Stochastic Surface Modelling for Volumetric Uncertainty

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Abstract

An accurate estimate of the gross rock volume *and* pore volume *of a reservoirs are important for reservoir management and decision making. These volumes, however, have significant uncertainty due to sparse well data and uncertainty in structural surfaces interpreted from seismic data. This report develops a classical geostatistical approach to surface simulation and uncertainty assessment.*

The top surface structure of a reservoir has greater uncertainty than subsequent layer thicknesses. This is handled by a sequential simulation of the top structure and then each following layer. The main controls on the uncertainty assessment are (1) the possible deviations from the base case seismic predicted surface, that is, a histogram of the possible deviations far away from well control, and (2) a variogram measure of spatial correlation, which specifies how fast the zero uncertainty at the wells increases to the global uncertainty far from well control.

The methodology is described, an example presented, and FORTRAN 90 programs documented for uncertainty assessment.
KEY WORDS: Bootstrap, Pore Volume, Gross Rock Volume, Seismic Data

Introduction

An accurate volumetric estimate of reservoir gross rock volume and an estimate of pore volume are important for reservoir management and decision making since the former defines the physical size of a reservoir and the later defines the actual oil/gas content in the reservoir. Early in the lifecycle of a reservoir, there are typically few wells to provide local hard data. Seismic is essential to provide spatial control in the vast interwell region. Uncertainties in interpretation and time-to-depth conversion lead to unavoidable uncertainty in the subsurfaces; deterministic estimates of gross rock volume and pore volume must be supplemented by a measure of uncertainty coming from Monte Carlo or geostatistical analysis. Our goal is to present a systematic methodology and software for this task.

Reservoirs consist of stratigraphic layers constrained by a top seal. The Gross Rock Volume (GRV) is the volume of a reservoir trapped between the top and bottom surfaces and above the oil water contact (OWC). When a gas cap is present the reservoir volume can be split by the OWC and gas oil contact (GOC). Generally, the OWC and GOC can be estimated quite accurately provided the reservoir is not divided by complex faulting or internal stratigraphic traps. Certain key surfaces such as the top and bottom surfaces are generally obtained from seismic interpretation. Seismic interpretation is performed in the time domain and transfered to depth with a time-to-depth conversion using some type of velocity model. There is no unique surface in units of depth because of uncertainties in the interpretation (in time) and uncertainties in the time-to-depth conversion. In general, the further away from the well locations, the larger the uncertainties in the surfaces. Therefore, the calculated GRV is uncertain. This uncertainty is often recognized but not quantified. The necessary stochastic simulation methods are implemented in this report to assess the uncertainty in the GRV calculation.

The actual oil and/or gas content of a reservoir is a product of the pore volume and the hydrocarbon saturation. The pore volume may be calculated using the GRV, the net-to-gross ratio, and the net porosity, that is, the porosity of the "net" rock. The *pore volume* is a product of *gross rock volume, net-to-gross ratio* and *net porosity.*

$$\text{Pore Volume} = \text{Gross Rock Volum} \times \text{Net–to–Gross Ratio} \times \text{Net Porosity}$$

The net-to-gross ratio and net porosity are generally taken from the well data together with any available seismic data and geological interpretations. There are also uncertainties existing in the determination of the net-to-gross ratio and the net porosity due to limited well data and uncertainty in the calibration of soft seismic and geological data. Uncertainties in all factors propogate to uncertainty in the final calculation of pore volume.

The uncertainty in pore volume is a function of the multivariate distribution of the three contributing factors: GRV, net-to-gross ratio, and net porosity. Inference of this multivariate distribution is difficult due to the poorly known dependencies such as the relationship between porosity and surface interpretation. A particular model of this multivariate distribution can be built assuming that the three factors are independent.

The distributions of uncertainty in the three controlling variables must be determined. An approach is proposed to stochastically model the top and bottom surfaces of reservoir to quantify the distribution of uncertainty in the GRV. This modelling is guided by well data. The uncertainty of the average net-to-gross ratio and the net porosity are determined by bootstrap resampling from the best distribution that can be inferred from limited well data and supplementary seismic and geologic data.

The *gross rock volume* is the reservoir volume above the oil/water contact (OWC) constrained by the top and bottom surfaces of reservoir. A gas-oil contact is needed for reservoirs with gas. Figure 1 shows a cross section view of a reservoir. The reservoir is constrained by a top and bottom surfaces (black curves). The OWC is represented by a red horizontal line and the gas-oil contact GOC is denoted by a green horizontal line. The oil-containing volume of the reservoir is the portion of the reservoir constrained by both top/bottom surfaces and the OWC/GOC levels (light blue shaded area), whereas the gas-containing volume is the portion of reservoir constrained by top/bottom surfaces and above the GOC level (pink shaded area). The oil and gas-containing volumes of the reservoir are of economic significance.

Once the distributions of the three factors are available, the uncertainty of *pore volume* is estimated by Monte carlo simulation. Values of gross rock volume, net-to-gross ratio and net porosity are sampled by Monte Carlo, and the value of pore volume is calculated. The procedure may be repeated many times and the distribution of *pore volume* is thus estimated.

