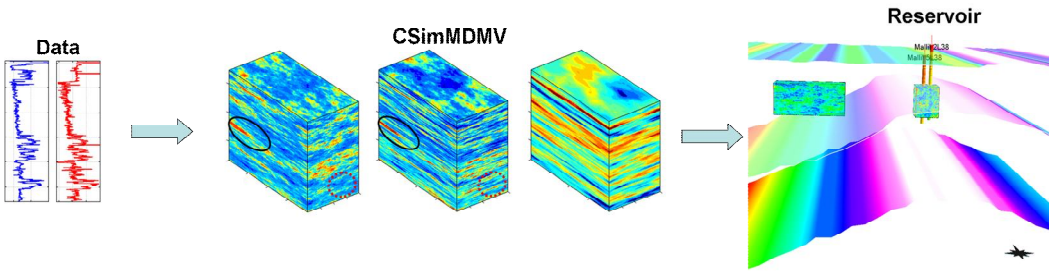
CSimMDMV User Manual Version 1.1

A Parallel Program for Stochastic Characterization of Multi-dimensional, Multi-variant, and Multi-scale Distribution of Heterogeneous Reservoir Rock Properties from Well Log Data



By

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Notice

This document provides the essential 4 steps for basic user to quickly start using the program. The theory can be found in the JGR and Geophysical Prospecting papers. The abstract of the Geophysical Prospecting paper is attached as Appendix A. Currently this program support up to three variants. To increase the number of variants, the spectral density matrix (*Huang et al*., 2009) and the lower triangle matrix can be obtained with some help of computer algebra systems such as MatLab™ symbolic toolbox or Maple™.

The core function of this program is to simulate multi-dimensional, multi-variable and multi-scale heterogeneous reservoirs according to:

Huang, J.-W., G. Bellefleur, and B. Milkereit, 2009. Seismic modeling of multidimensional heterogeneity scales of Mallik gas hydrate reservoirs, Northwest Territories of Canada, J. Geophys. Res., 114, B07306, doi:10.1029/2008JB006172.

Huang, J.-W., G. Bellefleur, and B. Milkereit, 2010. Stochastic Characterization of Multi-dimensional, Multi-variant, and Multi-scale Distribution of Heterogeneous Reservoir Rock Properties, Geophysical Prospecting, submitted.

PLEASE DO NOT DISTRIBUTE. PLEASE REFER OTHER PEOPLE TO THE AUTHOR.

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If we want to publish results calculated with this program please give a reference to the aforementioned papers.

History of important modifications:

15.01.2009	Version 1.0	Original implementation Theory submitted to JGR By Jun-Wei Huang
16.06.2009	Version 1.1	Conditional and nonconditional Monte Carlo simulation was added By Jun-Wei Huang
20.06.2010	Version 1.1	Documented By Jun-Wei Huang
26.06.2010	Version 1.1	Cleaned for publication on Computers and Geosciences By Jun-Wei Huang

Step 1: Compile and Installation

Assuming the home folder of the codes is "$CHome", to compile this program, navigate to the folder "$CHome/src" and type
[junwei@core23 src]$ ./CompileAll.sh

We will find 6 executable file under "$CHome/bin": CSim3D3V, CSim3D2V, CSim3D1V for 3D and CSim2D3V, CSim2D2V, CSim2D1V for 2D. Although program CSim3D3V can be used to simulate two and one variant models by disregarding the third output, the corresponding versions are recommend to reduce the demand of memory.

```
[junwei@core23 bin]$ ll
total 5224
-rwxr-xr-x 1 junwei users 743783 Jul 27 18:00 CSim2D1V
-rwxr-xr-x 1 junwei users 753287 Jul 27 18:00 CSim2D2V
-rwxr-xr-x 1 junwei users 766151 Jul 27 18:00 CSim2D3V
-rwxr-xr-x 1 junwei users 745607 Jul 27 18:00 CSim3D1V
-rwxr-xr-x 1 junwei users 757383 Jul 27 18:00 CSim3D2V
-rwxr-xr-x 1 junwei users 772135 Jul 27 18:00 CSim3D3V
-rwxr-xr-x 1 junwei users 767341 Jul 27 18:00 CSim3D3V_BENCH
```

Step 2: Input Parameter File

To construct we model, we need to have an input file (e.g., CSimMD3V.inp) and an ANSCII file containing logs information (e.g. testlogs.txt).

