast compared to predicting the residual at every grid node. To speed up the calculation of the residual, Cohiba calculates

$$\mathbf{w} = \mathbf{K}^{-1}\big(\mathbf{Z} - \widehat{\mathbf{m}}\big) \tag{17.40}$$

once, and use

$$\epsilon^{*l}(\mathbf{x}) = \mathbf{k}^{l\prime}(\mathbf{x}) \cdot \mathbf{w} \tag{17.41}$$

for every grid node. This is called the dual kriging system. The most time consuming task is therefore to calculate all the N covariances at every grid node for every surface.

The prediction errors (kriging error) that correspond to the three different kriging choices can not be formulated as one single formula, although they are closely related. The prediction errors are

$$\sigma^{*l^2}(\mathbf{x}) = \sigma^{l^2}(\mathbf{x}) - \mathbf{k}^{l'}(\mathbf{x})\mathbf{K}^{-1}\mathbf{k}^{l}(\mathbf{x}) \qquad \text{Simple kriging} \tag{17.42a}$$

$$\begin{aligned}\sigma^{*l^2}(\mathbf{x}) = \sigma^{l^2}(\mathbf{x}) &- \mathbf{k}^{l'}(\mathbf{x})\mathbf{K}^{-1}\mathbf{k}^{l}(\mathbf{x}) \\ &+ \left(\mathbf{f}^{l'}(\mathbf{x}) - \mathbf{k}^{l'}(\mathbf{x})\mathbf{K}^{-1}\mathbf{F}\right)\left(\mathbf{F}'\,\mathbf{K}^{-1}\mathbf{F}\right)^{-1} \\ &\cdot \left(\mathbf{f}^{l'}(\mathbf{x}) - \mathbf{k}^{l'}(\mathbf{x})\mathbf{K}^{-1}\mathbf{F}\right)'\end{aligned} \qquad \text{Universal kriging} \tag{17.42b}$$

$$\begin{aligned}\sigma^{*l^2}(\mathbf{x}) = \sigma^{l^2}(\mathbf{x}) &+ \mathbf{f}^{l'}(\mathbf{x})\,\boldsymbol{\Sigma}_0\,\mathbf{f}^{l}(\mathbf{x}) \\ &- \left(\mathbf{k}^{l'}(\mathbf{x}) + \mathbf{f}^{l'}(\mathbf{x})\boldsymbol{\Sigma}_0\mathbf{F}'\right)\left(\mathbf{K} + \mathbf{F}\,\boldsymbol{\Sigma}_0\,\mathbf{F}'\right)^{-1} \\ &\cdot \left(\mathbf{k}^{l'}(\mathbf{x}) + \mathbf{f}^{l'}(\mathbf{x})\boldsymbol{\Sigma}_0\,\mathbf{F}\right)'.\end{aligned} \qquad \text{Bayesian kriging} \tag{17.42c}$$

These expressions are more cumbersome to evaluate than the kriging predictor since we can't use the dual kriging system, Eq. 17.41, and must calculate the so-called kriging weights:

$$\mathbf{w}^{l'}(\mathbf{x}) = \mathbf{k}^{l'}(\mathbf{x})\mathbf{K}^{-1}. \tag{17.43}$$

This involves solving an N-dimensional linear equation system for every grid node for every surface. So execution time is longer when choosing to include the prediction error. This is chosen by `<depth-error>`.

To speed up calculations Cohiba divides the `<output-grid>` area into smaller rectangles[7]. A subset of the N well points are selected for each rectangle. The subset contains all well points within the rectangle as well as all well points within a neighborhood of the rectangle defined by the variogram ranges. The number of well points in the subset and therefore the size of $\mathbf{Z}$, $\mathbf{F}$, $\mathbf{k}(\mathbf{x})$ and $\mathbf{K}$, can be dramatically reduced in this way giving short execution time even with thousands of well points.

It is easy to see that Bayesian kriging becomes simple kriging if $\boldsymbol{\Sigma}_0 \to \mathbf{0}$ since all expressions involving $\boldsymbol{\Sigma}_0$ vanish. It is also possible to show that Bayesian kriging becomes unversal kriging if $\boldsymbol{\Sigma}_0 \to \boldsymbol{\infty}$ (Omre and Halvorsen, 1989). This limit is not numerically stable so we discourage the specification of large uncertainties in $\boldsymbol{\Sigma}_0$.

17.4.1 Measurement errors

Cohiba gives the possibility of considering vertical measurement errors in the well data. The measurement errors can be specified by the user and it is automatically added when Cohiba detects inconsistent well points at the same map location.

The user may add measurement errors to well points by using the last column in the Cohiba well points file. It is also possible to specify a vertical error (uncertainty) log for the well path using `<z-stddev-log-name>`.

A measurement error, ϵ^{err}, in the well points is introduced as

$$Z^{l\,\text{data}}(\mathbf{x}) = m^{l}(\mathbf{x}) + \epsilon^{l}(\mathbf{x}) + \epsilon^{l\,\text{err}}(\mathbf{x}). \tag{17.44}$$

The measurement uncertainty is assumed to be a Gaussian distributed error with zero expectation. It is assumed that the measurement error and the depth residual are uncorrelated.

The equations for the trend coefficient estimates and the kriging equations are unaltered, but the

7. Cohiba subdivides into rectangles and uses well points from neighborhoods if the number of well points exceed the number set by .

kriging matrix, $\mathbf{K}$, that is, the covariances between well points, is modified:

$$\begin{aligned}\mathbf{K} &= \mathrm{Var}\left\{\mathbf{Z}^{\mathrm{data}}\right\} \\ &= \mathrm{Var}\{\boldsymbol{\epsilon}\} + \mathrm{Var}\{\boldsymbol{\epsilon}^{\mathrm{err}}\}\,.\end{aligned} \tag{17.45}$$

The measurement errors specified in the Cohiba well points file are assumed independent by default, so that only the diagonal of $\mathbf{K}$ is affected. This can be modified by introducing correlated errors for well points using `<variogram>`. The measurement error specified by the error log is assumed correlated along the well path. This correlation can be modified using `<variogram>`.

The surfaces themselves have no measurement errors. So the measurement errors does not affect $\mathbf{k}^l(\mathbf{x})$ in the kriging predictor since $\mathbf{k}^l(\mathbf{x})$ is the covariances between all the well points and surface l at $\mathbf{x}$.

Adding measurement errors implies that the kriging predictor is no longer a perfect interpolator. This means that the predicted or simulated surfaces will not honor the well points exactly. Measurement errors will also increase the uncertainty in the trend coefficient estimates.

17.5 Depth conversion

Cohiba uses vertical depth conversion defined by the basic kinematic relation

$$z = v \cdot \Delta t, \tag{17.46}$$

where v is the *interval velocity* and Δt is the seismic *travel time* in the interval.

The interval velocities are not exactly known so they are modeled as the sum of an interval velocity trend and an interval velocity residual:

$$V_i(\mathbf{x}) = v_i(\mathbf{x}) + \epsilon_{v,i}(\mathbf{x}). \tag{17.47}$$

The interval velocity trend

$$v_i(\mathbf{x}) = \mathbf{f}_i{}'(\mathbf{x}) \cdot \boldsymbol{\beta}_i \tag{17.48}$$

consist of known trend maps $\mathbf{f}_i{}'(\mathbf{x})$ and the trend coefficients $\boldsymbol{\beta}_i$. The trends have exactly the same form as the interval thickness trend in Eq. 17.5. The interval velocity residuals, $\epsilon_{v,i}(\mathbf{x})$, are zero mean Gaussian random fields and they are assumed to be independent to residuals from other intervals. The residual models local interval velocity variations that the interval velocity trend is unable to capture.

The seismic travel times are modeled as

$$T^l(\mathbf{x}) = t^l(\mathbf{x}) + \epsilon_t^l(\mathbf{x}), \tag{17.49}$$

where $t^l(\mathbf{x})$ is the interpreted travel times to surface l and the travel time residual $\epsilon_t^l(\mathbf{x})$ is a zero mean Gaussian random field that accounts for measurement errors and interpretation uncertainty. The travel time residuals for different surfaces are assumed independent[8].

By inserting the interval velocity model and the travel time model into the basic kinematic relation Eq. 17.46, we get

$$\Delta Z_i(\mathbf{x}) = V_i(\mathbf{x})\, \Delta T_i(\mathbf{x}), \tag{17.50}$$

where $\Delta T_i(\mathbf{x})$ is the difference between $T^l(\mathbf{x})$ at the base and at the top of interval i.

According to Eq. 17.1 the depth to a surface l is obtained by adding (or subtracting) intervals:

$$Z^l(\mathbf{x}) = \sum_{i \in \mathcal{I}^l} \Delta Z_i(\mathbf{x}), \tag{17.51}$$

where $\mathcal{I}^l$ is the set of intervals that contributes to surface l. This general notation is inconvenient for explaining depth conversion of a set of surfaces. Therefore, the notation is simplified by assuming a set of stacked intervals that can be ordered by the surfaces between them. This makes it possible to replace the sum over all contributing intervals by an ordinary sum over surface and interval order:[9]

$$Z^l(\mathbf{x}) = \sum_{i=1}^{l} \Delta Z_i(\mathbf{x}). \tag{17.52}$$

8. The assumption of independence is unreasonable when two reflectors are close. It is therefore possible to relax this assumption. See `<correlate-close-reflectors>` for details.
9. Note that Cohiba always uses the general form Eq. 17.51 so Eq. 17.52 is only used to simplify the notation when explaining the details of the error models used for travel times and interval velocities.

This sum can be expanded and reordered in the following way:

$$
\begin{aligned}
Z^l(\mathbf{x}) &= \sum_{i=1}^{l} V_i(\mathbf{x})\,\Delta T_i(\mathbf{x}) \\
&= \sum_{i=1}^{l} \Big(v_i(\mathbf{x}) + \epsilon_{v,i}(\mathbf{x})\Big)\,\Big(t^i(\mathbf{x}) + \epsilon_t^i(\mathbf{x}) - t^{i-1}(\mathbf{x}) - \epsilon_t^{i-1}(\mathbf{x})\Big), \\
&= \sum_{i=1}^{l} v_i(\mathbf{x})\,\Big(t^i(\mathbf{x}) - t^{i-1}(\mathbf{x})\Big) + \epsilon_{v,i}(\mathbf{x})\,\Big(t^i(\mathbf{x}) - t^{i-1}(\mathbf{x})\Big) \\
&\quad + v_i(\mathbf{x})\,\Big(\epsilon_t^i(\mathbf{x}) - \epsilon_t^{i-1}(\mathbf{x})\Big) + \epsilon_{v,i}(\mathbf{x})\,\Big(\epsilon_t^i(\mathbf{x}) - \epsilon_t^{i-1}(\mathbf{x})\Big) \\
&= \sum_{i=1}^{l} v_i(\mathbf{x})\,\Delta t_i(\mathbf{x}) + \epsilon_{v,i}(\mathbf{x})\,\Delta t_i(\mathbf{x}) + v_i(\mathbf{x})\,\Big(\epsilon_t^i(\mathbf{x}) - \epsilon_t^{i-1}(\mathbf{x})\Big) + \mathcal{O}(\epsilon^2),
\end{aligned}
\tag{17.53}
$$

where $\Delta t_i(\mathbf{x}) = t^i(\mathbf{x}) - t^{i-1}(\mathbf{x})$. This can be written as

$$
Z^l(\mathbf{x}) = \sum_{i=1}^{l}\Big(\Delta m_i(\mathbf{x}) + \Delta\epsilon_i(\mathbf{x})\Big) + \epsilon_z^l(\mathbf{x}) + \sum_{i=1}^{l-1}\Delta\epsilon_t^i(\mathbf{x}) + \mathcal{O}(\epsilon^2),
\tag{17.54}
$$

where

$$
\begin{aligned}
\Delta m_i(\mathbf{x}) &= v_i(\mathbf{x})\,\Delta t_i(\mathbf{x}) \\
&= \big(\mathbf{f}_i{}'(\mathbf{x}) \cdot \boldsymbol{\beta}_i\big)\,\Delta t_i(\mathbf{x}) \qquad \text{(see Eq. 17.48)}
\end{aligned}
\tag{17.55a}
$$

$$
\Delta\epsilon_i(\mathbf{x}) = \epsilon_{v,i}(\mathbf{x})\,\Delta t_i(\mathbf{x})
\tag{17.55b}
$$

$$
\epsilon_z^l(\mathbf{x}) = \epsilon_t^l(\mathbf{x})\,v_l(\mathbf{x})
\tag{17.55c}
$$

$$
\Delta\epsilon_t^i(\mathbf{x}) = \epsilon_t^i\,\Big(v_i(\mathbf{x}) - v_{i+1}(\mathbf{x})\Big)
\tag{17.55d}
$$

$$
\mathcal{O}(\epsilon^2) = \sum_{i=1}^{l}\epsilon_{v,i}(\mathbf{x})\,\Big(\epsilon_t^i(\mathbf{x}) - \epsilon_t^{i-1}(\mathbf{x})\Big).
\tag{17.55e}
$$

These five contributions deserves some explanations:

$\Delta m_i(\mathbf{x})$ is the interval thickness trend formed by the interval velocity trend multiplied by the interpreted interval travel time. This thickness trend enters the surface models similar to interval thickness trend in Eq. 17.2.

$\Delta\epsilon_i(\mathbf{x})$ is the interval thickness residual obtained by multiplying the interval velocity residual by the interval travel time. This residual plays the exact same role as the interval thickness residual in Eq. 17.2.