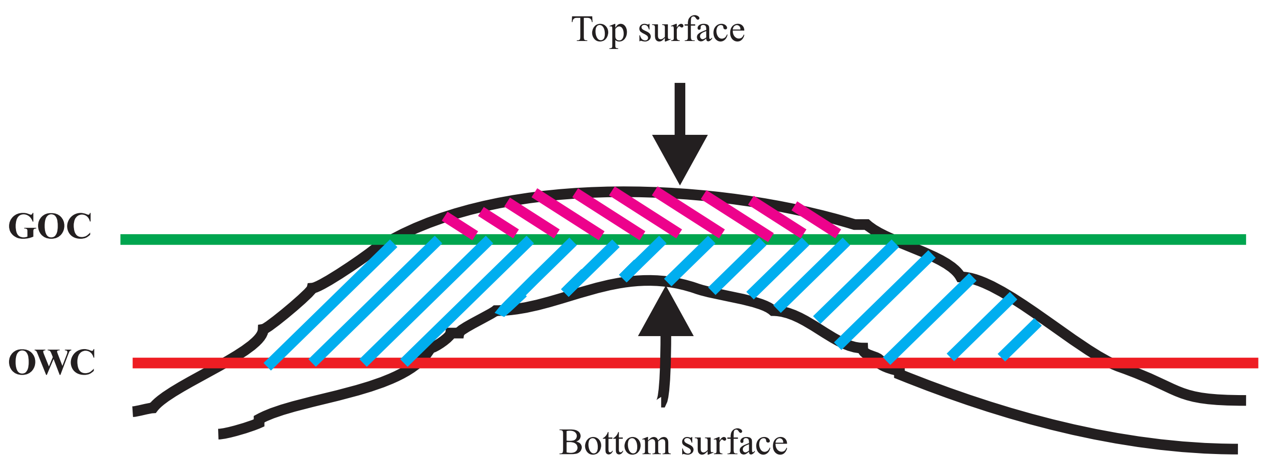


Figure 1: A cross section view of a reservoir: red horizontal line: OWC; green horizontal line: GOC; blue shaded area: Oil volume; pink shaded area: Gas volume.

Two FORTRAN 90 programs are writted for the proposed approach. One is `grv`, which calculates the distribution of *gross rock volume* by a stochastic surface modeling technique, and another is `pv`, which is a bootstrap approach to do Monte Carlo simulation by sampling the distributions of *gross rock volume, net-to-gross ratio* and *net porosity*. The approach and the implementation of the programs are described and demonstrated with a synthetic numerical example.

Methodology

In this report, a stochastic surface modeling approach is proposed to capture uncertainties in gross rock volume. The top and bottom surfaces from seismic interpretation are considered as reference surfaces, which have been forced to intersect the wells at the correct depths. Away from well locations, there exist uncertainties in the reference surfaces. The deviations from the refernce surfaces are assumed to follow a known distribution (we consider a normal distribution with zero-mean and some standard deviation). The deviation will be zero at the well locations and increase away from the well locations. Such deviations can be simulated by a conditional Gaussian simulation with conditioning data at the well locations. The deviations can then be added to the reference surfaces. Such simulation provides alternative scenarios, which quantifies the uncertainty in the GRV.

Uncertainty in the net-to-gross ratio and the net porosity are estimated by bootstrap resampling from the best available distributions of these quantities (see paper on declustering in this same report).

When the estimates of the GRV, net-to-gross ratio and net porosity are available, the pore volume is obtained by multiplication of the three factor terms. In this report, it is proposed to use a Monte Carlo or bootstrap technique to assess the uncertainty of pore volume estimate. The procedure consists of drawing values of GRV, net-to-gross ratio, and net porosity and then calculating the product of the three numbers. The process is repeated many timesto get a distribution of pore volume.

The proposed approach is carried out by two FORTRAN 90 programs, one is `grv` and the other is `pv`. The former is to get the distribution of the *gross rock volume* from stochastic simulations and the later is to estimate the uncertainty in *pore volume* through Monte Carlo simulation by using the distribution of *gross rock volume* estimated from `grv` together with bootstrap resampling the well data of *net-to-gross ratio* and *net porosity*.

An numerical example is designed to demonstrate the proposed appraoch. The results show the feasibility of the method.

Gross Rock Volume

As shown in the section view of Figure 1, reservoirs consist of stratigraphic layers, which are constrained by a top and bottom surface. The portions of the reservoir volume above the OWC and/or GOC has economic significance. The estimates of OWC and GOC (red and green horizontal lines) are usually quite accurate, but estimates of the top and bottom surfaces of the reservoir have significant uncertainty. Simulated top and bottom surfaces are obtained by adding the *reference* surface and normally distributed undulations. To ensure that the simulated surfaces honor the well data, the undulations generated by `sgsim` are conditioned to zeros values at well locations. Each simulated top/bottom surface thus represents a possible scenario of the reservoir and a GRV can be calculated.

The program `grv` implements the proposed approach for stochastic surface modeling and the subsequent assessment of uncertainty. The program was built from the sequential Gaussian simulation subroutine `sgsim` together with a subroutine for volume calculation. Figure 2 shows an example parameter file. The program requires the present top and base surfaces, which is supplied by the data file `topbase.txt`. For the gas and oil volume calculation, the levels of OWC and GOC are supplied by the file `contact.txt`. Subroutine `sgsim` requires regularly gridded cells with volumes specified by `scale`. Standard deviations of the undulation added to the *reference* surfaces account for the uncertainties in the top and bottom surfaces and they are directly responsible for the uncertainty in the volume estimate.

The uncertainty in the top surface cannot be assessed independently from that of the bottom surface. Once one surface, say the top surface, has been established there is less uncertainty in other surfaces. That is, the first surface captures uncertainty from the present-day surface down to the depth of the reservoir; subsequent surface uncertainty is the incremental uncertainty due to the distance between the reservoir layers. Therefore, different standard deviations should be used in the undulation generation for the top and bottom surfaces. In practice, the standard deviations used need to be determined based on knowledge of the uncertainty in the seismic interpretation of the surfaces. Usually, surfaces are interpreted with seismic data and then calibrated with well observations. The mismatch between seismic interpretation and well observations are removed in this calibration step. However, the mismatch information provides us valuable hints of the uncertainties on the top and bottom surfaces. `Grv1.out` and `grv2.out` are the files for outputting the simulated top and bottom surfaces and the *gross rock volume* (oil- and gas-containing volumes) in each simulation, respectively.

The rest parameters in the parameter file are for the sequential Gaussian simulation and their usages can be referred to the corresponding parameter file of `sgsim` in `gslib`.