Here is an example of the format of input file from CSimMD3V.inp:

```
#input parameter file created by Junwei Huang @ University of Toronto, Jan 3 2009
#====================
#Horizon X, Y, Top, Bottom, and Sampling interval (m)
200.0 400.0 850.0 1168.0 2.0
#Number of boreholes and logs file name, X,Y,depth, v1,lv1, v2,lv2, v3,lv3, …
#====================
testlogs.txt
#Number of variants N <= 3 for Version V1.1
3
# switch: nonconditional (0) / conditional (1)
0
#====================
#orgin point x0, y0, z0
513185 7705619 0
#====================
#ax ay range in meters:
#start step end
50        50        50
```

```
100      50       100
# maximum Monte Carlo Simulations: MaxMC
1
#cdf parameters: az, hurst number, nugget effect
#C(v1,v1~Vn), C(v2, V2~Vn), e.g.,
#C(Vp, Vp),
#C(Vs, Vp),
#C(Vs, Vs),
#C(Density,Vp),
#C(Density,Vs),
#C(Density, Density),and
#Must be in the order consistent with v1, v2, v3,…
#===================
#az(m)  v         n0
11.5116  0.24998         0
9.1185  0.20667          0
7.2964  0.27265          0
0        0        0
0        0        0
4.5868  1.0       0.70352
#===Output file name head string====
test
#===Output Rock Physics Model results tag
0
```

The order of the above input file parameter must NOT be altered!

The first 3 columns of logs file (e.g., testlogs.txt) must be UTM Easting,UTM Northing, and depth in meter. The following 2*N* columns are the physics property of interest and the linear trend, respectively. Here *N* is the number of variants. Currently CSimMDMV supports up to three variants in 1D, 2D and 3D. According to authors' experience, the primary properties (e.g., v_p) should be listed before secondary properties such as v_s and density. More than one borehole data can be included in testlogs.txt.

Step 3: Launch CSimMDMV

The format to use command CSim*D*V are, for example:
[junwei@core23 bin]$ mpirun -np 80 ../bin/CSim3D3V CSimMD3V.inp

The program output will be printed on the terminal screen as shown in Fig 1 in which the output of nonconditional 3D-3V simulation was performed. Input file CSimMD3V.inp can be used for 1D, 2D and 3D simulations without modifications.