$\epsilon_z^l(\mathbf{x})$ is a *depth residual* at surface l caused by the travel time uncertainty at surface l multiplied by the interval velocity in the interval above surface l. This residual is unique for seismic reflectors and have no parallel when considering interval thickness models.

$\Delta\epsilon_t^i(\mathbf{x})$ is a residual caused by the travel time uncertainties at all surfaces i above surface l. The residual is proportional to the interval velocity *contrast*, $v(\mathbf{x}) - v_{i+1}(\mathbf{x})$, at surface i. This residual is usually small compared to the depth residual, $\epsilon_z^l(\mathbf{x})$, since the interval velocity contrasts are small compared to the interval velocities[10].

10. The predecessor of Cohiba called HORIZON ignored this residual since it is dominated by the depth residual and the interval thickness residuals.

$\mathcal{O}(\epsilon^2)$ is the sum of all products of two residuals. This second order residual is ignored in the calculations since it would destroy the Gaussianity and thereby make it impossible to use the efficient methods used by Cohiba for prediction and conditional simulation. Ignoring $\mathcal{O}(\epsilon^2)$ is a good approximation since the product of two residuals will be small compared to other residuals given the reasonable assumptions that $t(\mathbf{x}) \gg \mathrm{Var}\{\epsilon_t^l(\mathbf{x})\}^{1/2}$ and $v_i(\mathbf{x}) \gg \mathrm{Var}\{\epsilon_{v,i}(\mathbf{x})\}^{1/2}$.

The principal difference between Eq. 17.1 for interval thickness models and Eq. 17.54 for interval velocity models are the additional residuals $\epsilon_z^l(\mathbf{x})$ and $\Delta\epsilon_t^i(\mathbf{x})$. These will enter the calculation of covariances so that for instance Eq. 17.16 must include contributions from these additional residuals.

Cohiba allows any combination of thickness interval models and velocity interval models. This may become quite complex when combined with the possibility to use multiple models (Section 11). However, Cohiba keeps track of the bookkeeping so this is not a problem.

17.6 Gridding effects

Cohiba represents surfaces and trend maps on regular grids. Well data however, are located at arbitrary locations and these are rarely at the grid nodes. Cohiba must therefor interpolate grid values at well data locations and this introduces an approximation.

Kriging is an exact interpolation technique and will always honor the well points provided that no measurement error has been introduced. However, Since Cohiba represent surfaces by regular grids so kriging is only performed at grid nodes. This implies that comparing surfaces to well points will always give a small gridding error unless the well point is located at a grid node. This is illustrated in Figure 17.1. The gridding error is reported in the `welldata.log` file as `Mismatch`. A similar problem will occur along well paths.

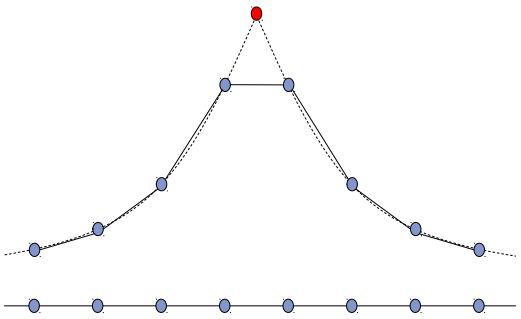


Figure 17.1. Vertical cross section of a surface. Grid nodes are marked as grey dots. A single well point is marked as a red dot. The dotted line is the kriging predictor and the solid line is a approximation by linear interpolation between the grid nodes. The gridding error is the vertical difference between the red dot and the line connecting the two grid nodes.

The gridding error is by default removed in the post processing. The four grid nodes closest to well points and sample points along the well paths are modified so that bilinear interpolation of these nodes will give perfect match at all the well points and sample points. All the affected grid nodes are adjusted so that the sum of all adjustments is as small as possible. There are rare situations where this approach will fail. The adjustment of grid nodes around well points can be turned off by `<make-surfaces-interpolate-well-points>` and the adjustment of grid nodes along sample paths can be turned off by `<allow-small-surface-adjustment-at-sample-points>`.

17.6.1 Bilinear interpolation

Bilinear interpolation provides a simple and fast way of interpolating four grid node values at any point inside a rectangular cell and is therefore widely used. Cohiba uses bilinear interpolation to interpolate trend values at well points and sample points.

Consider a rectangle defined by the four corners (x_1, y_1), (x_1, y_2), (x_2, y_1), and (x_2, y_2) and assume that a function $f(x, y)$ is known at these four corners. Bilinear interpolation provides an approximation to $f(x, y)$ at any arbitrary location in that rectangle and is defined as

$$f_{BL}(x,y) = c_{11}\, f(x_1,y_1) + c_{21}\, f(x_2,y_1) + c_{12}\, f(x_1,y_2) + c_{22}\, f(x_2,y_2), \quad \text{for} \quad x_1 \geq x \geq x_2, \text{ and } y_1 \geq y \geq y_2, \tag{17.56}$$

where

$$c_{11} = \frac{(x_2 - x)(y_2 - y)}{\Delta_x\, \Delta_y} \qquad c_{21} = \frac{(x - x_1)(y_2 - y)}{\Delta_x\, \Delta_y}$$

$$c_{12} = \frac{(x_2 - x)(y - y_1)}{\Delta_x\, \Delta_y} \qquad c_{22} = \frac{(x - x_1)(y - y_1)}{\Delta_x\, \Delta_y}$$

$$\Delta_x = x_2 - x_1 \qquad \Delta_y = y_2 - y_1.$$

Note that the weights sum to one: $c_{11} + c_{21} + c_{12} + c_{22} = 1$. The weights, c_{ij}, are proportional to the area of the rectangle opposite to the corner point. This is illustrated in Figure 17.2.

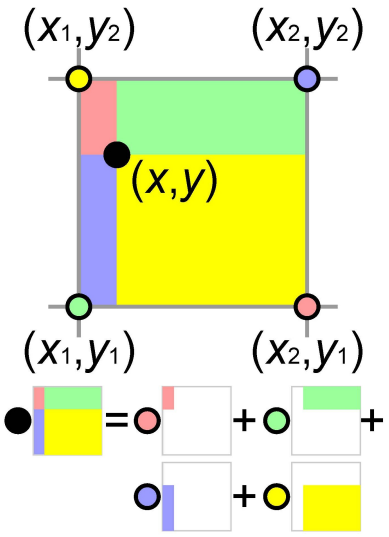
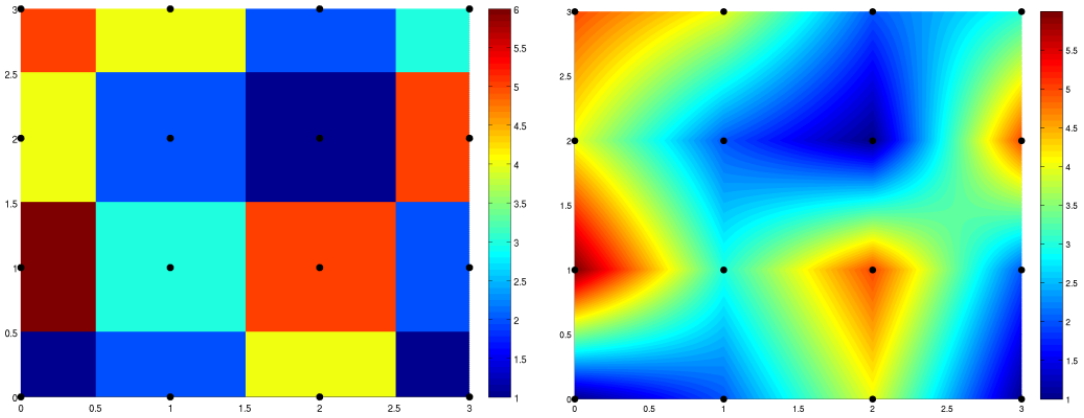


Figure 17.2. Illustration of bilinear interpolation. The value at the black dot, (x, y), is the weighted average of the values at the colored dots, (x_i, y_j); $i, j = 1, 2$, where the weights are proportional to the area of the rectangle of the same color. The illustration is taken from Wikipedia.

The bilinear interpolation surface is continuous but the derivatives are discontinuous perpendicular to cell edges. The bilinear interpolation surface follow straight lines along the x- and y-direction of the grid. Following any direction not parallel with the x- or y-direction gives a second order polynomial. Bilinear interpolation is illustrated in Figure 17.3.



(a) Nearest neighbor interpolation (b) Bilinear interpolation

Figure 17.3. The images show how interpolation is applied to a series of data points (black dots) in the box $[0, 3] \times [0, 3]$. Pictures are taken from www.codecogs.com.

The integral of the bilinear interpolation in the rectangle is

$$\int_{x_1}^{x_2} \int_{y_1}^{y_2} f_{BL}(x, y)\, \mathrm{d}x\, \mathrm{d}y = \Delta_x\, \Delta_y\, \frac{f(x_1, y_1) + f(x_2, y_1) + f(x_1, y_2) + f(x_2, y_2)}{4}. \tag{17.57}$$

This can be used for finding volume of the rectangle between two surfaces. The situation is slightly more complicated for the volume between two crossing surfaces since only the positive part contribute. This is also possible to calculate analytically and is used when `<volume-calculation-method>` is `bilinear`.

18 Stochastic simulation

Stochastic simulation is chosen by selecting `simulation` in `<mode>`. Stochastic simulation generates a set of realizations by randomly drawing all the trend coefficients and all the Gaussian residuals. The trend coefficients are drawn from the posterior distributions and the Gaussian residuals are drawn conditioned on the well points and well paths. The number of realizations can be specified by `<number-of-realizations>`.

Cohiba uses a simulation algorithm for conditional simulation that is based on

$$Z^{l\,s}(\mathbf{x}) = m^{l\,s}(\mathbf{x}) + \epsilon^{l\,s}(\mathbf{x}) + \mathbf{k}^{l}(\mathbf{x})\mathbf{K}^{-1}\big(\mathbf{Z} - \mathbf{m}^{s} - \boldsymbol{\epsilon}^{s}\big), \tag{18.1}$$

where superscript s indicates simulated (randomly drawn) and where

$$m^{l\,s}(\mathbf{x}) = \mathbf{f}^{l\,\prime}(\mathbf{x}) \cdot \boldsymbol{\beta}^{s} \tag{18.2a}$$

$$\mathbf{m}^{s} = \mathbf{F}\,\boldsymbol{\beta}^{s} \tag{18.2b}$$

$$\epsilon^{l\,s}(\mathbf{x}) = \sum_{i \in \mathcal{I}^{l}} \Delta\epsilon_{i}^{s}(\mathbf{x}). \tag{18.2c}$$

Eq. 18.1 should be compared to the kriging predictor Eq. 17.37. The differences are that a simulated trend is used instead of an estimated trend, and a simulated residual, $\epsilon^{l\,s}(\mathbf{x})$, is added to the trend. Note that the marginal expectation and standard deviation of $Z^{l\,s}(\mathbf{x})$ are $Z^{*l}(\mathbf{x})$ and $\sigma^{*l}(\mathbf{x})$. It is possible to show that $Z^{l\,s}(\mathbf{x})$ has the correct conditional spatial covariance.

Expression Eq. 18.1 gives the following simulation algorithm:

1. Estimate the trend coefficients in the linear trends. The estimation method will depend on the chosen `<kriging-method>`.
2. Randomly draw the trend coefficients from the multi-normal distribution

   $$\boldsymbol{\beta}^{s} \sim N_{P}\big(\widehat{\boldsymbol{\beta}}, \widehat{\boldsymbol{\Sigma}}\big),$$

   where $\widehat{\boldsymbol{\beta}}$ and $\widehat{\boldsymbol{\Sigma}}$ are the estimated expectations and the estimation variances. Use the drawn coefficients to form the *simulated trends* (Eq. 18.2a).
3. Randomly draw all the interval residuals, $\Delta\epsilon_{i}^{s}(\mathbf{x})$, using a Fast Fourier Transform (FFT) algorithm. These simulated interval residuals are added to form the simulated surface residuals according to Eq. 18.2c.
4. The *simulated residuals* are added to the simulated trends to obtain the *unconditionally simulated surfaces* $m^{l\,s}(\mathbf{x}) + \epsilon^{l\,s}(\mathbf{x})$.
5. Extract the simulated trends and residuals at the well points to form the vectors $\mathbf{m}^{s}$ and $\boldsymbol{\epsilon}^{s}$. Subtract these simulated trend values from the well point depths, $\mathbf{Z}$, and add the simulated residuals to obtain the vector $\mathbf{Z} - \mathbf{m}^{s} + \boldsymbol{\epsilon}^{s}$.
6. The final step is to condition the unconditionally simulated surfaces to the well points by performing simple kriging. This is done by solving $\mathbf{k}^{l}(\mathbf{x})\mathbf{K}^{-1}\big(\mathbf{Z} - \mathbf{m}^{s} + \boldsymbol{\epsilon}^{s}\big)$ and adding the result to the unconditionally simulated surfaces.

The first and the last step are by far the most time consuming, and they are identical to the operations performed when doing deterministic modeling using the kriging predictor, Eq. 17.37. Therefore, the CPU time for prediction and stochastic simulation is comparable.