When the distribution of the *GRV* is obtained from `grv`, the uncertainty in the *pore volume* will be estimated by `pv`. As mentioned above, the distributions of average *net to gross ratio* and *net porosity* can be estimated by bootstrap based on the limited well data. The distribution of *pore volume* is determined by Monte Carlo simulation. That is: draw value of *gross rock volume* (oil- and gas-containing volume) from the distribution of *GRV*, get average estimate of *net-to-gross ratio* and *net porosity* by bootstrap resampling from well data, calculate PV by multiplying the three values drawn. Repeat the process many times to get the distribution of PV. Figure 3 shows an example parameter file of the program `pv`. The input consists the output file `grv2.out` from `grv`, well data files of *net-to-gross ratio* `NTGwell.dat` and *net porosity* `NPwell.dat` and the output distribution file of PV (`histpv.out`). Parameter `nsim` defines the number of Monte Carlo simulation.

Illustrative Example

An numerical example is synthesized for demonstaring the proposed approach. Figure 4 and Figure 5 show 3-D viewes of the top and bottom surfaces of the reservoir. These surfaces are supposed to be obtained from seismic interpretation and are served as *reference* surfaces. The reservoir is gridded into a 100 by 100 cells and each cell represents 100 meters in the horizontal directions. The elevation of the reservoir is also in relative unit which is 50 meter per unit, hence the reservoir is about 10 meters thick and 10 km wide and long on the ground. Nine wells have been assumed in the locations shown in Figure 6 and they are used for conditioning in the generation of undulations for the *reference* top and bottom surfaces. Also, the values of *net-to-gross ratio* and *net porosity* are assumed known at the wells and their histograms are shown in Figure 7 and Figure 8. For simplicity, the OWC and GOC are assumed to be flat surfaces and have the relative elevations of 0.8 and 1.0, respectively. This simplification does not affect the efficiency of the proposed approach.

Results and Discussions

The oil-, gas-containing volume, and *GRV* of the reservoir cdefined by the *reference* top and bottom surfaces are 48.0319, 23.8241 and 71.8560 million cubic meters, respectively. As mentioned above, the reservoir scenario defined by the *reference* top and bottom surfaces is only one possible estimate of the reality. Even though this scenario matches the reality at the well locations, there might be uncertainties in the area away from the well locations. therefore, the volumes estimates cannot be treated as unambiguous results.

To assess the uncertainties of the *reference* scenario, it is assumed that normally distributed deviations existing in the surface areas away from the well locations. The standard deviations of the distributions should be estimated by referring to seismic interpretation and here are assumed to be 2.5 and 0.5 meters for the *refernece* top and bottom surfaces, respectively. Also it is assumed that the spatial continuity of the deviations is isotropic and can be modelled by a Gaussian type variogram with ranges 30 relative unit. The uncertainties in the *reference* surfaces are simulated and consequently the oil and gas containing volumes are calculated by using running `grv` and 200 realizations are generated.

Figure 9 shows the X-Z cross section view of the reservoir along four different Y coordinates. The first three sections intersect with three wells each along the corresponding Y coordinate and there is no well existing in the fouth section. The *reference* top and bottom surfaces of the reservoir are shown in red lines. The simulated top and bottom surfaces are shown in dark blue and green lines, respectively. The simulated surfaces form bands conveging towards the well locations. OWC and GOC levels are shown as pink and light blue horizontal lines, respectively and the well locations are represented by pink vertical lines. The corresponding oil and gas containing volumes have been calculated for each realization and Figure 10 shows the histograms of the distributions of oil and gas containing volumes of the reservoir. The value of the *reference* scenario is displayed as red vertical lines.

It is seen from Figure 9 and Figure 10 that the top and bottom surfaces of the reservoir contains fair amount of uncertainties which results in that the estimates of oil and gas containing volumes of the reservoir have some uncertainties. These uncertainties should not be ignored in the calculation of *pore volume* and the decision making afterwards.

The *pore volume* calculated based on the oil/gas containing volumes from the *reference* top/bottom surfaces and the average well values of *net-to-gross ratio* and *net porosity* are 8.2126 and 4.0735 million cubic meters for oil and gas, respectively. Figure 11 shows the histogram of 1000 estimated *pore volume* values by running `pv`. Red vertical lines are the *reference* values. It is seen from Figure 11 that the *reference* values contain fair amount of uncertainties.

In the uncertainty assessment of *pore volume*, the estimate of the distribution of *gross rock volume* is critical since the uncertainties on *net-to-gross ratio* and *net porosity* are determined from well data by bootstrap and there is no much can be done for them.

In the proposed approach, the magnitudes of undulations added on the *reference* top and bottom surfaces are important. The standard deviations of the undulations define how much variability existing in the *reference* surfaces, which finally influences the uncertainty in the estimate of oil and gas containing volumes.

The influence of the standard deviations of undulations on the uncertainty of estimated *GRV* is investigated. The values of the standard deviation on the top surface have been changed from 0.5 to 15 meters and those on the bottom surface have been changed from 0.1 to 3.0 meters, accordingly. The ratio between the standard deviations on the top and bottom surfaces remains a constant of 5. In these simulations, a Gaussian type variogram model with a fixed *range* value of 30 units is applied. The variogram model defines the spatial distribution of the undulations.

