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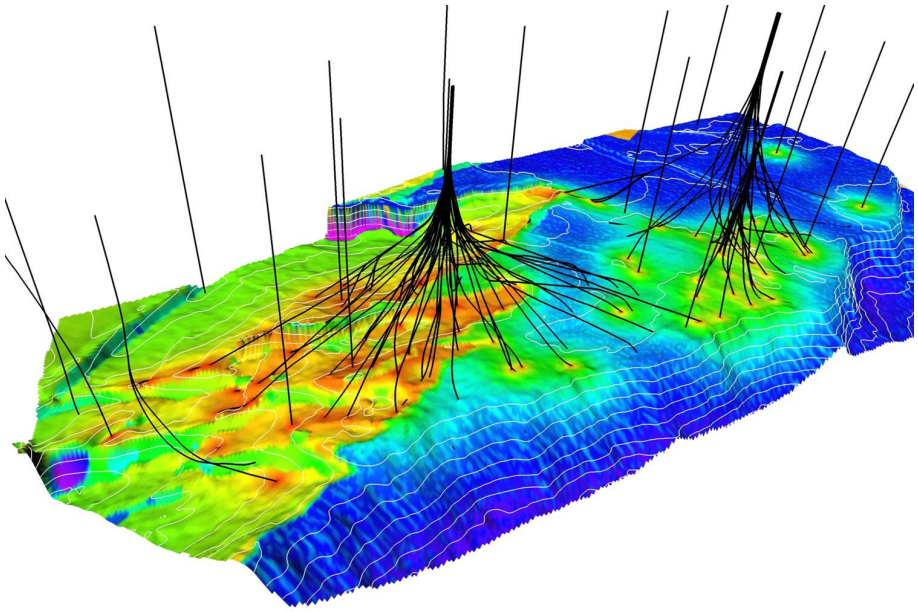
Note

# Cohiba User Manual
# Version 4.1




Note no SAND/02/2013



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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/en/COHIBA.

For Cohiba support contact Pal.Dahle@nr.no or Petter.Abrahamsen@nr.no.



| | |
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# 1 Introduction

Cohiba provides a fast and accurate method for generating a set of deterministic surfaces using prediction, or a set of stochastic 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.

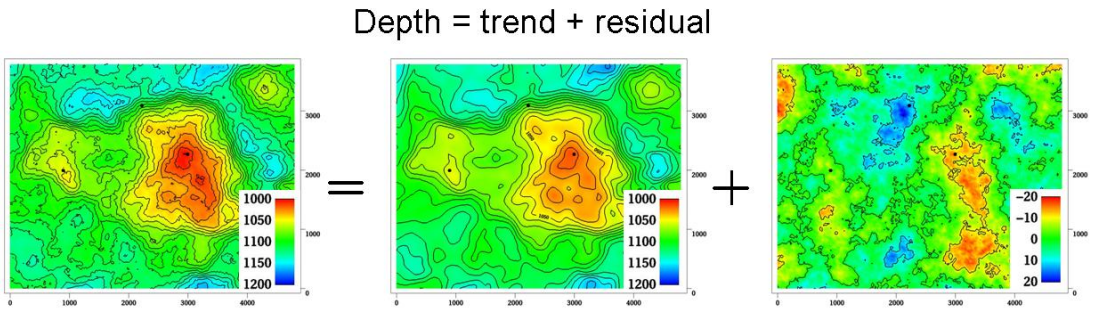
Cohiba uses the available data in a consistent manner to minimize the uncertainty. The accuracy is further improved by linking together all surfaces in a consistent multi-layered model.

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:

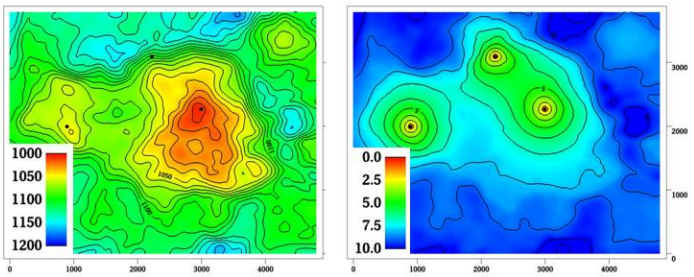



The trend can be a single known map or a linear combination of many known maps. The trend determines the main shape of the surface so the choice of trend maps is very important. The residual is usually small compared to the trend. The residual is specified by an residual uncertainty (standard deviation) 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 16.

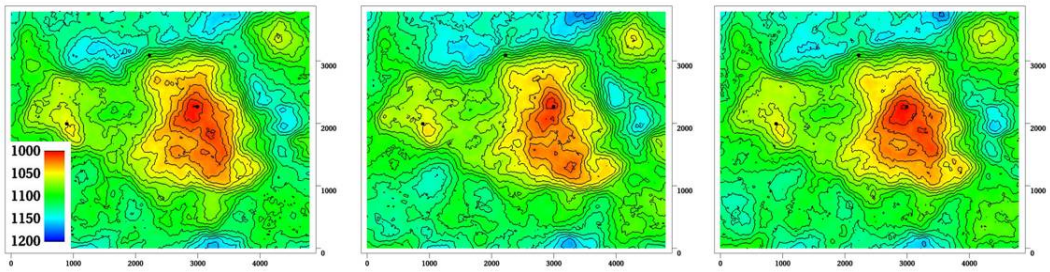
## 1.2 Cohiba main features

**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 make a stochastic simulation (Monte Carlo) to make alternative realizations that are consistent with all available data. This is typically used for sensitivity and uncertainty studies. Three stochastic simulations are illustrated here:



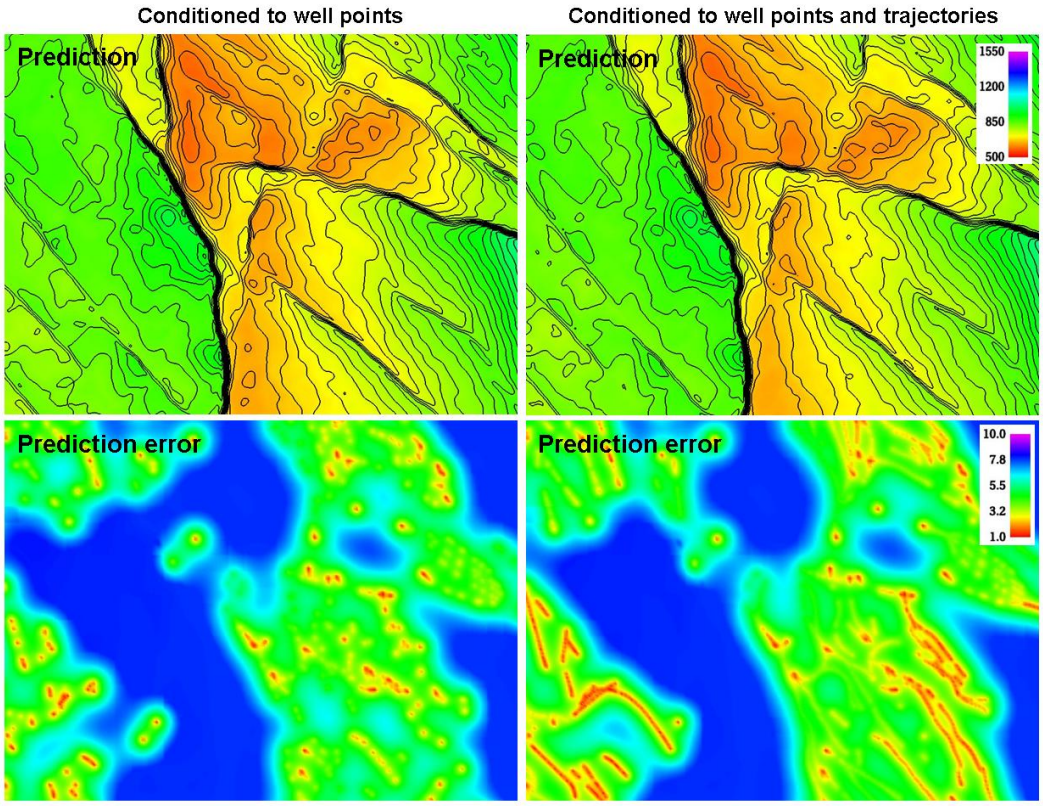

The average of a large set of stochastic simulations will coincide with a deterministic surface obtained using prediction. The standard deviation of the large set of stochastic simulations will coincide with the prediction error.

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.

**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 ensure 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:

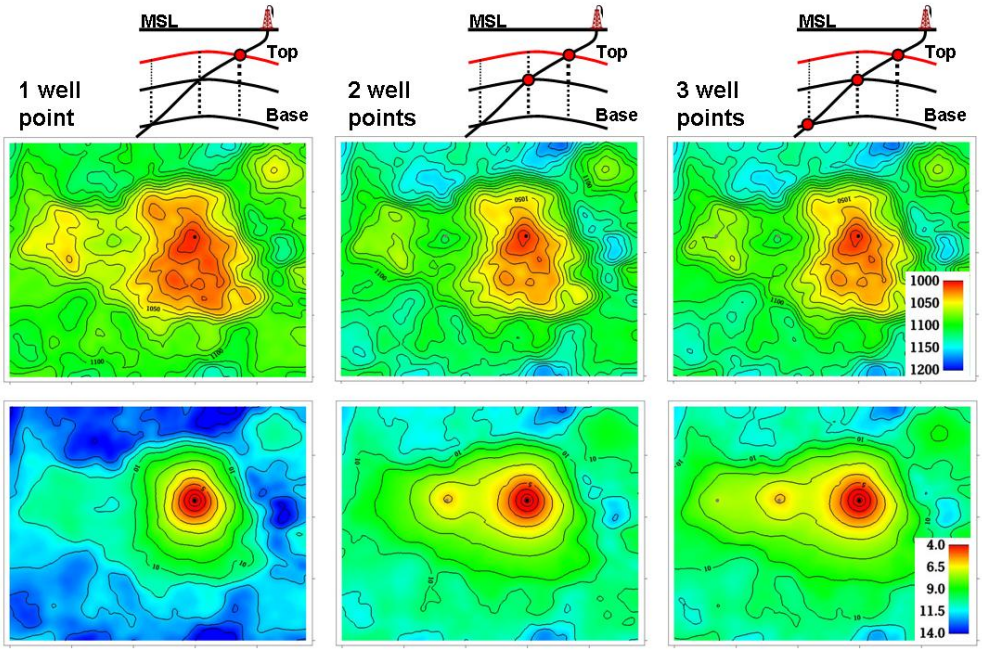



The two upper figures are the deterministic surfaces and the two lower figures are the corresponding prediction errors. The change in the deterministic surfaces are significant and the prediction errors has been significantly reduced along the well paths.

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:

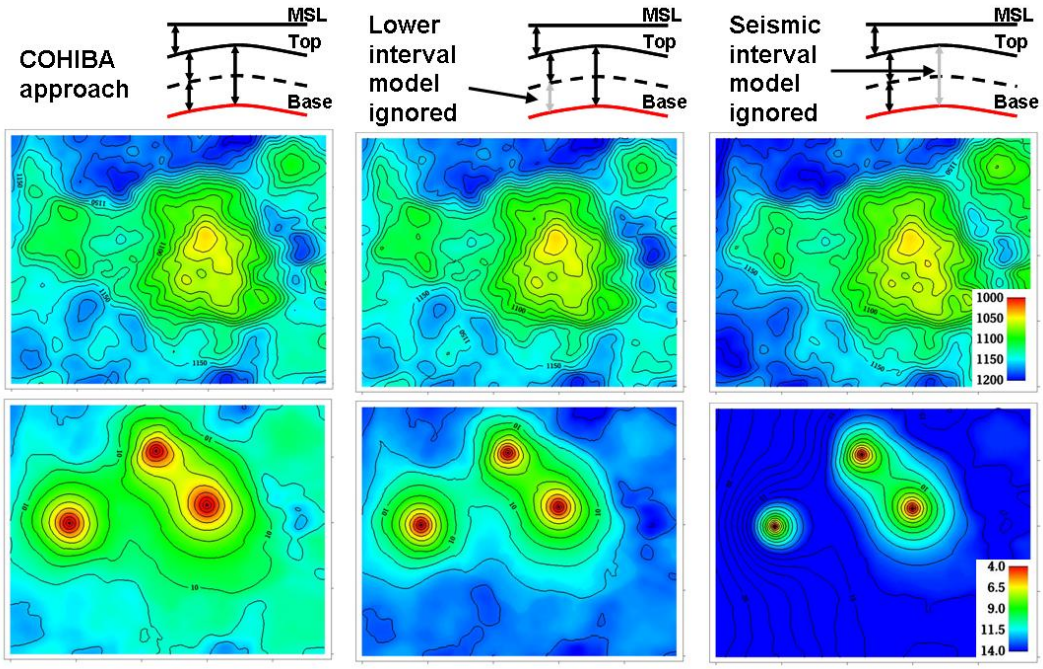
1. A particular surface is constrained by observations from surfaces above and below. This improves precision and reduces the uncertainty. The impact of observations below a surface is illustrated here:




   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:



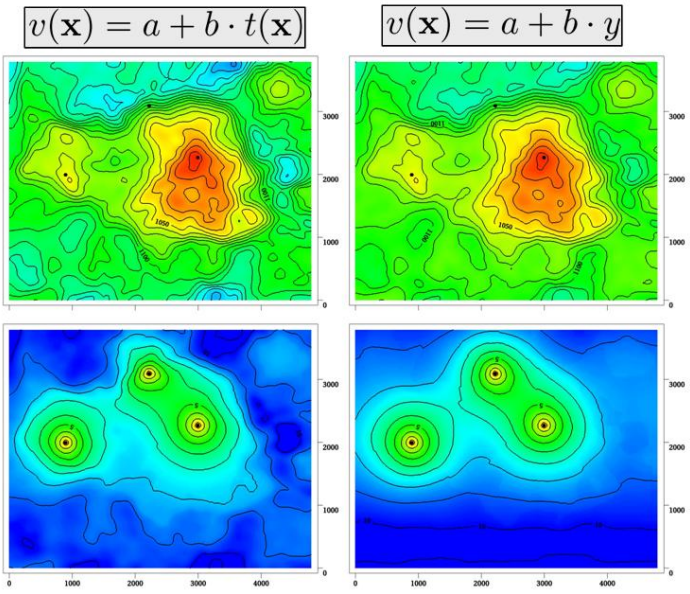

The illustration shows the base surface (and its prediction errors) from a model with three surfaces. This is the red surface in the schematic cross sections above the contoured maps. The top and base surfaces are seismic reflectors. The intermediate surface (dashed line) is not a seismic reflector. 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 10 includes a discussion of multiple models.

**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.

**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.

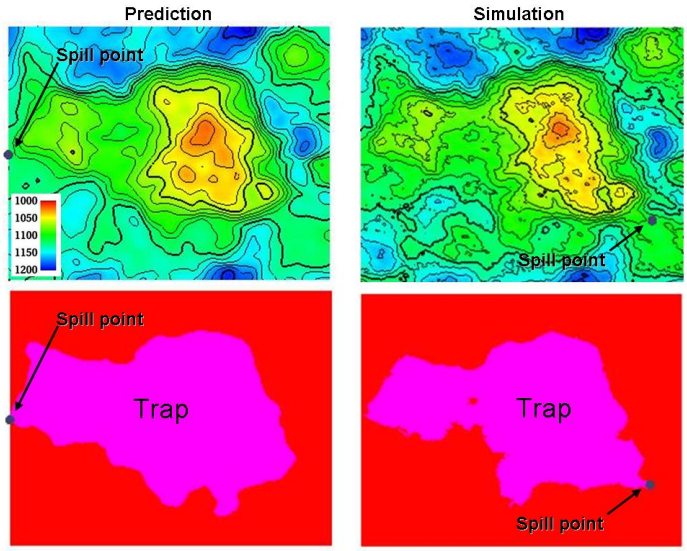
Example of two alternative depth conversion models:




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.

**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.

## 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 approach 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. The starting point is by default the shallowest point on the surface.

## 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 $v(x, y) = a+b\times t(x, y)$, 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: $\Delta z(x, y) = a + b \times x + c \times y + d \times m(x, y)$, where $a$, $b$, $c$, and $d$ are trend coefficients and $m(x, y)$ is any known map.
- Interval thickness trend using an isochore map: $\Delta z(x, y) = a \times m(x, y)$, 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.

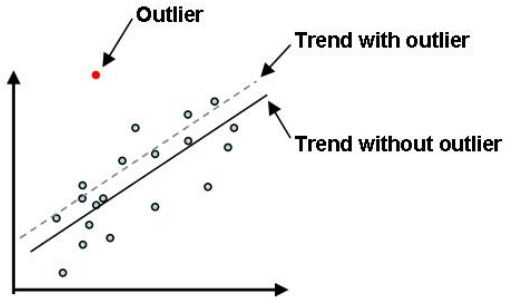
**Ordering of surfaces.** The surfaces in the model must be ordered according to their depth. This makes it possible to check if well observations are in correct order. Moreover, this ensures that erosion, pinch out, and on-laps can be handled properly. Free surfaces (Section 12) do not have any ordering.