The stochastic simulation algorithm is accurate and will ensure perfect agreement with the specified model (trends, variograms, uncertainties, etc.) and the supplied data. The expectation of Eq. 18.1 gives the kriging predictor Eq. 17.37. So the average of a large number of simulated realizations will be almost identical to the kriging predictor. Also the (pointwise) variance of a large set of simulated realizations will be almost identical to the prediction errors. However, $\boldsymbol{\beta}^s$ is drawn independently of $R^{l^s}(\mathbf{x})$ and this is not strictly correct since these are dependent.

The simulated residuals, $\Delta\epsilon_i^s(\mathbf{x})$, are realizations from Gaussian random fields. These are drawn using a fast Fourier transform (FFT) simulation algorithm (Ripley, 1987, Algorithm 4.4, p. 110). The FFT algorithm reproduces any variogram almost perfect. It is by far superior to any other algorithm for stochastic simulation of unconditional Gaussian random fields including the two most common approaches: Sequential Gaussian Simulation (SGS) and turning bands. See e.g. Abrahamsen (1999) for details. Section 19 contains examples of simulated residuals.

18.1 Fast approximate simulation

Fast simulation is chosen by selecting `fast-simulation` in `<mode>`. The purpose is to generate many stochastic realizations fast at the cost of accuracy.

The approximate simulation algorithm is based on

$$Z^{l^s}(\mathbf{x}) = Z^{*l}(\mathbf{x}) + \left(m^{l^s}(\mathbf{x}) + \epsilon^{l^s}(\mathbf{x}) - \widehat{m}^l(\mathbf{x})\right)\frac{\sigma^{*l}(\mathbf{x})}{\widehat{\sigma}^l(\mathbf{x})} \tag{18.3a}$$

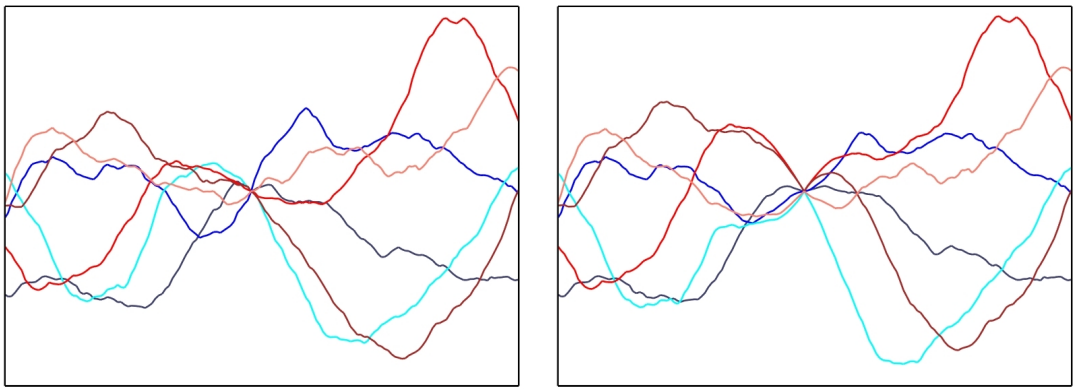
$$= Z^{*l}(\mathbf{x}) - \widehat{m}^l(\mathbf{x})\frac{\sigma^{*l}(\mathbf{x})}{\widehat{\sigma}^l(\mathbf{x})} + \left(m^{l^s}(\mathbf{x}) + \epsilon^{l^s}(\mathbf{x})\right)\frac{\sigma^{*l}(\mathbf{x})}{\widehat{\sigma}^l(\mathbf{x})}, \tag{18.3b}$$

where $m^{l^s}(\mathbf{x})$ and $\epsilon^{l^s}(\mathbf{x})$ are the simulated trends and residuals described by Eq. 18.2a and Eq. 18.2c. The marginal expectation and standard deviation of $Z^{l^s}(\mathbf{x})$ are $Z^{*l}(\mathbf{x})$ and $\sigma^{*l}(\mathbf{x})$. This is exactly the same as for the ordinary simulation obtained using and Eq. 18.1.

The difference between stochastic realizations made by the normal and the fast simulation algorithms are the spatial covariance structures close to well points. These are incorrect for the fast simulation approach. This is illustrated in Figure 18.1. The individual realizations from the fast simulation tend to make a sharp bend at the well point whereas individual realizations from the normal simulation pass the well point in a natural way. So well points may appear as bulls eyes in realizations made by the fast simulation algorithm. It is on the contrary impossible to detect the well points in realizations made by the ordinary simulation algorithm.

Calculating the prediction, $Z^{*l}(\mathbf{x})$, and in particular the prediction error, $\sigma^{*l}(\mathbf{x})$, takes a lot of CPU time. So making the first realization of a fast simulation takes more time than an ordinary simulation. Generating subsequent simulations however, is faster since $Z^{*l}(\mathbf{x})$ and $\sigma^{*l}(\mathbf{x})$ are reused. The most CPU demanding part of Eq. 18.3b for subsequent simulations is generating the Gaussian residuals, $\epsilon^{l^s}(\mathbf{x})$. The fast simulation is on the order of 3 – 5 times faster than the ordinary simulation.

When multiple models are in use (see Section 11) Cohiba calculates a set of weights for each model at every grid node. These calculations are time consuming. It is possible to calculate the weights on a coarser grid and save the weights for later use. Bilinear interpolation is used for interpolating the weights. The coarseness of the grid is determined by `<model-weight-resolution>`. We recommend to use 10 for fast simulation. This amounts to calculating the weights for every tenth grid node in both directions.



(a) Ordinary simulation (b) Fast approximate simulation

Figure 18.1. Cross section of six realizations conditioned on a single well point in the center. Note that the simulations in (a) and (b) coincide at the well point and outside the influence region of the well point. The influence region is determined by the variogram range.

18.2 Rejection sampling

Rejection sampling is a stochastic simulation technique tha can be used in simulation `<mode>` to draw realizations that are in agreement with some acceptance criteria.

Rejection sampling is a way of drawing perfect samples from a prior probability distribution conditioned on data such as well points or other constraints. The simple idea is to draw a random sample from the prior probability distribution and accept it as a realization if the sample is consistent with all the data. The set of realizations will be a perfect representation of the posterior distribution, that is the prior distribution constrained by the data.

Unfortunately, rejection sampling will often fail because the acceptance rate is too small. Just matching a single well point by coincidence is extremely unlikely and only possible because the computer has a finite numerical resolution. Therefore, conditioning to well points is done by calculating the posterior probability distribution using kriging and drawing from this probability distribution instead. Handling inequality constraints imposed by the well paths is also handled in this way.

Rejection sampling is used when the conditioning criteria are highly non-linear and no approximate analytic solution exist. Cohiba use rejection sampling to ensure that the following possible acceptance criteria are fulfilled: `<spill-point-above>`, `<spill-point-below>`, `<spill-point-at>`, and `<trap-larger-than>`. All of these criteria are related to spill point calculations triggered by the element `<spill-point>`. Note that it is possible to impose several acceptance criteria on multiple surfaces.

There is a risk of getting extremely high rejection (low acceptance) rates, and therefore extremely slow generation of accepted realizations. This is in particular true if multiple acceptance criteria are imposed. Cohiba will abort execution during the initial realizations if the rejection rate is higher than `<maximum-rejection-rate>`. The default maximum rejection rate is 90 %. The estimation of the rejection rate is performed during the first 10 % of the specified `<number-of-realizations>`. The estimation is performed during the 10 first simulations if the number of realizations is less than 100. If the estimated rejection rate is so high that it is improbable (less than 5 %) that it is less than the maximum rejection rate, then the simulation is aborted during these initial simulations. Cohiba will provide an estimate of the true rejection rate if the simulations are aborted.

If Cohiba estimates a rejection rate higher than `<maximum-rejection-rate>` the user must

make changes to obtain the required <number-of-realizations>. One possibility is to increase the <maximum-rejection-rate> and be patient. The alternative is to relax the <acceptance-criteria> or modify the stochastic model for the surfaces so that acceptance criteria are less challenging.

The average maps (see Section 7.1) will normally be similar to the predicted maps if the number of realizations is large[1]. This is not so if an <acceptance-criteria> apply, unless the rejection rate is zero. It is recommended to compare the predicted depth to the average map from a stochastic simulation. A difference shows that the acceptance criteria have a noticeable impact on the surface depths. It can also be interesting to compare the prediction error map to the empirical uncertainty (standard deviation) maps obtained from all the realizations. The empirical uncertainty maps are usually quite noisy but it is usually possible to see reduction in uncertainty due to the acceptance criteria.

For an example illustrating rejection sampling see Section 10.

1. In principle the average maps should approach the prediction exactly as the number of realizations becomes large. In practice this is not exactly so since Monte Carlo noise drops as slow as $1/\sqrt{n}$. Also, the prediction algorithms for well paths is an approximation and the simulation algorithm for `universal` and `bayesian` is an approximation. The approximation errors are minute but they may still make a small difference.

19 Variogram examples

This section contains some realizations made by stochastic simulation to illustrate different variograms specified by <type> in <variogram>. All realizations have the same expectation and standard deviation. The <range> is one fifth of the length of the sides. All realizations are generated using the same random <seed> so that many features appear similar.

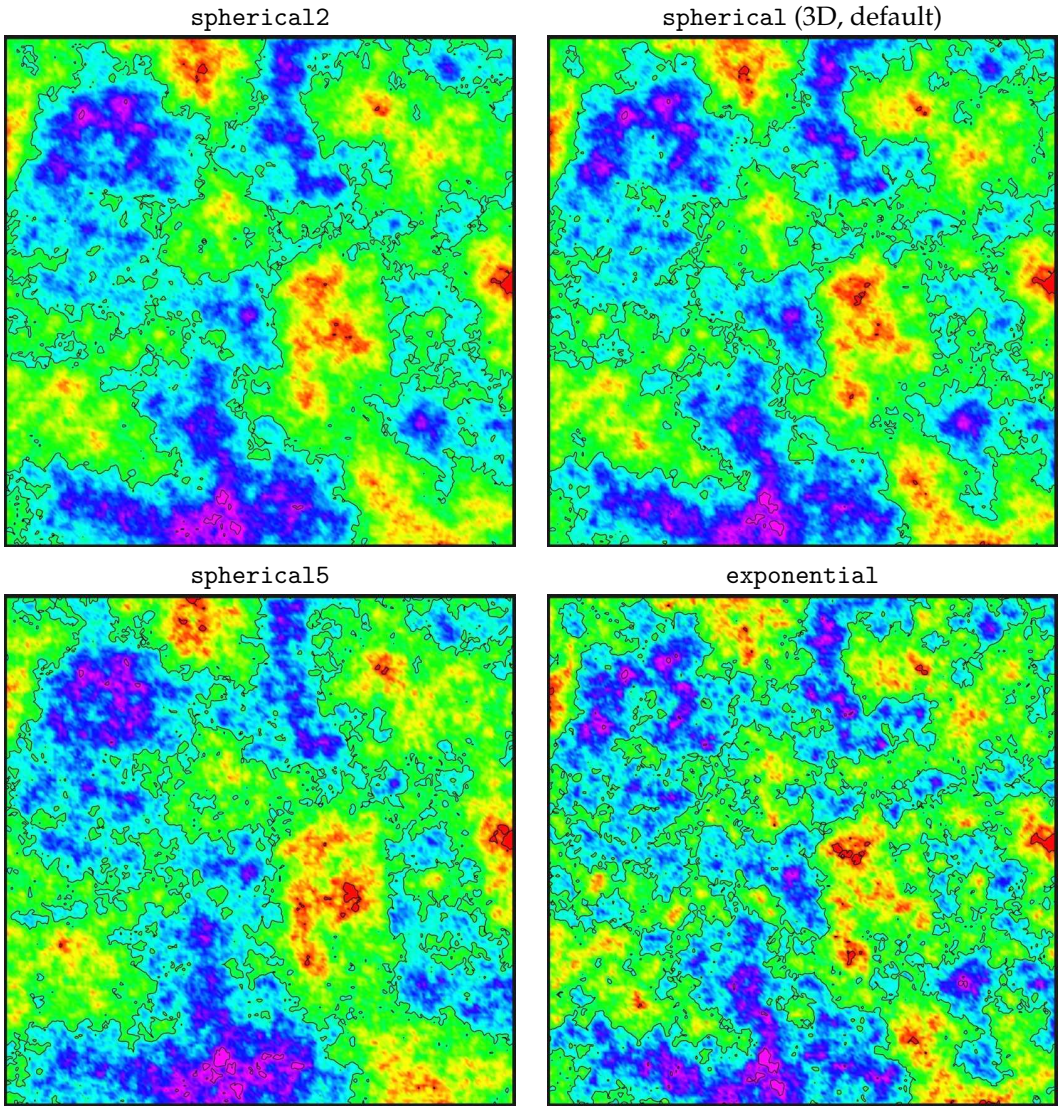


Figure 19.1. Spherical and exponential variograms.

