A Consistent Geostatistical Approach for Constraining Multiple Surfaces to Horizontal Wells

Petter Abrahamsen, Pål Dahle, Frode Georgsen, Arne Skorstad

Norwegian Computing Center, Oslo, Norway, www.nr.no/pages/sand/area_Cohiba

Presented at GEO 2010, 9th Middle East Geoscience Conference and Exhibition, 7 - 10 March 2010, Manama, Bahrain

Motivation

The robust use of horizontal wells in 3D stratigraphic surface modeling is an important challenge. In many reservoir models there are inconsistencies between horizontal wells and the zonation of the 3D model. The two main reasons for these inconsistencies are:

1) Zone log information is not fully used in the determination of the depth to the surfaces.
2) Well points (well picks) in deviated wells do not impact the depth of adjacent surfaces.

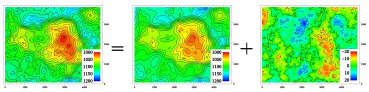
A robust, geostatistical approach for ensuring the correct modeling of multiple stacked stratigraphic surfaces constrained by long horizontal wells is presented. Universal or Bayesian cokriging is used for prediction of surface depth based on a variety of data including well points, zone logs, isochores, and seismic travel times. Uncertainty in data are used to balance the influence of the various information sources.

In contrast to standard approaches, all well data are treated simultaneously and will impact all surfaces.

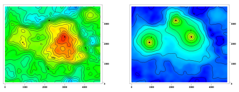
Basic concepts

Surfaces are modeled 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.

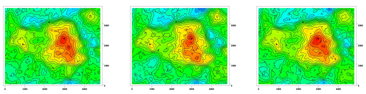
Depth = trend + residual



Prediction and prediction error:

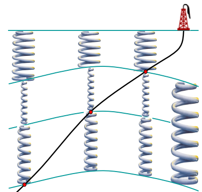


Three simulated realizations:



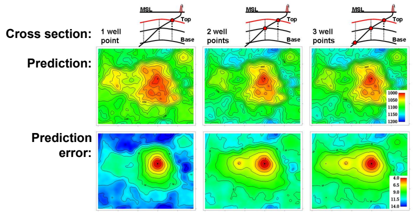
Multiple surfaces are linked together:

- Interval thicknesses are specified
- Surfaces are sum of thicknesses
- Surfaces becomes inter-dependent



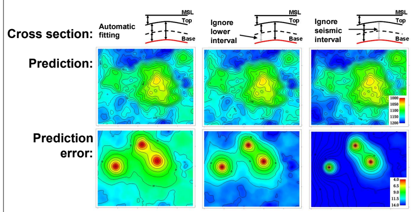
Large spring indicates small uncertainty.

The three columns show how the predicted top surface and associated prediction errors are modified when a deviated well is drilled into the lower zones.



Ambiguous multi-layer models

Below is a layered reservoir bounded by two seismic reflectors called Top and Base.



The Base surface can be obtained by:

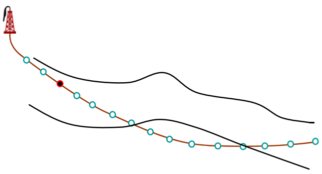
1. Automatically fit surfaces inside the envelope of seismic reflectors.
2. Ignore the lower interval.
3. Ignore the seismic interval.

Alternative 1 gives superior results since all data are used consistently.

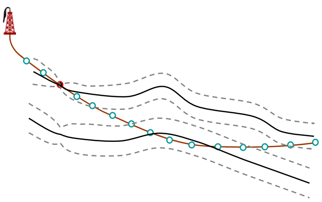
Conditioning on zone logs

Well trajectories impose soft constraints on the surfaces. Standard kriging techniques does not include the possibility to condition on soft constraints. Our approach is a development of the ideas in Abrahamsen and Benth (2001) that shows how to use inequality constraints in a kriging setting. Here we outline how this works for a multi-layered model.

