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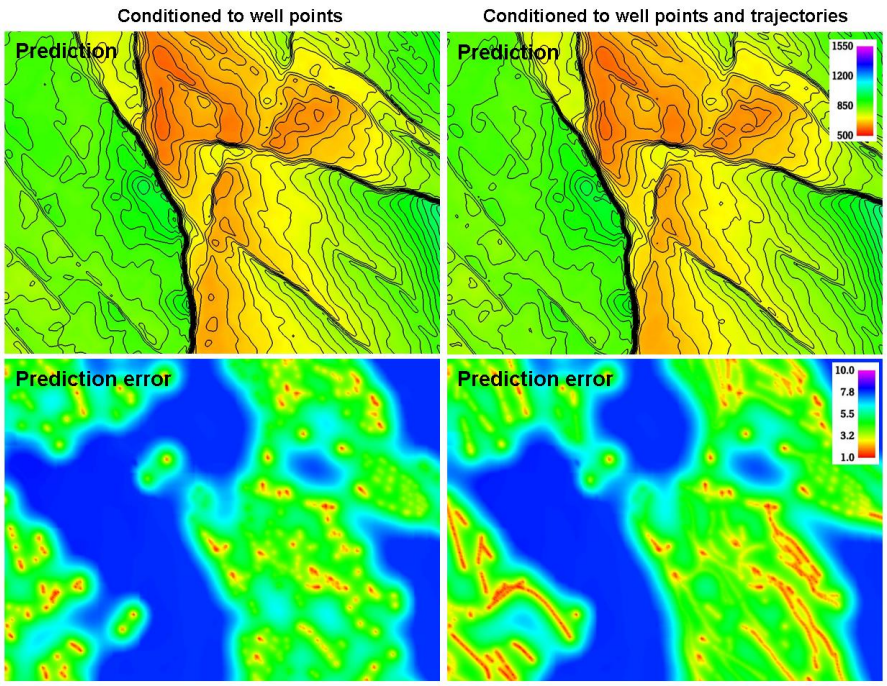
Note

# COHIBA user manual — Version 2.3





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Authors Ariel Almendral Vazquez, Frode Georgsen, Pål Dahle, Inge Myrseth, Petter Abrahamsen


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**Norsk Regnesentral**
Norwegian Computing Center
Postboks 114, Blindern
NO-0314 Oslo, Norway

**Besøksadresse**
*Office address*
Gaustadalléen 23
NO-0373 Oslo, Norway

**Telefon** · telephone
(+47) 22 85 25 00
**Telefaks** · telefax
(+47) 22 69 76 60

**Internett** · internet
www.nr.no
**E-post** · e-mail
nr@nr.no

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| **Authors** | **Ariel Almendral Vazquez , Pål Dahle , Petter Abrahamsen , Frode Georgsen , Inge Myrseth** |
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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.

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

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 surfaces. 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.

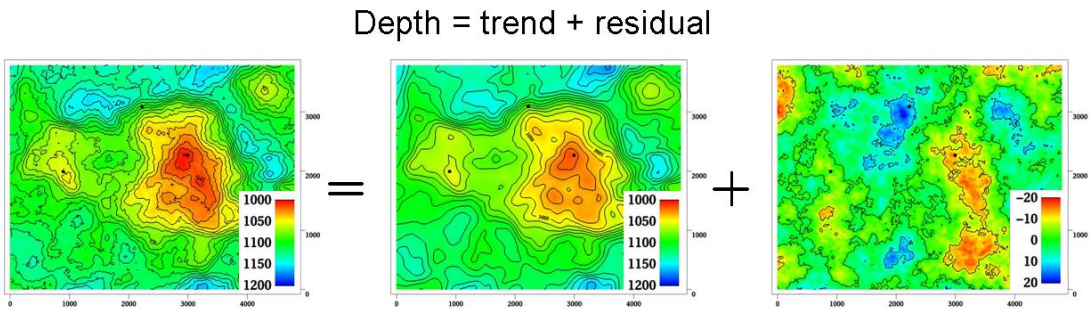
COHIBA uses the available data in a consistent manner to minimise the uncertainty. The accuracy is further improved by linking together all surfaces in a multi-layered model.

COHIBA provides two ways of evaluating uncertainty:

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

## 1.1 COHIBA basic idea

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

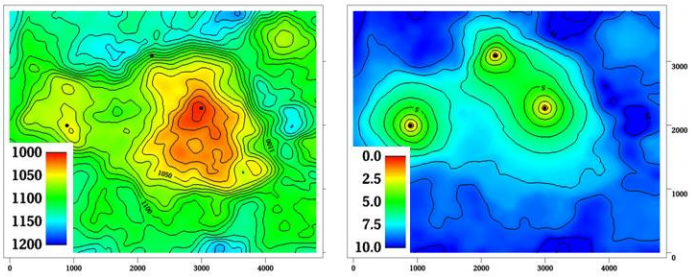



The trend can be a single known map or a linear combination of many known maps. The trend determines the main shape of the surface so the choice of trend maps is very important. The residual is usually small compared to the trend. The residual is specified by an residual uncertainty (standard deviation) 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 (Monte Carlo) simulation, just like the figure above. The residual is a smooth interpolation of the known residuals at the wells for prediction. This is illustrated on page 25.

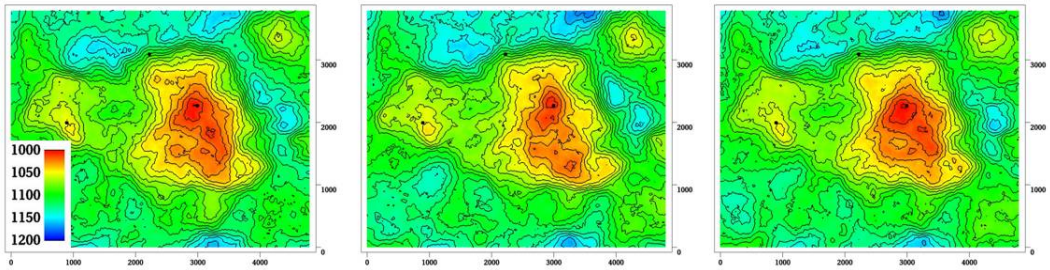
## 1.2 COHIBA main features

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




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

**Simulation of surfaces.** COHIBA can simulate (Monte Carlo) alternative realizations that are consistent with all available data. This is typically used for sensitivity and uncertainty studies. Three simulations are illustrated here:



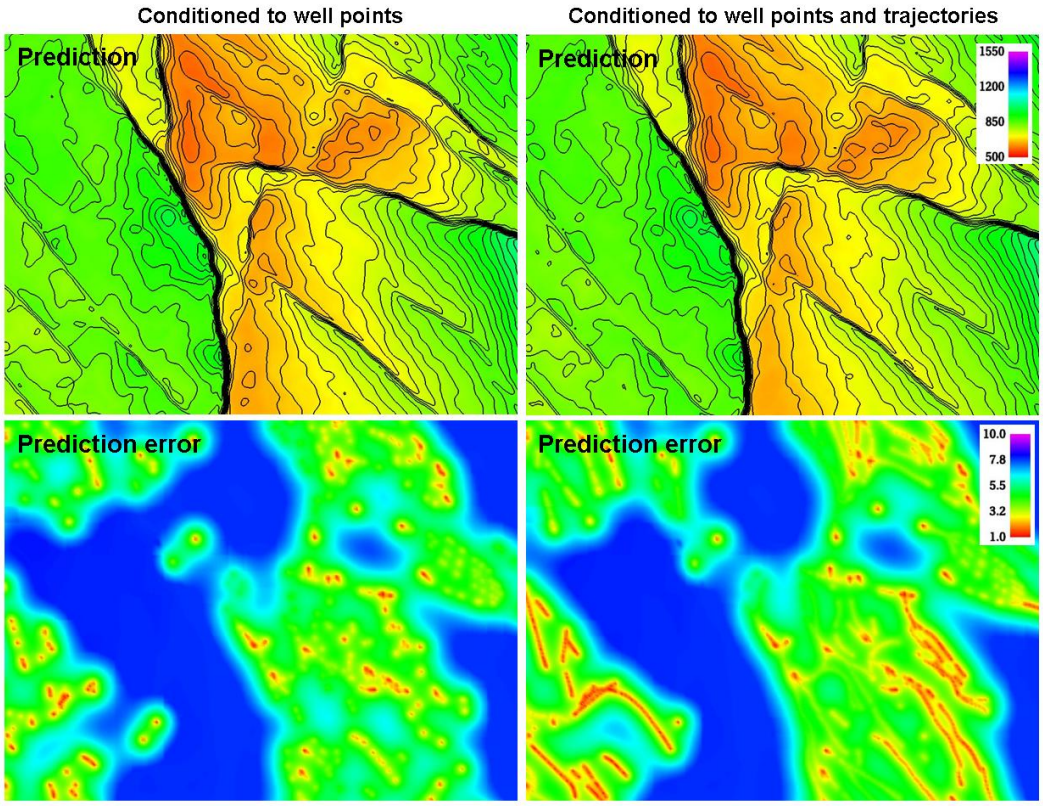

The average of a large set of simulations will coincide with a prediction. The standard deviation of the large set of simulations will coincide with the prediction error.

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

It is impossible to see where the 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.

It is common to say that the 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 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:

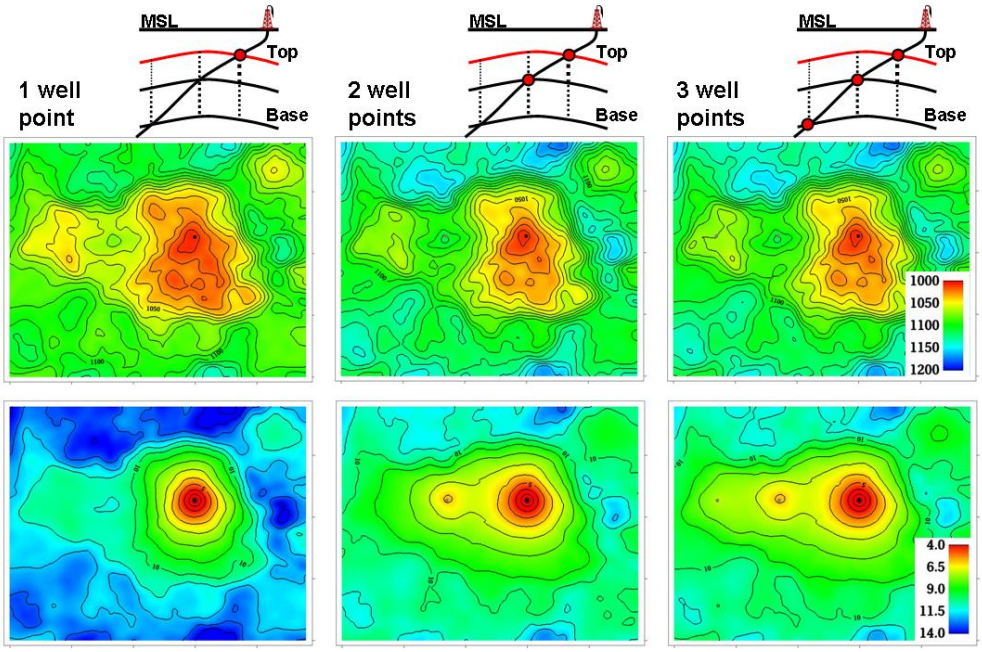



The two upper figures are the predicted depth to the surface and the two lower figures are the corresponding prediction errors. The change in the predicted depths are subtle in this case but the prediction errors has been significantly reduced along the well paths.

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

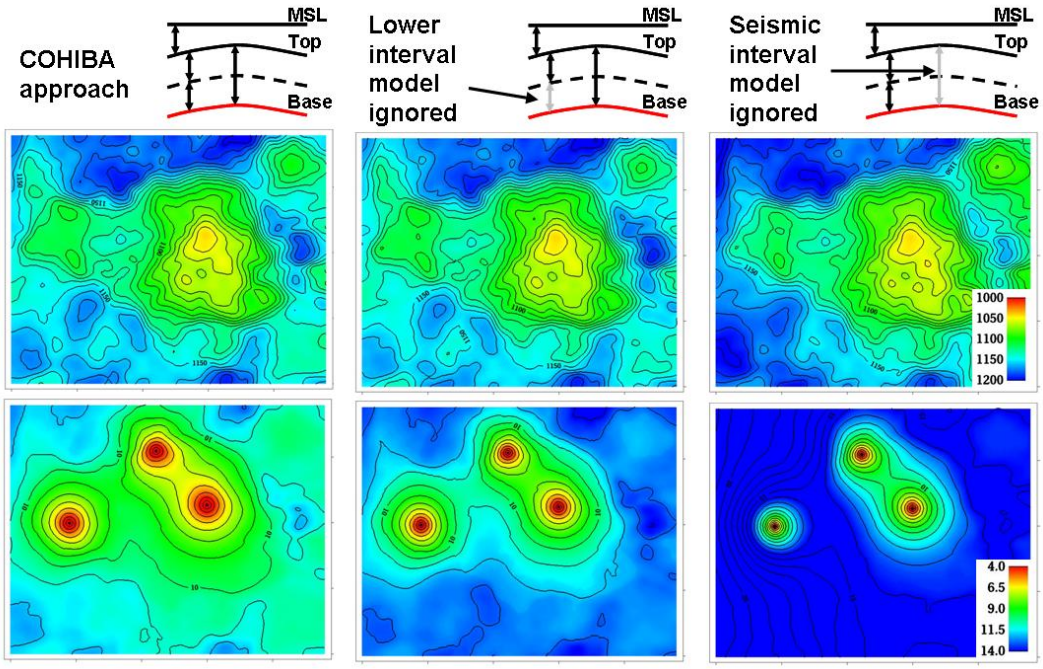
1. A particular surface is constrained by observations from surfaces above and below. This improves precision and reduces the uncertainty. The impact of observations below a surface is illustrated here:




   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 predicted 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 optimised. 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:



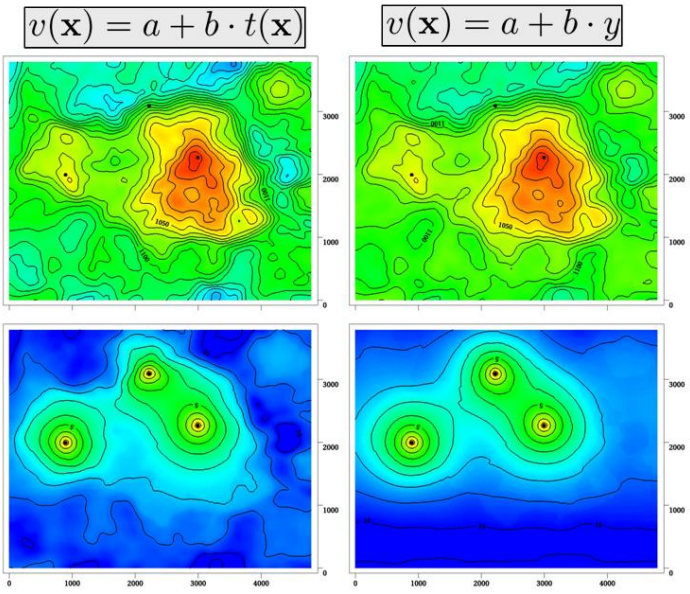

The illustration shows the base surface (and its prediction errors) from a model with three surfaces. This is the red surface in the schematic cross sections above the contoured maps. The top and base surfaces are seismic reflectors. The intermediate surface (dashed line) is not a seismic reflector.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

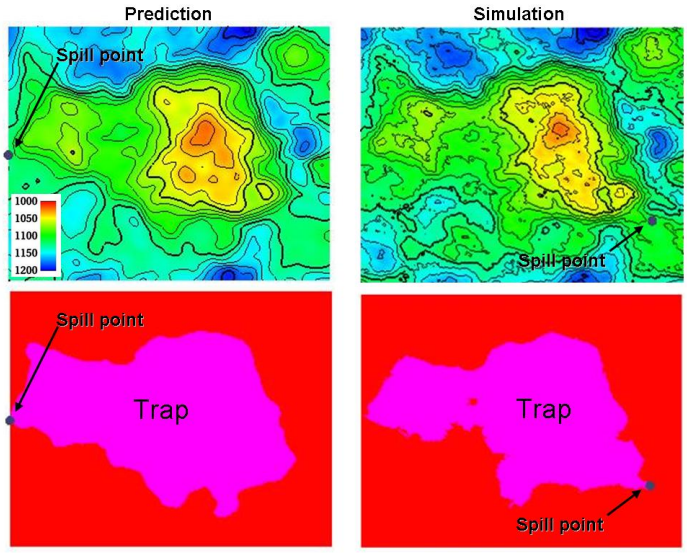
Example of two alternative depth conversion models:




The left prediction 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

Kriging is used for prediction, and conditional simulation (Monte Carlo) is used for creating alternative realizations. The conditioning data are the well points 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 conditional simulation see for instance the books by Isaaks and Srivastava (1989), Cressie (1993), Chilès 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) 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 in 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.

**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.

**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 4ms) 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 isochor map: $\Delta z(x, y) = a \times m(x, y)$, where $m(x, y)$ is a user specified isochor 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.

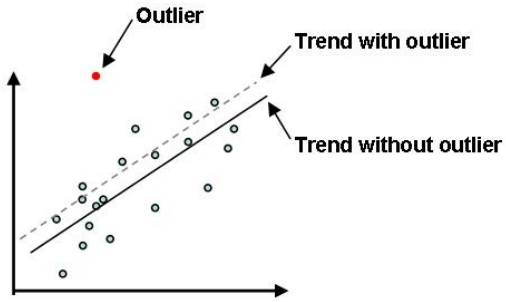
**Ordering of surfaces.** The surfaces in the model must be ordered according to their depth. This makes it possible to check if well observations are in correct order. Moreover, this ensures that erosion, pinch out, and on-laps can be handled properly.