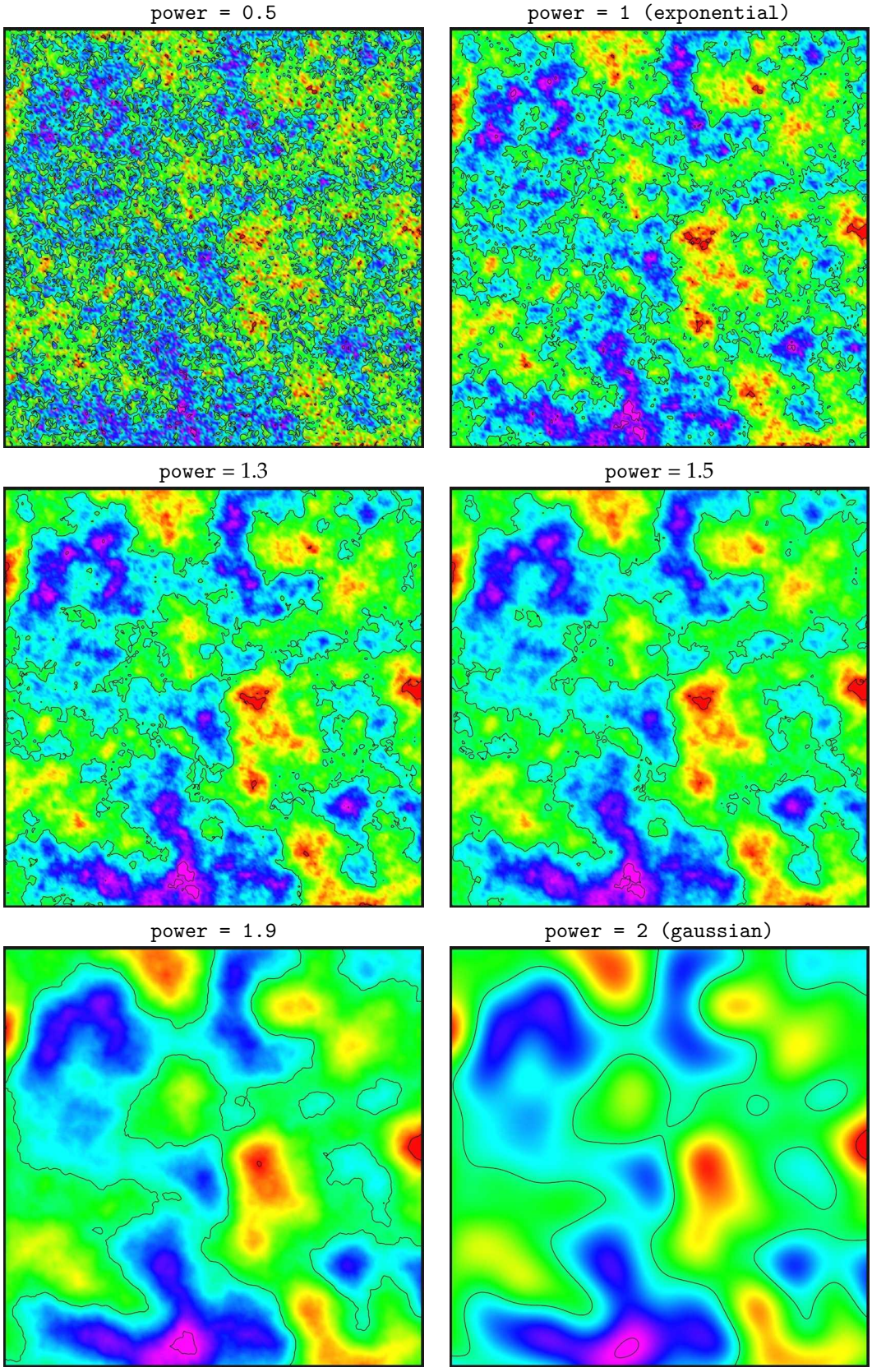


Figure 19.2. General exponential variograms for different <power>. Note that the exponential variogram is identical to power = 1 and the gaussian variogram is identical to power = 2.

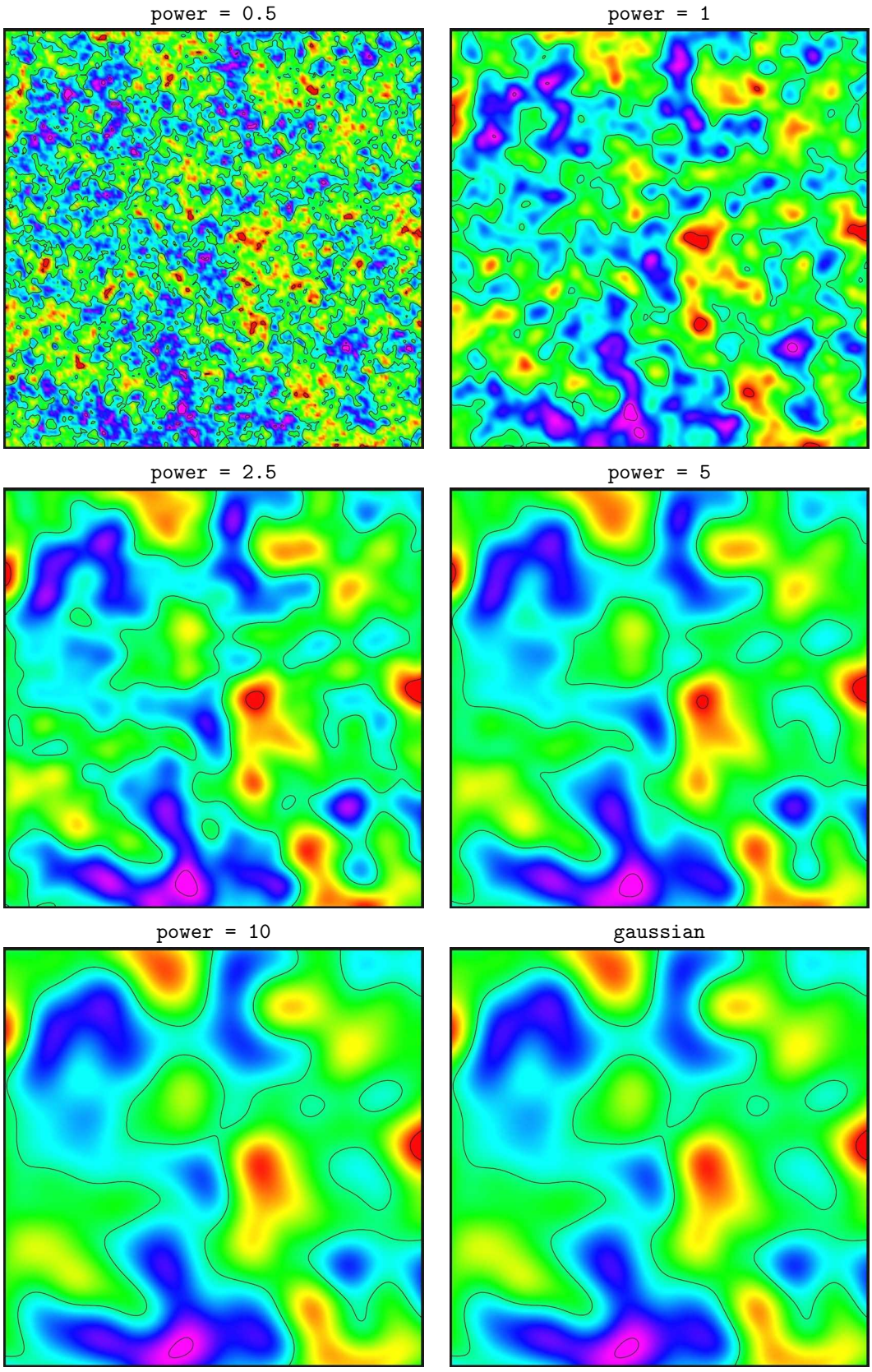


Figure 19.3. Rational quadratic variograms. Note that these variograms approach the `gaussian` variogram when `power` becomes large. This variogram is not numerically stable for large values of `power` so we recommend to use the `gaussian` variogram instead for `power` > 10.

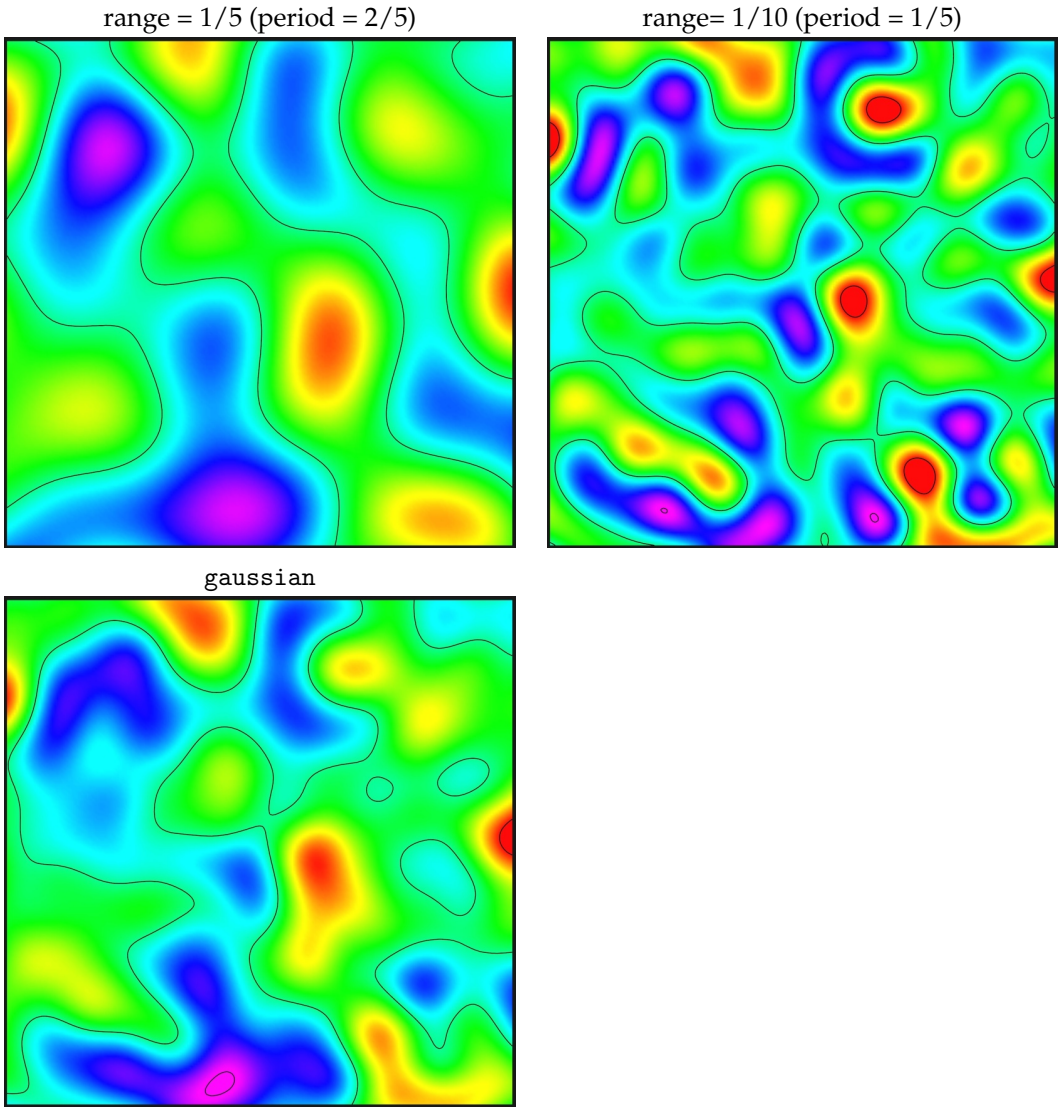


Figure 19.4. Damped sine variograms. The damped sine variogram gives a smooth regular cyclic appearance. The full period is twice the specified range. The `gaussian` variogram is added for comparison.

20 Conditioning to zone logs

The challenge of using the full well path is that these impose a soft restriction on the surfaces. The zone logs tells that surfaces are above or below the well path at any particular location. This boils down to conditioning surfaces to inequality constraints. Standard kriging techniques does not include the possibility to condition on constraints (or inequalities).

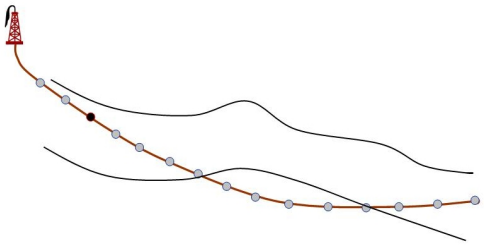
The approach used by Cohiba is a development of the ideas in Abrahamsen and Benth (2001). The article shows how to use inequality constraints in a kriging setting. Here we outline the basic ideas and the modifications necessary to make this work for a multi layered model.

Using zone log information is activated by choosing `yes` in the `<condition-to-well-paths>` element. This is the default.

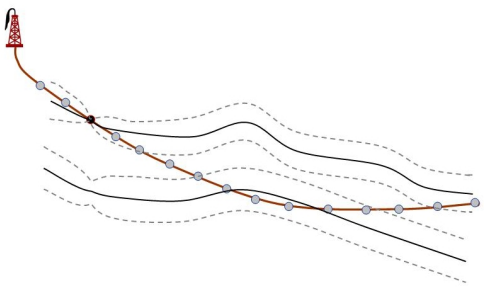
20.1 Procedure for conditioning to zone logs

The approach can be looked upon as a sequence of steps:

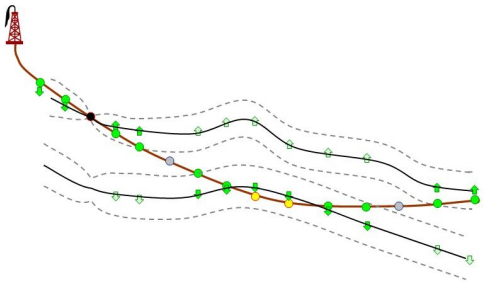
1. Sample the well paths at a resolution approximately twice the grid resolution. (Typically at 100 meter intervals.) The well path is shown as a red line. The well point is shown as a black disc and the **sample points** are the gray discs. The two black lines are cross sections of the surfaces above and below the main part of the well path.