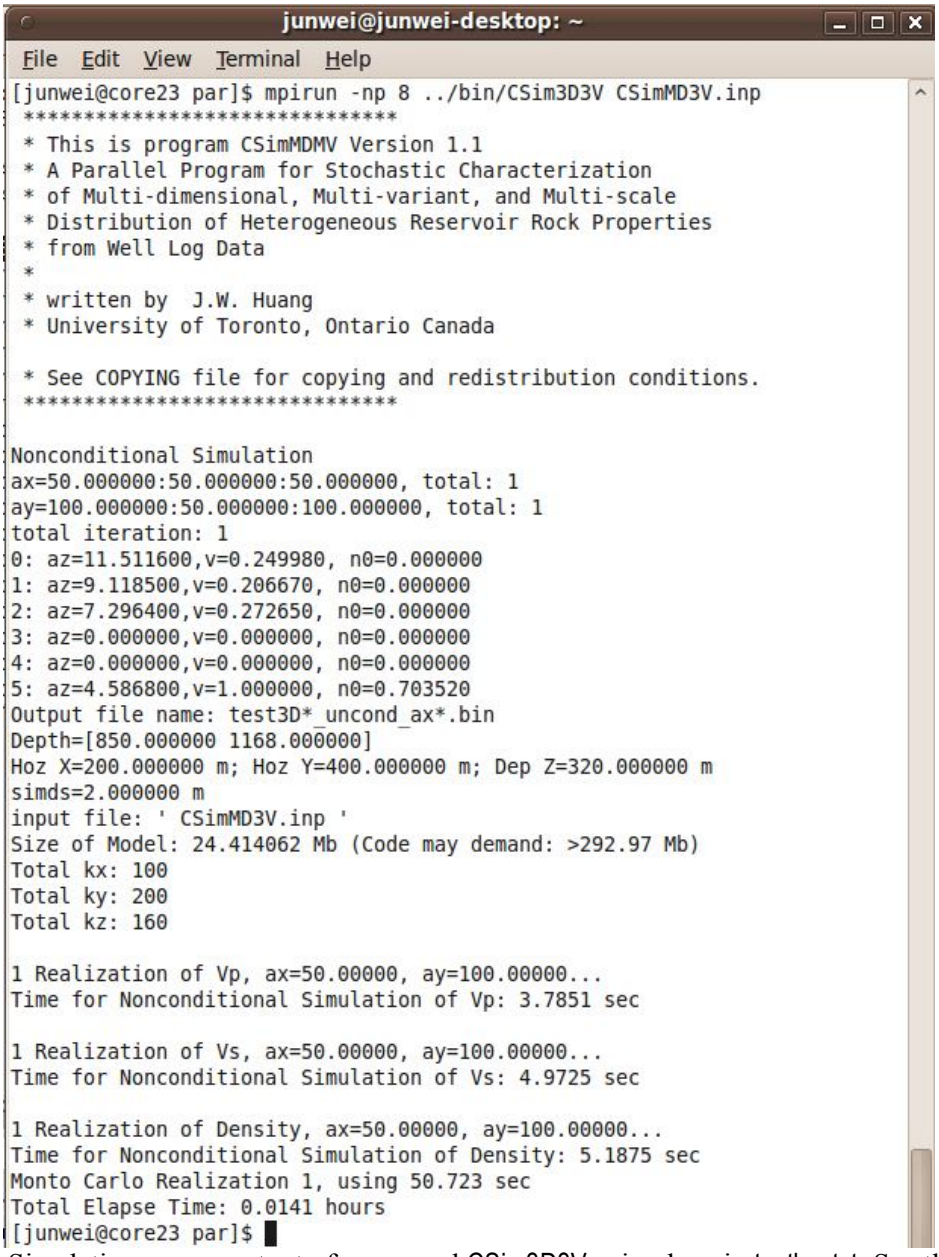

Figure 1. Simulation screen output of command CSim3D3V using logs in testlog.txt. See the results in Figure 3.

If the conditional simulation tag is on (i.e., condflag=1), conditional simulation will be followed after the above Nonconditional simulation. For example, a 2D conditional simulation was performed in Fig. 2.

Figure 2: Simulation screen output of command CSim2D3V using logs in testlog.txt. See the results in Figure 4.

Step 4: Visualization

After step 3, the output files can be found under "$CHome/models/".

```
[junwei@core23 models]$ ll -t
total 201932
-rw-r--r-- 1 junwei users 25600000 Jul 27 18:12 test3DRho_uncond_ax50_ay100.bin
```

```
-rw-r--r-- 1 junwei users 25600000 Jul 27 18:12 test3DVp_uncond_ax50_ay100.bin
-rw-r--r-- 1 junwei users 25600000 Jul 27 18:12 test3DVs_uncond_ax50_ay100.bin
```

MatLab™ is required to view the simulated 1D/2D/3D model. The m-files for visualization can be found under "$CHome/mfiles/".

```
[junwei@core23 mfiles]$ ll
total 28
-rw-rw-r-- 1 junwei users 2089 Jul 27 16:55 readbin2D1V.m
-rw-rw-r-- 1 junwei users 2652 Jul 27 16:55 readbin2D2V.m
-rw-rw-r-- 1 junwei users 3016 Jul 27 16:33 readbin2D3V.m
-rw-rw-r-- 1 junwei users 2284 Jul 27 16:48 readbin3D1V.m
-rw-rw-r-- 1 junwei users 3019 Jul 27 16:51 readbin3D2V.m
-rw-rw-r-- 1 junwei users 3423 Jul 27 16:42 readbin3D3V.m
```

Use the files accordingly to visualize the results. For example, to view the Nonconditional simulation of 3D-3V model and the conditional simulation of 2D-3V we have just created, run readbin3D3V.m and readbin2D3V.m under MatLab™, respectively. For nonconditional simulation one figure is plotted as shown in Fig. 3 and Fig 4, wherease for conditional simulation the intermediate kriging results will be displayed (Fig. 5).