## 1.5 Quality control

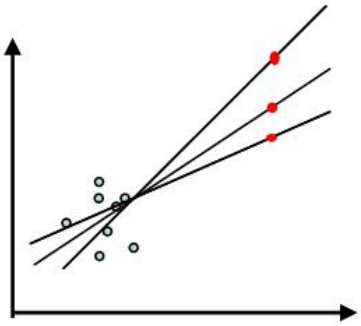
COHIBA has methods for performing quality control of the input data. Conflicts and ambiguities in the data are handled automatically and reported, so that actions can be taken when necessary. Quality control includes:

**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 uncertainty (error) 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 analysed. 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 analysed in e.g. Excel. This is illustrated in Figure 1.1.

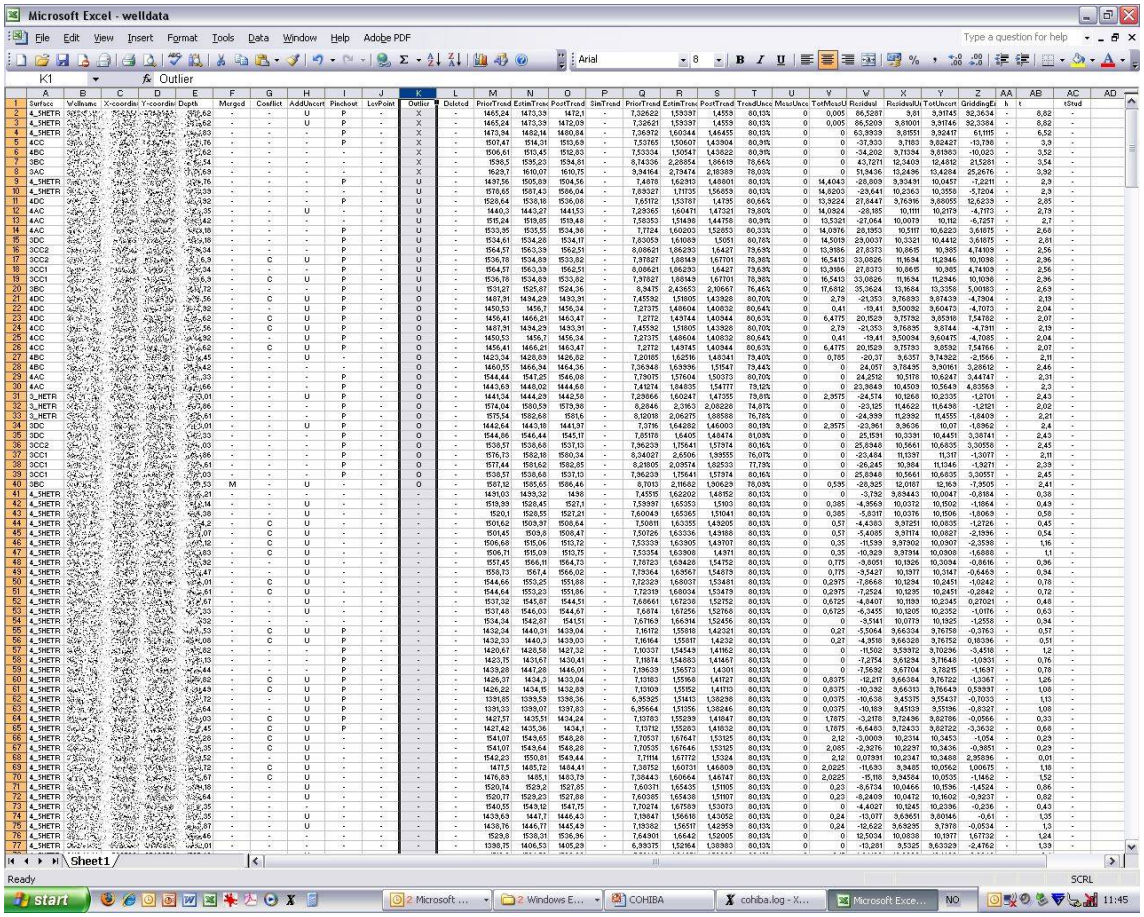



Figure 1.1. Log file for well points imported into Excel. Outlier status is reported in column K. The 7 first observations has been removed (row 2–8), the 12 next (row 9–20) are kept but an observation error has been added, and another 20 well points (row 21–40) are marked as outliers.

## 1.7 Platforms and portability

COHIBA has been developed and tested on Linux and Windows operating systems. Currently we suggest to use Windows 7 64bit or Linux RedHat 5 or later. Some features will not work for RedHat 3.

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 **C**orrelated **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.

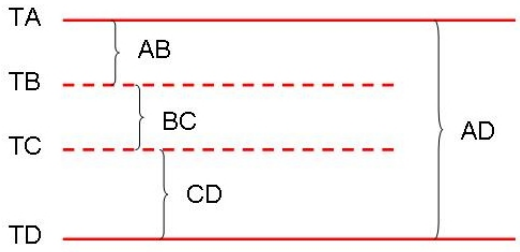
The previous versions of COHIBA were called HORIZON.

# 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.

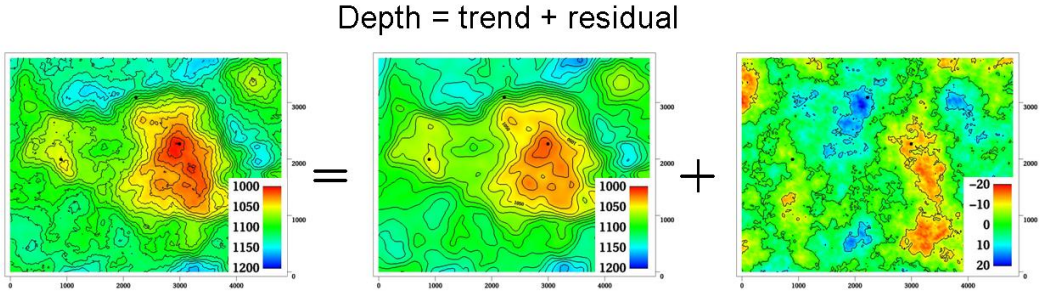
**Interval.** An interval in COHIBA has a top surface and a base surface. The top and base surfaces are two arbitrary surfaces but they must be in correct depth order (top above base). Any surface can be both a top surface and a base surface in several intervals. A common example is to have one interval 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 behaviour whereas the residual describes variations around the trend on a smaller lateral scale (typically 1000m). This is illustrated by the following picture:



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

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

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

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

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

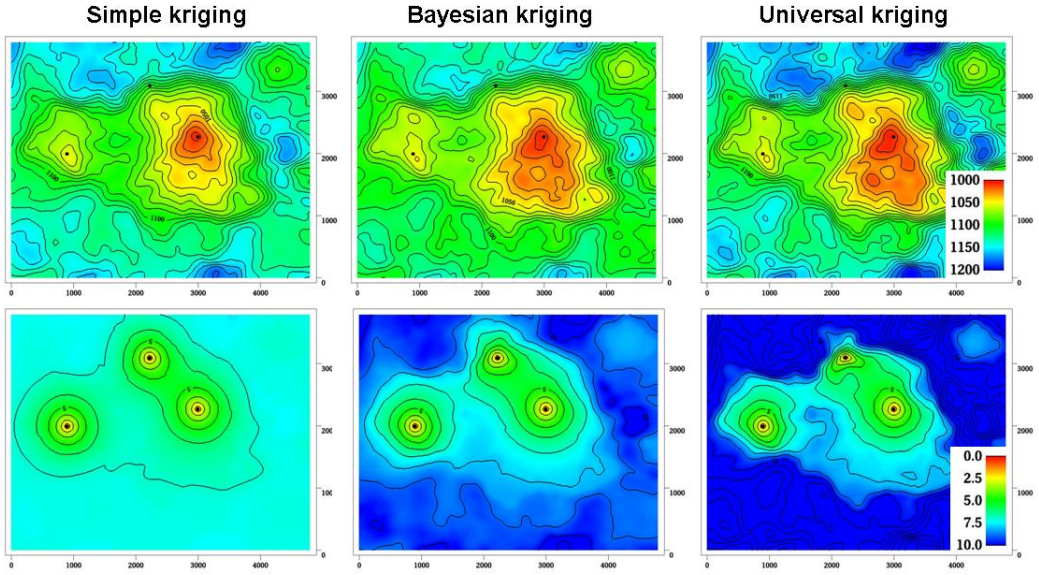
Similarly, interval velocity trends are used in combination with travel time maps for seismic depth conversion.

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

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

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

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




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

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

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

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

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

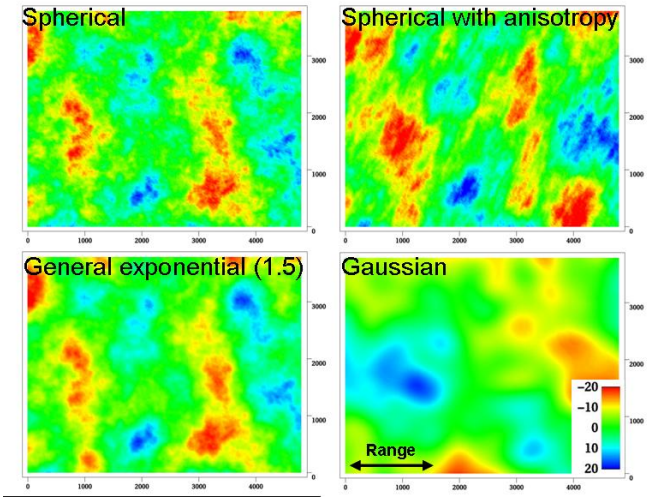
There are three types of residuals used by COHIBA:

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

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

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

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




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

An interval velocity trend can typically look like

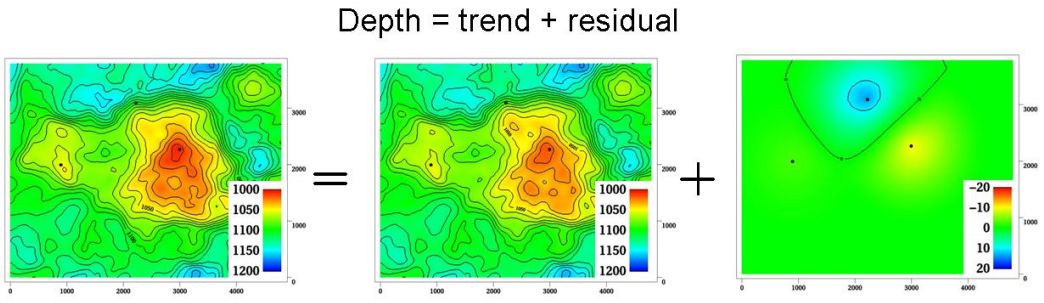
$$v = a \cdot 1 + b \cdot t(x, y).$$

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

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

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

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:




**Simulation.** Simulation is a Monte Carlo approach where trend coefficients and residuals are sampled from probability distributions to obtain a *realization*. 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 prediction.

The simulation can be thought of as a two step procedure. First, the trend coefficients are drawn from their estimated distribution and multiplied with the trend maps to form the

simulated trend. Then the residuals are drawn 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 uncertainty 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. Create a directory `test/` and copy `cohiba.exe` to this directory.
2. Create a file `model_file.xml` in `test/` using the following XML COHIBA model file:

```
<cohiba>
<project-settings>
  <messages>
    <screen>
      <detail-level>
        <overall> 5 </overall>
      </detail-level>
    </screen>
  </messages>
  <output-grid format="irapclassic">
    <xstart> 448300.0  </xstart>
    <xend>   449300.0  </xend>
    <ystart> 6736000.0 </ystart>
    <yend>   6739000.0 </yend>
    <nx>     30        </nx>
    <ny>     40        </ny>
  </output-grid>
</project-settings>
<modelling-settings>
  <mode>           prediction </mode>
  <kriging-method> bayesian   </kriging-method>
</modelling-settings>
<well-data>
  <surface-points>
    <files> wellpoints.coh </files>
  </surface-points>
</well-data>
<surfaces>
  <!--Surfaces must be listed in stratigraphic order -->
  <surface>
    <name>                      top    </name>
    <travel-time>
      <value>                     1.0    </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>
      <name>          MSL-to-top    </name>
      <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 a file `wellpoints.coh` with the following content:

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

   Create the directory `test/input/` and save `wellpoints.coh` in this directory.

4. From the command line type: `cohiba.exe 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 run a Bayesian prediction on the surface `top` using the well point with coordinates $(448800, 6737500, 1220)$. Several directories are created under `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 IRAP CLASSIC grid format. Log files are written under `logfiles/` and `wellpoints/` contains IRAP RMS well point files.

Almost at the end of the screen output you may find the following table:

```
-------------------------------------------------------------------------------
Interval     Coefficient   PriorMean   PostMean   PriorStd    PostStd    SimMean
-------------------------------------------------------------------------------
```