## 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:

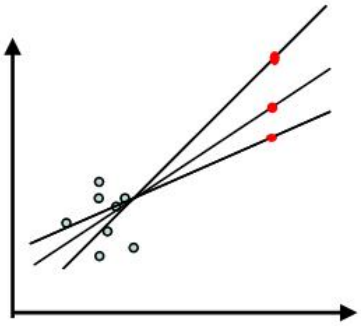
**Model conflicts.** Well points that are in conflict with the model are flagged. Well points are removed if the conflict may corrupt the results.

- Detection of *outliers* (Weisberg, 1985, pp. 114–118). 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.

- 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.

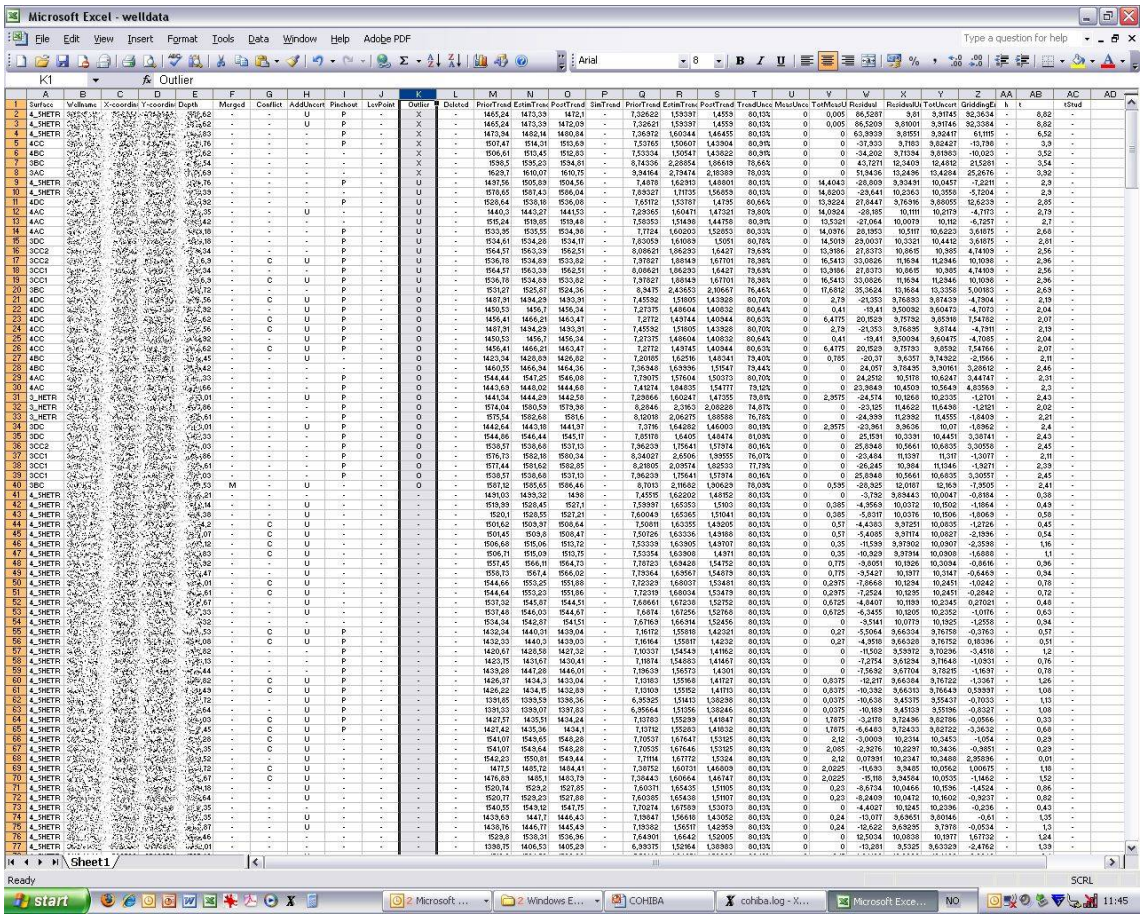



Figure 1.1. Log file for well points imported into Excel. Outlier status is reported in column K. The 7 first observations has been removed (row 2–8), the 12 next (row 9–20) are kept but a measurement error has been added, and another 20 well points (row 21–40) are marked as outliers.

## 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

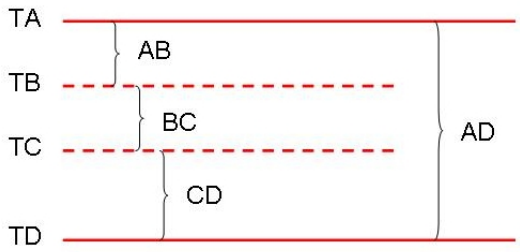
Cohiba is an acronym for **Co**rrelated **H**orizon **I**ntervals and **B**ayesian **A**nalysis. But more important it is a nice word that is easy to remember. It is also known to be a famous Cuban cigar. The previous versions of Cohiba were called HORIZON.

# 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.

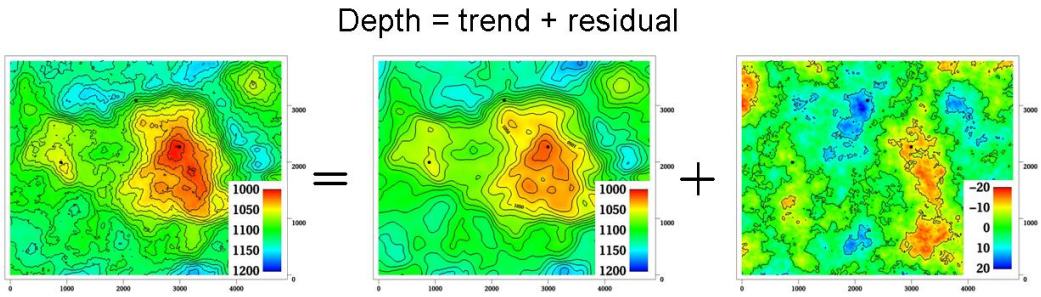
**Interval.** An interval in Cohiba has a top surface and a base surface. The top and base surfaces are two arbitrary surfaces but they must be in correct depth order (top above base). Any surface can be both a top surface and a base surface in several intervals. A common example is to have one interval 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

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

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.

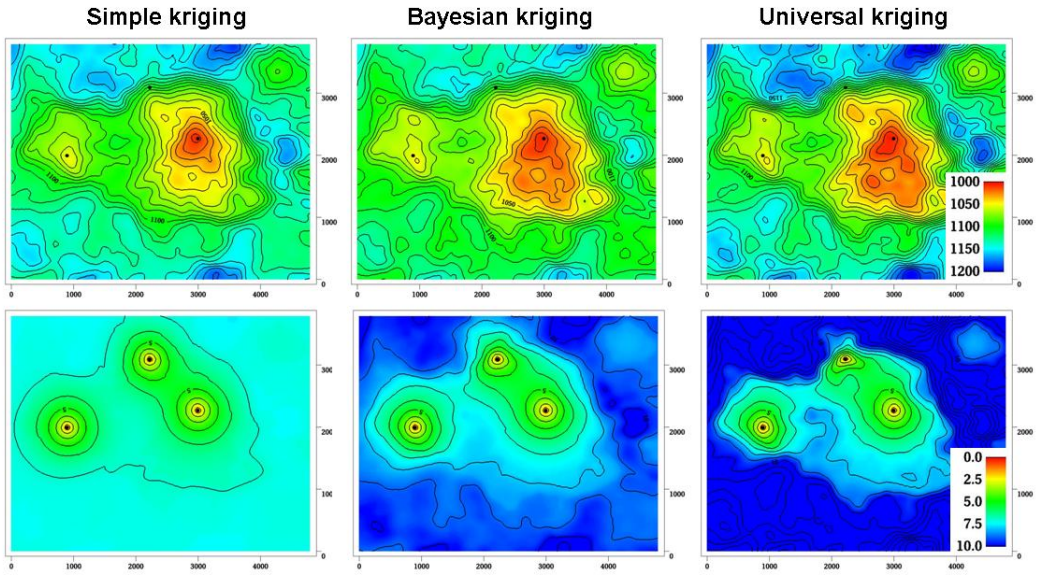
Cohiba supports any number of trend maps in the linear combination. But, most trends are quite simple and usually contains one or two trend maps.

**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.

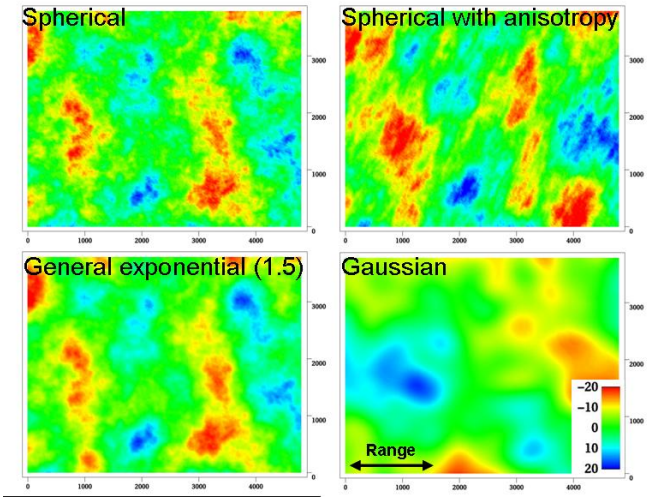
**Residual.** The residual is added to the trend to capture the difference between the trend and reality. The residual is assumed to be a *Gaussian random field* with known properties that must be specified by the user. The properties include a variogram (spatial correlation function) (variogram) and 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

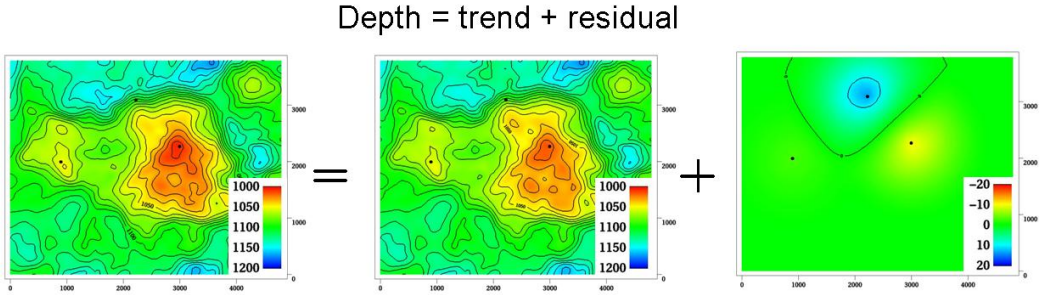
$$v = a \times 1 + b \times t(x, y).$$

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

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

**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:



**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.

# 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 `0_test/`.
2. Create a file `model_file.xml` in `0_test/` using the following XML Cohiba model file:

```
<cohiba>
<project-settings>
  <project-directory>    0_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 `0_test/input/` and create a file `wellpoints.cohiba` in `0_test/input/` with the following content:

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

4. From the command line type: `cohiba.exe 0_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 TEXT 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. See Section A.1.3 for details.

## 4.2 Spill point detection

Cohiba 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:

```
*********************************************************************
***                      COHIBA version 1.3.1                     ***
*********************************************************************

Irap classic grid: spillpoint.irap imported.

*********************************************************
***              Spill points summary                 ***
*********************************************************

Xstart          Ystart          XSpill          YSpill          ZSpill
-------------------------------------------------------------------------
349542.094      6426545.500     349292.094      6428595.500     1278.000
-------------------------------------------------------------------------

Irap classic grid: trap_spillpoint.irap exported.

Total CPU  time used in COHIBA:     0.80
Total Wall 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 A.4.2.5.1.
*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 key-word for the element and the `argument` is a value (string, number, etc.) or other elements. The attribute is omitted in most cases. Often `arguments` contains further elements in a nested structure. The Cohiba model file is divided into 5 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>`

There is a hierarchy of elements belonging to each of these 5 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 surface considered in the model.

An extensive example of a Cohiba model file is given in Appendix B.

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

## 5.1 Visualizing and editing the Cohiba model file

An XML file is a simple ASCII text file and almost any text editor (WordPad, 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 editor may be freely downloaded. This editor is illustrated in Figure 5.2.

### 5.1.1 Creating a mapping into Microsoft Excel

It is possible to create a workbook using an XML file. Follow the steps:

1. Start Excel.
2. Choose the Cohiba model file using the **File→Open...** menu.

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>
     <surface>
       ......
     </surface>
  </surfaces>
  <interval-models>
     <interval>
        .....
     </interval>
     <interval>
       ......
     </interval>
   </interval-models>
</cohiba>
```

Figure 5.1. Skeleton of a Cohiba model file.

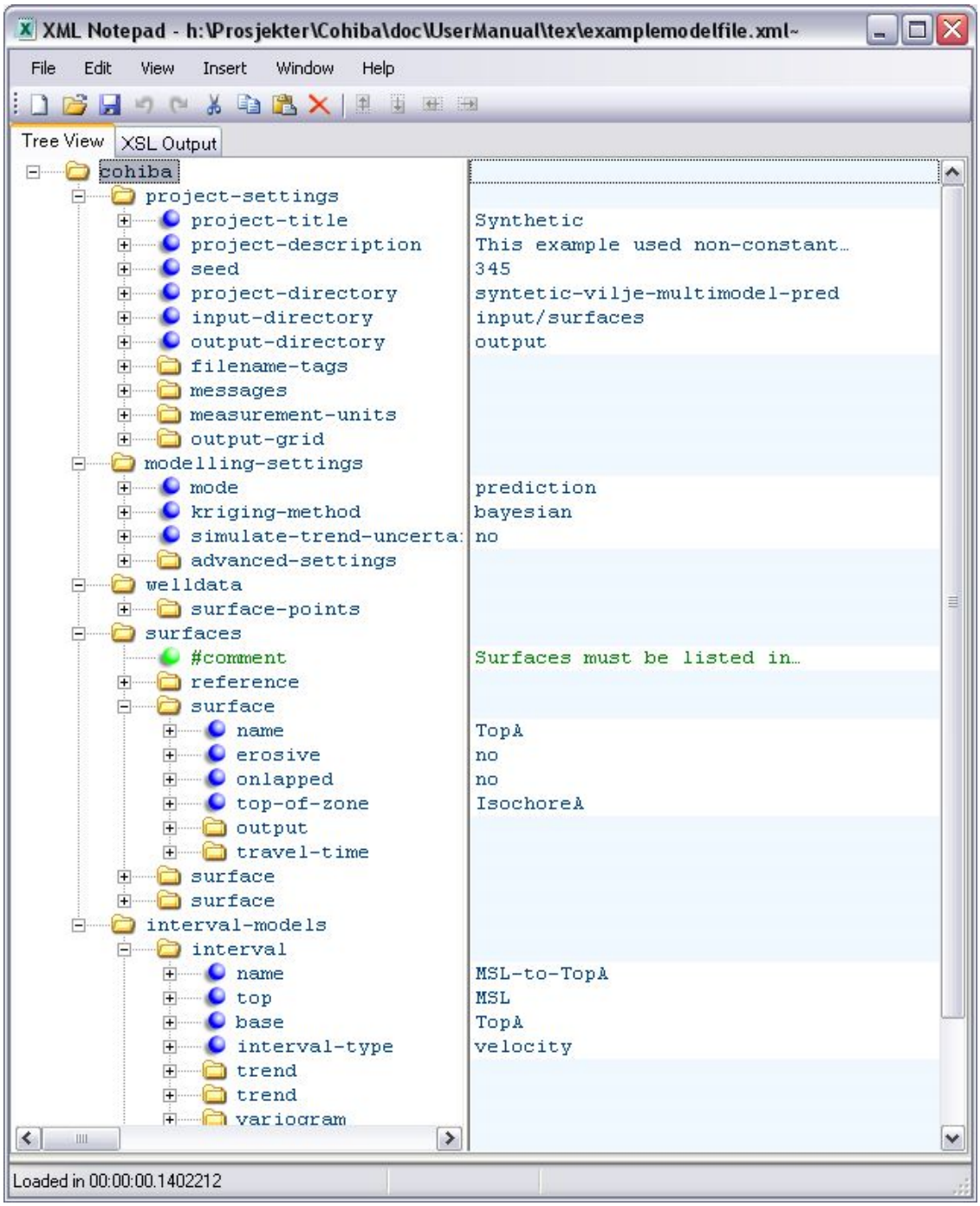



Figure 5.2. A Cohiba model visualized in the Microsoft XML NotePad 2007 editor. The entries in the right column can be edited.

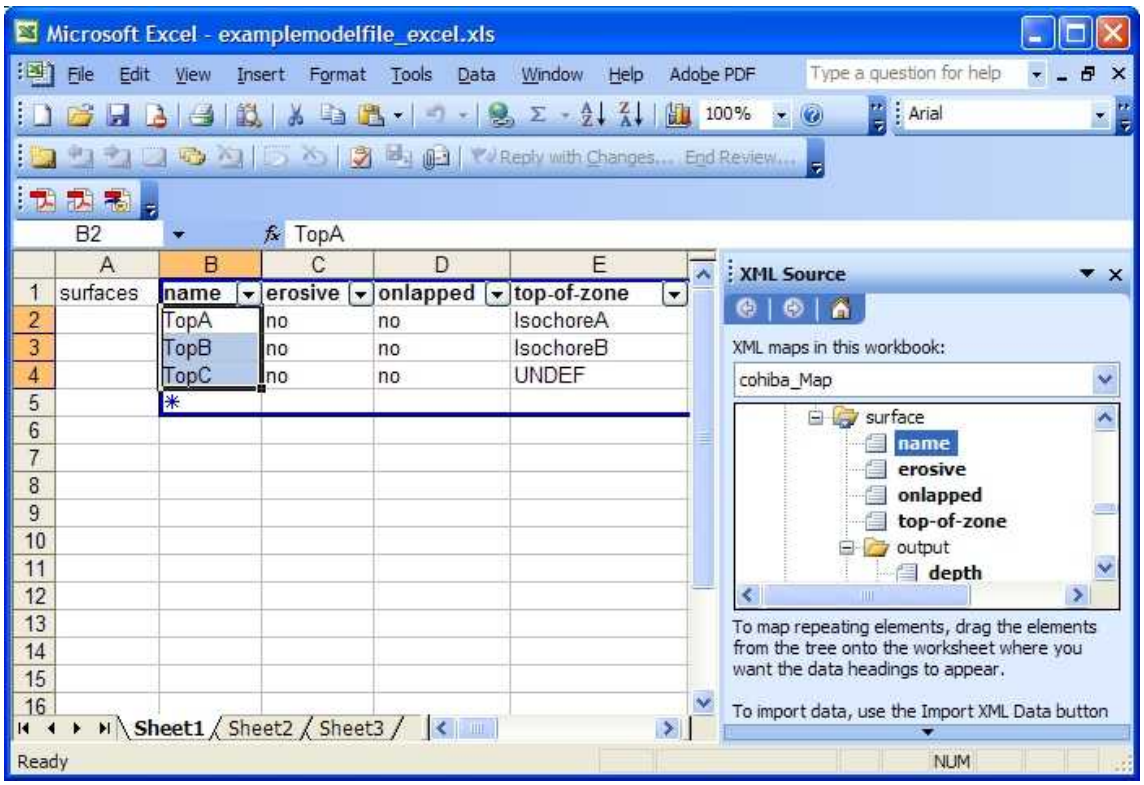



Figure 5.3. A mapping into Microsoft Excel of the repeated element `<surface>` in the Cohiba model file.

3. Select **Use the XML source task pane**. Excel will then create a tree from the XML source data. So far only the tree structure has been established and no data has been imported.

4. Follow the instructions below the tree: **To map elements, drag the elements from the tree onto your worksheet**. We suggest that you choose the repeated `<surface>` or `<interval>` elements.

5. Right click on the imported cells and select **XML->Import...**. Select the Cohiba model file again.

6. The values will be visible in a table format.

This procedure may be useful for inspection and comparison. It is possible to sort the input data according to variogram type, interval type, etc.

Modified data in the worksheet can be exported to XML format by right clicking on mapped cells and selecting `XML->Export`. Note that only the mapped section of the Cohiba model file will be exported so this is of limited interest.

## 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 a message will be issued to screen and the Cohiba log file. It 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 key-word 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 three surface file formats are supported:

**STORM BINARY** This is a binary format. See ROXAR ASA (2009) for information on this format.

**ROXAR TEXT** This is an ASCII file format. See ROXAR ASA (2009) for information on this format. This format supports rotated grids. The rotation is specified using `<grid-azimuth>`.

**Constant** Allows to define a constant surface with just a single value.

The input file formats are automatically detected when reading from file. Undefined areas with missing codes are allowed and will be automatically detected.

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

## 6.3 Well log file formats

Cohiba may import the following type of well data:

1. Well paths with logs given in the RMS WELL file format. See ROXAR ASA (2009) for documentation.

2. Well paths with logs given in the Log ASCII Standard (LAS 2.0) file format. See www.cwls.org for documentation.

All files are specified using <files> under the <well-log> element. Cohiba detects the file format for each file 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                                   uncer.
#-------------------------------------------------------------
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                                         uncer.
#-------------------------------------------------------------------
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
#-------------------------------------------------------------------
```