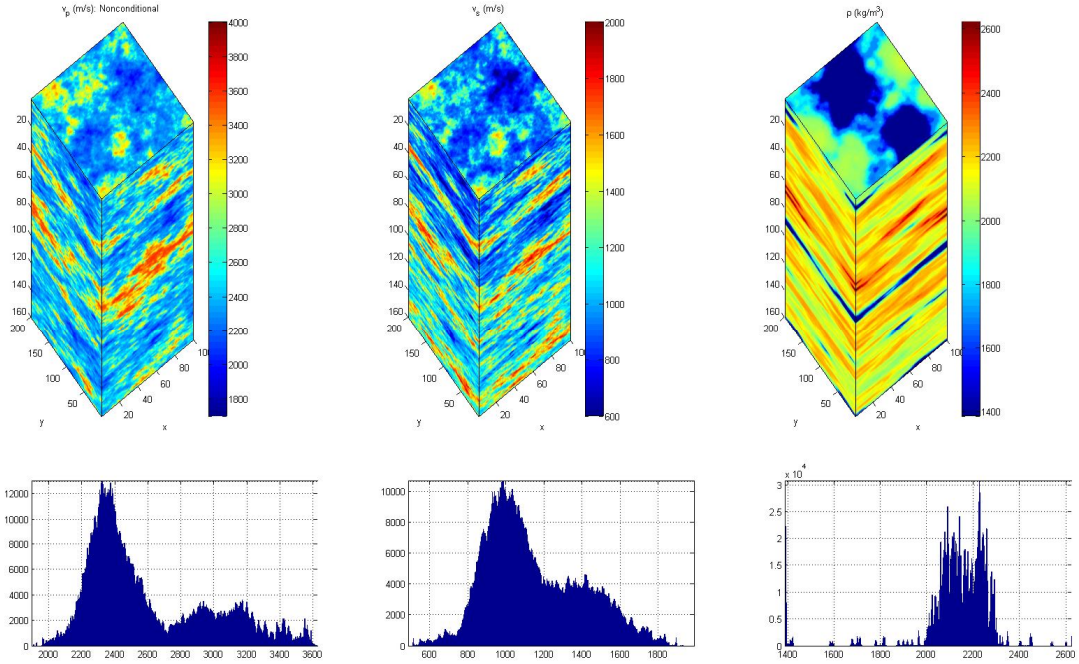

Figure 3: Visualization of simulated 3D-3V models without conditions.

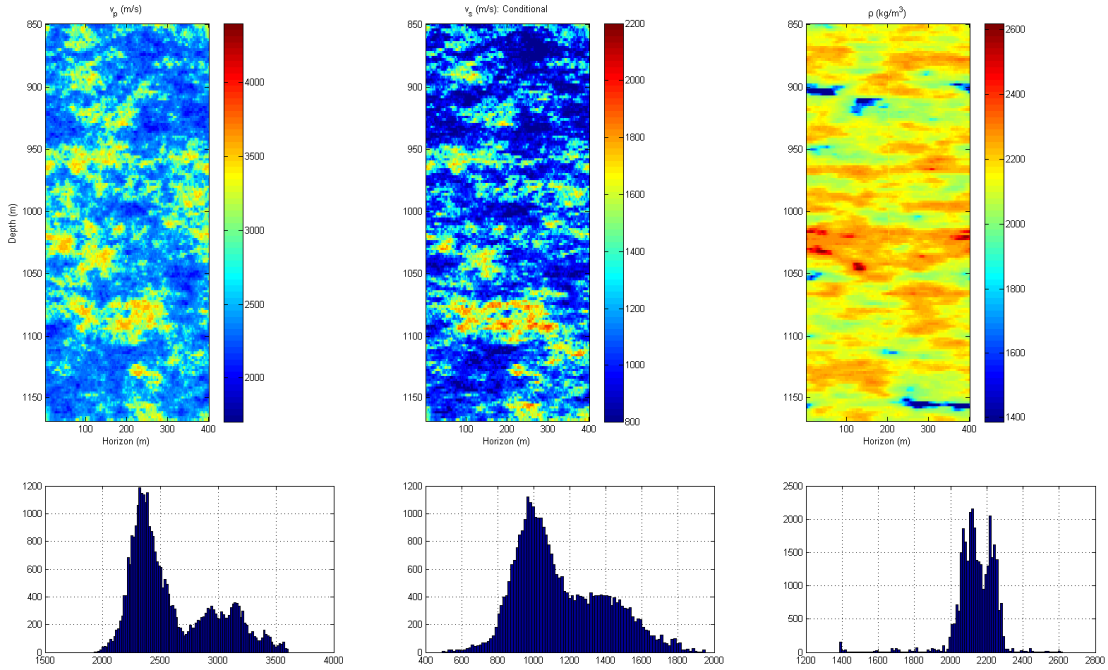

Figure 4: Visualization of simulated 2D-3V models with borehole constraint at the center (x=200 m).