For each pair of standard deviation values, one hundred realizations are generated. *GRV* (oil- and gas-containing volumes) has been calculated for each realization and the distributions of *GRV* is thus obtained. The standard deviations of the oil-, gas-containing volumes and *GRV* are plotted against the standard deviation used in the surface simulation, and are shown on Figure 12. As shown in Figure 12, the standard deviations in the reservoir volumes increase as the standard deviation used in the surfaces simulation increase. That is not beyond the expectation. Since the reservoir volumes are directly related to the constrained surfaces on the top and at the bottom, it is natural that the larger uncertainties in the constrained surfaces of the reservoir, the bigger the uncertainty in the calculated volumes. Except the last two points, the increase of the standard deviation in the volume estimates is almost linear to the standard deviation used in the surface simulation. When embedded in mind that the general increasing relation of the uncertainty in the *GRV* with the standard deviations used in the surface simulation, it should note that such a relation is actually not so simple and straightforward. The oil and gas-containing volume calculation relys *not only* on the top and bottom surfaces *but also* on the levels of OWC and GOC. The influence of undulation on the surfaces on the *GRV* is restricted by the levels of the OWC and GOC and the locations of wells. Recall the reservoir portion above the GOC will be accounted for the oil-containing volume and the portion between the GOC and OWC will be accounted for the oil-containing volume. Not all the variability in the reservoir surfaces will propogate to the volume calculation. Although the added Gaussian undulations are symmetrical around the *reference* surface, the resulting distribution of the *GRV* may not be symmetrical. Specifically, those portions of surfaces variabilities on the surfaces NOT accounted for the volume calculation are in the areas far away from the well locations, and have larger magnitude of undulations on the surfaces.

Let's take a close look at the last points in Figure 12. Considering the average thickness of the reservoir is about 10 meters, the standard deviations of 10 and 15 used in these two points are are too large to be true in practice. This can also be verified form Table 1. Table 1 list the standard deviations used in the surface simulation and the mean volumes of 100 realizations for both oil- and gas-containing volume together with *GRV*. It can be seen from Table 1 that the mean volume values of realizations related to standard deviation values in the surface simulation from 0.5/0.1 to 5.0/1.0 meters are around the *reference* values, but the mean volume values of volume estimates when standard deviation in the surface simulation took impractical high values of 10.0/2.0 and 15.0/3.0 are far away from the *reference* values. Obvious biases exist in the mean values. The gas-containing volumes are estimated higher and oil-containing volumes are estimated lower. This biases can be explained. In the gas-containing volume calculation, positive undulation on the top surface is accounted more than negative undulations and the volumes become larger. In a similar manner, positive undulation in the bottom surface and negative undulation in the top surface are accounted more in the oil-containing volume calculation and the volumes become shrinked. Biases should also exist when the situation changed (*e.g.*, different well spacing, different OWC/GOC levels etc), but may be in a different way.

In the surface simulation discribed above, the undulations around the *reference* surface have been assumed both obeying a normal distribution and having certain spatial structure (discribing by the variogram model used). The reason for assuming a spatial structure for the undulations is based on scentifical common sense. The *reference* surfaces honor well data, hence there is no uncertainty at the well locations. It is very natural to assume for the rest areas that the further away from well locations the bigger uncertainties exist. The questions, however, are how the uncertainties in the surfaces changing spatially, what is its spatial structure?

As the value of standard deviations in the surfaces should be consulted from the seismic interpretation, the *range* used in `sgsim` should also be obtained from the mismatch information in the seismic interpretation. The mismatch information will give us hints what the spatial structure on the reservoir surfaces is. The *range* of 30 units used in the simulation is arbitrary, but it will not affect the generality of the proposed approach.

Another question will be: is there any influence of the *range* to the uncertainty of the *GRV*? The first thought seems like that there will be no influence of the *range* on the *GRV*.

Since if the standard deviations for the surface simulation are defined, the variability on the *reference* surfaces are determined. The variogram model and *range* only change the spatial layout but not the histogram of the variability. Gaussian distribution is symmetrical, so the positive and negative deviations from the *reference* surface will counteract and should be no difference in the *GRV* uncertainty when using different values of *range* and a fixed standard deviation of undulations.

However, as we mentioned above, not all the variability on the *reference* surfaces will propogate into the volume calculation. The variability on the surfaces affecting the volume calculation is restricted by the surfaces themselves, by the levels of OWC and GOC, and by the layout of wells. Therefore, even in the situation of fixed standard deviations for the surface simulations, the amount of variability on the surfaces affecting the volume calculation will depend on their spatial structure. Thus, *range* has influence on the uncertainty of estimated volumes.

To investigate the influence of the value of *range* used in surface simulation to the uncertainties of reservoir volumes, simulations are conducted with varying *range* when the standard deviations on the top and bottom surfaces are fixed as 2.5/0.5 meters. Figure 13 shows how the uncertainties in the reservoir volumes changes as the *range* used in the surface simulation changes. Table 2 also tabulate the values of *range* used in the simulation, and the resulting mean and standard deviations of oil-, gas-containing volumes and *GRV*.

It is shown in Figure 13 and Table 2 that the uncertainties in the gas-containing volume and *GRV* increase and then drop down, and that of the oil-containing volume keeps increasing as the *range* increases. When a short *range* is used, it is assumed that the deviations of the simulated surfaces from the *reference* surfaces have little spatial correlation and the deviations with different magnitudes will randomly located among the *reference* surfaces. The assumption that the further away from the well locations the larger the variability on the *reference* surfaces is no longer existing. The pattern of simulated surfaces bands will not look like the one shown in Figure 9 but will become uniformly wide. Whereas a sufficient large *range* is used, it is assumed that the distribution of the deviations of simulated surfaces from the *reference* surfaces has certain spatial continuities. Since there will be no undulation for the surfaces on the well locations, the magnitude of undulations will increasse somehow continuously from the well locations. Under the restriction by the value of *range*, the further away from the well locations, the larger the magnitude of the undulations. The *range* actually defines how far away from the well locations the undulation will reach the assigned variance (standard deviation). The pattern of simulated surfaces bands will have representative shape shown in Figure 9. However, if the *range* is too big, the simulated surfaces may not have chances to deviate from the *reference* surfaces in the magnitude defined by the standard deviation adapted. Therefore the bands in Figure 9 will become narrow. The patterns and width of the bands reflect the spread of the simulated surfaces, consequently the volume estimates. The actual pattern of simulated surfaces bands, *i.e.*, the simulated reservoirs volumes depends on the *range* adapted and the spacing among wells and distance from wells to the reservoir borders.