2. Along the well paths, calculate the deterministic surface (solid lines), and the prediction error (dashed lines) given the well points. This is quite efficient since only a fraction of the grid nodes are close to the well paths.



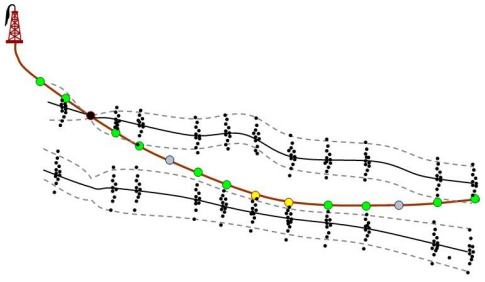
3. Select the sample points that are in conflict with the zone log, that is, they are on the wrong side of the deterministic surface. Two yellow sample points are on the wrong side. Also select the sample points that are on the correct side of the deterministic surface but are *close* to the deterministic surface. By close is meant less than 0.8 prediction errors for deterministic surfaces and less than 2.0 prediction errors for stochastic simulation.[1] These sample points are marked green in the figure. More sample points are selected for stochastic simulation than deterministic surfaces because there is a higher risk of ending up on the wrong side for stochastic simulation.



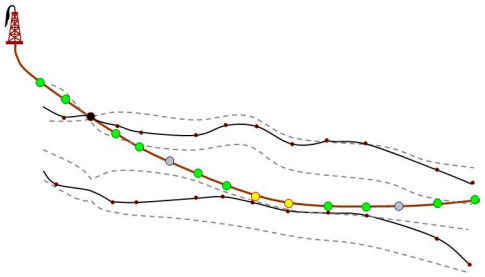
   The chosen sample points are called the **selected sample points** and the constraints imposed by the selected sample points are called **inequality points** for the surface. These are indicated by the green arrows.

   Inequality points usually come in pairs. One inequality point from the surface above the selected sample point and one inequality point from the surface below the selected sample point. This is to ensure that an inequality point does not force the other surface to violate the constraint imposed by the selected sample point. These additional inequality points are indicated by light green arrows. If one of the surfaces are far away from the well path, only the inequality point on the nearest surface is used.

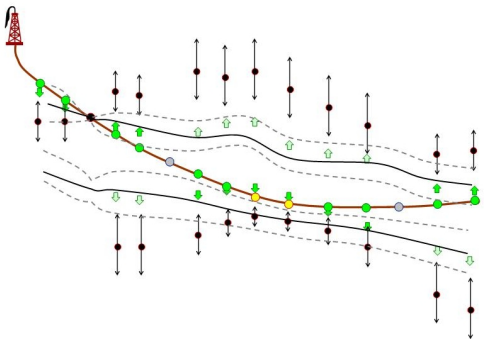
4. Run the Data Augmentation Algorithm to obtain 256 simulated realizations of the depth values at the inequality points. These 256 realizations represent the non-Gaussian probability distribution for depth at the inequality points. The 256 realizations will all be in agreement with the well points *and* the zone log constraints. The small black dots in the figure illustrates the spread of the 256 realizations at each constraint. The Data Augmentation Algorithm is a stochastic simulation technique for evaluating numerical integrals. The method was introduced by Tanner and Wong (1987).



5. **For stochastic simulation:** Select randomly one of the 256 realizations. This selection of well points is called **help points**. The simulated trend use the coefficients belonging to the selected realization. The help points are seen as small points along the surfaces. The selected help points are included as additional well points when conditioning the simulated realization. So the stochastic simulation is essentially made exactly as usual except that the additional help points make the kriging system (a lot) larger.



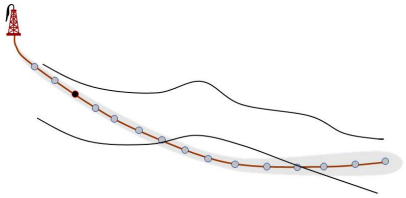
6. **For deterministic surfaces:** Calculate the expectation and the covariances of the 256 simulated realizations at the inequality points. The expectations at the inequality points are called **target points** since this is where we want the predicted surfaces to go. These target points and the covariances are used to calculate a set of **help points** that replace the inequality constraints. These help points have an associated measurement error that are illustrated by the error-bars in the figure. The help points are included as additional well points in the prediction and prediction error expressions. The expectations and measurement errors of the help points are chosen so that predictions and prediction errors exactly reproduce the target points along the sampled well paths.



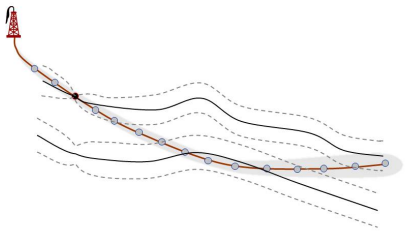
20.1.1 Procedure for conditioning to zone logs with uncertain well paths

Considering an uncertainty model for the vertical position of well paths is an extension of the steps oulined in 20.1. We repeat the steps with their extensions:

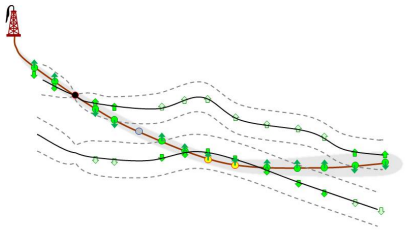
1. The well path is shown as a red line. The well point is shown as a black disc and the **sample points** are the gray discs. The two black lines are cross sections of the surfaces above and below the main part of the well path. The uncertainty envelope (shaded cone) represents one standard deviation away from the well path (cf. `<z-stddev-log-name>`).



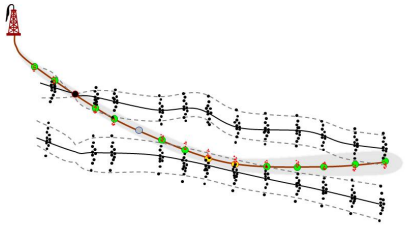
2. Along the well paths, calculate the deterministic surface (solid lines), and the prediction error (dashed lines) given the well points.



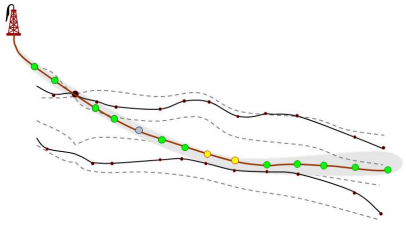
3. Select the sample points that are in conflict with the zone log or are *close*. The closeness criterion accounts for the uncertainty in the well path as well. Consequently, more points could become a **selected sample point** compared to the case with a certain well path. The constraints imposed by the selected sample points are called **inequality points** for the surface. These are indicated by green and light-green arrows.



4. Run the Data Augmentation Algorithm to obtain 256 simulated realizations of surface depth values at the inequality points *and* 256 samples of well depth values. The small black dots in the figure illustrates the spread of the 256 realizations at each surface constraint. The small red triangles shows realizations of well path constraints.

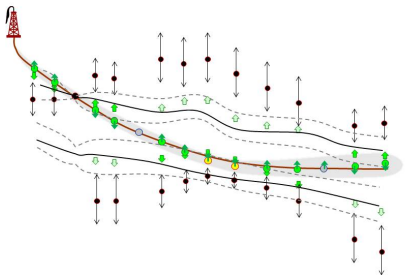


5. **For stochastic simulation:** Select randomly one of the 256 realizations of surface depths. Recall that this selection of well points is called *help points*. Select the realization of the 256 realizations of well depths that corresponds to the selected realization of surface depths.



6. **For deterministic surface:** Use the 256 simulated realizations to obtain **target points** and **help points** for the surfaces. See Step 6 in previous section for details.

   To predict a new well path, the average of the 256 realizations of the well path is used. The difference between these average values and the original well path is interpolated using simple kriging. This residual is added to the original well path.



20.2 Clusters

The drawing of the 256 samples at the inequality points in Step 4 above can be very time consuming if the constraints are strong and if there are many constraints. Therefore Cohiba splits the inequality points into *clusters* of highly correlated inequality points. A typical result is that clusters along the wells are split by the well points in the well. This is illustrated in Figure 20.1. The element `<threshold-for-trace-clustering>` specifies the threshold for the correlations. Specifying a high value means that inequality points must be strongly correlated to be in the same cluster. Small clusters are important to obtain fast performance. The default correlation threshold is 0.3. Inequality points from different well paths will belong to the same cluster if inequality points from different wells have a correlation larger than the threshold specified in element `<threshold-for-cluster-merging>`. A small value will cause large clusters. The default value is 0.5.

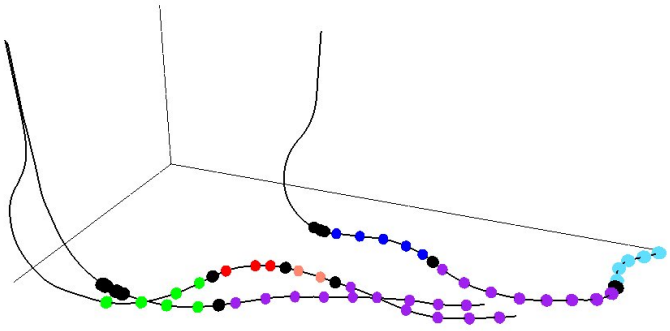


Figure 20.1. Different clusters in the three different wells have different colors. The well points are the black discs. Note how well points splits inequality points from a well into separate clusters. Also note that the largest clusters have inequality points from all three wells.

Part VI
Appendix

A Release notes

The tags, e.g. COH-49, are links to the Cohiba project management system called JIRA. Note that access permission is required to be able to open the links.

Changes from Cohiba Version 4.2 to Version 5.0

New features:

- It is now possible to generate many simulated realizations in one run. This is either triggered from the command line (see Section 4.2) or by specifying the `<number-of-realizations>`. Writing individual realizations to file can be suppressed by using `<write-realization-maps>`. See Section 7.1 for details. It is also possible to suppress the writing of some log files by using `<write-all-logfiles>`.

  Some parts of the Cohiba log file will contain repeated entries for every simulated realization. See Section 7.2.1 for details. COH-74, COH-458
- Possible to reuse the model weights when running multiple simulations. The weights can be stored on a coarse grid to save memory. The resolution of the coarse grid is determined by `<model-weight-resolution>`. COH-275, COH-482
- In simulation modes it is possible to reject surfaces with certain properties such as spill points and trap sizes that are inconsistent with observations. A set of acceptance criteria can be specified in `<acceptance-criteria>` for each surface. A global `<maximum-rejection-rate>` can be set in `<advanced-settings>` to avoid unacceptable long run times. COH-430
- It is possible to condition a surface on its spill points in simulation mode. Three criteria are available: `<spill-point-below>`, `<spill-point-above>` and `<spill-point-at>`. COH-431
- Fast approximate simulation that uses an initial calculation of the predicted surfaces and the corresponding prediction error. The fast simulation is triggered by choosing `fast-simulation` in `<mode>`. See Section 18.1 for details. COH-432
- Linking hydrocarbon contacts to spill points. A free surface can be set to the spill point depth of an other surface using `<condition-to-spill-point-at-surface>`. COH-433
- Possibility to calculate volumes between surfaces and hydrocarbon contacts. See Section 9 for details. COH-434, COH-462, COH-463, COH-464, COH-465, COH-466, COH-470, COH-471, COH-472, COH-473
- Column maps from the volume calculations can be generated. This is turned on using `<column-map>`. COH-435 COH-475
- New log level elements `<extra-points>`, `<spill-points>`, and `<volume-calculations>`. COH-460
- Only report volumes within trapped areas. This is turned on using `<only-trapped-volume>`. COH-474
- Remove (small) isolated volumes from volume calculations. This is turned on by `<remove-isolated-volumes-less-than>`. COH-488

- Only accept simulated surfaces with a trap above a certain size. The minimum size of the trap (in square meters) is specified using `<trap-larger-than>`. COH-501
- Write out target points in IRAP RMS internal point format. This can be used for QC. COH-506
- Possibility to only included connected volumes in the volume calculation. This is specified using `<connected-volume>`. COH-523

Improvements:

- Reduced memory usage by immediate writing of output maps for interval thickness, interval velocity, etc. COH-287
- Extract well point uncertainty from the uncertainty log `<z-stddev-log-name>`. This is only relevant if `<condition-to-well-paths>` is set to `no`. COH-398
- The element `<filename-tags>` and all its sub-elements has been removed. Also the possibility to select between prefix or postfix using `<type>` has been removed. This functionality was never used and only added to unnecessary complexity. The prefixes used are listed in Table 7.1. COH-407, COH-489
- A theory section is now found in Part V. COH-457
- Add the normal Cohiba header to the Cohiba log file when we use command line spill points approach. COH-459
- Speed up algorithm for simulation of Gaussian fields. Changed Box-Muller to Marsaglia-Bray algorithm for drawing the white noise field. The time used for generating the white noise field was reduced by a factor of four. COH-480
- Logging of trap in Cohiba log file. COH-485.
- The specification of the starting coordinates for the `<spill-point>` detection is now mandatory. This implies that the coordinates specified by `<xstart>` and `<ystart>` must be supplied in all situations where the spill point or the associated trap is needed. COH-499
- The default for `<missing-as-wall>` has changed to `no`. The opposite caused problems when a large output grid was chosen. Then the missing codes around the defined area would prohibit the spill point algorithm to reach a boundary. COH-500
- Make it impossible to read in two wells using `<files>` with the same well name. This ensures that duplicates are not included by accident. COH-509
- Simulated trend coefficients where not reported in the Cohiba log file. COH-510
- The trap map reported the first trap and successively shallower traps found between the starting point and the edge of the map. Now,only the trap containing the starting point is seen in the map. COH-513
- Obsolete maps generated from the spill point algorithm is not written to file anymore. COH-517
- Reduce memory usage for input grids. Unnecessary copies are removed. COH-521
- The spill point algorithm is modified so that the trap becomes smaller in some rare situations. If there are two traps connected by a saddle point that are at the exact same depth as the spill point (that is also a saddle point) then only the first trap is returned as the trap. Previously both traps could be included. COH-522
- Use more than two digits after the decimal place when writing adjusted RMS WELL's to avoid stair casing when visualizing the well. COH-530