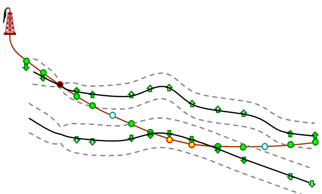
1. Sample the well trajectory (red line) at the grid resolution. The well point is shown as a red circle and the sampled points are the blue circles. The two black curves are surfaces.



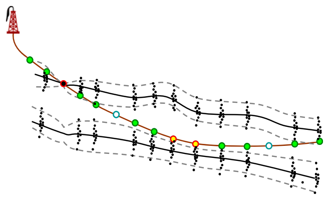
2. Along the well paths, calculate the depth prediction (solid lines), and the prediction error (dashed lines) given the well points using kriging. The upper surface cross the trajectory at the well point. The lower surface should be below the well trajectory.



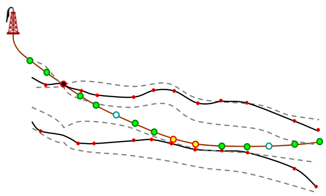
3. Select sample points in conflict (red) with the zone log or close (green) to the prediction. These points impose inequality constraints on the surfaces, as indicated by the green arrows.



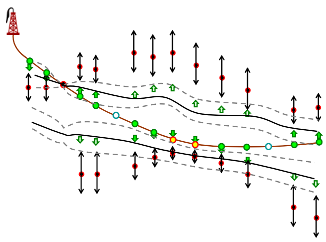
4. Run a Monte Carlo algorithm (Tanner and Wong, 1987) to obtain a representation of the non-Gaussian probability distribution for depth to the surfaces at the inequality constraints.



5. **For simulation**: Select randomly one set of depth points (red points) from the non-Gaussian probability distribution. These are included when conditioning the simulated surfaces.

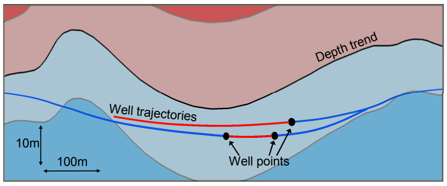


6. **For prediction**: Calculate the expectation and covariance of the non-Gaussian probability distribution. These are used to calculate a set of depth points at the inequality constraints, included when predicting the surfaces.

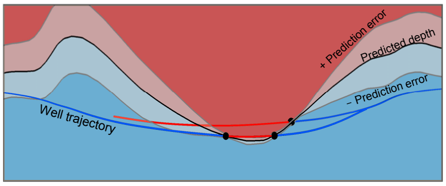


Prediction and simulation conditioned on well points and well trajectories

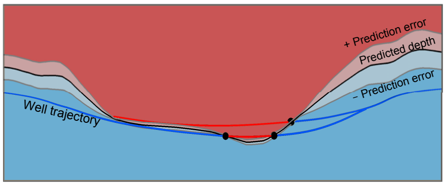
Consider cross sections of two zones, shale (red) above sand (blue). The transition between shale and sand is uncertain as indicated by the lighter colored areas. The well trajectories are colored red in the shale zone and blue in the sand zone. The well points are marked by black bullets. The example demonstrate that the method is able to constrain a surface between two very narrow well trajectories.



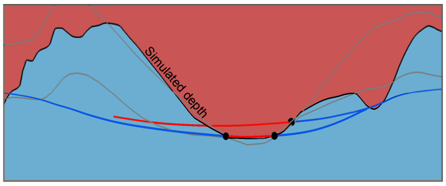
Depth trend is obtained from seismic depth conversion.



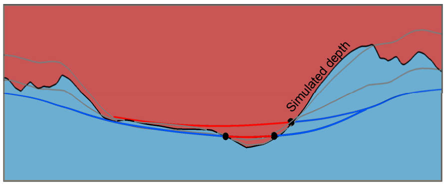
Depth prediction constrained to **well points**. The surface matches the well points but it incorrectly crosses the upper side-track.



Depth prediction constrained to **well points** and **well trajectories**. The surface now correctly follows the two side-tracks. Note the significant uncertainty reduction.