```
MSL-to-top              1      1.0000      1.2173      0.1000      0.0111          -
-------------------------------------------------------------------------------
```

This shows prior and posterior mean and standard deviations for the trend coefficient. The single data at 1220m has moved the prior guess at 1000m to 1217.3m and the uncertainty has dropped from $0.1 \times 1000m = 100m$ to $0.0111 \times 1000m = 11.1m$. This uncertainty should be compared to the residual uncertainties: $0.01s \times 1000m/s = 10m$ (travel time) and $5m/s \times 1s = 5m$ (interval velocity). Combining these gives a total uncertainty of $(10^2m^2 + 5^2m^2)^{1/2} = 11.2m$. 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 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 zeroes 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 7.

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:* Start 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:* Start 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.4.2.4.1.
*Argument:* `yes` / `no`.
*Default:* `yes`

# 5 The COHIBA model file

The COHIBA model file is a text file in XML (Extensible Markup Language) format. (see e.g. Wikipedia). 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[3] 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 Section B.

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

## 5.1 Visualising 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 specialised XML editor. For instance the Microsoft XML Notepad 2007 editor may be freely downloaded from: http://msdn2.microsoft.com/en-us/xml/default.aspx. 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. As an example, consider the COHIBA model file in Section B. Follow the steps:

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

3. An important exception is the order of surfaces. These *must* be specified in correct stratigraphic order to obtain correct ordering of the generated surfaces.

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

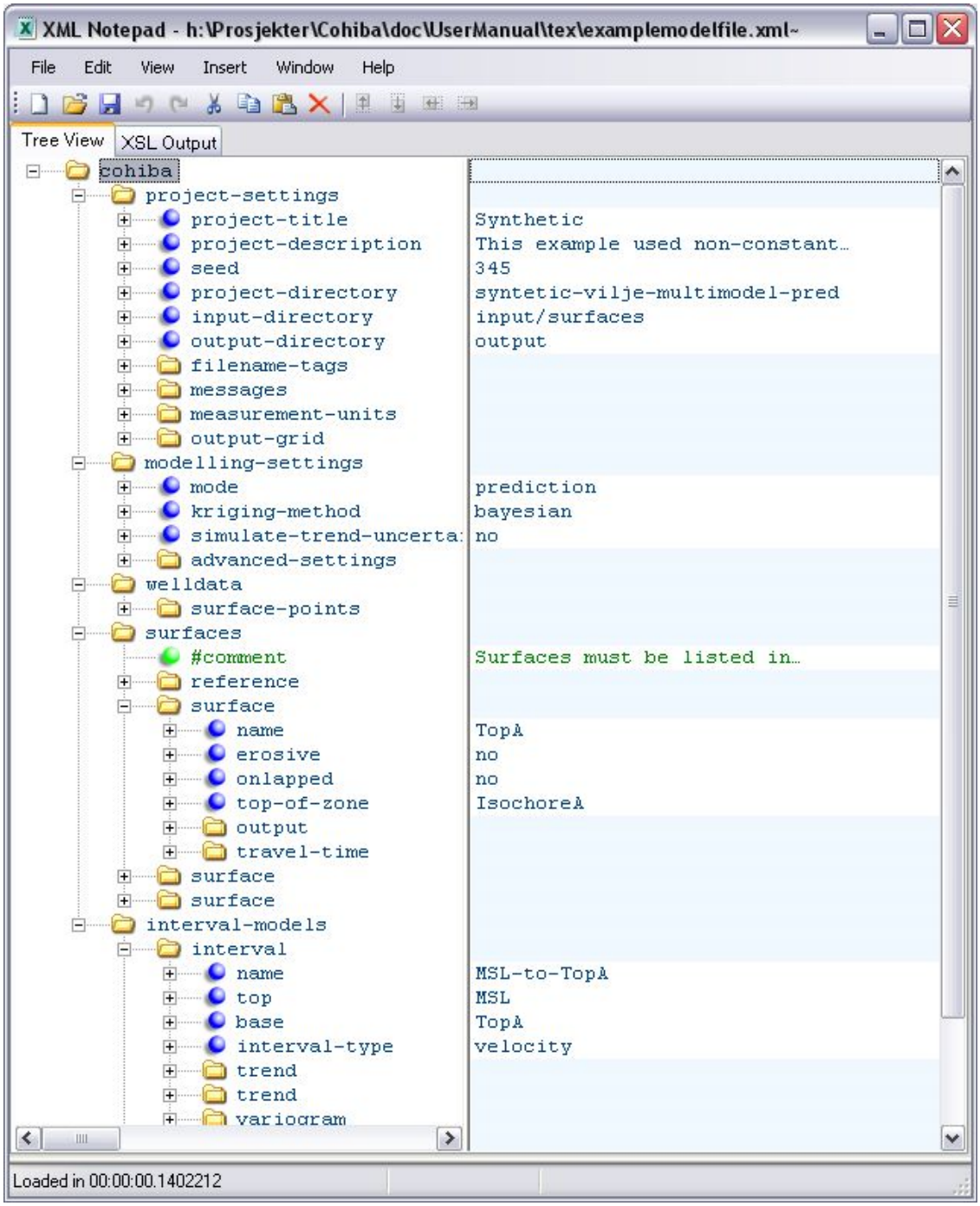



Figure 5.2. The COHIBA model file used in Section B visualised in the Microsoft XML NotePad 2007 editor. The entries in the right column can be edited.

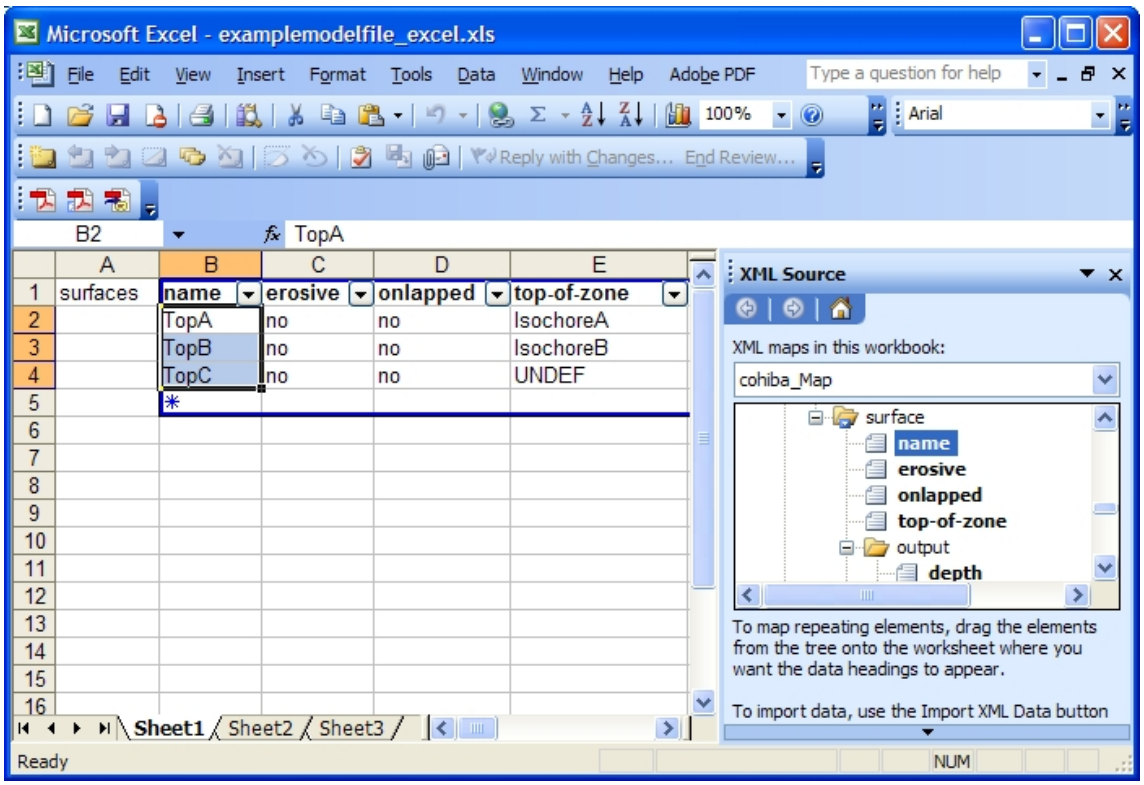



Figure 5.3. A mapping into Microsoft Excel of the repeated element `<surface>` in the COHIBA model file used in Section B.

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 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 organise 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>`. Input data is read from the specified input directory. The default input and output directories are `input/` and `output/` directly under the specified project directory. 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.

# 7 Surface file formats

The following three surface file formats are supported:

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

**IRAP CLASSIC** 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 file formats are automatically detected.

The surface files are specified in the elements `<output-grid>`, `<value>`, and `<stddev>` for various surfaces.

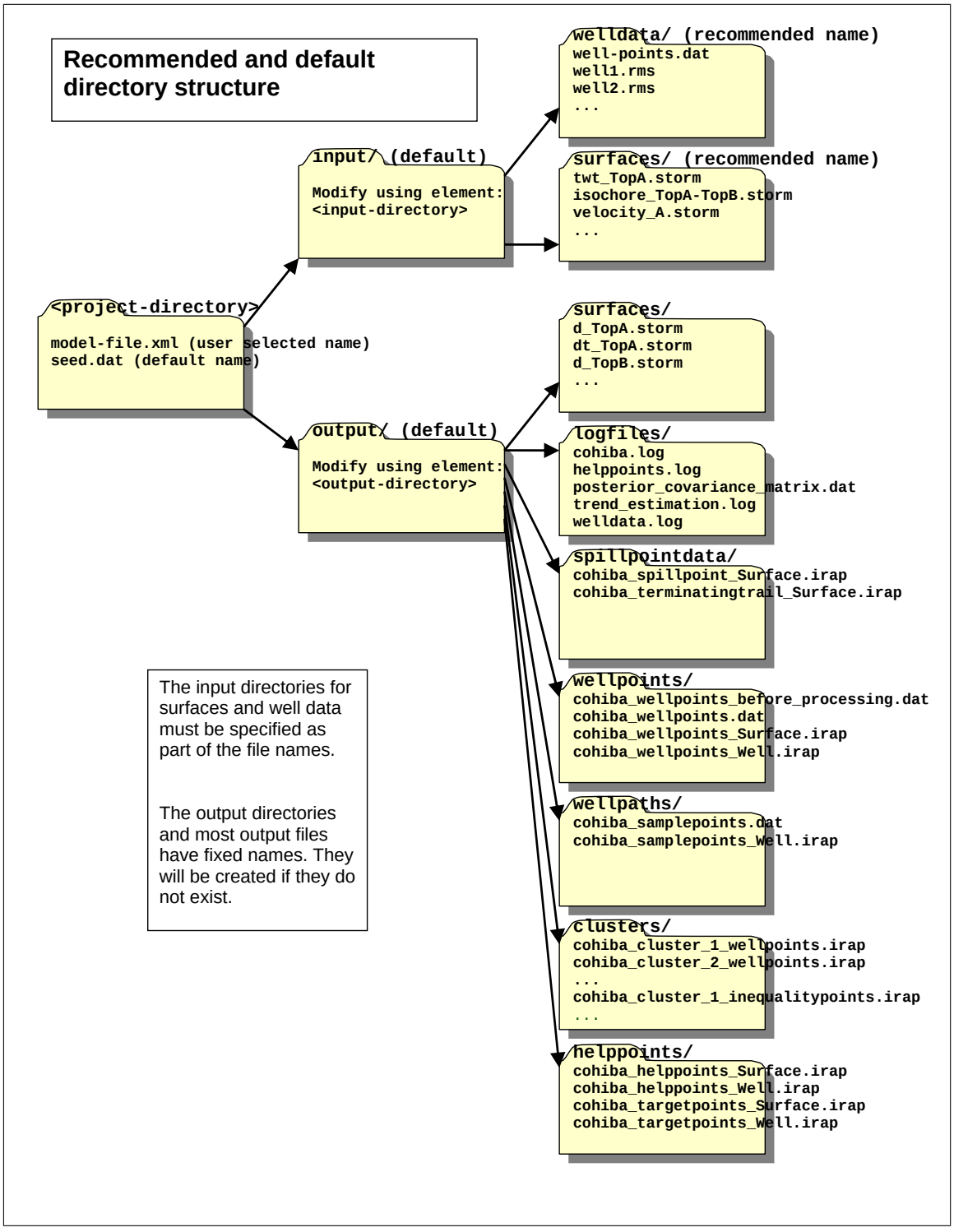



Figure 6.1. Recommended directory structure for COHIBA.

# 8 Well data

There are two types of well data used by COHIBA: *Well points* and *well paths* with *zone logs*, and optionally, fault indicator logs. Well points, which are sometimes called well picks or well markers, are the intersections between a well path and a surface, and these can be imported directly from file, or alternatively, extracted from a well path (well trajectory) using a zone log. COHIBA detects zone transitions and records a well point if the transition is associated with one of the surfaces in the model. If the well is deviated or horizontal, COHIBA can also use the well path and zone log to ensure that the surfaces are located correctly according to the zone log.

In summary, COHIBA may use the following type of well data:

1. Well paths with zone logs and fault indicator logs given in RMS WELL file format.
2. COHIBA well point format.
3. A combination of 1 and 2.

## 8.1 Using zone logs

The RMS WELL format is used for importing well paths with zone logs. See ROXAR ASA (2009) for information on this format. These files are specified in the `<well-log>` element.

There is no generic relationship between the surfaces in the COHIBA model and zones in the zone log, and the zone names for which a particular surface represents the top, must therefore be supplied using the `<top-of-zone>` element. Non-unique zone names are discussed in Section 8.5.5.

When zone logs are used as input, it is assumed that zones are logged as numbers, and that these numbers are linked to zone names in the log-specification part of the file header. This specification has the structure:

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

where `GM2005a` is the log name (specified by `<zone-log-name>` element), `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 positive integers that increase by one.

## 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 COHIBA well points 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 8.1. Each well point must contain the surface name, the well name, the x-, y-, and z-coordinate of the observation, and the vertical uncertainty (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.

## 8.4 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.

### 8.4.1 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 centimetre), and same z-coordinate (within one centimetre).

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

### 8.4.2 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 centimetre.

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.

### 8.4.3 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 individ-

Table 8.1. The COHIBA well points 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 in space, and the last column allows a measurement uncertainty (standard deviation) 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 space separated values in the same file.

Space separated:

```
#-------------------------------------------------------------
# Surface   Well    X-coord.    Y-coord.   Depth     Depth
# 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      Depth
# 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
#-------------------------------------------------------------------
```

ual 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.

### 8.4.4 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.

### 8.4.5 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`.

## 8.5 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.

### 8.5.1 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`.

### 8.5.2 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.

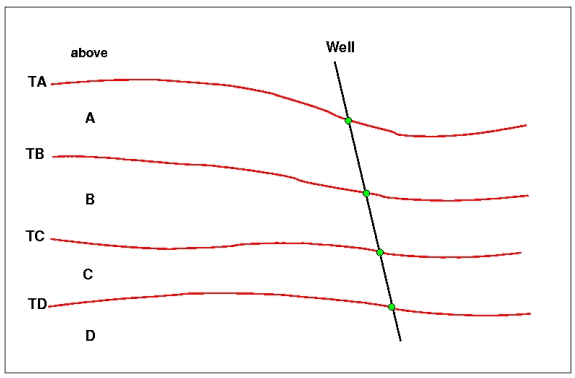



Figure 8.1. Transitions between a simple set of zones. The well points are given as green bullets.

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

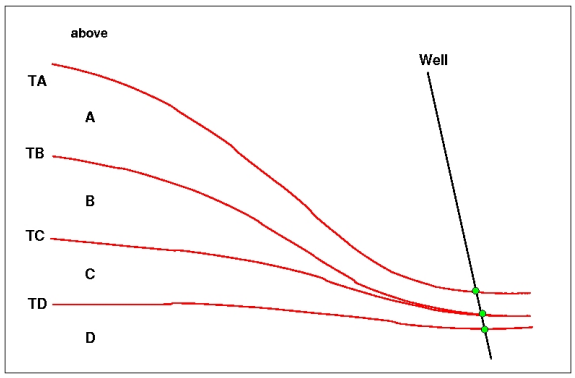



Figure 8.2. Zones with pinch out. The well points are given as green bullets.

A total of 12 different zone transitions may be observed between 5 zones. These are summarised in Table 8.2. 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.

### 8.5.3 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-

Table 8.2. 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 8.3. 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 | — |

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

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

In Table 8.3, we have summarised 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 8.2 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.

### 8.5.4 Faults

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

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>.

### 8.5.5 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

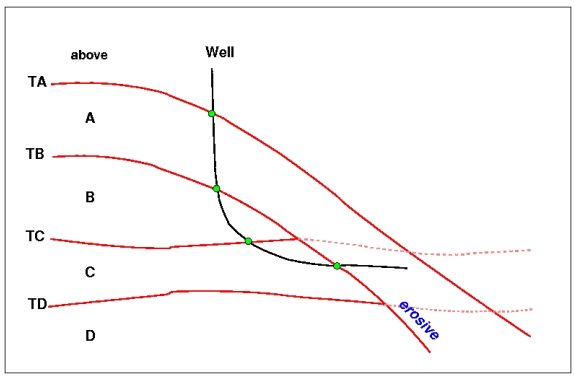



Figure 8.3. Zones where surface TB is erosive. The well points are given as green bullets.

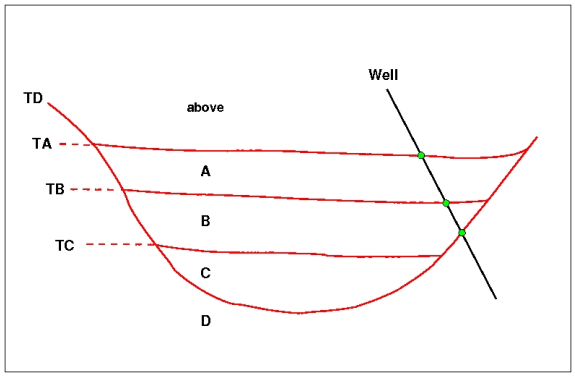



Figure 8.4. Zones where surface TD is on-lapped. The well points are given as green bullets.

four of these surfaces are of interest; the red surfaces labelled 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 is:

```
<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>
    ...
```

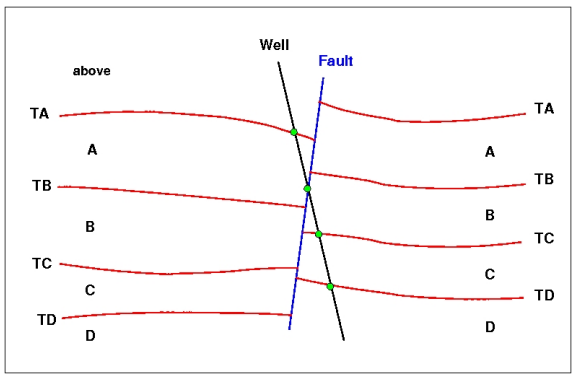



Figure 8.5. A set of faulted zones. The well points are given as green bullets.

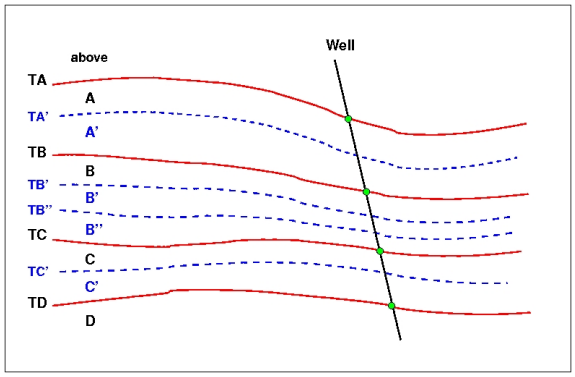



Figure 8.6. A simple set of zones with a zonation finer than the surface model. The well points are given as green bullets.

```
</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 minimise 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.)

## 8.6 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 coloured magenta in the region with incorrect zonation.

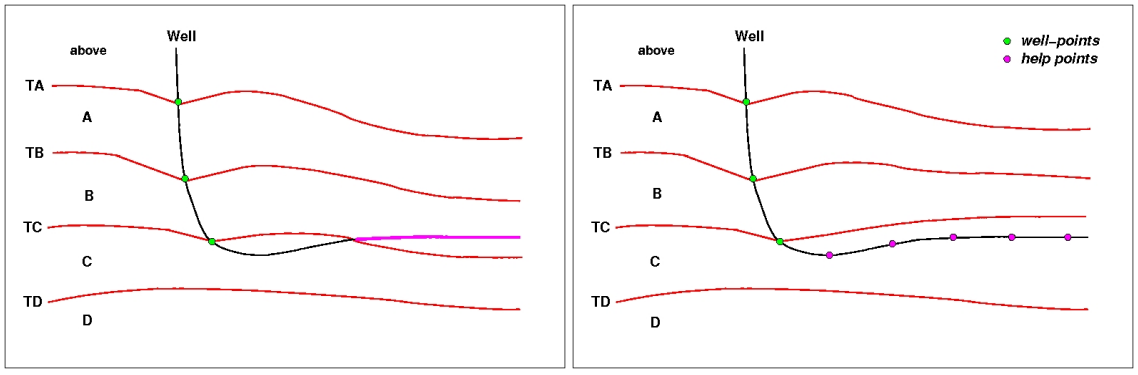



Figure 8.7. A horizontal well following a zone. In the left figure a part of the well (coloured magenta) have ended up in the wrong zone after the surface-adjustment. In the right figure this problem has been corrected by the introduction of help points that ensures that the surface match the correct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

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.

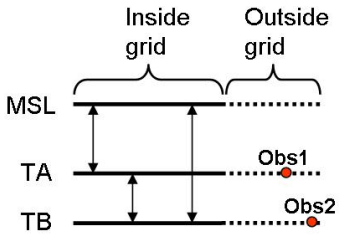
COHIBA handles constraints from zone logs according to the method developed in Abrahamsen and Benth (2001). Without going into the technical details, the approach boils down to finding some additional help (well) points used in the kriging equations. The additional help points are chosen so that surfaces 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 12 that discuss conditioning on zone logs.