Bug fixes:

- Ensure that depth surfaces are calculated whenever needed even though they are not written as output. For instance all eroding and on-lapped surfaces must be calculated if they truncate other surfaces. The truncation was not performed unless the truncating surface was written to file. COH-455
- Free surfaces are not affected by erosion and they do not lap on to other surfaces. Nor can free surfaces erode other surfaces or be on-lapped by other surfaces. This was not taken proper care of. COH-483, COH-484
- Error in spill point calculation if `<grid-azimuth>` different from zero. COH-486.
- Error in classification of leverage points. COH-491.
- Numerical instability cause different compilers to generate different results. This gave an error in well path conditioning in rare situations. COH-495, COH-526
- Incorrect reporting of redundant sample points. COH-497
- Allow only one occurrence of `<project-settings>`, `<modelling-settings>`, `<well-data>`, `<surfaces>`, `<interval-models>`, and `<volumes>` in the Cohiba model file. Previously Cohiba would accept repeated occurrences but the interpretation would be unpredictable. COH-503
- Error if an input surface contains only missing values. COH-504
- The output from the spill point algorithm was wrong if no spill point was found. Now the trap map gets zeroes everywhere and the file `spillpoint_Surface.xyz` will contain missing codes. COH-505
- The map of the trap was zero at the spill point algorithms starting point. COH-511
- Error in spill point algorithm leading to mismatch between trap and spill point. COH-514
- Additional sample points added at eroding and on-lapped surfaces where labeled incorrectly. This could lead to a crash. COH-519
- Incorrect maximum value reported for interval trend maps in rare situations. COH-525
- Surfaces above the reference surface was reported as a problem. This is quite common on-shore. COH-528
- Incorrect reporting of undefined zonation to multiple xyz-files. COH-529
- Parts of the adjusted well paths were not always updated. This could cause oscillating well paths. COH-532
- Information about deactivated help points were incorrect in the Cohiba log file. COH-533

Changes from Cohiba Version 4.1.2 to Version 4.2

Please note that Windows operating system now requires that the dynamically linked library file `libiomp5md.dll` must be distributed with the executable for parallelization to work.

New features:

- Additional constraints added at well points at eroding and on-lapped surfaces. Well points at e.g. *eroding* surfaces impose constraints on the *eroded* surfaces since the eroded surfaces must be above the eroding surface.

An identical but opposite situation occurs for on-lapped surfaces.

This is now handled by adding constraints and help points to ensure that eroded surfaces is located correctly. Note that this only affects air interpretations or other situations where surfaces are truncated by eroding or on-lapped surfaces. COH-404

- There is now support for the ROXAR BINARY surface file format. This is now the default format for output grids. See Section 6.2 for more details. COH-428

Improvements:

- The default value of `<onlapped>` is changed to `yes`. This is the geologically reasonable default. Note that this will affect all old models where the `<onlapped>` is not explicitly used. COH-426
- Allow combining `<relative-stddev>` and `<coefficient-mean>`. COH-436
- Set interval velocity undefined wherever Δz or Δt are undefined. All other surface plots will give undefined in these regions. Previously the posterior trend was used. COH-447

Bug fixes:

- Inconsistency and errors in reporting of residual uncertainties. COH-441
- Consistency check for calculated velocity was incorrect. COH-442
- Allow user specified seeds larger than 2^{31}. The seed must be less than 2^{32}. See Section 14.1.3. COH-444
- Filtering of input (velocity) trends failed and gave some odd border effects. COH-445
- On-lapping surfaces set to zero if on-lapped surfaces are not calculated. COH-449
- If any of the command line options in Section 4.3 where used, the Cohiba log file reported: `Random seed from command line`. This is the correct report if option `-s` is used *and* Cohiba runs in simulation mode. COH-454
- Updated well depths sometimes became wrong when parallelization was used. COH-456

Changes from Cohiba Version 4.1.1 to Version 4.1.2

Bug fixes:

- Error when updating the depth value of a well point. COH-438

Changes from Cohiba Version 4.1 to Version 4.1.1

Bug fixes:

- Error occurred when using `<correlate-close-reflectors>` and an eroding reflector (e.g. base Cretaceous) was used as the reference surface. COH-390
- Variogram uncertainties specified using `<stddev>` and `<relative>` became incorrect. COH-424
- Surface trend information summary had fallen out of the Cohiba log file. COH-429

Changes from Cohiba Version 4.0 to Version 4.1

New features:

- Gridding errors along the well paths are removed by default. This can be turned on/off using <allow-small-surface-adjustment-at-sample-points>.

  If well path points are less than 1 meter (default) on the wrong side of the surface or closer than 0.5 meter (default) to the surface, then the grid nodes are modified such that the surface becomes exactly 0.5 meter (default) away from the well path at these locations. These values can be modified using <maximum-residual-for-adjustment-at-sample-points> and <minimum-distance-from-surface-to-sample-points>.

  The adjustment of surfaces to remove the gridding errors for well paths are consistent with the removal of gridding errors for well points. COH-18

Improvements:

- Gridding errors at well points are removed by default. This can be turned on/off using <make-surfaces-interpolate-well-points>. However, gridding errors for well points in the same or neighboring grid cells could previously not be removed. A new algorithm adjusting all affected grid cell corners (grid nodes) simultaneously has been implemented.

  Gridding errors are removed if well points are not outliers and the well point uncertainty is less than 1 meter (default). The default value can be modified using <maximum-stddev-for-well-points-interpolation>.

  A well point with a large residual can create an unrealistic spike in the adjusted surface. In order to prevent such unlikely events, it is possible to exclude well points with large residuals using <maximum-residual-for-well-points-interpolation>.

  If two well points are close, the surface can also get spikes caused by the gradient between the well points. The maximum allowed gradient can be set using <maximum-gradient-for-surface-adjustment>. The default value is 100.0. COH-18
- Parallelization of data loading. The number of threads to be used are specified by <number-of-threads>. COH-297
- Removed elements <xend>, <yend>, <nx>, and <ny>. The definitions of these elements are unclear and where made obsolete by Cohiba Version 2.4. They can no longer be used. COH-281, COH-345
- Changed the interpolation method for cases with undefined cell corners. Now a plane through the three defined cell corners. Returns undefined if there is more than one missing corner. COH-405
- Simplified and robustified the code for reading the Cohiba model file. COH-402, COH-403

Bug fixes:

- Some well path points were not predicted (moved) when well trajectories had uncertainties. COH-393, COH-394
- Crash if a well did not contain the uncertainty log specified by <z-stddev-log-name>. It is now possible to use wells were the uncertainty log is missing even though it has been specified by <z-stddev-log-name>. The same applies to the fault indicator log specified by <fault-log-name>. COH-397

- Well points were not properly extracted when surfaces were on-lapped. COH-410
- Option `<first-log-entry-as-top>` failed when first zone entry was the zone under the reference surface. COH-411
- Error when removing redundant well data or well data outside project boundary. COH-413
- Default `<variogram>` for well paths was incorrect. The default was set to spherical with a range of 1000, whereas it was intended to be a generalized exponential variogram with exponent 1.8 and range 2000.
- The two `Checking zonation` reports in the Cohiba log file (see Section 7.2.1) had an inconsistency with regard to undefined zones. COH-415
- If an RMS well was given in the DOS file format, the zone log specification was incorrectly extracted when running under Linux.COH-416

B Known issues

- Conditioning to well paths using universal kriging does not work. COH-23
- Section numbering inconsistent when iterating to remove Broken zonation. COH-425
- May crash in drawing of help points in the well path conditioning in some rare cases. COH-527
- May crash if side tracks duplicates the path and the zone log. COH-531
- Missing column `Min` in table `DepthUncertainty(StdDev)` in Cohiba log file. COH-543
- CPU time to export interval velocities increased dramatically from Cohiba Version 4.2 to Version 5.0. COH-544

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Some of the references are available as pdf's at the bottom of this page: www.nr.no.

List of Figures

1.1 Log file for well points imported into Excel 12

5.1 Skeleton of a Cohiba model file. 26
5.2 Cohiba model file visualized in the NotePad++ editor. 27

6.1 Recommended and default directory structure for Cohiba. 32

8.1 Transitions between a simple set of zones 51
8.2 Zones with pinch out 51
8.3 Zones where a surface is erosive 53
8.4 Zones where a surface is on-lapped 53
8.5 A set of faulted zones 54
8.6 A simple set of zones with a zonation finer than the surface model. 55
8.7 A horizontal well following a zone 57
8.8 Well path uncertainty 57

9.1 Assigning volumes to grid nodes 66

10.1 Map of top surface in simulation example 67
10.2 Fence diagrams in example 68
10.3 Spill points in example 69
10.4 Volume distributions in example 70
10.5 Box plots from example 70
10.6 Mean surfaces compared to predicted surfaces 71
10.7 Empirical standard errors compared to prediction errors 71
10.8 Map of probability for being inside the trap 72
10.9 Column height maps, average and prediction 73
10.10 Column height maps, average and standard deviation 73
10.11 Volume distributions, fast simulation versus ordinary simulation 74

11.1 Example of multiple models 75
11.2 Specification of multiple models 78
11.3 Report of multiple models and their weights for the Brent case 79
11.4 Report of multiple models and their weights 79
11.5 Model weights 81

12.1 Cross section of a fault 83

14.1 Overview of elements used to specify the output grid definition 96
14.2 The use of <set-eroded-nodes-to-undefined> 102

17.1 Gridding error 166
17.2 Bilinear interpolation 167
17.3 Nearest neighbor interpolation versus bilinear interpolation 167

18.1 Comparison of ordinary simulation and fast simulation 170

19.1 Spherical and exponential variograms. 172
19.2 General exponential variograms 173
19.3 Rational quadratic variograms 174
19.4 Damped sine variograms 175

20.1 Clusters of inequality points and well points 180

List of Tables

6.1 Definition of the Cohiba well points file format 31

7.1 Output maps found in the `surfaces/` directory 34
7.2 The `trend_estimation.log` file. Description of columns 38
7.3 The `welldata.log` file. Description of columns. 39
7.4 File naming convention for zonation status files. 45
7.5 Sample point attributes used for choosing help points 46
7.6 Sample point attributes after conditioning to well paths 46
7.7 The possible values for `MatchText` and `MatchCode`, and `FixText` and `FixCode`. . . . 47

8.1 Surfaces observed for different zone-transitions. 52
8.2 Surfaces observed for different zone-transitions if surface `B` is erosive. 52

10.1 Acceptance criteria in example 68
10.2 Rejection rates, spill point depths and volumes 69
10.3 Volumes, fast simulation versus ordinary simulation 74

11.1 The Brent model specification 76
11.2 The Brent uncertainties and model weights 76
11.3 Multiple models weights for the Brent example 76

14.1 Measurement units. 95
14.2 Supported variogram types in Cohiba 119

17.1 Formulas used in `welldata.log` 159
17.2 Formulas used in `trend_estimation.log` 160

Index

<acceptance-criteria>, 33, 103, **121**, 172, 183
<advanced-settings>, **103**, 183
air interpretations, 100
algorithms, 103
<allow-sample-points-near-faults>, **104**
<allow-small-surface-adjustment-at-sample-points>, **101**, 104, 167, 187
alternative models, *see* multiple models
ambiguous models, *see* multiple models
approximation
  fast simulation, 98
  gridding error, 167
  ignoring spatial correlation, 156
  independent uncertainties, 82
  interpolation, bilinear, 167
  neighbourhood in kriging algorithm, 108
  second order residual, 166
  simulation, 172
  WLS replace GLS, 105
area name, 65, 132
area number, 65, 132
<area-file>, 64, 65, **131**, 132
<area-names>, 37, 64, 65, 131, **132**
argument in element, 25
ASCII text, 27, 42
attribute, 25
attribute value, 25
<azimuth>, **119**, 124, **128**, 130
azimuth, variogram, 119, 128

base, 153
  hydrocarbon contact, 64, 131
  surface of interval, 125
  surface of volume, 64, 131
<base>, 34, 78, 84, **125**, 130, 153
<base-contact>, 64, 65, 68, 85, 122, **131**, 132
<base-surface>, 64, 65, 68, **131**, 132
Bayesian estimation, 156
Bayesian kriging, 98
bilinear interpolation, 41, 101, **167**
  volume, 66
BLUE, 156
bugs, known, 189