Therefore, in the situation of fixed standard deviation for the surface simulation, the spread pattern of simulated top/bottom surfaces will be different when different value of *range* adapted. The portions of reservoir accounted for the volume calculation will be different, therefore the uncertainties in the volume estimates.

Std in top/bottom surfaces (m)	**Mean OCV**	**Std OCV**	**Mean GCV**	**Std GCV**	**Mean *GRV***	**Std *GRV***
0.5/0.1	47.970	0.400	23.820	0.390	71.780	0.630
1.0/0.2	47.870	0.795	23.890	0.781	71.760	1.256
1.5/0.3	47.730	1.178	24.050	1.176	71.780	1.876
2.0/0.4	47.550	1.541	24.310	1.574	71.860	2.487
2.5/0.5	47.340	1.886	24.660	1.975	72.000	3.090
3.0/0.6	47.100	2.213	25.110	2.373	72.210	3.683
3.5/0.7	46.820	2.520	25.650	2.768	72.470	4.264
4.0/0.8	46.510	2.802	26.290	3.156	72.800	4.829
4.5/0.9	46.180	3.052	27.020	3.540	73.210	5.373
5.0/1.0	45.860	3.273	27.830	3.920	73.690	5.900
10.0/2.0	43.160	4.440	39.040	7.629	82.210	10.460
15.0/3.0	41.550	4.830	53.250	11.310	94.800	14.517
Reference	48.032		23.824		71.856	

Table 1: Standard deviation in the surface simulation and in the resulting volume estimates

The smaller the *range*, the more uniformly distributed undulations, consequently the more significant counteract effect between positive and negative undulation around the *reference* surfaces in the mean volume calculation and the less uncertainty in the volume estimates. As the increase of the *range*, the pattern of the simulated surface band will change from uniformly band to the pattern shown in Figure 9 and the width of the band will be increased in the middle and converged towards the well locations. The counteract effect will be weaker and the uncertainty in the mean volume estimate will be larger. When the *range* is too large, the width of the simulated surface bands will become narrow again. More counteract effect will occur and the uncertainty in the mean volume estimates will decrease again.

Although the uncertainty in the oil-containing volume against the *range* does not show a drop off as the gas-containing volume and *GRV*, we believe if increasing the *range* further one may still see the same phenomenon. (For CVD: I did not increase *range* further because I fixed the search radii at 60 in all the simulations).

Another issue should be addressed is that the influence of *range* on the uncertainty of volume estimates is less than the standard deviations used in the surface simulations.

References

Range used in surface simulation	**Mean OCV**	**Std OCV**	**Mean GCV**	**Std GCV**	**Mean** $\boldsymbol{GRV}$	**Std** $\boldsymbol{GRV}$
1.0	47.300	0.122	25.210	0.154	72.510	0.201
5.0	47.260	0.441	25.180	0.435	72.430	0.678
10.0	47.250	0.859	25.160	0.870	72.420	1.368
15.0	47.290	1.176	25.070	1.296	72.360	1.941
20.0	47.290	1.450	24.940	1.677	72.230	2.470
25.0	47.300	1.696	24.800	1.897	72.100	2.862
30.0	47.340	1.886	24.660	1.975	72.000	3.090
35.0	47.410	2.034	24.550	1.918	71.950	3.180
40.0	47.470	2.162	24.470	1.764	71.940	3.183
45.0	47.550	2.264	24.410	1.563	71.960	3.144
50.0	47.630	2.338	24.360	1.352	71.990	3.085
55.0	47.710	2.381	24.320	1.162	72.020	3.022
60.0	47.480	2.395	24.270	1.300	72.050	2.950
Reference	48.032		23.824		71.856	

Table 2: Range used in the surface simulation and standard deviation in the resulting volume estimates

```
                  Parameters for GRV
                  ********************

START OF PARAMETERS:
..\data\welldata.dat          - file with data
1   2   0  3  0  0            - columns for X,Y,Z,vr,wt,sec.var.
-1.0e21       1.0e21          - trimming limits
0                             - transform the data (0=no, 1=yes)
---.trn                       - file for output trans table
0                             - consider ref. dist (0=no, 1=yes)
---.out                       - file with ref. dist distribution
1  2                          - columns for vr and wt
0.0    15.0                   - zmin,zmax(tail extrapolation)
1       0.0                   - lower tail option, parameter
1      15.0                   - upper tail option, parameter
0                             - debugging level: 0,1,2,3
GRV.dbg                       - file for debugging output
GRV1.out                      - file for surface simulation output
GRV2.out                      - file for volume simulation output
..\data\topbase.txt           - file of top/base surfaces
..\data\contact.txt           - file of Oil/Water & Gas/Oil contact levels
100., 100., 50.               - scale of grid in X,Y,Z directions (meter/cell)
2.5, 0.5                      - standard deviation of top surface, reservoir height
200                           - number of realizations to generate
100     1    1.0              - nx,xmn,xsiz
100     1    1.0              - ny,ymn,ysiz
1       1    1.0              - nz,zmn,zsiz
69069                         - random number seed
0     8                       - min and max original data for sim
16                            - number of simulated nodes to use
1                             - assign data to nodes (0=no, 1=yes)
1     3                       - multiple grid search (0=no, 1=yes),num
0                             - maximum data per octant (0=not used)
40.    40.     1.             - maximum search radii (hmax,hmin,vert)
 0.0    0.0    0.0            - angles for search ellipsoid
71     61     17              - size of covariance lookup table
0       0.0    0.0            - ktype: 0=SK,1=OK,2=LVM,3=EXDR,4=COLC
second.dat                    - file with LVM, EXDR, or COLC variable
1                             - column for secondary variable
1    0.0001                     - nst, nugget effect
3    0.9999   0.0   0.0   0.0   - it,cc,ang1,ang2,ang3
             30.0  30.0   1.0   - a_hmax, a_hmin, a_vert
```