## 8.7 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`:

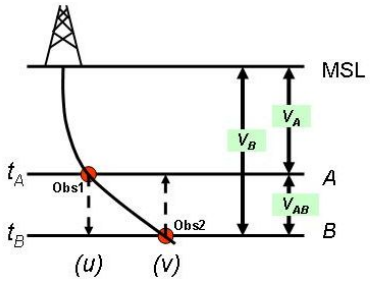



An outside grid well point (`Obs1`) at `TA` and an outside grid well point (`Obs2`) at `TB` require the following input:

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/isochor trend `TA->TB`
Two values for interval velocity/isochor residual `TA->TB`
Two values for interval velocity trend `MSL->TB`
Two values for interval velocity residual `MSL->TB`

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

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




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

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

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

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

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

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

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

```
   ......

  <values-outside-grid>
    <value well-name="my-outside-well" surface-name="TA"
              x="1e10" y="1e10" 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 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. 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/`.

## 9.1 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 9.1.

Table 9.1. Output surfaces.

| Surface | Prefix[a] | Description |
|---|---|---|
| **Depth** | `d` | The main product — depth to the surface. In prediction mode the most likely surface is generated. In simulation mode, one out of an infinite number of possible surfaces is generated. |
| **Depth trend** | `dt` | Similar to **Depth** but the residual is omitted. For prediction this means that the local adaption to well observations is omitted. For simulation, the simulated 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**. |
| **Trap** | `trap` | The trap determined by the spill point. The trap surface is 1 if the surface point is inside the trap and 0 otherwise. |
| **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. |

*a.* These are the default prefixes. These can be renamed using the respective elements in the `<filename-tags>` element.

## 9.2 The log files

The four 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.

### 9.2.1 The COHIBA log file

The COHIBA log file is specified in the `<logfile>` element described in Section A.1.8.1. The default name is `cohiba.log`. 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 paths/zone logs** Reports on processing of well paths with zone logs. Detail level set by `<well-paths>`.

**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[4] of the well points that correspond to observations of the true residual errors. The ratio between observed and specified residual errors are reported for each interval. This ratio can be multiplied to the residual uncertainty specified in `<stddev>` for the corresponding intervals.

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>`.

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

**Section 11: 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>`.

**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.

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

### 9.2.2 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 organised in columns described in Table 9.2. Missing or undefined entries are marked by an '–'.

The file is formatted for easy import into an Excel spreadsheet See Section 9.2.5.

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.

### 9.2.3 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`.

### 9.2.4 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 9.3 for a detailed description of the columns.

The file is formatted for easy import into an Excel spreadsheet. See Section 9.2.5 for a detailed description of how to import into Excel.

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

#### 9.2.4.1 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 uncertainty to all close well points to ensure numerical stability.[5] This is flagged in the `AddUncert` column. The amount of uncertainty added can be found by comparing the columns `TotMeasUncert` and `MeasUncert`. The added uncertainty depends on the mismatch between the potentially conflicting data and the difference in the merged data.

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

Mismatches and conflicts between the trend model and the well points are flagged in the `Outlier` column. If the data had a perfect Gaussian distribution, 5% of the data would be classified as outliers. Outliers are classified in three levels: *Could* be an error, *likely* to be an error, and *surely* an error. COHIBA automatically adds a measurement uncertainty 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.

#### 9.2.4.2 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`.

#### 9.2.4.3 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

5. A measurement uncertainty is only added if the well point has no initial measurement uncertainty.

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.

#### 9.2.4.4 Measurement uncertainty in `welldata.log`

Measurement uncertainty (error) is specified by using the last column (`Depth uncertainty`) in the well points files. These uncertainties are reported in column `MeasUncert`. COHIBA adds additional measurement uncertainty 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 uncertainty automatically added by COHIBA use the formula:

$$\sqrt{\texttt{TotMeasUncert}^2 - \texttt{MeasUncert}^2}.$$

(Variances add linearly.)

#### 9.2.4.5 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 surfaces are stored on grids and well observations will rarely coincide with the grid nodes. A gridding error is therefore inevitable and the `GriddingError` column shows the error at each observation. Note that the gridding error is proportional to the `Residual` values. Severe outliers can have large gridding errors.

#### 9.2.4.6 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 9.2. 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 generalised 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. 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. Not calculated unless Bayesian kriging is specified. |
| 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 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 generalised 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. |
| 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 9.3. 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 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` | 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. `X` means that this data *surely* is erroneous and it is removed from estimation and interpolation. |
| L | `Deleted` | `B/P/E/X/F/S` | The data has been excluded from *estimation* and *kriging*. There are 6 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 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. |
| 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 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 uncertainty (standard deviation): | | | |
| U | `MeasUncert` | Real | Measurement uncertainty specified by the user. |
| V | `TotMeasUncert` | Real | Total measurement uncertainty 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 | `GriddingError` | Real | Numerical resolution error due to gridding. |
| Statistical measures for outliers: | | | |
| AB | `h` | Real | Number between 0 and 1. Value above 2 × (`# of trend coefficients`)/(`# of data`) is classified as leverage point. (`'-'` if too few data.) |
| AC | `t` | Real | $t = \lvert$`Residual`$\rvert$/`ResidualUncert`. Value above 1.96 (5%) is flagged as `'O'` in `Outlier`. Value above 2.57 (1%) is flagged as error `'U'` and `Residual`/2 is added as measurement uncertainty. Value above 3.09 (0.2%) is classified as error `'X'` and data is ignored in trend estimation and kriging interpolation. |
| AD | `tStud` | Real | Same as `t` but takes into account `h`. Is used for outlier classification whenever `h` is available. |

### 9.2.5 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 colour coding that simplifies the investigation. Also, the log files have many columns so using the `Hide/Unhide` column possibilities that Excel offers 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**.

### 9.2.6 The `helppoints.log` file

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

## 9.3 Spill point files

In addition to the trap output grids written to `surfaces/`, COHIBA generates a set of IRAP CLASSIC point files containing the coordinates of the spill point for each surface and the trails to termination. These files are written to the directory `spillpointdata/` under the output directory.

### 9.3.1 The `cohiba_spillpoint_Surface.irap` file

Contains the spill point coordinates (x-, y-, and z-coordinate) calculated for the surface `Surface`.

### 9.3.2 The `cohiba_terminatingtrail_Surface.irap` file

This is the set of last points on surface `Surface` visited by the spill point detection algorithm before it terminates. The trail starts at the spill point and finish at some boundary point.

## 9.4 Well point files

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

### 9.4.1 The `cohiba_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 point 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.

This file is in the COHIBA well point format illustrated in Table 8.1.

### 9.4.2 The `cohiba_wellpoints.dat` file

COHIBA merges duplicate data and removes unnecessary or corrupt data. The remaining data after this pre-process is written to the `cohiba_wellpoints.dat` file.

This file is in the COHIBA well point format illustrated in Table 8.1.

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.

### 9.4.3 The `cohiba_wellpoints_Surface.irap` file

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

### 9.4.4 The `cohiba_wellpoints_Well.irap` file

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

## 9.5 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 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.

### 9.5.1 The `cohiba_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.

### 9.5.2 The `cohiba_samplepoints_Well.irap` 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.

## 9.6 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 well points and the inequality points are grouped into correlated clusters. Each cluster is handled separately when finding help points to replace the inequality points.

### 9.6.1 The `cohiba_cluster_#_wellpoints.irap` file

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

### 9.6.2 The `cohiba_cluster_#_inequalitypoints.irap` 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.

## 9.7 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. These help points enters the conditioning as ordinary well points. For prediction there are measurement errors associated with each help point and help points belonging to the same cluster can have correlations between the measurement

errors.

For prediction a target point is calculated for each inequality point. The target point is the expected location of the surface at the inequality point. The predicted surfaces should interpolate the target points. The Data Augmentation Algorithm is used for calculating the target points. For prediction, help points are chosen so that the surfaces interpolate the target points.

### 9.7.1 The `cohiba_helppoints_Surface.irap` 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.

### 9.7.2 The `cohiba_helppoints_Well.irap` file

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

### 9.7.3 The `cohiba_targetpoints_Surface.irap` file

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

These files are not generated for predictions.

### 9.7.4 The `cohiba_targetpoints_Well.irap` file

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

These files are not generated for predictions.

# 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.

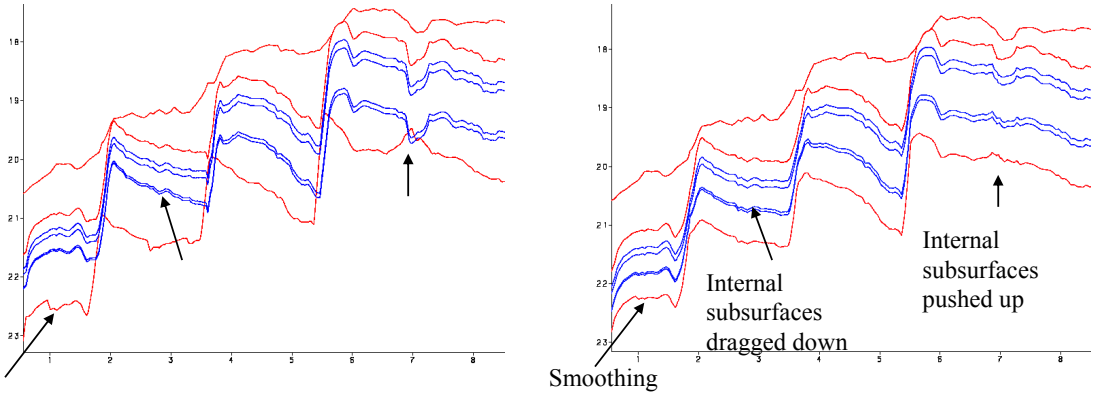



Figure 10.1. Cross section of two alternative ways of combining intervals. The red surfaces are seismic reflectors. The blue surfaces separates the internal zones that are assumed to have constant thickness. The figure to the left shows the surfaces when the internal zones are added to the seismic reflector 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 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 summarised in Table 10.2.

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.

Adding all the formations gives the accumulated uncertainty of the Brent interval as:[6]

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

6. 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.

The uncertainty of the thickness of the Brent interval using depth conversion is:[7]

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

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 isochor thicknesses ($\pm 29$m) for BaseBrent. The model weights will be:

$$\frac{29^2}{29^2 + 15^2} = 0.79 \qquad \frac{15^2}{29^2 + 15^2} = 0.21.$$

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

Table 10.3 shows a summary of the uncertainties and the model weights calculated by COHIBA. There are two important observations:

1. The COHIBA approach favour 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 minimised.

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 10.1 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 favoured more than a simple stacking of isochores from TopBrent.

Table 10.1. 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% |

7. 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.

Table 10.2. 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 isochor 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 10.3. 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 10.2 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 |

```
*************************************************************************************************
*****                  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: `cohiba.log`. 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`. 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`. 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 prediction (kriging) and simulation of surfaces are 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 $\cdot$ 30% = 60 m. If there are two equally thick zones they have 100 m $\cdot$ 30% = 30 m uncertainty, and if there are three equally thick zones they have uncertainty 66.6m $\cdot$ 30% = 20m and so on. If the number of zones are $N$, the accumulated uncertainty for the whole interval becomes:

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

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.

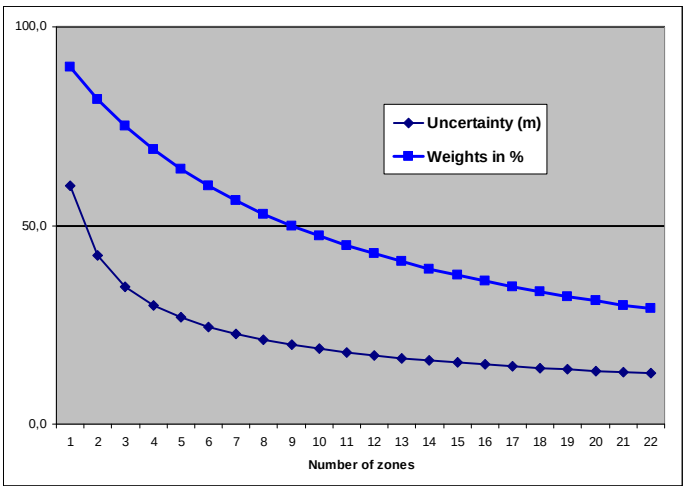



Figure 10.5. Model weights (blue line) as the number of subdivisions of the zone increase. The dark blue line is the accumulated uncertainty obtained using Equation 10.1.

### 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:

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

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

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

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

### 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[8]. 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:

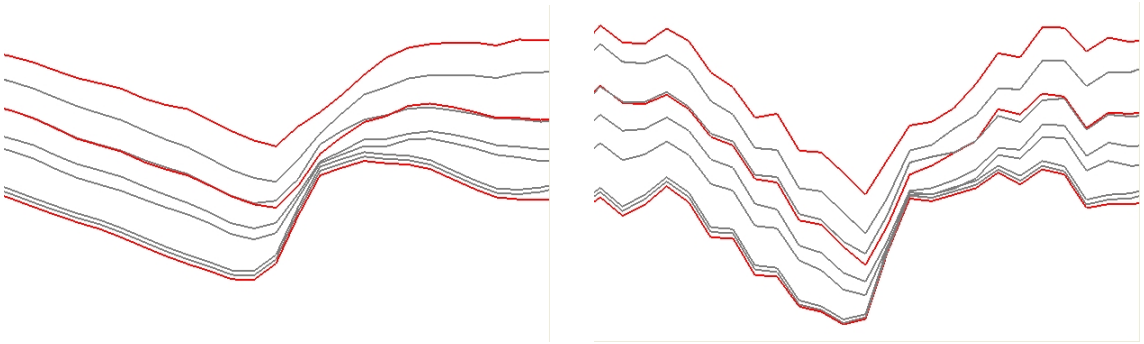
1. COHIBA assumes that the uncertainties to the travel times from different surfaces are independent. This is normally a good approximation, but it is unrealistic when two seismic reflectors are very close or coinciding. So now COHIBA automatically adjust the travel time uncertainties so that close or 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 `<post-process-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>`.

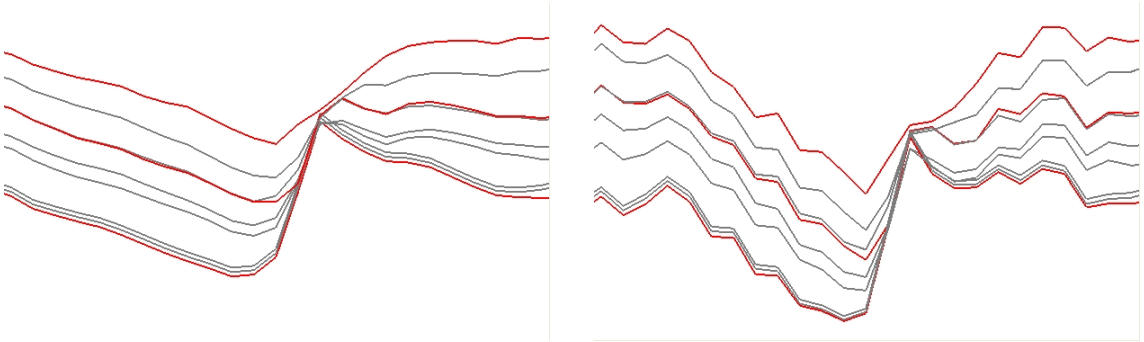
These features are illustrated in Figure 11.1.

8. 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 `<post-process-reflectors-as-eroding-and-onlapped>`):

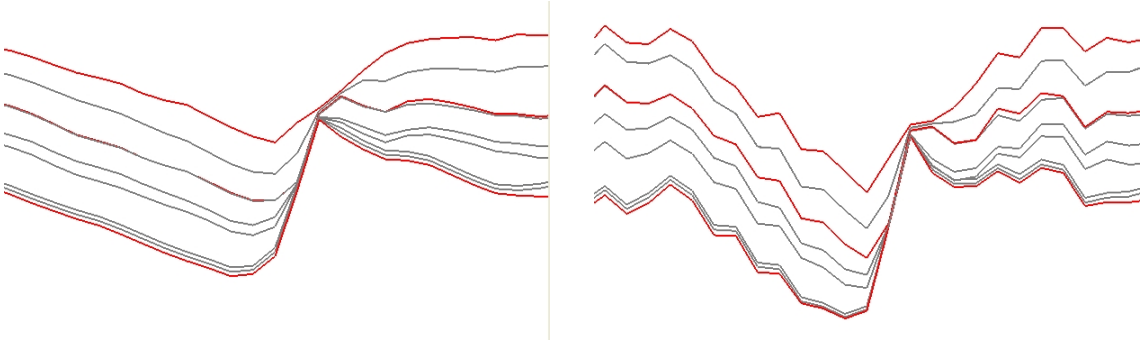


Figure 11.1. Cross section of a fault. Seismic reflectors are red. Prediction in the left column and simulation in the right column.

# 12 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).

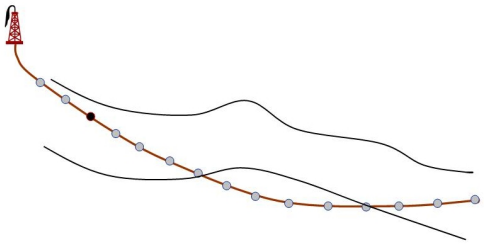
The approach used by COHIBA is a development of the ideas in Abrahamsen and Benth (2001). The article shows how to use inequality constraints in a kriging setting. Here we outline the basic ideas and the modifications necessary to make this work for a multi layered model.