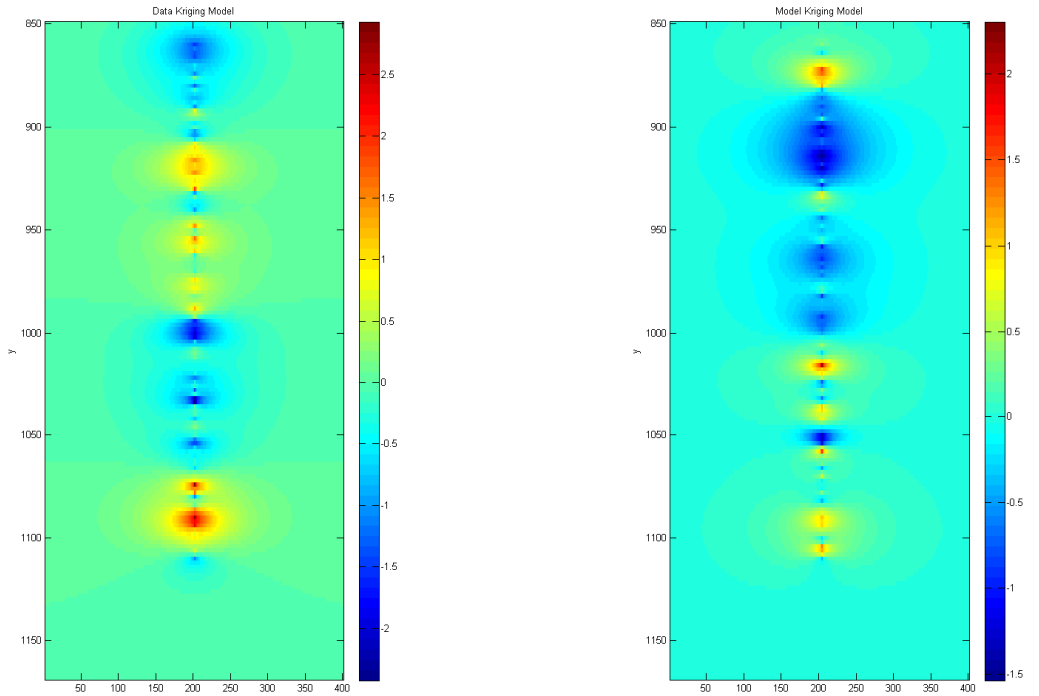

Figure 5: Intermediate kriging model based on field data (left) and Nonconditional simulated model (right).

To save the right model to binary for parallel visco-elastic finite difference modeling, turn on the savetag=1 in the above m-files.

Appendix A: Article Abstract

We present CSimMDMV, a software package to simulate two- and three-dimensional, multi-variant heterogeneous reservoir models from well logs at different characteristic scales. Based on multi-variant conditional stochastic simulation, this software is able to parameterize multi-dimensional heterogeneities and to construct heterogeneous reservoir models with multiple rock properties. The models match the well logs at borehole locations, simulate heterogeneities at the level of detail provided by well logging data elsewhere in the model space, and simultaneously honor the correlations among multiple rock properties. It provides a heterogeneous environment in which a variety of geophysical experiments can be performed. This includes the estimation of petrophysical properties and the study of geophysical response to the heterogeneities. This paper describes the theoretical basis of the approach and provides the details of the parallel implementation on a Linux cluster. The speedup of the parallel software is measured with different number of processors. A case study on the assessment of natural gas hydrate amount in Northwest Territory of Canada is provided. We show that the combination of rock physics theory with multiple realizations of three-dimensional and three-variant (3D-3V) gas hydrate reservoir petrophysical models enable us to estimate the average amount of gas hydrate and associated uncertainties using Monte Carlo method.

Appendix B: Beyond Three Variant

If you need to deal with problems requiring more than three variants, please send an email to the software author. If you have any comments on the software as well as the theory, please send an email to the author: juhuang@nrcan.gc.ca

Due to our limited time, there are errors in the guide, the code, and the paper. We appreciate your help, if you can notice us your findings.