Figure 2: Example parameter file for grv.

```
                Bootstrap for Uncertainty on Pore Volume
                ****************************************

START OF PARAMETERS:
GRV2.out                                  \input histogram of Gross Rock Volume
1   0                                     \column for value and prob
-1.0   1.0e21   0.0                       \tmin and tmax and cutoff
NGRwell.dat                               \input histogram of Net to Gross Ratio
1   0                                     \column for value and prob
-1.0   1.0e21   0.0                       \tmin and tmax and cutoff
NPwell.dat                                \input histogram of Net Porosity
1   0                                     \column for value and prob
-1.0   1.0e21   0.0                       \tmin and tmax and cutoff
histPV.out                                \output file of simulated Pore Volume
1000                                      \nsim
69069                                     \Random Number Seed
```

Figure 3: Example parameter file for `pv`.

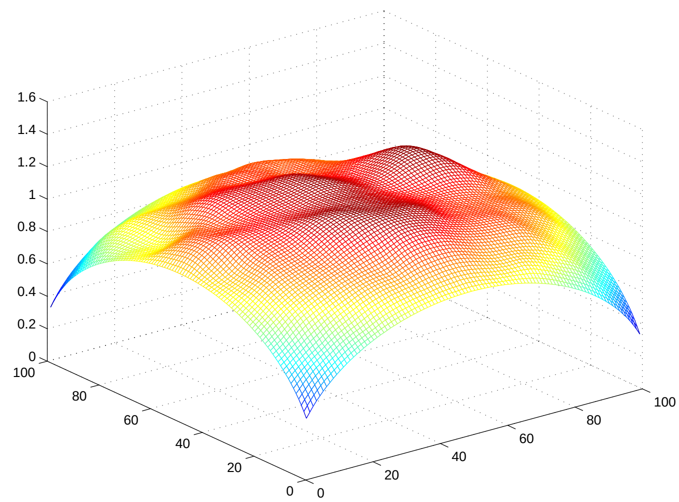


Figure 4: 3-D view of the *reference* top surface

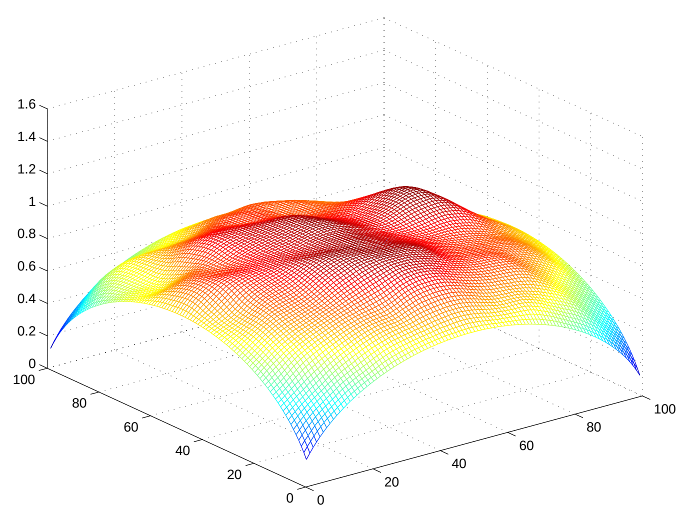


Figure 5: 3-D view of the *reference* base surface

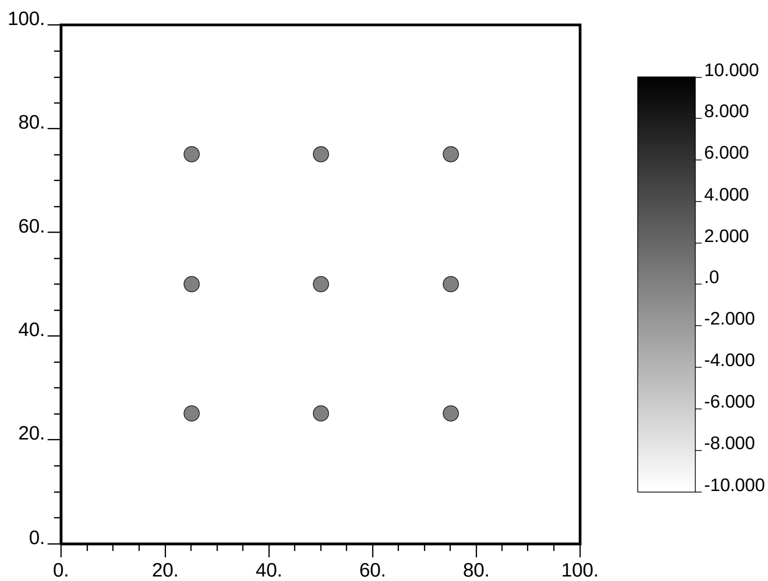


Figure 6: Locations of wells

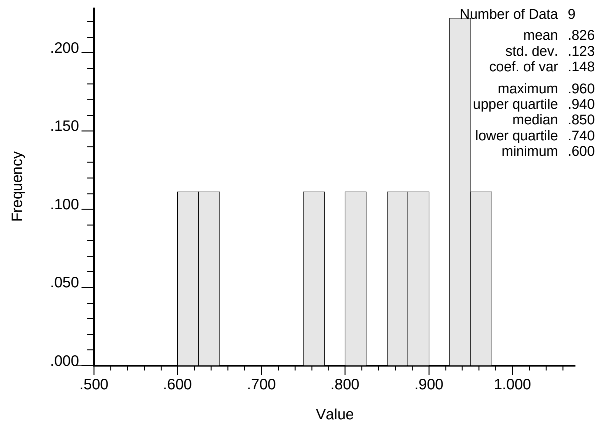


Figure 7: Histogram of *Net-to-Gross ratio* from wells

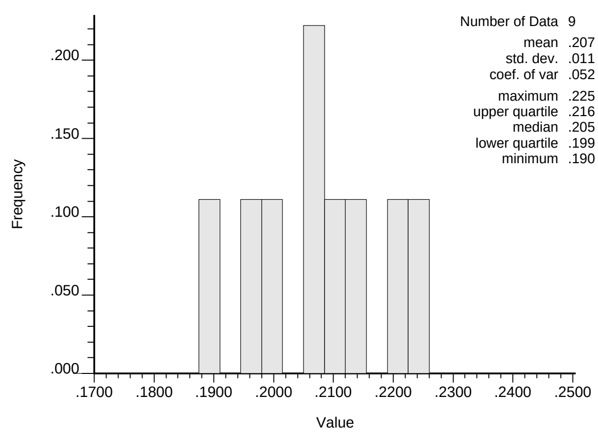


Figure 8: Histogram of *Net Porosity* from wells

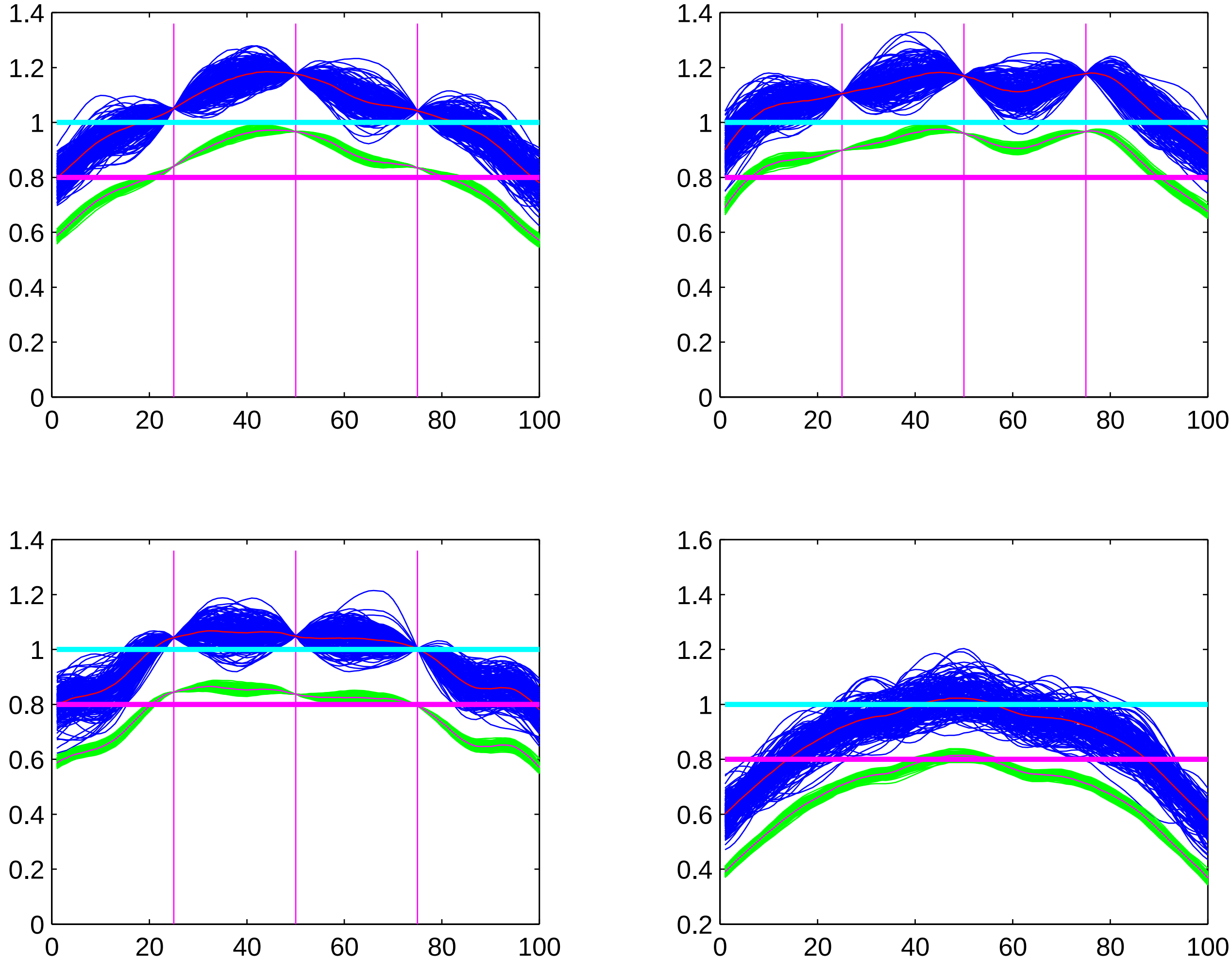
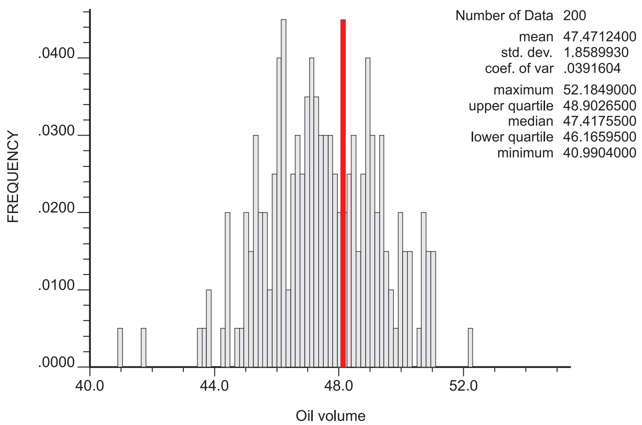