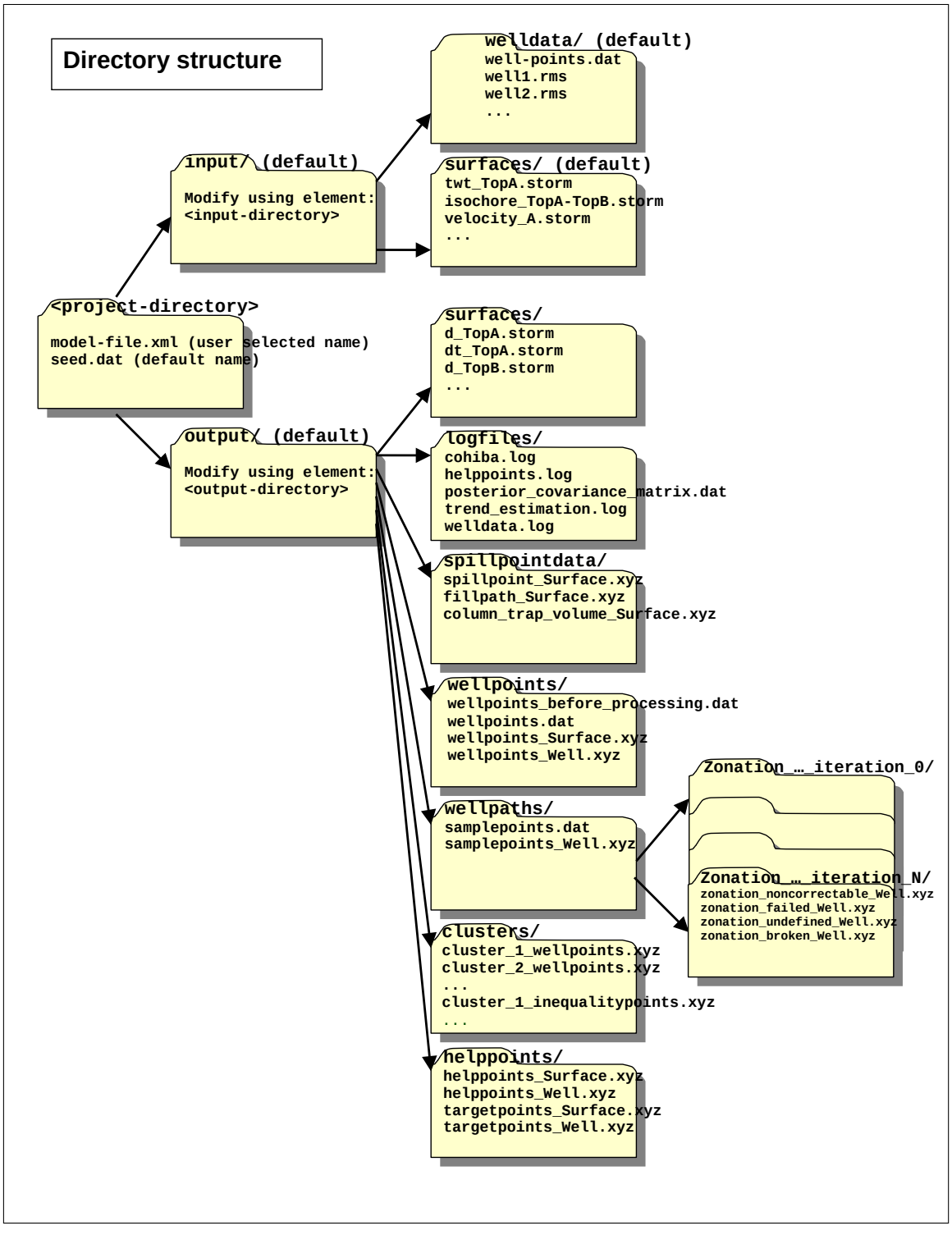



Figure 6.1. Recommended and default directory structure for Cohiba.

# 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 surfaces 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 QC. The files are stored in the directories `wellpoints/`, `wellpaths/` `clusters/`, and `helppoints/`.

## 7.1 Output surfaces

All the grids with output surfaces are written to the `surfaces/` directory. The grid files are named using the name of the surface (see `<name>` under the `<surface>` element) and a prefix (or postfix) depending on the type of output surface. The prefix (or postfix) tags can be modified using the `<filename-tags>` element. Cohiba can produce the surfaces found in Table 7.1.

## 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 A.1.12.1. The default name is `cohiba.log`. An extensive example is given in Appendix C.

There are currently 17 sections in the log file with their individual user specified level of detail:

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

Table 7.1. Output surfaces found in the `surfaces/` directory.

| Surface | Prefix[a] | Description |
|---|---|---|
| **Depth** | `d` | Deterministic (prediction) or stochastic simulated depth to the surface dependent on the specified `<mode>`. In prediction mode the most likely surface is generated. In stochastic simulation mode, one realization out of an infinite number of possible surfaces is generated. |
| **Depth trend** | `dt` | Similar to **Depth** but the residual is omitted. For deterministic surfaces (prediction), this means that the local adaption to well observations is omitted. For stochastic simulation, the residual is also omitted. |
| **Depth error (uncertainty)** | `de` | Prediction error; Standard deviation at each point on the surface. It should be zero at the well points but gridding errors will usually result in a non-zero value at the well points. |
| **Depth trend error (uncertainty)** | `dte` | Standard deviation caused by the uncertainty in trend coefficients. |
| **Depth residual** | `dr` | Difference between **Depth** and **Depth trend**. |
| **Interval thickness** | `t` | Interval thickness computed as the difference between the two depth surfaces defining the interval (specified in `<top>` and `<base>` elements). |
| **Interval thickness trend** | `tt` | Interval thickness trend computed as the difference between the two depth trend surfaces defining the interval. |
| **Interval 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 trend[b]. |
| **Interval velocity trend** | `vt` | The posterior interval velocity trend. |
| **Trap** | `trap` | The trap containing the starting point. The trap surface is 1 if the grid cell is inside the trap and 0 otherwise. |
| **Trapped column**[c] | `column_trap` | The column height between the top surface and the depth of the spill points for *each* trap. This applies to all traps detected along the search path of the spill point algorithm. |
| **Trapped volume**[c] | `volume_mask` | The volume for *each* trap in million meter$^2$ $\times$ z-unit. All grid cells in each trap is assigned the same volume. |
| **Cumulative trapped volume**[c] | `cumulative _volume_mask` | The cumulative volume for the traps in million meter$^2$ $\times$ z-unit. All grid cells in each trap is assigned the same volume. |

*a.* These are the default prefixes. These can be renamed using the respective elements in the `<filename-tags>` element.
*b.* Unrealistic interval velocities are usually related to thin intervals near faults and pinch outs. To get more realistic velocities a smoothing process can be performed. See `<smoothing-factor-calculated-velocities>` for details.
*c.* Trapped column and trapped volume is only generated when spill points are triggered from command line. See Section 4.2.

**Section 7: Trend coefficients based on well points** Reports the estimated values for the trend coefficients in the trends. Detail level set by `<trend-coefficients>`.

**Section 8: 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 9: 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>`.

**Section 10: Condition to 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 11: 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 12: 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 13: Conditioning surfaces on all available points** Makes a final report on the quality of the surfaces. Detail level set by `<well-path-conditioning>`.

**Section 14: Post process surfaces** Detail level set by `<post-processing>`.

**Section 15: 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 7.2.5.

**Section 16: Timings summary** Reports the amount of CPU time spent on different operations. Detail level set by `<timings>`.

**Section 17: Suggested tasks** This is a task list of possible problems the user should look into. Detail level set by `<tasks>`.

The 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`.

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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.

### 7.2.2 The `trend_estimation.log` file

This file 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 7.2.7 and Section 7.2.8.

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.

### 7.2.3 The `posterior_covariance_matrix.dat`

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`.

### 7.2.4 The `zonation_after_conditioning_to_wellpoints.csv`

This 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.

### 7.2.5 The `zonation_after_conditioning_to_all_points.csv`

This 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.

### 7.2.6 The `welldata.log` file

This 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 7.2.7 and Section 7.2.8 for a detailed description.

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

#### 7.2.6.1 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 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

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

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.

#### 7.2.6.2 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.

#### 7.2.6.3 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.

#### 7.2.6.4 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 measurement 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.)

#### 7.2.6.5 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.

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 unless there is a significant measurement error. The removal can be turned off using <make-surfaces-interpolate-well-points>.

#### 7.2.6.6 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.

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

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

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 error. If the well points had a perfect Gaussian distribution this would occur with a frequency of 5 %, 1 %, and 0.2 % respectively. These thresholds can be modified by the elements <t-value-outlier>, <t-value-severe-outlier>, and <t-value-error>.

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. See Abrahamsen et al. (2009) for more details.

Table 7.2. The `trend_estimation.log` file. Description of columns.

| 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.

| 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. |

### 7.2.7 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**.

### 7.2.8 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**.

### 7.2.9 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`.

### 7.3.2 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 4.2).

### 7.3.3 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 4.2).

### 7.3.4 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 4.2).

## 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 containes 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_..._Well.xyz` status files

Sample points where the zone log is inconsistent with the surfaces after the conditioning are written to files so that they can be easily visualized. The sample points are written to separate files for each well and zonation status type. The file naming convention is:

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

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>`.)

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

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 to be 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. These point attributes are

| **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? |

where the boolean values are 0 (no) and 1 (yes). For practical reasons, the boolean values are represented with type "Discrete" in the files.

If help points are present, similar status files are also made after conditioning to well points and help points. These files are stored in folders `zonation_at_samplepoints_iteration_#iter/` (see section 7.5.5), and the sample points are given a new set of attributes. These are

| 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 below) |
| MatchCode | Discrete | Number representation of MatchText |
| FixText | String | Was zonation fixed? (see below) |
| FixCode | Discrete | Number representation of FixText |

The possible values for MatchText and MatchCode and their explanations are

| Text | Code | Description |
|---|---|---|
| U | -999 | Zonation is undefined in either well of surface model |
| Y | 1 | Zonation matches |
| N | -1 | Zonation does not match |

whereas the possible values for FixText and FixCodes are

| Text | Code | Description |
|---|---|---|
| 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 element `<minimize-broken-zonation>` to activate. |

## 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.

## 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 *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 well logs. Files with different zone name specification will be discarded.

## 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.

### 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

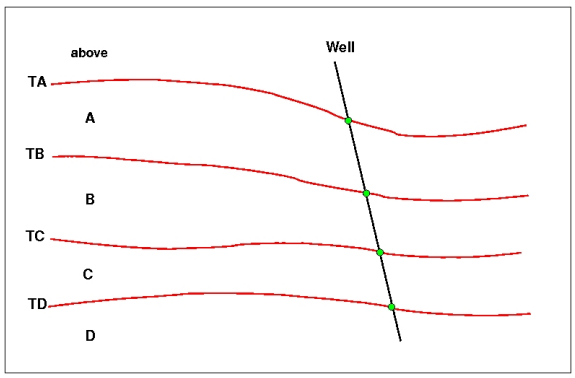



Figure 8.1. Transitions between a simple set of zones. The well points are given as green bullets.

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.

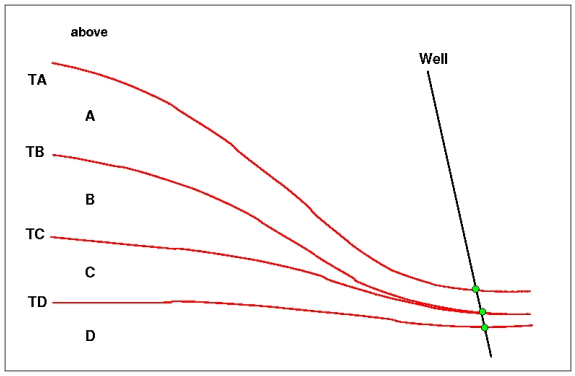



Figure 8.2. Zones with pinch out. The well points are given as green bullets.

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 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

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 | — |

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.

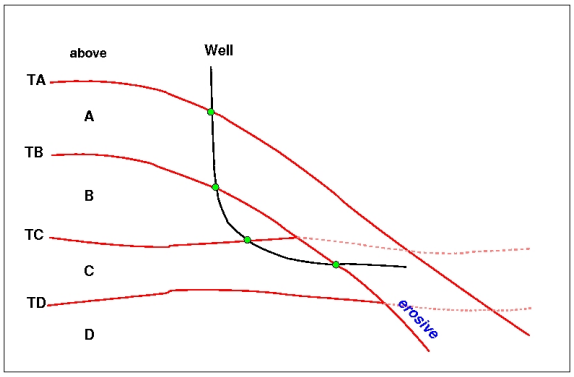



Figure 8.3. Zones where surface TB is erosive. The well points are given as green bullets.