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

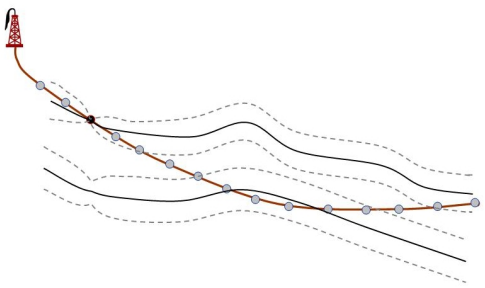
## 12.1 Procedure for conditioning to zone logs

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

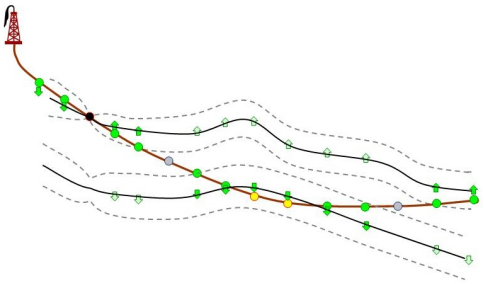
1. Sample the well paths at a resolution approximately twice the grid resolution. (Typically at 100 meter intervals.) The well path is shown as a red line. The well point is shown as a black disc and the *sample points* are the grey discs. The two black lines are cross sections of the surfaces above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



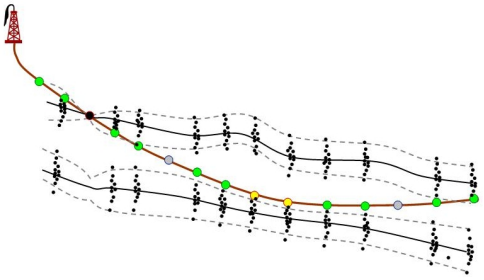
2. Along the well paths, calculate the depth prediction (solid lines), and the prediction error (dashed lines) given the well points. This is quite efficient since only a fraction of the grid cells are close to the well paths.



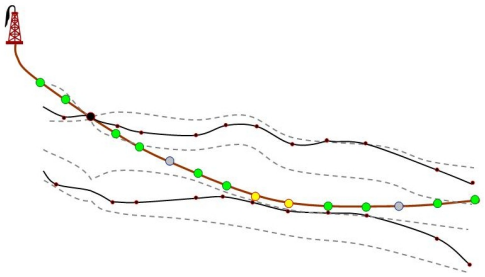
3. Select the sample points that are in conflict with the zone log, that is, they are on the wrong side of the predicted surface. Two yellow sample points are on the wrong side.
   Also select the sample points that are on the correct side of the prediction but are *close* to the prediction. By close is meant less than 0.8 (`<t-value-prediction-first-point>`) prediction errors for prediction and less than 2.0 (`<t-value-simulation-first-point>`) prediction errors for simulation. These sample points are marked green in the figure. More sample points are selected for simulation than prediction because there is a higher risk of ending up on the wrong side for simulation.
   The constraint 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.



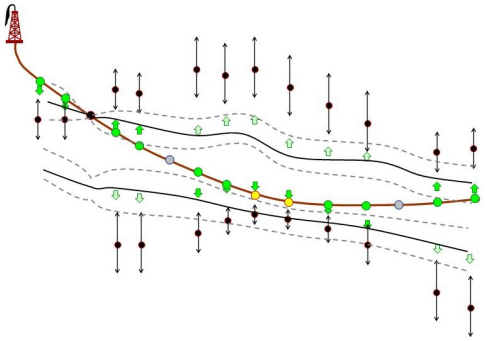
4. Run the Data Augmentation Algorithm to obtain 256 simulated realizations of the depth values at the inequality points.
   These 256 realizations represent the non-Gaussian probability distribution for depth at the inequality points. The 256 realizations will all be in agreement with the well points *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 Monte Carlo simulation technique for evaluating numerical integrals. The method was introduced by Tanner and Wong (1987).



5. **For 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 simulation is essentially made exactly as usual except that the additional help points make the kriging system (a lot) larger.



6. **For prediction:** 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.



## 12.2 Clusters

The drawing of the 256 samples at the inequality points in Step 4 above can be very time consuming if the constraints are strong and if there are many constraints. Therefore COHIBA splits the inequality points into *clusters* of highly correlated inequality points. A typical result is that clusters along the wells are split by the well points in the well. This is illustrated in Figure 12.1. The element `<threshold-for-trace-clustering>` specifies the threshold for the correlations. Specifying a high value means that inequality points must be strongly correlated to be in the same cluster. Small clusters are important to obtain fast performance. The default correlation threshold is 0.3. Inequality points from different well paths will belong to the same cluster if inequality points from different wells have a correlation larger than the threshold specified in element `<threshold-for-cluster-merging>`. A small value will cause large clusters. The default value is 0.5.

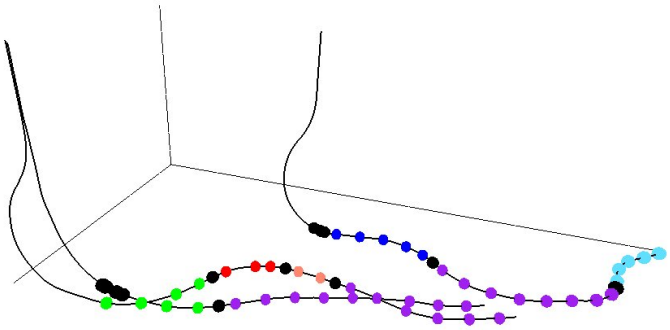


Figure 12.1. Different clusters in the three different wells have different colours. The well points are the black discs. Note how well points splits inequality points from a well into separate clusters. Also note that the largest clusters have inequality points from all three wells.

# A COHIBA model file reference manual

## <cohiba>

*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>

*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>

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

#### A.1.2 <project-description> (optional)

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

#### A.1.3 <seed> (optional)

*Description:* Sets the random seed for the random number generator used in 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 simulation, a new random seed is always written to the random seed file at the end of the 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>` (optional)

*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>` (optional)

*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:

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

*Example:* Absolute path can be to any location:

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

### A.1.6 `<output-directory>` (optional)

*Description:* Relative or absolute path to the COHIBA output directories. The output directory has 7 subdirectories: `surfaces/`, `logfiles/`, `spillpointdata/`, `wellpoints/`, `wellpaths/`, `clusters/`, and `helppoints/`. 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.1.7 `<filename-tags>` (optional)

*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.1.7.1 `<type>` (optional)

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

##### A.1.7.2 `<depth>` (optional)

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

##### A.1.7.3 `<depth-trend>` (optional)

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

##### A.1.7.4 `<depth-error>` (optional)

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

##### A.1.7.5 `<depth-trend-error>` (optional)

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

##### A.1.7.6 `<depth-residual>` (optional)

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

##### A.1.7.7 `<trap>` (optional)

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

#### A.1.7.8 `<thickness>` (optional)

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

#### A.1.7.9 `<thickness-trend>` (optional)

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

#### A.1.7.10 `<velocity>` (optional)

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

### A.1.8 `<messages>` (optional)

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

| Level | Description |
|---|---|
| 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 and so on.
*Argument:* Elements specifying output to log file and screen.
*Default:* Void.

#### A.1.8.1 `<logfile>` (optional)

*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.1.8.1.1 `<name>` (optional)

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

##### A.1.8.1.2 `<detail-level>` (optional)

*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.

`<overall>` (optional)

*Description:* Level of detail in output to log file. This level can be overruled within each output section mentioned below. See Section 9.2.1 for a brief explanation of each section.
*Argument:* 0 – 5
*Default:* 3

`<model-settings>` (optional)

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

`<data-loading>` (optional)

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

`<pre-processing>` (optional)

*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

`<surface-models>` (optional)

*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

`<well-points>` (optional)

*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

`<well-paths>` (optional)

*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

`<trend-coefficients>` (optional)

*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

`<residual-uncertainties>` (optional)

*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

`<outliers>` (optional)

*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

`<well-point-conditioning>` (optional)

*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

`<help-points>` (optional)

*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

`<well-path-conditioning>` (optional)

*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

`<post-processing>` (optional)

*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

`<zonation-checking>` (optional)

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

`<timings>` (optional)

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

`<tasks>` (optional)

*Description:* Level of detail in report on tasks.
*Heading text in log:* `Section 17: Suggested tasks`

*Argument:* 0 – 5
*Default:* 3

#### A.1.8.2 `<screen>` (optional)

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

##### A.1.8.2.1 `<detail-level>` (optional)

*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.

`<overall>` (optional)

*Description:* Level of detail in output to screen. This level can be overruled within each output section described in the logfile Section A.1.8.1.
*Argument:* 0 – 5
*Default:* 3

### A.1.9 `<measurement-units>` (optional)

*Description:* Wrapper for specifying measurement units. Available units:

| Unit | Description |
|---|---|
| m | Meter |
| s | Second |
| ms | Millisecond |
| m/s | Meters per Second |

Depth and length units are assumed to be in meters and interval velocities are assumed to be in meters per second.
*Argument:* Elements for each unit type.
*Default:* Void.

#### A.1.9.1 `<time-unit>` (optional)

*Description:* Unit of time.
*Argument:* `s` / `ms`
*Default:* `s`

#### A.1.9.2 `<angle-unit>` (optional)

*Description:* Unit of angle. Degrees ($360°$) or radians ($2\pi$).
*Argument:* `deg` / `rad`
*Default:* `deg`

#### A.1.9.3 `<two-way-time>` (optional)

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

*Default:* `no`

### A.1.10 `<output-grid format = "" >`

*Description:* Grid dimensions for the output grids.[9] The following grid consistency equations must be satisfied:

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

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

*Attribute:* `format` File format. See Section 7 for possible file formats.
*Attribute value:* `storm` / `irapclassic`
*Argument:* Elements specifying the grid dimensions.
*Default:* No default.

#### A.1.10.1 `<read-from-file>` (optional)

*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 IRAP CLASSIC or STORM. 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.

```
<output-grid format="irapclassic">
  <read-from-file> dS_IsochoreA.storm </read-from-file>
</output-grid>
```

Note that `dS_IsochoreA.storm` can have a different file format from the specified output format.

#### A.1.10.2 `<xstart>` (optional)

*Description:* Minimum X value.
*Argument:* Real.
*Default:* No default.

#### A.1.10.3 `<xend>` (optional)

*Description:* Maximum X value.
*Argument:* Real satisfying Equation A.1.
*Default:* No default.

#### A.1.10.4 `<ystart>` (optional)

*Description:* Minimum Y value.
*Argument:* Real.
*Default:* No default.

#### A.1.10.5 `<yend>` (optional)

*Description:* Maximum Y value.
*Argument:* Real satisfying Equation A.2.

9. Input grids can have different formats and dimensions.

*Default:* No default.

#### A.1.10.6 <xinc> (optional)

*Description:* X increment; optional if <nx> is given.
*Argument:* Positive real.
*Default:* No default.

#### A.1.10.7 <yinc> (optional)

*Description:* Y increment; optional if <ny> is given.
*Argument:* Positive real.
*Default:* No default.

#### A.1.10.8 <nx> (optional)

*Description:* Number of grid nodes in X; optional if <xinc> is given.
*Argument:* Positive integer.
*Default:* No default.

#### A.1.10.9 <ny> (optional)

*Description:* Number of grid nodes in Y; optional if <yinc> is given.
*Argument:* Positive integer.
*Default:* No default.

#### A.1.10.10 <grid-azimuth unit = ""> (optional)

*Description:* Azimuth angle for rotated grids. Angle is measured clockwise from north. The default units are degrees (360°). Note that this option only works for files using the IRAP CLASSIC grid format (see Section 7). Also note that all input and output grids must have identical rotation.
*Attribute:* unit
*Attribute value:* rad / deg
*Attribute default:* deg
*Argument:* Float
*Default:* 0.0
*Example:* Grids rotated 15° clockwise from north:

```
<output-grid format = "irapclassic">
  <xstart>          0.0 </xstart>
  <xend>         5000.0 </xend>
  <ystart>          0.0 </ystart>
  <yend>        10000.0 </yend>
  <xinc>          100.0 </xinc>
  <yinc>          100.0 </yinc>
  <grid-azimuth unit =  "deg" >   15.0 </grid-azimuth>
</output-grid>
```

### A.2 <modelling-settings> (optional)

*Description:* Wrapper for elements determining the methods and algorithms used.
*Argument:* Elements specifying overall modelling settings.

*Default:* No default.

#### A.2.1 `<mode>` (optional)

*Description:* The default mode is to generate a set of most likely surfaces using *prediction*. Alternatively a Monte Carlo sample can be drawn using *simulation*. Prediction is typically used for well prognosis, and simulation is typically used for uncertainty studies on volumes. The *estimation* mode gives the possibility to run through the initial adaption of the trend coefficients to well points without entering the more time consuming kriging steps in the prediction or conditional simulation steps.

*Argument:* `prediction` / `simulation` / `estimation`

*Default:* `prediction`

#### A.2.2 `<kriging-method>` (optional)

*Description:* The three available kriging method 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.

*Argument:* `simple` / `bayesian` / `universal`

*Default:* `bayesian`

#### A.2.3 `<simulate-trend-uncertainty>` (optional)

*Description:* This flag has only effect in 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.2.4 `<advanced-settings>` (optional)

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

*Argument:* Elements controlling algorithms.

*Default:* Void.

##### A.2.4.1 `<condition-to-well-paths>` (optional)

*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 prediction and simulation. If speed is critical set the value to `no`.

*Argument:* `yes` / `no`

*Default:* `yes`

##### A.2.4.2 `<max-obs-direct-estim-trend-coef>` (optional)

*Description:* When the number of well points is smaller than this threshold, the trend coefficients

and their covariance matrix are estimated using the formulas

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

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.2.4.3 `<max-obs-GLS-approx-trend-coef>` (optional)

*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.2.4.4 `<max-obs-update-trend-coef-using-well-paths>` (optional)

*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.2.4.5 `<threshold-for-trace-clustering>` (optional)

*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.2.4.6 `<threshold-for-cluster-merging>` (optional)

*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.2.4.7 `<threshold-for-removing-undefined-well-sections>` (optional)

*Description:* Maximum length of zone log section with undefined values (missing codes). COHIBA will extract a well point in the middle of the undefined section and add a measurement error that is 1/4 the 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.2.4.8 `<minimum-isochore-thickness>` (optional)

*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.2.4.9 `<threshold-for-mild-error>` (optional)

*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.2.4.10 `<t-value-outlier>` (optional)

*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.2.4.11 `<t-value-severe-outlier>` (optional)

*Description:* Threshold for flagging well point as uncertain. An observation 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.2.4.12 `<t-value-error>` (optional)

*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.2.4.13 `<t-value-extreme-error>` (optional)

*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.2.4.14 `<t-value-prediction-first-point>` (optional)

*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 73 for more details.

*Argument:* Positive real.

*Default:* `0.8`

#### A.2.4.15 `<t-value-prediction-second-point>` (optional)

*Description:* A close sample point and its associated inequality point might cause the neighbouring surface to violate the sample point. Therefore, inequality points usually come in pairs. See Step 3 on page 73 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.2.4.16 `<t-value-simulation-first-point>` (optional)

*Description:* The same as `<t-value-prediction-first-point>` but used in 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.2.4.17 `<t-value-simulation-second-point>` (optional)

*Description:* The same as `<t-value-prediction-second-point>` but used in simulation mode.

*Argument:* Positive real.

*Default:* `2.5`

#### A.2.4.18 `<maximum-generalized-eigenvalue-for-inequality-points>` (optional)

*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`

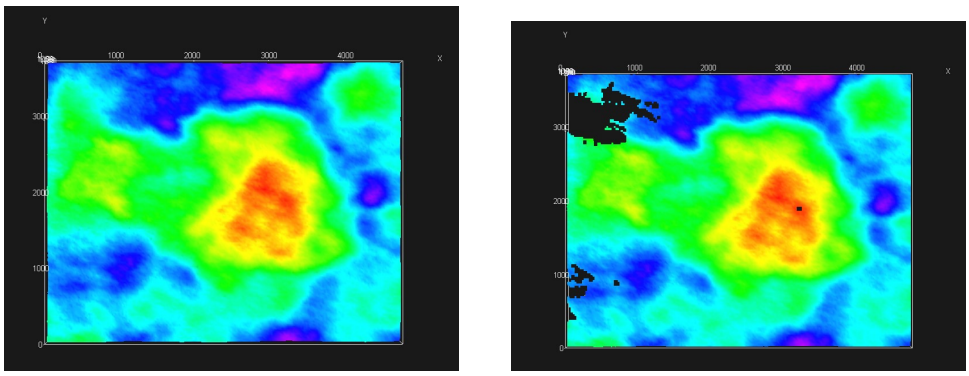


Figure A.1. Original surface to the left (default). To the right is <set-eroded-nodes-to-undefined> set to yes.

#### A.2.4.19 <pre-process-make-time-surfaces-consistent> (optional)

*Description:* When turned on (yes), COHIBA makes seismic reflectors consistent by letting the upper travel times erode the deeper travel times.
Note that this *must not* be used if air-interpretations are present.

*Argument:* yes / no

*Default:* no

#### A.2.4.20 <set-eroded-nodes-to-undefined> (optional)

*Description:* Eroded areas is set to undefined if value is yes. If <post-process-erosive-and-onlapping-surfaces> is set to no, this has no effect. See Figure A.1.

*Argument:* yes / no

*Default:* no

#### A.2.4.21 <correlate-close-reflectors> (optional)

*Description:* COHIBA assumes that all residuals are uncorrelated. This assumption fails for seismic reflectorscoinciding 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.correlated residual 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 $\Delta t = 0$.