<check-specified-residual-uncertainties>, 35, **99**
Cholesky decomposition, 104
close well points, 39, 49
cluster files, 45
cluster_#_inequalitypoints.xyz, 45
cluster_#_wellpoints.xyz, 45
clusters of inequality points, 181
clusters/, 29, 33, **45**, 89
coefficient, *see* trend coefficient
<coefficient-mean>, 38, **126**, 130, 157, 186
<coefficient-stddev>, 38, **126**, 130, 157
Cohiba, 2
  basic idea, 2
  input data, 10
  main features, 3
  methodology, 9
  name, 13
  quality control, 11
<cohiba>, 26, **87**
Cohiba log file, 33
  detail level, 91
  import into Excel, 42
  import into OpenOffice, 42
  name, 91
  specification of output, 91
Cohiba model file, 25, 157
  as argument, 20
  editing, 27
  reference manual for elements, 87
Cohiba well points file format, 30
cohiba.exe, **20**, 23, 88
cohiba.log, **33**, 91
cokriging, 9
collinearity, 156
column of reservoir volume, 133
<column-map>, 34, 64–66, 72, **133**, 183
column_Brent Oil.roxbin, 65
column_trap_volume_Surface.dat, 43
column_trap_volume_Surface.xyz, 43
command line, 20, 22
command line option

-g, 24
-m, 24
-s, 23, 88
-x, 24
-y, 24
concepts, 14
condition, 17
<condition-to-spill-point-at-surface>, 67, 85, **122**, 132, 183
<condition-to-well-paths>, **99**, 177, 184
conditional simulation, 169
conflict
between well point and model, 11, 40
between well points, 11, 39
conjugate gradient, 104
connected volume, 65
<connected-volume>, 64, 65, **132**, 132, 184
constant, 29
<correlate-close-reflectors>, 82, 83, **105**, 117, 164, 186
correlation function, 119
<correlations>, **127**, 130, 157
correlations, trend coefficients, 127
covariance matrix, posterior, 37
<cp-q>, **127**
CPU time, 80, 93, 105, 123
stochastic simulation vs. deterministic, 170

d_top.irap, 22
Data Augmentation Algorithm, 178
<data-loading>, 35, **91**
datum, 116
defining grid dimensions, 95
deleted well point, 39
depth, 116
map, 34
order, 10
output flags, 123
residual, 154
residual map, 34
trend, 154
trend map, 34
trend uncertainty map, 34
uncertainty map, 34
unit, 94
<depth>, 34, **116**, **123**, 124
depth conversion, 7, **17**, **164**
<depth-error>, 34, **123**, 124, 162
<depth-residual>, 34, **123**, 124
<depth-trend>, 34, **123**, 124, 157
<depth-trend-error>, 34, **123**, 124, 158
design matrix, 155
detail level, log file, 91
detail level, screen, 94
<detail-level>, **91**, **94**
deterministic, 3, 17, 98
deviated wells, 48
directory specification, 29
directory structure, 29
discarded well points, 114
dt_top.irap, 22

editing Cohiba model file, 27
element, 25
list of all, 134
reference manual, 87
unknown, 27
XML syntax, 25
Emacs, 27
equiprobable, 3
<erode-and-onlap>, **100**, 101, 102, 117
erosive, 51
<erosive>, 52, 82, 84, 100, 101, **117**, 124, 153
error
gridding, 34, 101
measurement, 11
prediction, 3
reading model file, 27
to small residual uncertainties, 50
estimate
Bayesian, 157
generalized least squares, 156
ordinary least squares, 155
weighted least squares, 156
estimation method, 157
estimation mode, 98
example
<top-of-zone> specification, 55
<interval> specification, 129
<surface> specification, 124
depth conversion, 7
fault, 83
getting started, 20
log file, 142
model file, 138
multiple models, 75
simulated residual, 16
spill point, 8

stochastic simulation, 173
variogram, 173
Excel, 37
import log files, 42
log file, 12
excluded_wellpoints_pointfile_Well.xyz, 43
excluded_wellpoints_surface_Surface.xyz, 43
excluded_wellpoints_zonelog_Well.xyz, 43
<extra-points>, 35, **92**, 183

Fast Fourier Transform, *see* FFT
fast-simulation mode, 98
fault, 84, 117
fault indicator log, 39, 48, 54, 110, 111
name, 111
<fault-log-name>, 49, 54, **111**, 187
faults, 54, 82
example, 83
normal, 82
reverse, 82
zone transition, 48, 54
FFT, 9, 169, 170
file
ignore points, 114
well path, 111
well points, 113
file directory structure, 29
file format
surface, 29
well path/log, 30
well points, 30
<files>, 30, 84, **111**, 112, **113**, **114**, 115, 184
fillpath_Surface.xyz, 43
<first-log-entry-as-top>, **112**, 188
flat spot, 84
fluid contact, *see* hydrocarbon contact
<format>, 29, **95**
free surface, 84, 105, 114, 117
fault, 84
hydrocarbon contact, 84
<free-surface>, 25, 84, 105, 114, 116, **117**, 122

Gaussian distribution, 15, 42
Gaussian random field, 9, 16, 154, 170
generalized least squares, *see* GLS
geological knowledge, 16
geophysical knowledge, 16
GLS, 15, 38, 156, 157
GOC, *see* hydrocarbon contact
grid
dimension, 95
file format, 29
rotated, 29, 97
trend, 126
grid effects, 167
<grid-azimuth>, 29, **97**, 185
gridding error, 34, 41, 101, 167
remove, 101, 167
GWC, *see* hydrocarbon contact

hat matrix, 41, 159
help point, 42, 47, 56, 57, **179**, 179
thin zones, 106
help point files, 47
<help-points>, 36, **93**
helppoints.log, **42**
helppoints/, 29, 33, **47**, 89
helppoints_Surface.xyz, 47
helppoints_Well.xyz, 47
HORIZON, 13, 165
horizontal wells, 4, 10, 18, 48, 56
hydrocarbon contact, 84, 117, 131
hydrocarbon contacts, 64
hyper-threading, 90

ignore points, 54
inequality constraints, 4, 177
inequality point, 45, 47, 54, 107, **178**, 178, 179, 181
cluster, 181
input directory, 89
surfaces, 89
well data, 89
<input-directory>, 29, **89**, 111, 113, 114
<input-directory-surfaces>, 29, **89**
<input-directory-well-data>, 29, **89**
input/, **89**
input/surfaces/, **29**
input/welldata/, **29**
interpolation
bilinear, 41, 167, 168
kriging, 160
nearest neighbor, 168
interval, **14**
base surface, 125
building block, 14
example of specification, 129
name, 125

residual, 127, 154
thickness, 34, 125
top surface, 125
trend, 125, 154
trend specification, 125
type, 125
uncertainty, 127
uncertainty checking, 35
velocity, 125
<interval>, 26, 84, 87, 116, **125**, 127, 129, 130, 153
interval thickness, 34, **154**
map, 34
model, 10
residual, 34, 127
trend, 10, 34, 125
trend map, 34
uncertainty, 10, 127
variogram, 114, 127
interval velocity, 7, 34, 125
map, 34
model, 7, 10
output flag, 129
posterior trend, 129
residual, 16, 127
trend, 17, 125
trend map, 34
uncertainty, 10, 127
variogram, 127
<interval-models>, 25, 26, 87, **125**, 185
<interval-type>, **125**, 130
isochore map, 154
isochores, 7

JIRA, project management, 183

kriging, 9, **160**
Bayesian, 15, 98
dual, 161
neighborhood, 108
predictor, 161
simple, 15, 98
universal, 15, 98
weights, 162
kriging error, 162
kriging matrix, 156
<kriging-method>, 40, 41, **98**, 105, 157, 158, 160, 161, 169

LAS 2.0 well file format, 30, 110
leverage point, 11, 39–42, **158**
classification, 159
libiomp5md.dll, **185**
linear regression, 9, 15, 38, 41, **155**
Linux operating system, 12
log file, *see* Cohiba log file
log files, 33
Cohiba log file, 33
posterior_covariance_matrix.log, 37
simulation.log, 37
tasks.log, 36
trend_estimation.log, 37
welldata.log, 37
prefix, 90
log, along well path, 48
<logfile>, 33, **91**
logfiles/, 22, 29, **33**, 33, 89, 91

<make-average-of-crossing-surfaces>, **101**
<make-surfaces-interpolate-well-points>, 41, **101**, 103, 104, 167, 187
<make-time-surfaces-consistent>, **100**
Matlab script, 43
<max-obs-direct-estim-trend-coef>, **105**, 157
<max-obs-GLS-approx-extreme-outliers>, **105**
<max-obs-GLS-approx-trend-coef>, **105**, 156, 157
<max-obs-update-trend-coef-using-well-paths>, **105**
<maximum-dxy-for-identical-well-points>, **108**
<maximum-dz-for-identical-well-points>, **108**
<maximum-generalized-eigenvalue-for-inequality-points>, **108**
<maximum-gradient-for-surface-adjustment>, 101, 102, **104**, 187
<maximum-iterations-to-avoid-broken-zonation>, 100, **104**
<maximum-range-factor-for-neighbourhood>, **109**
<maximum-rejection-rate>, 68, 69, **103**, 121, 171, 172, 183
<maximum-residual-for-adjustment-at-sample-points>, 102, **104**, 187
<maximum-residual-for-well-points-interpolation>, 101, **103**, 187

<maximum-slope-before-possible-conflict>, **108**
<maximum-stddev-for-well-points-interpolation>, 101, **103**, 187
measured depth, 57, 112
measurement error, 11, 18, 40, 162
  added, 12, 41
  automatically added, 40
  correlated, 57
  from zone log, 50
  variogram, 57
  well path, 57, 111
  well points, 31, 84, 114
<measurement-units>, **94**
merged data, 37
<messages>, **90**
<minimize-broken-zonation>, 44, 45, 47, **99**, 104, 106
<minimum>, **120**, **128**
<minimum-distance-from-surface-to-sample-points>, 102, **104**, 187
<minimum-generalized-eigenvalue>, 35, **109**
<minimum-isochore-thickness>, **106**
<minimum-range-factor-for-neighbourhood>, **109**, 109
<minimum-stddev-close-well-points>, **108**
missing code, 29
  in surfaces, 29
  in zone log, 54, 106
  spill point, 121
  spill point coordinates, 120
<missing-as-wall>, **121**, 124, 184
mode
  estimation, 98
  fast-simulation, 98
  prediction, 98
  simulation, 98
<mode>, 34, 40, 41, 69, 74, **98**, 99, 103, 169–171, 183
model, **14**
  interval, 153
  surface, 153
model file, *see* Cohiba model file
model weights, 75–77, 79–82
  example, 76, 77
  many zones, 81
  report, 79
<model-settings>, 35, **91**
<model-weight-resolution>, 98, **103**, 170, 183
model_file.xml, 20, 22, 23, 88
<modelling-settings>, 25, 26, 87, **98**, 185
Monte Carlo, 2, 3, 9
MSL (mean sea level), 116, 153
multiple models, 6, 75, 80, 82
  example, 75
  model weights, 75

<name>, 30, 55, 56, 64, 85, **91**, **116**, 122–124, **125**, 130, 131
name, of log file, 91
name, of reference surface, 116
name, of surface, 116
negative thickness, 101
neighborhood in kriging algorithm, 108
normal distribution, *see* Gaussian distribution
Notepad++, XML editor, 27
<number-of-realizations>, 23, 33, 69, **98**, 103, 169, 171, 172, 183
<number-of-threads>, **89**, 99, 187
numerical stability, 50

observation error, *see* measurement error
on-lapped, 100
on-lapped surface, 51
<onlapped>, 52, 82, 84, 100, 101, **117**, 124, 153, 186
<only-trapped-volume>, 64, 65, 85, **132**, 183
OpenMP, 90
OpenOffice, import log files, 42
operating system, 12
outlier, 11, 39, 107, **158**
  classification, 40, 41, 158
  classification code, 39
  figure, 11
<outliers>, 35, **92**
<output>, **123**, 124, **129**, 130
output flags, 123
output flags, interval, 129
output log file, 33
output logging to screen, 94
<output-directory>, 29, 33, **89**
<output-grid>, **95**, 116, 162
output/, 29, 33, **89**
outside grid well points, 58
<overall>, **91**, **94**
OWC, *see* hydrocarbon contact

parallel computing, 90
pinch out, 10, 39, 40, 51, 101

deleted, 49
flagged, 49
isochore map, 10
thickness residual, 16
post process, 167
<post-process-surfaces>, **100**
<post-processing>, 36, **93**
posterior covariance matrix, 37
posterior_covariance_matrix.dat, **37**, 37
<power>, **113**, **114**, **120**, **128**, 174
power, variogram, 113, 114, 120, 128
<pre-process-surfaces>, **100**
<pre-processing>, 35, **91**
prediction, 2–4, **17**
prediction error, 3, 4, 16, 34, 123, **162**
prediction mode, 98
predictor, 161
prefix log files, 90
<prefix-for-log-files>, **90**
<preprocess-range-factor-for-neighbourhood>, **109**
prior correlations, 127
prior distribution, 16
prior mean value (expectation), 126
prior specification, 15
prior uncertainty (standard deviation), 126
<project-description>, **88**
<project-directory>, 29, **88**
<project-settings>, 25, 26, 87, **88**, 185
<project-title>, **88**