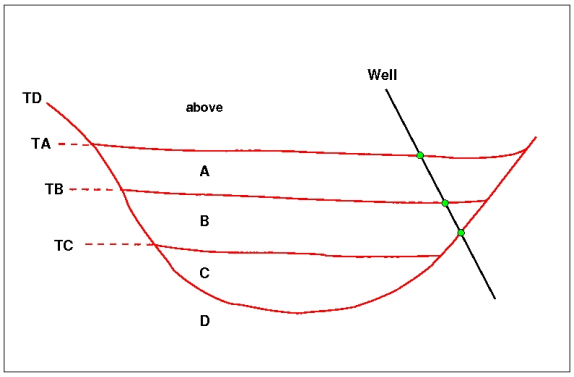



Figure 8.4. Zones where surface TD is on-lapped. The well points are given as green bullets.

### 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.

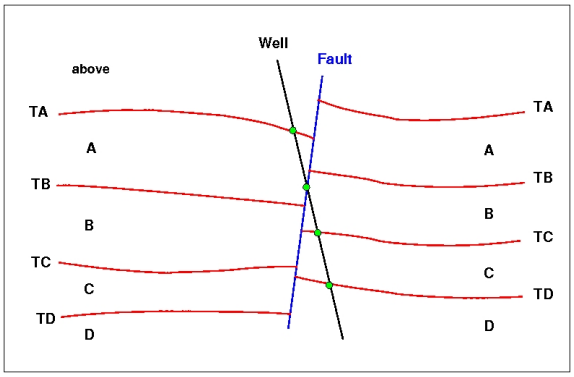



Figure 8.5. A set of faulted zones. The well points are given as green bullets.

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 9) at the edges of the undefined sections to ensure that surfaces are in the right position at these locations.

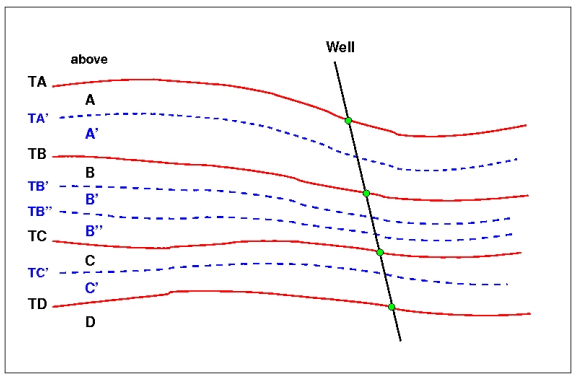



Figure 8.6. A simple set of zones with a zonation finer than the surface model. The well points are given as green bullets.

### 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

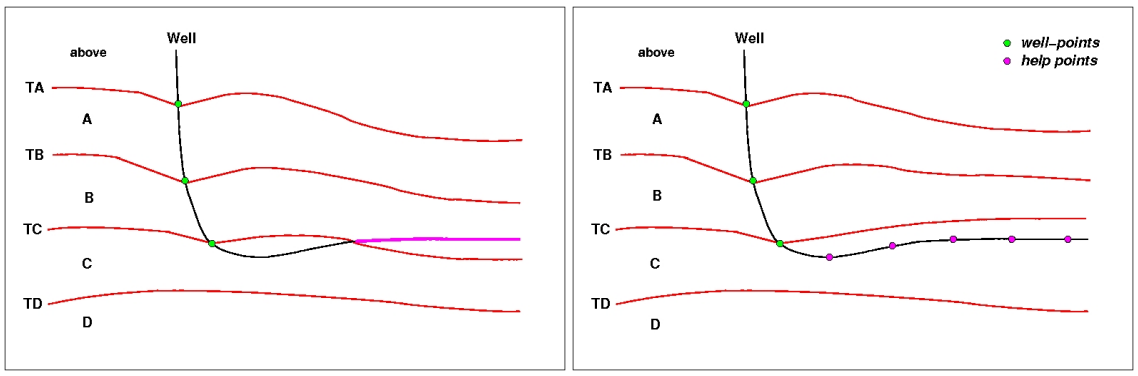



Figure 8.7. A horizontal well following a zone. In the left figure a part of the well (colored magenta) have ended up in the wrong zone after the surface-adjustment. In the right figure this problem has been corrected by the introduction of help points that ensures that the surface match the correct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

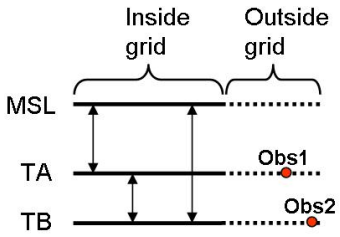
chosen so that surfaces are consistent with the model assumptions for trends and residuals and all the well data, well points and zone log constraints.

For more details see Section 9 that discuss conditioning on zone logs.

## 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`:



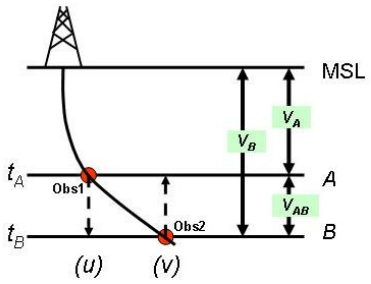

An outside grid well point (`Obs1`) at `TA` and an outside grid well point (`Obs2`) at `TB` require the following input:

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 assump-

tion 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>
```

# 9 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).

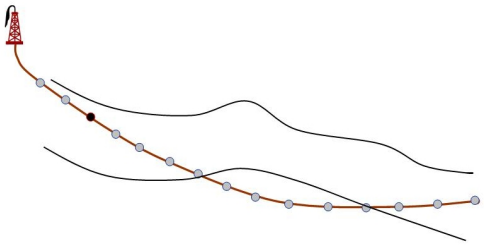
The approach used by Cohiba is a development of the ideas in Abrahamsen and Benth (2001). The article shows how to use inequality constraints in a kriging setting. Here we outline the basic ideas and the modifications necessary to make this work for a multi layered model.

Using zone log information is activated by choosing `yes` in the `<condition-to-well-paths>` element. This is the default.

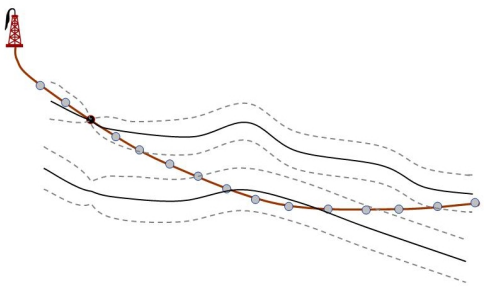
## 9.1 Procedure for conditioning to zone logs

The approach can be looked upon as a sequence of steps:

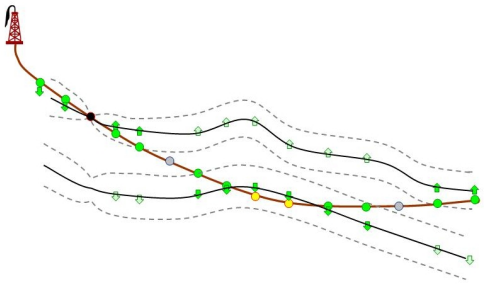
1. Sample the well paths at a resolution approximately twice the grid resolution. (Typically at 100 meter intervals.) The well path is shown as a red line. The well point is shown as a black disc and the **sample points** are the gray discs. The two black lines are cross sections of the surfaces above 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 cells are close to the well paths.



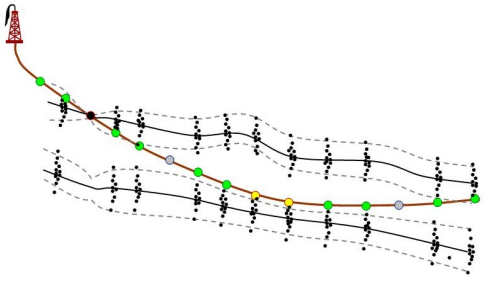
3. Select the sample points that are in conflict with the zone log, that is, they are on the wrong side of the deterministic surface. Two yellow sample points are on the wrong side. Also select the sample points that are on the correct side of the deterministic surface but are *close* to the deterministic 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.



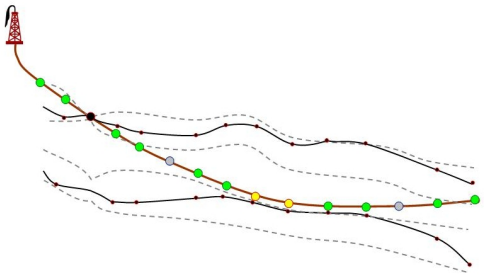
   The chosen sample points are called the **selected sample points** and the constraints imposed by the selected sample points are called **inequality points** for the surface. These are indicated by the green arrows.

   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.

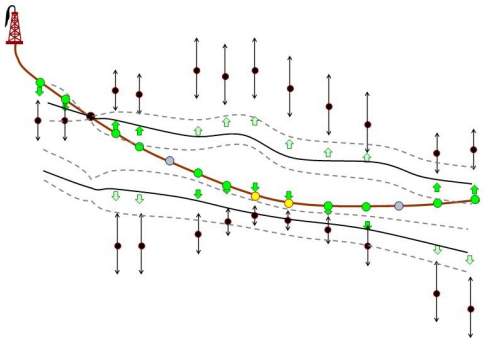
4. Run the Data Augmentation Algorithm to obtain 256 simulated realizations of the depth values at the inequality points. These 256 realizations represent the non-Gaussian probability distribution for depth at the inequality points. The 256 realizations will all be in agreement with the well points *and* 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.



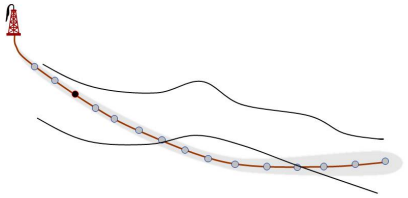
6. **For deterministic surfaces:** Calculate the expectation and the covariances of the 256 simulated realizations at the inequality points. The expectations at the inequality points are called **target points** since this is where we want the predicted surfaces to go. These target points and the covariances 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.



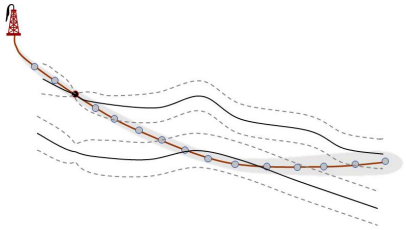
## 9.2 Procedure for conditioning to zone logs with uncertain well paths

Considering an uncertainty model for the vertical position of well paths is an extension of the steps oulined in 9.1. We repeat the steps with their extensions:

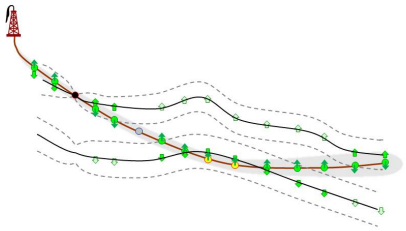
1. The well path is shown as a red line. The well point is shown as a black disc and the **sample points** are the gray discs. The two black lines are cross sections of the surfaces above and below the main part of the well path. The uncertainty envelope (shaded cone) represents one standard deviation away from the well path (cf. `<z-stddev-log-name>`).



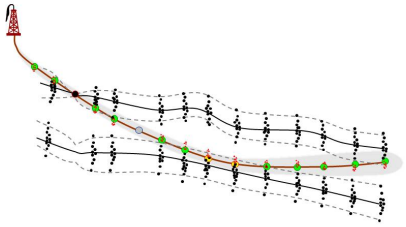
2. Along the well paths, calculate the deterministic surface (solid lines), and the prediction error (dashed lines) given the well points.



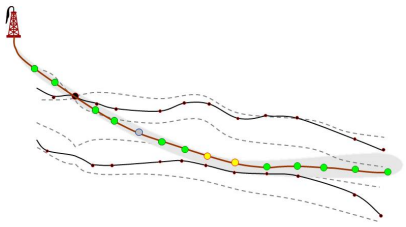
3. Select the sample points that are in conflict with the zone log or are *close*. The closeness criterion accounts for the uncertainty in the well path as well. Consequently, more points could become a **selected sample point** compared to the case with a certain well path. The constraints imposed by 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.

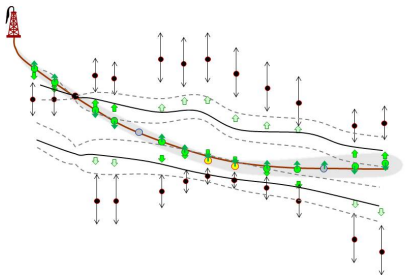


5. **For stochastic simulation:** Select randomly one of the 256 realizations of surface depths. Recall that this selection of well points is called *help points*. Select the realization of the 256 realizations of well depths that corresponds to the selected realization of surface depths.



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.

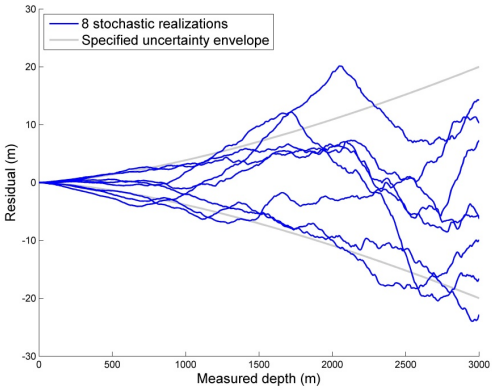
   To predict a new well path, the average of the 256 realizations of the well path is used. The difference between these average values and the original well path is interpolated using simple kriging. This residual is added to the original well path.



### 9.2.1 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 9.1 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:

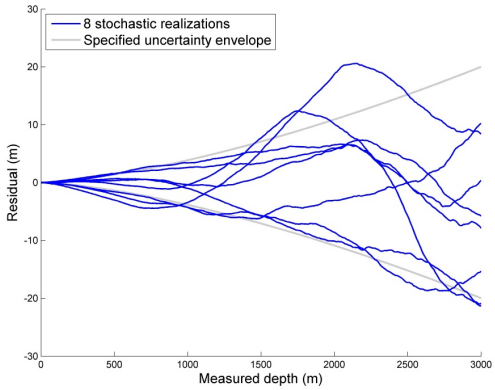



Figure 9.1. Possible models for the uncertainty of the vertical measurement error of the well paths. The uncertainty log specified by `<z-stddev-log-name>` is shown as grey lines. The blue lines are simulated realizations from the measurement error model.

## 9.3 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 9.2. 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.

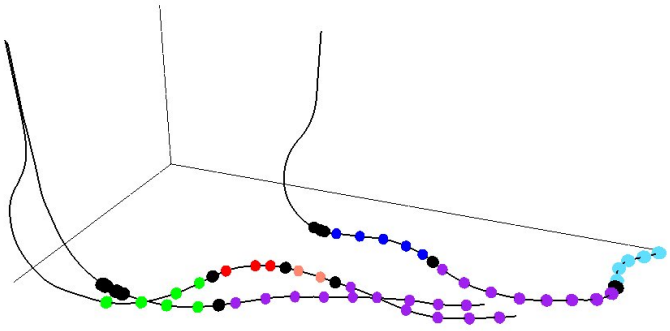


Figure 9.2. Different clusters in the three different wells have different colors. The well points are the black discs. Note how well points splits inequality points from a well into separate clusters. Also note that the largest clusters have inequality points from all three wells.

# 10 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 10.1 shows an example.

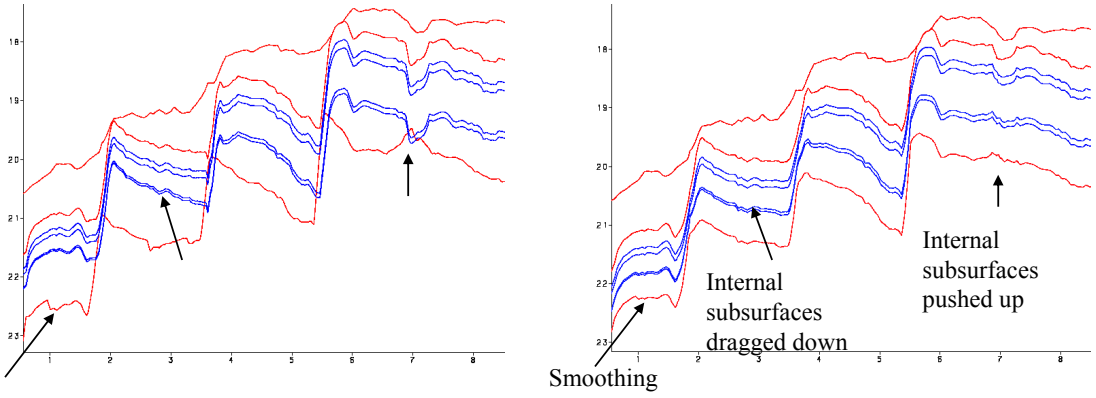



Figure 10.1. Cross section of two alternative ways of combining intervals. The red surfaces are seismic reflectors. The blue surfaces separates the internal zones that are assumed to have constant thickness. The figure to the left shows the surfaces when the internal zones are added to the seismic reflector 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.

## 10.1 An 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 10.1.

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 10.1. 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 10.2. 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 10.1 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 10.3. 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 ($\pm 15$ m) than using the isochore thicknesses ($\pm 29$ 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 10.2 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 10.2 shows how this is done for the Brent example.

Figure 10.3 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.

### 10.1.1 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 10.3 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 10.2. 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 10.3. 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 10.4. The report of the multiple models and their weights found in Cohiba log file. The arrows indicate an interval.

## 10.2 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 10.4 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.

## 10.3 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 10.1 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.

### 10.3.1 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:

$$\mathrm{Var}\{\Delta Z\} = N \times (30\,\% \times 200\,\mathrm{m}/N)^2. \tag{10.1}$$

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 10.5 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.

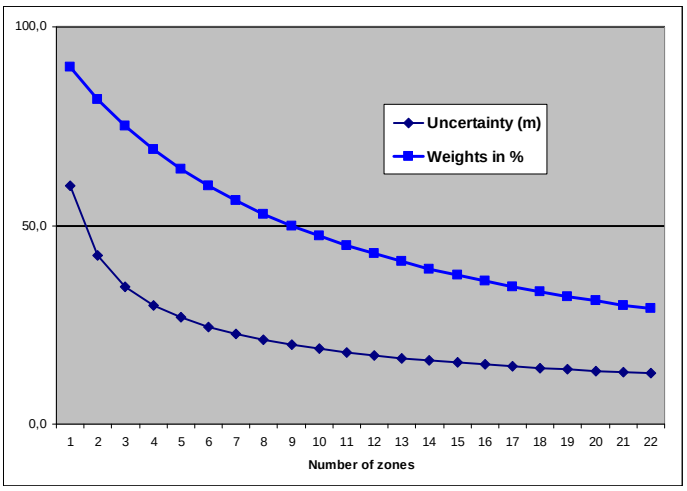



Figure 10.5. Model weights (blue line) as the number of subdivisions of the zone increase. The dark blue line is the accumulated uncertainty obtained using Equation 10.1.

### 10.3.2 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:

$$10^2\,\mathrm{m}^2 + 1^2\,\mathrm{m}^2 \approx 10.05^2\,\mathrm{m}^2 \tag{10.2}$$

$$10^2\,\mathrm{m}^2 + 2^2\,\mathrm{m}^2 \approx 10.2^2\,\mathrm{m}^2 \tag{10.3}$$

$$10^2\,\mathrm{m}^2 + 5^2\,\mathrm{m}^2 \approx 11.2^2\,\mathrm{m}^2 \tag{10.4}$$

$$10^2\,\mathrm{m}^2 + 10^2\,\mathrm{m}^2 \approx 14.1^2\,\mathrm{m}^2. \tag{10.5}$$

### 10.3.3 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.
```