*Argument:* yes / no

*Default:* yes

#### A.2.4.22 <threshold-for-conditioning-in-neighbourhood> (optional)

*Description:* Controls the use of neighbourhoods 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.2.4.23 <preprocess-range-factor-for-neighbourhood> (optional)

*Description:* Determines data neighbourhood size as the fraction of the range in the pre-processing step. The well points in the neighbourhood is used to find the prediction and prediction error at the sample points along the well paths. See the second step in Section 12.1 for some explanation.
*Argument:* Positive real value.
*Default:* 1.5

#### A.2.4.24 <minimum-range-factor-for-neighbourhood> (optional)

*Description:* Minimum data neighbourhood size as the fraction of the range.
*Argument:* Positive real.
*Default:* 1.0

#### A.2.4.25 <maximum-range-factor-for-neighbourhood> (optional)

*Description:* Maximum data neighbourhood size as the fraction of the range.
*Argument:* Positive real.
*Default:* 2.0

#### A.2.4.26 <target-number-of-data-in-neighbourhood> (optional)

*Description:* If the number of well points within the rectangle determined by <minimum-range-factor-for-neighbourhood> is less than this number, the rectangular neighbourhood 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 neighbourhood always remains at the size determined by <minimum-range-factor-for-neighbourhood>.
*Argument:* Non-negative integer.
*Default:* 0

#### A.2.4.27 <post-process-erosive-and-onlapping-surfaces> (optional)

*Description:* 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.2.4.28 <post-process-reflectors-as-eroding-and-onlapped> (optional)

*Description:* Will ensure that seismic reflectorserosive and on-lapped 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 <post-process-erosive-and-onlapping-surfaces> 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.2.4.29 <post-process-crossing-surfaces> (optional)

*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.2.4.30 `<post-process-make-surfaces-interpolate-well-points>` (optional)

*Description:* Removes gridding errors at well points. Modify the 4 grid values closest to a well point to ensure perfect bilinear interpolation. This is only done for well points with zero measurement uncertainty. Kriging is a perfect interpolator but the gridding of the surfaces introduce a smoothing of the bulls eye at the well point.

*Argument:* `yes` / `no`

*Default:* `yes`

#### A.2.4.31 `<remove-extreme-values-in-velocity-trends>` (optional)

*Description:* Preprocess every velocity trend. Looks for extreme values outside the limit trend, which is the mean $\pm$ 2.57583 (set by `<t-value-severe-outlier>`) standard deviations. Such extreme values are truncated to the limit value. This removes unrealistic velocity trend contributions occasionally found in input maps.

*Argument:* `yes` / `no`

*Default:* `yes`

#### A.2.4.32 `<check-specified-residual-uncertainties>` (optional)

*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.2.4.33 `<minimum-generalized-eigenvalue>` (optional)

*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>` (optional)

*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>` (optional)

*Description:* A wrapper for elements describing zone logs or 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-name>` (optional)

*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.3.1.2 `<fault-log-name>` (optional)

*Description:* Specifies the name of the fault indicator log.
*Argument:* A string.
*Default:* Empty string.
*Example:* `<fault-log-name> FaultIndicator </fault-log-name>`

#### A.3.1.3 `<files>` (optional)

*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. See Section 8.1 for details on the file format.
*Argument:* Any valid path relative to `<input-directory>`. Wildcards (*) are supported.
*Default:* Empty string.
*Example:* One file: `<files> wells/31-2_K-11H.w </files>`
*Example:* Two files: `<files> wells/W1.rms, wells/W2.rms </files>`
*Example:* All files in directory: `<files> wells/* </files>`

#### A.3.1.4 `<tops-as-mean-values>` (optional)

*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 uncertainty (standard deviation) equal to $|z1 - z2|/4$ is added to the well point. The typical logging distance is one foot which is approximately 30cm. The standard deviation will then be approximately 7.5cm.
2. The last (along the well path) point in the zone transition. This is select with argument `no`.

The method chosen affects all files imported in `<files>`.
*Argument:* `yes` / `no`
*Default:* `yes`

### A.3.2 `<well-points>` (optional)

*Description:* Wrapper for `<files>` elements which specify the files containing well points. The `<well-points>` element can be ignored or be used to add additional well points to the data extracted from zone logs.
*Argument:* `<files>` elements.
*Default:* Empty string.

#### A.3.2.1 `<files>` (optional)

*Description:* The well point files to be imported. This element can be repeated in order to import different files in different locations.See Table 8.1 on page 40 for details on the file format.
*Argument:* Any valid path relative to `<input-directory>`. Wildcards (*) are supported.
*Default:* Empty string.
*Example:* `<files> mywellpoints/* </files>`

### A.3.3 `<well-points-to-ignore>` (optional)

*Description:* Wrapper for `<files>` elements that specify well points that should be discarded.
*Argument:* `<files>` elements.
*Default:* Empty string.

#### A.3.3.1 `<files>` (optional)

*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 8.1 on page 40 for details on file format.
Any valid path relative to `<input-directory>`. Wildcards are supported.
*Default:* Empty string.
*Example:* `<files> ignorepoints/* </files>`

### A.3.4 `<values-outside-grid>` (optional)

*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 = "">` (optional)

*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>

*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 grid $[x_{start}, x_{end}] \times [y_{start}, y_{end}]$. The input grid must be the same as the 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> (optional)

*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 (horisontal 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 horisontal plane can be used.

*Argument:* Elements specifying the reference surface.

*Default:* No default.

#### A.4.1.1 <name> (optional)

*Description:* Name of reference surface.

*Argument:* String.

*Default:* MSL

#### A.4.1.2 <depth-value> (optional)

*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-value>` (optional)

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

### A.4.2 `<surface>`

*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>` (optional)

*Description:* A *unique* name for the surface. The name is used for identifying data in well points files 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>` (optional)

*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 `<post-process-erosive-and-onlapping-surfaces>`.
*Argument:* `yes` / `no`
*Default:* `no`

#### A.4.2.3 `<onlapped>` (optional)

*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 `<post-process-erosive-and-onlapping-surfaces>`.
*Argument:* `yes` / `no`
*Default:* `no`

#### A.4.2.4 `<spill-point>` (optional)

*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 coordinates to the starting point and how to interpret missing codes.
*Default:* Void

#### A.4.2.4.1 <missing-as-wall> (optional)

*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.4.2.4.2 <xstart> (optional)

*Description:* Start 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.4.2.4.3 <ystart> (optional)

*Description:* Start 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.4.2.5 <top-of-zone> (optional)

*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 8.5.5.
*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.4.2.6 <travel-time> (optional)

*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.4.2.6.1 <value> (optional)

*Description:* The travel time values.
*Argument:* File name or constant. See Section 7 for possible file formats.
*Default:* 0.0.

#### A.4.2.6.2 <values-outside-grid > (optional)

*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.4.2.6.2.1 `<value>` (optional)

*Description:* A travel time value for a well point outside the grid.
*Argument:* Real.
*Default:* No default.
*Example:* `<value> 0.1 </value>`

### A.4.2.6.3 `<variogram>` (optional)

*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.1.
*Argument:* Elements specifying the travel time uncertainty.
*Default:* Default values for child elements.

Table A.1. Supported variogram types in COHIBA. Variograms, $\gamma(x)$, are closely linked to correlation functions, $\rho(x)$ by the simple relation $\gamma(x) = 1 - \rho(x)$. Here $x = r/R$ where $r$ is the distance and $R$ is the `<range>`. See Section C 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` | $\rho(x) = 1/(1 + \text{scale} \cdot x^2)^p, \quad p > 0$ |
| `damped sine` | $\rho(x) = \sin \pi x / \pi x$ |

#### A.4.2.6.3.1 `<type>` (optional)

*Description:* The type of variogram.
*Argument:* The variograms in Table A.1.
*Default:* `spherical`

#### A.4.2.6.3.2 `<range>` (optional)

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

#### A.4.2.6.3.3 <subrange> (optional)

*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.4.2.6.3.4 <azimuth> (optional)

*Description:* The variogram azimuth. Angle is measured clockwise from north. Units are specified in the <angle-unit> element. The default units are degrees (360°).
*Argument:* Real.
*Default:* 0.0

#### A.4.2.6.3.5 <stddev>

*Description:* The standard deviation (square root of sill) value or grid.
*Argument:* File name or constant. See Section 7 for possible file formats.
*Default:* 1.0

#### A.4.2.6.3.6 <power> (optional)

*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.4.2.6.3.7 <values-outside-grid> (optional)

*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>.

<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.4.2.7 <output> (optional)

*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.4.2.7.1 <depth> (optional)

*Description:* The output depth surface.

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

#### A.4.2.7.2 `<depth-error>` (optional)

*Description:* The output depth prediction error surface. Note that turning this on will increase the CPU time significantly.
*Argument:* `yes` / `no`.
*Default:* `no`

#### A.4.2.7.3 `<depth-trend>` (optional)

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

#### A.4.2.7.4 `<depth-trend-error>` (optional)

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

#### A.4.2.7.5 `<depth-residual>` (optional)

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

#### A.4.2.7.6 `<trap>` (optional)

*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> dT_TopA.storm      </stddev>
        </variogram>
     </travel-time>
</surface>
```

## A.5 <interval-models>

*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> (optional)

*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> (optional)

*Description:* An interval name. All output concerning this interval will use this name.

*Argument:* String.

*Default:* Empty string.

#### A.5.1.2 <top>

*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>

*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>`

*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>` (optional)

*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.
*Argument:* Real.
*Default:* `1.0`

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

*Description:* Prior uncertainty (standard deviation) of trend coefficient.
*Argument:* Non-negative real.
*Default:* `0.0`

##### A.5.1.5.3 `<value>`

*Description:* A trend map (grid). This map is multiplied by its corresponding trend coefficient.
*Argument:* File name or constant. See Section 7 for possible file formats.
*Default:* `1.0`

##### A.5.1.5.4 `<values-outside-grid>` (optional)

*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>`.

`<value>` (optional)

*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>` (optional)

*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 <c*p*-*q*> (optional)

*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>

*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. See the <variogram> element under the <surface> element for details.

*Default:* No default.

### A.5.1.8 <output> (optional)

*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> (optional)

*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> (optional)

*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> (optional)

*Description:* The output interval velocity, i.e., the interval thickness divided by the time difference.
*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>                Vcorr_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>                  dV_Overburden.storm  </stddev>
    </variogram>
    <output>
      <thickness>               yes                   </thickness>
      <thickness-trend>         yes                   </thickness-trend>
      <velocity>                yes                   </velocity>
    </output>
</interval>
```

# B COHIBA model file example

```
<cohiba>
<project-settings>
  <project-title>
   Synthetic
   </project-title>
  <project-description>
   This example used non-constant surfaces and surfaces without UNDEFs
   </project-description>
  <seed> seed.dat  </seed>
  <project-directory>             example         </project-directory>
  <input-directory>               input/surfaces  </input-directory>
  <output-directory>              output          </output-directory>

  <filename-tags type="prefix" >
    <depth>                       d       </depth>
    <depth-trend>                 dt      </depth-trend>
    <depth-error>                 de      </depth-error>
    <depth-trend-error>           dte     </depth-trend-error>
    <depth-residual>              dr      </depth-residual>
    <trap>                        trap    </trap>
    <thickness>                   t       </thickness>
    <thickness-trend>             tt      </thickness-trend>
    <thickness-residual>          tr      </thickness-residual>
  </filename-tags>
  <messages>
    <logfile>
      <name>                      cohiba.log  </name>
      <detail-level>
      <overall>                   4       </overall>
      <model-settings>            0       </model-settings>
      <data-loading>              0       </data-loading>
      <well-points>               0       </well-points>
      <well-paths>                0       </well-paths>
      <trend-coefficients>        5       </trend-coefficients>
      <outliers>                  0       </outliers>
      <well-point-conditioning>   5       </well-point-conditioning>
      <well-path-conditioning>    5       </well-path-conditioning>
      <post-processing>           5       </post-processing>
      </detail-level>
    </logfile>
    <screen>
      <detail-level>
      <overall>                   5       </overall>
      <model-settings>            0       </model-settings>
      <data-loading>              0       </data-loading>
      <well-points>               0       </well-points>
```

```
        <well-paths>                4       </well-paths>
        <trend-coefficients>        5       </trend-coefficients>
        <outliers>                  0       </outliers>
        <well-point-conditioning>   4       </well-point-conditioning>
        <well-path-conditioning>    4       </well-path-conditioning>
        <post-processing>           4       </post-processing>
        </detail-level>
      </screen>
    </messages>
    <measurement-units>
      <time-unit>                   s       </time-unit>
      <angle-unit>                  deg     </angle-unit>
      <two-way-time>                no      </two-way-time>
    </measurement-units>
    <output-grid format="irapclassic">
      <xstart>                       0.0    </xstart>
      <xend>                      4800.0    </xend>
      <ystart>                       0.0    </ystart>
      <yend>                      3800.0    </yend>
      <xinc>                          25    </xinc>
      <yinc>                          25    </yinc>
      <nx>                           193    </nx>
      <ny>                           153    </ny>
      <azimuth>                      0.0    </azimuth>
    </output-grid>
  </project-settings>

  <modelling-settings>
    <mode>                         prediction </mode>
    <kriging-method>               bayesian   </kriging-method>
    <simulate-trend-uncertainty>   no         </simulate-trend-uncertainty>
    <advanced-settings>
       <condition-to-well-paths>         no   </condition-to-well-paths>
       <post-process-crossing-surfaces> yes   </post-process-crossing-surfaces>
    </advanced-settings>
  </modelling-settings>

  <well-data>
    <well-points>
      <files>           ../welldata/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>             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>
   <spill-point>
     <missing-as-wall>       no      </missing-as-wall>
     <xstart>                2000    </xstart>
     <ystart>                2500    </ystart>
  </spill-point>
  <travel-time>
    <value>                 T_TopA.storm      </value>
    <variogram>
      <type>                spherical         </type>
      <range>               1000              </range>
      <subrange>            2000              </subrange>
      <azimuth>             30                </azimuth>
      <stddev>              dT_TopA.storm     </stddev>
    </variogram>
  </travel-time>
</surface>

<surface>
  <name>                    TopB              </name>
  <erosive>                 no                </erosive>
  <onlapped>                no                </onlapped>
  <top-of-zone>             IsochoreB         </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>
  <spill-point>
     <missing-as-wall>      yes               </missing-as-wall>
   </spill-point>

</surface>
```

```
  <surface>
    <name>                      TopC              </name>
    <erosive>                   no                </erosive>
    <onlapped>                  no                </onlapped>
    <top-of-zone>               UNDEF             </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_TopC.storm      </value>
      <variogram>
        <type>                  spherical         </type>
        <range>                 1000              </range>
        <subrange>              2000              </subrange>
        <azimuth>               45                </azimuth>
        <stddev>                0.001             </stddev>
      </variogram>
    </travel-time>
  </surface>
</surfaces>

<interval-models>
  <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>              Vcorr_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>                dV_Overburden.storm </stddev>
  </variogram>
  <output>
    <thickness>             yes                 </thickness>
    <thickness-trend>       yes                 </thickness-trend>
    <thickness-residual>    no                  </thickness-residual>
  </output>
</interval>

<interval>
  <name>                    TopA-to-TopB        </name>
  <top>                     TopA                </top>
  <base>                    TopB                </base>
  <interval-type>           thickness           </interval-type>
  <trend>
    <coefficient-mean>      1                   </coefficient-mean>
    <coefficient-stddev>    0.2                 </coefficient-stddev>
    <value>                 S_IsochoreA.storm   </value>
  </trend>
  <variogram>
    <type>                  spherical           </type>
    <range>                 1000                </range>
    <subrange>              2000                </subrange>
    <azimuth>               60                  </azimuth>
    <stddev>                dS_IsochoreA.storm  </stddev>
  </variogram>
  <output>
    <thickness>             no                  </thickness>
    <thickness-trend>       no                  </thickness-trend>
    <thickness-residual>    no                  </thickness-residual>
  </output>
</interval>

<interval>
  <name>                    TopB-to-TopC        </name>
  <top>                     TopB                </top>
  <base>                    TopC                </base>
  <interval-type>           thickness           </interval-type>
  <trend>
    <coefficient-mean>      1                   </coefficient-mean>
    <coefficient-stddev>    0.2                 </coefficient-stddev>
    <value>                 S_IsochoreB.storm   </value>
  </trend>
  <variogram>
    <type>                  spherical           </type>
    <range>                 1000                </range>
    <subrange>              2000                </subrange>
    <azimuth>               60                  </azimuth>
    <stddev>                dS_IsochoreB.storm  </stddev>
```

```
      </variogram>
      <output>
        <thickness>              no                 </thickness>
        <thickness-trend>        no                 </thickness-trend>
        <thickness-residual>     no                 </thickness-residual>
      </output>
    </interval>

    <interval>
      <name>                     TopA-to-TopC       </name>
      <top>                      TopA               </top>
      <base>                     TopC               </base>
      <interval-type>            velocity           </interval-type>
      <trend>
        <coefficient-mean>       1                  </coefficient-mean>
        <coefficient-stddev>     0.2                </coefficient-stddev>
        <value>                  2500               </value>
      </trend>
      <variogram>
        <type>                   spherical          </type>
        <range>                  1000               </range>
        <subrange>               2000               </subrange>
        <azimuth>                120                </azimuth>
        <stddev>                  75                </stddev>
      </variogram>
      <output>
        <thickness>              no                 </thickness>
        <thickness-trend>        no                 </thickness-trend>
        <thickness-residual>     no                 </thickness-residual>
      </output>
    </interval>

  </interval-models>

</cohiba>
```

# C Variogram examples

This appendix contains some simulated realizations 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.