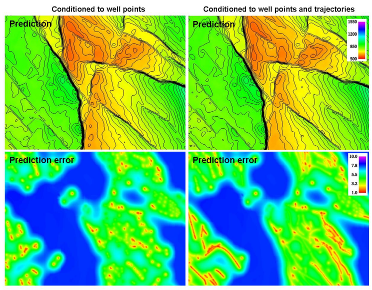
Surface simulation constrained to **well points**. The uncertainty bounds are seen as grey lines.

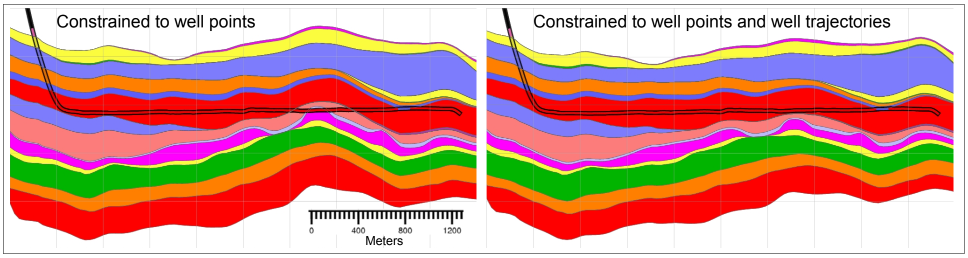


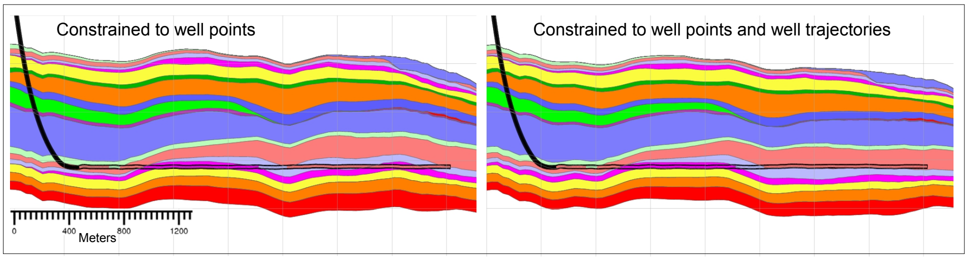
Surface simulation constrained to **well points** and **well trajectories**. The uncertainty bounds are seen as grey lines.

Case-study on large field

- 32 surfaces
- 294 000 grid cells in each surface
- 317 wells
    - 4361 well points
    - 3582 constraints along the trajectories
- 25 minutes CPU time







- All surfaces and zones are consistently adapted to well points and well trajectories
- Wells can follow very thin zones
- Uncertainty is significantly reduced near wells following thin zones
- Extensive QC and filtering of data
- Robust
- Efficient – no manual adjustment necessary

For more information: www.nr.no

References

•Abrahamsen, P. and Benth, F. E. (2001). Kriging with inequality constraints, Math. Geol., Vol. 33, no. 6, pp. 719–744.
•Tanner, M. A. and Wong, W. H. (1987). The calculation of posterior distributions by data augmentation (with discussion), J. Amer. Statist. Assoc., Vol 82, no. 398, pp. 528–550.
•Almendral, A., Dahle, P., Abrahamsen, P., Skorstad, A., Georgsen, F., and Myrseth, I. (2010). COHIBA user manual. NR-note SAND/01/2010, Norwegian Computing Center, P.O.Box 114 Blindern, N-0314, Oslo, Norway. Available from: www.nr.no/files/sand/Cohiba/cohiba_manual.pdf.

A Consistent Geostatistical Approach for Constraining Multiple Surfaces to Horizontal Wells, Petter Abrahamsen, Pål Dahle, Frode Georgsen, Arne Skorstad, Norwegian Computing Center, Oslo, Norway, www.nr.no
Presented at GEO 2010, 9th Middle East Geoscience Conference and Exhibition, 7 - 10 March 2010, Manama, Bahrain