# 11 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>`.

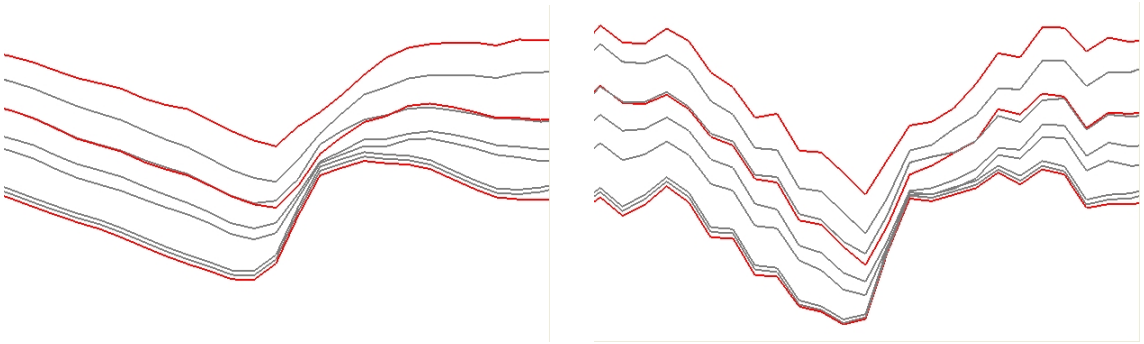
2. The zone thickness trends will in general disagree with the trends obtained from seismic depth conversion. This is solved by combining multiple models. If two seismic reflectors coincide, the thickness uncertainty between the seismic reflectors now becomes zero. This guarantees that the depth conversion 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>`.

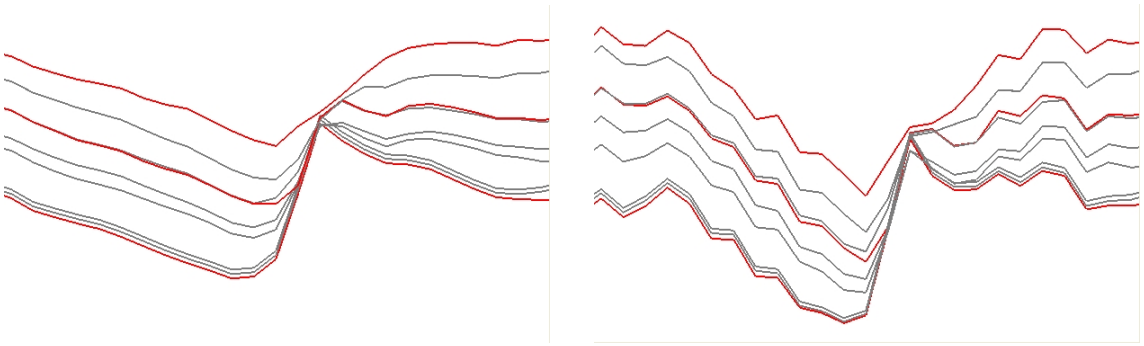
These features are illustrated in Figure 11.1.

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>`):

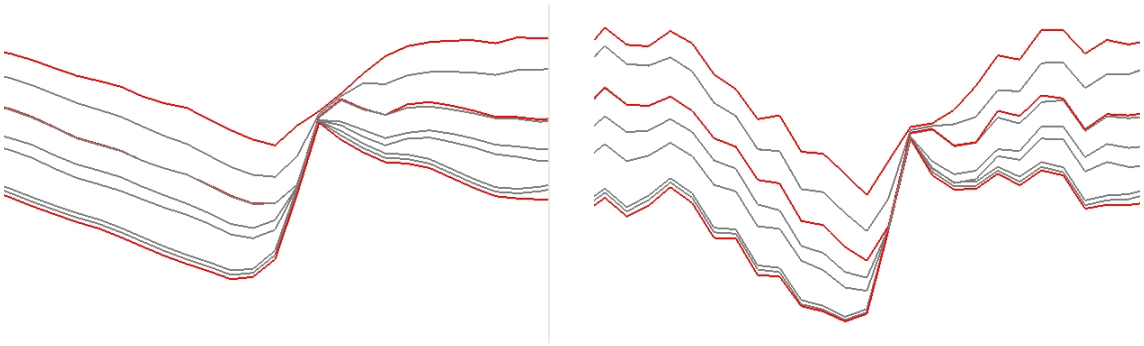


Figure 11.1. Cross section of a fault. Seismic reflectors are red. Deterministic (prediction) in the left column and one stochastic realization in the right column.

# 12 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 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>`.

## 12.1 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.

### 12.1.1 Control other surfaces using a flat spot

A flat spot is an almost horizontal gas-oil (GOC) or gas-water contact (GWC) that gives a strong seismic reflection. The seismic travel time to a flat spot will therefore have a very low uncertainty, say $\pm 1$ 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.

### 12.1.2 Control other surfaces using an 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 Stochastic simulation algorithm

Stochastic simulation mode is selected by `<mode>`.

Stochastic simulation of surfaces are done in a few steps:

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 estimated distribution and use the drawn coefficients to form the *simulated trends*.
3. Randomly draw all the residuals using a Fast Fourier Transform (FFT) algorithm[1]. The *simulated residuals* are added to the simulated trends to obtain the *unconditionally simulated surfaces*.
4. The final step is to condition the unconditionally simulated surfaces to the well points. This is algebraically (and numerically) identical to performing the kriging operations for prediction.

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. Therefore, the CPU time for deterministic surfaces and stochastic simulation is similar.

The stochastic simulation algorithm is very accurate and will ensure perfect agreement with the specified model (trends, variograms, uncertainties, etc.) and the supplied data.

1. 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.

# A Cohiba model file reference manual

Any XML file should contain an initial line

```
<?xml version="1.0" encoding="UTF-8" ?>
```

to identify the XML version and the character encoding.

### <cohiba> (required)

*Description:* Wrapper for all other elements of the Cohiba model file. This is called the root element in XML jargon.
*Argument:* The five main elements in the Cohiba model file.
*Default:* No default.

## A.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.

### A.1.1 <project-title> (required)

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

### A.1.2 <project-description>

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

### A.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. It is also possible to set the random seed employing the option -s on the command line. E.g.: cohiba.exe -s 123 model_file.xml. See Section 4.1. 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 number.
*Default:* seed.dat
*Example:* Random seed number:

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

*Example:* Specify a random seed file (default is `seed.dat`):

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

### A.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>
```

### A.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>
```

### A.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>
```

### A.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>
```

### A.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>
```

### A.1.9 <number-of-threads>

*Description:* Specifies the number of threads (parallel processes) that will be used when computing in parallel. 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.

Currently, the kriging operations 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>
```

#### A.1.10 `<prefix-for-log-files>`

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

#### A.1.11 `<filename-tags>`

*Description:* Specification of prefix (or postfix) on output grids. For example, a depth surface called TopA with a prefix `d` will be assigned the filename `d_TopA.irap`. Note that the underscore "_" is always added before (after) the name.
*Argument:* Elements for each grid type.
*Default:* Empty — default prefix for all grid types will be used.

##### A.1.11.1 `<type>`

*Description:* Type of tag.
*Argument:* `prefix` / `postfix`
*Default:* `prefix`

##### A.1.11.2 `<depth>`

*Description:* A tag describing the output depth.
*Argument:* String.
*Default:* `d`

##### A.1.11.3 `<depth-trend>`

*Description:* A tag describing the output depth trend.
*Argument:* String.
*Default:* `dt`

##### A.1.11.4 `<depth-error>`

*Description:* A tag describing the output depth prediction error.
*Argument:* String.
*Default:* `de`

##### A.1.11.5 `<depth-trend-error>`

*Description:* A tag describing the output depth trend error.
*Argument:* String.
*Default:* `dte`

#### A.1.11.6 `<depth-residual>`

*Description:* A tag describing the output depth residual.
*Argument:* String.
*Default:* `dr`

#### A.1.11.7 `<trap>`

*Description:* A tag describing the output trap connected to the spill point.
*Argument:* String.
*Default:* `trap`

#### A.1.11.8 `<thickness>`

*Description:* A tag describing the interval thickness.
*Argument:* String.
*Default:* `t`

#### A.1.11.9 `<thickness-trend>`

*Description:* A tag describing the interval thickness trend.
*Argument:* String.
*Default:* `tt`

#### A.1.11.10 `<velocity>`

*Description:* A tag describing the interval velocity.
*Argument:* String.
*Default:* `v`

#### A.1.11.11 `<velocity-trend>`

*Description:* A tag describing the interval velocity.
*Argument:* String.
*Default:* `vt`

### A.1.12 `<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.

#### A.1.12.1 `<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.

#### A.1.12.1.1 `<name>`

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

#### A.1.12.1.2 `<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.

##### A.1.12.1.2.1 `<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

##### A.1.12.1.2.2 `<model-settings>`

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

##### A.1.12.1.2.3 `<data-loading>`

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

##### A.1.12.1.2.4 `<pre-processing>`

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

##### A.1.12.1.2.5 `<surface-models>`

*Description:* Level of detail in reporting of surface models and possible multiple models for surfaces. See Figure 10.2 for an example of the output. There is no output if this level is less than 3.
*Heading text in log:* `Section 4: The alternative ways to build each surface`
*Argument:* 0 – 5
*Default:* 3

##### A.1.12.1.2.6 `<well-points>`

*Description:* Level of detail in reporting the processing of well points.

*Heading text in log:* `Section 5: Processing well points`
*Argument:* 0 – 5
*Default:* 3

#### A.1.12.1.2.7 `<well-paths>`

*Description:* Level of detail in reporting the processing of zone logs along well paths.
*Heading text in log:* `Section 6: Sampling well paths/zone logs`
*Argument:* 0 – 5
*Default:* 3

#### A.1.12.1.2.8 `<trend-coefficients>`

*Description:* Level of detail in reporting trend coefficients.
*Heading text in log:* `Section 7: Trend coefficients based on well points`
*Heading text in log:* `Section 12: Trend coefficients based on well points and well paths`
*Argument:* 0 – 5
*Default:* 3

#### A.1.12.1.2.9 `<residual-uncertainties>`

*Description:* Level of detail in reporting match between specified and observed residual uncertainties.
*Heading text in log:* `Section 8: Checking specified residual uncertainties`
*Argument:* 0 – 5
*Default:* 3

#### A.1.12.1.2.10 `<outliers>`

*Description:* Level of detail in reporting match between well points and trend models.
*Heading text in log:* `Section 9: Identifying well point outliers and leverage points`
*Argument:* 0 – 5
*Default:* 3

#### A.1.12.1.2.11 `<well-point-conditioning>`

*Description:* Level of detail in reporting of errors in conditioning (kriging).
*Heading text in log:* `Section 10: Conditioning on well points along well paths`
*Argument:* 0 – 5
*Default:* 3

#### A.1.12.1.2.12 `<help-points>`

*Description:* Level of detail in reporting of searching for help points sampled along the well paths.
*Heading text in log:* `Section 11: Finding help points for well path conditioning`
*Argument:* 0 – 5
*Default:* 3

#### A.1.12.1.2.13 `<well-path-conditioning>`

*Description:* Level of detail in reporting of errors from well points sampled along well path.
*Heading text in log:* `Section 13: Conditioning surfaces on all available points`

*Argument:* 0 – 5
*Default:* 3

#### A.1.12.1.2.14 `<post-processing>`

*Description:* Level of detail in report post processing. The post processing handles erosion, pinch outs, and gridding errors.
*Heading text in log:* `Section 14: Post process surfaces`
*Argument:* 0 – 5
*Default:* 3

#### A.1.12.1.2.15 `<zonation-checking>`

*Description:* Level of detail in report on checking zonation.
*Heading text in log:* `Section 15: Checking zonation`
*Argument:* 0 – 5
*Default:* 3

#### A.1.12.1.2.16 `<timings>`

*Description:* Level of detail in report on CPU time usage.
*Heading text in log:* `Section 16: Timings summary`
*Argument:* 0 – 5
*Default:* 3

#### A.1.12.1.2.17 `<tasks>`

*Description:* Level of detail in report on tasks.
*Heading text in log:* `Section 17: Suggested tasks`
*Argument:* 0 – 5
*Default:* 3

### A.1.12.2 `<screen>`

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

#### A.1.12.2.1 `<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.

##### A.1.12.2.1.1 `<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 A.1.12.1.
*Argument:* 0 – 5
*Default:* 3

Table A.1. Measurement units.

| Property | Unit | | Element |
|---|---|---|---|
| Lateral distance: | m | meter | |
| Vertical distance: | m<br>ft | meter<br>feet | <z-unit> |
| Travel time:<br><br>(one-way or two-way) | s<br>ms | second<br>millisecond | <time-unit><br><br><two-way-time> |
| Seismic velocity: | m/s<br>ft/s | meters per second<br>feet per second[a] | <z-unit> |

a. If vertical distance is measured in feet.

#### A.1.12.2.1.2 <...>

*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

### A.1.13 <measurement-units>

*Description:* Wrapper for specifying measurement units. See Table A.1 for available units.
*Argument:* Elements for each unit type.
*Default:* Void.

#### A.1.13.1 <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

#### A.1.13.2 <time-unit>

*Description:* Unit of time. Seconds or milliseconds.
*Argument:* s / ms
*Default:* s

#### A.1.13.3 <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

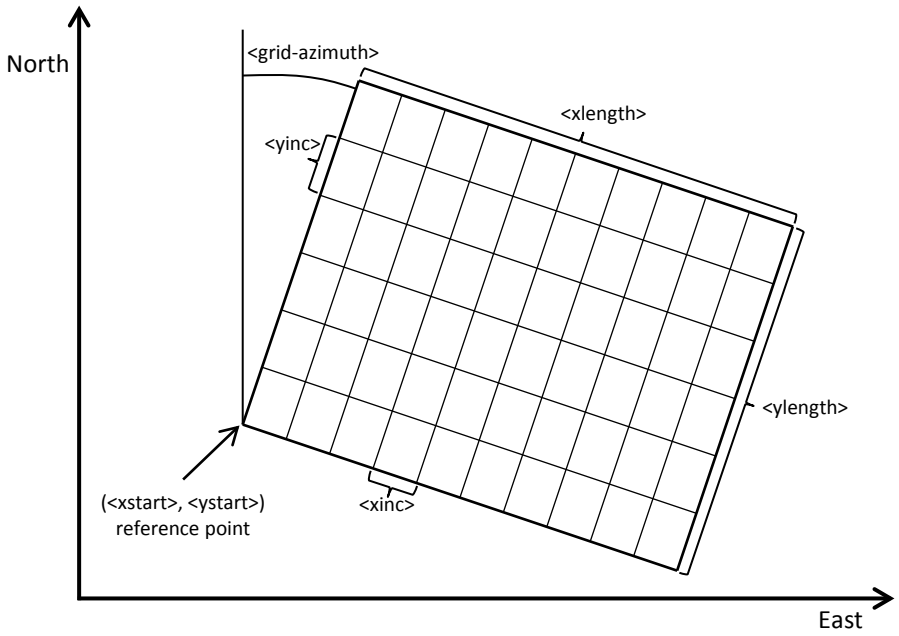



Figure A.1. Overview of elements used to specify the output grid definition.