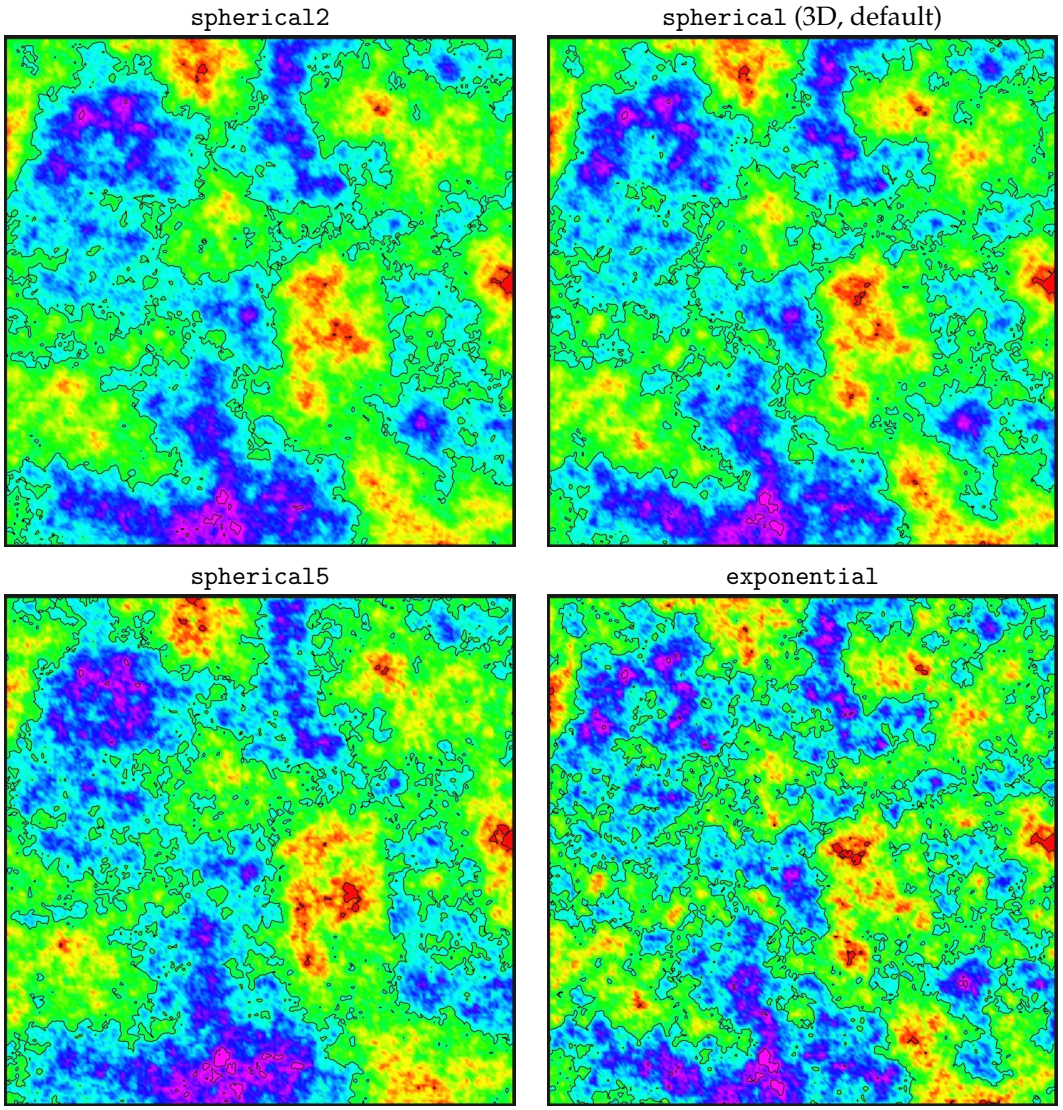



Figure C.1. Spherical and exponential variograms.

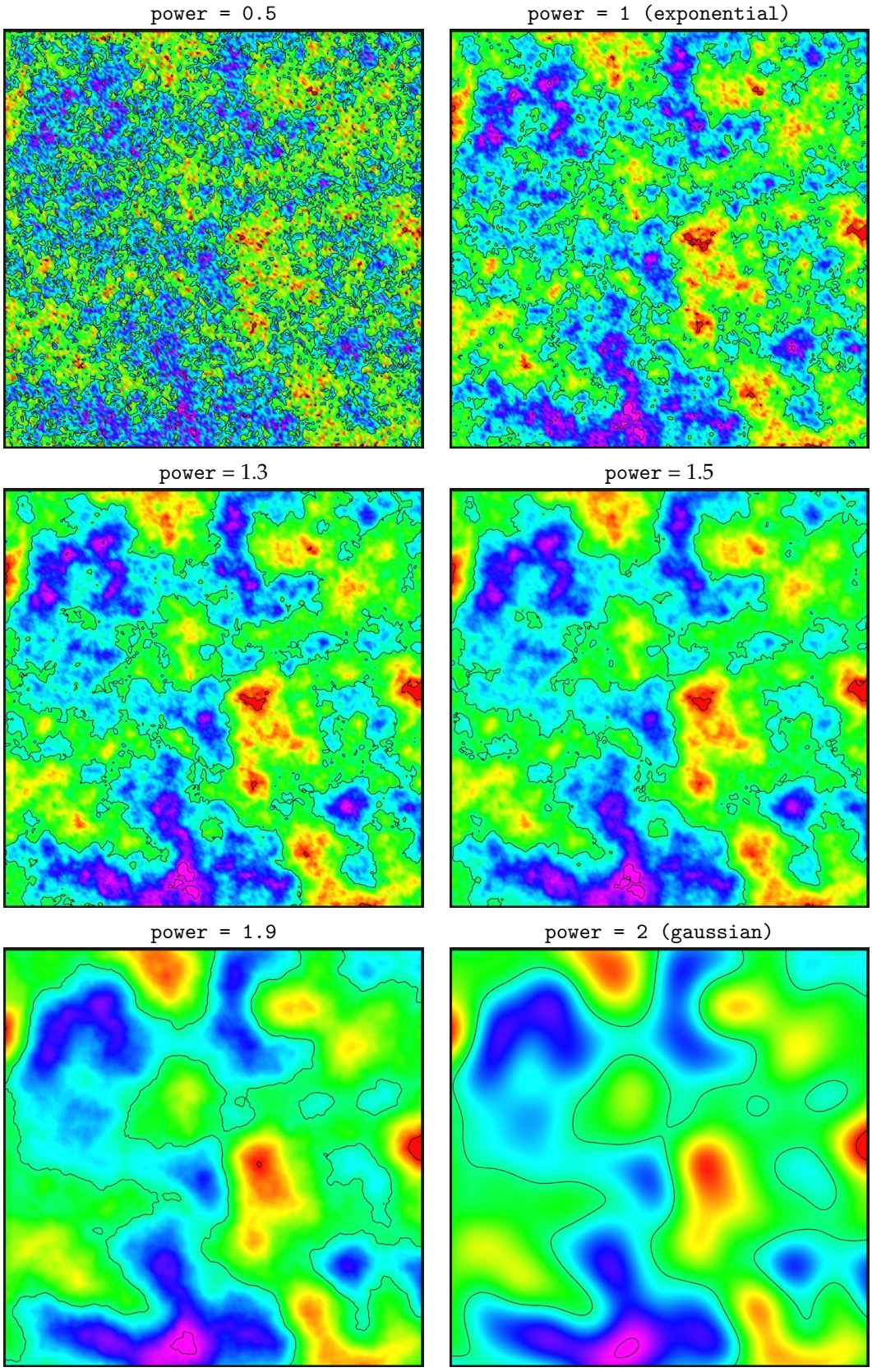



Figure C.2. General exponential variograms for different <power>. Note that the exponential variogram is identical to power = 1 and the gaussian variogram is identical to power = 2.

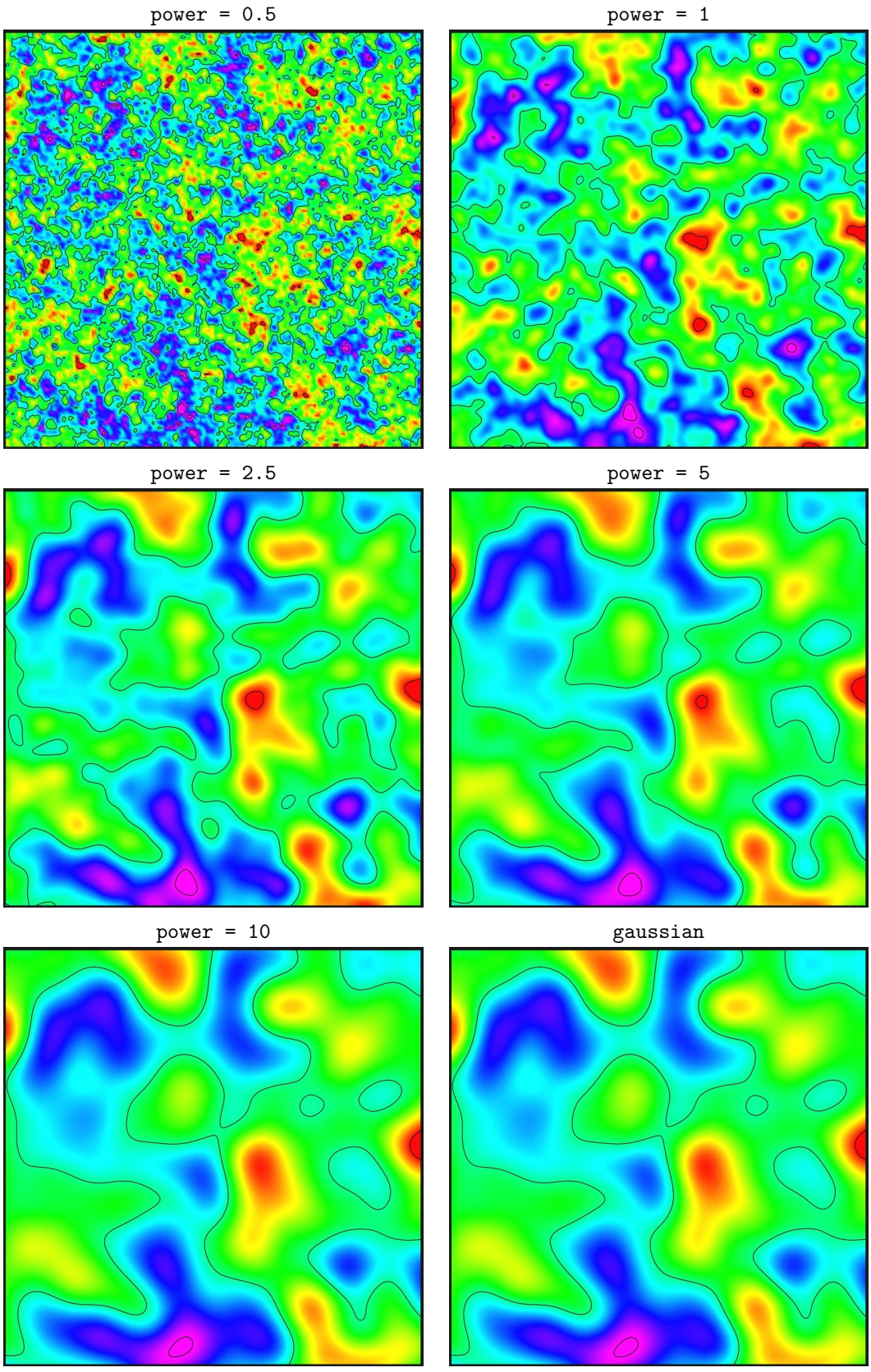



Figure C.3. Rational quadratic variograms. Note that these variograms approach the `gaussian` variogram when `power` becomes large. This variogram is not numerically stable for large values of `power` so we recommend to use the `gaussian` variogram instead for `power` $> 10$.

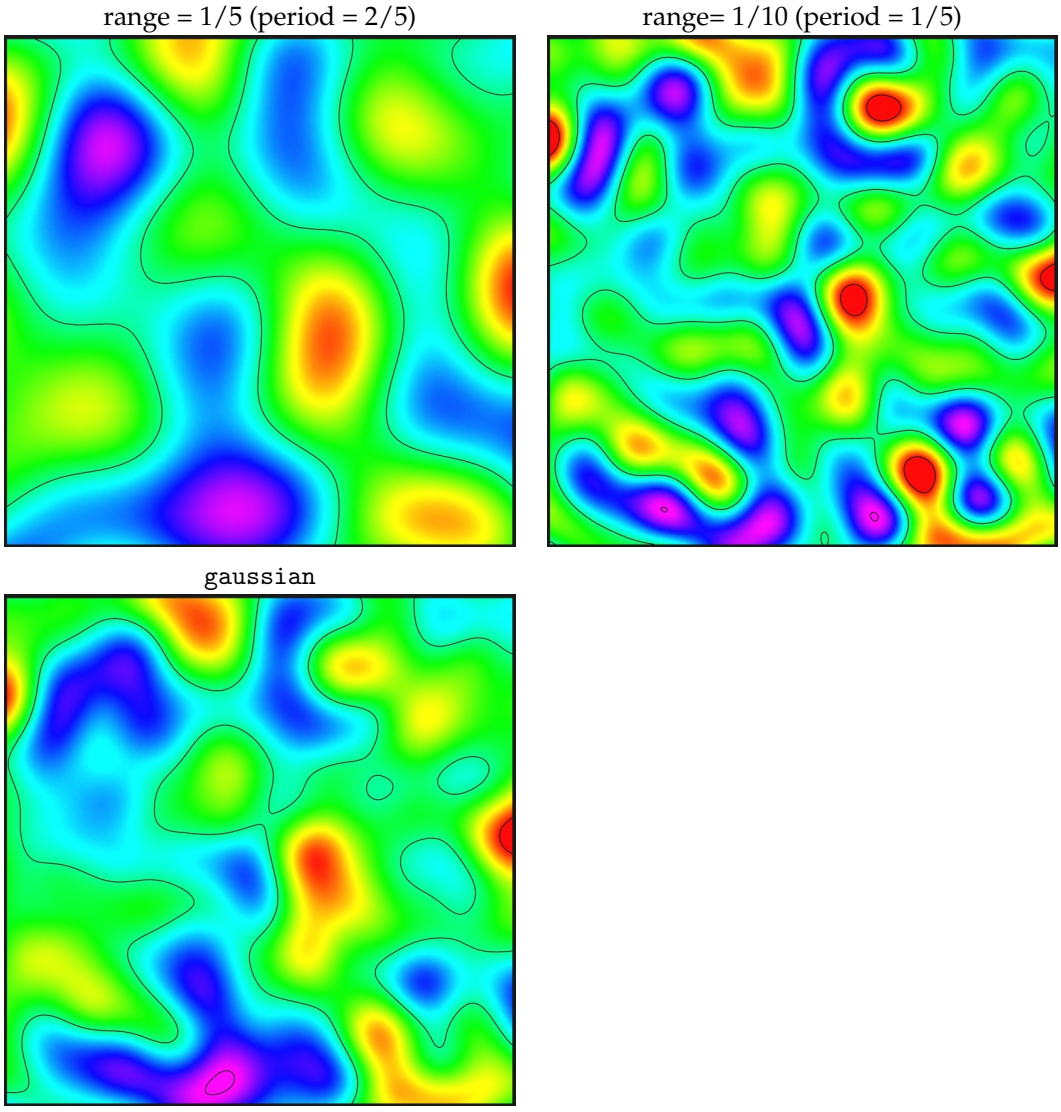



Figure C.4. Damped sine variograms. The damped sine variogram gives a smooth regular cyclic appearance. The full period is twice the specified range. The `gaussian` variogram is added for comparison.