Figure 9: Cross section view of the reservoir
red line: top and bottom surfaces
green lines: simulated bottom surfaces
dark blue lines: simulated top surfaces
pink horizontal line: OWC level
light blue horizontal line: GOC level
pink vertical lines: well locations



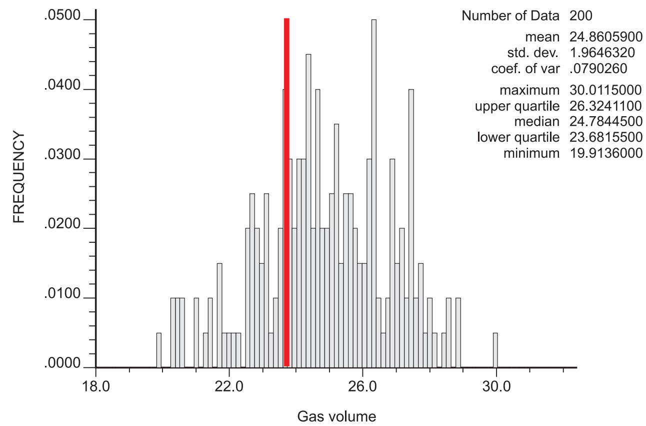
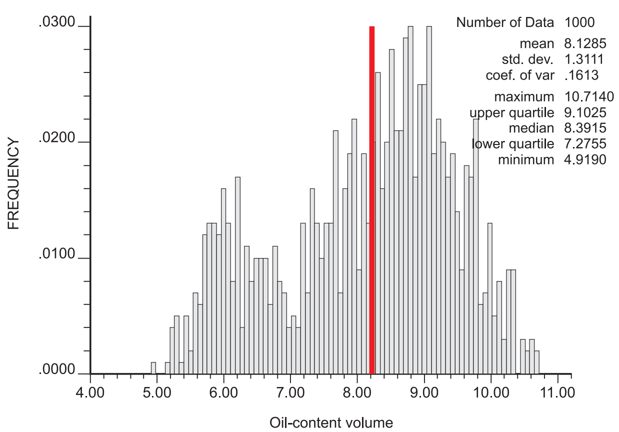


Figure 10: Histograms of the oil (left) and gas (right) containing volume of the reservoir. red vertical line: *reference value*



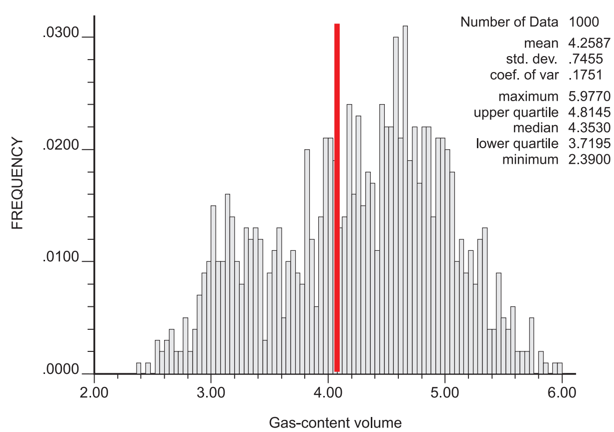


Figure 11: Histogram of oil and gas *Pore Volume*red vertical line: *reference value*

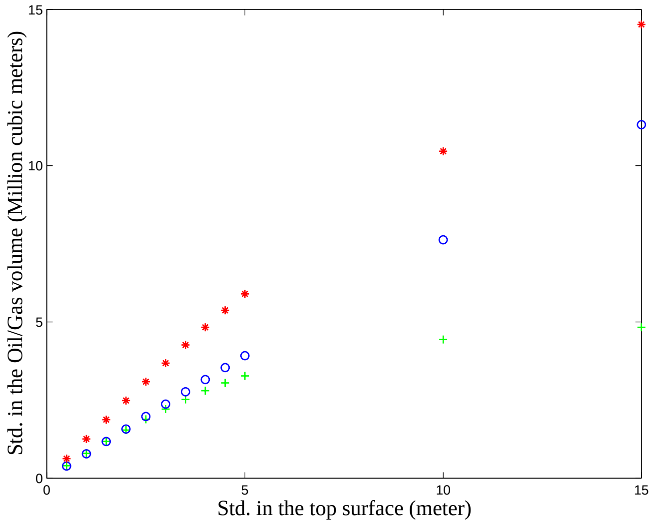


Figure 12: Scatter plot of standard deviation in the oil and gas containing volume of the reservoir versus the standard deviations used in the surface simulation
Green +: Oil-containing volume Blue o: Gas-containing volume Red *: em GRV

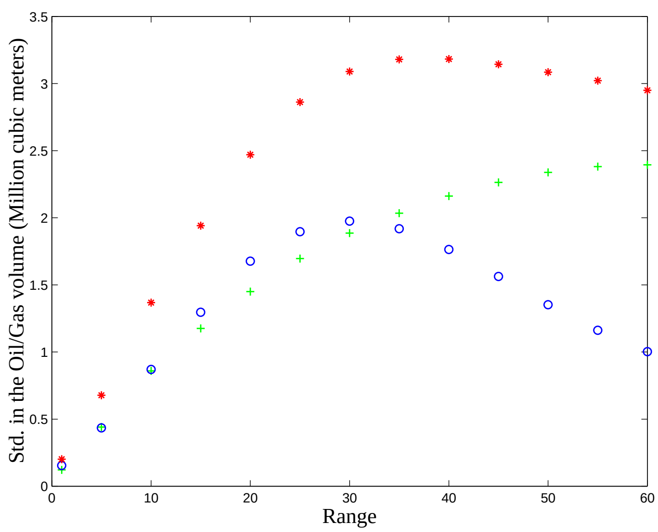


Figure 13: Scatter plot of standard deviation in the oil and gas containing volume of the reservoir versus *range* used in the surface simulation
Green +: Oil-containing volume Blue o: Gas-containing volume Red *: *GRV*