### A.1.14 `<output-grid>` (required)

*Description:* Container for elements specifying grid dimensions and grid resolution for the output grids.[1] 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 cells are calculated using

$$x_{\text{length}} = x_{\text{inc}} \times (n_x - 1) \tag{A.1}$$

$$y_{\text{length}} = y_{\text{inc}} \times (n_y - 1). \tag{A.2}$$

The rotation of the grids is specified using `<grid-azimuth>`. See Figure A.1 for an overview.

*Argument:* Elements specifying the grid dimensions.

*Default:* No default.

#### A.1.14.1 `<format>`

*Description:* Output format. See Section 6.2 for possible file formats.

*Argument:* `storm` / `roxar text`

*Default:* `roxar text`

#### A.1.14.2 `<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 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.

1. Input grids can have different formats and dimensions.

```
<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`.

#### A.1.14.3 `<xstart>`

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

#### A.1.14.4 `<ystart>`

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

#### A.1.14.5 `<xinc>`

*Description:* X-increment.
*Argument:* Positive real.
*Default:* No default.

#### A.1.14.6 `<yinc>`

*Description:* Y-increment.
*Argument:* Positive real.
*Default:* No default.

#### A.1.14.7 `<xlength>`

*Description:* Length of grid in the X direction.
*Argument:* Positive real.
*Default:* No default.

#### A.1.14.8 `<ylength>`

*Description:* Length of grid in the Y direction.
*Argument:* Positive real.
*Default:* No default.

#### A.1.14.9 `<grid-azimuth>`

*Description:* Azimuth angle for rotated grids. Angle is measured clockwise from north in degrees (360°). The rotation point is the reference point set by `<xstart>` and `<ystart>`. Note that this option only works for files using the ROXAR TEXT grid format (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>
```

## A.2 <modelling-settings>

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

### A.2.1 <mode>

*Description:* The default mode is `prediction`, that is, to generate a deterministic set of most likely surfaces using *kriging*. Alternatively a stochastic realization is made by stochastic simulation by choosing `simulation`. The `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. The `estimation` mode is provided for initial quality control.
*Argument:* `prediction` / `simulation` / `estimation`
*Default:* `prediction`

### A.2.2 <kriging-method>

*Description:* The three available kriging methods to be used, see Abrahamsen et al. (2009). *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.
*Argument:* `simple` / `bayesian` / `universal`
*Default:* `bayesian`

### A.2.3 <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`

### A.2.4 <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`

### A.2.5 <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.

*Argument:* yes / no

*Default:* yes

### A.2.6 <minimize-broken-zonation>

*Description:* Cohiba selects and use a set of sample points along the well trajectories to constrain the surfaces. See Section 9 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

### A.2.7 <pre-process-surfaces>

*Description:* Wrapper for elements controlling pre-processing of surfaces.

*Argument:* Elements controlling pre-processing.

*Default:* Void.

#### A.2.7.1 <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

#### A.2.7.2 <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.[2] If the impact is small the

2. 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

smoothing is dropped.
*Argument:* Real between 0 and 1.
*Default:* `0.5`

### A.2.8 `<post-process-surfaces>`

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

#### A.2.8.1 `<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.
*Argument:* `yes` / `no`
*Default:* `yes`

#### A.2.8.2 `<treat-reflectors-as-eroding-and-onlapped>`

*Description:* Will ensure that seismic reflectors truncate other surfaces. See Figure 11.1 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.
*Argument:* `yes` / `no`
*Default:* `yes`

#### A.2.8.3 `<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`

#### A.2.8.4 `<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. This is done by modifying 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 modifications.

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

- The well points 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 is 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 gra-

change relative to the value of trend and relative to the range of values in the trend respectively.

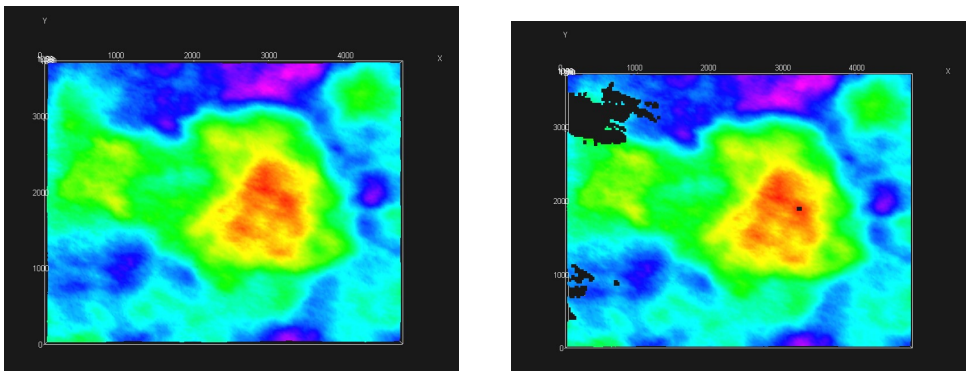


Figure A.2. Original surface to the left (default). To the right is <set-eroded-nodes-to-undefined> set to yes.

dient 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

#### A.2.8.5 <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 remove the gridding errors for well paths are consistent with the removal of gridding errors for well points. Also the value set by <maximum-gradient-for-surface-adjustment> affects the removal of gridding errors at sample 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 cell corners 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

#### A.2.8.6 <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 A.2.
*Argument:* yes / no
*Default:* no

#### A.2.8.7 <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, $\Delta t$. 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

### A.2.9 <advanced-settings>

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

#### A.2.9.1 <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

#### A.2.9.2 <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

#### A.2.9.3 <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

#### A.2.9.4 <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 surface grid cell values that are modified. Has only effect if <allow-small-surface-adjustment-at-sample-points> is yes.
*Argument:* Positive real (meter)
*Default:* 1.0

#### A.2.9.5 <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 surface grid cell values that are modified. Has only effect if <allow-small-surface-adjustment-at-sample-points> is yes.

*Argument:* Positive real (meter)
*Default:* 0.5

#### A.2.9.6 <allow-sample-points-near-faults>

*Description:* Allow sample points also where the fault indicator log indicates a fault.
*Argument:* yes / no
*Default:* no

#### A.2.9.7 <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

#### A.2.9.8 <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

#### A.2.9.9 <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 11.1.

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

#### A.2.9.10 <max-obs-direct-estim-trend-coef>

*Description:* When the number of well points is smaller than this threshold, the trend coefficients and their covariance matrix are estimated using the formulas

$$\widehat{\boldsymbol{\beta}}_{\text{Bayes}} = \boldsymbol{\beta}_0 + \boldsymbol{\Sigma}_0 \mathbf{F}' \big(\mathbf{K} + \mathbf{F}\, \boldsymbol{\Sigma}_0\, \mathbf{F}'\big)^{-1} (\mathbf{Z} - \mathbf{F}\, \boldsymbol{\beta}_0)$$
$$\widehat{\boldsymbol{\Sigma}}_{\text{Bayes}} = \boldsymbol{\Sigma}_0 - \boldsymbol{\Sigma}_0 \mathbf{F}' \big(\mathbf{K} + \mathbf{F}\, \boldsymbol{\Sigma}_0\, \mathbf{F}'\big)^{-1} \mathbf{F}\, \boldsymbol{\Sigma}_0,$$

where $\mathbf{F}$ is the design matrix, $\mathbf{K}$ is the kriging matrix, and $\mathbf{Z}$ is the vector of well points. These formulas are very robust for few well points, including zero well points.
*Argument:* Positive integer.
*Default:* 200

#### A.2.9.11 <max-obs-GLS-approx-trend-coef>

*Description:* When the number of well points is more than <max-obs-direct-estim-trend-coef> and less than <max-obs-GLS-approx-trend-coef>, the trend coefficients and their covariance matrix are estimated using the formulas:

$$\widehat{\boldsymbol{\beta}}_{\text{Bayes}} = \widehat{\boldsymbol{\Sigma}}_{\text{Bayes}}\left(\boldsymbol{\Sigma}_0^{-1}\boldsymbol{\beta}_0 + \mathbf{F}'\mathbf{K}^{-1}\mathbf{Z}\right)$$
$$\widehat{\boldsymbol{\Sigma}}_{\text{Bayes}} = \left(\boldsymbol{\Sigma}_0^{-1} + \mathbf{F}'\mathbf{K}^{-1}\mathbf{F}\right)^{-1}.$$

These formulas are equivalent to the formulas above if the kriging matrix, $\mathbf{K}$, is positive definite. These formulas are numerically better when there are many well points.
If the number of well points is larger than <max-obs-GLS-approx-trend-coef>, Cohiba uses the weighted least squares (WLS) approximation

$$\widehat{\boldsymbol{\beta}}_{\text{Bayes}} = \widehat{\boldsymbol{\Sigma}}_{\text{Bayes}}\left(\boldsymbol{\Sigma}_0^{-1}\boldsymbol{\beta}_0 + \mathbf{F}'\mathbf{D}^{-1}\mathbf{Z}\right)$$
$$\widehat{\boldsymbol{\Sigma}}_{\text{Bayes}} = \left(\boldsymbol{\Sigma}_0^{-1} + \mathbf{F}'\mathbf{D}^{-1}\mathbf{F}\right)^{-1}.$$

where $\mathbf{D}$ is the diagonal of the kriging matrix $\mathbf{K}$. The WLS approximation can handle a lot of well points.

*Argument:* Positive integer.
*Default:* 2000

#### A.2.9.12 <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

#### A.2.9.13 <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

#### A.2.9.14 <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`

#### A.2.9.15 `<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`

#### A.2.9.16 `<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`

#### A.2.9.17 `<threshold-for-help-point-deactivation>`

*Description:* Cohiba keeps those *selected sample points* (see page 61) 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`

#### A.2.9.18 `<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`

#### A.2.9.19 `<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`

#### A.2.9.20 `<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).

#### A.2.9.21 `<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).

#### A.2.9.22 `<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).

#### A.2.9.23 `<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).

#### A.2.9.24 `<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 61 for more details.
*Argument:* Positive real.
*Default:* `0.8`

#### A.2.9.25 `<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 61 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`

#### A.2.9.26 `<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`

#### A.2.9.27 `<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`

#### A.2.9.28 `<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`

#### A.2.9.29 `<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`

#### A.2.9.30 `<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`

#### A.2.9.31 `<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`

#### A.2.9.32 `<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`

#### A.2.9.33 `<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`

#### A.2.9.34 `<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 9.1 for some explanation.

*Argument:* Positive real value.

*Default:* `1.5`

#### A.2.9.35 `<minimum-range-factor-for-neighbourhood>`

*Description:* Minimum data neighborhood size as the fraction of the range.

*Argument:* Positive real.

*Default:* `1.0`

#### A.2.9.36 `<maximum-range-factor-for-neighbourhood>`

*Description:* Maximum data neighborhood size as the fraction of the range.

*Argument:* Positive real.

*Default:* `2.0`

#### A.2.9.37 `<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`

#### A.2.9.38 `<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 value in [0,1].

*Default:* `0.5`

## A.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 A.3.5 for a complete example.

### A.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.

#### A.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>
```

#### A.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 XML 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
```

#### A.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>`

#### A.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>`

#### A.3.1.5 `<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.

*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>
```

#### A.3.1.6 `<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`

#### A.3.1.7 `<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`

#### A.3.1.8 `<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>`

#### A.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 cor-

relation between A and B is computed as $\rho(r_{\text{MD}}/R_{\text{MD}})$, where $\rho$ is the correlation function specified by <variogram>, $r_{\text{MD}}$ is the measured depth at B minus the measured depth at A, and $R_{\text{MD}}$ is the variogram range.

The correlation for the euclidean distance is $\rho(r_{xyz}/R_{xyz})$, where $\rho$ 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 $\rho_z$ and $\rho_{xy}$ 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

#### A.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, $\rho_z$, and the second variogram defines the lateral correlation, $\rho_{xy}$.

*Argument:* Elements <type>, <range>, and <power>.
*Default:* See elements <type>, <range>, and <power>.

##### A.3.1.10.1 <type>

*Description:* The type of variogram.
*Argument:* The variograms in Table A.2.
*Default:* generalized exponential

##### A.3.1.10.2 <range>

*Description:* The variogram range.
*Argument:* Non-negative real.
*Default:* 2000.0

##### A.3.1.10.3 <power>

*Description:* The variogram power, $p$. Only used for the variograms generalized exponential and rational quadratic (see Table A.2).
*Argument:* Non-negative real. Can not exceed 2.0 for generalized exponential.
*Default:* 1.8

### A.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.

#### A.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 30 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>`

#### A.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 $\rho$ 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 $\rho_z$ and $\rho_{xy}$ 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`

#### A.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, $\rho_z$, and the second variogram defines the lateral correlation, $\rho_{xy}$.

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.

#### A.3.2.3.1 `<type>`

*Description:* The type of variogram.
*Argument:* The variograms in Table A.2.
*Default:* `generalized exponential`

#### A.3.2.3.2 `<range>`

*Description:* The variogram range.
*Argument:* Non-negative real.
*Default:* `2000.0`

#### A.3.2.3.3 `<power>`

*Description:* The variogram power, $p$. Only used for the variograms `generalized exponential` and `rational quadratic` (see Table A.2).
*Argument:* Non-negative real. Can not exceed 2.0 for `generalized exponential`.
*Default:* `1.8`

### A.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.

#### A.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 30 for details on file format.
Any valid path relative to `<input-directory>`. Wild-cards are supported.
*Default:* Empty string.
*Example:* `<files> ignorepoints/* </files>`

### A.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.

#### A.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>`

### A.3.5 Example of `<well-data>` specification

```
<well-data>
  <well-log>
    <zone-log-name>         GM2005a               </zone-log-name>
    <tops-as-mean-values>   yes                   </tops-as-mean-values>
    <files>                 ../welldata/*.rmswell </files>
  </well-log>
  <well-points>
    <files>                 ../welldata/synthetic_markers.dat </files>
  </well-points>
  <values-outside-grid>
    <value well-name="my-outside-well" surface-name="TopA" x="1e10" y="1e10" stddev="0.1">
      1010
    </value>
    <value surface-name = "TopB">  1040  </value>
  </values-outside-grid>
</well-data>
```

## A.4 `<surfaces>` (required)

*Description:* Wrapper for `<reference>` and `<surface>` elements in stratigraphic 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.

### A.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:* No default.

#### A.4.1.1 `<name>`

*Description:* Name of reference surface.
*Argument:* String.
*Default:* `MSL`

#### A.4.1.2 `<depth>`

*Description:* Depth at the reference surface (relative to the global datum).
*Argument:* A real number or a grid file.
*Default:* `0.0`

#### A.4.1.3 `<travel-time>`

*Description:* Seismic travel time at the reference surface.
*Argument:* A real number or a grid file.
*Default:* `0.0`

### A.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.

#### A.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 intervals. All output surface files concerning this surface will include this name.
*Argument:* String.
*Default:* No default.

#### A.4.2.2 `<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>`.
*Argument:* `yes / no`
*Default:* `no`

#### A.4.2.3 `<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>`.
*Argument:* `yes / no`
*Default:* `no`

#### A.4.2.4 <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. 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.

*Argument:* yes / no

*Default:* no

#### A.4.2.5 <spill-point>

*Description:* This element triggers the detection of the spill point of the surface and the optional calculation of the corresponding trap. Wrapper for elements specifying how to handle missing codes and the starting point for searching for the spill point. The starting point can be anywhere inside the trap. If the starting point is outside the trap the algorithm will fail. It is recommended to choose a location that is known to belong to the trap such as a producing well.

*Argument:* Elements specifying starting point and how to interpret missing codes.

*Default:* Void

##### A.4.2.5.1 <missing-as-wall>

*Description:* Determines how the spill point algorithm shall handle missing codes. They 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 cells with missing codes that are in contact with the map boundary.

*Argument:* yes / no

*Default:* yes

##### A.4.2.5.2 <xstart>

*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).

##### A.4.2.5.3 <ystart>

*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).

#### A.4.2.6 <top-of-zone>

*Description:* This defines a re-mapping of the zone log in case the zone log contains more zones than the zones defined by the surfaces. If zone numbers increase with increasing depth, it is

sufficient to take the first zone after *this surface*. For details see Section 8.4.6.

*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>`

#### A.4.2.7 `<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.

##### A.4.2.7.1 `<value>`

*Description:* The travel time values.

*Argument:* File name or constant. See Section 6.2 for possible file formats.

*Default:* `0.0`.

##### A.4.2.7.2 `<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>`.

###### A.4.2.7.2.1 `<value>`

*Description:* A travel time value for a well point outside the grid.

*Argument:* Real.

*Default:* No default.

*Example:* `<value> 0.1 </value>`

##### A.4.2.7.3 `<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 A.2.

*Argument:* Elements specifying the travel time uncertainty.

*Default:* Default values for child elements.

###### A.4.2.7.3.1 `<type>`

*Description:* The type of variogram.

*Argument:* The variograms in Table A.2.

*Default:* `spherical`

###### A.4.2.7.3.2 `<range>`

Table A.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 Appendix D 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.

*Description:* The variogram range parallel to the azimuth direction. (North-south direction by default)
*Argument:* Non-negative real.
*Default:* `1000.0`

#### A.4.2.7.3.3 `<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.

#### A.4.2.7.3.4 `<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`

#### A.4.2.7.3.5 `<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>
```