# D 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.

## D.1 Changes from COHIBA Version 2.2.1 to Version 2.3

**New features:**

- Allow input data to have grid dimension/resolution different from output grid. COH-26
- Auto-detection of surface format when finding spill points from command line. The flag `-f` for specifying the file format has been removed. Output surface format is now the same as the input surface. COH-183, COH-200
- Auto-detection of file format for surfaces. Makes the `format = constant / storm /irapclassic` attribute obsolete. COH-186
- New variogram type: damped sine. See Table A.1 and Figure C.4. COH-193
- The `format = rms / cohiba` is obsolete in the `<files>` elements used to specify well data files. COH-201
- The COHIBA well points format (see Section 8.3) now allows comma-separated in addition to space- and tab-separated values. This allows surface names and well names with blanks. COH-202

**Changes:**

- Better criteria for removing redundant well points at pinch-outs. Well points are now removed if they are within 1 cm of an other well point (all directions), are highly correlated ($\rho > 0.999$), *and* the surfaces have identical specified uncertainty. COH-10
- Optimised data neighbourhood strategy for better precision. Elements for modifying the behaviour: `<preprocess-range-factor-for-neighbourhood>`, `<threshold-for-conditioning-in-neighbourhood>`, `<minimum-range-factor-for-neighbourhood>`, `<maximum-range-factor-for-neighbourhood>`, and `<target-number-of-data-in-neighbourhood>`. COH-55
- The use of a reference surface different from MSL now works. Two new elements, `<depth-value>` and `<travel-time-value>`, has been introduced to specify depth and travel time at the reference surface. COH-81
- Make sure reference surface does not have any well data attached to it. COH-80
- Calculation of prediction error and depth trend error are now turned off when making simulations. This is to save CPU time and to avoid corrupt results away from wells. COH-180

**Bug fixes:**

- Switching from universal to Bayesian kriging resulted in a crash. COH-176
- With well path conditioning and no help points, bogus trend coefficients were made. COH-177
- Bayesian kriging fall-back did not work correctly. COH-179
- Output of thickness trend surfaces lacked prefix/suffix. COH-182

- Well-path conditioning with a well with a zone log with only one zone gave negative surfaces. COH-184
- Gaussian random fields were not simulated if there were no well points present. COH-190
- The `rational quadratic` variogram did not work properly. COH-195, COH-197

## D.2 Changes from COHIBA Version 2.2 to Version 2.2.1

**Bug fixes:**

- Removed a crash caused by a rare error in the Cholesky decomposition. COH-175

## D.3 Changes from COHIBA Version 2.1 to Version 2.2

**New features:**

- Report residual errors for the intervals to `cohiba.log`. The level of detail can be modified by the element `<residual-uncertainties>`. This calculation may take some time and can be switched off using the element `<check-specified-residual-uncertainties>`. Reporting residual errors does not work on Linux RedHat 3. COH-7
- It is now possible to extract grid dimension and resolution from an input surface. New element `<read-from-file>` in element `<output-grid>`. COH-24
- Make a summary of warnings and present them as a task list at the bottom of `cohiba.log`. Added the element `<tasks>` to `<detail-level>`. COH-148
- Handle side-tracks with reduced well log header specification. Often, side-tracks contains zone logs from kick-off only. In these cases, the zone log specification given in the well log header only contains information from the zones the side-track penetrates, but the numbering is the same as if the well contained all zones. For example, given the following header for main-stem:

  ```
  Zonelog DISC 0 FmA 1 FmB 2 FmC
  ```

  For a side-track taken in zone `FmC`, the header becomes

  ```
  Zonelog DISC 2 FmC
  ```

  COH-111

**Changes:**

- Fixed progress monitoring when finding help points.
- Removed incorrect warning about illegal values in leverage point calculation.
- Made table summary of number of truncated nodes in the post processing (regarding erosion and onlapping).
- New element `<minimum-generalized-eigenvalue>` used to adjust the algorithm used for estimating residual errors. COH-7
- Made several minor improvements to `cohiba.log`.

**Bug fixes:**

- Removed a crash caused by an index out of bounds in the Windows 7 version. COH-174
- Removed a crash caused by a NULL-matrix in the Windows 7 version. COH-169

## D.4 Changes from COHIBA Version 2.0 to Version 2.1

**New features:**

- Report average statistics for each surface. Results are in `cohiba.log` and in `average_statistics.log`. COH-6
- Added new element `<maximum-generalized-eigenvalue-for-inequality-points>` in `<advanced-settings>`. COH-155
- Added new elements `<t-value-prediction-first-point>`, `<t-value-prediction-second-point>`, `<t-value-simulation-first-point>`, and `<t-value-simulation-second-point>` in `<advanced-settings>`. These control the algorithm for selecting sample points and inequality constraints used for constraining the surfaces to zone logs along the trajectories. COH-159

**Changes:**

- Added QC to the export of interval velocity maps. Extreme values and negative values could occur. These are now modified to meaningful values. COH-151
- Improved sampling of well paths. The end point of wells are now always included. Moreover, points on the edges of sections with undefined zonation are also included. COH-13, COH-21, COH-164
- Accepts integer written as floating point values for zone log codes. This is necessary due to changes in the IRAP RMS 2010 well format. COH-166
- Code maintenance in Data Augmentation algorithm. COH-128, COH-129,

**Bug fixes:**

- Segmentation fault when reading well data with a short section of missing zonation data in the beginning of the well path. COH-163
- Vector subscript out of range error when running the Windows version. COH-161
- Error when running the spill point algorithm. Valid starting points for the algorithm were reported as outside the grid. COH-172

## D.5 Changes from COHIBA Version 1.4.3 to Version 2.0

**New features:**

- Input and output grids that are rotated relative to north-south can be used. The angle is specified using the element `<grid-azimuth>`. COH-131
- Improvement in fault handling. This is explained in some detail in Section 11. A new element `<correlate-close-reflectors>` to use this feature has been added. The default is `yes`. COH-144, COH-124
- Possibility to set eroded nodes to undefined. This feature is switched activated using element `<set-eroded-nodes-to-undefined>`. The default is `no`. COH-123
- Report model weight statistics for each multiple model. See Figure 10.4 on page 67 for an example. COH-5
- Write the excluded well points to ASCII Irap classic files both sorted on surfaces and on wells:
  `output/wellpoints/excluded_wellpoints_WELLNAME.irap`
  `output/wellpoints/excluded_wellpoints_SURFACENAME.irap` COH-100

- Possibility to truncate crossing travel time maps. The deeper travel time map will be eroded by the shallower travel time map. This feature is activated using the element `<pre-process-make-time-surfaces-consistent>`. The default is `no`. COH-132
- For robustness, COHIBA will disregard a well if the number of log entries in record differs from the number of logs specified in the header. For each well log record COHIBA checks that it has the right number of log entries and that well log positions can be read as real values and that zone-log and fault-ind-log can be read as integers. COH-106
- Added check for extremely erroneous well points that destroy results. These will be removed one-by-one. The threshold value is set by the element `<t-value-extreme-error>`. COH-107
- Surface names, interval names, well names and zone names can now be read with blanks. Zone names can not have an isolated number as part of their name:
  - Valid zone names: "Zone_13", "Zone13", "Top A - Top B", and "Zone one".
  - Invalid zone names: "Zone 13", "Top 3 - Top 4", and "Zone 1".

  Well names can not have an isolated number as part of their name in the header of the RMS WELL format files :
  - Valid well names are: "Well one", "31-2_K-11H"
  - Invalid well names are: "Well 1", "31 2_K-11H"

  Well names with numbers will not stop COHIBA but logging output will use truncated well names. Zone names with numbers will cause an error. COH-110
- Made new directories under output so that we now have the following subdirectories containing well data: `wellpoints/`, `wellpaths/` (new) `clusters/` (new), and `helppoints/`. All output related to well points has been moved to `wellpoints/` and all output related to well paths has been moved to `wellpaths/`. Finally, cluster information is now written to `clusters/`. The old directory `welldata/` is no longer in use. COH-118
- Added a warning to `cohiba.log` for surfaces with multiple models and no well points. Experience has shown that this often causes crossing surfaces. COH-119

**Changes:**

- Use explicit algebra instead of Cholesky decomposition when calculating model weights (see Section 10). This is only done when there are two alternative models. The advantage is speed and robustness. COH-134
- Improved algorithm for drawing help points. Makes the results more robust to numerical inaccuracies. COH-45
- Added new sections in the user manual: Section 10 on multiple models and Section 11 on faults. COH-120, COH-145
- Made new element `<post-process-reflectors-as-eroding-and-onlapped>`. It ensures that seismic reflectors are considered erosive and on-lapped in the post processing. Default is `yes`. See Section 11 on faults for details. COH-125, COH-157.
- COHIBA well point files (Section 8.3) now also accept tabs in addition to blanks as separators between names and numbers. COH-116
- Speedup for calculating weights in multiple models. A speedup factor of 3.8 was obtained for a case with 128 multiple models for some of the deeper surfaces (Snorre). For the Troll test case we got a 30% speed gain. COH-117

- There are now 14 sections in `cohiba.log` with the possibility for setting the logging level on each. New elements for setting the logging levels are `<pre-processing>`, `<help-points>`, and `<zonation-checking>`. COH-130
- Zone names in `<top-of-zone>` must now be separated by commas. Previously a semi-colon was used. COH-108

**Bug fixes:**

- The removal of severe outliers is iterative, and should not continue if there is no well points left to filter out. COH-103
- Help points incorrectly calculated due to numerical inaccuracies. Problem observed on the Grane field. COH-149, COH-150
- Indexing error in the use of help point uncertainty. Could cause serious errors in well path conditioning. COH-156
- Post processing the surfaces could not be used when there were no well points. COH-153
- Checking of correct zonation could not be used if surface output was turned off. COH-98
- Errors and inaccuracies in the conditioning on zone logs. COH-95, COH-96, COH-104
- Bug in the code handling short sections with undefined zone logs corrected. COH-105
- Wrong indexing in FFT routine. Could cause big problems if the number of grid-nodes in x- and y-direction was significantly different. COH-113
- Wrong t-value output in summary table `Well points compared to posterior trend surfaces` in `cohiba.log`. COH-114
- Some output in table `IntervalName OUTPUT [ Thickness Trend Residual ] IntervalTop IntervalBase IntervalType` in `cohiba.log` was missing. COH-115
- Duplicate inequality constraints where not properly removed. This would cause COHIBA to stop. COH-127
- Removed obsolete element `<seismic-reflector>`. A surface automatically becomes a seismic reflector if the travel time is specified using `<travel-time>`. COH-133.

## D.6 Changes from COHIBA Version 1.4.2 to Version 1.4.3

**New features:**

- New log file `helppoints.log` for analysing help points. Also, the directory `helppoints/` now contains numerous files with help points. COH-54

**Bug fixes:**

- Kriging was skipped in some rare cases leaving cells away from wells empty. COH-91
- Several bugs concerning drawing help points for conditioning on zone logs in combination with simulation. This resulted in COHIBA crashing. COH-82, COH-83, COH-84 COH-86, COH-88 COH-89, COH-90
- Improved the calculation of neighbourhoods used in kriging. This only effects anisotropic neighbourhoods. COH-64
- Fixed bug in classification of help points and added a new line (undefined zonation) to the help point summary in the log file. COH-93

## D.7 Changes from COHIBA Version 1.4.1 to Version 1.4.2

**New features:**

- Accept missing codes at zone transitions. A tolerance is introduced so that a zone transition is recognised even if there is a small section of the well path with missing codes. The tolerance can be set by the element `<threshold-for-removing-undefined-well-sections>`. COH-11
- Report detailed well path errors in the COHIBA log file.. Mismatches are classified as a mild error if they are less than 1 meter. This threshold can be modified by the element `<threshold-for-mild-error>`. COH-19
- Better QC on well path. Delete constraints that are more than approximately 3 (set by `<t-value-error>`) standard deviations on the wrong side of the surface. COH-20
- Allow modification of thresholds for outlier classification. New elements are: `<t-value-outlier>`, `<t-value-severe-outlier>`, and `<t-value-error>`. Default values are slightly modified to give exactly 5%, 1%, and 0.2% classification rates. COH-71

**Changes:**

- The element `<seed>` no longer needs the `format` attribute. The format is automatically detected by the argument.
- To ensure that repeated predictions give identical results, the random generator used by the Data Augmentation Algorithm now use a fixed random seed. Repeated simulations with the same random seed will also give identical results. COH-77

**Bug fixes:**

- Simulated surfaces did not change when the random seed was changed. This error was introduced in Version 1.4.0. COH-76
- More robust parsing of well point files. COHIBA now checks that there are six entries per line and that numbers are represented as valid number: 1.3 is fine but not 1,3 or x.3. COH-70
- Well path points located where surfaces/intervals are undefined are now deleted. COH-68

## D.8 Changes from COHIBA Version 1.4.0 to Version 1.4.1

**New features:**

- The extreme velocity contrasts truncation is changed into an option, where the default does the truncation, but can be switched off. This option is modified in the element `<remove-extreme-values-in-velocity-trends>`. COH-9

**Bug fixes:**

- Error in the calculation of help points when conditioning to zone logs. COH-66

## D.9 Changes from COHIBA Version 1.3.1 to Version 1.4.0

**New features:**

- Automatic truncation of extreme velocity contrasts. Models with large negative interval velocity contrasts, that is, a large interval velocity decrease when going from an interval into a deeper interval might give undesired results (crossing surfaces etc.). This typically

happens in thin zones where the input interval velocities have been obtained by dividing interval thickness by interval travel time. To remove this problem, COHIBA now truncates velocity trends outside 2.57 std.dev of each velocity trend. COH-9

**Changes:**

- Significant improvement of speed when conditioning to horizontal well paths. There are several major modifications of the Data Augmentation Algorithm (DAA):
  1. The trend coefficients are no longer modified by the horizontal well paths *if* the number of well points are more than 200 (default). This can be modified by the element `<max-obs-update-trend-coef-using-well-paths>`. COH-14
  2. Reuse of temporary matrices in the DAA. COH-49
  3. Splitting the inequality constraints into smaller dependent clusters. Previous COHIBA versions treated each well independently. Now, each well is split into small clusters when possible. This makes it simpler and faster to draw candidates in the DAA. The inequality constraints are split into separate clusters if they are less correlated than a specified threshold. This threshold is specified by the element `<threshold-for-trace-clustering>`. The current default value is 0.30. Choosing 0.0 gives the old solution where all constraints in the well will belong to the same cluster. COH-16
  4. Use a local set of well points in the DAA algorithm rather than *all* well points. The current solution is to use all well points belonging to the wells associated with the cluster. COH-16

  The computational time has dropped from 5 hours to 15 minutes in one large case. The improvement in efficiency is larger for cases with lots of well points.
- More robust conditioning to horizontal wells. Previously each well was treated independently. This caused an error in the rare occasions where two well paths were extremely close. Now, the clusters from different wells are merged if they are more correlated than a threshold given by the element `<threshold-for-cluster-merging>`. The current default is 0.5. Choosing 0.0 is likely to cause that all clusters are merged. COH-17

**Bug fixes:**

- Error message: Kriging matrix with inequality points is not well defined. Reported by StatoilHydro. This problem is solved. COH-48
- Corrupt result for some random seeds. Caused by an error in the random number generator. Reported by StatoilHydro. This problem is solved. COH-47
- Input RMS well files with Windows line feed will now run correctly on Linux. COH-60
- If COHIBA cannot calculate trend coefficients for universal kriging, COHIBA will use Bayesian estimation. However, COHIBA still used the very unstable universal kriging formulas to perform the surface prediction (kriging). This inconsistency is now removed so an Bayesian approach is used for trend coefficient estimation and the kriging. COH-59
- Depth trend errors are now correctly computed if outside points are close to (within the range) the output grid. COH-58
- The severe outliers that should be removed from all calculations are not reported in `cohiba_wellpoints.dat` anymore. COH-57
- Well points outside the grid are no longer incorrectly labeled as deleted in `welldata.log`. COH-56

## D.10 Changes from COHIBA Version 1.3.0 to Version 1.3.1

**Bug fixes:**

- Model file parsing: Travel time variogram not optional if travel time is specified.
- Output: Velocity of intervals not exported although it is asked for.
- Spill-point detection: Trap prefix not ok in the filename-tags, it is not set to "trap".
- Spill-point detection: Error in storm-filename suffix on terminating trail. Should be .irap (irapclassic ASCII)

## D.11 Changes from COHIBA Version 1.2.0 to Version 1.3.0

**New features:**

- Robust estimation of trends. Severe outliers are removed from the trend estimation.

**Improvements:**

- Robust estimation of trends. Severe outliers are removed from the trend estimation.

**Changes:**

- Improved sampling of well path conditioning. If two close points from different wells are detected, one is removed.

## D.12 Changes from COHIBA Version 1.1.0 to Version 1.2.0

**New features:**

- Fault indicator log may now be used.
- New element <max-obs-direct-estim-trend-coef> introduced.
- New element <max-obs-GLS-approx-trend-coef> introduced.
- New element <values-outside-grid> and <value> introduced.

**Changes:**

- Element <zonelog> changed to <well-log>.
- Element <logname> changed to <zone-log-name>.
- Element <fault-logname> changed to <fault-log-name>.
- Element <surface-points> changed to <well-points>.
- Element <ignore-points> changed to <well-points-to-ignore>.
- Improvements have been made to the well path conditioning option. A pair of help points above and below a well path is now drawn simultaneously from a binormal distribution.

## D.13 Changes from COHIBA Version 1.0.1 to Version 1.1.0

**New features:**

- Spill point detection. New elements under the <surface> element were added:
  1. <spill-point> and optional sub-elements <missing-as-wall>, <xstart>, and <ystart>.
  2. <trap> as sub-element of <output>.
  3. <trap> as sub-element of <filename-tags>.

Spill point detection can also be applied directly from the command line to an imported surface.

**Changes:**

- Improvements have been made to the well path conditioning option.

## D.14 Changes from COHIBA Version 1.0.0 to Version 1.0.1

**New features:**

- Correction for gridding error added. Can be switched on/off using new element <post-process-make-surfaces-interpolate-well-points>.
- The element <seed> now allows a filename as value. Random seed is read from the file before simulation a new random seed is written to the file after simulation.

**Changes:**

- Element <welldata> changed to <well-data>.
- Element <wellpoint> changed to <well-points>.
- Element <wellpoint-conditioning> changed to <well-point-conditioning>.
- Element <wellpath> changed to <well-paths>.
- Element <wellpath-conditioning> changed to <well-path-conditioning>.
- Element <condition-to-wellpaths> changed to <condition-to-well-paths>.
- Element <trend-parameters> changed to <trend-coefficients>.
- Element <kriging-in-segments-for-more-observations-than> changed to <threshold-for-conditioning-in-neighbourhood>.
- Default for <depth> changed from no to yes.
- Default for <depth-trend> changed from no to yes.

# E Known issues

## E.1 Conditioning to well paths using universal kriging

**Problem:** Equations not implemented.

**Solution:** Straight forward implementation. COH-23

## E.2 Bugs

- Incorrect handling of surfaces not connected to any zones. COH-121
- Some inequality points may trigger broken points in other wells. Need a better criteria for selecting inequality points. Must probably iterate. COH-154
- Random seed sequence is different on Linux and Windows. COH-168

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Some of the references are available as pdf's at the bottom of this page: www.nr.no.

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