QC, *see* quality control
quality control, 11, 33, 37
important, 37
trend estimation, 158

random number generator, 88
random seed, 17, 23, 88
increment, 65
unspecified, 88
random seed file, 88
<range>, **113**, **114**, **118**, 119, 124, **127**, 130, 173
range, variogram, 113, 114, 118, 127
<read-from-file>, **95**
realization, 17
simulated, 173
rectangular patches in output, 108
<reference>, 26, 64, 87, **116**, 131, 153
reference depth, 116
reference manual, Cohiba model file elements, 87
reference surface, 116
reference travel time, 116
reflector, *see* seismic reflector
regression, 155
rejection rate, 103
rejection sampling, 103, **171**
acceptance criteria, 121
rejection rate, 103
<relative>, **120**, **128**, 130, 186
<relative-stddev>, **126**, 186
release notes, 183
<remove-isolated-volumes-less-than>, 64, 65, **132**, 183
reservoir
name, 131
volume, 131
reservoir volume, *see* volume
<reservoir-name>, 37, 64, 65, **131**
residual, 2, 9, 14, **16**, 50, 154
examples, 16
interval thickness, 34, 127
interval velocity, 127
Studentized, 159
travel time, 118
uncertainty estimate, 35
well point, 114
residual uncertainty, 2
<residual-uncertainties>, 35, **92**
RMS internal point format, 42, 44
robust estimation, 12
rock column
map, 34
root element (XML), 87
rotated grids, 29, 97
Roxar binary file format, 29
Roxar text file format, 29

sample point, 44, **177**, 179
broken, 45, 99
failed, 45
non-correctable, 44
selected, 44, 45, 99, 178
samplepoints.dat, 44
samplepoints_Well.rmsinternal, 45, 46
samplepoints_Well.xyz, 44
<screen>, **94**
seawater, 112

seed, *see* random seed
<seed>, 23, **88**, 173
seed.dat, 23, **88**
segment name, 132
seismic reflector, 6, 7, 10, 14, 16, 17, 75, 80, 125
  coinciding, 105
  defining, 118
  erosive and on-lapped, 82, 101
  fault example, 83
  faults, 82
  interval between two, 125
  make consistent, 100
  specify interval velocity, 125
  specify surface as, 118
<set-eroded-nodes-to-undefined>, **102**
SGS, 170
side track, inconsistent data, 40
sill, 119, 128
simple kriging, 98, 99
<simulate-trend-uncertainty>, 38, **99**
simulated residual, 170
simulated trend coefficient, 38
simulation, *see* stochastic simulation
simulation algorithm, 170
simulation example, 67
simulation mode, 98
simulation.log, **37**
<smoothing-factor-calculated-velocities>, **102**
<smoothing-factor-velocity-trends>, **100**
<solver-for-weights>, **104**
spatial clustering, 15
spatial correlation, 7, 10, 38, 156
spatial correlation function, 16, 118, 127
special_samplepoints.xyz, 44
spill point, 8, 120
  algorithm, 9
  command line, 23
  condition to, 122
  coordinates, 42
  missing codes in surface, 121
  output files, 42
  output trap, 123
  starting point, 24, 34, 121
  trap map, 34
  trapped area, 8
  visited path, 43
<spill-point>, 23, 65, **120**, 122–124, 132, 133, 171, 184
<spill-point-above>, 68, **121**, 171, 183
<spill-point-at>, 68, **122**, 171, 183
<spill-point-below>, 67, 68, **122**, 171, 183
<spill-point-tolerance>, 68, **122**
<spill-points>, 36, **93**, 183
spillpoint_Surface.rmsinternal, 42
spillpoint_Surface.xyz, 42, 120, 185
spillpointdata/, 29, 33, **42**, 89
spillpointgrid.irap, 23
Spread sheet, 37
stacking velocities, 7
standard deviation, 18
<stddev>, **119**, 124, **128**, 130, 186
stochastic, 98
stochastic model, 14
stochastic simulation, 2, 9, 15, **17**, 88, 98, **169**
  algorithm, 169
  rejection sampling, 103, 121
stochastic simulation vs prediction, 3
Storm file format, 29
<subrange>, **119**, 124, **127**, 130
subrange, variogram, 119, 127
surface, **14**
  base of interval, 125
  depth, 14
  deterministic, 3
  erosive, 51, 117
  example of specification, 124
  file format, 29
  free, 117
  map, 34
  most likely, 3
  name, 116
  on-lapped, 51
  on-lapped flag, 117
  ordering, 10, 153
  output, 33
  prediction, 3, 98
  prediction error, 3
  realization, 3
  reference depth, 116
  relation to zone log, 117
  seismic reflector, 17
  specify as seismic reflector, 118
  stochastic, 3
  stochastic simulation, 3, 98
  top of interval, 125
  travel time
    specify map, 118

specify uncertainty, 118
trend
uncertainty, 34
trend map, 34
uncertainty, 34
zone log, 48
<surface>, 25, 26, 30, 55, 56, 64, 87, **116**, 124, 153
surface observation, *see* well point
<surface-models>, 35, **91**
<surfaces>, 25, 26, 87, **116**, 122, 185
surfaces/, 22, 29, **33**, 33, 34, 42, 65, 89, 133
synthetic well point, *see* help point

t-value, 37, 39
trend coefficient, 38
well point, 41
<t-value-error>, 39, 41, 44, **107**, 158
<t-value-extreme-error>, 105, **107**
<t-value-outlier>, 39, 41, **107**, 158
<t-value-prediction-first-point>, **107**
<t-value-prediction-second-point>, **107**
<t-value-severe-outlier>, 39, 41, **107**, 158
<t-value-simulation-first-point>, **107**
<t-value-simulation-second-point>, **108**
target depth, 57
target point, **179**
<target-number-of-data-in-neighbourhood>, **109**
targetpoints_for_wellpaths_Well.xyz, 44
targetpoints_Surface.xyz, 47
targetpoints_Well.xyz, 47
task list, 36
<tasks>, 36, **94**
tasks.log, **36**
terminology, 14
<thickness>, 34, **129**, 130
thickness residual, 16
<thickness-residual>, 34, **129**
<thickness-trend>, 34, **129**, 130
threads, number of, 90
<threshold-for-cluster-merging>, **106**, 181
<threshold-for-conditioning-in-neighbourhood>, **108**, **162**
<threshold-for-help-point-deactivation>, **106**
<threshold-for-mild-error>, **106**
<threshold-for-removing-undefined-well-sections>, 54, **106**
<threshold-for-trace-clustering>, **106**, 181
<time-unit>, **94**
<timings>, 36, **93**
top, 153
hydrocarbon contact, 64, 131
surface of interval, 125
surface of volume, 64, 131
surface of zone, 117
<top>, 34, 78, 84, **125**, 130, 153
<top-contact>, 64, 65, **131**
<top-of-zone>, 48, 55, 84, **117**, 124
<top-surface>, 64, 65, 68, **131**, 132
<tops-as-mean-values>, **111**, 115
trajectory, *see* well path
trap, 8, 34
map, 34
<trap>, 34, 72, 120, **123**, 124
<trap-larger-than>, **122**, 171, 184
trapped volume, 132
travel time, 17, 118
correlated residual, 82, 105
interpretation uncertainty, 118
make consistent, 100
residual, 118
uncertainty, 82, 118
units, 94
variogram, 118
travel time at reference surface, 116
travel time map, 7, 10
travel time residual, 16
<travel-time>, **116**, **118**, 124
<treat-reflectors-as-eroding-and-onlapped>, 82, 83, **101**
trend, 2, **15**, 154
coefficient, 15, 126
important, 38
interval, 125
interval thickness, 125
interval velocity, 125
linear model, 154
<trend>, 38, **125**, 128, 130, 154
trend coefficient, 10, **15**, 105
checking estimates, 159
estimated mean value, 38
estimation, 155
expectation, 126
posterior mean value, 38
prior distribution, 16
prior mean value, 38
relative standard deviation, 126

simulated value, 38
standard deviation, 126
trend error, 158
trend map, **16**, 154
grid, 126
value, 126
<trend-coefficients>, 35, 36, **92**
trend_estimation.log, 36, **37**, 37, 38, 42, 160, 161
turning bands, 170
two way time, 95
<two-way-time>, **95**
TWT, 95
<type>, **112**, **114**, **118**, 119, 124, **127**, 130, 173
type, variogram, 112, 114, 118, 127

unbiased, 16
uncertainty, **18**
interval thickness, 127
interval velocity, 127
reduction, 38
travel time, 118
well point, 114
uncertainty studies, 3
undefined section of zone log, 54
units, measurement, 94
universal kriging, 15, 98

<value>, 58, 115, **118**, **120**, 124, **126**, **127**, **129**, 130, 154
<value well-name="" surface-name="" x="" y="" stddev="">, **115**
values outside grid
travel-time, 118
trend, 126
variogram, interval thickness/velocity, 128
variogram, travel-time, 120
well points, 115
<values-outside-grid>, 58, 59, **115**, **118**, 118, **120**, **126**, 126, **128**, 129
variogram, 114, 127
azimuth, 119, 128
distance, 113
distance, positioning error, 112
example, 173
measurement error, 114
power, 113, 114, 120, 128
range, 113, 114, 118, 127
relative standard deviation, 120, 128
standard deviation, 119, 128
subrange, 119, 127
travel time, 118
type, 112, 114, 118, 127
well path, 112
well points, 113, 114
<variogram>, 28, 41, 57, 84, **112**, 113, **114**, **118**, 124, **127**, 130, 154, 163, 173, 188
<variogram-distance>, **112**, **113**, 114
<velocity>, 34, **129**, 130
<velocity-trend>, 34, **129**
vertical uncertainty log, 111
volume, 64, 131
area, 65, 131
area name, 132
base contact, 131
base surface, 131
calculation, 66
caprock, 131
contact, 131
map of column, 133
report, 65
reservoir, 64
reservoir name, 64, 131
top contact, 131
top surface, 131
trapped, 132
<volume>, 26, 34, 64, 65, 87, 116, 122, **131**
<volume-calculation-method>, 66, **109**, 168
<volume-calculations>, 36, **93**, 183
<volumes>, 25, 26, 64, 87, **131**, 185
volumes.csv, **37**, 65, 131

weighted least squares estimate, 156
well data, **18**, 43, 48
well file format
LAS 2.0, 30, 110
RMS WELL, 30
well log, 110
fault log name, 111
file format, 30
input files, 111
uncertainty log, 111
zone log name, 111
zone log specification, 110
well marker, *see* well point
well name, 31, 48, 111
well path, 10, 18, 48, 177
file format, 30
input files, 111

output files, 44
uncertainty log, 111
variogram, 112
well pick, *see* well point
well planning, 3
well point, 2, 10, 18, 48
automatically removed, 40
close, 49
conflict, 39, 40
deleted, reason, 39
file, 113
file format, 30
from zone logs, 50
help points, 56
horizontal well, 56
identical, 49
merged, 39, 40, 49
outside grid, added, 58
outside grid, removed, 39, 40
pinch out, 40, 49
potentially conflicting, 49
redundant, 40
residual, 114
similar, 49
uncertainty, 114
well points outside grid, *see* values outside grid
well trajectory, *see* well path
`<well-data>`, 25, 26, 58, 87, **110**, 115, 118, 120, 126, 129, 185
`<well-log>`, 30, 49, 54, 84, **110**, 115
`<well-path-conditioning>`, 36, **93**
`<well-paths>`, 35, **92**
`<well-point-conditioning>`, 36, **92**
`<well-points>`, 30, 35, 84, **92**, **113**, 113, 115, 117
`<well-points-to-ignore>`, 40, 43, 54, **114**
`welldata.log`, 36, **37**, 37, 39–42, 44, 49, 50, 159, 160
`welldata/`, **89**
`wellpaths/`, 29, 33, **44**, 89
`wellpoints.dat`, 43
`wellpoints/`, 22, 29, 33, **43**, 89
`wellpoints_before_processing.dat`, 43
`wellpoints_pointfile_Well.xyz`, 43
`wellpoints_surface_Surface.xyz`, 43
`wellpoints_Well.rmsinternal`, 44
`wellpoints_zonelog_Well.xyz`, 43
`wells/`, **89**
Wikipedia, 107
wild card in file path, 111, 113, 114
Windows operating system, 12
WLS, 156
Word, 27
`<write-all-logfiles>`, **99**, 183
`<write-realization-maps>`, 33, **98**, 183

`<xinc>`, **96**
`<xlength>`, **97**
XML, 25, 87
editor, 27
error, 27
syntax, 25
XML element, *see* element
XML Notepad 2007 editor, 27
xstart
grid reference point, 96
point in connected volume, 133
spill point algorithm, 121
`<xstart>`, 64, 65, **96**, 97, **121**, 122–124, **132**, 132, 133, 184

`<yinc>`, **97**
`<ylength>`, **97**
ystart
grid reference point, 96
point in connected volume, 133
spill point algorithm, 121
`<ystart>`, 64, 65, **96**, 97, **121**, 122–124, 132, **133**, 133, 184

`<z-stddev-log-name>`, 57, 84, **111**, 112, 115, 162, 179, 184, 187
`<z-unit>`, **94**, 111
zonation, 110
`<zonation-checking>`, 36, **93**
`zonation_at_samplepoints_iteration_0/`, 45
`zonation_at_samplepoints_iteration_#iter/`, 44–46
`zonation_broken_Well.xyz`, 45
`zonation_failed_Well.xyz`, 45
`zonation_noncorrectable_Well.xyz`, 45
`zonation_Status_Well.xyz`, 44
`zonation_undefined_Well.xyz`, 45
zone log, 18, 48, 99, 110, 111, 177
constraints, 56
file header, 48
log name, 48
undefined section, 54
well format, 48
zone name, 48, 55, 56, 117

non-unique, 55
zone numbers, 117
zone transition, 50, 51, 54, 111
caused by fault, 54
zone, top of, 117
<zone-log-name>, 48, **111**, 115
<zone-log-specification>, 48, **110**
<zone-log-specification-file>, **110**