#### A.4.2.7.3.5.1 <relative>

*Description:* The standard deviation relative to the travel time specified in <value>.
*Argument:* Positive real.
*Default:* 0.1

#### A.4.2.7.3.5.2 <minimum>

*Description:* Minimum standard deviation. This has only effect if <relative> has been used.
*Argument:* Positive real.
*Default:* 0.0

### A.4.2.7.3.6 <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

### A.4.2.7.3.7 <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>.

#### A.4.2.7.3.7.1 <value>

*Description:* A travel time residual value at the well point outside the grid.
*Argument:* Real.
*Default:* No default.
*Example:* <value> 0.001 </value>

### A.4.2.8 <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

#### A.4.2.8.1 <depth>

*Description:* The output depth surface.
*Argument:* yes / no.
*Default:* yes

#### A.4.2.8.2 <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

#### A.4.2.8.3 <depth-trend>

*Description:* The output depth trend surface.
*Argument:* yes / no.
*Default:* no

#### A.4.2.8.4 <depth-trend-error>

*Description:* The output depth trend error surface.
*Argument:* yes / no.
*Default:* no

#### A.4.2.8.5 <depth-residual>

*Description:* The output depth residual surface.
*Argument:* yes / no.
*Default:* no

#### A.4.2.8.6 <trap>

*Description:* The output trap surface associated to a spill point. This element triggers the detection of the spill point of the surface.
*Argument:* yes / no.
*Default:* no

### A.4.3 Example of <surface> specification

```
<surface>
    <name>                  TopA              </name>
    <erosive>               no                </erosive>
    <onlapped>              no                </onlapped>
    <spill-point>
      <missing-as-wall>     yes               </missing-as-wall>
      <xstart>              342292            </xstart>
      <ystart>              6426345           </ystart>
    </spill-point>
    <top-of-zone>           IsochoreA         </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>
      <trap>                yes               </trap>
```

```
    </output>
    <travel-time>
       <value>                  T_TopA.storm       </value>
       <variogram>
          <type>                spherical          </type>
          <range>               1000               </range>
          <subrange>            2000               </subrange>
          <azimuth>             45                 </azimuth>
          <stddev>
             <value>            dT_TopA.storm      </value>
          </stddev>
       </variogram>
    </travel-time>
 </surface>
```

---

## A.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.

### A.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.

#### A.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*.

#### A.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.

#### A.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.

#### A.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.

#### A.5.1.5 `<trend>`

*Description:* Wrapper for a single trend map and trend coefficient. An interval (thickness or velocity) may contain a sum of several trend maps so this element may be repeated any number of times.

*Argument:* Elements describing a trend map and its trend coefficient.

*Default:* Void.

##### A.5.1.5.1 `<coefficient-mean>`

*Description:* Prior mean value (expectation) of trend coefficient. The trend coefficient is multiplied by the value specified in element `<value>` below to obtain the trend value. When possible, we recommend to drop this element and thereby use the default value of 1.

*Argument:* Real.

*Default:* `1.0`

##### A.5.1.5.2 `<coefficient-stddev>`

*Description:* Prior uncertainty (standard deviation) of 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`

##### A.5.1.5.3 `<relative-stddev>`

*Description:* Prior relative uncertainty (standard deviation) of trend coefficient. Do not use this element in combination with `<coefficient-stddev>`.

*Argument:* Non-negative real.

*Default:* `0.1` (This means a 10 % uncertainty)

##### A.5.1.5.4 `<value>`

*Description:* A trend map (grid) or a constant. This map is multiplied by its corresponding trend coefficient.

*Argument:* File name or constant. See Section 6.2 for possible file formats.

*Default:* `1.0`

##### A.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>.

#### A.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>`

### A.5.1.6 <correlations>

*Description:* Correlations between 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>
```

#### A.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

### A.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.

#### A.5.1.7.1 <type>

*Description:* The type of variogram.

*Argument:* The variograms in Table A.2.

*Default:* spherical

#### A.5.1.7.2 <range>

*Description:* The variogram range parallel to the azimuth direction. (North-south direction by default)

*Argument:* Non-negative real.

*Default:* `1000.0`

#### A.5.1.7.3 `<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.

#### A.5.1.7.4 `<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`

#### A.5.1.7.5 `<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> dZ_IntervalAB.storm </stddev>
```

*Example:* Relative standard deviation:

```
<stddev>
   <relative>  0.10 </relative>
   <minimum>   1.00 </minimum>
</stddev>
```

##### A.5.1.7.5.1 `<relative>`

*Description:* The standard deviation relative to the thicknesses or interval velocities specified as the sum of the `<value>` elements.
*Argument:* Positive real.
*Default:* `0.1`

##### A.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`

#### A.5.1.7.6 `<power>`

*Description:* The variogram power, $p$. Only used for the variograms `generalized exponential` and `rational quadratic` (see Table A.2).
*Argument:* Non-negative real. Can not exceed 2.0 for `generalized exponential`.

*Default:* `1.0`

#### A.5.1.7.7 `<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>`.

#### A.5.1.7.7.1 `<value>`

*Description:* A travel time residual value at the well point outside the grid.

*Argument:* Real.

*Default:* No default.

*Example:* `<value> 0.001 </value>`

#### A.5.1.8 `<output>`

*Description:* Wrapper for elements specifying if a grid should be written to file.

*Argument:* Elements for each grid type.

*Default:* Void

#### A.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`.

#### A.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`.

#### A.5.1.8.3 `<velocity>`

*Description:* The output interval velocity, i.e., the interval thickness divided by the time difference.

*Argument:* `yes` / `no`.

*Default:* `no`.

#### A.5.1.8.4 `<velocity-trend>`

*Description:* The posterior interval velocity trend.

*Argument:* `yes` / `no`.

*Default:* `no`.

### A.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.storm   </value>
    </trend>
    <correlations>
     <c1-2> 0.1 </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>
```

## A.6 List of all Cohiba model file 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>
    <filename-tags>
        <type>
        <depth>
        <depth-trend>
        <depth-error>
        <depth-trend-error>
        <depth-residual>
        <trap>
        <thickness>
        <thickness-trend>
        <velocity>
        <velocity-trend>
    <messages>
        <logfile>
            <name>
            <detail-level>
                <overall>
                <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>
                <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>
    <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-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>
<well-data>
    <well-log>
```

```
            <zone-log-specification>
            <zone-log-specification-file>
            <zone-log-name>
            <fault-log-name>
            <files>
            <tops-as-mean-values>
            <first-log-entry-as-top>
            <z-stddev-log-name>
            <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)
            <erosive>
            <onlapped>
            <free-surface>
            <spill-point>
                <missing-as-wall>
                <xstart>
                <ystart>
            <top-of-zone>
            <travel-time>
                <value>
                <values-outside-grid>
                    <value>
                <variogram>
                    <type>
                    <range>
                    <subrange>
                    <azimuth>
                    <stddev>
                        <relative>
                        <minimum>
                    <power>
                    <values-outside-grid>
                        <value>
            <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>
        <velocity>
        <velocity-trend>

# B Cohiba model file example

See Appendix C 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>
    </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>
```

# C Cohiba log file example

The following Cohiba log file was generating using the Cohiba model file in Appendix B.

```
*************************************************************************************************
*****                                                                                      *****
*****                                C O H I B A  -  4.1.0                                 *****
*****                                                                                      *****
*****                        Copyright (c) 2012 by Norsk Regnesentral                      *****
*****                                                                                      *****
*************************************************************************************************

License expiration                            : Never
Licensed to                                   : Norsk Regnesentral/Statoil

Log written by                                : Unknown
Date and time                                 : Mon Feb 11 09:48:05 2013
Host                                          : troll.nr.no
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                             : /nr/project/sand/user/pdahle/Cohiba/trunk/test_suite/23_syntetic-vilje-c
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     OUTPUT [ Depth  Error  Trend  TrendError Residual ]    Erosive Onlapped Reflector FreeSurface  TopOfZones
-------------------------------------------------------------------------------------------------------------------------
MSL                  yes    no     no     no         no            no      no       yes        no          -
TopA                 yes    yes    yes    yes        yes           no      no       yes        no          A
TopB                 yes    yes    yes    yes        yes           no      no       no         no          B
TopC                 yes    yes    yes    yes        yes           no      no       no         no          C

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  Trend  Residual Velocity ]    IntervalTop  IntervalBase   IntervalType
-------------------------------------------------------------------------------------------------------------
MSL-to-TopA             no         no     no       no            MSL          TopA           velocity
TopA-to-TopB            no         no     no       no            TopA         TopB           thickness
TopB-to-TopC            no         no     no       no            TopB         TopC           thickness

*************************************************************************************************
*****                              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 )
```

| Wellname | MD | X | Y | Z | StdDev | FaultInd | Zones 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)
```

| Wellname | MD | X | Y | Z | StdDev | FaultInd | Zones 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  /nr/project/sand/user/pdahle/Cohiba/trunk/test_suite/23_syntetic-vilje-crossing-wells-meter/i

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%)

Memory usage for grids
----------------------
Memory needed to hold all input grids      ( 20) :     1.1MB
Memory needed to hold all output grids     ( 15) :     0.9MB
Total memory usage needed for grids              :     2.0MB

*************************************************************************************************
*****                          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          6.716      0.081      6.528      6.860    1: MSL -> TopA
TopB         12.046      0.045     11.942     12.127    1: MSL -> TopA -> TopB
TopC         15.037      0.036     14.954     15.102    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: 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 7: Trend coefficients based on well points                  *****
*************************************************************************************************

Computing a-posteriori coefficients using exact formulas.

Interval            Coef   PriorMean    PostMean PostMeanUpd    PriorStd     PostStd  PostStdUpd
-------------------------------------------------------------------------------------------------
MSL-to-TopA            1       1.000       0.972           -       0.080       0.003           -
MSL-to-TopA            2       1.000       1.019           -       0.500       0.426           -
TopA-to-TopB           1       1.000       1.025           -       0.200       0.163           -
TopB-to-TopC           1       1.000       1.043           -       0.200       0.142           -


*************************************************************************************************
*****                    Section 8: 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         0.408      1.602           5            OK
TopB-to-TopC         5.211         0.268      1.765           3     Too high
-------------------------------------------------------------------------------
Overall              1.528         0.646      1.354          15          High

Consider reducing the prior residual uncertainty for interval 'TopB-to-TopC'.
Try dividing the specified std.dev. by : 5.211

*************************************************************************************************
*****             Section 9: 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 10: 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 11: 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 12: Trend coefficients based on well points and well paths           *****
*****************************************************************************************************

Interval            Coef   PriorMean    PostMean PostMeanUpd    PriorStd     PostStd  PostStdUpd
-----------------------------------------------------------------------------------------------
MSL-to-TopA            1       1.000       0.972       0.972       0.080       0.003       0.003
MSL-to-TopA            2       1.000       1.019       1.019       0.500       0.426       0.426
TopA-to-TopB           1       1.000       1.025       1.067       0.200       0.163       0.160
TopB-to-TopC           1       1.000       1.043       1.043       0.200       0.142       0.142


*****************************************************************************************************
*****                Section 13: Conditioning surfaces on all available points                *****
```

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

 0%       20%       40%       60%       80%       100%
 |    |    |    |    |    |    |    |    |    |    |
 ^^^^^^^^^^^^^^^^^^^^^^^^^^^^^^^^^^^^^^^^^^^^^^^^^^^^

********************************************************************************************************
*****                              Section 14: Post process surfaces                               *****
********************************************************************************************************

The tables below summarises the number of nodes truncated from
either above (erosion) or below (onlapping):

TruncatingSurface       Erosive   Onlapped  Reflector
-------------------------------------------------------
TopA                        no         no        yes

Treating reflectors as erosive and onlapped surfaces.
No erosion truncations performed.
No onlap truncations performed.

********************************************************************************************************
*****                                Section 15: 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

WARNING: Crossing depth surfaces detected. To get details, you must run the calculation with
         the log level for section <zonation-checking> set to 5. The amount with which surfaces
         cross is normally small, but it might be worth while to check it out.

The table below summarizes the amount of crossing depth trend surfaces (negative trend isochores) if any:

Top        Base        MinThickness MaxThickness AvgThickness   NegValues
-------------------------------------------------------------------------
MSL        TopA            1015.555     1156.802     1088.524      0.000%
TopA       TopB               5.336       31.070       18.203      0.000%
TopB       TopC               5.215       42.947       24.081      0.000%

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

```
*****                              Section 16: Spill points                                *****
*****************************************************************************************************

No spill point detection has been requested.

*****************************************************************************************************
*****                             Section 17: Timings summary                                *****
*****************************************************************************************************

Section                                          CPU Time              Real Time
-----------------------------------------------------------------------------------
Loading input data                         0.08     1.12 %        1.00    20.00 %
Pre-processesing                           0.40     5.61 %        0.00     0.00 %
Processing well data                       0.13     1.82 %        0.00     0.00 %
Checking residual uncertainties            0.01     0.14 %        0.00     0.00 %
Predicting surfaces along well paths       0.04     0.56 %        0.00     0.00 %
Finding help point clusters                0.04     0.56 %        0.00     0.00 %
Finding help point probability dist.       4.59    64.38 %        4.00    80.00 %
Predicting surfaces                        0.90    12.62 %        0.00     0.00 %
Writing files                              0.18     2.52 %        0.00     0.00 %
Miscellaneous                              0.76    10.66 %        0.00     0.00 %
-----------------------------------------------------------------------------------
Total                                      7.13   100.00 %        5.00   100.00 %

*****************************************************************************************************
*****                             Section 18: Suggested tasks                                *****
*****************************************************************************************************

 1. A change of specified residual uncertainty has been suggested. See residual uncertainty section.
 2. Check zonation. Crossing depth surfaces detected.

Total CPU  time used in COHIBA:     7.13
Total real time used in COHIBA:     5.00
```

# D Variogram examples

This appendix 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.

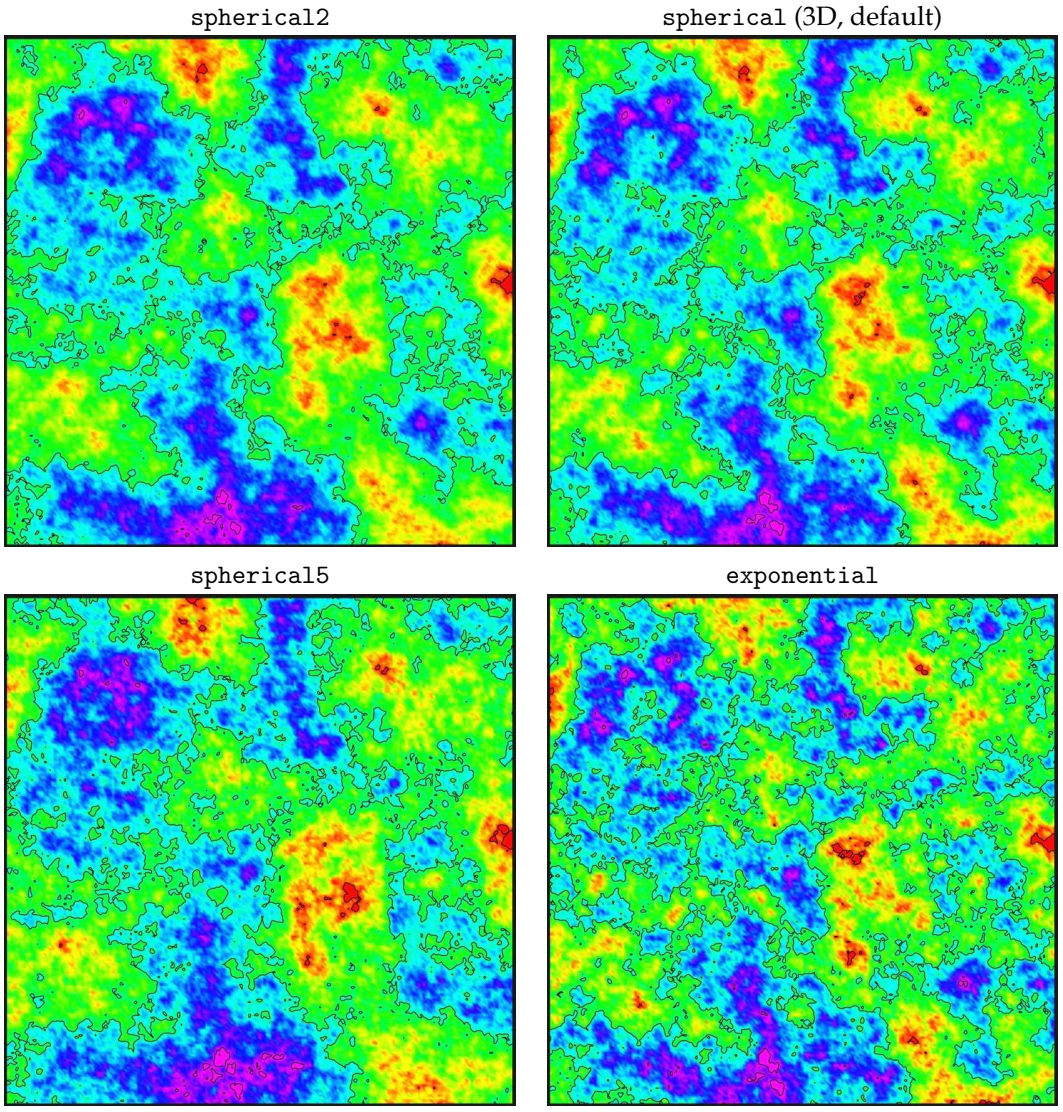



Figure D.1. Spherical and exponential variograms.

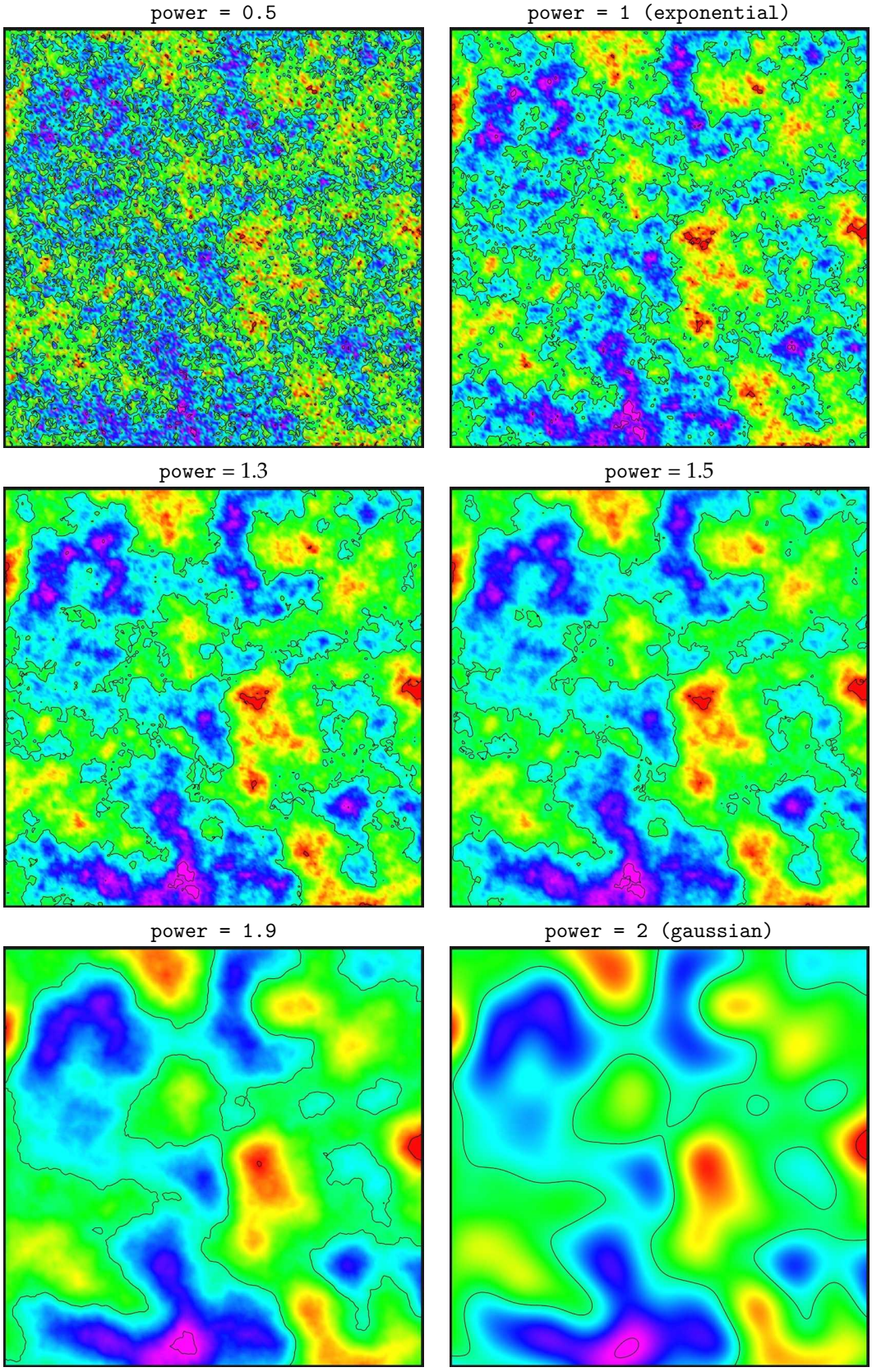



Figure D.2. General exponential variograms for different <power>. Note that the exponential variogram is identical to power = 1 and the gaussian variogram is identical to power = 2.

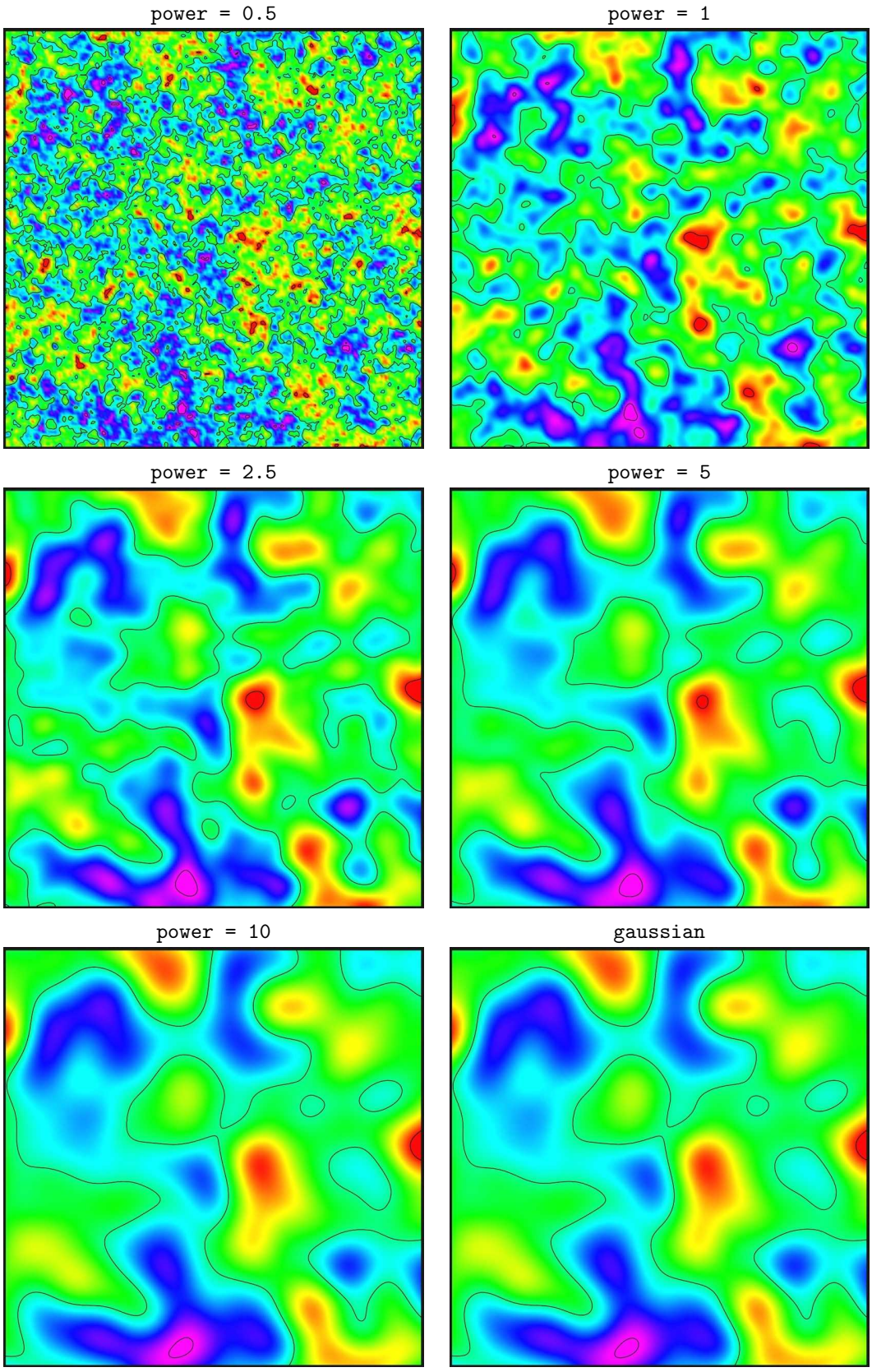



Figure D.3. Rational quadratic variograms. Note that these variograms approach the `gaussian` variogram when `power` becomes large. This variogram is not numerically stable for large values of `power` so we recommend to use the `gaussian` variogram instead for `power` $> 10$.

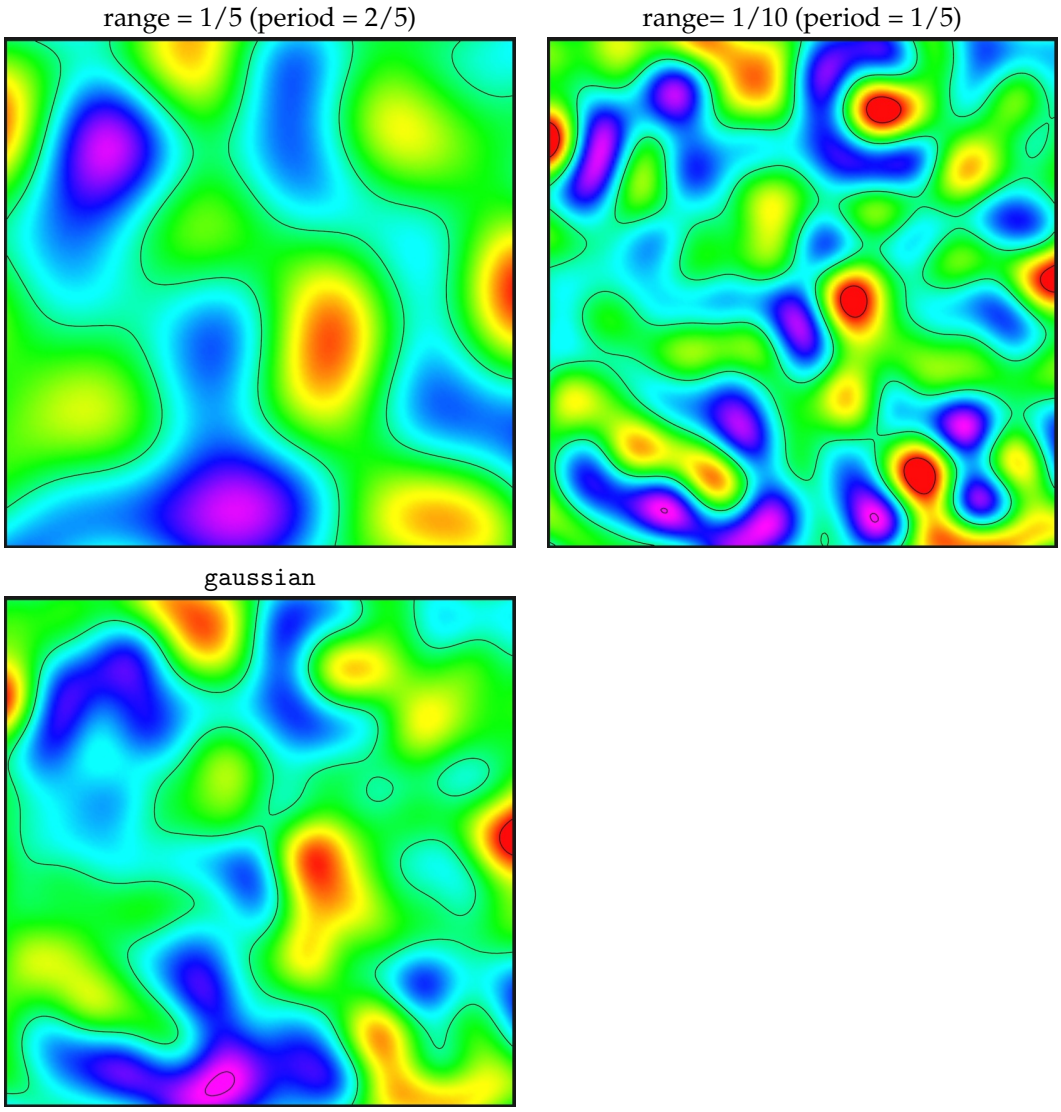



Figure D.4. Damped sine variograms. The damped sine variogram gives a smooth regular cyclic appearance. The full period is twice the specified range. The `gaussian` variogram is added for comparison.

# E 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 4.0 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 surface grid cells 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 neighbouring grid cells could previously not be removed. A new algorithm adjusting all affected grid cell corners 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-wellpath-ref>` 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

# F Known issues

- Conditioning to well paths using universal kriging does not work. COH-23
- The `<correlate-close-reflectors>` functionality can fail if we have coinciding reflectors (erosion). This is observed in a case where a reflecting erosional surface is used as the `<reference>` surface. COH-390

# References


Abrahamsen, P. (1993). Bayesian kriging for seismic depth conversion of a multi-layer reservoir. In Soares, A., editor, *Geostatistics Tróia '92*, pages 385–398, Dordrecht. proc. '4th Inter. Geostat. Congr.', Tróia Portugal, 1992, Kluwer Academic Publ. 8

Abrahamsen, P. (1997). A review of Gaussian random fields and correlation functions. Report 917, Norwegian Computing Center, P.O.Box 114 Blindern, N-0314 Oslo, Norway. Available from: http://publications.nr.no/2437/Abrahamsen_-_A_Review_of_Gaussian_random_fields_and_correlation.pdf. 108

Abrahamsen, P. (1999). FFT algorithm for simulating gaussian random fields. NR-note SAND/10/1999, Norwegian Computing Center, P.O.Box 114 Blindern, N-0314 Oslo, Norway. 76

Abrahamsen, P. (2005). Combining methods for subsurface prediction. In Leuangthong, O. and Deutsch, C. T., editors, *Geostatistics Banff 2004*, volume 2, pages 601–610, Dordrecht. proc. '7th Inter. Geostat. Congr.', Banff, Canada 2004, Springer-Verlag Inc. 8

Abrahamsen, P. and Benth, F. E. (2001). Kriging with inequality constraints. *Math. Geol.*, 33(6):719–744. 8, 54, 60

Abrahamsen, P., Dahle, A. A. V. P., Georgsen, F., and Skorstad, A. (2009). Cohiba — technical documentation. NR-note SAND/XX/2009, Norwegian Computing Center, P.O.Box 114 Blindern, N-0314 Oslo, Norway. 37, 88

Abrahamsen, P., Hauge, R., Heggland, K., and Mostad, P. (2000). Estimation of gross rock volume of filled geological structures with uncertainty measures. *SPE Reservoir Eval. & Eng.*, 3(4):304–309. 8

Chilés, J.-P. and Delfiner, P. (1999). *Geostatistics: Modeling Spatial Uncertainty*. John Wiley & Sons, New York. 8

Cressie, N. (1993). *Statistics for Spatial Data*. John Wiley & Sons, New York, revised edition. 8

Isaaks, E. H. and Srivastava, R. M. (1989). *An Introduction to Applied Geostatistics*. Oxford University Press Inc., New York. 8

Lantuéjoul, C. (2002). *Geostatistical Simulation: Models and Algorithms*. Springer-Verlag Inc., Berlin. 8

ROXAR ASA (2009). *Irap RMS User Guide*. Available from: www.roxar.com. 28

Tanner, M. A. and Wong, W. H. (1987). The calculation of posterior distributions by data augmentation (with discussion). *J. Amer. Statist. Assoc.*, 82(398):528–550. 61

Weisberg, S. (1985). *Applied Linear Regression*. John Wiley & Sons, New York, 2nd edition. 8, 10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